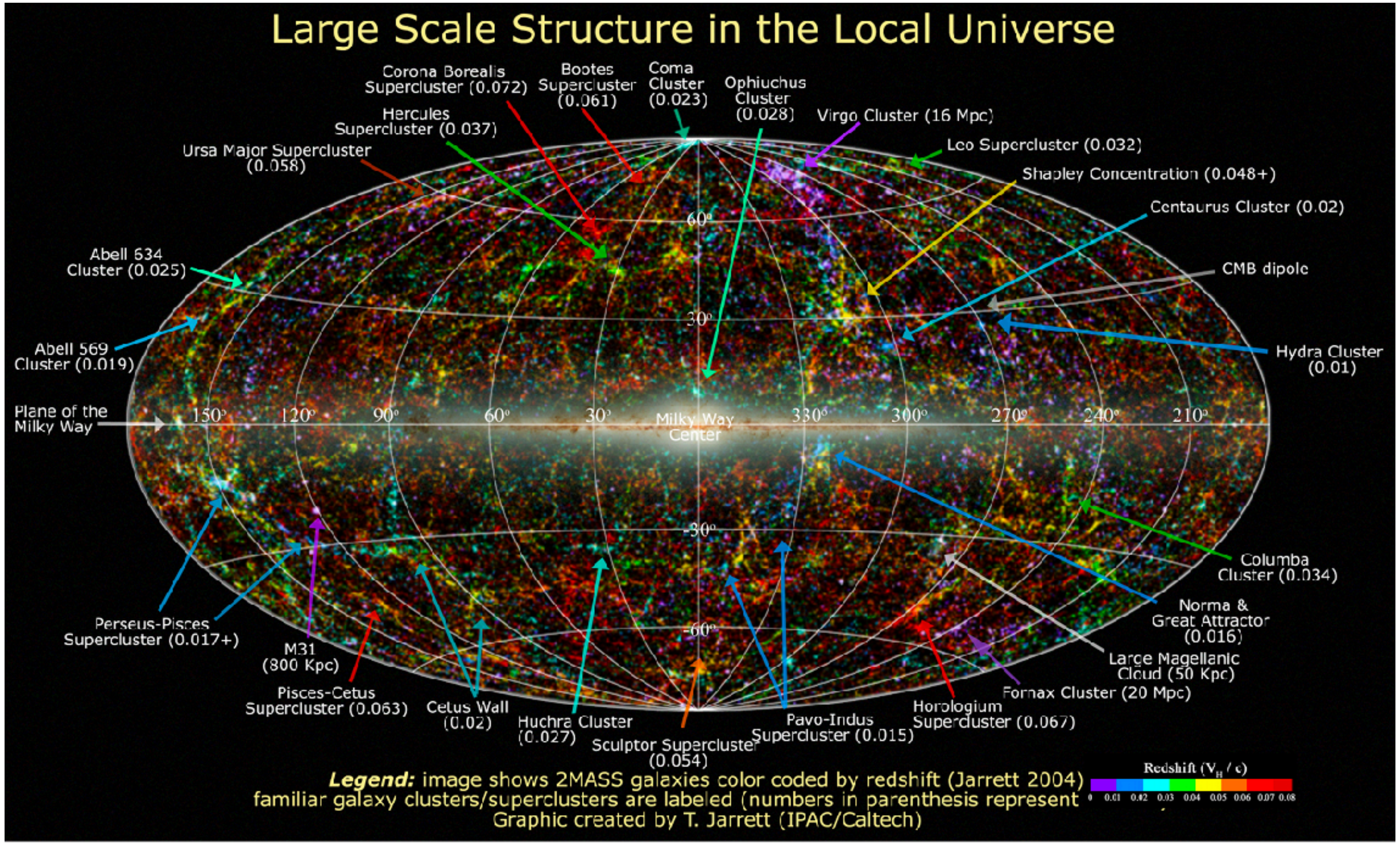
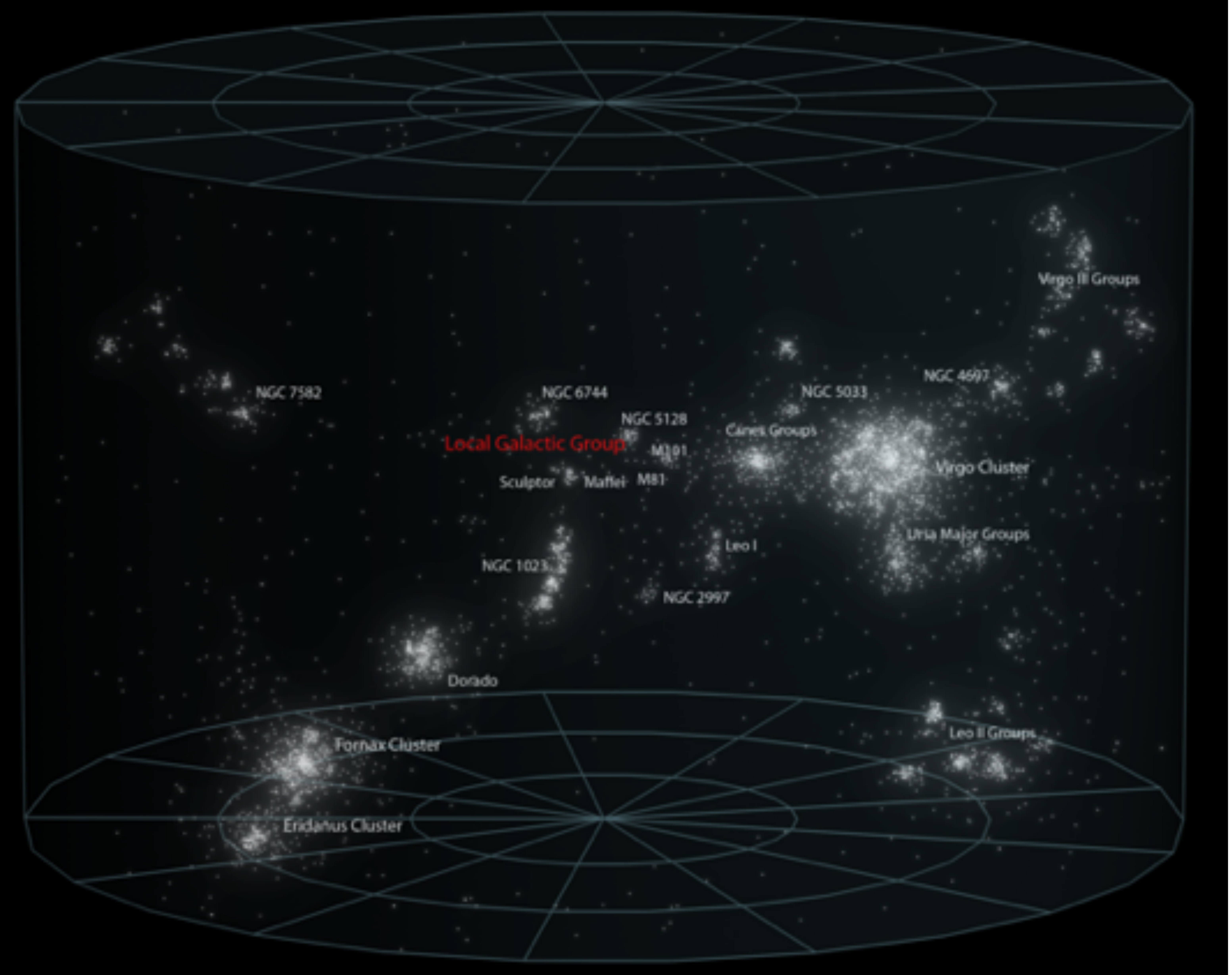
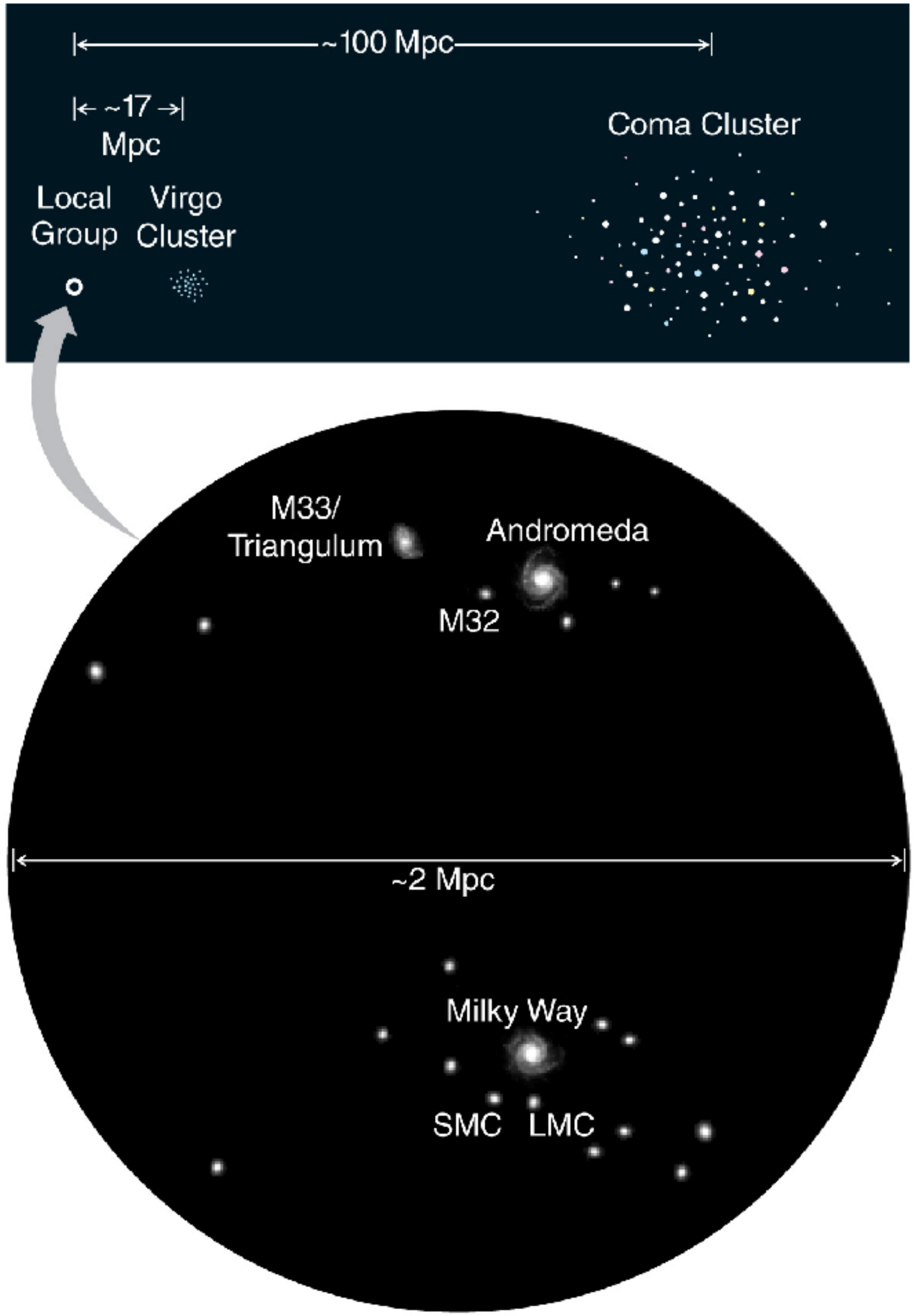
Chapter 17: Large Scale Structure

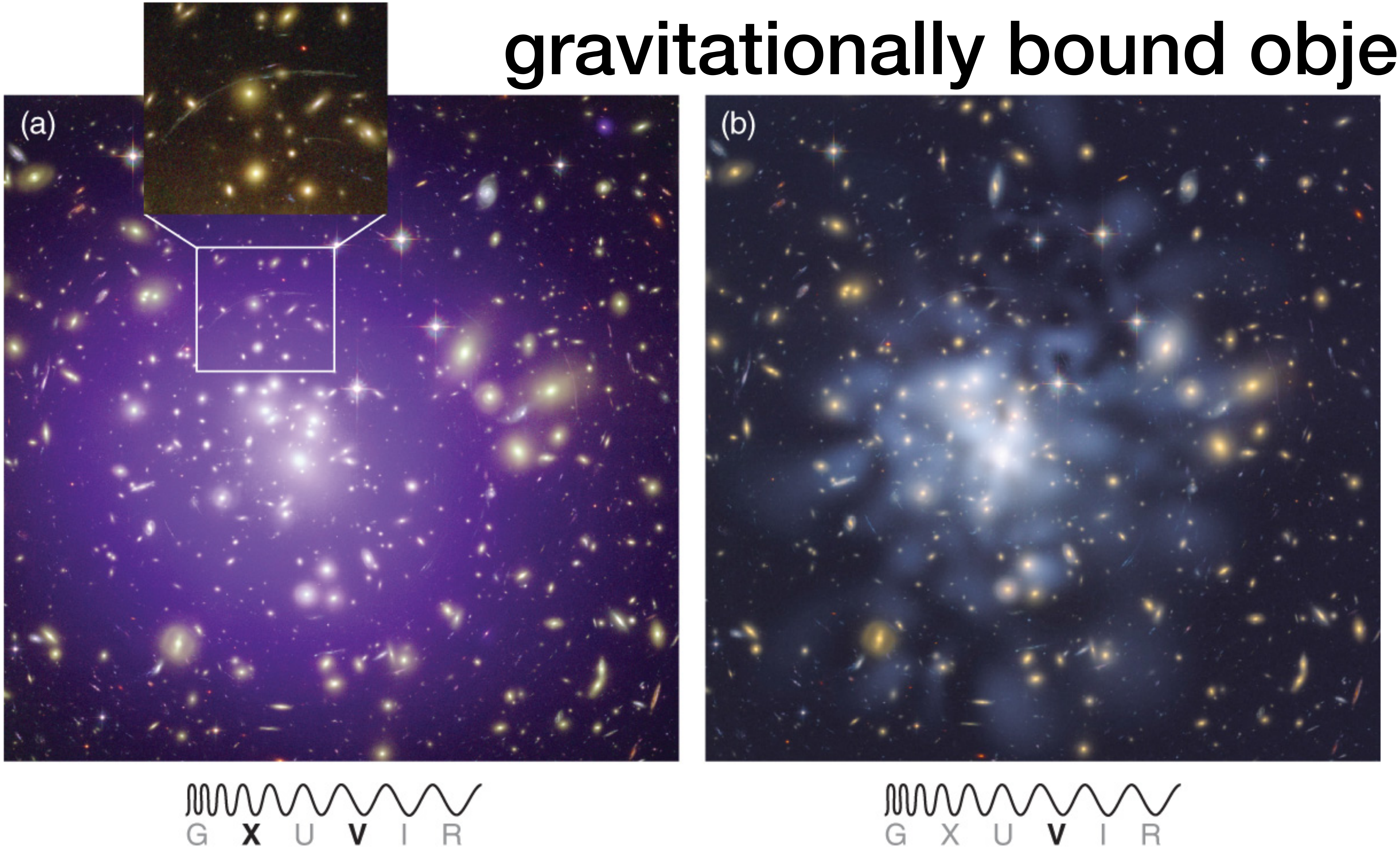


VIRGO SUPERCLUSTER

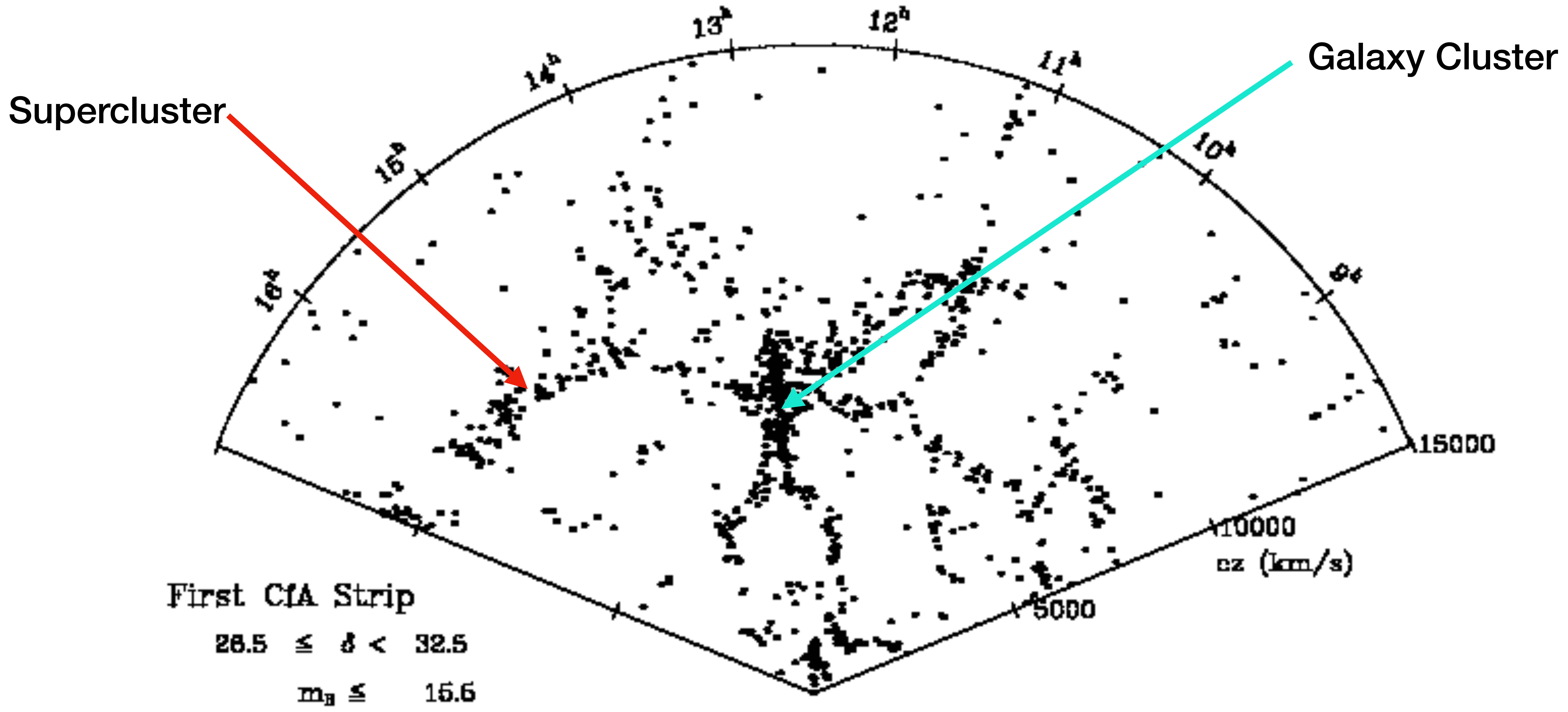


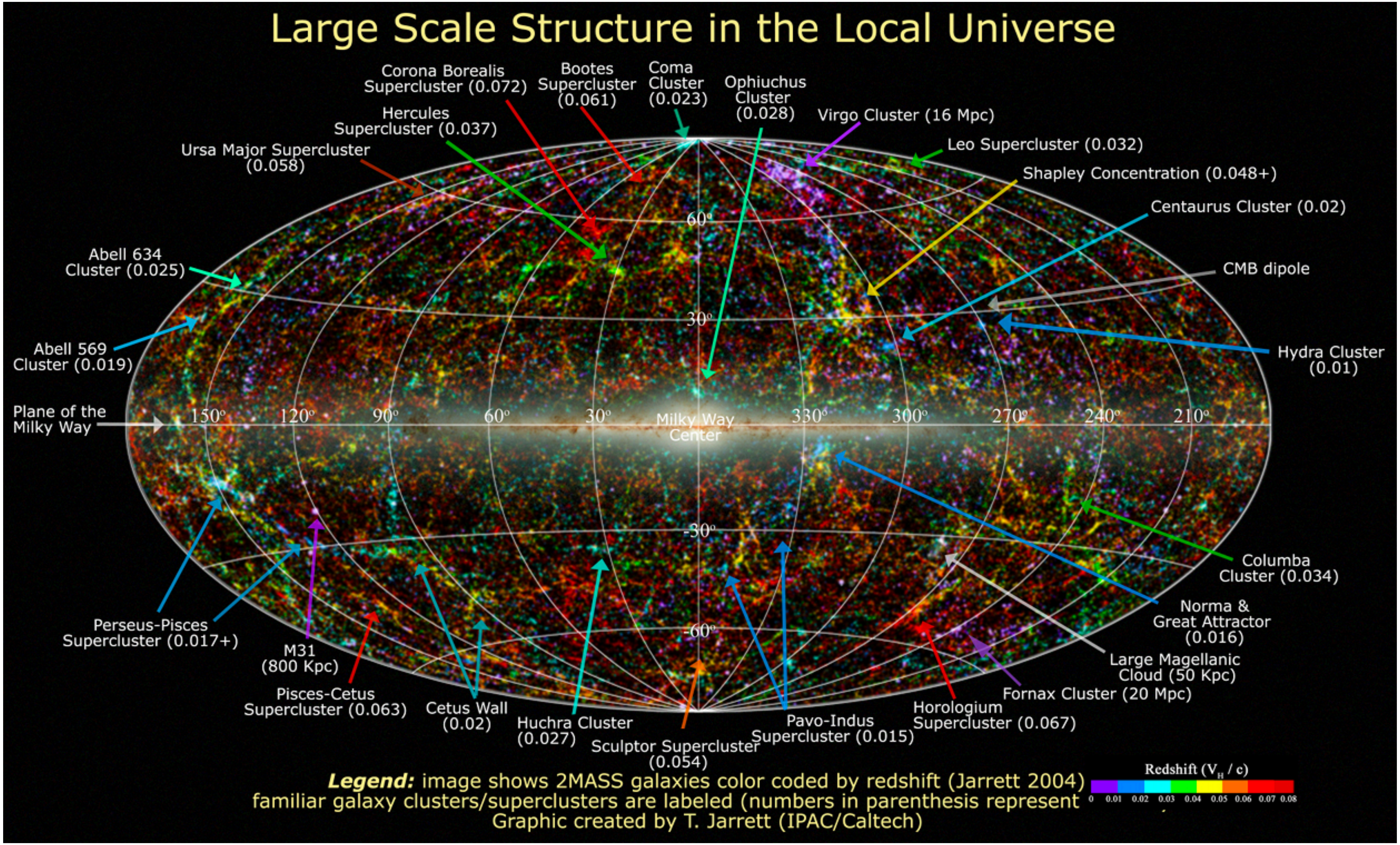


Galaxy Clusters: the largest gravitationally bound objects



Finger of God: the Coma Cluster

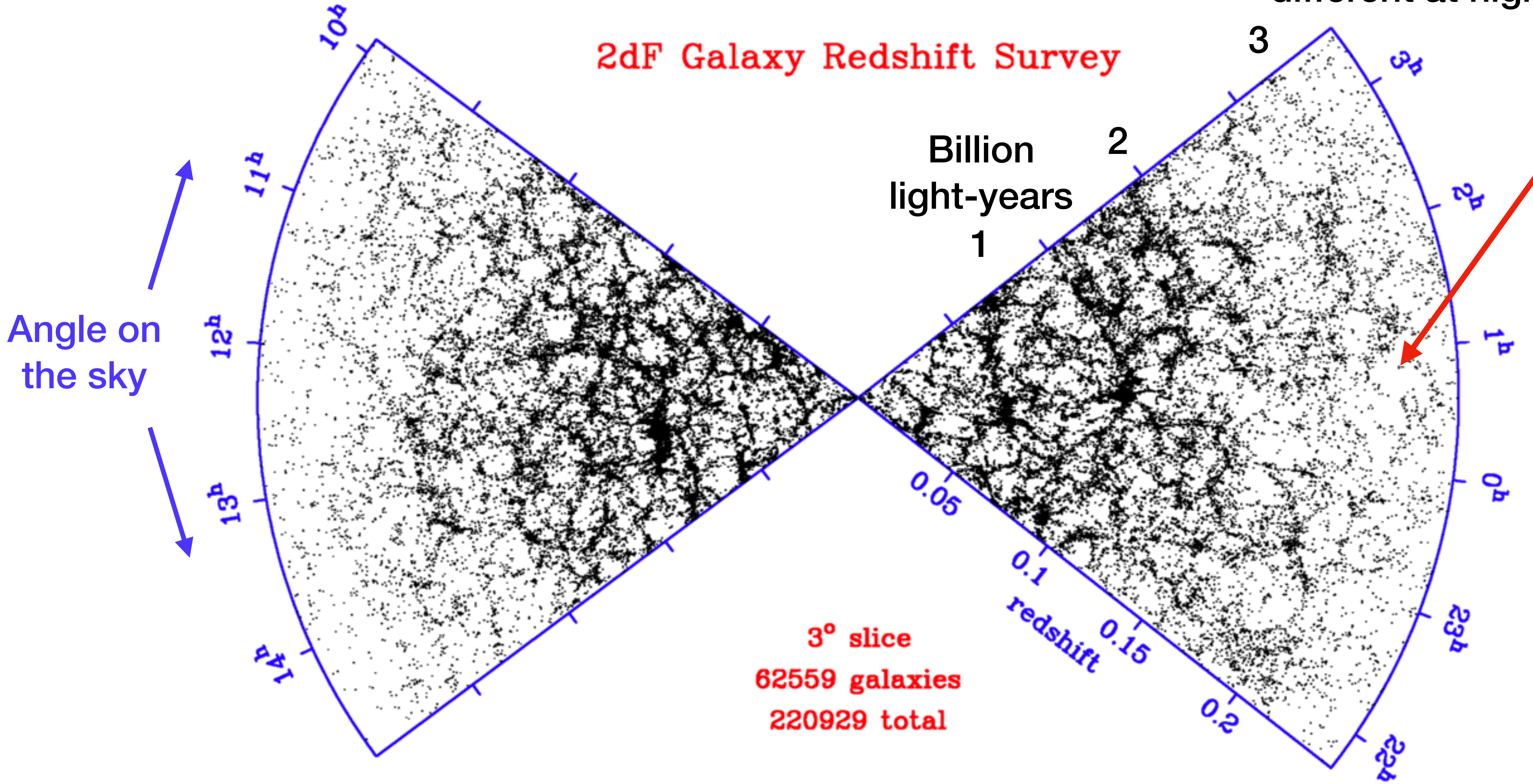




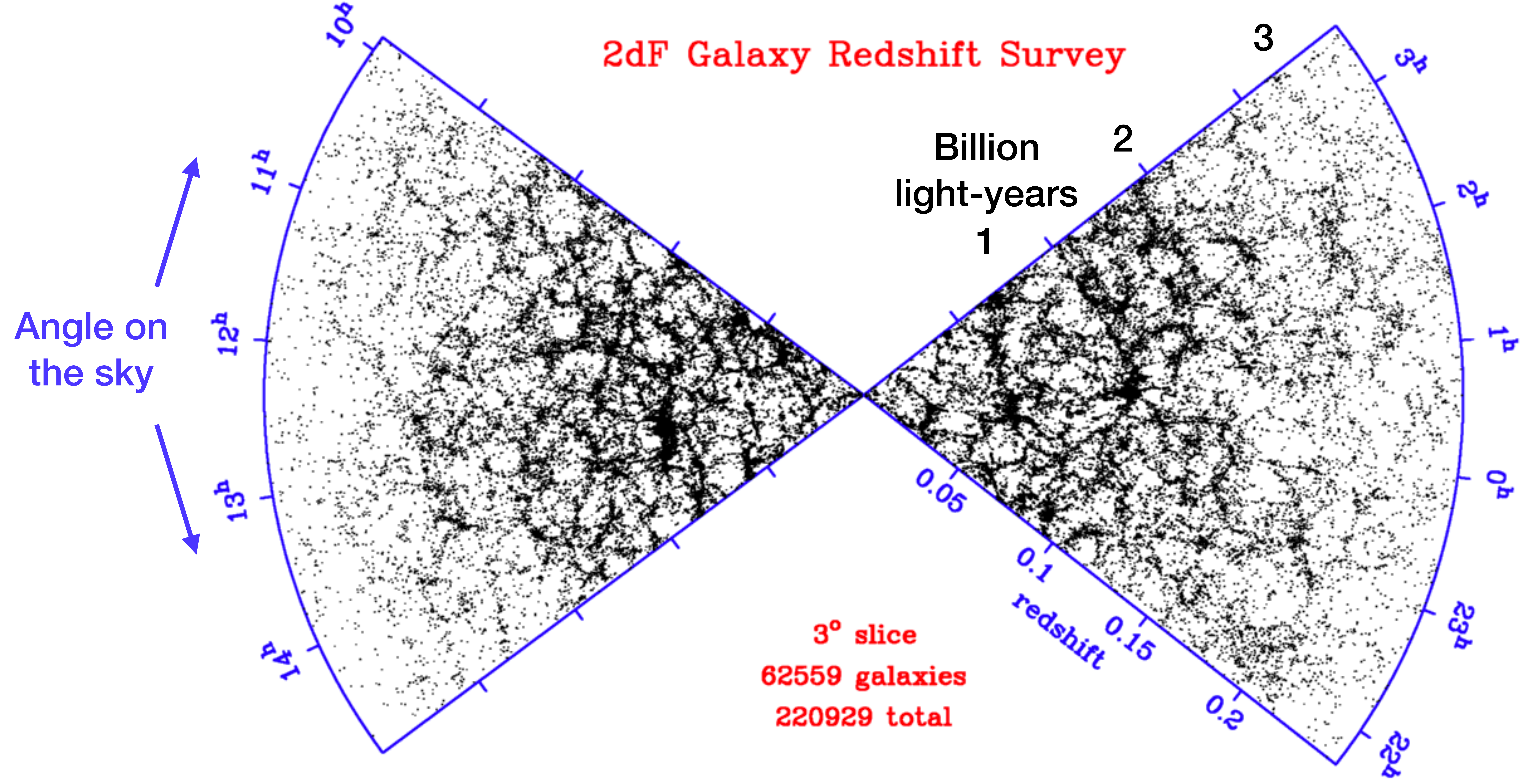
Large Scale Structure in the Local Universe
Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Ophiuchus Cluster (0.028)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Ursa Major Supercluster (0.058)
Leo Supercluster (0.032)
Shapley Concentration (0.048+)
Centaurus Cluster (0.02)
Abell 634 Cluster (0.025)
CMB dipole
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
Plane of the Milky Way
Milky Way Center
60°
30°
-30°
-60°
150°
120°
90°
60°
30°
330°
300°
270°
240°
210°
Columba Cluster (0.034)
Norma & Great Attractor (0.016)
Large Magellanic Cloud (50 Kpc)
Perseus-Pisces Supercluster (0.017+)
M31 (800 Kpc)
Fornax Cluster (20 Mpc)
Pisces-Cetus Supercluster (0.063)
Cetus Wall (0.02)
Huchra Cluster (0.027)
Pavo-Indus Supercluster (0.015)
Horologium Supercluster (0.067)
Sculptor Supercluster (0.054)
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)
Redshift (V_H / c)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08

Galaxy Surveys

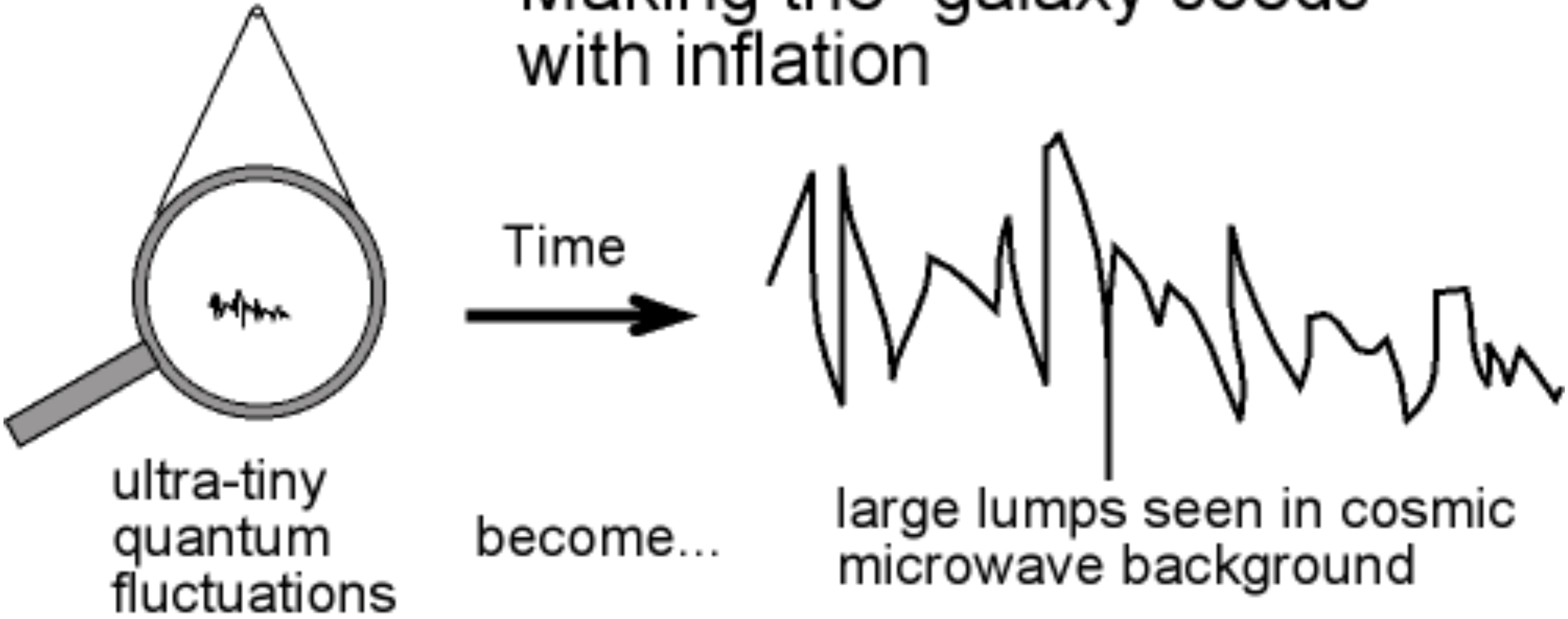
Why does the pattern look different at high redshifts?



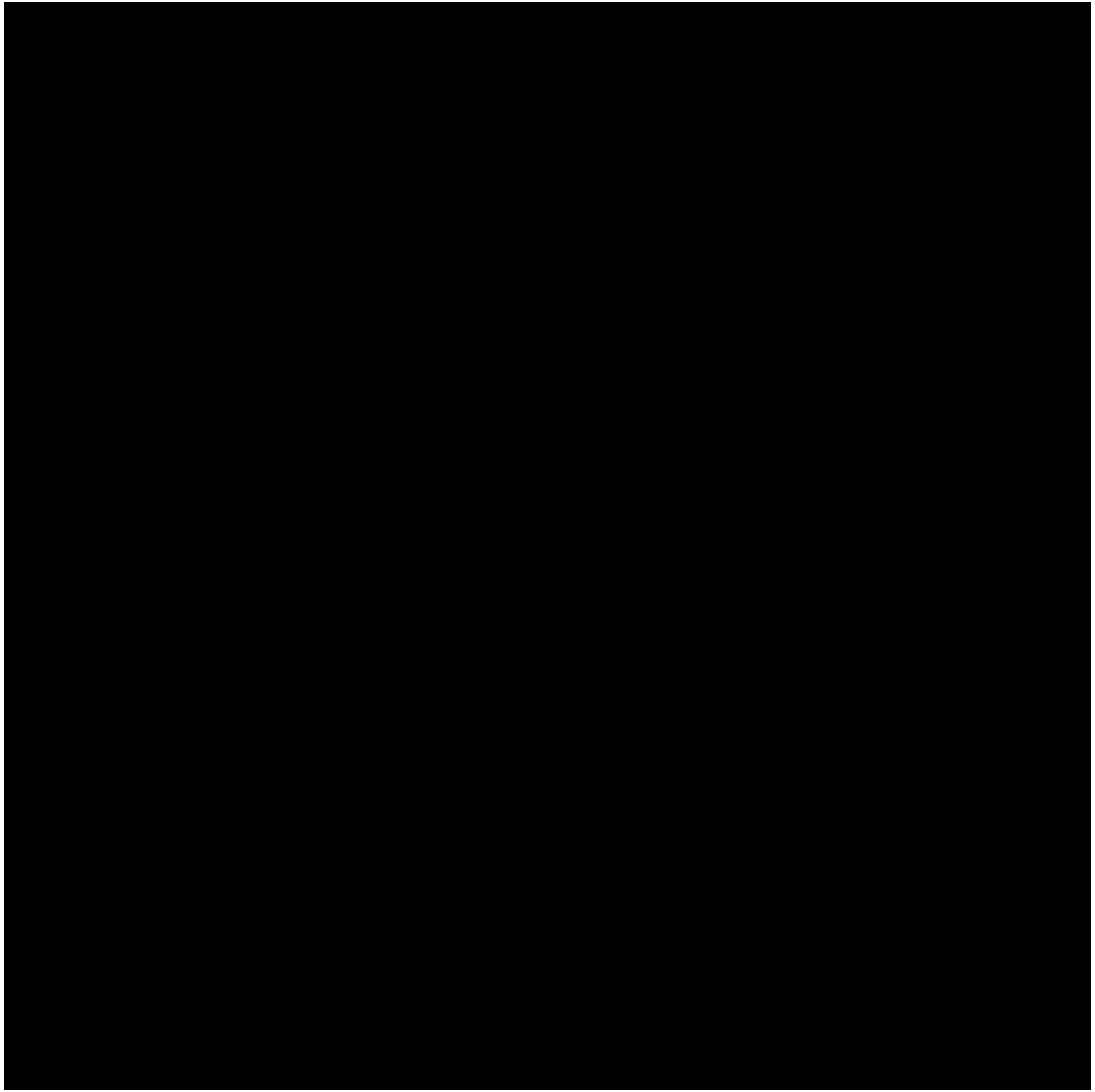
Galaxy Surveys



Making the “galaxy seeds” with inflation



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

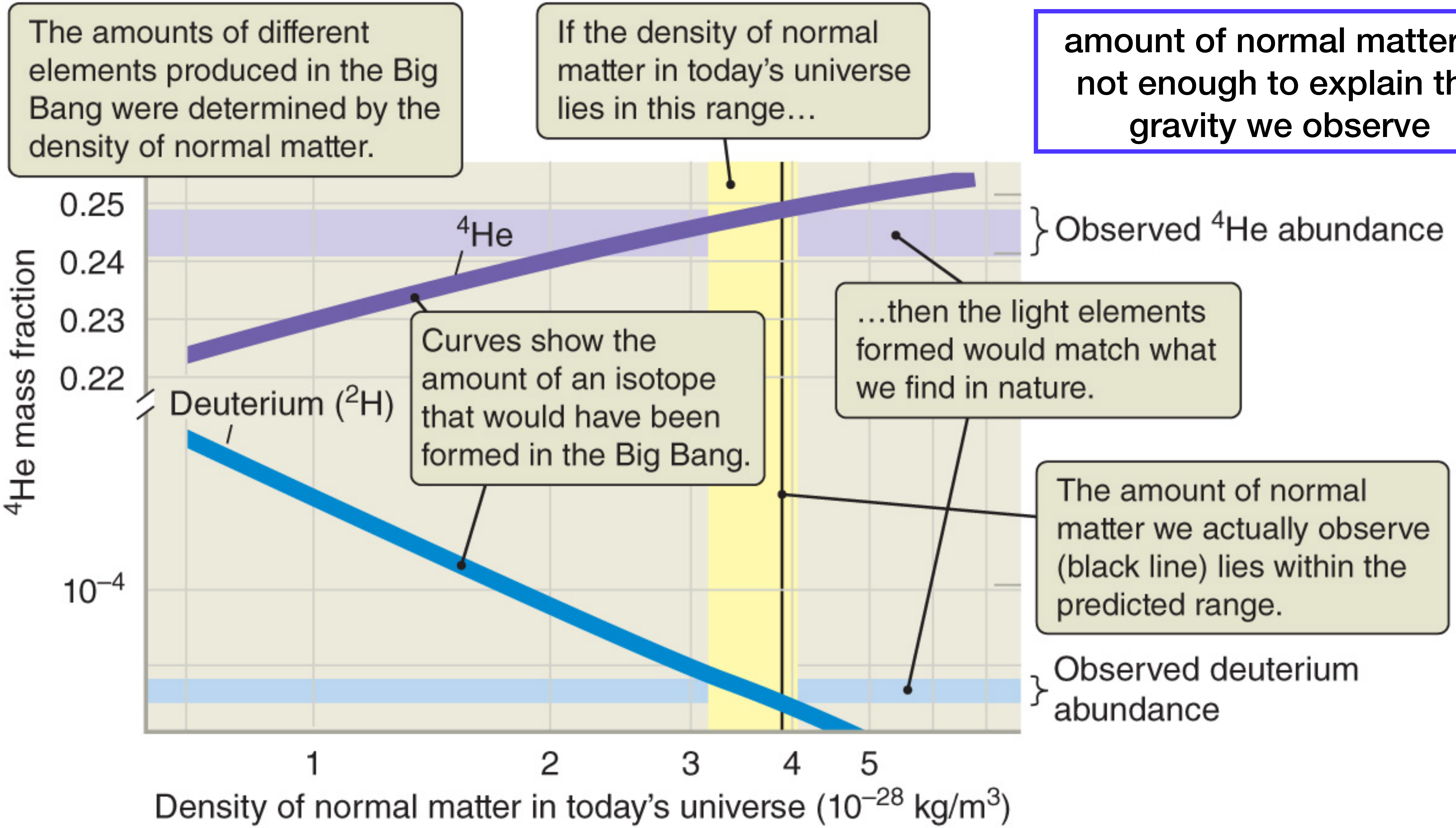


traveling through "slices" of a simulated universe

What is dark matter?

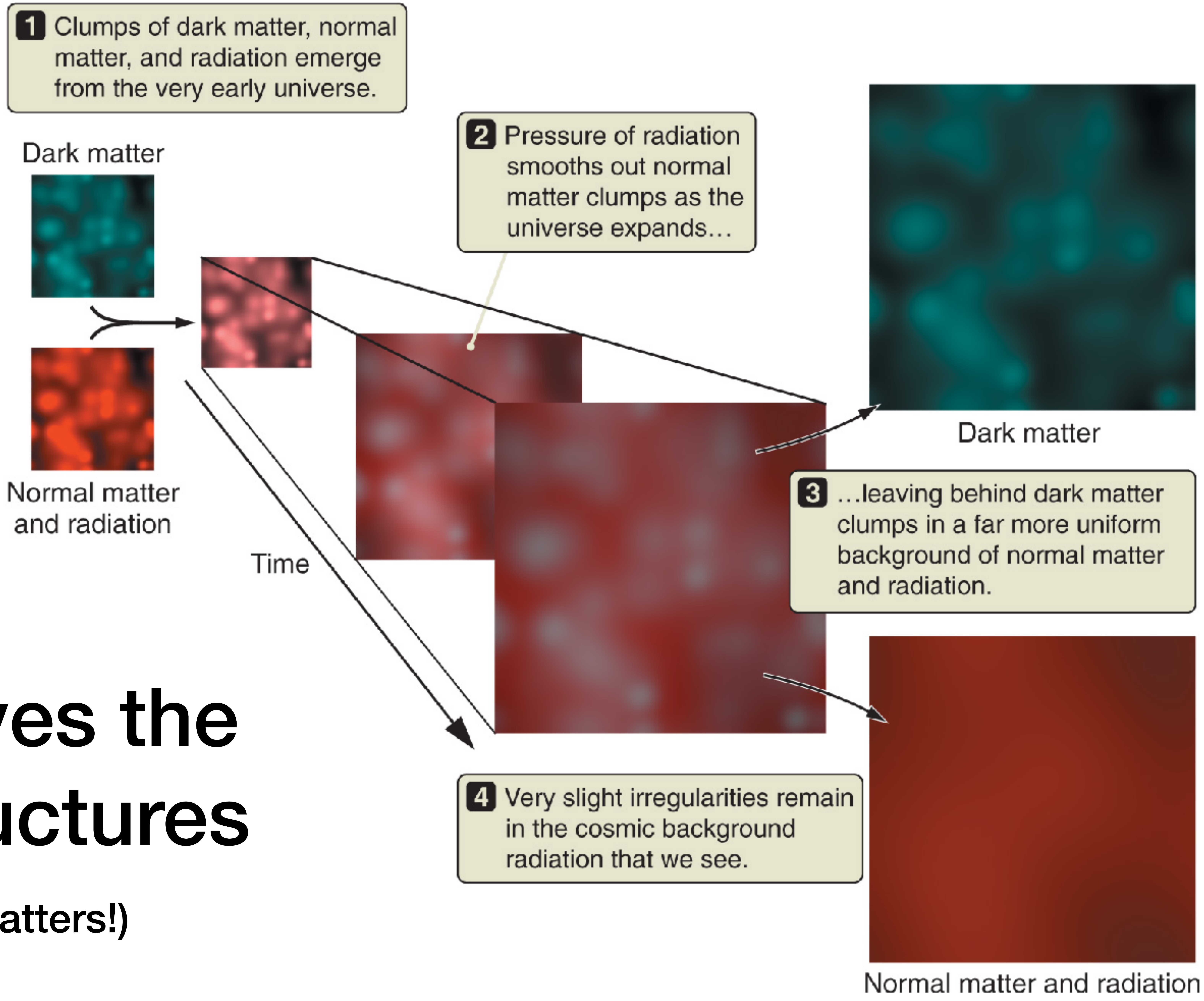
Must it be different than the matter you and I are made of?

amount of normal matter is not enough to explain the gravity we observe



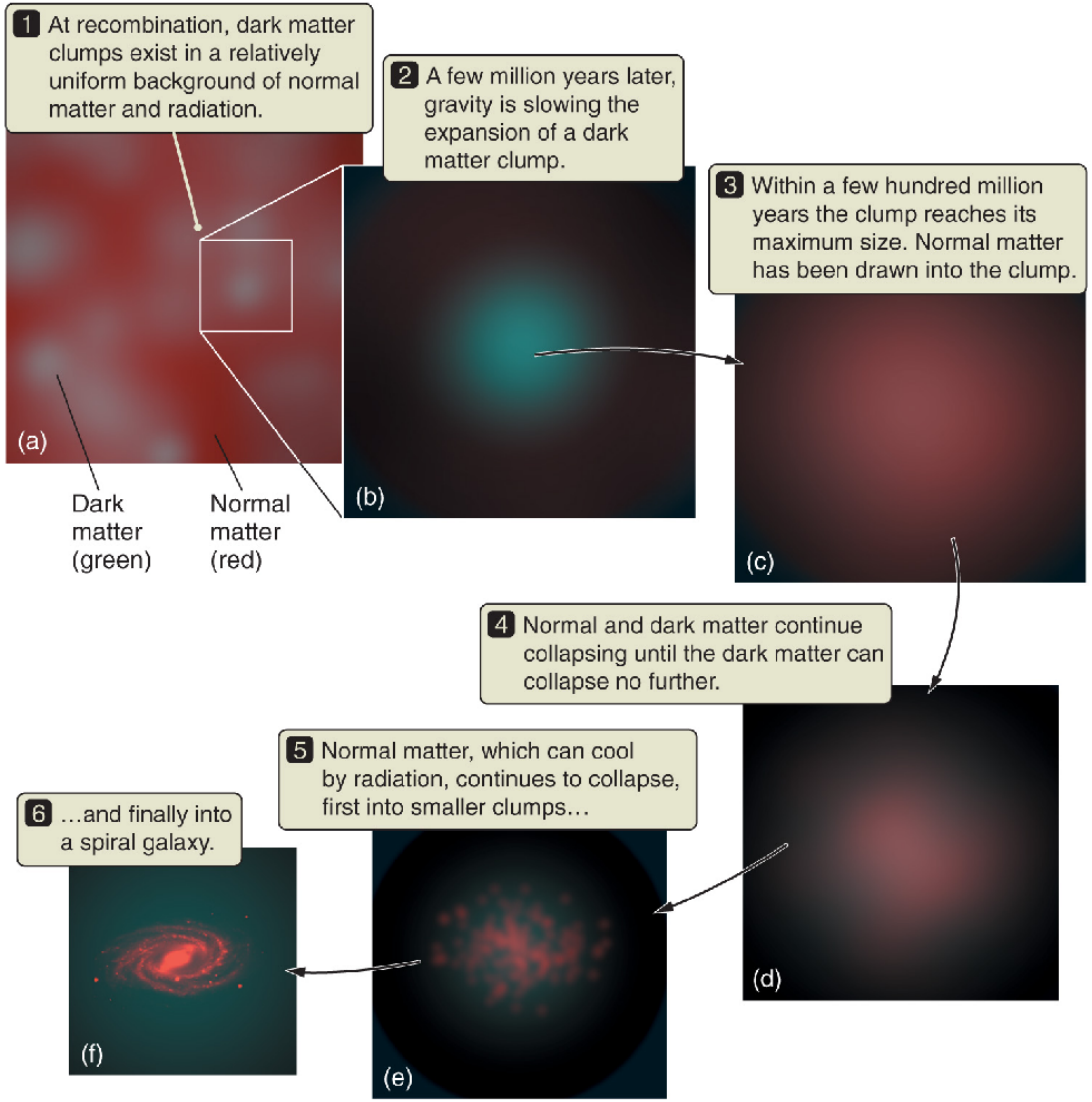
How do structures grow?

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!)

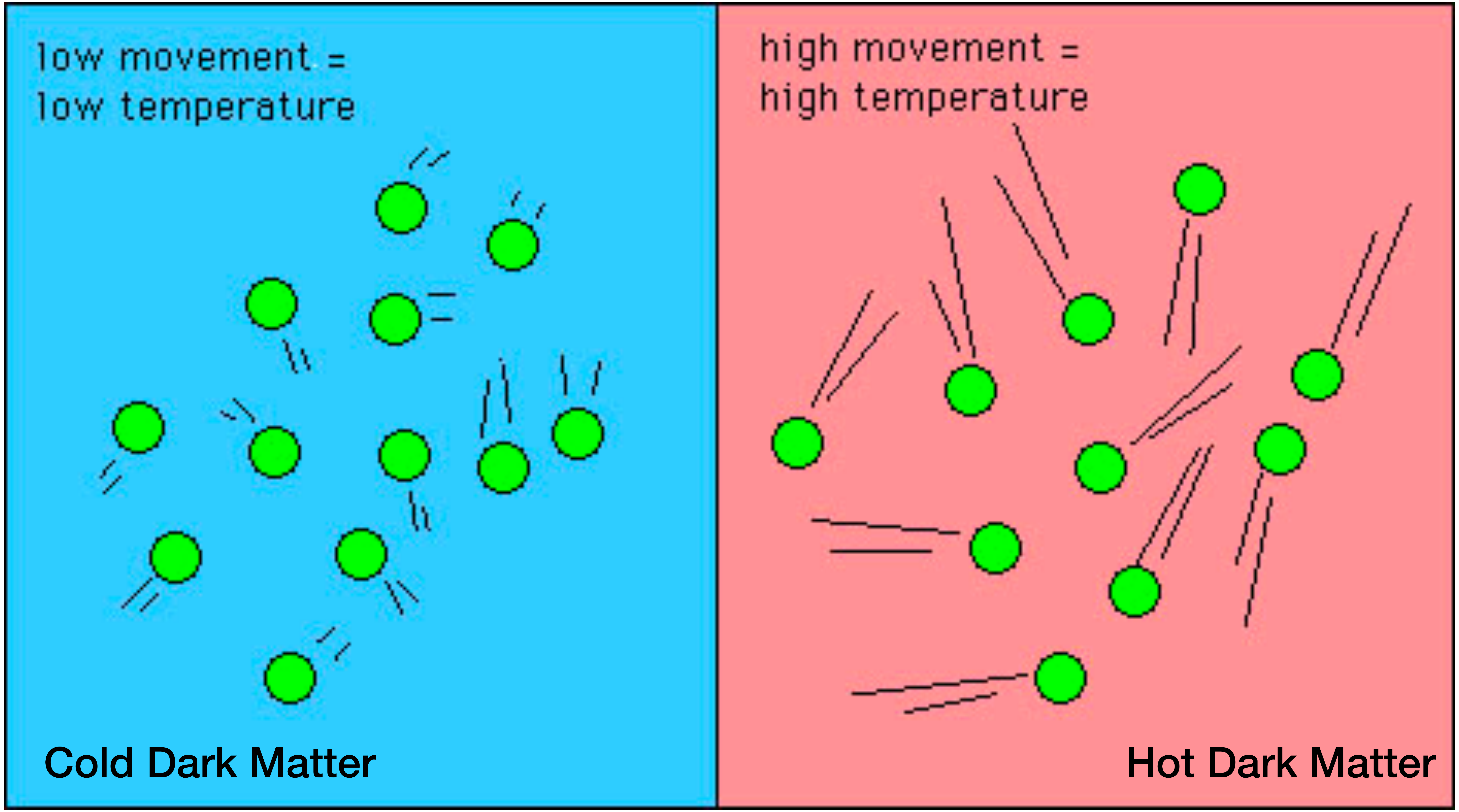


Galaxies form inside dark matter halos, becoming more compact in centers than the dark matter

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

Dark matter can be "hot" or "cold" - what does this mean?

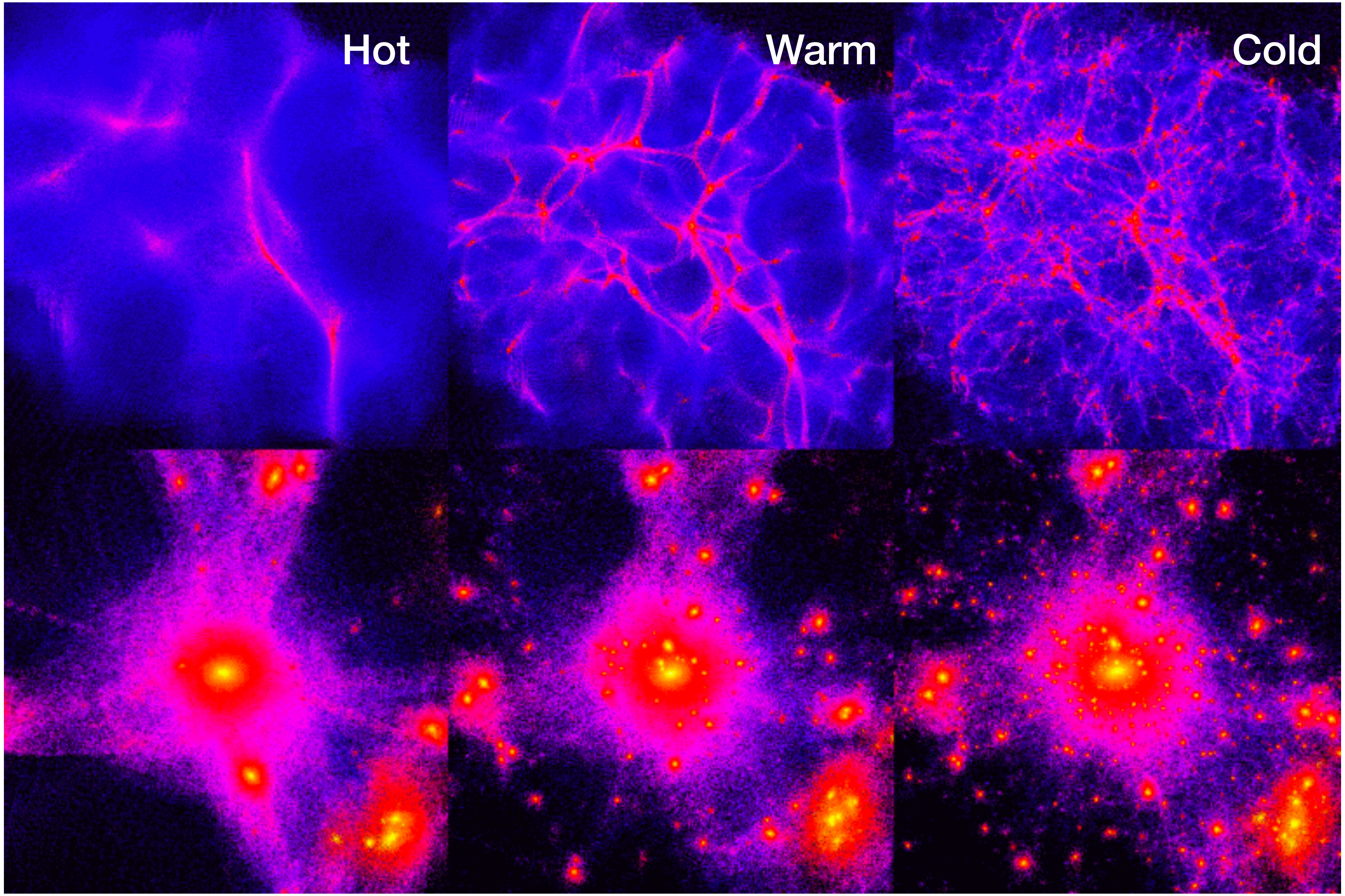
What is temperature?



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

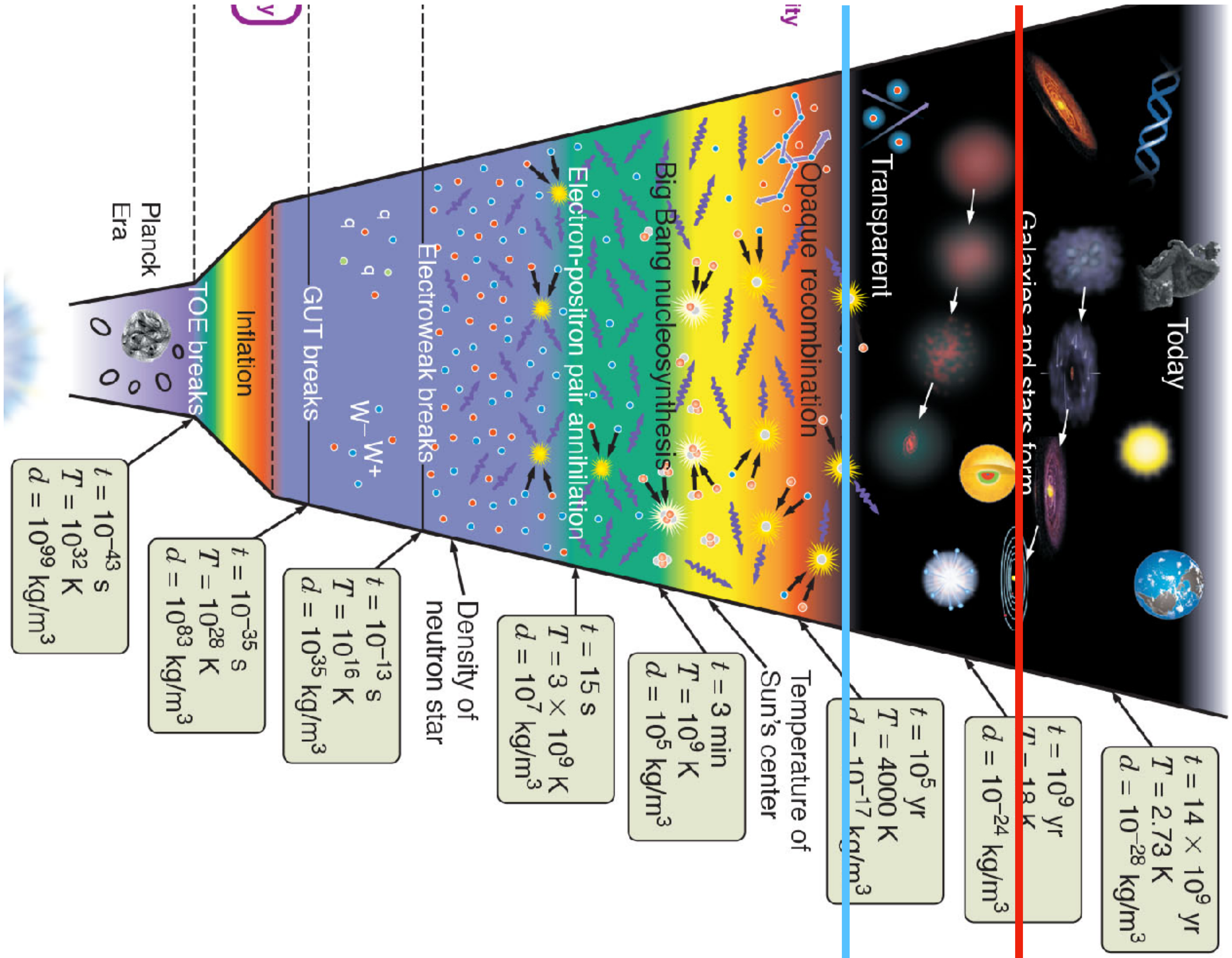
non-relativistic at time of collapse (like WIMPs): cold

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?

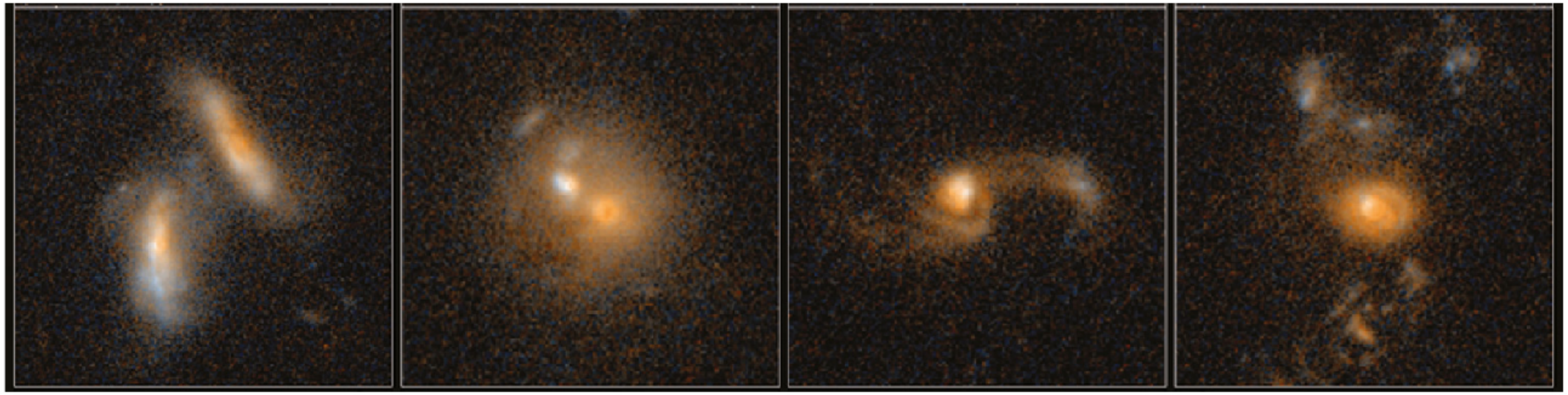
A) Density of electrons is too low to scatter light
B) Electrons and ions recombined again after the rate of star formation declined
C) Electrons and ions recombined again after the rate of supermassive black hole accretion declined


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

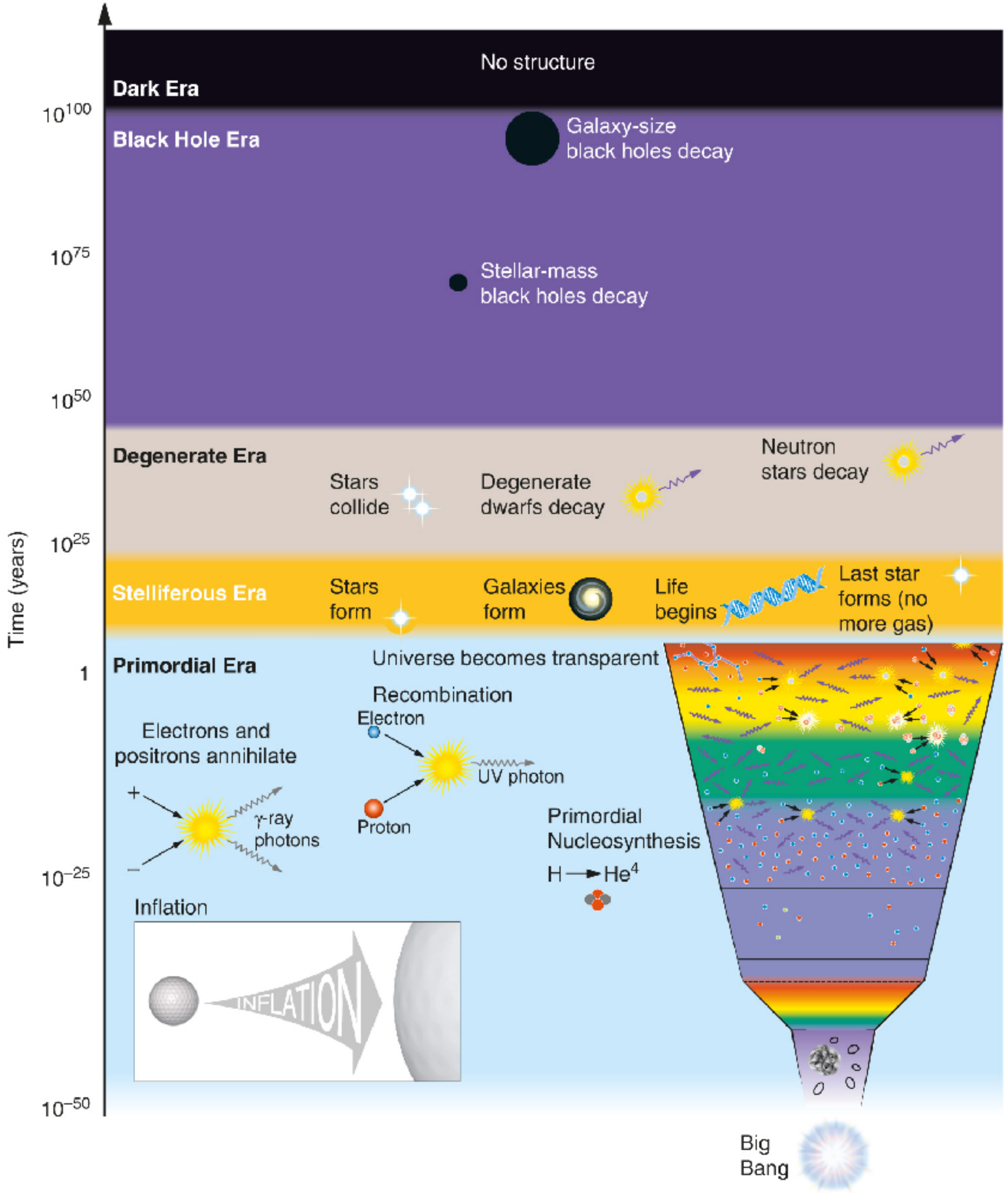
Galaxies grow in size through mergers



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?