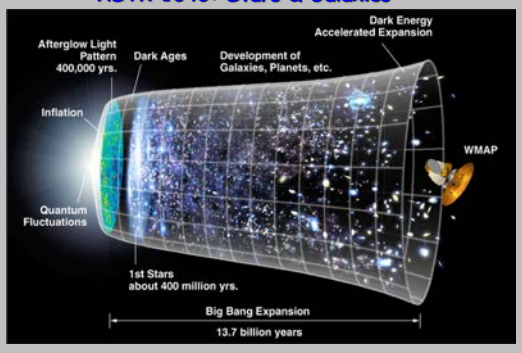
ASTR 1040: Stars & Galaxies



Prof. Juri Toomre TAs: Ryan Horton, Loren Matilsky
Lecture 28 Thur 6 Dec 2018
zeus.colorado.edu/astr1040-toomre

Our Schedule

- *Homework #13 due today*
- *Review Set #4 available -- final review on next Wed Dec 12, 5pm-7pm by Ryan*
- *Please do course evaluation (FCQ) online for course + recitation*
- *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 :

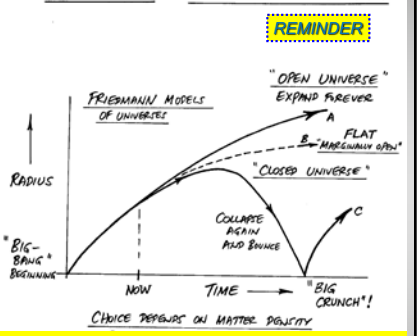
Z = *redshift*
= *change in wavelength/ "normal" wavelength*

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

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

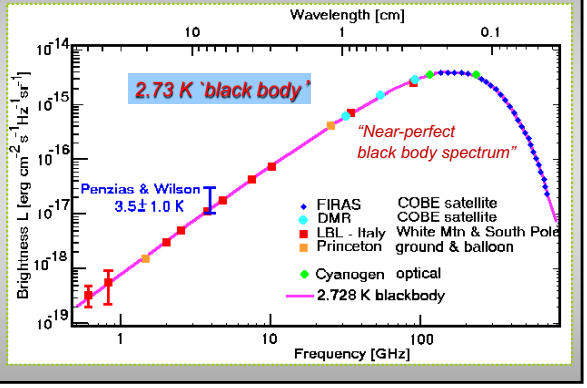
Models of our universe

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

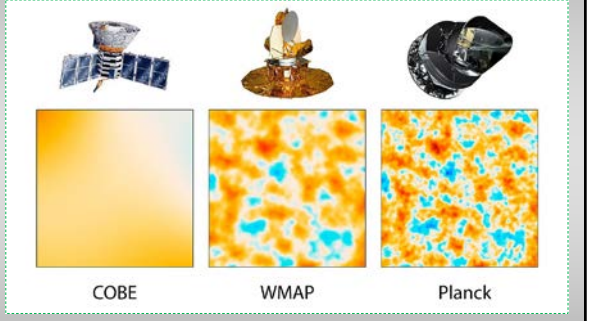


If enough mass, gravity eventually wins!

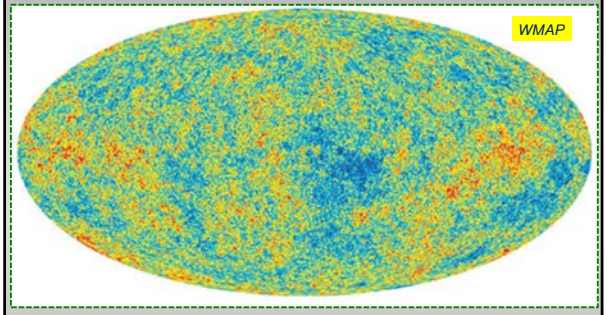
Spectrum of Cosmic Microwave Background (CMB)



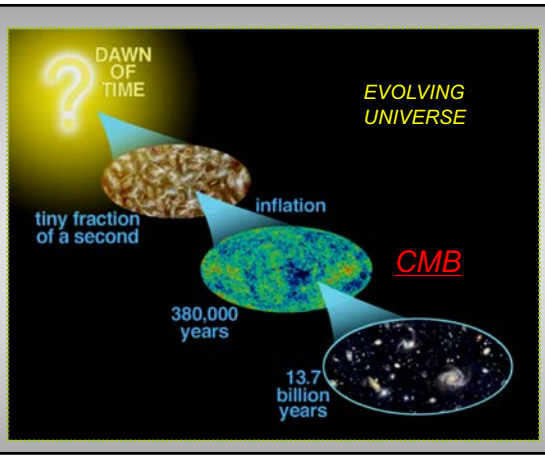
Major improvements in CMB spatial resolution and sensitivity



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)



Thinking clicker – 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?

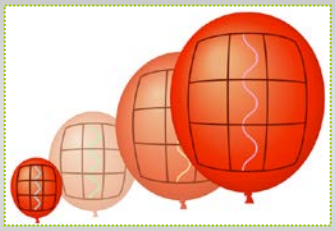
C.

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

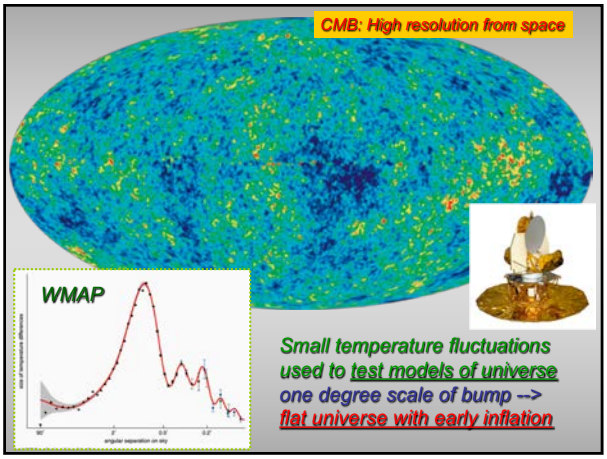
Redshift is "expansion factor"

REMINDER

1 + Z measures how much universe has expanded



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

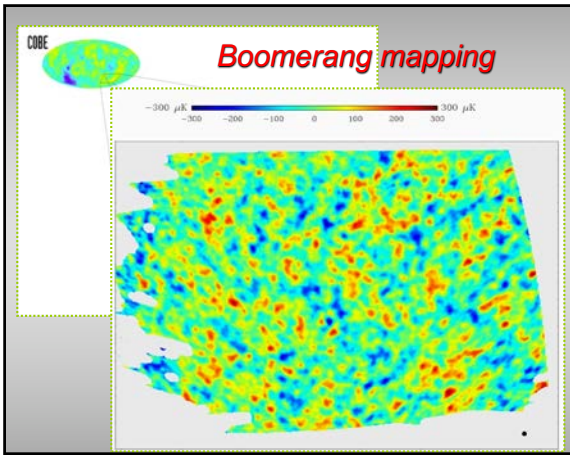


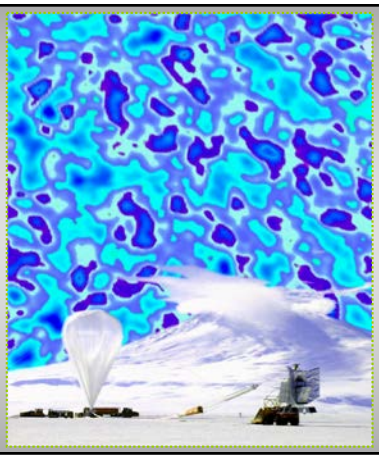
Small temperature fluctuations used to test models of universe
one degree scale of bump --> flat universe with early inflation

Boomerang: finer CMB mapping

Balloon – Mt Erebus Antartica

Boomerang mapping

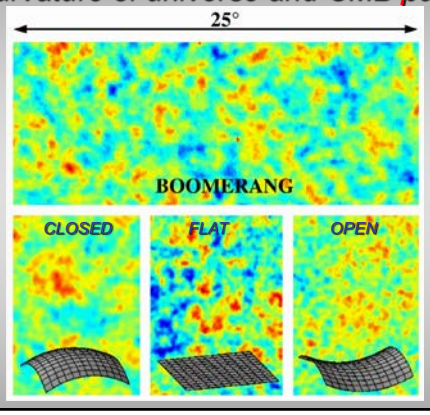




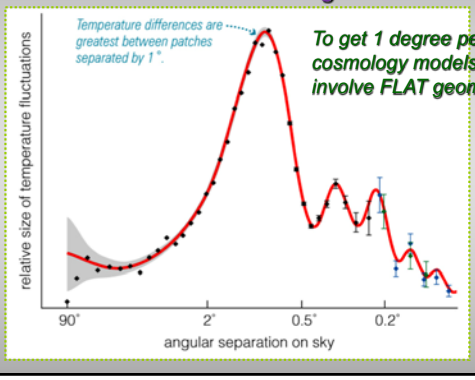
"Our view of CMB" to scale in sky

Boomerang

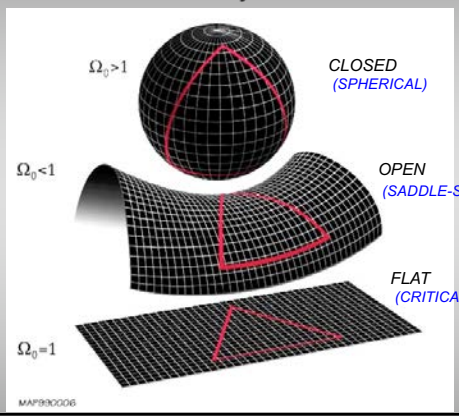
Curvature of universe and CMB pattern



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



"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

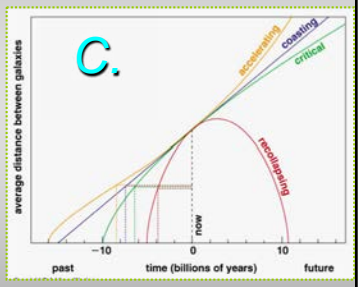
Dark matter: only about 25 % of what is needed

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

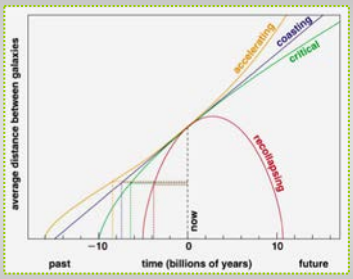
Universe will expand forever (or so it seems)

Clicker Question

- Which model predicts the greatest age for the universe today?
- A. Recollapsing (closed)
- B. Critical (flat)
- C. Coasting (open)



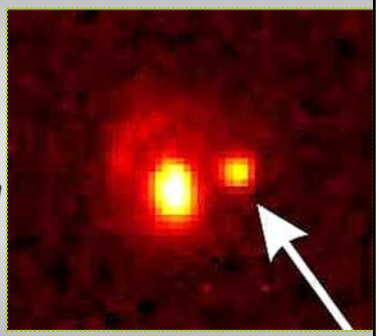
- C. Coasting
- Age of universe is how far to left curves hit horizontal axis (distance between galaxies = 0)



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)

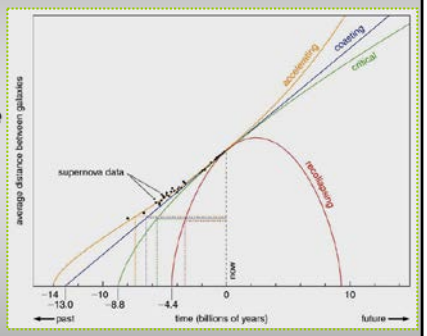
SN Type Ia: (1998) BIG DISCOVERY THAT SHOOK COSMOLOGY



Made especially possible by HST

Redshifts of SN plot their vertical position

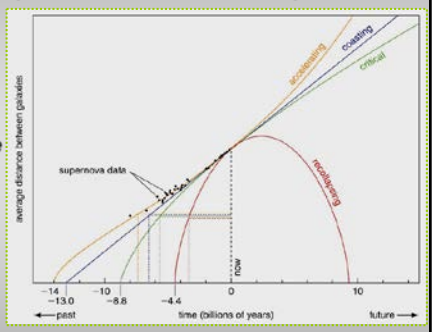
- Z = 1 means about halfway down from the "NOW" level
- Expansion factor = 1 + Z = 2



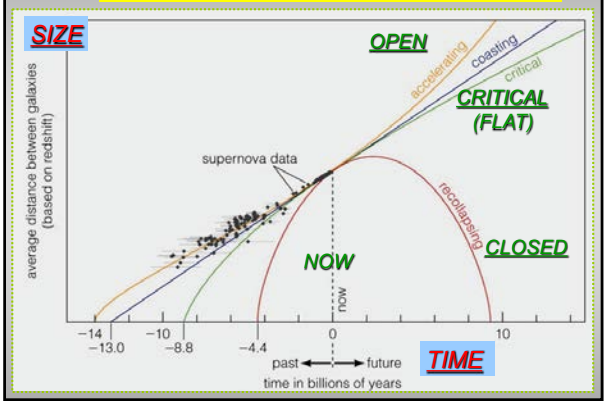
Brightness plots their horizontal position

Dimmer
= more distant
= longer ago

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



Models of universe – and its fates

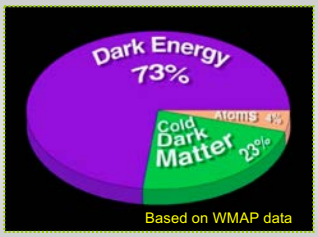


How can universe be accelerating??

A force that counteracts gravity?

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

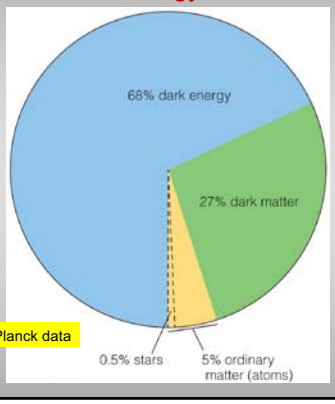
Truly an unknown force in all of physics!



(Read "Einstein's Biggest Blunder" Cosmological Constant - p 686)

Accelerating Universe: Mass-Energy Pie Chart

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



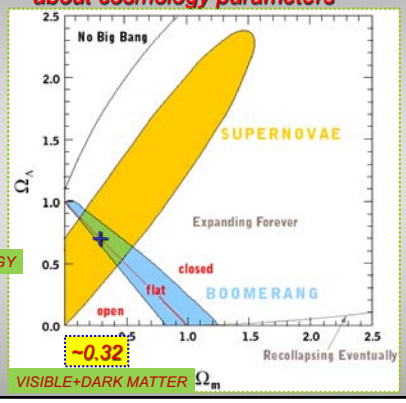
Based on using Planck data

What CMB ripples and distant SN imply about cosmology parameters

current favorite values:

~0.68

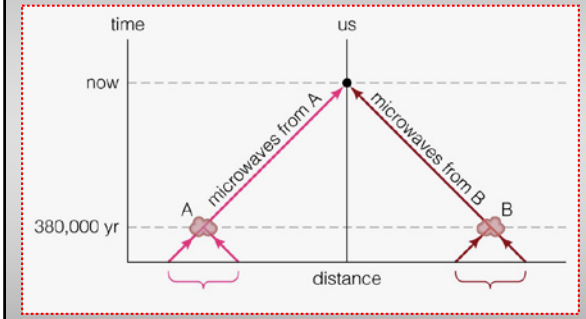
DARK ENERGY



~0.32

VISIBLE+DARK MATTER

Major puzzle: Why is CMB so uniform?

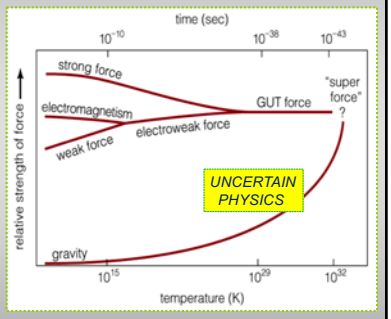


Major proposition: INFLATION

VERY EARLY:
- strong force becomes distinct from electroweak, huge amount of energy released

Universe INFLATES:
- atomic nucleus size to solar system size in 10^{-36} sec

DOES NOT COOL



Inflation: coupling all portions of universe