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RAM PRESSURE STRIPPING AND GALAXY ORBITS – OBSERVATIONAL CLUES

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We have studied the effect of ram pressure on the gas distribution of a spiral galaxy entering a galaxy cluster with the help of an N–body code. When the galaxy approaches the cluster center ram pressure pushes its neutral gas content out of the galaxy leading perturbations of the gas distribution and velocity field. We show first results of a direct comparison between the observed and the model gas distribution and velocity field for two cluster galaxies. For this comparison we use Hα, CO, and HI interferometric data.

1 Introduction

Since Gunn and Gott (1972) have introduced the concept of ram pressure stripping, which can affect galaxies moving inside an Intracluster Medium (ICM), this mechanism has been invoked to explain the observed HI deficiency of spiral galaxies in clusters (Chamaraux et al. 1980, Giovanelli & Haynes 1985). Nevertheless, it has not yet been unambiguously shown that ram pressure stripping is responsible for the HI distribution and kinematics of one given spiral galaxy. The possibility of a tidal interaction producing the distortion has never been completely ruled out. The best place to study the gas removal due to ram pressure is the Virgo cluster as it is the closest cluster which can be observed in great detail. Most of the spiral galaxies seem to have entered the cluster only recently (within several Gyr, Tully & Shaya 1984). About half of them became HI deficient (Giovanelli & Haynes 1985). Their HI disk sizes are considerably reduced (van Gorkom & Kotanyi 1985, Warmels 1988, Cayatte et al. 1990, 1994).

2 The Model

We made N–body simulations (Vollmer et al. 2000) of the gas content of a spiral galaxy falling into the Virgo cluster. In order to take into account the clumpiness of the ISM, we use a sticky particles model in which each particle represents a cloud complex with an assigned mass dependent radius. The viscosity of the clumpy ISM is due to inelastic collisions between the particles. The effect of ram pressure is modeled as an additional acceleration applied on the particles located at the front side of the galaxy motion. The outcoming gas distribution and velocity field can be directly compared to observations.

We made several simulations with different shapes of the galaxy orbits within the cluster and different inclination angles between the disk and the orbital plane.

3 Choice of the snapshot

In order to determine parameters of the orbit and the inclination angle between the disk and the orbital plane, we take into consideration

- its HI deficiency,
- its HI morphology.

Within the so found simulation we determine the snapshot (Δt) that we want to compare to observations in the following way:

Vollmer et al. (2000) have shown that perturbations due to ram pressure stripping can only observed *after* the galaxy's closest passage to the cluster center. The distance of the galaxy to the cluster center therefore determines Δt.

We show the application of this method to two examples: NGC 4522 (Virgo cluster) and NGC 4848 (Coma cluster).

4 NGC 4522

Kenney & Koopmann (1999) made optical broadband and Hα images of the Virgo cluster spiral galaxy NGC 4522 which is located at a distance of $\sim$1 Mpc from the Virgo cluster center. It has an HI deficiency of $DEF = 0.51$ (Giovanelli & Haynes 1985). These authors found a considerable part of the Hα emission arising from extraplanar HII regions, whereas the stellar disk, as seen on the R band image, is not disturbed.

We observed NGC 4522 with the Fabry-Perot Interferometer at the Observatoire de Haute Provence (OHP). We were able to recover its velocity field up to a radius of $\sim$60$''$.

The galaxy evolution is shown in Fig. 1.

For comparison with the model, we took a snapshot of the evolution of a spiral galaxy (last snapshot of Fig. 1), which has passed through the cluster core $\sim 6.5 \times 10^8$ yr ago. At that moment of the evolution, the gas, which has not been accelerated to the escape velocity during the stripping process, falls back to the galaxy, i.e. it is in the phase of re-accretion. The re-accreting gas hits the ISM in the disk forming an expanding gas ring.

4.1 Model versus Observations

Fig. 2 shows the observed Hα velocity field together with the model velocity field. The direct comparison shows that we are able to reproduce the main characteristics of the gas distribution *and* the velocity field.

5 NGC 4848

We show CO(1–0) observations of the UV brightest galaxy in the Coma cluster: NGC 4848. It is classified as blue disk galaxy in the sample of Bothun & Dressler (1986). Its characteristics are:

- distance from the cluster center: $\sim$0.7 Mpc

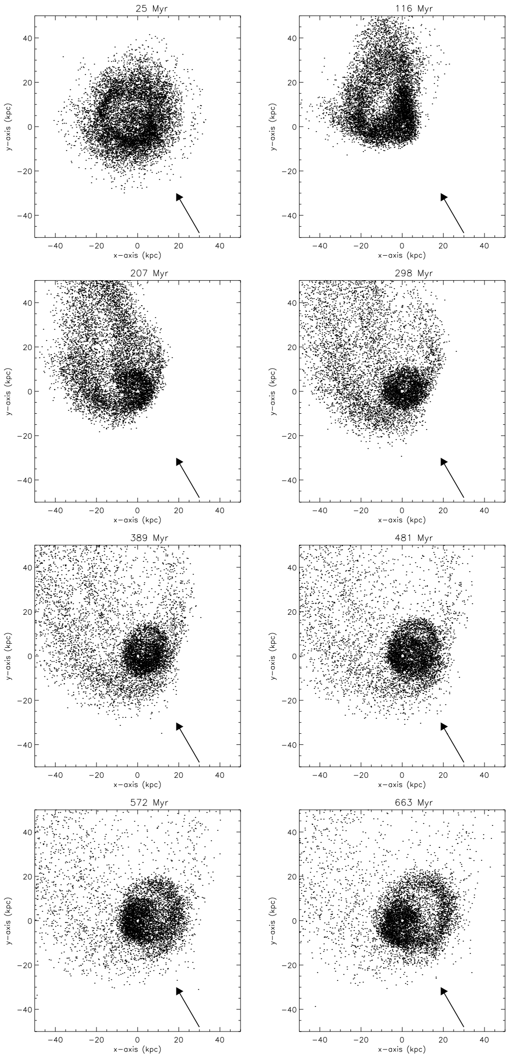

Figure 1: Snapshots of the simulation. The timestep is $\Delta t \sim 9 \times 10^7$ yr. The elapsed time is indicated at the top of each panel. The galaxy is seen face-on and is moving in the south-west direction, i.e. the wind is coming from the south-west. This wind direction is indicated by the arrows. The galaxy rotates counter-clockwise.

- HI deficiency $DEF = 0.61$ (Gavazzi 1989)
- rotation velocity: ~300 km s^{-1}

Main characteristics of the northern region:

- local CO emission maximum (Fig. 3 – Fig. 6)
- local Hα emission maximum (Fig. 4)
- HI emission maximum (Fig. 5)
- detection of 20 cm continuum emission (Fig. 6)

Thus, there is an enhanced star formation activity in the north.

5.1 Comparison with the Model

For comparison with the model, we took a snapshot of the evolution of a spiral galaxy, which has passed through the cluster core $\sim 4 \times 10^8$ yr ago. At that moment of the evolution, the gas,

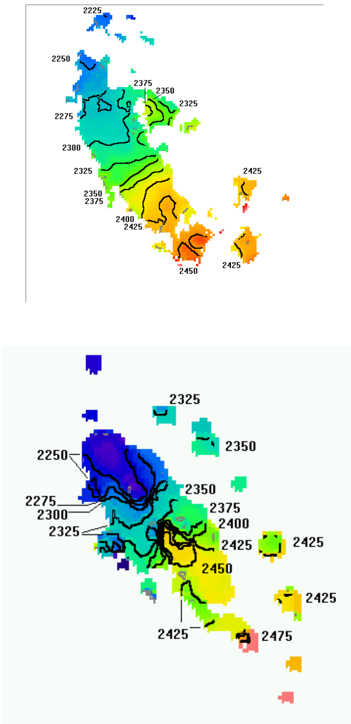

Figure 2: The Hα velocity field. Upper panel: observations. Lower panel: model.

which has not been accelerated to the escape velocity during the stripping process, falls back to the galaxy, i.e. it is in the phase of re-accretion. Fig. 7 shows the velocity field of the model snapshot that reproduces the main characteristics of the observations.

6 Summary and conclusions

- We made simulations of the gas dynamics of a spiral galaxy that enters a galaxy cluster.
- The model includes the effects of ram pressure stripping.
- Several simulations with different parameter for different galaxy orbits were made.
- The model gas distribution and velocity field can be directly compared with observations.
- We applied the model to two galaxies: NGC 4522 (Virgo) and NGC 4848 (Coma).
- We are able to reproduce both the gas distributions and the velocity fields within a coherent picture taking into account the galaxy orbit.
- We conclude that both galaxies are coming out of the cluster center.
- It seems that at these past stripping stages star formation activity triggered by ram pressure stripping is still observable.

Acknowledgments

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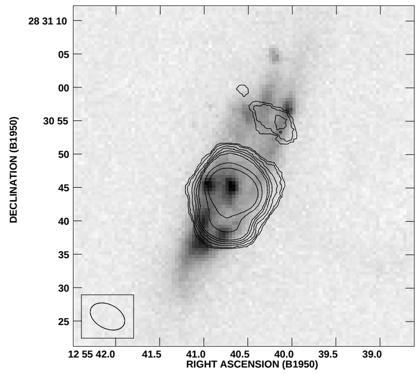

Figure 3: Contours: CO(1-0) line emission. Greyscale: B band image (Gavazzi et al. 1990)

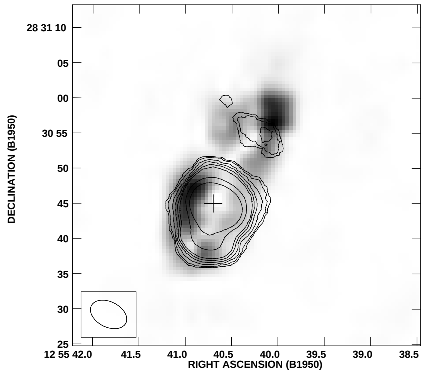

Figure 4: Contours: CO(1-0) line emission. Greyscale: Hα (Amram et al. 1992)

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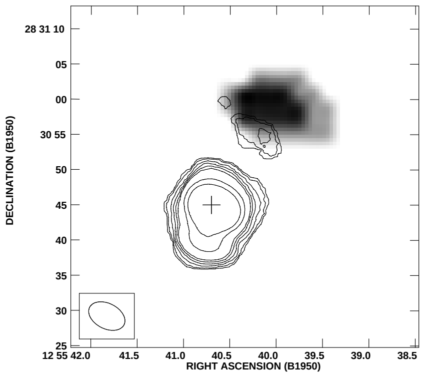

Figure 5: Contours: CO(1-0) line emission. Greyscale: HI (Bravo-Alfaro et al. 1990)

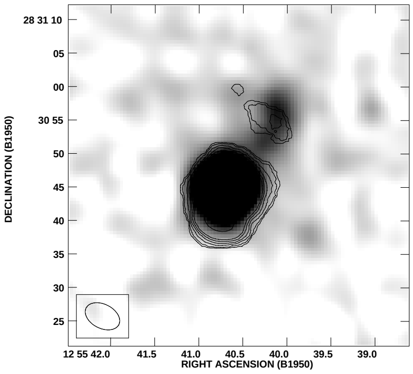

Figure 6: Contours: CO(1-0) line emission. Greyscale: 20 cm continuum

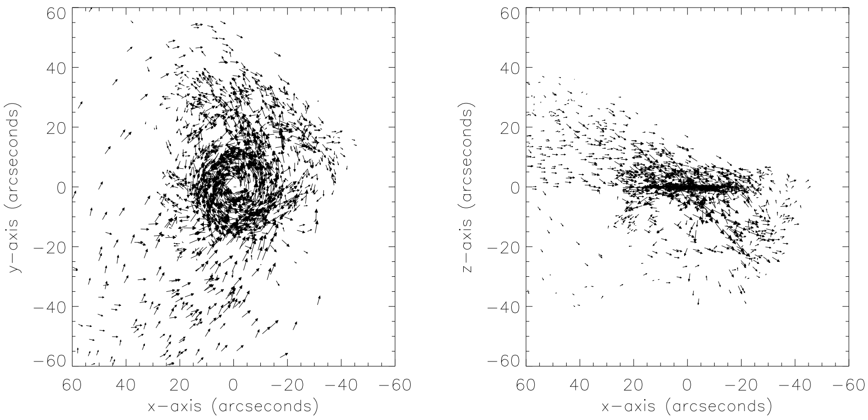

Figure 7: Velocity field of the model snapshot seen face-on (right) and edge-on (left).