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The Declining Rotation Curve of NGC 157

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Abstract: We have found strong evidence for an abrupt decline in the H I rotation curve of the isolated spiral galaxy NGC 157. Various mass models to account for this, and the implications for the dark matter content of NGC 157, are discussed.

Keywords: galaxies: individual (NGC 157) — galaxies: kinematics and dynamics — galaxies: spiral — radio lines: galaxies

1 Introduction

NGC 157 is a rather innocuous looking SAB(rs)bc galaxy that first came to our attention when major-axis optical spectra by Zasov & Kyazumov (1981) showed an abrupt drop (of at least 50 $\mathrm{km\,s^{-1}}$) in projected rotation velocity, but only on the northern side. The fact that this drop occurs across a ring of H II regions leads us to hypothesise that this velocity discontinuity may be the signature of an expanding H I 'superbubble'. Assuming a distance to NGC 157 of 20·9 Mpc (Tully 1988), such a superbubble would be among the largest yet known, with a diameter of 4 kpc! In order to test this theory, we have mapped the distribution and kinematics of the neutral atomic hydrogen using a combination of C- and D-array observations with the Very Large Array. In addition, we have obtained wide-field B, I and Hα images with the Kitt Peak National Observatory 0·9 m telescope, and measured the kinematics of the ionised gas in the inner disk using a Fabry–Perot spectrometer on the Special Astrophysical Observatory 6 m telescope. The reduction and analysis of these observations is described in Ryder et al. (1997); in this paper, we concentrate on mass models which can account for the unusual rotation curve of NGC 157.

2 The Dynamics and Mass Distribution of NGC 157

Our H I map of NGC 157 (Figure 1) shows a large-scale, ring-like structure underlying the optical disk, but with an extended, low surface density component going out to nearly twice the Holmberg radius. The velocity field shows the characteristic signatures of a warp in this extended outer disk, as well as closed contours near the edge of the star-forming disk (indicating a turnover in the *projected* rotation velocity), but none of the major distortions expected from the presence of an H I superbubble. We have carried out a tilted-ring analysis of the gas kinematics using the AIPS task ROCUR, which finds the best-fitting combination of inclination, position angle and rotation velocity while the dynamical centre and systemic velocity are held constant. The results of this analysis are shown in Figure 2, together with results from a similar analysis of the Hα kinematics in the inner disk, and orientation parameters from surface photometry of the I-band stellar distribution.

Beginning just inside the optical radius (r_{25} = 125″), the gas disk commences a 60° warp, while at the same time, the rotation velocity drops by almost half from its peak of ~200 $\mathrm{km\,s^{-1}}$, before levelling off in the outer parts. The possibility that the rotation velocity stays close to the maximum cannot be ruled out, but the combinations of position angle and inclination that lead to such an abrupt decline in the rotation curve do receive some support from the ionised gas kinematics and from the surface photometry. Only a handful of galaxies are observed to have truly declining H I rotation curves [e.g. NGC 2683, NGC 3521 (Casertano & van Gorkom 1991), and NGC 7793 (Carignan & Puche 1990)], consistent with having reached the edge of the *total* mass distribution, and although NGC 157 may not properly fall into this category, the actual shape of its rotation curve is most uncommon. For a galaxy with the luminosity of NGC 157 ($M_B = -20\cdot82 \pm 0\cdot06$; Ryder et al. 1997), inversion of the Tully–Fisher relation (Pierce & Tully 1992) predicts a maximum deprojected rotation velocity of 234^{+137}_{-86} $\mathrm{km\,s^{-1}}$; thus, it is more a case of the outer H I velocity being unusually low, than of the inner H I velocity peak being unusually high.

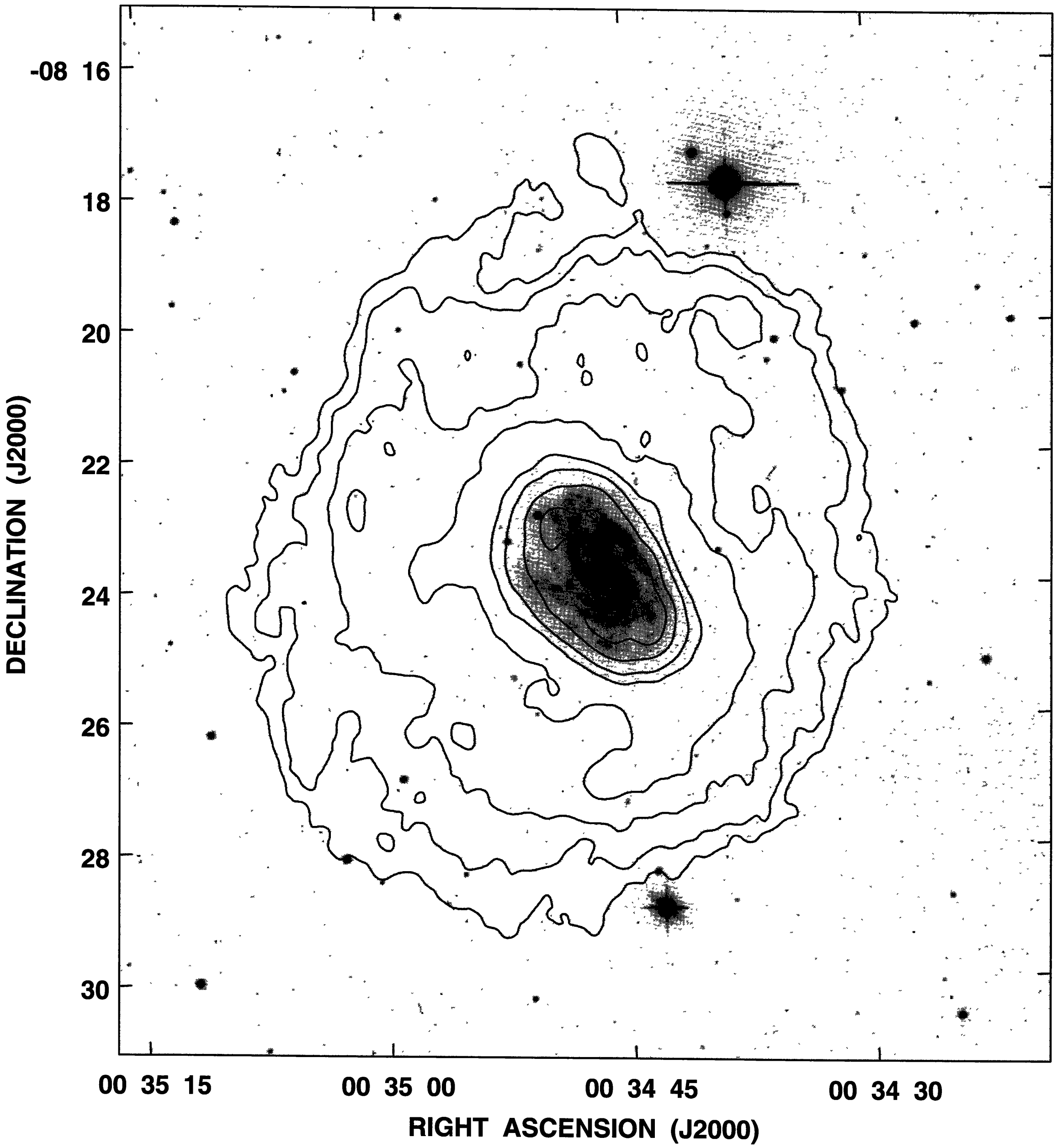

Figure 1—Contours of H I column density overlaid on a B-band image of NGC 157. The contours correspond to (projected) column densities of 0·5, 1·0, 2·0, 3·5, 7·0, 10·0, 15·0 and 20·0 × 10^{20} cm^{-2}.

There are a number of models that could potentially account for this unusual behaviour of the rotation curve:

- A standard 'maximum-disk' mass model which includes a $M/L_I = 1{\cdot}4$ stellar disk, a gas disk ($\sigma_{HI} \times 4/3$ to account for helium) and a pseudo-isothermal halo, yields a core radius of 15 kpc and a central density of $0{\cdot}002\,M_\odot\,pc^{-3}$. The gas mass to stellar mass ratio is therefore quite normal at 5%, but the dark to luminous matter ratio at the last measured point is unusually low at almost 1:1 (though NGC 801 has an even lower value; Broeils 1992).
- A strong spiral density wave pattern could partially mimic the behaviour of a warp (Walsh, Staveley-Smith & Oosterloo 1997). Additionally, our assumption of uniform circular motion at all radii may not be valid. In the absence of any significant bar component, however, the magnitude of any non-circular motions, particularly in the outer

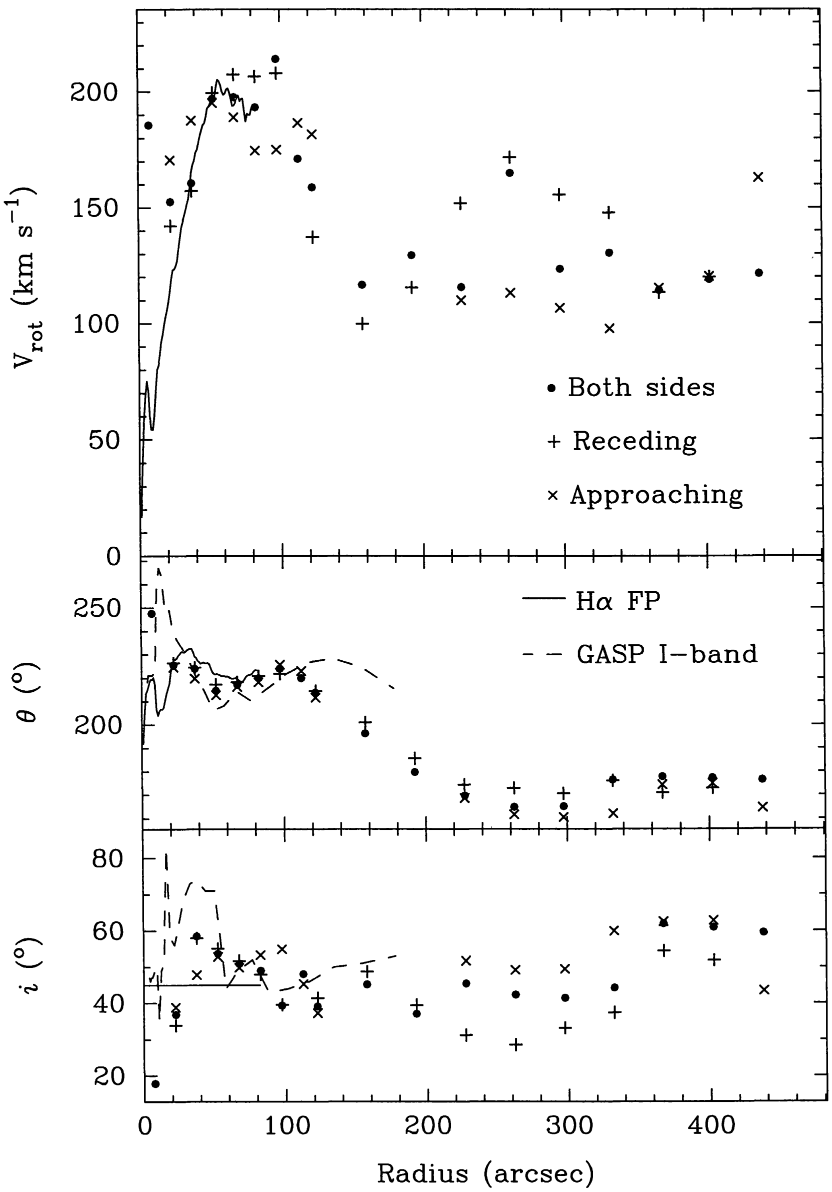

Figure 2—Variation of rotation velocity, major-axis position angle and inclination, assuming that the H I in NGC 157 moves in circular orbits. The solid line shows the equivalent kinematics of the ionised gas (inclination assumed constant at 45°), while the dashed line shows the results of ellipse-fitting to the stellar light distribution. For the H I, fits have been made to the entire disk (•), as well as just the receding (+) and approaching (×) halves. Errors in the formal fitting are much smaller than the differences between the separate halves.

regions of such an isolated galaxy, is almost certainly negligible.

- Truncated disks (Casertano 1983) can produce an abrupt turnover in rotation velocity. We have successfully modelled NGC 157 using one massive disk, truncated at 6 kpc, together with a second, less massive disk to maintain the observed rotation velocity at large radii, and match the observed radial surface brightness distribution. Certainly, both Figure 1 and the velocity field give the strong impression of an inner (gas + stellar) disk only loosely coupled to the outer gas disk. Disk edges are seldom apparent in radial luminosity profiles (van der Kruit 1988), but there is the hint of a fairly sharp drop across the northwest edge of the optical disk (Figure 1). The work of Sparke (1984), who showed that truncated disks may be the important factor in sustaining vertical oscillation modes, i.e. a warp (albeit interior to the truncation), may be of some relevance here.

Interestingly, the abrupt turnover in the H I rotation curve is consistent with that seen by Zasov & Kyazumov (1981) in Hα. Thus, rather than detecting the presence of a major H I superbubble, it is probable that they were observing *optically* the onset of this abrupt decline in the rotation curve. The dark matter content of NGC 157 is low (though not unprecedentedly so), and has presumably always been low, since the case for stripping is weak, given the isolated nature of NGC 157. The existence of an outer, slow-rotating gas disk surrounding a more rapidly spinning inner disk is consistent with the 'plateau' seen in the global H I profile of NGC 157 (Staveley-Smith & Davies 1987), and a search for similar profile shapes in other galaxies may turn up many more galaxies like NGC 157 with abrupt declines in their rotation curves.

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