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Clues on the Structure and Composition of Galactic Disks from Studies of 'Superthin' Spirals: the Case of UGC 3697

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We summarize results from an H I+optical imaging study of the "Integral Sign" galaxy, UGC 3697. UGC 3697 is a low-mass, Sd spiral that exhibits a "superthin" disk morphology despite a prounced gasous and stellar warp. Our new observations show evidence for a recent minor merger in this system that could account for its large-scale warp and a number of other properties of this galaxy. We speculate that UGC 3697 has been caught in a rather short-lived dynamical state, and may soon undergo significant structural and morphological changes.

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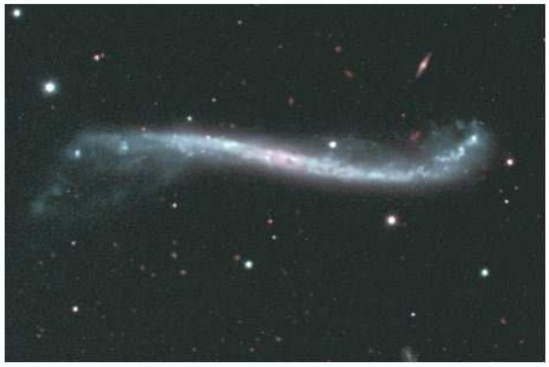

Figure 1. *Optical $B+R$ composite image of UGC 3697 obtained with the 3.5-m WIYN telescope at Kitt Peak, AZ. The field shown is $\sim$3.′5 across.*

1. Background

Among the latest-type spiral galaxies, there exist systems that when viewed edge-on, exhibit extraordinarily thin stellar disks (h_z $\sim$150-200 pc; $a/b > 10$), often of very low intrinsic surface brightness ($\mu(0)_{B,i} \gtrsim$23 mag arcsec^{-2}). The chemical, structural, and dynamical properties of these so-called "superthin" galaxies imply they are some of the least evolved disk galaxies in the local universe, both in terms of their dynamical properties and their star formation histories ([7],[1],[11]). This implies that the superthins can supply important constraints on the process of galaxy disk formation, the role of environment on the evolution of disk galaxies, and on the nature and distribution of galactic dark matter (e.g., [9],[11],[16]). Recently, we have been investigating these issues using a combination of optical and H I imaging of three nearby superthin galaxies ([16],[10],[12]). Here we describe preliminary results from the analysis of one of these systems, UGC 3697.

UGC 3697 has been referred to as the "Integral Sign" galaxy ([3]) owing to the pronounced *S*-shaped bending of its stellar disk (Fig. 1). Although some degree of warping is observed in the stellar and/or gaseous disks of a large fraction of galaxies ([14]), few are are warped as dramatically as UGC 3697. The rarity of warps with similar amplitudes ($\sim$15% of the disk diameter) suggests UGC 3697 is in a transient dynamical state.

Despite the ubiquity of galactic warps, their origin is still poorly understood ([2]). Accretion events are one means of exciting high-amplitude warps (e.g., [4]); however, accretion and minor mergers are expected to heat (thicken) disks dynamically (e.g., [17]), leading to the puzzle of how a galaxy like UGC 3797 can be so strongly warped, while preserving such a thin disk structure.

Table 1 presents a comparison between some of the global properties of UGC 3697 and a prototypical superthin galaxy, UGC 7321 ([11], [16]). Note that both galaxies have extremely small stellar scale heights, and share a number of other physical similarities (e.g., linear diameter; peak rotational velocity; H I mass). Both UGC 7321 and UGC 3697 are also pure disk systems with no obvious equatorial dust lane. On the other hand, UGC 3697 is roughly three times more luminous than UGC 3697 in the optical, and 23 times more luminous in the FIR. Its central CO luminosity is significantly higher ([12]), and its inner rotation curve much steeper ([7]). The combination of these similarities and differences strongly suggests that UGC 3697 is a typical superthin system in the throes of a structural and morphological transformation.

Table 1.

	UGC 3697	UGC 7321
D(Mpc)	18	10
$V_{\rm rot}$(km s^{-1})	95	104
A_{25}(kpc)	17.0	16.1
h_z(pc)	200	150
$M_{\rm HI}(\times 10^9 M_\odot)$	1.4	1.1
$L_B(\times 10^9 L_\odot)$	2.8	1.0
$L_{FIR}(\times 10^9 L_\odot)$	1.8	0.079

2. Results from New H I and Optical Imaging

Fig. 2 shows an H I total intensity image of UGC 3697 obtained with the Very Large Array (VLA).[1] These data were obtained in the C configuration with 12 hours of on-source integration, and reach a 3σ limiting column density of $\sim 2\times 10^{19}$ atoms cm^{-2} channel^{-1} with a velocity resolution of 5.2 km s^{-1} and a spatial resolution of $\sim 19''$.

Fig. 2 reveals that H I traces the stellar warp of UGC 3697, and also shows additional twists and extensions. On the eastern side of the galaxy, we find gas along the midplane, as well as a wide swath of more diffuse emission sweeping below the plane. In our optical images (Fig. 1), this latter region is faintly delineated by a very blue sheet of stars. Near this location, we also draw attention to a faint, newly-discovered dwarf near the southeastern edge of the disk, at (α_{2000}=07$^{\rm h}$11$^{\rm m}$57.1$^{\rm s}$, δ_{2000}=71°48′55″). This dwarf shows a rotational signature, and has an optical counterpart $\sim 10''$ across, with $L_B \sim 8\times 10^6 L_\odot$.

In contrast to normal edge-on spirals, where the brightest concentration of H I is typically found near the central regions of the galaxy, UGC 3697 shows a bright blob of emission near its western edge. Gas filaments also extend from this location, reaching up to ∼7 kpc from the plane. Neither the filaments nor the bright midplane clump have any obvious optical counterparts.

3. Interpretation

While UGC 7321 is a rather isolated system ([16]), UGC 3697 is part of a small galaxy group that includes the peculiar elliptical UGC 3714 and several dwarf galaxies ([5]). UGC 3714, at a projected distance of 39 kpc from UGC 3697, is the optically brightest group member, and has long been presumed to be responsible for exciting the warp of UGC 3697 via tidal effects (e.g., [13]). However, tides are rather inefficient warp drivers (e.g., [6]), and our new observations have for the first time revealed strong evidence that an accretion event rather than tidal effects are responsible for the present morphology of UGC 3697.

We estimate that a mass of H I of a few times $10^8 M_\odot$ has been recently accreted onto UGC 3697 from an infalling satellite. This mass is typical of the H I contents of dwarf irregular galaxies. Such an event would also be expected to trigger radial gas inflows ([8]) and may thus account for the centrally-enhanced CO and 21-cm radio continuum emission ([12]), as well as the steep appearance of its inner rotation curve compared with other superthins (see [4]). The faint dwarf we see near the southeastern tip of UGC 3697 may be the stripped core of this intruder.

While the infall of satellites is expected to heat (thicken) disks dynamically, the simulations of [15] showed that disks can remain thin during several passes of a low-mass intruder, before rapidly

[1]The Very Large Array of the National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

thickening via resonantly-excited bending waves once the satellite orbit has decayed suf£ciently. We speculate that UGC 3697 may be caught in a rather special state, en route to such a trasnformation. Such events are likely to have been common in low-mass disk galaxies during earlier epochs, implying studies of galaxies like UGC 3697 can shed insight into the evolutionary consequences of this process. Moreover, because superthin systems like UGC 3697 are structurally simple and dark matter-dominated, further observations and modelling of galaxies like these may supply important constraints on the amount of dark matter that resides in the disk versus the halo of late-type spirals.

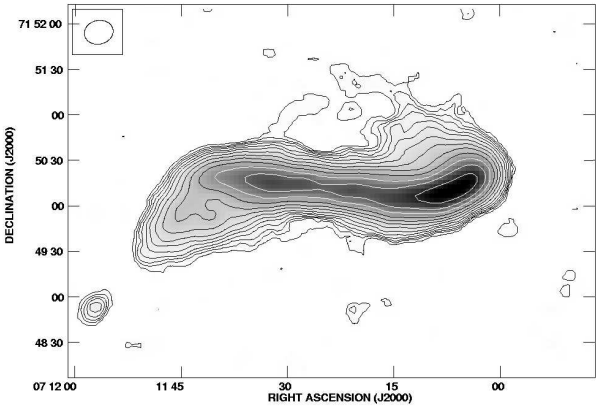

Figure 2 *Contour and greyscale representations of the H* I *intensity distribution in UGC 3697 based on VLA data. A previously uncatalogued dwarf is visible in the lower left. The contour levels are: 0.52,1.0,1.5,2.1,2.9...67* $\times 10^{20}$ *cm*$^{-2}$ *at a resolution of* $19'' \times 16''$ *(1.7*$\times$*1.4 kpc). The greyscale range is 0-5.5*$\times 10^{21}$ *cm*$^{-2}$.

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