

Tracing Cosmic Dawn

Anastasia Fialkov

ITC Fellow, Harvard

UAI



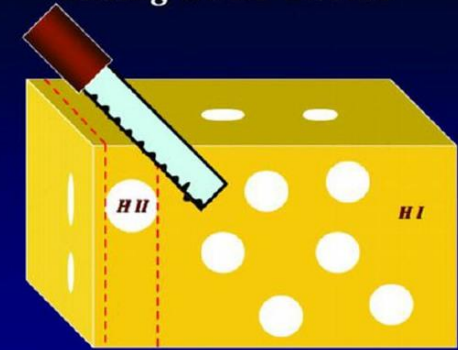
21-cm Signal of HI

Talk by A. Mesinger

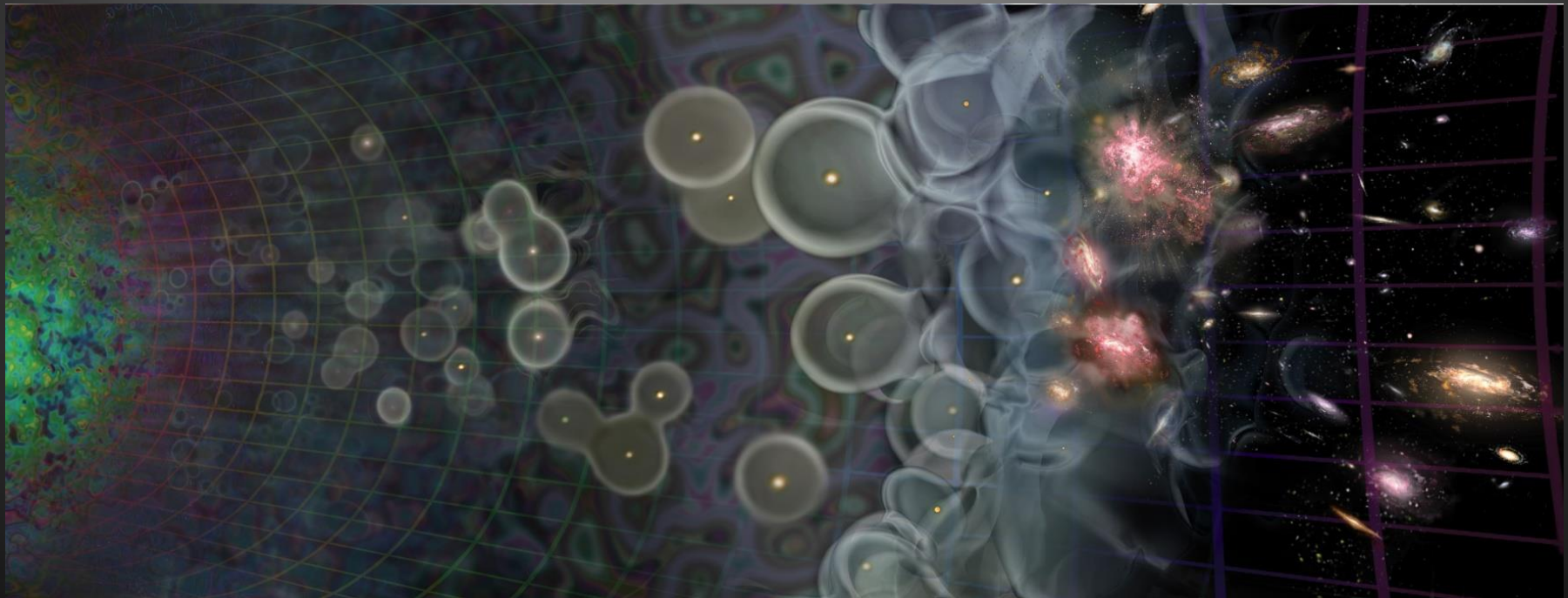
Probe of the ionization state $\delta T_b \sim x_{HI} \dots$

21cm Tomography of Ionized Bubbles During Reionization is like

Slicing Swiss Cheese



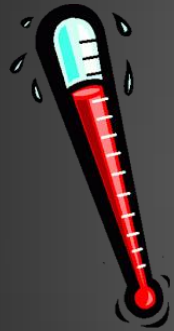
Observed wavelength \leftrightarrow distance
 $21\text{cm} \times (1+z)$



21-cm Signal of HI

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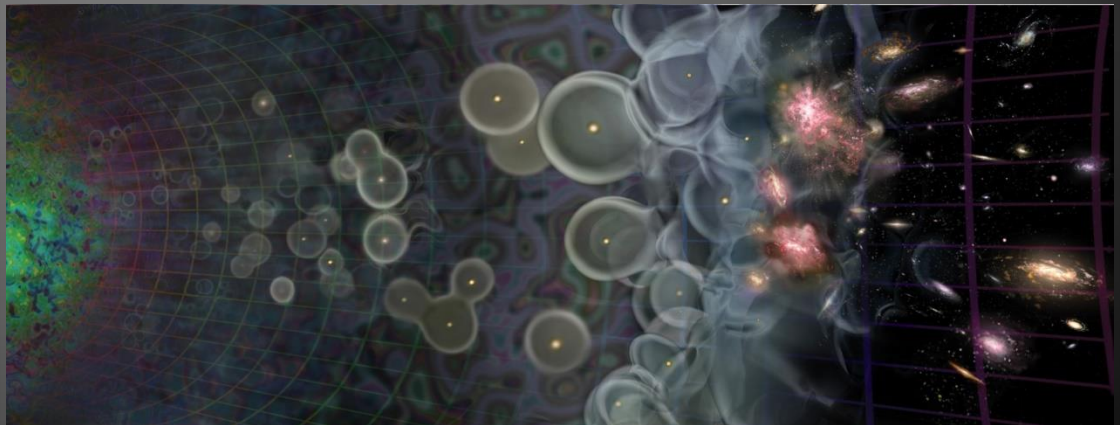
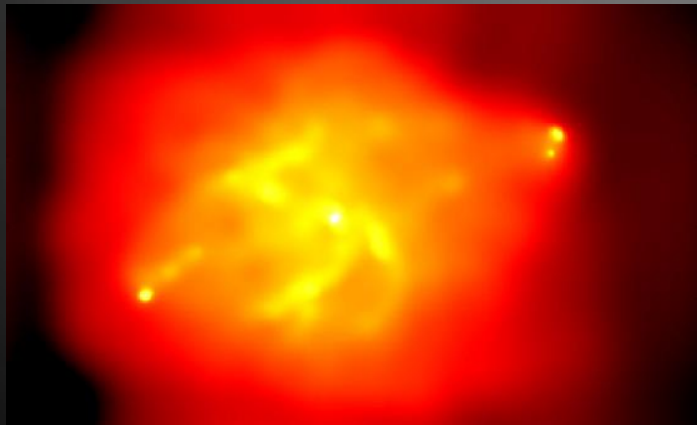
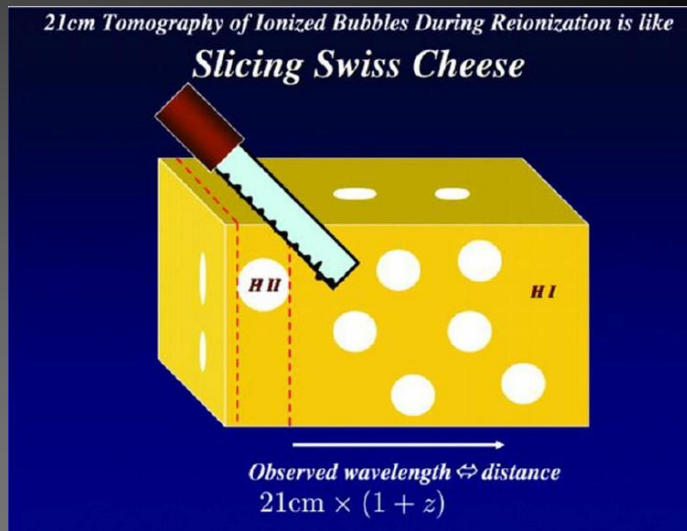


Not only!

It can also be used as a cosmic thermometer and radiometer

$$\delta T_b \sim x_{HI} \left[1 - \frac{T_{CMB}}{T_S} \right] \dots$$

- Ly-a coupling $\rightarrow T_S \approx T_{Gas}$
- Collisional coupling $\rightarrow T_S \approx T_{Gas}$



21-cm Signal of HI

Talk by A. Mesinger

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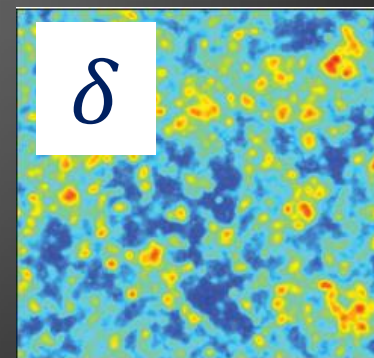
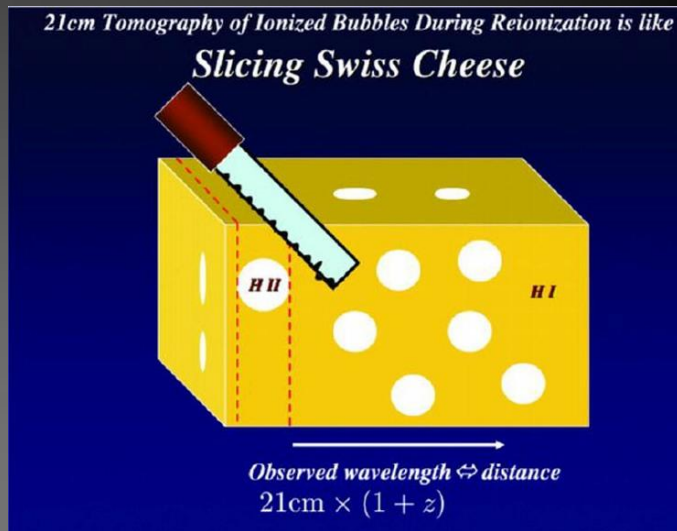
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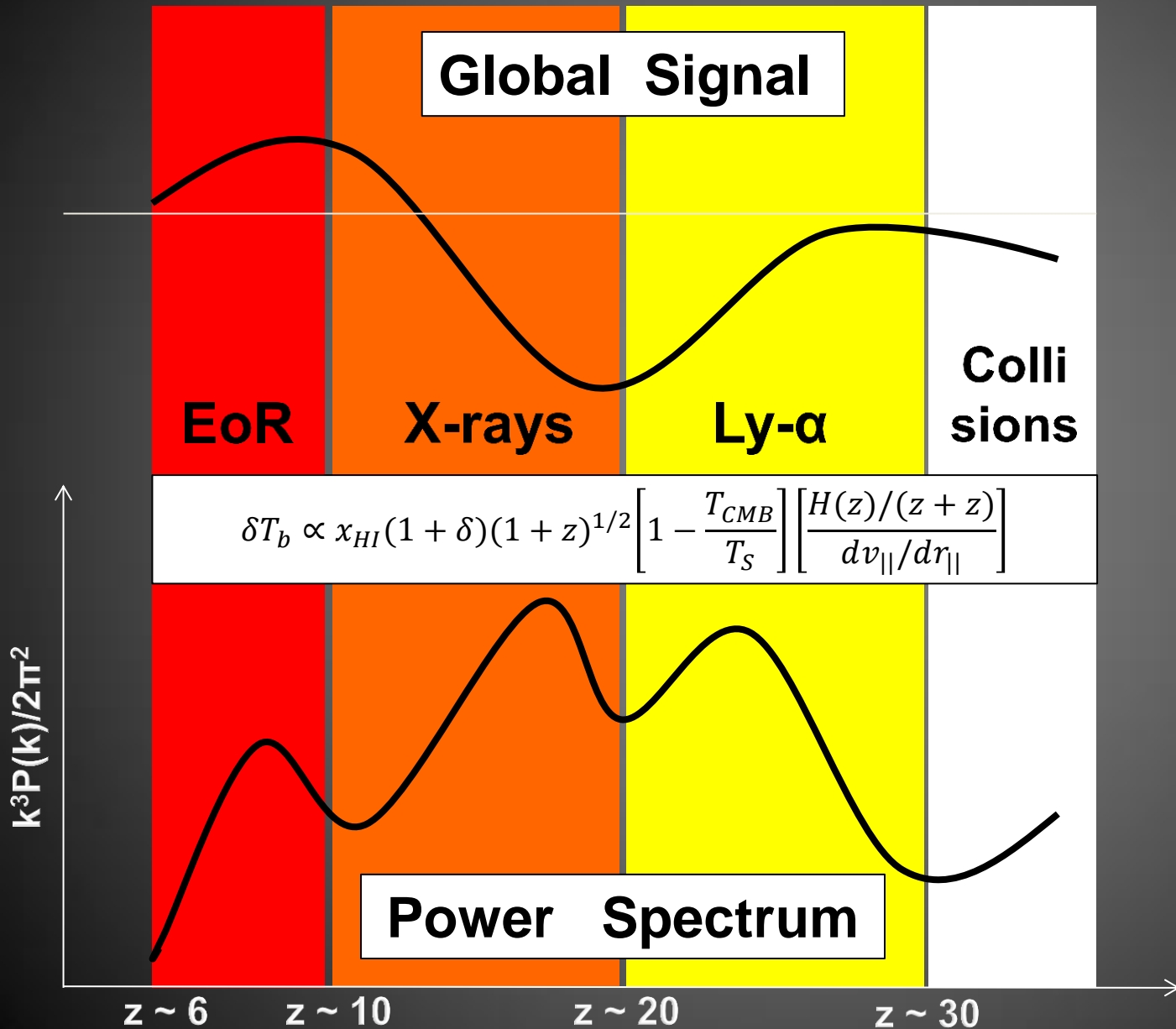
It can also be used as a cosmological probe

$$\delta T_b \propto x_{HI} \left[1 - \frac{T_{CMB}}{T_S} \right] (1 + \delta) \dots$$

- Growth of structure
- Total optical depth for the CMB (e.g., Liu et al. 2016)
- Nature of dark matter



Expected 21-cm Signal: An Example



Drivers:

Galaxies

Quasars

XRB

BHs

Hot Gas

SN

First stars

Feedbacks

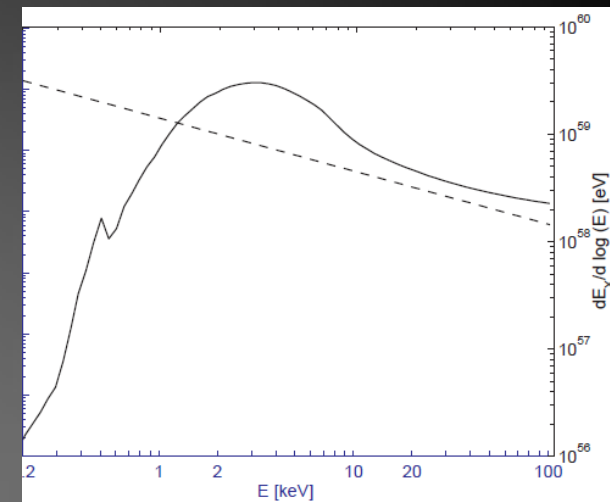
Velocity flows

Cosmology

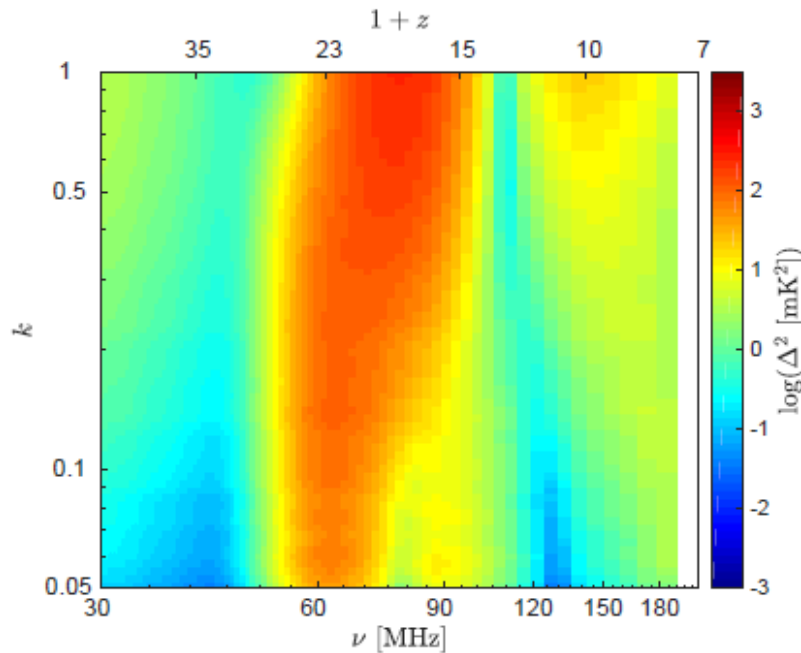
Atomic physics

DM physics

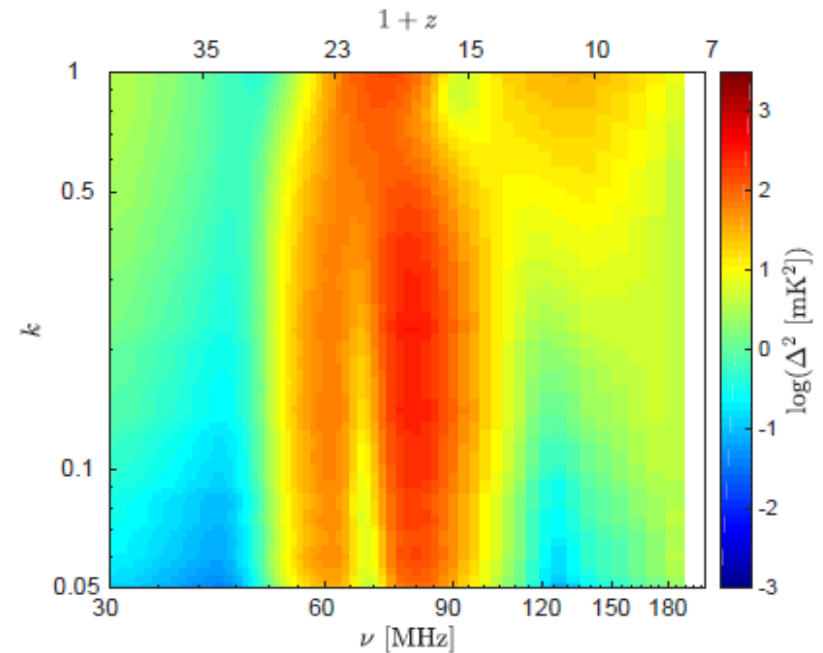
Dependence on Astro Parameters Signature of X- ray SED



Hard SED



Soft SED

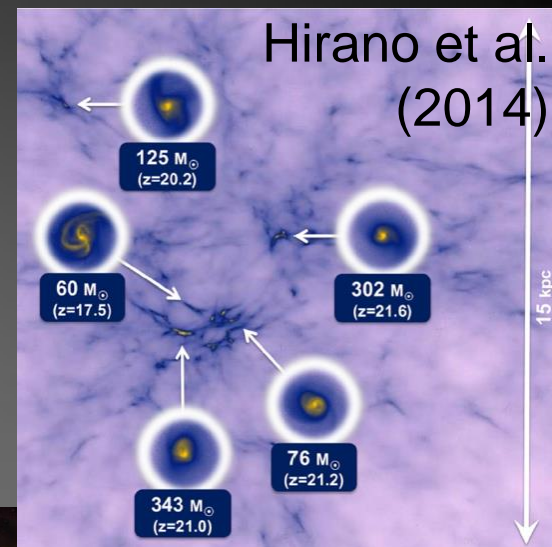
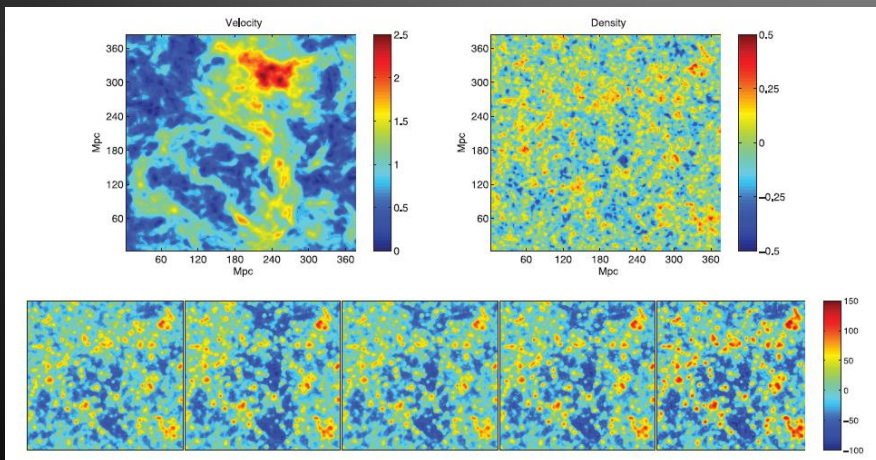


Cohen, Fialkov, Barkana (submitted)

Large Uncertainty in Astro Parameters



Minimal mass of star forming halos
Fialkov et al. (2013)
Supersonic velocity flow
Feedbacks



~200 models are ready
5 parameters

Star formation,
2 parameters
+ feedbacks

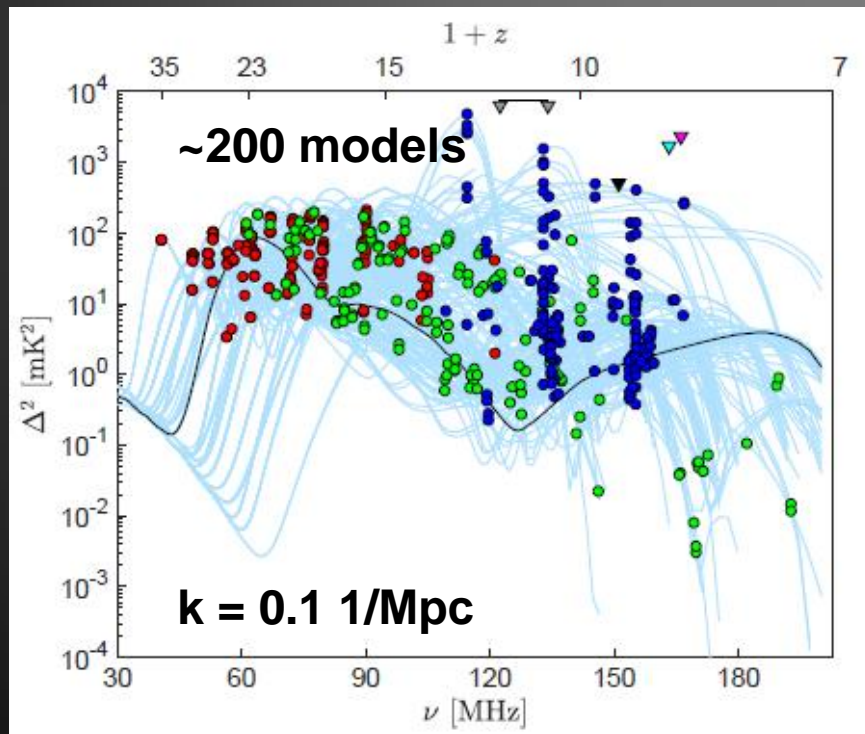
Heating,
2 parameters

EoR 1 parameters

Large Uncertainty in Astro Parameters

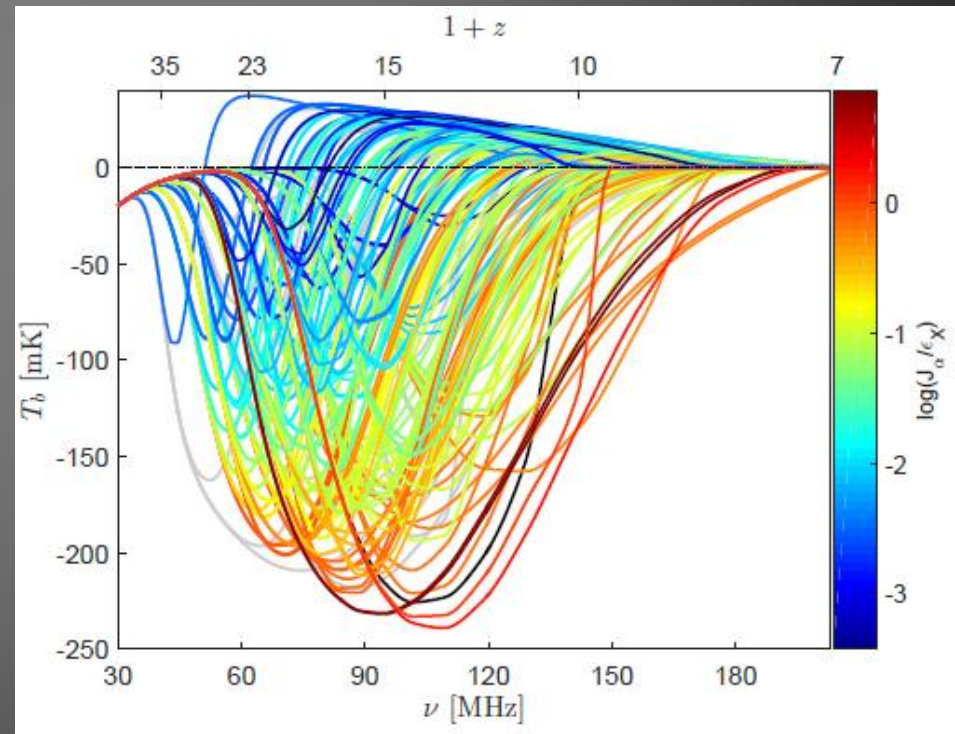
- Exact shape and amplitude of the 21-cm signal are unconstrained
- Global signal – shape is “fixed”. Direct constraints of astro properties
- PS – large variety of shapes. Ly- α transition & heating transition are unconstrained

Power Spectra

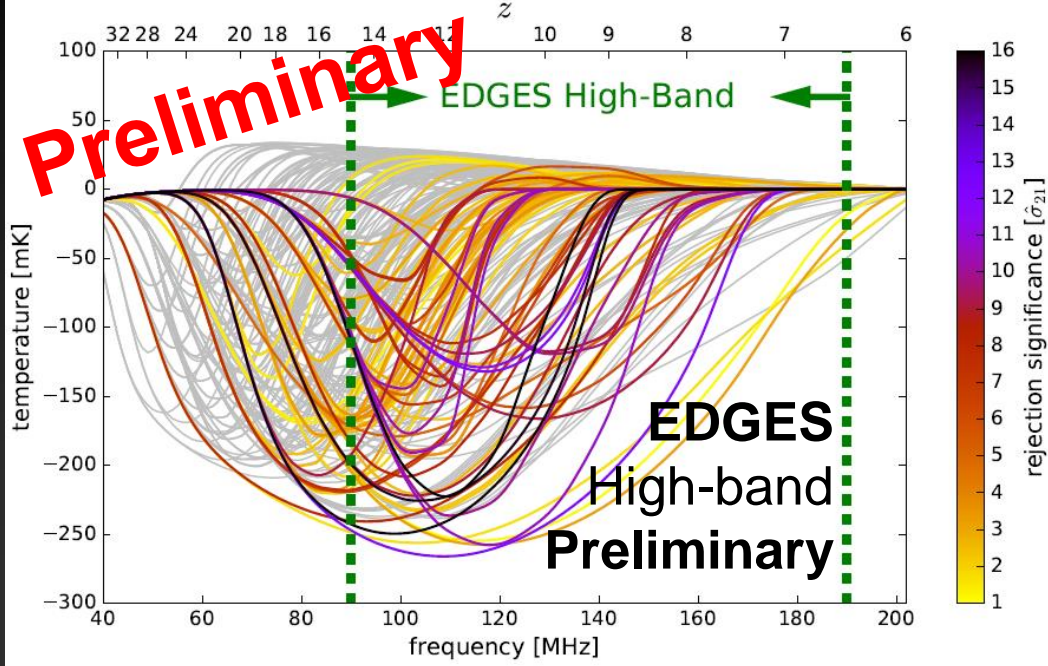


Cohen, Fialkov, Barkana (submitted)

Global 21-cm



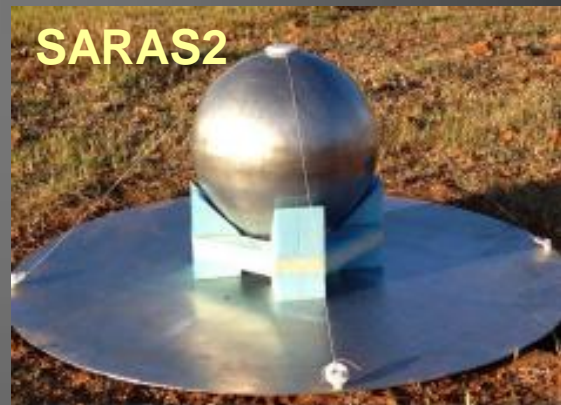
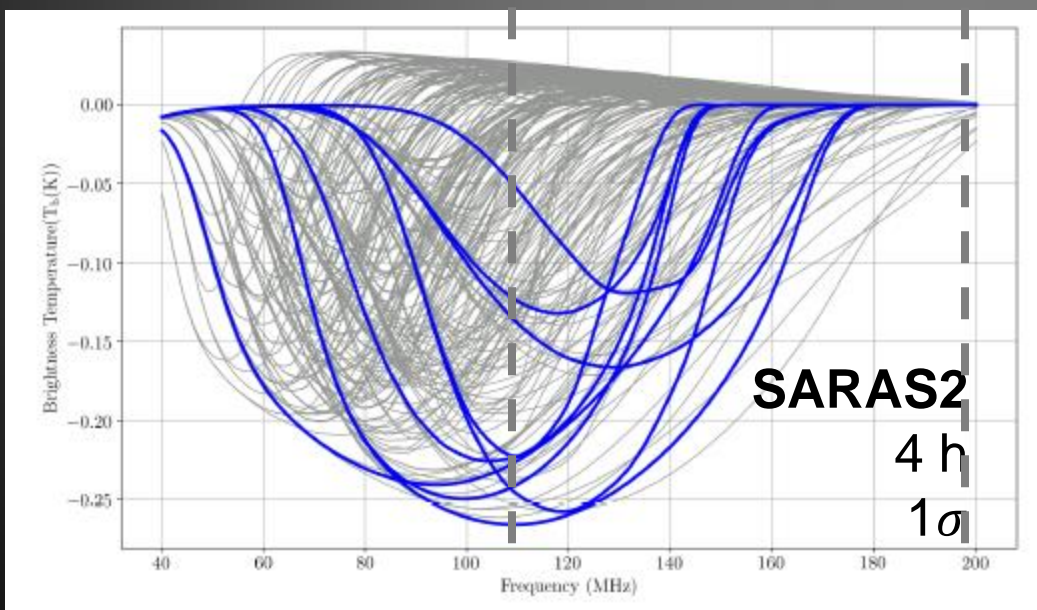
Cohen, Fialkov, Barkana (2017)



EDGES2 High-band



Preliminary
Talk by Judd Bowman



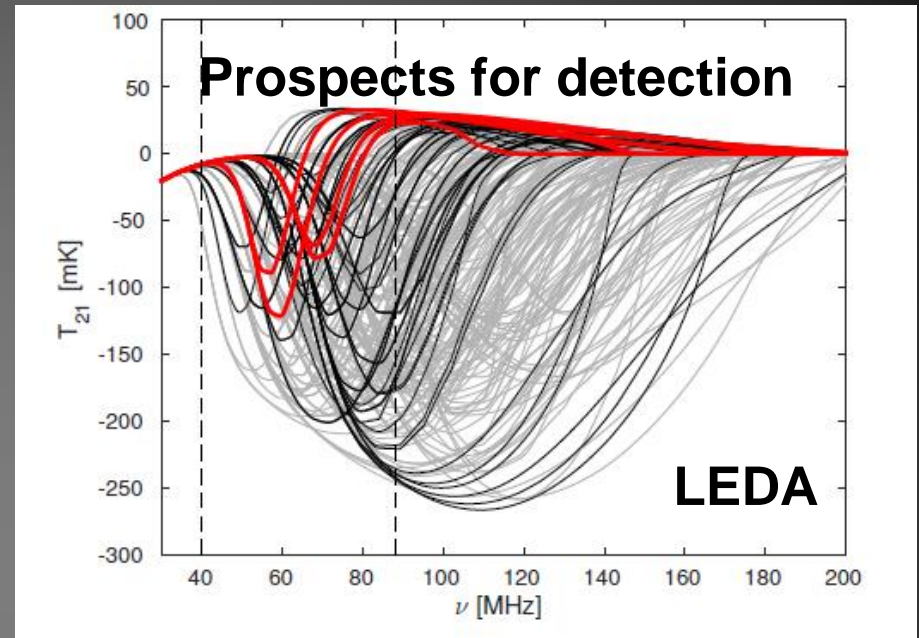
- Disfavour $f_X < 0.1$ and $\frac{dT_b}{dz} > 120$ mK at 1σ level
- Rule out models with no emission

Singh et al. 2017

Low-band Experiments are on their Way



Price et al. 2017



EDGES

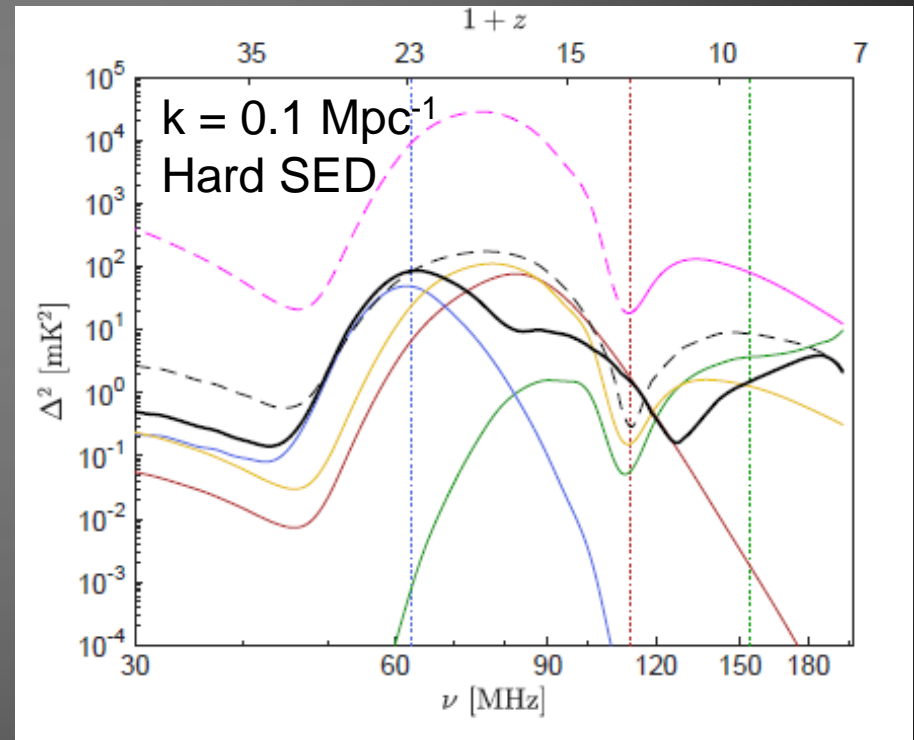
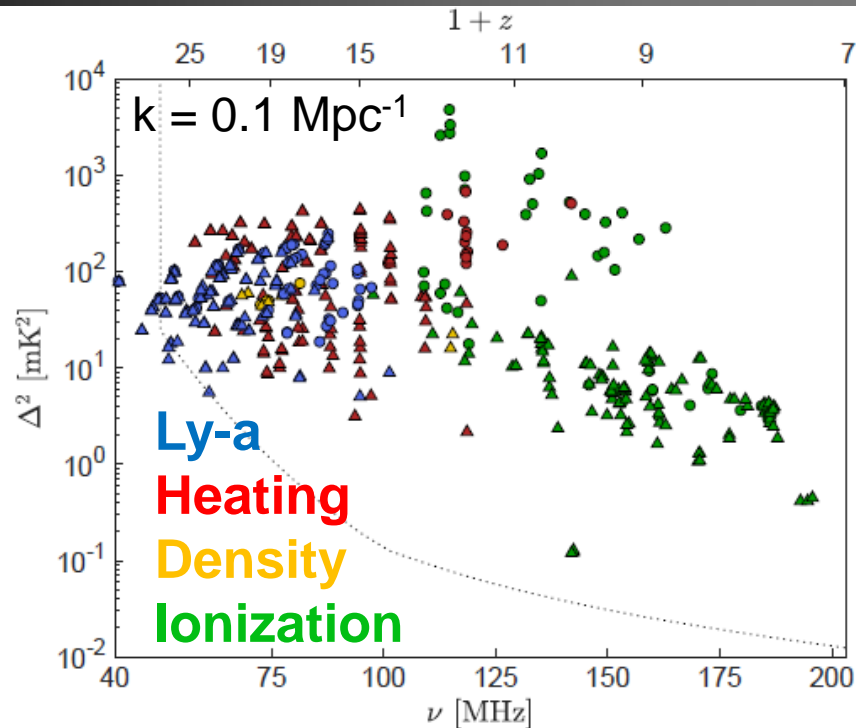
Low-band

Talk by Judd Bowman



Parameter Study : Lessons Learned

- Power at high z is higher – in the SKA range
- Fluctuations introduced by density and velocity, Ly α radiation, X-ray heating, and ionization
- Density fluctuations can play a significant role

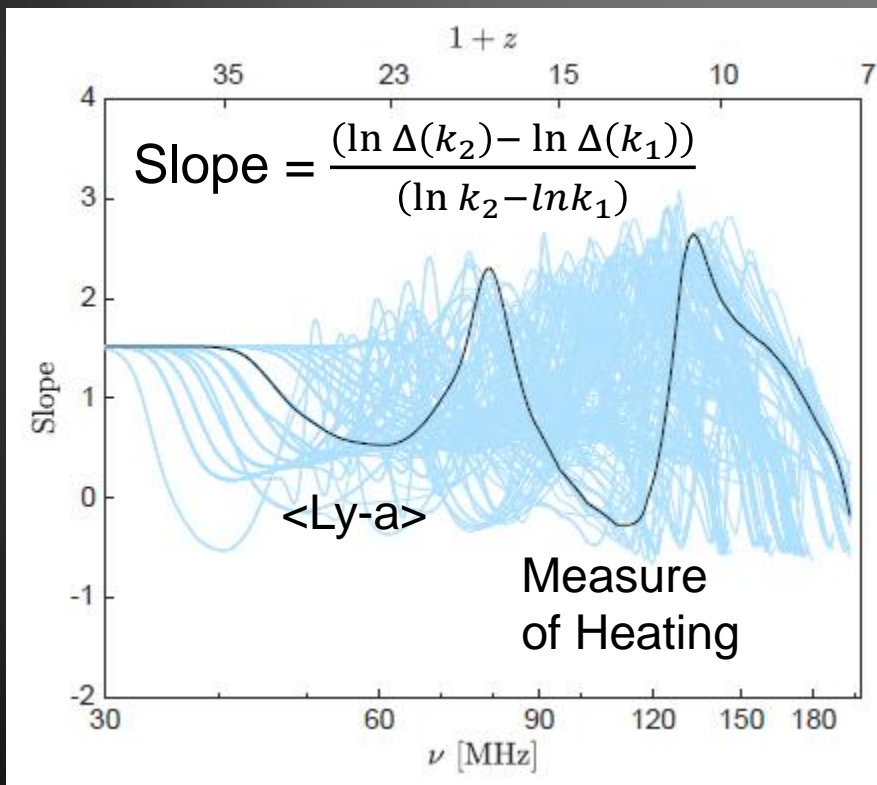


Cohen, **Fialkov**, Barkana (submitted)

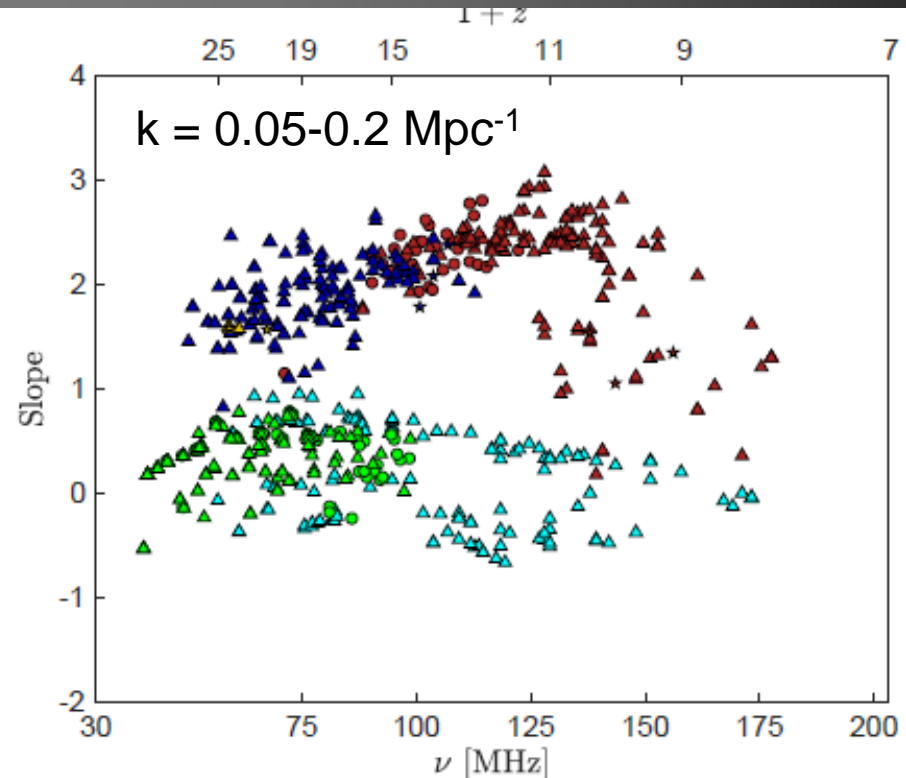
Parameter Study : Lessons Learned

- Slope of the PS shows universal redshift dependence
- Useful to identify source of fluctuations
- Negative slope at $z_{min,low}$ = hard SED

Slopes



Extrema of the Slopes



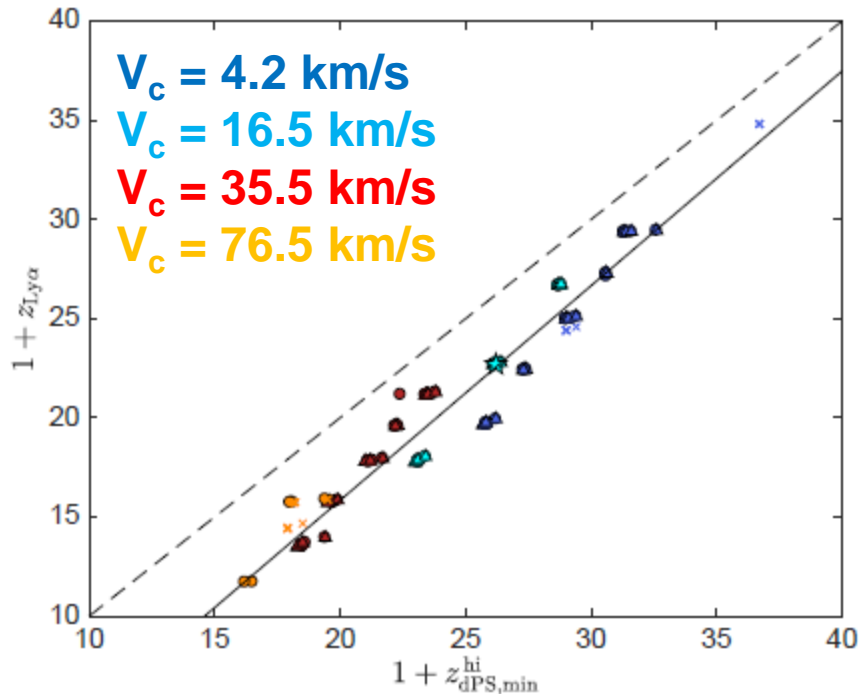
Cohen, Fialkov, Barkana (submitted)

Parameter Study : Lessons Learned

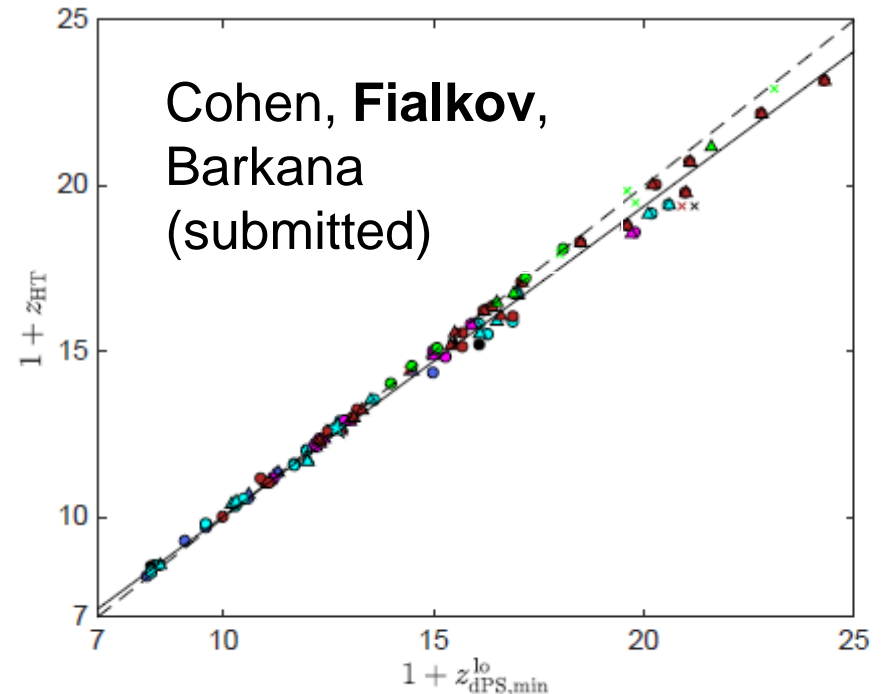
Astrophysical properties can be extracted from global, PS and slope

- Model independent way
- z of Ly- α transition \rightarrow z of the high- z minimum of the slope
- z of heating transition \rightarrow z of the low- z minimum of the slope

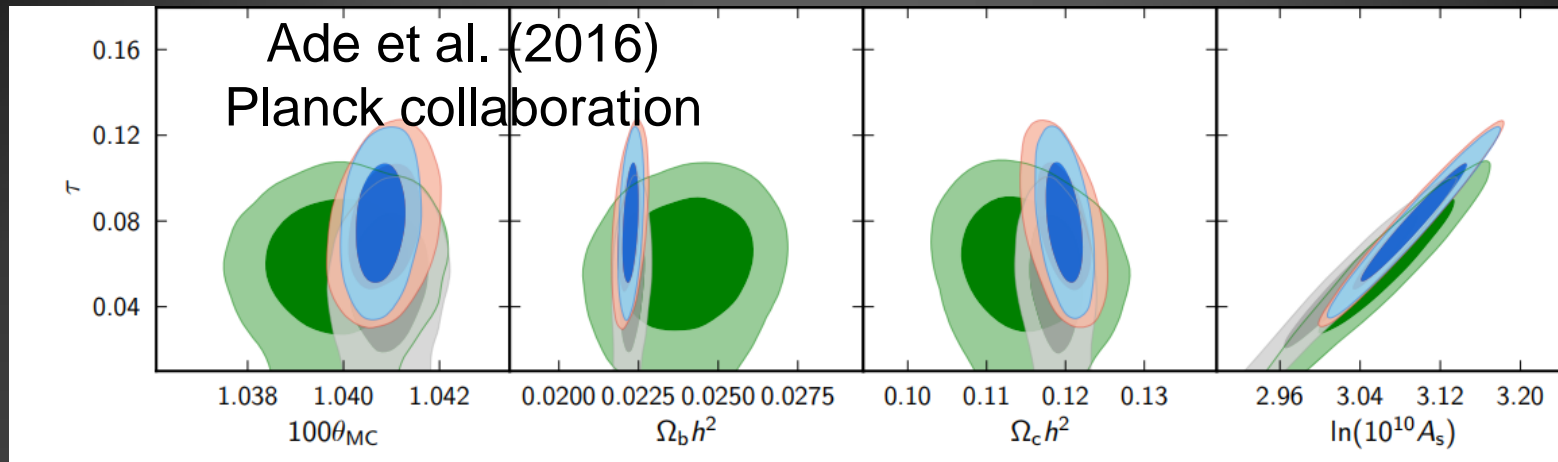
“Ly- α Era, $x_a = 1$ ”



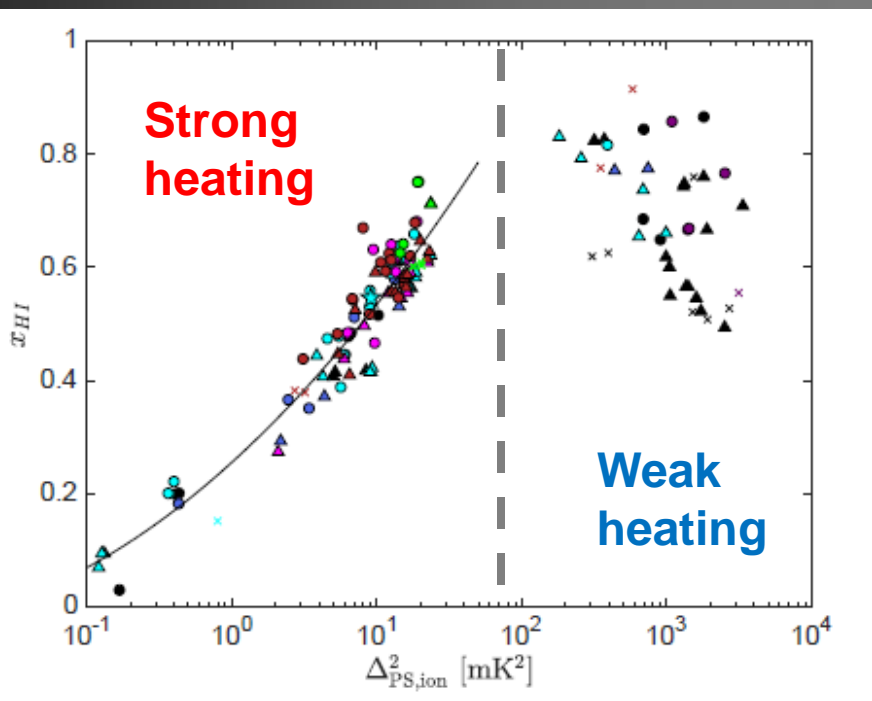
“Heating Era”



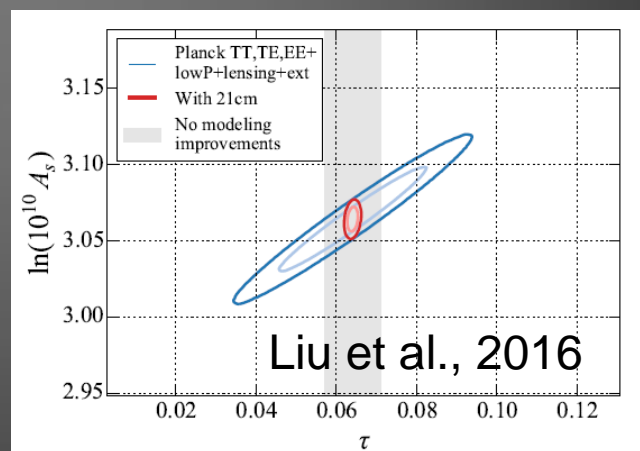
Alternative Way to Probe τ



- τ is a nuisance parameter (Talk by M. Langer).



- x_{HI} at the redshift of the peak vs the peak power
- PS traces x_{HI} when heating is weak

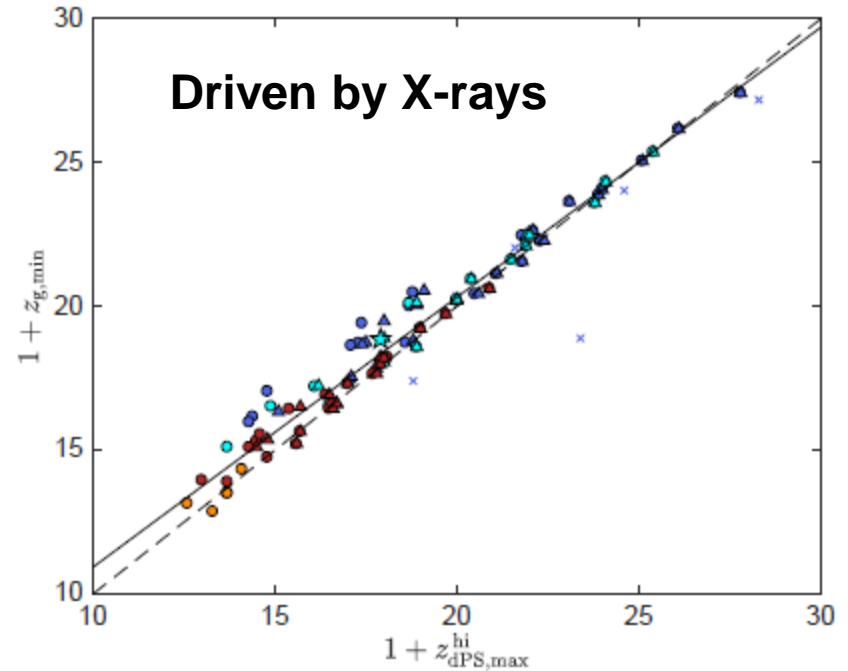
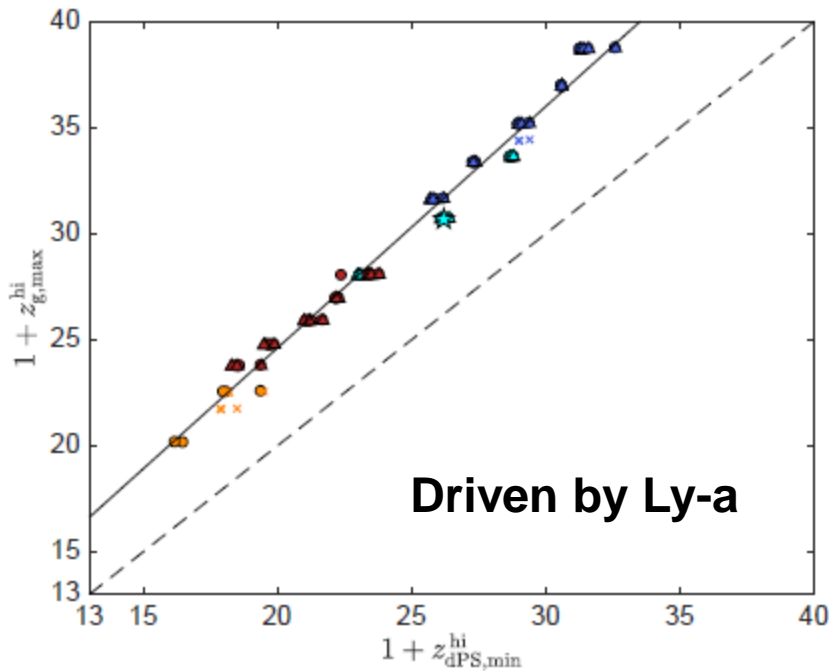


Consistency Checks

Features of the global signal and power spectrum (slope) are correlated

“Ly-a Era”

“Heating Era”



$$1 + z_{g,max} = 1.14 \left(1 + z_{dPS,min}^{hi} \right) + 1.83$$

$$1 + z_{g,min} = 0.94 \left(1 + z_{dPS,max}^{hi} \right) + 1.55$$

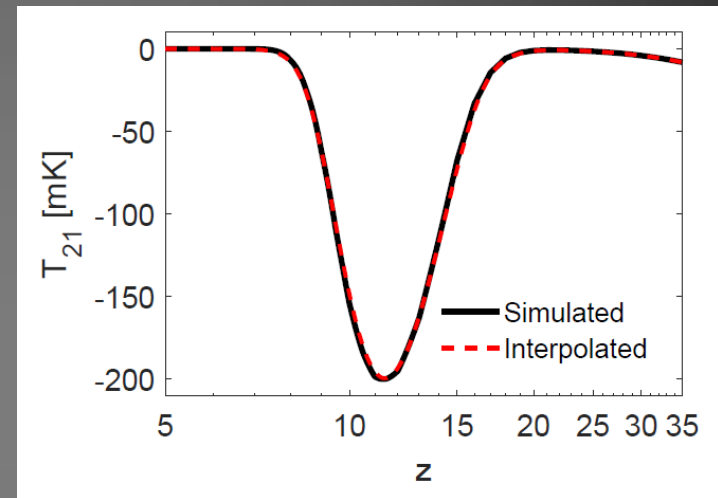
Cohen, Fialkov, Barkana (submitted)

Exploration of the Parameter Space is still Ongoing!

Interpolation scheme
Parameters \rightarrow Global signal



Odyssey Cluster (Harvard)

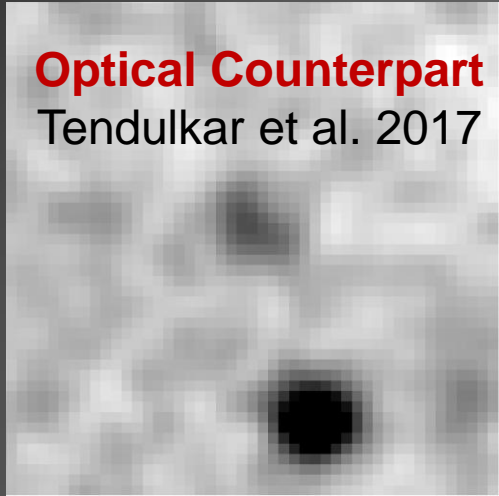


- **~20k models, 7 parameters**
- $f_* \leq 50\%$
- $V_C = 16.5 - 76.5$ km/s
- $\tau \geq 0.055$
- $R_{mfp} = 10 - 50$ Mpc
- X-ray sources: $\alpha = 1 - 1.5$,
 $f_X = 0 - 10$, $v_{min} = 0.1 - 3$ keV

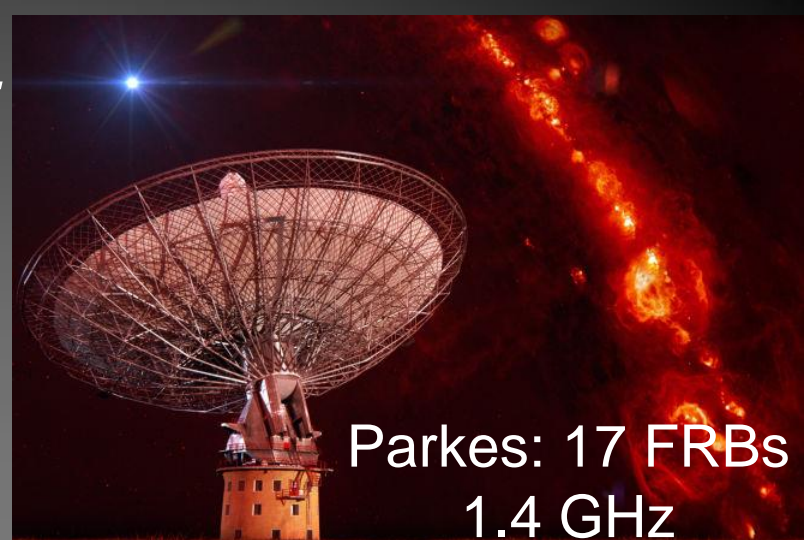
High-z FRBs: Probe of τ

Optical Counterpart

Tendulkar et al. 2017



- In total only 23 are known
- At least 1 is cosmological!
- Poor statistics at the moment



Parkes: 17 FRBs
1.4 GHz



UTMOST: 3 FRB
0.8 GHz



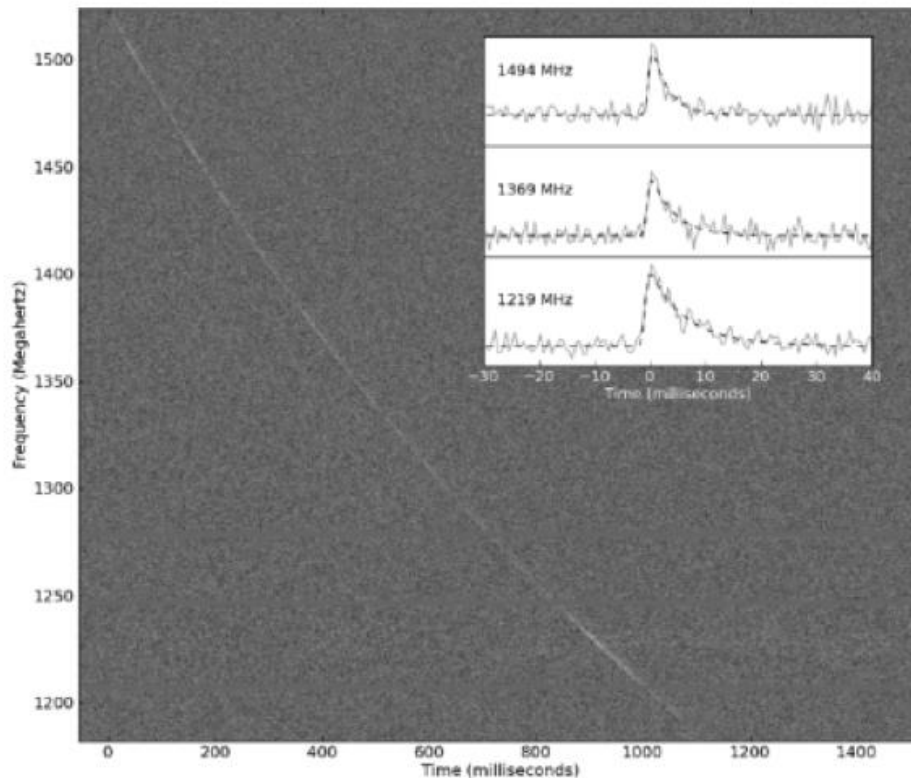
GBT: 1 FRB
0.7-0.9 GHz



ASKAP: 1 FRB
0.7-1.8 GHz

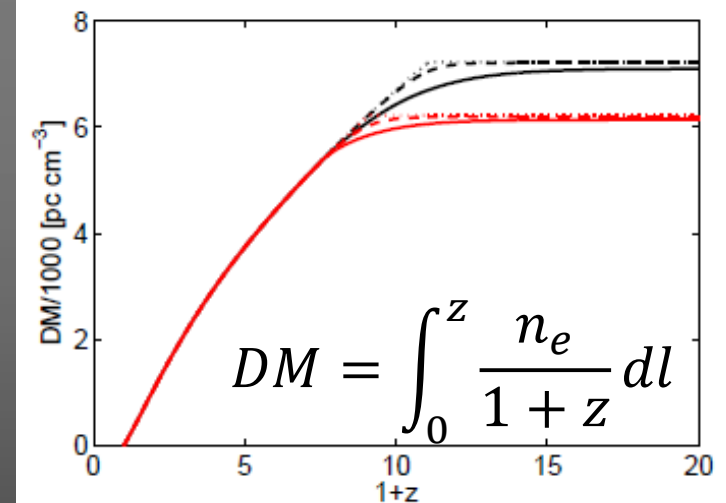
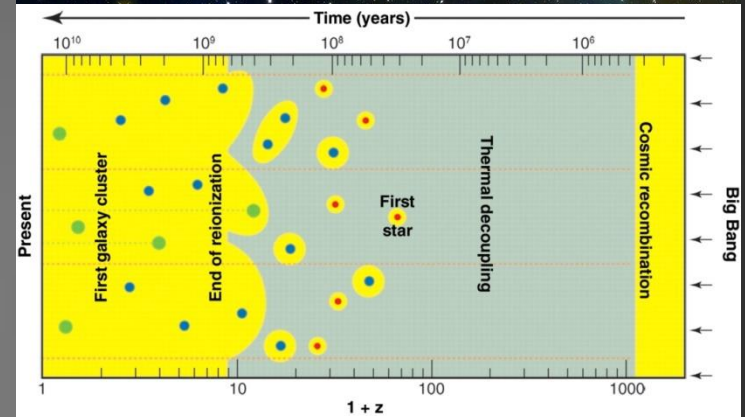
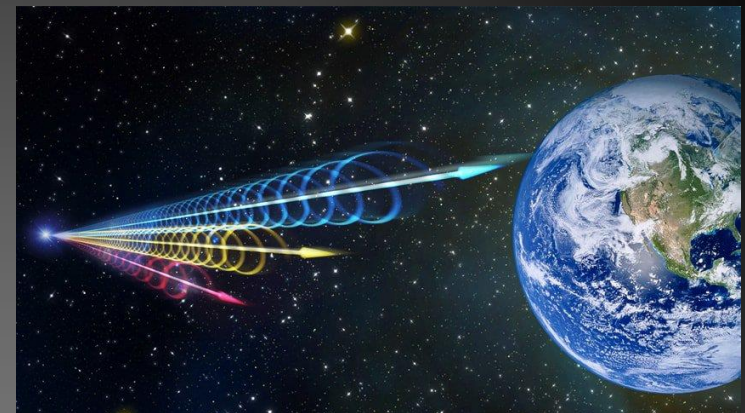


ARECIBO: 1 FRB
1.4 GHz



Lorimer et al. (2007)

- Ionized plasma leaves fingerprints on observed radiation
- Frequency-dependent time delay
 $\Delta t = 4 \times 10^{-3} DM / \nu^2$
- Pre-EoR: DM saturates



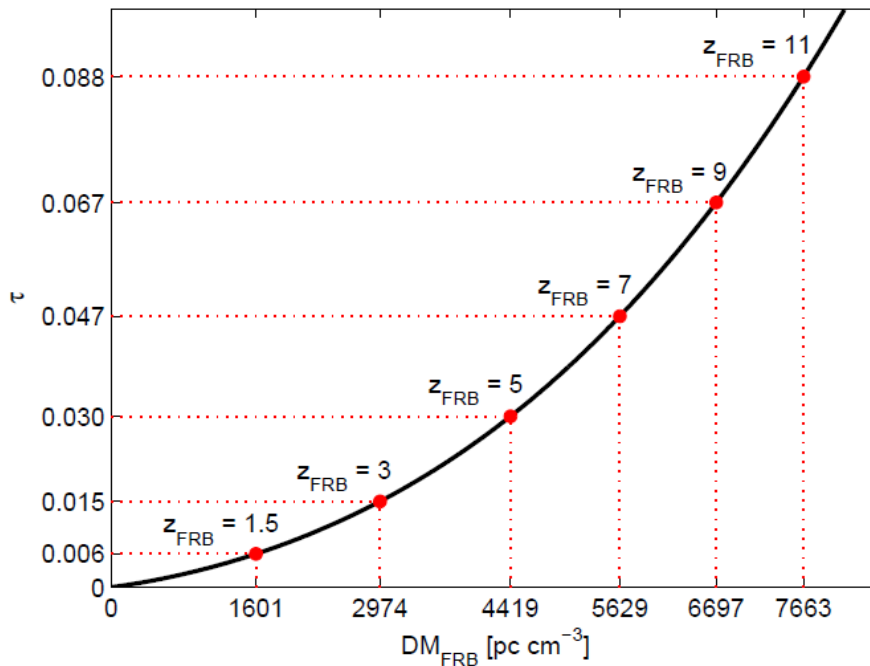
Fialkov & Loeb (2016)

Nuisance Parameter? Not with FRBs!

$$\tau(z) = \left[DM(z)(1+z) - \int DM(z') dz' \right] \sigma$$

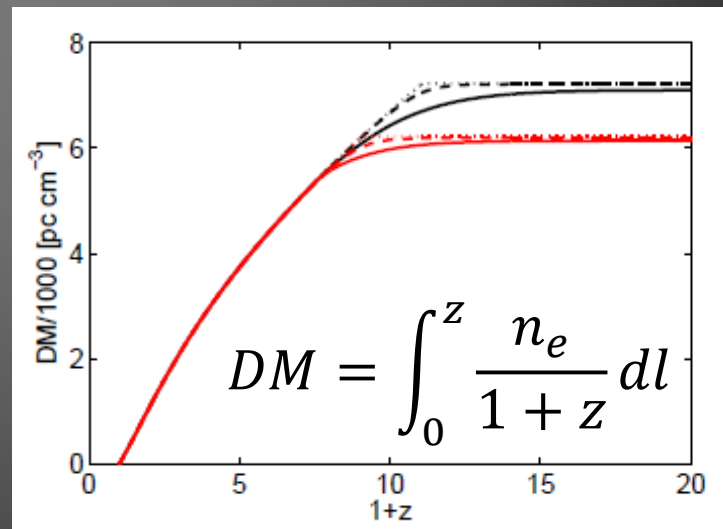
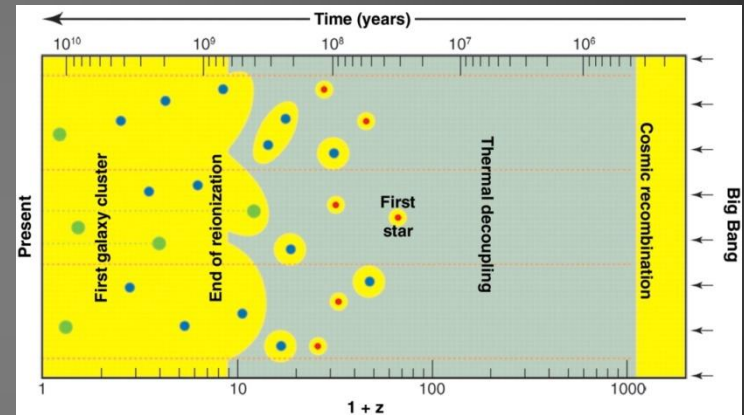
$$\Delta DM \sim 100 \text{ cm}^{-3} \text{ pc} \rightarrow \frac{\Delta \tau}{\tau} \sim 0.3\%$$

Optical depth vs DM



Fialkov & Loeb (2016)

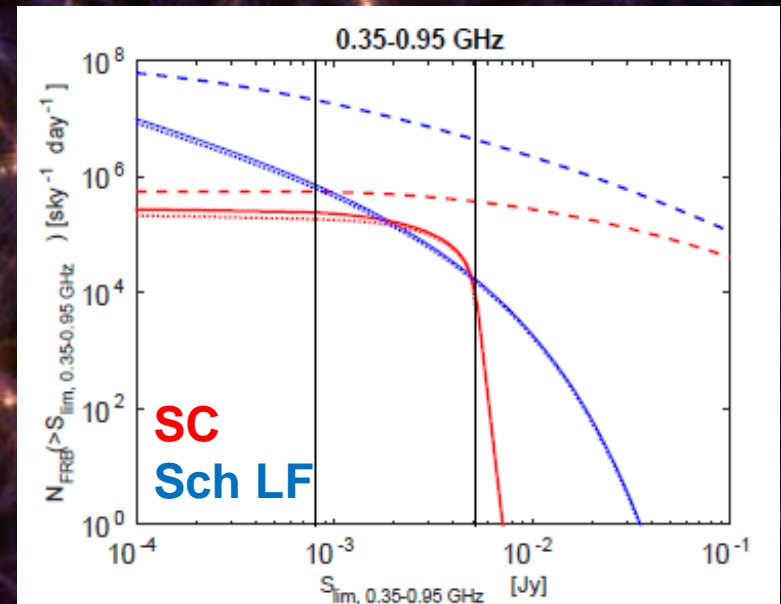
To probe $\tau = 0.055$:
FRBs from $z \sim 6-7$
DM of 6100 pc/cm^3



Fast radio bursts may be firing off every second

September 21, 2017

Predicted rates with SKA-MID



Fialkov & Loeb (2017)



ASPEN CENTER FOR PHYSICS

2018 WINTER CONFERENCE COSMOLOGICAL SIGNALS FROM COSMIC DAWN TO THE PRESENT

February 4 - 10, 2018
Sunday evening reception
Meetings Monday through Friday Evening

The high redshift Universe is an area of active research in both theoretical and observational astrophysics. The meeting will be broad and cover several hot and rapidly evolving topics in the field including:

- Line intensity mapping
- The 21-cm signal from the epoch of reionization and cosmic dawn
- First UV and X-ray sources
- Physics of reionization and cosmic dawn

Discoveries in these fields are likely soon, and they will be transformational for our understanding of the Universe. The goal of this conference is to foster fruitful discussions between observers, theorists, and simulators working on these related areas.

Application deadline is November 30, 2017

Please complete your application at:

<http://www.aspenphys.org/physicists/winter/winterapps.html>

Conference website:

<https://www.cfa.harvard.edu/~afalkov/SignalsCosmicDawn.html>

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Summary

- 21-cm wide parameter space
- Data will transform the field
- Density can be an important source of fluctuations at intermediate z
- 21-cm (global, PS and slope): direct correlation with astro properties
- Fast transients – could be a new way to probe τ

