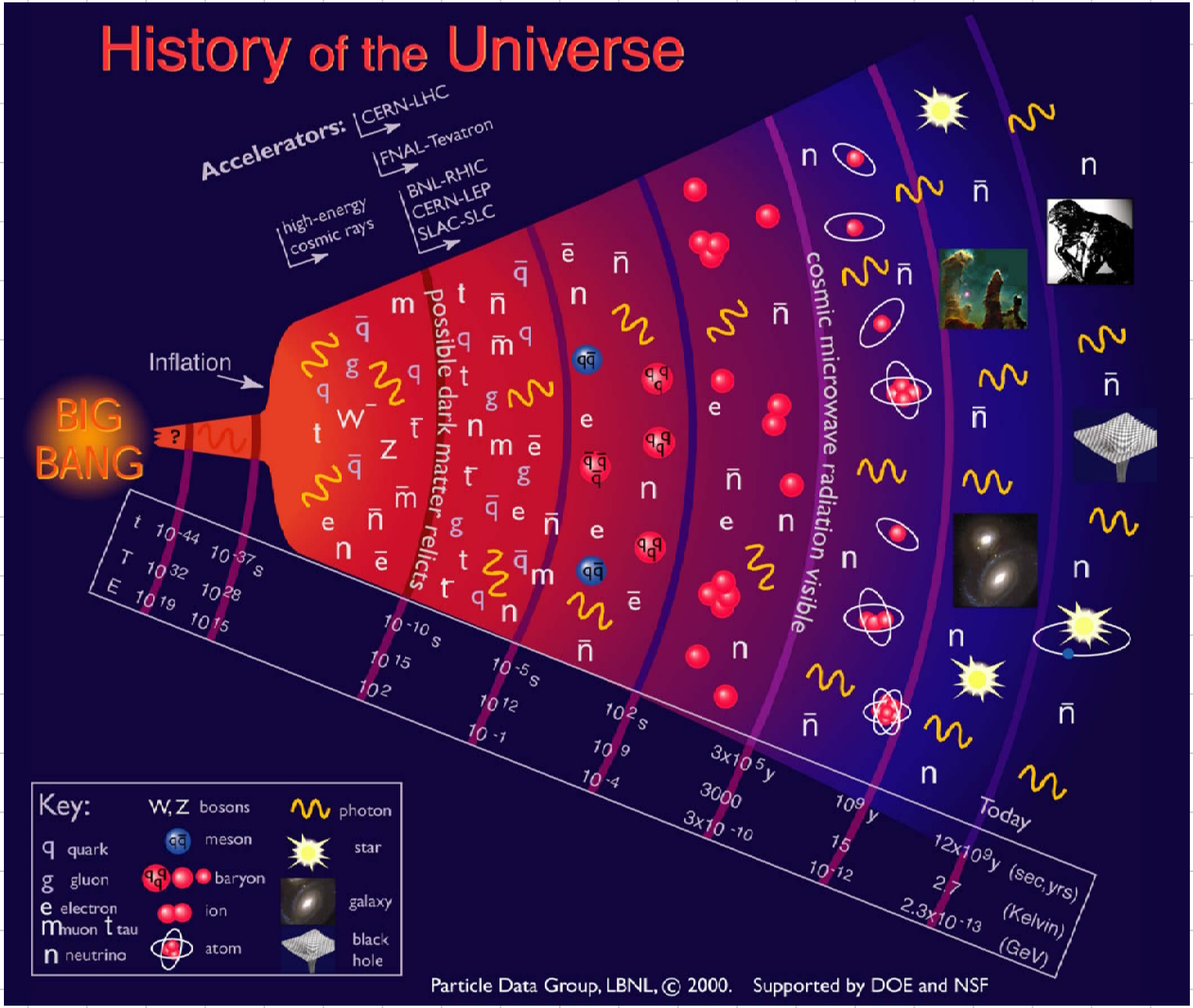
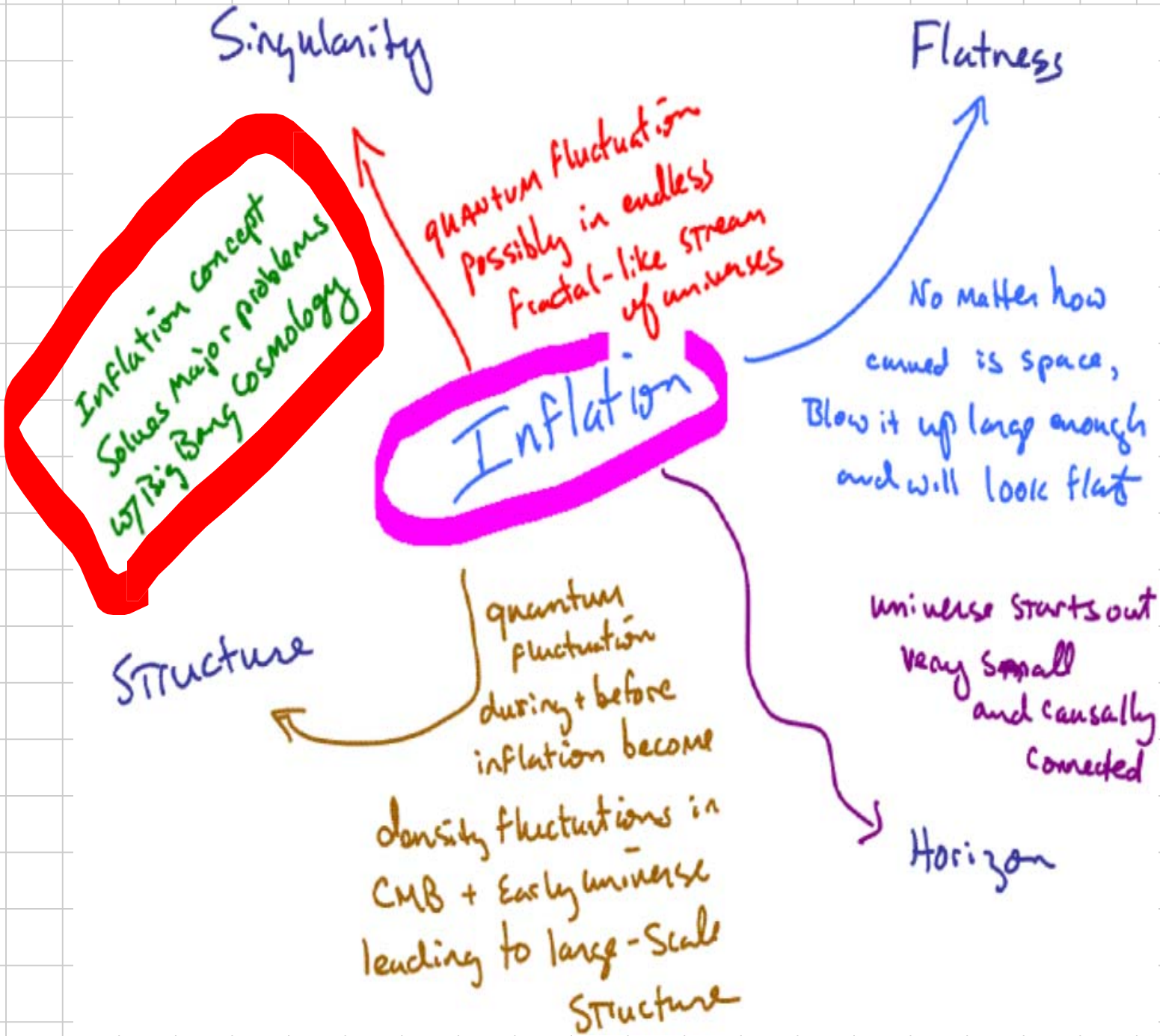
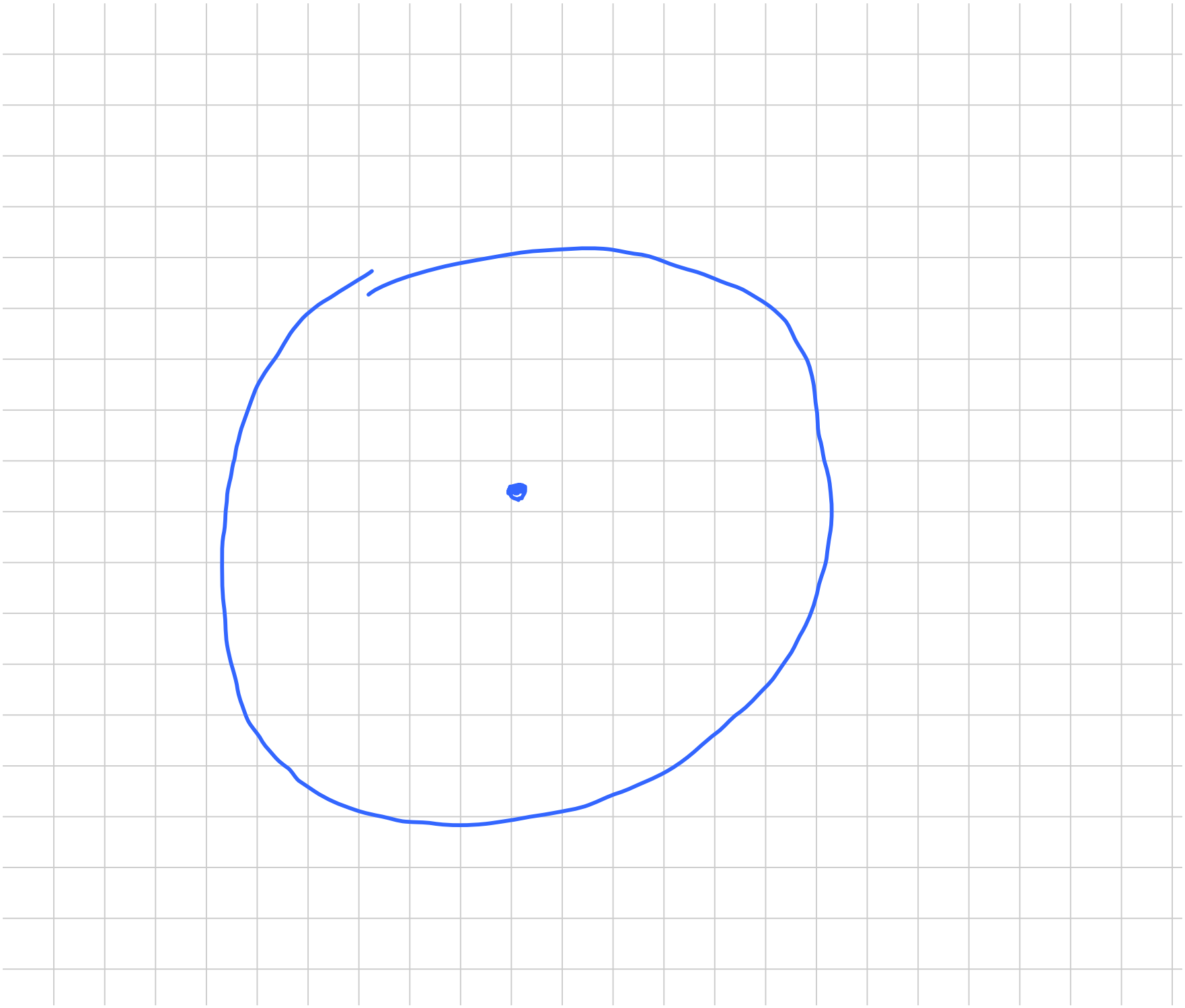
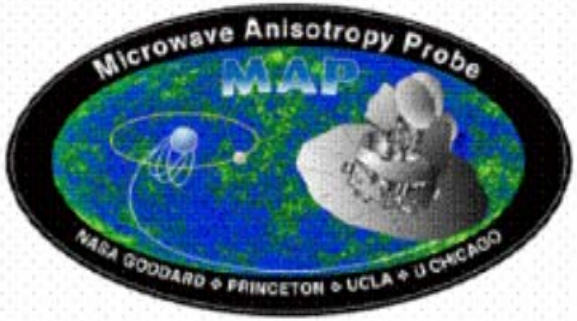
Physics 102 - April 14, 2014

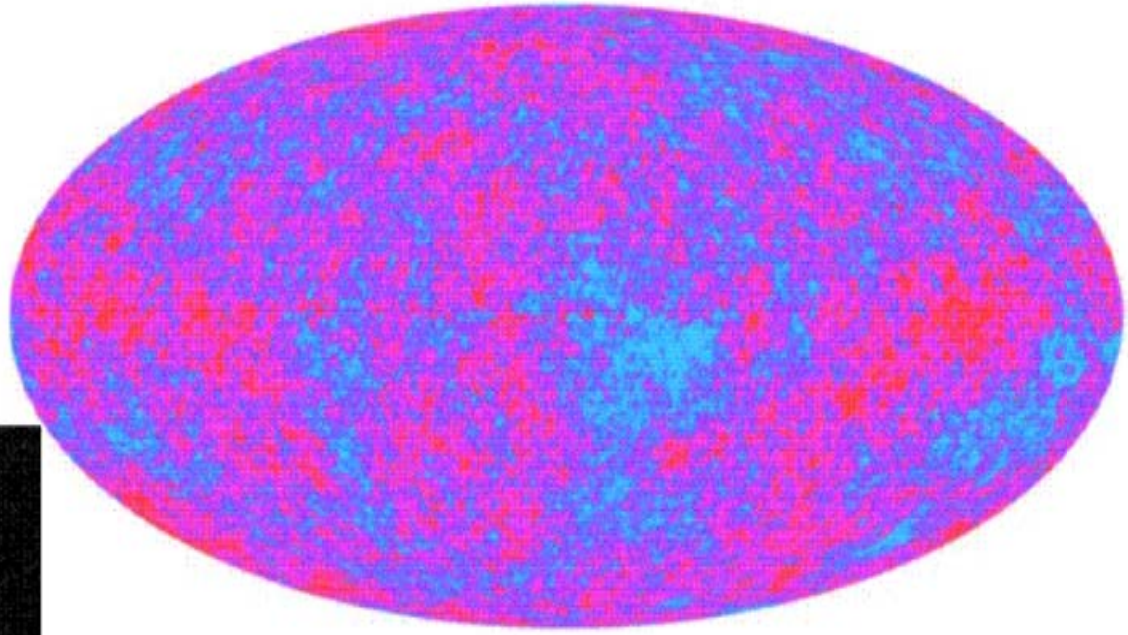


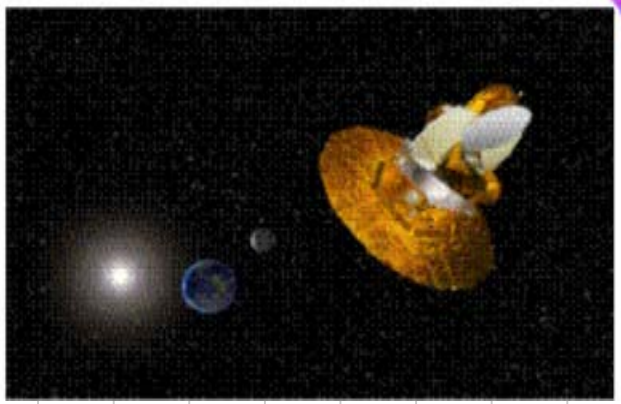

Singularity
Flatness
Inflation concept
Solves major problems
w/ Big Bang Cosmology
quantum fluctuation
possibly in endless
fractal-like stream
of universes
Inflation
No matter how
curved is space,
Blow it up large enough
and will look flat
universe starts out
very small
and causally
connected
Structure
quantum
fluctuation
during + before
inflation become
density fluctuations in
CMB + Early universe
leading to large-scale
structure
Horizon



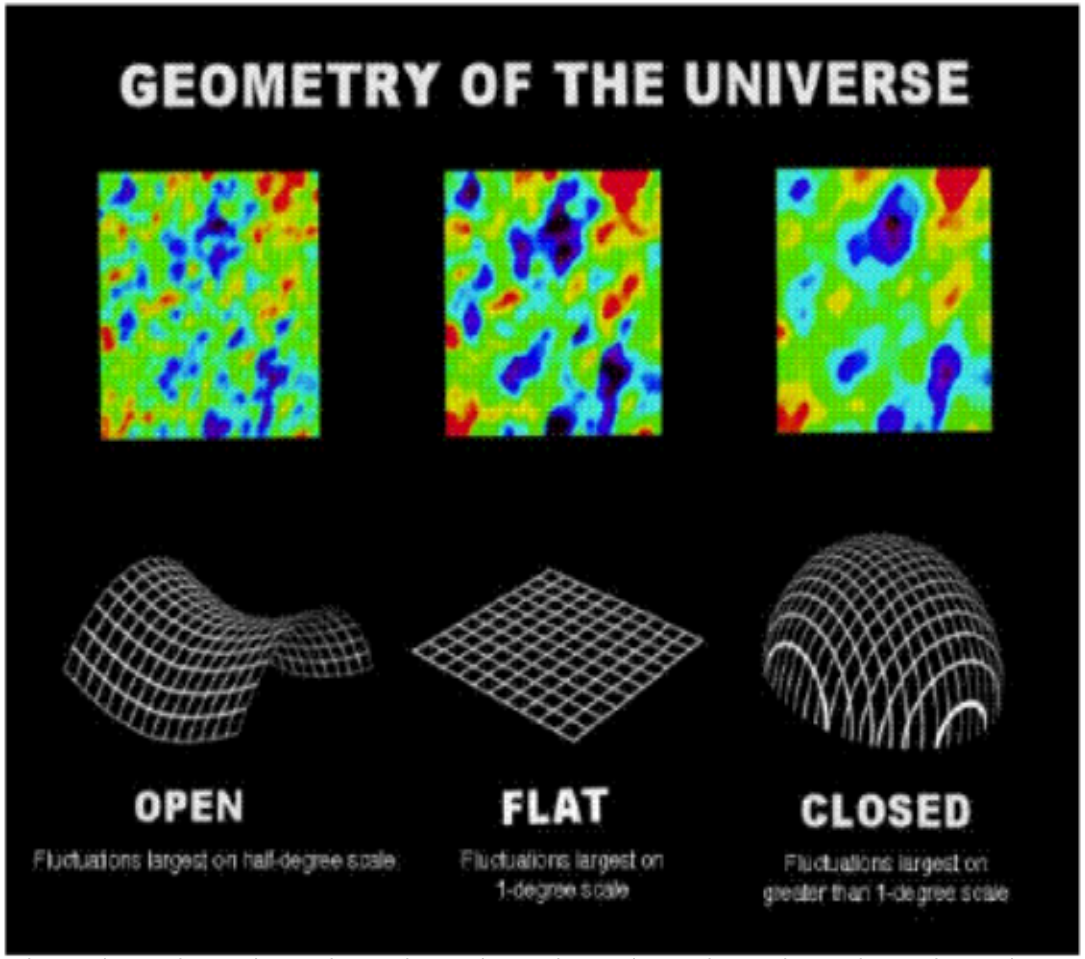
WMAp - Wilkinson Microwave Anisotropy Probe
(2003) High Resolution Study of CMB

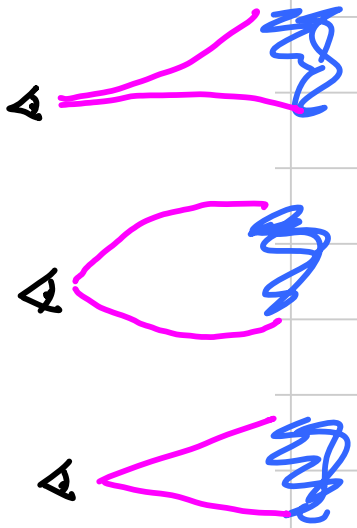






Size of fluctuations / structure in the CMB is sensitive to the geometry of the universe





Incredible new data in the last 10 years

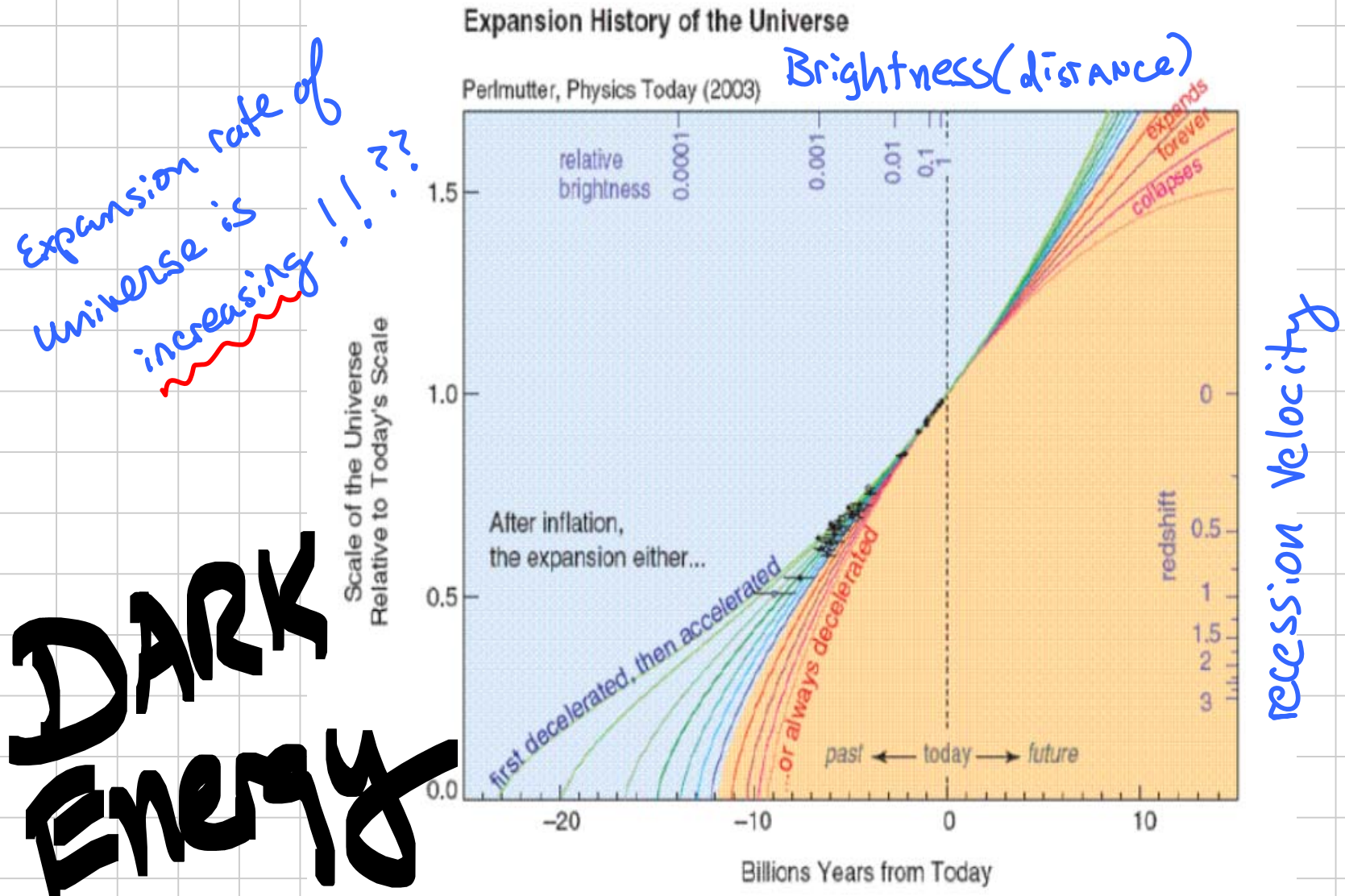
- Fluctuations in the Temperature/color of the CMB (1 part in 10^5)
  - Cobe, WMAP — satellites
- universe is "flat"
- Expansion of the universe is Accelerating
  - observations of supernovae in distant galaxies
    - Two groups of scientists:
      - Supernova Cosmology Project — Perlmutter at UC Berkeley
      - High-Z Team

Do "Hubble" study velocity vs. distance over vast distances (Time) by using Supernovae as "standard candles"

Expansion rate of universe is increasing !! ??

Brightness (distance)

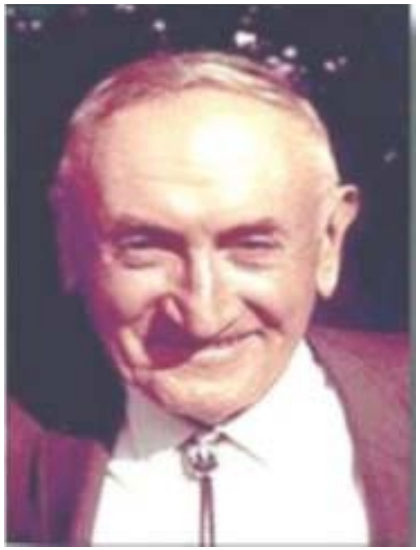
recession velocity



DARK Energy


Inflationary Big Bang Model
STANDard Model of Particle Physics
Much of the Puzzle is in place
Still some Missing Pieces ...

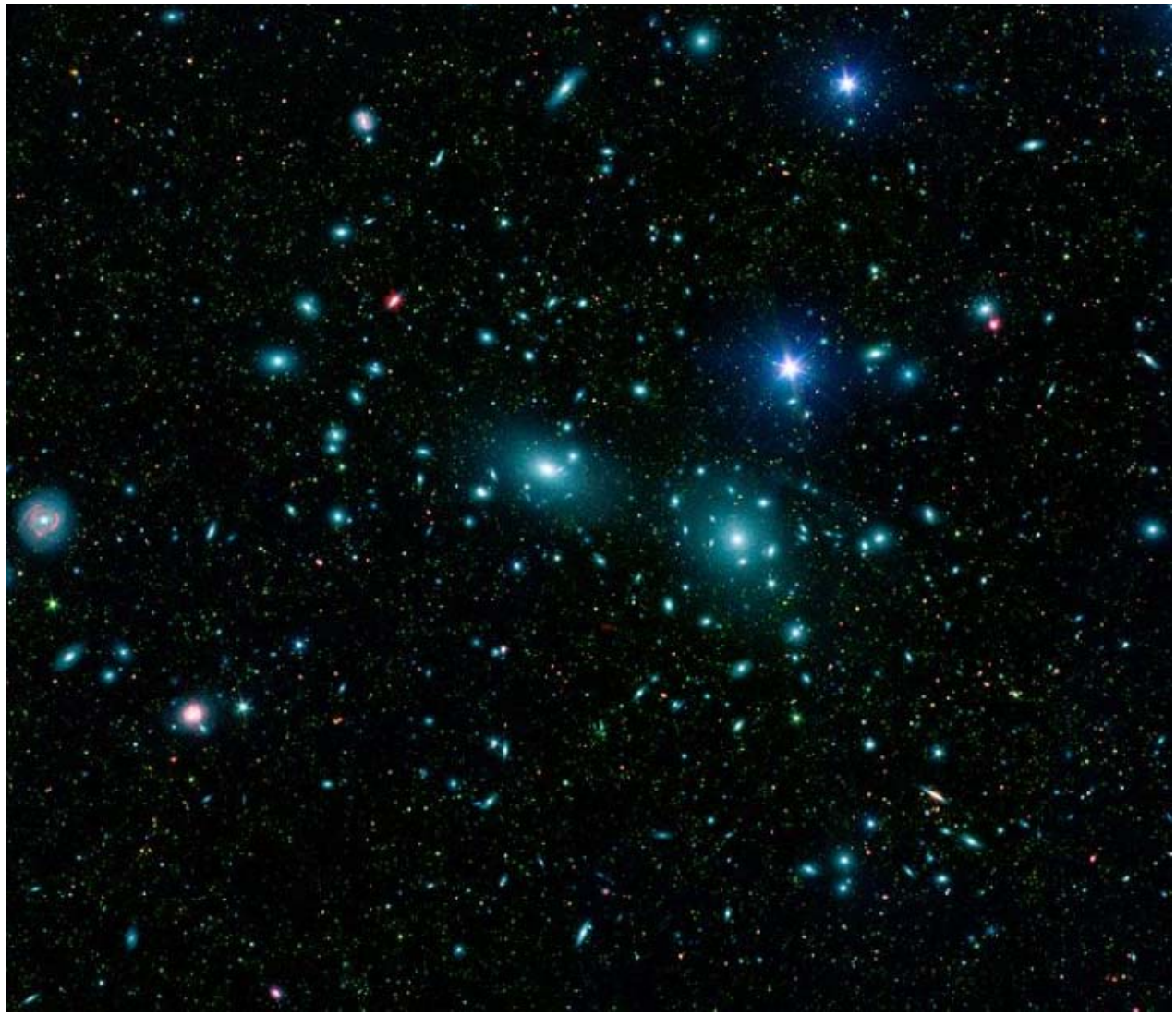
DARK MATTER



Fritz Zwicky (1898-1974)
CalTech astrophysicist

- jet engines
- "spherical bastard"
- Suggested galaxies could act as gravitational lenses
- Dark Matter

Coma Cluster of galaxies

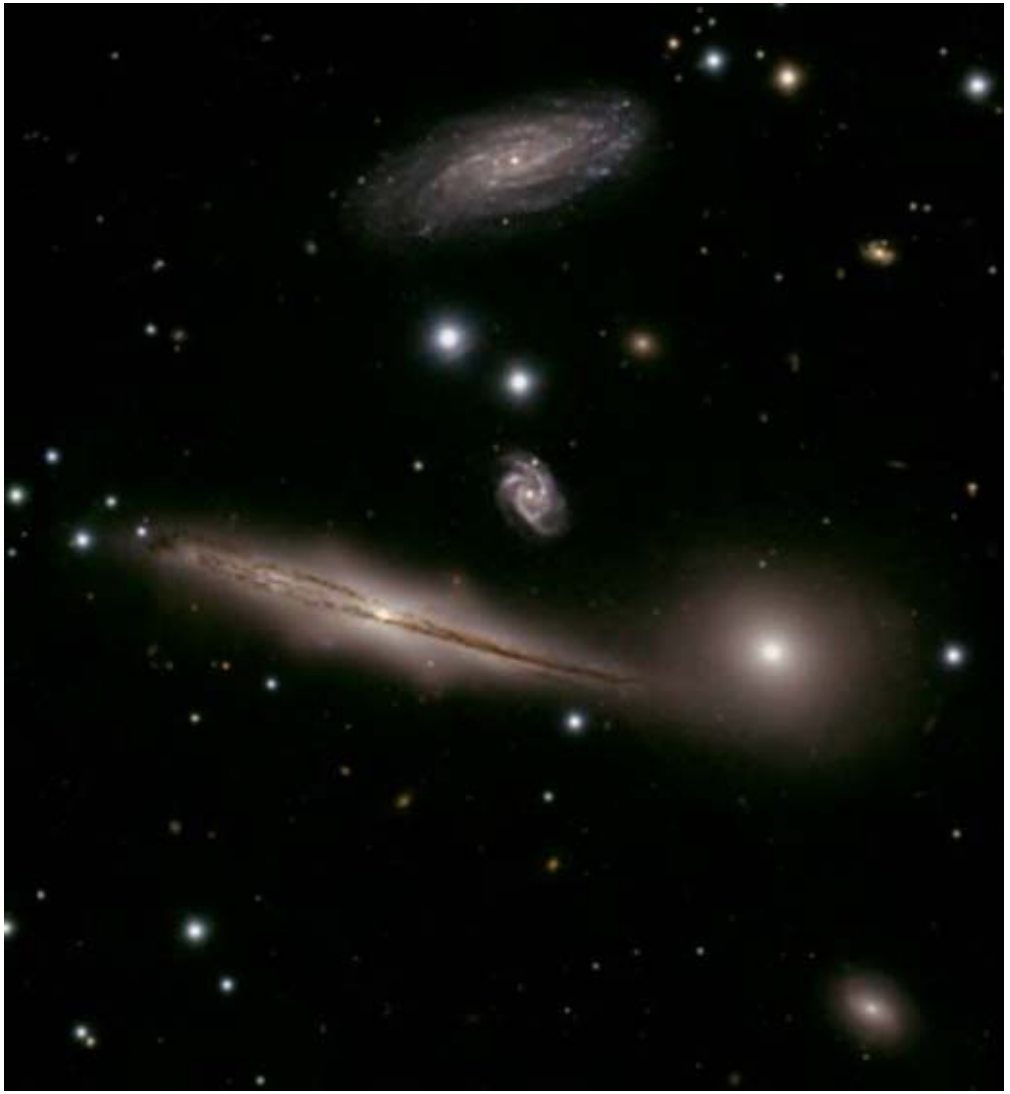


Nasa/JPL / Sloan Dig. Sky Survey

Zwicky compared mass of galactic cluster using two methods

① number + brightness of galaxies in cluster

② motion of galaxies at edge of cluster



galactic cluster

$Mass|_{method\ 2} >> Mass|_{method\ 1}$ → DARK Matter

1975

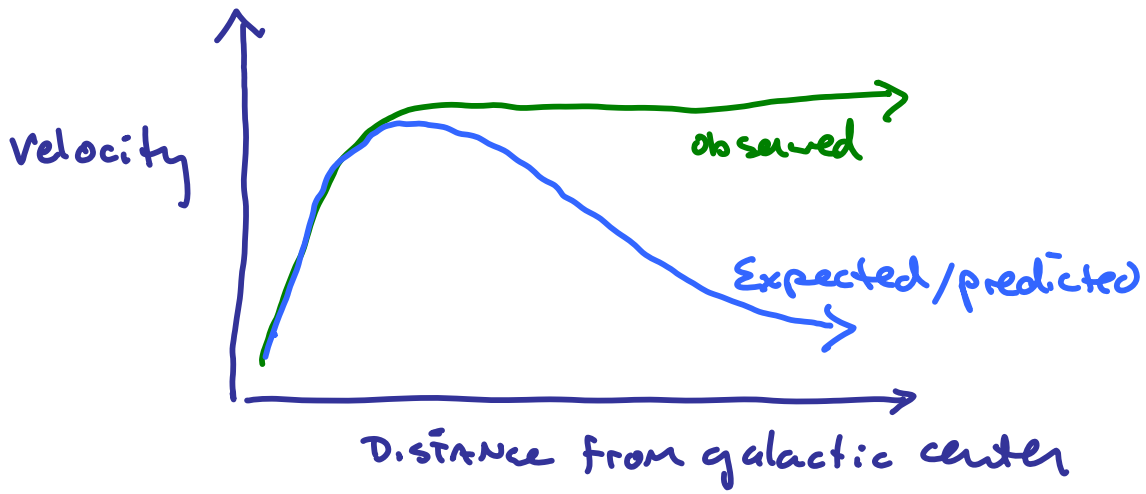
Vera Rubin

Kent Ford

Carnegie Institution of Washington

Vera Rubin

Measured velocities of stars in spiral galaxies



Dark Matter

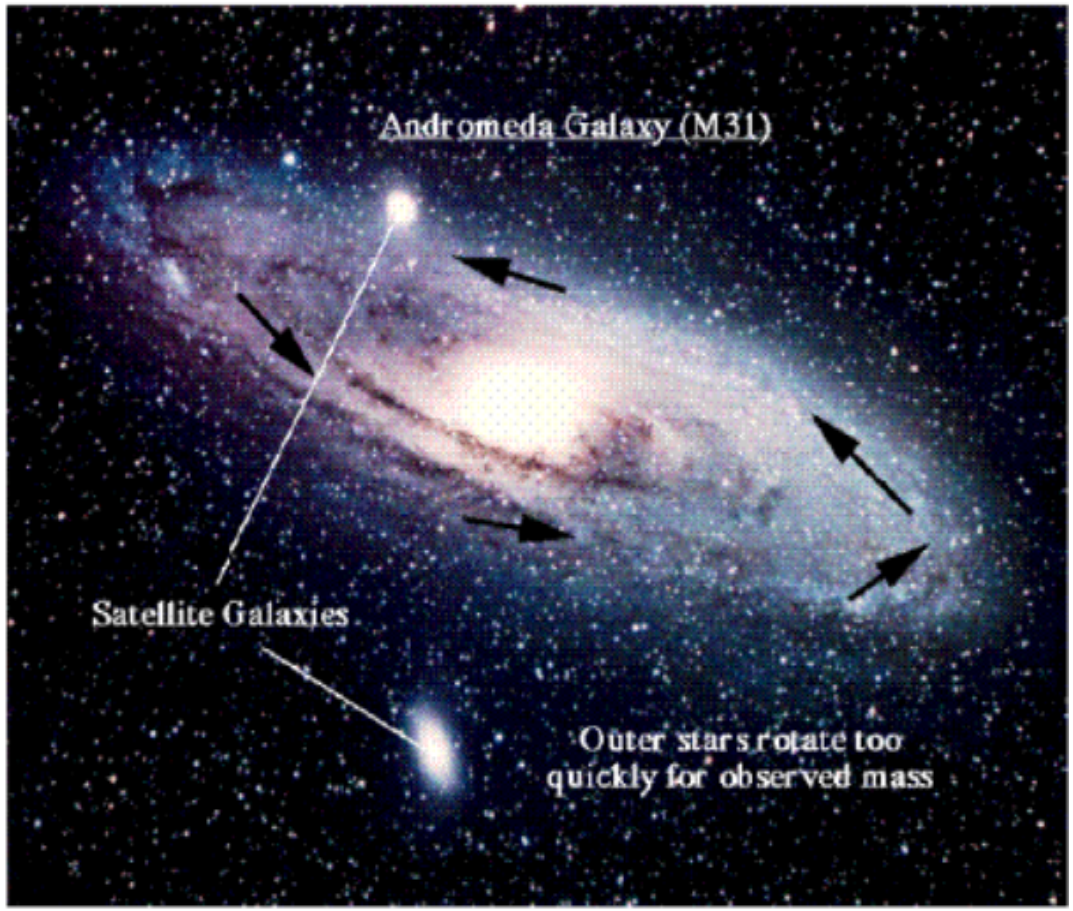
Orbits $F = \frac{mv^2}{R}$ $F = \frac{GMm}{R^2}$

Circular Motion

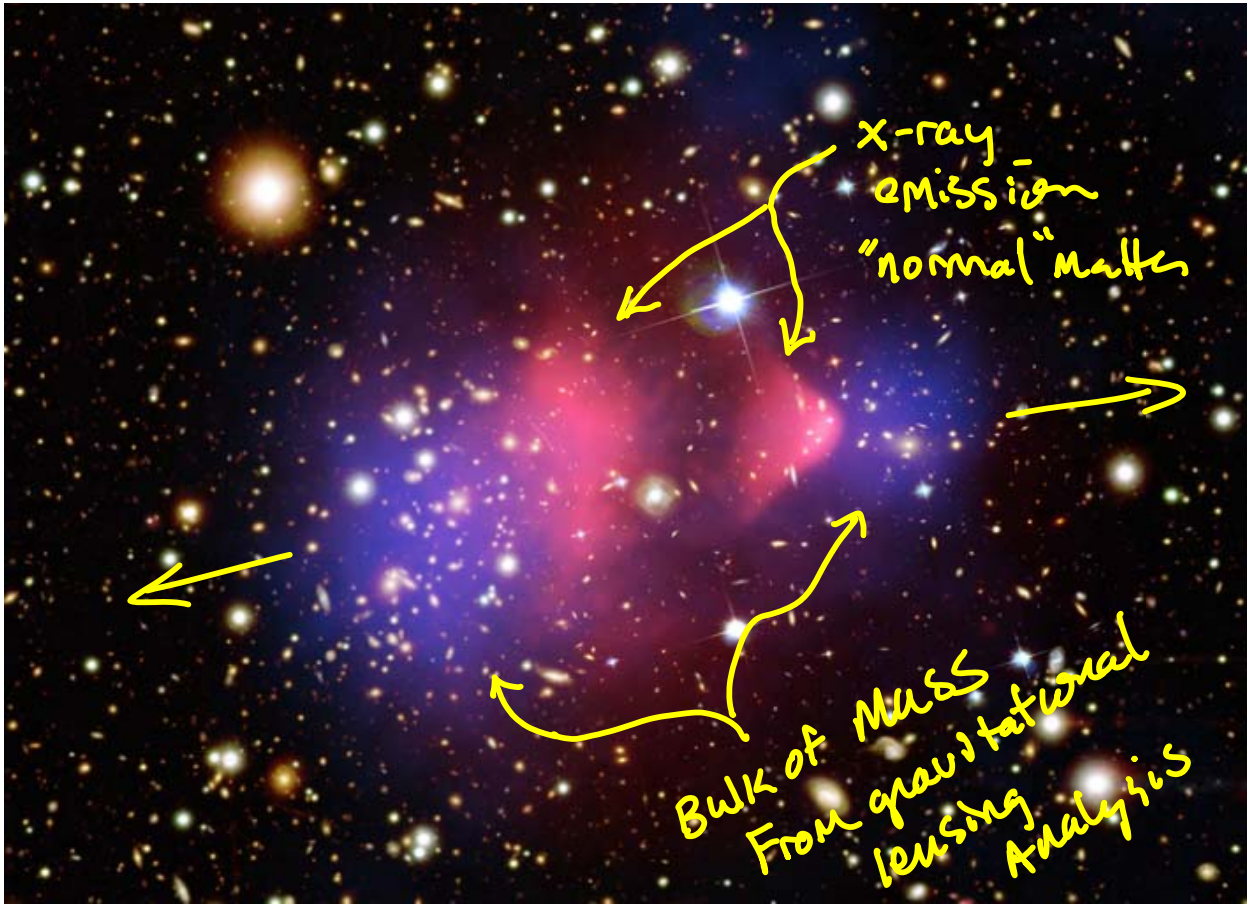
$\frac{mv^2}{R} = \frac{GMm}{R^2}$

Can relate velocity radius and force in orbits.

Have seen that orbits in stars and galactic clusters Require Stronger Gravitational force than can be explained by conventional Observable "visible" matter



-P. Cushman

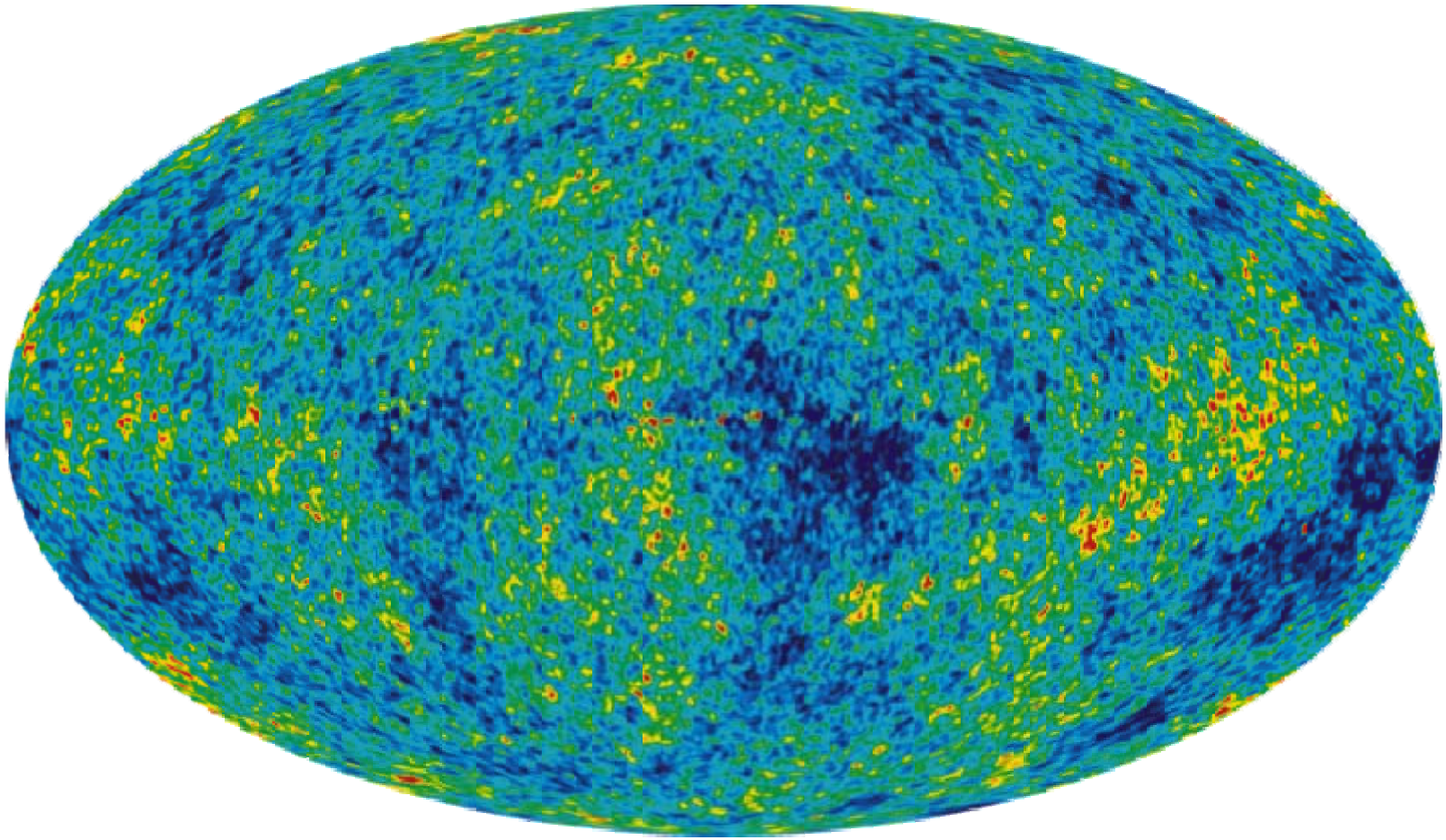


Bullet cluster
colliding galactic clusters

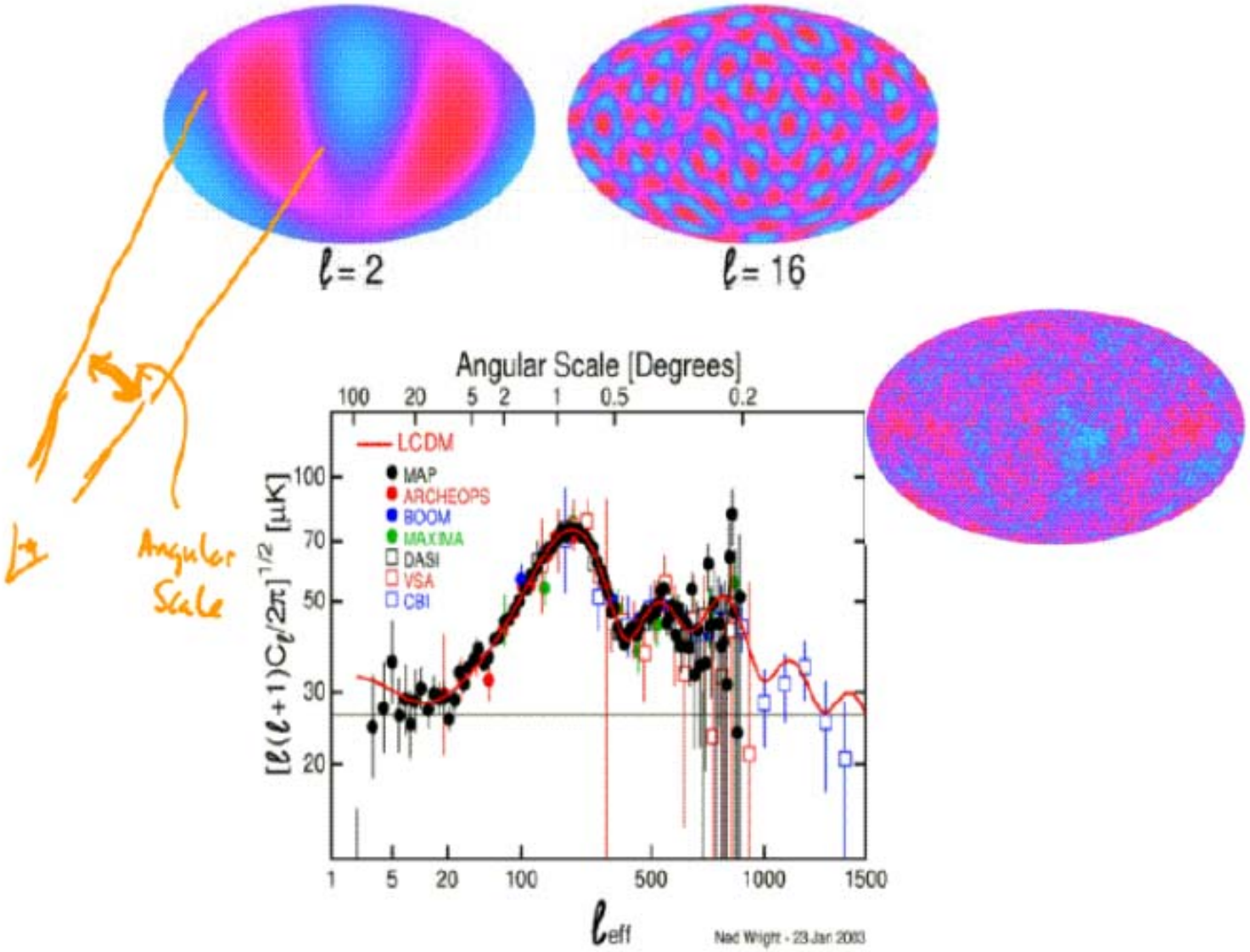
galaxies + Dark matter
zip past

intergalactic gas slowed down

The universe at $t = 400{,}000$ years

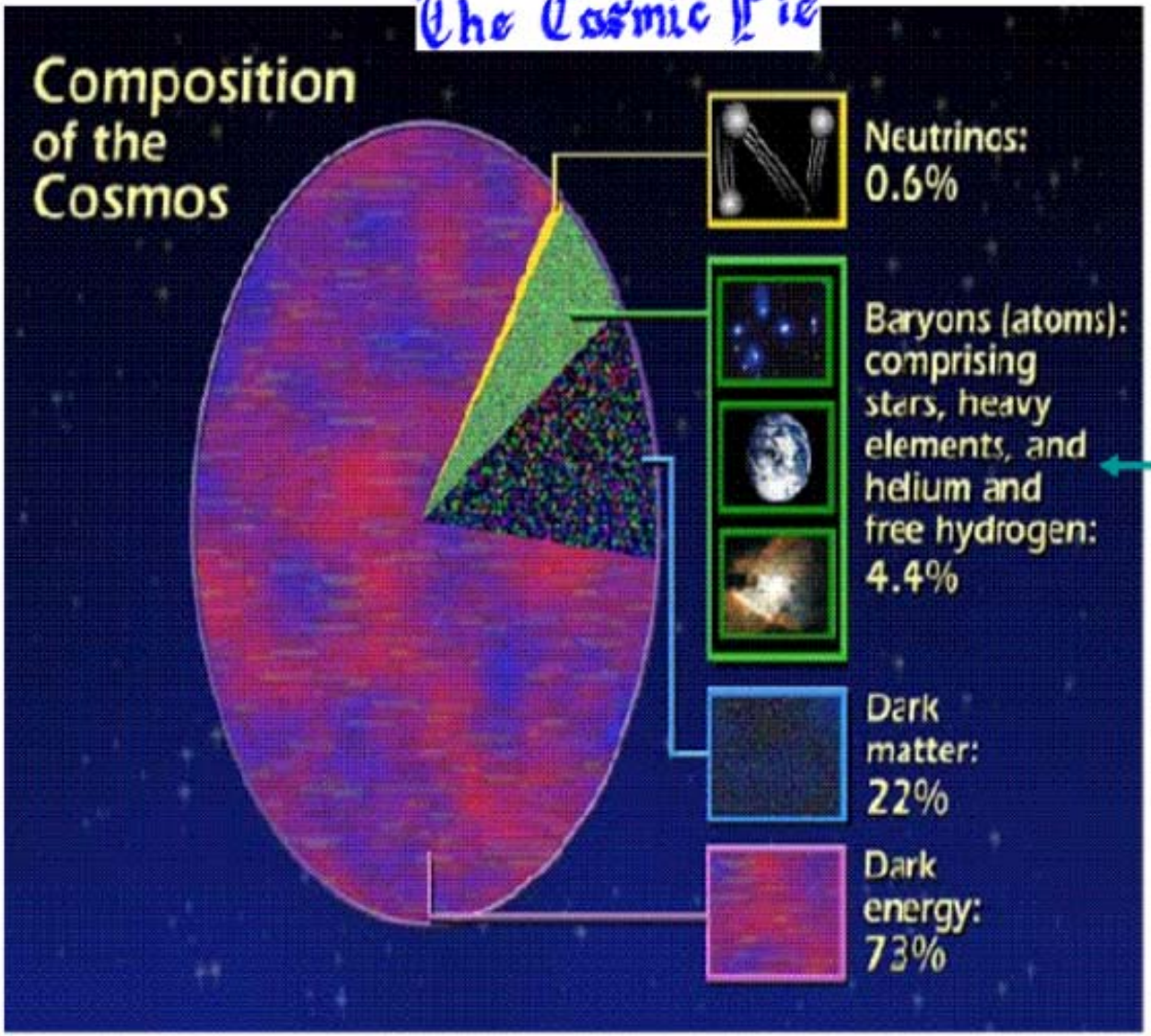


Cosmic Microwave Background from WMAP



"Power spectrum" (size) of temperature fluctuations sensitive to different matter/energy components of the universe

The Cosmic Pie



95% of the universe is unknown!

figure from E. Linder LBL