"Deep" Rotation Curves of Edge-on S0 Galaxies

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We present a sample of "deep" rotation and velocity dispersion curves from stellar (absorption) spectra obtained at La Silla in February 1989. These record observations are part of a long-term project conceived to investigate how the dynamical behaviour of galactic disks depends on the bulge-to-disk light ratio, and to unravel the three-dimensional shapes of dark haloes in early-type disk galaxies (for a review of this matter, see Bender et al., 1989, Capaccioli and Caon, 1989, and Capaccioli and Longo, 1989). The targets: NGC 2310, NGC 3115, and NGC 4179, are edge-on S0 galaxies, chosen among the few such objects with fairly large angular sizes (distances ≤ 25 Mpc) in order to minimize the resolution problems (see Fig. 1).

The spectra of the programme galaxies were secured with the ESO Faint Object Spectrograph and Camera (EFOSC), attached to the Cassegrain focus of the 3.6-m telescope, and equipped with the high resolution RCA CCD No. 8. In binned mode, this detector gives 320×512 pixels of 30 μm, equivalent to 0.″675 on the sky. We chose the grism coded as "Orange 150" in the ESO *Users Manual,* which provided us with a dispersion of 3.9 Å px^{-1} over the wavelength interval from 5000 to 7000 Å.

Several spectra along the major axis of each galaxy were obtained with exposure times ranging from 1500 to 3600 s. To best exploit the full length of the slit (3.′6), each galaxy was centred alternatively at one or the other end of the slit. This procedure was conceived to achieve both the wanted spatial coverage of the source and the simultaneous recording of a "clean" enough night sky spectrum; the latter must be extremely well sampled, since it is usually the dominant signal in the absorption spectra taken anywhere outside the effective isophotes of early-type galaxies. In our least favourable case – that of the most extended object NGC 3115 – the edge of the slit opposite to the nucleus viewed a region of the galaxy as faint as $\mu_B \simeq 24.5$, i.e. ~7 times fainter than the average night sky surface brightness. As further precaution, offsetting the telescope by ~20′ we obtained also several long exposure spectra of the blank night sky, as close as possible in time to the astrophysical exposures; during the reduction phase, they turned out to be fundamental for the successful reduction of the material of two of the three objects. Comparison spectra of a He-Ar lamp were secured before and after each exposure. Finally, spectra of some template stars in the range of spectral classes from G8 to K1 were also taken on the same nights.

The raw CCD data were processed with MIDAS. Standard recipes were applied for the bias and dark subtraction, and for the careful flat-fielding based on both dome and down-sky exposures at different count levels. The complex distortion pattern was mapped using the

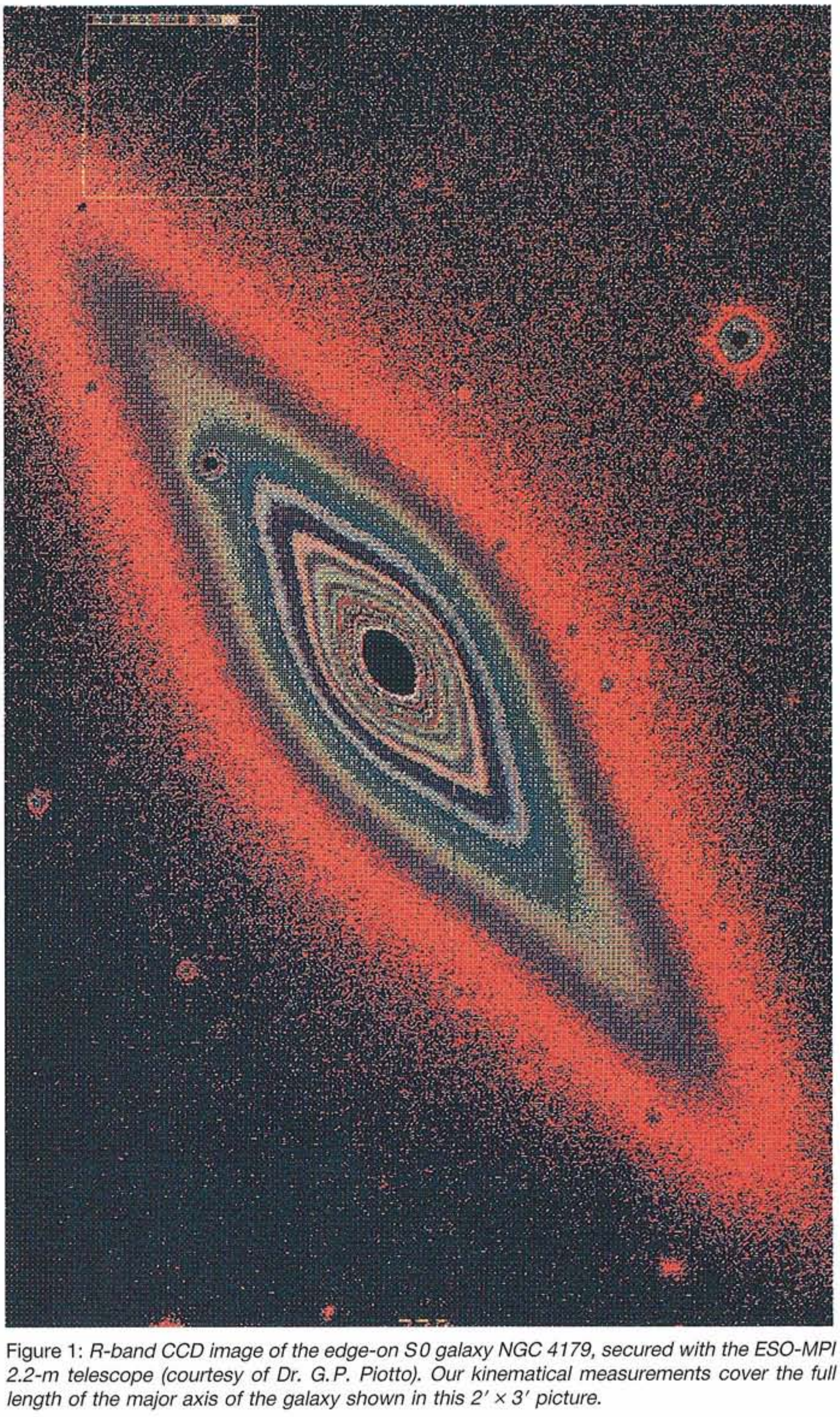

Figure 1: *R-band CCD image of the edge-on S0 galaxy NGC 4179, secured with the ESO-MPI 2.2-m telescope (courtesy of Dr. G.P. Piotto). Our kinematical measurements cover the full length of the major axis of the galaxy shown in this 2′ × 3′ picture.*

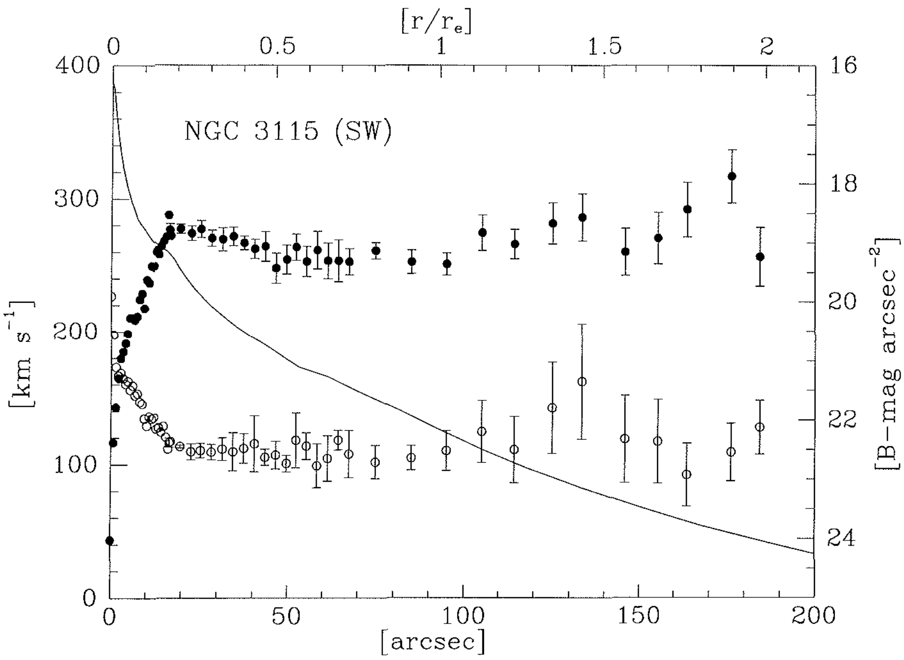

Figure 2: *Radial velocity V(r) (full dots) and velocity dispersion σ(r) (open circles) measurements as a function of the galactocentric distance (in arcseconds and in units of the effective radius) along the SW semimajor axis of the bright edge-on S0 galaxy NGC 3115. V(r) is corrected for the systemic velocity, and σ(r) is re-scaled by a factor 0.75 (see text). The error bars represent the dispersion of the actual data averaged within each bin. The solid line is the major axis B-band light profile taken from the photometric study by Capaccioli et al. (1987).*
Note that the kinematical data extend to $r \simeq 2r_e$, where $\mu_b \simeq 24$, a record for absorption line spectroscopy.

comparison spectra to derive a line-by-line wavelength calibration. In the material of this run, we find that the position of the comparison lines drifts over the detector during the night, the maximum displacement being of the order of 1 pixel. This is of consequence for the absolute velocity scale only, in that it leaves a zero-point uncertainty of ±50 km s^{-1}. In fact, the shift between two astrophysical exposures can be corrected by the match of the night sky emissions.

The crucial step in the reduction pipeline has been the subtraction, from the galaxy spectra, of the contribution by the night sky light. In the case of NGC 2310 – the smallest galaxy of the sample – the sky spectrum was extracted directly from the "free" side of the galaxy exposure, i.e. from that side of the slit opposite to the nucleus of the object. Instead, the spectra of NGC 3115 and NGC 4179 extend so much that no part of the slit is really free from the galaxy signal; thus, also the offset sky exposures had to be used for the sky subtraction. In both cases, the galaxy frames corresponding to the same semiaxis were individually sky subtracted, and then averaged by means of an algorithm allowing to correct for cosmic ray events.

The kinematical data were extracted by the package of programmes developed by Bender (1989). The core of the procedure is the cross-correlation, at each radial bin, of the continuum-subtracted galaxy spectrum with that of a template. No significant dependence of the results on the different template stars has been found.

Rotation and velocity dispersion curves for two of our three galaxies, together with the B-band light profiles along the major axes, are presented in Figures 2 and 3. The original data have been averaged within intervals whose sizes increase with the galactocentric distance; the scatter internal to each interval (r.m.s. of the mean) is shown by error bars in the figures. The kinematical centre (and the associated systemic velocity) of each galaxy was assumed to coincide with the peak in the velocity dispersion profile. Symmetry arguments relative to the two sides of the major axis rotation curves are not effectively applicable to our material, given the small overlap between opposite side spectra.

We want to warn explicitly the potential users of the preliminary data presented here that, contrary to the rotational velocities *V(r)*, the values of the velocity dispersion, *σ(r)*, produced by the plain application of our reduction procedure are 50–70% larger than previous literature measurements. Inspection of Figure 4 shows that the problem is in our scale since, after re-scaling by a constant factor, our data match very well the other measurements (which include some still unpublished photographic spectra obtained with the Boller & Chivens spectrograph at the ESO 1.5-m telescope). The reasons why the broadening functions of the long exposure galaxy spectra are significantly larger than the short exposures on the template stars are probably understood, but we still lack a procedure to compute the correction factors.

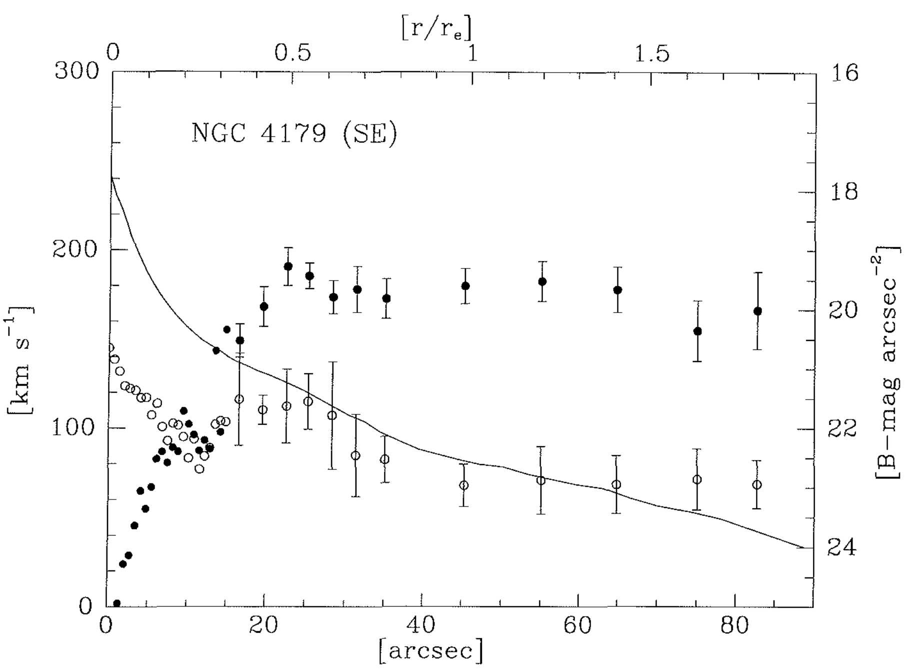

Figure 3: *Same as Figure 2, for SE semimajor axis of the edge-on S0 galaxy NGC 4179 shown in Figure 1. The photometric information is taken from a study by Capaccioli, Fasano, and Held (in preparation).*

Figures 2 and 3 show that our kinematical measurements reach the record distance, for absorption spectra, of $\sim 2\ r_e$; this is twice the size of the effective isophote (the one which encircles half of the total light of the galaxy), and corresponds of a surface brightness $\mu_B \simeq 24$.

In order to appreciate the improvement of these over the literature data on absorption line kinematics, one can see for example the "Atlas of velocity dispersion profiles and rotation curves for elliptical and lenticular galaxies" by Di Martino, Busarello and Longo (1989, preprint).

In all cases, our rotation curves exhibit the standard signatures of S0 galaxies, i.e. the bumps characteristic of systems where the "conspiracy" between the disk and the bulge is not finely tuned (cf. Capaccioli, 1979). More importantly, they confirm that the flat trend noted at small galactocentric distances – where disks may be still prominent – is maintained at larger distances, well in the range where the bulge is dominant; for instance, according to Capaccioli et al. (1987), the major axis light profile of NGC 3115 is dominated by the bulge at all galactocentric distances $> 0.45\ r_e$. In spite of the fact that, thanks to the unique performances of EFOSC, our measurements have almost doubled the range of radial distances covered by previous kinematical mapping, these deep data do not provide us with any strong evidence for dark matter in early-type disk galaxies, say comparable to the HI rotation curves in late-type disk galaxies. The reasons are the still "short" radial range, and the uncertainties introduced by the non-negligible velocity dispersion and by the modelling. All this matter is under investigation. A full account of the observations described here, and the relative astrophysical discussion, will be presented elsewhere.

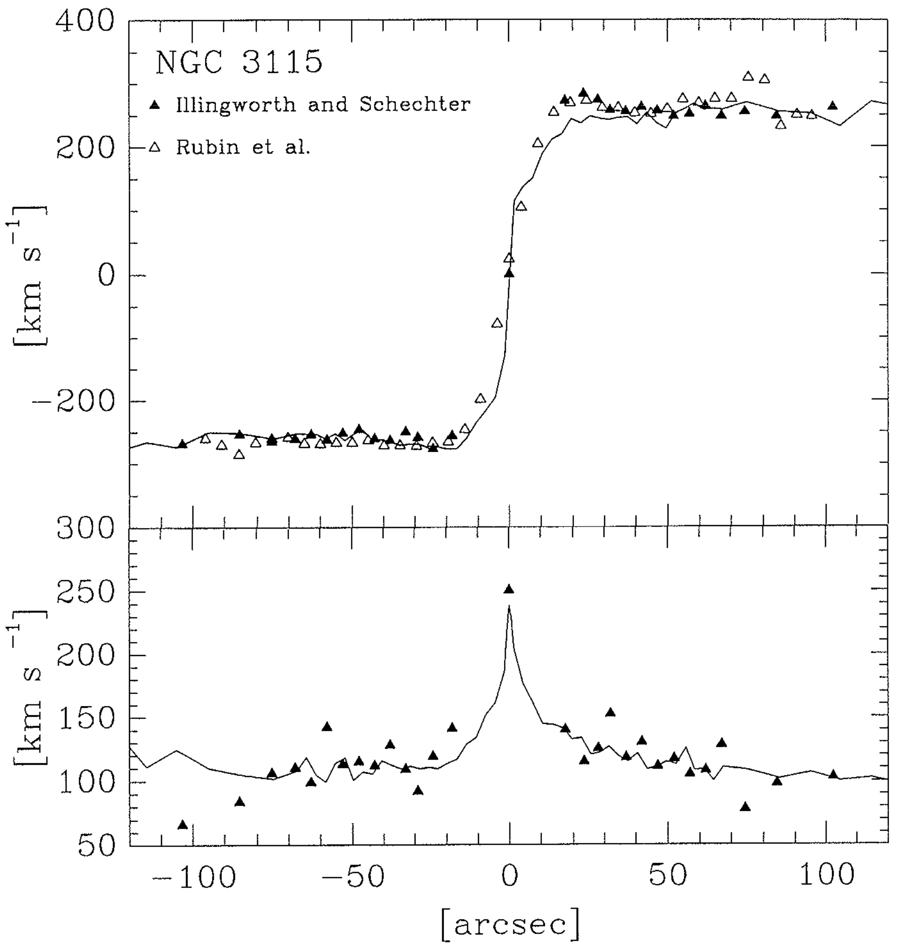

Figure 4: *Comparisons between the rotation and velocity dispersion curves of NGC 3115 from this study (solid line) and the kinematical data published by Rubin et al. (1980) and Illingworth and Schechter (1982).*

References

Bender, R., 1989, *Astron. Astrophys.*, in press.

Bender, R., Capaccioli, M., Macchetto, F., and Nieto, J.-L., 1989, *The Messenger,* **55,** 6.

Capaccioli, M., 1979, in *Photometry, Kinematics, and Dynamics of Galaxies* (Austin, Texas), ed. D.S. Evans, Texas Univ. Press: Austin, p. 165.

Capaccioli, M., and Caon, N., 1989, in *1st ESO/ST-ECF Data Analysis Workshop* (Garching, FRG), eds. P.J. Grosbøl, F. Murtagh and R.H. Warmels, p. 107.

Capaccioli, M., and Longo, G., 1989, in *Windows on Galaxies* (Erice, Italy), eds. J. Gallagher and G. Fabbiano, Kluwer Acad. Publ.: Dordrecht, in press.

Capaccioli, M., Held, E.V., and Nieto, J.-L., 1987, *Astron. J.,* **94,** 1519.

Illingworth, G., and Schechter, P.L., 1982, *Astron. J.,* **256,** 481.

Rubin, V.C., Peterson, C.J., and Ford Jr., W.Kl., 1980, *Astron. J.,* **239,** 50.

International Portrait Catalogue

One of the last days in September this year, I went to Berlin (West) to give a talk at the Wilhelm Foerster Volkssternwarte (People's observatory), on the occasion of the 100th anniversary of its "Bamberg" refractor.

Among the speakers was also Dieter B. Herrmann, Director of the Archenhold-Sternwarte in Berlin-Treptow, GDR, and noted astronomical historian, who had come over to celebrate this jubilee of one of the oldest, still functioning large telescopes, in this case exclusively installed for public education purposes.

Quite apart from the happy event which brought us together, I learned about Professor Herrmann's efforts to establish the world's most comprehensive collection of portraits of astronomers, in particular for the benefit of (future) historians. More than 7500 photos and drawings have already been gathered by this project which has been going on since 1971, under the auspices of IAU commission 41 (History of Astronomy).

However, it appears that many astronomers are unaware of the existence of this catalogue, that is at least my impression after having talked to some colleagues here in Munich. This is confirmed by Prof. Herrmann's difficulties in acquiring portraits of now living astronomers. He therefore asked whether it would be possible to place a small note in the ESO *Messenger* to this effect, at the same time hoping for reaction from our readers. I am happy to provide this space for this useful purpose.