Bull. Astr. Soc. India (1985) 13, 359–362

A tidal model for the interacting pair of galaxies VV 117

K. S. V. S. Narasimhan *Centre of Advanced Study in Astronomy, Osmania University, Hyderabad 500007 and Department of Mathematics, The New College, Madras 600 014*

Saleh Mohammed Alladin
Centre of Advanced Study in Astronomy, Osmania University, Hyderabad 500 007

Received 1985 June 19; accepted 1985 August 30

Abstract. Limber's (1965) tidal model for the interacting pair of galaxies VV 117 (= Arp 143 = NGC 2444–45) is improved upon in the light of subsequent H I observations. It is proposed that the spiral Sc component is being disrupted by the tidal effects of the elliptical (which is about twice as massive) in a close collision in a bound orbit.

Key words : interacting galaxies—stellar dynamics

1. Introduction

When two galaxies collide, the tidal force due to the perturber generally accelerates the constituent stars in the galaxies. Consequently the internal energy U of the system increases at the expense of the external (orbital) energy E. The transfer of energy from the orbital motion of the galaxies into internal motions within each galaxy leaves many signatures (*see* Alladin & Narasimhan 1982 for a review). The fractional increase in the internal energy $\Delta U/|U|$, where ΔU is the increment in the internal energy of the galaxy provides a convenient order-of-magnitude estimate of the change in the structure of the galaxy (Alladin 1965) If $\Delta U/|U| \geqslant 1$, there would be considerable disruption. Let $(\Delta V)_{\rm rms} \equiv [\langle \Delta V^2 \rangle]^{1/2}$ be the rms value of the velocity increment. For a spherical galaxy with predominant circular motions $\Delta U/|U| = [(\Delta V)_{\rm rms}/V_{\rm rms}]^2 \equiv \nu^2_{\rm tidal}$ (Dekel *et al.* 1980). Analytical expressions for $\Delta U/|U|$ when the relative orbit of the galaxies is the conic $l/r = 1 + e \cos \theta$ and under the impulsive approximation are given in Alladin & Narasimhan (1982) for $e \leqslant 1$ and in Narasimhan & Alladin (1983) for $e > 1$.

VV 117 (= Arp 143 = NGC 2444–45) is an interacting pair consisting of an elliptical galaxy E4 and a spiral Sc with a chaotic nucleus. The peculiar nature of this pair was first pointed out by Vorontsov-Velyaminov (1959). Burbidge & Burbidge (1959) who published large scale photographs of this peculiar system suggested that either the spiral has been disrupted after a very close encounter with the elliptical or the system may represent the formation of a new galaxy in the wake of the older one. The second possibility was ruled out by Sandage (1963) by means of his photoelectric studies of the pair. Thus the tidal model came to be preferred. Limber (1965) proposed a tidal model for the VV 117 pair based on the optical observations. In this paper we propose to improve Limber's model in the light of the H I observations made by Gallagher *et al.* (1981). An alternative model was proposed by Freeman & de Vaucouleurs (1974) who envisaged a collision of the spiral galaxy with an intergalactic H I cloud.

2. H I observations

Intergalactic H I gas has been discovered in several interacting galaxies (*see* Haynes *et al.* 1984 for a review). Velocity perturbations have been studied observationally from the distortions in the line profiles of neutral hydrogen. Compared to the stars, the H I in disc galaxies is more sensitive to galactic collisions as a consequence of its greater spatial distribution. The H I disc is generally rotationally supported and its velocity field is well ordered. The energy transfer in galactic collisions from the orbital motion into internal degrees of freedom tends to noncircularize the motion of the gas leading to the destruction of the steep edges of the H I velocity profiles and the development of broad wings or sloping shoulders in them. These distortions in the shape of the H I profiles are a convenient tool for detecting the intensity of the interaction between the galaxies. Observations of the H I widths give a reasonable measure of $(\Delta V)_{\rm rms}$ (Gallagher *et al.* 1981), and estimates of $V_{\rm rms}$ can be made from the rotation curves of normal spirals (Faber & Gallagher 1979). Hence $\nu_{\rm tidal} \equiv (\Delta V)_{\rm rms}/V_{\rm rms}$ can be evaluated from which the disruptive effects of the tidal forces can be inferred. The observations of Gallagher *et al.* (1981) give for VV 117, $V_{\rm rms} \sim 200$ km s^{-1} and $\nu_{\rm tidal} \sim 1$.

3. The tidal model

The present projected separation from the centre of the elliptical galaxy to the nucleus of the spiral is about 16700 pc. This is nearly the diameter of the main body of the spiral (Sandage 1963). From the optical measurements of Burbidge & Burbidge (1959), the radial velocities of the elliptic and chaotic components may be taken as 3965 and 4117 km s^{-1} (Gallagher *et al.* 1981). The H I observations of Gallagher *et al.* show sharp peaks at 3920 and 4120 km s^{-1} which they associate with each of the optical systems.

Using Alladin's (1965) theory, Limber (1965) presented a model of tidal interaction in which the mass of the elliptical is an order of magnitude greater than the mass of the spiral and showed that the system may be represented as the aftermath of a very recent slow collision leading to a considerable change in the structure of the spiral. Using $\eta = 4$ polytropic model of radius R for the galaxies and taking $M_{\rm E} = 2 \times 10^{11} M_{\odot}$, $M_{\rm Sc} = 1 \times 10^{10} M_{\odot}$, $R = 60$ kpc for each, $p/R = 0.2$ and $V_{\rm p} = 100$ km s^{-1} (where Vp is the velocity at minimum separation p of the galaxies) he obtained $\Delta U/|U| \gg 1$, a value which is inconsistent with the observations of Gallagher *et al.* (1981) which suggest $\Delta U/|U| \sim 1$.

We therefore propose the following model for the VV 117 pair. We take the rms velocity of the spiral galaxy as 200 km s^{-1} and the difference between the heliocentric velocities of the elliptical and the chaotic components as 200 km s^{-1} (Gallagher *et al.* 1981). On this basis we set $V_p \approx \sqrt{3}\,(200) \approx 345$ km s^{-1} to crudely take into account the motion of the galaxies in the plane of the sky. We infer from the photograph the rms radius of the spiral, $R_{rms} \sim 5$ kpc. Following Limber (1965) we take $p = 12$ kpc. The mass M_2 of the spiral is then obtained from the relation

$$V^2_{rms} \simeq \frac{GM_2}{2R_{rms}} \qquad \ldots(1)$$

Equation (1) gives $M_2 \approx 9 \times 10^{10}\, M_\odot$. The average mass of a typical Sc galaxy is $5.4 \times 10^{10}\, M_\odot$ (Sèrsic 1982).

In the impulsive approximation, the change in the internal energy ΔU_2 of the galaxy is the same as the change in the kinetic energy and is given by (Alladin & Narasimhan 1982)

$$\Delta U_2 = \left(\frac{\pi}{1+e}\right)^2 \frac{G^2 M_1^2 M_2}{p^4 V_p^2} R^2_{rms}, \quad e \leqslant 1, \qquad \ldots(2)$$

where e is the eccentricity of the relative orbit of the galaxies of masses M_1 (the perturber) and M_2 (the victim). This yields for the fractional change in the internal energy of the Sc galaxy

$$\frac{\Delta U_2}{|U_2|} \approx \frac{4\pi^2}{(1+e)^3} \cdot \frac{1}{M_{21} + M_{21}^2} \left(\frac{R_{rms}}{p}\right)^3, \quad M_{21} \equiv \frac{M_2}{M_1} \cdot \qquad \ldots(3)$$

For a conic

$$1 + e = \frac{pV_p^2}{G(M_1 + M_2)} \cdot \qquad \ldots(4)$$

In order to obtain $\Delta U_2/|U_2| \approx 1$ as suggested by H I observations we should take $M_1/M_2 \approx 1.5$ and $e \approx 0.3$. This gives $M_1 \sim 1.4 \times 10^{11}\, M_\odot$ for the elliptical. However, in view of the uncertainties in V_{rms}, V_p, p and R_{rms} a mass ratio of 2 or so seems quite reasonable. But a difference of an order of magnitude in masses as suggested by Limber does not seem appropriate in the light of the subsequent observations of the VV 117 pair. Even with the lower mass ratio suggested by us, the disruptive effects on the elliptical would be very small on account of its compactness.

4. Conclusion

We propose that the spiral galaxy is getting disrupted in a slightly overlapping encounter with the elliptical galaxy about twice as massive as the spiral in an elliptic orbit with $e \approx 0.3$. A closer collision with a larger value of e would also be consistent with observations. However the absence of ring structure rules out a face-on collision in a rectilinear orbit. It would be of interest to observationally detect signs of the tidal effects of the spiral on the elliptical.

Acknowledgements

This paper was completed at the Tata Institute of Fundamental Research, Bombay, and we thank Professor J. V. Narlikar for the invitation and encouragement. We are grateful to him and to Professor R. Cowsik for helpful discussions. S.M.A. thanks the University Grants Commission, New Delhi, for the award of a national fellowship.

References

Alladin, S. M. (1965) *Ap. J.* **141**, 768.
Alladin, S. M. & Narasimhan, K. S. V. S. (1982) *Phys. Rep.* **92**, 339.
Burbidge, E. M. & Burbidge, G. R. (1959) *Ap. J.* **130**, 12.
Dekel, A., Lecar, M. & Shaham, J. (1980) *Ap. J.* **241**, 946.
Faber, S. M. & Gallagher, J. S. (1979) *A. Rev. Astr. Ap.* **17**, 135.
Freeman, K. C. & de Vaucouleurs, G. (1974) *Ap. J.* **194**, 569.
Gallagher, J. S., Knapp, G. H. & Faber, S. M. (1981) *Astr. J.* **86**, 1781.
Haynes, M. P., Giovanelli, R. & Chincarini, G. L. (1984) *A. Rev. Astr. Ap.* **22**, 445.
Limber, D. N. (1965) *Ap. J.* **142**, 1346.
Narasimhan, K. S. V. S. & Alladin, S. M. (1983) *Bull. Astr. Soc. India* **11**, 221.
Sandage, A. R. (1963) *Ap. J.* **183**, 863.
Sérsic, J. L. (1982) *Extragalactic Astronomy*, Reidel, p. 58.
Vorontsov-Velyaminov, B. A. (1959) *Atlas and Catalogue of Interacting Galaxies*, Sternberg State Astr. Inst., Moscow.