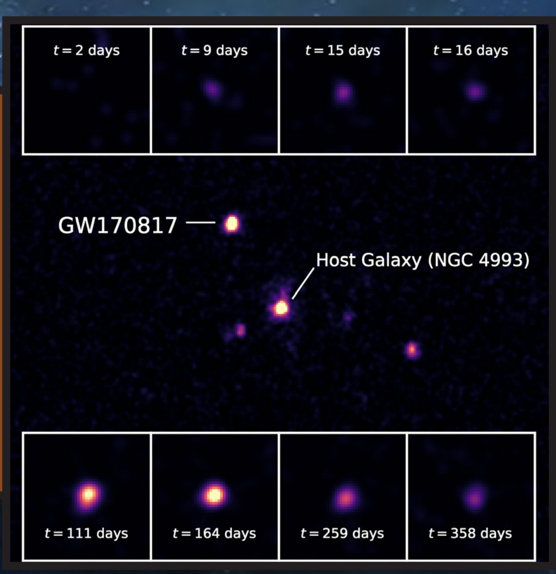
Chandra News Issue 26, Summer 2019

20 Years of Chandra



The X-Rays Also Rise

Raffaella Margutti, Wen-fai Fong, Daryl Haggard

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Celebrating 20 Years of *Chandra*

The year 2019 marks 20 years of superb performance by the *Chandra X-ray Observatory*. The CXC is planning a number of events and products for the science community and the general public. We give you an overview of plans on page 12.

Complete up-to-date calendar of events http://cxc.cfa.harvard.edu/cdo/chandra20/
20 Years of Chandra Science Symposium, Dec. 3–6 http://cxc.harvard.edu/symposium_2019/

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The X-rays Also Rise: *Chandra* Observations of GW170817 Mark the Dawn of X-ray Studies of Gravitational Wave Sources

Raffaella Margutti
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The Dawn of a New Era of Exploration

The first extraterrestrial X-ray photons to be detected were those from the Sun in the late 1940s, followed in 1962 by the discovery of the first cosmic X-ray source: Scorpius X-1 (Giacconi, Gursky, Paolini & Rossi 1962). Since then, for ~60 years the X-ray sky has revealed rich and violent phenomena, including jets from accreting black holes (BHs) and neutron stars (NSs), stellar explosions, mergers, eruptions and disruptions (e.g., Seward & Charles 2010). In August 2017, *Chandra* observations of the gravitational wave (GW) event GW170817 marked the beginning of a new field: X-ray studies of sources of gravitational waves (Haggard et al. 2017, Margutti et al. 2017, Troja et al. 2017).

The mergers of the most compact objects in nature (BHs and NSs) emit GWs that are now detectable by the Laser Interferometer Gravitational-wave and Virgo Observatories (LIGO/Virgo). LIGO/Virgo has thus far detected ten BH-BH mergers and one binary neutron star (BNS) merger GW170817 (Abbott et al. 2017c, 2018). The BNS merger GW170817 is the first GW event for which emission has been observed across the entire electromagnetic spectrum, from the gamma-rays to the radio band, including soft X-rays. The X-ray emission from GW170817 was first captured by the sharp eyes of *Chandra*, which continues to provide a detailed view of the rise and fall of the non-thermal (i.e., synchrotron) radiation associated with the fastest material flying out from the merger (Alexander 2018, Haggard et al. 2017, Margutti et al. 2017, 2018, Nynka et al. 2018, Piro et al. 2018, Pooley et al. 2018, Ruan et al. 2018, Troja 2017, 2018).

GW170817 was detected by LIGO/Virgo on 17 August 2017, and localized to within a 28 deg^2 (90% confidence region) area of the sky containing ~40 nearby galaxies at a distance of roughly 40 Mpc (Abbott et al. 2017b,c). The GW detection was followed approximately two seconds later by the detection of gamma-rays from a consistent location in the sky (Abbott et al. 2017b, Goldstein et al. 2017, Savchenko et al, 2017), and roughly half a day later by the detection of a rapidly-evolving transient shining brightly at UV/optical/NIR wavelengths (Arcavi et al. 2017, Chornock et al. 2017, Coulter et al, 2017, Drout et al. 2017, Evans et al, 2017, Kasliwal et al. 2017, Kilpatrick et al. 2017, Lipunov et al. 2017, Nicholl et al. 2017, Pian et al. 2017, Shappee et al. 2017, Smartt et al. 2017, Soares-Santos et al. 2017, Tanvir et al. 2017, Valenti et al, 2017), known as "kilonova" (KN, proposed by Li & Paczyński,1998 see Metzger 2017 for a recent review). The KN emission from GW170817 (and from BNS mergers) is powered by the radioactive decay of heavy chemical elements produced by the merger through "r-process'" nucleosynthesis, and tracks the slower moving material ejected by the collision, with inferred velocities of ~0.1–0.3c (Cowperthwaite et al. 2017, Kasen et al. 2017, Smartt et al. 2017, Villar et al. 2017, Tanvir et al. 2017). The observations of KN emission in GW170817 showed remarkable agreement with theoretical predictions on the luminosity evolution of the kilonova emission at optical/NIR wavelengths (Metzger 2017b). These observations signaled the birth of Multi-Messenger Astrophysics (MMA) with GWs (Abbott et al. 2017a).

Models of compact-object mergers have also proposed that these systems could launch energetic collimated outflows reaching ultra-relativistic speeds (i.e., relativistic jets) and could be the progenitor systems of short gamma-ray bursts (SGRBs, Eichler et al. 1989, Narayan et al. 1992). The interaction of these relativistic outflows with the merger's environment creates shocks that accelerate particles which then cool by radiating photons. The radiation, produced by electrons gyrating in amplified magnetic fields (i.e., synchrotron), is non-thermal in nature and dominates the observed emission at X-ray and radio wavelengths at all times, where the contribution from the KN is negligible (Fig. 5). The resulting electromagnetic transient is thus an excellent probe of the physics of compact-object mergers and their sub-parsec environments. The evolution of the resulting transient directly depends on the following factors: (i) amount of mass expelled by the catastrophic collision, (ii) speed of expelled material, (iii) collimation and direction with the line of sight, and (iv) density of the circum-merger medium (e.g., Piran 2004). This is where *Chandra*'s observations of GW170817 provided a fundamental contribution to the nascent field of MMA with GWs.

Chandra X-ray observations of GW170817 provided key constraints on the physical properties of the fastest ejecta launched into space by the NS merger and on its environment (Alexander 2018, Haggard et al. 2017, Margutti et al. 2017, 2018, Nynka et al. 2018, Piro et al. 2018, Pooley et al. 2018, Ruan et al. 2018, Troja 2017, 2018). In the following sections we highlight the impact of *Chandra* observations to constrain the nature of the X-ray emission in GW170817. We also consider other potential sources of X-ray emission that did not play a major role in GW170817, but might be relevant for future GW detections. Finally, we discuss other broad areas of astrophysics that can be impacted by X-ray studies of GW sources and we end with our views on discovery frontiers in the field.

Chandra Observations of GW170817 Reveal a Structured, Collimated, Relativistic Outflow in a BNS Merger

It all started with zero photons. The first deep X-ray observation of GW170817 was carried out by *Chandra* ~2 days after the merger and the non-detection provided an upper limit on the flux (Fig. 1, Margutti et al. 2017). This observation was followed on day 9 by the detection of ~14 photons from GW170817 (Fig. 1, Troja et al. 2017). These two *Chandra* observations established, at high statistical confidence, that GW170817 was associated with faint ($L_x \leq 10^{39}$ erg/s at t < 10 days) but rising X-ray source of emission (Fig. 2–3), setting GW170817 phenomenologically apart from all X-ray afterglows of Short Gamma-Ray Bursts (SGRBs) observed thus far (Fig. 4, Fong et al. 2017). Yet, accurate modeling of the non-thermal emission from GW170817 over one year of observations demonstrated that its intrinsic nature was similar to SGRBs (Alexander et al. 2018, D'Avanzo et al. 2018, Margutti t al., 2018, Troja et al. 2018b, Wu et al. 2018), and that its different appearance was simply due to a different viewing angle. While SGRBs are typically discovered through their powerful collimated gamma-ray emission and are viewed along the jet axis (see Fong et al. 2015 for a recent review), the GW emission detection of GW170817, whose jet is pointing ~30° away from our line of sight, allowed us to view a BNS merger "from the side" for the first time.

The X-ray emission from GW170817 showed a slow rise to a peak at t~160 days after the merger (Ruan et al. 2018, Margutti et al, 2018, Troja et al. 2018, D'Avanzo et al. 2018). After peaking at L_x~10^{40} erg/s, the X-ray luminosity started a fast decay, as ~t^{-2} (Alexander et al. 2018, Nynka et al. 2018, Troja et al. 2018b, Fig. 3–4). Meanwhile, the spectrum interestingly showed no evidence for any evolution (Fig. 5). At all times, the X-ray spectrum is well described by a fairly hard power-law model with $F_\nu \sim \nu^{-0.6}$ and no evidence for intrinsic absorption, all of which is consistent with the low densities expected in the immediate environments of BNS mergers and the early-type nature of the host galaxy of GW170817 (Blanchard et al. 2017, Fong et al. 2017, Levan et al. 2017). Indeed, the broad band radio to X-ray spectral energy distribution remarkably also showed no evidence for evolution, and continuously exhibited simple power-law behavior ($F_\nu \sim \nu^{-0.6}$) over nine order of magnitudes in frequency, from the earliest observations at ~9 days, to the most recent observation (~400 days since the merger, Fig. 5).

The combination of the slow rise to peak, the fast decay after peak, and the absence of spectral evolution provided by *Chandra* observations of GW170817 over ~400 days of its evolution, offered key observational evidence that the merger powered a collimated relativistic outflow directed away from our line of sight, i.e., an off-axis relativistic jet (Alexander et al. 2018, Margutti et al. 2018, Troja et al. 2018). Distinct from the on-axis jets of gamma-ray detected SGRBs for which the emission detected by the observer is always dominated by the jet core and decays with time, for off-axis jets the observer initially receives an increasing amount of energy flux as the jet decelerates in the environment and the relativistic beaming of the emitted radiation becomes less and less severe with time. As a result, the observer who does not view the jet along the jet axis detects an outflow carrying an increasing amount of energy with time until the entire jet cone becomes visible and the X-ray light-curve peaks (e.g., Granot et al. 2002). In this off-axis scenario, the apparent increase of energy detected by the observer is not intrinsic to the source but due to the increasing fraction of radiation from the jet that

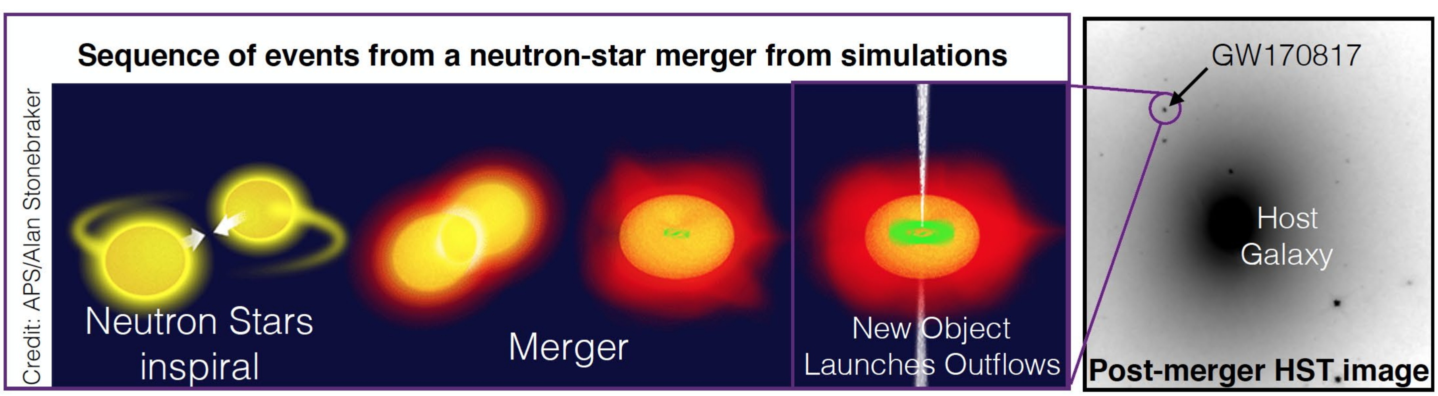

Figure 1 Left: Neutron-star merger from computer simulations (Baiotti et al. 2017). The collision creates a more massive neutron star or a black hole, and launches powerful outflows of material into the environment (white jet-like streams). These outflows are the primary source of radiation (i.e., they produce electromagnetic radiation). Such a source was detected on August 17, 2017 from GW170817. Right: Hubble Space Telescope image of GW170817 from Margutti et al. 2017; Blanchard et al. 2017.

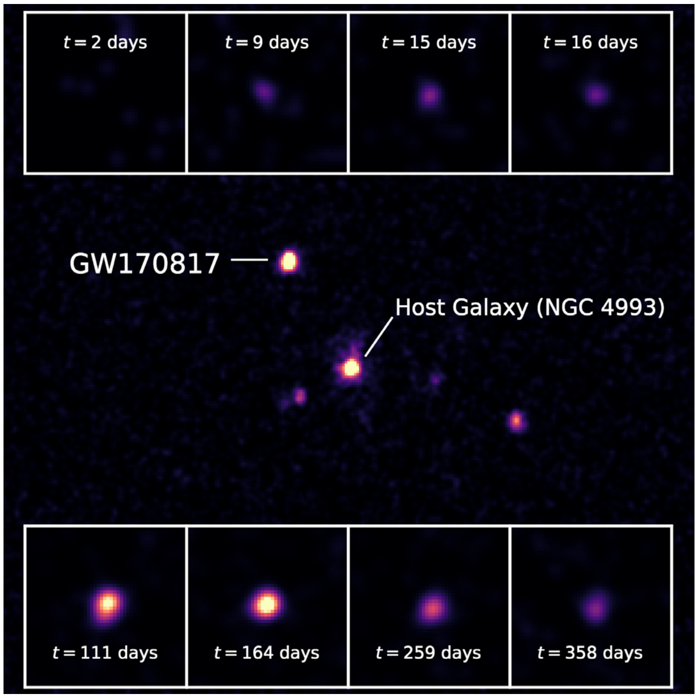

Figure 2: Deep Chandra 0.3-10 keV X-ray image of GW170817 and its host galaxy (main panel, 450 ks). Insets: zoom into the evolution of the X-ray emission from GW170817 in the first 400 days, from the first non-detection at ~2 days, its peak around ~160 days and the subsequent steep decline.

intercepts the observer's line of sight with time. After the peak, the emission detected by an on-axis and an off-axis observer evolves similarly, as both observers effectively "see" the entire jet cone (e.g., van Eerten et al. 2010, 2012). No spectral evolution is expected to accompany the rise and fall of the observed emission due to the off-axis location of the observer.

The basic framework of an outflow with an energetic relativistic core that is directed away from our line of sight successfully explains the non-thermal emission detected from GW170817 (Fig. 3). Our off-axis location is not surprising, as GW170817 was detected through its GW emission, which is not strongly beamed along the jet axis like it is for SGRBs. From probabilistic considerations it is significantly more likely for any observer to reside outside the jet cone than for the jet cone to be aligned with any observer's line of sight. The detection of very weak gamma-ray emission from GW170817 with an isotropic-equivalent energy a factor ~1000 smaller than the weakest SGRBs is consistent with this scenario, and provides important independent observational evidence that supports our off-axis perspective with respect to the jet. Future GW events are also likely to be detected from an off-axis perspective.

The detailed temporal evolution of the X-ray and radio emission before peak in GW170817 provided key information on the angular structure of the relativistic outflow (e.g., Lazzati et al. 2018, Wu et al. 2018) launched by a BNS merger for the first time. In the simplest incarnation of jet models invoked for SGRBs all the jet energy is confined within a cone of angular size θ_{jet}, and no energy is distributed at angles $\theta > \theta_{jet}$ (i.e., the jet has no "wings"). These models are referred to in the literature as "top-hat" jets, and successfully explain the observed phenomenology in SGRBs across the electromagnetic spectrum (Fong et al. 2015). SGRBs are preferentially viewed on-axis, as they are detected through their luminous, collimated gamma-rays. In this on-axis configuration the detected emission is dominated by the more energetic jet core, while radiation from the less energetic jet wings, when present, is always fainter. Hence, it is not surprising that top-hat jets have been successful at explaining SGRBs (Fong et al. 2015)—even though departures from the top-hat jet structure have been suggested in the GRB literature (e.g., Rossi et al. 2002)—and provide realistic expectations for jets that originate from BNS mergers. However, it was not until GW170817, that a clear "need" arose to invoke structured outflows to explain SGRBs afterglows, since there was no observationally-based method to quantitatively constrain the properties of the on-axis outflows beyond the ultra-relativistic jet core. For these reasons, structured outflows in SGRBs remained an intriguing, but difficult to constrain, theoretical possibility.

GW170817 offered the first observational evidence for a clear deviation from a top-hat jet structure. GW170817 showed a slow rise to peak compared with the expectations from top-hat jets viewed off-axis, suggesting the presence of mildly-relativistic jet "wings" around a collimated ultra-relativistic core. These wings of less collimated material are a direct product of the merger dynamics and jet launching process in NS mergers, and pre-peak observations of GW sources can constraint the physical properties of the angular structure of the outflow.

Modeling of the pre-peak X-ray to radio emission in GW170817 constrained the jet-wing's expansion velocity to be mildly relativistic with $\gamma \sim 3$ (e.g., Wu et al. 2018). As a comparison, modeling of the broad-band radio to X-ray emission demonstrates that the ultra-relativistic jet core was highly collimated (jet opening angle of ~5°), highly energetic ($E_k \sim 10^{50}$ erg), and expanding into a low-density medium with $n \leq 0.01$ cm^{-3}. The properties of the highly-relativistic outflow and the inferred properties of the environment of GW170817 are consistent with findings from cosmological SGRBs (Fong et al. 2015, 2017, Troja et al. 2018b).

After ~400 days of data acquisition, analysis and modeling across the electromagnetic spectrum and a strong debate amongst the astronomical community, we can now conclude with confidence that GW170817 shows all the

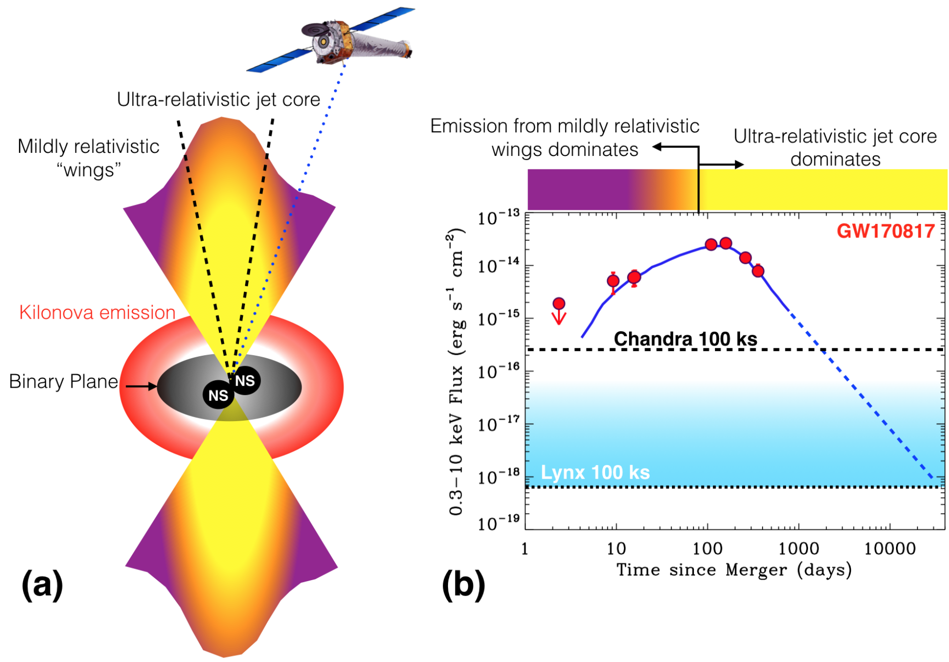

Figure 3: Panel (a): Cartoon showing the geometry of the outflows in GW170817 that give rise to the quasi-isotropic emission from the kilonova (red) and a collimated jet of ultra-relativistic material carrying $E \sim 10^{50}$ erg of energy. The collimated jet is characterized by a narrow cone ($\theta_{jet} < 5°$) with "wings" of mildly relativistic material with Lorentz factor $\Gamma \sim 3$ extending to wider angles. The observer is located ~30° off-axis. Panel (b): X-ray emission from GW170817 as captured by Chandra (red points), with best fitting off-axis relativistic jet model superimposed (thick blue line, from Wu & MacFadyen 2018). Before the peak, the detected emission was dominated by radiation coming from mildly relativistic material at large angles (i.e., the "wings"). At the peak, the jet core came into view and dominated the observed emission. Extrapolating the current flux decay rate, Chandra will be able to detect GW170817 for ~5 yrs after the merger, while with Lynx, the proposed successor to Chandra, we could monitor the evolution of GW170817-like systems for ~30 yrs after the merger.

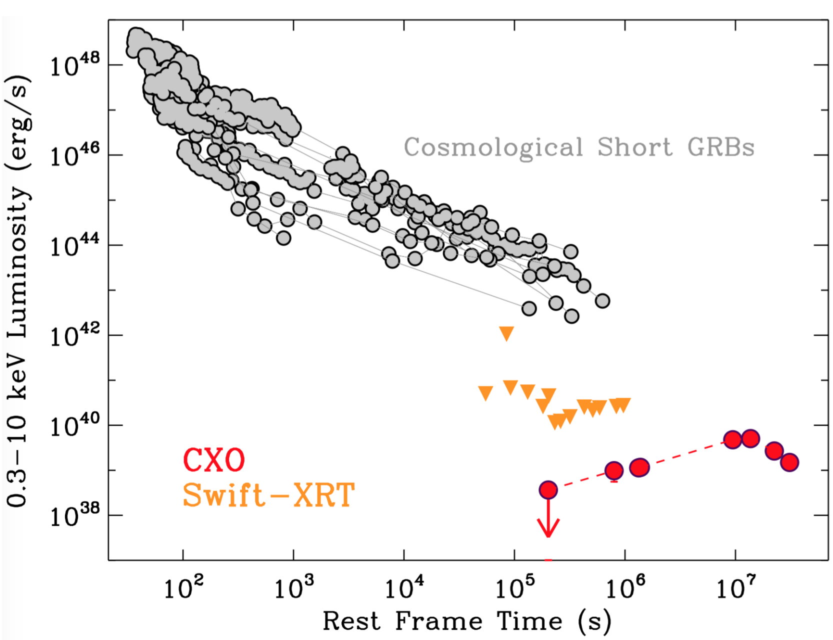

Figure 4: Comparison of the X-ray emission from GW170817 detected by Chandra (red filled circles, Alexander 2018; Haggard et al. 2017; Margutti et al. 2017, 2018; Nynka et al. 2018; Ruan et al. 2018; Troja 2017, 2018) with X-ray afterglows from cosmological short GRBs (Fong et al. 2015). The rising X-ray emission from GW170817 up to t<150 days and its low luminosity (despite being significantly closer than all previously detected SGRBs) sets GW170817 apart from all SGRB afterglows observed thus far. After the peak, the decline of the emission from GW170817 is consistent with SGRB afterglows extrapolated to later times. This phenomenology is expected from emission due to a jet pointed away from our line of sight. The entire jet becomes visible to the observer around the time of the peak. At this point the observed evolution of an off-axis jet (like the one in GW170817) and on-axis jet (like those of SGRBs) is similar. The proximity of GW170817 has allowed us to monitor the emission from a relativistic jet launched by a BNS merger to an unprecedented epoch of ~400 days. Further Chandra observations are ongoing.

properties of a relativistic jet similar to those observed from SGRBs. However, for the first time, thanks to our off-axis perspective, in GW170817 we can appreciate the presence of angular structure in the outflow outside the jet core, imprinted by the BNS collision. The major conclusion from this effort is that at least some SGRBs are indeed the result of the merger of NSs, as predicted ~30 years ago (Eichler et al. 1989, Narayan et al, 1992).

Other Sources of X-ray Emission in Compact Object Mergers

In GW170817 all of the X-ray emission detected thus far (~400 days since merger) is dominated by radiation from the deceleration of a relativistic outflow in the BNS environment that is directed away from our line of sight. However, there are other potential sources of X-ray emission that might be relevant in other GW events, or even manifest in the future evolution of GW170817. Here we discuss two other possible sources of X-ray emission in BNS mergers: (i) X-ray emission from the KN ejecta interacting with the medium; (ii) direct emission from the compact object formed by the merger.

In analogy with supernovae (e.g., Chevalier & Fransson 2006), the propagation of the KN ejecta in the BNS merger environment is expected to transfer kinetic energy to the circum-binary medium, and accelerate particles and electrons, which will radiate through synchrotron emission. The emission is expected to be brighter and peak when a sizable fraction of the kinetic energy of the ejecta has been transferred to the medium, and the ejecta are decelerating. This process has been investigated in the specific context of KNe at radio wavelengths (Nakar 2011) where, due to the typically low densities expected in BNS merger environments ($n < 1$ cm^{-3}), deceleration happens on long time scales. In the specific case of GW170817, the inferred density $n \sim 0.01$ cm^{-3} and KN ejecta mass of the order of 10^{-2} $M_\odot$ (e.g., Villar et al. 2017), imply a deceleration timescale of years.

Yet another source of X-rays in BNS mergers can be radiation coming directly from the newly formed compact object, either emission from an accretion disk around a BH, or spin-down radiation from a long-lived magnetar formed by the BNS merger. At early times $t<50$ days, for reasonable BNS ejecta mass and expansion velocities, the large optical depth of the BNS ejecta to X-ray radiation prevents the escape of X-ray photons potentially produced by an inner engine (Metzger 2017, Margutti et al. 2017, 2018). This implies that early X-ray observations are unlikely to be able to probe the intrinsic nature of the compact remnant, as X-ray photons from the remnant are unlikely to escape from the dense BNS merger ejecta and reach the observer, unless the X-ray source was powerful enough to fully photo-ionize the KN ejecta ($L_x>10^{44}$ erg/s; Margutti et al. 2017, much larger than observed in GW170817). However, it should be noted that such a large optical depth is not necessarily expected for on-axis viewers of SGRBs, since in those cases the relativistic jet can clear a low-density funnel through the ejecta perpendicular to the binary orbital plane. Our orientation to GW170817, argues against a central engine as the origin of the early X-ray emission in GW170817. In future GW events we might probe different configurations, where X-ray photons from the remnant do break out at early times.

At later times, however, the BNS merger ejecta expands and becomes transparent to X-ray photons. For standard KN ejecta parameters (mass of the order of $M_{ej}\sim0.01$ $M_\odot$ and expansion velocity $v \sim 0.1$–$0.3c$) and chemical composition, the optical depth to soft X-ray radiation is ~1 at ~100 days, thus allowing the X-ray photons produced deep inside the KN ejecta to escape and reach the observer. If the remnant object is a BH, then a possible source of long-lived X-ray emission is fallback accretion. The current X-ray luminosity of GW170817, $L_X\sim10^{40}$ erg/s, is well above the Eddington limit for a stellar mass BH, and thus far outshines X-ray emission expected from an accreting BH remnant. The constant radio to X-ray flux ratio over ~400 days of monitoring provides an independent line of evidence against the fall back accretion luminosity dominating the X-ray energy release at late times.

Alternatively, the remnant of a merger event can be a long-lived magnetar. The spin-down luminosity from a magnetar remnant is another potential source of X-ray radiation at late times. In the case of GW170817 the same magnetar engine required to explain the detected X-ray emission around 100 days would produce luminous optical emission at early times (Metzger & Piro 2014) above the observed bolometric luminosity of GW170817 (Margutti et al. 2018). The late-time *Chandra* monitoring of GW170817 emission also provides evidence against the formation of a long-lived magnetar in GW170817 (Pooley et al. 2018), which is also consistent with the inferences made from the blue colors of the early KN emission (e.g., Villar et al. 2017).

Fundamental Physics with Compact Object Mergers

Electromagnetic (EM) observations of GW events will advance our understanding of compact-object mergers, such as the physical conditions at the time of merger, and their exact locations within their host galaxies. GW observations will also shed light on the properties of their cosmic environments. EM observations of GW events may also enable potentially transformative applications outside the field of compact-object mergers, such as the equation of state of dense matter, shocks physics, and cosmology.

The amount of matter ejected by the merger and its velocity distribution are sensitive to the physical proper-

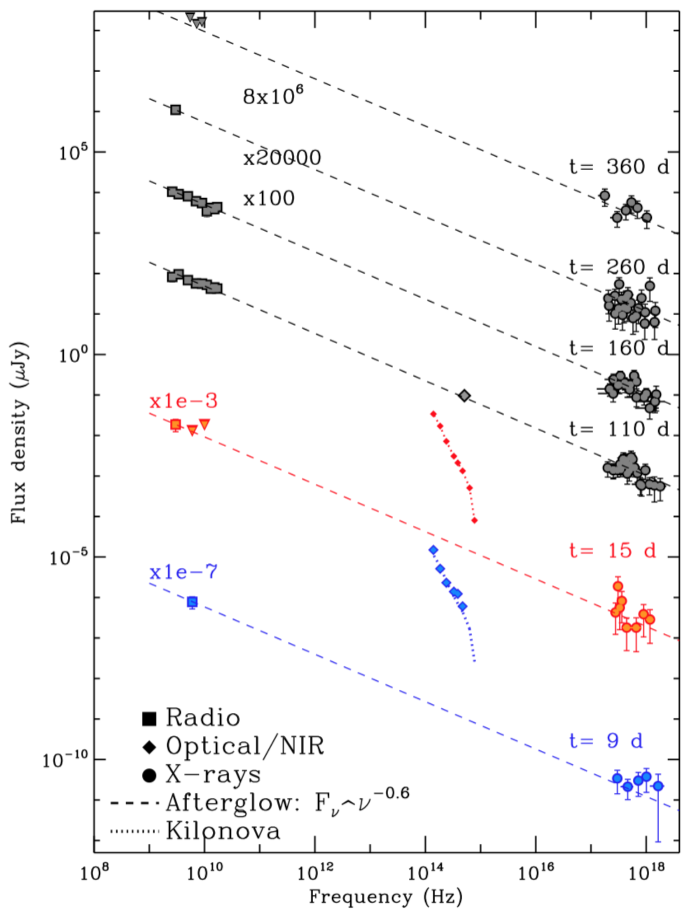

Figure 5: Broad band radio-to-X-ray spectral energy distribution of GW170817 and its (lack of) evolution in the first ~360 days after merger. The radio and X-ray data are dominated by non-thermal synchrotron emission from the GW170817 afterglow at all times and mutually consistent with $F_\nu \sim \nu^{-0.6}$ spectral power-law. Emission from the kilonova dominates in the UV/optical/NIR in the first 2 weeks, until ~100 days after merger, when the emission from the relativistic outflow dominates UV/optical/NIR. Updated from Margutti et al. 2018.

ties of the neutron stars, and, ultimately on the neutron star equation of state through their dependency on the NS radius (Metzger 2017). Astrophysical information about location within the host galaxy, an accurate distance, the inclination of the merging binary, and amount of matter ejected by the merger, all of which are derived from the analysis of electromagnetic data, can be combined with the GW strain data to produce tight constraints on the physical properties of the system, including the tidal deformability of neutron stars (e.g., Coughlin et al. 2018).

Additionally, the fastest relativistic outflows from mergers of compact objects constitute unparalleled physical laboratories for matter under extreme conditions that cannot be tested on Earth. While shocks (and the particle acceleration that follows) are ubiquitous phenomena in our Universe and regulate the emission that we observe from stellar explosions to disruptions of stars by supermassive black holes, fundamental questions remain unanswered. Among the most interesting are: (i) What is the maximum energy of particles accelerated by shocks?, (ii) What is the decay rate of the magnetic field behind the shock?, and (iii) What is the contribution of upstream particles to the observed emission? (Sironi et al. 2015). Addressing these questions will profoundly impact our understanding of the physics of particle acceleration. From an observational perspective, the key advantage of GW170817 has been an extremely well behaved simple power-law spectrum extending for more than nine orders of magnitude in frequency across the electromagnetic spectrum (Fig. 5) for ~400 days since the merger. This enabled the most precise spectral slope measurement of radiation due to particle acceleration from a relativistic outflow ($F_\nu \sim \nu^{-0.585}$; Alexander et al. 2018, Margutti et al. 2018, Troja et al. 2018). This precise measurement allowed us to estimate the shock Lorentz factor (Γ=3–10) — independent from the assumptions on the geometry of the outflow (Γ~3). Future GW events can be fashioned into real-time probes of relativistic shock acceleration.

Finally, joint studies of GW and EM radiation can provide independent constraints on cosmology. Significant disagreement remains between the expansion rates of the universe inferred from supernovae and from the cosmic microwave background (Riess et al. 2016, The Planck Collaboration 2016). This disagreement might signify the failure of the standard cosmological model and hint at new cosmological physics. GWs can provide a third independent measurement through the use of GW sources as standard sirens (Schutz 1986), i.e., sources that can be used to measure distances in our Universe. However, standard GW-based approaches suffer from degeneracies with other parameters (e.g., the inclination of the initial orbit of the two merging objects with respect to the observer) that limit their impact on cosmology. The inclination-distance degeneracy that is inherent in GW studies can be broken by the independent inclination measurement derived from modeling the electromagnetic emission from the merger's outflows, as shown for GW170817 in the pilot study by Guidorzi et al. 2017. In GW170817, based on modeling of the non-thermal radio and X-ray emission, a number of independent studies concluded that the jet launched by the merger was oriented ~30° away from our line of sight (e.g., Wu et al. 2018). The combined GW and electromagnetic observing program can significantly enhance the scientific impact of compact-object mergers on cosmology, and has the potential to solve one of the most challenging riddles posed by the cosmos: how fast is the Universe expanding?

The Future: Discovery Frontiers

Multi-messenger Astrophysics with GWs is a young and rapidly-evolving field. Although there is uncertainty about the future of a field wherein only one astrophysical object has been studied, some aspects of the future landscape are predictable.

First, among the list of potential MMA discoveries is the merger of a neutron star with a black hole. Black hole mergers are now routinely detected by LIGO/Virgo (Abbott et al. 2018); yet, unambiguous evidence for electromagnetic counterparts is still missing. The Fermi detection of gamma-rays associated with the binary black hole merger GW150914 (Connaughton et al. 2016) was very intriguing. A major future discovery will be the detection of radiation from a binary BH merger at multiple wavelengths. Finally, establishing the distribution of the intrinsic properties (ejecta masses, colors, energetics) from a population of BNS mergers may be within reach by the end of the next LIGO/Virgo observing run in 2019/2020.

The expected increase in the number of functional GW interferometers in the next decade (Abbott et al. 2018b) will substantially increase the localization accuracy of sources and, thus, improve the identification of electromagnetic counterparts. However, with the increased sensitivity, future GW interferometers will probe more distant populations of sources since GW interferometers are sensitive to the gravitational strain h, which scales as ~1/d (where d is the distance to a source), while EM telescopes are sensitive to the energy flux, which is proportional to ~1/d^2. The proposed A+ upgrades (*https://dcc.ligo.org/LIGO-T1800042/public/*) to Advanced LIGO (as early as 2025) will be sensitive to BNS mergers up to ~400 Mpc, which is a factor ~10 more distant than GW170817. At such a large distance, even the peak X-ray emission detected from GW170817 would fall below the *Chandra* detection threshold. Improved GW interferometers lead to farther GW sources with exceedingly faint X-ray counterparts, necessitating the need for larger collecting areas in future generation X-ray telescopes, such as Lynx (*https://www.lynxobservatory.com/*).

Meanwhile, if no additional GW+EM detections are made, *Chandra* and its successors will keep us busy monitoring the X-ray emission from GW170817 for the next 30 years (Fig. 3).

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Director's Log, *Chandra* Date: 670723206

Belinda Wilkes
https://twitter.com/BelindaWilkes

This year, 2019, marks *Chandra's* 20th year of operations. Multiple anniversaries start with the launch on the shuttle Columbia on 23rd July 1999. We are planning many forms of celebration, opening with an updated, large conference exhibit launched in Seattle at 233rd meeting of the American Astronomical Society (AAS). The meeting also featured a spectacular Plenary talk highlighting 20 years of ground-breaking *Chandra* science given by Ryan Hickcox (Dartmouth College) and a special HEAD session delving into more detail on selected sub-topics. The AAS events and exhibition booth were a great success, particularly the "*Chandra* photo booth" where visitors could pose in front of a new large artist's impression of *Chandra* and have a button of their photo created at the booth. Multiple talks (scientific and public) and exhibits are being organized throughout the year. These include special sessions at both the High Energy Astrophysics Division (HEAD) of the AAS and American Physical Society's (APS) Division of Astrophysics (DAP) meetings, and colloquia and public lectures in departments, planetariums and museums all over the US. We are generating new products, including pins, stickers, handouts, posters, 3-D images, and are preparing two books: for the community, an e-book reviewing 20 years of *Chandra* science results; and for a broader audience, a picture book of *Chandra* images. The year will close-out with a major international conference, 20 years of *Chandra* Science, in Boston in early December. For more information on our various activities and events, and/or to get involved, visit our 20 year events website http://cxc.cfa.harvard.edu/cdo/chandra20/. Please join us wherever and whenever you are able!

I have been working for *Chandra* since 1995, starting as Deputy Leader of the User Support Group (USG). Prior to that, I had been involved in preparing the successful SAO proposal to host the *Chandra* X-ray Center a number of years earlier. Working on *Chandra* has been, and continues to be an amazing experience. *Chandra* is a ground-breaking mission in the fullest sense of the word. It provides spatial resolution of ~0.5 arcsecs in the X-rays, comparable to ground-based telescopes for the first time, and is unique among all operating or planned X-ray missions. *Chandra*'s X-ray vision reveals the hottest and most violent places in the universe where much of the action is invisible to other wavebands. *Chandra* peers through dense gas and dust to find the youngest stars, and into the distance to find the oldest supermassive black holes in their youth. This new window on the Universe has resulted in exciting new discoveries and advanced our understanding of celestial sources across the full range of astrophysics, from exoplanet atmospheres to cosmology, through the birth, life and death of stars, to the unexpectedly tumultuous lives of clusters of galaxies, and the profound effects a relatively tiny, but massive, central black hole has on its host galaxy, and beyond. *Chandra*'s Legacy continues to grow, so stay tuned!

Like all ground-breaking new technology, *Chandra* was a long time in the planning. The first sketch of an imaging X-ray telescope, presented in a 1963 white paper on X-ray astronomy led by Riccardo Giacconi, looked amazingly similar to the final accepted design for what was then called the Advanced X-ray Astrophysics Facility (AXAF). This first seed grew into a mission unanimously approved by the 1980 Decadal Survey Panel as its highest priority for a major new program. Then followed years of designing and building the instruments, the spacecraft, and the greatest technological challenge: building and polishing the mirrors to the incredibly smooth and accurate surfaces required to focus at grazing incidence to <1 arcsec. For overcoming this last challenge we are forever grateful to Telescope Scientist, Leon Van Speybroeck, who sadly died in Dec 2002. We carried out 6 months of detailed ground calibration of the mirror and telescope system at the Marshall Space Flight Center (MSFC) X-ray Calibration Facility. Following this, the satellite was integrated, and successfully launched on 23rd July 1999.

Many dedicated, brilliant people worked together to bring *Chandra* to fruition, and many more continue this legacy in operating, supporting and carrying out science with *Chandra* over 20 years and counting. I joined the project in 1995 in time to take part in the ground calibration at MSFC, and to assist Fred Seward (my immediate boss) and the rest of the USG in preparing for and running the first *Chandra* proposal cycle and peer review in advance of launch. I also attended the launch. Having made a trip of it, with my husband and two small children, we were still in Florida for the third, and successful attempt on 23rd July. This is the only space shuttle launch I have witnessed, what an amazing experience! I cannot even begin to acknowledge all those who have worked on *Chandra* and contributed to its huge success. Most obvious are Riccardo Giacconi (Nobel Prize winner) and Harvey Tananbaum who spearheaded the original proposal. The incredible team of CXC Director, Harvey Tananbaum, Project Scientist, Martin Weisskopf (MSFC), and CXC Manager, Dr. Roger Brissenden, led the project from well before I joined the CXC, and together built the Project team and culture that make it the success it is today. It was my great honor and privilege to be selected to succeed Harvey as Director of the CXC when he retired in 2014. I thoroughly enjoy working with Martin, Roger, and Helen Cole, the MSFC Project Manager, and the amazingly talented and dedicated *Chandra* team, to continue our exciting journey to expand *Chandra*'s scientific legacy.

Coincidentally, 2019 also marks a major milestone in the opening of a new operations control center (OCC) in Burlington, MA. As described in the Manager's report (page 11), this move was required when the lease for our Cambridge, MA facility was not renewed. We completed our transition to the new location in the second quarter of this year. NASA's support of this move along with their recent extension of the SAO contract to potentially operate through 2027 with a subsequent 3-year closeout demonstrates their strong commitment to the *Chandra* mission.

While operations become more challenging due to the need to continually monitor and control the temperature of multiple subsystems as a result of degradation of the thermal insulation, the innovation and diligence of the operations and planning teams has resulted in *Chandra* continuing to maintain its high observing efficiency (70%; also see the Program Manager's Report on page 11). To maintain high efficiency as sub-system temperatures continue to increase, we recently initiated a new observing program aimed at increasing the number of *Chandra* cool targets (CCTs, formerly known as Cool Attitude Targets [CATs]) in the *Chandra* observation catalog (see page 38). The call for white papers of well-defined and large lists of targets at cool spacecraft attitudes that could yield scientifically interesting results generated a large and enthusiastic response from the community and was timely. The need for CCTs has increased since our return to normal operations following the gyro-based safemode which occurred in October and resulted in unplanned additional heating due to the newly implemented mixed gyro mode in which we are now operating (see Project Manager's Report on page 11). Approved CCT targets have been included in our schedules since early in the year. Our website provides links to details of the approved CCT programs (*http://cxc.cfa.harvard.edu/target_lists/CCTS.html*) and a list of observed CCT targets, which are non-proprietary (*http://cxc.cfa.harvard.edu/cda/CCT.html*).

The 2018 summer workshop, entitled "Accretion in Stellar Systems" held 8-10 Aug in Cambridge, MA, was a great success. Seventy-five attendees from all over the world discussed various aspects of stellar accretion. The program also included a special session dedicated to the late Jeff McClintock's (see article on page 40) legacy to the field, along with an evening of reminiscences and tributes to his impact on both our field and ourselves. Other activities during the year included *Chandra* exhibits at the AAS in Denver, CO, and the International Astronomical Union (IAU) in Vienna, Austria, both featuring demonstrations of the *Chandra* Source Catalog version 2.0, for which data is publicly available. The IAU *Chandra* exhibit saw a lot of traffic from an international community, which we rarely meet, and also won an award for being one of the "greenest" booths at the meeting based on IAU instructions to minimize handouts and emphasize online content!

The Cycle 21 Call for Proposals, released in Dec 2018, ushered in new proposal submission software, the *Chandra* Proposal Software (CPS), replacing our long-time, ancient workhorse "RPS" (Remote Proposal Submission). CPS requires a username and password account from which one can prepare, manage, review, update, and submit proposals, as well as providing access to co-Is. It is well-designed and generally easy to use, but as always we would love to hear your feedback as we work to improve and expand it (see page 51).

The saddest news of the past year was the death, in Dec 2018, of Dr. Riccardo Giacconi (page 12). Many of our team and our community worked closely with Riccardo from the earliest days of *Chandra*, and many more knew him well and/or interacted with him over the years, even as he expanded beyond X-rays to be a driving force in multiple other areas of astronomy. A slew of paper and web-based articles honoring his legacy were published, many by past or current members of the CXC staff. A fitting farewell to the father of X-ray astronomy and "our" Nobel Prize winner!

Project Scientist's Report

Martin C. Weisskopf

We note that this write up includes material from the draft of the prolog, written by Harvey Tananbaum and myself, to the ebook being prepared as part of the activities celebrating 20 years of Chandra operation.*

It turns out to be a bittersweet moment as we enter *Chandra*'s 20th year of operation. It is sad that this momentous anniversary effectively coincides with the recent passing of Riccardo Giacconi, who truly was the father of our field. I know that those associated with *Chandra* feel his passing on a personal level, as we belong to the many privileged to have been able to facilitate his vision of the 10-meter focal length X-ray telescope to probe, amongst many other things, the nature of the once unresolved X-ray background. More personally, I owe my position as the *Chandra* Project Scientist to Riccardo, without whose blessing and confidence I would not have had the opportunity to help build and operate one of humanity's greatest scientific "cathedrals".

*"The *Chandra* X-ray Observatory: Exploring the high energy universe", Eds. B Wilkes and W Tucker (Bristol: IOP Publishing Ltd) AAS-IOP ebooks *https://iopscience.iop.org/bookListInfo/aas-iop-astronomy*

As we look backwards, I feel fortunate that I, and the Project Science Team at Marshall Space Flight Center (MSFC), have been able to contribute to the success of *Chandra*. The entire community should take pride in its amazing accomplishments under MSFC's leadership. *Chandra* is one of the most successful astrophysics missions ever flown—successful on a myriad of metrics including cost, schedule, performance, and scientific output of an observatory designed for 3 years of operation with a goal of 5 and now in the midst of its 20th year. This success was the result of a momentous team effort involving scientists and engineers—members of Riccardo's (and then Harvey's) Mission Support Team prior to launch which then morphed after a competition into the *Chandra* X-ray Center run by SAO and MIT. Kudos to the Instrument teams and their original PIs (ACIS: Gordon Garmire, PSU; HRC: Steve Murray (deceased), SAO; LETG: Bert Brinkman, SRON; HETG: Claude Canizares, MIT) for developing the instruments which continue to serve the science community so well. Thanks to our prime contractor (TRW at the time, now Northrop Grumman) and the outstanding subcontractors such as Hughes Danbury Optical Systems (mirrors), Eastman Kodak (HRMA) and Ball Aerospace (SIM, ACA) to name a few. No retrospective of *Chandra* accomplishments would be complete without acknowledging the major contribution of the Telescope Scientist, Leon Van Speybroeck (also deceased).

The *Chandra* launch was scheduled for Tuesday, July 20, 1999. Notable celebrities in attendance included First Lady Hillary Clinton, composer/singer Judy Collins, who wrote and performed an original song in honor of Shuttle Commander Eileen Collins, the 1999 FIFA World Cup Champion U.S. women's soccer team, and the actor Fabio. Many of the notables were present, at least in part, to note the milestone of having the first female commander for a Shuttle mission. For his part, Fabio had received an invitation to attend as a guest of Mission Specialist Cady Coleman, although the invitation was actually extended by Cady's fellow crew members without her knowledge as a tension breaker of the sort often employed by the astronauts.

The countdown proceeded flawlessly until an indicator showed a possible fuel leak and the launch was aborted approximately seconds before liftoff. Subsequent analysis showed that the reading had been spurious, but of course no one knew that when the liftoff was canceled. Since the abort had occurred before the main engines had ignited, there would only be a 48-hour delay before a second attempt to launch could proceed. At a morning weather briefing on Wednesday, the lead meteorologist reported a zero percent chance of weather impacts for the launch. On the bus ride to the viewing bleachers that evening we saw regular light flashes. Alas, the flashes were due to lightning which had not been present on the earlier evening. Another delay.

Following another 24-hour wait, we were treated to a spectacular launch at 12:31 AM (EDT) on July 23, 2019. The Shuttle flight itself was not without challenges. A few seconds after liftoff a short circuit took out computers controlling two of the three engines but Commander Collins decided to continue using backup computers. When the Shuttle reached its parking orbit, it was a few miles short of the targeted altitude. Later analysis showed that a small patching plug had been blown out of a hydrogen tank and a bit of fuel was lost leading to the lower altitude. This leak was not a problem for *Chandra* given the capabilities of the Inertial Upper Stage (IUS) boosters and the engines built into the spacecraft for achieving the operational orbit, but these issues did lead to a subsequent grounding of the Space Transportation System lasting several months to checkout and rework the entire Shuttle fleet.

After the Shuttle achieved its orbit, the payload bay doors were opened and, about 8 hours after launch, *Chandra* was deployed. The Shuttle then backed away and shortly afterwards the IUS was fired—each of the two stages operated flawlessly for boosting *Chandra* to an intermediate orbit of around 200 × 30,000 miles (300 × 48,200 km).

Of course, none of us were yet sure that *Chandra* would be a success. Over the next two weeks the spacecraft engines were fired 5 times to boost *Chandra* to its initial highly-elliptical working orbit of approximately 6,000 × 86,500 miles (9,700 × 139,000 km). The day after the 5th firing was also special, since it marked a flawless opening of the ACIS door which had failed in the thermal vacuum test at TRW 14 months earlier. On August 12, almost 3 weeks after launch, the aft and then the front contamination doors on the mirror assembly were opened for the first time. Over the next hour or so, the observatory continued to point stably under gyro control, then the aspect camera locked on stars, and a first X-ray source was detected by the ACIS instrument. That source was about 3 arcseconds in size and was located around 3–4 arcminutes off-axis, just about the size expected for a point source that far off-axis per feedback from Telescope Scientist Leon Van Speybroeck. I, with concurrence of the team present, nick-named the source Leon X-1. We all left that day confident (perhaps knowing) for the first time that *Chandra* was going to be a great success.

Project Manager's Report

Roger Brissenden

Reporting Period: January – December 2018

The *Chandra* X-ray Observatory has carried out more than 19 years of highly successful and productive science operations. *Chandra* is unique in its capability for producing the sub-arcsecond X-ray images that are essential to accomplish the science goals of many key X-ray and multi-wavelength investigations in current astrophysical research. The project is looking forward to many more years of scientific productivity. In recognition of *Chandra*'s important role in high-energy astrophysics, NASA has chosen to continue the mission and has extended the contract to operate the *Chandra* X-ray Observatory, potentially through September 2027.

The *Chandra* Operations Control Center (OCC), from which we conduct mission operations, is in the process of moving from its current site in Cambridge, Massachusetts, to Burlington, Massachusetts. With the OCC facility lease ending in 2019, SAO, MSFC and the Smithsonian Institution collaborated to find a new location. After defining requirements and carrying out an extensive search, we identified and leased facility in Burlington, Massachusetts. Construction of the new space has been completed and testing of the data system and operations processes is underway. Following testing and readiness reviews, operations in the new facility will begin in the second quarter of 2019. The *Chandra* OCC was one of the first control centers for a major mission to be established outside of a NASA Center and we are pleased to continue operations for the mission in such an excellent facility.

The Observatory continues to operate extremely well overall, but with a number of incremental changes in performance. The gradual accumulation of molecular contamination on the UV filter that protects the ACIS detector reduces ACIS's sensitivity to low-energy X-rays (but does not affect the HRC). Recent measurements indicate that the accumulation rate of the contamination has decreased over the past year. Overall spacecraft heating due to the slow degradation of *Chandra*'s multi-layer thermal insulation requires extra effort in scheduling observations, but has not significantly affected *Chandra*'s observing efficiency. A 3-second burst of noise from one of *Chandra*'s gyroscopes led to a spacecraft safe mode in October 2018. Although the gyroscope has operated nominally since, to minimize risk the decision was made to hold that gyro in reserve and reconfigure the flight software to use one gyroscope from each of Chanda's two inertial reference units. The need to operate with both units powered on has caused an additional thermal load, adding to scheduling constraints. The safe mode resulted in a loss of ~900 ks of science time. Following the safe mode recovery, *Chandra* returned to nominal science operations.

The combined effects of accumulated radiation damage and increasing temperature on *Chandra*'s aspect camera CCD have begun to affect the camera's ability to detect faint stars. Left unchecked, this trend would present difficulty in acquiring and tracking guide stars, which could decrease mission efficiency or preclude observation of some targets. Several mitigation strategies have been successfully implemented, including development of an update for the aspect camera processor software to improve robustness of star tracking.

Release 2.0 of the *Chandra* Source Catalog (CSC) is nearing completion. CSC 2.0 incorporates data from observations made public through 2014 and includes data for ~316,000 unique X-ray sources over the sky. By co-adding observations prior to source detection and using an enhanced source detection approach, CSC 2.0 detects sources with as few as ~5 net counts for low-background observations (about half of *Chandra* observations). This capability translates to about 50% more identified sources per observation than the previous CSC (version 1.1). CSC 2.0 provides tables of measured source properties, including astrometric, photometric, spectral, and temporal variability data. The catalog includes over 30 TB of science-ready FITS-format data products that enable immediate analysis of detected sources without manipulating the underlying data. In addition, the catalog provides the full field of view for each observation, allowing users to carry out their own detailed analyses. Source- and field-based data products, including images, spectra, light-curves, and instrument responses, are accessible through multiple interfaces, including the CSCview data-mining application.

In response to the December 2017 call for proposals for Cycle 20 observations, scientists worldwide submitted 527 proposals, including 431 proposals for observing and 96 for archive and theory research. The observing proposals requested a total of 9.9 Msec of telescope time, an over-subscription factor of approximately 6. The Cycle 20 peer review, held in June 2018, approved 133 observing proposals and 24 proposals for archive and theory research. The call for proposals for Cycle 21 observations was issued in December 2018.

NASA announced the selection of 24 Fellows for the 2018 NASA Hubble Fellowship Program (NHFP), which supports postdoctoral researchers performing research across all of NASA astrophysics. NHFP postdocs are named as Hubble, Einstein, and Sagan fellows, depending on their research topics. Seven of those selected for the 2018 NHFP were named as Einstein Fellows. The Einstein Fellows Symposium was held at the Center for Astrophysics | Harvard & Smithsonian on October 2–3, 2018.

The CXC hosted a workshop, "Accretion in Stellar Systems" at the Sheraton Commander during August 8-10, 2018. The workshop brought together researchers working on accretion, outflows, and related processes in diverse astrophysical objects. The workshop included a special session dedicated to the late Jeffrey McClintock's legacy to the field.

The *Chandra* Press Office has been active in issuing image releases, science press releases and other communications of *Chandra* research results. A complete listing is available at http://chandra.harvard.edu/press. The annual Newsletter, which was released and distributed in April 2018, can be found online at: http://cxc.harvard.edu/newsletters/. Information about the *Chandra* Observatory and the *Chandra* X-ray Center can be found at http://cxc.harvard.edu/.

Twenty Years of *Chandra* Celebrations

Check out the calendar of events for complete info:
http://cxc.cfa.harvard.edu/cdo/chandra20

SPECIAL CONFERENCE SESSIONS: at various science conferences in 2019

COLLOQUIA: A nationwide series of Chandra-focused colloquia are in progress.

INVITATION-ONLY SPECIAL EVENTS: A special event is planned at the National Air & Space Museum. A private event will be held on July 23 at the new Chandra Operations Control Center (OCC) in Burlington, MA.

EVENTS OF GENERAL INTEREST: Pub nights, Astronomy on Tap events (AoT; https://astronomyontap.org/), a planetarium show, public talks and other public events have been planned to take place this year.

ART EXHIBIT: Chandra image panels and a 3D virtual reality station featuring the supernova remnant Cassiopeia A will be on exhibit at the Pryor Art Gallery on the campus of Columbia State Community College (TN).

BOOKS AND ARTICLES: Two books focusing on Chandra's 20 years of science will be published. One is a book of images to be published by Smithsonian Publishing. The other is a compendium of science commentary in an e-book format published through the Institute of Physics (IOP). Potential magazine articles might appear in Physics Today, Astronomy, Sky & Telescope, and RAS.

20 YEAR CELEBRATION MEMENTOS: No Chandra celebration would be complete without handouts! A new series of postcards, a bookmark, sticker, temporary tattoos, and two posters will be made available at various public events. Pins, buttons, pens, and other items are being handed out at the larger scientific events.

Remembering Riccardo Giacconi: The Father of X-ray Astronomy

Nobel prize-winner, and one of the most influential figures of modern astrophysics, Riccardo Giacconi died on 9 December 2018, at the age of 87. On the occasion of his passing, we present a brief retrospective on the father of X-ray astronomy, the originator of *Chandra*, a mentor, and a friend.

Over his unparalleled career, Riccardo opened up a new window for observing the universe, and as director or guiding force for major observatories spanning ten decades in wavelength, he revolutionized the way "big astronomy" is done.

From 1959 through 1981, first at American Science & Engineering and later at the Harvard-Smithsonian Center for Astrophysics (CfA), Riccardo created and led the group that discovered the first X-ray sources outside our solar system, found the first convincing evidence for the existence of black holes, developed the first focusing X-ray telescope and laid the foundation for the *Chandra* X-ray Observatory. In 1981, he became the first director of the Space Telescope Science Institute (STScI) and played a leading role in repairing the flawed optics for the *Hubble* Space Telescope. From 1993 to 1999, as director of the European Southern Observatory (ESO), he guided the development of the Very Large Telescope (*VLT*). After leaving ESO in 1999, Riccardo became President of Associated Universities, Inc. (AUI), the managing organization of the National Radio Astronomy Observatory (NRAO), and the North American Executive for the construction and operation of the Atacama Large Millimeter/Submillimeter Array (*ALMA*). In 2002, Riccardo was awarded half of the Nobel Prize in physics for "pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources."

In this remembrance, we focus primarily on the arc of Riccardo's career as it relates to X-ray astronomy and *Chandra*.

Riccardo was well-versed in the classics, and often spoke of being driven, like Odysseus, to pursue virtue and knowledge. We three were privileged to accompany him in one way or another on much of his epic journey as friends and colleagues beginning in the late 1960's when, still in our 20's, we came together at AS&E in Cambridge, Massachusetts.

In the theatre, there is a point in the drama called the "insighting moment," when the main character suddenly understands what he or she must do. Riccardo's insighting moment came in 1959 at a party at the home of Bruno Rossi, a professor at MIT and a member of the Space Science Board of the National Academy of Sciences. The Space Science Board had been created in 1957 in response to the launch of Sputnik by the Soviet Union. Bruno was also chairman of the board of American Science & Engineering, a startup high-tech company formed in Cambridge a year earlier by Martin Annis, one of his former students. Annis introduced Bruno to Riccardo, and explained that Riccardo had recently been hired to be the new head of the Space Science Division at AS&E. Bruno took Riccardo aside and suggested that he should consider starting a program in X-ray astronomy, a field that would require space-borne instruments. Suddenly, Riccardo, who had been frustrated by the lack of progress in his cosmic ray physics research, saw an opportunity. He began an intensive study of X-ray optics and the state of the field of X-ray astronomy.

He learned that a group led by Herbert Friedman of the Naval Research Laboratory (NRL) had previously observed X-rays from the Sun, and had set an upper limit of 2×10^{-8} erg cm^{-2} sec^{-1} for 6 keV photons for extrasolar X-rays. Based on the strength of the solar X-rays, the expected fluxes from nearby stars would be orders of magnitude less than that. Riccardo quickly hit upon a solution: build a telescope that could focus X-rays through grazing incidence reflection. He wrote a paper with Rossi on the concept, which was submitted to the Journal of Geophysical Research in December of 1959, only two months after the conversation with Rossi. About 9 months later, he also submitted a proposal to NASA to "design, construct, and test a prototype X-ray telescope".

Concurrently, Riccardo and George Clark of MIT explored the possibility that sources such as the Crab Nebula might be much more powerful sources of X-rays than stars, a possibility also suggested by Friedman. Realizing that the development of an X-ray telescope might take a while, Riccardo began designing rocket-borne experiments with a grant from the Air Force Cambridge Research Laboratory. Although the ostensible goal was to detect fluorescent X-rays from of the Moon, Riccardo's earlier work shows that he was on the hunt for bigger game.

The rocket flights used traditional Geiger counters as detectors. His approach was to build a detector with a much larger field of view and detection area than those used by NRL and to use the anti-coincidence techniques he had learned as a cosmic ray physicist to reduce the background. As a result, his detector was about 50 times more sensitive that the NRL ones.

> *"And so my point is that X-ray astronomy is especially interesting because of these new mechanisms and you cannot simply extrapolate from ordinary temperature considerations."*
>
> *Riccardo Giacconi [1]*

On June 18, 1962, after two previous launches had ended in failure, Riccardo and his group achieved success. The rocket spent five minutes above the atmosphere. In that time, it detected a strong source in the direction of the constellation Scorpius, which they named Scorpius X-1, as well as an all-pervasive X-ray background radiation. The field of X-ray astronomy had been born!

Giacconi moved quickly to use this new window for the exploration of the universe. In 1963, he and Herb Gursky laid out a bold program for the future of X-ray astronomy that included more rocket flights, an X-ray satellite to survey the entire sky, and within 5 years, an X-ray telescope. This time they received funding from NASA, and by 1967 the development of *Uhuru*, as the X-ray satellite would come to be named, was underway.

For this project Riccardo had engineers and scientists working side-by-side to establish requirements, develop a design, construct and test the hardware, and plan the operations for the satellite. Riccardo himself was familiar with

Figure 1: Ethan Schreier, Herbert Gursky, Riccardo Giacconi, and Harvey Tananbaum at the Nobel ceremonies in Stockholm in December 2002

all of the sub-systems –knowing which were critical, which could provide back-up capabilities for others, how the science operations would be carried out, and the like. He successfully applied this approach, which he called science systems engineering, for the rest of his career, refining and extending it from the *Uhuru* and *Einstein* X-ray missions, to the *Hubble* operations at the Space Telescope Science Institute, the building of the *VLT* at ESO, and the *ALMA* development at AUI.

On a personal level, although junior scientists by university standards and relatively new to the project, we and several colleagues received assignments on the project which challenged us to our limits while providing opportunities to develop technical, management, scientific, and communications skills from the very beginning. As Paul Gorenstein, another MIT graduate who had migrated to AS&E a few years earlier, put it, "Riccardo motivated people, got them to do things. Whether he did it by inspiration or by example, he got a lot of people to deliver their best."

For previous NASA science missions, data tapes were delivered by mail several weeks after acquisition. In another departure from business as usual, Riccardo pressed NASA to transmit 20% of the data back to AS&E within 24 hours of acquisition and directed the team to develop a software system to analyze the data as soon we received it. The quick turn-around on the data enabled Riccardo and the team to make important discoveries almost immediately and to rearrange the observing schedule and satellite configuration to follow-up and exploit those discoveries.

Even though Riccardo had multiple responsibilities as a senior executive at AS&E, he set aside part of each day to work with the other scientists to analyze the latest *Uhuru* data. He set up a desk in one of our offices in a building around the corner from the AS&E headquarters, and he gave us explicit directions to reply that we had not seen him if his office called to inquire about his whereabouts.

Within a few months, the team had discovered erratic, sub-second variability in the source known as Cygnus X-1 and a regular periodicity of 4.84 seconds in Centaurus X-3. With intensive follow-ups of Cen X-3, we determined that it orbits in a binary system with a period of 2.087 days. Further observations confirmed that Cen X-3 is powered by the gravitational energy released by matter falling from the companion star towards and onto a neutron star. Subsequently, Giacconi and the *Uhuru* team, along with a number of other observers and theorists, determined that Cygnus X-1 is most probably a black hole (with a mass later established as ~15 times the mass of our Sun) orbiting in a binary system and powered by matter from a companion star matter falling towards the black hole. This finding constitutes the first observational evidence of the existence of black holes.

"It was the scientific highlight of my career. It was the most mystical moment, when we suddenly understood."
Riccardo Giacconi [2]

During the *Uhuru* period, Riccardo met weekly with the *Uhuru* science group. In these often-stormy sessions, there was wide-open give and take regarding what we were seeing, what we thought we understood, what we were clueless about, and what we wanted to do next. Ideas, however wild, were floated with abandon and shot down remorselessly. There was respect for one and all, but no claims were sacrosanct and everyone had to defend their ideas based on logic and scientific merit. *Uhuru* meetings left most of the participants drained but also built confidence—in our results, in our plans for moving ahead, and in one another.

"Looking back on that time, I recognize that those intense interactions were a rather unorthodox way of doing science and certainly not to everybody's taste. But we were young, enthusiastic, intoxicated by our daily glimpses into a mysterious new universe, and more than a little giddy with success. It was a unique period, brought about by a singular combination of circumstances, people, events, and instruments that occurs rarely in science."
Riccardo Giacconi [3]

In 1973, Giacconi's core group moved a mile and a half away to the newly organized Harvard-Smithsonian Center for Astrophysics (CfA), where it formed the High Energy Astrophysics Division. It was there that one of Riccardo's earliest visions was fulfilled, with the development and launch, in 1978, of the *Einstein* X-ray Observatory, the first imaging X-ray telescope for extra-solar sources. *Einstein* demonstrated beyond doubt the importance of X-ray imaging, finding that essentially all types of astronomical objects and systems, from nearby stars to distant quasars, emitted X-rays. Innovations on this mission included the solicitation of proposals from the general community and the development of systematic procedures and techniques to plan, schedule and archive the *Einstein* observations, thereby opening access to the observatory for the broader astronomical community. This model, new at the time, has now been adopted by essentially all NASA astrophysics missions and most ground-based observatories.

In 1976, cognizant of the limited lifetime projected for *Einstein* and confident of the prospects it would engender, Riccardo and Harvey Tananbaum proposed *Einstein*'s successor which would become the *Chandra* X-ray Observatory. Even though the *Einstein* launch was still 2.5 years in the future, the proposal was well-received and technology work on the optics and mission studies led by Marshall Space Flight Center and SAO began in 1977. By the time

Figure 2: Harvey Tananbaum, Riccardo Giacconi, Martin Weisskopf, and Claude Canizares at the Chandra 4-year Symposium in Huntsville, AL

of the 1980 Decadal Study by the National Academy of Sciences, the successes of *Einstein* made a compelling case for an even more powerful and long-lived X-ray telescope mission.

In 1981, Riccardo left CfA to become the first director of the STScI. The scientific community insisted that the scientific operations of a large, unique, and expensive new facility—the first major, international optical observatory in space, later to be christened *Hubble*—be managed by the community itself, and not by a NASA center. Riccardo insisted on leaving the CfA group intact, but recognizing the need to transfer the scientific operations philosophy from the X-ray group to the optical community, brought Ethan Schreier to Baltimore to oversee the *Hubble* operations and data system.

At STScI Riccardo used many of the same system engineering and scientific principles that had been so successful with his path-breaking X-ray astronomy satellites to create from scratch an entirely new institution. Other innovations, now standard for large astronomy projects, were introduced by Riccardo and his staff for *Hubble*. These included a formal data archive, the distribution and archiving of calibrated data, a formal archival data analysis program, an AI-based planning and scheduling system, reserved time for large and "key" programs, and freely distributed portable data analysis software. The first internet-based networking between astronomy facilities was also developed under the auspices of *Hubble*, as were other programs which became models for other observatories, such as the first community-operated grants program to support *Hubble* users.

When the error in *Hubble*'s optics was discovered, Riccardo set up working groups comprised of both STScI staff and experts recruited from around the world, from many disciplines. What had started as an embarrassment became a major success with *Hubble* becoming a household word.

In 1993, Giacconi moved to Garching, Germany, where he became the first American citizen to serve as director general of the European Southern Observatory (ESO). There he guided the development of the *Very Large Telescope* (*VLT*) which was to be 30 times larger than the previous ESO-built *New Technology Telescope*. Riccardo applied his, by then, practiced science system engineering process, fully reorganizing ESO and introducing modern management techniques. By the end of his tenure at ESO, he had implemented the systems and procedures that had been proven on *Hubble*, applying them for the first time to ground-based optical astronomy.

Even as he successfully guided the *VLT* development, Riccardo came to believe that millimeter wave astronomy should be the next major direction for European research. The United States, via the National Radio Astronomy Observatory, had also been advocating a major facility in this wavelength. Under Riccardo, ESO developed a collaboration with NRAO to build what would become *ALMA*, the world's largest ground-based astronomy facility.

After leaving ESO in 1999, Riccardo became President of Associated Universities, Inc. (AUI), the managing organization of NRAO, and the North American Executive for the construction and operation of *ALMA*. Riccardo instituted many of the same concepts at NRAO that he had developed in his early X-ray career, then refined at STScI and at ESO. NRAO simultaneously expanded the *Very Large Array*, already the forefront radio observatory in the world, while building *ALMA* with several international partners. In addition, Riccardo played a leading role in setting up *ALMA*'s governance structure, a truly worldwide collaboration of North America, Europe, and East Asia, in coordination with Chile, with no single country or region in charge. While Riccardo formally represented North American interests in *ALMA* for the US National Science Foundation, his vision for science permeated the entire project, and *ALMA*'s success is on a par with that of *Hubble*, *Chandra*, and the *VLT*.

Meanwhile *Chandra* was launched in 1999. Although Riccardo had moved on to new challenges, he had remained involved "in spirit" as many of the people he had recruited and trained played key roles in making *Chandra* a reality, including, but not limited to, Leon Van Speybroeck as Telescope Scientist, Stephen Murray as Principal Investigator for the High-Resolution Camera, and Harvey Tananbaum as first Director of the *Chandra* X-ray Center. Scientifically, Riccardo was involved as team lead for the first few years of *Chandra* observations on the *Chandra* Deep Field South.

Piero Rosati of the University of Ferrara, Italy, who did his Ph.D. thesis with Riccardo and Colin Norman at Johns Hopkins University, was a co-investigator with Riccardo on the *Chandra* Deep Field South project. Here is his recollection of this work:

"The *Chandra* Deep Field Survey (CDFS), a very long exposure in a single field, unimpeded by confusion, which Riccardo had dreamed about for decades, was planned in his ESO director office in 1998. There was some pressure on us to carry out the survey in the *Hubble* Deep Field South; on the other hand, we clearly wanted to select a field in a region in the southern sky with the lowest HI column density, as indicated by the Leiden/Dwingeloo Survey. At that point Riccardo said: "Why should we pick the HDFS? just for the glamour? We will make glamour in another field!" And so it was: the CDFS soon became the center of a coordinated multi-wavelength campaign, which included public imaging and spectroscopic observations with the *VLT*, the GOODS-South survey with *HST*/ACS, as well as deep IR, millimeter and radio observations. The CDFS has since then stimulated a staggering variety of studies, with hundreds of refereed publications, which have reached well beyond the original goal of understanding the nature of the sources making up the X-ray background, Riccardo's lifelong scientific quest."

> *"In 40 years we had improved X-ray astronomy observations between one and ten billion times with respect to the first observation of Sco X-1. I wonder sometimes how Tycho Brahe would have felt if he could have contributed to the development of* Hubble *and could have used it himself."*
>
> *Riccardo Giacconi [4]*

Riccardo retired from AUI in 2003, but stayed active at Johns Hopkins University for another decade He followed the science results from his various projects while remaining engaged in the politics of astro-science until his final days.

In summing up his extraordinary career, Riccardo said: "I am grateful to live in this heroic era of astronomy and to have been able to participate and contribute to its evolution. [5]"

We are grateful that he did, too.

Riccardo is survived by his wife, Mirella, daughters Anna and Guia, and grandchildren Alexandra and Colburn. He was predeceased by his son Marc.

ACKNOWLEDGMENT:

Portions of this article have appeared in Scientific American [6], Physics Today [7] and Proceedings of the National Academy of Science [8].

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Prepared by Wallace Tucker,
Harvey Tananbaum,
and Ethan Schreier

Chandra–Related Meetings and Important Dates

Cycle 21 Peer Review:

June 24-28 2019

Cycle 21 Cost Proposals Due:

September 2019

Chandra Users' Committee Meeting:

Fall 2019

NASA Hubble Fellowship Symposium:

Oct 21-24 2019

Cycle 21 Call for Proposals:

December 2019

20 Years of Chandra Symposium

December 3-6 2019

ACIS Update

Paul Plucinsky, for the ACIS Team

The Advanced CCD Imaging Spectrometer (ACIS) is in good health and continues to produce spectacular results approaching its twentieth year in orbit. All ten CCDs are operating nominally, the electronics are functioning well without any failures or degradations, and the flight software (SW) continues to function well without any issues.

ACIS continues to be the workhorse for *Chandra* observations, conducting over 90% of the science observations. One of the first images that ACIS acquired after launch was that of the Galactic supernova remnant(SNR) Cassiopeia A (Cas A). In that "first light" image, *Chandra*/ACIS revealed the complex morphology of this SNR and it also discovered a point source close to the center of the remnant (Tananbaum 1999). This point source turned out to be the remains of the exploded star, a particular type of neutron star known as a "Compact Central Object" (CCO, Pavlov et al. 2000, Heinke & Ho 2010, and references therein). *Chandra* has continued to observe Cas A over the years, accumulating a rich data set that allows detailed studies of the X-ray emitting plasma on small spatial scales and the temporal evolution of the emission (see Patnaude & Fesen 2007, Patnaude & Fesen 2009, and Patnaude et al. 2011). The CXC Press Office produced this image of Cas A which is not only beautiful but visually demonstrates the power of spatially-resolved spectroscopy on arcsecond scales. The different colors in the image represent emission from narrow energy bands centered on prominent lines from the dominant elements, with Si in red, S in yellow, Ca in green and Fe in purple. The dark blue represents the high-energy continuum emission. The complex structures of the different elements in this remnant are readily apparent in this image showing that the distribution of ejecta from the supernova (SN) explosion and the interaction with the reverse shock is highly asymmetric (see Hughes et al. 2000 and Hwang et al. 2004 and references therein). The amount of each element produced in the SN explosion can be estimated from these data, thus providing constraints on the explosion mechanism and the nucleosynthesis models (Laming & Hwang 2003 and Hwang & Laming 2012). The location of the forward shock is also clearly seen in this image as delineated by the dark blue emission (Gotthelf et al. 2001). Also apparent in this image is a region in which some high velocity ejecta have apparently propagated beyond the forward shock. All of these results are possible because the combination of the arcsecond angular resolution of the High Resolution Mirror Assembly (HRMA) and the spectral resolution of the ACIS CCDs allows the fine-scale structure of this SNR to be studied in exquisite detail. Our understanding of SNRs such as Cas A and the physics of SN explosions and shock interactions with interstellar material have greatly advanced because of deep *Chandra* observations such as those of Cas A.

The ACIS hardware is in excellent shape, all equipment is operating on the primary side after nearly twenty years in orbit. The charge transfer inefficiency (CTI) of the CCDs continues to increase at a low rate (dCTI/dt = 2×10^{-6} yr^{-1} for the FI CCDs and dCTI/dt = 1×10^{-6} yr^{-1} for the BI CCDs) such that the scientific performance will not change significantly for many years. The ACIS flight SW has been patched six times since orbital activation and checkout to provide enhancements and a seventh patch is under development to allow ACIS to monitor its electronics temperatures and to send a signal to the *Chandra* on-board computer (OBC) to cease science observations if the temperatures exceed limits. In addition, the *Chandra* operations team has been verifying the EEPROM version of the flight software monthly since 2016 and the data indicate no corruptions in this memory after nearly twenty years in orbit.

The contamination layer continues to accumulate on the ACIS optical blocking filters (OBFs), however there have been significant changes over the last several years. The contamination is behaving differently on the ACIS-I filter compared to the ACIS-S filter. The accumulation rate at the center of the ACIS-I OBF from 2017 to 2019 is more than 5 times lower than it was from 2015 to 2017. While the accumulation rate at the center of the ACIS-S OBF has been roughly constant over the same period, with perhaps a small decrease in the accumulation rate in the 2017 to 2019

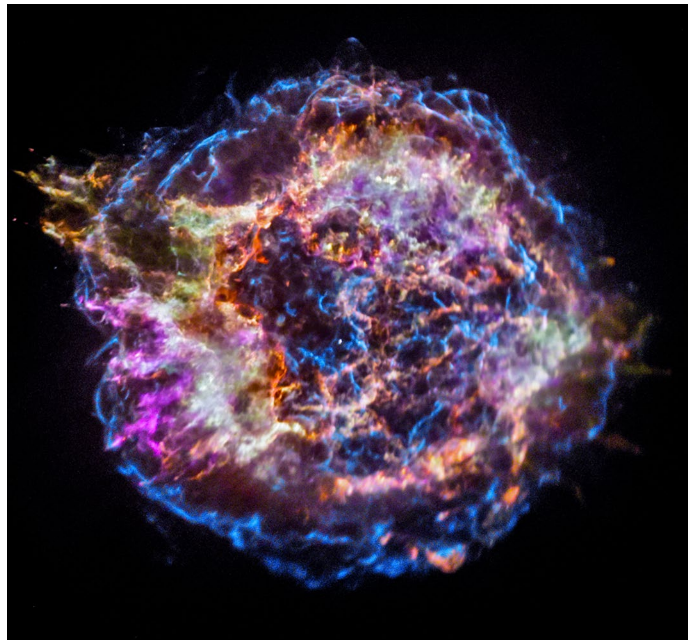

Figure 1: ACIS-S3 image of Cassiopeia A based on over 1.3 Ms of archival observations. The different colors represent narrow energy bands around prominent emission lines of the following elements: Si(red), S(yellow),Ca(green), and Fe(purple). The dark blue indicates the high-energy continuum. The CCO is visible as the white point source near the center.

period. The contaminant had accumulated faster at the center of the ACIS-I OBF than at the center of the ACIS-S OBF prior to 2017, with the the current ACIS-I thickness about 5% larger than the current ACIS-S thickness. One possible explanation is that the contaminant accumulated faster on the ACIS-I OBF because that filter has a larger view factor to the *Chandra* Optical Bench Assembly (the presumed source of the contamination) and now the contaminant is redistributing amongst the two filters as the center of the ACIS-I OBF is most likely slighty warmer than the center of the ACIS-S OBF. The details of the analysis are presented in an SPIE paper, Plucinsky, Bogdan, & Marshall 2018. Future observations will be crucial to monitor the behavior of the contamination layer. The CXC will continue to acquire calibration observations of A1795, E0102 and Mkn 421 to characterize the contaminant and to produce updated contamination files. Over the last year, the CXC has released two updates to the contamination file: N0011 in CALDB 4.7.9 with an updated ACIS-I model and N0012 in CALDB 4.8.1 with an updated ACIS-S model.

ACIS was properly safed during the 2018 October safe mode and there were no adverse effects on the instrument. The ACIS Operations Team (AOT) took advantage of the time available during the safe mode recovery to collect calibration data from the external calibration source (ECS) at a variety of focal plane (FP) temperatures. The ECS is a radioactive ^{55}Fe source with a half life of 2.73 years, meaning the flux is less than 1% of what it was at the start of the mission. Therefore, any additional ECS data are a significant benefit toward maintaining the calibration of ACIS. The AOT executed four realtime procedures during the recovery that resulted in a total of 315 ks of data at a range of temperatures from -119.7 C to -109.0 C. A large fraction of the data were acquired at FP temperatures near -114.0 to -115.0 C which will be particularly useful to calibrate the current response of the CCDs at those temperatures. The calibration team had been considering dedicated measurements at these temperatures and those new measurements may not be necessary now.

The thermal properties of the spacecraft and ACIS continue to be a major concern for the AOT as the observatory ages. The AOT team spends a substantial fraction of its time developing and maintaining thermal models that are used to predict the ACIS electronics and FP temperatures for a given week of observations. Observers are advised to read sections 6.20 and 6.22 of the Proposers Observatory Guide for the details that might affect their observations. The most significant change, which was implemented in Cycle 20, is that proposers may request up to 4 CCDs as required CCDs at the time of proposal submission. If a 5th and 6th CCD are desired, they must be requested as optional at the time a proposal is submitted. ACIS can still execute observations in any part of the sky that is currently visible with careful planning, but proposers should be aware that the uninterrupted durations of those observations may be limited depending on the spacecraft thermal environment at that time.

As with any project that spans two decades, the *Chandra* project has had it share of key personnel that have moved on to other projects or have retired. The ACIS team will celebrate Richard Edgar's many contributions to the *Chandra* project as he plans to retire this year. Richard started on the *Chandra* project as a member of the Mission Support Team that was integral in designing the measurements and analyzing the calibration data of the HRMA's properties at the X-ray Calibration Facility (XRCF) at MSFC. After launch, he transitioned to the calibration team within the CXC where he continued working on the HRMA calibration and began to work on calibration issues for ACIS. In particular, he was deeply involved in the creation of the maps of the charge traps in the CCDs that are a critical part of the CTI correction software. In 2013, Richard transitioned to the AOT and has been a valuable contributor ever since. He is an expert in Solar weather and has become critical in the development of thermal models for ACIS. Richard has over twenty years experience with different aspects of the *Chandra* mission and his expertise will be sorely missed. We wish him the best in retirement and look forward to any new novels he might write. The ACIS team will also celebrate the partial retirement of two key members from the instrument team at MIT. Robert Goeke, the ACIS Project Engineer, and Peter Ford, the ACIS Flight SW Manager, are both working part-time. Both Robert and Peter continue to make significant contributions to the current operation of ACIS and we are grateful that they are still available to answer questions and work on urgent issues.

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HRC Update

Grant Tremblay, Ralph Kraft,
Paul Nulsen, Dan Patnaude,
Esra Bulbul, & Bradford Snios

The High Resolution Camera (HRC) approaches its twentieth year of flight as healthy and productive as ever. From the shining poles of Jupiter to black holes in the distant Universe, *Chandra*'s sharpest eye continues to enable world-class science across the breadth of astrophysics.

Among the many exciting HRC results from the past year is a discovery found in the relativistic jet launched by a supermassive black hole. Peering into the heart of M87—the enormous central galaxy of the Virgo cluster—Snios et al. (2019) report results from two HRC-I observations spanning 5 years (2012–2017) in search of proper motions and brightness changes in X-ray emission along M87's jet. While proper motions have long been observed in radio and optical jets for a number of nearby active galaxies, Snios et al. have detected them in X-rays for the very first time, with superluminal motions up to 6.3 ± 0.4c (or 24.1 ± 1.6 mas yr^{-1}) observed parallel to the X-ray jet axis. Proper motion estimates are found for the two innermost knots, *HST*-1 and Knot D, while upper limits are placed on the remaining jet features.

Snios et al. compare these new X-ray results with previous measurements from optical and radio bands, and excellent agreement is observed both in spatial positions and proper motion speeds. It is therefore highly probable that the X-ray emission regions are co-moving with the emission regions observed in UV, optical, and radio. Brightness variations up to 53% are detected for the X-ray knots. By modeling the knots, synchrotron cooling is found to be the most probable source of the observed fading. Using the synchrotron cooling models, lower limits on magnetic field strengths of 700 μG and 150 μG were found for Knots *HST*-1 and A, respectively.

This remarkable result is thanks to the HRC's exquisite angular resolution. Offering the best point spread function available on *Chandra*, the HRC is capable of measuring proper motions on scales of better than 0.125″, thanks to the sharpness (and stability) of its imaging capability. In fact, the Snios et al. limit on Knot D's proper motion is only 50 mas (0.05″)—a spatial scale one order of magnitude finer than the PSF delivered by the High Resolution Mirror Assembly (HRMA). This is, therefore, one of the highest spatial resolution X-ray results ever obtained.

Meanwhile, the HRC remains stable and healthy, and the Instrument P.I. and Calibration teams have made substantial progress in optimizing the performance of the instrument. Even as we approach the twentieth launch anniversary of *Chandra*, the teams have managed to improve the background rejection algorithm employed in the data reduction pipeline over the past two decades. They are now testing the algorithm across the entire HRC database to quantify the percent improvement users might expect to see should they opt-in to a possible public release of this modified algo-

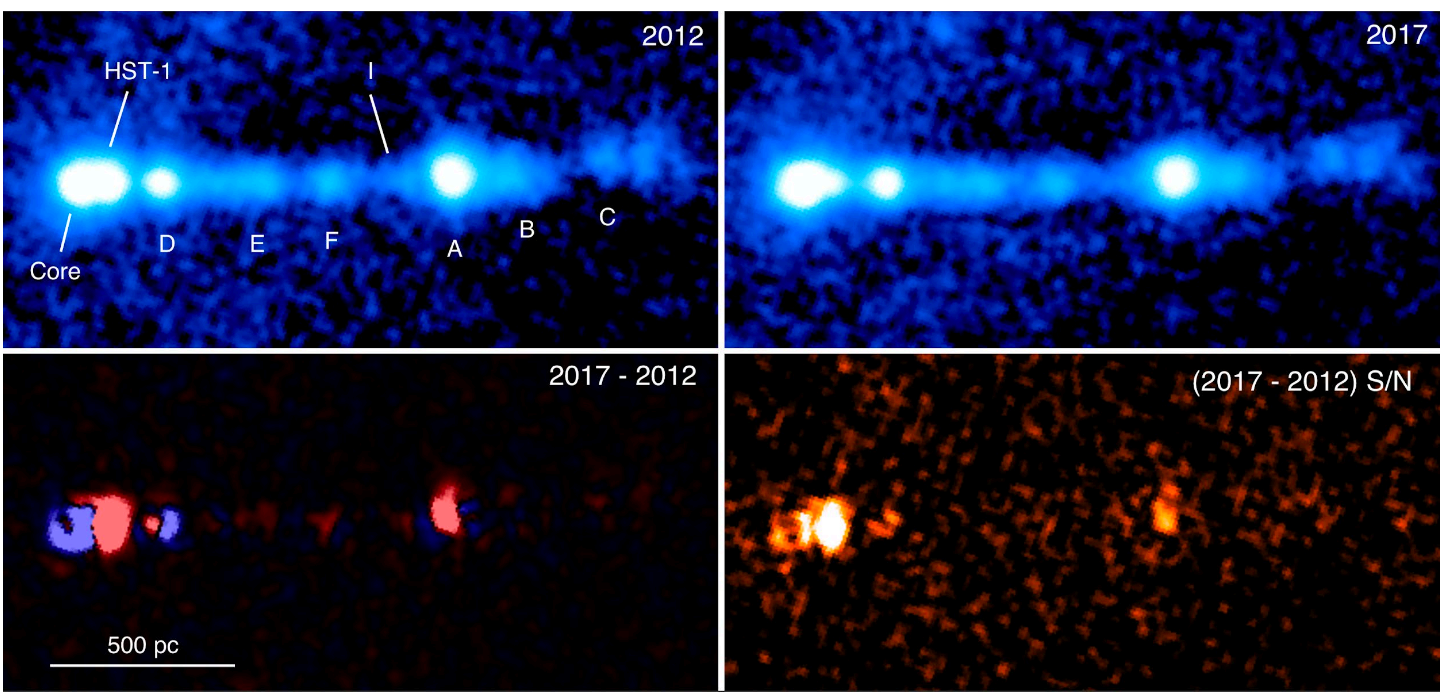

Figure 1: The HRC has recently observed proper motions of X-ray knots in M87's famous jet. Shown here are 0.1–10 keV HRC-I images (upper panels), a difference map (lower left panel), and a signal-to-noise map (lower right panel) of the M87 jet, showing clearly detected proper motion in its various knots across the five years spanning 2012–2017. Figure from Snios et al. 2019 (in prep).

rithm. Early results show that the new algorithm's 10–20% improvement in signal-to-noise could aid those in search of faint lines in their gratings spectra, or low surface brightness extended features in imaging data. The HRC IPI and Calibration teams look forward to updating the community on our progress and recommendations later this year.

Finally, a decision has been reached regarding management of the HRC gain sag effect, a long-known and well-characterized decline of detector gain that has persisted since the start of the mission. This gain sag can slowly decrease quantum efficiency (QE) and increase spatial variations within the detector. In an attempt to mitigate this sensitivity loss, the operating voltage of both HRC-S microchannel plates was increased in March of 2012, nearly restoring the instrument's sensitivity to what it had been at launch. The gain resumed dropping immediately following the voltage change, however, this time with a steeper decay rate. The gain sag has therefore "caught up", and is now roughly where it was just prior to the intervention in 2012. Nevertheless, our understanding of the issue has since increased, and the gain decline continues in a well-characterized and expected manner. As the associated QE drop is very small and entirely accounted for in calibration, no increase in the plate voltage is expected within the next year. The teams will keep the community apprised should these plans change, and look forward to many more exciting years of nominal HRC operations.

HETG Update

The HETGS Team

The HETGS at 20 (well, really 40)

This year we celebrate the 20th anniversary of the launch of the *Chandra* X-ray Observatory. In fact, the origins of the High Energy Transmission Grating Spectrometer (HETGS) go back 20 years earlier, to 1979. That was when Claude Canizares (HETG Instrument PI) and Mark Schattenburg initiated a collaboration with an MIT colleague in electrical engineering, Henry I. Smith, to develop the periodic nanostructures that would become the High Energy Grating (HEG) and Medium Energy Grating (MEG) elements (for details, see Canizares et al. 2005).

Our primary goal was to find a way to fabricate short period transmission grating facets (0.2 μm for HEG and 0.4 μm for MEG) that were thick enough (≥ 0.5 μm gold) to give good efficiency up to the Fe K line near 7 keV (for the HEG), rugged enough to survive launch vibration and acoustic loads—but with a support membrane thin enough to transmit down to 0.5 keV, and large enough (≈ 6 cm^2) so a reasonable number of facets (a few hundred) would cover the *Chandra* telescope aperture. Furthermore, the fabrication process had to be controlled well enough to produce those hundreds of grating facets with nearly identical periods (to within ≤ 100 ppm) so, when aligned to high enough tolerance on a suitable fixture, their spectra would overlap with little degradation. The final HETGS system, consisting of the High Resolution Mirror Assembly (HRMA), the HETG assembly and ACIS-S, would give high spectral resolution ($\lambda/\Delta\lambda$ of up to 1000) with reasonable effective area over the 0.5 to 7 keV band.

It took a good fraction of the next 20 years and the innovative talents of Mark and numerous other researchers to achieve those goals. By 1984 we had demonstrated a viable method for grating fabrication, and we were selected by NASA for Phase B development in 1985. At that time, AXAF (later renamed *Chandra*) was eight years from launch, and it remained eight years from launch for the next eight years. During that time we continued improving grating fabrication methods. There were also setbacks and even a near-death experience: in 1993 the supplier of a new, one-of-a-kind high intensity X-ray generator, which was essential to our intended fabrication process (and cost several million dollars), went bankrupt and was unable to deliver a working tool. This loss, just as we were about to start large-scale production, forced us to radically alter the method of grating fabrication. Miraculously, using the experience gained over the previous 14 years, Mark and colleagues rapidly devised an alternative production process that allowed us to meet our specified performance goals, within budget and on schedule. In 1996 we delivered the fully assembled HETG for calibration, integration and testing.

High resolution X-ray spectroscopy, as enabled by the HETGS (also the Low Energy Transmission Grating [LETG] and XMM-Newton Reflection Grating Spectrometer [RGS]), gives observers a powerful tool for probing the physics of astronomical objects. To date, well over one thousand observations of some 400 targets have been performed with the HETGS, including nearly every category of X-ray emitting astronomical object. Spectroscopy of emission lines enables the determination of physical parameters such as plasma temperature, emission measure distribution vs. temperature, degree of ionization, elemental abundance, Doppler velocity, density, and degree of non-equilibrium. Absorption line spectroscopy can reveal the presence and physical conditions of winds and outflows, the content and even the molecular composition of circum-stellar and inter-stellar matter, and the presence of a hot Galactic halo. In the rest of this update, we present some illustrative examples of HETGS science from the past two decades.

The Hybrid Stellar Wind of θ^1 Ori C

The fact that some massive stars emit hard X-rays and some do not came a bit as a surprise to the stellar commu-

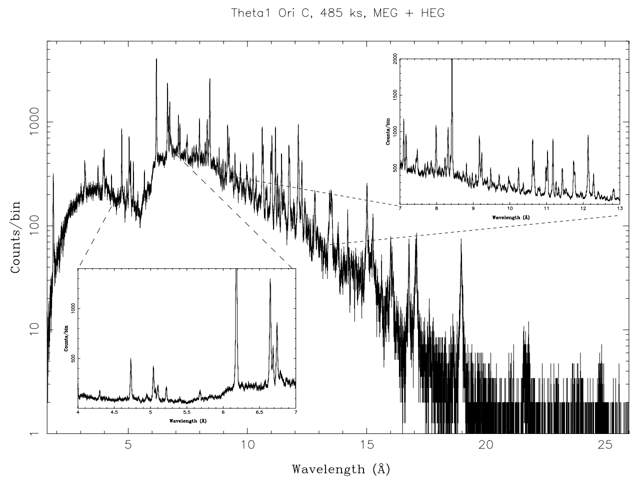

Figure 1: The HETGS Orion Legacy Project so far collected 485 ks exposure of the young O5.5V star θ¹ Ori C. The long exposure yields a high definition X-ray spectrum of a collisionally ionized plasma with temperature of up to 80 MK. The left inset shows the resolved S XV and Si XIII triplets at 5.06 Å and 6.68 Å. The right inset shows the Fe XXIX dominated line region of the hot plasma (see also Schulz et al. 2003).

nity in the early phases of the *Chandra* mission (*Chandra* press release, Nov. 9, 2000). The standard model is based on line-driven shock instabilities accelerating wind plasma to high velocities. This model predicts soft X-ray emissions up to about 20 MK in extreme cases, broad and asymmetric lines, and in some cases measurable blueshifts caused by self absorption in the wind. A prototype of such a wind was observed in the very early supergiant ζ Pup (Cassinelli et al. 2001). In contrast, Fig. 1 shows the X-ray spectrum of θ^1 Ori C in the Orion Trapezium. This spectrum is dominated by fairly narrow K- and L-shell emission lines from a broad range of plasma temperatures from 10 MK to 80 MK. This includes H-like and He-like lines from most abundant elements in the X-ray band between 0.4 and 7 keV (Schulz et al. 2003). Most impressive are K-lines from S XV, S XVI, Ar XVII, Ar XVIII, and Ca XIX, Ca XX as well as the forest of L-shell lines from Fe XVII to Fe XXIV (see insets in Fig. 1). The spectrum also shows that we are observing a hybrid wind in which most of the hard lines originate from a magnetically confined plasma, and the soft lines from an unconfined stellar wind (Schulz et al. 2003; Gagne et al. 2005). Resolving He-like triplet lines in massive stars provides a unique diagnostical tool as the flux ratio of the forbidden to intercombination line component is directly related to the UV flux (see below) and hence to the distance of the emitting ions from the stellar photosphere.

Plasma Density and UV Flux Diagnostics

The X-ray band covered by the HETG includes several radiative ionic transitions from meta-stable upper levels of abundant elements. Of particular interest are the electric dipole forbidden (f) transitions of the He-like ions of O, Ne, Mg, and Si, which the HETGS can clearly resolve from the nearby resonance and intercombination lines (commonly referred to as r and i). The metastable f-line's upper level is long-lived enough to be de-populated by collisional excitation or by UV photo-excitation, if the electron or UV flux densities are great enough. Hence, ratios of these line strengths can be very sensitive to plasma densities and/or UV fluxes (Blumenthal et al. 1972).

In actively accreting T Tauri (pre-main sequence) stars, HETGS observations can be used to distinguish between coronal (low density) and accretion shock (high density) X-ray emitting plasma and, in the latter case, be used to estimate accretion rate. Kastner et al. (2002) measured the ratios of He-like lines of O VII and Ne IX in the actively accreting T Tauri star TW Hya which indicated a plasma density of about $10^{12.75}$ cm^{-3} which is consistent with accretion. This region is shown in Fig. 2 (left). Subsequent deeper observations of TW Hya with HETGS by Brickhouse et al. (2010) were able to detect the density-suppressed f-line in O VII and Mg XI; they found that simple theoretical expectations of temperature-density profiles in accretion shocks were not satisfied.

The f/i ratio is also important to determinations of coronal structure in late-type stars. Testa et al. (2004) surveyed the diagnostic in a sample of stars, finding a clear upper limit to coronal densities, based on the fact that Si XIII was always at its low-density limit (< 10^{13} cm^{-3}), that hotter plasma is denser (10^{12} cm^{-3} for Mg XII and 10^{10} cm^{-3} for O VII), and that more active stars (higher X-ray luminosity) have modestly higher densities.

Even higher plasma densities can occur in the accretion onto highly magnetic white dwarfs from binary companions (the "intermediate polars" class). Mauche et al. (2001, 2003) used density sensitive lines of Fe XVII and XXII to measure densities of 10^{14} cm^{-3} or greater in EX Hya (Fig. 2, right).

Doppler Line Emission in the Ultra-Compact Binary 4U1626-67

The accretion powered pulsar 4U 1626-67 is a rare example of a strongly magnetized (≈10^{12} G) neutron star in a low-mass X-ray binary (LMXB) in contrast to more common weakly magnetized (≈10^8 G) cousins. Its ultra-compact nature implies a hydrogen-deficient companion, likely a C-O or O-Ne white dwarf with accretion material rich in C, O and Ne. Strong line complexes at Ne and O detected with ASCA (Angelini et al. 1995) were resolved with the *Chandra* HETGS into Doppler-broadened line complexes (Schulz et al. 2001) with blue- and red-shifted components separated by over 4000 km s^{-1}. In 2008 the pulsar experienced a torque reversal and went into a spin-up. The X-ray flux jumped by several factors and the Doppler line complexes (shown in Fig. 3) could now be identified as broad disklines originating at the boundary of the pulsars magne-

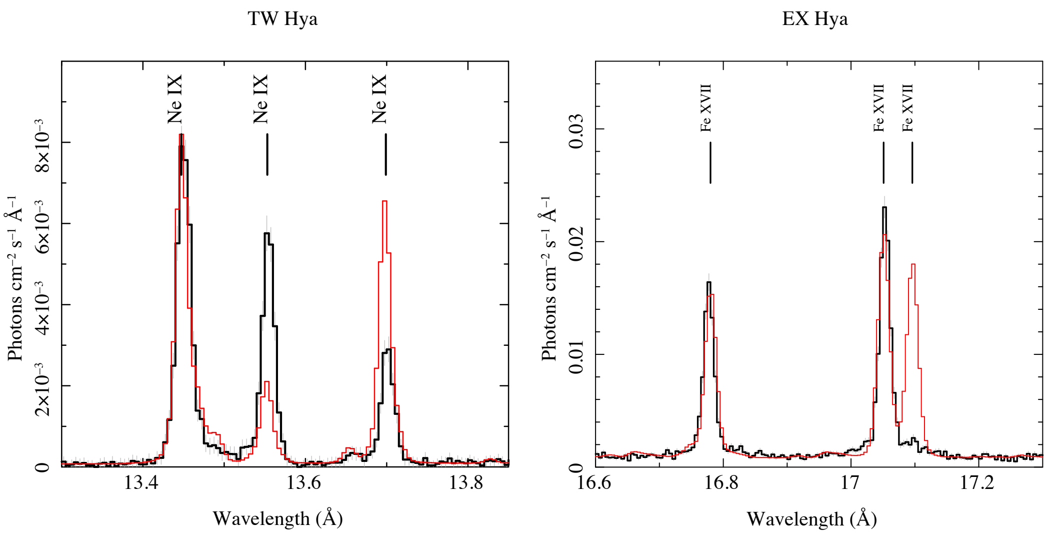

Figure 2: Left: The Ne IX *f (13.7 Å) and i (13.55 Å) lines are sensitive to density; their sum, relative to the 13.44 Å r line is sensitive to temperature. The black curve shows the 500 ks MEG spectrum of the pre-main- sequence star TW Hya in this region. The red curve is a model spectrum at the low density limit (with the appropriate temperature of about 2 MK). The observed ratio requires a density of about 3.0 × 10^{12} cm^{-3}. Right: The Fe* XVII *17.10 Å line, relative to Fe* XVII *16.78 Å, is sensitive to density for densities above 10^{13} cm^{-3}. The black curve shows the 500 ks MEG spectrum of the accreting magnetic white dwarf binary system (an "intermediate polar") EX Hya in this region. The red curve is a model spectrum at the low density limit. The observed ratio requires a density in excess of 10^{14} cm^{-3}, or photoexcitation by a radiation field in excess of 55 kK assuming blackbody emission.*

tosphere. Detailed plasma model fits to the HETGS spectrum also revealed that the X-ray line emission is a result of collisional ionization at the boundary of the magnetosphere and likely a result of coronal type magnetic reconnection processes (Schulz et al. 2019).

Structure and Conditions of the SS 433 Jets

The Galactic X-ray binary SS 433 features highly relativistic red- and blue-shifted emission lines whose Doppler shifts vary sinusoidally. The so-called kinematic model (e.g. Margon & Anderson, 1989) gives the time dependence of the oppositely-directed jets, whose average bulk velocity is about 0.26c, and which precess with a 162 day period. The X-ray spectra are best described by thermal emission from an expanding gas, cooling from a temperature over 10^8 K. HETGS spectra (Fig. 4) have been used to show that the gas doesn't change speed as it cools and the opening angle of the flow is about 1.2 deg, probably set by the temperature at the base (Marshall et al. 2002). The HETGS spectra also show that the gas is overabundant in metals by 2 times over solar, with Ni being overabundant by a factor of 15, perhaps an indication that the compact object resulted from an unusual supernova. Also, HETGS data taken during an eclipse by the companion were used to constrain the length of the jets to less than 2 × 10^{12} cm and the density at the base to 10^{10-13} cm^{-3} (Marshall et al. 2013).

Winds in the Black Hole Binary GRS 1915+105

The stellar mass black hole GRS 1915+105 is unique for its high luminosity, its bright, variable, and superluminal radio jets, the 27-year duration of its current outburst, and its impressive array of erratic, high-amplitude X-ray variability. In addition, the black hole is a strong source of narrow absorption lines from an accretion disk wind, whose properties vary with the X-ray state (e.g. Lee et al. 2002; Neilsen & Lee, 2009; Miller et al. 2015, 2016). The appearance of an ionized wind in the presence of strong variability in the radiation field provides an unrivaled opportunity to track the time-dependent evolution of a black hole outflow. Indeed, time-resolved spectroscopy with the HETGS reveals complex changes in the ionization state of the wind that are measurable on timescales as short as 5 seconds. Combined with measurements of the broadband spectrum, these changes make it possible to infer variations in the mass loss rate of the wind itself, which may be as large as 25 times the accretion rate (Neilsen et al. 2011). In Fig. 5 (left), we show an example of data taken when the source was exhibiting 30-minute oscillations, called the β state. HETGS spectra from high- and low-flux intervals indicate an absorber whose column density changes significantly over this cycle but whose ionization parameter is nearly constant; this is consistent with a wind launching mechanism that only operates at high flux (Neilsen et al. 2012b).

Miller et al. (2015, 2016) pushed the power of the HETGS by studying the third order HEG spectrum of GRS 1915+105. This gives three times the normal first order spectral resolution (or ≈ 12 eV at 7 keV), albeit with only a small fraction of the effective area. This high resolution reveals the doublet structure of the Fe XXVI H-like Ly-α absorption line and separates the resonance and intercombination lines of He-like Fe XXV (see Fig. 5, Right). The authors find four wind components with velocities up to 0.03 c, and they deduce launching radii of r ≈ 10^{2-4} GM/c^2.

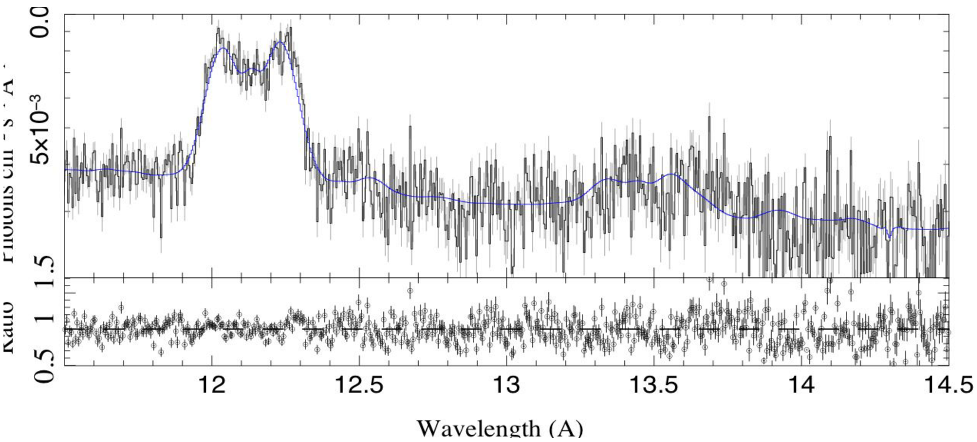

Figure 3: Spectral fit of the Ne X *(12 Å) and* IX *(13.5 Å) regions of the 2010 HETG observation using a collisional ionized plasma model and diskline functions of 4U1626-67.*

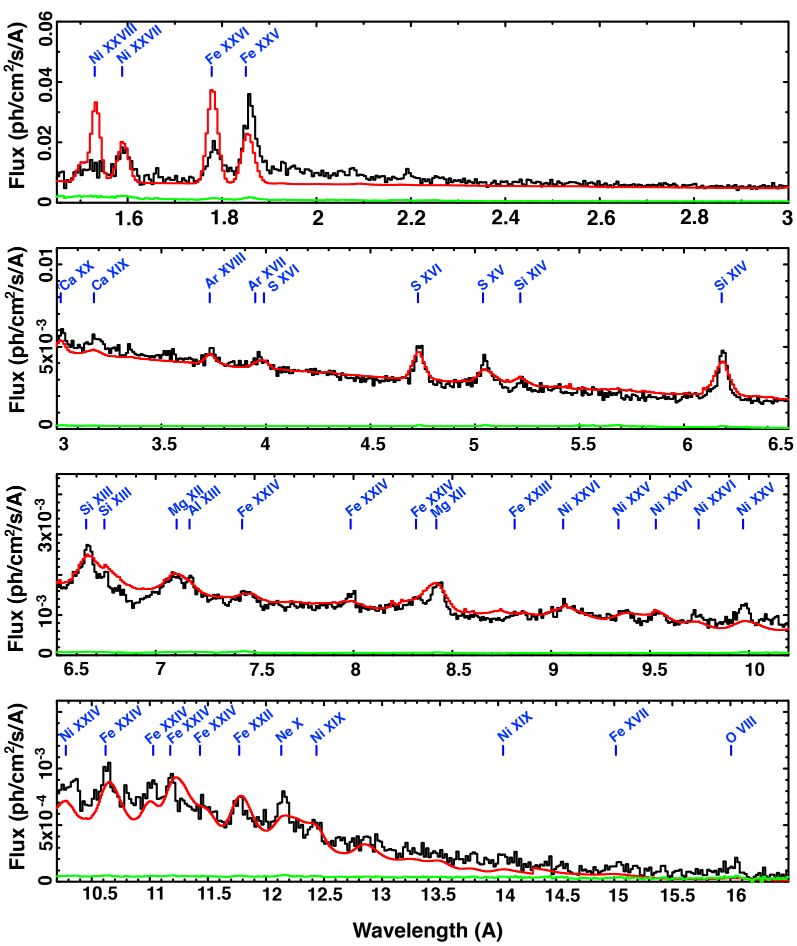

Figure 4: X-ray spectrum of SS 433 from HEG (top panel only) and HEG+MEG after correcting for the Doppler shift of the blueshifted jet (Marshall et al. 2013). Green line: Statistical uncertainties in the flux measurements. Red line: Four temperature plasma model providing an adequate fit to the spectrum. Residuals near 2 Å are primarily due to the redshifted jet's continuum, which is somewhat weaker than those of the blueshifted jet. Lines are identified where there are features in the spectrum accounted for by the model.

Imaging the Reverse Shock in SNR E0102-72

E0102-72 is a well-studied member of the oxygen rich class of supernova remnants. It is located in the SMC, has a primary shock radius of ~20″ (6.4 pc) and an estimated age of 1000 yr. Its moderate extent and the dominance of X-ray line emission makes it an excellent target for HETGS observations. The dispersed spectrum is analogous to a spectroheliogram, showing a series of monochromatic images of the source in the light of individual spectral lines. Fig. 6 shows the dispersed image of the reverse-shocked ejecta in E0102-72 in the light of O VII (He-like resonance, Left) and O VIII (H-like, Right) lines. It is clear that the more ionized H-like oxygen lies at larger radii (by ~1″−2″). Because the plasma is still ionizing slowly at these low densities, the images trace the progression of the reverse shock, which proceeds from larger to smaller radii (in the frame of the expanding remnant) as the ejecta are slowed by the surrounding medium. This trend of ionization age vs. radius is confirmed and refined by study of multiple ionization states of different elements (Flanagan et al. 2004). The authors estimate that ≈ 6 $M_\odot$ of Oxygen are emerging from this core-collapse explosion of a massive star. Doppler velocities of up to ± 1000 km s^{-1}, which appear as small distortions of the image in the dispersion direction, suggest the remnant forms a non-uniform spherical shell inclined to the line of sight.

Photoexcitation of Gas Outflowing from the Nucleus of NGC 1068

The HETGS spectrum of NGC 1068 (Fig. 7) is dominated by strong emission lines that are well resolved spectrally. The high signal spectrum (450 ks) was analyzed in detail by Kallman et al. (2014), building on previous work by Young et al. (2001), Kinkhabwala et al. (2002), and Ogle

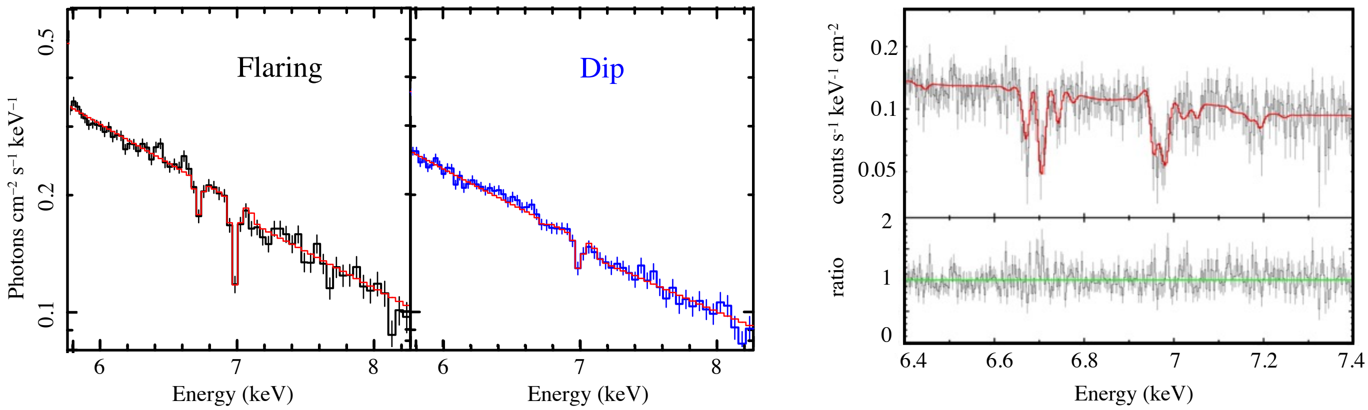

Figure 5: Left: The Chandra HETGS spectra and residuals for the flaring and dip intervals of the state of GRS 1915+105. We detect strong absorption lines from Fe xxvi during both time periods, and Fe XXV *during the X-ray flaring (Neilsen et al. 2012b) Right: Third-order HETG spectrum of GRS 1915+105 with best-fit model. Four photoionization zones with paired absorption and re-emission are required. The He-like Fe* XXV *line is resolved into i and r components (rest-frame energy: 6.70 keV). Instances of H-like Fe* XXVI *absorption lines close to the rest-frame value of 6.970 keV and blueshifted up to 7.05 and 7.2 keV are apparent. The Fe* XXVI *line shape is a doublet owing to the expected spin-orbit splitting in the H-like atom (Miller et al. 2016).*

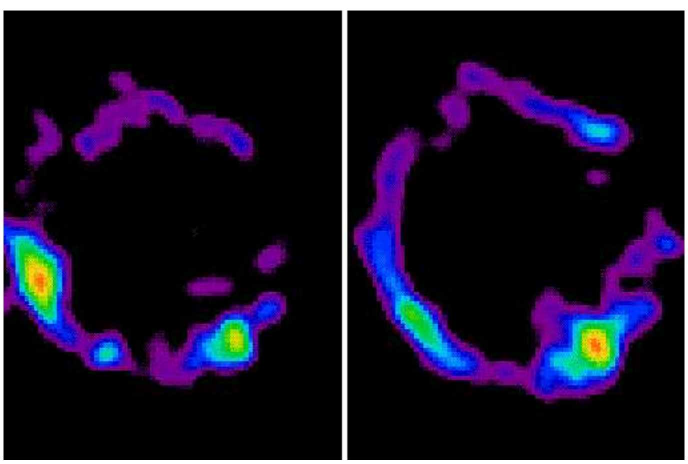

Figure 6: The HETGS dispersed image of E0102-72 in the light of O VII *(He-like resonance, Left) and O* VIII *(H-like Ly-α, Right) lines. The images trace the progression of the reverse shock, which proceeds from larger to smaller radii (in the frame of the expanding remnant).*

et al. (2003). Over 80 lines were identified from a wide range of ionization states resulting from photoexcitation by nuclear X-ray emission. Outflows of 450 km s^{-1} were found and lines are also broadened by > 1200 km s^{-1}. The best fitting model consisted of three photoionized emitters ranging in log ξ from 1 to 3 (where ξ is the ionization parameter) with a filling factor of only a few percent. Most of the emitting gas is actually found beyond 100 pc from the core and has a substantial mass outflow rate of ~0.3M$_{\odot}$ yr^{-1}, ~10 times greater than the nominal accretion rate.

Still Going Strong at 40

The current state of the HETGS is strong. The spectral resolution and the line-spread function remain unchanged since launch. However, the build-up of contamination on the ACIS-S optical blocking filter has degraded the effective area below 2 keV (see Chapters 6 and 8 of the *Chandra* Proposers Observatory Guide (POG): (http:cxc.harvard.edu/proposer/POG/). For example, the effective area at the O VIII Ly-α line at 0.654 keV has decreased to ~6% of its value at launch. The good news is that the band above 2 keV is only modestly affected (effective areas of ~70% the launch value at 1 keV and ~92% at 2.5 keV). So, having reached middle age, the HETGS at 40 continues to be a unique and powerful probe of astrophysical processes in the cosmos.

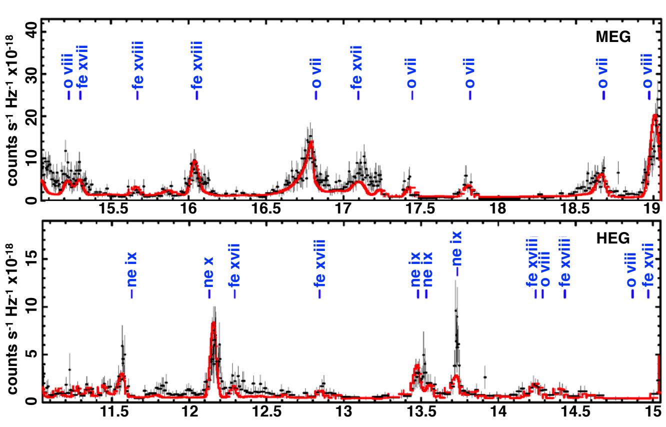

Figure 7: A portion of the HETGS spectrum of NGC 1068 obtained with MEG (top) and HEG (bottom). The best-fit model, consisting of three photoionization components, is shown in red with identified lines indicated in blue. Lines are blue-shifted by 450 km s^{-1} and Doppler-broadened by 1500 km s^{-1}; in addition, the width of the O VII *radiative recombination continuum feature (at 16.8 Å) provides an estimate of the gas temperature, which is less than 105 K.*

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LETG Update

Jeremy J. Drake, for the LETG Team

Seven Minutes to Midnight

Worryingly, the metaphorical HRC "doomsday clock" now stands at 7 minutes to midnight.

The LETG prime detector, the High Resolution Camera Spectroscopy array (HRC-S), has had a well-documented secular loss of gain and quantum efficiency (QE) since it was launched. This has been described in detail in previous Newsletters. The gain loss itself is not a problem, until it gets so low that X-ray photon events are no longer recognized as such because the event pulse height—essentially the amount of charge generated—falls below a level at which it is ignored. That level is called the "event threshold". The event threshold is designed to easily veto events that have pulse heights inconsistent with X-rays to eliminate unwanted background and wasted telemetry. Unfortunately, X-ray events are now beginning to fall below the event threshold.

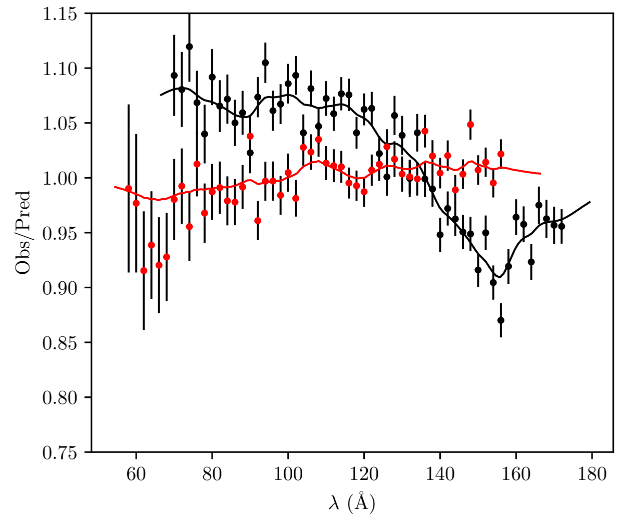

Figure 1: Quantum efficiency calibration corrections computed by Pete Ratzlaff as a function of wavelength from 2018 calibration observations of the hot white dwarf HZ43. These wavelength-dependent corrections are applied together with a constant grey correction factor to arrive at the final calibration. Black corresponds to positive first order and red to negative.

Until recently, the slow rate of QE loss, which remains unexplained in detail but is attributed loosely to space weathering of the microchannel plates, has been equally affecting all wavelengths of the LETGS. In the last two or three years, signs that this is no longer the case have been growing. We see this when we compare the flux vs wavelength in successive calibration observations of the hot white dwarf HZ43. Pete Ratzlaff, one of our talented computer specialists and data analysts, has been looking at these observations taken since launch and using them to devise corrections to apply to the detector QE to bring observed fluxes back into agreement with the reference model.

Figure 1 illustrates the wavelength-dependent correction factors derived by Pete from observations in 2018 and used for the long wavelength QE of the HRC-S. They are applied together with a constant that accounts for a steady grey QE decline, such that wavelength-dependent correction factors larger than 1 are possible in detector regions where the actual decline is lower than the mean grey rate. The region covering approximately 120–180 Å shows a decrement in QE amounting to 10% relative to the steady QE decline grey correction near 160 Å. This detector region also has significantly lower gain than other detector regions. We have verified that the QE loss here is due to photon events falling below the event discriminator.

All this sounds rather gloomy. The loss of QE would eventually render some wavelength regions with low gain effectively blind. Fortunately, there is a way to try to mitigate the gain loss: raise the high voltage across the microchannel plates. This procedure was carried out back in 2012

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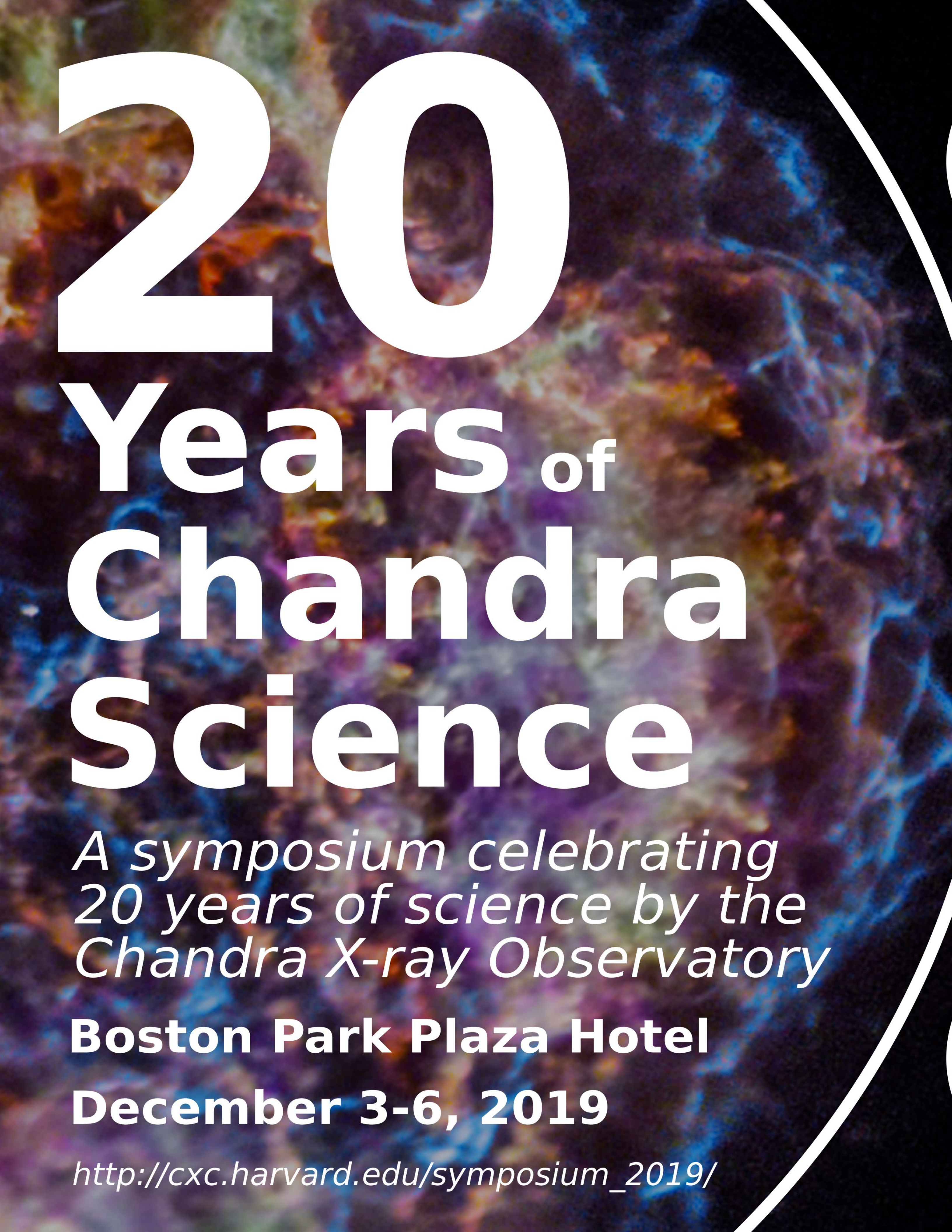
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Years of
Chandra
Science
A symposium celebrating
20 years of science by the
Chandra X-ray Observatory
Boston Park Plaza Hotel
December 3-6, 2019
http://cxc.harvard.edu/symposium_2019/

continued from page 25

and did succeed in raising the gain. Slightly worryingly though, the gain decay in successive years was more rapid than before the voltage increase. The downside: a painful and lengthy re-calibration of the detector, which requires considerable calibration observations. There is also the, hopefully small, possibility that the detector does not like the higher voltage and ends up damaged.

So what time are we at with the HRC-S voltage increase clock? We still have a year or so to go before we feel it necessary to try and recoup the gain loss with another voltage increase.

I first learned of the Doomsday Clock metaphor through a terrific song "Seven Minutes to Midnight" by the British new wave band Wah! Heat that was inspired by the concept of the clock, with lyrics "...seven minutes to analyse, my instinct must be quick, seven minutes to midnight, I feel sick...". So the HRC-S clock is about 7 minutes to, I would think.

The author thanks the LETG team for their useful comments, information and discussion.

Chandra Calibration Update

Larry David

The calibration team continues to monitor the build-up of molecular contamination onto the ACIS filters through imaging observations of the rich cluster of galaxies Abell 1795 and the oxygen-rich supernova remnant E0102-72 and gratings observations of the blazar Mkn 421. These observations are designed to track the time-dependence of the condensation rate onto the ACIS filter, the chemical composition of the contaminant, and the spatial distribution of the contaminant on the ACIS filters. Abell 1795 is observed semi-annually at the ACIS-I and ACIS-S aim-points. In addition, a more extensive raster scan of Abell 1795 on ACIS-I and ACIS-S is performed annually to map out the spatial distribution of the contaminant. A set of LETG/ACIS-S observations of Mkn 421 are carried out semi-annually in "Big Dither" mode (i.e., with a large enough dither to cover approximately one-fourth of the ACIS-S array). *All of these observations showed that the current build-up rate of contaminant is less than that predicted by the previous ACIS contamination model.* Thus, the calibration team released new ACIS-I and ACIS-S contamination models during 2018 with updated time-dependencies. The most recent contamination measurements (ACIS-I and ACIS-S observations of Abell 1795 in November 2018) are fully consistent with the current version of the ACIS contamination model in the CALDB.

The ACIS detector gain continues to be calibrated in six month intervals by co-adding observations of the ACIS external calibration source (ECS). ACIS is exposed to the ECS whenever it is in the stowed position, which occurs during each radiation belt passage. The ECS flux has declined significantly since launch due to the 2.7 year half life of ^{55}Fe. However, even with the significant decline in ECS flux, the calibration team is still able to calibrate the ACIS gain in six month intervals within 16″ by 16″ regions to within 0.3%, on average. Within the next few years it will probably become necessary to broaden the region over which the gain is calibrated. The calibration team has also completed a study of potential astronomical sources for use as gain calibration targets once the ECS flux has faded even further.

A re-analysis of previous ACIS gain calibration revealed that there is a 32 pixel column region on both sides of the central node boundary of the front-illuminated (FI) chips where the ACIS gain droops by up to 1-2%. This gain droop is present in the ACIS "det_gain" file, which was derived from the first three months of ECS data taken after ACIS was cooled to -120C. All subsequent time-dependent gain corrections are computed relative to the ACIS "det_gain" file. Work is underway to correct this problem by calibrating the ACIS gain on smaller scales in the region close to the central node boundary. These corrections will be applied to the "det_gain" file which will automatically correct the ACIS gain at all subsequent times.

Gain calibration only requires the measurement of line centroids, while QE calibration requires the measurement of the total flux in a line. The latter requires considerably better photon statistics. In the past, the calibration team has released QE Uniformity (QEU) maps every two years by co-adding ECS data. Due to the fading of the ECS source, the next set of QEU maps, which are under development, will cover a four year interval.

Both the HRC-I and HRC-S continue to undergo a steady decline in detector gain. In addition, the HRC-S has also shown a continuous wavelength-dependent decline in QE. The calibration team corrects for these effects by releasing annual updates to the HRC-I and HRC-S detector gains and the HRC-S QE. The calibration team monitors the HRC-I QE with annual observations of HZ43 (a soft source) and G21.5-09 (a hard source). Throughout most of the *Chandra* mission, the count rate of these two sources has been constant. Recently, the HZ43 count rate has begun to decline, while the G21.5-09 count rate remains constant. In 2018, the calibration team released the first set of time-dependent HRC-I QE files to correct for the low energy QE loss. At present, all four focal plane detectors have a set of time-dependent QE files in the CALDB. CIAO default processing automatically corrects for the time-dependent gain and QE losses. The detector effective area files used by PIMMS will continue to be updated prior to each cycle.

During the recent safe mode event in October 2018, the HRMA warmed up to temperatures (~76 F) significantly greater than its nominal operating temperature (71 F). The calibration team monitors the imaging properties of *Chandra* with semi-annual HRC-I observations of AR Lac. Due to potential detrimental effects on the HRMA due to running warm during the recent safe mode, the calibration team scheduled an HRC-I observation of AR Lac for December 2018. The AR Lac PSF obtained during this observation is fully consistent with previous AR Lac observations. Thus, the recent safe mode event did not have any effect on the imaging properties of *Chandra*.

Chandra Source Catalog

Ian Evans, for the *Chandra* Source Catalog team

The latest version of the *Chandra* Source Catalog (CSC Release 2.0, or CSC 2.0) includes scientifically useful properties for roughly 316,000 distinct X-ray sources on the sky. These properties were extracted from almost 375,000 source detections included on more than 10,000 *Chandra* ACIS and HRC-I imaging observations that were released publicly through the end of 2014. The sky coverage of CSC 2.0 is approximately 600 deg^2.

Source detection is performed on “stacked” (co-added) observations of the same field to improve detection sensitivity for fields with multiple observations. The use of multiple detection algorithms, graded by a maximum likelihood estimator, yields an on-axis source detection limit of about 5 net counts for exposures < 15 ks (for longer exposures, background becomes increasingly important, effectively raising the net count detection threshold).

Numerous detection properties are evaluated at both the stacked-observation and single-observation levels (see Table 1). Multiple detections of the same source are grouped together where appropriate using a Bayesian blocks algorithm to identify detections with similar multi-band aperture photometry photon fluxes, thus improving signal-to-noise (S/N) ratios, even for variable sources. The longest-exposure block is used to populate “best estimate” master source properties for each source on the sky. Multi-band limiting sensitivity is computed for the entire sky coverage of the catalog at a resolution of 3.22 arcsec × 3.22 arcsec.

Numeric properties have associated uncertainties, usually independent lower and upper confidence limits, and most properties are evaluated in 5 energy bands for ACIS observations, and a single energy band for HRC-I observations. As a result of this multiplexing, the catalog databases include approximately 1700 columns of information, split across several tables.

In addition to the tabulated source properties, CSC 2.0 also provides roughly 40 different types of science-ready FITS data products (see Table 2). Since these data products are pre-computed by applying all of the appropriate calibration steps (e.g., matching astrometry, merging observations, applying exposure corrections, removing background) included in the catalog pipelines, they can be used directly by the end-user to simplify significantly the effort required to perform detailed scientific analyses of properties for extensive samples of sources.

Data access and documentation for CSC release 2.0 is available through the release 2 website (http://cxc.cfa.harvard.edu/csc2/). The documentation describes the content and organization of the catalog in detail and lists import-

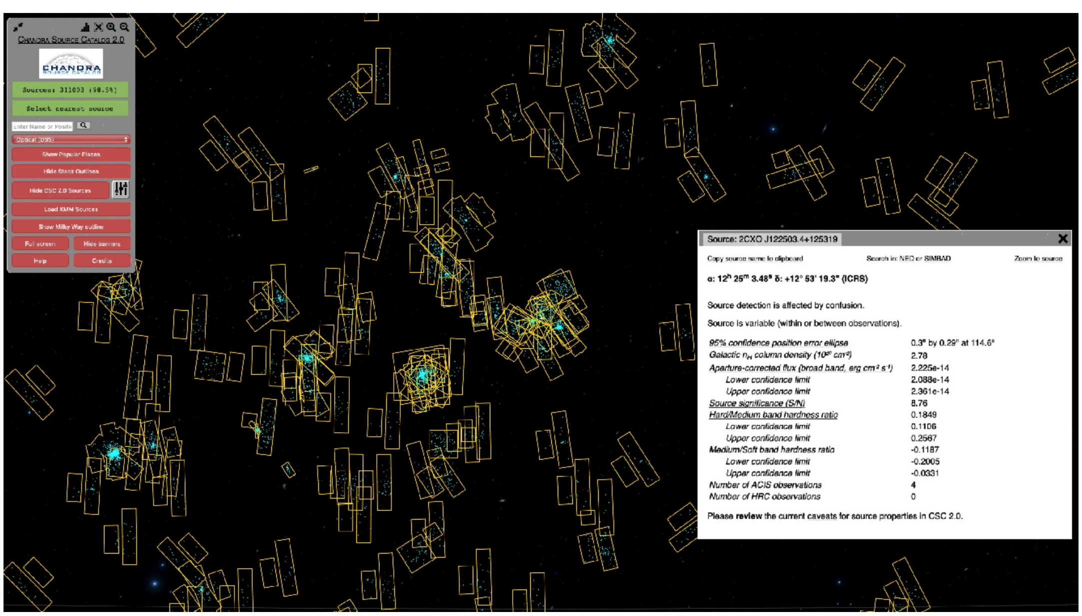

Figure 1. A new WWT-based interface provides graphical access to CSC 2.0. The interface displays the outlines of the stacked-observations included in the catalog, as well as the catalog sources. Basic information about each source is available directly on the screen. Recent enhancements allow source properties and stacked-observation event lists to be sent via SAMP to VO-enabled tools such as TOPCAT and DS9.

ant caveats and limitations that should be reviewed prior to using the catalog data.

The primary end-user data query and access tool for CSC 2.0 is the downloadable CSCview application (http://cda.cfa.harvard.edu/cscview/), which allows arbitrary sets of tabulated properties to be retrieved based on combinations of positional searches and user-specified constraints on any set of properties. CSCview returns tabulated results that may be saved to a file or shared with another application through the SAMP messaging protocol, as well as providing options to retrieve any desired science-ready FITS data products.

New this year is a visual interface to CSC 2.0 (see Figure 1), developed using the WorldWide Telescope (WWT). The sky coverage and content of the catalog can be explored through this interface, which exposes the outlines of the stacked-observations as well as the locations of the catalog sources. Clicking on a source displays a box with a basic set of source properties.

Tip: When viewing the basic source properties in the WWT interface, click on "Copy source name to clipboard" to capture the source name. This name can then be pasted into a CSCview search on name to retrieve more properties or data products associated with the source.

The WWT interface will continue to be enhanced over the coming months. Additionally, standard Virtual Observatory (IVOA) protocol interfaces to CSC 2.0, such as TAP, SCS, and SIAP, will be available shortly.

Table 1. CSC 2.0 Tabulated Source and Detection Properties

FITS Data Products

Master Source	Aperture photometry probability density functions (PDFs) Multi-band aperture photometry (photon and energy fluxes, spectral model energy fluxes), hardness ratios, spectral model fits for each Bayesian block
Detection Region	Stacked-observation and single-observation region definitions, event lists Multi-band stacked-observation and single-observation images, exposure maps, position error MCMC draws, aperture photometry PDFs Multi-band single-observation PSFs, light curves Single-observation PHA spectrum, RMF, ARF
Stacked-Observation Full Field	Event list, Field-of-View (FoV), merged detection list Multi-band images, background images, exposure maps, limiting sensitivity
Single-Observation Full Field	Event list, aspect solution and histogram, bad pixel map, FoV, pixel mask Multi-band images, background images, exposure maps

Table 2. CSC 2.0 Science-Ready

Master Source	Source name, position and position error ellipses, significance, source flags, multi-band deconvolved extent, multi-band aperture photometry (photon and energy fluxes, spectral model energy fluxes), hardness ratios, spectral model fits, multi-band intra- and inter-observation temporal variability
Stacked-Observation Detection	Position and position error ellipses, multi-band significance, detection flags and codes, multi-band deconvolved extent, multi-band aperture photometry (net counts and count rates, photon and energy fluxes), aperture parameters, hardness ratios, multi-band intra- and inter-observation temporal variability
Single-Observation Detection	Detector position, multi-band significance, detection flags and codes, multi-band raw, PSF, and deconvolved extent, multi-band aperture photometry (total counts, net counts and count rates, photon and energy fluxes, spectral model energy fluxes), masked aperture parameters, spectral model fits, multi-band intra-observation temporal variability

CIAO 1.0 to CIAO 4.11: A World Apart

Antonella Fruscione, for the CIAO team

4 October 1999:

```
The Chandra X-ray Center is pleased to announce
the first release of

the data analysis software:

 CIAO (Chandra Interactive Analysis of Observations)

                    V1.0

How to get the software

The software may be obtained via the WWW:

   by clicking on "Data Analysis" on the main WWW
page: asc.harvard.edu

or directly from the ftp area:

                    asc.harvard.edu

We will also distribute the software on CDROM or
DAT tape on request.

Help/Comments

Please send requests for help and comments to the
CXC helpdesk, click on

"Help Desk" on our main WWW page: asc.harvard.edu.

                Belinda Wilkes

          User Support Group, CXC

  on behalf of: Data Systems

                           Science Data Systems

                           User Support
```

This is the first email announcement[1] to all *Chandra* Cycle 1 Guest Observers and Guaranteed Time Observers about the new software to analyze data from the newly launched *Chandra* X-Ray Observatory. CIAO 1.0 contained ~30 tools, was available for 3 platforms (Solaris 2.6, Redhat Linux 5.2 and Slackware Linux 3.5) and had essentially no "WWW" documentation. The word "ciao" comes from an old expression in the Venetian language, "s'ciavo", that means "I am your servant" (Fruscione & Siemiginowska 2000) and CIAO has been the servant of users of *Chandra*—and later other observatories—since its inception.

Fast forward 20 years and more than 50 versions and we arrive to CIAO 4.11 which was released on 14 December 2018. This newest version is distributed for several Linux and Mac OS X operating systems, includes Python 3.5 and, for the first time, the *Jupyter notebook system*. The Sherpa application (the modeling and fitting application that has been part of CIAO since the beginning) is now also distributed as a standalone application on *GitHub*. Will Python, Jupyter notebook, and GitHub fall out of use and make us smile in 20 years time like the mention of Solaris and Slackware do now?

CIAO is comprised of a large and complex set of tools, applications, scripts and online documents, all of which have evolved incredibly during the last 20 years as the scientific needs, user and instrument demands and technology have changed. Here, we briefly highlight some of the historical changes that have occurred in a variety of aspects in the system.

From Expert X-ray Astronomers to All Astronomers

The first releases of the CIAO software were directly aimed at enabling users to do Guest Observer science. And while the design of the software was mission independent from the start, CIAO was almost exclusively used by expert X-ray astronomers to analyze *Chandra* data. While the support of *Chandra* science is still the main goal, the new versions of the software are striving to make it more accessible to a larger audience with a wide range of expertise and available resources: from novice to experienced X-ray astronomers, high school, undergraduate and graduate students, archival users (many new to X-ray or *Chandra* data), users with a large amount of resources and users from smaller countries and institutions. Additionally, many users now utilize CIAO tools and applications for more than just *Chandra* data. With our goal to continue to teach about *Chandra* and CIAO to the new generations of astronomers, we have organized 15 CIAO workshops in the last 20 years, from Cambridge to India to Seattle (at the last AAS meeting). Students come ready to learn, with new questions and new challenges that we try to answer, and their feedback helps us improve the software and the documentation.

From Individual Tools to Complex Scripts

The first releases of CIAO included only individual tools aimed at performing specific and generally narrowly scoped analysis tasks. The CIAO documentation, and in particular the CIAO threads, were—and still are—helping users string together individual tools to perform more complex analysis procedures. In the early years of the mission scientists (from the CXC and elsewhere) immediately started writing scripts to automate some of the most common and repetitive tasks or to fulfill specific analysis needs that CIAO was not ready to satisfy at the time. These "contributed" scripts, which we were gathering and advertising for users, were a collection of software programs written in several scripting languages, without specific coding standards or global consistency. After the integration of Python into CIAO, we started a concerted effort to review the code of all these heterogeneous scripts and to rewrite and update

1. Note the signature by Belinda Wilkes, current CXC Director, and at the time Deputy Leader of the User Support Group

them making them uniform (both in terms of code and documentation) and easier to maintain (Galle et al. 2011, Burke 2011). The first versions of several new powerful scripts were also written to automate some of the most common and complex tasks. Scripts like `chandra_repro`, `specextract`, `fluximage`, and `srcflux` have now become essential items in the CIAO system and encode the crucial steps and actions of many individual tools and threads.

From Zero to S-Lang to Python

CIAO tools are mostly written in the C or C++ language but in the early 2000s the need to introduce a scripting language in CIAO became compelling. A document of required features from the time stated:

> *On top of the usual benefits one expects from the use of a scripting language (e.g., extensibility, rapid prototyping, dynamic/loose typing, no compilation, etc.), there were several additional requirements: (a) powerful mathematical capability (with transparent support for multi-dimensional arrays) that would serve as a basis for rapid scientific algorithmic development (b) concise syntax that will be as natural as possible for scientists to adopt (c) embeddability into existing applications (d) as small a footprint as possible (CIAO is already fairly large)*

Several scripting languages were considered and ultimately the S-Lang scripting language was deemed as the best choice—but Python was a strong contender. As explained in Primini et al. (2005):

> *S-Lang is an open-source interpreted language, bundled with Linux and installed on millions of machines world-wide. It provides most of the usual benefits one expects from a scripting language [...] and is especially well-suited to scientific and engineering tasks due to its powerful, native multi-dimensional numerical capabilities. For example, it supports complex numbers [...] achieving performance and capability on a par with compiled code and commercial analysis packages. These features are built in to S-Lang and distinguish it from more widely known languages like Perl, Python, or Tcl, which lack native high-performance multi-dimensional numerical capability.*

The capabilities of Sherpa and Chips applications were immediately improved by the introduction of the scripting language (Burke et al. 2005, Doe et al. 2005) and S-Lang remained the scripting language in CIAO for several years.

But the usage of computing languages evolved and the trend in the astronomical community changed. By 2010 the use of Python in astronomy had reached critical levels and many astronomy-related packages were being developed in the Python language. The widespread use of Python and the vast amount of documentation (probably one of the weakest point for S-Lang) convinced us to gradually move our own project toward Python. For a while the two scripting environments coexisted within CIAO, though eventually the use of S-Lang in CIAO was finally deprecated in 2010. Python was adopted as the primary scripting language in CIAO 4.0 (in December 2007) and in the following years the entire collection of contributed scripts (a mix of shell, Perl, S-Lang and slsh scripts) was reviewed and rewritten in Python.

Also in CIAO 4.0 the original design of Sherpa was completely modified and a new version was implemented in Python (Doe et al. 2007, Refsdal et al. 2009). Currently Sherpa is also available as a stand-alone (i.e., independent of CIAO) modeling and fitting application for Python that is actively developed via GitHub and that users can use in their own Python scripts.

From Chips to Matplotlib

ChIPS (the *Chandra* Imaging and Plotting System) has been the plotting package of CIAO since the early versions of the software, but was completely redesigned in CIAO 4.0 (in 2007) to make it a powerful plotting system that

Figure 1: Students at the last in the series of Chandra/CIAO workshops: #15 at the AAS 233 in Seattle, WA

could be used to prepare high quality plots for scientific publications (Germain et al. 2006). ChIPS was designed so that "figures" (which include not only curves and histograms, but also contours and images) could be generated and changed interactively and could be easily saved, printed, restored and exchanged with collaborators. ChIPS is the underlying plotting system for all CIAO applications (in particular Sherpa and Prism) but in the past few years upgrades to the underlying technology and compatibility with newer operating systems (particularly the Mac OS) made it too difficult and time consuming to maintain the system as it was originally designed. As of the latest version (CIAO 4.11), we made the difficult decision to stop any further development of the ChIPS application. As the announcement of the ChIPS webpage says:

> *As of the CIAO 4.11 release, the development of ChIPS has stopped and the CXC's plan is to retire ChIPS in the next year or so. CIAO 4.11 includes version 2.2.3 of Matplotlib alongside ChIPS, and a ChIPS to Matplotlib conversion guide is provided to help CIAO users convert. Please contact the CXC Helpdesk if you need help or have questions about this conversion.*

In CIAO 4.11, ChIPS is still the default plotting package for Sherpa (although it is possible to switch to using Matplotlib), and ChIPS is also used by prism and the ds9 analysis extension (dax) for DS9.

ChIPS is powerful and produces very nice figures for scientists, but it is time to move on. In the Python world the majority of users have adopted Matplotlib and we are following in the same footsteps, vowing to help ChIPS users to learn the new system. Citing the matplotlib documentation "*Matplotlib tries to make easy things easy and hard things possible*." It is a good promise for ChIPS users who will need to switch!

From Plain Text to Threads to Jupyter Notebooks

The analysis of *Chandra* data is still not "easy" but certainly it was not easy at the beginning of the mission. A lot of individual tools existed but were not necessarily linked together and limited documentation was available on how to run the tools sequentially. Support to early users was mostly in the form of ad hoc emails (or answers to HelpDesk tickets!) delineating all the steps needed with some additional explanations.

A major milestone happened with CIAO 2.0 (in 2000) when concurrently with the release of the software an entirely new set of webpages was introduced to help and guide users during their data analysis (Fruscione 2002, Galle & Fruscione 2003). In particular a strong emphasis was put into the "data analysis threads" "processing recipes designed to teach users by leading them, step-by-step, through a procedure".

Fun Facts about CIAO

There are ~150 downloads of CIAO every month.

CIAO users are almost evenly split between Linux (55%) and Mac (45%) based on downloads.

CIAO originally included tools required for Chandra proposal planning (PIMMS), which is why it is released annually in December with the Chandra Call For Proposals.

CIAO now includes over 160 individual command line tools; almost 80 contributed scripts, and 1245 individual help files.

Combined (CIAO+Chips+Sherpa) there are over 2,300 web pages.

The CXC HelpDesk on average answers at least one CIAO related question every day of the year. The median response time is less than an hour and most are resolved within a day.

The tools in CIAO are a subset of the same tools used in standard Chandra pipeline processing, as well as in the production of the Chandra Source Catalog.

The data analysis threads became a signature documentation within CIAO and cover many of the tasks that scientists are trying to perform: from the most basic ones to the more complicated.

"*Threads are "living" documents and are being updated and improved continuously and great care has been taken in making sure that they faithfully reproduce the behavior of each tool, especially when new software patches or releases are distributed.*" (Fruscione 2001)

The format and the underlying technology used to generate the documentation webpages changed over the years but the threads are still the most used components of the CIAO documentation and now number in the hundreds.

As cited above, threads are living documents and they are updated frequently but they are not interactive. They are documents which include code, figures, links, and equations... sounds familiar? This is the definition of a Jupyter notebook! "Notebook documents" are not only readable documents which contain the description of the analysis steps and the results (output, figures, tables, etc.) but are also executable documents that can be run to perform data analysis. This is an expansion that could make the current CIAO threads even more useful. Presently, we are prototyping some CIAO threads as Jupyter notebooks, but none are publically available to users, yet. However, students at the most recent CIAO workshop (Jan 2019) were able to run the CIAO workshop exercises as Jupyter notebooks for the first time! Stay tuned for even more expanded and interactive CIAO documentation over the next 20 years.

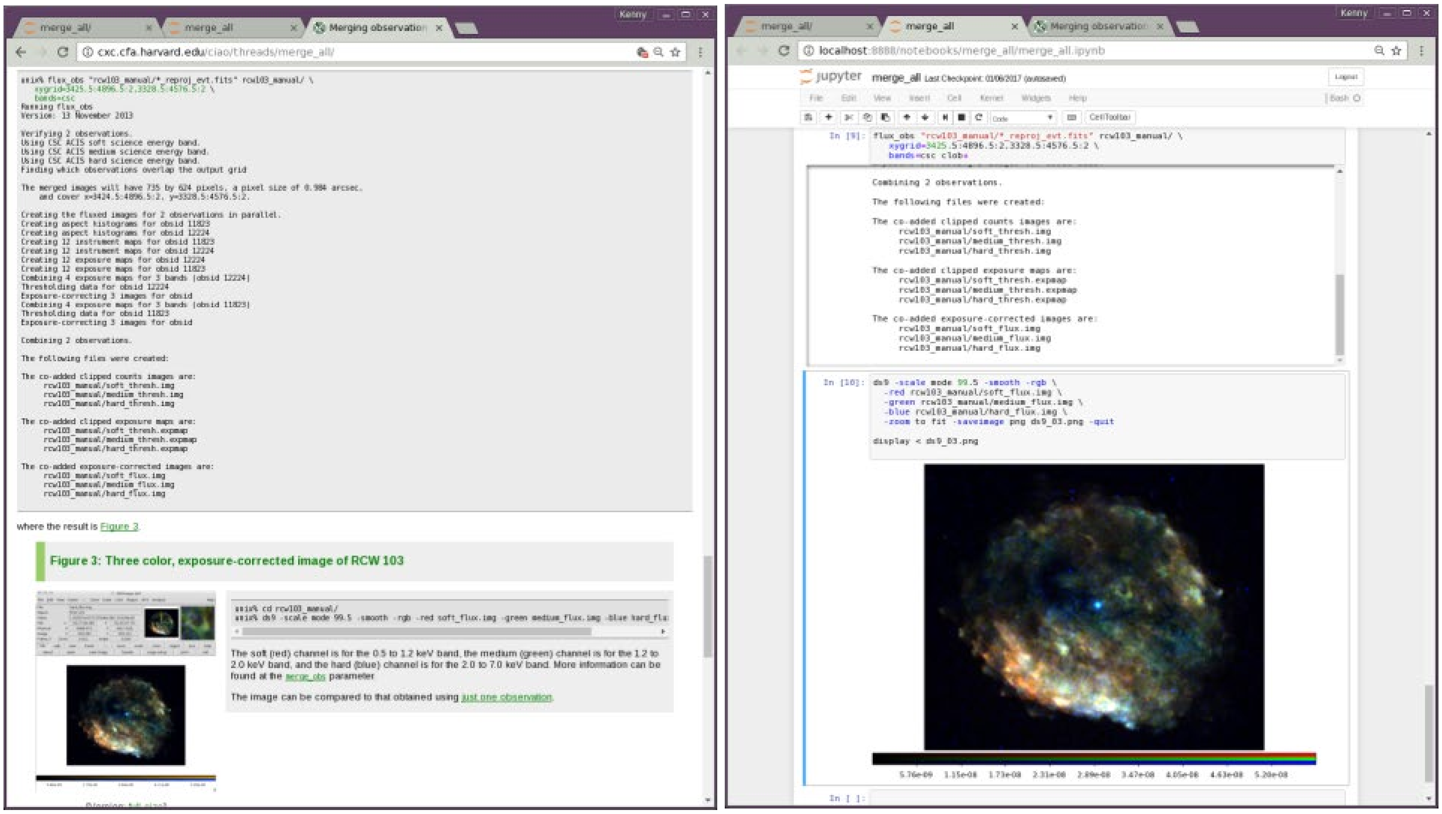

Figure 2: Prototype Jupyter notebook version of for the "Using merge_obs to combine observations and create exposure-corrected images" thread.

From RSS Feed to Social Media

"*The small orange button (the RSS feed button) that became so familiar to website visitors in the early 2000's was as dominant as a Twitter button on any of today's websites*." cites an online page reflecting about RSS. CIAO News has had *its own RSS feed* since 2010 and users embracing this way of getting new information can still subscribe to it to get updates regarding CIAO releases. It is, in fact, a very streamlined and simple way to get new content and updates. But if you belong to the social media generation, CIAO is on Twitter (*@ChandraCIAO*) and Facebook (*ChandraCIAO*) since 2015 and has even its own YouTube channel (*4ciaodemos*). Announcements of new software or calibration releases, important updates to documentation and various other items of interest to the CIAO community are all posted on these social media platforms! Follow and like us… but don't forget to check your RSS reader too.

Hidden Gems

Chandra is 20 years old and the software used to analyze its data is mature, well tested and well documented. It has evolved over time and has been used to perform analysis tasks that were not even thought of when we started.

CIAO is still "at the service" of very beginner users (some of whom were not even born when *Chandra* was launched!) and very experienced users (some of whom were students at launch!). The former group should check out the new *http://cxc.cfa.harvard.edu/cdo/xray_primer.pdf*

For the latter group: do you know that CIAO can even skeletonize? *http://cxc.harvard.edu/ciao/gallery/thumbnail.html*

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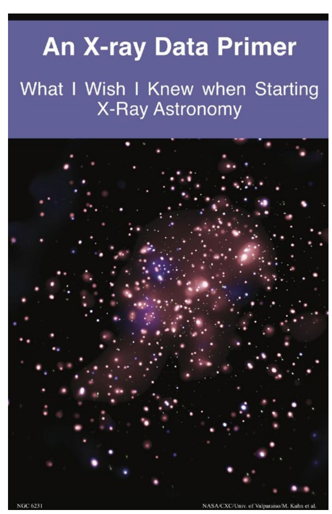

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Doe, S.M. et al 2007, ADASS XVI ASP Conference Series, Vol. 376, proceedings of the conference held 15-18 October 2006 in Tucson, Arizona, USA. Edited by Richard A. Shaw, Frank Hill and David J. Bell., p.543

Fruscione A. and Siemiginowska, A. 2000, *Chandra* Newsletter, Vol. 7, p.4

Fruscione A. 2002, *Chandra* Newsletter, Vol. 9, p. 20

Galle E.G. and Fruscione A. 2003, *Chandra* Newsletter Vol. 10, p. 20

Galle, E.G. et al. 2011 ADASS XX. ASP Conference Proceedings, Vol. 442, proceedings of a Conference held at Seaport World Trade Center, Boston, Massachusetts, USA on 7-11 November 2010. Edited by Ian N. Evans, Alberto Accomazzi, Douglas J. Mink, and Arnold H. Rots. San Francisco: Astronomical Society of the Pacific, 2011., p.131

Germain et al. 2006, ADASS XV ASP Conference Series, Vol. 351, Proceedings of the Conference Held 2-5 October 2005 in San Lorenzo de El Escorial, Spain. Edited by Carlos Gabriel, Christophe Arviset, Daniel Ponz, and Enrique Solano. San Francisco: Astronomical Society of the Pacific, 2006., p.57

Refsdal, B. et al. 2009, Proceedings of the 8th Python in Science conference (SciPy 2009), G Varoquaux, S van der Walt, J Millman (Eds.), pp. 51-571

Primini F. et al. ADASS XIV ASP Conference Series, Vol. 347, Proceedings of the Conference held 24-27 October, 2004 in Pasadena, California, USA. Edited by P. Shopbell, M. Britton, and R. Ebert. San Francisco: Astronomical Society of the Pacific, 2005., p.17

Chandra's High Impact Science Papers

Sherry Winkelman

The *Chandra* X-ray Center (CXC) is periodically asked to give examples of the scientific impact *Chandra* has in astronomy. One such measure is to identify High Impact Science Papers (HISPs) that represent the most influential types of science coming from the observatory. Observatories classically identify these papers based on the total number of refereed citations to the papers. For *Chandra* that has been a list of the 50–100 highly-cited refereed *Chandra* Science Papers (CSPs). But total citation count alone is an incomplete measure of the scientific impact from *Chandra*. Absolute total number of citations is skewed towards older papers that have accumulated citations over the years. HISPs can be relatively new and still have a great impact. By using a differential analysis of the citation history of a paper, we can identify those papers which have a large number of citations over a limited period as another indicator of science impact.

Establishing importance of *Chandra* observations in a given CSP is an essential step in determining the publication's scientific contribution (see last year's *Chandra* Newsletter article "The *Chandra* Bibliography" for further details). Since the scientific contribution from *Chandra* in CSPs varies widely, citation history must to be combined with an assessment of whether the science contribution from *Chandra* is integral to the findings in the paper. It is only after such consideration that we can identify a HISP. At the moment, we prefer to err on the side of caution and retain a comprehensive subset of CSPs that qualify as potential HISPs. The metadata generated for this list of papers allows for easy revision should the criterion on the *Chandra* contribution to the scientific content of the paper change. Our list of resulting *Chandra* HISPs contains 139 refereed journal articles or about 2% of the total CSPs. The list was last compiled in June 2018 by applying the objective measures to all CSPs (giving us 165 potential HISPs) and then applying the subjective evaluation to whittle the list to 139 [1][2]. The general characteristics of the *Chandra* HISPs are:

- 105 papers have more than 200 refereed citations
- 72 papers have more than 40 refereed citations in a single year (with 9 papers having more than 70 citations in a single year)
- 50% of the papers include multi-observatory analysis of some sort (compared to 43% for non-HISPs)
- 28% of the papers with direct analysis of data are purely based on archival observations where neither the PI nor observer of any of the data linked to the paper are authors of the paper.

Recently we were asked to provide a list of high impact papers to help identify *Chandra* science topics for future *Chandra* articles and workshops. This question lead to an exploration of scientific impact based on the science topics covered in CSPs. Our initial list of science topics is based on the science categories used for *Chandra* proposals, in part because all *Chandra* data are linked to one of these categories and the majority of CSPs use data that originated from within a single science category. While the science categories are broad, the distribution of total time awarded in each science category roughly represents the amount of time proposed for in each category. We assigned one of the 10 science categories to each HISP in our current list using the title, abstract, and keywords in the paper. The process was very informative and highlighted some perhaps not so unexpected discoveries:

- The distribution of HISPs between proposal science categories does not track the distribution of time awarded in those categories. This is not too surprising given that data are often used for science studies other than what they were proposed for.
- The proposal science categories are too broad to be used to classify CSPs and some science studies can span more than one category. This was particularly true for studies of x-ray binary populations. There are two binary categories, one for black hole and neutron star binaries and one for white dwarf binaries and cataclysmic variables and classification is not always straightforward.
- A more descriptive set of science topics (and perhaps subtopics) for papers can be derived from the keywords, title, and abstract. These three elements tend to focus on the science goals of the paper in a succinct manner.
- The Unified Astronomy Thesaurus (UAT) is proving to be a useful resource for developing a relatively short list of

science topics and subtopics to assign to papers by providing relationships between broader, related, and narrower terms for the concepts expressed in a paper. Development of a list of science topics for *Chandra* is a manual process, but as journals adopt the use of the UAT for their keywords, it may be possible to match the UAT URIs to the *Chandra* science topic list in an automated fashion as an initial assessment of the science topic(s) for a paper.

- The publication and citation rates for different branches of astronomy must be accounted for when determining the scientific impact and identifying HISPs in order to fairly represent the broad range of astrophysics being explored with *Chandra* data.
- Multiple science topics are essential for some papers.

We have embarked on a process of assigning science categories and subcategories to CSPs to better identify, with higher granularity, the branches of astronomy and astrophysics where *Chandra* has made contributions. We plan to apply our HISP analysis by science topic to gain a more detailed picture of the overall scientific impact *Chandra* has made in astronomy.

Finally, we present a list of the top two papers in each of the *Chandra* proposal categories based on our simplistic approach to gauge the science impact of *Chandra*. Enjoy.

Active Galaxies and Quasars

Ueda et al. (2003), "Cosmological Evolution of the Hard X-Ray Active Galactic Nucleus Luminosity Function and the Origin of the Hard X-Ray Background" (2003ApJ...598..886U)

Ranalli et al. (2003), "The 2-10 keV luminosity as a Star Formation Rate indicator" (2003A&A...399...39R)

BH and NS Binaries

Baganoff et al. (2003), "*Chandra* X-Ray Spectroscopic Imaging of Sagittarius A* and the Central Parsec of the Galaxy" (2003ApJ...591..891B)

Yuan et al. (2003), "Nonthermal Electrons in Radiatively Inefficient Accretion Flow Models of Sagittarius A*" (2003ApJ...598..301Y)

Clusters of Galaxies

Clowe et al. (2006), "A Direct Empirical Proof of the Existence of Dark Matter" (2006ApJ...648L.109C)

Vikhlinin et al. (2006), "*Chandra* Sample of Nearby Relaxed Galaxy Clusters: Mass, Gas Fraction, and Mass-Temperature Relation" (2006ApJ...640..691V)

Extragalactic Diffuse Emission and Surveys

Alexander et al. (2003), "The *Chandra* Deep Field North Survey. XIII. 2 Ms Point-Source Catalogs" (2003AJ....126..539A)

Gilli et al. (2007), "The synthesis of the cosmic X-ray background in the *Chandra* and XMM-Newton era" (2007A&A...463...79G)

Galactic Diffuse Emission and Surveys

Wang et al. (2002), "A faint discrete source origin for the highly ionized iron emission from the Galactic Centre region" (2002Natur.415..148W)

Revnivtsev et al. (2009), "Discrete sources as the origin of the Galactic X-ray ridge emission" (2009Natur.458.1142R)

Normal Galaxies

Martin et al. (2002), "The Metal Content of Dwarf Starburst Winds: Results from *Chandra* Observations of NGC 1569" (2002ApJ...574..663M)

Gilfanov (2004), "Low-mass X-ray binaries as a stellar mass indicator for the host galaxy" (2004MNRAS.349..146G)

SN, SNR, and Isolated NS

Smith et al. (2007), "SN 2006gy: Discovery of the Most Luminous Supernova Ever Recorded, Powered by the Death of an Extremely Massive Star like η Carinae" (2007ApJ...666.1116S)

Soderberg et al. (2006), "Relativistic ejecta from X-ray flash XRF 060218 and the rate of cosmic explosions" (2006Natur.442.1014S)

Solar System

Cravens (2002), "X-ray Emission from Comets" (2002Sci...296.1042C)

Gladstone et al.(2002), "A pulsating auroral X-ray hot spot on Jupiter" (2002Natur.415.1000G)

Stars and WD

Preibisch et al. (2005), "The Origin of T Tauri X-Ray Emission: New Insights from the *Chandra* Orion Ultradeep Project" (2005ApJS..160..401P)

Landi et al. (2013), "CHIANTI—An Atomic Database for Emission Lines. XIII. Soft X-Ray Improvements and Other Changes" (2013ApJ...763...86L)

WD Binaries and CV

Papitto et al. (2013), "Swings between rotation and accretion power in a binary millisecond pulsar" (2013Natur.501..517P)

Guillot et al. (2013), "Measurement of the Radius of Neutron Stars with High Signal-to-noise Quiescent Low-mass X-Ray Binaries in Globular Clusters" (2013ApJ...772....7G)

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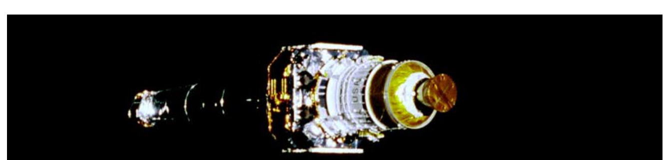
Winkelman, S., D'Abrusco, R., & Rots, A. 2018, Society of Photo-optical Instrumentation Engineers (SPIE) Conference Series, 1070418. ADS



Chandra X-Ray Observatory backdropped against the darkness of space not long after its release from Columbia's payload bay. (Photo: NASA)

Rino Giordano (1955–2018)

On March 11th, 2018, the *Chandra* Flight Operations Team (FOT) lost one of its long-time members, a valued colleague, and friend. Rino Giordano passed away after a short but brave battle with cancer.

Rino joined the FOT in 1997, following distinguished service in the U.S. Air Force and over a decade supporting the TDRSS mission. He initially trained as a Thermal Subsystem Engineer for *Chandra*, but also made significant contributions towards the development and execution of training simulations to help prepare the team for *Chandra*'s launch. Not long after launch, Rino expanded his responsibilities and level of contributions by becoming the lead Electrical Power Subsystem (EPS) Engineer. During this time, he also continued in the role of "Sim Sup" for team-level training events, cleverly (some would say deviously) coming up with new ways to manipulate the spacecraft simulator (ASVT) and challenge the team to respond to a wide range of potential on-board faults. In 2008, Rino took on the role of lead engineer for the *Chandra* Communications, Command and Data Management (CCDM) subsystem. Over the years, Rino was also responsible for, and contributed to, a number of critical system-level special projects that crossed subsystem and space-ground system boundaries.

Throughout his time on the *Chandra* program, Rino embodied a unique set of technical strengths and personal traits that allowed him to succeed, tremendously improving *Chandra* operations processes and products while also setting standards for others to follow. His inquisitiveness, diligence, "out-of-the-box" thinking skills, and self-motivation and learning contributed greatly to his achievements. Early in the mission, he strove to vastly improve how eclipse events were handled with the spacecraft, simplifying the preparation work considerably and reducing the overall risk of such events. When the on-board Command & Telemetry Unit (CTU) and Interface Unit (IU) began to experience unexpected resets, he dug deeply into schematics, unit specs, command/telemetry bit definitions and processing routines, and any/all other available documentation from the factory and the equipment vendor to truly understand the spacecraft performance issues and share that gained knowledge with the rest of the team. As the spacecraft continued to age and the need for more diagnostic data grew, Rino again demonstrated his skills to think outside the box and implemented a robust and comprehensive diagnostic capability in the on-orbit CTU. From scouring the CTU schematics, to the EEPROM update process and tool changes, to coordinating ground system updates, to executing detailed test scenarios Rino made sure all the pieces were in place to deploy and productively use this new diagnostic capability. Over the years, Rino demonstrated a tremendous skill for effectively updating the Standard Operating Procedures (SOPs) used to interact with and control the *Chandra* observatory. He had the ability to take a complex process, focus in on the essential elements, and produce improved procedure documents and commanding scripts to effectively and safely accomplish required spacecraft commanding and telemetry monitoring activities. This skill was most recently demonstrated in the major reworking of the material used to respond to nominal and off-nominal Safe Mode transitions. From laying out the concepts for improving the approach to both nominal and off-nominal Safe Mode transitions, to the detailed work developing and checking the improved products, to setting up and executing detailed scenarios for training team members using the satellite simulator, he made sure all the bases were covered. As demonstrated in the several Safe Modes encountered since Rino completed this work, the team is in a much better position for dealing with future anomalies as the spacecraft ages. These are just a few examples of how Rino was a highly creative and reliable problem solver, who repeatedly went the extra mile to insure product excellence and mission success.

To many on the team, Rino was truly a trusted friend and colleague. He inspired others by setting a good example of hard work and a willingness to extend himself and personally take on difficult tasks to meet program objectives. He had strong and positive work relationships with others at various levels of the organization and could communicate technical knowledge in an understandable way. He gave freely of his time and talents, and at times served as a thoughtful work/life mentor for more junior team members. Outside of work, he also frequently made time to support and help others, whether it be for family and co-worker home projects, or looking forward to the marathon of helping to cook more than 140 turkeys at his local fish & game club to help feed families in need at Thanksgiving. He was also adept at keeping the mood light during what could be intense mission moments, with a ready joke or light-hearted anecdote, and with his hearty exuberant laugh regularly echoing down the halls. Many a time, stories of his escapades with his Mach 1 Mustang in his youth, or the latest challenges with his self-designed and built solar water heating system (which, with all the valves, lines, and manifolds, could put an ocean liner's engine room to shame) would lead to laughing so hard the tears would flow.

The *Chandra* program and the FOT have benefited greatly by Rino's dedicated efforts over the years. While he may now be gone from us, his legacy of accomplishments, personal inspiration, and camaraderie will endure.

Prepared by Paul Viens

Reflected in the waters near Launch Pad 39-B, Space Shuttle Columbia launching with *Chandra* on board on July 23, 1999 on mission STS-93. (Photo: NASA)

Chandra Cool Targets (CCT, formerly CATs)

Andrea Prestwitch

Most readers of this Newsletter are aware that there are significant restrictions on the length of a single *Chandra* observation for a given pitch angle. The pitch angle is the angle between the viewing direction of *Chandra* and the direction to the sun. These restrictions are necessary to avoid the overheating of various observatory subsystems and are described in detail in the Proposer's Observatory Guide (POG) Section 3.3.3.

The scheduling of *Chandra* targets must simultaneously satisfy any science-driven constraints on the observations (e.g., must be done within a specific time window) and the requirement to keep various subsystems within operational thermal limits. The final schedule for any given week is a delicate balance of heating and cooling: if a target is constrained to be observed at a hot pitch such that the temperature of a particular subsystem approaches the operational limit, a target at a cool pitch must be observed directly afterwards to lower the subsystem temperature. Sometimes it is necessary to pre-cool a particular subsystem before observing a target at hot pitch. To date, it has been possible to schedule targets while maintaining subsystem temperatures within operational limits, without impacting observing efficiency, in other words, *Chandra* has never been pointed at a random patch of sky to "cool off" because a cool pitch target was not available. However, the thermal constraints are becoming more restrictive as the multi-layer insulation on *Chandra* continues to degrade. To avoid future impacts on observing efficiency, the CXC Director, in consultation with MSFC Project Science and the *Chandra* Users Committee, authorized a White Paper call for *Chandra* Cool Targets (CCT).

The call for white papers was issued on Friday 21 September 2018 and originally referred to Cool Attitude Targets (CATs), but we quickly realized that the acronym "CATs" is easily confused with sources in the *Chandra* Source Catalog, and switched to *Chandra* Cool Targets (CCT) for clarity. The response to the CCT call was very enthusiastic: a total of 41 White Papers were submitted by the deadline of October 22 2018. A series of four mini-reviews, based on science topic, were held between December 2018 and February 2019. The panelists were comprised of scientists from the CXC, MSFC and outside experts. The committees were asked to recommend which programs were likely to return excellent science, and to assign a priority (1, 2 or 3, with 1 being the highest priority) to each accepted program. Twenty two programs were approved, ten at priority 1, seven at priority 2 and five at priority 3. There are approximately 21,000 CCTs, with good sky coverage. The first CCTs were scheduled in January 2019.

The aim of the CCT program is to ingest a large pool (many thousands) of targets distributed across the sky (but avoiding the ecliptic poles) so that a cool target is always available for mission planning. The database of CCTs is maintained by the science mission planning group. CCTs are inserted into the schedule if no GO or GTO targets are available at a required cool pitch angle. The review-assigned priority of approved CCT programs will be used in the event that more than one CCT can provide the required spacecraft cooling (i.e., priority 1 will be picked over priority 2 or 3). Since there is no guarantee that a particular CCT will be picked for scheduling, GO and GTO observers can apply for CCT targets to address their own science in response to the annual Call for Proposals. If a GO/GTO proposal for a specific CCT is approved, it will be deleted from the CCT database.

Useful *Chandra* Web Addresses

Chandra
http://chandra.harvard.edu/

CXC Science Support
http://cxc.harvard.edu/

Science Publication Guidelines
http://cxc.harvard.edu/cdo/scipubs.html

CIAO Software
http://cxc.harvard.edu/ciao/

***Chandra* Calibration**
http://cxc.harvard.edu/cal/

ACIS: Penn State
http://astro.psu.edu/astro-research/facilities/chandra

High Resolution Camera
http://cxc.cfa.harvard.edu/cal/Hrc/

HETG: MIT
http://space.mit.edu/HETG/

LETG: MPE
http://www.mpe.mpg.de/33019/Chandra

LETG: SRON
https://www.sron.nl/missions-astrophysics/chandra

MSFC: Project Science
http://wwwastro.msfc.nasa.gov/xray/axafps.html

NASA's *Chandra* Page
https://www.nasa.gov/mission_pages/chandra/main/

The NHFP Einstein Postdoctoral Fellowship Program

Paul Green

In 2018, the NASA Hubble Fellowship Program (NHFP) was inaugurated as the merger of NASA's Einstein, Hubble and Sagan prize postdoctoral fellowships. Up through the fellowship class of 2017, these latter were administered separately by the CXC, STScI and NExScI, but starting with the class of 2018 they are now considered three 'flavors' of NHFP, all administered through STScI. The application and selection process, symposia and overall science policies are guided cooperatively by three leads - Andy Fruchter at STScI for the Hubble, Dawn Gelino at NExScI for the Sagan, and myself at CXC for the Einstein.

The NHFP covers all of NASA astrophysics with science themes that broadly reflect these questions:

- How does the Universe work? → NHFP Einstein Fellows
- How did we get here? → NHFP Hubble Fellows
- Are we alone? → NHFP Sagan Fellows

The 2019 NHFP Announcement of Opportunity was released September 4th 2018, yielding 383 complete applications by the deadline on November 1st, 2018.

We recruited 50 panelists, who reviewed and ranked NHFP applications in mid-January 2019. The huge range of scientific topics demanded seven science panels. Even within those, it was a challenge to span all the expertise appropriate to the task. In the first review phase, applications were initially read and graded by three experts within the assigned panel, but also by two reviewers from a different panel, to ensure that each proposed research program has broad support and appeal. The most highly-ranked 220 applications were then promoted to be read by all the reviewers within the appropriate topical panel for further discussion at the in-person selection review near the Miami airport. Just a handful from each topical panel, with the precise number determined by the original proposal pressure, were then promoted for consideration by the Merging Panel, which consists of the topical panel Chairs and a distinct senior Merging Panel Chair. The Merging Panel then reviewed and discussed all those highest-ranked applicants to arrive at a ranked list, from which to start making offers.

The week following the review, we sent our regrets as quickly as possible to all but the top-ranked few dozen applicants. We then made 24 initial offers. If offers are declined, we move down the waitlist until all 24 positions are filled. A press release about the NHFP featuring a list of the 2019 Fellows has been posted to http://hubblesite.org/news_release/news/2019-24 with photos and bios of all of them available at http://www.stsci.edu/stsci-research/fellowships/nasa-hubble-fellowship-program/meet-the-fellows

This October 21–24 in Washington, D.C., we will host the first NHFP Symposium to include all NHFP fellows together. In the meantime, current fellows continue to produce important and exciting scientific advances, with just a few highlighted here:

- Daniel Siegel ('16) and Jennifer Barnes ('17) (Siegel, Barnes, & Metzger, 2019, Nature, 569, 241) show that a rare subclass of core-collapse supernovae —those associated with the collapse of a rapidly rotating massive star ("collapsars") and triggering long gamma-ray bursts - can synthesize rapid neutron capture (r-process) elements. Indeed, taken together with recent results from the binary neutron star merger detected by advanced LIGO and Virgo, their simulations suggest that such collapsar events dominate the total production of r-process elements in the Galaxy.
- Using *Chandra*, XMM-Newton and Swift, Dheeraj Pasham ('16) discovered a highly-stable, quasi-periodic oscillation in the X-ray emission following the tidal disruption of a star by a supermassive black hole. By assuming an association with epicyclic frequencies predicted from General Relativity, they measured the black hole's spin parameter to be at least 0.7, implying that the event horizon of the supermassive black hole is moving at more than 40% the speed of light. (Pasham et al. 2019, Science 363, 531)
- Ke Fang ('18) worked with the High-Altitude Water Cherenkov Gamma-Ray Observatory Collaboration (HAWC) to discover very-high-energy gamma rays from the jets of the microquasar SS433, the first time that very-high-energy particle acceleration has been observed directly from astrophysical jets (Abeysekara, A. U. et al. 2018, Nature, 562, 82).
- Benedikt Diemer ('18) maintains a community python package called Colossus (Diemer 2018, ApJ, 239, 35) that provides an easy interface for cosmological and structure formation calculations, aimed especially at students and people who may not be experts in these fields.

The NHFP is headquartered on the web at https://nhfp.stsci.edu, and questions can be addressed to *nhfp@stsci.edu.*

Accretion in Stellar Systems

Jeremy Drake & Doug Swartz

Rudy: *Can you organize the summer CXC meeting this year? It will be fun!*

Jeremy: *"Organize a meeting" they said. "It will be fun" they said. Knowing full well that "organize a meeting" and "fun" do not go in the same sentence, except a stingingly negative or sarcastically pejorative one, like "organizing a meeting is as much fun as sticking your head into a vat of boiling oil", I was adamant I would not get sucked into such a thankless escapade.*

Doug: *I was game to help organize the summer CXC workshop, as long as I got along with the people involved. Since there was only one person at CXC I would not want to work with I was good to go ahead.*

Rudy: *Jeremy has enthusiastically agreed to co-chair on the CXC side.*

Doug: *Count me out.*

Rudy: *Doug is definitely in on the MSFC side!*

Jeremy: *Doug Swartz! He's a great friend - I knew him back in postdoc days in Austin! Those were the days - I'd always be keeping him out of trouble! No way I'm organizing a meeting with him though.*

Doug: *Back in Austin I spent the whole time trying to keep Drake from getting into trouble. Organizing a meeting with him will be the same all over again—trouble!*

Rudy: *Something on stars. That's what the meeting should be on this summer. How about accretion?*

Jeremy: *Accretion in stars? Hmm, yes, it could include T Tauri stars, CVs… X-ray binaries. Even the ULXs that Doug likes....*

Rudy: *Right, that was what I was thinking! So glad you can organize it - thanks!*

Jeremy: *What...?*

And thus was the beginning of Accretion in Stellar Systems. There was actually another reason for Accretion in Stellar Systems, and that was to honour the late Jeff McClintock who passed away in November 2017. We never really had any doubts that we both wanted to do this.

Hashtag

On the one hand it was insane to attempt to cover all stellar mass acreting objects in the the two and a half days available for the summer workshop. Any one subfield could easily fill a week long conference. On the other, there is that perennial irresistible temptation to unify and see common threads and parallels between the different classes of object. "See, if we plot the mass accretion rate normalized to the Halpha flux to some power of the disk gravitational settling time at the corotation radius against the radiation pressure during the soft high state…"

Choosing the program was then a major challenge. But there was a much bigger problem than that: what was to be the meeting Twitter hashtag? The ideal hashtag has to be snappy, instantly recognizable and unique—a social media fingerprint of the meeting itself. Errr…. #accr2018 why not? And so it was. Apart from a minor clash with the Asian Road Cycling Championships #ACCR2018 it all went well, enough…

> After a very interesting AXIS workshop I'm now at the "accretion in stellar systems" Chandra science workshop. And it has an official hashtag: #accr2018! Yay! :)
>
> **Felix Fuerst** @BIGfalke
> 11:40am - 8 Aug 2018

There was the attempt to garner interest from the generally non-accreting stellar systems meeting held across the river at BU the previous week...

> As the sun sets on @CoolStars20 #CoolStars20 don't despair at the prospects of a dreary trip home back to the same old dreary routine... stick around for "Accretion in Stellar Systems" #accr2018 next week! All about how stars misbehave when they get too close to each other.... twitter.com/cosmodrake/sta…
>
> **Jeremy Drake** @cosmodrake
> 1:03pm - 3 Aug 2018

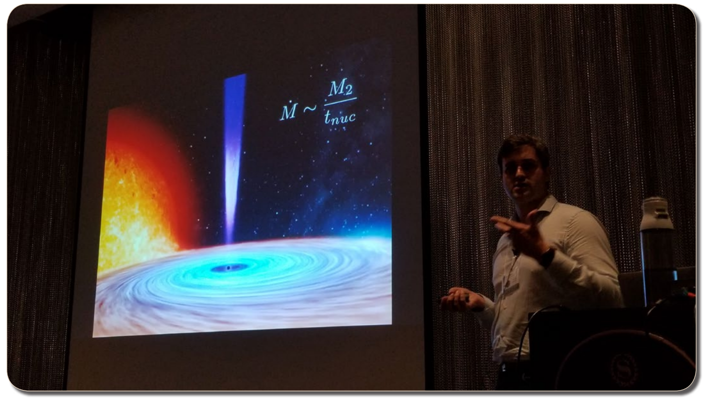
And so, on the morning of 2018 August 8 we began to settle in to the fancy conference room at the Sheraton Commander, Cambridge MA 02138.

Wednesday

After some tedious boilerplate introductory rambling blather from the local SOC chair, our intrepid observatory directory, Belinda Wilkes, started us off with an encouraging review of the prospects for the next ten years of the *Chandra* mission.

Yes, we do have some challenges with thermal constraints going forward which narrows down the time we can dwell and the area of the sky we can point to at any given time. But there is better news on the contamination - the rate of accumulation is palpably slowing. We look forward to organizing #accr2028!

Invited speakers for the meeting were asked to try and draw parallels between the different types of accreting stellar objects - with of course the motivation of imposing at least some degree of failure and creating good rib poking opportunities during post-session relaxation ("....super-Eddington accretion in T Tauri disks, ha ha…!").



First up for the challenge was Matt Middleton, whose talk "ULXs - our window into the extreme", while masterfully reviewing that comparatively new field and the key role that super Eddington accretion plays, utterly failed to yield to the temptation. Next time Matt. But his concluding bullet point was tremendously uplifting: "Our options for getting more data over the next 5, 10, 20 (?) years are looking pretty good."

> Matt Middleton from @unisouthampton on the empirical definition of Ultra-Luminous X-ray Sources: "always be careful of anything defined empirically because it means we drop-kicked the physics out of the window" #accr2018 twitter.com/rudy_phd/statu…
>
> **Jeremy Drake** @cosmodrake
> 10:10am - 8 Aug 2018

..out of the Window into the Extreme, no less.

The session continued with three speakers addressing different aspects of ULXs. Breanna Binder gave us a rundown on NGC 300 ULX-1, a fascinating beastie initially identified as a supernova and now ingloriously known as a "supernova imposter". Breanna found geometric beaming effects to be minimal and that the ULX-1 system is "one of only a few bona fide ULXs to be powered by accretion onto a neutron star." Interspersed among the ULXs, Paul Hemphill reprised "The peculiar case of 4U 1626-67". It is dead simple: loads of neon in the *Chandra* X-ray spectrum of this ultra-compact X-ray binary means an ONeMg white dwarf donor. But, err, there is no Mg. And it was time to roll out the white dwarf physicsy stuff to work out how to hide it.

Konstantinos Kovlakas pointed out the difficulties of studying individual ULXs and determining the properties of source counterparts and argued for statistical studies of larger numbers of objects. Cross-matching with the Chandra Source Catalog, he reported finding about 900 galaxies that host ULXs. These will be useful for teasing out the ULX luminosity function, and the effects of metallicity and age on ULX behaviour and formation.

Then Yanli Qiu spoke about a Wolf-Rayet ULX in the Circinus Galaxy, arguing that its intriguing dipping and eclipse behaviour are a defining property of this class of super-Eddington HMXBs.

Yes, it was time for coffee and posters. Vladimir Karas made us feel energetic with a paper on acceleration of electrically charged particles and the onset of chaos near a magnetised black hole, while Zhuo Chen raised the interesting physical challenge of including complex equations of state in astrophysical hydrodynamics. Evan Nunez did a show and tell on characterizing the intermediate mass pre-main sequence stars in the Carina complex via their X-ray emission, and Mike McCollough showed phase- and time-dependent HETG spectra of his favourite source of all time—the Wolf-Rayet X-ray binary Cygnus X-3. Just before the bell rang, there was time to take in Norbert Schulz's observations of 400 km/s outflows from Circinus X-1 in the low state, and conjecture that all can be explained by a precessing oblate Be star.

And round two began.

M31 is where it's at for testing nova evolution and explosion models. In a tour de force of extragalactic nova studies, Martin Henze pointed out that it is much easier to study novae in M31 than it is in our own Milky Way - pesky gas and dust getting in the way of most of the action. One particular highlight is a nova, M31N 2008-12a, with recurrent outbursts every year. Martin emphasised their importance for the single-degenerate channel of Type-Ia supernova progenitors, noting that, in his unbiased opinion, M31N 2008-12a is the best Type 1a SN progenitor system to date

Martin is a guru on novae and in particular in our nearest spiral galaxy neighbour M31. "I'm 70% and X-ray observer, 30% optical, and I also enjoy hiking and long walks on the beach" @chandraxray #accr2018 twitter.com/rudy_phd/statu…


Jeremy Drake @cosmodrake
11:32am - 8 Aug 2018

Next we heard from Karleyne Silva on Modeling Accretion Columns of Polars, in particular, the AM Her-type CV EV UMa. Karleyne brandished some impressive modelling of optical and X-ray data that found a low system inclination with only one extended accretion region that is self-eclipsed works jolly well.

I think Martin Henze wins the quote of the morning: "Sorry I did not have time to show that - I was concentrating more on getting some jokes in." #accr2018 @chandraxray twitter.com/rudy_phd/statu…


Jeremy Drake @cosmodrake
12:36am - 8 Aug 2018

Fred Walter fizzed a salvo of southern nova observations just over our heads. Among other things one does with observations of southern novae, Fred has been trying to establish what happens to the accretion disk in a nova explosion, and how rapidly the disk is reformed. Evidence is there that the disks do reform, but no firm answers on the timescale yet.

Then Felipe Jimenez Ibarra on determining orbital velocities from IR/optical emission lines of LMXB with big and bright disks, which is devilishly tricky, even with GTC-10.4m spectroscopy. Nevertheless, Filipe was able to place strong constraints on the accretion disc opening angle of the neutron star binary Aquila X-1, finding results consistent with theoretical predictions for highly irradiated accretion discs.

And yes! A talk on protoplanetary disks! Both soft X-rays and UV emission in accreting T Tauri stars like TW Hya arise in the accretion columns. That has generally been the story, at least. Showing that these disks can be at least as devilish as those of X-ray binaries, Mark Reynolds found no correlation between the softest X-ray and UV variations in extensive Swift observations, perhaps pointing to a different origin of the coolest X-rays.

Time for lunch.

Then, in his invited review talk Christian Knigge actually does try and look for parallels and connections between different types of accreting objects! Way to go Christian!

After talking up the universal processes in accretion disks—such as outbursts and jets, he then tries to sell us "GOALS: The Great Observatories Accretion Legacy Survey." Coming to a review panel near you. He made AAVSO chief, Stella Kafka, happy too by showing an abundance of AAVSO light curves.

Tim Waters then dragged the audience firmly onto theoretical territory with a foray into magnetothermal disk wind modelling. The initial surprise from the modelling of disk winds launched in the high/soft state was that including a magnetic field suppressed the thermal wind to some extent - essentially closing down regions of acceleration. But kinetic luminosities at mid-latitudes can be increased, apparently in-line with expectations from observations of the LMXB system GRO J1655-40. Moritz Guenther pulled us back to protoplanery disks and a bizarre observation of enhanced iron in RW Aurigae.

Following that interlude, it was back to numerical modelling of disks by Daniel Proga, who strapped us in and raced us around thermal winds, radiation driving, enhancements through radiation pressure, and working out where the acceleration takes place - it felt like "everywhere". At that point, heading out with wobbly legs we needed a stiff beverage, but it was only coffee time. And poster time.

Thanawuth Thanathibodee had a really scary poster title, beginning with "The End of Accretion"! But, phew, it was just for the slowly accreting T Tauri star CVSO 1335. Saeqa Vrtilek pointed to the great promise of identifying point X-ray sources in external galaxies - essentially all of which are accreting objects at current survey sensitivities - while Dipanka Maitra reported on heart-warming observations of the 2015 outburst of V404 Cyg with a 12" telescope. Sibasish Laha went supermassive, probing AGN torus structure using X-ray variability, and David Principe next door was using high resolution X-ray and optical spectroscopy to investigate star disk interactions in T Tauri systems. Valliant SOC member Vallia Antoniou showed us clues about the formation efficiencies of different generations of HMXBs in the Magellanic Clouds before it was time to sit down again.

And then…

Nathalie Degenaar reviewed outflows in X-ray binaries, navigating the event horizon or not comparison with the agility, speed and precision of a happy gazelle after a double espresso. Among the highlights was a discussion of how X-ray bursts can probe winds and jets, and jet formation in neutron stars with high magnetic fields.

And on to the high resolution spectroscopy master, Jon Miller, whose grist has been anything gravitation-y potential-y enough and bright enough to point the *Chandra* HETG at. Pushing the order envelope by analysing 3rd order spectra, Jon has been finding much faster and more highly ionized outflows that lead to orders of magnitude increases in estimates of the mass outflow rates and kinetic power inferred from disk winds.

While fewer than 1 in $3{\times}10^6$ Americans attended #accr2018, three out of the 2 million Canary Islands inhabitants attended...

Teo Munoz-Darias presented the discovery of an impressive optical wind in the outbursting black hole host V404 Cygni; and perhaps more importantly, evidence that such outflows are common in such systems. These winds appear

to carry as much material as is accreted. Then Ruchit Panchal went through simulations of light curves of the IC10 X-1 X-ray binary, which has a Wolf-Rayet secondary. Absorption in the wind of the WR star leads to interesting diagnostics of the wind density and acceleration.

Finally, finishing us off, in more ways than one during a blisteringly intense and exhilarating afternoon session, Rozenn Boissay Malaquin sneaked in something a bit more massive than a star. Using *Chandra*/HETGS and NuSTAR observations he found two ultrafast outflows in PDS 456, which, I'm sorry to report, is only quasi-stellar. It was time to leave the meeting and go to the pub - now that was an ultrafast outflow.

Thursday

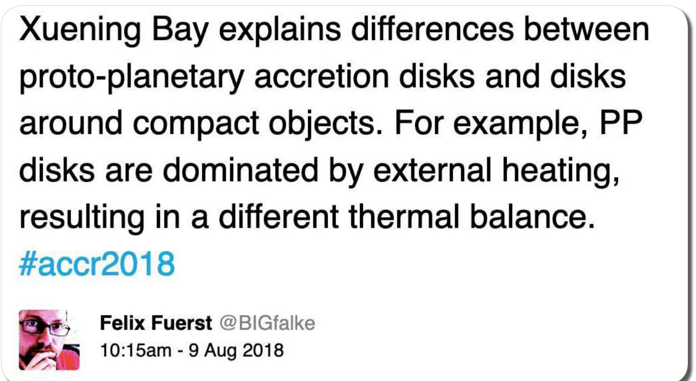
Fresh and sprightly, we returned…

The phenomenal physicist Felix Fuerst's magnificent manifest of the variable cyclotron line energy due to relativistic beaming in GX 301-2 was a good starter. Two separate cyclotron resonant scattering features were inferred, and appear to originate at different heights above the neutron star surface, where they sample different magnetic field strengths. Then, Rene Ludlam explained how NuSTAR and NICER observations of relativistic disk lines in neutron star low-mass X-ray binaries can determine the neutron magnetic field strengths and help place limits on the radius of the compact object itself.

And just when the long-sought solution to the NS equation of state appeared to be within our sweaty grasp, it was time to return to T Tauri stars, and specifically the closest one we know, TW Hydrae.

Costanza Argiroffi and colleagues have been busy measuring spectral line velocity shifts in *Chandra* high resolution spectra and have been able to deduce that infalling material channeled by magnetic fields impacts the star at fairly low latitudes. Brooks Kinch then presented some nifty Fe Kα profile simulations based on general relativistic magnetohydrodynamic simulations using a Monte Carlo method. He asked the question on everyone's mind "Can MHD simulations of disks really predict the light we see?". And they sort if did look a bit like Cyg X-1 in the soft state.

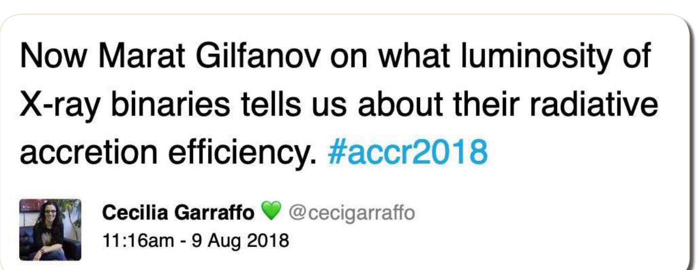
The other question on everyone's mind was whether one of our invited reviewers would take up the challenge today to address how accretion compares in different types of object?



It all came over as very sensible too. The rest of Xuening Bay's talk was a stunning rendition of the MHD and microphysics that need to be accounted for in protoplanetary disks. And if you last looked into them some years ago, MRI appears to have been ousted by disk winds as the primary angular momentum loss antagonist.

Break and poster time brought us Matthew Coleman's paper on convection and and magnetic turbulence in white dwarf accretion disks, Sergei Dyda's clumpy outflows from 3D line-driven winds and Kristen Dage ULXs in extragalactic globular clusters. Then there was a poster that, ehem, did not show up on the first day from some Drake fellow on the peculiar X-ray/UV accretion rate schism in the dM+DA binary QS Vir.

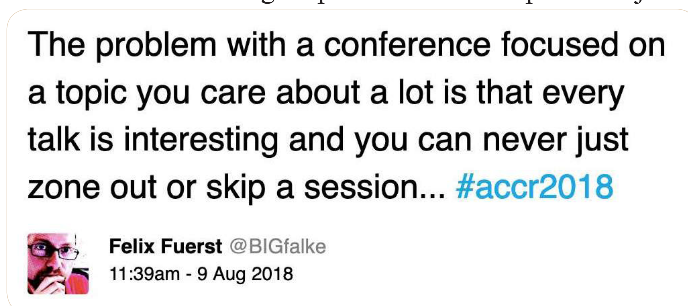
Reinvigoration by coffee rendered us suitable recipients of the wide range of accretion on offer the next session….



And it gets pretty low for ULXs, dropping sharply for the most luminous objects such that they must lose about 90% of the accreting material in outflows. Silas Laycock drew our attention to massive X-ray binaries in starburst galaxies, asking "What do they look like and how massive are they really?", with special big foam finger pointing at IC10… at which point it was time for an invited review.

Andreas Zezas gave us a Greek epic that especially emphasised the utility of the Magellanic clouds for teasing out environmental factors in binary production.

Leading up to lunch, Dacheng Lin successfully modelled accretion in neutron star low-mass X-ray binaries using a combination of disk and boundary layer models, while Rigel Cappallo presented a method for modelling X-ray pulsars that will be useful for looking at trends and statistics of derived emission region parameters in samples of objects.



The scientist with the best name at the meeting, Montserrat Armas Padilla, got us going with a talk on how multiwavelength analysis of ultra-compact and very faint X-ray binaries can provide us with new insights into accretion physics at low mass transfer rates. Salvko Bogdanov took up the same theme but using transitional millisecond pulsars—compact neutron star binaries that switch between accreting and rotation-powered pulsar states.

And then it was time to dream a little bit as Ann Hornschemeier gave a consummate review on "Future Observations of Compact Objects with Athena and LISA". Enormous credit must go to Ann for resisting the temptation to use the "multi-messenger" cliche in both her abstract and talk, which related the merciless pincer movement that LISA and Athena would enact on the hapless hitherto recondite mysteries of the full gamut of black hole, neutron star and white dwarf binaries.

We could not help but think about #accr2028 again… Before Laura Shishkovsky launched us back into the present with the possibility that black holes could be found in globular clusters, despite there being no convincing candidates yet. Until now perhaps - their MAVERIC survey having dished up a promising one in M62 from VLA observations.

While the VLA has done some nifty things with T Tauri stars, one gets the impression Connor Robinson's druthers would be more for the UV that is formed in accretion columns on T Tauri stars and can reveal accretion rate variations. He finds that large UV flux, and therefore accretion rate, variations are likely linked to inhomogeneities in the innermost disk, and could have an impact on disk heating and chemistry, as well as planet formation. What, coffee time already? Time to mosey over to the posters.

Rosaria Bonito presented on how observations, simulations and laboratory experiments (a true science trifecta!) can join forces against the mysteries of accretion onto young stars with disks, SOC member Elena Mason presented insights into classical novae from high resolution multiband spectroscopy, and Eric Schlegel wrapped up with some neat Kepler K2 observations of accretion variations and stunted bursts on the CV AC Cnc.

And it was around the last corner and onto the home straight for Thursday, as Iminhaji Ablimit got us all to think again about SN 1a and in particular the evolution of magnetic white dwarf binaries toward conflagration.

Rosanne Di Stefano then regaled us with tales of hierarchical triple systems as a channel to gravitational mergers. The drift is that a third body in a wider orbit donates mass to a more compact binary, and shortens to the "time to merger" in the process. Cecilia Garraffo instead showed us how cataclysmic variables can go incognito in the CV period gap if the magnetic complexity of the M dwarf secondary increases in the evolution toward shorter periods. Magnetic braking is closed down, and the M dwarf slips back into thermal equilibrium within its Roche lobe and keeps its hands to itself.

Then it was straight into a wonderful treatise on what #accr2018 is really all about: mass transfer and "The story of q and ζ, and, to some extent, of α,β,γ" by Natasha Ivanova. Swirling us about the theory like we were in the accretion disk itself with the most lucid view of the fundamentals. Stable mass transfer appears to be possible even at high mass ratios and should be a more common phase that once thought for some object classes.

Then..

> Last talk of the day by Morgan MacLeod on common envelope accretion, and how that transfers the binary and the objects in it. #accr2018
>
> **Felix Fuerst** @BIGfalke
> 5:29pm - 9 Aug 2018

The common envelope phase is a bit like the matchmaker bringing together widely separated stars into a more intimate relationship. Morgan described how accretion during the common envelope phase can modify the masses and spins of compact objects, potentially with observable signatures for gravitational wave detectors like the LIGO-VIRGO network. ANd Thursdays science sessions were over.

It was time to bring our common envelope into the reception room for victuals and liquid refreshment. We had a more grave, bitter-sweet duty ahead of us for the evening: honouring and remembering the late Jeff McClintock

Eulogies and reminiscences were given by many meeting attendees, as well as several guests who came in especially for the occasion.

Jack Steiner, one of Jeff's students and mentees, speaks at a special evening session dedicated to his work and memory.

Friday

Our final sessions were to be more focused on topics of especial interest to Jeff—black holes. Ramesh Narayan's talk on advection-dominated accretion flows, and how they naturally lead to the jets that are observed, was mesmerizing, profound, magnificent.

> Its going to be tough to beat Ramesh Narayan's quote "X-ray data imply that black holes really are really black!" #accr2018
>
> **Jeremy Drake** @cosmodrake
> 9:28am - 10 Aug 2018

Shane Davis' "Giving Spectral Modelers an f" followed. Unfortunately, it was not a cue for all the observers to rib the theorists, but an exposé of the correction term applied to pseudo-blackbody models used to model accreting sources. Shane, one of the creators of the BHSPEC XSPEC model finds f ~ 1.4-2, but f < 2 for photon-starved disks at accretion rates much below the Eddington limit.

Joey Neilsen showed some really NICER new data on GRS 1915+105, revealing how winds change on timescales as short as a second in response to X-ray variability and the implications for the inner and outer accretion flow. Jerome Orosz then gave a lucid mini-lecture on how Jeff's interest in measuring black hole spin was realised by obtaining independent distances and applying stellar models to constraint system geometry. Conspicuous was the palpable sense of suspense Jerome left us with, noting the many near-future distances to X-ray binaries that should come from Gaia.

Coffee punctuated the proceedings, followed by Jack Steiner's moving talk on his work with Jeff on measuring black hole spins. In addition to being intrinsically fascinating, Jack showed how spin is crucially important for how black holes form and the mechanism by which relativistic jets are launched. Javier Garcia made the natural progression to "Probing the innermost region of accreting compact objects" with some gratifyingly physics-y modelling of disk reflection spectra.

I think Javier Garcia @jaj_garcia is now winning the quote of the day - both scientific and heartwarming! "I was so proud of these model fits that I put the plot on my grandma's fridge" #accr2018 twitter.com/BIGfalke/statu…


Jeremy Drake @cosmodrake
11:54am - 10 Aug 2018

And it was time for Josh Grindlay's much anticipated talk on…. Josh? Time dilation effects within the strong gravitational field of Josh's office apparently having skewed his schedule, Charles Bailyn stepped up to report on 20 years of observations of the dynamically-confirmed black hole candidate A0620-00, and an overall trend toward increased disk luminosity. Charles explained how we might be witnessing a gradual build-up of the disk as the source progresses toward its next outburst. #accr2028

Jonathan Grindlay on BH populations: why is there only one Cyg X-1 in the galaxy? #accr2018


Cecilia Garraffo 💚 @cecigarraffo
12:29am - 10 Aug 2018

Speaking of outbursts, Josh arrived! Josh is a prime instigator of the Digital Access to a Sky Century @ Harvard project to scan all the Harvard plates. He gave a wonderful overview of estimating the population of black hole X-ray binaries in the Galaxy and how DASCH can help tease them out.

And we were at an end, uplifted and inspired as by a moving spiritual ceremony... And all wanting to ditch our current tedious research projects and study black holes.

So, that's the end of #accr2018! It was a really great meeting, thanks to @chandraCDO, @cosmodrake, @rudy_phd, and all the other people involved! I learned a lot and had a great time! Now, back to science and white paper writing ;-)


Felix Fuerst @BIGfalke
3:02pm - 10 Aug 2018

In addition to the two authors of this article, the long-suffering SOC of #accr2018 who put together the science program,were Vallia "Another HMXB Survey" Antoniou, Rosanne "Mine's a Triple" Di Stefano, Catherine "Protoplanetary" Espaillat, Elena "New Star" Mason, Jon "High Res" Miller, Roberto "Ultra-Luminous" Soria and Jack "Black Hole" Steiner. Local arrangements and logistics were blended smoothly by Jason Conry, Karla Guardado, Ray Hemond, Lauren Robbins and Aldo Solares.

No meeting at all would have happened without the supreme stewardship of Rudy "Can We Fix It? Yes We Can!" Montez. No talk of revenge or anything, bygones being bygones, forgive and forget, all friends together, but, dear reader, why not hit him up sometime for... SOC chair? #accr2028.

Twenty Years of *Chandra* Peer Reviews

Andrea Prestwich

A lot has changed since the first *Chandra* proposal deadline on February 2 1998. In 1998 *Chandra* was still called the Advanced X-ray Astrophysics Facility (AXAF) and the first call for proposals was issued by NASA, not the CXC, and was titled "NASA Research Announcement for AXAF Cycle 1". 779 proposals were received and the peer review was held in Waltham, MA. Proposals were delivered to reviewers on paper and reviewer comments were typed by a team of dedicated secretaries who saved the results of their labor on floppy disks! Hard copies of reviews were hand-carried to panelists who made revisions using pen and ink. There were stacks of paper in panel rooms but no laptops. Although the technology used to process proposals has since changed, the time requested per cycle and the oversubscription has remained remarkably constant over the lifetime of the mission.

As the mission matures, there has been a trend towards larger and more complicated programs. In Cycle 1, the median approved proposal exposure time was 30 ks whereas in Cycle 20 the median is more like 100–200 ks. Large Projects (> 300 ks) were introduced in Cycle 2 in recognition of the fact that many important science programs require larger chunks of time—for example, surveys and deep exposures of a single object. The trend continued with the introduction of Very Large Projects in Cycle 5 and X-ray Visionary Projects in Cycle 13. The "golden years" of XVPs lasted 4 years during a period when *Chandra* spent significantly more time above the earth's radiation belts, resulting in an increase in science observing time (see the jump in available time in Figure 2). *Chandra* programs have become more complex over time. Despite increasing challenges with thermal management of the spacecraft, the mission planning teams routinely coordinate *Chandra* observations with multiple ground-based and space-based observatories. including initiatives like the Event Horizon Telescope and even solar system missions (e.g., New Horizons). *Chandra* is doing excellent target of opportunity (TOO) science, including gamma ray bursts, supernova, changing states in black hole and neutron star binaries, and the famously detected X-ray emission from GW170817 - a feat that would fall into the "in my wildest dreams" category in Cycle 1!

Cycle 20 Proposal Statistics

The programs approved for *Chandra*'s 20th observing cycle are now underway. The Cycle 21 Call for Proposals (CfP) was released on 13 December 2018 and the proposal deadline was 14 March 2019. Cycle 19 observations are close to completion.

Cycle 20 proposal statistics can be found in Figures 1-7 and on the CXC website at:

http://cxc.harvard.edu/target_lists/cycle20/cycle20_peer_results_stats.html

The distribution of science panels is shown in Table 1 and Joint Program statistics in Table 2.

Cycle 20 included a call for Very Large Proposals (VLP), a category requiring > 1 Ms of observing time. The total amount of time allocated in Cycle 20 was 17.3 Ms including 4.3 Ms to 7 approved LPs. No VLP proposals were approved in Cycle 20.

Cost Proposals

PIs of proposals with US collaborators were invited to submit Cost Proposals, due in Sept 2018 at SAO. Each project was allocated a budget based on the details of the observing program (see CfP Section 10.4). Awards were made at the allocated or requested budget levels, whichever was lower. The award letters were e-mailed in December, in time for the official start of Cycle 20 on 1 Jan 2019.

Table 1: Panel Organization for Cycle 20

Topical Panels	
Galactic:	
Panels 1,2	Normal Stars, WD, Planetary Systems and Misc
Panels 3,4	SN, SNR + Isolated NS
Panels 5,6	WD Binaries + CVs, BH and NS Binaries, Galaxies: Populations
Extragalactic	
Panels 7, 8, 9	Galaxies: Diffuse Emission, Clusters of Galaxies
Panels 10, 11, 12	AGN, Extragalactic Surveys
Big Project Panel	
BPP	Large and Very Large Proposals

Table 2: Time awarded by the Chandra Peer Review on other facilities

Observatory	# Accepted Proposals	Total Time
Hubble	7	37 orbits
NuStar	3	210 ks
NRAO	7	50.5 hours
Swift	3	157 ks
XMM-Newton	2	248 ks
NOAO	4	6.03 nights

Table 3: Chandra Time Awarded by other facilities

Observatory	# Accepted Proposals	Total Time (ks)
Hubble	4	254.0
XMM-Newton	1	22.0
NRAO	4	136.2

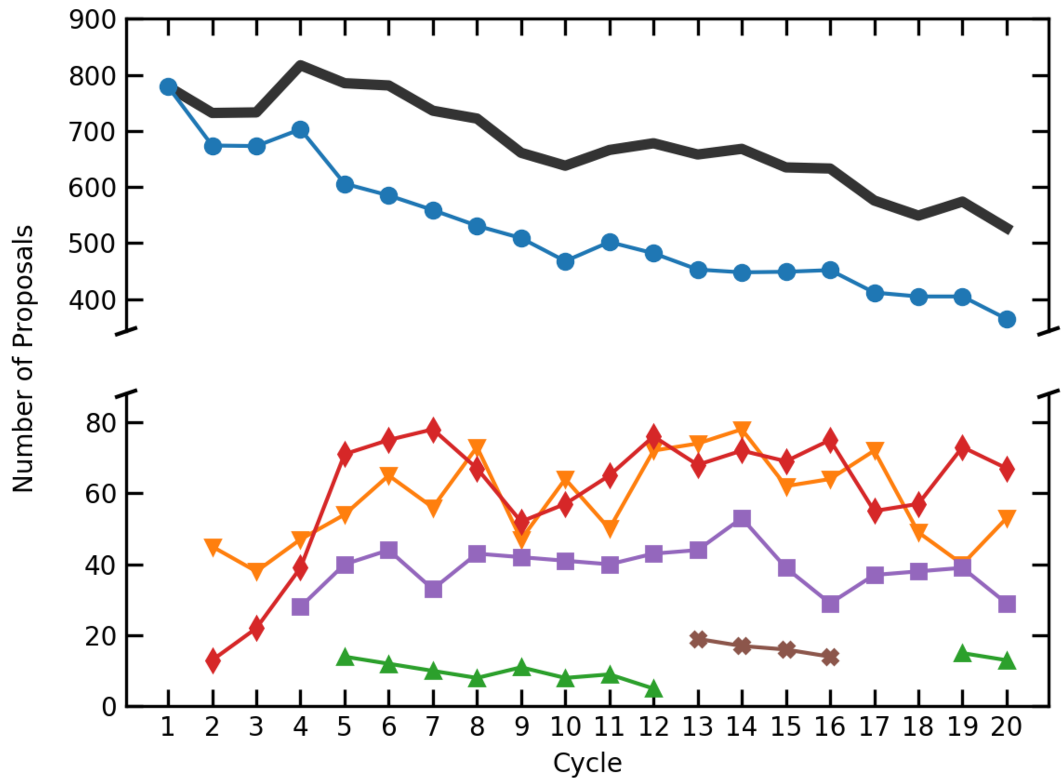


Figure 1: The number of proposals submitted in each proposal category (e.g., GO, LP, Archive etc.) as a function of cycle; note the vertical axis is broken at ~400 proposals to better show the individual proposal categories. Since more proposal categories have become available in each cycle, the number classified as GO has decreased as others increased. The total number of submitted proposals (solid black line) is remarkably constant. Proposal category legend found in Figure 3 on page 49.

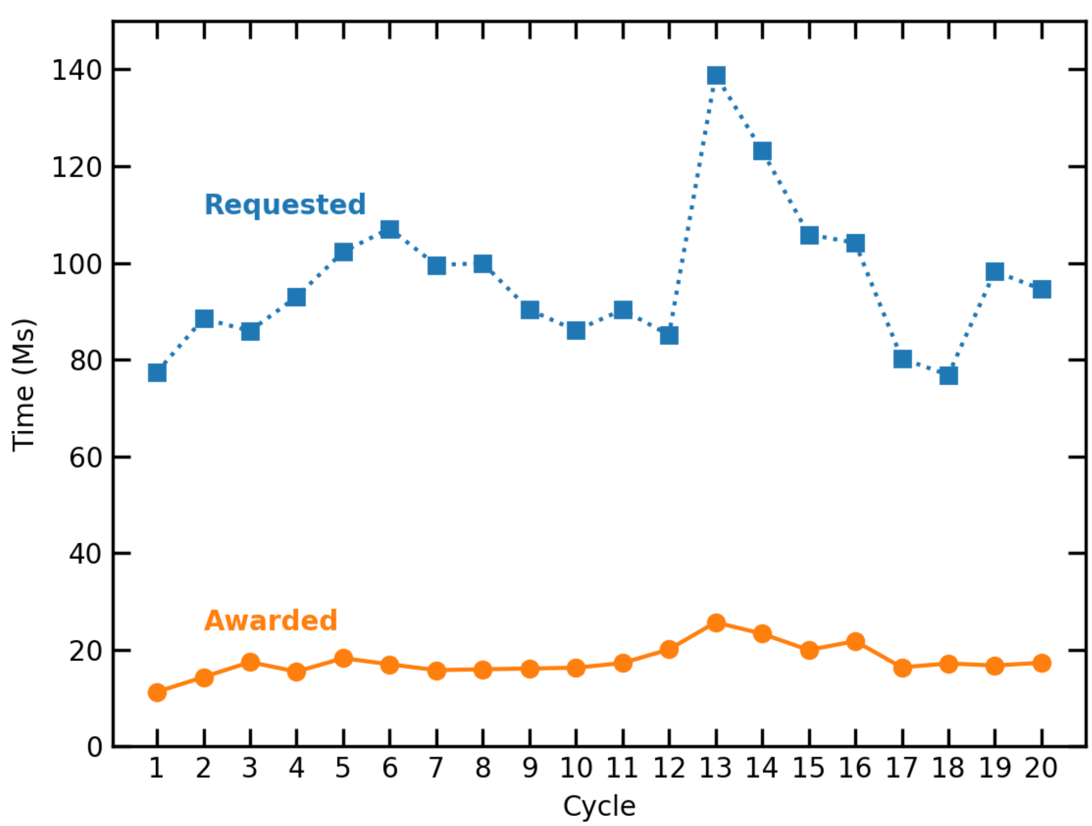


Figure 2: The requested and approved time as a function of cycle in ks including allowance for the probability of triggering each TOO. The available time increased over the first three cycles, and in Cycle 5 with the introduction of Very Large Projects (VLPs). The subsequent increase in time to be awarded due to the increasing observing efficiency and the corresponding increase in requested time in response to the calls for X-ray Visionary Projects (XVPs) in Cycles 13-16 is clear.

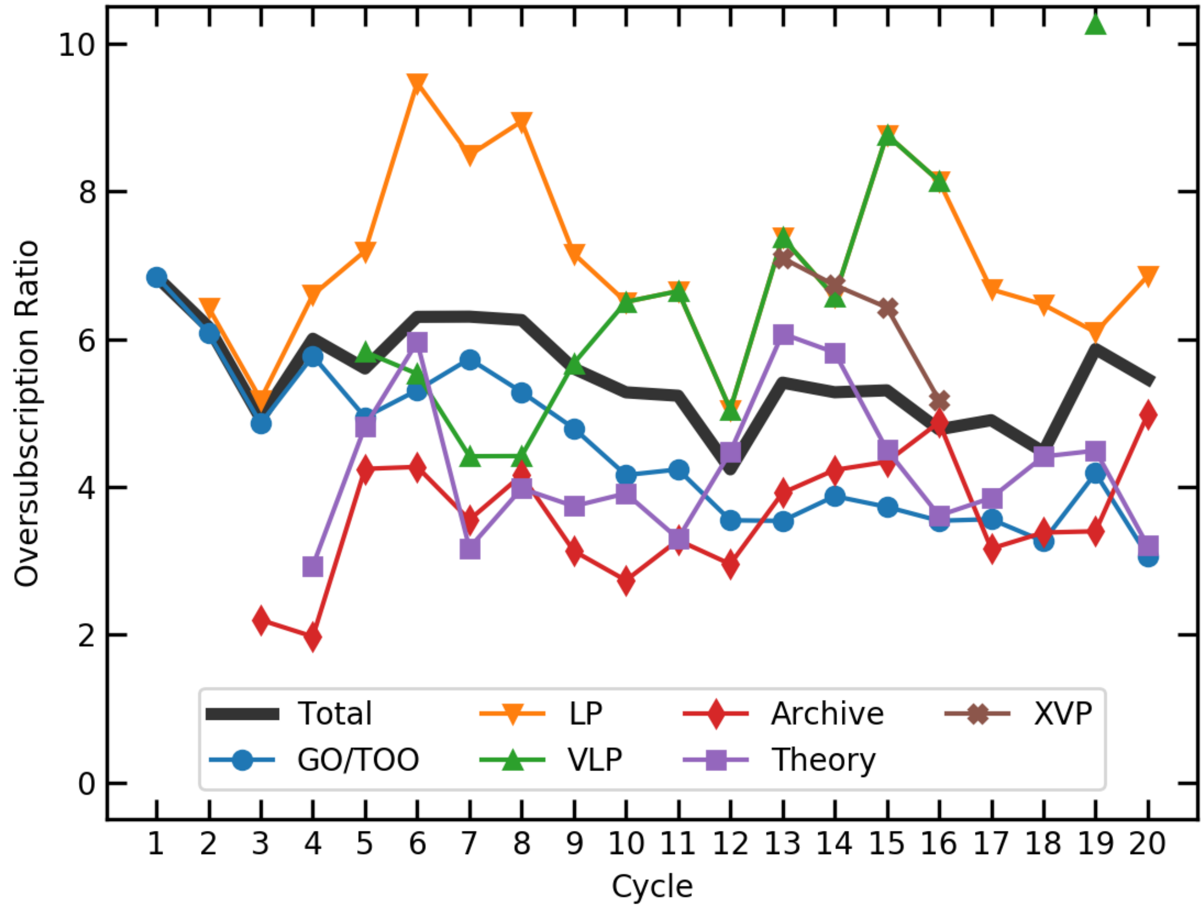


Figure 3: The effective oversubscription ratio in terms of observing time for each proposal category as a function of cycle. Note that some of the fluctuations are due to small number statistics (e.g., Theory proposals).

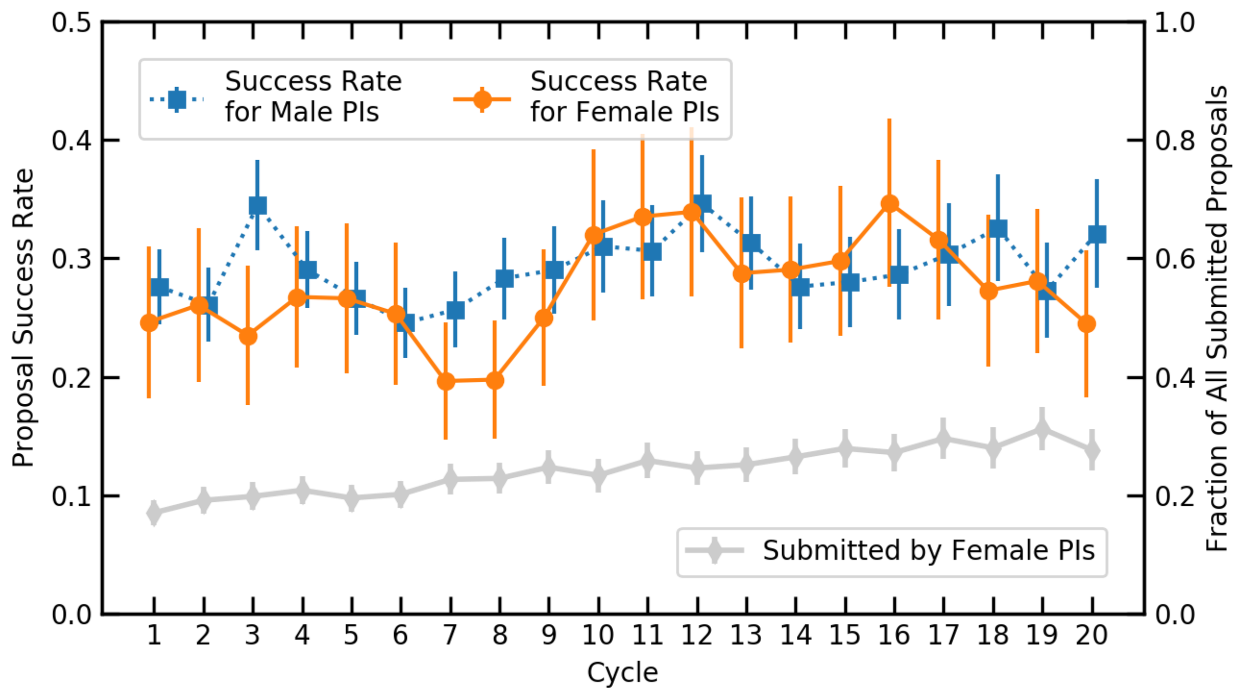


Figure 4: The success rate of male (blue) and female (orange) Chandra PIs as a function of cycle, and the overall fraction of female PIs (gray). Since Cycle 10, the success rate for female and male PIs has been statistically indistinguishable.

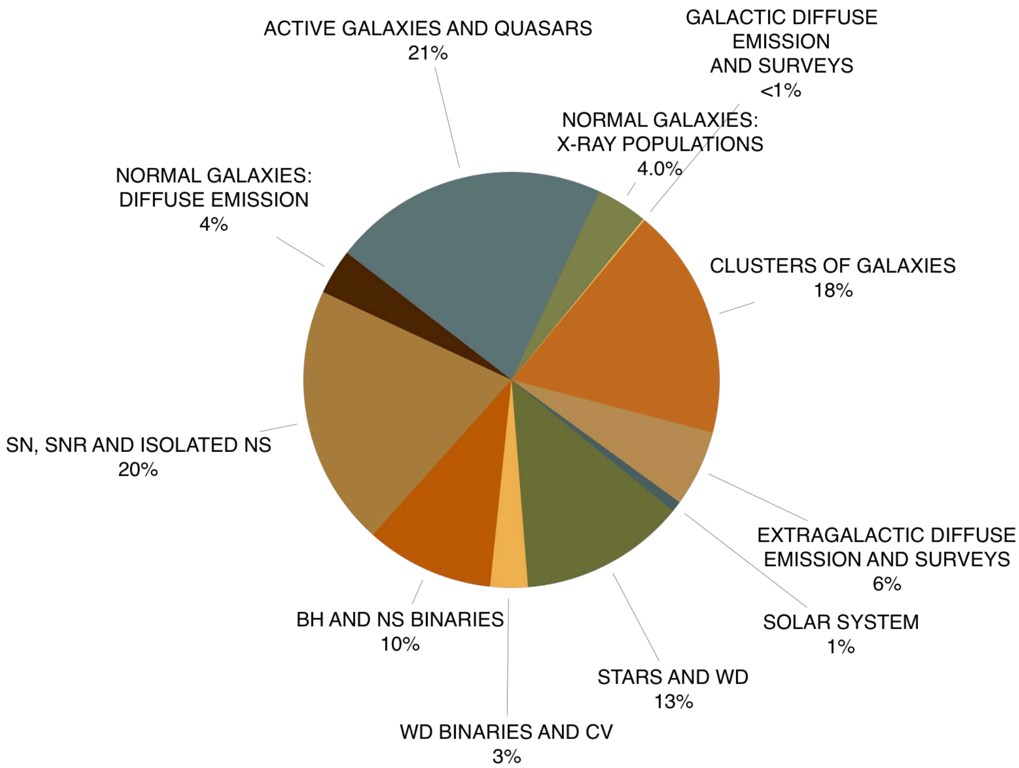


Figure 5: A pie chart indicating the percentage of Chandra time allocated in each science category. Note that the time available for each science category is determined by the demand.

Table 4: Requested and Approved Proposals by PI Country

Requested			Approved	
Country	**#Prop**	**Time**	**#Prop**	**Time**
Belgium	2	570.00		
Bulgaria	1	100.00	1	100
Canada	7	1497.00	2	362
China	7	520.00		
France	2	480.00		
Germany	19	5623.30	6	386
Greece	2	414.40	1	150
India	6	934.00		
Israel	1	450.00		
Italy	27	8210.00	6	1272
Japan	10	1320.00	3	150
Korea	1	85		
Mexico	1	400		
Netherlands	10	1230	5	480
Russia	1	130		
Serbia	1	125		
South Africa	1	120		
Spain	4	385	1	60
Sweden	2	350		
Switzerland	2	280		
Taiwan	1	83		
Turkey	2	200	1	50
UAE	1	24		
UK	22	6482.53	7	1392
USA	**394**	**68487.55**	**124**	**15655.36**
Total Foreign	**133**	**30013.23**	**33**	**4402**

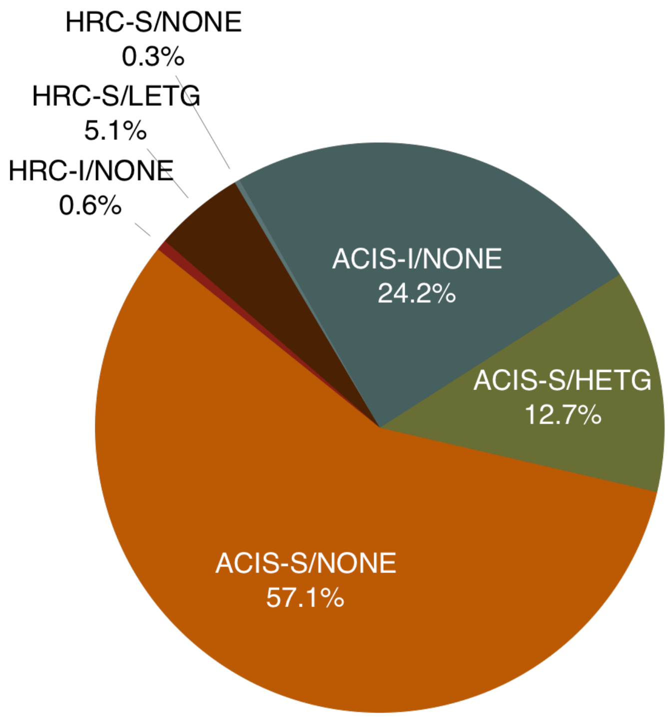


Figure 6: A pie chart showing the percentage of Chandra time allocated to observations for each instrument configuration.

Replacing RPS after 20 Years: Introducing New *Chandra* Proposal Software (CPS)

Tara Gokas
Rodolfo Montez Jr.
Antonella Fruscione

The Remote Proposal Software (RPS) was state of the art when the CXC started using it...two decades ago. Over the last few proposal cycles, the Director's Office noticed that many Helpdesk tickets from newer users posed the same questions:

- How do I save my proposal?
- How do I fix a mistake in my proposal?
- Why is my proposal assigned a new number each time I submit an updated version?
- Wait...can I check what I actually submitted?

In 2016, a small group of Director's Office staff and software developers initiated a revamp of the proposal submission software that would preserve the functionality and flexibility of RPS while meeting the expectations of the modern community. Early in the design process, the new software was refered to as the *Chandra* Proposal Software (CPS), and that name eventually stuck.

The resulting design allows users to easily save, update and access their proposals at any stage of the submission process. It also allows users to read any proposal that they are linked to as a co-investigator.

The biggest change from RPS was the introduction of user accounts. To minimize the impact of this change, it was decided that only one person per proposal would be required to have an account.

An account is also required for any additional people who want to have read access to a proposal within the CPS system. Those people have to opt-in to having their name and institution visible to other users for this functionality to work. That option is available from the account profiles and users can opt-in or opt-out at any time.

The proposal and target information collected in CPS has not changed significantly from RPS. However, instead of presenting the user with one long web form to complete, related input fields have been collected into separate sections that can be saved independently.

CPS was presented to the *Chandra* Users' Committee (CUC) in the Fall of 2017. Meanwhile, testing by a pool of volunteer scientists with varying levels of RPS experience informed some design changes. After additional iterations of testing and updates, the final product was made available to GTO proposers in 2018 as a small-scale introduction to the community.

Later that year, multiple announcements were made to the wider community about the new software, and to encourage users to create their accounts. The full system was opened for use in December 2018 when the Cycle 21 Call for Proposals was released.

As incentive for creating accounts ahead of the proposal deadline, the CXC offered to link accounts to existing proposals from the last three cycles. Since CPS also allows users to 'clone' proposals: a user can now easily re-submit a previously-requested program. Nearly 100 users created their accounts after the first announcement in November. And by the end of February, there were hundreds of old proposals that had been linked to new user accounts.

In the end, over 500 proposals were successfully submitted with the new system before the Cycle 21 deadline and the number of proposal-related questions to the CXC Helpdesk was noticeably reduced from last year.

A couple of patches to the software have addressed minor bugs and improved functionality. Soon, CPS will also be in use by DDT proposers, and after that RPS will be completely retired.

Users may send their comments, questions or suggestions for updates to CPS to the CXC Helpdesk (cxchelp@cfa.harvard.edu).

Chandra Users' Committee Membership List

The Users' Committee represents the larger astronomical community for the *Chandra* X-ray Center.

If you have concerns about *Chandra*, contact one of the members listed below.

Name	Organization	Email
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Ex Officio, Non-Voting

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CXC Coordinator

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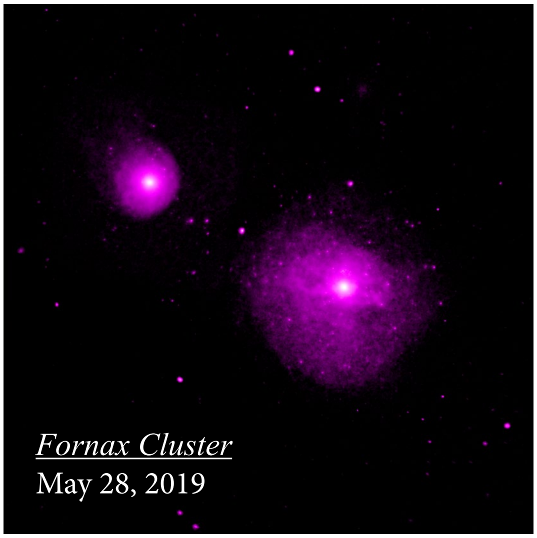
Chandra Press Releases

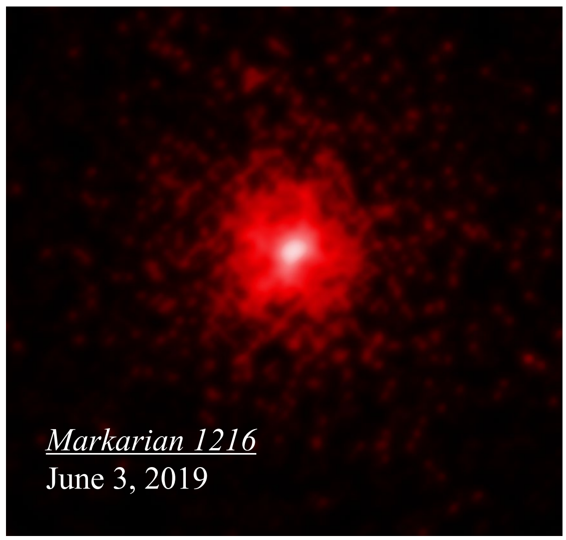
For the latest *Chandra* news, including all 2018 press releases, see
http://chandra.harvard.edu/



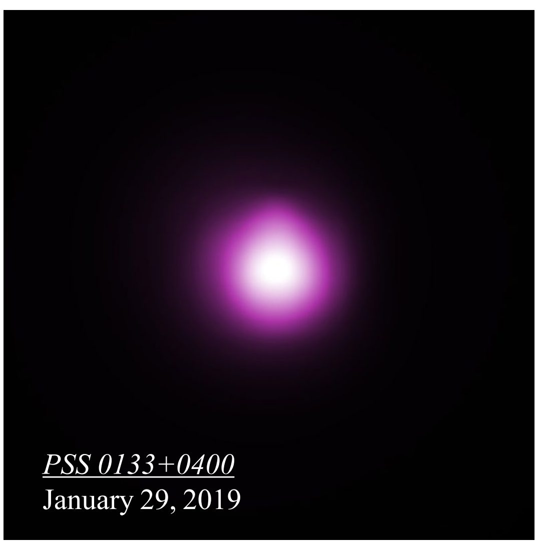
Fornax Cluster
May 28, 2019

1E2215 and 1E2216
June 25, 2019

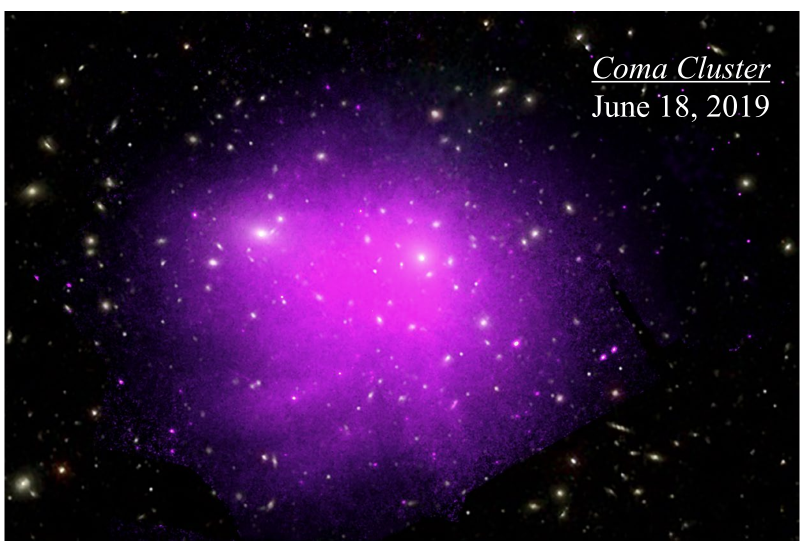
Cygnus A
January 9, 2019



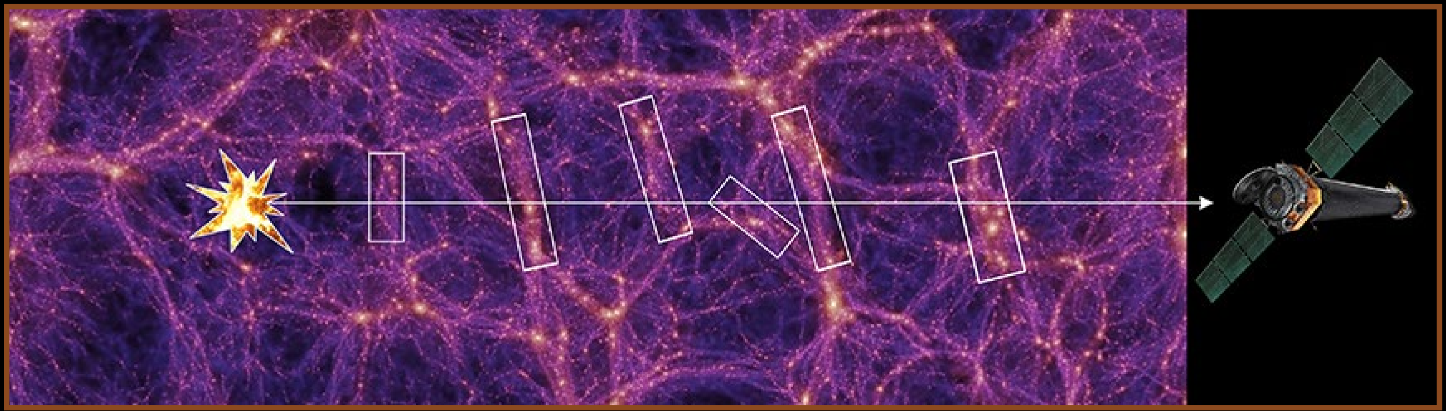
Markarian 1216
June 3, 2019



PSS 0133+0400
January 29, 2019



Coma Cluster
June 18, 2019



Where is the Universe Hiding its Missing Mass?

Astronomers used *Chandra* observations to potentially identify the universe's missing mass in 17 possible filaments lying along the light path between *Chandra* and a distant quasar. The missing mass is seen in absorption spectroscopy acquired with the Low Energy Transmission Gratings (LETG) onboard the *Chandra* X-ray Observatory.

Credit: Illustration: Springel et al. (2005); Spectrum: NASA/CXC/CfA/Kovács et al.

Press Release: February 14, 2019

http://chandra.harvard.edu/press/19_releases/press_021419.html