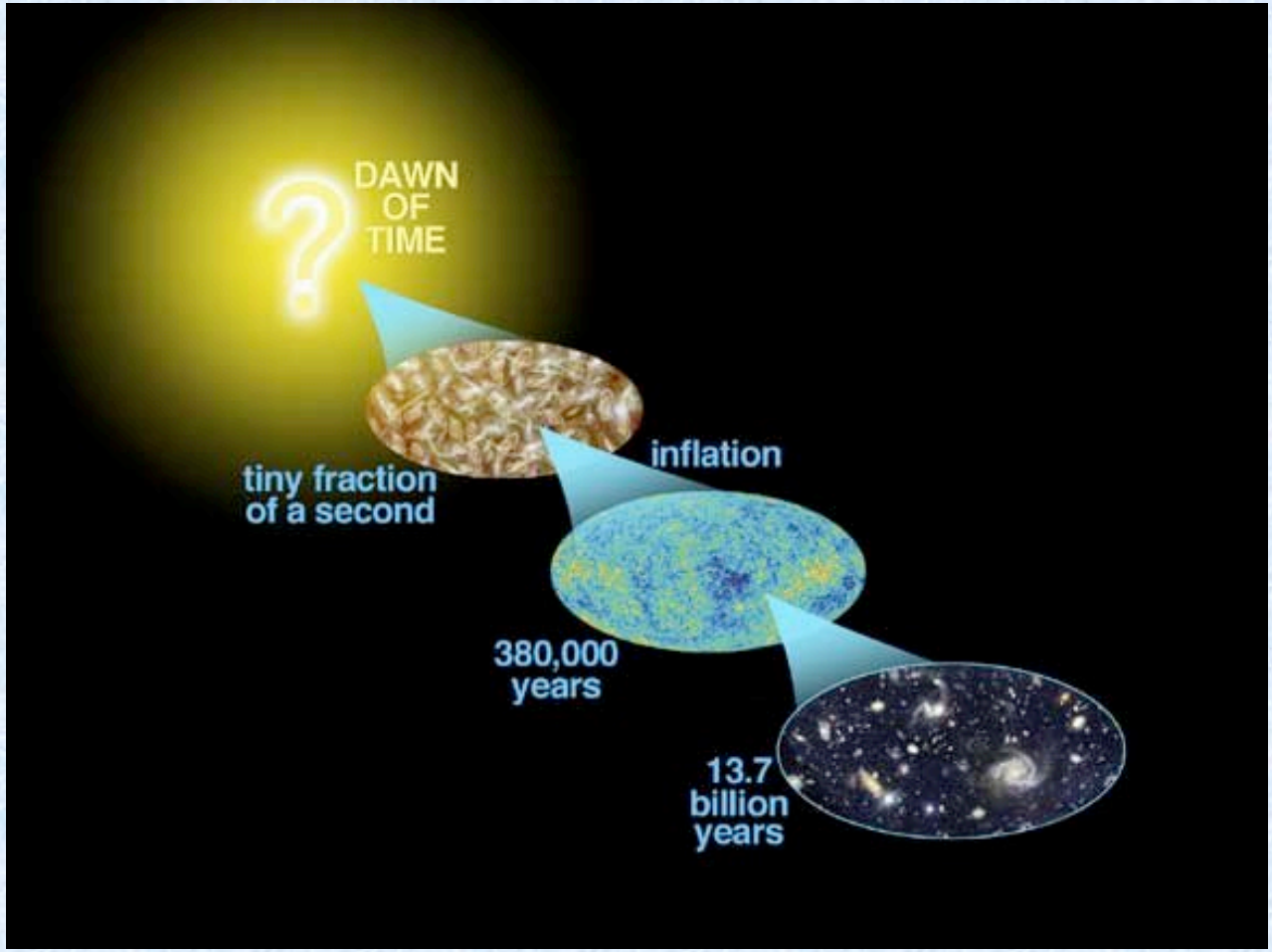
Astro-2: History of the Universe



Lecture 16; May 31 2011

Previously… on astro-2

- Jeans instability arises when a self-gravitating object is heavier than its pressure can support
- After inflation small quantum fluctuation are amplified to macroscopic scales and we see them as anisotropy in the CMB.
- Before decoupling they do not collapse because radiation is keeping the sound speed very high.
- After decoupling, chunks of the universe of about 100,000 solar masses become Jeans unstable and form the first “objects” in the universe..

Previously… on astro-2

- Until z~20 the universe has been neutral since recombination
- Neutral hydrogen is opaque to UV radiation and so light from the first stars cannot propagate far. These are called the cosmic dark ages.
- However, the first stars and quasars carve bubbles of ionized gas around them
- When enough bubbles are formed and start to fill in the entire universe UV radiation can finally travel again, this is called reionization
- Finding out the epoch of reionization and its sources is one of the hot topics in cosmology at this time.
- We may be close to an answer
- Between z=8 and 10 maybe?

Previously… on astro-2

- In the currently standard picture of galaxy formation galaxies form hierarchically from the initial quantum fluctuations amplified by inflation.
- Halos grow “bottom” up, assembling small chunks into larger and larger halos
- Inside halos there are baryons
- Torques from nearby halos spin up the halos (and the baryons)
- Baryons cool by emitting radiation and collapse because of Jeans instability
- As the baryons collapse, they need to preserve their spin and so they settle into a rotating disk

Previously… on astro-2

- Spheroids are formed by mergers of disks.
- The details of galaxy formation are poorly understood.
- As stars are born, evolve and die, they disperse heavy elements in the gas between stars via supernovae winds
- New stars are born from this gas starting the cycle over and over again
- At every cycle the gas is more abundant in heavy elements which them form planets, dust, etc

Previously… on astro-2

- What is Drake's equation?
- How do we detect planets?
- Is there life out there?
- Is there intelligent life?
- How do we communicate with them?

Today.. On Astro-2.

1. Alternatives to Big Bang
    1. Tired light
    2. Steady state universe
    3. The phoenix universe
    4. The cyclic / ekpyrotic universe

Tired light cosmologies

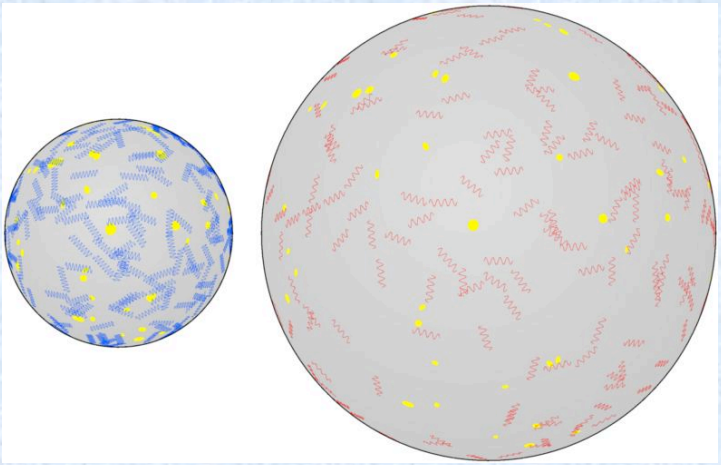
- What if we are totally wrong and cosmological redshifts are not due to expansion?
- An alternative explanation is the so-called tired light cosmology.
- In this model, photons loose energy as they travel in space, in a manner proportional to the distance traveled.
- The universe is static, i.e. steady state
- Experiments on Earth do not have enough precision to rule this alternative out.

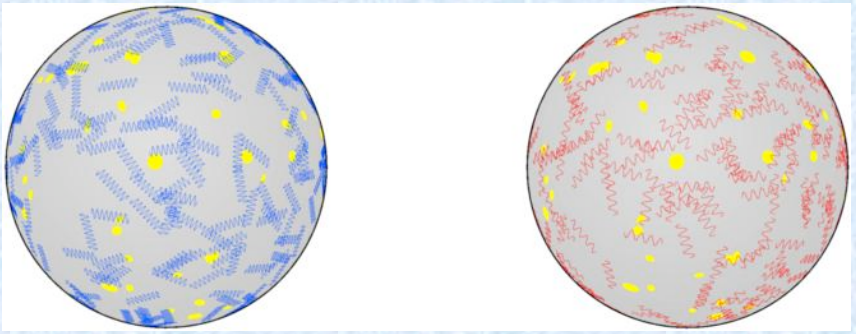
Problems with tired light?

- Time dilation of supernovae light curves
- Tolman test on the expansion of the universe
- Surface brightness in an expanding universe scales as $(1+z)^{-4}$
  - One power for photon redshift
  - One power for time delay
  - Two powers for difference between luminosity distance and angular size distance
- In tired light there should be only one power
- CMB should not be a blackbody

Tired light and CMB

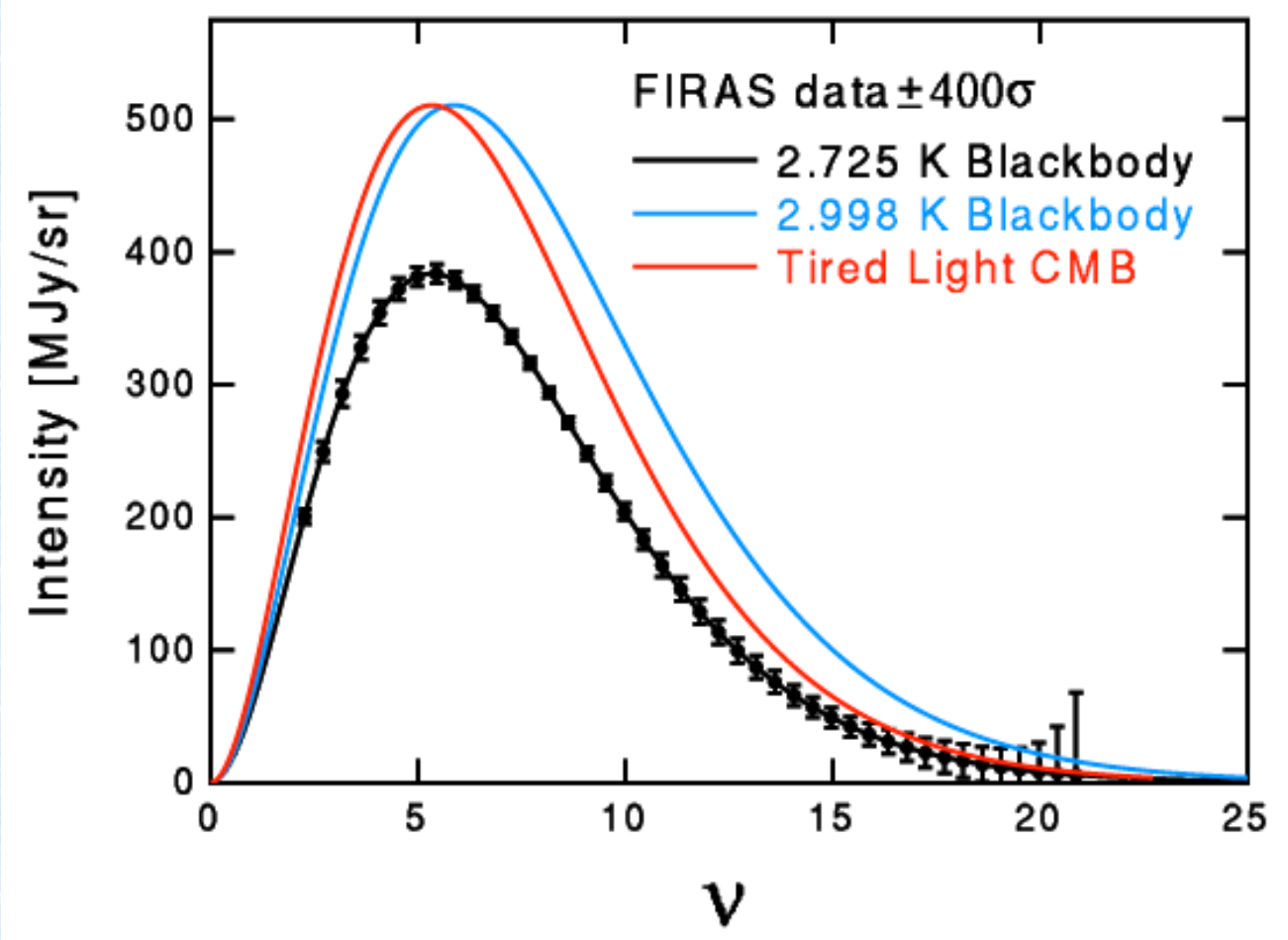
- In the standard BB cosmology as the universe expands the CMB photons loose energy and they become less dense, preserving the blackbody intensity
- In a tired light cosmology as the photons travel they loose energy but their number is preserved
- So the blackbody has the wrong intensity!





Cartoons from Ned Wright's UCLA website

Tired light and CMB



Main observational facts vs tired light

- The night sky is dark
- No!
- Spectra of distant objects appear redshifted
- Ok
- Helium abundance is ~25% very homogeneously
- No explanation
- Deuterium in distant gas clouds
- No (deuterium is only burned in stars)
- The Universe is filled with a blackbody radiation at ~3K
- No! (cannot be a blackbody all the time)
- This blackbody radiation is extremely isotropic
- No! (see above)
- No object older than ~15 Gyrs has ever been found
- No explanation
- Galaxies at high redshift look different than today
- No!

- The cosmic star formation rate changes as a function of time
- No!
- No detections of cosmic annhilations
- Ok
- Light curves of supernovae are observed to be stretched at high-z
- No!
- Surface brightness at high-z fades as $(1+z)^{-4}$
- No!

- The universe is flat [inflation]
- No explanation
- No magnetic monopoles have ever been observed [inflation]
- No!
- The CMB is isotropic over the entire sky [inflation]
- No!

Steady state expanding universe

- What if the universe is expanding, eternal and time invariant?
- The main problem is that as the universe expands matter density decreases
- In the steady state model (popular in the 50s) matter was constantly being created everywhere at the exact required rate (few atoms per MW every year).
- After all if matter is created at the Big Bang why not create it all the time everywhere?
- CMB is produced by scattered star light

Problems with steady state?

- Number counts of galaxies follow a well defined law because distances and volume changes with z
  - In SS the density of objects is smaller than in BB by a factor $(1+z)^3$ because of continuum creation vs matter conservation
- Data agree with BB taking into account evolution (which is not SS!)
- CMB can be introduced ad hoc but its temperature doesn't scale right with z! (It should be constant because it's steady state, while it's observed to increase; how?)

Main observational facts vs steady state cosmology

- The night sky is dark
- Ok
- Spectra of distant objects appear redshifted
- Ok
- Helium abundance is ~25% very homogeneously
- No, He abundance should scale with that of O
- Deuterium in distant gas clouds
- No (deuterium is only burned in stars)
- The Universe is filled with a blackbody radiation at ~3K
- Perhaps but should not evolve with z
- This blackbody radiation is extremely isotropic
- No explanation
- No object older than ~15 Gyrs has ever been found
- No explanation
- Galaxies at high redshift look different than today
- No!

- The cosmic star formation rate changes as a function of time
- No!
- No detections of cosmic annhilations
- Ok
- Light curves of supernovae are observed to be stretched at high-z
- Ok!
- Surface brightness at high-z fades as $(1+z)^{-4}$
- Ok!

- The universe is flat [inflation]
- No explanation
- No magnetic monopoles have ever been observed [inflation]
- No!
- The CMB is isotropic over the entire sky [inflation]
- No explanation

Alternatives to Big Bang 1. Summary

- Many alternative scientific theories to Big Bang have been formulated over the course of XX and XXI century.
- As in all good scientific theories, the assumptions imply quantitative predictions that can be measured.
- No single theory alternative to Big Bang to date has been able to stand the test provided observations.
- Tired light and steady state for example are falsified by a number of facts, e.g. the blackbody spectrum of the CMB.
- The search is not over, but it is more and more difficult because of the amount of precise observational data collected in the past decades.

Alternatives to Big Bang 2

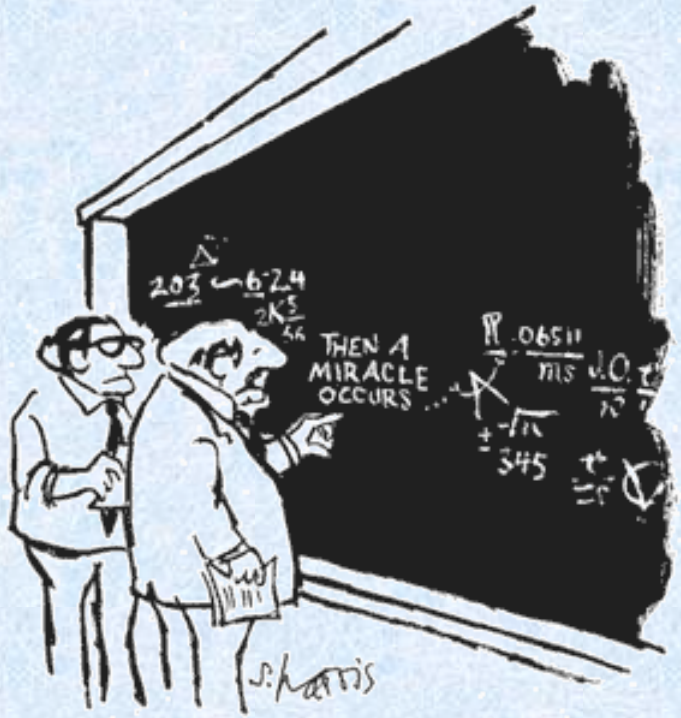
- In the Big Bang theory we suspend our judgement as to what happens before Planck time
- What is Planck time?
- Why do we suspend our judgement?
- However some human minds cannot but wonder what happened before Planck time, and whether there was really a singularity.
- Is this a legitimate scientific question?
- Yes, but we can only accept scientific answers, i.e. testable with experiments

Early attempts: The Oscillating Universe

- One theory that was once popular (formulated in the 1930s) is the so called oscillating universe
- In this theory a Big Bang is followed by a Big Crunch
- After the Big Crunch a Big Bang follows and so on…

Problems with the classic oscillating universe

- Nobody knows why and how the universe should "bounce" through the singularity.
- With the current value of cosmological parameters the universe will not recollapse and therefore there is no big crunch in our future!



"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

Additional problems with the classic oscillating universe

- A fundamental physical properties of complex systems is entropy
- Entropy measures the amount of order of a physical system
- Statistically entropy can only increase, e.g. when you put sugar in coffee

Additional problems with the classic oscillating universe

- Defining entropy correctly is a very subtle and difficult problem
- It is not settled how to define entropy for the universe at all times
- However, one of the qualitative arguments against oscillating universe is that entropy increases during the lifetime of the universe (due to processes like stellar evolution or you mixing your coffee with sugar) and if entropy carries over from one big bang to the next as increased energy in the CMB
- The ratio of total energy in radiation produced by stars as opposed to that in the CMB is a measure of how many previous cycles there have been.
- If you do the math it turns out that there cannot have been more than ~100 cycles before this one

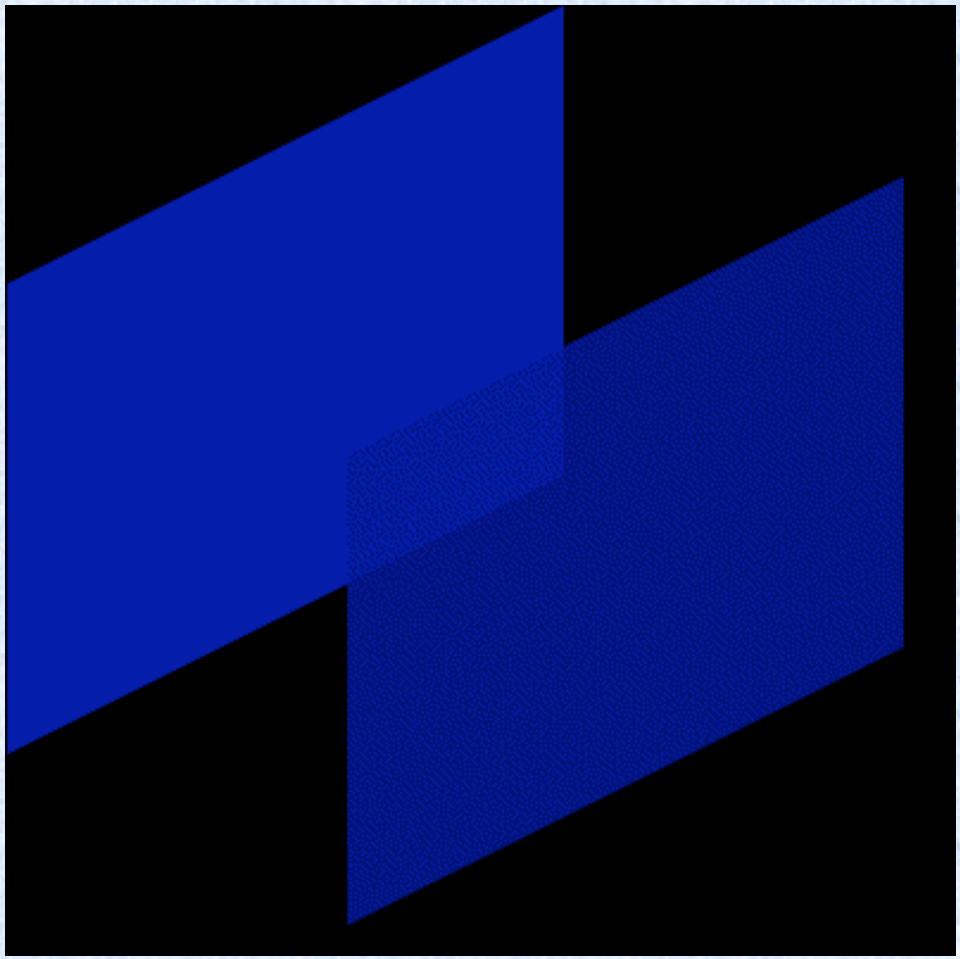
Problems with the classic oscillating universe model

- Fact: there won't be a big crunch in our future
- No testable prediction has been made as to the consequences of a previous cycle before our Big Bang, so this is not a scientific theory.

Contemporary attempts: The Cyclic/Ekpyrotic Universe

- A recent idea inspired by string theory is that there are more dimensions than 4, but we are restricted to live into a 4D subspace called a "membrane" or "brane"
- Membranes move expand and collide
- When two membranes collapse energy is dumped from the brane to the space inside the brane, causing a hot dense space like a Big Bang

Contemporary attempts: The Cyclic/Ekpyrotic Universe



See URL http://www.physics.princeton.edu/~steinh/npr/

Features of the Cyclic/Ekpyrotic Universe

- The cyclic ekpyrotic does not replace the main ideas of the Big Bang model
- The universe is expanding from a hot dense phase, so that the CMB, primordial nucleosynthesis etc are all ok
- The main difference is that the early stages are not described by inflation but this collision of branes
- The esthetic appeal is that it does not require a beginning of time and could be a comprehensive more fundamental theory

More Features of the Cyclic/Ekpyrotic Universe

- The cyclic/ekpyrotic scenario is very recent (2002) and it has not been fully calculated nor tested for internal consistency.
- At this stage it is more of a conjecture that a full self-consistent scientific theory
- The alternative – inflation - is much more well developed and understood at a fundamental level
- Time is needed to understand whether this is areal competitor for inflation
- There are however testable predictions regarding:
  - The statistical properties of the initial density perturbations
  - A specific distribution of energies for fossil gravitational waves
- One day it may be falsified and that's what matters

Alternatives to Big Bang 2. Summary

- Some of the alternatives to Big Bang seek a physical understanding of a universe without a beginning and end of time
- The classic oscillating universe is not a scientific theory because it does not make testable predictions. Furthermore no big crunch is expected in the future
- The current proposal of a cyclic/ekpyrotic universe is build to be consistent with the observed properties that are the foundations of the Big Bang theory but replaces inflation with a collision of branes in a higher dimensional universe
- It is not clear if this is a fully self consistent scientific theory. More time is needed to evaluate it
- Its proponents do claim however to make testable predictions and this is a key step.

The End

See you on Thursday!