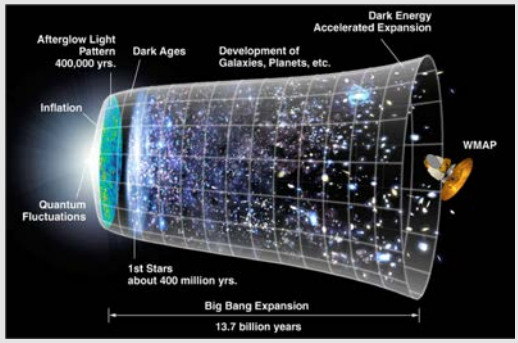
ASTR 1040: Stars & Galaxies



Prof. Juri Toomre TAs: Daniel Sega, Max Weiner
Lecture 28 Thur 23 Apr 2020
zeus.colorado.edu/astr1040-toomre

Our Schedule

- *Mid-Term Exam 3 essay grading* not yet finished (from "L" onward) – will post details
- *Homework #13 due today (flexible)*
- Please turn in extra-credit *Observatory Night project* by next Tues Apr 28
- *Please do course evaluation (FCQ) online for course + recitation this week*
- Focus on *22.2 Evidence for Big Bang* and on *22.3 Big Bang and Inflation*
- Complete detailed read *Chap 23: Dark Matter, Dark Energy, Fate of Universe*

Cosmology topics and issues

- Look at *models for our universe*
- *Cosmic microwave background (CMB)* and all its implication
- Ideas of "*dark energy*" arising from:
- *White-dwarf supernova data*
- *CMB mapping*
- Imply *"accelerating universe"*

REMINDER

Cosmological (Big) Redshifts
(from expansion of universe)

Alternative definition of redshift :

Z = *redshift*
= *change in wavelength/ "normal" wavelength*

$1 + Z$ =
observed wavelength / "normal" wavelength

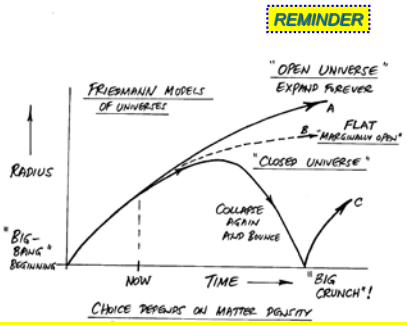
redshifts always have $Z > 0$
(redder light has larger wavelengths)

Models of our universe

Dark matter has big influence on "open" vs "closed"

COSMOLOGY : NATURE OF THE UNIVERSE

REMINDER



If enough mass, gravity eventually wins!

REMINDER

Predictions of General Relativity Theory (GRT)

- *Einstein in 1917 realized GRT (1915) predicted universes in motion, but preferred `steady state' – added `cosmological constant' (CC) as repulsive force in space-time to counteract attractive force of gravity*
- *Willem de Sitter (A, Dutch, 1917) solves GRT equations with no CC and low density of matter : showed universe must expand*
- *Alexander Friedmann (M, Russian, 1920) solves GRT with no CC but any density of matter : universes can expand forever, or collapse again, depending on mean matter density*

REMINDER

More on … Predictions of GRT

- Georges Lemaitre (P, Belgian, 1927) rediscovers Friedmann solutions, told Hubble (observing redshifts since 1924) that cosmic expansion suggests more distant galaxies should have greater redshifts (Hubble publishes $V = H_o d$ in 1929)
- Einstein visited Hubble in 1932, said CC "biggest blunder"

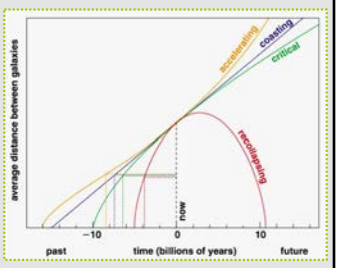
REVIEW

Vital diagram

"Average distance between galaxies"
= 1 / expansion factor
= 1 / (1 + Z)

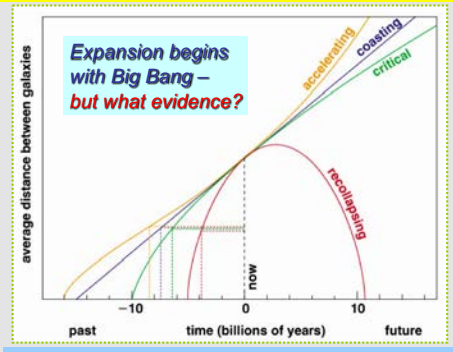
NOW is fixed in time (Z=0)

Hubble constant NOW sets slope of line = how fast universe is expanding NOW



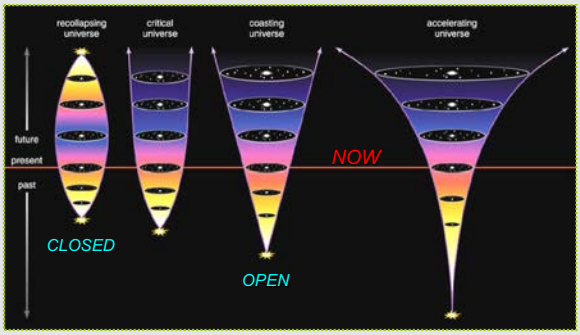
Big Bang = when distance zero
Z = infinity

Dark Matter and Fate of the Universe



Several different models for Past and Future

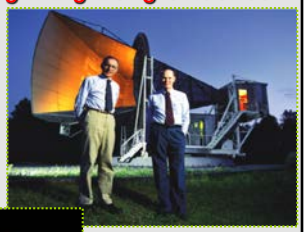
Four models for fates of universe



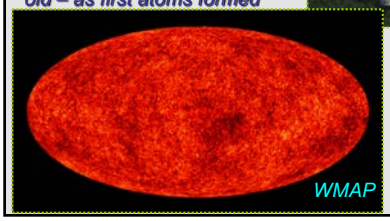
Questions or Comments

Big shift in thinking .. Big Bang evidence

Penzias & Wilson in 1965 discovered Cosmic Microwave Background (CMB) radiation
--> 2.73 K "black body"



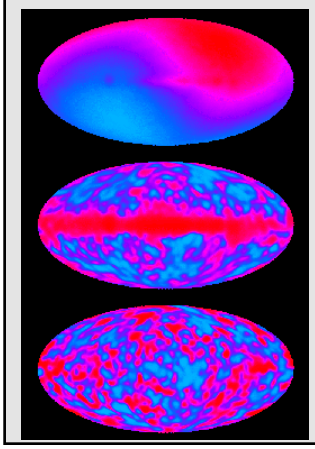
Photons created when hot universe was only 380,000 yrs old – as first atoms formed



Very uniform radiation from everywhere – (few parts in 100,000) severely redshifted by expansion of universe

CMB (Accidental) Detection Story

- George Gamow, Robert Dicke and Jim Peebles are some players in predicting (1946-1960s) that a remnant radiation signal (microwave background temperature) should survive from "Big Bang" beginning of universe
- Spectrum "temperature" estimates ranged from 50K to 20K or less
- Robert Dicke at Princeton in 1964 was building a horn with his earlier WWII design (Dicke radiometer) to look for background microwave radiation
- Arno Penzias and Robert Wilson at nearly same time used big horn antenna at Bell Labs (with cooled Dicke radiometer) to start radio mapping of Milky Way
- Their *"background noise" at 4000 MHz (7.35 cm)* was inexplicable – *Bernie Burke* told them to talk to Dicke!



COBE (satellite) Mapping Steps

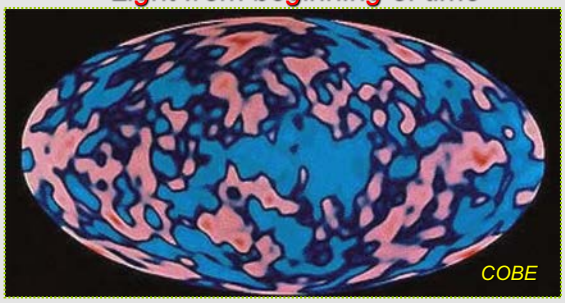
Remove big "Dipole asymmetry": solar system moving at 600 km/s (few parts in 1000)

Glow from dust in plane of Milky Way (few parts in 100,000)

Cleaned up: glow from "cosmic photosphere" when universe ~380,000 yrs old (few parts in 100,000)

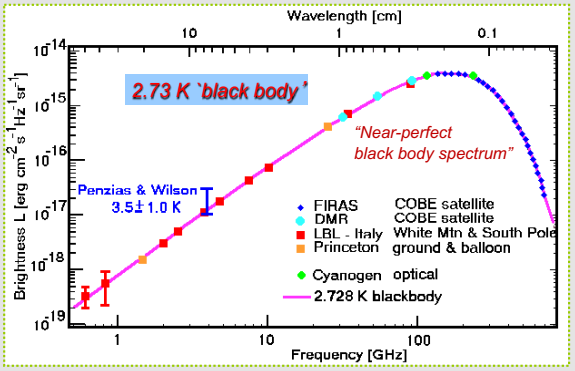
Cosmic Background Explorer 1989-1993

Light from beginning of time

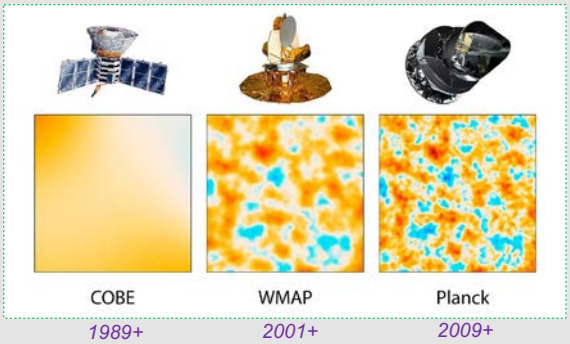


- This faint light looks light a solid glowing wall
- Thermal spectrum at 3000 K, if redshifted by factor ~1000 → microwaves !

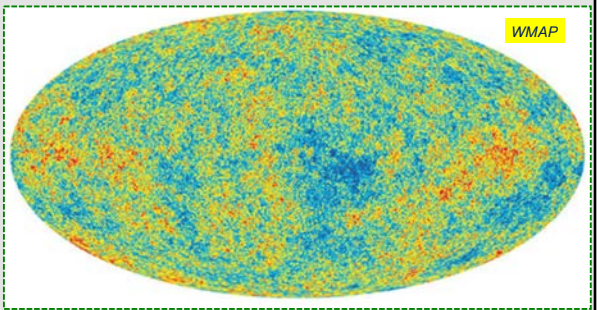
Spectrum of Cosmic Microwave Background (CMB)



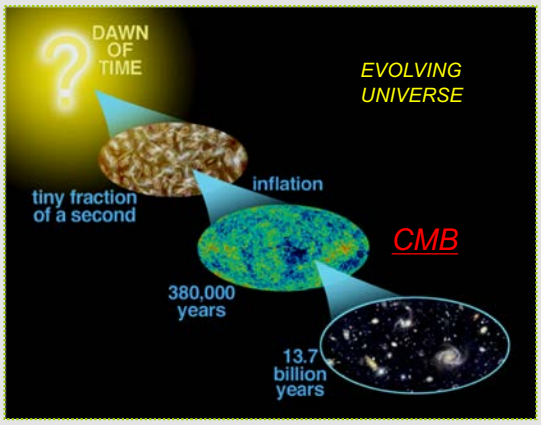
Major improvements in CMB spatial resolution and sensitivity



CMB: Light from beginning of time



- This faint light looks like a solid glowing wall
- Thermal spectrum at 3000 K (visible), if redshifted by factor ~1000 → 3 K ! (microwaves)



Poll 1: looking back in time

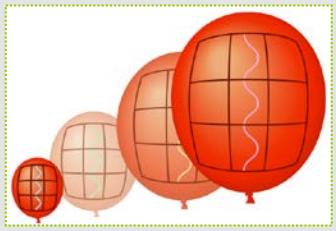
- If we can detect light from a quasar and decide that its emission line spectrum is at redshift Z = 4, how much bigger has the universe grown since that light left?

- A. 2 times bigger
- B. 3 times bigger
- C. 5 times bigger
- D. 16 times bigger

Redshift is "expansion factor"

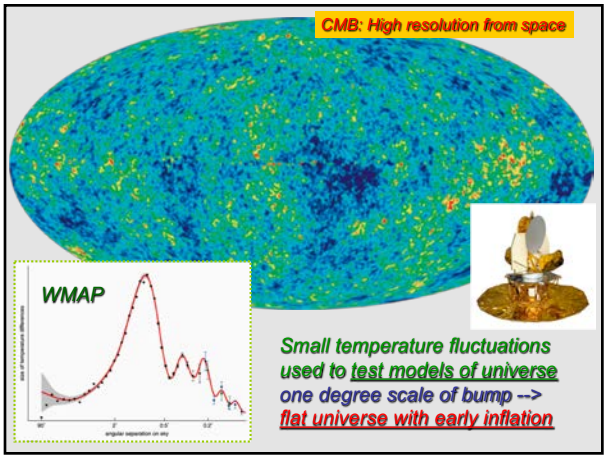
REMINDER

1 + Z measures how much universe has expanded



1 + Z = distance between galaxies now / distance between galaxies then

Questions or Comments

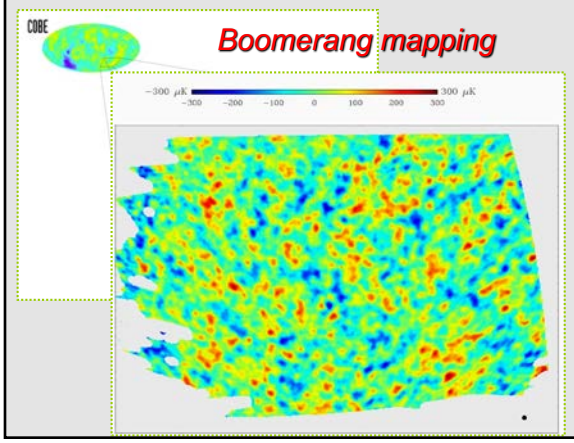


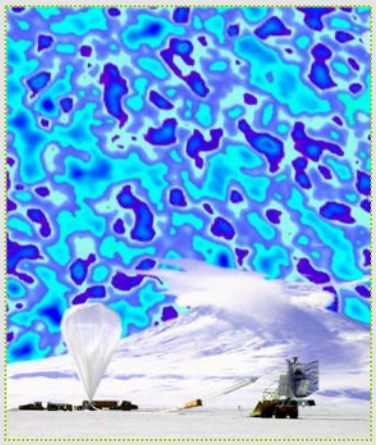
Small temperature fluctuations used to test models of universe
one degree scale of bump --> flat universe with early inflation

Boomerang: finer CMB mapping

Balloon – Mt Erebus Antartica

Boomerang mapping

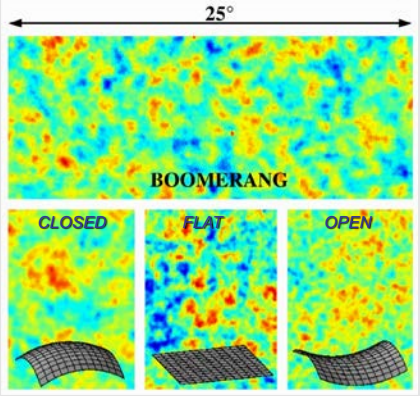




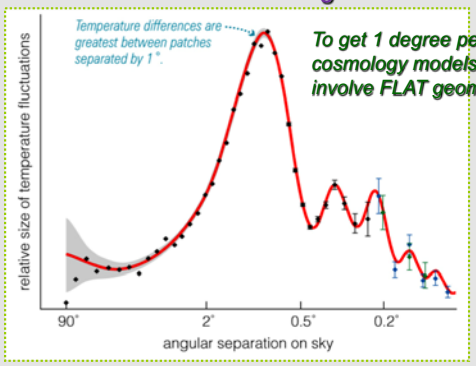
"Our view of CMB" to scale in sky

Boomerang

Curvature of universe and CMB pattern

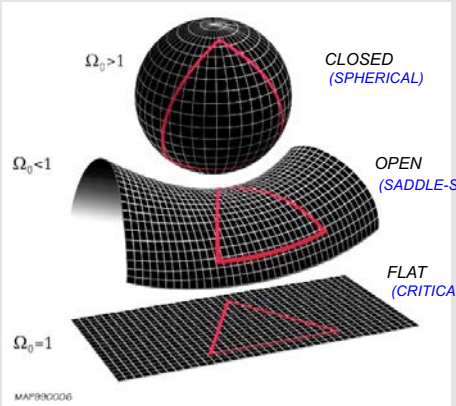


Variations in CMB on small scales: "sound waves bouncing around"



To get 1 degree peak, cosmology models involve FLAT geometry

"Overall Geometry" of Universe



What is the fate of the Universe?

- Recollapse to gnaB giB ? : crushing heat, destruction of all matter (Big Crunch) Rebirth ?
- Eternal expansion ? : cold, galaxies dimming star formation slowing
- Everything winds up as a brown dwarf black dwarf, neutron star or black hole

Which is it ?
Is there enough dark matter to recollapse the universe?

Baryonic matter: only few % of critical density

Dark matter: only about 25 % of what is needed

Looks like Universe is between the "coasting" and "critical" models

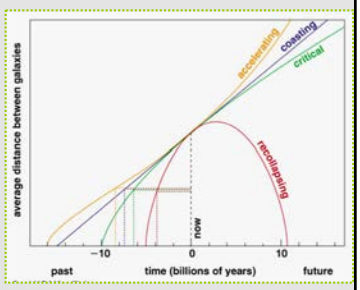
Universe will expand forever (or so it seems)

Questions or Comments

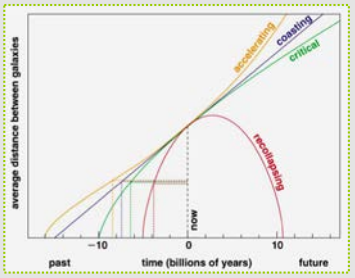
- Which model predicts the greatest age for the universe today?

Poll 2: Question

- A. Recollapsing (closed)
- B. Critical (flat)
- C. Coasting (open)



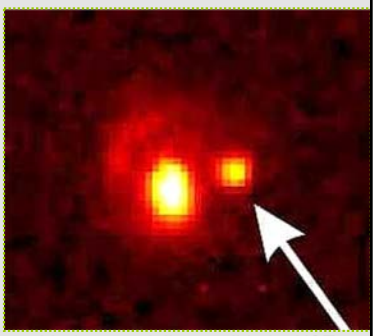
- C. Coasting
- Age of universe is how far to left curves hit horizontal axis (distance between galaxies = 0)



New twist in the new millenium

- White dwarf supernovae: standard candles at Z ~ 1
- Explosions bright enough to be seen very far away (back in time)

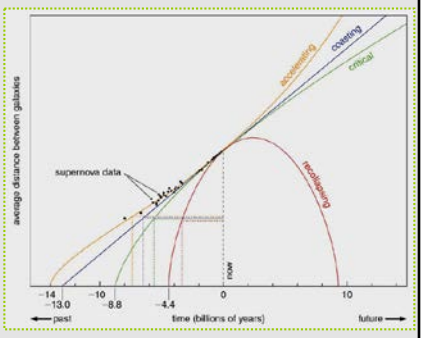
SN Type Ia: (1998) BIG DISCOVERY THAT SHOOK COSMOLOGY



Made especially possible by HST

Redshifts of SN plot their vertical position

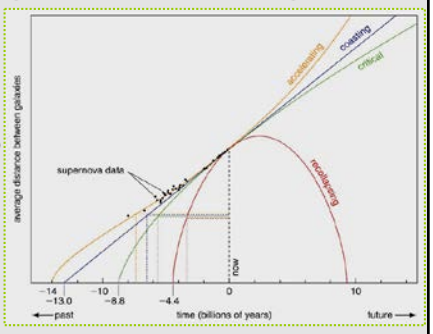
- Z = 1 means about halfway down from the "NOW" level
- Expansion factor = 1 + Z = 2



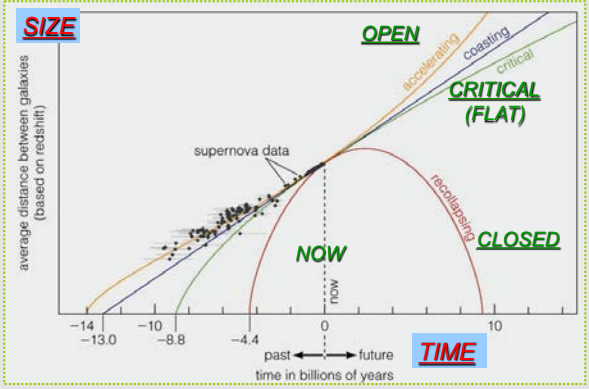
Brightness plots their horizontal position

Dimmer
= more distant
= longer ago

- Supernovae are DIMMER than expected for a coasting universe
- Universe is accelerating ??



Models of universe – and its fates

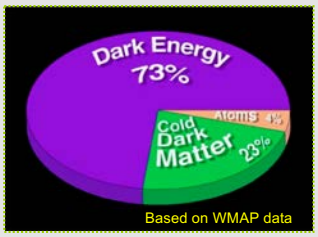


How can universe be accelerating??

A force that counteracts gravity?

"Dark energy" – outweighs every other form of mass/energy!

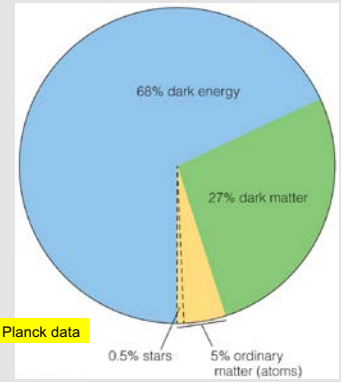
Truly an unknown force in all of physics!



(Read "Einstein's Biggest Blunder" Cosmological Constant - p 685)

Accelerating Universe: Mass-Energy Pie Chart

- **Dark energy** — more prevalent than every other form of mass/energy !
- A repulsive force that counteracts gravity?



Based on using Planck data