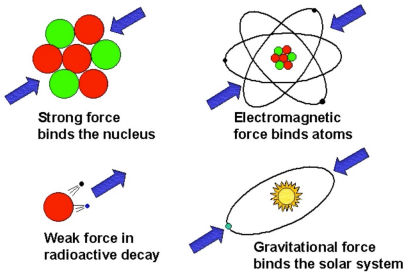
The Big Bang Theory

- The Big Bang theory is a detailed scientific model that describes conditions in the early universe and how they changed with time.
- The very early universe was so hot that energy could be transformed into matter and vice-versa.

4

Fundamental Forces

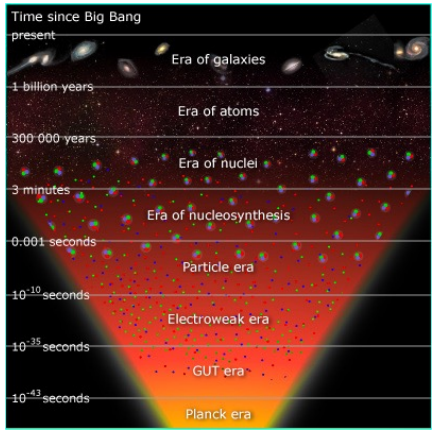
- Four forces of nature:
  - Gravity
  - Electromagnetism
  - Strong force
  - Weak force
- For a brief instant after the Big Bang, the four forces may not have been distinct.



5

Big Bang Theory

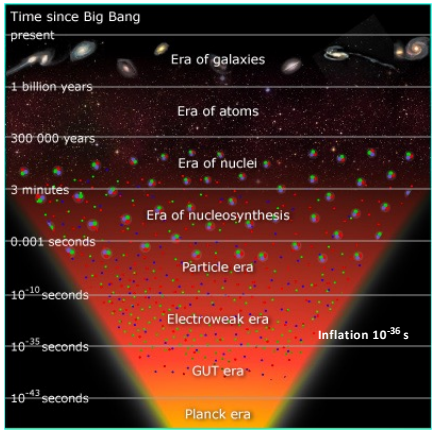
- First four eras were over in the first 0.001 seconds.
- Planck Era – the four forces may have been unified as one superforce.
- GUT (Grand Unified Theories) Era – gravity became distinct. The rest of the forces combined into GUT force.



6

Big Bang Theory

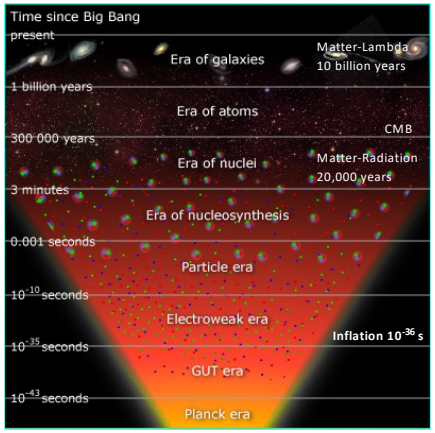
- End of GUT Era – GUT force split into strong force and electroweak force, resulting in inflation.
- End of Electroweak Era – four fundamental forces now distinct.
- Particle Era – spontaneous exchange of matter and energy continues.



7

Big Bang Theory

- Particle Era ended when temperature fell to 1 trillion Kelvin.
- Era of Nucleosynthesis – fusion of protons and neutrons, resulting in 75% hydrogen and 25% helium in the universe.
  Trace amounts of Deuterium and Lithium
- Era of Nuclei – hydrogen nuclei, helium nuclei, and electrons all moving independently.
  Photon-Baryon Fluid
  Ended after 380,000 years
  Era of Recombination (atoms)



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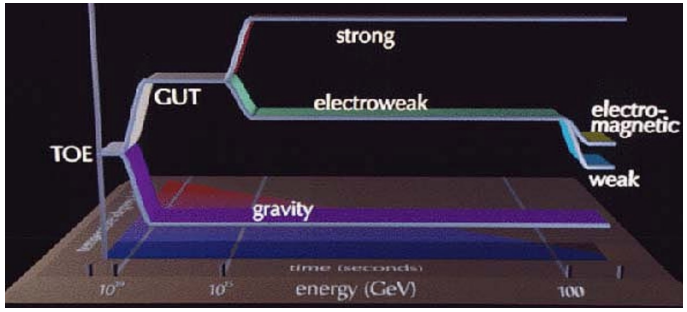
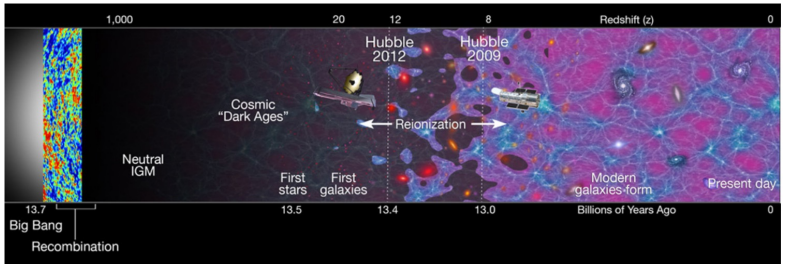


10

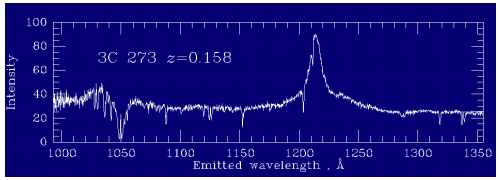
Reionization
z ~ 10-6 ?

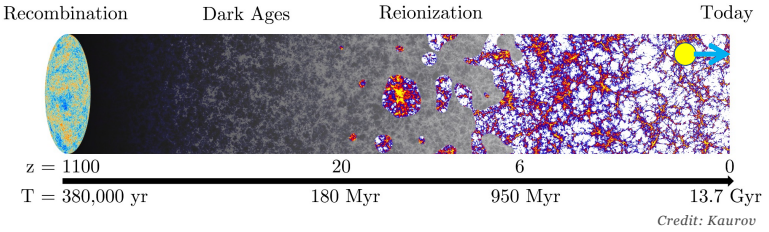


Reionization is Patchy: https://www.youtube.com/watch?v=kifF3RYcfn0

11

Low Z QSO





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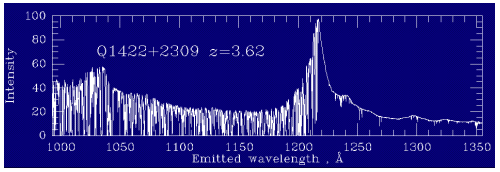
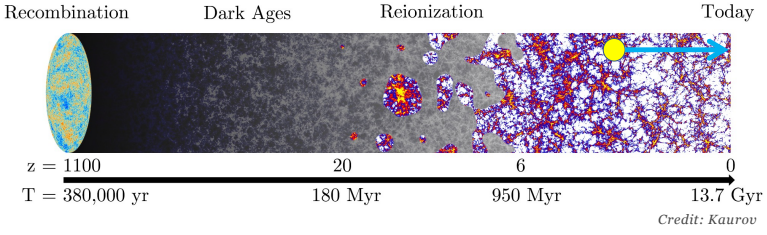
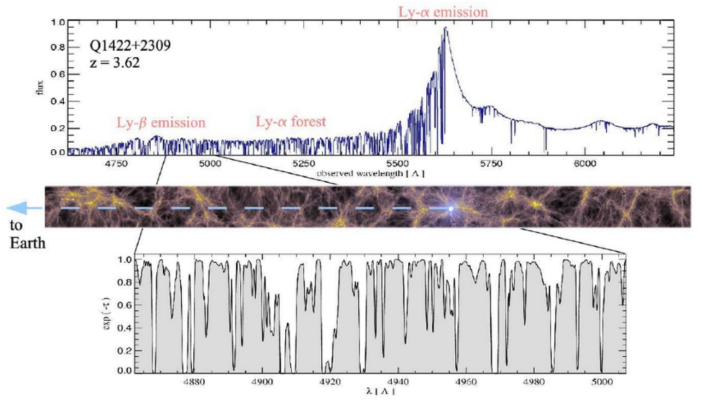
Mid Z QSO:
Lyman Alpha Forest





13

z=3.62 QSO spectrum, showing the Ly-alpha forest from intervening neutral H clouds:



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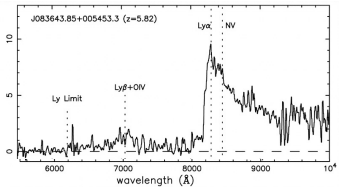
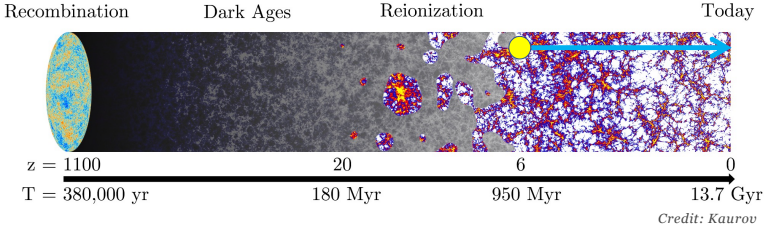
High Z QSO:
Gunn Peterson Trough



Fan+2002



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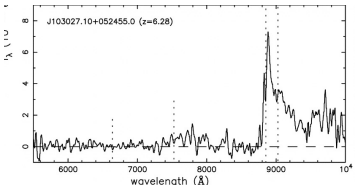
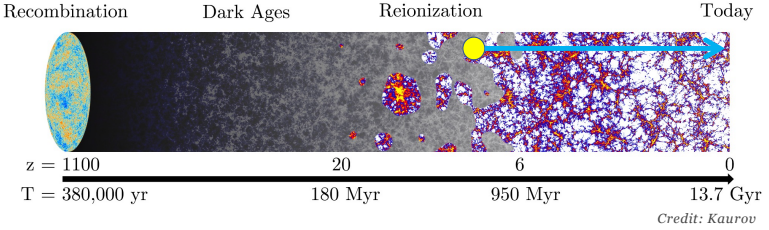
High Z QSO:
Gunn Peterson Trough
Shows up in QSOs around z~6 ....
Significant Hydrogen absorption.

Suggests we're reaching the end of the Epoch of reionization.



Fan+2002



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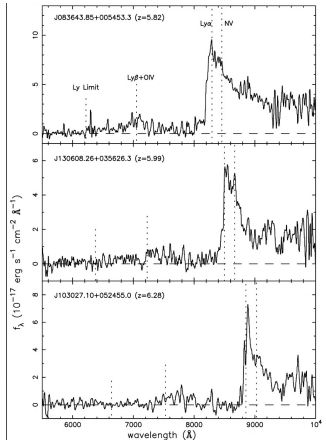
Gunn Peterson Trough



Fan+ 2002

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What were the sources of reionization?

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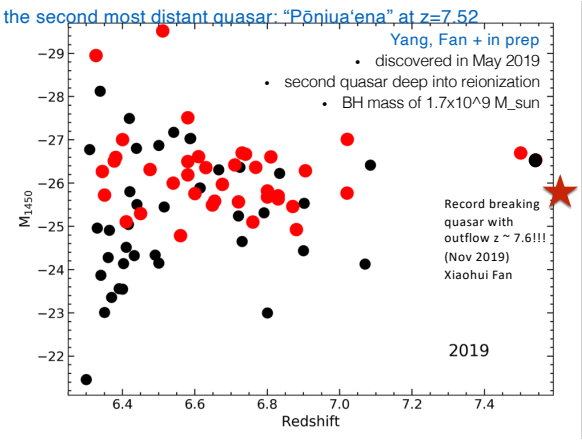
QSOs



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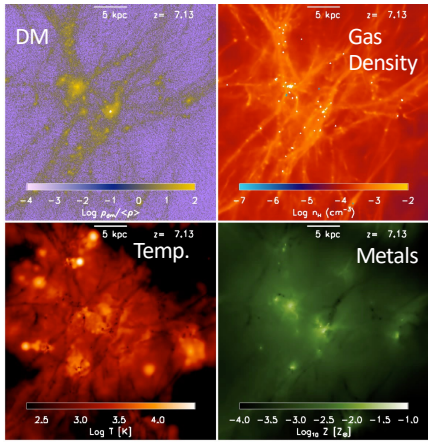
First Stars → Massive stars in low mass galaxies



Jeon, Besla+2017

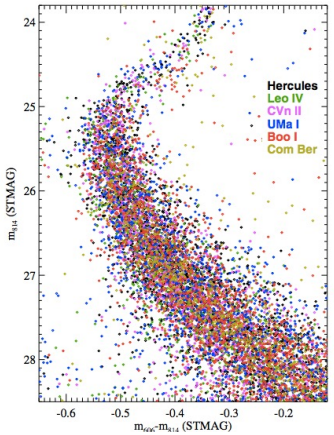
21

Brown +2014

CMD of each Ultra Fain Dwarf Galaxy (colored points) shifted to the distance and reddening of Hercules dwarf and zoomed into the CMD region most sensitive to age.

The similarities of the six CMDs imply that the UFD populations are extremely similar in age and metallicity.

A global event caused quenching



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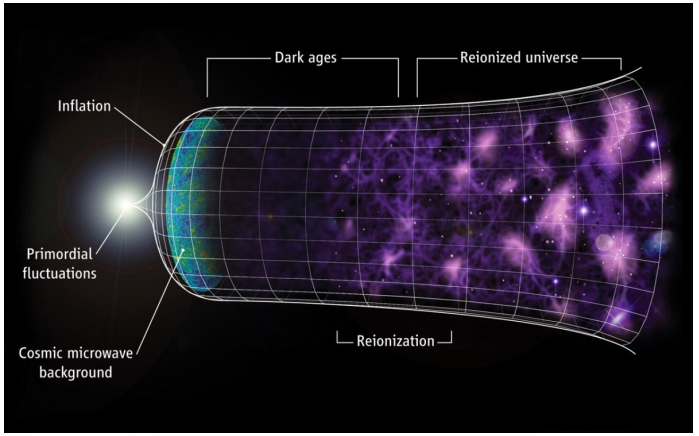

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