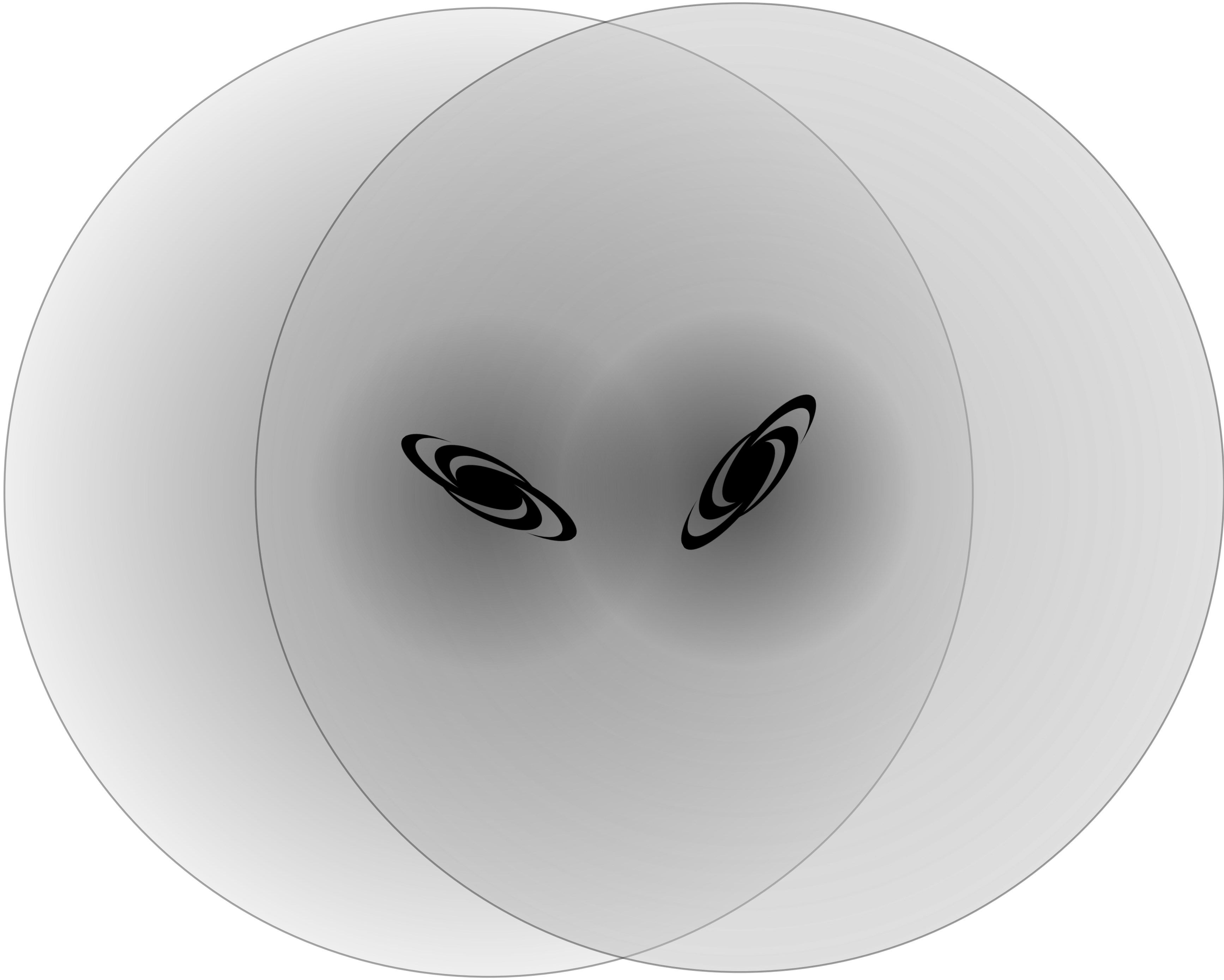
Galaxy Mergers

The overlapping dark halos means that dynamical friction is important. This causes the orbit to decay and the galaxies to merge.

This is a purely gravitational process, there are virtually no direct collisions of stars.

Violent relaxation: the rapidly changing gravitational field as the galaxies merge scatters the orbits of stars wildly.

Rotating disks are destroyed, high velocity dispersion spheroids are created.



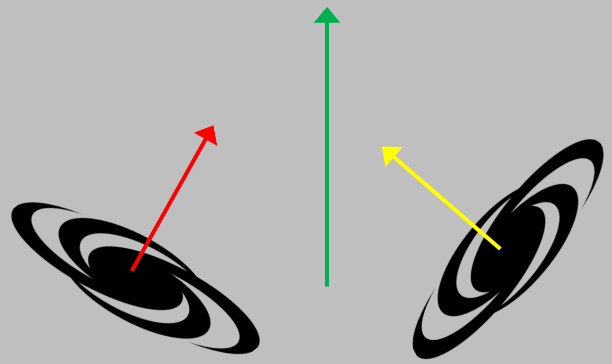
Galaxy Mergers and conservation laws

Remember that total energy and total angular momentum are conserved quantities and do not change over time. Break up energy and angular momentum in terms of internal and orbital terms:

$$\vec{L}_{tot} = \vec{L}_{spin,1} + \vec{L}_{spin,2} + \vec{L}_{orb}$$

and

$$E_{tot} = E_{kin,1} + E_{kin,2} + E_{orb} + \boldsymbol{\Phi}_{grav}$$



After galaxies have merged, $\vec{L}_{orb} = 0$ and $E_{orb} = 0$. But $\vec{L}_{tot}$ and E_{tot} ***couldn't*** have changed – they are conserved. So where did that orbital energy and angular momentum go?

Some went into the stars kicked out in the tidal tails.

But most went into the energy and angular momentum of the dark halos: they expanded a little bit, and they gained a bit of rotation.

Dark halos are good "dynamical sponges"!

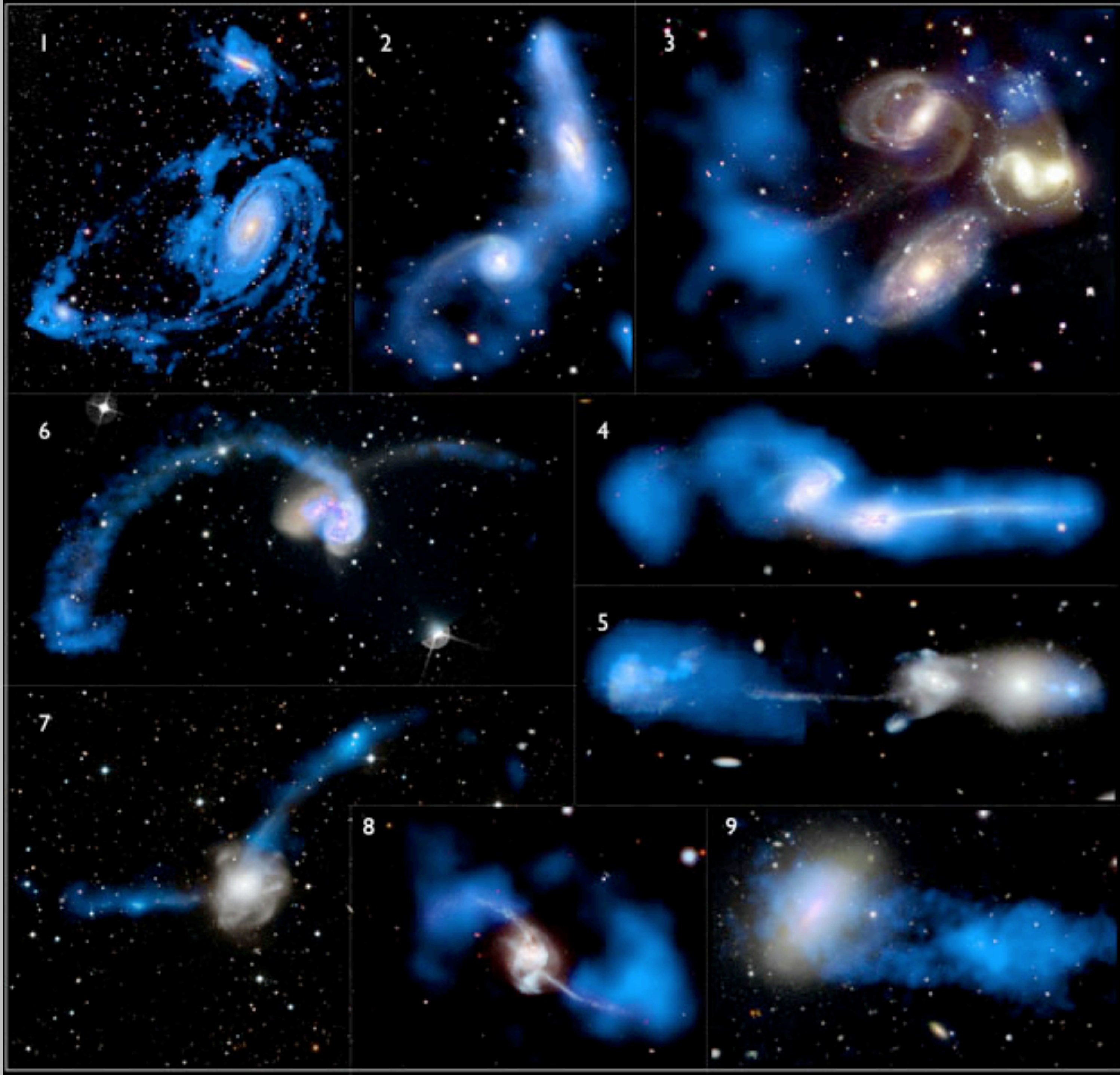
Interactions, Mergers, and Gas Dynamics

Gas Ejection: Lots of gas in the outskirts of colliding galaxies can be ejected in the tidal tails.
(Neutral hydrogen gas shown in blue, from Duc & Renaud 11)

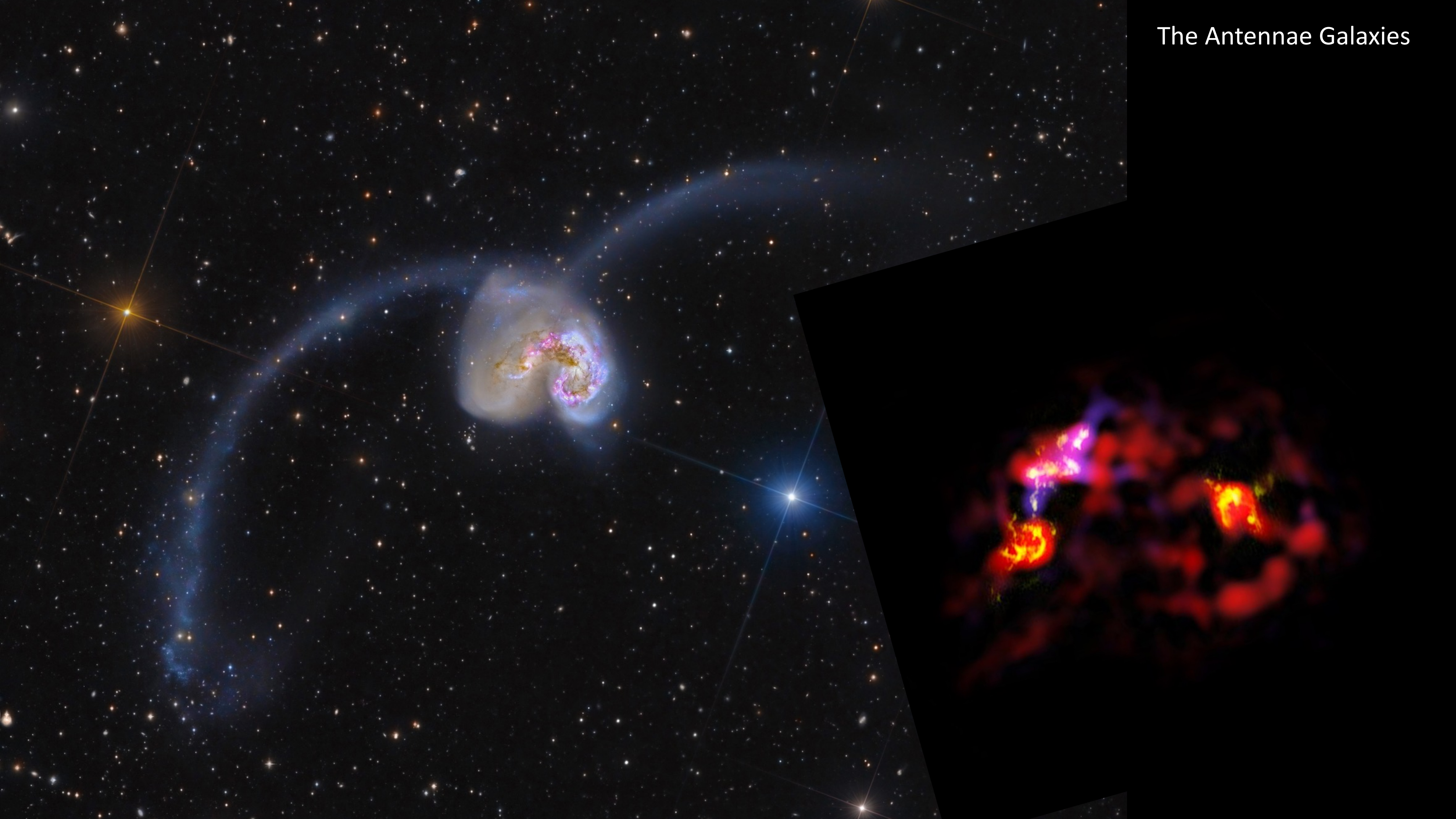
Gas Inflows: While stars don't collide, gas clouds do. These cloud collisions are "sticky", and compress and heat the gas. This converts kinetic energy to heat, so the clouds lose kinetic energy and start to flow towards the center.

Starburst activity: Compressed gas triggers star formation throughout the galaxy and often in centrally-concentrated starbursts.

Colliding galaxy images, with neutral hydrogen gas shown in blue ⇒
(from Duc & Renaud 11)



The Antennae Galaxies



Mergers and Galaxy Transformations: A galaxy evolution story

Spiral Galaxies
Thin disks of stars
High rotation, low dispersion (kinematically cold; $V_c/\sigma \gg 1$)
Lots of cold neutral and molecular gas
Very little hot gas
Ongoing-star formation, with a mix of stellar ages

???

Mergers and Galaxy Transformations: A galaxy evolution story

Spiral Galaxies	Merger Effects
Thin disks of stars	Disks destroyed, spheroids formed
High rotation, low dispersion (kinematically cold; $V_c/\sigma \gg 1$)	Stars scattered, orbits randomized
Lots of cold neutral and molecular gas	Gas ejected in tails, or driven inwards to form nuclear starbursts
Very little hot gas	Starbursts drive “winds” of hot gas outwards
Ongoing-star formation, with a mix of stellar ages	Gas used up or ejected, star formation ceases

???

Mergers and Galaxy Transformations: A galaxy evolution story

Spiral Galaxies	Merger Effects	Elliptical Galaxies
Thin disks of stars	Disks destroyed, spheroids formed	Spheroidal shapes
High rotation, low dispersion (kinematically cold; $V_c/\sigma \gg 1$)	Stars scattered, orbits randomized	Very little rotation, mostly random motion (kinematically hot $V_c/\sigma \ll 1$)
Lots of cold neutral and molecular gas	Gas ejected in tails, or driven inwards to form nuclear starbursts	Very little cold gas
Very little hot gas	Starbursts drive "winds" of hot gas outwards	Hot gaseous halos
Ongoing-star formation, with a mix of stellar ages	Gas used up or ejected, star formation ceases	Very little star formation, old stellar populations

Getting Distances to Galaxies

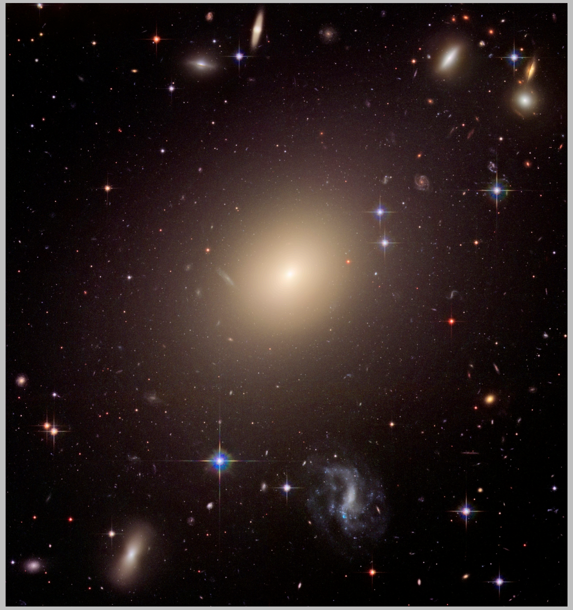
Galaxies are all way way too far away for parallax, so what can we do?

Nearby galaxies (< 20 Mpc)

- spirals: Cepheid variables (evolving massive young stars, period-luminosity relationship)
- ellipticals: RR Lyrae variables (evolving low mass old stars, (different) period-luminosity relationship)
- all types: Luminous red giant stars (TRGB: “tip of the red giant branch”)

More distant galaxies (> 20 Mpc)

- spirals: Tully-Fisher relationship (connecting circular speed and luminosity/absolute-mag)
- ellipticals: Fundamental plane (connecting physical size with velocity dispersion and surface brightness)
- Type Ia supernovae



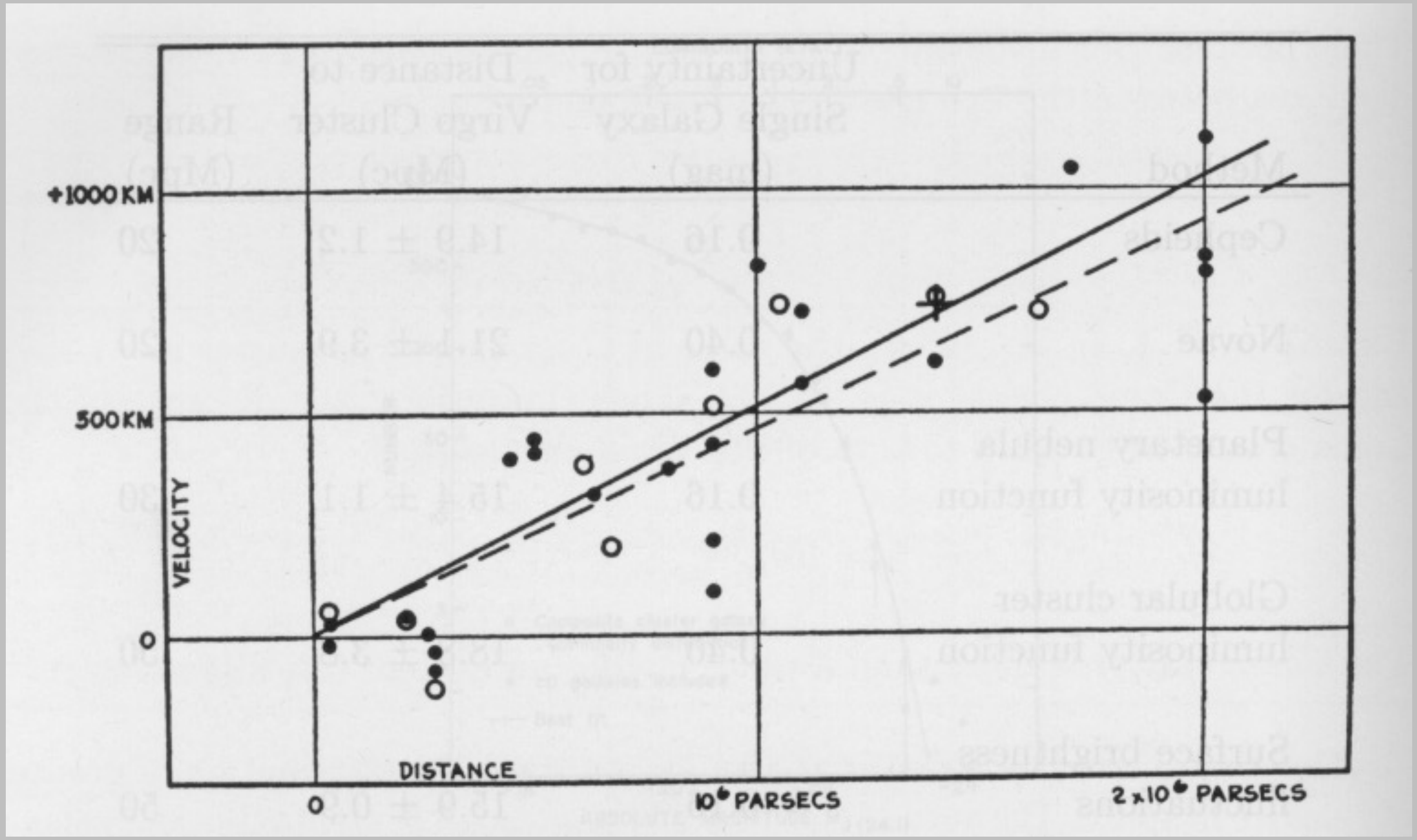
But...

- These methods don’t work on all galaxies, so what else can we use?
- And these are data-intensive methods requiring a lot of work. Are there simpler methods?

Hubble's Law

1920—1930s: After demonstrating that the spiral nebulae are distant galaxies, he finds another amazing result: a correlation between a galaxy's distance from the Milky Way and its radial velocity:

(Hubble 1936)



Hubble realized this meant the Universe must be expanding, and that galaxies are being carried away from us in all directions by this expansion. 😲🤯😵‍💫

More distant galaxies are moving away faster. This is now called Hubble's Law:

$$v = H_0 D$$

H_0 is referred to as Hubble's constant and has a value of $H_0 \approx 72$ km/s/Mpc.

Can easily measure a velocity from an emission line, then instantly have a distance from $D = v/H_0$. Yay! 🥳🤩

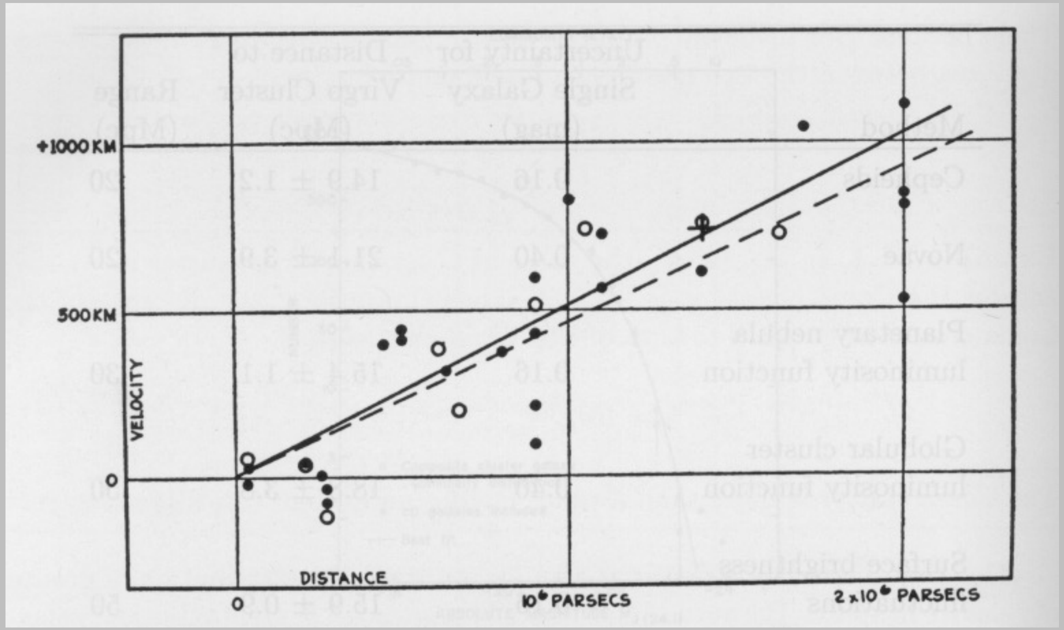
Since we get the distance from redshifted emission lines ("redshifts") and Hubble's law, these are referred to as "Hubble distances".

Complications using Hubble's Law

1. Not all motion is due to the expansion of the universe.

Galaxies also have motions due to the effect of gravity. Think about interacting galaxies, for example. $v = v_{Hubble} + v_{grav}$

And we live near a very massive galaxy cluster (Virgo, $D = 16$ Mpc) whose gravity alters the velocities of nearby galaxies. So Hubble distances are pretty untrustworthy in the local universe.



2. Uncertainties in the Hubble constant (H_0)

To work out the value of H_0 we need very accurate distances using some other technique, and that's hard!

Also, different techniques to determine H_0 give different answers.

Distance measures (astronomers 😇): $H_0 = 73 \pm$ a few km/s/Mpc
Cosmological measures (physicists 👺): $H_0 = 68 \pm$ a few km/s/Mpc