



When did the first stars form?

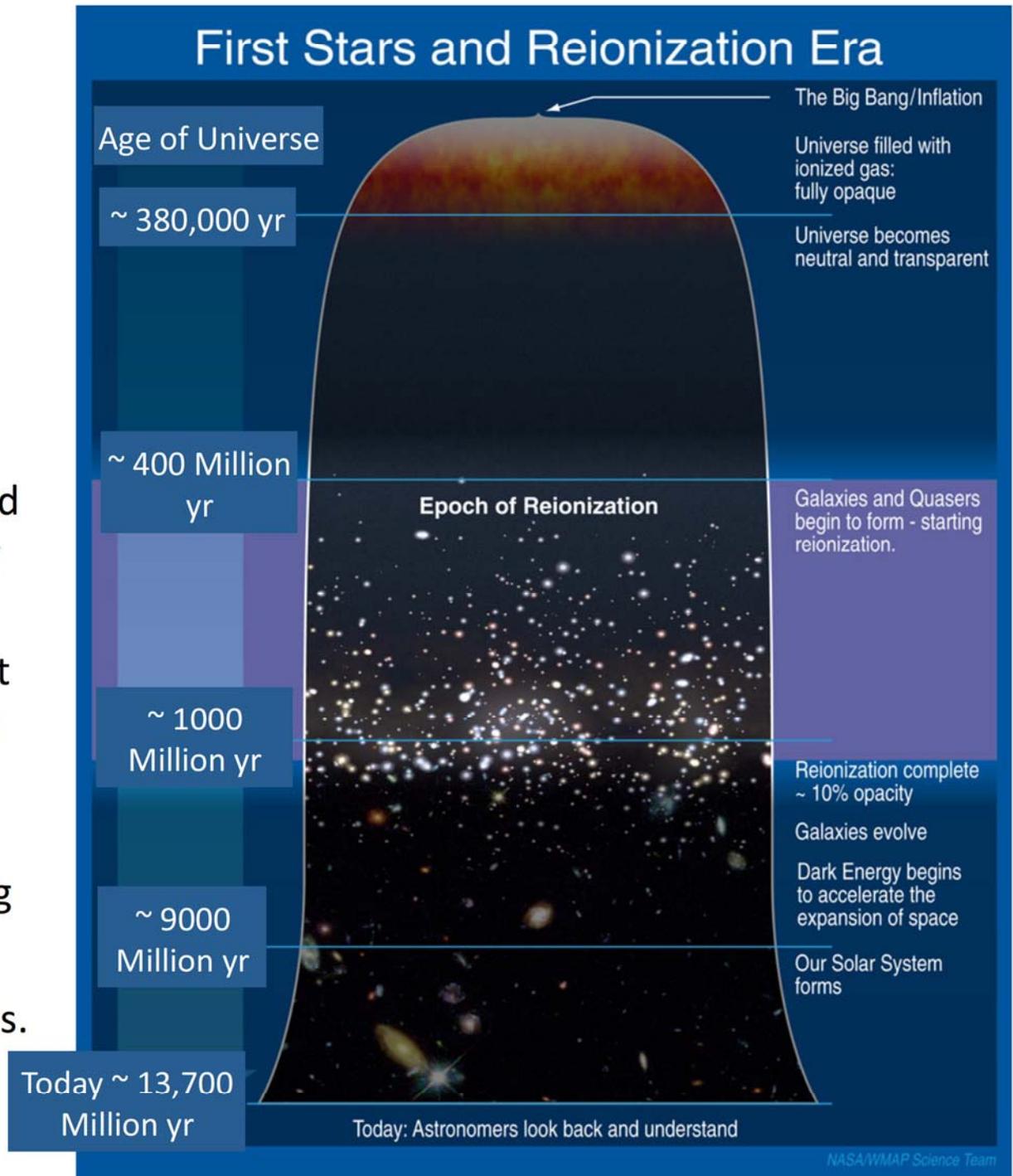
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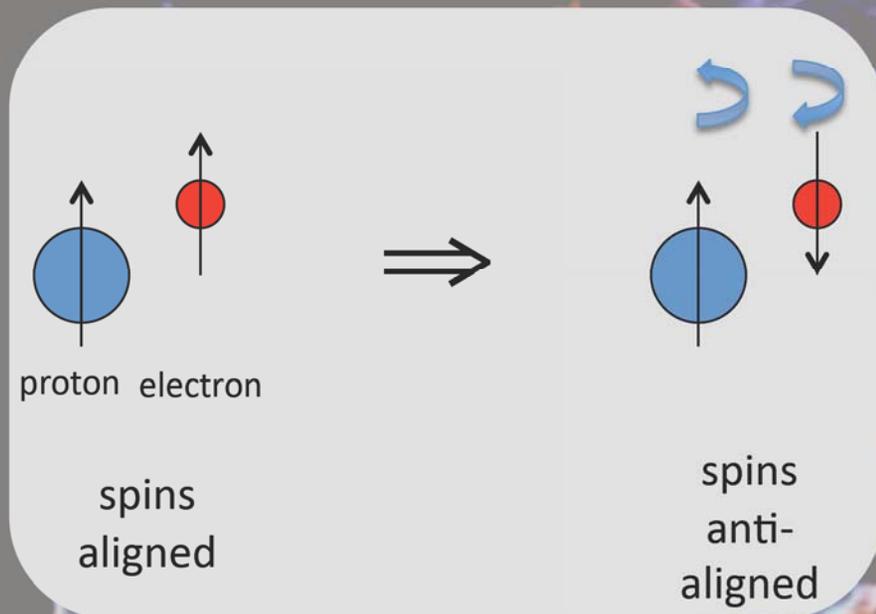
The First Stars and Galaxies

What we know (or think we know) from optical and mm-wave observations ...

- Many galaxies being detected by about 750 Million yr after Big Bang
- An exploding star seen about 600 Million yr after Big Bang
- Indirect measurement suggesting lots of stars by about 500 Million yr after Big Bang
- Stars form from hydrogen gas.



Hydrogen Atom



Change to/from aligned to anti-aligned state produces radio radiation

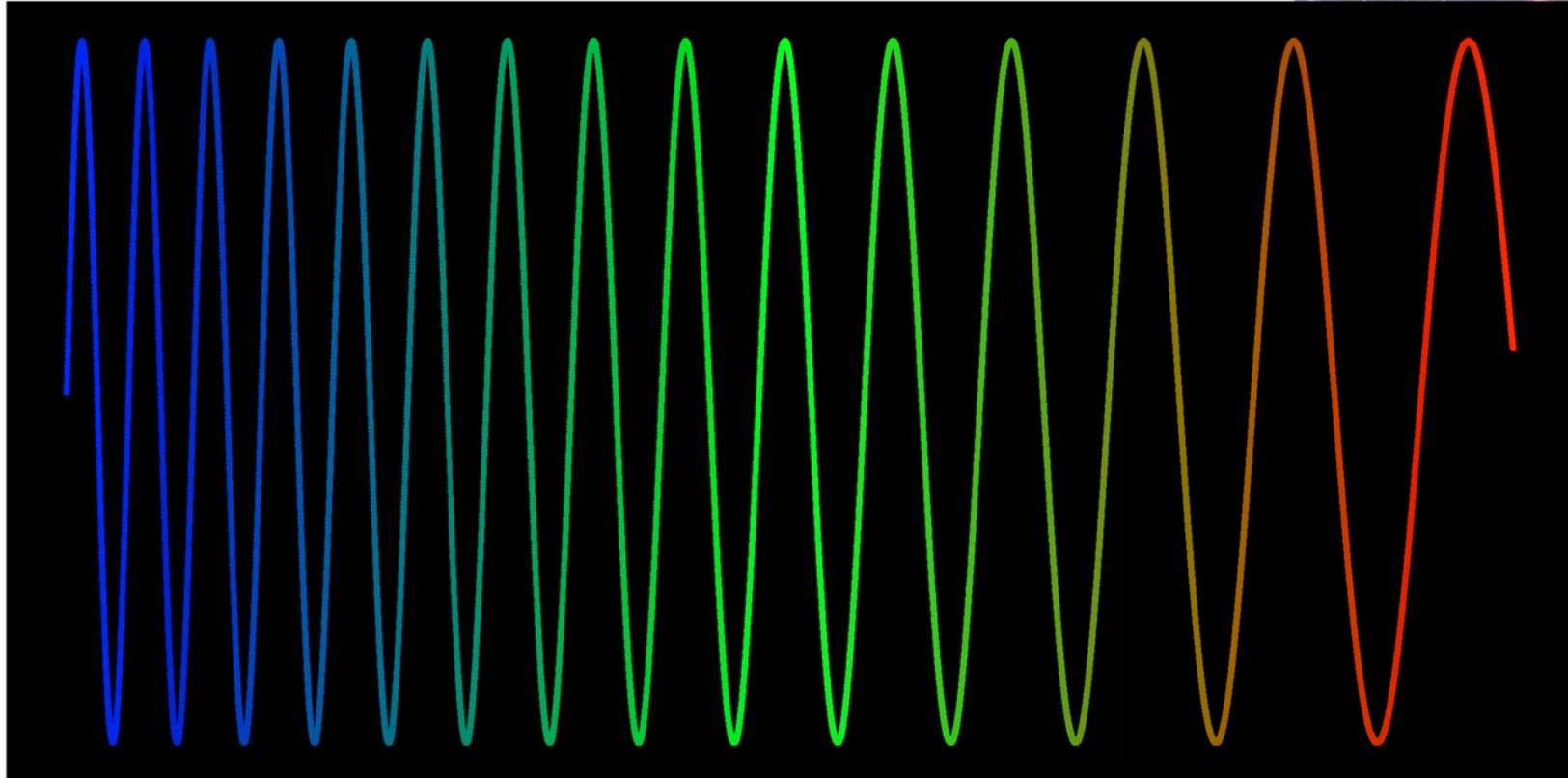
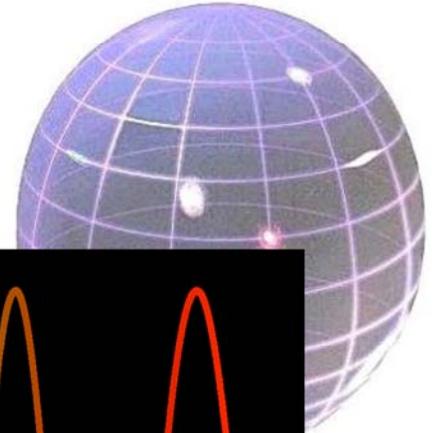
$$\nu = 1420.405752 \text{ MHz}$$

$$\lambda = 21 \text{ cm}$$

	MOBILE **	FIXED	1395
	LAND MOBILE		1400
RADIO ASTRONOMY	EARTH EXPL SAT (Passive)	SPACE RESEARCH (Passive)	1427
	LAND MOBILE	Fixed (TLM)	1429.5
	LAND MOBILE (TLM)	FIXED (TLM)	1430

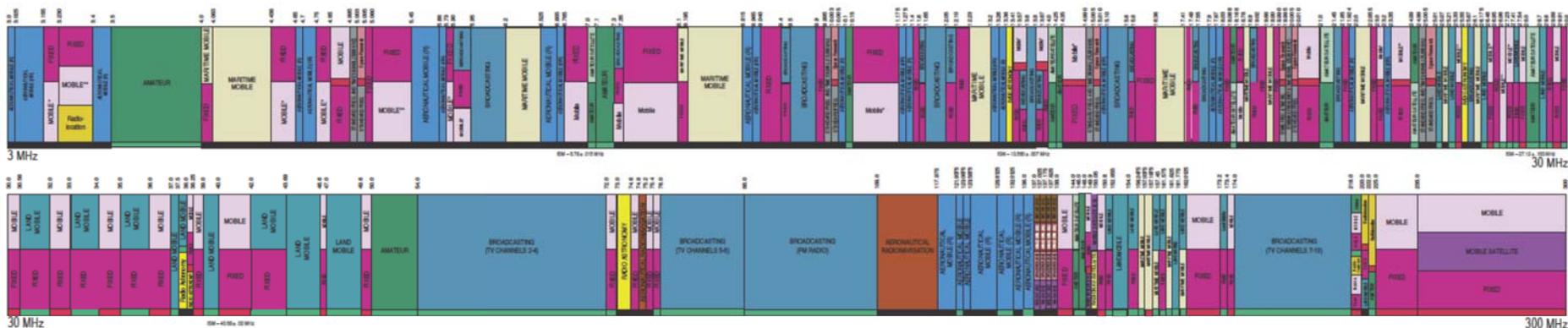


Universal Expansion and Redshift



- Universe is expanding ...
i.e., distances between galaxies increases with time.
- Wavelength of radiation increases as radiation travels through expanding Universe.

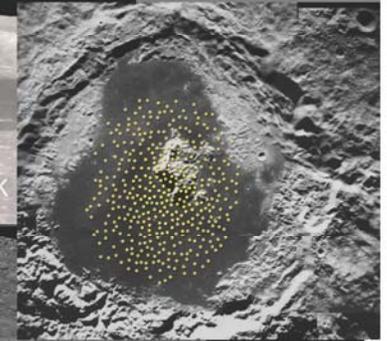
Radio Astronomy Service and Cosmology



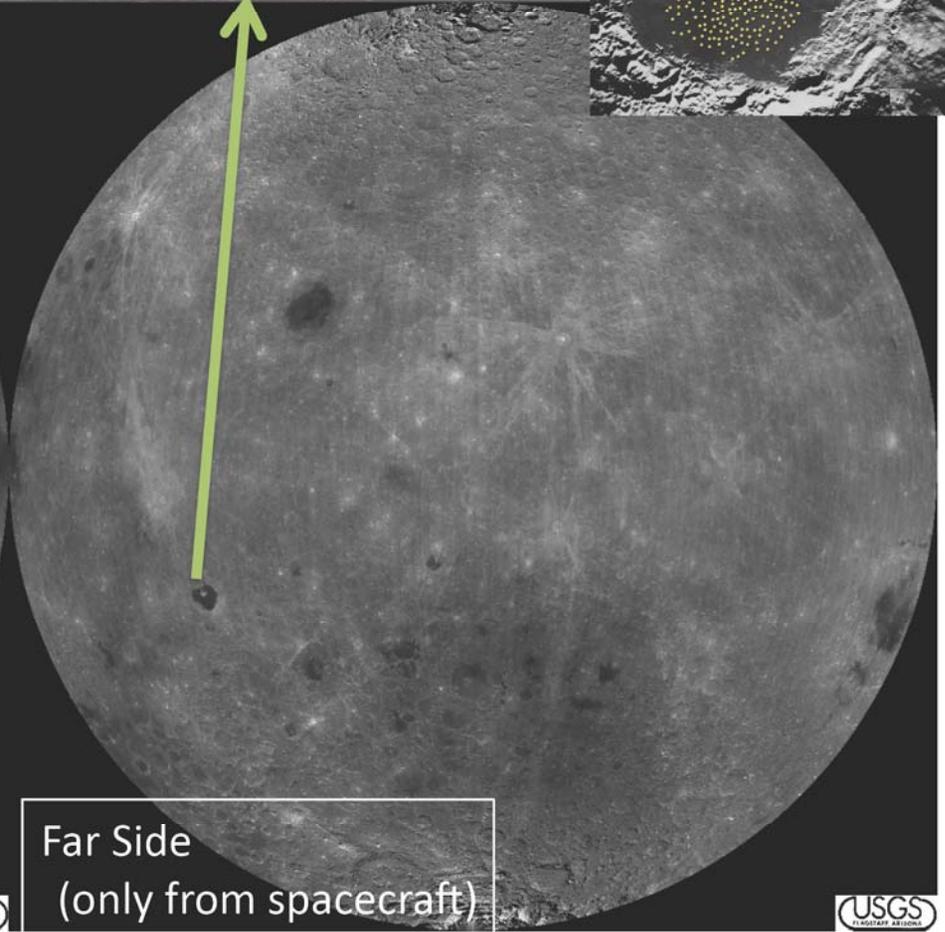
Radio astronomy service allocations at

- 73 MHz–74.6 MHz = about 200 Million yr after Big Bang ($z \sim 18$)
- 37.5 MHz–38.25 MHz = about 75 Million yr after Big Bang ($z \sim 35$)
- 25.55 MHz–25.67 MHz = about 40 Million yr after Big Bang ($z \sim 55$)
- [First stars predicted to start forming about 20 Million yr after Big Bang ($z \sim 60$).]
- 13.36 MHz–13.41 MHz = about 15 Million yr after Big Bang ($z \sim 105$)
[Observing the Universe **before** the first stars!]

Radio Telescope in Shielded Zone of the Moon ITU-R RA.479



Near Side
(what we see)



Far Side
(only from spacecraft)



Cosmic Dawn and the Radio Spectrum

Understanding the formation of the first stars, first accreting black holes, and first galaxies requires

- Microwave, infrared, and X-ray telescopes in space, with communication to them;
 - **E-S**: 2110–2120 MHz, 7145–7190 MHz, 34.2–34.7 GHz
 - **S-E**: 2290–2300 MHz, 8400–8450 MHz, 31.8–32.3 GHz
- Telescopes on the ground operating in the HF and VHF radio bands (**50–250 MHz**); and
- Radio telescope in the Shielded Zone of the Moon (far side, **10–250 MHz**) eventually.

