Does a Galaxy Fly?

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Abstract

Disk galaxies in a cluster of galaxies move in hot gas filling the cluster. Generally, they move at transonic or supersonic velocities. If ram-pressure stripping is insufficient to destroy the gas disk, the galaxies should be affected by the wind of the surrounding hot gas, similar to an airfoil. In this study, it is considered whether the aerodynamic interaction can be strong enough to force a disk galaxy to deviate from the orbit that it would have been in. It is shown that while the lift force is not effective, the drag force could affect face-on disk galaxies in poor clusters on a long time scale.

1. Introduction

Clusters of galaxies are filled with hot gas (intracluster medium or ICM). Most galaxies move at transonic or supersonic velocities in the ICM. So far, the interaction between disk galaxies and the surrounding ICM has been considered mostly in terms of "ram-pressure stripping" (Fig 1).

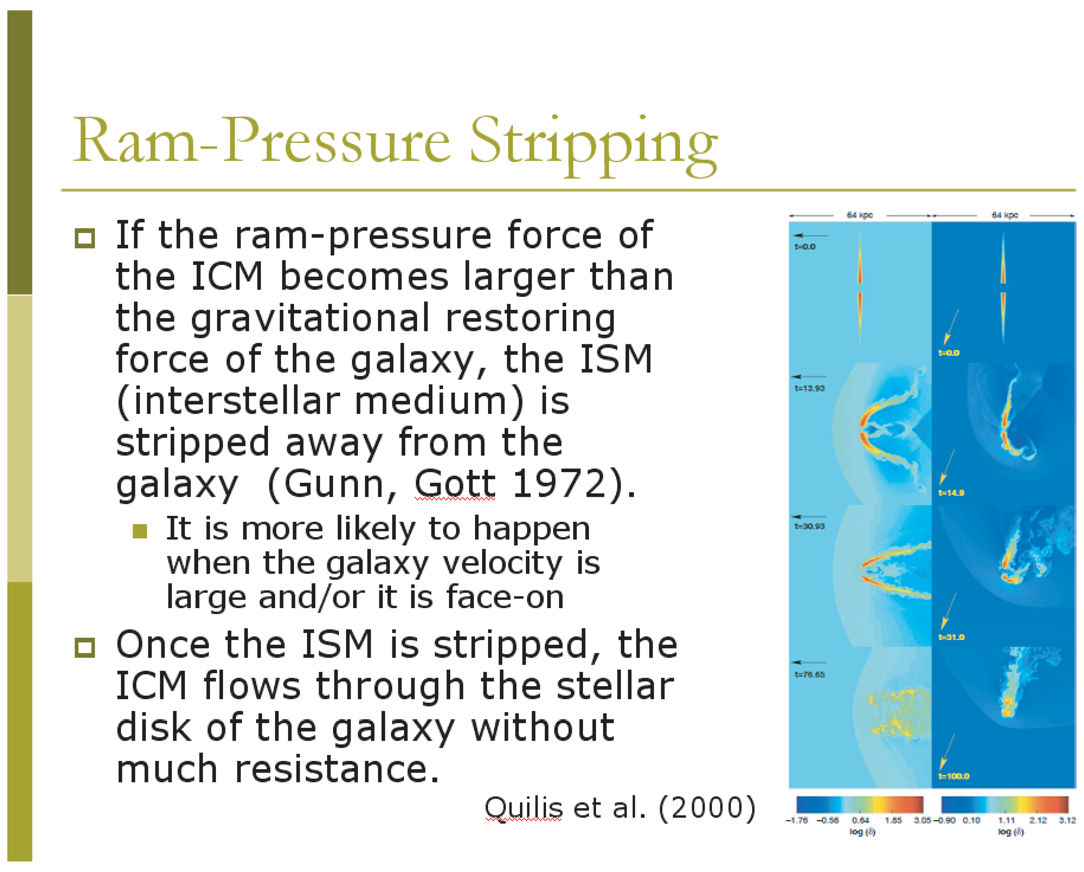


Figure 1
What is ram-pressure stripping?

On the other hand, if ram-pressure stripping is insufficient to destroy the gas disk, the galaxies should be affected by the wind of the surrounding hot gas, similar to an airfoil.

2. Estimation of Aerodynamic Forces

From now on, only a massive disk galaxy ($M \sim 10^{11} M_{\odot}$) is considered. Fig.2 is the longitudinal section of the galaxy.

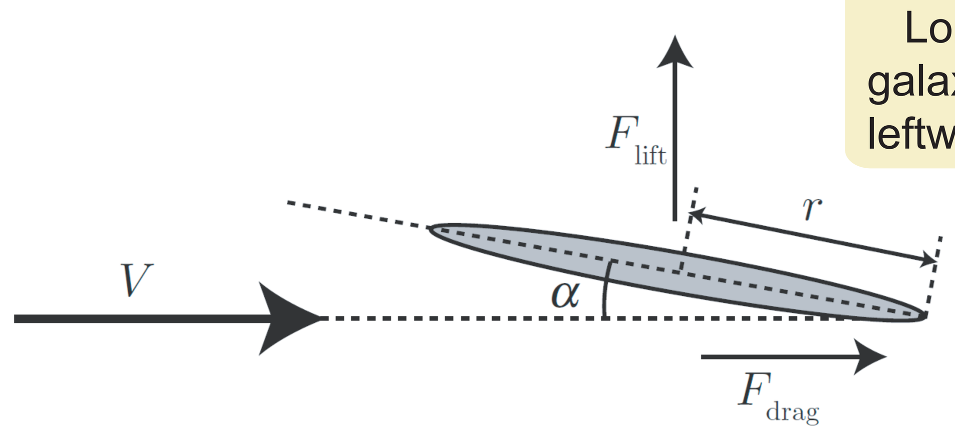
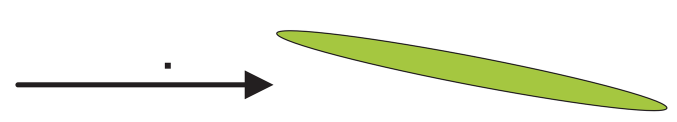


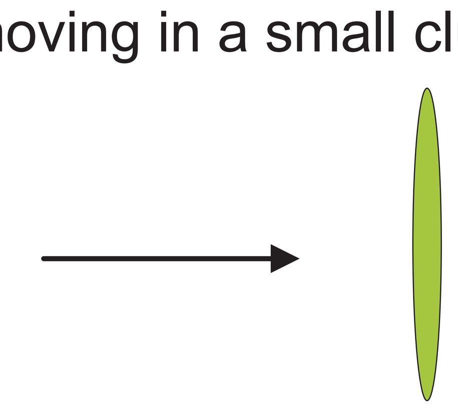
Figure 2
Longitudinal section of the galaxy. The galaxy is moving leftward.

I considered two possible cases where ram-pressure stripping is ineffective (not too strong ram-pressure) and aerodynamical forces could not be ignored.

Case 1 (mainly lift force)
A galaxy moving in a massive cluster with a non-zero but small attack angle.



Case 2 (mainly drag force)
A face-on galaxy moving in a small cluster.



3. Results

Case 1 (mainly lift force)

The lift force is represented by

$$F_{\rm lift} \approx 2\rho_{\rm ICM} V^2 S\alpha/\sqrt{\mathcal{M}^2 - 1}\,,$$

where $\rho_{\rm ICM}$ is the ICM density, V is the galaxy velocity, S is the disk area, α is the attack angle, and $\mathcal{M}$ is the Mach number (Fig.1; e.g. Landau and Lifshitz 1987, Fluid Mechanics).

For typical values, it is

$$F_{\rm lift} \approx 3.1\times 10^{34}\,{\rm dyn}\left(\frac{\rho_{\rm ICM}}{2.3\times 10^{-27}\,{\rm g\,cm^{-2}}}\right)\left(\frac{V}{3000\,{\rm km\,s^{-1}}}\right)^2 \times\left(\frac{r}{5\,{\rm kpc}}\right)^2\left(\frac{\alpha}{10^\circ}\right)\left[4\left(\frac{\mathcal{M}}{2}\right)^2-1\right]^{-1/2}.$$

The effective disk radius r has been reduced from the original value ($r \sim 25$ kpc) because of ram-pressure stripping. The galaxy gains extra velocity perpendicular to its original direction of travel, $\Delta V \sim (F_{\rm lift}/M)\, t_{\rm cross} \sim 25$ km s^{-1}, where M ($\sim 10^{11}$ $M_{\odot}$) is the galaxy mass, and $t_{\rm cross} \sim 5{\times}10^8$ yr is the time for the galaxy to cross the central region of the cluster. Since this is much smaller than the velocity dispersions of galaxies in rich clusters ($\sim$ 1000 km s^{-1}), the lift force can be ignored.

Case 2 (mainly drag force)

The drag force is represented by

$$F_{\rm drag} = \frac{1}{2} C_D \rho_{\rm ICM} V^2 \pi r^2\,,$$

where C_D is the drag coefficient. For a disk of $\alpha = 90°$, the coefficient is $C_D = 1.17$, while for a sphere with the same radius, the coefficient is $C_D = 0.2$–0.47 depending on the Reynolds number (White 1986, Fluid Mechanics). The values of C_D are for incompressible fluids ($\mathcal{M} \lesssim 0.3$); they rise by a few tens percent at $\mathcal{M} \sim 0.6$–0.8 (Henderson 1976, AIAA J., 14, 707).

For typical values, it is

$$F_{\rm drag} \approx 5.4\times 10^{33}\,{\rm dyn}\left(\frac{C_D}{1.2}\right)\left(\frac{\rho_{\rm ICM}}{9\times 10^{-28}\,{\rm g\,cm^{-3}}}\right) \times\left(\frac{V}{580\,{\rm km\,s^{-1}}}\right)^2\left(\frac{r}{10\,{\rm kpc}}\right)^2.$$

Considering weak ram-pressure pressure stripping, the disk radius is assumed to be r = 10 kpc. After t = 10 Gyr, which is the typical age of poor clusters, the galaxy velocity decreases by $\Delta V \sim (F_{\rm drag}/M) \times t \sim 90$ km s^{-1} and the deviation from the orbit that the galaxy would have been in if it were not for the ICM is $D \sim$ (1/2)$(F_{\rm drag}/M)\, t^2 \sim 0.4$ Mpc, which is comparable to the size of poor clusters (~ 1 Mpc). Thus, the drag force could not be ignored.