DYNAMICAL FRICTION IN THE LOCAL GROUP

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ABSTRACT. In this paper we consider dynamical behavior of the astrophysical objects in the Local Group. The motion of Andromed and The Milky Way is studied. We distinguish two different models: for the first one we do not take into account the influence of the Intra-Group Matter (IGrM), for the second one we take into account the dynamical friction due to the IGrM. We obtained some characteristic IGrM parametres such as particle masses for principle cases of the collision between the giant galaxies and the situation when the merger becomes problematic. We also define the region in the vicinity of our Local Group where the formation of the Hubble Flows starts.

Key words: Local group; Hubble flows; Galaxies: Milky Way, Andromeda.

1. Introduction

Modern observational cosmology provides enough data to confirm that there is no clear evidence of spatial homogeneity up to sizes ~ 150 Mpc [1]. Deep inside of such scales Universe now consists of a set of discrete inhomogeneities (galaxies, groups and clusters of galaxies), which disturb the background Friedmann Universe. Hence, classical mechanics of discrete objects provides more adequate approach than hydrodynamics with its continuous flows. In [2] this approach has been elaborated for an arbitrary number of randomly distributed inhomogeneities on the cosmological background.

In this paper we continue this investigation. First we consider the Andromeda and the Milky Way relative motion in the free-fall approximation and reveal the conditions for the possible collision and recession. We show that in the absence of IGrM for the currently known parameters of this system the collision is hardly plausible in future because of the angular momentum. For the second model we take into account the dynamical friction due to the IGrM. Here, we find a characteristic value of the IGrM particle velocity dispersion. For the values less than the characteristic one the merger will take place but for bigger values the merger can be problematic.

Then we define a region where the formation of the Hubble flows starts. There is no zero-acceleration surface in the vicinity of the Local Group, but there is a nearly closed area around the MW and M31 where the absolute value of the acceleration is approximately equal to zero. The Hubble flows are formed outside of this area.

2. Free-fall approximation

We consider our Local Group of galaxies which consists of two giant galaxies (our Milky Way and Andromeda) and approximately 40 dwarf galaxies. At the present time the giant galaxies are located at the distance 0.78 Mpc and move towards each other with the speed 120 km/sec. For these two galaxies we can apply our method up to the separation distance of the order of 100 Kpc, where the process of the merger starts.

In the centre of mass system the Lagrange function is

$$\tilde{\mathcal{L}}_{AB} = G_N \frac{m_A m_B}{L} + \frac{1}{2}\frac{m_A m_B}{m_A + m_B}\left(\frac{\dot{a}^2}{a^2}L^2 - \right.$$
$$\left. -2\frac{\dot{a}}{a}\dot{L}L + \dot{L}^2 + L^2\dot{\psi}^2\right), \qquad (1)$$

where without loss of generality we put $\theta = \pi/2$. Therefore, the Lagrange equation for the separation distance is

$$\ddot{L} = -G_N \frac{2\overline{m}}{L^2} + \frac{M^2}{\mu^2 L^3} + \frac{\ddot{a}}{a}L, \qquad (2)$$

where we introduced the reduced mass, the average mass and the angular momentum:

$$\frac{m_A m_B}{m_A + m_B} \equiv \mu, \quad \overline{m} = \frac{m_A + m_B}{2},$$
$$\mu L^2 \dot{\psi} \equiv M = \text{const}. \qquad (3)$$

The first term in the right hand side of (2) is due to the gravitational attraction, the second term is the centrifugal force and the third term originates from the cosmological expansion of the Universe.

The observations indicate the proper motion of Andromeda perpendicular to our line of sight. This transverse velocity $V_{\perp 0} \sim 100$ km/sec [3]. The collision of

the galaxies is possible if the smallest separation distance between them (which corresponds to the turning point) is less then the merger distance 100 − 150 Kpc. For the given transverse velocity the smallest separation distance is $L \approx 290$ Kpc at time $t \approx 4.44$ Gyr from present. This distance is much bigger than the merger distance. Therefore, for the chosen initial conditions, the collision between the Milky Way and Andromeda is absent. The collision may take place for a smaller transverse velocity.
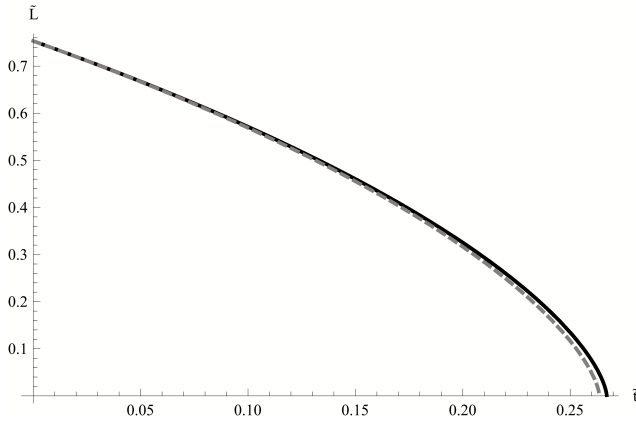

Figure 1: Evolution of the separation distance between the MW and M31 in the case of the zero angular momentum.
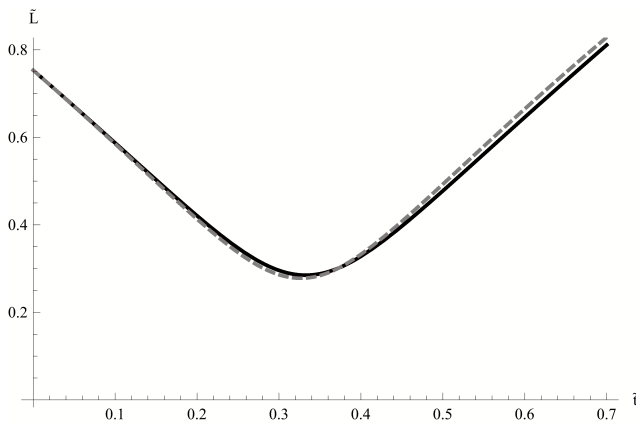

Figure 2: Evolution of the separation distance between the MW and M31 in the case of the non-zero angular momentum.

Figures 1, 2 show the change with time of the separation distance between the Milky Way and Andromeda starting from the present ($\tilde{t} = 0$) in the case of the absence of the dynamical friction. The solid black lines take into account both gravitational attraction and cosmological expansion, while the grey dashed lines disregard the cosmological expansion. The transverse velocity is absent on the Fig. 1. On the Fig. 2, the transverse velocity is equal to 100 km/sec.

3. Dynamical Friction

It is well known that a massive body with a mass M moving through surrounding matter, which consists of discrete particles of the mass m, will lose its momentum and kinetic energy due to the gravitational interaction with these particles. Such effect is called dynamical friction. The force of the dynamical friction is given by the Chandrasekhar formula [4]:

$$\frac{d\mathbf{V}_M}{dt} = -\frac{4\pi Q\, G_N^2\, M \rho_{ph,m}}{V_M^3} \times$$
$$\times \left[\mathrm{erf}(\chi) - \frac{2\chi}{\sqrt{\pi}} \exp\left(-\chi^2\right)\right] \mathbf{V}_M\,, \qquad (4)$$

where $\mathbf{V}_M$ is the physical velocity of the mass M, $\rho_{ph,m}$ is the physical rest mass density of IGrM, $\chi \equiv V_M/(\sqrt{2}\sigma)$ and erf is the error function. Here, $Q \equiv (1/2)\ln\left(1 + \lambda^2\right)$ is the so called Coulomb logarithm defined by the largest impact parameter b_{max}, the initial relative velocity V_0 and the masses M and m: $\lambda = b_{max}V_0^2/[G_N(M + m)] \approx b_{max}V_0^2/(G_N M)$. The formula (4) is defined with respect to a frame where the IGrM particles have the Maxwell's speed distribution with the dispersion $\sigma = \sqrt{kT/m}$. The typical value of the IGrM temperature in the Local Group is $T \sim 10^5\,\mathrm{K} \rightarrow kT \sim 8.6$ eV [3].

Therefore, the Milky Way and Andromeda should slow down moving through the IGrM because of the dynamical friction (4).

Comparatively little is known about truly intergalactic medium. Most probably this is a mixture of the baryonic matter (mainly in the form of ionized hydrogen) and dark matter. There is a great variety of candidates for dark matter with masses ranging from μeV$\div$eV (e.g., axions) to TeV (e.g., WIMPs). Therefore, in the formula for the dispersion σ, the parameters T and m are some effective values. It makes sense not to specify them separately, but to consider their ratio, i.e. σ^2. As we mentioned above, our approach works up to the first touch of the galaxies which occurs approximately at the separation distance 100 Kpc between their centers. On the figures 3, 5, this event is marked by the grey points on the bottom black solid lines. In this case, the merger of the galaxies will take place. Our approach does not describe this process. The continuations of the lines (the separation distance) after the first touch is very schematic. On the figures 4, 6, this event corresponds to the touch of two thin grey circles. The distance between their centers is equal to 100 Kpc. We do not continue the trajectories after this first touch.

We found two characteristic values for the dimensionless parameter $\tilde{\sigma}$. The first one is $\tilde{\sigma}_1 = 1.17$ and

corresponds to the situation when the first close passage occurs at the separation distance $L = 100$ Kpc (see the grey point on the Fig. 3 and two grey touched circles on the Fig. 4) which corresponds to the touch of the galaxies. Obviously, for all $\tilde{\sigma} < \tilde{\sigma}_1$, this distance will be less than 100 Kpc and the first touch of the galaxies will take place during the first passage. For the bigger values of $\tilde{\sigma}$, the first passage occurs at the separation distance larger than 100 Kpc. The second characteristic value is $\tilde{\sigma}_2 = 2.306$ and describes the situation when the galaxies, after the first close passage, grow apart to the turning point at the separation distance 1 Mpc from each other (see the black point on the upper black line on the Fig. 5). At these and greater distances, the rest mass density of IGrM decreases and the dragging effect of the dynamical friction can be too small to force the galaxies to converge again. Therefore, for $\tilde{\sigma} > \tilde{\sigma}_2$, the merger of the galaxies becomes problematic. For $\tilde{\sigma}_1 < \tilde{\sigma} < \tilde{\sigma}_2$, the touch will take place during the second passage. It is of interest to estimate masses of the IGrM particles which correspond to these characteristic values of $\tilde{\sigma}$. The masses m can be expressed via the temperature T and dimensionless dispersion $\tilde{\sigma}$ as follows: $m(\text{MeV}) \approx \left\{ \left[kT(\text{erg})/8.464 \times 10^{13}(\text{cm}^2/\text{sec}^2) \right] \times 0.5604 \times 10^{27}(\text{MeV/g}) \right\} / \tilde{\sigma}^2$. The temperature of IGrM in the Local Group is usually estimated as $T \sim 10^5$ K [3]. Then, for this value of T, we get $m_1 \sim 67$ MeV and $m_2 \sim 17$ MeV for $\tilde{\sigma}_1$ and $\tilde{\sigma}_2$, respectively. Therefore, for the chosen initial conditions and the value of T, the touch of the galaxies will take place during the first passage for the IGrM particle masses $m \geq 67$ MeV and the merger can be problematic for masses lighter than 17 MeV.
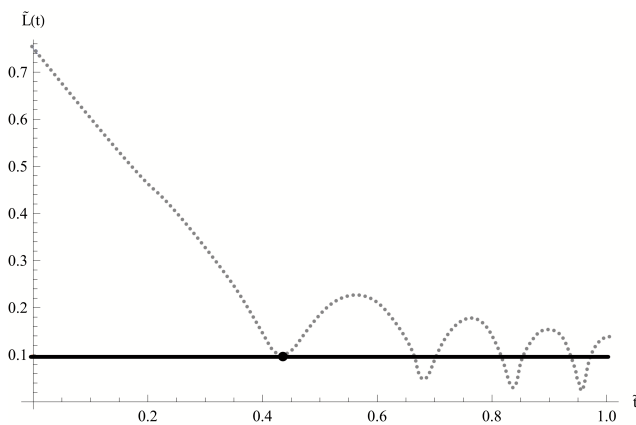

Figure 3: Evolution of the distance between the MW and M31 in the case of the dynamical friction. $\tilde{\sigma} = \tilde{\sigma}_1 = 1.17$.

These figures show the change with time of the separation distance between the Milky Way and Andromeda (Fig. 3) and the corresponding trajectories for the MW (the solid line) and M31 (the dashed line)
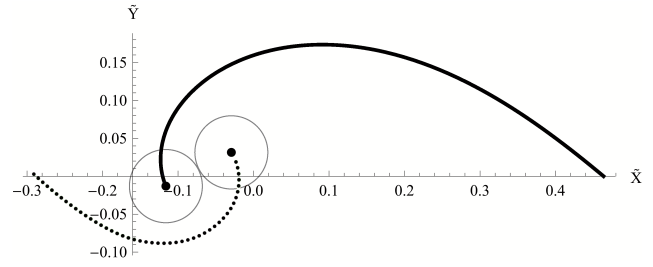

Figure 4: Trajectories of the MW and M31 in the case of the dynamical friction. $\tilde{\sigma} = \tilde{\sigma}_1 = 1.17$.

on the Fig. 4 in the case of dynamical friction. The initial conditions are chosen as on the Fig. 2. The dynamical friction is calculated for the dispersion parameter $\tilde{\sigma} = \tilde{\sigma}_1 = 1.17$.
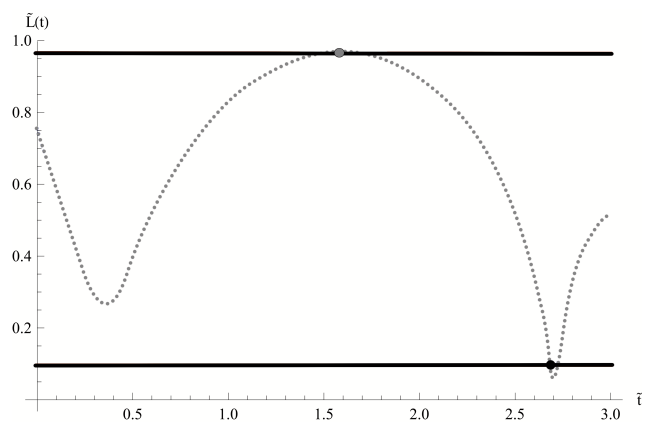

Figure 5: Evolution of the distance between the MW and M31 in the case of the dynamical friction. $\tilde{\sigma} = \tilde{\sigma}_2 = 2.306$.

These figures are drawn in the case of the dynamical friction with the dispersion parameter $\tilde{\sigma} = \tilde{\sigma}_2 = 2.306$. For this value of $\tilde{\sigma}$, there is no touch of the galaxies during the first passage because the closest separation distance here is larger than 100 Kpc (the bottom black line on the Fig. 5). After that, the galaxies grow apart to the turning point at the separation distance 1 Mpc from each other (see the black point on the upper black line in the left panel). At these and greater distances, the rest mass density of IGrM decreases and the dragging effect of the dynamical friction can be too small to force the galaxies to converge again. Therefore, for $\tilde{\sigma} > \tilde{\sigma}_2$, the merger of the galaxies becomes problematic.

4. Formation of Hubble flows in the vicinity of the Local Group

To study the formation of the Hubble flows in the vicinity of our group of galaxies, we need to determine the spatial distribution of vectors of acceleration of as-
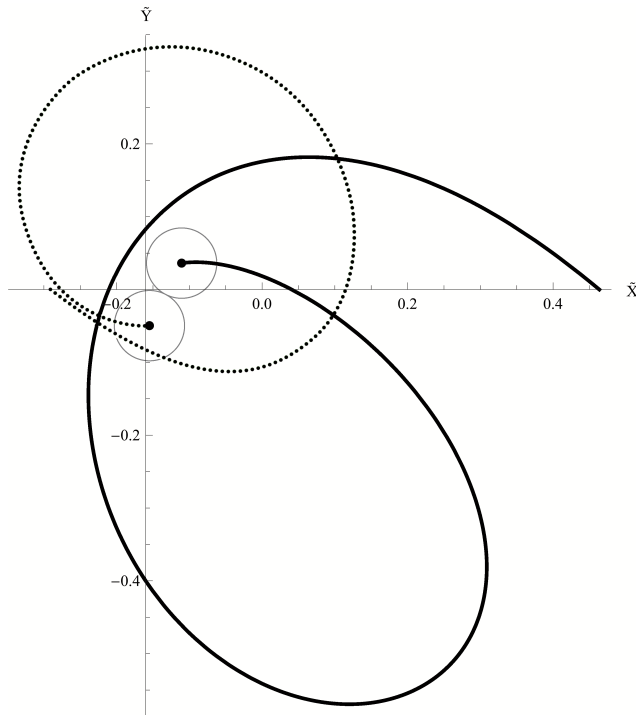
Figure 6: Trajectories of the MW and M31 in the case of the dynamical friction. $\tilde{\sigma} = \tilde{\sigma}_2 = 2.306$.
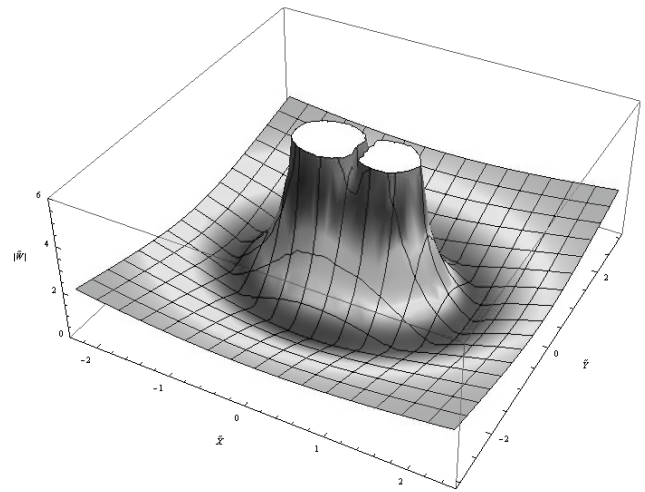

Figure 7: This plot shows the absolute value of the acceleration of dwarf galaxies in the Local Group. The dark area around the peaks corresponds approximately to the zero acceleration region.

trophysical objects (e.g. dwarf galaxies) in the gravitational field of two giant galaxies taking into account the cosmological expansion of the Universe. Obviously, near the galaxies, the vector must be oriented in the direction of galaxies due to the gravitational attraction, and with the distance from galaxies he has to turn in the opposite direction due to the cosmological accelerated recession.

On the Fig. 8 vectors are directed towards the MW and M31 (the black points) in the vicinity of the galaxies and turn out with the distance from the galaxies. The solid and dashed lines correspond to the conditions $\tilde{W}_x = 0$ and $\tilde{W}_y = 0$, respectively.

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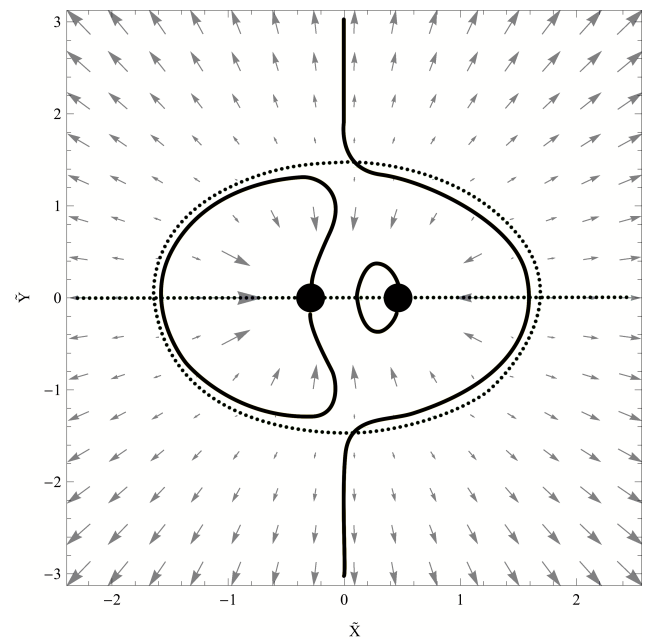Binney J., Tremaine S.: 1987, *Princeton University Press,* 741.

Figure 8: This figure shows the vector field of the dwarf galaxy acceleration.