High-redshift AGNs & galaxies behind the lensing cluster Abell 2744

with Chandra

Orsolya Kovács, Masaryk University

Abell 2744

- gravitational lens
- Observed with JWST (Early Release Science program)
    - high galaxy density at z>9
    - discovery of a new population of galaxies: "little red dots" at z=3-9
- follow-up Chandra observations
    - >2 Ms (~3 weeks) data
    - X-rays are a ubiquitous signature of BH accretion

I. A $z \approx 10$ AGN in UHZ1

*Ákos Bogdán, Andy D. Goulding, Priyamvada Natarajan, **Orsolya E. Kovács**, Grant R. Tremblay, Urmila Chadayammuri, Marta Volonteri, Ralph P. Kraft, William R. Forman, Christine Jones, Eugene Churazov, and Irina Zhuravleva*

Evidence for heavy seed origin of early supermassive black holes from a z ~ 10 X-ray quasar

2024, Nature Astronomy, 8, 126

II. A $z \approx 10$ AGN in GHZ9

***Orsolya E. Kovács**, Ákos Bogdán, Priyamvada Natarajan, Norbert Werner, Mojegan Azadi, Marta Volonteri, Grant R. Tremblay, Urmila Chadayammuri, William R. Forman, Christine Jones, and Ralph P. Kraft*

A Candidate Supermassive Black Hole in a Gravitationally Lensed Galaxy at z ≈ 10

2024, ApJL, 965L, 21K

III. "Little red dots" at $z \approx 3 - 8.5$

*Tonima Tasnim Ananna, Ákos Bogdán, **Orsolya E. Kovács**, Priyamvada Natarajan, Ryan C. Hickox:*

X-ray View of Little Red Dots: Do They Host Supermassive Black Holes?

2024, Submitted to ApJL


z ≅10 AGNs
behind Abell2744

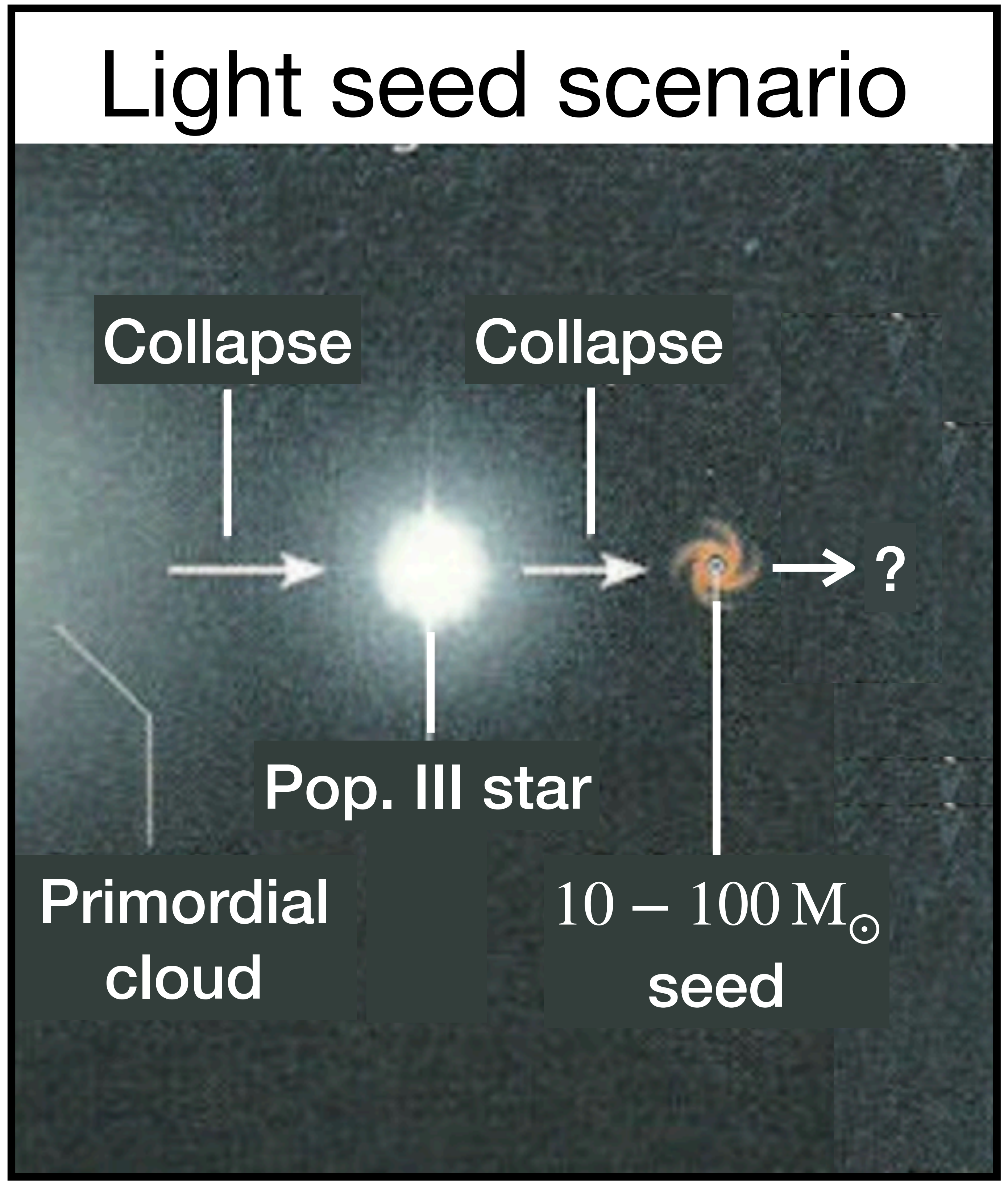
SMBH formation scenarios

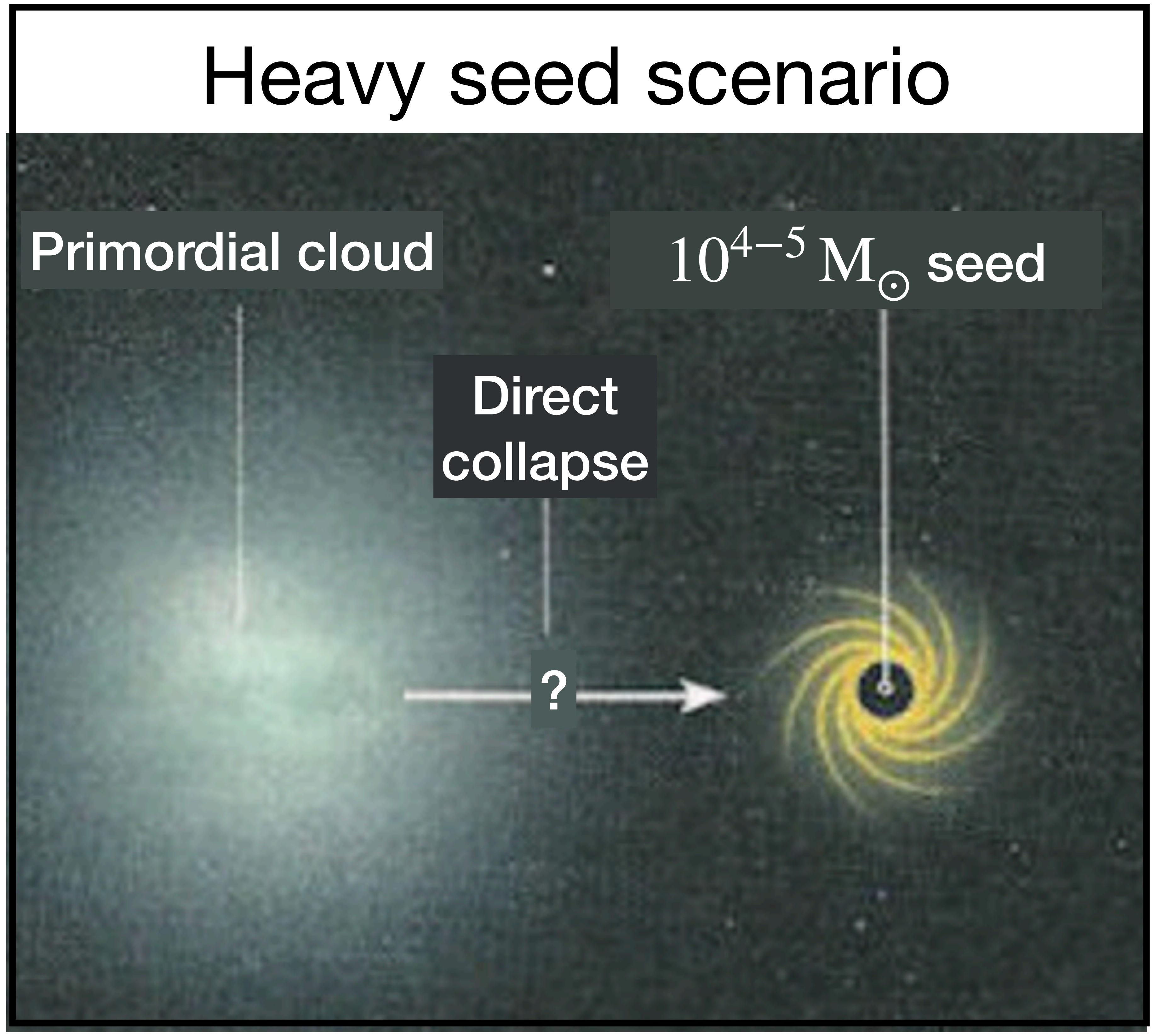
deep optical surveys:

more than 200 bright, $M_{\rm BH} \lesssim 10^9\,{\rm M}_\odot$ quasars at z > 6

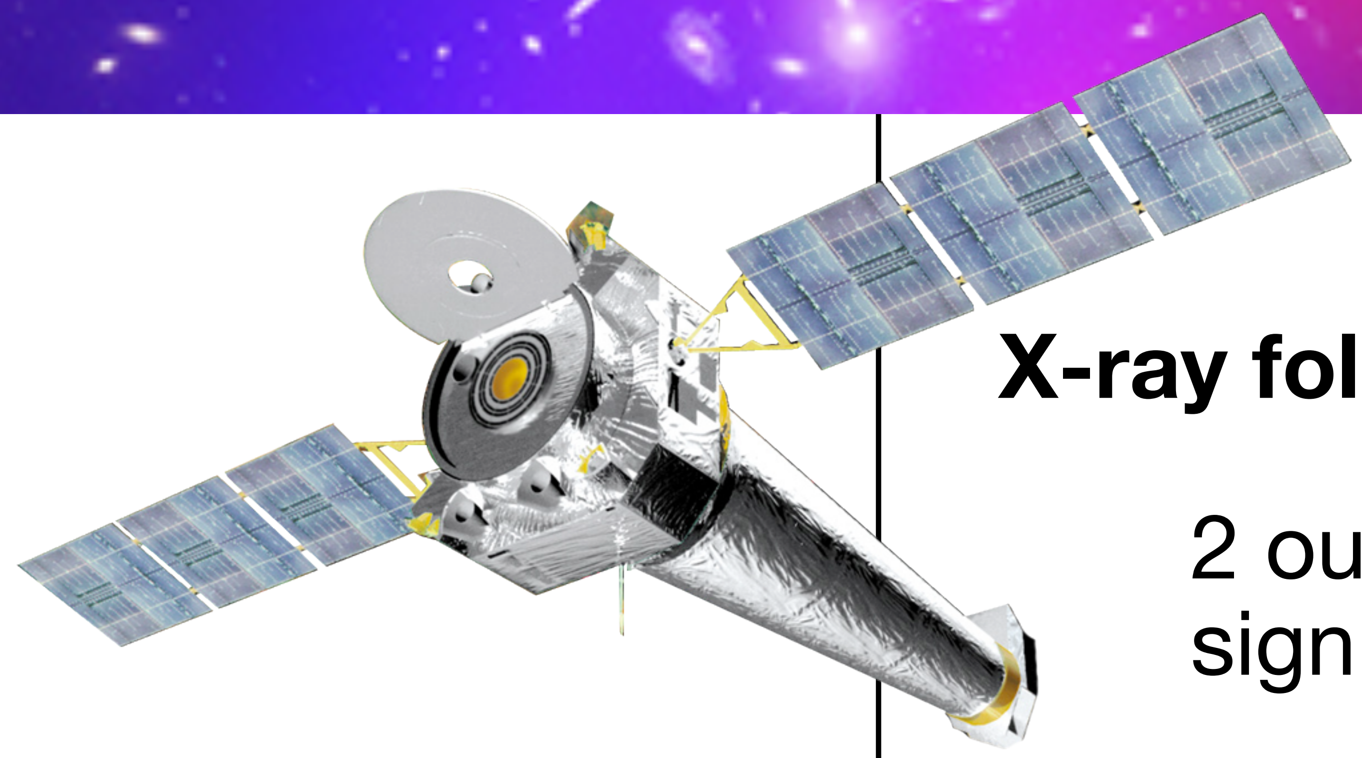
↓

accretion-powered black holes at the center of galaxies (BHs) already exist ~1 billion years after the Big Bang





Observations



X-ray follow-up with Chandra

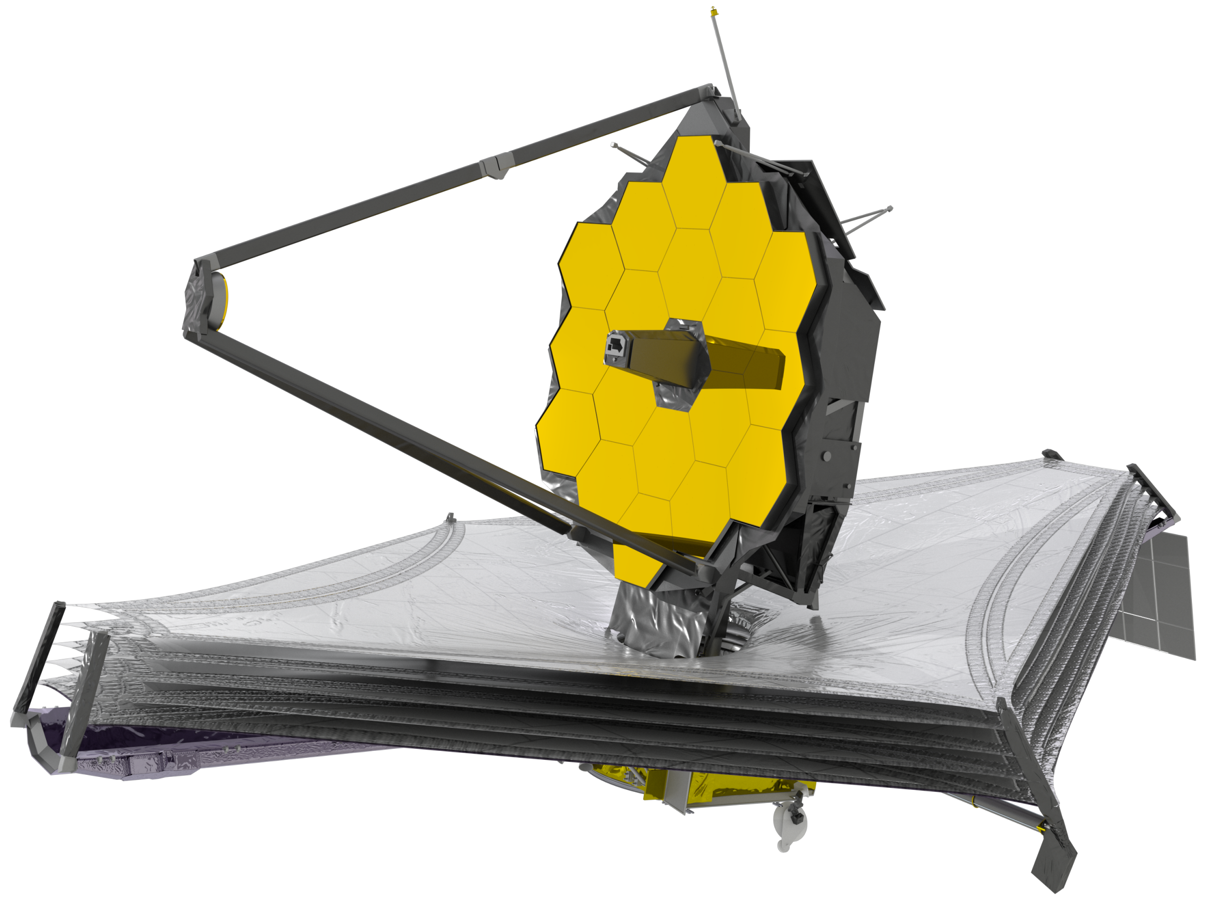
2 out of the 19 lensed galaxies show statistically significant X-ray emission

JWST UNCOVER survey

(Atek et al. 2023, Castellano et al. 2023)

19 z>9 lensed galaxies behind A2744

- photometric redshift
- physical properties from SED fitting (stellar mass, SFR)

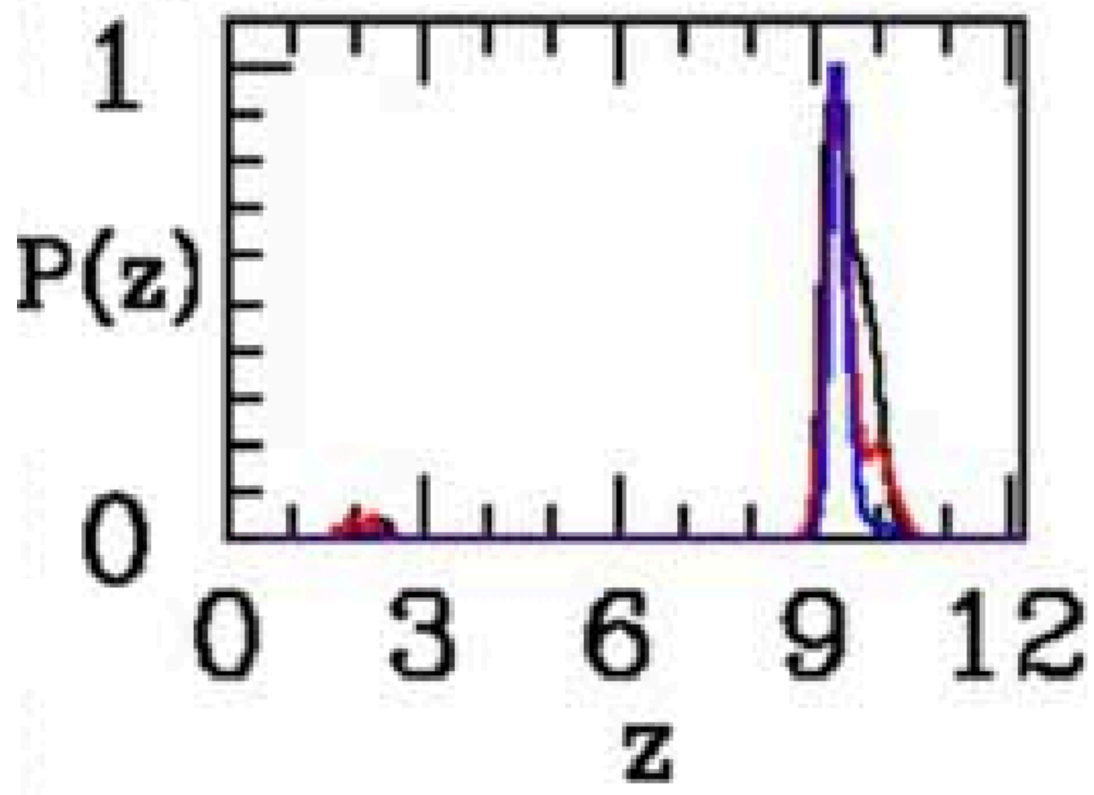


UHZ1

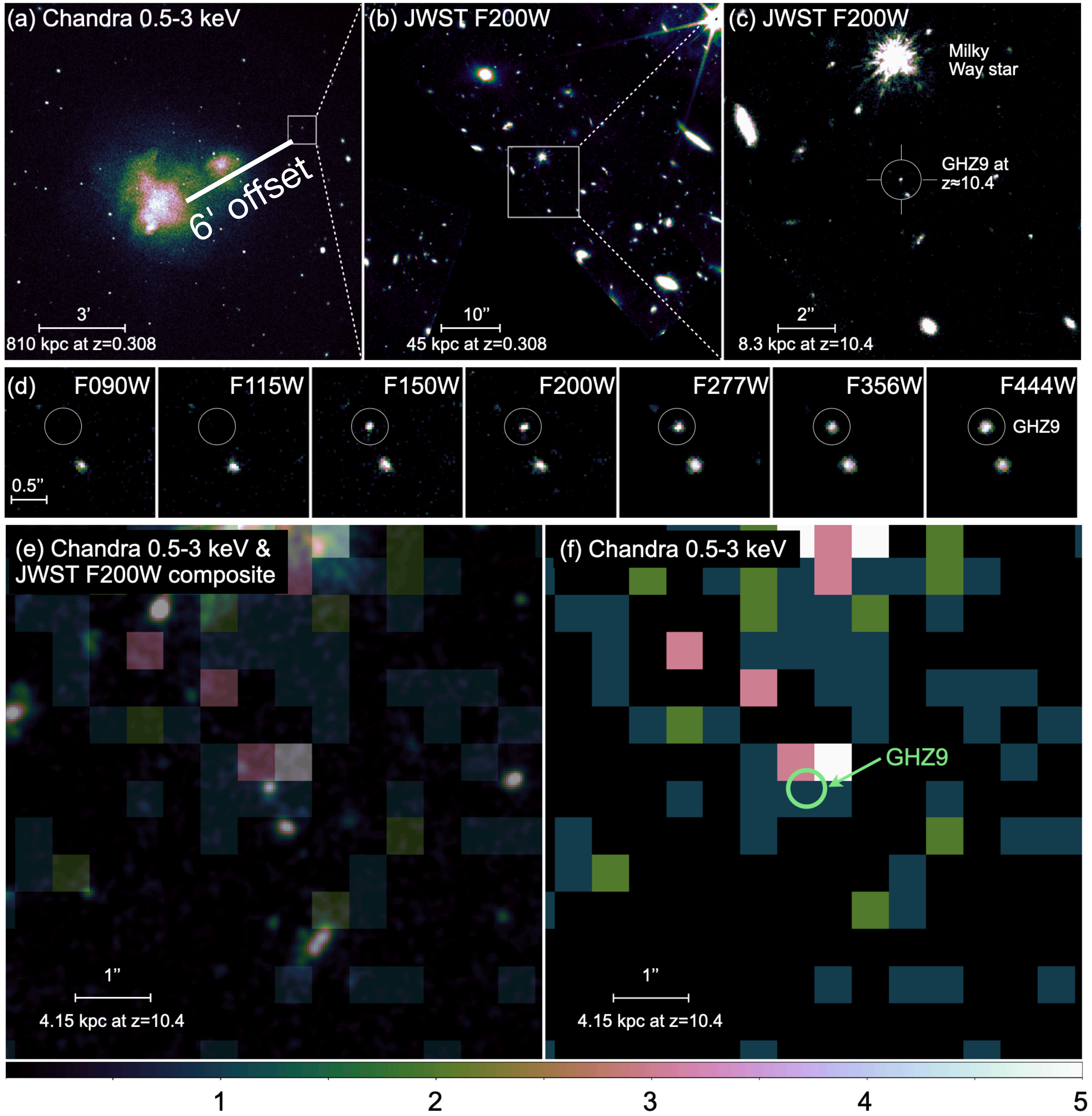
- $z_{\mathrm{spec}} = 10.07$ *spectroscopically confirmed*
- hard band detection (2-7 keV)

GHZ9

- $z_{\mathrm{phot}} \approx 10.4$
- soft band detection (0.5-3 keV)

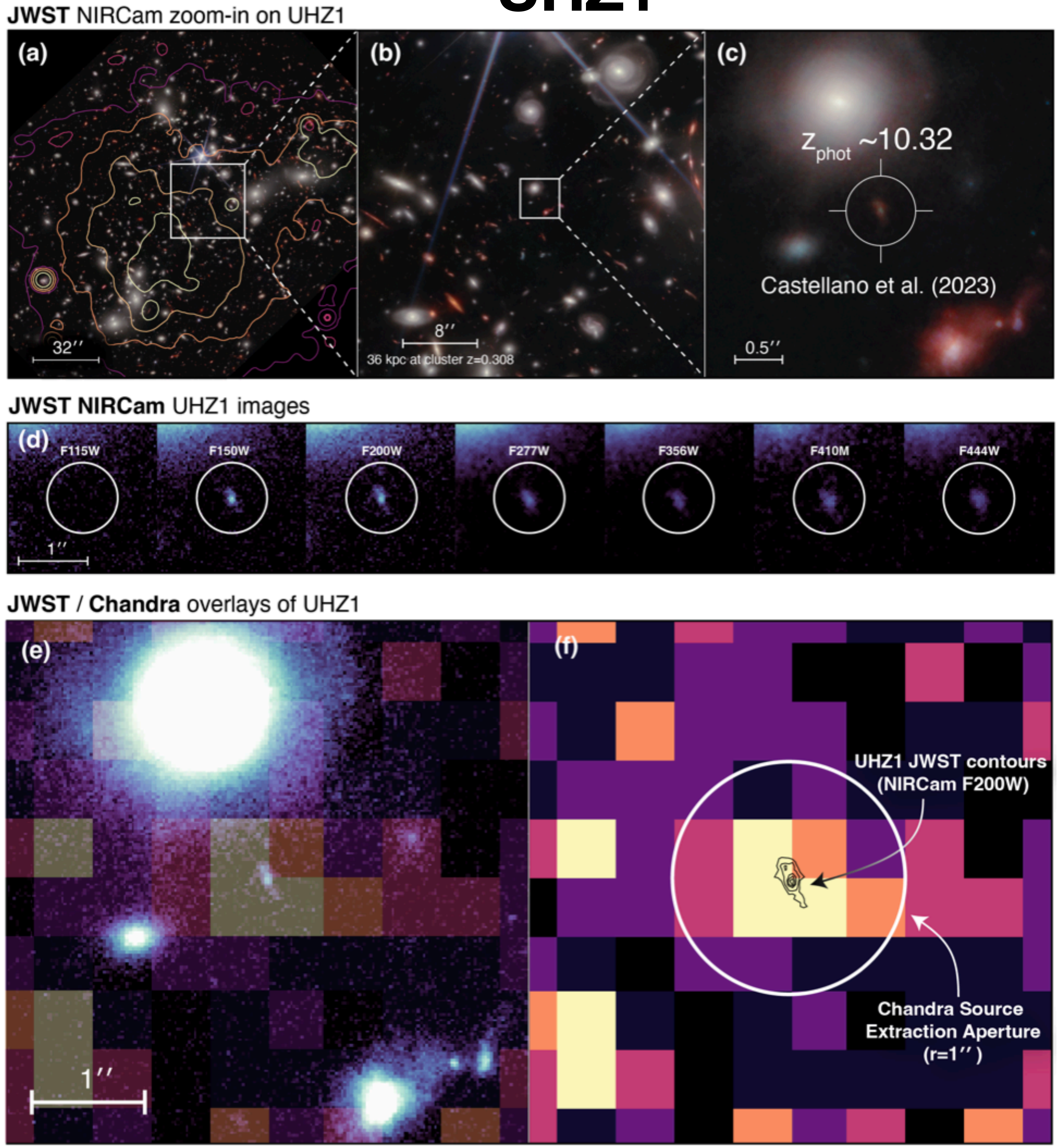


GHZ9



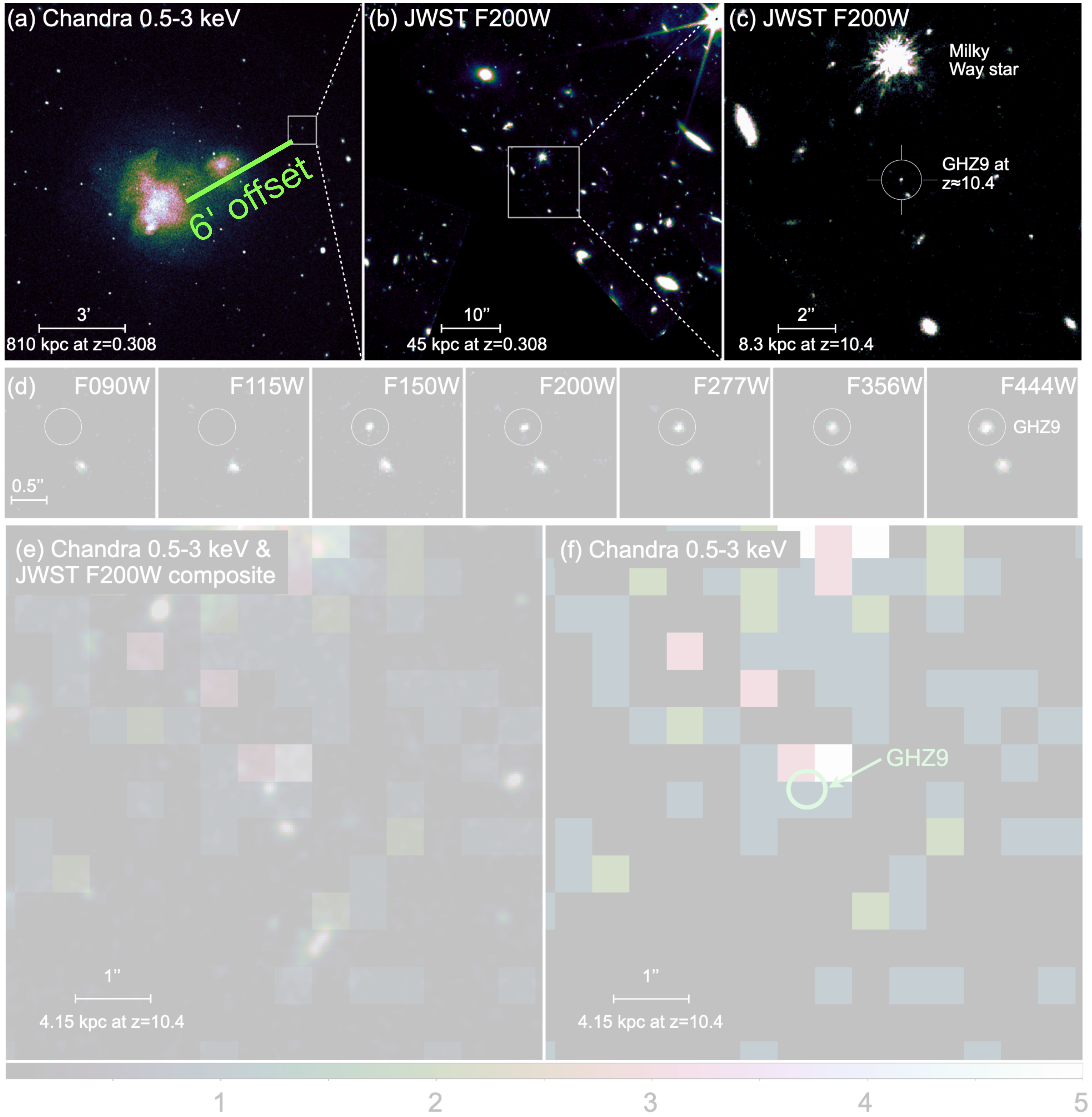
(a) Chandra 0.5-3 keV
6' offset
3'
810 kpc at z=0.308
(b) JWST F200W
10"
45 kpc at z=0.308
(c) JWST F200W
Milky Way star
GHZ9 at z≈10.4
2"
8.3 kpc at z=10.4
(d) F090W
F115W
F150W
F200W
F277W
F356W
F444W
GHZ9
0.5"
(e) Chandra 0.5-3 keV & JWST F200W composite
1"
4.15 kpc at z=10.4
(f) Chandra 0.5-3 keV
GHZ9
1"
4.15 kpc at z=10.4
1
2
3
4
5

UHZ1



JWST NIRCam zoom-in on UHZ1
(a)
32''
(b)
8''
36 kpc at cluster z=0.308
(c)
z_{phot} ~10.32
Castellano et al. (2023)
0.5''
JWST NIRCam UHZ1 images
(d)
F115W
F150W
F200W
F277W
F356W
F410M
F444W
1''
JWST / Chandra overlays of UHZ1
(e)
1''
(f)
UHZ1 JWST contours (NIRCam F200W)
Chandra Source Extraction Aperture (r=1'')

GHZ9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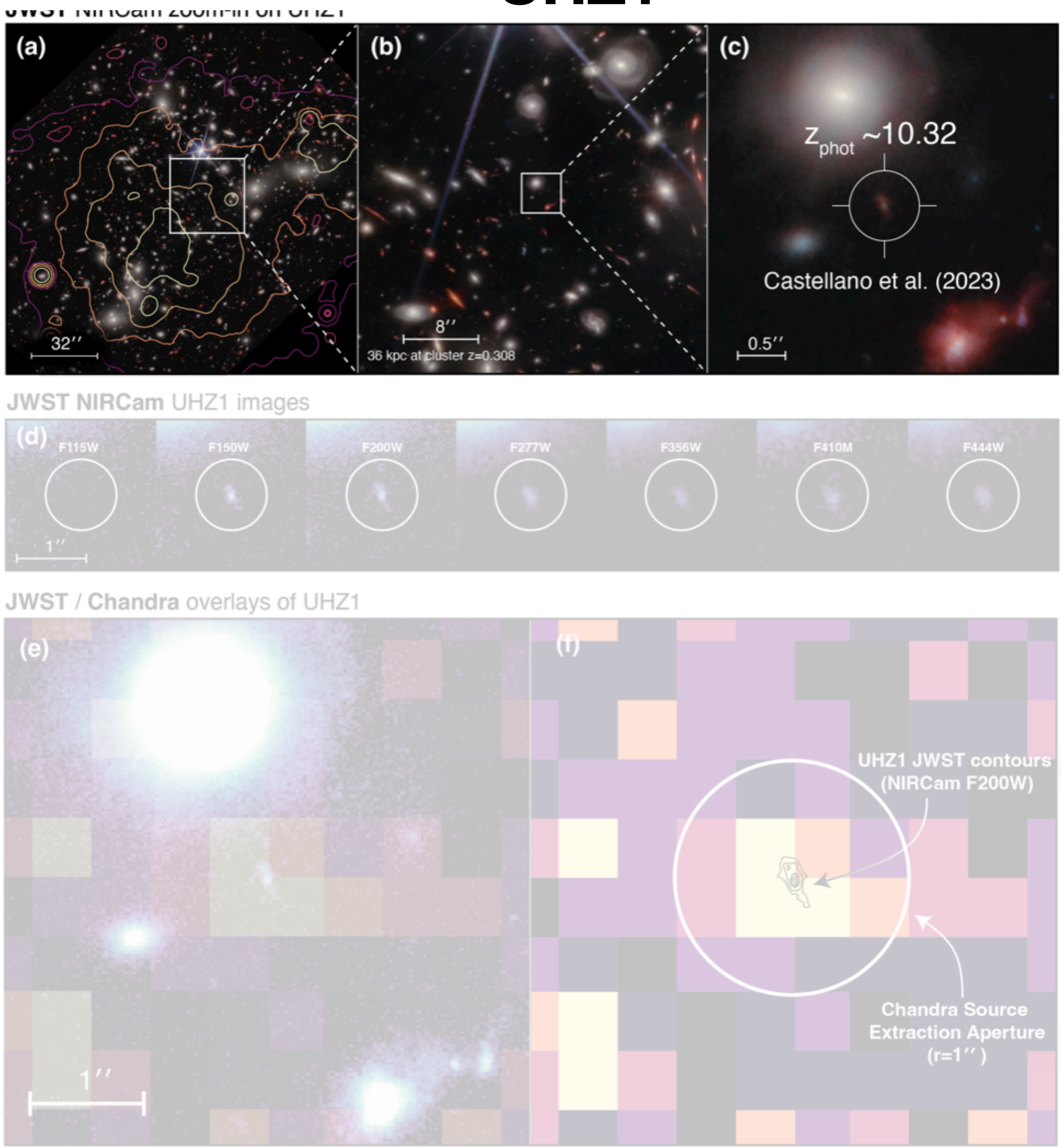
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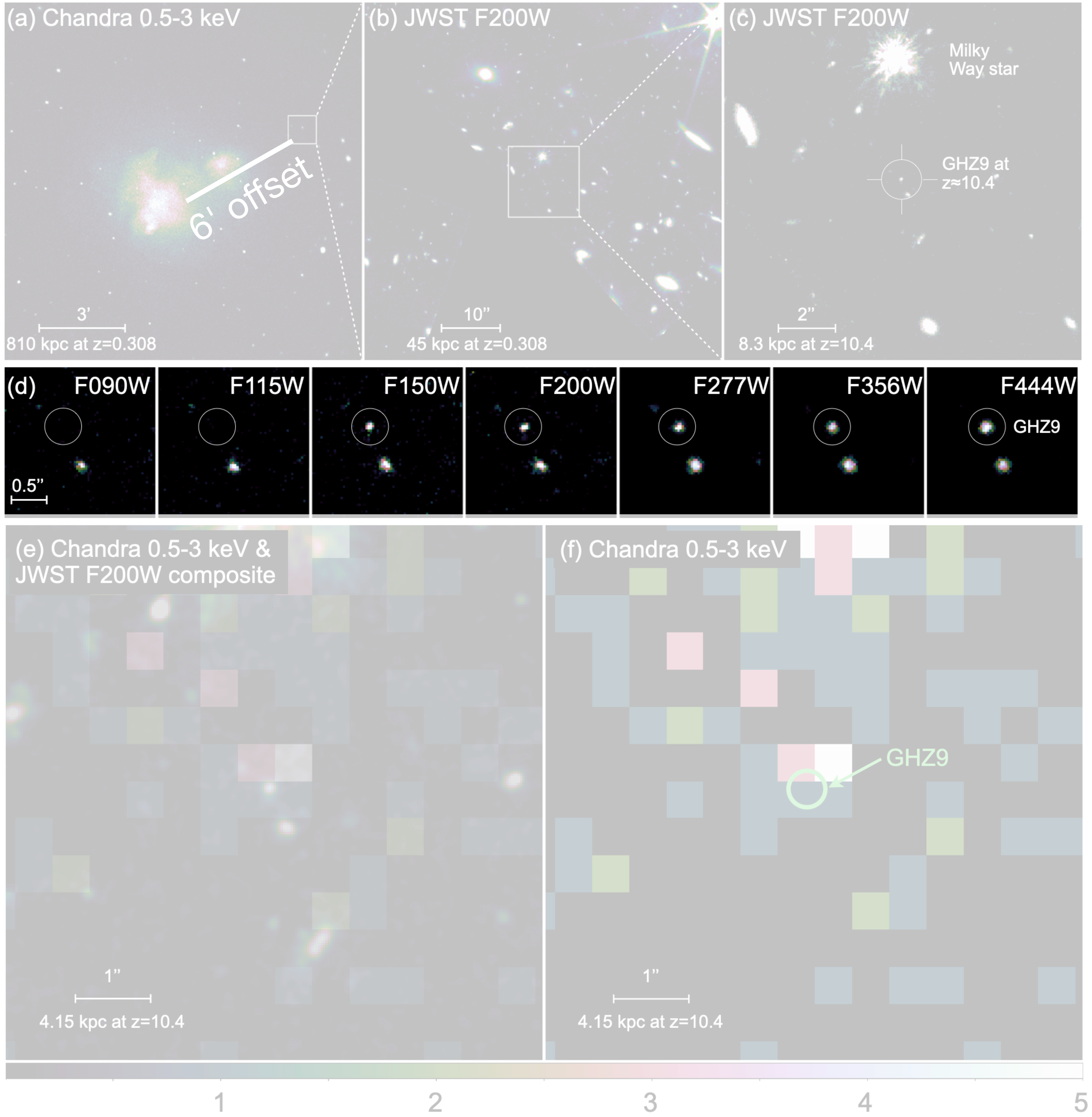
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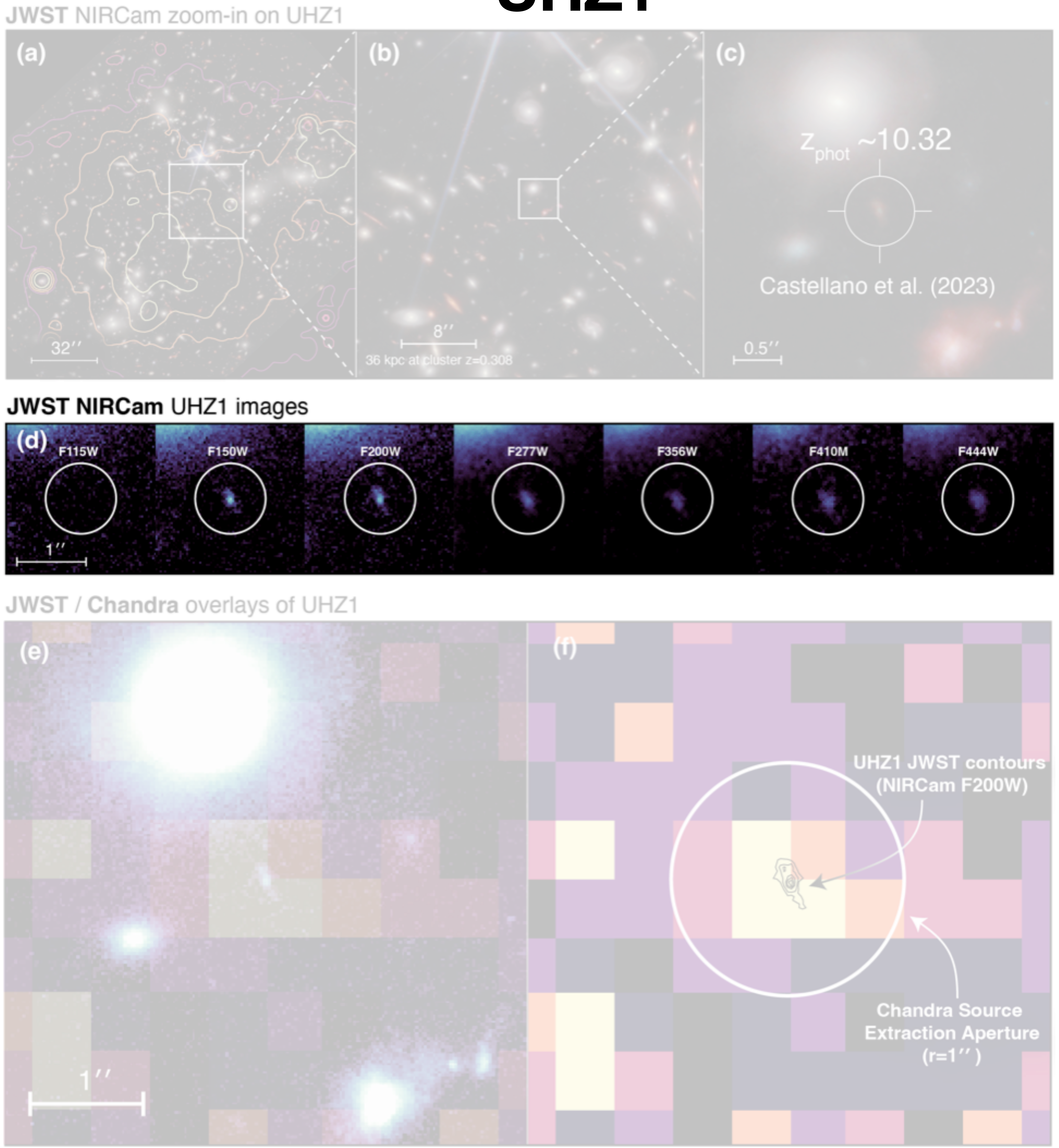
UHZ1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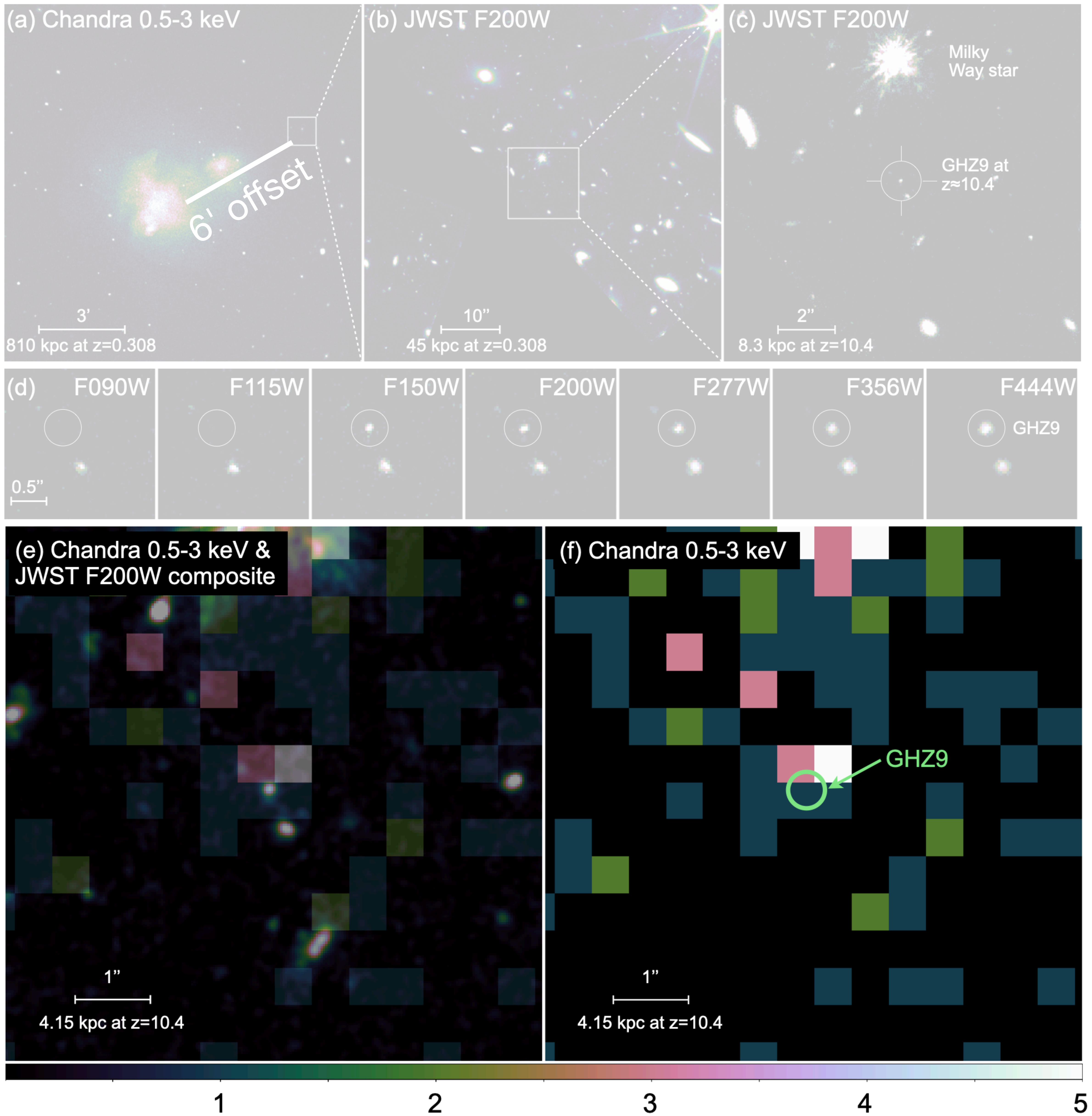
GHZ9



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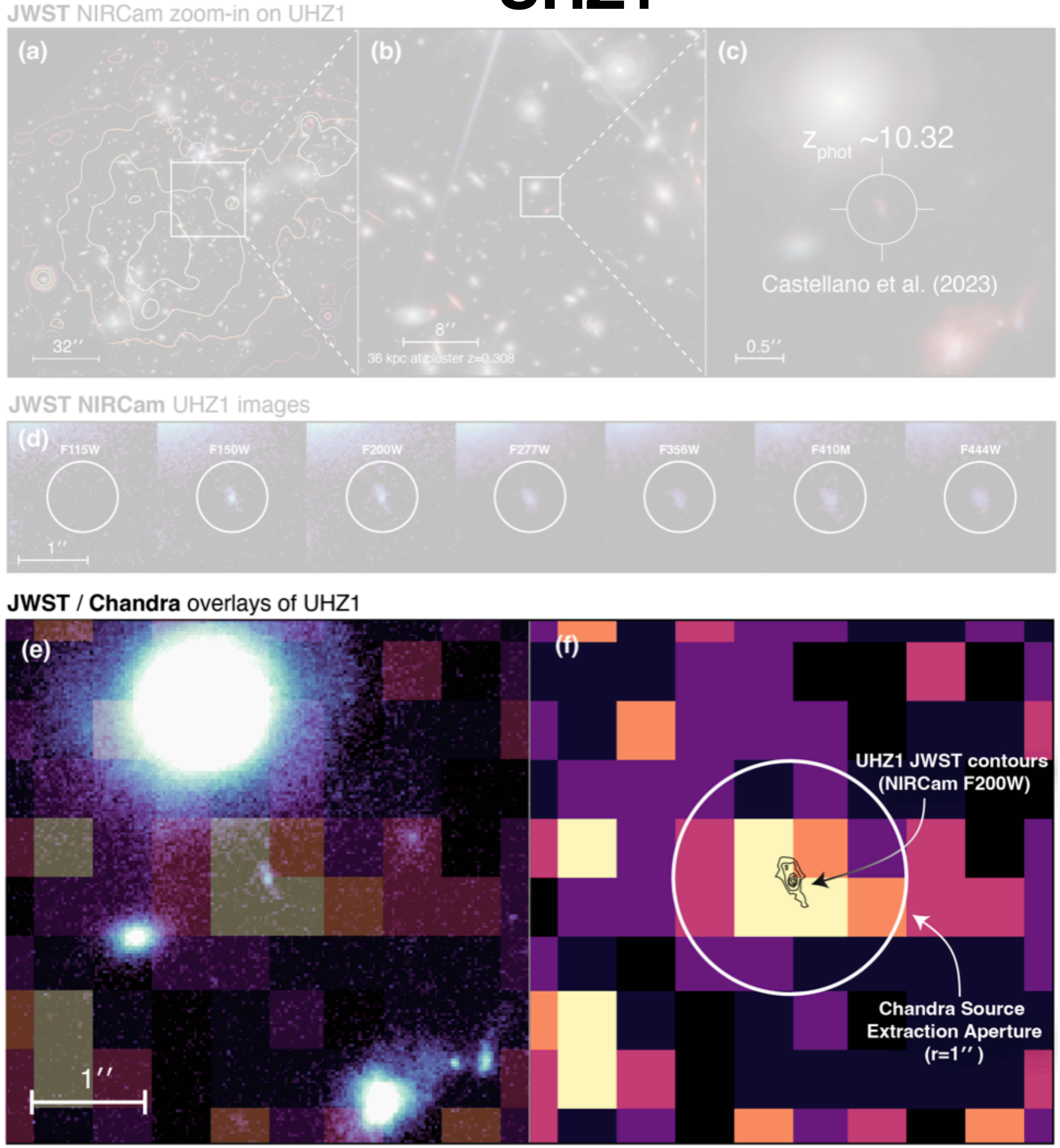
UHZ1



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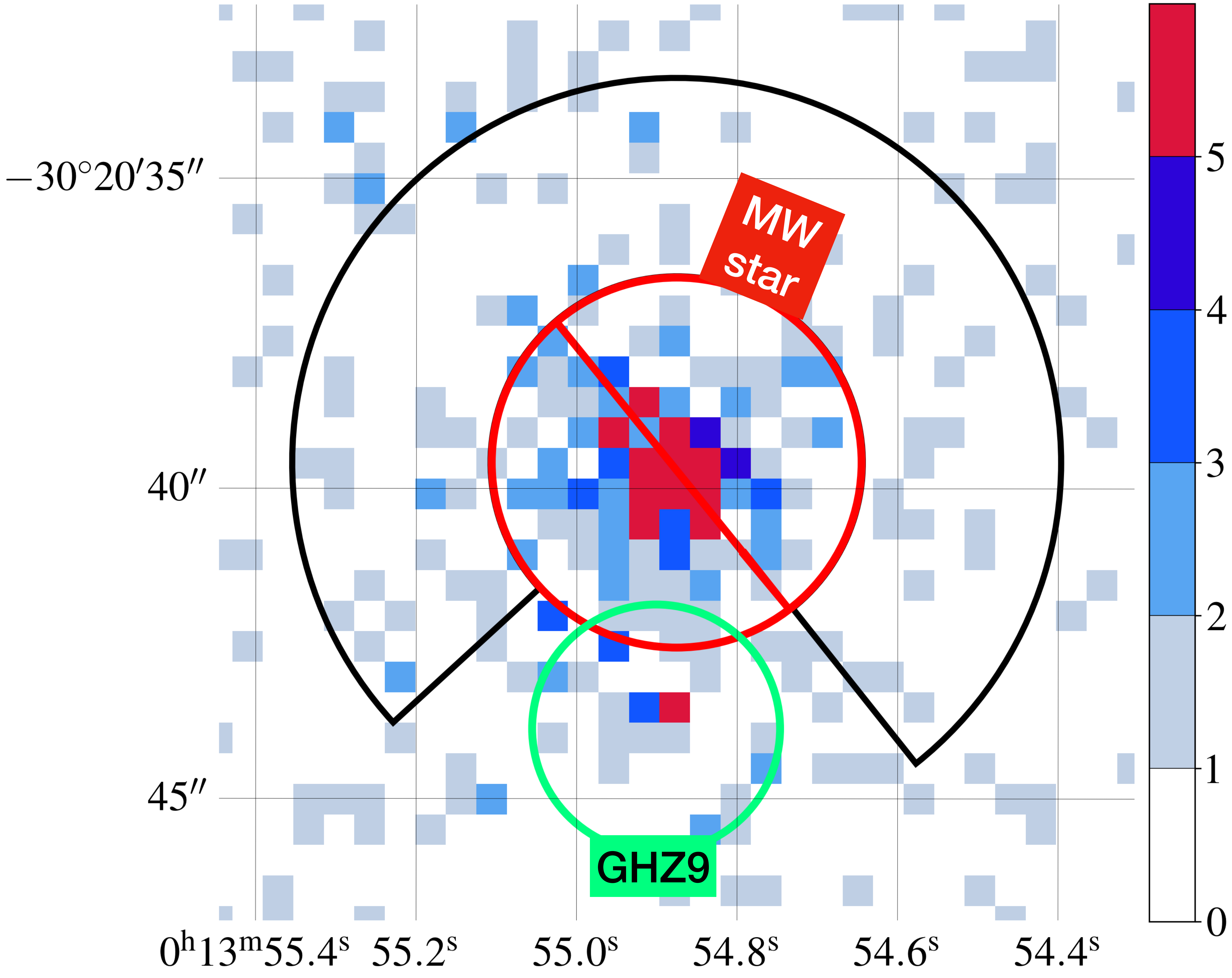
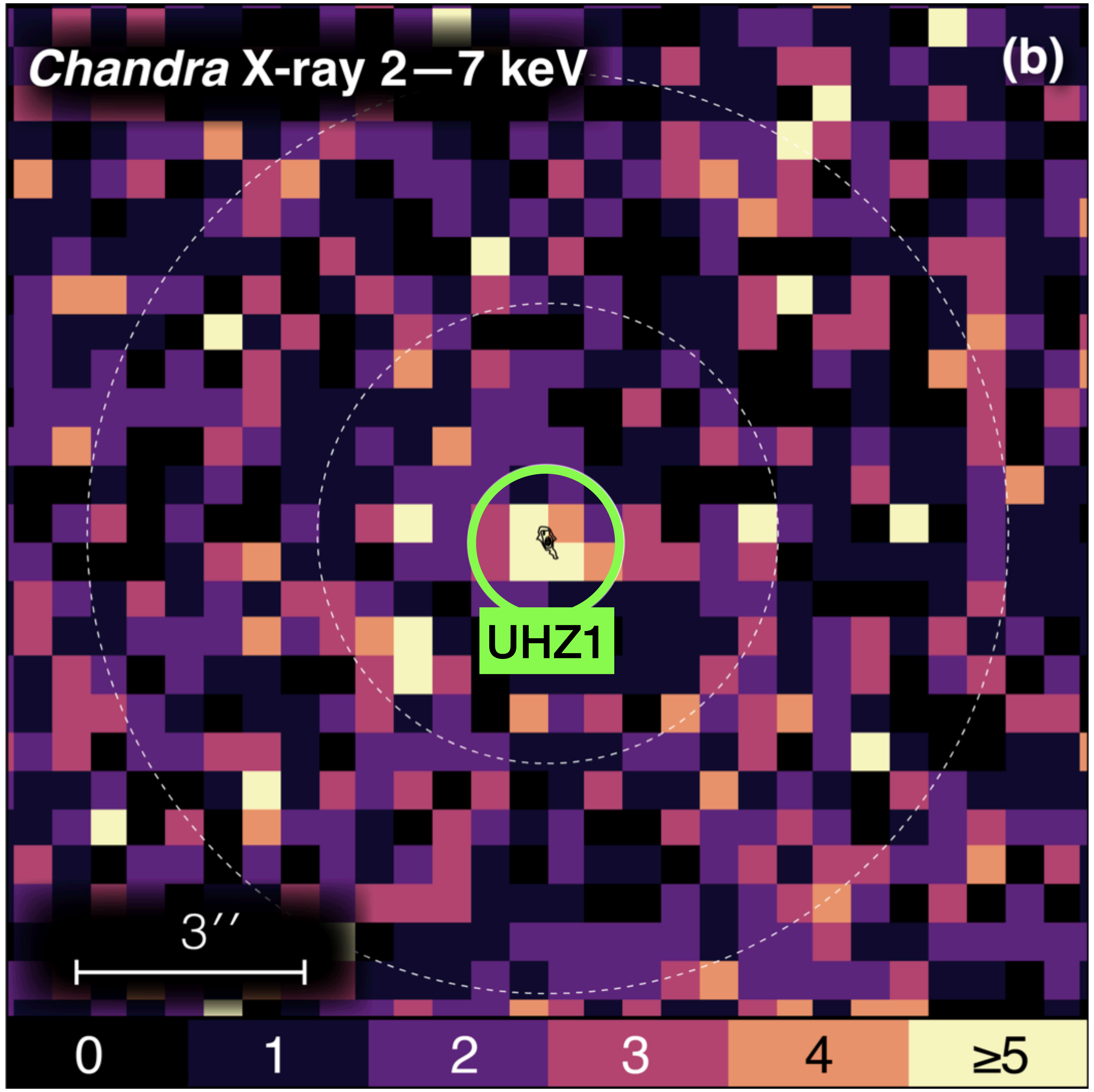
GHZ9


MW star
GHZ9
−30°20′35″
40″
45″
0h13m55.4s
55.2s
55.0s
54.8s
54.6s
54.4s
0
1
2
3
4
5

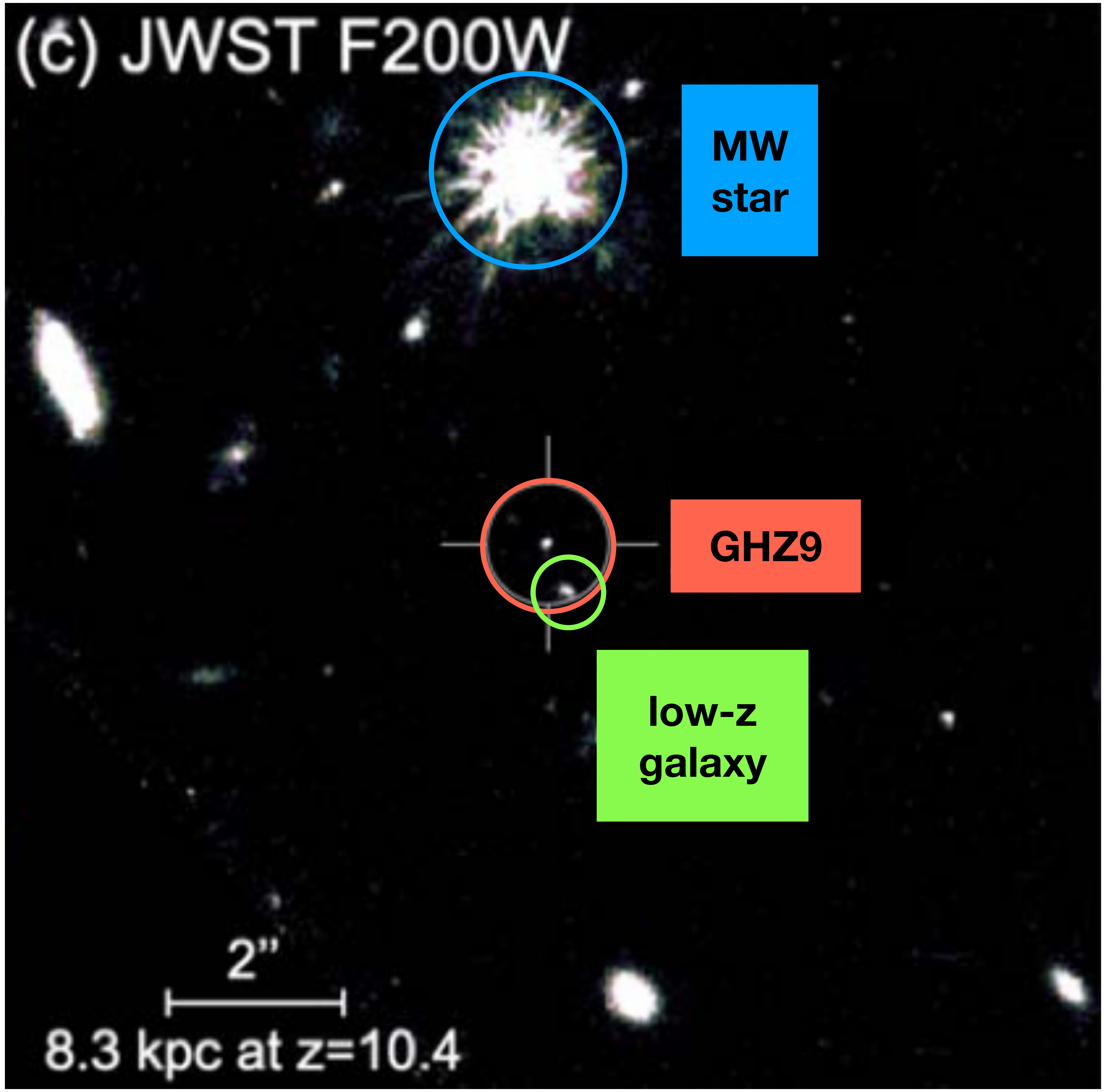
UHZ1


Chandra X-ray 2—7 keV
(b)
UHZ1
3″
0
1
2
3
4
≥5

Low-z galaxy neighbour of GHZ9

- low-mass, low-z galaxy
- 0.6" projected distance from GHZ9
- at large offset on the Chandra image, broad PSF

Could it be associated with the X-ray source?



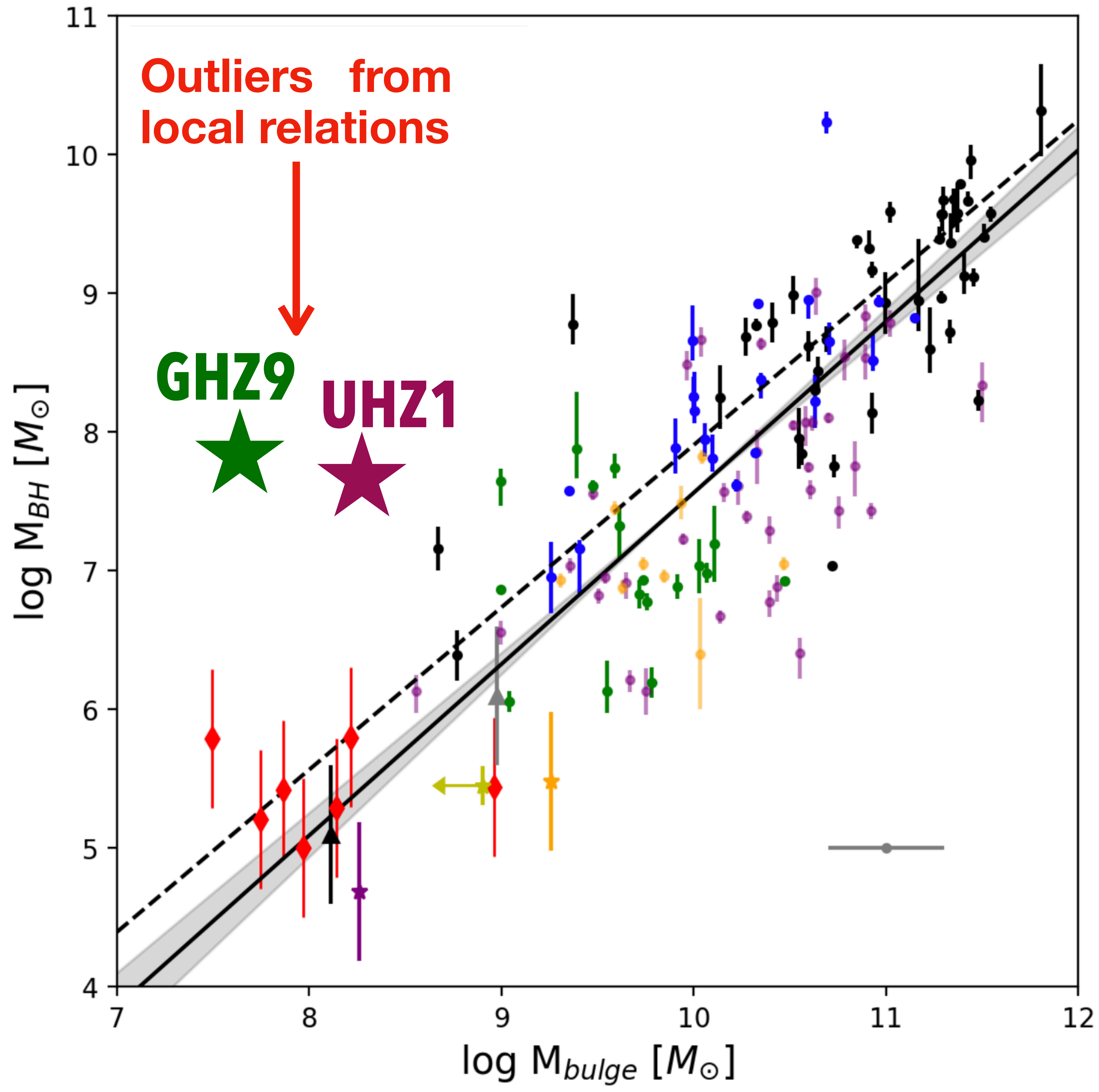
Luminosity and BH mass of the candidate X-ray AGNs

	GHZ 9	UHZ 1
$L_{\rm bol}$ [erg s^{-1}]	$\sim 1 \times 10^{46}$	$\sim 5 \times 10^{45}$

Assuming accretion at the Eddington limit

	GHZ 9	UHZ 1
$M_{\rm BH}$ [$M_\odot$]	$\sim 8 \times 10^{7}$	$\sim 4 \times 10^{7}$

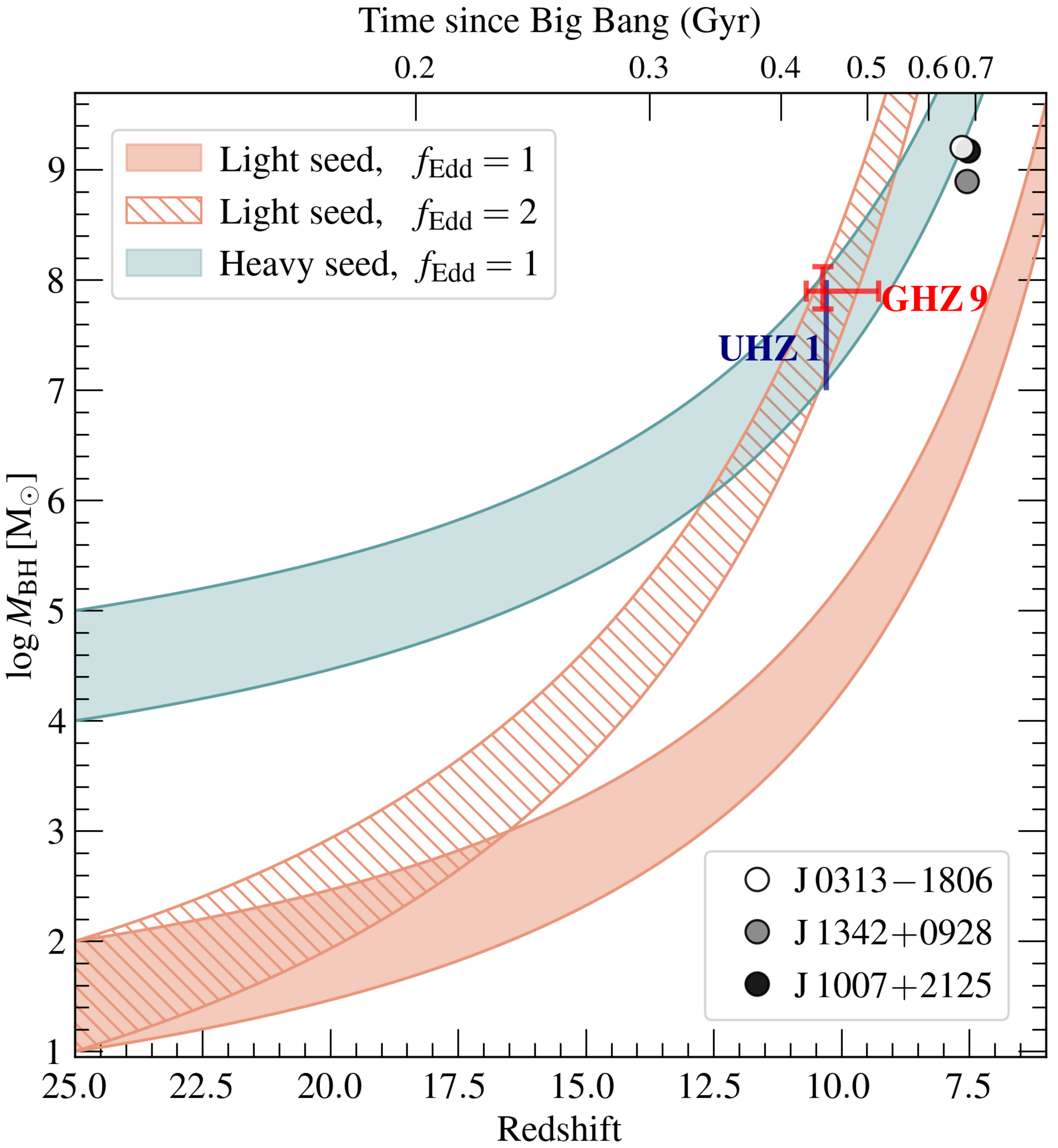
Comparable to the $M_\star$ of the host galaxy



BH growth tracks

- assembly history of light and heavy seeds
- by $z \approx 10$ (i.e. $450\,\mathrm{Myr}$ after the big bang) with $f_{\mathrm{Edd}} = 1$
  - light seeds reach masses of $10^{4-5}\,\mathrm{M}_{\odot}$
  - heavy seeds reach masses of GHZ9 and UHZ1

Their extreme mass at such an early cosmic epoch suggests the **heavy seed origin** for GHZ9 and UHZ1.

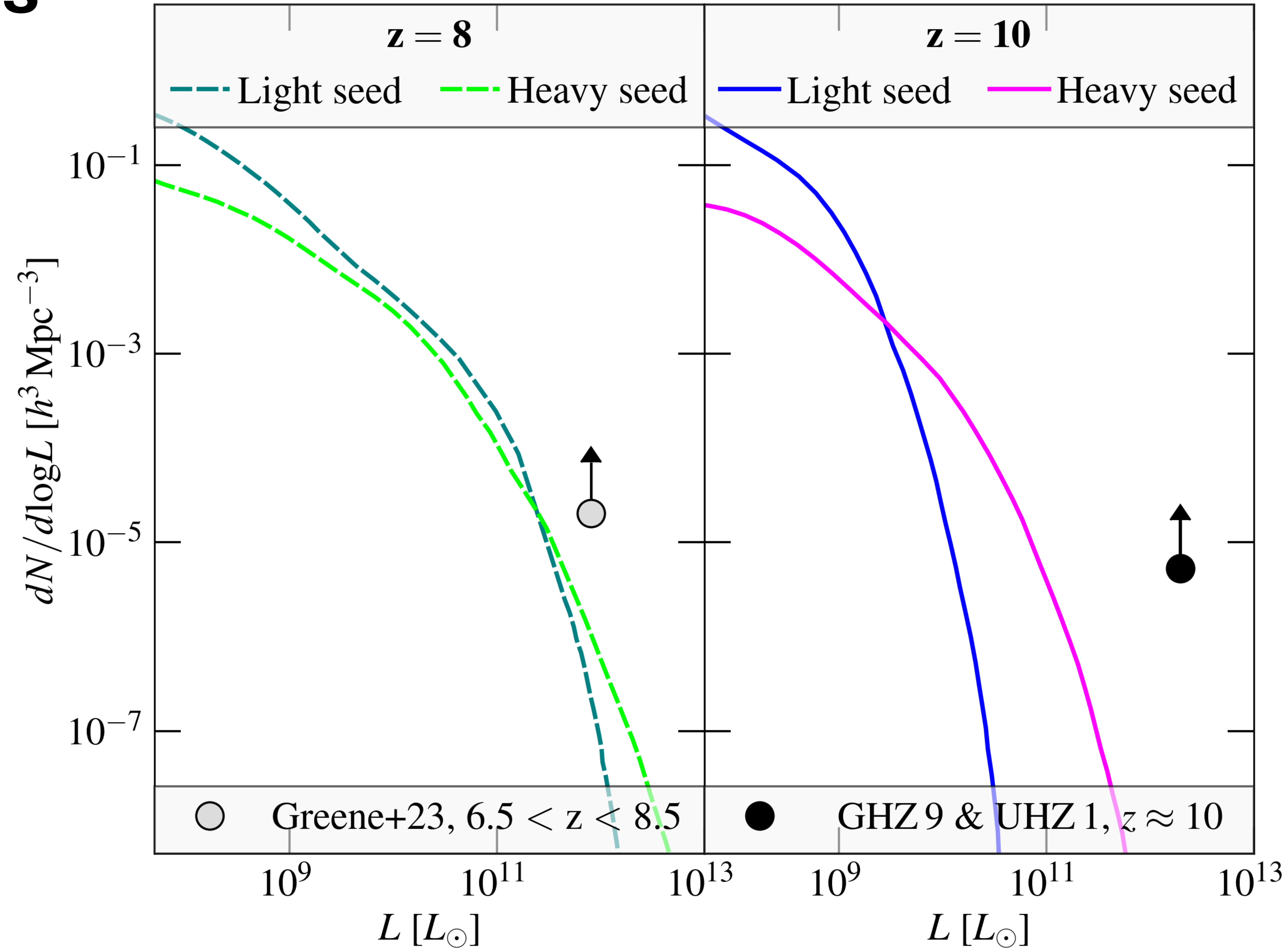


AGN luminosity functions

- predicted luminosity functions vs. observed number density
- at $z = 8$ theoretical curves are nearly identical

over-abundant $z \approx 10$ SMBH population

- **higher-than-expected seed formation efficiency**
- **heavy seed formation in multiple channels**




"Little red dots"
behind Abell2744

- newly discovered population of high-redshift galaxies
- $3 < z < 9$
- NIR characteristics:
  - compactness
  - red color

- follow-up observations with JWST
  - JWST NIRSpec
    - LRDs show broad $\mathrm{H}\alpha$ emission: SMBHs
    - $M_{\mathrm{BH}} - M_{\star}$ ratio of LRDs is higher than the local ratio
  - JWST MIRI images
    - LRDs' energy output is dominated by the emission from OB stars

Where does LRDs' NIR emission come from?

LRDs with Chandra

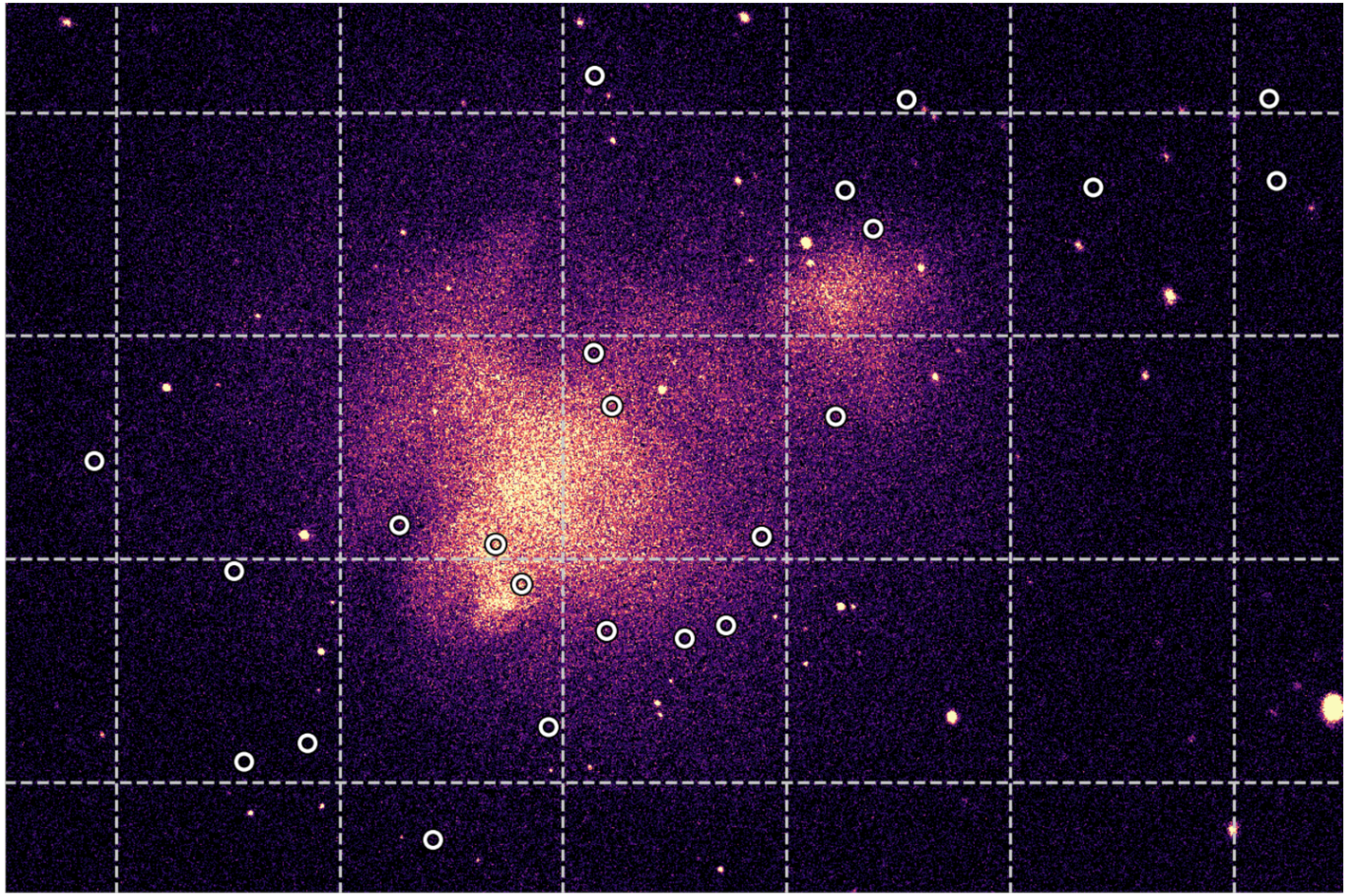
massive accreting BHs can easily be detected in X-rays

↕

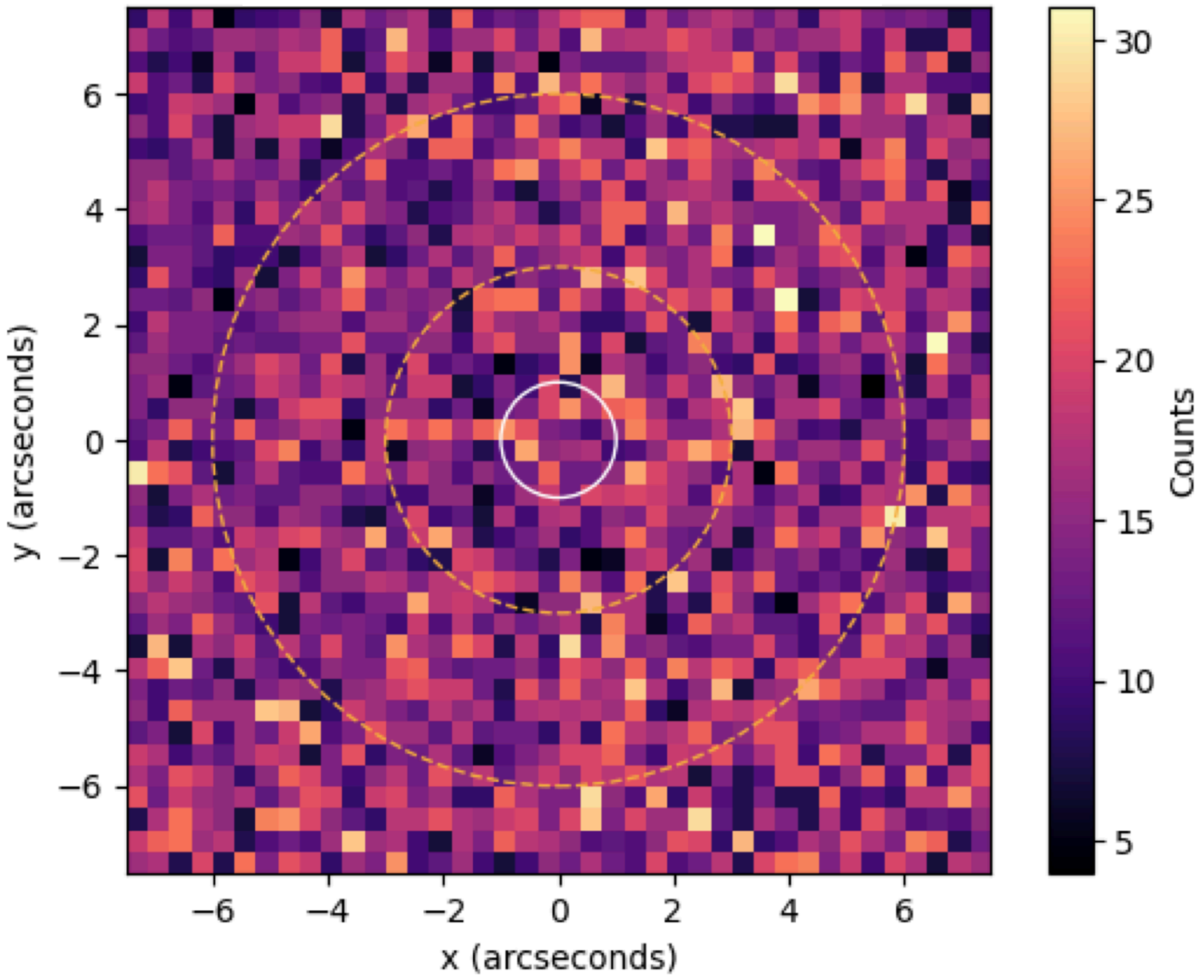
X-ray emitting processes associated with star formation are a few orders of magnitude fainter

Do LRDs host SMBHs?

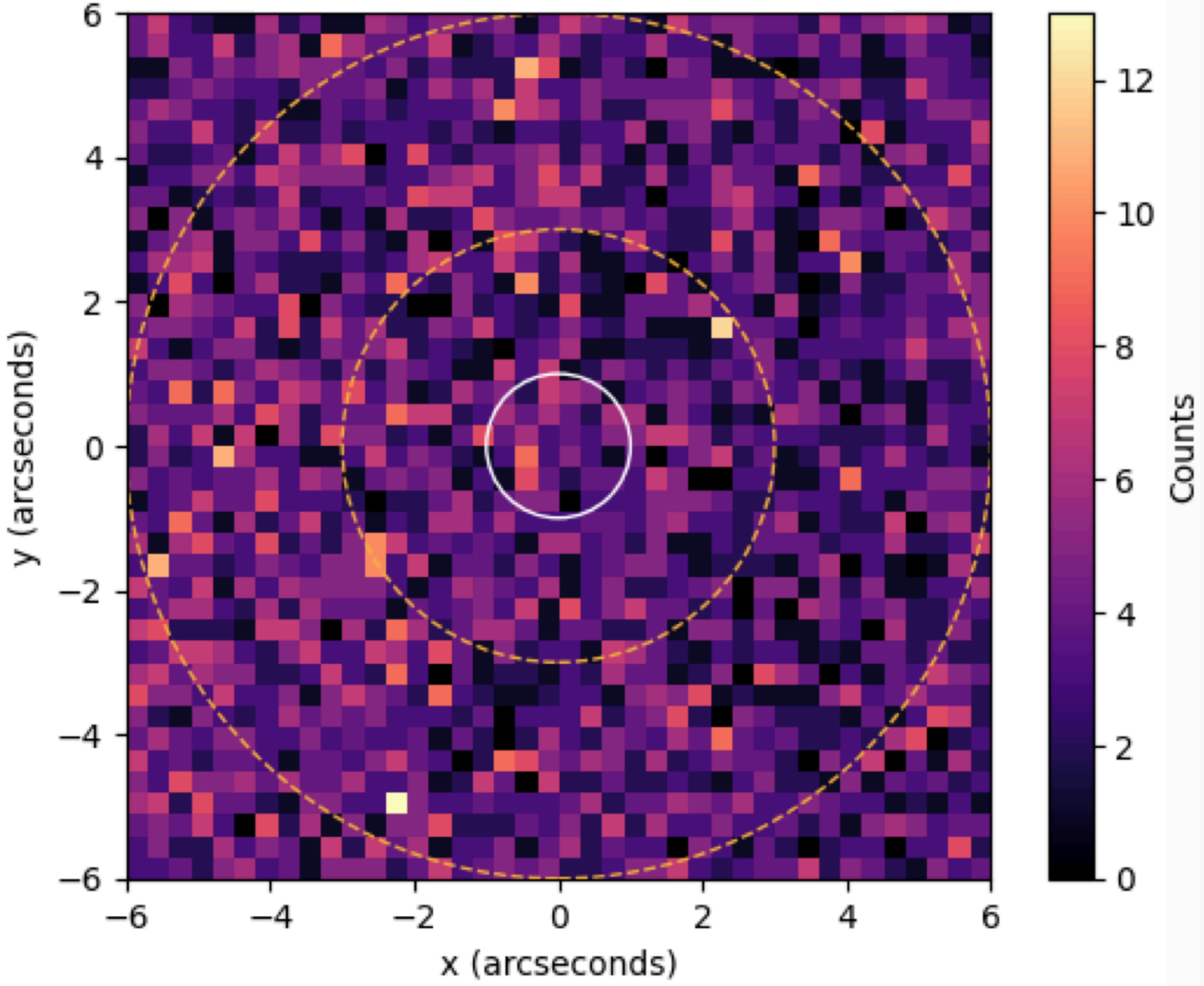
None of the individual LRDs show statistically significant X-ray emission

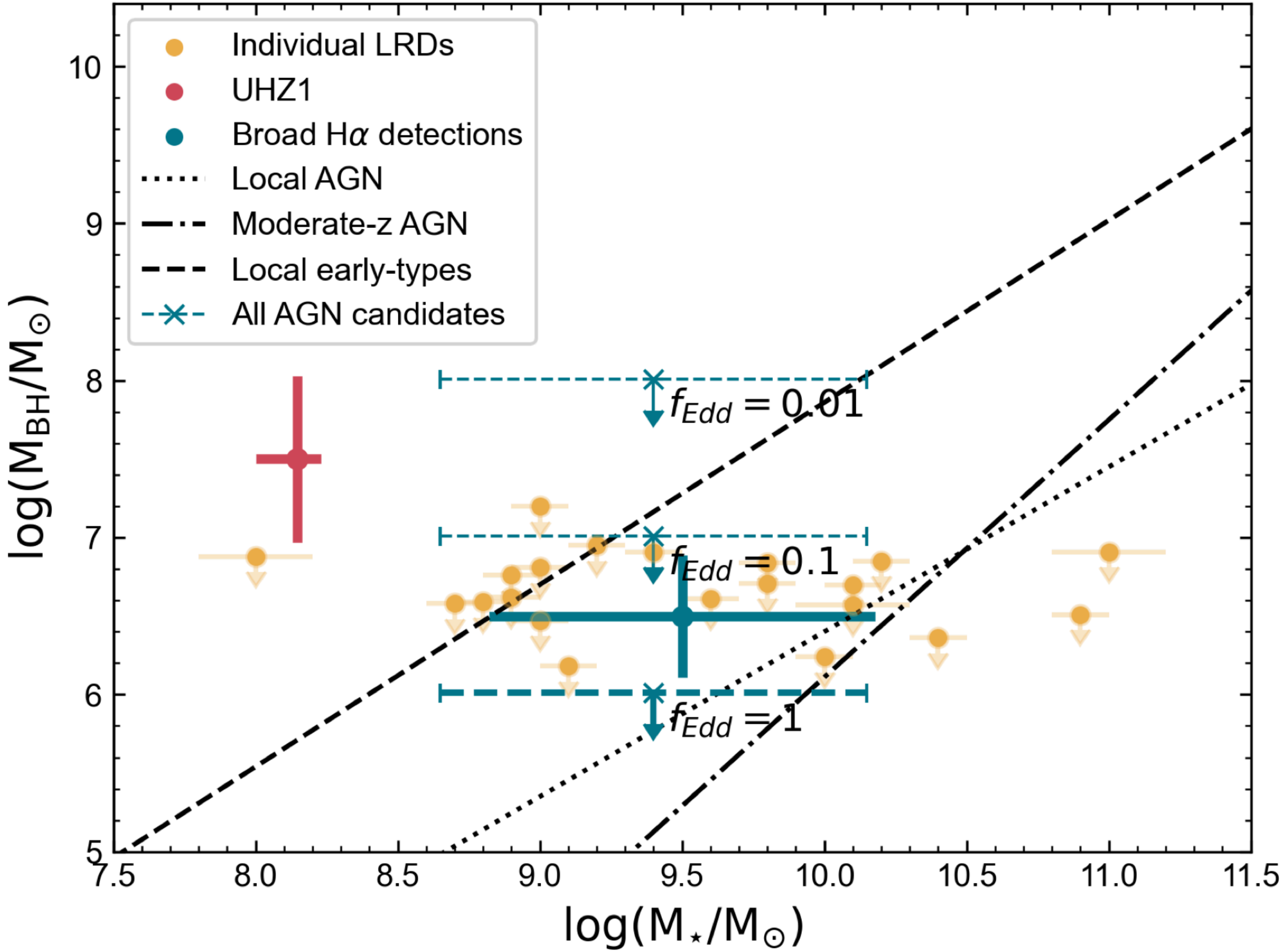


A sample of 21 LRDs behind A2744 in the $2-7\,\mathrm{keV}$ band stack of 21 AGN candidates ⟶ non-detection



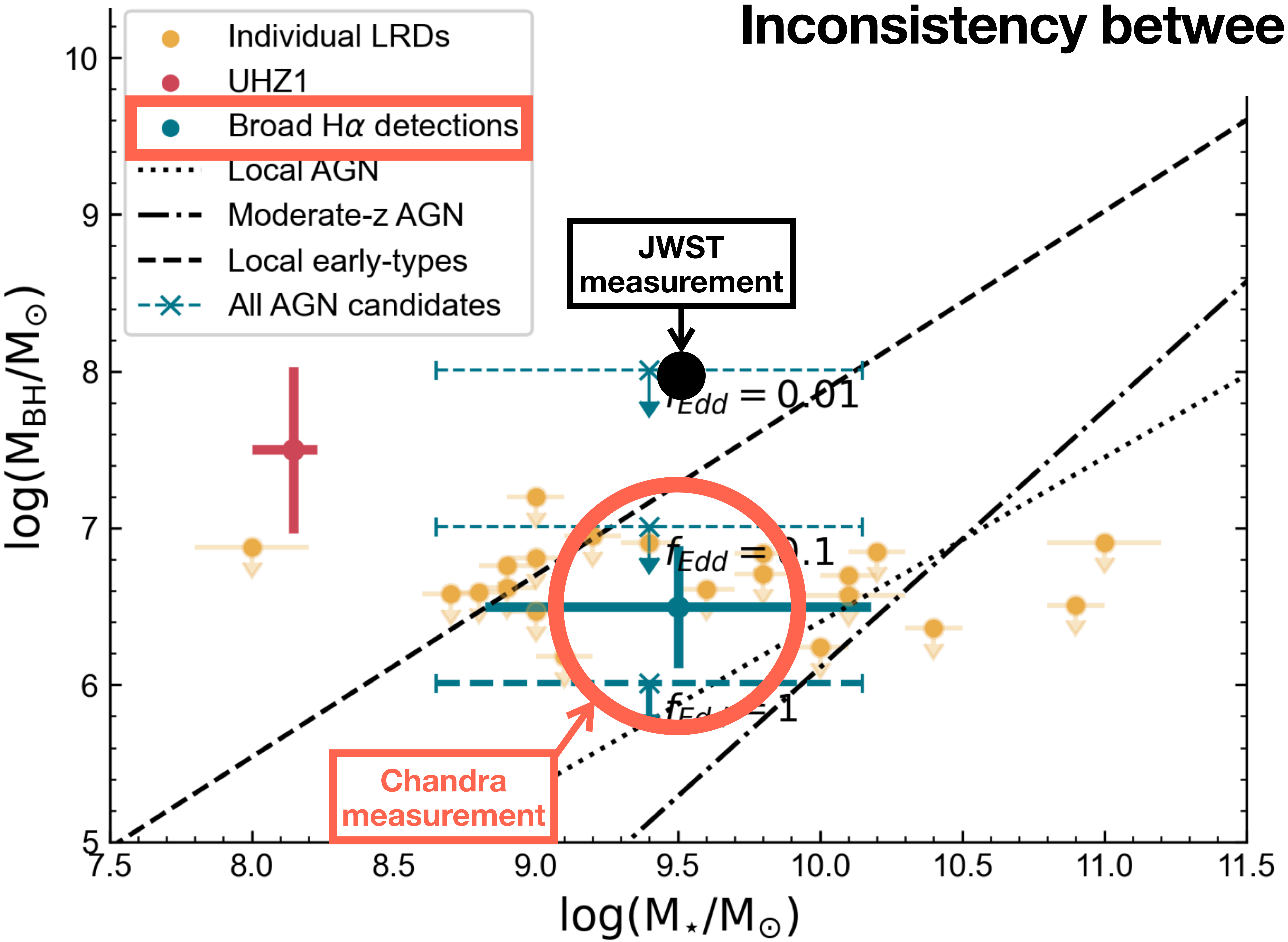
stack of 9 AGN candidates with broad-line $\mathrm{H}\alpha$ emission ⟶ 2.6σ detection





- LRDs may host SMBHs, whose masses are consistent with the scaling relations established for local and moderate redshift AGN.
- X-ray observations suggest that the population of LRDs do not host over-massive SMBHs.
- Or they accrete at a small fraction of their Eddington limit.

Inconsistency between JWST and Chandra



SMBH mass of the 9 AGN candidates with broad-line $H\alpha$ emission

- from NIRSpec data (median): $10^8\,M_\odot$
- from the 2.6σ stacked X-ray signal: $3.2 \times 10^6\,M_\odot$

systematic uncertainties in the mass measurements from the NIRSpec data?

Thank you!