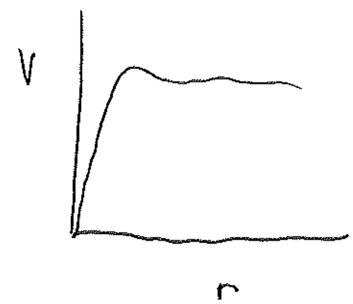
L17 - Galaxy Interactions

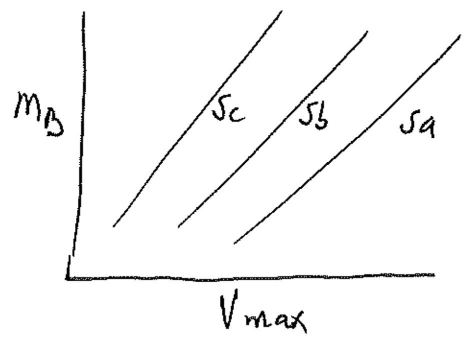
First: Tully-Fisher Relation



Spiral galaxies differ greatly in V_{max}, the maximum orbital speed in the rotation curve.

> Generally, earlier-type galaxies have greater V_{max} (at fixed M_B).

> Also, more luminous galaxies have greater V_{max} (within a given Hubble type).



How is V_{max} obtained? Usually, from 21-cm profiles, which are double-peaked:

Since much gas rotates at V_{max}, there is usually a peak in intensity. Actually, there are two peaks: one redshifted & one blueshifted.

Origin of the relation

For a truly flat rotation curve, $\frac{V_0^2}{r} = \frac{GM_r}{r}$ (approximately)

Applying this to the whole Galaxy, & letting $V_0 = V_{max} \rightarrow$ $M = \frac{V_{max}^2 R}{G}$

(If) $\langle M/L \rangle$ is the same for all spirals, $L \propto \frac{V_{max}^2 R}{G}$

(If) all spirals have the same surface brightness, $L \propto R^2 \rightarrow R \propto L^{1/2}$

$\rightarrow$ $\boxed{L \propto V_{max}^4}$ where the coefficient depends on Hubble type

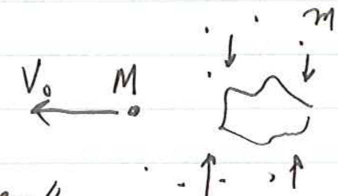
This is just like the Faber-Jackson relation, & is useful for getting cosmological distances.

Evidence of Galaxy Interaction

- The spacing between galaxies in a cluster is only 100 × the galaxy size.
- The richest clusters (like Coma) have more massive ellipticals at the center than sparser clusters.
- Many spirals have <u>warps</u> — perhaps due to close passage of satellites.

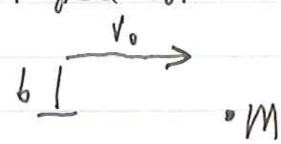
<u>Dynamical Friction</u>

When galaxies "collide," the stars pass by each other, so the effect is gravitational. For example, a small satellite can spiral inside the halo of a larger galaxy. The satellite experiences "dynamical friction."



Lower-mass objects surrounding heavy mass M form an over-dense <u>wake</u> that tugs back on M.

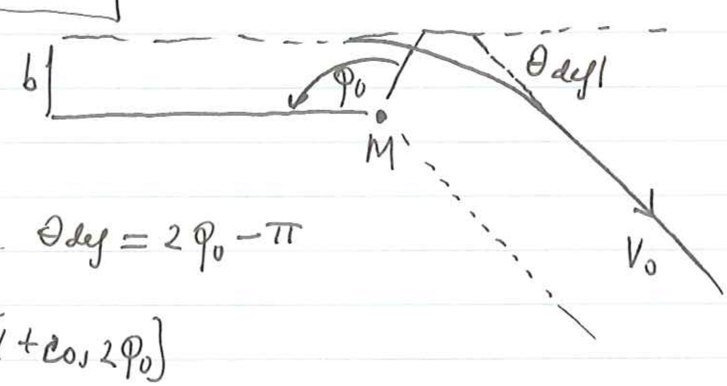
In more detail, M sees each m-star passing by with speed V_0. The m-star imparts momentum $\Delta p_{\parallel}$ parallel to $\vec{V}_0$.



To calculate this, we first find $\Delta \vec{V}_{m}$, the change in velocity of m. Since the c of m is fixed

$$m \Delta \vec{V}_m + M \Delta \vec{V}_M = 0 \longrightarrow m \Delta V_{m\parallel} + M \Delta V_{M\parallel} = 0$$

so that
$$\boxed{\Delta V_{M\parallel} = \frac{-m}{M} \Delta V_{m\parallel}}$$



Now to calculate $\Delta V_{m\parallel}$:
For the hyperbolic orbit,

[to prove in HW5]
$$\tan \varphi_0 = \frac{b V_0^2}{GM} \qquad \text{and} \quad \theta_{defl} = 2\varphi_0 - \pi$$

$$|\Delta V_{m\parallel}| = V_0 - V_0 \cos \theta_{defl} = V_0 [1 + \cos 2\varphi_0]$$

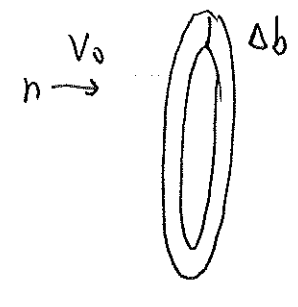
$$\cos 2\varphi_0 = 2\cos^2\varphi_0 - 1 \longrightarrow \frac{1+\cos 2\varphi_0}{2} = \cos^2 \varphi_0, \text{ and } \frac{1-\cos 2\varphi_0}{2} = \sin^2\varphi_0$$

$$\tan^2 \varphi_0 = \frac{1-\cos 2\varphi_0}{1+\cos 2\varphi_0} \longrightarrow \cos 2\varphi_0 = \frac{1-\tan^2\varphi_0}{1+\tan^2\varphi_0}$$

Thus, $1+\cos 2\varphi_0 = \frac{2}{1+\tan^2\varphi_0} \rightarrow |\Delta V_{M\parallel}| = \frac{2V_0}{1+\tan^2\varphi_0}$

$$= \frac{2V_0}{1+\frac{b^2V_0^4}{G^2m^2}}$$

$$\boxed{\Delta V_{M\parallel} = \frac{2mV_0}{M\left(1+\frac{b^2V_0^4}{G^2m^2}\right)}}$$



Let n be the number of m-stars per volume. Then nV_0 is their number flux. The number per time penetrating the annulus shown is

$$2\pi b\, \Delta b\, n V_0$$

Multiplying by $\Delta V_{M\parallel}$, the $\vec{V}$-change caused by a single m-particle, we find

$$\frac{dV_\parallel}{dt} = 2\pi n V_0 \int_0^{b_{max}} b\,db\, \frac{2mV_0}{M\left(1+\frac{b^2V_0^4}{G^2m^2}\right)}$$

$$= 2\pi n V_0 \left(\frac{mV_0}{M}\right)\left(\frac{G^2m^2}{V_0^4}\right)\int d\left(\frac{b^2V_0^4}{G^2m^2}\right)\frac{1}{1+\frac{b^2V_0^4}{G^2m^2}}$$

$$= 2\pi n V_0 \frac{mV_0}{M}\frac{G^2M^2}{V_0^4}\ln(1+\Lambda^2), \text{ where } \boxed{\Lambda \equiv \frac{b_{max}V_0^2}{GM}}$$

$$= \frac{2\pi m n M G^2 \ln(1+\Lambda^2)}{V_0^2} \simeq \frac{4\pi n M\cdot G^2 M \ln\Lambda}{V_0^2} \quad \text{for } \Lambda >> 1$$

$$\boxed{F = M\frac{dV_\parallel}{dt} = \frac{4\pi\rho G^2M^2}{V_0^2}\ln\Lambda}$$

$\boxed{\text{where } \rho \equiv mn}$

$= \text{"}C\text{"} \frac{G^2M^2\rho}{V^2}$ [eqn (26.1) in Carroll & Ostlie]

Application: Globular Cluster in Dark Halo etc

> More massive globular clusters in dark halo spiral inward over the lifetime of the galaxy. Textbook says upper mass limit is $5\times10^6 M_\odot$ for g clusters in M31.

> Similarly, central galaxies in clusters may consume satellite galaxies.

Incidentally, more than 1/2 of cD galaxies have multiple nuclei!

Rapid Encounters: Negative Heat Capacity

Suppose one galaxy penetrates one quickly. The stellar positions, and hence the potential energy W of the host does not have time to change. But the kinetic energy is increased by ΔK.

Initially, $2K_i + W_i = 0$, $E_i = U_i + K_i = -K_i$

Right after penetration, K (and therefore E) increases by ΔK.

Since W has not changed, the galaxy is "out of virial equilibrium."

As it virializes, E is conserved. After,

$$K_f = -E_f = -(E_i + \Delta K) = -E_i - \Delta K$$

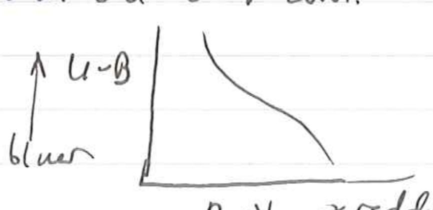
→ The kinetic energy decreases as a result of energy addition! [Heat Capacity, $C < 0$]

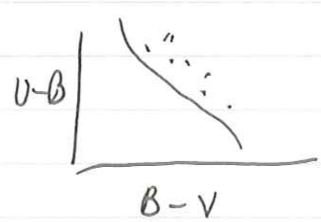
The galaxy can decrease K by throwing off matter — ring galaxies. Some S0 galaxies have polar rings of dust & gas & stars.

Starburst Galaxies

- Dwarf irregular galaxies — gas-rich, but metal-poor. Many contain giant HII regions, 100's of O stars. A burst of star formation, occurring $\sim 3 \times 10^6$ yr in the past [The entire ISM could have been blown out, after which the gas had to be regenerated. Explains low metallicity.]

- Larger galaxies — Starbursts first seen by anomalous colors. Along the Hubble sequence, there is a well-defined relation between, eg, U−B color and B−V color.





[show my Fig. 19.13]

Now look at "peculiar" galaxies w/ "tails & bridges." At a given B−V, they are uncommonly blue. Indicates recent star formation, with past 10^8 yr. Interestingly, the galaxies are interacting — most SF occurs near the nucleus

The SF rate/mass is not extremely high. It's just that the mass of the <u>nucleus</u> is very large, eg $10^{10} M_\odot$.

So in large galaxies, starbursts created by mergers; not in dwarf irregulars.

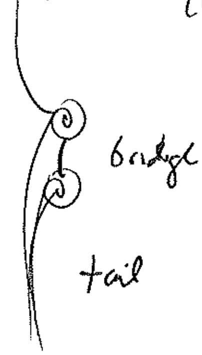
<u>Bridges and Tails</u>

Many "peculiar" galaxies shrouded in dust & most of the L is in the IR.

$L_{IR} > 10^{11} L_\odot$ luminous IR galaxies (LIRG)

$L_{IR} > 10^{12} L_\odot$ ultraluminous " " (ULIRG) [$SFR = 10^3 M_\odot yr^{-1}$]

In the optical, many show <u>double nuclei</u>
Nuclei can be connected by a "bridge".
Can also sprout "tails."



The Antennae
$D = 19$ Mpc

Both features are created by tidal gravity ripping away stars during the encounter.

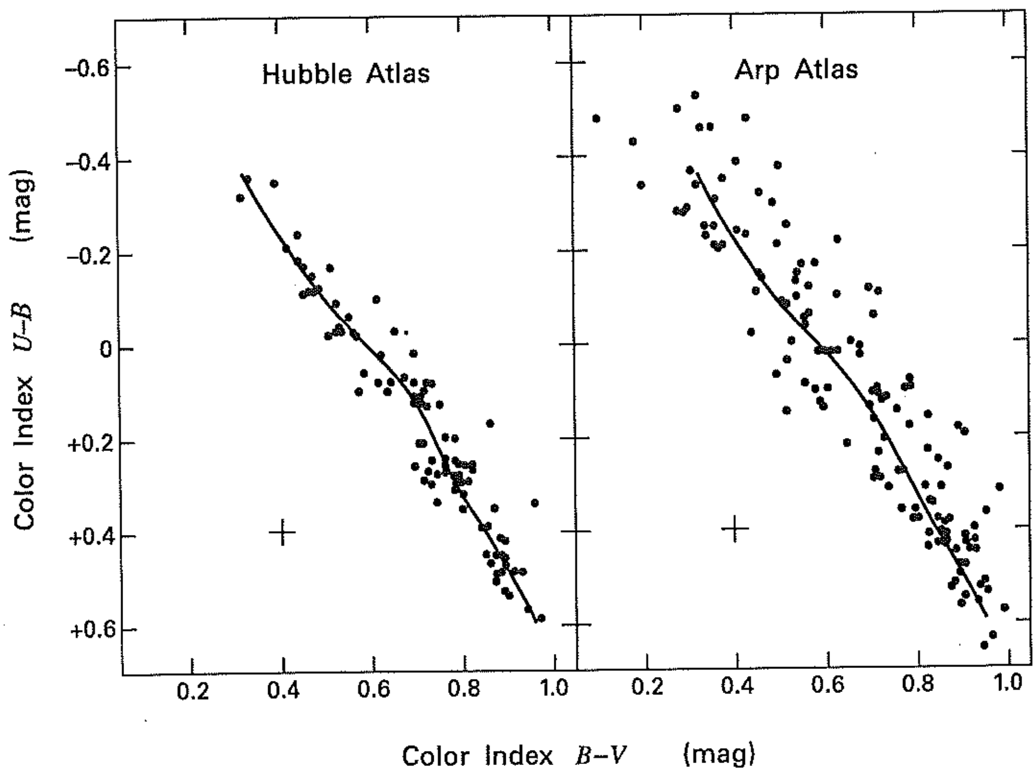
> Stars close to the projectile galaxy are drawn toward it, creating a <u>bridge</u>.
> Stars on the opposite side are pushed away, creating a <u>tail</u>.

Both effects are strongest when the projectile galaxy approaches <u>in the same direction</u> as the target galaxy is rotating (prograde encounter)

There is also <u>resonance</u> – The response is strongest for those stars in the target galaxy whose orbital speed matched most closely to that of the projectile galaxy.

– This explains the extreme narrowness of the streams.

Gas – While the stars of two colliding galaxies interpenetrate, the gas <u>does not</u>. Shocks are created. The gas loses energy and spirals toward the nucleus, creating the starburst.



Hubble Atlas
Arp Atlas
Color Index U–B (mag)
Color Index B–V (mag)
-0.6
-0.4
-0.2
0
+0.2
+0.4
+0.6
0.2
0.4
0.6
0.8
1.0