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

New Frontiers in Astronomy

What are the most important high energy astrophysics questions in the 2020's?

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 Msun!

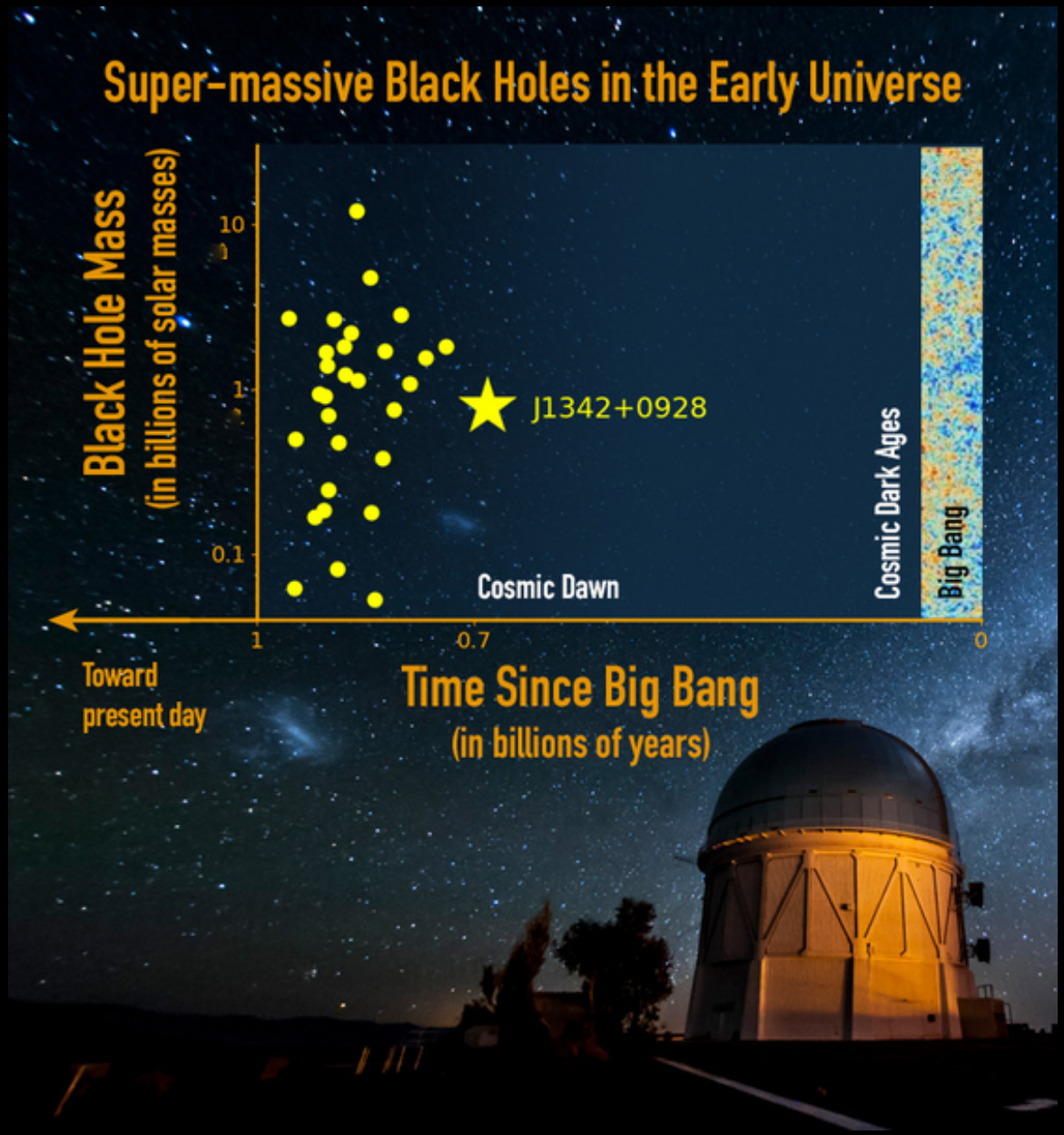


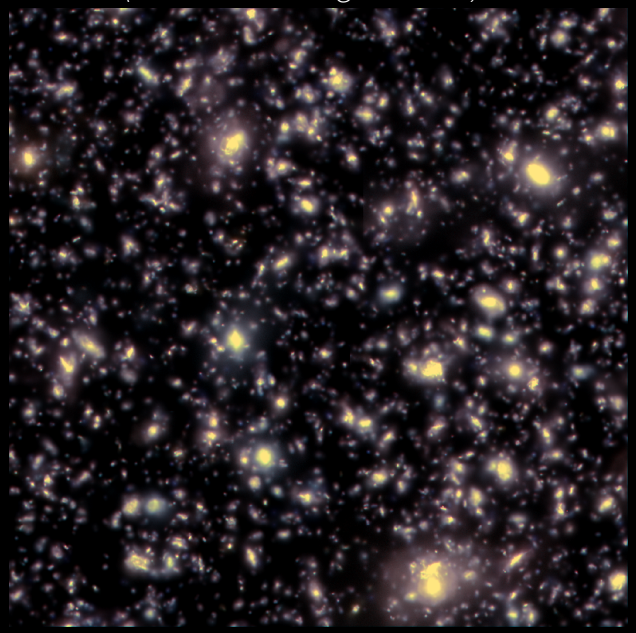
Image credit: Jinyi Yang/UA; Reidar Hahn/Fermilab; M. Newhouse/NOAO/AURA/NSF

Bañados et al. 2017, Nature

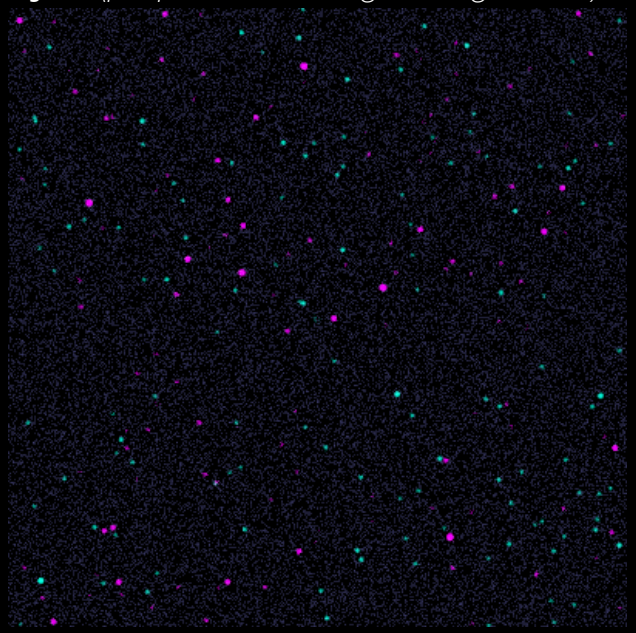
The Dawn of Black Holes

Simulated 2'×2' deep fields:

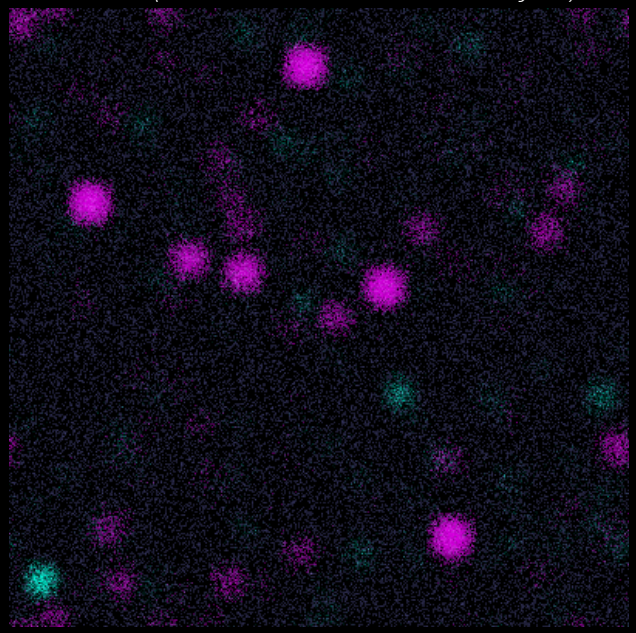
JWST *(Illustris-TNG light cone)*



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.

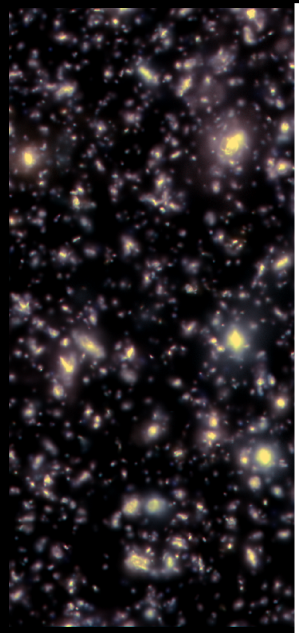
<u>Required observations:</u> Wedding cake surveys

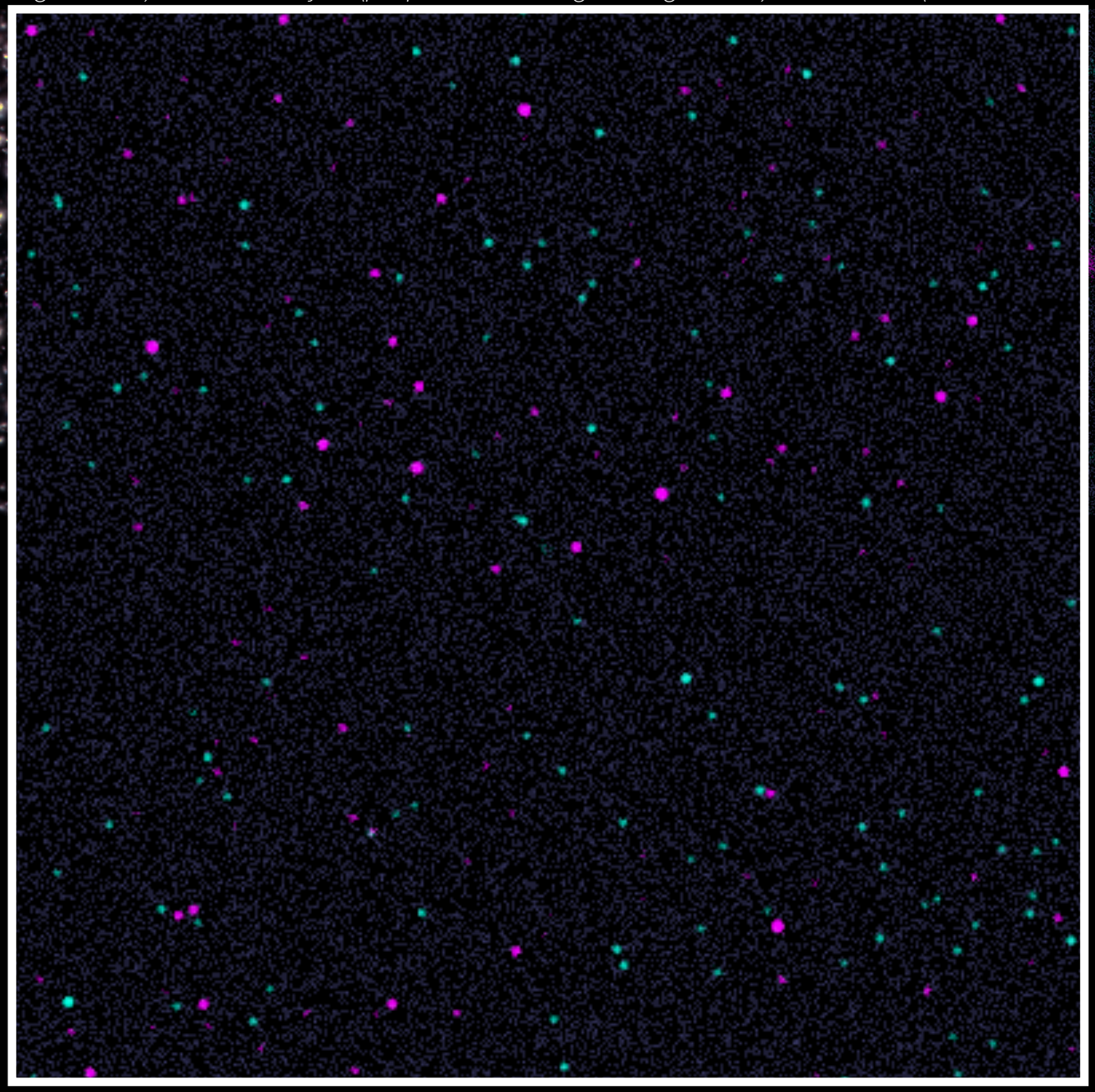
1-4 Ms deep fields to cover ~ 1 square degree

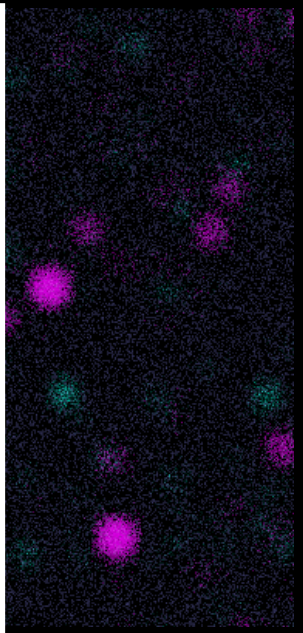
The Dawn of Black Holes

Simulated 2'×2' deep fields:

JWST (Illustris-TNG light cone) *Lynx (purple = AGNs, green=galaxies)* *Athena (5" PSF, same area as Lynx)*







The Dawn of Black Holes

Simulated 2'×2' deep fields:

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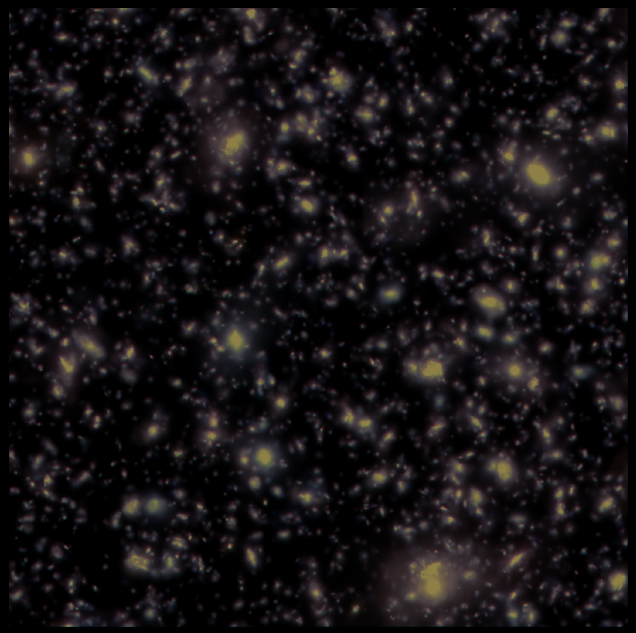

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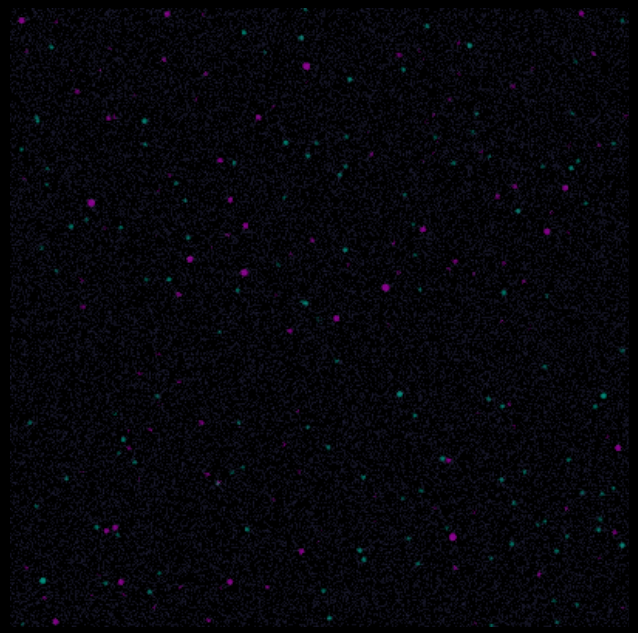

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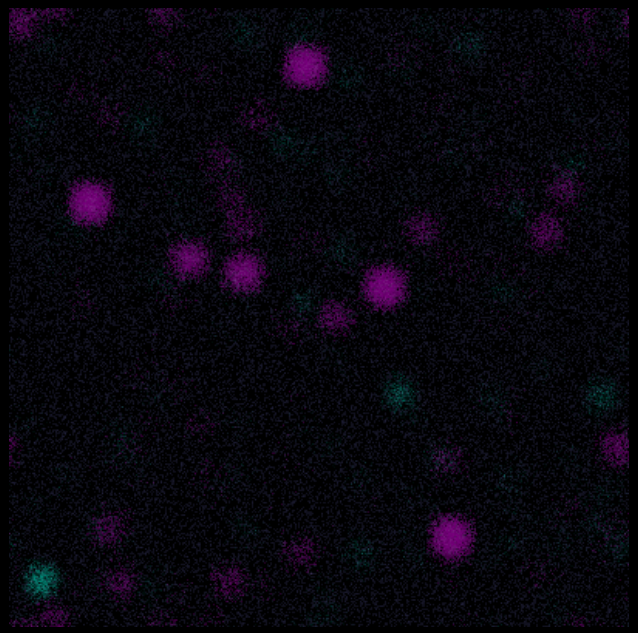
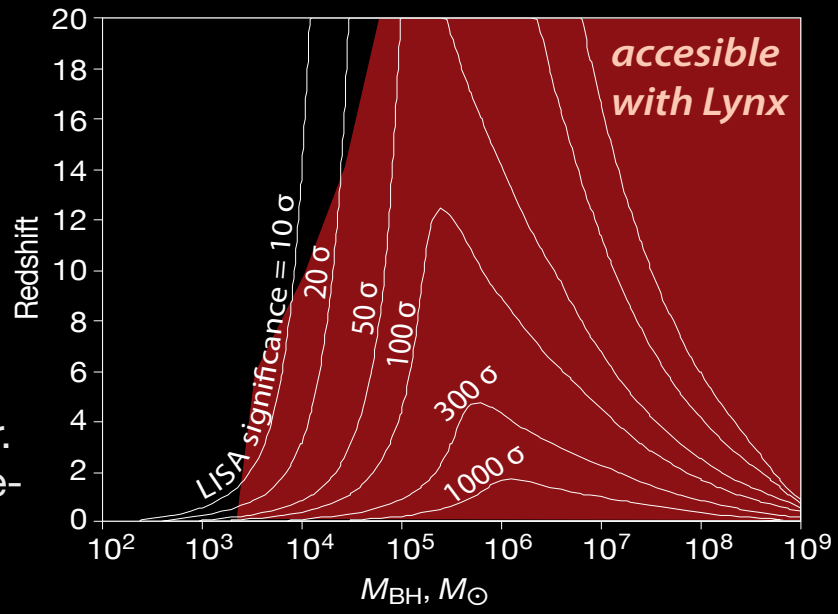


Synergies with gravitational wave experiments:

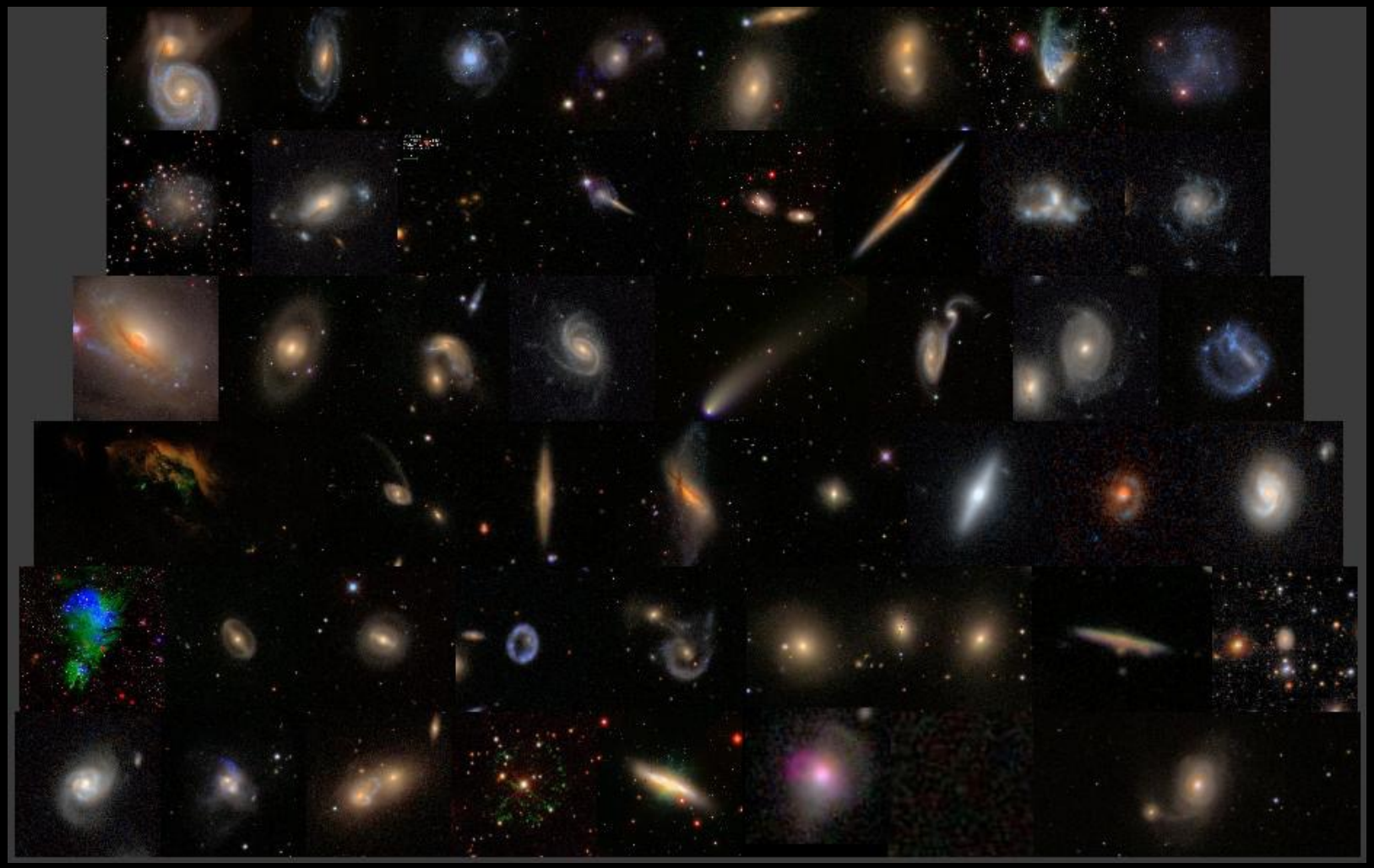
- Similar parameter space is covered at high-z.
- *Lynx* is sensitive to black hole growth through accretion (dominant mode).
- *Lynx* can respond to high-significance LISA triggers of SMBH mergers at z<2, localized to 1–10 deg^2 days before the merger. *Lynx* observations will establish how accretion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



Advances in Galaxy Formation

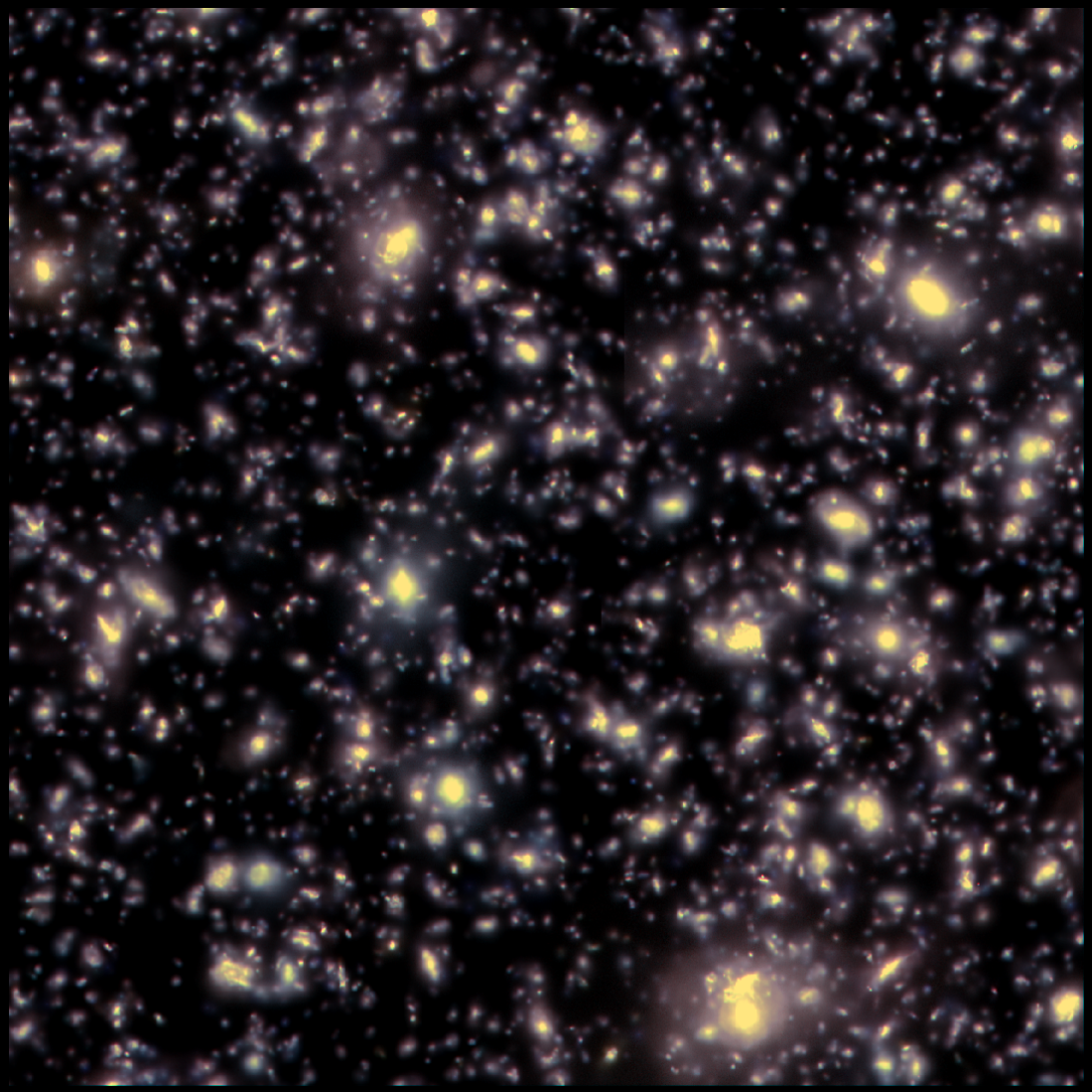
SDSS: Clustering properties and metallicities
Galaxy Zoo: Morphologies
HUDF, Frontier Fields: High-z frontier

Composite image from Galaxy Zoo

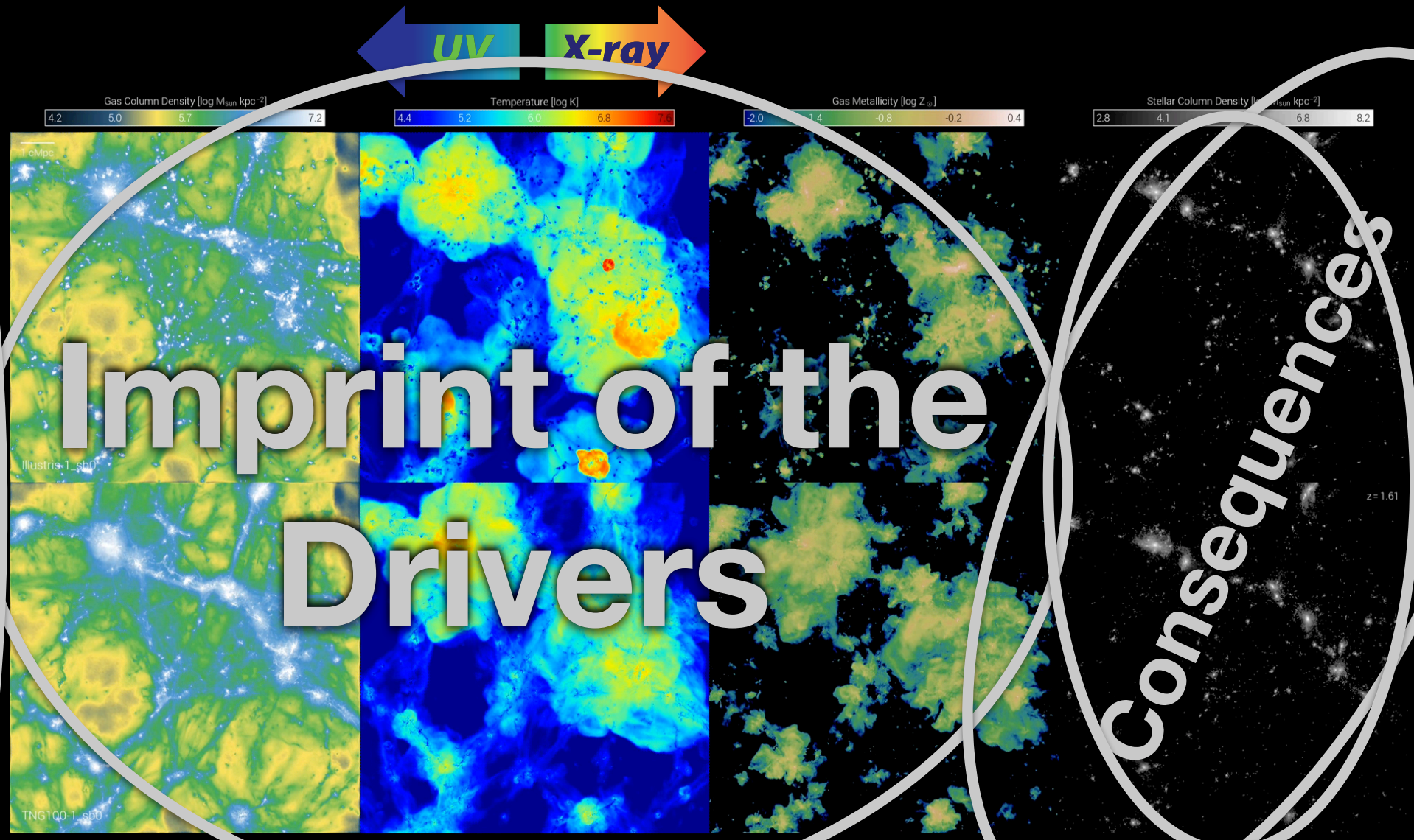


Advances in Galaxy Formation: JWST

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



The Invisible Drivers of Galaxy and Structure Formation



Illustris

Illustris TNG

Imprint of the Drivers

Consequences

ρ_{gas}

T_{gas}

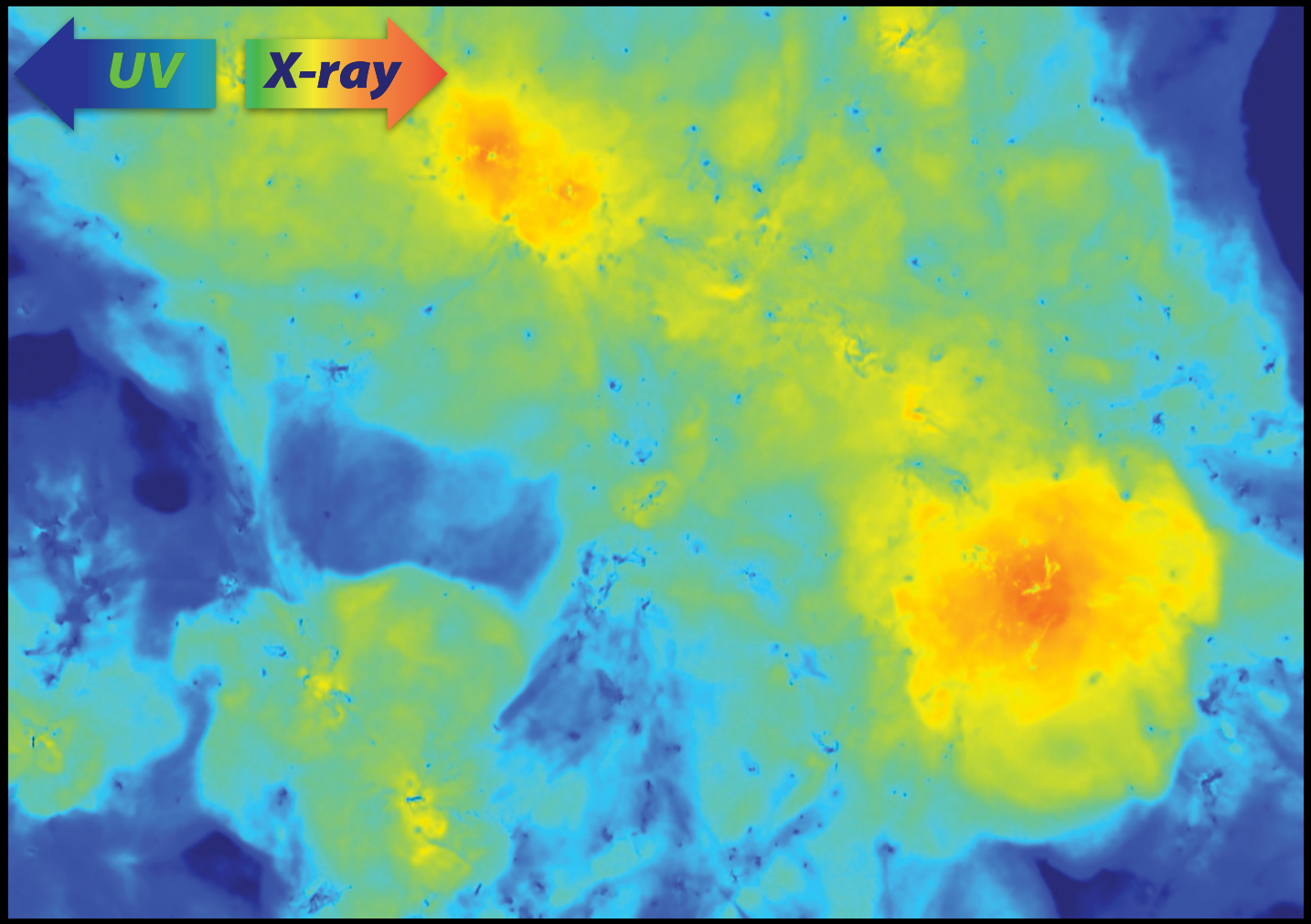
Metals

Galaxies: stellar mass

Same numerics, different physics

Indistinguishable galaxies

The Invisible Drivers of Galaxy and Structure Formation

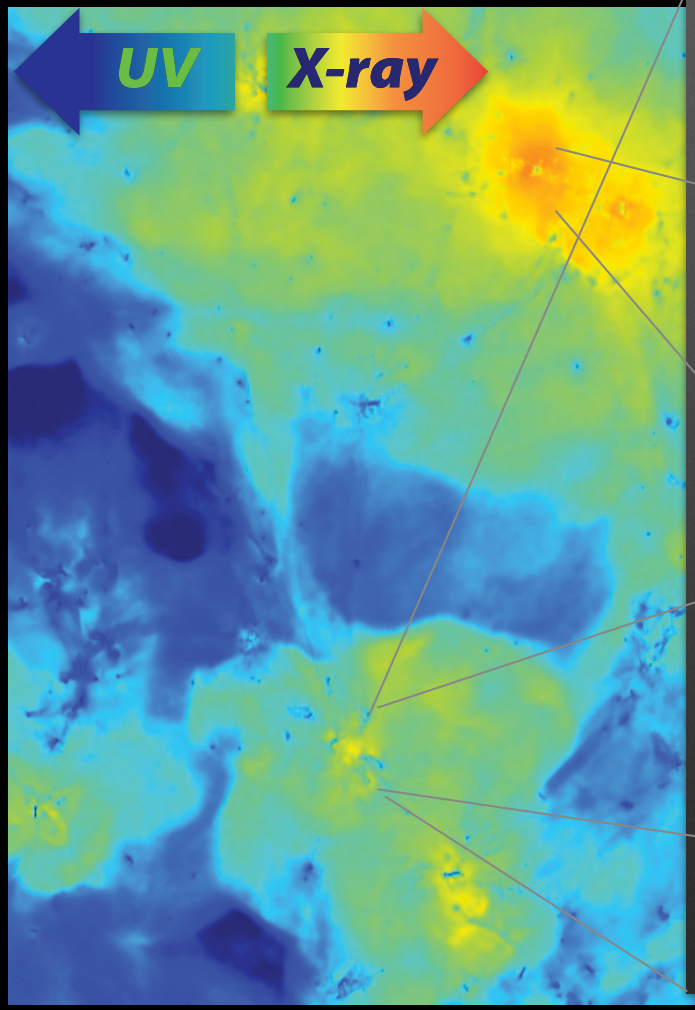


- Violent processes that produce and disperse large amounts of energy and metals into CGM drive the assembly, growth, and state of visible matter in cosmic structures.

- For galaxies $M > M_{MW}$, the baryonic component is heated and ionized to X-ray temperatures.

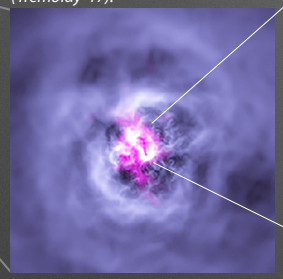
- Mapping this hot gas in CGM and the Cosmic Web and characterizing in detail all modes of energy feedback requires high resolution X-ray imaging and spectroscopy.

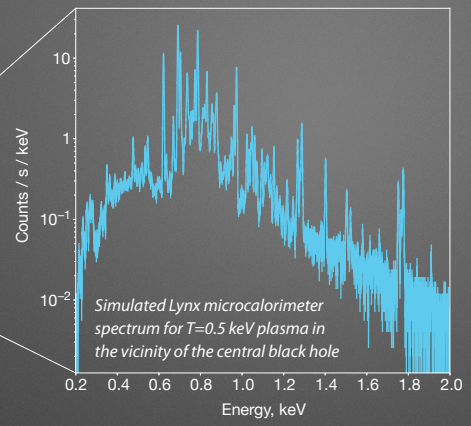
The Invisible Drivers of Galaxy and Structure Formation



Feedback

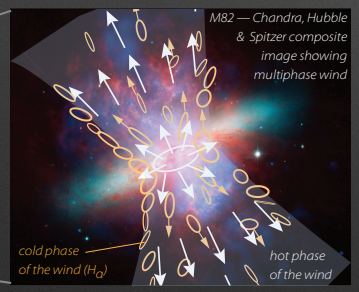
A2597 cluster — Chandra/X-ray (blue) and VLT-MUSE/H_α (purple) overlay (Tremblay '17).

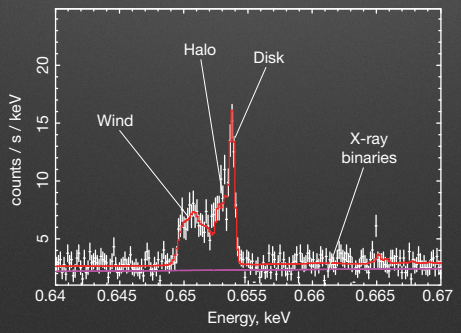




BH feedback:

- *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*

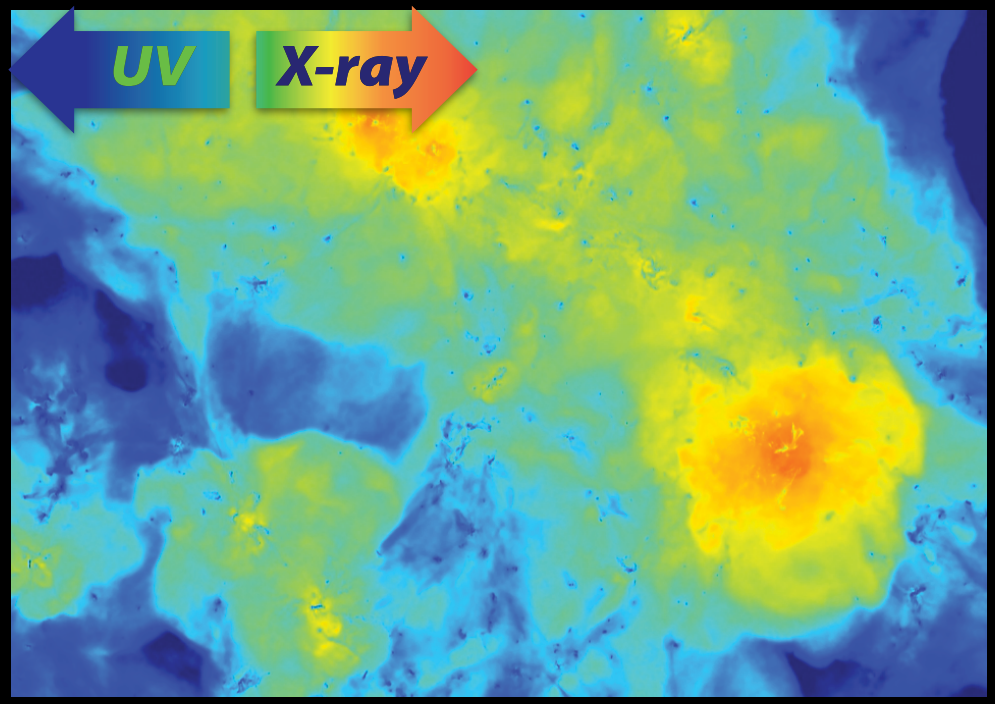




Galactic winds feedback:

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

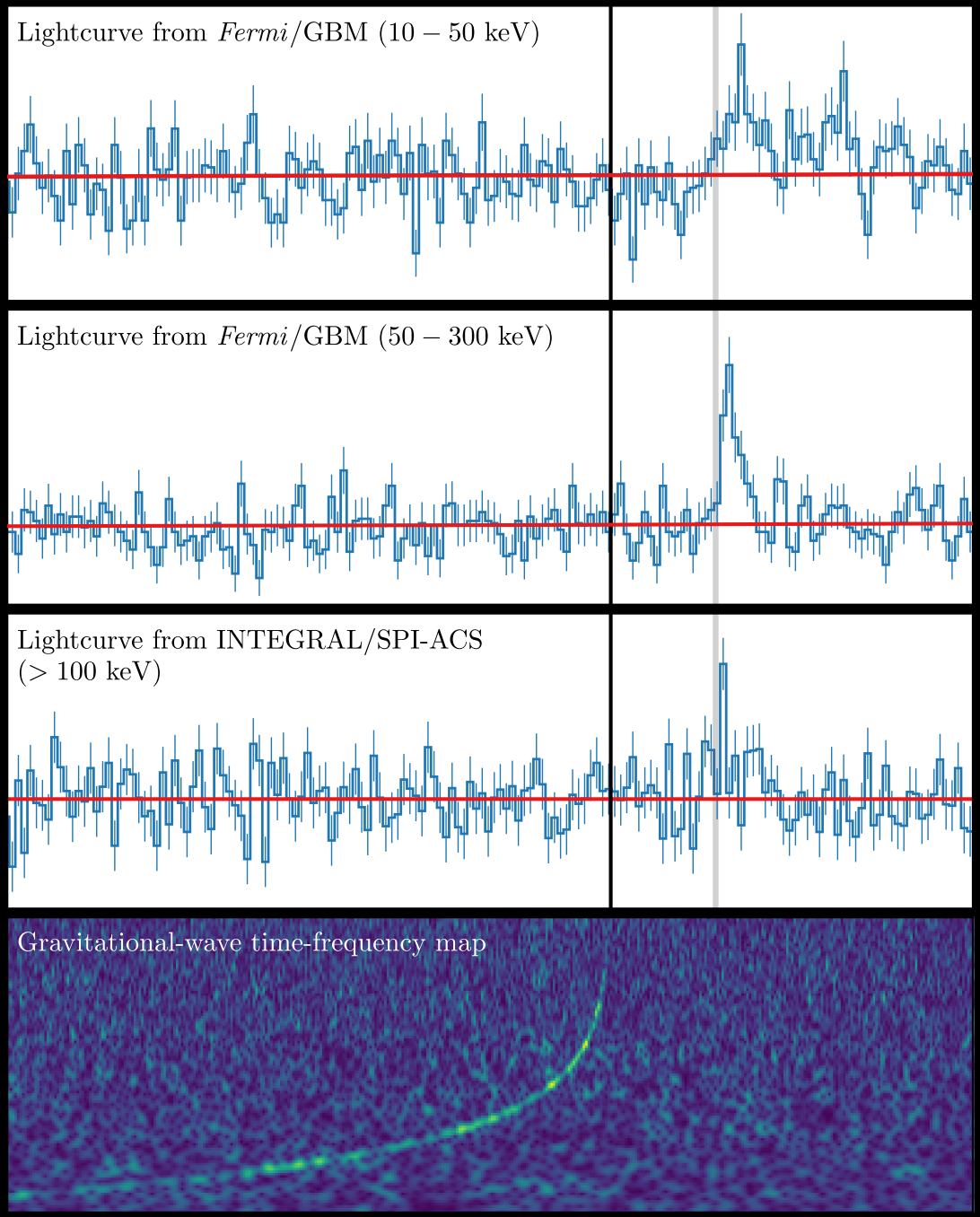
The Invisible Drivers of Galaxy and Structure Formation



<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

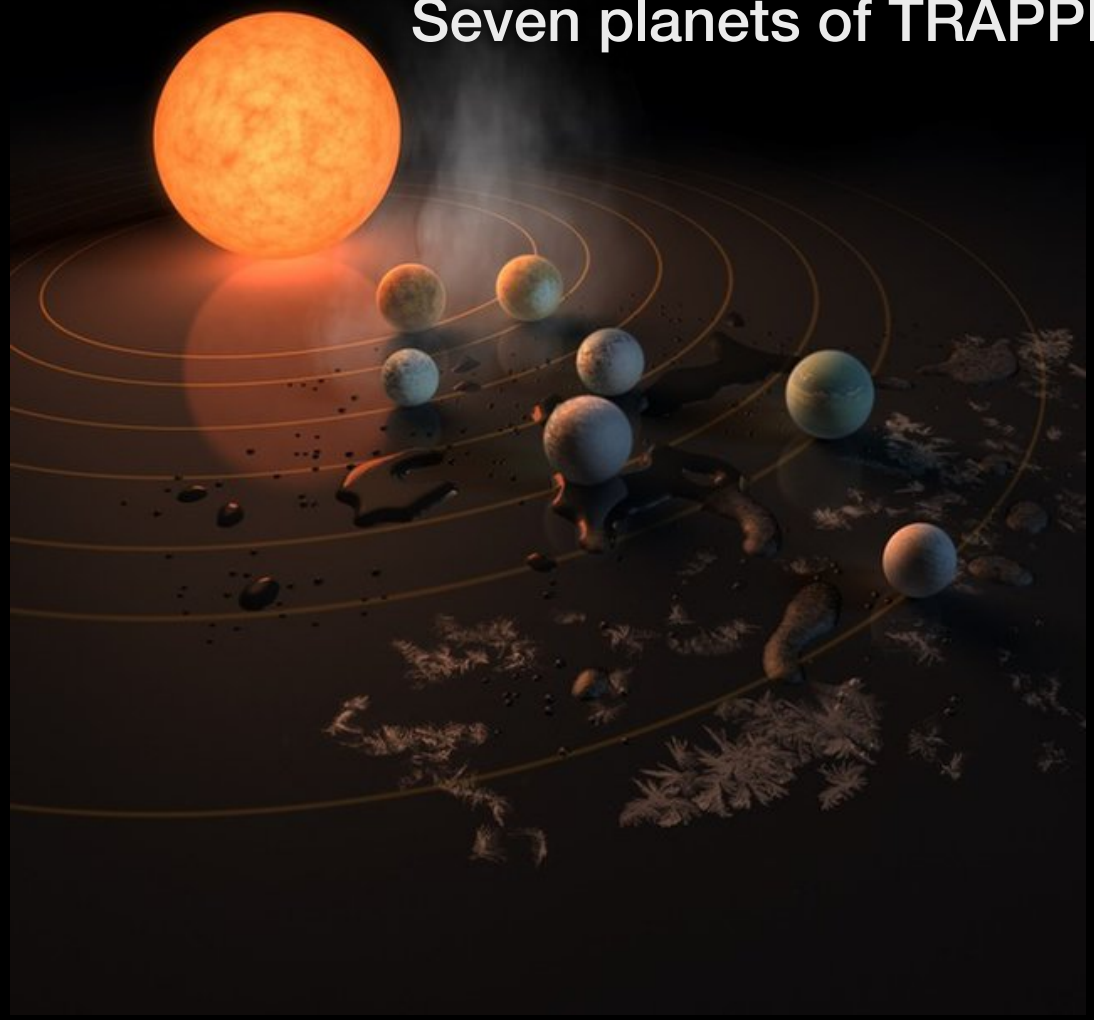
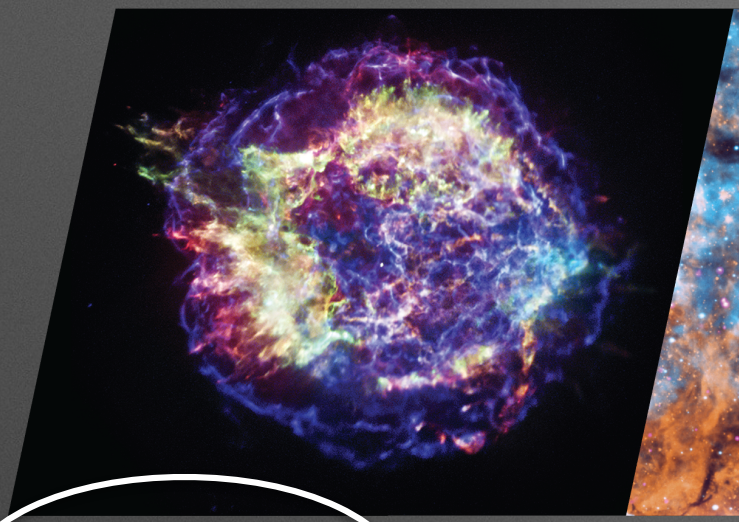
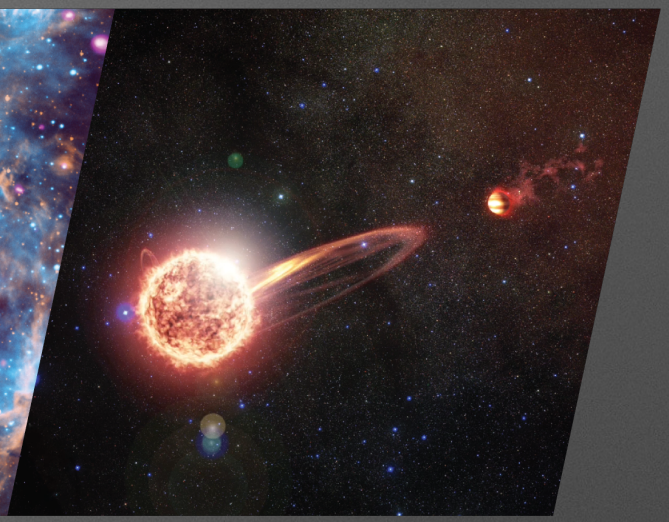


Image credit: NASA and JPL/Caltech

The Energetic Side of Stellar Evolution and Stellar Ecosystems





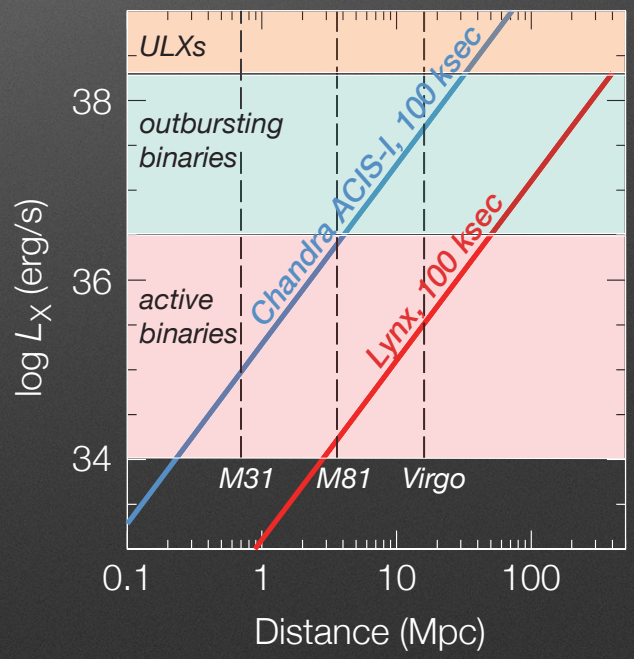
Endpoints of stellar evolution

Stellar birth, coronal physics, feedback

Impact of stellar activity on habitability of planets

SNRs:

- 3D maps of dozens of remnants, revealing explosion physics
- Understand how metallicity effects explosions by resolving the LMC & SMC remnants and establish parent SN types within the Local Groupy
- Find young neutron stars in MW by increasing sensitivity.
- Spectral studies of recent core-collapse SNe within ~10 Mpc to probe the circumstellar material —> evolution of massive stars



X-ray Binaries: XRB populations in dozens of nearby galaxies down to L_X~10^{34}–10^{35} erg/s; binary evolution models; evolutionary paths to LIGO sources.

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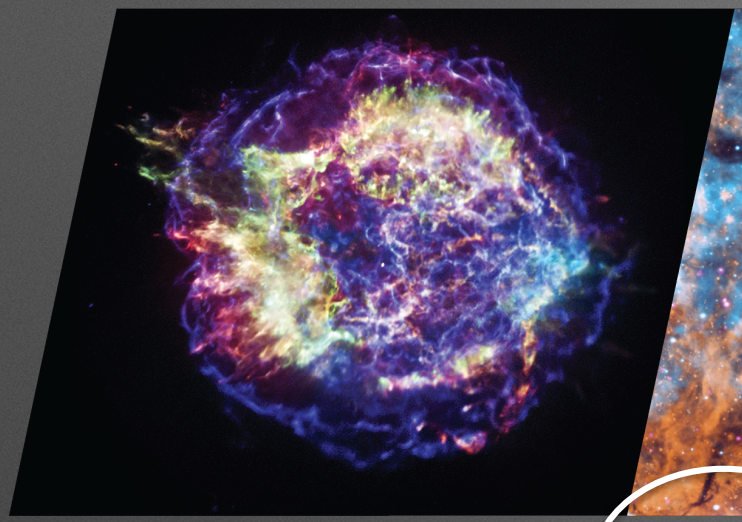
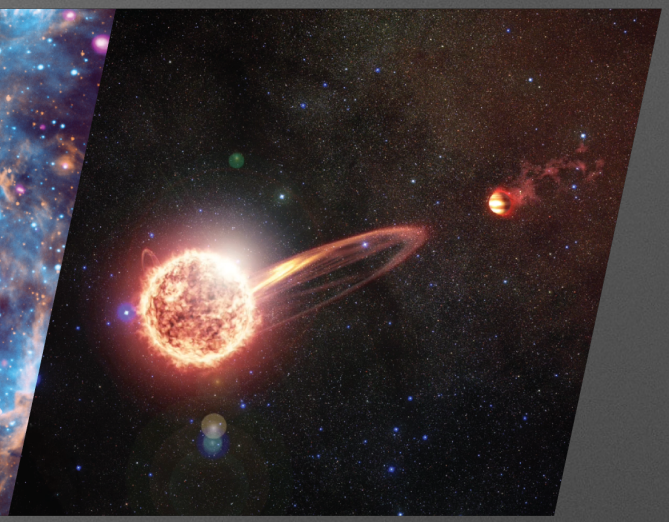
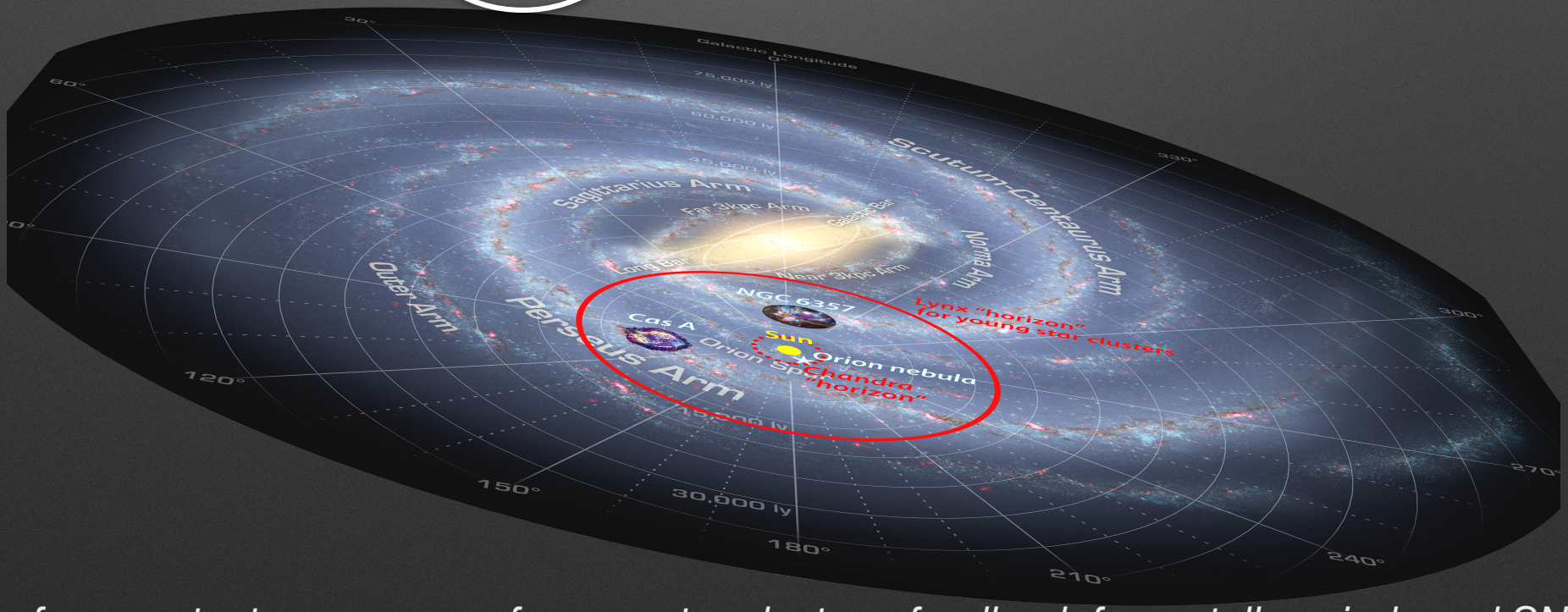


Endpoints of stellar evolution

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

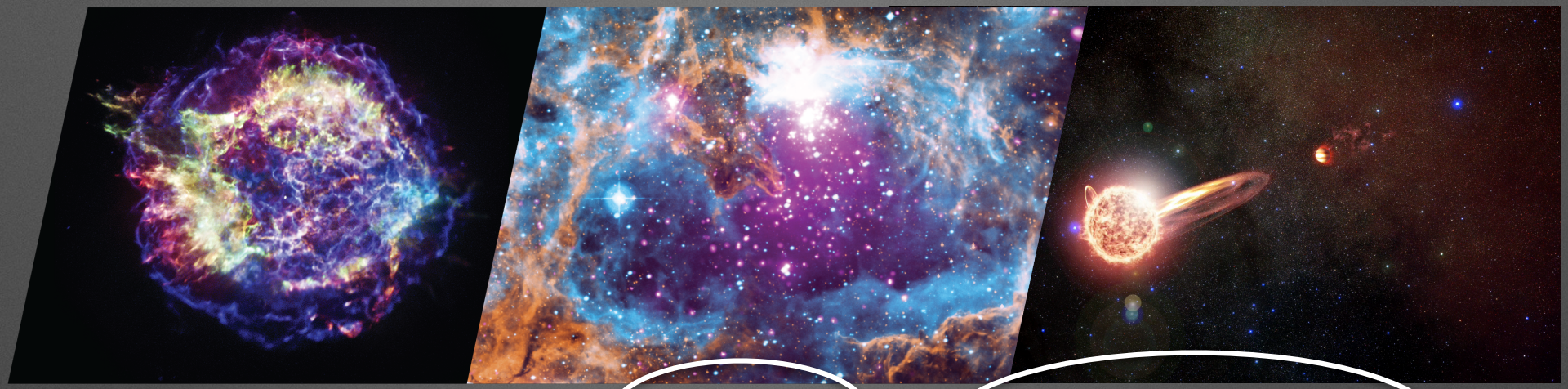


Impact of stellar activity on habitability of planets



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*

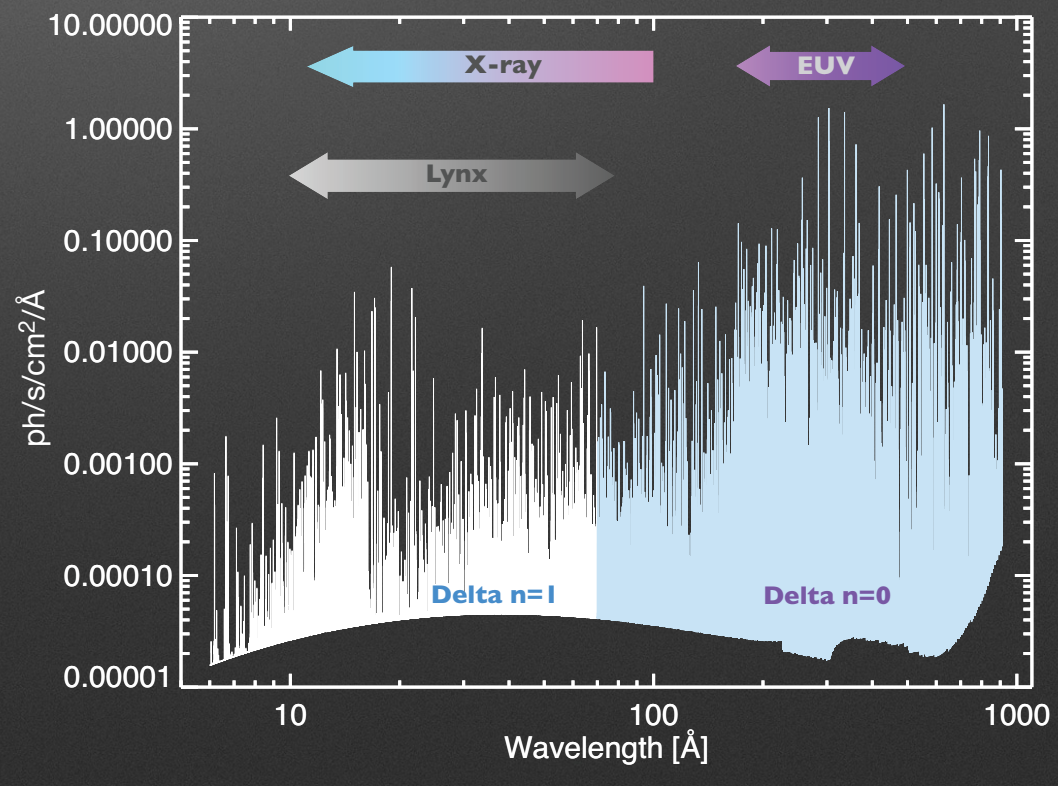
Impact of stellar activity on habitability of planets

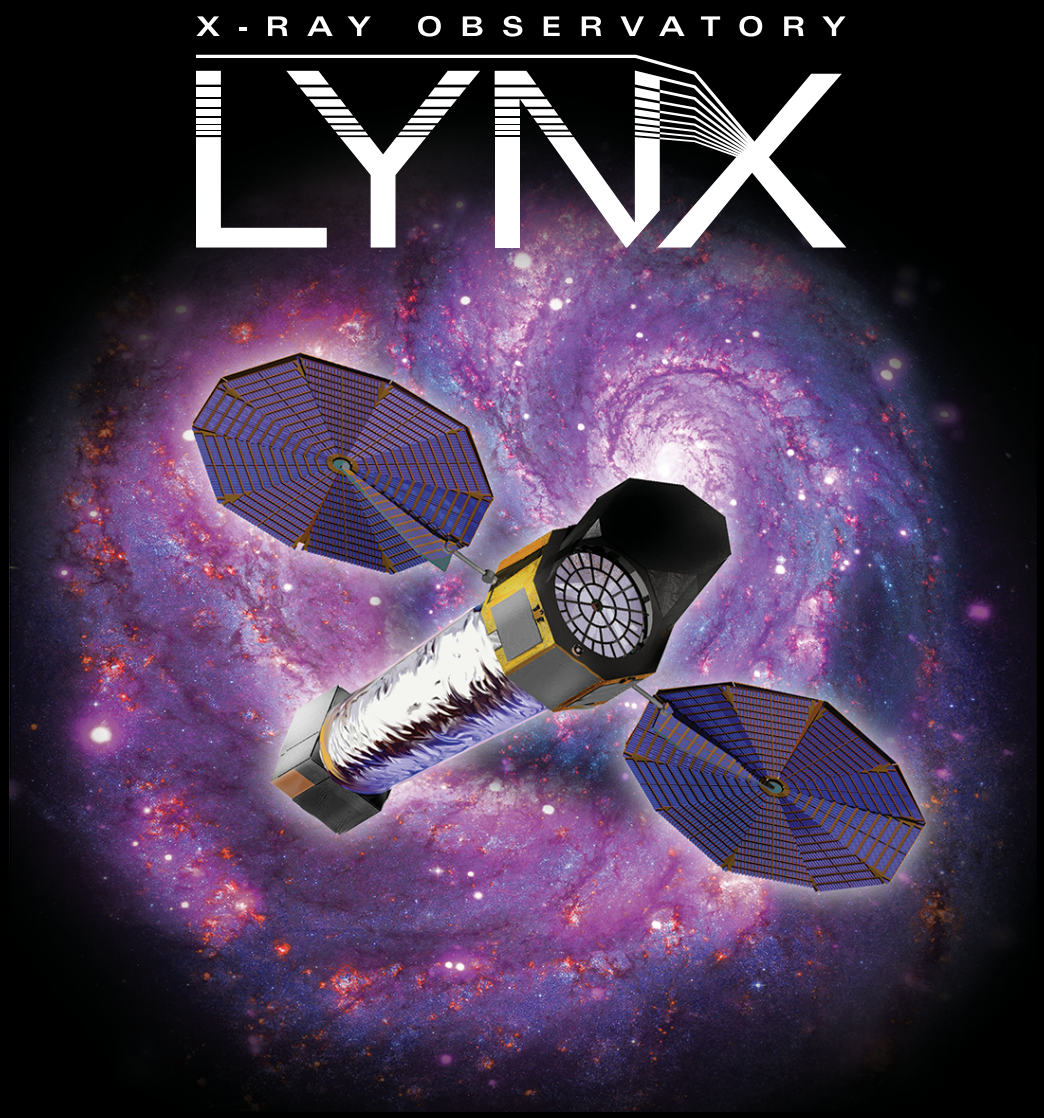
Grating observations to resolve triplet, satellite, and dielectric recombination lines from C, N, O, Ne, Mg, Fe (K, L, and M-shells) in stellar coronae.

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.



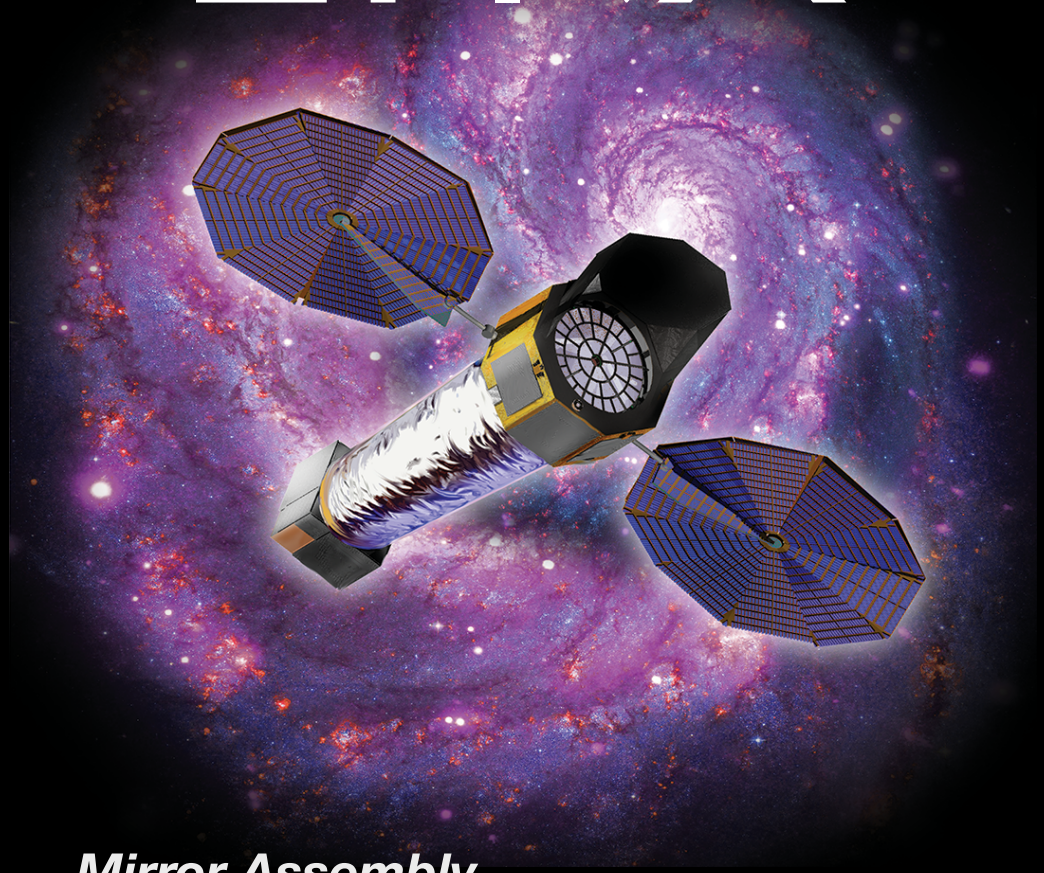


These science pillars require a mission like *Lynx*, with leaps in capability over *Chandra* and *ATHENA*:

- 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.

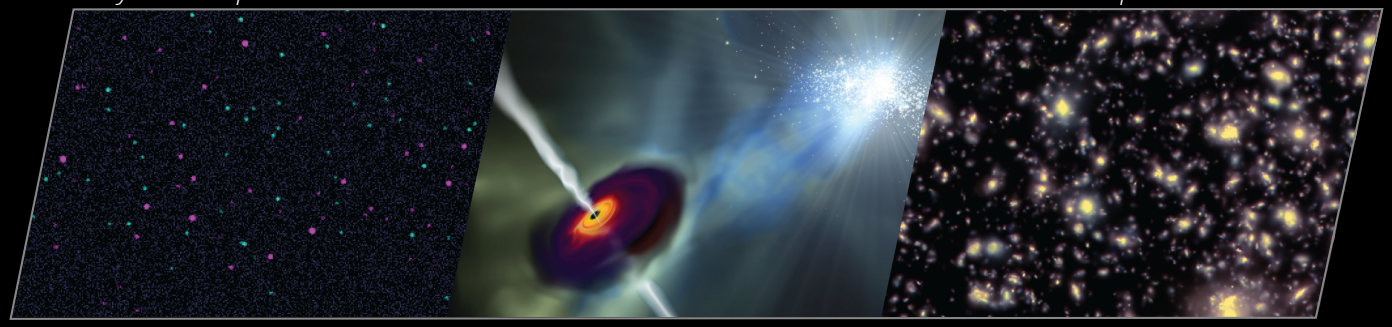
X-ray grating spectrometer

- 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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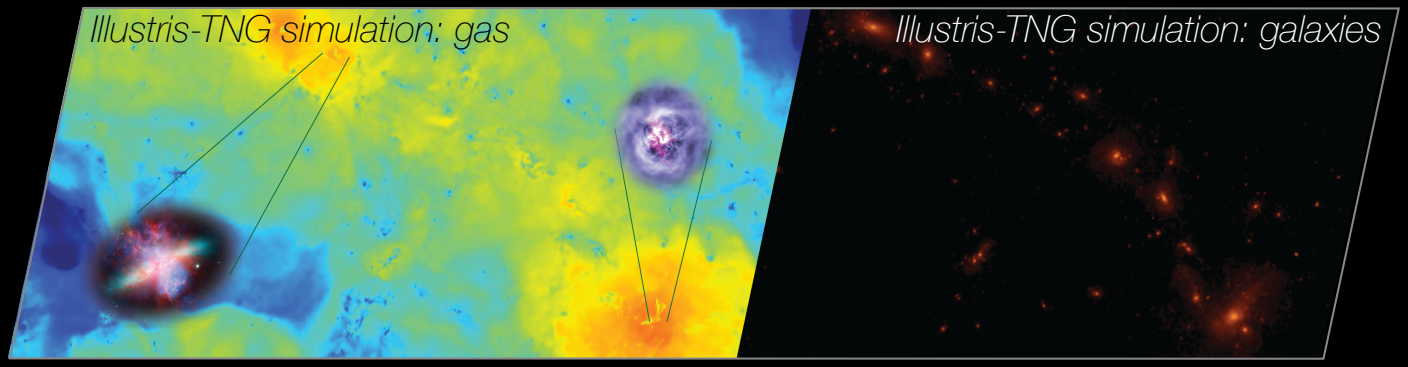

The Energetic Side of Stellar Evolution and Stellar Ecosystems

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.***

Come to the Lynx special session at 7:30 pm!