Magnus effect on Disk Galaxies

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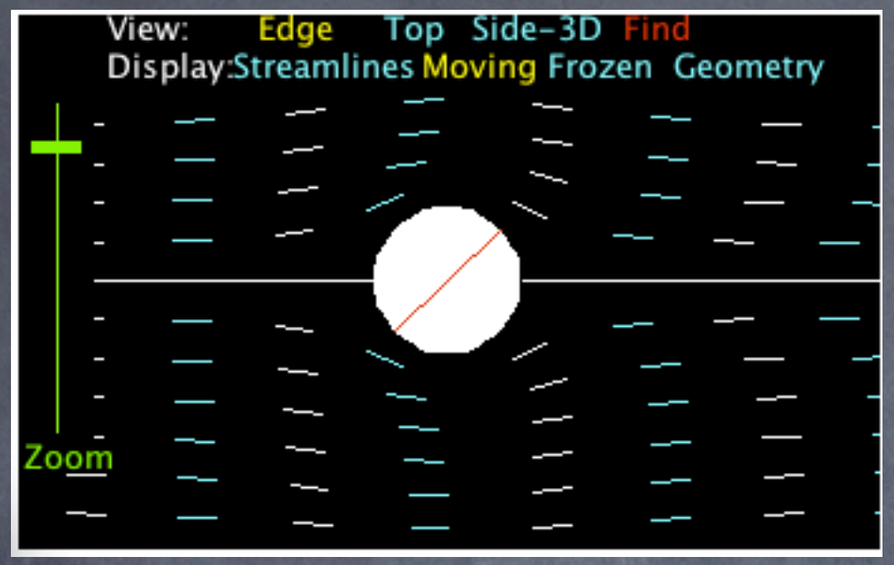
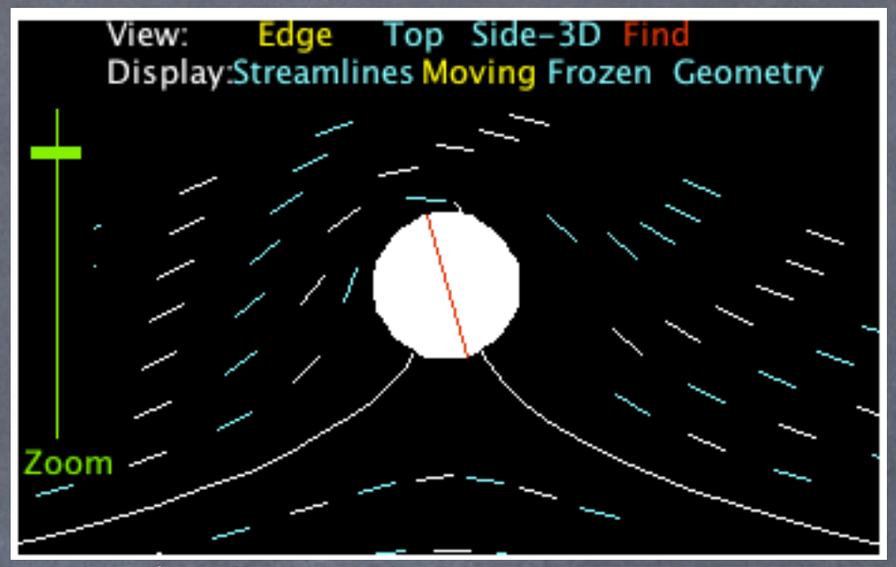
Magnus Effect



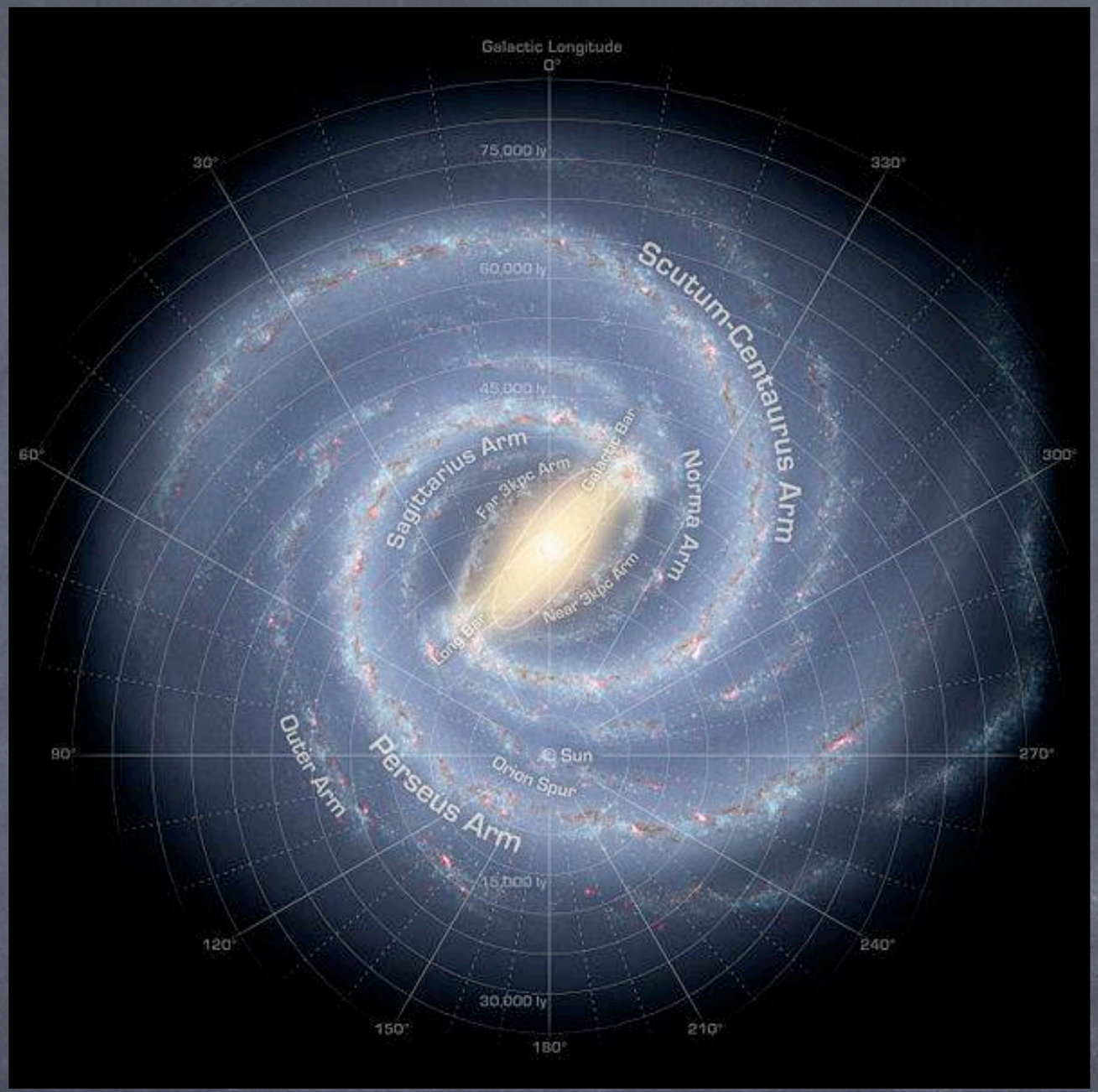
No rotation



clockwise rotation

A Spinning moving object creates pressure difference at the two edges, which generates a "lift force".

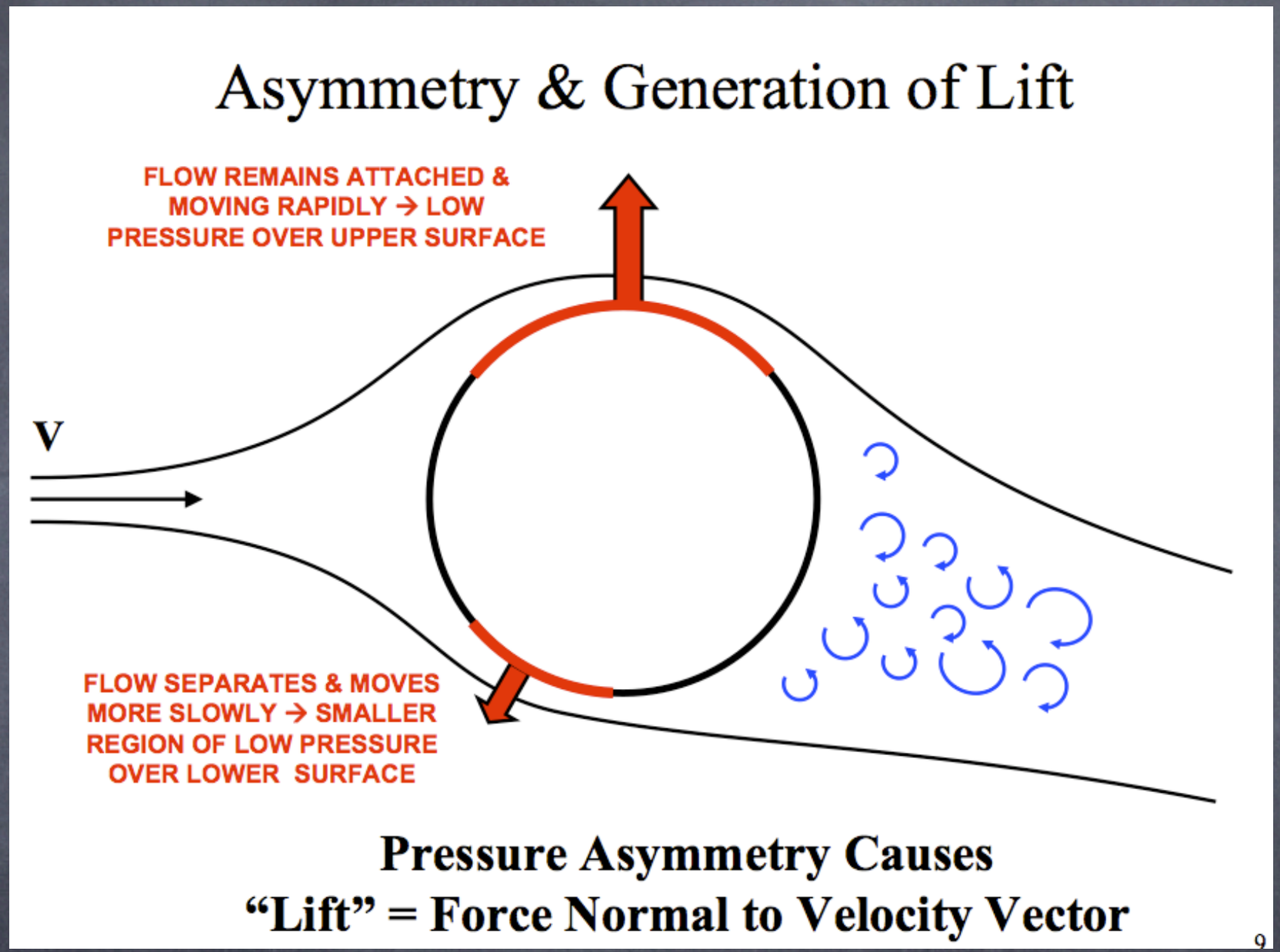
Pressure difference ~ $\rho_{medium} \cdot (V_{flow} \times \omega)$



Disk Galaxies are spinning and moving in the IGM fluid - will they have Magnus force ?

ISM can be considered as a rigid body in the IGM fluid as the density ratio of the two is at least 1000 and mean free path of IGM particles (< 100 pc) are much less than size of galaxy.

Theory of Magnus force :



Asymmetric Boundary Layer separation due to clockwise rotation of sphere

!! This force requires that the thickness of the boundary layer should be significantly less than the size of the object.

The condition on thickness of the boundary layer requires that the flow must be turbulent for the Magnus effect to operate.

BL thickness ~ $L/\sqrt{Re}$

Re is the Reynolds number and L is the size of the object.

Therefore, Reynolds number must be large.

A Brief theory of IGM flow :

The viscosity of the medium is given by Spitzer (1962) :

$$\mu = 2.2 \times 10^{-15}\ T^{2.5} (ln\Lambda)^{-1} g\ cm^{-1} s^{-1}$$

IGM/ICM Viscosity is believed to be suppressed.

Considering suppression (1/10th; from cluster filaments studies) of viscosity due to magnetic field and taking (ln Λ) as 30 :

$$\mu_m = 7.3 \times 10^{-3}\ T_6^{2.5} g\ cm^{-1} s^{-1}$$

The Reynolds number $(R_e = \rho V L/\mu)$ of the flow is then :

$$R_e \sim 7 \times 10^3 \; V_{100} \; L_{10} \; T_6^{-2.5} \; n_{-4}$$

where :

V_{100} is the flow velocity in units of 100 km/s.

L_{10} is the size of the galaxy in units of 10 kpc.

T_6 is IGM temperature in units of 10^6 K.

n_{-4} is the IGM density in units of 10^{-4} cm^{-3}.

Using σ - T relation in x-ray groups/clusters (Mulchaey 2000), the Re for a 10 kpc size galaxy becomes :

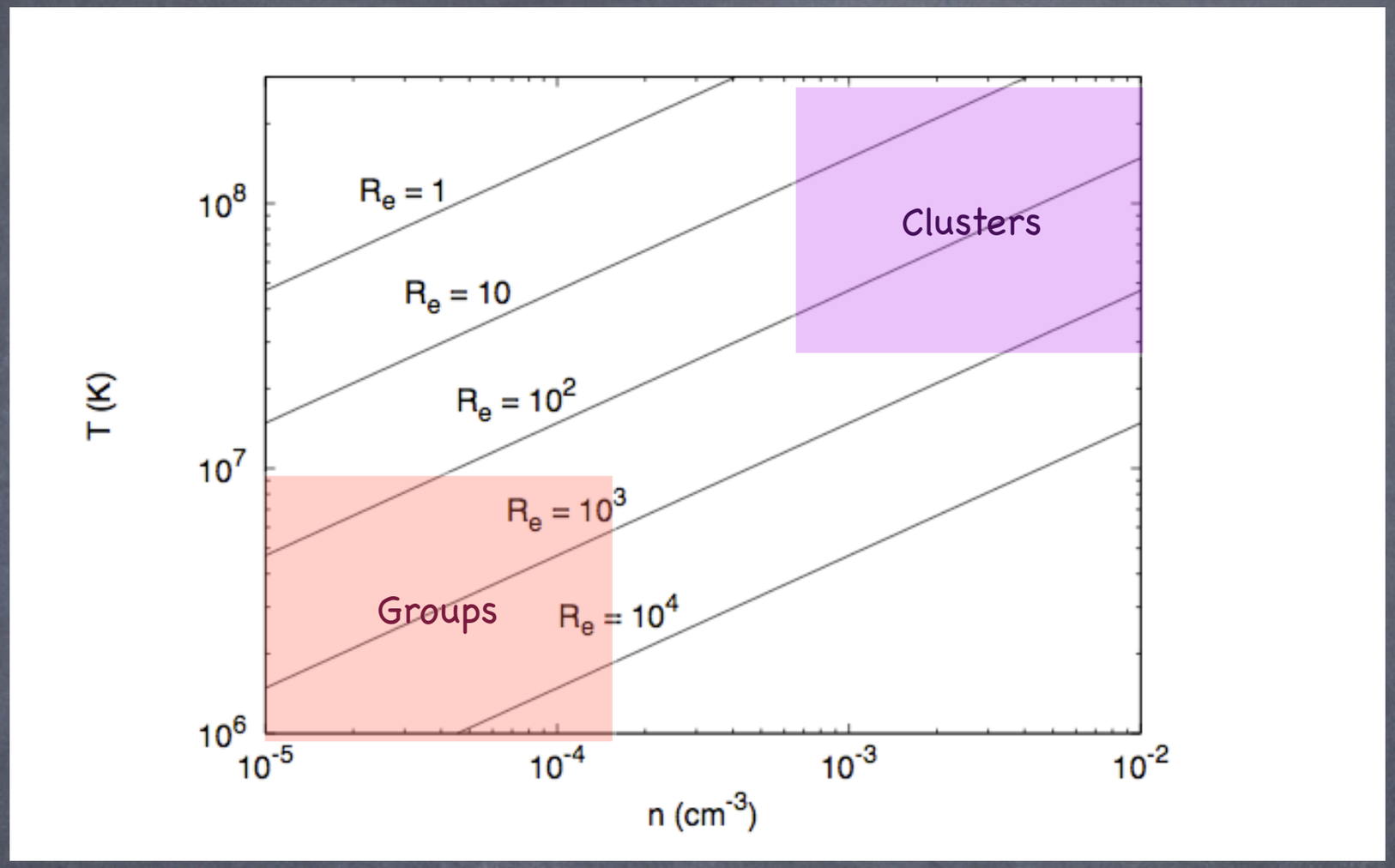
$$R_e \sim 7 \times 10^3 \; V_{100} \; L_{10} \; T_6^{-2.5} \; n_{-4}$$

$$R_e \sim 2.2 \times 10^4 \; T_6^{-2} \; n_{-4}$$

i.e., after taking typical velocity of a galaxy (V) as the velocity dispersion (σ) in the medium.

The Reynolds number :

$$R_e \sim 2.2 \times 10^4 \; T_6^{-2} \; n_{-4}$$



In Clusters of galaxies (T ~ 10^7 - 10^8 K and n ~ 10^{-2} - 10^{-3} cm^{-3}), the flow remains largely viscous.

In groups of galaxies (T ~ 10^6 - 10^7 K and n ~ 10^{-4} - 10^{-5} cm^{-3}), the flow becomes turbulent.

Magnus effect should therefore be most effective in groups.

The Magnus Pressure :

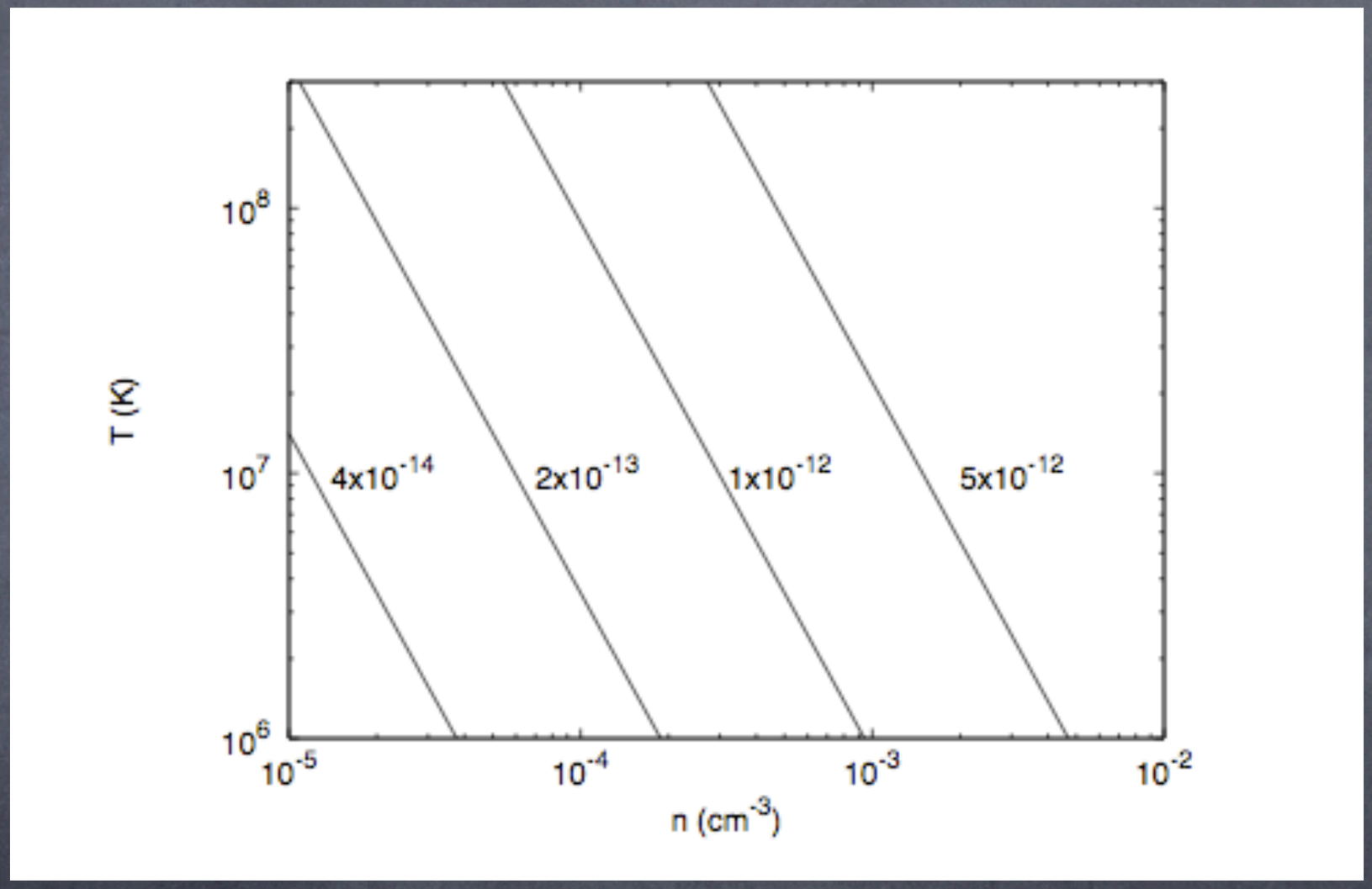
$$\Delta P \sim 1.7 \times 10^{-18}\ n_{-4}\ V\ V_r \sim 5.3 \times 10^{-16}\ V_r\ T_6^{0.5}\ n_{-4}\ dyn\ cm^{-2}$$

where :
V_r is the rotation velocity of the galaxy.

The Pressure is
1). Maximum when galaxy moves edge-on.
2). zero when galaxy moves face-on.

The direction of the pressure is always outwardly in the plane of the disk.

Magnus Pressure (dyn/cm^2) for rotation velocity of 200 km/s



For Milky-Way :

V_{rot} = 300 km/s
V_{flow} = 100 km/s
n = 10^{-4} cm^{-3}
T = 10^{6} K
R = 20 kpc
Σ_{gas} = 10^{19} cm^{-2}

$P_{magnus} \sim 6 \times 10^{-14}$ dyn/cm^2
$P_{thermal} \sim 3 \times 10^{-13}$ dyn/cm^2
$P_{gravt.} \sim 3 \times 10^{-13}$ dyn/cm^2

Where $P_{gravt.}$ is given by $m_H \Sigma_{gas} V_r^2 / R$
Σ_{gas} being gas column density at radius R

The Magnus pressure is within 20% of the thermal/grav. pressure

Possible effects of Magnus Pressure

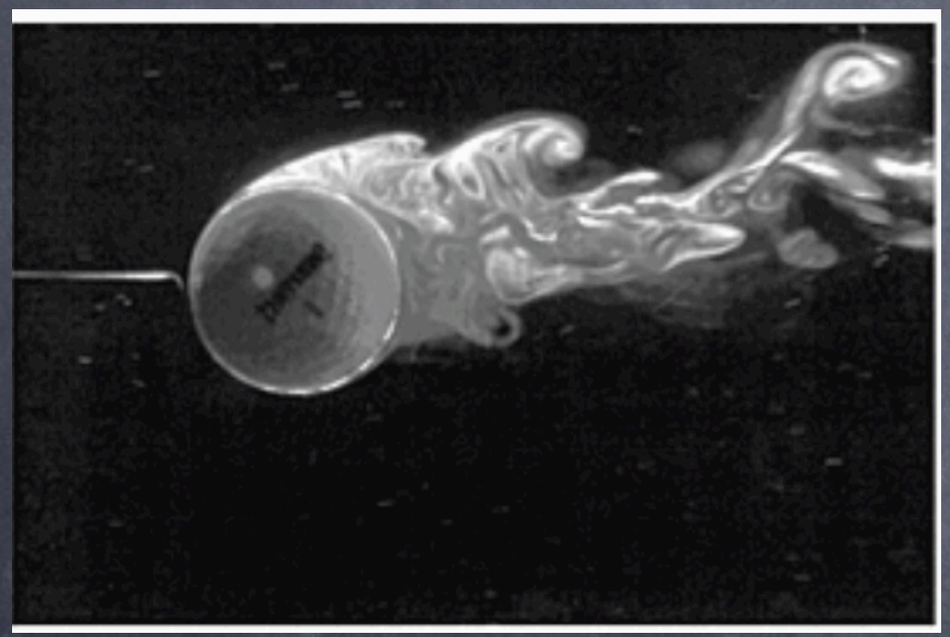
Stellar disks expected to be un-affected

Gas disk will experience extra lateral outward pressure

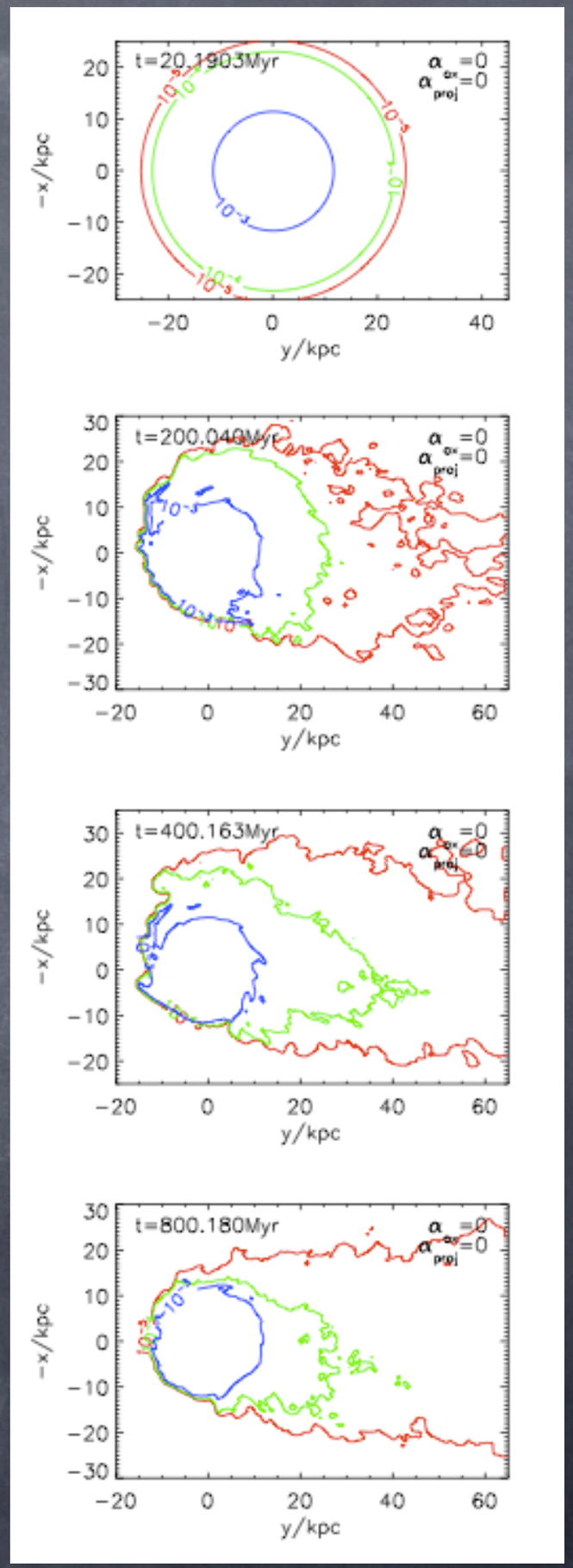
Gas morphological asymmetries are expected in disk galaxies.

Unfortunately, most of the IGM-ISM interaction simulation (e.g., ram-pressure) do not include galaxy rotation explicitly.

In a (ram-pressure) simulation by Roediger (2006), rotation of galaxy disk possibly showed asymmetric boundary layer separation.



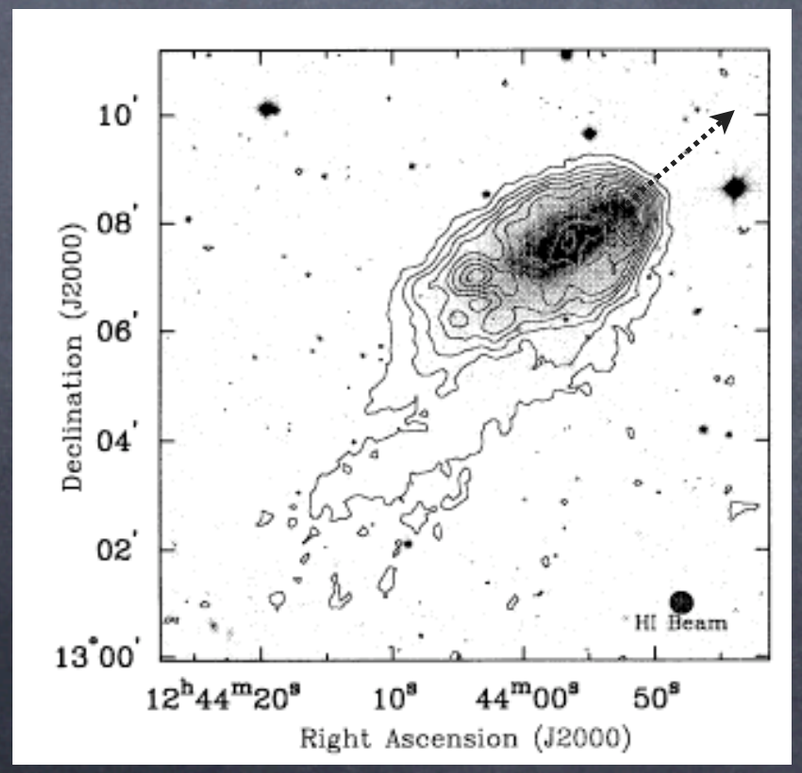
Aerodynamic experiments on a ball (anti-clockwise rotation).



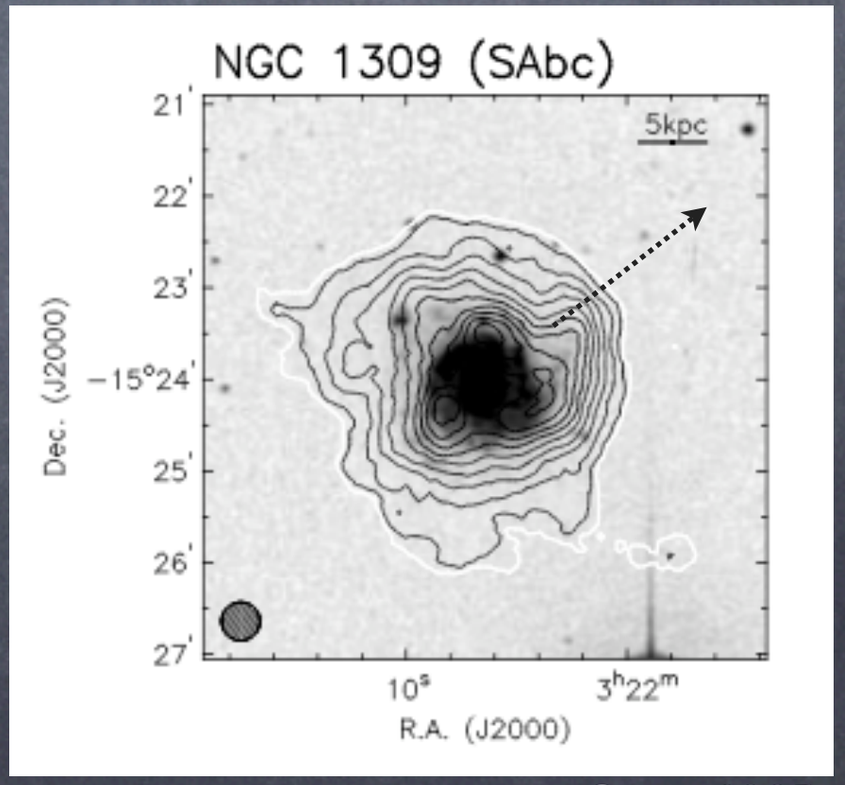
Observationally,

Cases of mild lopsidedness, and one-sided gaseous tails are quite common in galaxies in group environments.

Such asymmetries can be due to rotation of the disk and ISM-IGM interaction.



Phookun 1995



Omar 2005

Arrow denotes inferred direction of motion. Clockwise rotation in both the cases

Observationally, there are enough cases where gaseous asymmetries are not well understood.

Some of them can be understood due to effect of disk rotation during ISM-IGM interactions.

It strengthens the case of asymmetric boundary layer separation and hence of Magnus pressure.

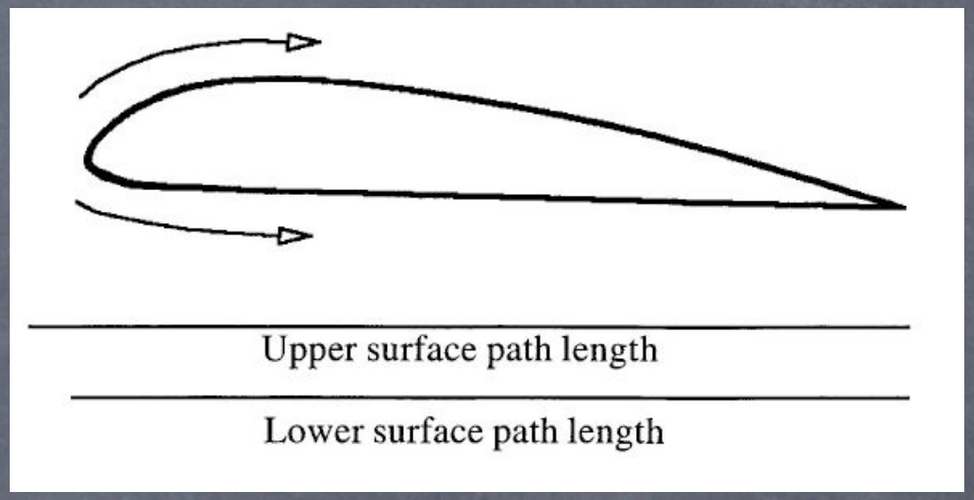
Conclusions

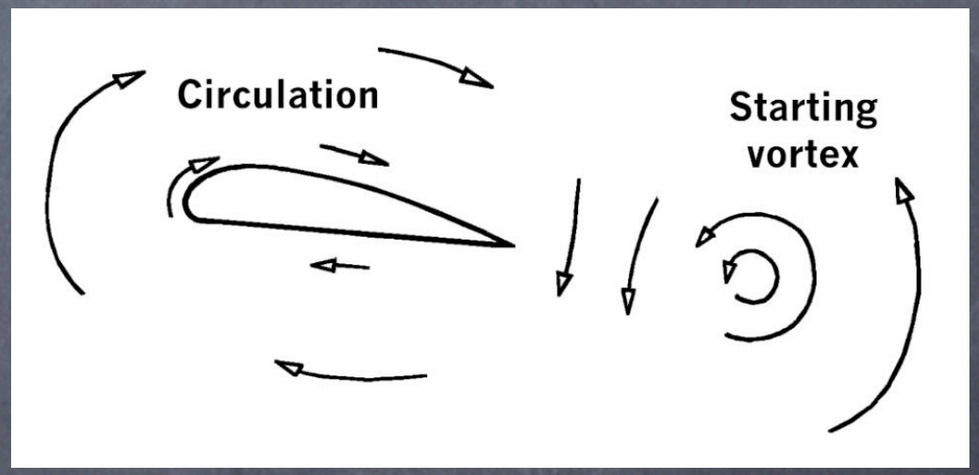
Magnus pressure can be of the order of thermal and gravitational pressure in disk galaxies in group environments.

The hydrodynamical N-body simulations for IGM-ISM interactions needs to be performed afresh including disk rotation in order to understand the role of Magnus effect on galaxy evolution.

It is also important to see the effects at high redshifts, where IGM density scales up by $(1+z)^3$.

Thanks





Flight of an Aeroplane

Circulation produces lift through "Magnus" Effect