Professor David Cinabro
Wayne State University
is DOOMED,
INSIGNIFICANT,
and IGNORANT

(and you are too)

Outline

- DOOMED: The Fate of the Universe
- INSIGNIFICANT: The Dark Sector
- IGNORANT: Only 5%?
- CONCLUSION: Outlook

Einstein's Cosmology

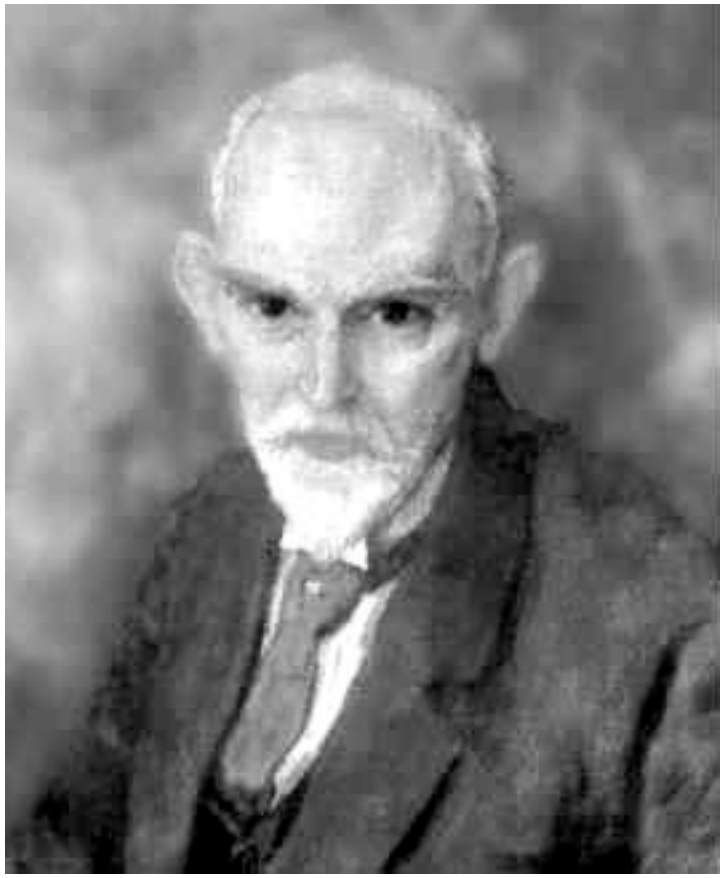
- Einstein began to consider the Universe after completing the General Theory of Relativity in 1915
  - describes how gravity works.
  - Space is malleable thus Einstein's cosmology is in terms of spatial distortions
- Considered a Universe of bodies interacting only via attractive gravity
- At the time Universe = Milky Way galaxy and only cosmic motion was "clockwork" style

Einstein's Answer

- Not stable. Either gravity dominates and all collapses, or no gravitationally bound object, such as the Milky Way, forms.
- Einstein added a force that opposes gravity to produce a static Universe.
- Universal "tilt" to space. Everything slides away from everything else.
- Called the "Cosmological Constant" and labeled Λ.

A Dissenting View

- de Sitter in 1919: no evidence for the Cosmological Constant Λ
- Without it, Universe must be expanding or contracting
- His cosmology was unphysical as it assumed an “empty” universe.



Great Debate of 1920

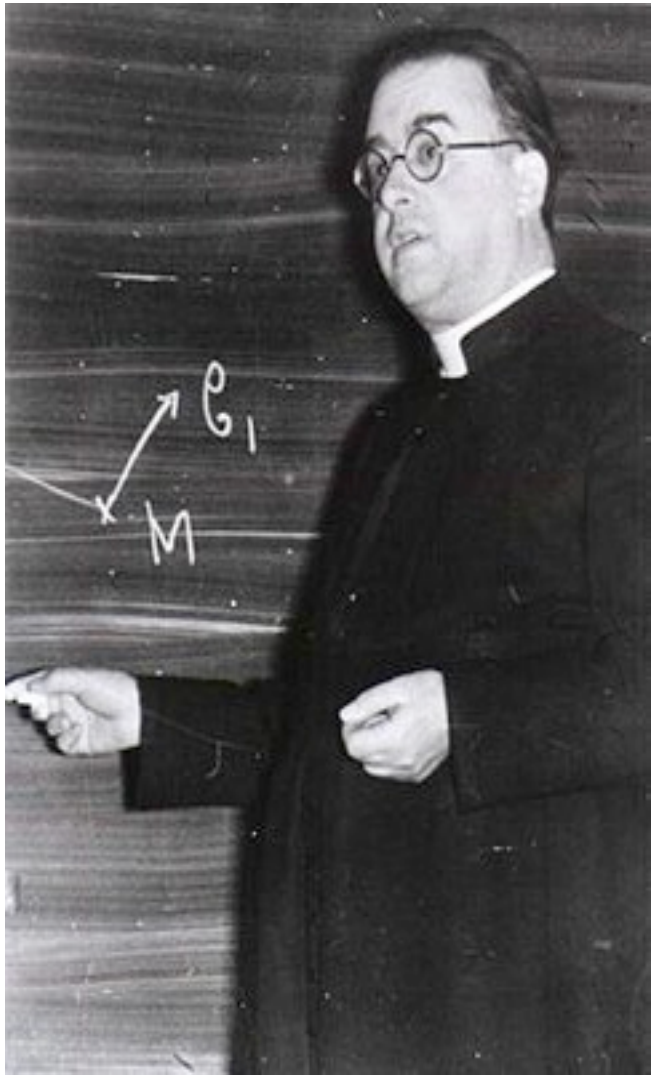
- What is the nature of "spiral nebula"
- Shapely - Clouds of dust and gas within Milky Way which was measured to be ~100,000 LY across.
- Curtis - "Island Universe" like Milky Way and must be much further away.

Hubble Measures Distance to M31

- Debate resolved by Edwin Hubble in 1924
- Measures distance to Andromeda (millions of LY) with a variable star
- The Universe is incredibly vast

Lemaitre Proposes the Cosmic Egg

- Further evolution of Einstein's cosmology, as criticized by de Sitter, in 1927
- Noted that an expanding Universe implies a small, hot, dense Universe in the past.
- He called this the Cosmic Egg or Primeval Atom
- Weak evidence for an expanding Universe
- Einstein at first ridiculed this but…

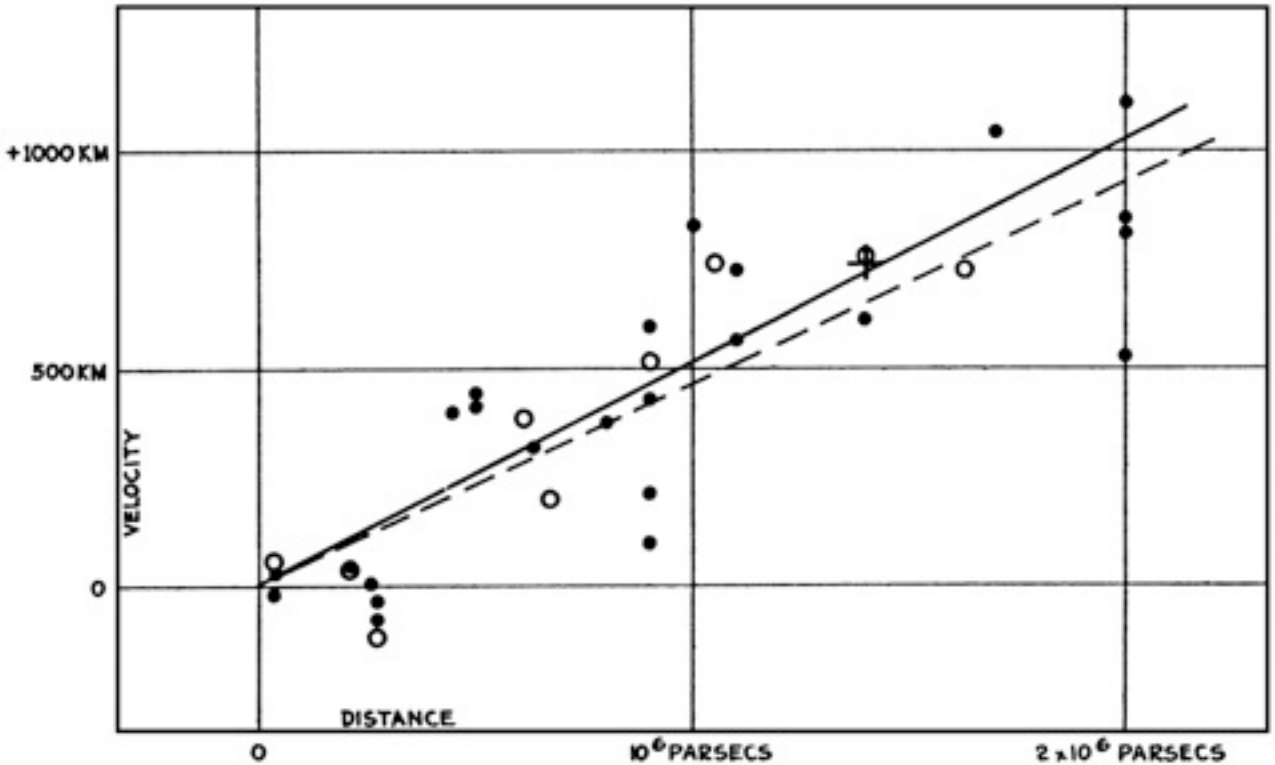


Discovery of the Expanding Universe: Hubble 1929

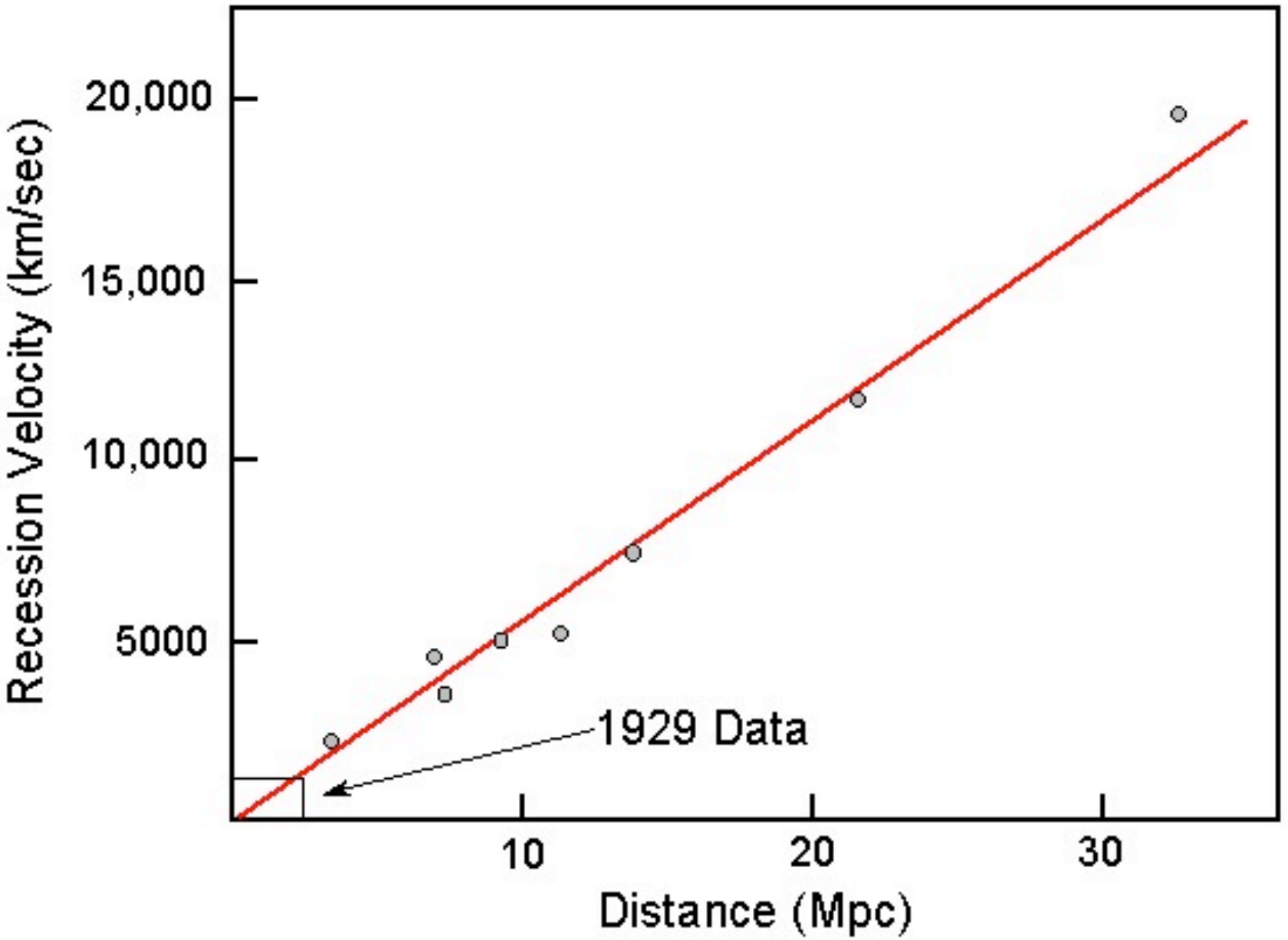
Measured distances to 25 galaxies:

- Used cepheids for Andromeda and Local Group
- Used brightest stars in the others
- Compared distances with recession velocities.

Finds that the velocity gets larger with distance, the Hubble Law, and slope is the Hubble parameter, H

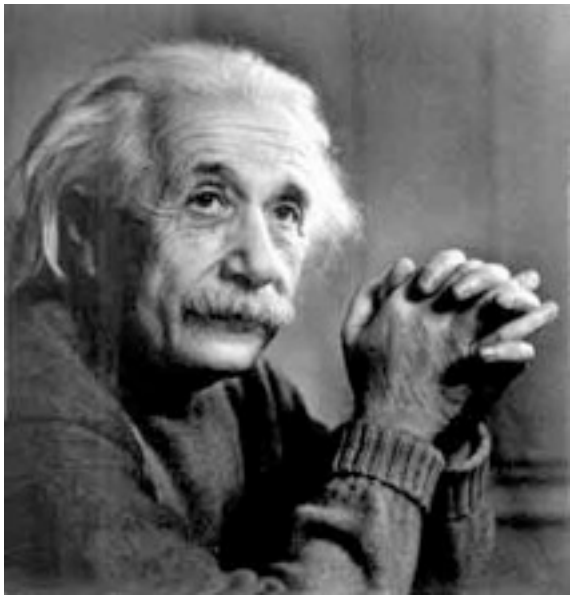


Hubble & Humason (1931)



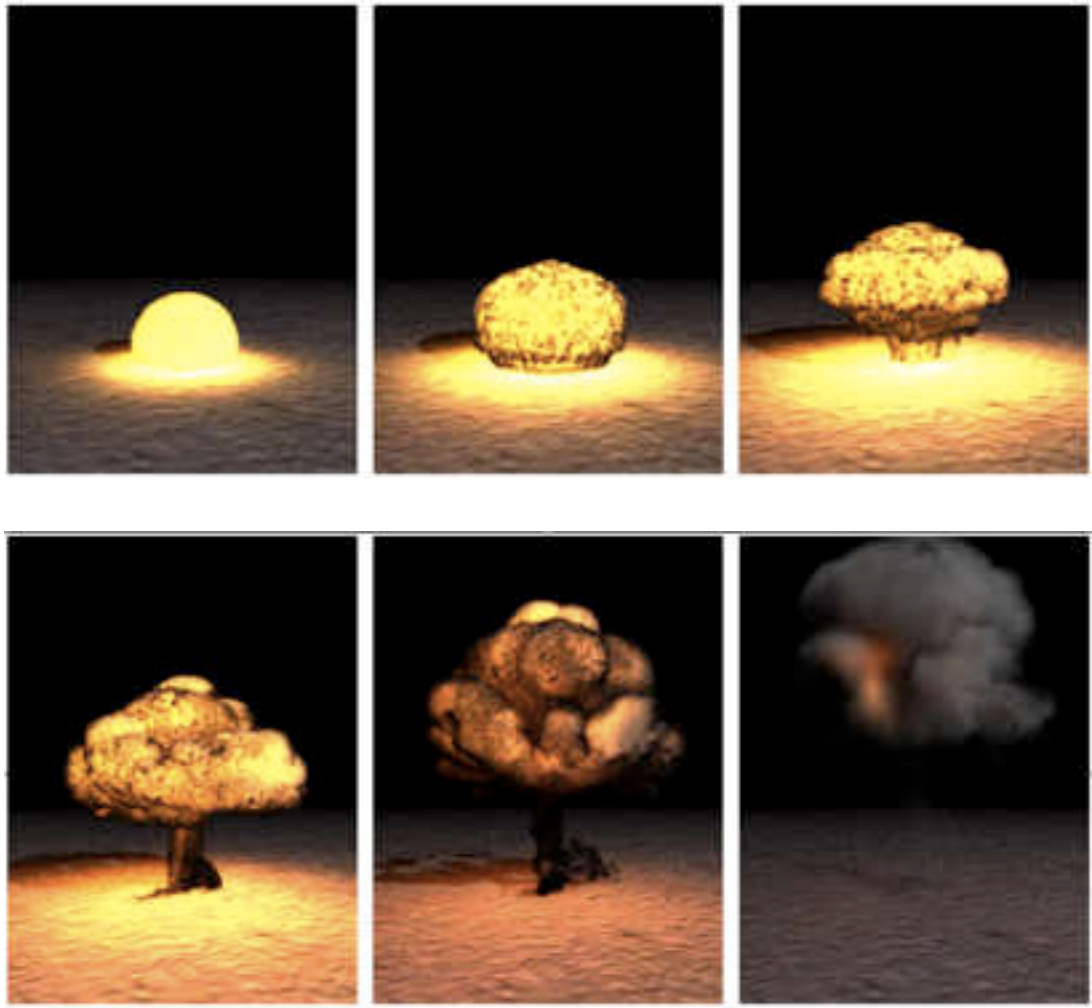
Einstein's Greatest Blunder?

- Nearly everyone convinced that Einstein was wrong about the Cosmological Constant.
- "Greatest Blunder" tag is undeserved.
- We call the General Relativity based expanding universe cosmology Einstein-deSitter cosmology (+Lemaitre).
- Alternative Steady State Cosmology is still viable.



Echo of the Explosion: Gamow (1948)

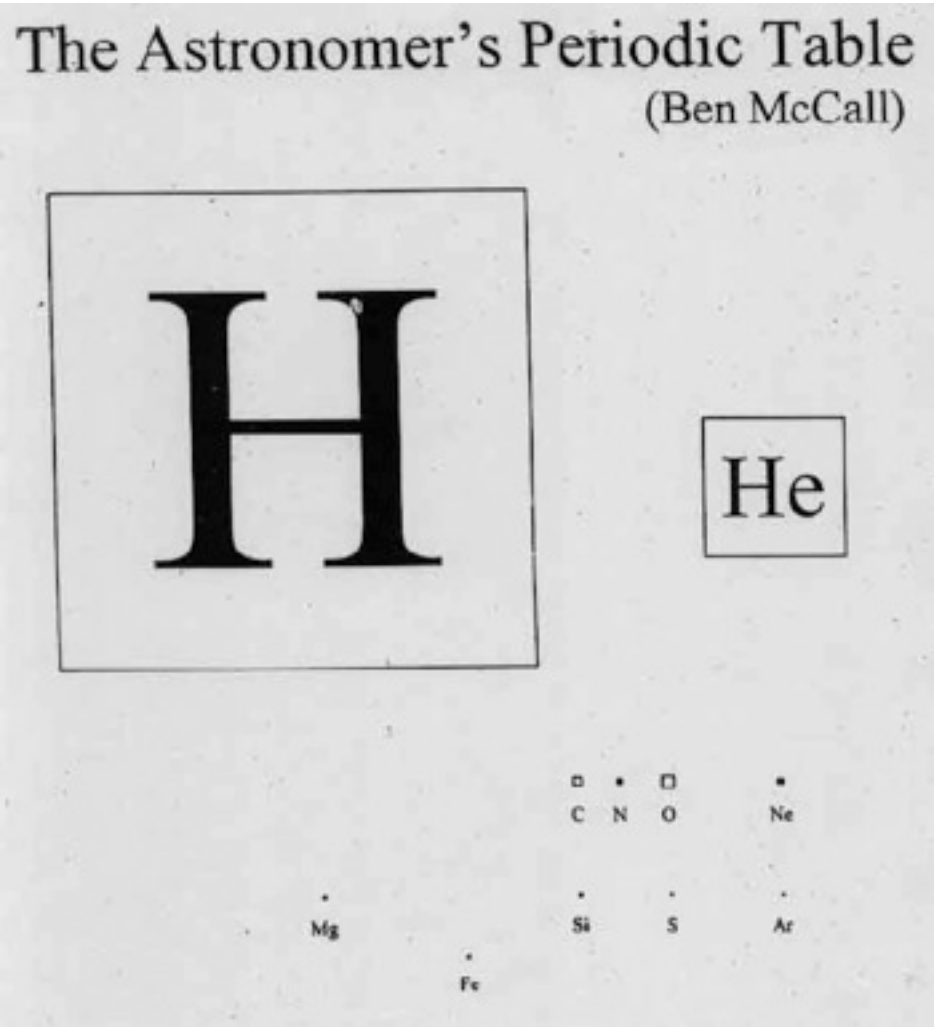
- Gamow and Alpher consider the consequences of an expanding Universe.
- First conclusion is that the Universe should be filled with E+M radiation left over from when it was small and hot.
- Today should be Microwaves (Blackbody with T = 3K).



Cosmic Microwaves (1963)

- Serendipitously observed at Bell Labs using a communications instrument.
- Death blow to alternate Steady State cosmology of Fred Hoyle.

Astronomer's Periodic Table



- Gamow, Alpher, Herman add in Nuclear Physics to calculate the abundances of the elements arising from the hot, dense early Universe (1948-56).
- Agrees with observations that grow increasingly precise.

Triumph of the Big Bang

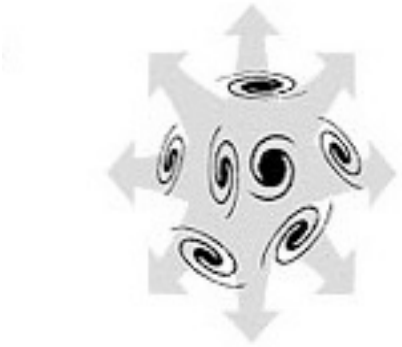
- Ironically the term was coined ironically by Fred Hoyle in a 1949 radio broadcast.
- Three pillars:

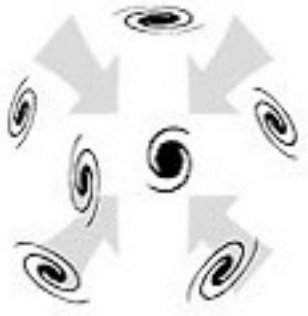
    1) Expanding Universe

    2) Cosmic Microwave Background

    3) Cosmic Elemental Abundances
- Only serious Cosmology by the mid-1970's
- Unfortunately it leaves only two alternatives for the fate of the Universe…

Big Bang starts the expansion of the universe. But there is enough mass in the universe that gravity captures all the galaxies, the universe begins to contract, making gravity stronger, accelerates contraction, and eventually the universe is compressed into a single point(?). We call this…





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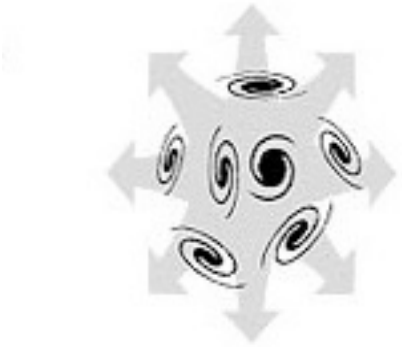
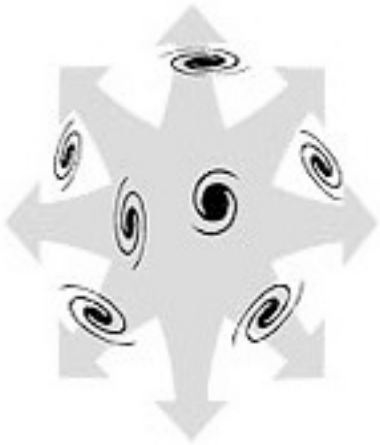
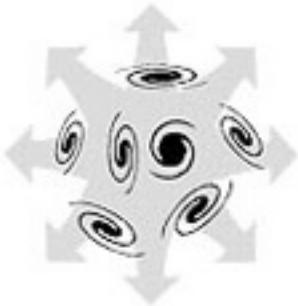
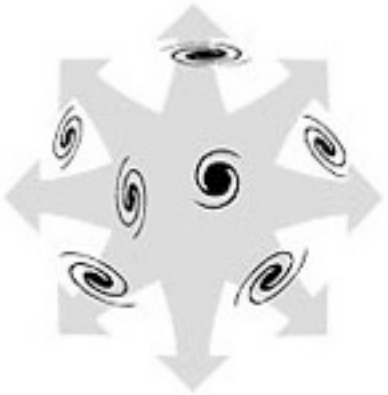


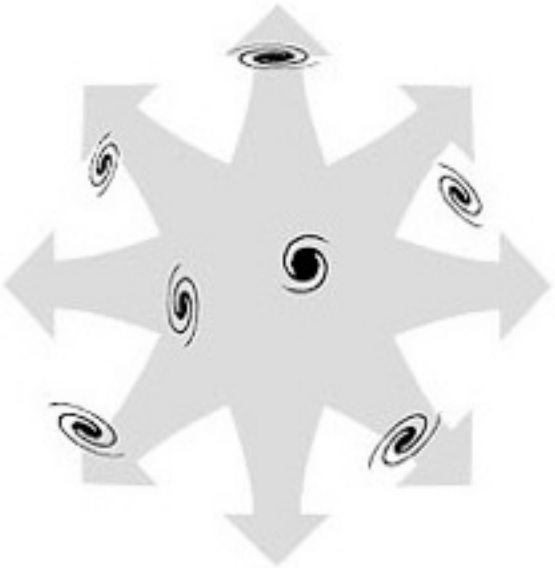


The Big Crunch

Big Bang starts the expansion of the universe. But there is not enough mass in the universe for gravity to capture the galaxies, and the universe expands, at an ever slowing rate, forever. Stars begin to run out of fuel and burn out, and since the universe gets less and less dense no new stars form. It gets colder and colder until the







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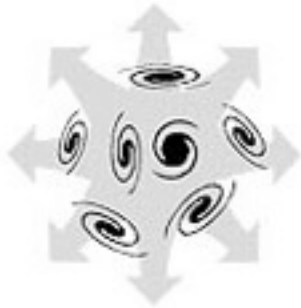
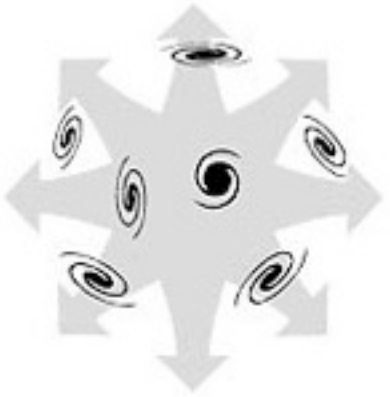
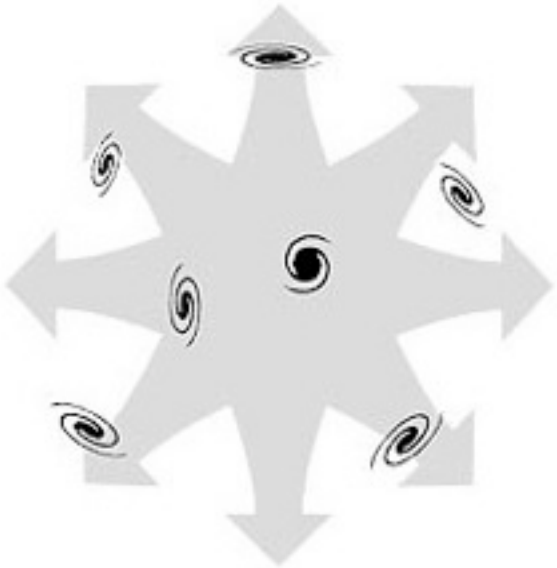
The Big Chill

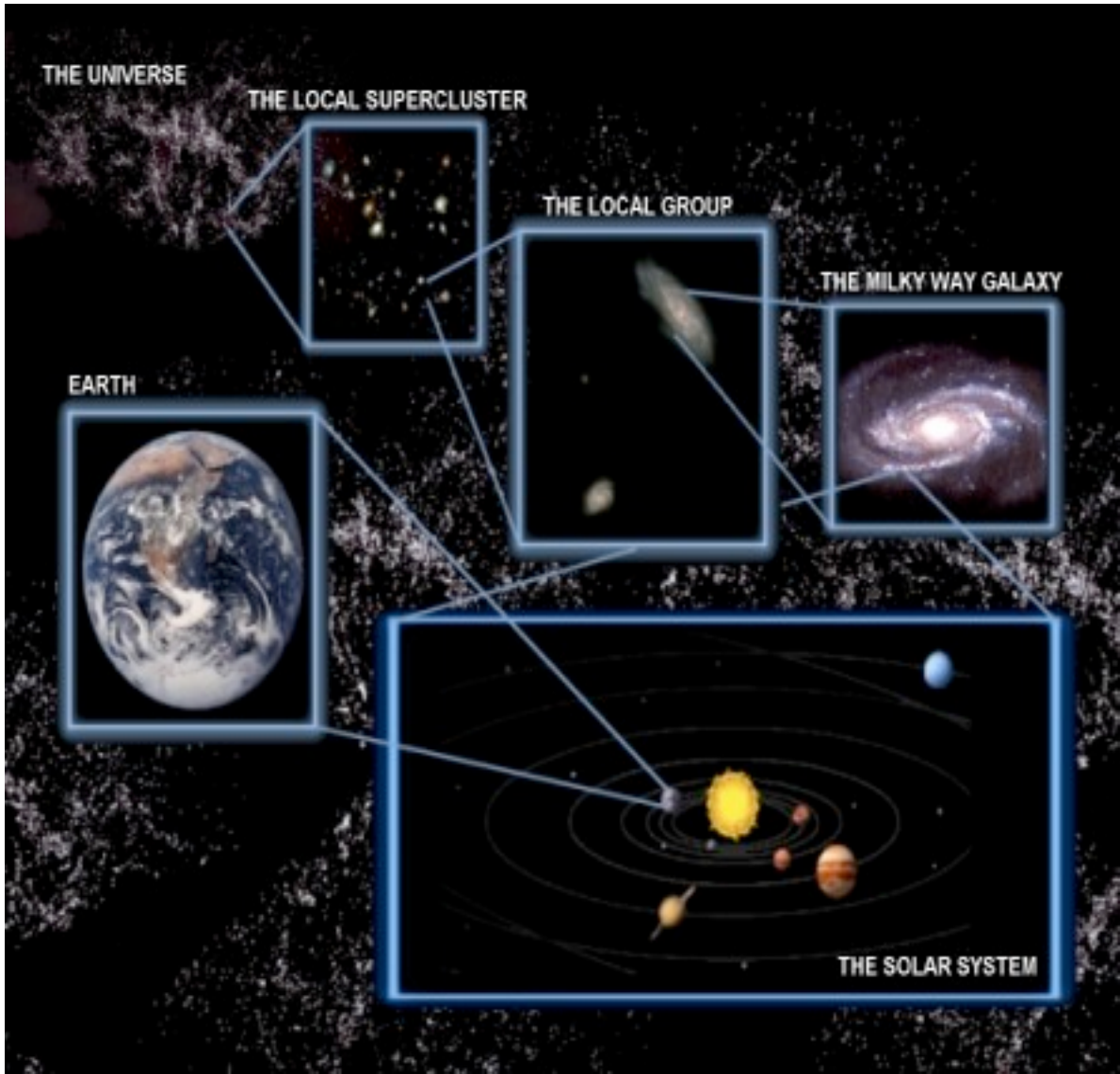






INSIGNIFICANT: Our Place in the Cosmos

- It should already be clear that we are only a small part of the Universe.
- 99.86% of the mass of solar system is in the sun.
- The sun is 1 of 200-400 billion stars in the Milky Way
- The Milky Way is 1 of ~100 billion galaxies in the Universe.
- Every time we think we are special, we have found it not to be so.
- It is even worse…



The Dark is Rising

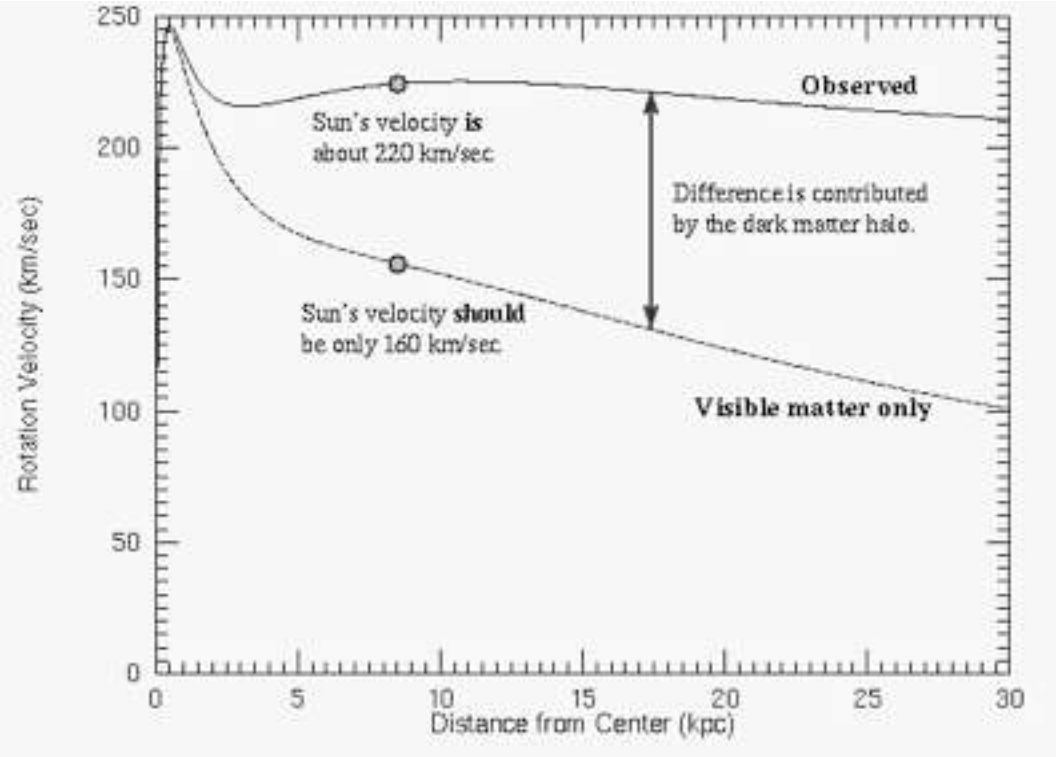
- 1933: Fritz Zwicky measured the motions of galaxies in the Coma galaxy cluster
  - Found velocities of +/-1000 km/sec relative to the cluster center.
  - This is greater than the escape velocity computed by adding up the light of the cluster galaxies.
- Zwicky suggested that a component of "dark matter" adds extra gravity to hold the cluster together.
- No suggestion that it is anything other than ordinary matter that is simply not glowing.
- Confirmed by other observations in other galaxy clusters.

Galaxy Rotation Curves

Observe star's orbital period vs. distance from center of mass(Volders, Rubin, and Ford)

Kepler's Third Law ⇒ mass within orbit

- earth orbit ⇒ sun's mass
- masses of known stars ⇒ orbital rotation speed
- disagrees with observed rotation speed
- Also observed in other near by galaxies.
- Result was viewed with great skepticism during '70's and '80's



FIND: more mass than is glowing -> **dark matter** halo

Dark Matter Halos

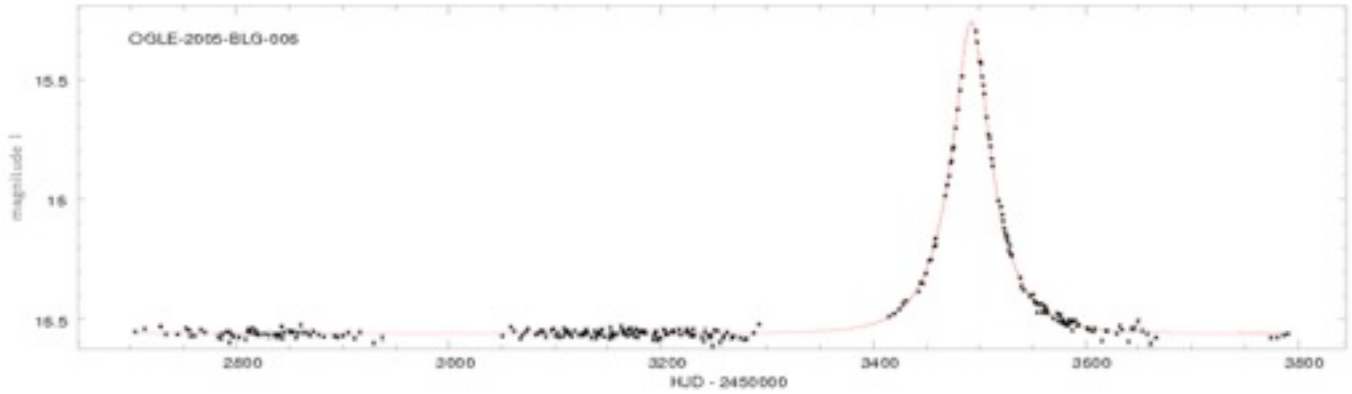
Not enough regular matter in the galaxy, non-glowing gas and dust between the stars observed with radio astronomy in the 1960's, to account for the observed gravitational attraction.

Dark Matter Halo Properties:

- Contains ~90% of the galaxy's mass
- more extended than the starlight component
- The orbital motions of satellite galaxies suggest it may extend out as far as 10 times the glowing component.
- In fact regular matter seems to be a nuisance component of a standard galaxy.
- INSIGNIFICANT: Dark Matter dominates the mass of the Universe. Regular matter, atoms like us, is a nuisance compared to it.

What is it the Dark Matter?

- Baryonic Dark Matter
  - –Ordinary matter ("baryons") made of protons and neutrons?
  - –Should clump into Massive Compact Halo Objects
  - –Observed via gravitational lensing:

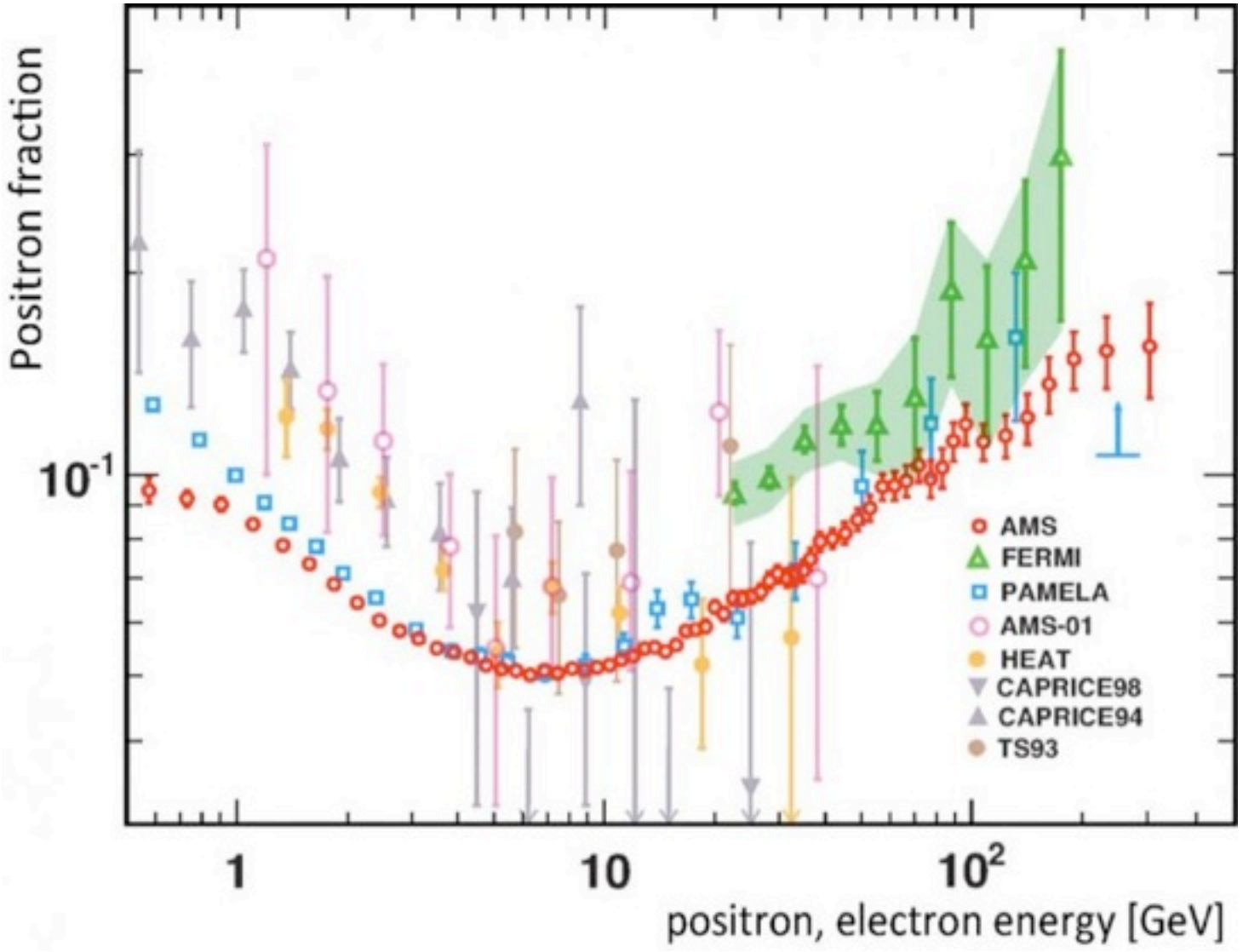


✓ Not nearly enough MACHO's to account for the Dark Matter Halo

Non-Baryonic Dark Matter

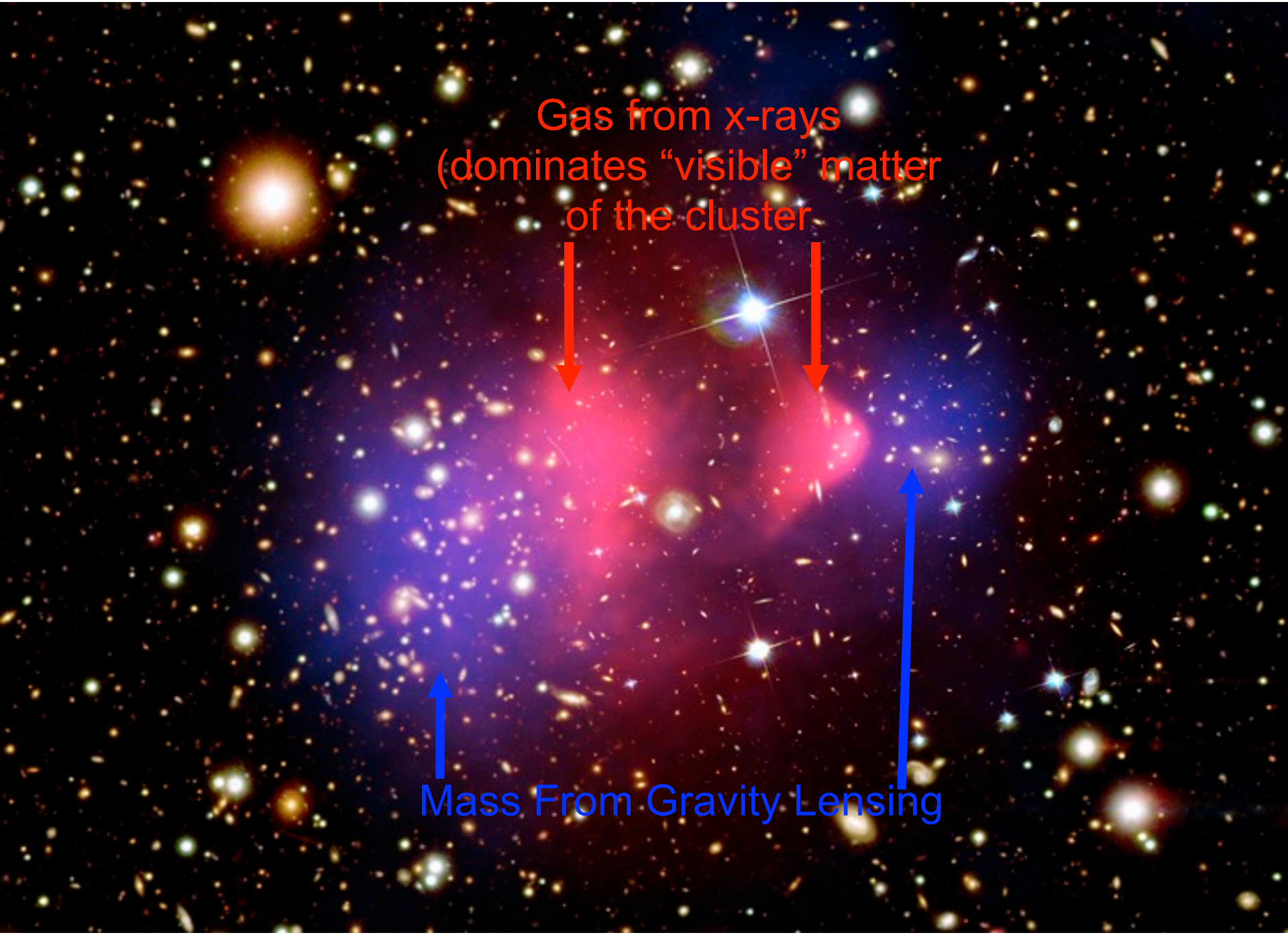
- Fundamental particles that only interact via gravitation and the weak force.
- Massive neutrinos:
  - Produced in large numbers in the Big Bang?
  - Not heavy enough to account for the observed halo
- Exotic new particles:
  - Predicted by some particle theories.
- Collectively Called Weak Interacting Massive Particles.
- Hint in Cosmic rays?
- No evidence in direct searches?
- Hope to find them at LHC.

Antimatter in Cosmic Rays



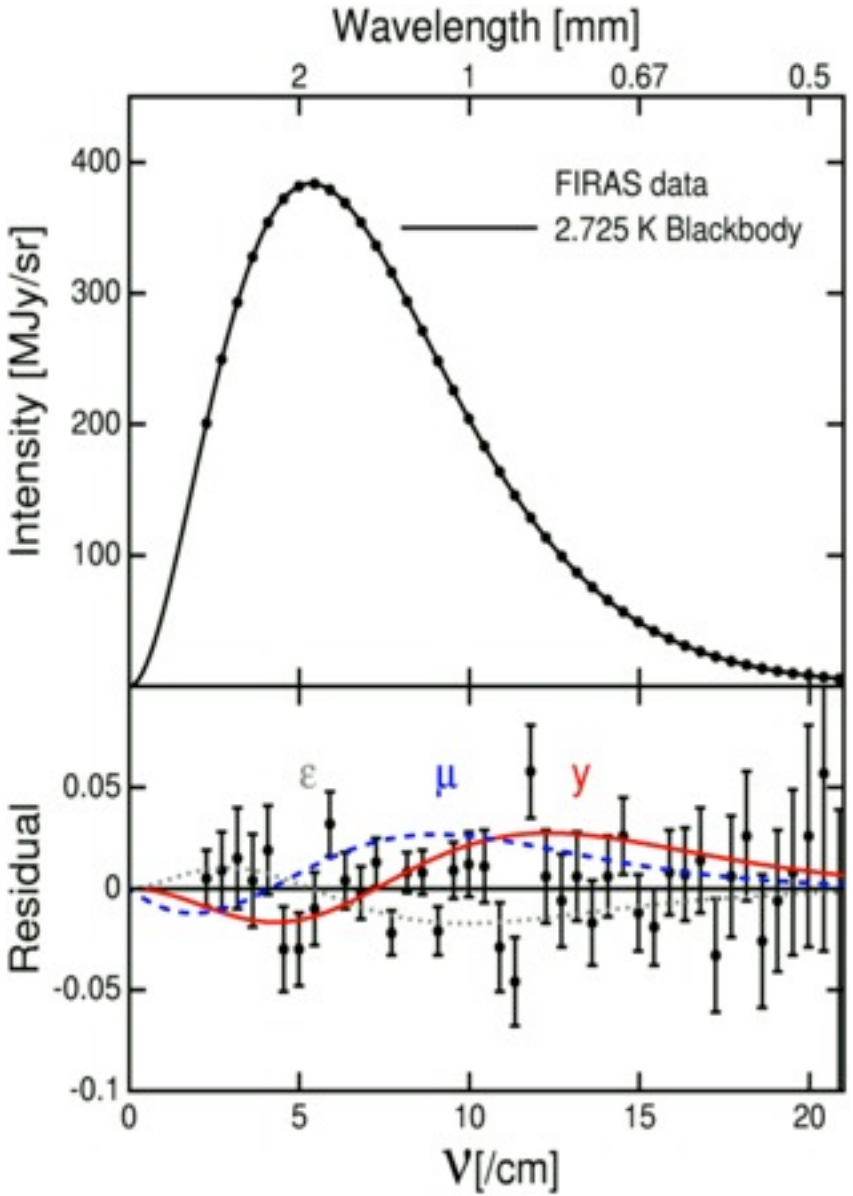
An Alternative Explanation

- In 1983 Milgrom suggests that perhaps gravity needs to be altered.
- Change only at very low accelerations thus called Modification Of Newtonian Dynamics (MOND)
- Gets good agreement with galaxy rotation curves
- Has trouble with some objects (Bullet Cluster)


Gas from x-rays
(dominates “visible” matter
of the cluster
Mass From Gravity Lensing

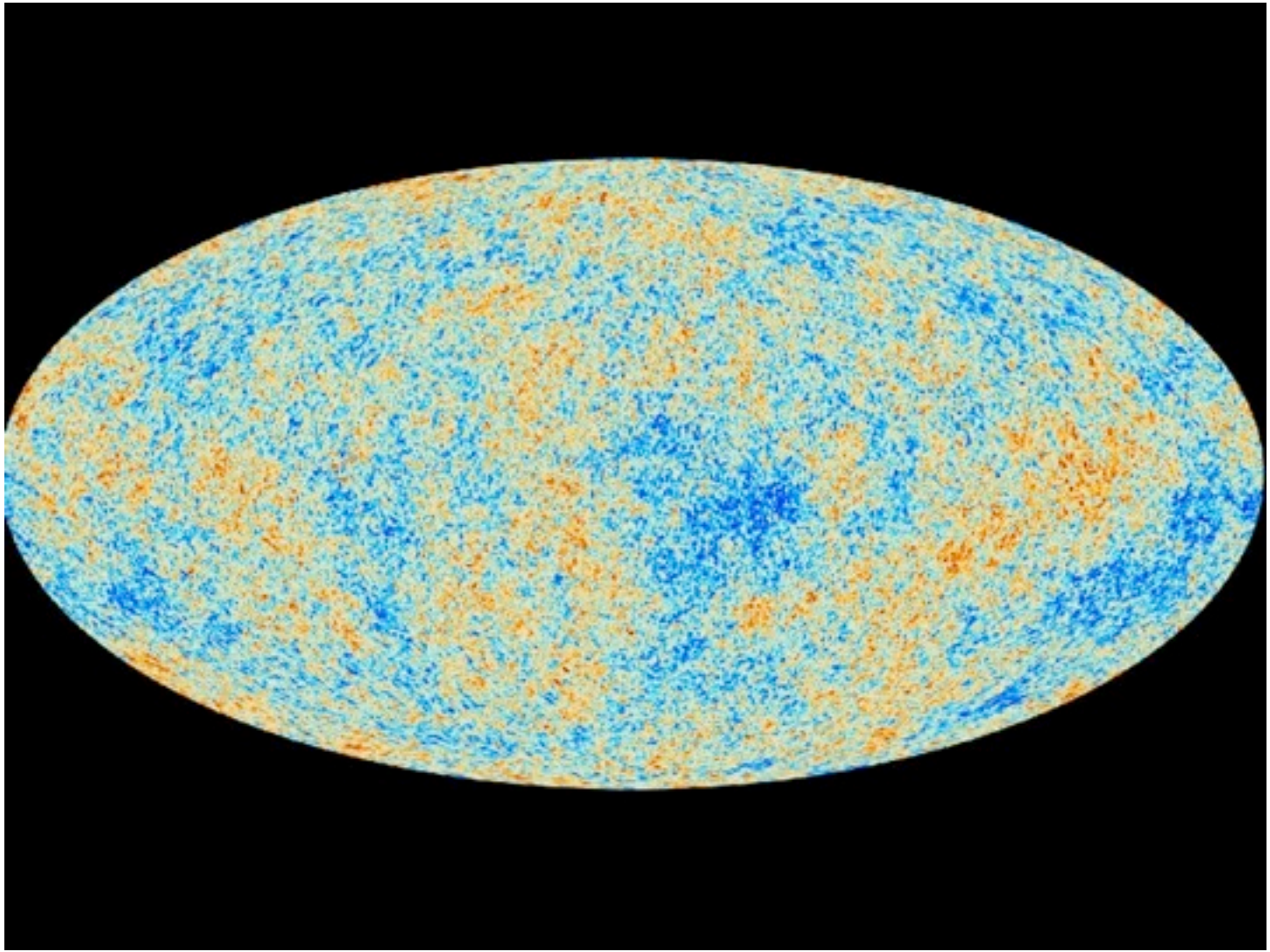
IGNORANT: Cosmic Microwave

- First precision measurement from COBE in 1992
  - Spectrum is a blackbody (CMB compared to on board blackbody)
  - Anisotropies observed at few in 10^5



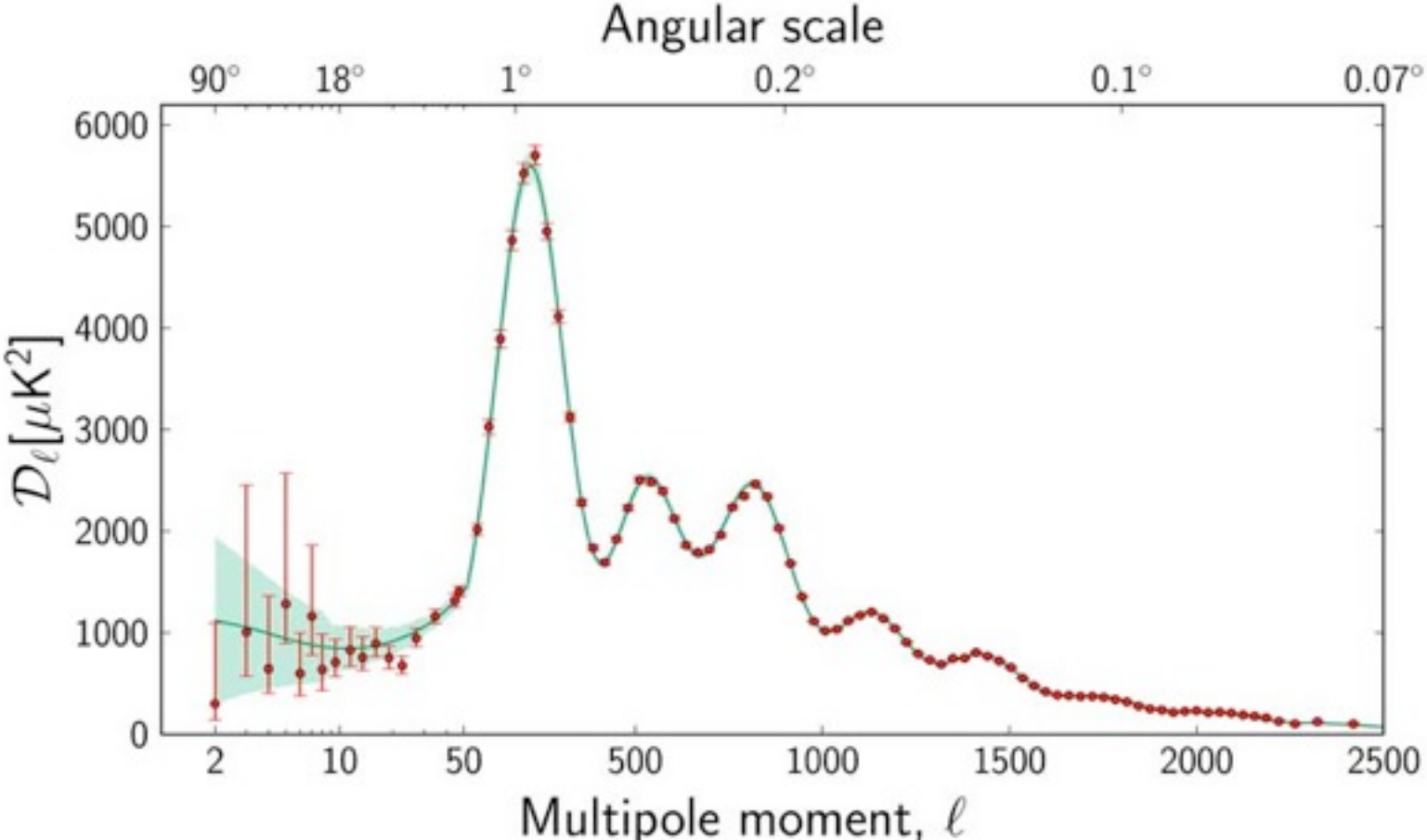
Cosmic Microwave Background

Snap shot of matter density of the universe at the photon surface of last scattering. Most accurate from Planck satellite.



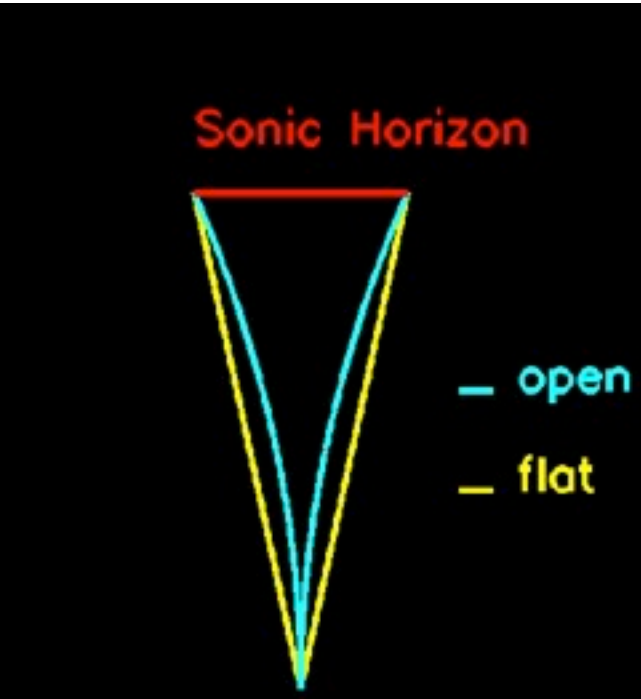
Cosmic Microwave Background: Planck+

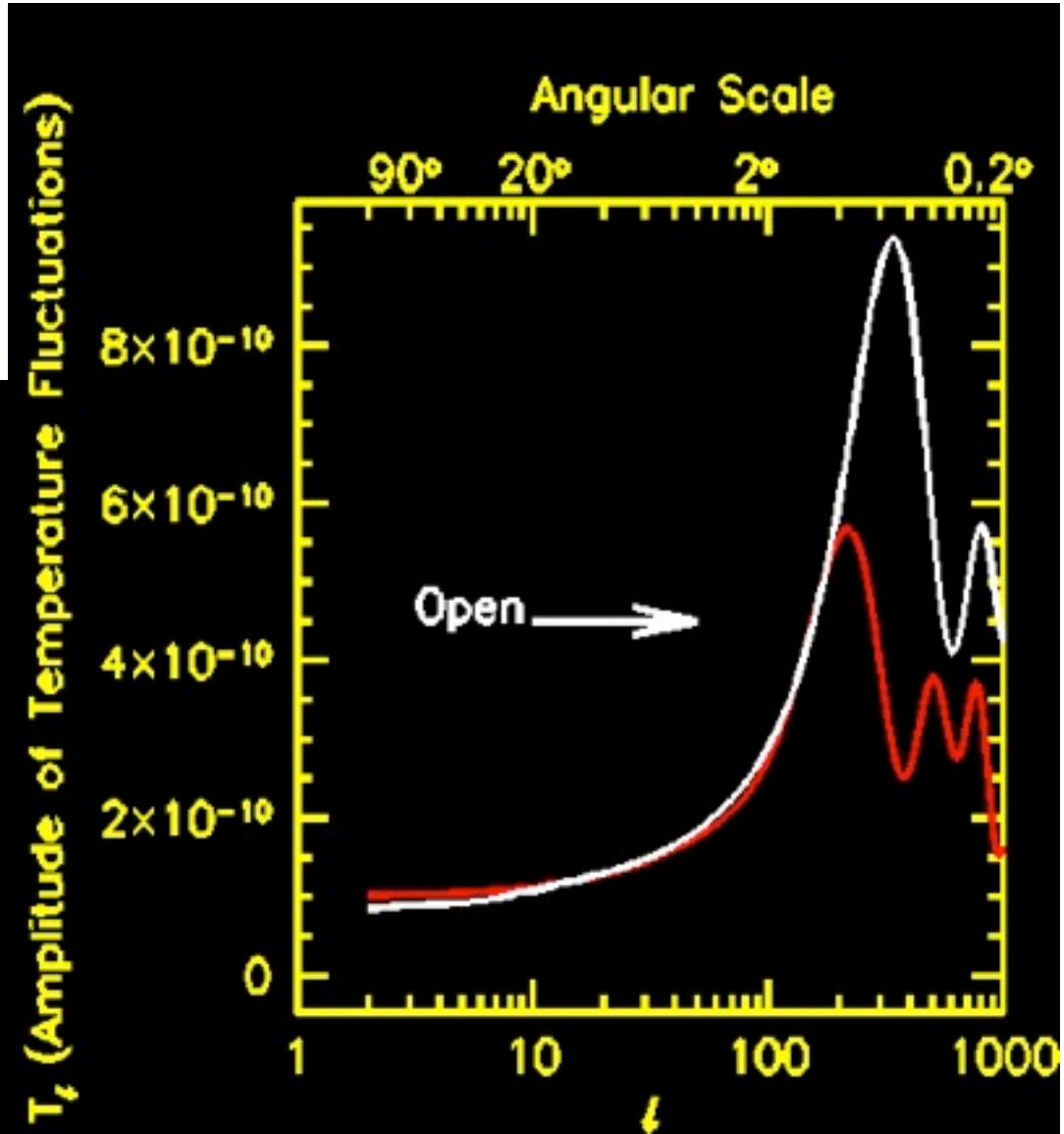
Describe data as sum of spherical harmonics and fit for coefficients. Each amplitude corresponds to an angular scale.



Cosmic Microwave Background

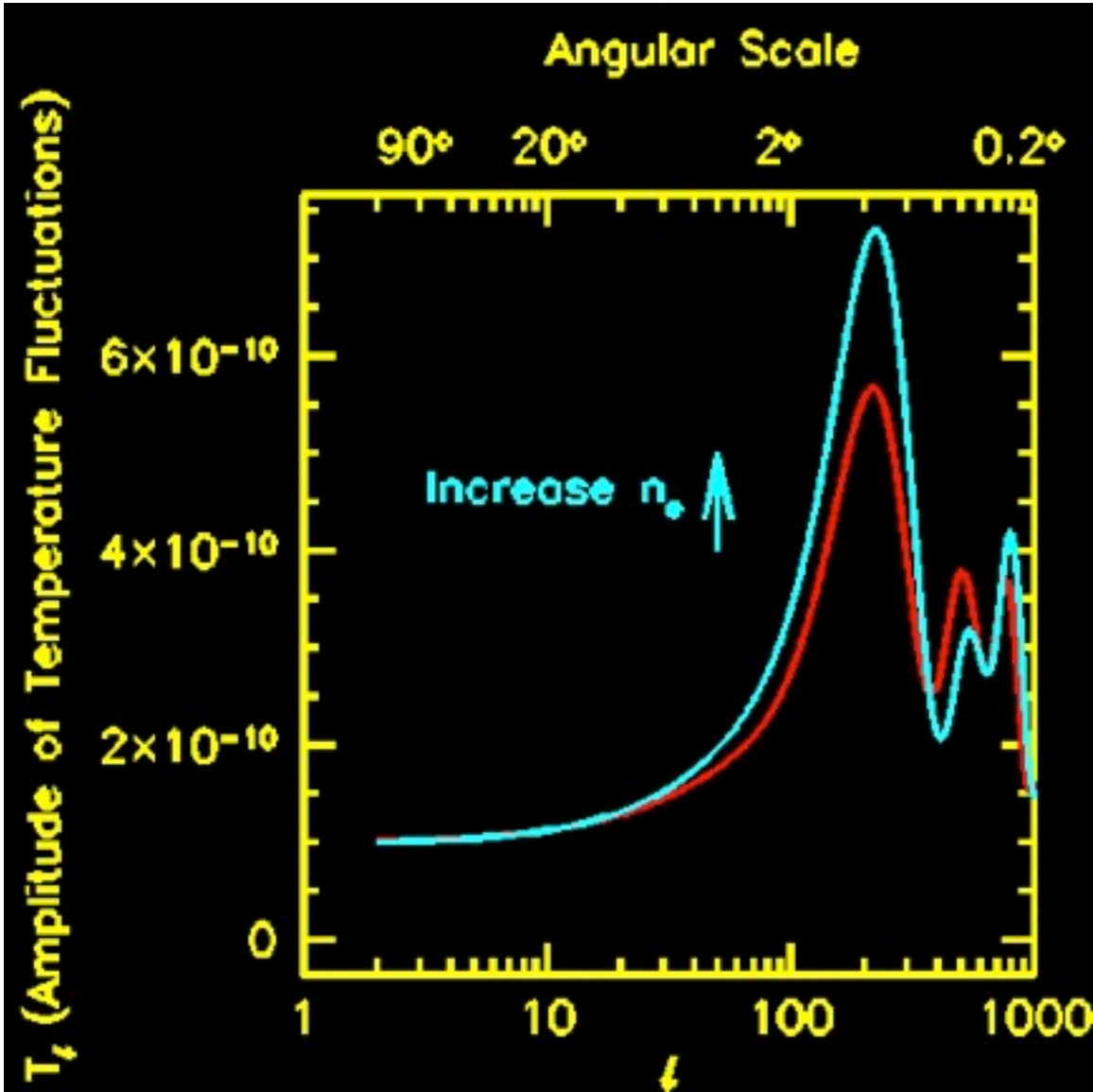
Peak position sensitive to the geometry of the Universe





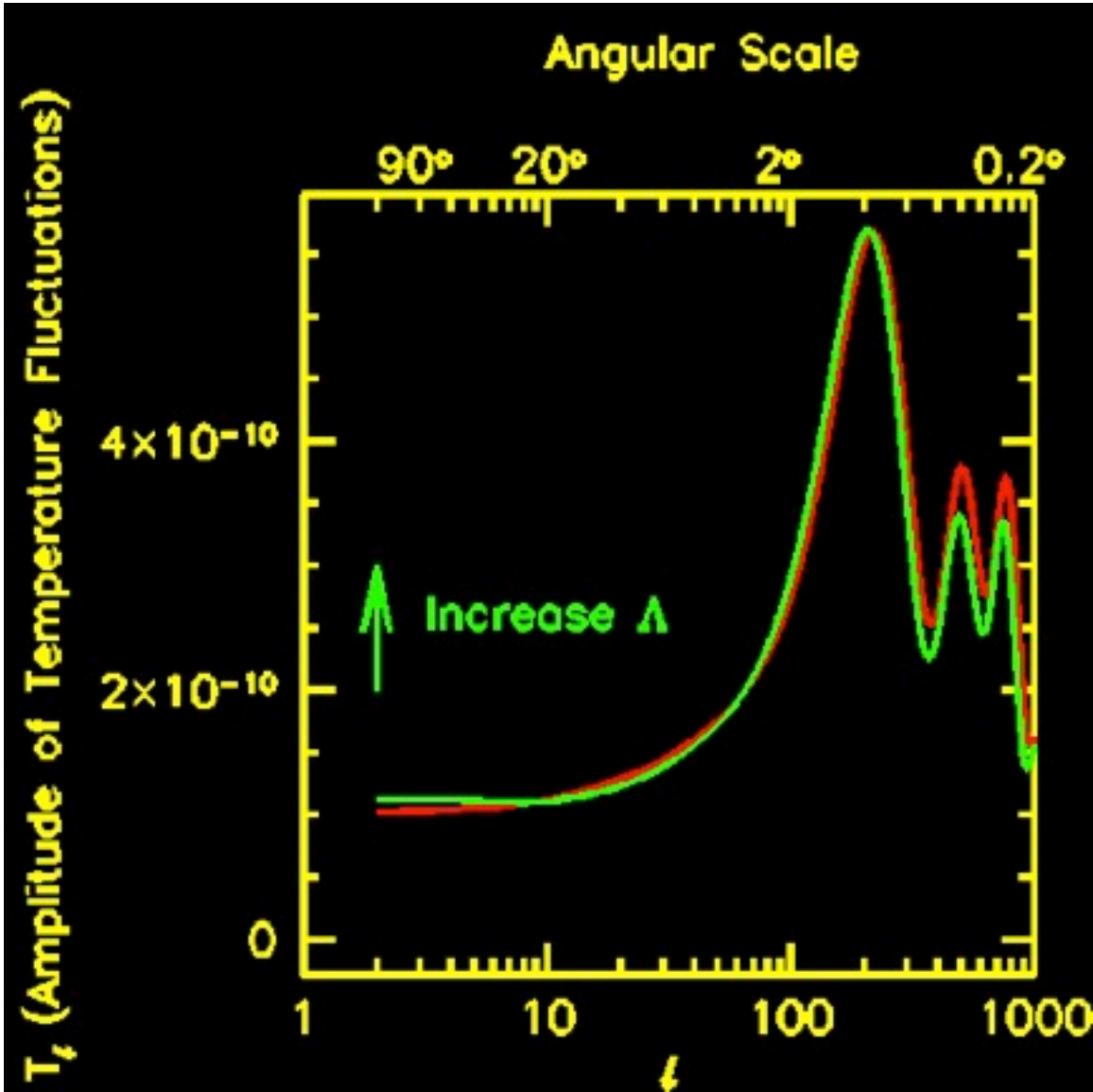
Cosmic Microwave Background

Relative heights of peaks are sensitive to mass density.



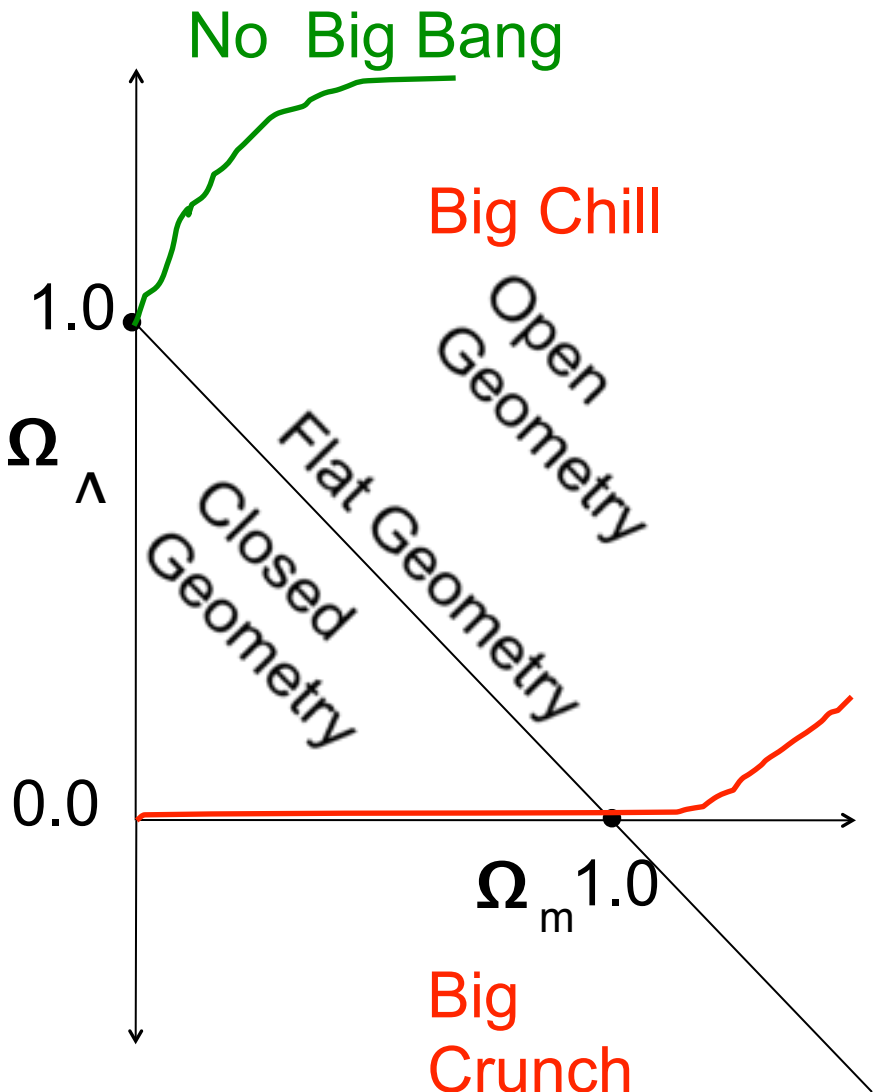
Cosmic Microwave Background: WMAP

Weak sensitivity to a cosmological constant from details of shape.

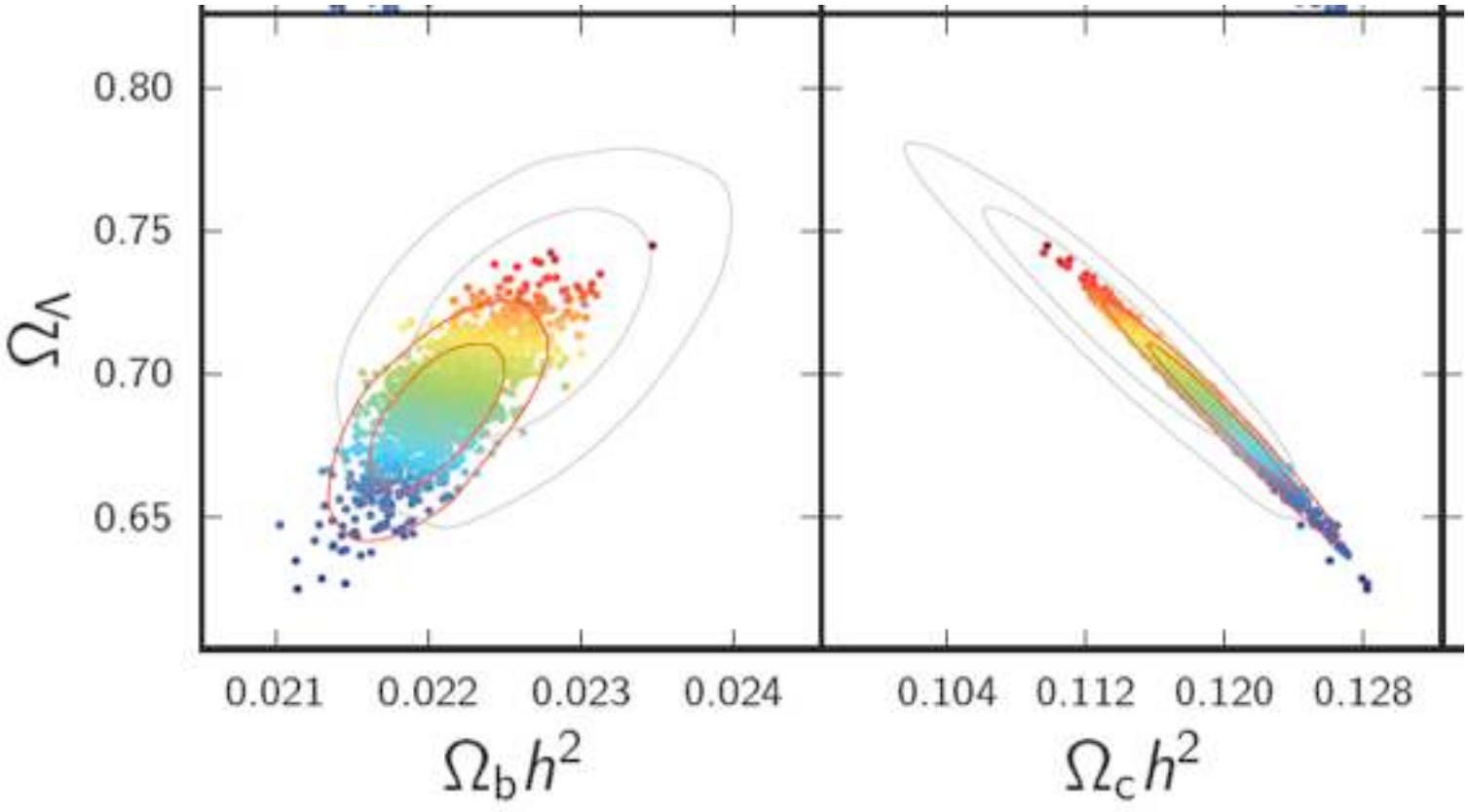


Describing the Universe

- How Astronomers describe the Universe on the cosmological scale.
- Repulsive cosmological constant(Λ) versus attractive mass(m).
- 1.0 = Enough attractive to force Big Crunch.



Cosmic Microwave Background

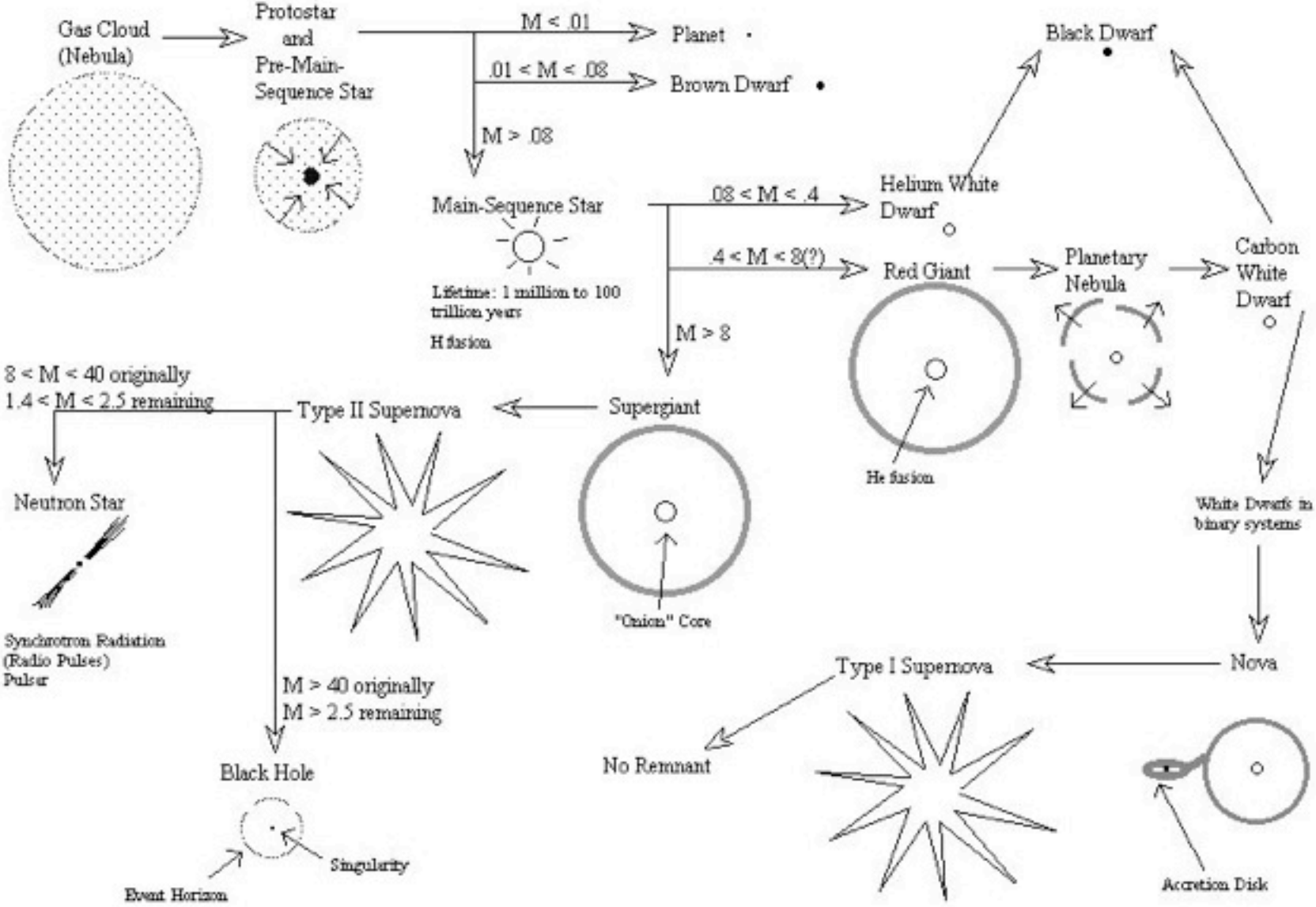


Geometry of the Universe is very likely flat ($\Omega_\Lambda+\Omega_m+\Omega_c\approx1$, $h\approx0.67$)
Matter density ≈30% of recollapse density
Favors a Cosmological Constant?!?

M51: June 2005

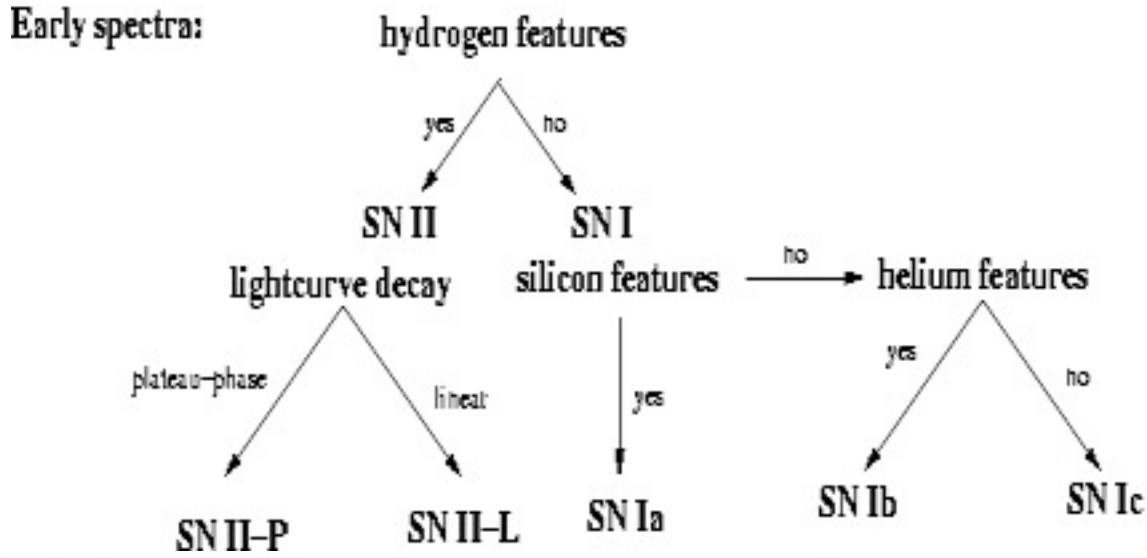
M51: July 2005

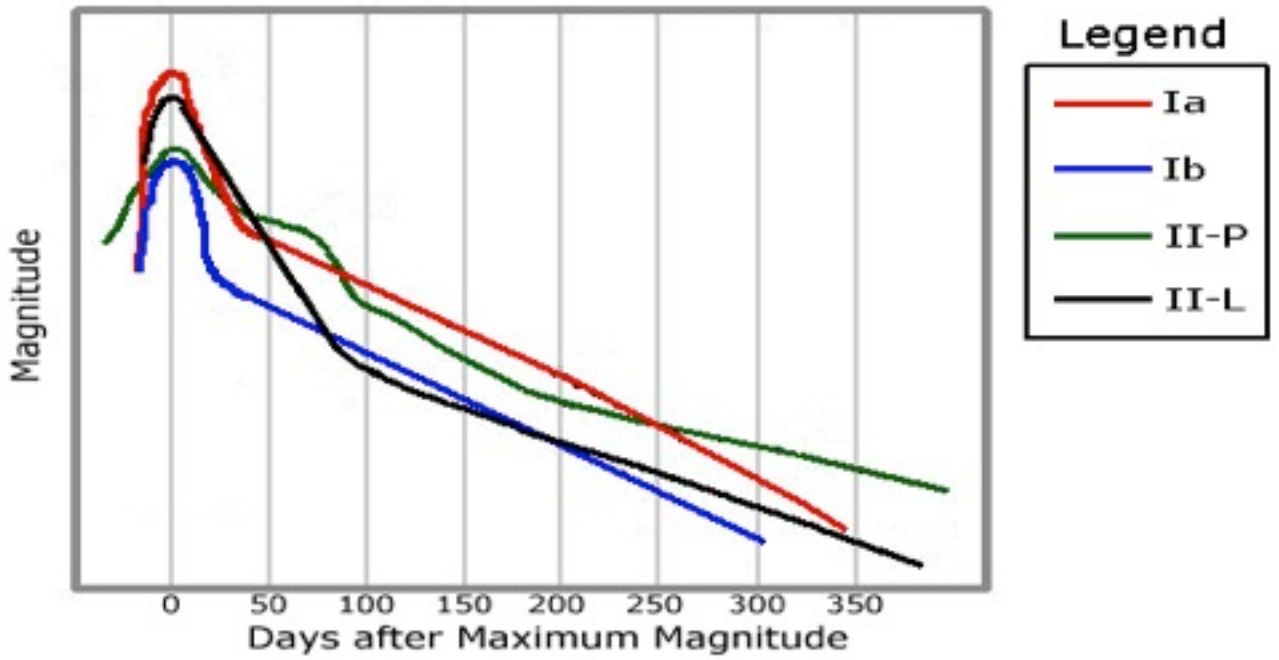
Stellar Evolution Review (All masses in units of solar masses.)



Type Ia Supernovae

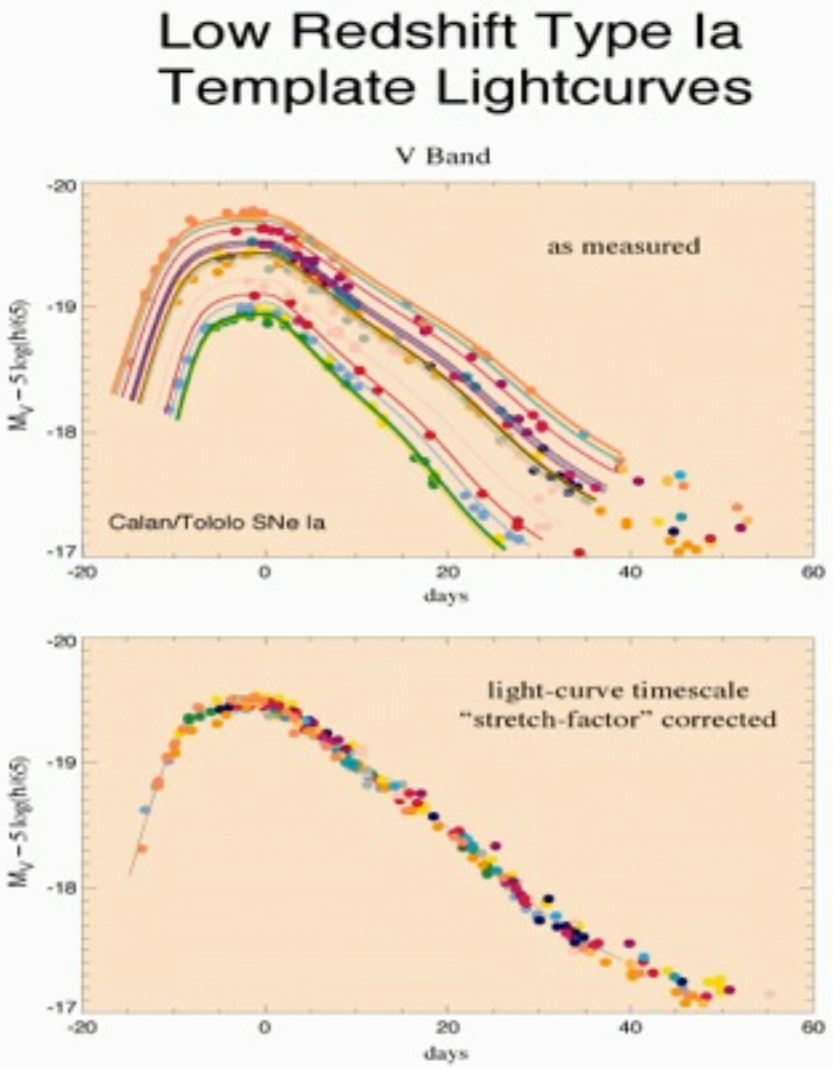
- "Easy" to identify
- No Hydrogen or Helium but Silicon in spectra
- Light curve is unique





Type Ia Supernovae

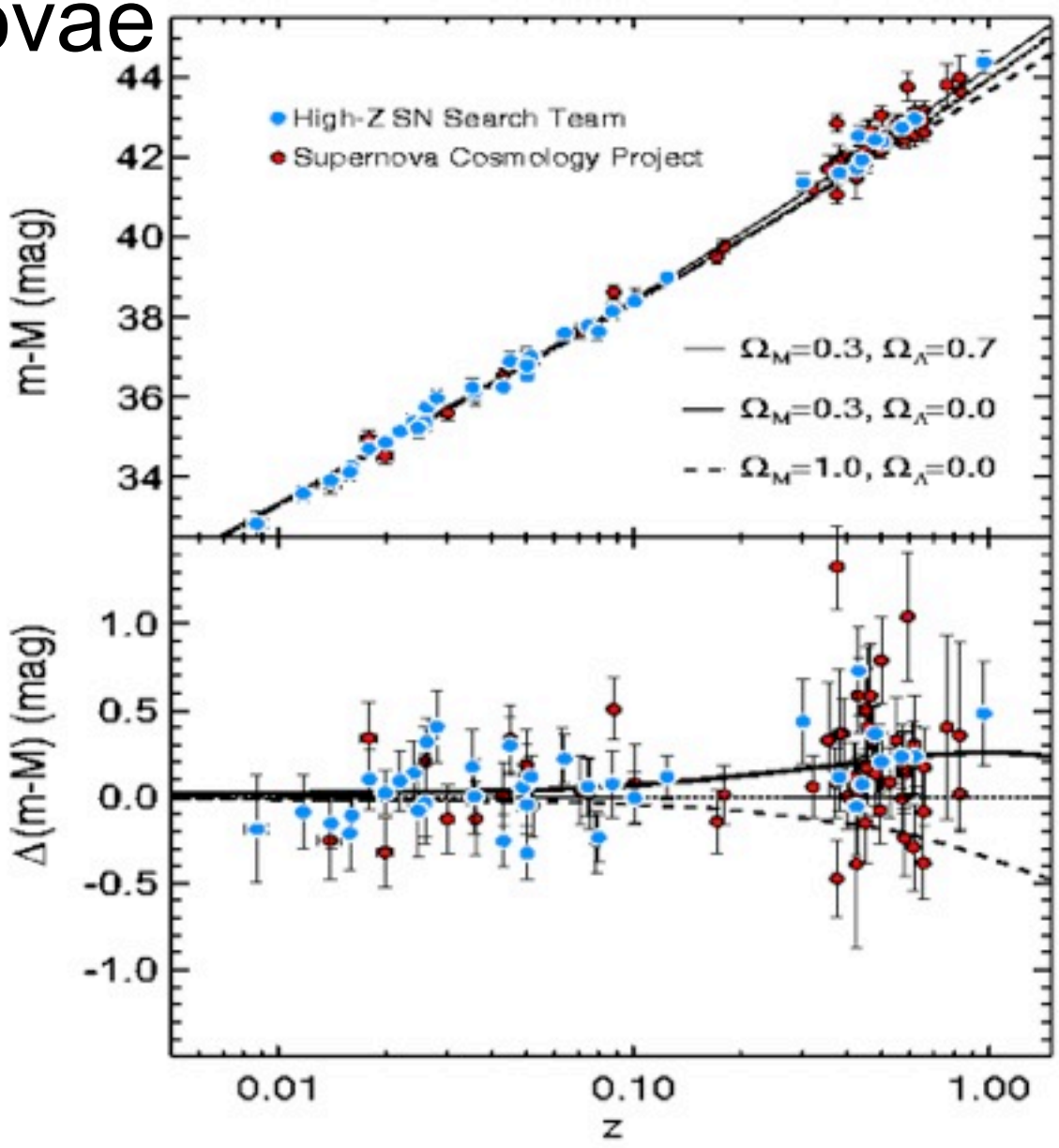
Key observation by Phillips in early 1990's of the Stretch-Luminosity relation
Qualitative understanding that this is related to how much metal is in the White Dwarf
Scatter on distance from ~20% to ~7%
Standardizable Candle



Type Ia Supernovae

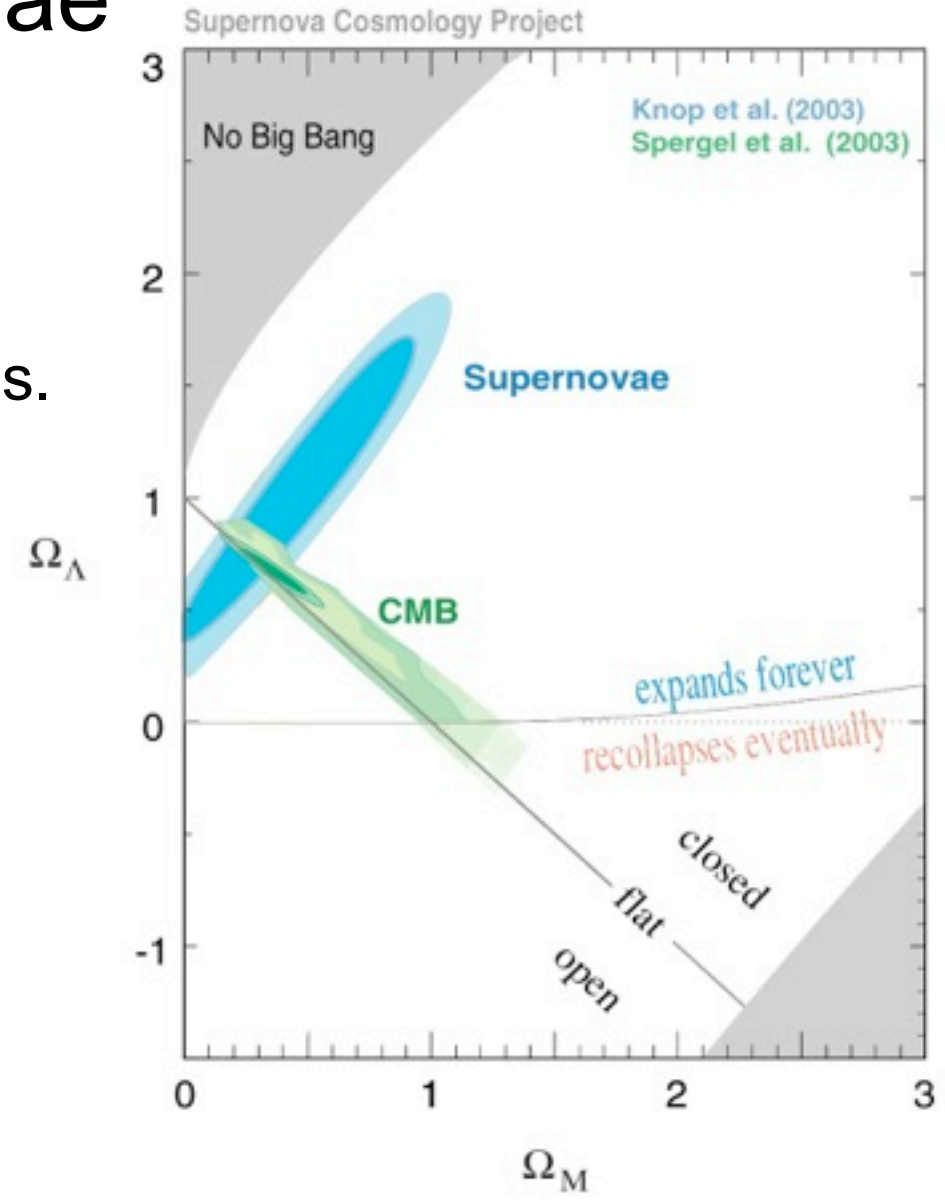
Still an amazement from 1998-1999
Clear observation of Cosmological Constant (now dubbed Dark Energy)
Subsequent observations (more, higher redshift) rule out alternative explanations

2011 Noble prize for Perlmutter, Schmidt, and Riess for this.

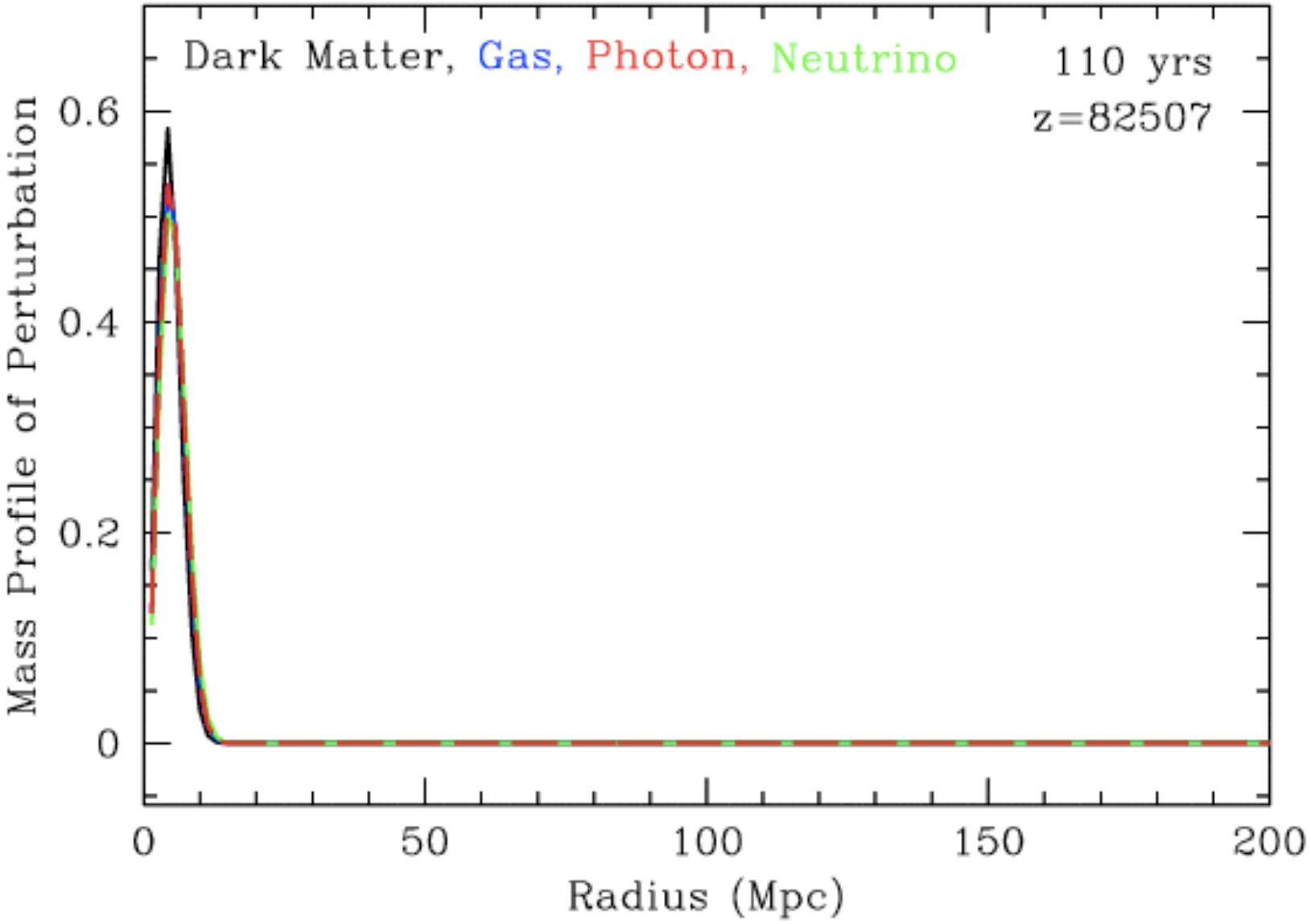


Type Ia Supernovae

Combination of CMB and Type Ia SN is unambiguous.
Geometry is flat.
~70% Dark Energy.
~30% Matter.
There was a Big Bang.
There will be a Big Chill.
No longer is there talk of Einstein's "greatest blunder", but rather Einstein's Cosmological Constant is the dominant thing in the Universe.



Galaxy Clustering(Daniel Eisenstein)



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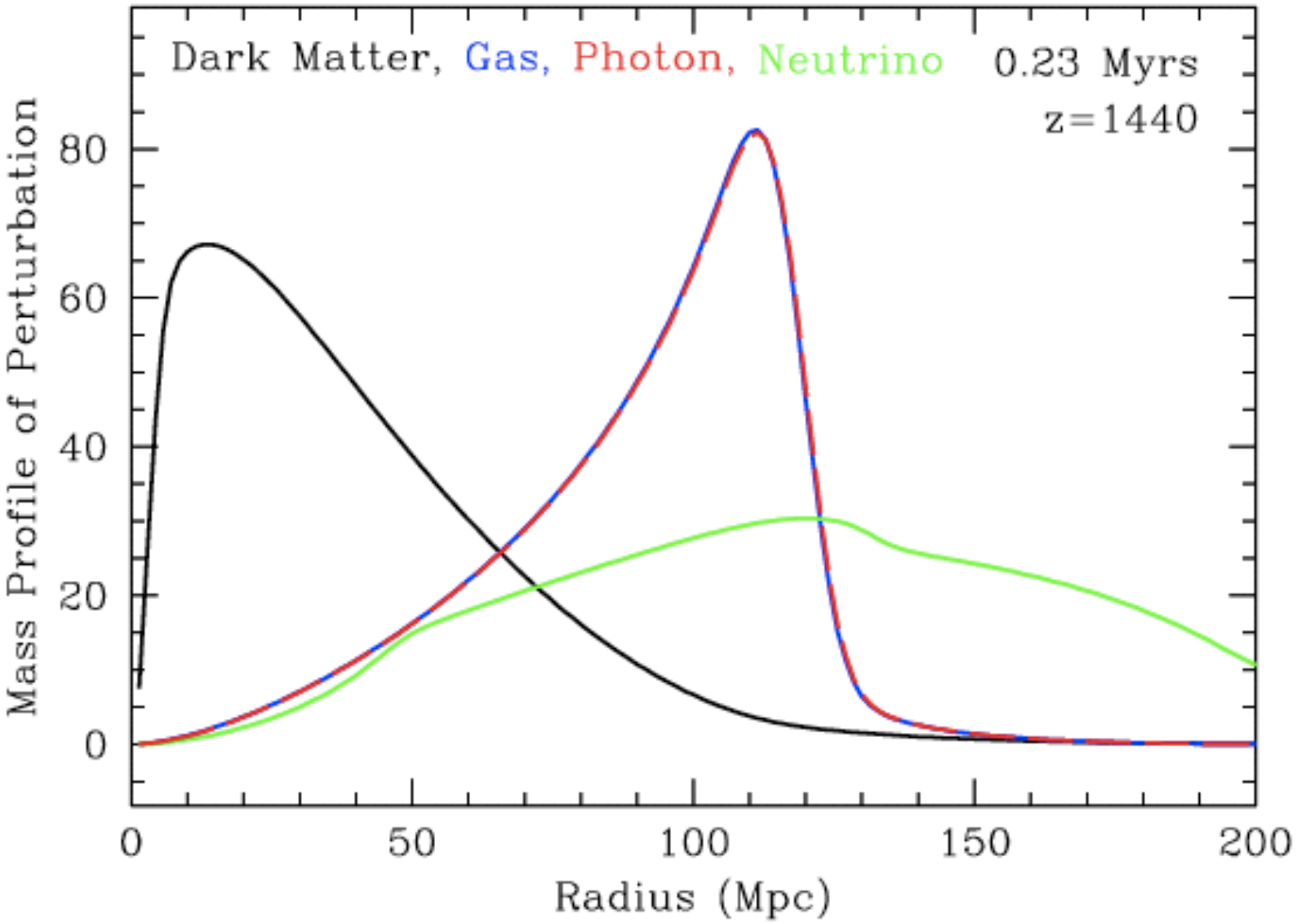

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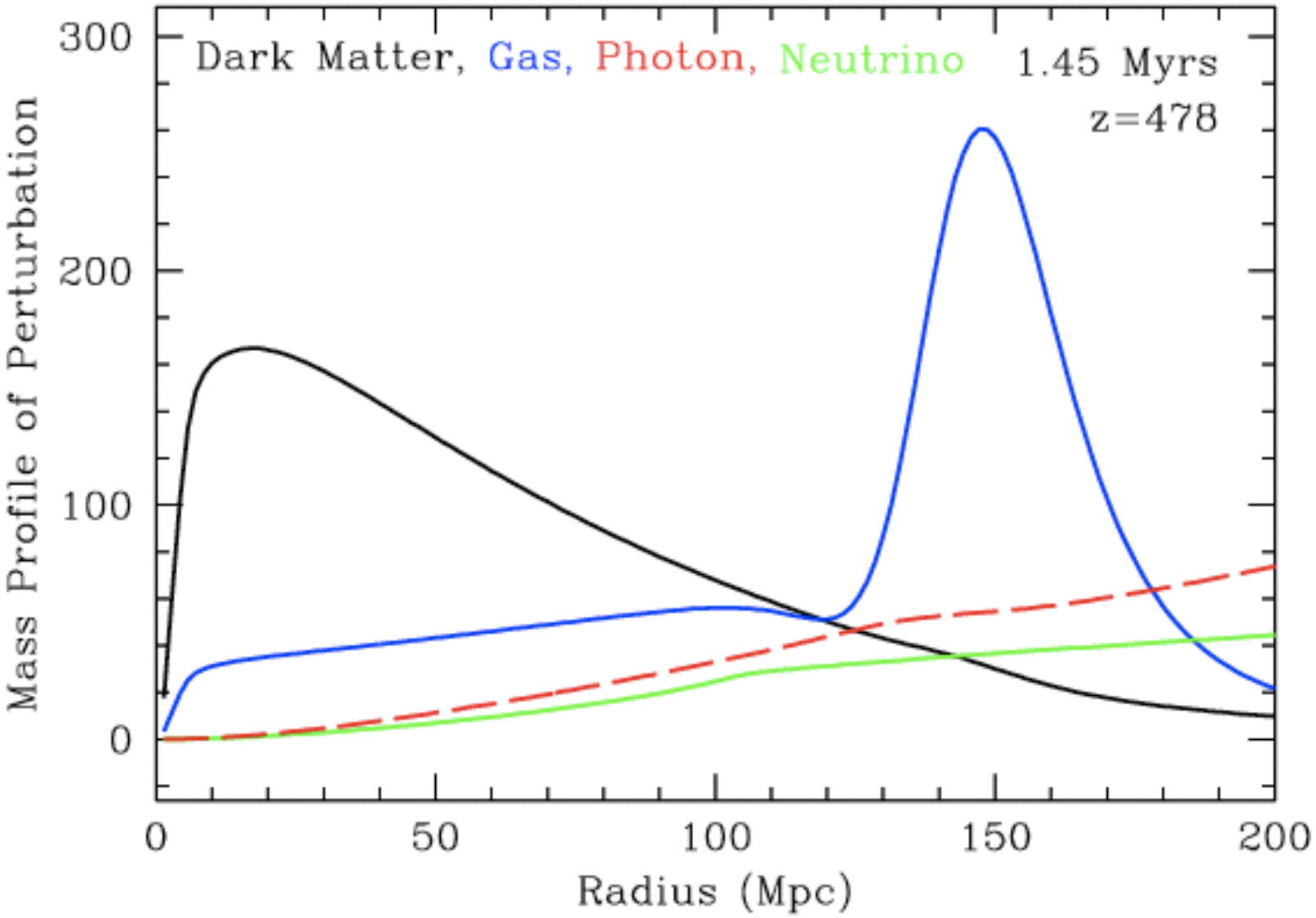

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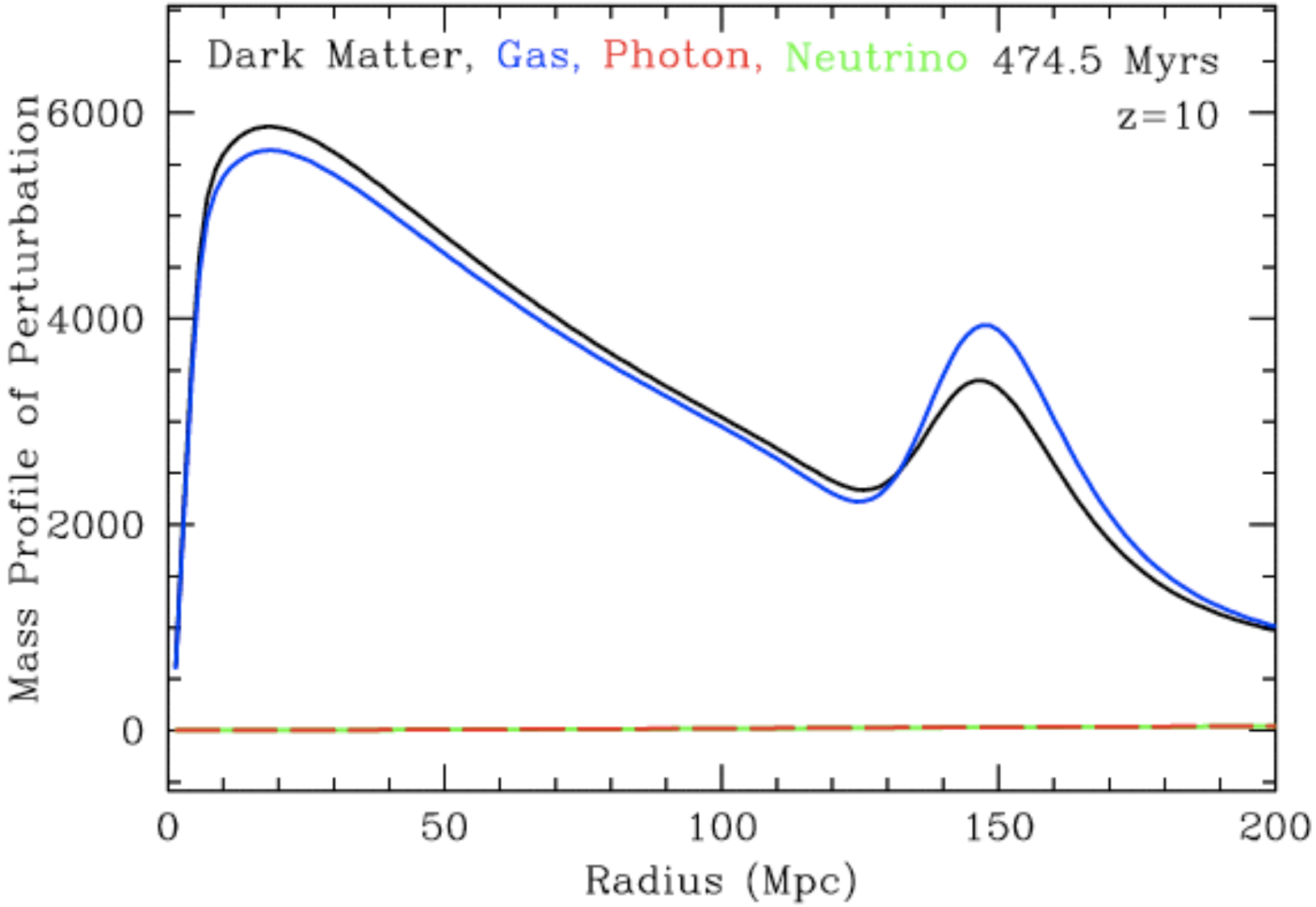
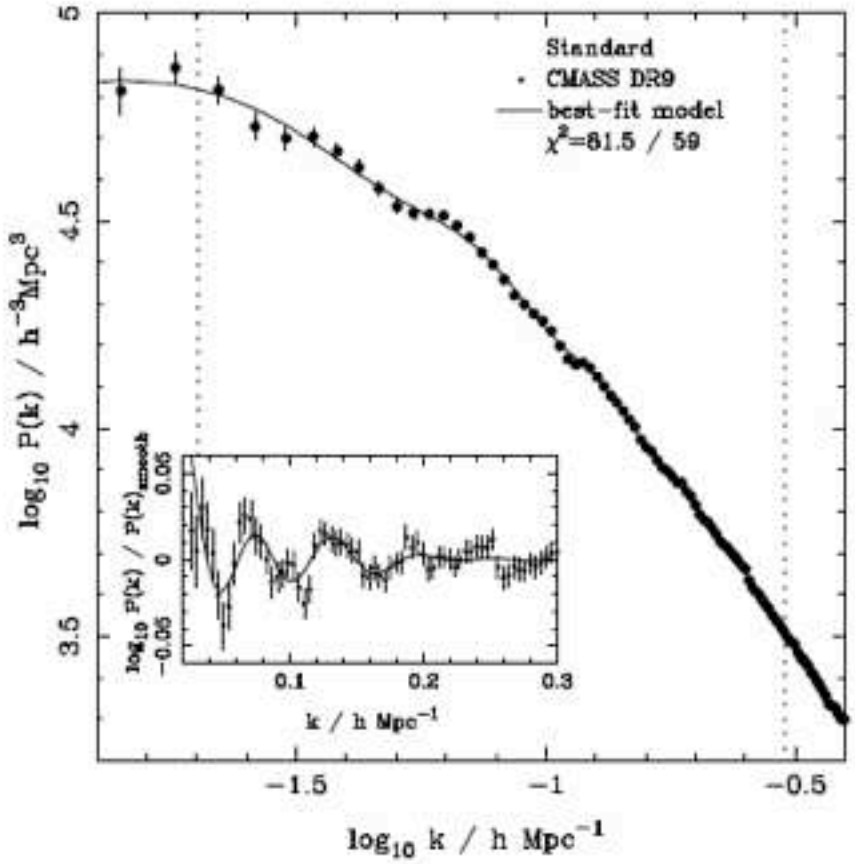
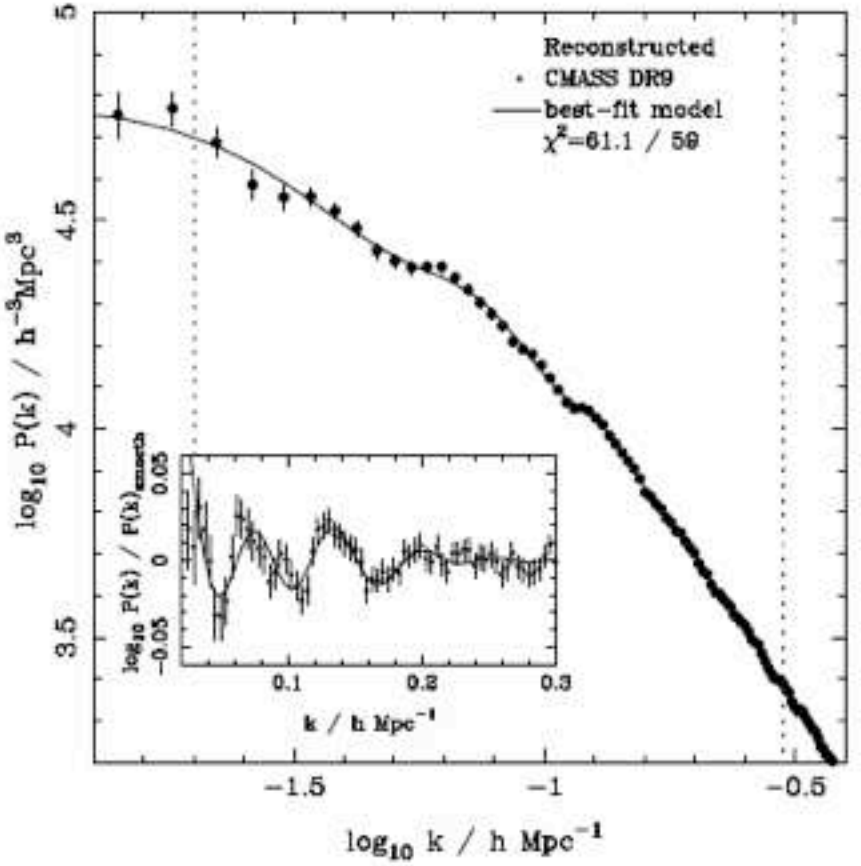


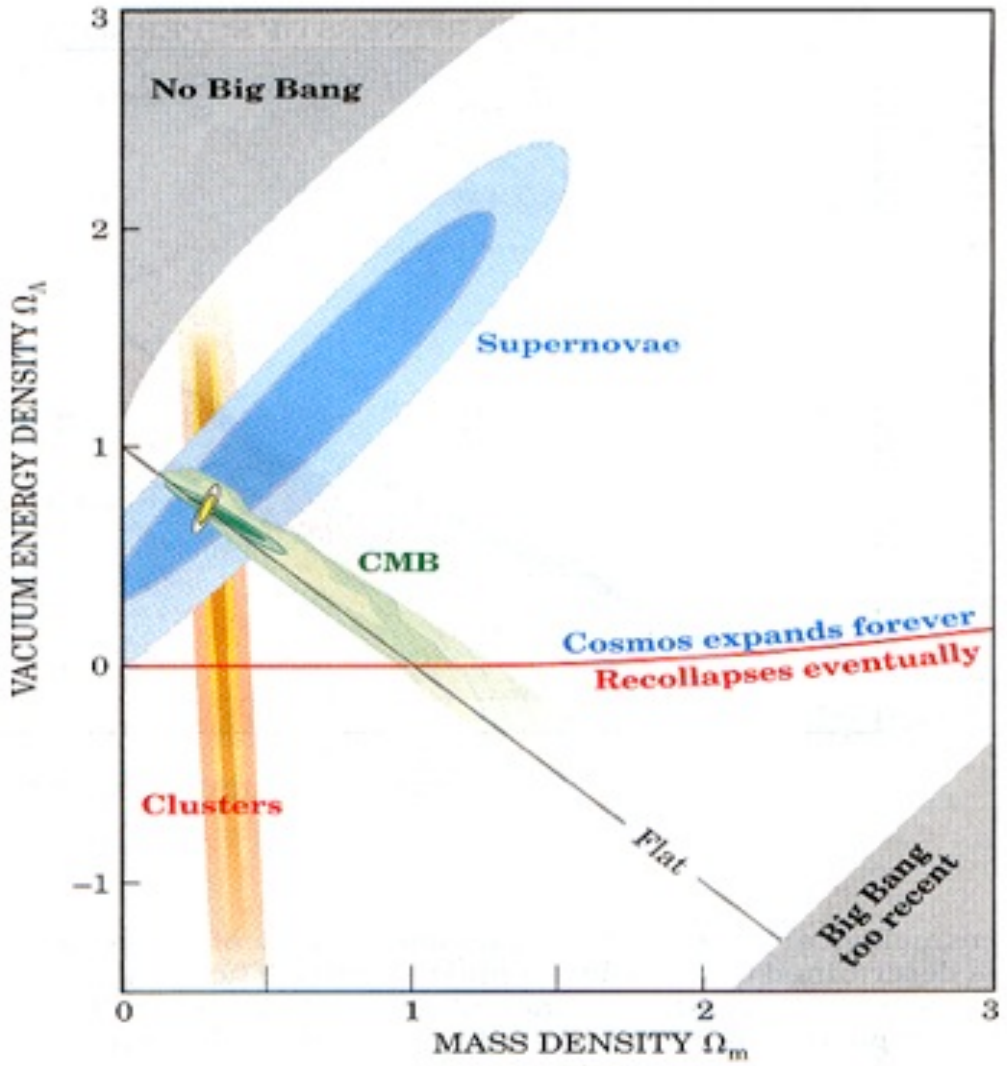
Galaxy Clustering

Observe this in the distance between neighboring galaxies in large galaxy surveys such as Sloan Digital Sky Survey





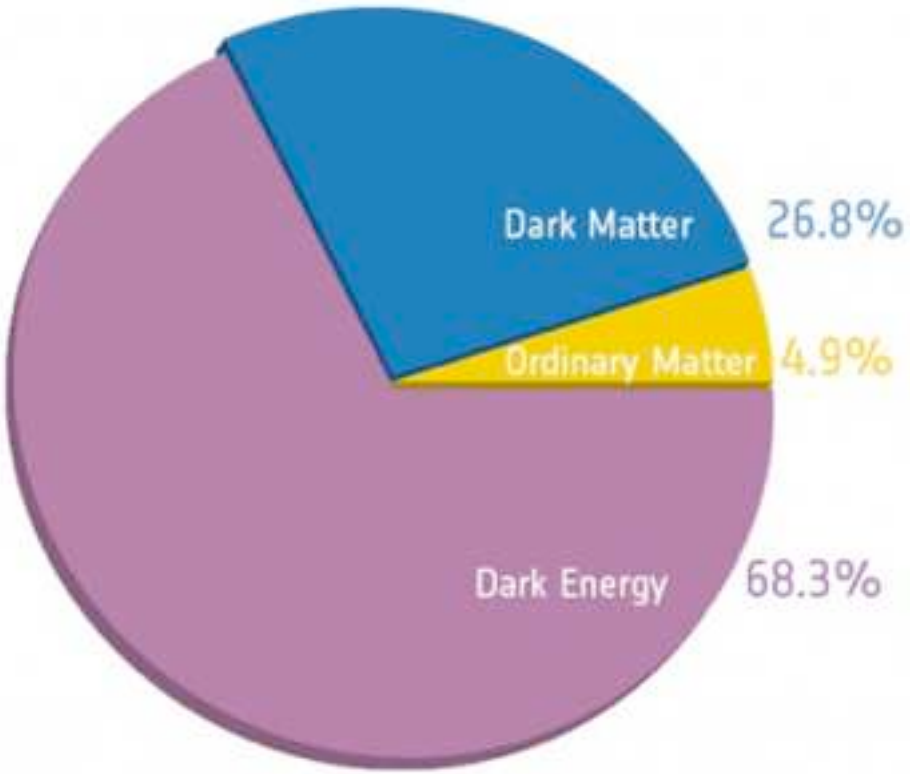
Concordance Model Cosmology



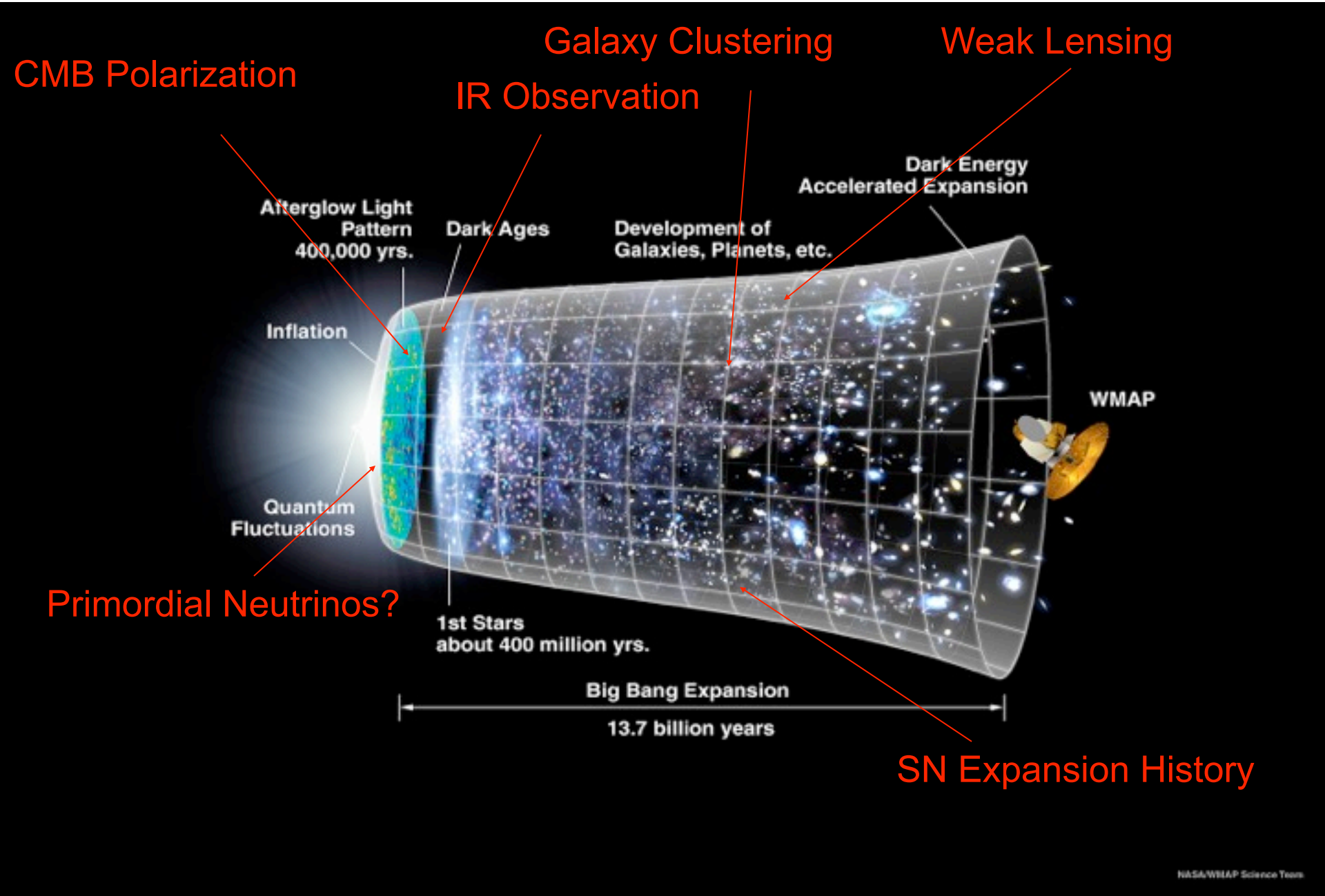
- Another three pillars
  1) CMB map
  2) SNIa vs redshift
  3) Galaxy clustering
- Dark Energy is most like a strong version of Einstein's Cosmological Constant

Cosmologies Golden Age

- The Universe is mostly stuff about which we are IGNORANT.
- Countless explanations, but none are very satisfying and as yet no experiment or observation are decisive on the nature of the Dark Sector.



What Next? Remain IGNORANT?



DOOMED, INSIGNIFICANT, IGNORANT

- Hot, Big Bang cosmology, origin of the Universe, rests on three pillars:
  1) Expansion
  2) CMB
  3) Elemental Abundances
- Concordance Model Cosmology three pillars:
  1) Precision CMB
  2) SNIa
  3) Galaxy Clustering
- The past 20 years of Cosmology has revealed that the Universe is being driven to the Big Chill by Dark Energy, the matter in the Universe is dominated by Dark Matter, and we are basically ignorant about 95% of the Universe or perhaps we are wrong about how gravity works.
- There are huge on-going and planned efforts to understand.

Mysteries

- Just because we are DOOMED, INSIGNIFICANT, and IGNORANT we can still ask questions.
- How does the universe go from very simple at the time of the CMB to very complex as seen today?
- Why is it so uniform at the CMB?
- Why is it dominated by matter? Is it?
- Nature of the Dark Sector versus modification to gravity?

Further Reading