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HYDRODYNAMICAL MODELS OF ELLIPTICAL GALAXIES

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ABSTRACT. Stellar hydrodynamical (Jeans) equations and the de Vaucouleurs' $r^{1/4}$ law for the intensity profile are used to obtain expressions for the projected rotational velocity and dispersion profile along the major axis of elliptical galaxies.

We assume that the galaxies are ablate ellipsoids of constant axial ratio.

The numerical results are applied to the elliptical galaxy NGC 3379.

Key Words; Elliptical galaxies
Dynamics of galaxies.

I - INTRODUCTION

Observation has shown that a growing number of elliptical galaxies have peak rotation velocities which are much smaller than their central velocity dispersion.For such galaxies the ratio

$$\frac{VMAX}{\tau_o} = \frac{\text{PEAK ROTATION VELOCITY}}{\text{CENTRAL VELOCITY DISPERSION}}$$

is much smaller than that predicted by models which interpret the flattening as being due to rotation alone. This means that anisotropy of stellar velocities should play an important role in the structure and dynamics of such systems. In this work we present models based on the hydrodynamical Jeans equations which allow one to investigate the dynamics of elliptical galaxies in presence of velocity anisotropy. The models are then applied to the elliptical galaxy NGC 3379.

II - MODELS

Our models treat the elliptical galaxies as oblate ellipsoids of constant ellipticity and assume that their intensity distribution is described by the de Vaucouleurs profile

$$I\,(r) = I_e \,\mathrm{Exp} \left\{ - 7.66922 \left[(r/re)^{1/4} - 1 \right] \right\}$$

where I_e is the intensity along the effective isophote and re is the effective radius of the galaxy. Using the de Vaucouleurs intensity profile we can calculate the distribution of mass ρ via a mass-luminosity ratio f which, in general, may vary with distance. The distribution of mass determines then the potentical Φ (or the forces) which enters the the Jeans hydrodynamical equations.

In cylindrical coordinates these equations have the form

$$\frac{\partial}{\partial Z} \left(\rho \tau^2_{zz}\right) = - \rho \frac{\partial \Phi}{\partial z} = - \rho K_z$$

$$\frac{\partial}{\partial R} \left(\rho \partial^2_{RR}\right) - \frac{\rho}{R} \left(V^2 + \tau^2_{tt} - \tau^2_{RR} \right) = - \rho \frac{\partial \Phi}{\partial R} = - \rho K_R$$

here V is the rotational velocity and τ_{ZZ}, τ_{RR}, τ_{tt} are the velocity dispersions along the coordinate axes. The quantities τ_{RR}, τ_{ZZ}, τ_{tt} describe the anisotropy in the galaxy.

Assuming the ratios $\beta 1 = \tau^2_{tt}/\tau^2_{RR}$, $\beta 2 = \tau^2_{RR}/\tau^2_{ZZ}$ to be constant and using the analytical expressions for the forces K_z, K_R adequate to our models, given by Schmidt (1956)

$$K_Z = 4\pi G \left\{1-\ell_o^2\right\}^{1/2} \ell_o^{-3} Z \int_0^{\arcsin \ell_o} \rho(\alpha)\ \mathrm{tg}^2\, \beta d\beta$$

$$K_R = 4\pi G \left(1-\ell_o{}^2\right)^{1/2} \ell_o^{-3} R \int_0^{\arcsin \ell_o} \rho(\alpha) \sin^2 \beta d\beta$$

where ℓ_o is the real eccentricity of the ellipsoid and the variable α satisfies the relation

$$R^2 \sin^2 \beta + Z^2\, \mathrm{tg}^2\, \beta = \alpha^2 \ell_o^2$$

we can find the projected luminosity — weighted dispersion τ_p and the rotational velocity V_p.

We note that in evaluating τ_p and V_p, due consideration has been taken of the variation along the line of sight. This corresponds more closely to the conditions of observation. So, por example, the component of the rotational velocity along the line of sight is

$$V_z = V_{\sin i} \frac{y}{\left[y^2+(x\cos i + z\sin i)^2\right]^{1/2}}$$

where x, y, z, are Cartesian coordinates in the observer's system of reference and i is the inclination angle of the galaxy. In this formula V depends on the coordinates and this function enters in the evaluation of V_p.

The models furnish the quantities τ_p and V_p along the galaxian major axis for comparison with observations.

III - APPLICATION

As an application we have chosen the E1 galaxy NGC 3379 which has been observed by various authors and whose luminosity distribution is well fitted by the de Vaucouleurs law (de Vaucouleurs and Capaccioli, 1979).

We have used the major axis data by Davies and Illingworth (1983) and report here some results for the isotropic model $\beta 1 = 1.0$, $\beta 2 = 1.0$ and for the anisotropic case $\beta 1 = 1.0$, $\beta 2 = 1.3$. In both models we consider the mean value 0.62 for the oblate intrinsic axial ratio (Binney and de Vaucouleurs, 1981).

Fig. 1 and Fig. 2 show the dispersion profile and the rotation velocity curve for the isotropic model. The fitting of the calculated dispersion and rotational velocity to the data gives for the blue mass-to light ratio the values $f_B = 7.8 \pm 3.6$ and $f_B = 1.5 \pm 0.7$ respectively.

In the anisotropic model $\beta 1 = 1.0$, $\beta 2 = 1.3$ the dispersion profile changes only slightly relative to the isotropic model, giving the value $f_B = 7.0 \pm 3.3$. However, the rotation curve changes significantly (see Fig. 3) yielding the value $f_B = 5.7 \pm 2.8$. (Fig. 3)

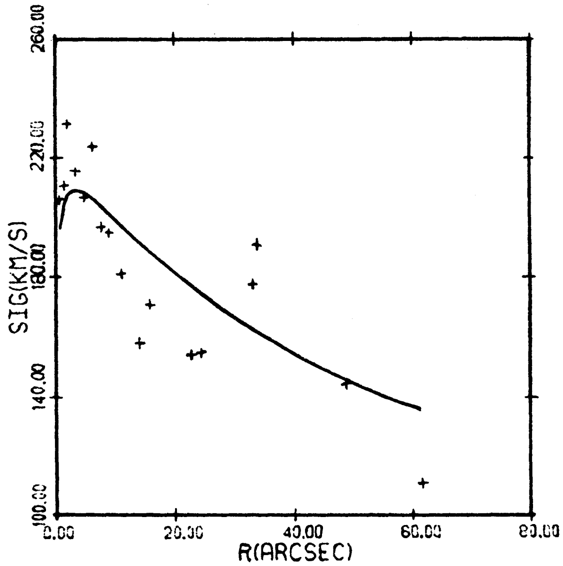

FIGURE 1
Dispersion Profile

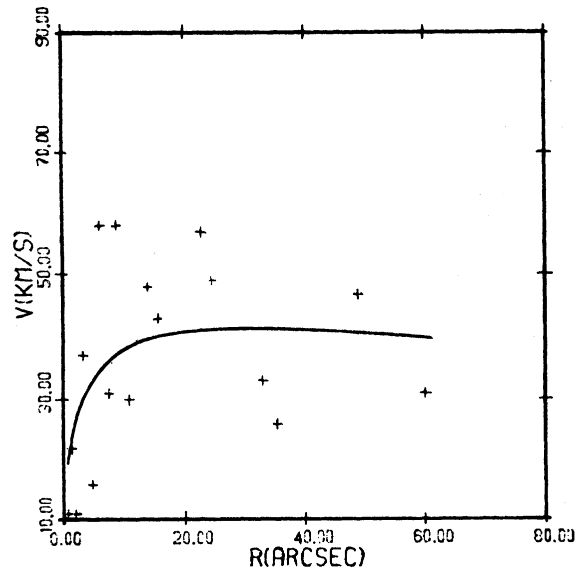

FIGURE 2
Rotation Velocity
Isotropic Model

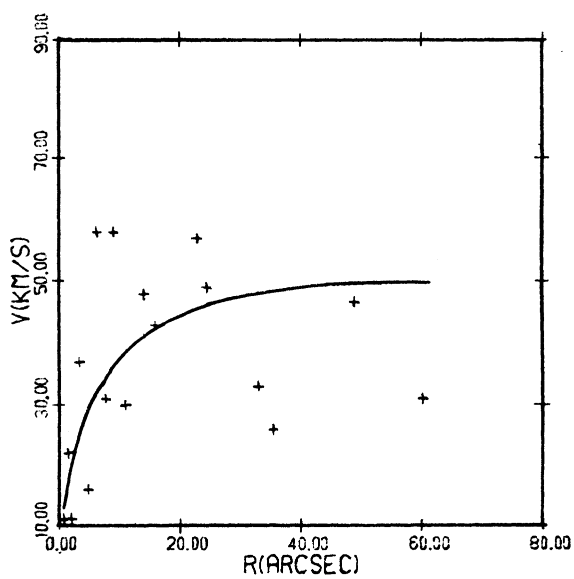

FIGURE 3
Rotation Velocity
Anisotropic Model

Clearly, the anisotropic model furnishes more consistent values for the blue mass-luminosity ratio than the isotropic model.

Further, the anisotropic model gives for the ratio V_{MAX}/τ_o the value 0.25, in good agreement with Davies and Illingworth (1983) who give a value of 0.23.

For the galaxy NGC 3379 we have used the effective parameter r_e = 59" (reference 2), the distance D = 14.32 M_{pc} calculated from group velocity and Hubble constant H_o = 50 km/S.M_{pc} and the absorption corrected blue magnitude BT=10.18 (reference 3).

IV - CONCLUSION

We have constructed anisotropic non-spherical hydrodynamical models under the following assumptions.

a - the galaxies are oblate ellipsoids of constant ellipticity,

b - the anisotropy parameters $\beta 1 = \tau^2_{tt}/\tau^2_{RR}$ and $\beta 2 = \tau^2_{RR}/\tau^2_{ZZ}$ are constant and

c - the luminosity distribution in the galaxies is given by the de Vaucouleurs profile.

The application of the models to the elliptical galaxy NGC 3379 has shown that the analysis of both the dispersion profile and the rotation velocity curve offers the possibility to discriminate between competing models.

In the case of NGC 3379 we have shown that if this galaxy is considered as an ellipsoid with real axial ratio equal to 0.62 then the anisotropic model $\beta1 = 1.0$, $\beta2 = 1.3$ gives a more consistent description than the isotropic model $\beta1 = 1.0$, $\beta2 = 1.0$.

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