HI CONTENT, 3D STRUCTURE AND DYNAMICS OF THE VIRGO CLUSTER REGION

T. Sanchis and E. Salvador-Solé
Departament d'Astronomia i Meteorologia, Universitat de Barcelona. Av. Diagonal 647; E–08028 Barcelona, Spain

J.M. Solanes and S. Gómez
Dept. d'Enginyeria Informàtica i Matemàtiques, Universitat Rovira i Virgili. Av. dels Països Catalans, 26; E–43007 Tarragona, Spain

Abstract

The H I content and Tully-Fisher distances of 161 spiral galaxies in the region of the Virgo cluster are used to gain insight into the complicated structure of this galaxy system and to constrain the role played by interactions with the hot intracluster medium on the exhaustion of the interstellar H I. We confirm previous findings that the spiral distribution is substantially more elongated toward the line-of-sight than in the plane of the sky. The filamentary structure is also reproduced in the H I deficiency distribution, which shows a central enhancement suggestive of bearing the Virgo cluster proper, extending from around 16 to 22 Mpc in radial distance, but also important enhancements in the cluster front and in a group of background galaxies. The fact that some of the spirals on the Virgo outskirts exhibit gas deficiencies as strong as those of the inner galaxies has led us to explore, by means of a dynamical model, the possibility that some peripheral objects are not newcomers. We conclude that it is not unfeasible that some of the galaxies far from the cluster, including the H I-deficient background group, have already plunged in the past into the Virgo cluster.

1. Motivation and Data Sources

Galaxies in clusters experience strong interactions that can considerably alter their properties. The Virgo cluster is, because of its proximity and richness, and ideal candidate to carry out studies of the environmental effects on galaxy evolution.

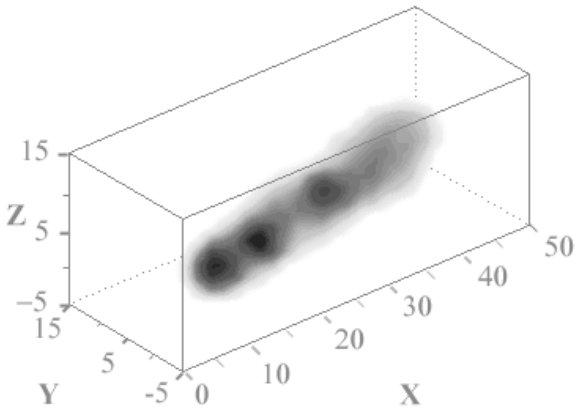

Figure 1. Voxel projection of the 3D distribution of H I deficiency in the VIC region. The plot is in rectangular equatorial coordinates with distances given in Mpc. The xy-plane corresponds to Decl. = 0°, the x- and y-axis point to R.A. = 12 and 18 hr, respectively, and the z-axis points to the north. Our position is at the origin of the coordinate system.

Solanes et al. 2001 found in a 2D distribution of the H I deficiency of the spiral galaxies of the cluster peaks of H I-deficiency placed in peripheral zones away from the cluster core, contrarily to the radial pattern characteristic of rich clusters, where H I deficiency increases monotically towards the center.

To investigate if those were real enhancements and not a superposition effect we decided to combine the H I data with Tully-Fisher distance estimators in order to construct a catalog with as many spiral galaxies as possible with known H I deficiency and TF distance. Our primary source for the neutral hydrogen contents is the Arecibo General Catalog, a private database maintained by R. Giovanelli and M.P. Haynes at the Cornell University. Galaxy distances are extracted from 8 surveys based on the Tully-Fisher (TF) method (see bibliography). All the TF datasets have been homogenized by a regression analysis. Our final catalog has 161 galaxies with reliable H I content and distance data.

2. Tridimensional H I Distribution

In Figure 1 we show the 3D distribution of the H I-deficient galaxies in the Virgo I Cluster (VIC) region. The shade intensity informs on the average H I deficiency of the galaxy distribution. We identify three dark spots with a dearth of neutral hydrogen. The central one corresponds to the cluster core, at line of sight (LOS) distances ranging from ~ 16 up to 22 Mpc. Two more enhancements of H I deficiency can be seen. One in the frontside associated with galaxies at LOS distances $\sim$ 10-15 Mpc and another one in the backside, related to a background group of galaxies at LOS distances $\sim$ 25-30 Mpc lying in the region of the classical W' cloud. In the Virgo region the H I content of the galaxies is therefore not a fair indicator of cluster membership.

3. Infall Model with Rebound

The background enhancement of H I deficiency arises from a tight aggregation of galaxies segregated in the four-dimensional position-radial velocity phase space. We count up to 15 objects related to this clump, one third of them having deficiencies deviating more than 2σ from normalcy. Such values of deficiency are comparable to those found in galaxies near the cluster core where ram pressure stripping can naturally account for the dearth of neutral hydrogen. However, this mechanism can hardly explain the gas deficiency of galaxies located so far away from the cluster center unless they were actually not newcomers but had plunged into the VIC core in the past with very high relative velocities.

We have investigated this interesting possibility by means of a straightforward dynamical spherical model for a zero-pressure fluid that treats galaxies as test particles under the potential created by a constant mass in the center of the cluster. We extend the calculations beyond the first passage of the galaxies through the cluster core until galaxies recollapse again in order to place those galaxies in second infall in the virgocentric velocity field. Our model involves parameterization in terms of t_0, $M_{\rm VIC}$, $R_{\rm VIC}$, and $V_{\rm VIC}$. Three of these parameters are independent but, the complexity of the virgocentric velocity field (see Figure 2) along with the simplicity of our model, made us fix $V_{\rm VIC}$ to 980 km s^{-1} while varying freely the Virgo mass and distance. We put all the weight of the fits on the observations on the envelope to the streaming velocities expected to approach asymptoticaly the local Hubble law because these observations offer the highest constraining power, are unaffected by shell crossing (effect that our model neglects) and are also insenstive to the angular distance from the VIC center. In Figure 2 we present our best fit corresponding to $M_{\rm VIC} = 2.8 \times 10^{15}$ M$_\odot$, $R_{\rm VIC} = 21.0$ Mpc and

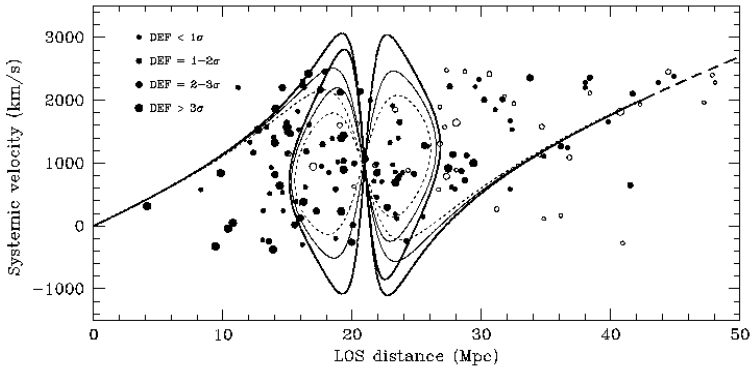

Figure 2. Systemic velocity vs. LOS distance for Virgo spirals. The curves demonstrate the predicted velocities for $\theta = 4°$ (thick solid), $\theta = 6°$ (thin solid), and $\theta = 8°$ (dotted). The dashed portion at large Virgocentric distances is for unbound shells. Galaxies with uncertain distances (open symbols) have been excluded from the fit. Parameter DEF measures H I deficiency in units of the mean standard deviation for field objects (= 0.24).

$t_0 = 13.5$ Gyr, values in reasonable agreement with previous estimates in the literature. We can see in this figure that various H I-deficient galaxies (including those belonging to the background group in the region of the W' cloud) can be accomodated on an orbit following rebound. We are therefore compelled to conclude that it is not unfeasible that these galaxies are not recent arrivals but have already plunged into the VIC center in the past and lost their H I through interactions with the hot intracluster medium.

References

Ekholm T., Lanoix, P., Teerikorpi, P., Fouqué, P., & Paturel, G. 2000, A&A, 355, 835

Federspiel, M., Tammann, G.A., & Sandage, A. 1998, ApJ, 495, 115

Fouqué, P., Bottinelli, L., Gouguenheim, L., & Paturel, G. 1990, ApJ, 349, 1

Gavazzi, G., Boselli, A., Scodeggio, M., Pierini, D., & Belsole, E. 1999, MNRAS, 304, 595

Kraan-Korteweg, R.C., Cameron, L.M., & Tammann, G.A. 1988, ApJ, 331, 620

Mould, J., Aaronson, M., & Huchra, J. 1980, ApJ, 238, 458

Pierce, M.J., & Tully, R.B. 1988, ApJ, 330, 579

Solanes, J.M., Manrique, A., González-Casado, G., García-Gómez, C., Giovanelli, R., & Haynes, M.P. 2001, ApJ, 548, 97

Yasuda, N., Fukugita, M., & Okamura, S. 1997, ApJS, 108, 417