

ASTR 1040: Stars & Galaxies

Prof. Juri Toomre TAs: Piyush Agrawal, Connor Bice
Lecture 28 Thur 27 Apr 2017
zeus.colorado.edu/astr1040-toomre

- ### Our Schedule
- Homework #13 due today
 - **Review Set #4** available -- final review on next Wed May 3, 5pm-7pm by Piyush
 - Course evaluation (FCQ) in last 15 min of class today
 - 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 further 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**"

REMEMBER

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)

REMEMBER

COSMOLOGY : NATURE OF THE UNIVERSE

Models of our universe

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

CHOICE DEPENDS ON MATTER DENSITY

If enough mass, gravity eventually wins!

REVIEW

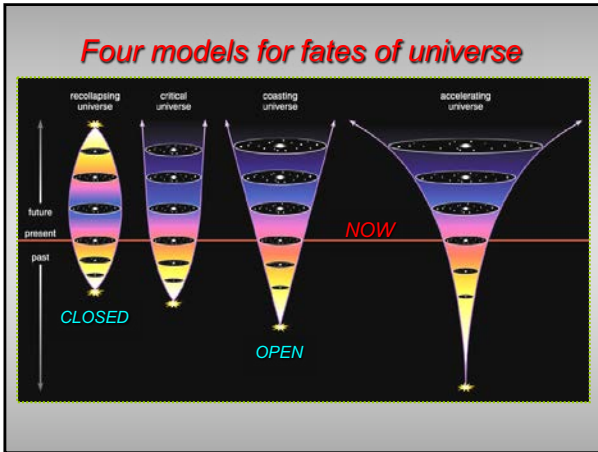
Vital diagram

"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
 $Z = \text{infinity}$



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

WMAP

- ### 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)

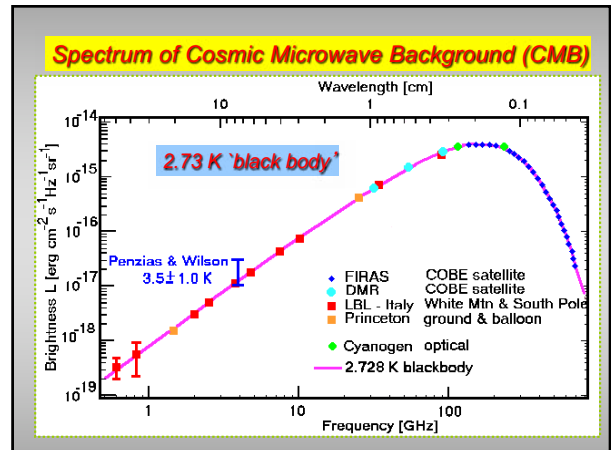
Glow from dust in plane of Milky Way (few parts in 100,000)

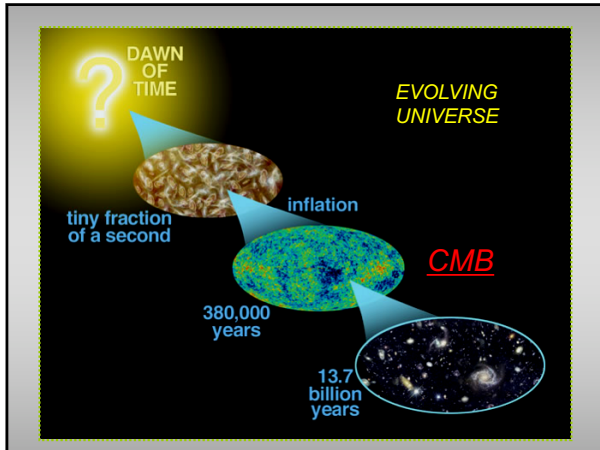
Cleaned up: glow from "cosmic photosphere" when universe ~380,000 yrs old (few parts in 100,000)

Light from beginning of time

COBE

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

$1 + Z = \frac{\text{distance between galaxies now}}{\text{distance between galaxies then}}$

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?

C.

- 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 $Z \sim 1$
- 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

SIZE

OPEN (accelerating, coasting, critical)

CRITICAL (FLAT)

CLOSED (recollapsing)

NOW

TIME

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)