Australian National University

APSERa

On the detection of spectral ripples from the Epoch of Recombination

Mayuri Sathyanarayana Rao

CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

Raman Research Institute
Bangalore

Advisory Panel

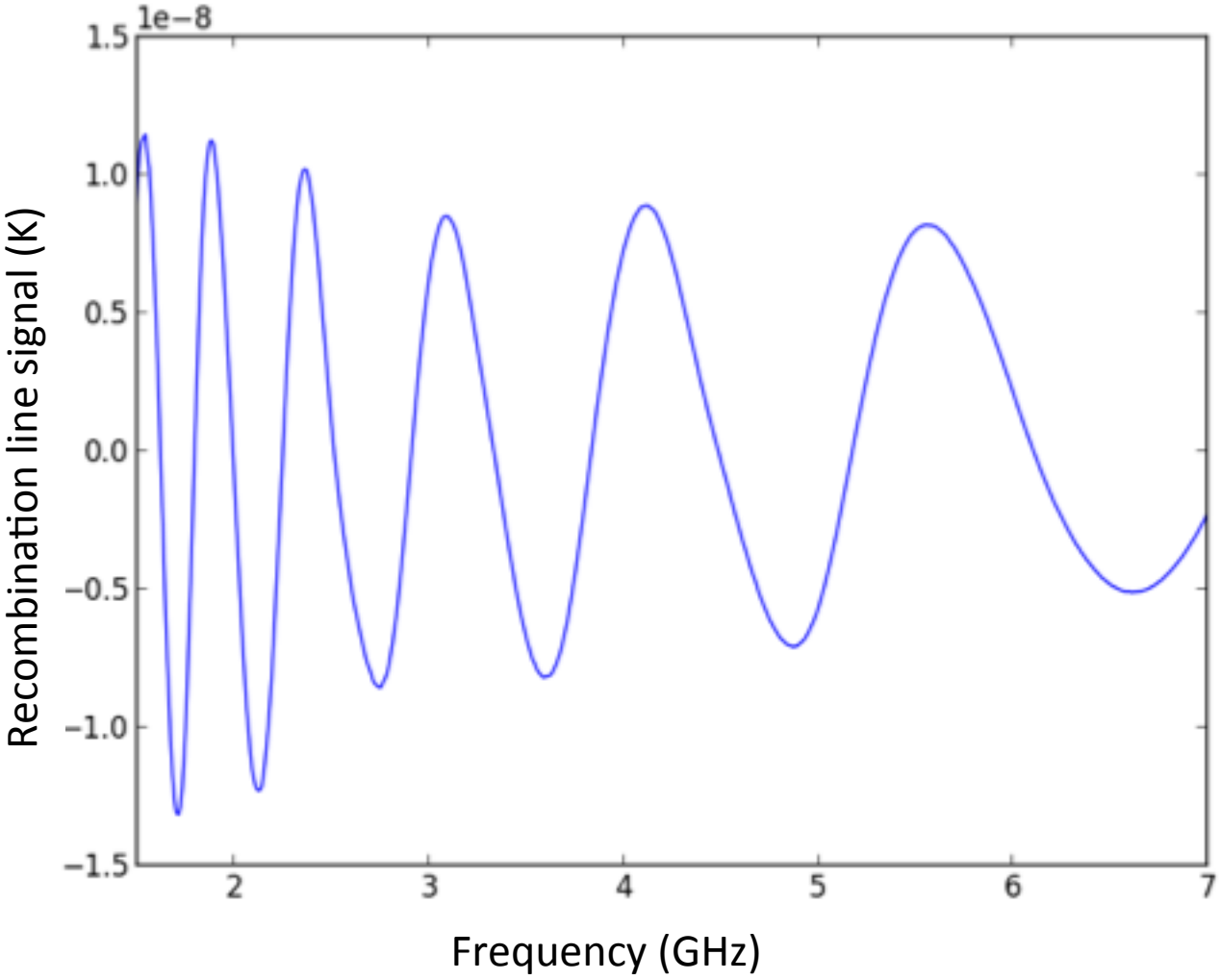
- Chair — Frank Briggs RSAA, ANU
- Supervisor — Ravi Subrahmanyan RRI, India
- Advisor — Brian Schmidt RSAA, ANU
- Advisor — Charley Lineweaver RSAA, ANU

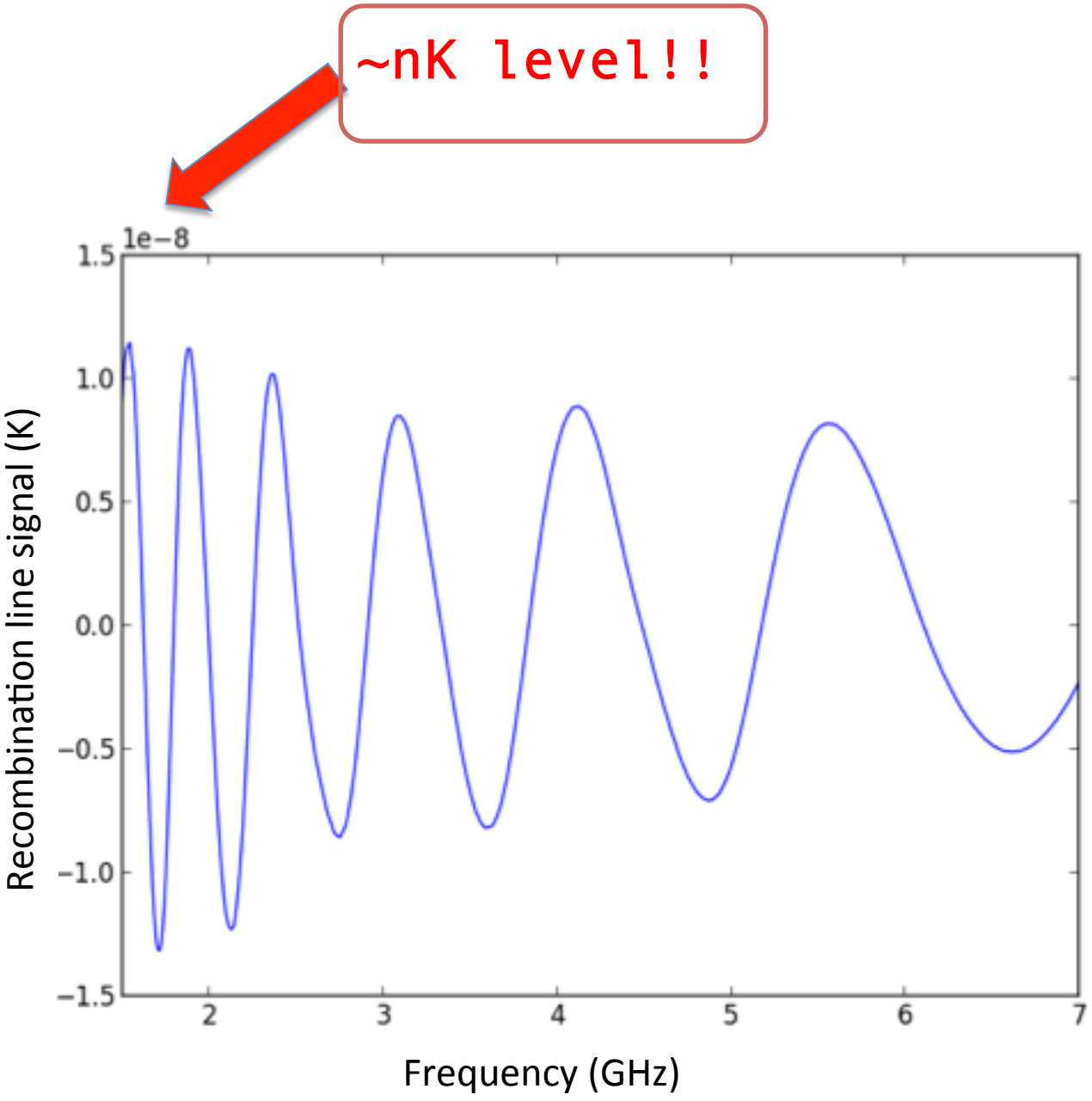
COLLABORATOR — Jens Chluba JHU, USA

Plan of the talk

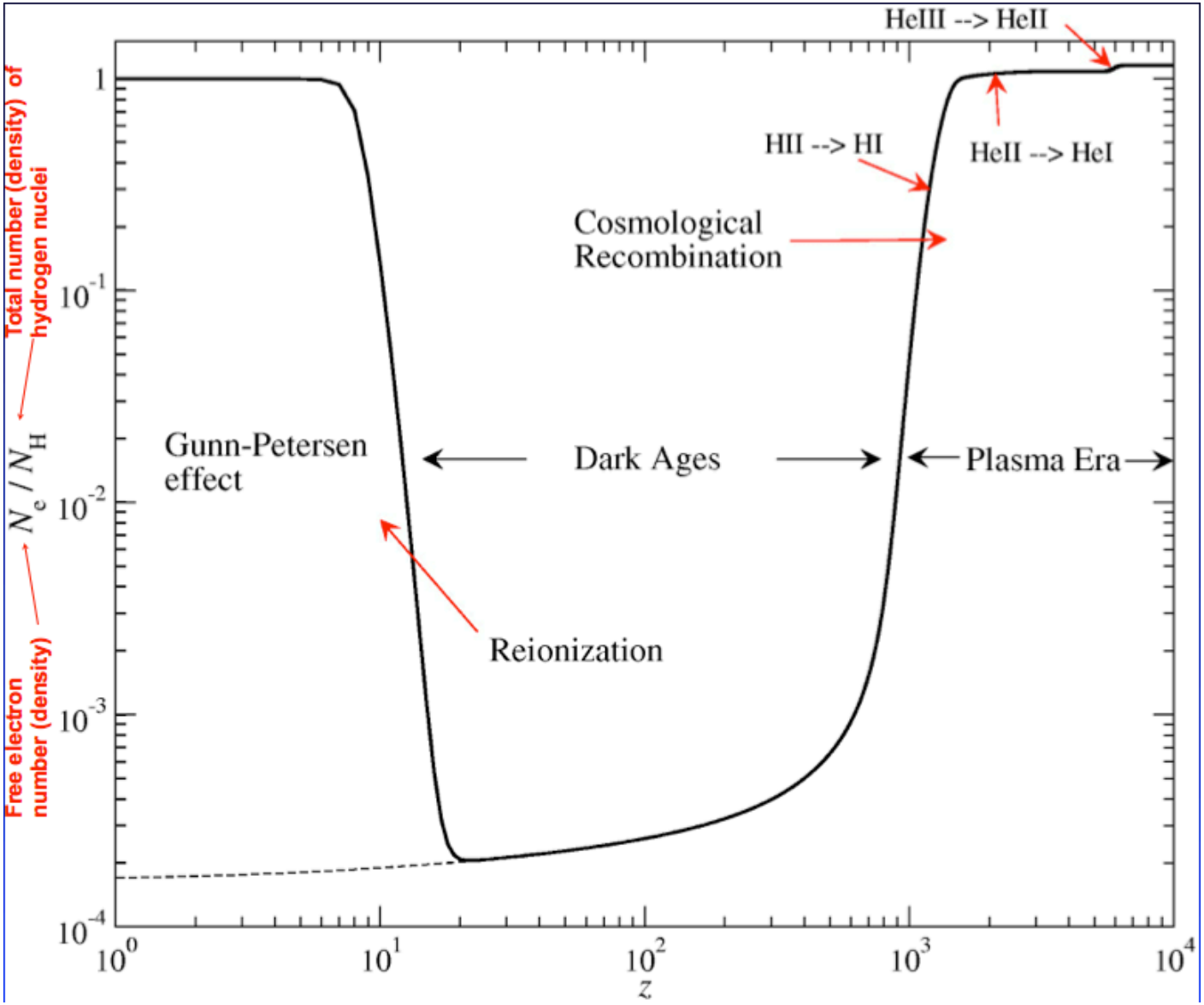
- Introduction
- The Epoch of Recombination
- Motivation
- APSERa
- Thesis plan of action

What I mean by ‘ripples’

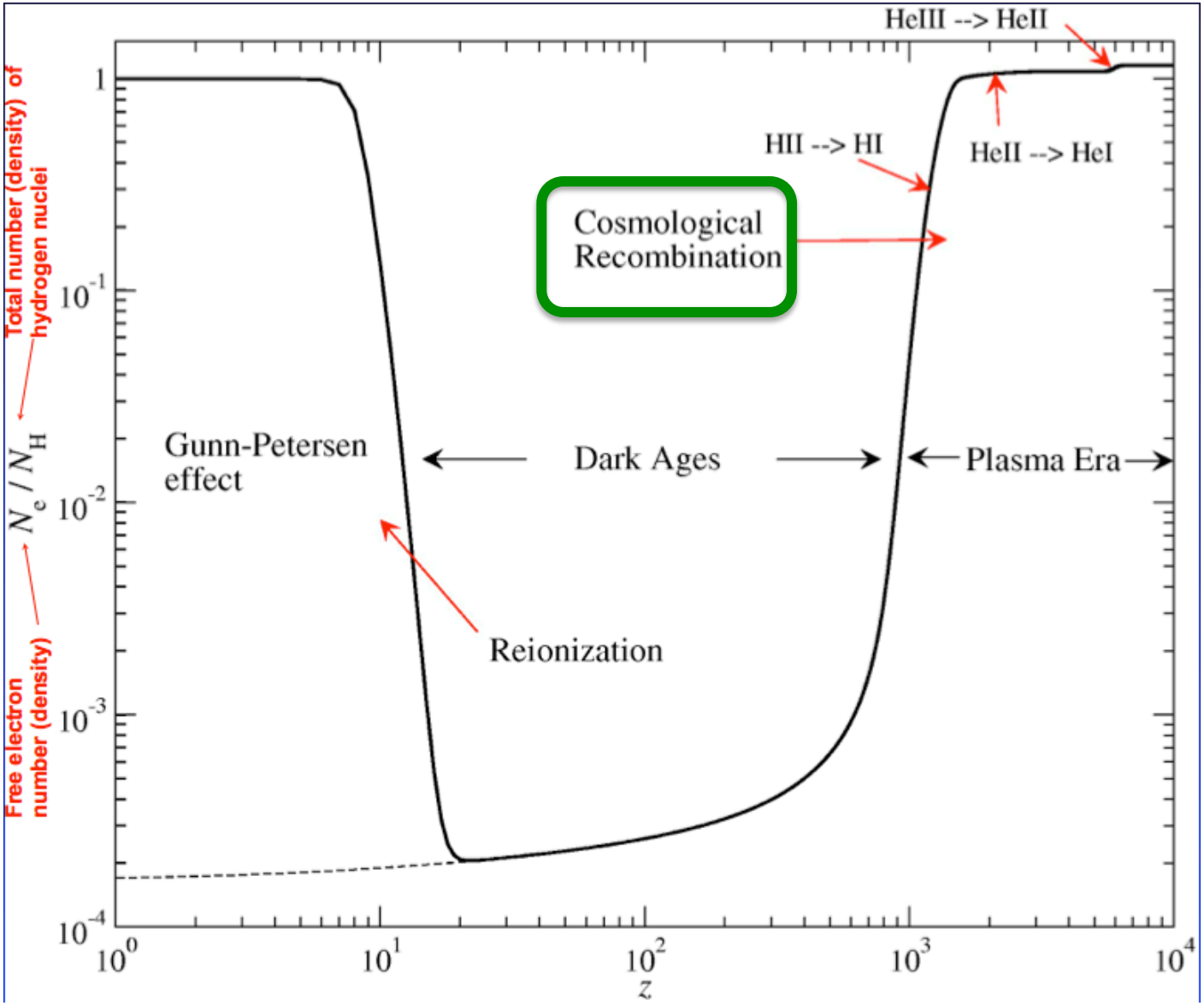



~nK level!!
1e−8
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Recombination line signal (K)
2
3
4
5
6
7
Frequency (GHz)

Cosmic Ionization History



Cosmic Ionization History



A view of the universe

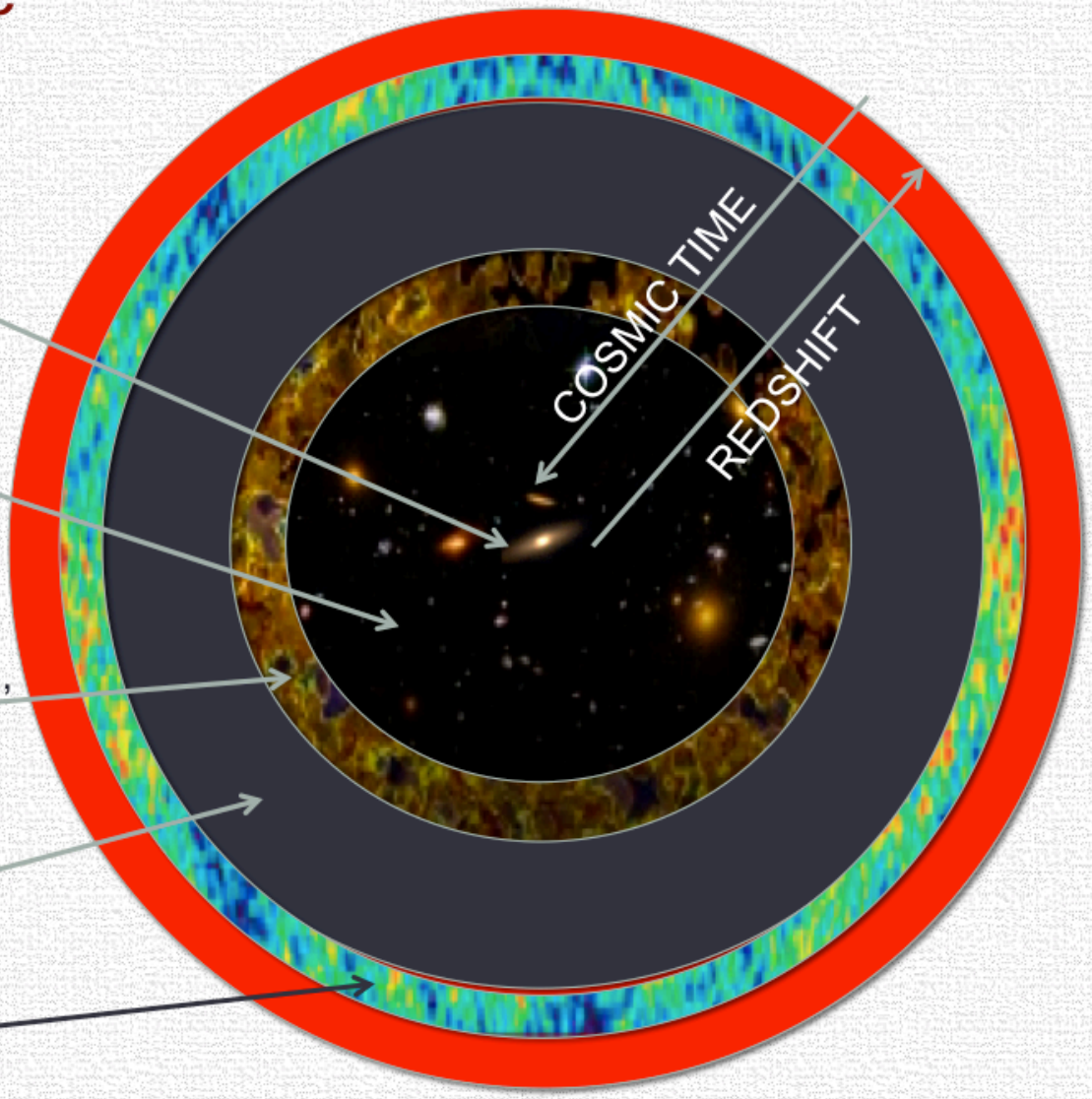
Galactic foreground:
Synchrotron, thermal
(z ~ 0)

Discrete radio sources:
AGNs, Star-forming gal.,
normal gal.
(z ~ 0-7)

21-cm from the cosmic dawn,
re-ionization
(z ~ 6-15)

21-cm from the dark ages
(z ~ 15-150)

CMB from recombination
(z ~ 1090)



A view of the universe

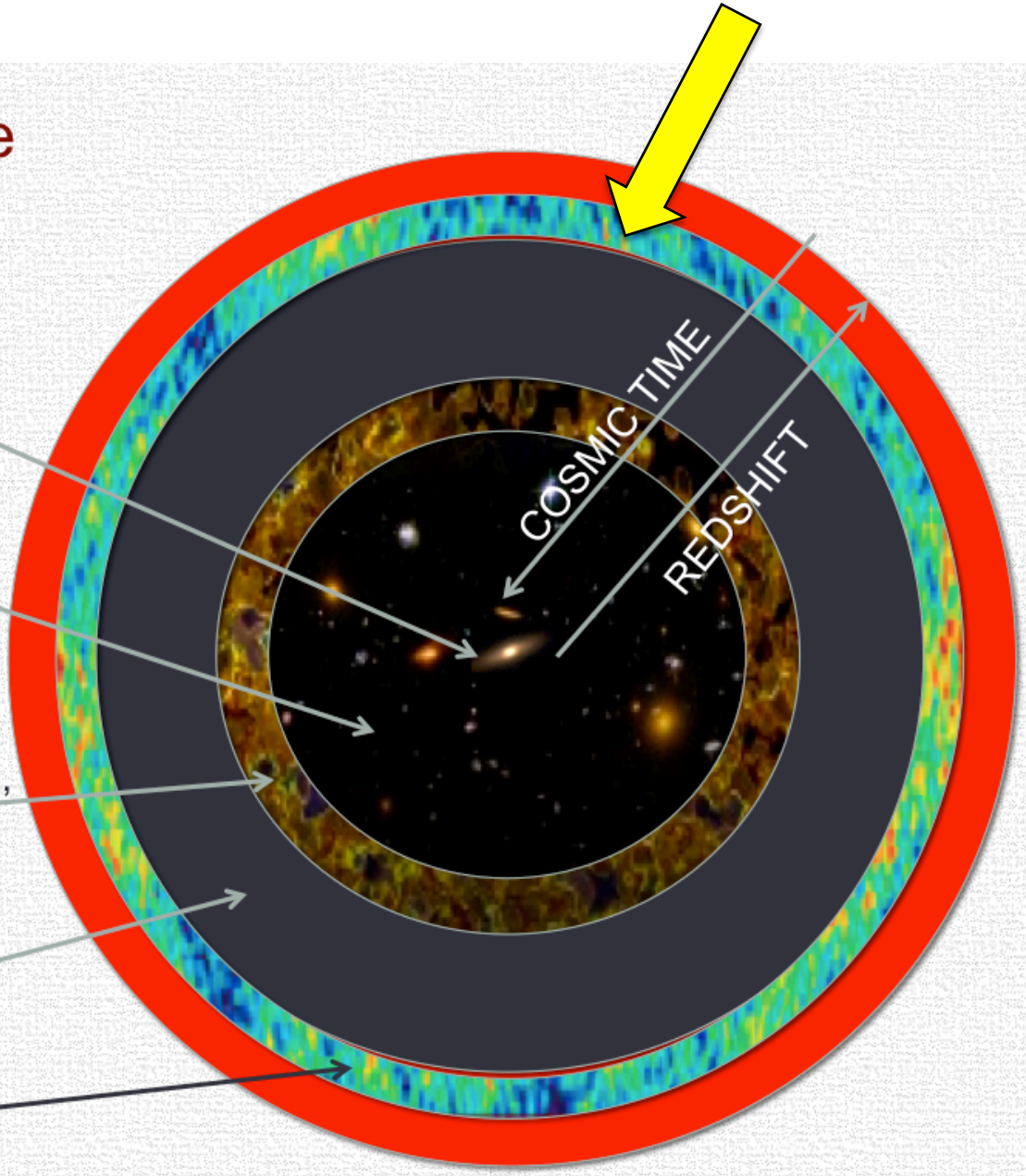
Galactic foreground:
Synchrotron, thermal
(z ~ 0)

Discrete radio sources:
AGNs, Star-forming gal.,
normal gal.
(z ~ 0-7)

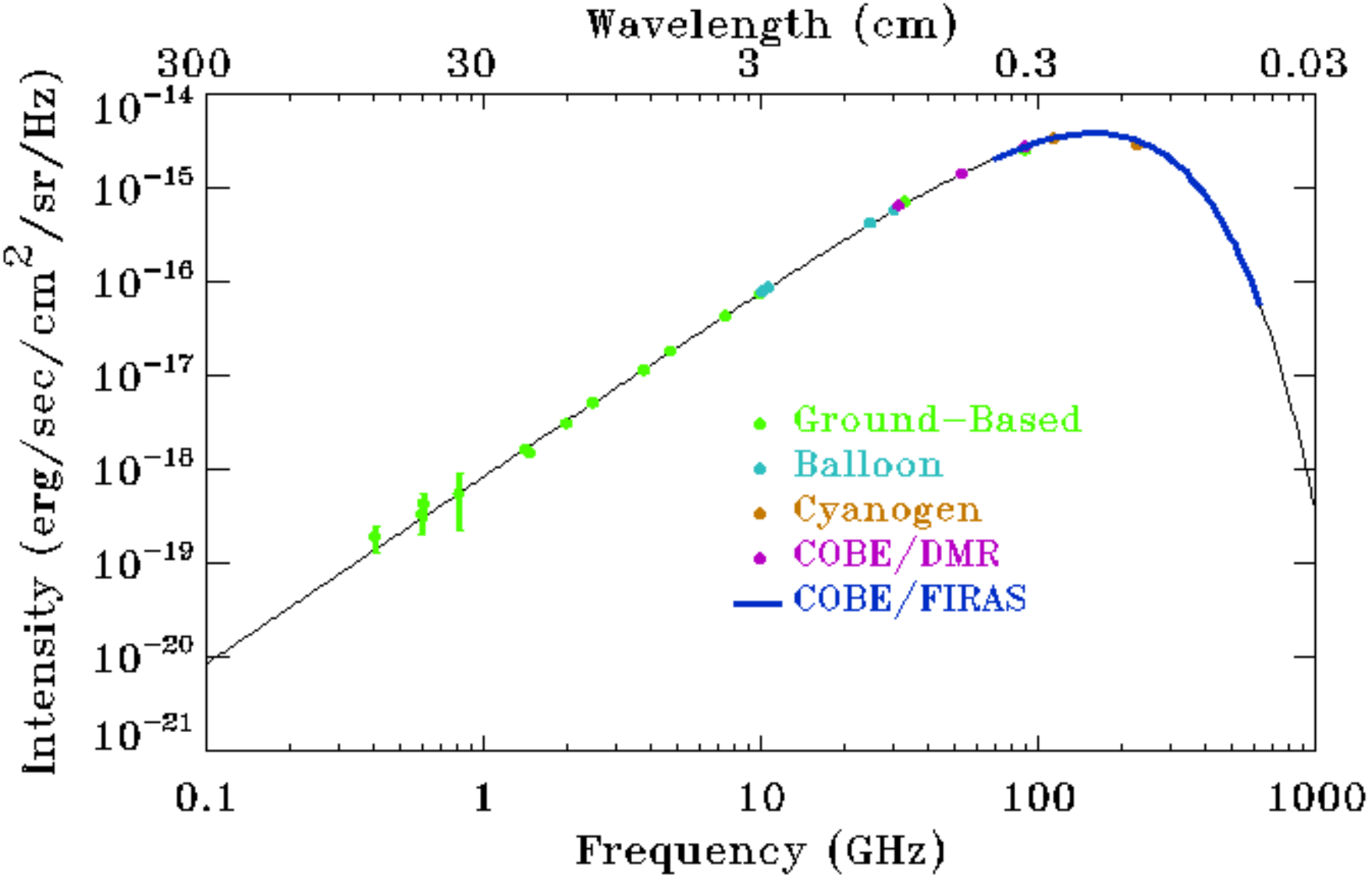
21-cm from the cosmic dawn,
re-ionization
(z ~ 6-15)

21-cm from the dark ages
(z ~ 15-150)

CMB from recombination
(z ~ 1090)



The CMB spectrum



Thermalization

- Bremsstrahlung

$$e^- + X \leftrightarrow e^- + X + \gamma$$

- Compton

$$e^- + \gamma \leftrightarrow e^- + \gamma$$

- Double Compton

$$e^- + \gamma \leftrightarrow e^- + \gamma + \gamma$$

$$z_{th} = z = 2 \times 10^6 \text{ or } T \approx 5 \times 10^6 \text{ K}$$

Not a perfect blackbody!!

- Small distortions in CMB spectrum are allowed!

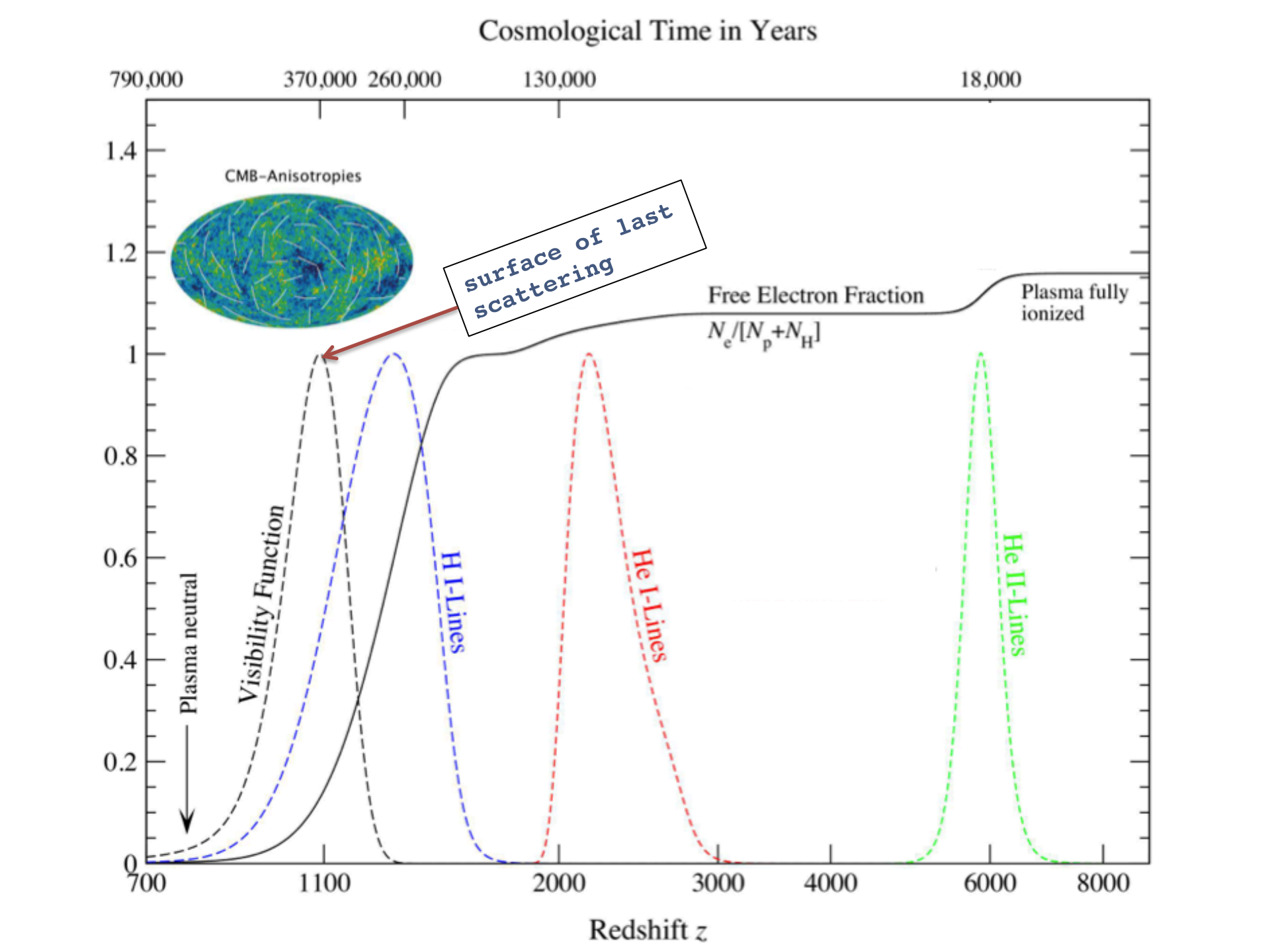
The Epoch of Recombination

- What is/was it?
  - $e^- + p^+ \rightarrow H + \gamma$

- When was it?

  - HeIII → HeII $5000 \leq z \leq 8000$
  - HeII → HeI $1600 \leq z \leq 3500$
  - HII → HI $500 \leq z \leq 2000$

Beyond the surface of last scattering!


Cosmological Time in Years
790,000
370,000
260,000
130,000
18,000
CMB-Anisotropies
surface of last scattering
Free Electron Fraction
$N_e/[N_p+N_H]$
Plasma fully ionized
Visibility Function
Plasma neutral
H I-Lines
He I-Lines
He II-Lines
1.4
1.2
1
0.8
0.6
0.4
0.2
0
700
1100
2000
3000
4000
6000
8000
Redshift z

Conditions during Epoch of Recombination

- $z \sim 1400$
- $T_e = T\gamma \sim 3815$ K
- $n_e = 500$ cm^{-3}
- $n\gamma = 1.1 \times 10^{12}$ cm^{-3}

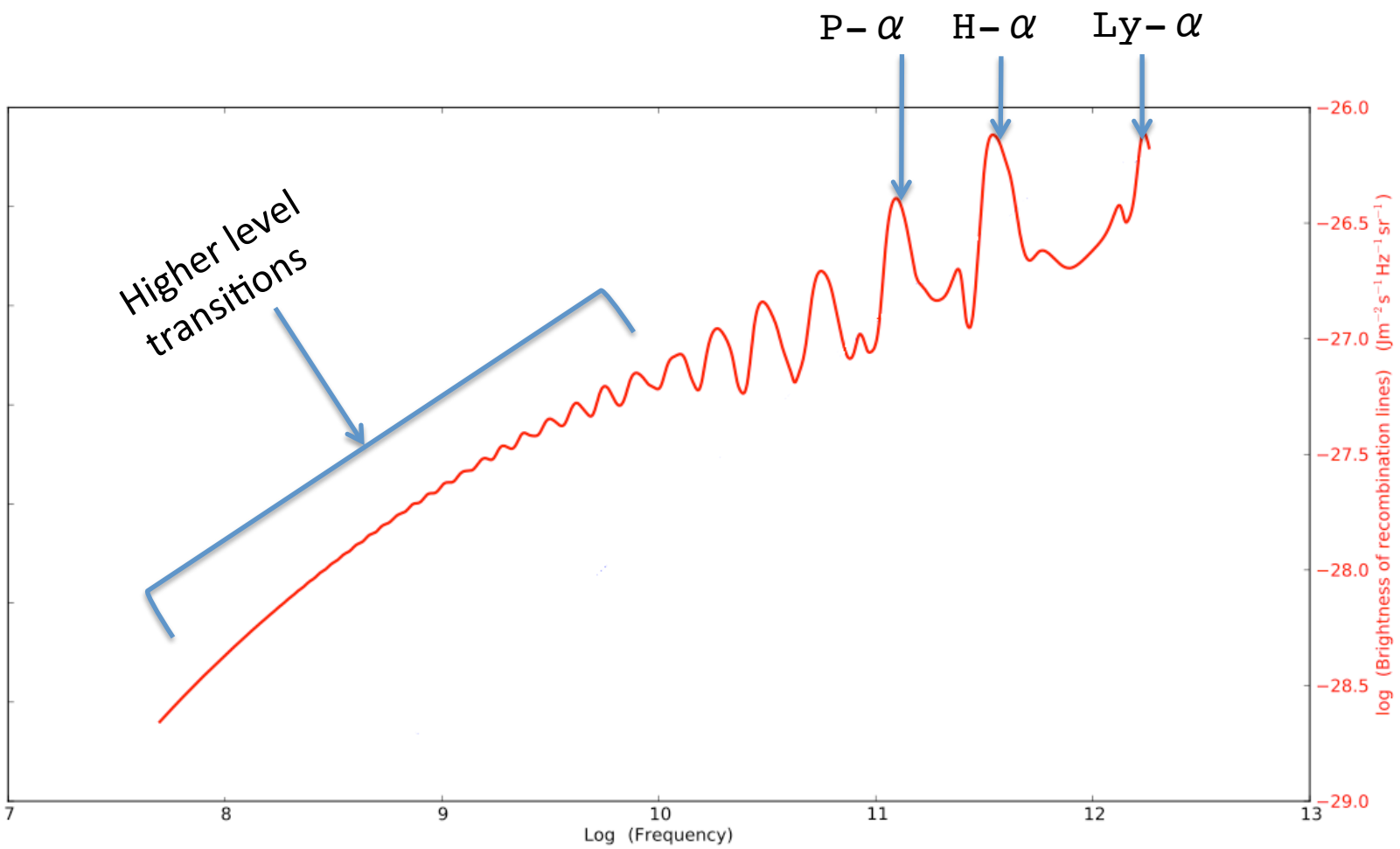
Conditions during Epoch of Recombination

- $z \sim 1400$
- $T_e = T$ [illegible] K
- $n_e = 500\ cm^{-3}$
- $n_\gamma = 1.1 \times 10^{12}\ cm^{-3}$

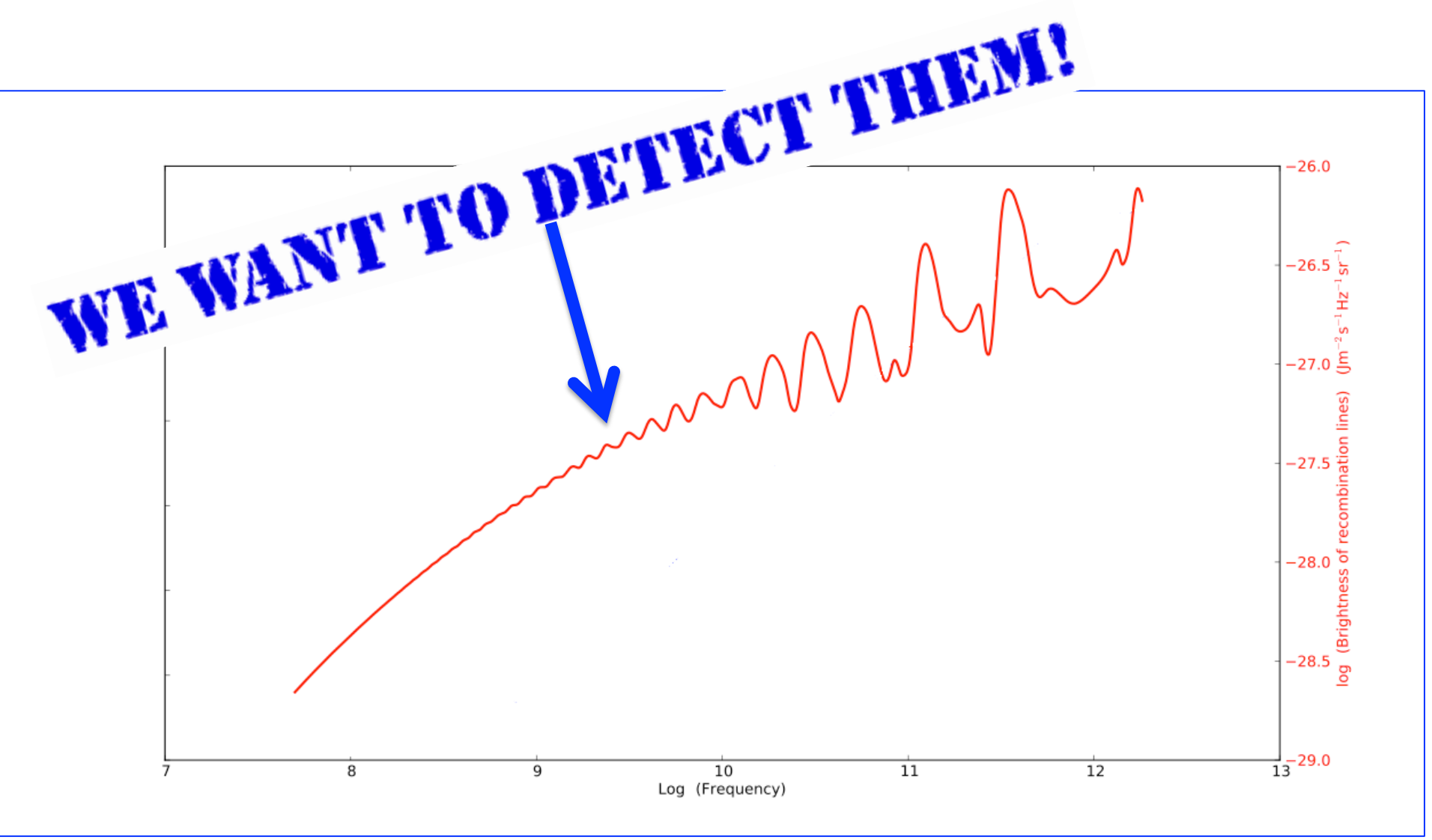
LOW BARYON-PHOTON RATIO

- Recombination occurs at redshifts $z < 10^4$
- Thermalization not effective
- There should be some ***small*** spectral distortion due to the photons released during recombination!

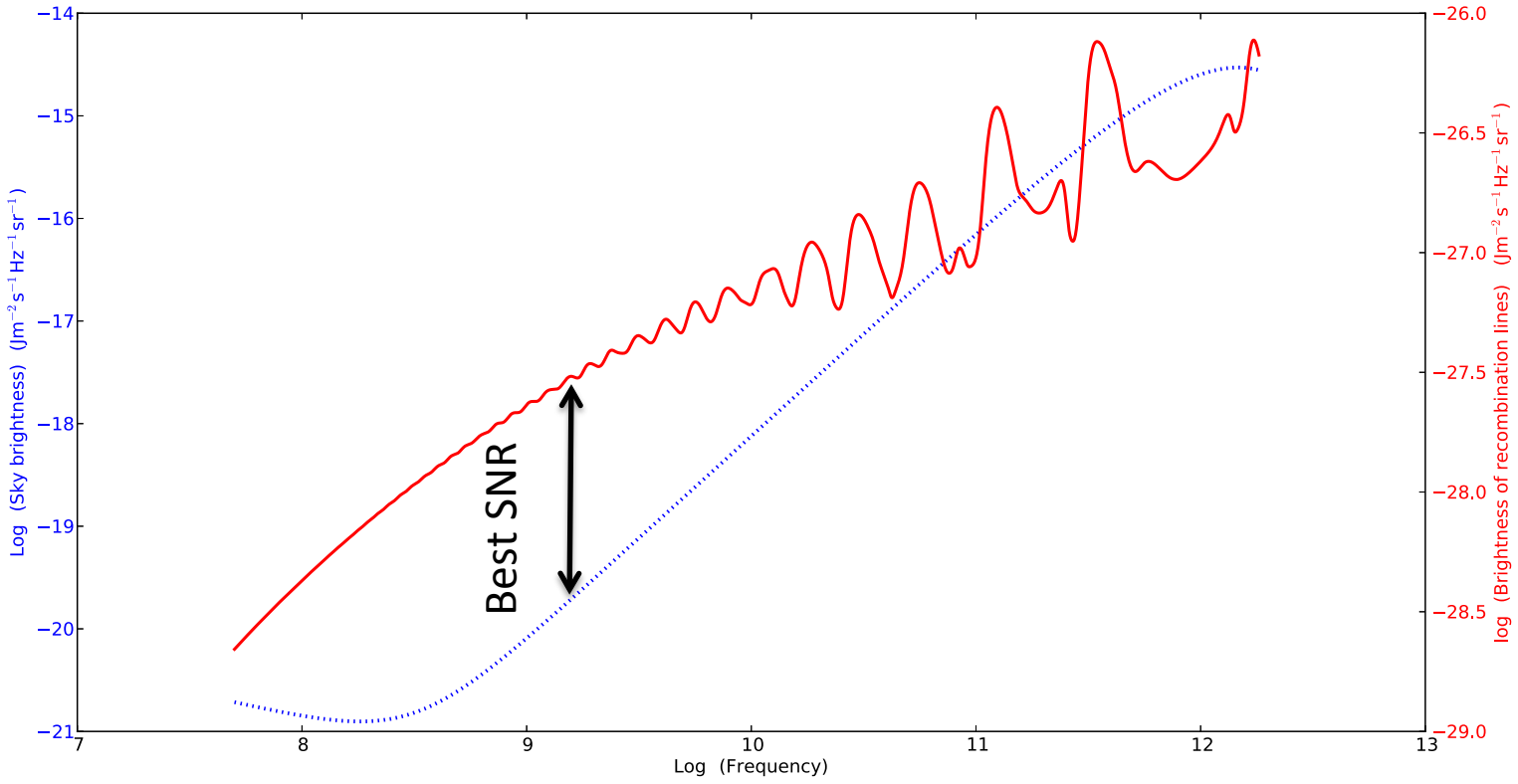
Predicted recombination lines



Predicted recombination lines

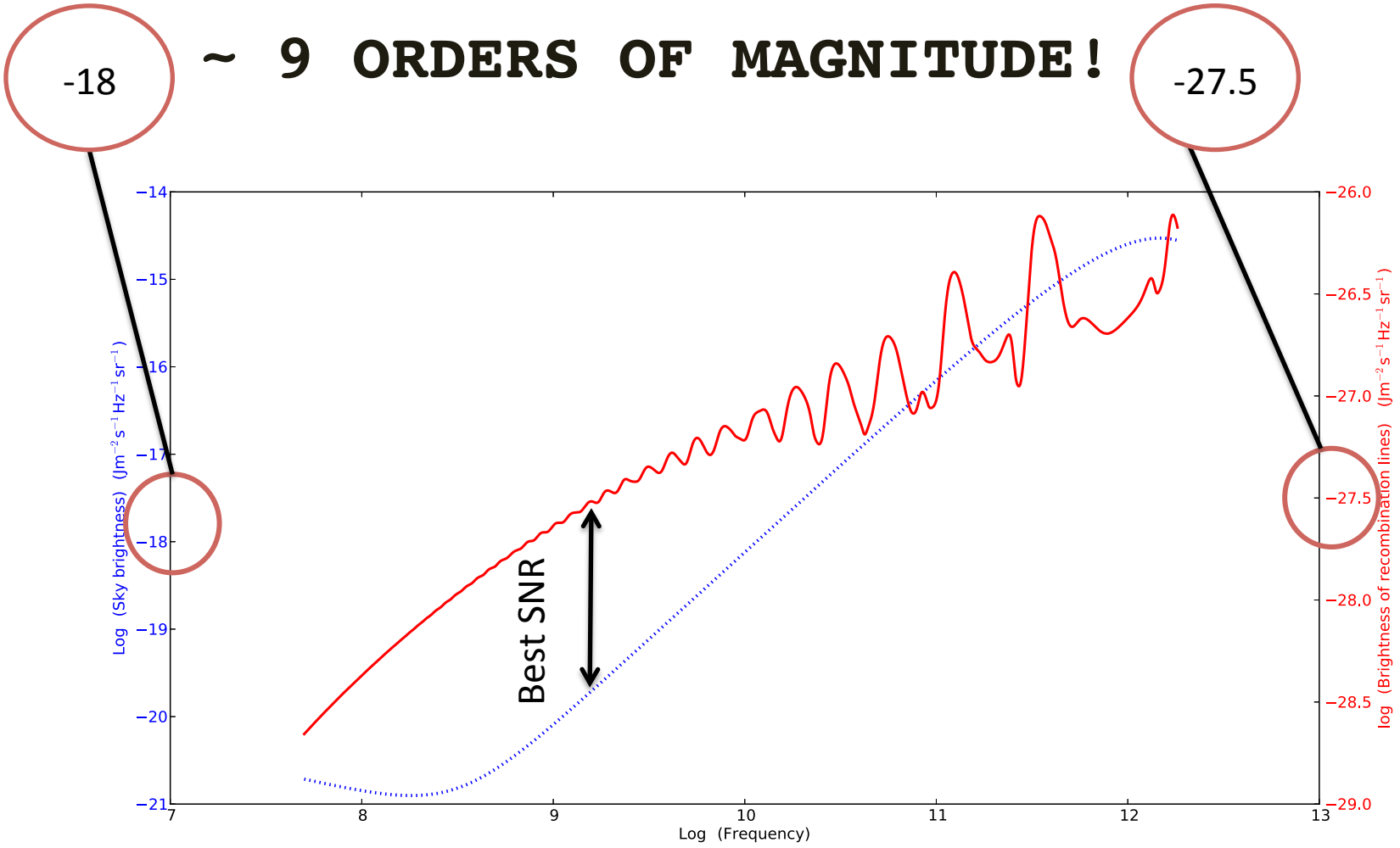


To get a sense of scale



To get a sense of scale

~ 9 ORDERS OF MAGNITUDE!

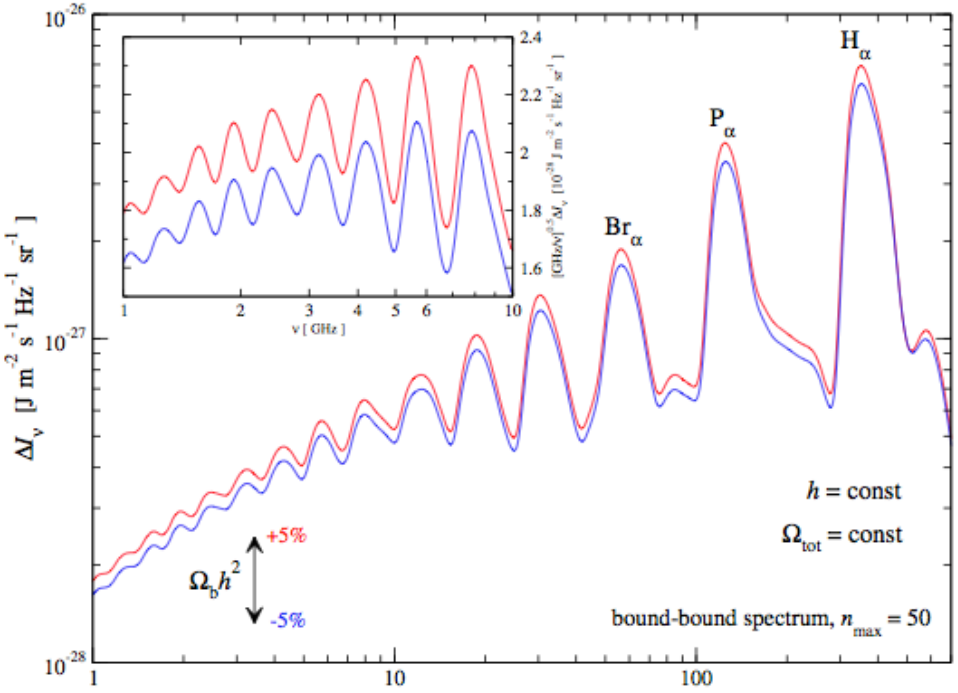


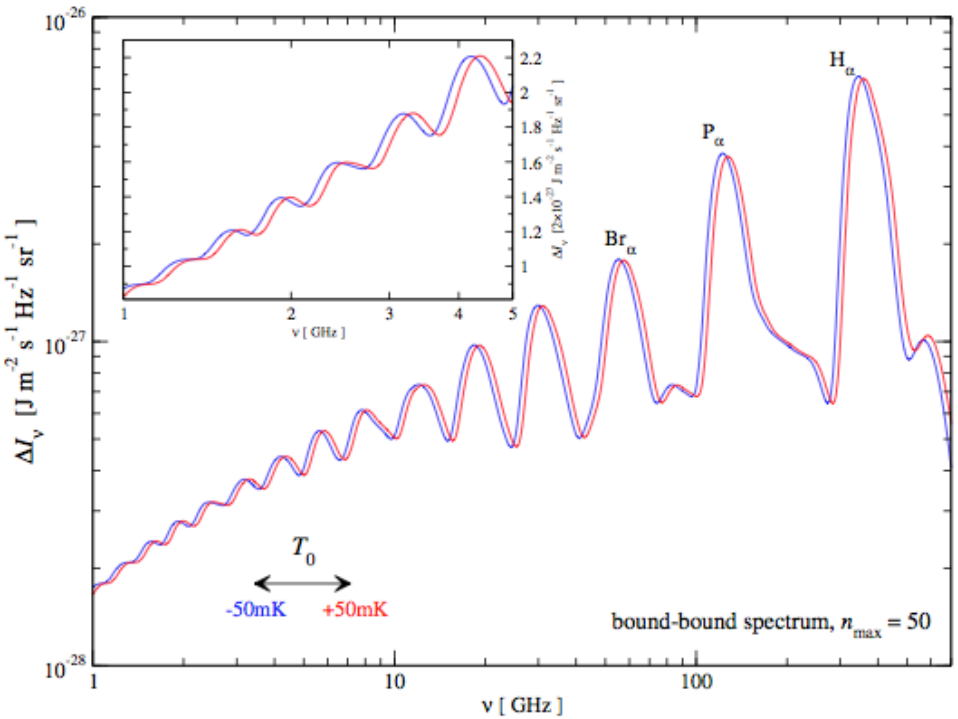
WHY DO IT ?!

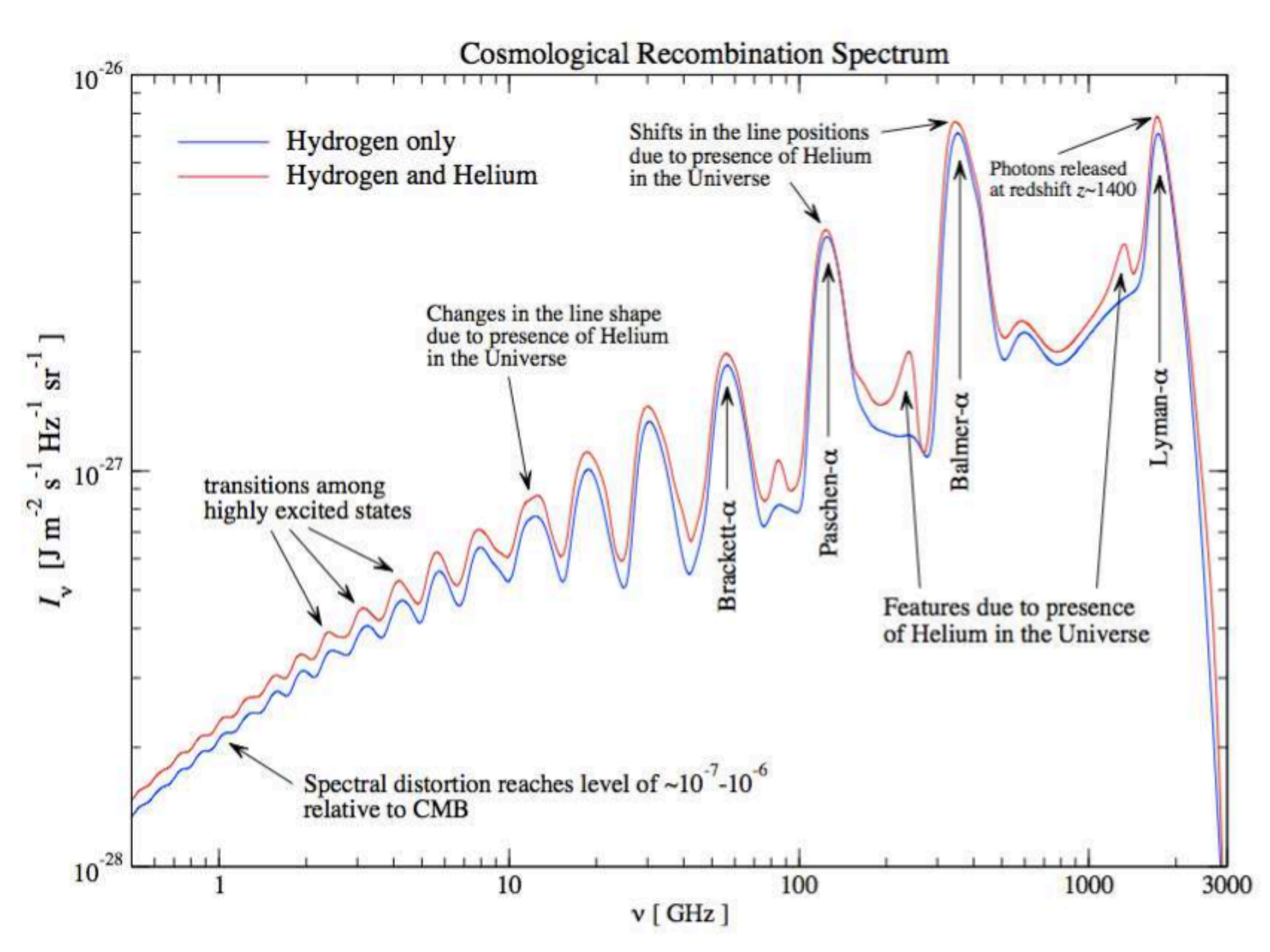
- Confront our detailed understanding

- Additional way to determine key parameters of the Universe
  - Pre-stellar Helium abundance!

- Thermal & Ionization history


10^{-26}
10^{-27}
10^{-28}
ΔI_ν [J m^{-2} s^{-1} Hz^{-1} sr^{-1}]
1
10
100
H_α
P_α
Br_α
h = const
Ω_{tot} = const
+5%
$\Omega_b h^2$
-5%
bound-bound spectrum, n_{max} = 50
ν [GHz]
[GHz/ν]$^{0.5}$ ΔI_ν [10^{-24} J m^{-2} s^{-1} Hz^{-1} sr^{-1}]

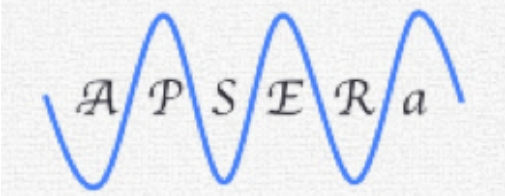

10^{-26}
10^{-27}
10^{-28}
ΔI_ν [J m^{-2} s^{-1} Hz^{-1} sr^{-1}]
1
10
100
H_α
P_α
Br_α
T_0
-50mK
+50mK
bound-bound spectrum, n_{max} = 50
ν [GHz]
ΔI_ν [2×10^{-25} J m^{-2} s^{-1} Hz^{-1} sr^{-1}]


Cosmological Recombination Spectrum
Hydrogen only
Hydrogen and Helium
Shifts in the line positions due to presence of Helium in the Universe
Photons released at redshift z~1400
Changes in the line shape due to presence of Helium in the Universe
transitions among highly excited states
Brackett-α
Paschen-α
Balmer-α
Lyman-α
Features due to presence of Helium in the Universe
Spectral distortion reaches level of ~10^-7-10^-6 relative to CMB
10^-26
10^-27
10^-28
I_ν [J m^-2 s^-1 Hz^-1 sr^-1]
1
10
100
1000
3000
ν [GHz]

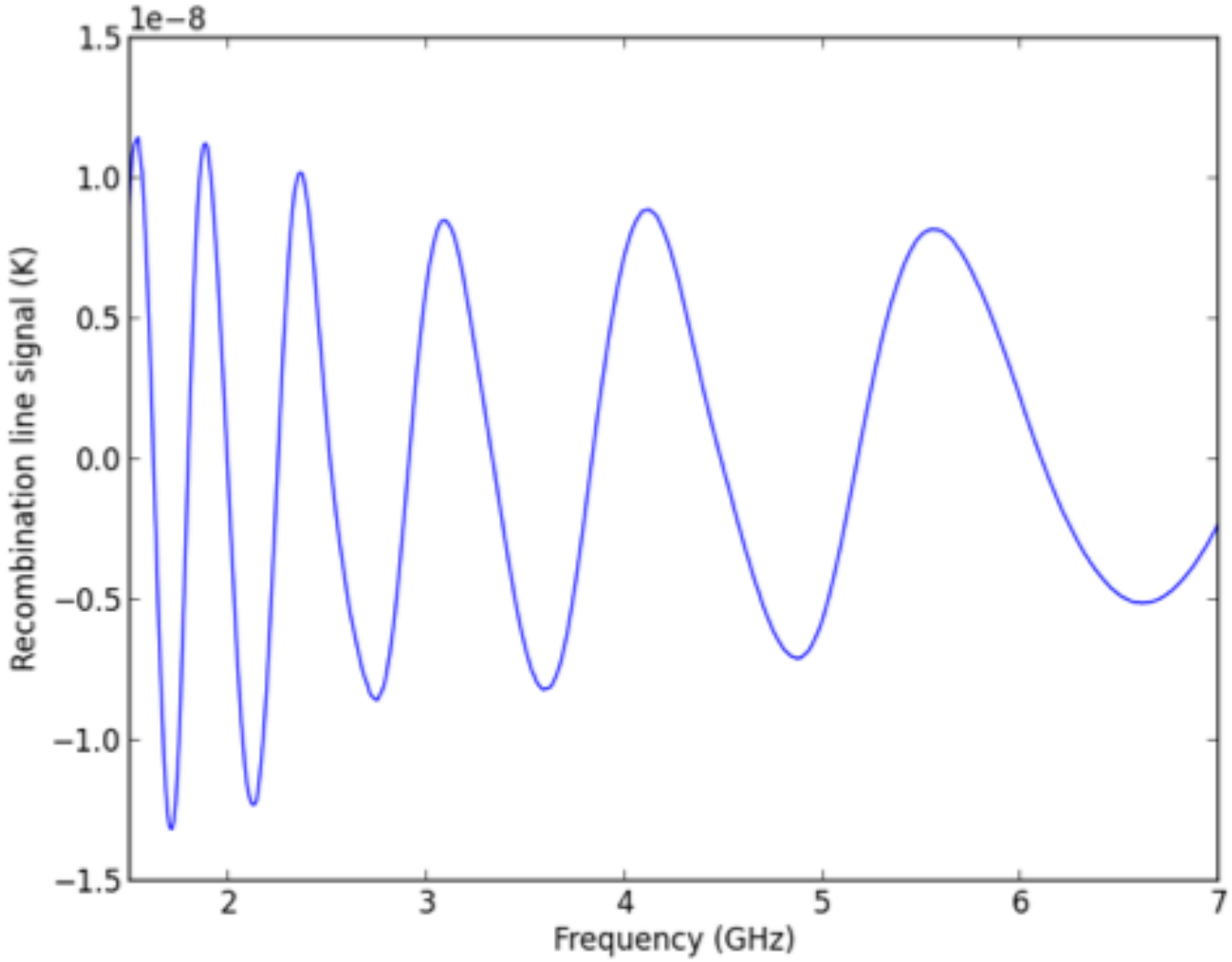
$\mathcal{APSERa}$

- Array of Precision Spectrometers for the Epoch of RecombinAtion – APSERa
- Array of 128 small telescopes
- 2-6 GHz range
- Radio receivers - designed and built at the Raman Research Institute

http://www.rri.res.in/apsera



What we are looking for



Challenges

- It's a tiny signal
- Foreground estimation and subtraction
  - It's a broad signal
- Need to accurately model, estimate systematics –
  - Careful receiver design
  - Intelligent calibration scheme(s)
  - Choice of site – minimal RFI

Thesis plan

- Feasibility Study
- Potential of SKA
- Real-World Issues
- Prototype Design
- Prototype Deployment

Time line

- Feasibility Study -- Mid July 2014
- Potential of SKA -- End December 2014
- Real-World Issues -- End December 2015
- Prototype Design -- Mid July 2016
- Prototype Deployment -- March 2017

References