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AN ESTIMATE OF THE TIDAL EFFECTS IN THE DYNAMICS OF THE BINARY GALAXIES

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RESUMEN. Se ha estimado los efectos de marea en los pares dinámicos de galaxias elípticas. Para poder estudiar tales efectos hemos expandido el potencial gravitacional en potencias del cociente ρ/r hasta en el orden 3 correspondientes a las fuerzas de marea. Hemos examinado la influencia de este término en el movimiento orbital. Se encontró el valor de $M/L_B = 10\pm7$ (en unidades solares) para un ejemplo de 46 pares E-E usando la aproximación de marea. De este resultado, no podemos concluir que existen alrededor de las galaxias halos grandes y obscuros. Hemos encontrado también que la suposición de masas puntuales es una buena aproximación para el sistema físico. Sin embargo, tal aproximación sobreestima ligeramente el cociente masa-luminosidad.

ABSTRACT. In the present work we have estimated the tidal effects in the dynamics of pairs of elliptical galaxies. In order to study such effects we have expanded the gravitational potential in power of the ratio p/r up to order 3 corresponding to tidal forces. We examined the influence of this term in the orbital motion. The value of $M/L_B = 10\pm7$ (in solar units) was found for a sample of 46 E-E pairs using the tidal approximation. From this result, we cannot conclude that large dark haloes exist around galaxies. We have also found that the assumption of point masses is a good approximation for the physical system. However, such an approximation overestimates slightly the mass-luminosity ratio.

Key words: GALAXIES-DYNAMICS

I - Introduction

Several works (Faber and Gallagher,1979; White et al, 1983; Schweizer,1987; Demin,1988 and others) have shown that the statistical analysis of the dynamic of binary galaxies is a powerful tool to estimate the masses of galaxies. In general, for a statistical analysis it is necessary a sample of double galaxies as large as possible to be representative. There are several samples published in the literature (Picchio and Tanzella-Nitti,1985; Karachentsev,1972) with some differences due to different criteria used in the selection of the objects. However the problem of contamination by spurious pairs due to projection effects is not yet totally solved. The sample used in the present work (Demin,1988) was selected using only pairs with apparent interaction between the galaxies for minimizing the contamination problem.

Frequently the equations of a two-body system are used to describe the dynamic of pairs of galaxies. The galaxies are assumed to be point masses, interacting through a Newtonian potential. Our method of analysis is detailed in Pacheco and Junqueira (1988), here in after PJ. In that paper the main equation relating the observable dynamical variables is

$$\log(\Delta V_z^2 \, rp) = \log(f) + \log(GLF), \qquad (1)$$

where ΔV_z is the observed radial velocity difference of the pair, rp is the linear projected separation , G is the gravitational constant, L is the total luminosity of the system, F is a function which caracterizes the properties of the orbit and f is the mass-luminosity ratio, assuming that galaxian masses are proportional to their luminosities, i. e., $M_i = f L_i$ (i=1,n galaxies).

It was shown in PJ that if equation (1) is a reasonable representation of reality, then the frequency distribution of the observed quantity $\log(\Delta V_z^2 \, rp)$ must reflect the frequency distribution of the quantity log(GLF), excepting by a scale factor equal to log(f). The frequency distribution of log(GLF) can be obtained by a Monte Carlo simulations. For a sample of 233 pairs of galaxies, the comparison between the observed frequency and the simulated one (continous line) is presented in figure 1.

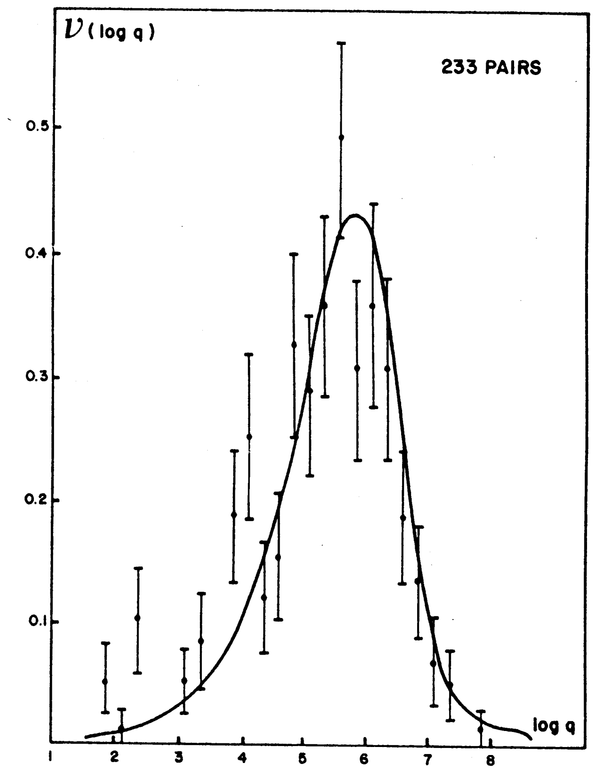

figure 1

The best fit was achieved for log(f) = 1.25 ± 0.25, which corresponds to M/L_B = 18 ± 11 (in solar units). The agreement between data and model indicates that the assumptions and approximations made are reasonable and the use of all the information contained in the sample distribution minimizes the effects due to inclusion of optical pairs. In our calculations we have assumed for the Hubble parameter a value of Ho = 60 Km $s^{-1}Mpc^{-1}$.

II - Tidal correction

In order to verify the effects of the tidal forces in the analysis by PJ, we have included aditional terms in the interaction potential. The galaxies are now considered as being extended bodies. The term r^{-3} in the potential expansion corresponds to the tidal force and it introduces a correction in the Keplerian velocity (Bisnovathy-Kogan, 1984). The geometry of the problem is given in figure 2.

The potential of a body with an arbitrary shape is given by

$$U = G \int \frac{dM}{r\,(\,1 - 2q\alpha + \alpha^2)^{1/2}} \,, \qquad (2)$$

where $q = \cos\theta \le 1$ and $\alpha = \rho/r < 1$.

Expanding the potencial up to terms of $O(r^{-3})$ we obtain

$$U = \frac{GM}{r} + \frac{G}{2r^3}\,(\, Ix + Iy + Iz - 3IX\,) \,, \qquad (3)$$

where Ix, Iy, Iz and IX are the moments of inertia of the body relative to the axes Ox, Oy, Oz, OP respectively.

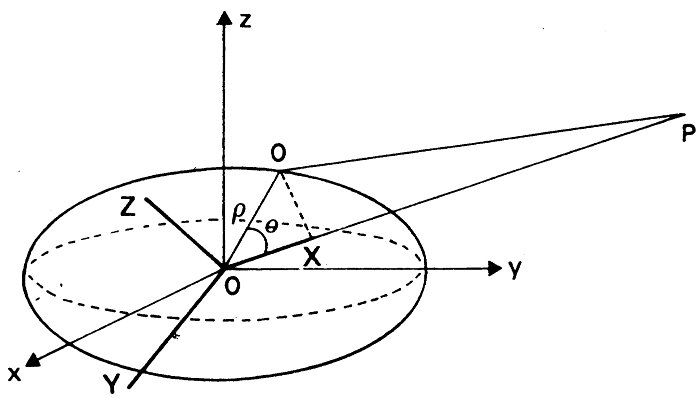

figure 2

The circular velocity, considering that point P is in the y-axis (i.e. X=y, Z=z and Y=x) is given by

$$V^2 = \frac{GM}{r} + \frac{3G}{r^3}\left(\frac{Ix + Iz}{2} - Iy\right) . \qquad (4)$$

Considering now the reciprocal action of both galaxies, we have

$$V^2 = \frac{G(\,M1 + M2\,)}{r}\,(\,1 + T_{12}\,) \,,$$

where the tidal term T_{12} is given by

$$T_{12} = \frac{3}{r^2 M1}\left(\frac{Ix_1 + Iz_1}{2} - Iy_1\right) + \frac{3}{r^2 M2}\left(\frac{Ix_2 + Iz_2}{2} - Iy_2\right) ,$$

where M1 and M2 are the galaxian masses.

The total mass can be decomposed in components as M_i= Mb + Md + Mh (i=1,2 galaxies), where Mb, Md and Mh are the mass of the bulge, disk and halo, respectively.

Let us define $\xi_b = Mb/M_i$, $\xi_d = Md/M_i$ and $\xi_h = Mh/M_i$, such that $\xi_b + \xi_d + \xi_h = 1$. Let us also assume that the moments of inertia can be similarly decomposed into $I_j = I_{jb} + I_{jd} + I_{jh}$ (j=x,y,z).

Using eq. (1) and considering that the orbital motion of the galaxies is circular we get

$$\log(\,\Delta V_z^2\, rp\,) = \log(\,f\,) + \log(\,GLF(\theta_o, i_o)\,(\,1 + T'_{12}\,)) \,, \qquad (5)$$

where

$$T'_{12} = \frac{S(\theta_o, i_o)}{2\,rp^2} \sum_j \left(\left(1-3\cos^2\psi_j \sin^2 i_j \right) \sum_k R^2_{kj}\, \zeta_{kj} (1-q^2_{kj}) \right) ,$$

j=1 (galaxy 1), j=2 (galaxy 2) and k=b,d,h. In this last equation i_o is the angle between the orbital plane and line of sight, θ_o is the orbital phase angle, the i_j's are the angles between the equatorial planes of the components (bulge, disk and halo) and the orbital plane, ψ_j's are the angles between the spins's projections in the orbital plane and the direction of the centers, R_{kj}'s are the radii of giration and q_{kj}'s are the ratios between the minor and the major axis of each component of the galaxy.

For the disk and the bulge components, we have supposed that the mass distribution can be represented by the luminosity distribution. In order to evaluate the radius of giration of the disk component we have used a Freeman profile and we get

$$Rd^2 = \frac{9R_e^2}{\zeta^2 q_a} , \tag{6}$$

where R_e is the effective radius, ζ=1.678 and q_a is the apparent axial ratio. For the bulge component we have used a de Vaucouleurs profile and we get

$$Rb^2 = 43.36\frac{R_e^2}{q_a} . \tag{7}$$

For the halo component, we have adopted a density distribution similar to that used by de Zeeuw (1985) and Binney & May (1986). In this case we obtained

$$Rh^2 = \frac{a_{max}^2}{3} , \tag{8}$$

where a_{max} is the semi-major axis.

III - Data and results

The method described above was applied to a sample of 46 pairs of elliptical galaxies, selected from a list elaborated by Demin (1988). The Demin's catalogue gives the angular effective diameter, the absolute magnitude M_B, the radial velocity, the apparent axial ratio and the projected linear separation. We have considered that the elliptical galaxies have only two components (main and halo).

From the observational data we have the effective diameter which allows us calculate the effective radius for the main component. Furthermore, we have used the apparent axial ratio to calculate the radius of giration of the main component. The intrinsic axial ratio was calculated using the observed apparent ratio through the relation

$$1 - q^2_{kj} = \frac{1 - q_a^2}{\cos^2 i_j} . \tag{9}$$

It is important to emphasize that observationally we do not have access to the angles in equation (5). We have simulated them by Monte Carlo technics. We have compared the frequency distribution of the dynamical quantity $\log q = \log(\Delta V_z^2\, r_p)$ with the frequency distribution of the simulated quantity $\log \rho = \log(GLF)$, for the mass point model. The best fit for the scale factor is $\log(f) = 1.00 \pm 0.25$, which corresponds to $M/L_B = 10 \pm 7$ (in solar units). The same procedure was followed with the inclusion of the tidal term, but in this case, we have compared the distribution of quantity $\log q$ with simulated quantity $\log \rho' = \log(GLF(1+T'_{12}))$. The best fit for the scale factor is $\log(f) = 1.00 \pm 0.25$, the same result obtained from the mass point model, taking into account the uncertainties expected in our estimates, which are still quite large.

IV - Conclusion

The value of M/L_B obtained from the method described above confirms the conclusion of PJ. Our result is consistent with the linear increase of the mass at least until distances of about 30 Kpc, since the median of the true separation between the pairs of our sample is about 60 Kpc. Ortega and Pacheco (1986,1989) studing hydrodynamical models for E-galaxies concluded that those objects have probably dark haloes and Demin (1988) obtained a mass-to-light ratio quite compatible with our results. These studies, including the present work, suggest that E-galaxies have dark haloes but such a component cannot accomodate masses in excess by a factor of 2-3 the values derived from the amount of light present in the system.

The comparison between the frequency distribution of the quantity $\log \rho'$ and the frequency distribution of the quantity $\log \rho$ (point mass) suggests that the statistical determination of the M/L_B ratio is not affected by the inclusion of the tidal forces. The difference between both distributions is minimum and within the errors of the methodology adopted here. The mean value of the tidal term is $\langle T'_{12} \rangle = 0.1025 \times 10^{-4} \pm 0.9749 \times 10^{-4}$. This fact suggests that the mass point model represents quite well the real physical situation, overestimating only slightly the mass-luminosity ratio.

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