STELLAR KINEMATICS OF ELLIPTICAL GALAXIES IN PAIRS[1]

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1. Introduction: General properties of Arp 166 and 3C 278

Observations of elliptical galaxy pairs allow the study of different states of tidal interaction between galaxies. The comparison with normal elliptical galaxies directly reveals the disturbed morphological and kinematical properties. Numerical simulations have shown that with the known initial luminosity profile, the time elapsed since closest approach between two galaxies can be estimated from the radial position of the disturbances (Aguilar and White, 1986).

The two galaxy pairs Arp 166 (NGC 750/1) and 3C 278 (NGC 4782/3) considered here exhibit distorted and nonconcentric isophotes (cf. Madejsky, 1989). In Arp 166 the major relative shift of the centers of the isophotes occurs in the outer parts while in 3C 278 the nonconcentric isophotes are more pronounced in the inner parts of the galaxies, suggesting that more time has elapsed since the moment of closest approach in Arp 166 than in 3C 278. Furthermore, in Arp 166, both galaxies have the same radial velocity, implying that their orbital plane is perpendicular to the line of sight. In turn, the galaxies NGC 4782 and NGC 4783 are moving with a very high radial velocity difference of 680kms^{-1}. Taking into account the location of both galaxies, which are the dominant members of a small group of about 25 galaxies (De Souza and Quintana, 1990), the true velocity difference probably is not much higher than the observed radial velocity difference. Therefore it is very likely that we are viewing at high inclination onto (i.e. nearly parallel to) the orbital plane of the galaxies NGC 4782 and 4783.

CCD photometry for both galaxy pairs was obtained at the 1.23m telescope of the German-Spanish Astronomical Center on Calar Alto, Spain. The morphology of both galaxy pairs is displayed and briefly discussed in Madejsky (1989).

2.Spectroscopy of Arp166 and 3C278

The long-slit spectroscopic data for NGC 4782 and 4783 were obtained at the ESO 3.6m telescope (for details see Madejsky et al, 1990). The result for the southern galaxy NGC 4782 for position angle 70° is displayed in Fig. 1. The velocity dispersion increases from the center towards the east by a large amount and also slightly towards the west. The region of maximum velocity dispersion is nearly coincident with the centers of the outer isophotes.

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The spectroscopic data for Arp 166 were obtained at the 3.5m telescope on Calar Alto, Spain. For each galaxy, NGC 750 and NGC 751, we obtained longslit spectra for two slit positions, at position angle 60° and 90°, respectively. All slit positions are nearly perpendicular to the line connecting both galaxies and always the slit was centered on the galaxy center. The results for position angle 60° are displayed in Fig. 2 (the kinematical data for slit position 90° are comparable to those displayed here). The central radial velocity of the northern galaxy NGC 750 is 5200($\pm$10)kms^{-1} and there are only slight variations of the radial velocity with radius. No rotation seems to be present in this direction. The central velocity dispersion increases from the central value of 220($\pm$10)kms^{-1} radially outwards. The increase towards the east is very small. Towards the west, however, there is a substantial increase over a large region of more than 10 arcsec (or 5 kpc). The velocity dispersion does not decrease for larger radii within the observational radial limit. The southern galaxy NGC 751 perhaps was rotating rapidly before the tidal interaction. A strong gradient of the radial velocity indicates rotation, but the central part (innermost 6 arcsec or 3kpc) seems to be kinematically separted from the motion of the surrounding envelope. Also in the east part the radial velocity exhibits irregularities. The central radial velocity is 5225($\pm$10)kms^{-1}. The velocity dispersion increases from the central value of

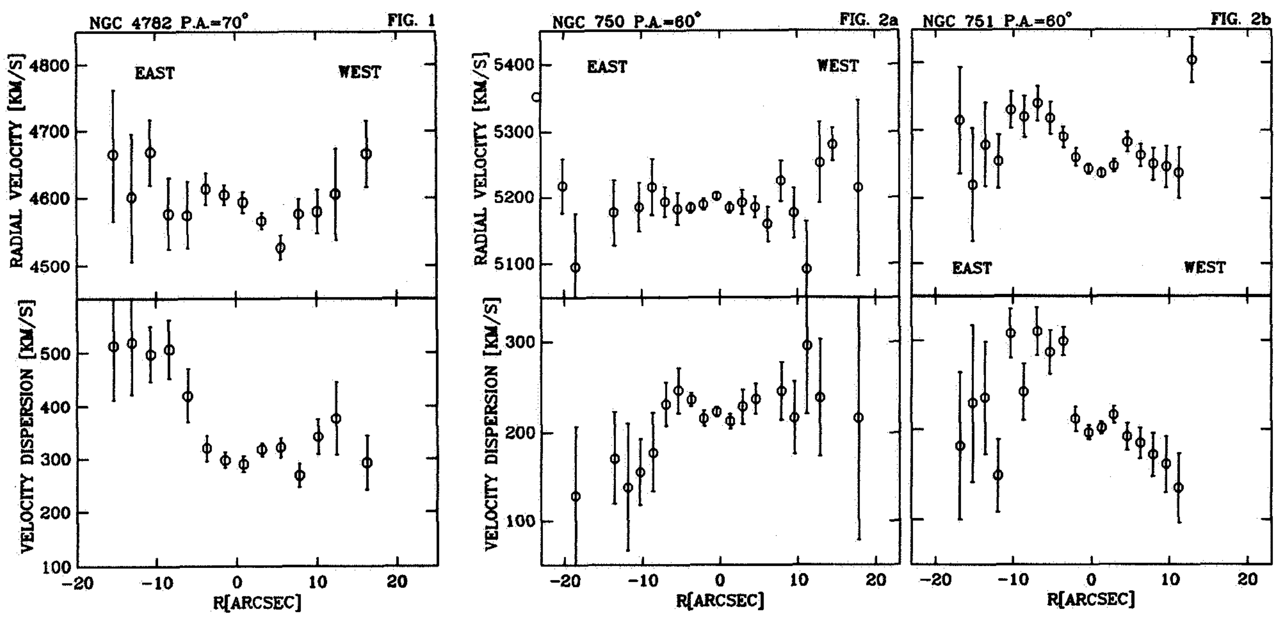

Fig. 1.(left) Radial velocity (upper panel) and velocity dispersion of NGC 4782 along slit position 70°. The velocity dispersion increases radially from the center towards the east by a large amount. Note the slight increase towards the west. The region of maximum velocity dispersion is located near the center of the outer isophotes

Fig. 2a and b.(right) The kinematical results for a) NGC 750 and b) NGC 751 for slit position 60°. In the upper panels are displayed the radial velocities, the lower panels give the velocity dispersions of the stars. Note that the velocity dispersions in both galaxies reach their maximum values outside the centers (see text).

$200(\pm 10)\text{kms}^{-1}$ radially towards the east and reaches a maximum value of $300(\pm 25)\text{kms}^{-1}$ in the region 4...10 arcsec (or 2...5 kpc) east of the center of the galaxy. Like in the galaxies NGC 4782 and NGC 4783 we find radially increasing velocity dispersion in both galaxies NGC 750 and NGC 751. In all galaxies the regions of maximum velocity dispersion are found near the centers of the **outer** isophotes, and in both pairs, the galaxy with a steeper luminosity profile exhibits the more pronounced increase of the velocity dispersion.

3. Conclusions

In both galaxy pairs Arp 166 and 3C 278 we find radially increasing velocity dispersions indicating a perturbed, non-equilibrium state of the galaxies after the tidal interaction. In all galaxies, the increase is most pronounced in the regions which correspond to the centers of the outer isophotes. We suggest a scenario in which the galaxies are strongly decelerated on their orbits during the encounter. The deceleration depends on the radial position in the perturbed galaxy and vanishes in the center of the perturbed galaxy (Spitzer, 1958). In addition, the crossing time of the stars near the center is very short, implying that the tidal perturbations can be averaged over several orbital periods (e.g. Binney and Tremaine, 1987). In consequence, the central parts are not affected by the tidal interaction while the outer parts are strongly decelerated. This leads to a displacement of the central parts of the galaxies with respect to their envelopes in an antisymmetrical way for the two components of each galaxy pair. The motions of the central parts subsequently are opposed by dynamical friction with the surrounding envelopes. Due to dynamical friction, the density of the stars increases in the wakes of the moving central parts (Mulder, 1983). The overdensity of stars in the wakes of the moving central parts efficiently decelerates the motions of the central parts. The reaction of the stars in the overdensity regions leads to an increase of the velocity dispersion mainly along the orbits of the moving central parts. The presented observations, especially the asymmetrical luminosity profiles and the radially increasing velocity dispersions support consistently the above scenario of tidal interaction between galaxies. Further spectroscopic observations are necessary in order to investigate the degree of anisotropy in the kinematically perturbed regions.

References

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DISCUSSION

Roos: The impulsive approximation gives you only an order of magnitude estimate for the cases you discussed. Did you compare your observational results with the numerical M-body models that have been done for this interacting pair?

Madejsky: In this case of a high-velocity encounter of two galaxies the impulsive approximation probably gives a very good estimate for the energy exchange of most stars. However, detailed numerical simulations are necessary to verify whether the proposed scenario is true. Our observational results are very new and we have not yet combined with numerical simulations, but we will do so.

Navarro: You're a little surprised that galaxies undergoing such a violet encounter are still well-fitted by a deVaucouleurs law. Could you comment on this?

Madejsky: From the morphological and kinematical properties we estimate a time of $\sim 2 \cdot 10^7$ yrs elapsed since the moment of closest approach. In the inner parts of the galaxies where the crossing times of the stars are comparatively short, the dynamical response to the violent encounter can directly be seen in the azimuthal variations of the luminosity profiles (inside 15"). The outer parts are highly disturbed; however, due to the recent tidal interaction, damage on these outer parts is not yet visible.

Chatterjee: What is the ratio of the distance between the nuclei of the two galaxies, compared to their total extent (from luminosity profiles)?

Madejsky: The galaxy centers are separated by 40 arcsec. This corresponds to $\sim$15 kpc. The luminosity profiles I have shown extend out to 130 arcsec corresponding to $\sim$50 kpc. The real extent of both galaxies is not known. The luminosity profiles most probably are limited by the S/N-ratio of the CCD images. We are doing further very deep CCD photometry to study the distribution of globular clusters, then I can tell you whether both galaxies extend beyond 50 kpc or not.

Khachikian: Have you data about distribution of radial velocities along these galaxies?

Madejsky: Yes, we have detailed kinematical information along the line connecting both galaxy centers. The high radial velocity difference of 680 km s^{-1} is indicated by the radial velocity curves; however, no internal rotation can be seen. The range between both galaxies cannot be considered since both luminosity profiles are superposed there and do not give correct kinematical information.

Fridman: What may you say about percent of interacting elliptical galaxies with relative spin direction of components?

Madejsky: In our sample of interacting galaxy pairs, we have observed spectroscopically only double elliptical galaxies, where most galaxies appear very round; i.e., at present we do not expect to detect considerable rotation. Only five galaxy pairs exhibit considerable rotation in both components. Therefore, no statistical conclusion can be drawn on relative spin.