DARK MATTER REVEALED BY THE FIRST STARS ?

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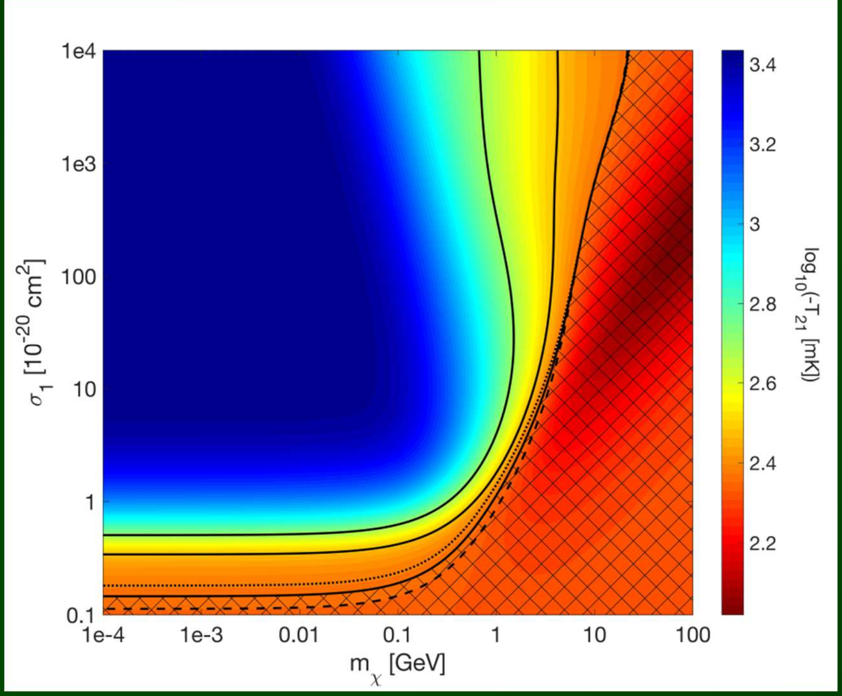
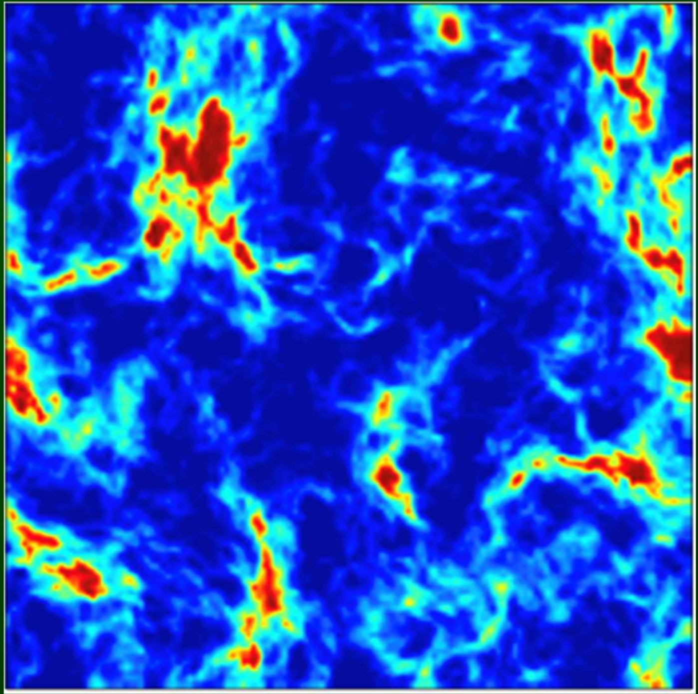
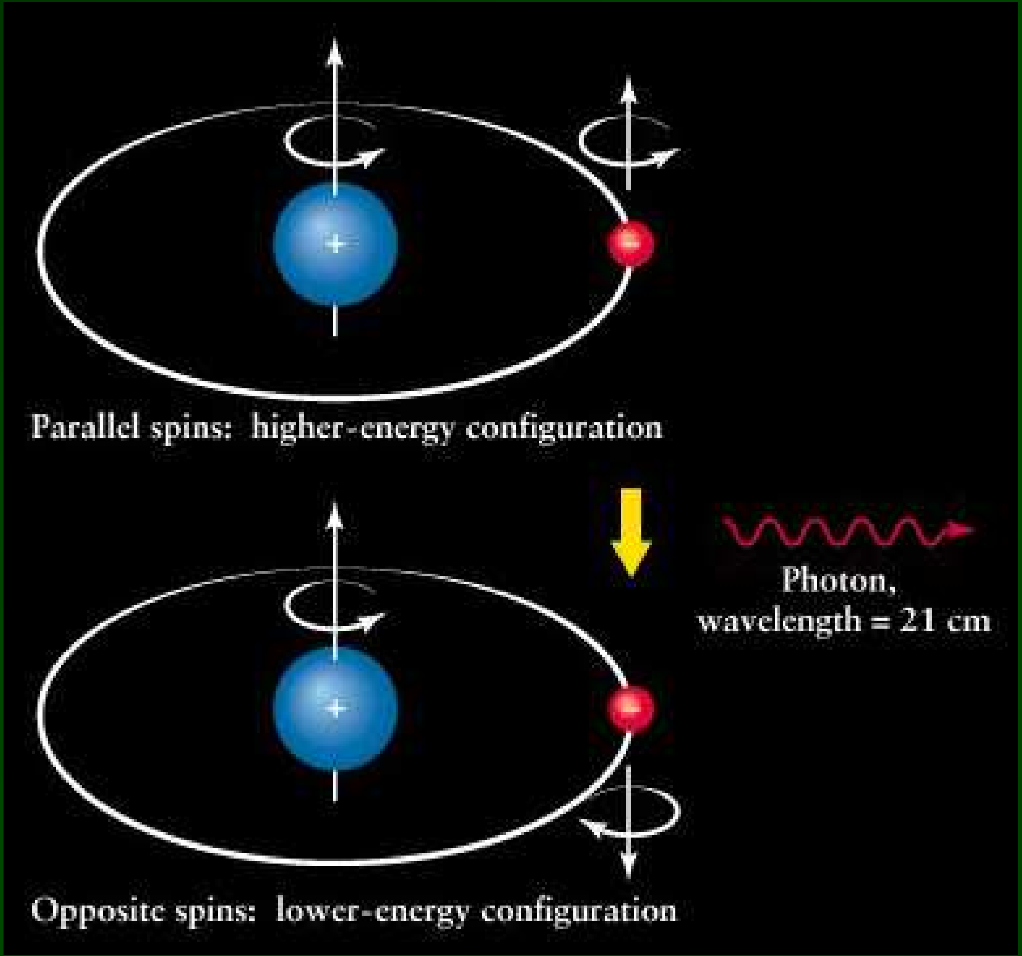
TEL AVIV UNIVERSITY אוניברסיטת תל-אביב





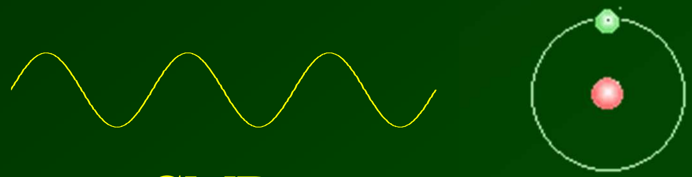
21-cm Cosmology: The Spin Temperature



$$\lambda = 21\,\mathrm{cm}$$
$$\nu = 1420\,\mathrm{MHz}$$
$$E = 5.9 \times 10^{-6}\,\mathrm{eV}$$
$$\frac{E}{k_B} = T_* = 0.068\,\mathrm{K}$$

$$\frac{n_1}{n_0} = 3\exp\left\{-\frac{T_*}{T_S}\right\}$$

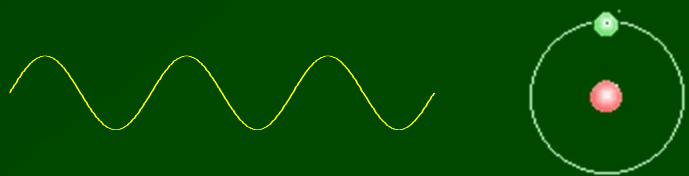
What determines T_S?



CMB

$$T_S \rightarrow T_{\rm CMB}$$

$$T_S \rightarrow T_{\rm gas}$$



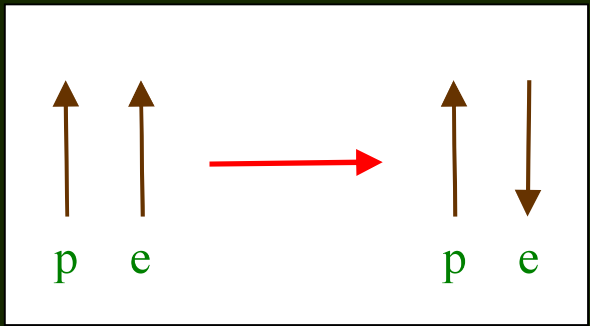
Lyα

$$T_S \rightarrow T_{\rm gas}$$

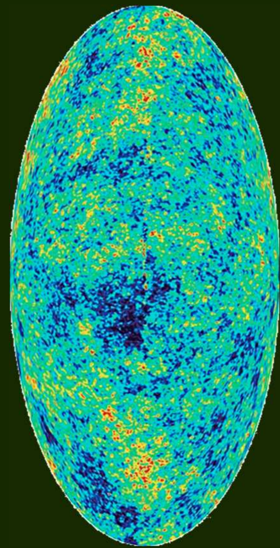
Wouthuysen 1952

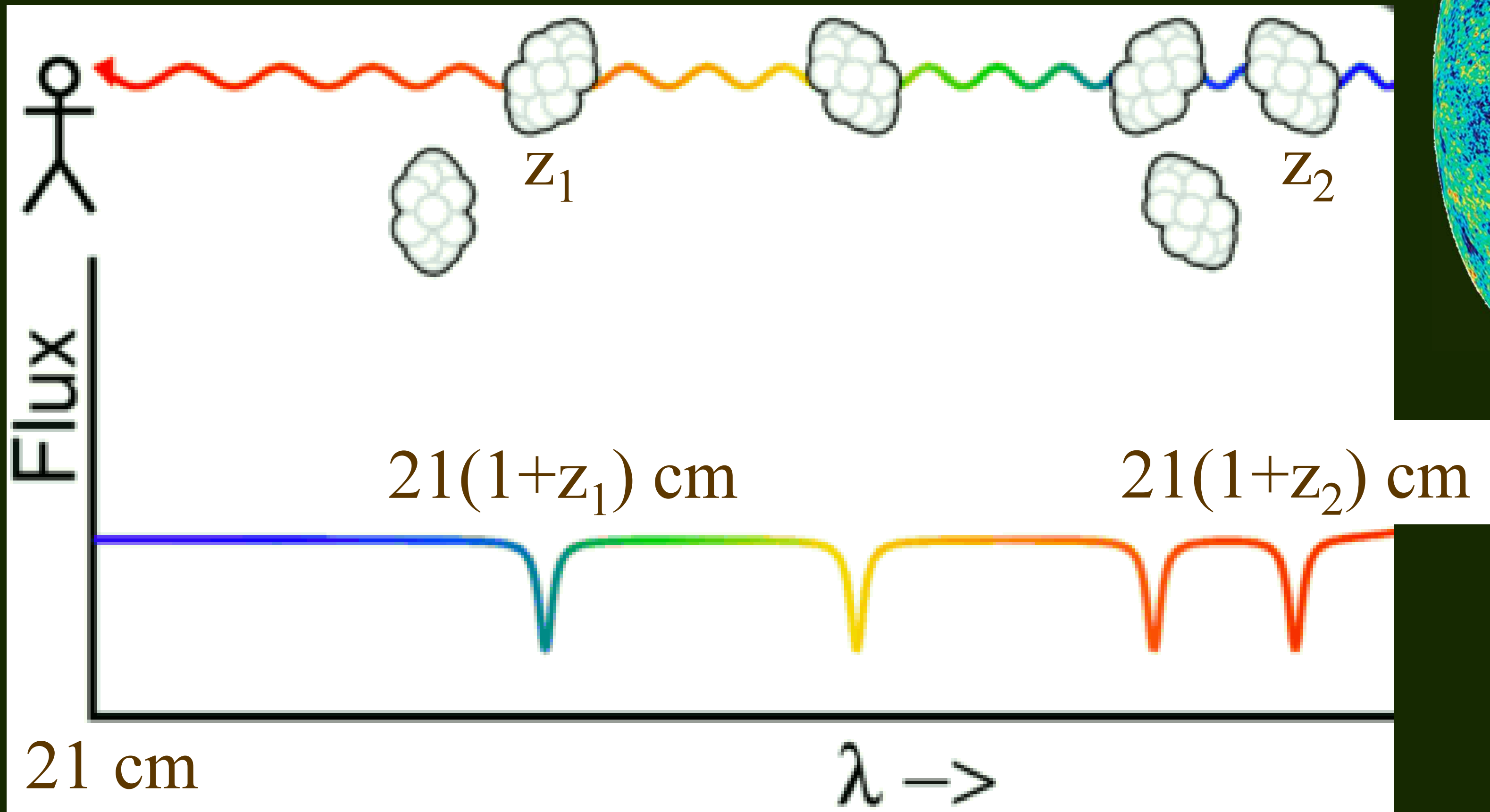
Field 1958

21-cm Spectra



Resonance Line +
Cosmological Redshift





$$T_{\rm b} = (1+z)^{-1}(T_{\rm S} - T_{\rm CMB})(1 - e^{-\tau})$$

$$T_{21} = 26.8\, x_{\rm HI}\, \frac{\rho_{\rm g}}{\bar{\rho}_{\rm g}} \left(\frac{\Omega_{\rm b} h}{0.0327}\right) \left(\frac{\Omega_{\rm m}}{0.307}\right)^{-1/2} \left(\frac{1+z}{10}\right)^{1/2} \left(\frac{T_{\rm S} - T_{\rm CMB}}{T_{\rm S}}\right) \,\mathrm{mK}$$

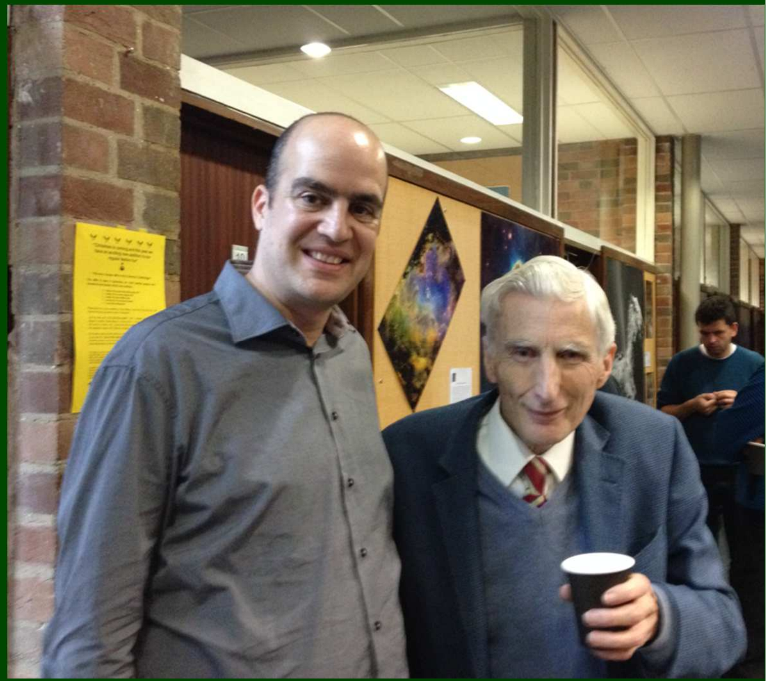
Ancient History

Reionization:

Gunn & Peterson 1965

……

21-cm Cosmology:



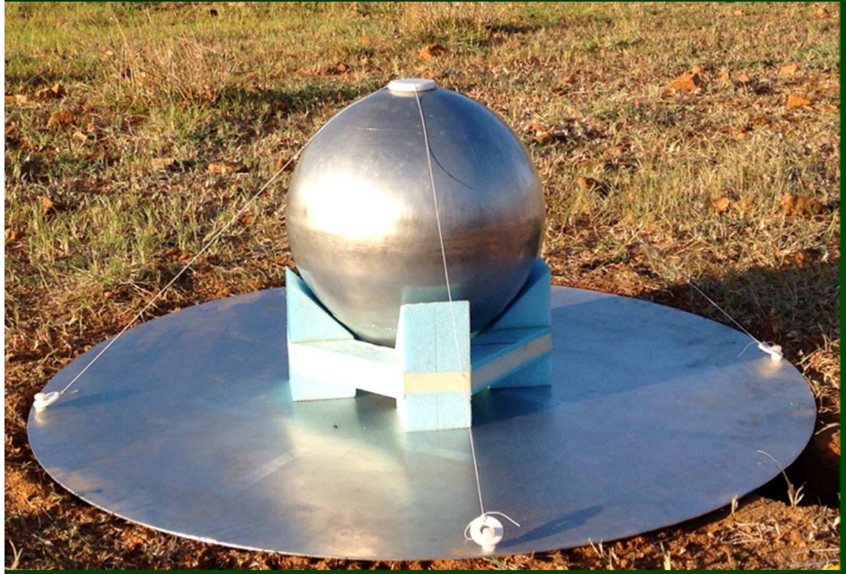
Hogan & Rees 1979: Basic ideas (ρ, T, T_s)

Scott & Rees 1990: CDM + reionization

Madau, Meiksin & Rees 1997: Cosmic Dawn (Ly-α and heating)

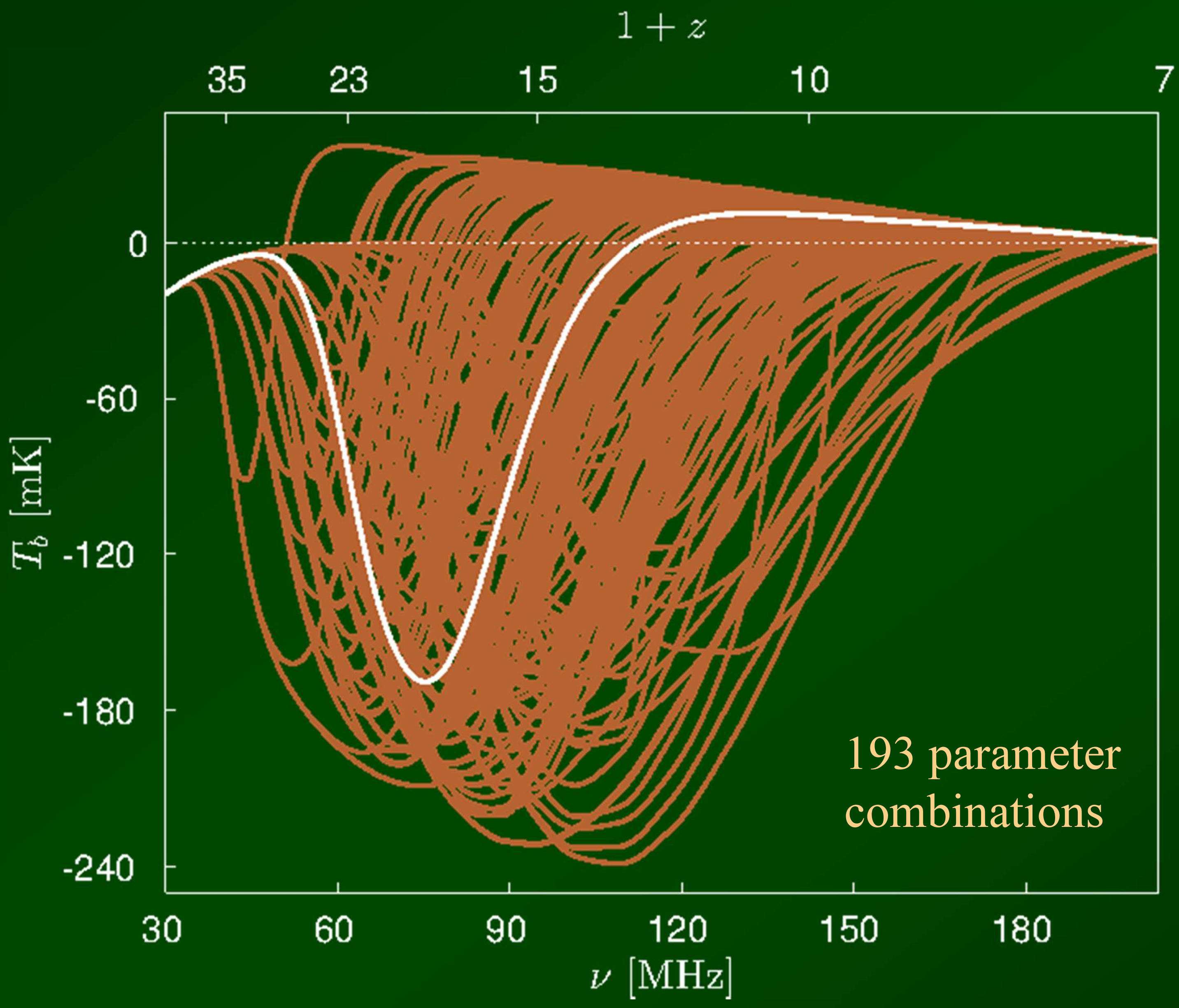
Global 21-cm Experiments

SARAS

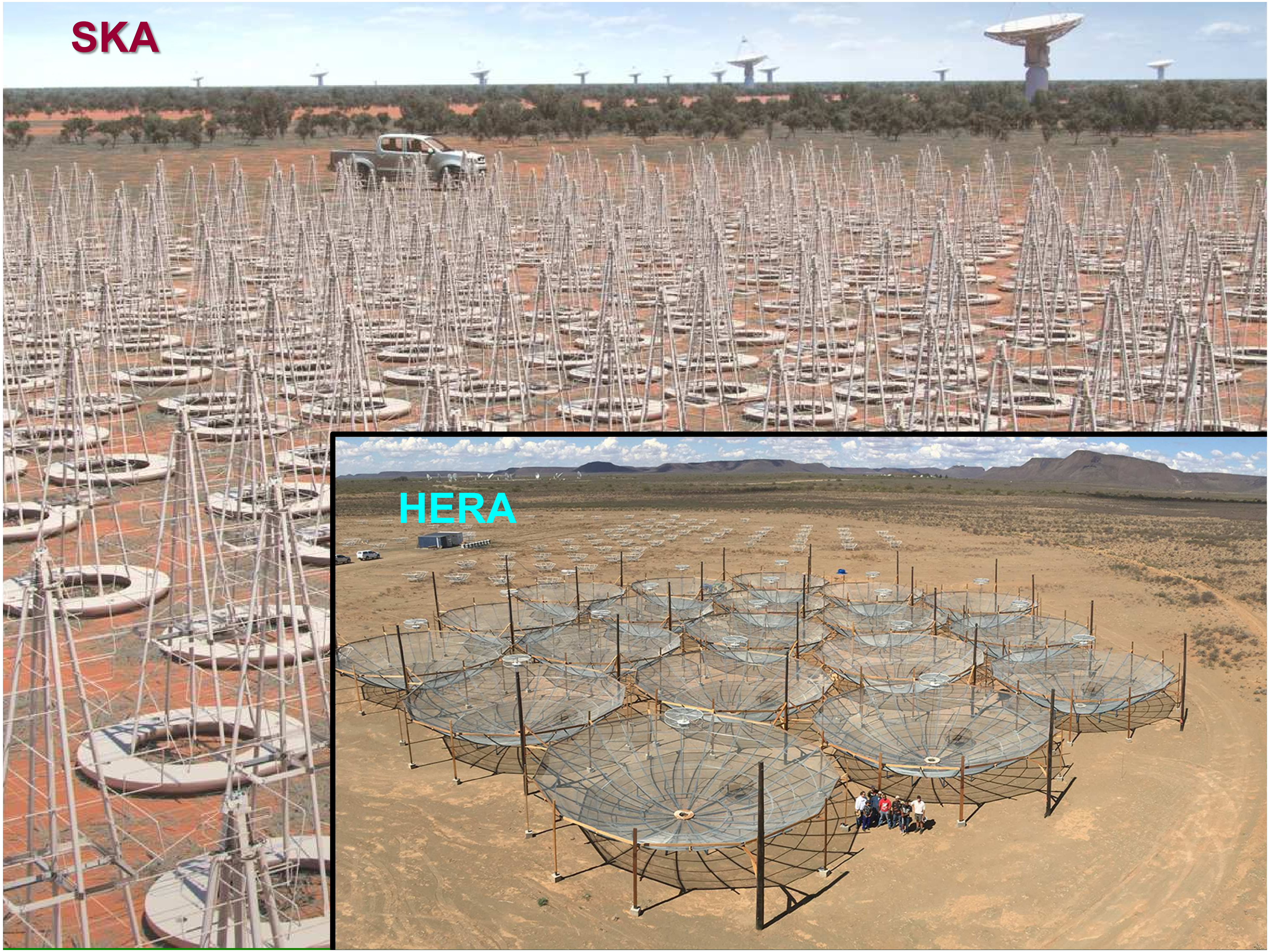


EDGES high

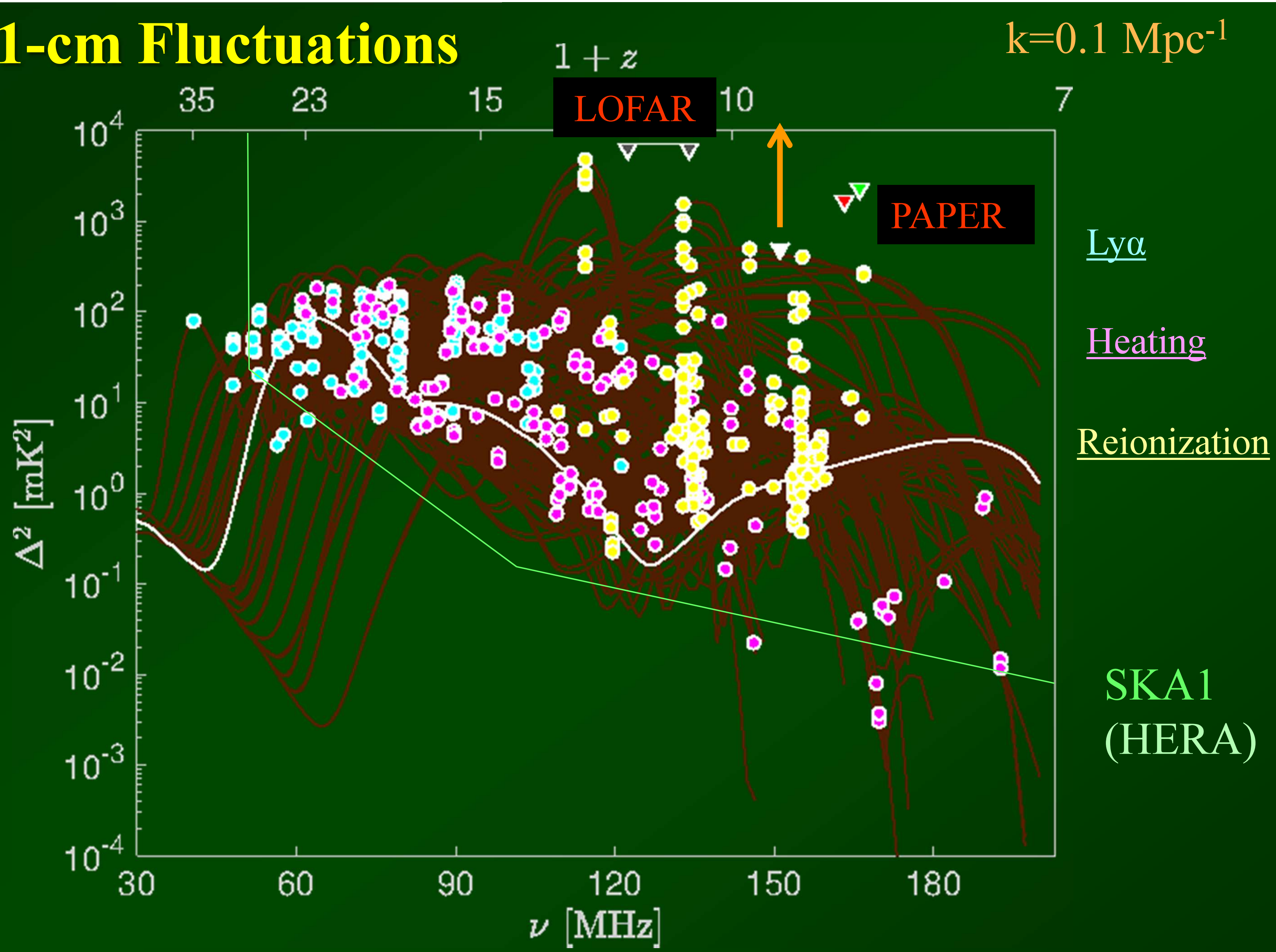
Global 21-cm



Cohen, Fialkov, RB, & Lotem 2017


SKA
HERA

21-cm Fluctuations

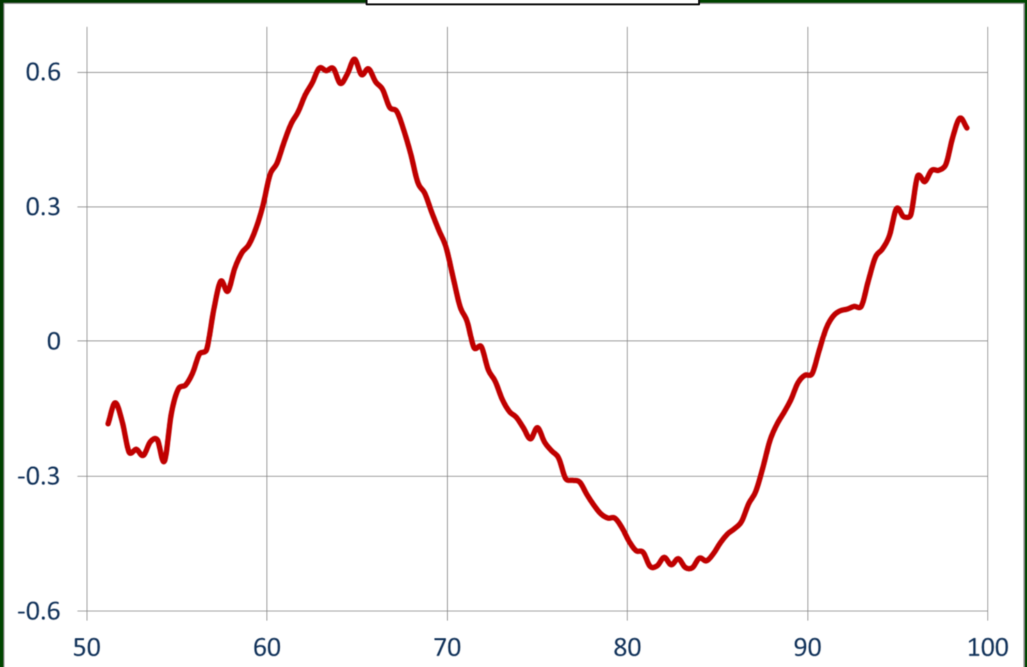


Cohen, Fialkov, RB 2017

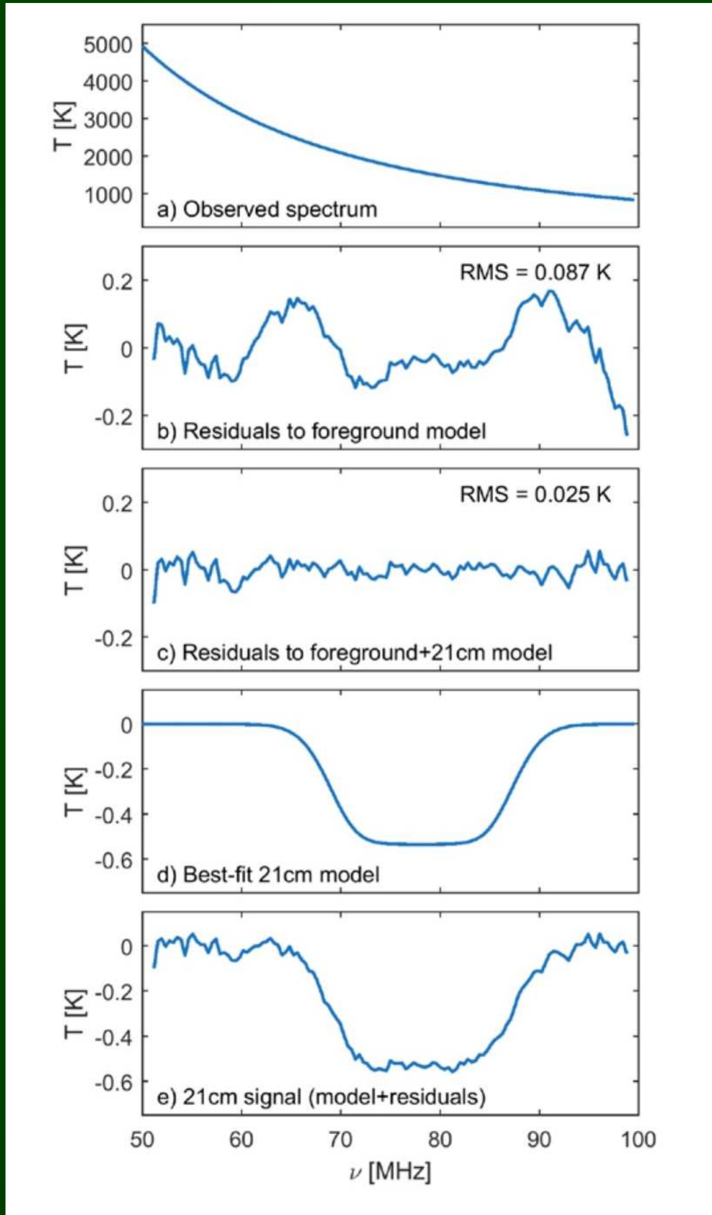
EDGES-Low

EDGES-Low

T[K] vs. ν[MHz]

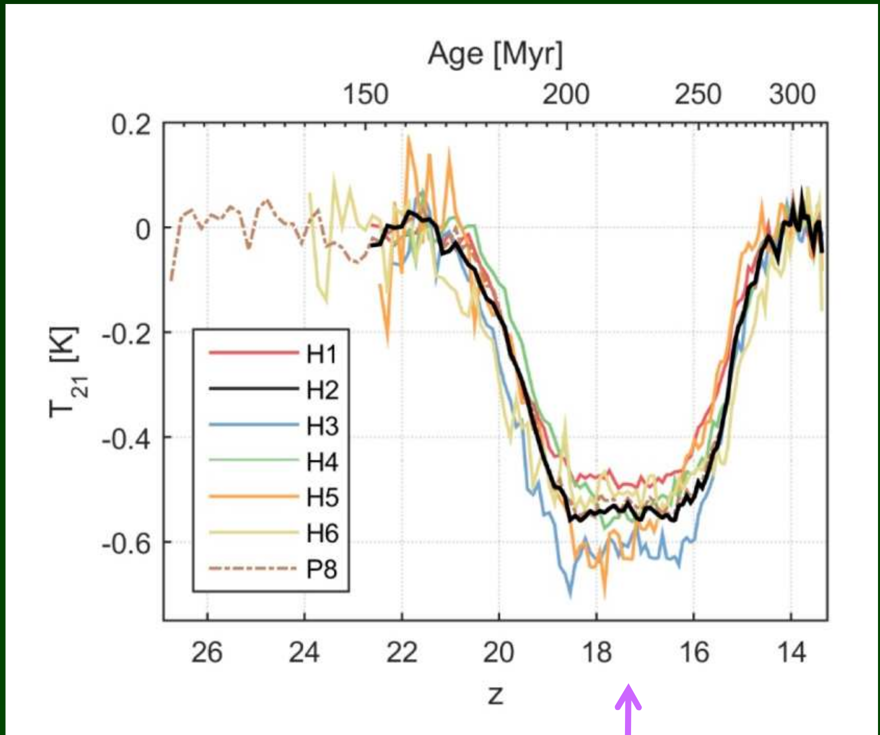


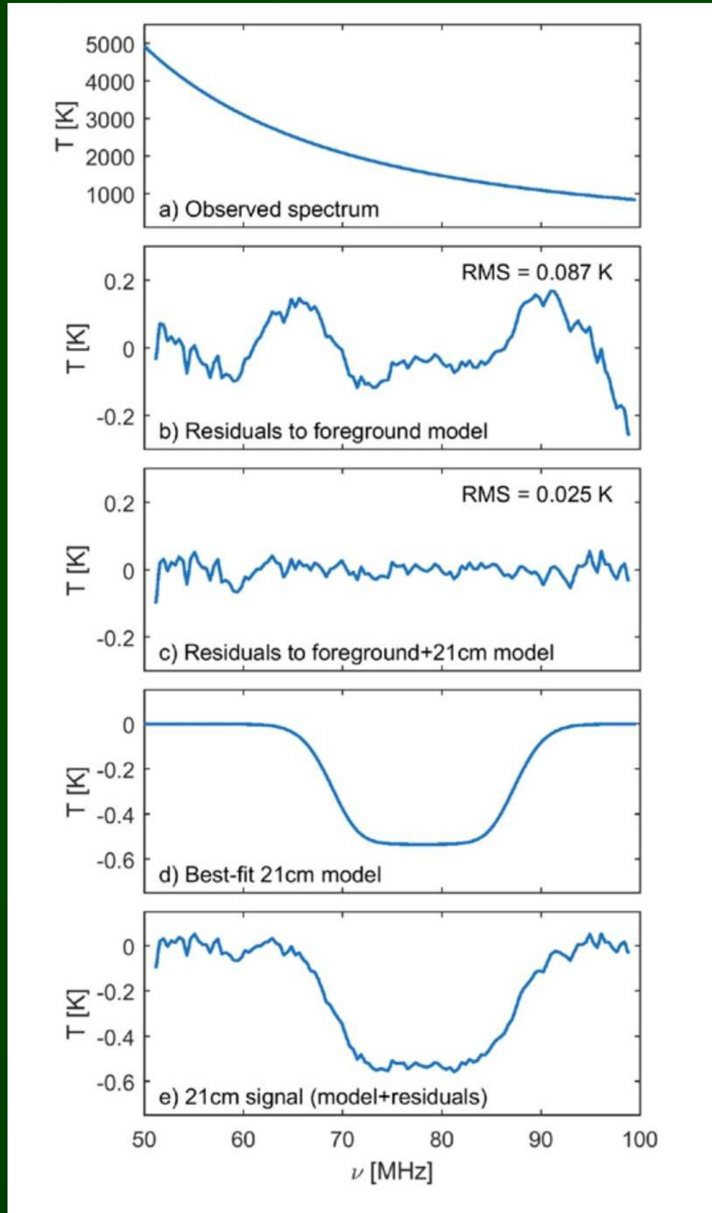
(2-term polynomial)



Bowman et al. 2018

EDGES-Low

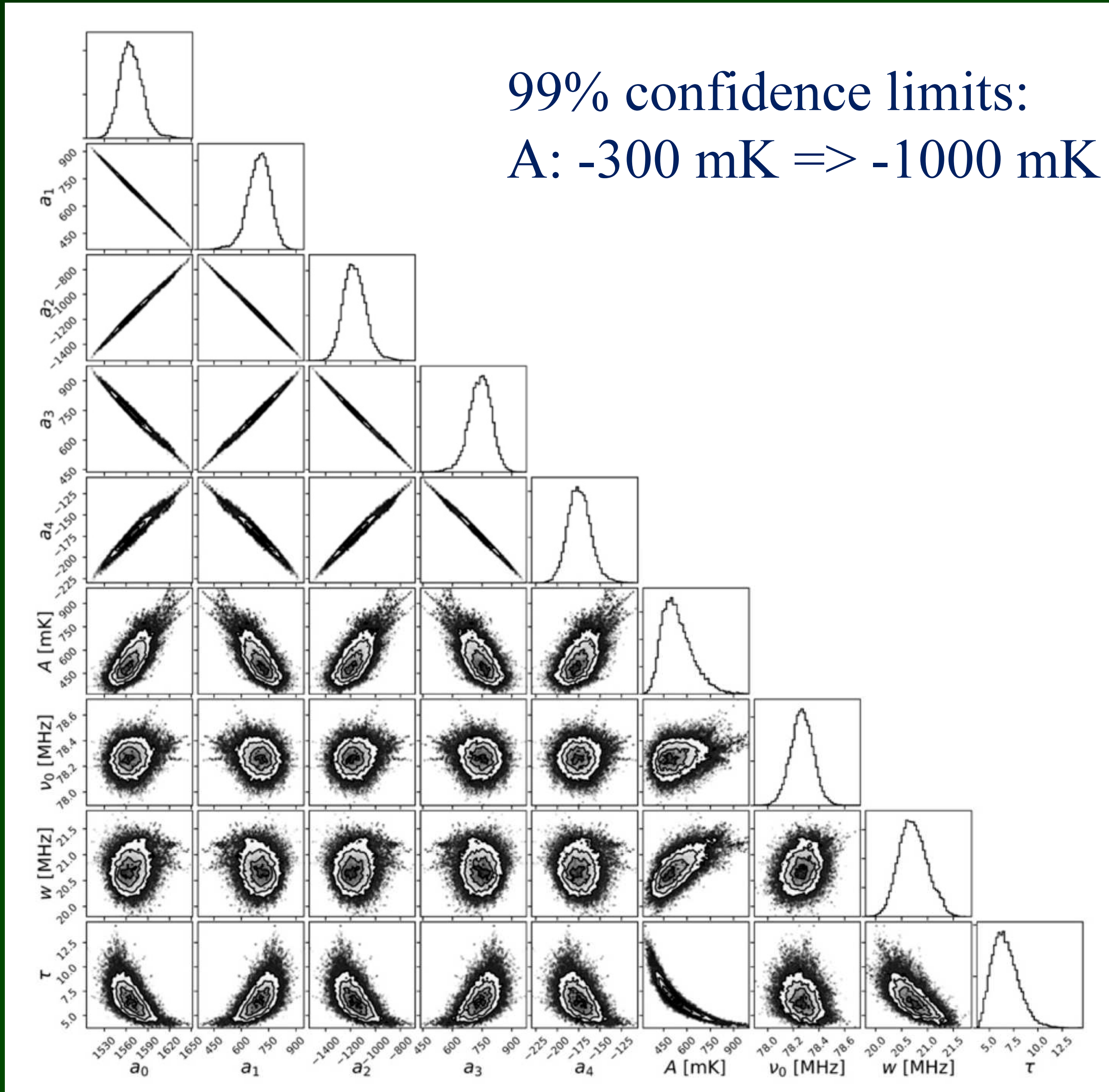




Flat with sharp edges?

Bowman et al. 2018

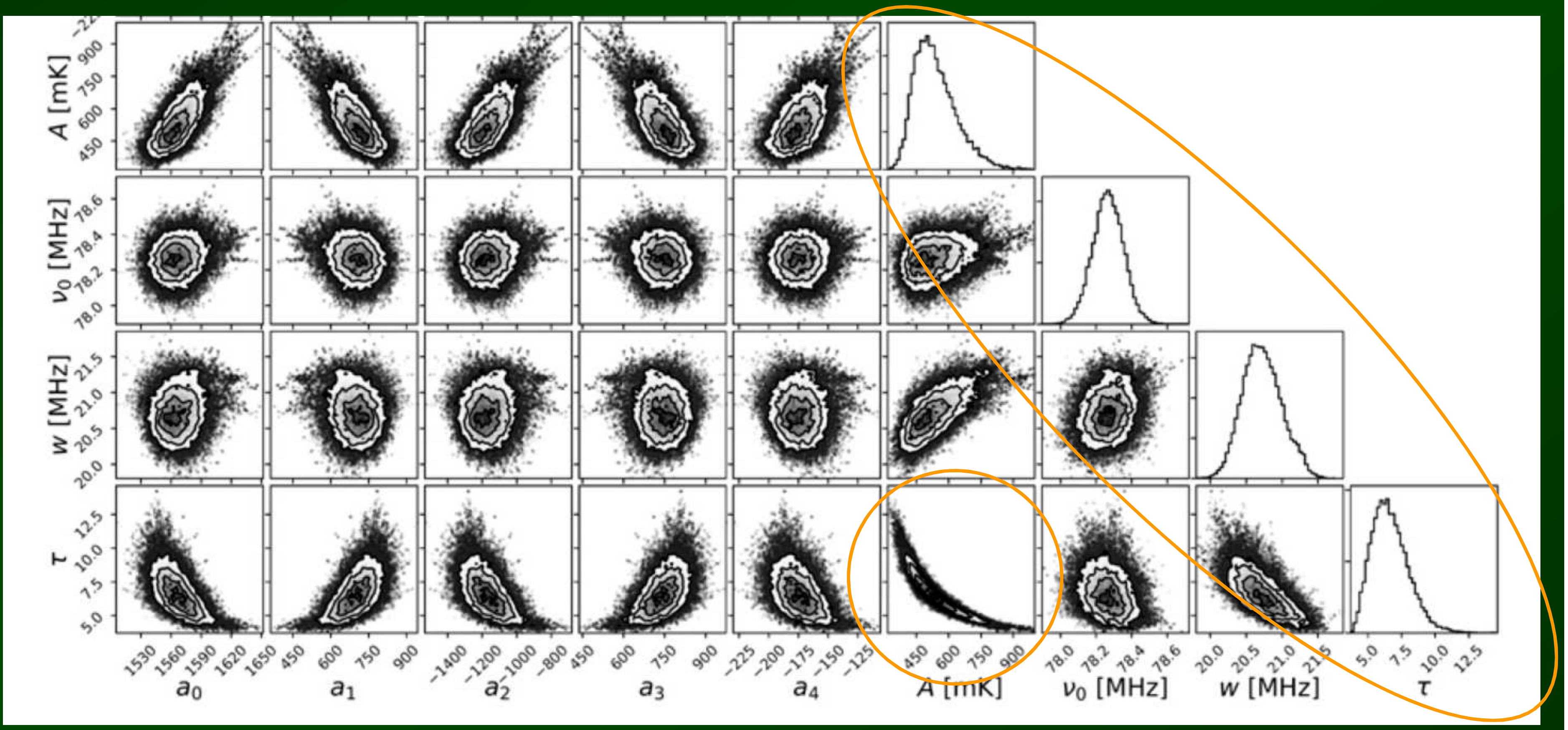
EDGES-Low: MCMC



Bowman et al. 2018

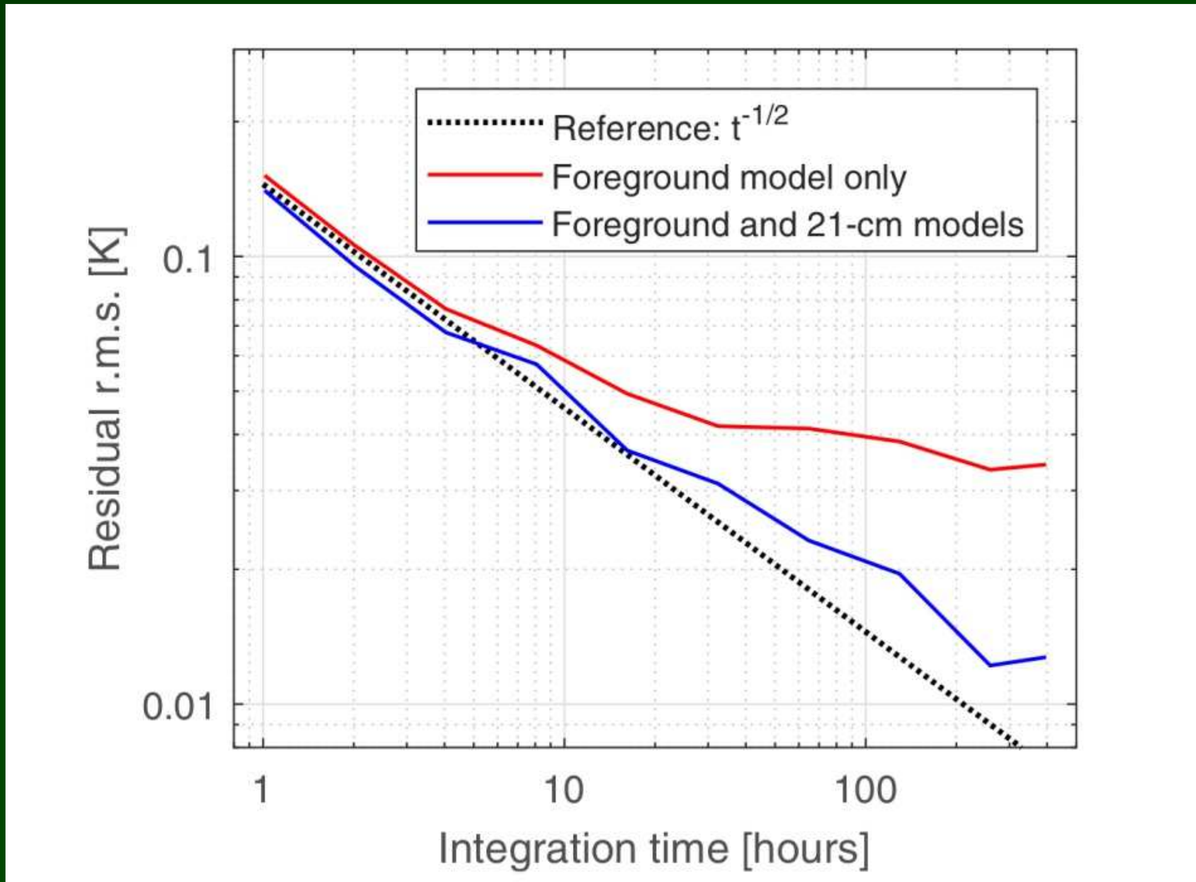
EDGES-Low: MCMC

99% confidence limits:
A: -300 mK => -1000 mK



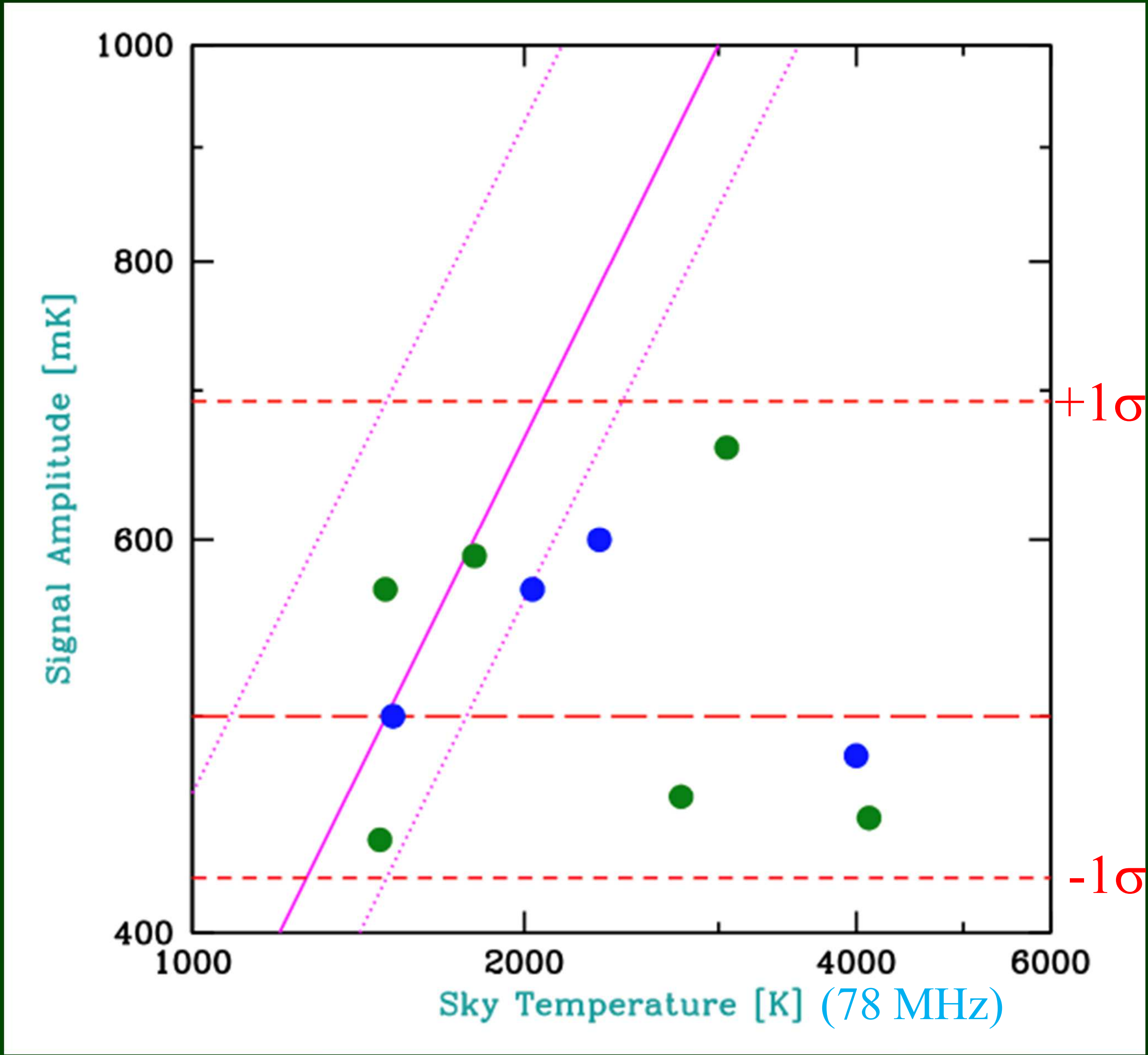
Bowman et al. 2018

EDGES-Low



Bowman et al. 2018

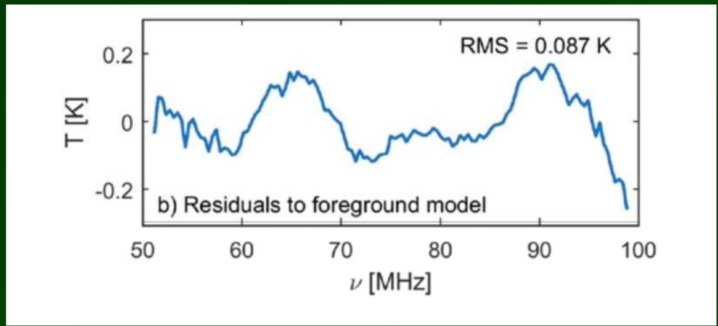
EDGES-Low

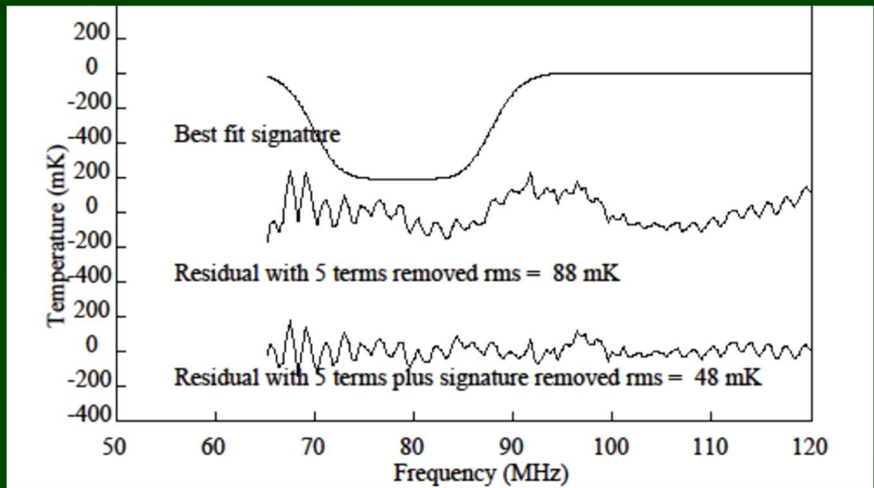


Based on:

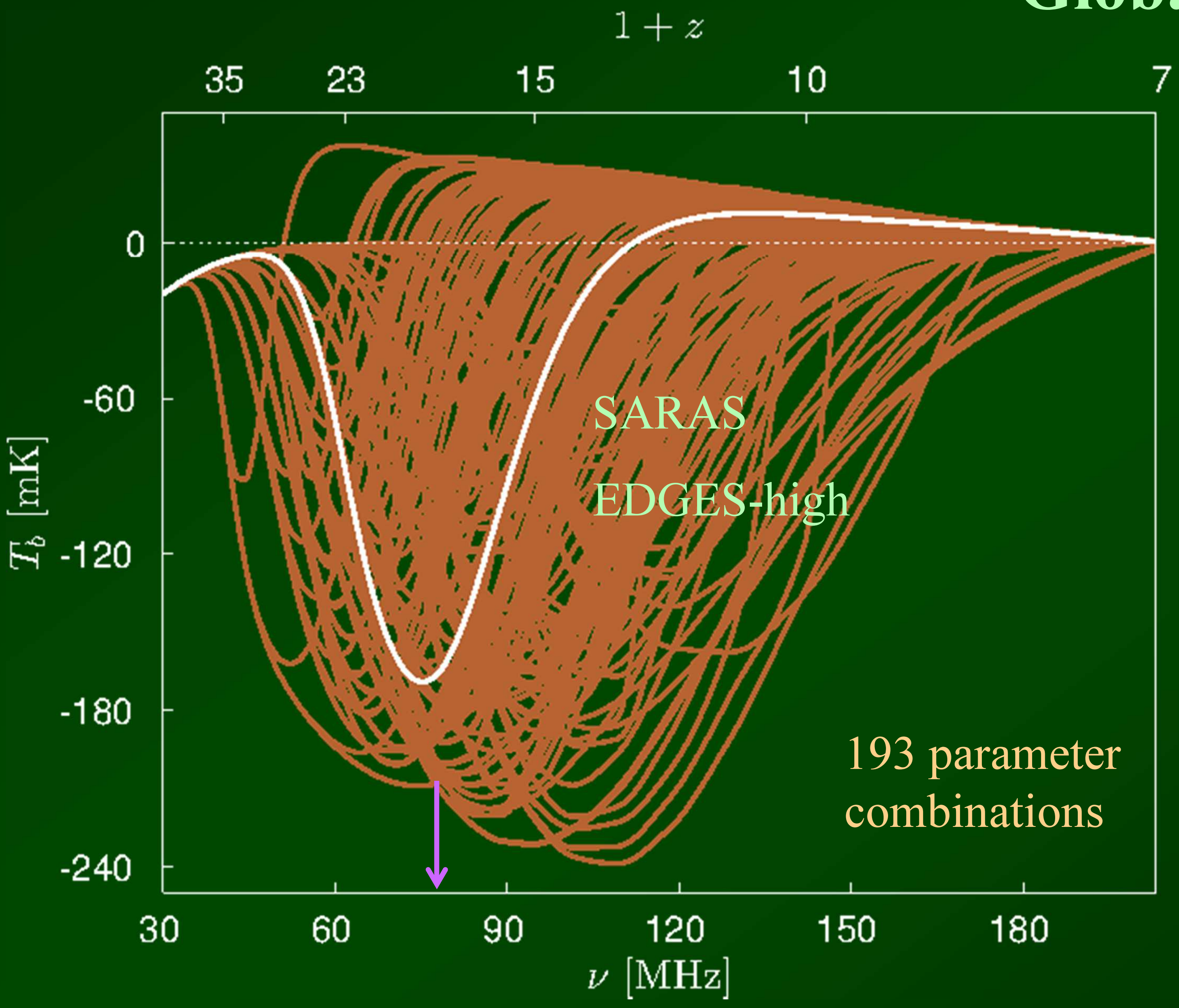
Bowman et al. 2018

EDGES-Mid

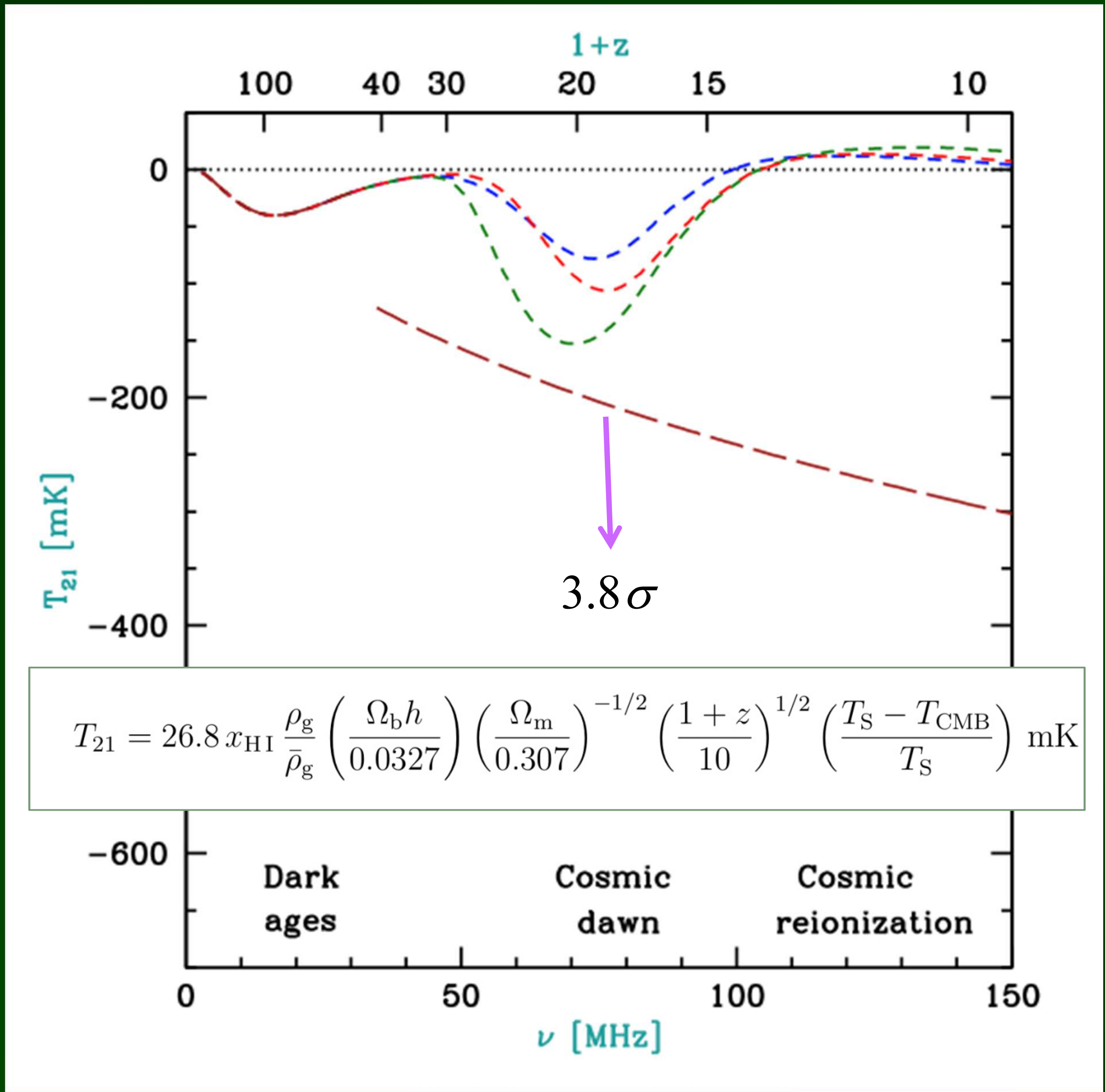

RMS = 0.087 K
T [K]
0.2
0
-0.2
b) Residuals to foreground model
50
60
70
80
90
100
ν [MHz]


Best fit signature
Residual with 5 terms removed rms = 88 mK
Residual with 5 terms plus signature removed rms = 48 mK
Temperature (mK)
200
0
-200
-400
Frequency (MHz)
50
60
70
80
90
100
110
120

Global 21-cm



Cohen, Fialkov, RB, & Lotem 2017



$$T_{21} = 26.8\, x_{\rm HI}\, \frac{\rho_{\rm g}}{\bar{\rho}_{\rm g}} \left(\frac{\Omega_{\rm b} h}{0.0327}\right) \left(\frac{\Omega_{\rm m}}{0.307}\right)^{-1/2} \left(\frac{1+z}{10}\right)^{1/2} \left(\frac{T_{\rm S} - T_{\rm CMB}}{T_{\rm S}}\right)\ \text{mK}$$

Max absorption:

- No reionization.
- Saturated coupling.
- No heating.

RB, Nature 2018

$$\left(\frac{T_{\rm S} - T_{\rm CMB}}{T_{\rm S}}\right)$$

Gas is colder than adiabatic cooling =>

Something cooled it down (heating is easy) =>

X must be even colder (than 5 K at z=17) =>

(Cold) dark matter

Dark matter interactions
(Cooling: Dark ages)

Cosmic dawn (WF coupling)
(DM annihilation: heating)

PHYSICAL REVIEW D **89,** 023519 (2014)

Constraining dark matter-baryon scattering with linear cosmology

Cora Dvorkin[*] and Kfir Blum[†]
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Einstein Drive, Princeton, New Jersey 08540, USA

Marc Kamionkowski[‡]
Department of Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland 21218, USA
(Received 22 November 2013; published 27 January 2014)

PHYSICAL REVIEW D **90,** 083522 (2014)

Effects of dark matter-baryon scattering on redshifted 21 cm signals

Hiroyuki Tashiro,[1] Kenji Kadota,[2] and Joseph Silk[3,4,5]

PHYSICAL REVIEW D **92,** 083528 (2015)

Heating of baryons due to scattering with dark matter during the dark ages

Julian B. Muñoz, Ely D. Kovetz, and Yacine Ali-Haïmoud

$$\sigma \propto v^n$$

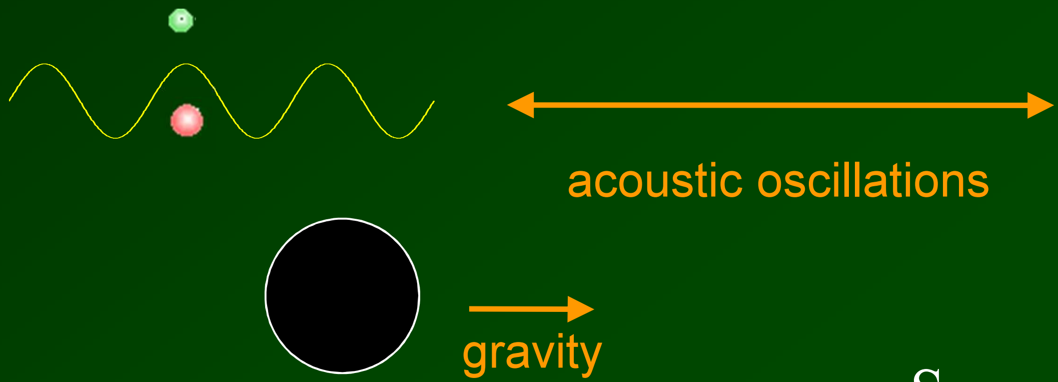
Large at small v => n=-4
(Rutherford/Coulomb)

Cosmic dawn: min T/v

↓

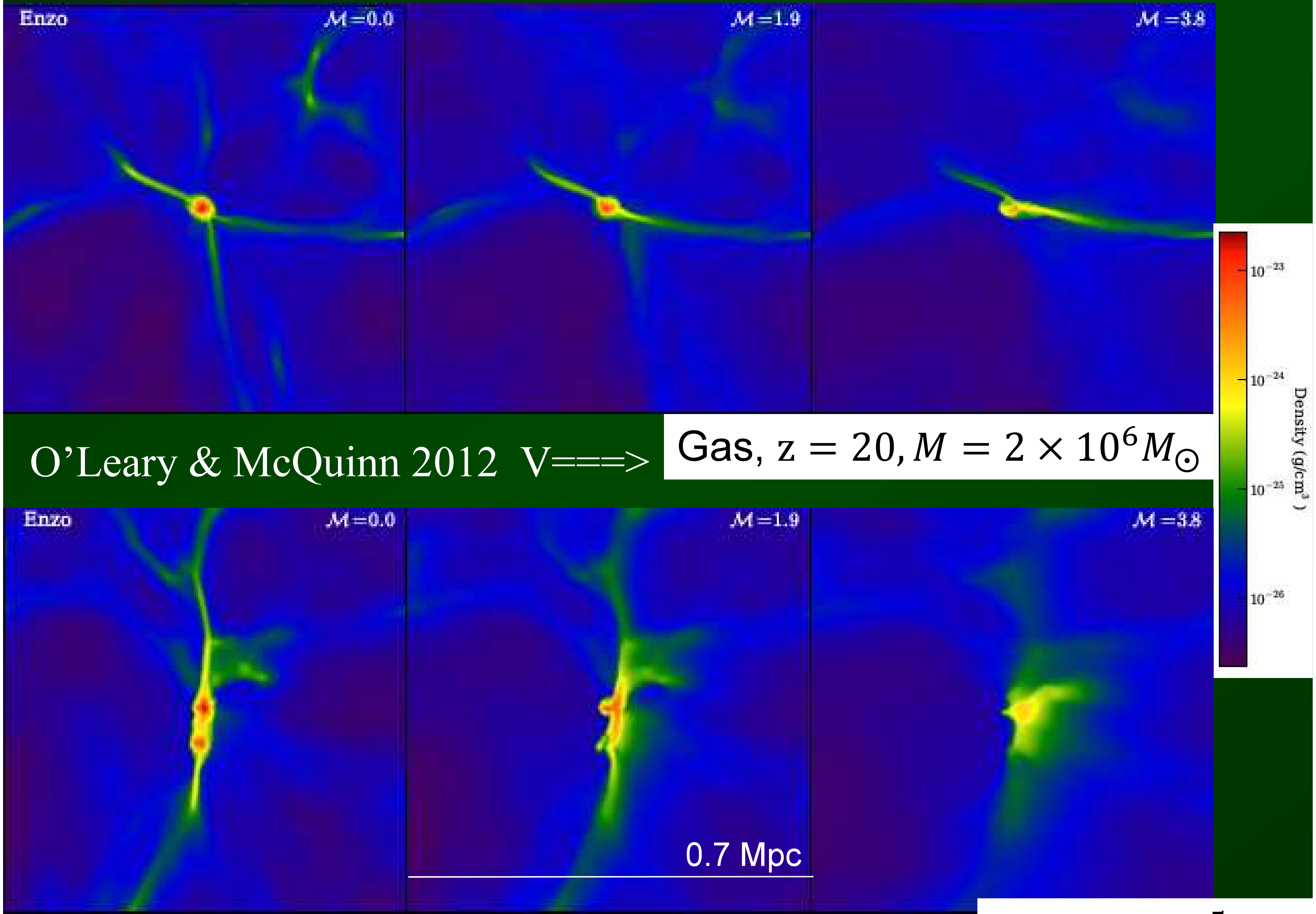
The streaming velocity! *

Baryon – Dark Matter Relative (Streaming) Velocity



Sunyaev & Zeldovich 1970

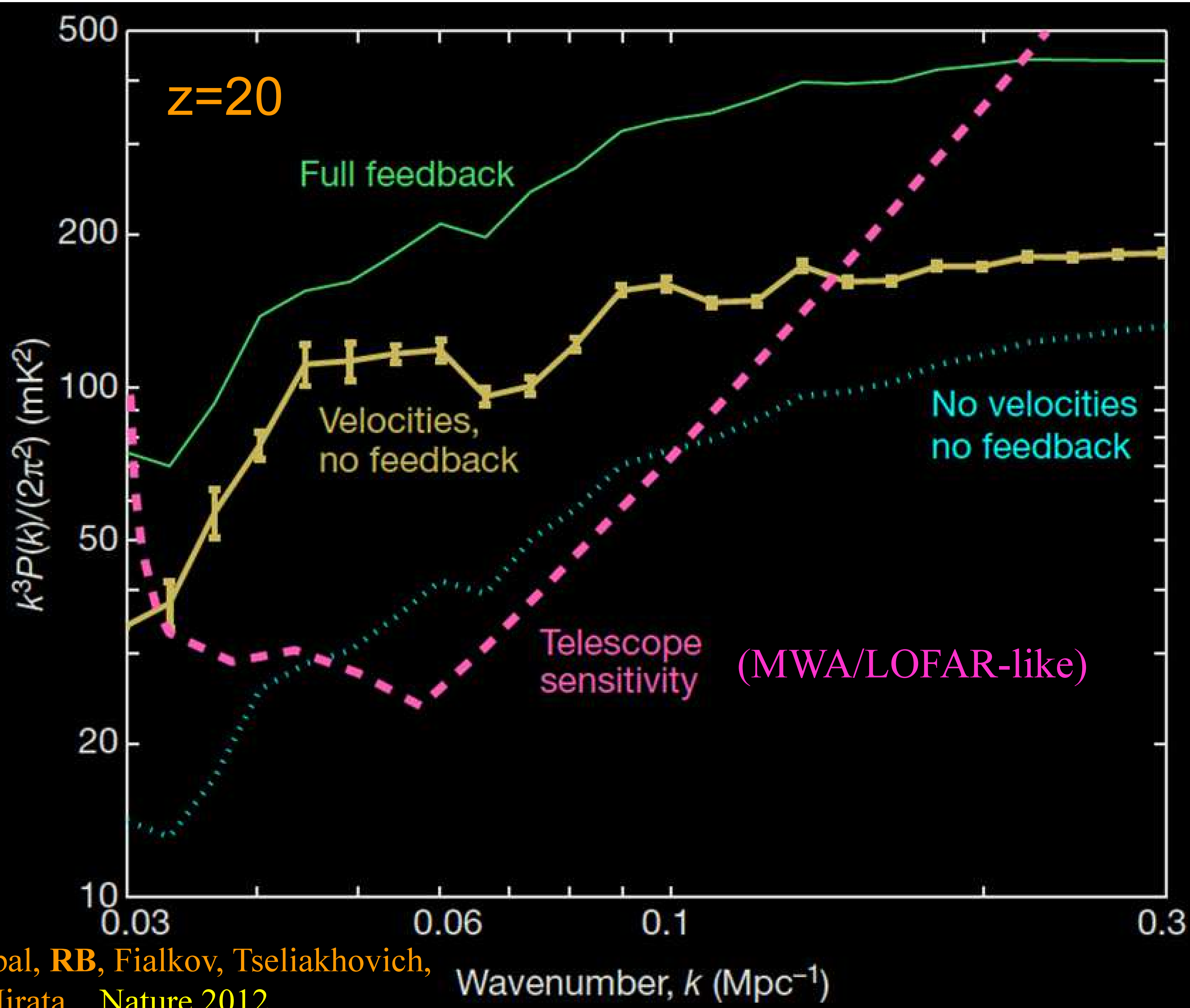
Tseliakhovich & Hirata 2010



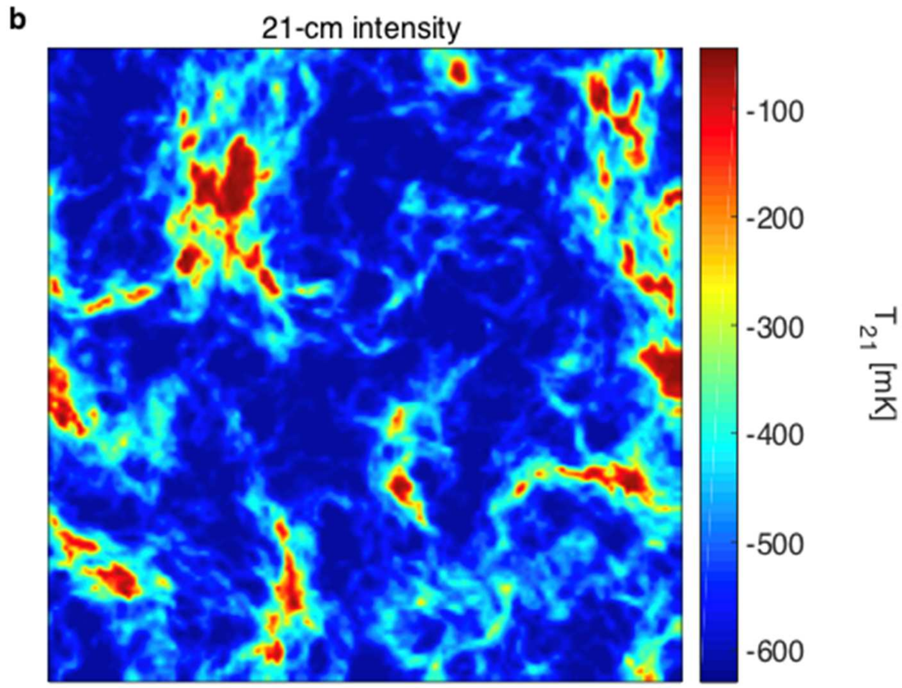
O'Leary & McQuinn 2012 V===>

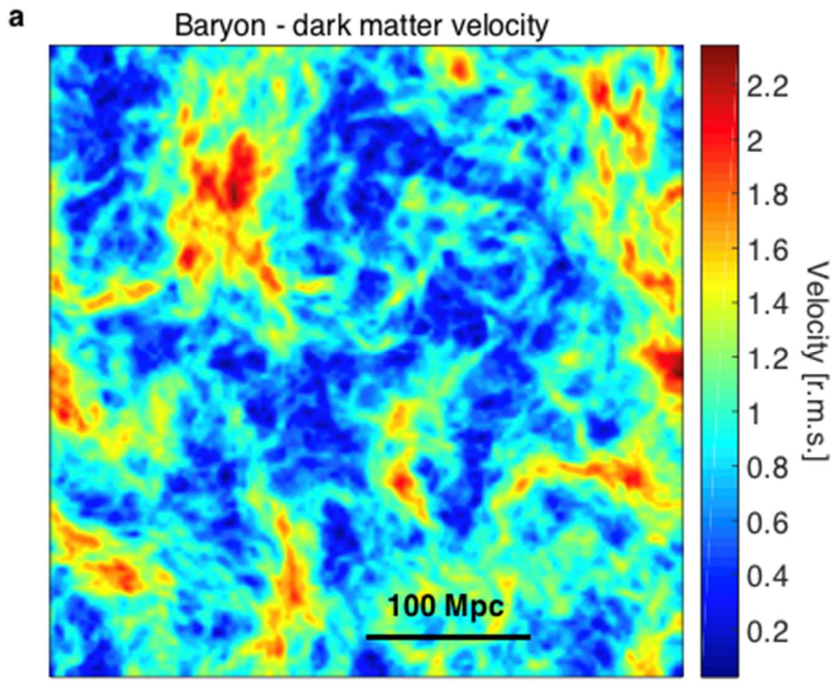
Gas, $z = 20, M = 2 \times 10^6 M_\odot$

$M = 8 \times 10^5 M_\odot$

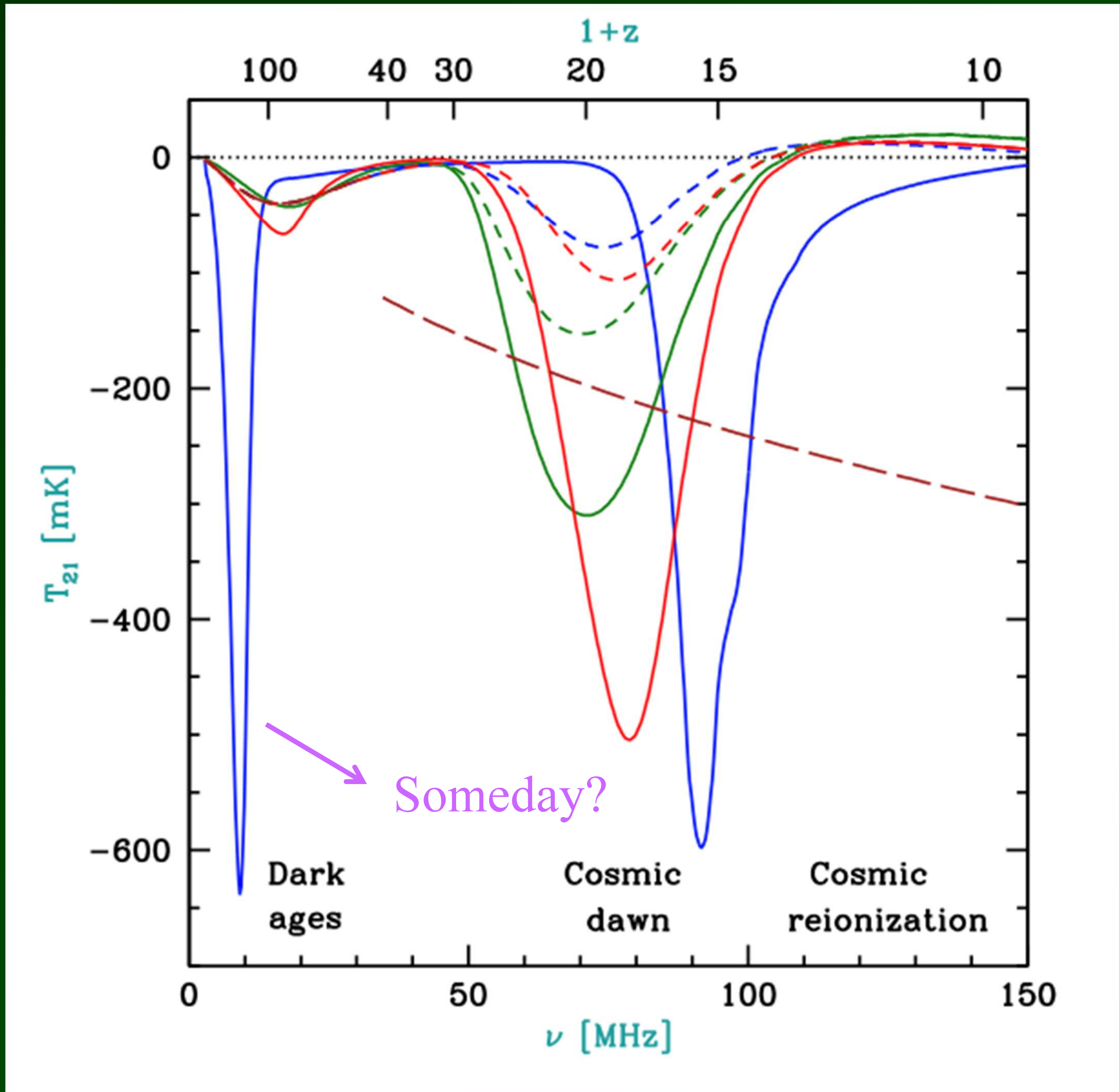


Visbal, **RB**, Fialkov, Tseliakhovich, & Hirata Nature 2012





RB, Nature 2018

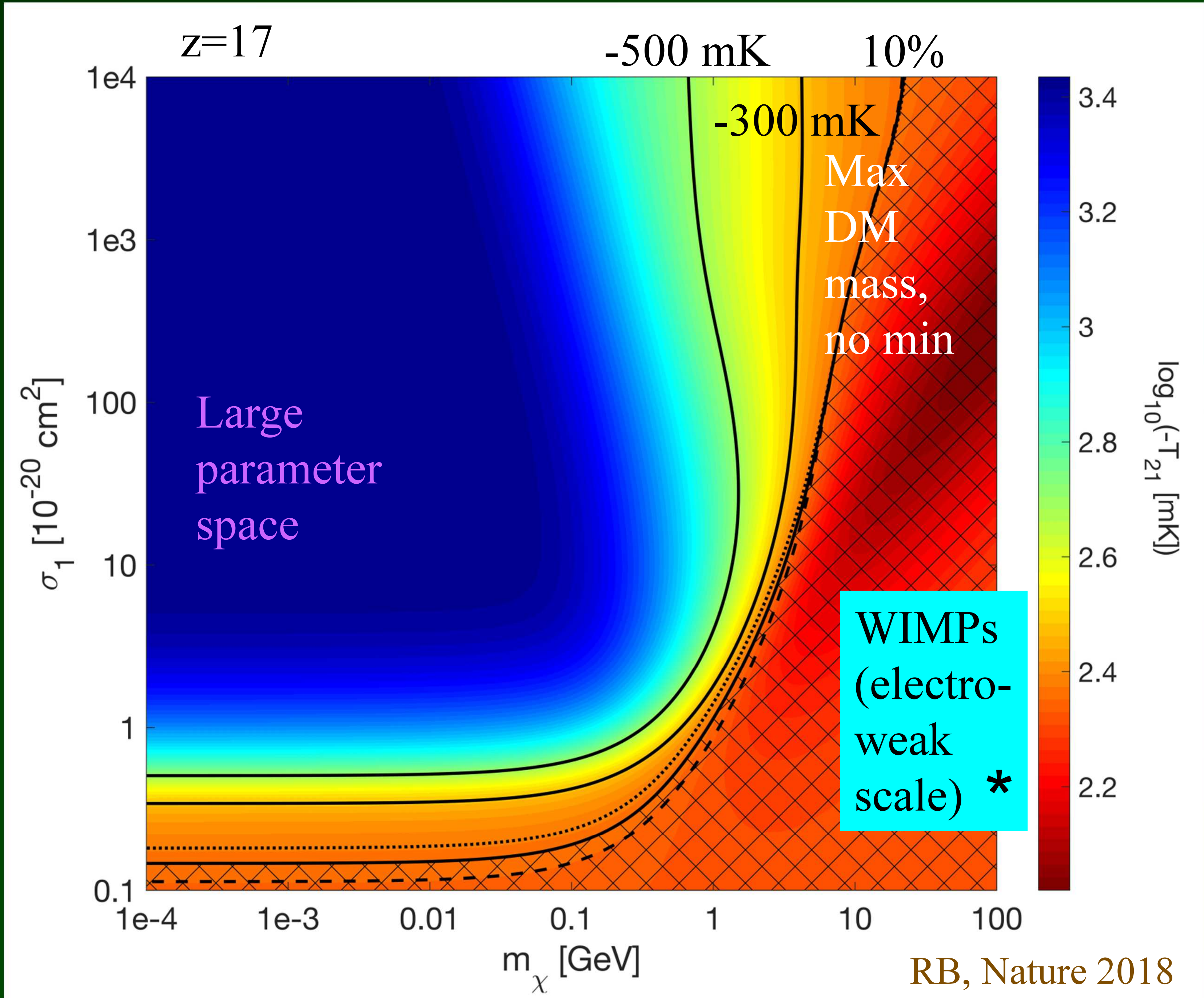


m_χ=0.3 GeV

m_χ=3 GeV

m_χ=0.01 GeV

RB, Nature 2018



z=17
-500 mK
10%
-300 mK
Max
DM
mass,
no min
Large
parameter
space
WIMPs
(electro-
weak
scale) *
σ_1 [10^{-20} cm^2]
1e4
1e3
100
10
1
0.1
1e-4
1e-3
0.01
0.1
1
10
100
m_χ [GeV]
$\log_{10}(-T_{21}$ [mK])
3.4
3.2
3
2.8
2.6
2.4
2.2
RB, Nature 2018

Alternative explanation

$$\left(\frac{T_S - T_{CMB}}{T_S}\right) \rightarrow T_{rad}$$

Bowman et al. 2018
Feng & Holder 2018

↓

10% of extragalactic radio excess
ARCADE-2: 2006 NASA balloon, 3-90 GHz
Residual with $\nu^{-2.6}$

Subrahmanyan & Cowsik 2013

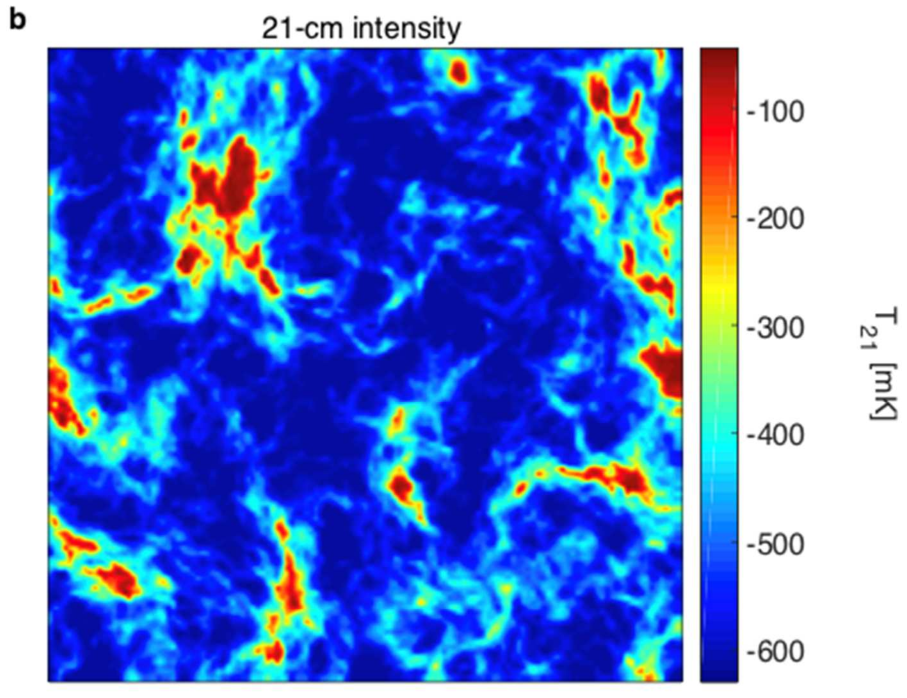
Realistic Galactic modeling => no excess.

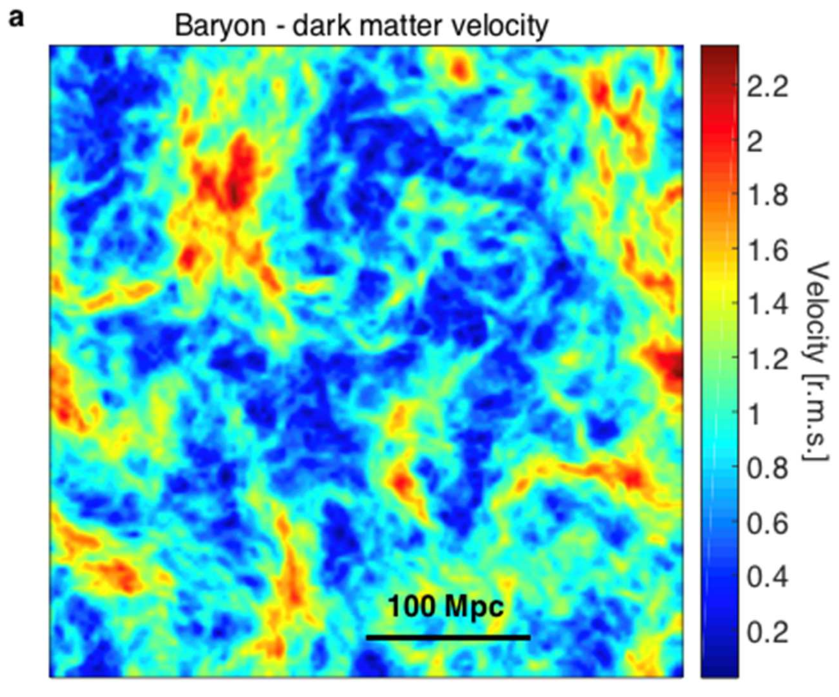
Need z=20 radio background at MW level, without X-rays.
Mirocha & Furlanetto 2018: $\varepsilon \times 10^3$

RMS fluctuation ~ 140 mK

100 Mpc at z=17: 30'

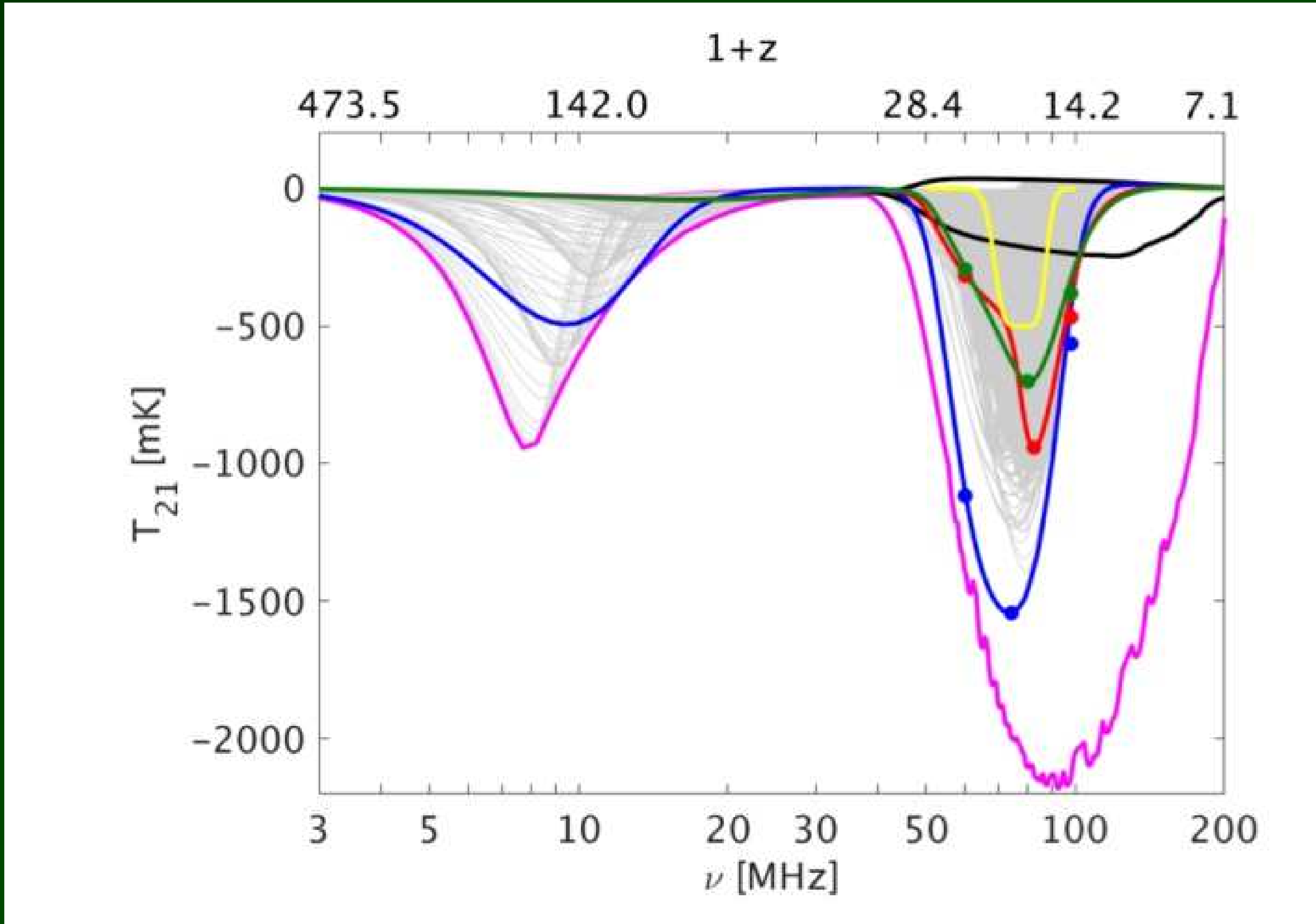
DM cooling fluctuations only





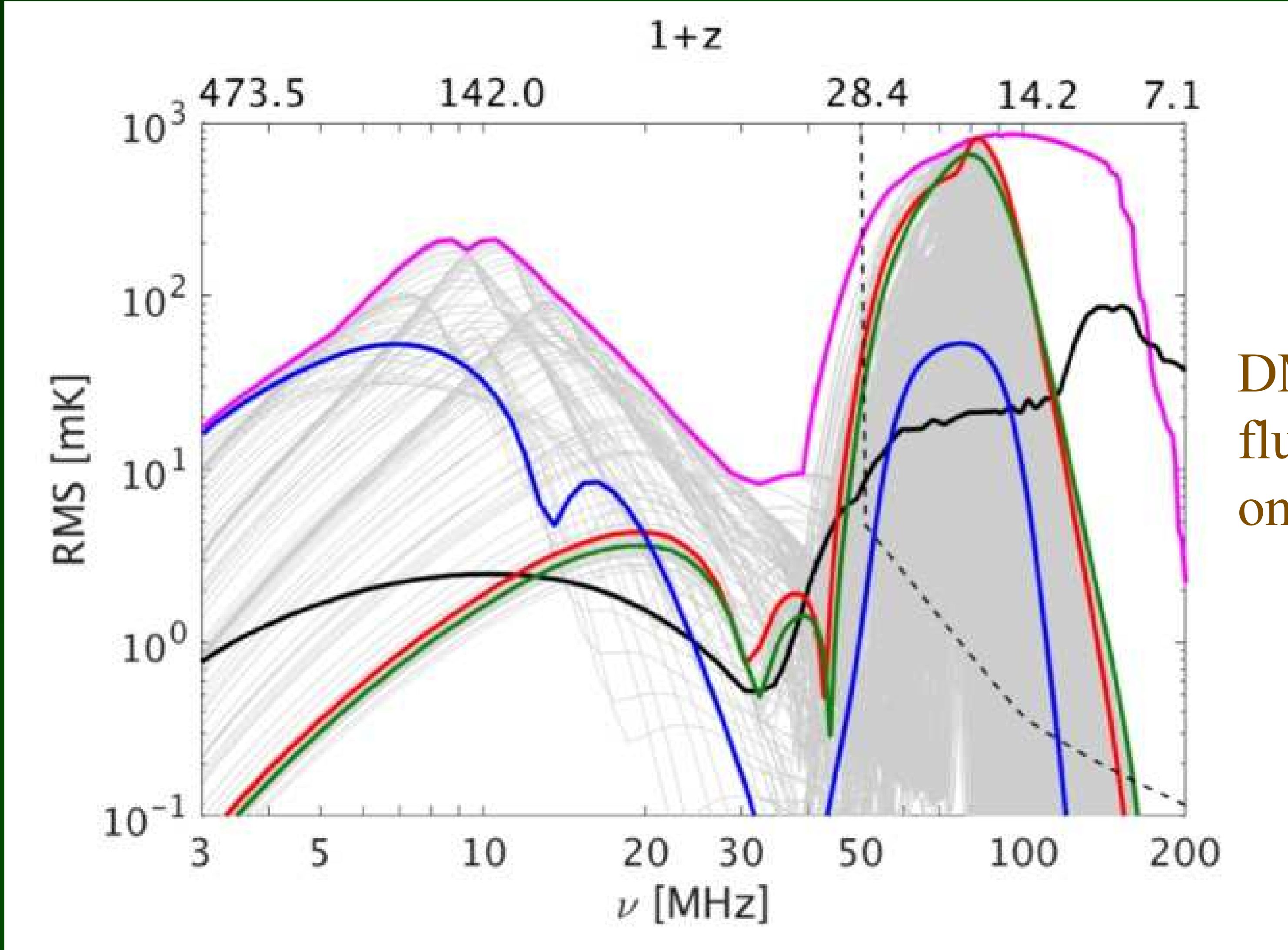
RB, Nature 2018

Range (Global)



Fialkov, RB, Cohen, PRL 2018

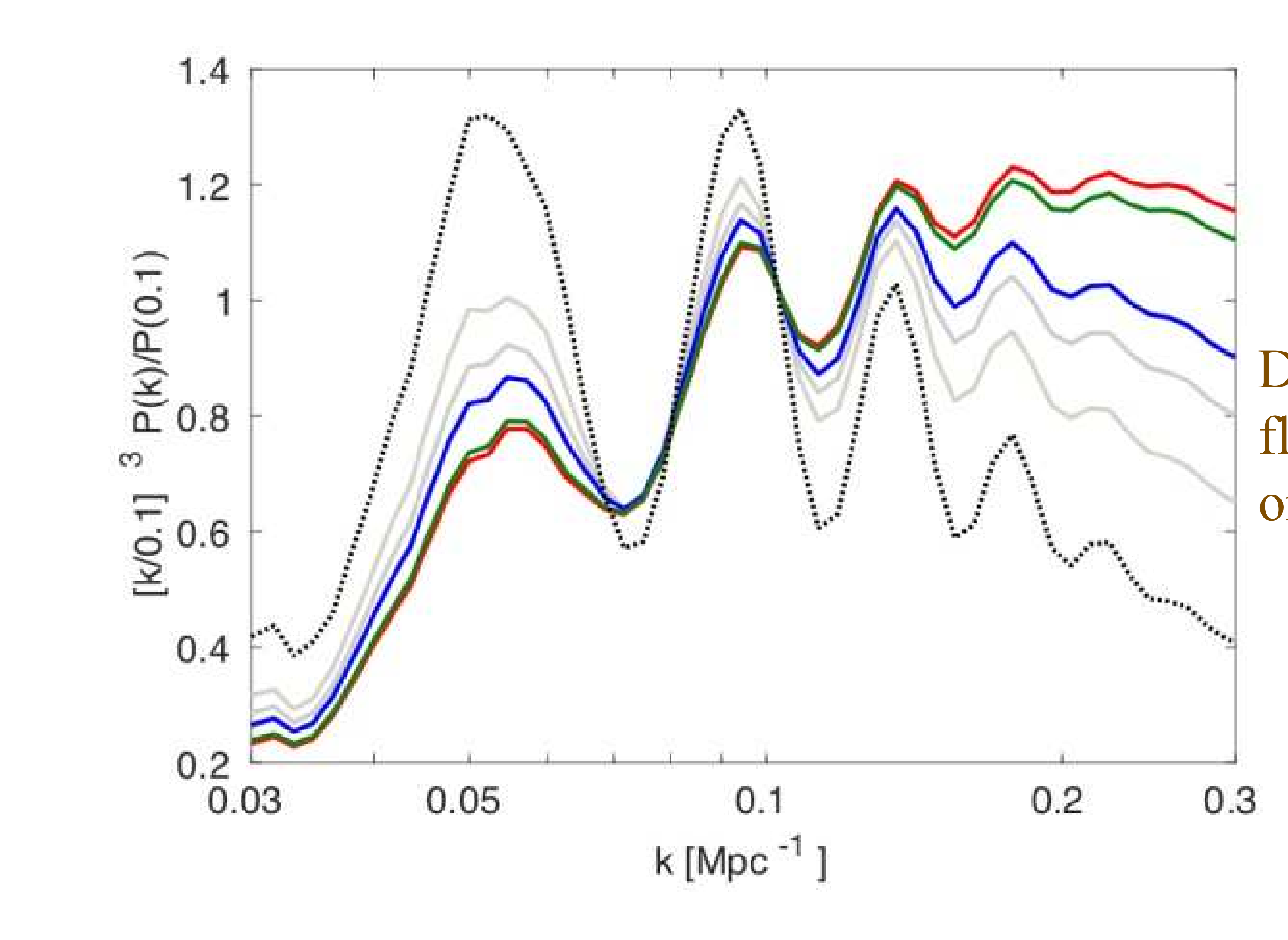
Range (Fluctuation)



DM cooling fluctuations only

Fialkov, RB, Cohen, PRL 2018

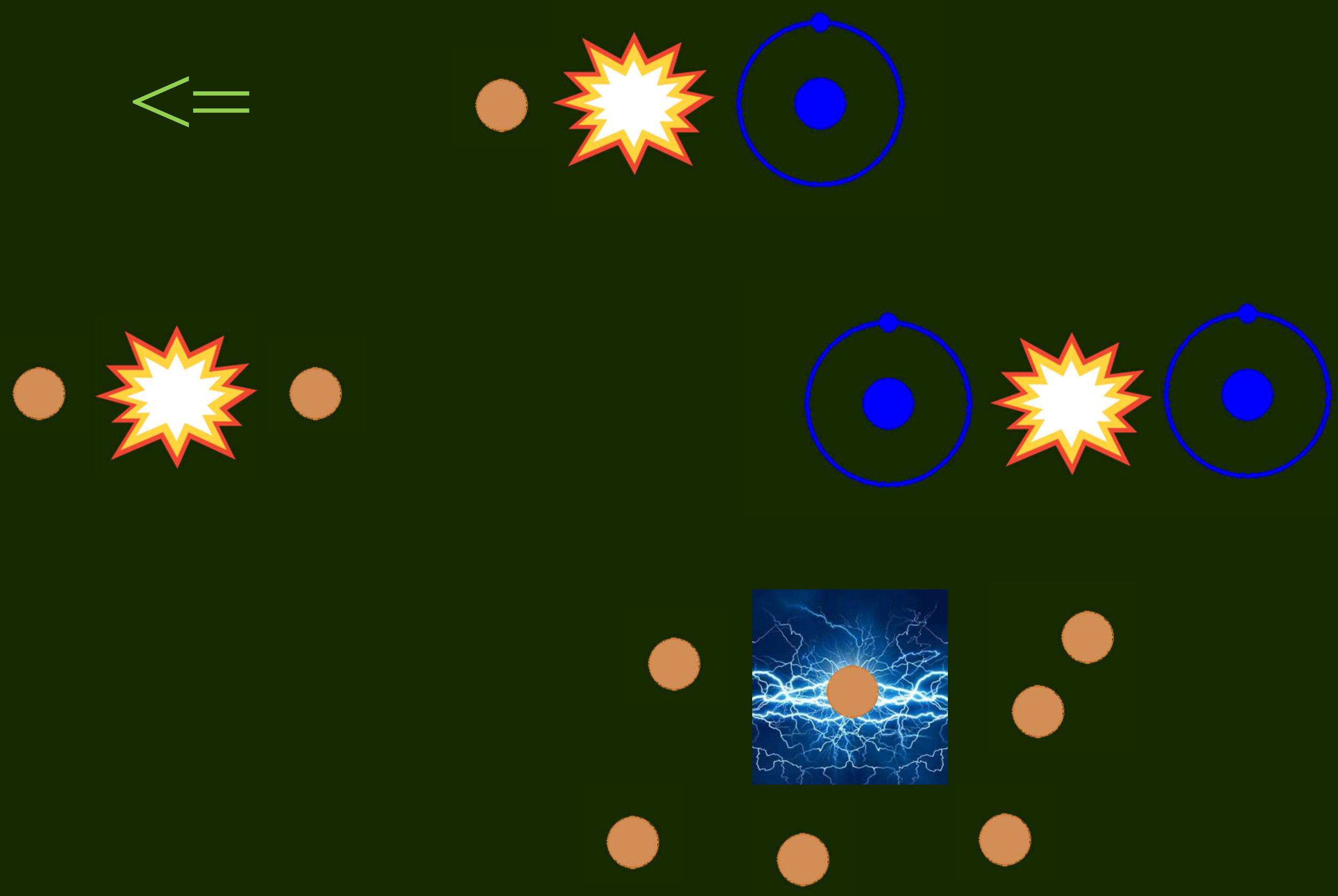
Range (Fluctuation)



DM cooling fluctuations only *

Fialkov, RB, Cohen, PRL 2018

Particle physics models



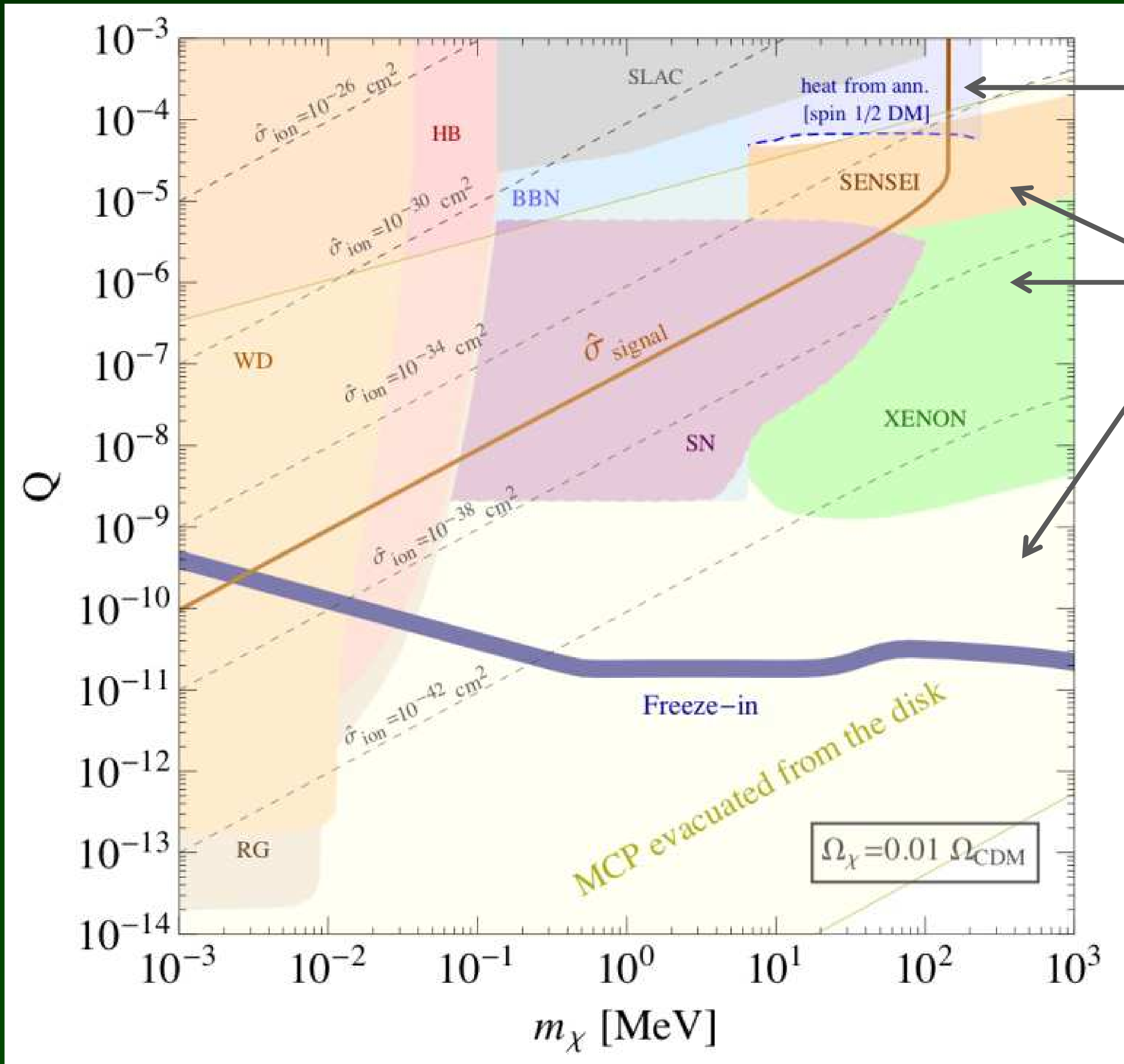
Munoz & Loeb 2018: subcomponent millicharged DM

$$m_\chi = 1 - 60\,\text{MeV},\ \varepsilon = 10^{-6} - 10^{-5},\ f_{\text{DM}} = 10^{-4} - 3\%$$

RB, Outmezguine, Redigolo, Volansky 2018
Berlin, Hooper, Krnjaic, McDermott 2018

Long-range forces, hidden photon: 5'th force, self-interaction, cooling in SN, HB, WD, RG, N_{eff} of CMB/BBN.

$$m_\chi = 10 - 80\,\text{MeV},\ \varepsilon = 10^{-6} - 10^{-4},\ f_{\text{DM}} = 0.1 - 2\%$$



fermionic DM for which the annihilation is s-wave

RB et al. 2018

Summary

EDGES-Low

- Amp < -300 mK (99%), < -210 mK (3.8 σ)
- Cool gas => Cooled by DM
- b-DM scattering at low v, min σ, max m_χ

Follow-up (50)

- Detailed particle physics models
- New 21-cm parameter space

Tests

- Independent 21-cm global measurements
- 21-cm power spectrum: Large, BAOs
  [HERA, SKA (imaging)]