Part 1
Conference Summary

Conference Summary

James Binney

Theoretical Physics, Oxford University,
1 Keble Road, Oxford OX1 3NP, England

Abstract. The competition between CDM and MOND to account for the 'missing mass' phenomenon is asymmetric. MOND has clearly demonstrated that a characteristic acceleration a_0 underlies the data and understanding what gives rise to a_0 is an important task. The reason for MOND's success may lie in either the details of galaxy formation, or an advance in fundamental physics that reduces to MOND in a suitable limit. CDM has enjoyed great success on large scales. The theory cannot be definitively tested on small scales until galaxy formation has been understood because baryons either are, or possibly have been, dominant in all small-scale objects. MOND's predictive power is seriously undermined by its isolation from the rest of physics. In view of this isolation, the way forward is probably to treat CDM as an established theory to be used alongside relativity and electromagnetism in efforts to understand the formation and evolution of galaxies.

1. Introduction

In the widely accepted Popperian interpretation of the scientific process, we proceed in two stages. First we use established theory and a mixture of observation, intuition and phantasy to set up a theory of how things work. Then we (or more likely our friends) make a determined effort to falsify our theory by finding a measurement or observation that is inconsistent with the theory. In most cases this effort succeeds fairly quickly, and we have to construct a new theory to continue the game. Occasionally resolute attempts to falsify the theory fail, and people gain confidence in the accuracy of its predictions. The theory is then considered established and becomes part of the infrastructure that is called upon in the first phase of the scientific process.

Sitting through this meeting, the conviction has grown on me that the Cold Dark Matter (CDM) theory has now reached the point at which it should be admitted as a Candidate Member, to the Academy of Established Theories, so that it can sit alongside the established theories of Maxwell, Einstein and Heisenberg and be used as a standard tool in the construction of new theories.

I start by summarizing the status of the CDM and MOND theories, followed by lists of headaches that the protagonists on each side have to confront, all interlarded with my current views on relevant issues. I finish with a 'to do' list. Since space is limited, I mostly rely on other contributors to the meeting for

citations to individual papers: the word BLOGGS is shorthand for "Bloggs, this volume and references therein."

2.   Cold Dark Matter's Resumé

It is now about twenty years since cosmology became dominated by the theory that gravitational clustering is driven by CDM. This theory was honed by interaction with observations of galaxy clustering, the Lyα forest, the CMB and type Ia supernovae. At this meeting several speakers have concluded that astronomical data, especially those connected with gravitational lensing, agree with the predictions of the CDM theory. Recently the theory was rigorously tested by the WMAP satellite and passed brilliantly (SPERGEL). It will be further tested when data for additional years have been analysed. It is a theory with a significant hinterland in high-energy physics and as such can be tested in terrestrial experiments: attempts to detect the particles of cosmic CDM as they pass through the Earth are currently entering an exciting phase (SELLWOOD), and from around 2007 the LHC at CERN is expected to probe aspects of the underlying physics, which probably involves supersymmetry.

  In the last few years it has been widely argued that there are conflicts between the predictions of CDM and observations of the internal structure of galaxies of various types. Much of this meeting has been taken up with discussion of these important questions. I argue below that these problems probably reflect difficulties in correctly deducing the predictions of the theory, rather than problems with the underlying physics.

3.   Modified Newtonian Gravity's Resumé

Milgrom made an important contribution to our subject by having the courage to suggest that flat rotation curves reflected a failure of General Relativity rather than the existence of vast quantities of unseen matter (Milgrom 1983). In a series of lucid and painstaking papers he explored in considerable depth this possibility, which he dubbed MOND. The essential ingredient of MOND is the assertion that there is a characteristic acceleration, $a_0 \sim cH_0/2\pi$, below which Newtonian gravity fails: when Newton predicts a gravitational acceleration $g_N \lesssim a_0$, the actual acceleration is $g_M = \sqrt{g_N a_0}$.

  Physicists are generally reluctant to give MOND the time of day because, despite the best efforts of Bekenstein & Milgrom (1984), a Lorentz covariant theory that has MOND for a Newtonian limit has not come to light. Astronomers tend to be more open-minded, and several studies have demonstrated that Milgrom's MOND fitting formula enables one to predict the rotation curves of galaxies from their light profiles (SANCISI; SELLWOOD; Sanders & McGaugh 2002). What makes these fits impressive is that the mass-to-light ratios Υ_C that they assign to each galaxy vary with waveband C and with galaxy type very much as one would expect on astrophysical grounds if the galaxies contained only stars and the observed gas (BOSMA; DE JONG). These studies have clearly established that a characteristic acceleration a_0 is involved in the relation between galaxy photometry and dynamics. This fact is at least as important for

our understanding of galaxy structure and formation as the Tully-Fisher and Faber-Jackson relations.

There now seems to be little doubt that Einstein's equations give an adequate account of the data only when a significant cosmological constant Λ appears in them. Physically, the non-zero value of Λ implies that the vacuum is a medium in which the energy density is non-zero, and Λ quantifies the density of this 'dark energy'.[1] The existence of dark energy strongly suggests that our understanding of the way the vacuum responds to weak stimuli is seriously in error. Milgrom and others have suggested that there is a connection between the phenomenon of dark energy and the breakdown of the predictions of standard gravity when small accelerations are involved in the sense that both phenomena reflect differences between what actually happens and the predictions of Einstein's theory with $\Lambda \sim 3(a_0/c)^2$ set to zero (Milgrom 2002).

I find extremely seductive the idea that a better understanding of the nature of the vacuum would simultaneously explain the requirement for non-zero Λ and modify the way that particles moved in weak gravitational fields. MOND is a proposal for what the low-energy predictions of the correct dynamical model of the vacuum would look like. So while MOND itself could never become a member of the Academy of Established Theories, its parent theory most certainly could.

Thus CDM and MOND do not compete on equal terms: the former is a natural outgrowth of established physics, whilst the latter is a thing apart, a single visible peak of a mountain range that is otherwise enshrouded in cloud; a peak that is connected to the known world in an unkown way. The result is that in our efforts to understand how the Universe got to its present state, CDM can be used to form hypotheses and make predictions in a way that MOND cannot.

4. Headaches for MOND

4.1. Falling circular-speed curves

We heard that the Planetary Nebula Spectrograph on the William Herschel telescope has measured velocity dispersions in the outer parts $R \gtrsim 2R_e$ of three intermediate-luminosity elliptical galaxies and find them all to fall in Keplerian fashion (ROMANOWSKY). These data do not absolutely require the circular speeds of these galaxies to be Keplerian, but this is the most plausible interpretation of the data. Only two other intermediate-luminosity elliptical galaxies have had their stellar kinematics probed at $R \gtrsim 2R_e$ and only one of these (NGC 2434; Rix et al., 1997) shows evidence for DM. Milgrom & Sanders (2003) point out that these very high surface-brightness galaxies generate accelerations around R_e that are an unusually large multiple of a_0. Consequently, MOND is expected to push the circular-speed curve above Newton's prediction only after a significant section of Keplerian fall. Hence, the work reported by ROMANOWSKY is perhaps a triumph for MOND.

---

[1]This is a poor name because dark energy comes in two forms. The simplest form is 'dark matter' (DM). This exerts negligible pressure. The form quantified by Λ is associated with a large negative pressure, i.e., a tension. So the physical quantity associated with Λ ought to be called 'dark tension' rather than dark energy.

4.2.   Non-universality of a_0

The value of a_0 required to banish DM from rich clusters of galaxies is about a factor of two larger than that fitted to data for disk galaxies (Sanders & McGaugh 2002 and references therein). GERHARD argued that the highest-quality data for elliptical galaxies at $R \lesssim 2R_e$ implies that DM manifests itself at accelerations $a \sim 10^{-9}\,\mathrm{m\,s^{-2}}$ that are about an order of magnitude larger than the value of a_0 that is inferred from the dynamics of disk galaxies (Gerhard et al. 2001). However, this conclusion would appear to conflict with the subsequent results from planetary nebulae, which demonstrate that in two of the galaxies in the Gerhard et al. sample (NGC 3379 and NGC 4494), even 4 to 6 times further out than Gerhard et al. were able to go, there is no convincing evidence of DM. Baes & Dejonghe (2002) point out that scattering by dust at large radii of photons emitted near the centre can generate the kinematic signature of a DM halo when none is really present. Perhaps this effect is significant at the largest radii reached by Gerhard et al.

4.3.   Halo flattening

Weak lensing studies, like studies of polar rings, suggest that the gravitational potentials of disk galaxies are significantly flattened. Is this a problem for MOND, as HOEKSTRA argued? It was not clear to me that those who answer 'yes' have borne in mind the strange behaviour of multipoles in MOND. Milgrom (1983) shows (i) that you cannot determine the quadrupole of the potential from the only quadrupole of the mass distribution, and (ii) that outside the body the quadrupole of the potential decays as $r^{-\sqrt{3}}$, rather than r^{-3} as in Newton's theory. Moreover, weak lensing is generated by accelerations that are only a few percent of a_0. To impart the velocity $\sim 600\,\mathrm{km\,s^{-1}}$ of the Local Group with respect to the CMB in a Hubble time, takes an acceleration $a \sim cH_0/500 = 0.012a_0$. Hence a single galaxy is unlikely to dominate the deflections probed by weak lensing, and non-circular isopotentials are not unexpected in MOND.

4.4.   Merging galaxies

A famous photograph by Schweizer (1982) left little doubt that the merger of two disk galaxies of comparable mass yields an elliptical galaxy. The photograph shows the two long tidal tails of NGC 7252, together with the galaxy's nearly relaxed core. The timescale on which the tidal tails evolve will be the same regardless of whether galactic rotation curves are kept flat by massive dark halos or modification of the law of gravity, because speed and distance are both fixed by the observations. Thus the time since the galaxies came into close contact is known. Schweizer showed the brightness distribution of the core obeys the $R^{1/4}$ law that is characteristic of elliptical galaxies. Thus the nuclei of the two galaxies have already completely merged. Simulations show that the nuclei can only spiral together in the time available if they can effectively surrender their energy and angular momentum to dark halos (CARIGNAN; Barnes 1988). If we banish the halos by modifying the law of gravity, the galactic nuclei take much longer to merge because the vacuum cannot relieve them of their energy and angular momentum.

5.   CDM and Galaxy Formation

History shows that even when we have the correct theory, prediction can be very difficult, even problematic: Newton published the *Principia* in 1686 but it was not until 1882 that Newcomb gave the now accepted value for the Newtonian precession of the perihelion of Mercury, and it is only ten years ago that Wisdom and others showed that there is significant chaos in the solar system; Euler wrote down his equation for hydrodynamics in 1755, but even in the sixth edition of his magisterial survey *Hydrodynamics* Lamb (1932) displayed a very incomplete understanding of shock fronts and in Art 284 ridiculed the Hugoniot jump condition. It is only in the last quarter century, with the development of chaos theory, that we have begun to understand the devastating impact that the non-linearity of Euler's equations has on the equations' predictive power.

CDM is a theory of the invisible. Apart from experiments designed to detect wimps in the laboratory and gravitational lensing work, tests of the CDM theory centre on the effect that CDM has on baryons. Hence galaxy-scale *tests* of CDM are inextricable entwined with the theory of galaxy formation, which nobody imagines is well understood. Because baryons interact with each other and electromagnetic radiation in tremendously complex ways, much cosmology is done with just CDM and dark energy. We do however now think that the mean density of baryons is $\sim \frac{1}{5}$ that of dark matter, so the exclusion of baryons from the calculations is far from safe even on large scales. And baryons contribute much more heavily to the density precisely at the locations, in or near galaxies, where we make observations. So CDM-only simulations are, prima facie, unlikely to be reliable guides to the configuration of dark matter in and around galaxies. It's not going to be easy to wring reliable predictions for galaxy-scale phenomena from the CDM model. Just as the fact that it is difficult to calculate the long-term dynamics of the solar system is no criticism of Newtonian dynamics, so the difficulty of predicting the dark-matter distribution expected in the Milky Way is no criticism of the CDM theory.

Pure CDM simulations and galaxy-formation models tend to be done by the same workers on the same computers, but they are sharply different activities. The dynamics of pure CDM is reasonably clear-cut and well understood. We can feel confidence in the predictions it yields for large-scale phenomena, to which baryons contribute only modestly. These predictions are in excellent agreement with observation (SPERGEL). I have the impression that the predictions of pure CDM theory are in conflict with observation only where baryons either are, or likely have been, dynamically important. During this meeting I have come to the conclusion that we should treat these conflicts not as falsifications of CDM theory, but as pointers to failings in our understanding of galaxy formation. We are not even sure how baryons should be accumulated at the centres of dark-matter halos in the purely dissipative case: the widely adopted prescription of conserving the adiabatic invariants of the dark matter as the potential gets deeper is probably quite wrong in the likely case that baryons accumulate through a series of mergers (PRIMACK).

There is abundant evidence that non-gravitational energy is important for the dynamics of baryons that fall into DM halos of a wide range in mass, from dwarf galaxies right up to groups and even clusters of galaxies. The dynamics

associated with this non-gravitational energy is currently no more than speculation.

6.   Headaches for CDM

Many of the difficulties that CDM faces on small scales derive from the result that the centres of pure CDM halos are very cuspy. Even in the case of pure CDM, I believe we don't understand properly how cores form, or what the smallest radius is at which we can trust the simulations. There are two problems: (i) the simulations still don't reach as far down the mass function as the observations do, and (ii) we have an inadequate understanding of the role of discreteness effects. In the simulations the latter are important at early times when the Zel'dovich waves break, and they are distinct from the effects of two-body relaxation.[2] However, through the cries and smoke of battle, something like a consensus seems to be emerging from the groups that do large-scale simulations of gravitational clustering (NAVARRO): in a pure-CDM halo the density profile rises in to the smallest resolvable radii with a slope $\alpha = -\mathrm{d}\log\rho/\mathrm{d}\ln r$ that gradually lessens inwards, but is still $\gtrsim 1$ when last believable. The density profile of an individual halo depends weakly or not at all on the power spectrum from which the simulation starts (Knebe et al. 2002).

6.1.   LSB galaxies

Stimulated by this prediction, observers have invested significant effort in determining the density profiles at the centres of the most dark-matter dominated galaxies, since these clearly provide the cleanest tests. Although the controversy has yet to die, my impression is that they have shown that Low Surface Brightness (LSB) galaxies are unlikely to have such cuspy central mass profiles as the pure CDM simulations predict (BOLATTO, BOSMA, DE BLOK, GENTILE, MATEO, SWATERS, TROTT). Dwarf spheroidal galaxies show the highest degree of dark-matter domination (WILKINSON), and the conclusion of Kleyna et al. (2003) that the UMi dwarf has a nearly harmonic core is certainly a headache for CDM, but Draco does have a cuspy potential (Kleyna et al. 2002). It seems that in many, perhaps all LSB galaxies, the potentials are less cuspy than pure-CDM theory predicts. Will this problem be resolved at some future date by correctly adding baryons to the CDM simulations? The resolution will be hardest for the dSph galaxies, because their present baryon content is negligible. However, these are precisely the galaxies that are expected to lose most gas during galaxy formation, so it is not clear that their baryon contents were always negligible.

6.2.   Halo substructure

In the last few years the worry has been abroad that DM halos are predicted to contain more substructure than the observed number of satellite galaxies suggests exists. It seems that this problem may have gone away: the number

---

[2]I used to worry about the latter, but I feel that Binney & Knebe (2002) showed that two-body relaxation is unimportant – see however Diemand et al. (2003) for a different point of view.

of objects predicted is a steep function of the sub-halo's peak circular speed. Mapping this circular speed onto quantities observed for satellites, such as luminosity or central velocity dispersion, is non-trivial. It is now argued that when this mapping is done correctly, the CDM model correctly predicts the observed number of satellite galaxies (PRIMACK). Moreover, in one interpretation of phenomena associated with strong gravitational lensing, a high level of halo substructure is inferred (SCHNEIDER, MAO and below).

6.3. HSB galaxies

Many arguments now indicate that the centres of high surface brightness (HSB) galaxies are baryon-dominated:

- Gerhard et al. (2001) find that the dynamics of elliptical galaxies is well explained by assuming that dark matter makes a negligible contribution to their central mass densities. The mass-to-light ratios then required are in the range expected on astrophysical grounds and vary with the colour of the galaxy in the expected way (GERHARD). Significant contributions to the mass density from dark matter would spoil this picture.

- The shapes of rotation curves are intimately connected to the underlying stellar light profile (SANCISI). The rotation curves of early-type disk galaxies peak at extremely small radii and must be dominated by stellar mass over most of the radial range probed (NOORDERMEER).

- In disk galaxies we more often than not see a fast bar (one that extends to $\sim$ 0.8 of its corotation radius). The timescale for this to surrender most of its angular momentum to a slowly-rotating, embedding dark halo is $f \sim \frac{1}{2}(x + 1/x)$ times the dynamical time, where $x = \rho_{\rm bar}/\rho_{\rm DM}$ (ATHANASSOULA). Since the high frequency of bars at the centres of galaxies implies that f is quite large, x must be far from unity.

- The non-axisymmetric velocities that a bar drives in surrounding gas are proportional to the mass of the bar, while the mass of the halo is limited by the overall rotation curve and the masses of bar and disk. Near maximal disks are required to generate velocities as high as those observed in some external galaxies (BOSMA, WEINER). Similarly, the Milky Way's 'forbidden' velocity features, such as the 3 kpc arm in the (l, v) plots for CO and HI, require all available mass in the inner few kiloparsecs to be associated with the bar and the disk (Bissantz, Englmaier & Gerhard, 2003; Fux, 1999).

- We can weigh the Milky Way's disk near the Sun and all recent investigators conclude that its entire surface density of $\sim 41\,{\rm M}_\odot\,{\rm pc}^{-2}$ can be accounted by known stars and interstellar gas (VAN ALTENA; Crézé et al. 1998; Holmberg & Flynn 2000; Olling & Merrifield 2001). Given that the total column density within 1.1 kpc of the plane is only $71\,{\rm M}_\odot\,{\rm pc}^{-2}$ (Kuijken & Gilmore, 1991), one can show that even as far out as the solar neighbourhood ($R_0/R_{\rm d} \gtrsim 2.7$), dark matter makes a smaller contribution than stars to the local circular speed (Binney & Evans, 2001).

- The microlensing optical depth to the Galactic centre has to be due to stars. Even the much reduced current values ($\tau_6 \equiv 10^6\tau \sim 1.5$: Popowski et al. 2001; Alfonso et al. 2003) can be explained only if all the mass that the circular-speed curve can accommodate in the central few kiloparsecs is invested in stars (Bissantz & Gerhard 2002).

I'd like to abuse my privilege of having the last word to contribute to the controversy about the implications of measurements of τ_6. I coauthored two papers (Binney, Bissantz & Gerhard 2000; Binney & Evans 2001) that used an upper limit on the optical depth that can be achieved with a given mass when it is distributed smoothly around an ellipse. In the first paper we argued that the values, $\tau_6 \sim 3$, that were then current were physically impossible. Obligingly, Popowski et al. (2001) shortly afterwards reduced to 2 ± 0.4 the most reliable value of τ_6, that for red clump stars, which are bright enough for blending not to be a problem. In the second paper we showed that even the optical depth of Popowski et al. places a tight constraint on the power index α of the dark halo's density profile between the Sun and the centre because we know the local density of dark matter, and τ_6 limits the density of dark matter at the centre.

Recently the EROS collaboration have reported $\tau_6 = 1.08 \pm 0.3$ (Alfonso et al. 2003) and at this meeting Merrifield has argued that flattening the dark halo to axis ratio $q = 0.8$ allows α to be as large as unity without lowering τ_6 below its likely value. Hence I hear it said on all sides that the Galactic microlensing data are now compatible with an NFW halo.

This conclusion is very wrong! What has been lost in the debate is how *absurd* the distributions of stars considered in our two papers are. These distributions are the ones that maximize the optical depth along $b \sim -3.8°$ for a given mass subject only to the constraints (i) that the density decreases exponentially with distance z from the plane, with a scale-height $z_0(R)$, (ii) that the matter distribution is elliptical, with unconstrained ellipticity and a principal axis inclined at $20°$ to the Sun-centre line, and (iii) that the disk's radial density profile is exponential. The resulting scale heights z_0 increase linearly with distance D from the Sun so that $z_0/D = |b|$, the latitude at which the value of τ_6 is set. The Galaxy's stars are not distributed in this way! We used these absurd models to make the point that with the old data there was no way in which the lenses could be distributed through the Galaxy to achieve the required optical depth. Now that the microlensing measurements have been refined and are producing plausible values, it is time to add the constraint that the lenses, which are almost certainly ordinary stars, are distributed like the starlight. Since this distribution does not maximize the optical depth along a particular line of sight from the Sun, it produces a smaller optical depth per unit stellar mass than Binney & Evans assumed. The analysis of the COBE near-IR light distribution by Bissantz & Gerhard (2002) provides our best estimate of the distribution of stars near the centre. If these stars contain *all* the mass that is allowed in the centre, Bissantz & Gerhard conclude that $\tau_6 = 1.27$. So at the present time there is very little room for dark matter in the inner few kiloparsecs, even with the new lower optical depths.

7. Things to do

I have argued that ab initio prediction of the DM distribution in galaxies is hard because it involves solution of the full galaxy-formation problem. If we accept this conclusion, we should concentrate on *mapping* DM in galaxies, in an open frame of mind. This enterprise has two arms: (i) use of all available dynamical probes (stars, X-ray gas, atomic and molecular gas, gravitational micro- and macro-lensing) to map total mass, while (ii) using the most sophisticated models of stellar populations and interstellar gas to infer baryonic mass. As we have heard from many speakers, arm (i) is rather fully developed. By contrast, arm (ii) requires much more work, especially as regards the ISM. I feel the work described by DE JONG is a valuable step along the right path.

We must go after cold molecular gas like bloodhounds, while avoiding a false dichotomy between 'missing mass is all in dark matter', and 'missing mass is all in the ISM'. In the LSB regions of galaxies it is natural that gas should condense into very cold clouds that are hard to see in emission (PFENNIGER). Observations in the 21 cm line have long told us that galaxies have HI disks that extend into extremely LSB regions. If the ISM in these regions were several times more massive than its HI component, we could understand a number of things:

- The existence of spiral structure in the extended disk around NGC 2915 (MASSET).

- Why polar-rings lie above the Tully-Fisher relation for normal spirals, while their embedded disk galaxies lie on it (ARNABOLDI).

- The existence of the baryonic Tully-Fisher relation (COMBES; Matthews et al. 1998; McGaugh et al. 2000).

- The presence $\sim 20\,\mathrm{kpc}$ from the centre of M31 of a surprising amount of dust and star formation. If stars are forming, there must be unobserved H_2 present, and if the ISM has the low metallicity expected so far out, the observed level of reddening is hard to understand without a significant column of H_2 (ALLEN, PFENNIGER).

Data from the new X-ray observatories have yet to have a big impact on studies of individual galaxies because they require extremely long exposure times, and we need to be more sophisticated in our modeling of hot gas. In particular, models need to include the spin of the body of trapped gas. I think there is considerable scope for linking our knowledge of stellar populations to the composition and global dynamics of the ISM.

We need to clarify the situation regarding DM in elliptical galaxies. Studies of gravitational lensing suggest that at $\sim 2R_e$ both stars and DM make significant contributions (SCHNEIDER, SCHECHTER). The flux ratios in the images of strongly lensed background objects require the mass distribution in the lensing galaxy to be lumpy (MAO). SCHNEIDER took the lumpiness to be substructure in the DM halo, such as that predicted by the DM clustering simulations. SCHECHTER argued that the lumpiness of the stellar contribution to the mass distribution was responsible to the observed flux ratios. Observations of

the variability of narrow and broad emission lines in the background source will resolve this issue within a few years and greatly clarify the distribution of dark matter in elliptical galaxies.

If we exclude cluster-centre galaxies, the dynamics of stars provides only very weak evidence for DM: the data favour some DM at $R \sim 2R_e$, but what there is does not prevent the circular speed dropping in near Keplerian fashion at $R \gtrsim 2R_e$ (GERHARD, ROMANOWSKY). Compact DM halos that yield falling rotation curves have long been favoured by studies of tidal-tail formation and evolution (Dubinski et al. 1999 & references therein). There must be a worry that the rather different picture provided by the lensing data is biased: even if only a minority of ellipticals have massive dark halos, nearly all the observed lenses will belong to that minority.

Last but by no means least we have to press on with developing our understanding of how galaxies form. This is going to be a long job, but an immensely worthwhile one. We'll probably crack it soonest if we accept CDM as background theory.

References

Alfonso, C., et al. 2003, A&A, 404, 145

Baes, M., & Dejonghe, H. 2002, MNRAS, 335, 441

Barnes, J. E. 1988, ApJ, 331, 699

Bekenstein, J., & Milgrom, M. 1984, ApJ, 286, 7

Binney, J., & Knebe, A. 2002, MNRAS, 333, 378

Binney, J., Bissantz, N., & Gerhard, O. E. 2000, ApJ, 537, L99

Binney, J., & Evans, N. W. 2001, MNRAS, 327, L27

Bissantz, N., & Gerhard O. E. 2002, MNRAS, 330, 591

Bissantz, N., Englmaier, P., & Gerhard O. E. 2003, MNRAS, 340, 949

Crézé, M., Chereul, E., Bienaymé, O., & Pinchon C. 1998, A&A, 329, 920

Cuillandre, J.-C., Lequeux, J., Allen, R. J., Mellier, Y., & Bertin E. 2001, ApJ, 554, 190

Diemand, J., Moore, B., Stadel, J., & Kazantzidis, S. 2003, astro-ph/0304549

Dubinski, J., Mihos, J. C., & Hernquist, L. 1999, ApJ, 526, 607

Fux, R. 1999, A&A, 345, 787

Gerhard, O. E., Kronawitter, A., Saglia, R. P., & Bender, R. 2001, AJ, 121, 1936

Holmberg, J., & Flynn, C. 2000, MNRAS, 313, 209

Kleyna, J. T., Wilkinson, M. I., Evans, N. W., Gilmore, G., & Frayn C. 2002, MNRAS, 330, 792

Kleyna, J. T., Wilkinson, M. I., Gilmore, G., & Evans, N. W. 2003, ApJ, 588, L21

Knebe, A., Devriendt, J. E. G., Mahmood, A., & Silk J. 2002, MNRAS, 329, 813

Kuijken, K., & Gilmore G. 1991, ApJ, 367, L9

Lamb, H. 1932, Hydrodynamics, 6th ed., Cambridge University Press

Matthews, L. D., van Driel, W., & Gallagher, J. S. 1998, AJ 116, 1169

McGaugh, S. S., Schombert, J. M., Bothun, G. D., & de Blok W. J. G. 2000, ApJ, 533, L99

Milgrom, M. 1983, ApJ, 270, 365

Milgrom, M. 2002, New Astron. Rev., 46, 741

Milgrom, M., & Sanders, R. H. 2003, astro-ph/0309617

Olling, R. P., & Merrifield, M. R. 2001, MNRAS, 326, 164

Popowski, P., et al. 2001, in Microlensing 2000: A New Era of Microlensing Astrophysics, eds. J. W. Menzies & P. D. Sackett (San Francisco: ASP), p.244

Rix, H.-W., de Zeeuw, P. T., Cretton, N., & van der Marel R. P. 1997, ApJ, 488, 702

Sanders, R. H., & McGaugh, S. S. 2002, ARA&A, 40, 263

Schweizer, F. 1982, ApJ, 252, 455