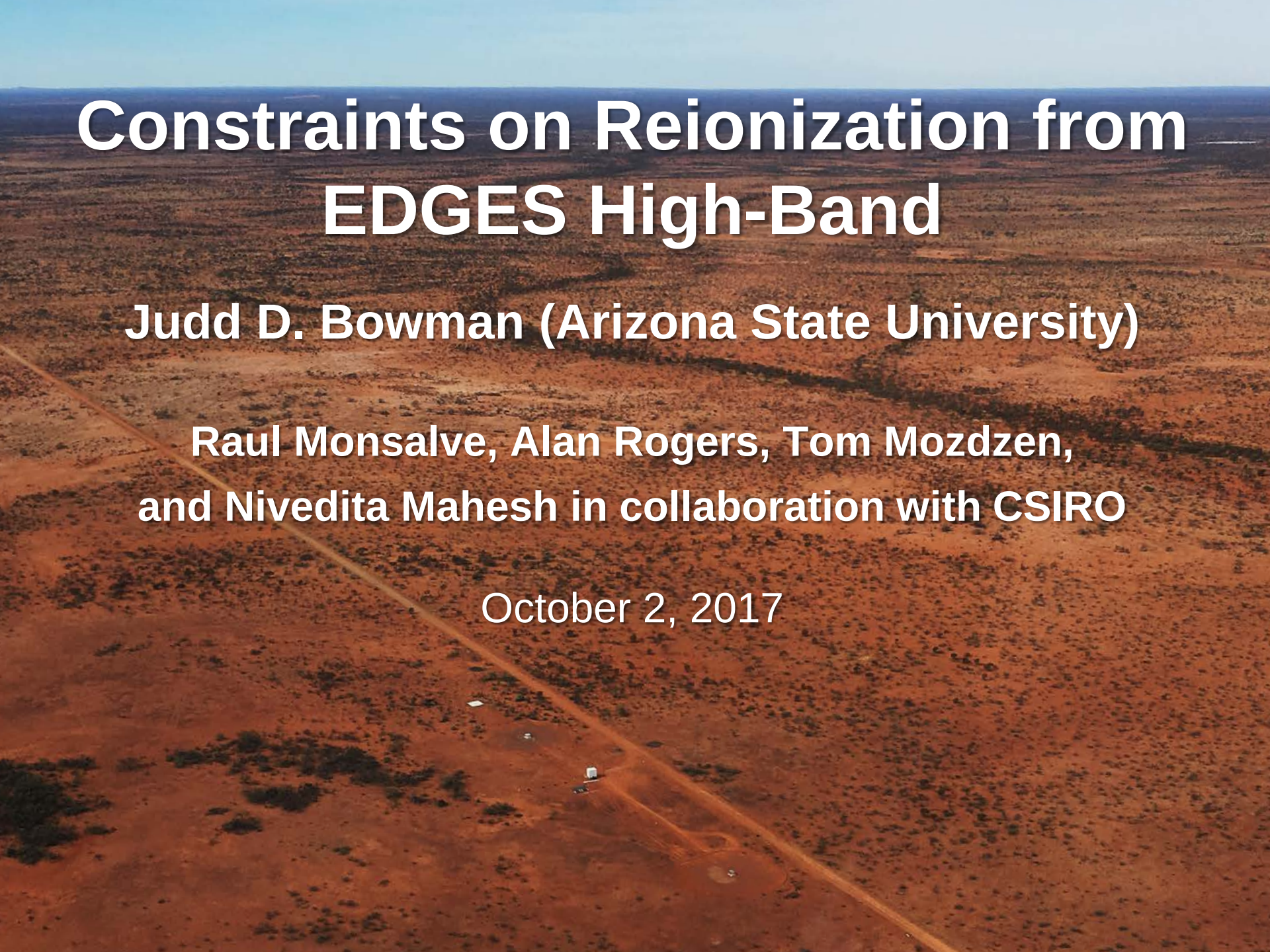


Constraints on Reionization from EDGES High-Band

Judd D. Bowman (Arizona State University)

Raul Monsalve, Alan Rogers, Tom Mozdzen,
and Nivedita Mahesh in collaboration with CSIRO

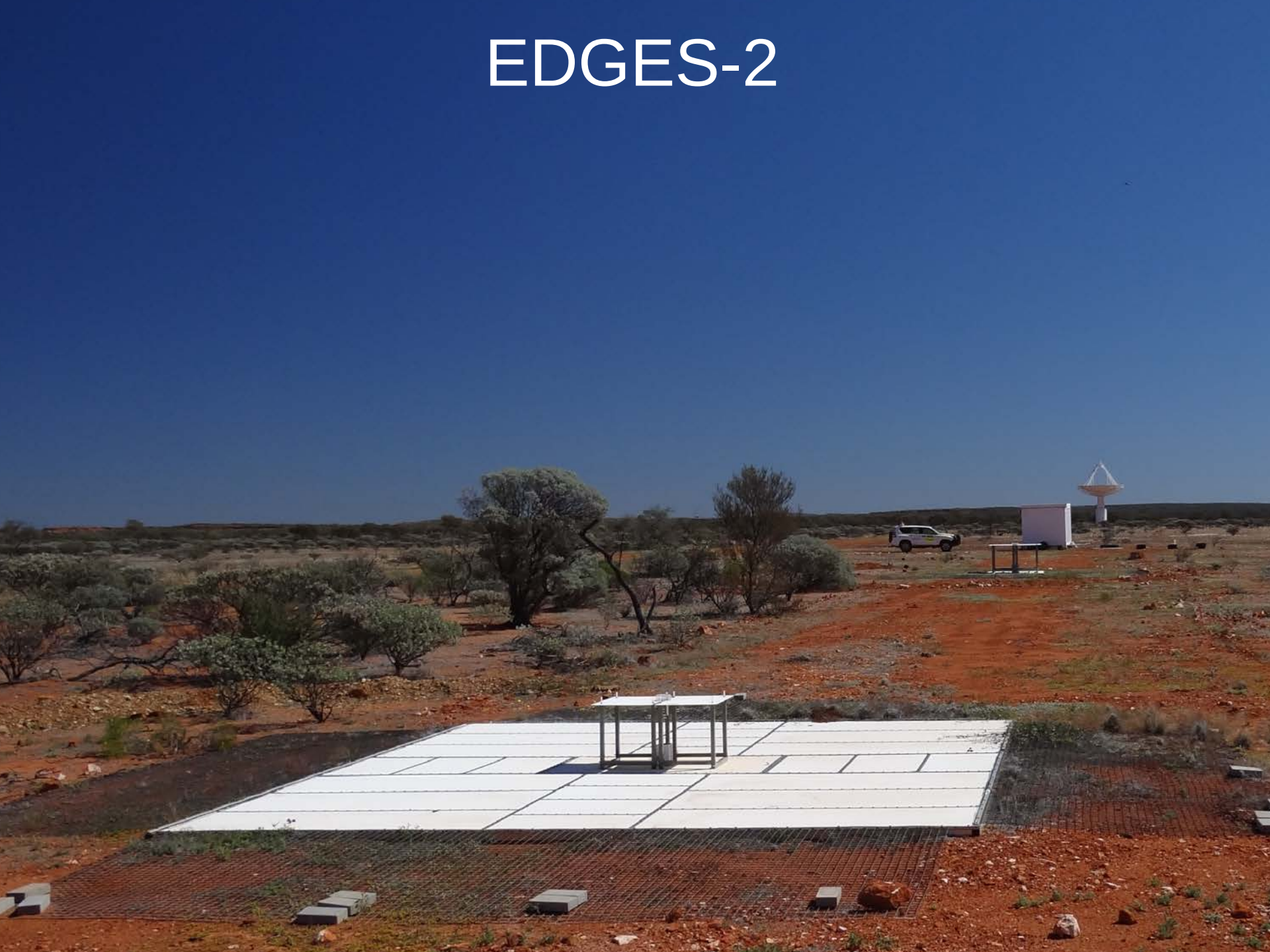
October 2, 2017

EDGES-2 (2012-2016)

- Goal
  - Detect/constrain reionization durations less than $\Delta z \sim 1\text{-}2$
  - Detect/constrain Cosmic Dawn absorption trough
- Design
  - Two frequency bands, two instruments:
    - Low-band: 50-110 MHz (25>z>12)
    - High-band: 90-200 MHz (13>z>6)
    - Balance between antenna reflection coeff. and beam chromaticity
  - Absolute calibration of receiver and antenna
- Calibration procedure
  - In the lab: First-principle sources (cables, loads, reflection coeffs., varying temperatures, etc.)
  - In the field: Reflection measurement of antenna, 3-position switch
  - In processing: Galaxy up/down to provide a calibration signal for the entire system

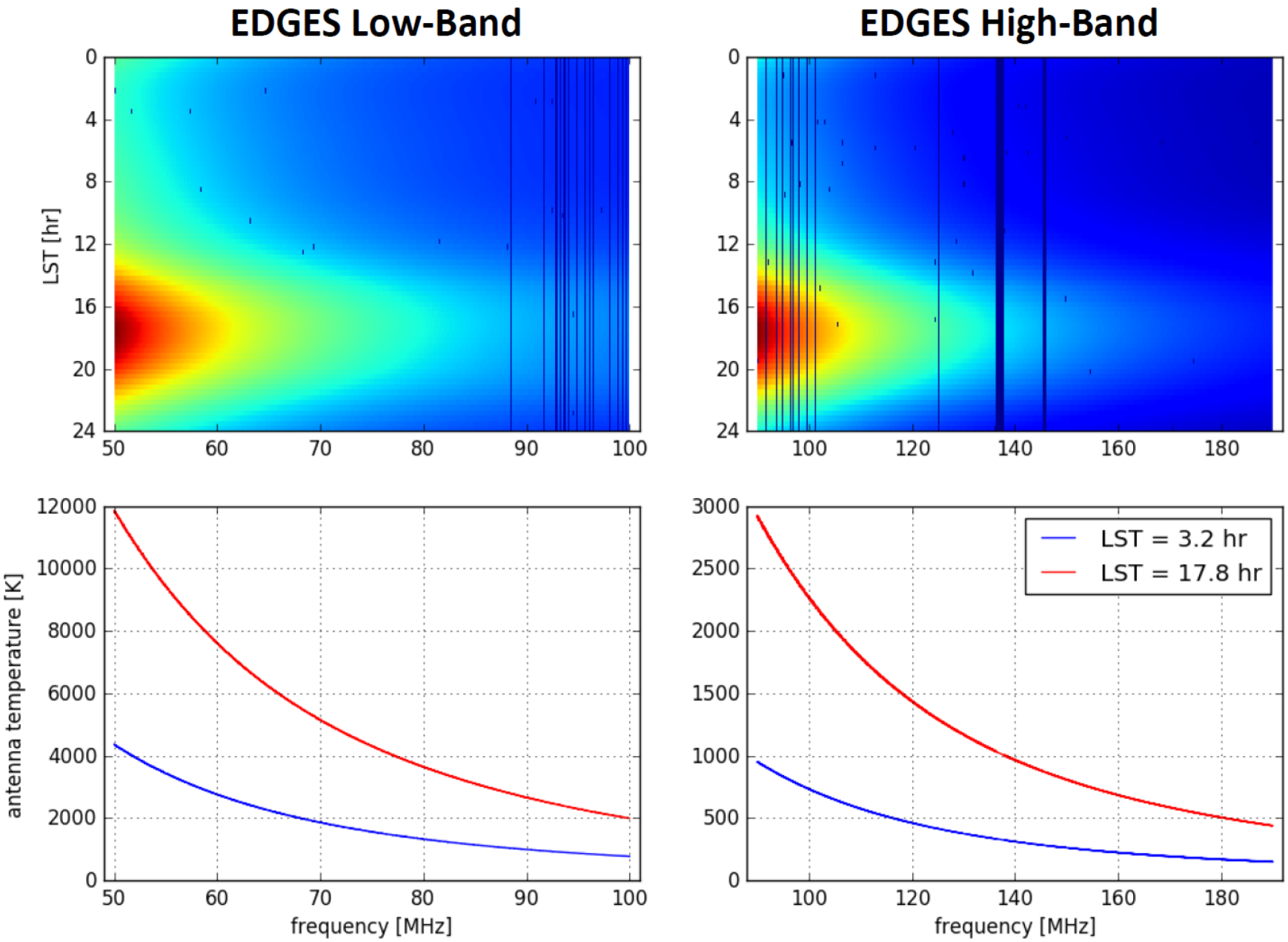
Rogers & Bowman 2012

EDGES-2



Low-band 1

Receiver

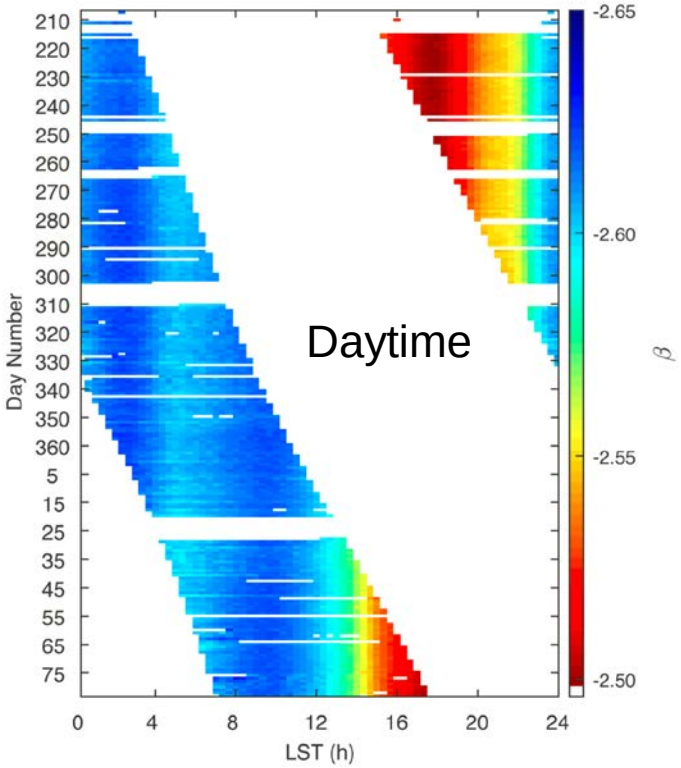

EDGES Low-Band
EDGES High-Band
LST [hr]
0
4
8
12
16
20
24
50
60
70
80
90
100
120
140
160
180
antenna temperature [K]
12000
10000
8000
6000
4000
2000
0
3000
2500
2000
1500
1000
500
frequency [MHz]
LST = 3.2 hr
LST = 17.8 hr

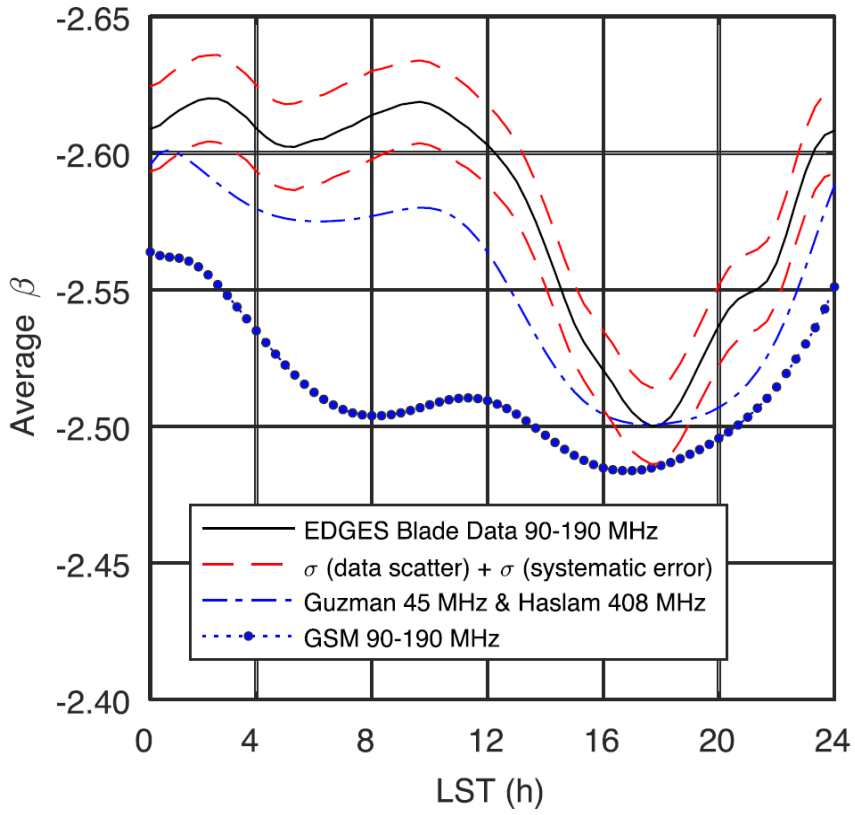
R. Monsalve

Diffuse spectral index (90-190 MHz)

Fit Model:
Two-parameter Power Law:

$$T_{\rm sky}(\upsilon) = T_{150}\left(\frac{\upsilon}{150\ \rm MHz}\right)^{+\beta} + T_{\rm CMB}$$



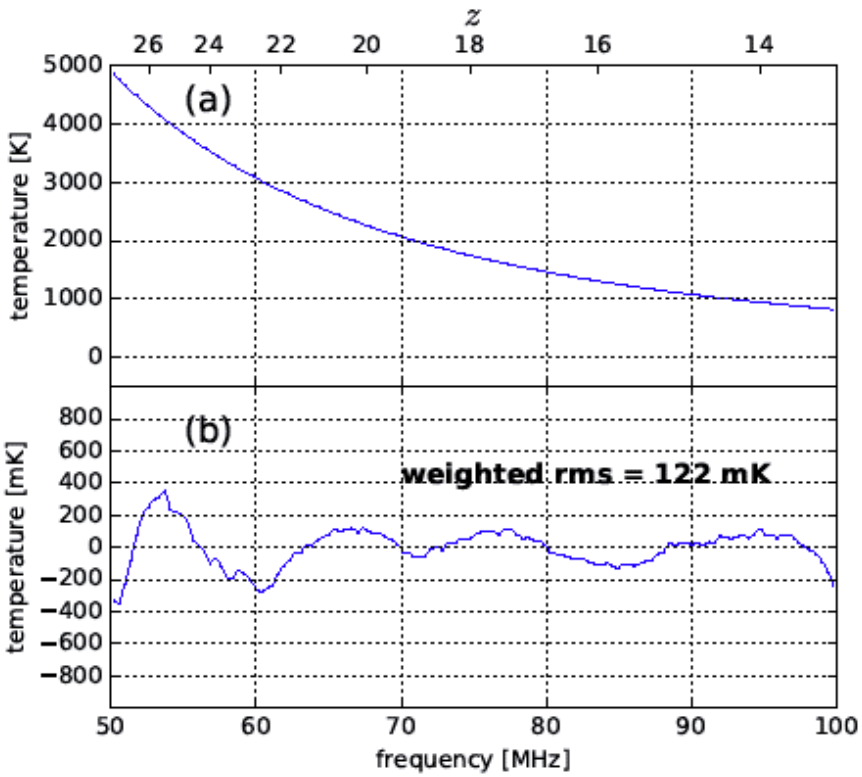


- Typical residuals <1 K (0.1-1%)
- Night-to-night variation over 6 months: $\sigma_\beta < 0.003$
- GSM (de Oliveira-Costa et al. 2008) poor fit at high latitudes

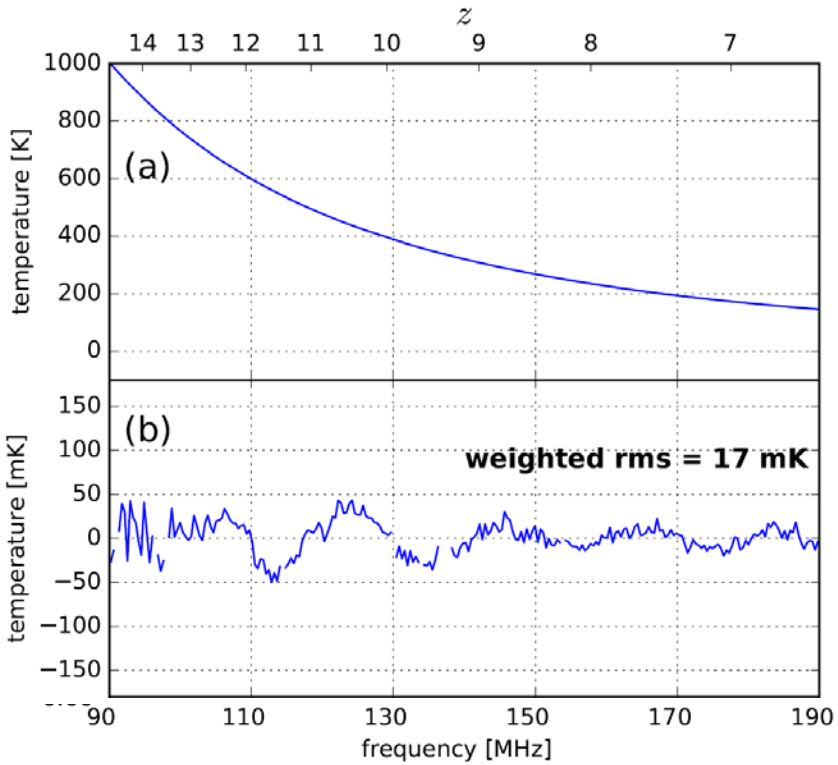
Mozdzen et al. 2017

Long integration residuals (typical)

Low-Band



High-Band

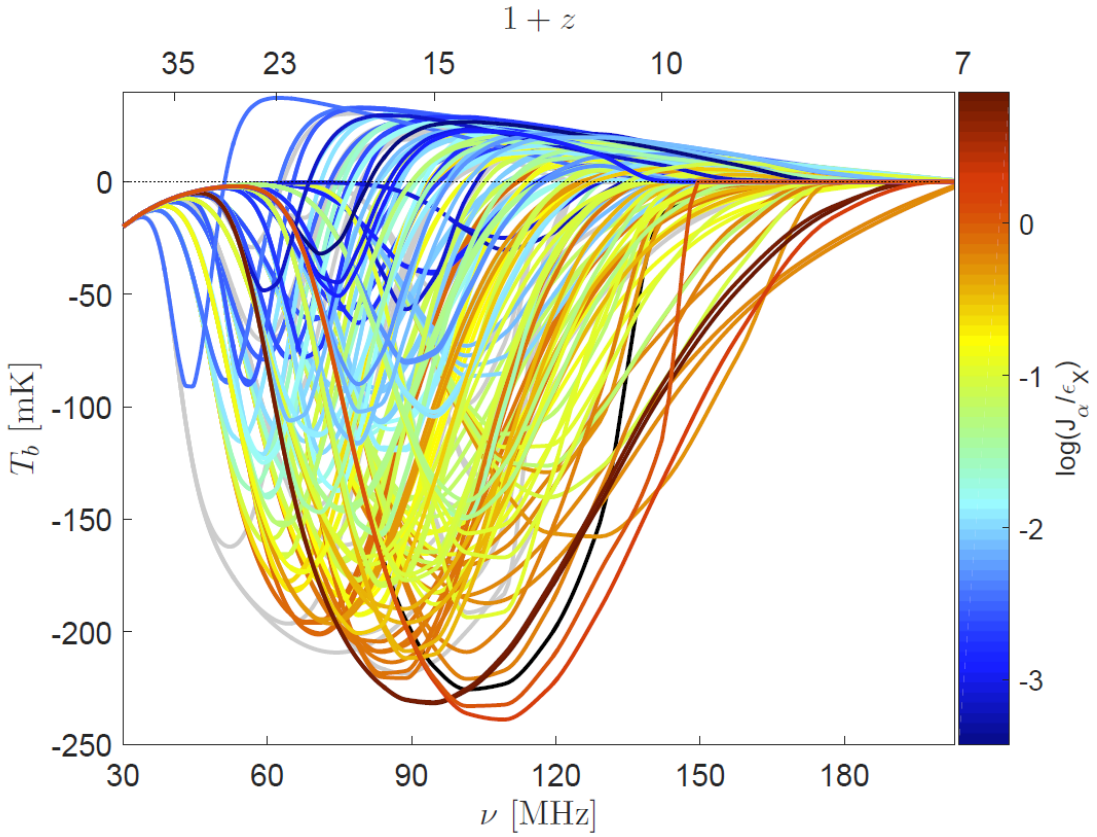


- 5-term polynomial fit and removed, RMS < 0.01% sky power
- Hundreds of nights in each band

R. Monsalve

EDGES reionization constraints

- Three general scenarios
  - High X-ray emission – gas is *hot* during reionization (blue curves)
  - Low X-ray emission – gas is *cold* during reionization (red curves)
  - Low X-ray and late UV – late Gaussian-like absorption feature
- Sample of specific astrophysical models



Cohen et al. 2017

Phenomenological models

21 cm model

$$T_{21}(z) = \mathrm{a}_0\, x_{HI}(z) \left[\frac{1+z}{10}\right]^{1/2} \left[1 - \frac{T_R(z)}{T_S(z)}\right] \mathrm{mK}$$

Hot and cold IGM models (cases a and b) assume:

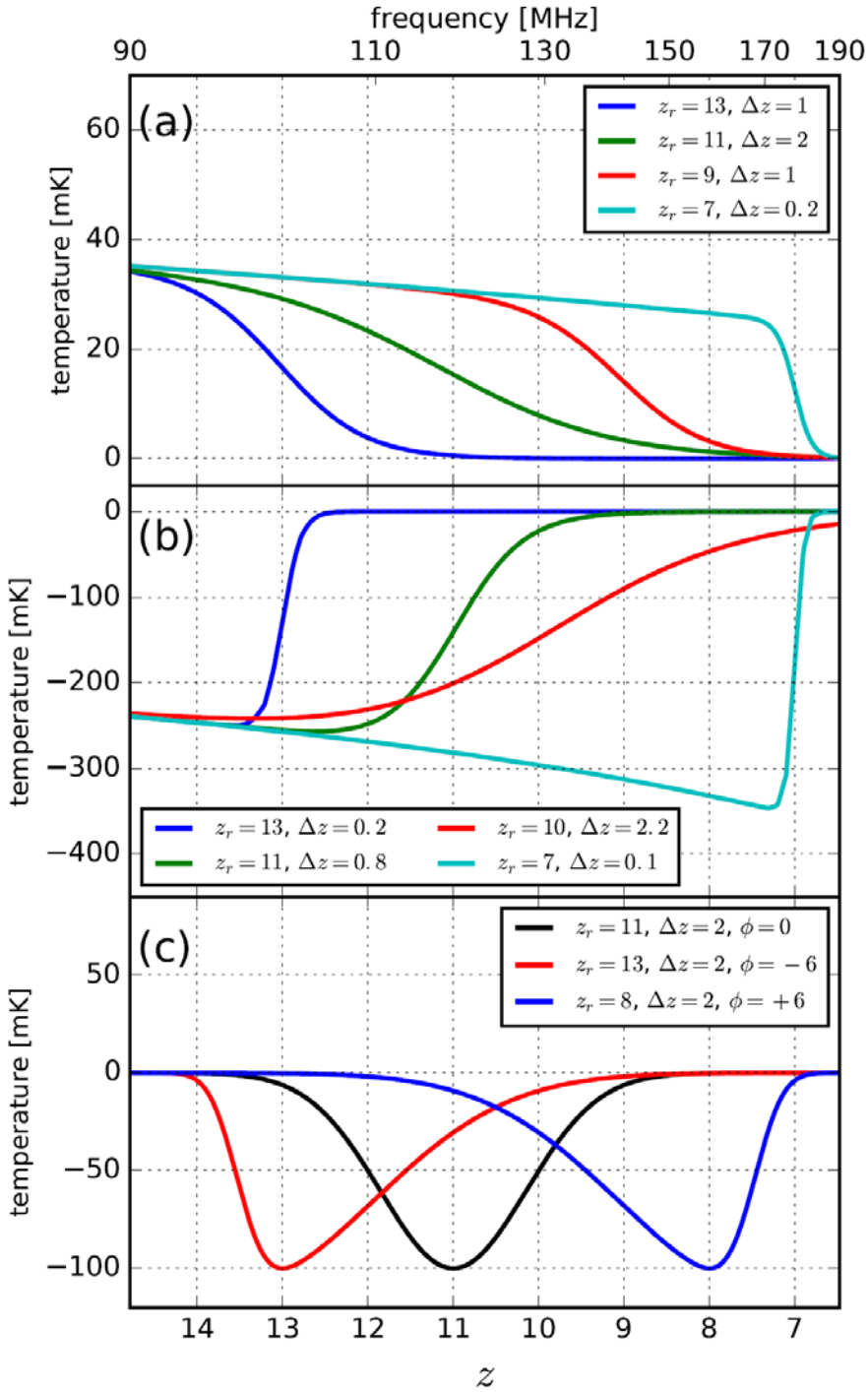
- Saturated spin temperature ($T_s = T_{gas}$)
- *tanh* reionization

$$x_{\mathrm{HI}}(z) = \frac{1}{2}\left[\tanh\left(\frac{z - z_r}{\Delta z}\right) + 1\right]$$

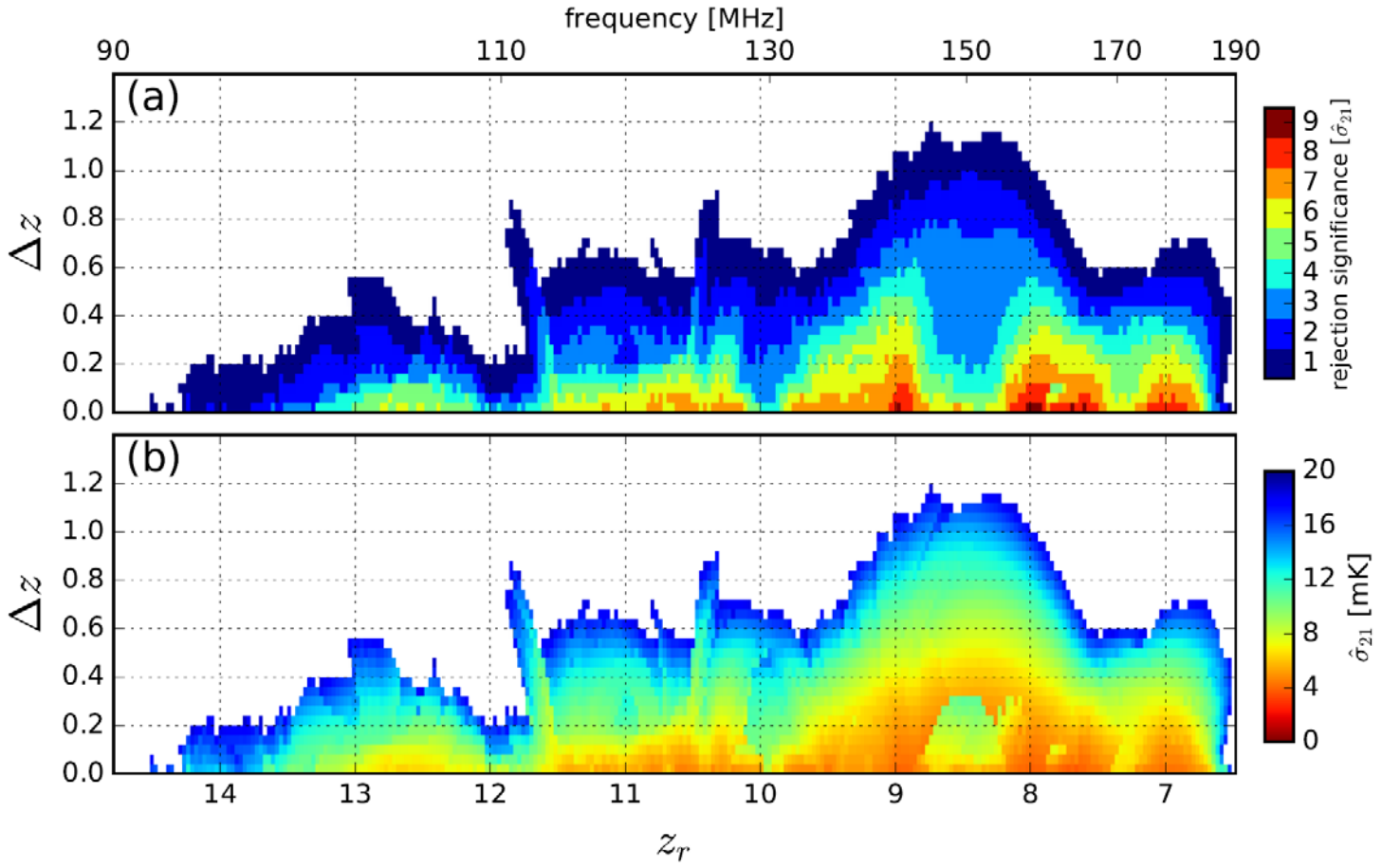
Foreground model:

$$\hat{T}_{\mathrm{fg}}(\nu) = \sum_{i=0}^{4} a_i \nu^{-2.5+i}$$

Monsalve et al. 2017b



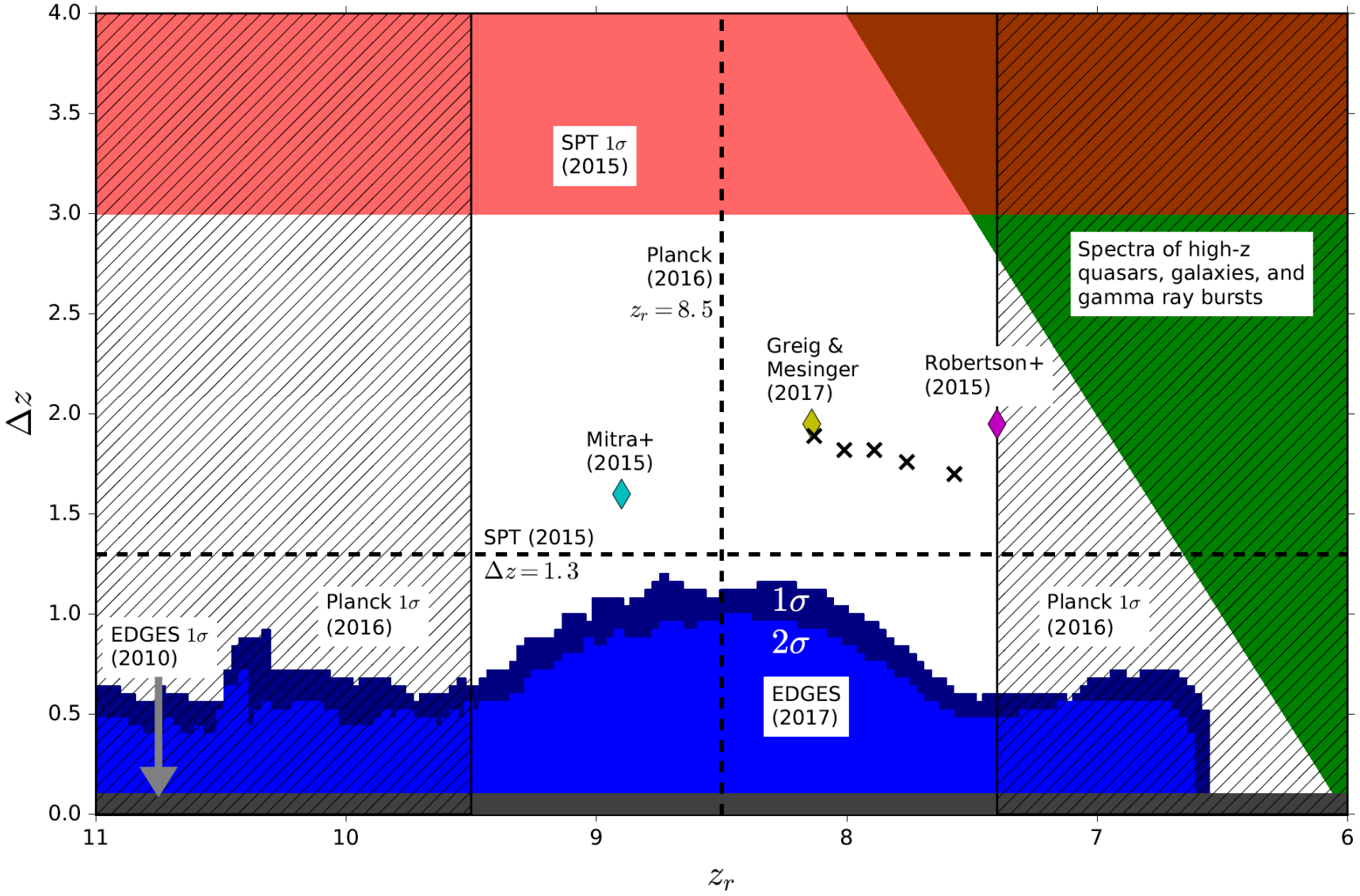
Hot gas: Constraints on duration



- Sweep over redshift and duration and fit for amplitude along with foregrounds
- Factor of ~10 better than Bowman & Rogers (2010) with same assumptions

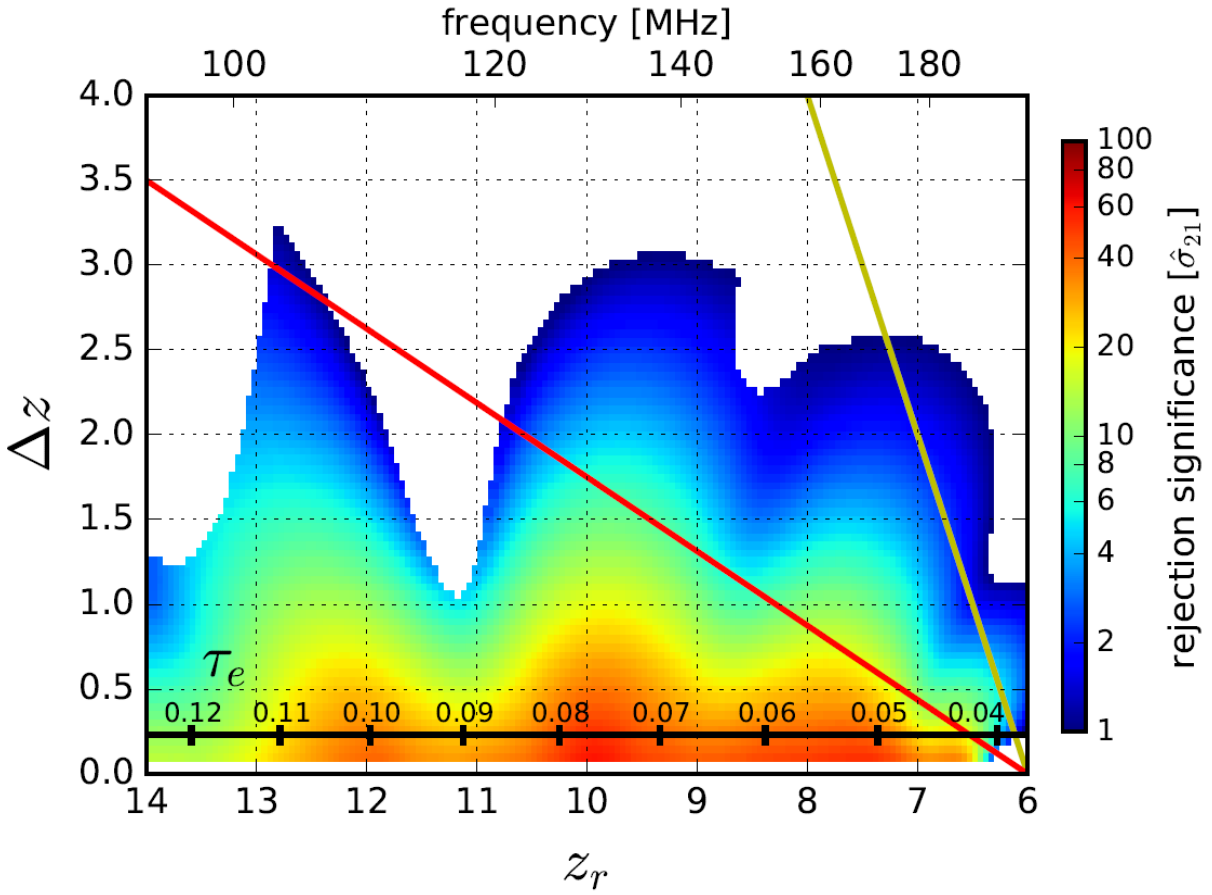
Monsalve et al. 2017b

Hot gas: EDGES plus external limits



Monsalve et al. 2017b

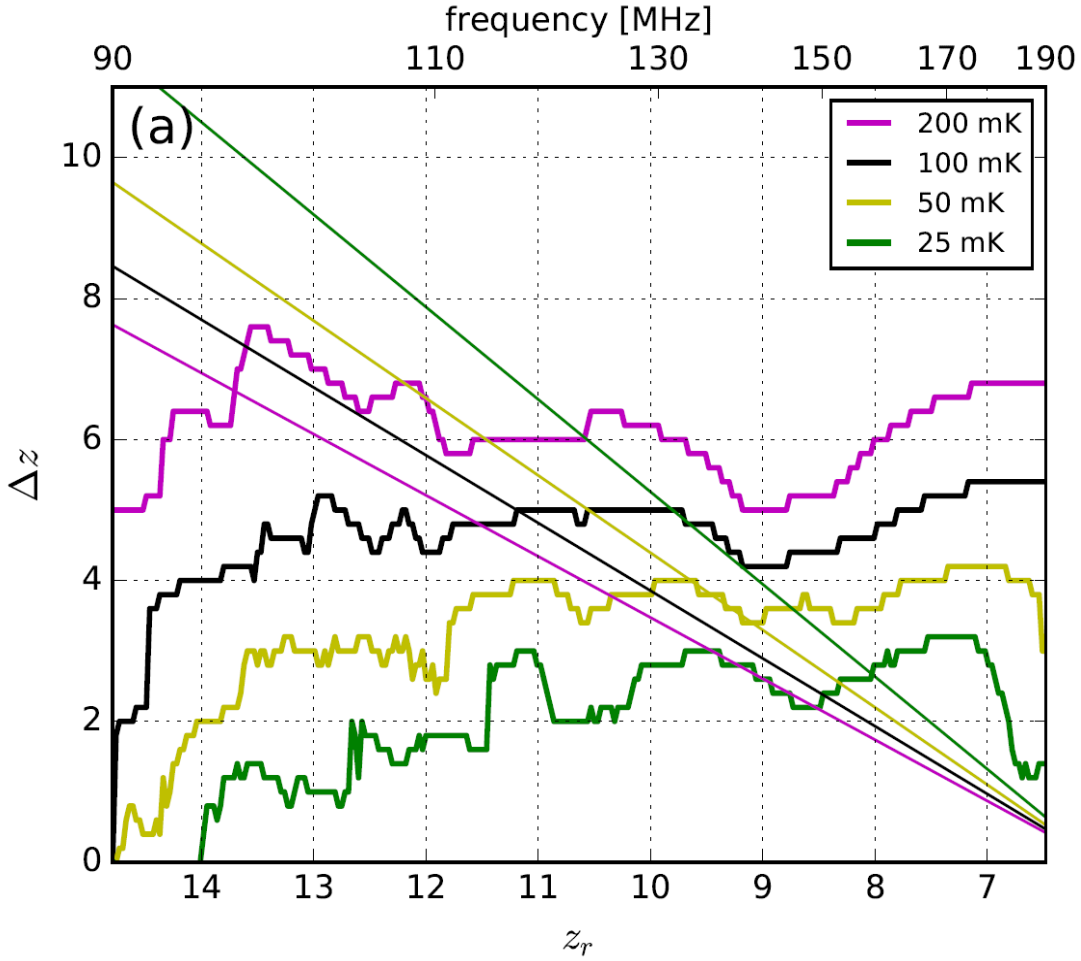
Cold gas: Constraints on duration



- Many scenarios ruled-out, including best estimates from Planck, SPT, Greig & Mesinger, Robertson, etc.
- Hence, disfavors lack of X-ray heating (cold IGM) with saturated spin temperature at time of reionization

Monsalve et al. 2017b

Gaussian absorption troughs

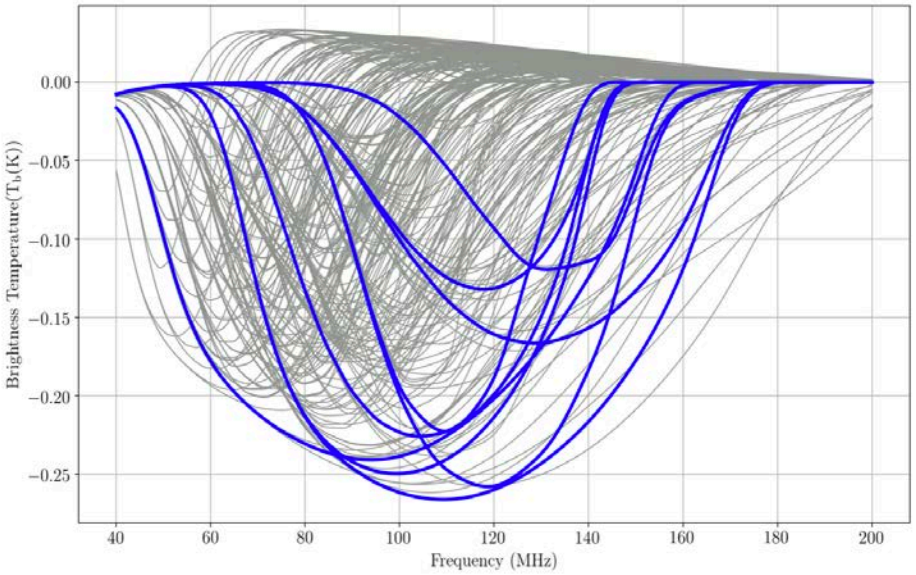


- Disfavors troughs with amplitude >25mK
- Combined with Planck, SPT, galaxy, etc., disfavors late UV and late/low X-ray, even for partial spin temperature saturation

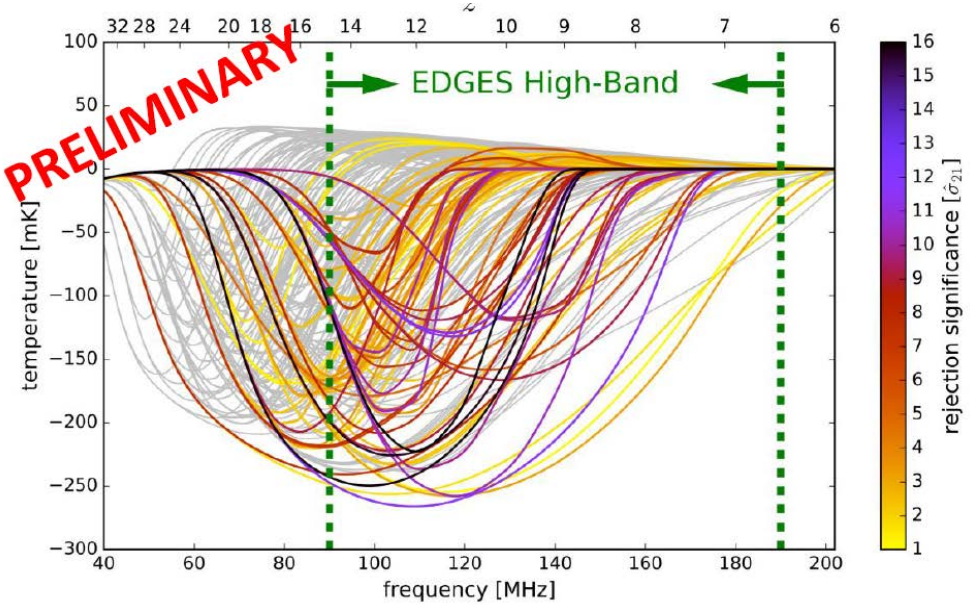
Monsalve et al. 2017b

Astrophysical model constraints

SARAS-2 disfavored



Example EDGES disfavored



- Numerical simulations from Fialkov et al. (2016), Cohen et al. (2017)
  - Probing: star formation efficiency, minimal mass of star-forming halos, efficiency and spectral distribution of X-ray sources, reionization history

- Also investigating Mirocha et al. and Greig & Mesinger (21CMFast) models

Singh et al., *in press*

Monsalve et al., *in prep*

Conclusion

- EDGES-2 based on absolute calibration and antenna trade-off design
  - Improved calibration and characterization of VNAs at low-frequencies (Monsalve et al. 2016)
  - “Artificial antenna” and laboratory calibration standards
  - Antenna design and EM model verification (Mahesh et al., in prep)

- First full-scale deployment being analyzed now:
  - Monsalve et al. 2017b
    - Constrain “standard” reionization duration to $\Delta z > \sim 1$
    - Disfavor “cold” reionization models
    - Rule out subset of astrophysics models
  - Mozdzen et al. 2017
    - Improved spectral index measurements of diffuse radio emission

- Future work:
  - Add mid-band instrument by end of 2017
  - Ongoing antenna and receiver improvements
  - Stay tuned for low-band results later this year!

Aspen Meeting

Cosmological Signals from Cosmic Dawn to the Present
Feb 4-10, 2018

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

Organizers: Rennan Barkana, Judd Bowman, Tzu-Ching Chang, Anastasia Fialkov (Chair), Adam Lidz, Anthony Pullen.