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DISTANCE AND DYNAMICAL MASS OF THE VIRGO CLUSTER

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Tolman-Bondi-model and distances from the Tully-Fisher relation yield a distance to Virgo cluster 20-24 Mpc. Comparison with Virgo core galaxies (Federspiel *et al.* [3]) seems to favour 24 Mpc. High quality distances from the extragalactic Cepheid PL-relation support 21 Mpc, which is our preferred value (Ekholm *et al.* [1], [2]) . The Virgo cluster mass is 1.5-2 times larger than the Virgo virial mass (Tully & Shaya [8]). We find a steeper density profile for the gravitating matter (2.5-2.85) than for luminous matter (2.3).

1 The Tolman-Bondi model

The Tolman-Bondi solution describes the behaviour of a spherically symmetric pressure-free dust universe:

$$ds(r,\tau)^2 = d\tau^2 - \frac{R'(r,\tau)^2}{1+f(r)}dr^2 - R(r,\tau)^2 d\Omega^2, \tag{1}$$

where $d\Omega^2 = d\theta^2 + \sin^2\theta d\phi^2$. There are three unknown functions of the comoving radial coordinate. $f(r)$ is proportional to the total energy of the hypersurface of radius r, $F(r)$ is proportional to the mass inside r and $\tau(r)$ is the "bangtime" function. We assume a single bangtime for all mass shells, i.e. all the shells emerged at the beginning of the universe (Olson & Silk [5]).

As regards the mass model we adopted a simple density profile given as a sum of an excess density distribution and a uniform cosmological background. We assumed Einstein-deSitter universe. For technical details confer Ekholm et al. [1].

2 On the Distance to Virgo cluster

Ekholm *et al.* [1] found using the simple density model described above that the distance to Virgo cluster is about 21 Mpc. This result was based on 12 galaxies within a 30 degree cone from the centre of Virgo having distance moduli based on the extragalactic Cepheid PL-relation (see the Lyon Extragalactic Cepheid Database at www-obs.univ-lyon1.fr and Lanoix *et al.* [4])

Fig. 1

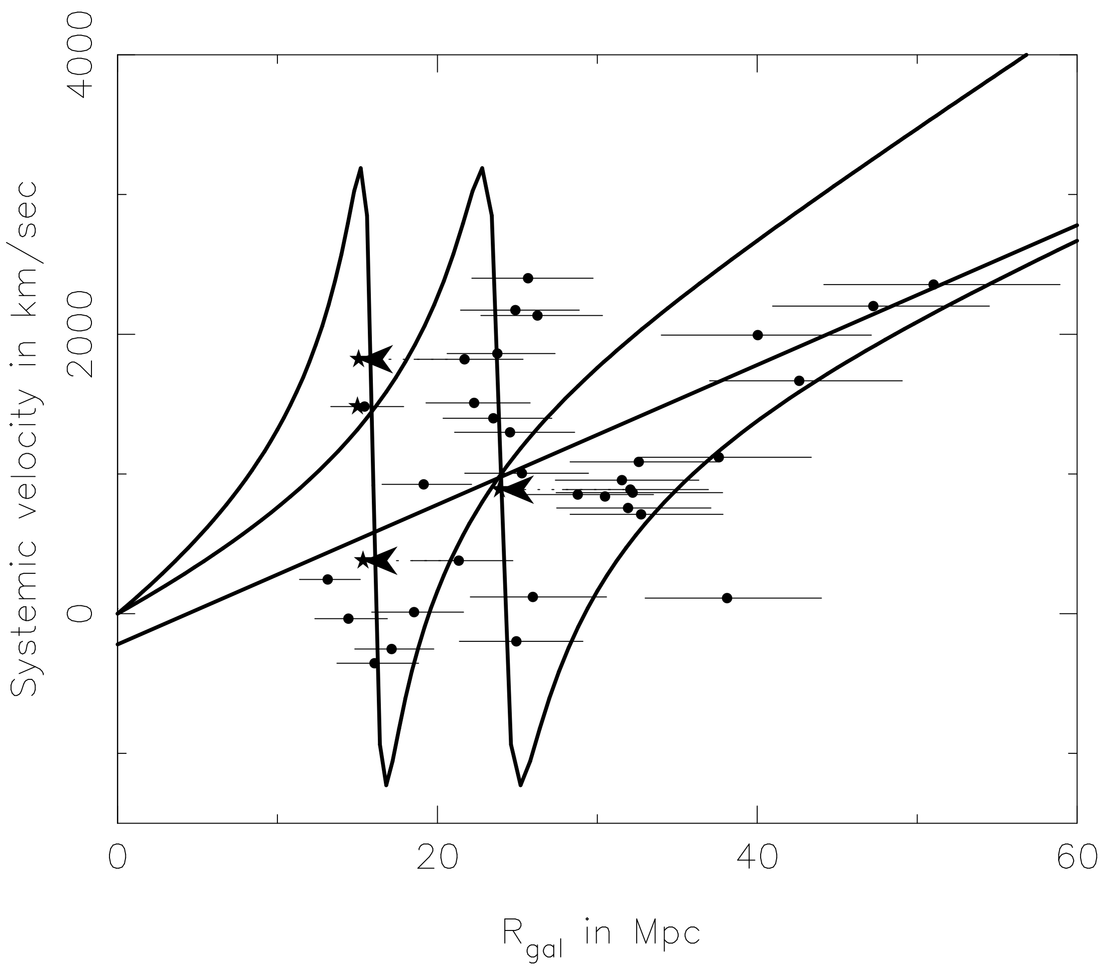

Figure 1: Galaxies with Tully-Fisher distances in the direction of the core of the Virgo cluster. The curves are the Tolman-Bondi solutions for 16 and 24 Mpc. The straight line is the adopted Hubble law with $H_0 = 57\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$. The stars refer to distances with extragalactic PL-distances. The concentration of galaxies behind the centre are obviously galaxies around M49.

Galaxies with Cepheid distance moduli did not trace the backside of the Virgo Supercluster well enough. Ekholm *et al.* [2] studied the background using the B-band magnitude Tully-Fisher relation (Theureau *et al.* [7]). They also compared the central Virgo cluster region with the data provided by Federspiel *et al.* [3].

Ekholm *et al.* [2] found out that the Tully-Fisher distances predict a rather large distance to Virgo cluster (24 Mpc). Only 15% of the Virgo core galaxies disagreed with the model adopted at 2σ level. Quite recently Tully & Pierce [9] argued that Virgo cluster is at 16 Mpc. The closer 'S'-curve in Fig. 1 is the Tolman-Bondi prediction for 16 Mpc. One can see how the majority of points agrees better with the more distant prediction (24 Mpc). In particular, the low velocity population can be be interpreted as galaxies ejected from the core.

3 Mass Estimate for Virgo Cluster

In order to determine the dynamical mass of the Virgo cluster we used the high-quality galaxies with Cepheid distances and selected them spherically around the Virgo core. We also adopted a two-component mass model in which we fixed the mass within 6 degrees at Virgo distance to

Fig. 2

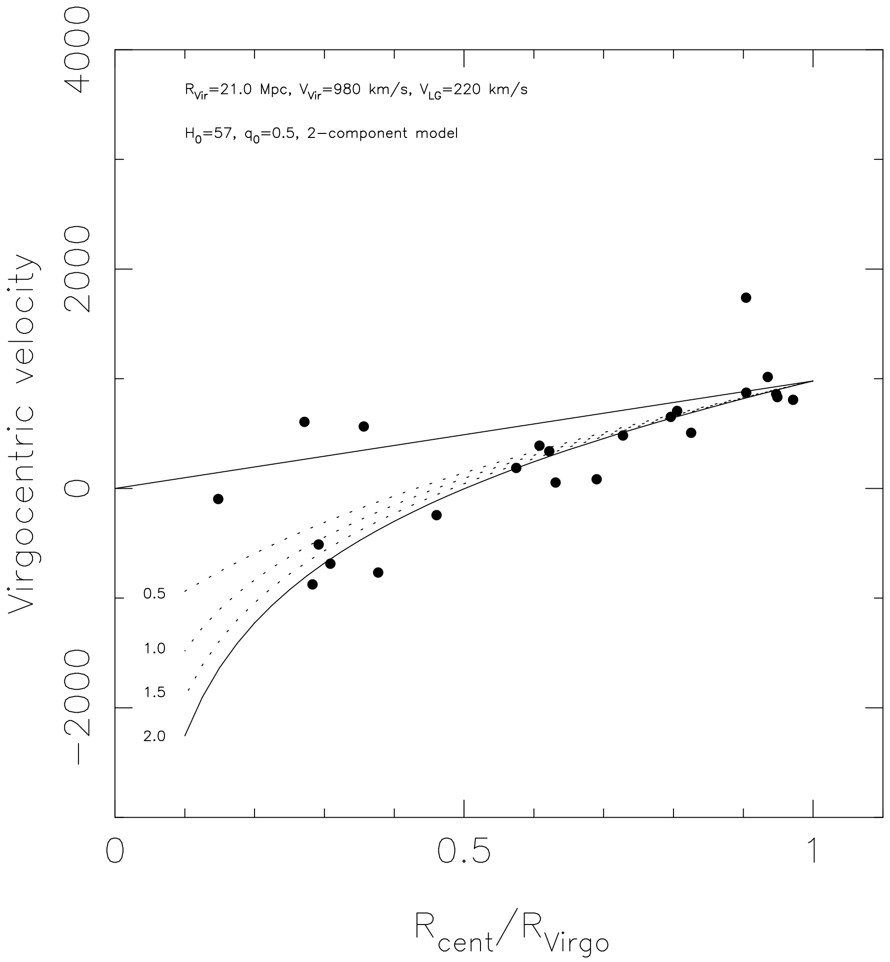

Figure 2: Galaxies with Cepheid distances as seen from the centre of Virgo cluster. These galaxies fit best the distance to Virgo 21 Mpc. Galaxies at small distance from Virgo and having relatively high velocity are probably ejected from the centre.

be proportional to the virial mass given by Tully & Shaya [8]. Outside this region the mass obeys the declining density model of Ekholm *et al.* [1].

It turns out that the Cepheid-based distances agree with 21 Mpc also when studying the structure as it would be seen from the centre (Fig. 2). We note that the difference between 21 Mpc and 24 Mpc – in terms of the distance modulus – is only 0.39 magnitudes which is clearly within the 1σ error of the Tully-Fisher relation. In agreement with Teerikorpi *et al.* [6] we found out that the dynamical mass estimate is about 1.5 - 2 times larger than the virial mass.

Finally, we estimate that the gravitating mass has a density gradient 2.5 - 2.85 while the luminous matter has less steep gradient (2.3). This supports the idea that the dark matter is more concentrated and more symmetrically distributed in clusters.

Acknowledgments

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References

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