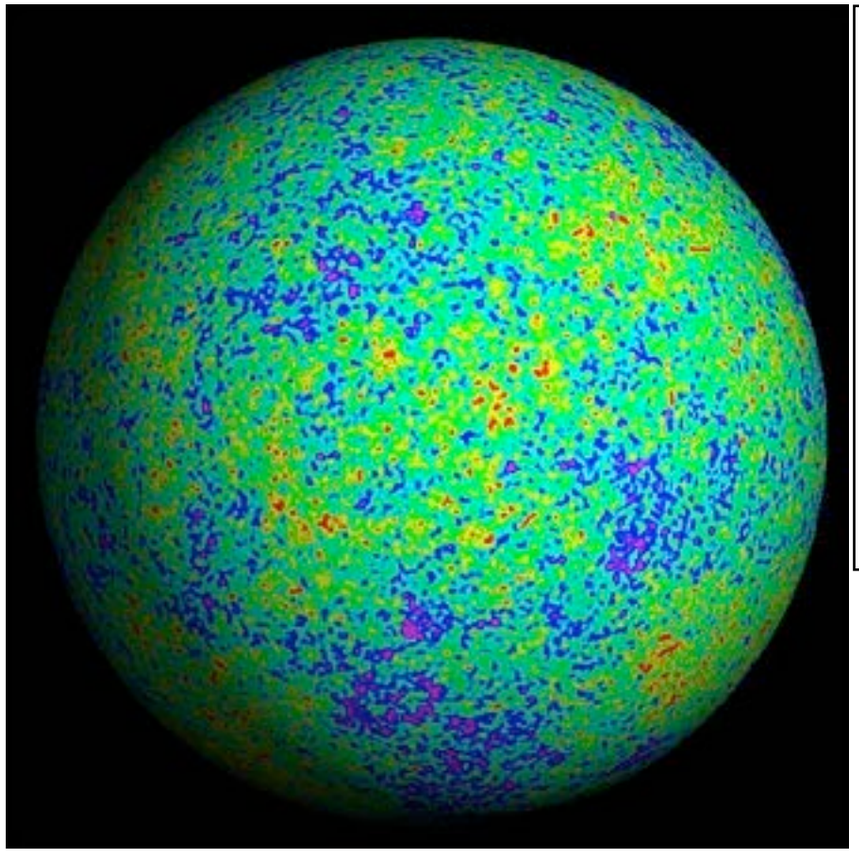
Lecture 7: origin of complexity II, galaxies

How big is the visible universe?
13 Billion l.yr? or 40 billion l.yr?
http://www.youtube.com/watch?v=vJayxpt482g

Initial conditions for the universe (post CMB)



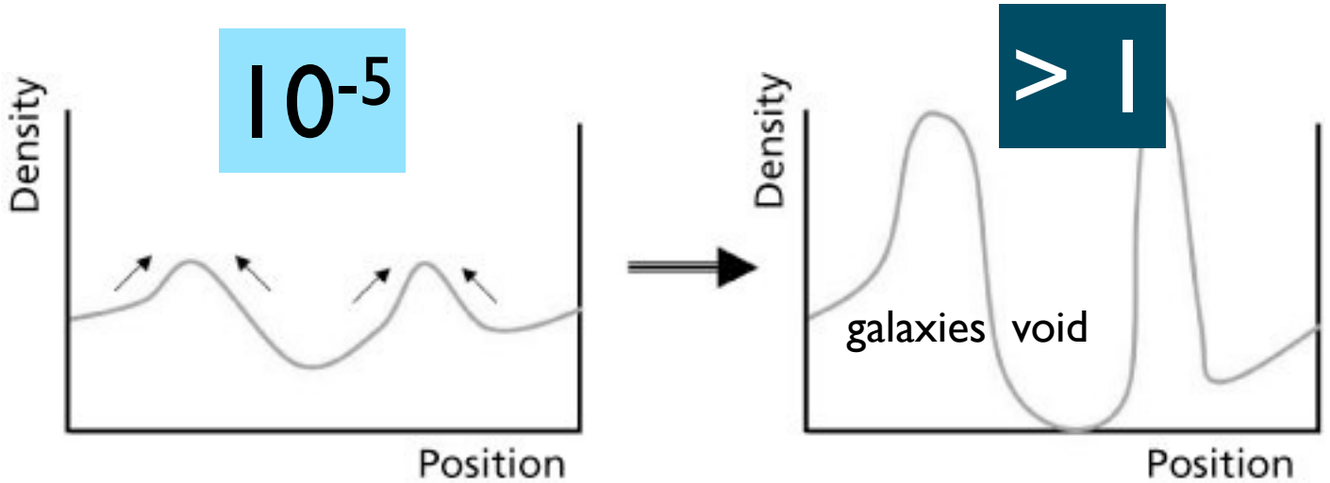
$\Omega_{tot} = 1$ +/- 0.01
T ~ 3000K
matter (dark matter + sprinkle baryons)
10^{-5} level density fluctuations
75% H + 25% Helium

anthropic concerns:

enough time to form galaxies/stars before torn apart?
enough time to accumulate metal for planets?
enough time to make life and evolve life?
enough time to prepare for the final exam?

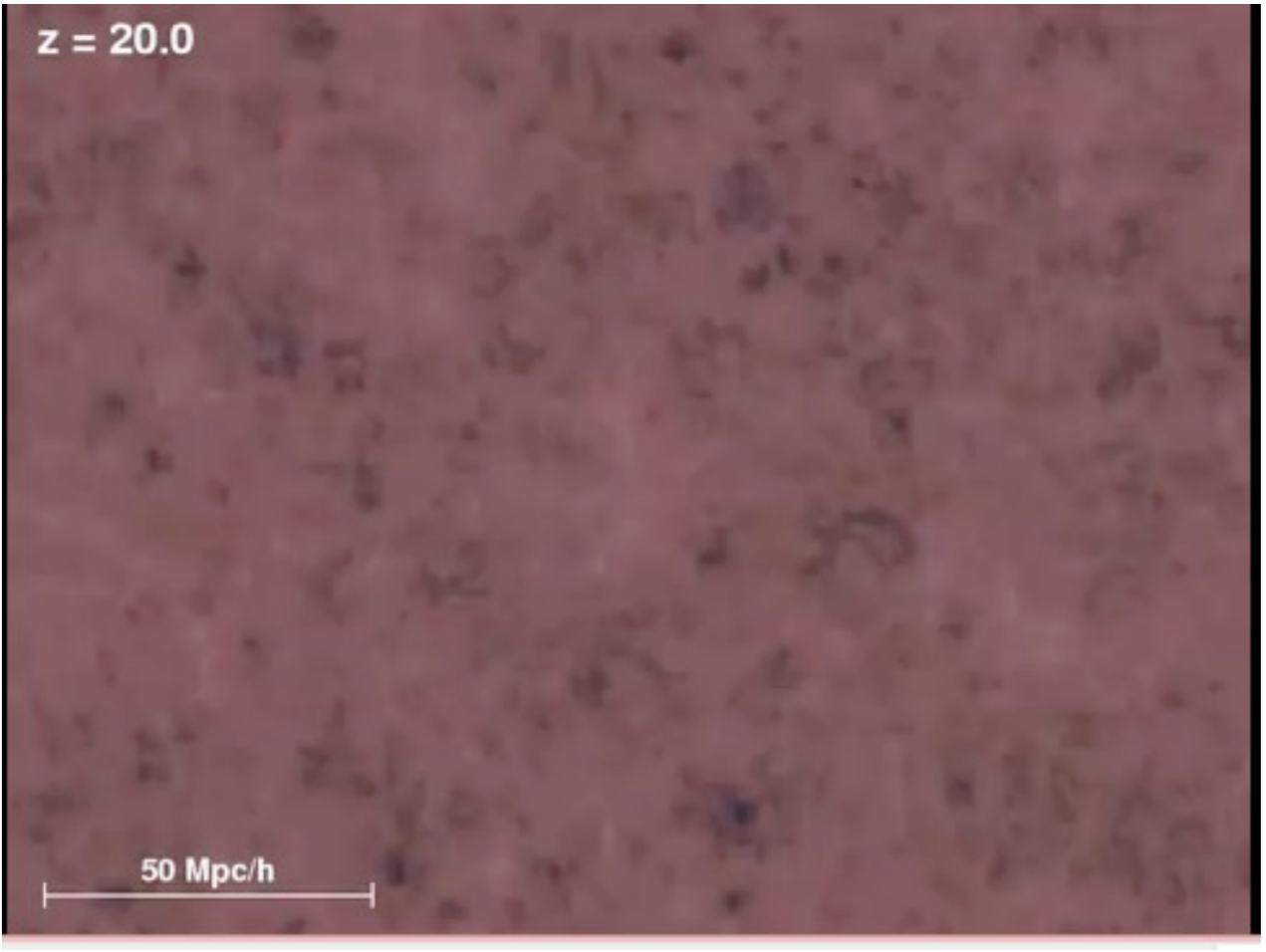
Gravity took over ever since the early universe

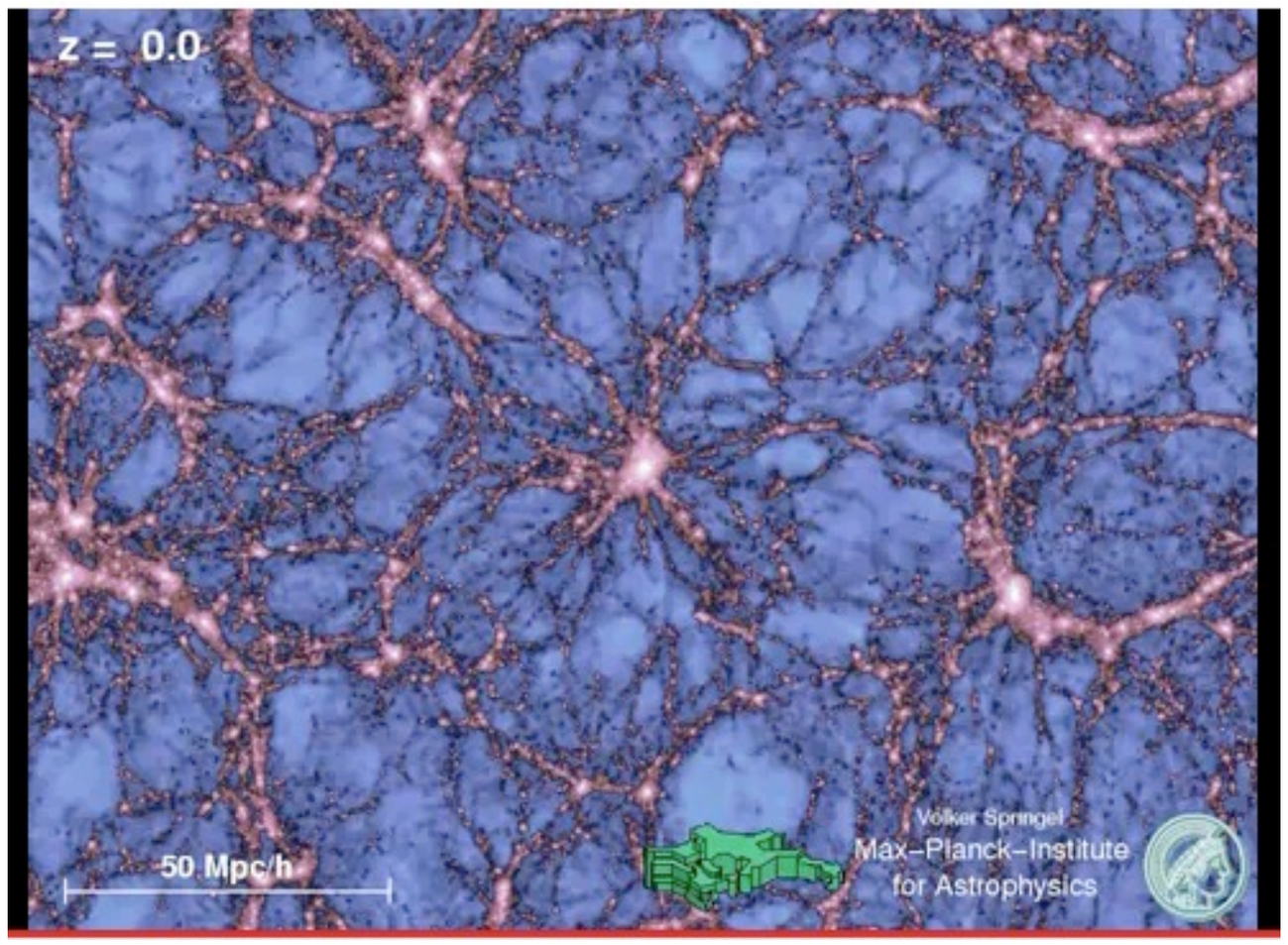
magnifying tiny primordial fluctuations



gravity causes primordial density fluctuations to self-amplify, allowing complex structure to rise

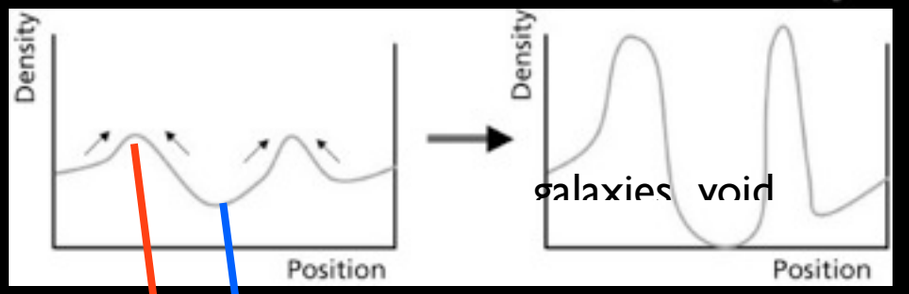
The Millennium Simulations (the largest modelling of our universe)





Answer: *Gravitational Instability*

Low density—universe expands forever



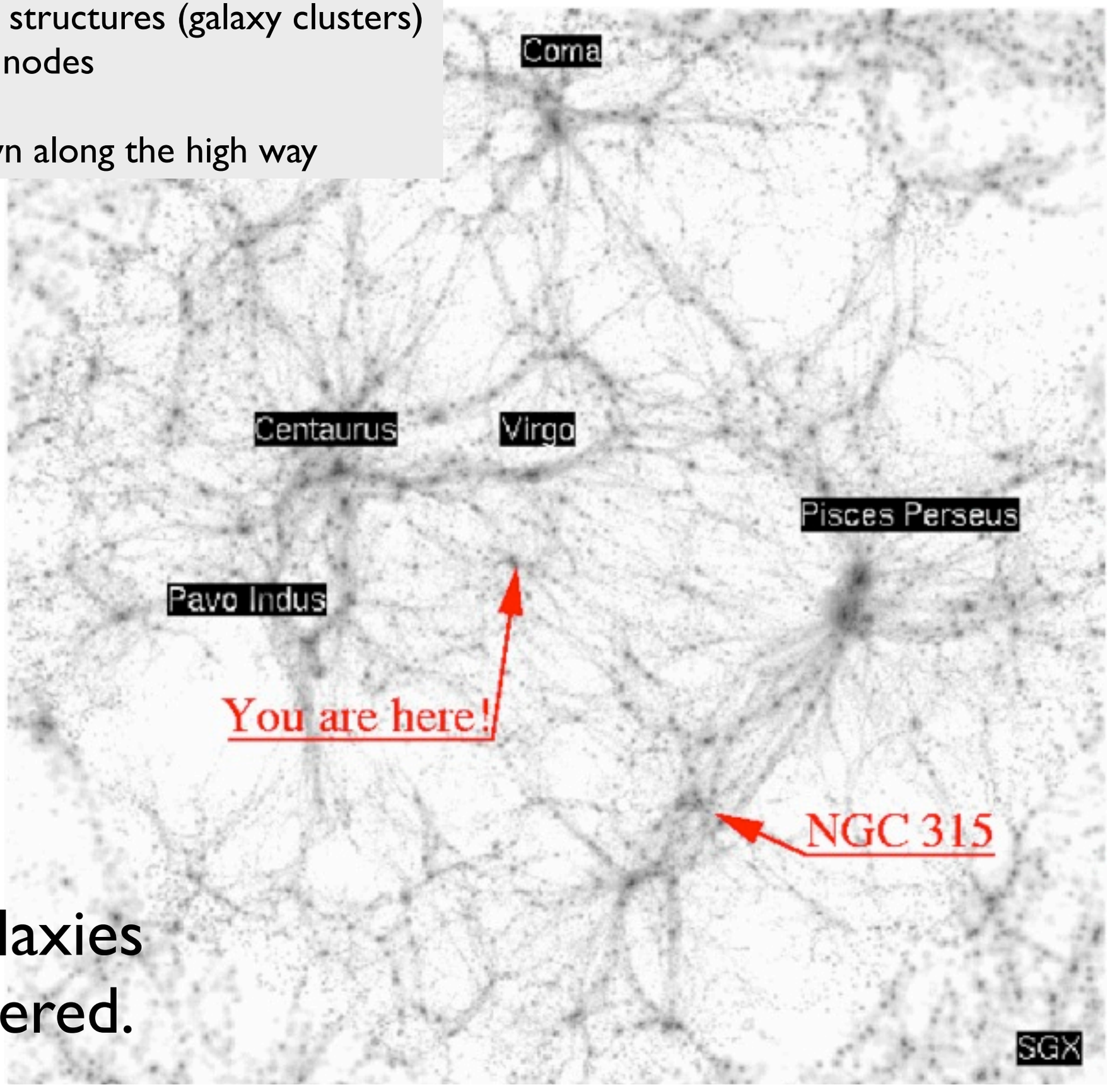
High density—universe collapses

Time

Big Bang

Simulation results

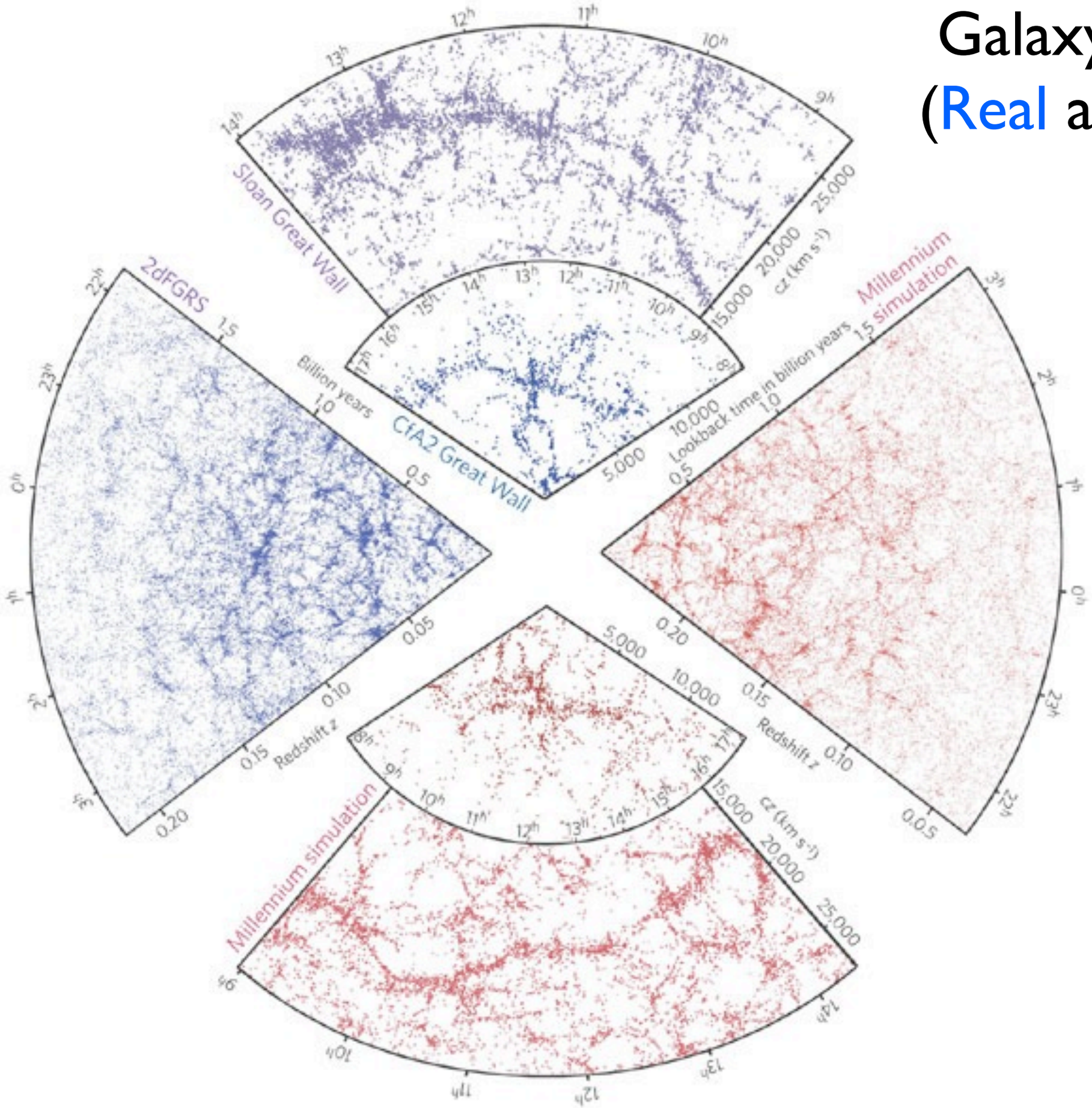
- A galaxy is a tiny node.
- Galaxies cluster to form bigger structures (galaxy clusters)
- filaments of matter connecting nodes
- large regions of 'Voids'
- we are a little "gas station" town along the high way



Gravity causes galaxies to be highly clustered.

people gravitate to cities, highways feed the cities (w/ people, fuel...)

Galaxy distribution (Real and Simulated)



'Cosmic Concordance' (or 'standard cosmological model')

$\Omega_{tot} = 1$

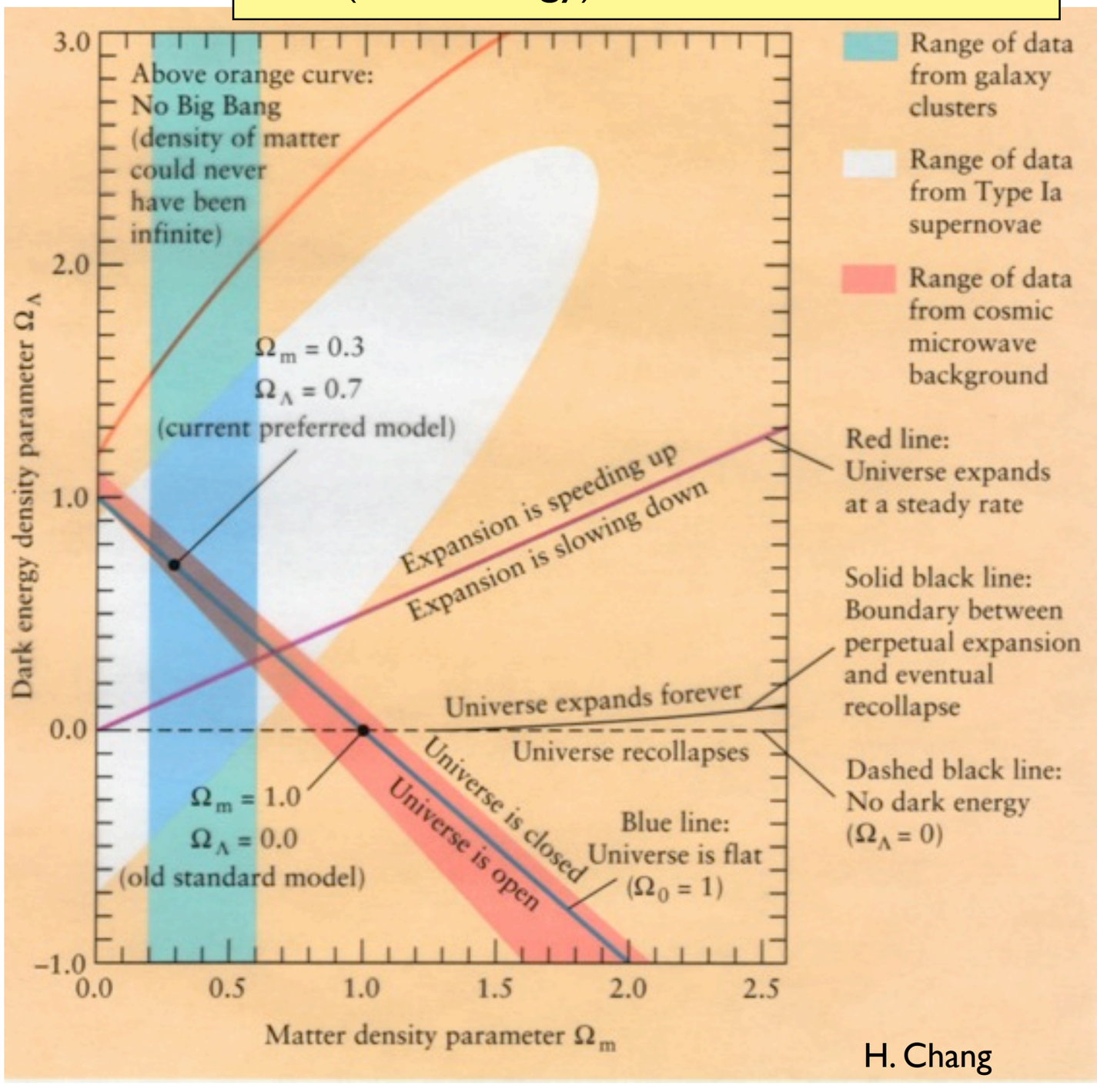
Ω_{matter} (dark matter + baryon) ~ 0.3

Ω_{Λ} (dark energy) ~ 0.7

- by comparing statistics of galaxy clusters (how tightly clustered, how rich...) against simulations, we can also measure the total matter density

- the value obtained concurs with that from looking at the CMB ($\Omega_m+\Omega_\Lambda = 1$) and at supernova

- there appears to be a consensus about the universe from diverse measurements



H. Chang

Origin of the Milky Way Galaxy

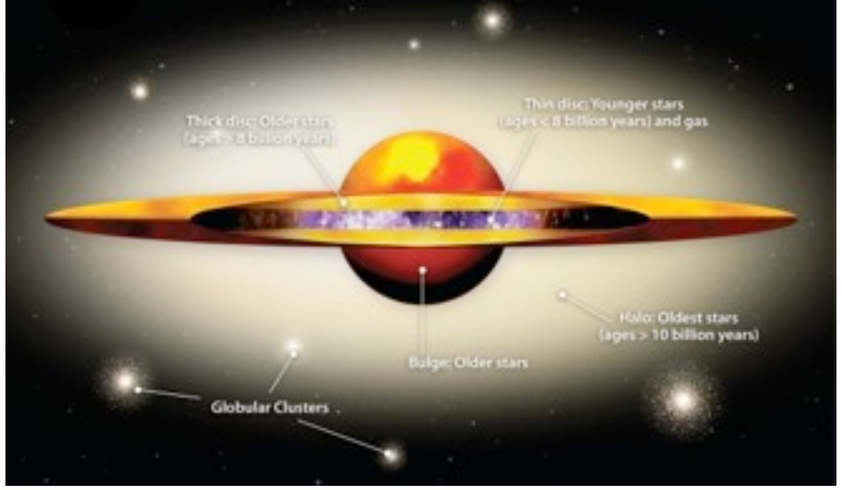
- The Milky Way is a Spiral Galaxy.
- Most stars in the Milky Way are ~ a few Gyrs old.
- A trickle of new stars being made (~ 2 M_{sun}/yr).
- Stars can be sorted into a disk, a bulge and a halo.
- The dark matter looms far out (90% of the mass)

How does the sky look inside a galaxy?

Artist's conception

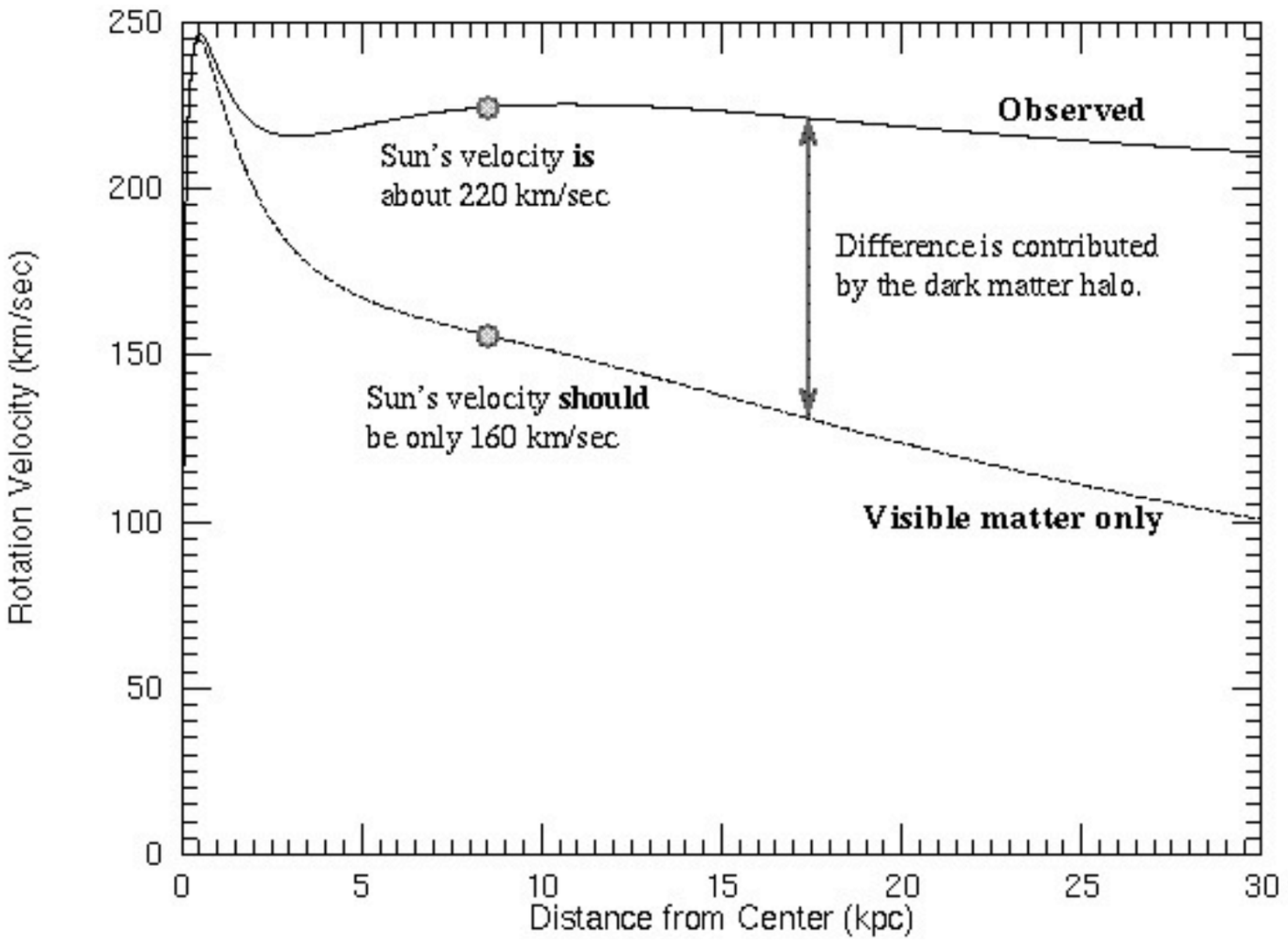
Stars in the Milky Way Galaxy

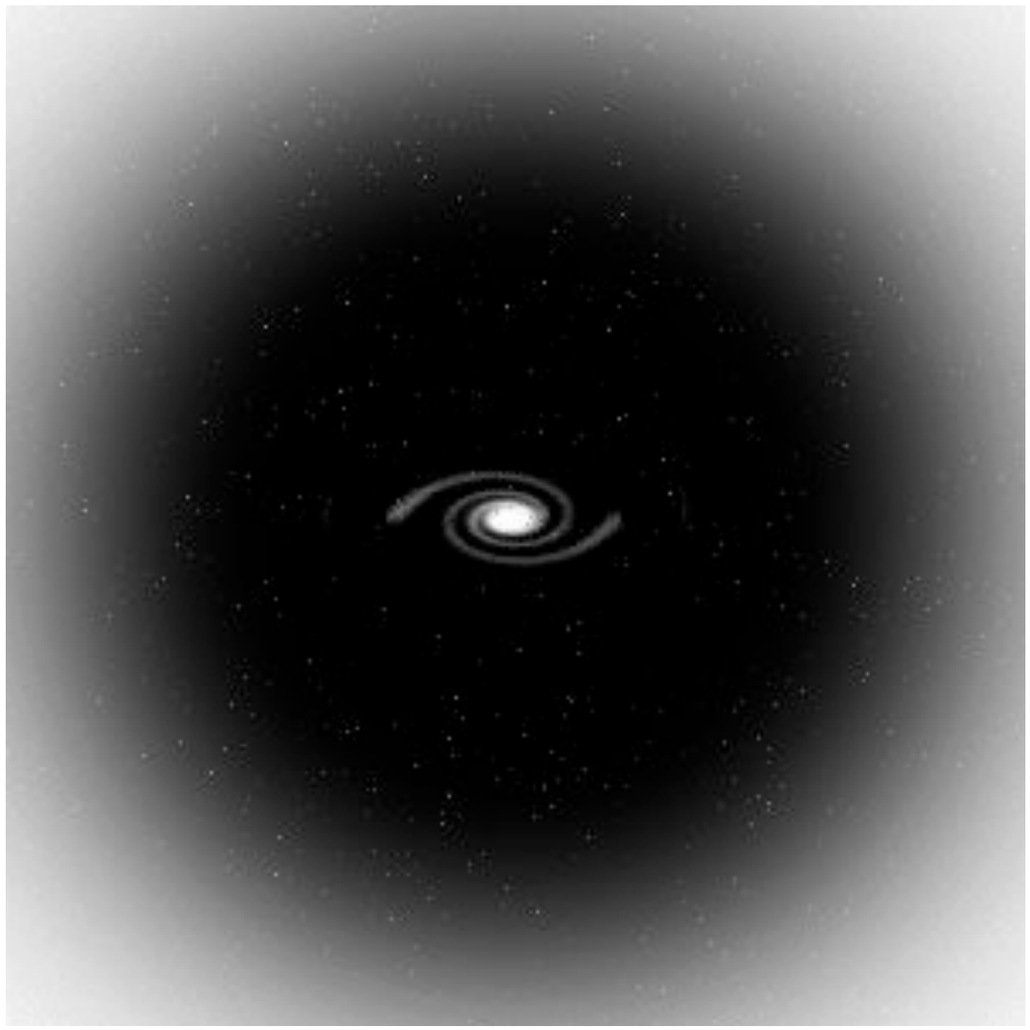
3 stellar components with different ages and kinematics



	shape	age	star mass	metal	rotating?	
disk	flat	<9 Gyrs	90%	rich	yes	incl. Sun, star forming ~ 2 M_{sun}/yr
halo	spherical	>12 Gyrs	1%	very poor	isotropic orbits	globular clusters & dark matter
bulge	spherical	> 10 Gyrs	9%	very rich	~yes	close to center

Stars @ the centre, dark matter further out.



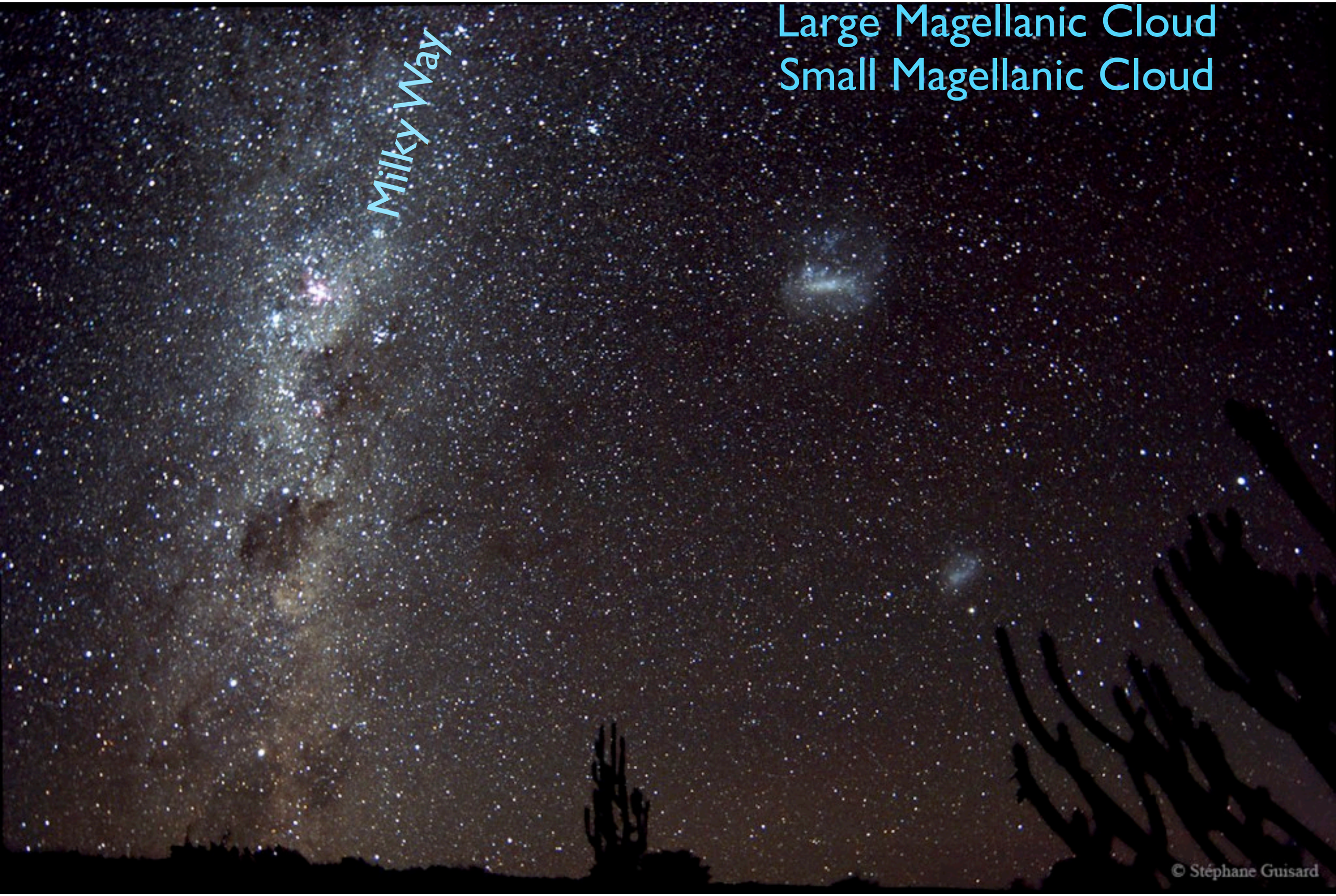


When falling into the potential well of a galaxy,

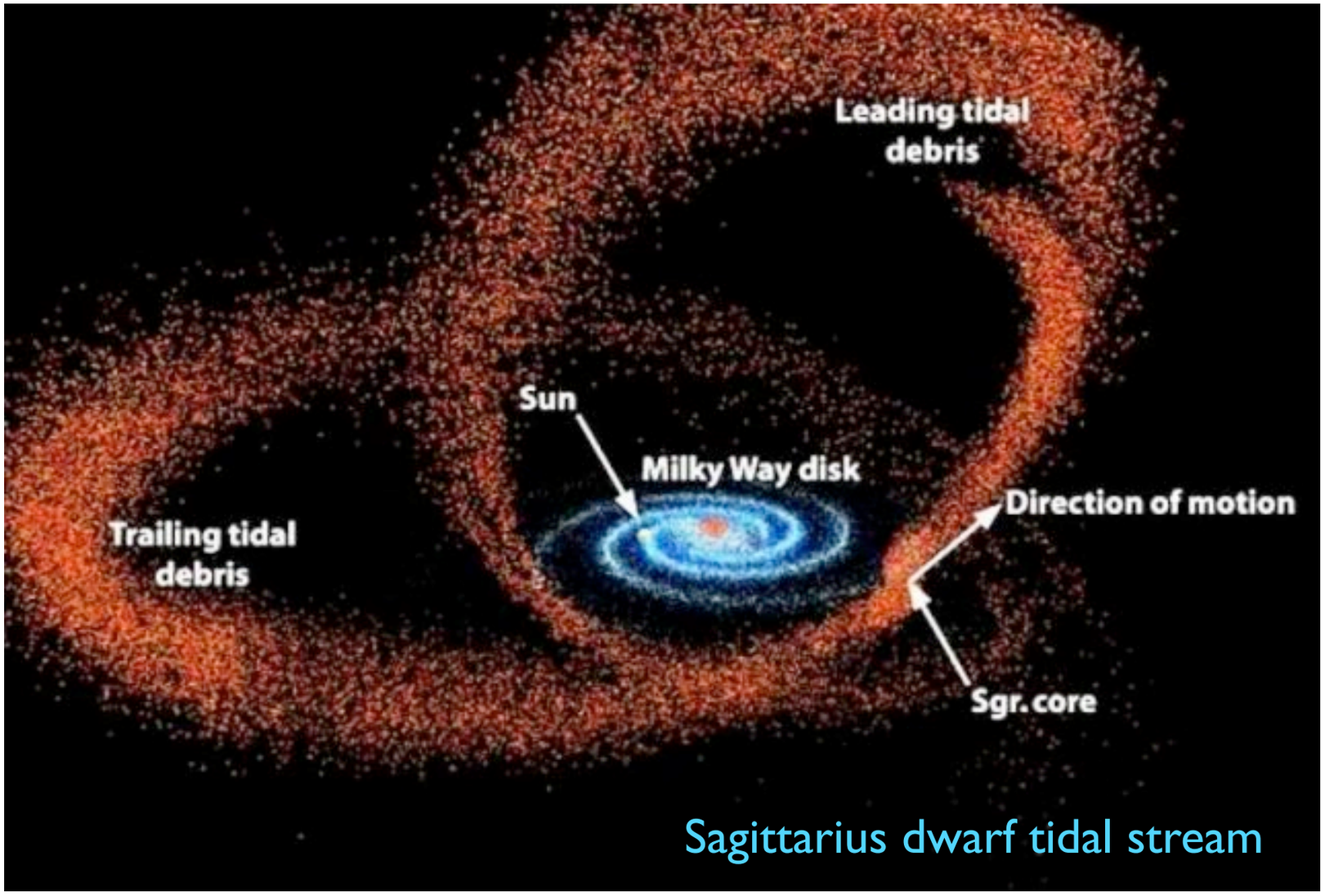
gas: collides and loses angular momentum, forms disk/bulge in the inner part of the galaxy

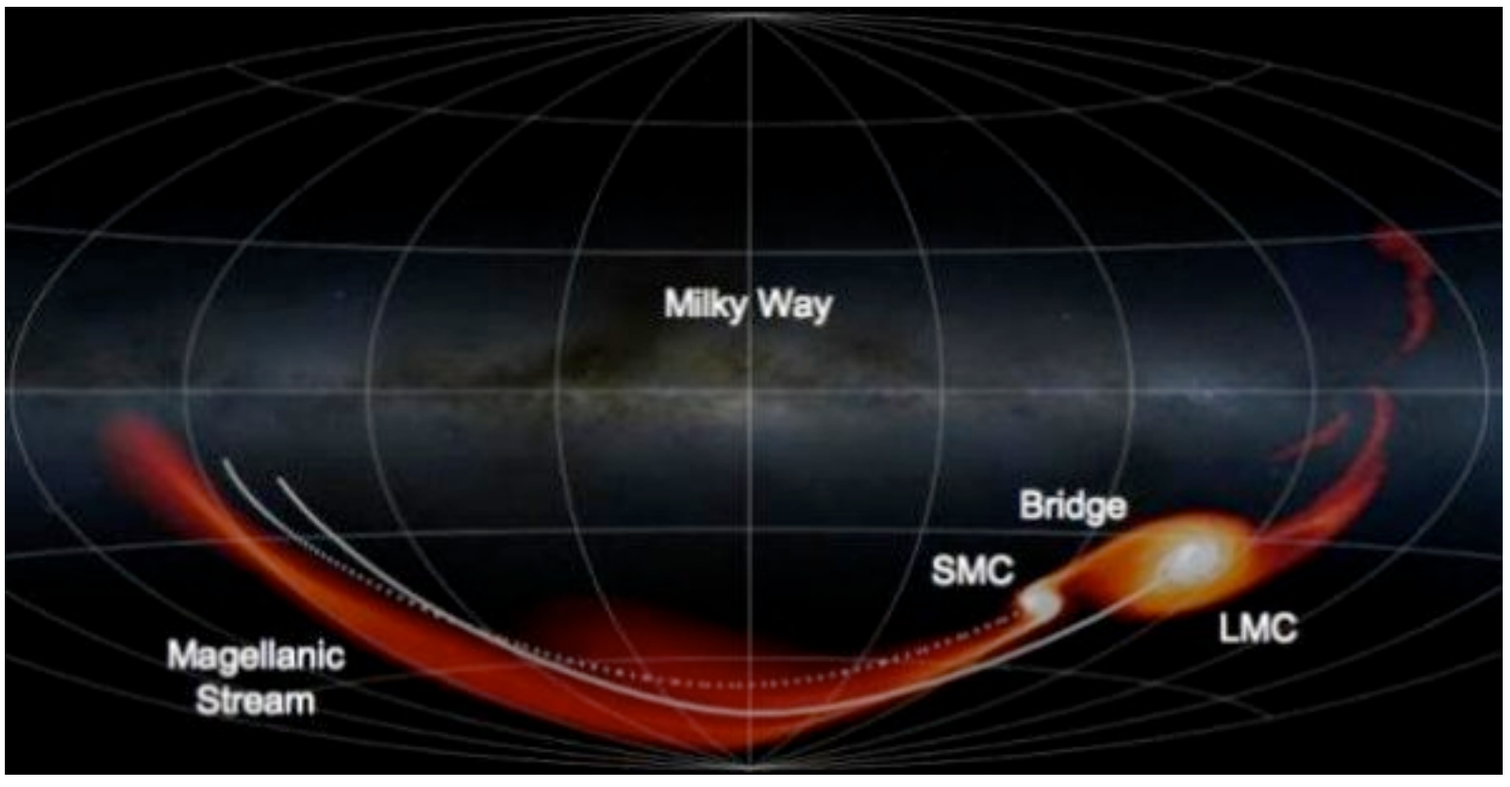
dark matter: no collision, can not lose angular momentum, orbit further out with nearly isotropic velocity dispersion (halo)

We have two large satellite galaxies:



Fate of LMC/SMC





The Milky Way continuously disrupts smaller galaxies and absorbs them

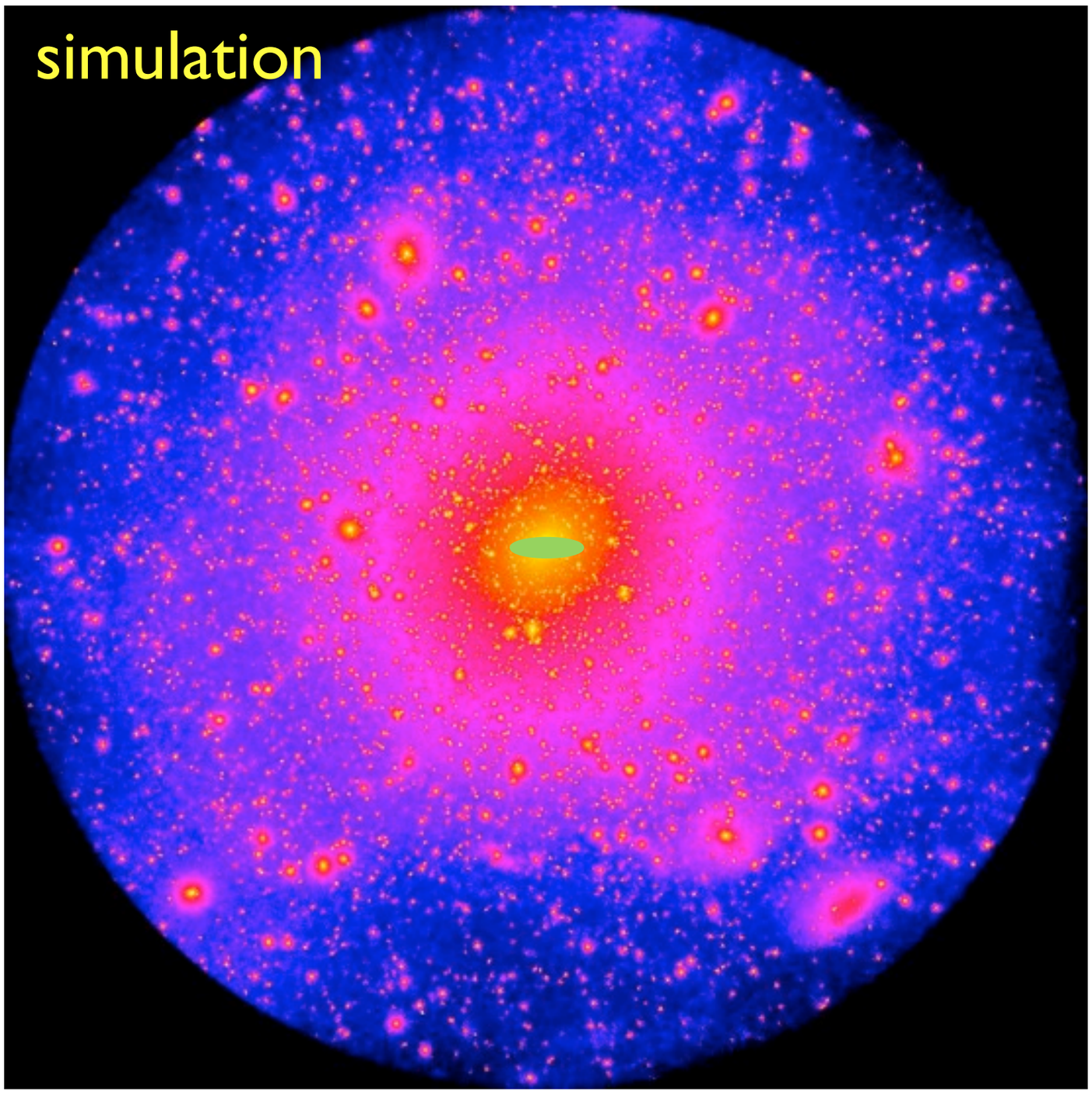
The Sagittarius dwarf galaxy is being ripped apart now -- we see its debris stream.

In the past, many small galaxies have been cannibalized -- the stellar halo.

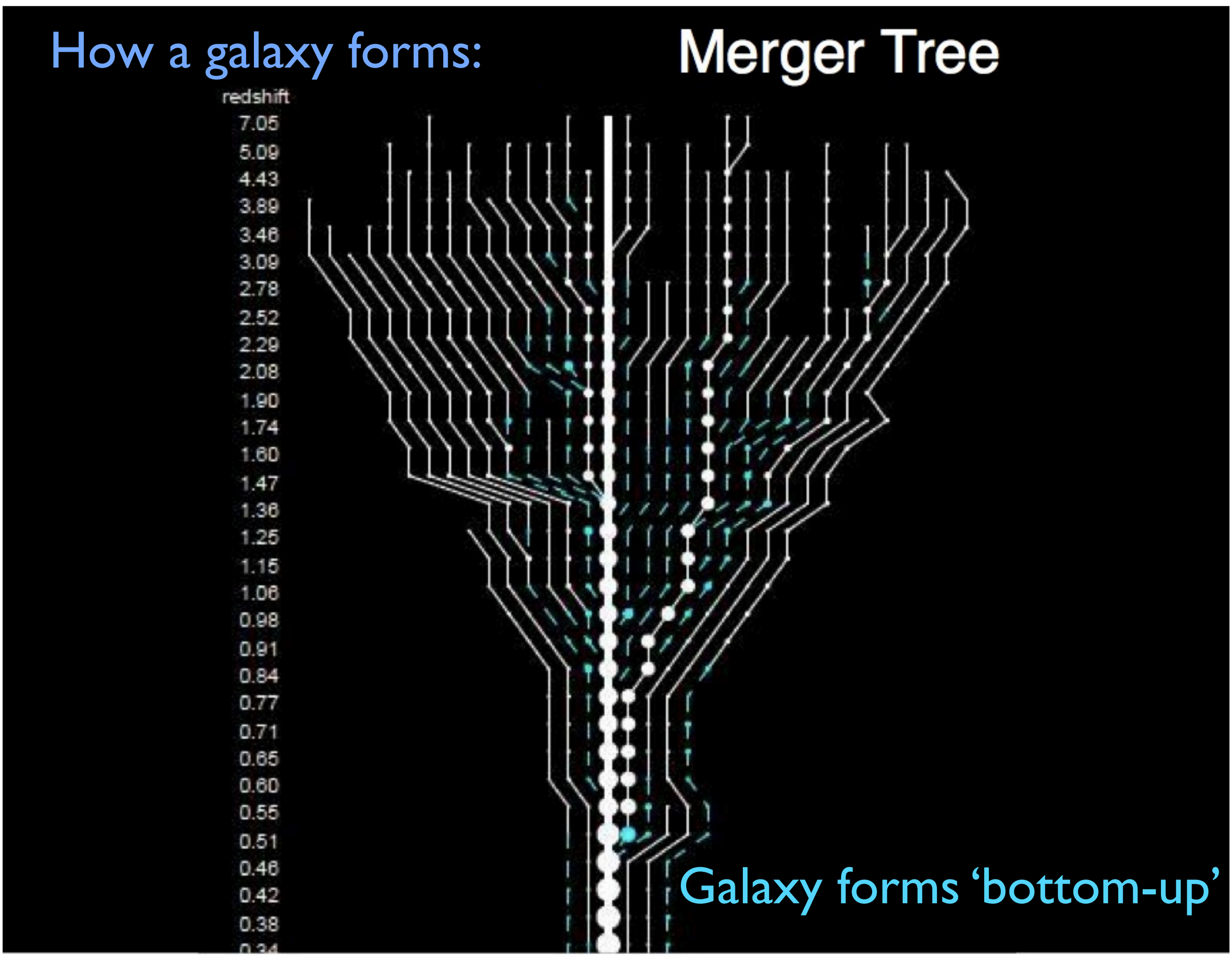
Continuous Consumption of Smaller Galaxies

- newly absorbed galaxies bring along their dark matter,
- dark matter can't dissipate
- the Milky Way acquires a dark matter halo that's full of structure, and memory of the past
- it can be triaxial, it can be lumpy, it can have many streams...

if we can 'see' dark matter...



How a galaxy forms:



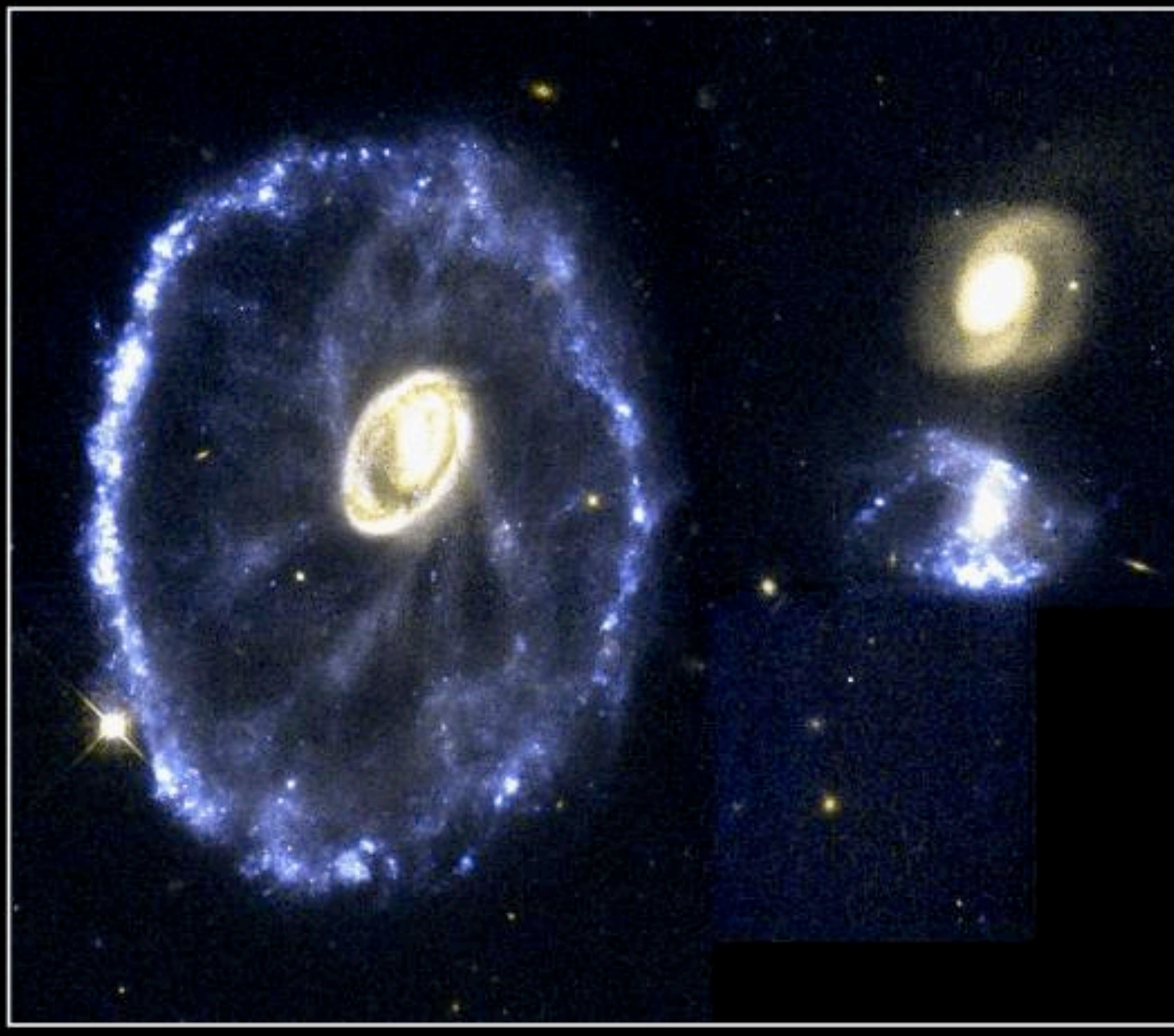
The Milky Way Galaxy will be absorbed as well...

Milk-dromeda?
What about us?

The after-math?

an elliptical galaxy

Galaxy collision is common-place



Cartwheel Galaxy

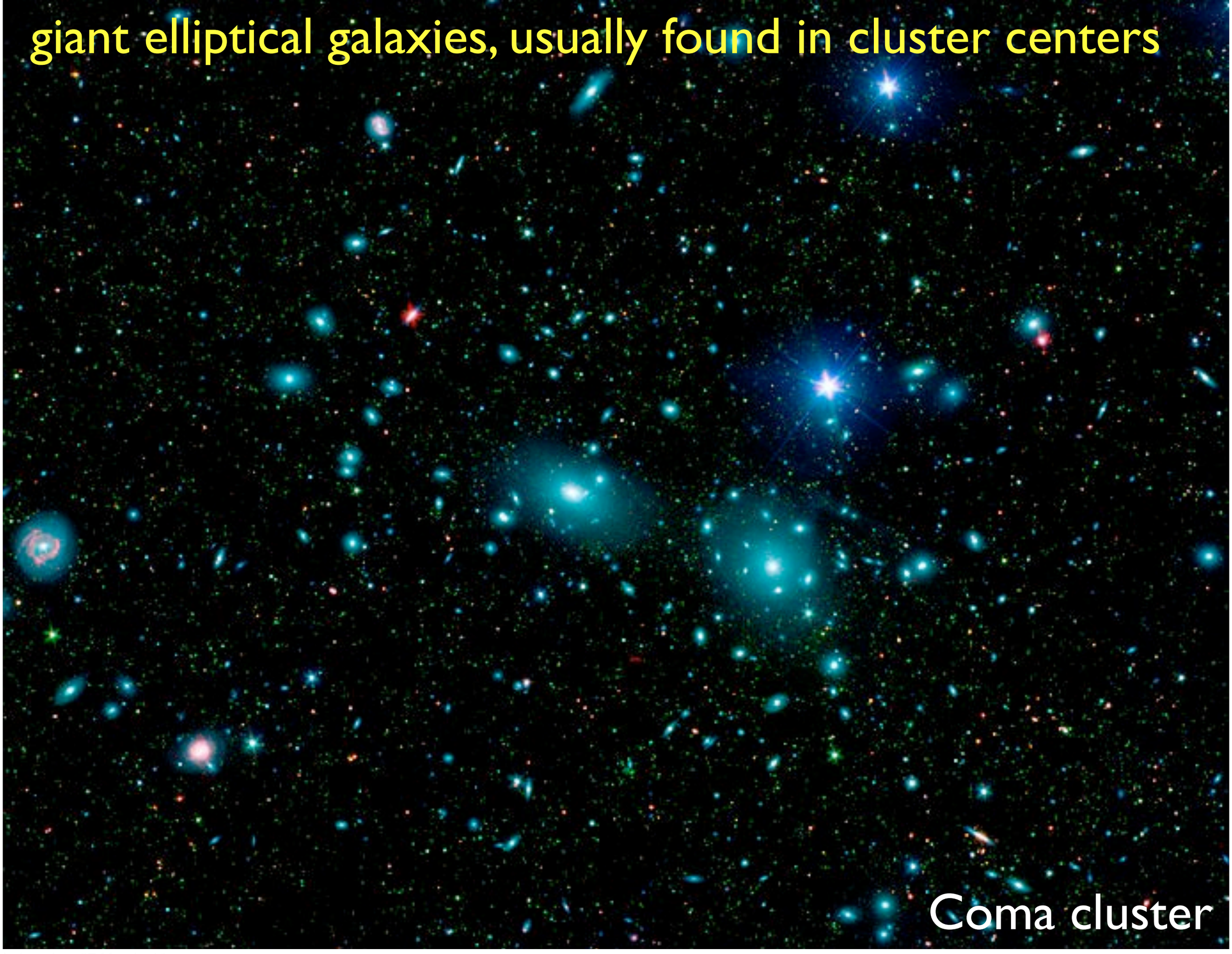
HST · WFPC

PR95-02 · ST ScI OPO · January 1995 · K. Borne (ST ScI), NASA

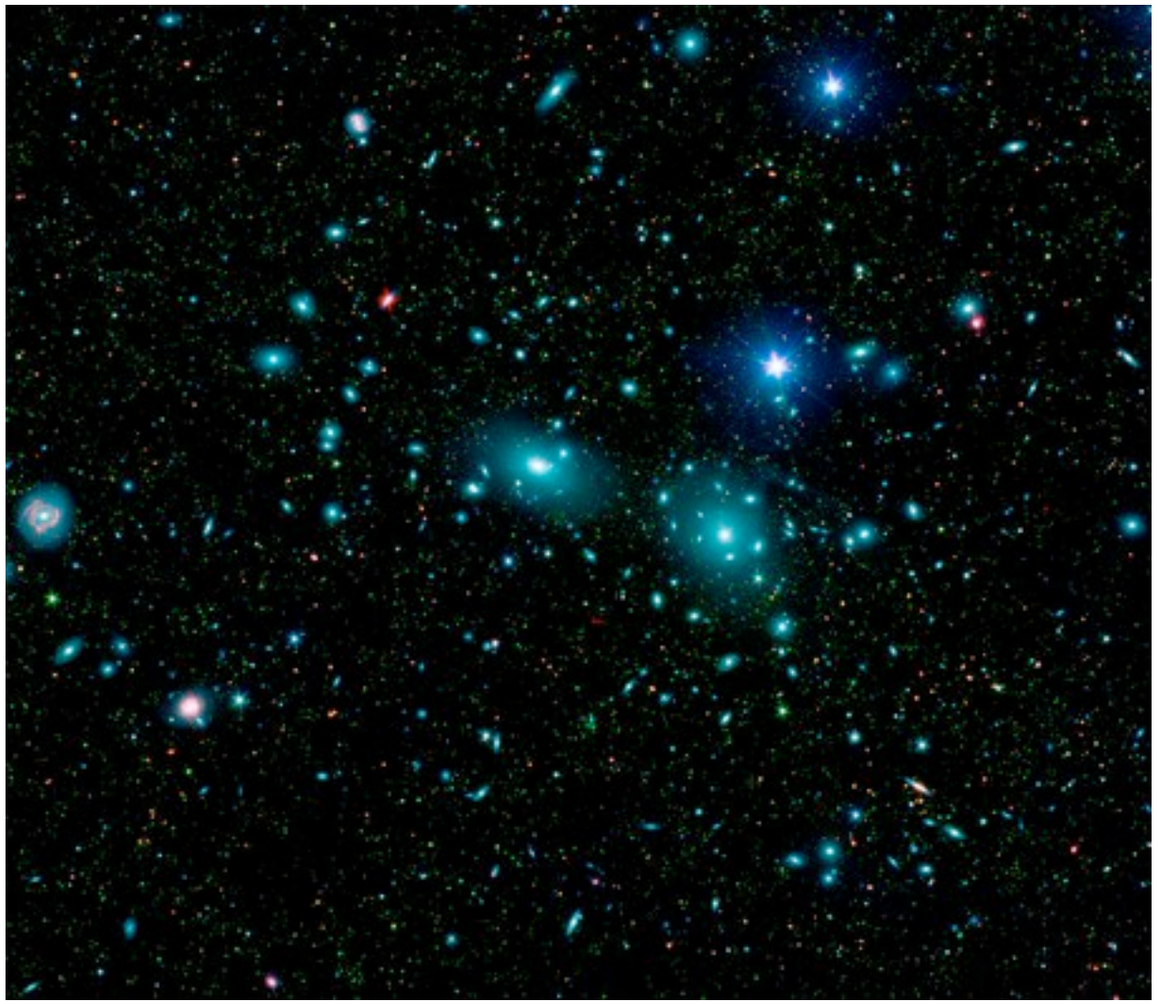
12/23/94

Hubble image of two merging galaxies
Photograph courtesy of Garth Illingworth, UCSC/LO

giant elliptical galaxies, usually found in cluster centers



Galaxies collide all the time. Yet stars rarely do. Why?



size of galaxies ~ 10^4 light-yrs
distance of galaxies~10^6 light-yrs

size of star ~1 light-sec
distance of stars ~ 1 light-yr