# Line Emission Mapper – the Astrophysics Probe for the 2030s


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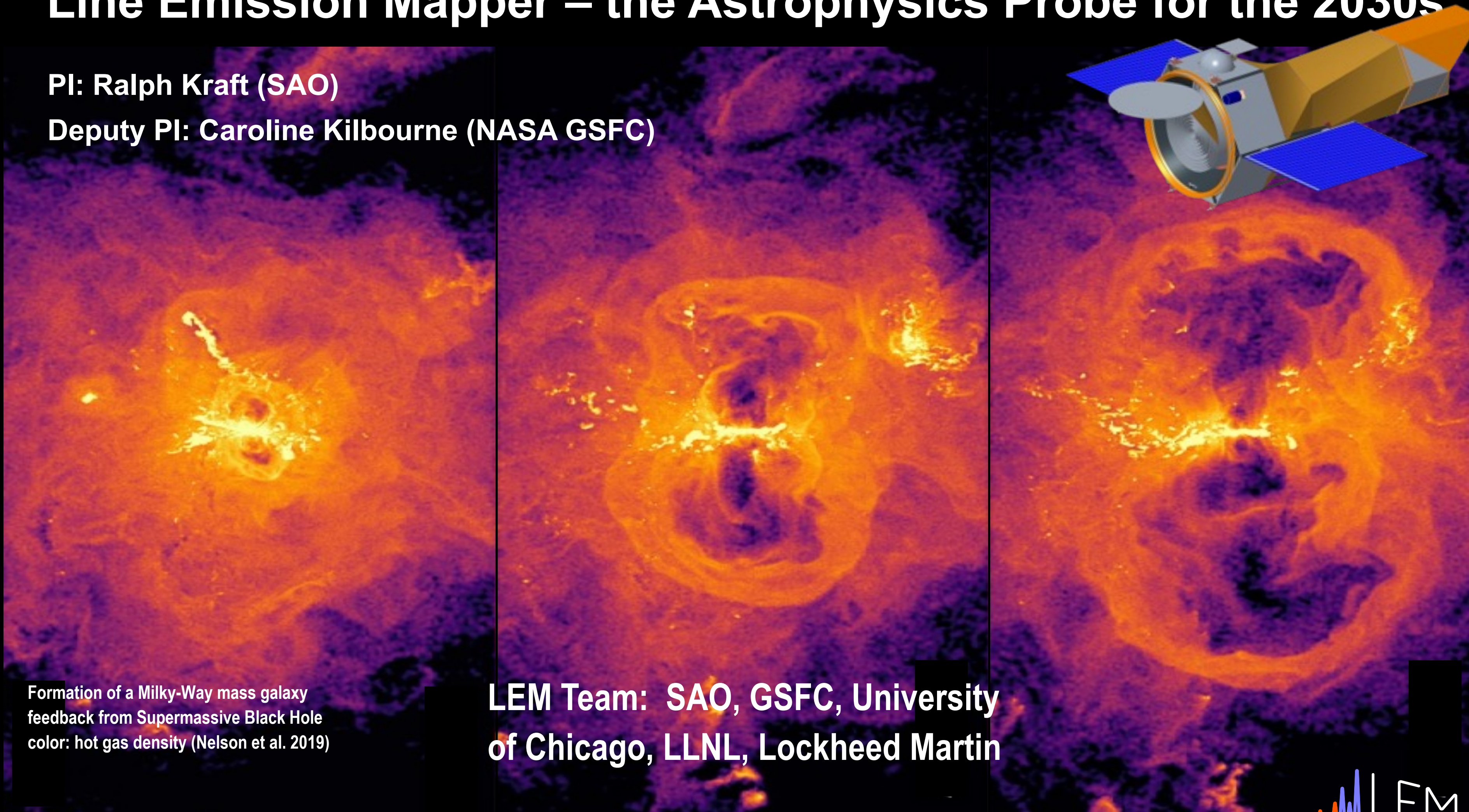
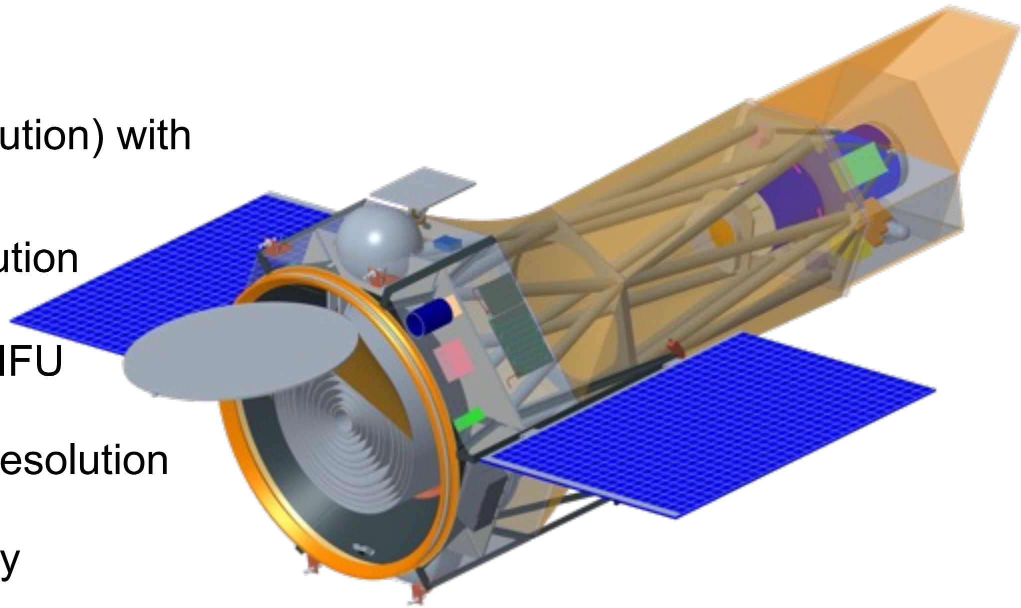


Formation of a Milky-Way mass galaxy feedback from Supermassive Black Hole color: hot gas density (Nelson et al. 2019)

LEM Team: SAO, GSFC, University of Chicago, LLNL, Lockheed Martin

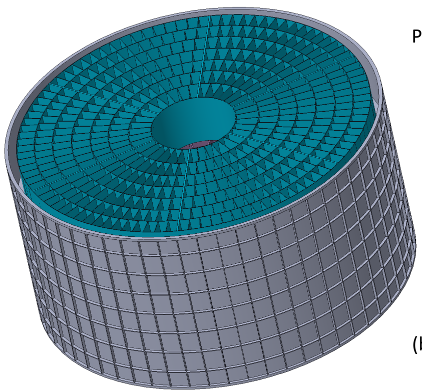
# LEM mission concept

- Designed to study faint, extended X-ray emission in 0.2–2 keV band with calorimeter spectral resolution – Cosmic Ecosystems
- Large-area Si-shell X-ray mirror (10" resolution) with X-ray microcalorimeter array covering 30'×30' FOV with 15" pixels, 1–2 eV resolution
  - 50× FOV, 20× grasp of newAthena XIFU
  - XMM-like imaging with 50× spectral resolution
- Deep pointed observations + all-sky survey
- **Opens enormous discovery space for Guest Observations in all areas of X-ray astrophysics**

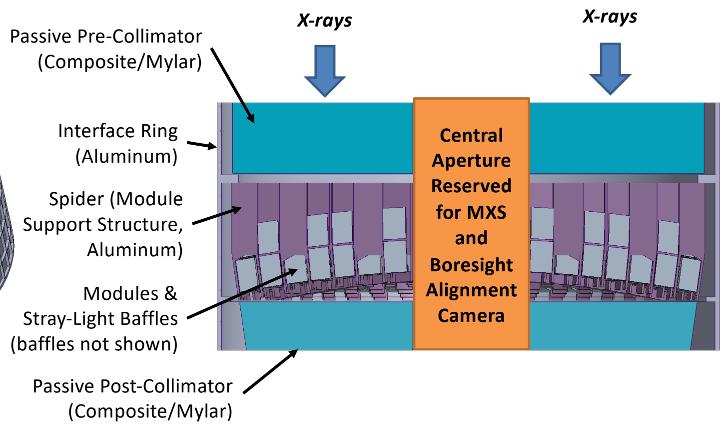


# LEM Technical Capabilities – the X-ray Optic

- Pt-coated Si thin-shell grazing-incidence mirror, d = 1.5m, f = 4m
- Require 10" HPD angular resolution
  - 2.7" HPD already demonstrated at 4.5 keV in the lab (Mar 2021) for single module
  - A 15” detector pixel contains 90% of the PSF
- Synergy with mirror development for STAR-X (as well as AXIS and HEX-P
  - **TRL 6 demonstration required as part of STAR-X phase A – the LEM optic is effectively undergoing a TRL 5 demonstration**

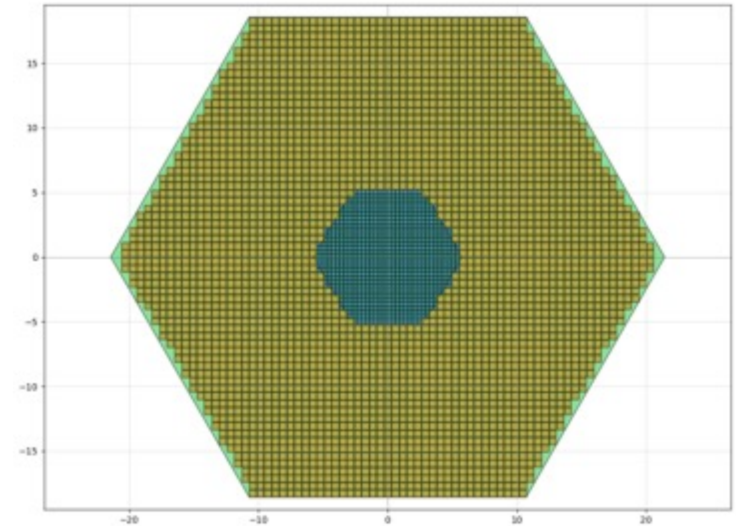


**LEM XMA CAD Model**

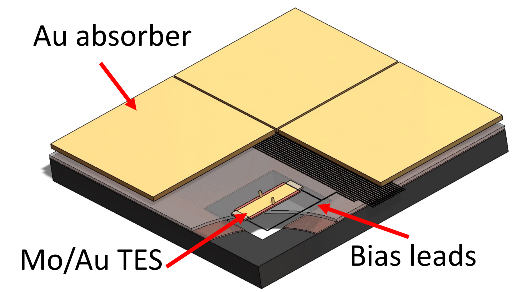


# LEM Microcalorimeter Spectrometer (LMS)

- Lockheed-Martin dewar and cryocoolers
- **GSFC detectors, focal-plane assembly, sub-50-mK cooler, aperture filters**
- Detectors based on Transition-Edge Sensor (TES) detectors being developed for Athena/X-IFU
  - Same basic sensor design, but lower $T_c$ and absorber composition optimized for <2 keV
  - 15” (0.29 mm) pitch
  - 7’ x 7’ square interior sub-array
    - 1 pixel / TES
    - 1 eV resolution
- outer array filling out to hexagonal perimeter - area equivalent to
  30’ x 30’ square
  - Hydras (4 pixels/TES) to provide more FOV/channel with same angular resolution - 2 eV resolution



LEM absorbers will be 0.64 μm Au



# LEM Capabilities and Science

***LEM provides transformative capabilities in all the science areas highlighted at this workshop***

- ✓ Supernovae and their Remnants
- ✓ Stars I/II/II
- ✓ Diffuse Gas and Emission
- ✓ Diffuse Gases and Absorption
- ✓ AGN I/II
- ✓ Compact Objects and Novae
- ✓ Compact Objects: Binaries
- ✓ Compact Objects: Winds

| | LEM | XRISM Resolve | ATHENA XIFU | HUBS |
|---|---|---|---|---|
| Energy band, keV | 0.2–2 | 0.4–12 | 0.2–12 | 0.2–2 |
| Effective area, $cm^2$ 0.5 keV | 1600 | 50 | 6000 | 500 |
| Effective area, $cm^2$ 6 keV | 0 | 300 | 2000 | 0 |
| Field of view | 30' | 3' | 5' | 60' |
| Grasp, $10^4$ $cm^2$ $arcmin^2$ | 140 | 0.05 | 12 | 180 |
| Angular resolution | 15" | 75" | 5" | 60" |
| Spectral resolution (FWHM) | 1 eV central 7x7'<br>2 eV rest of FOV | 7 eV | 3 eV | 2 eV |
| Detector size (equiv. pixels) | 118 x 118 | 6 x 6 | 50 x 50 | 60 x 60 |

Comparison of LEM and other **future** X-ray imaging spectrometers XRISM Resolve, Athena XIFU (pre-reformulation), and the notional Chinese HUBS mission

(There are no past or present imaging spectrometers to compare to)

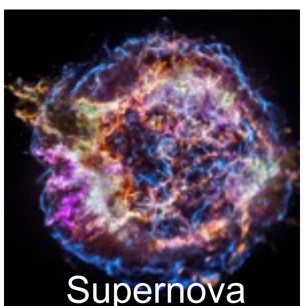
# LEM Science: Understanding Cosmic Ecosystems

LINE EMISSION MAPPER

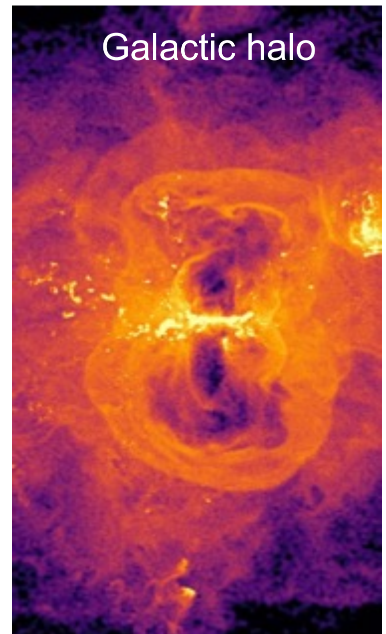
## LEM will transform our understanding of formation of cosmic structure over 7 orders of magnitude in linear scale (from pc to tens of Mpc)

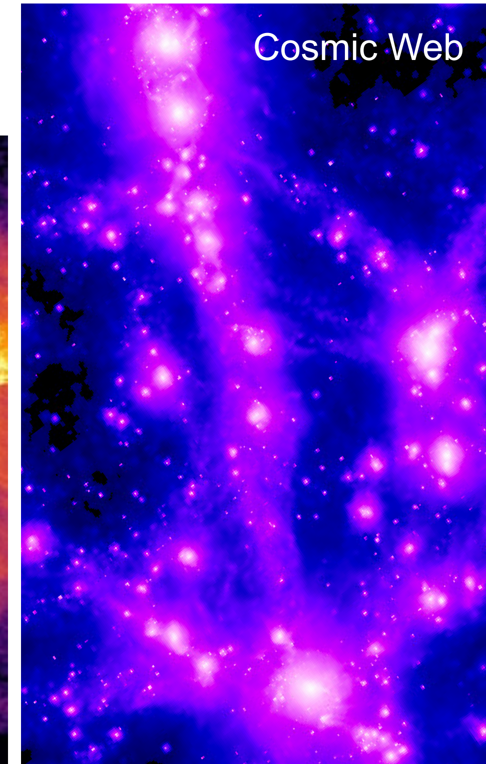
- **Map** galactic gas halos – "key missing link" in our understanding of galaxy formation
- **Map** metals in the Cosmic Web to probe history of galactic feedback
- **Map** effects of stellar feedback on galaxies: supernova remnants, superbubbles, galactic winds

***See talks by I. Zhuravleva, A. Ogorzalek, and J. Zuhone***





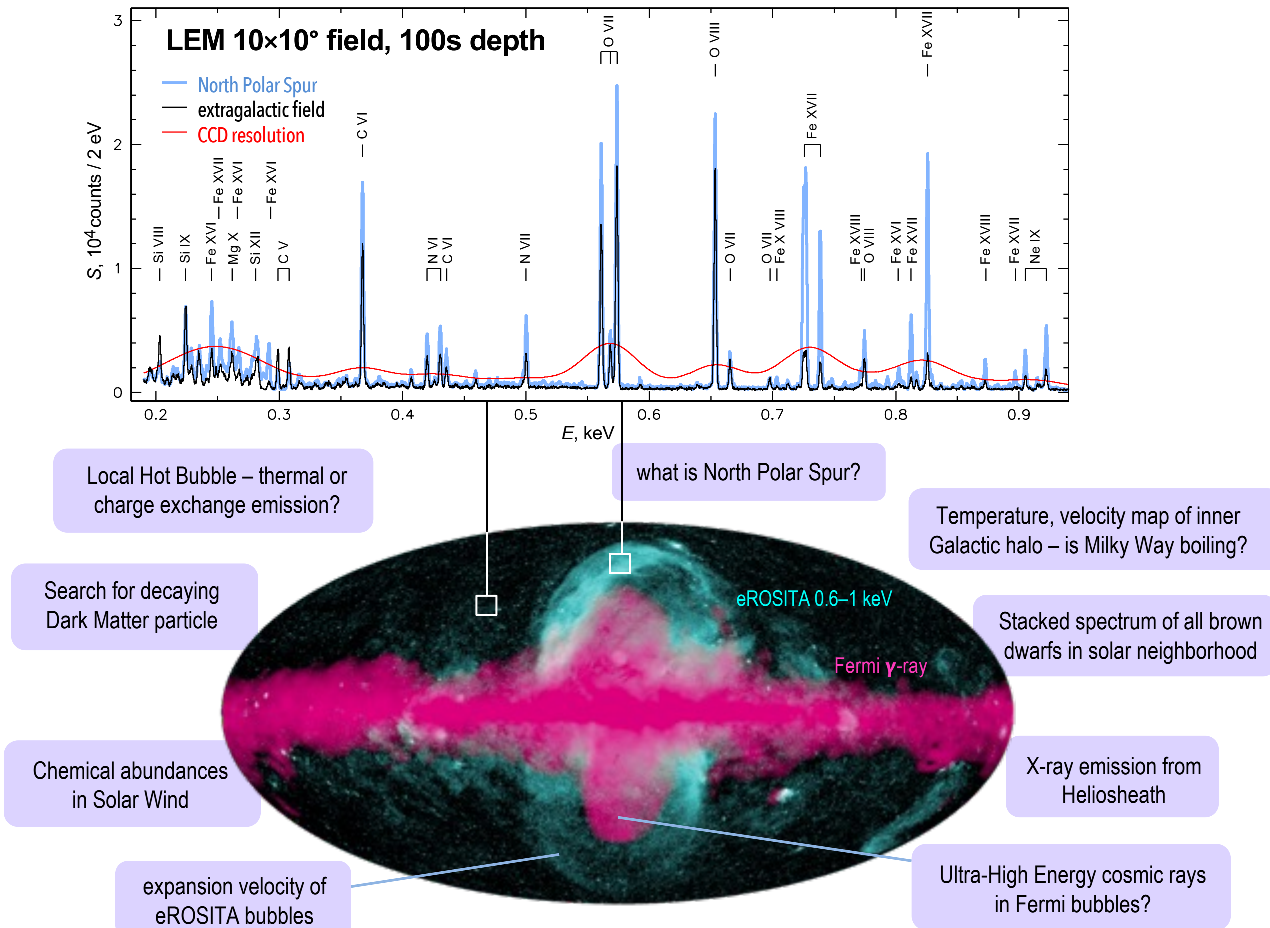




100 | 1,000 | 100,000 | 1,000,000 | 10,000,000

Size, light years

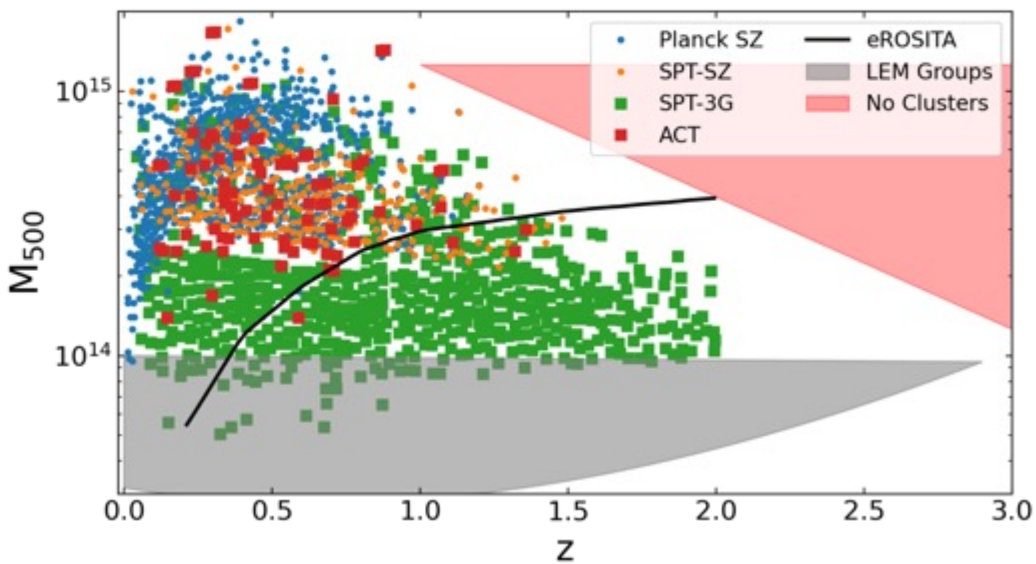
# Shallow All-Sky Survey

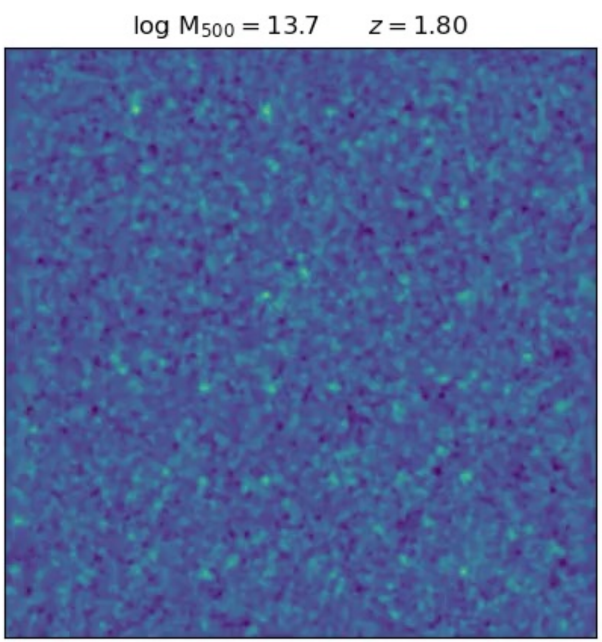



- First-ever calorimetric survey of the whole sky – **enormous discovery space**
- Uniquely detailed perspective on the physics of galactic feedback – a view from inside a Milky Way mass galaxy!
- **Because we can** – LEM has the grasp
- Spend 10% of total mission lifetime on survey (uniform 100 s depth), in several snap-scans over 5 years

# LEM serendipitous science with an imaging calorimeter

- Thousands of AGN, dozens of galaxy clusters and groups in every 30'×30' LEM field – some at very high z
- Example: search for high-z galaxy clusters using matched filtering in energy space (using the known thermal plasma line energies):

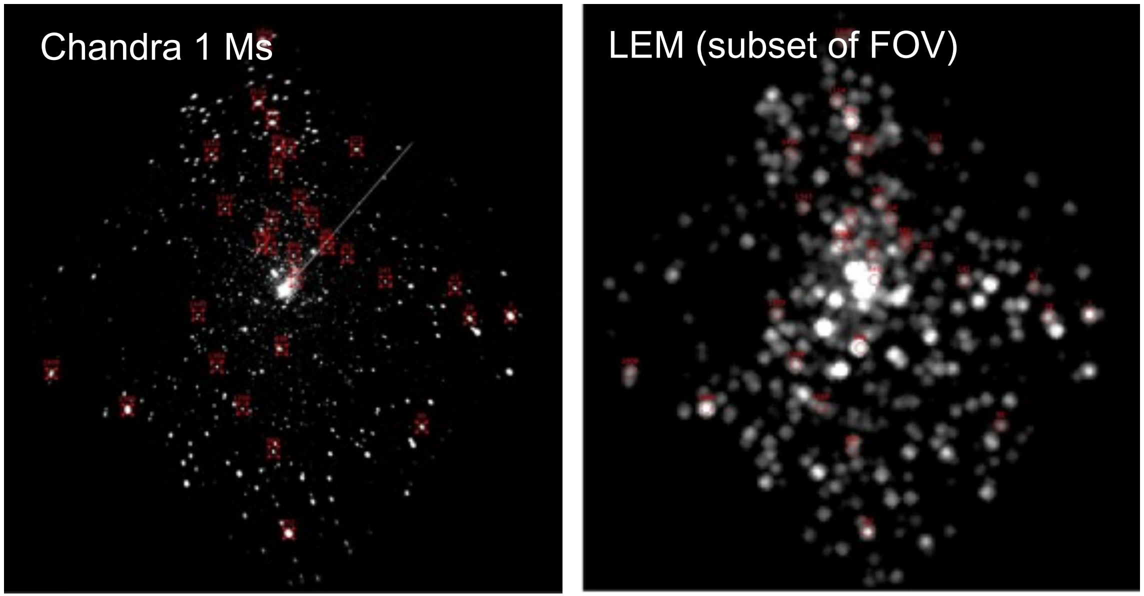


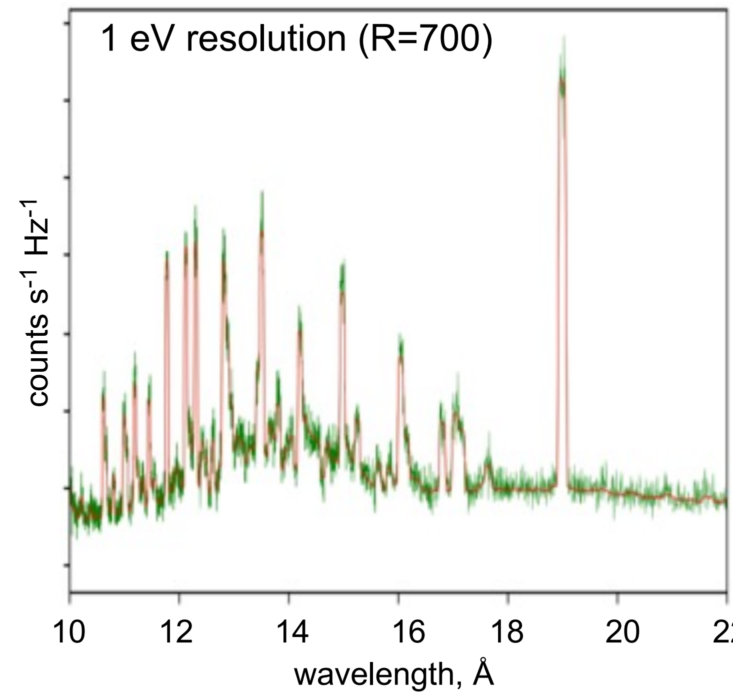

Courtesy: G. Schellenberger

# LEM view of planet-forming stars

## Orion nebula



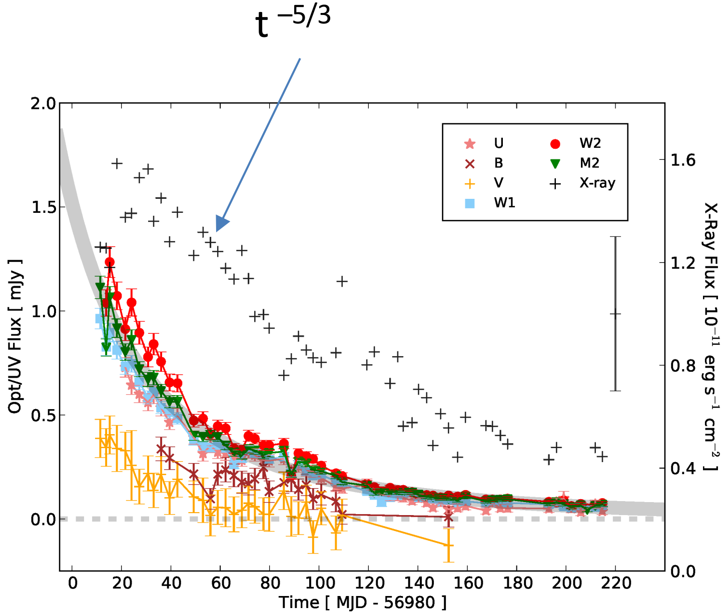

LEM spectrum of a flaring star COUP 7




- time-resolved spectroscopy with 20-100× effective area of Chandra LETG/HETG

Courtesy: J. Drake

# LEM Time Domain Science - TDEs




Example: ASASSN14li

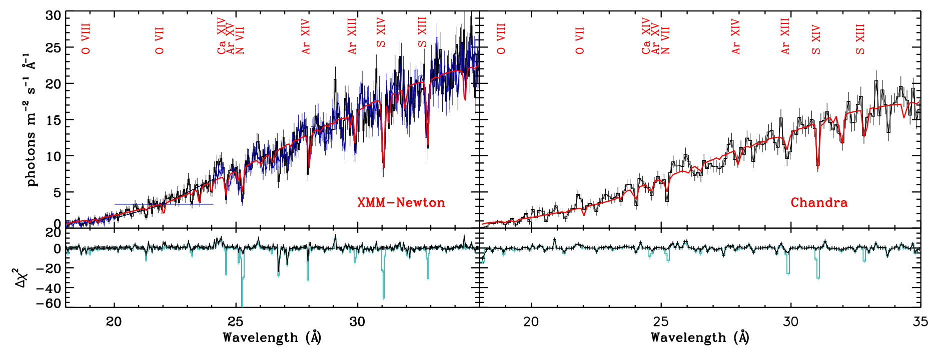



**Figure 2** | **The high-resolution X-ray spectra of ASASSN-14li reveal blue-shifted absorption lines.** Spectra from the long stare with *XMM-Newton* and the combined *Chandra* spectrum are shown. *XMM-Newton* spectra from the RGS1 and RGS2 units are shown in black and blue, respectively; the RGS2 unit is missing a detector in the 20–24Å band. The best-fit photoionized absorption model for the outflowing gas detected in each spectrum is shown in red (see *Methods*), and selected strong lines are indicated. Below each spectrum, the goodness-of-fit statistic ($\Delta\chi^2$) is shown before (cyan) and after (black) modeling the absorbing gas.

Figures from Miller et al. 2015

- Hundreds of TDEs per year will be detected by ground-based methods, many expected to be X-ray bright for months to years
- Follow-up of these and other nuclear transients can probe powerful winds
- Example: TDE ASASSN14li was one of the brightest and best-studied TDEs

Courtesy: J. Steiner

# Why THE excitement about LEM?

LEM team outside Phillips Auditorium in Cambridge, MA during First LEM Science Workshop – Feb 2023

- LEM science directly responsive to Decadal
  - Paradigm-changing in area of Cosmic Ecosystems
  - Powerful new capabilities for GO investigations in all areas of astrophysics
- The mission enabling technologies are ready after decades of investment
- The required mission architecture is implementable at $1B
- LEM capabilities span the astrophysics community
- LEM will have great synergies with other facilities in the 2030s
- LEM team working hard to finish proposal!