Chandra's
Legacy of Discovery in Transient Astrophysics

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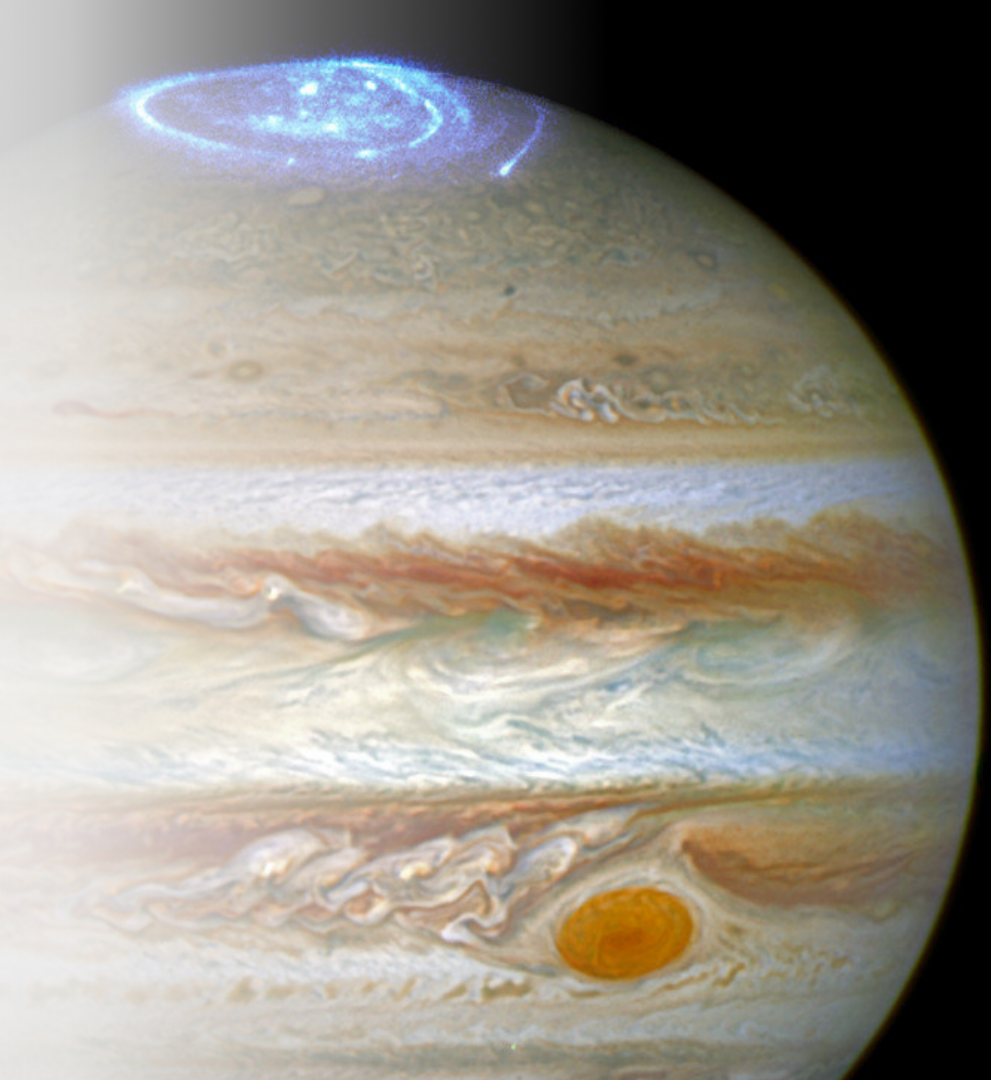
Canada Research Chair

X-ray Transients

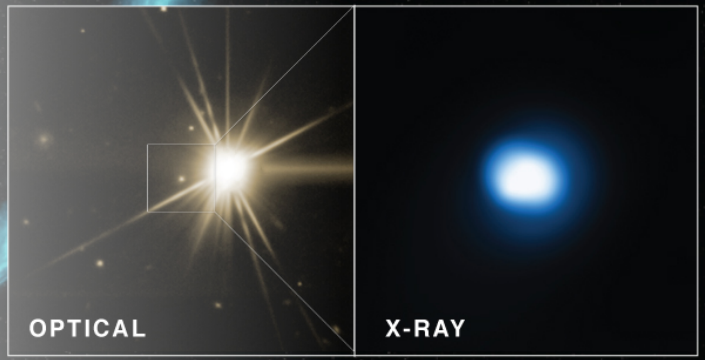
- This is a ***technique*** rather than a study of a ***class*** of source
- Means different things to different people
- ***What does "X-ray transient" mean to you?***



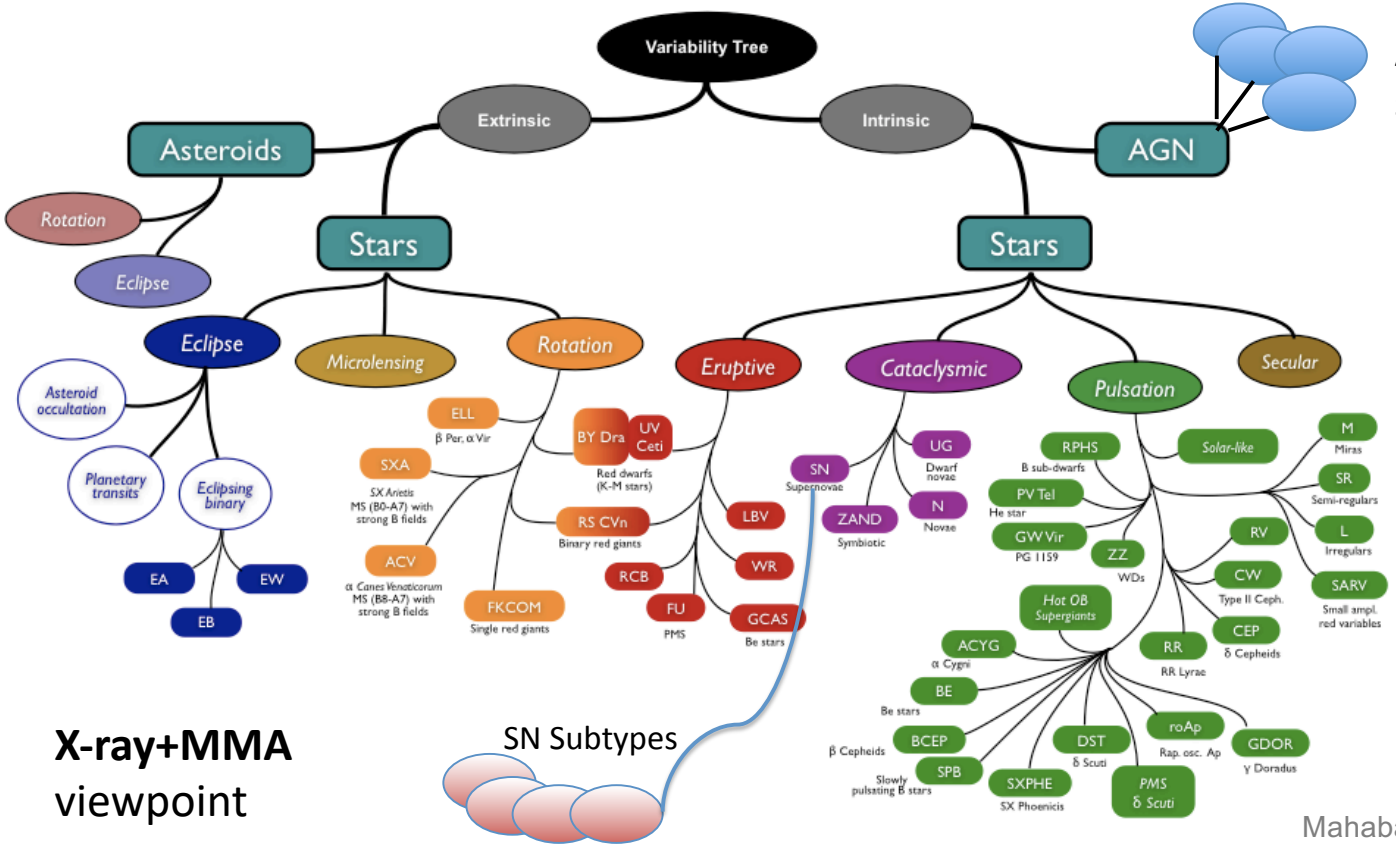
Classes of X-ray Transients

- Gamma-ray bursts
- Supernovae & SNR
- Tidal Disruption Events
- BH & NS Outbursts
- Stellar Outbursts
- Jupiter

… and more!?!



Schematic of Variables/Transients



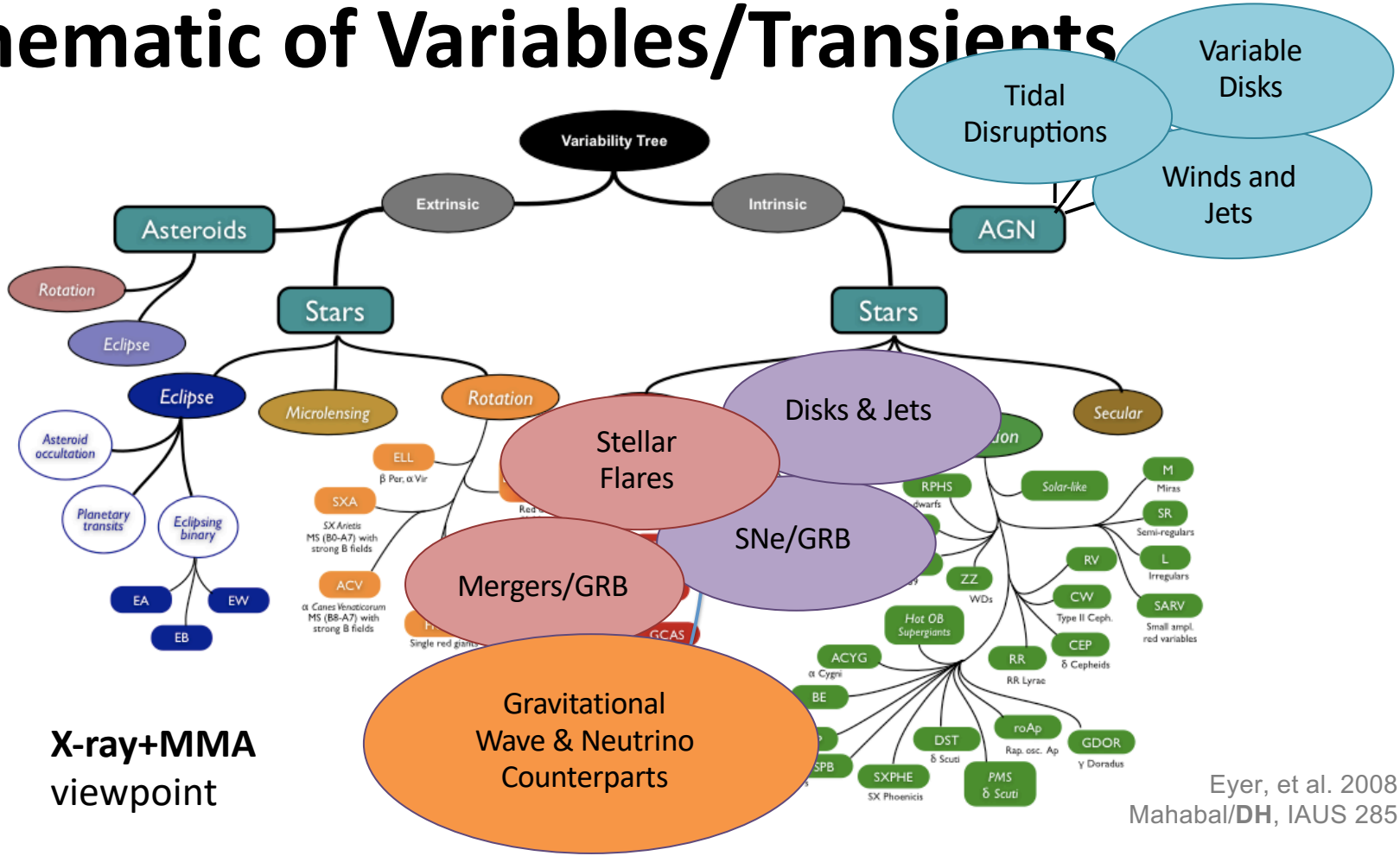
AGN subtypes

SN Subtypes

X-ray+MMA viewpoint

Eyer, et al. 2008
Mahabal/**DH**, IAUS 285

Schematic of Variables/Transients



X-ray+MMA viewpoint

Eyer, et al. 2008
Mahabal/**DH**, IAUS 285

High Energy Time Domain Desirati

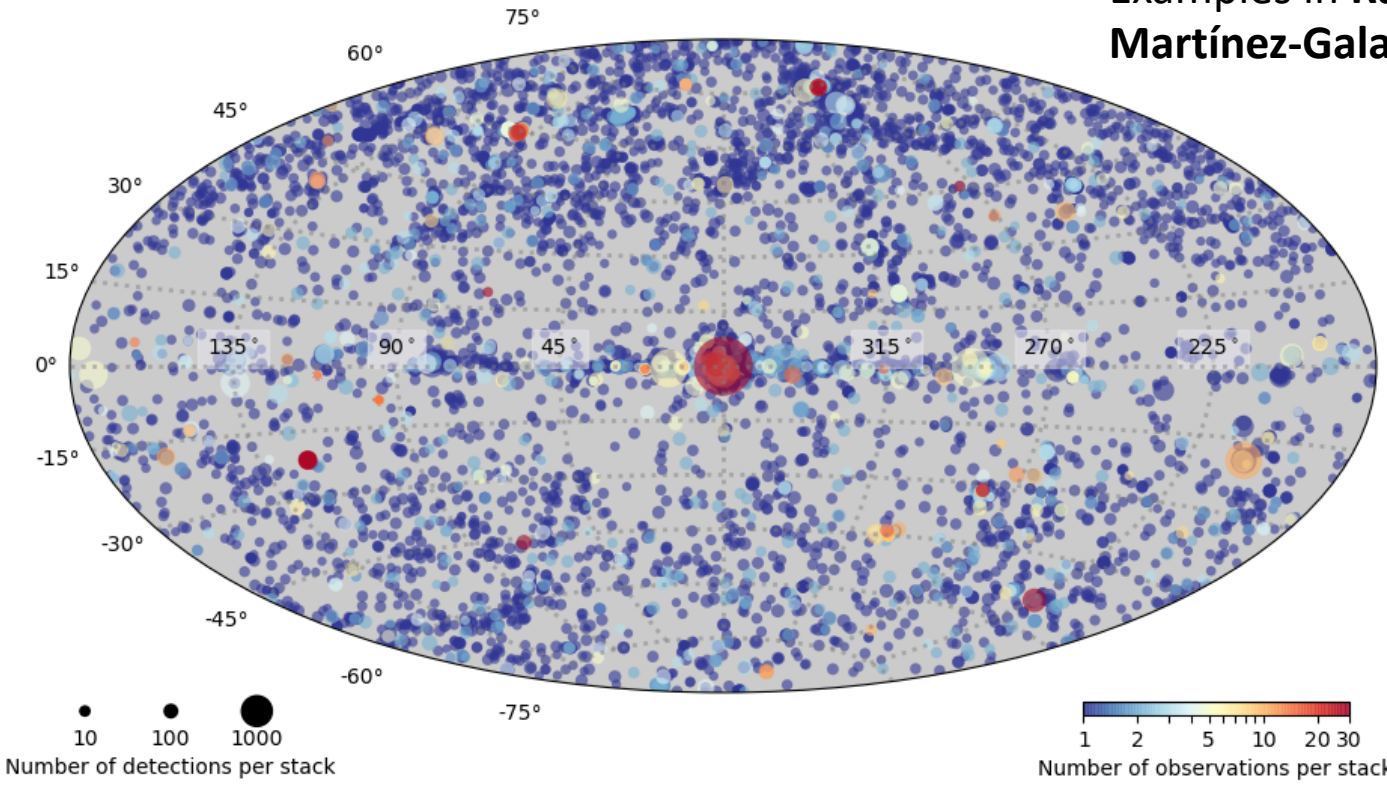
Discovery & Monitoring	Rapid Response	High Time Resolution
• All Sky Monitor and/or Localization • Science drivers: GW cntrparts, GRBs, SNe shock breakout, accretion, tidal disruptions • High Resolution	• Rapid slew (< hr) • Science drivers: GW cntrparts, GRBs, stellar flares/space weather, transients • High Availability	• Sub-ms timing • Science drivers: Strong gravity, neutron star physics, XRB/AGN physics, QPOs • High Sensitivity

Chandra's Unique Niche

- Sub-acrsec resolution
- High sensitivity
- Target of Opportunity Programs
- Joint Facility Programs
- Archives

X-ray Catalogs & Archives

Examples in **Rafael Martínez-Galarza's** talk!



CSC2.0

By the numbers

~374,000
detections

560 deg^2
total area covered

1999-2014
years of observations

7287
stacks (overlapping observations whose aimpoint is within 60" of each other)

5 *lowest number of counts for on-axis sources*

~315,000
unique sources

10382
imaging observations included

New

- Bayesian determination of multi-band aperture photometry, time variability, and hardness ratios.
- PSF modeling is used to determine source location and properties, improving off-axis sensitivity.
- Expanded Model List for Spectral Fits to sources with more than 150 counts.
- Extra Data Products available: full field event lists, multi-band images, limiting sensitivity maps, merged source lists, photometry probability density functions, pulse-invariant spectra and optimally-binned light curves in addition to more products already available in release 1.

CSCview

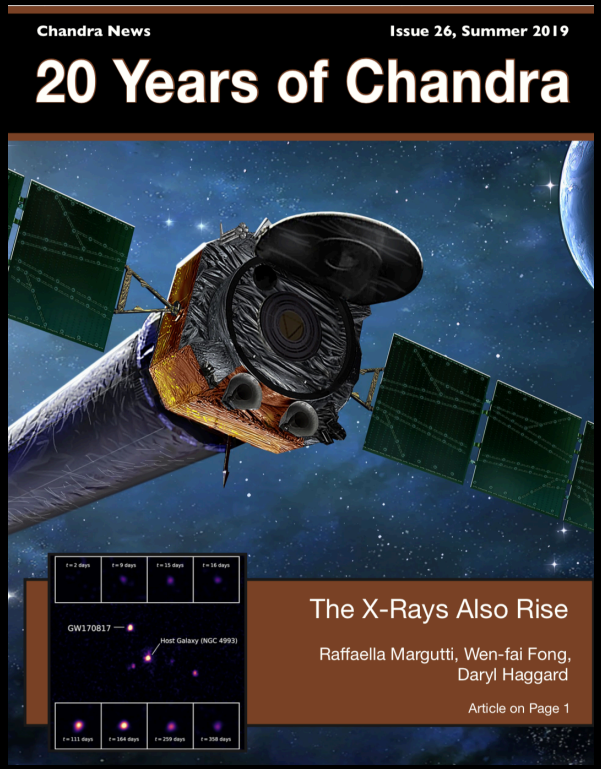
CSCview is a GUI application which provides direct access to the catalog via user-specified queries. Source properties and data products can be sent to GUI data discovery, plotting, and analysis tools like DS9, Topcat, Aladin, etc. using technology developed by the IVOA.

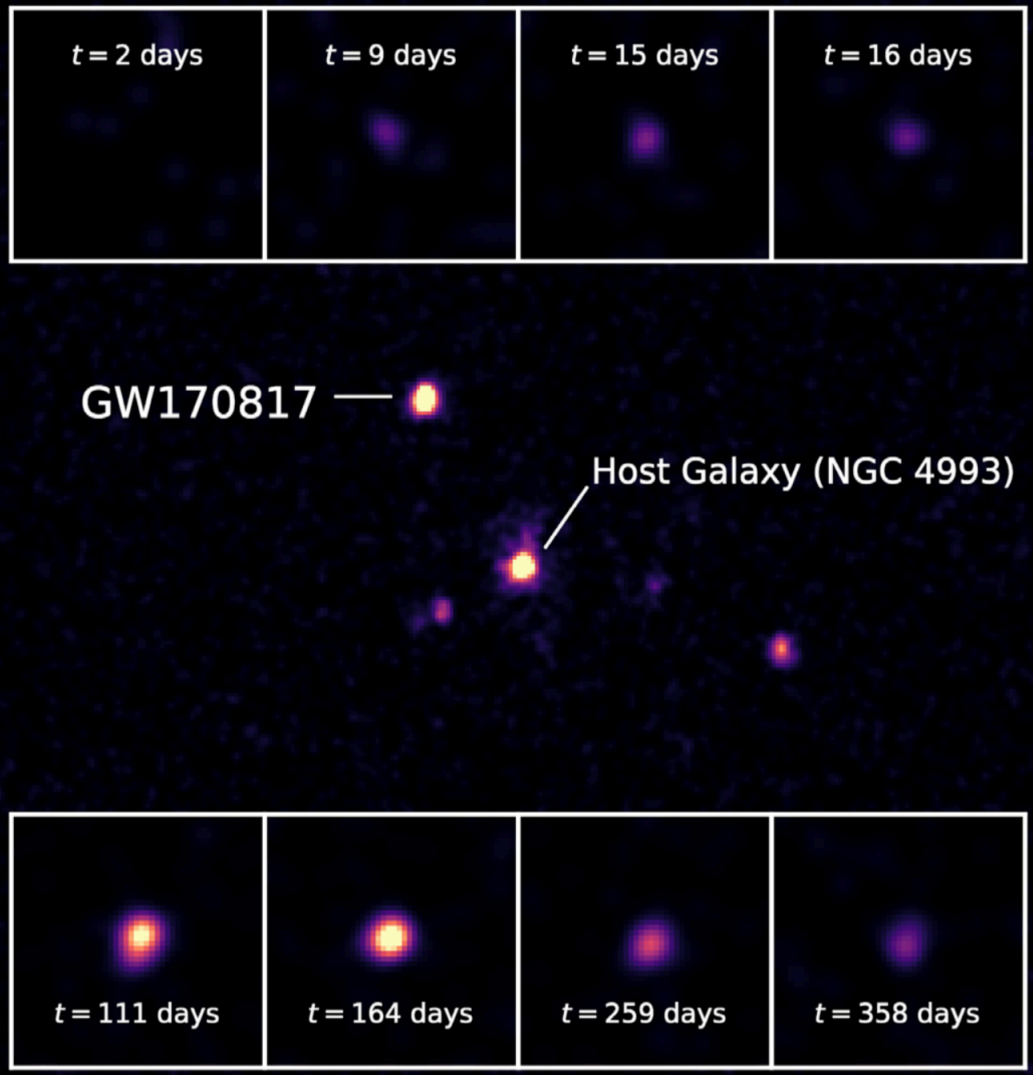
CHANDRA SOURCE CATALOG

http://cxc.cfa.harvard.edu/csc/

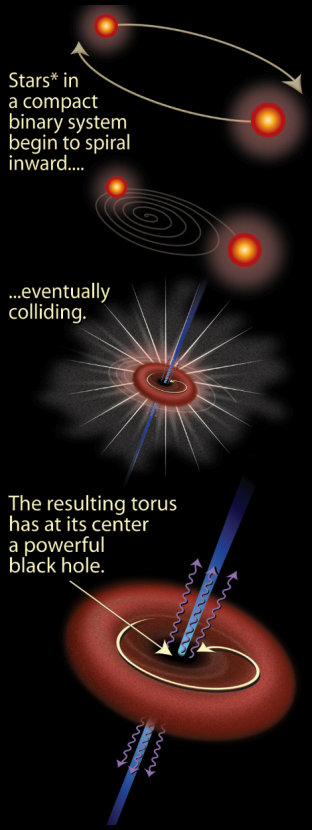
Slide Credit: **F. Civano** (2018)

NS Merger!


Chandra News
Issue 26, Summer 2019
20 Years of Chandra
The X-Rays Also Rise
Raffaella Margutti, Wen-fai Fong, Daryl Haggard
Article on Page 1

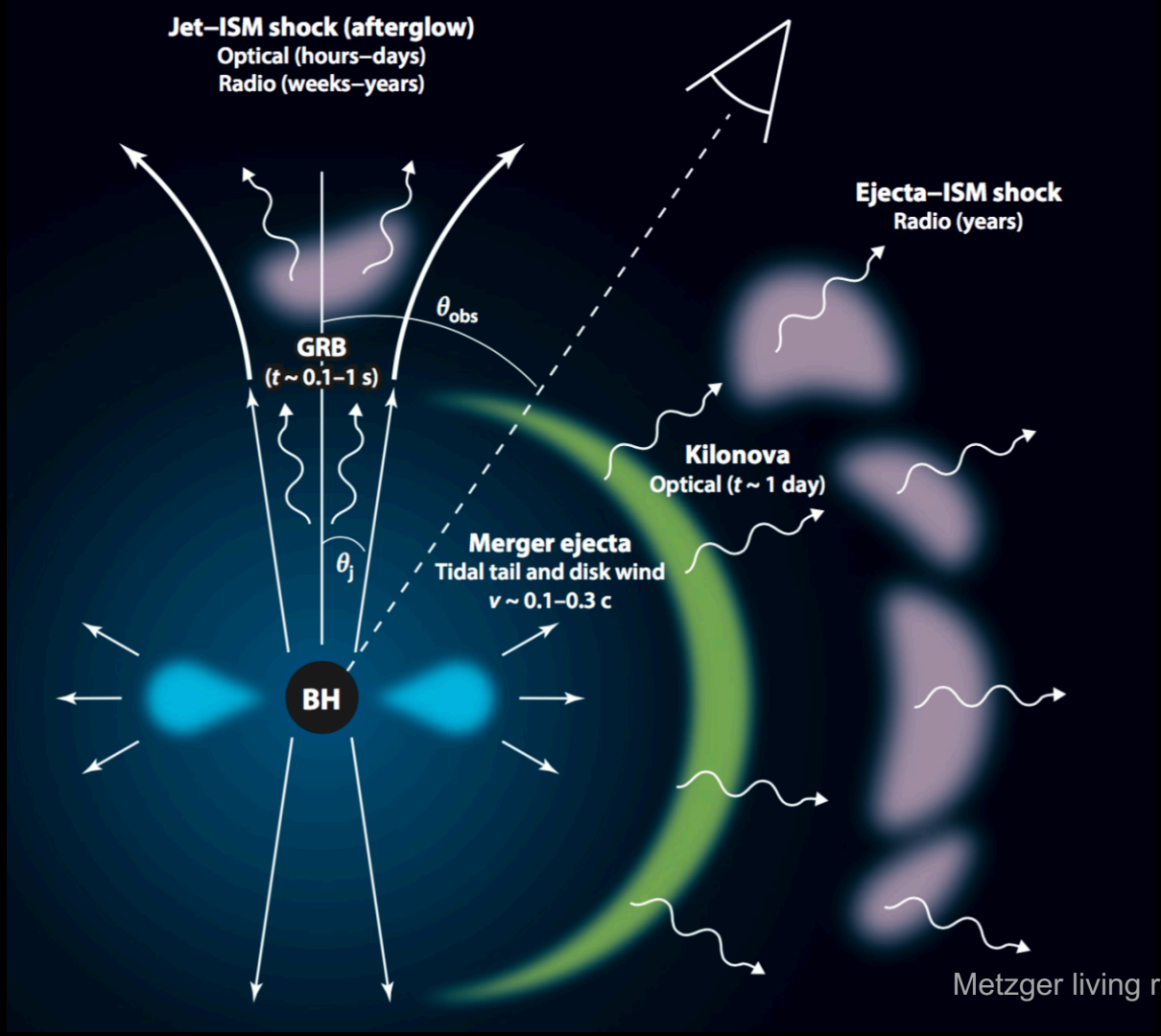

t = 2 days
t = 9 days
t = 15 days
t = 16 days
GW170817
Host Galaxy (NGC 4993)
t = 111 days
t = 164 days
t = 259 days
t = 358 days

GW170817 confirms NS merger origin for short GRBs

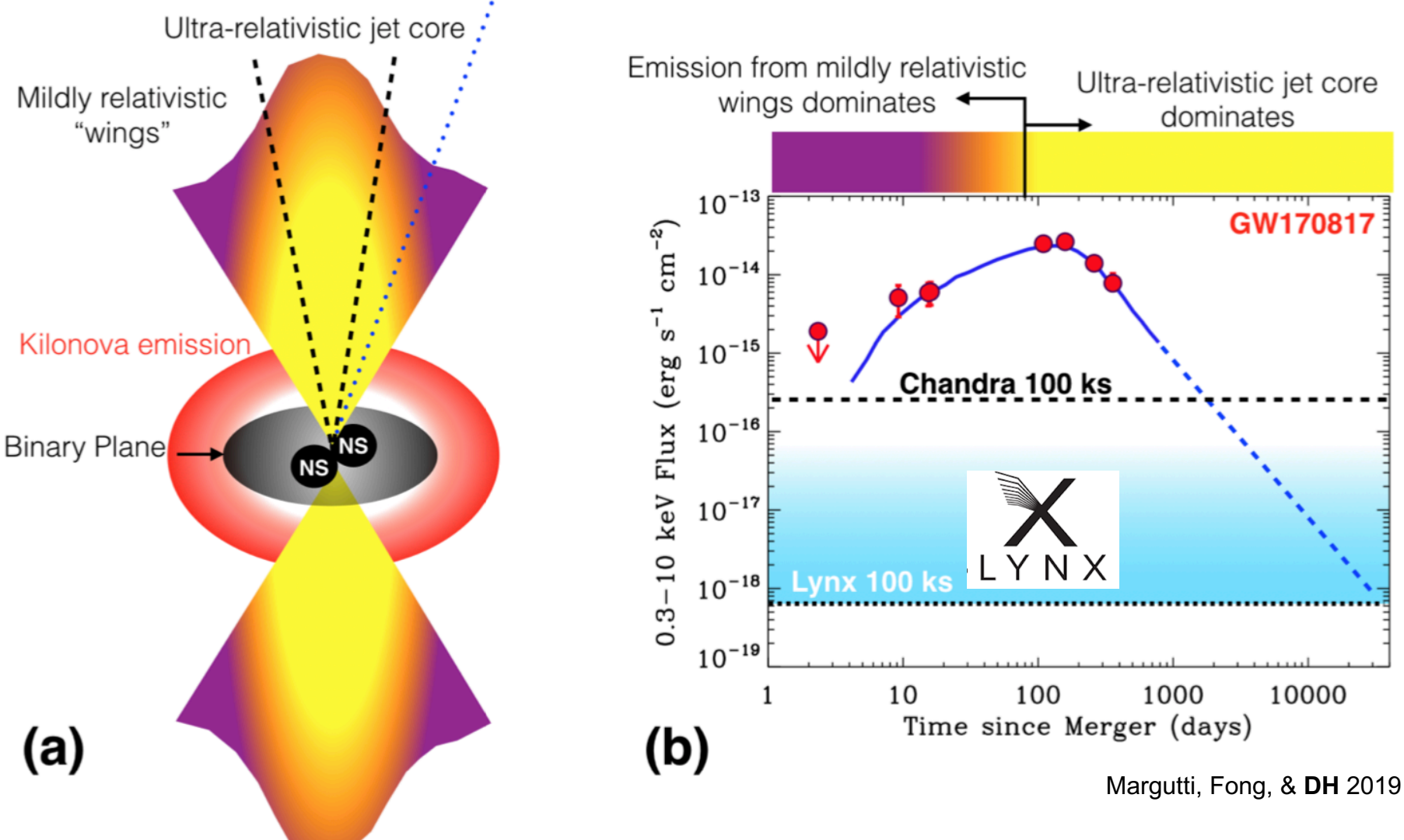


- Accretion onto central compact remnant launches relativistic jet
- Shocks within the jet emits short pulse of Gamma-rays
- Relativistic jet shocks the ISM, producing synchrotron afterglow emission from X-ray through radio

Slide Credit: **J. Ruan** (2018)



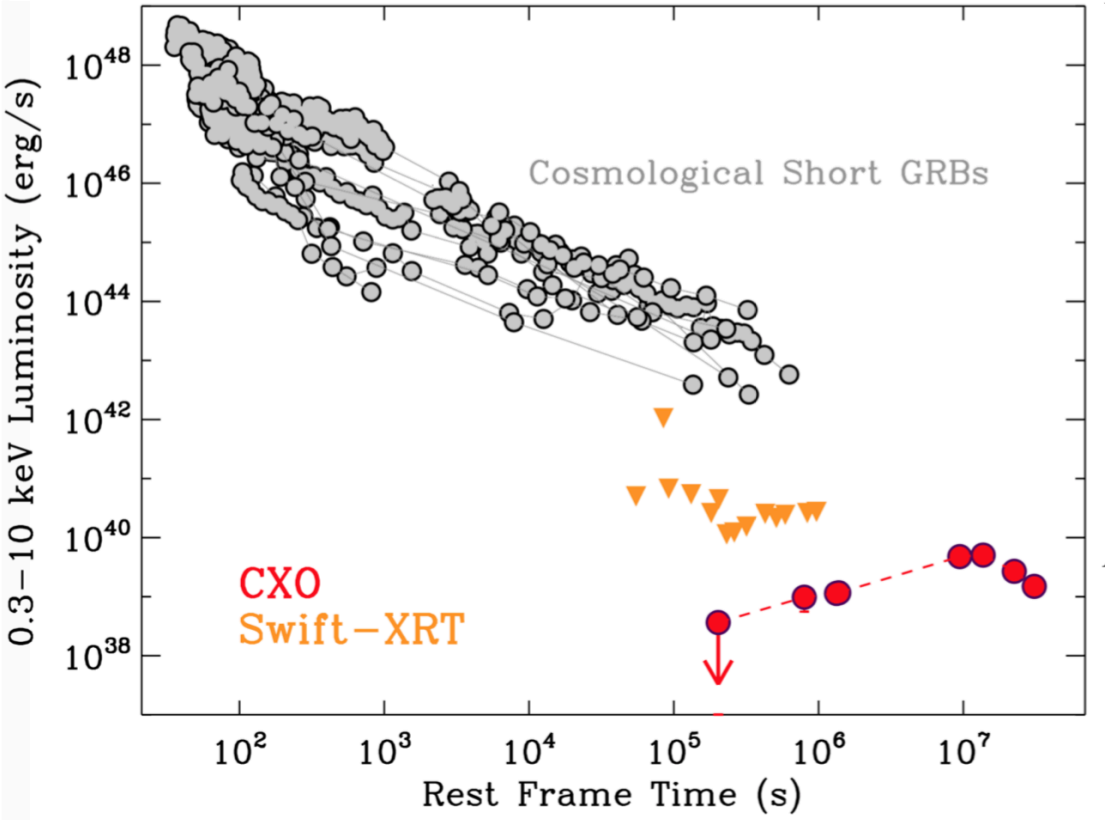
Metzger living review



Margutti, Fong, & **DH** 2019

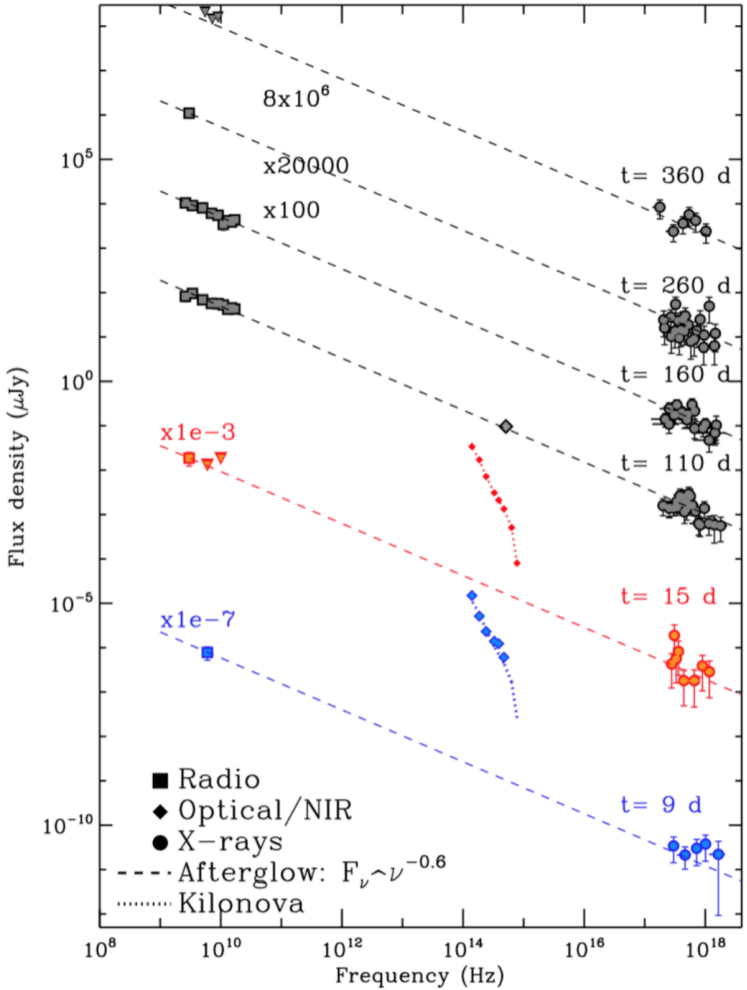
GW170817 vs. sGRBs

Margutti, Fong, & **DH** 2019



- GW170817's rising X-ray emission & low luminosity (despite being close!) set it apart from most sGRBs
- After peak, the decline is consistent with SGRB afterglows
- Expected from a jet pointed away from our line of sight

Margutti, Fong, & **DH** 2019



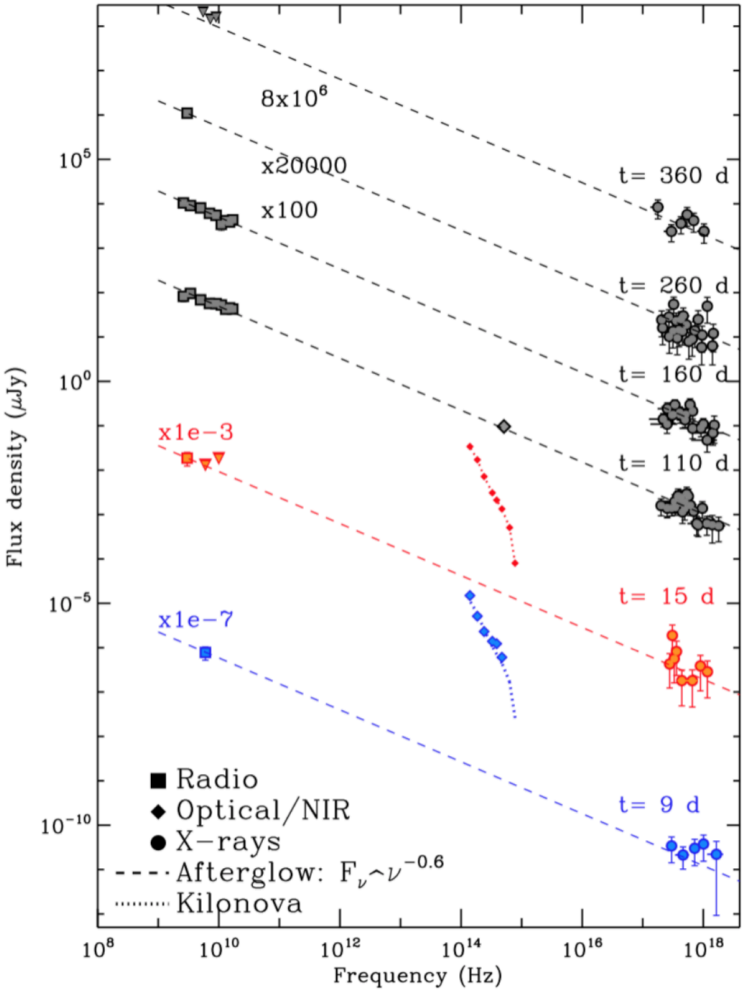
GW170817 SED

- Radio-to-X-ray SED shows *no evolution* in the first ~360 days after merger

$$F_\nu \propto \nu^{-\alpha},\ \alpha = 0.6$$

- Radio & X-ray from non-thermal synchrotron afterglow emission
- UV/optical/NIR from kilonova until ~100 days post-merger
- Relativistic outflow emission dominates UV/optical/NIR after 100 days

Margutti, Fong, & **DH** 2019



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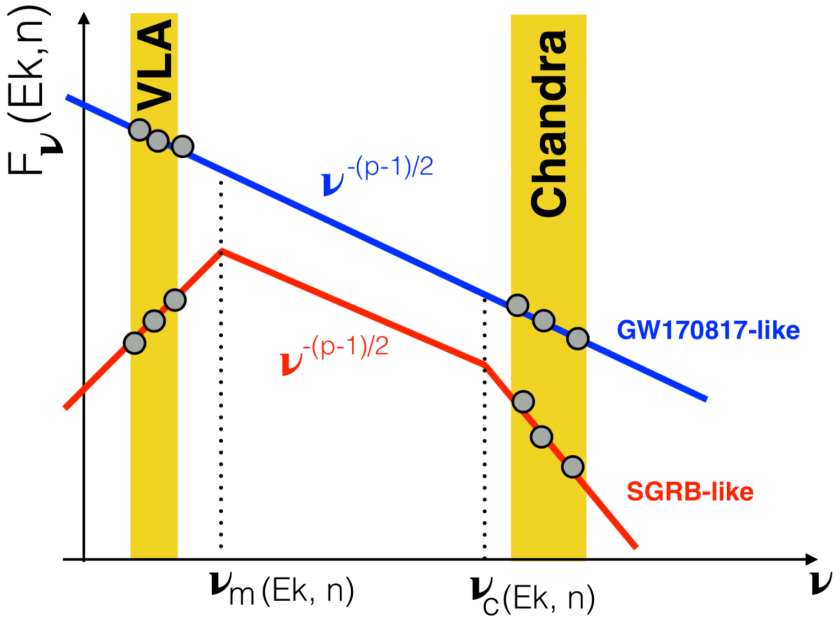
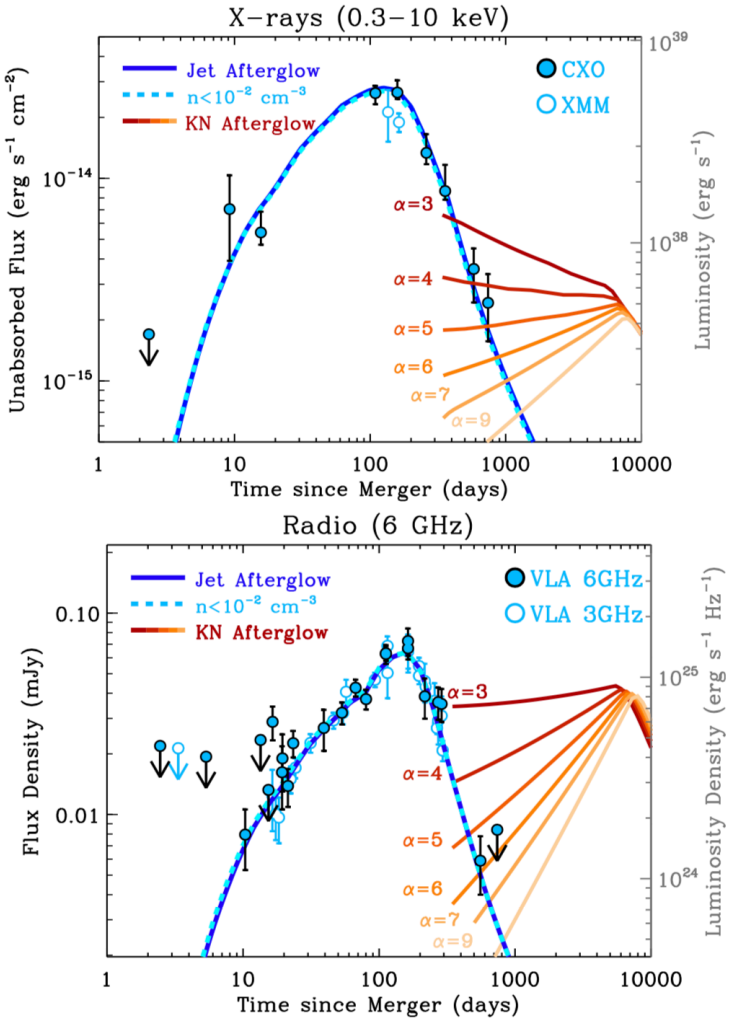
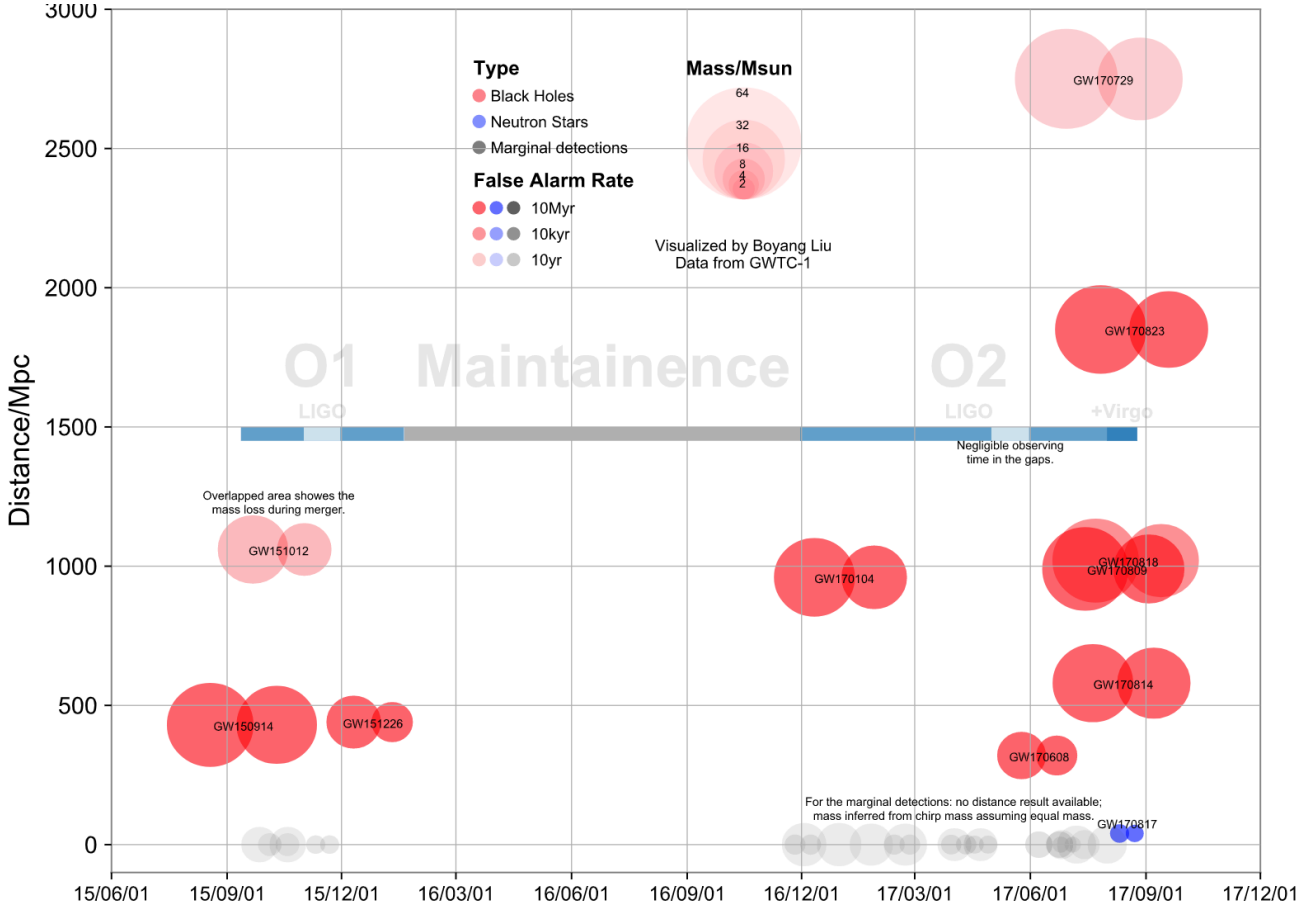


Hajela et al. 2019

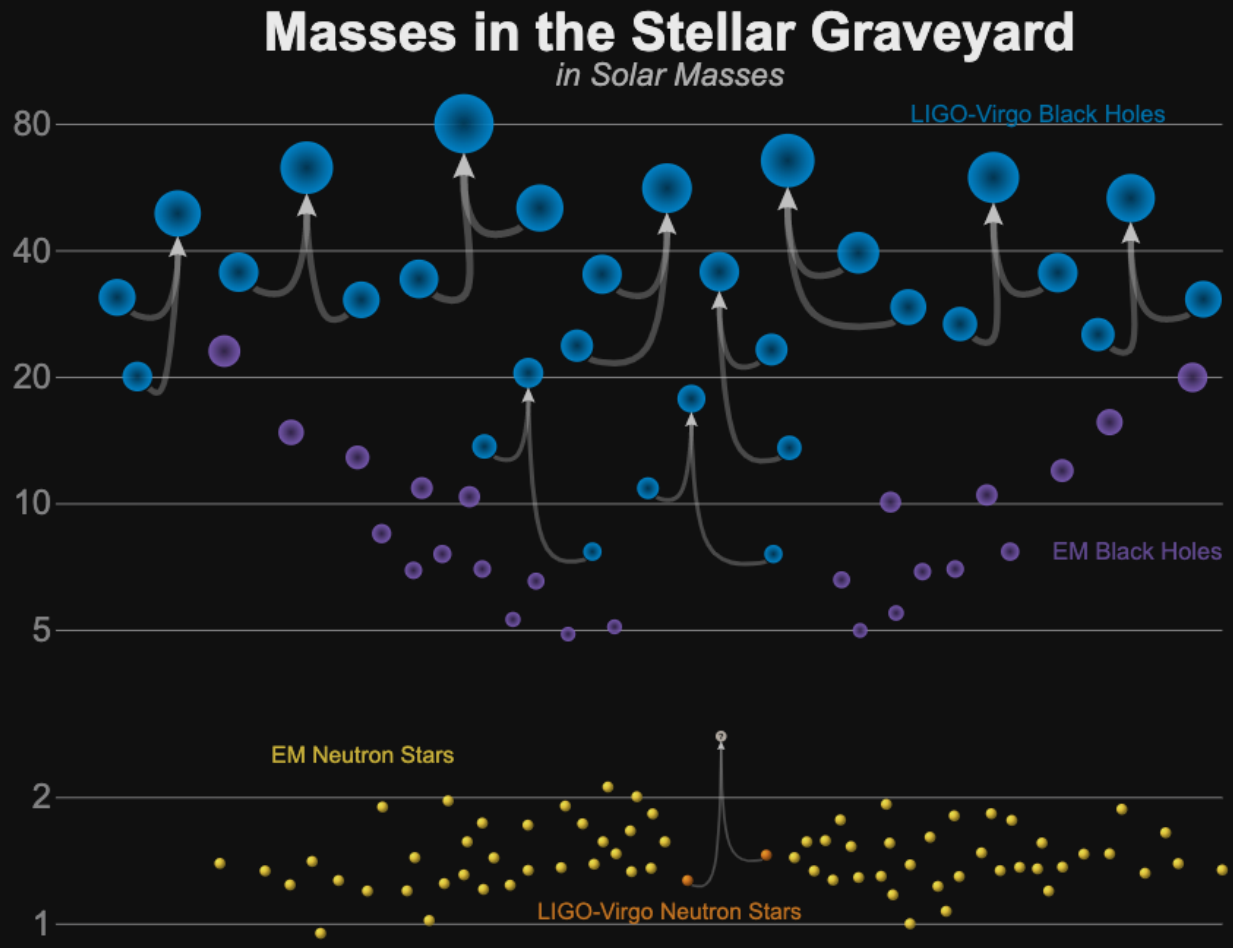


GW170817 Afterglows

- X-ray and radio observations of GW170817 over the first ~743 days
- Emission modeled by off-axis (~30°) structured relativistic jet w/ $E_{tot} \sim 10^{50}$ erg and low density medium ($n \sim 10^{-2}$ cm^{-3}; **blue lines**)
- Anticipated emission from the deceleration of the Kilonova ejecta, the "Kilonova afterglow" (**red lines**)
- *Next Chandra obs early March 2020!*



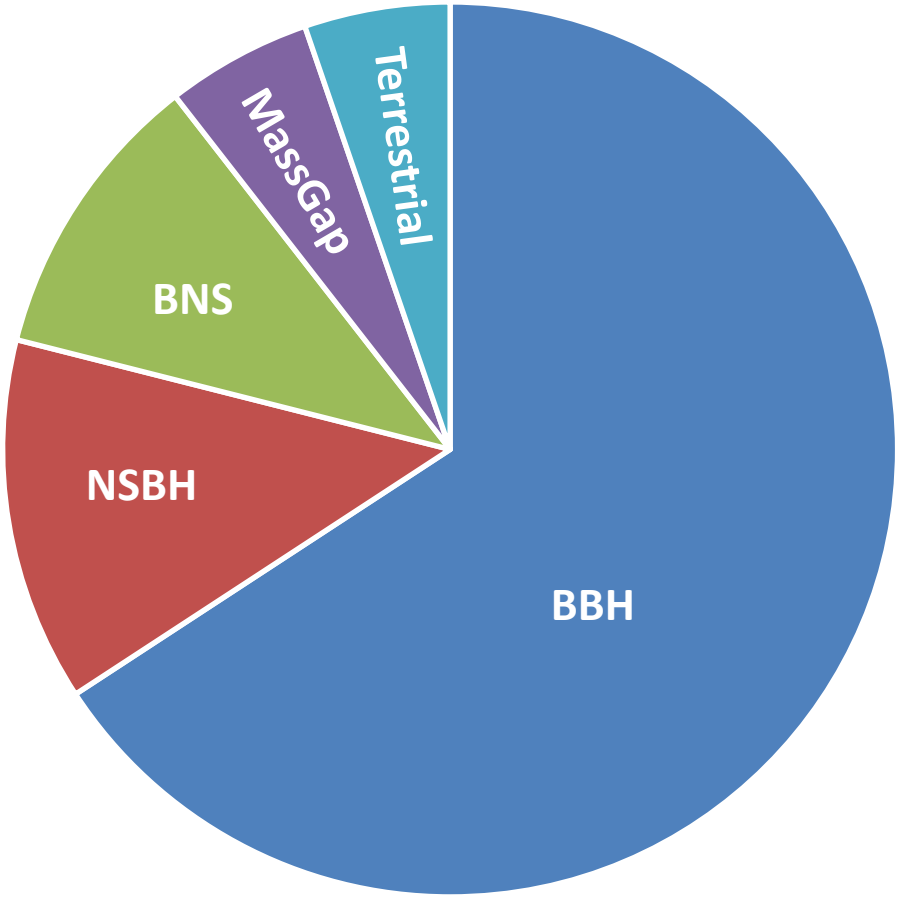
LIGO-Virgo O1 & O2

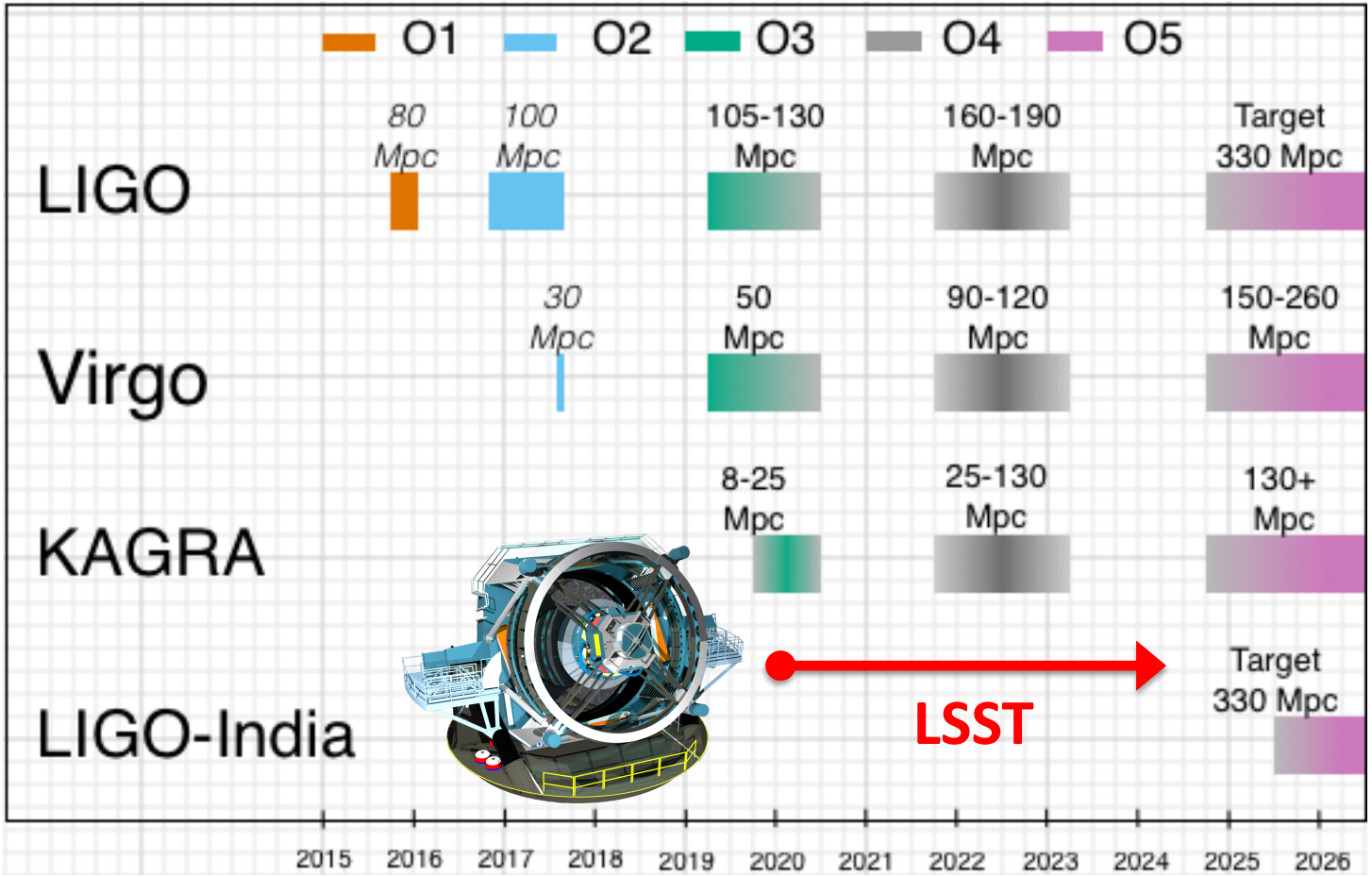

Masses in the Stellar Graveyard
in Solar Masses
80
40
20
10
5
2
1
LIGO-Virgo Black Holes
EM Black Holes
EM Neutron Stars
LIGO-Virgo Neutron Stars

LIGO-Virgo O3 (*so far*)

BBH	25
NSBH	5
BNS	4
MassGap	2
Terrestrial	2
Retractions	14
Total	**38**

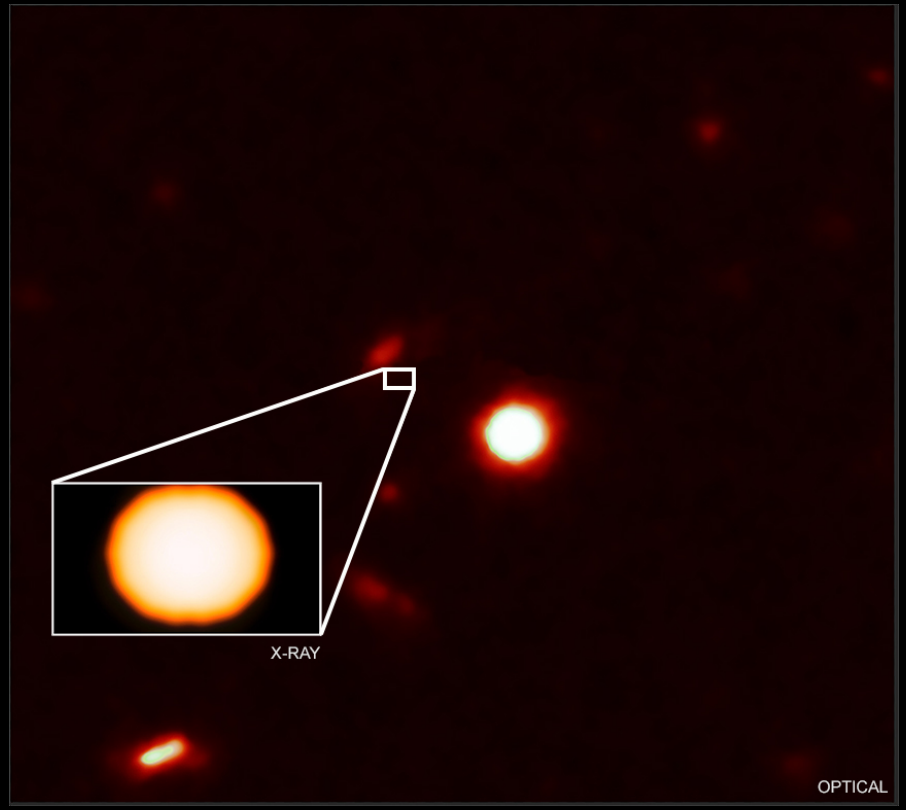
LIGO alerts are now ***public***!!




O1
O2
O3
O4
O5
LIGO
80 Mpc
100 Mpc
105-130 Mpc
160-190 Mpc
Target 330 Mpc
Virgo
30 Mpc
50 Mpc
90-120 Mpc
150-260 Mpc
KAGRA
8-25 Mpc
25-130 Mpc
130+ Mpc
LIGO-India
Target 330 Mpc
LSST
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026

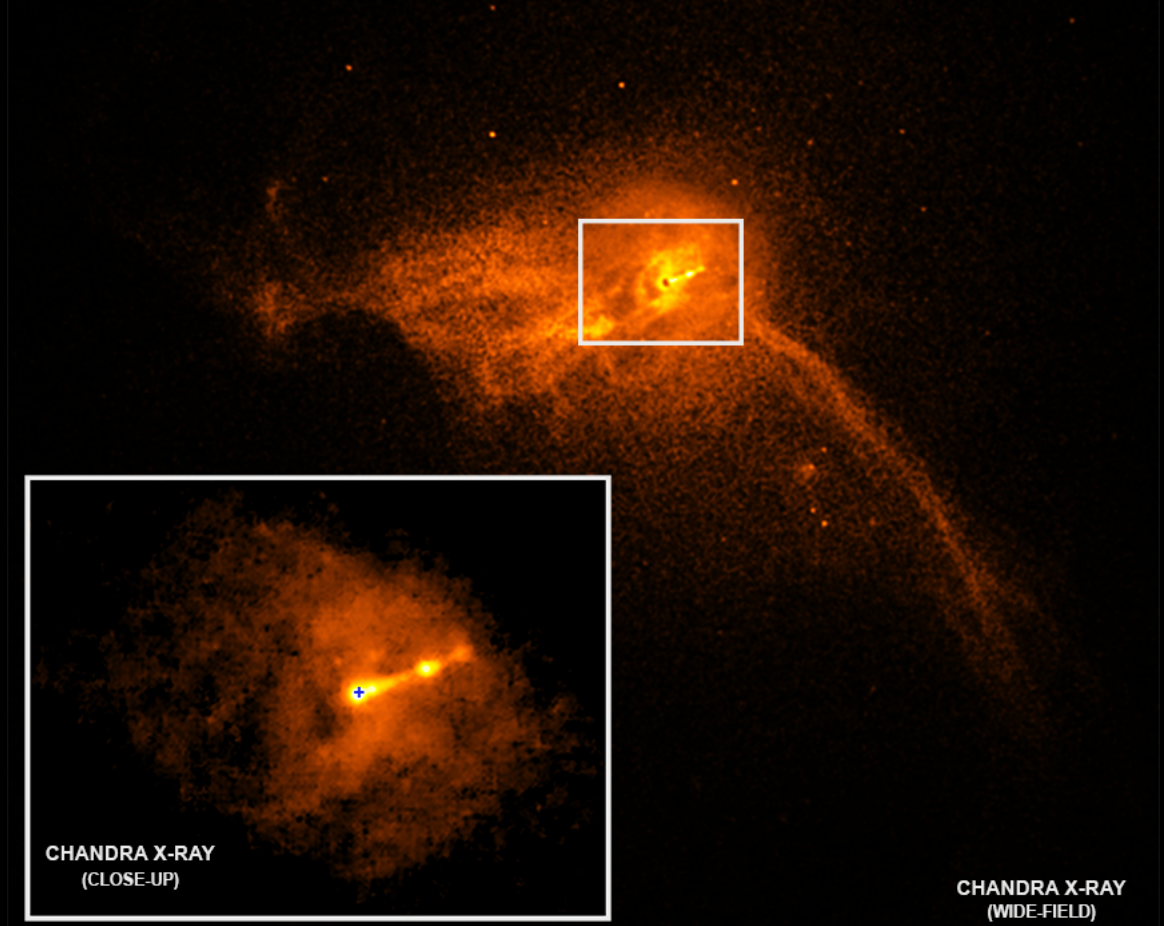
Fast X-ray Transients

- Likely binary neutron star mergers w/ magnetar remnants
- New IDs in Chandra Deep Field South (CDF-S XT1 & CDF-S XT2)
  - **CDF-S XT1** (z = ?): could be off-axis/ low-luminosity sGRB or TDE of a white dwarf by IMBH
  - **CDF-S XT2** (z = 0.738): consistent with X-ray transient powered by a millisecond magnetar
- Plus three more – **Dacheng Lin's** talk this session
- Candidate explanation for FRBs!?!



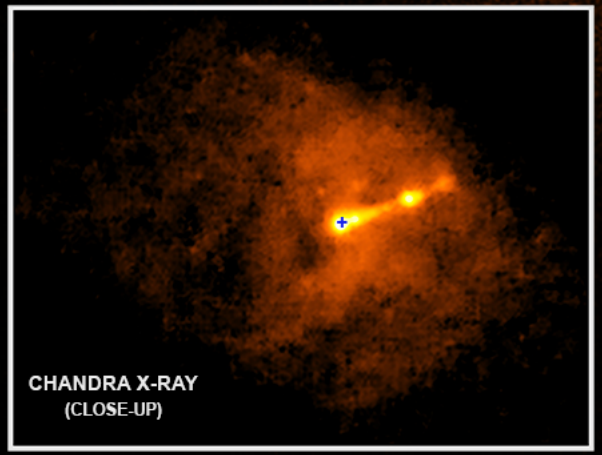
Xue et al. 2019

M87 w/ EHT & Chandra



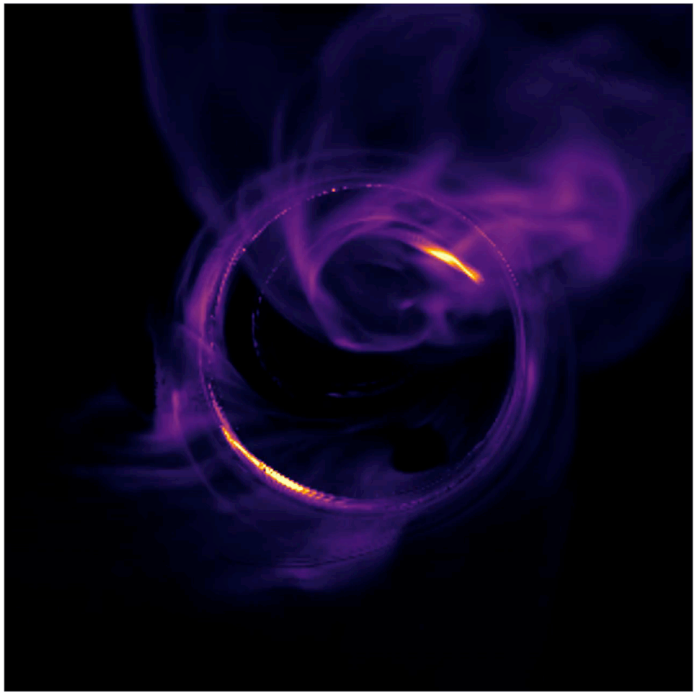
M87 w/ EHT & Chandra

And… Sgr A*?



New Sgr A* VLT/GRAVITY NIR Flares

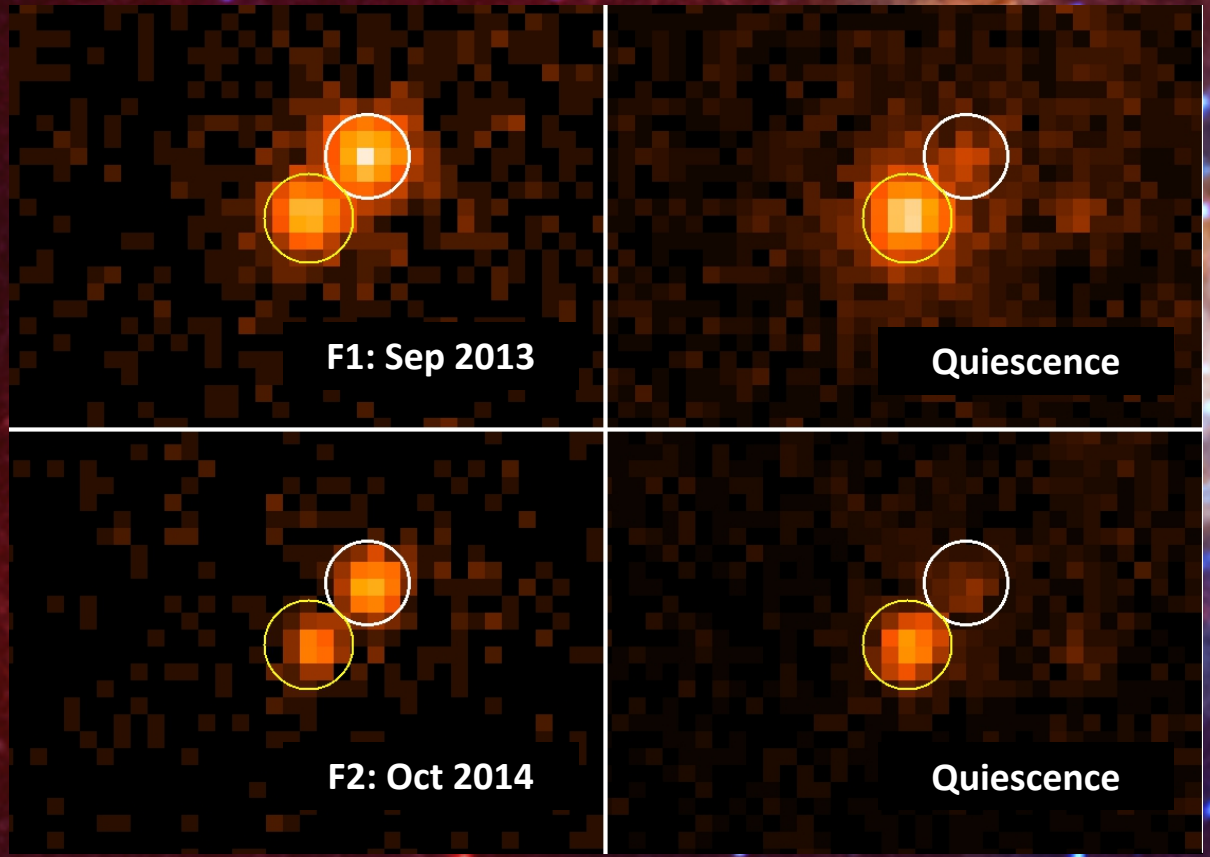
GRAVITY Collaboration 2018



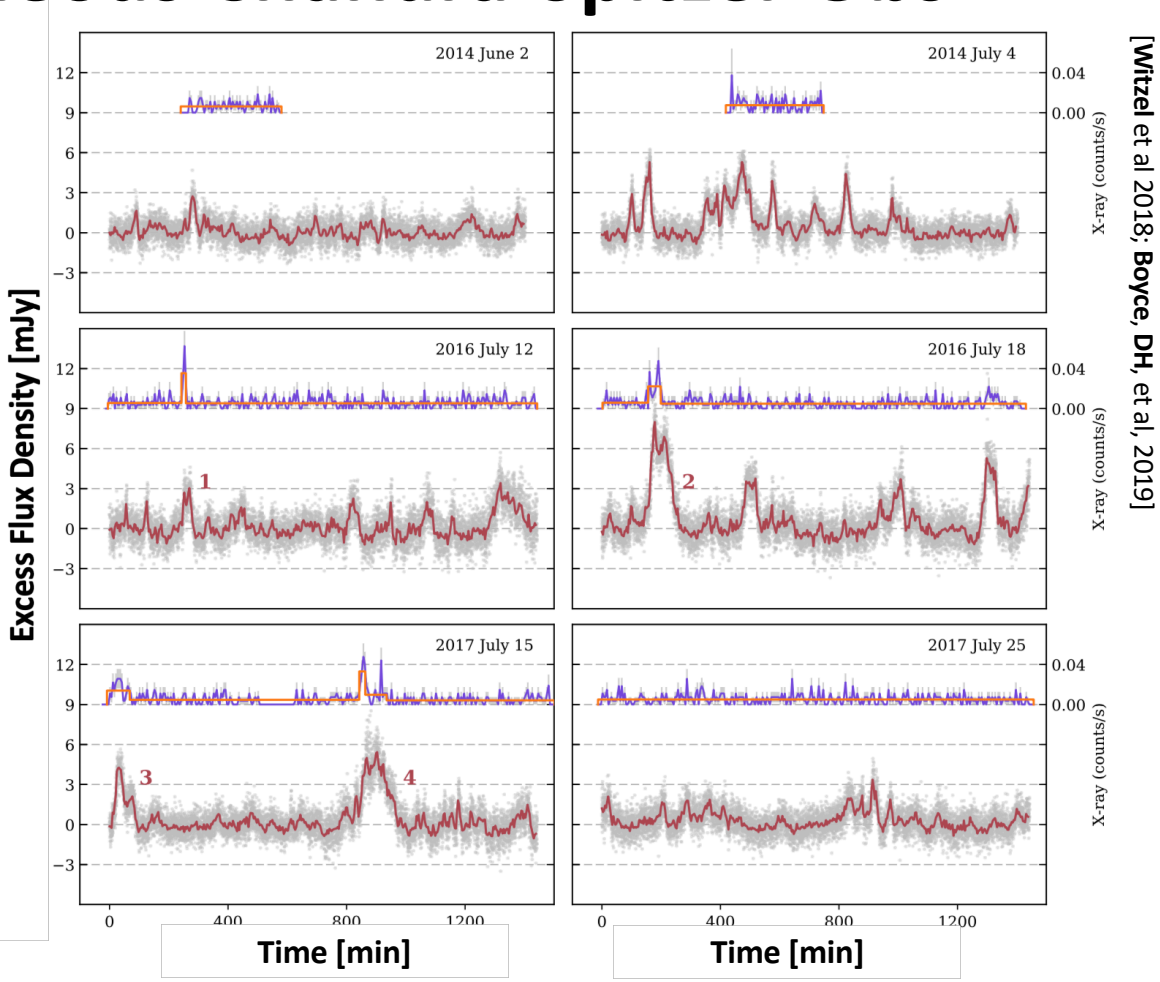
Direct measure of Sgr A*'s black hole event horizon/ISCO?!?

- Monitoring S0-2 during periapse
- 3 NIR flares detected from Sgr A*'s accretion flow
- Energetics consistent with magnetic reconnection or mag. shocks between e^- and hot gas near ISCO
- Flare durations 30-90 minutes, similar to e^- cooling time or dispersal due to diff. rotation
- Peak flux 2x Sgr A*'s median K_s-band flux (similar to S0-2)

Sgr A* Flares

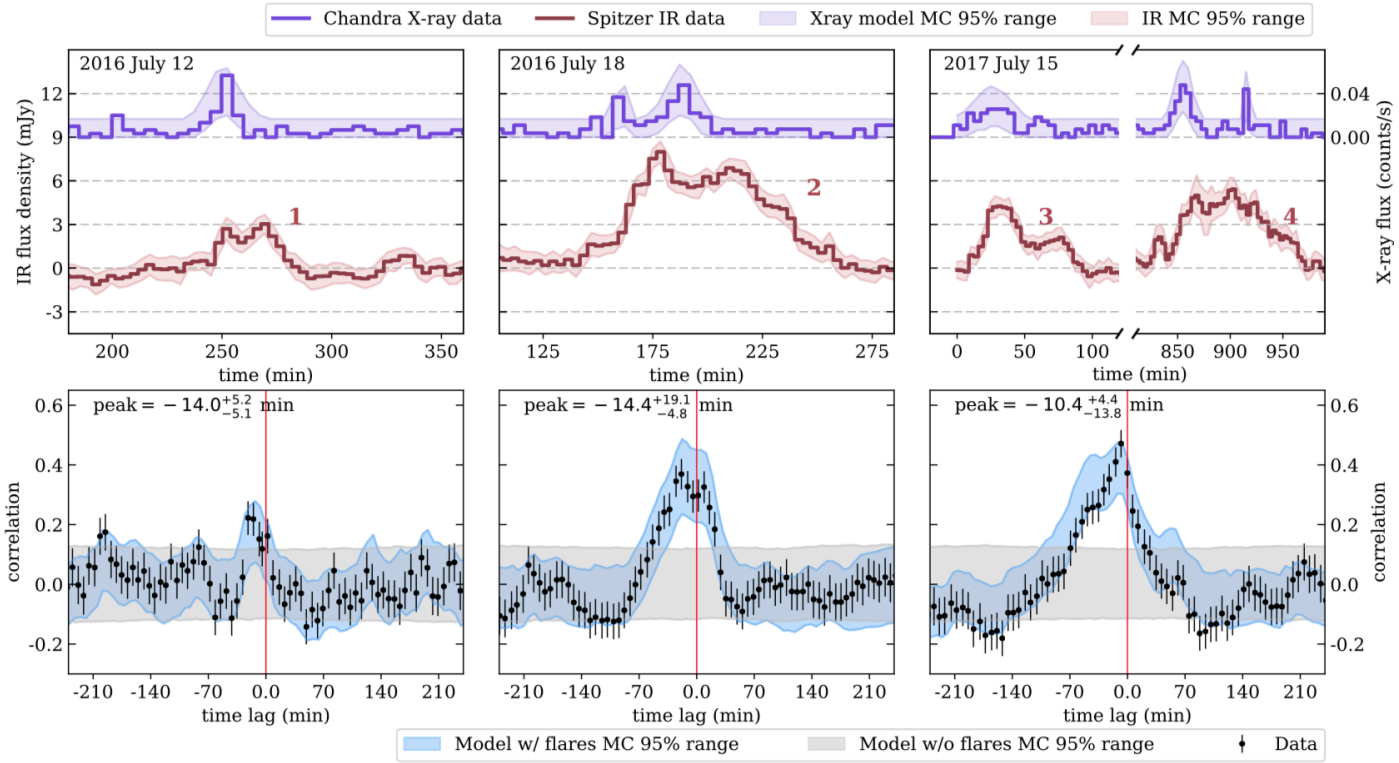


Simultaneous Chandra-Spitzer Obs



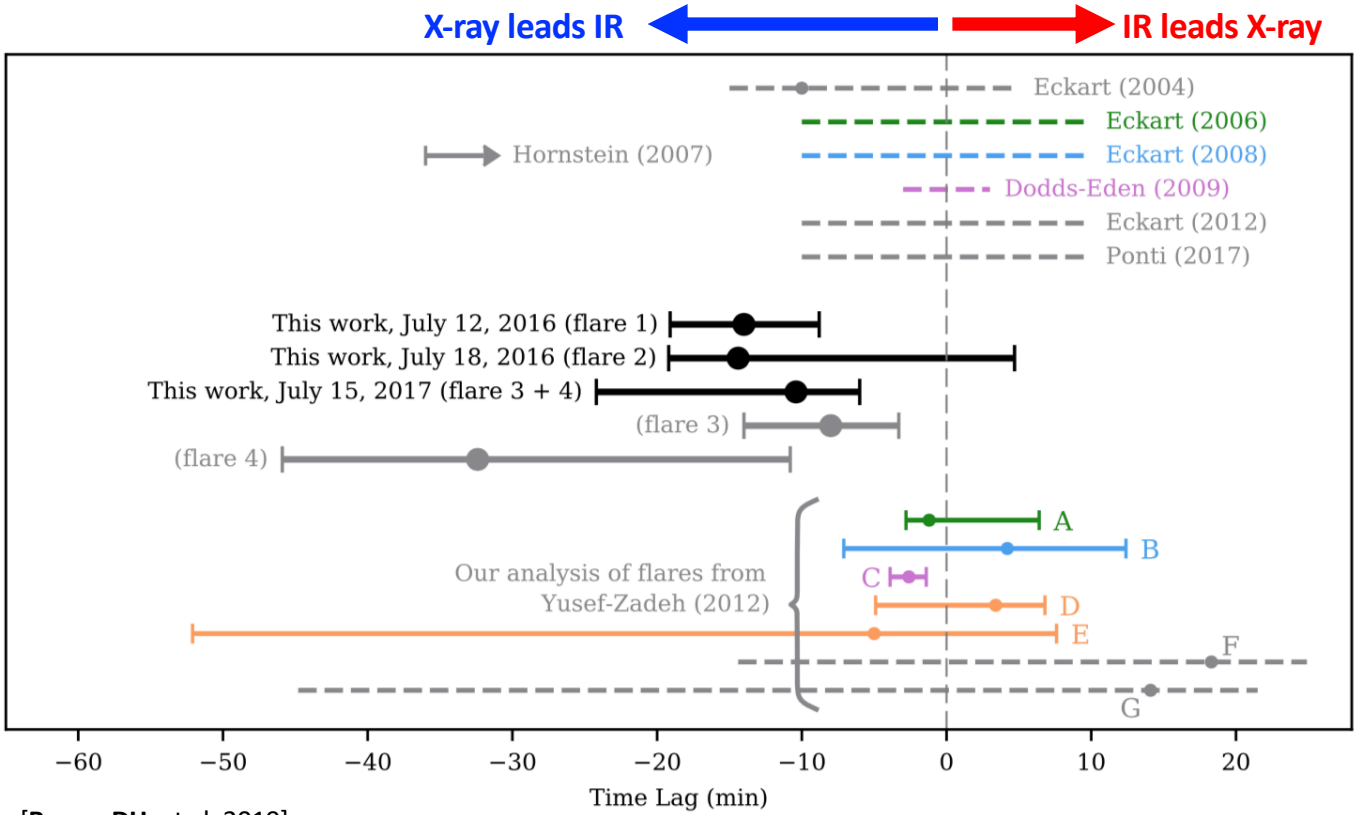
[Witzel et al 2018; Boyce, DH, et al, 2019]

X-ray/IR Cross-Correlations (ZDCF)



[**Boyce**, **DH**, et al, 2019]

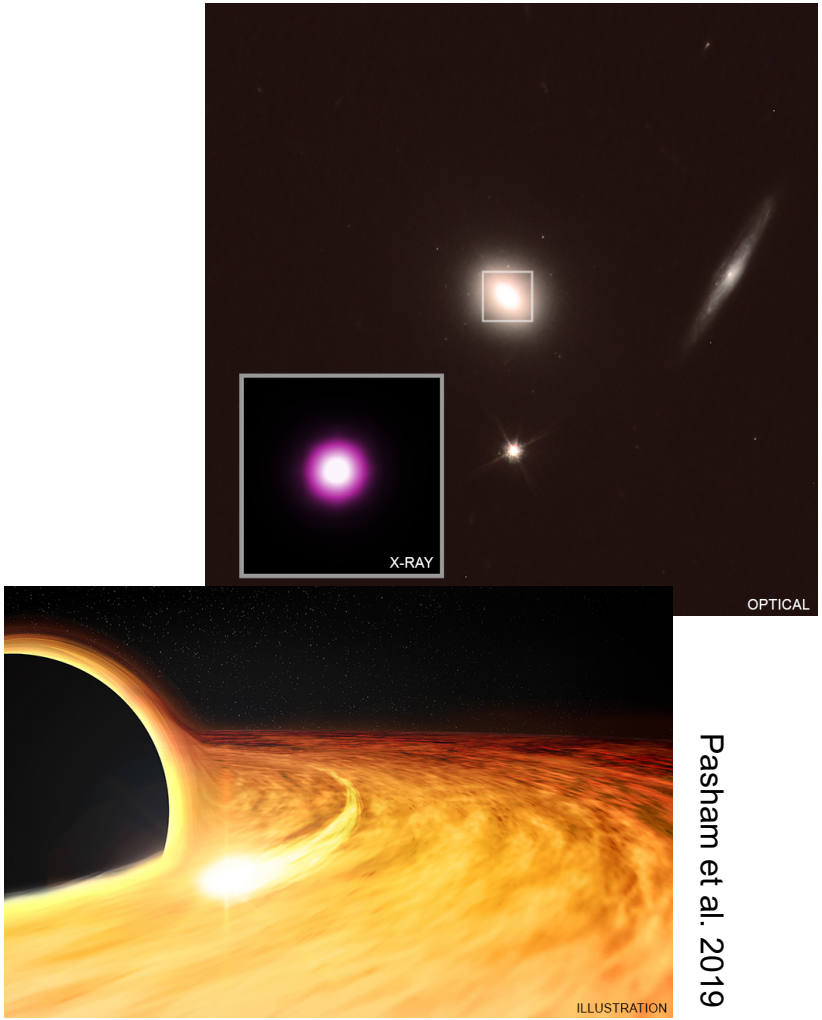
X-ray/IR Timelags



[**Boyce**, **DH**, et al, 2019]

Tidal Disruption Events

- Tidal disruption events from capture or “spaghettification” of unlucky stars by black holes
- Subsequent accretion of the star’s mass onto the SMBH
- **ASASSN-14li**
  - 131-second quasi-periodicity from likely tidal disruption event
  - periodicity originates from very close to the SMBH’s event horizon
  - BH seems to be spinning rapidly (a>0.7)
- More in **Jack Steiner’s** talk!



Pasham et al. 2019

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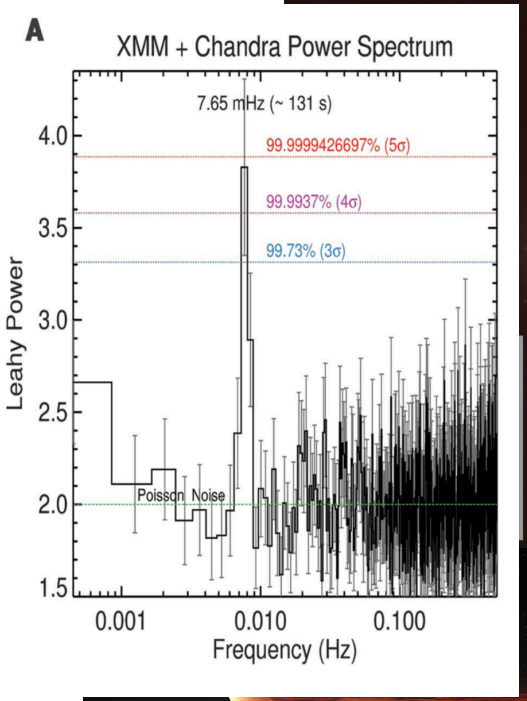

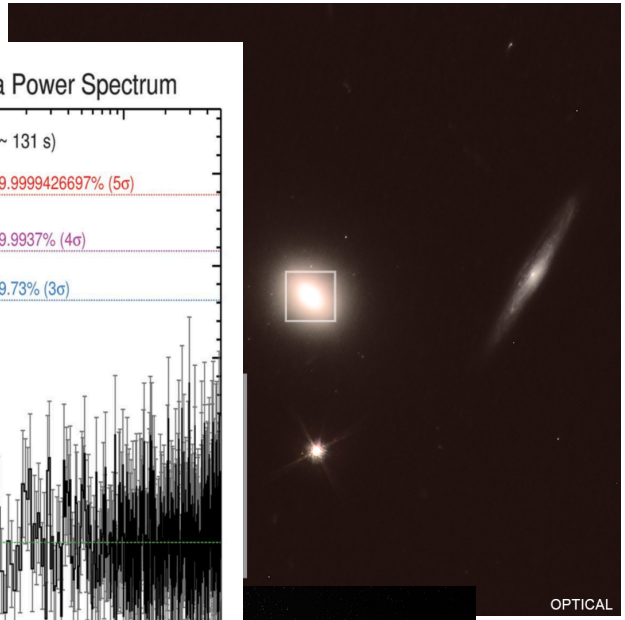

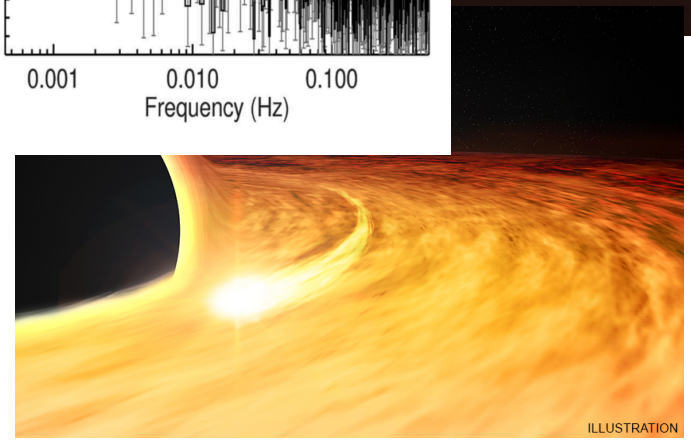

Pasham et al. 2019

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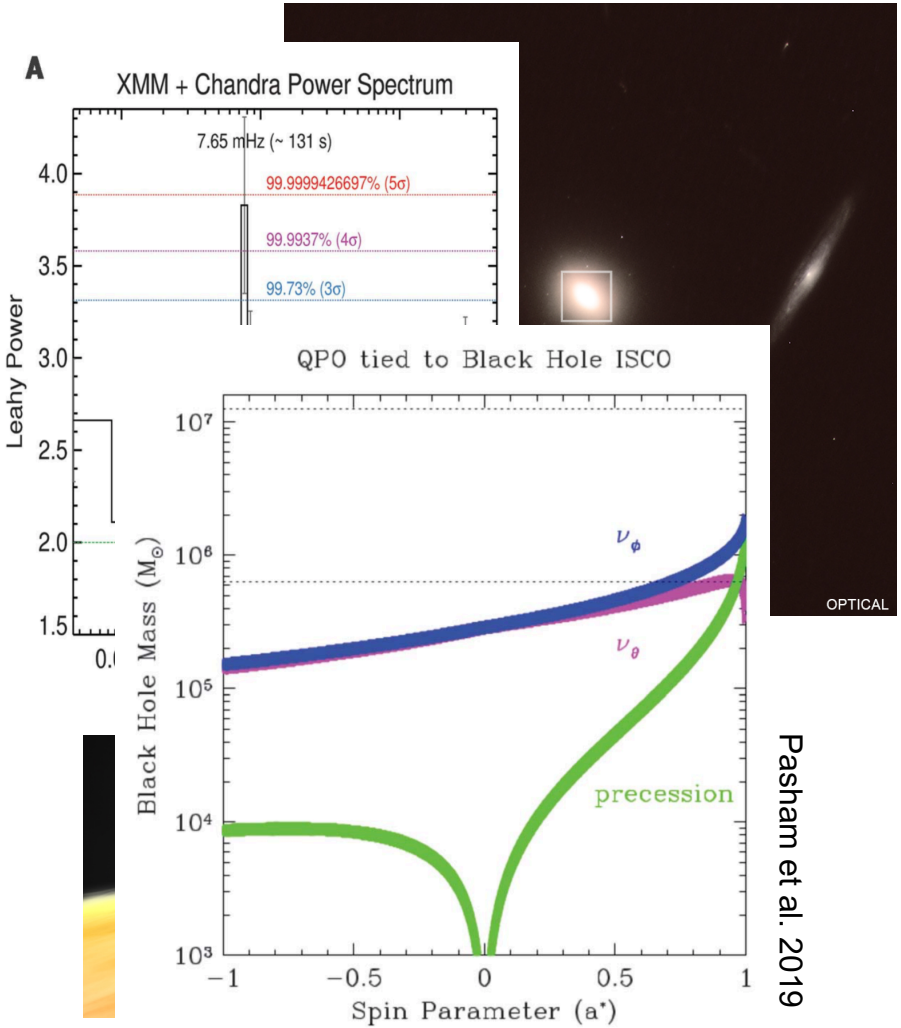
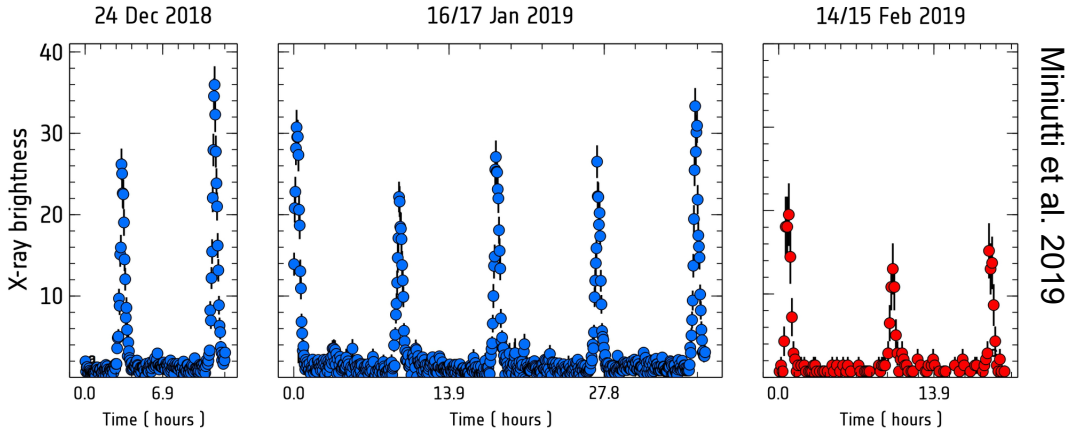


And soooo many more…

- **Super-bright supernova**, e.g., SN 2016iet which may be a pulsational or pair instability SNe
- **Changing-look quasars** & other QSO variability
- SMBH QPOs or **quasi-periodic eruptions**, e.g., GSN 069
- **ULX** & extreme variables, V404 Cygni & MAXI J1820
- **Pulsars** & **Magnetars**
- **Stellar flares / CMEs**
- **X-ray dust tomography**



Summary

- Time domain and multi-messenger astronomy are experiencing a HUGE expansion w/ LIGO-Virgo (and KAGRA!) and LSST online soon
- X-ray observatories make excellent / unexpected contributions (Chandra, XMM, Swift, Fermi, MAXI, INTEGRAL, NuSTAR)
- Rapid response and high sensitivity/resolution don't usually go together
- Need strategic joint-observing programs (multi-wavelength, multi-messenger, multi-mission) to optimize for time domain science


20 YEARS
CHANDRA
X-RAY OBSERVATORY