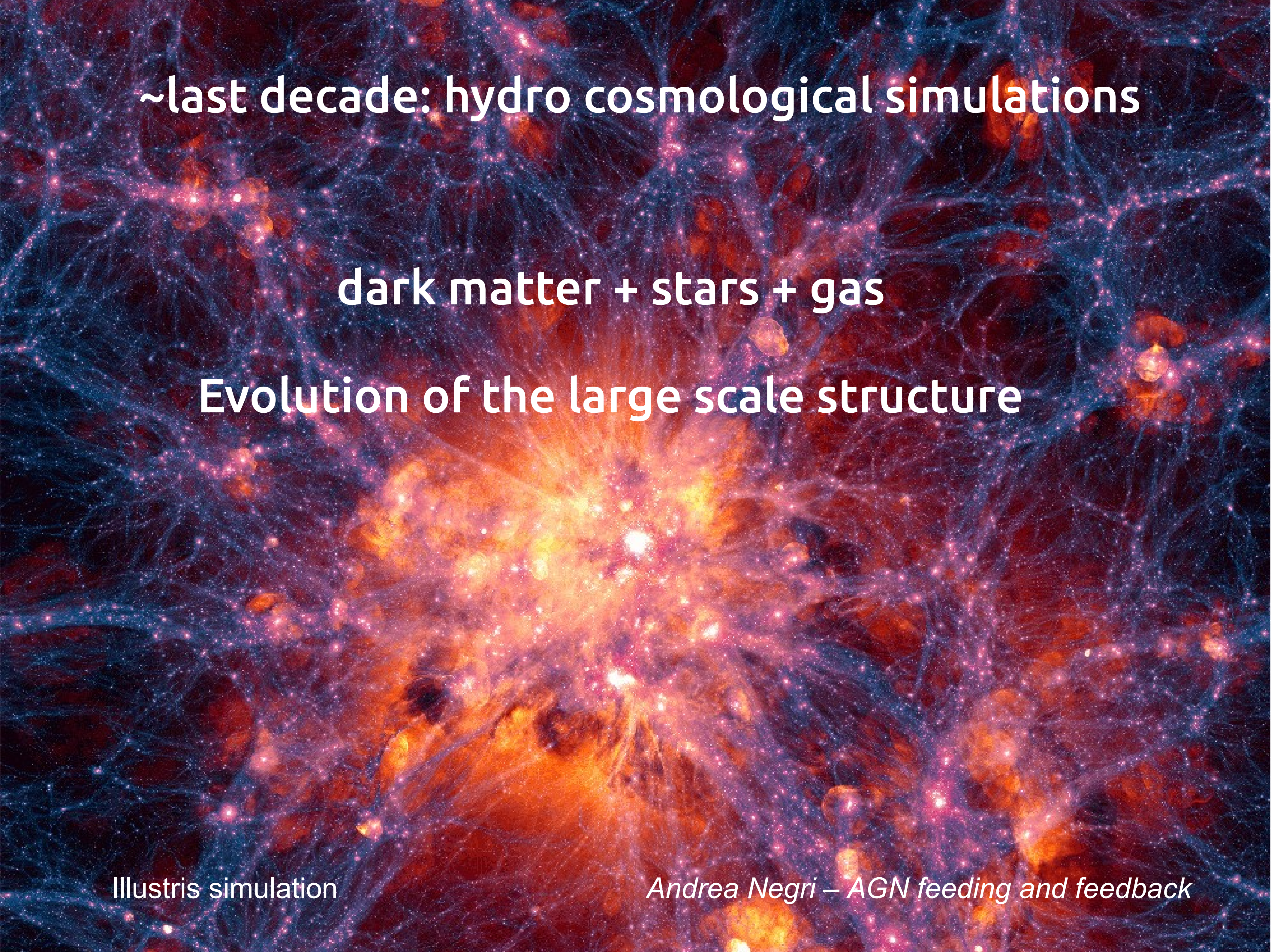
# AGN feeding and feedback: beyond sub-grid physics

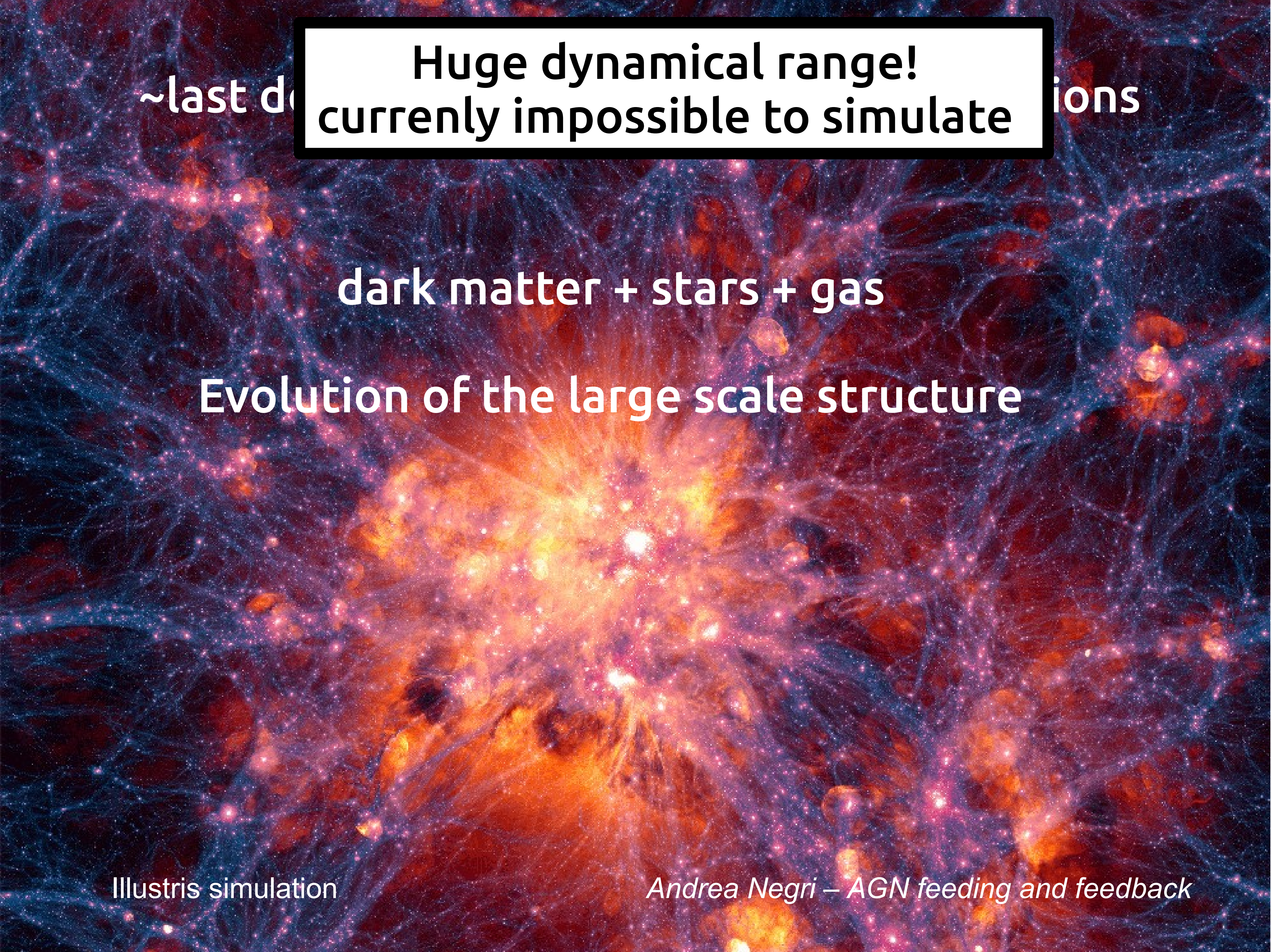
Andrea Negri

In collaboration with Marta Volonteri

Hot spots in the XMM sky: Cosmology from X-ray to Radio
Friday 17 June 2016



Illustris simulation



~last d ions

**Huge dynamical range!**
**currenly impossible to simulate**

dark matter + stars + gas

Evolution of the large scale structure

Illustris simulation

~last d… …ions

**Huge dynamical range!**
**currently impossible to simulate**

Simulations are forced to adopt lower resolution

~ 6 kpc for MassiveBlack at z=0 (Di Matteo+2012)
~ 1 kpc for Horizon-AGN (Dubois+2012)
> 750 pc Illustris (10 pc hydro, Vogelsberger+14)
350 pc EAGLE simulation, z=0 (Schaye+14)

need to resort to subgrid models for BH accretion

Illustris simulation

# Subgrid models for BH accretion

# Subgrid models for BH accretion

**Various models are present in literature, most of them based on Bondi accretion**

$$\dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{c_s^3}$$

formal solution of:

- spherically symmetric accretion problem
- adiabatic, no feedback, no rotation

# Subgrid models for BH accretion

Various models are present in literature, most of them based on **Bondi** accretion

$$\dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{c_s^3}$$

formal solution of:

- spherically symmetric accretion problem
- adiabatic, no feedback, no rotation

In simulations we have:

- non spherical accretion
- multiphase gas
- rotation

# How accretion is implemented

$$\dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{c_s^3}$$

$\rho$ and $c_s$ are calculated using information on the surrounding gas, plenty of ways (every code/author)

- Volume weighted (GADGET, Booth+09, Vogelsberger+13)
- Mass weighted (Dubois+12)
- ISM subgrid model (hot/cold phase, Pelupessy+07)
- Global mass w. averages from all the cells (Choi+2012)
- Direct accretion of hot and cold gas when hydro is more resolved than gravity (Steinborn+15)

Sometimes it is not even mentioned!

# How accretion is implemented

$$\dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{c_s^3}$$

$\alpha$ (~100-300) is a **boost factor**, depends on resolution and sub-grid models of ISM

- Constant (Springle+05, Dubois+12, Curtis+15)
- Depends on ISM density (Booth+09, Steinborn+15)
- Depends on feedback (Vogelsberger+13)
- Sometimes not used (Pelupessy+07, Choi+12)
- Sometimes is not even mentioned!

# How accretion is implemented

$$\dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{c_s^3}$$

$\alpha$ (~100-300) is a **boost factor**, depends on

Philosophy behind $\alpha$:

Low resolution: ISM cold phase not resolved

Bondi radius not resolved

- $\rho$ underestimated
- $c_s$ overestimated

BH accretion rate underestimated

# Past attemps to compare few schemes with simulation employing Bondi accretion (again?!)

**see Wurster+13, Elahi+16**

# A simple idea

**Comparison with**

Sims with same setup but with Bondi accretion:
- Different schemes of weighting
- Different resolution

# A simple idea

Simulations of an isolated galaxy:

- High resolution ~ 0.1 pc (cold and hot phase)
- Well resolved Bondi radius for all the T
- No parametrized accretion

**Comparison with**

Sims with same setup but with Bondi accretion:

- Different schemes of weighting
- Different resolution

# Simulations in a nutshell

Code: ZEUSMP (modified in Novak et al. 2011)

- 2D axisymmetric
- $M_{BH} = 3 \times 10^7 M_\odot$
- $R_{bondi}$ = 0.1 pc at T=$10^8$ K
- r from 0.1 pc to 250 kpc

- Mechanical Feedback from broad absorption line (BAL) winds
- Radiative feedback
- Compton heating/cooling
- Radiative cooling

# Simulations in a nutshell

Code: ZEUSMP (modified in Novak et al. 2011)

- 2D axisymmetric

T=$10^8$ K

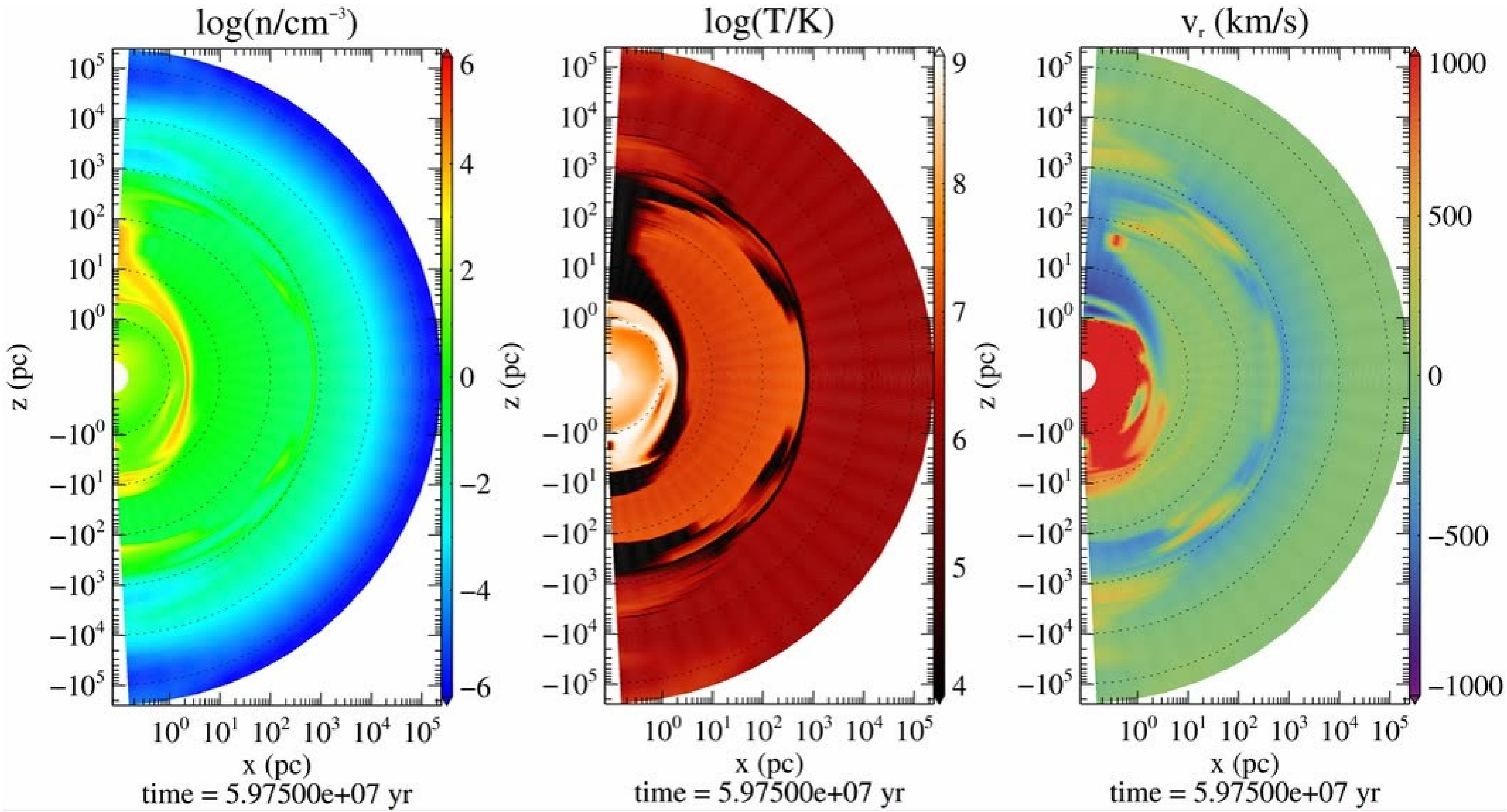
- r from 0.1 pc to 250 kpc

- Mechanical Feedback from broad absorption line (BAL)

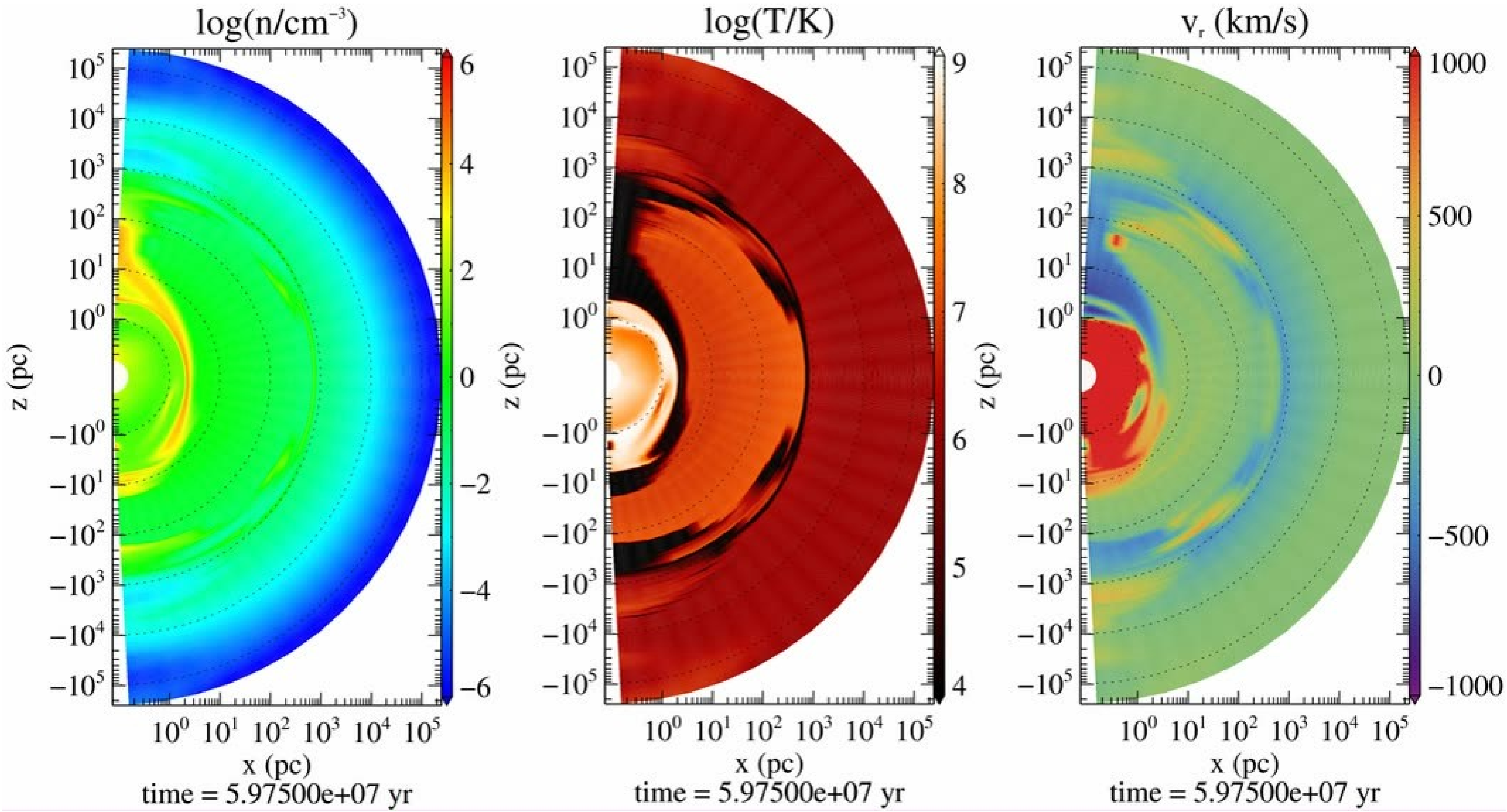
- Compton heating/cooling

- Radiative cooling

**fiducial model:**
**BH accretion is flux on the innermost radial grid**

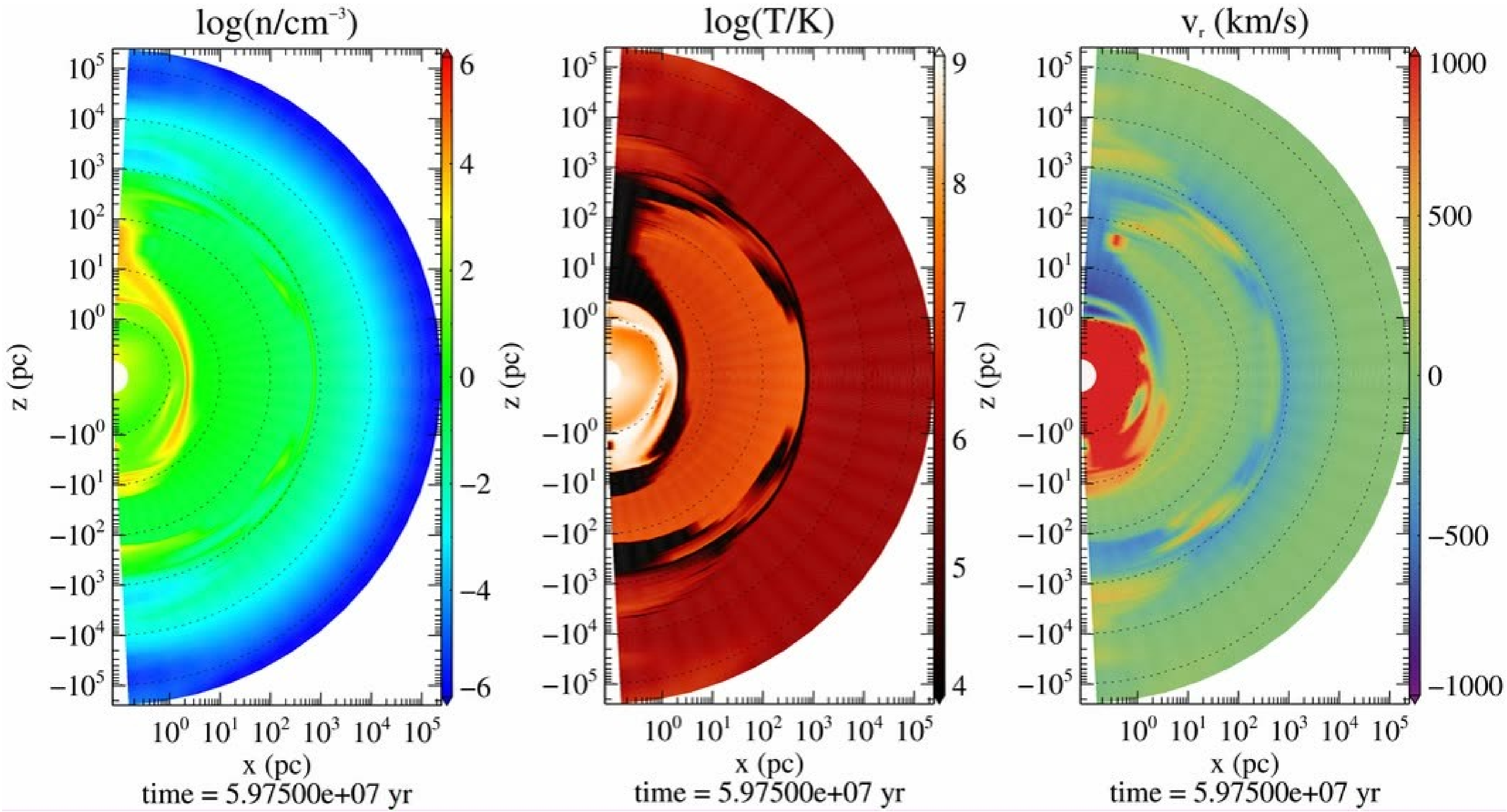



# cooling – accretion – feedback – hot bubble cycle




# cooling – accretion – feedback – hot bubble cycle

## CHAOTIC ACCRETION

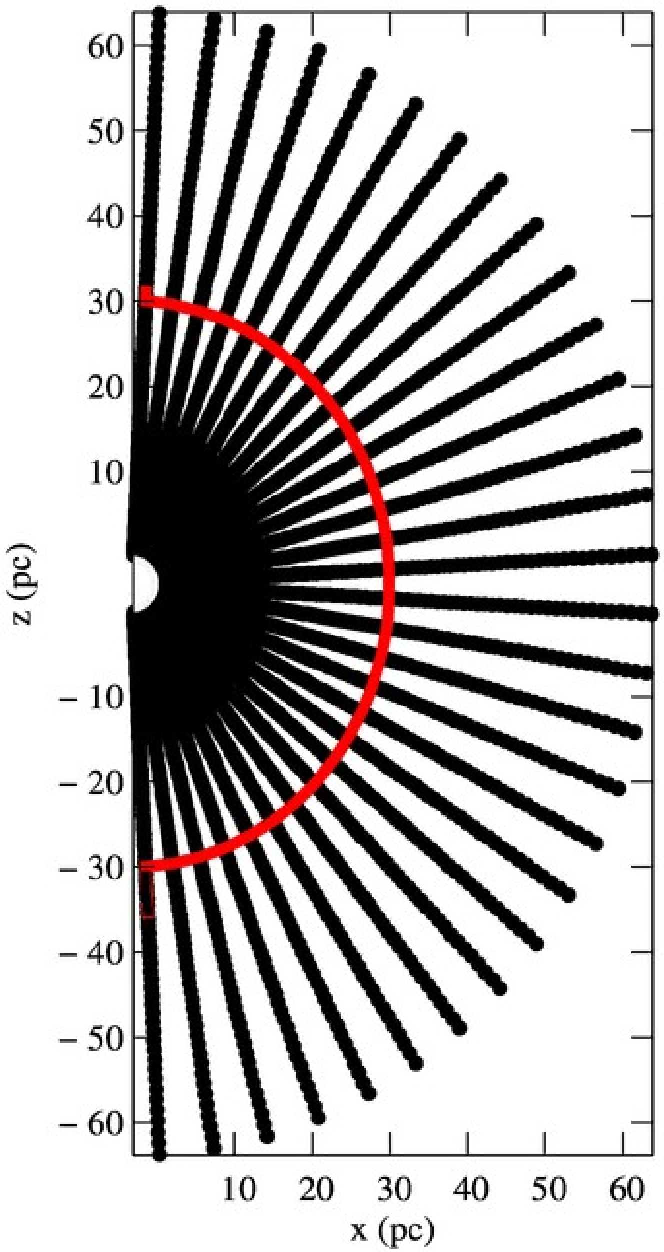



cooling – accretion – feedback – hot bubble cycle

CHAOTIC ACCRETION

Feedback self-limits accretion to sub-Eddington values

# What happens with Bondi?




*Computational grid*

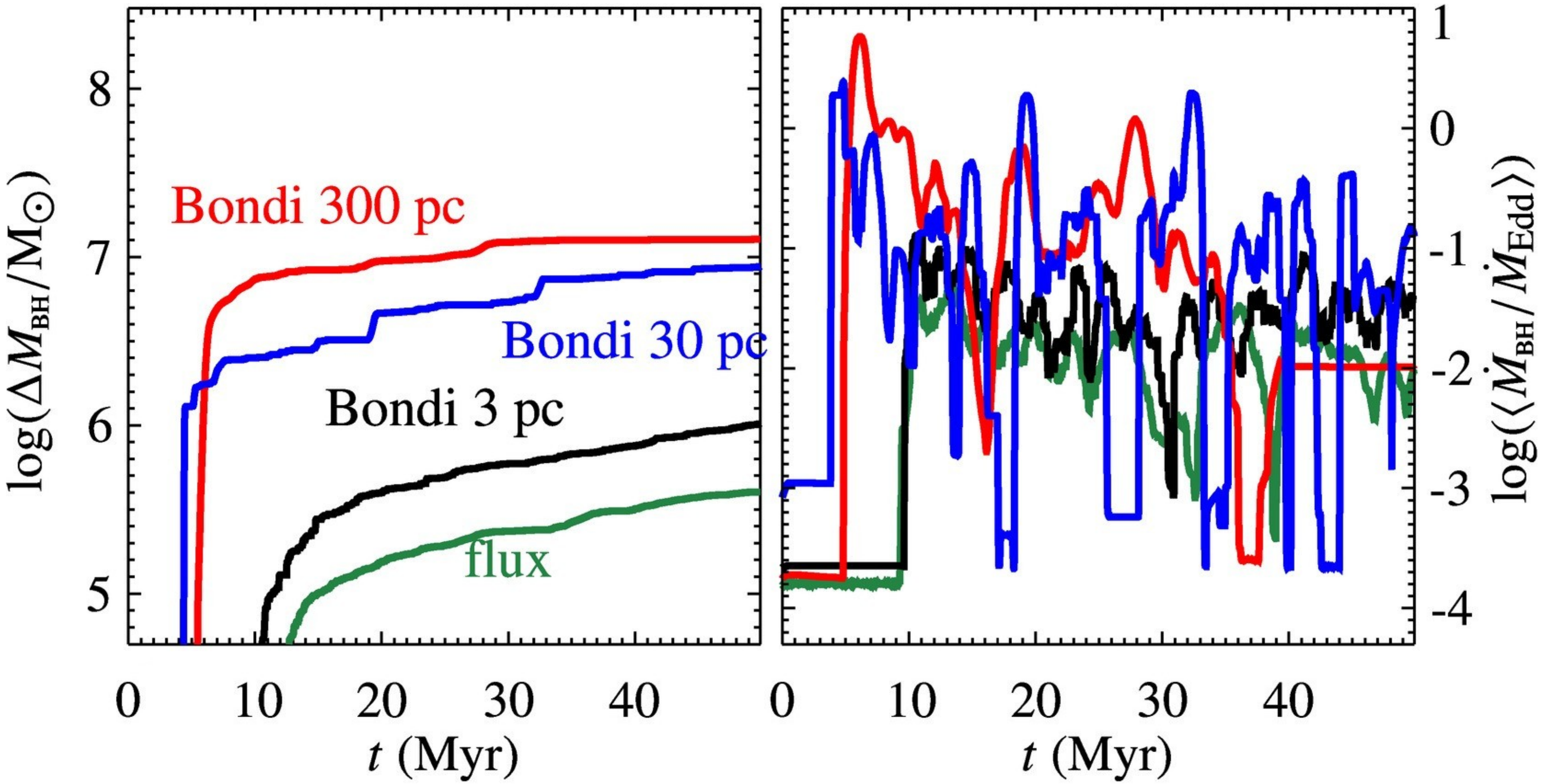
1) We keep the same grid
2) Define accretion radius $r_{acc}$
3) Calculate $\rho$ and $c_s$ as mass weighted inside $r_{acc}$
4) no boost factor

# Bondi high resolution mass weighted

Explored $r_{acc}$ = 3, 30, 300 pc

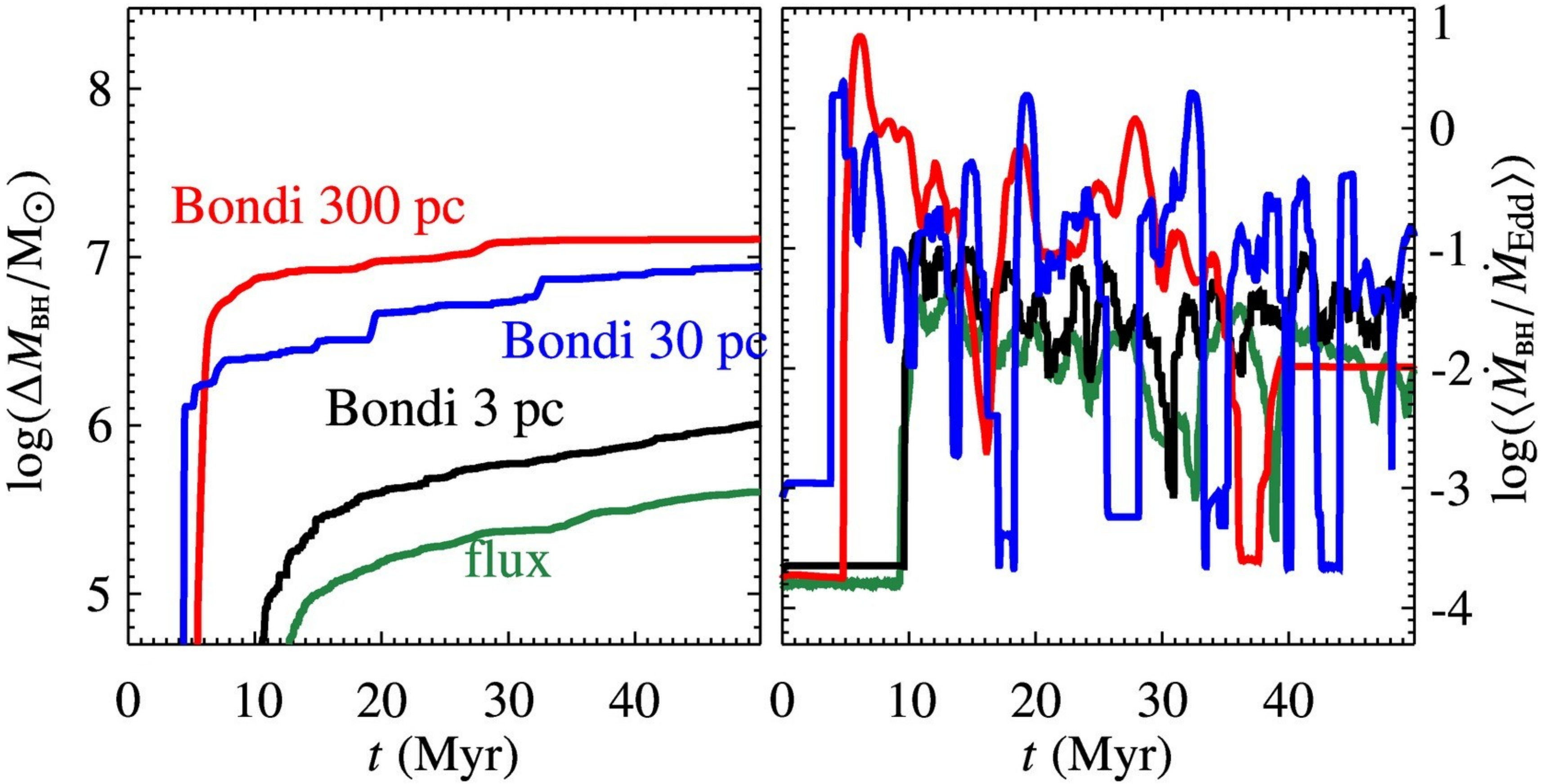
# Bondi high resolution
# mass weighted

## Explored $r_{acc}$ = 3, 30, 300 pc



# Bondi high resolution mass weighted

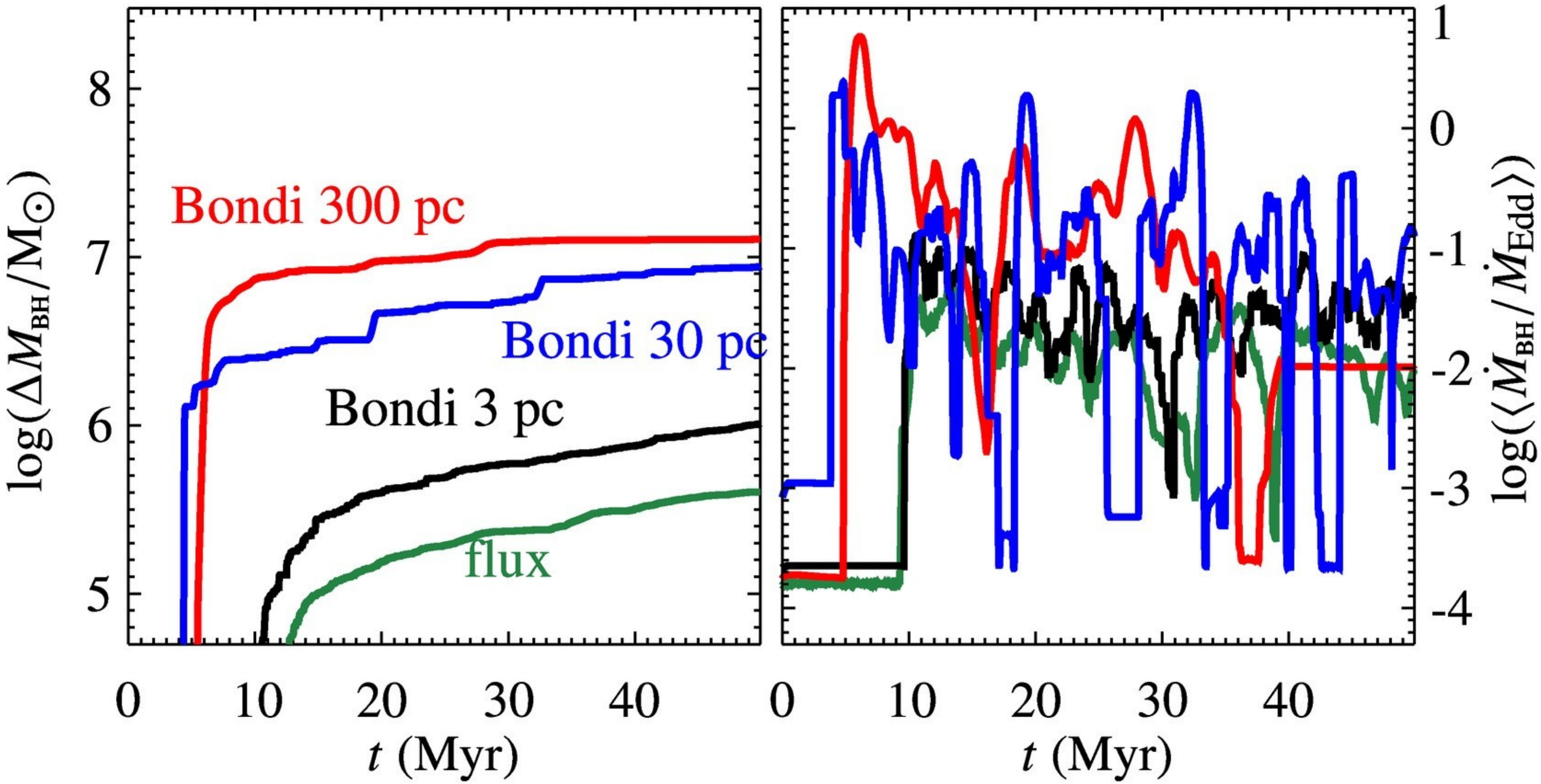
## Explored $r_{acc}$ = 3, 30, 300 pc




**Trend:** **the larger $r_{acc}$ the larger $\Delta M_{BH}$!**

# Bondi high resolution mass weighted

## Explored $r_{acc}$ = 3, 30, 300 pc




**Trend: the larger $r_{acc}$ the larger $\Delta M_{BH}$!**

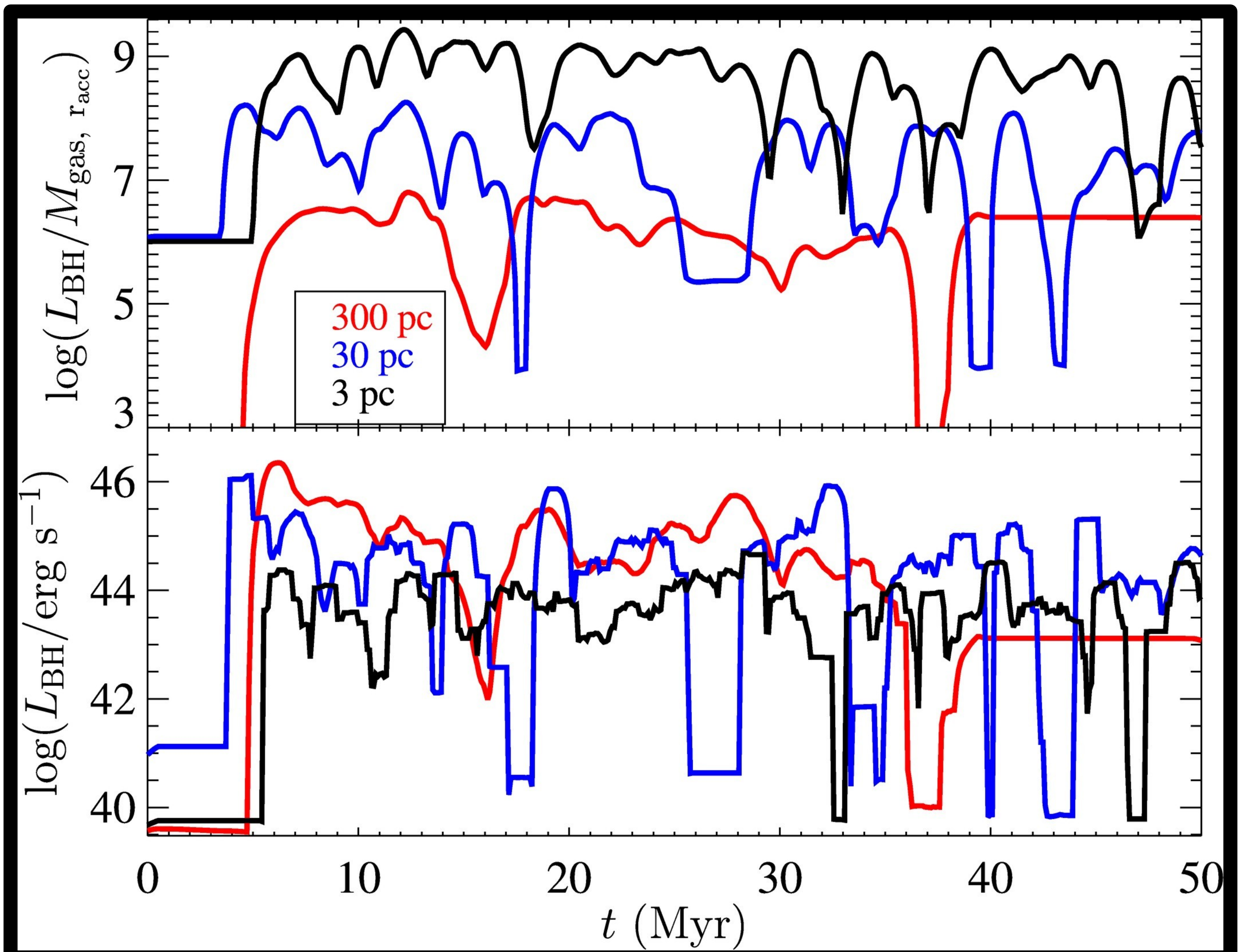
**I was expecting the opposite! Why?**

# Bondi high resolution

Sims with large $r_{acc}$ there is a **stronger feedback** but a **larger gas** mass to heat/sweep away to stop the accretion

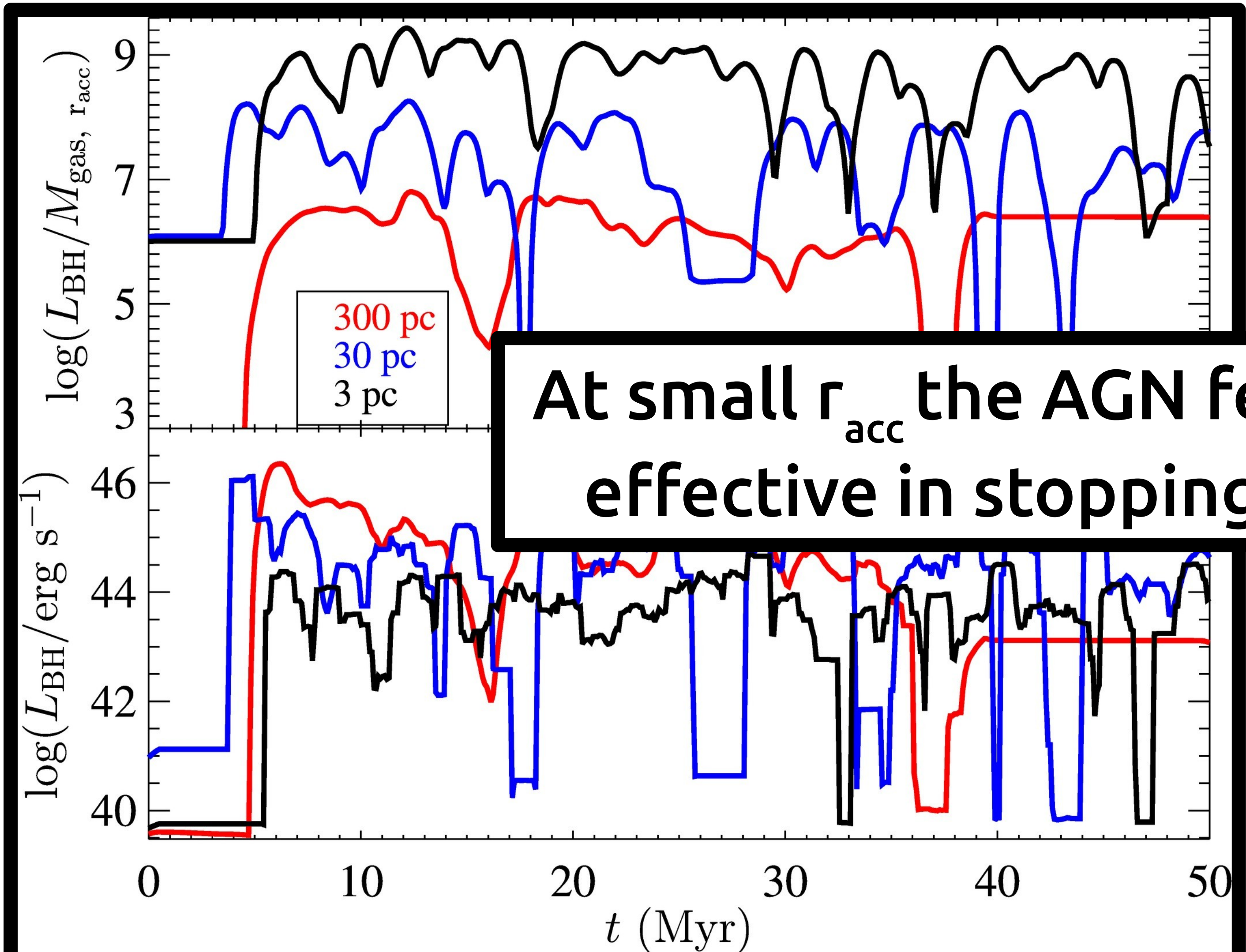
# Bondi high resolution

Sims with large $r_{acc}$ there is a **stronger feedback** but a **larger gas** mass to heat/sweep away to stop the accretion



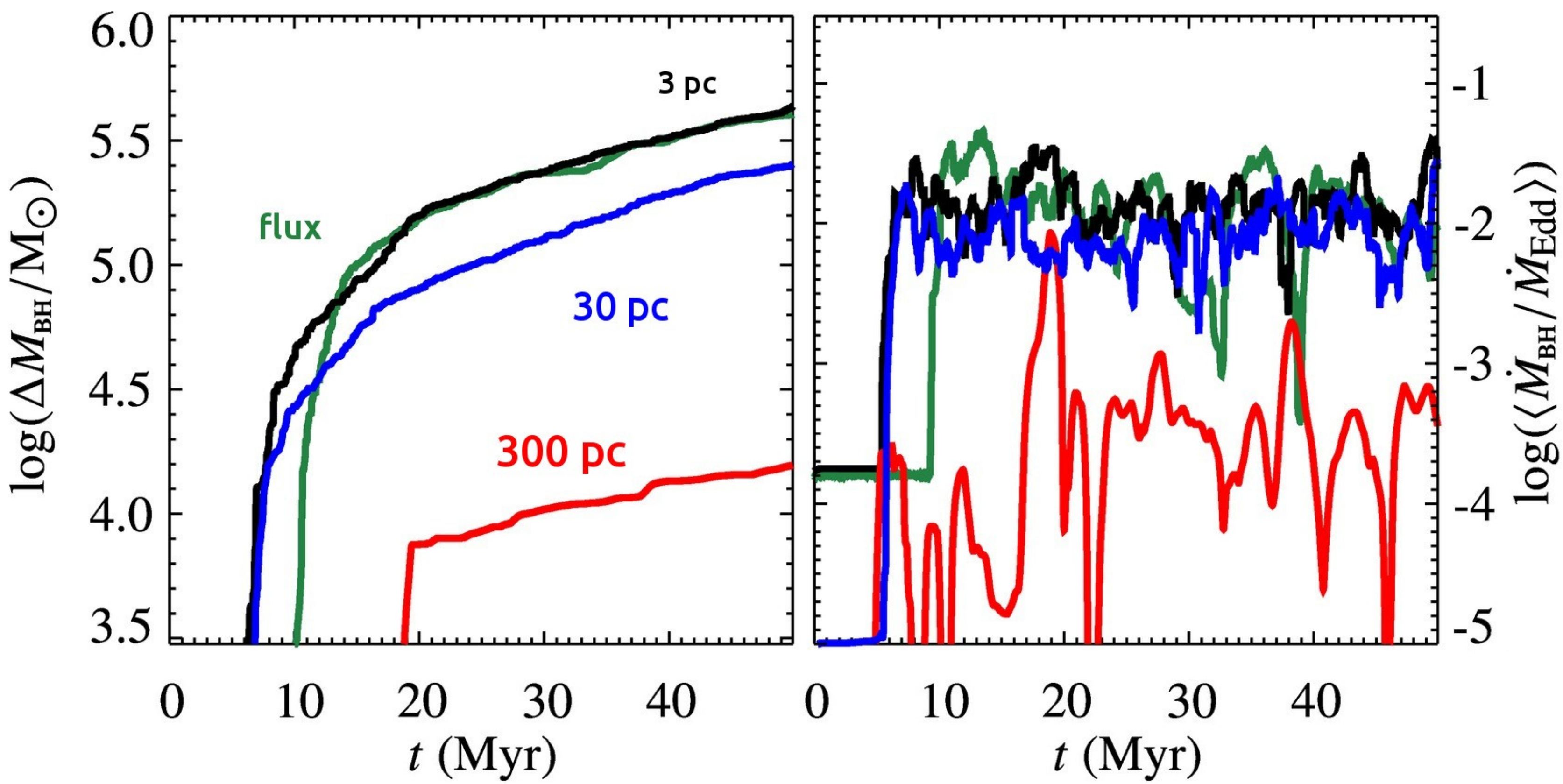
# Bondi high resolution

Sims with large $r_{acc}$ there is a **stronger feedback** but a **larger gas** mass to heat/sweep away to stop the accretion




At small $r_{acc}$ the AGN feedback is more effective in stopping the accretion

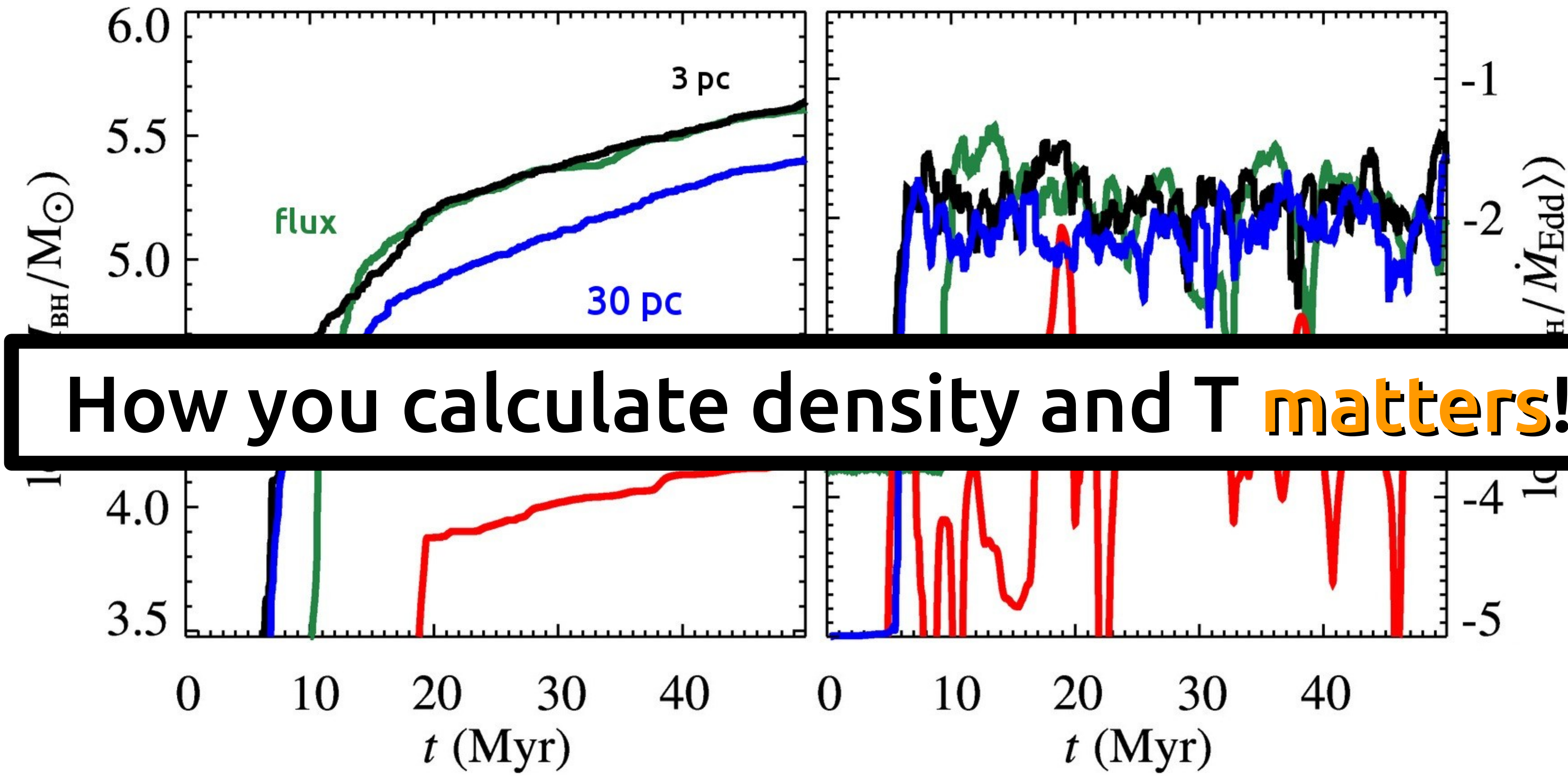
# Bondi high resolution volume weighted




**Opposite situation!**
**In this case the accretion is dominated by hot mode**

*Andrea Negri – AGN feeding and feedback*

# Bondi high resolution volume weighted

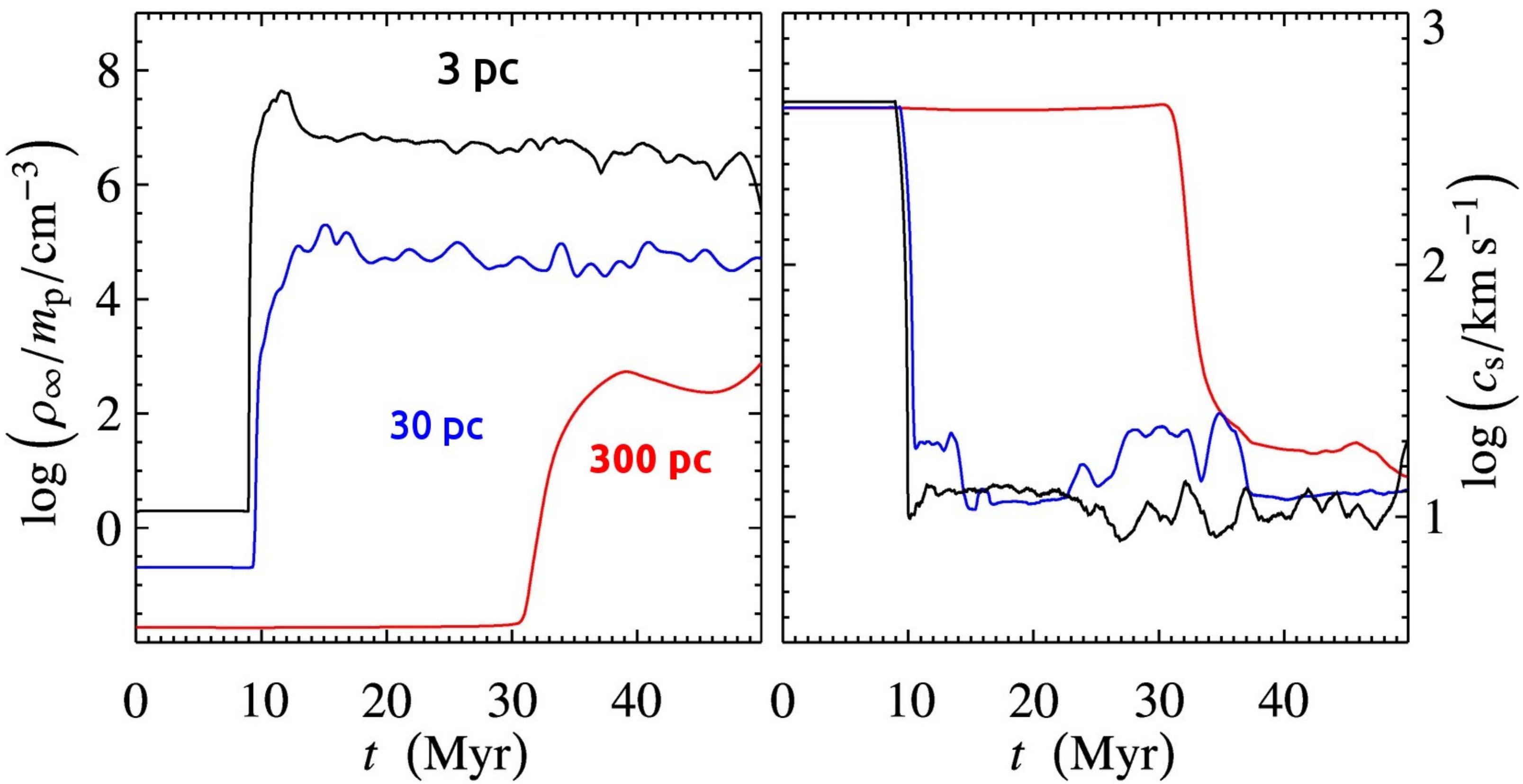



**How you calculate density and T matters!**

Opposite situation!
In this case the accretion is dominated by hot mode

# Bondi low resolution mass weighted
# NO AGN

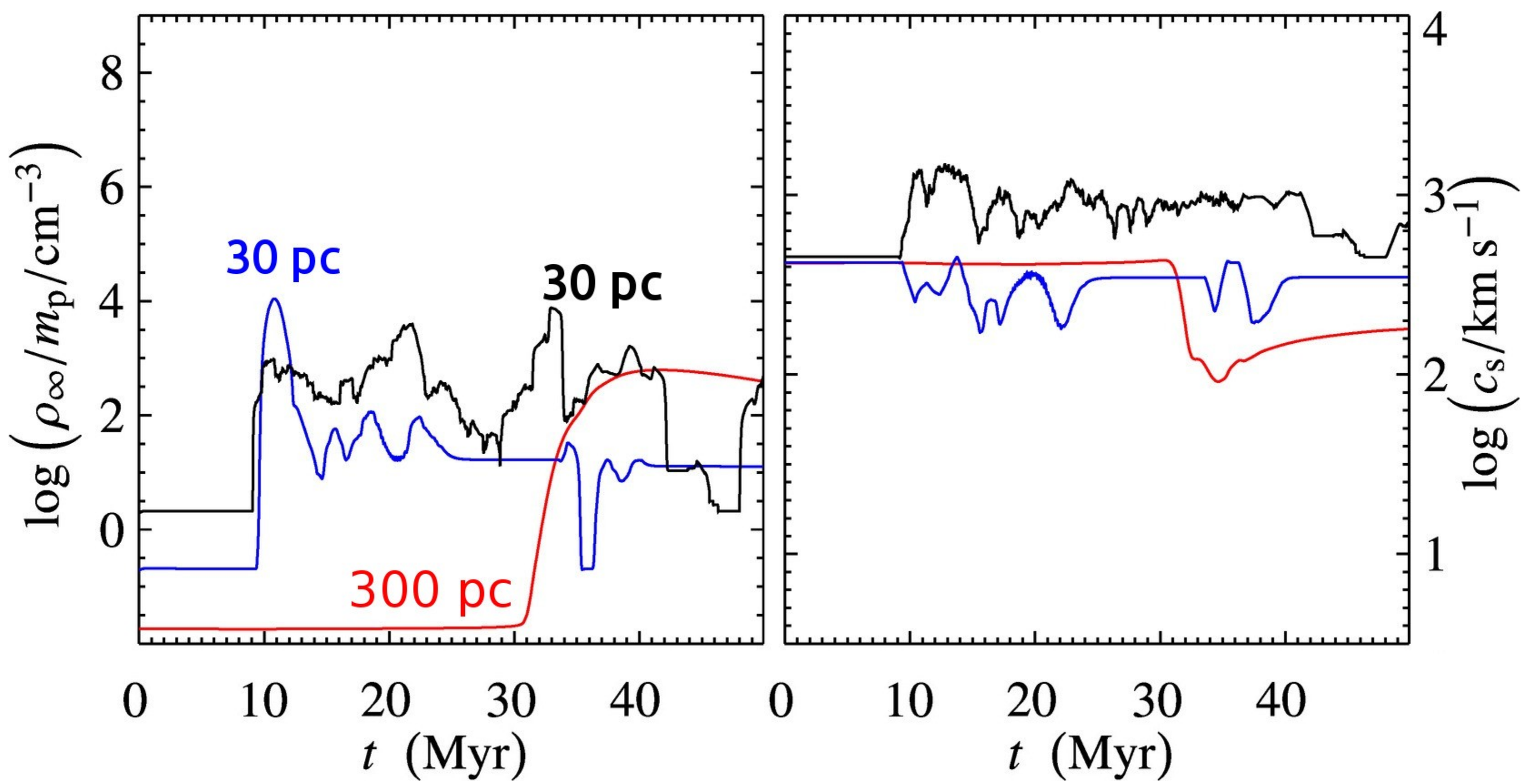
## The central resolution is 3, 30 and 300 pc




## The expected trend is recovered in absence of AGN feedback

# Bondi low resolution mass weighted full feedback

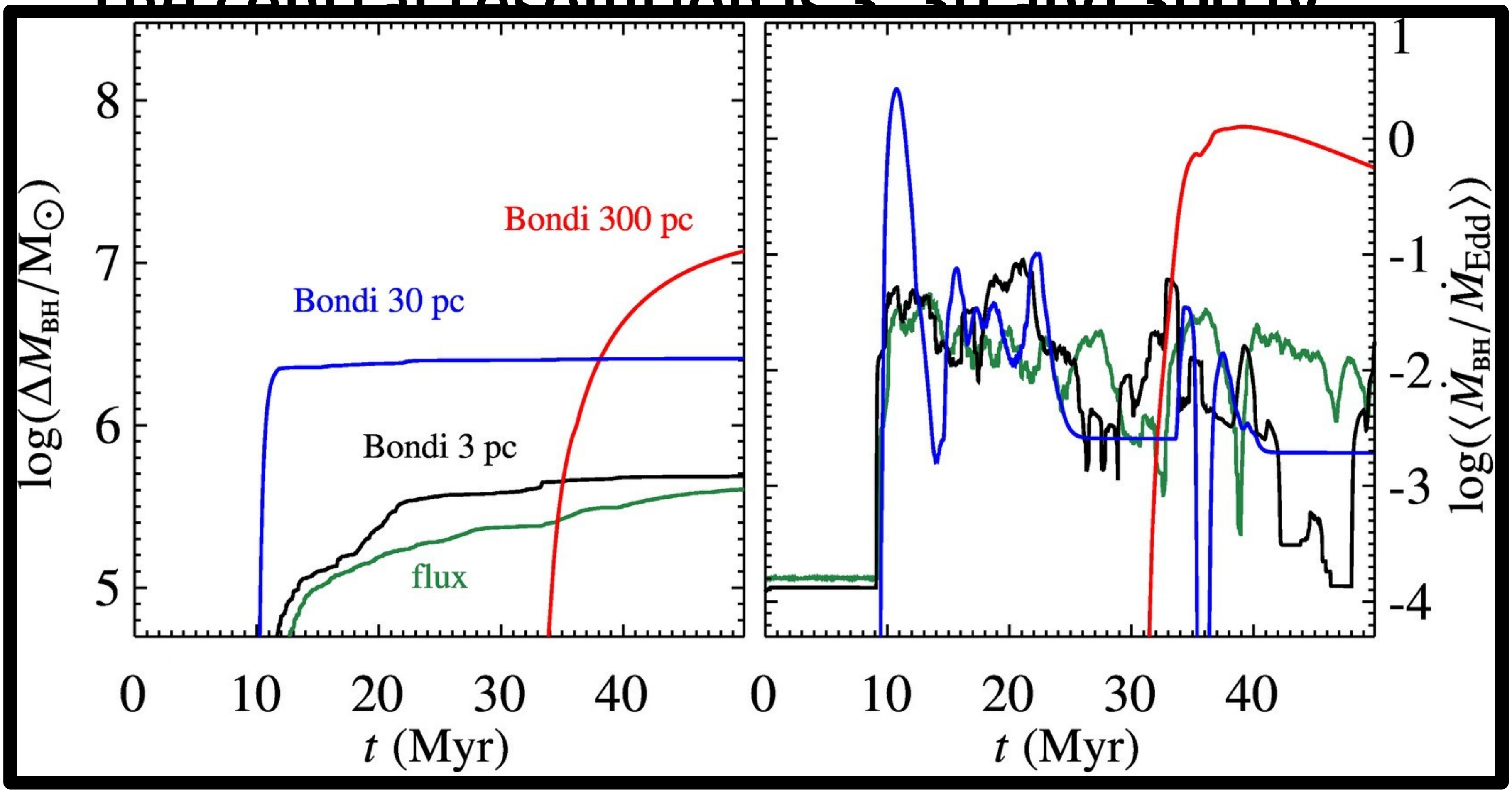
## The central resolution is 3, 30 and 300 pc




## Same trend as in the high resolution runs

# Bondi low resolution mass weighted full feedback

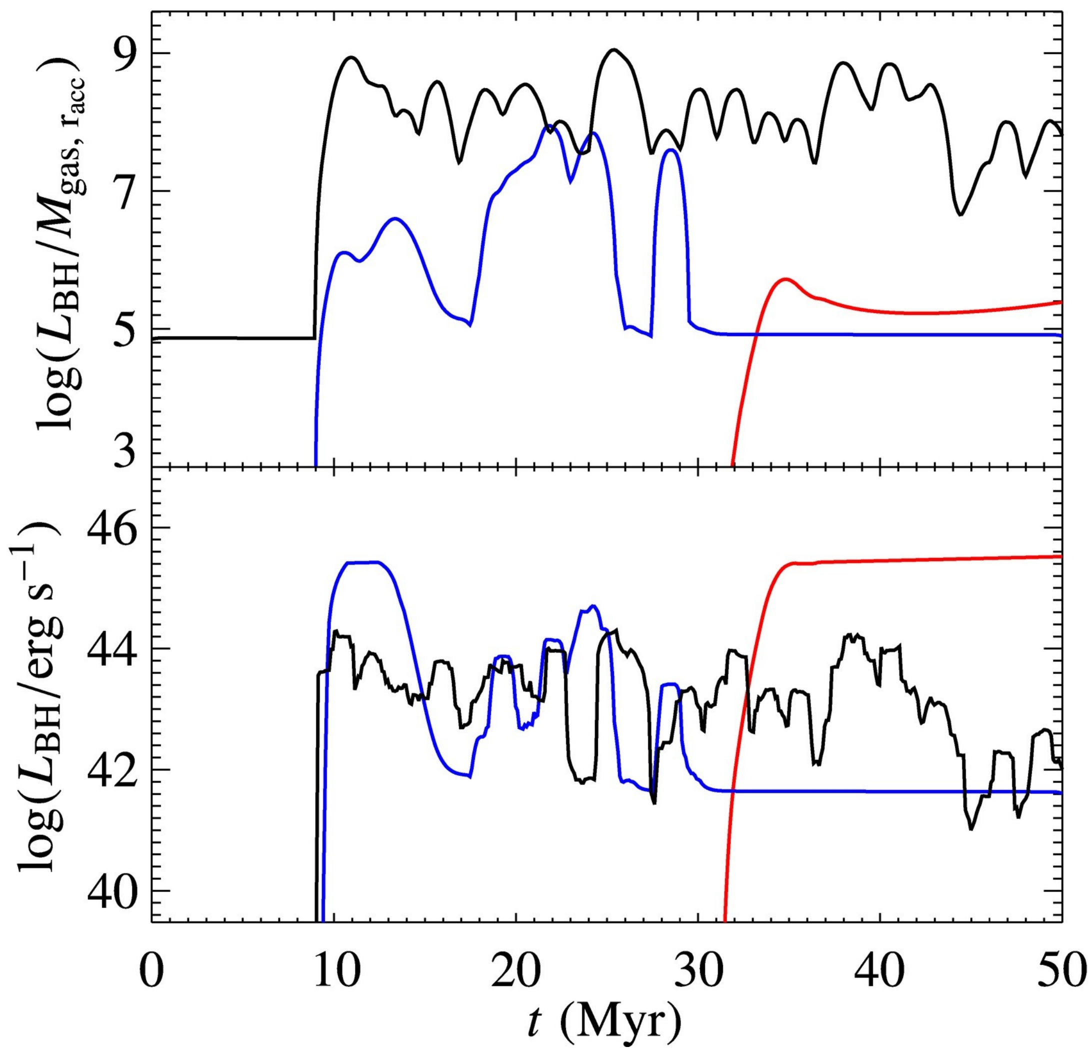
The central resolution is 3, 30 and 300 pc




Same trend as in the high resolution runs

# Bondi low resolution mass weighted

## Again, at low resolution the AGN feedback is less efficient



# Take home points

- Force people to write EVERYTHING on papers

- The adopted method used to calculate the Bondi accretion rate is relevant

- The common assumption of low resolution = low accretion is not verified in presence of feedback

- Efficency of (mechanical) feedback in stopping accretion is low at low resolution

# THANKS!

# THANKS!