Growing massive black holes via super-critical accretion on to stellar-mass seeds

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Introduction

BH SEED FORMATION

Two main scenarios for massive black hole formation:

LIGHT seeds ($M \lesssim 10^2 M_\odot$)

- PopIII remnants

HEAVY seeds ($M \gtrsim 10^4 M_\odot$)

- Direct collapse of a massive gas cloud
- SMS/Quasistar

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Open issues

- Sustained accretion at or above the Eddington limit

- Gas fragmentation
- Angular momentum
- Inflow rates of at least 1 $M_\odot$/yr

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- Direct collapse of a massive gas cloud
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Open issues

- Sustaine

Further and more detailed investigations would be necessary

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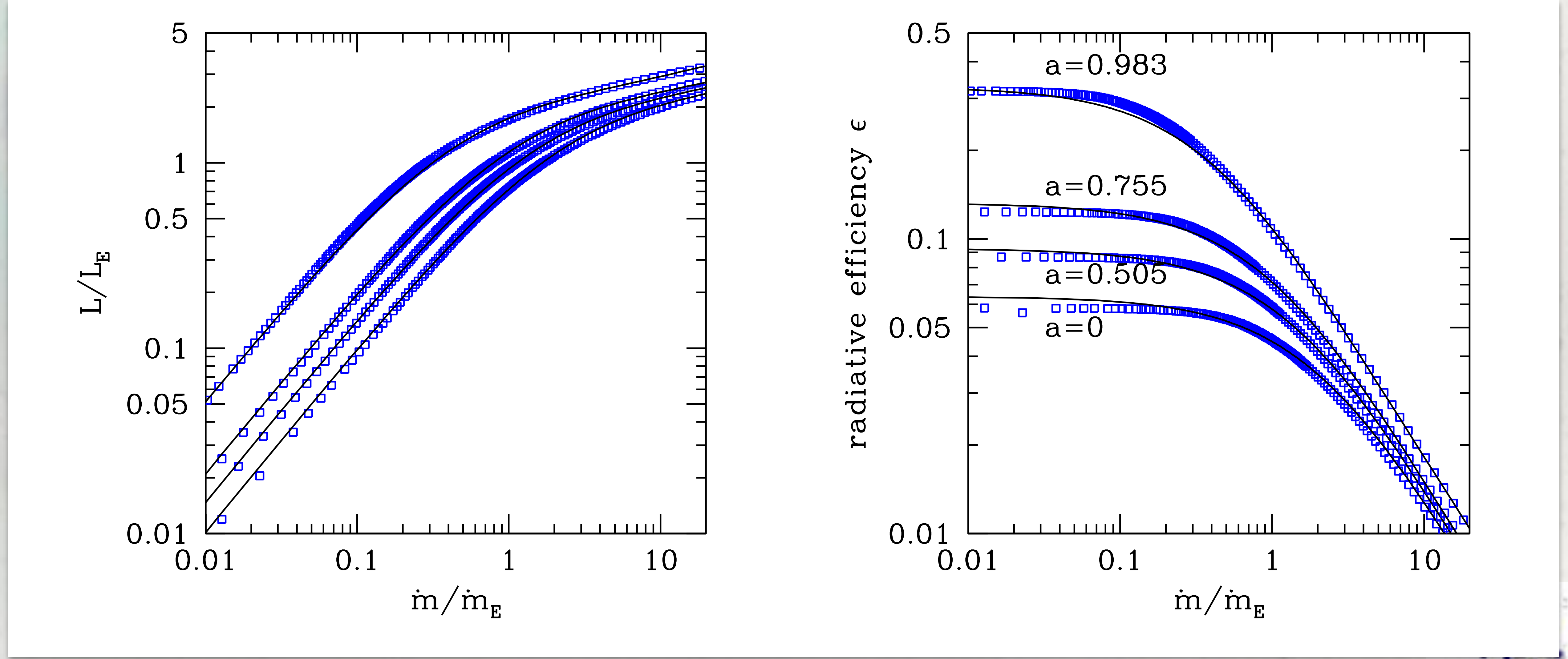
1 $M_\odot$/yr

Super-critical accretion

RADIATIVELY INEFFICIENT ACCRETION: THE SLIM DISC MODEL

(Abramowicz et al. 1988; Sadowski et al. 2009, 2014)

Madau, Haardt & Dotti (MHD, 2014): super-critical accretion on to stellar mass BHs to bypass the difficulties associated to other scenarios



Super-critical accretion

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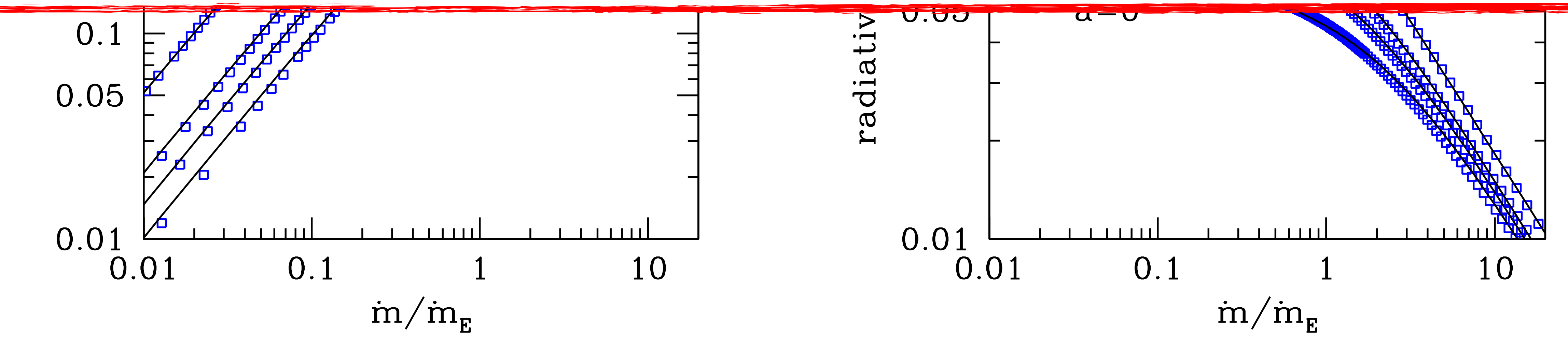
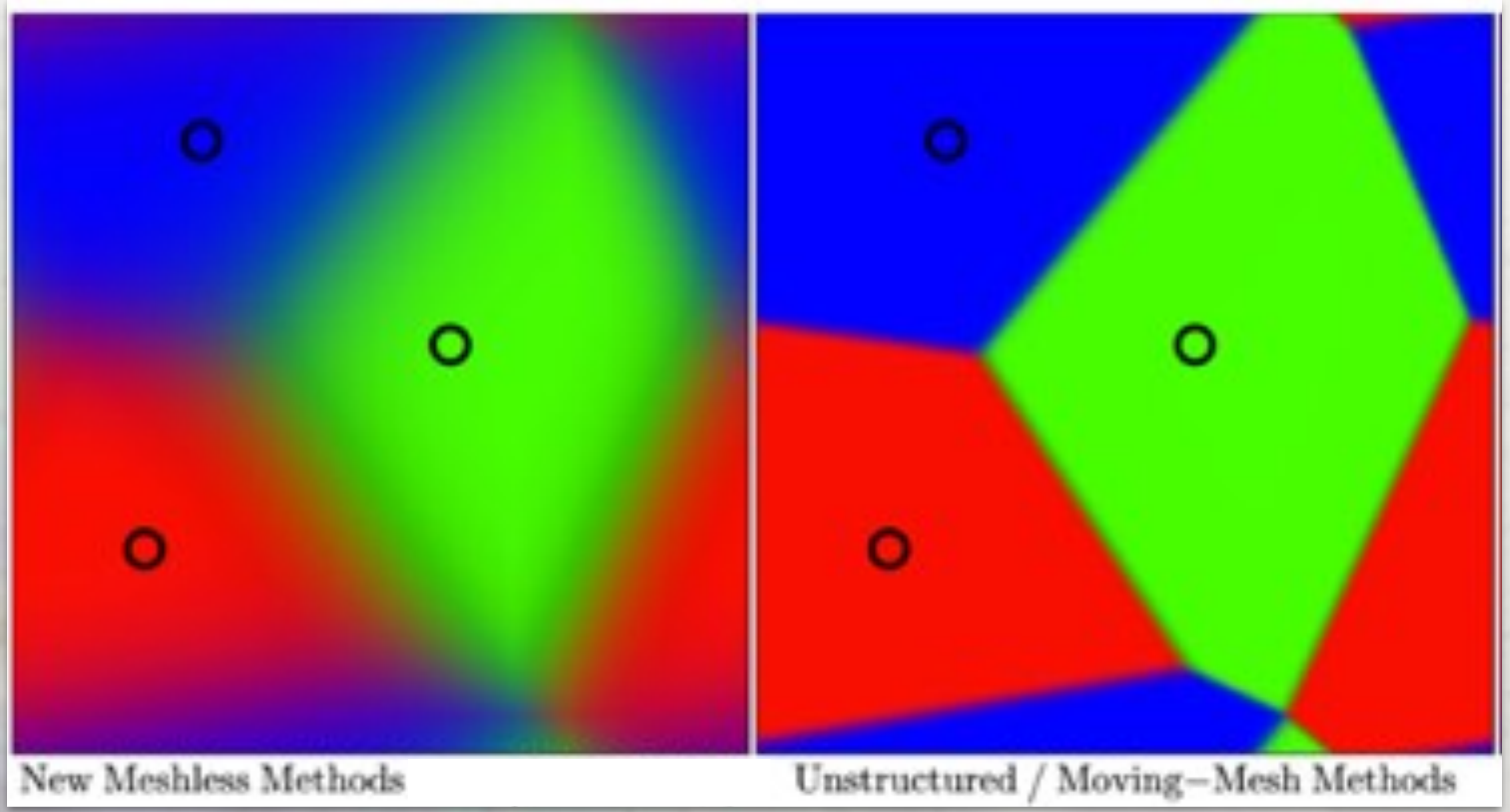
MHD (and Volonteri, Silk & Dubus, 2014) discussed how the conditions for super-critical accretion are plausible in the dense environments of high redshift massive proto-galaxies.



Simulation setup

THE MESH-FREE CODE GIZMO (Hopkins 2015)



Particle based code with kernel-based partition scheme

Gravity: Tree algorithm

Hydrodynamics:
Second-order Godunov-like method

Sub-grid model

BH ACCRETION AND FEEDBACK

- Flux accretion prescription (Bleuler et al., 2014)

$$\dot{M}_{\mathrm{flux}} = -\int_{\Omega_{\mathrm{acc}}} \mathrm{div}\left(\rho(\boldsymbol{v} - \boldsymbol{v}_{\mathrm{sink}})\right)\mathrm{d}V.$$

- BH feedback, following Booth & Schaye (2009), assuming the radiative efficiency - accretion rate relation derived in MHD:

$$\eta = \frac{r}{16} A(a) \left[\frac{0.985}{r + B(a)} + \frac{0.015}{r + C(a)} \right]$$

$$\begin{aligned} A(a) &= (0.9663 - 0.9292a)^{-0.5639}, \\ B(a) &= (4.627 - 4.445a)^{-0.5524}, \\ C(a) &= (827.3 - 718.1a)^{-0.7060}. \end{aligned}$$

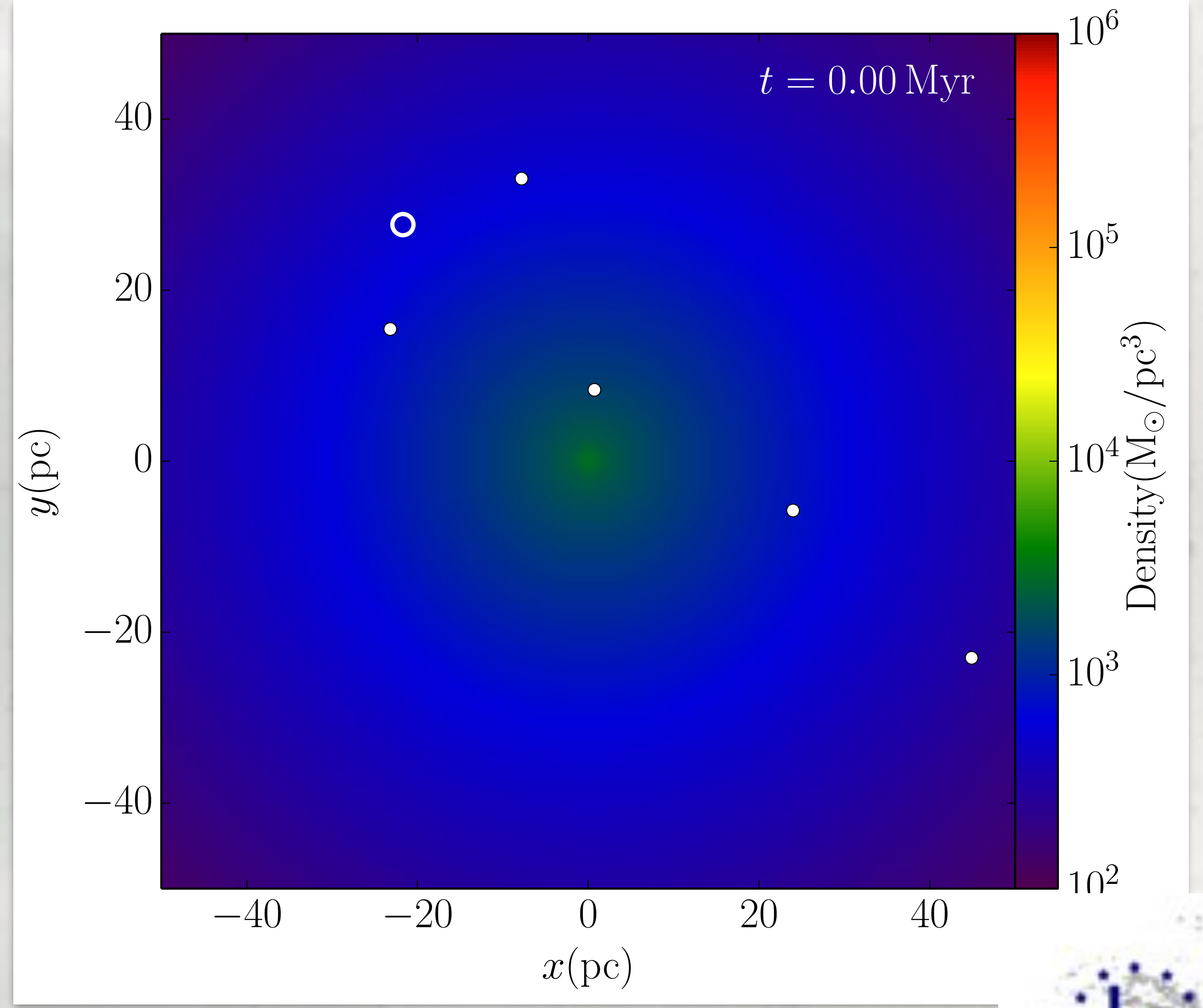
$$r = \dot{M}_{\mathrm{E}} / \dot{M}$$

Super-critical accretion in gas-rich galaxy nuclei

Lupi et al. 2016

- **GASEOUS DISC**
  - M = $10^8\ M_\odot$
  - R_0 = 50 pc
  - T_0 = 10^4 K

- **STELLAR BACKGROUND**
  - M = $2\times10^8\ M_\odot$
  - R_0 = 100 pc

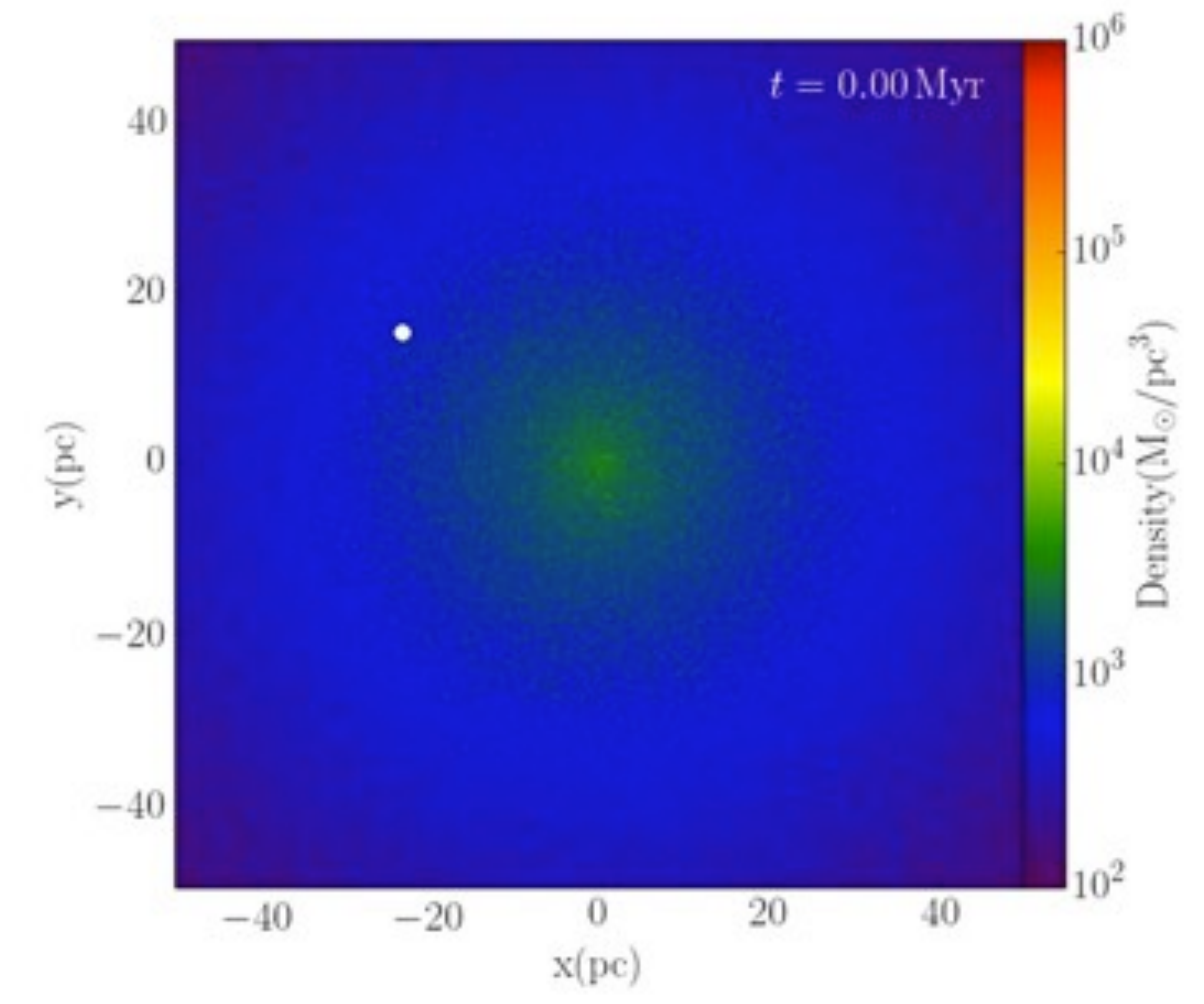


- 20 **STELLAR MASS BHs**

  $\mathbf{v}_{BH}(R) = \mathbf{v}_{circ}(R) + \mathbf{v}_{rnd}$

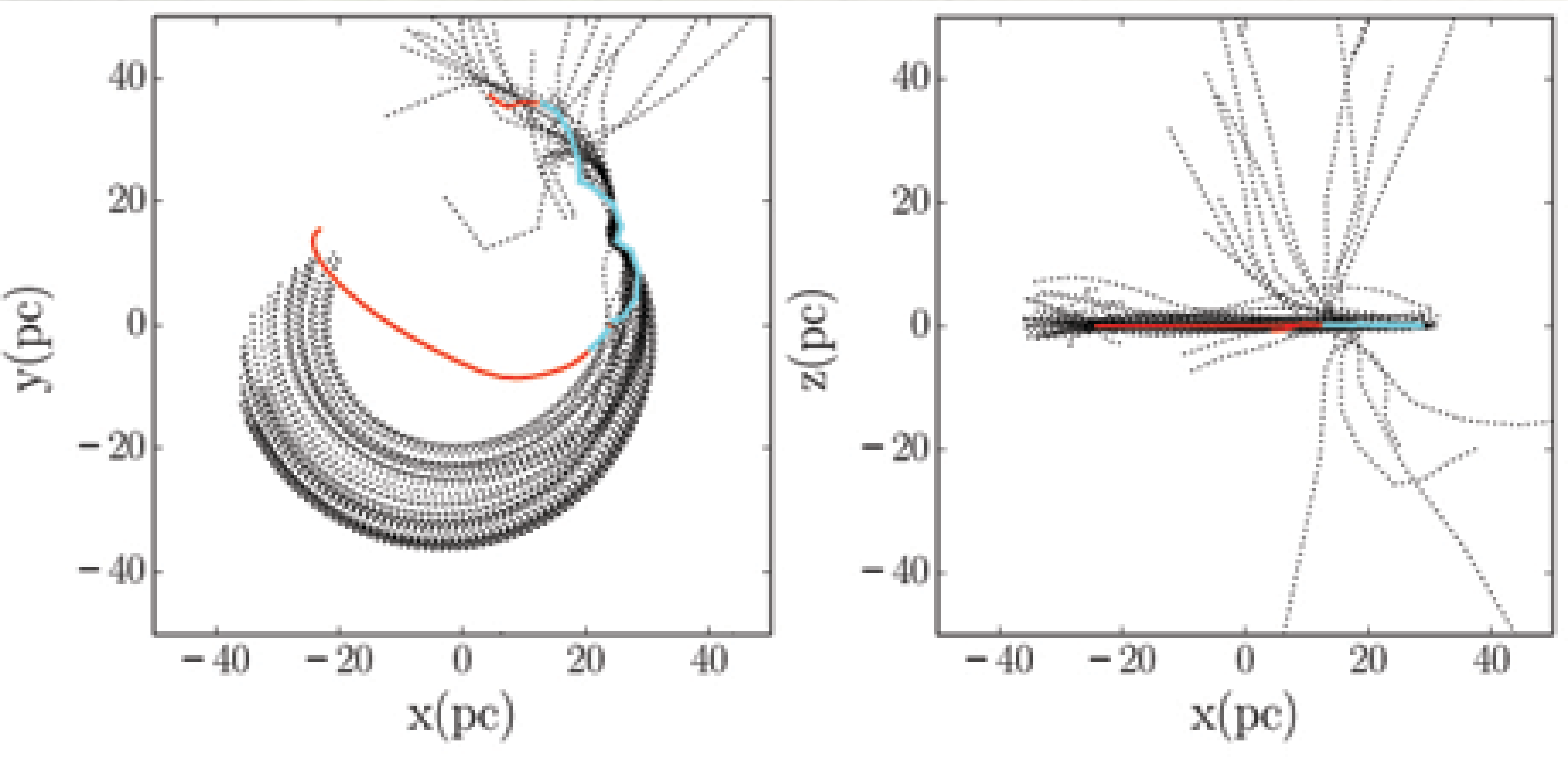
- Gas cooling, SF and Type II SNe

Super-critical accretion in gas-rich galaxy nuclei

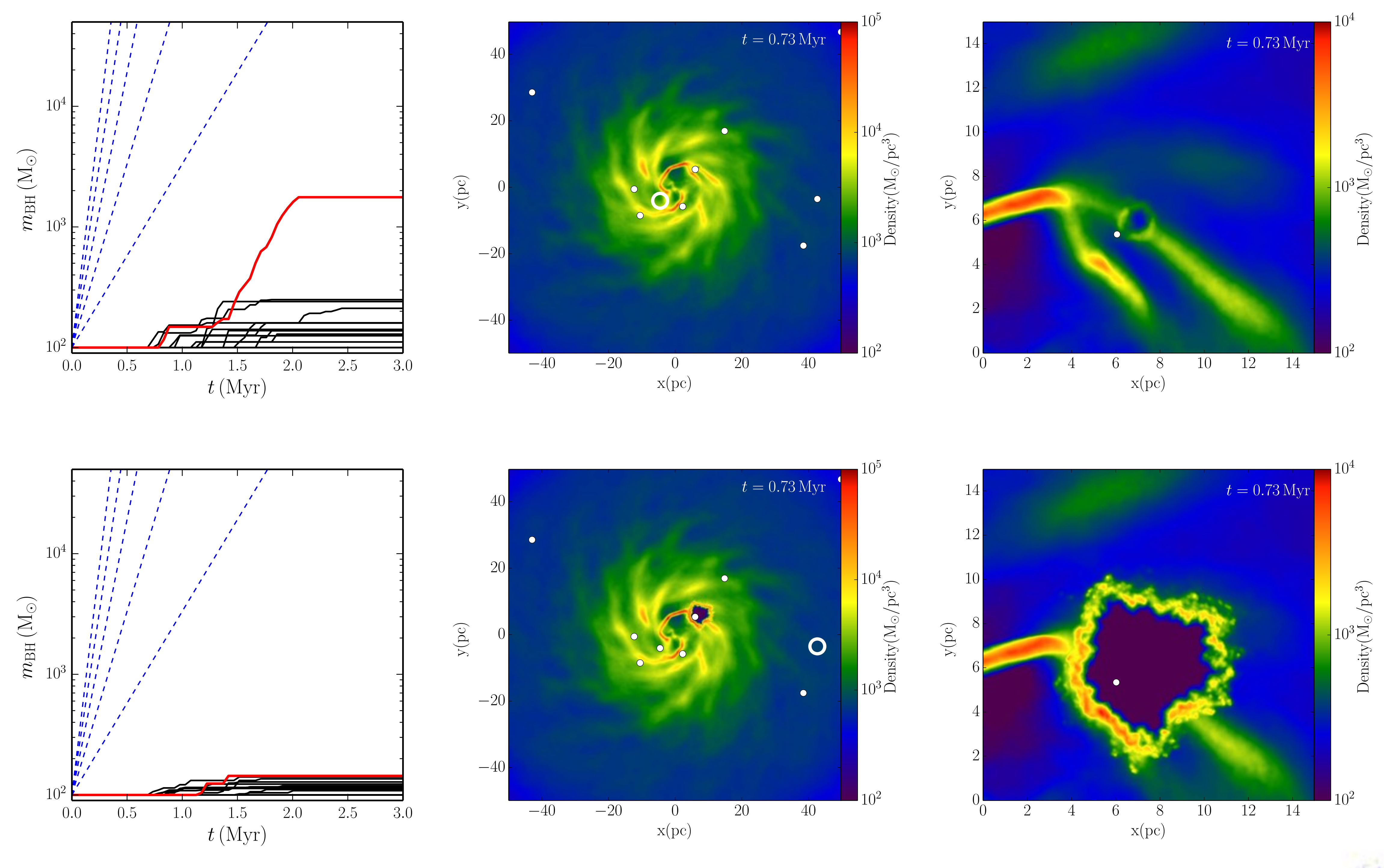


Super-critical accretion in gas-rich galaxy nuclei

BH-CLUMP CAPTURE PROCESS



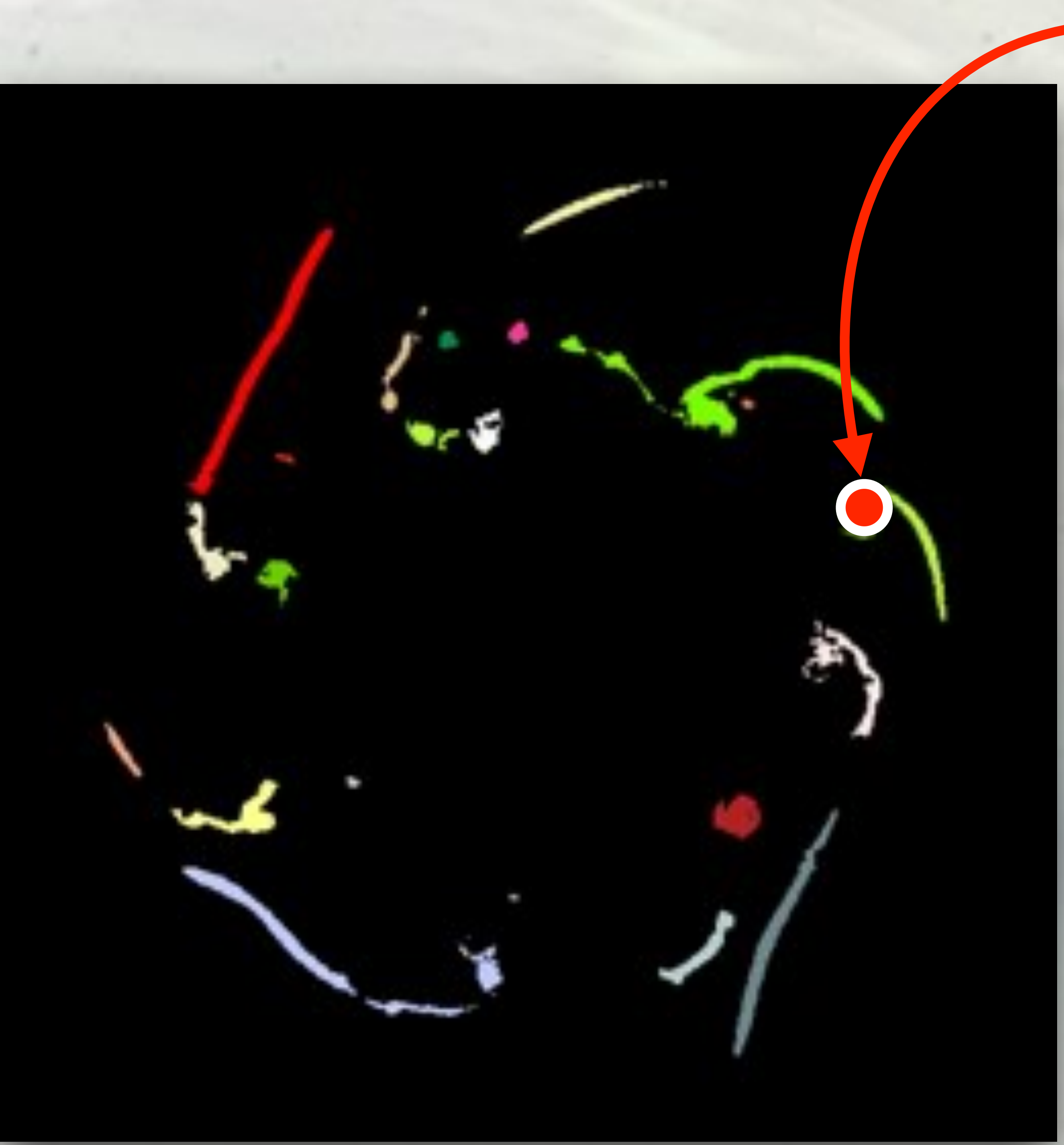
Radiative efficiency



Super-critical accretion in gas-rich galaxy nuclei

BH-CLUMP CAPTURE PROCESS

t= 1.6 Myr (accretion phase of the most massive BH)



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

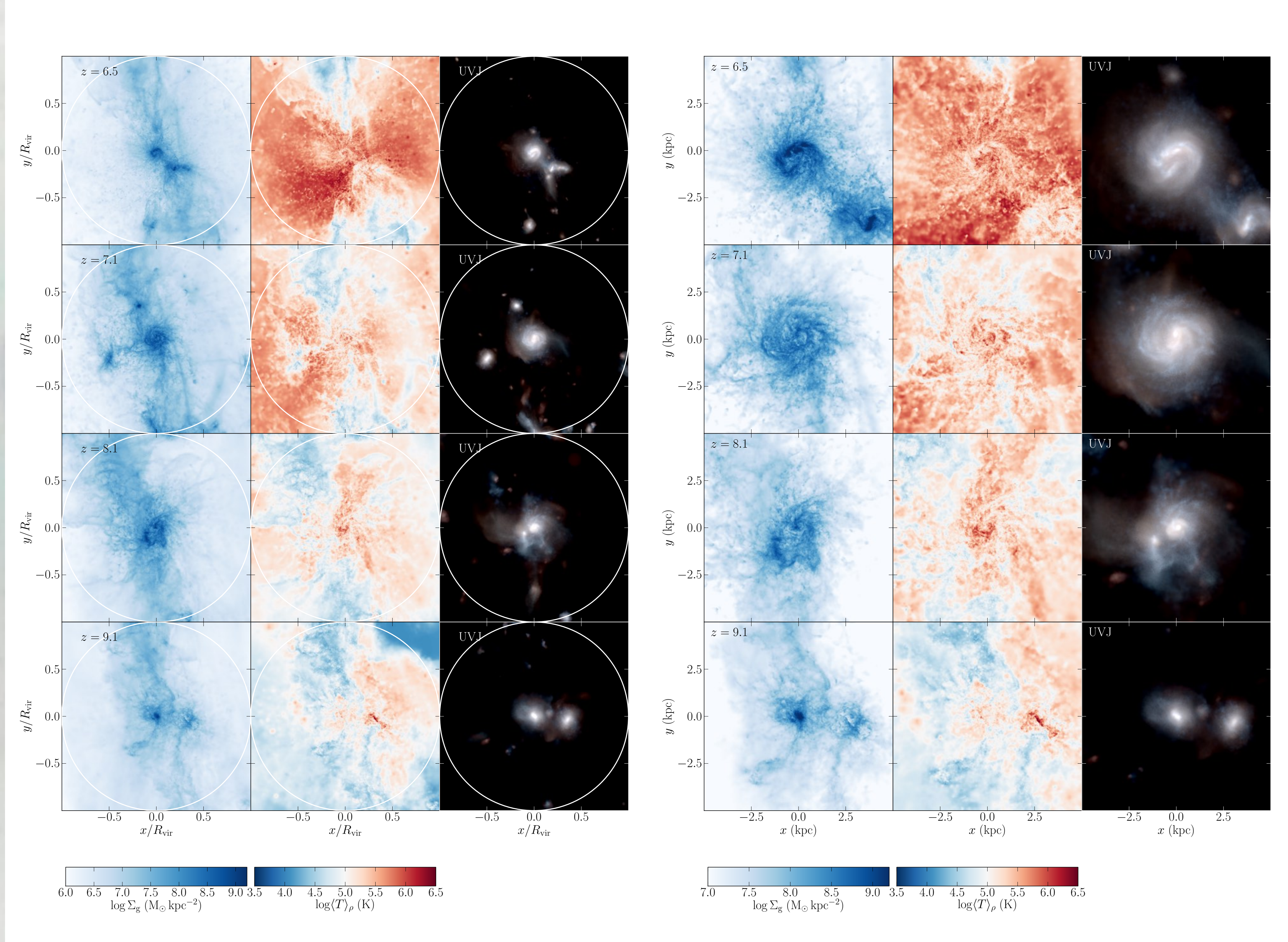
$R_{cloud} \sim 1$ pc

$n_{cloud} \sim 10^5\text{-}10^6\ \mathrm{cm}^{-3}$

slightly more compact than local GMCs

Super-critical accretion in gas-rich galaxy nuclei

DISC FORMATION: FIACCONI et al. in preparation



Gas flows in high redshift galaxies

Conclusions

SUMMARY

- A radiatively inefficient accretion is a necessary condition to grow supermassive BHs in less than 1 Gyr, able to explain the most massive quasars
- A stellar mass BH embedded in a fragmenting CND can experience a gravitational capture by a massive gaseous clump, which provides a large enough inflow to trigger a phase of super-critical accretion
- The radiatively inefficient accretion on to the BH prevents the clump disruption, allowing for an unimpeded fast growth.

OPEN ISSUES

- Despite the high resolution reached we barely resolve the Bondi radius for stellar mass BHs, hence the estimated accretion rates can be larger than in reality.
  → A quantitative convergence is far from being reached.
- Highly idealised setup. We did not consider galactic scale inflows able to replenish the nucleus previously depleted from the gas as consequence of SNa explosions.
- The BH-clump capture process can occur only when the BH mass is much smaller than the clump mass (up to $\sim 10^4\,M_\odot$).

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Thank you