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New H I Observations of the prototype Polar Ring Galaxy NGC 4650A

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Abstract: New, high-resolution observations of the H I emission line and 20 cm continuum at the Australia Telescope Compact Array (ATCA) for the prototype polar ring galaxy NGC 4650A are presented. They show the presence of a far more extended H I distribution than previously observed with the VLA, and a very regular velocity field out to a distance of ~50 kpc. The combined analysis of the H I data with optical and near-infrared (NIR) images argues against previous warp models used to describe the dynamics of this object. Further analysis of the new B-band image obtained at the European Southern Observatories New Technology Telescope (NTT) indicates clearly that the polar structure extends continuously to within about 200 pc of the nucleus of the central host galaxy, ruling out the presence of a 'hole' in the central region of this component. The presence of two spiral arms stretching out in the polar disk seems to represent the most likely explanation for the observed morphology and kinematics.

Keywords: galaxies: individual (NGC 4650A) — galaxies: kinematic and dynamics — dark matter

1 Introduction

Polar ring (PR) galaxies have been the targets several attempts to constrain the shape of dark matter halos, e.g. by Schweizer, Whitmore & Rubin (1983), Whitmore, McElroy & Schweizer (1987, WMS), Sackett & Sparke (1990, SS), and Sackett et al. (1994, S94). They are early-type galaxies with a ring or annulus of gas, stars, and dust orbiting in a plane nearly perpendicular to the equatorial plane of the host galaxy. This peculiarity allows the sampling of the velocity field in two nearly perpendicular planes, which may give constraints on the shape of the dark halo mass distribution. This is a difficult measurement because it is based on the extrapolation of the inner mass model, determined mainly by the visible mass, into the outer polar region, where the information is given only by the PR H I gas.

So far the results on the dark halo shape have been contradictory. WMS concluded that the dark halo associated with the S0 was nearly spherical; the same optical data were analysed by SS in a more detailed study, and they showed that a range of dark halo flattenings, from E0 to E8, were compatible with the data. Their best fit was E5, and the spherical case gave a relatively poor fit. Recently S94 proposed a dynamical model for NGC 4650A using new optical observations of the radial velocities and velocity dispersion for the host S0 galaxy, which rules out the spherical halo option for the dark halo aligned with the S0. The S94 best-fit model includes a dark halo with an E6 to E7 flattening.

A recent dynamical model proposed by Combes & Arnaboldi (1996) for the kinematics of the prototype PR galaxy NGC 4650A (Whitmore et al. 1990) shows that the dark halo is only needed to account for the kinematics of the PR H I gas. This result is very similar to the situation observed for late-type spirals: here the luminous component completely accounts for the observed kinematics in the inner regions, while the dark halo is needed to explain the kinematics in the far outer regions. The similarity between spirals and the wide PR of S0 systems is strengthened by a recent study of the BRK broadband photometry for a sample of PR galaxies (Arnaboldi et al. 1995). This survey shows (i) a colour gradient in the polar annuli towards bluer colours at larger radii, very similar to the observed colour gradients of the late-type spiral disks (de Jong & van der Kruit 1994); and (ii) that the integrated B–R, R–K colours of PRs are very similar to those of spirals. In spiral galaxies, there is some evidence that the dark matter surface density distribution is proportional to the H I distribution (see Freeman 1993). In the PR galaxy NGC 4650A, the H I lies entirely in the PR (van Gorkom, Schecter & Kristian 1987, vGSK87). This led Combes and Arnaboldi to try a dynamical model for NGC 4650A, in which the dark component is flattened with the same axes as the PR itself. In this model, the dark matter

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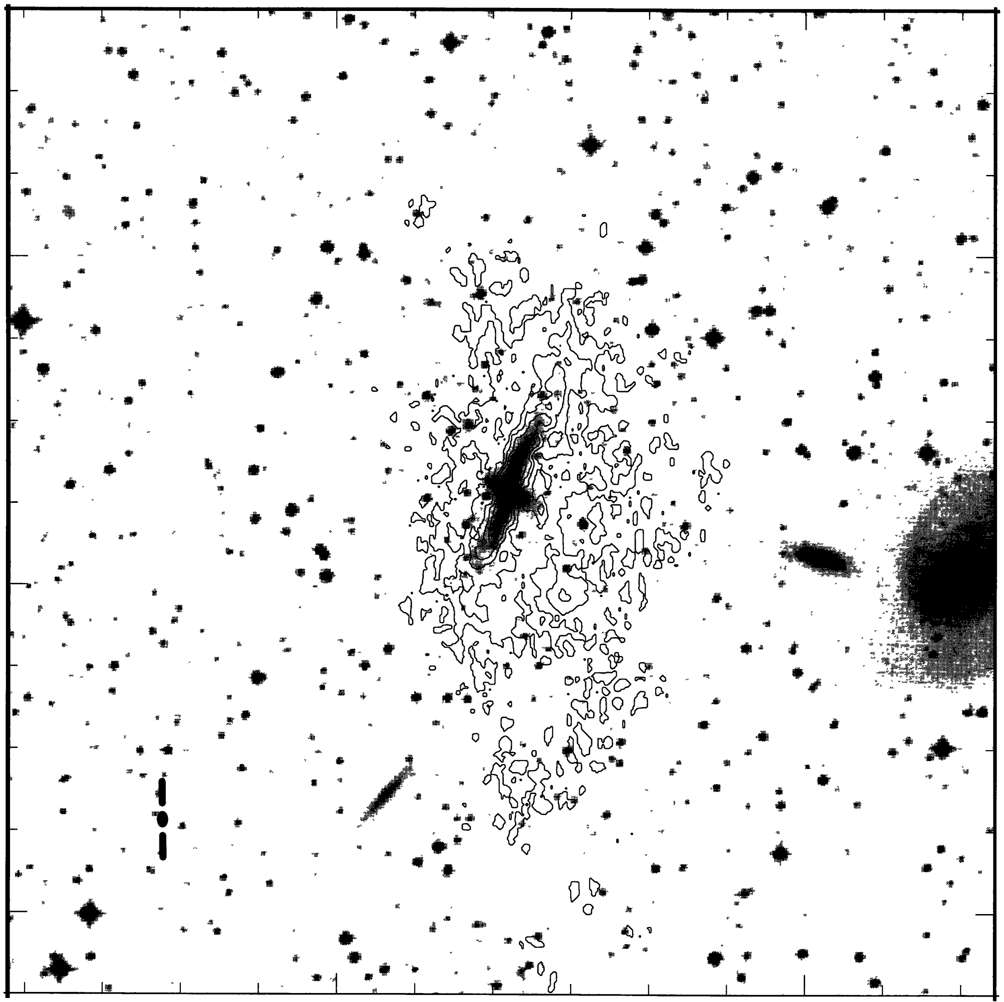

Figure 1—Contours of H I column density for NGC 4650A from the high-resolution data superposed on the Digitised Sky Survey image. Contours are drawn from $1{\cdot}6 \times 10^{20}$ atoms cm^{-2} or $1{\cdot}62$ $M_\odot$ pc^{-2}, in steps of $1{\cdot}6 \times 10^{21}$ atoms cm^{-2} or $12{\cdot}6$ $M_\odot$ pc^{-2}. The size of the synthesised beam is $12'' \times 8''$ with P.A. $=0{\cdot}8°$, and is shown by the small shaded ellipse in the lower left corner.

distribution is then simply proportional to the H I gas distribution of the NGC 4650A system, just as it appears to be in spiral galaxies. The model was able to explain very nicely the published optical rotation curves and velocity dispersion profiles along the major axis of the S0 and the PR, and the low angular resolution H I velocity field obtained by vGSK87. This question of the dark halo shape is very important because cosmological simulations of Cold Dark Matter universes predict the 3D halo shapes to be triaxial spheroids with a maximum flattening $c/a = 0{\cdot}4$ (Warren et al. 1992), so there is an urgent need to test the Combes–Arnaboldi hypothesis more thoroughly. To this aim, we have obtained high resolution 21 cm data with the ATCA for the PR galaxy NGC 4650A; these results are discussed in Section 2.

2 Results

The H I observations were carried out in 1995 April–May with the ATCA in three configurations: 1·5B, 1·5C and 6C. The integration time for each configuration was 12 hr. We observed with an 8 MHz bandwidth and 512 channels, centred at a frequency of 1407 MHz (corresponding to 2830 km s^{-1}). The data were calibrated using the standard ATCA procedures in the MIRIAD environment. The cubes were produced from the data using a robust weighting with robustness set to 0·3, and a channel width of 10 km s^{-1}. The noise in each channel map of the high-resolution data is 0·8 mJy beam^{-1}. The continuum was observed at a frequency of 1380 MHz, and we determined a total flux for NGC 4650A of 5·4 mJy.

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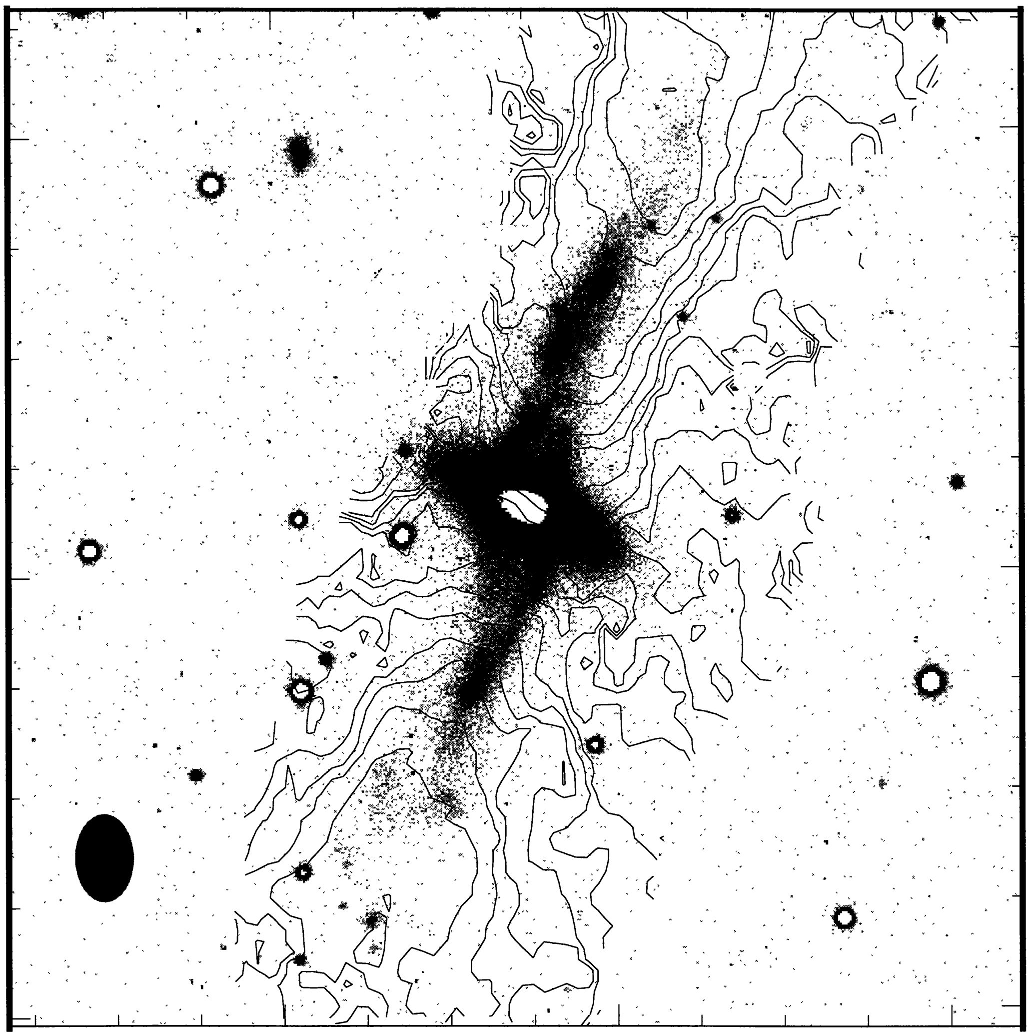

Figure 2—High-resolution 2D velocity field superposed on the ESO NTT B-band image; iso-velocity contours are drawn in steps of 10 km s^{-1}. Where the polar structure is clearly seen in front of the S0 there are perturbations in the velocity contours, and no peaks in the H I distribution. The size of the synthesised beam is shown by the shaded ellipse in the lower left corner.

The new ATCA observations show, in addition to the H I detected by vGSK87 a faint, more extended H I structure. We detect additional filaments and/or detached H I clouds out to 4′ north and south of the galaxy centre. The total H I flux in the map is 23 Jy km s^{-1}. The inner parts of the H I distribution are very elongated, the projected axis ratio of the H I contours is $b/a \simeq 0{\cdot}16$ which implies a nearly edge-on H I distribution out to ~60″ from the galaxy centre, while it becomes more face-on in the outer regions ($b/a \simeq 0{\cdot}38$, see Figure 1). The H I intensity map shows several secondary peaks and wiggles in the central distribution, with spatial scales of ~10″. The very regular velocity field is shown in Figure 2, superposed on the ESO NTT B-band image. The new high-resolution H I data, combined with the optical and NIR images, allow us to test the proposed models for the PR galaxy NGC 4650A. Models for this galaxy should simultaneously account for the morphology of the polar structure in the optical and NIR, plus the H I distribution and kinematics. We must discuss published geometries for the PR which were formulated prior to the acquisition of the NIR images and the high-resolution H I data. SS suggested a warped geometry for the PR which assumed a linear change in inclination beginning at 60° to face-on at the centre and becoming edge-on at a distance of 50″. S94 proposed a descriptive warp model based on the assumption that the bisymmetric knots seen at ~30″ in the PR B-band image are caused by orbit crowding and superposition, and in rough agreement with the axis ratio of the H I contours of the vGSK87 data at large radii: the S94 warp model assumes that all orbits are polar,

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but that their inclinations to the sky plane vary linearly with galactocentric radius along the ring major axis such that the ring is 10° from edge-on at the centre, is edge-on at 30″, and −20° from edge-on at $r = 90''$. As stated by S94 in their Section 4·1, this warp differs only slightly from that assumed by SS, and we test this last one against our new data. This model is in agreement with the 2D H I velocity field, but fails to reproduce the clear 'S' shape-morphology of the PR in the NIR K-band image (Arnaboldi et al. 1996). The comparison of the H I map with the new NTT B-band image obtained in good seeing (FWHM = 1″) indicates that the H I peaks do not follow peaks in the light, but they coincide with absorption features (Arnaboldi et al. 1996), contrary to what is expected from projected warp geometries (see for example the case of NGC 660: van Driel et al. 1995; Arnaboldi & Galletta 1993). The H I data and the optical and NIR images can be reconciled by the presence of spiral arms in the edge-on polar disk (Arnaboldi et al. 1996): a very deep image of the field around NGC 4650A obtained by David Malin shows low surface brightness features NW of the PR which follow the spiral arm structure proposed by Arnaboldi et al. (1996).

These new ATCA H I observations contradict the basic hypothesis assumed so far in the modelling of the dynamics of NGC 4650A, i.e. that the polar structure is a ring and that its dynamics are driven by the potential generated by the mass distribution (luminous + dark) associated with the S0. The presence of spiral arms in the polar structure indicates that the polar disk is very massive. These new results do strengthen the relationship between wide PR galaxies and spirals previously pointed out by Arnaboldi et al. (1995) and Combes & Arnaboldi (1996). The scenarios for the formation of such a polar disk will have serious implications about the nature of the dark matter which must be investigated: for an accretion event to produce such a flat disk, dissipative dark matter might be essential.

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