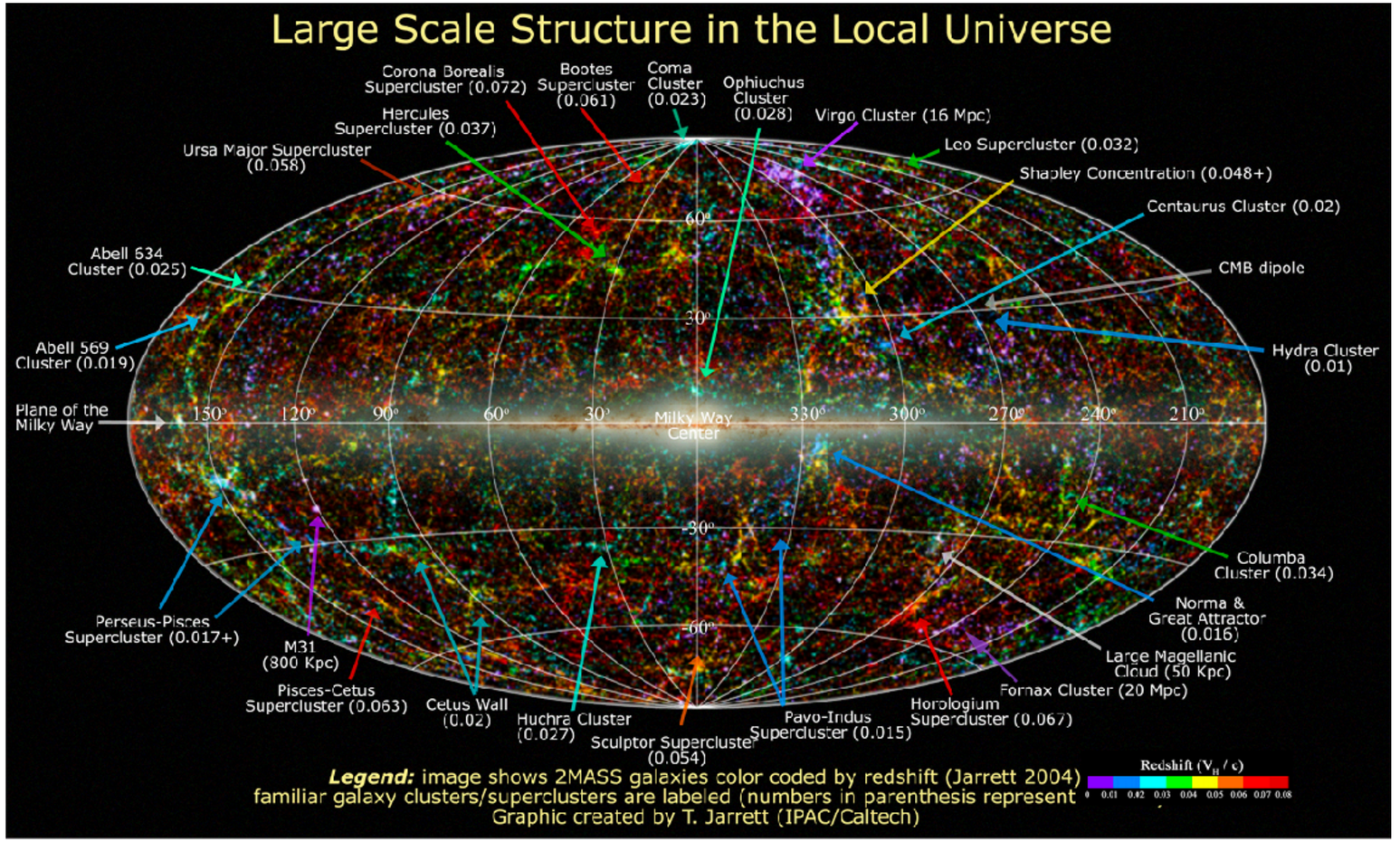
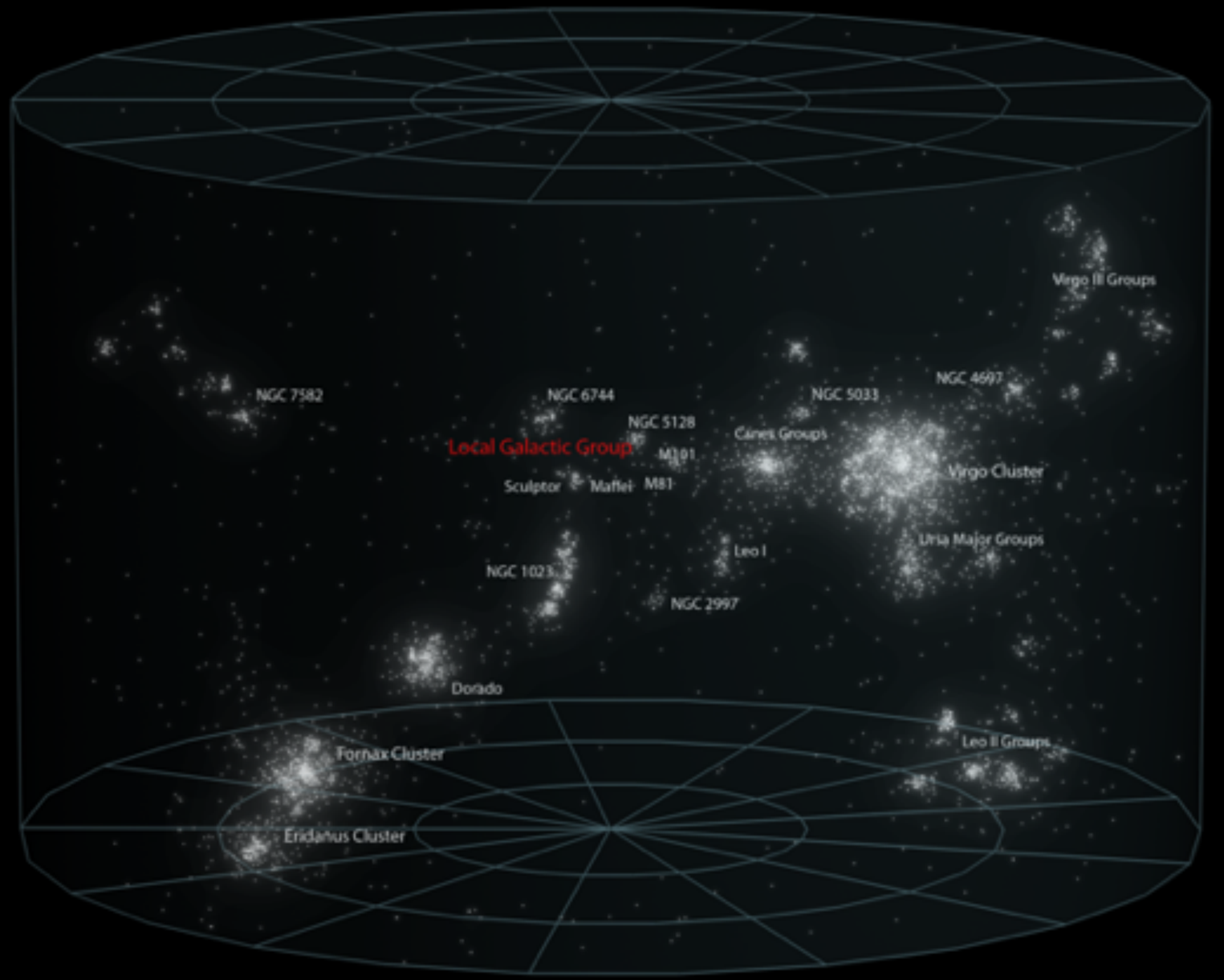
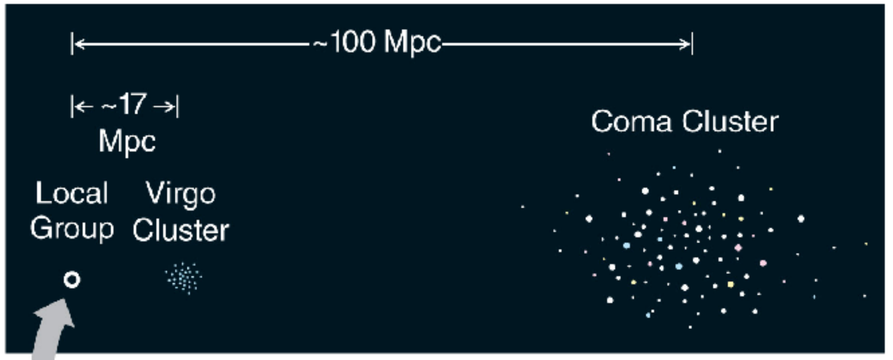
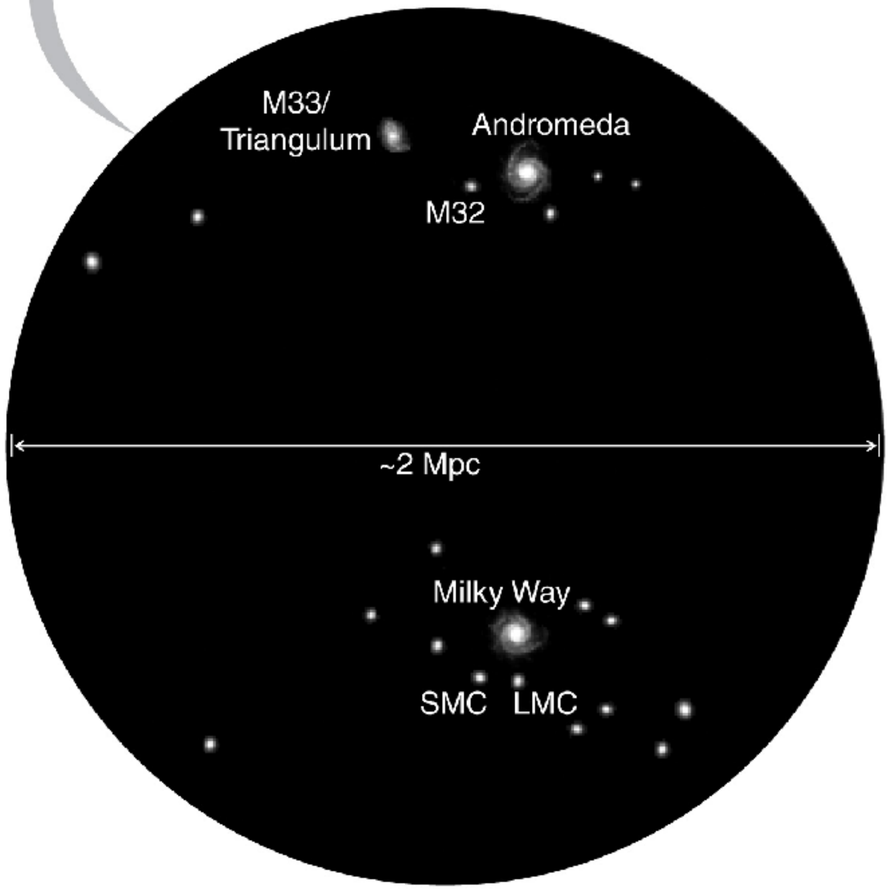
Chapter 17: Large Scale Structure



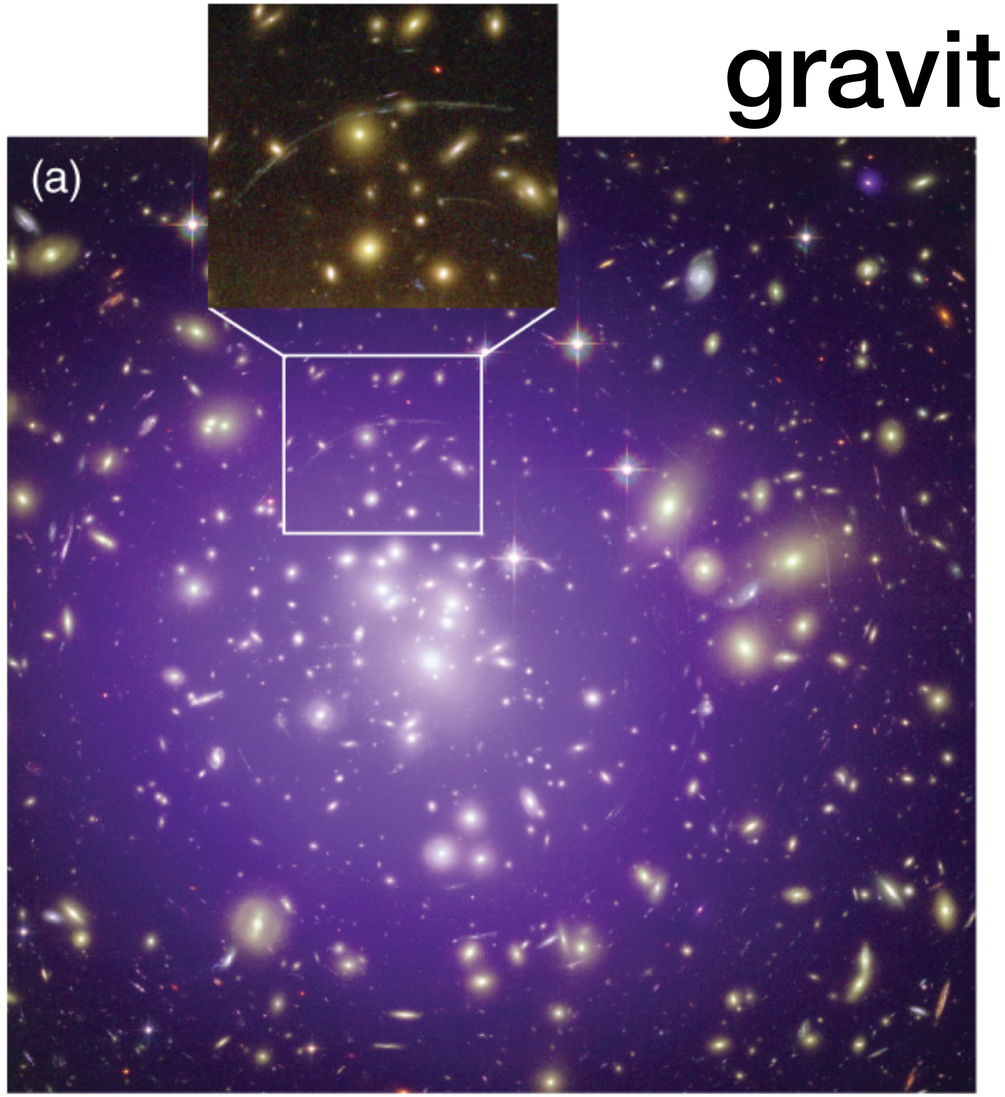
VIRGO SUPERCLUSTER

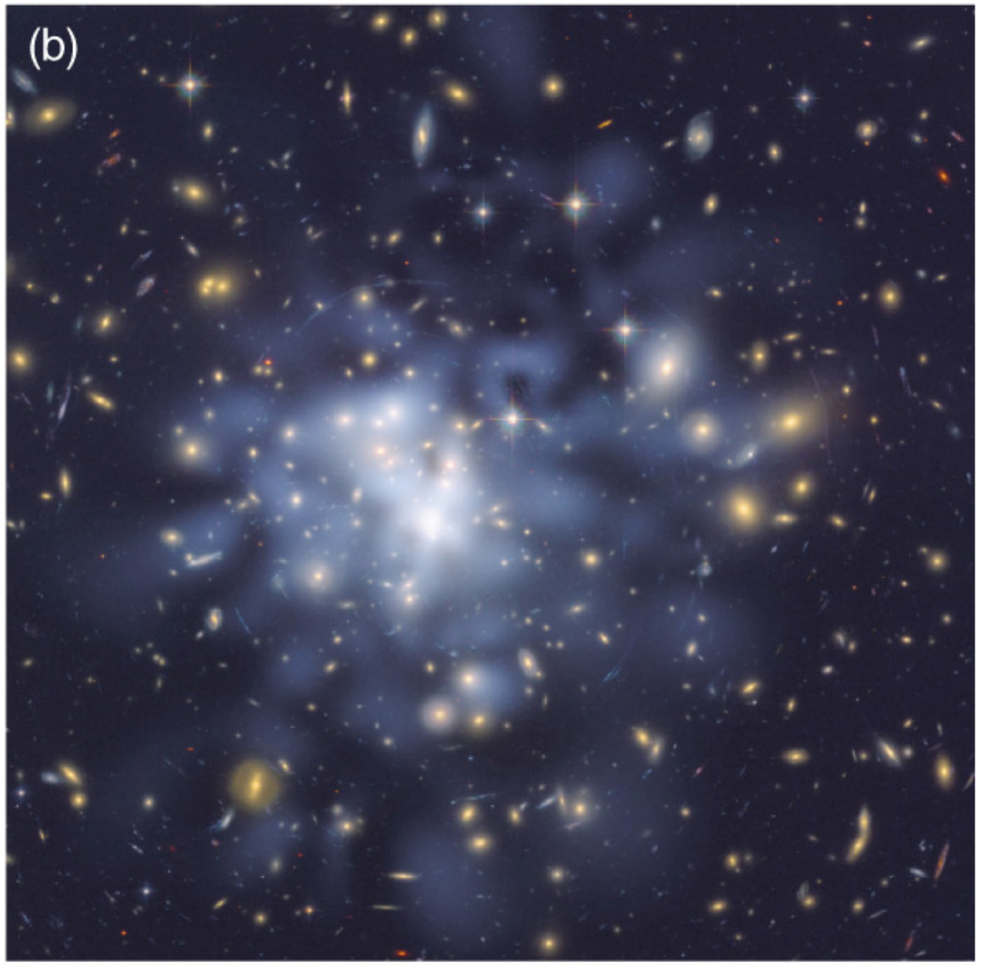




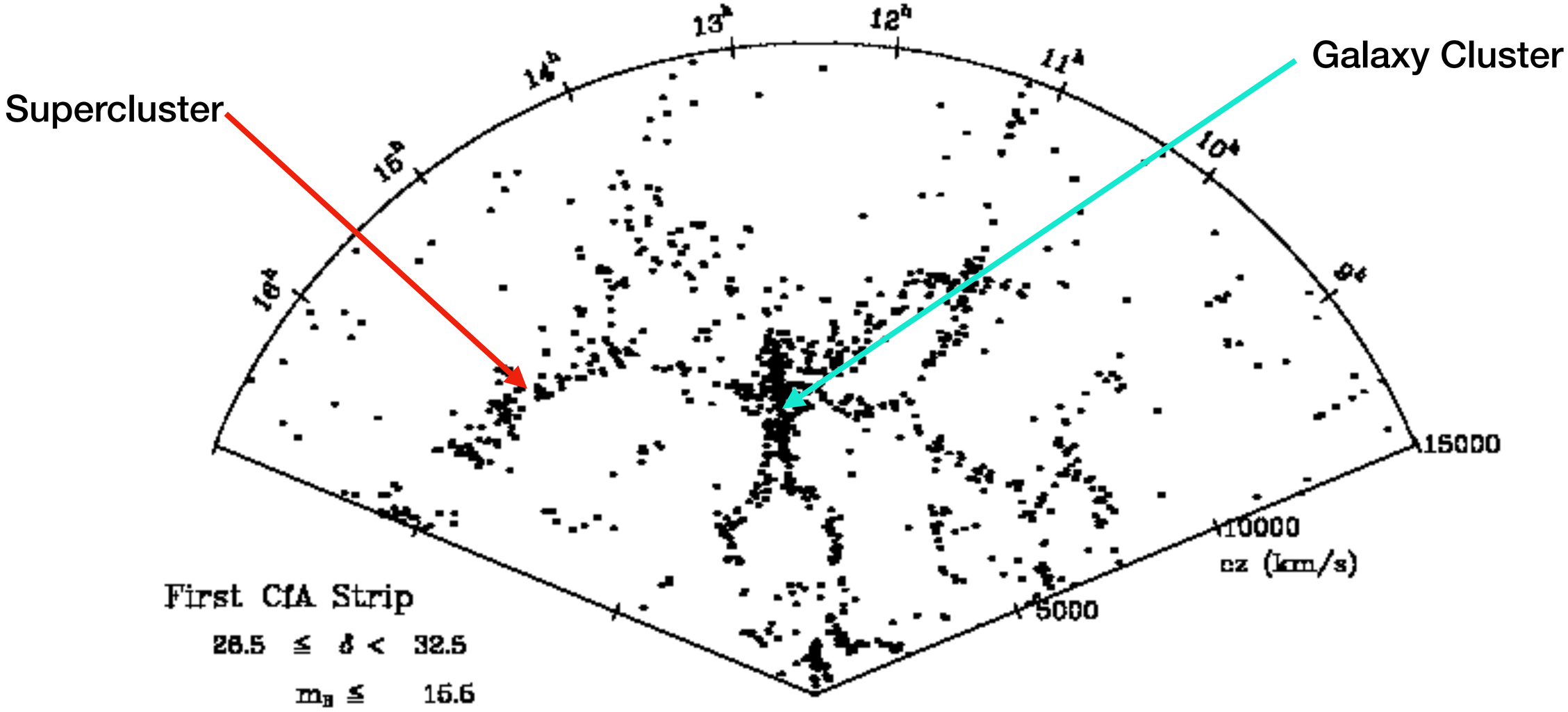


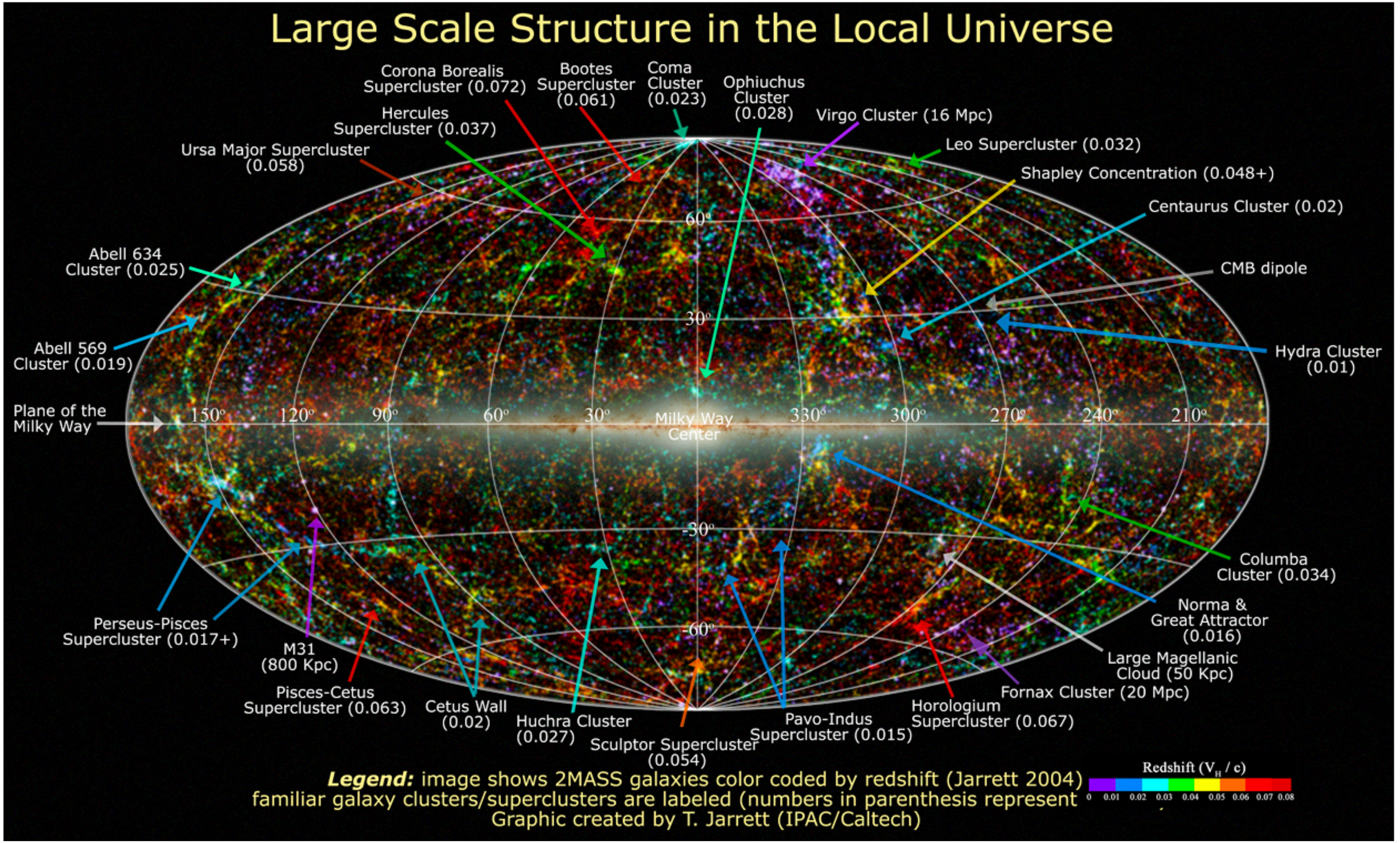
Galaxy Clusters: the largest gravitationally bound objects

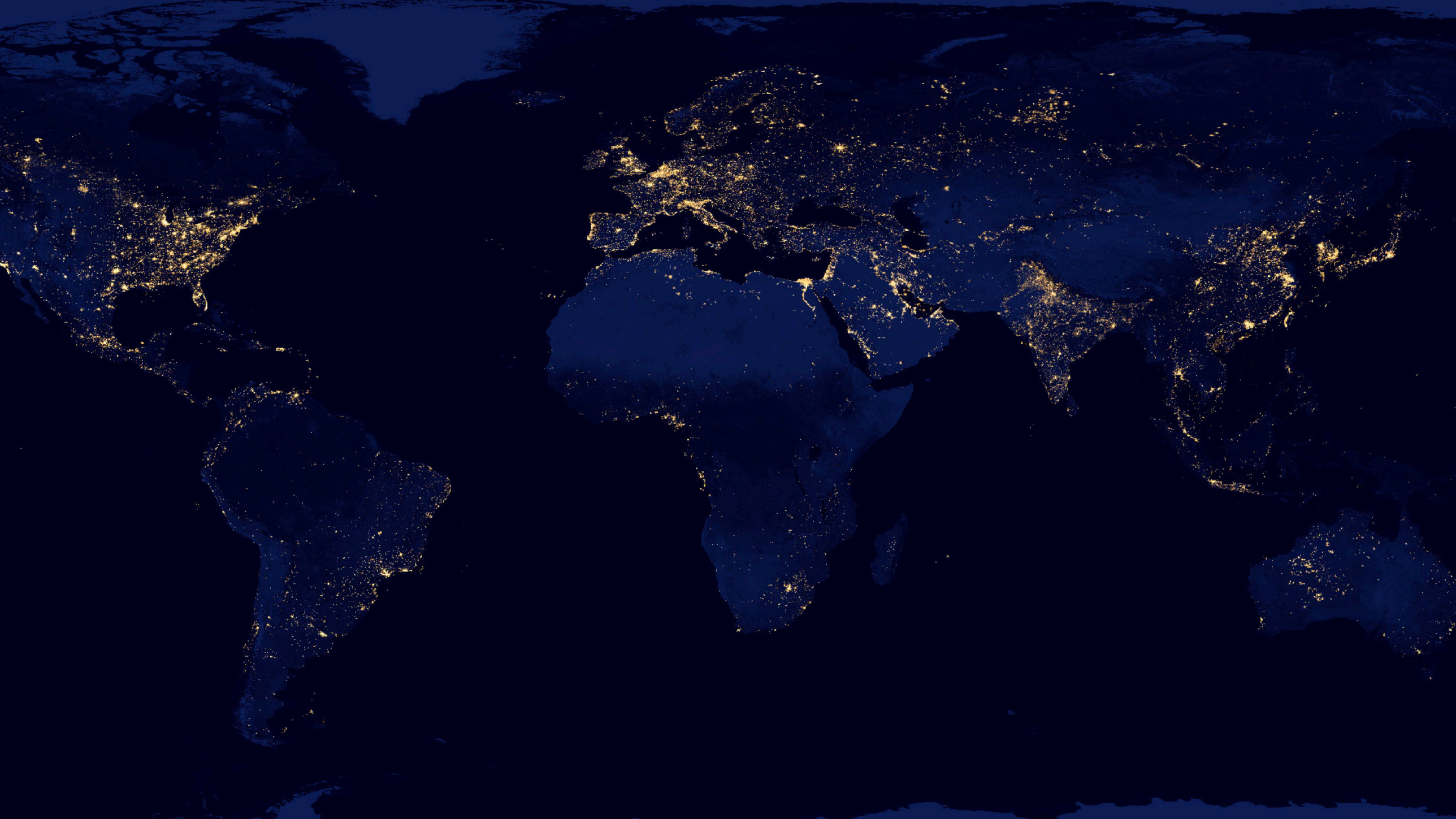




Finger of God: the Coma Cluster




Large Scale Structure in the Local Universe
Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Ophiuchus Cluster (0.028)
Hercules Supercluster (0.037)
Virgo Cluster (16 Mpc)
Leo Supercluster (0.032)
Ursa Major Supercluster (0.058)
Shapley Concentration (0.048+)
Centaurus Cluster (0.02)
60°
Abell 634 Cluster (0.025)
CMB dipole
30°
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
Plane of the Milky Way
150°
120°
90°
60°
30°
Milky Way Center
330°
300°
270°
240°
210°
-30°
Columba Cluster (0.034)
Norma & Great Attractor (0.016)
Perseus-Pisces Supercluster (0.017+)
M31 (800 Kpc)
-60°
Large Magellanic Cloud (50 Kpc)
Fornax Cluster (20 Mpc)
Pisces-Cetus Supercluster (0.063)
Cetus Wall (0.02)
Huchra Cluster (0.027)
Sculptor Supercluster (0.054)
Pavo-Indus Supercluster (0.015)
Horologium Supercluster (0.067)
Redshift (V_H / c)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004)
familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent
Graphic created by T. Jarrett (IPAC/Caltech)



Chapter 17: Large Scale Structure

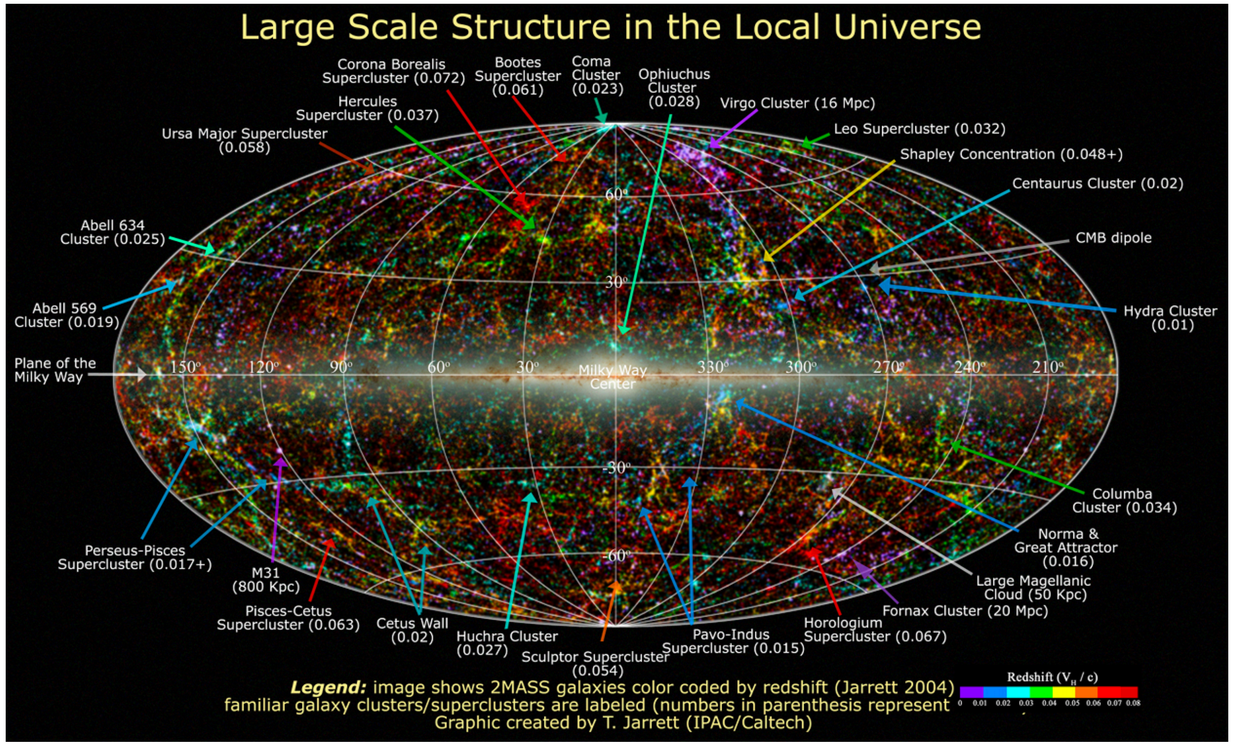
Current grade is ~4pts higher than what's in Canvas

Last Reading Assignment due tomorrow

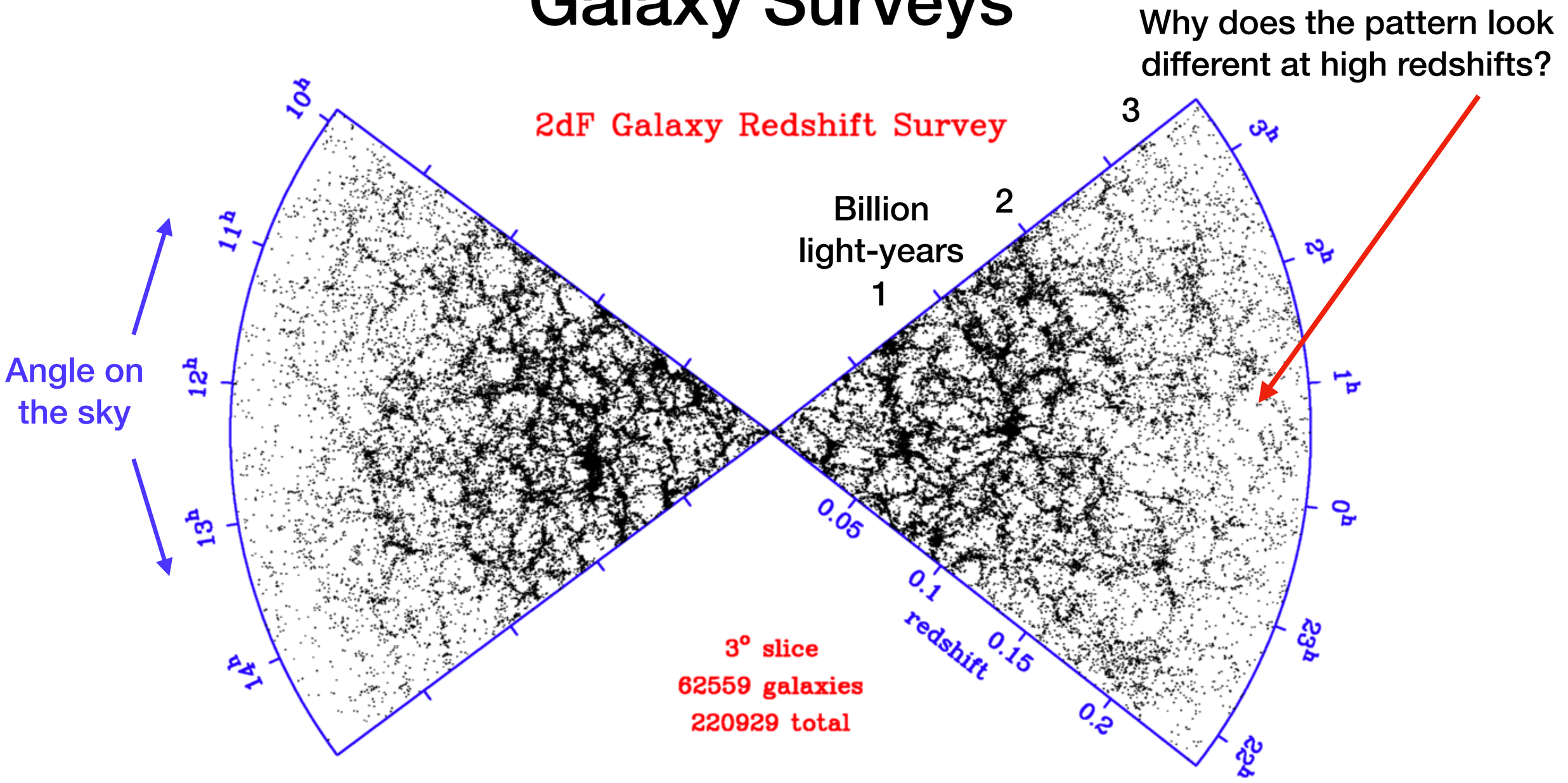
Midterm 2 up front

All EC due December 5th

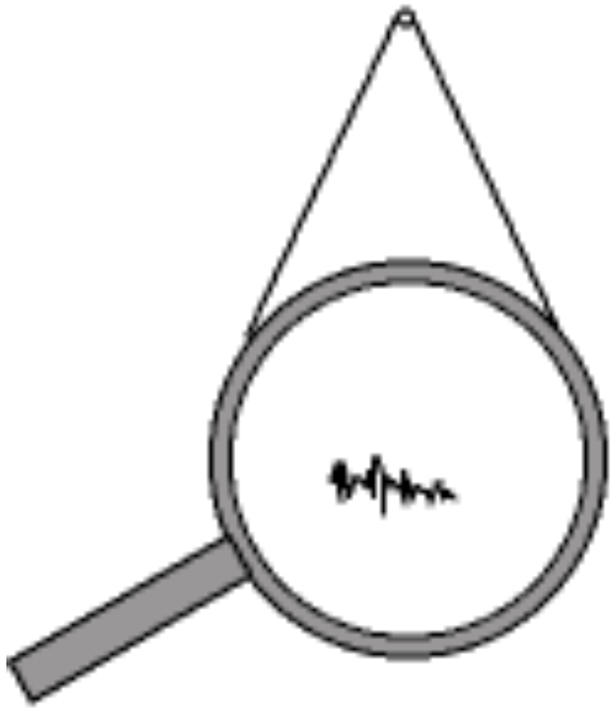
Check your grades in Canvas!



Galaxy Surveys



Making the "galaxy seeds" with inflation



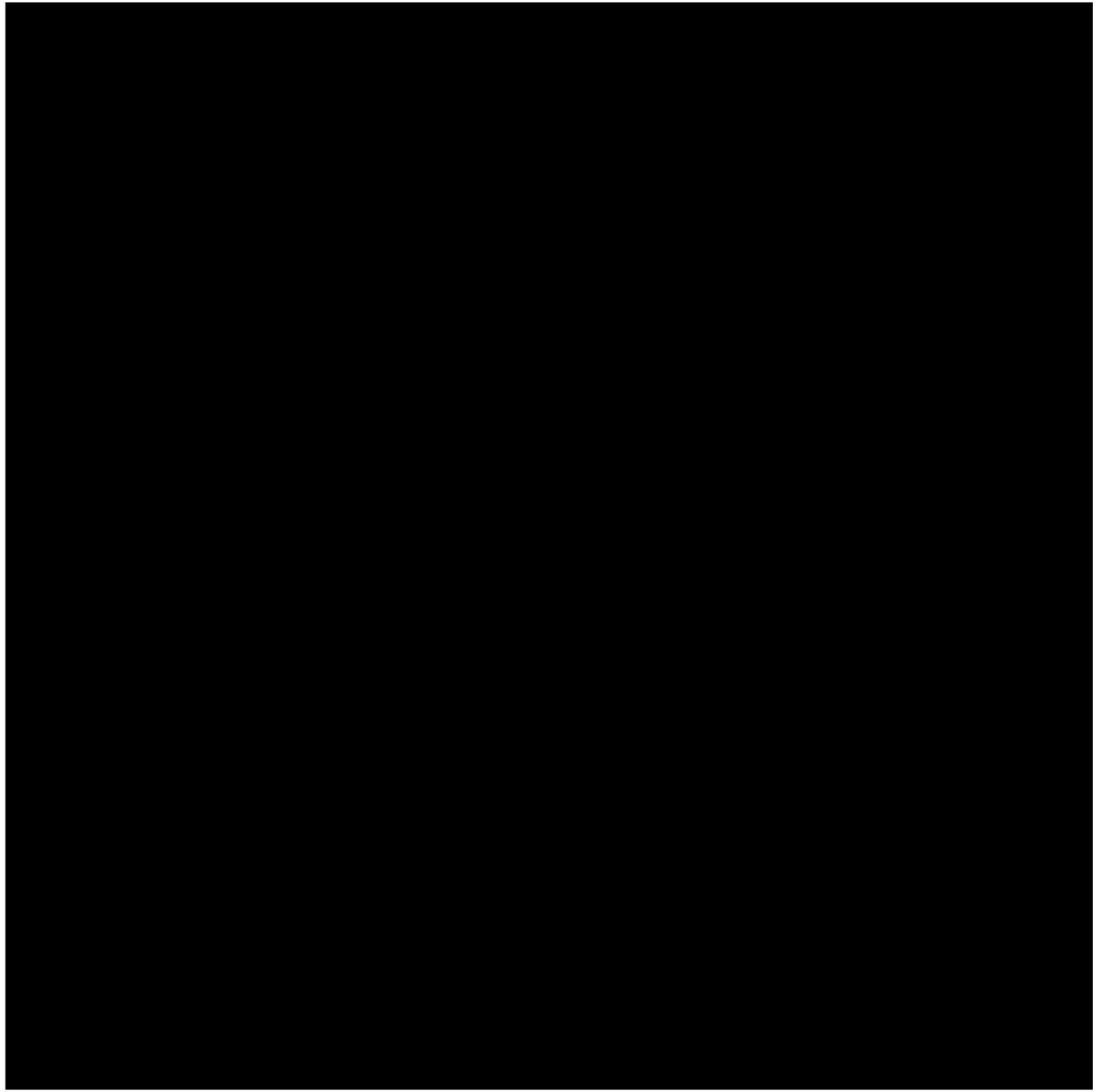
ultra-tiny quantum fluctuations

Time

become...

large lumps seen in cosmic microwave background

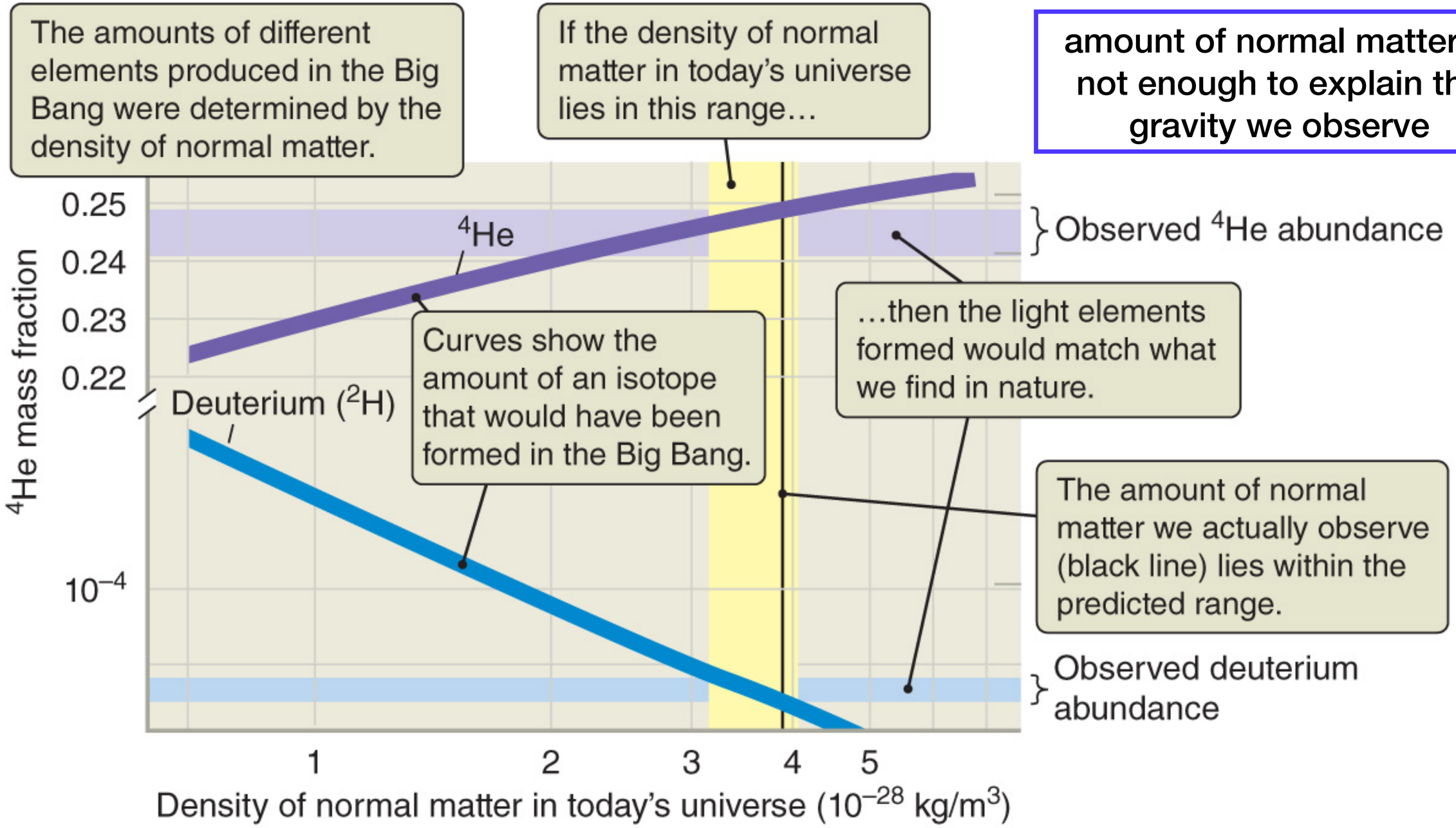
Process is random and becomes “non-linear,” need to simulate this growth with computers



traveling through “slices” of a simulated universe

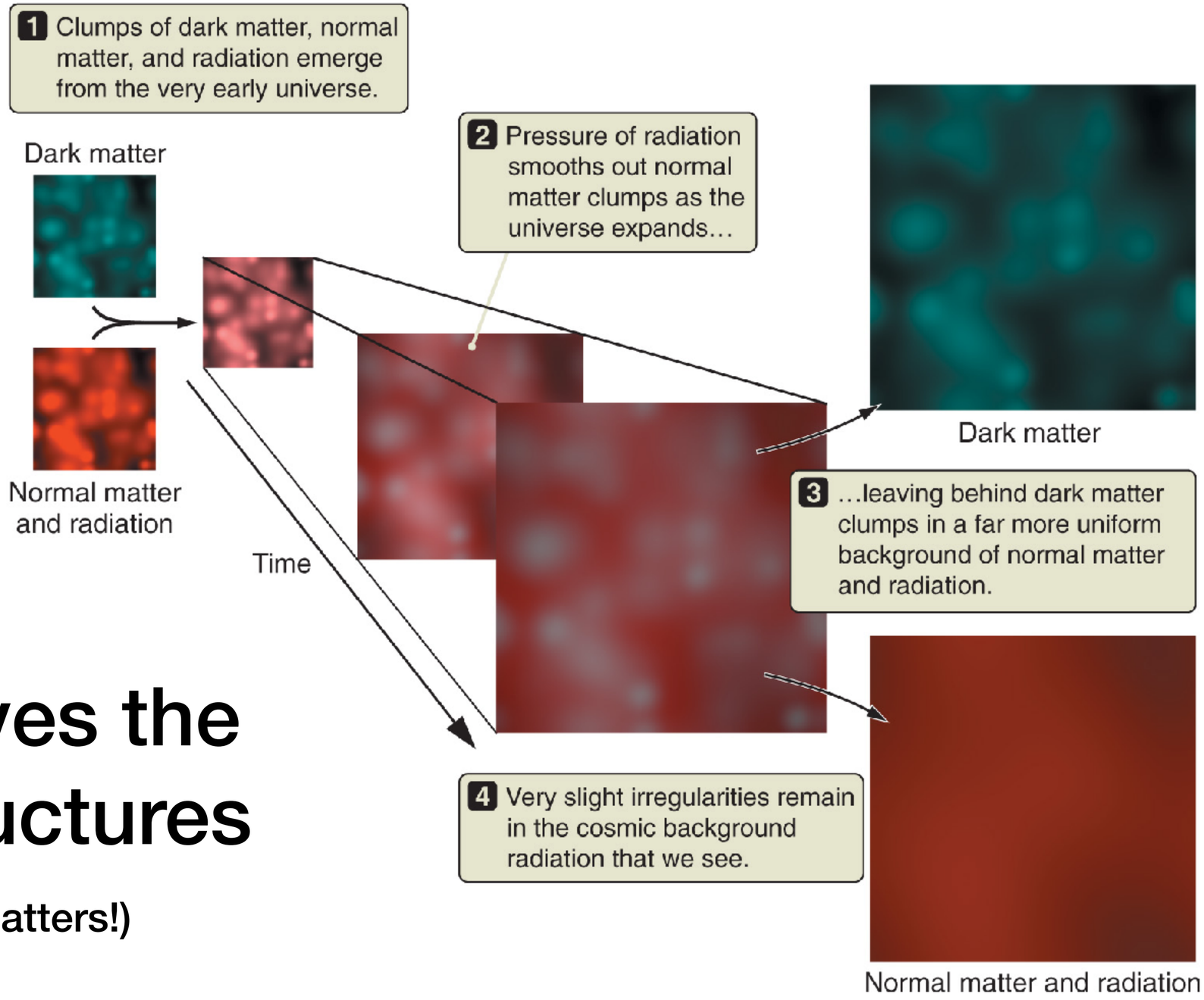
What is dark matter?

Must it be different than the matter you and I are made of?


The amounts of different elements produced in the Big Bang were determined by the density of normal matter.
If the density of normal matter in today's universe lies in this range…
amount of normal matter is not enough to explain the gravity we observe
0.25
0.24
0.23
0.22
10^{-4}
^{4}He mass fraction
^{4}He
Deuterium (^{2}H)
Curves show the amount of an isotope that would have been formed in the Big Bang.
…then the light elements formed would match what we find in nature.
The amount of normal matter we actually observe (black line) lies within the predicted range.
Observed ^{4}He abundance
Observed deuterium abundance
1
2
3
4
5
Density of normal matter in today's universe (10^{-28} kg/m^3)

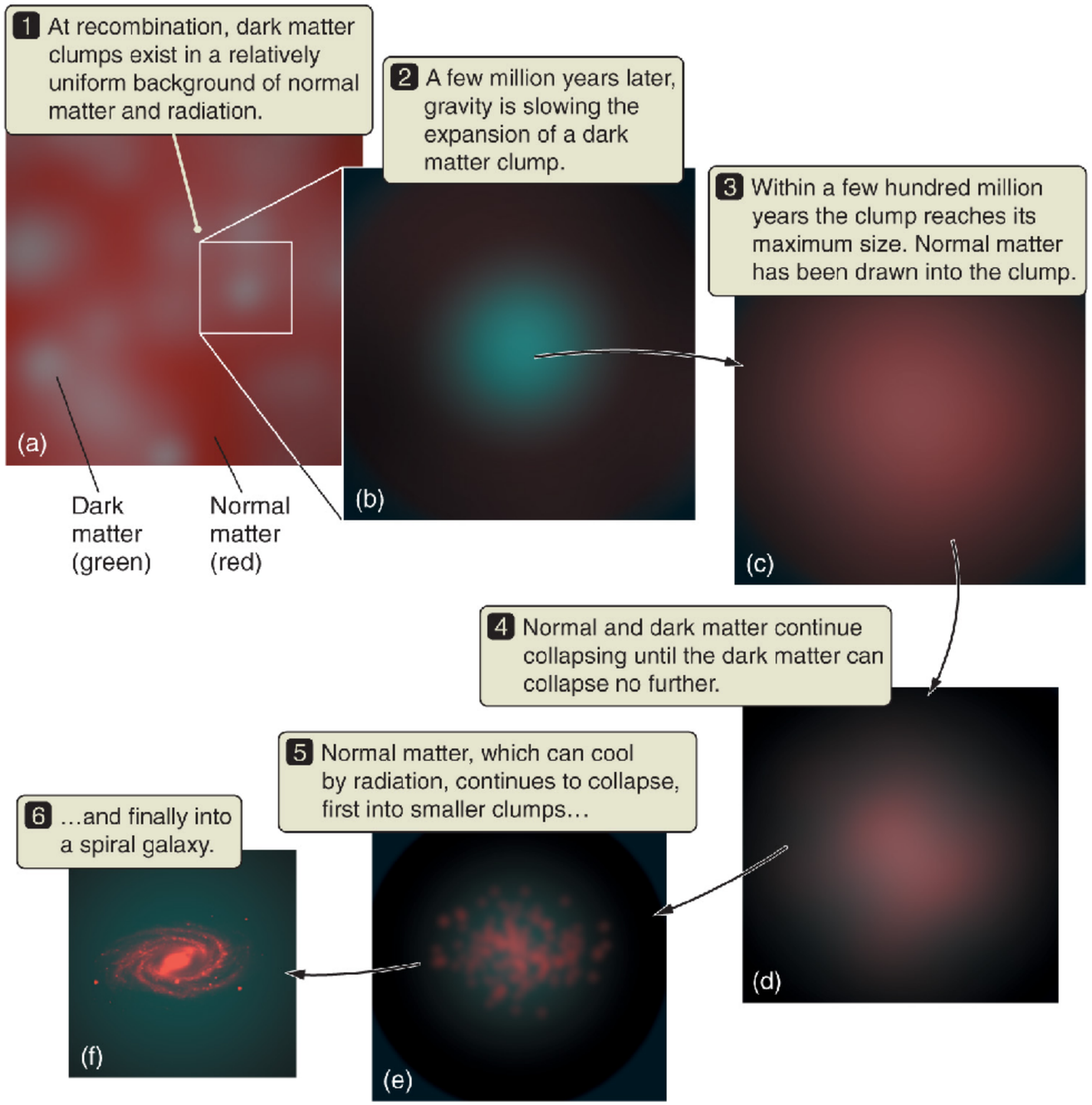
How do structures grow?

A) Galaxies form (medium size), then stars (small size), then clusters (large size)
B) Stars form (small size), then clusters (large size), then galaxies (medium size)
C) Clusters form (large size), then galaxies (medium size), then stars (small size)
D) Stars form (small size), then galaxies (medium size), then clusters (large size)



Dark matter drives the formation of structures

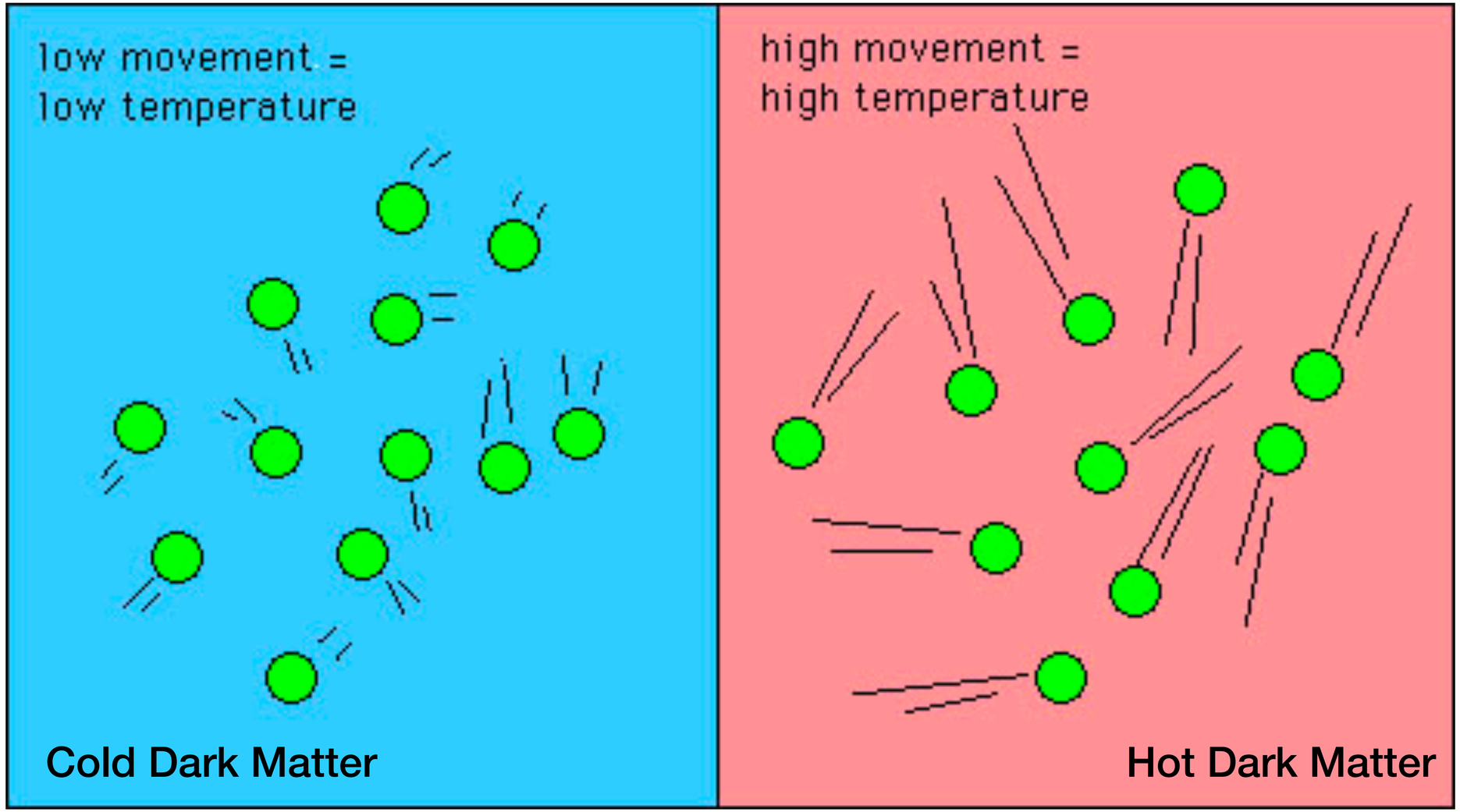
(the type of dark matter matters!)



Galaxies form inside dark matter halos, becoming more compact in centers than the dark matter

So, the distribution of galaxies is related to the distribution of dark matter that was able to collapse and form halos

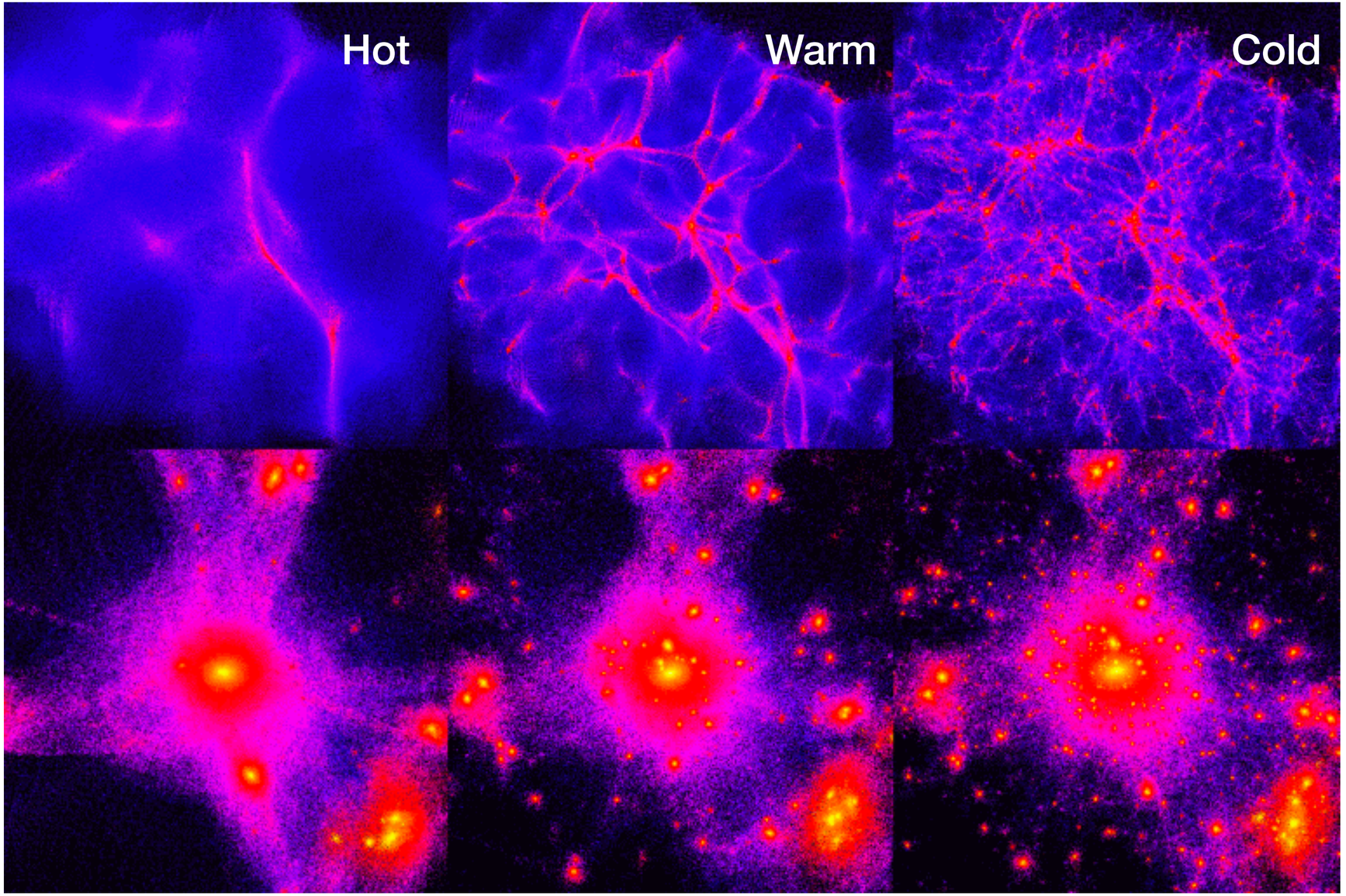
What is temperature?



How does the temperature of dark matter affect how it grows?

A) Hot dark matter grows small structures first
B) Cold dark matter grows small structures first
C) Temperature doesn't affect the size scale that grows first

Temperature of the Dark Matter



velocity of particles compared to the speed of light

relativistic at time of collapse (like neutrinos): hot

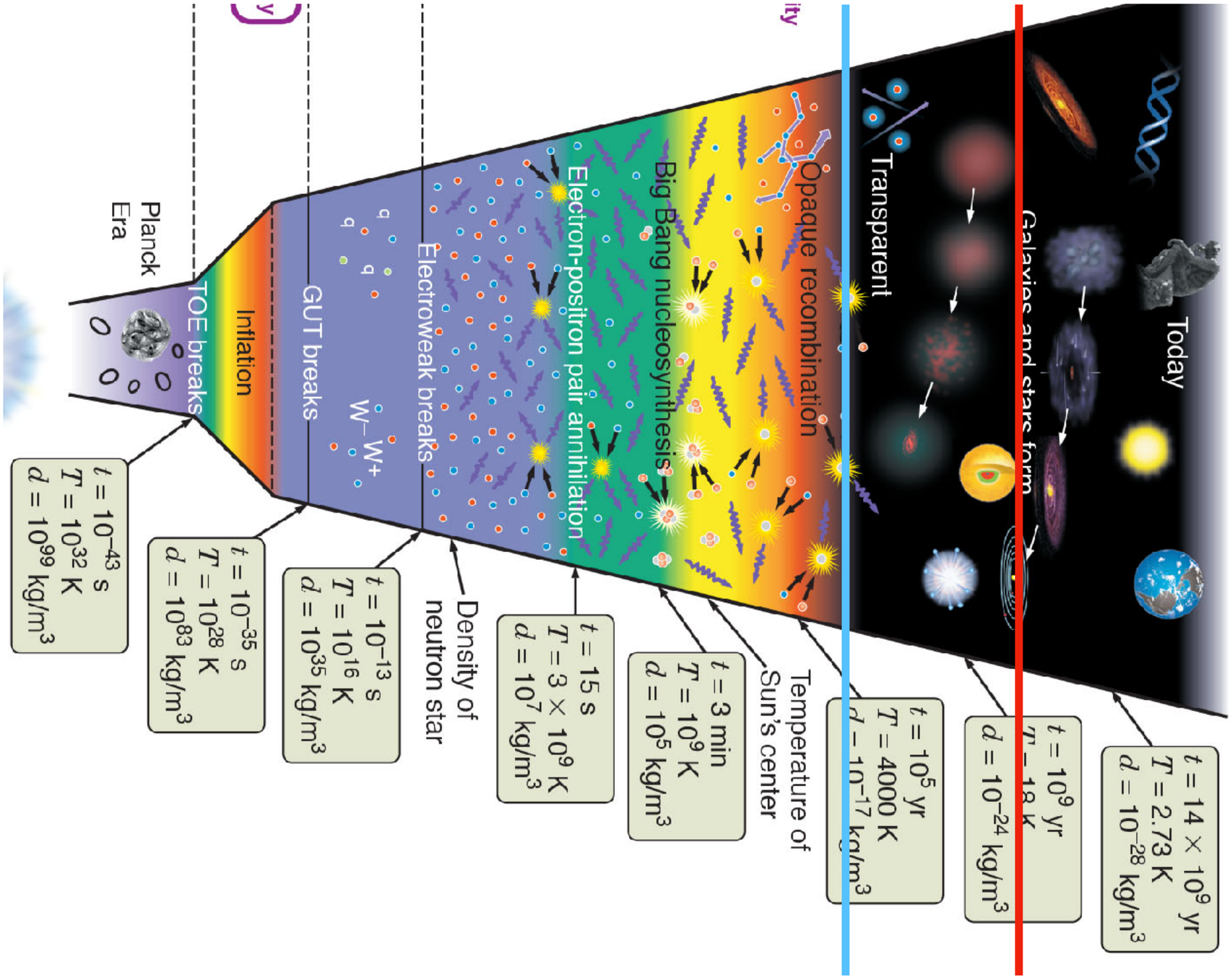
non-relativistic at time of collapse (like WIMPs): cold

fast motions wipe out initial overdensities on small scales: “free-streaming”

Universe is opaque

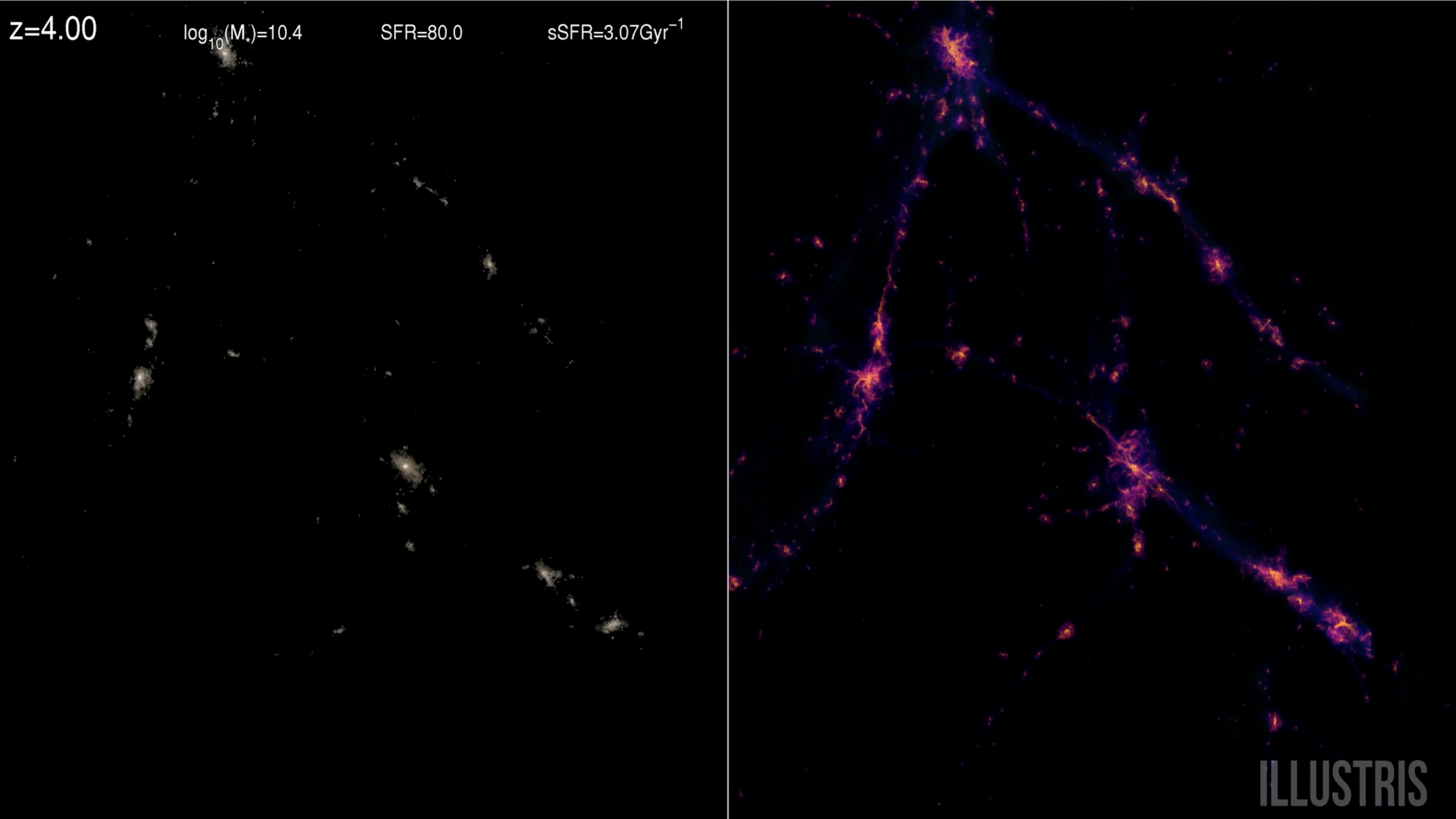
Electrons & ions combine (recombination)

Universe gets ionized again (reionization)



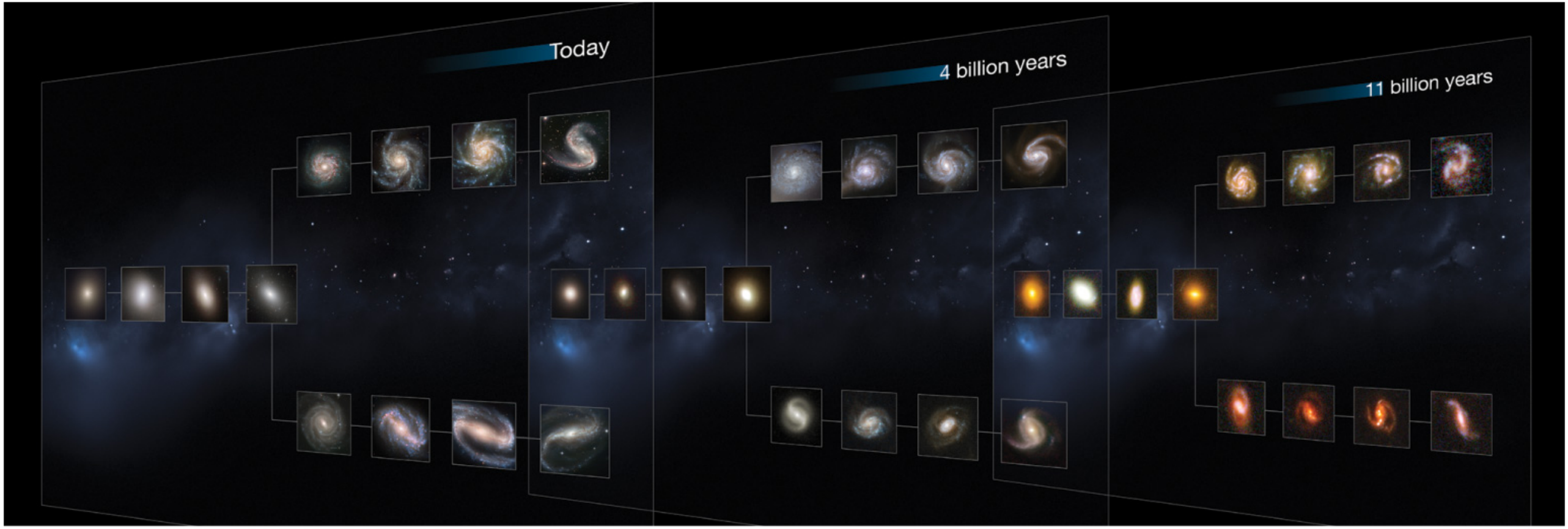
If the universe got reionized, why can we see through it?

A) Density of electrons is too low to scatter light
B) Electrons and ions recombined again after the rate of star formation declined
C) Electrons and ions recombined again after the rate of supermassive black hole accretion declined

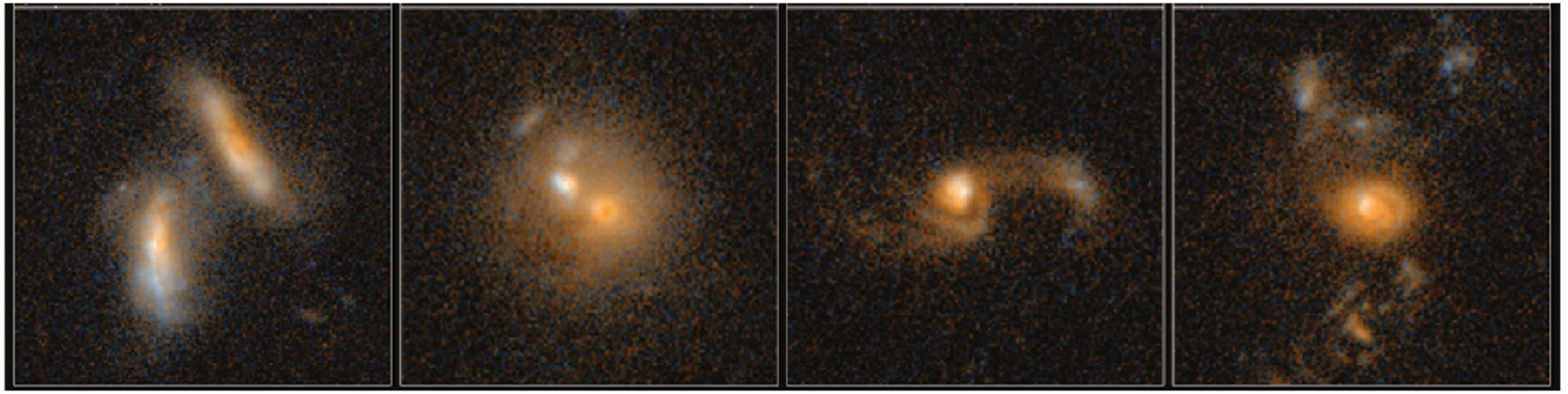

z=4.00
log10(M*)=10.4
SFR=80.0
sSFR=3.07Gyr−1
ILLUSTRIS

Spirals take time to form

galaxies get smaller the farther back in time you look

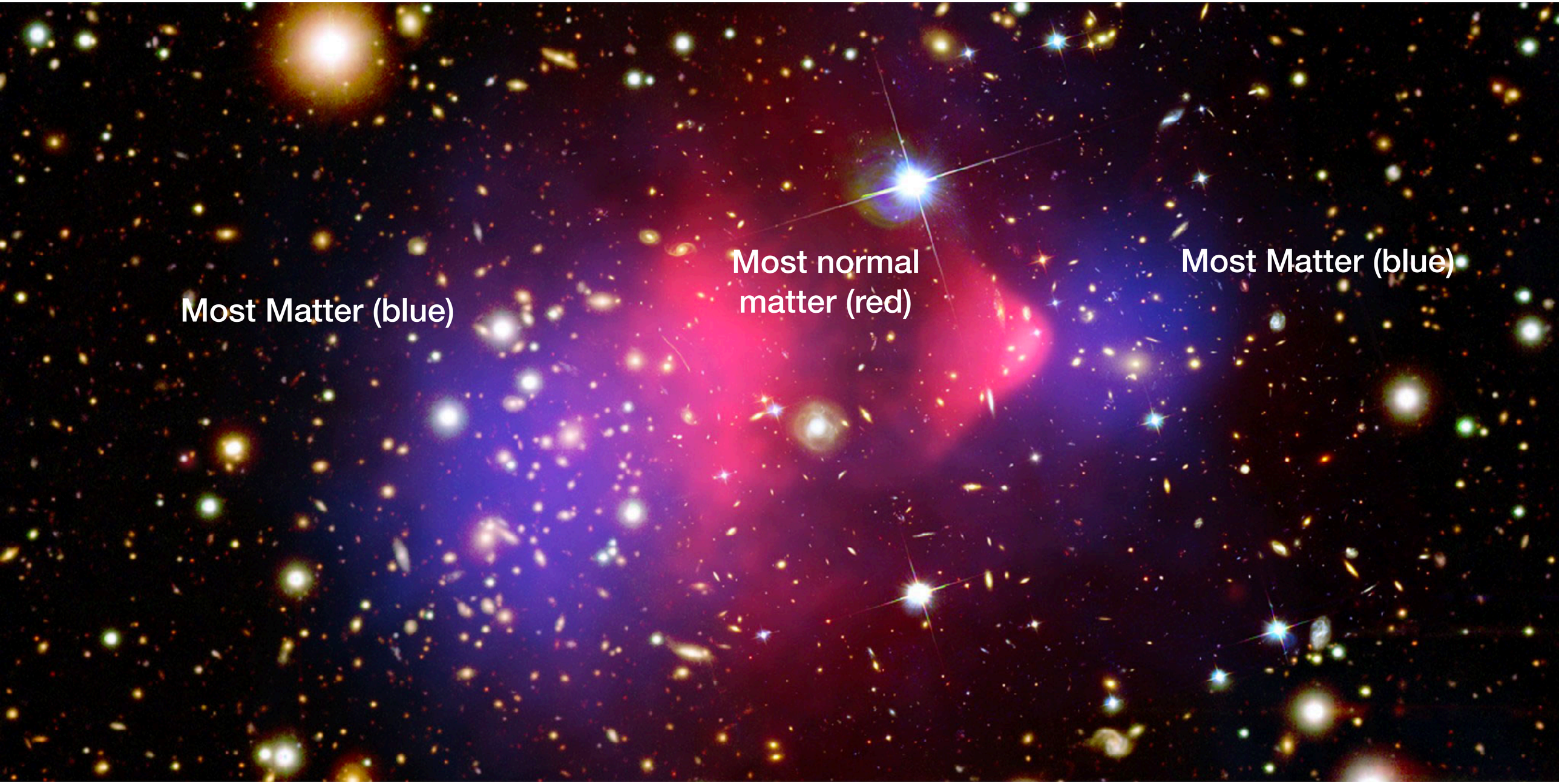


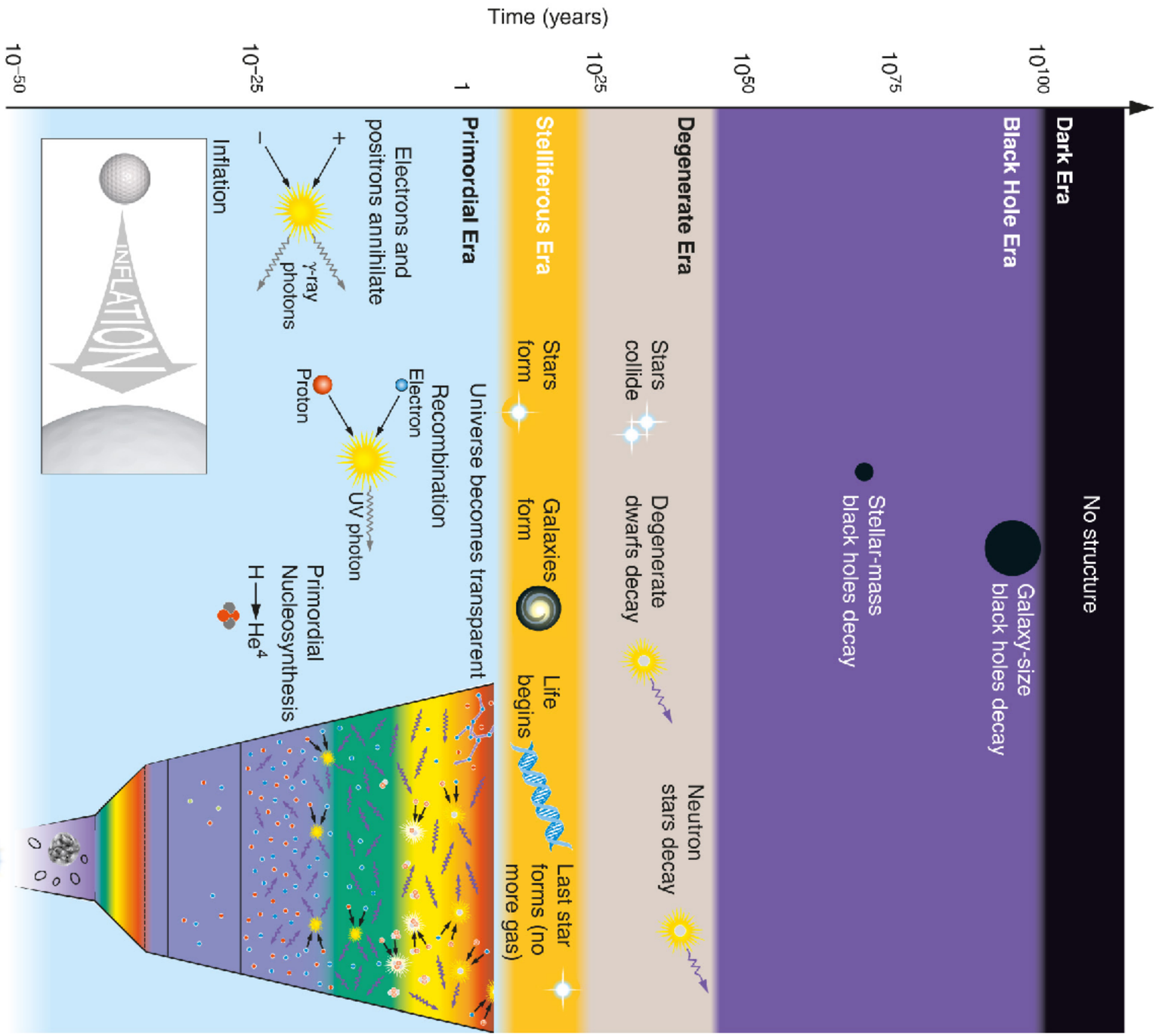
Galaxies grow in size through mergers



Distant

More Nearby


Most Matter (blue)
Most normal matter (red)
Most Matter (blue)



The Deep Future (maybe?)

Primordial Era	10^5 yr
Stelliferous Era	10^{14} yr
Degenerate Era	10^{39} yr
Black Hole Era	10^{100} yr
Dark Era	infinity?