Simulating Galaxy Clusters at High Resolution @ Inaf-Cineca

Veronica Biffi

S. Borgani, G.L. Granato, G. Murante, E. Rasia

INAF-Cineca Class A project: *Simulating Galaxy Clusters at High Resolution*

ICT meeting @ Bologna 30.11.2017

Outline

- Scientific goals of the project
- Cosmological hydro-simulations of galaxy clusters
  - Code
- Tests & ongoing work
- Future developments

Scientific Goals

High resolution zoom-in simulations of galaxy clusters to study in detail:

- the cluster formation at high redshift
- the interaction between member galaxies & ambient ICM
- the population of member galaxies

Go from low resolution (LR) to medium & high resolution, by increasing mass resolution of a factor 3x (MR) and 10x (HR).

Numerical Simulations of Clusters

- Cosmological simulations of GCs: huge dynamical range (from Mpc to sub-pc scale)

  ➡ *cosmological hydrodynamical sims* of large cosmic volume, including gravity+baryonic physics -- limits on resolution

  ➡ *zoom-in re-simulation technique*: zoom on high-resolution region populated with dark matter + baryons -- less expensive, can push resolution

- Necessary sub-grid modelling of baryonic physics (e.g. gas cooling, star formation, production of chemical elements, stellar feedback and accretion onto BH which powers AGN feedback)

Numerical Code: Gadget-3

- TreePM+SPH code: discretizes dark & baryonic matter into massive particles
  - gravity: Tree code (Barnes&Hut 1986) + Particle-Mesh algorithm;
  - baryonic physics: Smoothed Particle Hydrodynamics (Monaghan&Lattanzio 1985) - quantities smoothed on a kernel; eqs discretized

- Parallelization: MPI between computing nodes + OpenMP inside a single shared-memory node

- Gadget-3 version: non-public evolution of Gadget-2 (Springel 2005) w/ improved SPH scheme (Beck et al. 2016; higher-order kernel + artificial viscosity + artificial conduction)
- Scalability: well tested on Marconi BRD, still slower than expected (factor of ~10 instead of 2) on Marconi KNL

Gadget-3 re-sims of Galaxy Clusters

- Reference Set:
  - parent simulation: DM-only, 1024^3 particles, 1 Gpc/h-side box
  - cosmology: ΛCDM with $\Omega_m = 0.24, \Omega_\Lambda = 0.76, \Omega_b = 0.04, h = 0.72, \sigma_8 = 0.8, n_s = 0.96$
  - 29 regions centered on cluster-size haloes:
    - 24 with $M_{vir} > 10^{15} M_\odot, \quad M_{200} > 8 \times 10^{14} M_\odot/h$
    - 5 with $10^{14} < M_{vir}[M_\odot] < 10^{15}, \quad M_{200} \sim [1\text{–}4] \times 10^{14} M_\odot/h$

Rasia+2015; Biffi+2016,2017a,b; Planelles, Fabjan+2017; Truong+2017

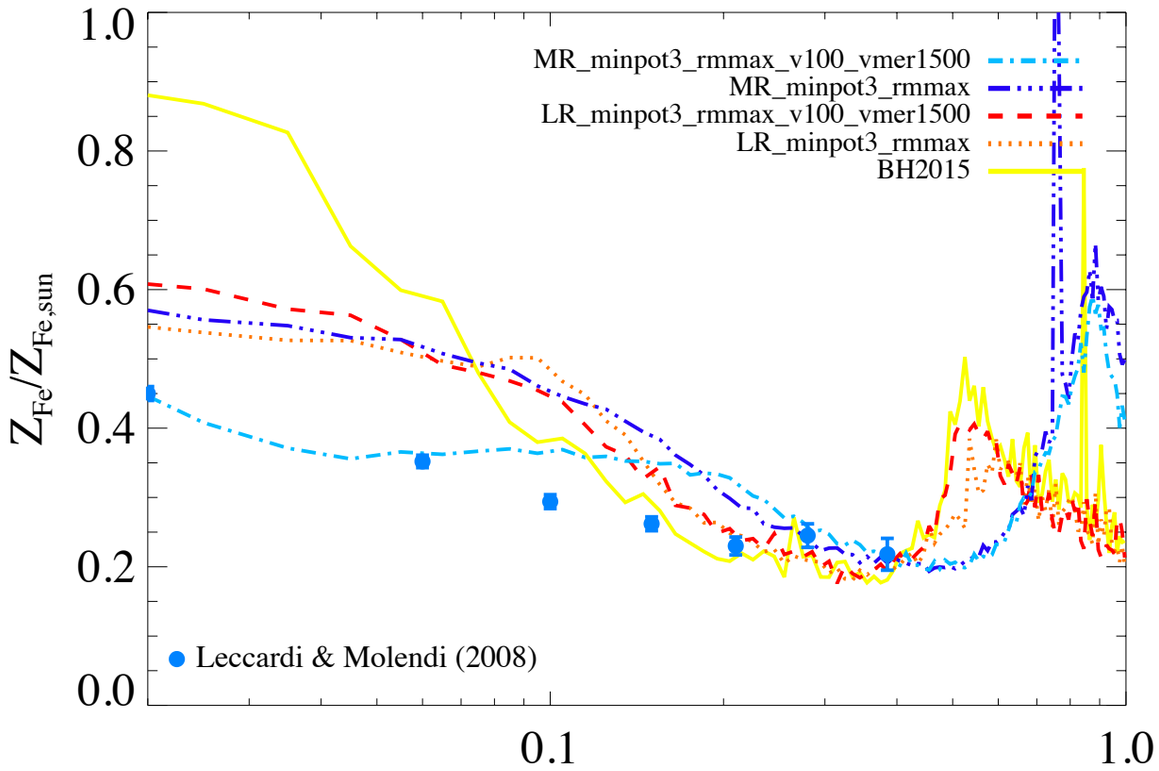
- LR(Ref): m_{DM}=8.43e8 M_{sun}/h, m_{gas}=1.56e8 M_{sun}/h --- *reference res*
- MR(3x): m_{DM}=2.53e8 M_{sun}/h, m_{gas}=4.69e7 M_{sun}/h --- *intermediate step*
- HR(10x): m_{DM}=8.43e7 M_{sun}/h, m_{gas}=1.56e7 M_{sun}/h --- *final goal*

Tests

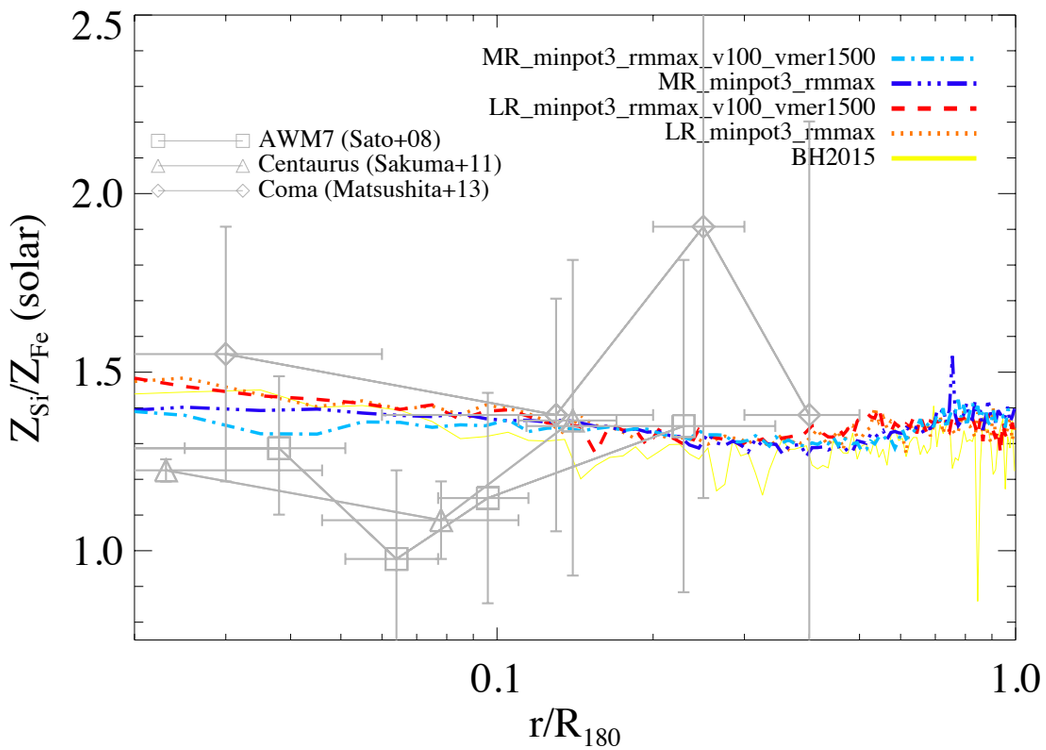
- Control-tests of BH positioning (important during merging of substructures onto main halo)
- Several tests on population of BHs (in-depth study of the effects of ‘orphan’ BHs on global features)
- Parameter calibration for MR & HR

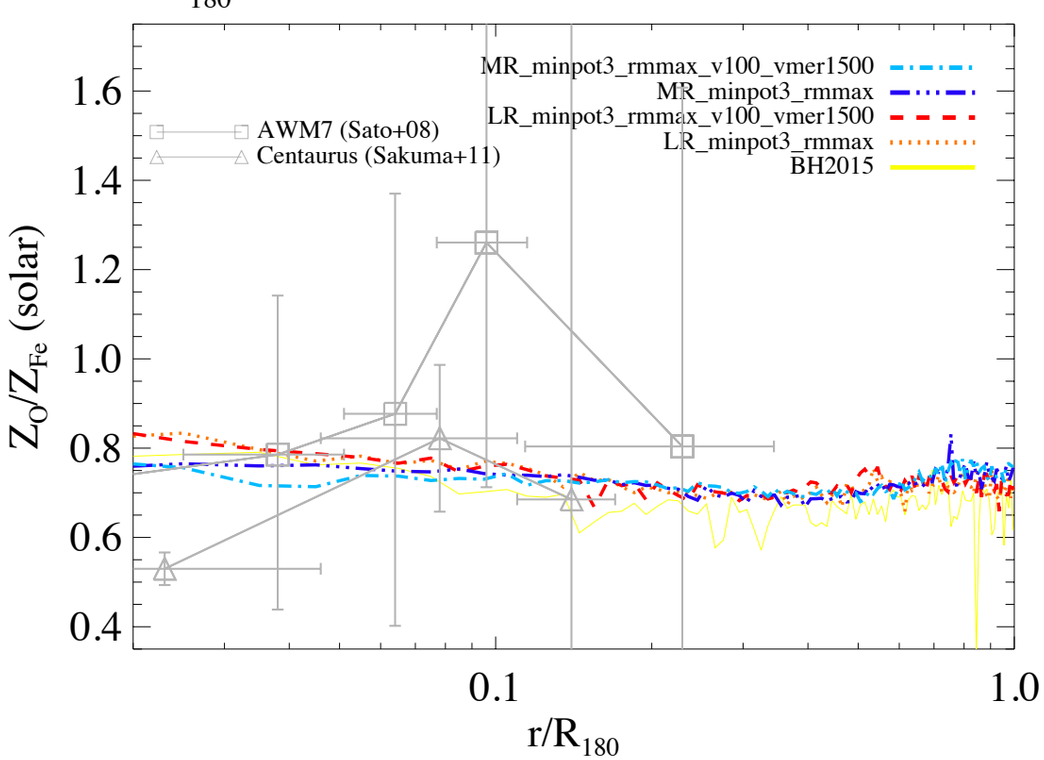
Tests

Study on the effects of the ‘orphan’ BHs onto ICM global properties: impact is minor and stable against resolution (LR -> MR)



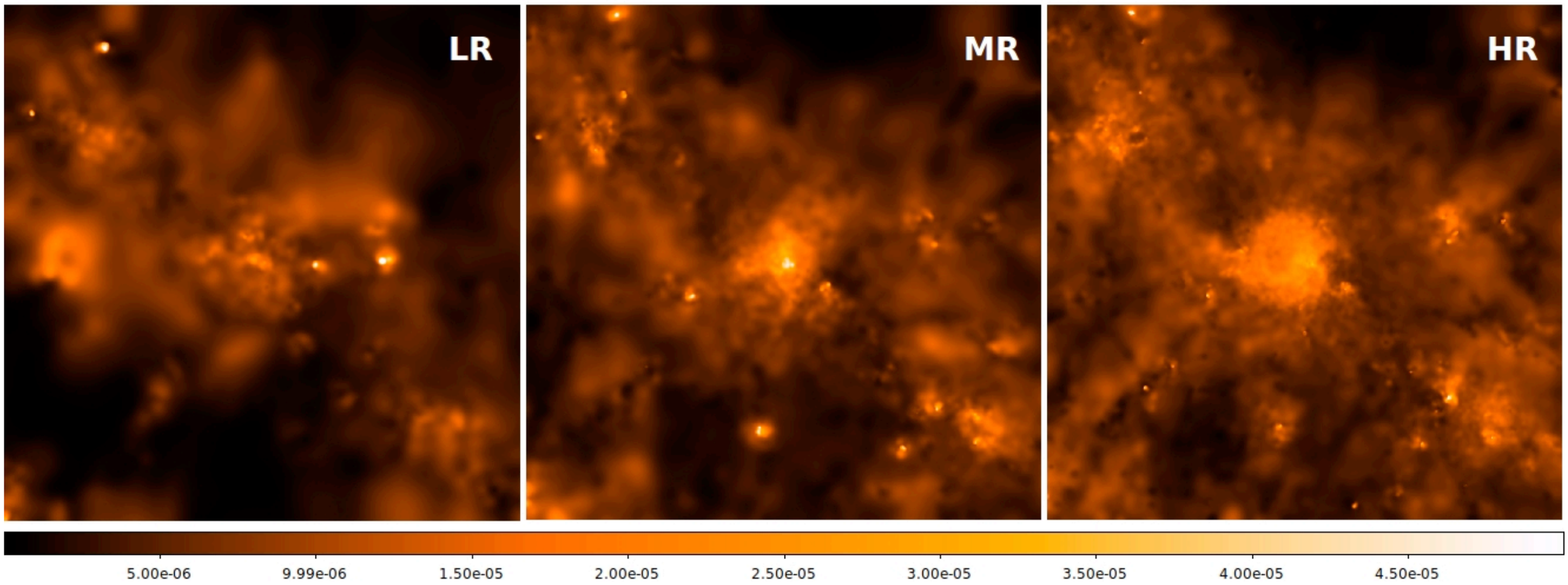
exmp: chemical properties of the ICM @ z=0





MR/HR sims

Study case: D2 cluster z=2



Oxygen bundance map

Current Status & Next Steps

- Awarded time: 550,000 std hours (~85% @Marconi KNL)
- Consumed time so far: ~83%
- Several tests made on the MR D2 study cluster
  -- achieved final optimal configuration of the code
- Starting production runs @HR

biffi@oats.inaf.it

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA
OSSERVATORIO ASTRONOMICO
DI TRIESTE