Cosmology for Everyone

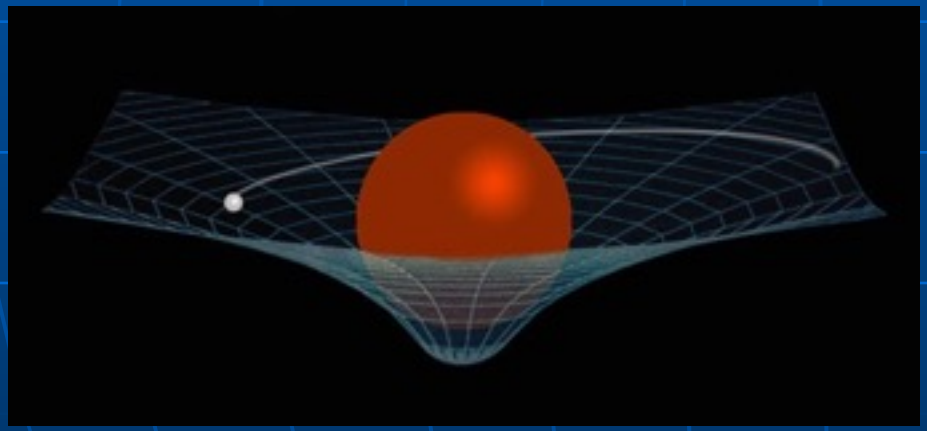
http://cdn.spacetelescope.org/archives/images/wallpaper5/hubble_in_orbit1.jpg

Dr. Steven Ball
Professor of Physics
LeTourneau University

Hubble Telescope eXtreme Deep Field

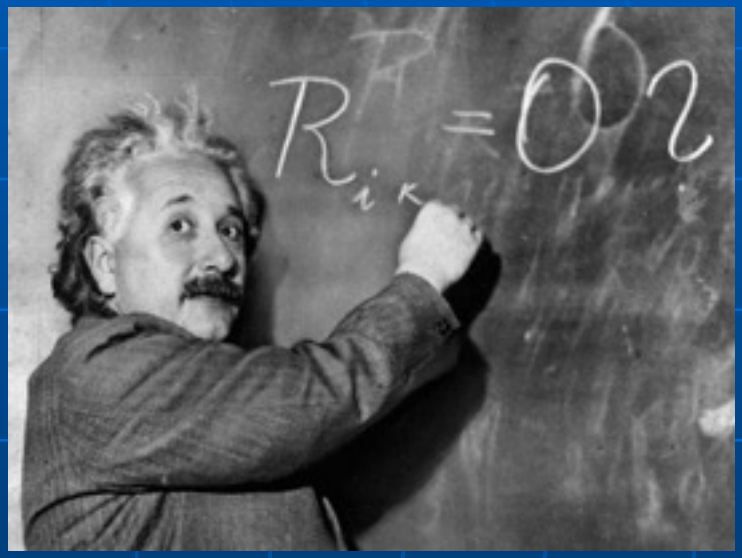
Modern Cosmology Begins

- Albert Einstein (1879-1955)
- Special Relativity (1905)
- General Relativity (1915): matter-energy <=> space-time



www.science4all.org/wp-content/uploads/2013/05/Gravity.jpg

- Contrast to Newtonian Gravity, objects follow curvature of space induced by matter

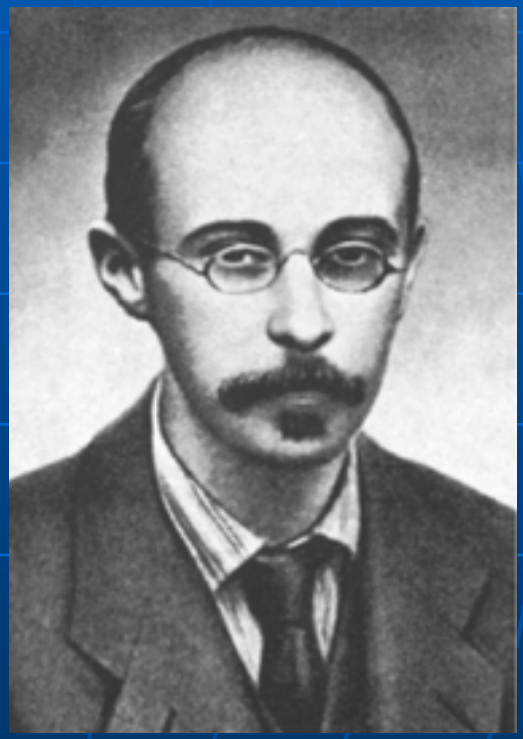


www.universetoday.com/56612/einsteins-general-relativity-tested-again-much-more-stringently/

Philosophical Bias to expect static cosmos (unchanging)
Had to modify equations to yield static cosmos solution

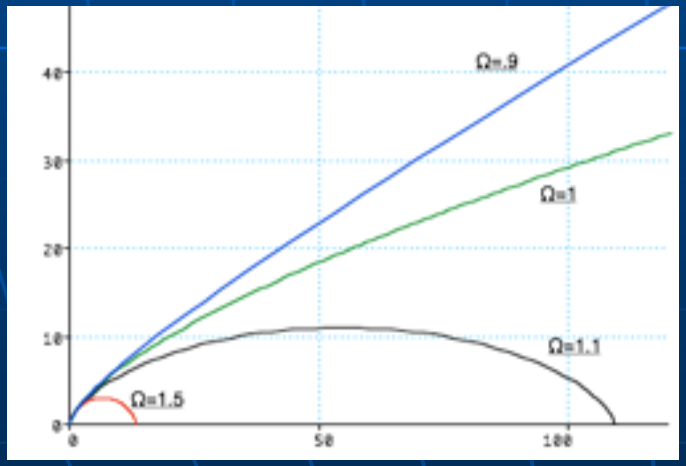
Expanding Universe

- Alexander Friedmann (1888-1925)
- Solved Einstein's Field Equations (correcting algebraic mistake and eliminating cosmological constant)
- Predicted expanding universe from 3 solutions: open (expands forever), closed (will collapse), and flat



en.wikipedia.org/wiki/File:Aleksandr_Fridman.png

Size of universe



Time

Great Debate of 1920

- Astronomers Harlow Shapley vs. Heber Curtis
- Are the spiral nebulae part of the Milky Way Galaxy or island universes far beyond the Milky Way?
- Inconclusive debate due to lack of observational evidence.

en.wikipedia.org/wiki/File:Andromeda_Galaxy_(with_h-alpha).jpg

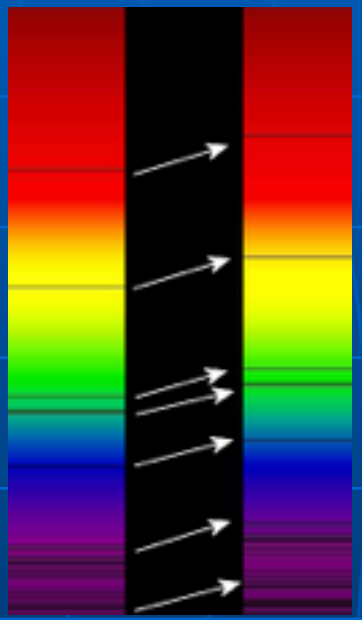
Expanding Universe Confirmed

- Edwin Hubble (1889-1953)
- Using Mt. Wilson Observatory 100 inch reflector telescope (1920)
- By 1925 confirmed that the Andromeda nebula lies far beyond the Milky Way and is also a vast galaxy of stars
- There are billions of galaxies stretching out in space billions of light years away from us.
- By 1929 confirmed that the further a galaxy is from us, the faster it recedes from us.

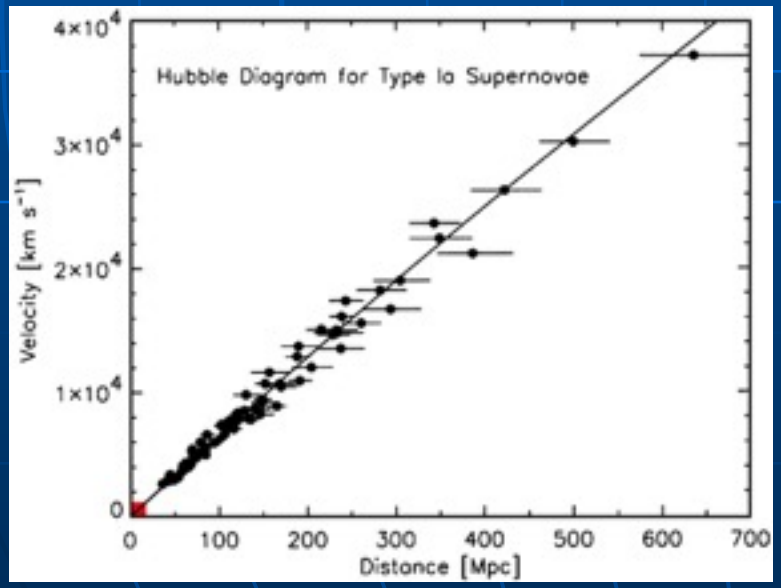
www.tumblr.com/search/mount+wilson+observatory

Hubble's Law

- Expansion of Universe seen in slight change in wavelengths of spectral lines in receding galaxies (redshift $z = \Delta\lambda/\lambda$)
- Hubble's Law: Recesion Velocity = Constant times Distance ($v = H\,d$)



en.wikipedia.org/wiki/File:Redshift.png



From Filippenko & Riess, Phys.Rept. 307 (1998) 31-44

Using present data we now know $H_o = 72 \pm 1$ km/s/Mpc.

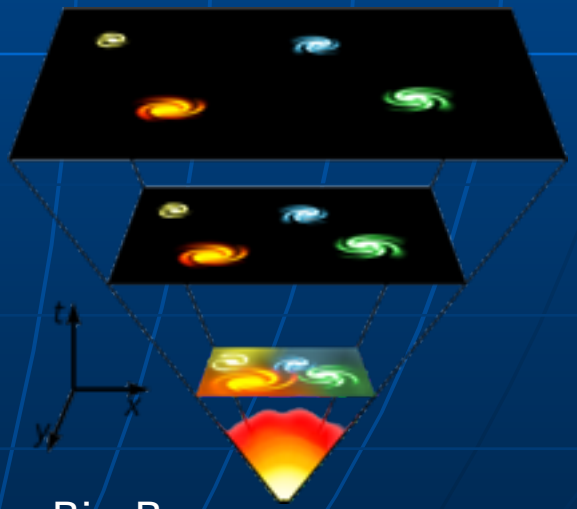
Age of the universe is then (assuming constant expansion)

$T = d/v = 1/H_o = 13.6$ billion yrs

The Big Bang Theory

- George Gamow (1904-1968)
- Used physics to extrapolate universe back in time to when it was very small and exceedingly hot and dense! (1948)
- Proposed that Hydrogen and Helium were synthesized during the first few minutes of "Big Bang" expansion, but could not account for heavier elements!
- With Ralph Alpher & Robert Herman predicted hot radiation background then at 10 mill K, released when temp drops to 3000 K, eventually cools to only 5 K with continued expansion today.

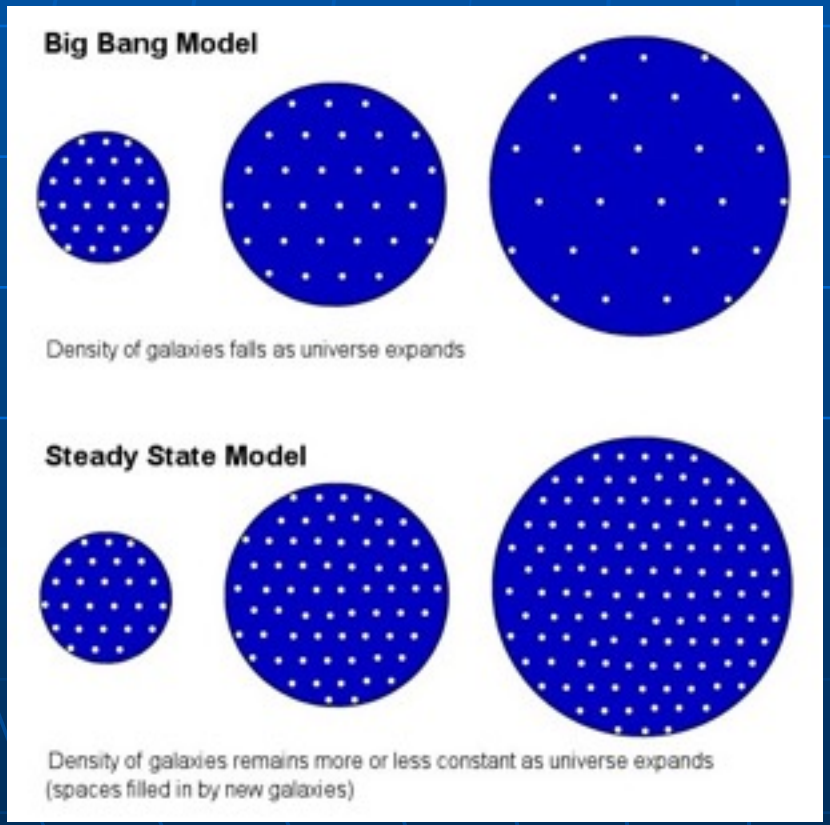
www.aip.org/history/cosmology/ideas/images-ideas/gamow-b1.jpg



Big Bang

Steady State Theory

- Fred Hoyle (1915-2001)
- Denounced "Big Bang" (1949)



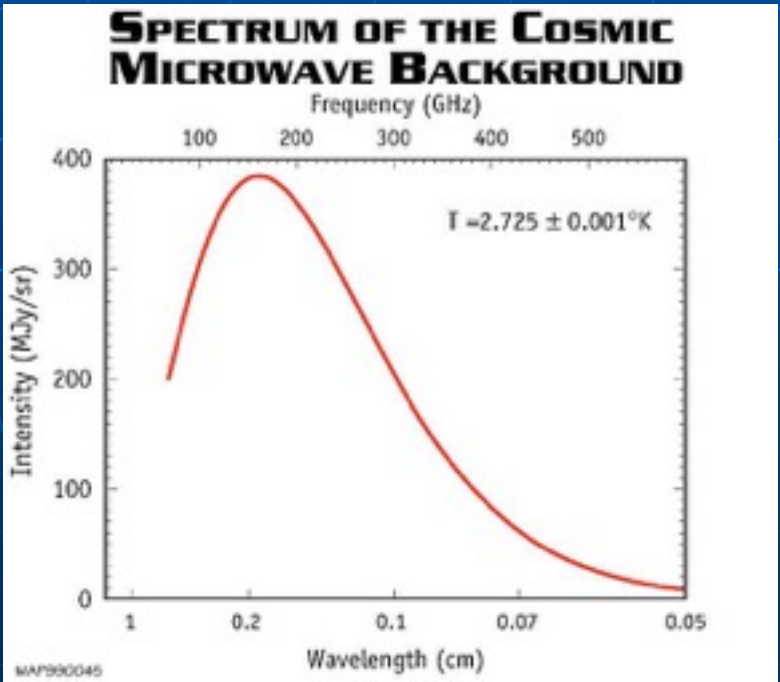
outofthisworldsc663a.weebly.com/the-steady-state-theory.html

en.wikipedia.org/wiki/File:Fred_Hoyle.jpg

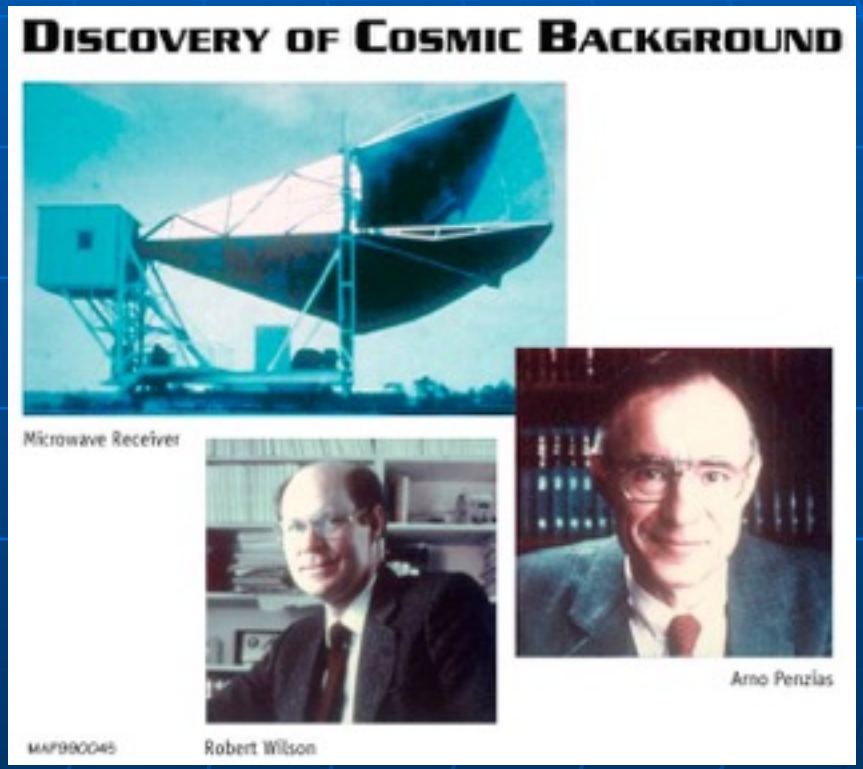
Offered Steady-State Theory of Cosmology – continuous creation

Cosmic Microwave Background

- Discovered by accident by Bell Lab scientists Arno Penzias and Robert Wilson (1965)



map.gsfc.nasa.gov/media/ContentMedia/990015b.jpg

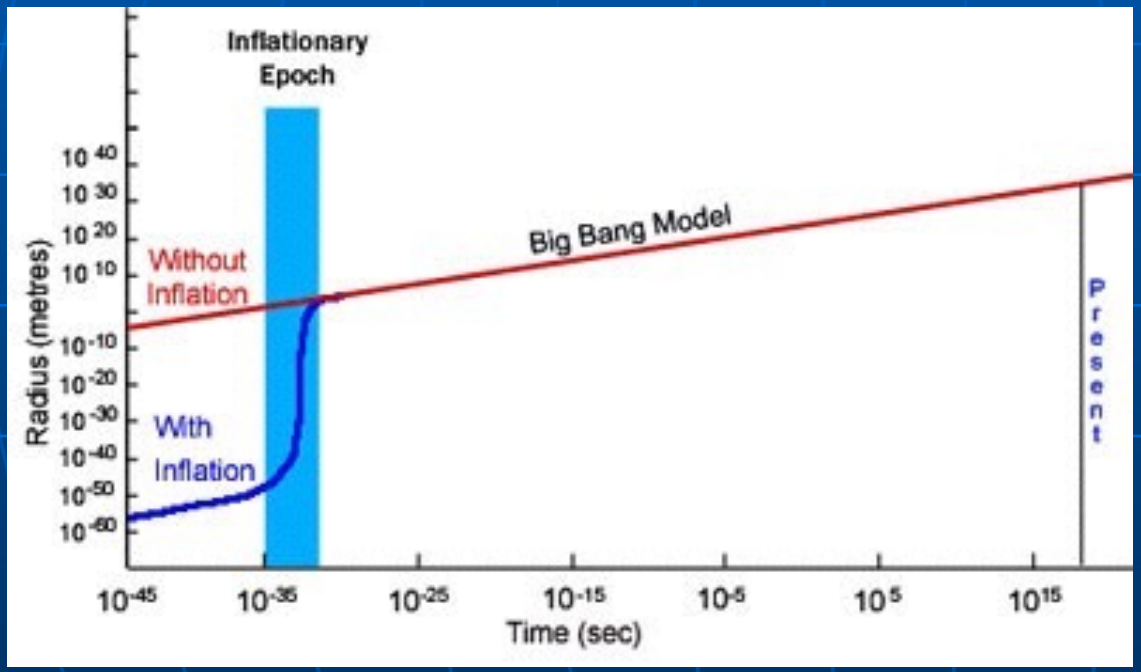


map.gsfc.nasa.gov/media/ContentMedia/990045b.jpg

Proved Hot Origin of Universe!

Horizon Problem – Too Smooth!

- Solution: Brief Inflationary Expansion – Alan Guth 1980



astronomy.swin.eud.au/cms/imagedb/albums/userpics/bigbang2.jpg

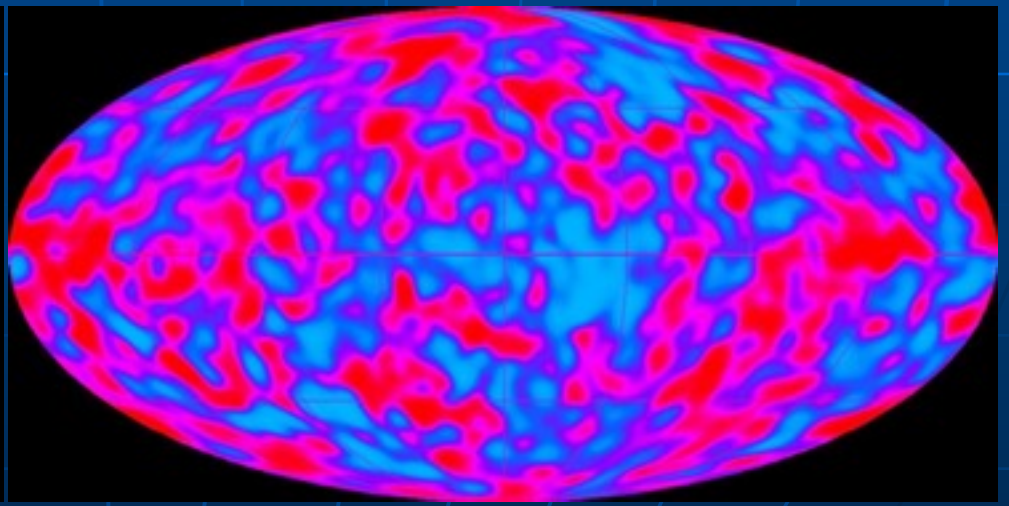
web.mit.edu/physics/images/faculty/guth_alan.jpg

- Predicts Slight Non-Uniformity of CMBR from Quantum Fluctuations

Search for Variations in Cosmic Microwave Temperature

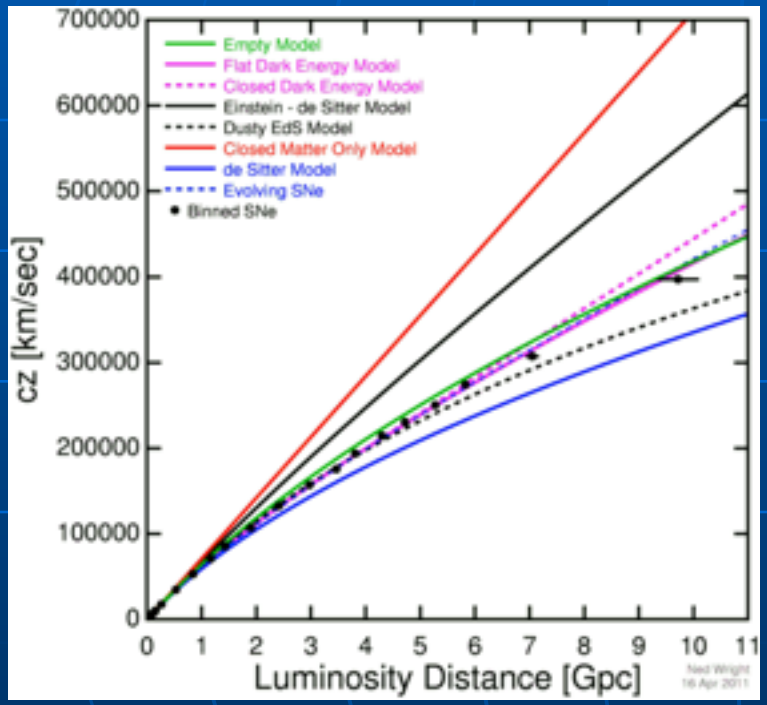
- Galaxy Formation implies radiation background could not be entirely uniform – hotter spots needed to initiate it
- Original Expectations: variation in T / T = 0.001
- With Cold Dark Matter present (another discussion) revised expections: variation in T / T = 0.00001
- Cosmic Background Explorer (COBE 1992)

upload.wikimedia.org/wikipedia/commons/thumb/a/af/Cobe_vision1.jpg/230px-Cobe_vision1.jpg



en.wikipedia.org/wiki/File:COBE_cmb_fluctuations.gif

Discovery of Accelerating Expansion of Universe! (1998)



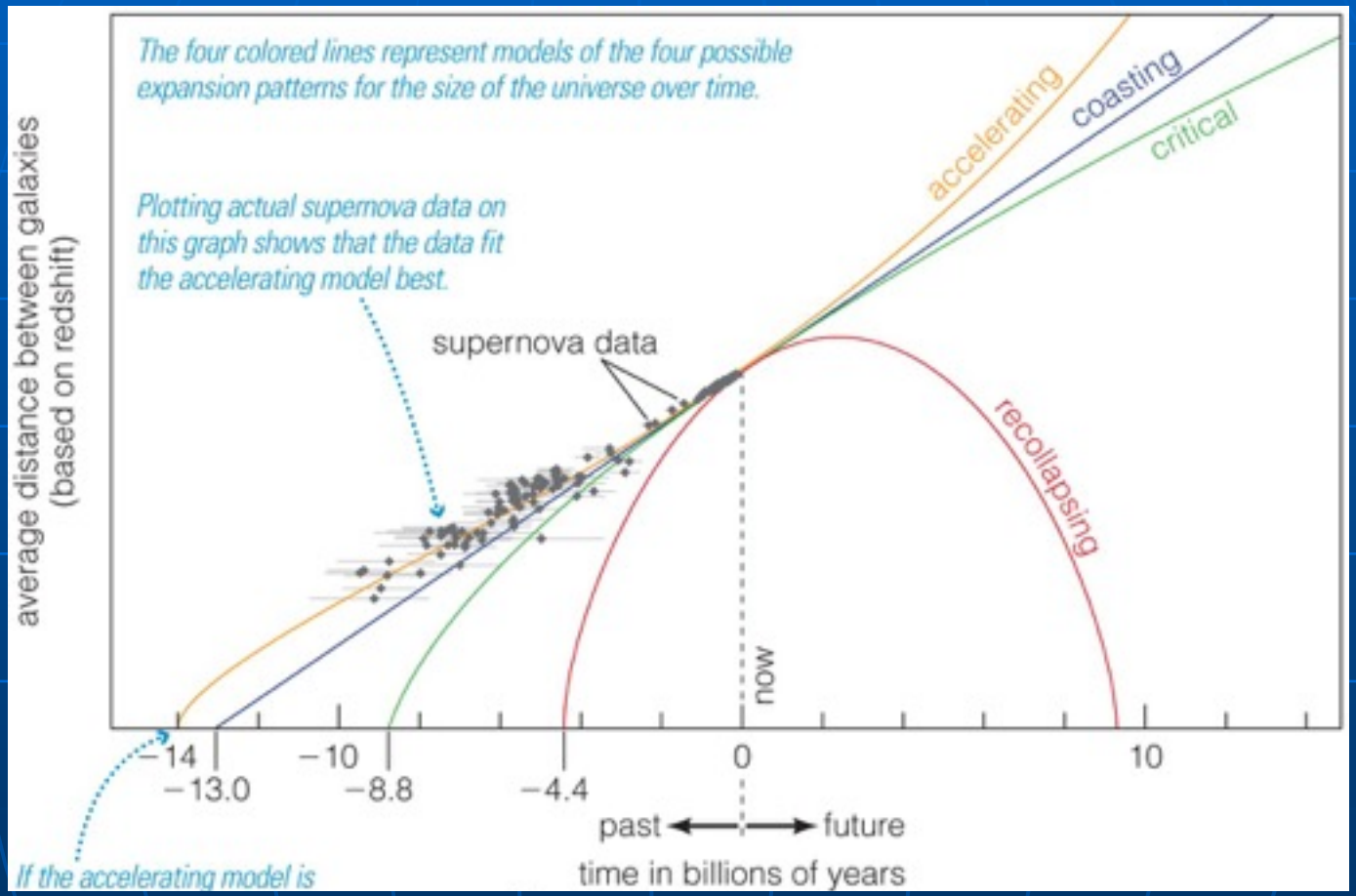
From Conley, et al ApJS (2011), 192, 1

2 Teams: Supernova Cosmology Project and High Z Supernova Search Team find unexpected result: expansion increasing!

http://www.physast.uga.edu/~rls/1020/ch22/22-18.jpg

Rather than slowing down (decelerating) the universe is expanding faster today than in the past! "Dark Energy"

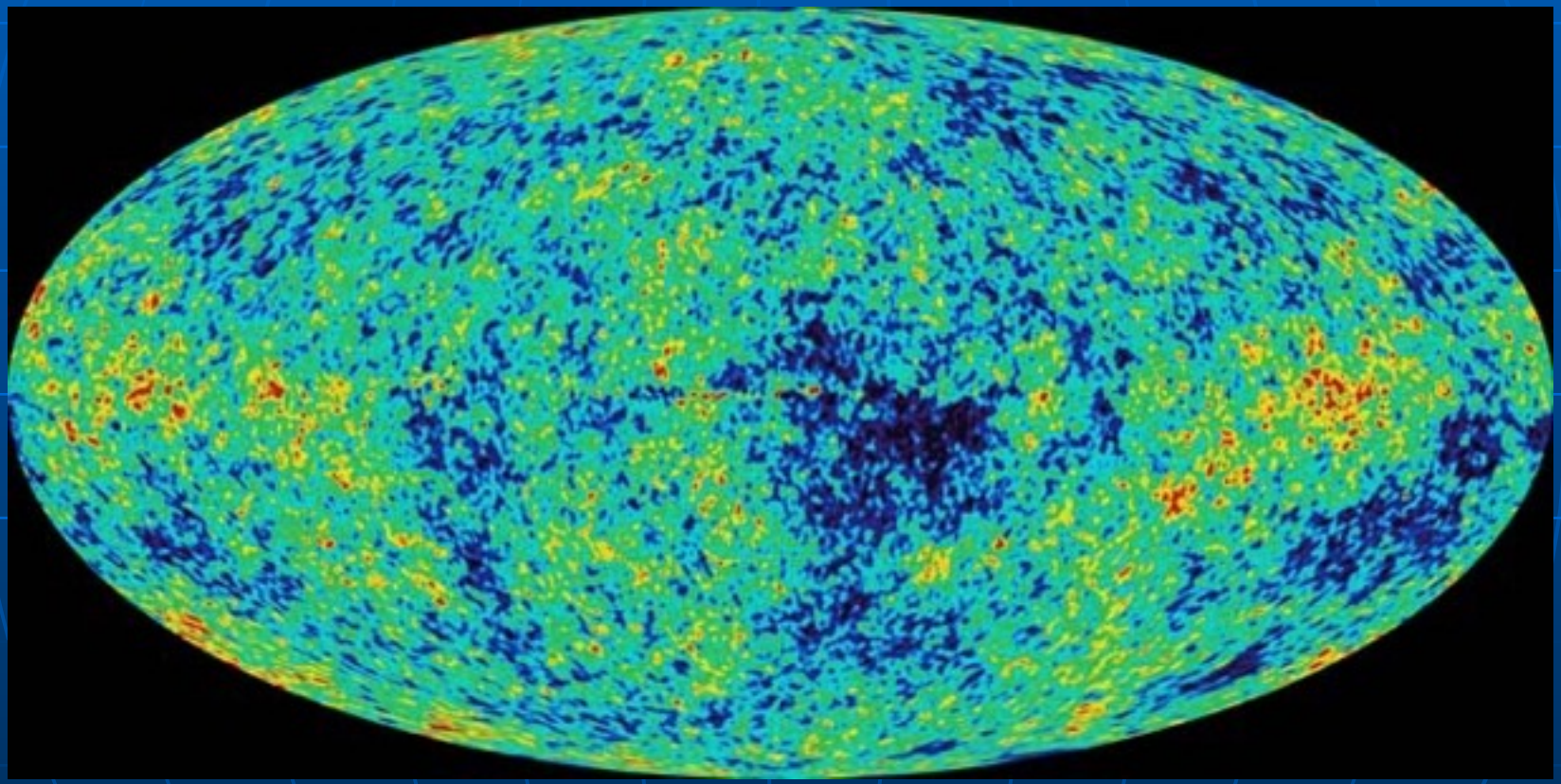
History of Universe Revised



http://daedalus.as.arizona.edu/~gwalth/Astr170B1/Lectures/images/22_18_Figure-Anno.jpg

Dark Energy now dominates Energy Density of Universe, implying universe will continue expanding faster & faster!

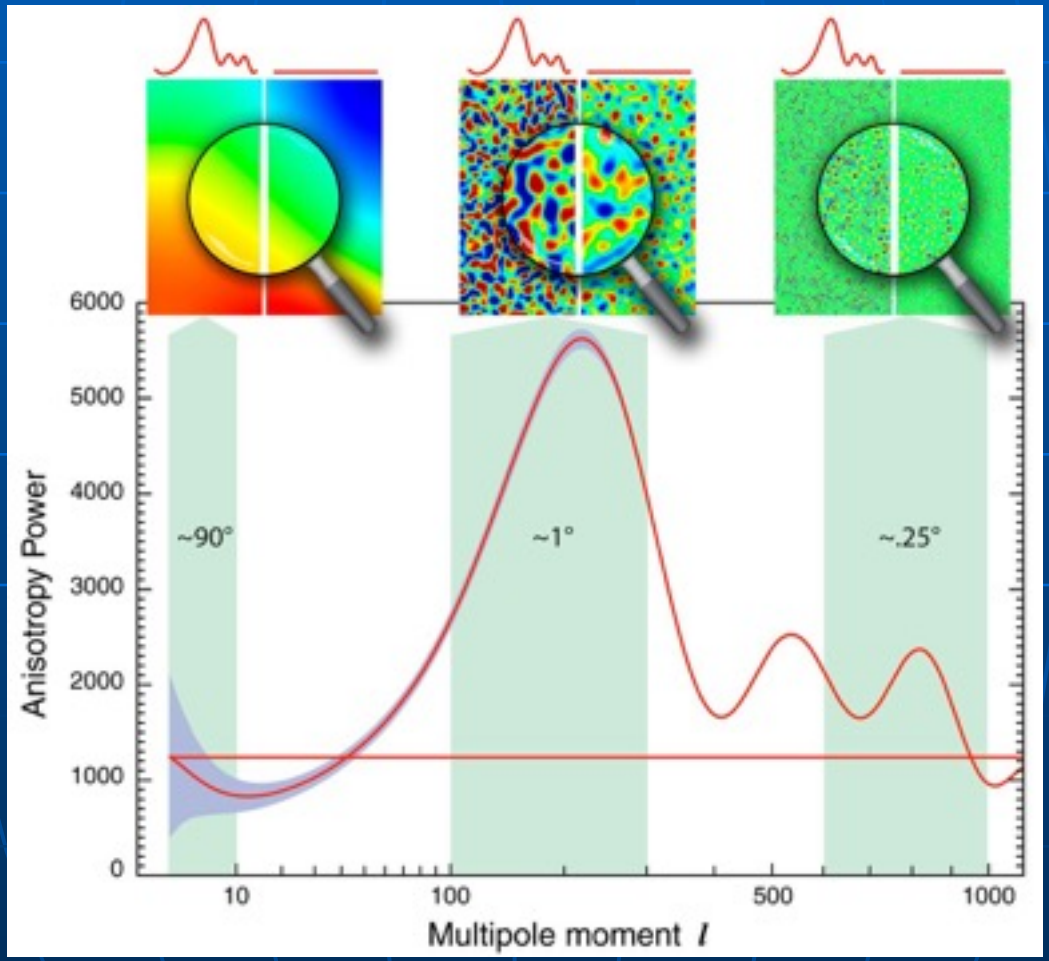
Wilkinson Microwave Anisotropy Probe (WMAP 2003)



http://map.gsfc.nasa.gov/media/101080/101080_7yrFullSky_WMAP_320W.jpg

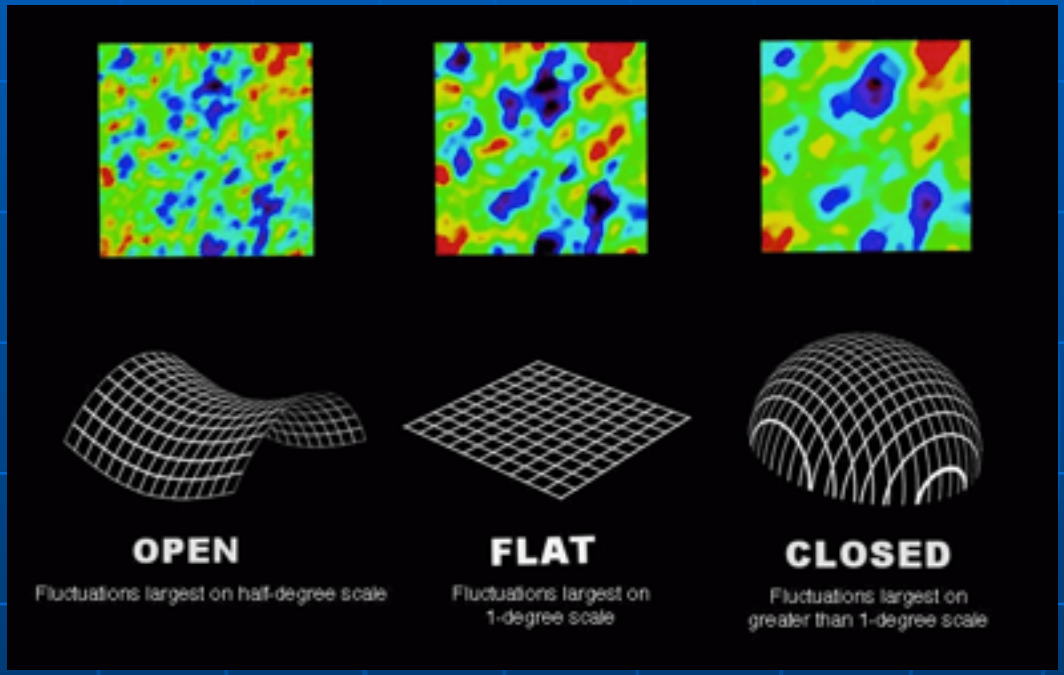
Cosmology Becomes a Precision Science!

Angular Size of Fluctuations Establishes Geometry of Universe



http://map.gsfc.nasa.gov/media/070950/070950b.jpg

WMAP Data reveal a Flat Geometry for the Universe!

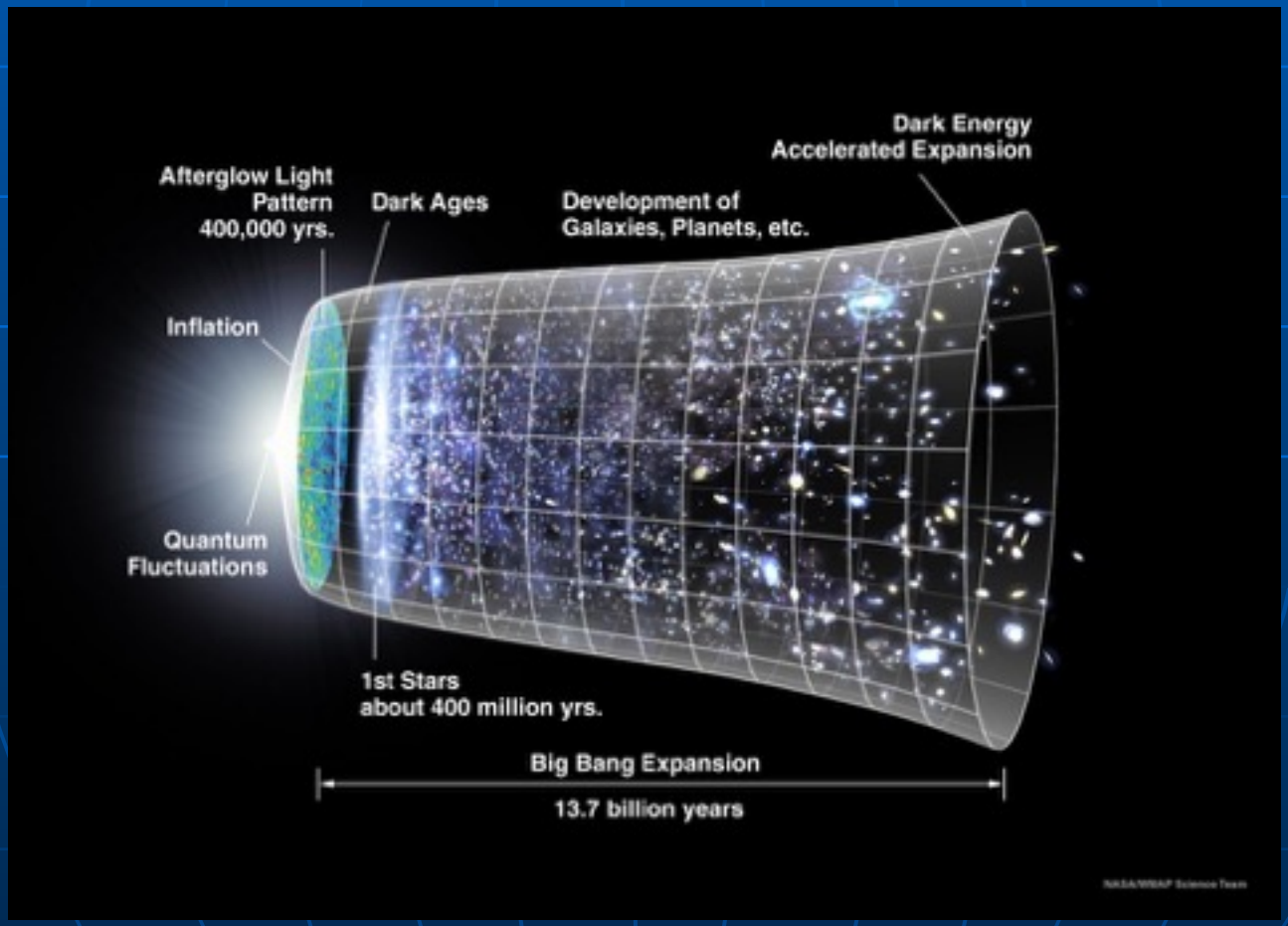


http://csp.res.in/ICSP-WEB/Docs/Pop_cd/Material/Quiz/cosmos/wmap-findgeometrysmg.gif

- Total Mass-Energy Density is precisely the Critical Density: 71% Dark Energy, 24% Dark Matter, only 4.6% Ordinary Matter
- Establishes Age of Universe: 13.7 billion years

Galaxy Formation

- Dark Ages end after around 400 million years, when large halos of dark matter spawn growth of stars and galaxies



upload.wikimedia.org/wikipedia/commons/thumb/6/6f/CMB_Timeline300_no_WMAP.jpg/350px-CMB_Timeline300_no_WMAP.jpg

Cosmology begs Bigger Questions

- Does the vast scale of our cosmos imply that we are insignificant?
- Are we just a cosmic "accident"?
- Or does the vast and elegant universe point to a purposeful plan?
- Can an ancient religious faith in a transcendent God and humanity as the apex of creation be reconciled to what we see in modern cosmology today?