Research Interests

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Summary

• I am interested in the study of the high redshift Universe (formation of the first stars and reionization). In this respect, I am considering the modifications to the standard scenario that may be due to neglected physical processes, such as the influence of HD molecules, the effects of decaying or annihilating dark matter (DM) particles, and especially the feedback effects from mini-quasars.

• I am interested in the study of Local Group dwarf galaxies, as they provide an important test for cosmological models of structure formation.

• I address these problems from a theoretical point of view. My methods of choice are numerical simulations, such as 1-D codes for the formation of primordial protostars, and SPH codes for the study of dwarf galaxies.

High redshift Universe

My scientific interests are directed towards theoretical cosmology, and in particular to the study of the transition from the almost uniform, neutral and dark universe of the so-called "dark ages" to the clumpy and ionized universe that we know from observations at low redshifts.

This includes the study of the formation of the first structures, of the properties of the first luminous objects (stars or accreting black holes) inside them, and of feedback effects such as the metal enrichment, the heating and the reionization of the inter-galactic medium (IGM).

In my Ph.D., I studied the formation process of the very first stars, investigating their collapse in the high density regime ($n > 10^{10}$ cm^{-3}). Because of radiative transfer effects, such regime was inaccessible to numerical 3-D simulations until very recently (see Abel, Bryan & Norman 2002; Bromm, Coppi & Larson 2002; and the more recent results of Yoshida *et al.* 2006, reaching $n \simeq 10^{16}$ cm^{-3} for the first time). I developed a Lagrangian, spherically symmetric 1-D hydrodynamical code including the treatment of chemical reactions in a metal-free gas, the detailed radiative transfer of continuum and especially line radiation, and the effects of shocks and radiation pressure. This code can follow the contraction of a gas clump up to densities ~ 1 g cm^{-3}, so that the differences between primordial and present-day star formation can be assessed, and luminosities and the spectra of primordial protostars can be estimated (Ripamonti *et al.* 2002).

Results from this code were used also for other purposes (see Ripamonti & Abel 2004): (i) gauging approximate cooling rates at densities up to $n \sim 10^{16}$ cm^{-3}, to be included in 3-D hydrodynamical codes, and (ii) assessing the stability of the protostellar cloud against fragmentation: we found that fragmentation is unlikely, as the various instabilities (due to fast H_2 formation, or to the onset of continuum cooling) develop quite slowly. Both results are in good agreement with the more recent Yoshida *et al.* 2006 calculations.

I also explored in detail the effects of HD molecules upon primordial structure formation, and upon the properties of the first objects. H_2 molecules are the main coolants of metal-free gas in the first virializing halos; but at low temperatures (≤ 200 K) HD molecules dominate the cooling, despite their low number abundance. I found that HD has no influence upon the critical mass which is needed for a halo to collapse and form a luminous object (cfr. Tegmark *et al.* 1997), but substantially reduces the Jeans mass (and probably the typical stellar mass) inside halos with mass just above the critical mass (Ripamonti 2007).

A similar analysis was applied to to estimating how decaying or annihilating DM particles can inject energy into the high-redshift IGM, and whether the effects of this energy injection are significant. This possibility is a natural consequence of the properties of some DM candidates, and could also provide an explanation for the measurement of 511 keV photons coming from the Galactic center by INTEGRAL/SPI (Knödlseder *et al.* 2005). Such effects depend on the properties of the considered DM candidate; but their contribution to the IGM heating is generally significant, although difficult to detect (Ripamonti, Mapelli & Ferrara 2007a). DM decays and annihilations can also delay the structure formation by increasing the critical mass; however, this effect appears to be quite small, too (Ripamonti, Mapelli & Ferrara 2007b), and alter the 21 cm emission from the high redshift IGM (Valdés *et al.* 2007). I am now looking at whether DM annihilations can affect the final phases of the collapse of primordial protostellar clouds: such objects are believed to coincide with high density cusps of DM halos, where the annihilation rate is very high so that they might provide an important source of heating (see e.g. Spolyar, Freese & Gondolo 2007; Ripamonti & Ferrara 2008, in preparation)

I have also studied the influence on the IGM of the emission from accreting primordial black holes (BHs). Such emission should be able to heat the IGM up to 10^4 K, and its effects might be detected by future 21-cm experiments. Also the effects upon structure formation should be much stronger than in the decaying/annihilating DM scenarios (Ripamonti, Mapelli & Zaroubi 2008). I am now looking also at the local feedback effects of BHs (e.g, a BH in the progenitor of a large galaxy might prevent star formation in small satellite halos; Ripamonti & Zaroubi 2008a, in preparation), and at observational signatures of the high redshift BHs in order to distinguish their effects from those of high mass X-ray binaries which might be associated to primordial star formation (see e.g. Pritchard & Furlanetto 2007; Ripamonti & Zaroubi 2008b, in preparation)

Dwarf galaxies

Dwarf galaxies, and especially those of the Local Group, can be used to test several predictions of cosmological theories, such as the hierarchical paradigm. For example, their number counts can be compared to the predictions of numerical simulations, and the abundance patterns in their stars should be similar to what is observed in the Milky Way (MW) halo or thick disk. It is also believed that at least some of them are “fossils” which can provide us with informations about their formation epochs.

Actually, the observational results about dwarfs pose a significant challenge to the standard theoretical models of galaxy formation, because there exists a substantial tension between theory and observations. For example, the number of MW satellites predicted by numerical simulations is significantly higher than what is observed, and the metal abundance patterns of stars inside these satellites is different from those of MW stars, which is difficult to reconcile with the hypotesis that a large fraction of the MW was built up by mergers.

Given the wealth of observational data which is becoming available through large projects such as DART (Dwarf Abundance and Radial velocity Team), I started building a numerical code which could give us a deeper understanding of dwarfs, and in particular of their metal enrichment properties.

In fact, their small size and relatively unevolved status makes dwarfs particularly suitable for this kind of numerical simulations. The code is based upon the public SPH code Gadget (Springel 2001, Springel 2005), which accounts for gravity and hydrodynamics, and incorporates a star formation criterion and the dynamical and chemical feedback from supernovae and stellar winds. The small size of the simulated halos allows to follow the star formation and evolutionary history of the galaxy in great detail, so that it is possible to obtain the metallicity distributions and abundance patterns of the stars, together with their dependence on parameters such as the position inside the galaxy and their kinematical status.

Preliminary results (Ripamonti *et al.* 2006; Ripamonti *et al.* 2008, in preparation) indicate that this kind of models can reproduce several interesting observational features.

For example, in the case of the Sculptor and Fornax dwarfs , the simulations can reproduce the observed radial density profile of stars, and also more subtle effects such as the radial metallicity gradient between the centre and the periphery (see Tolstoy *et al.* 2004; Battaglia *et al.* 2006).

Another important fact emerging from observations is that all Local Group dwarfs exhibit a sharp cutoff at the low end of their stellar metallicity distribution (stars with $[Fe/H] \leq -3$ are nearly absent). This cutoff cannot be reproduced with simulations, unless the dwarfs formed from pre-enriched gas, or their initial IMF was poor in low mass ($m \leq 1 M_{\odot}$) stars. In both cases, this can be an important clue for our understanding of the primordial Universe.

Furthermore, the comparison of the metallicity distributions obtained from observations and from simulations indirectly confirms that metals in SN ejecta are easily expelled from dwarf galaxy (see e.g. Mac Low & Ferrara 1999).

I also checked the hypothesis of recent star formation in the Draco and Ursa Minor dwarf spheroidals by looking at a sample of blue straggler star (BSS) candidates. The analysis of observations and the comparison with theoretical models indicate that the properties of these stars are compatible with predictions for real BSS, even if intermediate age stars still provide a viable alternative explanation (Mapelli et al. 2007).

Further interests

I am collaborating with Dr. M. Mapelli and the University of Zürich numerical group (led by Prof. Ben Moore) in a project about the formation mechanism and the fate of ring galaxies. Numerical simulations indicate that ring galaxies might be the product of a galaxy collision in which the intruder galaxy collided with a disk galaxy from a direction nearly perpendicular to the disk, and might evolve into giant low surface brightness galaxies such as Malin 1 (Mapelli et al. 2008a, 2008b).

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