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GALAXY GROUPS AND MODIFIED DYNAMICS

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ABSTRACT

I estimate median, modified dynamics (MOND) M/L values for recently published catalogs of galaxy groups. While the median, Newtonian M/L values quoted for these catalogs are 110–200 h_{75} $(M/L)_\odot$, the corresponding values for MOND are less than 10 $(M/L)_\odot$ (where the mass includes contributions from galactic and intragroup gas).

Subject headings: dark matter — galaxies: kinematics and dynamics

1. INTRODUCTION

Modified dynamics (MOND)—propounded as an alternative to dark matter (Milgrom 1983a)—has been extensively tested on individual galaxies (e.g., Sanders 1996; McGaugh & de Blok 1998; Sanders & Verheijen 1998; and references therein). The next rung on the ladder—binary galaxies—is notoriously unwieldy (mainly because of the high contamination by false pairs). The situation improves for small galaxy groups, for example because identification becomes more secure with an increasing number of members. Still, the uncertainties in the mass determination for an individual group are very large, enough to render the result useless for constraining the amount of dark matter in Newtonian dynamics or for testing MOND. This is reflected in the fact that the dispersion in M/L values deduced for groups is very large. It is hoped that "typical" values deduced for a carefully selected sample of groups—such as median values for the sample—are a faithful representation of the dynamics of groups. Newtonian analyses yield high (median) M/L values for group catalogs: $M/L \sim 110$–$200\ h_{75}\ (M/L)_\odot$.

The only published MOND analysis of groups (Milgrom 1983b) was based on two small group catalogs and employed a primitive, MOND mass estimator in default of a more adequate one, which we have now. Here I revisit the problem with the much more extensive group catalogs that have been published in the meanwhile, using an improved mass estimator. My main source is Tucker et al. (1997), who list a catalog gleaned from the Las Campanas Redshift Survey (LCRS). I also use results based on the groups identified in the CfA survey, CfA1 (Nolthenius & White 1987); in the Southern Sky Redshift Survey (SSRS; Maia, da Costa, & Latham 1987); and in the CfA2 group catalog (Ramella, Pisani, & Geller 1997), all listed for comparison in Tucker et al. (1997). In § 2 I describe the estimator used, in § 3 I summarize the results, and in § 4 I discuss the sources of uncertainty.

2. METHOD

The MOND mass estimator I use for groups is based on the relation

$$\langle\langle(v - v_{\rm com})^2\rangle\rangle_t = \frac{2}{3}(MGa_0)^{1/2}\left[1 - \sum_i (m_i/M)^{3/2}\right] \qquad (1)$$

(Milgrom 1994, 1997a). Here, v is the three-dimensional velocity, $v_{\rm com}$ is the center-of-mass velocity, $\langle\cdots\rangle$ is the mass-weighted average over the constituents, whose masses are m_i, $\langle\cdots\rangle_t$ is the long time average, and M is the total mass. The acceleration constant of MOND is taken to be $a_0 = 1.2 \times 10^{-8}\ h_{75}^2$ cm s^{-2} (Begeman, Broeils, & Sanders 1991). Relation (1) is exact in the deep-MOND limit (all accelerations much smaller than a_0) of the formulation of MOND as modified gravity (Bekenstein & Milgrom 1984). Interestingly, the fact that the time-average rms velocity depends solely on the constituent masses (and not, e.g., on system size) follows from the conformal invariance of this deep-MOND limit (Milgrom 1997a). It is also assumed that the system is isolated in the MOND sense, i.e., is not subject to an external field, and, of course, that it is decoupled from the Hubble flow (the crossing time is much shorter than the Hubble time). To use equation (1) for deriving total masses from existing velocity data, we need to make further approximations: (i) We drop the long time average, conceding that the estimate might be in large error for an individual group. It will still be correct statistically if the sample contains enough "replicas" so that the sample average covers the time average. (ii) Since only line-of-sight velocity data are available, I replace $\langle(v - v_{\rm com})^2\rangle$ by $3\langle(v - v_{\rm com})^2_{\rm los}\rangle$ (again assuming that system average accounts for angular average). Assumptions (i) and (ii) are also made in the Newtonian analysis. (iii) Group catalogs list, almost exclusively, not the mass-weighted velocity dispersion that appears in equation (1) but the number-weighted dispersion, $\sigma_{\rm los} \equiv [\sum_i (v_i - \hat{v})^2_{\rm los}/(N-1)]^{1/2}$, with $\hat{v} = \sum_i v_{i,\rm los}/N$ and N the number of member galaxies in the group. The luminosity-weighted velocity dispersion would be a better measure of the mass-weighted one, but the data for individual groups needed to calculate it are not available to me, so I shall use $\sigma_{\rm los}$ instead. (iv) I approximate the right-hand side of equation (1) by $\frac{2}{3}(MGa_0)^{1/2}$, which is valid in the limit of a large number of constituents, each having a mass $\sim M/N \ll M$ (when all the masses are equal, the correction factor is $\sim 1 - N^{-1/2}$). Implementing these approximations, we get from equation (1)

$$M \approx \frac{81}{4}\sigma^4_{\rm los}(Ga_0)^{-1}. \qquad (2)$$

This is the group-mass estimator I shall use. The large majority of the groups in the catalogs I consider are indeed in the deep-MOND regime (with median acceleration estimates of only a few percent of a_0; see below). The effects of approximations (iii) and (iv) above, as well as a discussion of the effects of external fields, will be discussed in § 4.

3. RESULTS

Table 1 of Tucker et al. (1997) lists the median group properties for their own sample, together with those for the other catalogs listed above. The relevant entries (normalized to $H_0 = 75$ km s^{-1} Mpc^{-1}) are reproduced in my Table 1, together with the results of the MOND analysis:

Row (*1*).—The number of groups in the sample, N. (Tucker et al. 1997 have extracted from their full catalog of 1495 groups a subsample of higher quality for analysis, containing 394 groups.)

Row (*2*).—The median line-of-sight velocity dispersion, $\bar{\sigma}_{\rm los}$.

Row (*3*).—The median, Newtonian, dynamical mass, $\bar{M}_{\rm N}$.

Row (*4*).—The median, MOND mass, $\bar{M}_{\rm M}$. This is obtained by substituting the mean velocity dispersion in equation (2).

Row (*5*).—The median luminosity, $\bar{L}$ (no luminosity data are given for the SSRS catalog).

Row (*6*).—The median, Newtonian M/L value, $\overline{(M/L)}_{\rm N}$.

Row (*7*).—The Newtonian, median-mass–to–median-luminosity ratio.

Row (*8*).—The MOND median-mass–to–median-luminosity ratio.

Row (*9*).—The quantity $\bar{a} \equiv 3\bar{\sigma}^2_{\rm los}/\bar{r}_h$ (where $\bar{r}_h$ is the median, harmonic group radius)—which is some measure of the typical acceleration in the groups—in units of a_0. We see that indeed the typical accelerations are much smaller than a_0.

I do not calculate M/L values for individual groups (the required data are not available to me in some cases), and so I do not give median M/L values for MOND. One may take $\bar{M}/\bar{L}$ as the "typical" M/L value for the catalog. This would be somewhat different from the median M/L value, but the difference is insignificant in comparison with the uncertainties. For comparison, I also give in Table 1 the corresponding values for the Newtonian case.

Note that the catalog-to-catalog variations in the MOND median quantities are larger than those in the corresponding Newtonian quantities. I believe this is largely due to the high sensitivity of the MOND mass estimator to the velocity dispersion. A variation of 50% in the median dispersion, as we see here, is amplified into a variation of a factor of 5 in the median masses, for example. Some intercatalog variations are expected because the groups come from rather different galaxy pools (e.g., different limiting redshifts) and are selected in different ways. For example, the LCRS results are based on a small, choice subsample of groups, while no such culling was implemented in the other catalogs.

Considering the uncertainties, one may conclude that the data are consistent, in the framework of MOND, with no dark matter in galaxy groups.

4. SOURCES OF UNCERTAINTY

An extensive discussion of the various sources of possible errors and uncertainties that beset the selection of groups and their analysis can be found, for example, in Ramella et al. (1997 and references therein). For example, they estimate (by comparison with simulations) that some 50%–75% of their three-member groups might be fictitious (10%–30% for four-member groups). Because false groups tend to have higher velocity dispersions, this leads to a systematic overestimation of the masses and M/L values. This is particularly true in MOND, where the mass scales as the fourth power of the velocity dispersion. Since the surveys are flux limited, the analysis might miss some dimmer members, so the listed values of the luminosity might be too small. There are also contributions from gas inside the galaxies (and possibly from intragroup gas). So the deduced M/L values (Newtonian and MOND) overestimate stellar M/L values of groups.

TABLE 1
MEDIAN NEWTONIAN, AND MOND, PARAMETERS FOR THE GROUP CATALOGS

Parameter	LCRS	CfA1	SSRS	CfA2
1. $\bar{N}$	394	166	87	406
2. $\bar{\sigma}_{\rm los}$ (km s^{-1})	164	123	183	192
3. $\bar{M}_{\rm N}$ (10^{11} h_{75}^{-1} $M_\odot$)	253	207	216	248
4. $\bar{M}_{\rm M}$ (10^{11} h_{75}^{-2} $M_\odot$)	9.2	2.9	14.2	17.2
5. $\bar{L}$ (10^{11} h_{75}^{-2} $L_\odot$)	2.5	1.2	...	2.0
6. $\overline{(M/L)}_{\rm N}$ [h_{75} $(M/L)_\odot$]	115	198	...	180
7. $\bar{M}_{\rm N}/\bar{L}$ [h_{75} $(M/L)_\odot$]	102	171	...	124
8. $\bar{M}_{\rm M}/\bar{L}$ $(M/L)_\odot$	3.7	2.4	...	8.6
9. $\bar{a}/a_0$ (10^{-2} h_{75}^{-1})	2.8	1.4	4.2	5.2

There are additional sources of uncertainty that are specific to MOND. In deriving the mass estimator, it was assumed that the system is not subject to external acceleration fields. When it is, the estimated MOND masses should be higher. If the external acceleration is comparable to the intrinsic one, the mass should be increased by about $2^{1/2}$. It is impracticable to correct the above results for this effect, but we note that a group will have to be rather near a prominent mass to have a material effect on its mass estimate. For example, for a group whose internal acceleration is $(3 \times 10^{-2})a_0$—which I find typical—at a distance of 20 Mpc from the center of a cluster whose line-of-sight velocity dispersion is 750 km s^{-1}, the effect is small (the estimated mass has to be increased by about 50%). At a distance of 10 Mpc, the increase is by a factor of about 2. Nearer yet we have to use a different estimator, which is $M_{\rm M} \sim (a/a_0)M_{\rm N}$. I present another example: for a segment of the Perseus-Pisces large-scale filament, Milgrom (1997b) finds a typical acceleration of $[(3\text{–}5) \times 10^{-2}]a_0$, which is similar to what I find here for groups. So, for groups in an environment such as this, M will have to be corrected up by $\sim 2^{1/2}$.

To get an idea of the error introduced by making approximations (iii) and (iv) in the mass estimator, I now consider two special cases of stationary, and isotropic, groups for which the comparison is simple: (*a*) a group made of N equal masses m, and (*b*) a group comprising one massive galaxy with all the others of negligible (and equal) test masses. In case *a*, the ratio, η, of the correct mass to that given by equation (2) is

$$\eta = \left(\frac{1 - N^{-1}}{1 - N^{-1/2}}\right)^2. \tag{3}$$

So equation (2) *underestimates* the mass by a factor of 2.5 for $N = 3$, by a factor 9/4 for $N = 4$, and so on. For case *b*, we use the fact that for a test particle in an arbitrary (low acceleration) orbit around a mass M, the line-of-sight velocity, averaged over the orbit and over all lines of sight, is given by $\langle v^2 \rangle = MGa_0/3$; hence, for a system as in case *b*, $M \approx 9\sigma^4_{\rm los}(Ga_0)^{-1}$. The correction factor is thus 4/9, and equation (2) *overestimates* the mass by a factor of 9/4.

The uncertainties introduced by these last two MOND-related approximations are, by and large, small compared with those associated with group identification and unknown geometry and do not change the conclusion that group dynamics is consistent, within the framework of MOND, with no dark matter in groups.

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