

Lynx+ Mission: Discoveries Impacting Lynx Science & Design

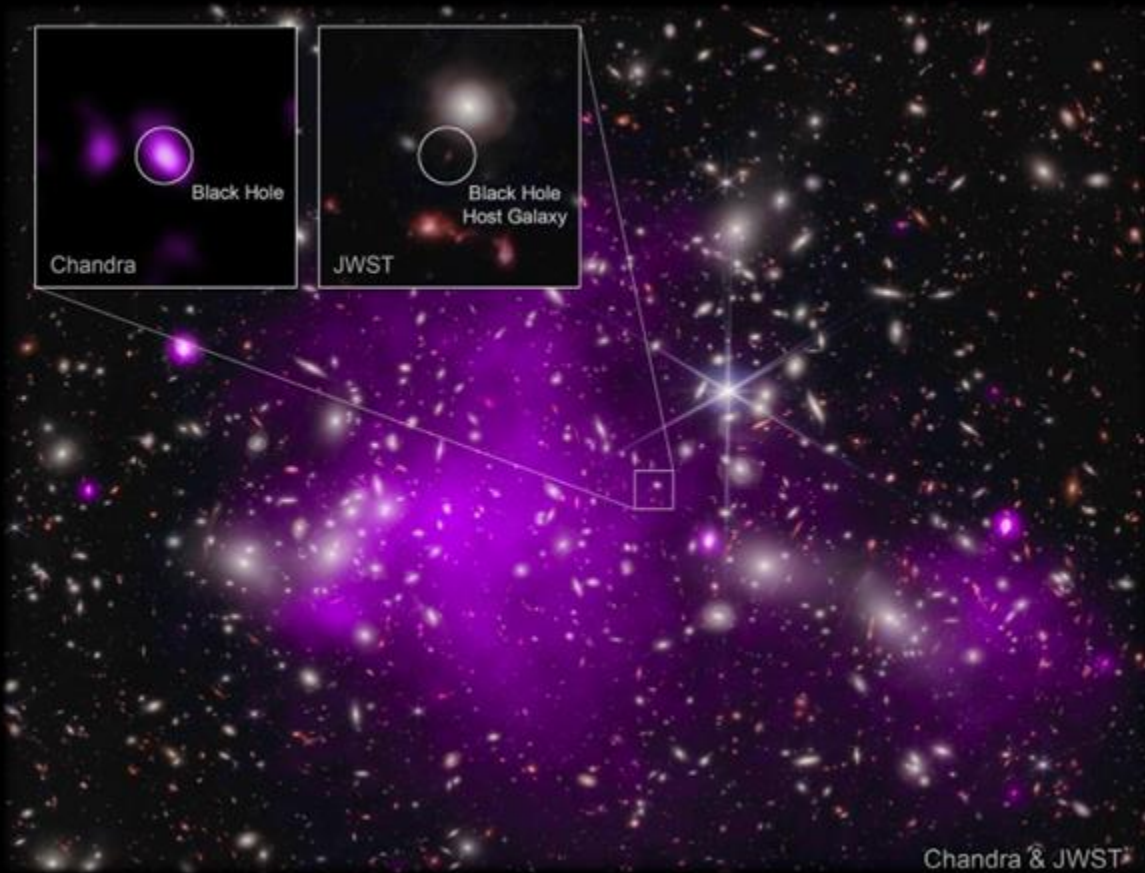


Fabio Pacucci
Astrophysicist
Senior Member of the
Institute for Theory and Computation

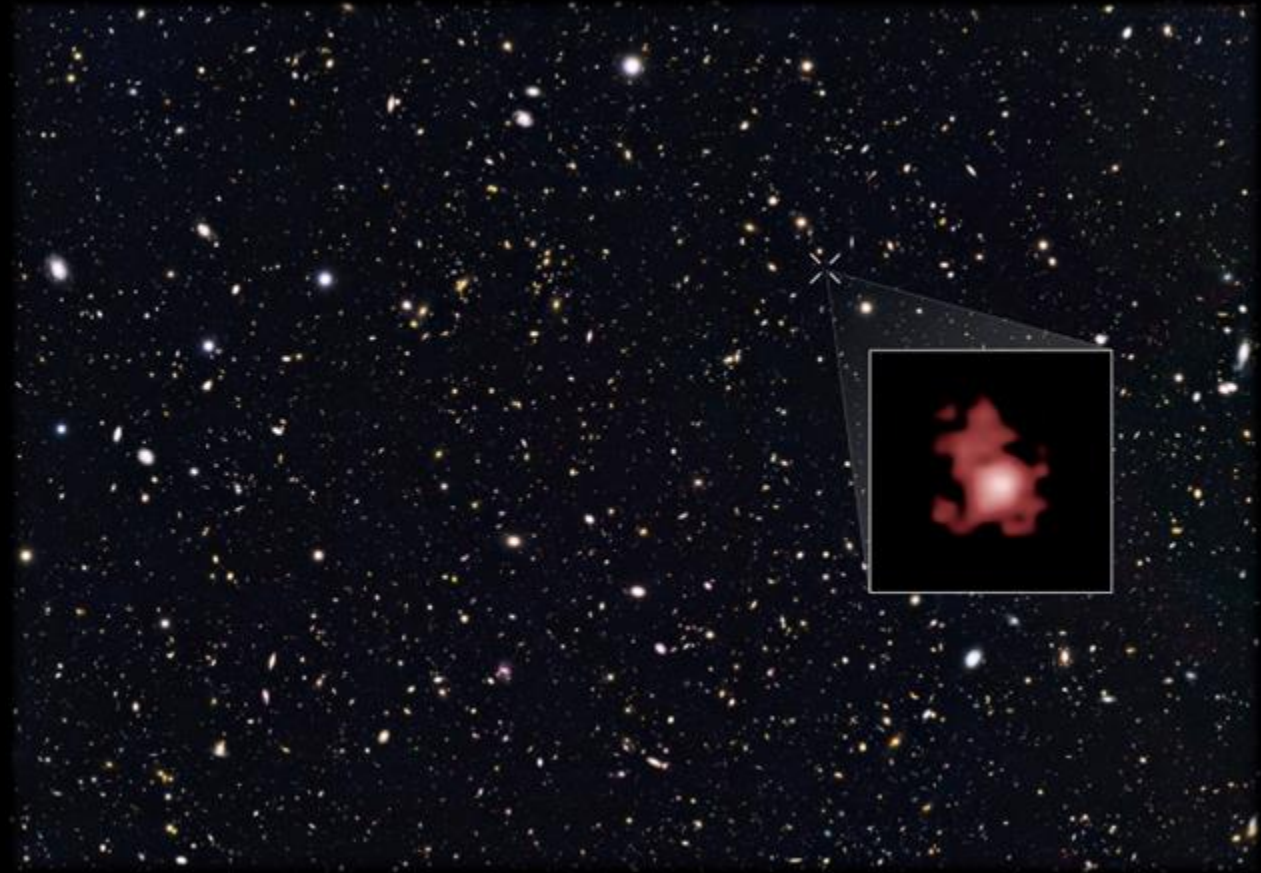
The Future of X-ray Astrophysics Series, August 8, 2025

CENTER FOR **ASTROPHYSICS**

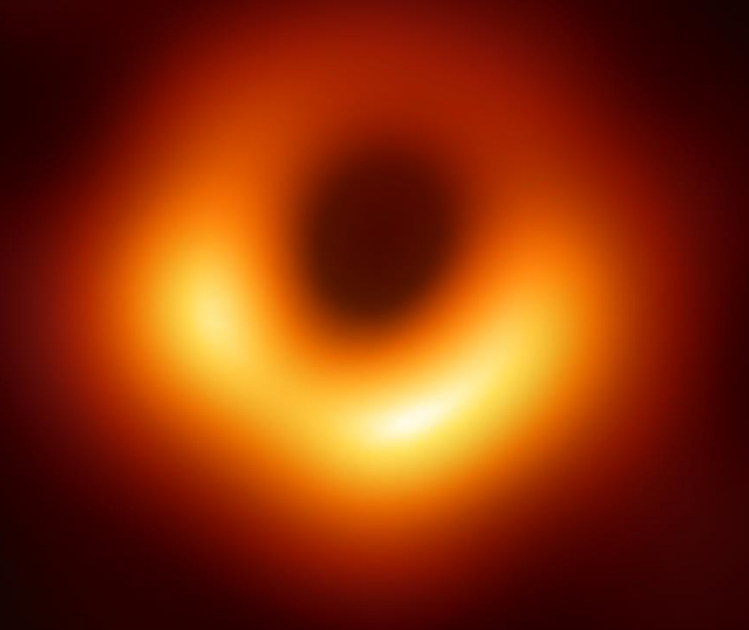
HARVARD & SMITHSONIAN



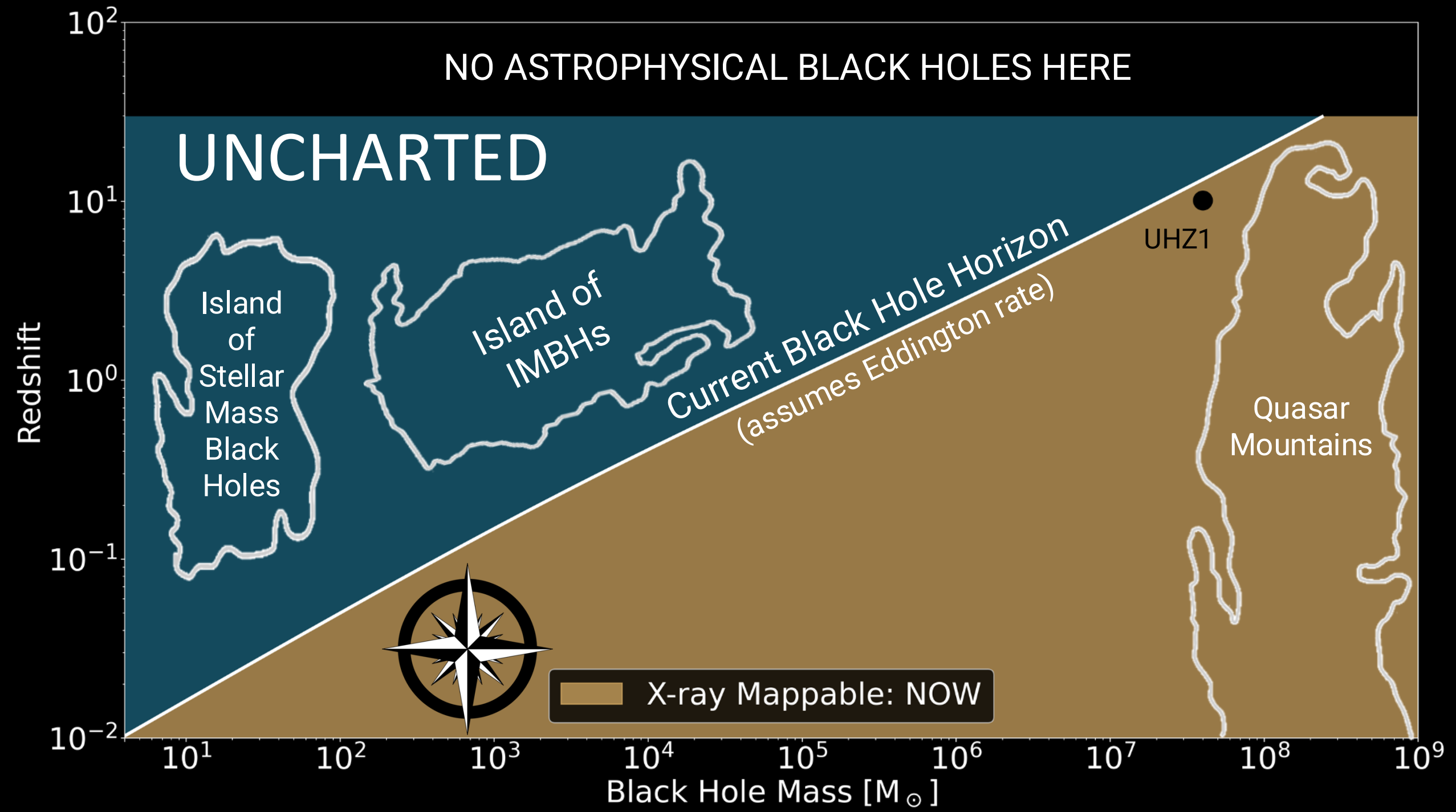
UHZ1: Bodgan+ 2023
 $z \sim 10$

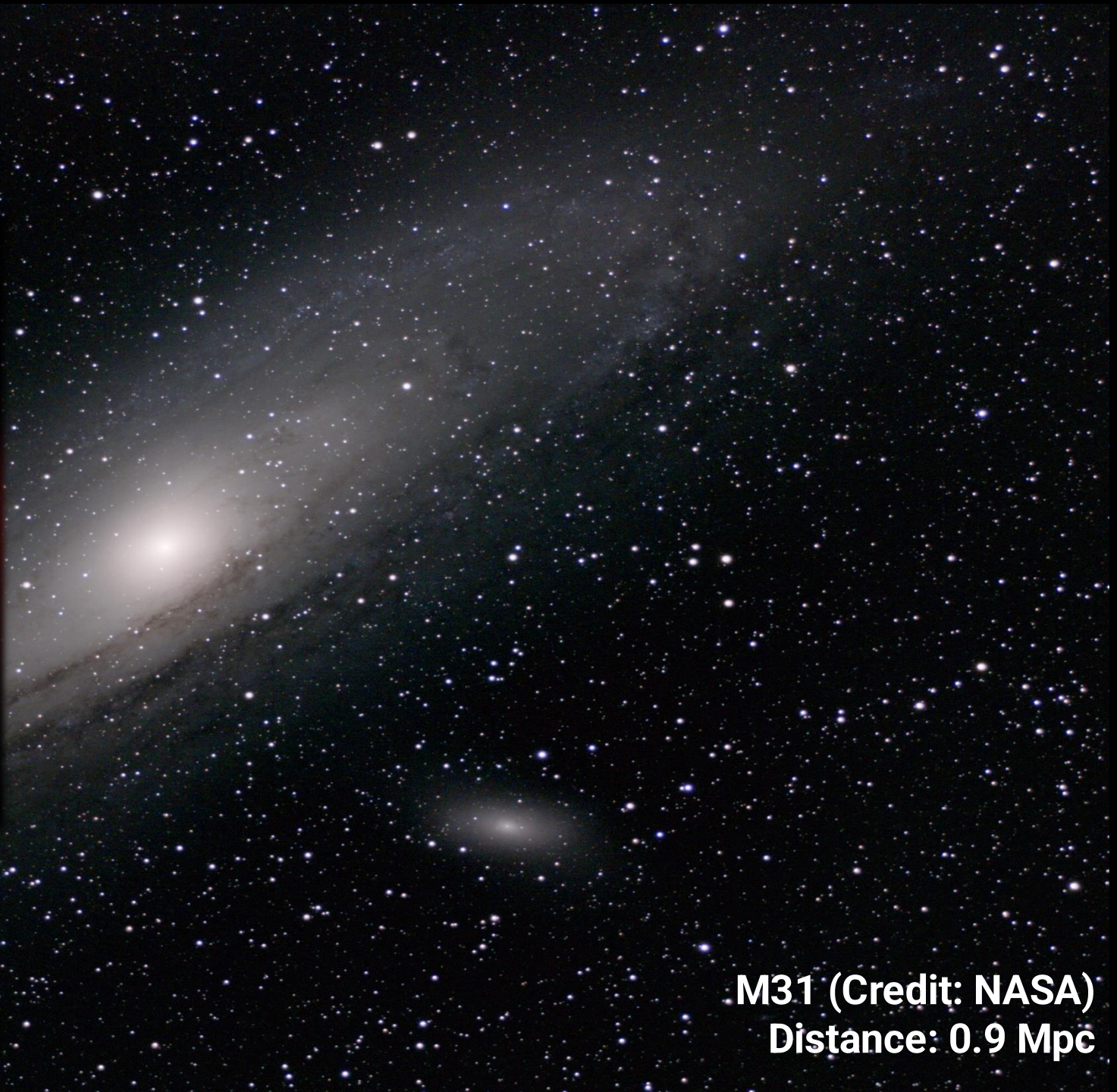
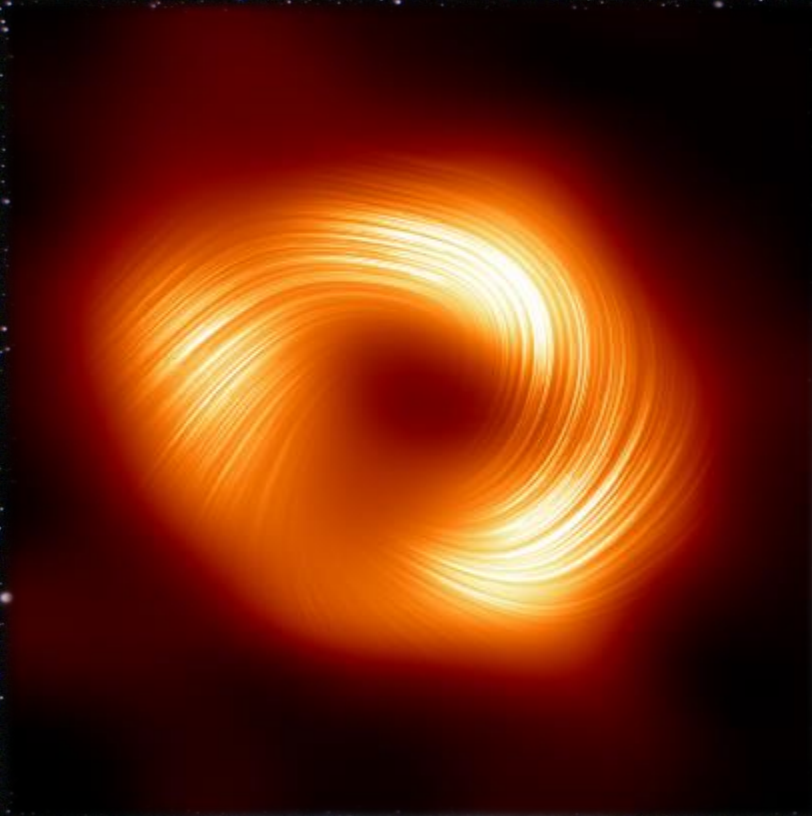


GNz11: Maiolino+ 2024
 JADES Collaboration
 $z \sim 10.6$



Event Horizon Telescope Collaboration, 2019
Distance: 16 Mpc





M31 (Credit: NASA)
Distance: 0.9 Mpc

BLACK HOLE
D A W N

DRIVERS *of*
G A L A X Y
E V O L U T I O N

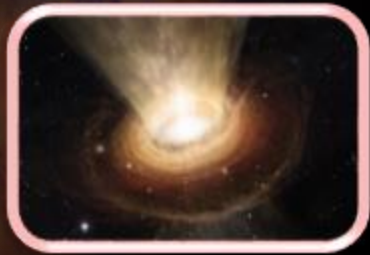


Lynx Concept Study

the E N E R G E T I C S I D E *of*
S T E L L A R E V O L U T I O N



Dark Ages
(Black Hole Dawn)



Black Hole Seeds

Epoch of
Reionization
(Drivers of Galaxy
Evolution)



Little Red Dots

Local Universe
(Energetic Side of
Stellar Evolution)



Wandering Black Holes
Dormant Black Holes

#1: The Cosmic Dark Ages

Black Hole Seeds



The Black Hole Origins Problem

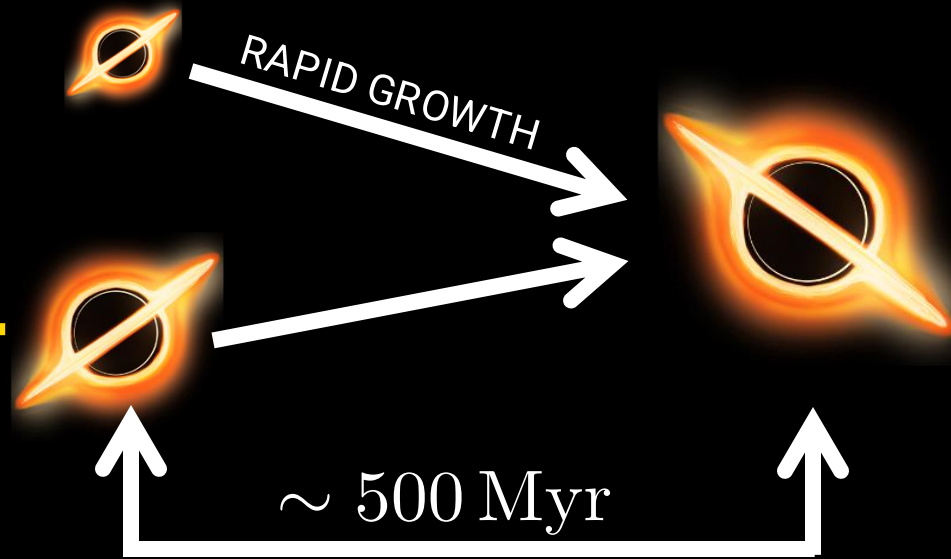
$M_{\bullet} \sim 10^2 M_{\odot}$
LIGHT SEED



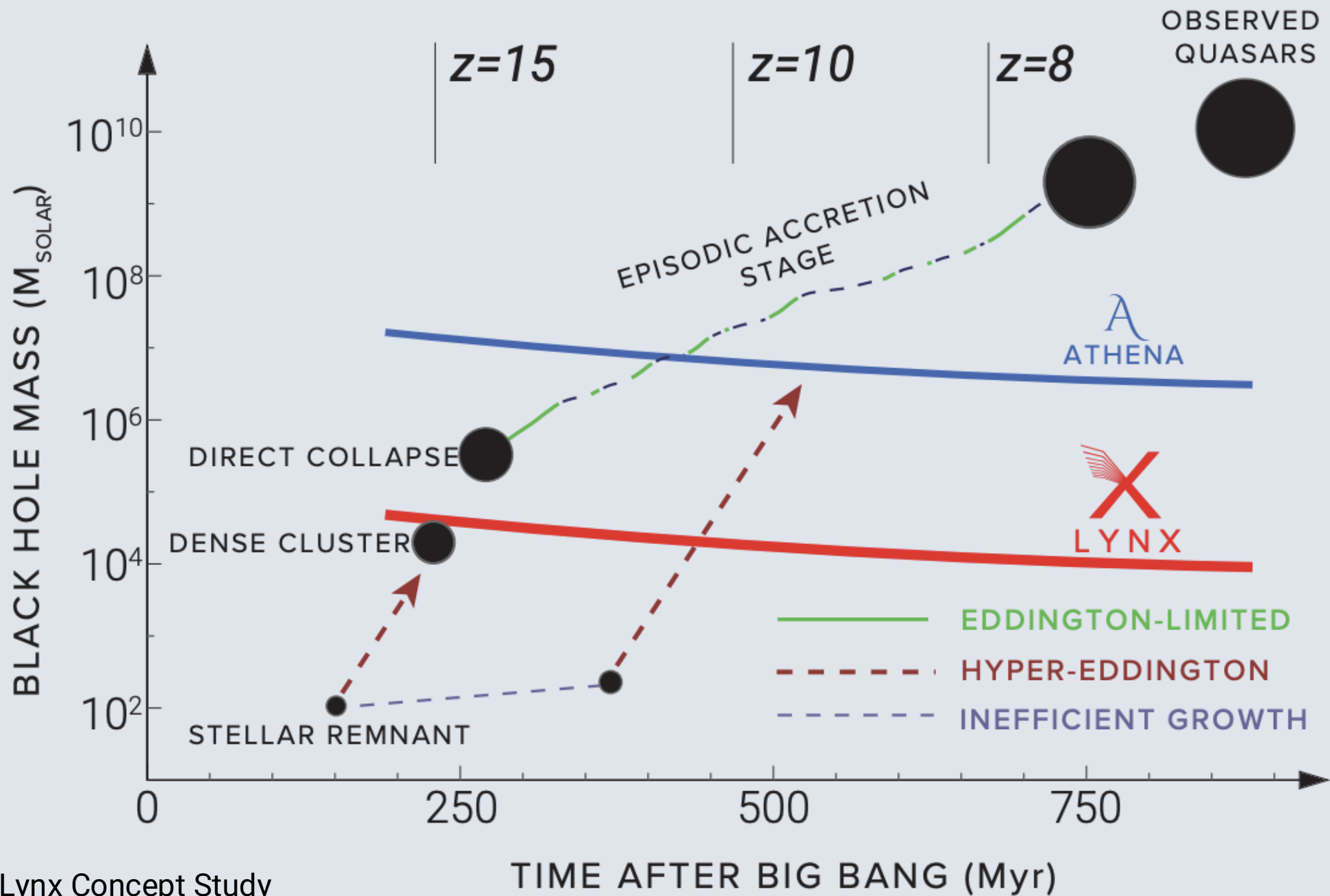
HEAVY SEED

$M_{\bullet} \sim 10^{4-5} M_{\odot}$

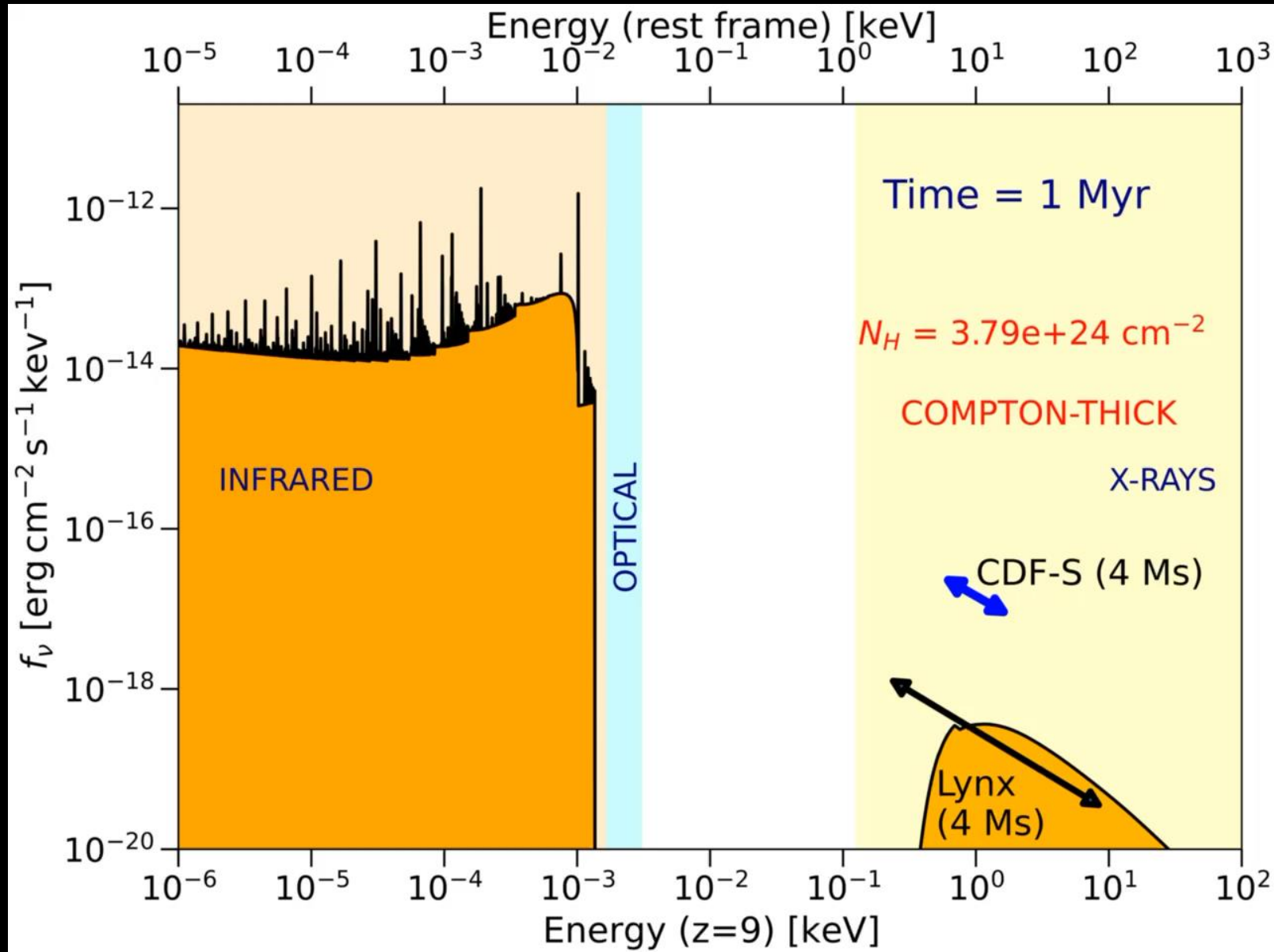
$M_{\bullet} \sim 10^9 M_{\odot}$



$z > 7$

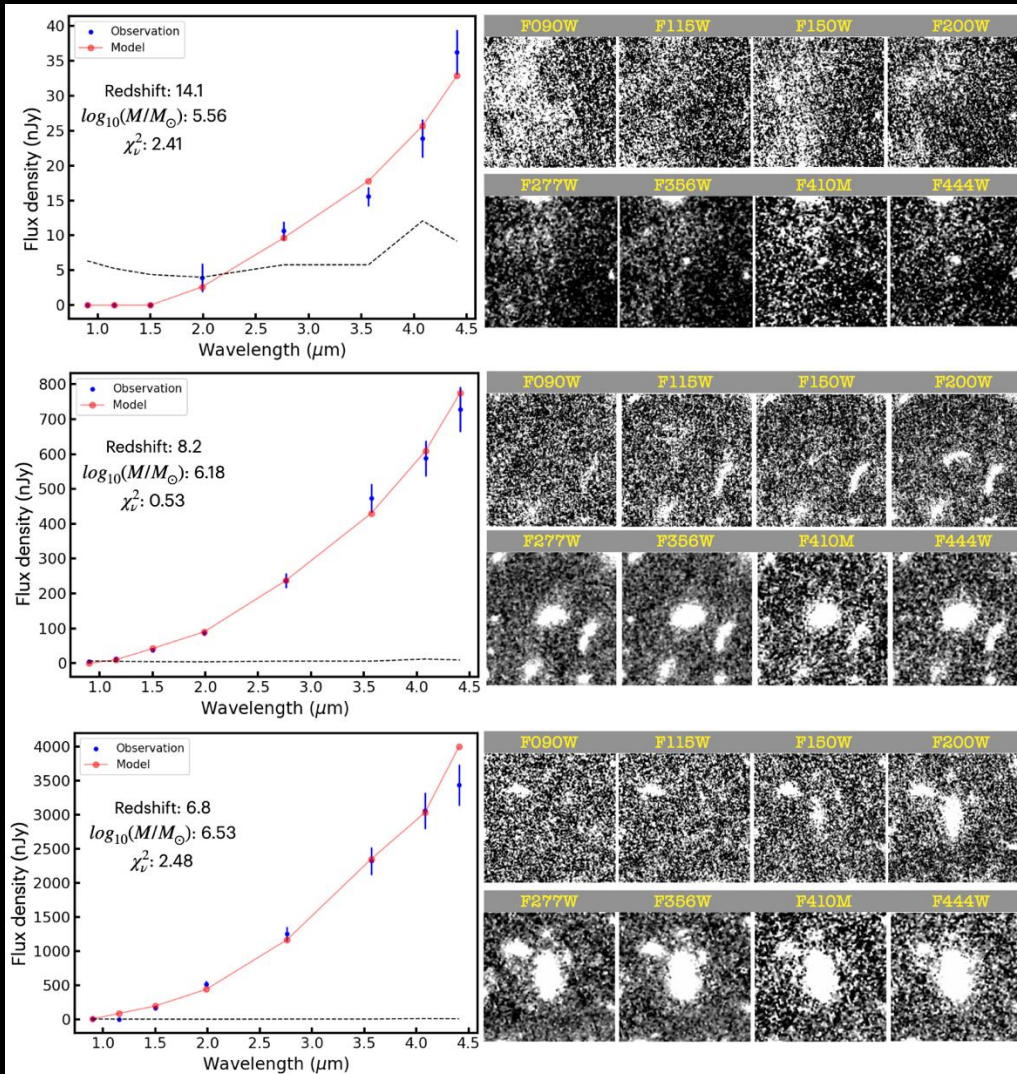


Direct Detection of Heavy Seeds

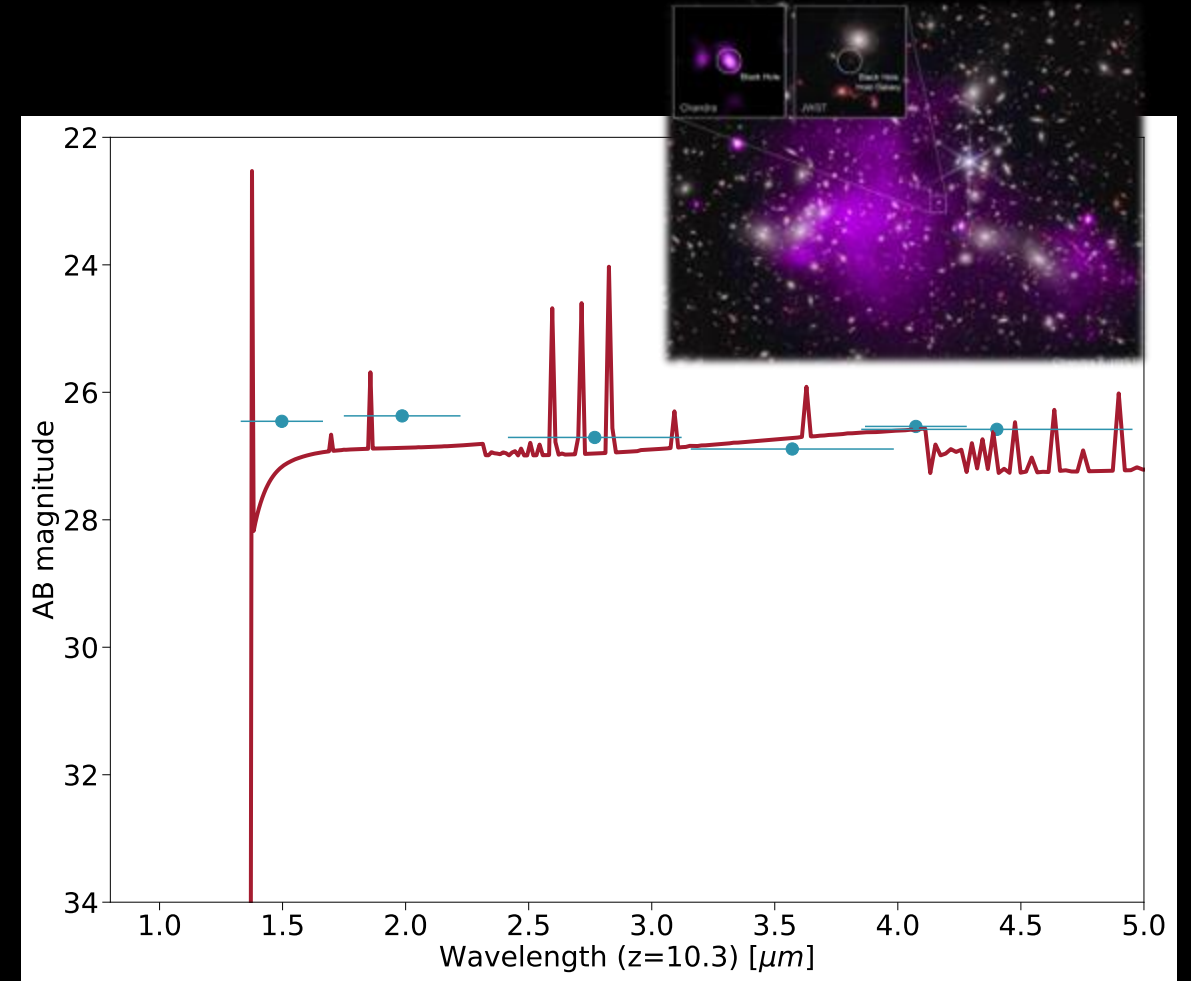


Pacucci+ 2015;
Pacucci+ 2016;
Natarajan,
Pacucci+ 2017;
Pacucci+ 2018

DCBH Candidates from JWST

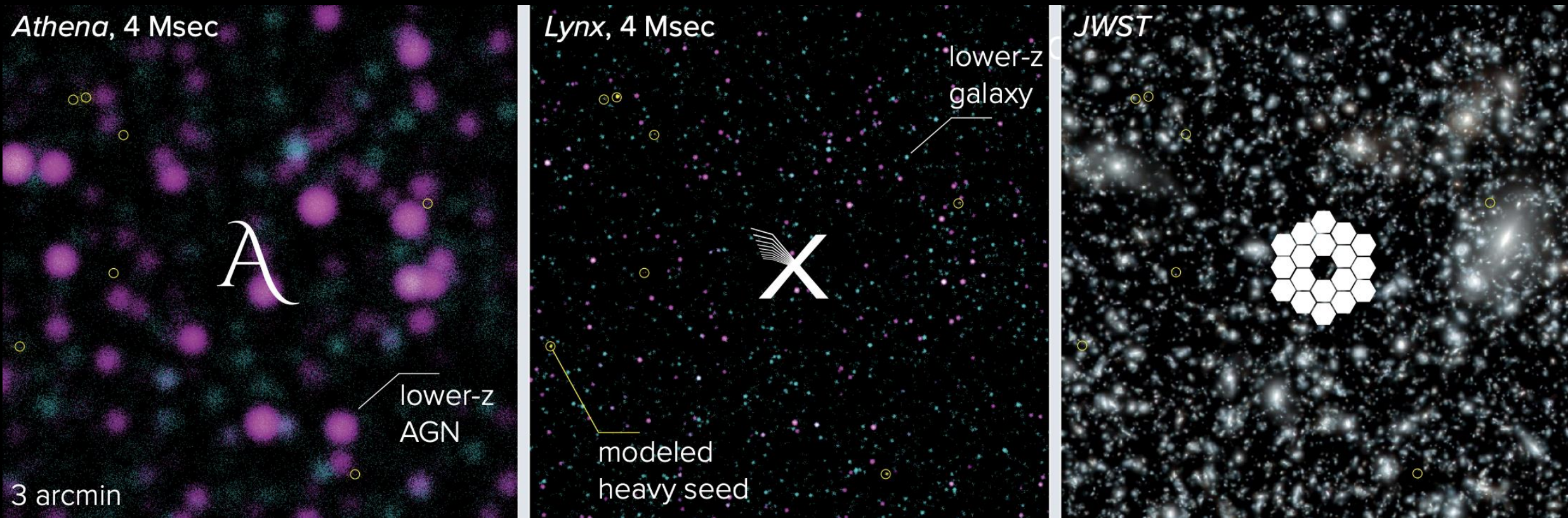


Nabizadeh, Zackrisson, Pacucci+ 2023



Natarajan, Pacucci+ 2023

Synergies with JWST



The Search in the Next Decades

DETECTING THE DAWN OF BLACK HOLES

<u>FUTURE OBSERVATORY</u>	<u>IMPORTANCE FOR SEEDS</u>
JWST (LAUNCH: 2021) 	• DETECT PEAK EMISSION OF TYPICAL SEEDS • DETECT HEAVILY OBSCURED SEEDS
ATHENA (PLANNED: 2031) 	• LARGER FIELD OF VIEW FOR SURVEYS • DETECT COMPTON-THIN SOURCES
LYNX (CONCEPT STUDY) 	• HIGHER ANGULAR RESOLUTION • DETECT HEAVILY COMPTON-THICK SOURCES
LISA (PLANNED: 2034) 	• UNEQUIVOCALLY DETERMINE MAIN FORMATION CHANNEL OF SEEDS

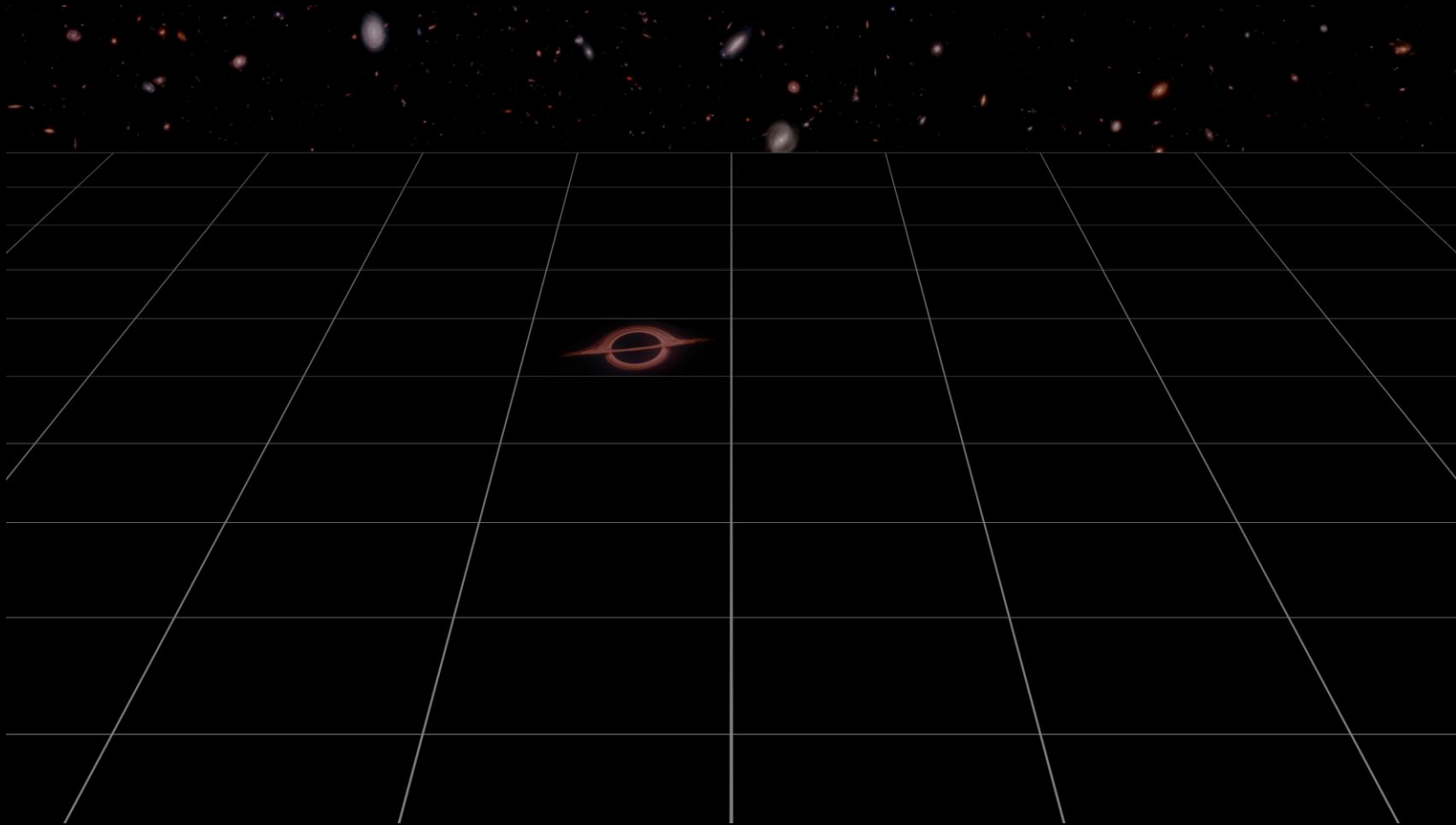
Lynx is needed
to directly
detect the seeds!

AXIS X-ray Surveys

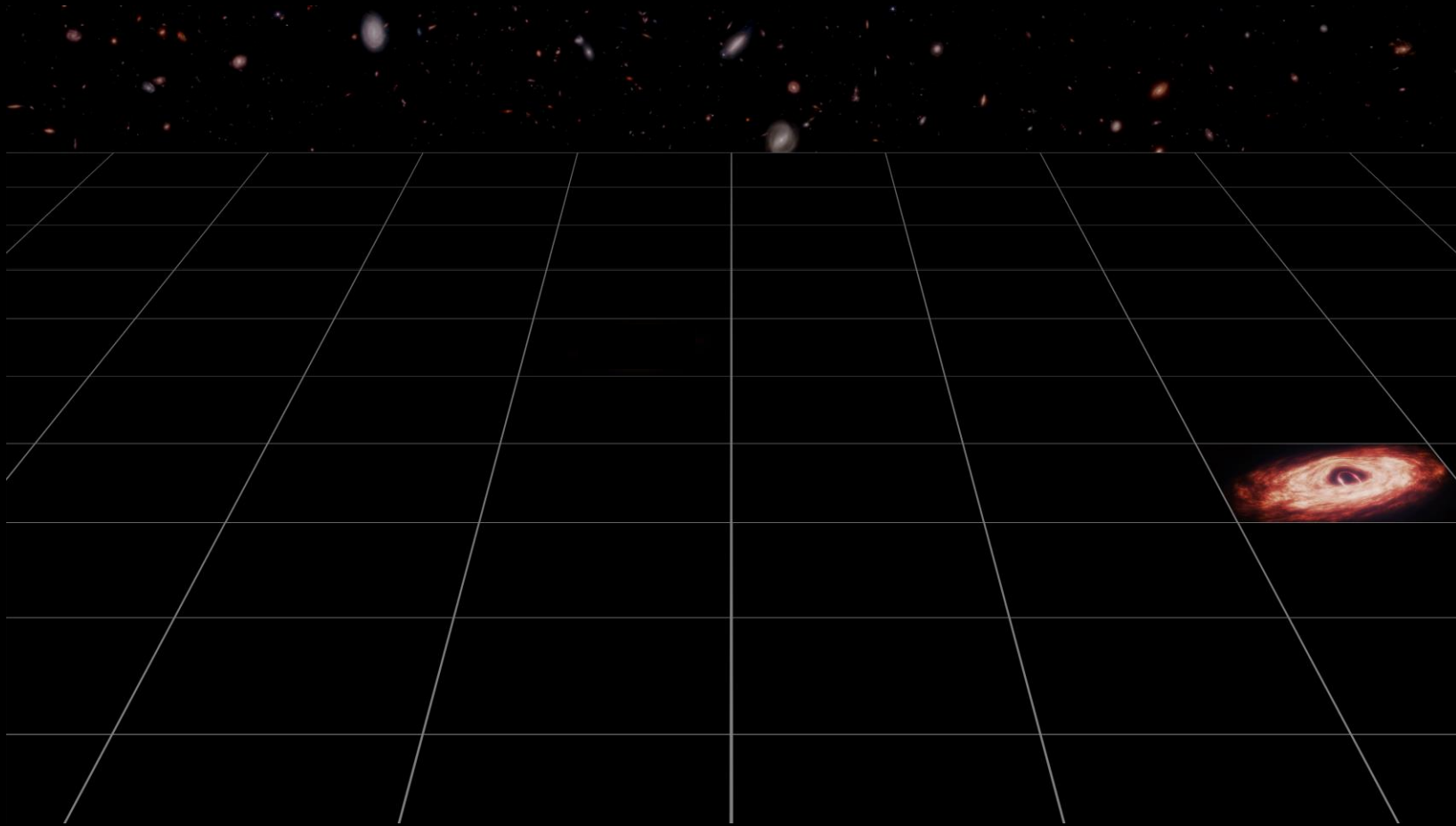
Current X-ray Surveys



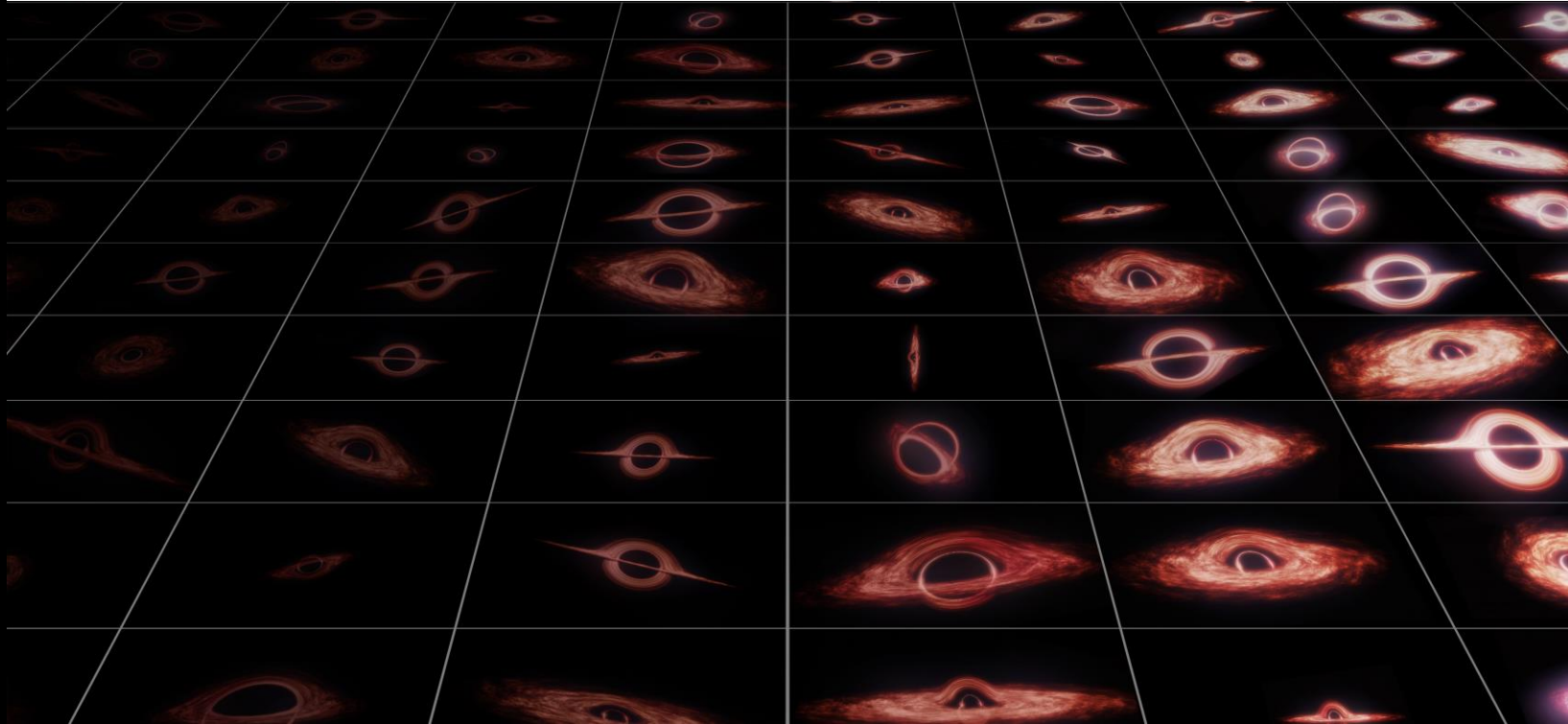
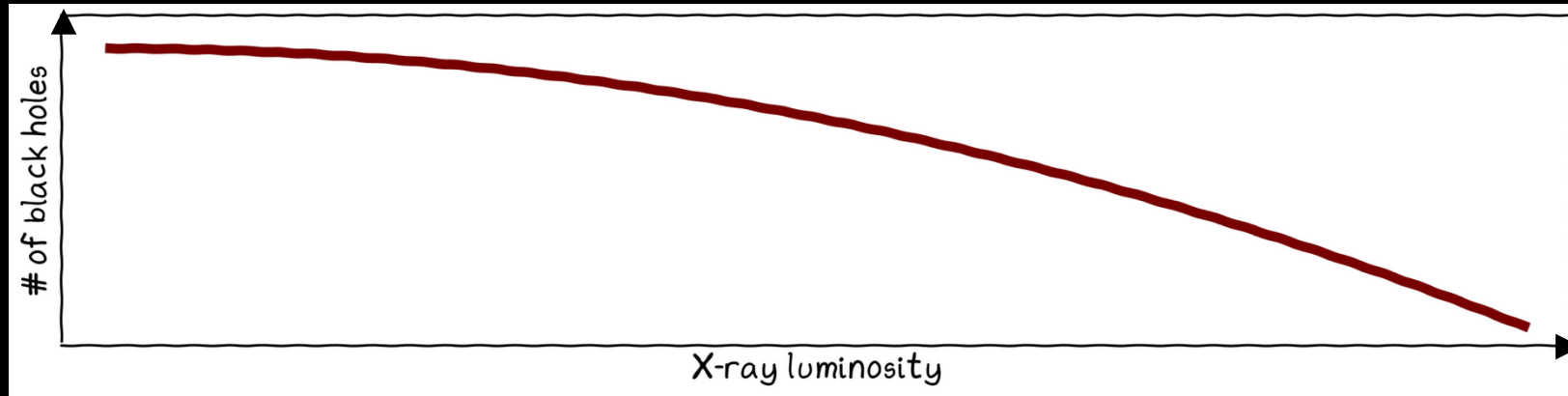
The Black Hole Luminarium



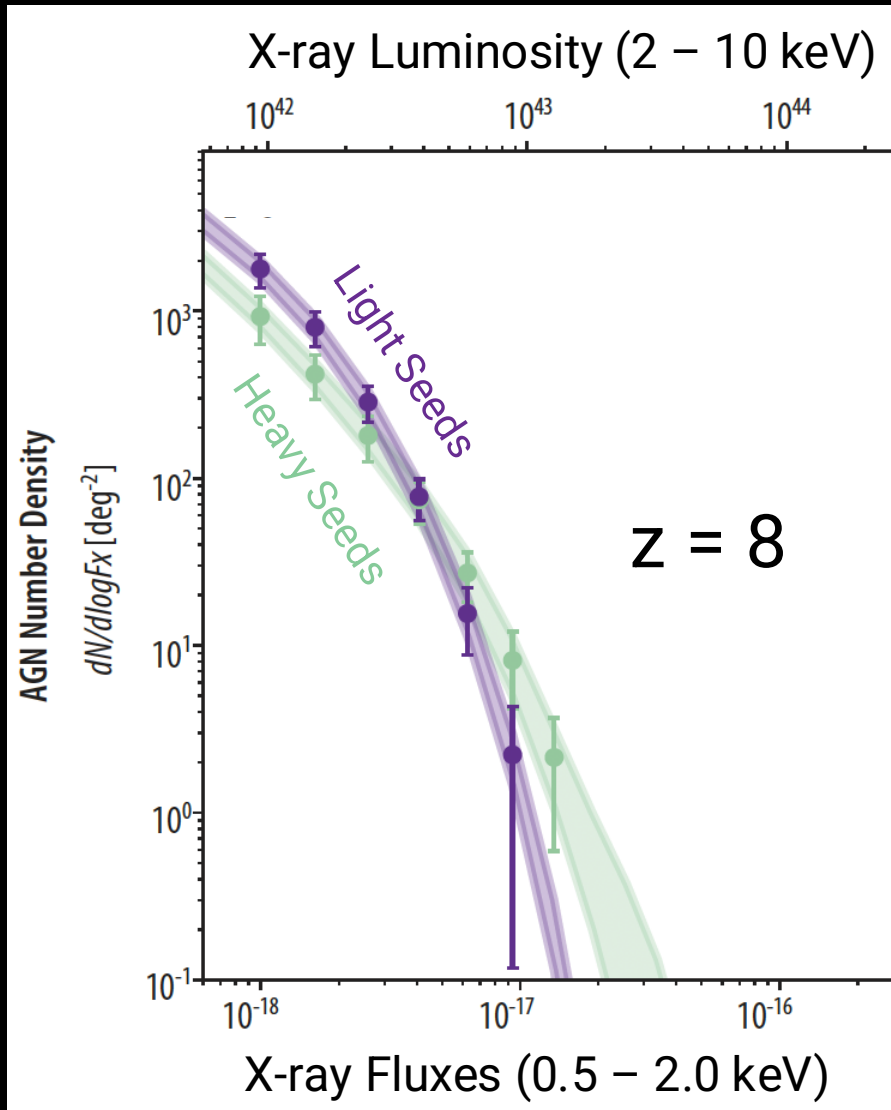
The Black Hole Luminarium



The Black Hole Luminarium



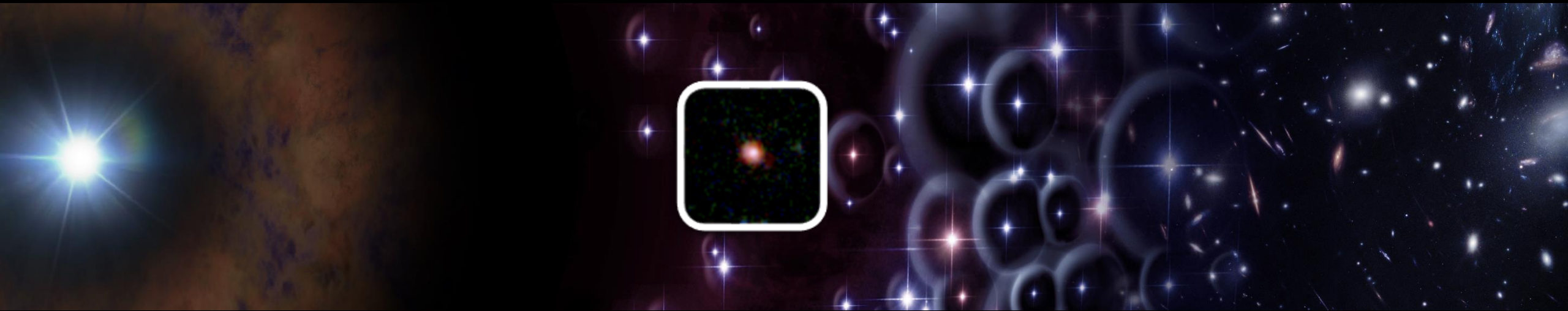
Discriminating Between Seed Models



AXIS Proposal; See also Ricarte+ 2018; Cappelluti+ (incl. **Pacucci**) 2024; **Pacucci**+ 2024

#2: The Epoch of Reionization

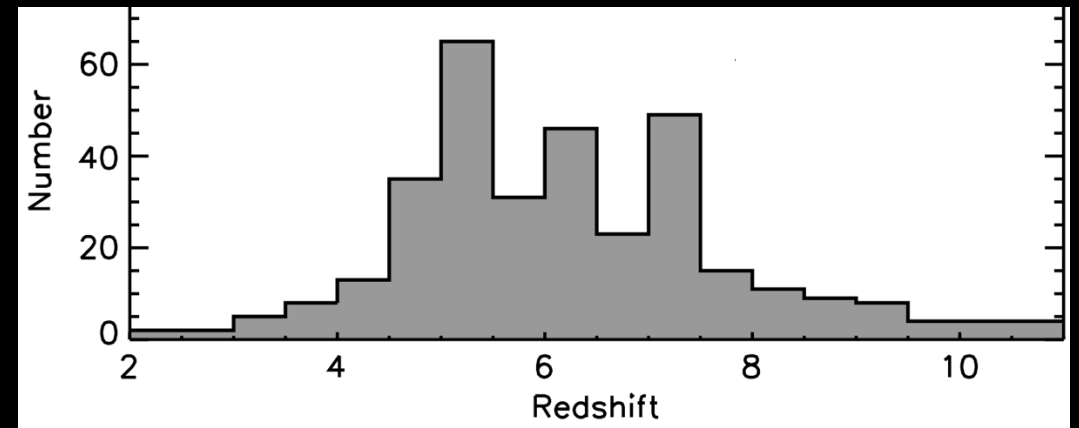
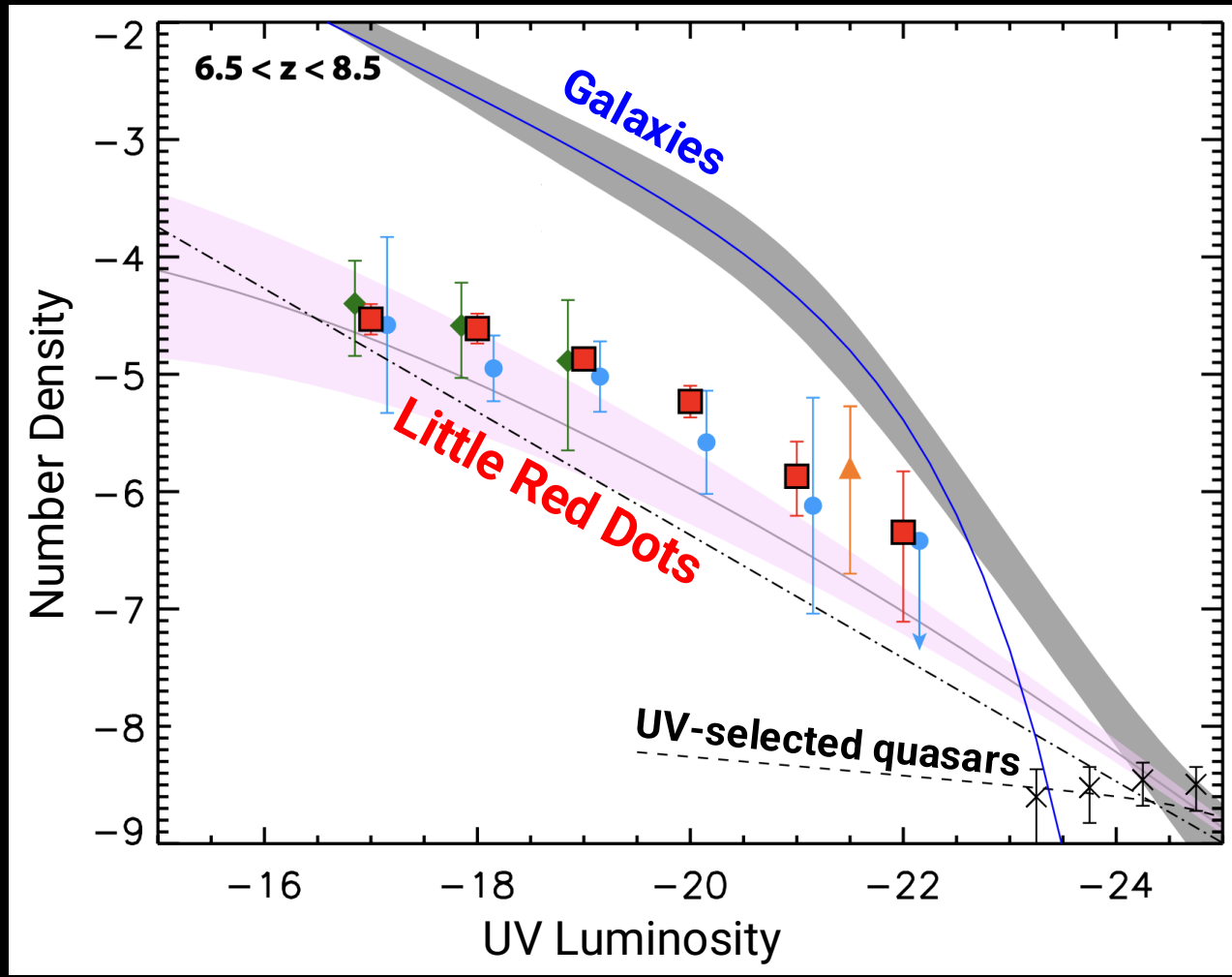
JWST's Little Red Dots





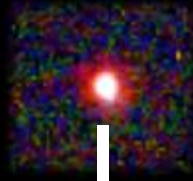
NASA press release, January 2025, Kocevski+ (incl. **Pacucci**)

The “Little Red Dots” Are Common



Kocevski+ (incl. **Pacucci**) 2024; Taylor+ (incl. **Pacucci**) 2024

What Are They?



COMPACT ($R_{\text{eff}} \sim 100 \text{ pc}$)



AGN DOMINATED

see, e.g., Greene+ 23,
Akins+ 24, Casey+ 24,
Baggen+ 24, Taylor+ 24,
Leung+24, Pacucci+ 24

STAR FORMATION DOMINATED

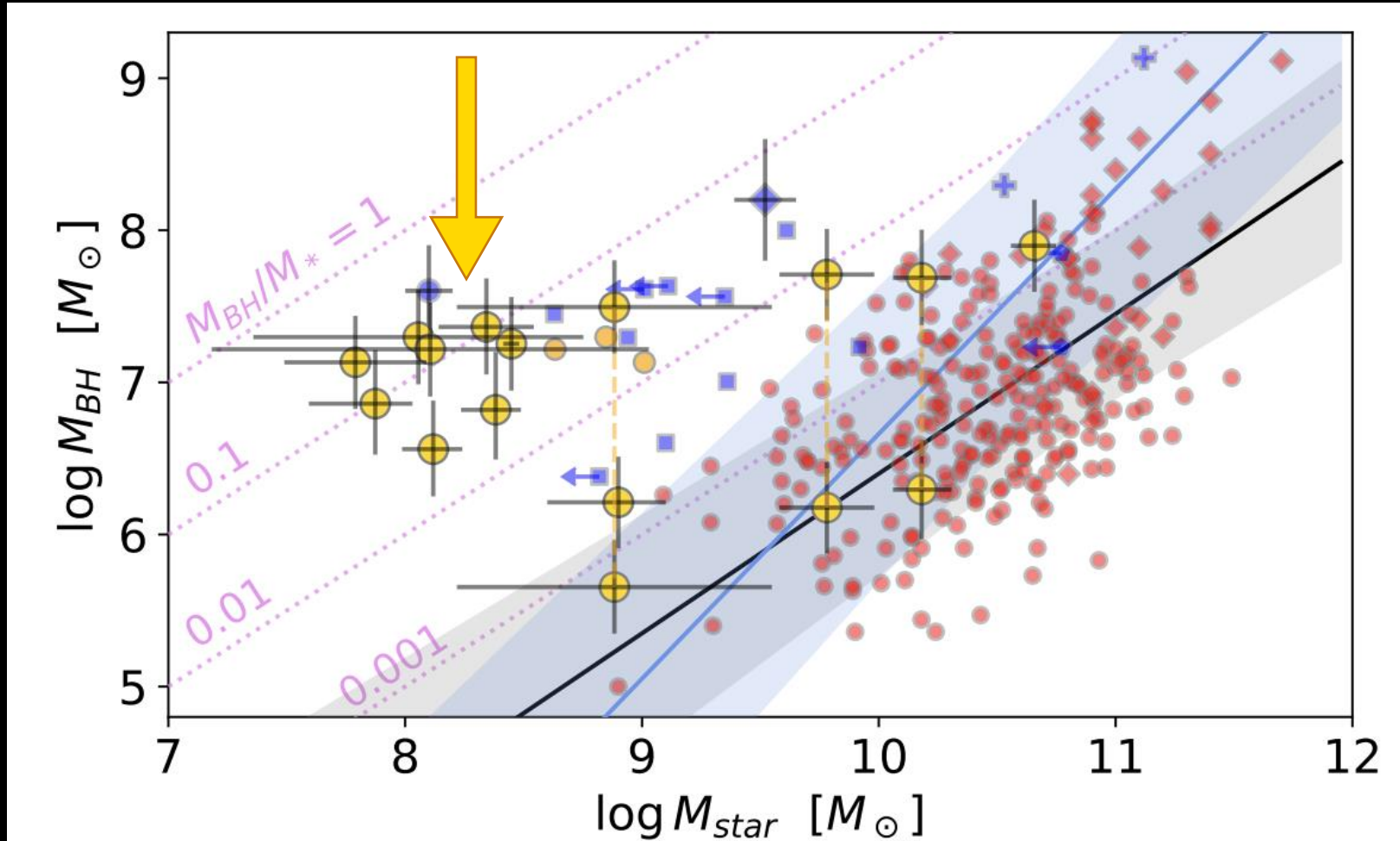
Caveats:

- 1) Black holes seem overmassive
- 2) Black holes are undetected in X-rays

Caveats:

- 3) Implied stellar densities are extreme

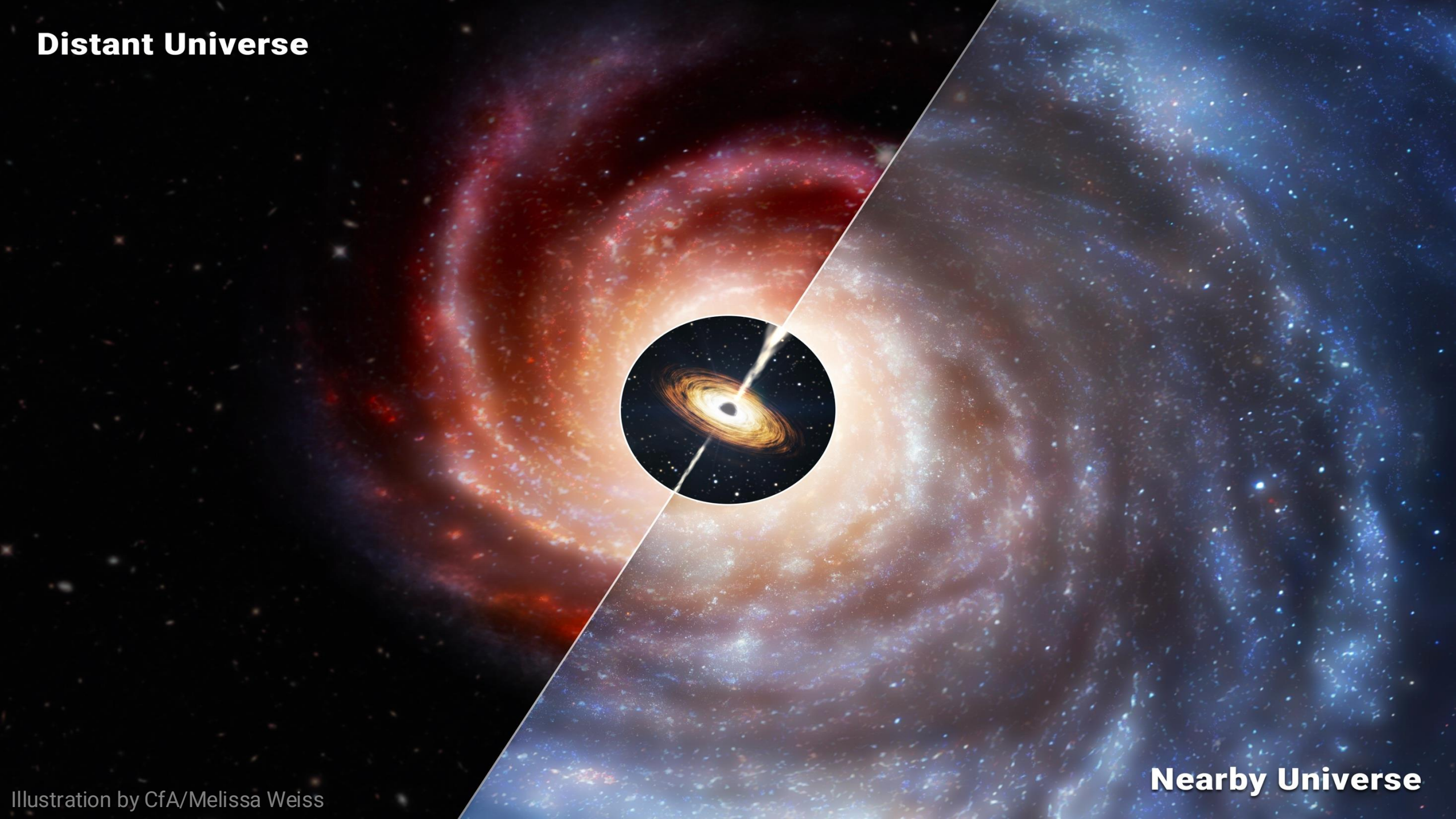
Problem #1: Overmassive Black Holes



Maiolino+ 2023b (JADES Collaboration)

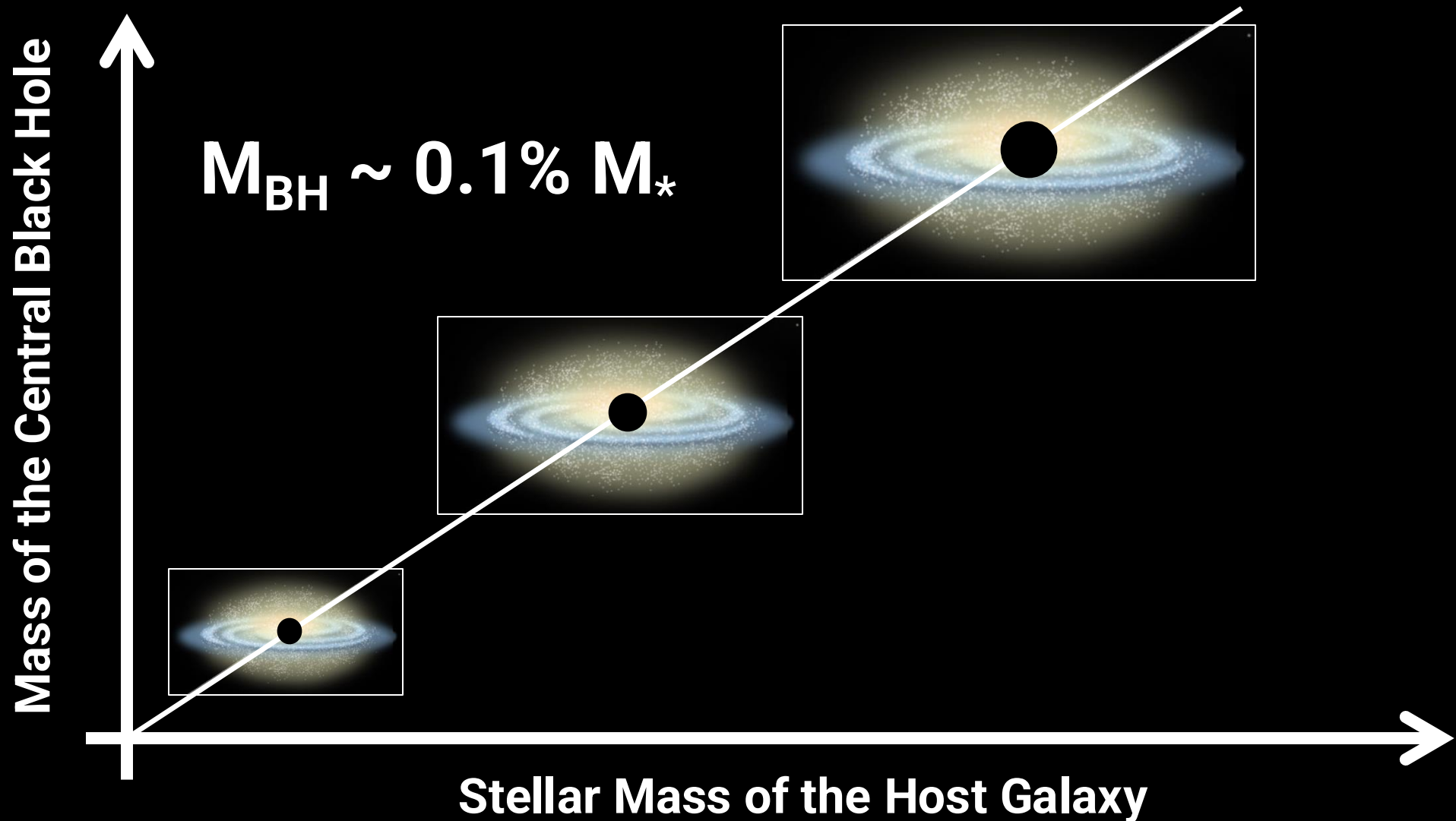
See also Pacucci+ 2023

Distant Universe

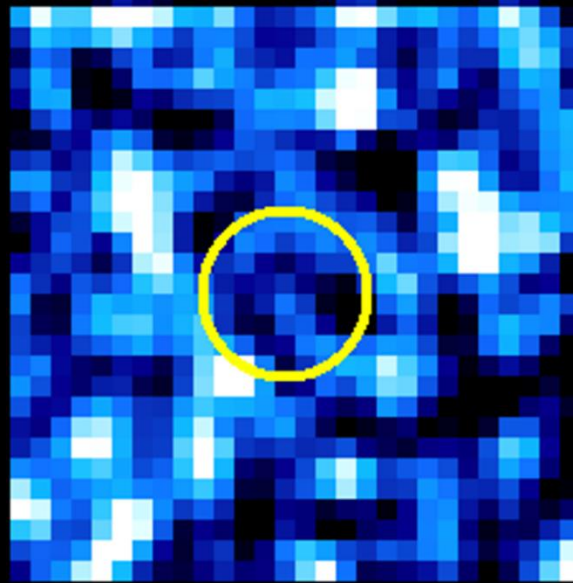


Nearby Universe

Galaxies and Black Holes Co-Evolve



Problem #2: X-ray Weakness

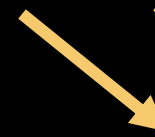


Maiolino+ 2024
Yue+ 2024
Ananna+ 2024

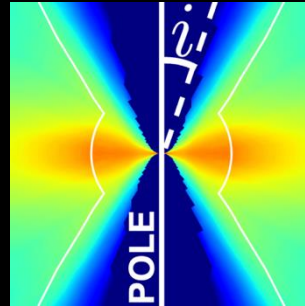
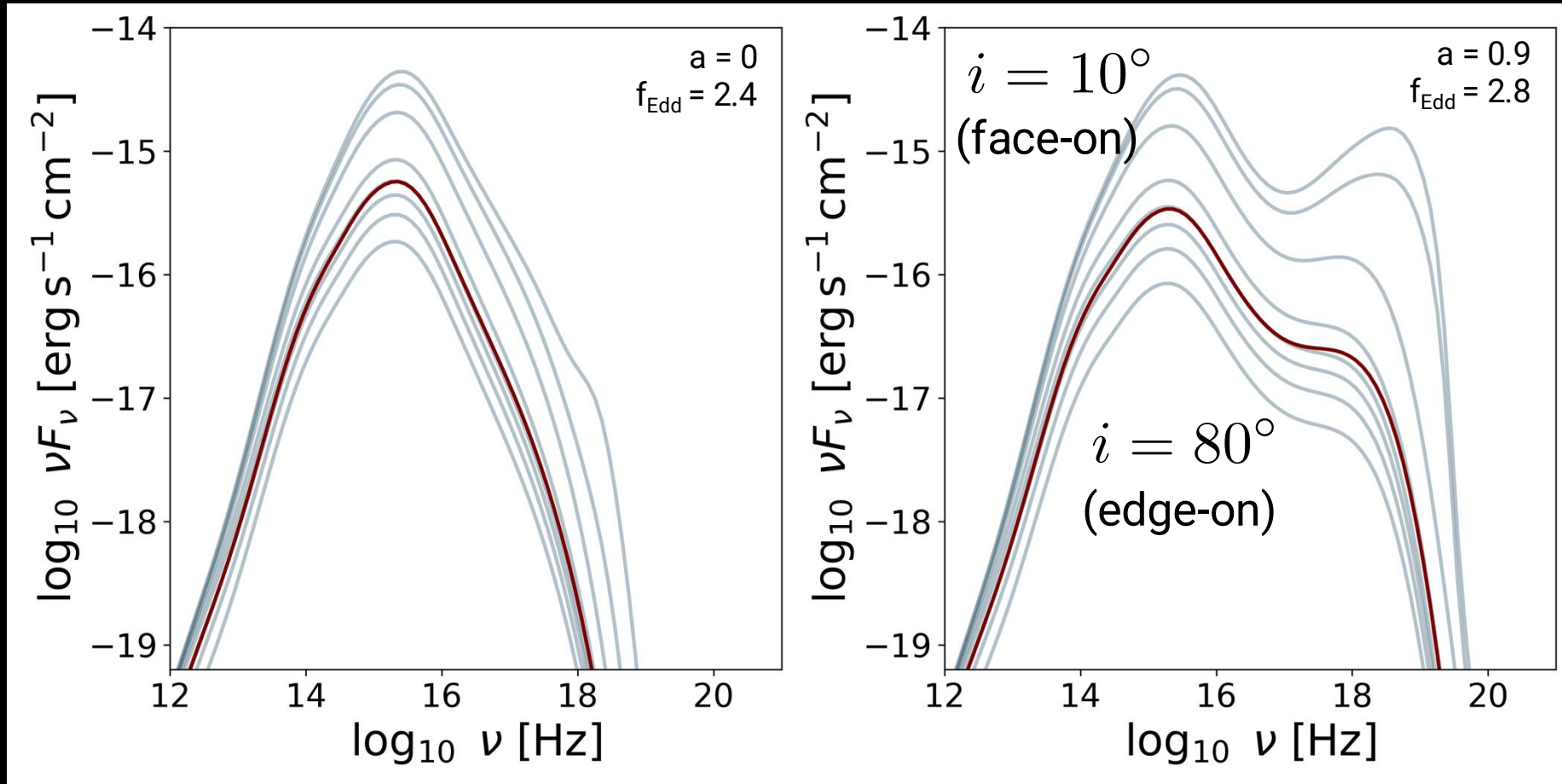
Pacucci & Narayan, 2024
Codes by Sadowski; Narayan

See also:
Lambrides+ (incl. **Pacucci**) 2024;
King 2024; Lupi+ 2024;
Madau & Haardt, 2024

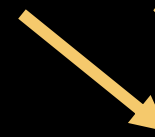
X-ray **Weak** and X-ray **Strong** SEDs



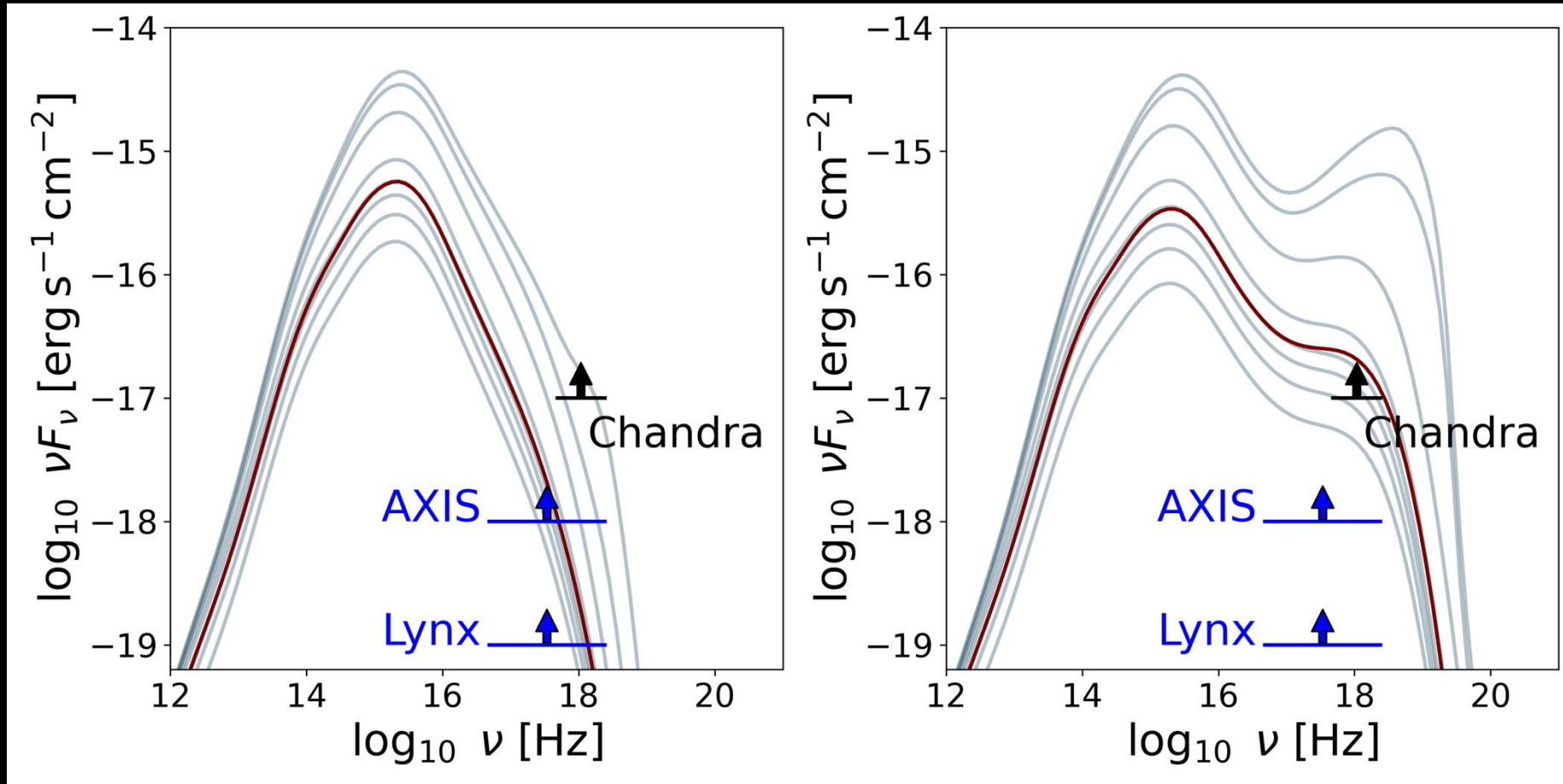
$z = 6$



X-ray **Weak** and X-ray **Strong** SEDs



$z = 6$

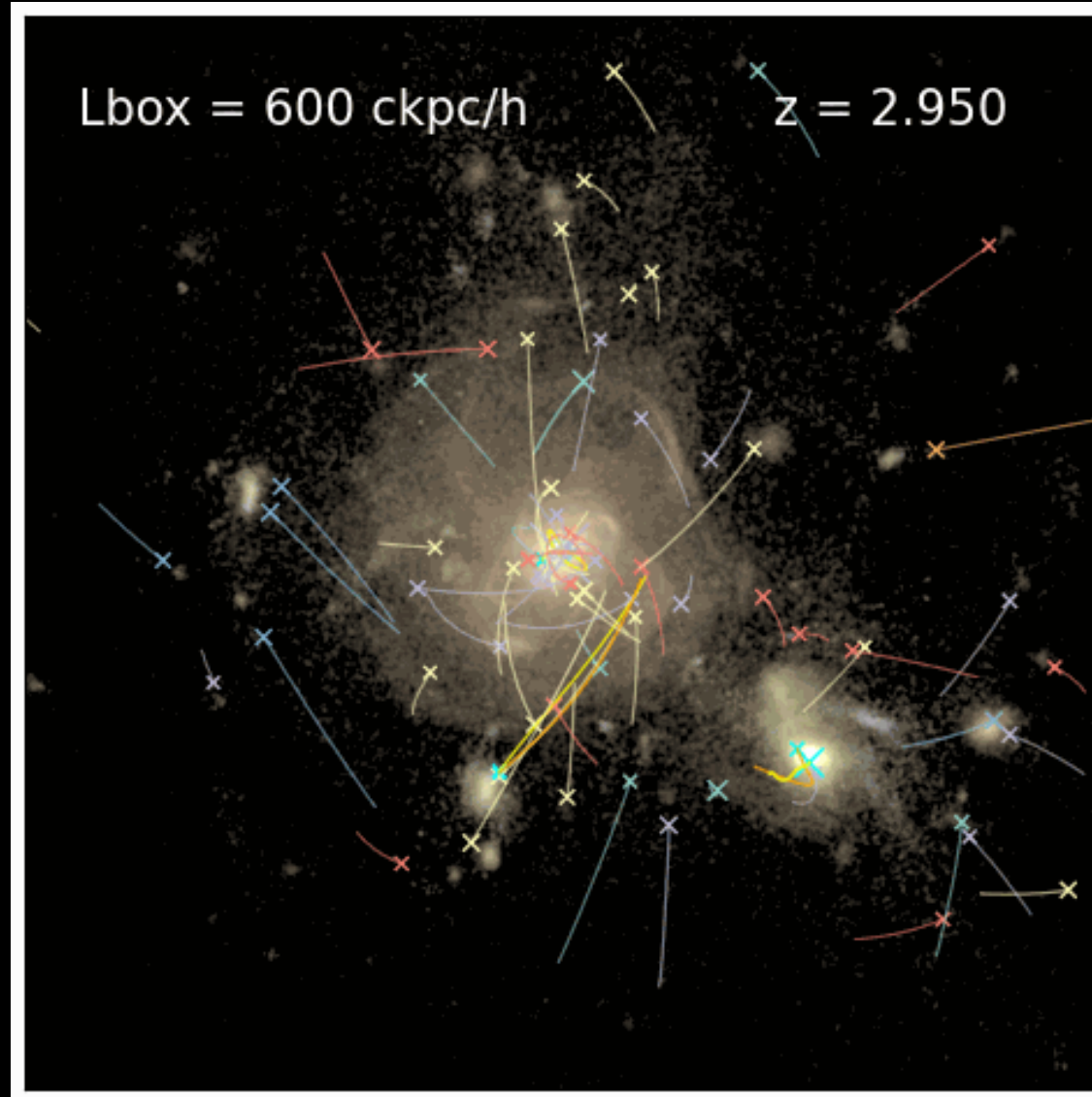


#3: The Local Universe

Wandering Massive Black Holes

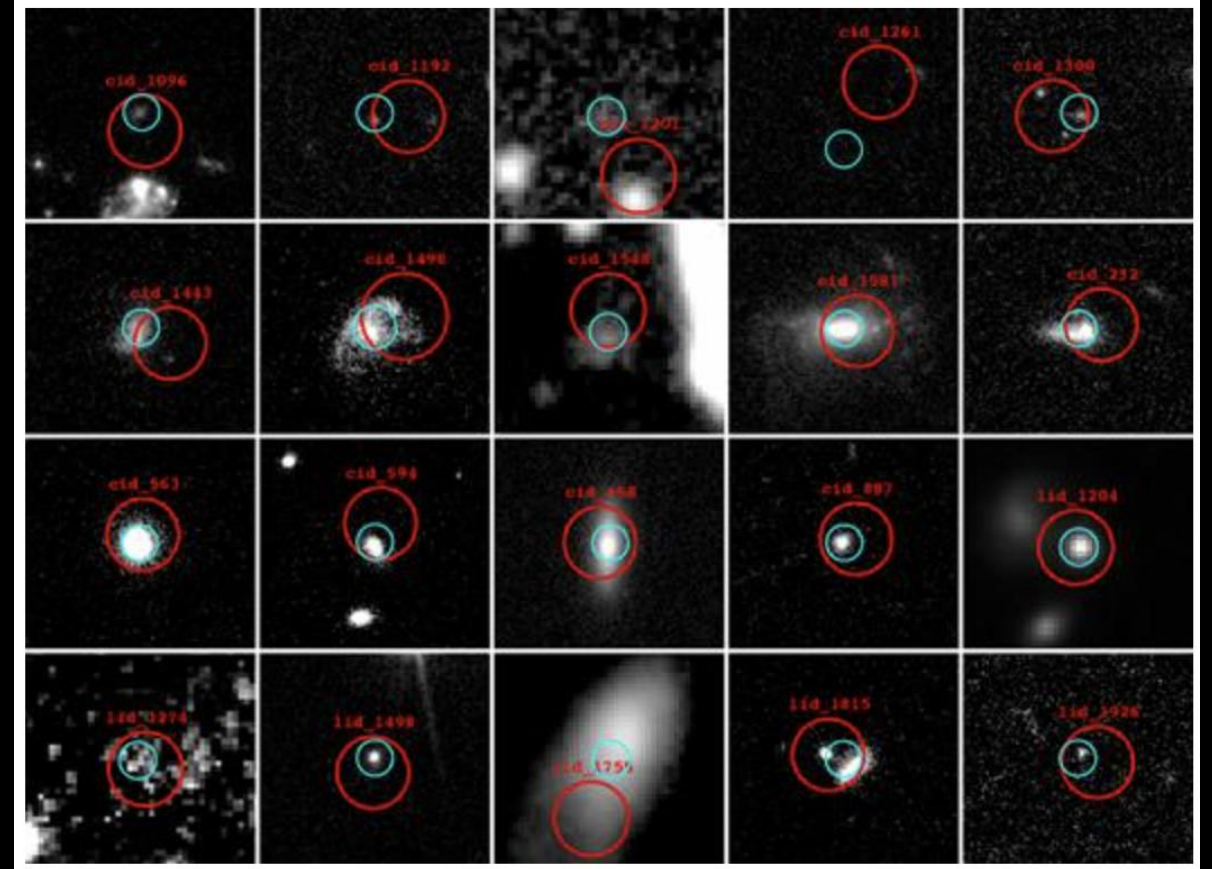
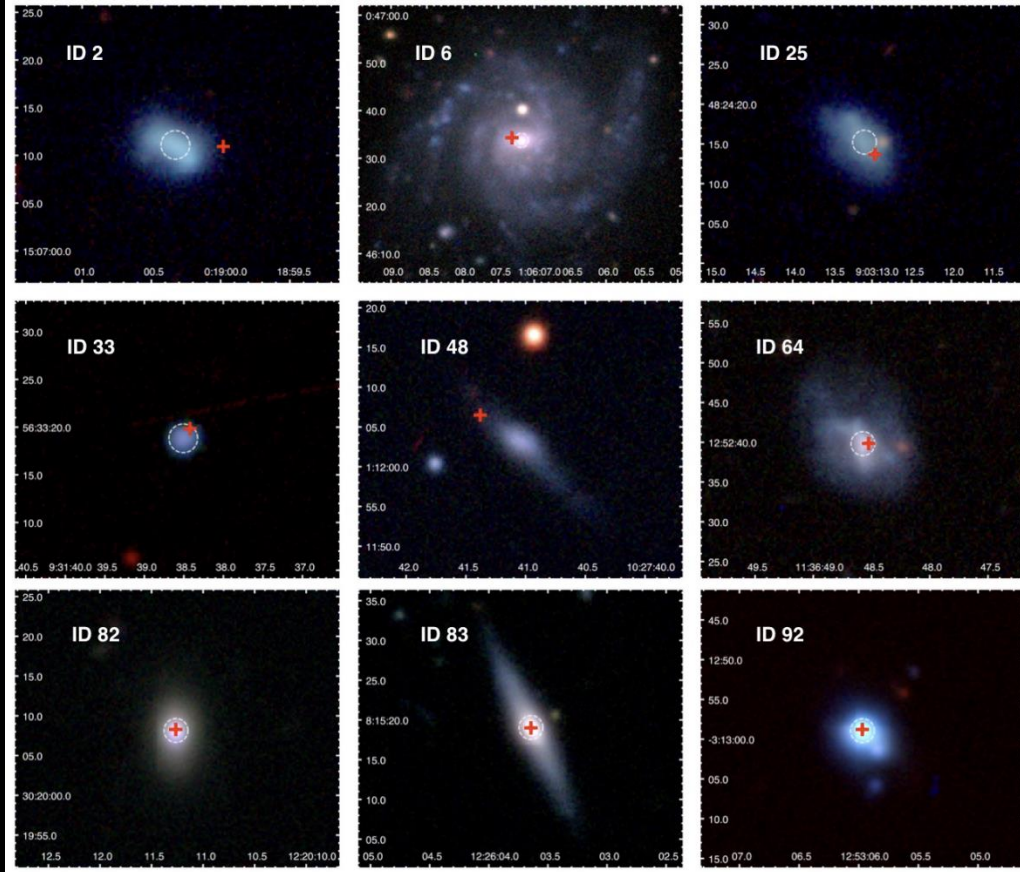


Local Wandering Massive Black Holes

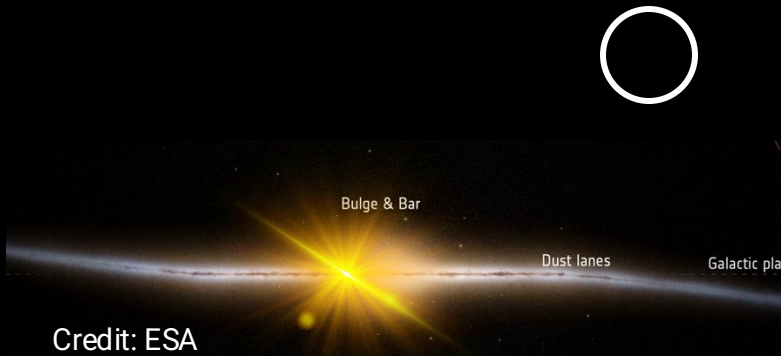


Astrid Simulation; Ni+ 2022; Bird+ 2022; Di Matteo+ (incl. **Pacucci**) 2023

Local Wandering Massive Black Holes



Dynamical and Radiative Properties



Weller, **Pacucci**, Hernquist 2022

Weller, **Pacucci+** 2023a

Weller, **Pacucci+** 2023b

Weller, **Pacucci+**, 2024

Several collaborations with the whole
IllustrisTNG and Astrid Teams

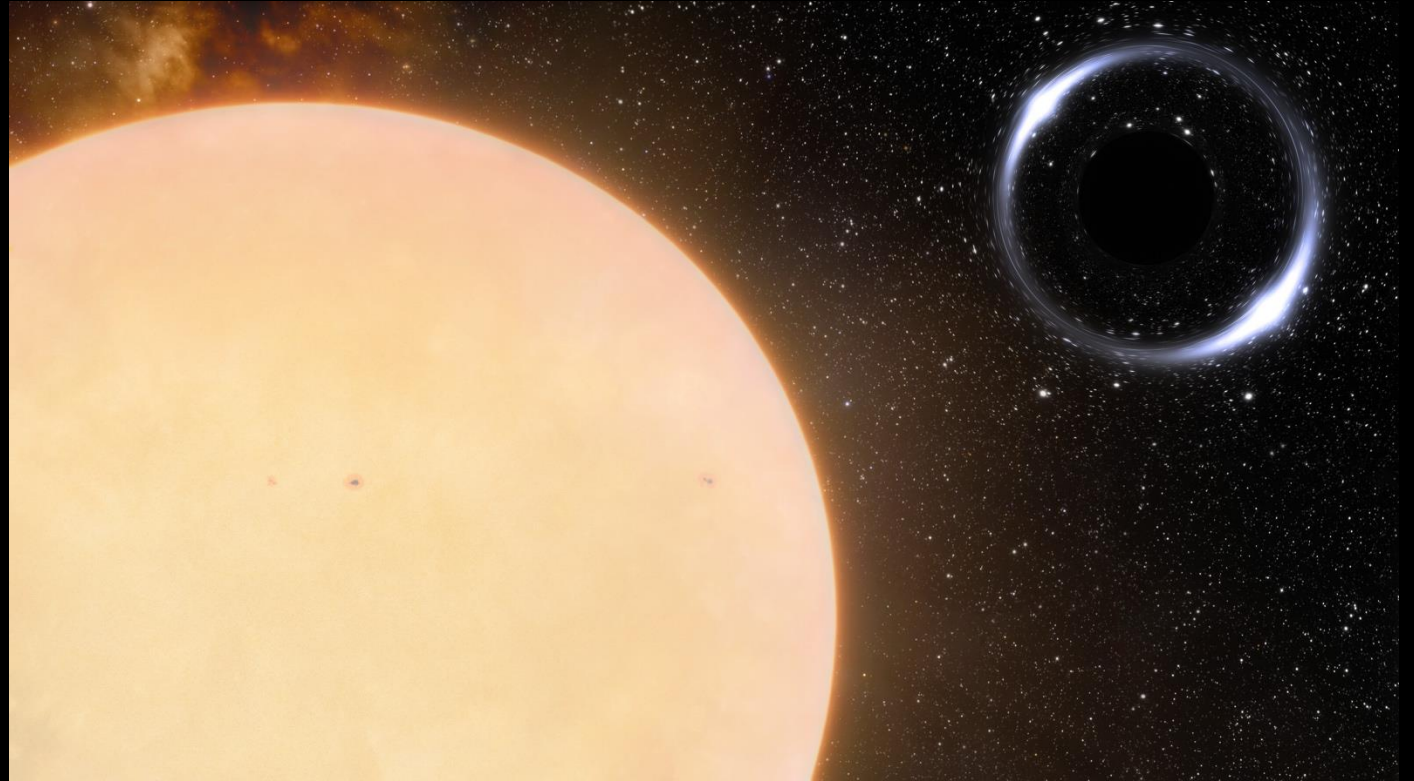
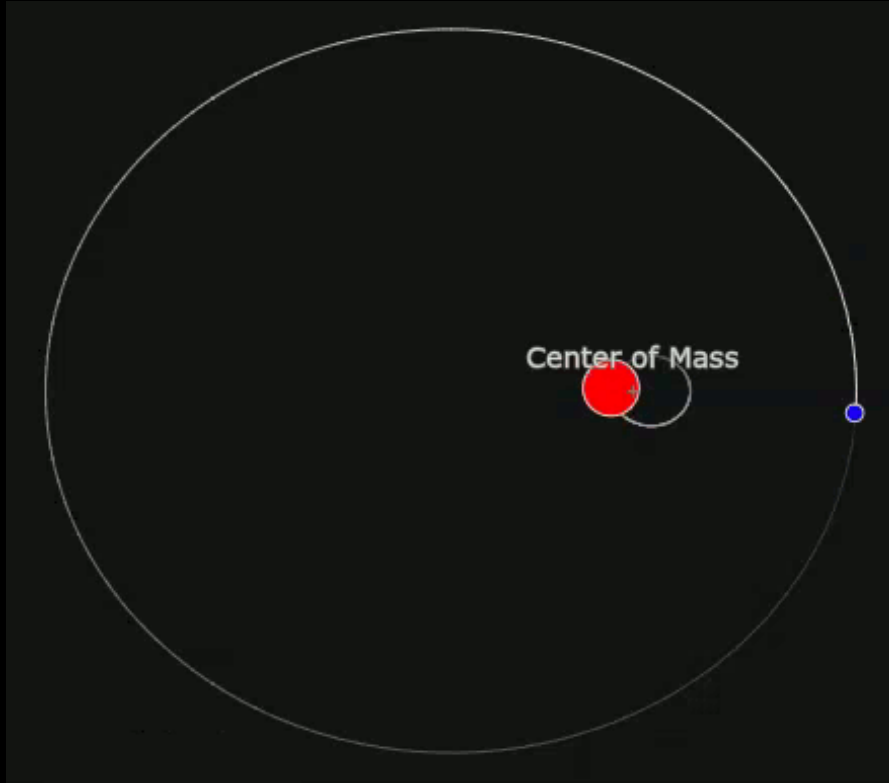


#3: The Local Universe

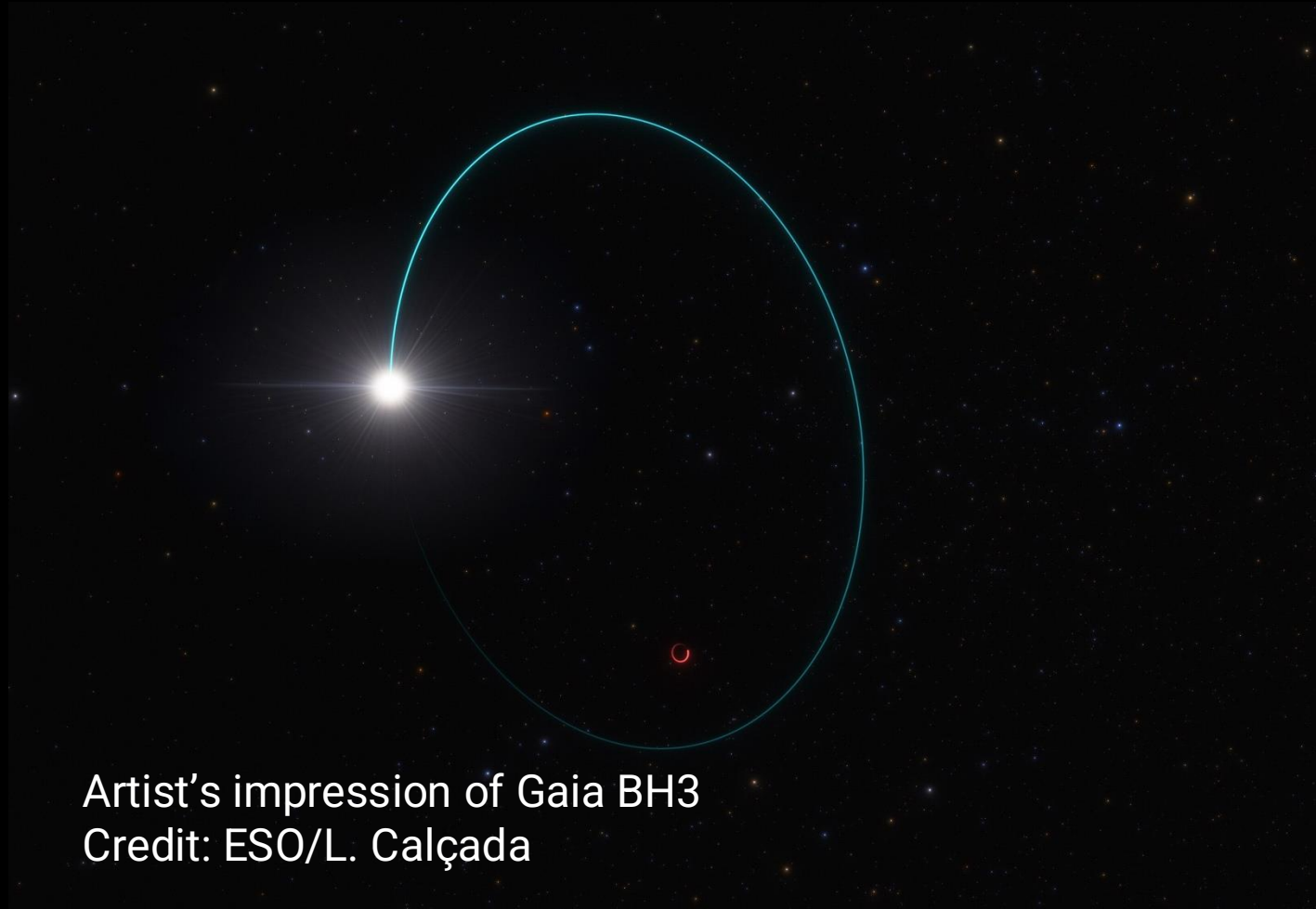
(Quasi) Dormant Stellar Mass Black Holes



Detecting (Quasi) Dormant Black Holes

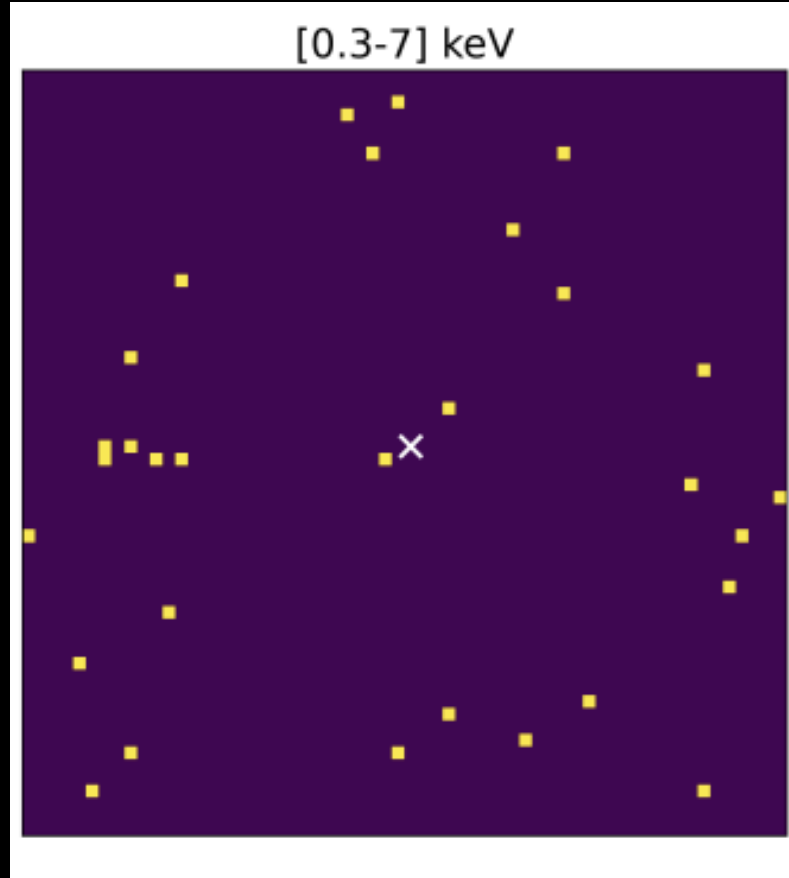


Detecting (Quasi) Dormant Black Holes



Artist's impression of Gaia BH3
Credit: ESO/L. Calçada

Detecting (Quasi) Dormant Black Holes



Chandra, 10 ks, PI: Pacucci

Detecting (Quasi) Dormant Black Holes

