Epoch of Reionization 21 cm Signal in Redshift Space

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Collaborators

& LOFAR Reionization Group

The Epoch of Reionization: An Introduction

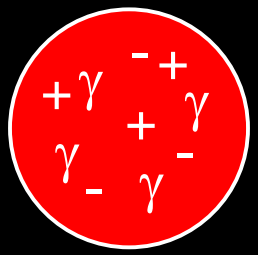
Big bang

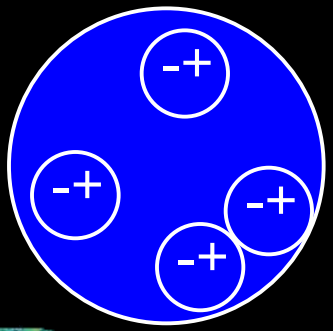
Present Universe

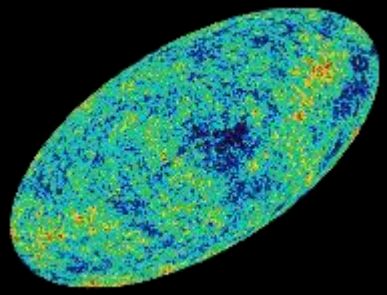
The Epoch of Reionization: An Introduction

Big bang

Present Universe





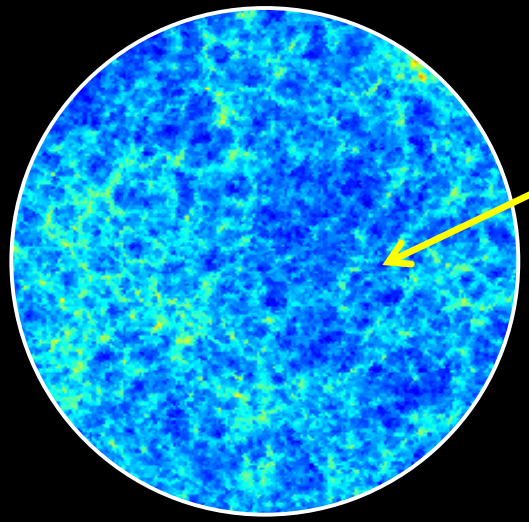


CMB

The Epoch of Reionization: An Introduction

Big bang

Dark Ages

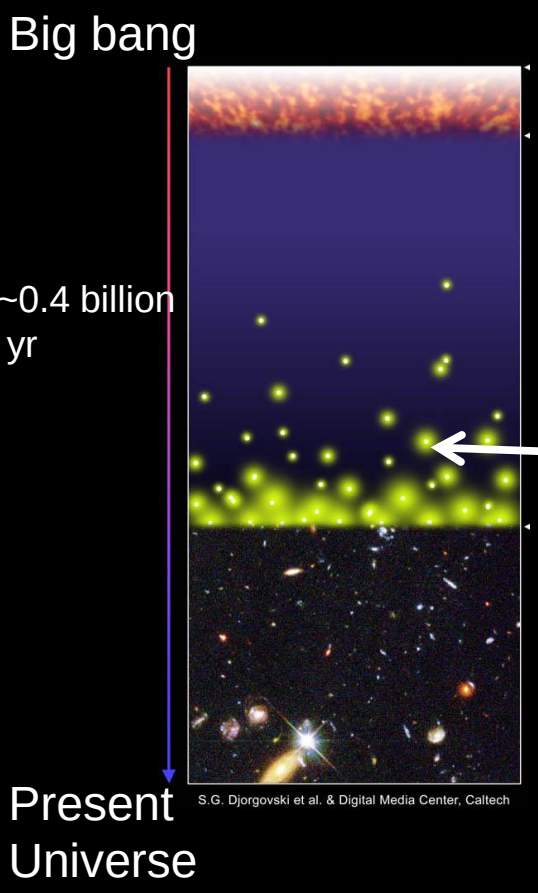


Neutral Hydrogen + Helium

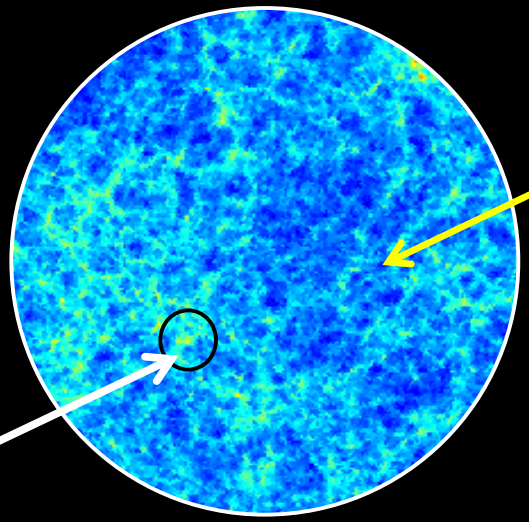
Dark Ages: no source of visible light

Protons and electrons combined to form neutral Hydrogen (75%) and Hellium (24%) atoms

The Epoch of Reionization: An Introduction



Dark Ages



Neutral Hydrogen + Helium

Source of ionizing photons

Sources of First Light –star, QSO etc

The Epoch of Reionization: An Introduction

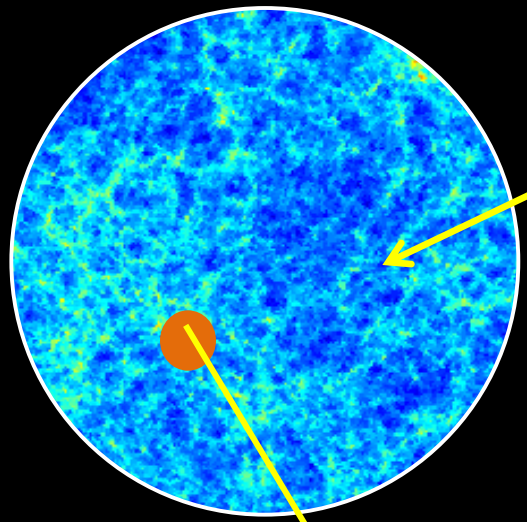
Big bang

~0.4 billion yr

Dark Ages

Present Universe

S.G. Djorgovski et al. & Digital Media Center, Caltech



Neutral Hydrogen
+
Helium

Ionized Hydrogen

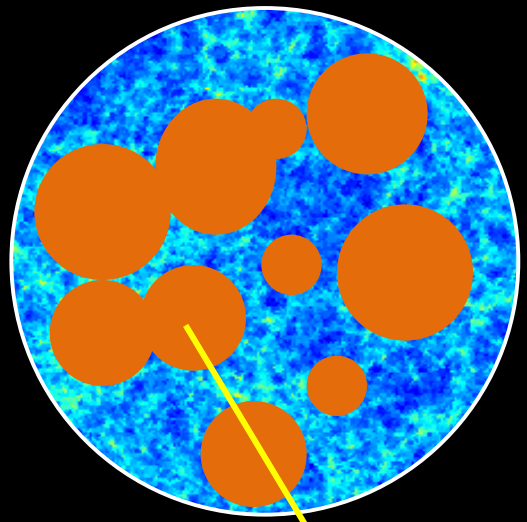
The Epoch of Reionization: An Introduction

Big bang

~0.4 billion yr

Dark Ages

Present Universe



Ionized Hydrogen

The Epoch of Reionization: An Introduction

Big bang

~0.4 billion yr

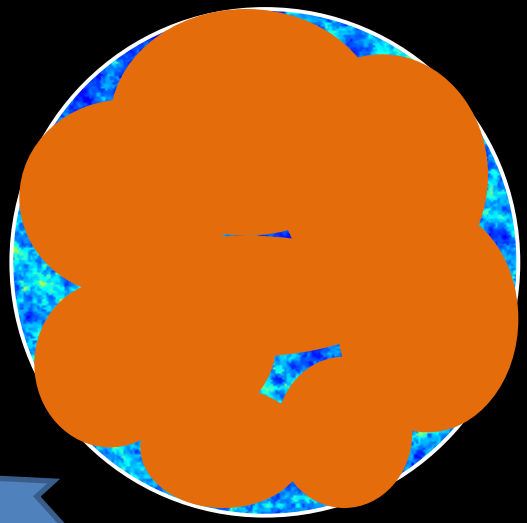
Dark Ages

Epoch of Reionization

~ 1 Billion year

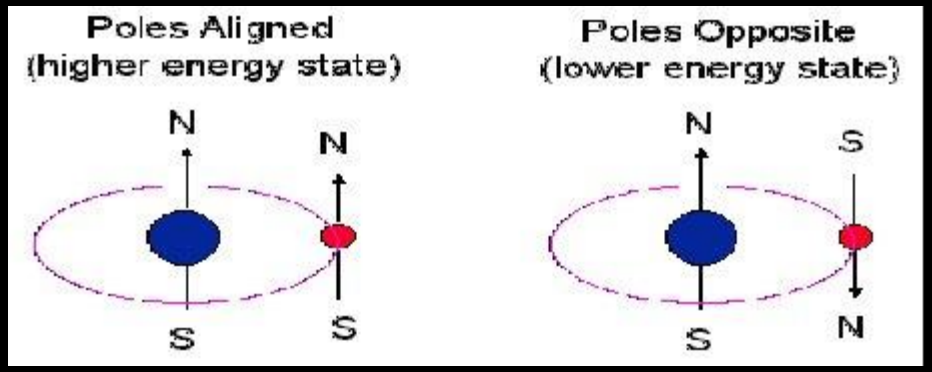
~ 14 Billion year

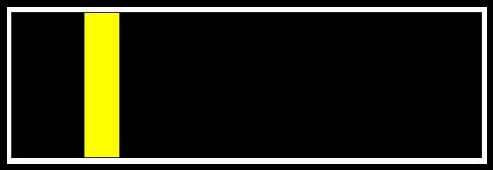
Present Universe



An important missing link

Radio Signal : Redshifted 21 cm tomography (1.5 -3 meter)





21 cm (1420 MHz)

Neutral Hydrogen (HI) atom

Redshifts

$$z = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}}$$

$$\nu_o = 1420 \text{ Mhz } / (1+z) \qquad \lambda_o = 21 \text{ cm } (1+z)$$

15> z > 6

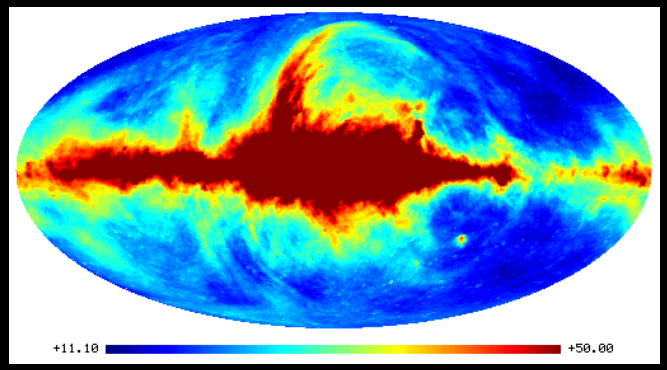
Challenges (See Sk. Saiyad Ali's talk)

Foregrounds

Galctic synchrotron

Extra-galactic radio sources etc.

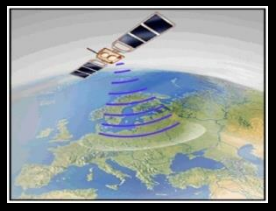
(1000-10,000 times stronger than Reionization 21 cm signal)



Turbulent Ionoshpere

Instrumental noise

Man made signal:



Experiments

LOFAR: LOw Frequency ARray (Netherlands -Europe)
GMRT : Giant Metrewave Radio Telescope (India)
MWA : Murchison Widefield Array (Australia)
PAPER: Precision Array for Probing Epoch of Reionization (US)
SKA : Square Kilometer Array (International)

Reionization Simulations

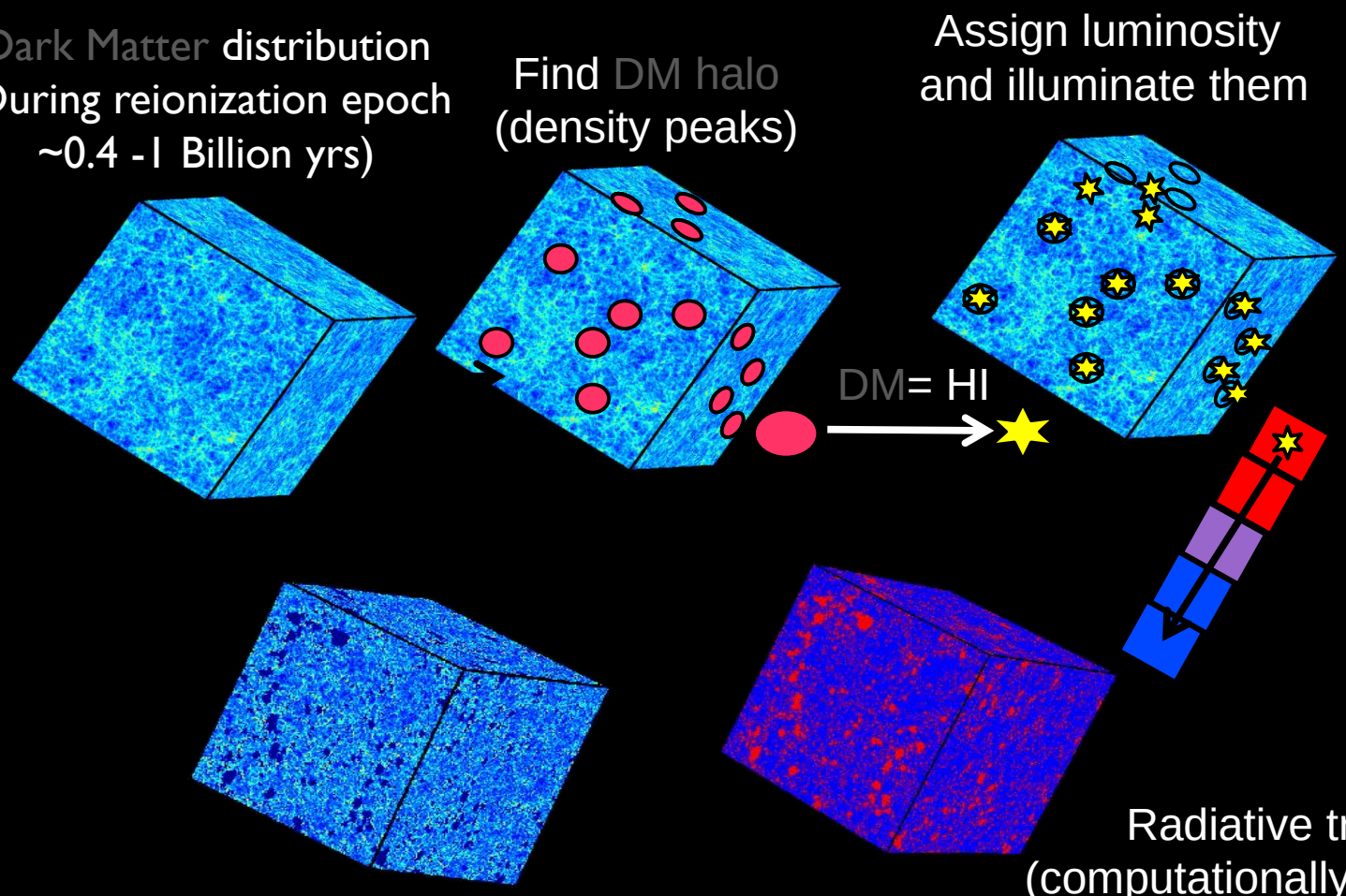
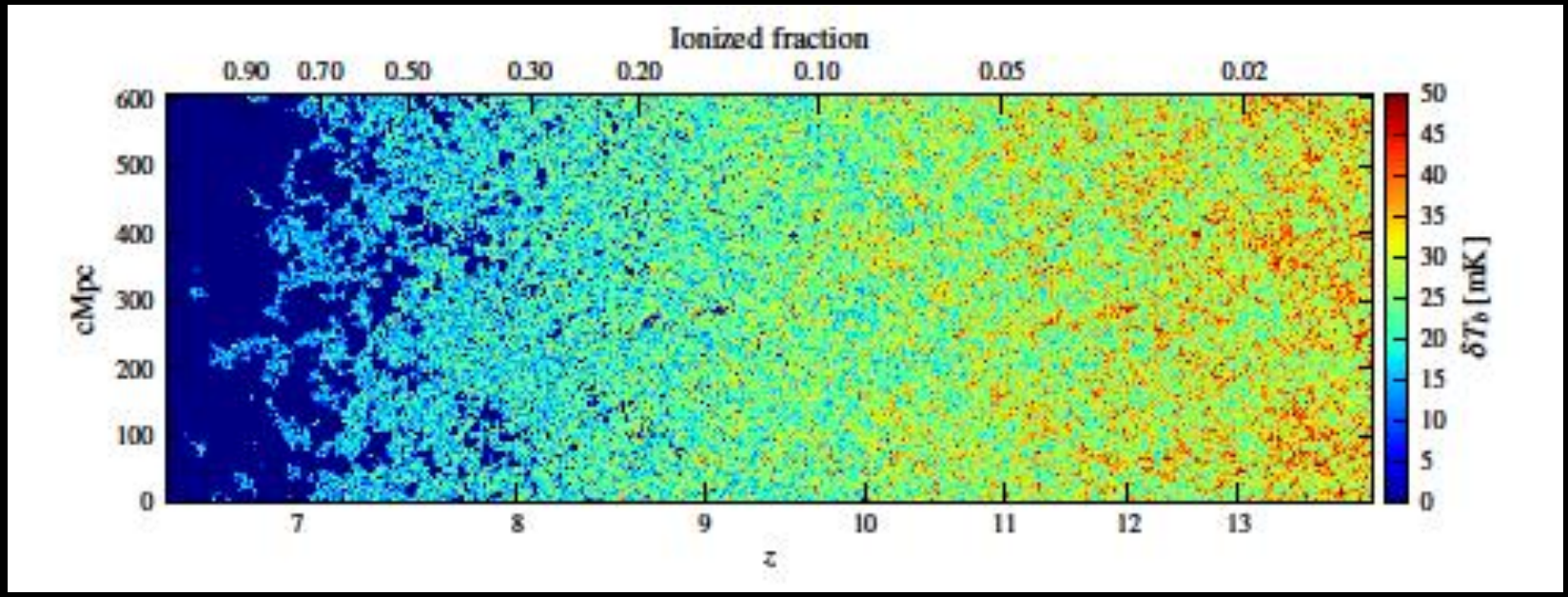
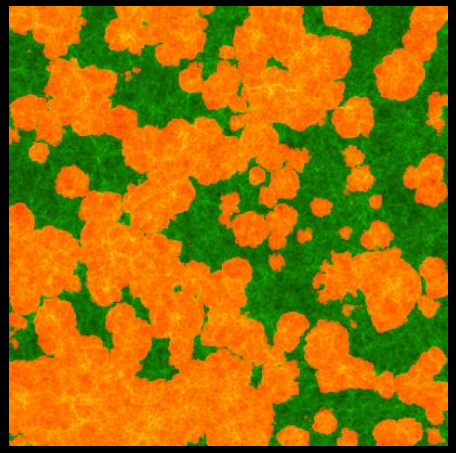


Figure credit: Martina Friedrich

Reionization Simulations

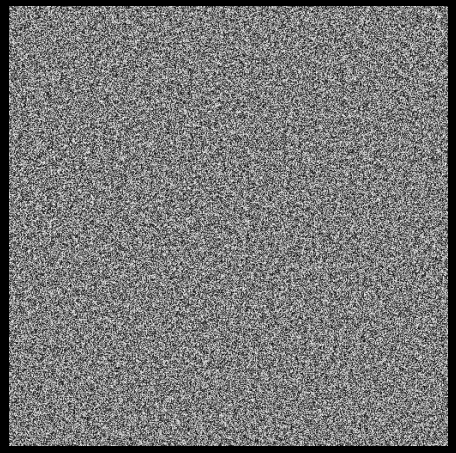


21 cm signal



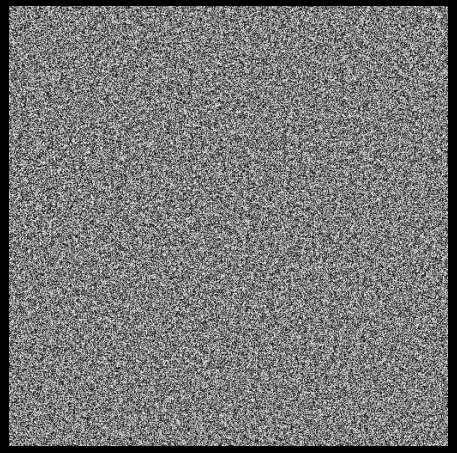
Signal rms ~ 5 -10 mK

Instrument Noise



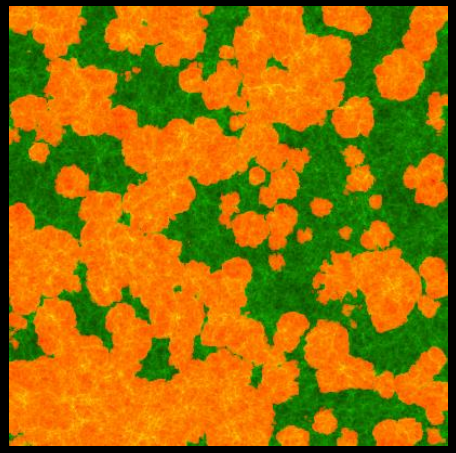
Noise rms ~ 70 -100 mK

Signal+Noise



~~Imaging~~

21 cm signal



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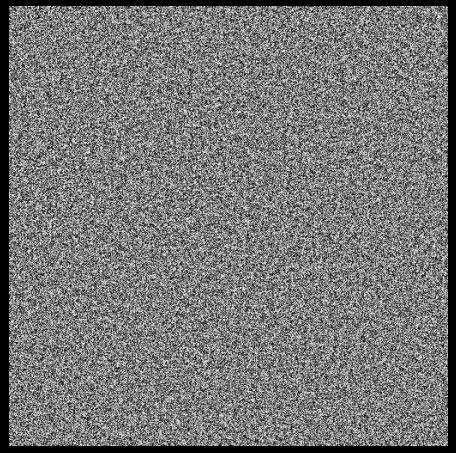

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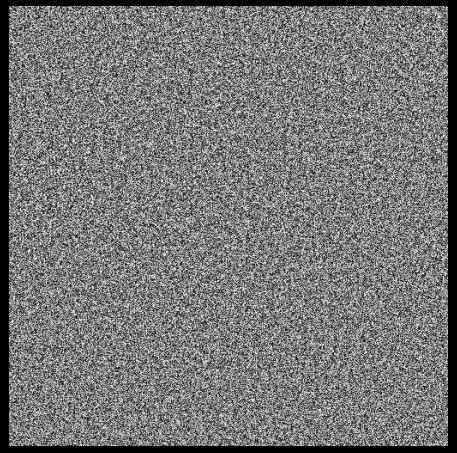
Signal+Noise

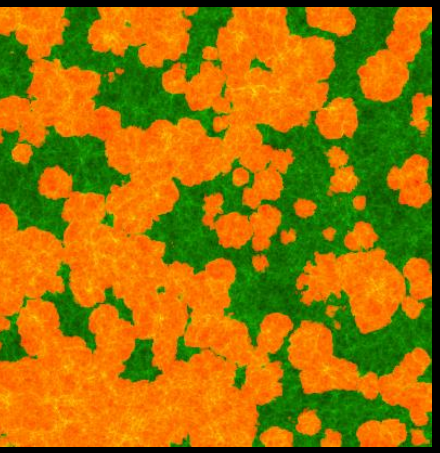


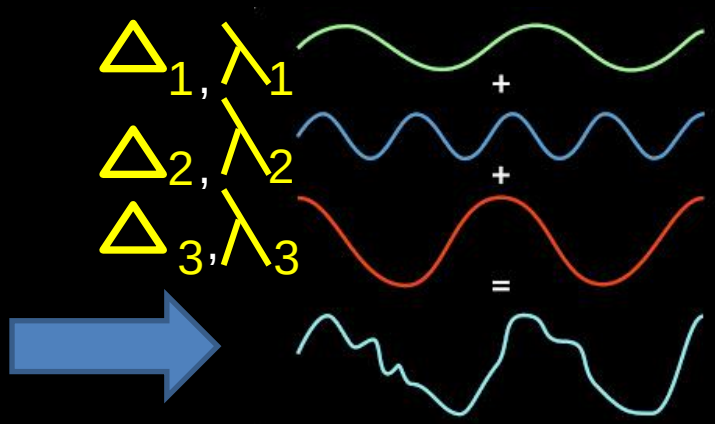
~~Imaging~~

Statistical detection of 21 cm signal has been proposed !!!

21 cm Power Spectrum

- GMRT (also LOFAR, MWA etc) will try to measure reionization 21 cm power spectrum.



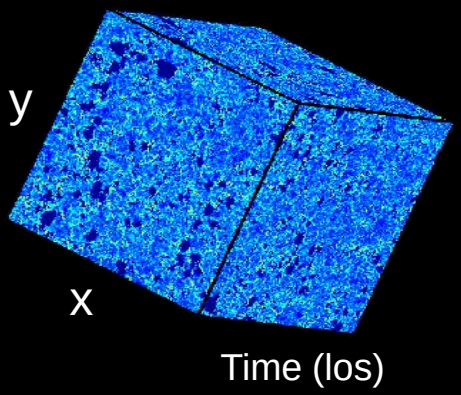


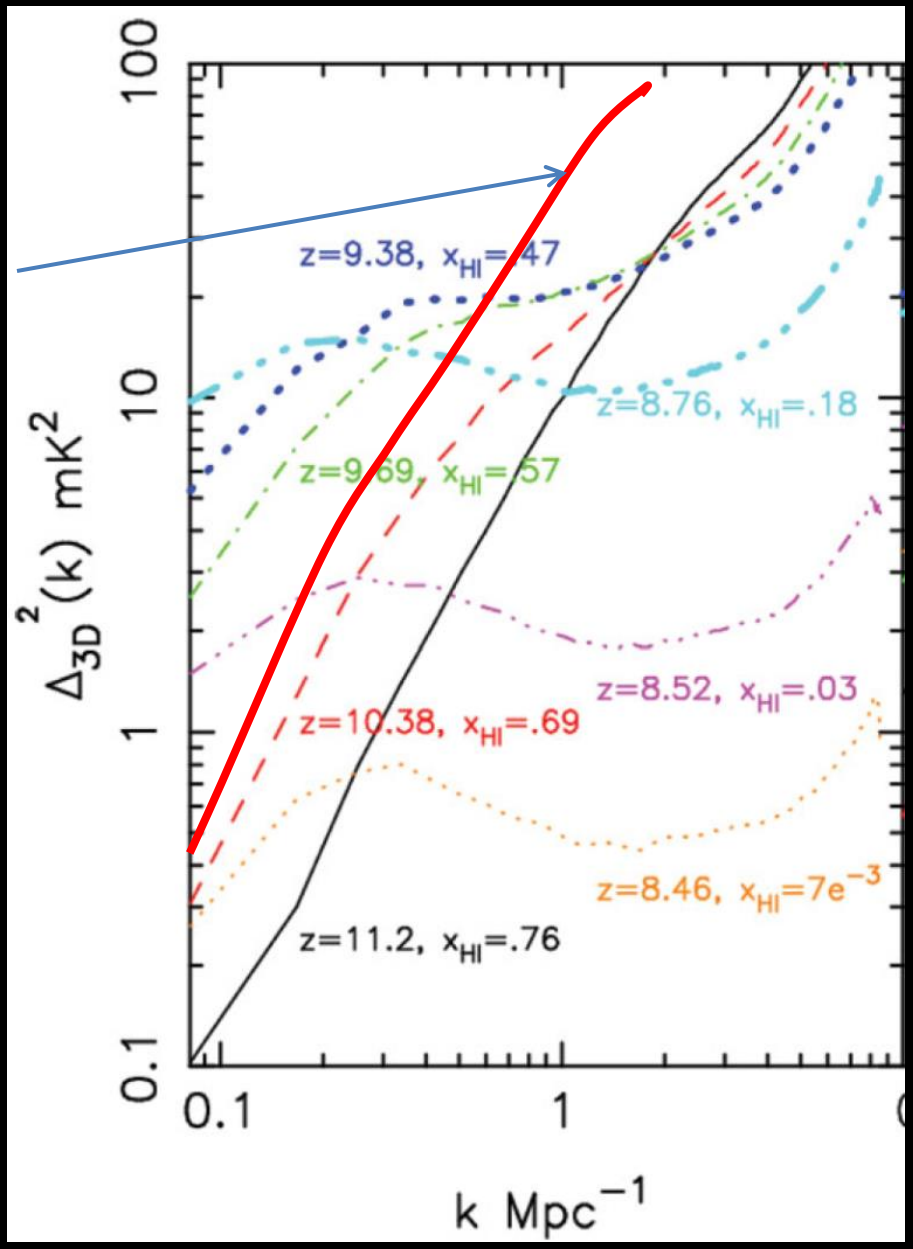
Decompose into different fourier modes

$$P(k) = \langle \Delta^2(k) \rangle$$

$$k = 2\pi / \lambda$$

Spherically Averaged Power Spectrum



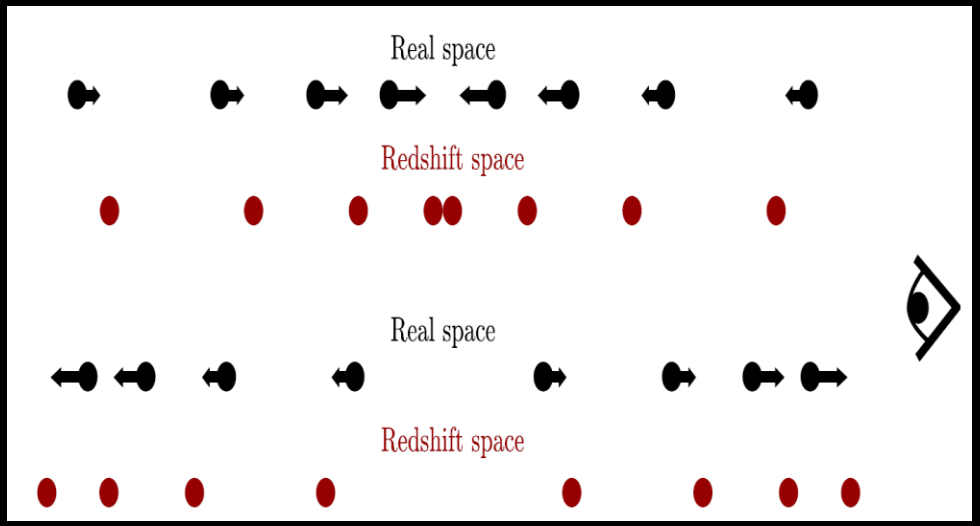


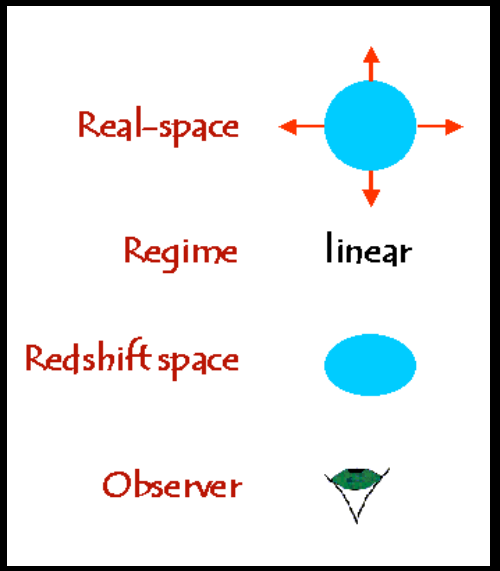
Datta, K.K, Mellema, G., Mao, Y. et al, MNRAS, 2012, 424, 1877

21 cm Power Spectrum in Redshift Space

Experiments measure redshift caused by moving objects. Redshift is higher for distant objects.

Distance = f (redshift) **-Hubble law**

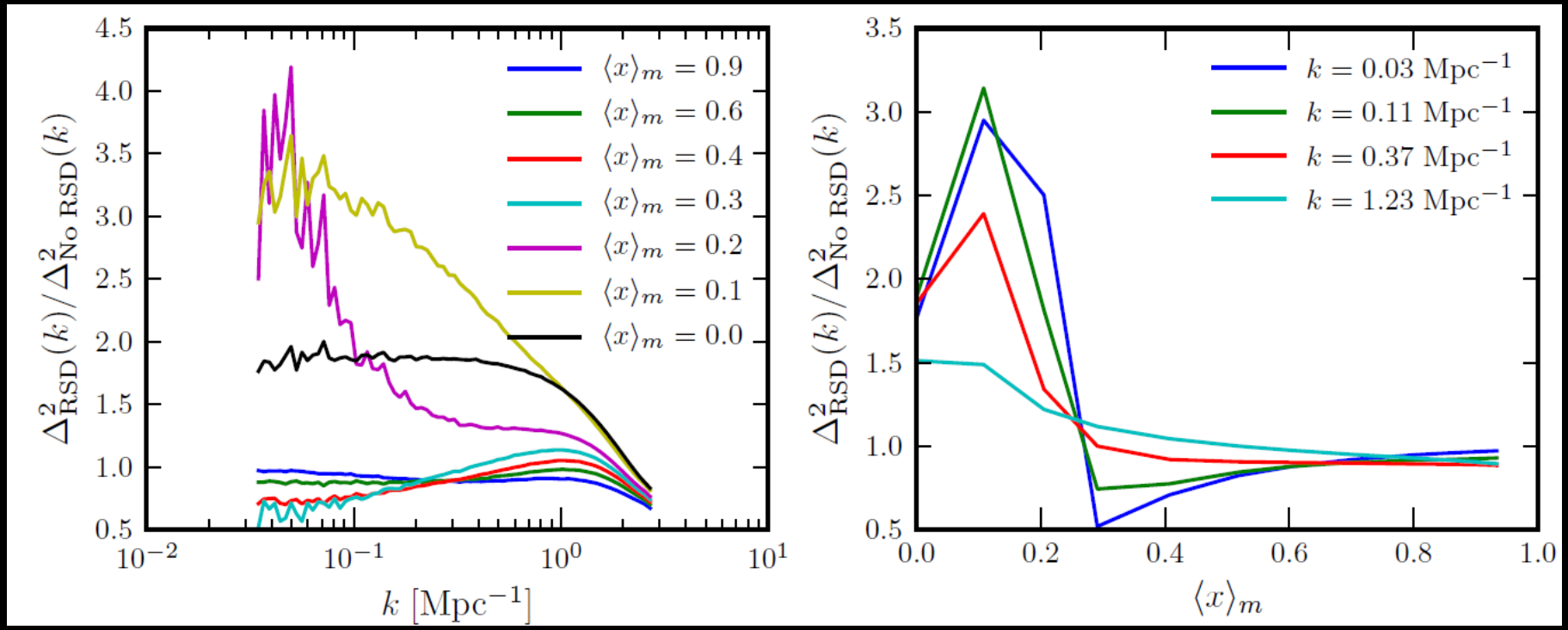




Overdense regions will apear more **dense** and under-dense will apear less d e n s e (Keiser Effect)

Bharadwaj et al (2001, 2004) first introduced this effect in HI 21 cm signal

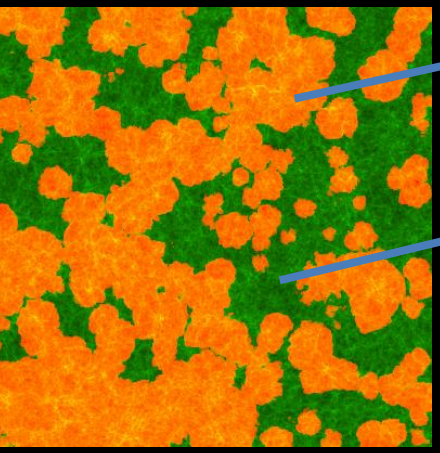
21 cm Power Spectrum in Redshift Space



Jensen, H; Datta, K. K., & LOFAR EoR Group, MNRAS,2013

21 cm Power Spectrum in Redshift Space

$$P_{\Delta T}^{s,\mathrm{lin}}(\mathbf{k},z) = P_{\mu^0}(k,z) + P_{\mu^2}(k,z)\mu_{\mathbf{k}}^2 + P_{\mu^4}(k,z)\mu_{\mathbf{k}}^4 \,,$$

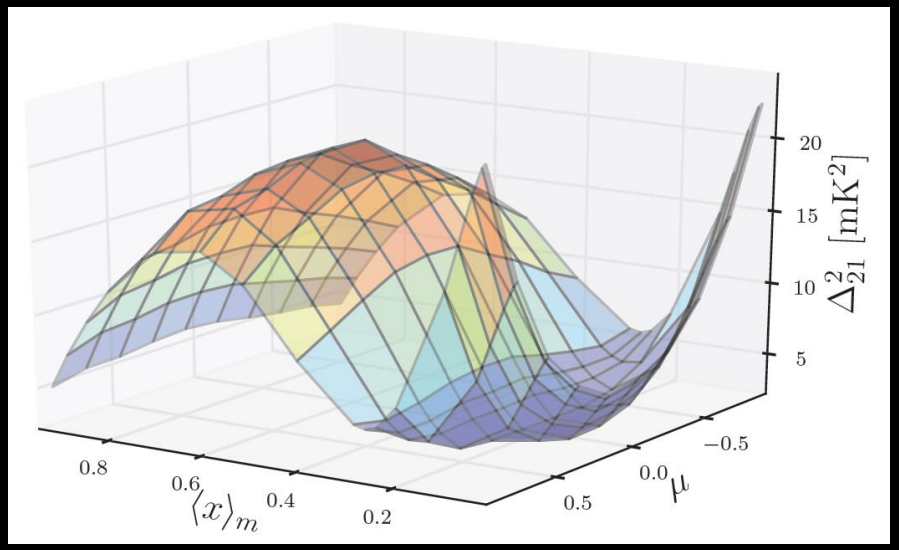


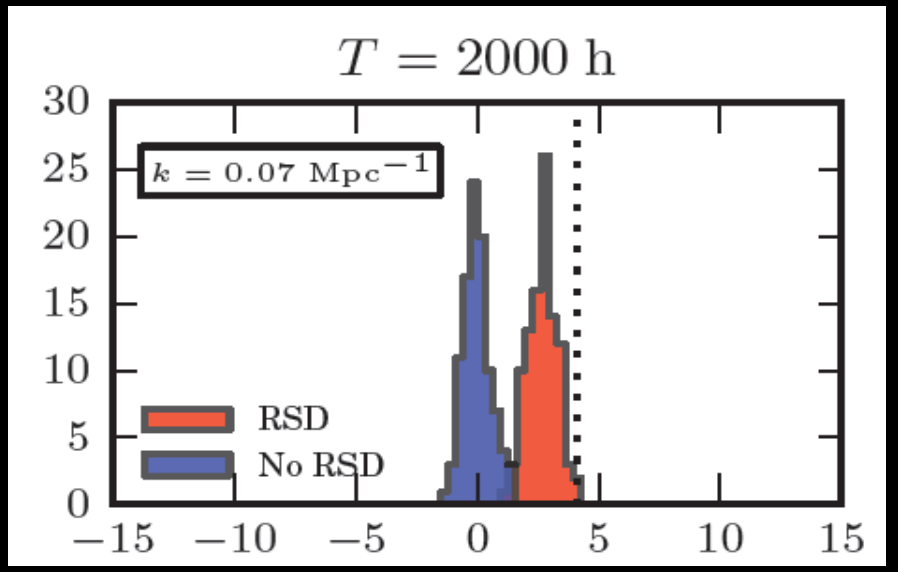
Astrophysics
(QSOs, Stars)

DM power spectrum
(probe early Universe,
Cosmology)

Can be used to measure cosmological parameters, dark energy

21 cm Power Spectrum in Redshift Space





Jensen, H; Datta, K. K., & LOFAR EoR Group, MNRAS,2013

Summary

Redshift space distortion effect is found to be an important especially at the early stages of reionization

This makes HI 21 cm power spectrum anisotropic which can be detected with LOFAR 2000 hrs of observations.