Galaxies and Galaxy Clusters

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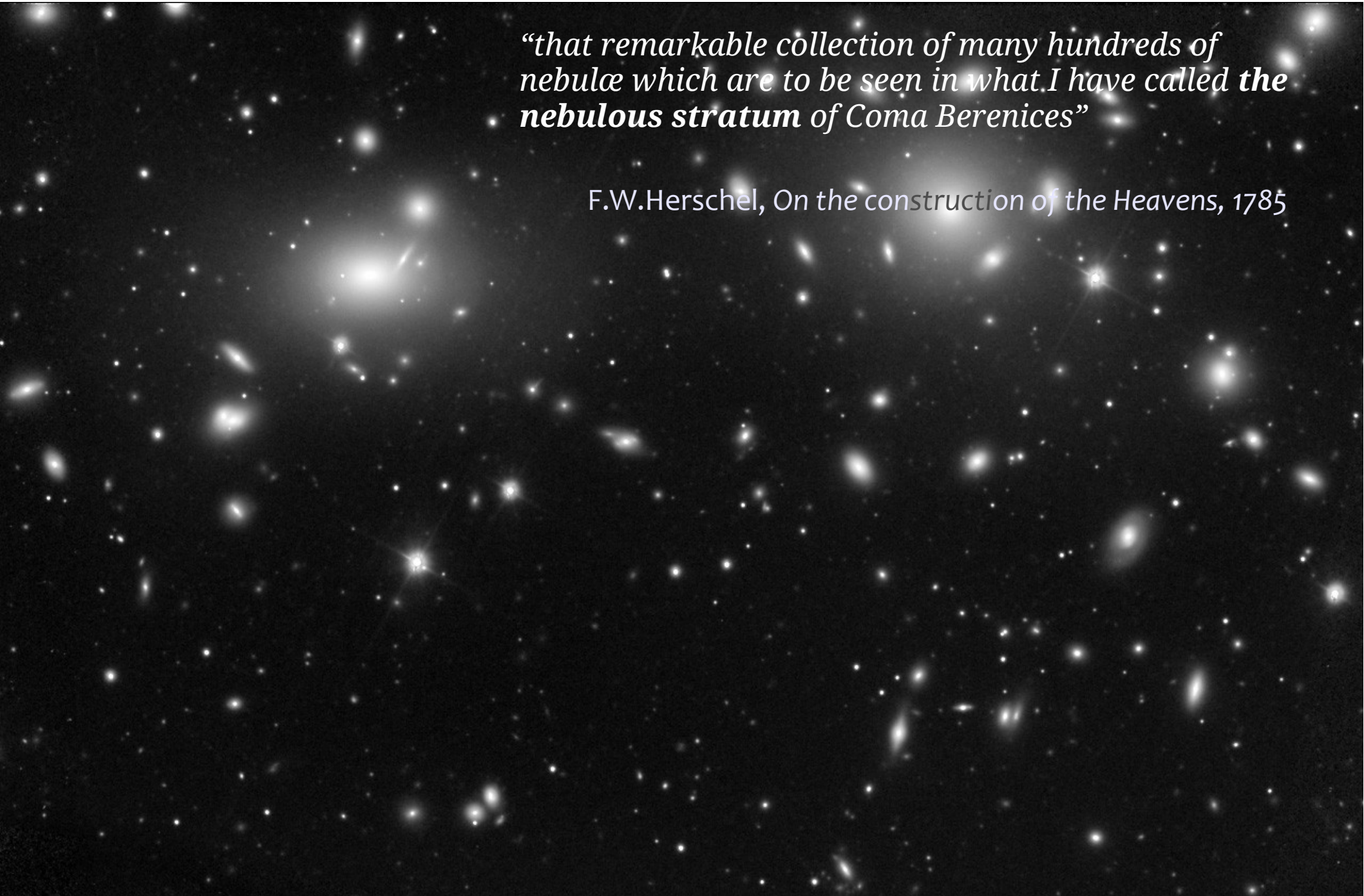
IVOA InterOp, Madrid, 22/5/2014

Outline

- Science with galaxies and galaxy clusters
- Looking to baryons in the universe:
  - Cosmological hydro simulations
  - Semi-analytic models of galaxy formation
- Description of simulations
- Science questions
- Development

Science with galaxies and clusters



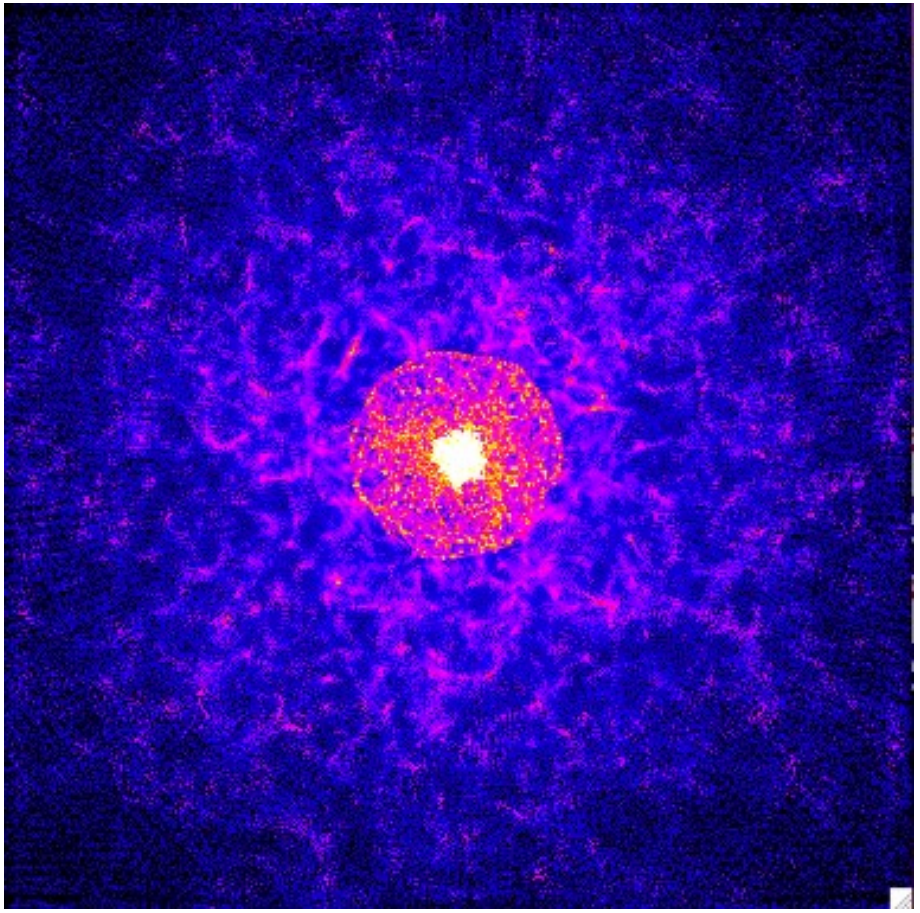
"that remarkable collection of many hundreds of nebulæ which are to be seen in what I have called ***the nebulous stratum*** *of Coma Berenices"*

F.W.Herschel, *On the construction of the Heavens, 1785*

Science with galaxies and clusters

- **Galaxy clusters and their evolution**
  - study cluster **gas properties** (thermodynamical, chemical...) and properties of the stellar and DM component as well as their evolution
  - understand the effect that **different physical mechanisms** as star formation, feedback (from stars and ActiveGalactic Nuclei), gas-dynamics have on cluster properties and their evolution
- **Evolution and properties of galaxies in clusters**
  - properties of substructures and of the **galaxy population** in clusters and protoclusters, galaxy mergers, evolution of galaxies, characterisation of the intracluster light

What is a cosmological hydro simulation?



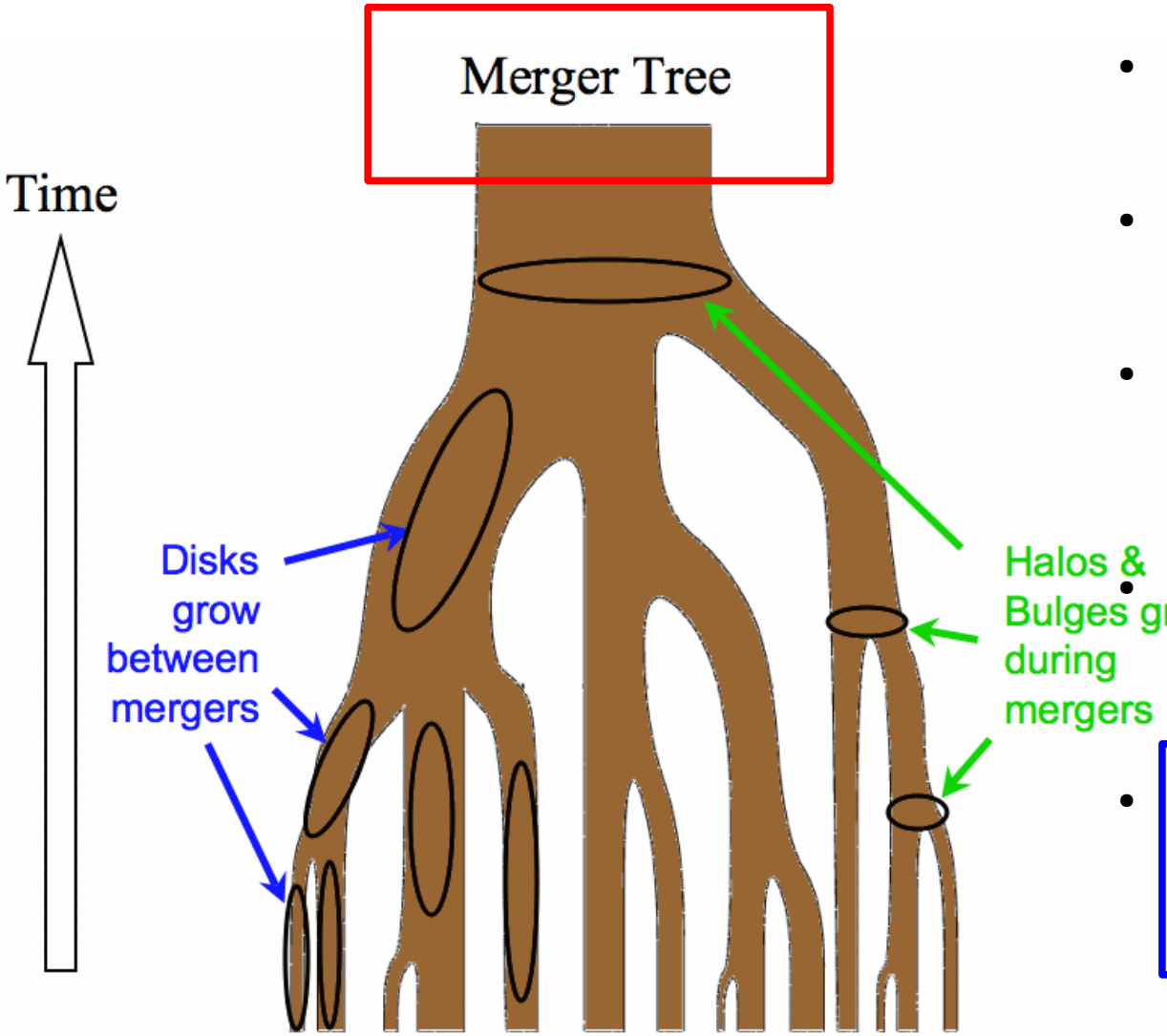
Dark matter density field

- **N-body integrator** for (DM dominated) gravity **+ hydrodynamic scheme** for collisional (gas) fluid elements.
- **Initial conditions** to reproduce the the CMB anisotropies.
- Integration performed in comoving coordinates.
- **Products:** positions, velocities, densities, temperatures, SFR, metallicities, ...

Several tens of snapshots, 1-100 GB each

100 GB => 1-10 TB per run

What is a semi-analytic model (SAM)?

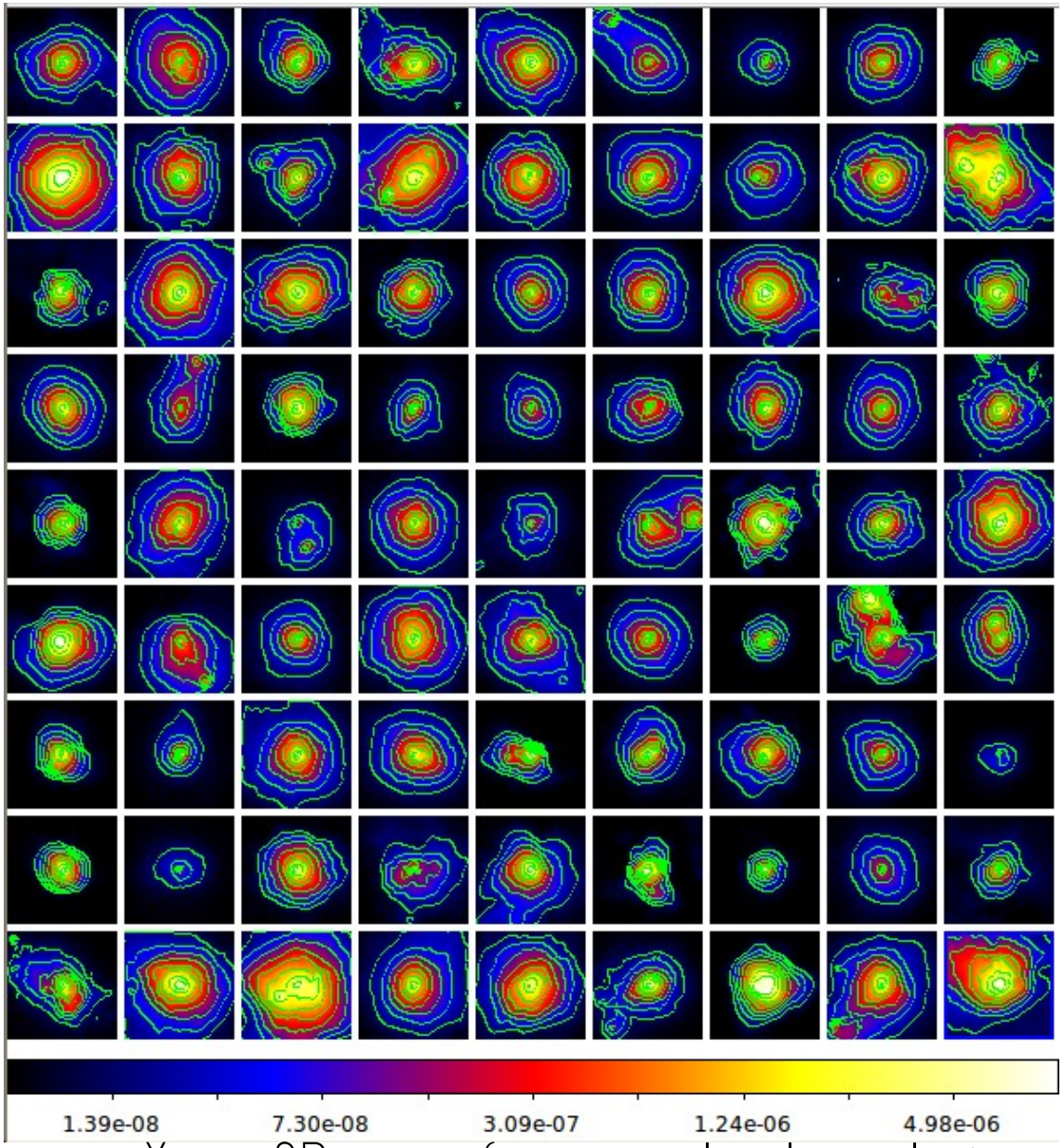


- **Merger trees** constructed **based on DM only N-body simulations**
- The evolution of each galaxy is traced by the **galaxy merger tree**
- **Gas dynamics** and physical processes are treated with simple physical and/or observationally motivated recipes
- **Main advantage:** predicting properties for the whole galaxy population using a short amount of computing time
- **Products:** dynamical and physical properties (also spectrophotometric) of main and satellite galaxies

Galaxy cluster simulations used at OATS

- Bonafede et al. 2011
- Fabjan et al. 2011
- Ettori et al. 2012
- Rasia et al. 2012
- Killedar et al. 2012
- Contini et al. 2012
- Rasia et al. 2012
- Cui et al. 2012
- Planelles et al. 2013
- Munari et al. 2013
- Roncarelli et al. 2013
- Ragone-Figueroa et al. 2013
- Rasia et al. 2013
- Contini et al. 2014

and more



X-ray SB maps for several galaxy clusters

Large statistical cluster sample

Cosmological box:

- size: 1 Gpc/h
- # part: 1024^3
- cosmology: WMAP-7 ΛCDM

Resimulations:

- 29 Lagrangian regions
- ZIC (Tormen et al. 1997)

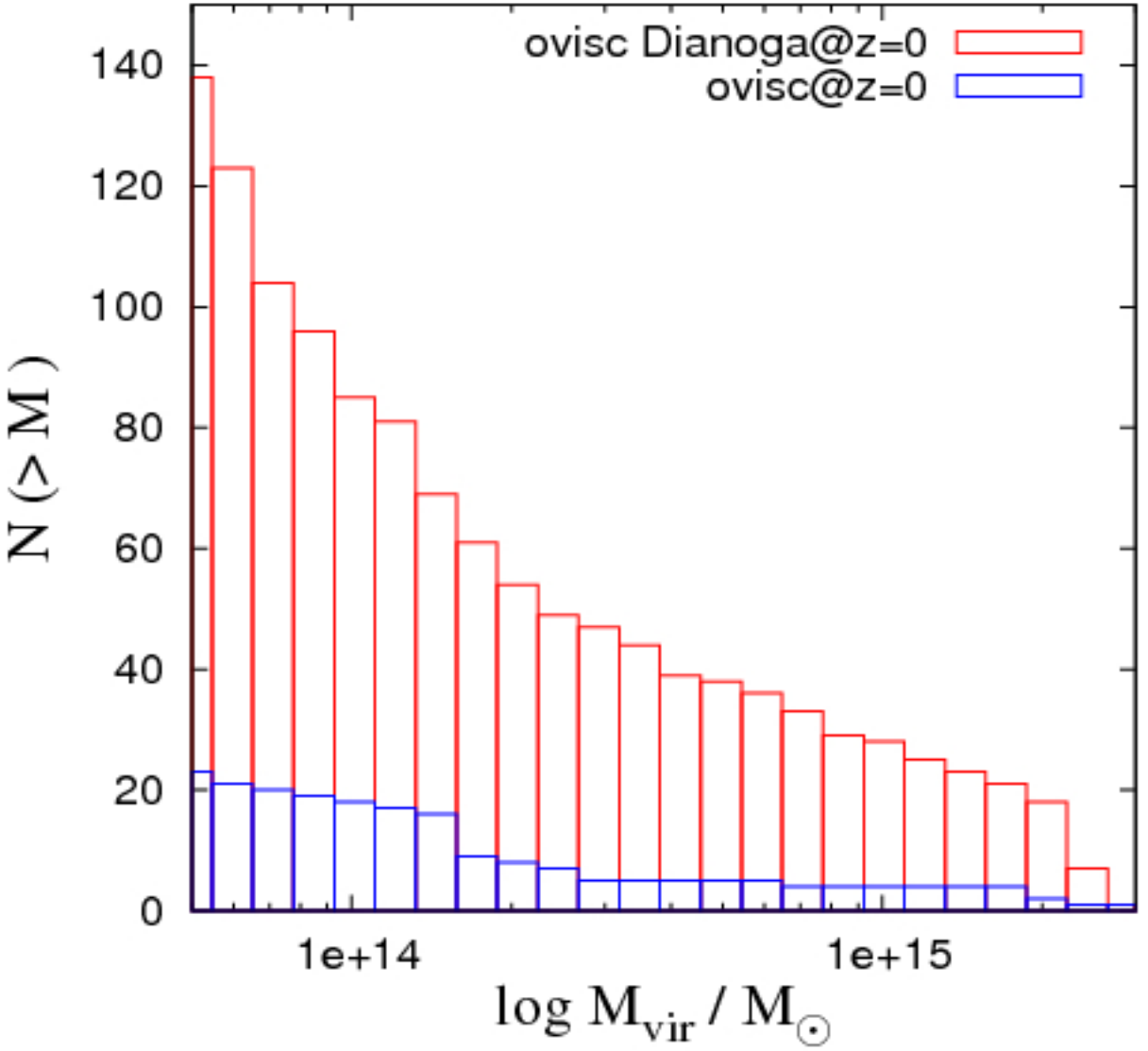
Large statistical sample

with ~140 clusters

$M_{vir} > 5 \times 10^{13} M_{sun}$

<u>Code:</u>

Gadget 3 Tree-PM SPH



cumulative number of clusters

in a large and a small set of clusters

Physics included in simulations

DM – Dark matter only

- $m_{DM} = 10^9\ M_\odot/h$

NR – non radiative physics

- $m_{DM} = 8.47 \cdot 10^8\ M_\odot/h$
- $m_{gas} = 1.53 \cdot 10^8\ M_\odot/h$
- No radiative cooling included

different protocols for hydro simulations

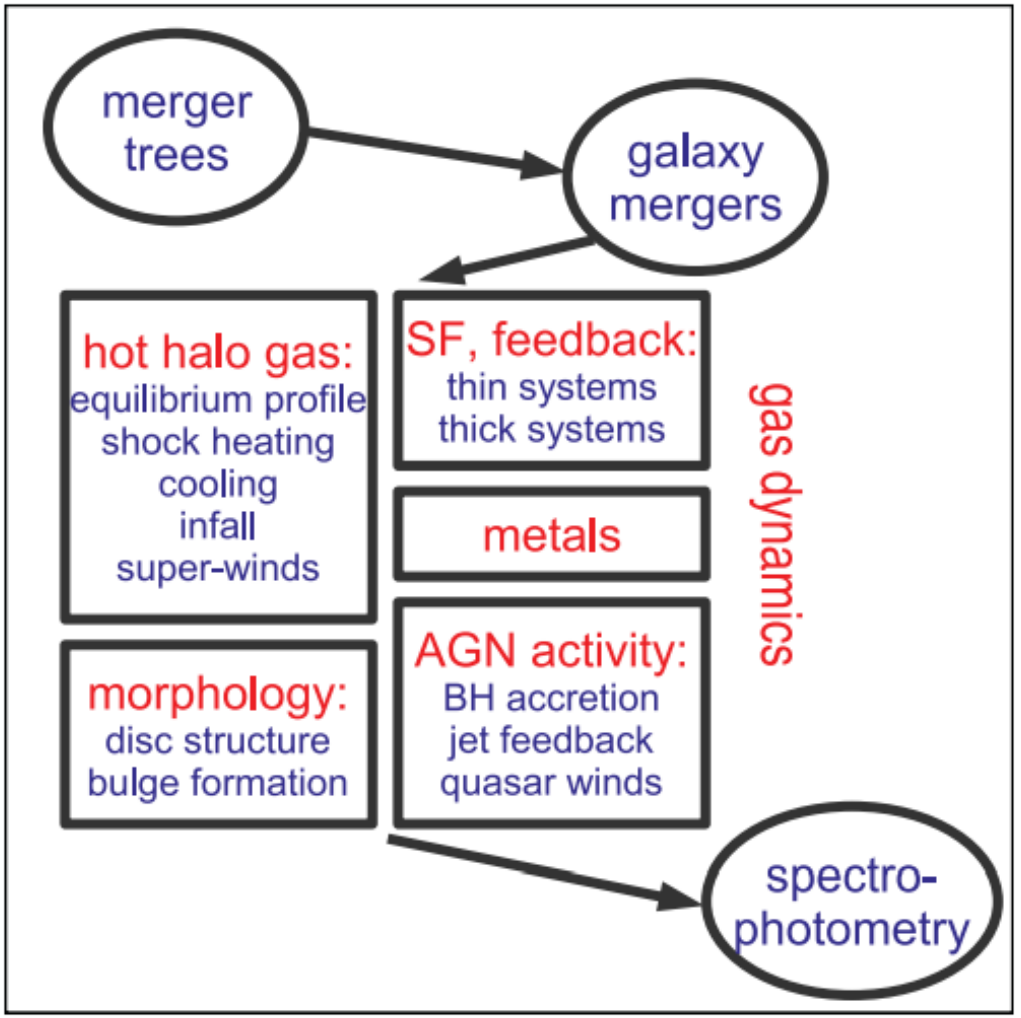
CSF – Cooling + Star formation + SN feedback

- rad. cooling from *11 elements*
- Chabrier IMF (Chabrier 2003)
- SNII kinetic feedback with winds v_w=500 km/s

AGN –
Cooling + SF + SN and BH feedback

- v_w=500 km/s
- BH seeds with 0.05 $m_{DM,10}$ in $2.5 \cdot 10^3$ $m_{DM,10}$ halos
- Radiative BH feedback $\varepsilon_r = 0.1$
- Thermal BH feedback $\varepsilon_f = 0.05$ or 0.2

Physics included in SAMs



different protocols for SAM models

- **MORGANA code**

(Monaco et al. 2007)

- **DeLucia 2006a** model

Addressed science questions (so far)

- Intracluster medium thermodynamical properties: analysis of cluster shapes and triaxiality and the effect of gas dynamics on them, shape of gas density, temperature, metallicity and other profiles, connection with cluster dynamical history
- Pressure profiles and the effect of clumping
- Hydrostatic equilibrium in simulated galaxy clusters
- Concentration-Mass Relation (evolution with redshift, comparing optical and X-ray catalogues)
- Baryon census in clusters
- Understanding the origin of observed X-ray and SZ scaling relations (theoretical relations, observational effects)
- Analysis of the internal dynamics
- Properties of the stellar component (diffuse stellar component, cluster galaxy population, effect of gas-dynamics/feedback on statistics of giant arcs and strong lensing cross-section)
- Analysis of the substructure mass distribution and ICL from SAM of galaxy formation

Outputs

- Simulation output:
  - ~90 snapshots with 33 blocks (some non standard!)
  - Outputs from the Friend-of-friend (Fof) algorithm
  - Additional information (SFR, BHs, metals...)
- Postprocessing output (experiments):
  - Intracluster medium properties computed and stored locally for all physics schemes included in hydro simulations
  - Merger trees (DM and galaxies)
  - Galaxy properties (global and profiles) extracted with a suitable postprocessing code (eg. ExtractGalaxies)

Output, postprocessing, ...

- Other (future) outputs (experiments) to add:
  - Idealized observations (e.g. Smac)

    Dolag et al. 2005
  - X-ray mock maps (e.g. X-MAS, PHOX)

    Gardini et al., Rasia et al. 2005/08, Biffi et al. 2012, 2013
  - Strong lensing and giant arc statistics

    Meneghetti et al., Killedar et al. 2012
  - Infrared maps of dust in galaxies (from MORGANA)

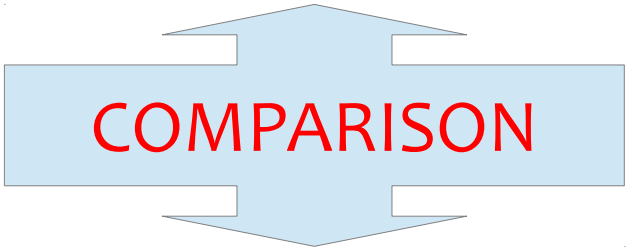
    Monaco et al. 2007, Grasil code (Silva et al. 1998)

Galaxies and galaxy clusters @ INAF-OATs

- data
- potential users
- goals
- first steps in the implementation

Data

- Numerical simulations of galaxy clusters
  - postprocessing results on properties of baryons for different physical models



- Galaxy formation based on the assembly of DM halos
  - merger trees of halos and galaxies
  - galaxy properties

Potential users

→ experience so far: often DB users are not from the same scientific area (numerical simulations)

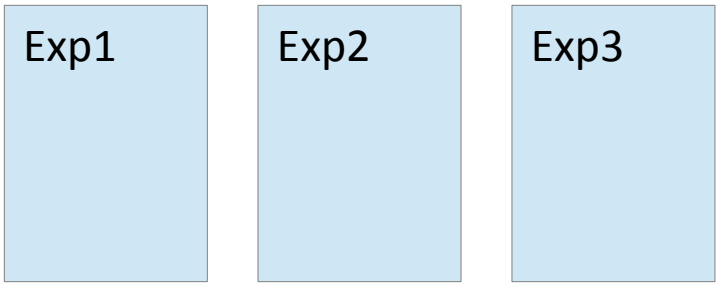
- researchers already using the same simulations
  - e.g. for quick comparison of data, learning developed VO tools
- students
  - e.g. short projects for bachelor students to familiarize with the database
- wider numerical community
  - e.g. comparison with their set of simulations/models
- observational astronomers
  - postprocessed data free to download, comparison with observational data

Goals

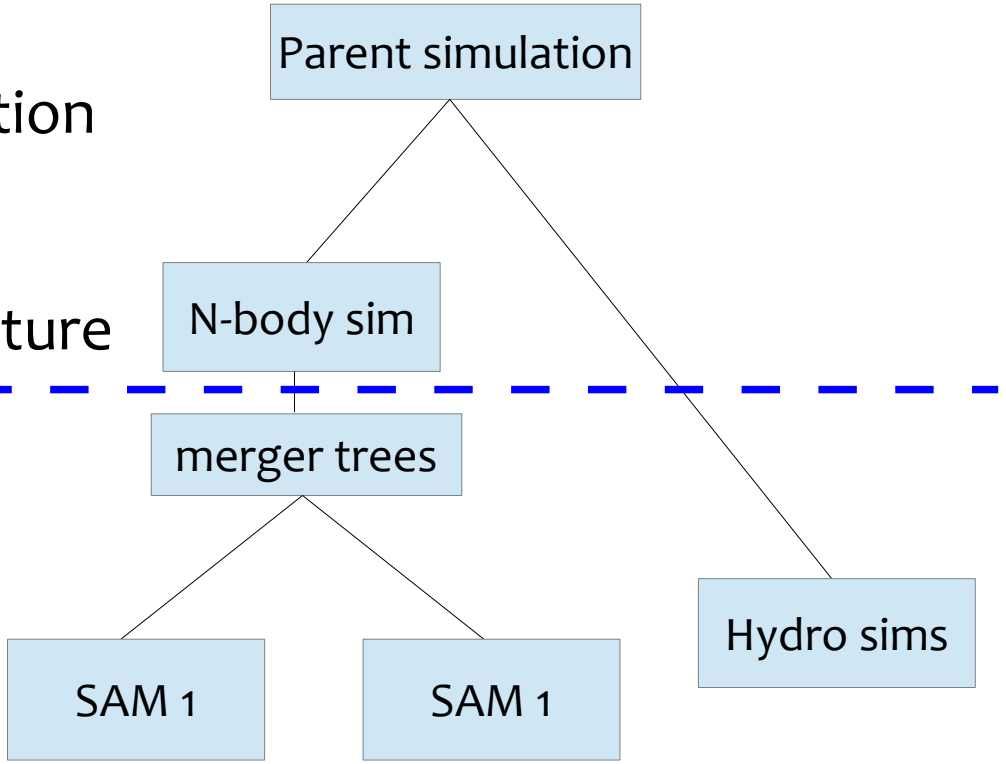
- Comparison between simulations and SAMs with different physics to exploit all the available information
- Comparison with theoretical and observable relations (e.g. L-T relation, entropy, temperature, metallicity profiles, gas/stars/baryon fraction...)
- Easy to add new experiments *(postprocessing data)*
- Storing postprocessing data and keep documentation up to date
- VO tools to be used for visualizing data (possibly on the fly) and to search through different simulations/models

Construction

- model with “parallel” experiments
  - simple descriptions
  - easy interaction btw experiments



- tree model
  - complex description
  - only lower part
  - preliminary structure



Conclusions

- Comparison between simulations and SAMs with different physics to exploit all the available information
- Be scientifically **useful** to a wider community
- Provide not just an archive of raw data, but:

  a) All information to avoid simulations to be used as “black boxes”.

  b) Detailed explanation of the DB content;

  c) Downloadable post-processing results;

  d) Pre-digested data: files of interesting regions, merger trees.
- **Easy to import** new simulations, data, maps...
- (in future) **contain** interactive tools:

  a) For a flexible visualization and simple analyses;

  b) To produce *mock observations*
- Continuous communication, update and collaboration

Thank you!