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Effects of Grazing Encounters on Spiral Galaxies

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Abstract. We made radio, optical, and CO observations of three pairs of spiral galaxies involved in recent, grazing encounters and compared our data with numerical simulations. The tidal structures seen in the galaxy undergoing a prograde, in-plane encounter share a number of key features which are adequately explained by our simulations. It is shown that the objects IC 2163/NGC 2207, NGC 2535/36, and NGC 5394/95 represent distinct stages in the evolution of the type of interactions discussed here.

1. Introduction and Results

To see the effects of grazing encounters on the structures and internal kinematics of spiral galaxies, we made radio, optical, and CO observations of the galaxy pairs IC 2163/NGC 2207, NGC 2535/36, and NGC 5394/95, and modeled the interactions with computer simulations. Each system contains a galaxy (IC 2163, NGC 2535, NGC 5394) that has two long, symmetric, tidal arms with high arm-interarm contrast and a large misalignment between kinematic and photometric

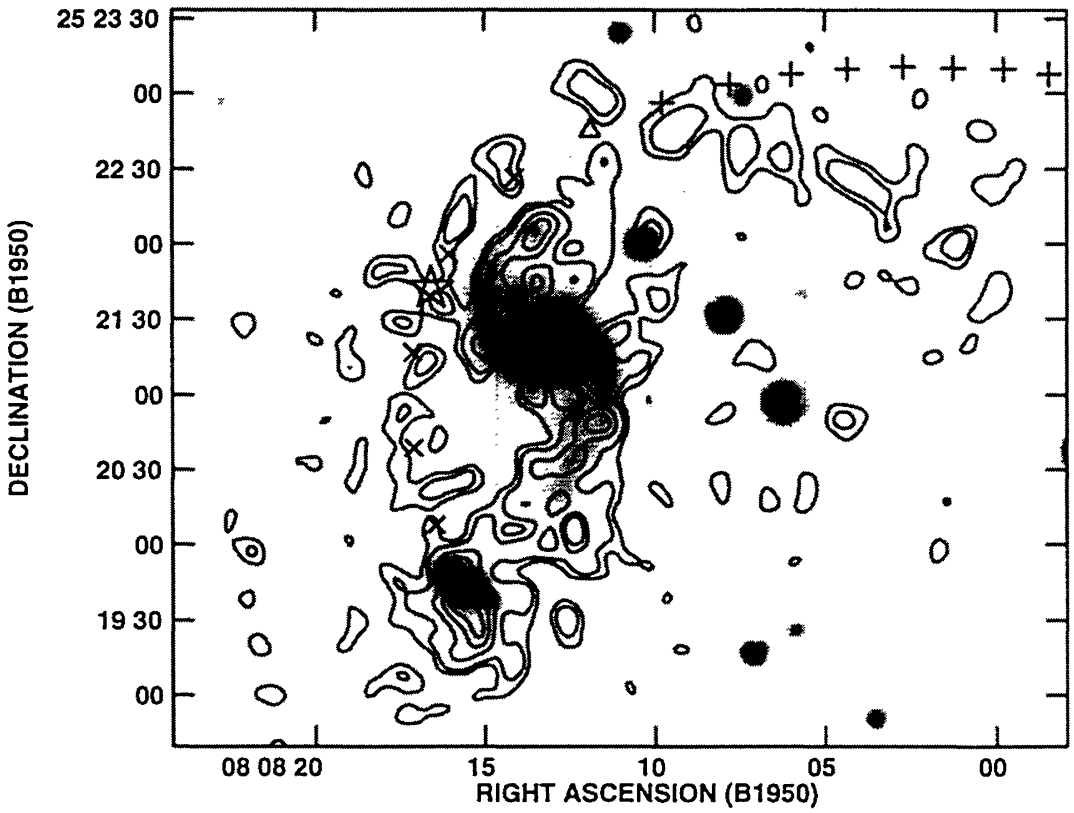

Figure 1. N(H I) contours overlaid on a B-band image of NGC 2535/36 in greyscale. In the optical image, NGC 2535 has an eye-shaped structure with two long tidal arms, similar to IC 2163. The symbols mark the sky-projection of the computer-simulated orbit of NGC 2536; it was chosen to reproduce the observed stellar tidal features and not subsequently adjusted to fit the H I data. The coincidence between this orbit and the long, outer, elliptically-shaped H I arc suggests that the H I arc is a gravitational wake.

axes, indicative of an intrinsically oval disk. These properties imply that the galaxy has suffered a very recent, prograde, in-plane encounter. Our detailed results are given in Elmegreen et al. (1995a, b; 2000) and Kaufman et al. (1997; 1999), and some highlights are summarized here.

The tidal structures in these galaxies form an "age" sequence. IC 2163, the least evolved interaction, has star formation typical of normal spiral disks. NGC 2535, whose morphology suggests a slightly later stage, has somewhat enhanced star formation and a starburst companion. NGC 5394, the most evolved interaction, has a central starburst. All three pairs contain widespread high velocity dispersion regions in the H I gas and massive H I clouds, some of which may become tidal dwarf galaxies.

Our *HST* image of IC 2163/NGC 2207 provides a radical new view of density-wave induced structure of a spiral arm, as seen in the arm of NGC 2207 "X-rayed" against the disk of IC 2163. The backlit arm of NGC 2207 contains several parallel, knotty, dust filaments, spanning the full width of the arm. Thus *the density-wave shock occurs in several separate places across the width of the*

arm. HI observations of the tidal tail of IC 2163 reveal large streaming motions with two velocity components differing by $100\,\mathrm{km\,s^{-1}}$ in line-of-sight velocity, and the *HST* image displays numerous, parallel filaments here. Comparing the observations with a smoothed particle hydrodynamics (SPH) encounter model, we conclude that the tidal tail filaments are tidally-stretched flocculent spirals. The high-velocity gas at the inside edge of the tail originated in the HI dominated outer disk of IC 2163 and is now streaming outwards, whereas the low-velocity HI component along the outer edge of the tail is gas flowing back inwards.

In HI, NGC 2535 has an extended envelope, a tidal bridge and tail, and a long, outer, elliptically-shaped arc. Coincidence between the elliptical arc and the computer-simulated orbit of NGC 2536 (see Figure 1) suggests that the HI elliptical arc is a *gravitational wake* produced by the passage of NGC 2536 within or close to the extended HI envelope of NGC 2535.

NGC 5394 has very bright inner spiral arms, disjoint from the outer tidal arms. The encounter simulation finds that the inner spiral structure developed from an eye-shaped structure, like that seen at earlier stages of similar interactions such as IC 2163 and NGC 2535. NGC 5395 has a long HI tidal arm distinct in velocity from its disk at the same projected location and thus not in the same plane as the disk.

IC 2163, NGC 2535, and NGC 5394 form an evolutionary sequence of structures resulting from prograde encounters and confirm the models of such collisions.

References

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Turkey vultures, Socorro, NM,
29 April 1994 (courtesy E. Greisen/NRAO)