Brainstorming the Universe in High-Resolution X-ray Spectra

From August 19-21st, 2015 a group of ~100 X-ray astronomers met in Cambridge, MA to present recent results from X-ray grating spectroscopy with Chandra and XMM-Newton, as well as to discuss possibilities for the future (http://cxc.harvard.edu/cdo/hrxs2015/). During the meeting, a 'brainstorming' session was held, following a similar format as has been used in looking at future concepts for WISE (http://arxiv.org/abs/1505.01923) and the X-ray Surveyor (http://cxc.harvard.edu/cdo/xray_surveyor/presentations/Brainstorming-Results.pdf). Approximately 60 astronomers took part in the two-hour exercise, separated into 9 tables with 6-8 people each who swapped tables after each question. Four questions were addressed:

1. What **important science questions** could data from the existing or near-term X-ray high-resolution spectrometers answer? Would data from other existing observatories be needed as well?
2. What improvements in **calibration, lab astrophysics data, or analysis tools** are needed to enable us to answer these questions?
3. What **future observations (or new archives with different processing)** are needed to answer these questions?
4. What **observations could Chandra or XMM-Newton do today** that would complement future Astro-H or act as pathfinders for Athena or X-ray Surveyor observations?

Discussion Leaders:

1. Elisa Costantini
2. Martin Elvis
3. Dave Huenemoerder
4. Delphine Porquet
5. Tim Kallman
6. Takayuki Yuasa
7. Nancy Brickhouse
8. David Cohen
9. Lia Corrales

Summary

The first question focused on issues that could be addressed using existing X-ray observatories, possibly in conjunction with other facilities. A recurring theme was the need for high-resolution spectroscopic monitoring and variability studies of a range of sources, including stars, X-ray binaries (XRB), stellar mass black holes, novae, and young supernovae. Winds from stars, XRB, and Active Galactic Nuclei (AGN) were also mentioned in the timing/monitoring context but also generally as an area that could be productive with more observations. Finally, abundance studies were highlighted in a range of contexts such as iron-peak element studies in supernova remnants and galaxy clusters, either with the XMM-Newton RGS or Hitomi, as well as absorption studies in the Galaxy using bright XRB or beyond using flaring AGN. Another topic frequently mentioned was the need to better exploit the archives of all of these missions.

The second question delved into what must be done to help support progress on these issues. The two topics most frequently mentioned (at seven out of the nine tables) were improvements in atomic data and analysis tools. In regards to the atomic data, the participants argued for improvements for some Fe-peak ions (e.g. Mn, Cr, Ni) as well as inner-shell K lines (and for AGN warm absorbers, the M-shell and L-shell inner shell lines), along with better charge exchange rates and diagnostics. A key need was to make it easier for users to access/assess the physics in the models. Another request was a more thorough cross-calibration of optically thin X-ray plasma codes (both collisional and photoionization) to better understand when and where differences arise from various codes. Analysis tools were also held up as needing improvement, starting with the idea that such tools work best if they are constructed collaboratively, not "owned" by one person. General requests were made for better extended-source modeling as well as more flexible photoionization models. Participants expressed the need for IRAF-like automatic tools that could extract intensities of temperature/density diagnostic lines and then search a spectral database to find similar spectral shape/lines. Similarly, spectral-timing tools were mentioned as being underdeveloped, as well as ways to improve calibration facilities. Calibration in general was frequently mentioned, with a number of specific issues such as wavelength calibration accurate to < 100 km/s for wind studies, line profiles in 1^{st} and higher order, and easier-to-use background models.

The third question, on what future observations are needed, provided mixed results – possibly because of the difficulty of determining what precisely would answer the issues raised so far, and possibly because participants were already planning out new proposals to submit. However, there were a number of monitoring proposals described, matching the focus on timing and monitoring raised in the first issue. In this context, it was noted that time allocation committees should be explicitly told that re-observing sources is allowable when the purpose is monitoring. A number of groups also described the benefits from simplifying proposals for coordinated observations with other facilities, especially if ways to increase the available time for such proposals could be found.

Finally, the last question focused on what Chandra or XMM-Newton could do to prepare for future Hitomi, Athena, or X-ray Surveyor observations. Nearly all the tables identified deep observations of crowded/complex fields such as M82, Galactic SNR, and galaxy clusters as a key need, especially for Chandra as similar angular resolution will not be available until X-ray Surveyor launches. Similarly, the participants highlighted the need for grating spectra on point sources, since even the Athena calorimeter will have lower resolution below 1.5 keV than the Chandra and XMM-Newton gratings. Deep imaging observations of nearby galaxies and especially the LMC and SMC were mentioned, along with the Galactic center region. Finally, it was noted that Chandra's angular resolution would be needed to separate the nuclear regions of AGN from the surrounding gas.

Question #1: What important science questions could data from the existing or near-term X-ray high-resolution spectrometers answer? Would data from other existing observatories be needed as well?

Recurring Themes

- Monitoring / Time Variability (Tables 1, 2, 5, 6, 7, 8, 9)
  - Triplet variation in stars (CMEs), microquasars, HMXB outflows/ejecta
  - What is the connection between the different states in XRBs?
  - Super Eddington accretion in outburst of stellar mass BHs
  - Supernova expansion in time (incl. spatially resolved work)
- Winds in Stars, XRB, AGN (Tables 2, 3, 4, 6, 7, 8)
  - Feedback, ionization/velocity structure
  - What are the actual wind mass-loss rates of O stars?
- SNR metallicity/progenitor identification (Tables 1, 2, 3, 4, 6, 7, 8)
  - What are the abundances of iron-peak elements in supernovae remnants and galaxy clusters?
  - Emission lines from low-abundance elements, e.g. Al, Na
- Better exploit archives/multiwavelength work (Tables 1, 5, 7, 9)
- Diffuse gas from Galaxy to LSS scales (Tables 2, 5, 9)
  - Make catalog of high-res ISM spectra from bright LMXBs
  - Stack residuals or deeper observations of XRBs to get at photoelectric absorption features and structure
- Broad-band science at 6 keV (Tables 2, 9)
  - Only 1 Chandra Gratings/NuSTAR proposal in two cycles
- What is the equation of state of a neutron star? (Tables 3, 4)
- Monitoring Novae long term in soft band (Tables 6, 7)

Other Topics of Interest

- What is the spin of a black hole? (Table 3)
- What are the redshifts of transients, e.g GRB, EM signatures of GWs? (Table 3)
- Where is charge exchange important? (Table 3)
- What is the nature of accretion in non-magnetic CVs (Table 6)
- Find dust beyond the galaxy in Seyfert I, II (Table 7)
- Search for more elements to study FIP effect via deep obs on a few stellar coronae (Table 7)
- What is the origin of diverse magnetic fields in neutron stars (Table 7)
- Longer observations with gratings on AGN WA with Hitomi (Table 7)
- What is the intracluster medium heating mechanism? (Table 8)
- How are stellar coronae heated? (Table 8)
  - How do coronal properties vary along evolutionary sequences?
  - What are the trends of nitrogen enrichment in OB stars?
- What is the source of the iron in Jupiter's magnetosphere? (Table 8)

Question #2: What improvements in calibration, lab astrophysics data, or analysis tools are needed to enable us to answer these questions?

Calibration (Tables 1, 2, 3, 7, 8, 9)

- Better absolute energy calibration.
- Effective areas to 1%, cross-calibrated between missions, instruments, modes
  - Needed for cluster masses for cosmology.
- Wavelength calibration to <100 km/s.
  - Need ~50km/s for wind clumps in stars, binaries
- Instrumental line profile calibration (also impacts wavelength calibration)
  - Crucial for measuring weak absorption lines (incl. higher orders)
- Better calibration of energy scale/CTI for CC grating mode.
- Easier to use background models
- Low energy calibration is very important (e.g., 1/4 keV regime)
- Learn lessons from Kepler re. long term calibration
- High N_H in CC-mode --- blurs edges
  - Need background plus dust scattering halo
  - Need calibration plus a tool
- Documentation is not always complete or available.

Lab Astrophysics (Tables 1, 2, 5, 7, 9)

- Lab recreation of astrophysical situations
  - measurements of interstellar dust-analogues or so?
  - simulate e.g. accretion disks or jet interaction with matter.
  - Density diagnostics should have lab measurements
- Better lab astro measurements of line/edge energies
  - Fe XVII oscillator strengths
  - gas AND solid O (since it is going to be a mix of solid and gas in space)
  - Si, O, and Fe simultaneously
- Better lab astro measurements of molecules and dust features
  - Range of samples to produce a large table
  - Have to account for scattering
- Talk to industry about creating glass samples for lab studies of solids

Atomic Data (Tables 1, 2, 3, 4, 7, 8, 9)

- Make it easier for users to access/assess the physics in the models
- Include other physics, e.g. resonant scattering (for clusters), abundances.
- Work with other users, esp. plasma physics/laser physics communities.
- Can Astrophysics supply useful data, esp. wavelengths?
- Cross-calibration of optically thin plasma codes (eg SPEX, APEC, Cloudy)
- In particular:

    - Good atomic data for Mn, Cr, Ni (at least).
    - Inner-shell K-lines, auto-ionization rates, absorption cross-sections;
    - AGN warm-absorber forest of inner-shell lines requires better atomic data.
    - CX data
    - For line asymmetries, we need better benchmark lines, from lab energies

Analysis Tools (Tables 3, 4, 5, 6, 7, 8, 9)

- Best if constructed collaboratively, not "owned" by one person.
- General Modeling tools
    - Better extended-source modeling tools are needed.
    - 3D spatially resolved spectroscopic data.
    - Reflection models with photoionization, more flexible geometries
    - Better wind-model infrastructure such as a community code
    - Photoionization codes need to do time-dependent ionization
- Tool to extract physics from high-resolution spectrum
    - Need more automatic tools to analyze high resolution data
    - IRAF-like software for the fit of lines as in optical.
    - extract intensities of temperature/density diagnostic lines
    - search spectral database to find similar spectral shape/lines
    - Bring machine learning techniques into this
- Timing Analysis tools (intelligent time dependent gratings analysis)
    - tools for creating dynamic power spectra
    - 2 dimensional change point analysis of spectrum and time
    - tool for automated detection of variability between spectra
- Calibration tools
    - more general cross-observatory tools for handling pileup analysis
    - tools for cross calibration issues associated with higher order data
    - PSF web tool that does SAO ray trace & MARX all-in-one

Statistics (Tables 2, 5, 9)

- Include error estimates/flags in atomic database and calibration files
    - Adapt fitting codes to use.
    - Propagate errors properly to final parameters
- understand statistical criterion for detection of absorption (vs. emission)
- a clearer understanding of limitations of emission measure measurements
- What problems could arise from stacking images?

Archives (Tables 1, 4, 5, 7)

- Archives that are easy to access with fully processed data.
    - TGcat is a good example (but not perfect)
    - RGS system (BIRD?) not as good as tgcat
- For Hitomi, need Chandra for good imaging in for crowded sky regions.

Question #3: What future observations (or new archives with different processing) are needed to answer these questions?

Long Observations

- Multiple MSec-class observations for missing baryon studies (Tables 3,9)
- Deep Stellar Observations
    a. Long monitoring of Capella: why doesn't the corona flare? (Table 1)
    b. HETG spectrum of e.g zeta Pup for line profile & variability (Table 3)
- Msec each on brightest sources at high S/N: 6 LMXB, 6 HMXB, 6 AGN (Table 2)
- SNRs (Tables 2, 7)
    a. Try to detect cosmic ray precursor before shock (SN1006, VLP, ACIS)
    b. Mn/Cr in SNR to get mass of Type Ia
    c. More work (need new tools b/c it's hard) on SN 1987a

Monitoring

- Monitor AGN WA for stability; changes give density->radius (Table 2)
- Detailed (more frequent) monitoring of XRB outbursts (Table 9)
    a. not 1 ks every few days; too much missed opportunity!
- Exoplanets: look for tidal phenomena, star-planet interaction. (Table 1)
- CVs monitored in different states to see gas motions. (Table 1)
- Time resolved high-resolution spectrum of an NS outburst in a slowly rotating neutron star to look for pressure broadening and get EoS. (Table 3)
- TACs OK to reobserve to study variability in physical processes. (Table 8)

Coordination / Constrained

- Better multi-wavelength observation coordination, maybe to increase the possibility for joint proposals, i.e. through only one submission. (Tables 4, 8)
- More *constrained* observations for GO proposals, if possible. (Tables 8, 9)
- Simultaneous observation with e.g. NuSTAR to measure continuum variability of AGN and Galactic black holes. (Table 1)

Surveys / Archives

- Survey Galactic plane to understand homogeneity of dust and gas (Table 1)
    a. Search for trace elements of e.g. supernova explosion.
- ICM enrichment process via Fe/Ni ratio: If SNIa form at Chandrasekhar mass (single degenerate origin). Archival? Hitomi? (Table 2)
- Map of close cluster of galaxies: core + extension with Hitomi plus super deep imaging with Chandra, i.e., 1-2 Ms. (Table 4)
- Dust beyond galaxies via X-ray scattering (Table 7)
    - Archives, but need TOOs to get source early (V404 Cyg exemplar)

Other

- Workshop about archive tools such as the VO to learn how to use it. (Table 4)
- Need a new version of the Chandra source catalogue from stacking (Table 7)
- Need new technique to observe sources that are so bright (Table 7)
- Apply new calibration based on improvements of the CC mode. (Table 6)

Question #4: What observations could Chandra or XMM-Newton do today that would complement future Astro-H or act as pathfinders for *Athena* or *X-ray Surveyor* observations?

- Deep obs of crowded/complex fields - M82, SNR, clusters (Tables 1,3,4,5,7,8,9)
    a. Some simultaneous with Hitomi for variable sources (Table 3)
    b. Concentrate on bright spot in Tycho (Table 5)
    c. Look at star forming regions less crowded than Orion (Table 7)
- Survey of Galactic sources for ISM studies. (Table 1, 9)
- Deep grating observations of known ULX (Tables 1, 9)
- LMC and SMC deep imaging observation (Tables 1, 9)
- Better coverage of shocked regions on clusters of galaxies (Tables 1, 5, 8)
- Deep/stacked observations of galaxy clusters for abundances (Table 4)
- Deep obs of extended emission in GC; variability, study reflection. (Table 1)
- Map nearby globular clusters (Josh Grindlay the expert on this) (Table 7)
- Nearby galaxy mapping (Tables 7, 9)
- Simultaneous star binary systems (WR, O stars) for colliding winds (Tables 1,2)
    a. WR140 perisatron in 2016 (P~7 years). (Tables 2,
- More time on prototypical sources with gratings (Table 7)
- Eclipsing CVs: Get geometry w/EPIC for timing, Hitomi for velocity. (Table 2)
- Characterize dust scattering halo in Hitomi sources (Tables 3, 5)
- XRBs: we use XTE now for Chandra; will need Chandra for Hitomi (Table 7)
- Grating spectra of all Hitomi point sources for <2 keV region (Tables 2,3,6,7,9)
    - AGN WA, Flare stars, Low N_H XRBs simultaneous (Tables 1, 2, 6, 7)
    - Secure Chandra/XMM grating proposal time for Hitomi (Tables 6,
- Chandra observations of AGN nucleus vs surrounding. (Tables 4, 7
- Very deep Chandra and/or RGS for star-planet interaction (Table 4)
- Deeper spectra on sources that are hard to analyze now, will want in future:
    - Novae years post-explosion (2-4 year) E<1 keV gratings. (Table 2)
    - e.g. LETG for novae, supersoft sources (Sumner Starrfield) (Table 7)
- Look harder for more sources with high He-like forbidden lines (Table 7)
    - CX or NEI recombining

Specifically with Athena or X-ray Surveyor

- O-stars: variability for wind structure. Msec now, 10's ksec in ~2030 (Table 2)
- Long Hitomi SXS obs of AGN outflow for variability to guide Athena (Tables 6)
- 1ES1533 Msec as test case for IGM to guide plans (Table 2)
- Msec on z>3 quasar for feasibility; need 6.4keV shifted <2.1 keV edge (Table 2)
- Observe SN now, SNR in ~2030 (Table 2)
- Shock acceleration/precursor: Msec Chandra (~Ms order) to follow the proper motion of SNR over decades. (Table 4)
- Use Chandra source catalog to identify potential high-z objects (which might be blurry due to off-axis pointing). Follow up with Chandra. (Table 9)

Detailed Responses

Table 1 – Chair Elisa Costantini

Q1: *Summary: the discussion revolved around monitoring and time variability of different important phenomena:*

- *monitoring of triplets variability in stars, micro-quasar for both density and temperature diagnostic.*
- *Supernova expansion in time and study of abundances ratio (Mn/Cr) to understand the progenitor metallicity.*
- *Time studies of coronal mass ejections in stars and HMXB ejecta.*
- *Study of radial velocity in a variety of environment. Outflows in HMXB, turbulence in galaxy clusters, molecular ejecta etc.*
- *Spatially resolved study of abundances in SNR (e.g. in CasA)*
- *A better exploitation of X-ray archives and multiwavelength data, as well as a better calibration (3^{rd} order of HETG) was also mentioned.*

Details

- Higher time resolution monitoring/variability
- 3 order grating of Chandra 1-4Å (as path finder with Astro-H)
- atomic lines to do density diagnostics of micro-quasar
- Timing analysis with high spectral resolution non equilibrium ionization.
- Cool stars with coronae: Short term variability of flares. Temperature diagnostic through triplets OVII, NeIX.
- Radial velocity studies of X-ray emitting objects.
- Element abundances of SNR, projenitor metallicity. Mn/Cr, Fe k-alpha.
- Astro-H- Cas A is a core – collapse little iron in the inner ejecta and a lot outside. We have to quantify how much iron there is the ejecta. Consequence would be that there is a second explosion.
- Good use of IR spectroscopy-Herschel-Spitzer. In general archives should be better exploited.
- Coronal mass ejection observation through high timing resolution.
- Better understanding of interstellar dust and revisiting previous results on e.g. X-ray binary spectra.

Q2: *Summary:*

- *We should agree on a set of atomic data. There should be a common effort to include all processes and a comprehensive inclusion of updated measurements.*
- *Archives that are easy to access (TGcat-type) with fully processed archived data.*
- *Can we re-create astrophysical situations on Earth like measurements of interstellar dust-analogues or so? It was proposed to simulate e.g. accretion*

disks or jet interaction with matter.

Details

- better absolute energy calibration.- Documentation on calibration is not always complete or available. –
- Agree on a set of atomic data.
  - Comprehensive inclusion of atomic processes.
  - Should be a common effort to create a data base of atomic data.
- Can we create astrophysics situation in a lab? jets moving in a medium, simulate an accretion disk.
  - Earth based experiments (e.g. dust-analog measurements, or even real dust (from the stardust mission).
- Prepare archives with fully processed data for a better exploitation.

Q3: *Summary:*

- *velocity resolved chemical composition of young SN type II. Search for rare elements (Na, Al) to constrain supernova explosion models. Astro-H is the instrument which may solve this issue.*
- *Cataclysmic variables observed in different states to see the motion of the gas. On the same line, a long monitoring of Capella was proposed in order to understand what is that prevents the corona to flare. Finally, a long monitoring of stars hosting planets, to understand possible tidal phenomena and star-planet interaction.*
- *Survey of the galactic plane to understand homogeneity of dust and gas in the Galaxy. Search for trace elements of e.g. supernova explosion.*
- *AGN and XRB continuum monitored with multi-mission effort (e.g. w/Nustar)*

Details

- Simultaneous observation with e.g. Nustar to measure continuum variability of AGN and Galactic black holes.
- Velocity diagnostics composition using Astro-H. Tycho: two sets of lines, one associated with shocks.Young type II remnants bright sensitive search rare element Na, Al, to learn nucleosynthesis and pin down supernova models and the explosion.
- CV observed in different states to see the motion of the X-ray emission gas. Several hours. 1 hour to 20 hours period. 100ks with multiple exposure.
- Capella for 5 years: it's a binary. It doesn't flare, therefore whatever control the corona is in the surface. Planet hosting stars, to understand the interaction.
- Complete survey of the galactic plane to unveil dust chemistry in different environments.

Q4: *Summary: The following was proposed as a legacy for future missions:*

- *Deep observation of crowded fields, like starbursts (M82-type) to obtain imaging of different regions.*
- *Survey of Galactic sources for ISM studies.*
- *Deep grating observations of known ULX*
- *LMC and SMC deep imaging observation*
- *Better coverage of shock regions on cluster of galaxies*
- *Long final look at the extended emission in the Galactic center to observe variability and study reflection.*
- *Sources which should be studied simultaneously with Astro-H: AGN continuum (soft excess variability), star binary systems (WR, O stars) for colliding wind studies.*

Details:

- PSF is a unique feature that should be exploited.
- Survey of grating of ULX.
- Deep observation of a starbust M82-like to get the imaging of different regions. With Chandra- AGN soft excess simultaneous with AstroH.
- Survey of galactic sources for soft X-ray ISM.
- LMC and SMC deep observations for imaging.
- Have a last long look to extended emission in the galactic centre, to
- observe variability, study reflection.
- Shock regions in cluster of galaxies which are not completely covered so far.
- Star binary systems simultaneous with Astro-H. Colliding wind binary (WR and O star)

Table 2: Martin Elvis

Q1:

- Winds from X-ray binaries and AGN. For:
    - Feedback onto accretion process;
    - Total energy/mass budget;
    - Structure in Ionization, geometric, velocity
- Clusters of Galaxies:
    - Enrichment process: contributions from SNI, SNII, AGB stars; is spatial distribution important?
    - What is the 3.5 keV line?
- Diffuse gas on scales from galaxy to Large Scale Structure:
    - ISM, CGN, ICM, IGM.
    - In both emission and absorption, if possible.
- Broad band science:
    - Crucial for complex structure around the 6 keV Fe-K region.
    - Only 1 Chandra-Gratings + NuSTAR observation in 2 cycles. Unused allotment of time returned to NuSTAR. C.f. XMM awarded 400ksec and added 1 Msec.

Q2:

- Effective areas to 1%, cross-calibrated between missions.
- For e.g. cluster masses for cosmology.
- Cross-calibration of optically thin plasma codes.
    - Esp. Spex, APEC, Cloudy.
    - De-bug differences
    - Include other physics, e.g. resonant scattering (for clusters), abundances.
- Wavelength calibration to <100km/s.
    - Need ~50km/s for wind clumps in stars, binaries
    - Puts requirements on RMF/LSF accuracy in wings.
- Include error estimates/flags in atomic database and calibration files
    - Adapt fitting codes to use.
    - Propagate errors properly to final parameters
- Complete missing atomic physics data.
    - Work with other users, esp. plasma physics/laser physics communities.
    - Can Astrophysics supply useful data, esp. wavelengths?
    - How to motivate atomic physicists? (funding!)

Q3:

- Large >Msec Projects: Observe…
    - Two dozen of the brightest sources at high S/N, e.g.:
        - 6 HMXRB
        - 6 LMXRB
        - 6 AGN
        - 6 SNR
    - Monitor AGN Warm Absorbers
        - Stability
        - Changes give density, hence radius
    - 3.5 keV line. Use ASTRO-H on "many" individual objects with sufficient S/N.
    - ICM enrichment process via Fe/Ni ratio: If SNIa form at Chandrasekhar mass (single degenerate origin). Archival? ASTRO-H
- Tools: Extract spatial information from Chandra, XMM-Newton grating data.

Q4:

ASTRO-H:

- Good Chandra images of ALL ASTRO-H targets.
- Simultaneous preferred
- Extended sources are higher priority.
- ~200 observations/year. 50%[TBR] extended.
- WR140 perisatron passage in 2016 (P~7 years). Last chance for all 3 satellites.

- Eclipsing CVs: Solve geometry using EPIC for 1min time resolution, ASTRO-H for Doppler shifts.
- Novae years post-explosion (2-4 year) E<1 keV gratings. (too faint?)
- AGN Warm Absorbers simultaneous w. ASTRO-H + low energy gratings to get lies at ALL ionizations.
- Flare stars simultaneous w. ASTRO-H + low energy gratings to get lies at ALL ionizations.
- Low N_H galactic binaries simultaneous w. ASTRO-H + low energy gratings to get lies at ALL ionizations.

Athena, X-ray Surveyor:

- O-stars: variability for wind structure. Msec now, 10's ksec in ~2030
- 1ES1533 Msec as test case for IGM to guide plans
- Msec on high z quasar for feasibility. Must have 6.4keV shifted well below 2.1 keV Ir/Au edge so z>~3
- Observe SN now, SNR in ~2030.

Table 3: Dave Huenemoerder

Q1:

1. Can we measure the mass loss rate and abundances of massive stars to better than a factor of 2?
2. Where are the missing Baryons?
3. Can we characterize Inter-Cluster Medium (ICM) characteristics? Important issues are:
    a. amount of turbulence
    b. particle acceleration mechanisms
    c. roll of turbulence in AGN feedback
    d. heating of inter-cluster plasma
4. What is the origin and long-term evolution of AGN winds?
5. What are the abundances of iron-peak elements in supernovae remnants and galaxy clusters?
6. What are dark matter annihilation lines?
7. Is charge exchange important? Where?
8. What is the equation of state of a neutron star?
9. What is the spin of a black hole?
10. What are the redshifts of transients? (gamma ray bursts, or a soon-to-be-detected electromagnetic signature of a gravitational wave detection)

Q2:

1. Atomic data needed: Inner-shell K-lines, auto-ionization rates, absorption cross-sections;
    a. Better wind-model infrastructure (i.e., code for community use, ways to fit

to data).

2. Instrumental line profile calibration is crucial for accurately measuring weak absorption lines (e.g., scattering wings can weaken a line).
3. Better extended-source modeling tools are needed.
4. AGN warm-absorber forest of inner-shell lines requires better atomic data.
    a. Very good calibration of instrumental line profiles is needed (and also for higher orders)
5. Need good atomic data for Mn, Cr, Ni (at least).
6. Calibration, calibration, calibration (esp of effective area) for measurement of weak broad emission lines against a continuum.
7. For CX: Lab data ("coming soon");
8. Low energy calibration is very important (e.g., 1/4 keV regime);
9. Good background models - something easy to use.
10. n/a - not a lab data or methods issue. ("Lab data are adequate") ("Analysis methods probably OK") (measuring a redshift is easy, given the data)

Q3:

1. We probably need a megasecond class HETG spectrum for line profile shape details and for variability, of one O-star (e.g., zeta Pup)
2. Observations on many sight-lines, large effective area, high resolution.
3. Simultaneous high spectral and high spatial resolution.
4. Astro-H-like hard response and long-term monitoring.
5. High spectral resolution over a broad band, and high spatial resolution.
6. Calorimeter resolution (like Astro-H).
7. Calibrated soft spectra of emission lines of important ions of C, N, O (e.g., in 1/4 keV band).
8. Time resolved high-resolution spectrum of an outburst in a slowly rotating neutron star (to look for pressure broadening).
9. ("we have enough data...")
10. quick response

Q4:

1. Imaging of extended sources to understand spatial structure which will be unresolved by Astro-H, Athena. (a lot of this has already been done)
2. Imaging of crowded fields simultaneously with Astro-H, Athena (because some sources are highly variable, and doing it ahead of time, as in 1, is not useful)
3. Grating spectra of all point sources to be observed with Astro-H (calibration and science) (because the <2keV region is also important to have at high resolution)
4. Characterize dust scattering halo in sources to be observed by Astro-H

Table 4: Delphine Porquet

Q1:

- AGN feedback with
  - Galactic outflows
  - ISM (all are linked)
  - Will also require mm (e.g., ALMA), UV and optical observatories
- Redshifted absorption lines from neutron stars: equation of state
- Cluster of galaxies: turbulence, cooling flows, thermal dynamics
  - Requires good X-ray imaging too. Optical observatories (Halpha) and Herschel (CO).
- Type I SNR : progenitor ?

Q2:

- Atomic data, e.g., inner-shell transitions.
- Very good gain calibration, especially for forthcoming X-ray satellites: e.g., Astro-H, ATHENA, X-ray surveyor.
- For Astro-H : it will be very important to have Chandra pointings for good imaging especially for crowded sky region.
- Analysis tools:
  - 3D spatially resolved spectroscopic data.
  - IRAF-like software for the fit of lines as in optical.
- Important to maintain the expertise of fitting codes and to continue the development of ISIS, SPEX, XSPEC, atomdb, xstardb, etc.
- Also important to have advertisement and workshop on the existing tools!

Q3:

- Map of close cluster of galaxies: core + extension with Astro-H plus super deep imaging with Chandra, i.e., 1-2 Ms.
- Workshop about archive tools such as the Virtual Observatory to learn how to use it.
- Better multi-wavelength observation coordination, maybe to increase the possibility for joint proposals, i.e. through only one submission.

Q4:

- Shock acceleration and precursor: very deep imaging Chandra observation (~Ms order) to follow the proper motion of SNR over decades.
- Chandra observations of SMBH binaries for angular resolution.
- Cluster of galaxies: deep or stacked observations for abundance determination

- X-ray sky survey imaging with Chandra, through for example Legacy program, to disentangle source contribution for X-ray spectral analysis with Astro-H, and Athena.
- LSST + X-ray observations: star formations.
- Very deep Chandra and/or RGS (stacked over period) of star-planet interaction
- Snapshot surveys with Chandra to increase sky survey coverage.

Table 5: Tim Kallman

Q1: Note: this one may have morphed from 'how can current chandra and xmm data be used ...' to 'what chandra and xmm data would be desired...'

- comprehensive catalog of high resolution ism spectra from bright lmxbs.
  - Every source with F> specified threshold (~10 mcrab?)
  - this would provide a testbed for atomic physics and lab measurements of features associated with Fe, Si, Mg, O; where in energy are ism features?
  - plus search for molecules
- comprehensive attempt to push the limits if deconvolving extended sources?
  - what do spatially resolved spectra of of snrs look like?
- monitoring of variable sources (eg. X-ray binaries) on various timescales to disentangle variability due to wind from variability due to X-ray source.
  - is variability due to clumps in wind vs. change in Lx?
- Long time baseline studies which utilize data over time baseline of mission.

Q2:

- better lab astro measurements of line/edge energies; better lab astro measurements of molecules and dust features
- understand statistical criterion for detection of absorption (vs. emission)
- tools for deconvolving extended sources spectra
- tools for creating dynamic power spectra
- 2 dimensional change point analysis of spectrum and time
- learn lessons from Kepler re. long term calibration
- should be tgcat for every observatory, instrument
- tool for automated detection of variability between spectra
- more general cross-observatory tools for handling pileup
- analysis tools for cross calibration issues associated with higher order data
- a more clear understanding of limitations of emission measure

Q3:

- do we learn more by looking at new objects for ~50 ksec each, or by looking deeper (~500 ksec) on old targets

?? very unsatisfying discussion …

Q4:

- Concentrate on bright spot in tycho
- use chandra image for brightness dist in snr --> use to disentangle spectrum seen by astro-h
- concentrate on faint sources with chandra even though astro-h will likely focus on bright sources initially, eg. agn, black holes, neutron stars
- preliminary survey for cluster shocks
- imaging of dust halos which can also be studied with astro-h. needs to be simultaneous?
- few deep observations of Fe K band to look for compton shoulder

Table 6: Takayuki Yuasa

Q1:

- Short-term variability of lines in galactic binaries.
    - e.g. to probe properties of individual stellar wind clumps.
- Metal enrichment in clusters of galaxies.
    - detecting emission lines from new elements e.g. Al and Na.
    - (related comment) Al recently detected in an HETG spectrum of nova.
- Long-term monitoring of novae in soft band (0.1-1 keV).
    - to study how hydrogen burning proceeds on the WD surface.
- (ASTRO-H) Relativistic Fe K lines in galactic binaries (BH/NS) and AGNs.
    - maybe difficult because of its broad (continuum-like) nature if really broadened.
    - was difficult with HETG.

Q2:

- Promote projects that analyze existing data (e.g. by increasing funding on those projects).
- Improvement of calibration of the continuous clocking mode of grating instruments (energy scale/CTI).
- Update/maintenance of atomic structure code widely used for atomic database construction.

    - FAC energy level calculations are not very accurate and calibrated using e.g. NIST data.
    - FAC is no longer maintained due to the developer leaving the field.
- A software tool that can extract physics from high-resolution spectrum (without complex model fitting).
    - extract intensities of lines that can be used for temperature/density diagnostics
    - search spectral database to find a spectrum that has a similar spectral shape/lines as newly obtained one (to characterize/categorize spectrum without fitting)
- SPEX can analyze optical/X-ray data simultaneously (useful in self-consistent broad-band spectral analyses)
    - Xspec?
- Summarize possible technique of energy scale calibration using observed lines (where sub-eV energy scale accuracy is required with ASTRO-H)

Q3:

This seemed a little difficult question for participants/facilitator, and could not get specific answers. Below is direct record of what was mentioned.

- Observe with larger collecting area.
- Re-observations of selected target with ASTRO-H (e.g. Vela X-1 eclipse).
- Apply new calibration based on improvements of the continuous clocking mode.
- Appropriate prioritization in target selecting.
    - e.g. bright galactic binaries require shorter exposure time to generate science output than those for typical diffuse sources (SNR/clusters)

Q4:

- Simultaneous observations using grating and calorimeter.
- Lines below 2 keV can only be extensively studied by grating.
    - Long observations strongly necessary for ISM studies using background AGNs.
- Long observations carolimeter may allow detection of time variability in AGN outflow.
    - or, using ASTRO-H data, identify nice targets of time variability study for Athena.
- Need to secure proposal time dedicated to grating observations (a request for Chandra/XMM GO programs).

Table 7: Brickhouse

Q1:

- Structure of accretion in non-magnetic Cataclysmic Variables.
- Electron density in AGN winds (this will tell us where they are located
    - f/I lines
    - time-dependent photoionization
- WHIM/CGM need to also have HI Ly alpha emission.
- UV is also good.
    - What happens after HST?
- Mass of White Dwarf in Type Ia SNe (from SNR)
- Fe K alpha "reverberation mapping" of young star accretion disks with Astro-H
- ICM of clusters of galaxies using turbulence measurements
- Origin of super soft excess in novae (need timing)
- Dust beyond the galaxy (Seyfert I, II)
- Physics of collisionless shock waves
    - Ion-ion, ion-electron equilibration
    - Cosmic ray acceleration
    - Use line widths --- need to separate thermal widths from turbulent broadening
- Super Eddington accretion (outburst of stellar mass BHs)
- Origin of diverse magnetic fields in neutron stars
- Line asymmetry in O star winds
- ^{26}Al line in novae
- Warm dark matter (?) feature ~3.5 keV in clusters?
    - Astro-H will verify energy, blending
    - Search for other features from warm dark matter
    - Use Fermi and NuStar
- Go deeper on a few stellar coronae with the gratings.
- Search for more elements to study FIP effect
- Test atomic physics
- Longer observations with gratings on warm absorbers in conjunction with AstroH
- Maximize timing and throughput

Q2:

- To study line asymmetries, we need better benchmark lines, from lab energies
- Density diagnostics should have lab measurements
- Photoionization codes need to do time-dependent ionization
- Wavelength measurements or [accurate] calculations are needed for weak lines
- Reflection models with photoionization
- Relativistic effects in atomic data
    - Geometry --- need more flexible tools
- Need more automatic tools to analyze high resolution data

  - Important if studying lots of source (>100) not just a few
  - Need to be more customizable
  - Bring machine learning techniques into this
- Can we teach blind search algorithms to "know about":
  - Other related lines from the same ion
  - Couple to temperature to get other lines from more ions
- Publicize/train how to use new tools
  - See Vinay's poster on timing tool
- What is the best strategy for time-dependent ionization?
- RGS system (BIRD?) not as good as tgcat
  - Tgcat could stand to be improved as well
- Make Astro-H analysis easier
- Better dust models, lots of data needs, lab studies needed
  - Electron microscope, synchrotron facilities
  - Range of samples to produce a large table
  - Have to account for scattering
- Talk more to industry people about creating glass samples for lab studies of solids
  - Most glasses are crystalline, probably need to study amorphous
  - glass
- There are discrepancies in depletion values along different lines of sight
- Need accurate flux calibration to do multi-wavelength observations
  Intra-instrument, e.g. RGS vs EPIC, NuStar
  Different modes from same instrument (CC mode)

- High N_H in CC-mode --- blurs edges
  - Need background plus dust scattering halo
  - Need calibration plus a tool

Q3:

- Mass of White Dwarf --- measure gravitational redshift spectroscopically with SXS
  - Important for WDs near the Chandrasekhar limit
- Turbulence in the ICM
  - SXS measurement of Doppler broadening
  - Confirm resonance scattering analysis

- Dust beyond galaxies
  - Transient (rings) X-ray scattering
  - Might be some in archives, but have to get on the source early
  - V404 Cyg example, need more TOOs
  - Need new technique to observe sources that are so bright
- Need a new version of the Chandra source catalogue from stacking

- Collisionless shocks
    - Try to detect cosmic ray precursor before shock
    - VLP w/ Chandra ACIS on SN1006
- Will need strategies for really bright sources using Astro-H
- Mn/Cr in SNR to get mass of Type Ia
- Need lab measurements for atomic benchmarks
- Gratings on Cas A (note the paper by Jasmina Lazendic and Dan Dewey was a lot of work!
    - Need a tool for grating observations of extended sources
- What about more work (tools b/c it's hard) on SN 1987a
    - Very little has been published
- WA's in AGN will need more throughput (Athena, X-ray Surveyor)
- Need support for 3rd order in the gratings
    - Archive support
    - Calibration issues?
    - CC mode
- Bright sources in TE mode, variability from scattering
- More support for tools that combine timing and spectroscopy
- Need high resolution at lower energies to study young star accretion
- Better coordination between observatories

Q4:

- More time on prototypical sources with gratings
- Warm absorbers
- WHIM
- IGM
- Stellar coronae
- X-ray binaries --- use XTE now for Chandra
    - Will need Chandra for Astro-H
- More joint observations, e. g. Chandra HETG + NuStar
- AGN WA
- CV's
- Maybe stellar coronae with flares
- Charge exchange
- Look harder for more sources with high He-like forbidden lines
    - CX or NEI recombining
- Use Chandra ACIS + grating on same source to inform Astro-H
- Look at star forming regions less crowded than Orion
- Look at AGN nucleus vs surrounding
- Look for variability
- Wider fields with Chandra to know what is there for planning future observations
- Nearby galaxy mapping
- Map nearby globular clusters (Josh Grindlay the expert on this)

- Take deeper spectra on grating sources that are hard to analyze now but we will want in the bank for future studies
  - e.g. LETG for novae, supersoft sources (Sumner Starrfield)
- More LETG observations to inform X-ray Surveyor

Table 8: David Cohen

Q1:

- Is Fe K broad or narrow (in various contexts)?
- What is the connection among various types of outflows from AGNs?
- What is the intracluster medium heating mechanism?
- Is the current abundance of ICM explained by star formation in the early universe?
- What are the actual wind mass-loss rates of O stars?
- What are the yields of the various types of supernovas?
- What is the physical nature of shocks in SNRs?
- How are stellar coronae heated? And how do coronal properties vary along evolutionary sequences?
- How do cold and hot material coexist in the centers of clusters?
- What is the source of the iron in Jupiter's magnetosphere?
- What is the connection between the different states in XRBs?
- What are the trends of nitrogen enrichment in OB stars? And what are the nitrogen abundances in galaxy cluster gas?

Q2:

- Better reflection models
- With current rich data sets and increasingly complex models, more effort needs to be made to make it easier for users to access/assess the physics in the models they're using; and modeling tools would be better to use if they were constructed collaboratively rather than "owned" by one person.
- Continue to improve wavelength calibration of spectrometers
- We need better *awareness* in the user community of issues related to calibrations, atomic data uncertainties, etc.

Q3:

- It is obvious, but increasing exposure time/SNR would be really helpful for answering most of the questions.
- Perhaps more emphasis on multi-wavelength supporting observations (joint proposals). Making joint proposals (seem) less risky.
- If possible at all, making more *constrained* observations available for GO proposals would be valuable.

- Are there questions that could be better answered by putting more focus on one or two objects rather than going for lower-quality observations or more objects? Similarly, perhaps for some important objects, there should be long observations from multiple X-ray instruments.
- (The group had trouble coming up with realistic answers that went beyond trying to obtain longer exposures.)
- More willingness to reobserve objects that already have good datasets to study changes in their physical processes.

Q4:

- For extended objects that will be observed with imaging spectroscopy (Astro-H), getting a higher spatial resolution image with Chandra could be very useful for the interpretation of eventual Astro-H data.
- Deep observations of nearby clusters to provide complementary information for Astro-H turbulence studies. Similarly, interesting radio emission from the outskirts of distant clusters could be followed up with Astro-H; having Chandra imaging ahead of time to, e.g. eliminate point sources, could be valuable.
- If there are interesting - but X-ray dim - objects in crowded fields, Chandra imaging could be used to determine whether the object of interest dominates nearby sources (which the would enable us to know that an Astro-H observation wouldn't be seriously affected by blending/contamination).

Table 9: Lia Corrales

Q1:

- Cross correlate X-ray & UV absorption from CGM / WHIM
    - science: missing baryons, composition/phase
- Iron line diagnostics:
    - early type stars?
    - reverb mapping
    - XRBs
    - spin
    - density
    - outflows
- Stack residuals or deeper observations of XRBs to get at photoelectric absorption features and structure
    - same with WHIM
    - emission from hot gas in halos?
    - determine phase states of the interstellar medium (distinguishing neutral from warm and hot ISM)
- Variations of XRBS and other complex systems over the long term
    - what's going on with accretion and jets?

- High res spectrum of dust scattering halos gives the dust composition
- High res spectrum of SNR and other extended sources
  - get metallicity, abundance values from rare metals, determine progenitor
  - get velocity diagnostics (important for clusters as well)

Q2:

- Data analysis for gratings with extended sources
  - proper treatment of gratings background
  - look at images in cross-dispersion direction?
  - e.g. with SN 1006 with RGS, need to get an off-axis response
- Lab astrophysics — which elements are most important?
  - Fe XVII oscillator strengths
  - gas AND solid O (since it is going to be a mix of solid and gas in space)
  - more EBITs
  - Si, O, and Fe simultaneously

- Some uncertainties on the atomic data would be nice!
  - how correlated are they?
  - how to handle correlated data in the modelling
- Same questions as above for calibration uncertainties in general
  - What's the big calibration problem for X-ray observatories right now? Absolute effective area
- What problems could arise from stacking images? (e.g. for results like 3.5 keV line)
  - being dominated by the brightest objects or objects with anomalous features
  - other systematic errors (chip gaps, hot pixels)
  - source contamination in gratings spectra when another objects lines up along dispersion axis (causes a bump or false line)
- Other issues
  - high res telescope sensitivity below 1 keV (basically we only have XMM for energies < 0.7 keV)
  - source brightness: telemetry limits on Astro-H will make it difficult to observe extremely bright objects (or XRBs in flare state)

Q3:

- We want TGcat for every observatory
  - i.e. uniform processing techniques / pipelines applied to all datasets
  - needed for stacking or cross-correlations
- Detailed (more frequent) monitoring of XRB outbursts
  - not 1 ks every few days; too much missed opportunity!

    - problem: there is not so much TOO time and there are tight limits on time allocated for projects with time constraints
    - Chandra TAC should be more free / opened up to do more time constrained observations
- PSF web tool that does SAO ray trace + MARX simulation given a few basic inputs
    - right now, requires running web tools some times, then downloading MARX and simulating
    - are there more accessible ray trace tools for other observatories?
- All Chandra and NuSTAR observations should be joint
- Future observations / observatories:
    - polarimetry, which will pick up any type of scattering
    - dust, disk reflection
- More exposure + more observations for CGM/WHIM absorption
    - what ever happened to DIOS (Japanese mission)? apparently it was delayed for two years :(
    - more stacking?
- 2-D archive: spectra vs time
    - intelligent time dependent gratings analysis
    - piggy back on TGcat
    - what about imaging vs time archive? e.g. for timing analysis of dust echoes

Q4:

- Because Astro-H is so LOW RES, we should start cataloging images with Chandra so we can compare image with spectra from Astro-H. Create a legacy catalog. Do all the prominent:
    — SNRs (to resolve structures)
    — galaxy clusters (to resolve gas structures)
    — stellar clusters (need to resolve individual stars)
    — nearby galaxies (for ULXs)
    — LMC and SMC survey
- Note that Chandra has currently observed about 400 deg^2 (only 1% of the total sky)
    — but what's the point of surveying when we have eRosita coing?
    — star clusters, resolution; deeper or new?
    — let's do 0.5 Ms projects
- Chandra should look at certain objects before Astro-H to resolve diagnostic line brightness ratios, essential for planning Astro-H observations
- Pathfinding for Athena:
    — Use Chandra source catalog to identify potential high-z objects (which might be blurry due to off-axis pointing)
    — follow up with deeper Chandra observations

    - this might help us resolve out any source (e.g. dual AGN or lensed quasars)
- Use more observations to get at photoelectric absorption edges at low energies (1-4 keV)
    - since Astro-H will have better resolution at high energy end, we can combine with Chandra and XMM to create Legacy spectra data sets that have high resolution from 0.3 - 10 keV!!