Peculiar Galaxies: Starbursts and Interactions

M82 – *NASA/ESA*

The Antennae – *Rolf Olsen*

The “Star-forming Main Sequence” of Galaxies

Star forming galaxies generally follow a relationship between stellar mass and star formation rate: more massive galaxies form stars at a higher rate.

Growth time: time it would take to build its current stellar mass at its current star formation rate:

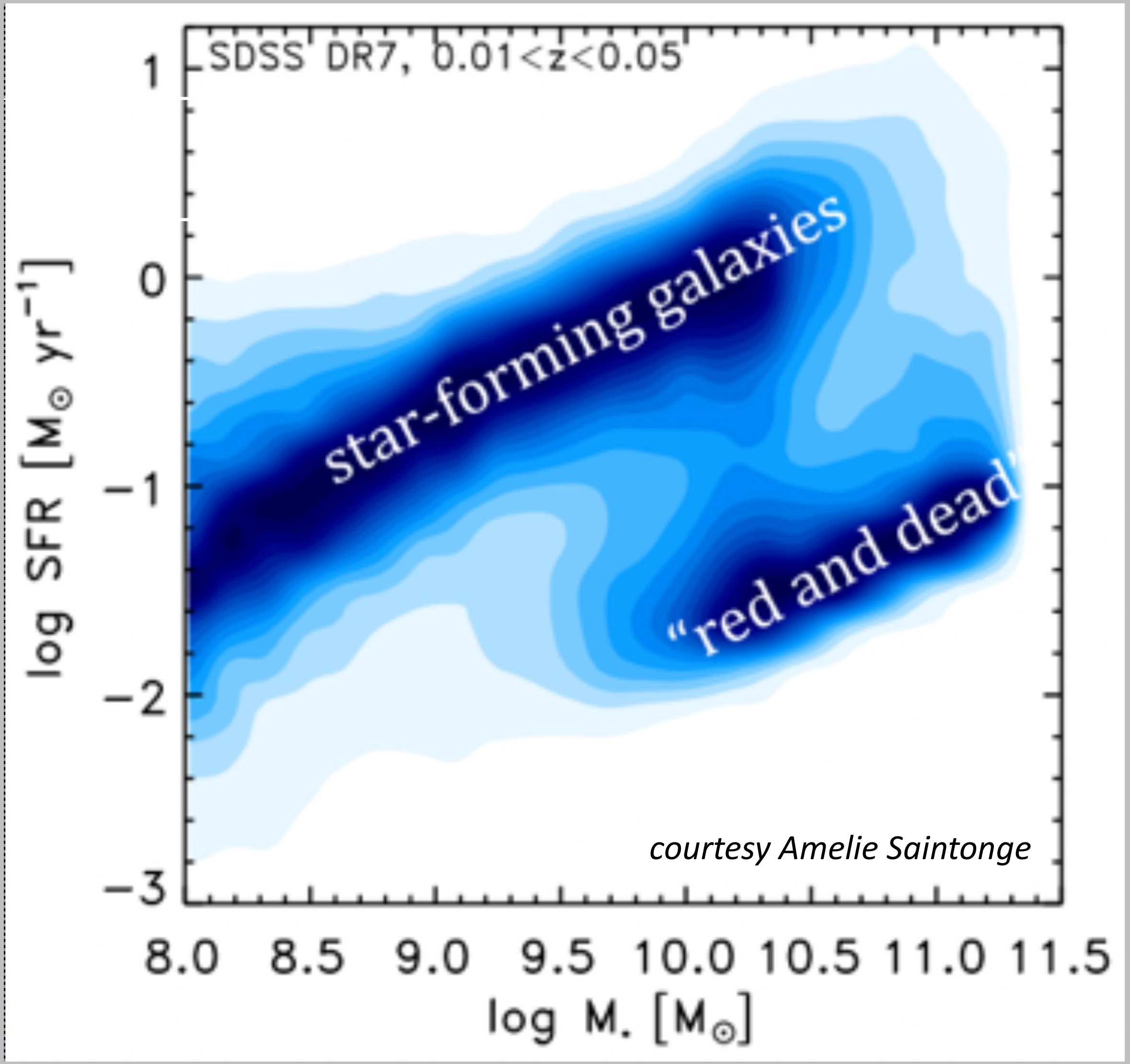
$$t_{grow} = M_*/SFR$$

$\log M_*$	$\log SFR$	t_{grow}
8.0	≈ -1.4	≈ 2.5 billion years
9.0	≈ -0.7	≈ 5 billion years
10.0	≈ 0.0	≈ 10 billion years

A “red and dead” elliptical is quite different:

$\log M_*$	$\log SFR$	t_{grow}
11.0	≈ -1.2	≈ 1500 billion years

Outliers: some galaxies have very high star formation rates for their mass: $t_{grow} < 100$ million years.



The "Star-forming Main Sequence" of Galaxies

Alternatively, think about gas depletion time: how long can galaxies maintain their current rate of star formation?

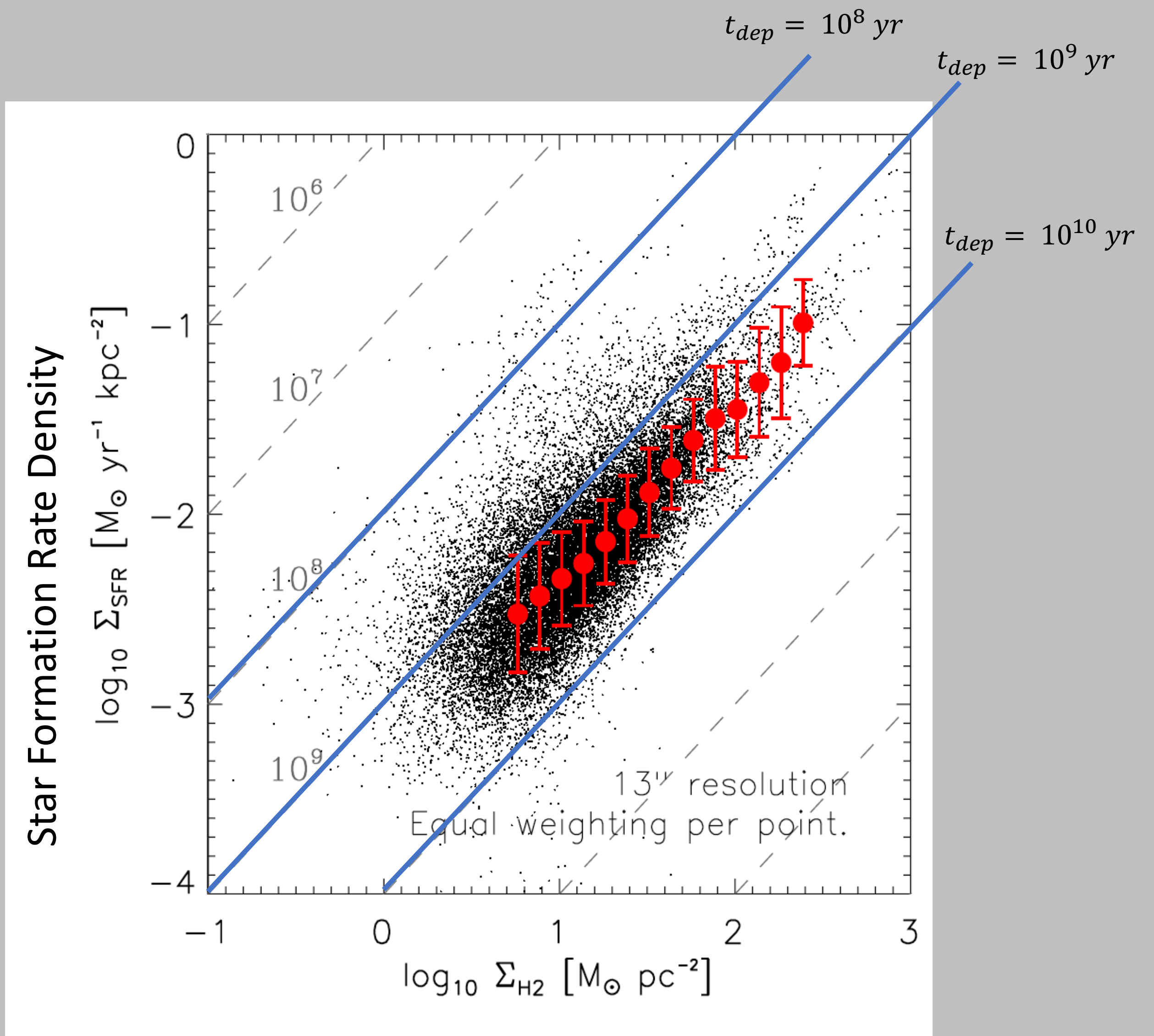
Depends on how much gas they have, and how fast they are using it:

$$t_{dep} = M_{gas}/SFR$$

For most star-forming galaxies, $t_{dep} \approx 1 - 10$ billion years.

Outliers: some galaxies have $t_{dep} < 100$ million years.

Starburst galaxies: Galaxies that are forming stars at a furiously high and unsustainable rate.



Bigiel+ 11

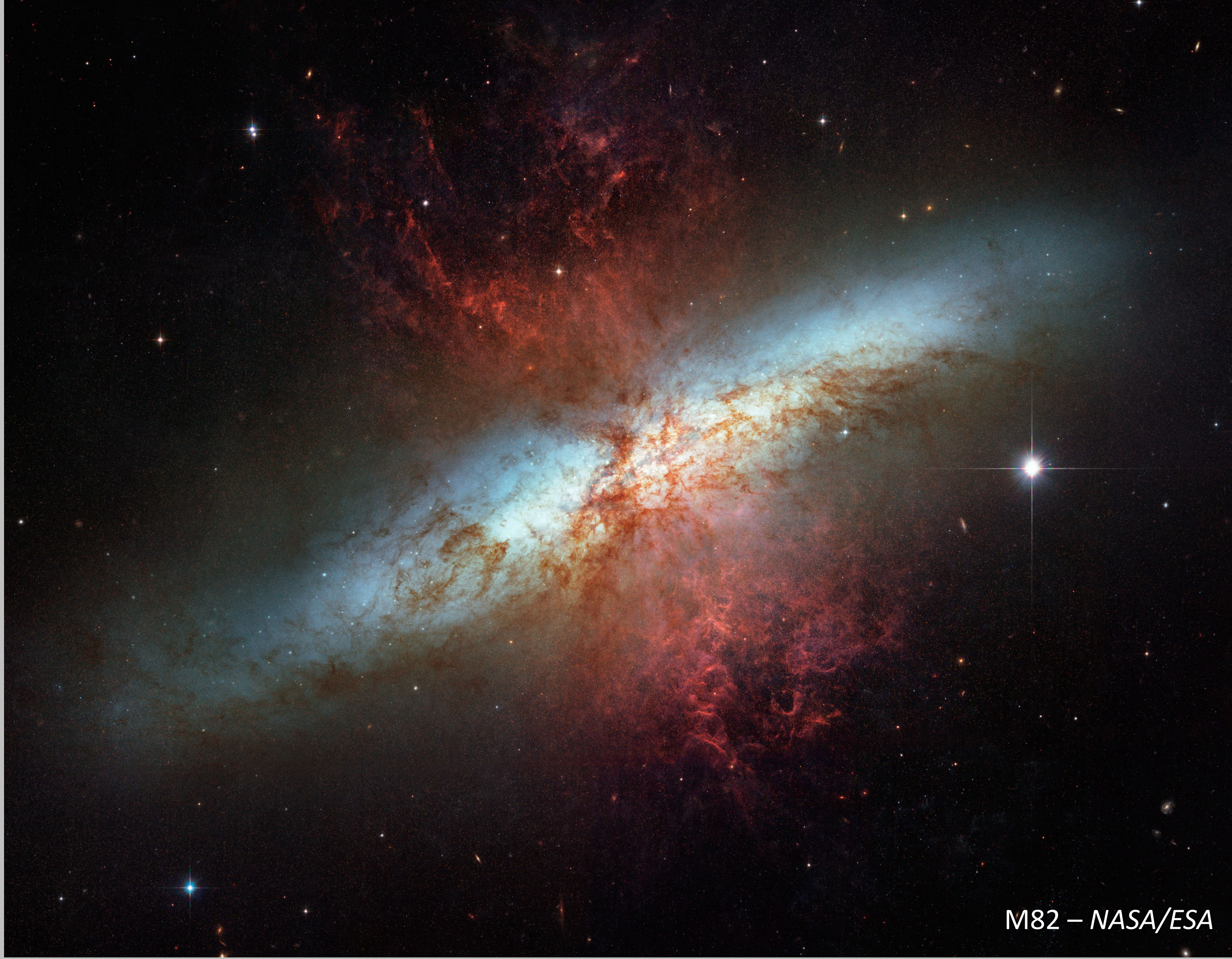
Starburst galaxy M82 (distance ≈ 3.5 Mpc)

Edge on disk, with giant filaments of Hα emission: ionized gas.

Gas is moving at high velocity: racing outwards

Star formation rate (SFR) ≈ few $M_\odot$/yr

Many supernovae seen (via radio emission) embedded in its dusty core.



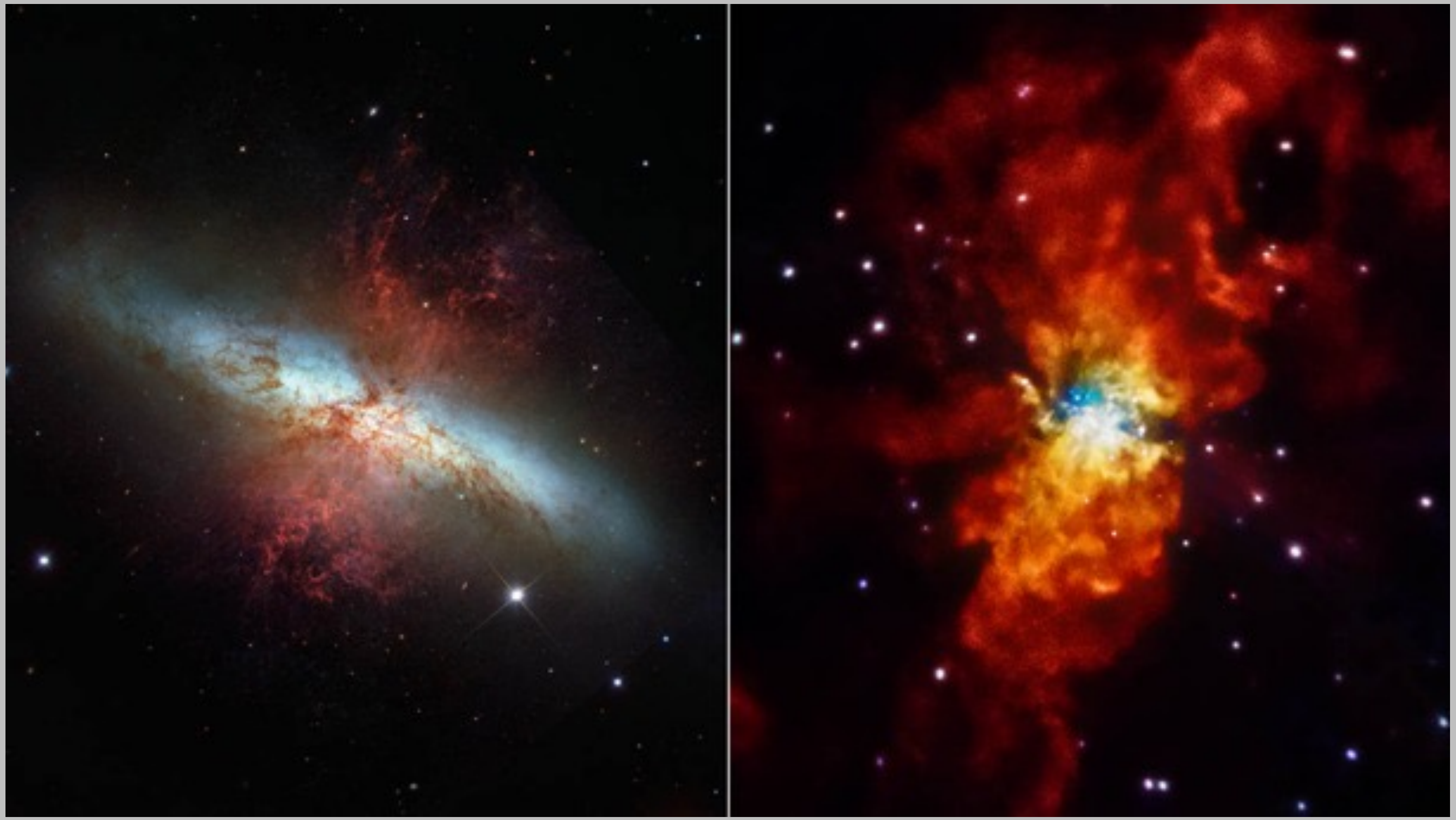
M82 – *NASA/ESA*

Blueish-white: optical starlight
Reddish filaments: Hα emission

M101 and M82 have similar star formation rates, but M82 is much smaller, less massive, and has a very short gas depletion time. That makes M82 a starburst galaxy.

Starburst winds

Massive star outflows and supernovae combine together to deposity a lot of energy in the surrounding gas, heating it up and blowing it outwards: **starburst winds**.



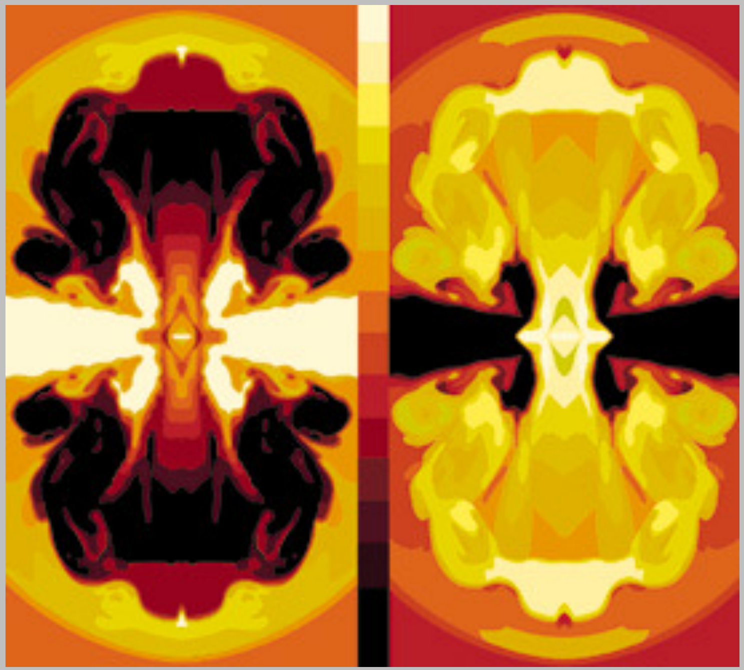
M82: starlight + ionized Hα

M82: very hot X-ray emitting gas

computer model of a starburst wind

gas density
bright = dense

gas temp
bright = hot



Starburst wind videos
(Evan Schneider, Pittsburgh):
Density evolution
Temperature evolution

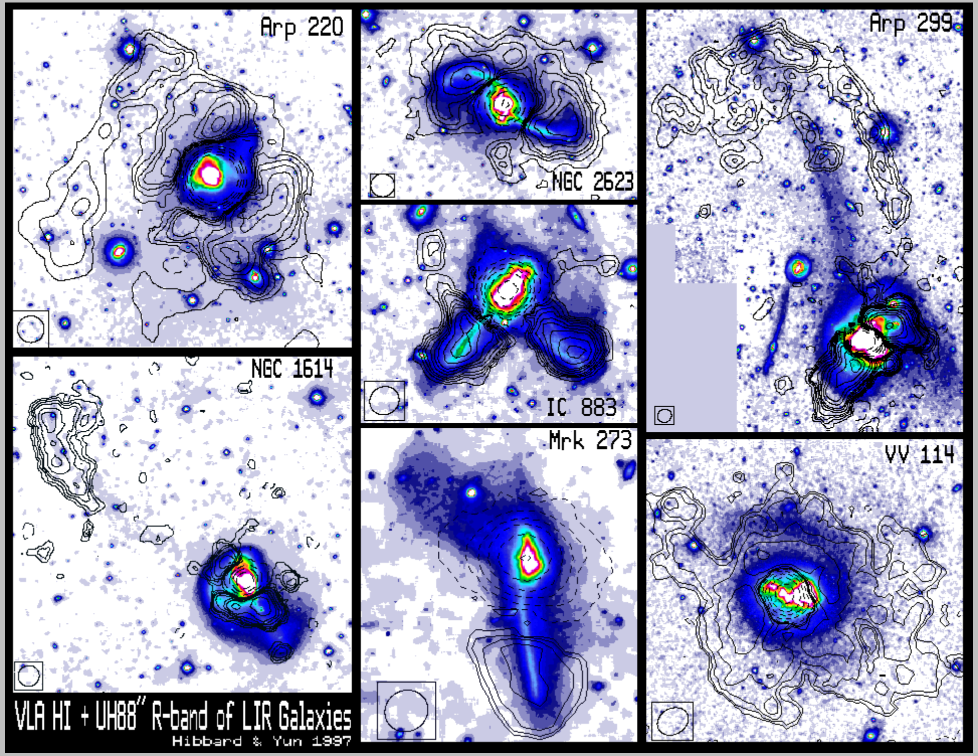
Combination of gas depletion (star formation) and heating/expulsion (winds) works to shut down the starburst relatively quickly.

Big uncertainties in how much gas is actually ejected

Starbursts and Luminous Infrared Galaxies

Starburst galaxies are generally gas-rich, with lots of dust. This dust absorbs a lot of the light from the young stars, masking them from our view.

But absorbing all that energy makes the dust heat up to ≈ 40 − 60 K, emitting far infrared (blackbody) radiation. So dusty starburst galaxies are bright in the far infrared, with luminosities $L_{FIR} = 10^{11} - 10^{12}\ L_{\odot}$. Which would need SFR ≈ 10 − 100 $M_{\odot}$/yr!



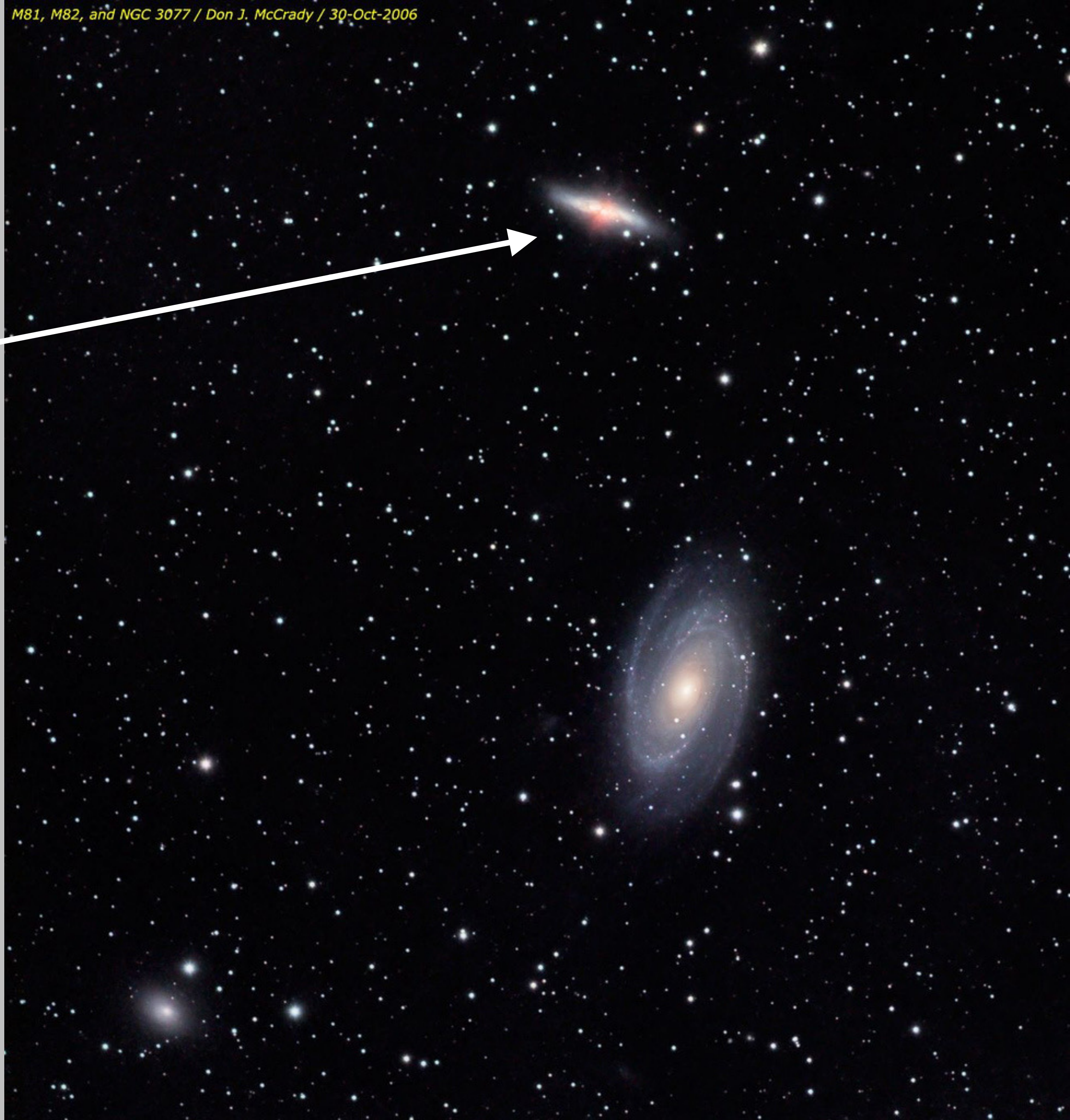
late 1980s: The Infrared Astronomy Satellite (IRAS) began detecting large numbers of luminous infrared galaxies: starbursts.

Followup optical imaging showed many of them to have very peculiar morphologies: interacting and merging galaxies.

⇐ Optical images of LIRGs (color shows surface brightness; contours show gas density). From Hibbard and Yun 1998.

What about M82? Is it interacting?

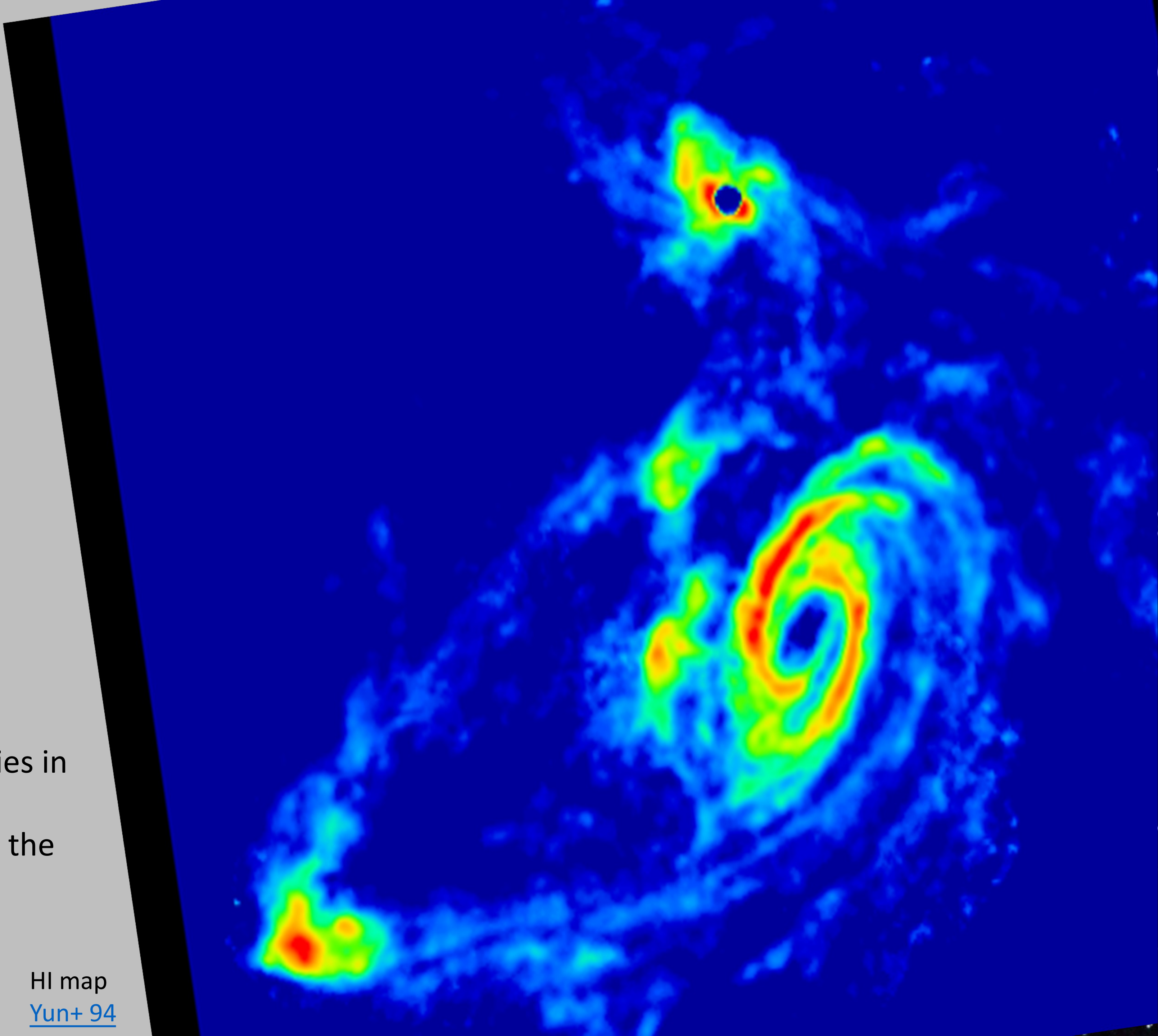
M82 is part of the M81 galaxy group....



What about M82? Is it interacting?

M82 is part of the M81 galaxy group....

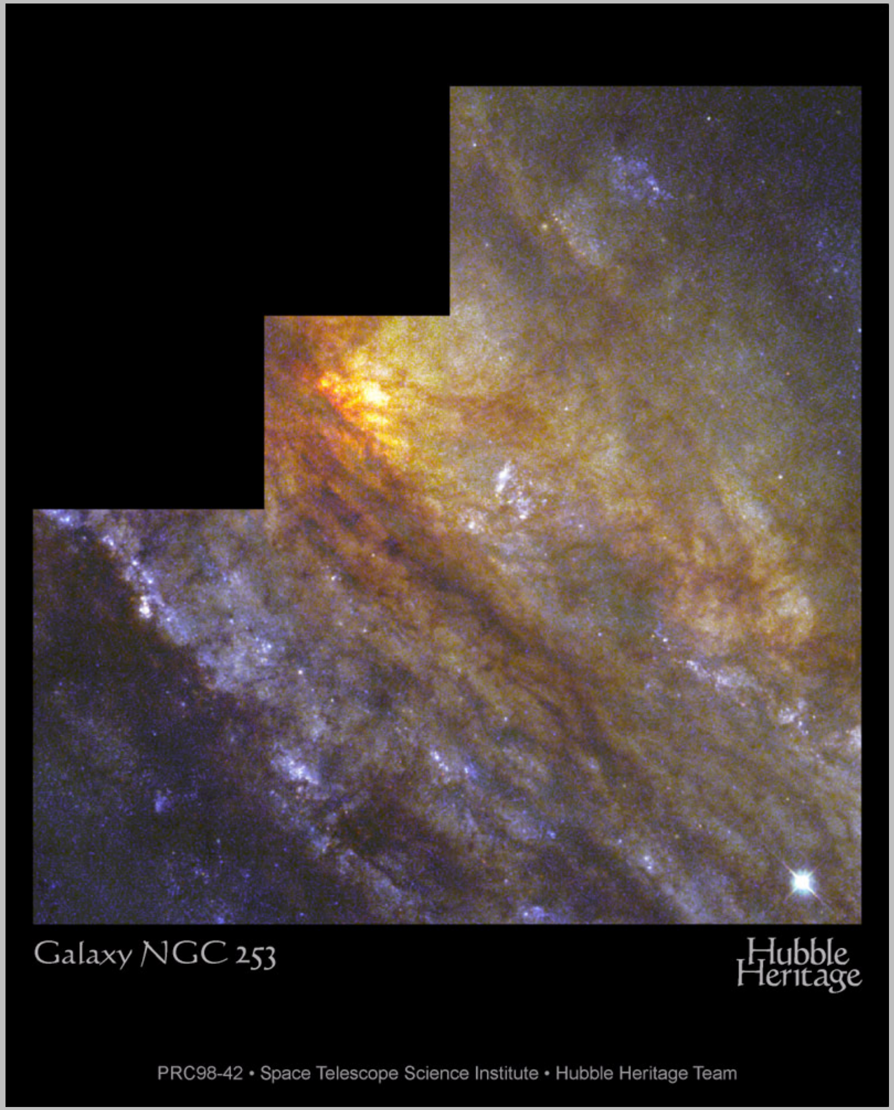
....and 21-cm HI observations show the galaxies in the group all connected by filaments of gas, probably pulled out by gravitational forces as the galaxies have interacted with each other!



HI map
Yun+ 94

But not every starburst galaxy is interacting!

NGC 253 (D=3.5 Mpc)




Arp 87
NASA/STScI
Galaxy Interactions

Galaxy Interactions: Timescales

Think of two galaxies passing by one another. How long does this take?

Let's say "passing" means moving 5x their diameter, then:

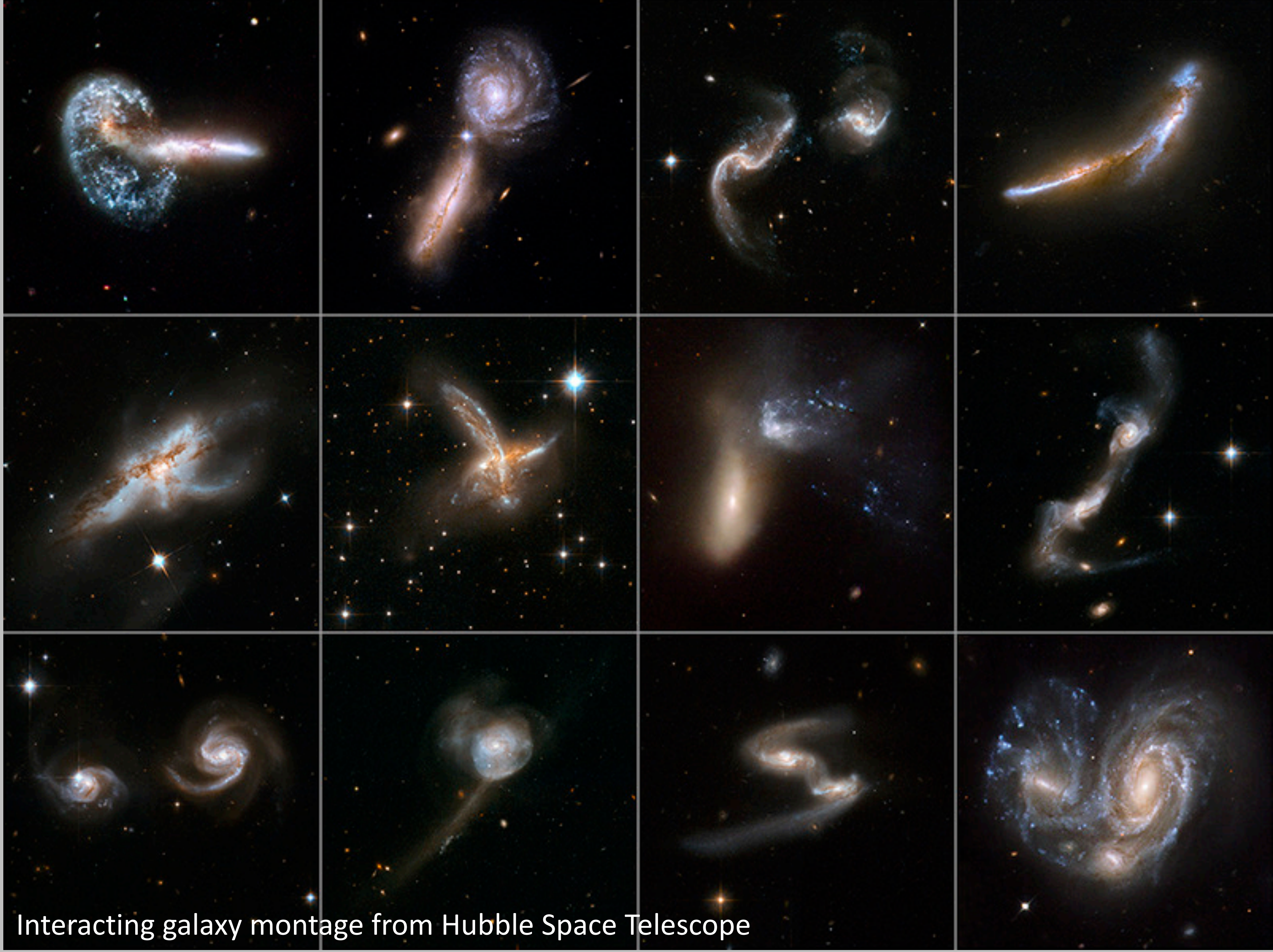
$$t_{pass} \approx \frac{5 \times D}{V_{rel}}$$

Using typical numbers:

$$D \approx 40\ kpc$$
$$V_{rel} \approx 400\ km/s$$

we get:

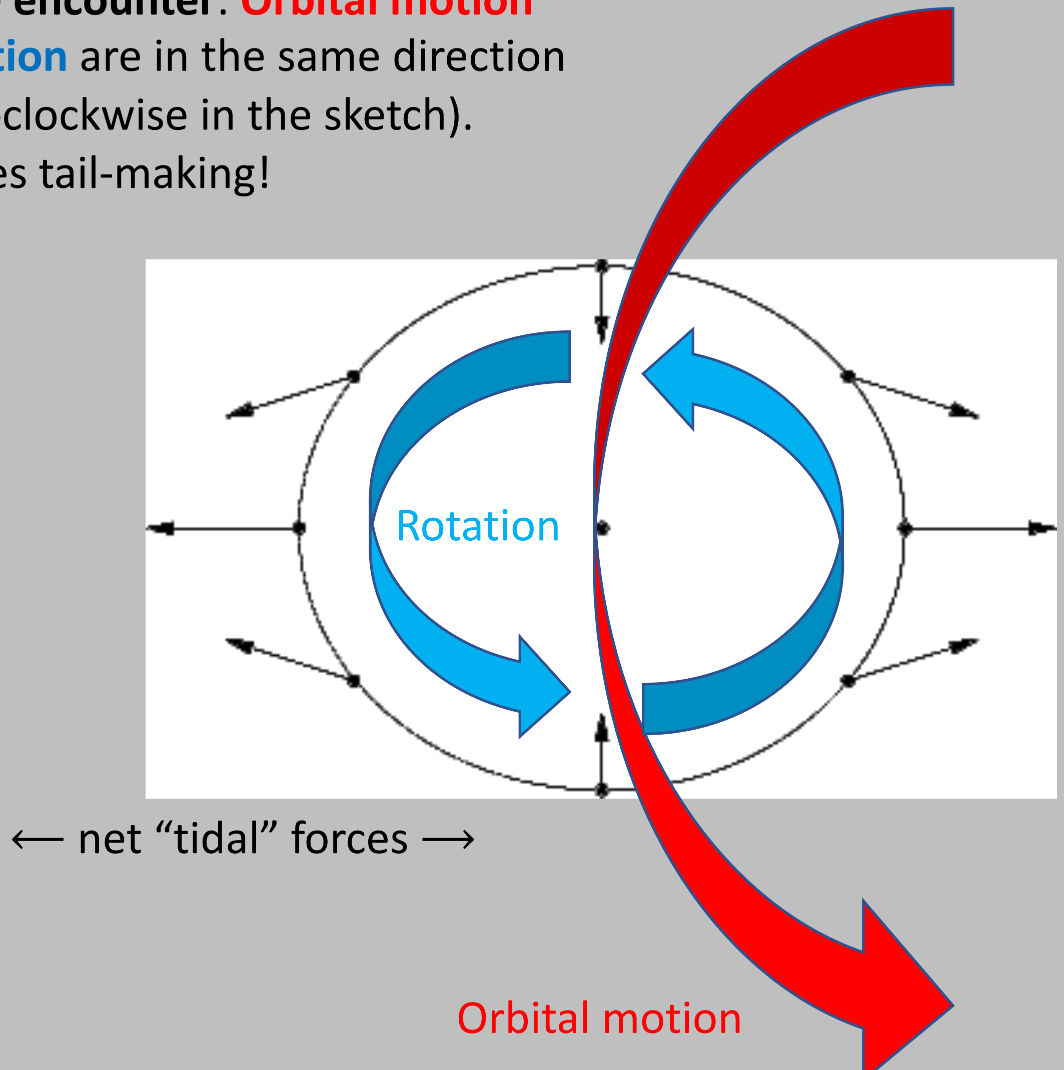
$$t_{pass} \approx \frac{5 \times 40000\ pc}{400\ pc/Myr} \approx 500\ Myr$$

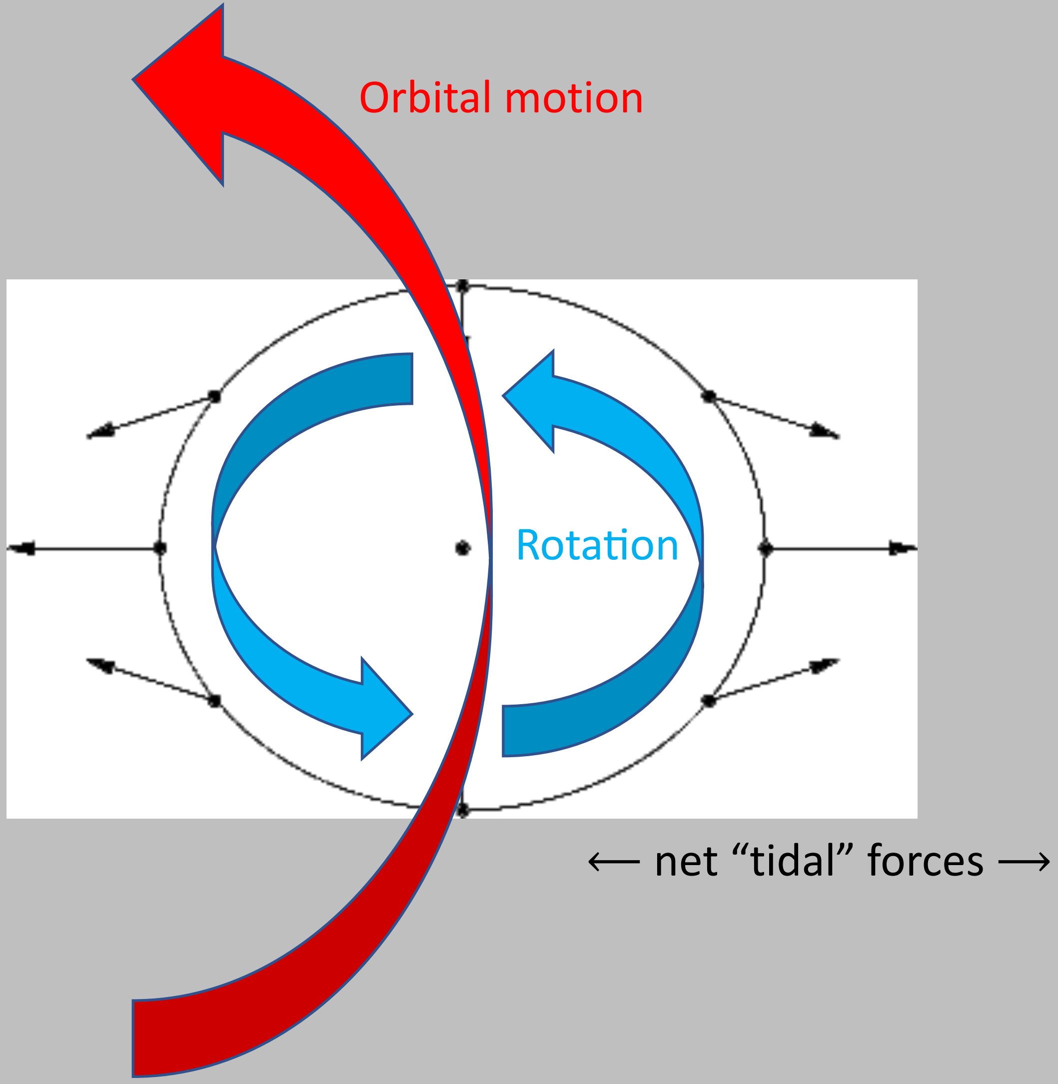

Interacting galaxy montage from Hubble Space Telescope

Interaction Dynamics: Tidal Forces, Tails, and Bridges

Tidal forces from each galaxy's gravity stretches the other one, stripping stars off both the near side and the far side. The coupling of orbital motion and rotation acts to strip stars out in long tidal tails and (sometimes) "bridges".

Prograde encounter: **Orbital motion** and **rotation** are in the same direction (counter-clockwise in the sketch). Maximizes tail-making!





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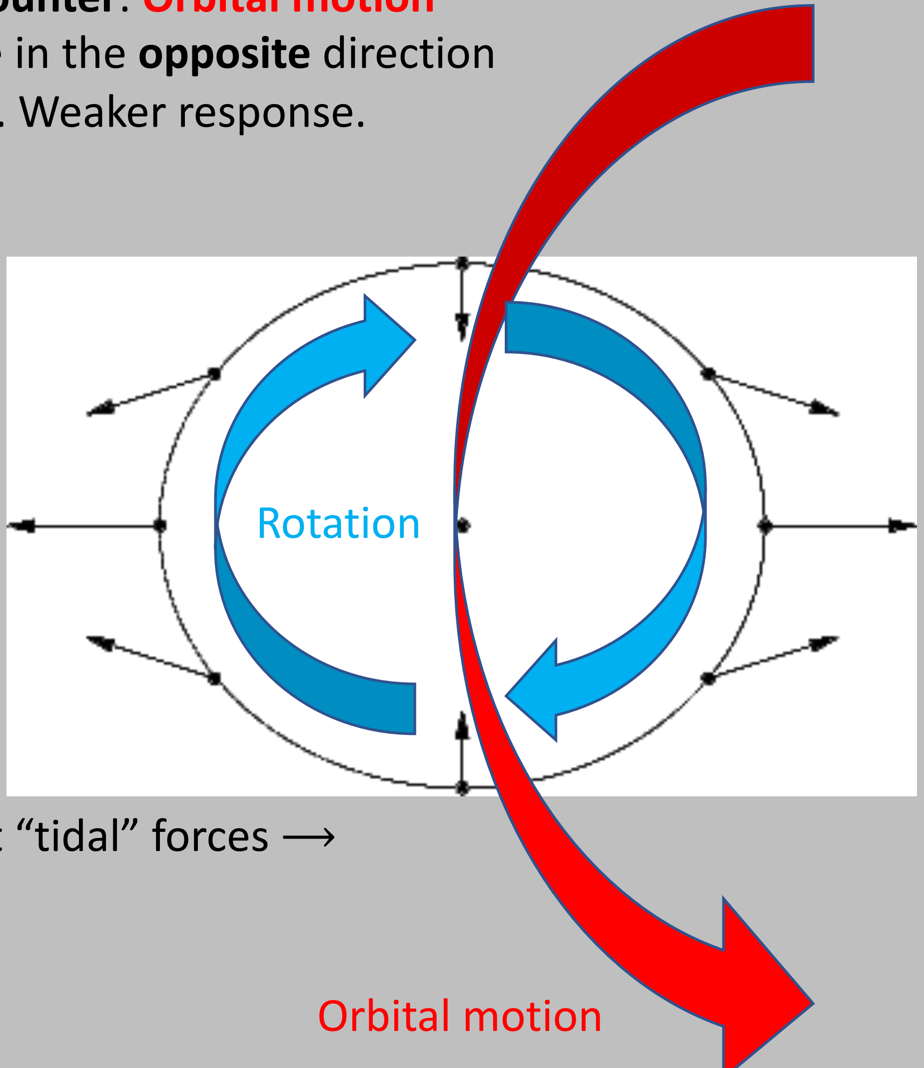
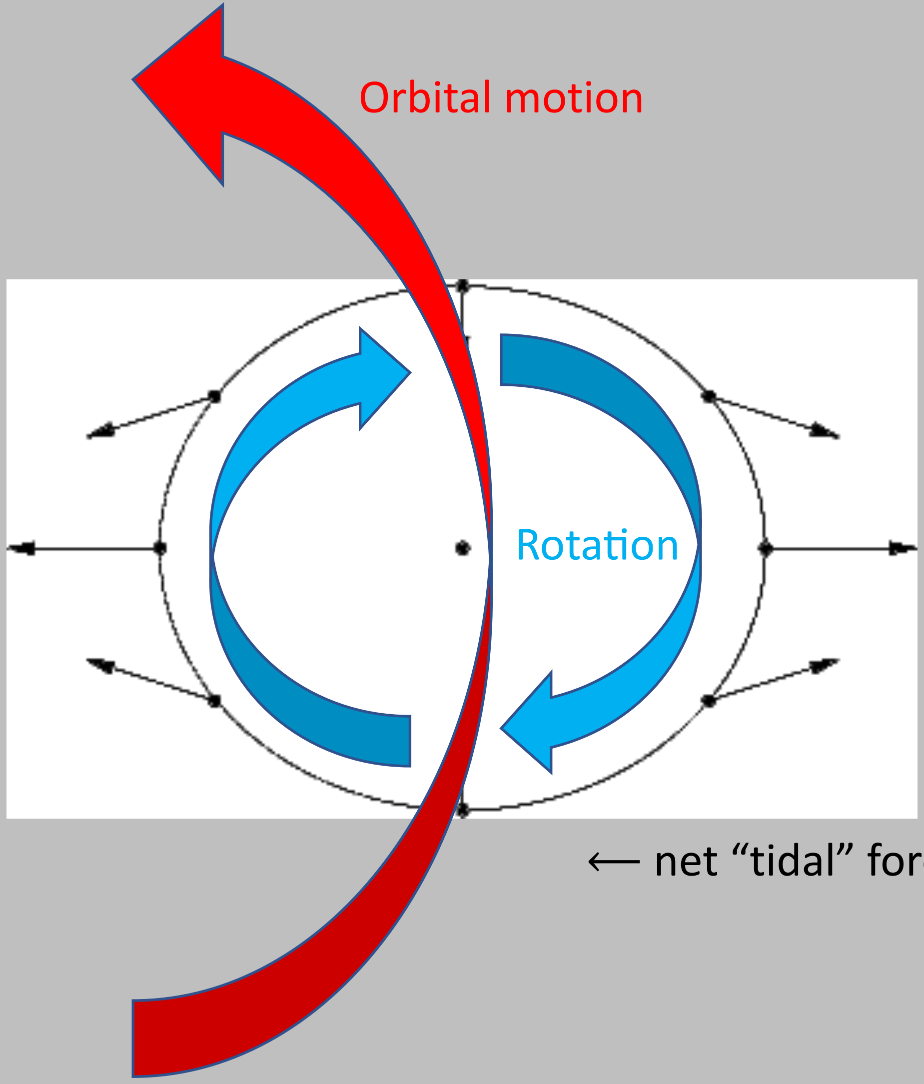
Retrograde encounter: Orbital motion and rotation are in the **opposite** direction from each other. Weaker response.





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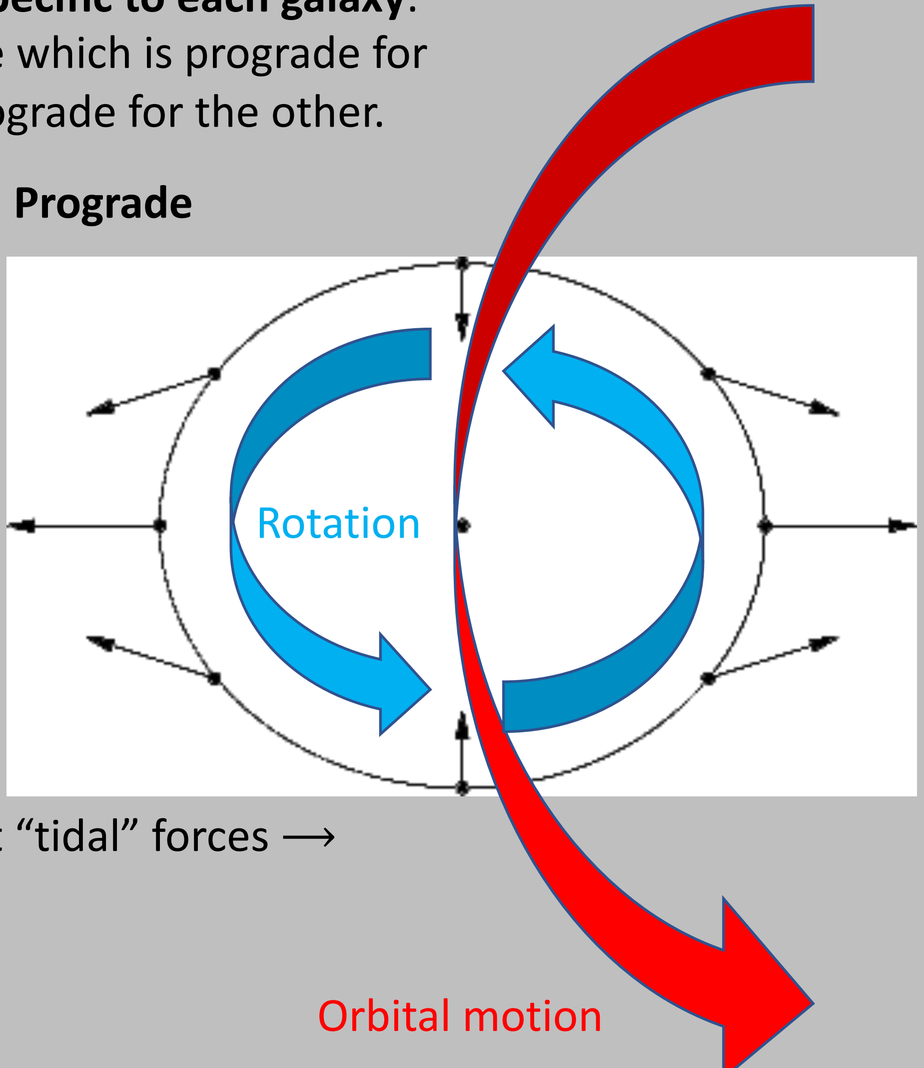
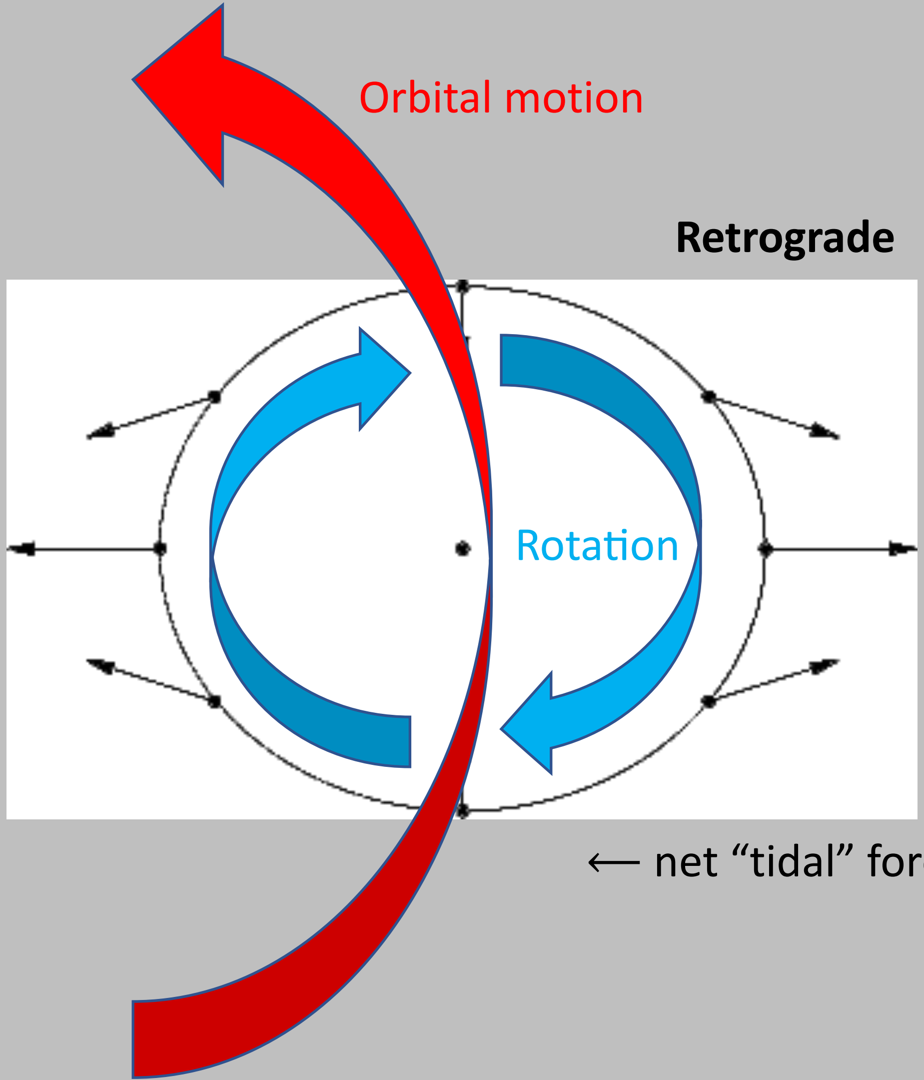
Orientation is specific to each galaxy: Here's a passage which is prograde for one galaxy, retrograde for the other.

Prograde



← net "tidal" forces →

Retrograde



← net "tidal" forces →

Interaction Dynamics: Tidal Forces, Tails, and Bridges

Tidal forces from each galaxy's gravity stretches the other one, stripping stars off both the near side and the far side. The coupling of orbital motion and rotation acts to strip stars out in long tidal tails and (sometimes) "bridges".

But there is a huge diversity in the outcome of a galaxy interactions, due to many factors.

Geometry: Encounters are rarely "pure prograde" or "pure retrograde": the orbital plane and disk planes can be tilted in different ways, creating complex geometries.

Mass: Tidal forces scale as $\boldsymbol{M}/R^3$. A bigger galaxy does more damage to a little galaxy than the other way around.

Distance: Tidal forces scale as $M/\boldsymbol{R^3}$. A closer encounter does more damage than a distant encounter.

Velocity: Slow encounters do more damage than fast encounters; the galaxies feel tidal forces for a longer time.

Galaxy Type:

- Spirals have ordered rotation, ellipticals do not -- tidal features in ellipticals are much more diffuse ("plumes").
- Spirals have cold gas, ellipticals generally do not – spirals have a strong star forming response.

Viewing angle: Tails, plumes, etc can look very different from different angles.

Time: The view changes with time as the galaxies collide and reshape each other.

From snapshots in time...