Dark matter dominated dwarf disc galaxy Segue 1

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ABSTRACT
Several observations reveal that dwarf galaxy Segue 1 has a dark matter (DM) halo at least \( \sim 200 \) times more massive than its visible baryon mass of only \( \sim 10^3 \, M_\odot \). The baryon mass is dominated by stars with perhaps an interstellar gas mass of \( \lesssim 13 \, M_\odot \). Regarding Segue 1 as a dwarf disc galaxy by its morphological appearance of long stretch, we invoke the dynamic model of Xiang-Gruess, Lou & Duschl (XLD) to estimate its physical parameters for possible equilibria with and without an isopedically magnetized gas disc. We estimate the range of DM mass and compare it with available observational inferences. Due to the relatively high stellar velocity dispersion compared to the stellar surface mass density, we find that a massive DM halo would be necessary to sustain disc equilibria. The required DM halo mass agrees grossly with observational inferences so far. For an isopedic magnetic field in a gas disc, the ratio \( f \) between the DM and baryon potentials depends strongly on the magnetic field strength. Therefore, a massive DM halo is needed to counteract either the strong stellar velocity dispersion and rotation of the stellar disc or the magnetic Lorentz force in the gas disc. By the radial force balances, the DM halo mass increases for faster disc rotation.

Key words: galaxies: haloes — galaxies: ISM — galaxies: kinematics and dynamics — magnetic fields — MHD — waves

1 INTRODUCTION
Segue 1 has been scrutinized among other Milky Way (MW) satellites (e.g. Putman et al. 2008; Martin et al. 2008; Geha et al. 2009) since its recent discovery a few years ago (Belokurov et al. 2007). There is an ongoing debate on the classification of Segue 1, i.e. whether Segue 1 is a dwarf galaxy or a stellar cluster. Belokurov et al. (2007) and Niederste-Ostholt et al. (2009) argue that Segue 1 is likely a stellar cluster with a distorted outer stellar part whereas Geha et al. (2009) suggest that Segue 1 is a dwarf galaxy. The most remarkable result of Geha et al. (2009) is the inferred dark matter (DM) halo of Segue 1 which is up to a factor \( f \sim 2000 \) times its baryon mass. The lower limit for this ratio \( f \) between DM and visible baryon matter is \( \sim 200 \); this is extraordinary as such ratio between DM and baryon mass in normal disc galaxies is typically \( f \sim 10 \). In spite of observational uncertainties, we may presume that Segue 1 has an unusually large ratio \( f \) calling for further observational and theoretical confirmations. In this Letter, we presume Segue 1 as a dwarf disc galaxy, apply our composite model for disc galaxies (Xiang-Gruess, Lou & Duschl 2009; XLD hereafter) and focus on relevant aspects of this DM issue as well as the possible role of a magnetic field in its interstellar gas disc.

Ultra-faint dwarf galaxies like Segue 1, which have such large fractions or amounts of DM, bear profound implications for the formation and evolution of galaxies. In the framework of cold DM cosmology, massive galaxies such as our MW are predicted to be accompanied by a large number of DM-dominated satellite halos. Extensive observations in the 1990s (e.g. Kauffmann et al. 1993; Willman et al. 2005) however have revealed a much smaller number of such satellites. This discrepancy is known as the missing satellite problem (e.g. Klypin et al. 1999; Moore et al. 1999).

The recent results for Segue 1 and other dwarf satellites of our MW have several implications. For example, the earlier hypothesis that all dwarf spheroidals (dSphs) are embedded in DM halos of the same mass (Mateo et al. 1993) must be treated with care for ultra-faint dwarf galaxies, as they do not fit into the predicted curves for the mass-to-light ratio (Simon & Geha 2007). Here, dwarf galaxies like Segue 1 have DM halos that are much more massive than the baryon mass. Another example is that, by applying the results for the ultra-faint dwarf galaxies such as Segue 1, Simon & Geha (2007) were able to provide a possible solution to the missing satellite problem in the so-called reionization scenario (e.g. Bullock et al. 2000; Benson et al. 2002; Somerville 2002; Ricotti & Gnedin 2005; Moore et al. 2006). The key assumption of this reionization scenario is that only halos which acquire a significant amount of mass before the redshift of reionization are able to form stars. DSpHs formed before the ionization era, are prevented from forming stars by photoionization feedbacks (e.g. Babul & Rees 1992; Quinn et al. 1996; Weinberg et al. 1997; Navarro & Steinmetz 1997).
In Section 2 we summarize observational results and inferences. In Section 3 the surface mass densities of the stellar and gas discs are estimated according to XLD model. Regarding Segue 1 as a dwarf disc galaxy, we construct possible stellar equilibrium configurations in Section 4. In Section 5 we further assume that gas and magnetic field are also present in Segue 1. For this configuration, we construct possible equilibrium configurations and estimate magnetic field strength as well as the resulting ratio $f$.

2 OBSERVATIONS OF DWARF GALAXY SEQUE 1

Segue 1 does not appear spherical or bulge-like visually in figure 1 of Geha et al. (2009); it has a fairly long stretch with a projected thickness. By this morphological appearance, Segue 1 is most likely a dwarf disc galaxy almost edge-on to be consistent with figure 1 of Geha et al. (2009). In Table 1 observational results of Geha et al. are summarized. To determine the total dynamic mass $M^{tot}$ within $\sim 50$ pc, they used two methods leading to two slightly different masses (see Table 1). Instead of a disc galaxy, both methods assume that Segue 1 is a relaxed, self-gravitating, spherically symmetric system without rotation.

The first method assumes a sphere where mass follows light. The density is described by King’s model (1966) in a virial equilibrium. The total mass is determined according to Illingworth (1976) to be $M^{tot} = 16\pi r_c^2\sigma_s^2$, where $\beta^* = 8$ for typical dSphs (e.g. Mateo 1998), $r_c = 18.6^{+3}_{-4}$ pc is the core radius of King’s profile for Segue 1, and $\sigma_s$ is the mean stellar velocity dispersion.

The second method is detailed in Strigari et al. (2008). The two main assumptions used by Geha et al. (2009) are that the light profile follows the observed Plummer profile with effective radius $r_{eff} = 29$ pc, and that the DM follows a five-parameter density profile (Strigari et al. 2008). By marginalizing over these parameters for the DM density profile, the mass at any radius $r$ is determined.

Putman et al. (2008) noted that Segue 1 has little to almost no HI gas, with an upper limit of $\sim 13 M_\odot$ for the gas mass. In Table 1 we include the corresponding ratios $f$ between DM and baryon masses, or equivalently, the DM potential to the baryon potential.

3 ESTIMATES OF SURFACE MASS DENSITIES

Our recent XLD model involves the rotational equilibrium of a composite scale-free disc system embedded in an axisymmetric DM halo; this composite disc system contains a thin stellar disc and an isopdraulically magnetized thin gas disc. Using the XLD model for a scale-free thin stellar disc in cylindrical coordinates $(r, \theta, z)$ and a total stellar mass $M^s \sim 10^7 M_\odot$ (Geha et al. 2009) within $\sim 50$ pc, the stellar surface mass density profile in radius $r$ is

$$\Sigma_0^s(r) = S^s(r)^{-2\beta - 1}. \tag{1}$$

Here, the coefficient $S^s(\rho)$ of eq. (12) in XLD is determined by

$$M^s(50 \text{ pc}) = \int_0^{50 \text{ pc}} \int_0^{2\pi} \Sigma_0^s(r) r dr d\theta, \tag{2}$$

$$S^s = \left(1 - 2\beta \right)^{10^8 M_\odot} \frac{2\pi}{2\pi r_{1-2\beta}^{2/3}\text{pc}^2}. \tag{3}$$

For the valid range of scaling index $\beta = (0, 1/2)$, we estimate $S^s(\rho) \in (2.06 \times 10^{15}, 2.5 \times 10^{31})$ g cm$^{-2}$ in expression (1).

For a thin gas disc with a gas surface mass density of

$$\Sigma_0^g(r) = S^g(r)^{-2\beta - 1}, \tag{4}$$

and a total gas mass of $M^g \lesssim 13 M_\odot$ within $\sim 50$ pc, the constant coefficient $S^g(\rho)$ is similarly estimated by

$$M^g(50 \text{ pc}) = \int_0^{50 \text{ pc}} \int_0^{2\pi} \Sigma_0^g(r) r dr d\theta, \tag{5}$$

$$S^g = \frac{(1 - 2\beta) 13 M_\odot}{2\pi r_{1-2\beta}^{2/3}\text{pc}^2}. \tag{6}$$

For the same range $\beta = (0, 1/2)$, eq 6 then gives the corresponding $S^g(\rho) \in (2.68 \times 10^{13}, 3.26 \times 10^{31})$ g cm$^{-2}$.

The ratio of the two disc surface mass densities is then

$$\delta_0 = \frac{\Sigma_0^g(r)}{\Sigma_0^s(r)} = \frac{S^g}{S^s} = \frac{13 M_\odot}{10^8 M_\odot} = 0.013. \tag{7}$$

This ratio $\delta_0$ characterizes the global evolution of a dwarf disc galaxy as stars form out of the gaseous interstellar medium (ISM).

4 EQUILIBRIUM STATES WITHOUT GAS DISC

For a single thin stellar disc without gas disc, the equilibrium is sustained by the radial momentum balance (see XLD), viz. $\left[v^{s}_{\theta}\right]^2 + \left[a^{s}(\rho)\right]^2(2\beta + 1) = 2\beta r G Y_0(\beta) \Sigma_0^s(1 + f)$, \tag{8}

where $a^{s}(\rho)$ is the stellar disc rotation speed, $a^{s}(\rho)$ is the mean stellar velocity dispersion, $G = 6.67 \times 10^{-8} \text{ cm}^3 \text{g}^{-1} \text{s}^{-2}$ is the gravitational constant, and $Y_0(\beta)$ is related to the Gamma functions $\Gamma(z)$ by $Y_0(\beta) = \frac{\pi}{\Gamma(1/2 - \beta)\Gamma(1/2 + \beta)}$, \tag{9}

(see eq (26) of XLD). Without $v^{s}_{\theta}$, the corresponding ratio $f^{\rho}_{\min}$ between the DM potential $\Phi_0$ and baryon mass potential $\Phi^{s}_{\rho}$ can be determined from eq (8) within the following range of $f^{\rho}_{\min} = \frac{[a^{s}(\rho)]^2}{2\beta r G Y_0(\beta) \Sigma_0^s} - 1 = \left\{ \begin{array}{ll} 85.7 & \text{for } \beta = 0.49, \\ 208.5 & \text{for } \beta = 0.01, \end{array} \right. \tag{10}$

where we adopt $a^{s}(\rho) \sim 4.3 \text{ km s}^{-1}$ at $r = 10 \text{ pc}$. This range of $f^{\rho}_{\min}$ shifts upwards for a larger $a^{s}(\rho)$. Scaling index $\beta$ has a theoretically allowed range of $\beta \in (0, 0.5)$. This range of lower limits for $f^{\rho}_{\min}$ already indicates that $f$ must be unusually large for Segue 1, as the stellar disc itself is not sufficiently massive to counteract the 'stellar pressure' mimicked by the stellar velocity dispersion $a^{s}(\rho)$.

For $v^{s}_{\theta} \neq 0$, the ratio $f$ should be even higher by eq (8).

For the observed stellar velocity dispersion $a^{s}(\rho)$ and $f = \Phi_0/\Phi^{s}_{\rho}$ between the DM potential $\Phi_0$ and the baryon potential $\Phi^{s}_{\rho}$, we determine the necessary disc rotation speed $v^{s}_{\theta}$ using eq (9). In Fig. 1 we show the disc rotation speeds for the upper limit $f^{\rho}_{\min, \text{obs}} = 214.2$ and the lower limit $f^{\rho}_{\min, \text{obs}} = 196.4$ inferred by Geha et al. (2009) as a function of our disc scaling index $\beta$. For $f^{\rho}_{\min, \text{obs}} = 214.2$, the equilibria for all allowed $\beta$ can persist for $v^{s}_{\theta} \neq 0$. For $f^{\rho}_{\min, \text{obs}} = 196.4$ and $\beta \equiv 0.04$, $v^{s}_{\theta} = 0$ allows an equilibrium, whereas for all $\beta > 0.04$, one infers $v^{s}_{\theta} \neq 0$ for the stellar disc.

For a single stellar disc without rotation embedded in an axisymmetric DM halo, the minimum $f$ falls in the range $\sim 86 - 209$ depending on $\beta$ value. This trend grossly agrees with recent observations that Segue 1 is a DM dominated dwarf galaxy. Nevertheless, for $f$ approaches several hundreds or even $\sim 2000$ as shown in Geha et al. (2009), a stellar disc rotational speed is necessarily required as XLD model cannot accommodate such large
Table 1. Key parameters of dwarf galaxy Segue 1 as inferred by Geha et al. (2009). The mean heliocentric radial velocity in the first row is the radial velocity from the Sun to Segue 1. Parameter \( f \) in the 9th row is the ratio between the DM mass \( M^{DM} \) and the baryon mass \( M^{b} \) consisting of stellar mass \( M^{(s)} \) and gas mass \( M^{(g)} \). The total dynamic mass \( M^{(tot)} \) includes \( M^{DM} \) and \( M^{b} \). The stellar mass \( M^{(s)} \) is determined by using a ratio of \( M^{(s)}/L_{V} \sim 3 \) (e.g. Maraston 2005) between the mass and the luminosity in the absence of DM. In the 10th row, \( f_{\text{min}} \) and \( f_{\text{max}} \) are the minimum and maximum values estimated for \( f \) parameter.

| Variables | Values |
|-----------|--------|
| Mean heliocentric radial velocity | 206.4 ± 1.3 km s\(^{-1}\) |
| Stellar velocity dispersion \( \sigma^{s} \) | 4.3 ± 1.2 km s\(^{-1}\) |
| Total stellar luminosity \( L_{V} \) within 50 pc | \( \sim 340 \) L\(\odot\) |
| Total stellar mass \( M^{(s)} \) by using \( M^{(s)}/L_{V} \sim 3 \) | \( \sim 10^{3} \) M\(\odot\) |

| Mass-follow-light model results | Two-component maximum-likelihood model results |
|------------------------------|-----------------------------------------------|
| The calculated total dynamic mass \( M^{(tot)} \) within 50 pc | \( 4.5^{+0.7}_{-0.5} \times 10^{5} \) M\(\odot\) | \( 8.7^{+1.3}_{-0.5} \times 10^{5} \) M\(\odot\) |
| The resultant mass-to-light ratio \( M^{(tot)}/L_{V} \) | \( 1320^{+2680}_{-940} \) | \( 2440^{+1580}_{-1775} \) |
| \( f = M^{(DM)}/M^{(d)} = [M^{(tot)} - M^{(d)}]/M^{(d)} \) | \( 443.2^{+446.0}_{-246.8} \) | \( 857.9^{+1283.4}_{-513.3} \) |
| \( f_{\text{min}} \) and \( f_{\text{max}} \) | 196.4 | 2142.2 |

5 EQUILIBRIUM DISC SYSTEM IN THE PRESENCE OF AN ISOPEDICALLY MAGNETIZED GAS DISC

By including a thin scale-free isopeditically magnetized gas disc according to XLD, the equilibrium state involves two coupled radial momentum balances for two discs embedded in a DM halo, viz.

\[
\begin{align*}
\left[ v^{(s)}_{\|} \right]^{2} + \left[ \sigma^{s} \right]^{2}(2\beta + 1) &= 2\beta G\Phi_{0}(\beta) \left[ \Sigma^{(s)}_{0} + \Sigma^{(g)}_{0} \right] (1 + f) , \\
\left[ v^{(g)}_{\|} \right]^{2} + \Theta \left[ \sigma^{g} \right]^{2}(2\beta + 1) &= 2\beta G\Phi_{0}(\beta) \left\{ \left[ \Sigma^{(s)}_{0} + \Sigma^{(g)}_{0} \right] (1 + f) - (1 - \epsilon) \Sigma^{(s)}_{0} \right\} ,
\end{align*}
\]

where \( v^{(g)}_{\|} \) is the gas disc rotation speed, \( a^{(g)} \) is the gas sound speed, \( \Theta \) and \( \epsilon \) are functions of the isopedic magnetic field strength \( B_{z} \) with \( \lambda = 2\pi G^{1/2} \Sigma^{(s)}_{0}/B_{z} \), \( \eta = \beta Y_{0}(\beta)/\pi \), \( \epsilon = 1 - \lambda^{2} \), \( \Theta = 1 + (1 + \eta^{2})/\lambda^{2} + \eta^{2} \) and \( \lambda = (1 + \delta_{0}^{-1}) \lambda \) (see Lou & Wu 2005 and XLD for more details).

For this composite disc system embedded in a massive DM halo, the ratio \( f \) is defined as \( f = \Phi_{0}/[\Phi^{(s)}_{0} + \Phi^{(g)}_{0}] \). Taking the total gas mass inside \( \sim 50 \) pc as \( M^{(g)}(50 \text{ pc}) \sim 13 \text{M}_{\odot} \), we now explore consequences of radial momentum balances (11) and (12).

5.1 Composite equilibria without disc rotations

We first assume that both disc rotation speeds \( v^{(s)}_{\|} \) and \( v^{(g)}_{\|} \) vanish as in Geha et al. (2009). By eqn (11) with \( v^{(s)}_{\|} = 0 \), the ratio \( f^{(s)}_{\text{min}} \) for the stellar disc is allowed in an equilibrium. This \( f^{(s)}_{\text{min}} = f^{(g)}_{\text{min}} \) must also be set in eq (12) as for a composite system \( f \) is the same for stellar and gas discs. By also using \( v^{(g)}_{\|} = 0 \) and a certain gas sound speed \( a^{(g)} \), the corresponding magnetic field strength characterized by \( \Theta \) and \( \epsilon \) parameters is found. In this way, we can construct an equilibrium for the composite system of a stellar and a magnetized gas disc without rotation and infer a magnetic field strength. We calculate below the corresponding isopedic magnetic field strength \( B_{z} \) in order to discuss its observational diagnostics (Lou & Fan 2003; Lou & Wu 2005; Wu & Lou 2006).
For the magnetized gas disc, \( f_{\text{min}}^{(s)} \) for \( v_{\theta0}^{(s)} = 0 \) km s\(^{-1}\) is given by
\[
 f_{\text{min}}^{(s)} = \frac{[\alpha^{(s)}]^{2} (2\beta + 1)}{2\beta r G Y_{0}(\beta) \left[ \Sigma_{\text{g}}^{(s)} + \Sigma_{0}^{(s)} \right]} - 1 \quad (13)
\]
\[
 f_{\text{min}}^{(g)} = \frac{\Theta [\alpha^{(g)}]^{2} (2\beta + 1) + (1 - \epsilon) \Sigma_{0}^{(g)}}{2\beta r G Y_{0}(\beta) \left[ \Sigma_{\text{g}}^{(g)} + \Sigma_{0}^{(g)} \right]} - 1 . \quad (14)
\]
For a gas disc sound speed \( a^{(s)}(10\text{pc}) = 0.5 \text{ km s}^{-1} \), we find \( f_{\text{min}}^{(s)} = 84.6 \) for \( B_{z}(1\text{pc}) = 1.05 \mu G \) with \( \beta = 0.49 \) or \( f_{\text{min}}^{(g)} = 205.8 \) for \( B_{z}(1\text{pc}) = 1.87 \mu G \) with \( \beta = 0.01 \). These magnetic field strengths are commonly inferred in many disc spiral galaxies (e.g. Fan & Lou 1996; Lou & Fan 1998) and should be observationally searched for Segue 1 as a test or a constraint of XLD model. We thus advance a model configuration for Segue 1 by using a composite system containing stellar and magnetized gas disc components embedded in a massive axisymmetric DM halo (XLD).

For zero magnetic field with \( \epsilon \rightarrow 1 \) and \( \Theta \rightarrow 1 \), the gas disc must rotate in order to have the same \( f \) as the non-rotating stellar disc. For \( \beta = 0.49 \), the ratio \( f_{\text{min}}^{(s)} \), of a non-rotating stellar disc is 84.6; for \( \beta = 0.5 \) km s\(^{-1}\), the corresponding \( v_{\theta0}^{(s)} \) is 6 km s\(^{-1}\) by eq \( (12) \). For \( \beta = 0.01 \), the ratio \( f_{\text{min}}^{(s)} \) of a non-rotating stellar disc is 205.8 and the \( v_{\theta0}^{(s)} \) is 4.3 km s\(^{-1}\) for the same \( a^{(s)} \).

5.2 Influence of an isodic magnetic field in the ISM disc

We now examine eqn \( (14) \) with the emphasis on the influence of magnetic field on \( f \) for Segue 1. By assuming \( v_{\theta0}^{(s)} = 0 \), we plot the corresponding \( f_{\text{min}}^{(s)} \) for \( \beta = 0.49, a^{(g)} = (10 \text{pc}) = 0.5 \text{ km s}^{-1} \) and for \( B_{z} \in (1, 5) \mu G \) at \( r = 1 \text{ pc} \) or \( \lambda \in (0.01, 0.003) \) in Fig. 2. One should note the inverse proportionality of \( \lambda \) to \( B_{z} \), i.e. a stronger magnetic field corresponds to a smaller \( \lambda \) and vice versa. For magnetic field strengths up to \( 10 \mu G \), the corresponding \( f_{\text{min}}^{(g)} \) grows to very large values. It is remarkable that relatively weak magnetic fields of a few \( \mu G \) can cause a rapid increase of \( f_{\text{min}}^{(g)} \) (XLD). Thereby, \( f \) may grow into a range for which the stellar disc cannot maintain an equilibrium without a rotation speed as discussed above. For Segue 1, if it is possible in the near future to estimate the magnetic field strength via synchrotron radio emissions, then we could also infer the stellar disc rotation speed.

Physically, the composite model of a magnetized gas disc may thus correspond to a large \( f \) ratio without the requirement of gas disc rotation, in contrast to the stellar disc where we can only reach \( f \sim 200 \) without disc rotation given the currently estimated stellar velocity dispersion.

For zero magnetic field on the other hand, we find a lower limit of \( f_{\text{min}}^{(s)} \sim 14 \) which lies well beneath the lower limit \( f_{\text{min}}^{(s)} \) found for the stellar disc. In this case, the gas disc must rotate in order to reach the high \( f \) determined by the stellar disc. The gas disc rotation speeds \( v_{\theta0}^{(g)} \) for the two ratios \( f_{\text{min}}^{(s)} \) of \( \beta = 0.01 \) and \( \beta = 0.49 \) are calculated for Segue 1 at the end of the last subsection.

Therefore for weak or no magnetic fields, the gas disc, if there is indeed one in Segue 1, must then rotate. For magnetic field strengths of at least \( \sim 2 \mu G \), the ratio \( f_{\text{min}}^{(g)} \) given by the gas disc is larger than the ratio \( f_{\text{min}}^{(s)} \) of the stellar disc without rotation. In this case, the stellar disc must be in rotation. For magnetic field strengths in the range of \( [2, 10] \mu G \) at radius 1 pc, the corresponding stellar disc rotation speeds \( v_{\theta0}^{(s)} \) for \( \beta = 0.49 \) are \([9.7, 45.5]\) km s\(^{-1}\), while for \( \beta = 0.01 \), we have \( v_{\theta0}^{(s)} = [1.6, 22.5] \) km s\(^{-1}\). By estimating the magnetic field strength and/or the \( f \) ratio for Segue 1, we can infer which disc must or can be in rotation.

6 DISCUSSION AND SPECULATIONS

At this stage of investigation, two aspects of Segue 1 still remain uncertain in terms of observations. (i) It is not sure whether Segue 1 has a gas disc or not; only an upper mass limit can be estimated at present. (ii) While no rotation is inferred so far for Segue 1 (GeHa et al. 2009), a disc rotation still cannot be excluded definitely due to the small number of stars sampled so far.

Because of these uncertainties, we performed several calculations for two different cases, i.e. without and with gas disc. By assuming Segue 1 in an equilibrium, we test the hypothesis that the baryon component is distributed in a thin disc whereas the DM is in an axisymmetric halo surrounding Segue 1. We mainly use the results for the stellar disc velocity dispersion \( a^{(s)} \) and the upper and lower limits \( f_{\text{max}, \text{obs}} \) and \( f_{\text{min}, \text{obs}} \) inferred by GeHa et al. (2009).

In the first study, we assume no gas disc in the dwarf disc galaxy Segue 1. The stellar disc mass is set to be \( \sim 10^{3} M_{\odot} \) inside \( r \sim 50 \text{ pc} \) and the stellar velocity dispersion is mimicked as the sound speed of the stellar disc. Without rotation, we are able to derive the corresponding ratio \( f_{\text{min}}^{(s)} \) as a function of scaling index \( \beta \). By comparing our \( f^{(s)} \) with the lower and upper limits \( f_{\text{min}, \text{obs}} \) and \( f_{\text{max}, \text{obs}} \) found by GeHa et al. (2009), we find that for \( \beta \geq 0.04 \), a disc rotation is necessary in order to reach the lower limit \( f_{\text{min}, \text{obs}} \). For the upper limit \( f_{\text{max}, \text{obs}} \), for all theoretical allowed \( \beta \), a disc rotation speed is needed. Our solutions for \( f \) ratio hence agree with \( f_{\text{min}, \text{obs}} \) and \( f_{\text{max}, \text{obs}} \) if disc rotations are allowed. If it is found observationally that no disc rotation is present, then our composite model provides a range of \([86, 209]\) for \( f \). The large amount of DM is required due to the large stellar velocity dispersion representing an ‘effective pressure’ in the stellar disc compared to the low stellar surface mass density. Since the stellar disc is not capable to counteract the strong disc ‘pressure’, the massive DM halo is required. Our upper limit \( f_{\text{max}} = 209 \) is much smaller than \( f_{\text{max}, \text{obs}} \cong 2142 \). If a \( f_{\text{max}} = 2142 \) is indeed necessary, then
a disc rotation speed of $v_{80}^{(s)} \approx 30$ km s$^{-1}$ (for $\beta = 0.49$) and $v_{80}^{(s)} \approx 13$ km s$^{-1}$ (for $\beta = 0.01$) is needed. Our solutions for $f$ hence agree with inferred $f_{\min, \text{obs}}$ and $f_{\max, \text{obs}}$ of Geha et al. (2009), only if disc rotations are allowed. In short, our disc model analysis suggests that a determination of $f$ with only the estimated velocity dispersion is insufficient.

In the second study, we assumed a much less massive gas disc component in Segue 1. Without magnetic fields, the DM amount is mainly associated with the stellar disc and the gas disc is expected to be in rotation. For an isopedic magnetic field of at least $\sim 2 \mu$G, the influence of the magnetic field is so strong that the value of $f_{\min}^{(s)}$ exceeds the $f_{\min}$, i.e. the stellar disc has to rotate in order to reach $f_{\min}^{(s)}$. With increasing magnetic field strengths, $f_{\min}^{(s)}$ increases rapidly in order to counteract the magnetic Lorentz force in the gaseous ISM disc.

In terms of dynamics, we offer a plausible theoretical explanation for the large amount of DM in the dwarf galaxy Segue 1. Our main assumption is a baryon disc embedded in an axisymmetric DM halo to sustain a global equilibrium.

The two major forces which the DM halo has to confine are the strong effective pressure in the stellar disc and in the presence of gas disc and isopedic magnetic field therein, the magnetic Lorentz force in the gaseous ISM disc. Without rotation, these forces are essential to counterbalance the self-gravity of a massive DM halo.

An important conclusion of this study is, that a large amount of DM may not completely correspond to the stellar dynamics in Segue 1 type dwarf disc galaxies, but might also correspond to magnetic fields embedded in gas discs of such dwarf galaxies.

As stellar velocity dispersions alone cannot determine $f$ uniquely, we discuss potentially possible independent means of estimating DM halo mass of Segue 1, e.g. gravitational lensing. First mentioned by Einstein (1936) and Zwicky (1937a,b), the gravitational lensing effect was detected by Walsh et al. (1979). Recently, the possibility of detecting DM halos of dwarf galaxies was studied by Zackrisson et al. (2008), Riehm et al. (2009) and Zackrisson & Riehm (2009). Theoretically, gravitational lensing effects can be utilized to determine the DM halos of dwarf galaxies. Practically, the expected effects of DM halos are still too weak to be observed. But this method is a possible method for the future to estimate masses of dwarf galaxies.

Another point is that in the gas disc, a magnetic field could be the counterpart of the massive DM halo preventing the necessity of gas disc rotation. For this study, a determination of magnetic field is crucial for Segue 1. Blasi et al. (2003) discussed synchrotron radio emissions from galactic satellites. In DM dominated dwarf galaxies, high-energy electrons and positrons may be expected as by-products of high-energy photons (from the $\pi^0$ decay chains) which might be on their part products of DM annihilations. In the presence of magnetic fields threading through a gas disc, these high-energy electrons and positrons may be revealed via synchrotron radio emissions. Due to its massive DM halo, Segue 1 could be a promising candidate for high-energy electrons and positrons. Along this line, the question whether there is a magnetic field or not can be tested observationally for Segue 1 by searching for extended synchrotron radio emissions (Lou & Fan 2003). In reality, other magnetic field configurations are also possible (e.g. Lou & Zou 2004, 2006).

Finally, the issue, whether Segue 1 is a dwarf galaxy or a stellar cluster, is still not answered definitively. The XLD model adapted here for Segue 1 can be applied to other dwarf disc galaxies or flat stellar clusters. Dwarf galaxies of similar stellar and/or gas masses and velocity dispersions should lead to similar conclusions according to our hydrodynamic model considerations.

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