Garrotxa simulations: Hot gas distribution around Milky Way size galaxies at z=0

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Abstract

We present a new set of cosmological Milky Way size galaxy simulations using ART. In our simulations the main system has been evolved inside a 28 Mpc cosmological box with a spatial resolution of 109 pc. At z=0 our systems have an $M_{vir} = 6-8\times10^{11}$ $M_{\odot}$. In several of our models we have observed how a well defined disk is formed inside the dark matter halo and the overall amount of gas and stars is comparable with MW observations. Several non-axisymmetric structures arise out of the disk: spirals, bars and also a warp. We have also observed that a huge reservoir of hot gas is present at large distances from the disk, embedded in the dark matter halo region, accounting for only a fraction of the "missing baryons". Gas column density, emission (EM) and dispersion (DM) measure have been computed from inside the simulated disk at a position of 8 kpc from the center and in several directions. Our preliminary results reveal that the distribution of hot gas is non-isotropic according with observations ([6], [7]). Also its metallic content presents a clear bimodality what is a consequence of a recent accretion of a satellite galaxy among others. After a careful analysis we confirm that due to the anisotropy in the gas distribution a new observational parameter needs to be defined to recover the real distribution of hot gas in the galactic halo ([11]).

1   Introduction

Nowadays it is commonly accepted that the amount of baryons observed in the local universe is much below the one inferred from cosmology. This lack of baryons in galaxies is known as

the "missing baryons problem".

To solve this missing baryons problem several authors proposed that galactic winds, SNe feedback or strong AGN winds ejected part of the galactic baryons to the dark matter halo and circumgalactic medium (CGM) as hot gas. Others authors proposed that also part of the gas never collapsed into the dark matter halos as it was previously heated by SNe of Population III.

From the point of view of large volume hydrodynamical galaxy formation simulations, some attempts have been made in order to investigate the presence and detectability of hot gas halo corona (e.g. [10]) and some succeeded in obtaining realistic results when compared with observations (e.g. [4]).

From an observational point of view, first detections where done by [5] in external galaxies and later on several authors get better detections in other systems and studied them deeper (e.g. [1]). These detections were done by the analysis of X-ray absorption lines from OVII and OVIII which only exist in environments with temperatures between 10^6 and 10^7 K. The problem of using this technique is that these X-ray absorption lines only can be observed in the directions of extragalactic luminous sources (QSO, AGN, ...) or galactic X-ray emitters as X-ray binaries.

Here we have studied how the hot gas component embedded in the DM halo can account for part of the missing baryons in galaxies and also its distribution and properties, using new high resolution simulations. We also studied possible *observational biases* in the determination of total hot gas mass, when only a small number of line of sight observations are used.

2   GARROTXA models

Simulations used here have been run using the Eulerian hydrodynamics + N-body ART code ([8], [9]) and the commonly used zoom-in technique. Selected DM halos have had not major mergers since z=1.5 and that at z=0 have not a a similar mass companion inside a sphere of 1 Mpc h^{-1}. For more details on the code and halo selection process see [2], [11] and [3].

All selected halos have been simulated up to z=0. At this time all of them host a massive disk galaxy with several non-axisymmetric structures such as bars or spirals. The disk scale height and length in our models depends on the age of the stellar population, while the former is higher the latter is smaller when the population gets older. Gas distribution in all our models is not isotropic and depends on gas temperature: cold gas is present inside the young stellar disk and hot gas fills the out-of-plane region and is embedded in the DM halo.

3   Discussion and conclusions

3.1   Hot gas spatial distribution and origin

We define hot gas as gas with T $> 3\times10^5$ K. This definition is observationally motivated as real hot gas mass is inferred from observations of the ionized oxygen emission ([6]). In this work we computed the hot gas column density, emission measure and dispersion measure

from a position that is at 8 kpc from the galactic center, inside the simulated galactic disk, resembling the Sun position, and assuming arbitrary azimuthal angles. We have obtained values that fall near the observational ranges, if a solar metallicity is assumed. The distribution of hot gas inferred from all estimations is far from homogeneous (see Fig.1 and 2). In order to quantify the hot gas anisotropy we computed the amplitude of the first spherical harmonics (Y_l^m from l,m=0 to 5) and the filling factor. Our results show that the dominant spherical harmonic is Y_1^0, that is an indicator of the dipolar component. The computation of the mean filling factor from line of sights distributed all along the sky gives as a value of $f_v \sim 0.33 \pm 0.15$. This value for the filling factor also suggests that hot gas is concentrated in a few regions of the sky.

We also analyzed the metals distribution and we have found that it exists a clear bimodality between the northern and southern latitudes and also that several vertical motions and metallicity gradients are present in the hot gas halo. We have found that some low metallic gas is falling from the IGM (cold flows) and hot metallic departs from the stellar disk region (SN feedback, stellar winds...). We have also observed that some hot metallic gas is also falling to the system, associated with a small gaseous satellite that is passing through the system at z=0.

3.2   Missing baryons, halo virial mass and the total hot gas in galaxies

The baryonic fraction in our simulated galaxies reaches (0.107−0.120). These values are still far from the cosmic baryon fraction ($F_{b,U}$=0.17) even after adding the hot gas mass component inside halos. However, because we do not include the feedback effect of an AGN, that may eject the gas outside the halo, we can consider our estimates as an upper limit to the halo hot gas mass. We argue that the still missing baryons must be placed both in the IGM and along the filaments and far from the main galactic systems.

Another result we have obtained after analyzing several models of MW-sized systems, a few of more massive or lighter and also some with different feedback recipes, is that M_{vir} correlates well with total hot gas mass. If finally confirmed this linear correlation will provide a new constraint to virial mass in galaxies, including the Milky Way.

3.3   Observational biases

We have used simulations to detect possible observational biases that arise from observational technique and used assumptions. With such aim we have located a mock observer at 8 kpc from the galactic center inside our MW-sized simulations. We have computed the column density and the Emission Measure, and from them the total galactic hot gas mass. We have found that using the spherical uniform approach, the total hot gas mass is systematically overestimated or underestimated depending on the technique (see [11]). This result is a consequence of that the real density distribution of our model is not uniform but decreasing with radius as a power law.

As a conclusion we state that using both, column density plus imposed optical depth or a combination of column density and emission measure, we are not able to obtain the real hot halo gas mass, when assuming it is isotropically distributed in the galactic halo. Nevertheless,
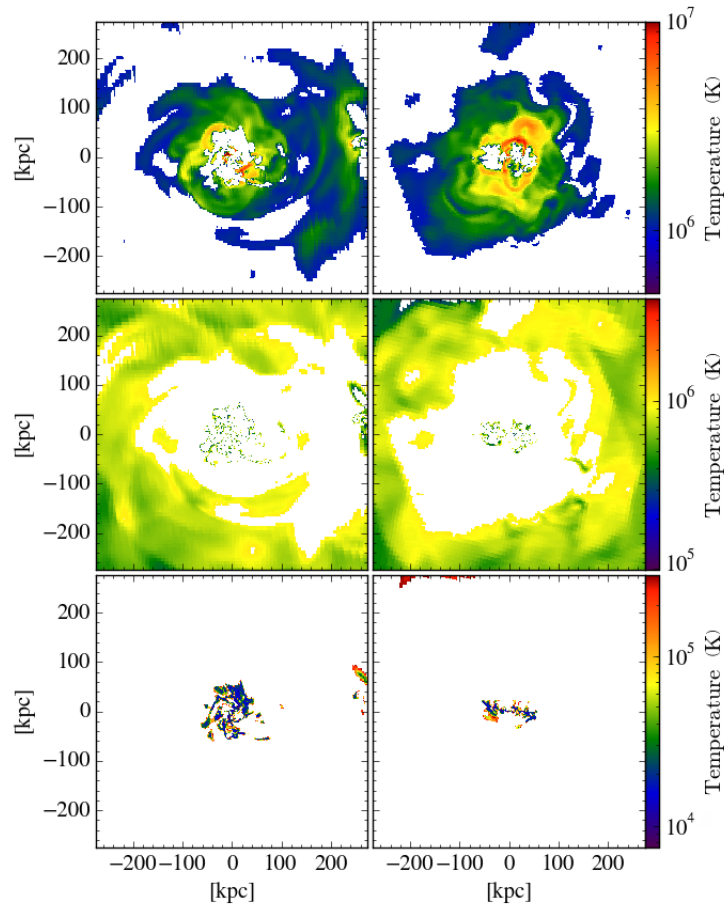
Figure 1: Face-on (left) and edge-on (right) distribution of hot, warm and cold gas components (top, middle and bottom, respectively), colored by temperature. In this plot we show the main GARROTXA model at z = 0.
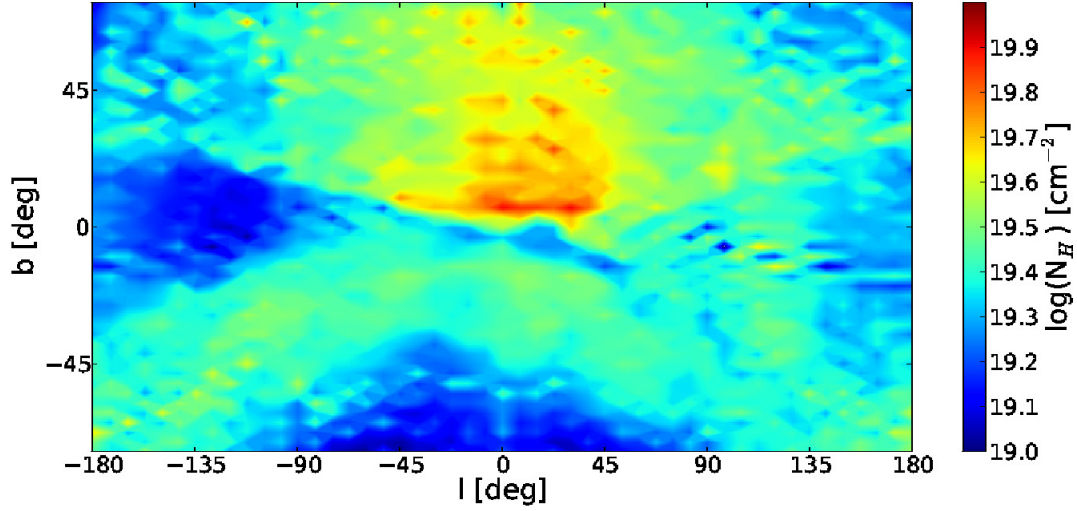
Figure 2: Hot gas column density in a full sky view in galactic coordinates, at z = 0.

these measurements, particularly the observational method in the literature using both, N_H and EM are useful to get an order of magnitude estimate of the total hot gas mass of the halo. The work is in progress to find the density profile that will allow us to get the best hot halo gas mass estimation, from observations.

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