Feryal Ozel, co-chair of *Lynx* STDT
University of Arizona

New Frontiers in Astronomy

What are the critical science questions across astrophysics to be addressed in the following decades?

New Record Breaking Quasars

J1342+0928; z=7.54; 800 million $M_\odot$!

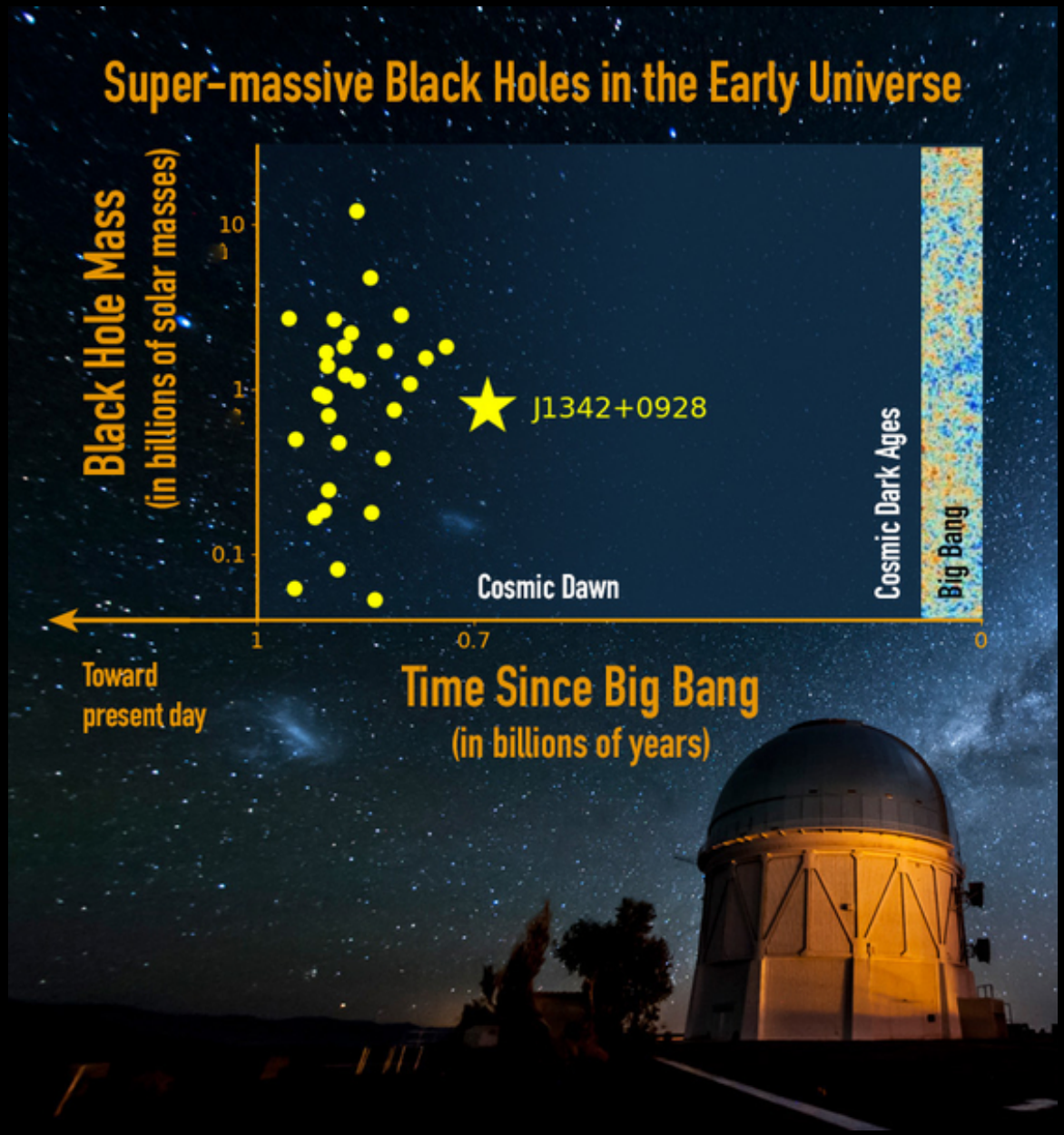


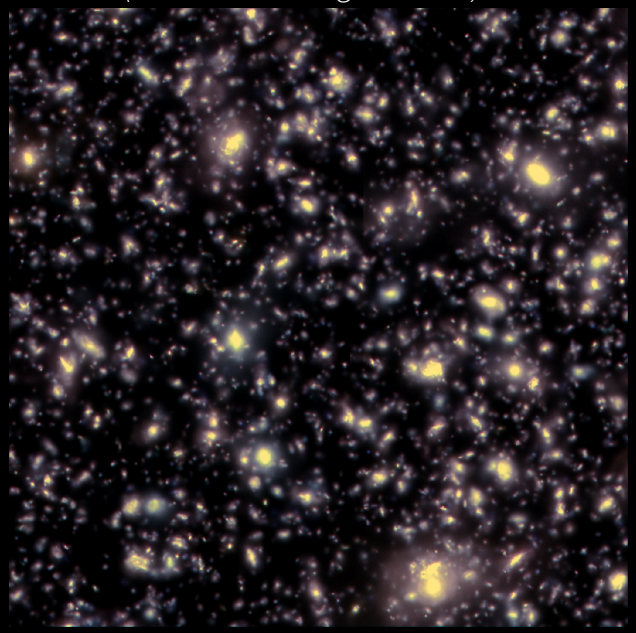
Image credit: Jinyi Yang/UA; Reidar Hahn/Fermilab; M. Newhouse/NOAO/AURA/NSF

Bañados et al. 2017, Nature

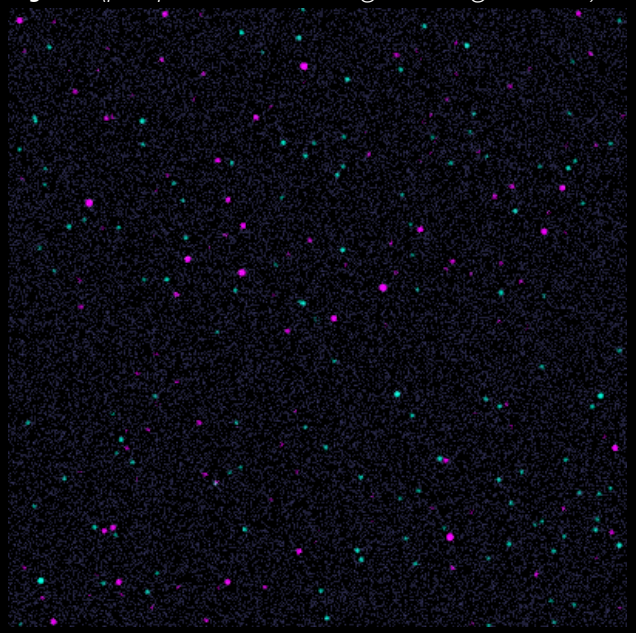
The Dawn of Black Holes

Simulated 2'×2' deep fields:

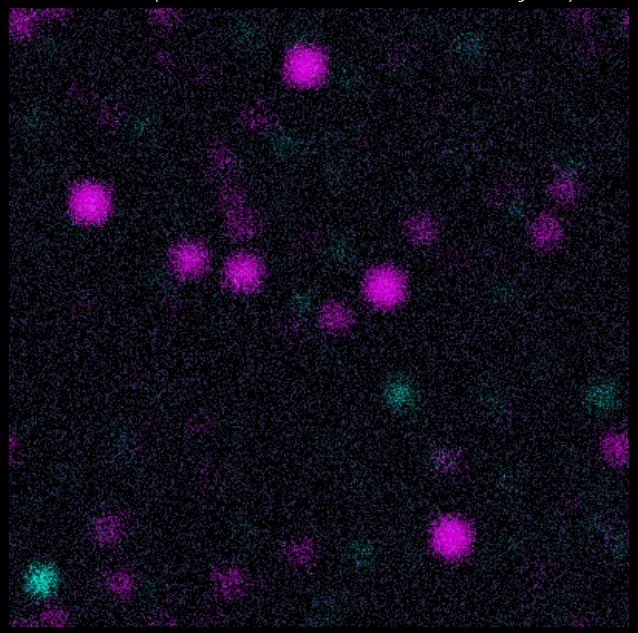
JWST *(Illustris-TNG light cone)*



Lynx *(purple = AGNs, green=galaxies)*



Athena *(5" PSF, same area as Lynx)*



We need to **find the first supermassive black holes** in the first galaxies detected by JWST, **trace their growth** from the seed phase, and shed light on how they **shape their host galaxies**.

<u>Required sensitivities:</u> $F_X=10^{-19}$ erg/s/cm^2

~ 200× below *ATHENA* confusion limit.

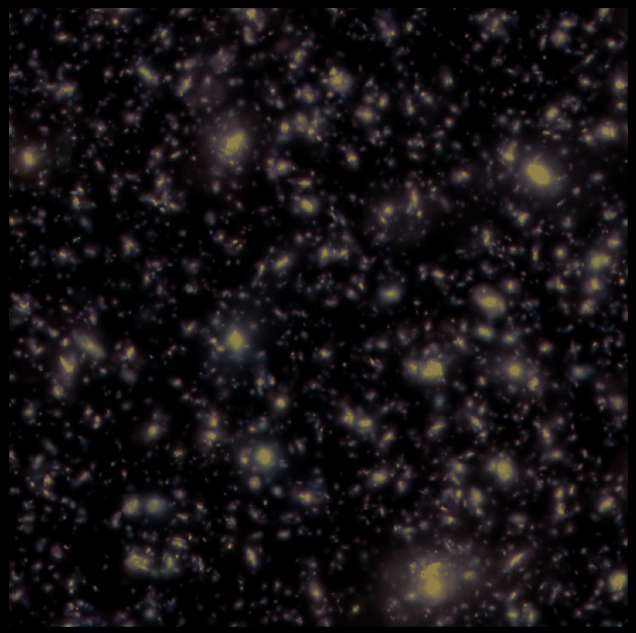
<u>Required observations:</u> Wedding cake surveys

1-4 Ms deep fields to cover ~ 1 square degree

The Dawn of Black Holes

Simulated 2'×2' deep fields:

JWST (Illustris-TNG light cone)



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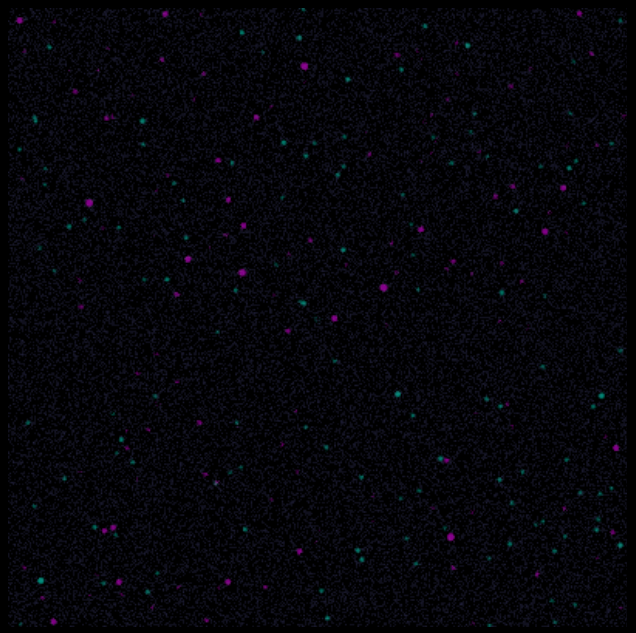

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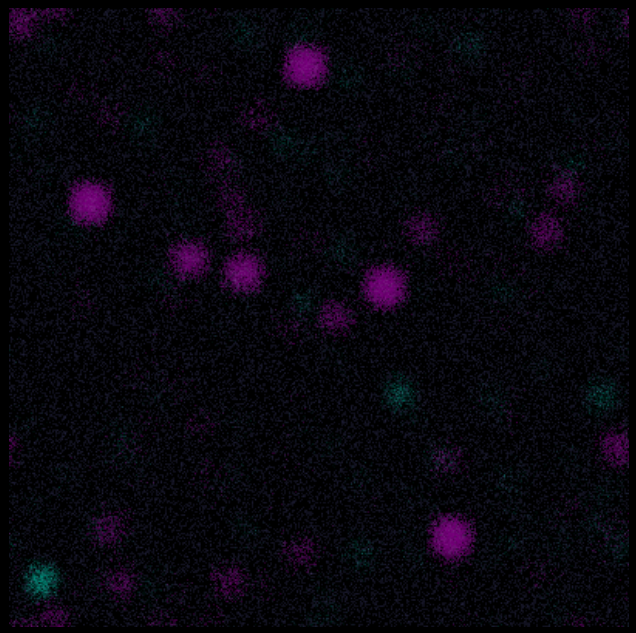
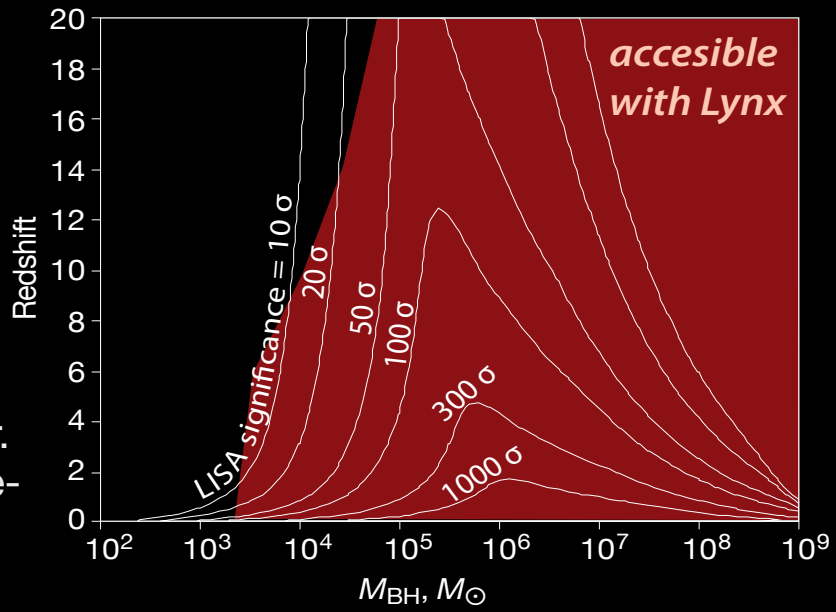


Synergies with gravitational wave experiments:

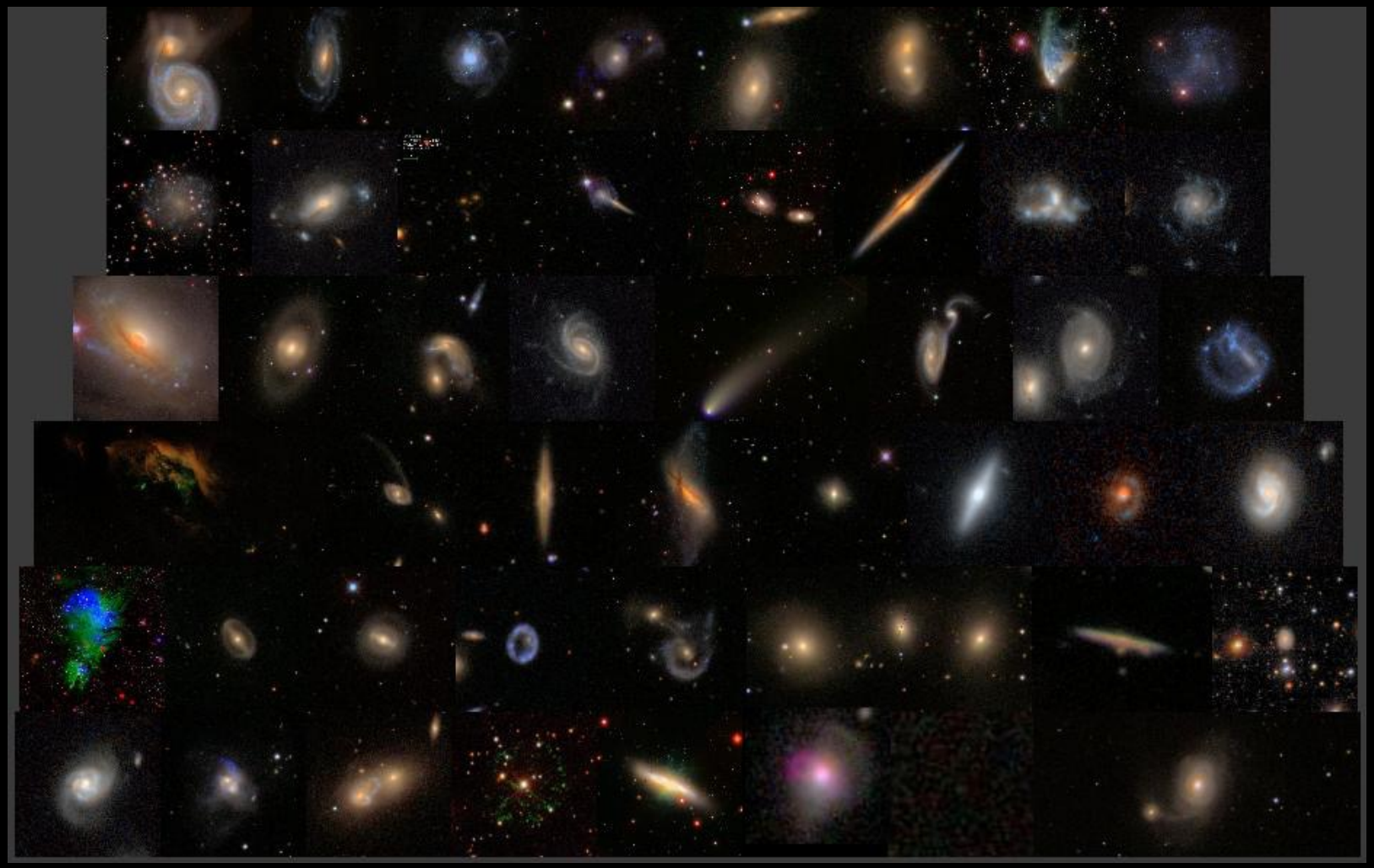
- Similar parameter space is covered at high-z.
- *Lynx* is sensitive to black hole growth through accretion (dominant mode).
- *Lynx* can respond to high-significance LISA triggers of SMBH mergers at z<2, localized to 1–10 deg^2 days before the merger. *Lynx* observations will establish how accretion proceeds in pre-merger BH binaries.



Advances in Galaxy Formation

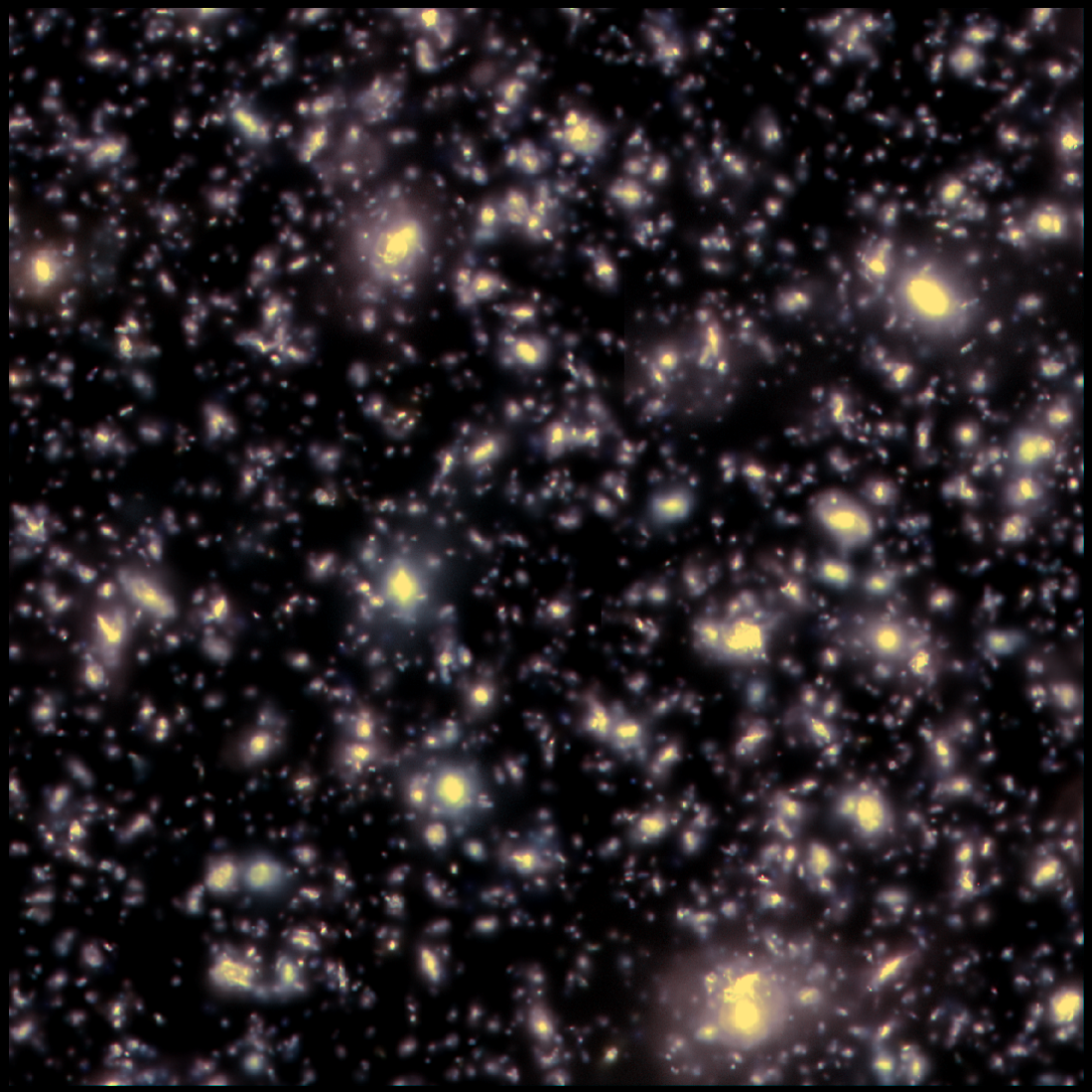
SDSS: Clustering properties and metallicities
Galaxy Zoo: Morphologies
HUDF, Frontier Fields: High-z frontier

Composite image from Galaxy Zoo

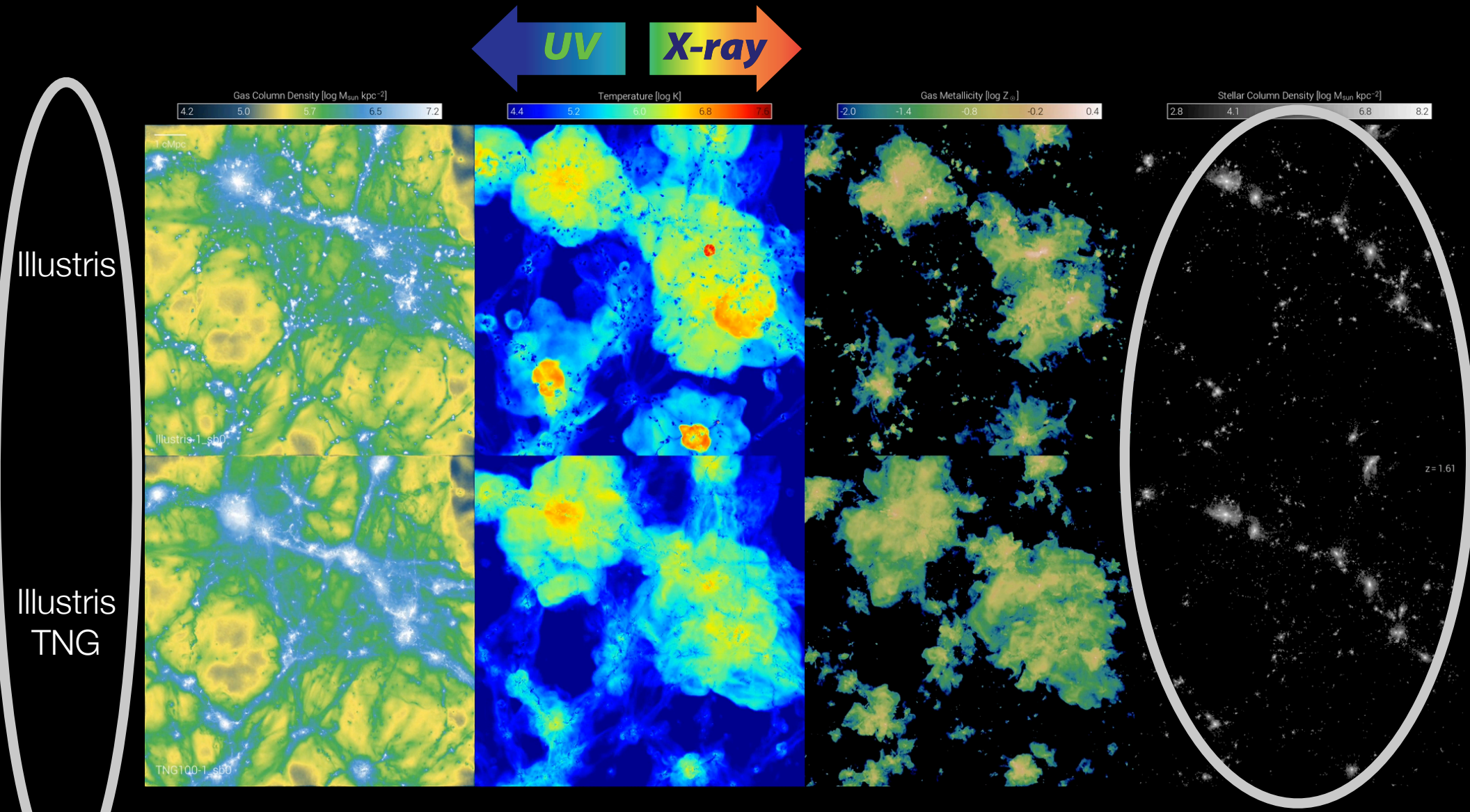


Advances in Galaxy Formation: JWST

Simulated 2’×2’ deep fields:
JWST (Illustris-TNG light cone)



The Invisible Drivers of Galaxy and Structure Formation

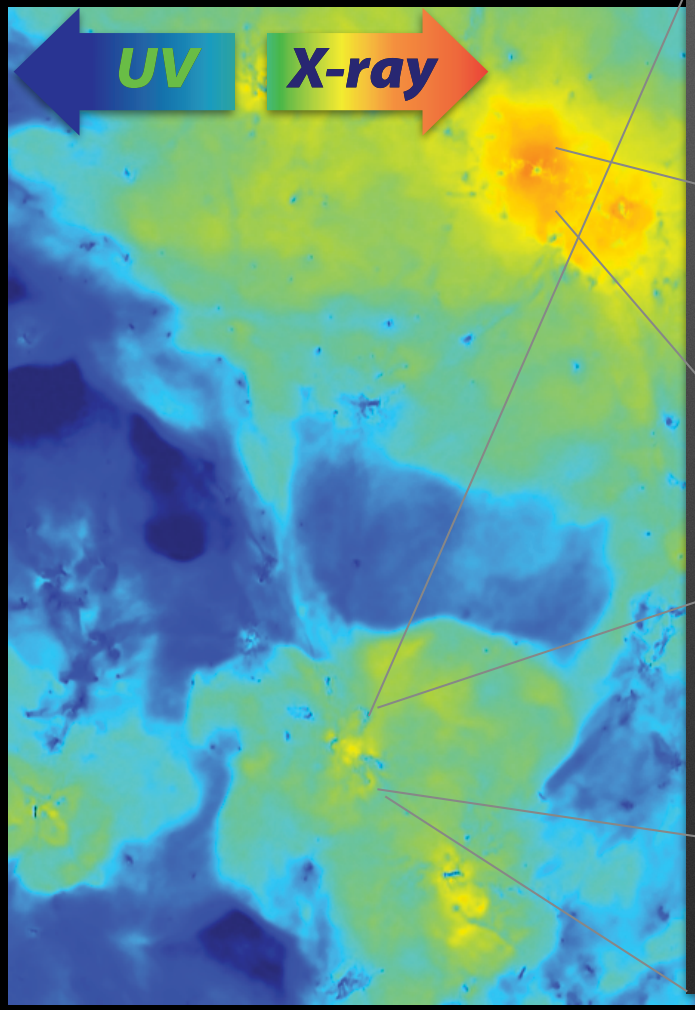


ρ_{gas} T_{gas} Metals Galaxies: stellar mass

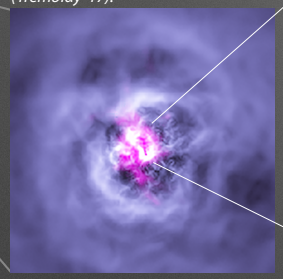
Same numerics, different physics

Indistinguishable galaxies

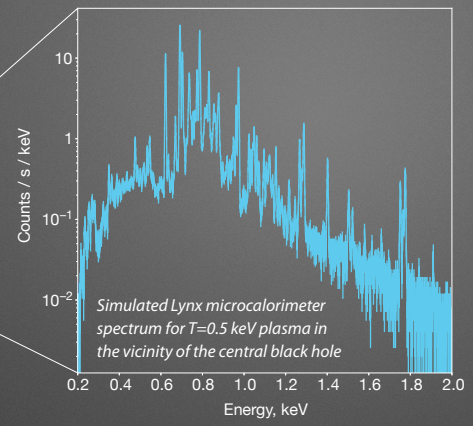
The Invisible Drivers of Galaxy and Structure Formation



Feedback

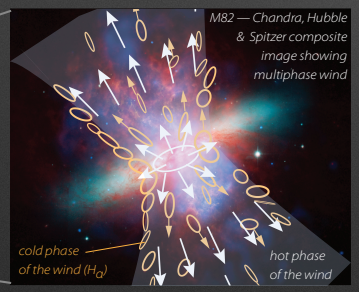


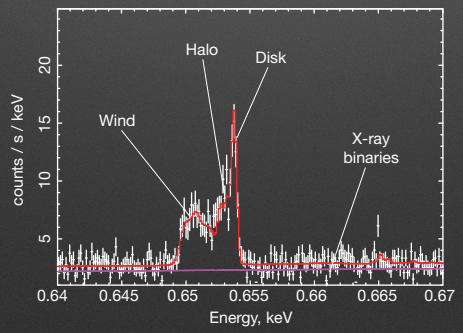
A2597 cluster — Chandra/X-ray (blue) and VLT-MUSE/H_α (purple) overlay (Tremblay '17).



BH feedback:

- *spectro-imaging of SMBH spheres of influence*
- *density diagnostics in AGN winds*
- *extended narrow emission line regions*
- *AGN-inflated bubbles in elliptical galaxies*
- *plasma physics*

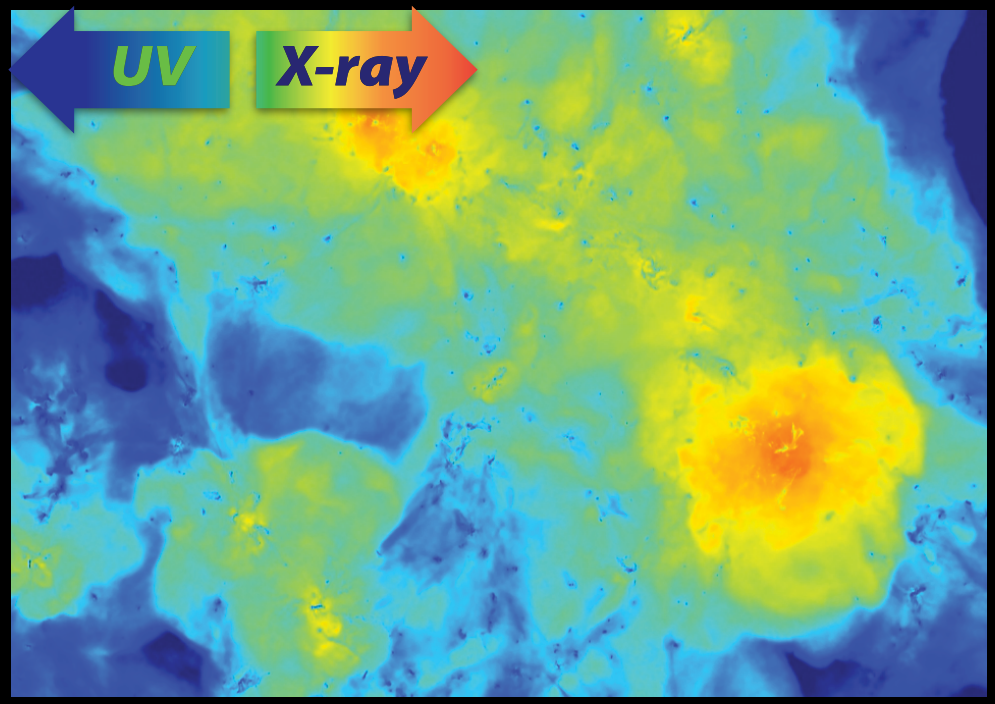




Galactic winds feedback:

- *Spatially and spectrally resolve hot phase of galactic winds with 0.3 eV energy resolution microcalorimeter subarray*

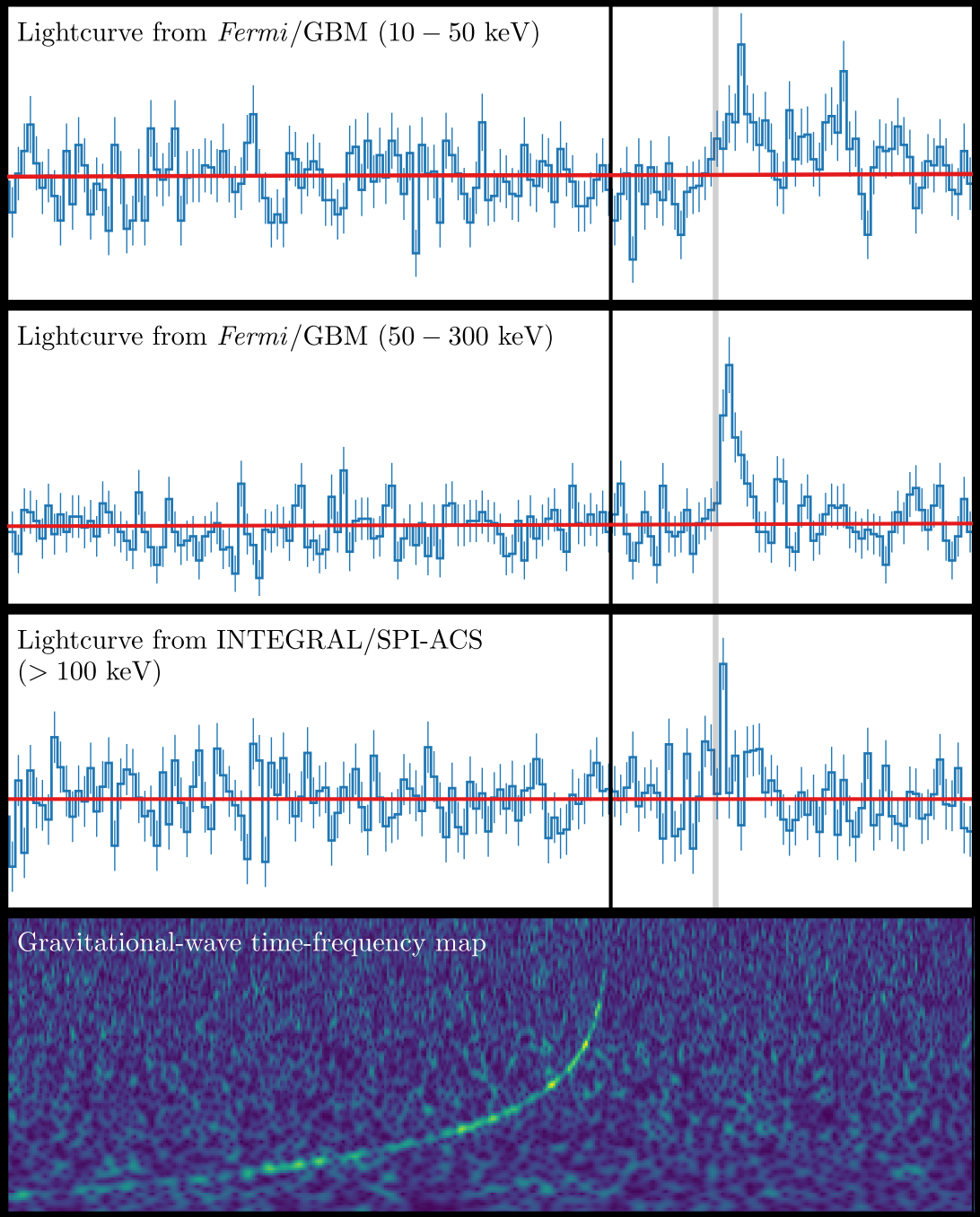
The Invisible Drivers of Galaxy and Structure Formation



<u>Required capabilities and observations:</u>

- Detecting and mapping low surface brightness continuum emission
- R ~ 2000 spectroscopy of extended sources on arcsecond scales
- High-resolution spectroscopy (R ~ 5000) of background AGN

New Frontier: Multi-messenger Events



GW170817; Abbott et al. 2017

New Frontier: Habitable Planets

Seven planets of TRAPPIST-1

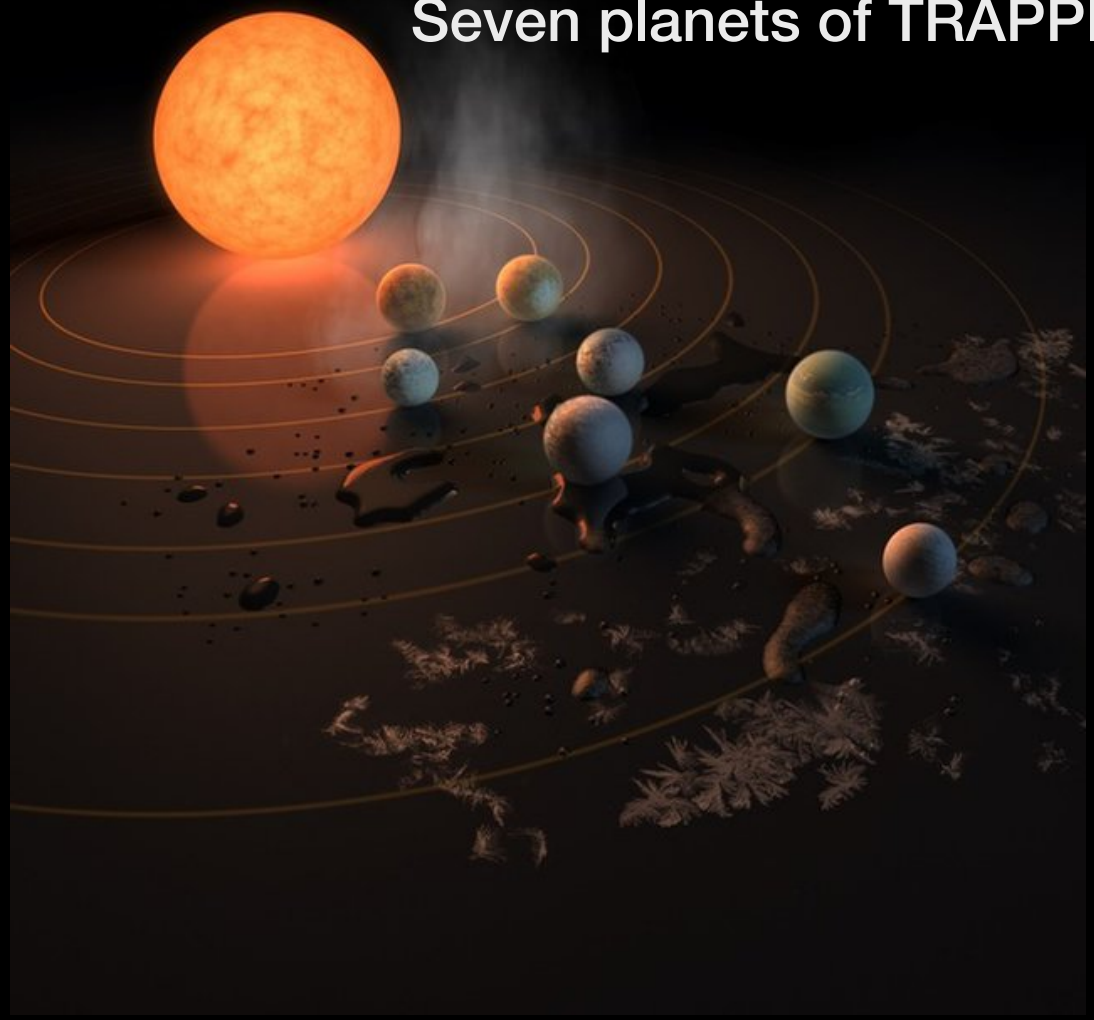
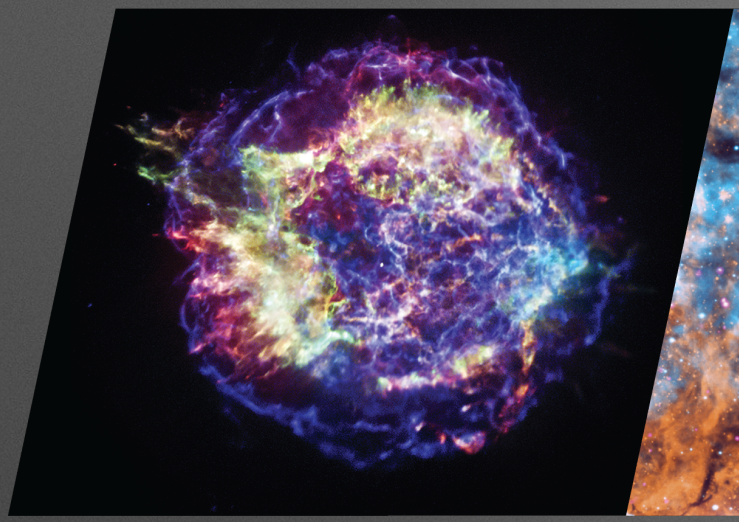


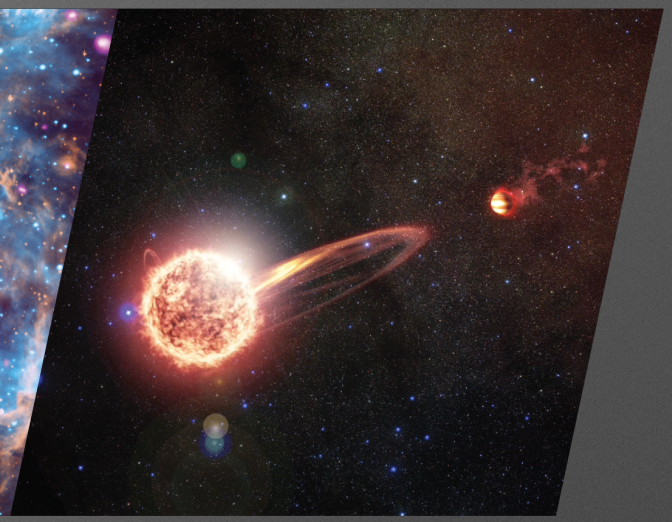
Image credit: NASA and JPL/Caltech

The Energetic Side of Stellar Evolution and Stellar Ecosystems



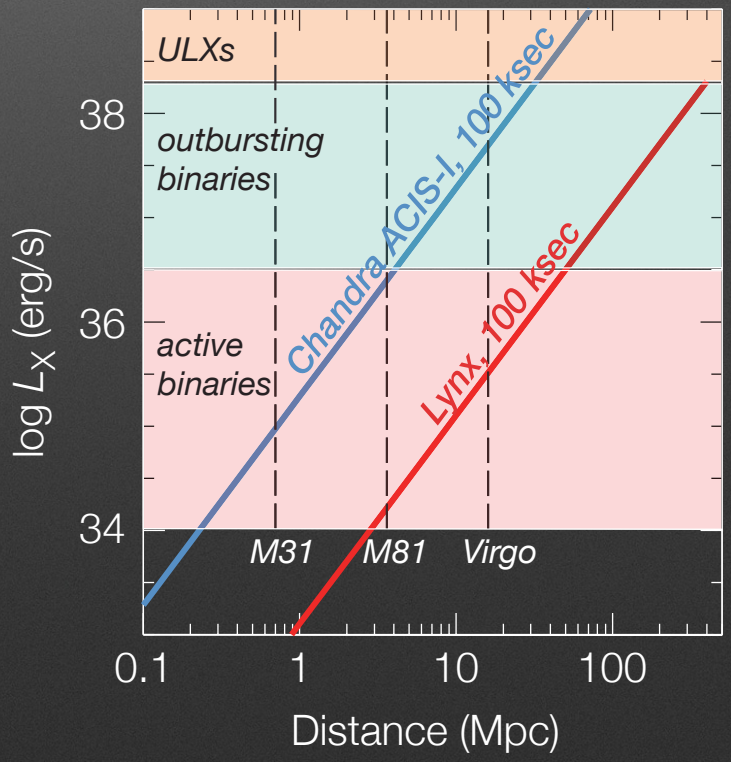
Endpoints of stellar evolution

Stellar birth, coronal physics, feedback



Impact of stellar activity on habitability of planets

- 3D maps of dozens of SNRs, revealing explosion physics, understand how metallicity effects explosions.
- Pin down binary evolution and understand the evolutionary paths to LIGO sources.



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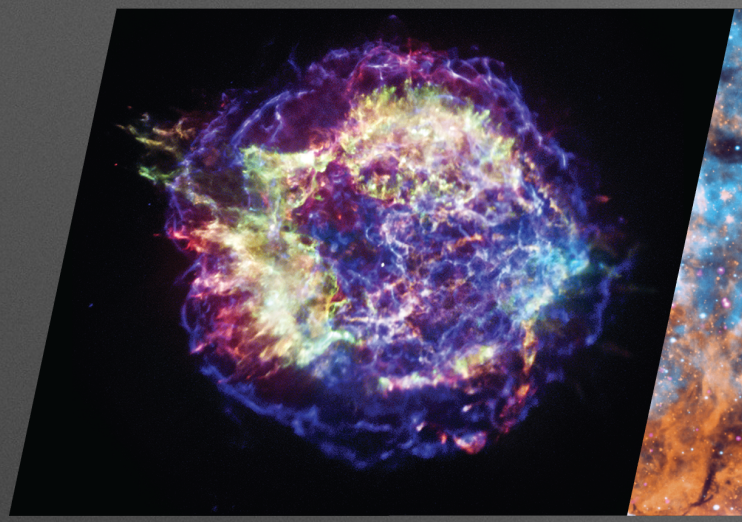
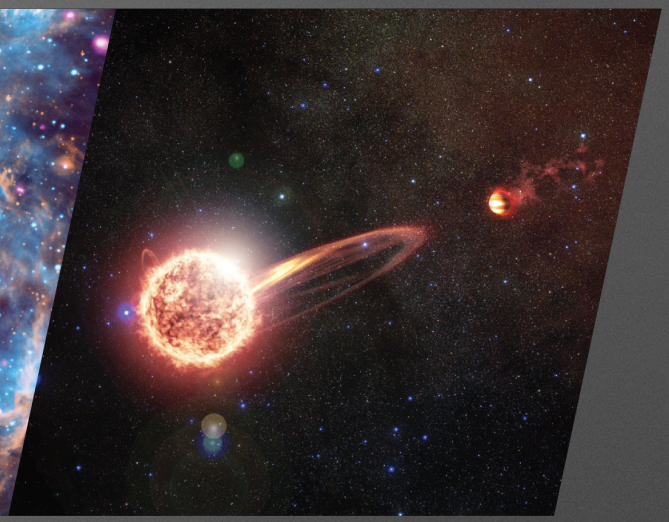


Endpoints of stellar evolution

Stellar birth, *coronal physics,* ***feedback***



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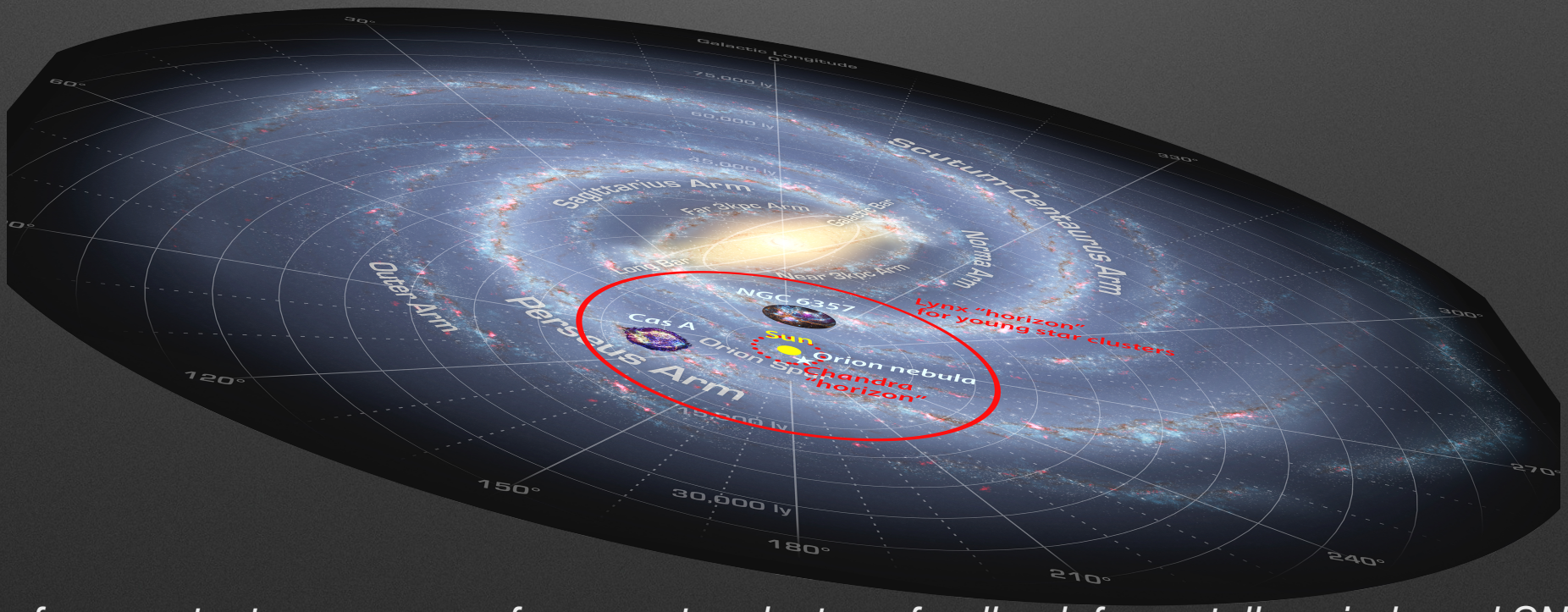


X-rays from protostars; census of young star clusters; feedback from stellar winds and SNe.

The Energetic Side of Stellar Evolution and Stellar Ecosystems

Endpoints of stellar evolution

Stellar birth, ***coronal physics****, feedback*

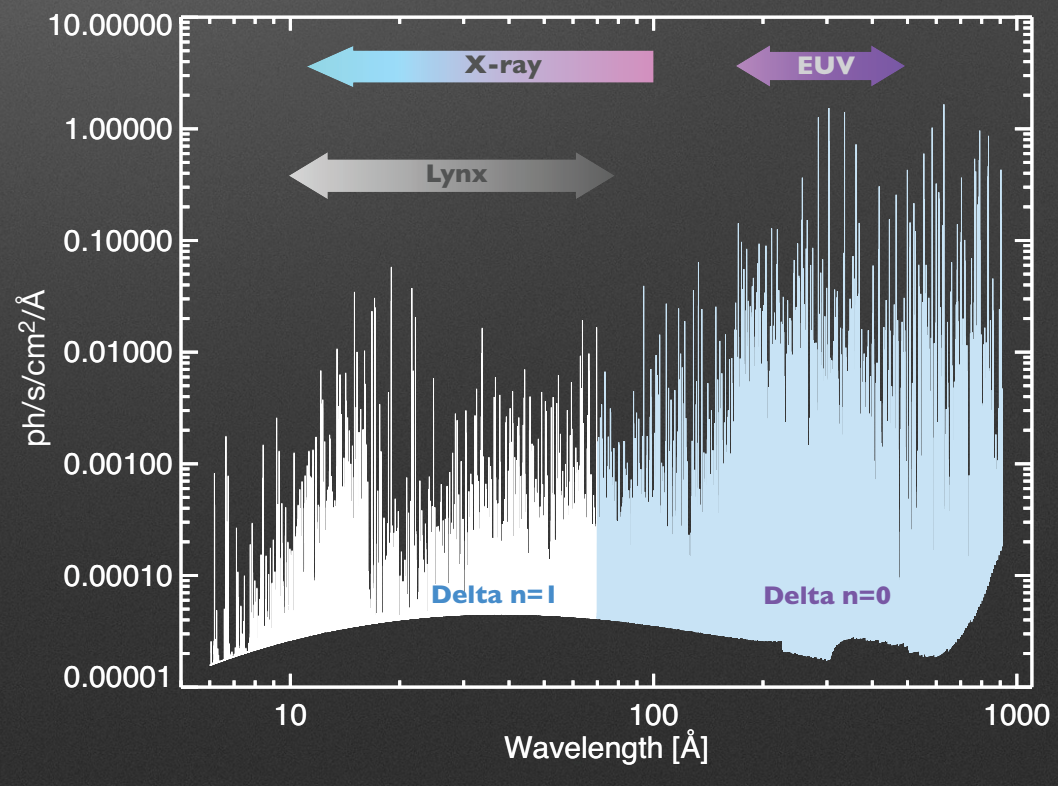
Impact of stellar activity on habitability of planets

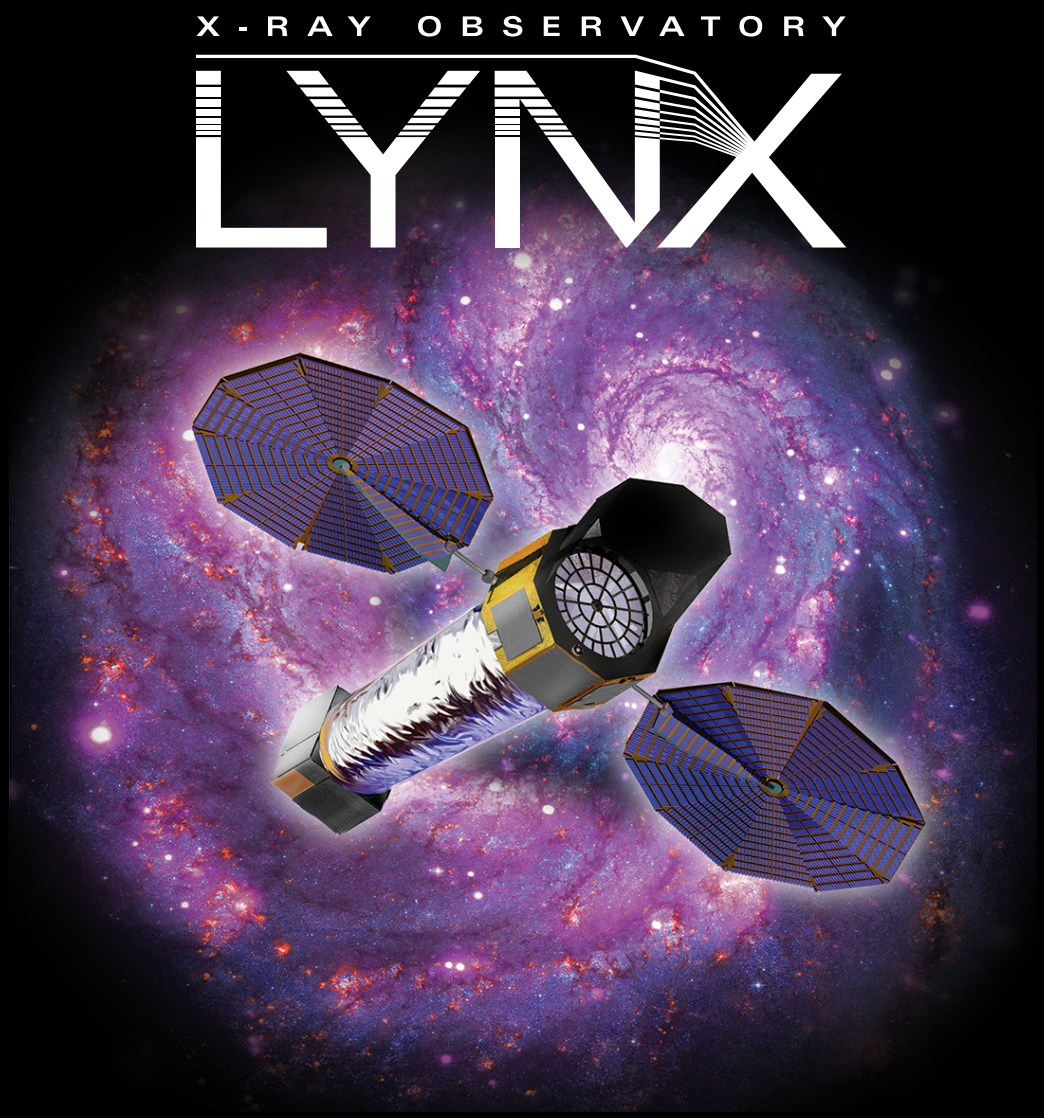
Grating observations to resolve triplet, satellite, and dielectric recombination lines from C, N, O, Ne, Mg, Fe (K, L, and M-shells) in stellar coronae.

First precise diagnostics of T, n_e, velocities, and sizes of emission regions in stellar coronal structures.

Reaching the Orion Nebula for detailed studies of stellar coronae, covering the full range of stellar types and ages.

Model X-ray to EUV spectrum of Proxima Cen.



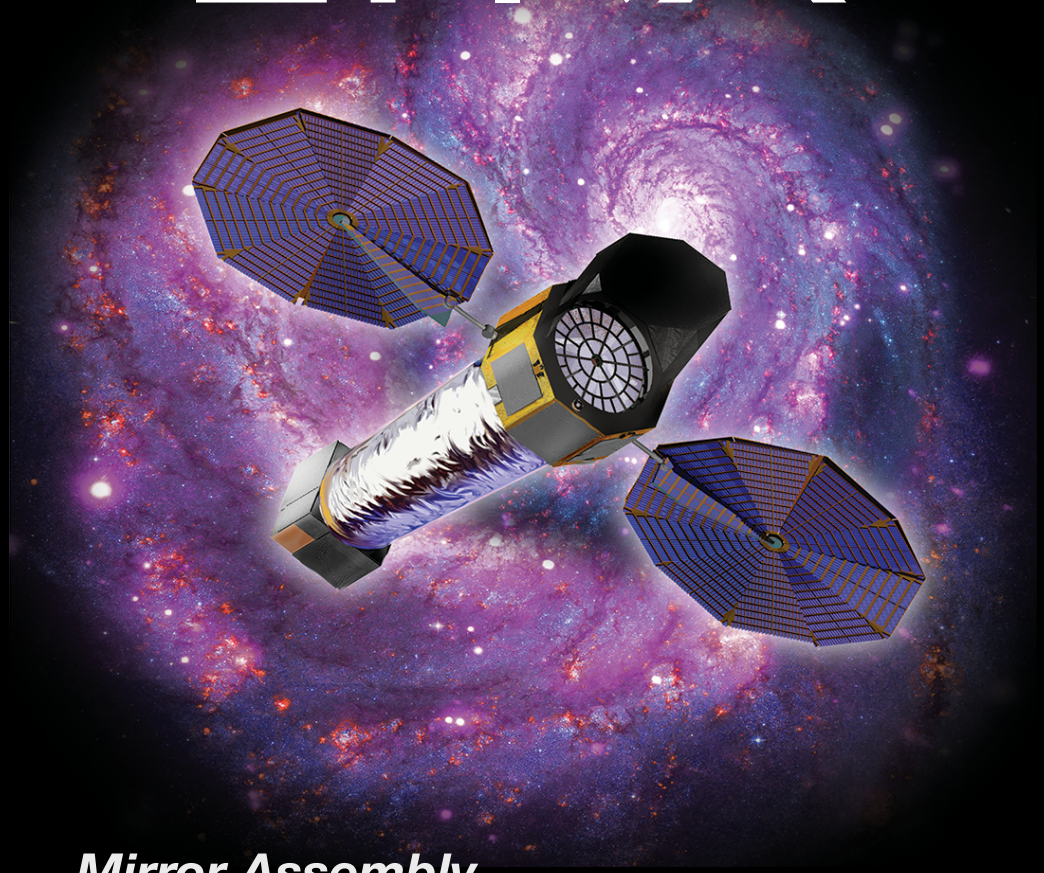


These science pillars require a mission like *Lynx*, with leaps in capability over *Chandra* and *ATHENA*:

- 50× increase in sensitivity achieved by coupling superb angular resolution with high throughput;
- 16× larger field of view for sub-arcsecond imaging, leading to a 800× faster survey speed;
- 10–20× higher spectral resolution for both point-like and extended sources.

X-RAY OBSERVATORY

LYNX



High-definition X-ray imager

- Silicon sensors with ~0.3″ pixels, closely following the optimal focal surface. FOV ≥ 20′×20′.
- $\Delta E \sim 100$ eV over 0.1–10 keV band.
- High frame rates to minimize pile-up.

X-ray microcalorimeter

- Main array for non-dispersive spectroscopy with $\Delta E < 3$ eV over the 0.2–7 keV band and imaging with 1″ pixels over a 5′×5′ FOV.
- Subarrays are optimized for sub-arcsec imaging or 0.3 eV energy resolution

Mirror Assembly

- Densely packed, thin, grazing incidence mirrors.
- Outer diameter of 3m and effective area > 2 m^2 at 1 keV.
- 0.5″ on-axis PSF (50% power diameter).
- Sub-arcsec PSF out to 10′ off-axis.

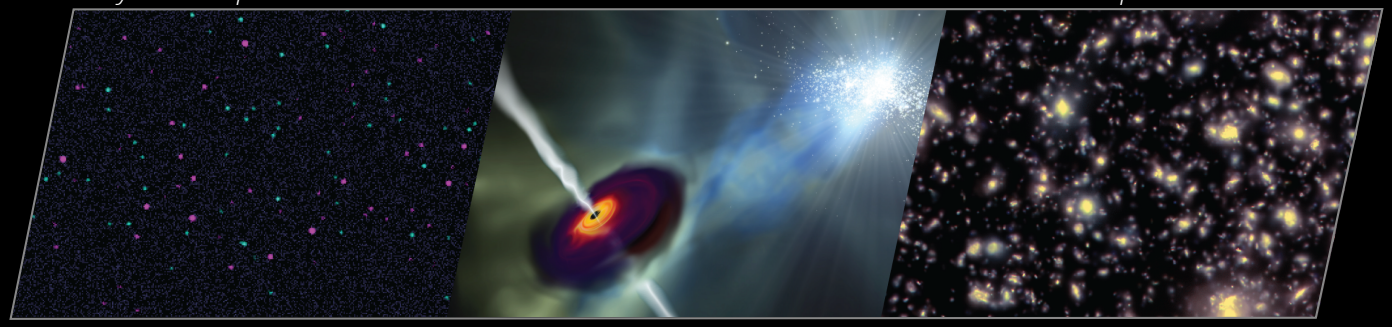
X-ray grating spectrometer

- Resolving power $\lambda/\Delta\lambda > 5000$
- Effective area > 4000 cm^2 covering X-ray emission and absorption lines of C, O, Mg, Ne, and Fe-L.

X-RAY OBSERVATORY

LYNX

The Dawn of Black Holes



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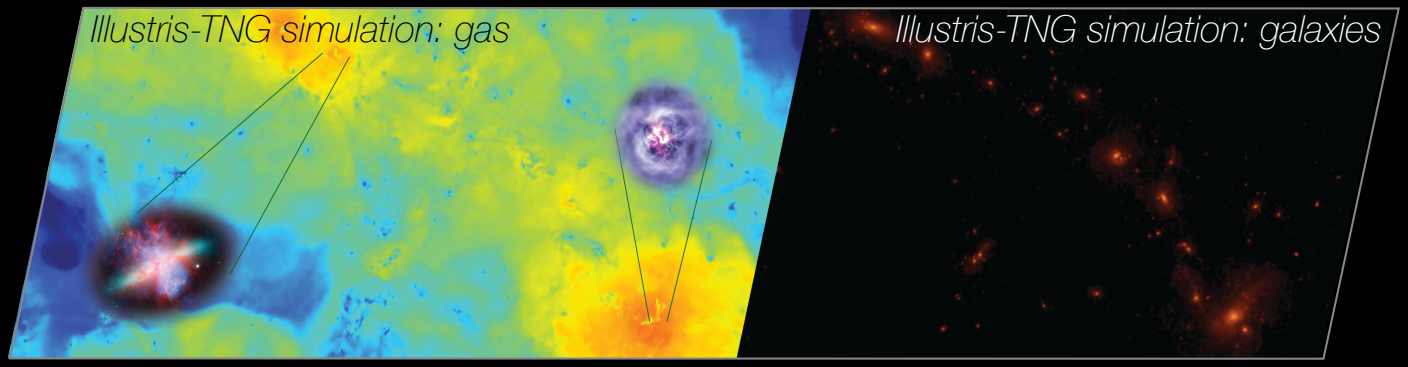

The Energetic Side of Stellar Evolution and Stellar Ecosystems

Endpoints of stellar evolution

Stellar birth, coronal physics, feedback

Impact of stellar activity on habitability of planets

- to see ***the dawn of black holes***,
- reveal ***what drives galaxy formation and evolution***, and
- unveil ***the energetic side of stellar evolution and stellar ecosystems.***