10 Things Everyone Should Know About the Universe

Dragan Huterer

KICP, University of Chicago

1. What is Dark Matter?

DM is the unseen matter that forms “halos” of galaxies and clusters of galaxies. There is much more of DM than luminous matter.

1. What is Dark Matter?

DM is the unseen matter that forms “halos” of galaxies and clusters of galaxies. There is much more of DM than luminous matter.

- Fritz Zwicky suspected it in 1933, strong evidence in 1970 from work by Vera Rubin and others.
- DM clumps exactly like ordinary matter.
- We do not know exactly what particle(s) it’s made up of, but searches are in progress.
- Most of DM is non-baryonic – *not* protons, neutrons etc.

2. What is Dark Energy?

This is the “stuff” (it has energy) that makes expansion of the universe *accelerate*.

2. What is Dark Energy?

This is the “stuff” (it has energy) that makes expansion of the universe *accelerate*.

- DE is smooth (doesn’t cluster like matter) – otherwise we would’ve detected its clustering.
- It is repulsive (unlike matter) to make the universe accelerate.
- We have no idea what it really is. New laws of physics? Weird matter-type stuff? General Relativity modified?
- Efforts are underway to measure DE properties but it will be very hard.

3. When were the elements produced?

Light elements were produced when the universe was about a minute old in Big Bang Nucleosynthesis.

3. When were the elements produced?

Light elements were produced when the universe was about a minute old in Big Bang Nucleosynthesis.

- This means, Deuterium, Helium, and a bit of Lithium, Berilium...
- Other, heavier elements produced in stars.
- The very heaviest elements produced in Supernova explosions.

4. What is the Cosmic Microwave Backgrou

It is the leftover radiation from early universe (“from the Big Bang”).

4. What is the Cosmic Microwave Backgrou

It is the leftover radiation from early universe (“from the Big Bang”).

- CMB are photons with wavelength of roughly 1mm.
- They last scattered when the universe was about 380,000 years old (redshift=1000, roughly). They streamed freely after that.
- Anisotropies (non-uniformities) of one part in 100,000 in the CMB – they later grew and led to formation of objects in our universe.

5. What about CMB anisotropies?

Anisotropies (non-uniformities) of one part in 100,000 in the CMB are the seeds that later grew and led to formation of objects in our universe.

5. What about CMB anisotropies?

Anisotropies (non-uniformities) of one part in 100,000 in the CMB are the seeds that later grew and led to formation of objects in our universe.

- Discovered in 1992 by COBE satellite (Hawking: “the discovery of the century, if not all time").
- CMB anisotropies are a fantastic probe of the early universe and its physics. “Rosetta Stone of cosmology” (Turner & White).
- You can think of anisotropies as sound waves in the early universe. Their pattern has oscillatory behavior which was predicted in the 1970s-1990s and then confirmed (!) by experiments such as COBE, DASI, WMAP, ...
- CMB anisotropy is *polarized*: predicted in late 1960s, discovered by DASI in 2002.

6. What is inflation and why we think it happ

Inflation is a rapid phase of expansion (and acceleration) of the universe early on. It neatly solves several cosmological conundrums. Alan Guth (MIT) invented it in 1981.

6. What is inflation and why we think it happ

Inflation is a rapid phase of expansion (and acceleration) of the universe early on. It neatly solves several cosmological conundrums. Alan Guth (MIT) invented it in 1981.

- Inflation solves:
  - Horizon problem: why separate directions on the sky have the same CMB temperature.
  - Flatness problem: Why the universe is very nearly flat today; equations show that it is incredibly unlikely that it is close to flat.
  - Relic problem: where are the weird, exotic particles (i.e. monopoles) expected to be left over from early universe?
  - How did the structure form (remember the CMB anisotropies)?

Inflation (continued)

- Testing Inflation:
  - Nearly flat universe (check).
  - Nearly “scale-invariant” density perturbations (check).
  - B-modes of polarization expected (Holy Grail).

7. How do the structures in the universe form

Structure formation is complicated! But it is all just gravity at work.

7. How do the structures in the universe form

Structure formation is complicated! But it is all just gravity at work.

- Smallest structures form first (remember, galaxies observed at high redshift)
- Largest structures form last (remember, there are no clusters at high redshift).
- The pattern is best simulated through numerical (“N-body”) simulations.
- Typically, at late times (i.e. today) a web-like structure is observed in simulations and, of course, in the real universe too.

8. What about exotic things *not* found?

You shouldn’t worry about this too much but who can resist:

8. What about exotic things *not* found?

You shouldn't worry about this too much but who can resist:

- Failures of Einstein's GR: *not* found (so far).
- Failures of quantum mechanics: *not* found (so far).
- Exotic objects (magnetic monopoles, cosmic strings): *not* found (so far).
- Supersymmetry: *not* found so far (but will be searched for at CERN starting in 2007).

9. What happened in earliest moments after

Inflation, and before inflation – we don’t exactly know (yet).

9. What happened in earliest moments after

Inflation, and before inflation – we don't exactly know (yet).

- Before Big Bang – a few bold ideas (cyclic universe etc), although very speculative and *in no way* testable right now.
- From BB until the "Planck time" – need quantum gravity!
- From Planck time until inflation and beyond – lots of ideas from particle physics, some leads, currently tested in accelerators (CERN, Fermilab) and via cosmology.

10. What is the future of the universe?

We do not know – it depends on future behavior of dark energy!

10. What is the future of the universe?

We do not know – it depends on future behavior of dark energy!

- *If* DE continues to accelerate the expansion of the universe, then the universe will soon become DE dominated
- In that case, galaxies will start *leaving* our observable horizon and, after some tens of billions of years, there will be nothing to see outside of our galaxy cluster.