

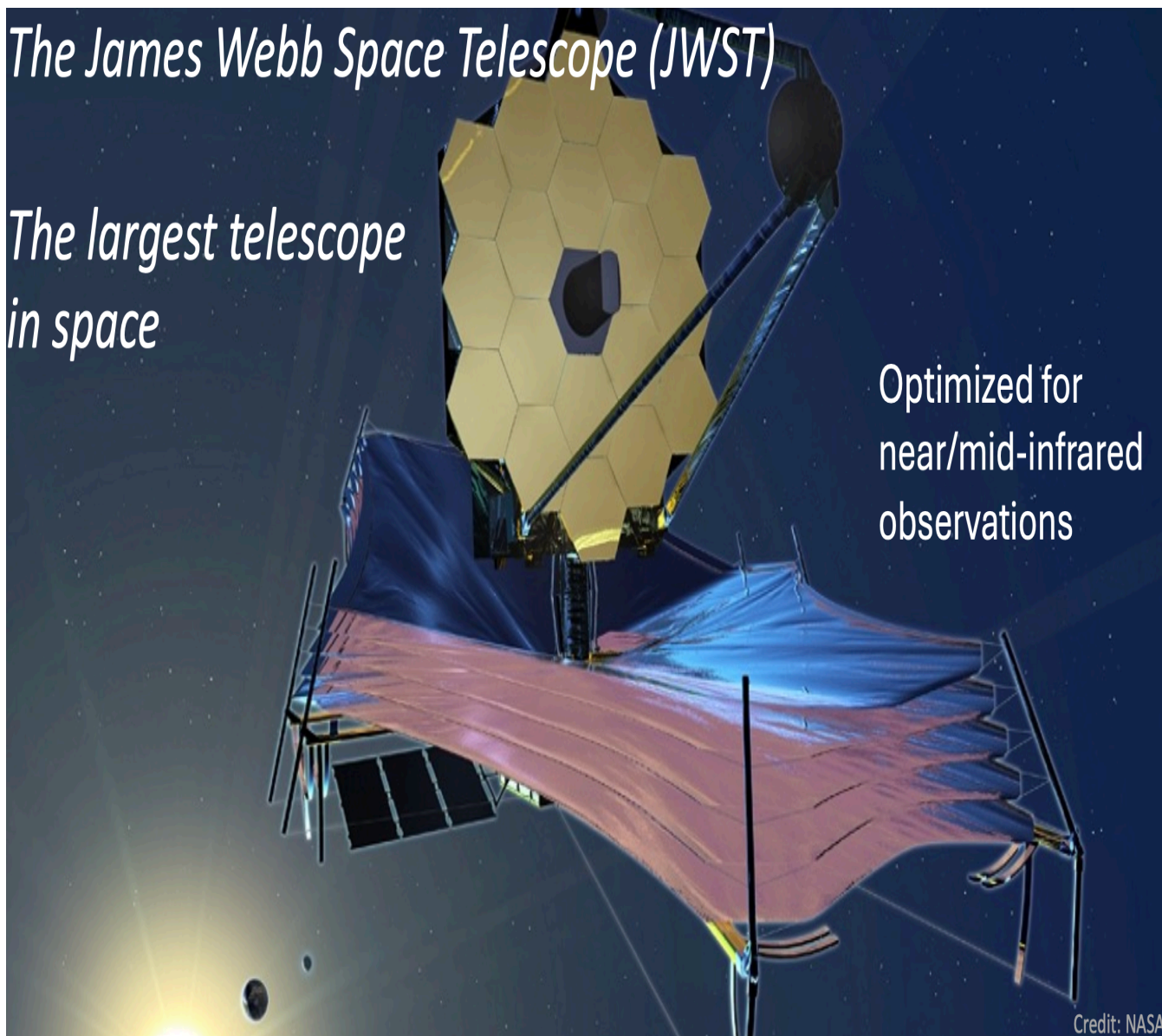
AGN high-energy emission: Highlights from selected space missions

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*The many tones of accretion to the memory of Tomaso Belloni
Cefalù - September 10, 2026*

“OUTLINE”



Credits: R. Maiolino

*The many tones of accretion to the memory of Tomaso Belloni
Cefalù - September 10, 2026*

Science with JWST

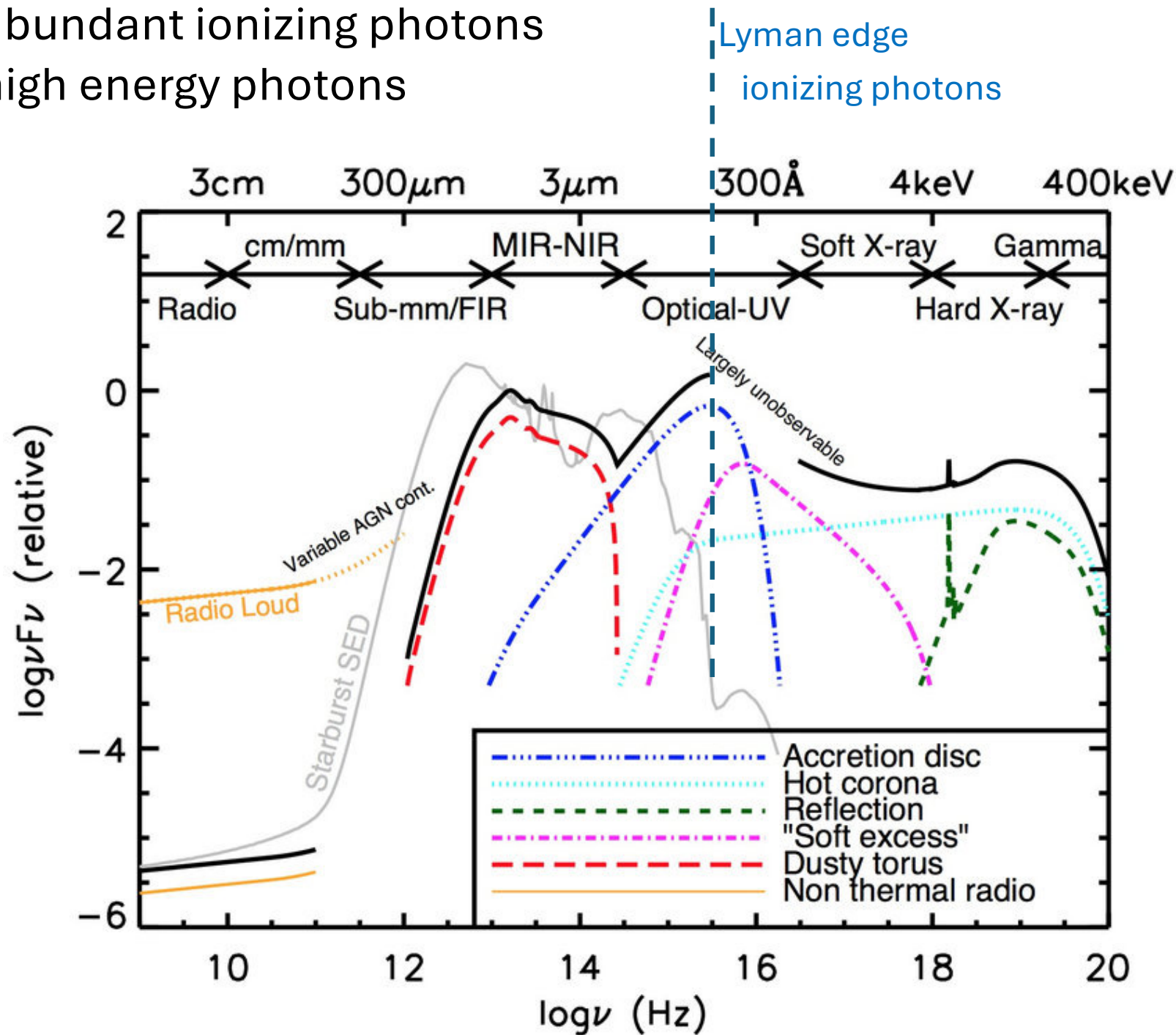
JWST has revealed that the early Universe is much more exciting and puzzling than what we thought

- **Early galaxies:** too luminous too early
- **Quenched galaxies:** too passive too early, too many stars formed too early
- **Chemical enrichment:** too rich too early, too whacky... too poor
- **Black holes:** too massive too early, too naked, too weird, ...

AGN SED

Active Galactic Nuclei (AGN) Spectral Energy Distribution

- abundant ionizing photons
- high energy photons



UV bump produced
by the accretion disc

X-rays produced
by a hot corona

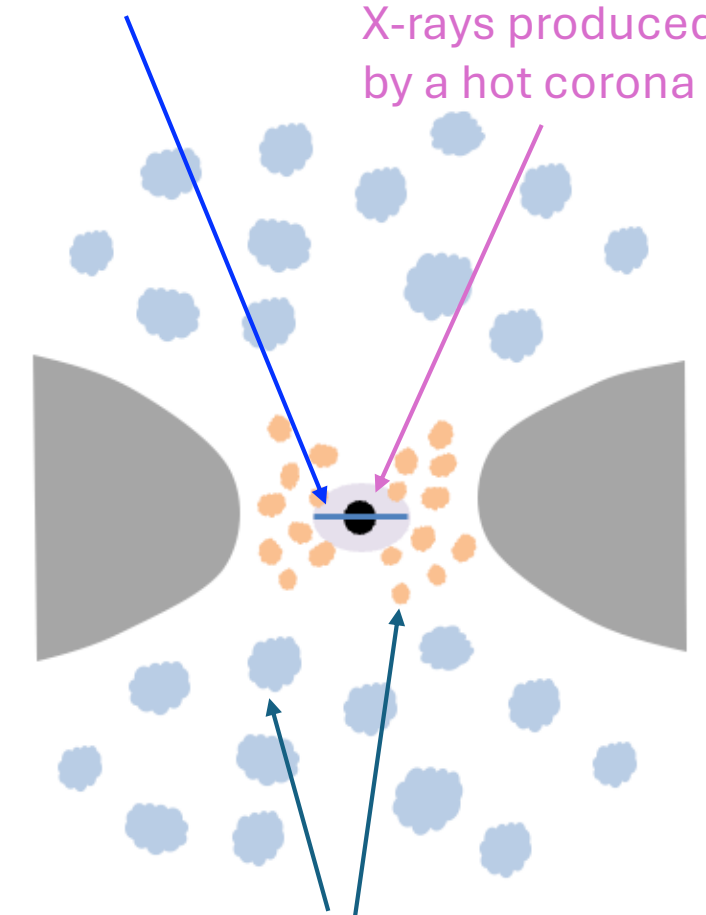
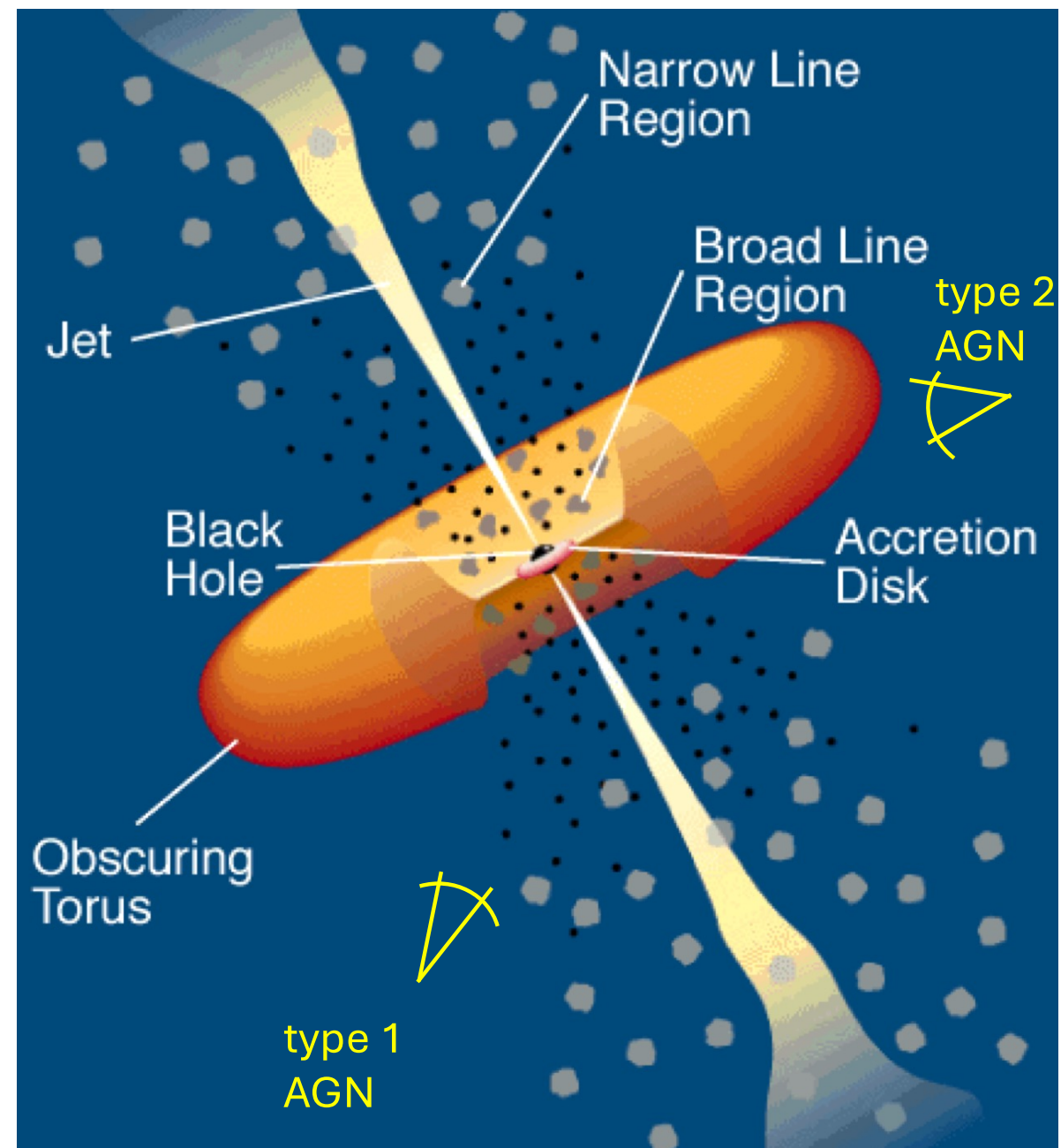
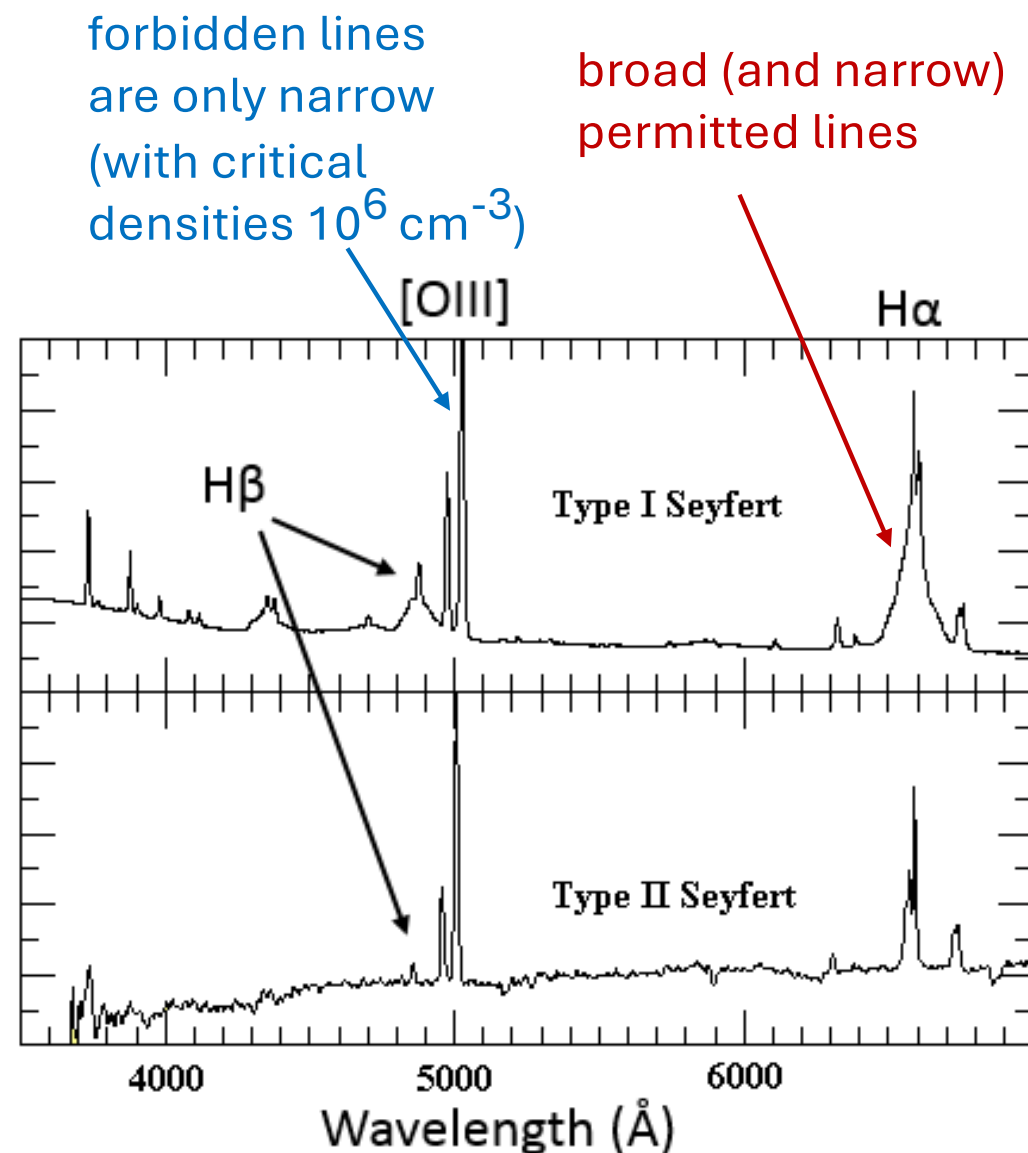


Photo-ionizes
the surrounding gas

“Unified model” Type 1/2



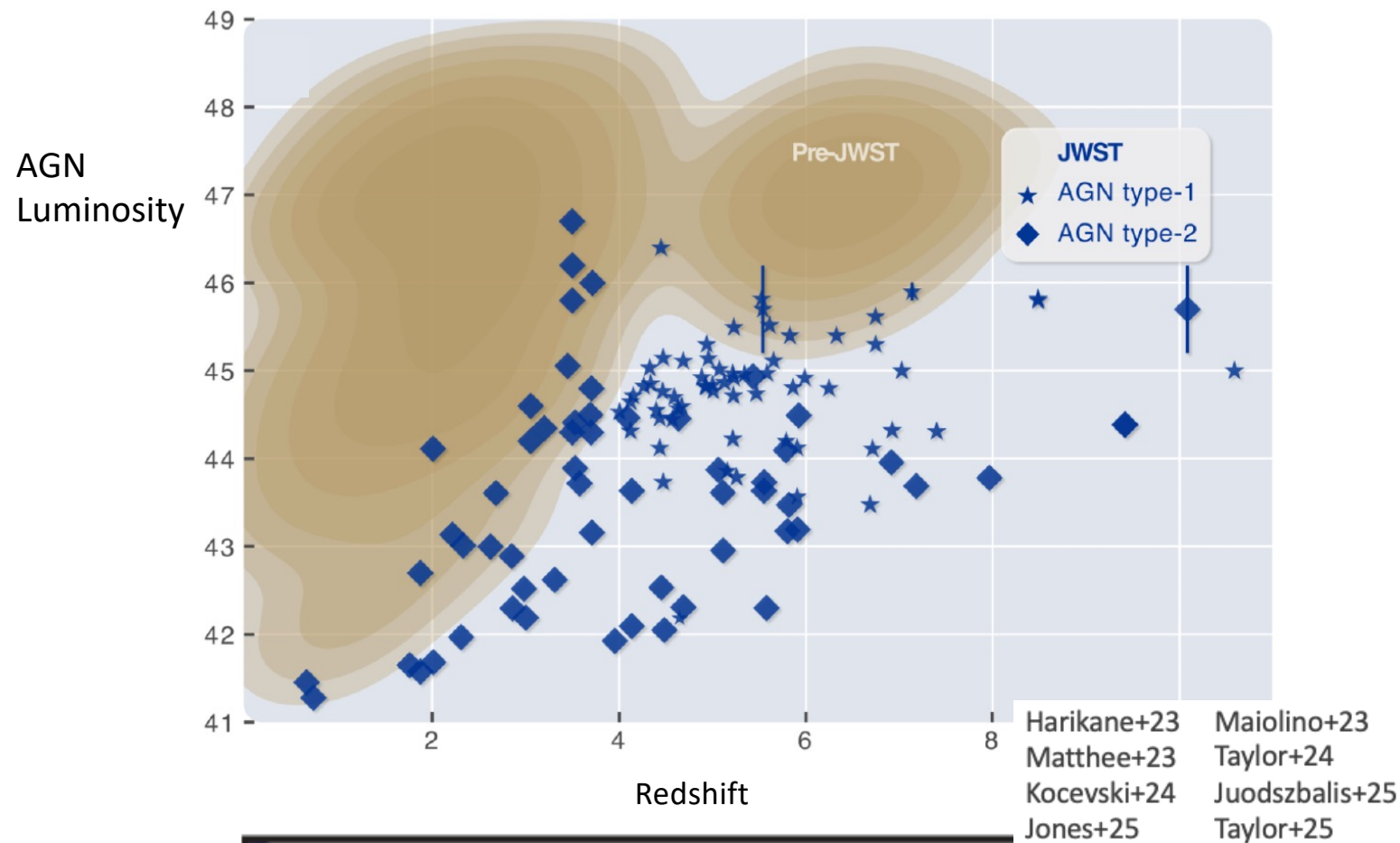
Narrow Line Region (NLR)

- $\sim$ galactic velocity dispersion (100 km/s)
- size $\sim 100 \text{ pc}$
- density $\sim 10^{2-4} \text{ cm}^{-3}$

Broad Line Region (BLR)

- high velocity dispersion ($> 1,000 \text{ km/s}$, likely in BH sphere of influence)
- size $< 0.1 \text{ pc}$ (from variability)
- density $> 10^8 \text{ cm}^{-3}$

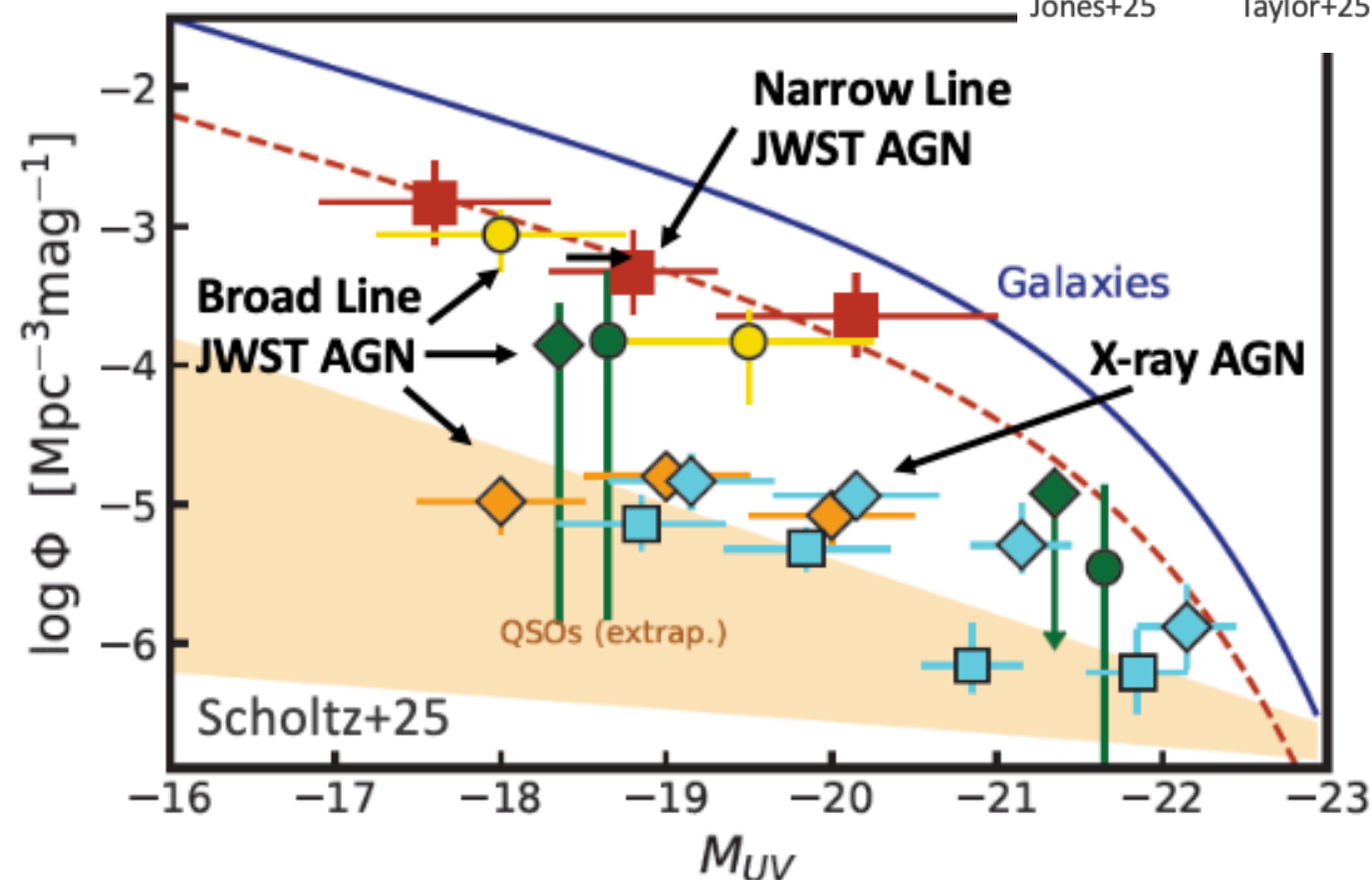
BH discovery space



AGN fraction: strongly luminosity-dependent

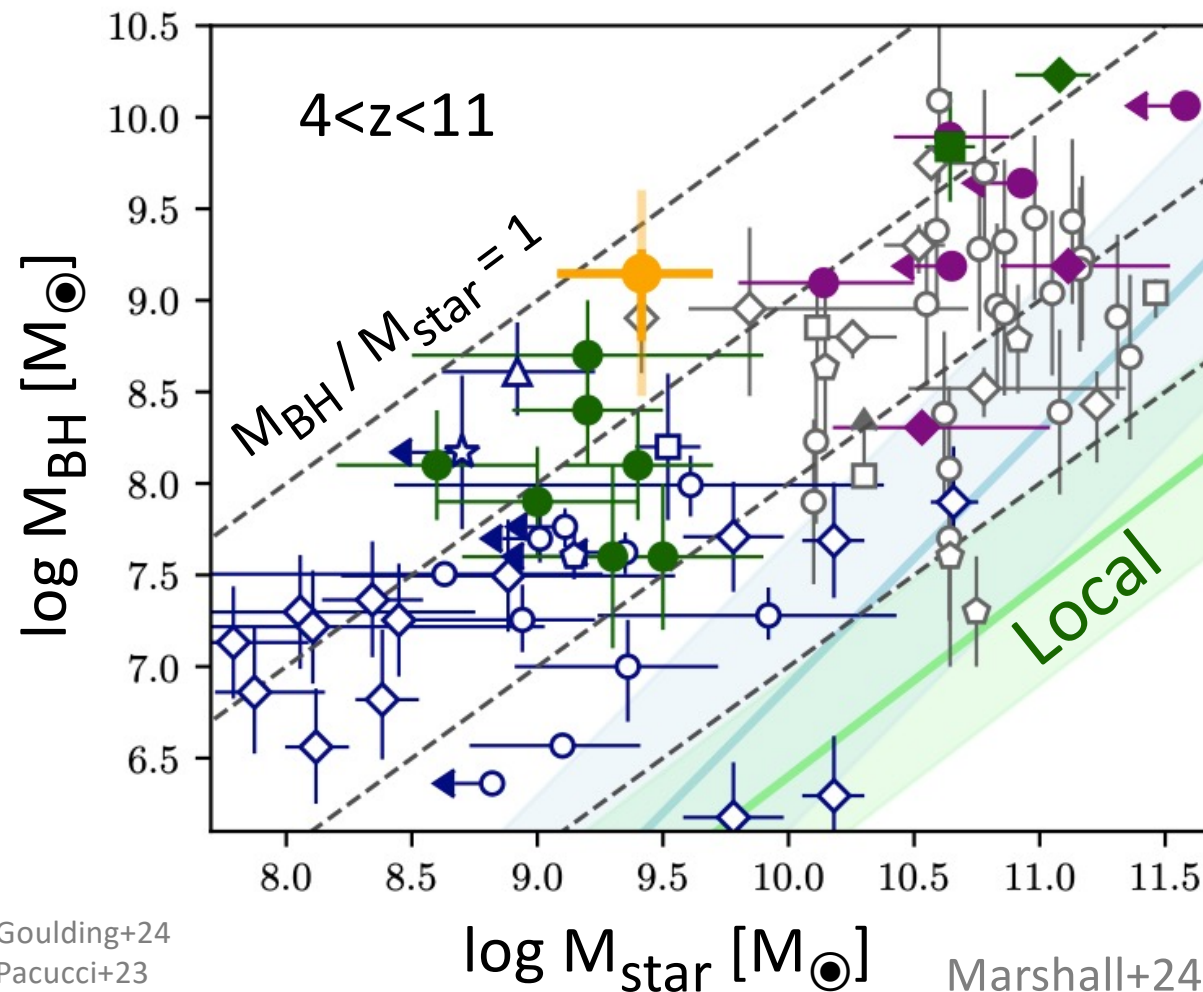
~ 10% - 1% of galaxies at $z \sim 4-6$ host an AGN with $L > 10^{44} - 10^{45}$

Well above the extrapolation of luminous quasars and X-ray selected AGN



Overmassive BHs?

At $z > 4$ large population of “over-massive” Black Holes...
...nearly as massive as their host galaxies



Early galaxies formed
faster than originally thought...
... black holes formed even faster!

Schneider+24
Trinca+24,25
Natarajan+24
Rantala+24
Zhang+24

Issues:

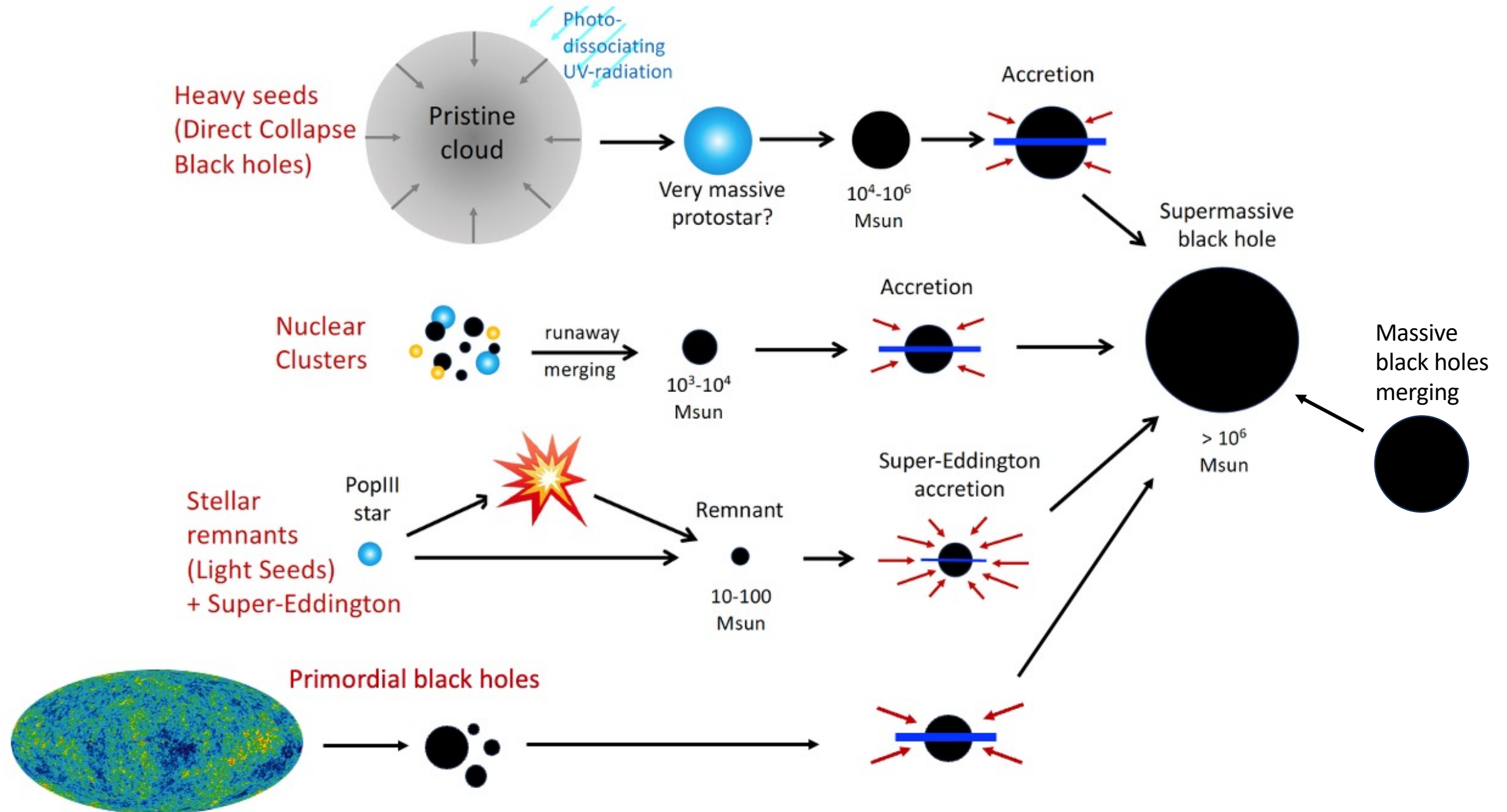
- Selection effects (more massive BHs easier to detect) -> yet, it is still remarkable that **the** **somehow manages to produce monster BHs in tiny galaxies**
- Are the black hole masses correct?

Li+2024
Zhang+2024
Juozbalis+2024
Zipari+26
Silverman+26
Tanaka+26

BH masses measured by the width of a single line
using calibrations from reverberation mapping techniques

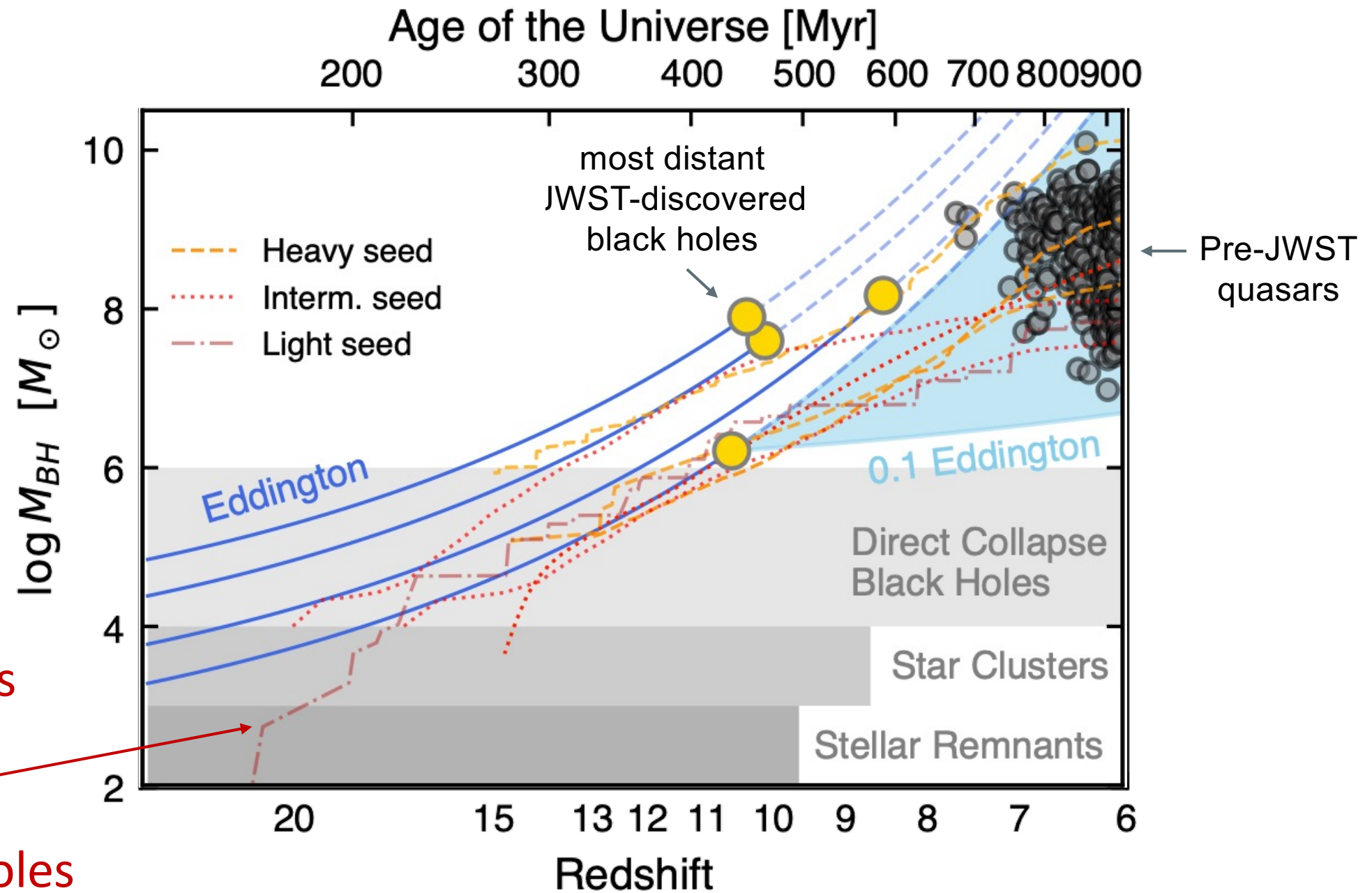
Marshall+24
Übler+23
Juozbalis+24
Maiolino+23
Newman+25
Harikane+23
Bogdan+23
Goulding+24
Pacucci+23
Kokorev+23
Juozbalis+24
Furtka+24
Ding+23
Jones+25
Brooks+25

SMBHs formation paths



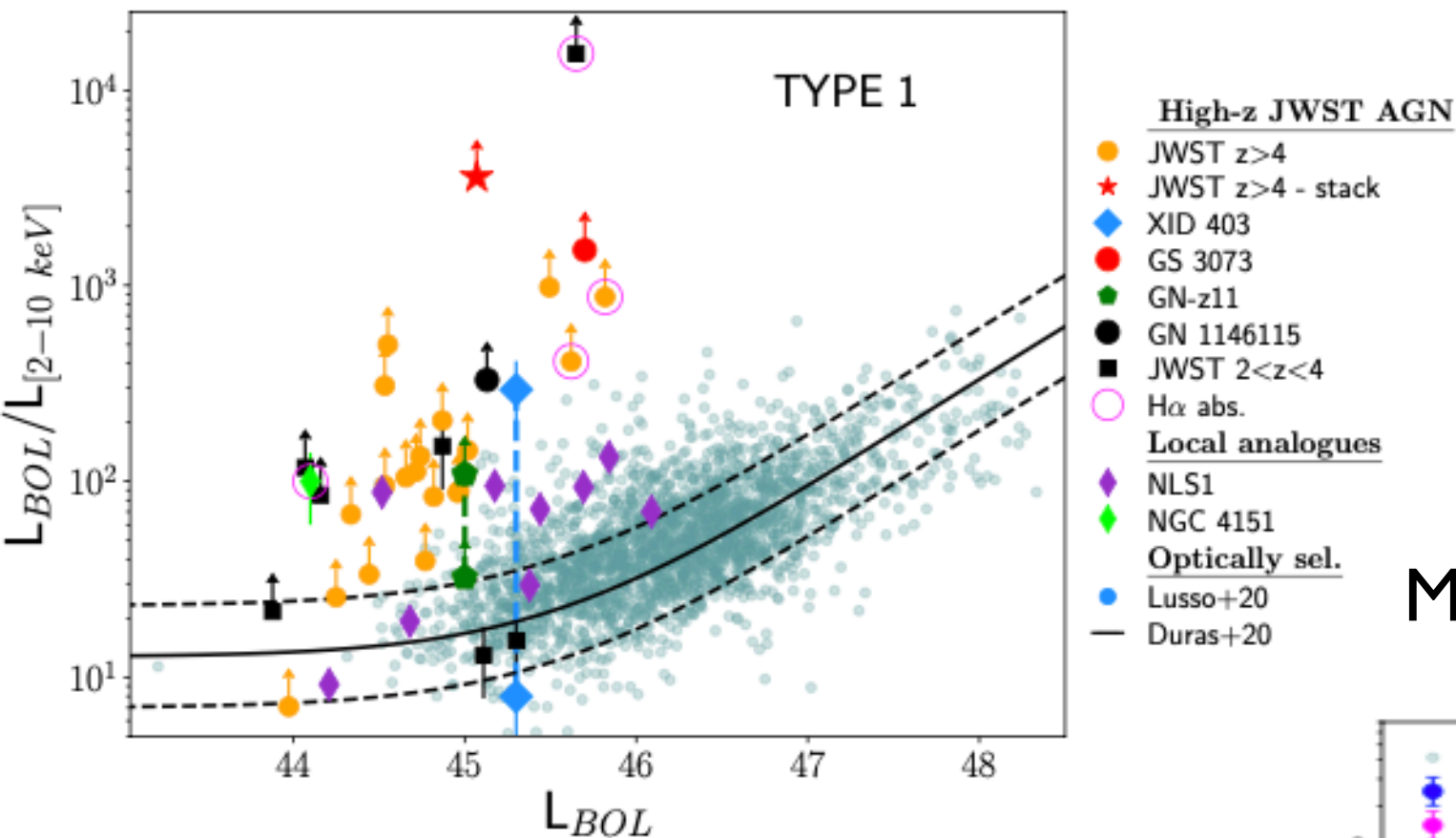
SMBH at the dawn of the cosmic epoch

Alternative seeding
and growth scenarios
can potentially
reproduce the
most distant black holes



X-ray Weakness

With a few exceptions, the vast majority of the newly discovered JWST AGN are X-ray undetected and remain so after stacking



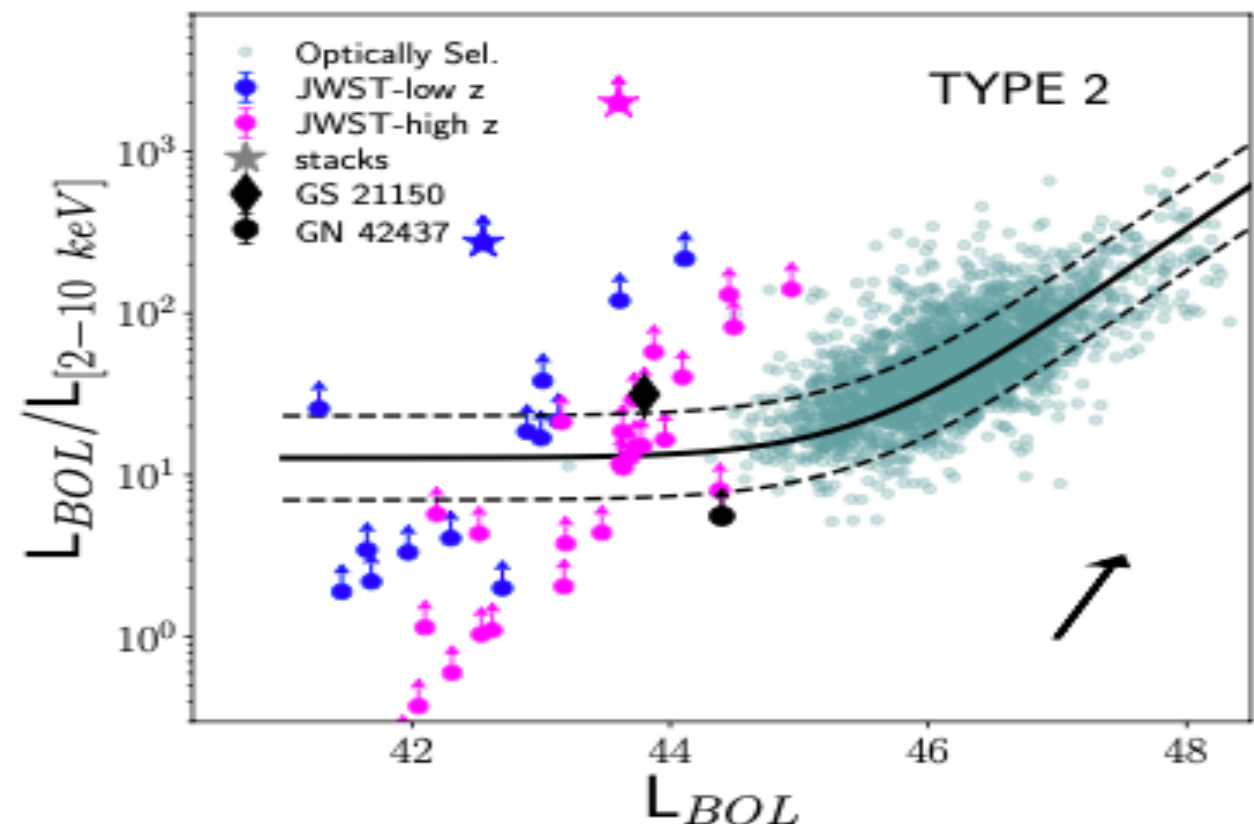
The Type 2 X-ray weakness is not as extreme as for Type I (at least from the L_{BOL} vs L_X plot), yet many are much fainter than “expected.”

Maiolino+25

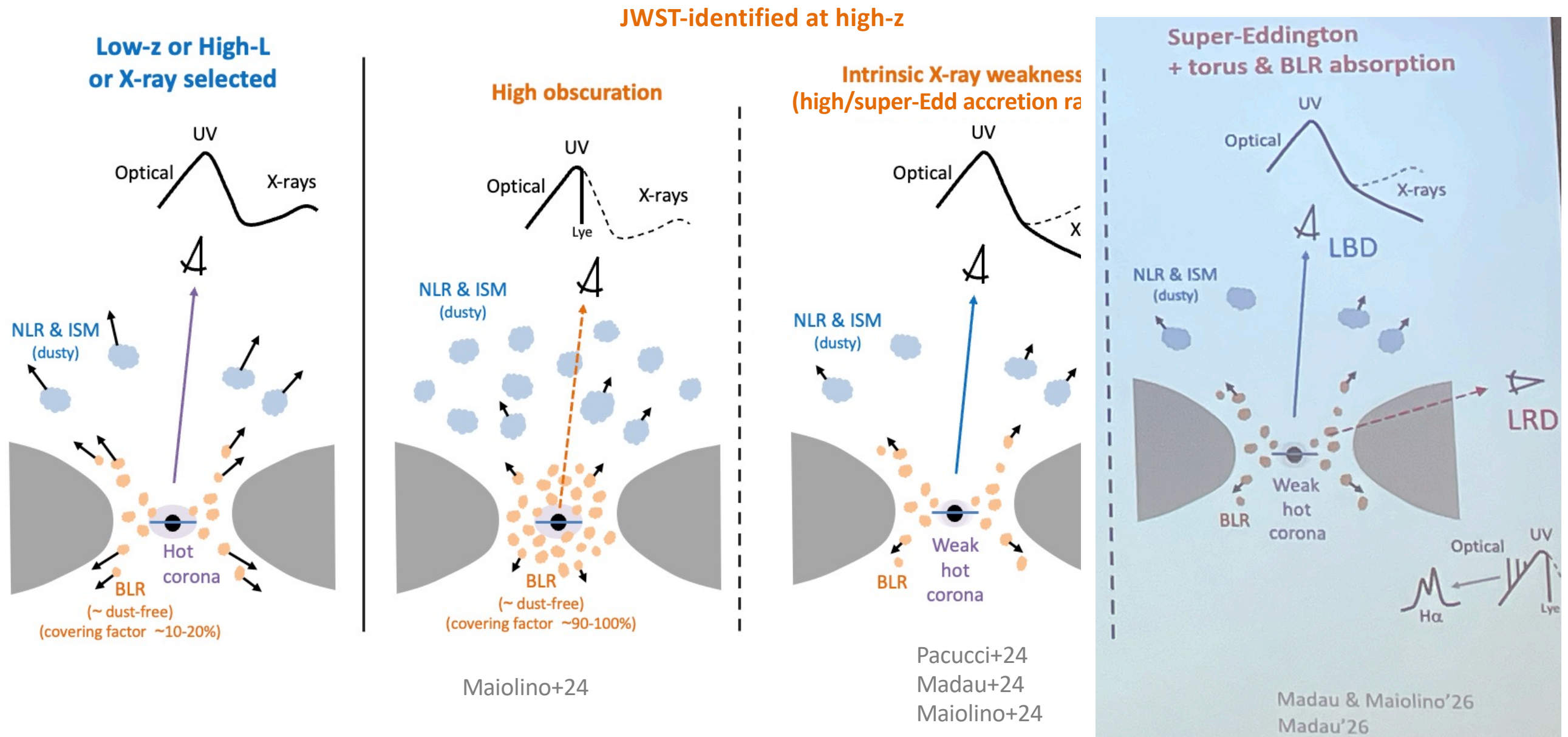
If the JWST Type II AGNs are obscured, the covering factor must be very high: close to 4π

Also Radio Weakness

Mazzolari+25



Possible Explanation



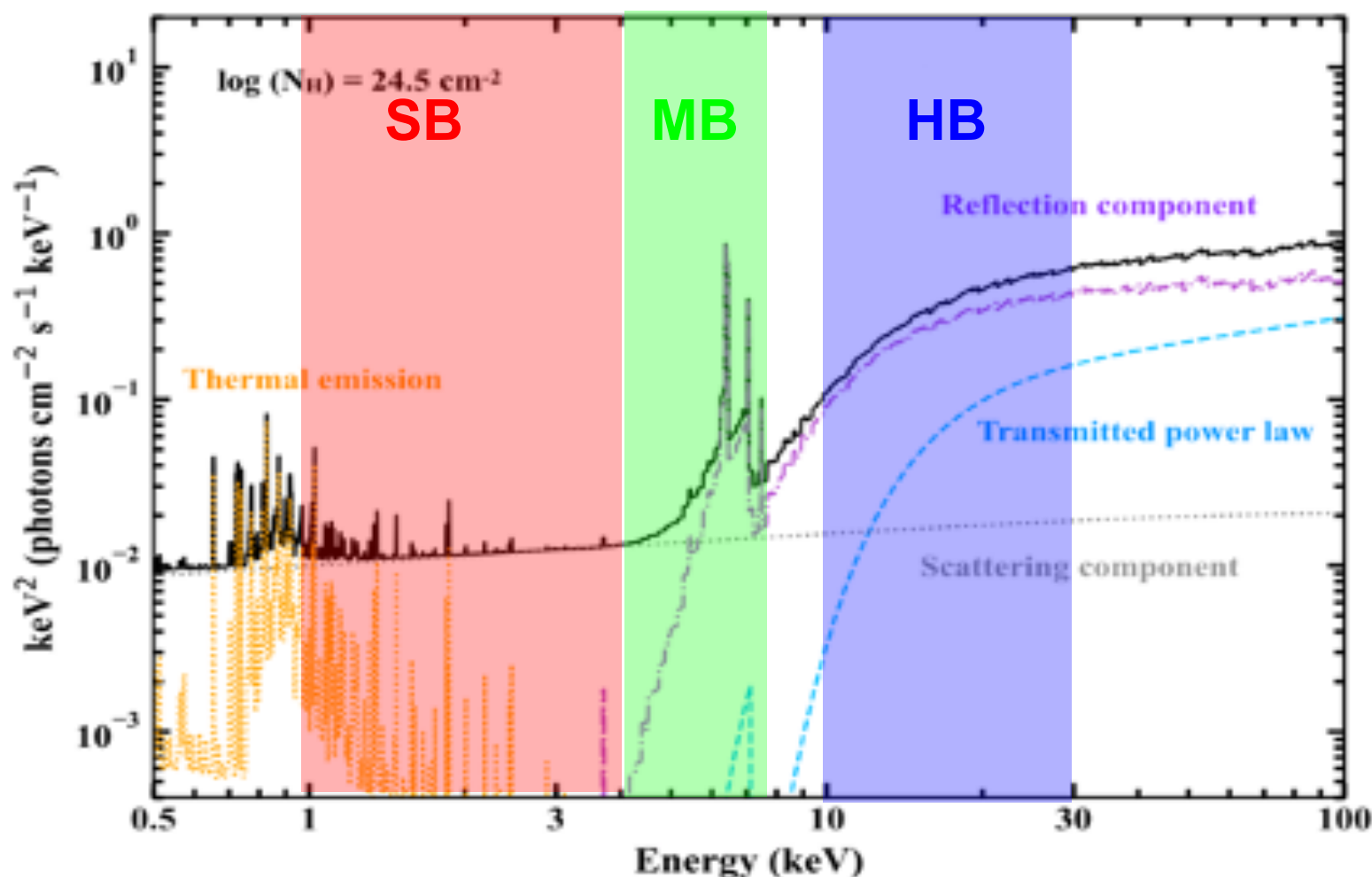
X-ray weakness could originate in (mildly) super Eddington ($\dot{M}/\dot{M}_{\text{Edd}} \sim 10$) accretion flows. In some models, the expected X-ray spectrum is exceptionally soft with slopes as steep as $\Gamma \sim 4-5$, low coronal plasma temperatures: $kT_e < 30$ keV, and high bolometric corrections: $k_{\text{Bol}} > 1000$

Stacking in CDFS

Rest frame stacking in customized energy ranges to enhance the probability of detecting specific/characteristic features.

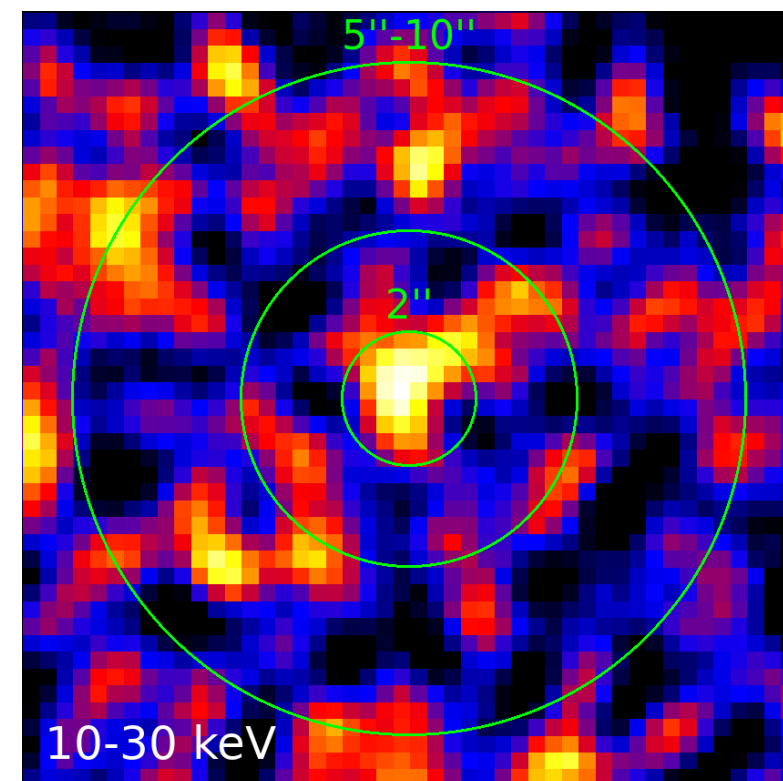
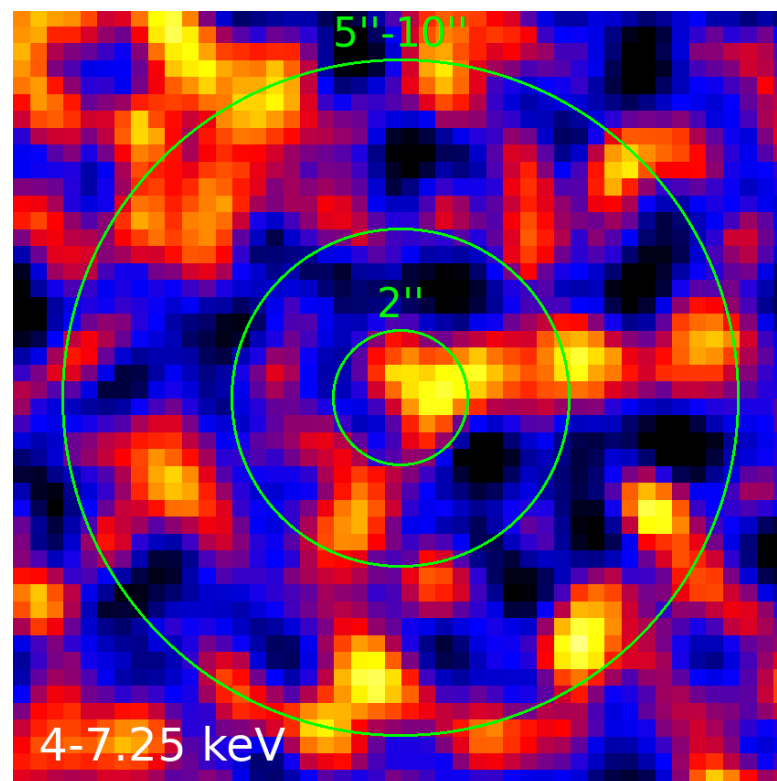
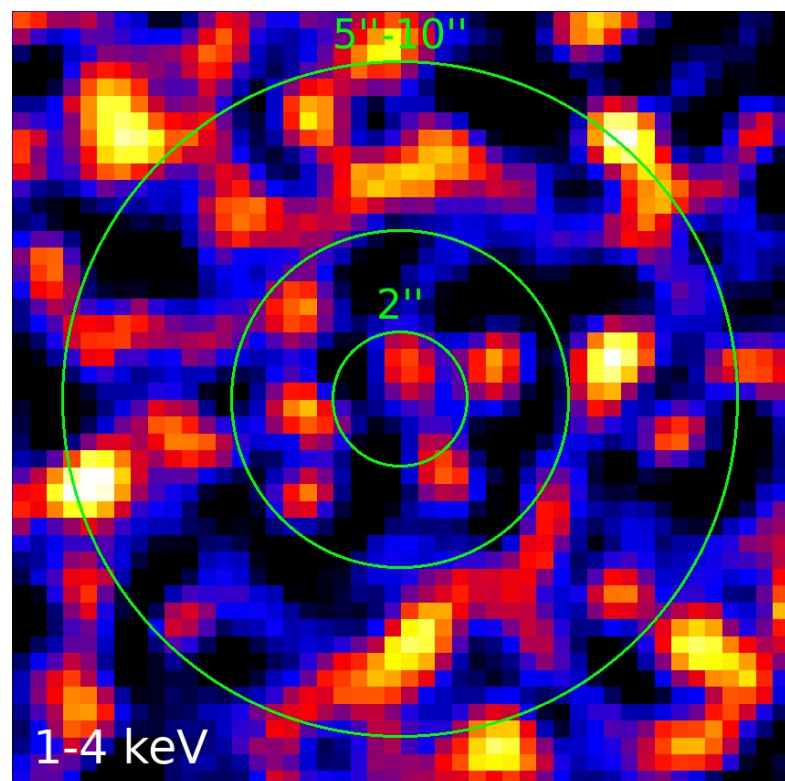
Within the assumption/prior they are heavily obscured, the “optimal” rest—frame bands are **1-4 keV (SB)**, **4-7.25 keV (MB)**, **10-30 keV (HB)**

We consider Type 2 AGN in CDFS and Type 1 AGN in the combined CDFS+CDFN (maximize the product of X-ray exposure and publicly available data).



Results

36 Type 2 AGN over the redshift range $\sim 2-9$ $z_{\text{median}}=4.1$



Src Counts
Bkg. Counts

< 16.6
 263.8 ± 3.8

< 41.7
 295.5 ± 4.0

123 ± 38
 1272.2 ± 8.3

Hard Band: Poisson Significance: 99.98%
Gaussian Significance: 99.97%

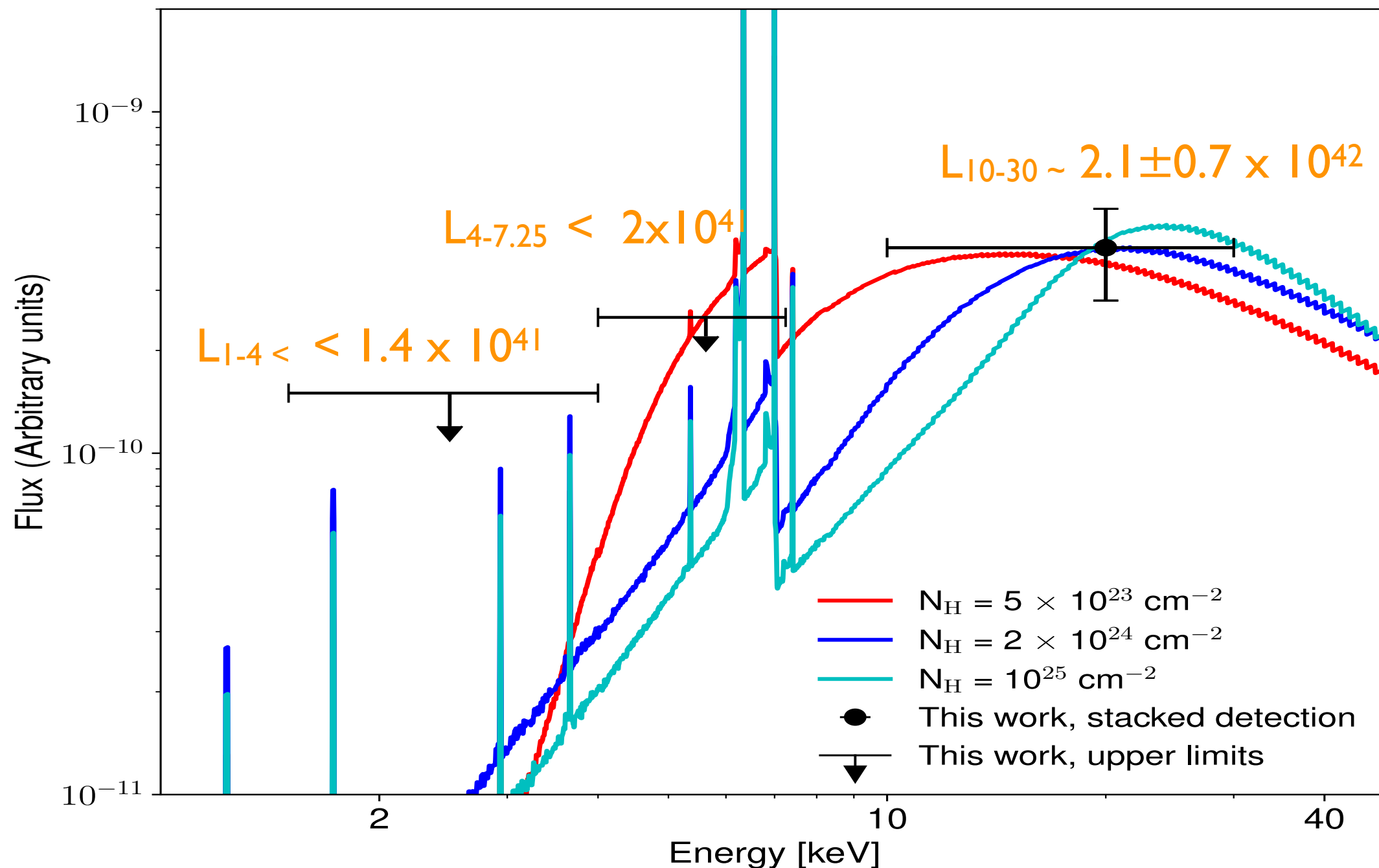
Undetected in the rest-frame Soft (1-4 keV) and Medium (4-7.25 keV) bands.

3 sigma detection confirmed by simulations

$F_{10-30} \sim 1.15 \pm 0.36 \times 10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1}$ 209 Megasec of stacked exposure

X-ray Spectrum

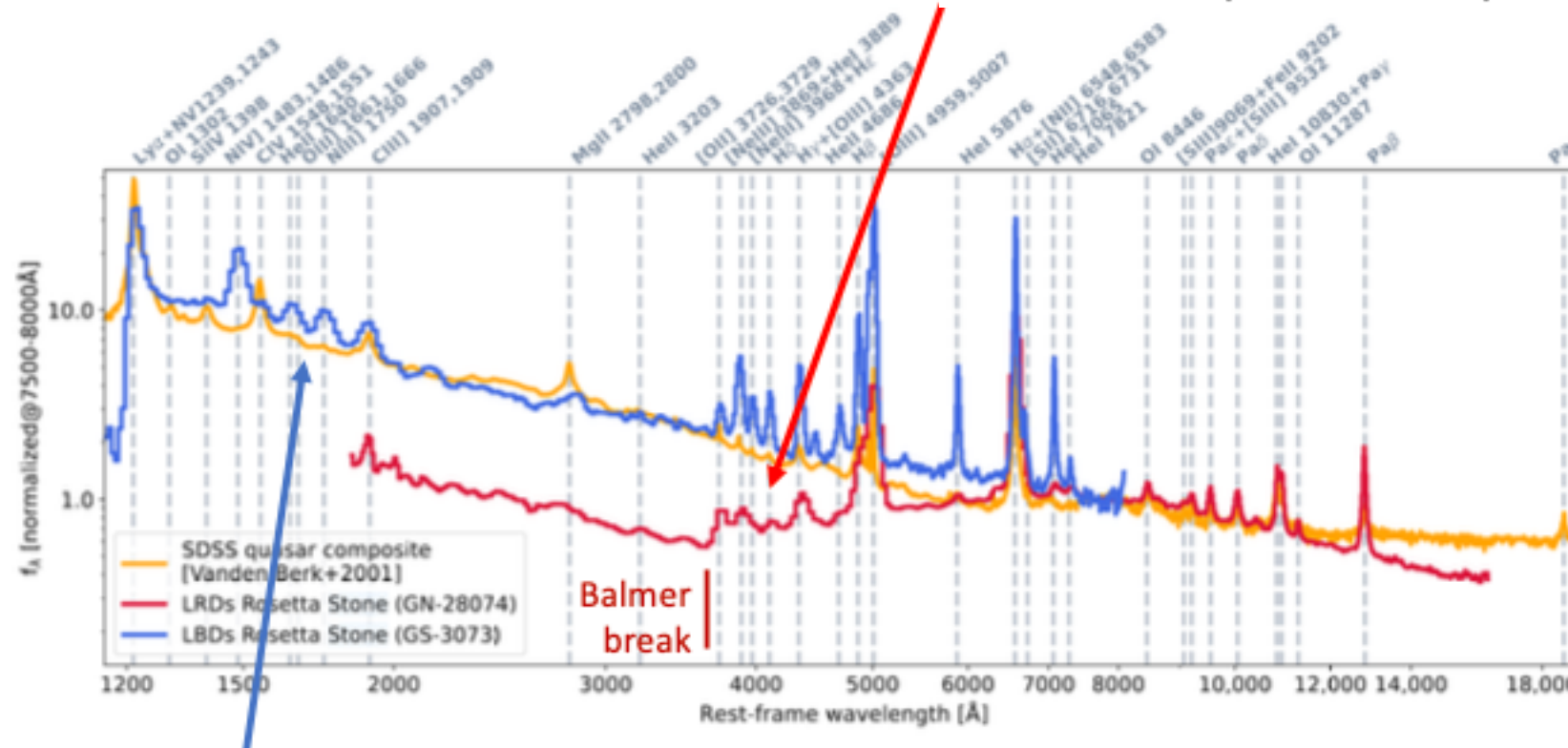
The average fluxes and luminosities in the rest frame 10-30 keV band were computed by averaging the instrument response at the source positions for two different assumptions on the obscuring column density: 10^{24} and 10^{25} cm^{-2} (transmission and reflection dominated):



Type I remains undetected!!!

SED properties of the new broad line AGN population found by JWST

10%-30% are “Little Red Dots”:
blue UV slope & red optical slope



Hainline+24
Kocevski+24
Matthee+24
Brazzini+26

70%-90% are “Little Blue Dots”
blue UV and optical slopes (similar to normal QSOs)

LRDs:

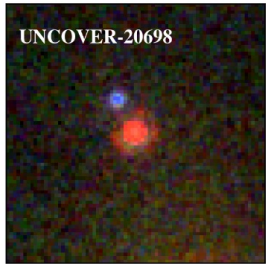
- Red rest-frame optical slope $\beta_{\text{opt}} > 0$ at $>2\sigma$
- Blue rest-frame UV slope with $-2.8 < \beta_{\text{UV}} < -0.37$ (to exclude brown dwarfs, to avoid dust reddened systems)
- Compactness, $F_{444W}(0.5'')/F_{444W}(0.25'') < 1.8$, or $\text{Reff} \leq 0.06''$
- Have a broad Balmer line component without a counterpart in [OIII]

LBDs:

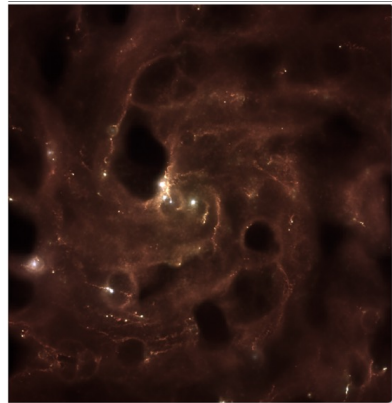
- Blue rest-frame optical slope $\beta_{\text{opt}} < 0$ at $>2\sigma$
- Blue rest-frame UV slope with $\beta_{\text{UV}} < -0.37$
- Compactness, using the same tests as for LRDs
- Have a broad Balmer line component without a counterpart in [OIII]
- *Are not detected in the X-ray data from the ultra-deep Chandra fields. (To differentiate LBD from normal quasars, which meet all the bullets above)*

Multiple seeding processes and early growth paths in different systems, different environments, at different epochs

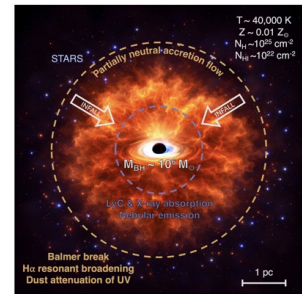
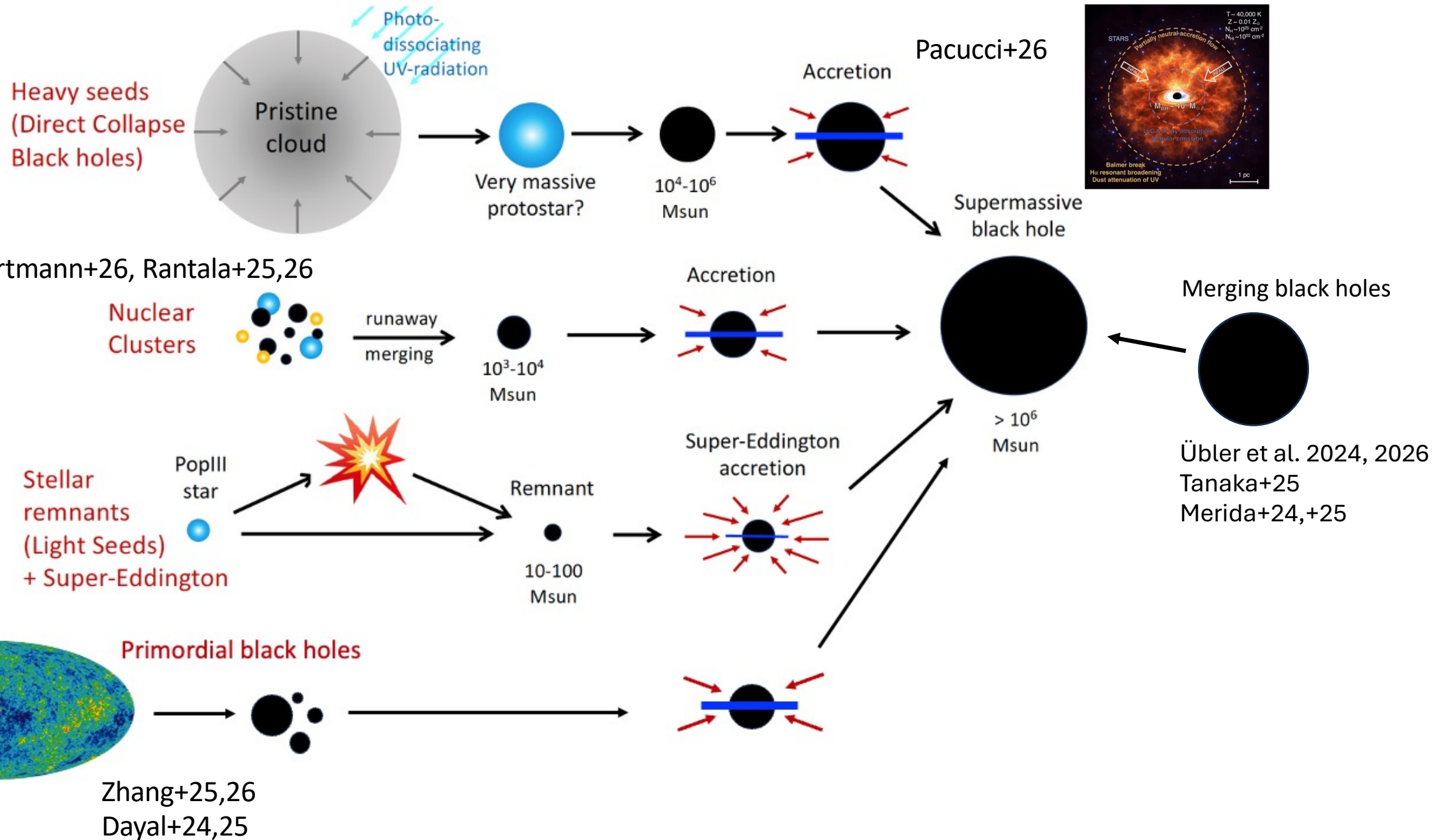
Baggen+26



Begelman & Dexter '26



Schneider+23
Trinca+24,25
Banik+19



Science with XRISM

XRISM

X-ray Astronomy Satellite



XMA
X-ray Mirror
Assembly

Resolve
microcalorimeter

Xtend
CCD imager

Science with XRISM

XRISM

X-Ray Imaging and Spectroscopy Mission

JAXA/NASA with ESA participation • launched 6 Sept 2023 UT

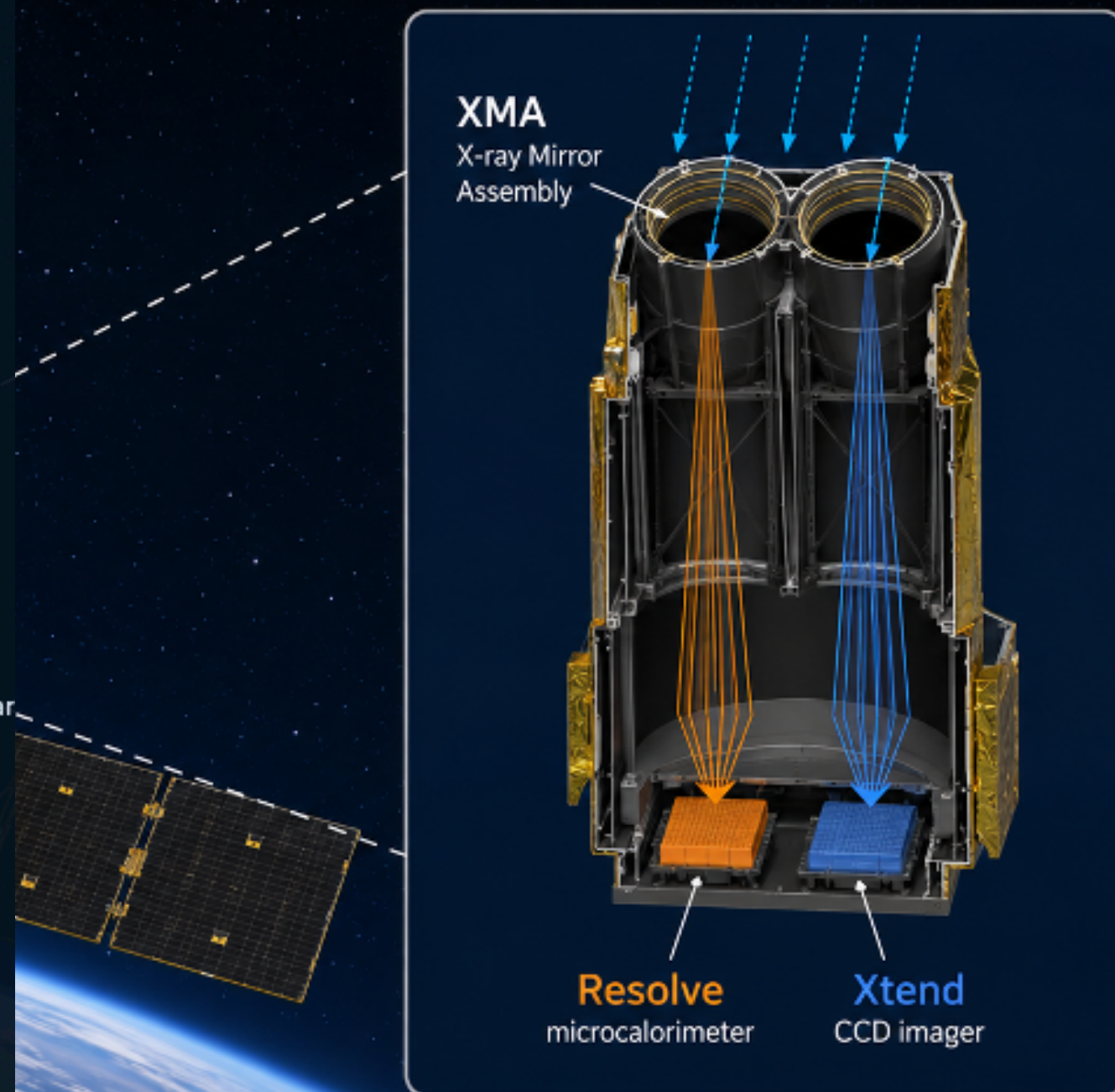
RESOLVE: non-dispersive spectroscopy

$\Delta E \approx 5 \text{ eV FWHM}$

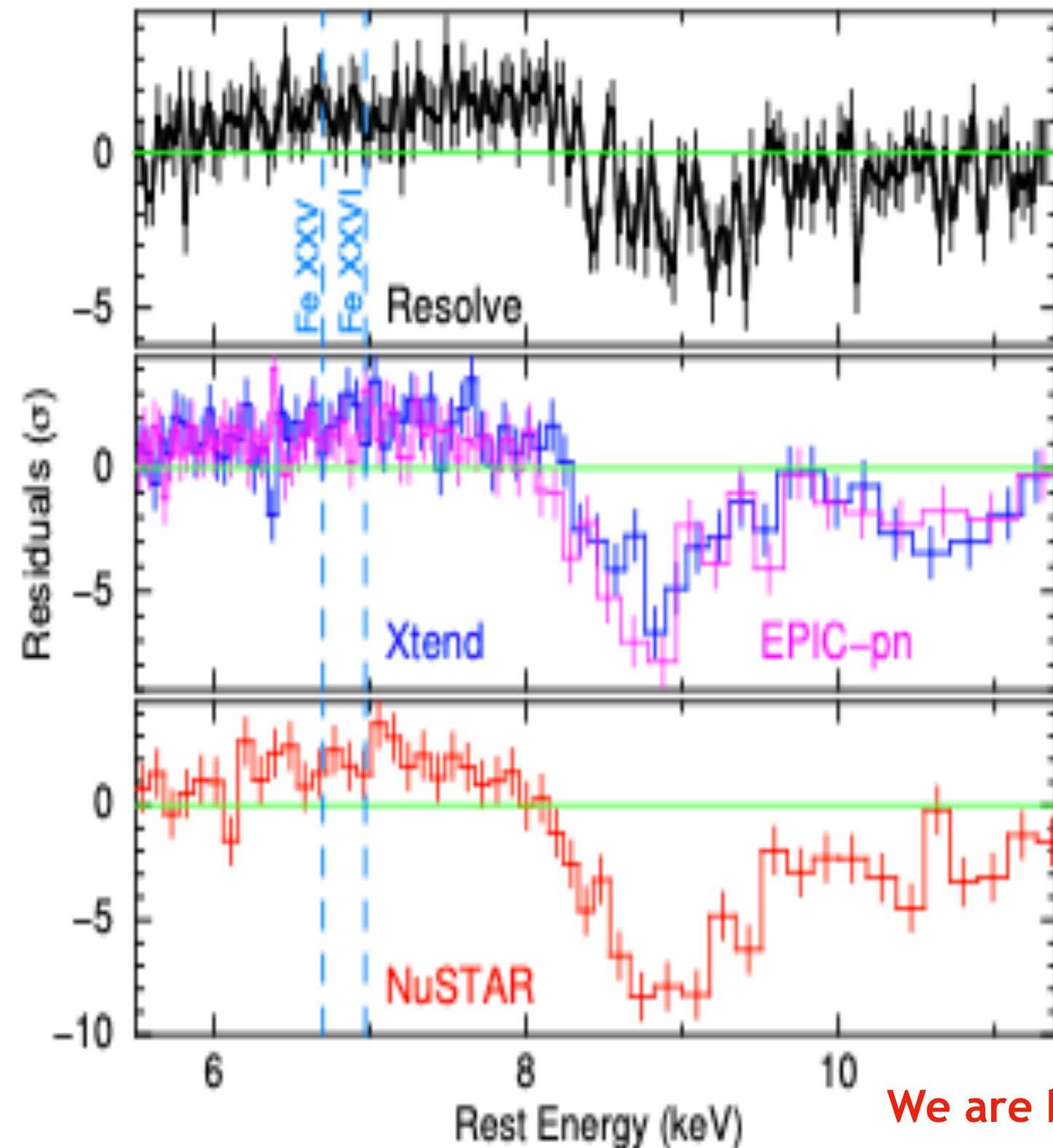
over most of the 1.7–12 keV band; requirement/reference <7 eV at 6 keV

- **Detector:** 6×6 X-ray microcalorimeter; 35 science + 1 calibration pixel
- **Operation:** ~50 mK; photon-by-photon measurements in a cryogenic dewar
- **FOV / PSF:** 3.1'×3.1'; HPD ~1.3'; $A_{\text{eff}} \sim 180 \text{ cm}^2$ @ 6 keV
- **Xtend:** simultaneous CCD imaging, 38'×38', 0.4–12 keV

Doppler scale: $\Delta v \approx c \cdot \Delta E / E \approx 225 \text{ km s}^{-1}$ @ Fe-K (6.7 keV)



PDS 456



Simultaneous XRISM/XMM-Newton/NuSTAR iron-K line profiles of PDS 456.

Strong absorption troughs are observed between 8.4–9.4 keV in the quasar rest frame.

The expected energies of the **He** and **H-like** iron lines are at 6.70 keV and 6.97 keV (dashed vertical lines).

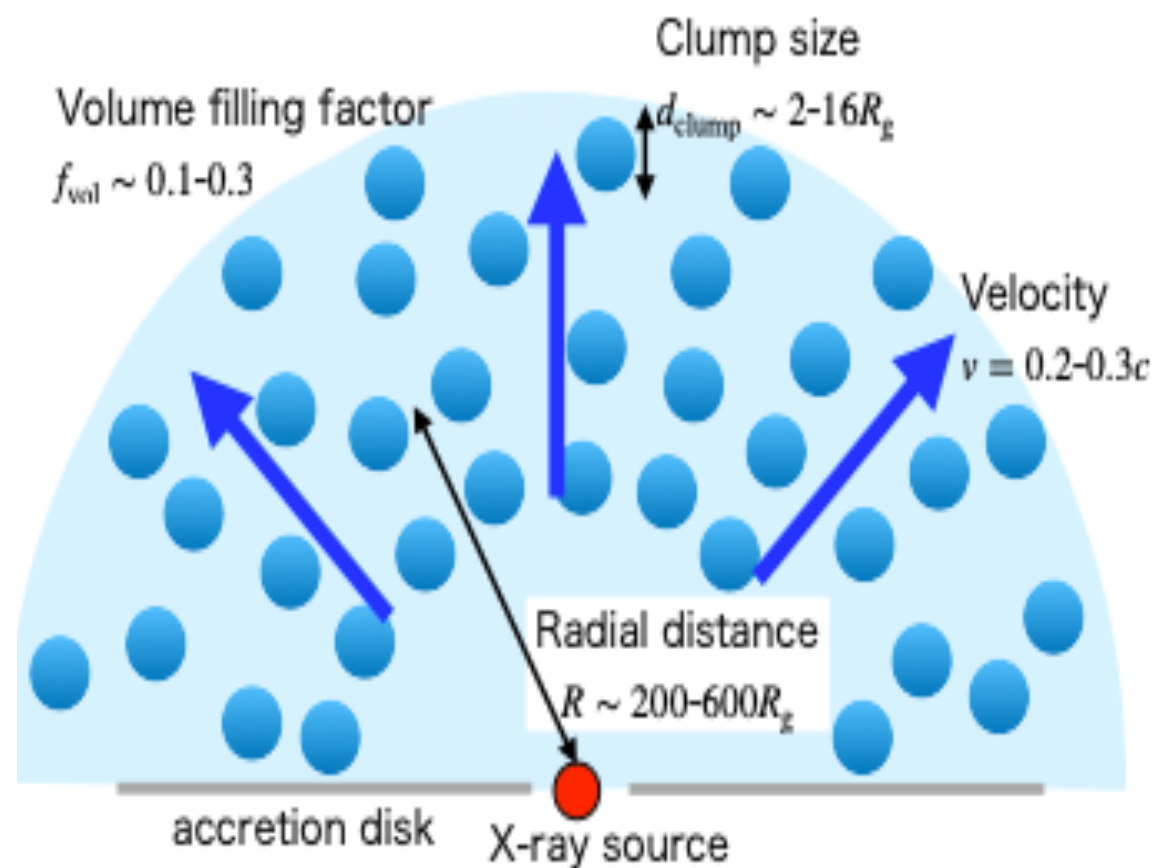
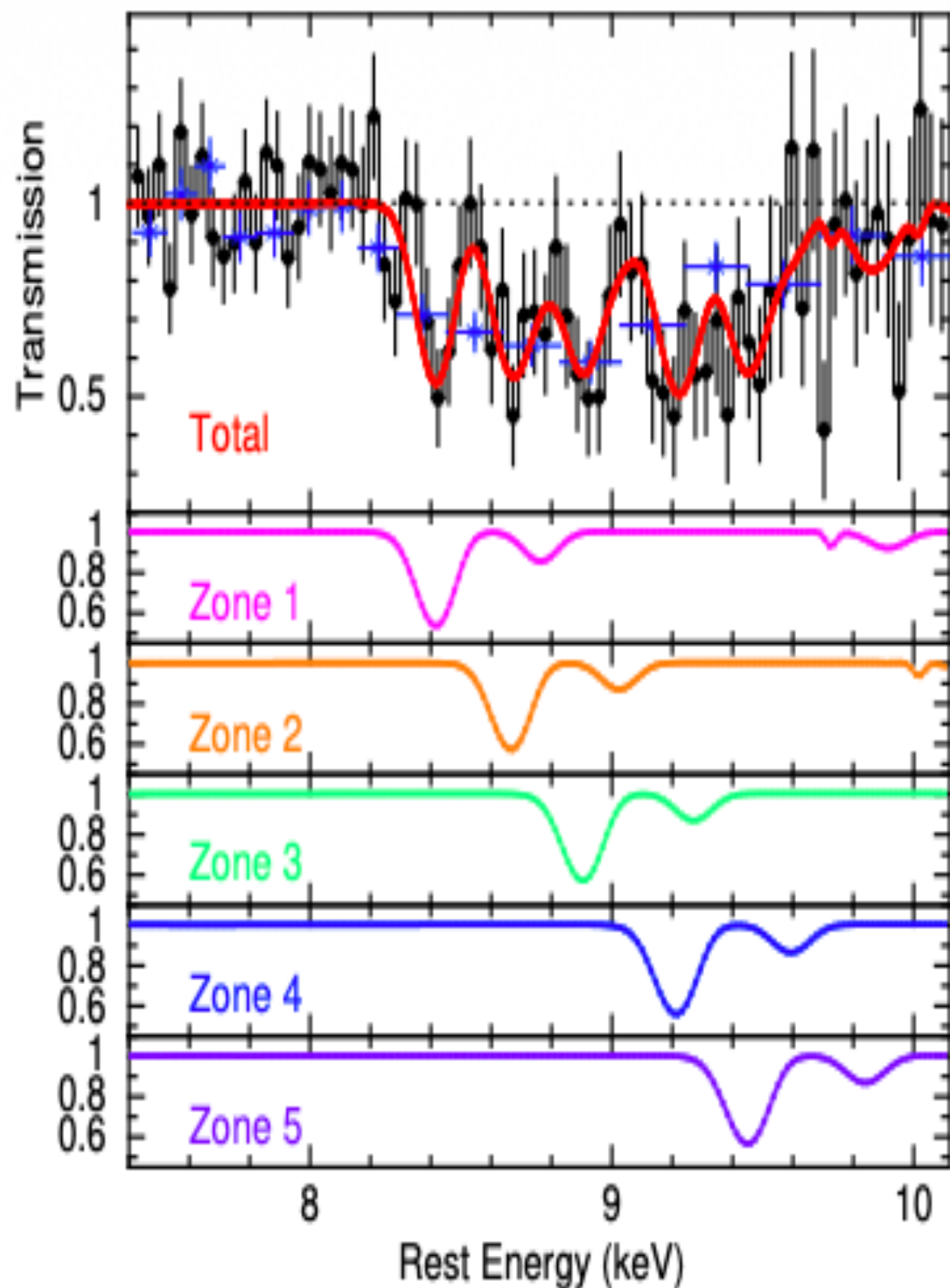
This implies a range of blue-shifted velocities between 0.2 and 0.3 c

The continuum model was determined by combining Xtend onboard XRISM and NuSTAR provides broadband spectra ranging from 0.4 keV to 40 keV.

A broad emission feature can also be discerned below 8 keV.

We are beginning to watch winds being launched

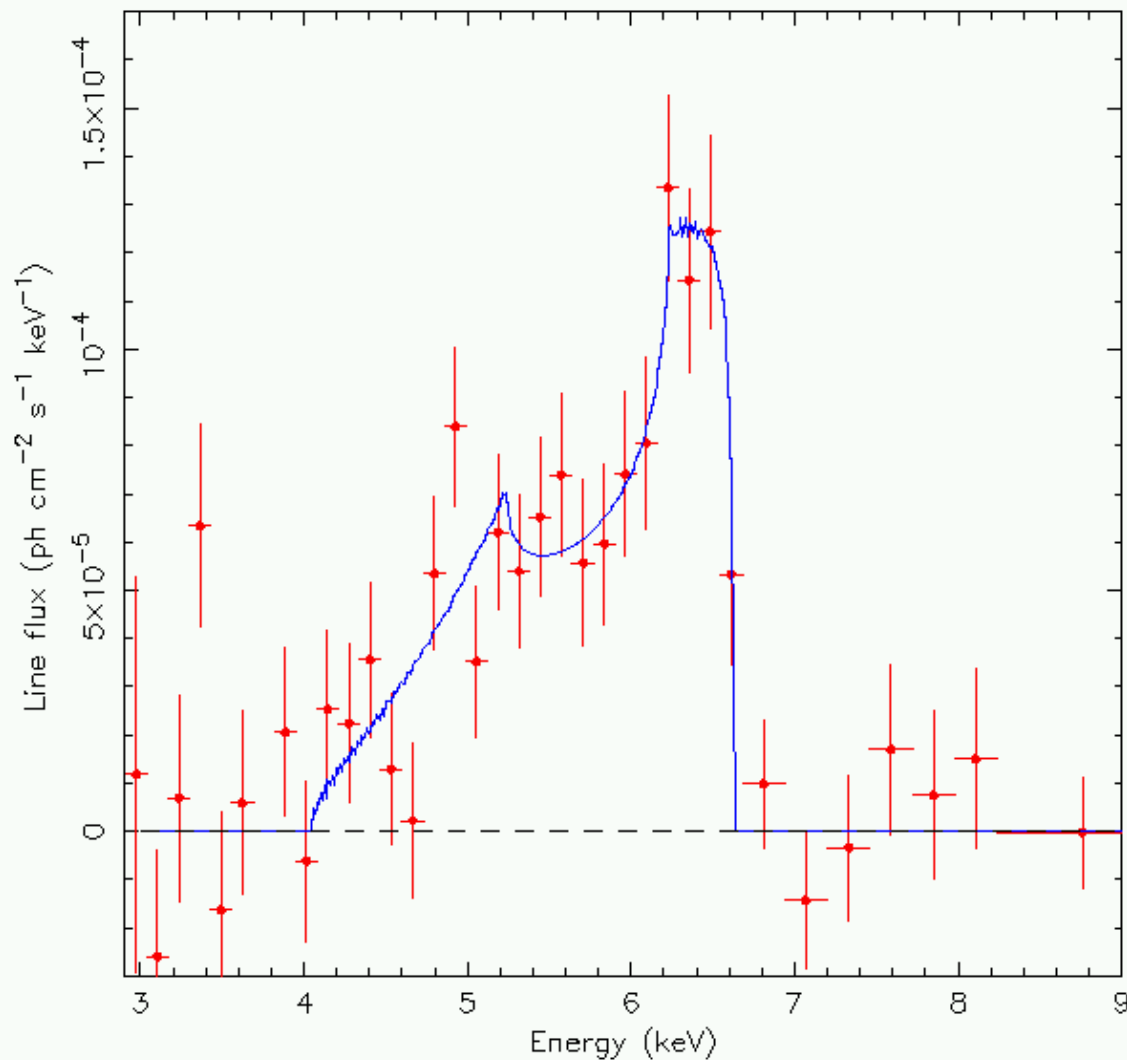
XRISM collaboration 2025



The wind structure is highly inhomogeneous, inferred to consist of up to a million clumps, each $(0.2-1.2) \times 10^{15}$ cm in size, located $(2-4) \times 10^{16}$ cm from the X-ray source.

The mass outflow rate is about $60-170 M_{\odot} \text{ yr}^{-1}$. The wind kinetic power $> 10^{47} \text{ erg s}^{-1}$, exceeding the Eddington luminosity limit and more than enough to significantly impact the galaxy.

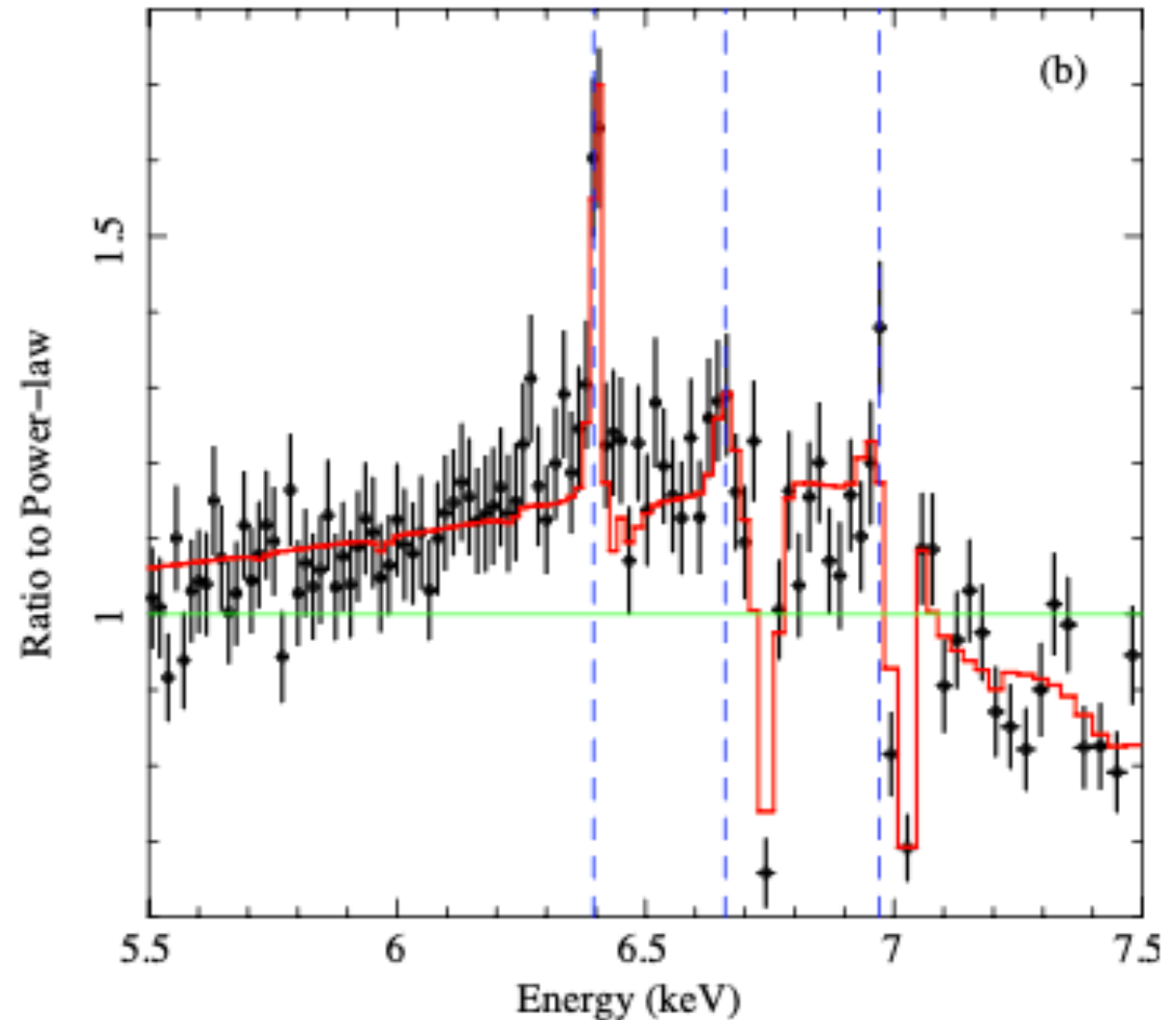
MCG-6-30-15



Tanaka+1995

A relativistic broad asymmetric Iron line was discovered by the Japanese satellite ASCA, in the innermost region of a Schwarzschild BH.

Later XMM data suggested a rapidly spinning Kerr object

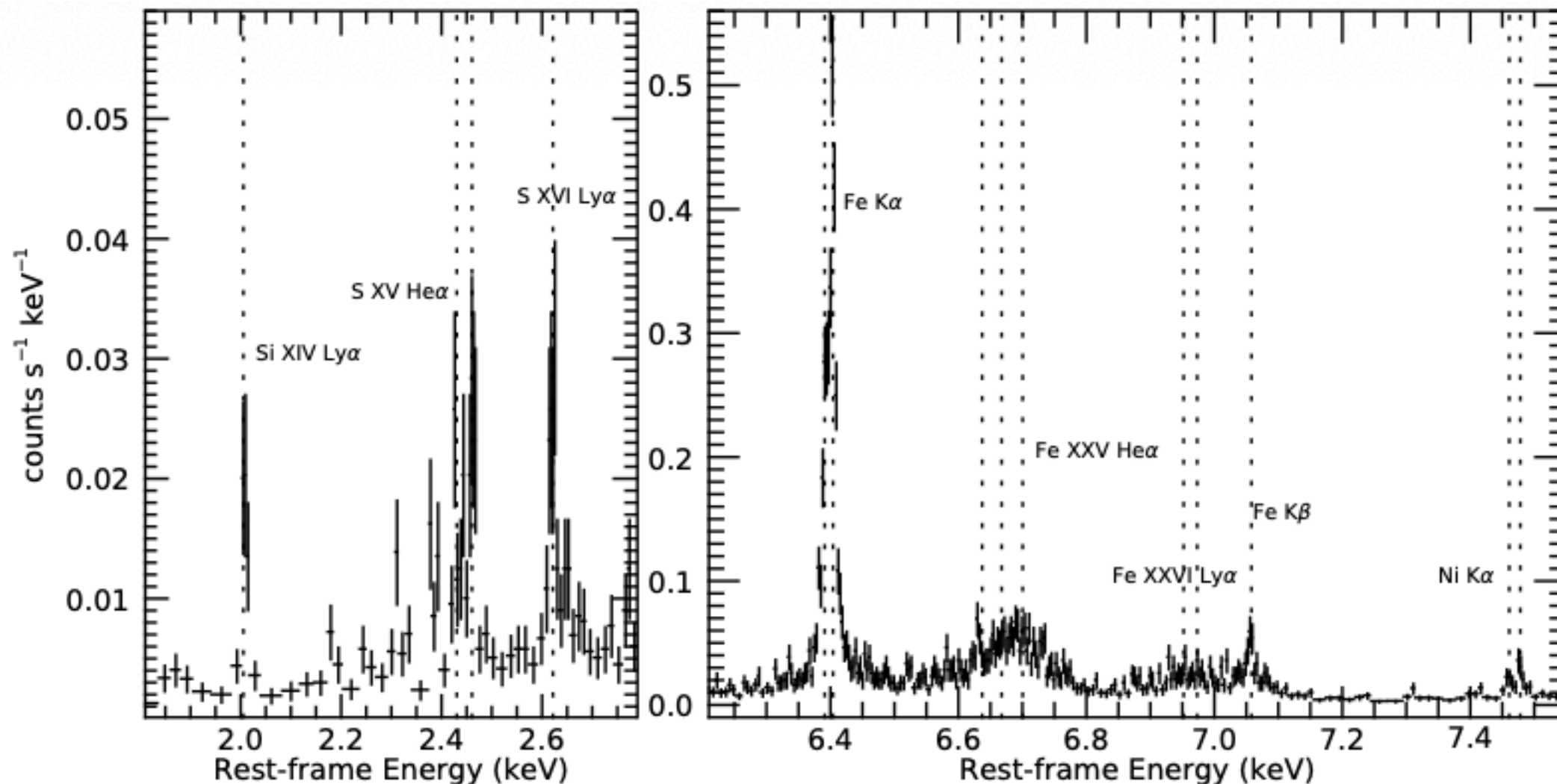


Brenneman+2026

Joint XRISM+XMM+NuSTAR confirms the need for a relativistically broadened Iron line. On top of that outflowing highly ionized gas (FeXXV and FeXXVI) is detected with a velocity of about -2300 km s^{-1} . Rotating BH is preferred, though spectral variability is playing a key role

NGC 1068

The prototypical Type 2 (Compton thick) Seyfert Galaxy



Bianchi+2026

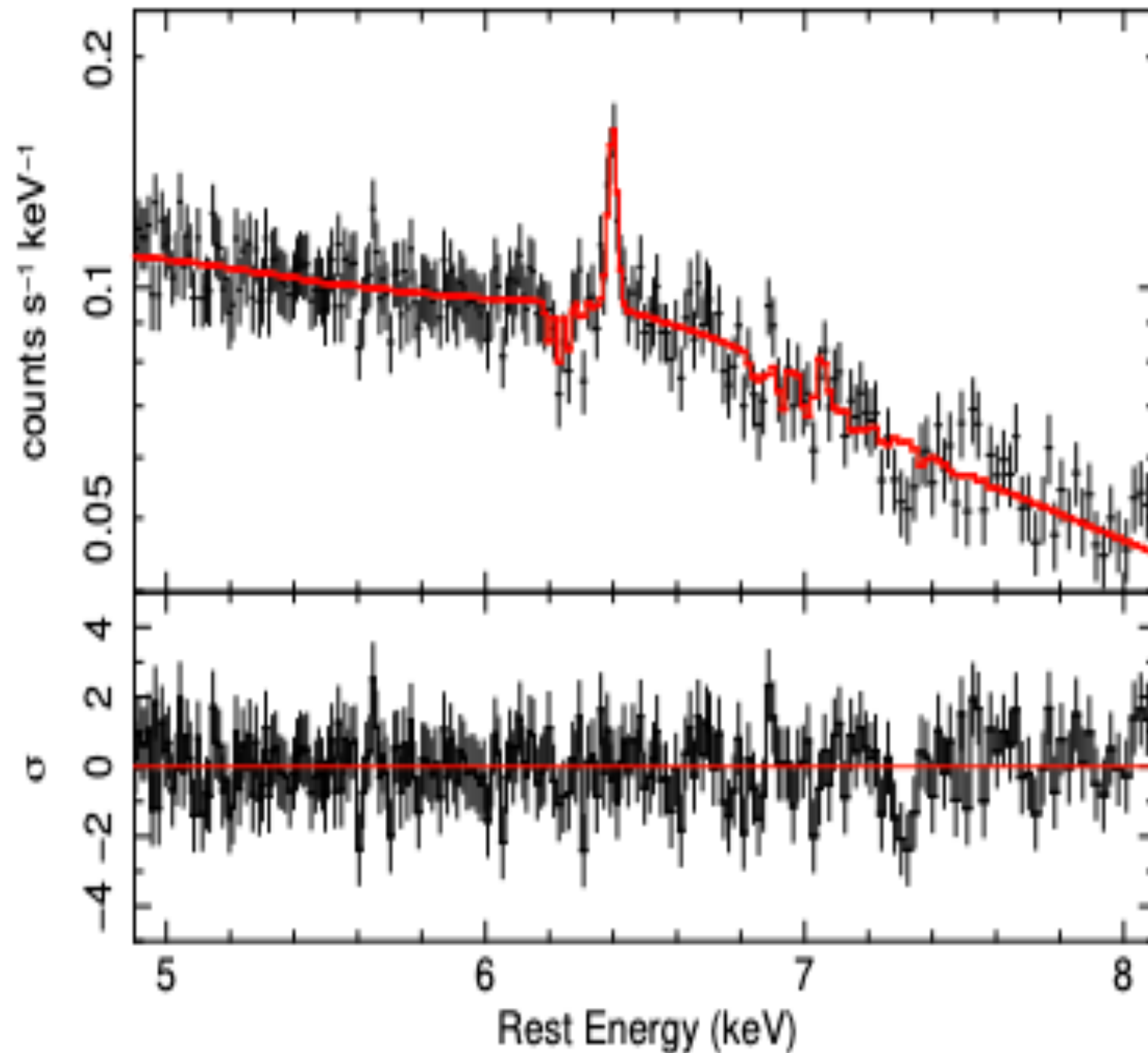
The iron-K emission reveals a stratified circum-nuclear environment in which neutral and highly ionized components arise in physically distinct regions.

The neutral Fe K fluorescence originates predominantly in optically thin or mildly Compton-thick material, despite the persistently Compton-thick line-of-sight obscuration, indicating a geometrically complex cold reprocessor.

The “torus” is probably not a torus — at least not a simple one

The highly ionized iron emission lines trace a fast component consistent with a bipolar outflow on parsec scales, which may represent an efficient channel for feedback.

MKN 509



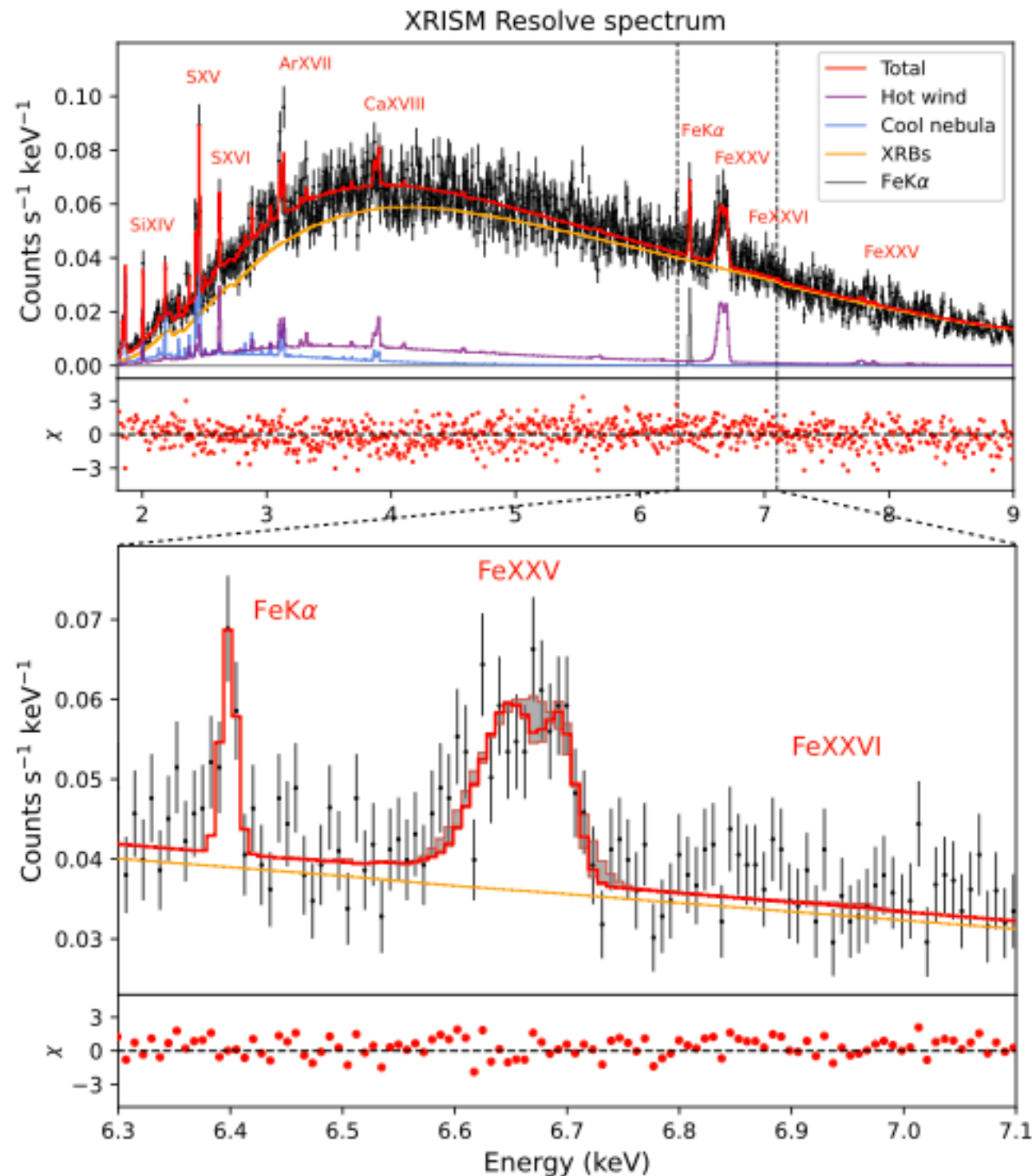
Absorption features at rest-frame energies of $E \sim 6.2$ keV. The gas is redshifted relative to the systemic velocity, corresponding to an inflow of material with $v_{\text{IN}} \sim 11,000$ km s⁻¹, located within the inner few thousand gravitational radii.

The inner edge of the emitting region to distances greater than $\sim 27 R_G$

Dadina+2026

M82

A prototypical nearby ($z < 0.001$) Starburst Galaxy



Thermal gas pressure is driving the multiphase wind due to SN and fast stellar winds

$$kT \sim 2 \times 10^7 \text{ K} \quad M \sim 6 \times 10^5 M_{\odot} \quad \sigma \sim 600 \text{ km s}^{-1}$$

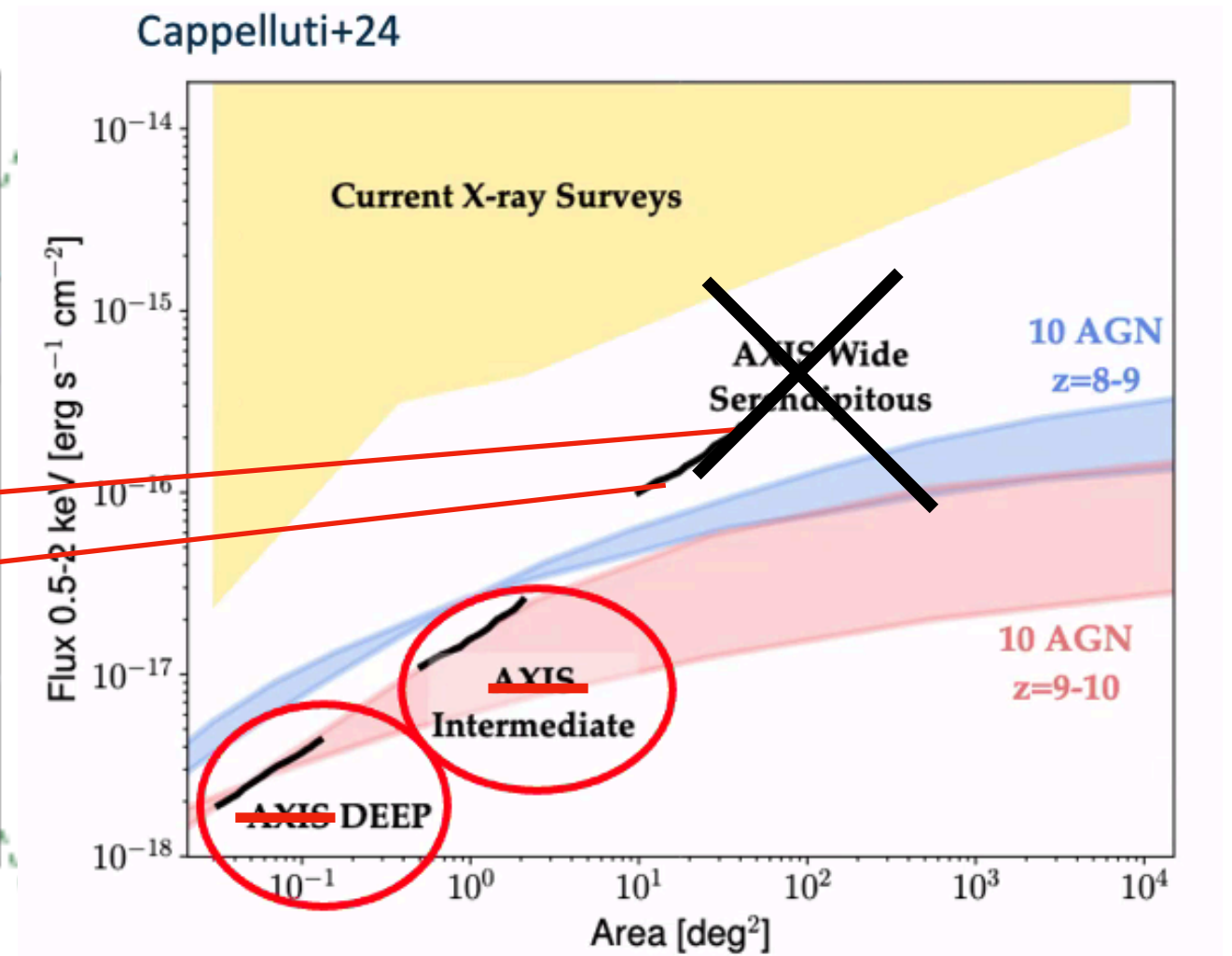
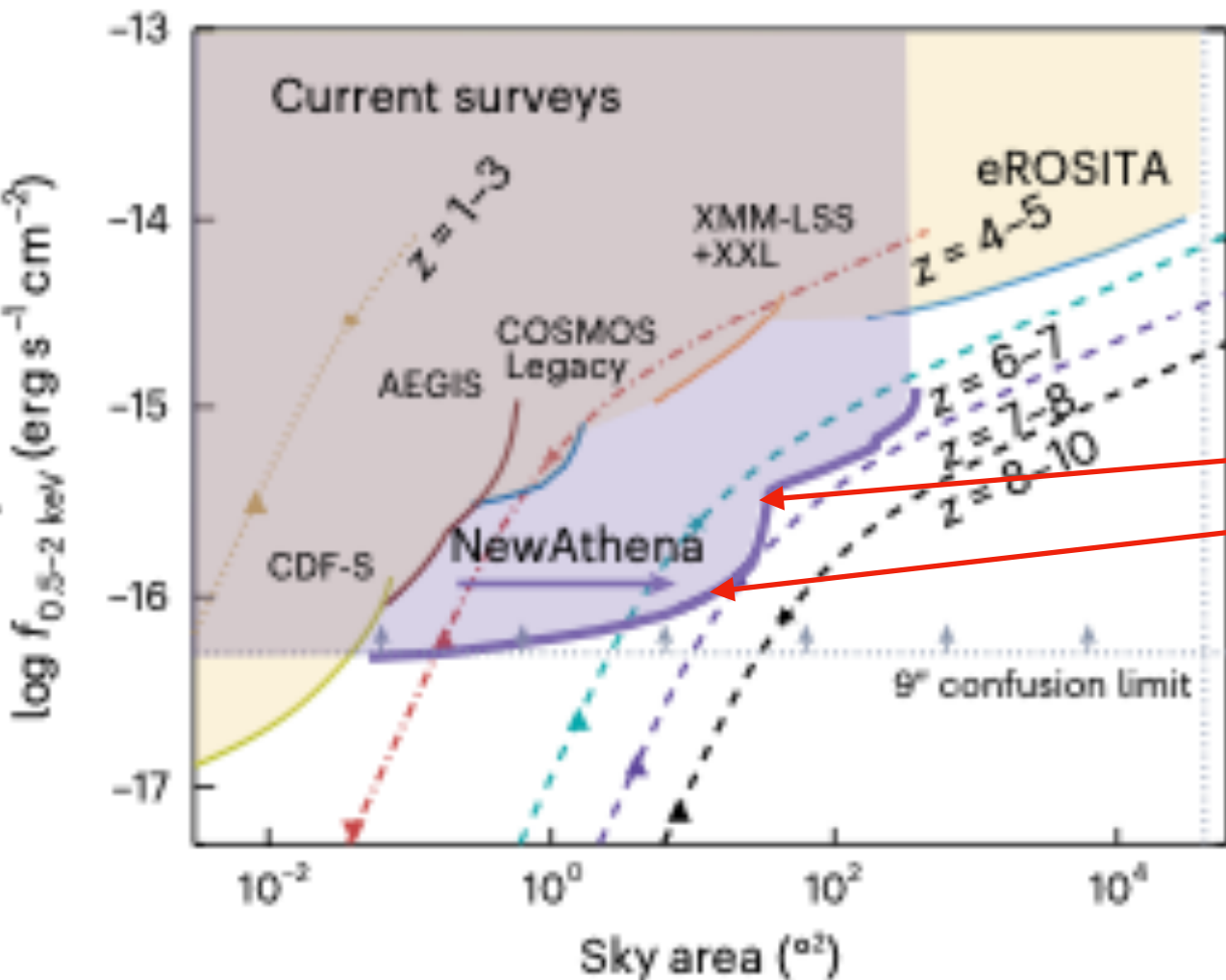
From the size of the Fe XXV-emitting region the hot gas outflow is of the order of $4 M_{\odot} \text{ yr}^{-1}$, carrying a total energy of $dE/dt \sim 2 \times 10^{42} \text{ erg s}^{-1}$

The energy is sufficient to drive the molecule, atomic and ionized outflow while “moving” about $2 M_{\odot} \text{ yr}^{-1}$ hot gas in the IGM

About 60% of the SN energy must be thermalised in hot gas

Perspectives: NewATHENA WFI

Cruise+25 NewAthena SRDT



DETECTOR: CCD

FIELD OF VIEW 40' x 40'

RESOLUTION: 8-9'' HEW @ 1 keV

X-ray counterpart to JWST/Euclid/Roman deep fields

Rare populations: high-z, Compton-thick, transients

AGN luminosity functions and environment

JWST reveals candidate galaxies and black holes; WFI supplies the X-ray census

Perspectives: **NewATHENA XIFU**

NewAthena/X-IFU: from spectra to physical diagnostics

XRISM demonstrates microcalorimeter astrophysics; X-IFU adds area, imaging, and sample size.

RESOLUTION

<4 eV @ 7 keV

Field of View

4' diam.

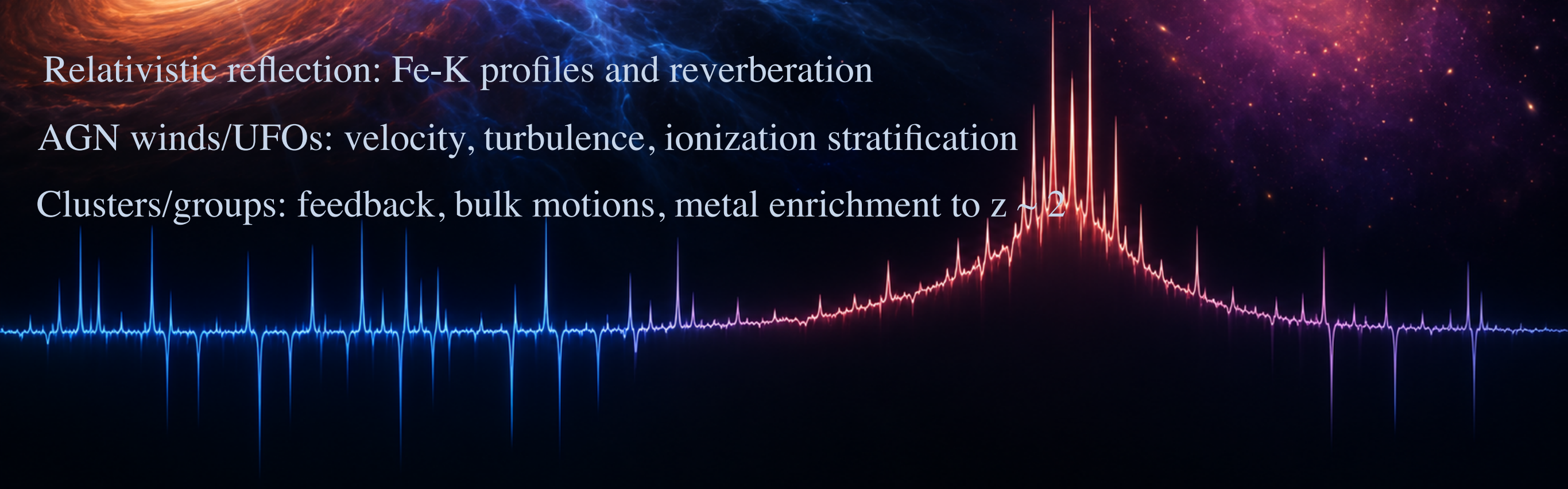
DETECTOR

~50 mK

Relativistic reflection: Fe-K profiles and reverberation

AGN winds/UFOs: velocity, turbulence, ionization stratification

Clusters/groups: feedback, bulk motions, metal enrichment to $z \sim 2$



Summary

Black Holes too massive, too early, too naked, too weird, ...

- Plausible physical scenarios are being developed to explain these new, intriguing findings
- JWST has revealed that in the early Universe, everything happened quicker, more dynamically, and more dramatically than previously thought

X-ray spectroscopy is becoming an abundance diagnostic for galactic nuclei

- XRISM has moved high-resolution AGN spectroscopy from line detection to physical diagnostics of geometry, dynamics, and feedback.
- JWST reveals where the first black holes and galaxies are; XRISM shows what high-resolution X-ray spectroscopy can do; NewAthena will connect both into a physical and statistical picture of cosmic growth.