Understanding Cosmic Dawn

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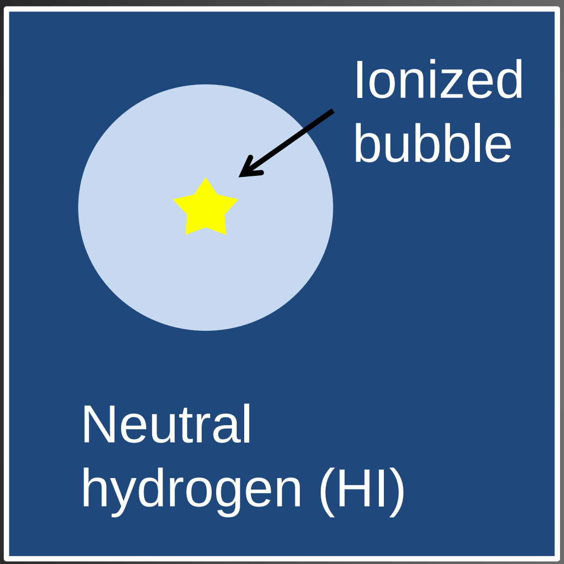
AAS, June 6, 2018

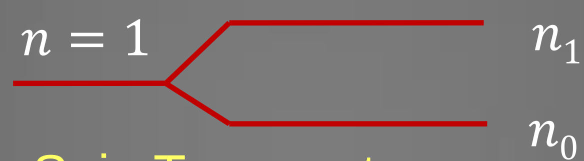
Low Radio Frequency Observations from Space

Observation: Cosmological 21-cm Signal

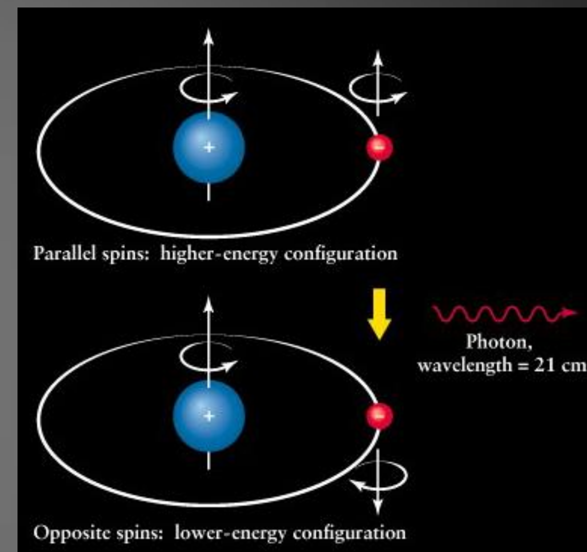
- 21-cm line (hyperfine transition of neutral hydrogen)
- Can be observed today in Radio

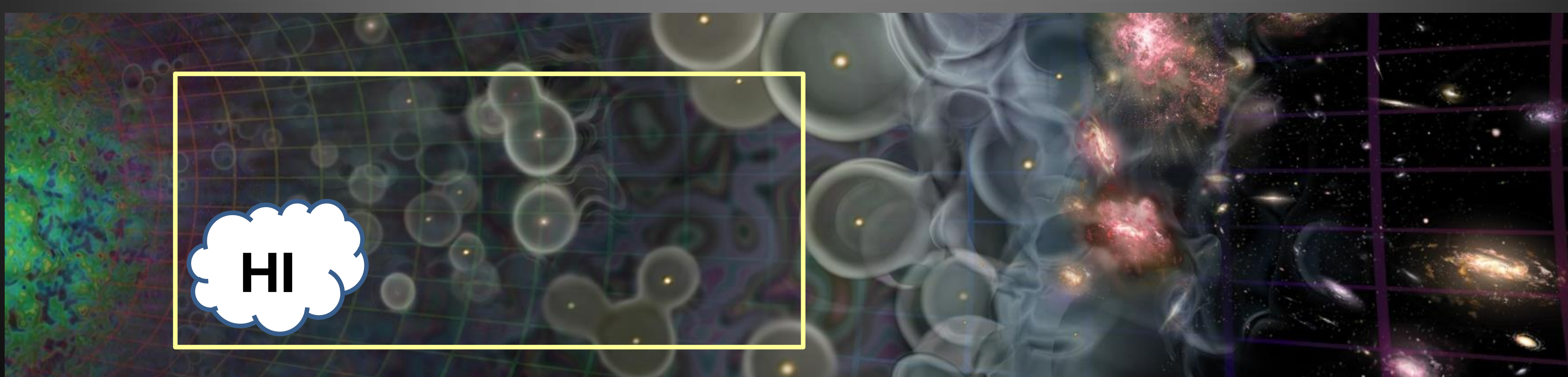


λ = 21 cm
ν = 1420 MHz



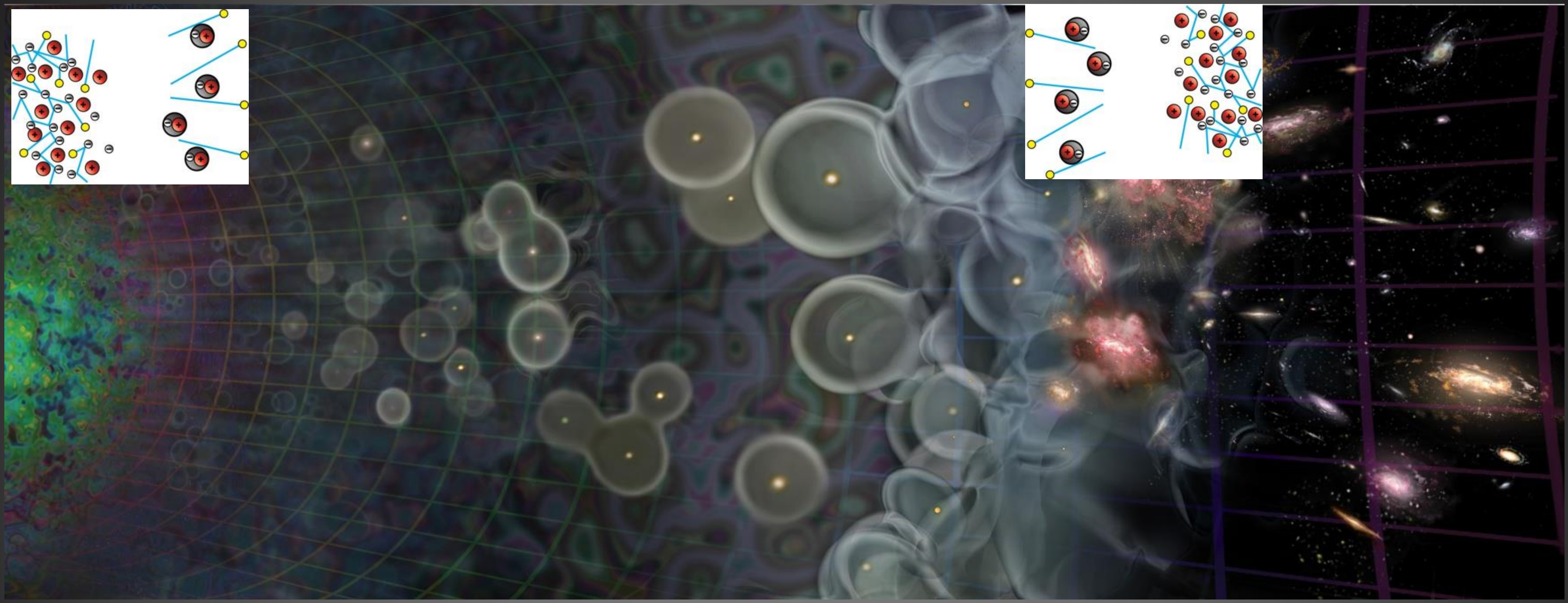
Spin Temperature
$n_1/n_0 \equiv 3\exp(-T_*/T_S)$,
$T_* = 0.068$ K





Observational Effort
$50 \lesssim \upsilon \lesssim 200$ MHz,
$5 \lesssim z \lesssim 30$

Cosmological context
Dark Ages, Cosmic Dawn and EoR



$t_{Universe} \sim 0.38\ Myr$ $t_{Universe} \sim 14\ Gyr$

Cosmic Microwave Background:

- Cosmological model
- Initial conditions for structure formation

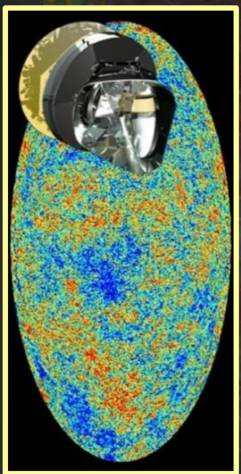
Cosmic Dawn and Reionization

- Formation of first stars
- Black holes
- Radiative feedbacks

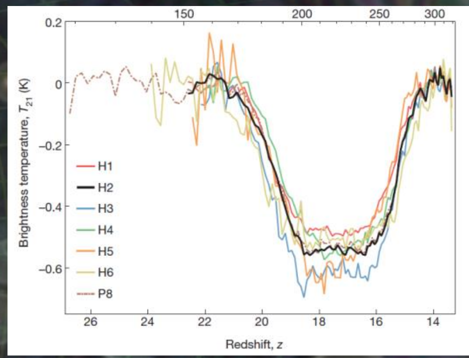
"Local" Universe

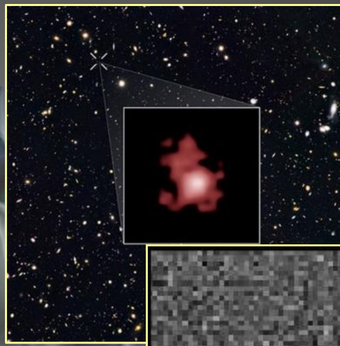
- Stars and planets
- Galaxies
- Black holes
- Large scale structure

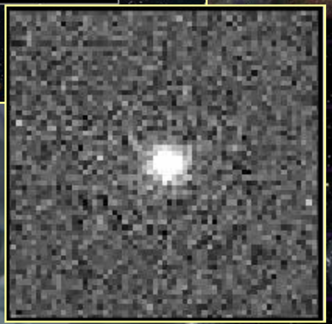
Existing observations

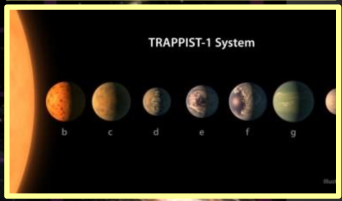


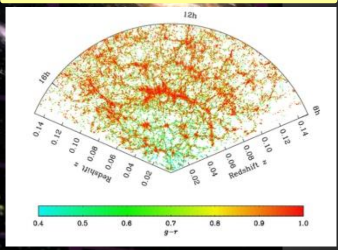
Bowman et al. (2018)











21-cm from Dark Ages, Cosmic Dawn and EoR

$t_{Universe} \sim 0.38\ Myr$ $t_{Universe} \sim 14\ Gyr$

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“Local” Universe
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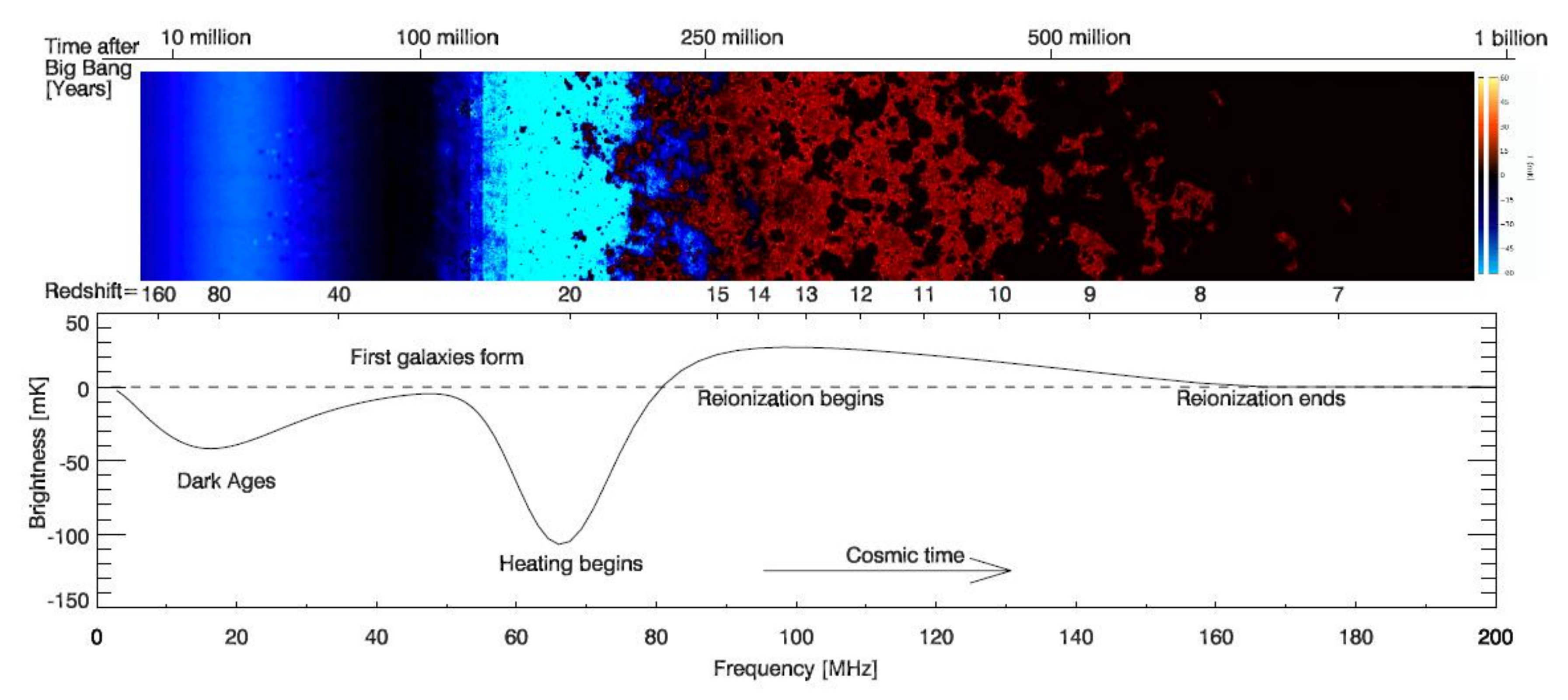
21-cm: The Entire Frequency Range

Unique probe of high-redshift astrophysics and properties of Dark Matter

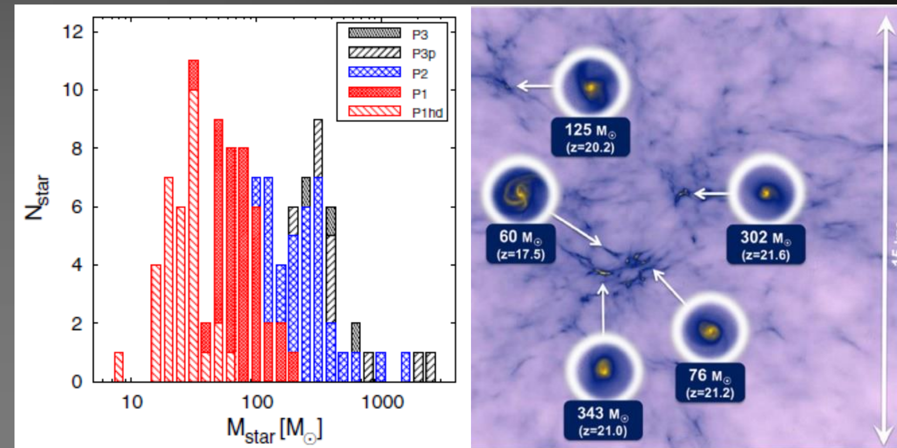
3D scan of the Universe

Space

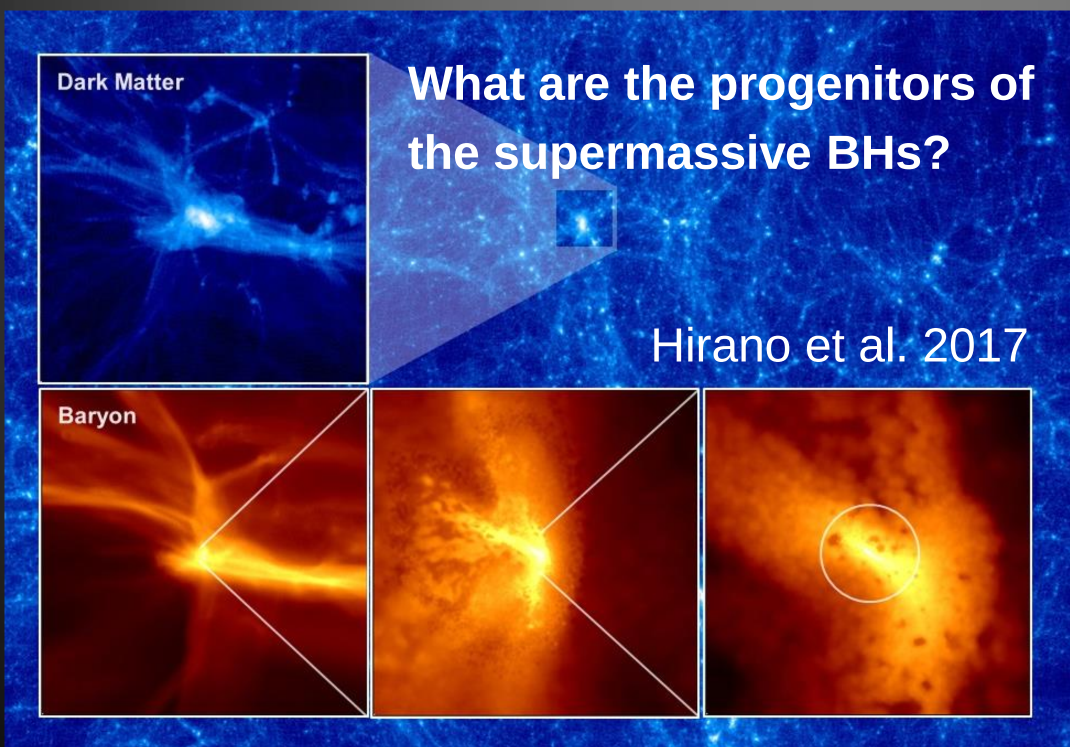
Ground and space



Pritchard & Loeb (2011)



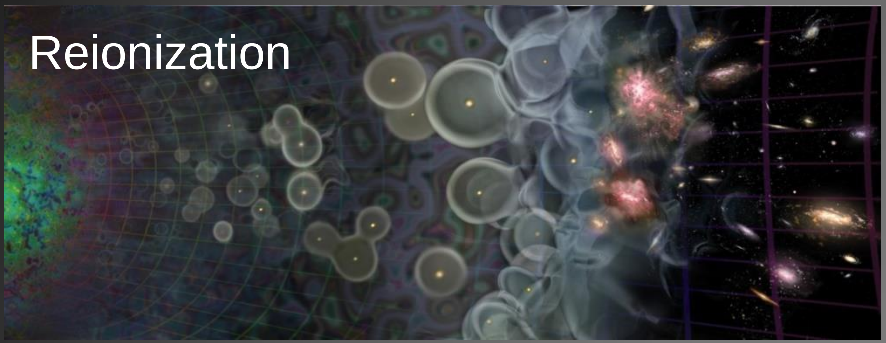
Massive stars (Hirano et al. 2014)

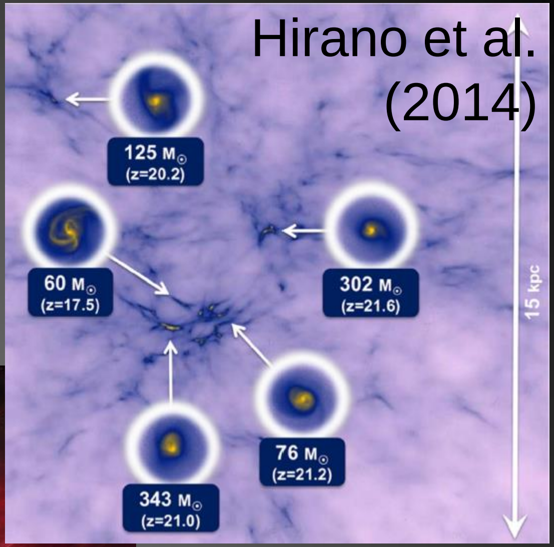


Cosmic Dawn

Onset of star and black hole formation

"Traditional" Modeling Cosmic Dawn and EoR



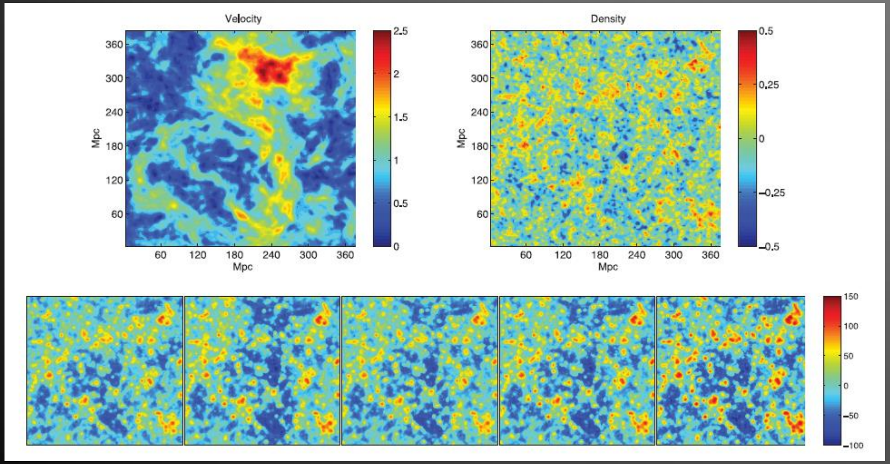


Cosmic Dawn + EoR:

Minimal mass of star forming halos

Supersonic velocity flow

LW Feedback



~40000 models! 7 parameters

$f_* \leq 50\%$

- $V_C = 4.2 - 76.5$ km/s
- $\tau \geq 0.055$
- $R_{mfp} = 10 - 50$ Mpc
- X-ray sources: $\alpha = 1 - 1.5$, $f_X = 0 - 10$, $\upsilon_{min} = 0.1 - 3$ keV

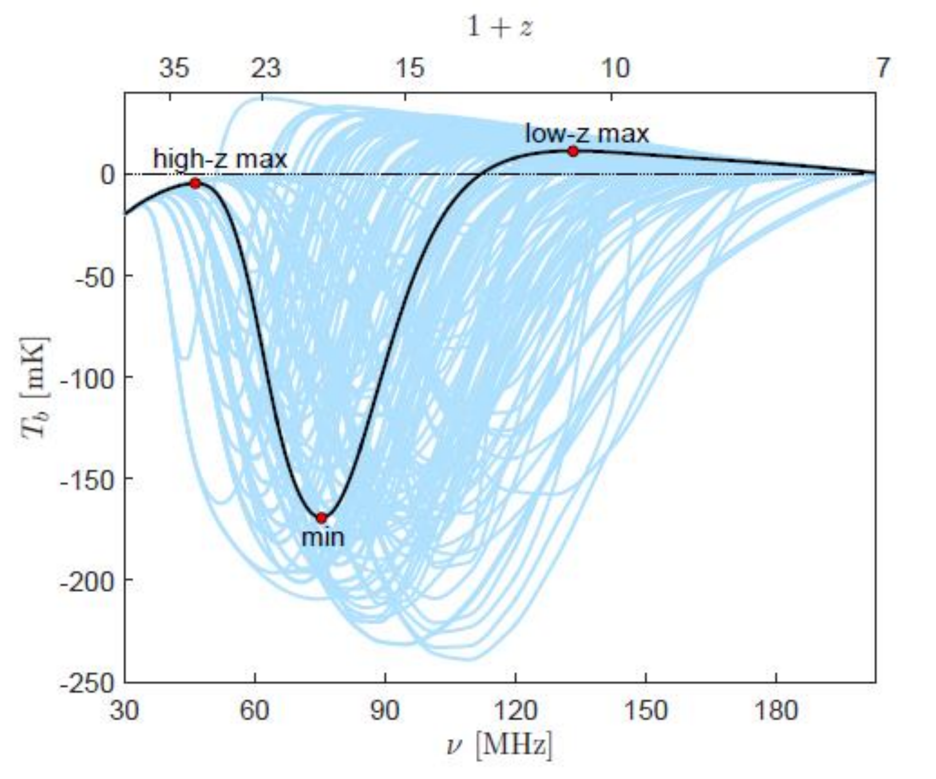
Interpolation code

Cohen, **Fialkov**, et al. in prep.

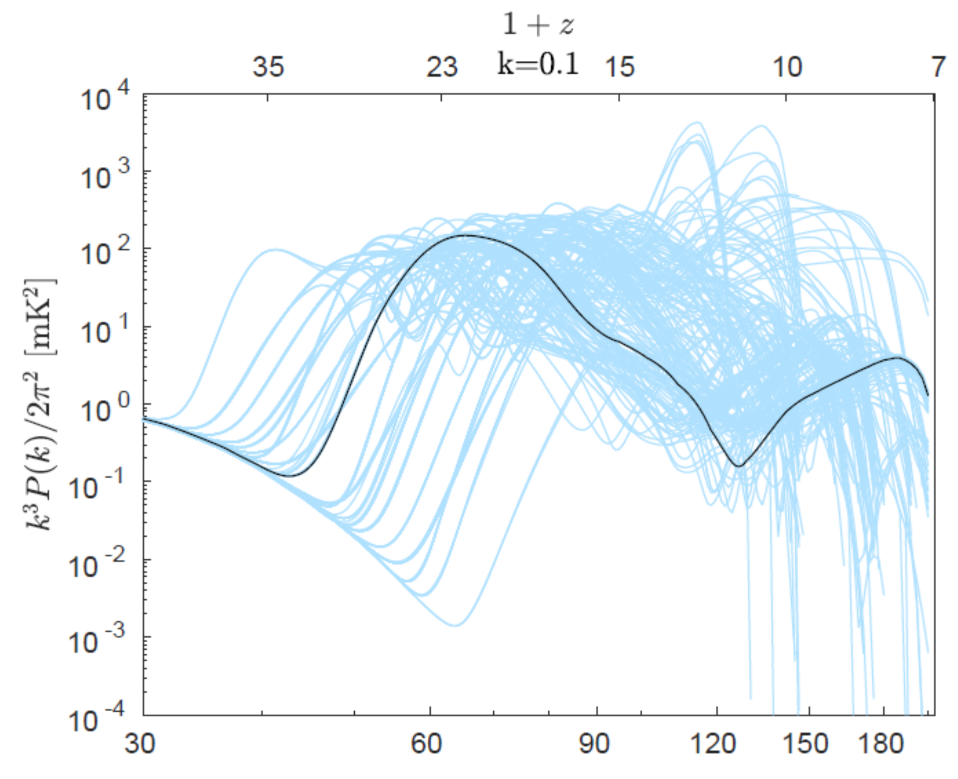
Expected Global Signal and Power Spectrum

Parameter study based on 200 models
(***) Now extended to 40k models, interpolation code.
Varying properties of star formation, X-ray heating, structure formation, Reionization.

Global 21-cm



Power Spectra



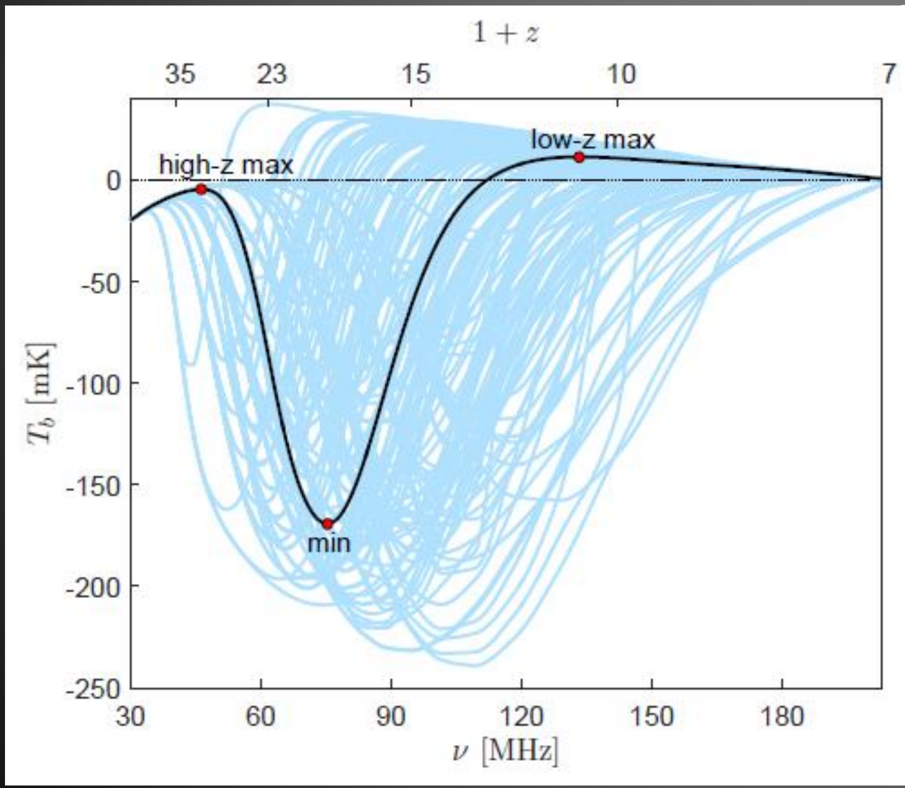
Cohen, **Fialkov**, Barkana (2017)

Cohen, **Fialkov**, Barkana (2018)

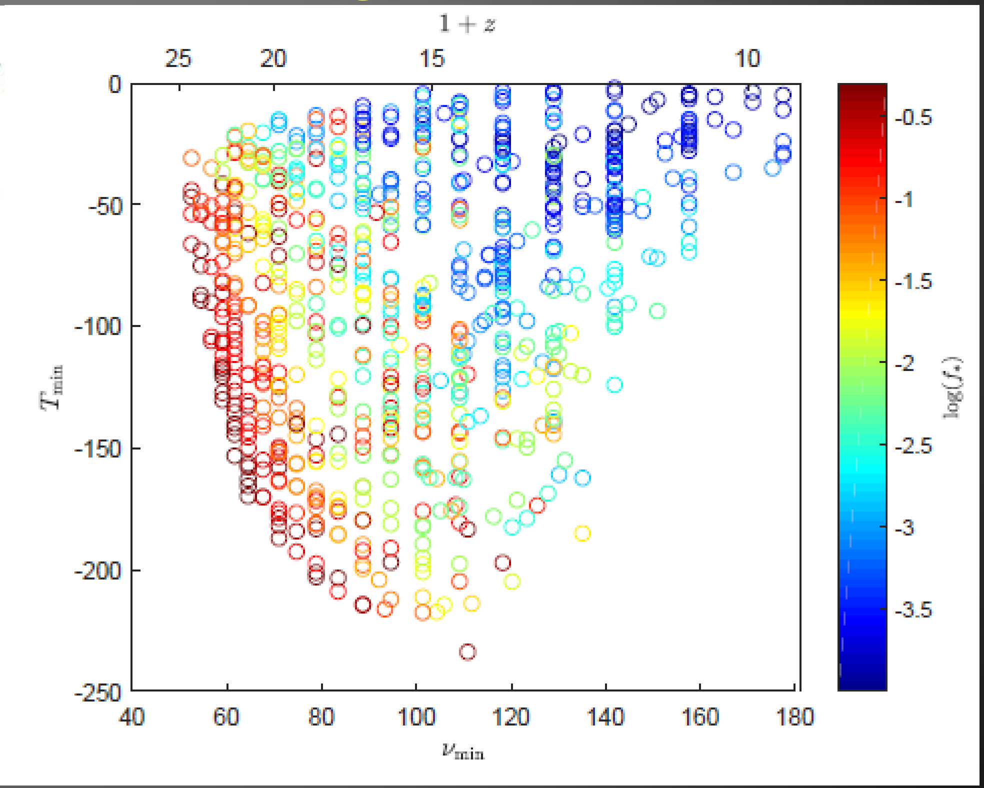
Absorption Trough vs Astro Parameters

Parameter study based on 200 models
(***) Now extended to 40k models, interpolation code.
Varying properties of star formation, X-ray heating, structure formation, Reionization.

Global 21-cm

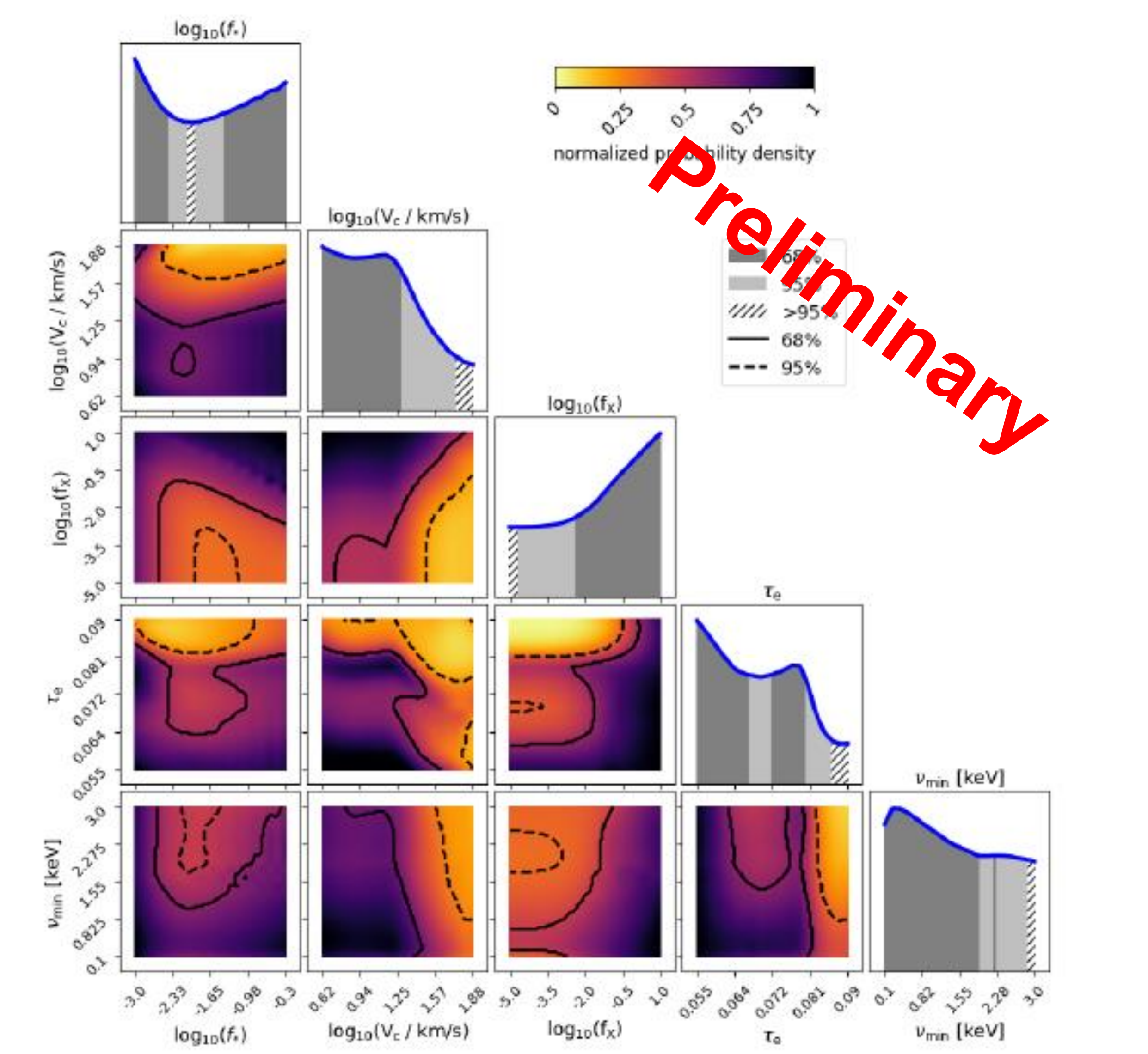


Timing of Cosmic Events



Cohen, **Fialkov**, Barkana (2017a)	Cohen, **Fialkov**, et al. in prep.

Constraints with EDGES High-Band



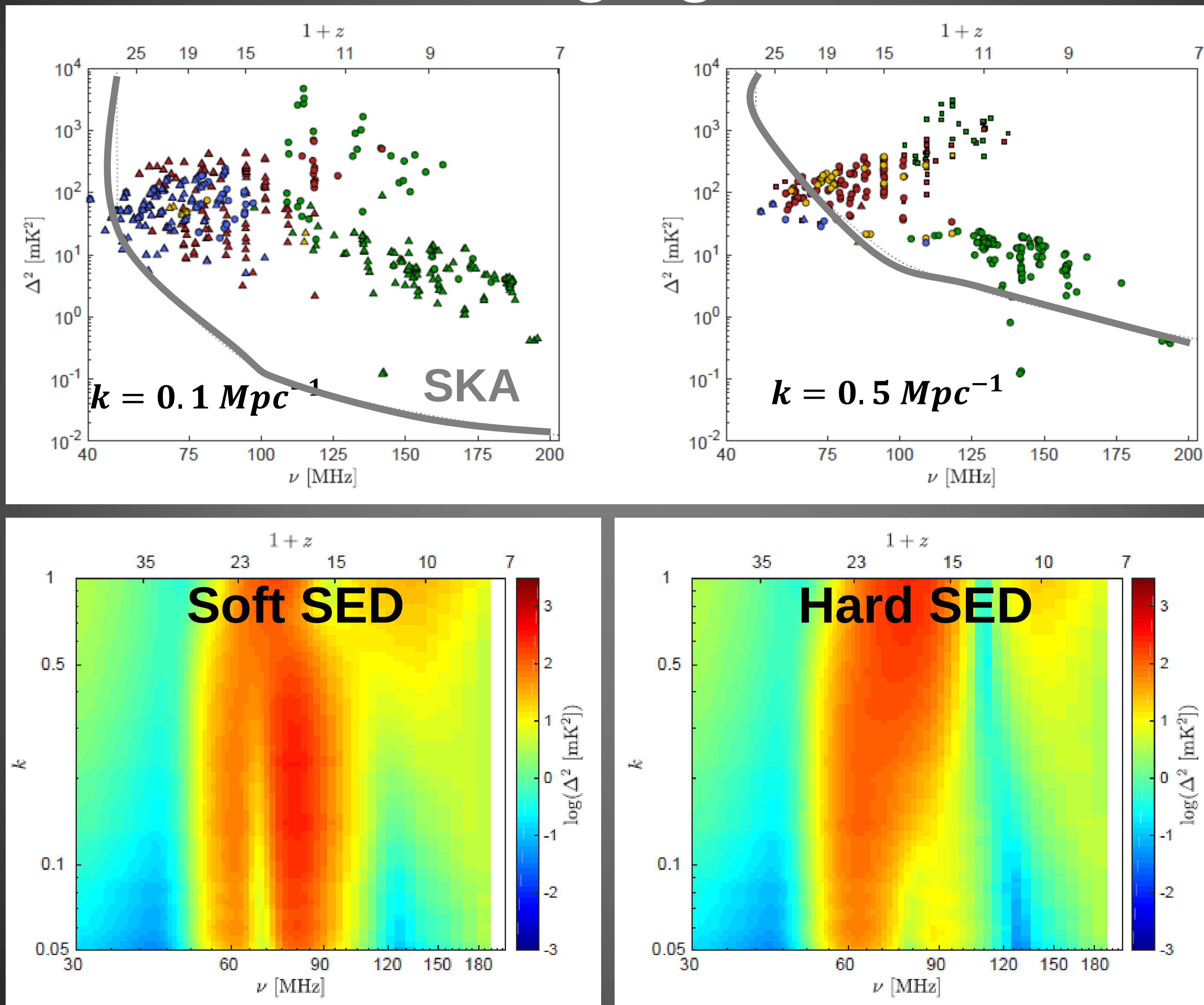
υ = 90 − 190 MHz
(14.8 > z > 6.5)

Some 68% constraints:

$$M_{min} < few \times 10^8\ M_\odot$$
$$f_X > 0.004$$

Monsalve, **Fialkov**, et al., in prep.

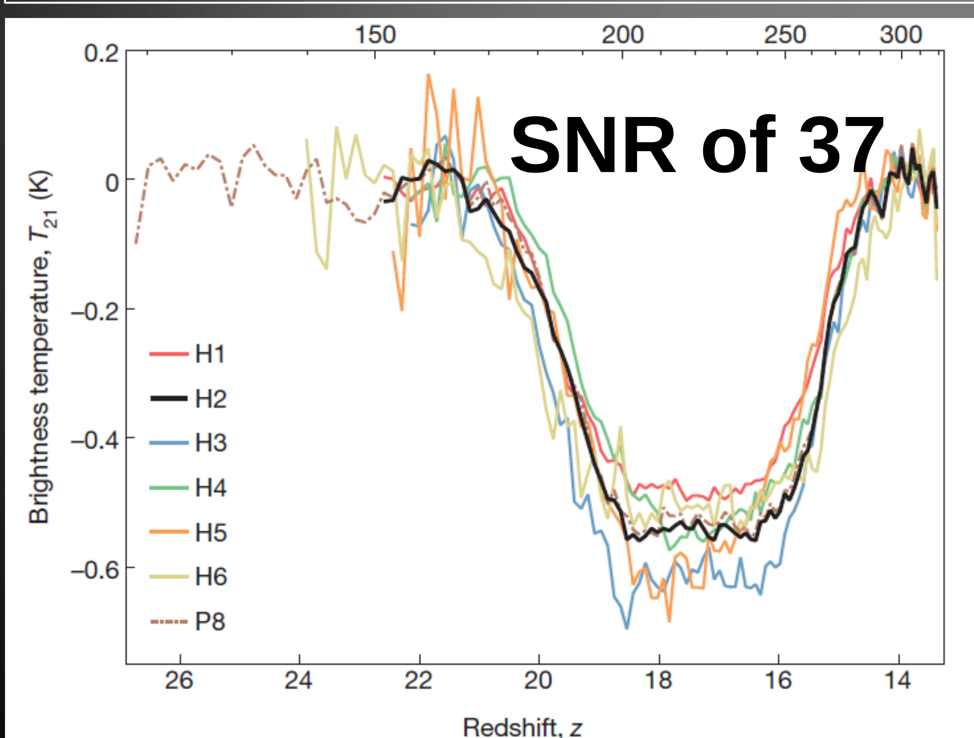
More Information in Power Spectrum/ Higher Order Statistics/ Imaging



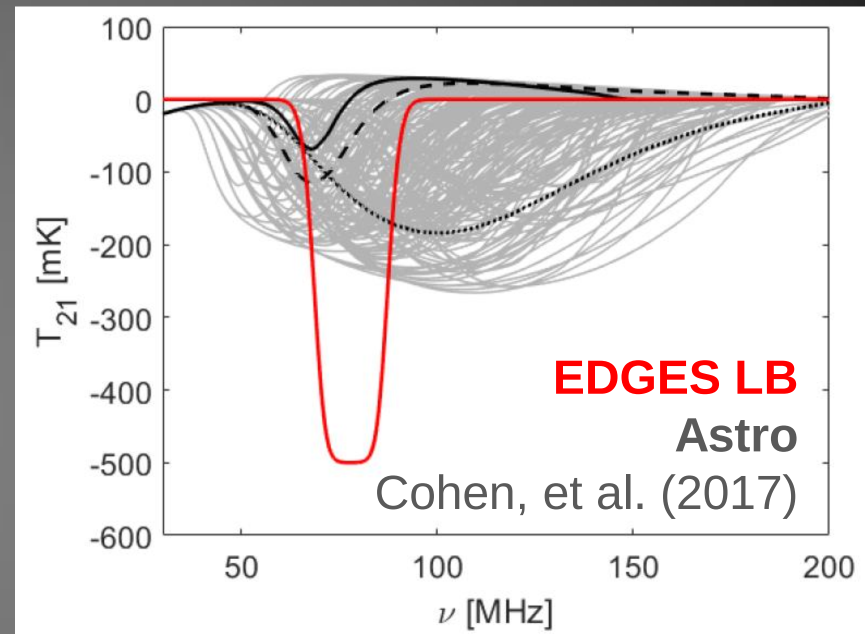
Cohen, **Fialkov**, Barkana (2018)

Cosmic Dawn with EDGES Low-Band

Bowman, Rogers, Monsalve, Mozdzen, Mahesh (2018)



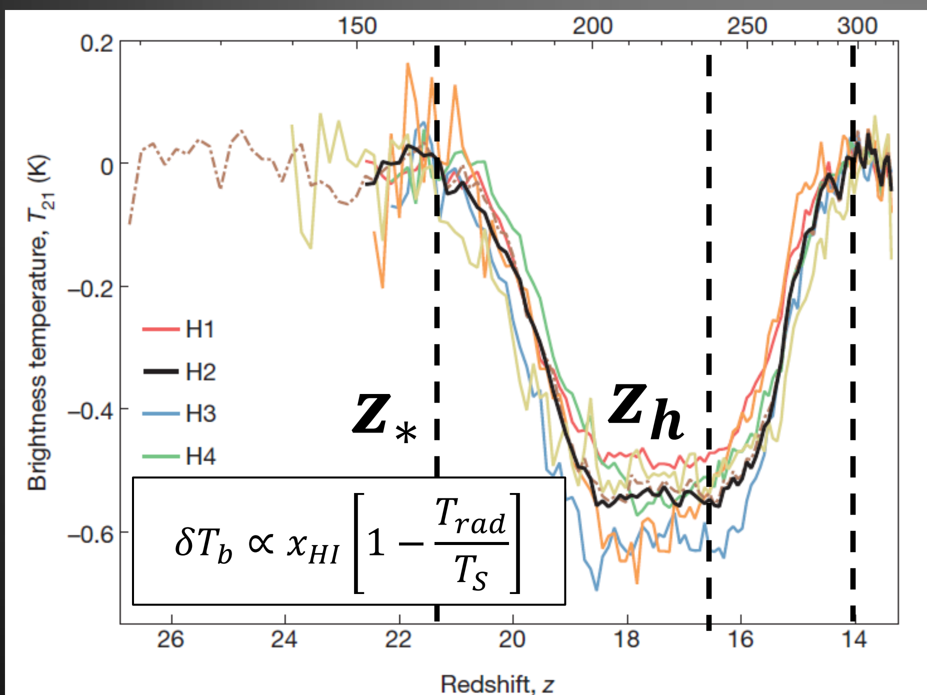
Best Fit in the Context of Standard Scenarios



OL: “The biggest tension of the week”

What Do we Learn if Confirmed?

$\upsilon = 50 - 100$ MHz, (*26 > z > 14*)



Bowman et al. 2018

Timing:

- First stars formed around z ~ 22
- $M_{min} < few \times 10^8\ M_{sun}$
- Steeper than expected UVLF (Mirocha & Furlanetto 2018)
- Heating starts around z ~ 16
- The Universe is heated by z ~ 14

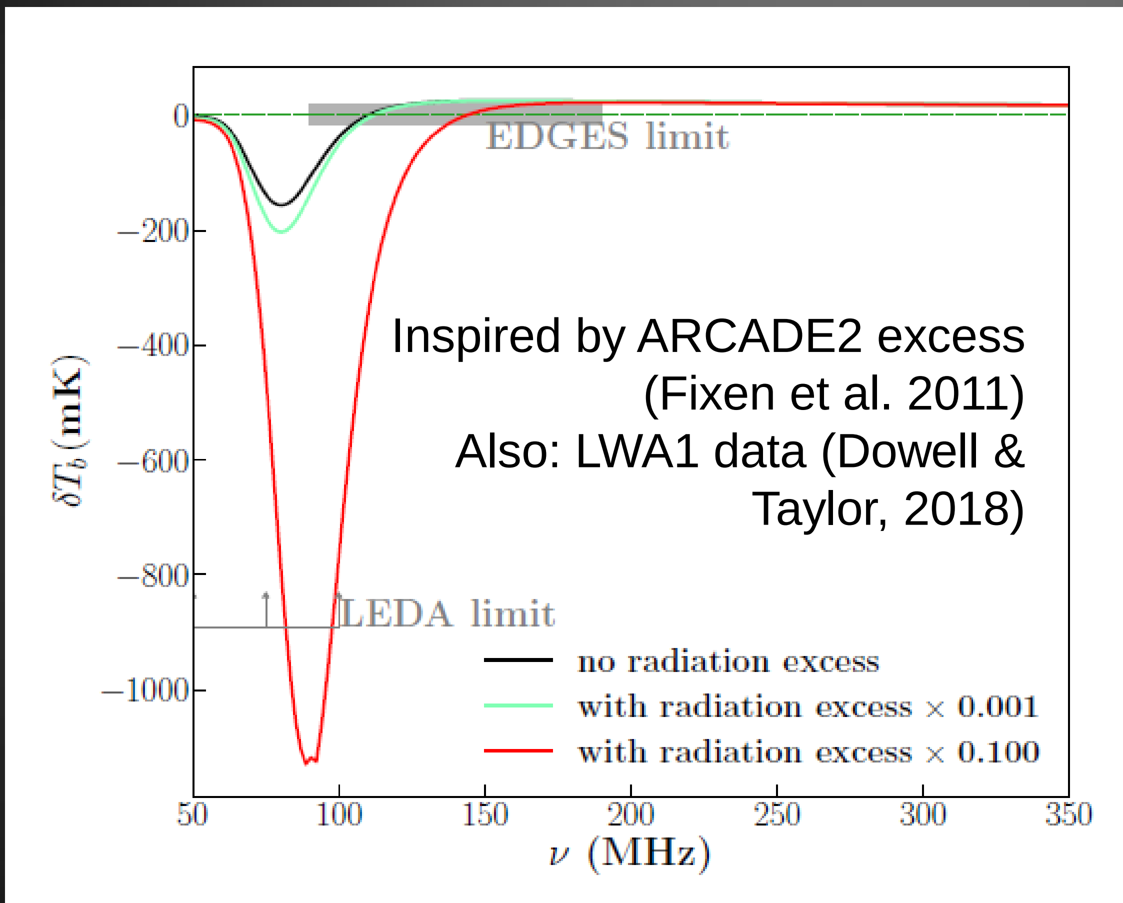
The amplitude and shape don't fit standard astro scenarios:

For the best-fit amplitude of 0.5 K:
$T_{Rad}/T_S > 15$ at z~17 (max is 7)

- T_{Rad} >104 K (CMB ~ 50 K)
- T_{gas} < 3.2 K (min is ~7 K)

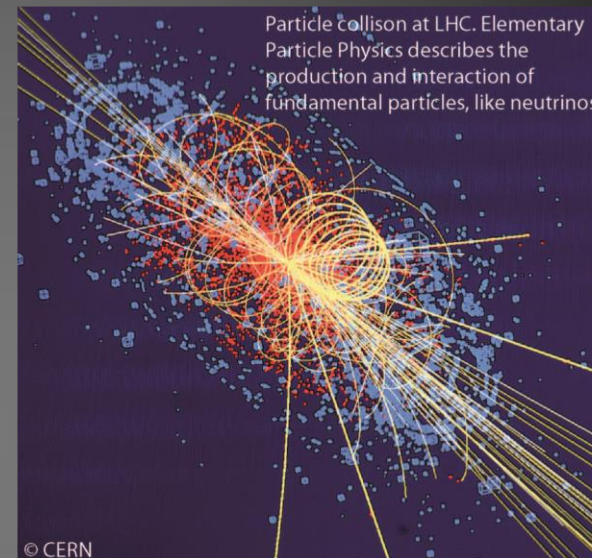
Deep Absorption via Extra Radio Background

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



Feng, Holder 2018

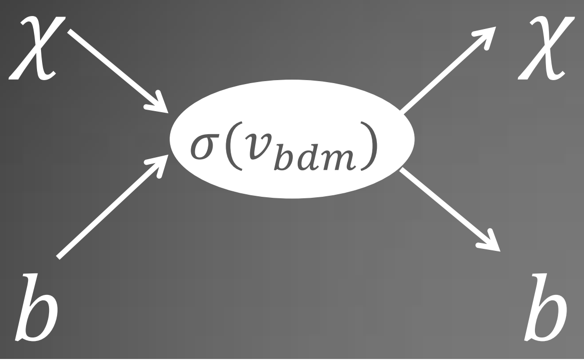
Effect of neutrino or DM?
Chianese et al. (2018)

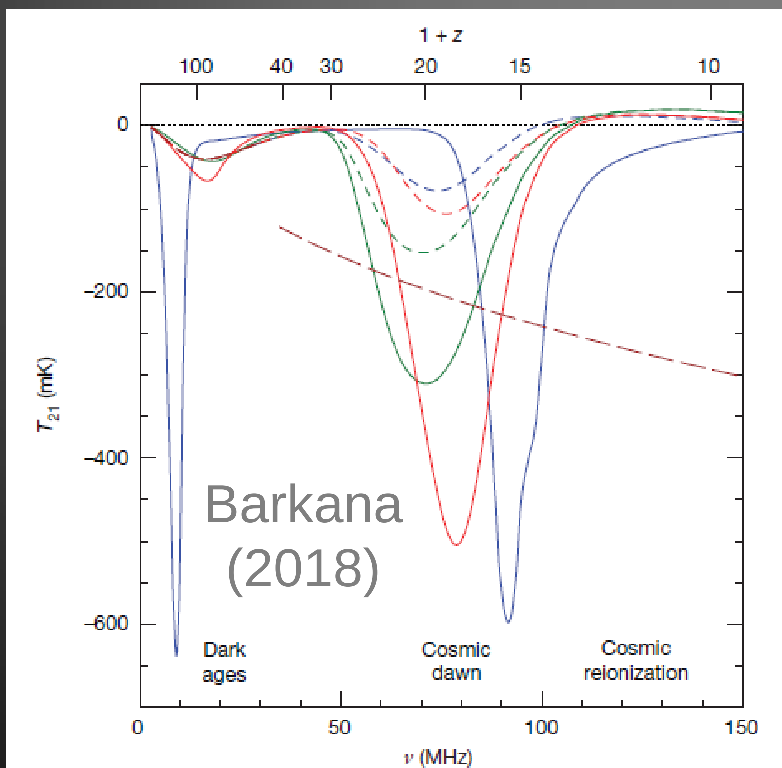


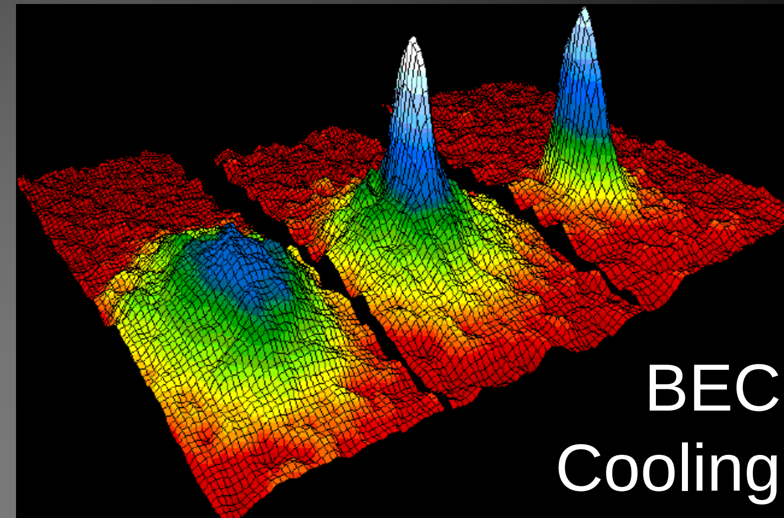
Exotic quasars at high z?
Ewall-Wice et al. (2018)

Deep Absorption via Extra Cooling

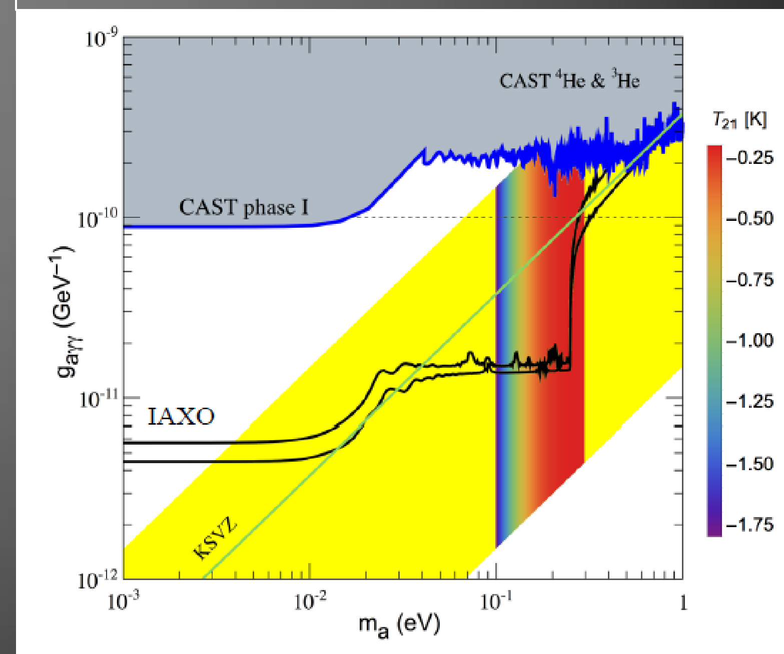
$$\delta T_b \propto x_{HI}\left[1 - \frac{T_{CMB}}{T_S}\right]$$



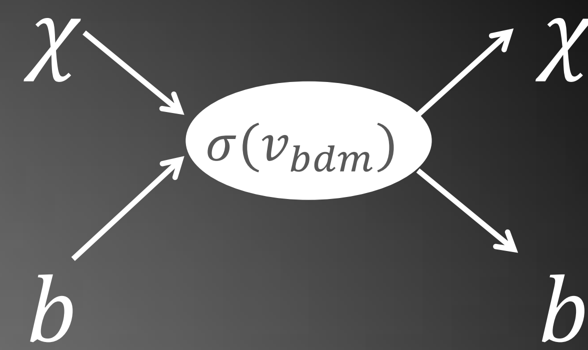


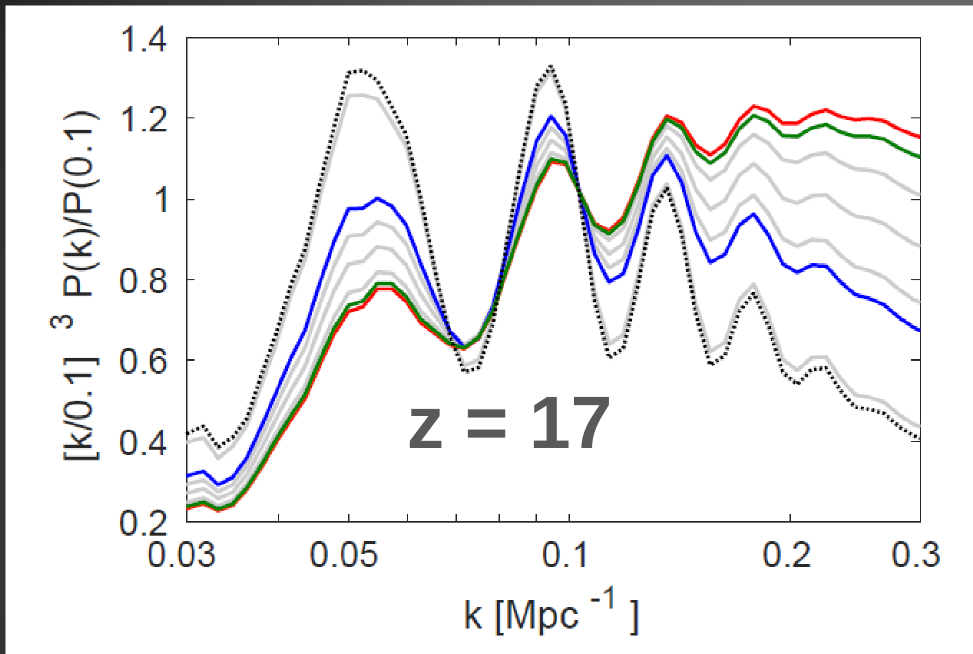


Sikivie 2018
Houston et al. 2018

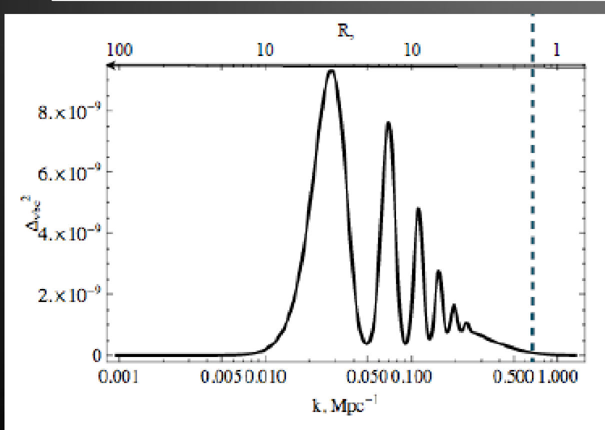


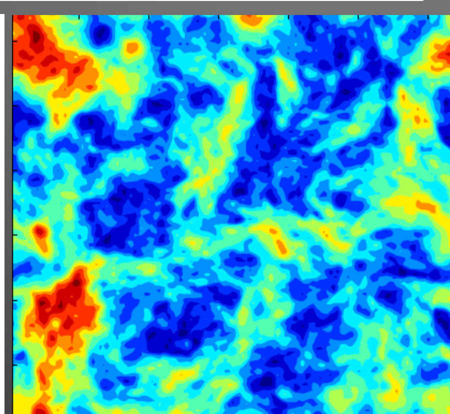
Smoking Gun Signature: Enhanced BAO



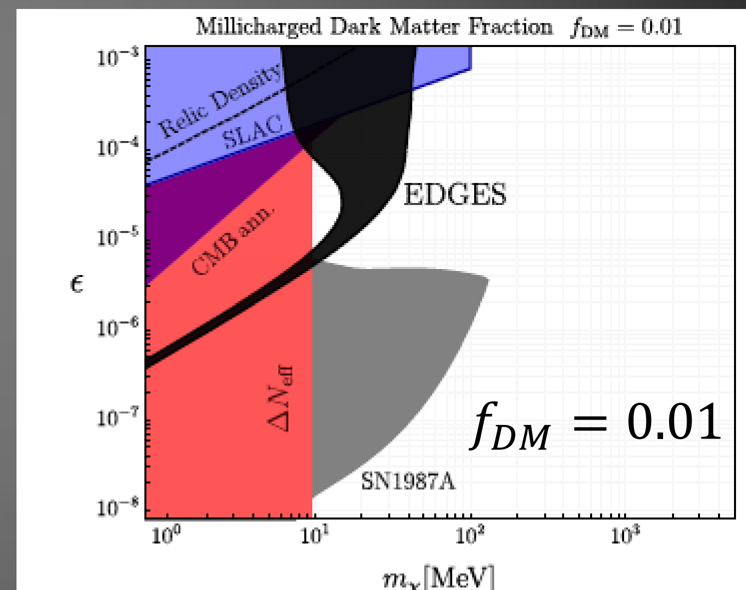


Fialkov, Barkana, Cohen (PRL)





Tight Constraints



Asher et al. 2018

See also Munoz & Loeb (2018), Barkana et al.(2018)

Observational Verification on the Way

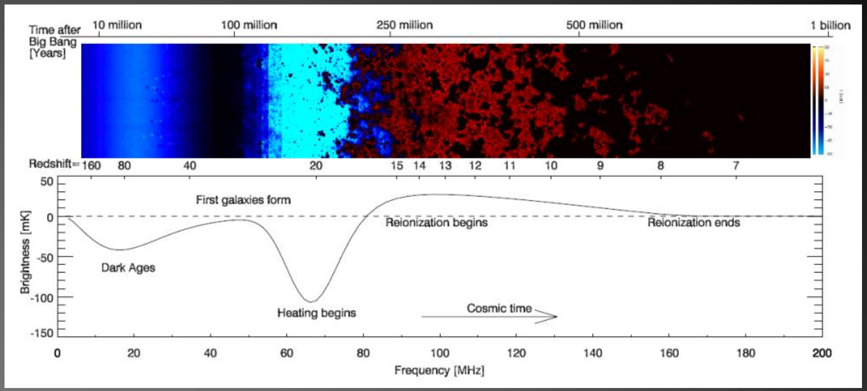
- EDGES-Mid (75% scaled version) has been deployed, the first data analyzed (Nov-Jan).
- SARAS Low has been deployed. Optimization in progress.
- PRISM taking data (?)
- LEDA
  - Upper limit $T_{21} > -890$ mK at z ~ 20 (95%, Bernardi et al., 2016)

LEDA

Dark Ages

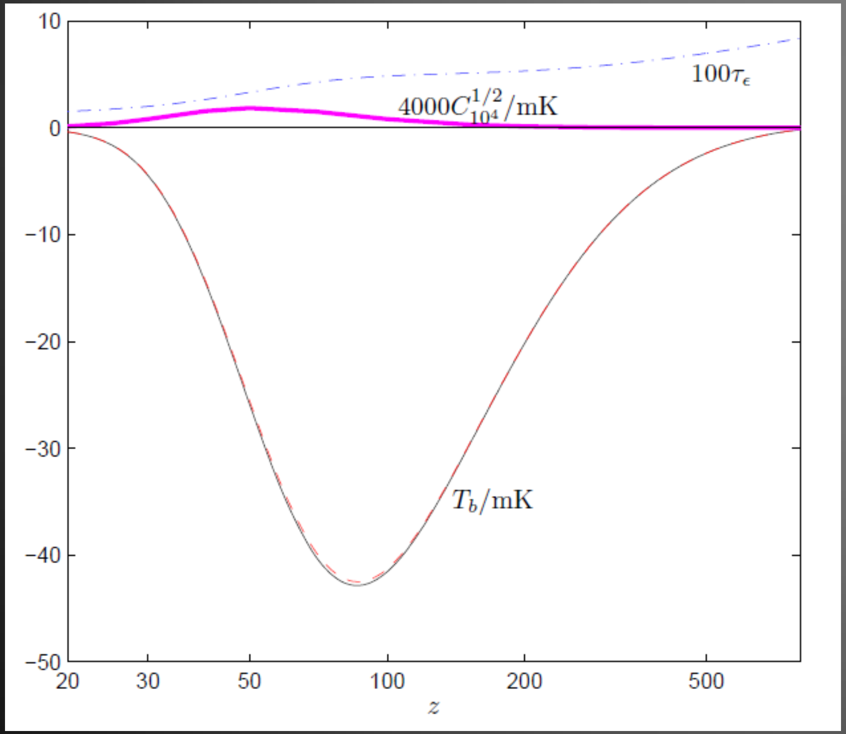
Dark Ages $\upsilon \lesssim$ 40 MHz
Only from Space

The signal is driven by atomic physics, cosmology
Dark Ages – unique cosmo. probe

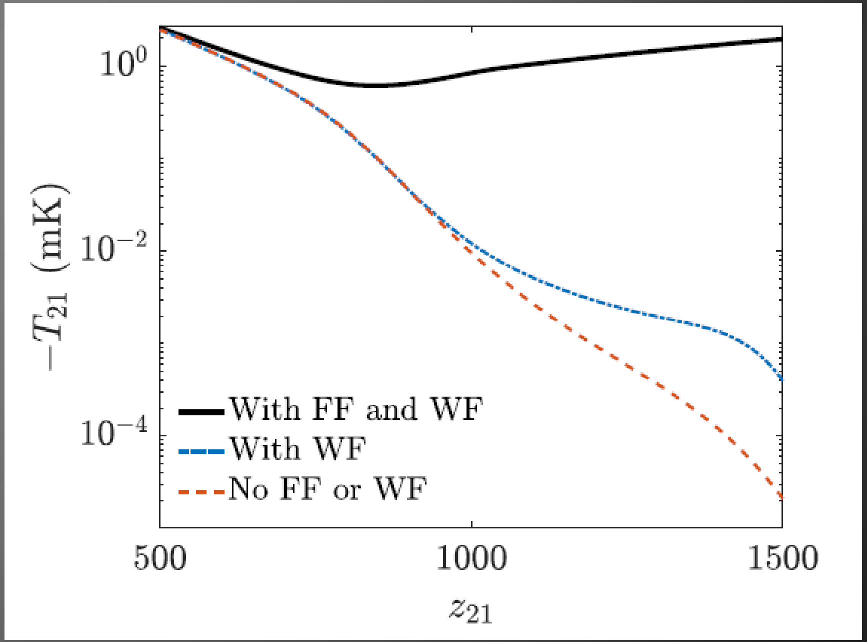


High-resolution Ly-a radiative transfer calculation, coupled to a state-of-the-art primordial recombination code

Standard Physics

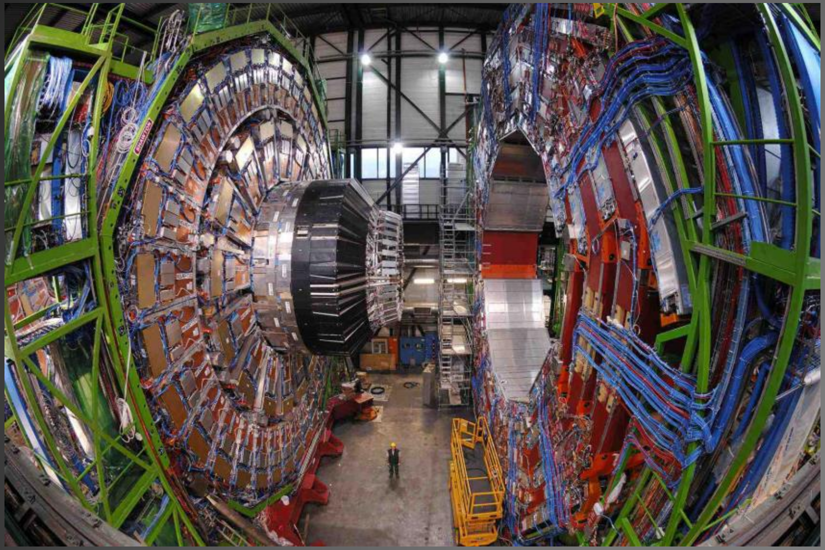


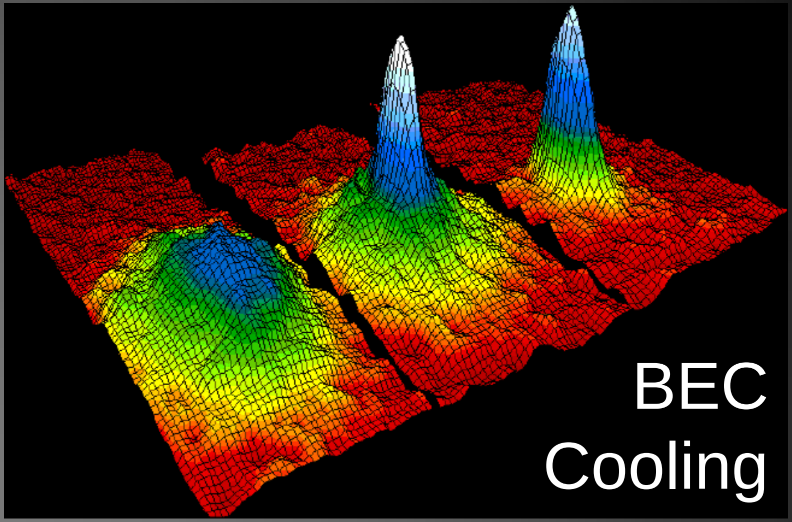
Lewis & Challinor (2007)



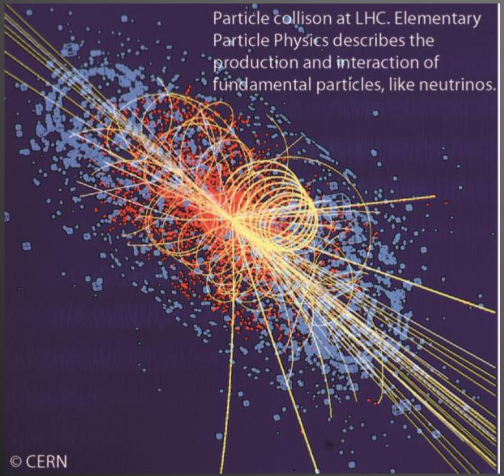
Breysse, Ali-Haimoud, Hirata (2018)

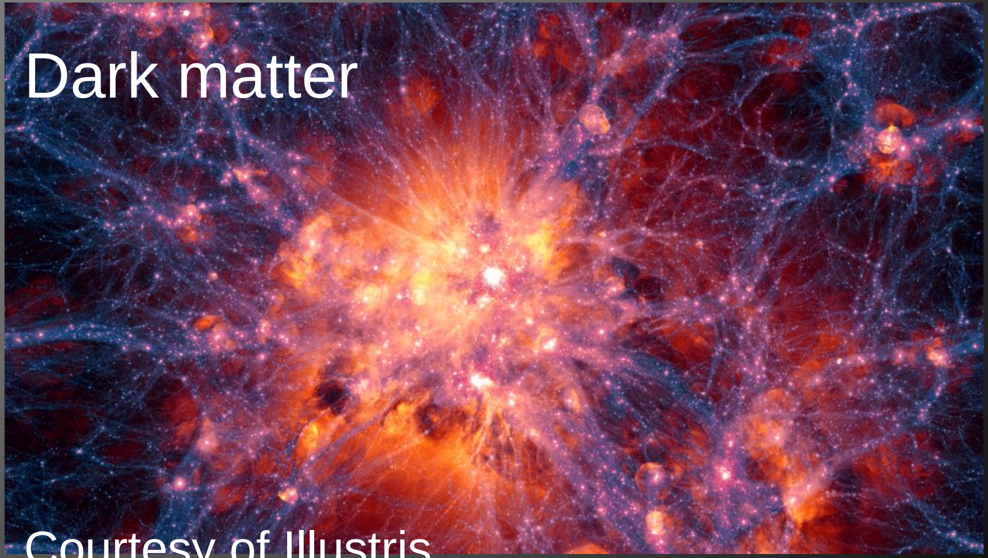
The Universe is bigger than the LHC! New tests of DM physics





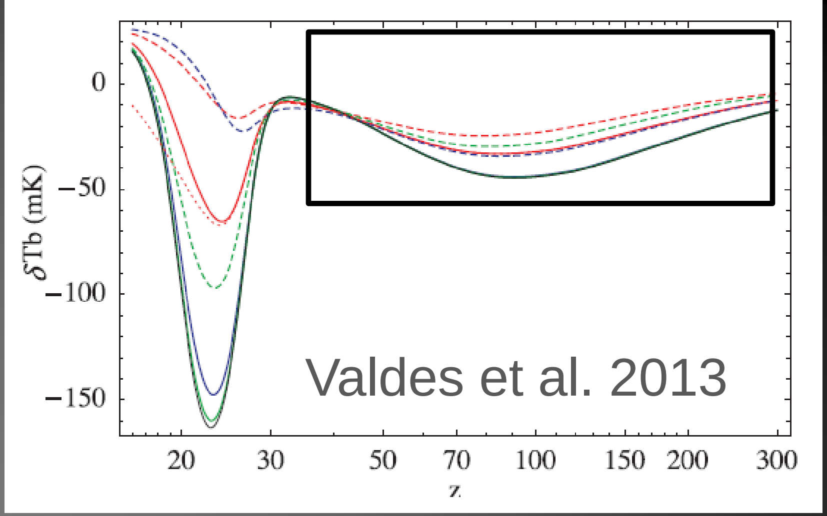
Dark Ages –Window Into the Dark Sector

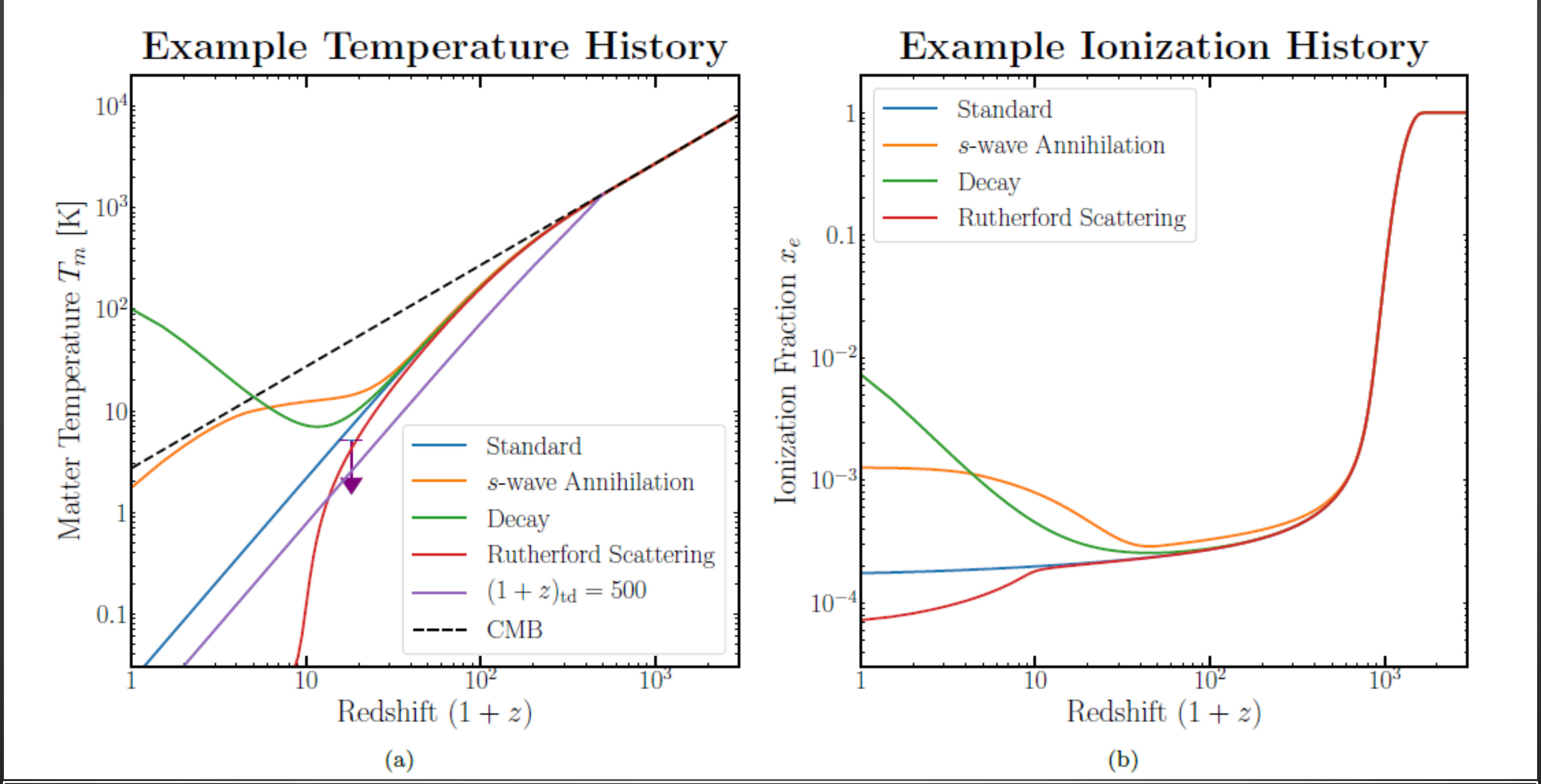




Dark Ages as a Probe of DM Annihilation and Decay

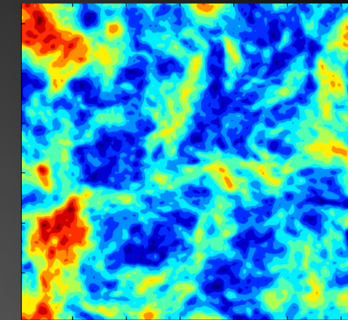
Affects thermal and ionization histories.

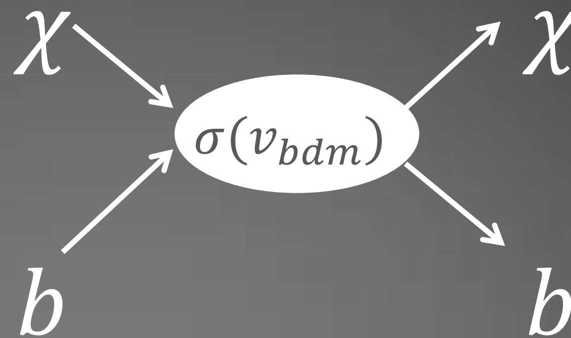




Liu & Slatyer (2018)

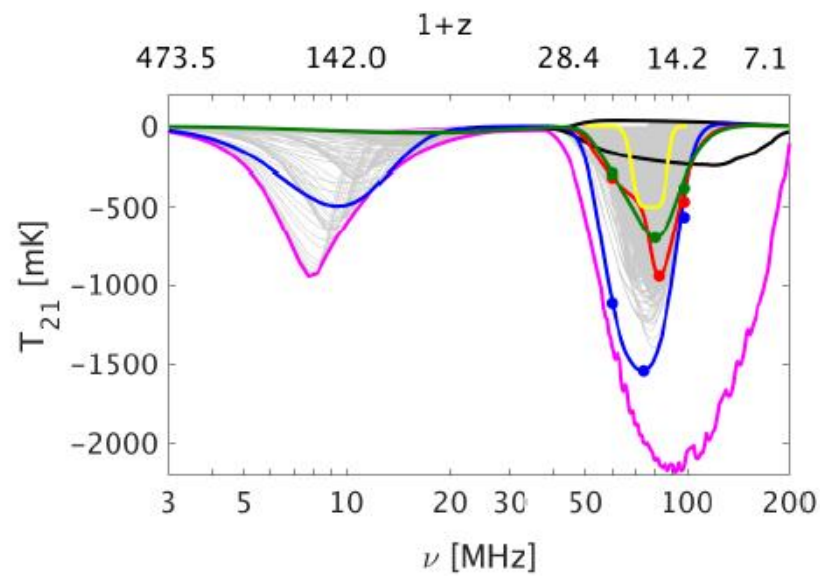
Dark Ages as a Probe of Dark Matter
B-DM Scattering



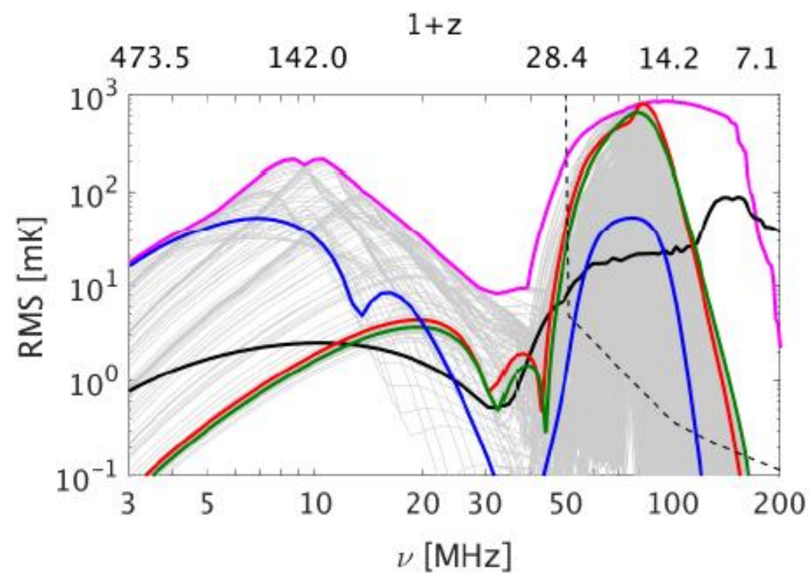


Affects thermal and ionization histories (cooling and heating)

Global 21-cm



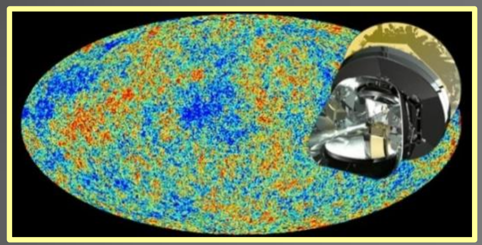
Power Spectra



Fialkov, Barkana, Cohen, PRL, accepted

Conclusions: Exciting times for 21-cm cosmology!

21-cm: 3D scan of the Universe
Aspiration: Precision analysis at all redshifts



Cosmic Dawn & EoR: probe of astrohysics and DM. First stars & black holes.

Dark Ages: cosmology and DM physics