SPH Simulations of Spherical Bondi Accretion: First Step of Implementing AGN Feedback in Galaxy Formation

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Abstract

Our motivation is to numerically test the assumption of Black Hole (BH) accretion (that the central massive BH of a galaxy accretes mass at the Bondi-Hoyle accretion rate, with ad-hoc choice of parameters), made in many previous galaxy formation studies including AGN feedback. We perform simulations of a spherical distribution of gas, within the radius range 0.1 - 200 pc, accreting onto a central supermassive BH (the Bondi problem), using the 3D Smoothed Particle Hydrodynamics code Gadget. In our simulations we study the radial distribution of various gas properties (density, velocity, temperature, Mach number). We compute the central mass inflow rate at the inner boundary (0.1 pc), and investigate how different gas properties (initial density and velocity profiles) and computational parameters (simulation outer boundary, particle number) affect the central inflow. Radiative processes (namely heating by a central X-ray corona and gas cooling) have been included in our simulations. We study the thermal history of accreting gas, and identify the contribution of radiative and adiabatic terms in shaping the gas properties. We find that the current implementation of artificial viscosity in the Gadget code causes unwanted extra heating near the inner radius.

Introduction

- Accretion of matter onto Supermassive Black Hole (SMBH)s, existing at the centers of active galaxies, and the resulting energy/momentum feedback from them influences properties (e.g., star formation) of the host galaxy and the large-scale IGM
- Large dynamic range of length scales
  - BH accretion --- sub-pc
  - Galaxy physics --- kpc

➢ <u>Computational Challenges :</u>

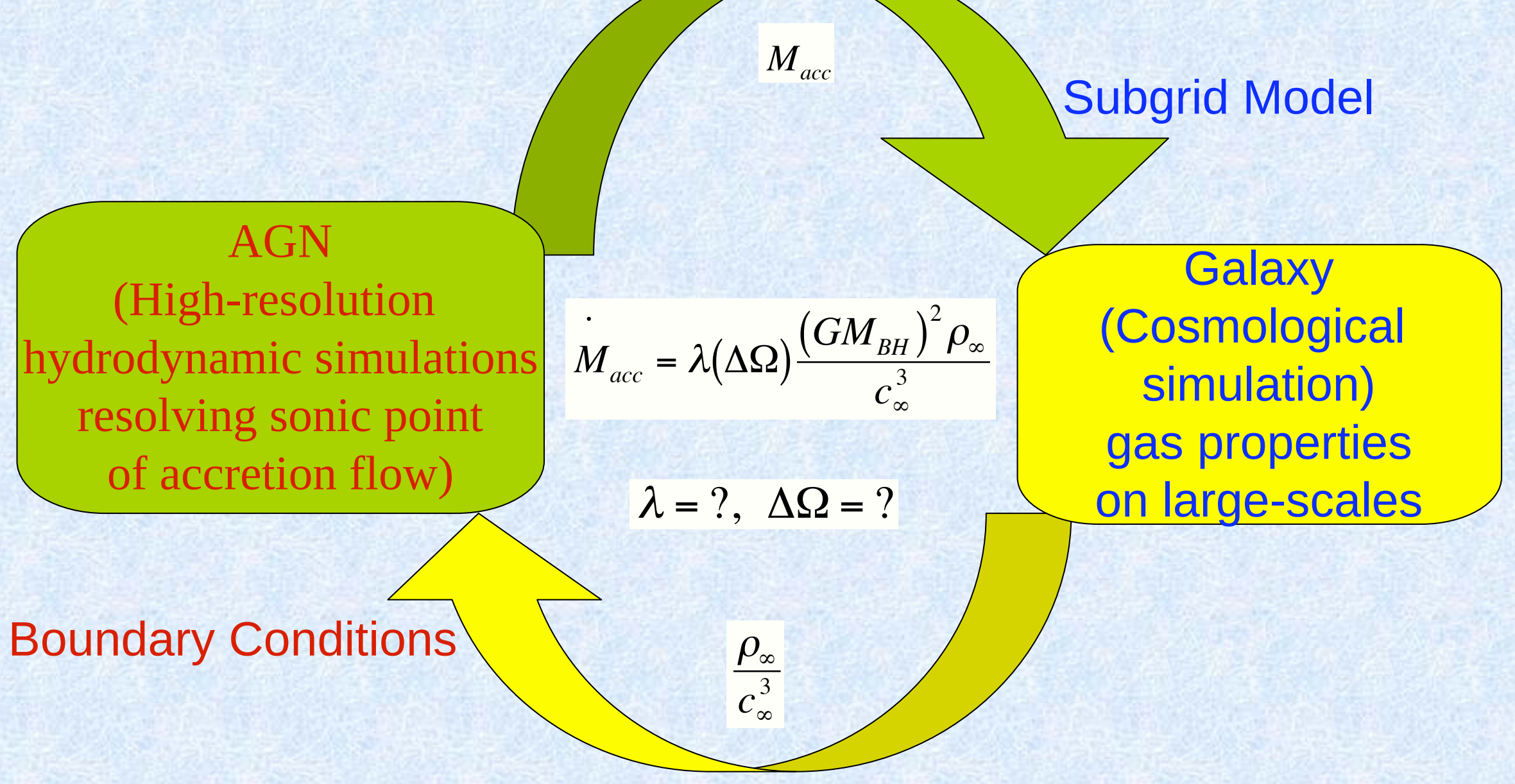
- Cosmological simulations cannot resolve the Sonic Point, which is important to properly model BH accretion
- Previous subgrid models of AGN feedback [9] have assumed the Bondi-Hoyle accretion rate, with ad-hoc choice of parameter values

➢ <u>First step of subgrid model of AGN in galaxy formation ⇒ Test :</u> [1]

- How well can SPH reproduce Bondi accretion?

Methodology

- How does mass accretion rate (BH microphysics) depend on galaxy-scale gas properties?



M_{acc}

Subgrid Model

AGN
(High-resolution
hydrodynamic simulations
resolving sonic point
of accretion flow)

$$\dot{M}_{acc} = \lambda(\Delta\Omega)\frac{(GM_{BH})^2\rho_\infty}{c_\infty^3}$$

$\lambda = ?, \ \Delta\Omega = ?$

Galaxy
(Cosmological
simulation)
gas properties
on large-scales

Boundary Conditions

$\frac{\rho_\infty}{c_\infty^3}$

- <u>Tool :</u> Smoothed-Particle Hydrodynamics (SPH)
  - Can handle large dynamical range
- Simulate a spherical distribution of gas accreting onto a SMBH
  - Using 3D Tree-PM SPH code Gadget-3 [8]
- Central BH represented with a static Paczynsky-Wiita potential [6]

$M_{BH} = 10^8 M_{Sun}$ $\quad$ $\Psi_{PW} = \frac{GM_{BH}}{(r - R_{Sch})}$

Table 1. Simulation runs: $r_{in} = 0.1$ pc. Initial condition: $\rho_{init} = \rho_{Bondi}$. For Heat-Cool runs: $L_X = 5 \times 10^{-4} L_{Edd}$.

Run No.	Case	γ_{run}	r_{out} [pc]	N	γ_{init}	T_∞ [K]	R_{Bondi} [pc]	t_{Bondi} [yr]	ρ_∞ [g/cm^3]	T_{init}	$\dot{M}_{in}(r_{in})$ [$\dot{M}_{Bondi}(\gamma_{run}, T_\infty)$]
1	Bondi	1.01	20	128^3	1.01	10^7	3.0	7.9×10^3	10^{-19}	T_∞	$1 - 1 - 0.2$
2	Heat-Cool	5/3	20	128^3	5/3	10^7	1.84	3.7×10^3	10^{-21}	T_{rad}	$1.6 - 80 - 0.1$
3	Heat-Cool	5/3	200	256^3	5/3	10^5	183.9	3.7×10^6	10^{-23}	T_{rad}	$1 - 3$

Adding Extra Physics : Radiative Heating & Cooling

- Spherical X-ray corona around central BH [2, 4, 7]
- Optically thin gas
- Compton heating-cooling
- X-ray photoionization heating - recombination cooling
- Bremsstrahlung & line cooling

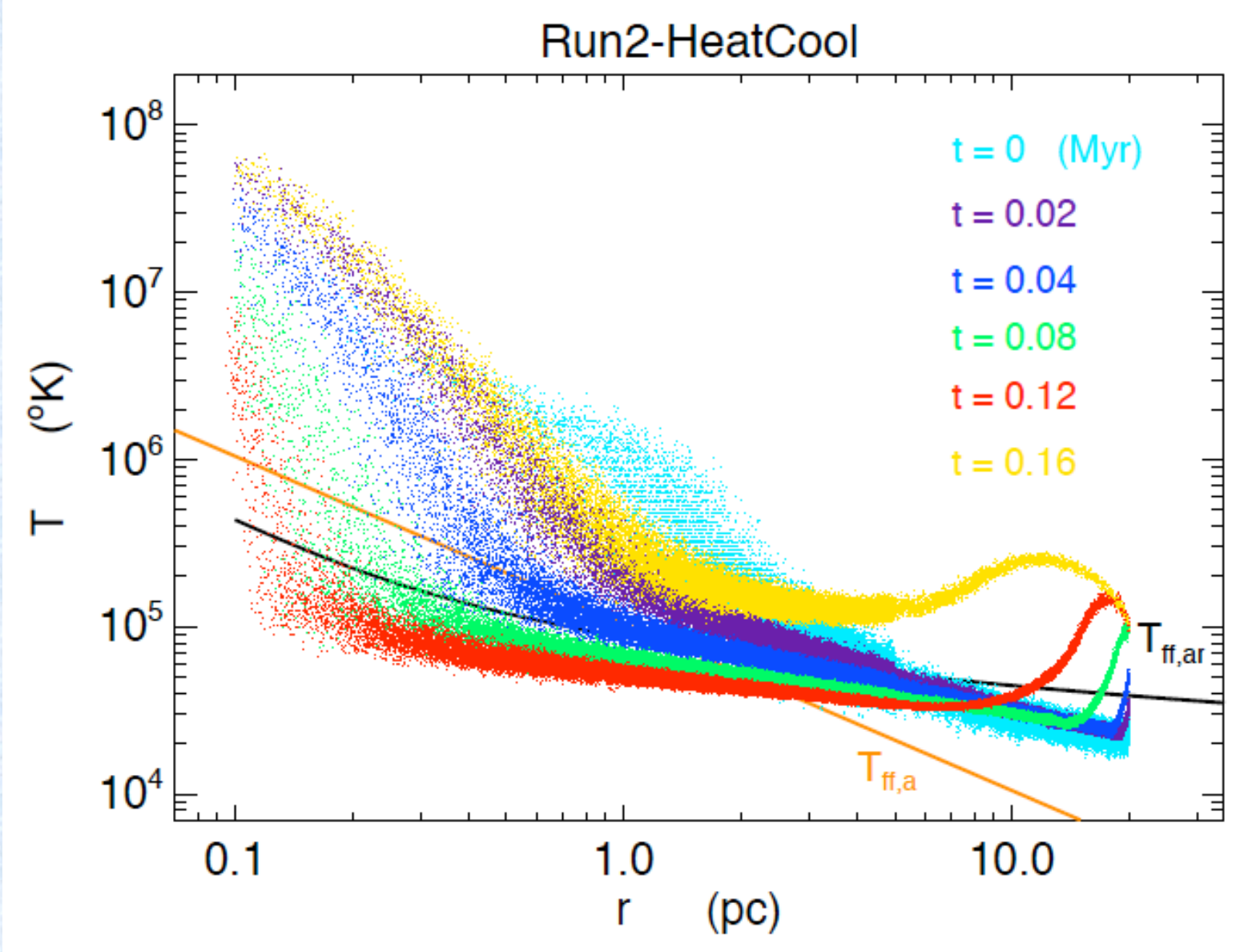


Fig. 3 --- Evolution of radial temperature profile of gas, overplotted with theoretical predictions.

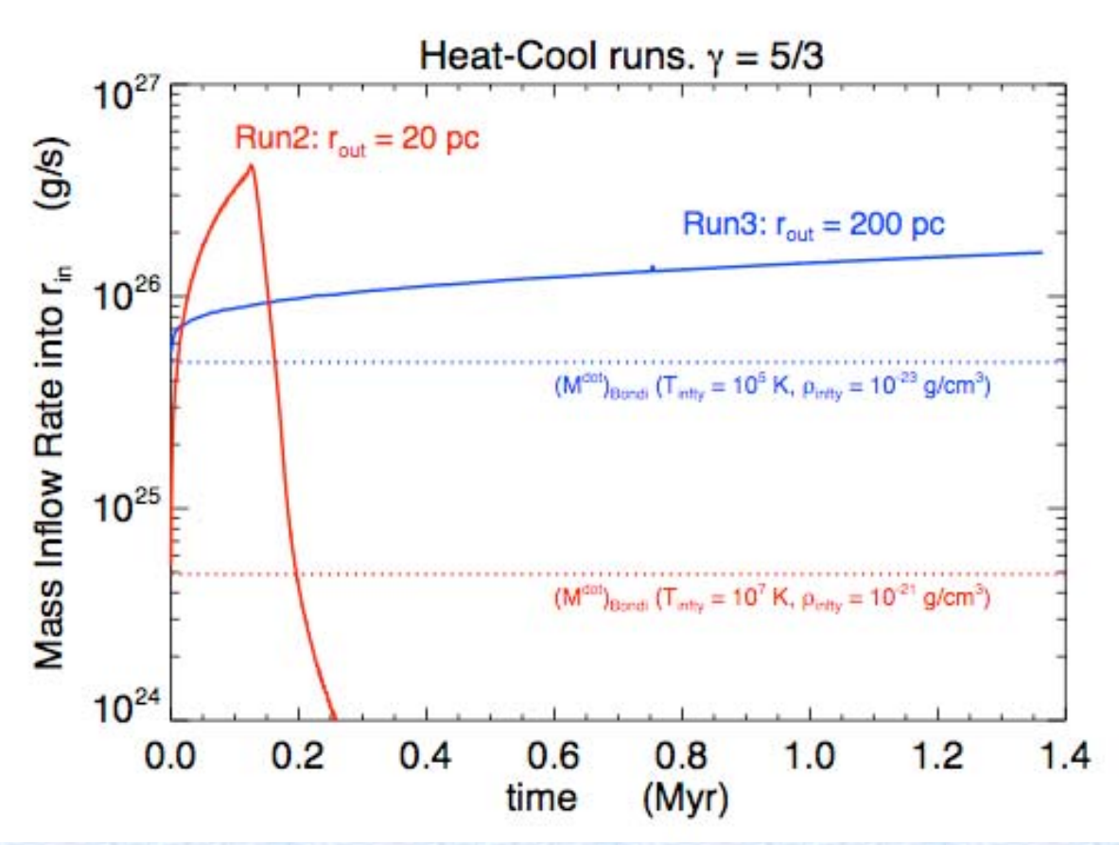


Fig. 5 --- Mass inflow rate at inner boundary. Close to steady-state with larger outer boundary.

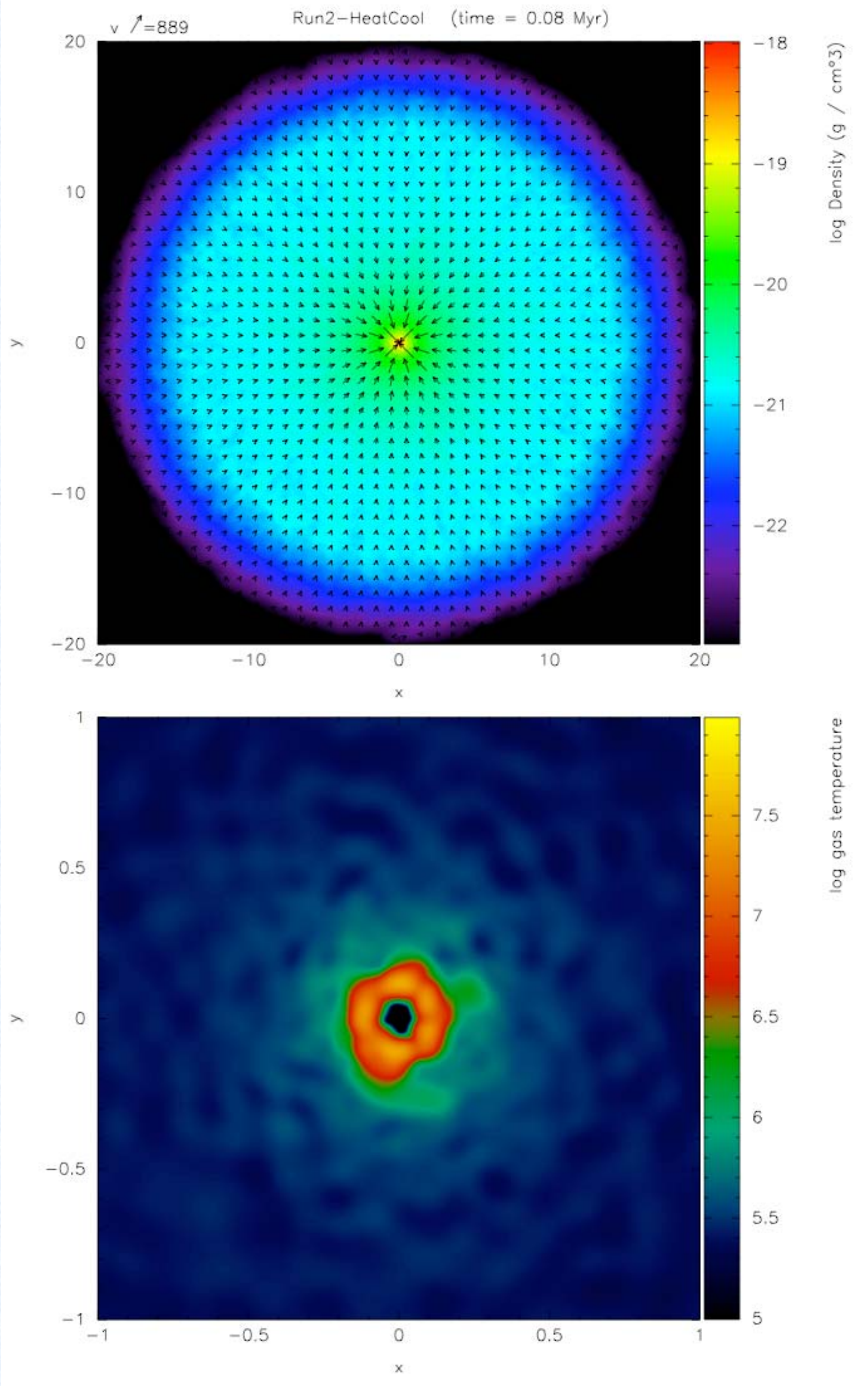


Fig. 4 --- Density and temperature of a cross-section slice through z = 0. The central heating is due to artificial viscosity.

Reproduce Original Bondi Problem

- Spherically-symmetric accretion of gas [3] having given density and temperature at infinity
- Bondi radius and time : $R_{Bondi} = \frac{GM_{BH}}{c_{s,\infty}^2}, \quad t_{Bondi} = \frac{R_{Bondi}}{c_{s,\infty}}$ $\qquad \Delta\Omega = 4\pi$

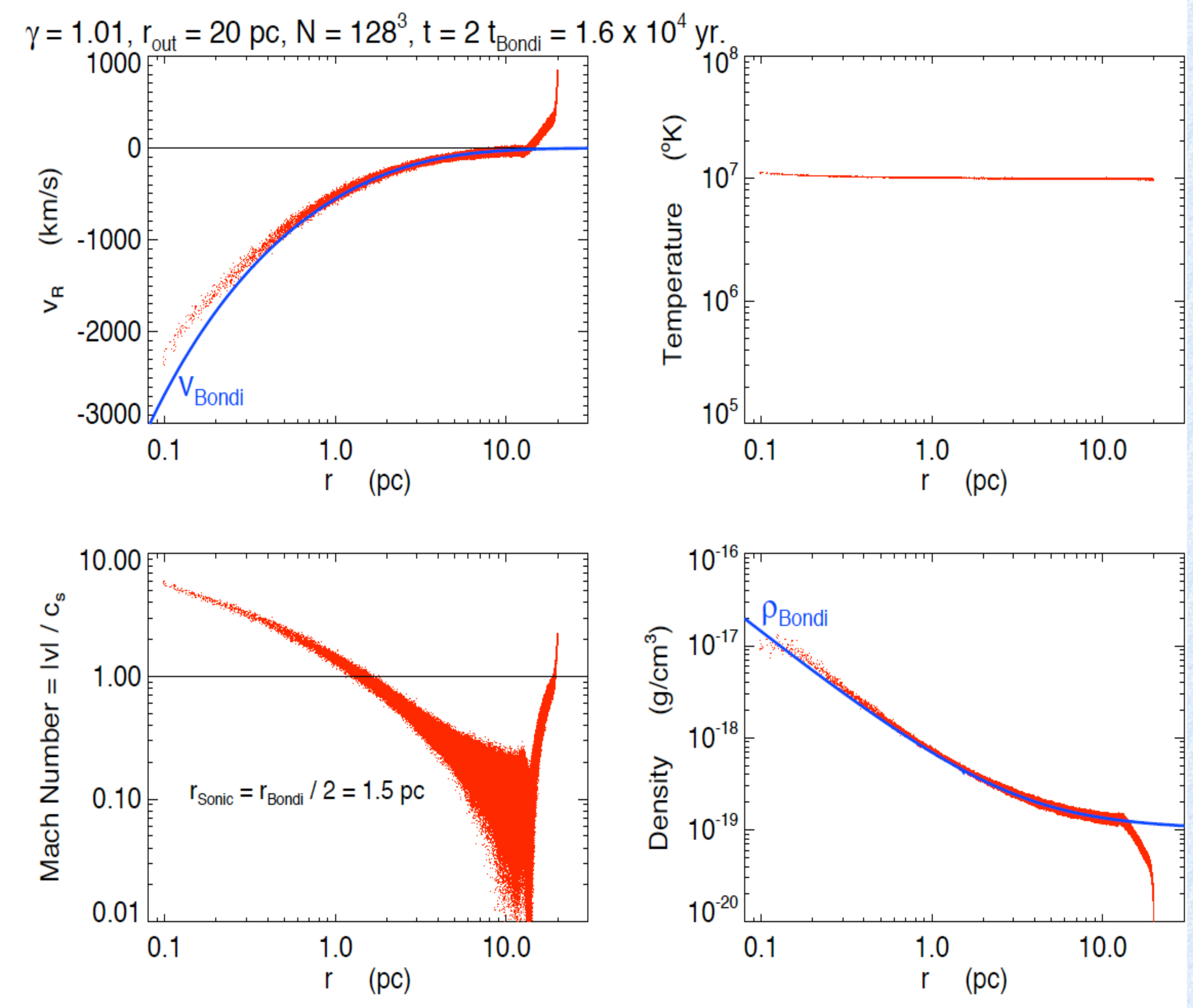


Fig. 1 --- **Blue:** Bondi solution. **Red:** Particles from simulation Run 1. Note the group of particles flowing out of the computational volume at r_{out}, because of finite pressure gradient at the outer boundary .

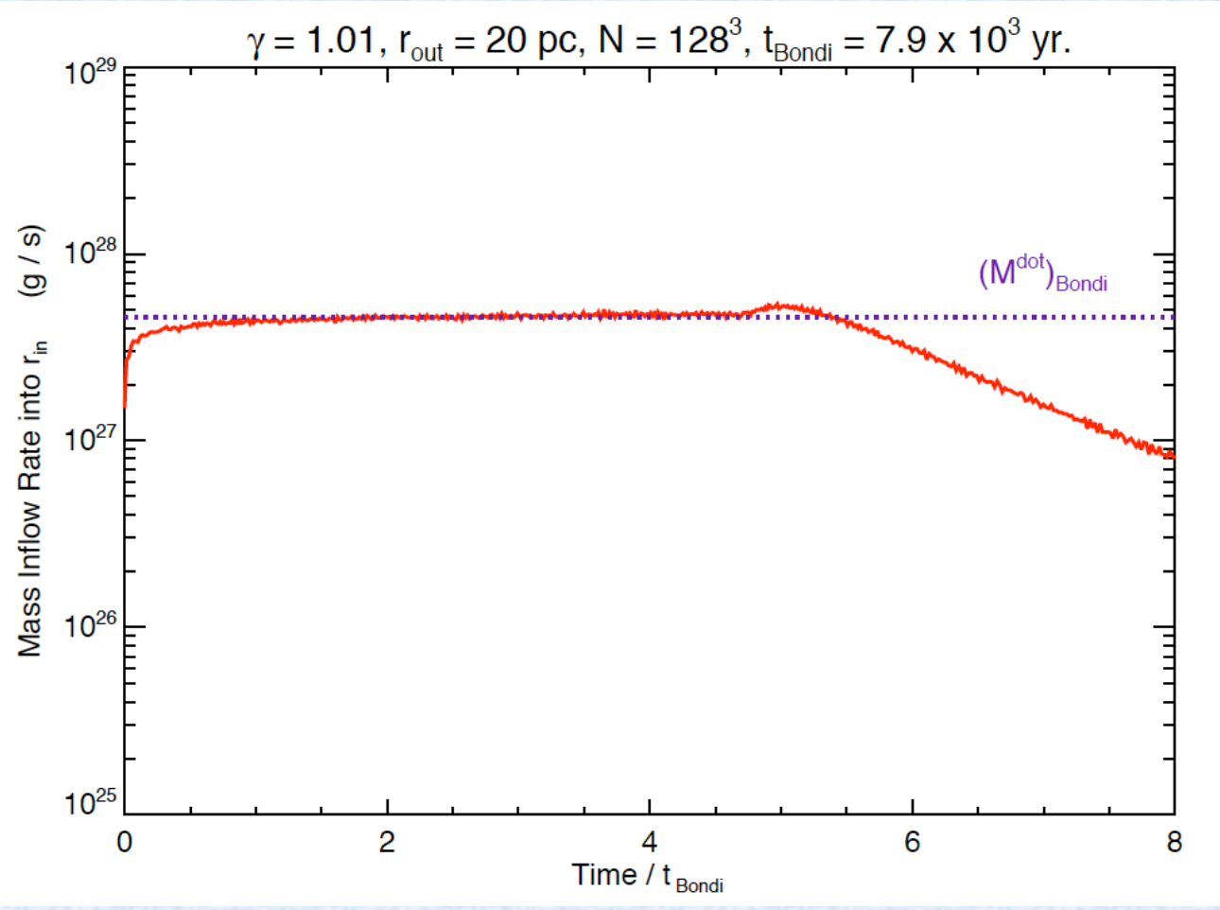


Fig. 2 --- Mass inflow rate at inner radius. Bondi accretion rate is reproduced within limited time domain (for 4 x 10^4 yrs).

Conclusions

⌖ SPH can reproduce adiabatic Bondi accretion for few dynamical times at the Bondi radius [Fig. 2], the duration increasing with the outer radius

  ➢ Issue: Mass loss due to outflow of particles at the outer boundary [Fig. 1]

⌖ Radiative heating & cooling has been incorporated in the code [Fig. 3]

  ➢ Gas follows spherically-symmetric [Fig. 4], nearly steady-state [Fig. 5] Bondi accretion

⌖ Artificial viscosity in the Gadget code causes excessive heating near the inner boundary [Figs. 3, 4], preventing attempts to study radiative feedback accurately

References

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