The specific frequency and the globular cluster formation efficiency in Milgromian dynamics

Xufen Wu¹, Pavel Kroupa¹,²
¹ Argelander-Institut für Astronomie der Universität Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany
² Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Nussallee 14-16, D-53115 Bonn

11 May 2014

ABSTRACT
Previous studies of globular cluster (GC) systems show that there appears to be a universal specific GC formation efficiency \( \eta \) which relates the total mass of GCs to the virial mass of host dark matter halos, \( M_{\text{vir}} \) (Georgiev et al. 2010; Spitler & Forbes 2009). In this paper, the specific frequency, \( S_N \), and specific GC formation efficiency, \( \eta \), are derived as functions of \( M_{\text{vir}} \) in Milgromian dynamics, i.e., in modified Newtonian dynamics (MOND). In Milgromian dynamics, for the galaxies with GCs, the mass of the GC system, \( M_{\text{GC}} \), is a two-component function of \( M_{\text{vir}} \) instead of a simple linear relation. An observer in a Milgromian universe, who interprets this universe as being Newtonian/Einsteinian, will incorrectly infer a universal constant fraction between the mass of the GC system and a (false) dark matter halo of the baryonic galaxy. In contrast to a universal constant of \( \eta \) in a Milgromian universe, for galaxies with \( M_{\text{vir}} \leq 10^{12} M_{\odot} \), \( \eta \) decreases with the increase of \( M_{\text{vir}} \), while for massive galaxies with \( M_{\text{vir}} > 10^{12} M_{\odot} \), \( \eta \) increases with the increase of \( M_{\text{vir}} \).

Key words: galaxies: star clusters - galaxies: general - galaxies: stellar content - galaxies: kinematics and dynamics

1 INTRODUCTION
The previous studies on the relation between the specific frequency, \( S_N \), of globular clusters (GCs), i.e., the number of GCs per unit luminosity of the host galaxy, and the luminosity of the host galaxy, imply that the formation of GCs has a universal mode, irrespective of galaxy morphology (Kissler-Patig 2000; van den Bergh 2000; Kissler-Patig 2000; van den Bergh 2000; Harris 1991; Brodie & Strader 2006). The observations of GCs show that \( S_N \) varies greatly with galaxy luminosity. In addition, there is an overall trend of \( S_N \) with galaxy luminosity: \( S_N \) decreases with decreasing luminosity for the most massive Elliptical galaxies to reach a broad plateau at Milky Way class galaxies. In the dwarf galaxy regime \( S_N \) bifurcates by being zero for star-forming galaxies while achieving very high values for some dwarf elliptical and dwarf spheroidal galaxies (Harris 1991; Peng et al. 2008; Miller & Lotz 2007; Spitler et al. 2008; Georgiev et al. 2010; McLaughlin 1994). McLaughlin (1994) analyzes the total mass of the GC systems, \( M_{\text{GC}} \), and the mass of baryons, \( M_b \), in three giant galaxies, and finds that these two global observables have a constant ratio, \( M_{\text{GC}}/M_b = 0.26\% \), within any galactocentric radius inside each galaxy and for different galaxies. However, Spitler & Forbes (2009, Fig. 2) show that the relation \( M_{\text{GC}}(M_b) \) has a different slope for massive and dwarf galaxies, thus \( M_{\text{GC}}(M_b) \) is not a linear function for the whole mass range of the host galaxies.

According to the Standard Model of Cosmology, dark matter halos drive the formation and the evolution of galaxies. Correlations between dark matter halos and various baryonic properties of the galaxies have been discovered. For example, the correlation between the specific frequency of GCs and the virial mass of the hosting dark matter halo has been interpreted to mean that more massive dark matter halos yield a larger efficiency of GC formation. It is suggested by Blakeslee et al. (1997) and Blakeslee (1999) that in both giant elliptical galaxies and also in brightest cluster galaxies (BCGs), the ratio between the total mass of GCs in a galaxy and the total virial mass of the galaxy (with dark halo), \( M_{\text{GC}}/M_{\text{tot}} \), is a more fundamental constant. Blakeslee (1999) finds that \( \eta_{\text{tot}} = 1.71 \pm 0.53 \times 10^{-4} \). Spitler & Forbes (2009) study the total mass of GCs and the virial mass of theirhosting dark halo in a cold dark matter (CDM) universe, and show that the total mass of GCs is proportional to the virial mass of a galaxy for galaxies with different morphologies, except for a few local group dwarf galaxies, which are thought to be due to a sample bias in the stellar masses of these low mass galaxies. For such a relation, the GC formation efficiency \( \eta_{\text{tot}} = 7.08 \times 10^{-5} \).
can be derived. The recent work by Georgiev et al. (2010) gives a mean value of $n_{tot} = 5.5 \times 10^{-9}$ from the $S_L(M_V)$ relation for a wide range of galaxy masses for both early-type and late-type galaxies from a variety of observations (Miller & Lotz 2007; Peng et al. 2008; Spitler et al. 2008; Georgiev et al. 2008, 2009a,b), where $S_L$ is the specific GC luminosity (Harris 1991).

Georgiev et al. (2010) derive scaling relations of GCs, such as $S_N$, specific mass and specific luminosity, as functions of dark matter halo mass (including the baryonic matter in the halo) for both low mass and massive galaxies, which are, respectively, probably regulated by supernova feedback and virial shock-heating of the infalling gas. The halo masses of the galaxies are based on the cold dark matter (CDM) paradigm. However, in the derivation of Georgiev et al. (2010) a universal central halo mass of the isolated baryonic mass of a galaxy, $M_{b,3kpc} = 10^7 M_\odot$, is used. This value is extracted from the observations by Strigari et al. (2008). Moreover, based on the co-added rotation curves of about 1000 spiral galaxies, it is found that $M_{b,3kpc} = 1.35 \times 10^7 M_\odot$ (Donato et al. 2009), which is consistent with Strigari et al. (2008)'s observations. However, Kroupa et al. (2010) show that the values of the dark matter masses, $M_{b,3kpc}$, obtained from various CDM cosmological simulations do not agree with Strigari’s observations. Therefore currently there are no existing CDM halo models from cosmological simulation with such a central halo mass. Actually, the dark matter halo adopted in the derivation of Georgiev et al. (2010) is an empirical combination of observations in the centre and of simulations in the outer regimes of a galaxy, rather than one that is naturally obtained from cosmological halo models.

On the other hand, Milgrom (2009) and Gentile et al. (2004) show that there is an upper limit of the apparent central dark matter: surface density in Milgromian dynamics (Milgrom 1983; Bekenstein & Milgrom 1984), which is $\Sigma_M \equiv a_0/2\pi G = 138 M_\odot pc^{-2}$, and the central (within 300 pc) apparent halo projected mass is $1.24 \times 10^7 M_\odot$. This agrees well with the observations by Strigari et al. (2008) and Donato et al. (2009). Here $a_0 \approx 3.7 pc/Myr^2$ is Milgrom’s (1983) acceleration constant (Milgrom 1983; Bekenstein & Milgrom 1984; Milgrom 2009; Fabian & McGaugh 2012). In Milgromian dynamics each isolated baryonic mass of a galaxy, $M_b$, generates an effective force field which is mathematically equivalent in Newtonian dynamics to a logarithmic dark matter potential. Given the success of Milgromian dynamics on accounting for observed properties of galaxies in the central (Milgrom 2009) and outer regimes (see the recent reviews of Fabian & McGaugh 2012; Kroupa et al. 2012) and the problems of the $\Lambda$CDM model (Kroupa 2012), we study here how the specific frequency of GCs and other quantities correlate with the phantom dark matter halos that surround each baryonic system.

The apparent (Newtonian) virial masses, $M_{vir}$, for galaxies used in Georgiev et al. (2010) and the apparent (Newtonian) dynamical mass-to-light ratios are studied in this paper in Milgromian dynamics. The relationship between $M_{GC}$ and $M_{vir}$ of galaxies is quantified. The GC scaling parameters, i.e., $S_N$ and $\eta$, are derived as functions of apparent CDM halo virial mass. We explicitly note that the following usage of language here: In a Milgromian universe there is no cold or warm dark matter which plays a dynamically significant role on galactic scales. Anyone who (wrongly) interprets the data by applying Newtonian dynamics will, however, (wrongly) introduce the presence of cold or warm dark matter in galaxies. We refer to this as apparent or phantom dark matter throughout this contribution.

2 ANALYSES AND RESULTS

The observed samples of galaxies are the same as those used in Georgiev et al. (2010). A plot of $M_{GC}/M_b$ as a function of $M_b$ is shown in Figure 1. The $M_{GC}/M_b$ versus $M_b$ data is described as a three-part function of $M_b$. For galaxies with $M_b < 3 \times 10^{10} M_\odot$, $M_{GC}/M_b$ either decreases as $M_b$ increases, or $M_{GC}/M_b = 0$, i.e., in some dwarf galaxies no GC systems are observed. For galaxies with $M_b > 3 \times 10^{10} M_\odot$, $M_{GC}/M_b$ increases as $M_b$ increases. For the galaxies with GCs, the fit parameter for the relation of $M_{GC}/M_b$ and $M_b$ are given in the figure.

2.1 The apparent virial mass and apparent dynamical mass-to-light ratio

Milgrom’s original proposal for a new effective gravitational dynamics (Milgrom 1983; Bekenstein & Milgrom 1984) which is sourced purely by baryonic matter, has passed all tests that have been performed until now on galactic scales. It accounts for the baryonic Tully-Fisher relation, the shapes of rotation curves of galaxies, the dark matter effect in tidal dwarf galaxies, the universal scale of
baryons, and the projected surface density of apparent dark matter within the core radius of the apparent dark matter halos (Tully & Fisher 1977; Milgrom & Sanders 2003; Sanders & Noordermeer 2007; Gentile et al. 2007, 2009). In Milgromian dynamics, the Newtonian gravitational acceleration \( g_N \) is replaced with \( g = \sqrt{g_N a_0} \) when the gravitational acceleration is much smaller than \( a_0 \approx c^2M/L \), while the strong gravity behaves Newtonian. Here \( \Lambda \) is the cosmological constant. The weak field approach empirically links the gravity in galaxies with the baryonic distribution without any cold or warm dark matter. The modified Poisson equation in Milgromian dynamics is

\[
\nabla \cdot \left( \frac{\rho_b}{a_0} \mathbf{g} \right) = -4\pi G \rho_b,
\]

where \( \rho_b \) is the baryonic density and \( \mu(\mathbf{g}/a_0) \) is an interpolating function, \( \mu \rightarrow \mathbf{g}/a_0 \) when \( g \ll a_0 \) and \( \mu \rightarrow 1 \) when \( g \gg a_0 \) (Bekenstein & Milgrom 1984; Famaey & McGaugh 2012). A review of observational successes and problems of Milgrom’s dynamics, Milgromian dynamics can be related to space-time scale invariance (Milgrom 2012; Kroupa et al. 2012) and quantum-mechanical processes in the vacuum (Milgrom 1999; Zhao 2008, see also Appendix A in Kroupa et al. 2010).

From the weak field approach, the circular velocity at large radii of a galaxy follows as being

\[
v_c = (G a_0 M_b)^{1/4}.
\]

This implies flat rotation curves and thus, in terms of Newtonian dynamics, an apparent phantom dark matter distribution with an isothermal profile at large radii. Here \( G \) is the gravitational constant and \( M_b \) is the total baryonic mass of a galaxy. The apparent virial radius \( r_{\text{vir}} \) and the mass of the phantom dark matter halo can be derived from the asymptotic behaviour of the rotation curve. The apparent phantom dark matter halo (Newtonian) virial masses, \( M_{\text{vir}} \), and the apparent (Newtonian) dynamical mass-to-light ratios of the Georgiev et al. (2010) galaxies are here studied in Milgromian dynamics. The virial radius is defined as the radius where the average density of enclosed apparent dynamical matter which leads to the flat rotation curve of a galaxy (baryonic matter and phantom dark matter) is 200 times the critical density, \( \rho_{\text{crit}} \), of the universe, i.e.,

\[
M_{\text{vir}} \equiv p^3 v_c^3 r_{\text{vir}}/G.
\]

The virial mass of the phantom dark matter halo can be written as

\[
M_{\text{vir}} = v_c^2 p^{-1/2} G^{-3/2},
\]

where \( p = \frac{4}{3} \pi \times 200 \rho_{\text{crit}} \), here \( \rho_{\text{crit}} \) is the critical density of the universe and \( H \) is the Hubble constant, \( H = 70 \text{ km s}^{-1} \text{ Mpc}^{-1} \). Therefore the apparent virial mass is proportional to \( M_b^{1/4} \). The apparent virial mass is plotted in dependence of the V-band absolute magnitude, \( M_V \), of the galaxies used in Georgiev et al. (2010) in the upper left panel of Figure 2. Clearly, there is a tight anti-correlation between \( M_{\text{vir}} \) and \( M_V \). Such a correlation can indeed be expected, since the apparent virial mass is determined by the total mass of the baryonic matter in Milgromian dynamics.

The observed \( M_V \) and \( L_V \) data of the galaxies (here \( L_V/L_{\odot V} = 10^{-0.4(M_V-M_{\odot V})} \), where \( L_{\odot V} \) and \( M_{\odot V} \) are the luminosity and absolute magnitude of the Sun in the V band) and of \( M_{\text{GC}} \) in each galaxy used in this paper are originally taken from various observations (Miller & Lotz 2007; Peng et al. 2008; Spitzer et al. 2008; Georgiev et al. 2008, 2009a,b), and the data for \( M_b \) of the galaxies are obtained by performing the same calculation as Georgiev et al. (2010, see §3.2.1 in their paper): The masses of most of their sample galaxies are computed by using a luminosity-\( M/L \) relation derived from Bell et al. (2003), except for the dwarf galaxies from Miller & Lotz (2007), for which a constant mass to light ratio of 3 is assumed. Combining Equations 2 and 4 the virial mass of the phantom dark matter halo is derived as

\[
M_{\text{vir}} = (G a_0 M_b)^{3/4} p^{-1/2} G^{-3/2}.
\]

The apparent dynamical mass-to-light (V band) ratios of the galaxies, \( M_{\text{vir}}/L_V \), are shown in the lower left panel of Figure 2, \( M_{\text{vir}}/L_V \) correlates with \( M_V \), for brighter galaxies the \( M_{\text{vir}}/L_V \) ratios are small, while for fainter galaxies the \( M_{\text{vir}}/L_V \) ratios are large.

### 2.2 \( M_{\text{GC}} \), Specific frequency \( S_N \) and \( \eta \) values

It has been suggested that \( M_{\text{GC}} \propto M_{\text{vir}} \) in CDM models of galaxies (Blakeslee et al. 1997; Blakeslee 2009; Spitzer & Forbes 2009). \( M_{\text{GC}} \) and apparent \( M_{\text{vir}} \) in Milgromian dynamics are compared in the upper right panel of Figure 2 (log is log_{10} hereafter). The slopes of log \( M_{\text{vir}} \) in Milgromian dynamics and log \( M_{\text{GC}} \) are given in this panel by a linear fit function, for \( M_{\text{vir}} \leq 10^{12} M_{\odot} \) on the top left and for \( M_{\text{vir}} > 10^{12} M_{\odot} \) on the bottom right. For galaxies with apparent \( M_{\text{vir}} \leq 10^{11} M_{\odot} \), \( M_{\text{vir}} \propto M_{\text{GC}}^{1/3} \), while for massive galaxies with apparent \( M_{\text{vir}} > 10^{12} M_{\odot} \), \( M_{\text{vir}} \propto M_{\text{GC}}^{0.43} \approx M_{\odot}^{1/7} \). However a rather good agreement with the empirical CDM scaling (Spitzer & Forbes 2009), see the gray line in the upper right panel of Fig. 2 is evident. For the massive galaxies, in Milgromian dynamics, the ratio \( M_{\text{GC}}/M_{\text{vir}} \) is larger than for the less massive galaxies, since \( M_{\text{GC}}/M_{\text{vir}} \) is smaller for the massive galaxies. The above trend comes from the observed non-universality of \( M_{\text{GC}}/M_b \) (see Figure 1) and the one-to-one relation between \( M_{\text{vir}} \) and \( M_b \).

The \( M_{\text{vir}}/L_V \) values of the galaxies are plotted in dependence of \( M_{\text{GC}} \) in the lower right panel of Figure 2. \( M_{\text{vir}}/L_V \) decreases faster when \( M_{\text{GC}} \) is increasing and \( M_{\text{GC}} \) is smaller than about \( 2 \times 10^7 M_{\odot} \) (i.e., where \( M_{\text{vir}} \leq 10^{12} M_{\odot} \)), and the decreasing trend becomes shallower for systems with larger \( M_{\text{GC}} \) (i.e., where \( M_{\text{vir}} > 10^{12} M_{\odot} \)). This agrees with the trend of \( M_{\text{vir}} \) as a function of \( M_{\text{GC}} \).

From \( S_N \) and \( \eta \) of Milgromian dynamics. It is known that \( S_N = N_{\text{GC}} \times 10^{0.3(M_{\text{vir}}+15)} \propto M_{\text{GC}} L_V^{1/2} \). Since the stellar mass to light ratios of galaxies, \( M_b/L_V \), are determined by the stellar population and stellar evolution, and also the dark baryonic components like hot gas, the relation of \( M_b \) and \( L_V \) is not simply \( M_b \propto L_V \). A power law relation between \( L_V \) and total baryonic mass in a galaxy is fitted in Georgiev et al. (2010), which is \( M_b \propto L_V^{1.4} \). So \( S_N \propto M_{\text{GC}} M_{\text{vir}}^{0.8} \). Therefore \( S_N \) is a function of apparent \( M_{\text{vir}} \):

\[
S_N \propto M_{\text{vir}}^{3/4} \times M_{\text{vir}}^{6/5} = M_{\text{vir}}^{9/20}, \quad M_{\text{vir}} \leq 10^{12} M_{\odot}
\]

\[
S_N \propto M_{\text{vir}}^{7/3} \times M_{\text{vir}}^{6/5} = M_{\text{vir}}^{17/15}, \quad M_{\text{vir}} > 10^{12} M_{\odot}
\]

The specific frequency \( S_N \) is shown in dependence of \( M_{\text{vir}} \).
in the left panel of Figure 3. The values of $S_N$ are from Georgiev et al. (2010). It is confirmed that the trend of data points has two components, as expected in Eq. 3. The two-component function for galaxies with GCs implies that for low mass galaxies with $M_{\text{vir}} \leq 10^{12} \, M_\odot$ the number of GCs decreases with the apparent virial mass; for massive galaxies with $M_{\text{vir}} > 10^{12} \, M_\odot$, the number of GCs increases with the apparent halo mass.

Since apparent (phantom) dark matter halos in Milgromian dynamics have different density profiles compared to the dark halos obtained from CDM cosmological simulations, it is therefore unnecessary that the $M_{\text{GC}}/M_{\text{vir}}$ ratio is a universal constant. From the trend of the $M_{\text{GC}}$ as a function of $M_{\text{vir}}$ in the upper right panel of Figure 2, the trend of the $\eta$ values for galaxies with GCs can be obtained: for galaxies with apparent halo mass $M_{\text{vir}} \leq 10^{12} \, M_\odot$, $\eta \propto M_{\text{vir}}^{-1/4}$; for massive galaxies with $M_{\text{vir}} > 10^{12} \, M_\odot$, $\eta \propto M_{\text{vir}}^{4/3}$. Thus the mass fraction of GCs in galaxies decreases with increasing apparent halo virial mass when the galaxies are less massive than $10^{12} \, M_\odot$, and for the massive galaxies the mass fraction of GCs increases with increasing apparent virial mass.

The $\eta$ values for Georgiev’s galaxies (Georgiev et al. 2010) are shown in the right panel of Figure 3, and they agree with what is expected from the above discussion. The function of $\eta$ in Milgromian dynamics comes from the 100% conspiracy of apparent dark matter with baryons, and implies non-constant $M_{\text{GC}}/M_{\text{vir}}$ ratios for the GC-hosting galaxy systems. This is a natural expectation if the star formation rate (SFR) of a galaxy and thus its production of massive clusters (Weidner et al. 2004) depends on the depth of the potential well, although details need to be worked out.

### 3 DISCUSSION AND SUMMARY

In this work, it has been found that the apparent virial mass of the phantom dark matter halo (observed with Newtonian eyes) predicted in Milgromian dynamics tightly anti-correlates with the $V$-band galaxy absolute magnitude $M_V$, and that the apparent Newtonian dynamical mass-to-light ratios correlate with $M_V$ in a Milgromian dynamics universe. The relationship of total GC mass in a galaxy and the apparent dark matter halo virial mass of the hosting galaxy in Milgromian dynamics has been studied here. It follows that $M_{\text{GC}}$ is a two-part function of the apparent dark matter halo virial mass $M_{\text{vir}}$ for galaxies with GCs. For dwarf galaxies with $M_{\text{vir}} \leq 10^{12} \, M_\odot$, $M_{\text{GC}} \propto M_{\text{vir}}$, while for massive galaxies with $M_{\text{vir}} > 10^{12} \, M_\odot$, $M_{\text{GC}} \propto M_{\text{vir}}^{7/3}$. Therefore, the overall mass of a GC system increases more slowly with the increase of apparent virial mass for galaxies with shallower potential wells (i.e., $M_{\text{vir}} \leq 10^{12} \, M_\odot$), whereas the total mass of a GC system increases more rapidly with the increase of the apparent virial mass for galaxies with deeper potentials (i.e., $M_{\text{vir}} > 10^{12} \, M_\odot$).

For galaxies with GCs, the specific GC formation efficiency is $\eta \propto M_{\text{vir}}^{-1/4}$ for galaxies with $M_{\text{vir}} \leq 10^{12} \, M_\odot$, while for massive galaxies with $M_{\text{vir}} > 10^{12} \, M_\odot$, $\eta \propto M_{\text{vir}}^{4/3}$ in contrast to a universal constant $\eta$ obtained assuming CDM halos to be real. The scaling relations of specific frequency $S_N$ and specific GC formation efficiency $\eta$ as functions of apparent halo mass are different to what is derived from CDM models. The two-component functions of $S_N(M_{\text{vir}})$ and $\eta(M_{\text{vir}})$ indicate that GCs form more efficiently in mas-
sive galaxies in Milgromian dynamics and in dE galaxies with small apparent virial mass.

4 ACKNOWLEDGMENTS

Xufen Wu gratefully acknowledges support through the Alexander von Humboldt Foundation. We thank Iskren Georgiev for providing the observed data from Georgiev et al. (2010) and for the useful comments to the manuscript.

REFERENCES

Bekenstein J., Milgrom M., 1984, ApJ, 286, 7
Bell E. F., McIntosh D. H., Katz N., Weinberg M. D., 2003, ApJS, 149, 289
Blakeslee J. P., 1999, AJ, 118, 1506
Blakeslee J. P., Tonry J. L., Metzger M. R., 1997, AJ, 114, 482
Brodie J. P., Strader J., 2006, ARA&A, 44, 193
Donato F., Gentile G., Salucci P., Frigerio Martins C., Wilkinson M. I., Gilmore G., Grebel E. K., Koch A., Wyse R., 2009, MNRAS, 397, 1169
Famaey B., McGaugh S. S., 2012, Living Reviews in Relativity, 15, 10
Gentile G., Famaey B., Combes F., Kroupa P., Zhao H. S., Tiret O., 2007, A&A, 472, L25
Gentile G., Famaey B., Zhao H., Salucci P., 2009, Nature, 461, 627
Georgiev I. Y., Goudfrooij P., Puzia T. H., Hilker M., 2008, AJ, 135, 1858
Georgiev I. Y., Hilker M., Puzia T. H., Goudfrooij P., Baumgardt H., 2009, MNRAS, 396, 1075
Georgiev I. Y., Puzia T. H., Goudfrooij P., Hilker M., 2010, MNRAS, 406, 1967
Georgiev I. Y., Puzia T. H., Hilker M., Goudfrooij P., 2009, MNRAS, 392, 879
Harris W. E., 1991, ARA&A, 29, 543
Kissler-Patig M., 2000, in Schielicke R. E., ed., Reviews in Modern Astronomy Vol. 13 of Reviews in Modern Astronomy, Extragalactic Globular Cluster Systems: A new Perspective on Galaxy Formation and Evolution. p. 13
Kroupa P., 2012, Publications of the Astronomical Society of Australia, 29, 395
Kroupa P., Famaey B., de Boer K. S., Dabringhausen J., Pawlowski M. S., Boily C. M., Jerjen H., Forbes D., Hensler G., Metz M., 2010, A&A, 523, A32
Kroupa P., Pawlowski M., Milgrom M., 2012, International Journal of Modern Physics D, 21, 30003
McLaughlin D. E., 1999, AJ, 117, 2398
Milgrom M., 1983, ApJ, 270, 365
Milgrom M., 1999, Physics Letters A, 253, 273
Milgrom M., 2009, MNRAS, 398, 1023
Milgrom M., 2012, ArXiv e-prints
Milgrom M., Sanders R. H., 2003, ApJ, 599, L25
Miller B. W., Lotz J. M., 2007, ApJ, 670, 1074
Peng E. W., Jordán A., Côté P., Takamiya M., West M. J., Blakeslee J. P., Chen C.-W., Ferrarese L., Mei S., Tonry J. L., West A. A., 2008, ApJ, 681, 197
Sanders R. H., Noordermeer E., 2007, MNRAS, 379, 702
Spitler L. R., Forbes D. A., 2009, MNRAS, 392, L1