RUM
Sept. 17
Lyon

Supermassive black hole dynamics under the grid

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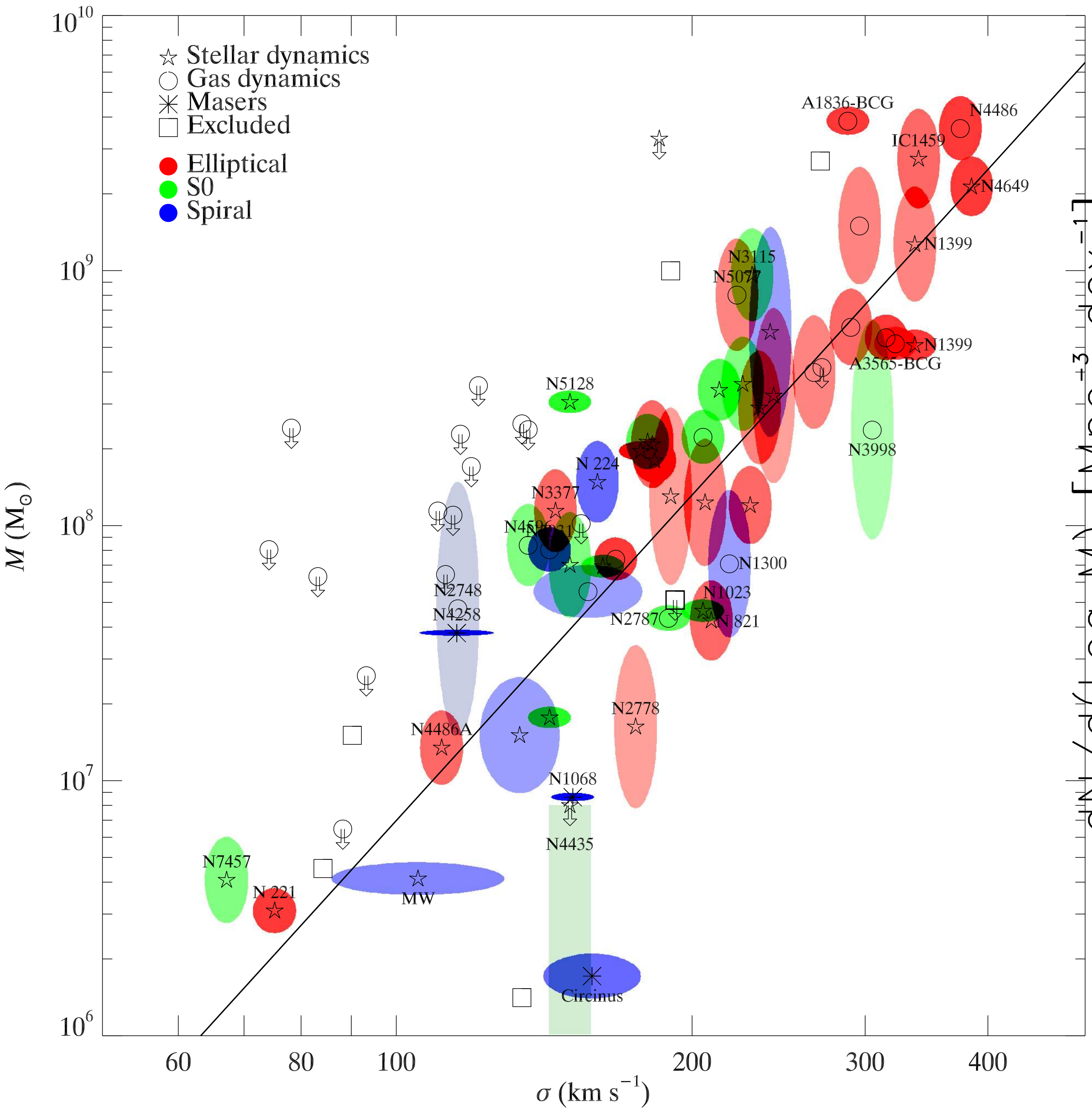
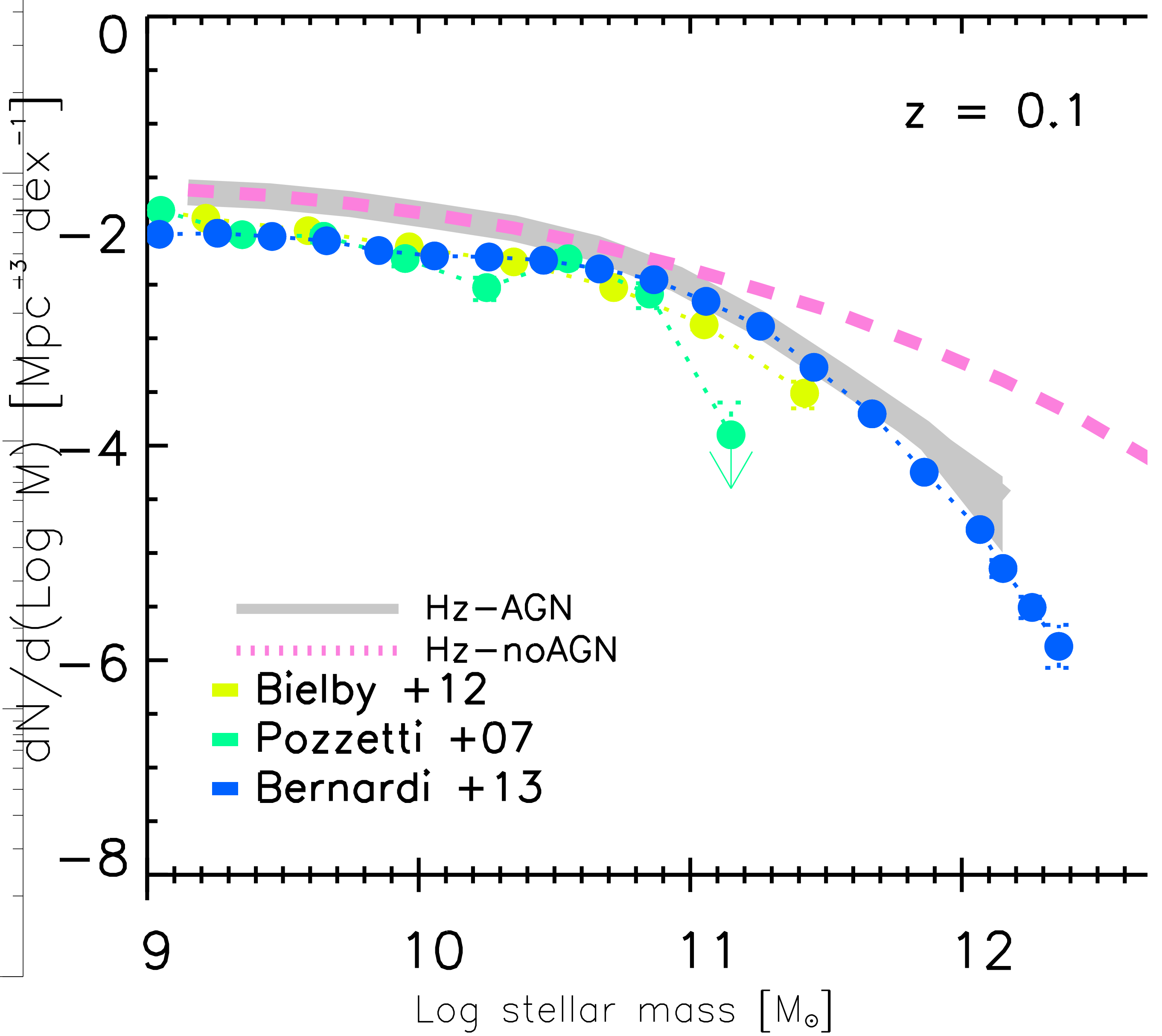
The need of BHs



Gultekin+09



Kaviraj+17

Outline

A. The current model of BHs in RAMSES
   i. Accretion and friction
   ii. Limits

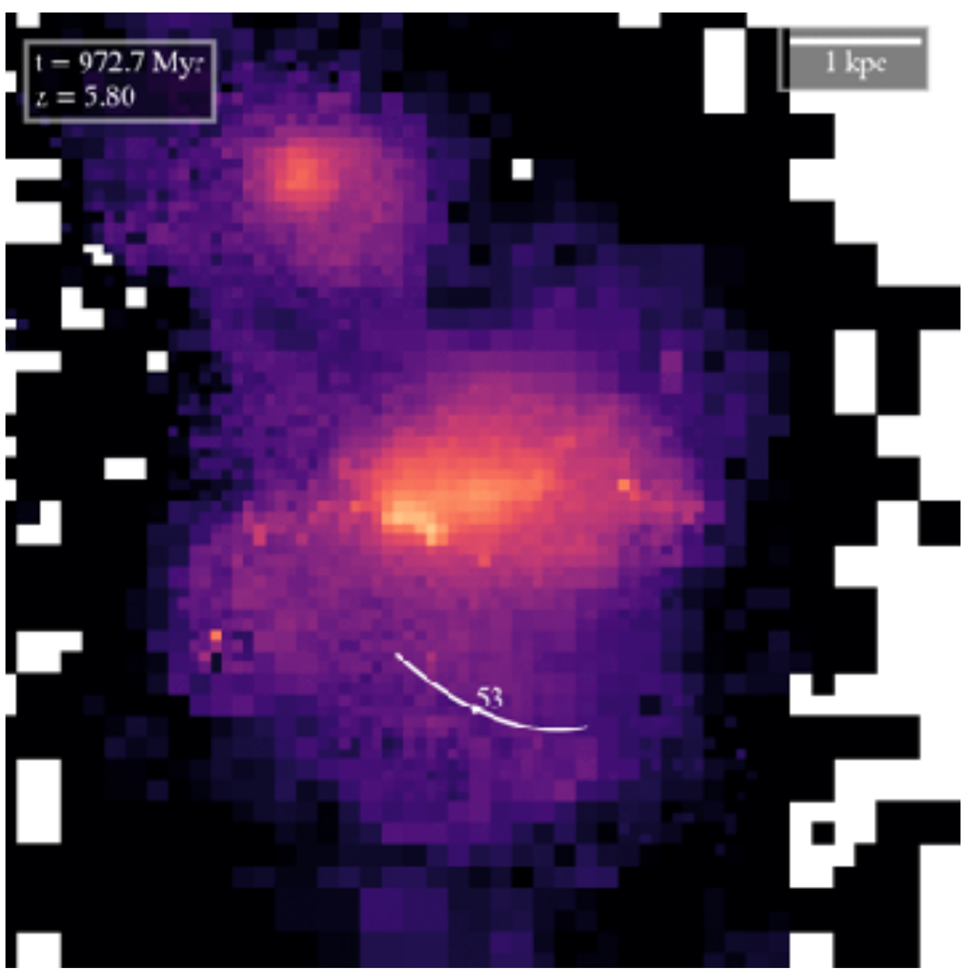
B. Dynamical friction from particles

C. The lonely life of high redshift black holes

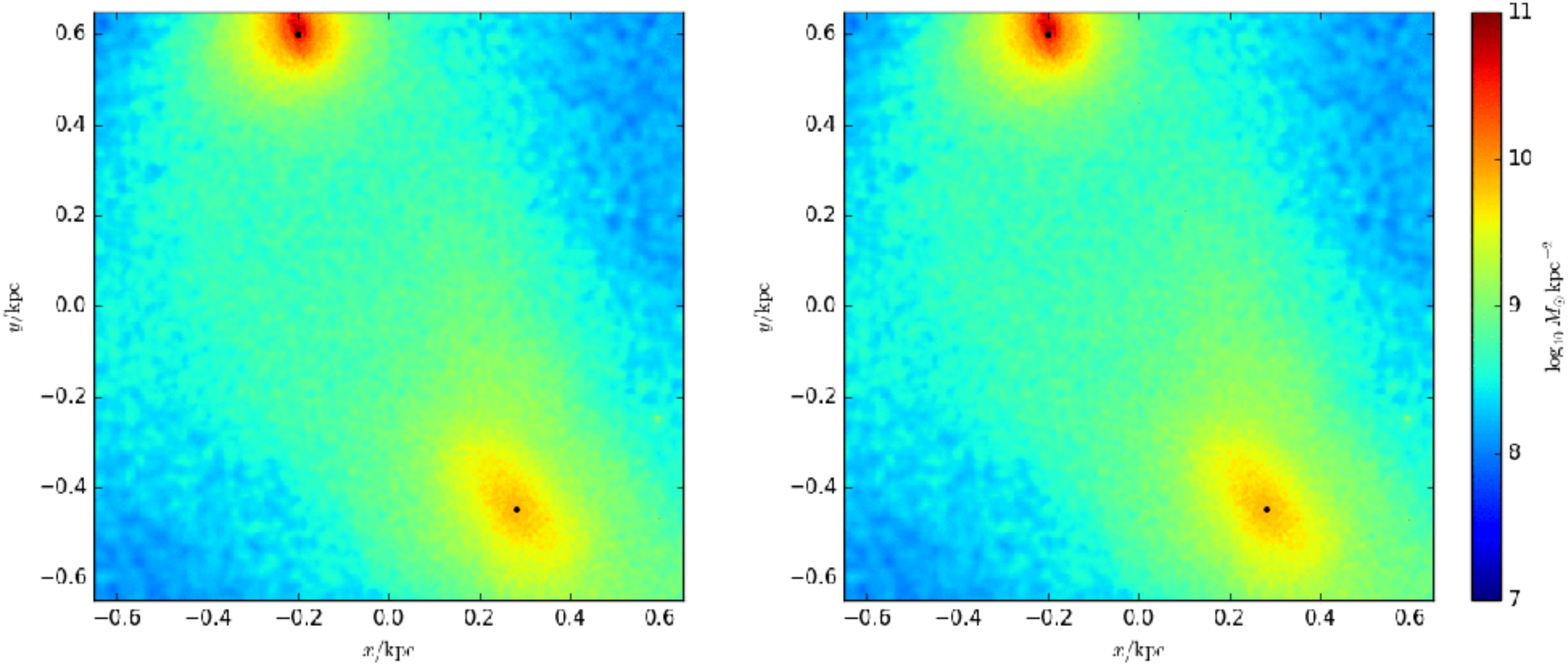
Accretion and friction

Bondi accretion (Bondi+52):

$$\dot{M}_{BH} = \frac{4\pi G^2 M_{BH}^2 \rho}{\left(c_s^2 + v^2\right)^{3/2}}$$



Accretion and friction

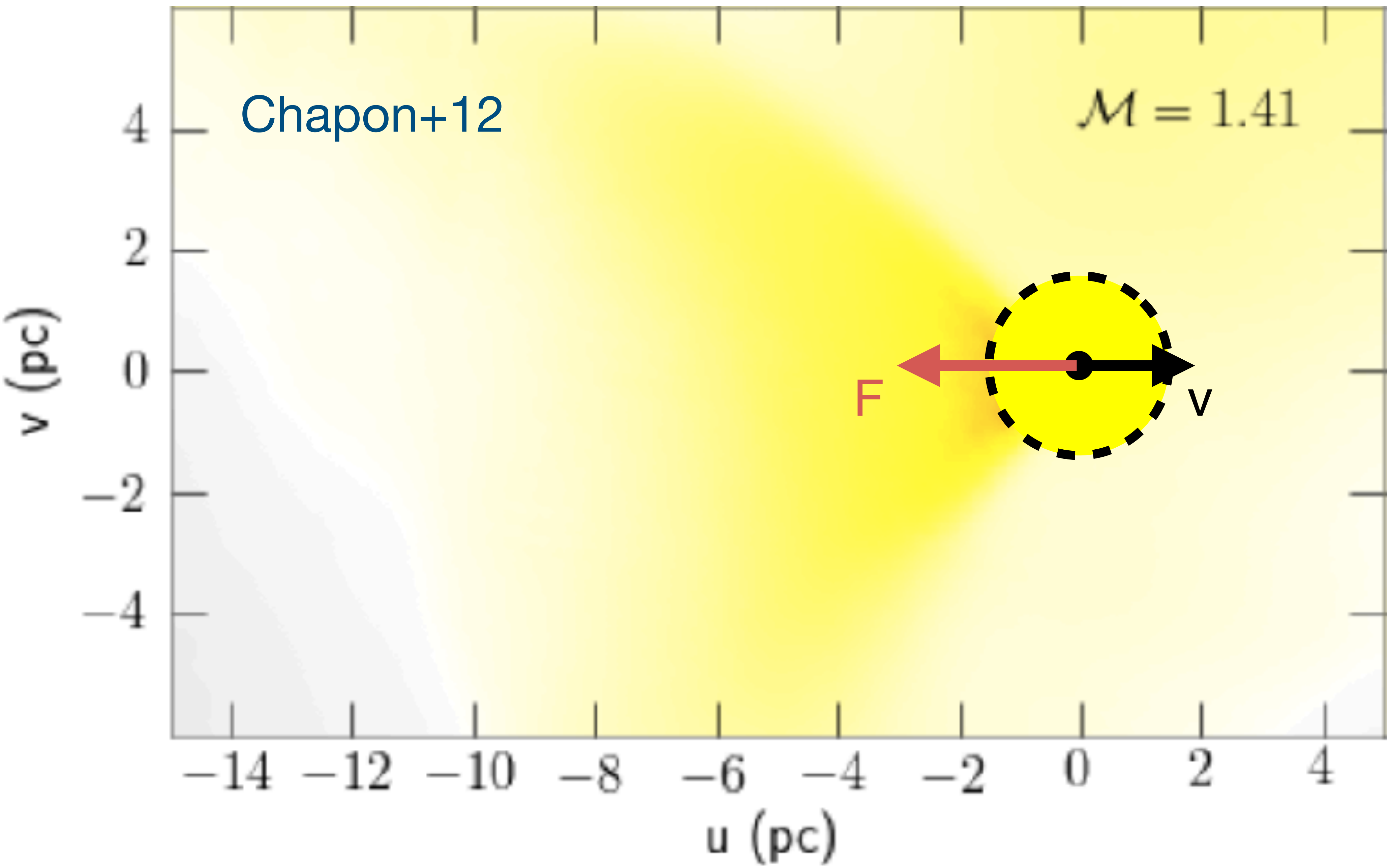


20 pc resolution

1 pc resolution

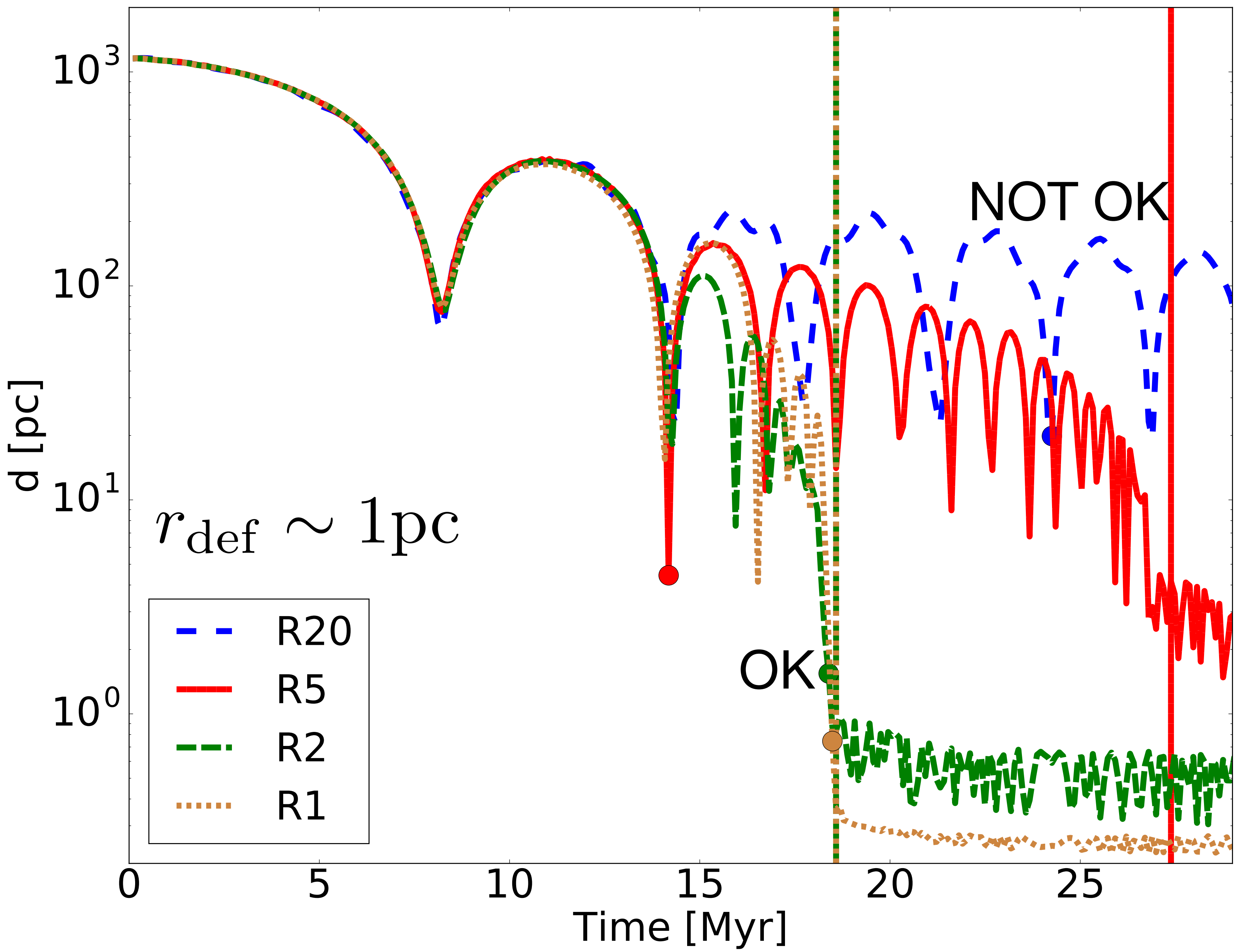
Pfister+17

Accretion and friction



$$r_{\rm def} = 1\ {\rm pc}\left(\frac{M_\bullet}{10^7 M_\odot}\right)\left(\frac{v}{200{\rm km\ s}^{-1}}\right)^{-2}$$

Accretion and friction



Accretion and friction

Bondi accretion (Bondi+52):

$$\dot{M}_{BH} = \frac{4\pi G^2 M_{BH}^2 \rho}{\left(c_s^2 + v^2\right)^{3/2}} \left(\frac{\rho}{\rho_0}\right)^2$$

Friction from gas (Ostriker+99):

$$\mathbf{F} = -f(\mathcal{M})\rho \left(\frac{G M_{BH}}{c_s}\right)^2 \frac{\mathbf{v}}{v} \left(\frac{\rho}{\rho_0}\right)^2$$

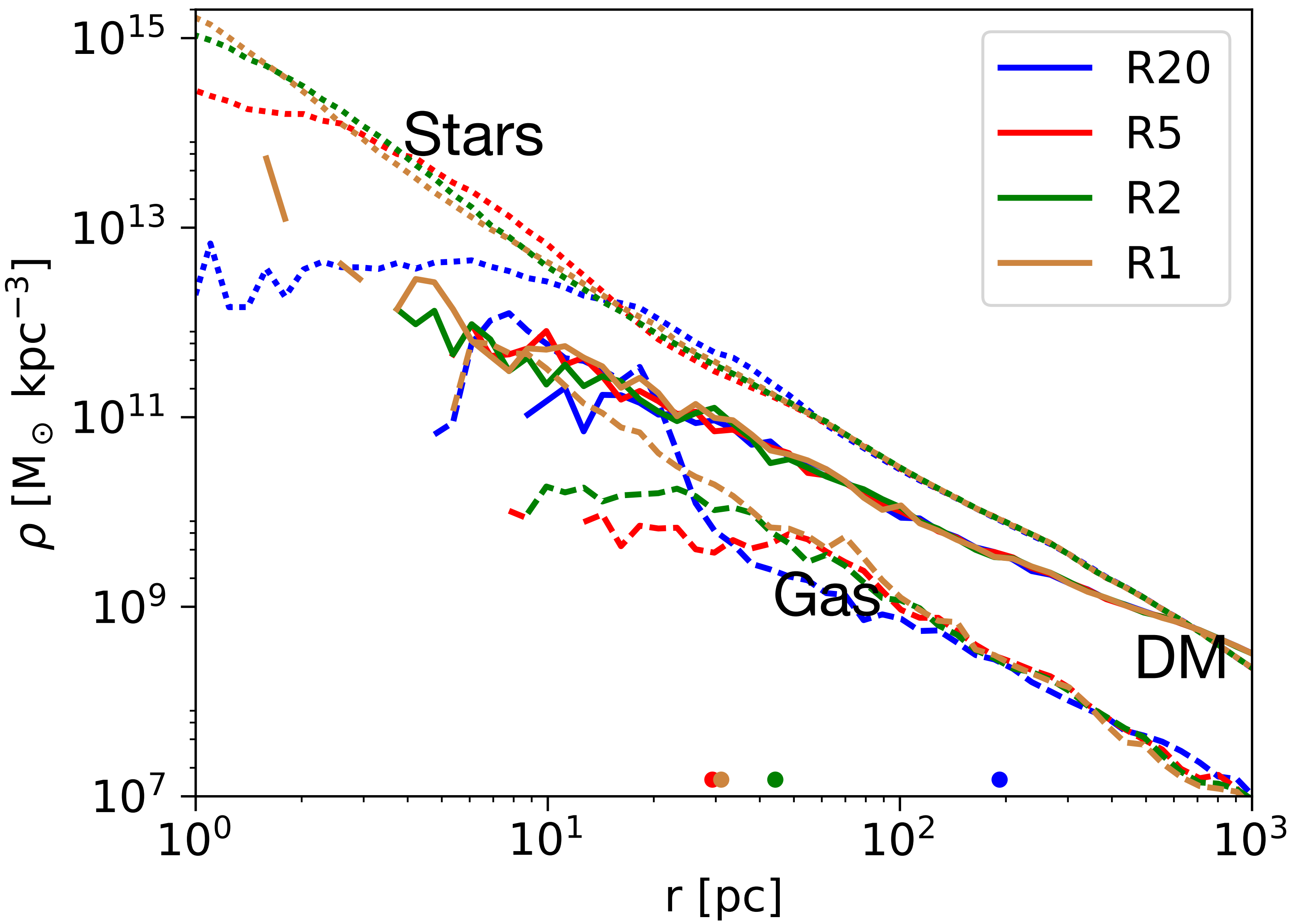
It makes little difference because “our resolution is too poor to capture the coldest and densest region of the ISM, therefore accretion and friction must be boosted”.

This gives you the Horizon-AGN BHs. As shown earlier, this model is excellent in reproducing the properties of galaxies. However…

Limits

- Which value should be given to ρ_0
- No physically motivated argument to this boost (calibrated by Booth&Schaye 09)
- In the central region, stars are likely to dominate the dynamics

We can implement unresolved DF from stars/DM similarly to what exists for gas, and see what happens!



Overview

A. The current model of BHs in RAMSES

B. Dynamical friction from particles

   i. The model

   ii. Technical issues

   iii. Tests

   iv. Scaling

C. The lonely life of high redshift black holes

The model

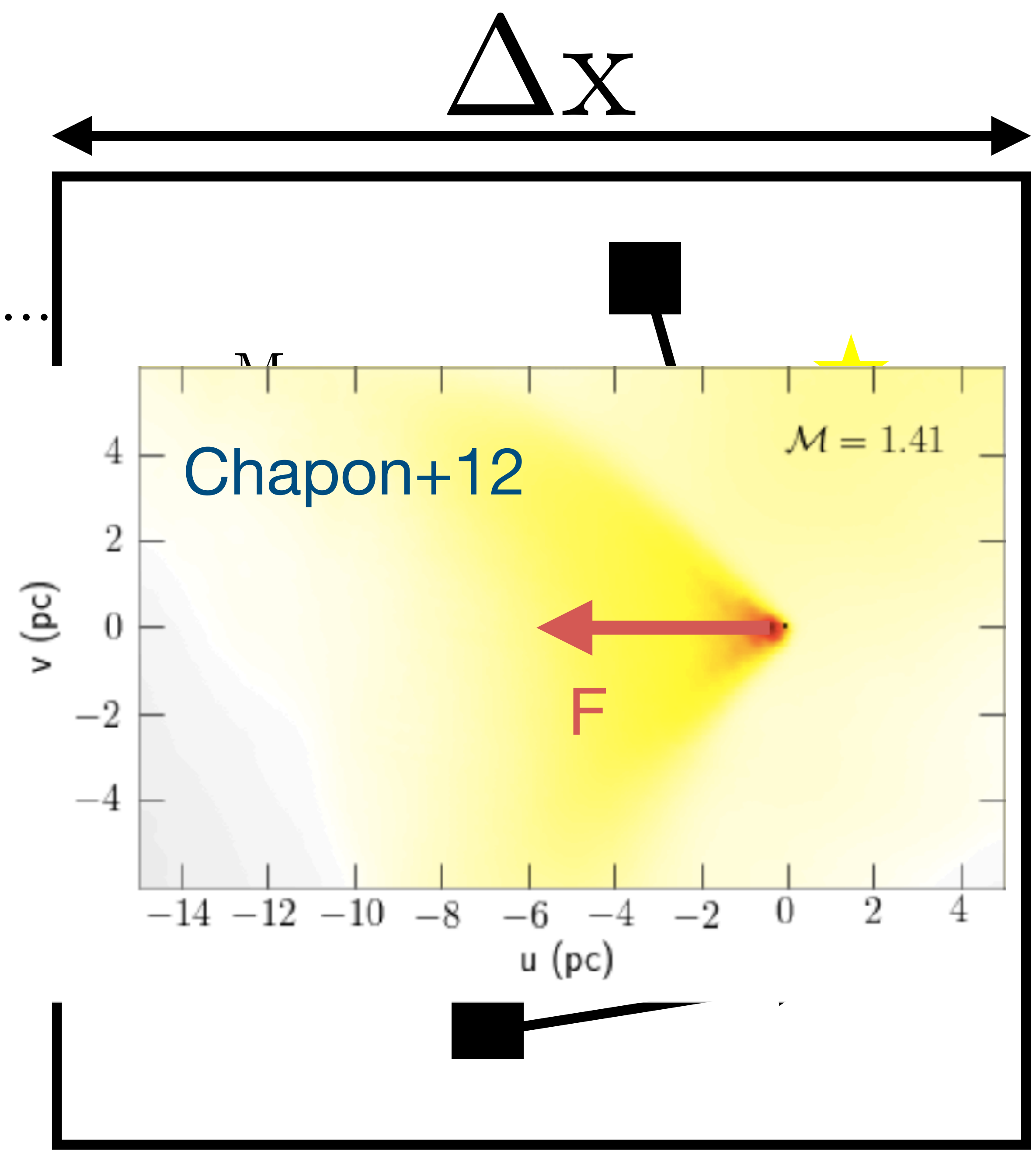
$$\vec{F}_\star = -4\pi \mathrm{G}^2 M_\bullet^2 \frac{\vec{v_\bullet}}{v_\bullet^3} \left\{ \ln\Lambda \int_0^{v_\bullet} 4\pi v^2 f(v) dv + \dots \right.$$

$$\left. \dots \int_{v_\bullet}^{\infty} 4\pi v^2 f(v) \left[\ln\left(\frac{v+v_\bullet}{v-v_\bullet}\right) - 2\frac{v_\bullet}{v} \right] dv \right\}$$

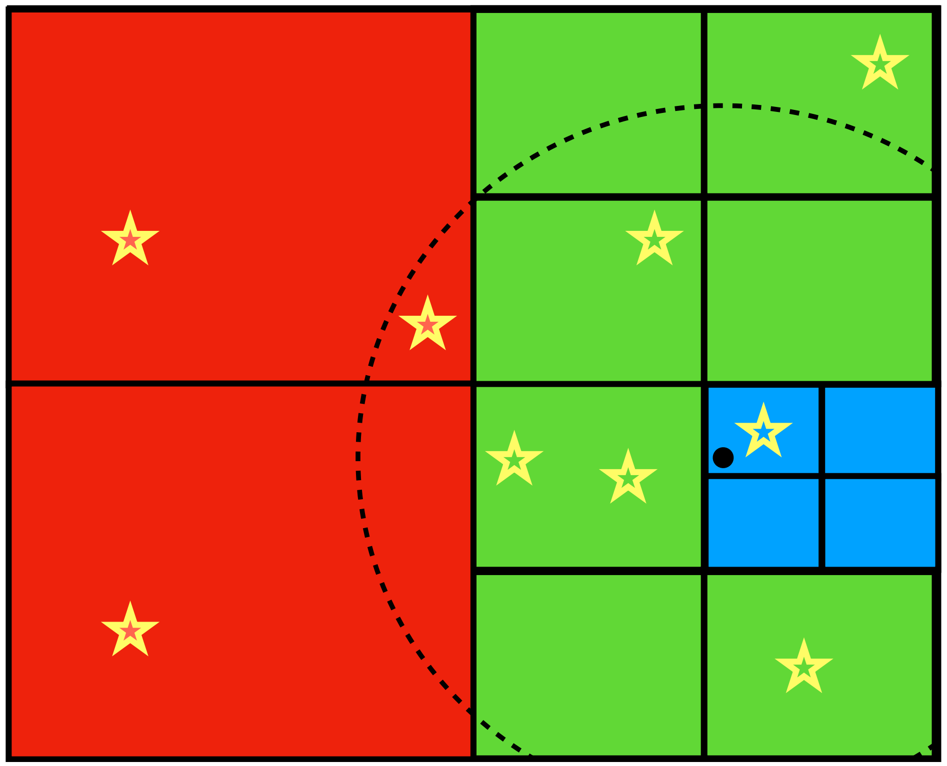
with:

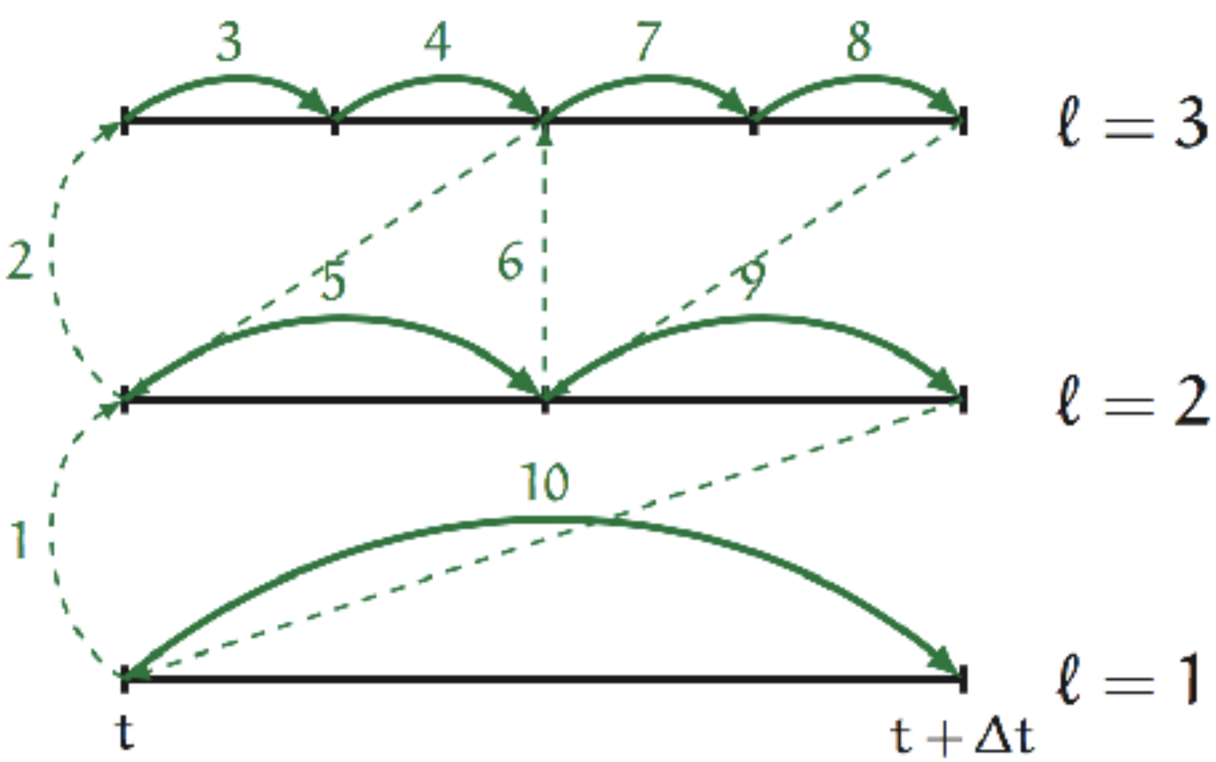
$$\ln\Lambda = \ln(4\Delta x / r_{\mathrm{def}})$$

$$4\pi v^2 f(v) = \frac{3}{256\pi\Delta x^3} \sum_{i\in\mathcal{S}} m_i \delta(v_i - v)$$



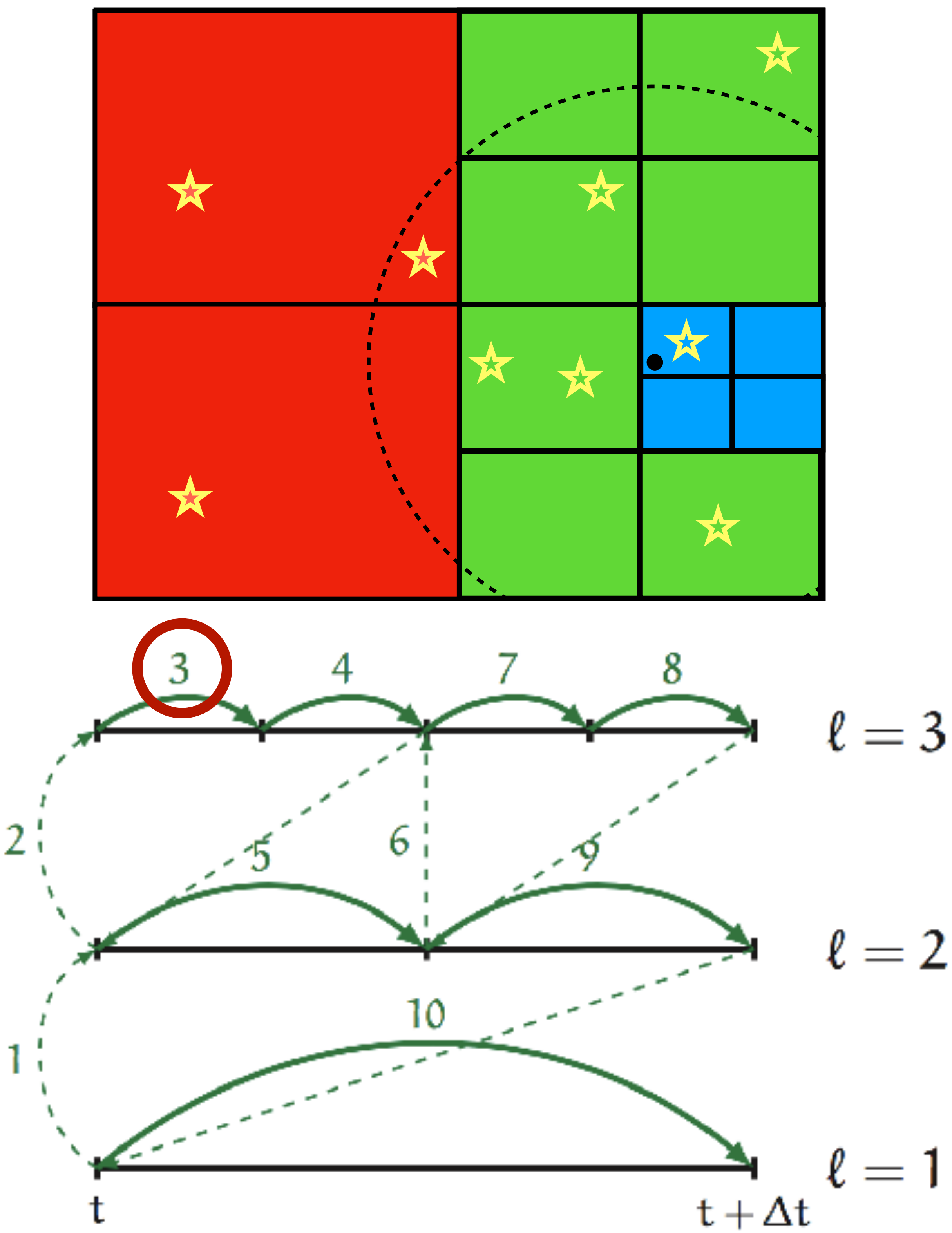
Technical issues





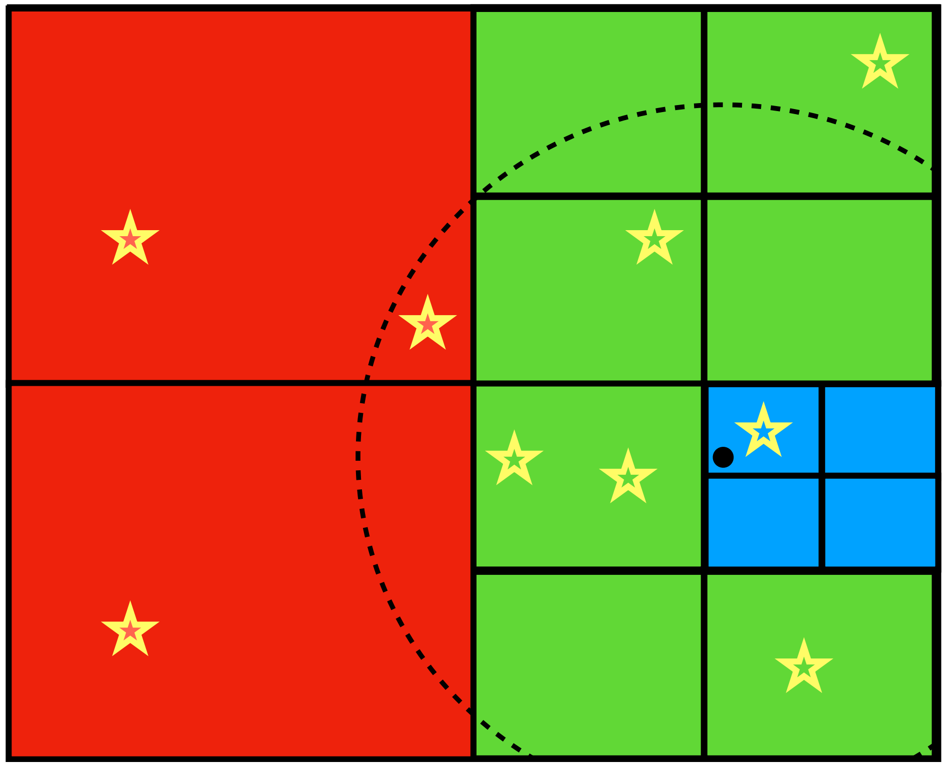
	v	m
ℓ=3	v_n	m_n
ℓ=2	v_n	m_n
ℓ=1	v_n	m_n

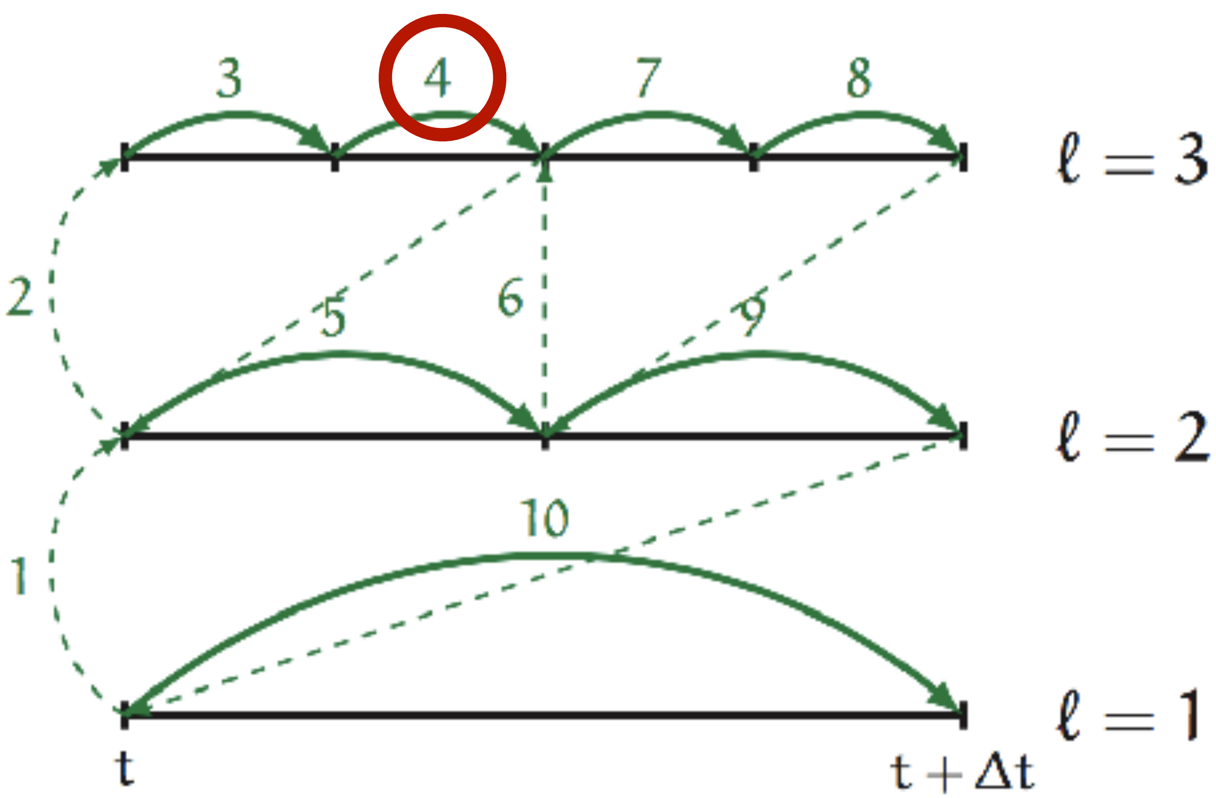
Technical issues



	v	m
ℓ=3	v_(n+1/4)	m_(n+1/4)
ℓ=2	v_n	m_n
ℓ=1	v_n	m_n

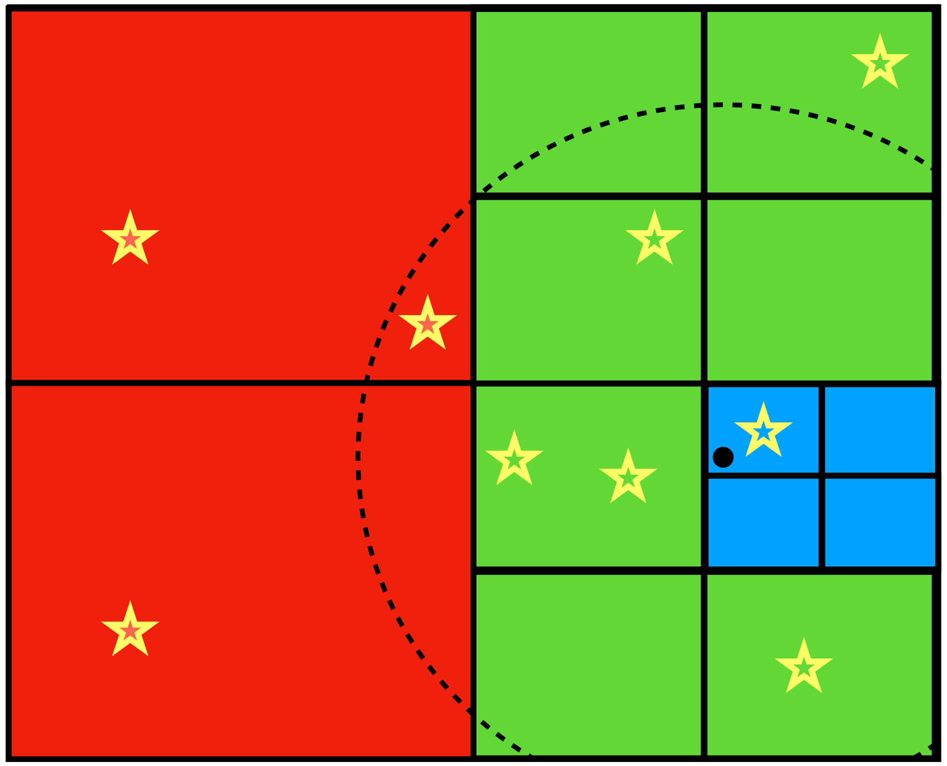
Technical issues

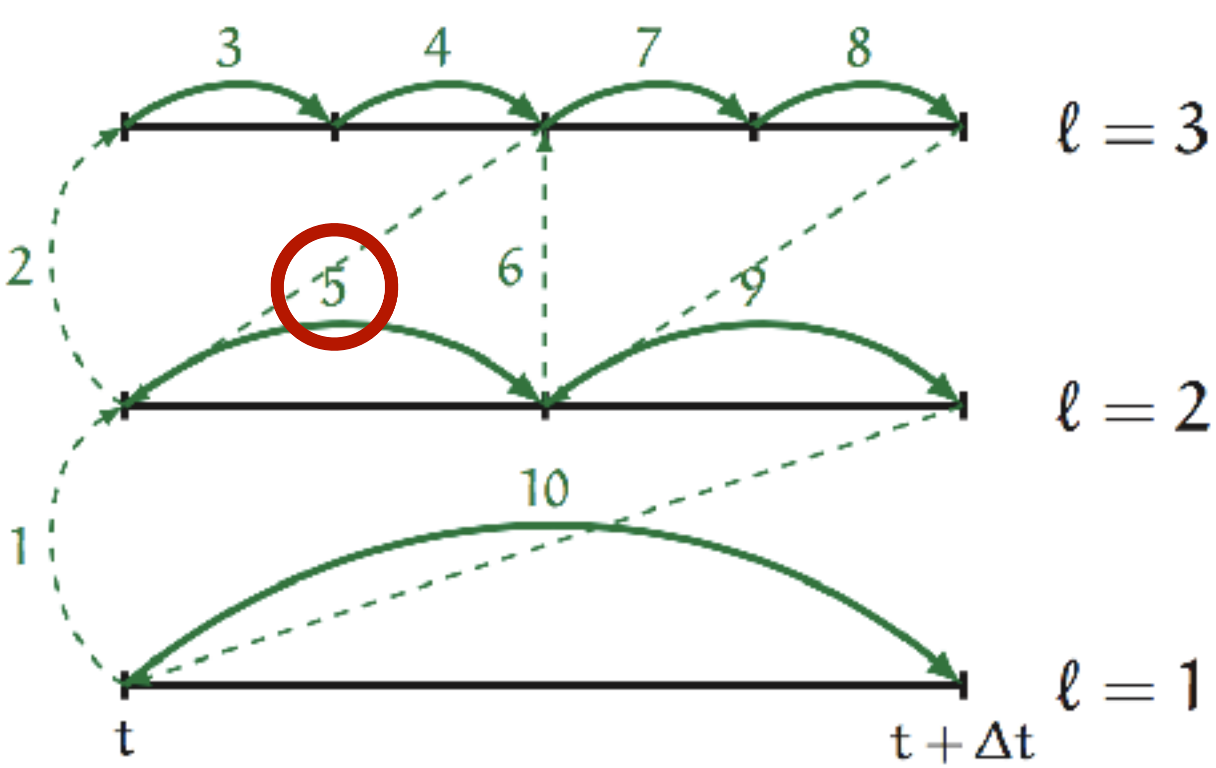




	v	m
ℓ=3	v_(n+1/2)	v_(n+1/2)
ℓ=2	v_n	m_n
ℓ=1	v_n	m_n

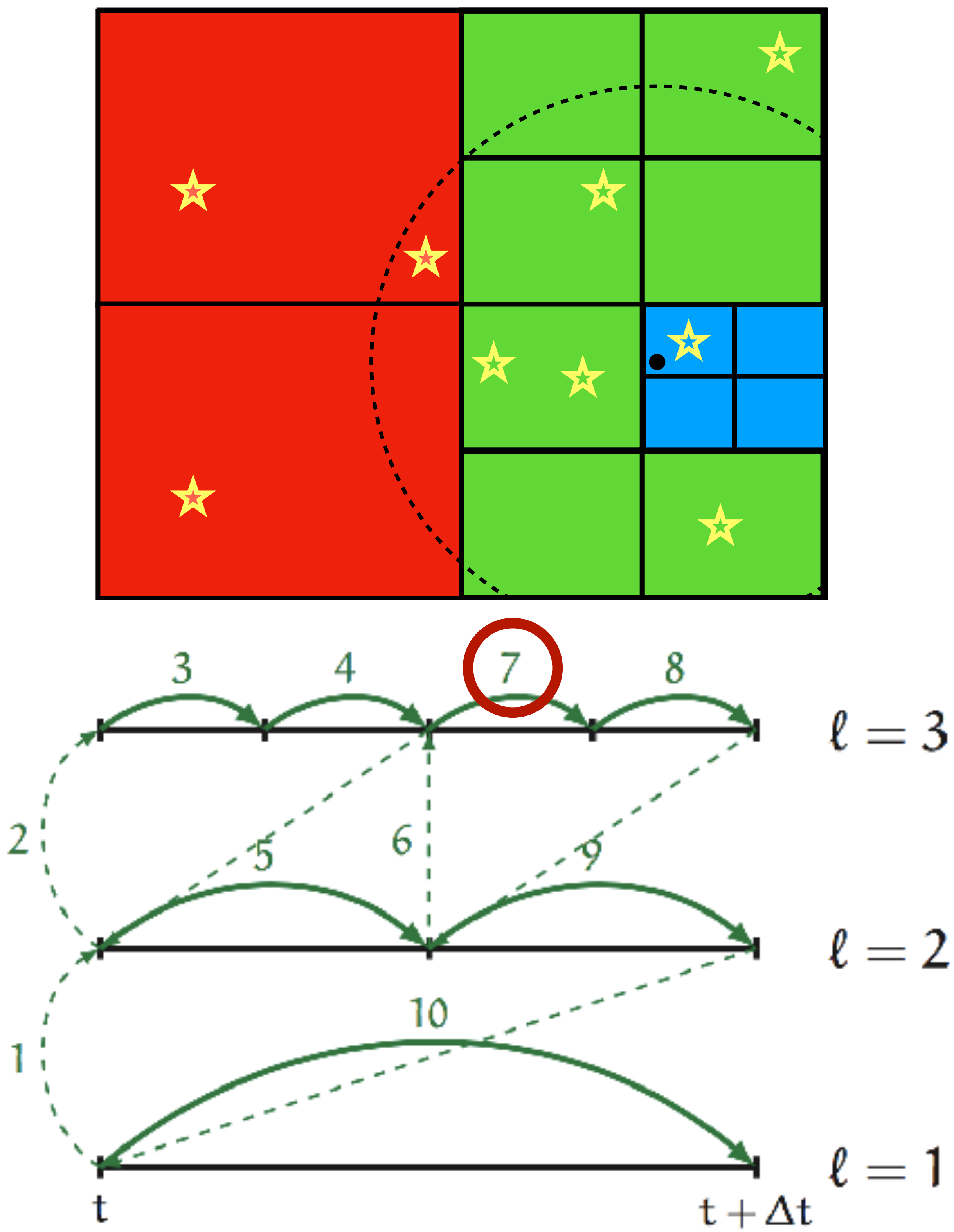
Technical issues





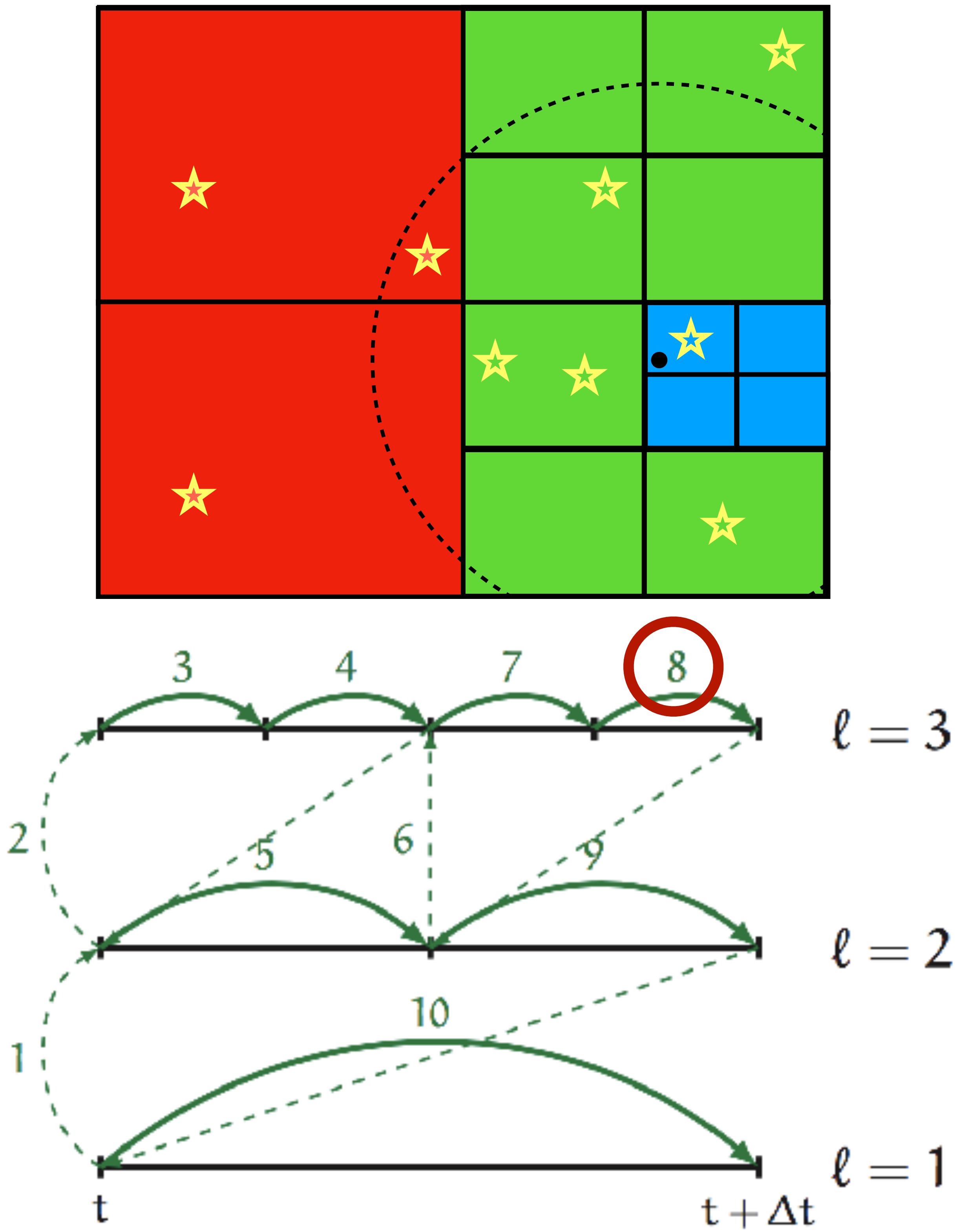
	v	m
ℓ=3	v_(n+1/2)	v_(n+1/2)
ℓ=2	v_(n+1/2)	m_(n+1/2)
ℓ=1	v_n	m_n

Technical issues



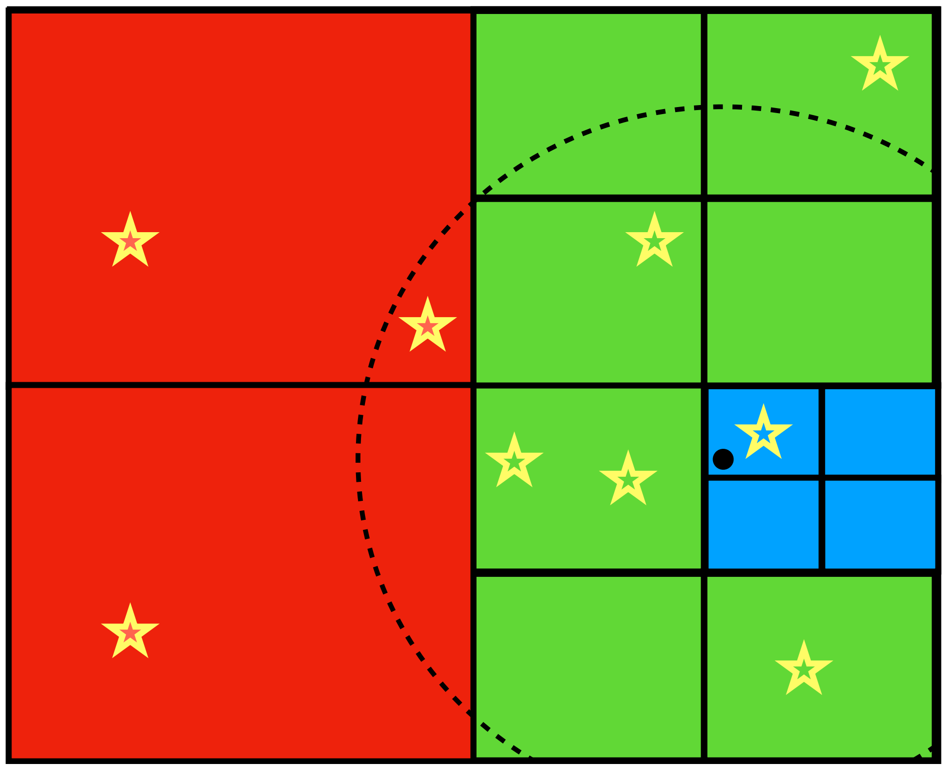
	v	m
ℓ=3	v_(n+3/4)	v_(n+3/4)
ℓ=2	v_(n+1/2)	m_(n+1/2)
ℓ=1	v_n	m_n

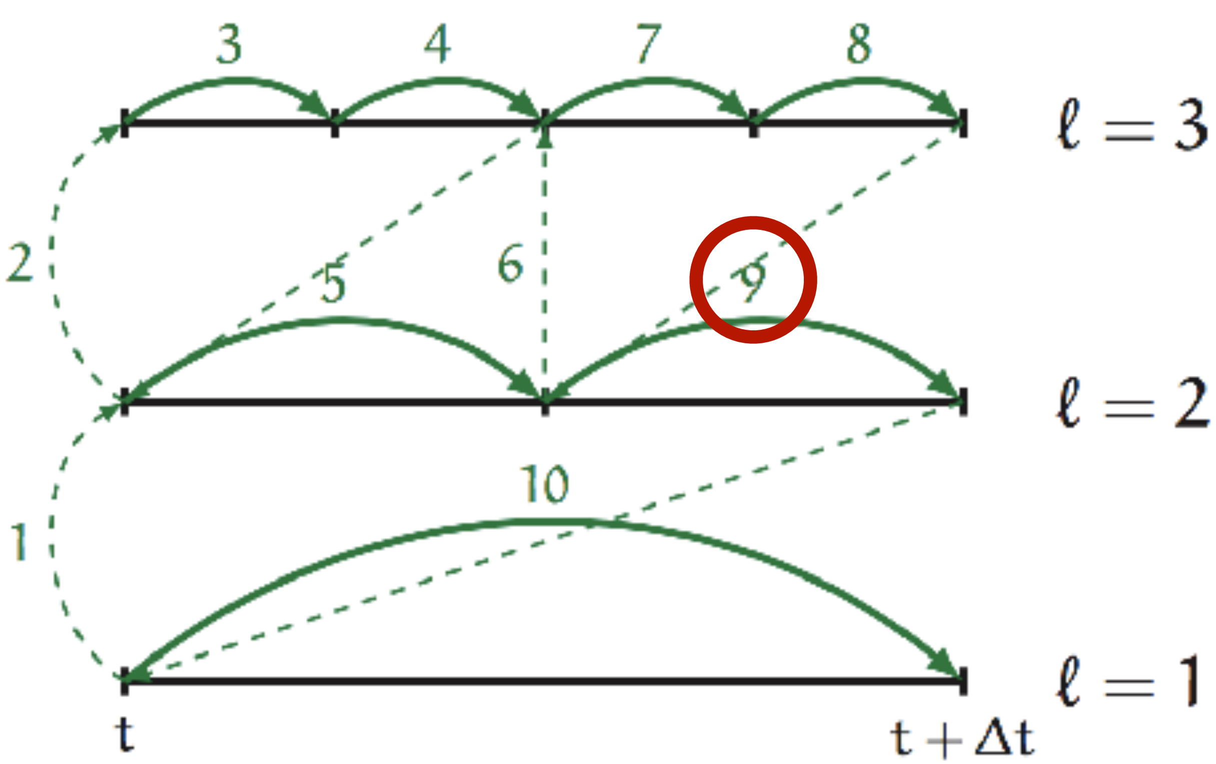
Technical issues



	v	m
ℓ=3	v_(n+1)	v_(n+1)
ℓ=2	v_(n+1/2)	m_(n+1/2)
ℓ=1	v_n	m_n

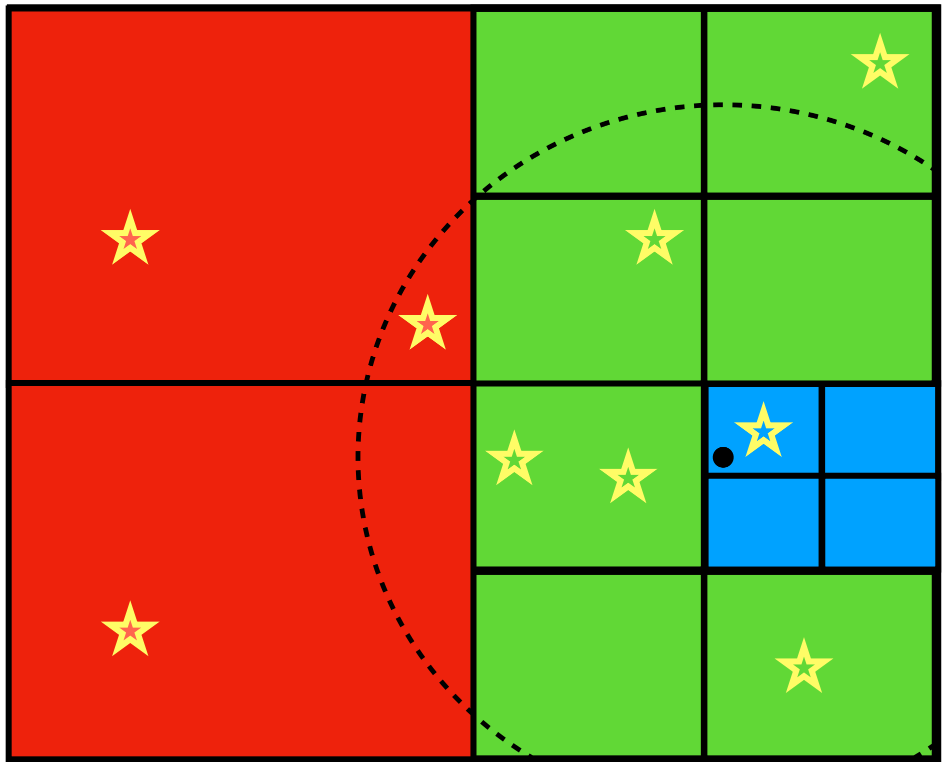
Technical issues

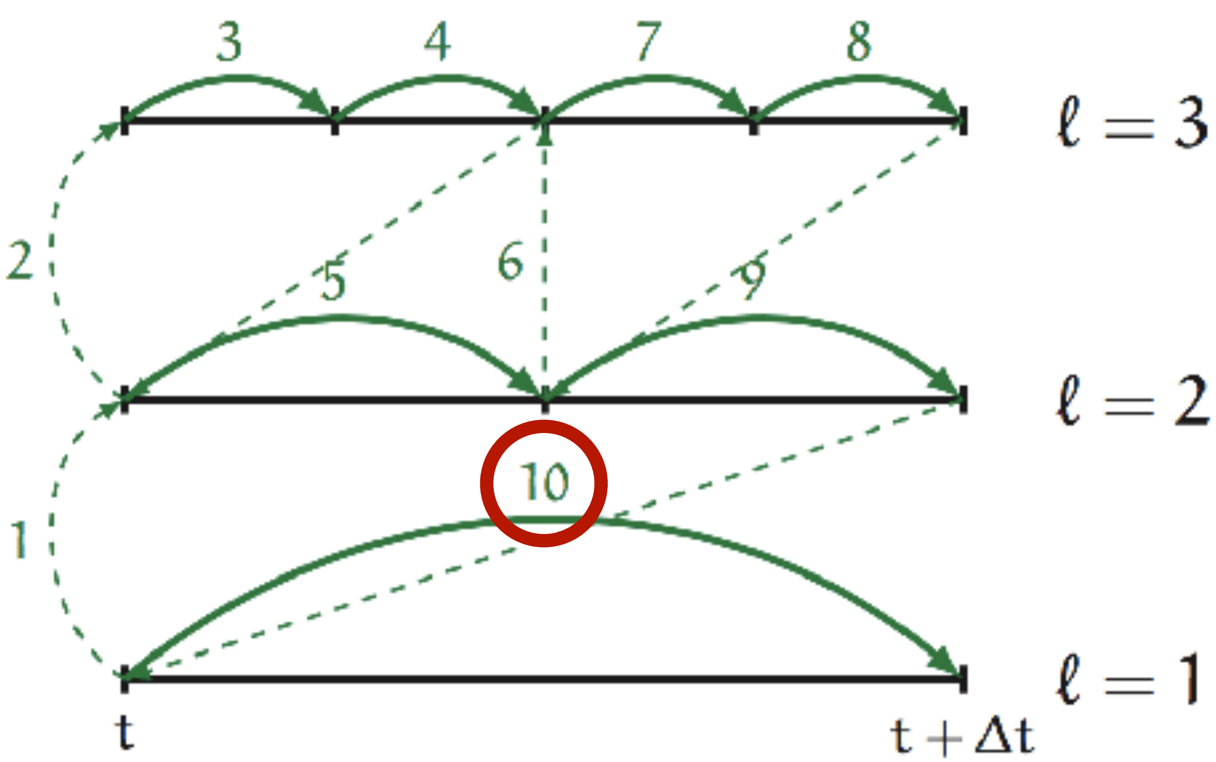




	v	m
ℓ=3	v_(n+1)	v_(n+1)
ℓ=2	v_(n+1)	m_(n+1)
ℓ=1	v_n	m_n

Technical issues

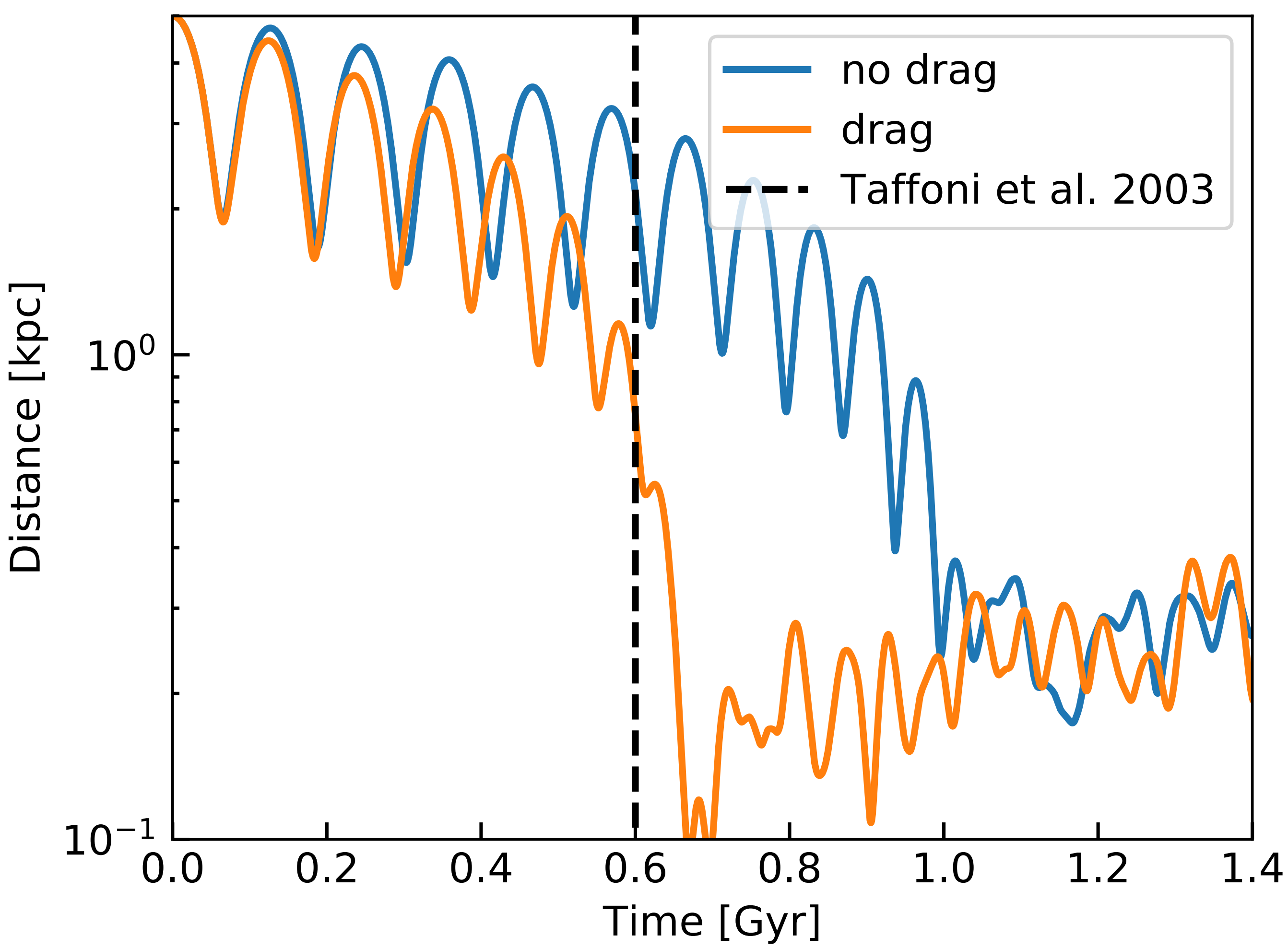




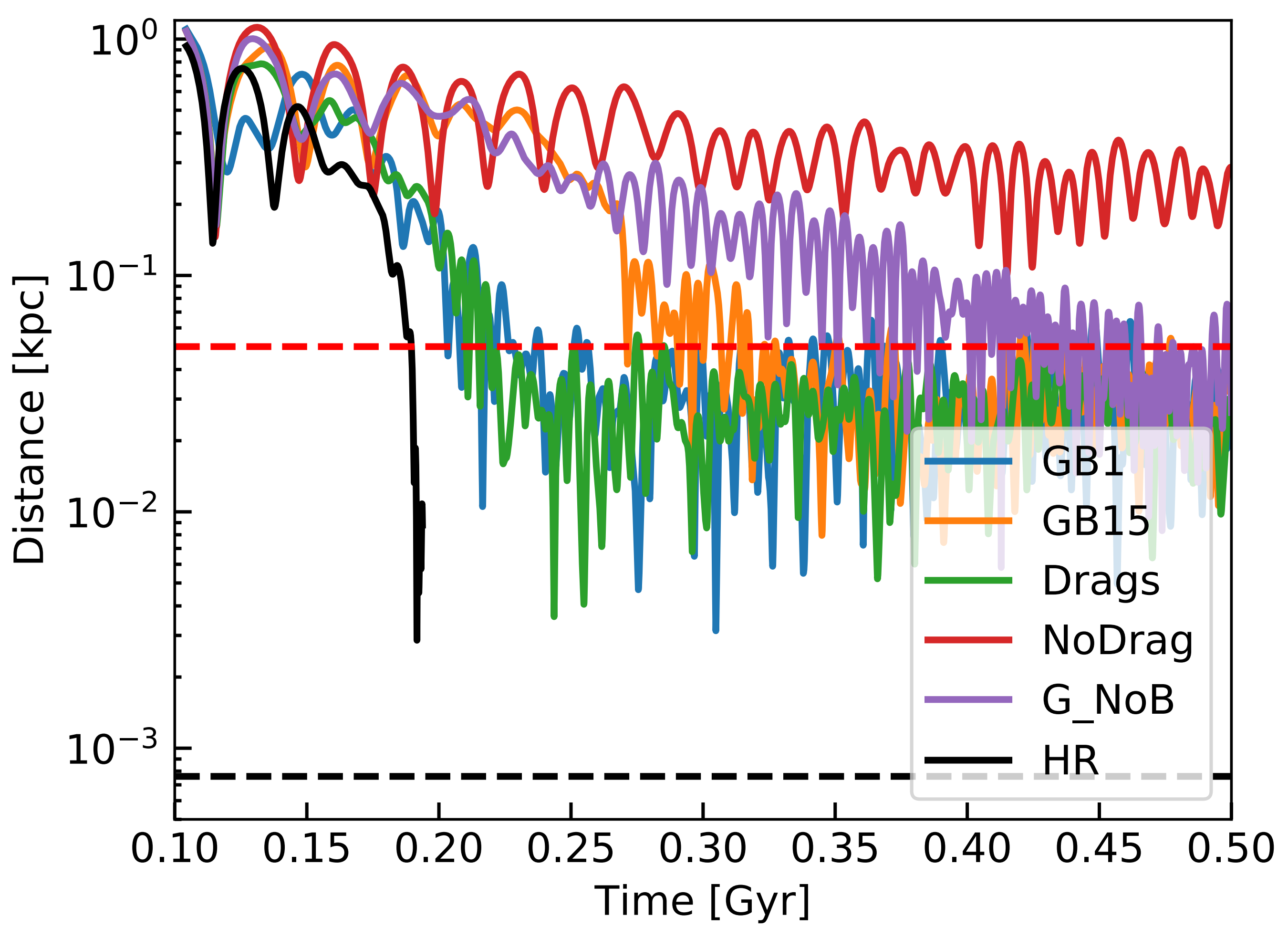
	v	m
ℓ=3	v_(n+1)	v_(n+1)
ℓ=2	v_(n+1)	m_(n+1)
ℓ=1	v_(n+1)	m_(n+1)

Tests

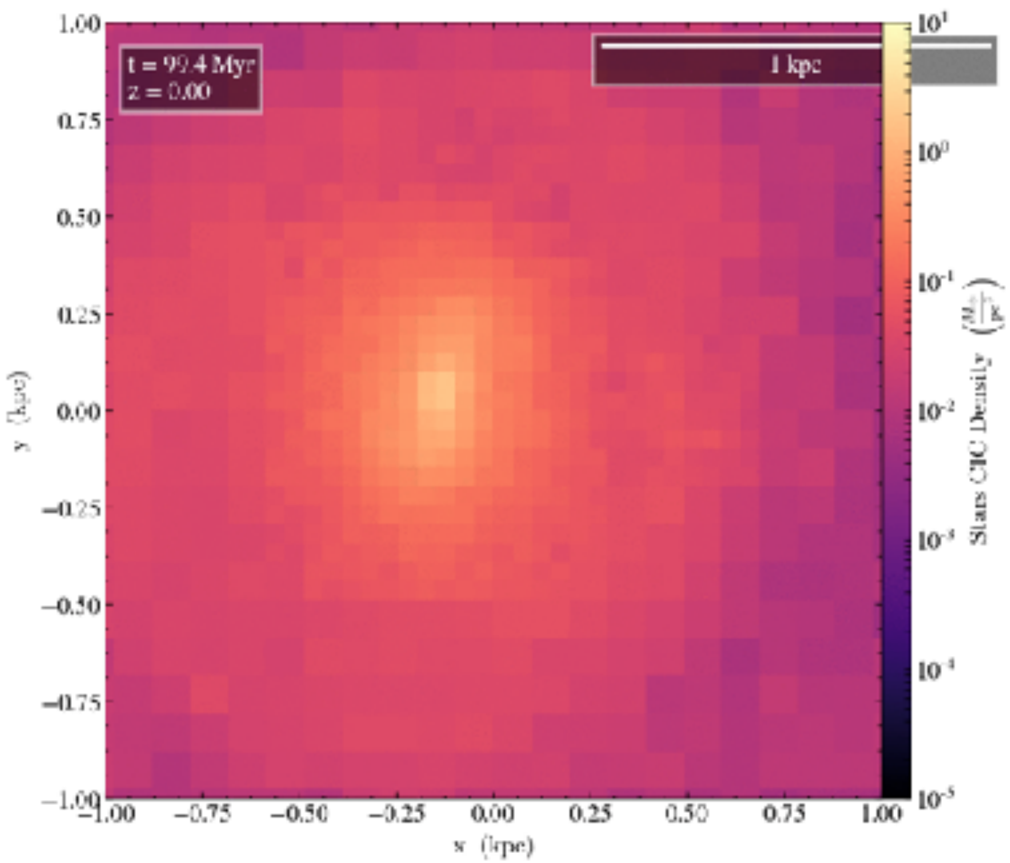
- BH falling in a NFW halo.
- Comparison with theoretical estimates of Taffoni+03.
- Resolution 50 pc > r_{def} ~ 10 pc



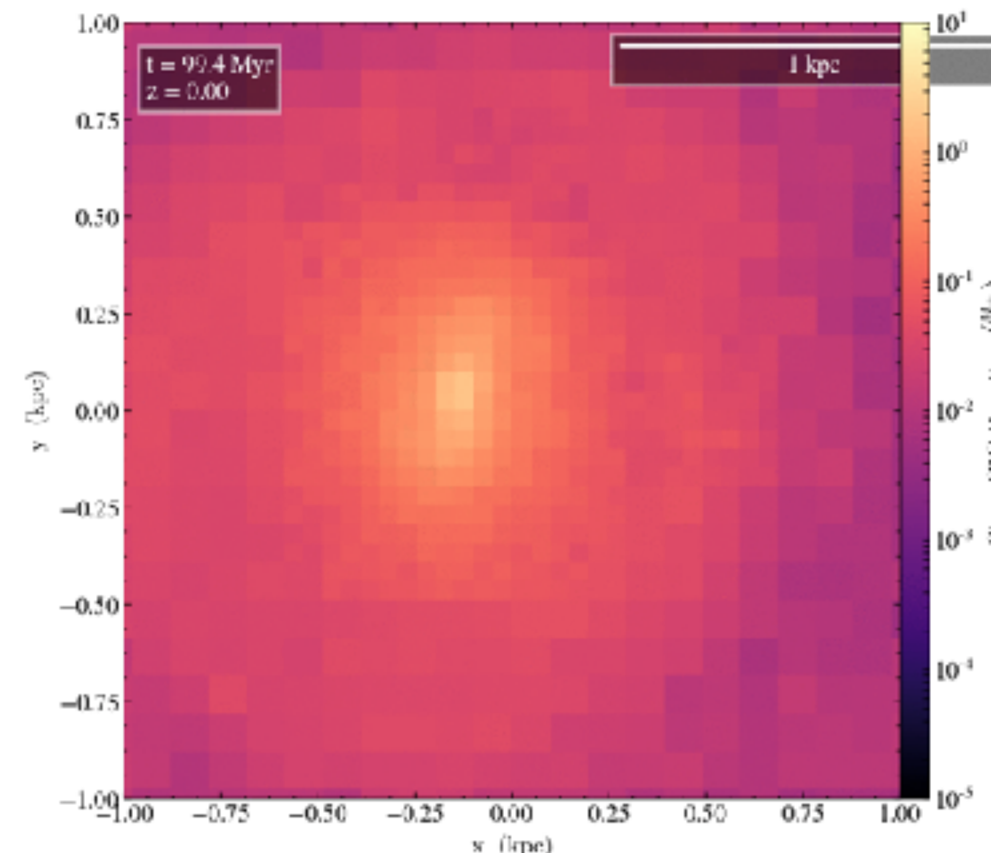
- BH falling in a 'complete' galaxy with DM, stars, gas and many physical processes such as star formation, cooling, feedback etc…
- Comparison with a very high resolution simulation



Tests

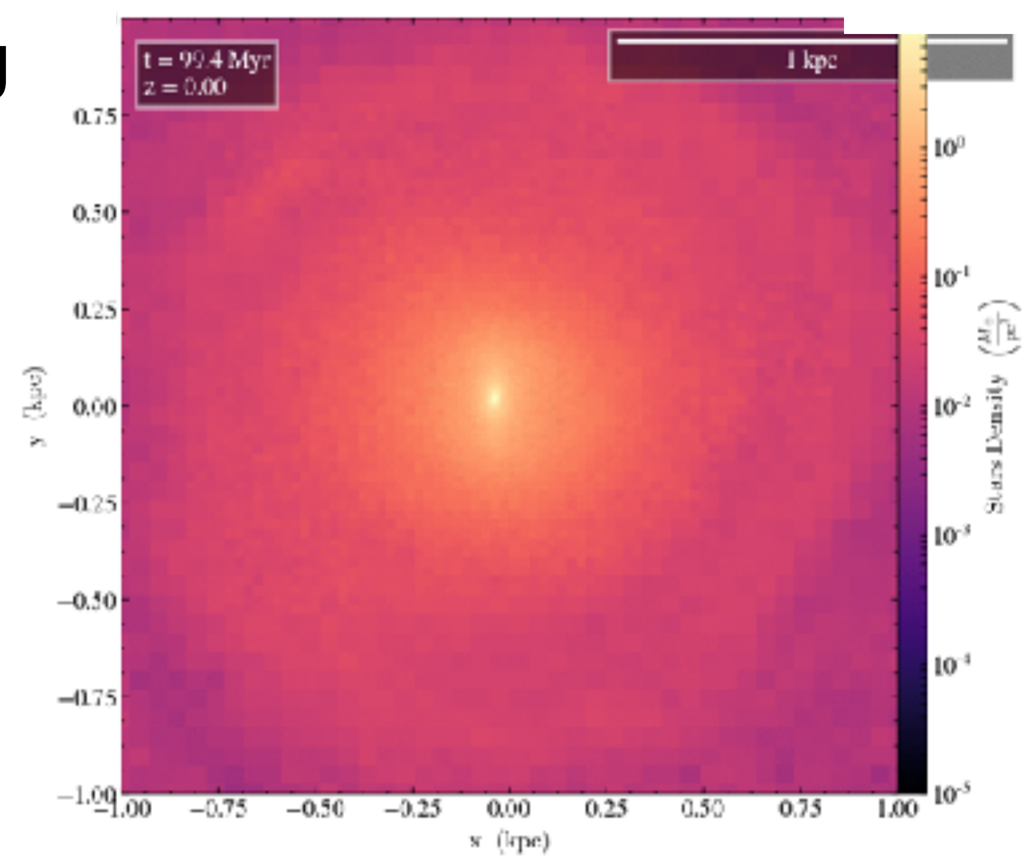


DF unresolved - no drag

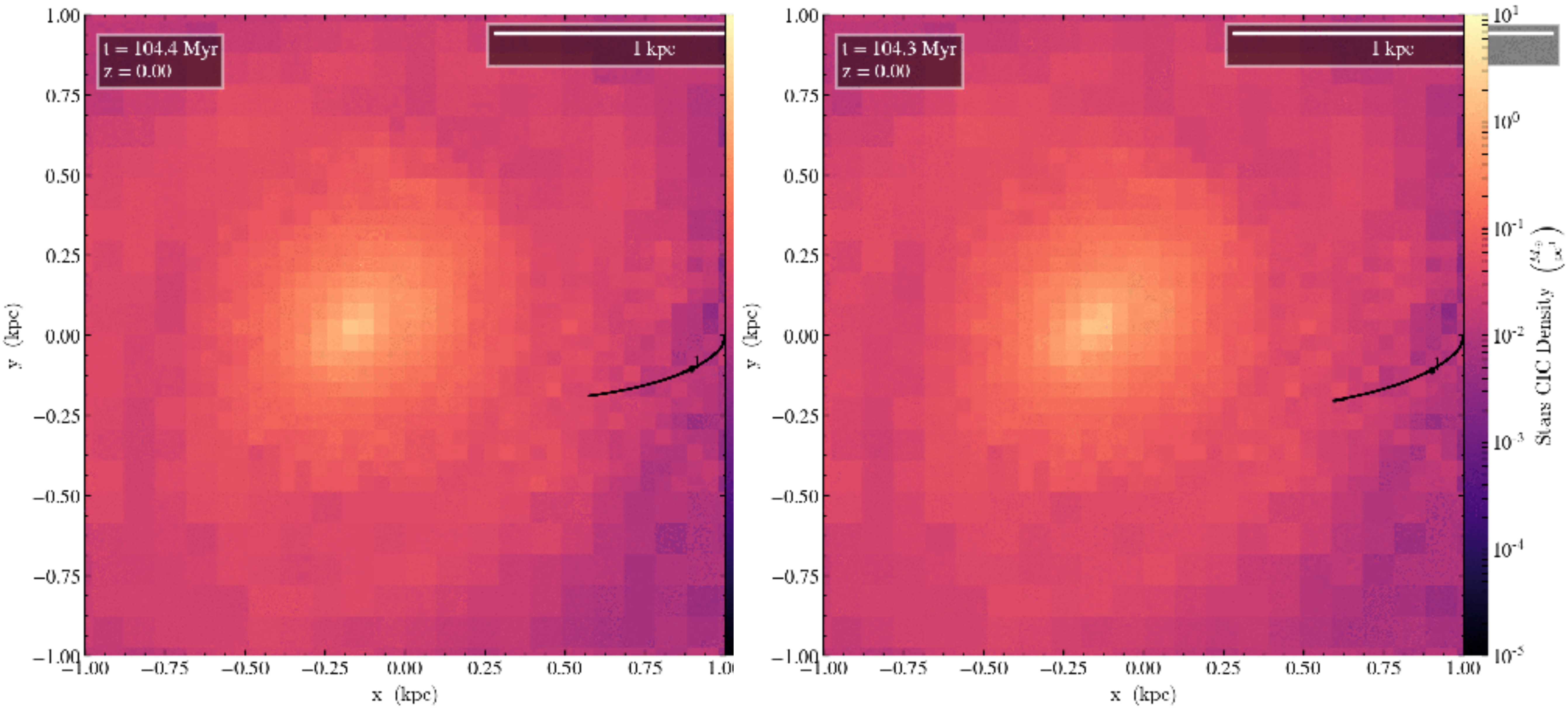


DF unresolved - drag

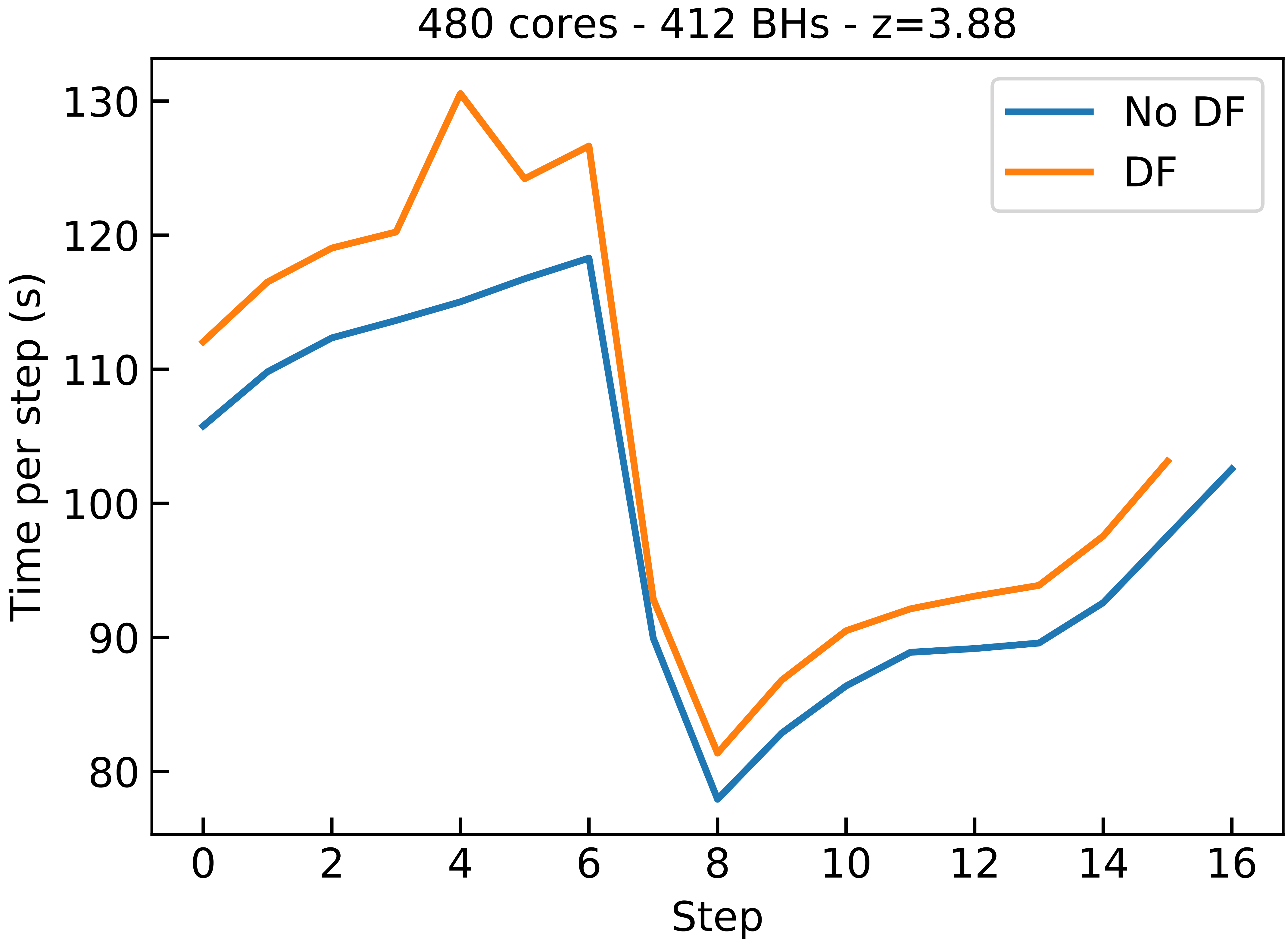
DF resolved



Tests


t = 104.4 Myr
z = 0.00
1 kpc
t = 104.3 Myr
z = 0.00
1 kpc
y (kpc)
x (kpc)
Stars CIC Density

Scaling



480 cores - 412 BHs - z=3.88
No DF
DF
Time per step (s)
130
120
110
100
90
80
0
2
4
6
8
10
12
14
16
Step

Overview

A. The current model of BHs in RAMSES

B. Dynamical friction from particles

C. The lonely life of high redshift black holes

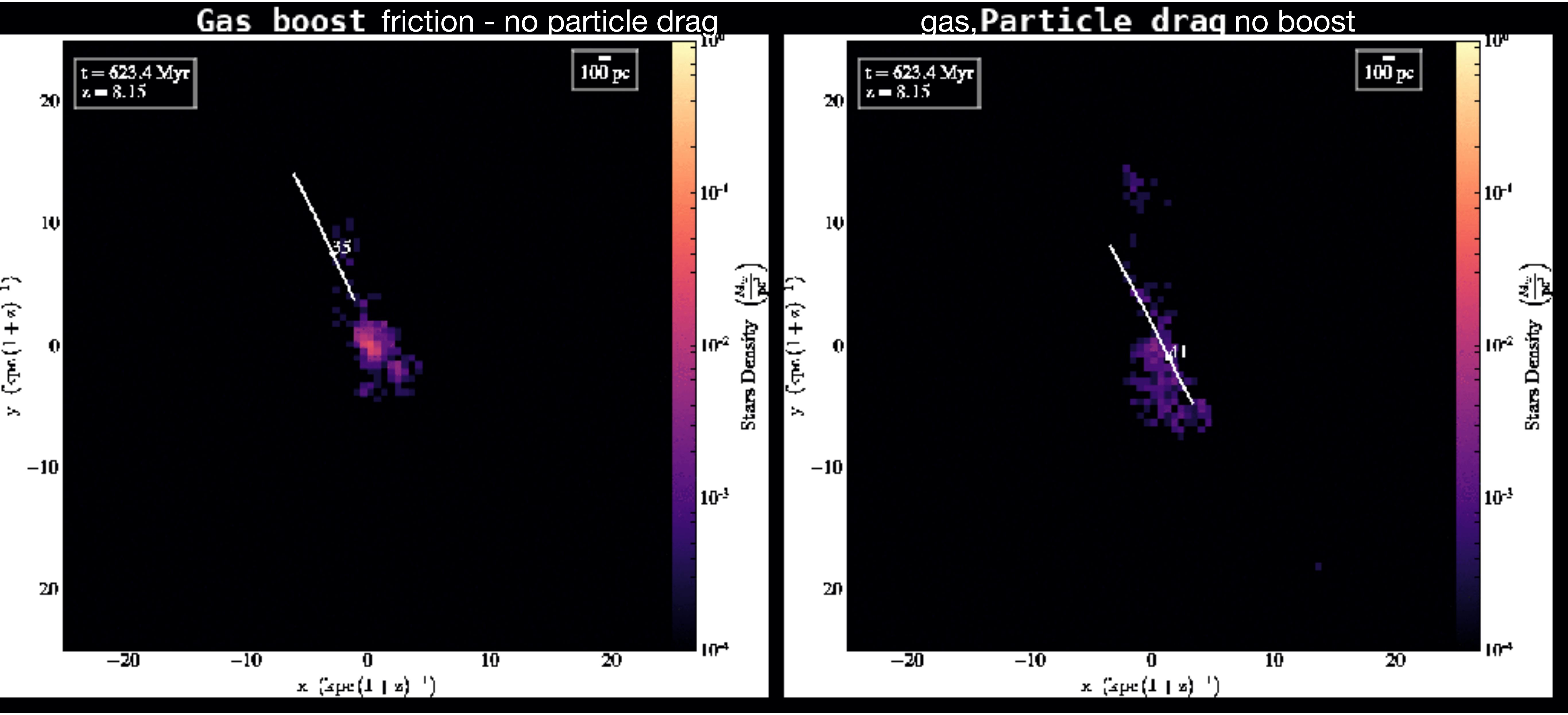
   i. Numerical set-up

   ii. Preliminary results

Numerical set-up

- 1e12 Msun halo at z=1.5
- 70 pc resolution, 1e6 Msun DM particles, 1e4 Msun stellar particles
- Mechanical feedback, Turbulent star formation, cooling
- The seed mass of BHs is 1e4 Msun
- 1 simulation with the gas dynamical friction **boosted**
  1 simulation with the gas, stellar and DM dynamical friction
  others to come and analyse…

Preliminary results



Conclusions

- RAMSES includes a new physically motivated subgrid model for DF from stars and DM.
- The mergers of BHs might take longer than what previous simulations indicate.
- This model is not enough to solve the ‘non growing BHs issue’ (at least for 1e4 Msun seeds).