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Collisional Ring Galaxies in Small Groups

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Abstract.

The probability of plunging orbits is enhanced in groups of galaxies and indeed, observations show that ring galaxies, which are believed to form when a galaxy passes through the center of a larger rotating disk, are often found in small groups. Numerical simulations combined with a knowledge of the large-scale H I distribution provide strong constraints on the dynamical history of these systems and on the identity of the intruder. Here we present a numerical model of the Cartwheel galaxy which supports the suggestion that the most distant companion is the intruder. We also present high-resolution H I observations of the more irregular system Arp 119 that reveal a possible connection to the most distant companion.

1. Introduction

The evolution of galaxies in small groups is governed by gravitational interaction. Even if the lifetime of a dynamical system is 5–10 times larger than the crossing time, small groups of galaxies should have merged into one single galaxy in much less than a Hubble time. It has been suggested that small groups are constantly replenished through infall of galaxies in looser groups (Diaferio, Geller & Ramella 1994). Another scenario supported by numerical simulations is that dark matter halos may delay the merging process of small groups, in particular if the halo envelopes the whole group (Barnes 1985; Athanassoula et al. 1997).

The presence of a ring galaxy in a group may help provide constraints to a number of parameters, such as the dynamical timescales and the dark matter distribution. Rings form after the passage of a smaller galaxy through the center of a disk galaxy. They are expanding ring waves made more visible through the blue light of the young stars born from the gas that has been compressed in the ring wave. From the size and the expansion velocity of the ring (as measured for instance by high-resolution emission line observations), it is possible to estimate the age of the ring. The relative spacing of the rings gives information on the dark matter distribution in that galaxy. The large-scale atomic gas distribution traces the history of the interaction and, combined with numerical N-body simulations, provides some insight into the evolution of those groups. One of the best studied northern ring systems is VIIZw466 for which H I observations have provided information on the kinematics of the gas in the ring and its nearby companions and have revealed the presence of

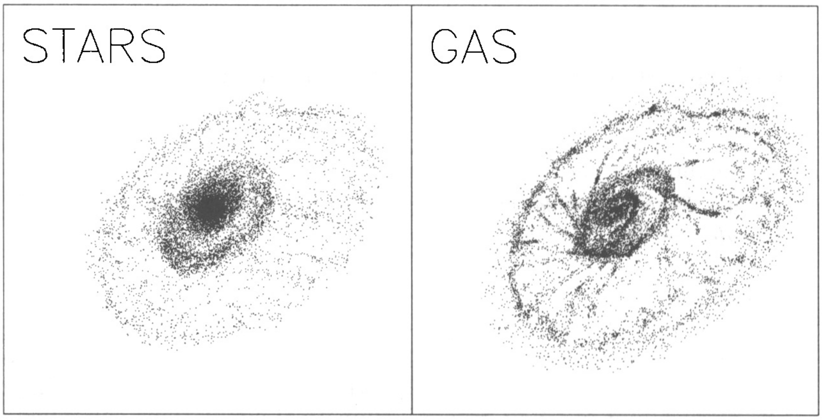

Figure 1. Numerical simulation of the Cartwheel. The intruder (not visible on this figure) lies on the plane of the sky close to G3, the most distant companion of the Cartwheel

a plume extending from one of the companions towards the ring (Appleton, Charmandaris & Struck 1996). The effect of an asymmetric compression in the ring was seen in the mid-infrared (using *ISO*) and the radiocontinuum emission (Appleton, Charmandaris, Horellou et al. 1999). Here we discuss two more ring galaxies located in small groups: the Cartwheel and Arp 119; we present a model of the Cartwheel that reproduces most of the observed features, and the first high-resolution H I observations of Arp 119.

2. A Model for the Cartwheel

The results of our simulation assuming the Cartwheel's most distant companion (called G3) as the intruder are shown in Fig. 1. We choose G3 as the "bullet" rather than one of the two nearer companions because of the existence of an extended H I plume reaching from the Cartwheel towards that galaxy (Higdon 1996). Our model is based on the nearly central collision of a rigid companion galaxy with a self-gravitating disk containing both stars and gas (see Horellou & Combes 2000a for more details). The halo of our computer-made Cartwheel is about three time as massive as the disk+ bulge, and the mass of the companion is half that of the target. The model reproduces the main features of the Cartwheel and the observed position and radial velocity difference between the Cartwheel and G3. It is interesting than a good fit can also be obtained by assuming one of the nearer companions as the intruder on a trajectory that is perpendicular to that of the Cartwheel's disk (Bosma et al., this volume). However, neither Bosma et al.'s model nor ours involving a rigid intruder is able to reproduce the $\approx$ 100 kpc long H I tail towards G3. In a more elaborate calculation in which both the companion and target are deformable, we found that a gas-rich companion plunging through the center of the target on a prograde orbit can extrude a gaseous plume reminiscent of that in the Cartwheel (Horellou & Combes 2000b).

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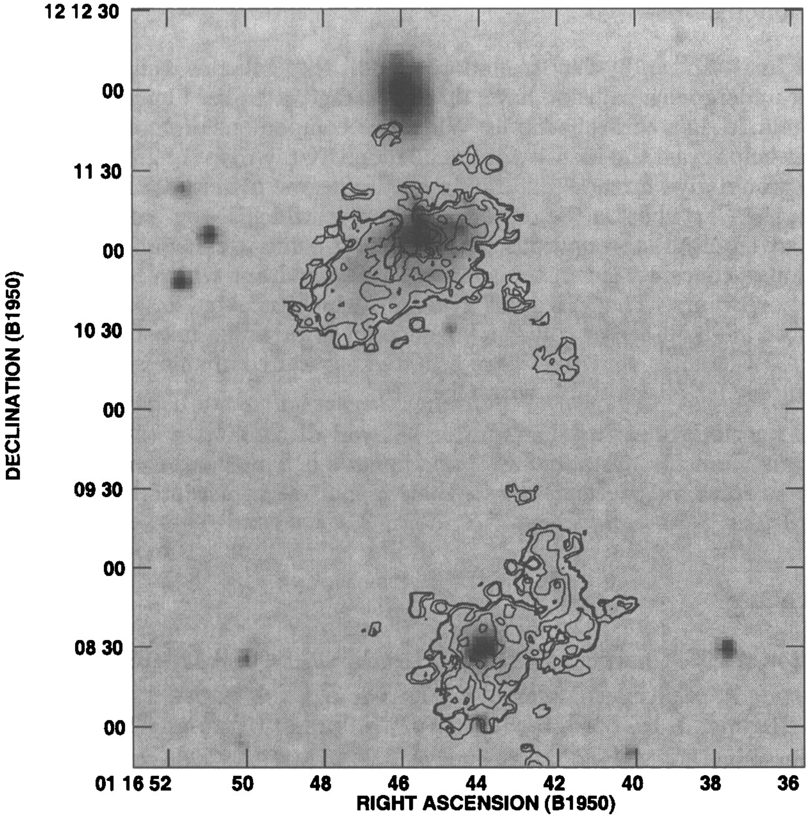

Figure 2. Atomic gas distribution in Arp 119 (contours: VLA B-array total H I intensity map; grey-scale: optical image from the Digitized Sky Survey). The angular resolution of the H I map is 10″.

3. Arp 119

Arp 119 is a more distorted system with two nearby companions, an elliptical and an irregular. In addition to the material directly associated with the galaxies, H I emission is detected south of the ring-like one and north of the southern irregular companion Mrk 983 (see Fig. 2; Horellou, Charmandaris & Combes, in prep). The two features may be connected, forming a bridge between the two galaxies. The H I in Arp 119 is distributed in a broad rotating ring with several condensations, some of which coincide with the knots terminating the "spokes" that are visible on the optical picture. Those features may be due to the head-on collision between Mrk 983 and Arp 119. The nucleus of Arp 119 presents characteristics of a LINER. It is not clear whether the head-on collision of two gas-rich galaxies can trigger an active nucleus, although the fraction of ring galaxies with a Seyfert nucleus is rather high (four out of about 30).

4. Conclusions

As originally shown by Few & Madore (1986), ring galaxies which show signs of having undergone a collision have, on the average, a higher number of neighbors than galaxies in a control sample. When two companions are present, H I observations help reveal the identity of the intruder. X-ray maps of groups containing a ring would give further constraints on the degree of relaxation of the group. So far, the Cartwheel is the only ring galaxy in which X-ray emission has been detected (ROSAT observations by Wolter, Trinchieri & Iovino 1999) and the emission is concentrated in the southern ring quadrant where most of the star formation occurs. The VIIZw466 system – which contains an asymmetric ring produced in an off-center collision, an edge-on spiral and a massive ellipical with distorted isophotes that may have accreted several companions – would be an ideal target for observations with Chandra.

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