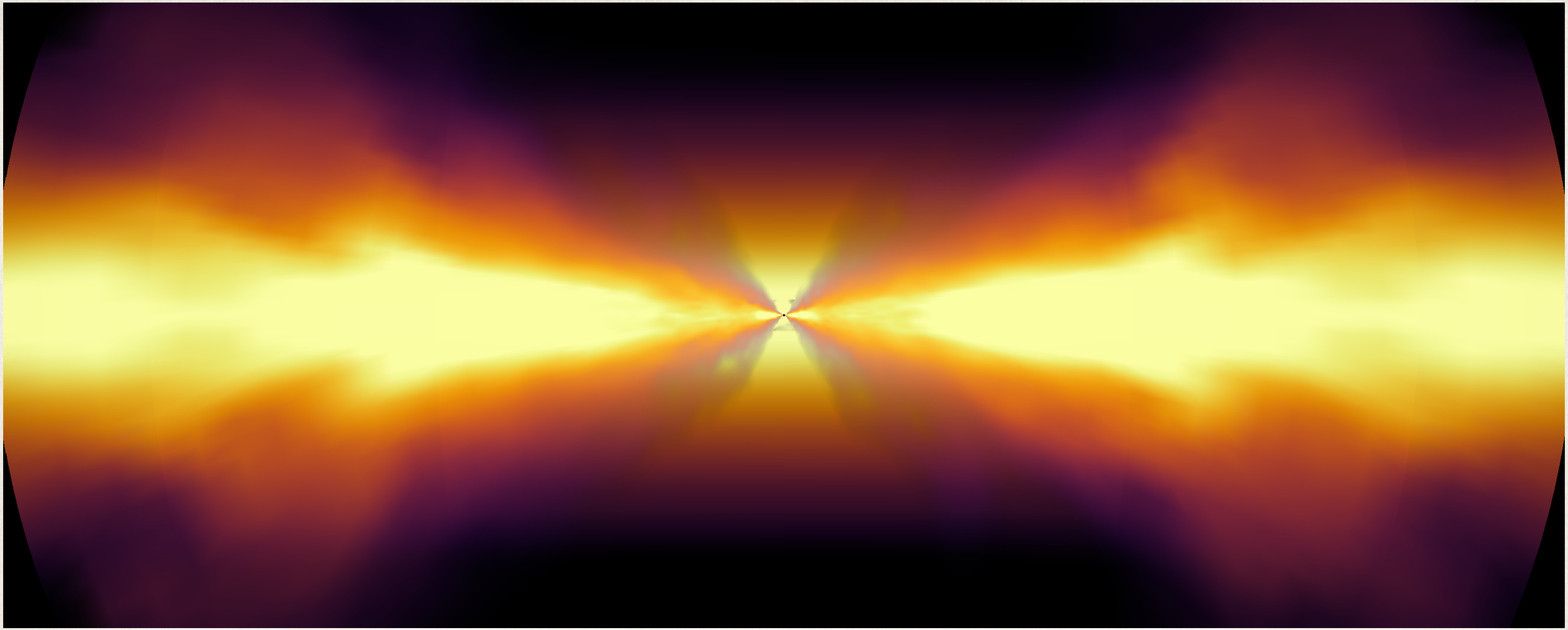

Long Timescale Numerical Simulations of Large, Super-Critical Accretion Discs

P. Chris Fragile, College of Charleston

6 May 2025

ReFCO25

Relativistic Fluids around Compact Objects

Simulations of super-critical accretion disks

- Goal #1: Study super-critical accretion in the context of large, thin disks
  - Particularly in the context of ultra-luminous X-ray sources (ULXs)
  - Results may be applicable to growth of supermassive black holes
- Goal #2: Assess the (quasi-)steady-state structure
  - Advection dominated ("slim" disk) vs. Outflow dominated ("critical" disk)
  - Role of thermal instability/magnetic support
- Goal #3: Study the interplay of radiation and magnetic pressure at extreme accretion rates

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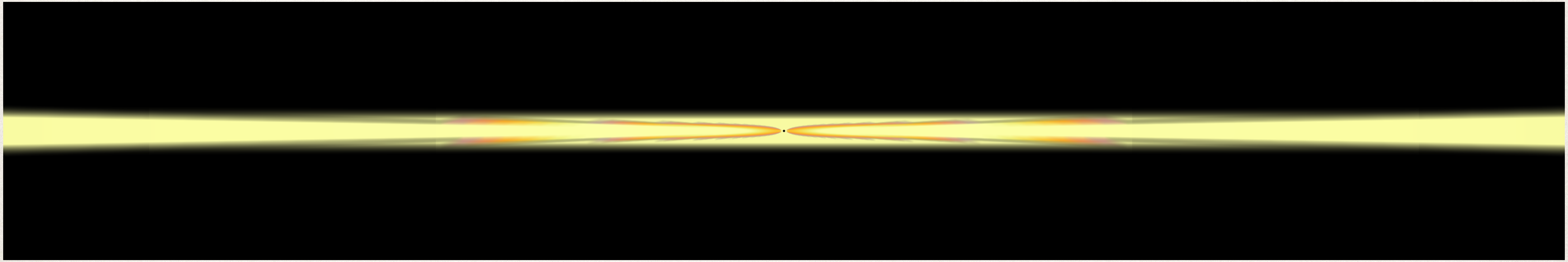
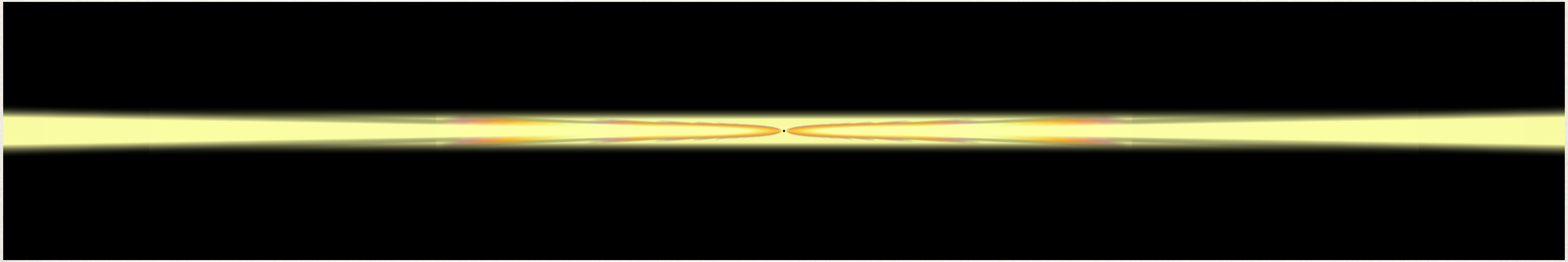
Simulation setup

- Start from a large Shakura-Sunyaev/Novikov-Thorne disk
- General Relativistic Radiation Magnetohydrodynamic (GRRMHD) [Cosmos++]

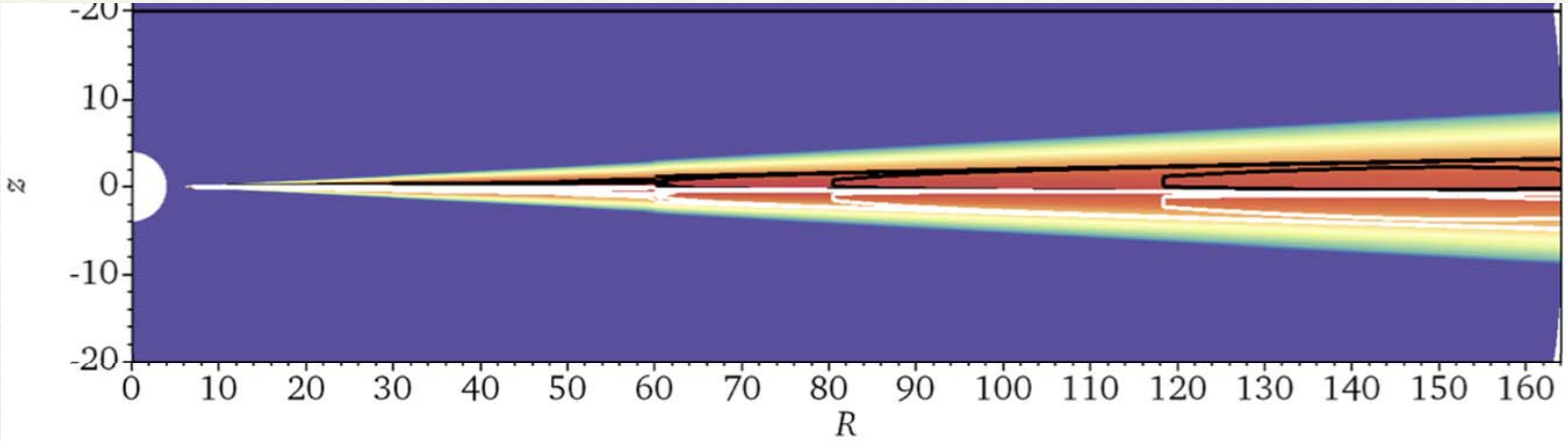


Simulation setup

- Start from a large Shakura-Sunyaev/Novikov-Thorne disk
- General Relativistic Radiation Magnetohydrodynamic (GRRMHD) [Cosmos++]



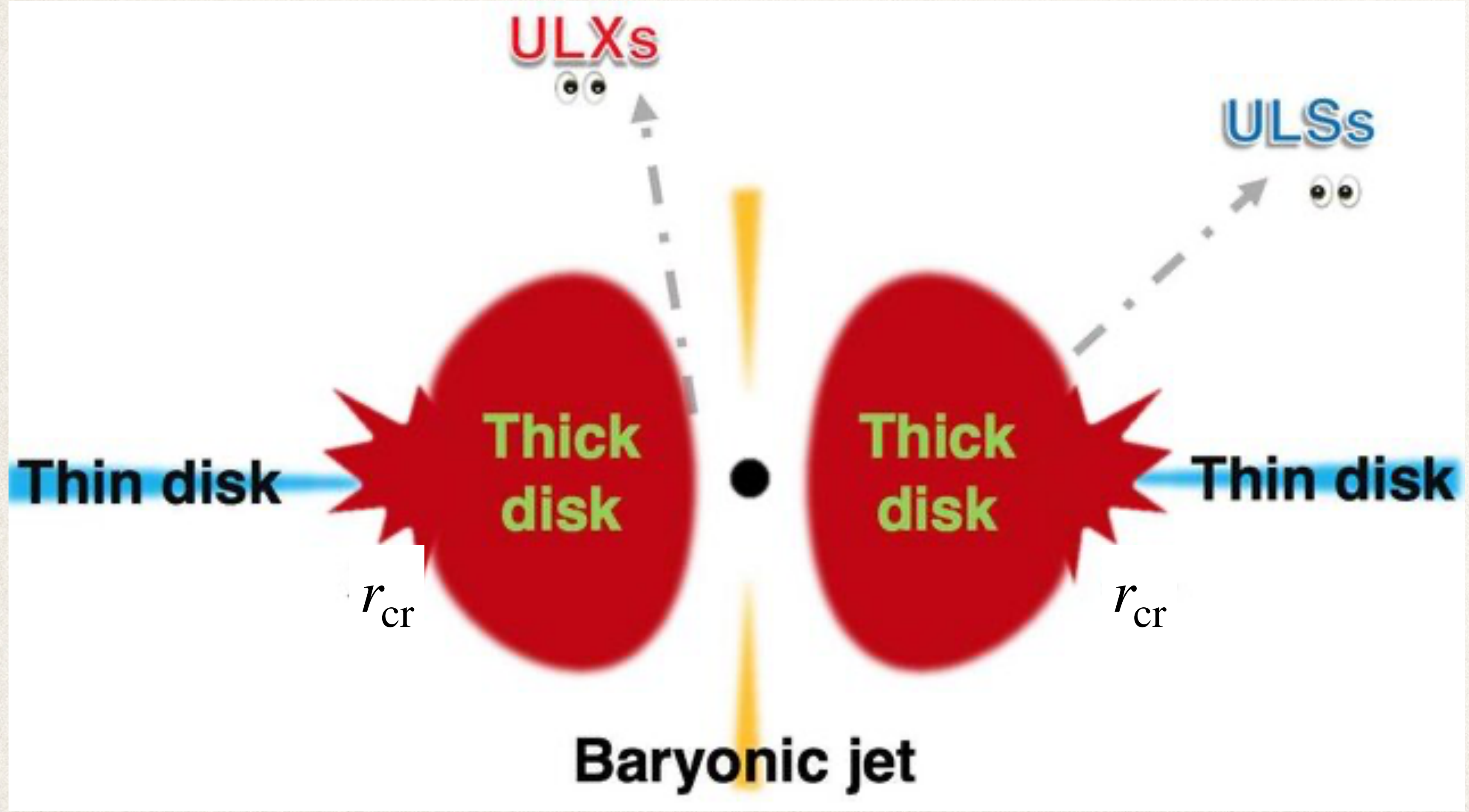
- What about thermal instability?
  - Use a radially extended quadrupolar field to provide magnetic support

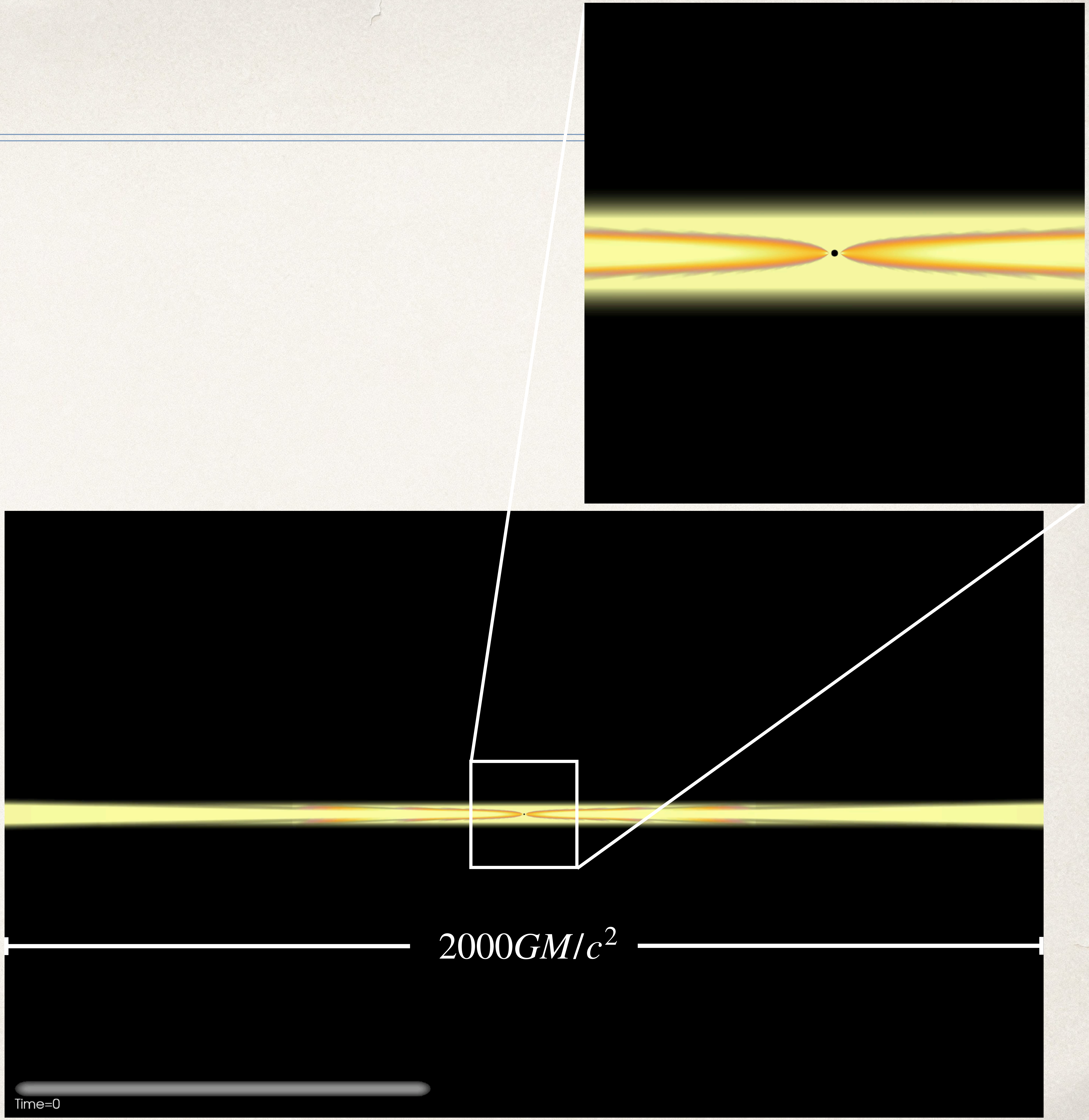


Simulation setup

- Large radial domain ($r_{max} = 1{,}000\, r_G$)
- Long duration ($t_{stop} \geq 70{,}000\, t_G$)
- 3 simulations

	a_*	r_{cr}	$\dot{m}$
a9r5	0.9	5	1
a9r20	0.9	20	4
a9r50	0.9	50	10





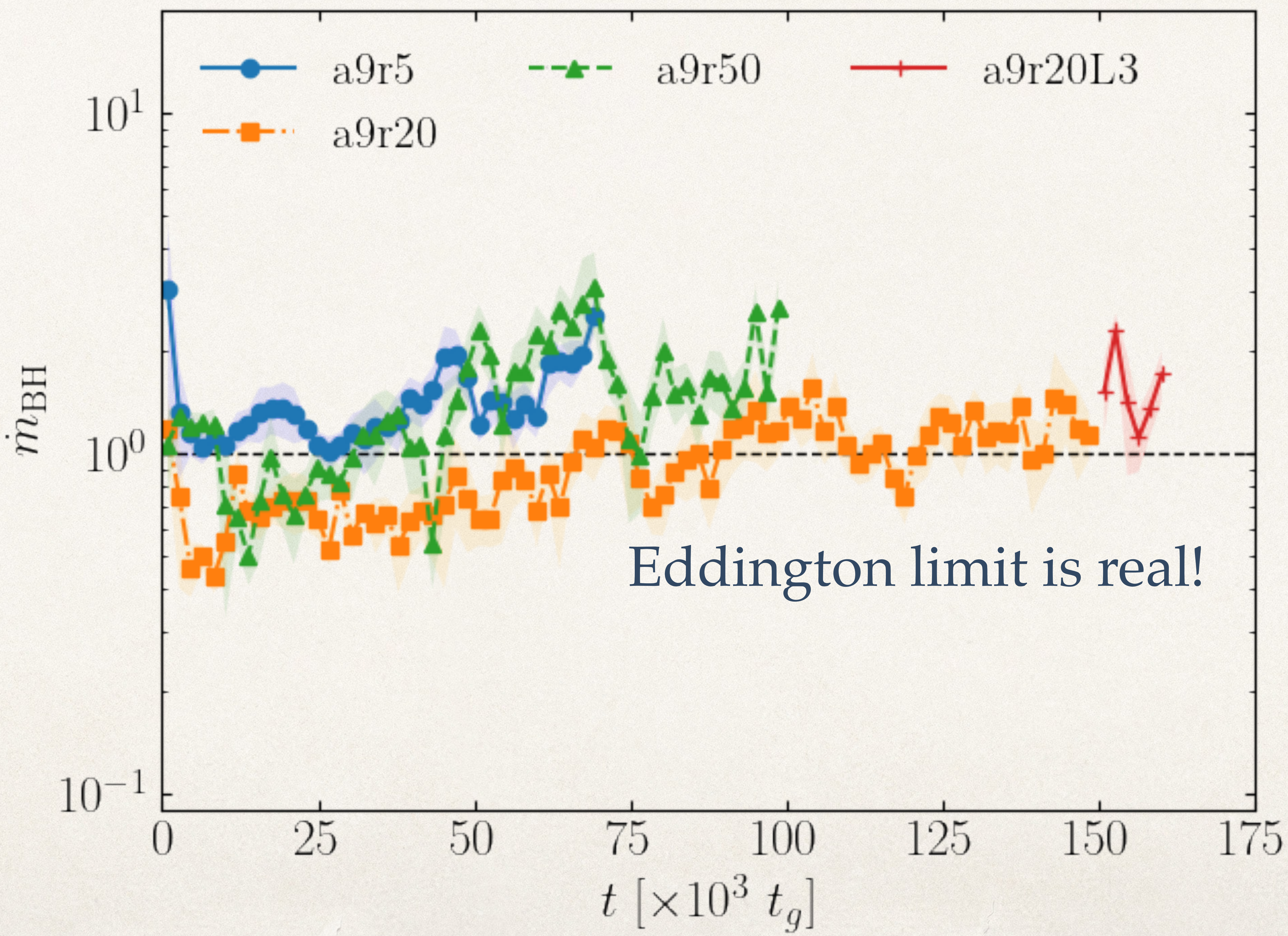
Reference: Gu et al. 2016; Fragile et al. 2025

Mass accretion onto the black hole

- Takeaway #1: All cases obey the Eddington limit ($\dot{m}_{\rm BH} \approx 1$)

$$\dot{m} = \dot{M}/\dot{M}_{\rm Edd}$$

$$\dot{M}_{\rm Edd} = L_{\rm Edd}/(\eta c^2)$$



Eddington limit is real!

Reference: Fragile et al. 2025

Mass accretion onto the black hole

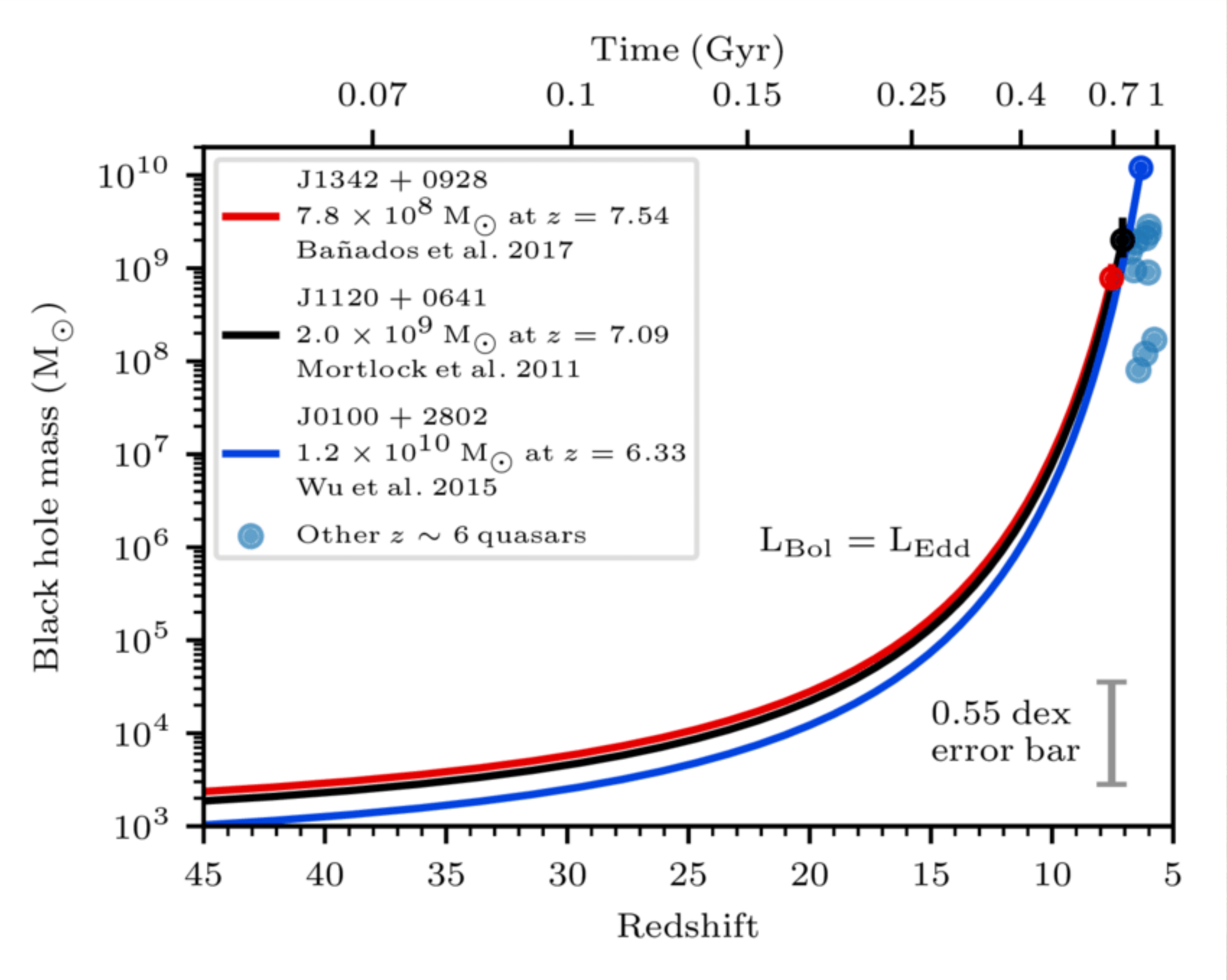
- Takeaway #1: All cases obey the Eddington limit ($\dot{m}_{\rm BH} \approx 1$)
  - Could be problematic for supermassive black hole growth
  - Whenever $\dot{M}_{\rm BH} \approx \dot{M}_{\rm Edd}$

$$M_{\rm BH}(t) = M_{\rm BH}(t_0)e^{t/\tau_{\rm grow}}$$

$$\tau_{\rm grow} \approx M_{\rm BH}(t_0)/\dot{M}_{\rm Edd}$$

$$\dot{M}_{\rm Edd} = L_{\rm Edd}/(\eta c^2)$$

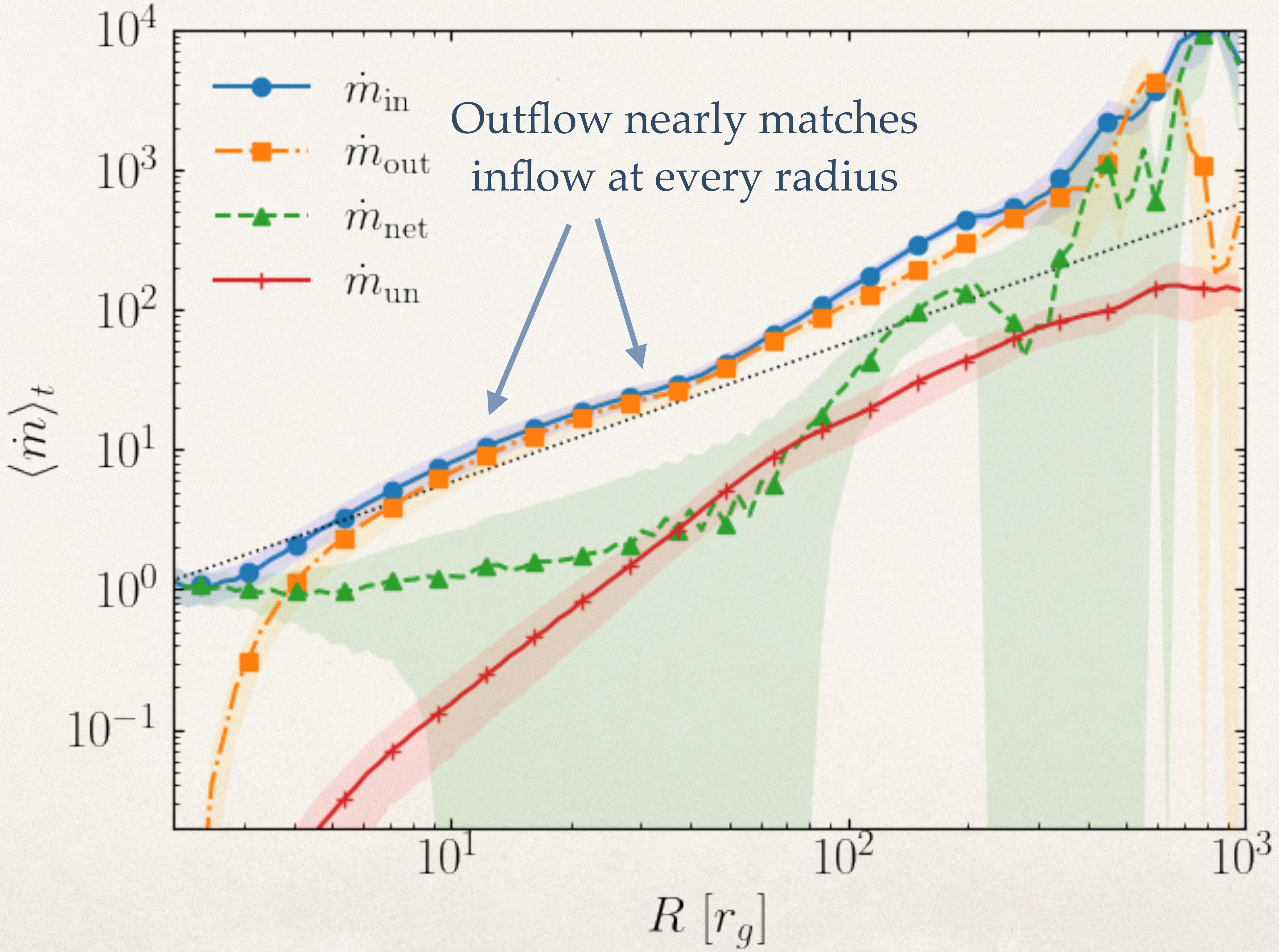
$$\tau_{\rm grow} \approx 4.4 \times 10^8 \eta \text{ yr}$$

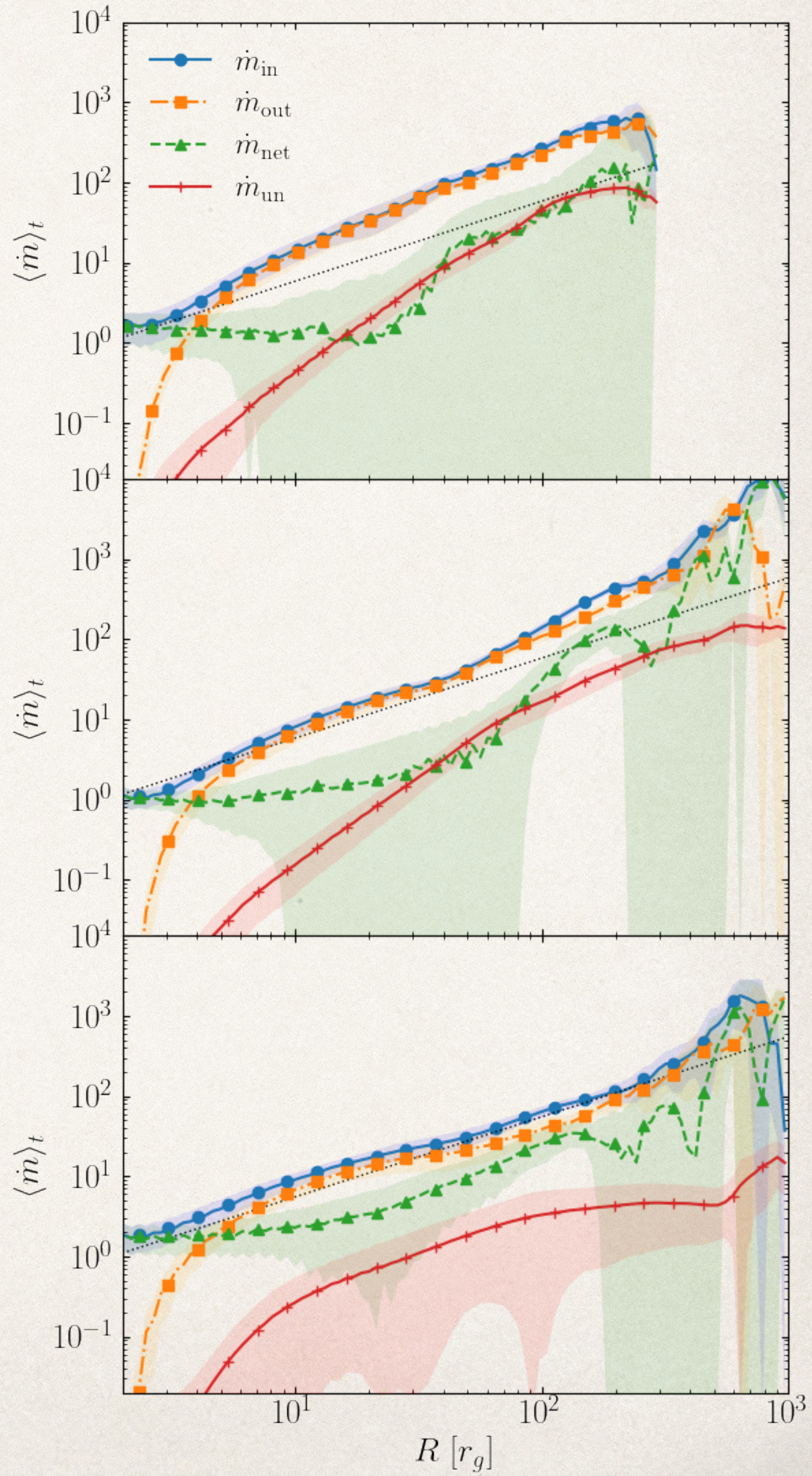


Reference: Bañados et al. 2018

Mass accretion profiles

- Takeaway #1: All cases obey the Eddington limit ($\dot{m}_{\rm BH} \approx 1$)
  - Outflow nearly matches inflow at each radius
  - Residual gives net accretion

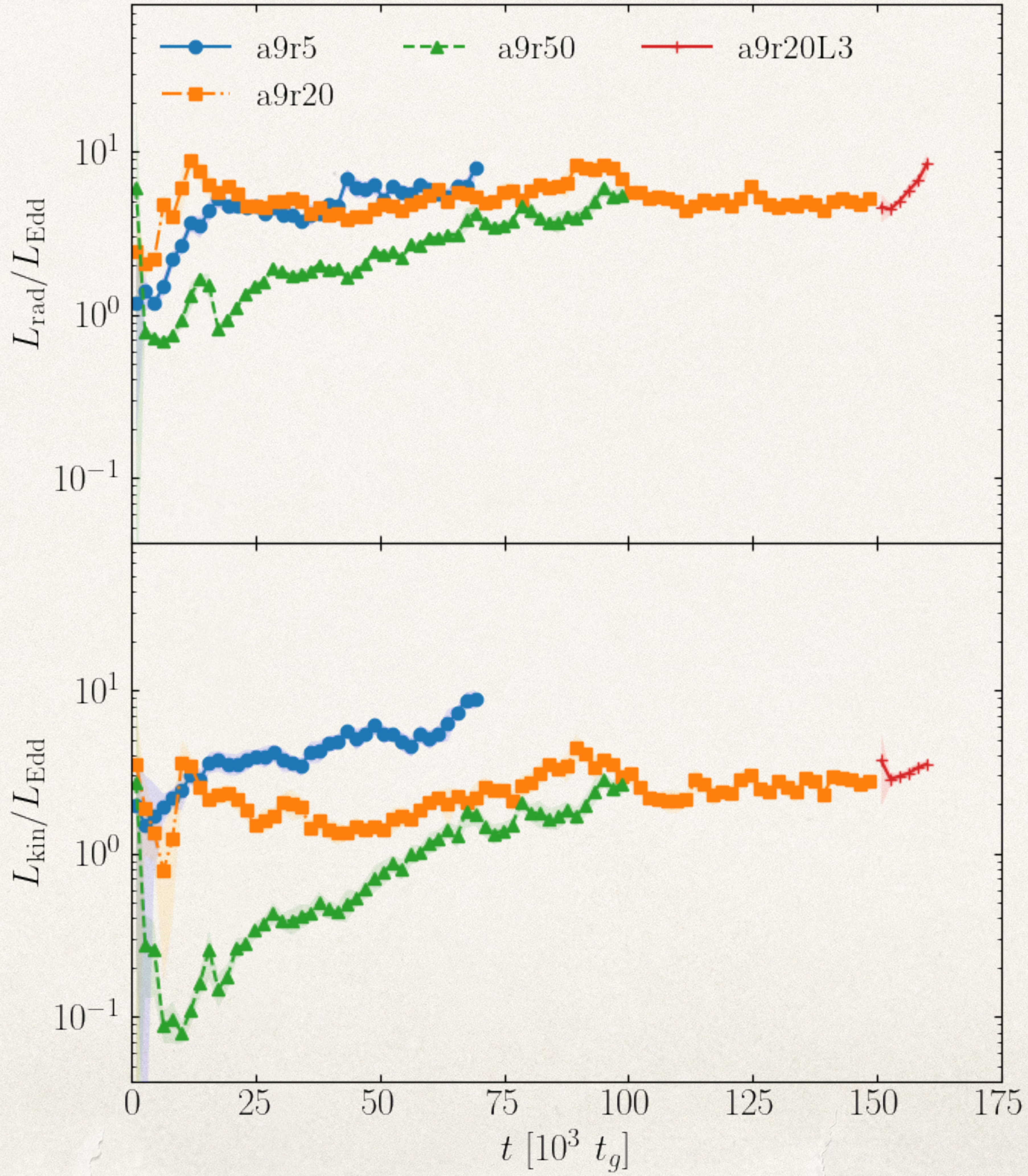




Reference: Fragile et al. 2025

Luminosity at equilibrium radius

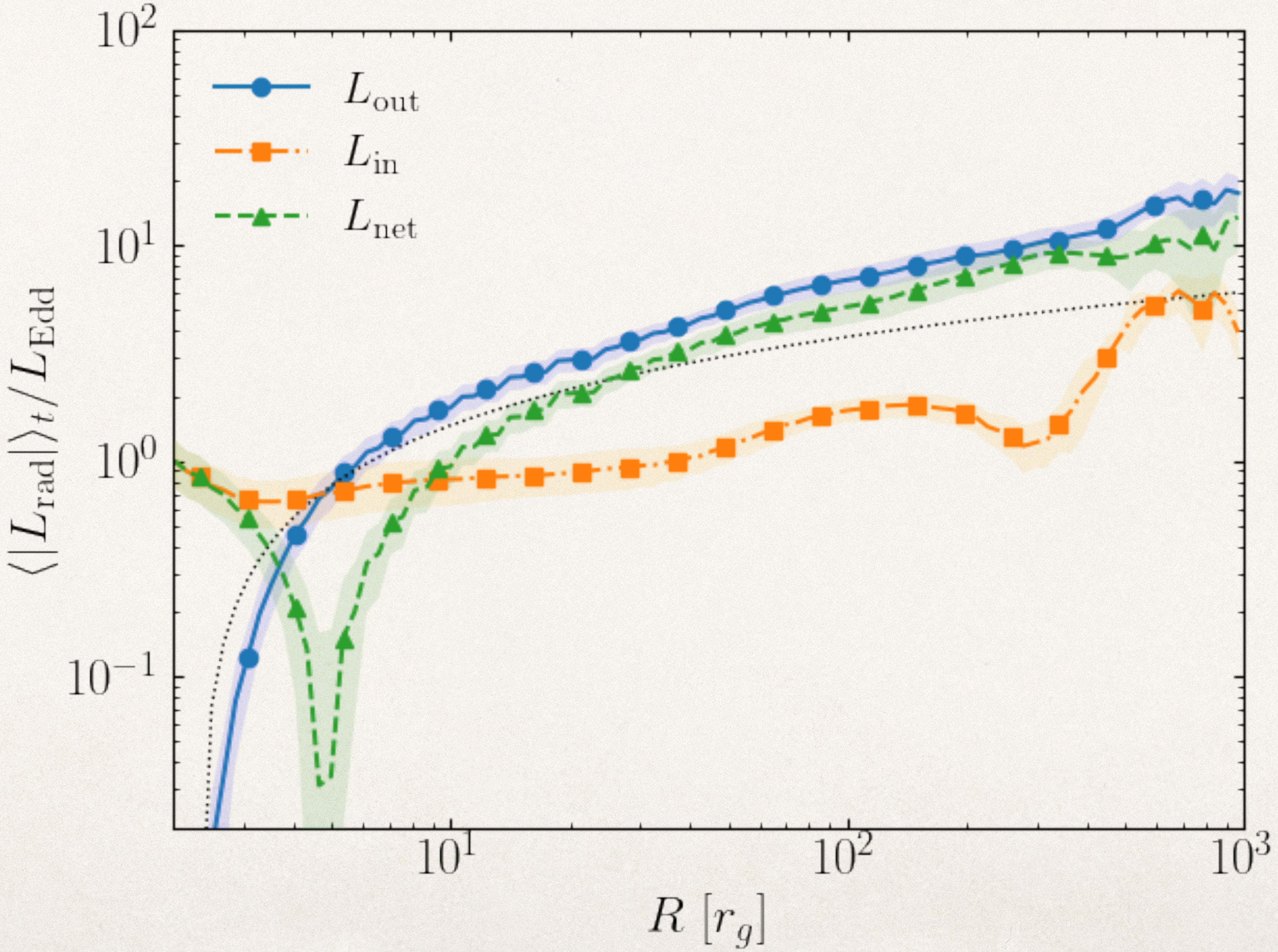
- Takeaway #2: Total luminosity (measured at $r_{\rm eq}$) is $\lesssim 10\, L_{\rm Edd}$

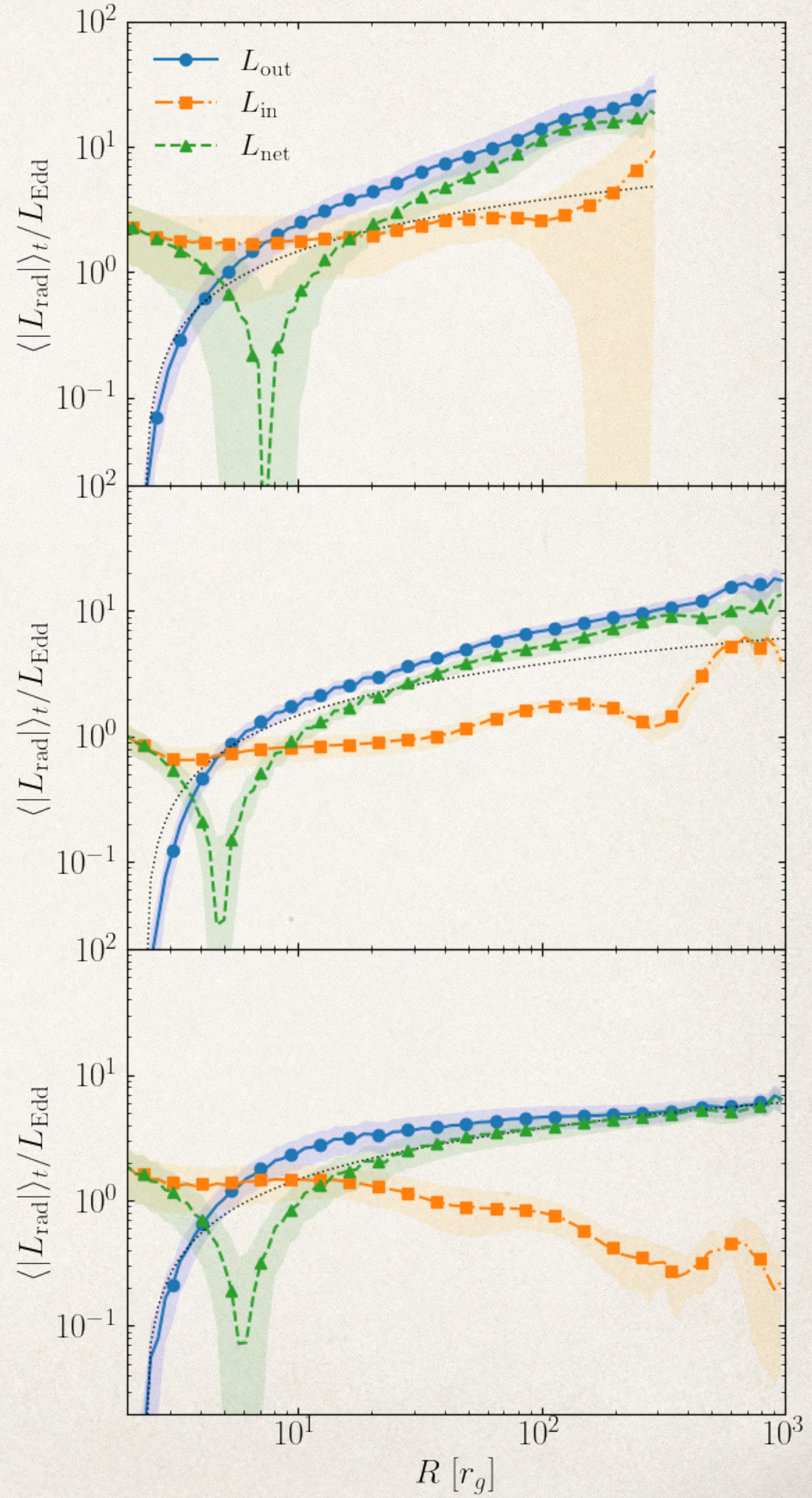


Reference: Fragile et al. 2025

Luminosity profiles

- Takeaway #2: Total luminosity is $\lesssim 10\, L_{\rm Edd}$
  - Trapping radius is close to BH ($r_{\rm tr} \leq 10\, r_g$)





Reference: Fragile et al. 2025

Simulations are outflow dominated

- Takeaway #3: Simulations do match outflow-dominated solution

Reference: Fragile et al. 2025; Fukue 2004

Summary

- Takeaway #1: Eddington limit is real!
  - At least for large, Keplerian accretion disks
  - Could be problematic for SMBH growth
- Takeaway #2: Total luminosity is $\lesssim 10\, L_{\rm Edd}$
  - Trapping radius is close to BH ($r_{\rm tr} \leq 10\, r_g$)
- Takeaway #3: Simulations do not match slim disk solution/Do match outflow solution
  - Significant mass outflow
  - Small trapping radius
  - Nearly perfectly Keplerian velocity profiles

Students

- Jessica Anderson
- Jay Ball
- Aidan Blankenship
- Deepika Bollimpalli
- Erika Hamilton
- Cesare Harvey
- Callaway Hudson
- Bridget Ierace
- Christian Kohnle
- Christopher Lesoine
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- Chris Nolting
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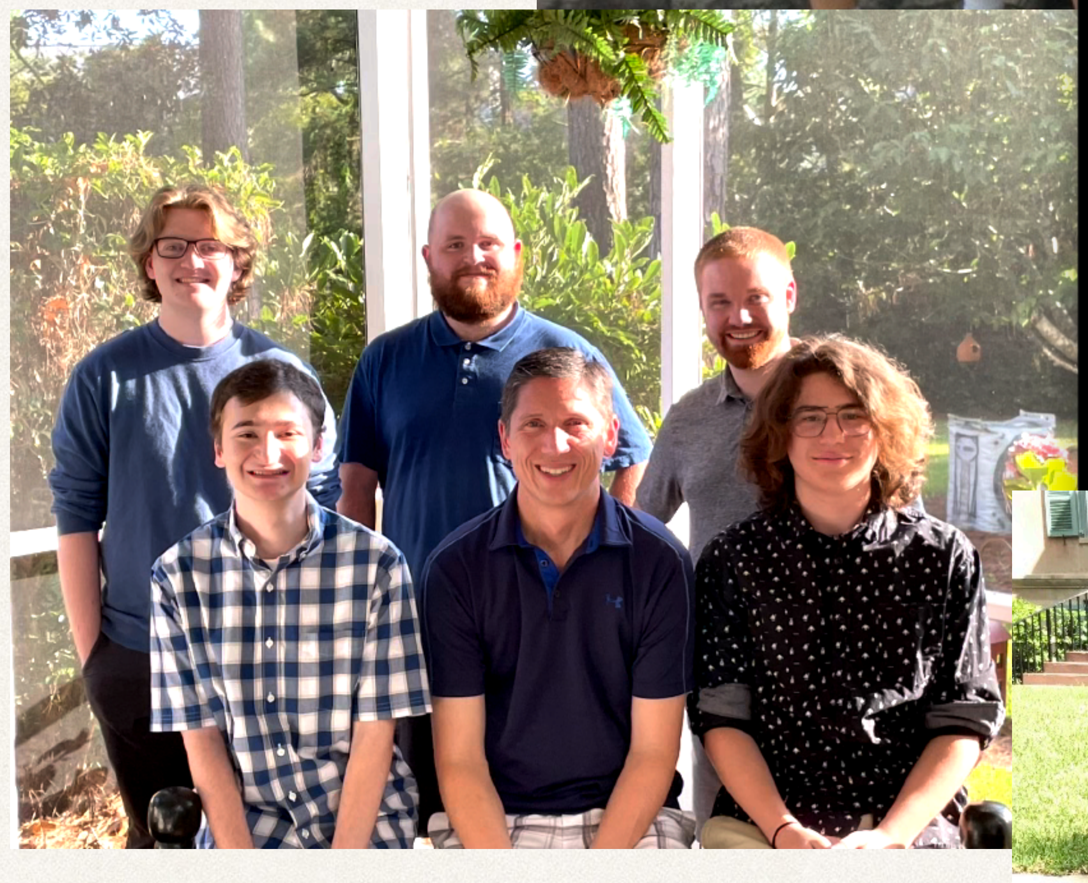

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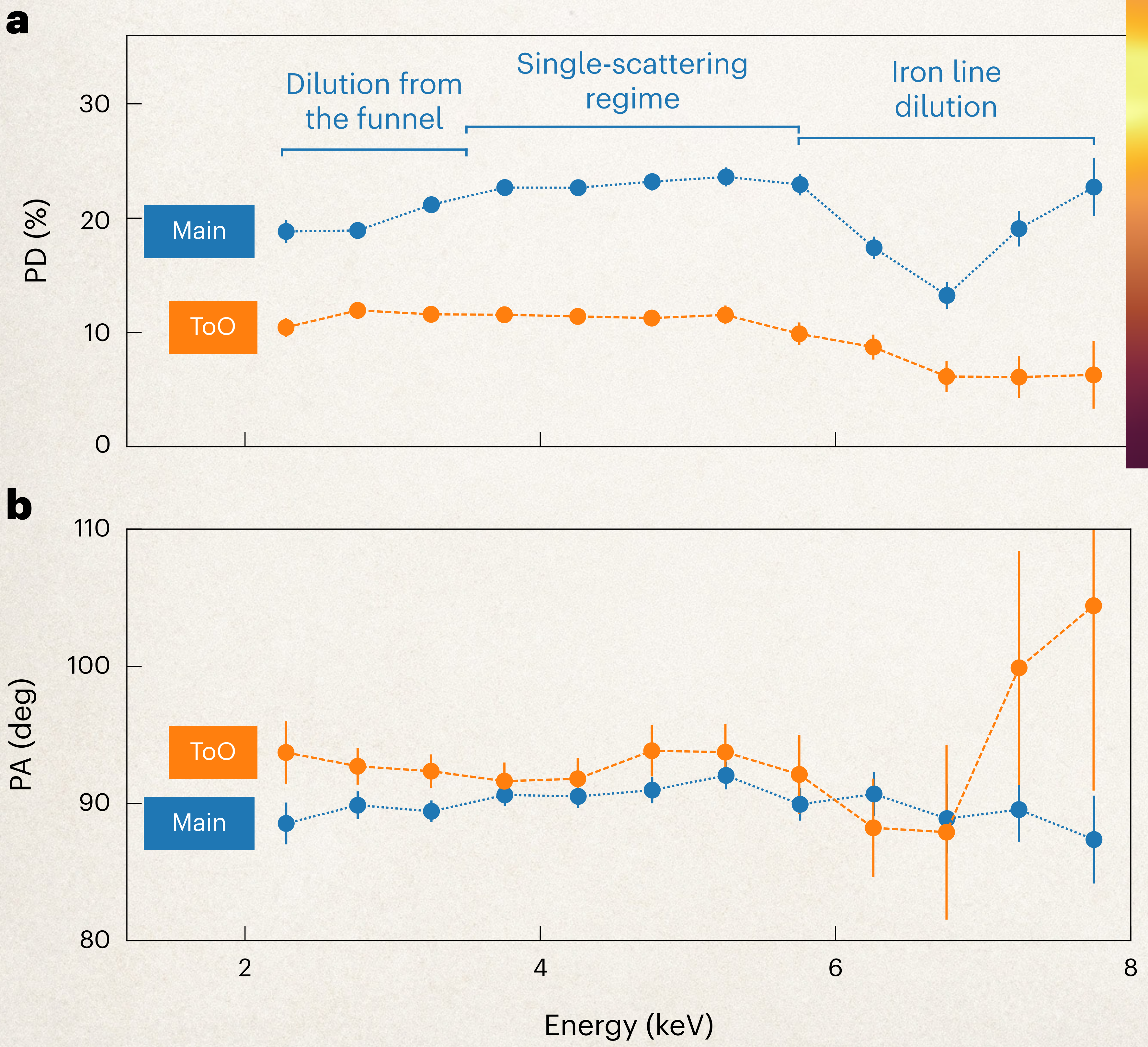
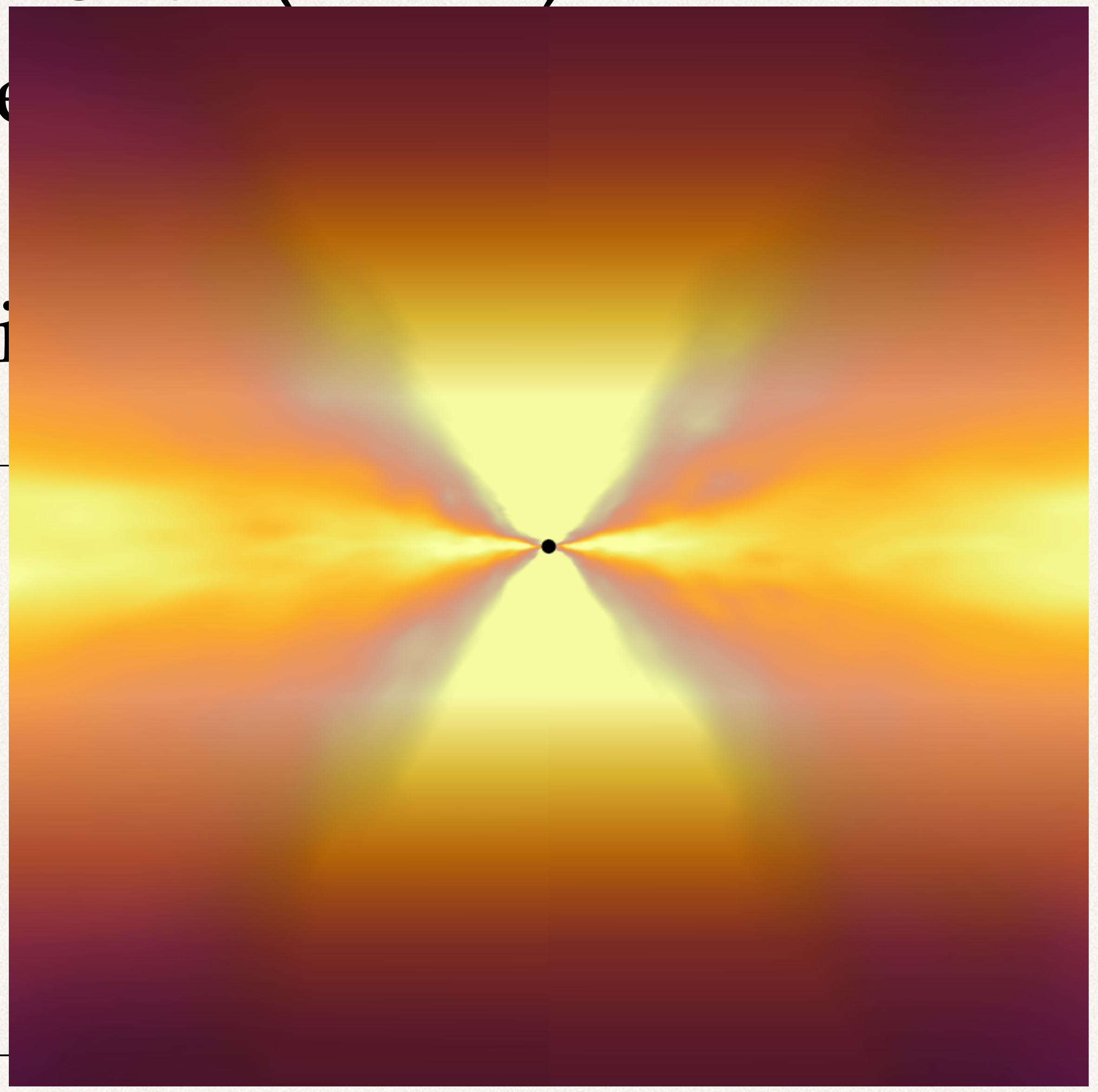
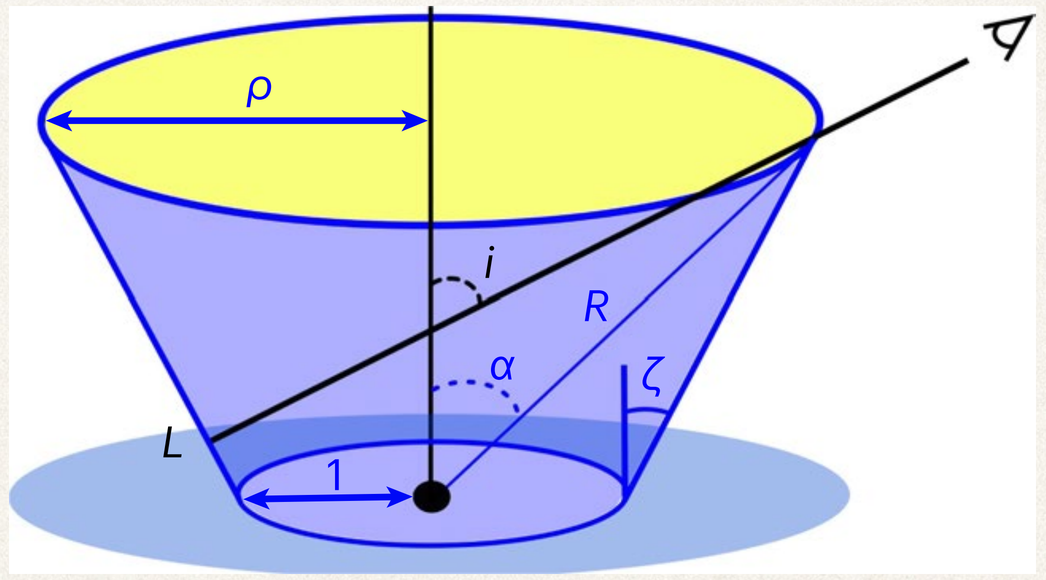
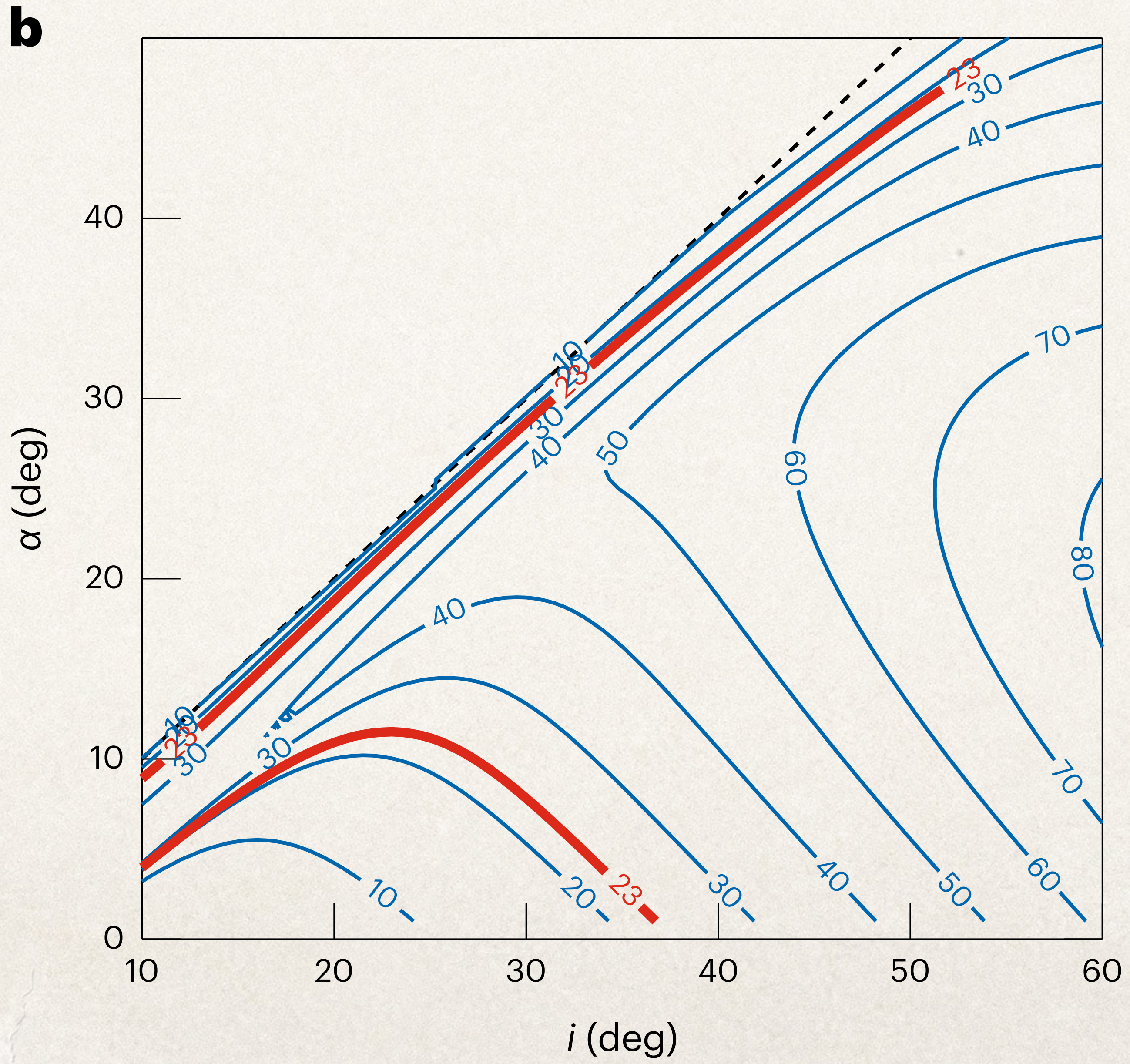
X-ray polarization signatures of ULXs

- Imaging X-ray Polarimetry Explorer (IXPE)
  - Cyg X-3 measured polarization de
    - ULX beamed away from us
    - High polarization from scatteri









Reference: Veledina et al. 2024