

THEORETICAL COSMOLOGY AND STRUCTURE FORMATION

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The main research interests of the group are in the following fields:

(i) the formation, structure and properties of dark matter haloes: their merging history tree, mass functions, formation times and masses, and the environmental dependence of these properties; the properties and evolution of subhaloes: mass accretion history of satellites; mass function of subhaloes, evolution of their orbital and structural properties;

(ii) the formation and evolution of galaxy groups and clusters using numerical techniques: N-body and hydrodynamical codes (SPH); the study of the dynamics of dark matter and ICM in simulated galaxy clusters; the role of different physical processes. Cosmology with galaxy clusters

Specific scientific goals for 2000-2004 have been:

- A new description of the formation and clustering properties of dark matter haloes based on the ellipsoidal collapse model; generalization of the extended Press-Schechter formalism (mass functions, bias models; formation mass and redshift; dependence on environment); a comparison with cosmological N-body simulations to assess applicability and limitations of the excursion sets model.
- A study of the subhalo mass function: definition of mass function of accreted satellites; a parametrization of orbital properties of subhaloes and of their mass loss.
- The creation of a database of galaxy groups and clusters, simulated with hydrodynamics, at high resolution, in a fully self-consistent cosmological framework;
- A study of the formation history of these clusters and its correlation with various dynamical properties and observables (e.g. dark matter density concentration, gas density, temperature and entropy structure, gravitational lensing properties)
- A study of the dynamical state of the ICM in galaxy groups and clusters, and its relation to X-ray morphology and dynamics at high redshift; its influence on X-ray mass estimators;
- The creation of an original software to simulate X-ray observations of these clusters; test, calibration and applications;

In the period 2000-2004 the active participation of our group members have produced 44 publications on international refereed journals, plus a number of conference proceeding, for a total of almost 1200 ADS citations.

Project 1: Ellipsoidal collapse and properties of dark matter haloes

Sheth & Tormen (1999) and Sheth, Mo and Tormen (2001) propose a refinement of the classical Press-Schechter theory using the ellipsoidal collapse model instead of the spherical one. Using the excursion set formalism, this change amounts to taking a linear collapse threshold δ_c that depends on halo mass instead of being constant: $\delta_c(M)$.

This simple modification leads to analytical prediction in much better agreement with numerical simulations (Sheth & Tormen 2002), so that the ellipsoidal collapse model can now be used to accurately predict the mass function of collapsed object over a wide range of masses and redshifts.

Project 2: Accretion history of dark matter haloes

Press-Schechter-like (PS) theories can predict the mass function of dark matter haloes, but not their specific mass growth history. The latter must be obtained using numerical simulations. The PS models, expressed through excursion sets formalism, suggests a way to appropriately rescale physical masses, so that the shape of the mass accretion history becomes independent of halo mass. A further ingredient in the accretion

history of dark matter haloes – or galaxy clusters – is the mass function of satellites accreted onto the most massive halo progenitor.

The mass function of accreted satellites, and an expression for the mean mass growth history for the host halo, are starting ingredients to calibrate an analytical expression for the mass function of subhaloes, a quantity to be compared to the mass function of galaxies in a galaxy cluster, or of satellites of a galaxy (Van den Bosch et al. 2005).

Our group is working on this subject using different sets of numerical simulations. On one hand large N-body runs with only dark matter, in order to have a large statistical sample for the calibration. On the other hand a set of high resolution hydrodynamical simulations of galaxy clusters, in order to study the evolution of subhaloes more in detail, both for the dark matter and the gas component.

Project 3: Structure and dynamics of galaxy clusters

We have been using a large set of hydrodynamical simulations of galaxy clusters and groups to study the structure of dark matter and gas in these systems.

In Rasia et al. (2004) we obtain simple analytic formulae for the dark matter and hot gas distribution, in the spherical approximation. We use these models to test the dynamical equilibrium hypothesis through the Jeans equation. We then extend our analysis to the hot gas component, obtaining analytic fits for the gas density, temperature and velocity structure, with no further hypothesis on the gas dynamical status or state equation. We use a generalization of the hydrostatic equilibrium equation, where the gas motion is properly taken into account, and assess the accuracy of mass estimates based on the spherical approximation.

In Tormen et al. (2004) we analyse the dynamical and thermal evolution of dark matter and the intra-cluster medium, by following the build-up of the systems in dark matter and hot gas through the repeated merging of satellites along their merging history trees. We measure the self-bound mass fraction of subhaloes as a function of time after the merging, estimate the satellite mean orbital properties as a function of the mass ratio with the main cluster at merging time, and study the evolution of their internal velocity dispersion, gas temperature and entropy as the substructure is disrupted by various dynamical processes, eventually reaching thermodynamic equilibrium in the gravitational potential of the main cluster. We model some relevant properties of subhalo orbits, as the time of the first pericentric and apocentric passages, and the typical distances and velocities at the corresponding times, and use these results to interpret the dynamics of observed merging clusters.

Project 4: Simulations of X-ray observations of galaxy clusters

A comparison of the X-ray properties of simulated galaxy clusters to those of observed clusters may be performed at different levels of sophistication, using different observable cluster features. An important quantity is the projected temperature of the intra-cluster medium (ICM). However, observational estimates of X-ray temperature differ from any simple estimate obtained with simulations. This is due to many different causes, both physical ones (non isothermal cluster, emissivity is a function of temperature,...) and instrumental ones (limited X-ray band; background noise,...).

In order to overcome these problems at least partially, simulated X-ray observations are needed. Such simulations will take a numerically simulated cluster and reproduce the instrumental features and observational procedure in the most accurate possible way.

Our group has developed a software: X-Ray Map Simulator (X-MAS) capable of accurately reproduce observations from the ACIS-S3 sensor of the Chandra X-ray telescope (Gardini et al. 2004). This software has been used to estimate temperature bias introduced in comparisons between observations and simulations where the above mentioned effects are not properly taken into account (Mazzotta et al. 2004). Our next goal is to determine the best observational approach capable to extract from these observations the most unbiased information on cluster dynamics and on cosmological parameters (Rasia et al. 2005).

Project 5: Strong gravitational lensing from galaxy clusters

Galaxy clusters are powerful gravitational telescopes. Their gravitational field magnifies and distorts the images of background galaxies, creating features ranging from giant arcs, to arclets, to weak and microlensing effects. The position, shape and statistics of giant arcs can be used to map the shape of the gravitational well of the clusters, and eventually to constrain cosmological parameters. In Meneghetti et al. (2000,2001,2003) and Torri et al. (2004) we study different problems and their impact on arc statistics: the effect of cluster galaxies, the effect of the presence of a cD galaxy, the effect of changing the background cosmology as influenced by the presence of a dark energy field, the importance of major mergers in enhancing the arc production capability, the effect of gas physics on arc production.

Personnel:

Tormen Giuseppe (ricercatore)
Moscardini Lauro (ricercatore: 2000-2002)
Meneghetti Massimo (PhD 2000-2003; Post-doc 2004)
Dolag Klaus (Post-doc Marie Curie: 2002-2004)
Gardini Alessandro (Assegnista: 2001-2002)
Rasia Elena (PhD 2003-)
Maturi Matteo (PhD 2003-)

Collaborations:

Prof. Ravi Sheth (Univ. of Pennsylvania);
Prof. Matthias Bartelmann (ITA Heidelberg),
Prof. Simon White (MPA Garching);
Prof. Stefano Borgani (Univ. Trieste).
Prof. Lauro Moscardini (Univ. Bologna 2003-)

Research Products:

2000: 6 refereed papers + 3 conference proceedings
2001: 5 refereed papers + 4 conference proceedings
2002: 4 refereed papers + 2 conference proceedings
2003: 5 refereed papers + 2 conference proceedings
2004: 24 refereed papers + 12 conference proceedings

List of 5 most representative publications:

1. Sheth R. K., Mo H. J., Tormen G. 2001, Ellipsoidal collapse and an improved model for the number and spatial distribution of dark matter haloes, *Monthly Notices of the Royal Astronomical Society*, Volume 323, Issue 1, pp. 1-12., 323, 12
2. Sheth R. K., Tormen G. 2002, An excursion set model of hierarchical clustering: ellipsoidal collapse and the moving barrier, *Monthly Notices of the Royal Astronomical Society*, Volume 329, Issue 1, pp. 61-75., 329, 75
3. Rasia E., Tormen G., Moscardini L. 2004, A dynamical model for the distribution of dark matter and gas in galaxy clusters, *Monthly Notices of the Royal Astronomical Society*, Volume 351, Issue 1, pp. 237-252., 351, 252
4. Borgani S., Murante G., Springel V., Diaferio A., Dolag K., Moscardini L., Tormen G., Tornatore L., Tozzi P. 2004, X-ray properties of galaxy clusters and groups from a cosmological hydrodynamical simulation, *Monthly Notices of the Royal Astronomical Society*, Volume 348, Issue 3, pp. 1078-1096., 348, 1096
5. Gardini A., Rasia E., Mazzotta P., Tormen G., De Grandi S., Moscardini L. 2004, Simulating Chandra observations of galaxy clusters, *Monthly Notices of the Royal Astronomical Society*, Volume 351, Issue 2, pp. 505-514., 351, 514