From *Chandra* to *Lynx*: A Summary of the Conference

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A few weeks after the eighteenth anniversary of *Chandra*'s launch, the workshop "From *Chandra* to *Lynx*: Taking the Sharpest X-ray Vision Fainter and Farther" was held at Harvard University in Cambridge, MA, from August 8–10, 2017. Over one hundred astronomers attended the meeting, and the program included fourteen invited and twenty-nine contributed talks along with twenty-one poster presentations. The workshop spanned virtually all topics in X-ray astronomy, from supermassive black holes to objects in our Solar System and everything in between. *Chandra* has revolutionized our understanding of the high-energy Universe, and *Lynx*'s improved sensitivity and spectral resolution will enable substantial breakthrough progress beyond *Chandra.*

Belinda Wilkes opened the meeting with remarks on the status of *Chandra* (it is doing great!), and Alexey Vikhlinin followed with a summary of the progress on the *Lynx* mission concept study. The invited speakers at the symposium included Steve Allen, Niel Brandt, Joel Bregman, Lia Corrales, Bret Lehmer Laura Lopez, Helen Russell, Nancy Brickhouse, Jeff Linsky, Laura Brenneman, Megan Donahue, Mike McDonald, Francesca Civano, and Benny Trakhtenbrot. They were asked to discuss the strengths and limitations of *Chandra* and to identify the *Lynx* capabilities that would be necessary to advance their fields. Many presentations emphasized the importance of high spatial resolution (at or better than *Chandra*) to limit source confusion in deep or crowded fields and to identify multiwavelength counterparts. The need for large effective area (~50 × *Chandra*) and low background was also a common refrain. The greater throughput of *Lynx* would enable it to detect faint sources in tens of kiloseconds, whereas *Chandra* would require many megaseconds to achieve the same sensitivities. For example, Figure 1 shows a simulated image of a galaxy cluster observed for 1 Ms with *Chandra* (left) and for 10 ks with *Lynx* (right).

Presentations and discussions at the *Chandra* to *Lynx* conference helped to refine two well-established *Lynx* pillars and motivated a third pillar on Galactic and stellar science. The *Lynx* Science and Technology Definition Team (STDT) has now identified three major science pillars that define the optics and instrument requirements: 1) the invisible drivers of galaxy formation and evolution; 2) the dawn of black holes; and 3) the energetic side of stellar evolution and stellar ecosystems.

The first pillar, *The Invisible Drivers of Galaxy Formation and Evolution*, broadly ties to many active areas of extragalactic science, including active galactic nuclei (AGNs), galaxy clusters, the hot circumgalactic medium (CGM), and numerical cosmology. The workshop speakers gave excellent presentations across these subfields, emphasizing the importance of understanding the cycle of baryons into, within, and out of galaxies as well as the role of AGN and stellar feedback in galaxy evolution. With *Lynx*, hot gas in galactic halos and cosmic web filaments will be observable in emission with imaging and in absorption with spectroscopy. X-rays are especially suited to investigate the metals of the CGM as e.g., ~80% of oxygen there is observable as O VII or O VIII at 0.5–0.7 keV. To make significant advancements, programs to study hot halos of galaxies require high-resolution spectra (R~5000) of background AGN, the ability to detect low surface brightness, soft X-rays, and R~2000 spectroscopy of extended objects on arcsecond scales.

The second pillar, *The Dawn of Black Holes*, is focused on the mystery of the origin of supermassive black holes (SMBHs). *Chandra* and *XMM-Newton* data have led to significant progress in our understanding of SMBHs, such as enlarging the sample of known X-ray selected AGN at $z \approx 4$–7. With *Lynx*'s planned sensitivity (of ~10^{-19} erg cm^{-2} s^{-1}), obscured and/or faint AGN populations at z ≈ 5–10 will become accessible (see Figure 2).

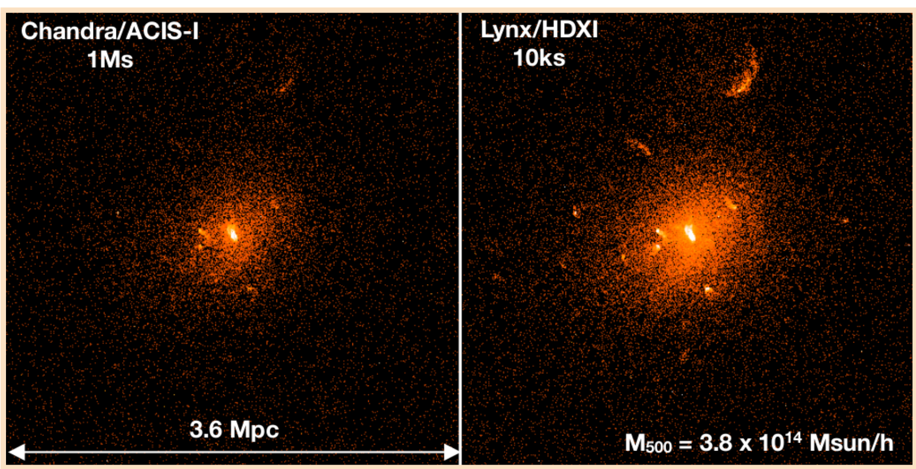

Figure 1: Figure from Camille Avestruz's presentation at the workshop comparing the *Chandra* (left) versus *Lynx* (right) view of a simulated galaxy cluster from the Omega500 simulation run at Yale University. Mock map generated by Erwin Lau using pyxsim and SOXS packages developed at SAO. The tremendous effective area of *Lynx* would allow it to readily detect the extended diffuse gas and faint point sources in a much shorter observation than *Chandra*. Additionally, *Lynx* has a relatively higher effective area in the soft X-ray band making it more sensitive to the soft X-ray emission coming from fainter substructures.

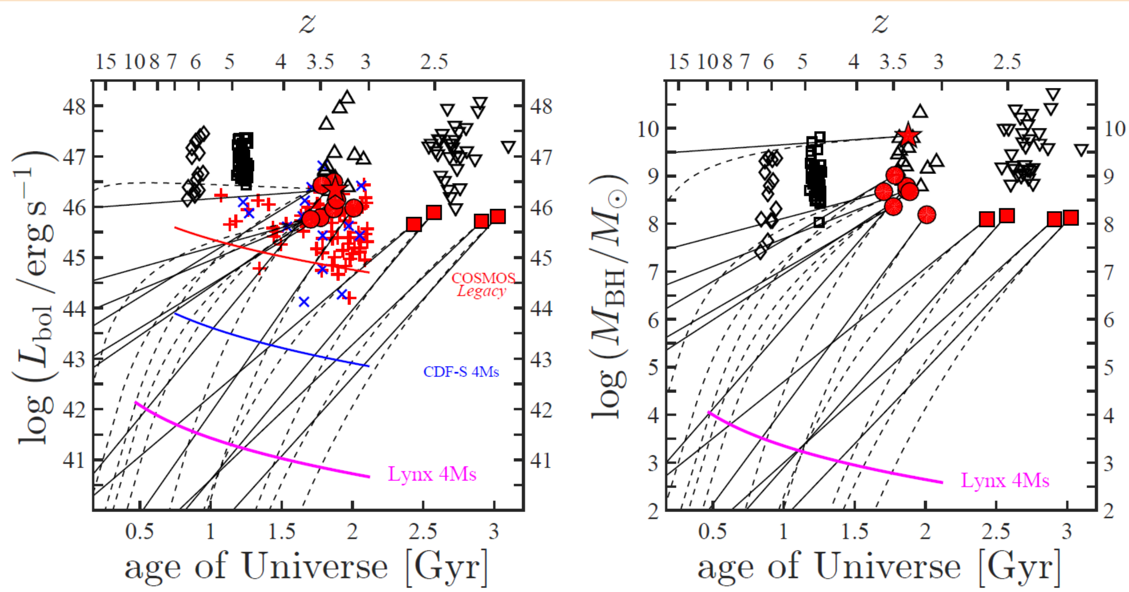

Figure 2: Figure from Benny Trakhtenbrot's presentation showing the limits on bolometric luminosity L_{bol} (left) and the corresponding Black Hole mass (right) that *Lynx* will be able to achieve. With 4 Ms of observation, *Lynx* will be able to detect the faint/low-M counterparts of the highest-redshift, high-mass luminous quasars, and trace the progenitors of high-redshift SMBHs.

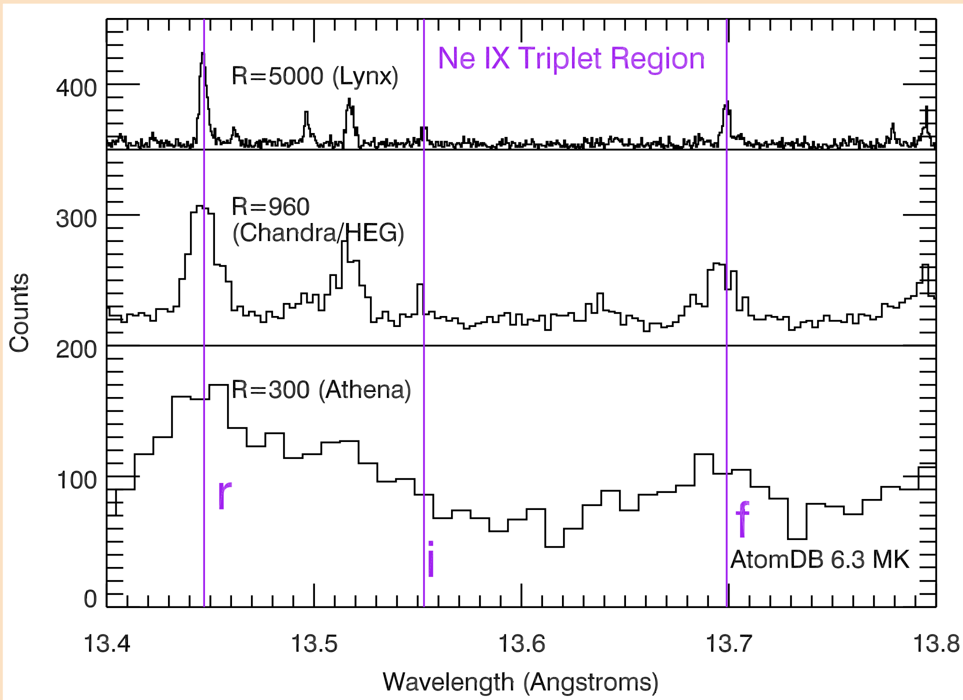

Figure 3: Figure from Nancy Brickhouse's presentation at the workshop comparing the spectral resolution for density and temperature sensitive lines among *Lynx* (top), *Chandra* (middle) and Athena (bottom). The Ne IX triplet feature is critical to measuring coronal conditions, including accretion rates in young stars. With *Chandra*, this experiment has been performed on only a couple of stars. With gratings, the tremendous effective area of *Lynx* would allow it to observe this feature in dozens of stars in a single, short observation.

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Lynx is predicted to detect ~10^3 SMBH seeds at $z \sim 8$–10 of mass $M \approx 3\times10^4\ M_\odot$ in a 1 deg^2 field. Furthermore, *Lynx* will be able to trace the growth of these seeds and their co-evolution with host galaxies. Aside from low background and high throughput necessary to find high-z SMBHs, sub-arcsecond spatial resolution (both on–and off-axis) is also crucial to limit source confusion.

The design requirement to enable the first two pillars will allow for tremendous advances in understanding *The Energetic Side of Stellar Evolution and Stellar Ecosystems*. This third pillar covers a range of galactic science, from stellar birth to death and beyond. Several speakers discussed how high-resolution imaging will allow unique science on star-forming clusters where each star imaged will have R~500 spectra generated. The 50-year baseline of high-resolution imaging from *Chandra* and *Lynx* will also enable measurement of proper motions of most Galactic center X-ray sources with velocities >100 km s^{-1}. The resultant low background (relative to the other X-ray missions flying in the 2030s) will allow deeper surveys. Soft X-ray sensitivity will be crucial to probe the most abundant metals in the Universe (e.g., oxygen). The inclusion of dispersive gratings will enable measurement of physics as diverse as the multi-phase interstellar medium and the details of coronal structure. The separate cross-dispersed spectra of multiple sources in a field enable breathtaking multiplexing capabilities–perhaps 100 high quality spectra, with 5 times HETG resolution, in a single (< 1 day) exposure (see Figure 3)!

The meeting ended with a lively discussion about the path from *Chandra* to *Lynx*. Part of this discussion included a suggestion of a special call for proposals which could be viewed as testbeds of *Lynx* science. Following receipt and review of 29 white papers on candidate *Lynx* Pathfinder science, the *Chandra* Director's Office released a call for *Chandra* observing proposals to carry out pathfinder science for a potential *Chandra* successor mission (CSM). Up to 1 Ms of *Chandra* Director's discretionary observing time will be made available through the CSM call for proposals. 27 proposals requesting a total of 9.49 Ms were received by the 24 January deadline. The review panel met on the 14th of February at SAO. The results were announced and can be found at *http://cxc.harvard.edu/target_lists/cycle19/csm_cyc19.html*. ■

All of the presentations from the workshop are available online at *http://cxc.harvard.edu/cdo/cxo2lynx2017.*