

Seeing the Universe through 21 cm Radiation

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Study of the Universe as a whole

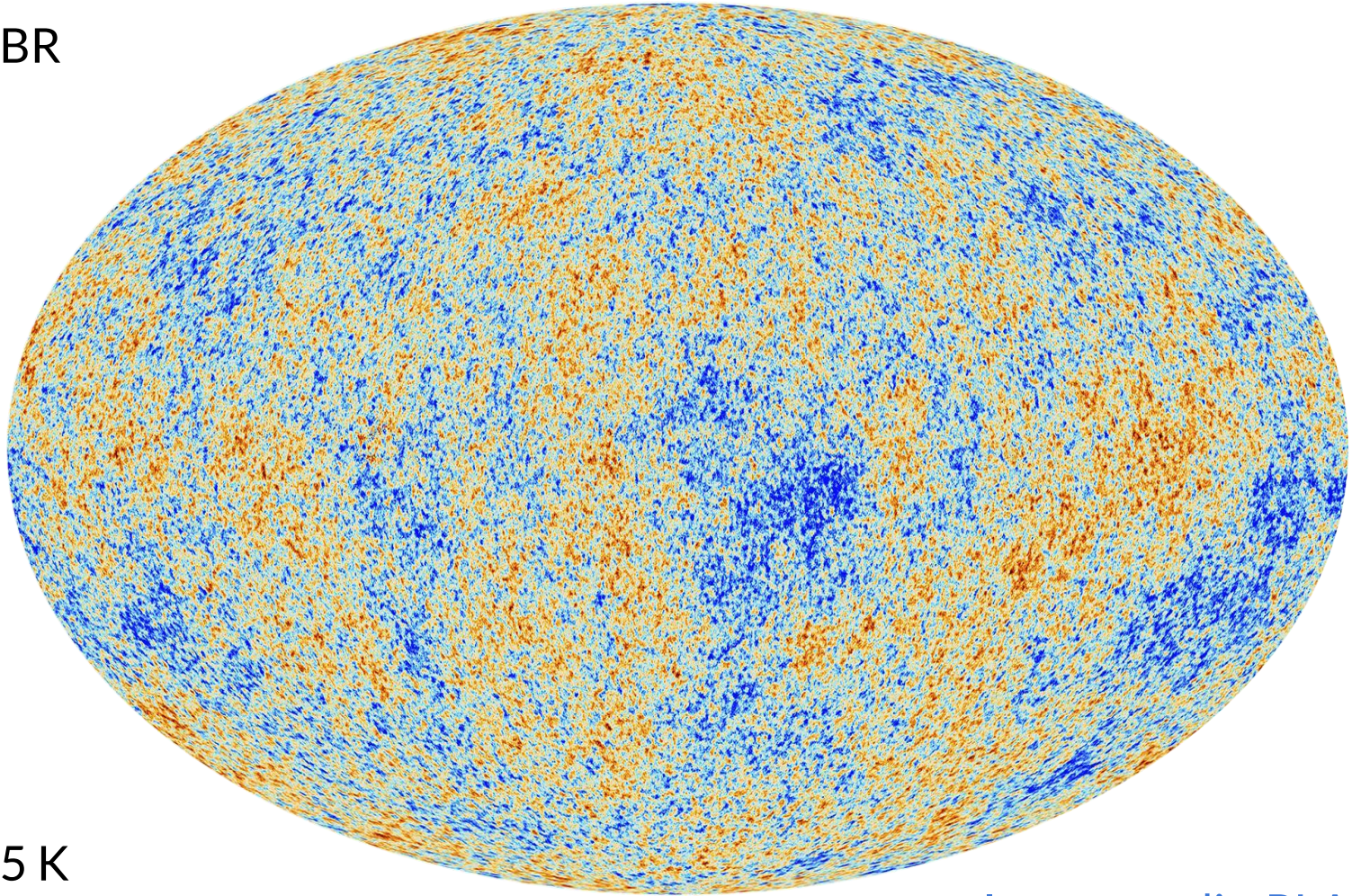
Cosmology

How much do we know actually about
our universe?

Early Universe

T ~ 379,000 years

CMBR



T=2.725 K

Nearly isotropic $\Delta T \sim 10$ micro K

Image credit: PLANCK

Local Universe

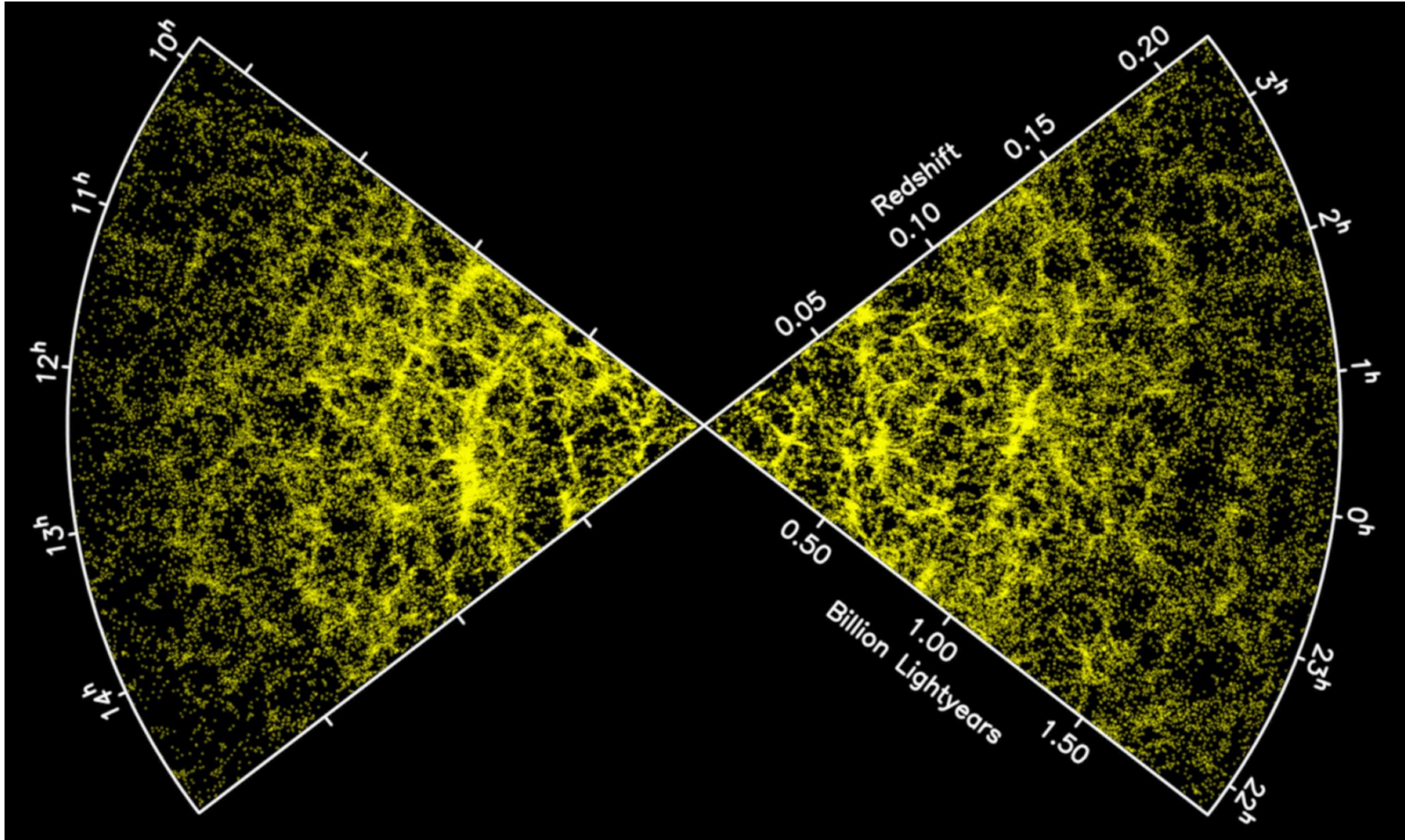
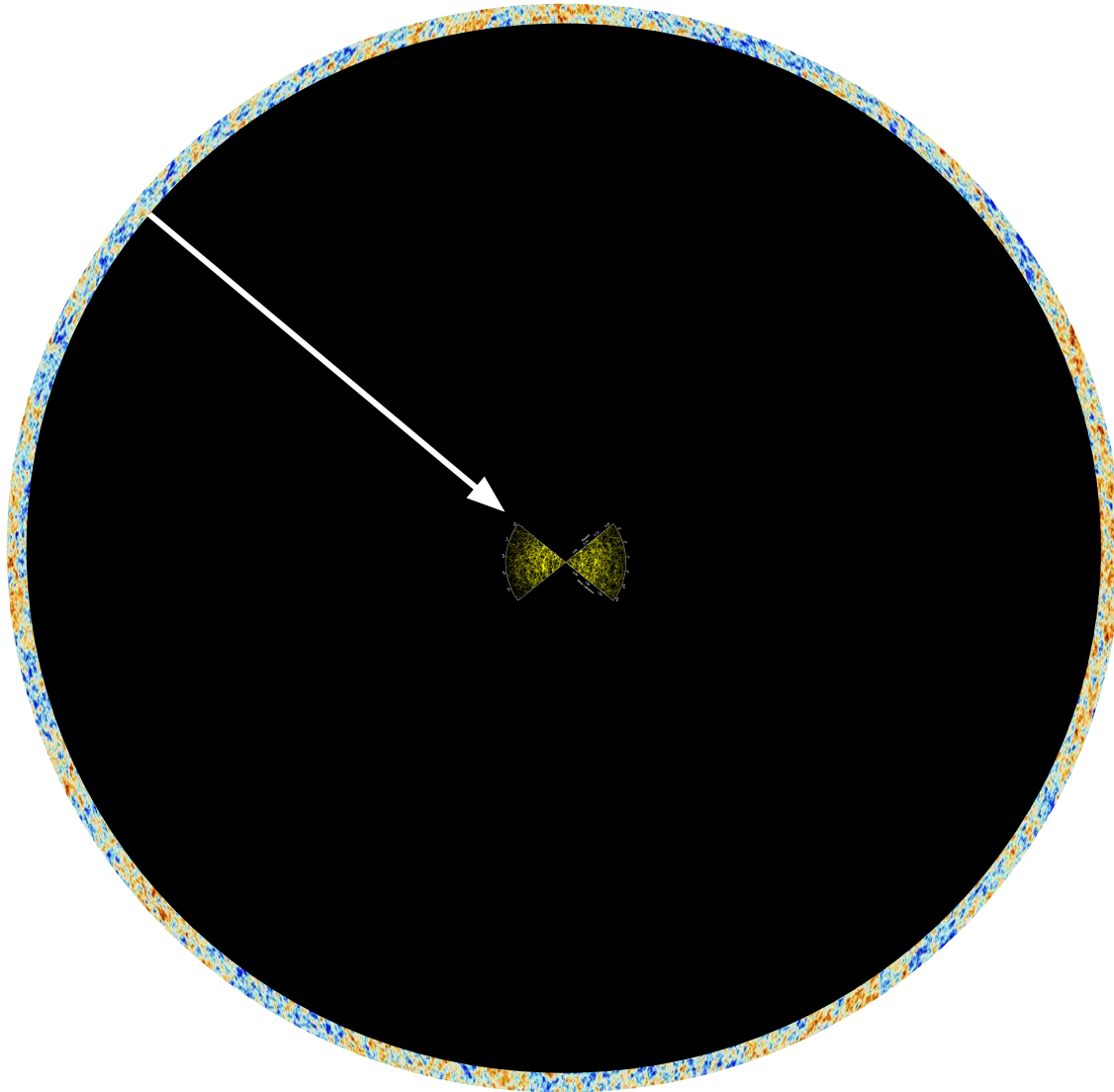
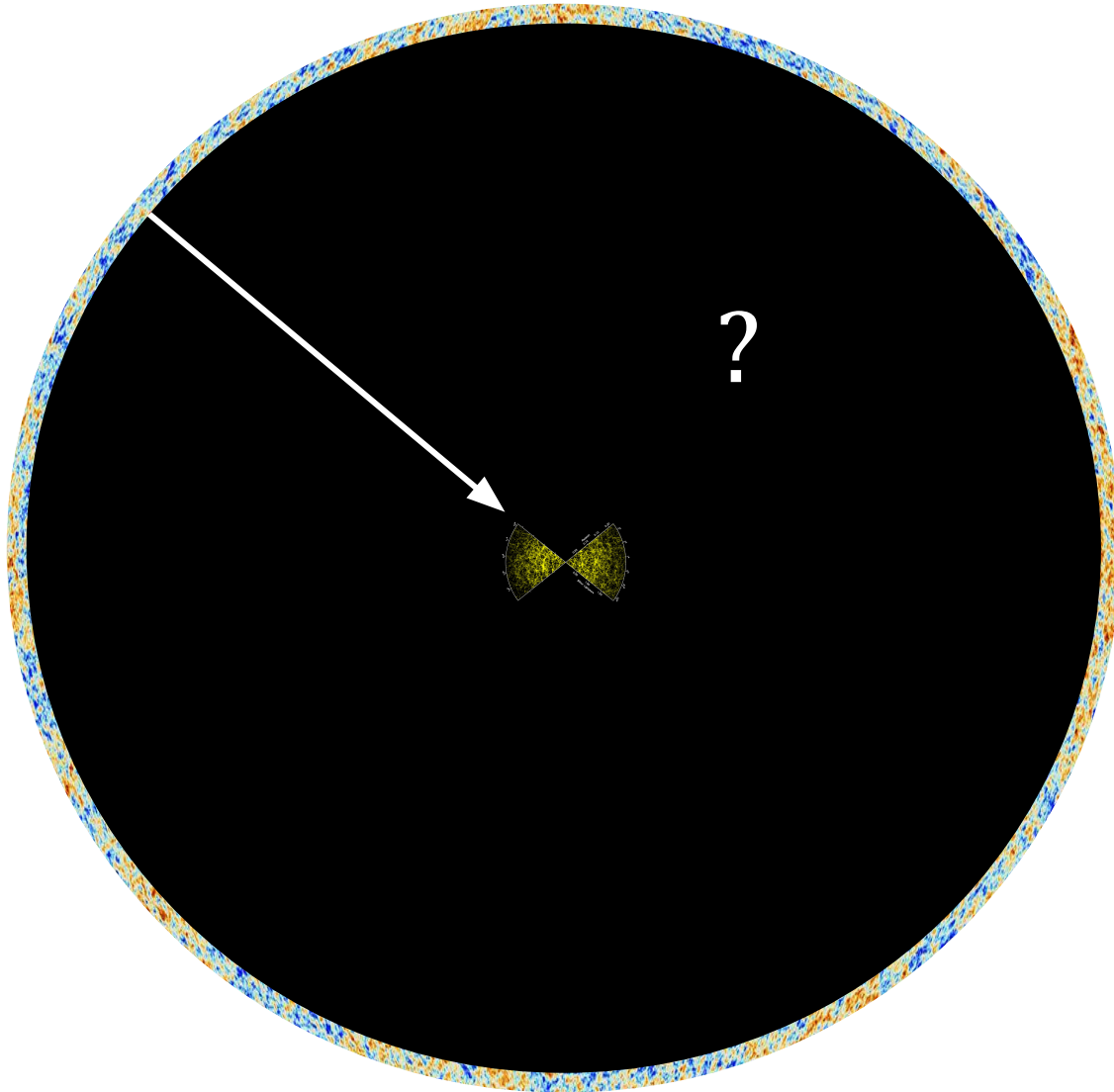


Image credit: 2dF Galaxy Redshift Survey

Our observable Universe



Our observable Universe



Evolution of the Universe

Big Bang

Today

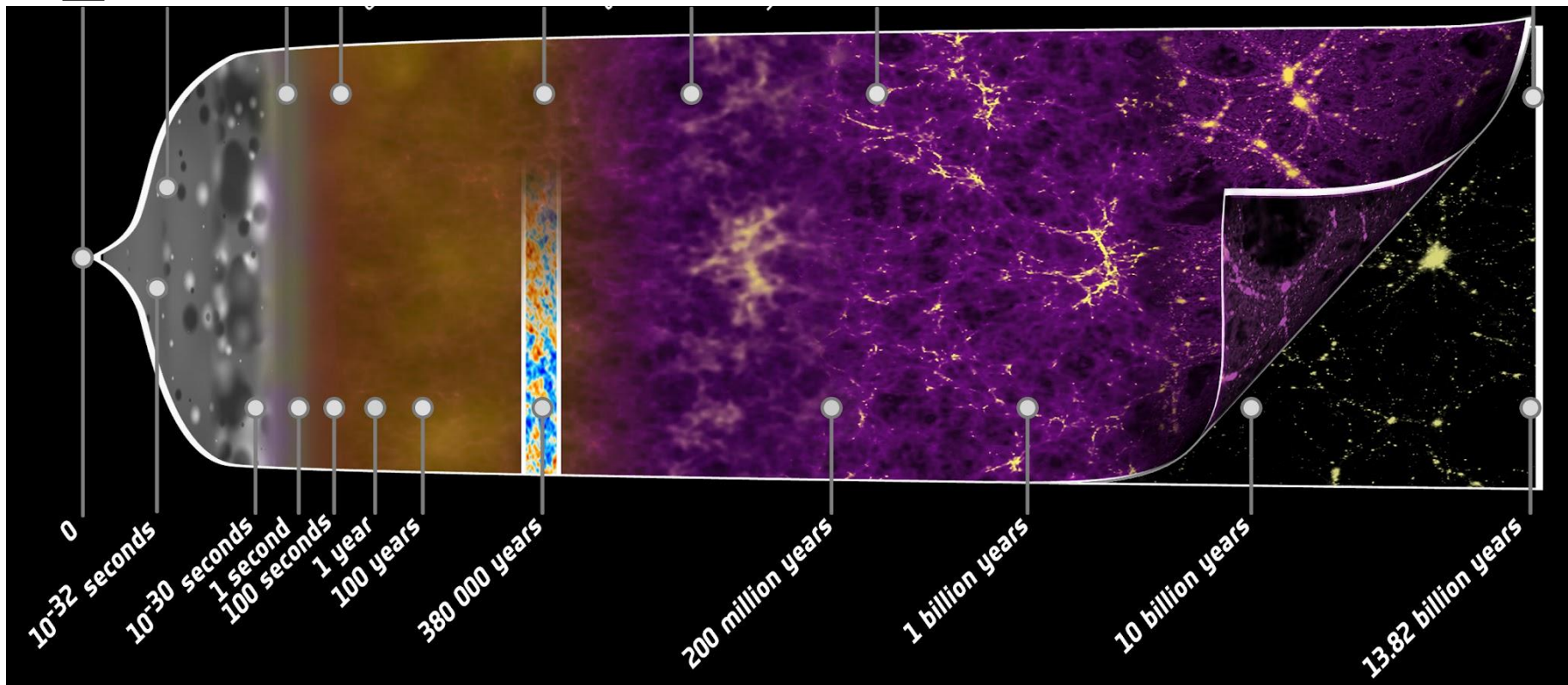
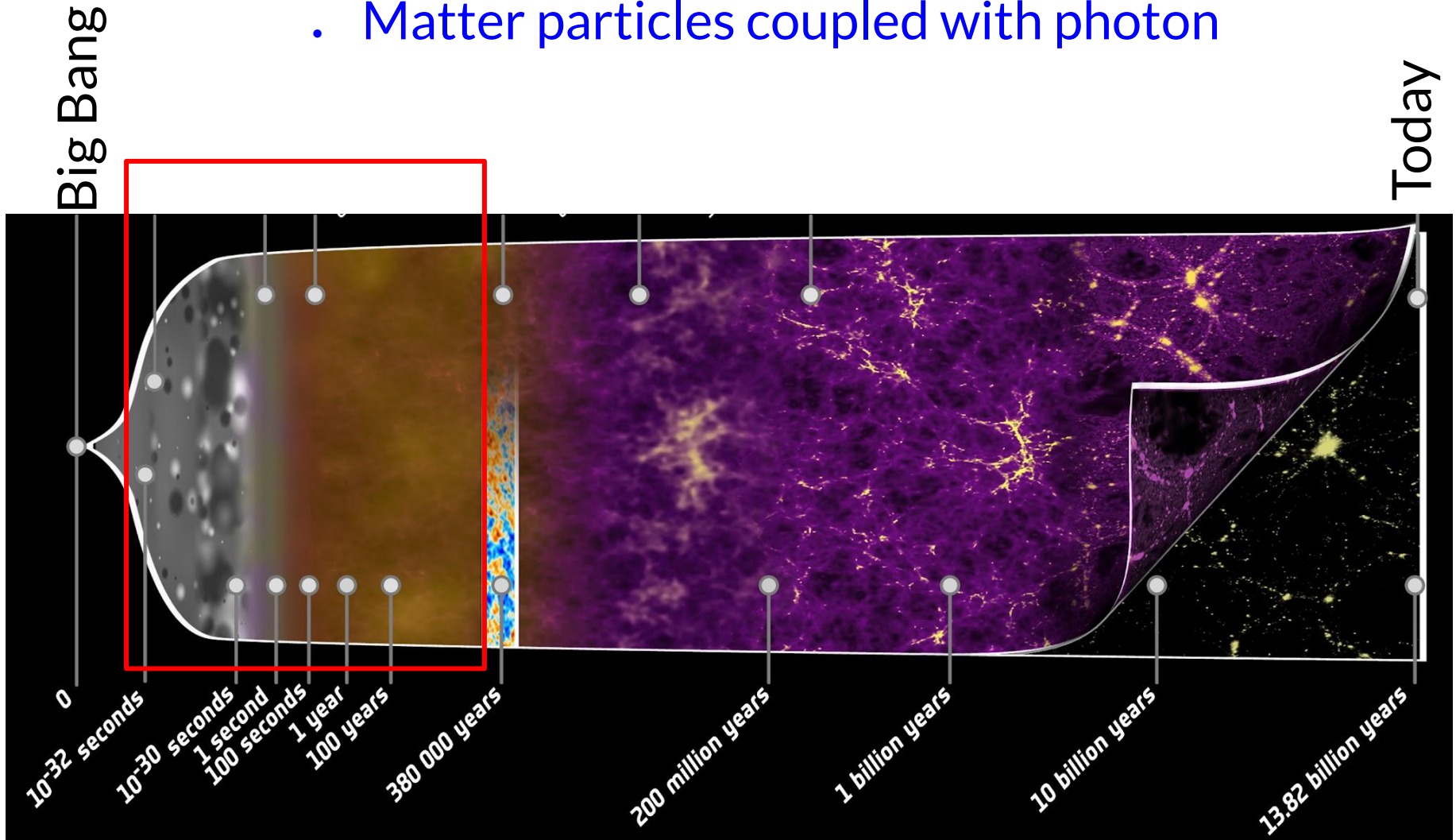


Image credit: NASA

Early Universe:

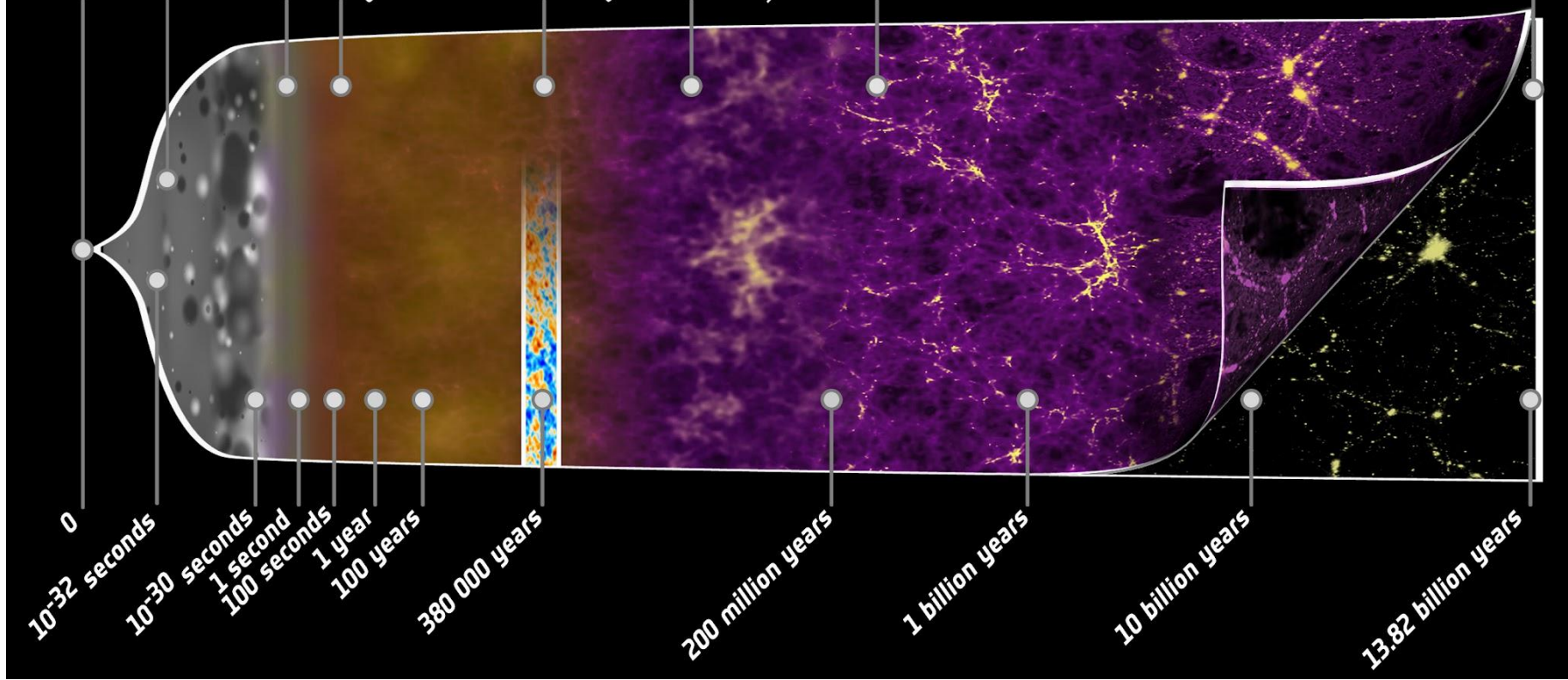
- Hot, dense
- Matter particles coupled with photon



Big Bang

Hot, ionized
Early Universe

Today



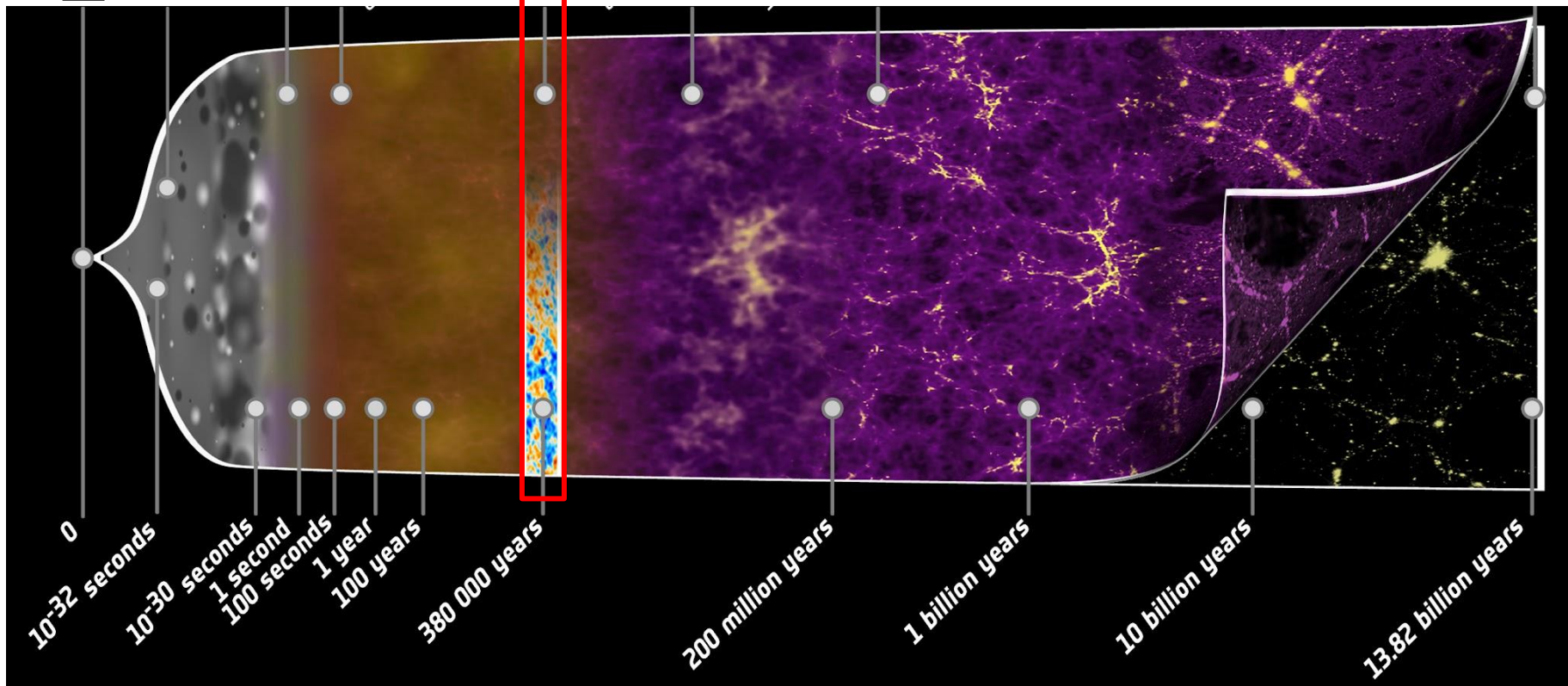
Big Bang

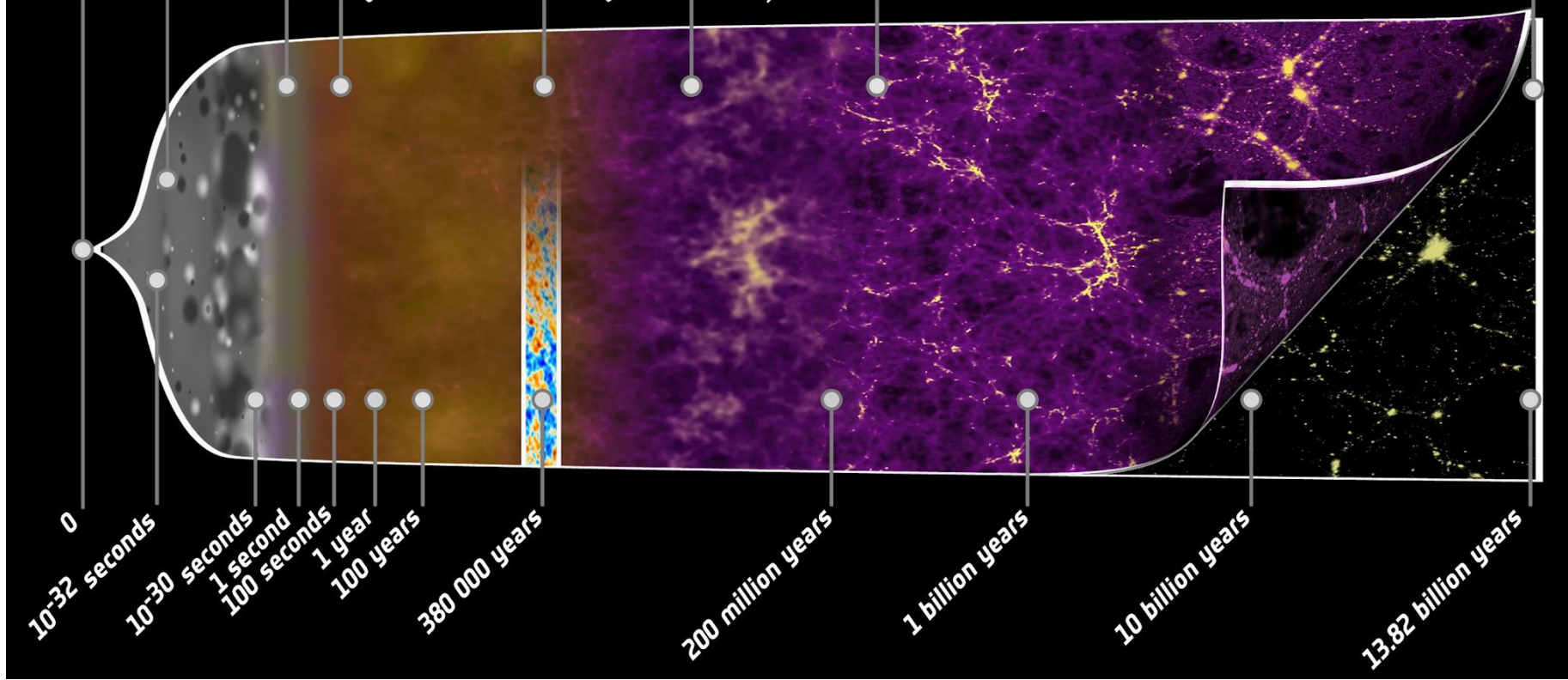
Hot, ionized
Early Universe

Recombination:

- Universe become neutral
- CMB released

Today





Big Bang

Hot, ionized
Early Universe

Recombination
(CMB)

Today

0

10^{-32} seconds

10^{-30} seconds

1 second

100 seconds

1 year

100 years

380 000 years

200 million years

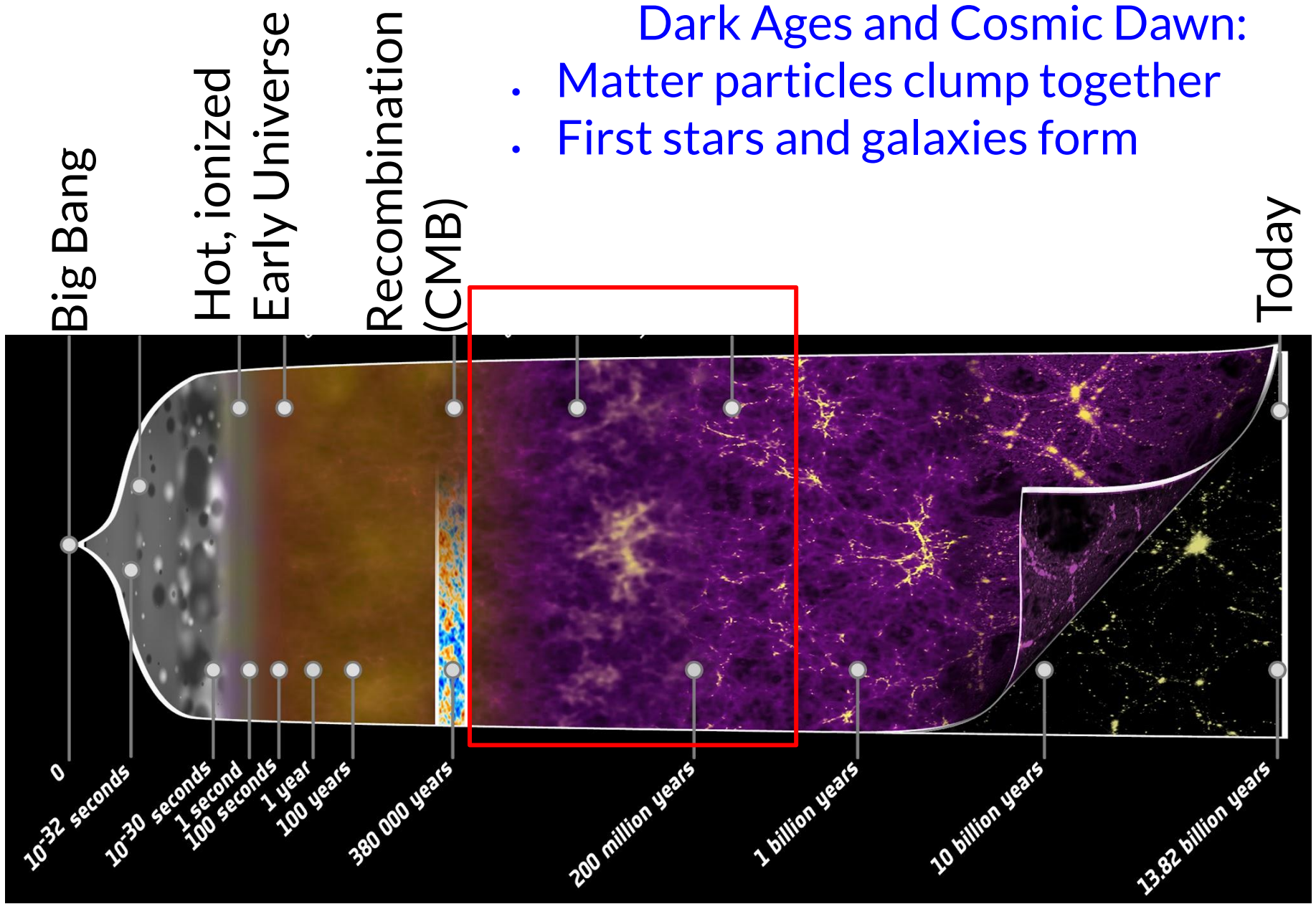
1 billion years

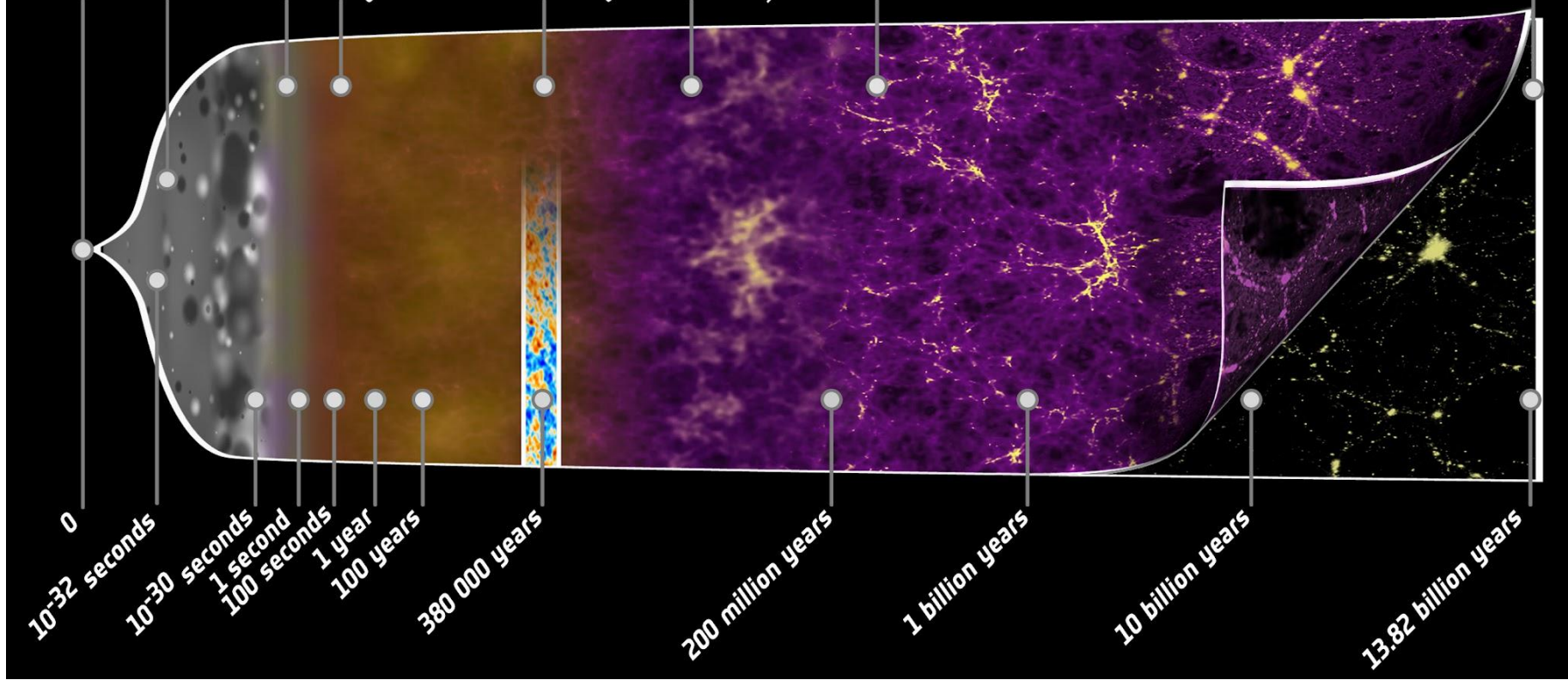
10 billion years

13.82 billion years

Dark Ages and Cosmic Dawn:

- Matter particles clump together
- First stars and galaxies form





Big Bang

Hot, ionized
Early Universe

Recombination
(CMB)

Dark Ages

Cosmic Dawn

Today

0

10^{-32} seconds

10^{-30} seconds

1 second

100 seconds

1 year

100 years

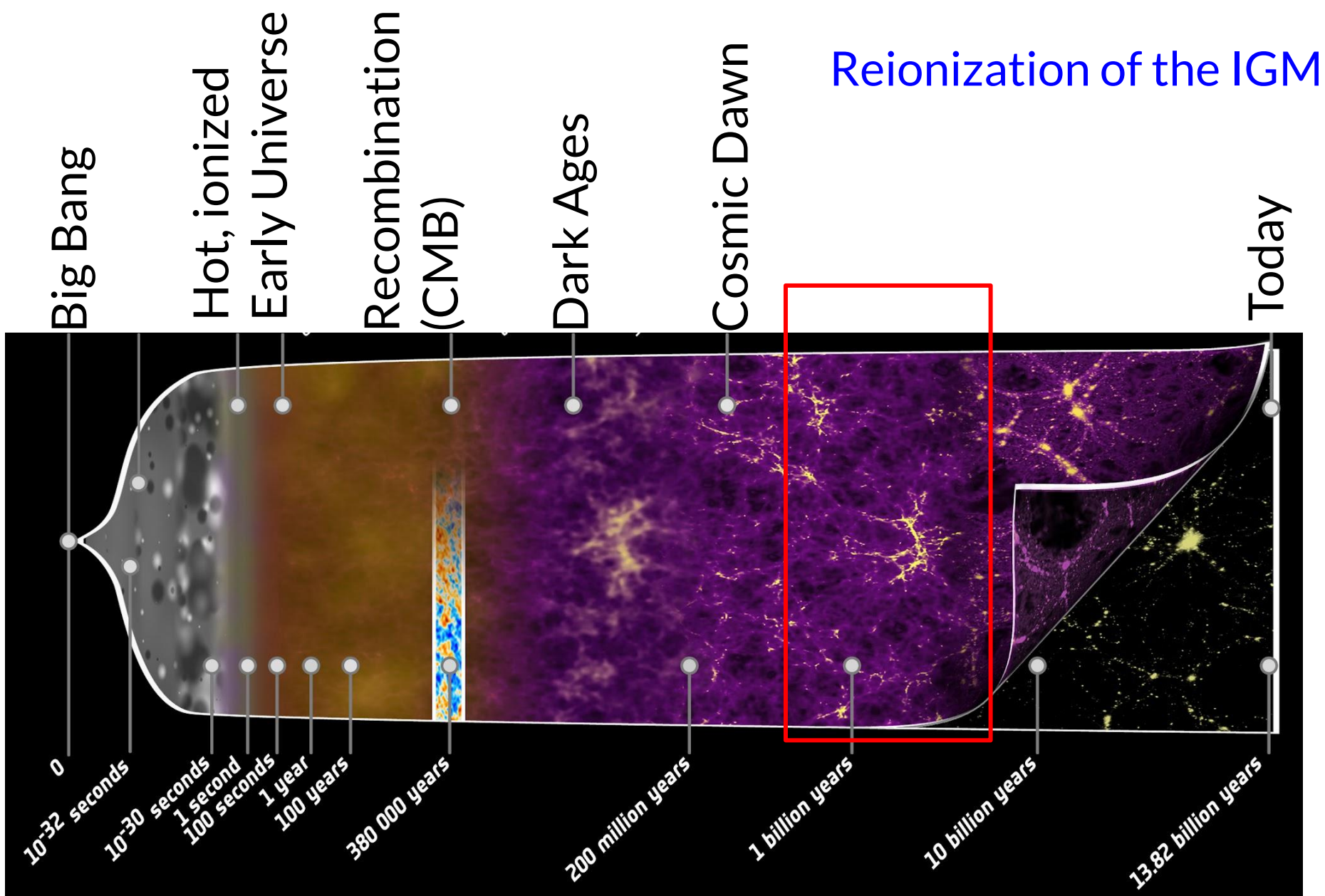
380 000 years

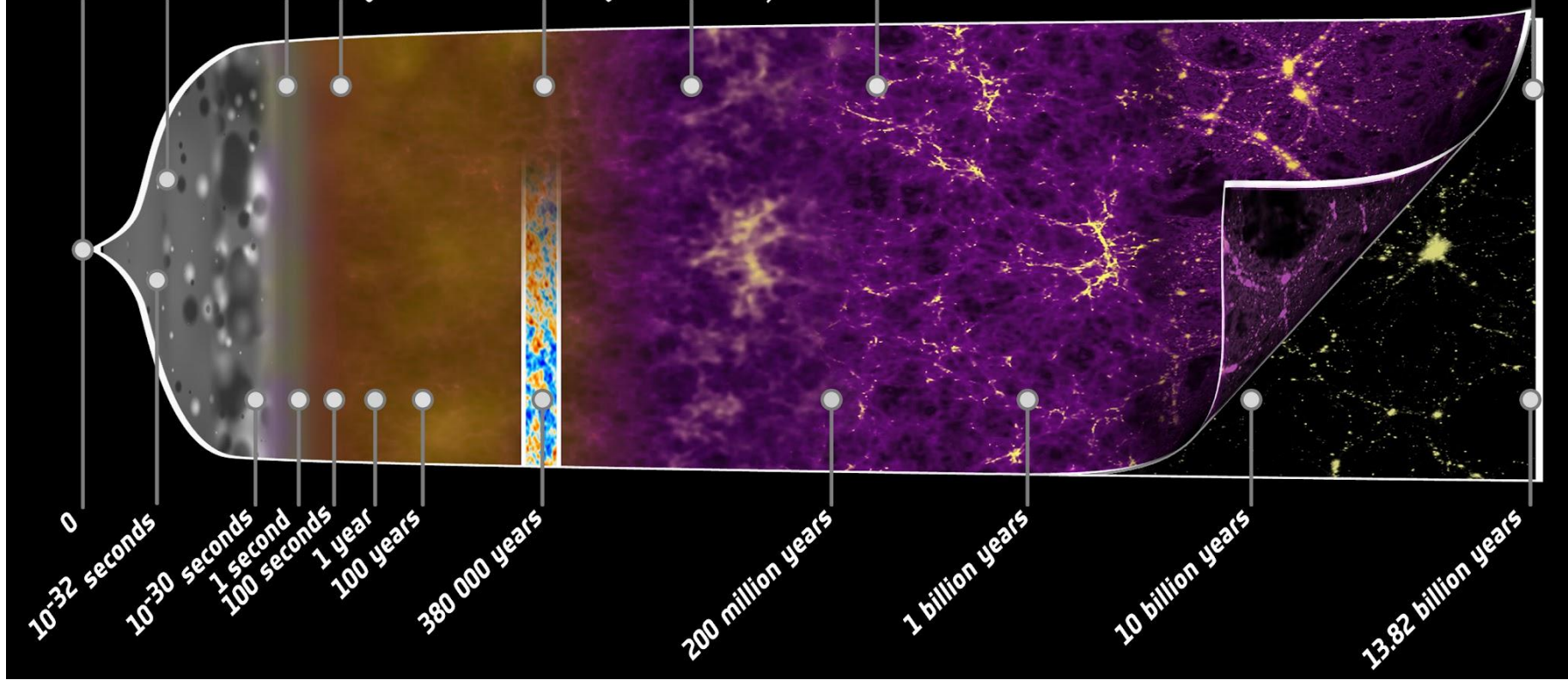
200 million years

1 billion years

10 billion years

13.82 billion years





Big Bang

Hot, ionized
Early Universe

Recombination
(CMB)

Dark Ages

Cosmic Dawn

Reionization

Today

0

10^{-32} seconds

10^{-30} seconds

1 second

100 seconds

1 year

100 years

380 000 years

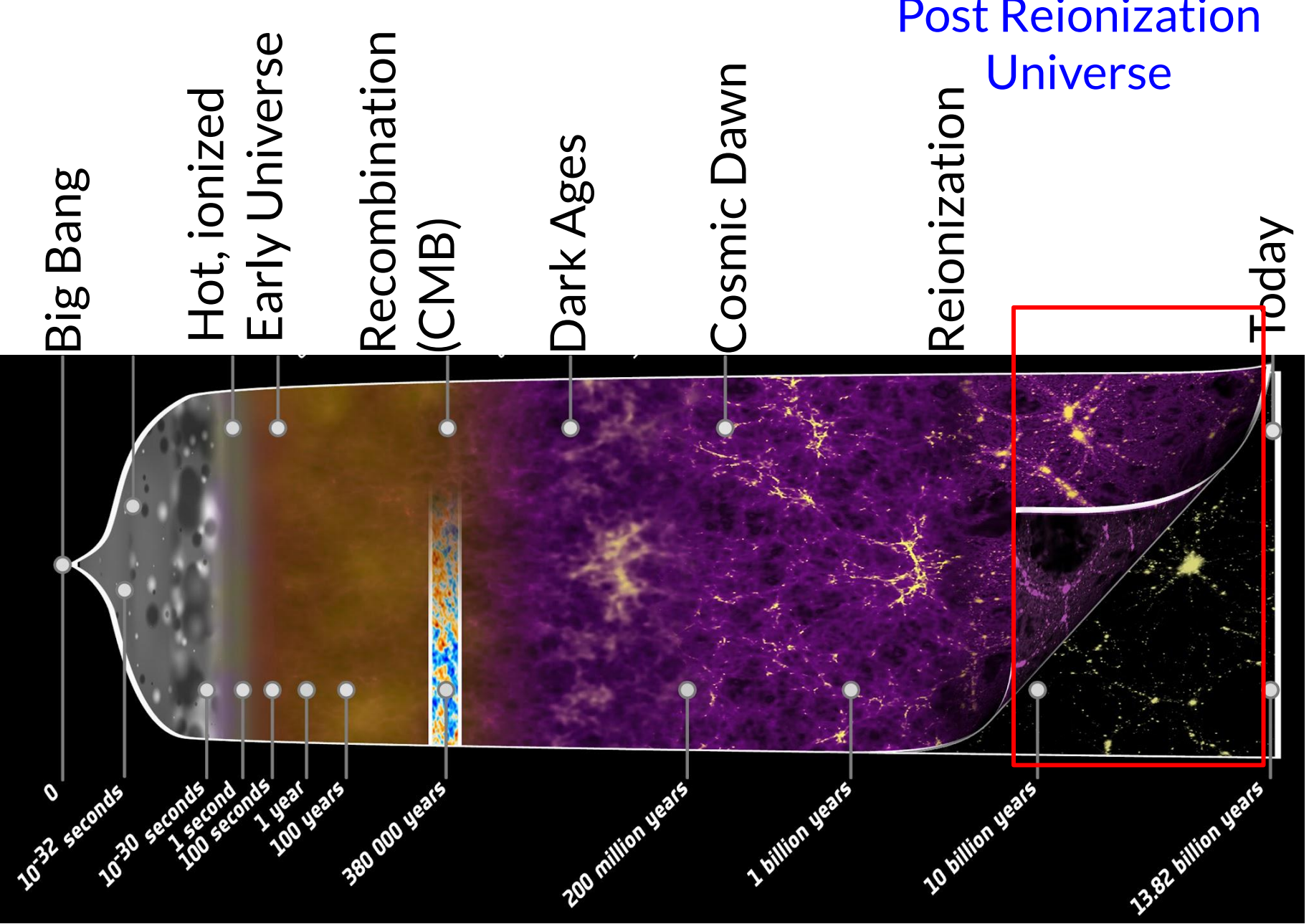
200 million years

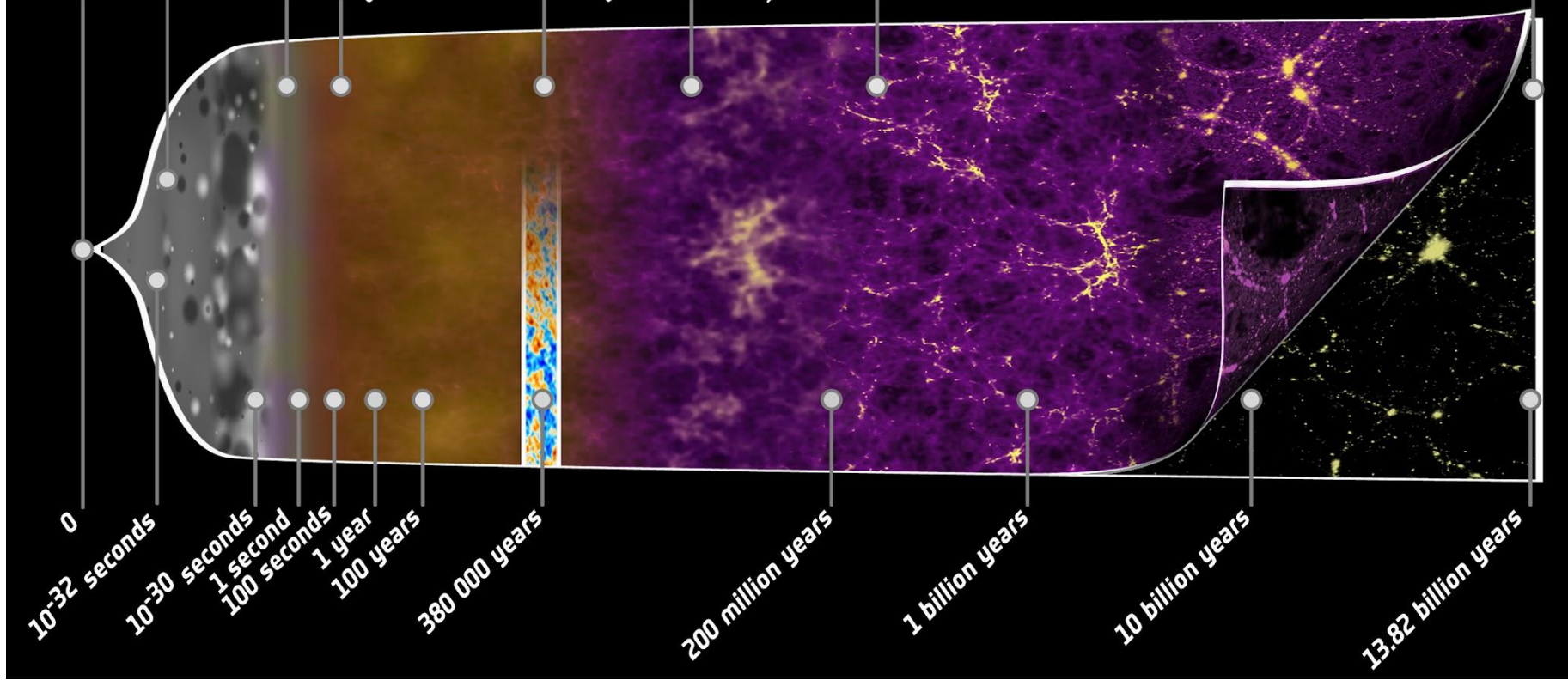
1 billion years

10 billion years

13.82 billion years

Post Reionization Universe





Big Bang

Hot, ionized
Early Universe

Recombination
(CMB)

Dark Ages

Cosmic Dawn

Reionization

Post
Reionization

Today

0

10⁻³² seconds

10⁻³⁰ seconds

1 second

100 seconds

1 year

100 years

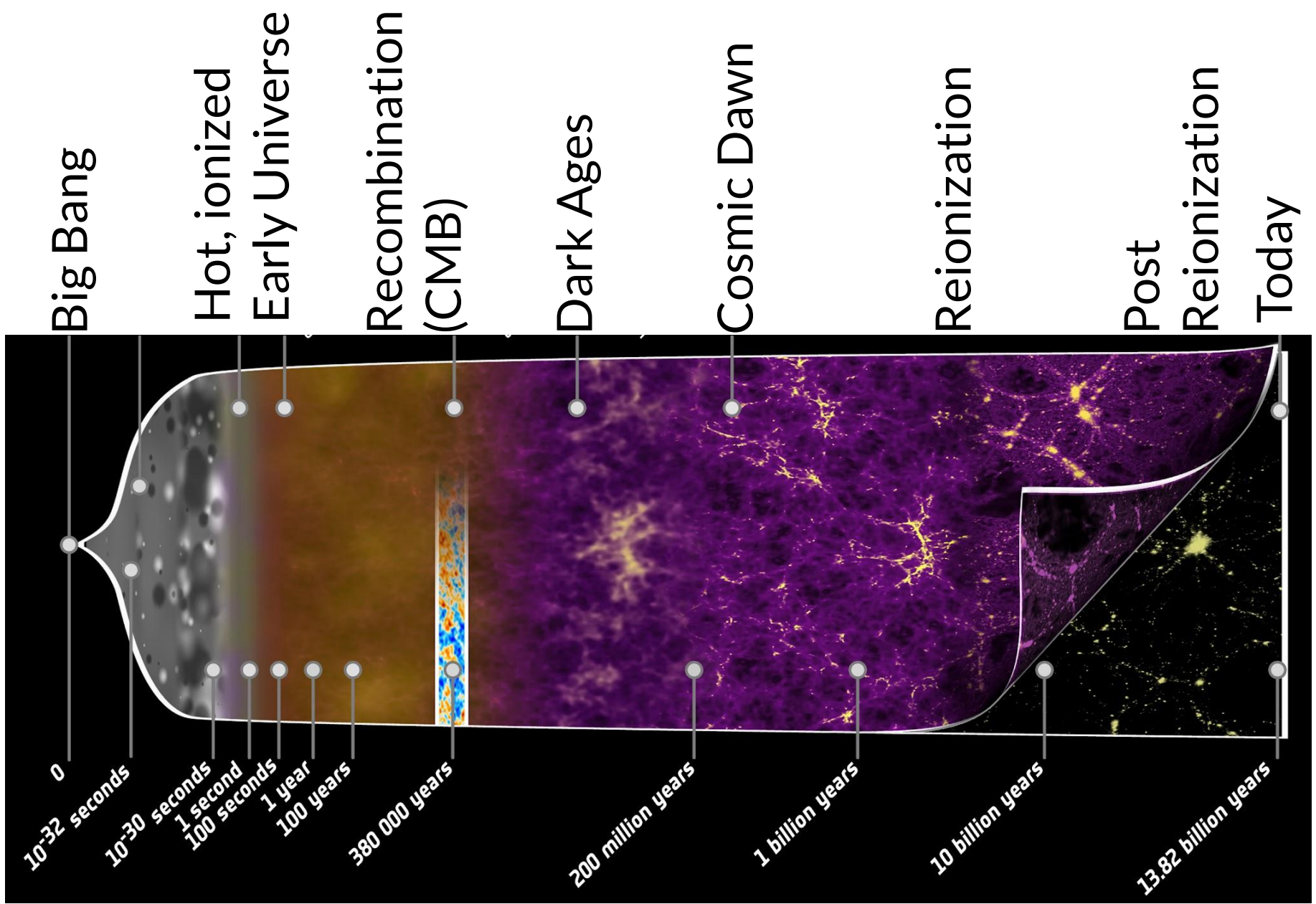
380 000 years

200 million years

1 billion years

10 billion years

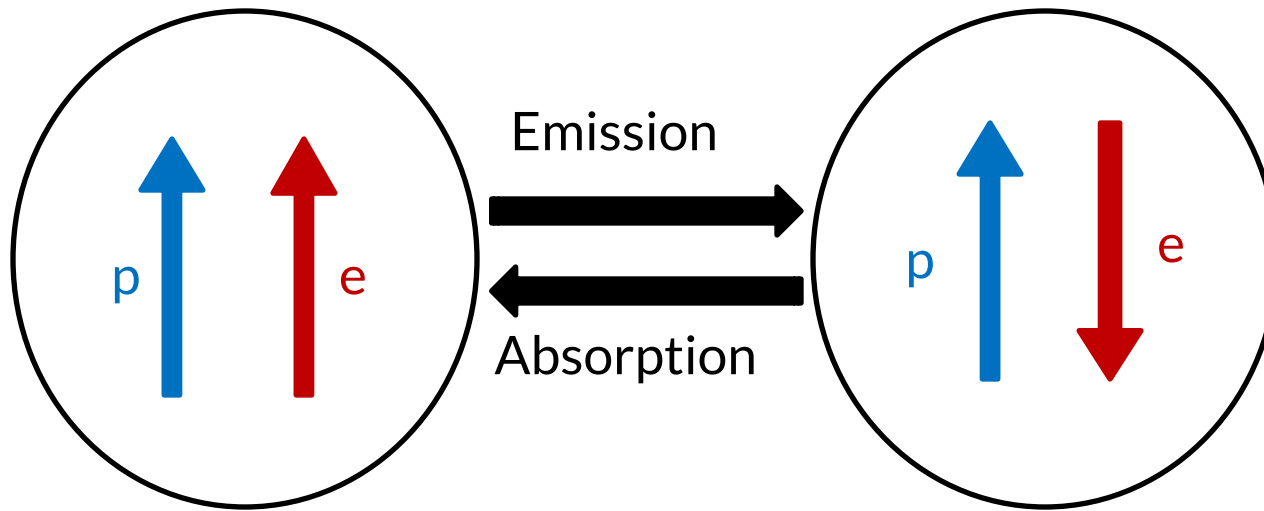
13.82 billion years



No observational evidence

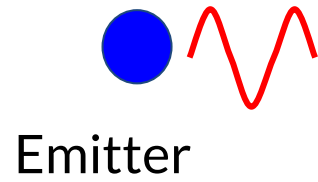
21-cm Line

21 cm / 1420 MHz

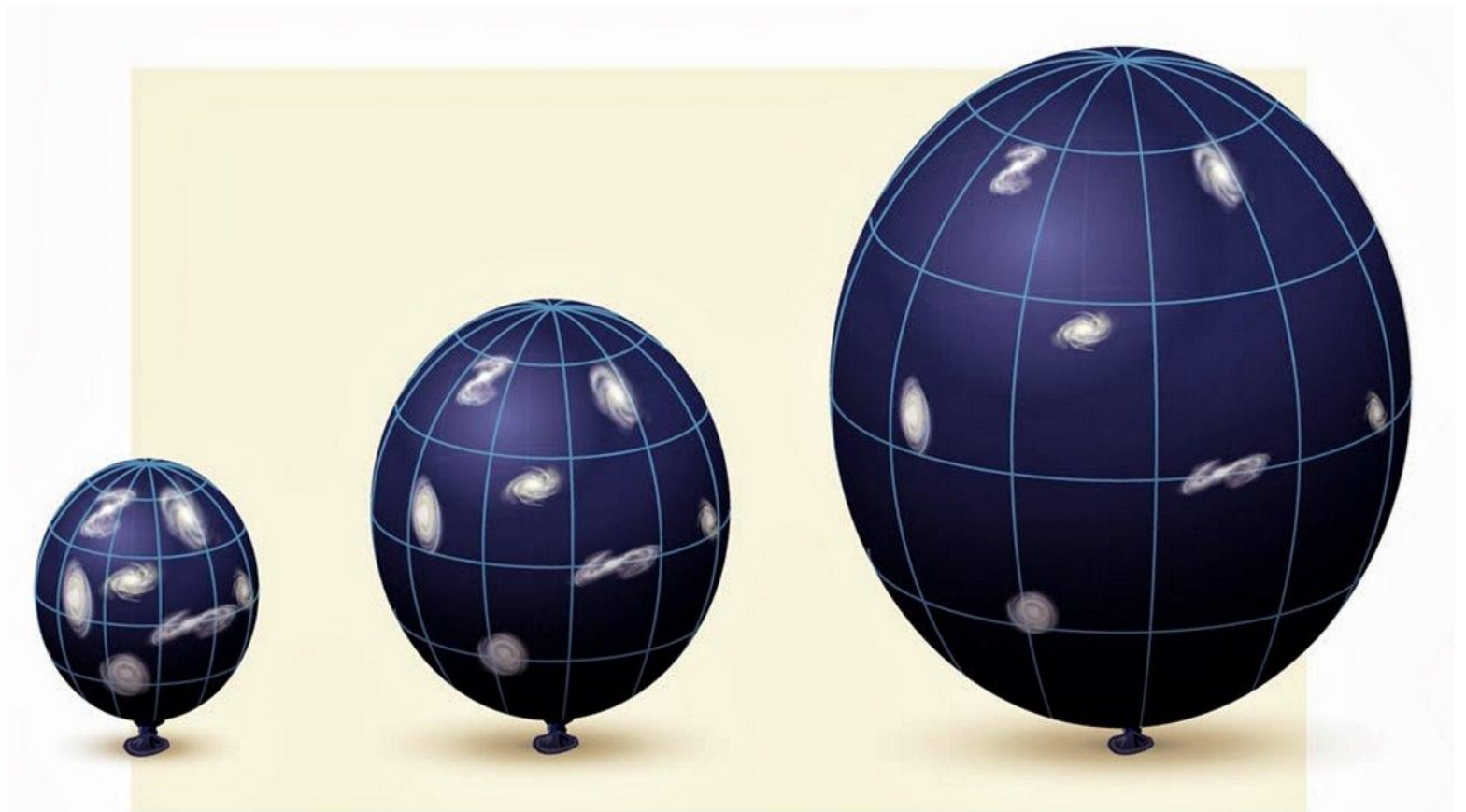
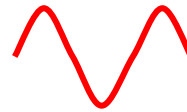


Hydrogen is the most abundant component of the Universe and can be traced through 21-cm radiation.

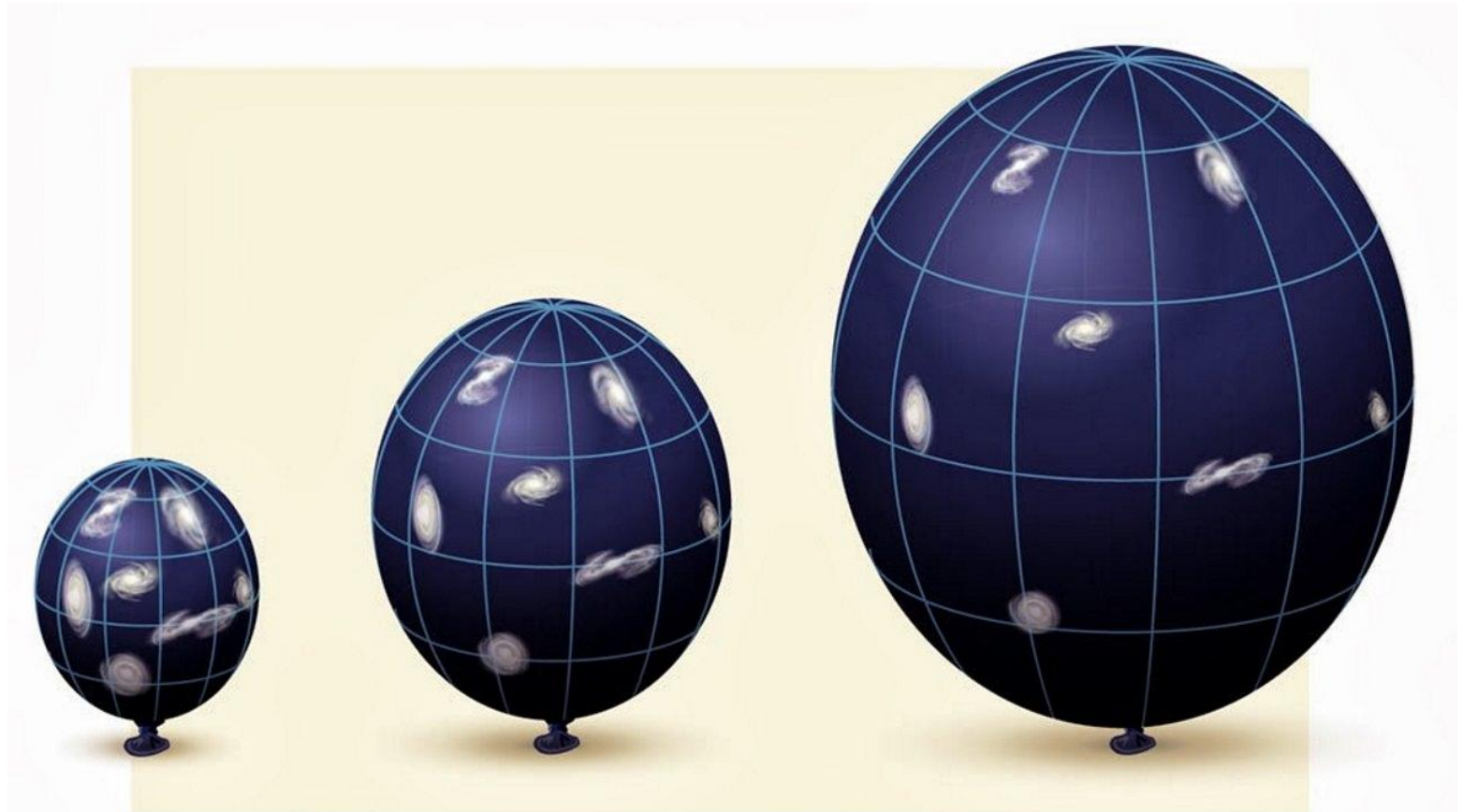
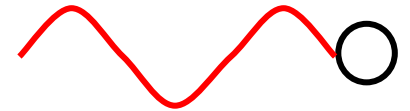
21-cm Line



21-cm Line



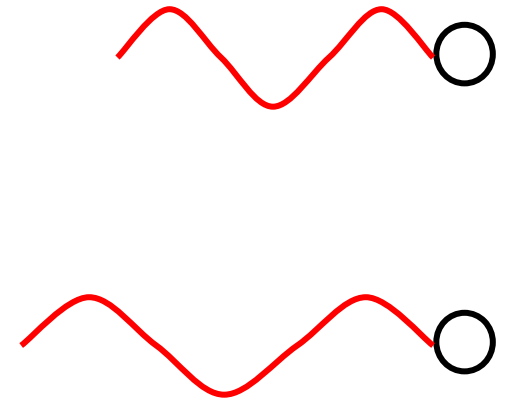
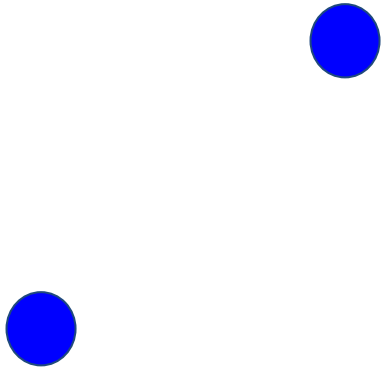
21-cm Line



21-cm Line



21-cm Line



$$\lambda_o = 21 (1+z) \text{ cm}$$

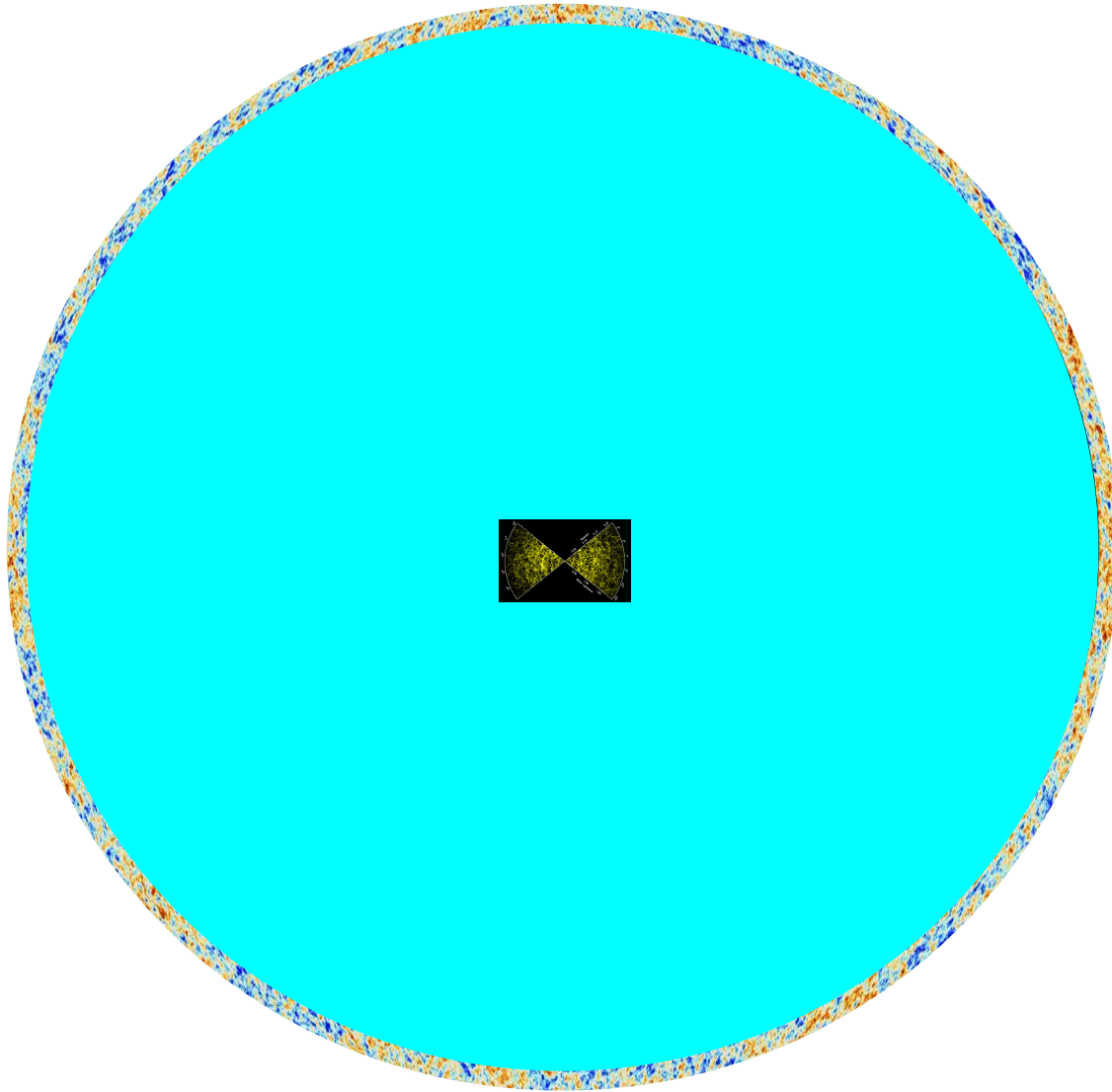
21-cm Line



$$\lambda_o = 21 (1+z) \text{ cm}$$

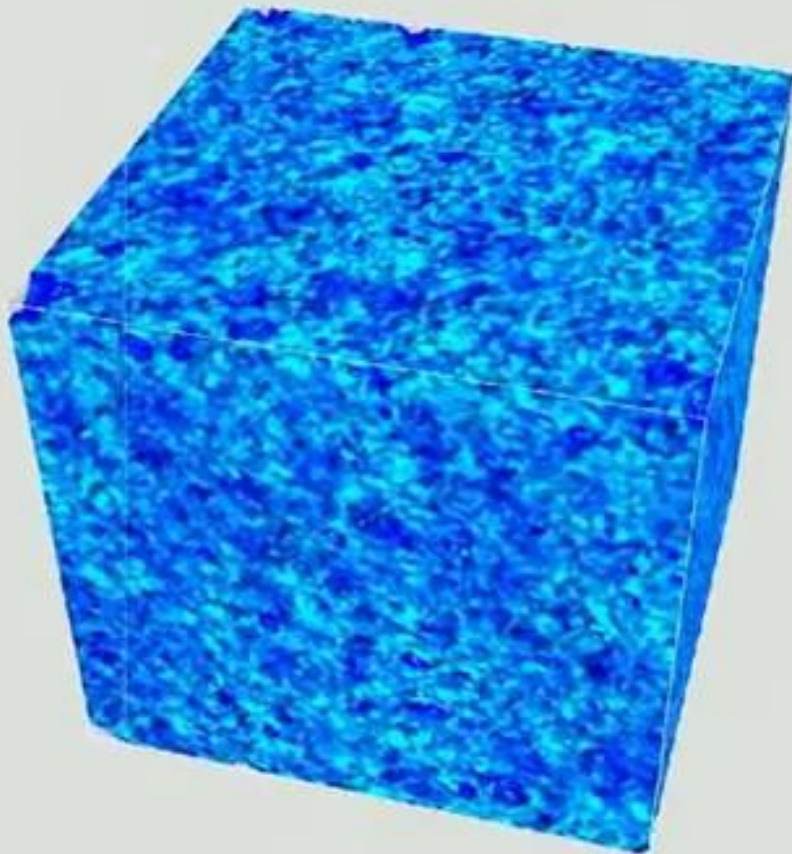
We can tune the receiver to observe the 21-cm signal from different distances.

In principle, we can see the whole evolution using 21-cm radiation.



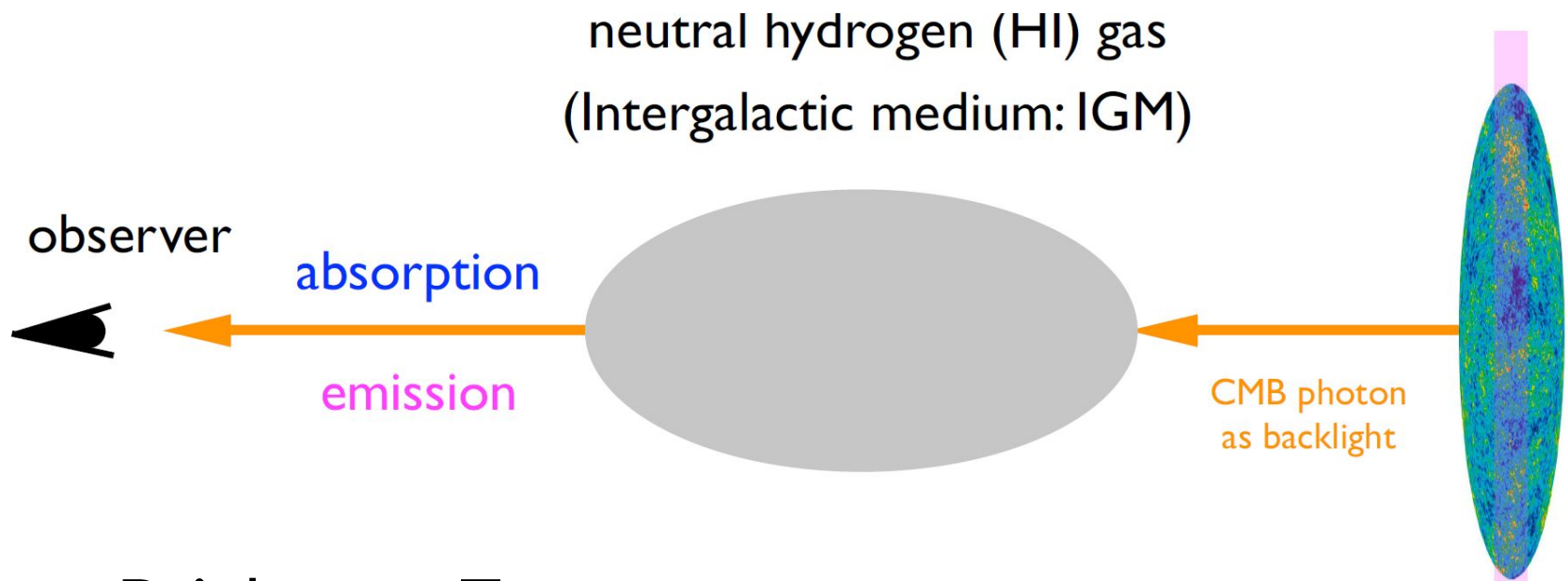
Promise of 21-cm cosmology

- ❑ Timing and duration of EoR
- ❑ Properties of EoR sources
- ❑ IGM properties
- ❑ Physical processes involved



credit: Rajesh Mondal

What do we observe?



21cm Brightness Temp

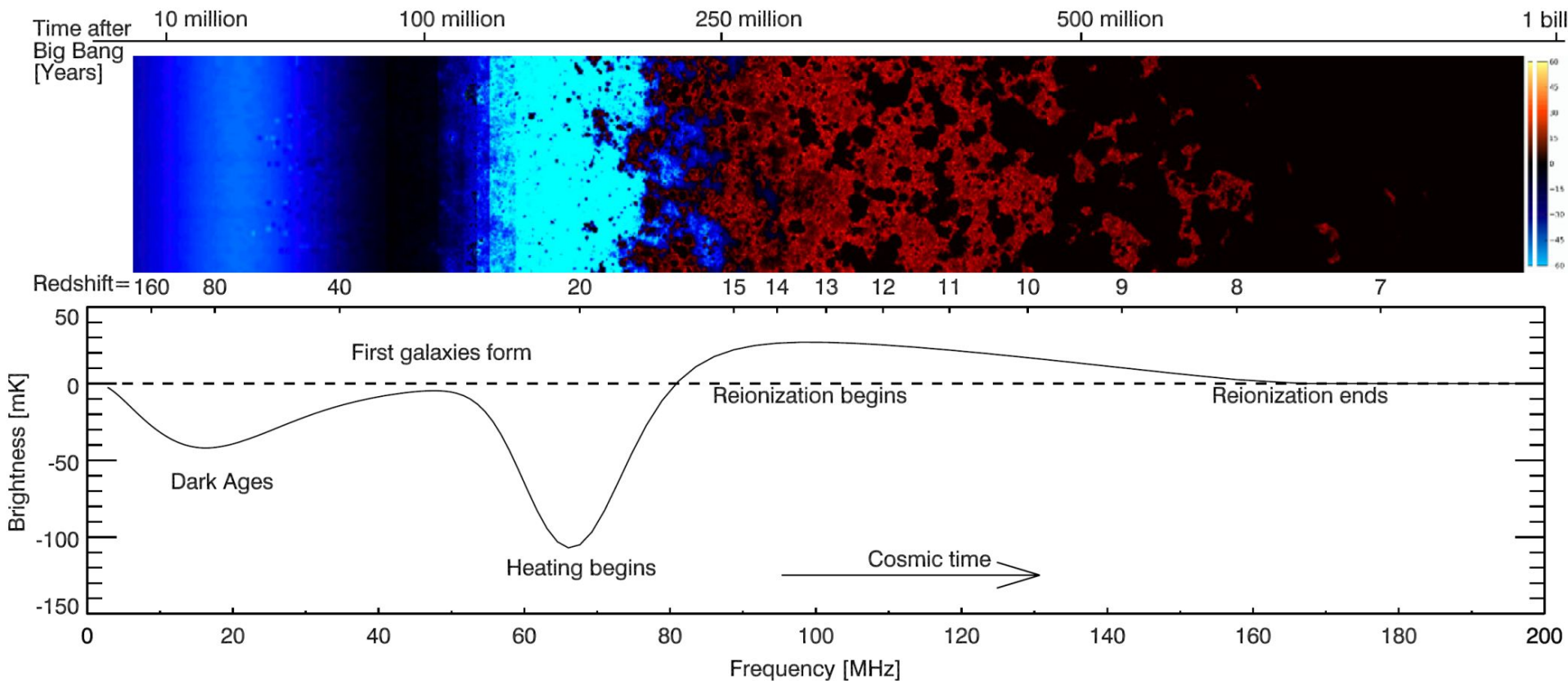
$$\delta T_b \approx 27 x_{\text{HI}} (1 + \delta_b) \left(\frac{\Omega_b h^2}{0.023} \right) \left(\frac{0.15}{\Omega_m h^2} \frac{1+z}{10} \right)^{1/2} \left(\frac{T_S - T_R}{T_S} \right) \text{mK}$$

$T_S > T_R$: Emission

$T_S < T_R$: Absorption

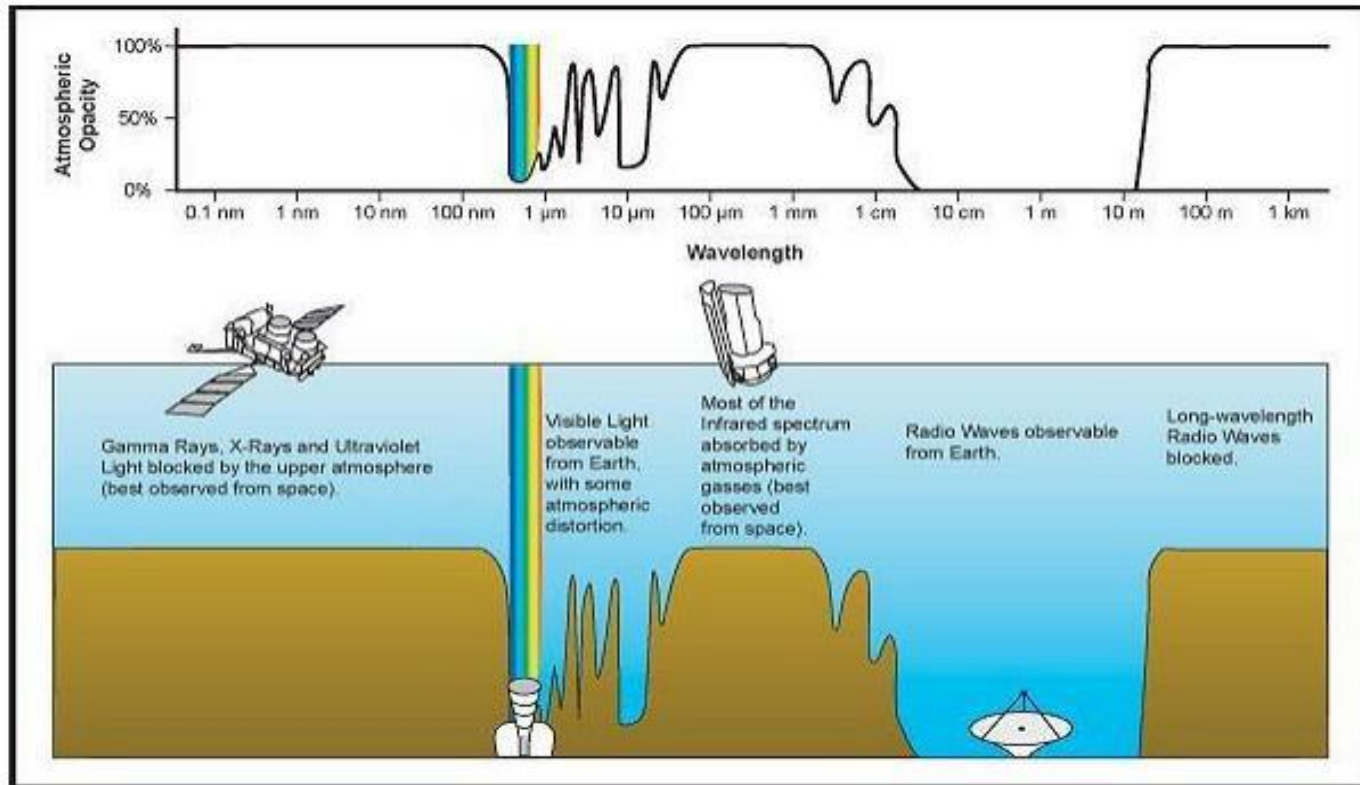
What do we observe?

21-cm Signal: Mean and Fluctuations



Towards detection of 21-cm radiation

Atmospheric Transmission



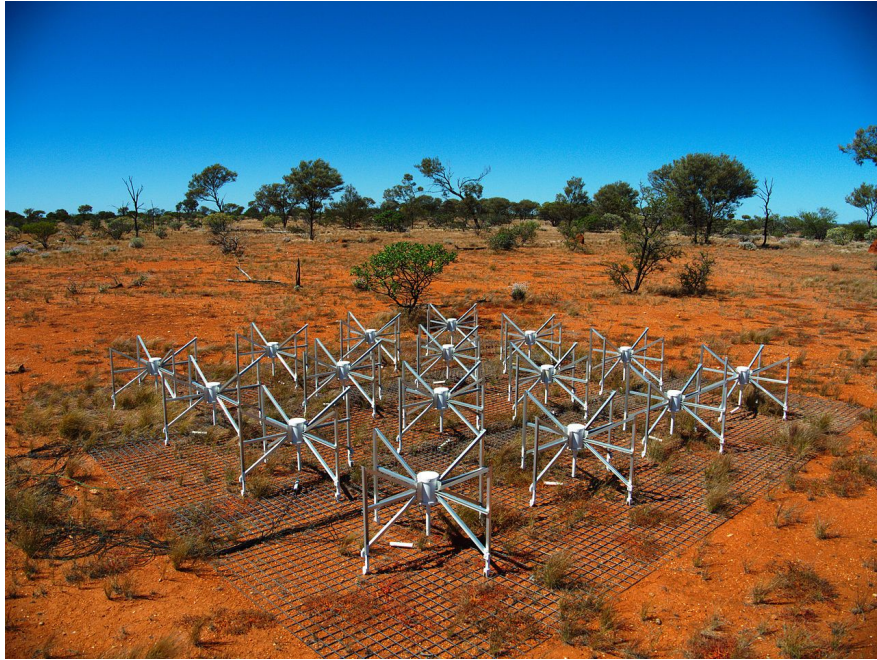
- The 21 cm spectral line appears within the radio spectrum.
- can easily pass through the Earth's atmosphere.

Radio Interferometer

GMRT

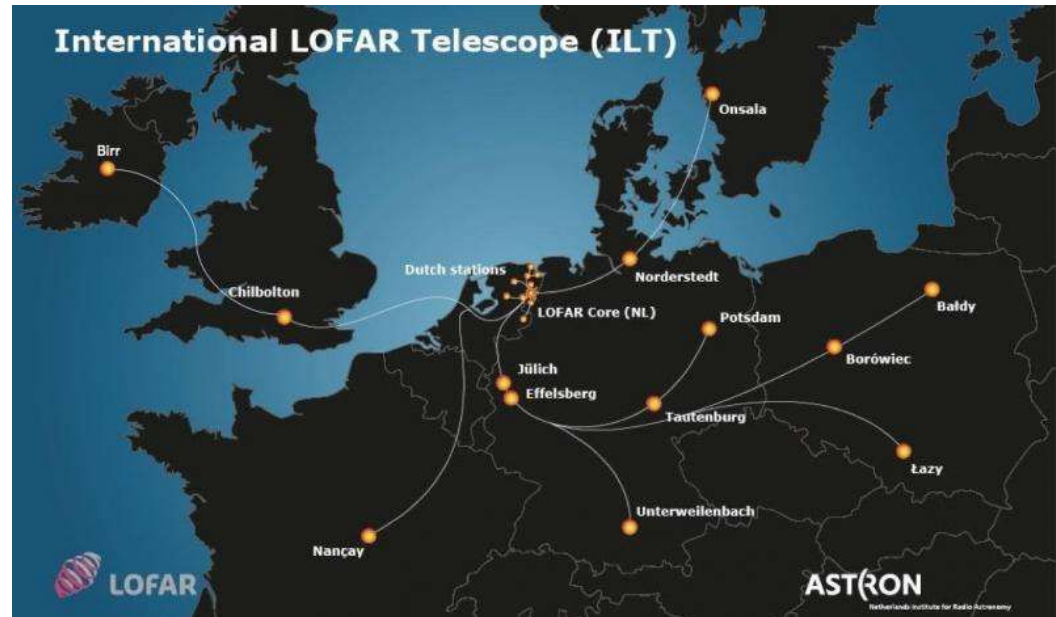


MWA

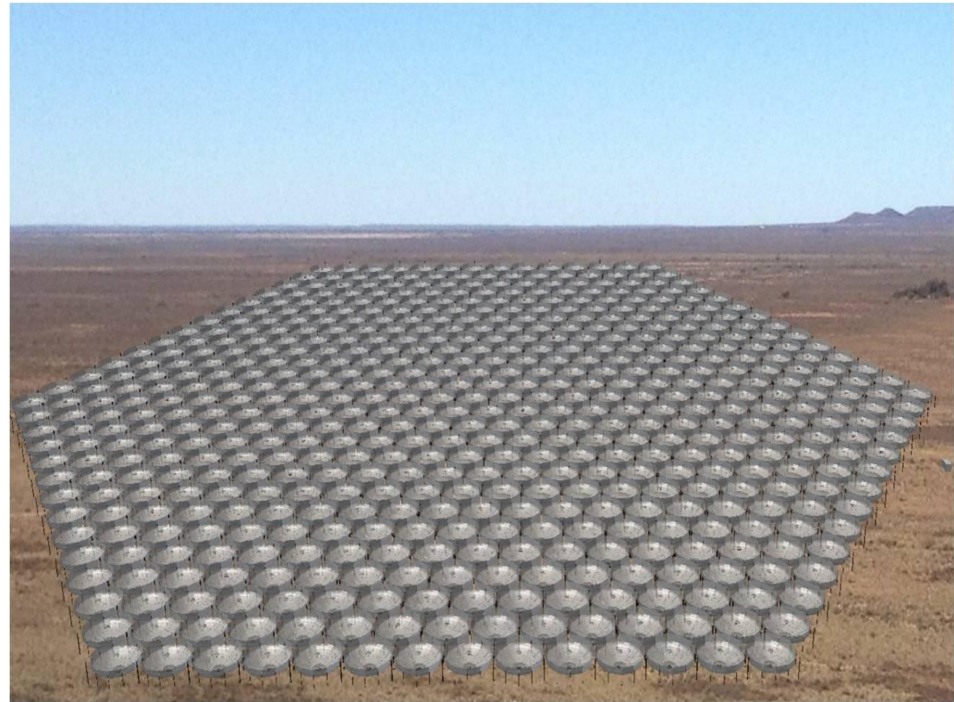


- 256-elements, 70 - 300 MHz

LOFAR



HERA



HERA collaboration 2021

Future Telescopes

OWFA



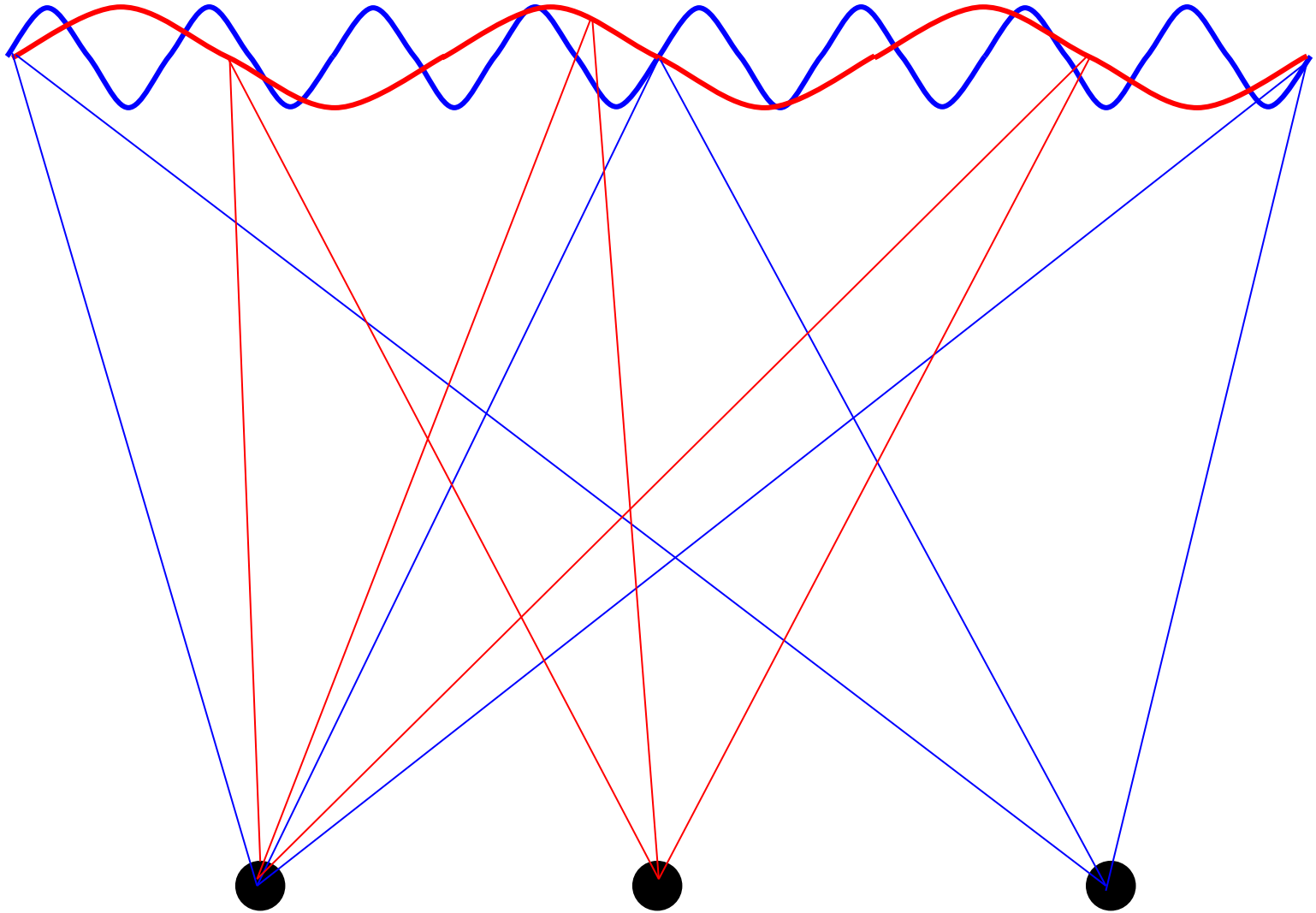
Future Telescopes

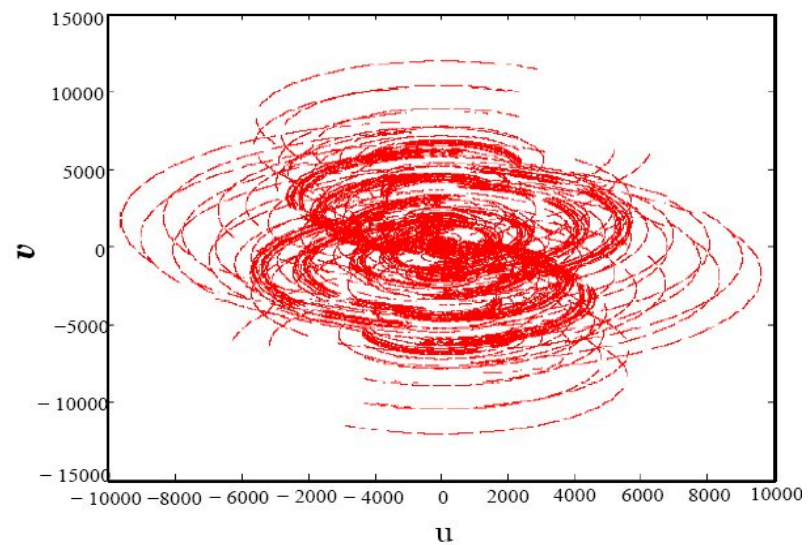
Square Kilometre Array





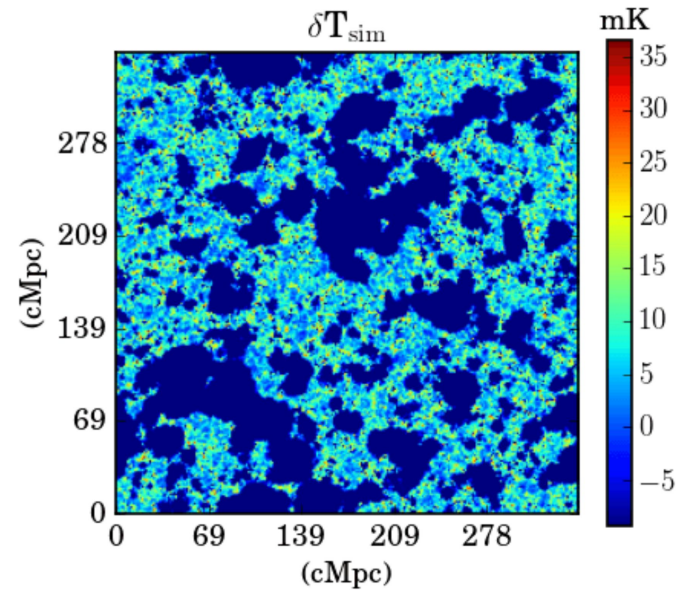
Radio Interferometers measure the different Fourier modes of the sky.
longer wavelength \sim short baselines





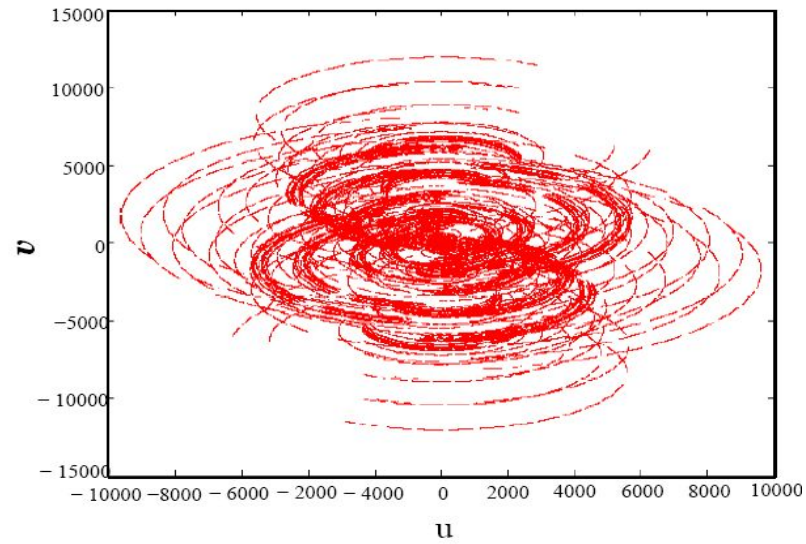
Fourier modes

IFT
→



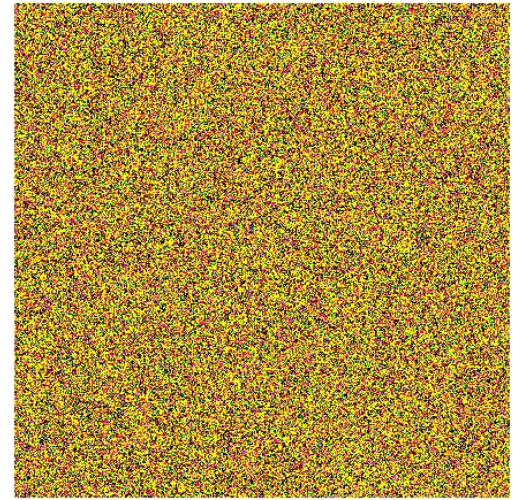
21-cm Signal

Challenges: Noise



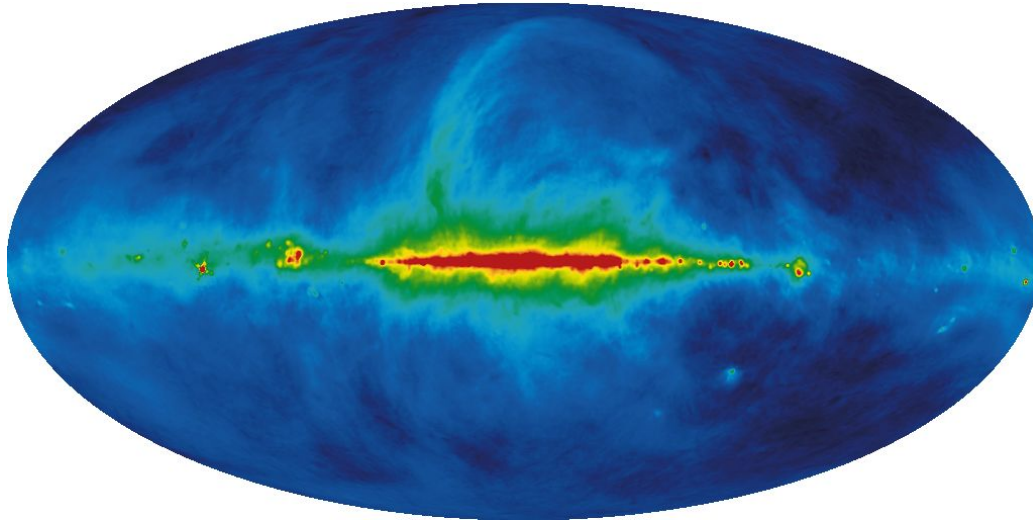
Fourier modes

IFT
→

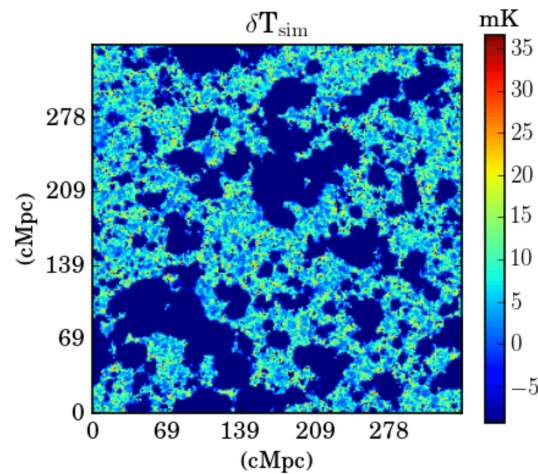


Noise

Challenges: Foregrounds



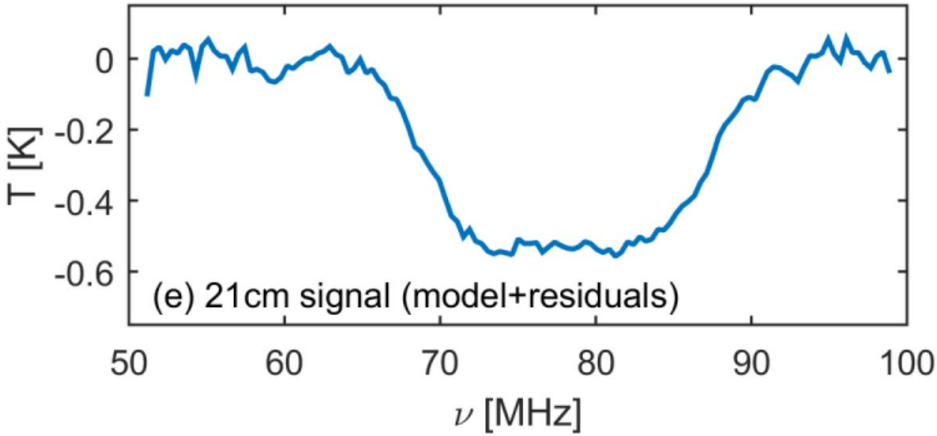
$\sim 10^{10} \text{ mK}^2$



$\sim 10 \text{ mK}^2$

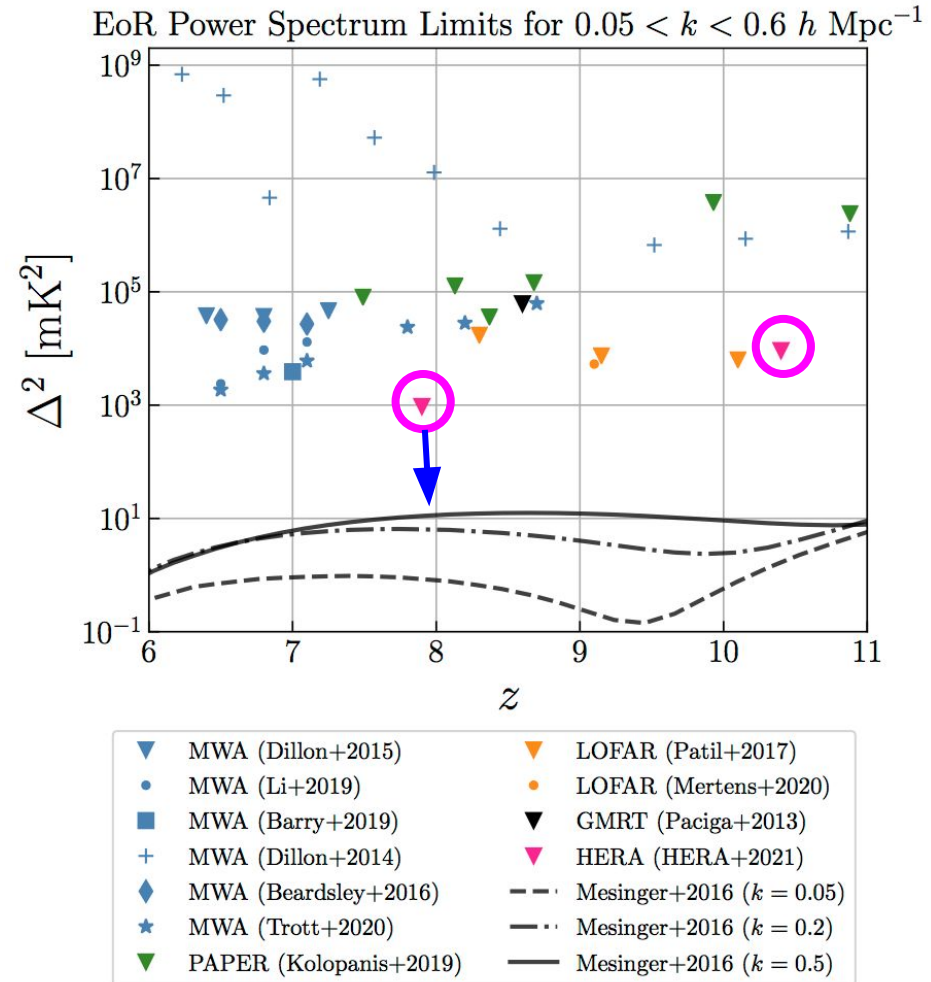
Toward Detection

Exciting detection of 21cm absorption at $z=17$!



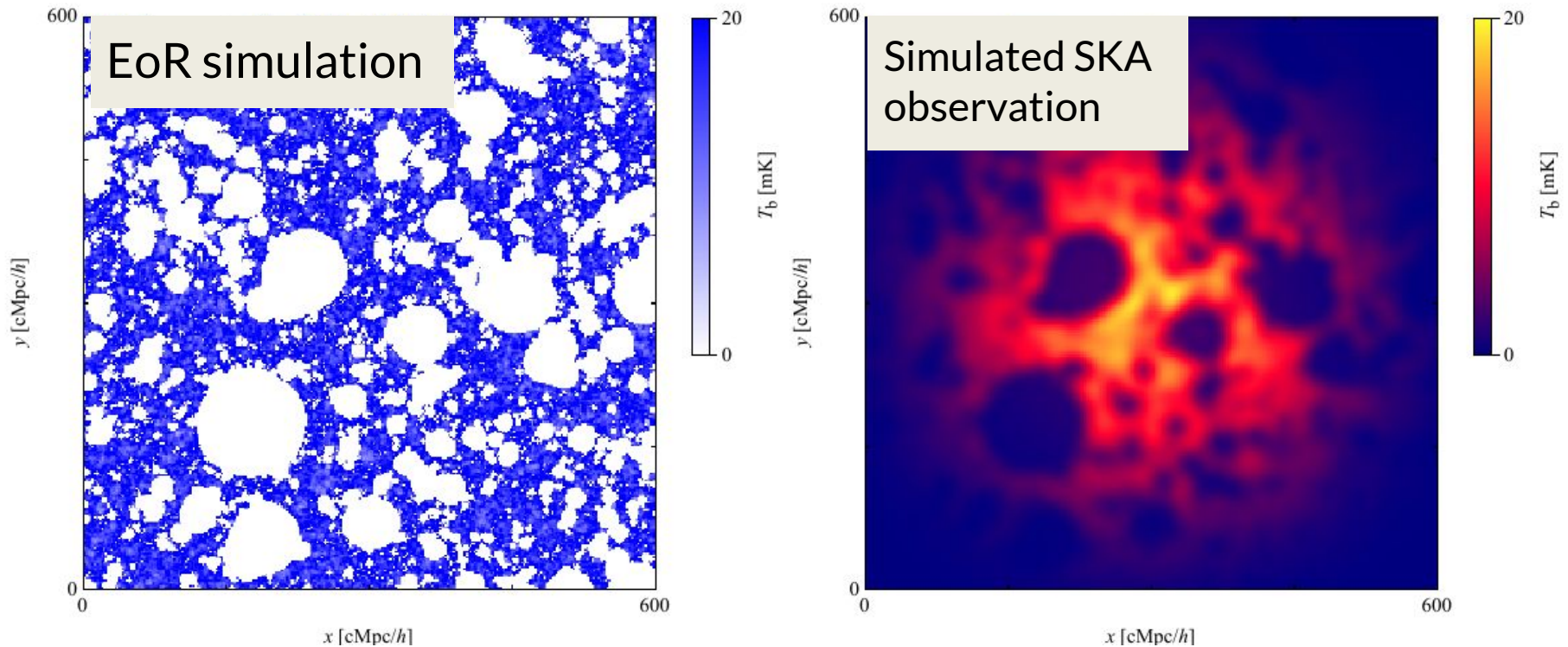
EDGES in Western Australia
Bowman et al 2018, Nature, 555, 67

Best-ever upper-limit on statistical signal (HERA)



Karoo Desert in SA
HERA collaboration, ApJ, 2021

Square Kilometre Array (SKA): A global effort



- SKA: Next-generation radio array in South Africa + Australia
- ***SKA will be able to directly image the first ionized regions!***
- India is a part of the SKA of organization.

Summary

- 21-cm radiation is an important tool to study the evolution of the Universe.
- 21-cm cosmology is a growing research field in radio astronomy.
- People across the globe are trying to detect this faint 21-cm signal with sensitive instruments.
- Future radio telescopes (HERA and SKA) will be able to constrain the underlying physics of the Universe accurately.

Thank You