SPH Simulations of AGN Feedback in Galaxy Formation: Doing First Things First - Tests of Bondi Accretion

Abstract

We aim to numerically test the assumption, that the central massive BH of a galaxy accretes mass at the Bondi-Hoyle accretion rate (with ad-hoc choice of parameter values), made in previous studies of cosmological simulations including AGN feedback. We perform simulations of a spherically accreting system in the scale 0.1 - 200 pc, using the 3D SPH code Gadget-3. Our system consist of a spherical distribution of gas accreting onto a central BH (the Bondi problem), wherein we have studied how different gas properties (initial density and velocity profiles) and computational parameters (simulation outer boundary) affect the central mass inflow rate. We have included radiative heating and cooling in our simulations. Our ultimate goal is to incorporate these small-scale results into large-scale cosmological simulations, and refine the AGN feedback prescription using our numerically computed parameters for BH accretion and feedback [4].

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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

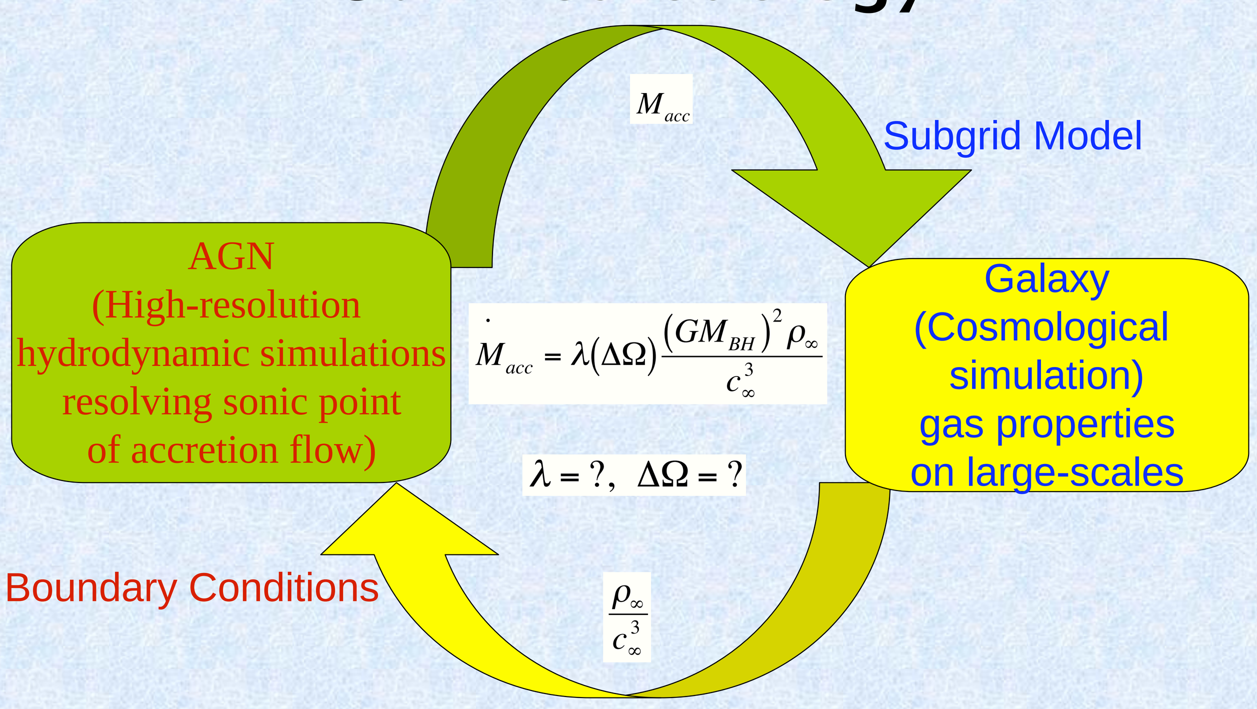
➢ **Computational Challenges :**

- Cosmological simulations cannot resolve the Sonic Point, which is important to properly model BH accretion
- Previous subgrid models of AGN feedback [8] have assumed the Bondi-Hoyle accretion rate, with ad-hoc choice of parameter values

➢ **Our Goal :**

- Develop a numerically well-tested subgrid model for the incorporation of AGN feedback in cosmological simulations of ΛCDM Universe

Our Methodology



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

- **Tool :** Smoothed-Particle Hydrodynamics (SPH)
  - Can handle large dynamical range
- **Test :** How well can SPH address the issue of Bondi accretion?

- Using 3D Tree-PM code Gadget-3 [7], simulate a spherical distribution of gas accreting onto a SMBH
- Central BH represented with a static Paczynsky-Wiita potential [5]

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

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/cm³]	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 of luminosity L_X around central BH [1, 3, 6]
- Photo-ionization parameter : $\xi = \frac{4\pi F_X}{n} = \frac{L_X}{r^2 n}$
- Optically thin gas
- Compton heating-cooling
- X-ray photoionization heating - recombination cooling
- Bremsstrahlung & line cooling

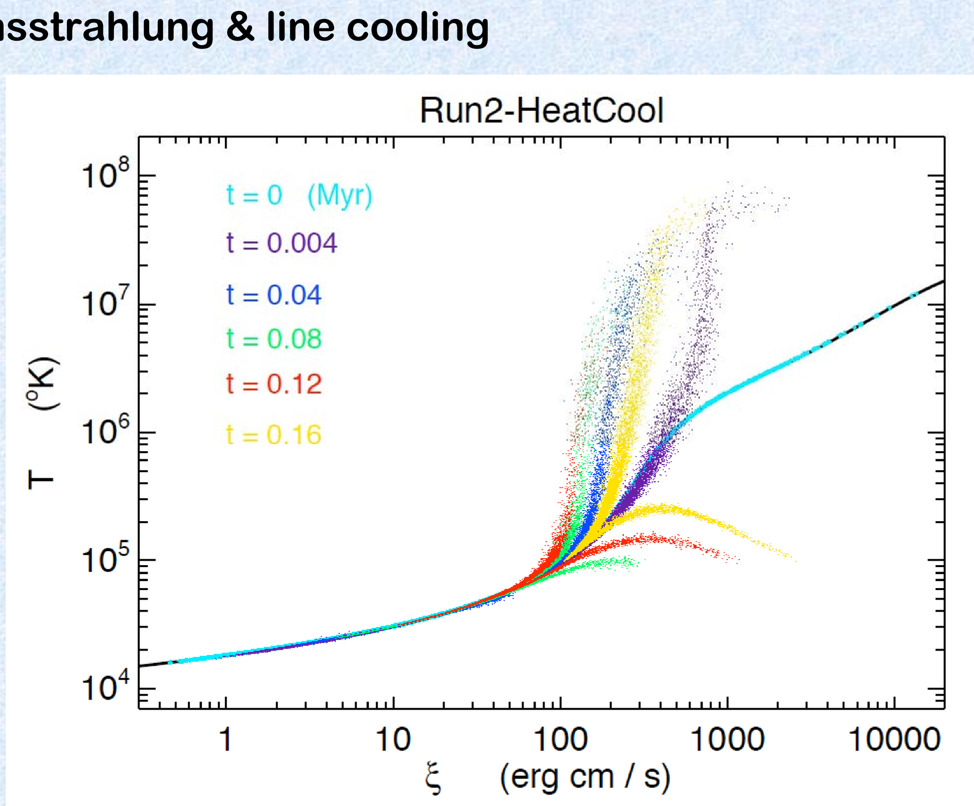


Fig. 3 --- Temperature vs. photo-ionization parameter of particles, overplotted with the implemented cooling curve.

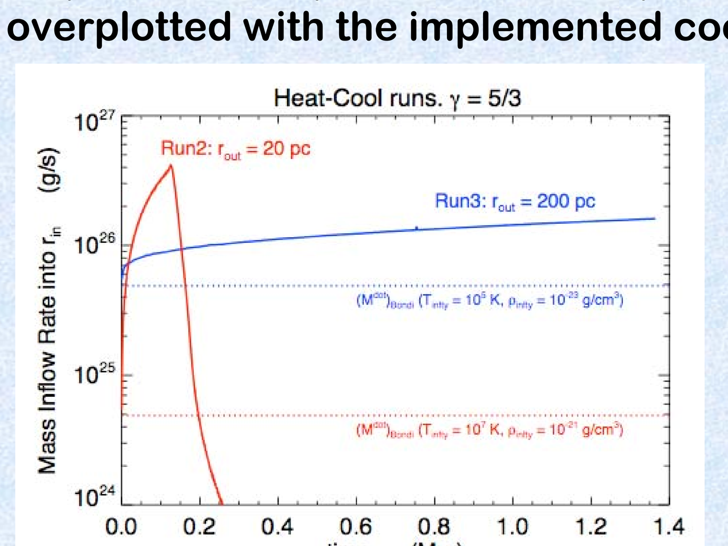


Fig. 5 --- Mass inflow rate at inner boundary. Close to steady-state with larger outer boundary.

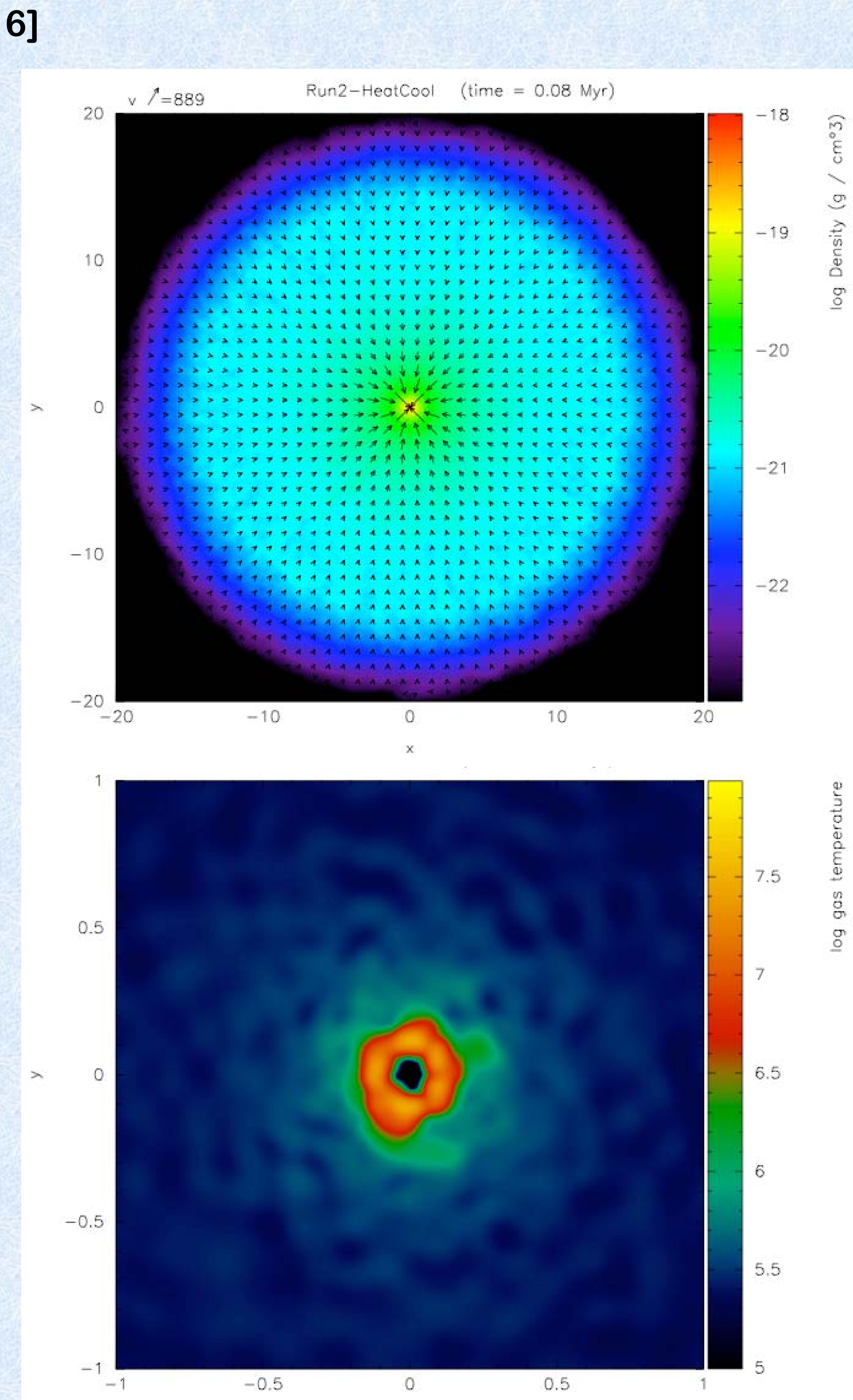


Fig. 4 --- Density and temperature rendering of a cross-section slice through z = 0.

Reproduce Original Bondi Problem

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

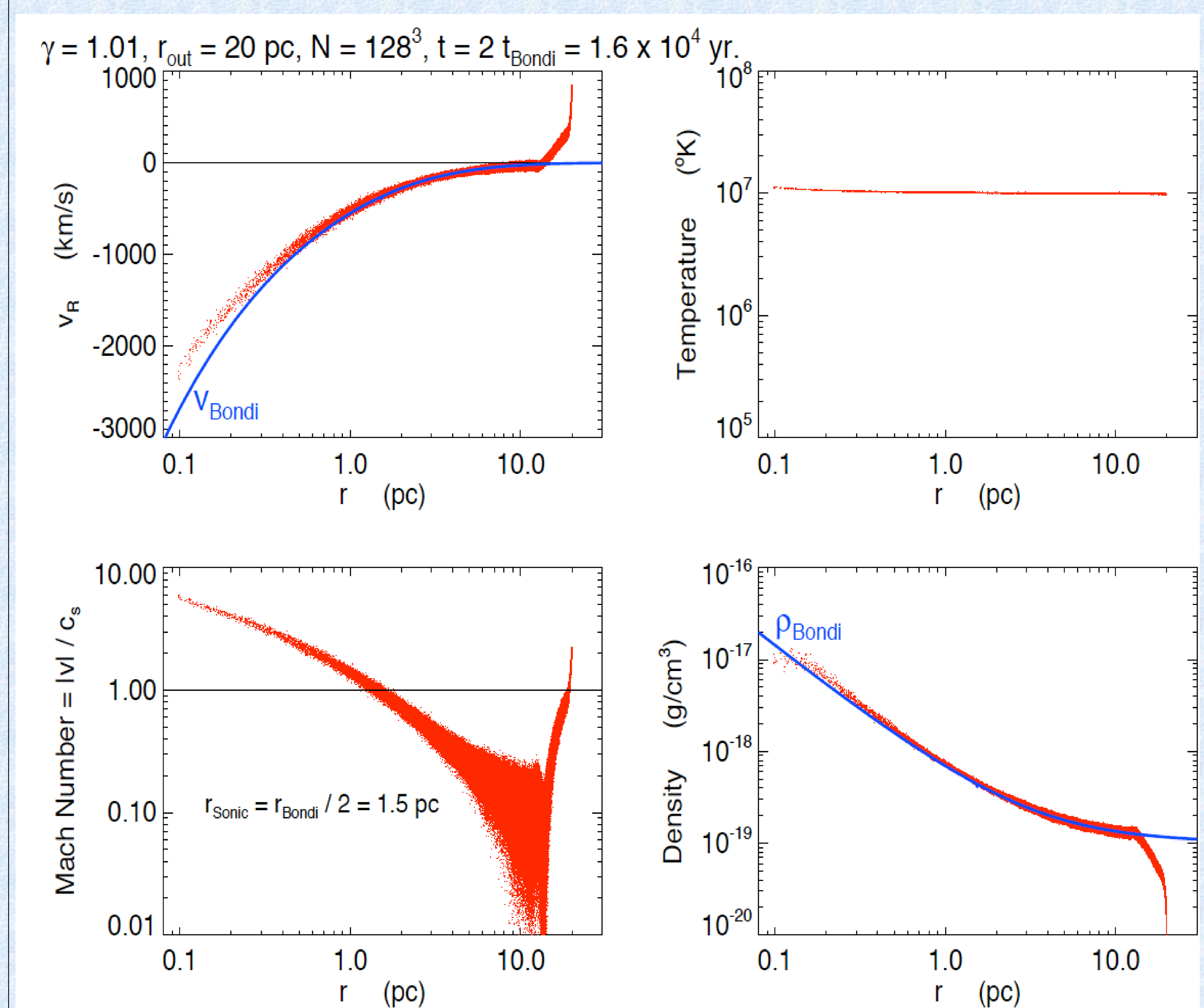


Fig. 1 --- **Blue:** Bondi solution. **Red:** Particles from simulation run 1. Note the group of particles flowing out of the computational volume at r_{out}, because of finite pressure gradient at the outer boundary .

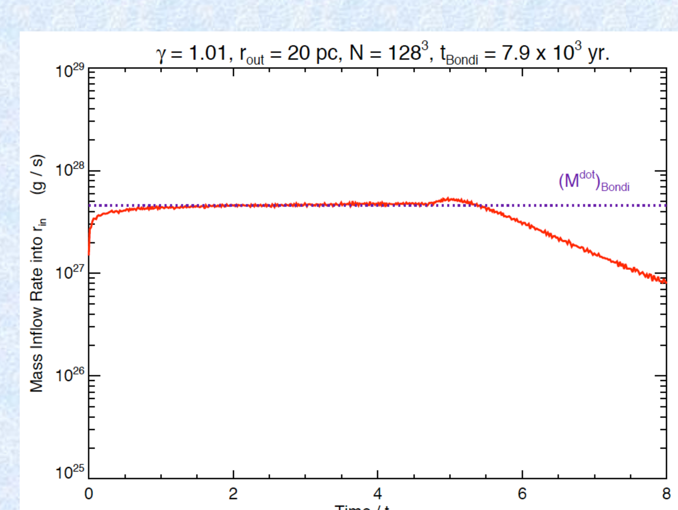


Fig. 2 --- Mass inflow rate at inner radius. Bondi solution is reproduced within limited time domain (for 4 x 10⁴ yrs).

Conclusions

- SPH can reproduce Bondi accretion for few times t_{Bondi} [Fig. 2], the duration increasing with the outer radius
  - ➢ Issue: Outflowing particles near outer boundary [Fig. 1]
- Radiative heating & cooling has been incorporated in the code [Fig. 3]
  - ➢ System follows spherically-symmetric [Fig. 4], nearly steady-state [Fig. 5] Bondi accretion
- Cooling increases the mass accretion rate w.r.t. the Bondi rate [Table] (as expected)

References

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