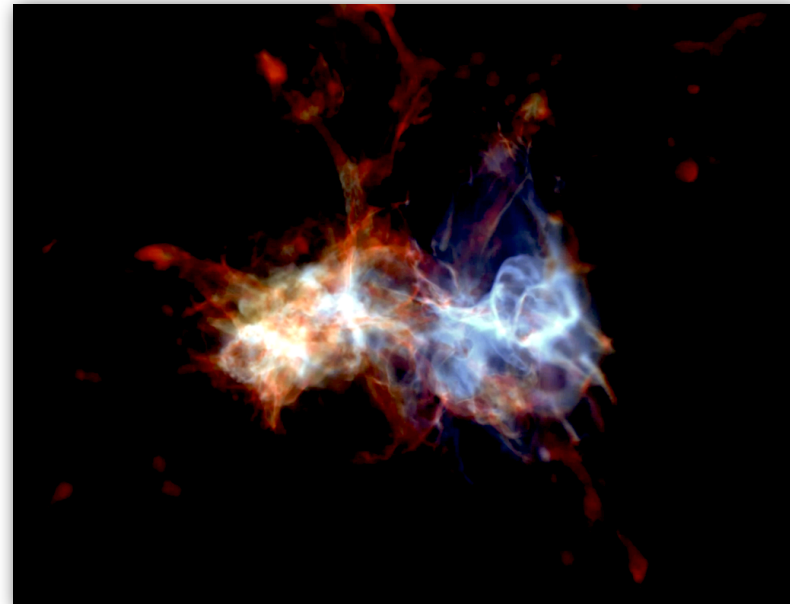


I

Composition of the Universe

What's it all made of?



Tom Abel

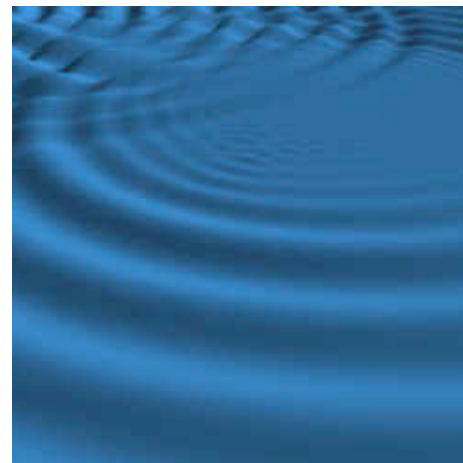
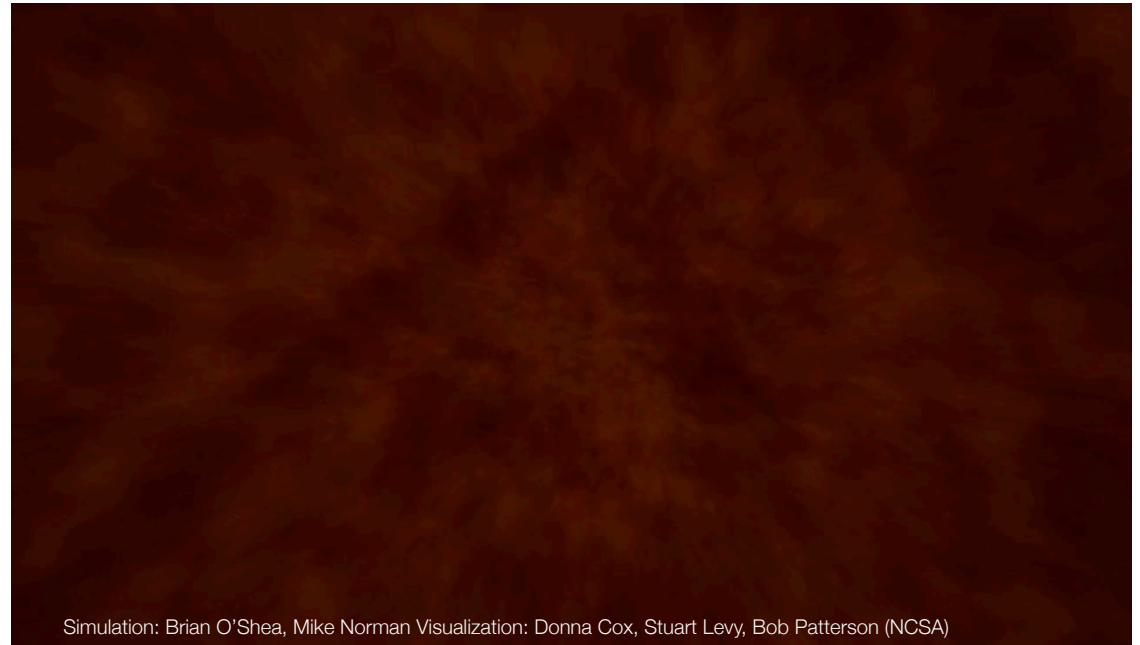
Kavli Institute for Astroparticle Physics and Cosmology

Stanford Physics Department

Stanford Linear Accelerator Laboratory

Taking it personal

- Much of you is 13.7 billion years old
- practically nothing of you is younger than 4.5 billion years
- somewhere between ten and one hundred million massive stars have helped in making you
- about the amount of one of your fingers came from the earliest stars
- you used to be about a million light years across



The first 100 million years in one sentence 13.5 billion years ago ...

Small dark matter halos form first, gas follows, hydrogen molecules form and make the gas shine, it collapses 10 million times further, ignites hydrogen fusion, makes a massive star, radiation disperses birth-cloud, explodes in a supernovae which releases carbon, oxygen, etc., collapses again, makes more stars, more explosions, more than 10 million massive stars later:

us



Our Place in the Universe

Galactic halo

300,000 light-years

100,000 light-years

Globular clusters

Galactic bulge

Sun

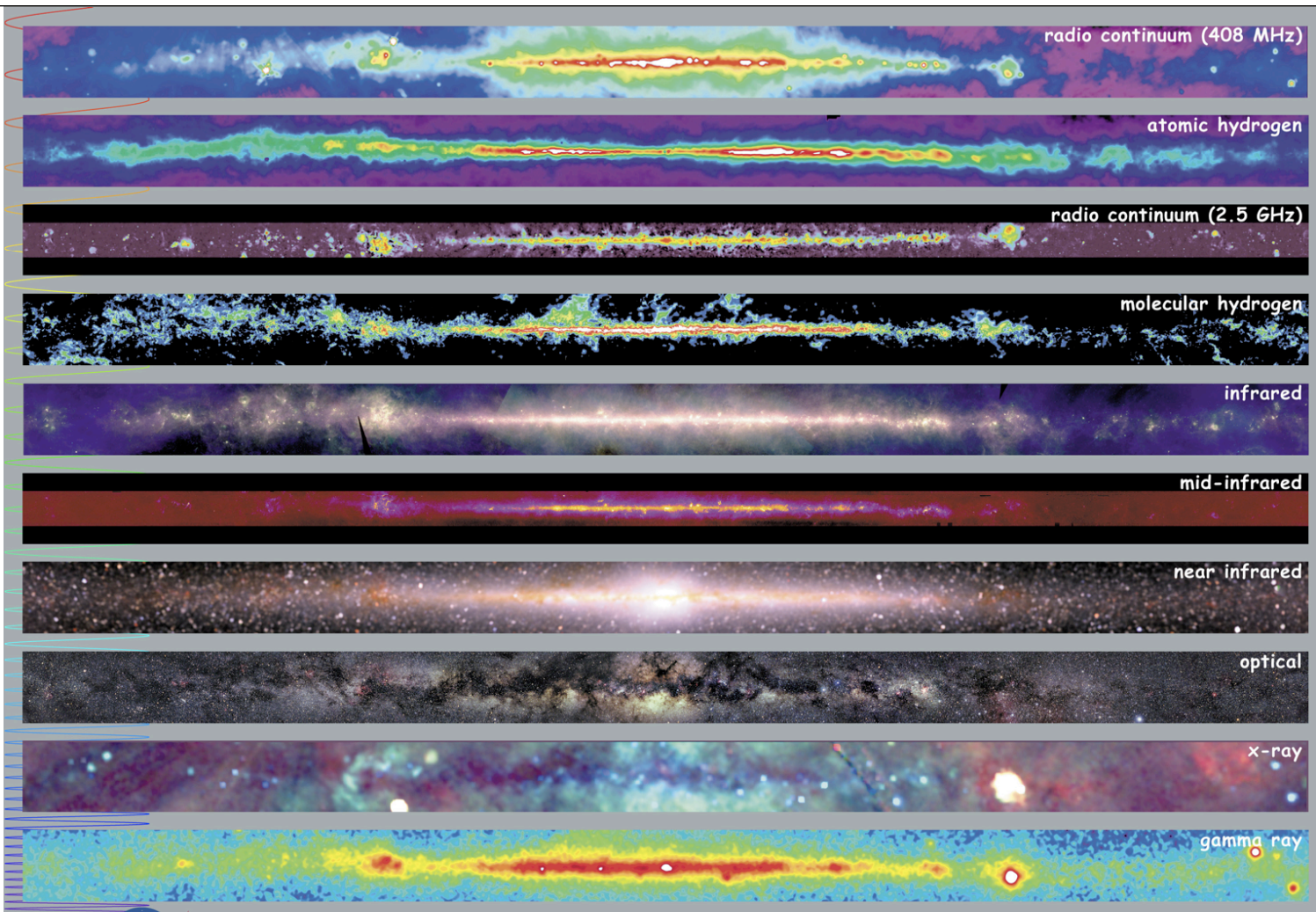
Galactic disk

27,000 light-years

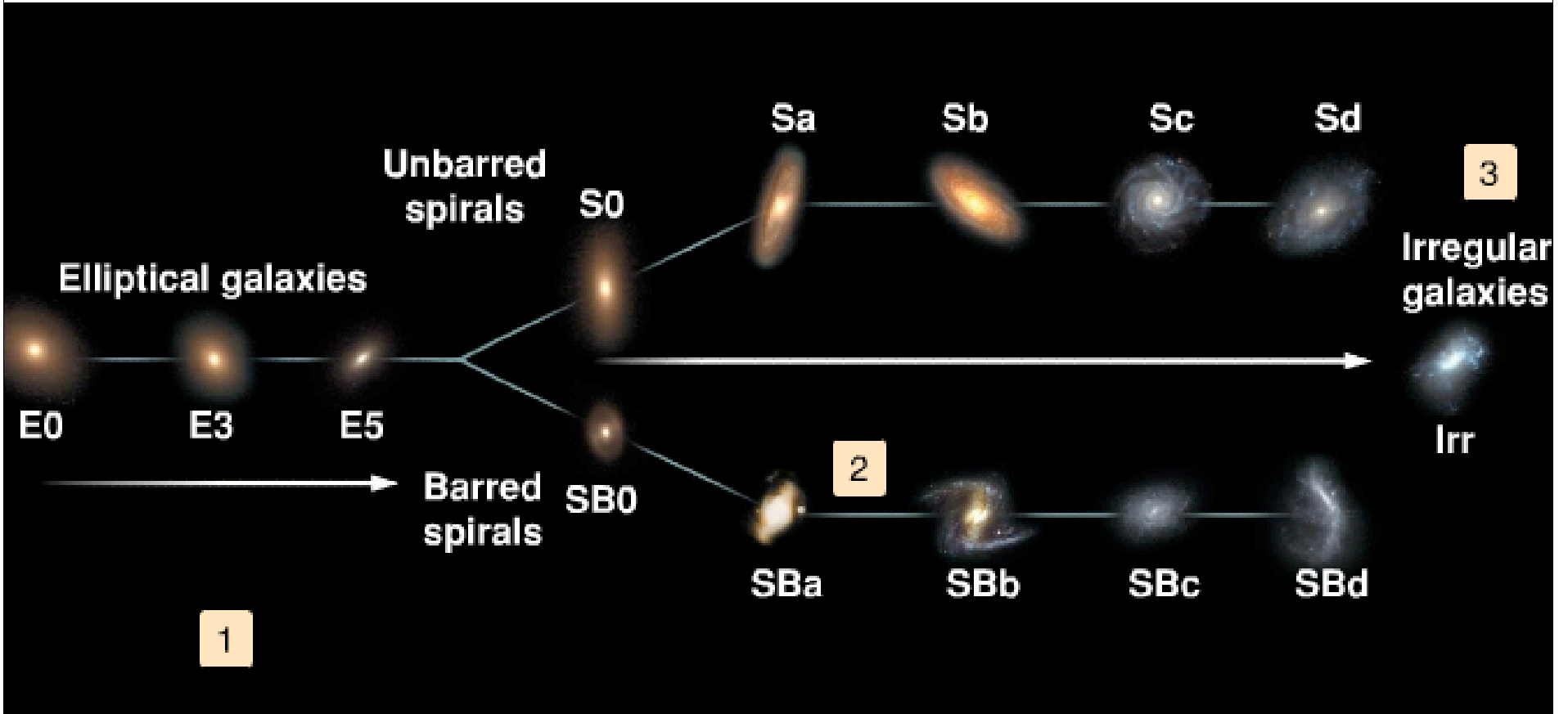
Magellanic clouds



The Milky Way



Galaxy Types



History of Galaxy Studies

- First Records:
 - Andromeda (M31): obs 905AD, rec'd 964 Al Sufi
 - Also M31 on pre-telescopic western sky charts
 - Magellanic Clouds: reported in west in 1519
- Telescopic Discoveries
 - Starting in 1610 → Messier 1780s
 - Messier List: 103 brightest comet duds
 - Herschels (Fr ~1800, Son~1840) General Catalog
~5000 `nebulae'

History of Galaxy Studies

- Nature of the Nebulae:
 - Kant 1790 – speculation of ‘Island Universes’
 - Rosse w/ ‘Leviathan of Parkinstown’ ~1850
spiral structure in M51
 - First spectra of nebulae: some continuum, some gas
- 1920 Shapley-Curtis ‘Great Debate’
 - Curtis: other spiral nebulae are like Milky way
 - Shapley ~1920 Sun off center, by 300,000 lty
 - Spiral nebulae just little clouds, forming stars?
 - 1924 Hubble – Standard Candle stars in nearby galaxies

at large gravity is all that matters

Simulation: Chris Mihos (Case Western)
Viz: Bob Patterson, Stuart Levy, Donna Cox (NCSA)

How do you weigh a galaxy?

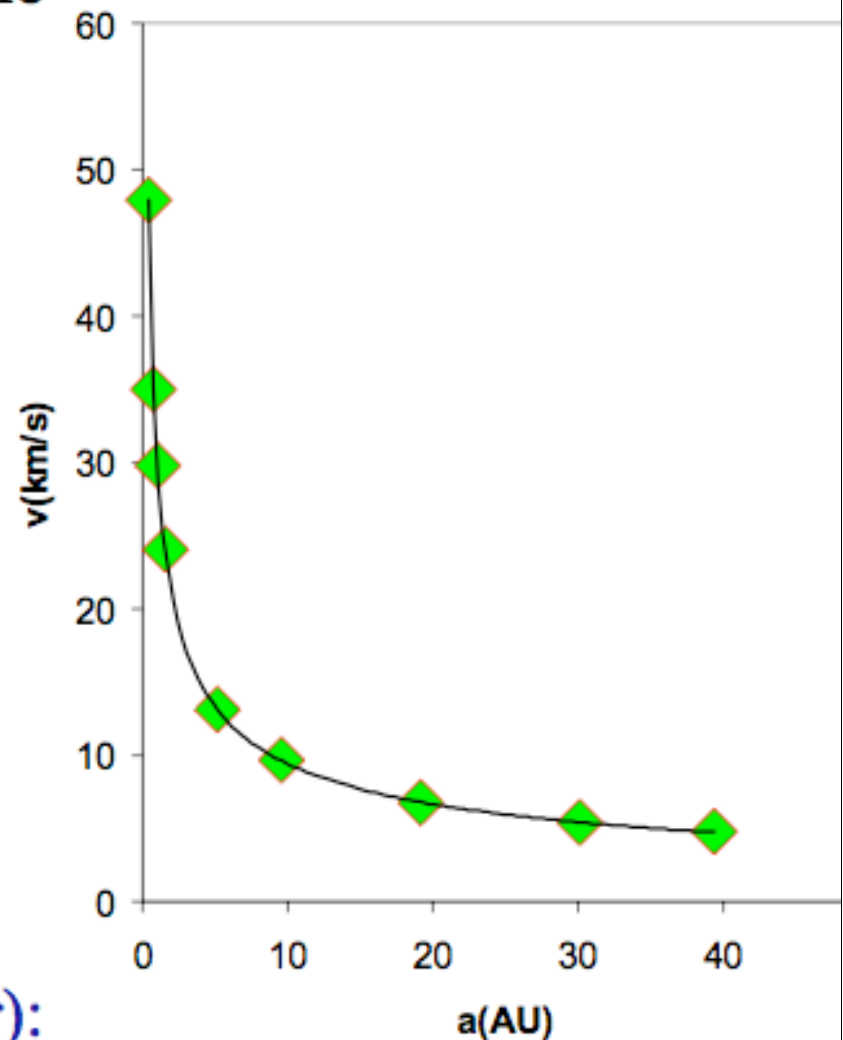
Rotation of Keplerian Disks

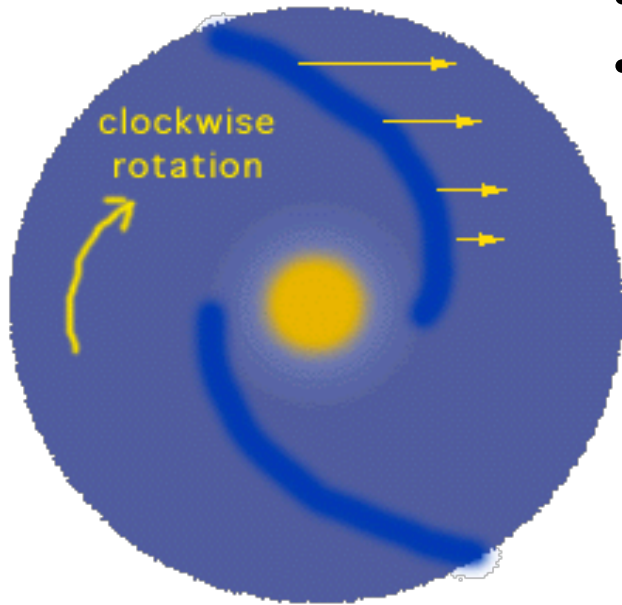
Start with rotation of orbits in the
Solar System: Kepler's law

- $P^2 \propto r^3 \rightarrow P \propto r^{3/2}$
- Outer planets take longer to go around.
- Farther to go, and slower:
Key formula: $V_c(r) = (GM/r)^{1/2}$

Galaxy: bright bulge in center,
fainter arms

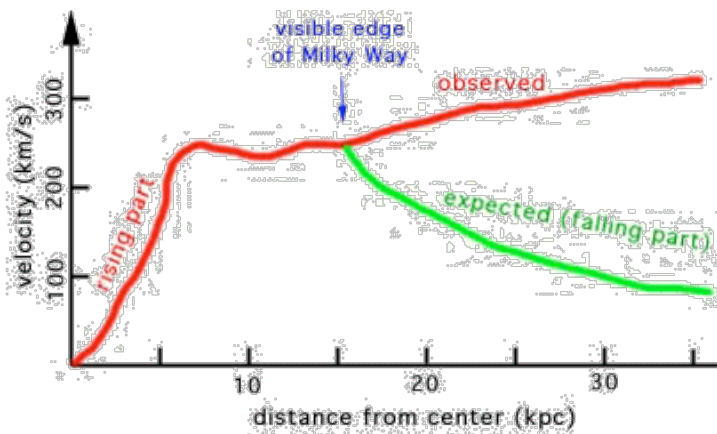
- Expect outer parts of arms to take longer to orbit \rightarrow lag behind
- Expect stars to have Keplerian $v(r)$:
they didn't, big surprise...

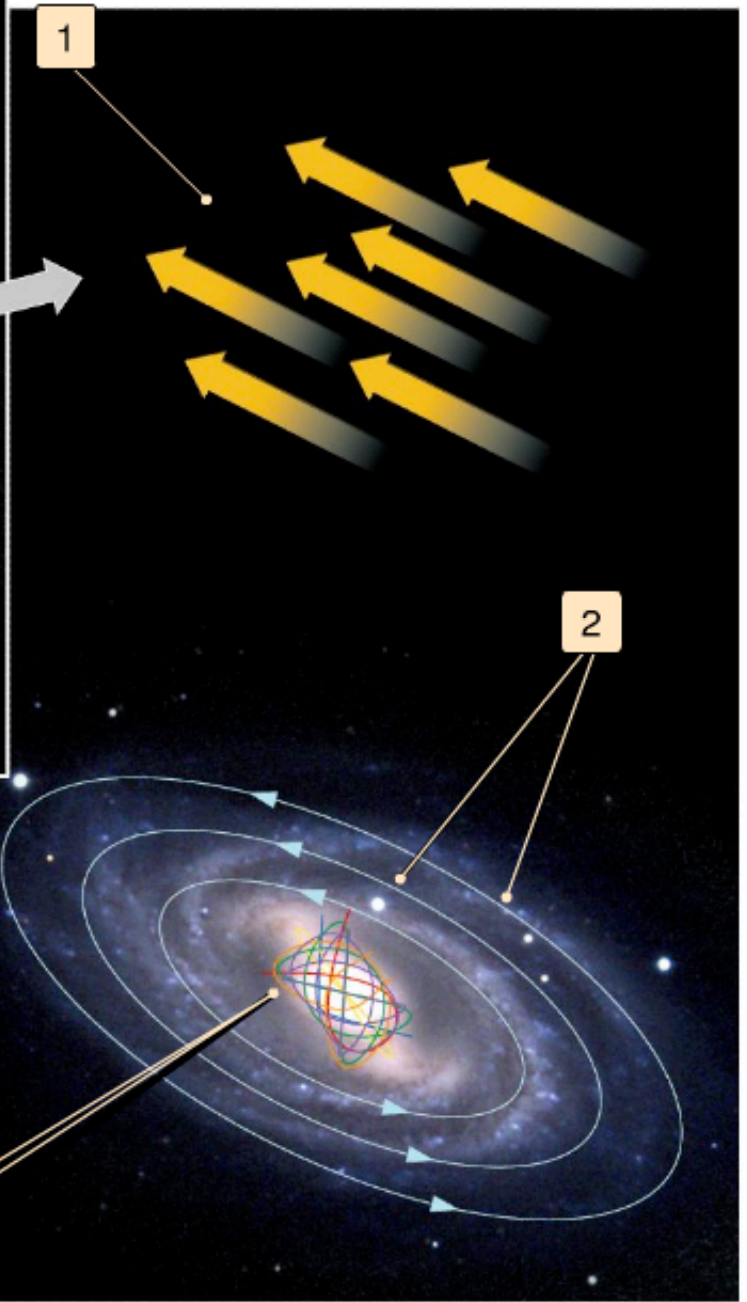
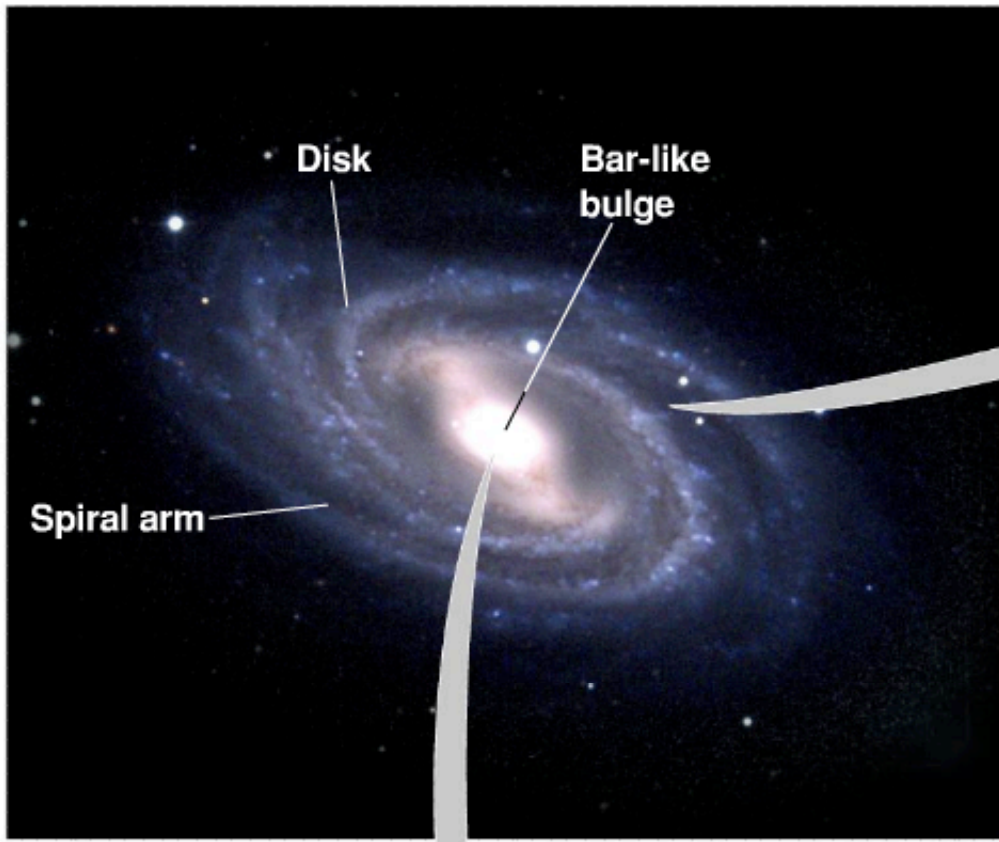


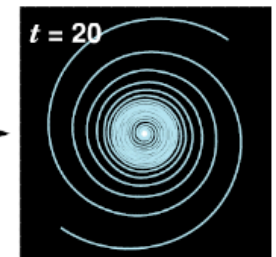
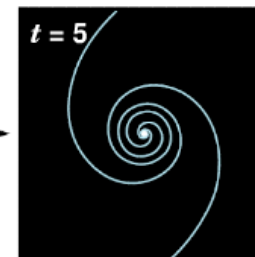
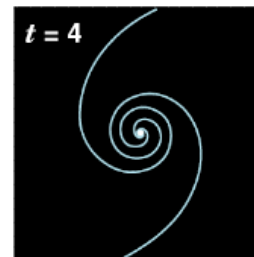
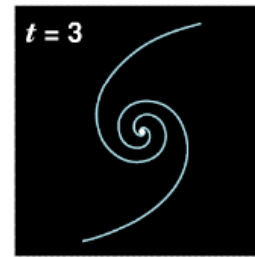
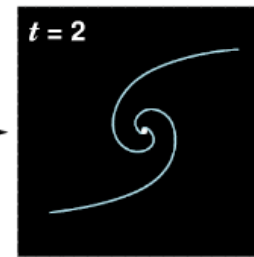
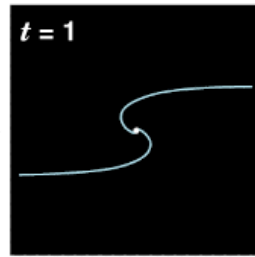
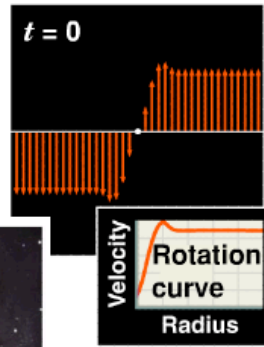
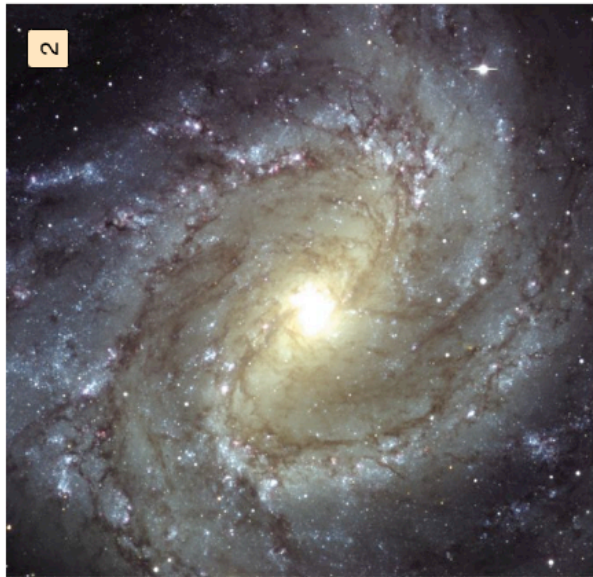


• 2. Rotation Curves.

- A rotation curve is a plot of the velocities of stars or gas in a galaxy versus distance from the center (see illustration in the figure on the right). It can be used to find the mass of spiral galaxies, including the Milky Way. The mass can be found by applying Kepler's and Newton's laws, just as the mass of the Sun can be found by measuring the orbital periods of the planets and their distances from the Sun. Note however that **the mass that one determines by measuring the velocity of a gas cloud or a star in the disk of a spiral galaxy is the mass contained within the circle made by the orbit of that object.** To find the total mass of a galaxy one has to measure the velocity and distance from the center of an object (gas cloud or star) at the edge of the disk of the galaxy.



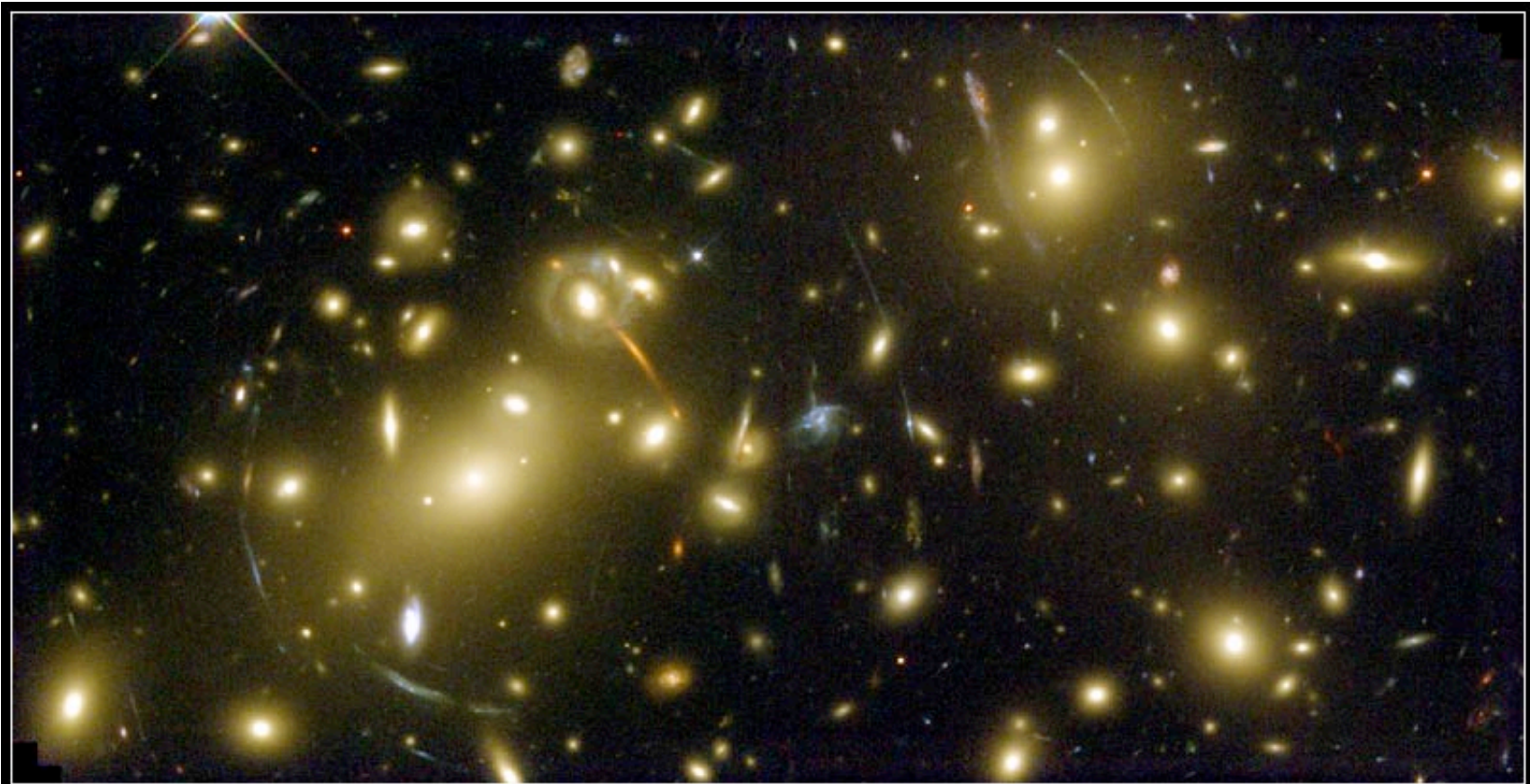




3

4

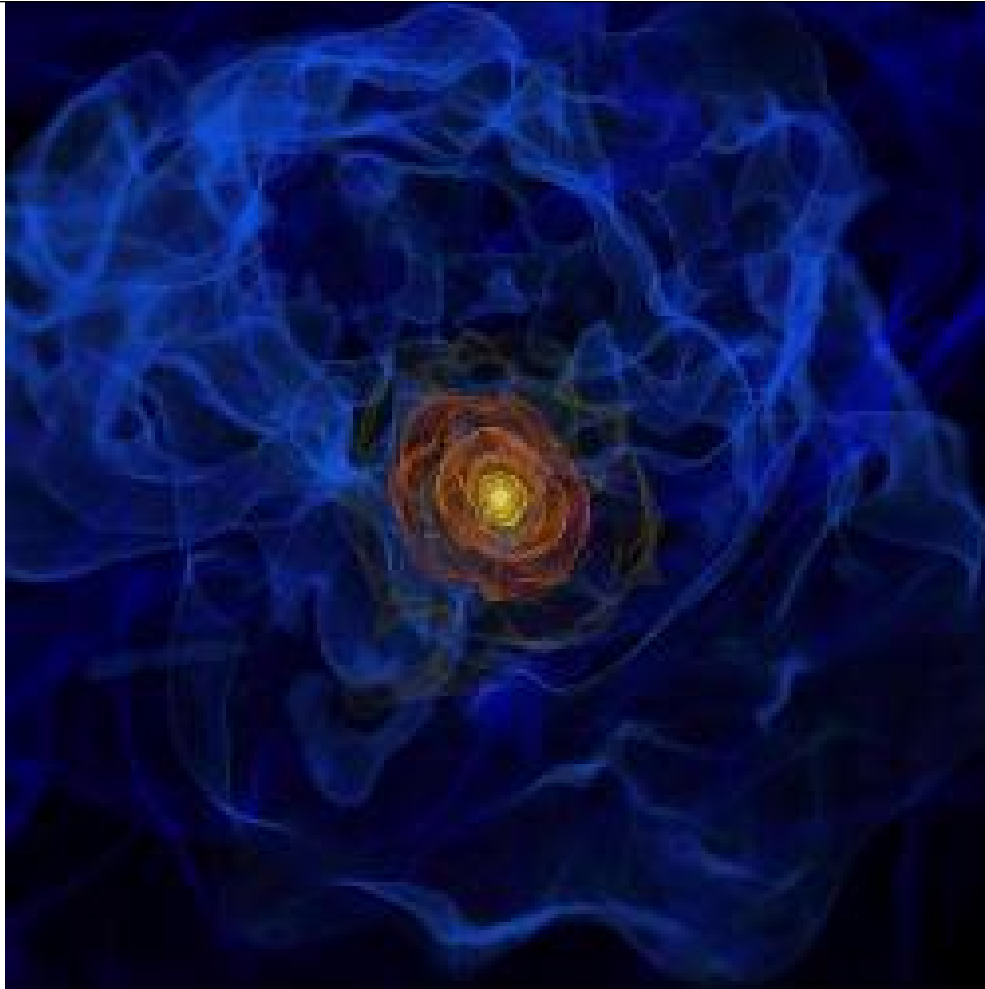
Dark Matter “seen” with your naked eye gravitational lenses



Galaxy Cluster Abell 2218

HST • WFPC2

NASA, A. Fruchter and the ERO Team (STScI, STECF) • STScI-PRC00-08



Cosmology