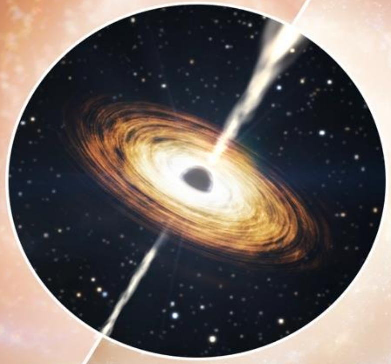
# JWST's Little Red Dots: Masters of Disguise in the High-z Universe




## Fabio Pacucci

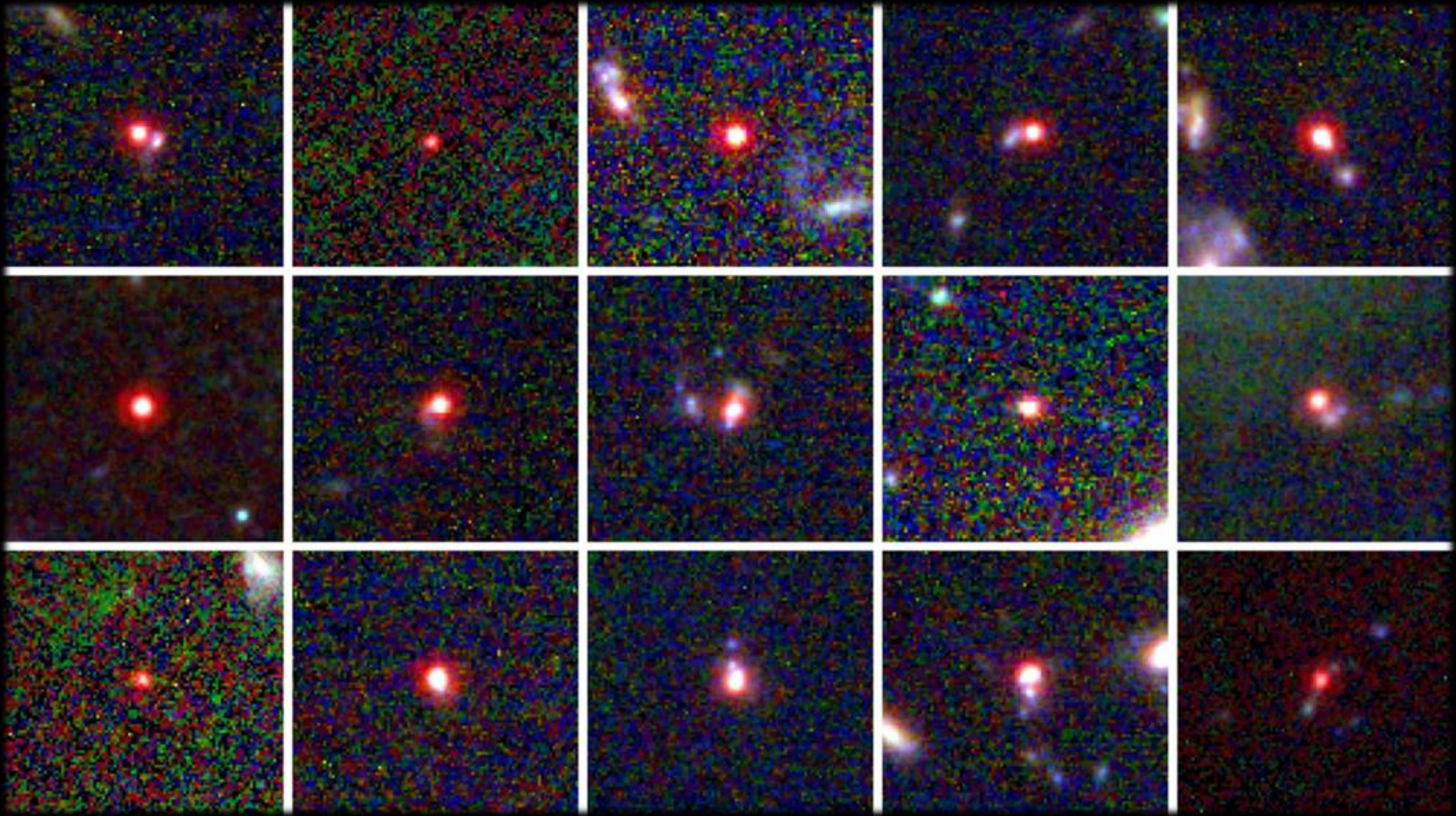
BHI & Clay Fellow

Center for Astrophysics | Harvard & Smithsonian


25 Years of Science with Chandra

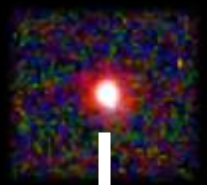
Boston, November 20th, 2024

Illustration by Melissa Weiss/CfA



Images from Kocevski et al. 2024

# What are they?



COMPACT ($R_{eff}$~100 pc)

**AGN DOMINATED**

$L_{bol} \sim 10^{45} - 10^{47}$ erg/s

**STAR FORMATION DOMINATED**

$M_{*} \sim 10^{8.5} - 10^{11} M_{\odot}$

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

**WARNING!**

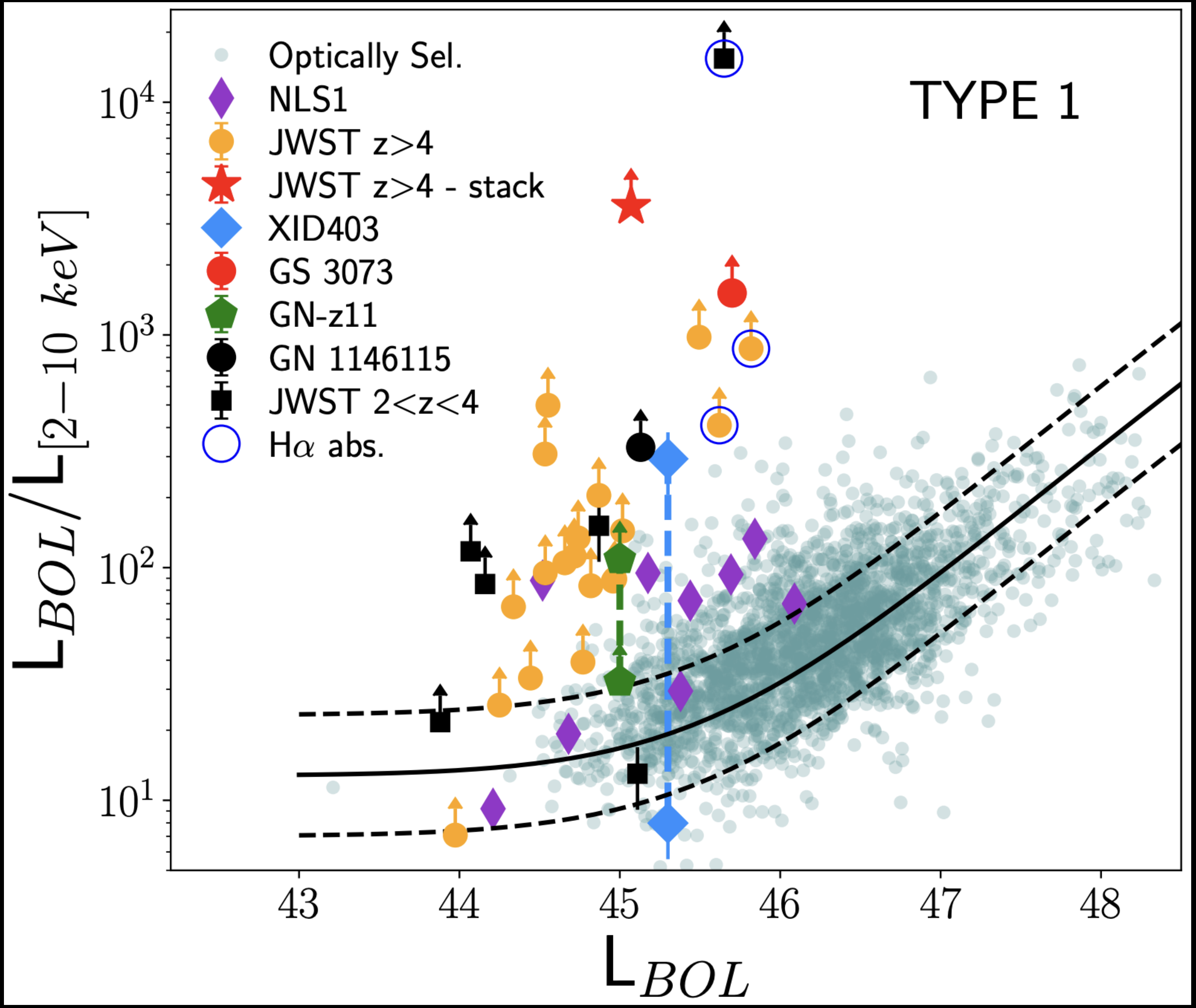
2) Black holes are undetected in X-rays

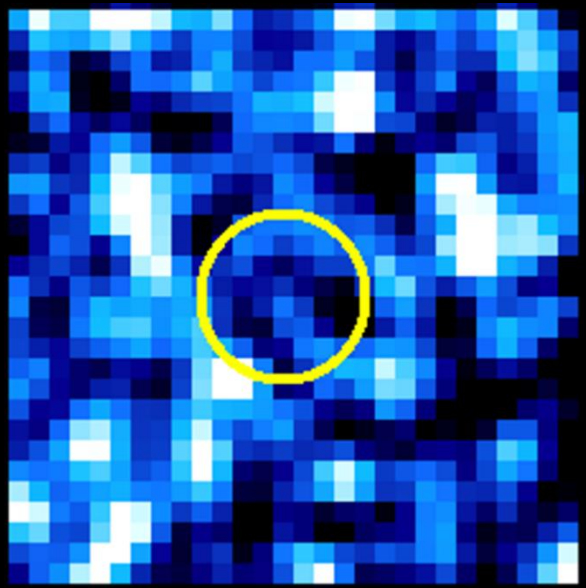
**WARNING!**

3) Implied stellar densities are extreme

# #2: The X-ray Weakness Problem

# X-ray Weakness of JWST's Type-1 AGN

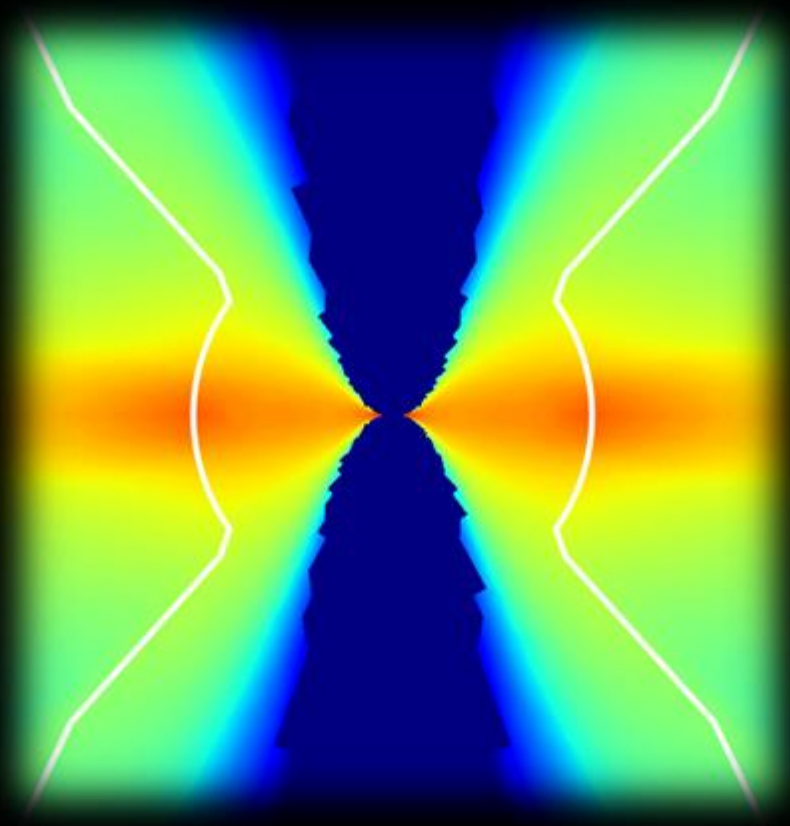


Maiolino et al. (2024)

See also:
Yue et al. (2024)
Ananna et al. (2024)

# Our Solution: Mildly Super-Eddington Accretion



We used detailed GRRMHD simulations of super-Eddington accretion onto $M_\bullet = 10^7 M_\odot$ at $z = 6$.

The SEDs that we obtain are intrinsically X-ray weak.

The highest levels of X-ray weakness occur in SMBHs accreting:

- at mildly super-Eddington rates ($1.4 < f_{Edd} < 4$);
- with zero spin;
- viewed at angles >30° from the pole.

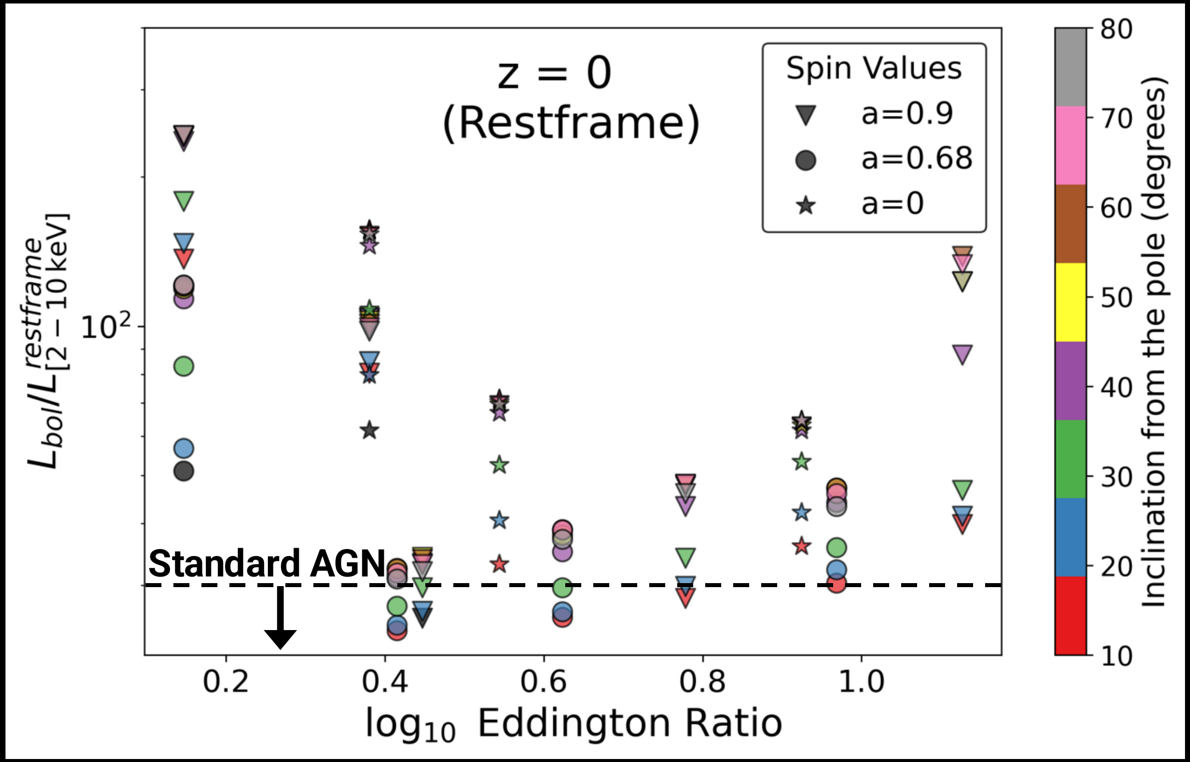
Pacucci & Narayan, 2024
ApJ, arXiv:2407.15915

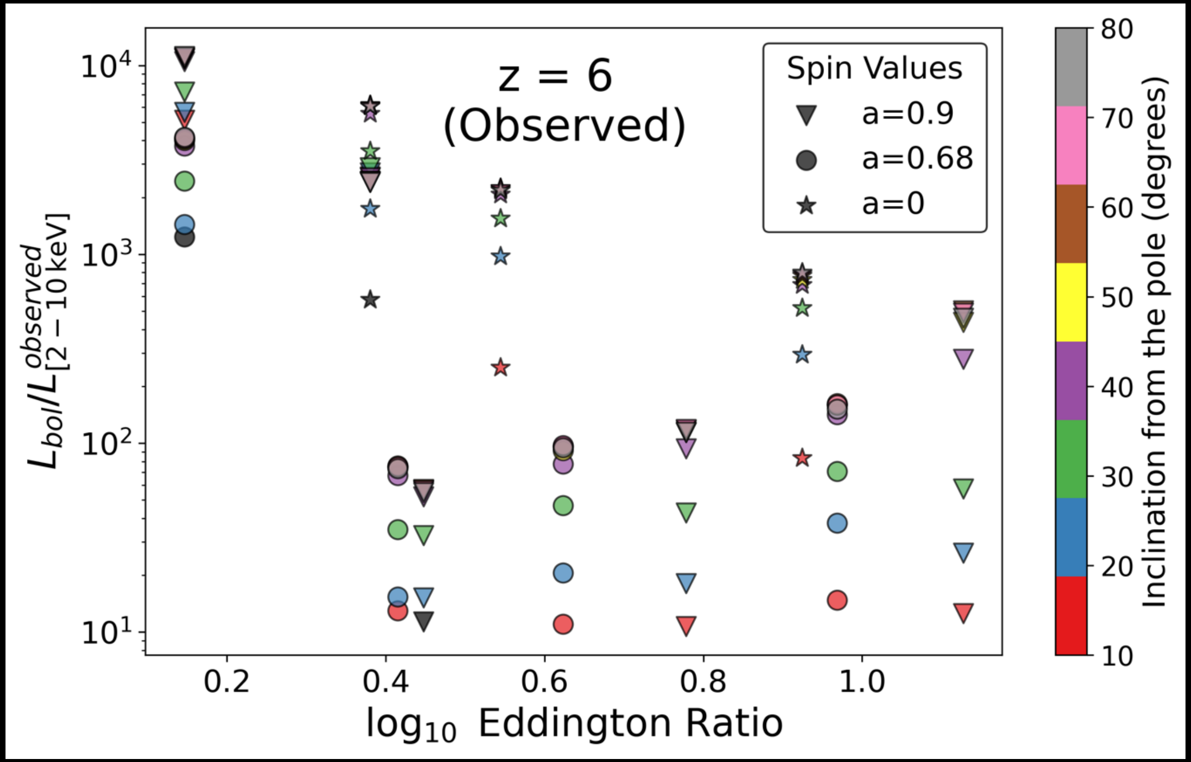
See also:
Lambrides et al. (incl. FP), 2024;
King 2024; Lupi et al., 2024;
Madau & Haardt, 2024

# X-ray Bolometric Corrections

$$k_X = \frac{L_{\rm bol}}{L^{z=0}_{2-10\,{\rm keV}}}$$

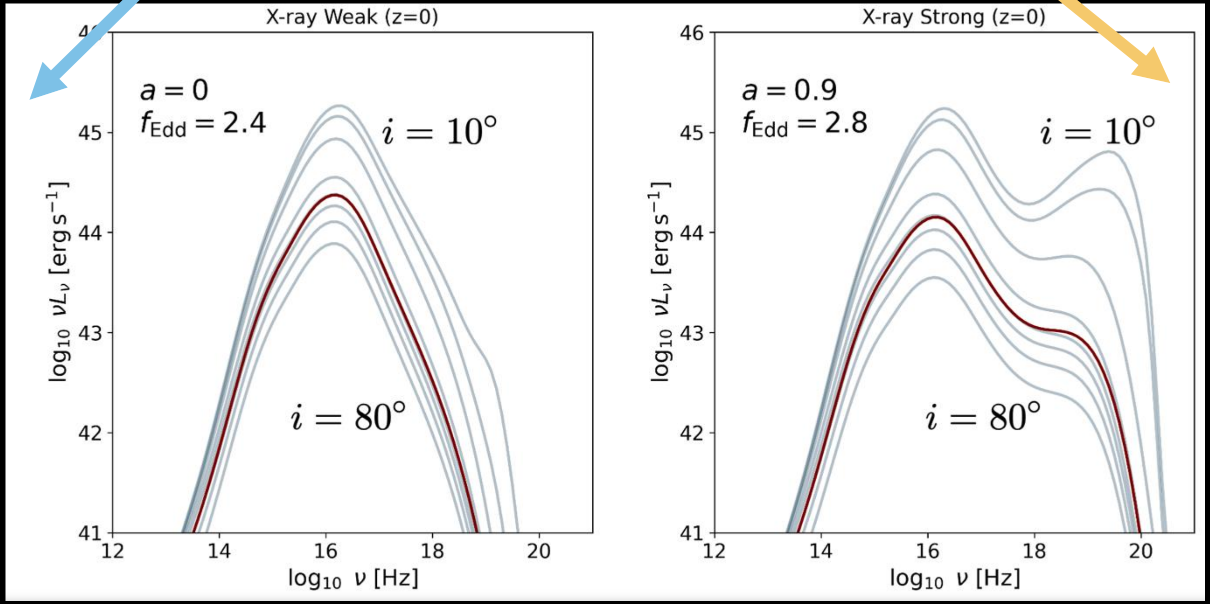
$$k_X^{z=6} = \frac{L_{\rm bol}}{L^{z=6}_{2-10\,{\rm keV}}}$$




Pacucci & Narayan, 2024

# X-ray Weak and X-ray Strong SEDs

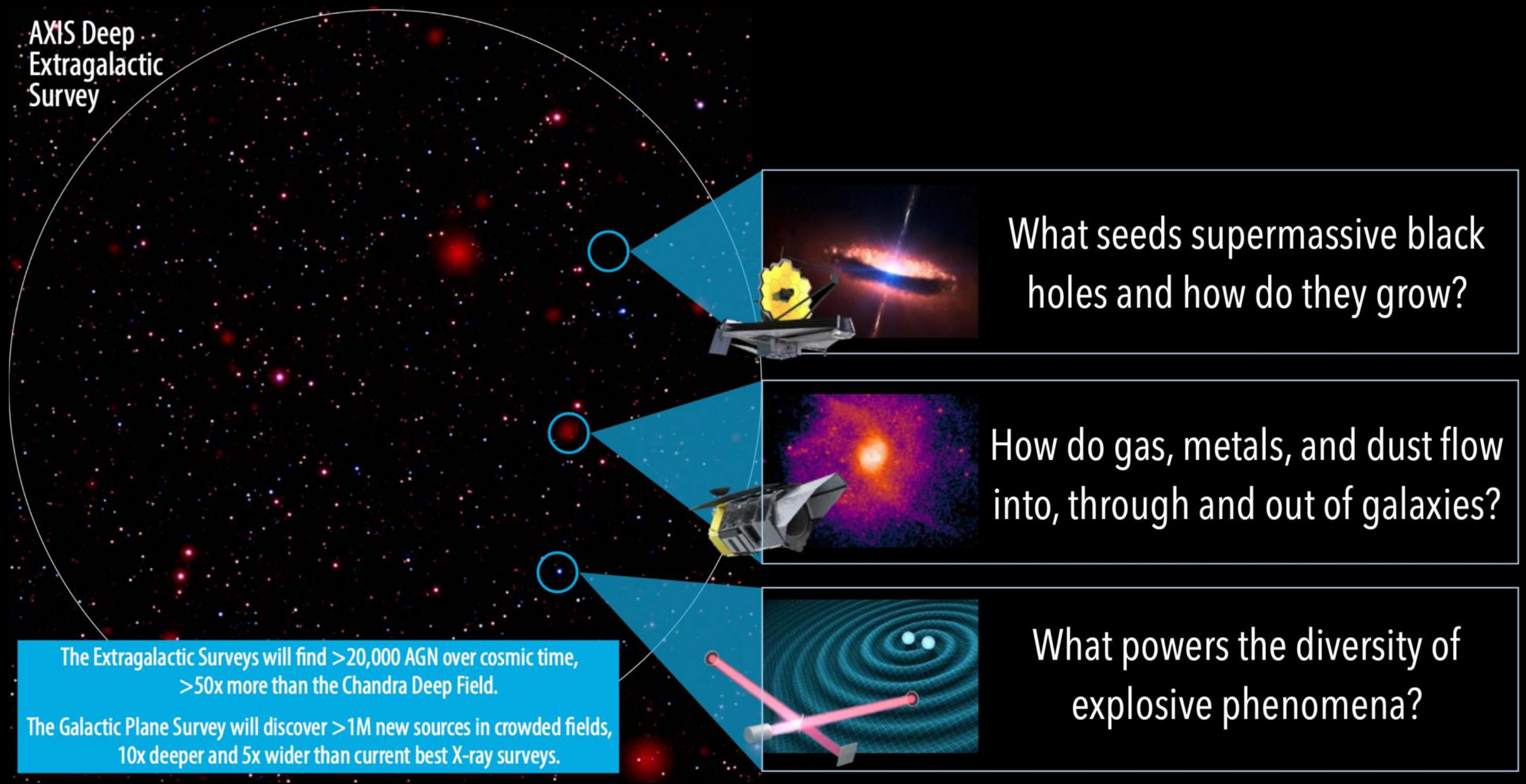


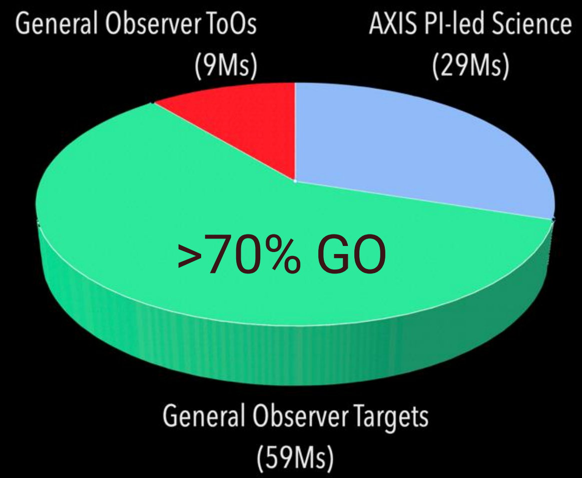

z = 0

z = 6

Pacucci & Narayan, 2024

# AXIS Will Detect These Sources!

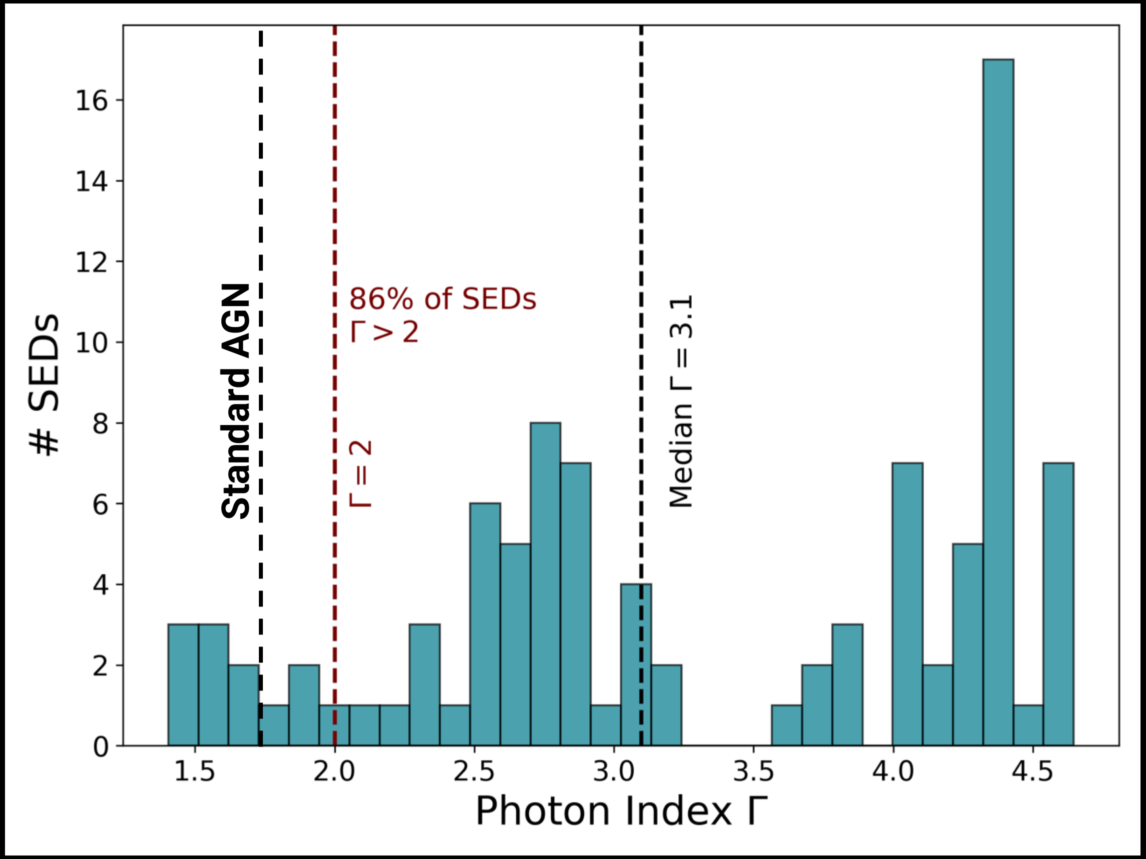


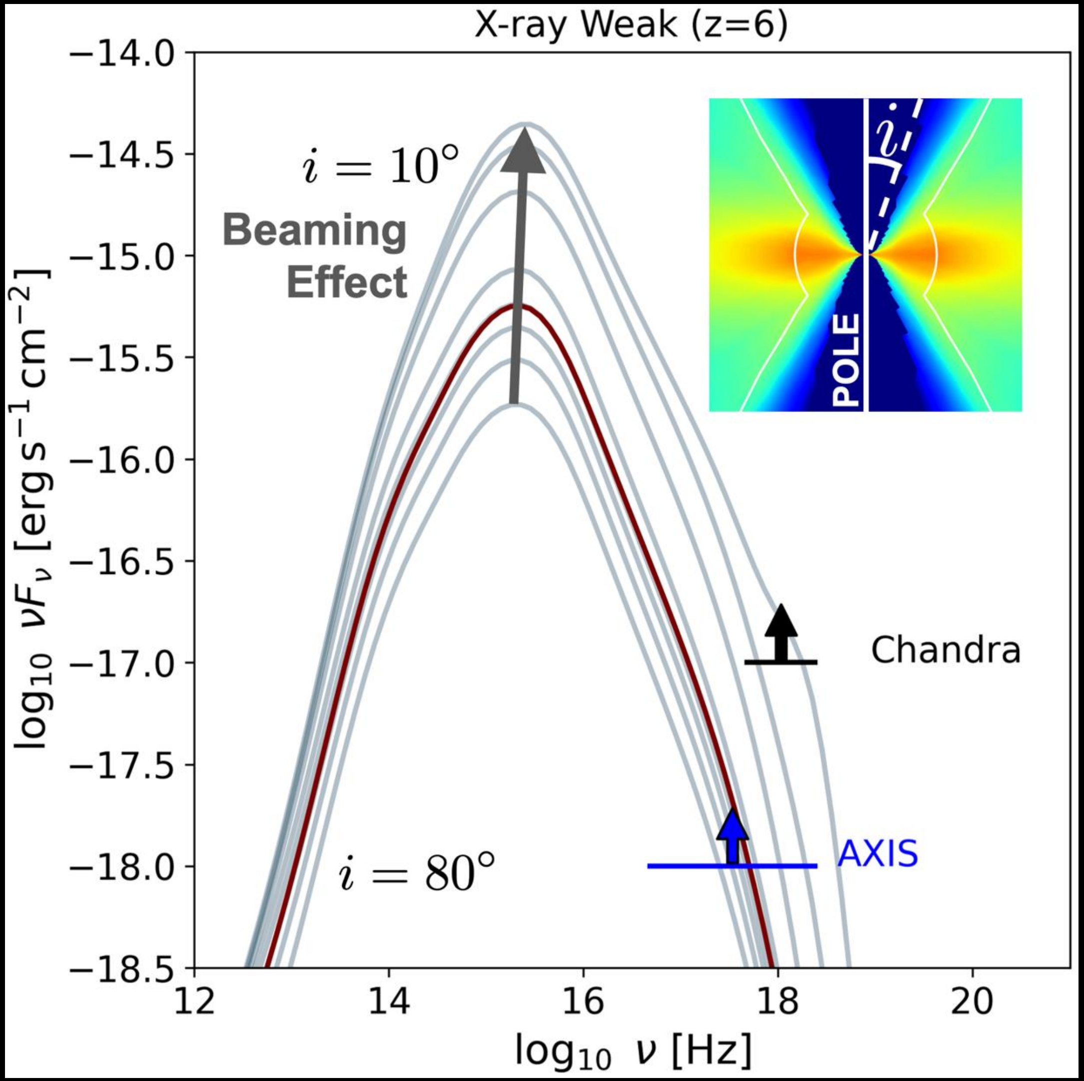




axis.astro.umd.edu

Chris Reynolds (UMD; PI)
Erin Kara (MIT; DPI)

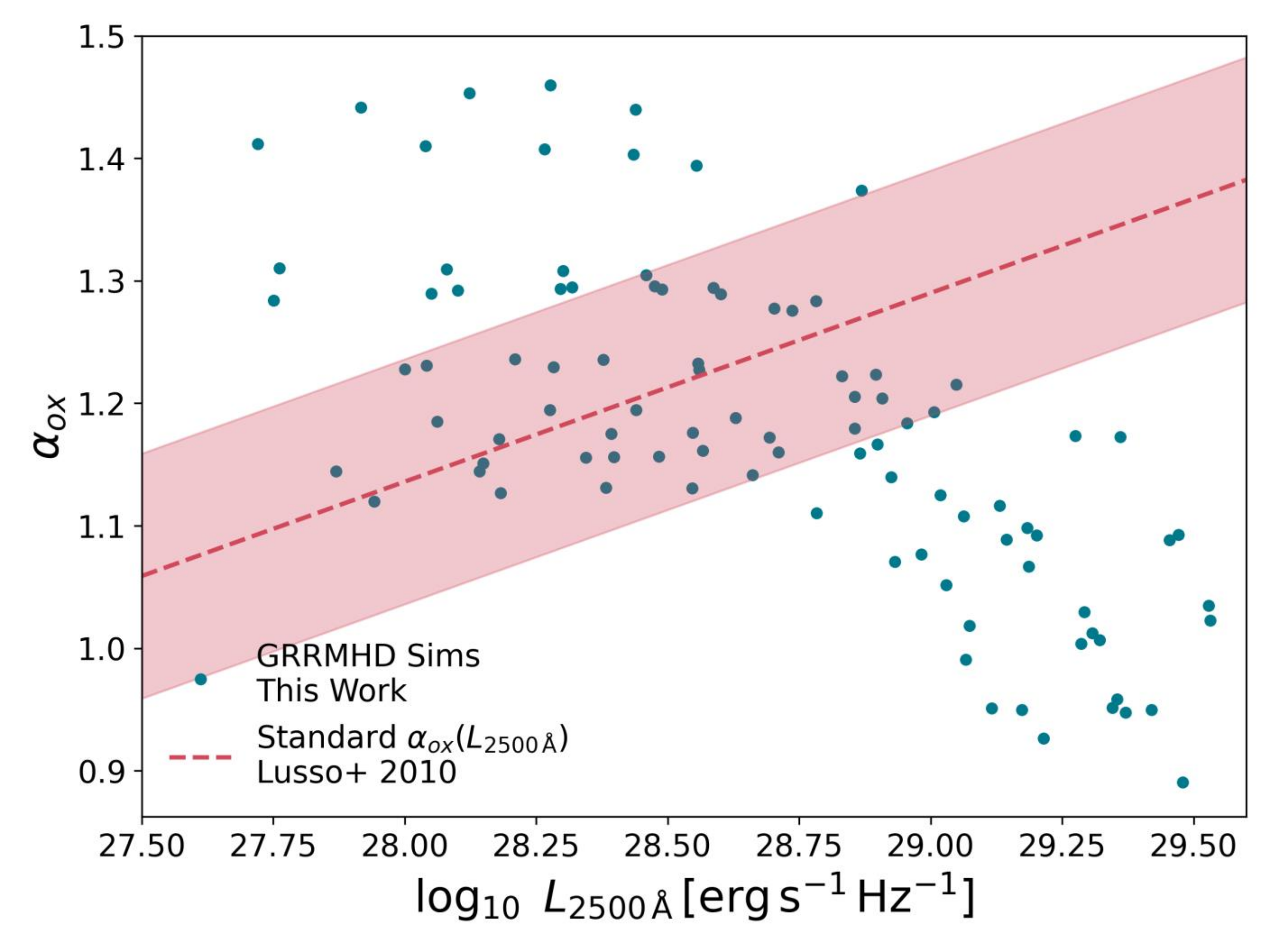
# Photon Index and Inclination Angle



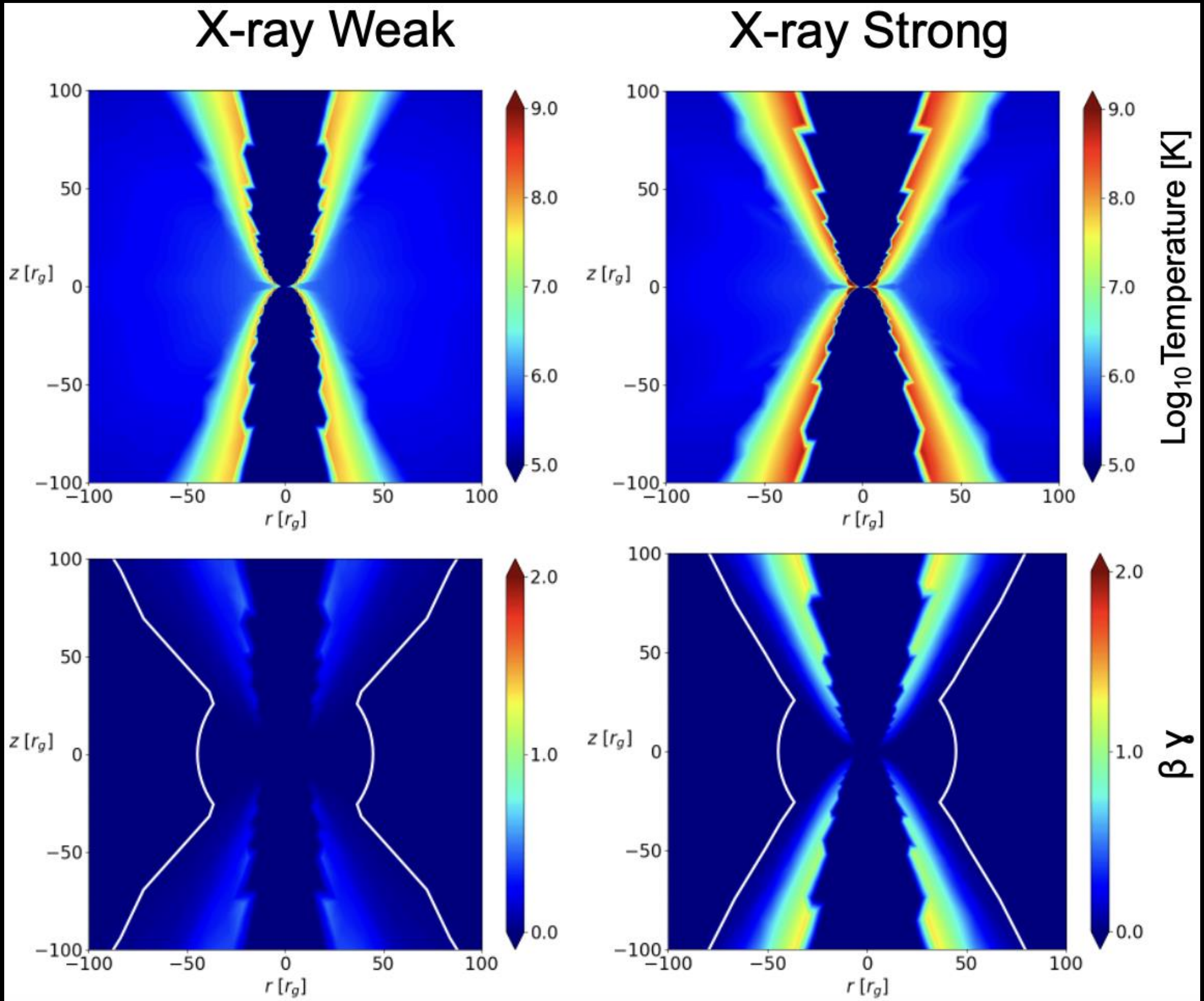

Pacucci & Narayan, 2024

# Optical/UV to X-ray: the $\alpha_{ox}$



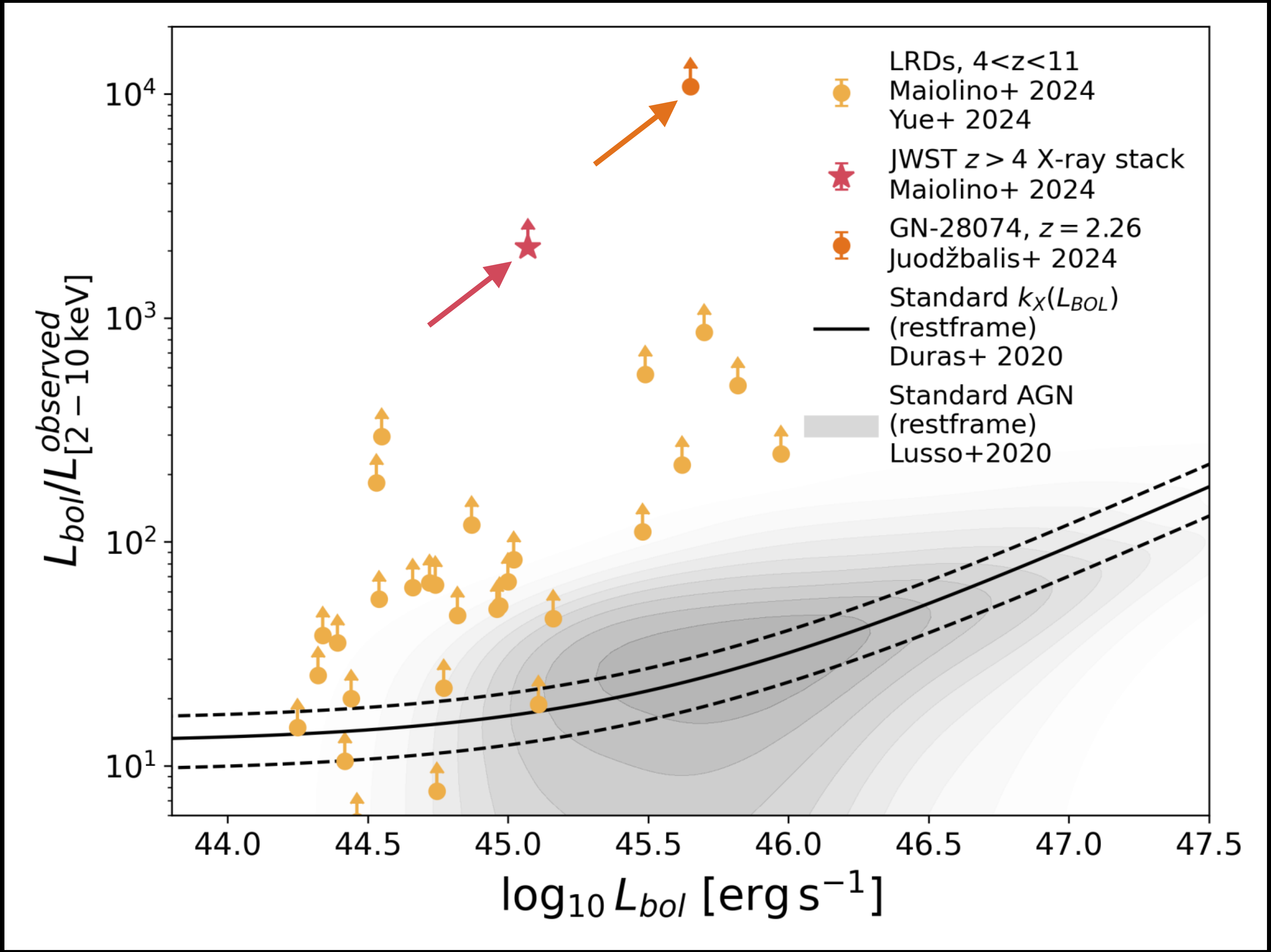

Pacucci & Narayan, 2024

# Structure of the Accretion Flow



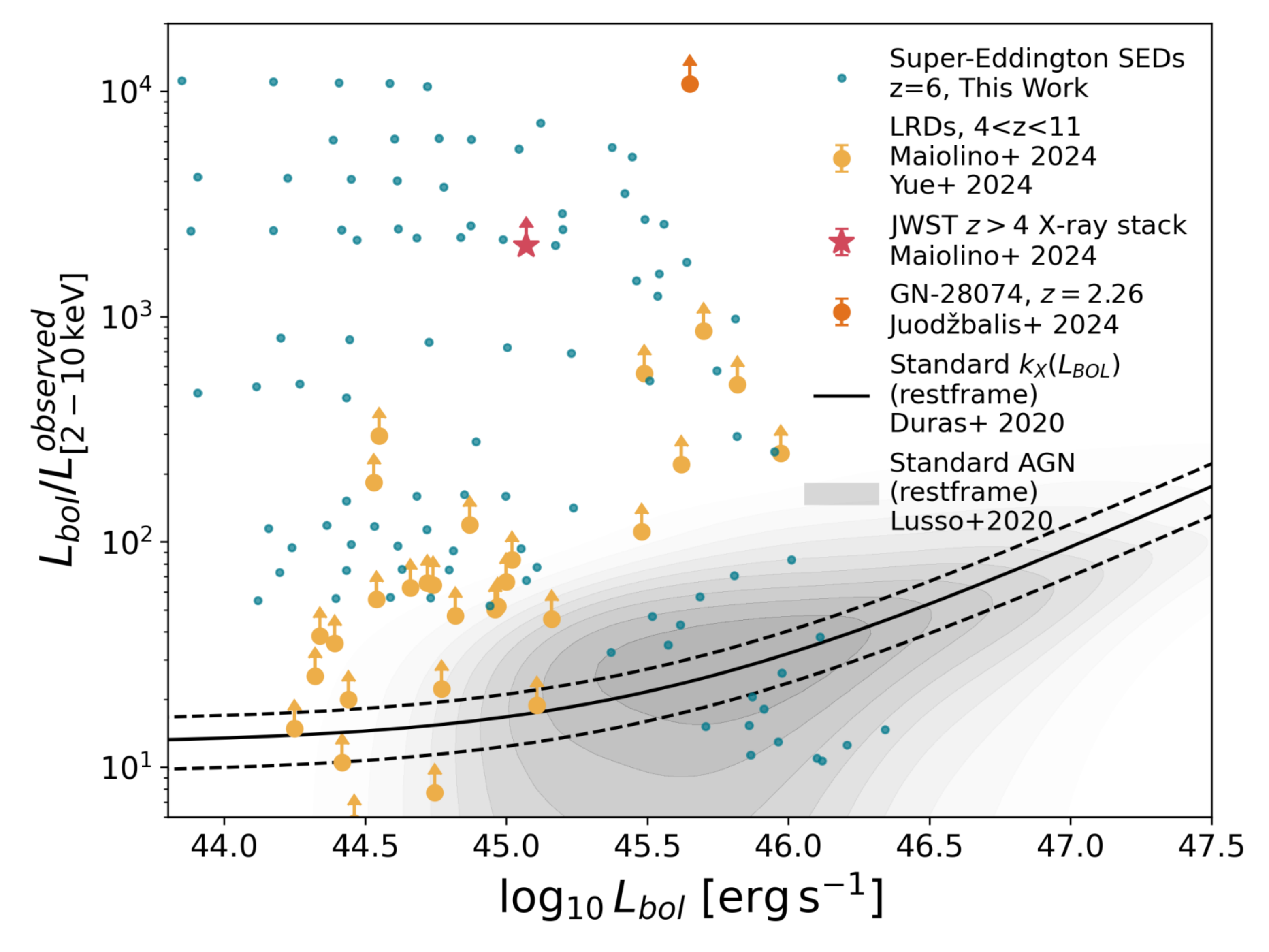

Pacucci & Narayan, 2024

# Application to the “Little Red Dots”




Pacucci & Narayan, 2024

# Application to the "Little Red Dots"



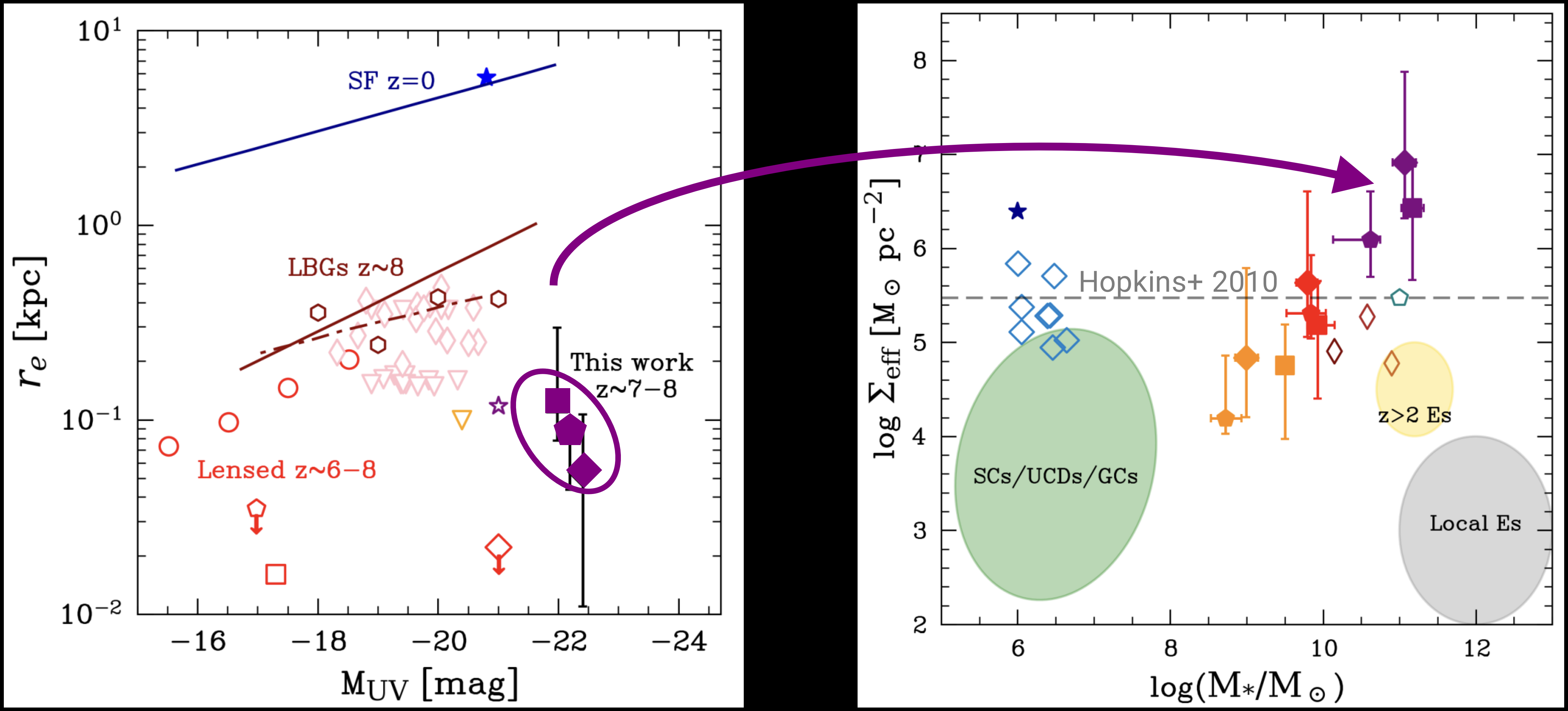

Pacucci & Narayan, 2024

# #3: The Stellar Density Problem

# Just How Dense?

# Just How Dense?

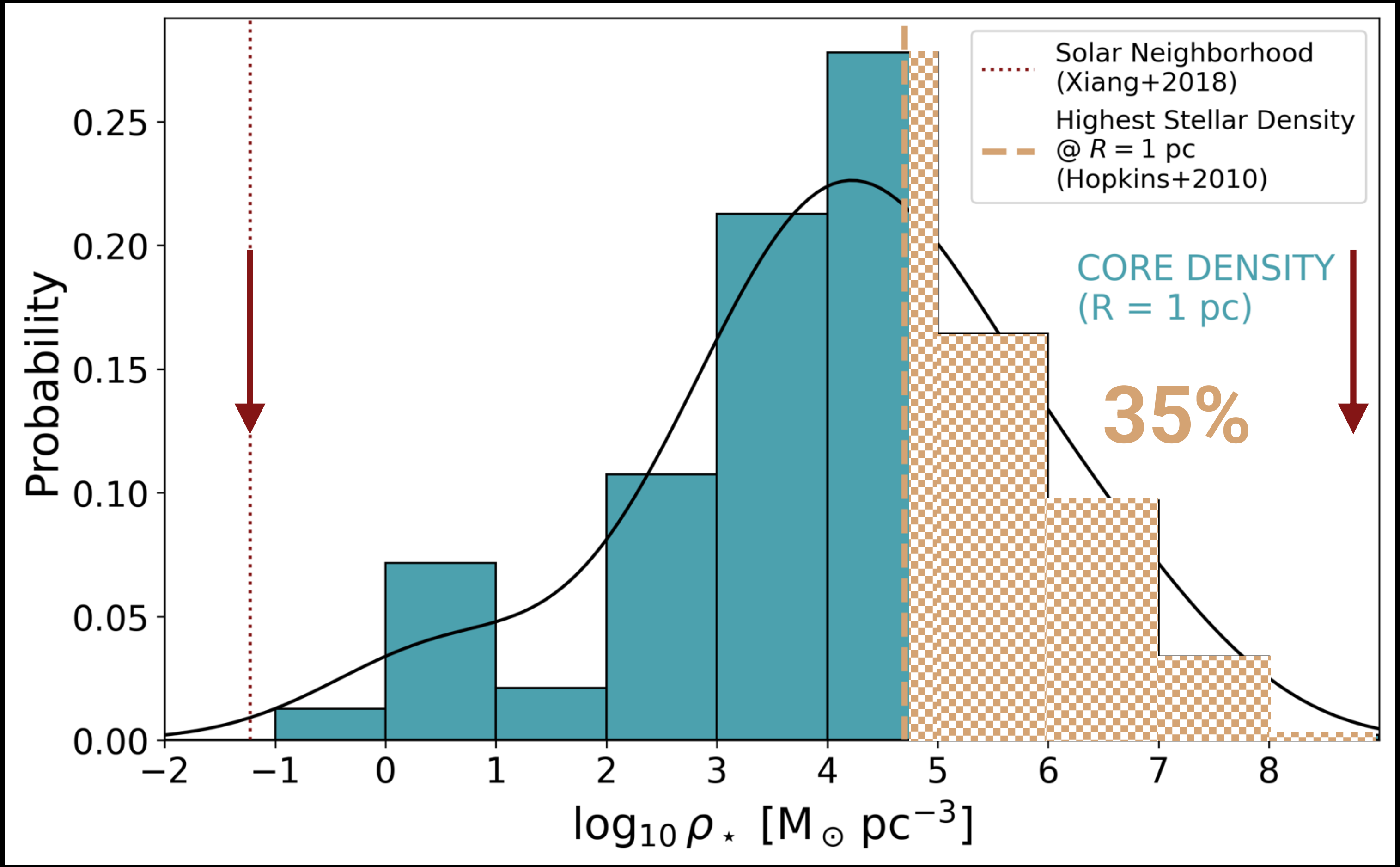
# Immense Stellar Densities




Baggen et al. (2024)

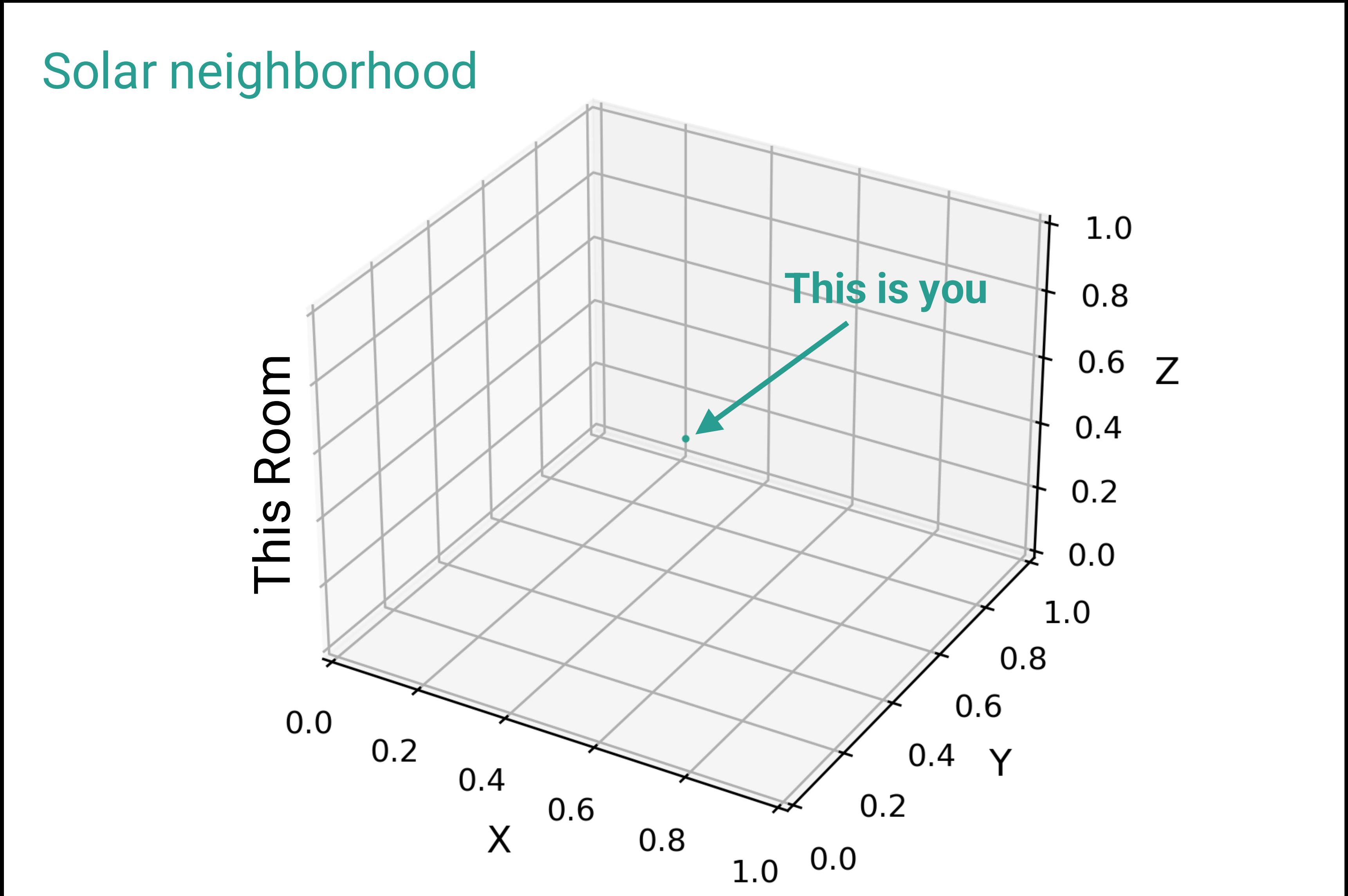
See also, e.g., Labbe et al. (2023)

# Immense Stellar Densities

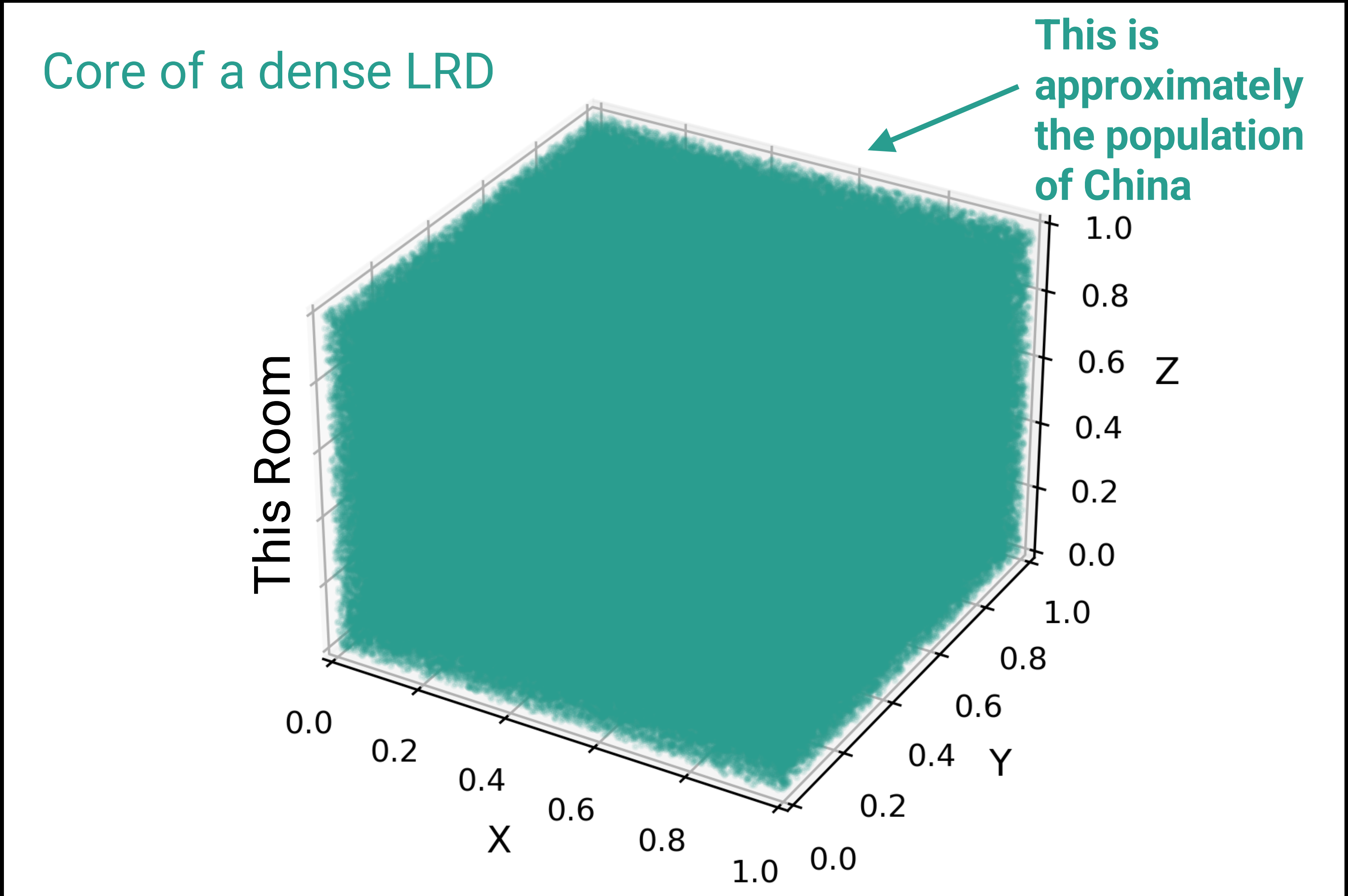



Guia, FP & Kocevski, RNAAS, 2024
arXiv:2408.11890

# Immense Stellar Densities



# Immense Stellar Densities



# Does the Stellar Core Collapse?

We investigate with three, complementary approaches:

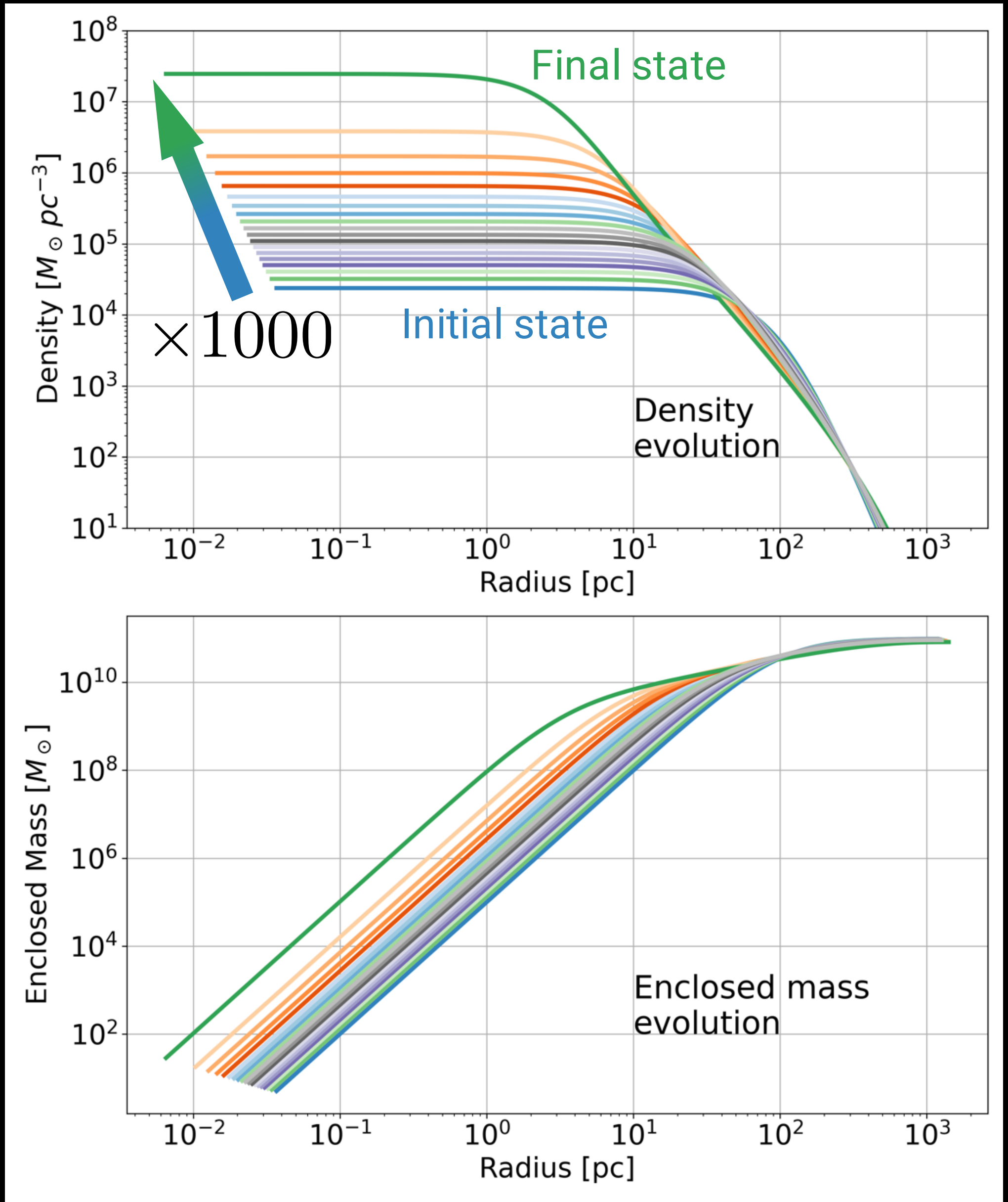
Fokker-Planck evolution of the stellar density profile

Analytical calculation of the mass of the
very massive star (VMS) which should form at the core

N-body simulations of the core of the stellar system

Pacucci, Hernquist & Fujii,
in prep.

# Fokker-Planck Approach




$$T_{rel} \approx 500\,\mathrm{Myr}$$

Pacucci et al., in prep.

# Analytical Approach

$$\dot{M}_{\mathrm{VMS}} = \dot{M}^{+}_{\mathrm{VMS}} + \dot{M}^{-}_{\mathrm{VMS}}$$

Mass change for the VMS

Mass added via stellar collisions

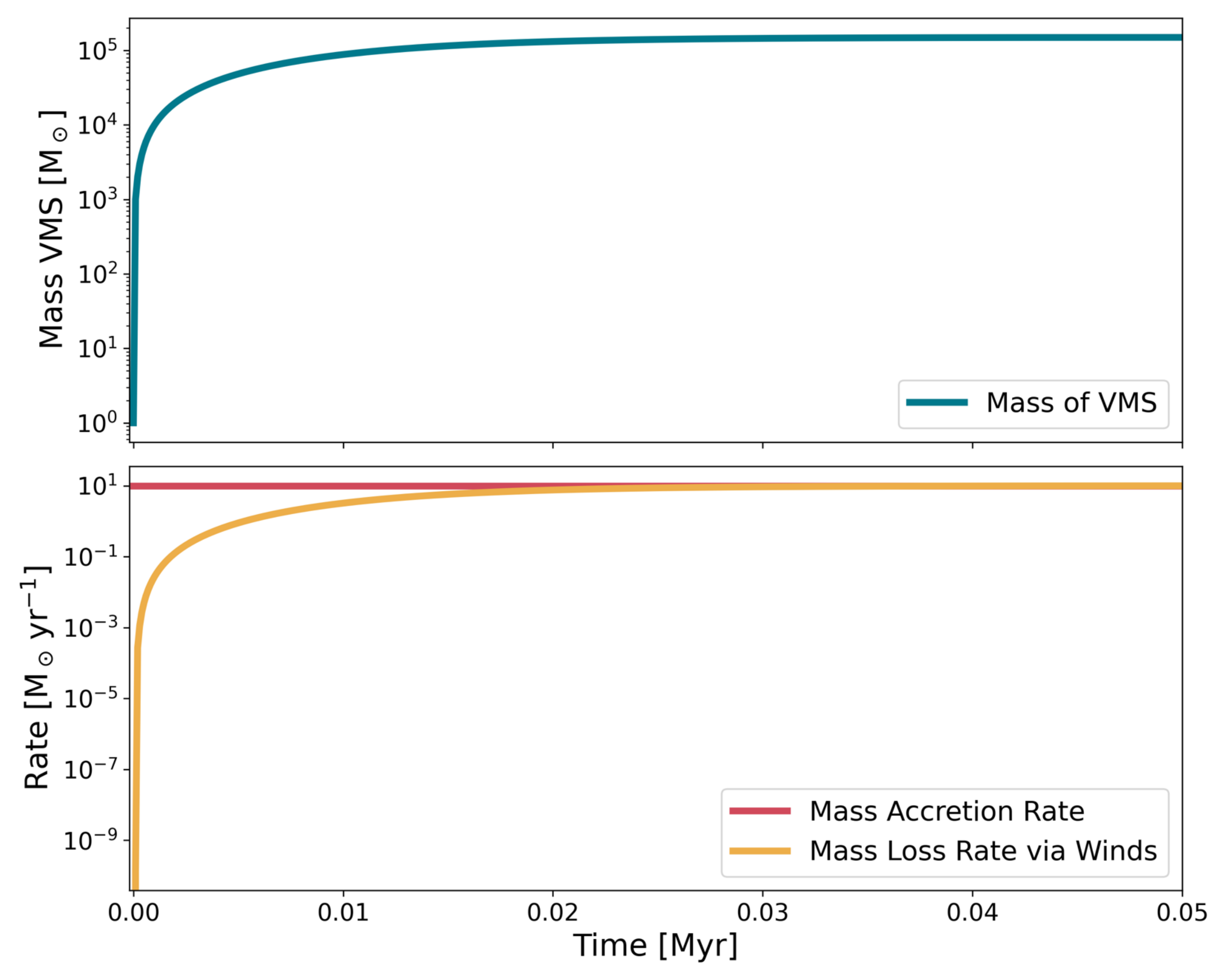
Mass subtracted via stellar winds

$$\dot{M}^{+}_{\mathrm{VMS}} \sim 0.03 \times \dot{M}_{\mathrm{SFR}}$$

$$\dot{M}^{-}_{\mathrm{VMS}} = \dot{M}_{\mathrm{SW}}(m, Z)$$

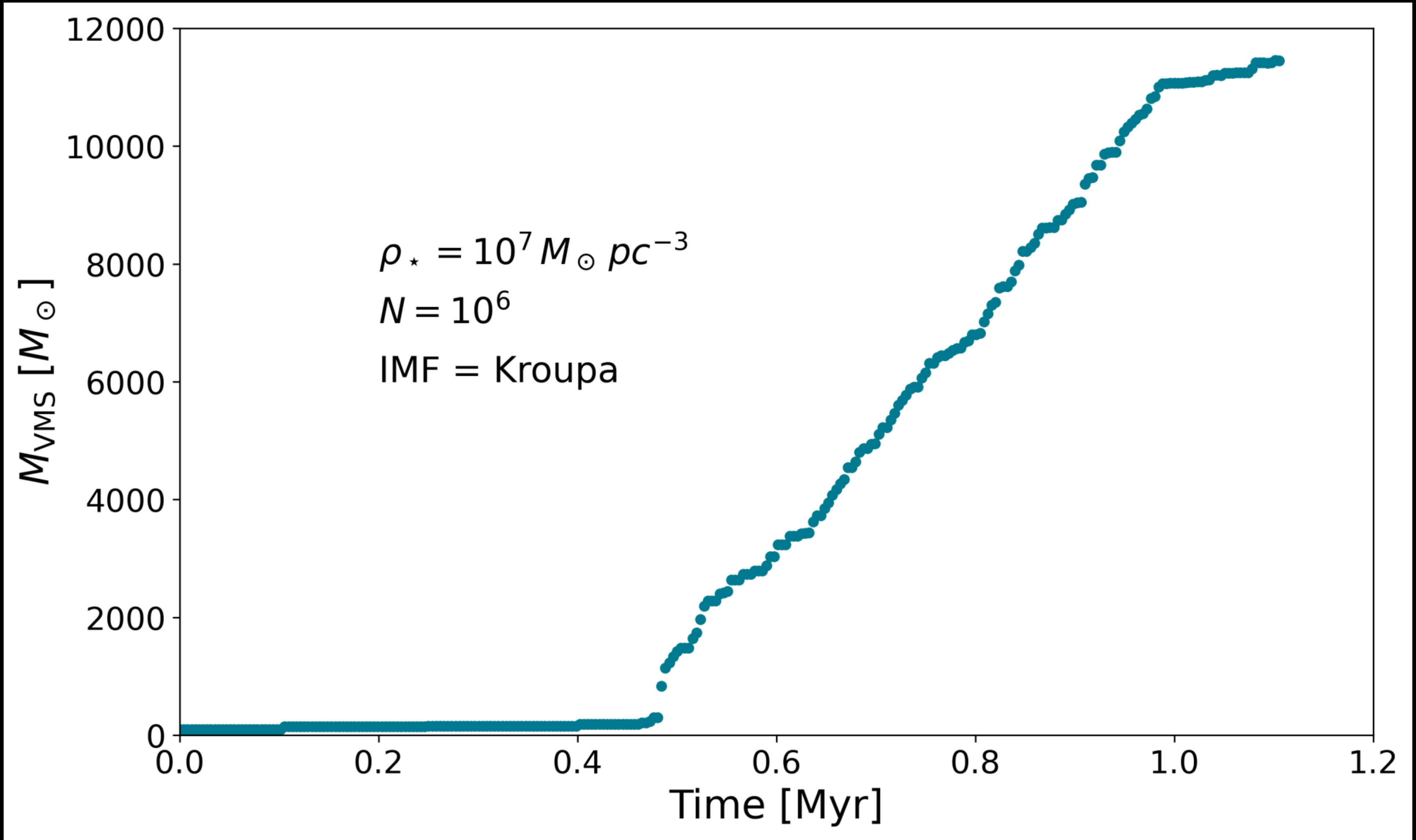
Pacucci et al., in prep.

# Analytical Approach




Pacucci et al., in prep.

# N-Body Simulation




Pacucci et al., in prep.

# Does the Stellar Core Collapse?

It seems so.

Fokker-Planck evolution of the stellar density profile

Analytical calculation of the mass of the very massive star (VMS) which should form at the core

N-body simulations of the core of the stellar system

$$10^4 < M_{\rm VMS}\ [\rm M_\odot] < 10^5$$

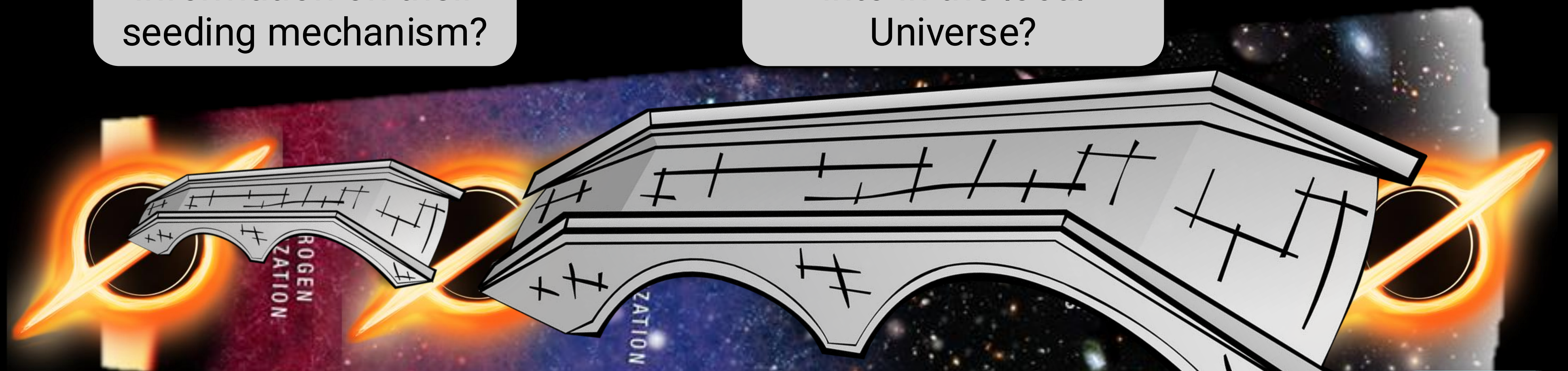
Pacucci et al., in prep.

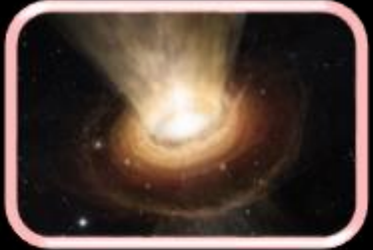
# LRDs: Bridging Nearby and Faraway Universe

TIME →

Do they contain information on their seeding mechanism?

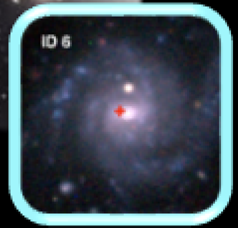
What do they morph into in the local Universe?





Black Hole Seeds

Little Red Dots:
- Intermediate mass
- Intermediate z




Local Black Holes