Shape of Line Profiles and Dark Matter in E Galaxies

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1. Introduction

The mass distribution in elliptical galaxies can in principle be derived by means of distinct dynamical approaches. At large radii – outside the optical body of the galaxy – one can resort either to radio observations of HI disks (e.g. NGC 5266, Morganti et al. 1995, Proc. Astr. Soc. Austr. in press) or to X-ray observations of the hot (10^7 K) gas surrounding the most luminous ellipticals (e.g. Forman et al. 1985, ApJ 293 102). On the other hand, inside the optical region one has to make use of optical spectroscopy. An approach of this kind was recently adopted in the context of our ESO Key Programme "A Search for Dark Matter in Elliptical Galaxies" (Bertin et al. 1989, The Messenger 56 19; Buson et al. 1993, A&A 280 409; Saglia et al. 1993, ApJ 403 567; Bertin et al. 1994, A&A 292 381) by investigating both the velocity field of the gaseous component for those ellipticals which possess a disk of ionized gas and by measuring stellar velocity dispersion profiles out to large radii. The kinematics of the ionized gas can be modeled assuming that the gas occupies closed non-circular orbits in a triaxial potential; this constrains the shape and the mass distribution of the inner regions of host galaxies (e.g. Bertola et al. 1991, ApJ 373 369). On the contrary, the basic information about the dynamics of the outer (up to $r \sim 2\ R_e$) regions of the optical galaxy is provided by the absorption-line kinematical data: the most remarkable feature noticed in the context of the above project was the large variety of velocity dispersion profiles which appear often decreasing but also nearly constant or even slowly increasing.

Two complementary modeling techniques have been applied to these data to address the problem of dark matter. One was to fit physically plausible 2-Component (2C) models to derive the properties of dark halos (Bertin et al. 1992, ApJ 384 423; Saglia et al. 1992, ApJ 384 433). The other was to conservatively assume that no dark halos were present and trying, through the Quadratic Programming (QP) technique (Dejonghe 1989, ApJ 343 113), to derive a distribution function able to fit the data. Since in the QP method the distribution is in principle free, models may turn out to be tangentially anisotropic. While decreasing velocity dispersion profiles are always consistent with a constant mass-to-light ratio (i.e. with dark matter distributed as the luminous matter or simply absent) we find that both flat and outwardly increasing profiles can be modeled with or without dark matter, depending on the orbital structure of the distribution function.

Obviously the presence of a large amount of tangential velocity anisotropy can cause the observed nearly constant velocity dispersion profiles, thus mimicking the existence of a dark halo. In order to disentangle the relative contribution of the two phenomena, one may resort to the analysis of the shape of absorption-line profiles (usually referred as "line profiles" or "velocity profiles") as a function of radius. When tangential motions prevail in the orbital structure of the outer parts of ellipticals, the observed line profiles are more flat-topped than a gaussian profile (e.g. Dejonghe 1987, MNRAS 224 13; Dehnen & Gerhard 1994, MNRAS 268 1019). As a consequence, if the observational data are suitable – both in S/N ratio and resolution – to detect deviations of line profiles from Gaussians, by applying a proper method to parameterize such deviations one can estimate at which extent the apparent dynamics of the galaxy is affected by orbital anisotropies (cf. van der Marel & Franx 1993, ApJ 407 525). The method adopted here is the so-called Fourier Correlation Quotient Technique (FCQ, Bender 1990, A&A 229 441; Bender et al. 1994, MNRAS 269 785). Besides the radial velocity and velocity dispersion profiles, it provides – by expanding the observed line profile into a sum of Gauss-Hermite polynomials – the moments h_3, h_4, which represent the lowest-order antisymmetric and symmetric deviations from the gaussian profile, respectively. The value of h_4 parameter is of particular importance as it discriminates between line profiles which are more centrally peaked ($h_4 > 0$) and more flat-topped ($h_4 < 0$) than a gaussian profile, thus constraining the level of tangential anisotropy.

2. Observations

Major-axis spectra of nine ellipticals obtained in the context of the above Key Programme (or specifically as a follow-up of the same project) have been analysed by means of the FCQ technique. The data come from three separate observing runs characterized by a different choice of the telescope and/or instrumental setup: ESO/MPI 2.2-m Telescope equipped with B&C spectrograph and 1024×640 15μm pixel RCA CCD detector (NGC 7507, NGC 7796), ESO NTT Telescope equipped with EMMI and 2048×2048 15μm pixel Ford CCD detector (NGC 4472, NGC 7144, IC 4296) or 1024×1024 19μm pixel Thomson CCD detector (NGC 4649, NGC 5090, NGC 6851, NGC 7097). The wavelength resolution corresponds to σ_{instr} ~60–90 km s^{-1} depending on the adopted rebinning. A detailed description of data reduction and analysis will be provided in a forthcoming paper.

3. Individual Objects

We make here some remarks on the objects for which large amounts of dark matter might indeed dominate the observed dynamics. Their kinematical pro-

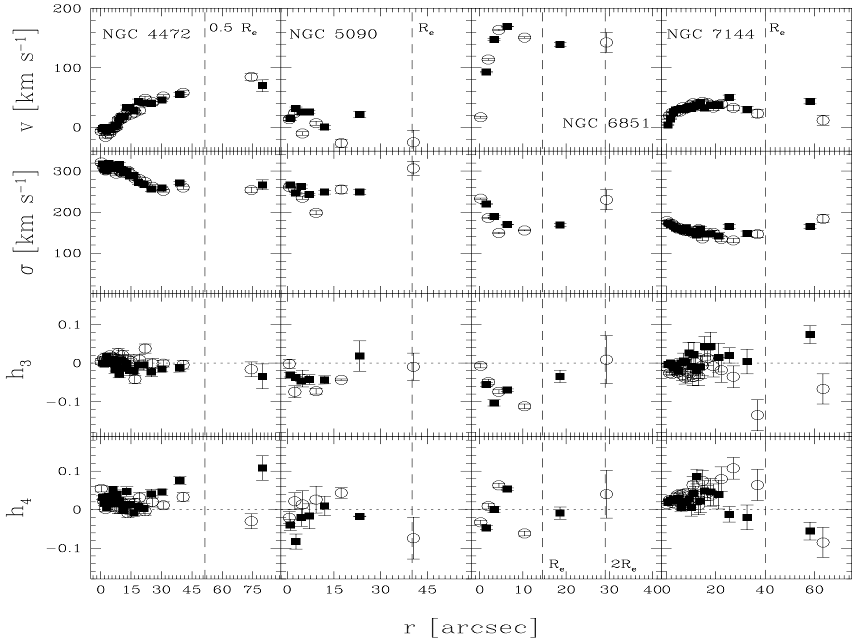

Figure 1. Folded kinematical (v, σ, h_3, h_4) profiles for NGC 4472, NGC 5090, NGC 6851 and NGC 7144. Open and filled circles represent opposite sides of the galaxy.

files – to be regarded as preliminary – are shown in Fig. 1.

NGC 4472: this object turned out to be a good case for dark matter when applying 2C models (Saglia et al. 1992, ApJ 384 433; 1993, ApJ 403 567) but can also be fitted by *constant* M/L QP models. The case for dark matter in this galaxy is now strengthened, owing to the small observed values of h_4 up to $\sim$1 R_e, compatible only with a moderate (probably radial) anisotropy. In effect, the tangential anisotropy required by the QP model would imply a line profile characterized by sizeable anisotropy ($h_4 < -0.1$) which is not observed.

NGC 5090: the kinematical data of this galaxy extend as far as $\sim$1 R_e and appear consistent with a model basically isotropic. The nearly flat velocity dispersion profile points therefore to a good case for dark matter. Simple estimates from models close to isotropic (see Bertin et al. 1992, ApJ 384 423) indicate a dark mass inside R_e twice the luminous, with a minimum (3σ limit) dark matter amount identical to the luminous mass. The result appears similar to that NGC 4472, although we have not yet carried out detailed modelling for this latter object.

NGC 6851: this galaxy, which shows very extended kinematical profiles with flat rotation and velocity dispersion curves, appears to be a potentially very good case for dark matter. However, since it is a strongly rotating system, before making conclusive statements it is necessary to model it accurately. We expect for this object evidence for dark matter at least as strong as that for NGC 3706 by Carollo et al. (1995, ApJ 441 L25).

NGC 7144: This galaxy remains a complex case as neither 2C models nor constant M/L QP models are able to reproduce its slowly rising velocity dispersion. Actually, this is a galaxy for which a dark halo is required *also* by the latter QP models, no matter what the distribution function is. However, an extreme tangential anisotropy is also necessary and such an anisotropy appears incompatible with the small measured h_4 values. The possibility that we are actually looking at an oblate rotator seen close to face on cannot be ruled out (Saglia et al. 1993, ApJ 403 567).

4. Conclusions

The h_4 coefficients we derive for our sample galaxies are usually within the range ±0.1, thus indicating that the observed profiles are not too different from gaussian, at least in the inner regions of galaxies. The lack of clearly flat-topped line profiles matches the predictions of the 2C models, in the sense that for these models – characterized at large radii by *radial* anisotropy – h_4 should remain close to zero, as observed. Even taking into account the limitations in S/N ratio and spectral resolution of our data, the above results suggest that the observed kinematical profiles are not significantly biased by anisotropy. This likely implies that, in the majority of the objects we studied, the presence of dark mass *does* affect the dynamics also within the optical volume of the galaxy.

Acknowledgments. We thank Ralf Bender for providing his Fourier Correlation Quotient. MB thanks the Universitäts-Sternwarte München for the hospitality. RPS acknowledges the financial support by the Deutsche Forschungsgemeinschaft under SFB 375.

Discussion

T. de Zeeuw: Regarding NGC 6851, in order to derive evidence for/against a dark matter halo you *have* to use σ_e and z_4 for the *even* part of the velocity profile; these are fixed by ρ, as M. Carollo just showed in her talk. Since v rises to $\sim$200 km s^{-1} and then drops, σ_e differs significantly from σ and z_4 differs from h_4, thus implying that your conclusions might be modified.

T. Statler: To amplify Tim de Zeeuw's point: your data on NGC 4472 suggest an increasing amount of rotational support at large radii, so that despite the weakly declining σ profile the more relevant quantity $(v^2 + \sigma^2)^{1/2}$ would be flatter. Our data on NGC 1700 show a major axis $(v^2 + \sigma^2)^{1/2}$ profile that is almost exactly flat out to 4 R_e, which is consistent with a dark halo.

L. Buson: The approach suggested by Tim de Zeeuw for NGC 6851 is formally correct, though, as in the case of NGC 4472, the quantity $(v^2 + \sigma^2)^{1/2}$ appears approximately constant with radius and – as such – in any way consistent with the existence of dark matter.