

Wide-field Soft X-ray Imaging Spectroscopy

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+

Lynx2030SAG Microcal WG

LEM APEX team (~200 scientists)

ExCEED MIDEX team

ARDUA team

Proposition for Lynx2030

- The microcalorimeter array should be made as large as possible to be the primary survey/mapping instrument while maintaining the 0.5” angular resolution over as much of the FOV as possible over a wide energy band.

Changes in astrophysics landscape 2016->2026

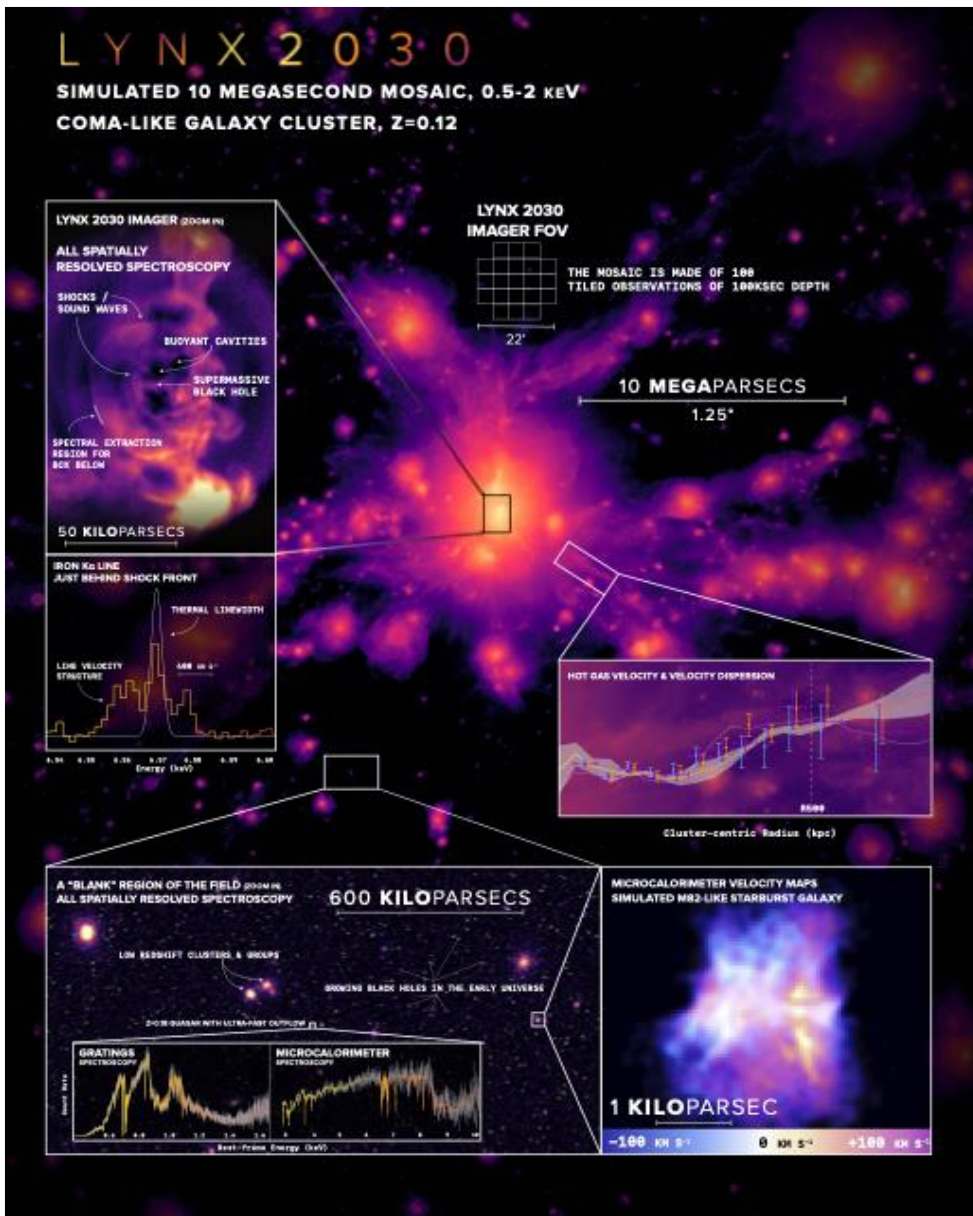
- Informed by JWST results (and Roman soon hopefully)
- Microcalorimeter technology has advanced considerably
- Galaxy formation theory has advanced considerably
- APEX endeavor brought multiple strong science teams together to competitively reshape our perspective

Perspective from Chandra and Lynx2020

- Chandra was not designed primarily as a survey/mapping instrument
 - CDF-S/CDF-N and SZ survey were the only surveys as part of the pre-launch/AO-1 'directed' (GTO really) science
- Many surveys came later – COSMOS, Bootes, etc. with varying strategies about depth versus size of field with differing science goals

Lynx Legacy survey - HDXI

- Notional HDXI survey of a nearby galaxy cluster and filaments
- Uses 22'x22' FOV HDXI – 10 deg²
- 100 ks per field – 10 Msec total (~1/3rd of a year)
- Depth of each observation comparable to CDF-S
- Host of science objectives:
 - High-z AGN
 - Cosmic web
 - Evolution of groups
 - Plus many others



Lynx Observing Plan

Pillar	Program	Typical Observation	Instrument	t_{exp}
The Dawn of Black Holes	Origin of SMBH seeds [*] §1.1	Surveys over 1 deg ² to depth $f_x = 1.6 \times 10^{-19} \text{ erg s}^{-1} \text{ cm}^{-2}$ [0.5–2 keV band] plus a deeper survey over 400 arcminute ² to $f_x = 7 \times 10^{-20} \text{ erg s}^{-1} \text{ cm}^{-2}$	HDXI	23 Msec
	SMBH growth from Cosmic Dawn to the Present. AGN & environments. Triggering, quenching, relation to galactic star formation. §1.2	Survey down to $f_x = 2 \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2}$ over 2 deg ²	HDXI	2 Msec

The Energetic Side of Stellar Evolution and Stellar Ecosystems	Young star forming regions §3.1	Surveys to detect entire mass distribution of stars in active star forming regions to $d = 5 \text{ kpc}$	HDXI	2 Msec
	Stellar coronal physics, impact of stellar activity on planet habitability, accretion on young stars. §3.2	Spectroscopic survey of 80 stars within 10 pc	XGS	2 Msec
	Endpoints of stellar evolution: SNRs [*] . §3.3	Transit spectroscopy of planets around dwarf stars down to super-earth regime	XGS, LXM, ultra-high resolution array	1 Msec
		Targeted observations of the youngest SNRs in the Milky Way, up to ~ 50 objects	LXM, main array	2 Msec
	Endpoints of stellar evolution: X-ray binary populations. §3.4	Statistics and typing of SNRs in different environments in nearby galaxies		1 Msec
		Survey of X-ray binary populations in nearby galaxies	HDXI, LXM	2 Msec

Drivers of Galaxy Formation and Evolution	State of diffuse baryons in galactic halos — direct imaging [*] §2.1	Survey of ~ 15 low-redshift isolated (spiral) galaxies, pushing 10% thermodynamic (gas density) measurements to $0.5 r_{500}$ for $M \sim 3 \times 10^{12} M_{\odot}$ and to r_{200} for $M \sim 1 \times 10^{13} M_{\odot}$.	HDXI	7.5 Msec
	State of diffuse baryons in galactic halos — absorption line spectroscopy [*] §2.1.5	Observe ~ 80 AGN ($f_{\text{agn}} \sim 1 \times 10^{-11} \text{ erg s}^{-1} \text{ cm}^{-2}$) to detect ~ 30 absorption line systems in $M \sim 10^{12} M_{\odot}$ galaxy halos down to ~ 1 mÅ EW. Use same sightlines to characterize the Milky Way Halo and for blind detections of the Cosmic Web.	XGS	5 Msec
	State of gas and feedback in high-redshift galaxy clusters and groups. §2, 4.4.2, 4.6	Gas temperature, density and metallicity profiles in ~ 30 clusters and groups at $z > 2$	LXM, main array	6 Msec
	Characterization of the first galaxy groups at $z = 3 - 4$. §2, 4.4.1	Imaging observations of ~ 10 high- z galaxy groups	HDXI	2 Msec
	Spectroscopic survey of AGN to determine energetics of the AGN feedback. §2, 4.2.3	Soft-band spectroscopy with $R > 1,000$ down to 0.2 keV to measure density-sensitive spectral features	XGS, LXM, ultra-high resolution array	3 Msec
	Characterize the supply side of AGN energy feedback. §2	Measure thermodynamic state of diffuse gas near the Bondi radius of SMBHs in nearby elliptical galaxies	LXM, enhanced spatial resolution array	2 Msec
	Measure the energetics and effects of AGN feedback on galactic scales [*] §2	Observe AGN-inflated bubbles in the ISM of low-redshift elliptical galaxies	LXM, enhanced spatial resolution array	2 Msec
		Spectro-imaging of extended narrow emission line in nearby spiral galaxies		2 Msec
	Energetics and mechanics of galactic winds [*] . §2.2	Observe galaxy winds in ~ 20 objects, with the ability to characterize velocities to $< 100 \text{ km/s}$ on arcsecond scales	LXM, ultra-high resolution array	2.5 Msec
	Galaxy cluster-scale feedback §2, 4.10	LXM observations of nearby galaxy clusters to constrain plasma physics effects in the cluster cores	LXM, main array	2 Msec

Table 5.1 (page 94) of the Lynx concept study

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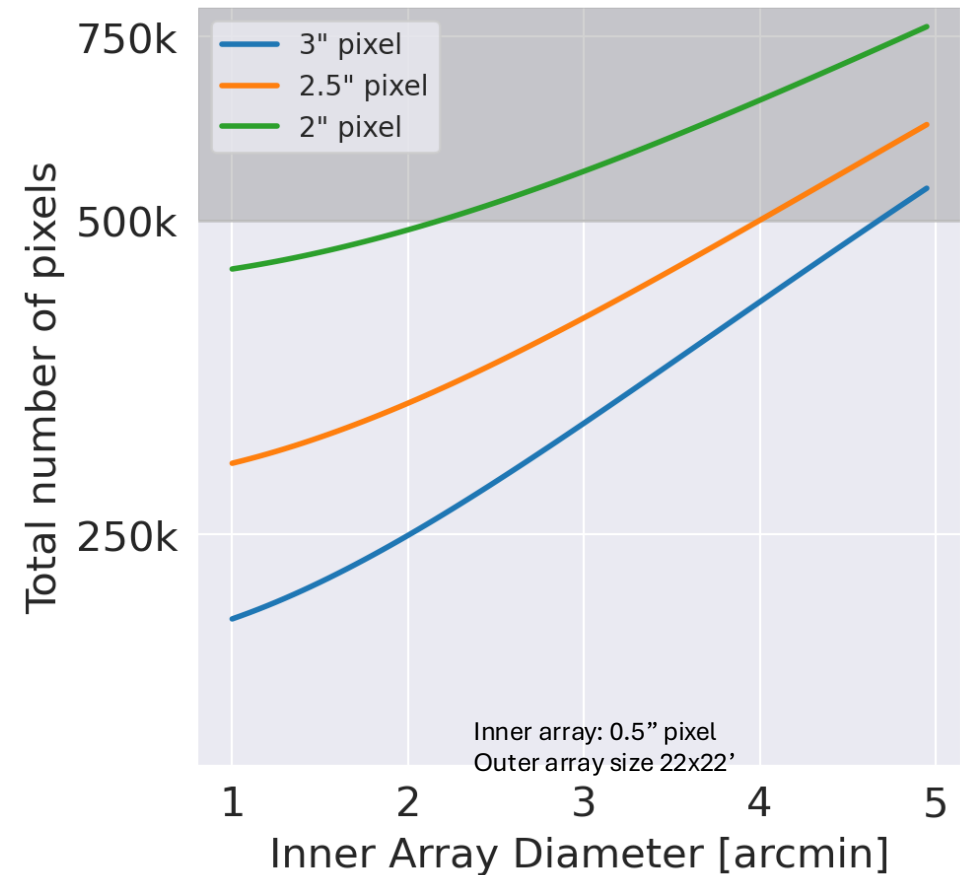
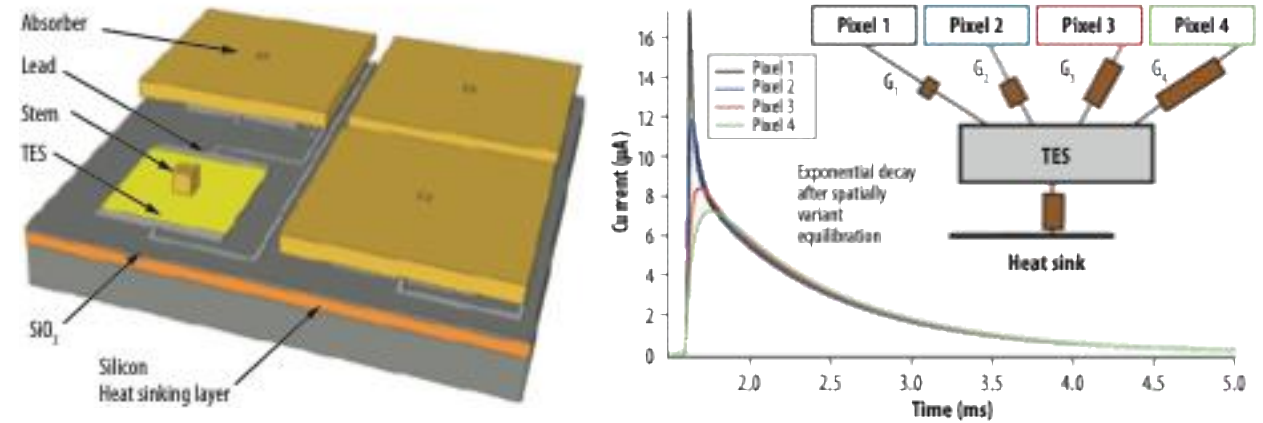
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 Wide FOV microcalorimeter array would go well beyond nominal Lynx 2020 baseline

How to enable this survey/mapping science - Expand the LMA focal plane for Lynx2030

- 22' × 22' FOV is
~6.97 Mpix (0.5" sq pixels)
 - Can we retain 0.5" resolution over the expanded FOV?
Do we need to?
 - Do we need to curve the FP to match optic?
If so, how complex is this?
- On the timescale of Lynx2030
microcalorimeter arrays of 10^{5-6} pixels are
entirely feasible

Figure 6.20 of Lynx STDT report



Science investigations of this configuration – this list only touches the surface of the possibilities

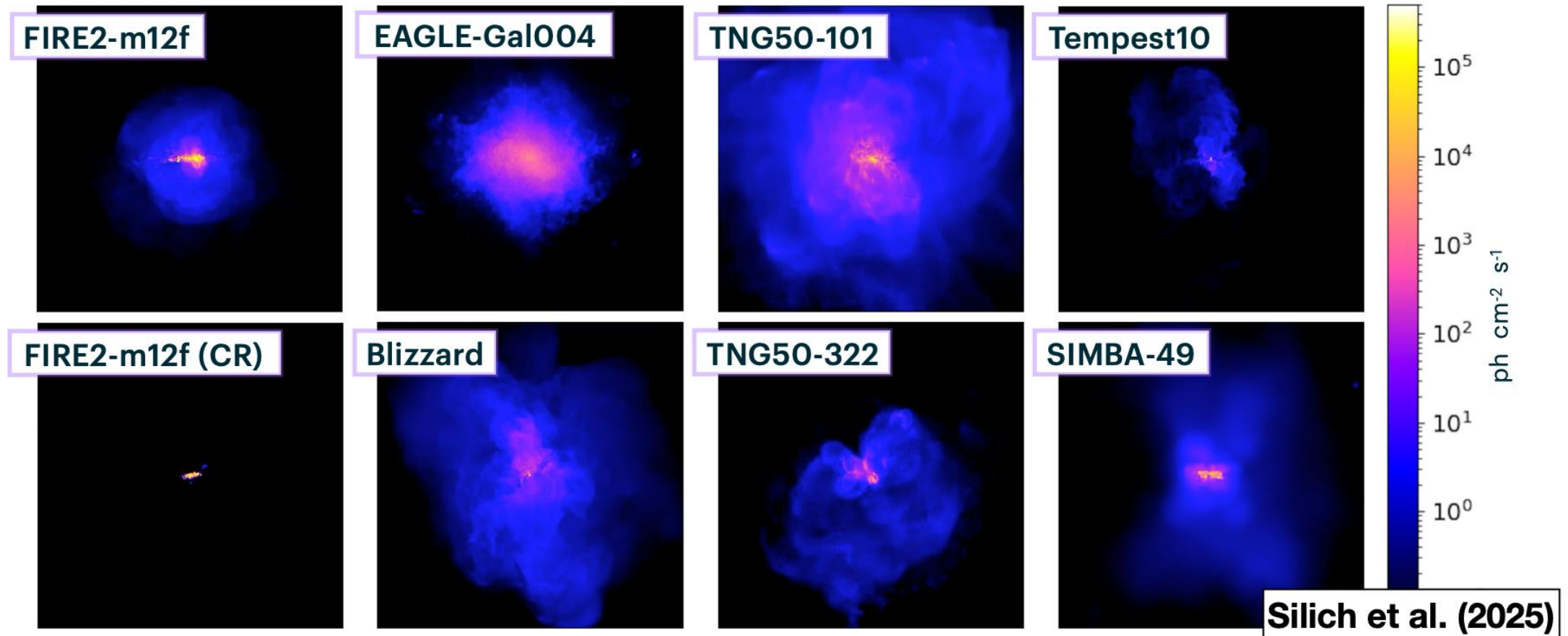
- **Enables a wide range of survey options at microcalorimeter spectral resolution**
 - Map the cosmic web in emission
 - AGN survey at high spectral resolution
 - Map galaxy haloes in emission to R_{500} and beyond
 - Map cluster outskirts and filaments (e.g. Lynx Legacy survey but with ~ 2 eV spectral resolution)
- **Large grasp facilitates efficient, high-cadence surveys for time domain science**
 - Galactic plane and Galactic center surveys at microcalorimeter resolution
 - Surveys of LMC/SMC/M31
 - Young stars in star forming regions
 - All-Sky survey (?)
- Broad synergies with Roman, Rubin, SKA, SPT-3G, etc.
- Enormous discovery space for serendipitous science from all pointed observations
- **While retaining the 0.5'' imaging at ~ 1 -2 eV spectral resolution**

Mapping the hot gas haloes of galaxies in emission

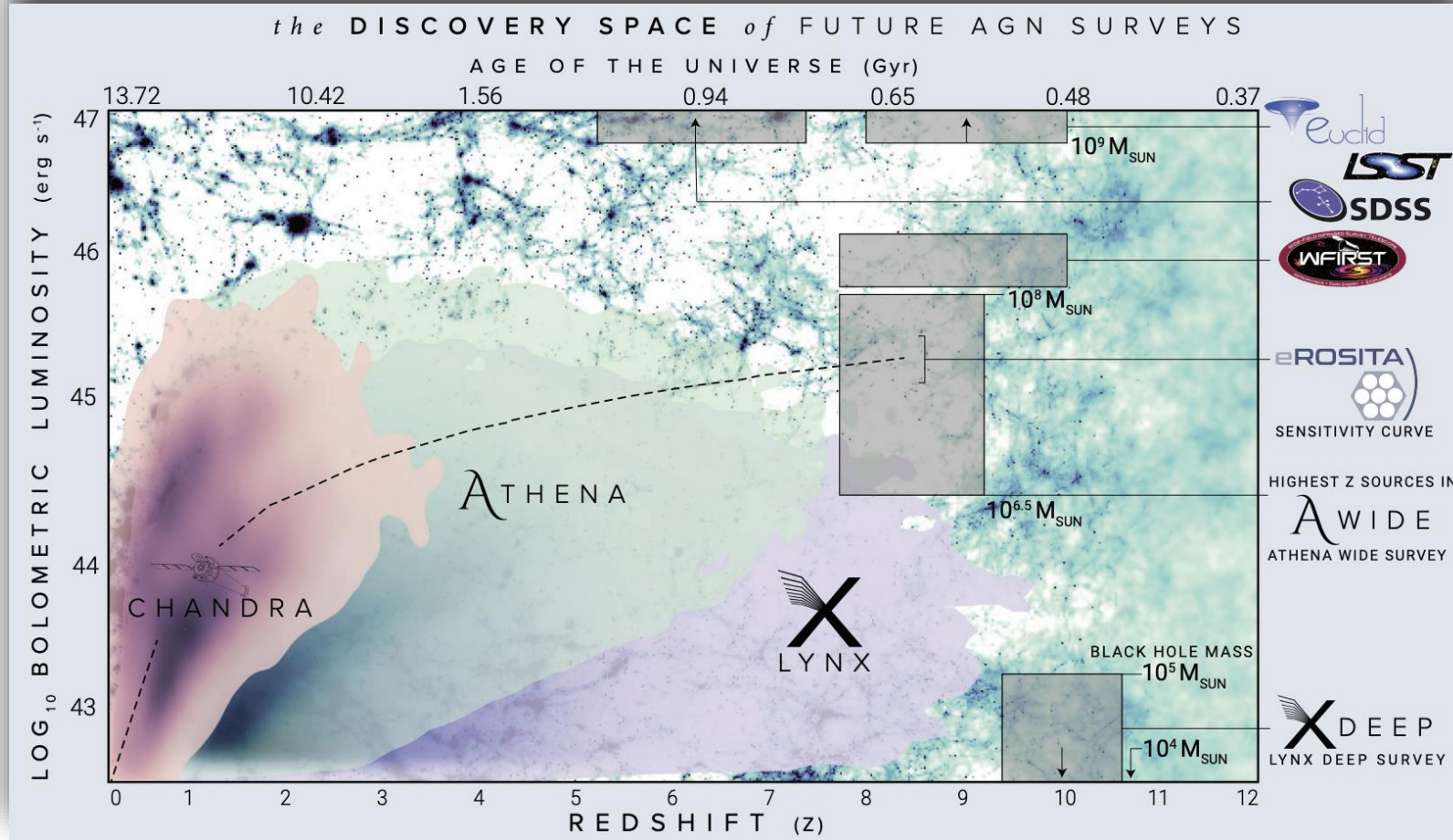
The Circumgalactic Medium

Goal: How does the hot circumgalactic gas regulate galaxy growth?

Simulations do not agree on the extent or morphology of hot CGM—the culprit is differing prescriptions for modeling feedback from AGN and stars

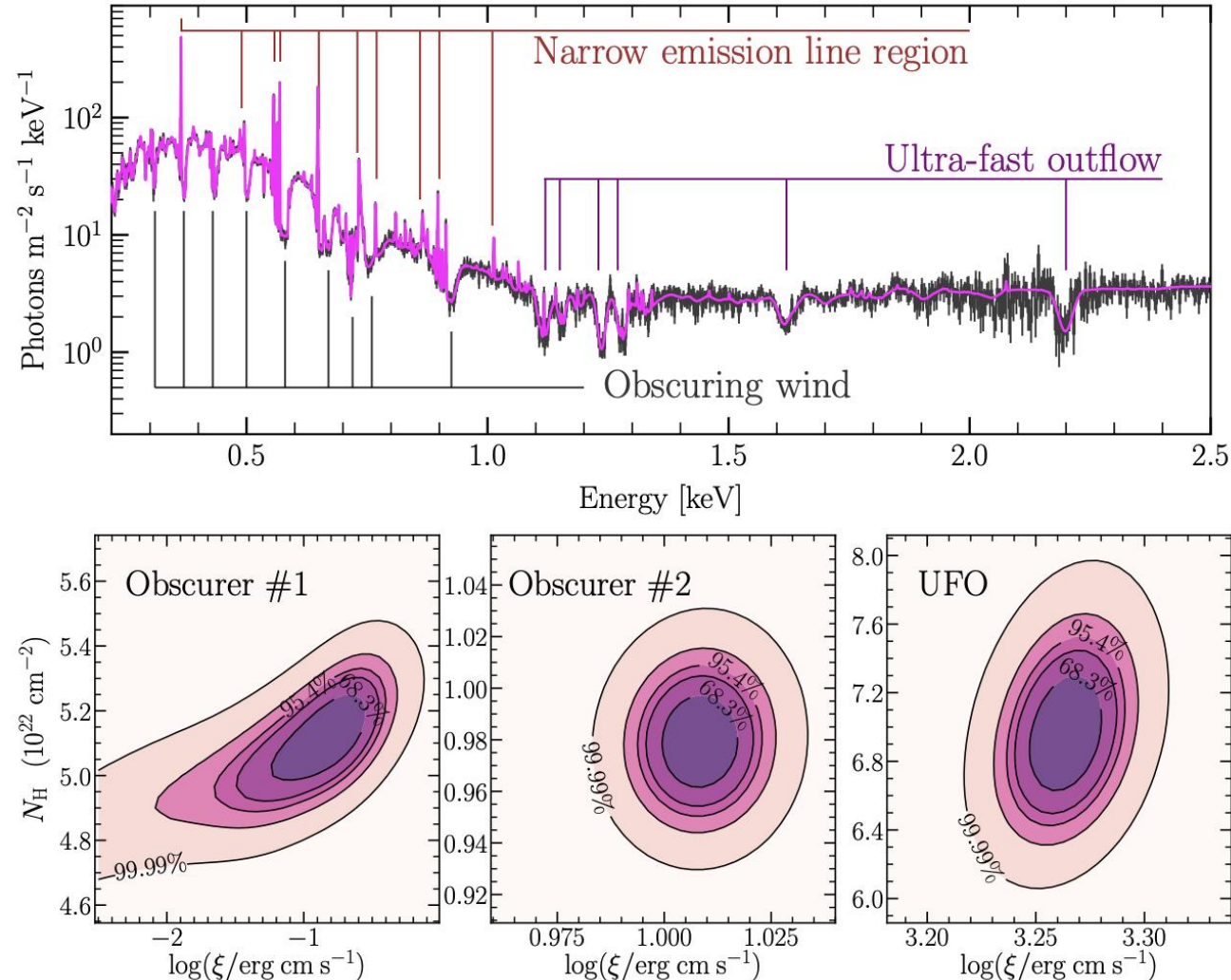


High-z Supermassive Black Holes: Demographics



- X-ray AGN demographics at $z \gtrsim 6$: luminosity distributions, obscured fractions, and Fe-K line incidence
- Protocluster deep fields deliver **environment-dependent SMBH growth** tests — spectroscopy disentangles **Compton-thick AGN Fe-K** from surrounding hot gas and background
- Sub-arcsec imaging is what makes the high-z program feasible in crowded regions
- Calorimeter offers much improved (sky) background rejection

Multiphase obscuration: measuring the hidden growth channel



- Separate multiple absorber components using **resolved lines + edges** → tighter N_{H} and **ionization** per phase
- Broadband data constrains **reflection + Fe-K** simultaneously, reducing degeneracy in intrinsic luminosity and obscured fraction
- Outcome: robust, physically grounded **obscuration-corrected accretion** measurements (how much BH growth is hidden, and when)

Stellar Activity Shaping Planetary Environments

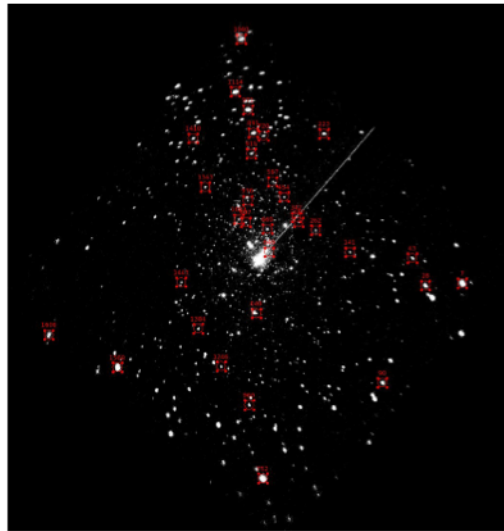
• How do stars evolve and influence the formation and environments of exoplanets?

Objective 1: How do stellar flares generate energetic radiation and outflows impacting planets and disk?

Objective 2: How do stellar rotation and inner disk composition evolve and regulate planetary formation?

High-resolution, time-resolved soft X-ray spectroscopy

- ✓ High spectral resolution 1) Time-resolved Doppler shifts → **detecting CMEs**
2) High-sensitivity diagnostics → **star/disk abundance evolution**
- ✓ Wide FoV → **dramatically increase the sample** by observing star-forming regions



1 Ms Chandra observation of Orion SFR

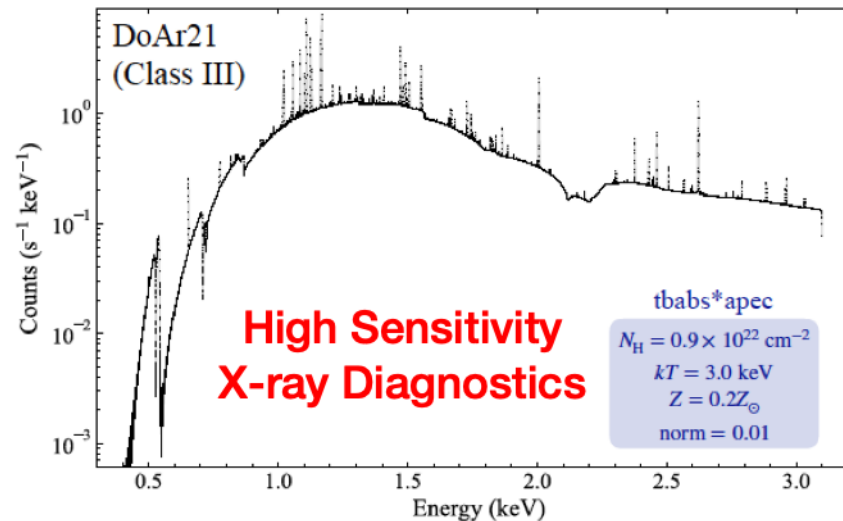


Fig. X-ray flare spectrum from a pre-main sequence star (Credit: S. Inoue)

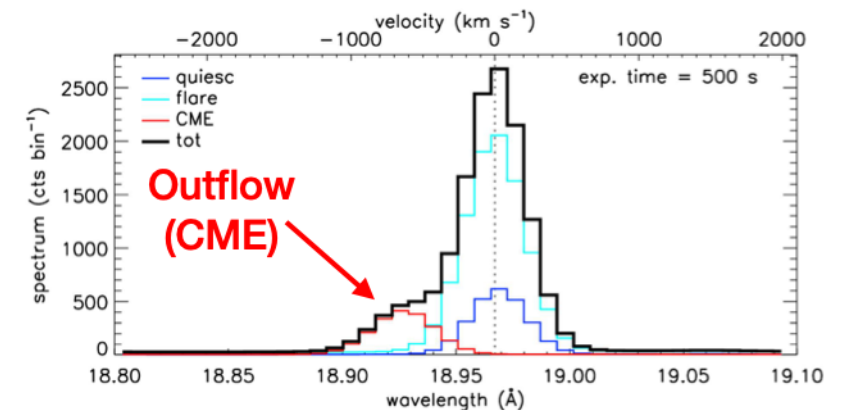
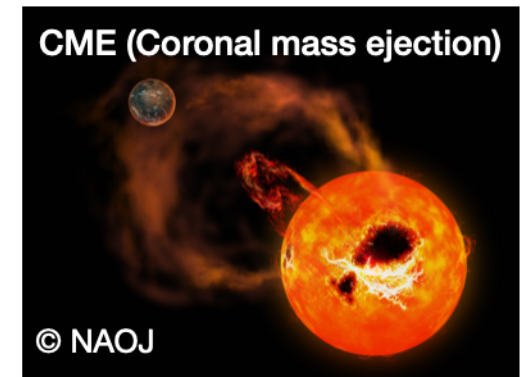


Fig. Modeling of stellar coronal mass ejection (Credit: Drake et al. LEM team)

Conclusions:

- A microcalorimeter array will be the prime science instrument on any post-2030 X-ray flagship mission – we will not be doing flagship science without it
- The pixel size of the array should be well-matched to the PSF of the optic to provide high spectral resolution images at the full capability of the optic over wide band
- **Significant change from Lynx2020 – the microcalorimeter array should be as physically as large as possible to enable wide-field observations and efficient large-area surveys at microcalorimeter resolution**

Related presentations

Abstract #43 – Ardua: Unveiling the Baryon Cycle from Stars to the Cosmic Web – C. Vargas

Abstract #78 – De-risking the next X-ray flagship: A dedicated technology development and proto-flight strategy – S. Bandler

Abstract #89 – Ardua: UV instrument technology and design trades for wide-field, ultra-low surface brightness circumgalactic medium mapping – H. Cheung

Backup