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A Bird's Eye View of Ocular Galaxies

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Abstract. Ocular galaxies are systems undergoing an in–plane, near grazing, prograde encounter. In addition to the interaction causing the formation of two long, symmetrically opposite tidal tails, during a short period after perigalacticon a characteristic "eye"–shape develops, hence the name. This short lived feature develops under certain initial conditions, so ocular galaxies set strict constraints on numerical models leading to unique fits to the observations. A summary of our results on three interacting systems, IC 2163/NGC 2207, NGC 2535/36, and NGC 5394/95, and new HST observations of IC 2163/NGC 2207 is presented.

1. Introduction

Interactions between galaxies are known to be common and they probably have been more numerous in the past. The almost exponential growth in computing power has improved research in this field as more and more realistic simulations have become possible (see Struck 1999 for a recent review).

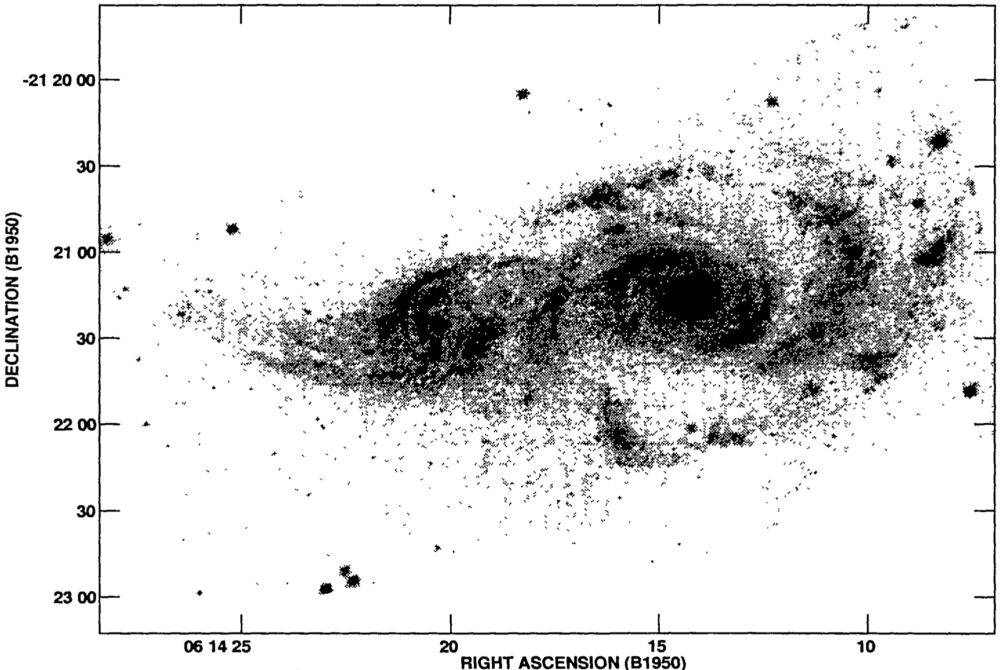

Figure 1. HST B–band mosaic of the interacting galaxy pair IC 2163/NGC 2207. IC 2163 is the object to the left (east). The pixel size of 0.0995" of the HST WFPC2 camera corresponds to 17 pc at the assumed distance of 35 Mpc of the system. A true color version of this image (which can be retrieved from the Hubble Heritage Team's web-site at http://heritage.stsci.edu) is reminiscent of the face of an owl, hence the title of this contribution.

A persistent problem in studying interactions is that in general observations provide at most three of the six phase–space coordinates for each of the galaxies involved. Hence, ambiguity remains regarding the true orbits of the interacting galaxies and, though sophisticated, unique three–dimensional model solutions are rare. To restrict some of the degrees of freedom in the models we concentrate on interacting systems which show some peculiar feature, or a short–lived signature, indicative of a particular orbit configuration. One such class is that of ocular or caustic galaxies, systems in which an in–plane, near grazing, prograde interaction creates a short–lived, strong response in one of the systems involved.

2. Observations and Results

On a multi–wavelength study of a small sample of carefully chosen interacting systems we have collected broad–band optical, NIR and Hα imaging (in one case using Fabry–Perot mapping). These observations have been complemented with high resolution NRAO[1] Very Large Array (VLA) HI imaging and CO observations with SEST and the Onsala 20–m telescope, providing, in addition to the stellar distribution, the morphology and kinematics of the gaseous component.

[1]NRAO is a NSF facility operated under cooperative agreement by Associated Universities, Inc.

To date, we have studied three systems, IC 2163/NGC 2207, NGC 2535/36 and NGC 5394/95 represennting an age sequence; IC 2163 is the least evolved encounter whereas NGC 5394/95 is the most evolved one. They all show the following trends (Kaufman et al. 1997; 1999): the galaxy which suffers the prograde encounter develops two long tidal arms with a large arm–interarm contrast. A marked misalignment between the kinematic and photometric major axes implies an intrinsically oval inner disk due to strong tidal forces. In all three disks, irrespective of their orientation, we have found regions of high velocity dispersion of HI gas as a consequence of the interaction (Elmegreen, Kaufman, & Thomasson 1993).

3. The IC 2163/NGC 2207 System

IC 2163/NGC 2207, has been the topic of several papers already (Elmegreen et al. 1995a; 1995b; 1998; 2000). To study the grazing encounter in more detail, nine orbits with HST were dedicated to this pair in May 1996 and November 1998 using UBV and I filters to create a mosaic based on three pointing centers. A B–band mosaic is shown in Fig. 1. This stunning picture shows a wealth of detail at an angular resolution of 0.0995" (corresponding to a linear resolution of 17 pc). Based on the HI data (Elmegreen et al. 1995a) we know that IC 2163 shows two symmetrically opposed spiral arms. The western arm, however, is hidden by NGC 2207, which is located in front of IC 2163. The eastern arm shows numerous, near–parallel dust filaments which are about 85 pc wide and lie perpendicular to the flow direction of the gas. Towards the southern edge the filaments seem to merge into two parallel dust filaments.

A numerical model using an 18,000 particle SPH code for IC 2163 reproduces well the general shape of the eastern tidal tail. NGC 2207 is represented by a pure halo with half the scale length and a mass of 1.25 times that of IC 2163. Several hundred Myr ago IC 2163 moved from the near side of NGC 2207 to the far side, some two galaxy radii away from its center and moved behind it in an easterly direction. It reached perigalacticon some 40 Myr ago. The in–plane tidal forces developed an ocular or caustic feature midway in the disk of IC 2163 as a result of rapid inward motion induced by the tidal forces and amplified by self–gravity in its disk (Elmegreen et al. 2000). This leads to an intrinsically oval shape and explains why the kinematic and photometric major axes don't coincide.

The model suggests that the delicate parallel dust filaments in the tidal arm, are in fact stretched flocculent spiral arm segments which were present in the disk of IC 2163 before the interaction took place. Material at the inside edge of the tidal tail originated in the outer part of IC 2163 and is now moving outwards. A shock front develops near the outside edge of the tidal arm where outward streaming gas from the middle of the tidal tail meets material rushing back inwards. Our HI data, although of much lower resolution than the HST observations, show clearly two velocity components on the tidal tail, consistent with the asymmetry of the HI profile in a north–south cut across the tidal arm.

The HST observations provide us with another revealing view in the area where NGC 2207 is seen projected along the line of sight on top of IC 2163. The background light of the latter results in what almost corresponds to an X–ray image of a prominent spiral arm in the former. What appears in ground–based images as a single dust lane is seen at the resolution provided by HST to be made up of 4 to 7 nearly parallel dust streamers, spanning the full width of the spiral arm. The arms in NGC 2207 are most likely due to density waves. The narrow dust lanes probably suggest that the shock wave is far more complex and that shocks occur in several places across the arm. Blue, stellar–like objects in these dust filaments are probably young clusters.

4. Conclusions

All systems studied in detail share a characteristic eye–shaped structure in the galaxy which is undergoing an in–plane, near grazing, prograde encounter and develops two opposite tidal tails. The interstellar medium in both galaxies involved in the interaction is stirred violently, leading to a high velocity dispersion. Massive clumps of gas (traced by HI) stable against self–gravity can form. High resolution HST optical imaging of IC 2163/NGC 2207 has provided us with a much improved understanding (backed up by numerical SPH simulations) of the formation mechanism in the tail of IC 2163. These observations also reveal a radically new view of density–wave induced structure in a spiral arm of NGC 2207 which is seen backlit by IC 2163.

5. Acknowledgement

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