Over-Massive Black Hole Detection

Presentation to the Astrophysics Journal Club

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JWST & Chandra Images

UHZ1:

https://www.flickr.com/photos/nasawebbtelescope/53314359793/in/album-72177720305127361/

Closer galaxies with BHs at their center:

https://chandra.harvard.edu/photo/2022/imbhs/

Video of UHZ1:

https://www.youtube.com/watch?v=aJAc-ENcbDI

Chandra X-ray image:

Figures 1 & 2 of Bogdan et al. (arXiv:2305.15458)

Glossary

UHZ1—Naming??

JWST—James Webb space telescope

SED—Spectral energy distribution

DCBH—Direct collapse black hole

SMBH—Supermassive black hole

OBG—Obese black hole galaxy

LW—Lyman-Werner (radiation)—Ultraviolet radiation associated with H_2 molecule

Lyman-break galaxies—Star-forming galaxies at high redshift that are selected using the differing appearance of the galaxy in several imaging filters due to the position of the Lyman limit

Observations

JWST has found bright galaxies at $z > 9$. See Figure 1 of Castellano et al. (2212.0666) for observations and the source plane magnification map for Abell 2744.

Galaxy UHZ1 is in the direction the cluster Abell 2744 (nicknamed *Pandora's Cluster*) in the constellation Sculptor

UHZ1 is 3.2 billion ly away, at a red shift of 0.31

BH discovery by Bogdan et al. (2023)

BH is 13.5 billion ly away, behind UHZ1, at a red shift of 10.1 based on X-ray emission spectrum (see Figure 3).

Galaxy candidates are selected via two different renditions of the Lyman-break technique, isolating objects at $z \sim 9$-11, and $z \sim 9$-15, respectively, supplemented by photometric redshifts obtained with two independent codes.

See Figure 3 of Castellano et al. for the UHZ1 spectrum.

Fundamental Theoretical Questions

How did the first black holes arise?

When did they arise?

How did they evolve?

Theoretical Considerations

Light versus heavy seeds for BHs:

10 - 100 $M_\odot$ from early, Population III stars

versus 10^4 - 10^5 $M_\odot$ from direct collapse of gas clouds

Other seeding scenarios include primordial BHs

Abell 2744 is a well-calibrated cluster lens

X-rays are a ubiquitous signature of BH accretion

Formation Schemas

Figure 1 of Natarajan et al. (2017) (1610.05312v2)

Figure 1 of Natarajan et al. (2023) (2308.02654v3)

Scenario Under Study by Natarajan et al. (I)

Viable DCBH formation sites in the Cold Dark Matter-dominated cosmogony are pristine atomic cooling halos, satellites bound to the first star-forming galaxies

Satellite DCBH subhalo is then predicted to rapidly merge within ~ 1-5 Myrs with the parent star-forming halo to produce a new, transient class of high-redshift objects, Outsize Black hole Galaxies (OBGs)

Merger product, an OBG, would then harbor a growing central heavy BH seed from the satellite and the stellar population contributed by the parent galaxy.

Post-merger, the stars and the BH would continue to grow self-consistently as the same gas reservoir that feeds the BH also forms stars.

This yields a strikingly different BH-to-host galaxy stellar mass ratio than observed in the local Universe, where the mass of the central BH is ~ 0.1% of the stellar mass

Scenario Under Study (II)

This is the only scenario in which the entire arc of the formation, early growth of the DCBH seed, and properties of the stellar population of the host galaxy and its observational consequences in terms of high-redshift multi-wavelength signatures via spectral predictions have been predicted.

Are the peaks in Figure 3 of Natarajan et al. (2023) actual spectral lines? Note there that the AB magnitude in that figure relates to a flux density:

$m_{AB} \approx -2.5 \log_{10} [f_\nu / (3631\ \mathrm{Jy})]$

Go to Natarajan et al. (2023) for still further details>>>>>

BH Inferred Characteristics

Abell 2744 is a Frontier Fields cluster lens at $z \sim 0.31$ with an extremely well-calibrated lensing mass model. Bogdan et al. (2023) through page 7 report the $(4.2 - 4.4)\,\sigma$ detection of an X-ray emitting source in the $z \simeq 10.1$ galaxy UHZ1.

The source has an intrinsic 2− 10 keV luminosity of $\approx 9 \times 10^{45}$ erg s^{-1} after correcting for the $\mu = 3.81$ lensing magnification factor at the location of UHZ1

This suggests the presence of an obscured, likely Compton- thick, accreting BH in UHZ1.

The BH mass satisfies $10^7\,M_\odot < M_{BH} < 10^8\,M_\odot$ and arose from a heavy seed mass of $10^4\,M_\odot$

References

Papers:

M. Castellano et al., “Early Results from GLASS-JWST. XIX: A High Density of Bright Galaxies at $z \approx 10$ in the Abell 2744 Region,” arXiv:2212.06666v3

P. Natarjan et al., “First Detection of an Over-Massive Black Hole Galaxy UHZ1: Evidence for Heavy Black Hole Seed Formation from Direct Collapse,” arXiv:2308.02654v3

A. Bogdan et al., “Evidence for heavy seed origin of early supermassive black holes from a z ~ 10 X-ray quasar,” arXiv:2305.15458

X. Fan et al., “Quasars and the Intergalactic Medium at Cosmic Dawn,” Ann. Rev. Astron. Astroph. 61, 373 (2023).

P. Natarajan et al. 2017, ApJ, 838, 117

Web sites:

https://webbtelescope.org/
https://chandra.harvard.edu/

https://en.wikipedia.org/wiki/UHZ1

https://en.wikipedia.org/wiki/Abell_2744