SPECTRAL SIGNATURES OF COSMIC BARYON EVOLUTION

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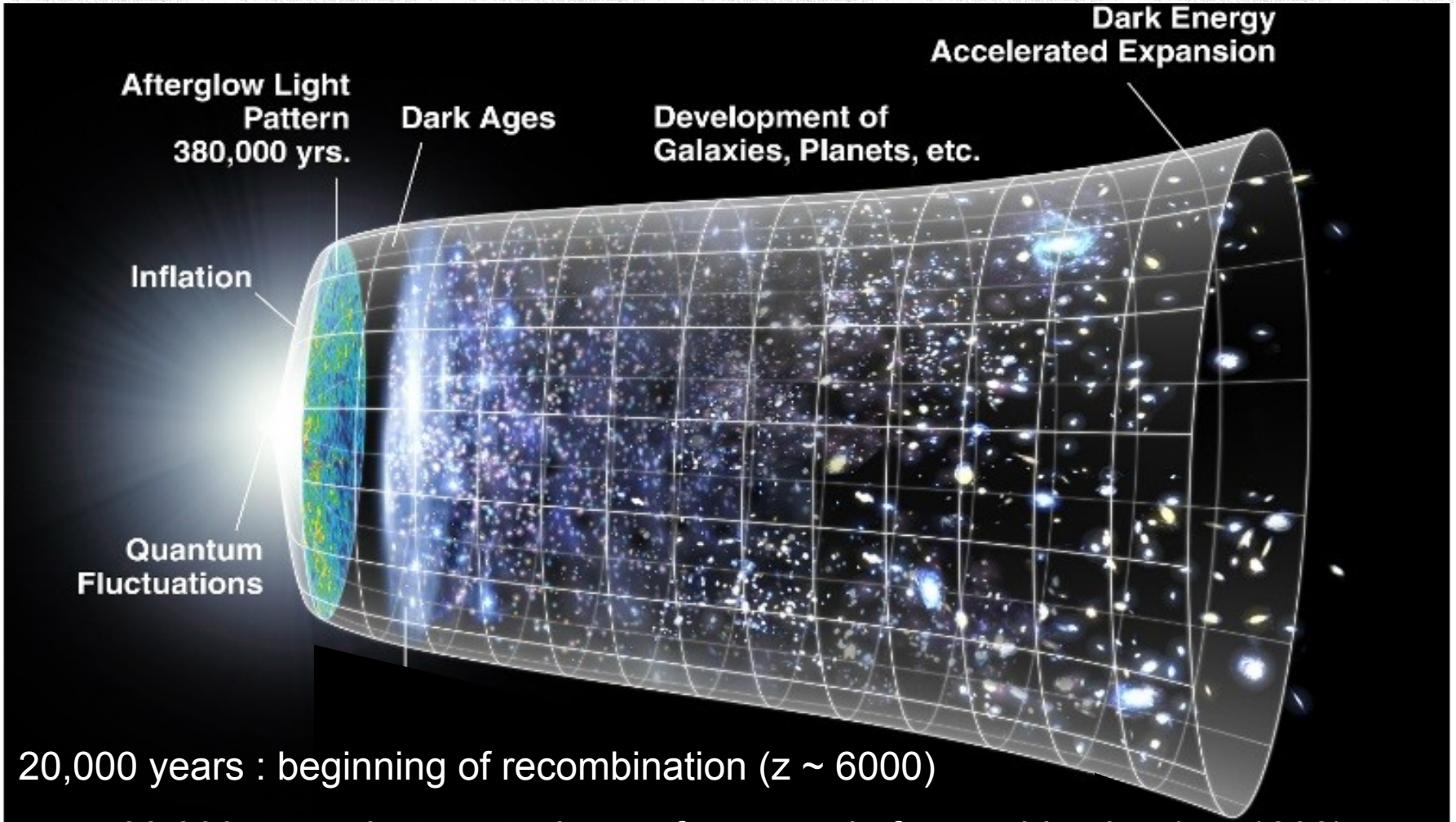


20,000 years : beginning of recombination (z ~ 6000)

400,000 years: last scattering surface ~ end of recombination (z ~ 1000)

10 million years: thermal decoupling of baryons (z ~ 150)

100 million years: first stars (z ~ 30)

300-900 million years: reionization (z ~ 15-6)

H + He lines in the radio background from z = 6 to 6000

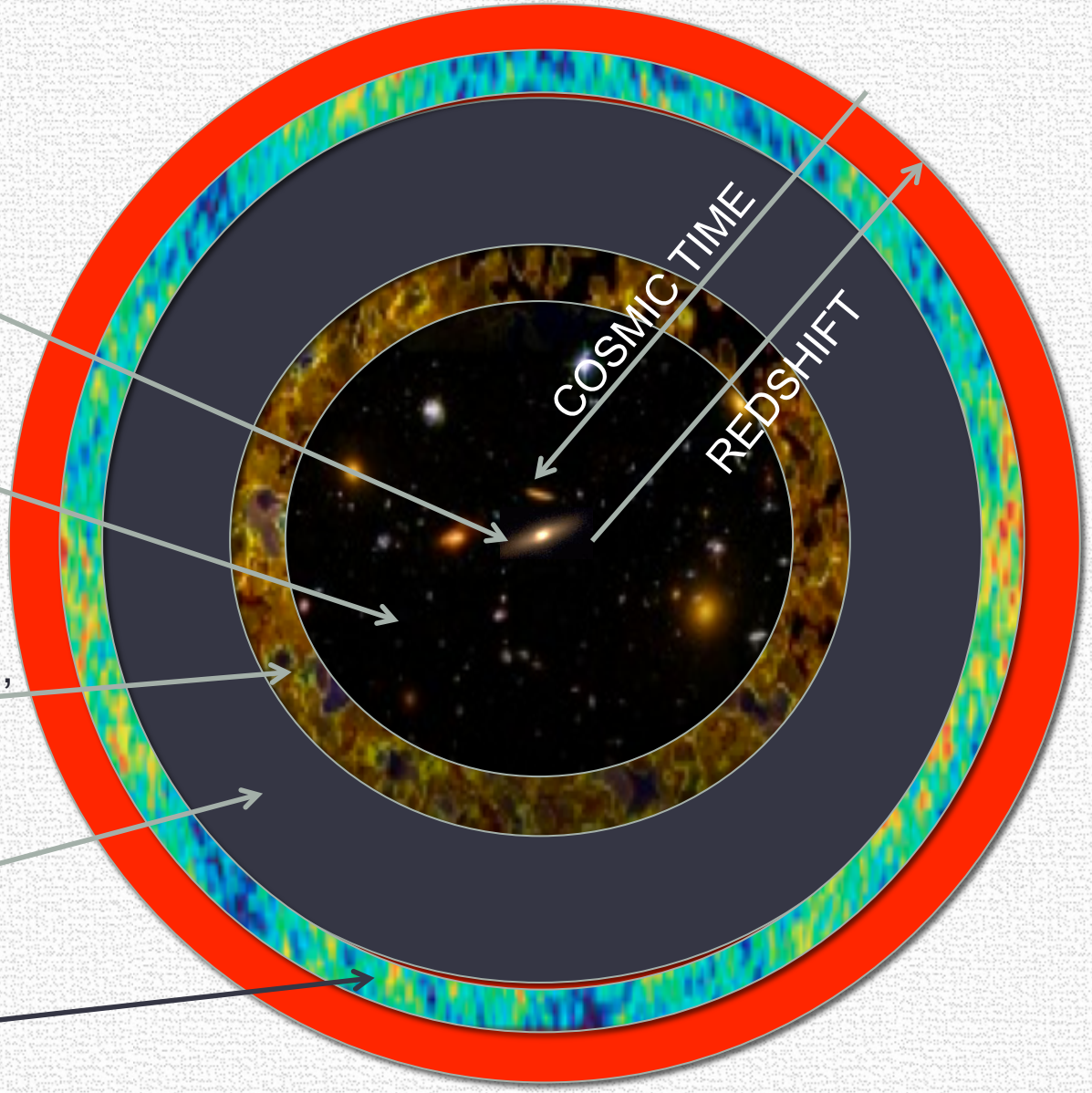
Galactic foreground:
Synchrotron, thermal
(z ~ 0)

Discrete radio sources:
AGNs, Star-forming gal.,
normal gal.
(z ~ 0-10)

21-cm from the cosmic dawn,
reionization
(z ~ 6-30)

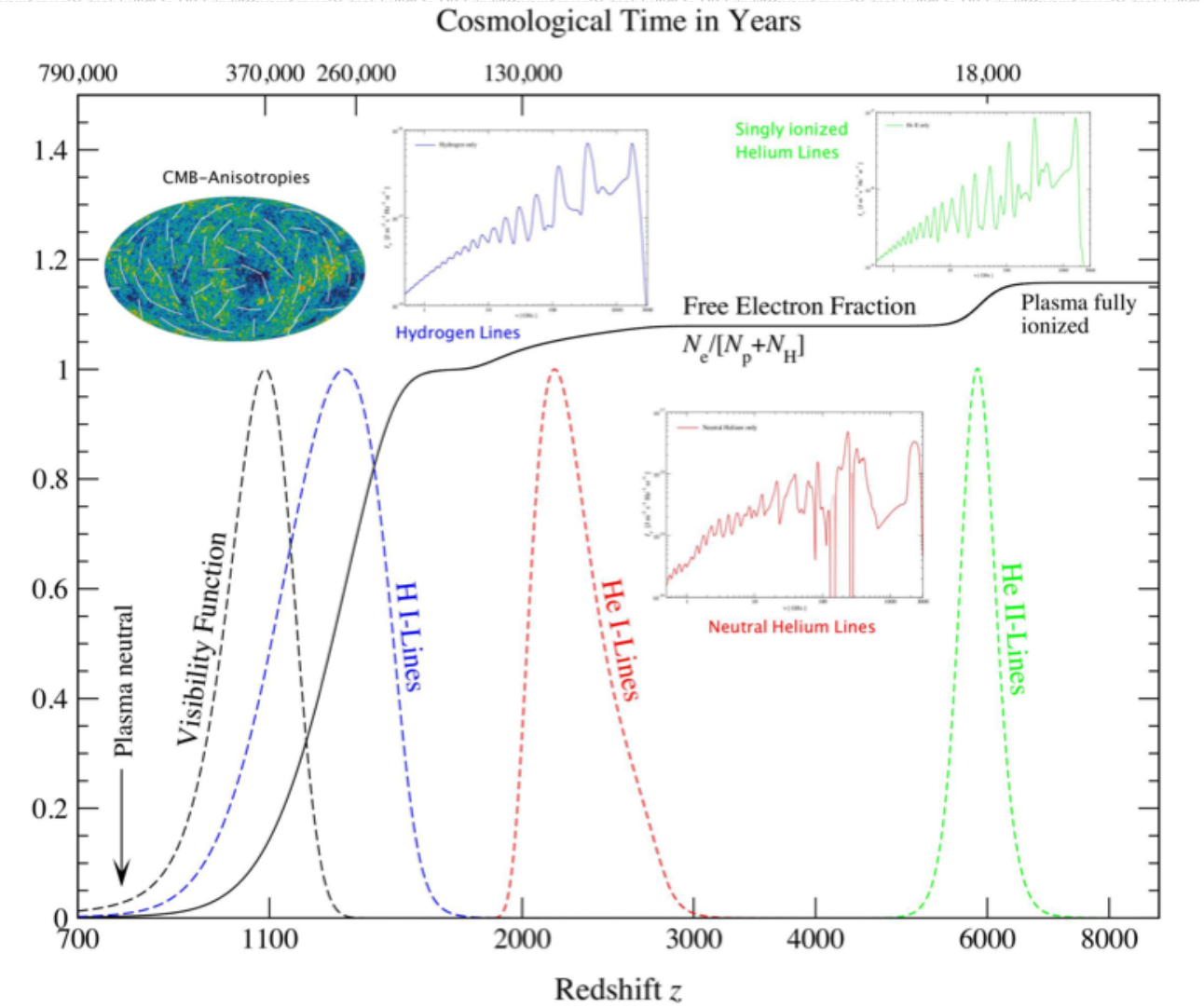
21-cm from the dark ages
(z ~ 30-150)

H & He Recombination
(z ~ 1000 to 6000)



Cosmological Recombination at $z \sim 6000$-1000

TIME



REDSHIFT

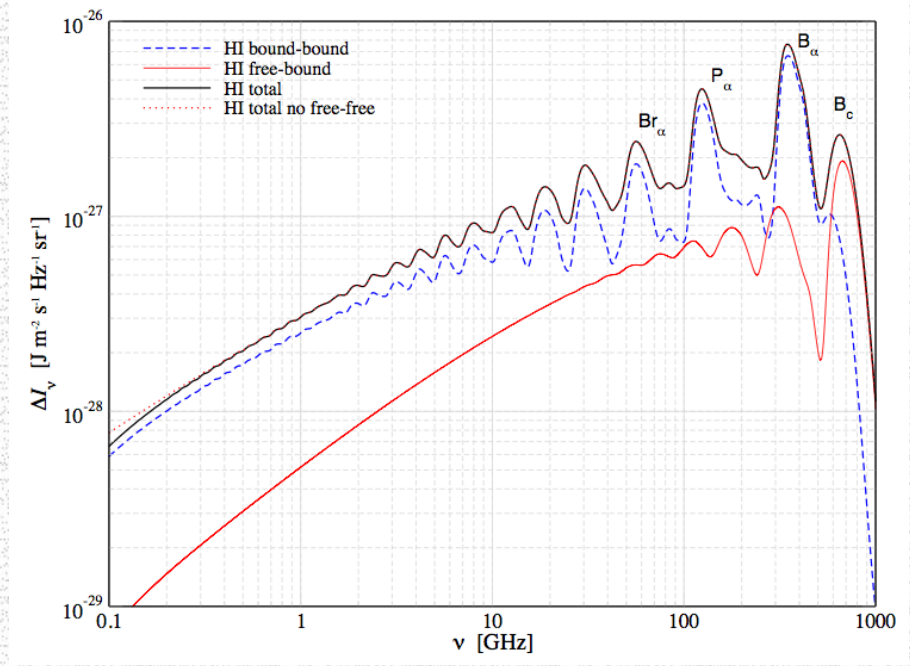
He II lines are a view of the universe at 1/20 of the time till the last scattering surface!

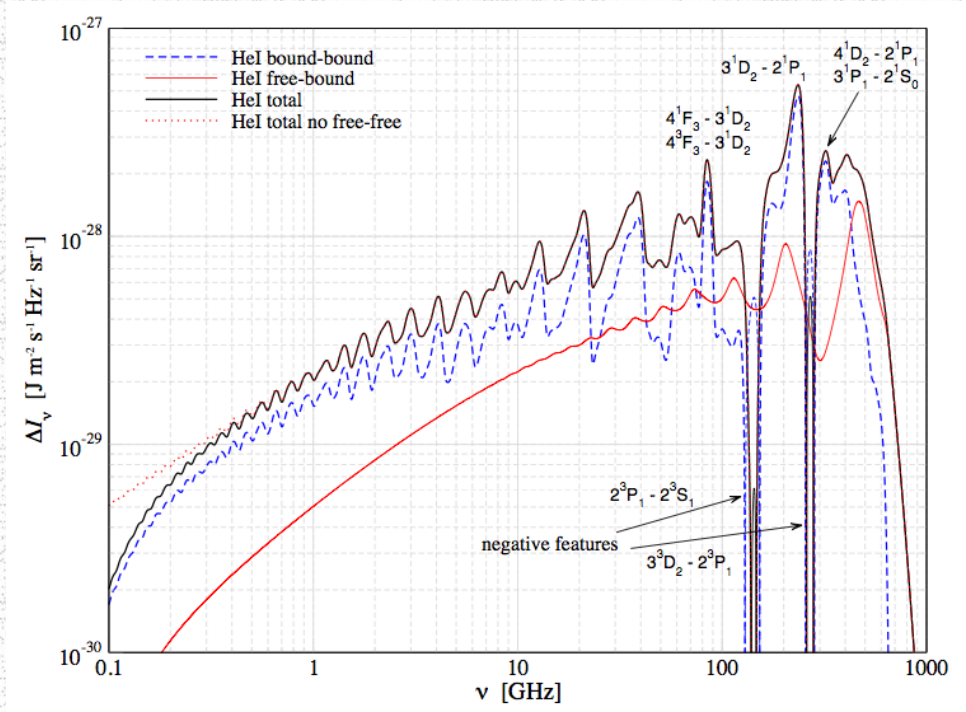
At z = 6000
t = 20,000 yr

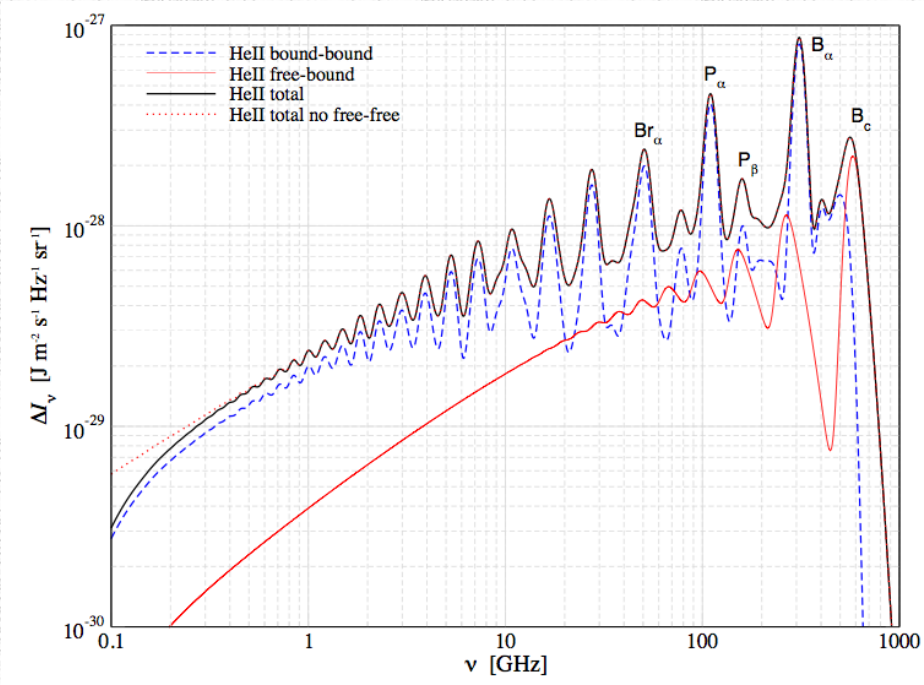
[Sunyaev & Chluba 2009]

H + He recombination distortions in CMB

Including 500 shell H + He bound-bound, free-bound. Also free-free absorption and electron scattering.
[Chluba & Haimoud 2015]





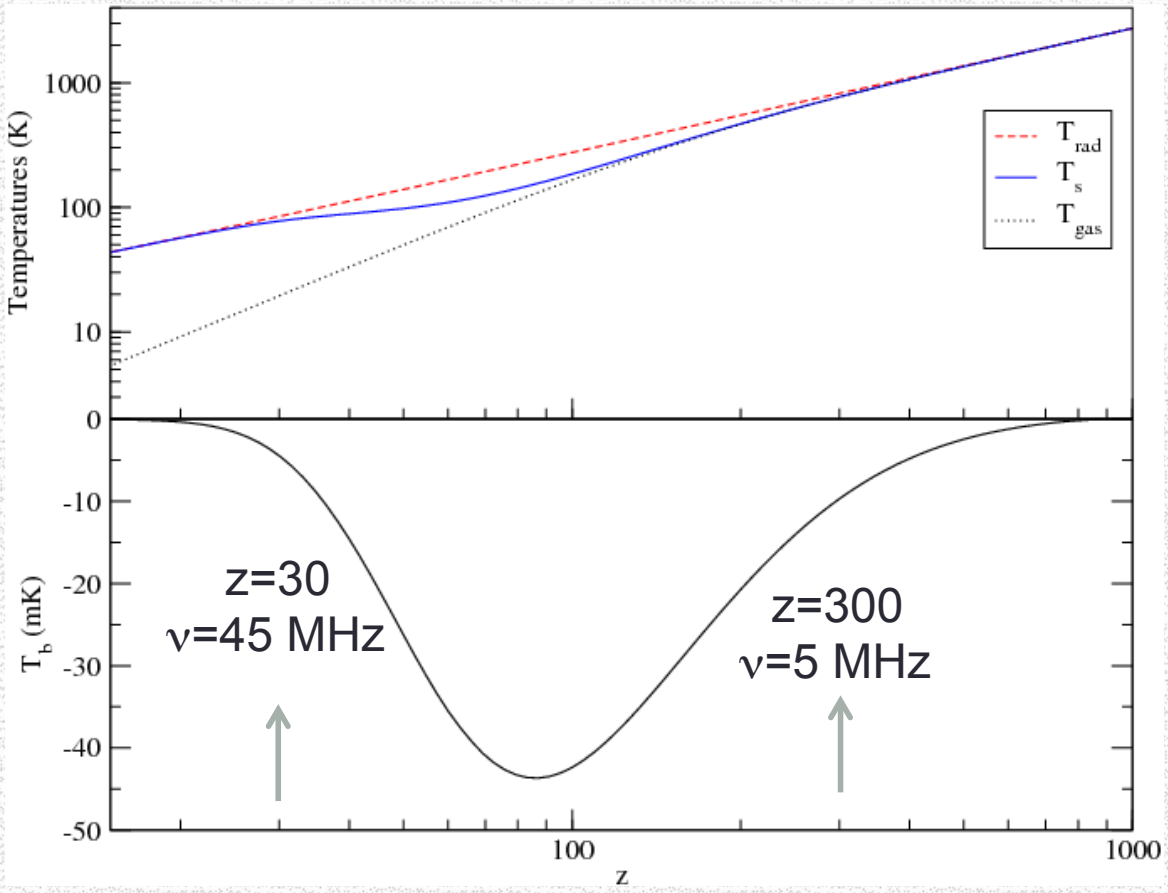


Spectral features post recombination (Dark ages)

Post-recombination and prior to reionization
z > 30 absorption feature

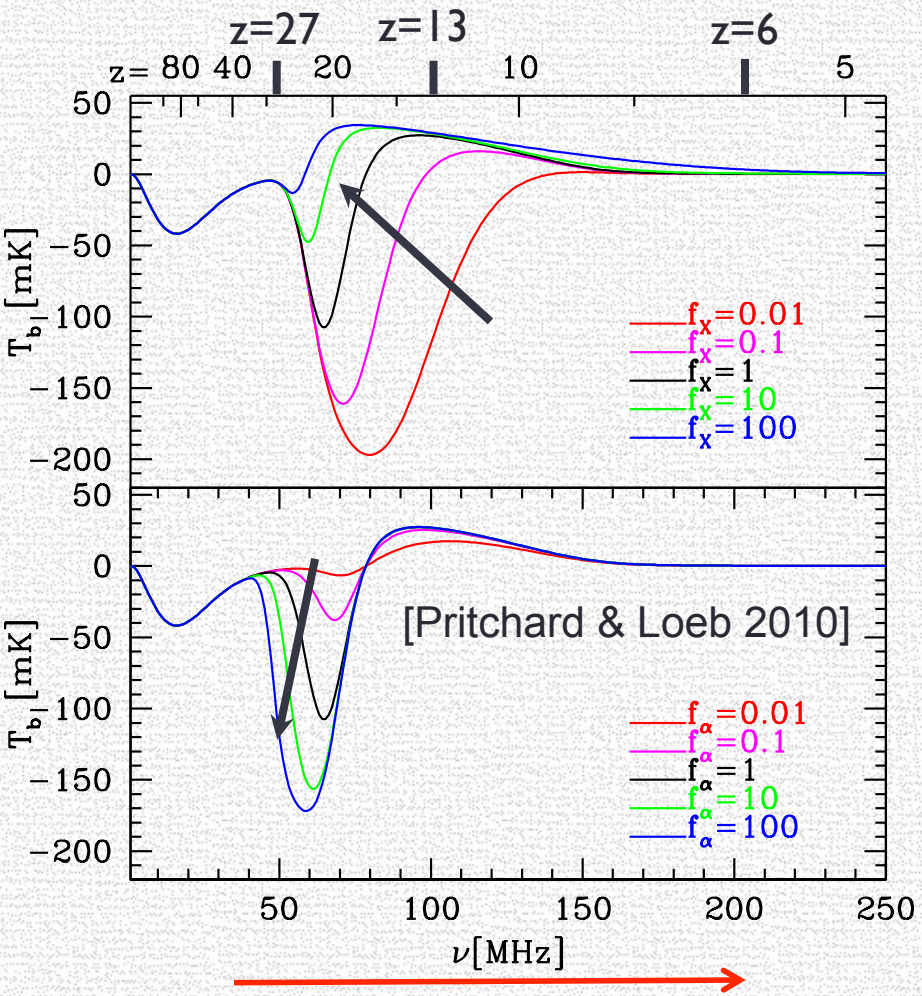
This gives an absorption feature between 5–45 MHz.

The absorption profile is well defined by the cosmology, cosmological parameters, matter density perturbation spectrum.



TIME

H 21-cm CMB distortions post recombination & pre reionization



First stars/galaxies – Lyman α – coupling of HI spin temperature to the low kinetic temperature.

UV + X-ray + Structure Formation heating followed by ionization

- Timings
- X-ray and UV spectra
- X-ray and Lyman-α luminosities fx & fα
- Their abundance and distribution

Non-standard models:

- DM decay
- Primordial magnetic fields

Spectral features from cosmological reionization

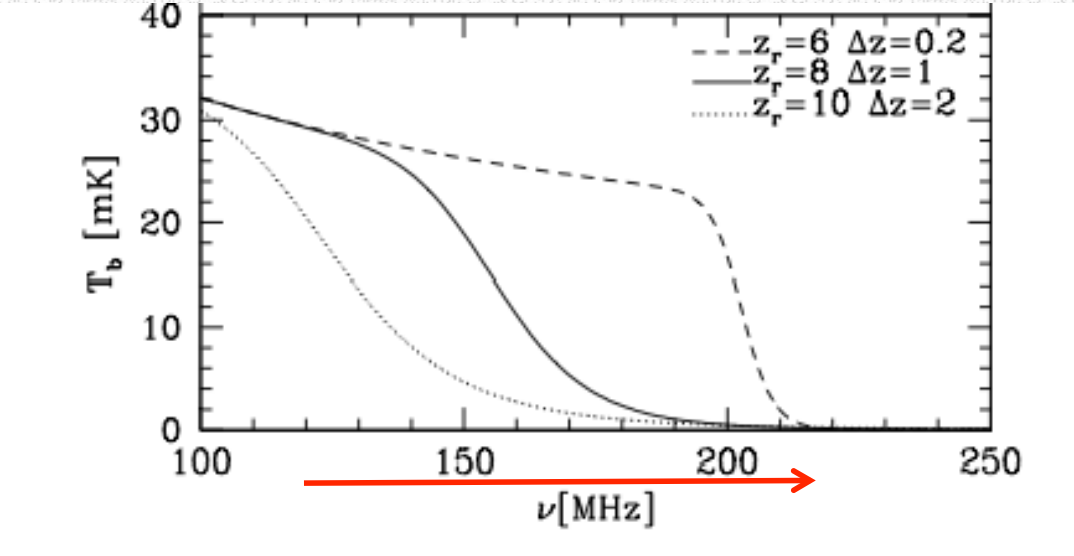
Reheating of the neutral gas by sources in the reionization epoch

$$T_b = 25 x_{HI} \left(\frac{1+z}{10}\right)^{1/2} \left(1 - \frac{T_{CMB}}{T_S}\right) \text{mK}$$

25 mK reionization step

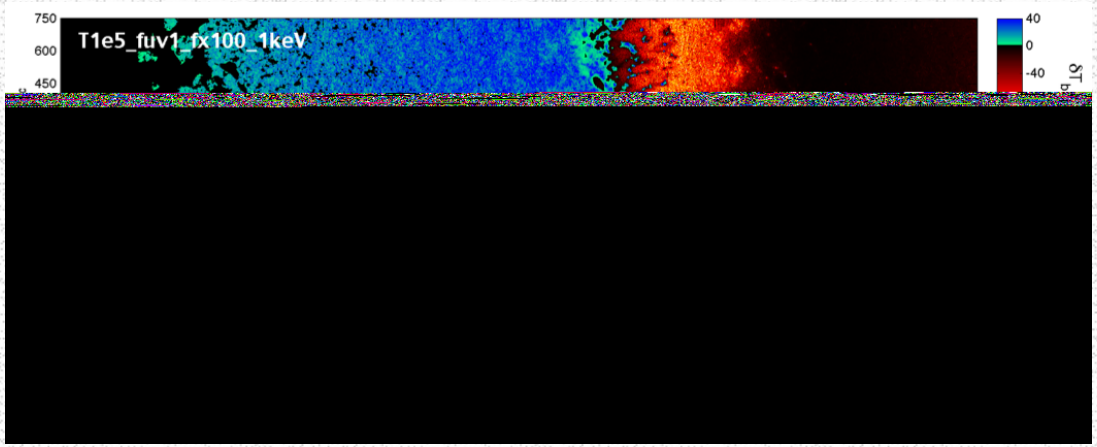
Followed by ionization of the gas

The shape of the 'step' depends in detail on the time evolution in the global ionization fraction

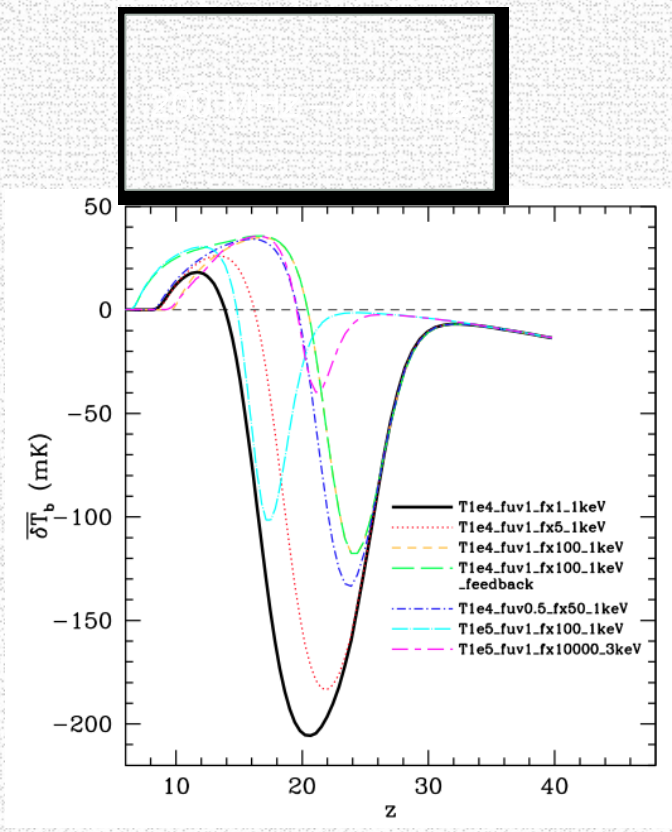


[Bowman Rogers & Hewitt 2008]

Different histories lead to different spectral signatures in long wavelength images and spectra of the Cosmic Radio Background



TIME



TIME

[Mesinger et al. 2012]

SKA-low stations: outriggers for EoR global signal

[RS ++ 2015
SKA Science case
PoS (AASKA14)014]

- Interferometer calibration for band pass and beam shape.
- Interferometer continuum images provide a foreground model to solve for mode-coupling of continuum structure into spectral structure.

ACFs/outriggers provide zero-baseline measurement for EoR

And low spatial frequencies for imaging

Observational constraints on cosmic baryon evolution

- CMB: recombination last-scattering surface redshift z = 1090
- PAPER-64 limits on 21-cm power at z=8.4: Gas kinetic temperature at z=8.4 exceeds 10 K (for neutral fraction between 30% and 70%) [Pober et al. 2015]
- Planck TT, TE & EE: (instantaneous) reionization z = 8.8 [Ade et al. 2015]. Perhaps lower?
- EDGES: Reionization is less quickly than $\Delta z = 0.06$ [Bowman & Rogers 2010]
- SPT-SZE survey upper limits on secondary anisotropy at large multipoles: reionization $\Delta z < 5.4$ [George et al. 2014]
- SDSS QSO spectra – rapid rise in flux decrement beyond z=5.5: end of reionization is at about z=6.