# Science from the Cosmic Dawn

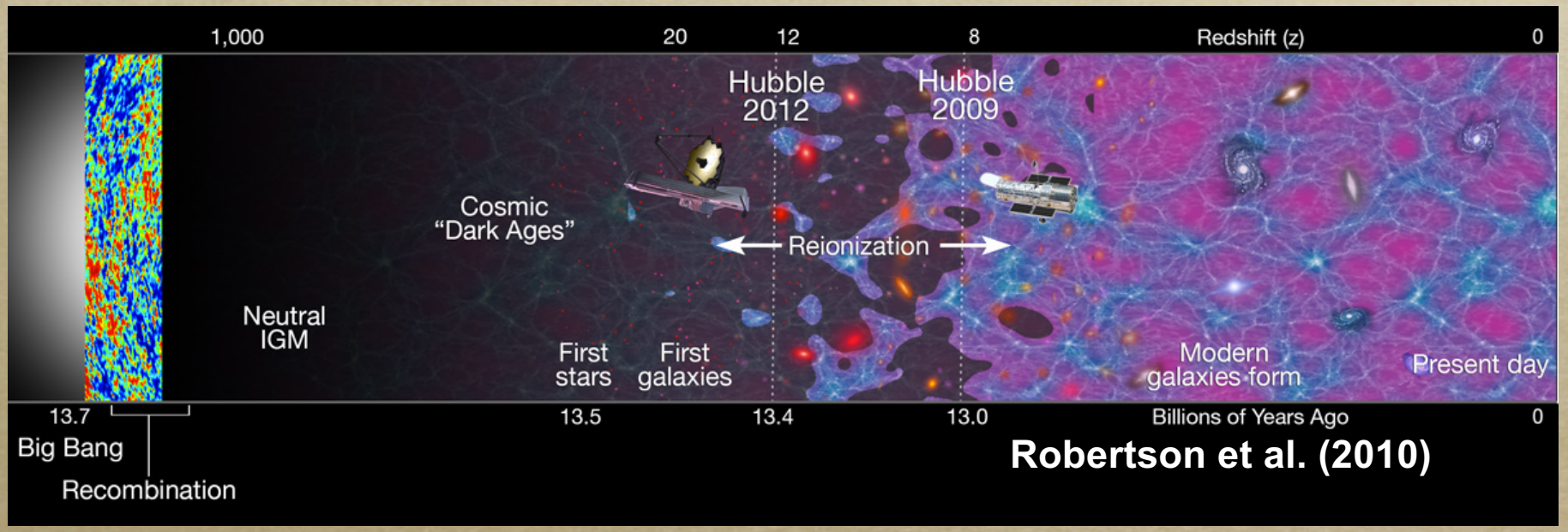
*NESS Kickoff Meeting*

*Steven Furlanetto*
*UCLA*
*May 25, 2017*

# Outline

- *Introduction and context*
- *Physics from the spin-flip transition*
- *Recent developments*
- *Year 1 plans*

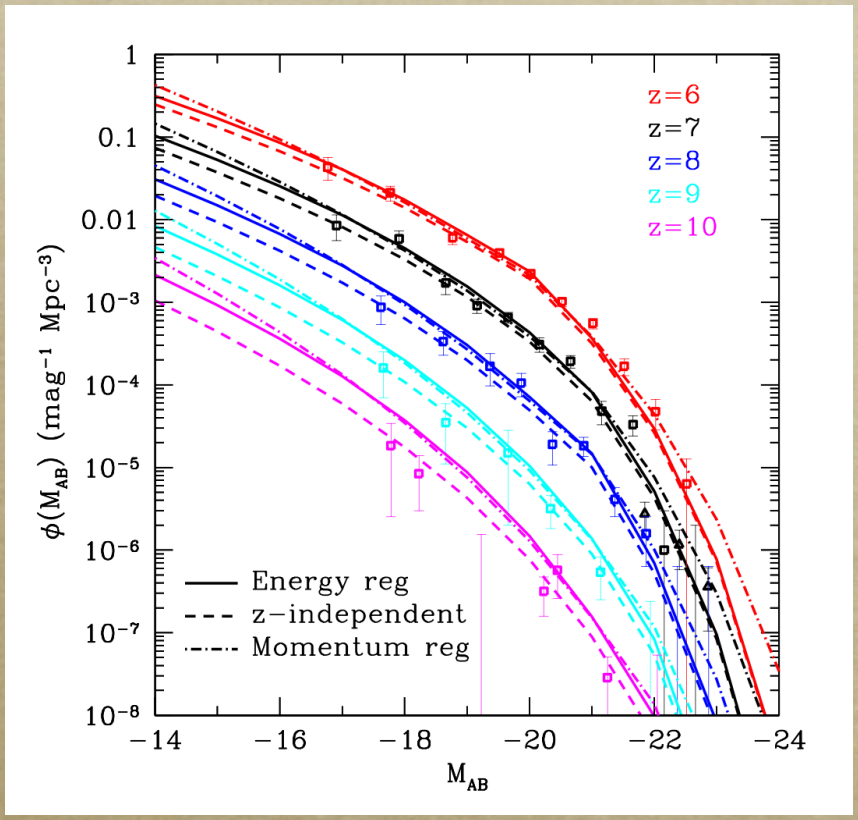
# The “Cosmic Dawn”



# Reionization

M. Alvarez

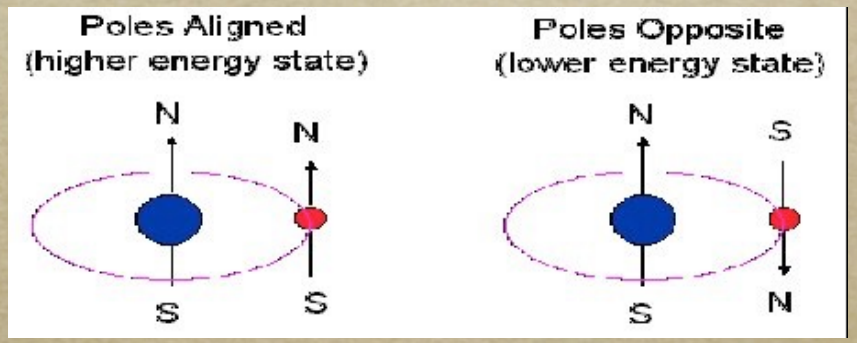
# Galaxies in the Cosmic Dawn




**Furlanetto et al. (2017)**

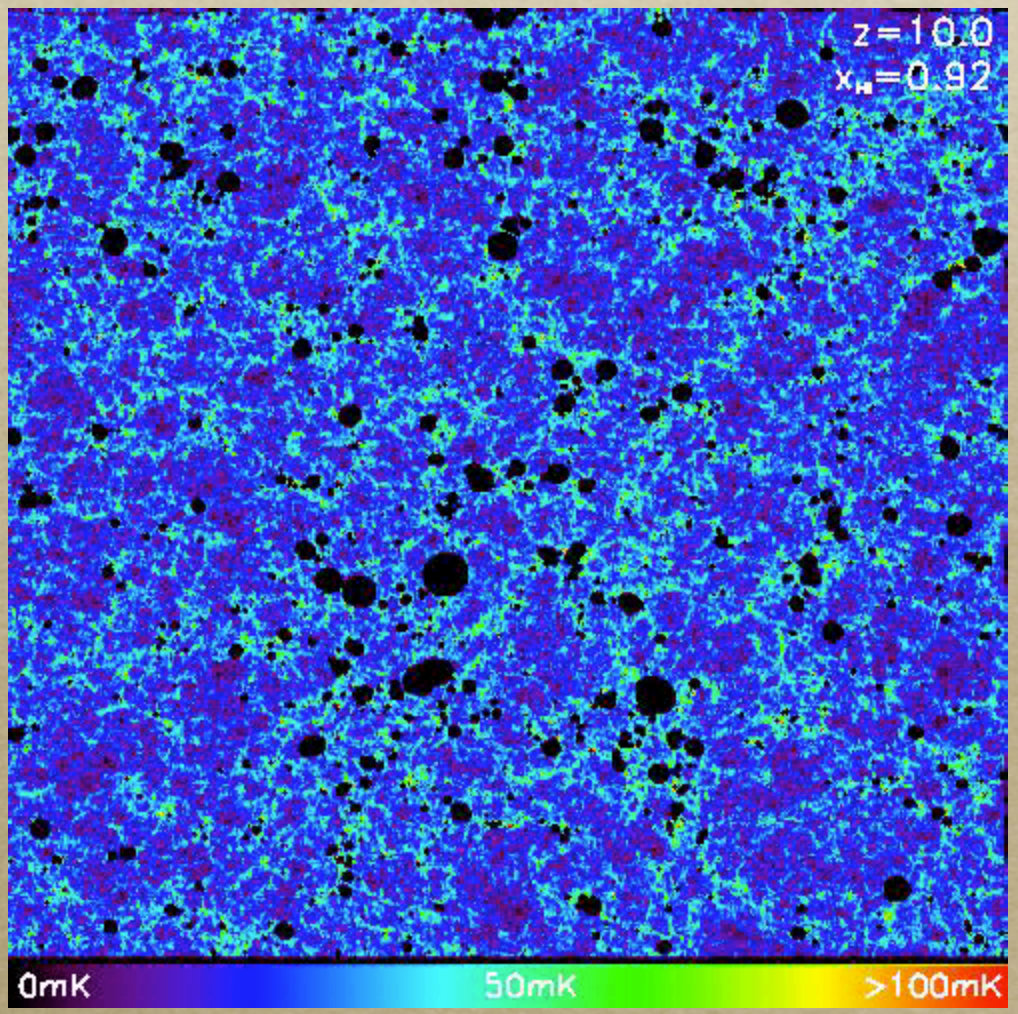
# Studying Reionization: The Spin-Flip Transition

- *Protons and electrons both have spin and hence magnetic moments*
- *Produces 21 cm photons (ν~1.4 GHz)*



# The 21-cm line

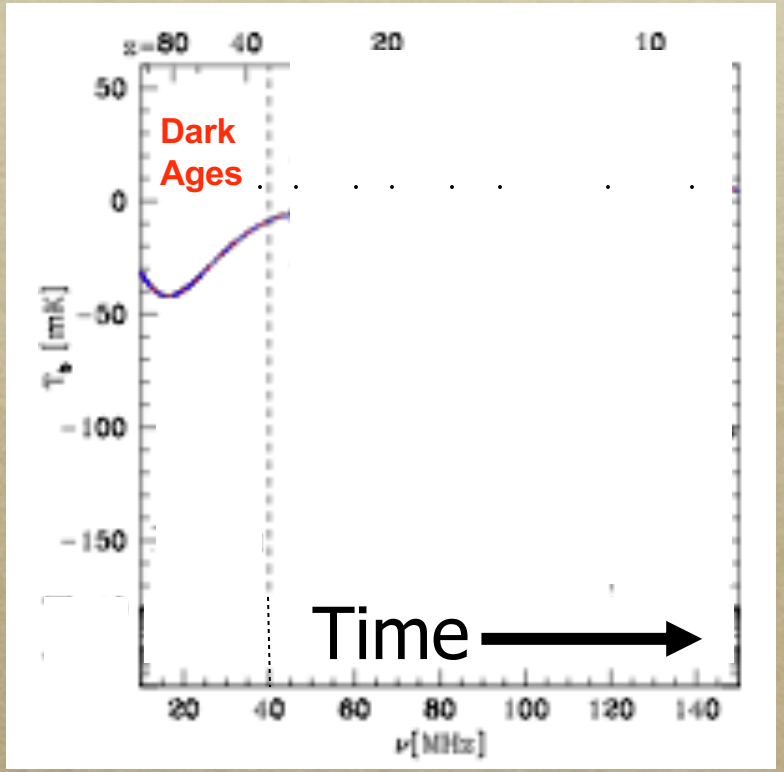
- *Spectral line measures entire history*
- *Directly measures intergalactic gas*
- *Weak absorption*




Mesinger & Furlanetto

# How does the spin-flip background teach us about source populations?

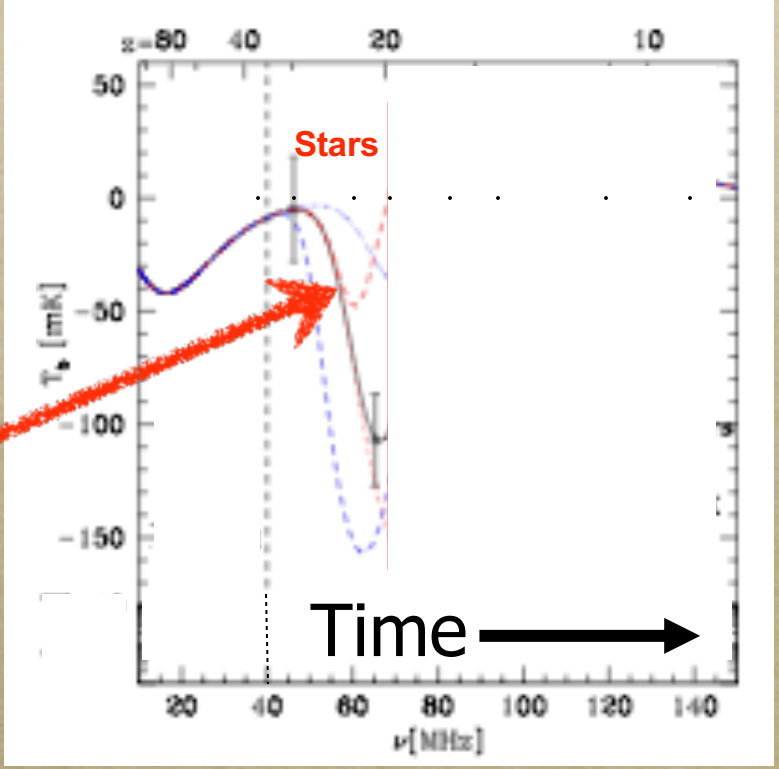
- *Four Phases to the spin-flip background*
  - *Dark Ages (potential probe of exotic physics)*




J. Pritchard

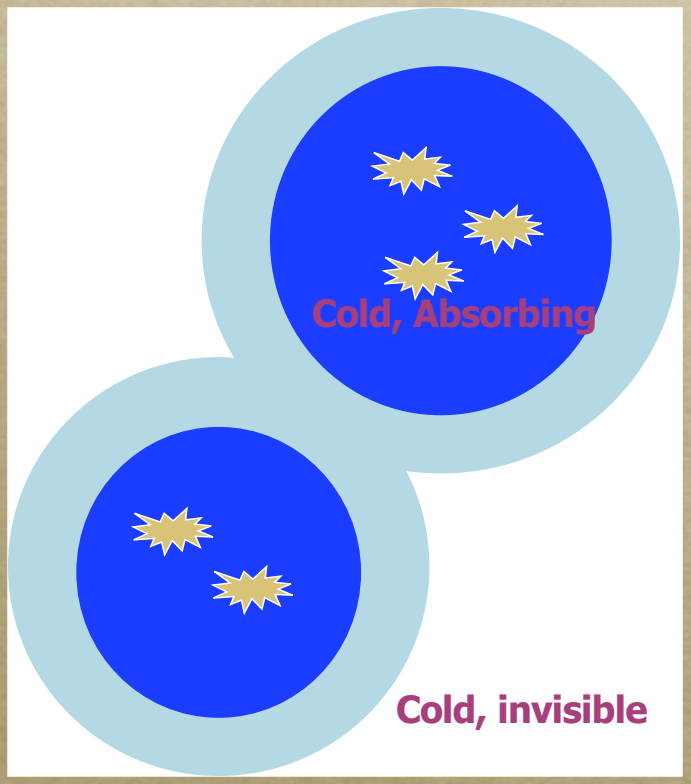
# How does the spin-flip background teach us about source populations?

- *Four Phases to the spin-flip background*
  - *Dark Ages*
  - *First Stars*




J. Pritchard

# The First Stars: Lyα Fluctuations

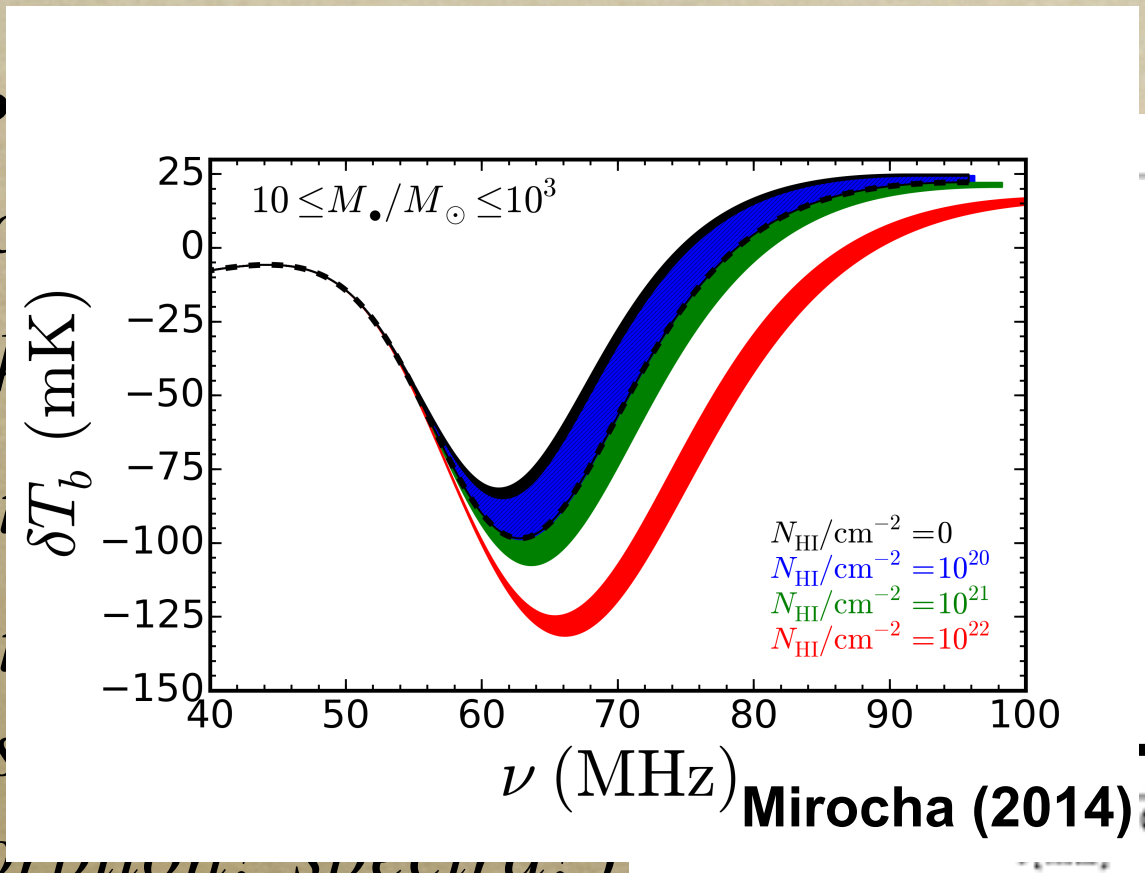



- *Strong absorption near first galaxies*
- *Eventually saturates*

**Barkana & Loeb 2004, Pritchard & Furlanetto 2006, Mesinger et al. 2011**

# How does the spin-flip background teach us about source populations?

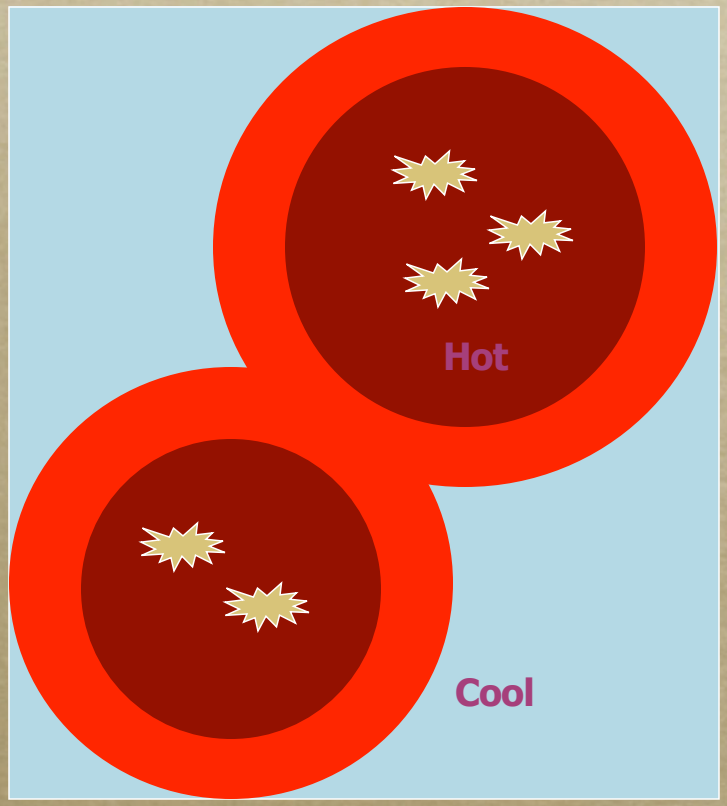
- *Four P*
  - *flip bac*
    - *Dar*
    - *Firs*
    - *Firs*
      *(mas*
      *absorption? spectra?)*




**Mirocha (2014)**


**J. Pritchard**

# The First Black Holes

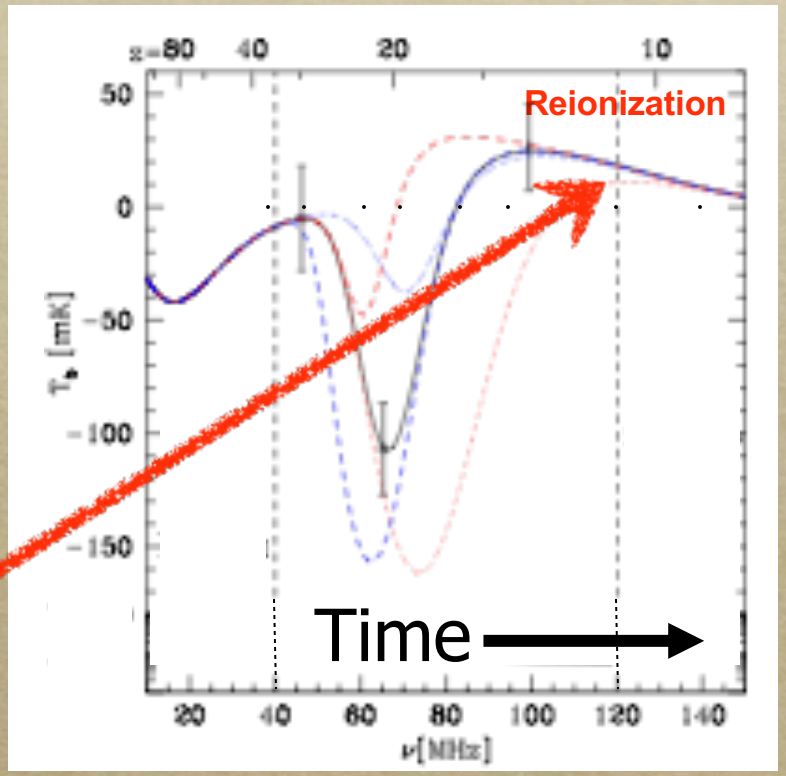



- *X-ray photons heat gas around first black holes*
  - *Supernovae*
  - *Stellar remnants*
  - *Quasars*
- *Hot IGM near them, cool IGM elsewhere*

**Pritchard & Furlanetto 2007, Chuzhoy et al. 2007, Chen & Miralda-Escude 2008, Santos et al. 2009, Mesinger, Furlanetto, & Cen 2011, Baek et al. 2010**

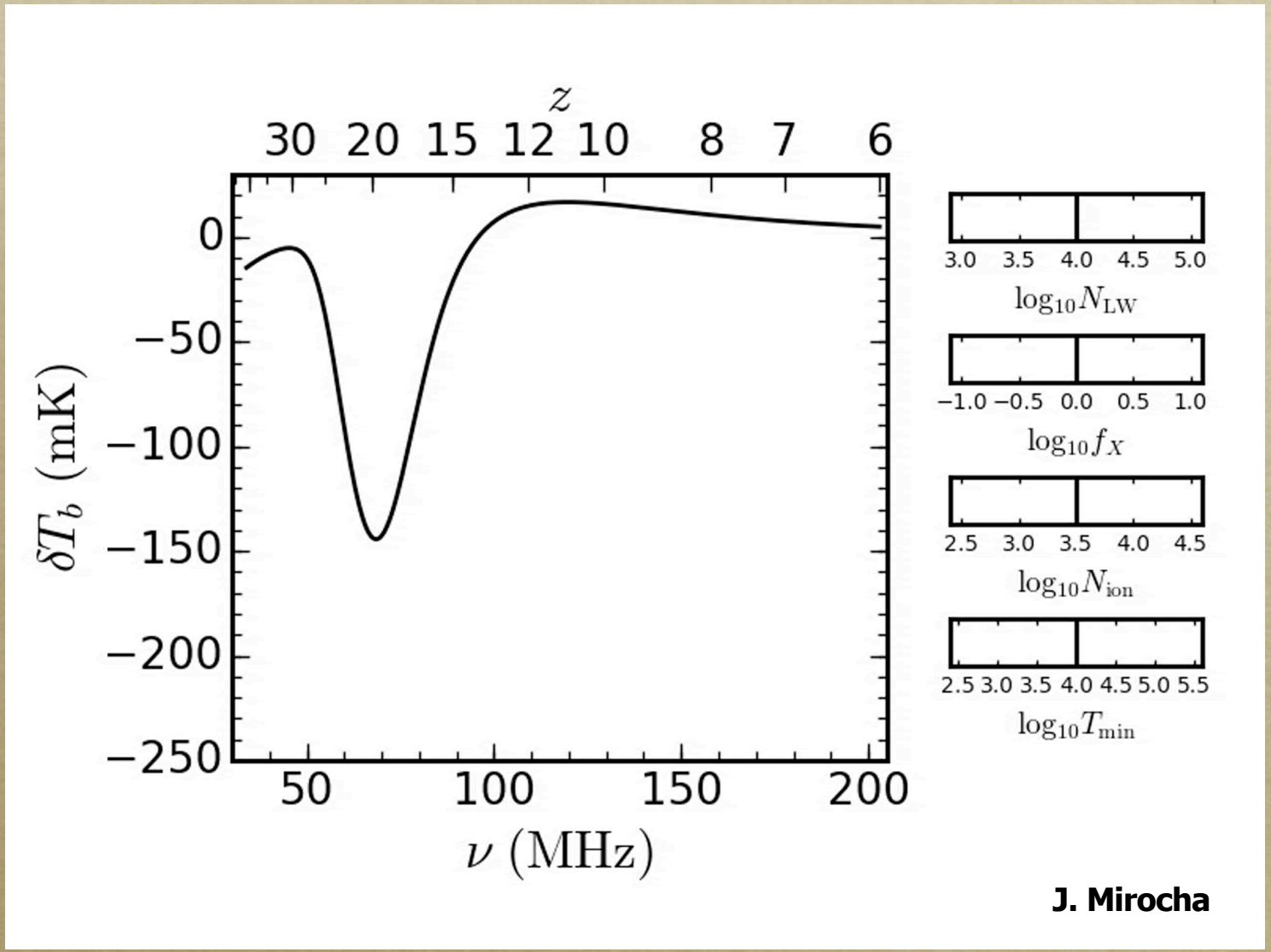
# How does the spin-flip background teach us about source populations?

- *Four Phases to the spin-flip background*
  - *Dark Ages*
  - *First Stars*
  - *First Black Holes*
  - *Reionization*




J. Pritchard

# The 21-cm Background

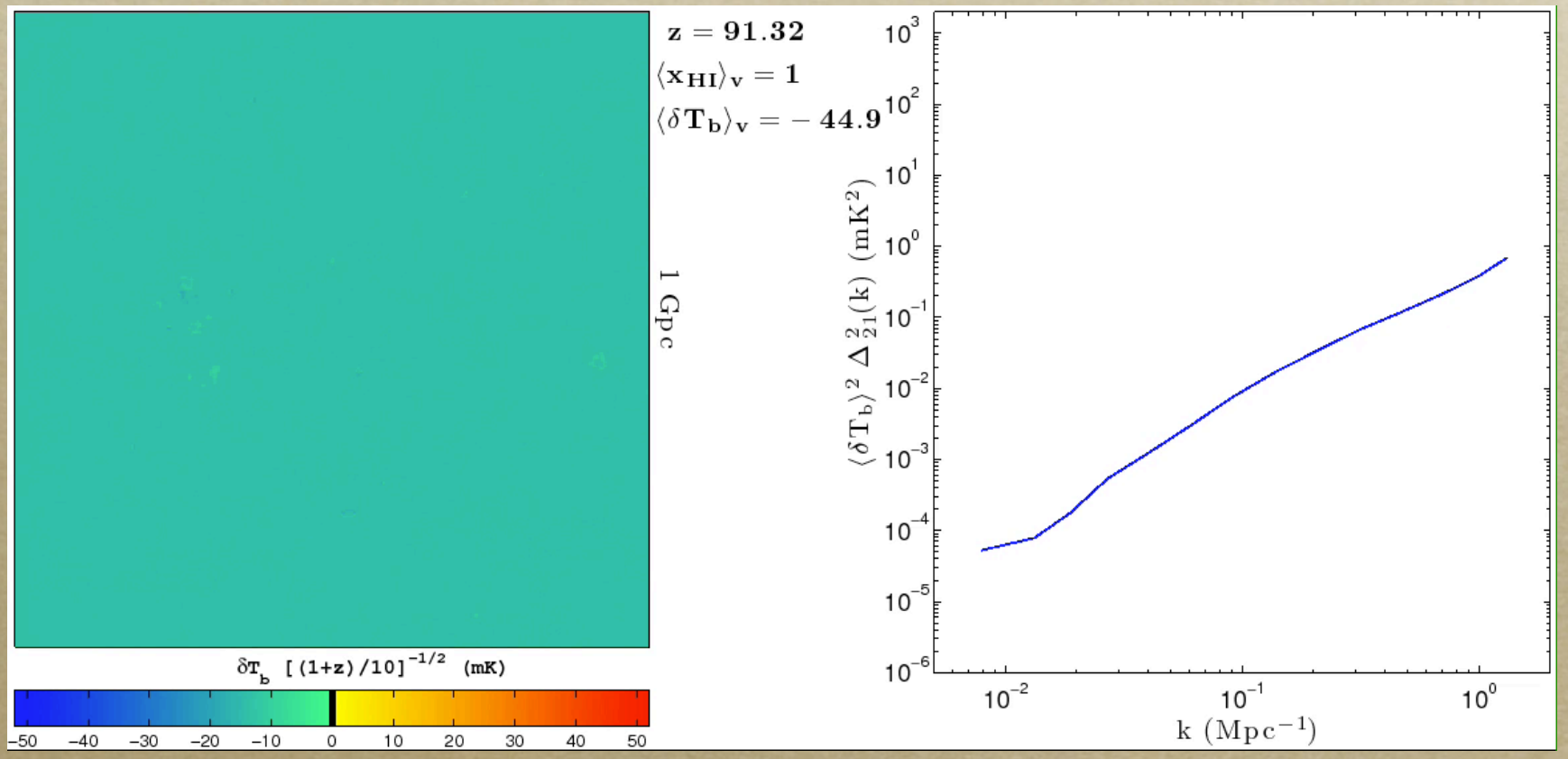



**J. Mirocha**

# But can we see it?

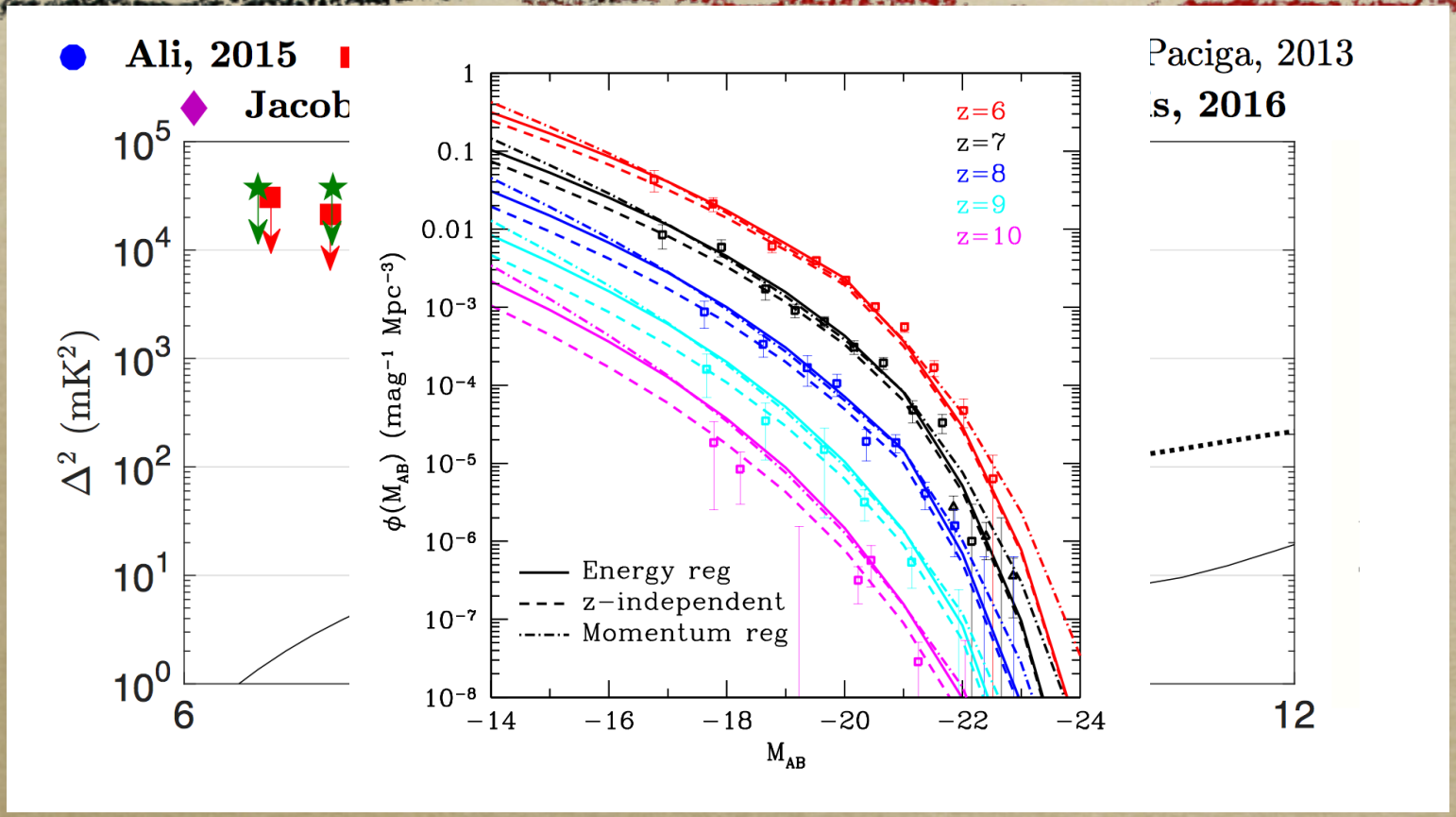
- *Terrestrial foregrounds*
- *Ionosphere*
- *Astrophysical fo*

# The 21-cm Background




Mesinger, Furlanetto, & Cen (2011)

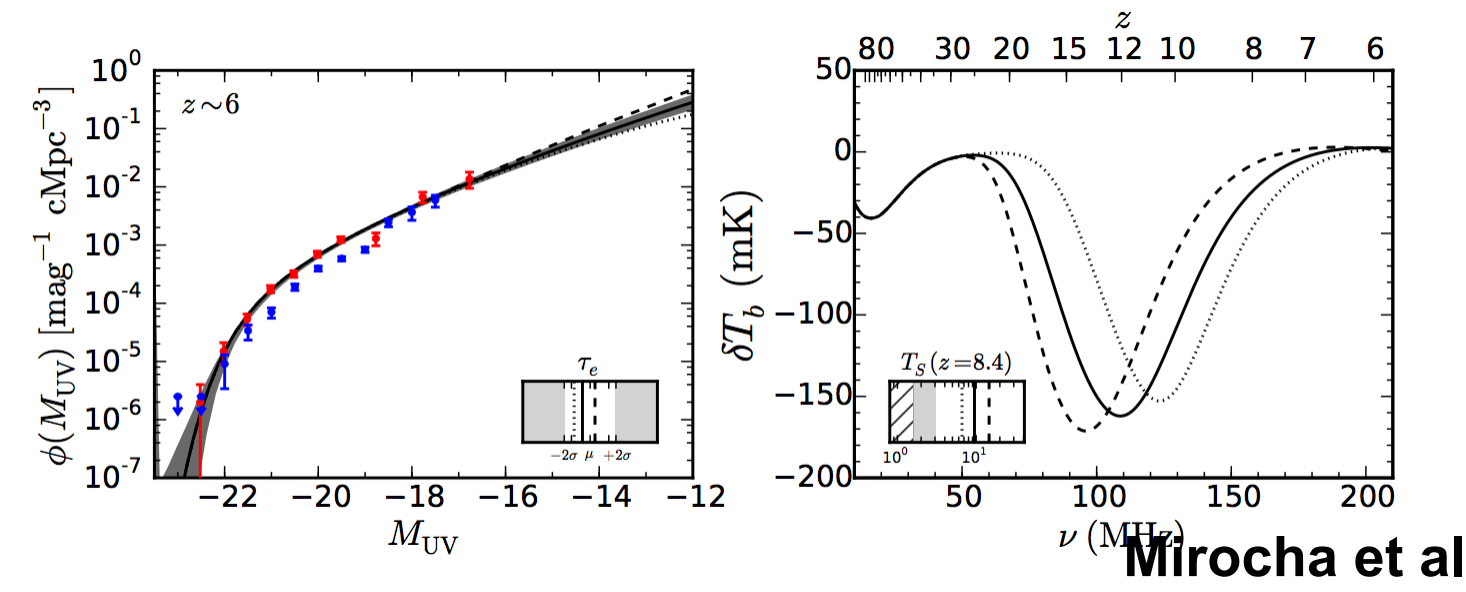
# The Story So Far




**J. Pritchard**

- *Four active interferometers: LOFAR, GMRT, MWA, PAPER*
- *Best constraints so far from PAPER*
- *New results from EDGES (Bowman, Monsalve, et al.)*
- *Rule out cold IGM at z~8 (Pober et al. 2015)*

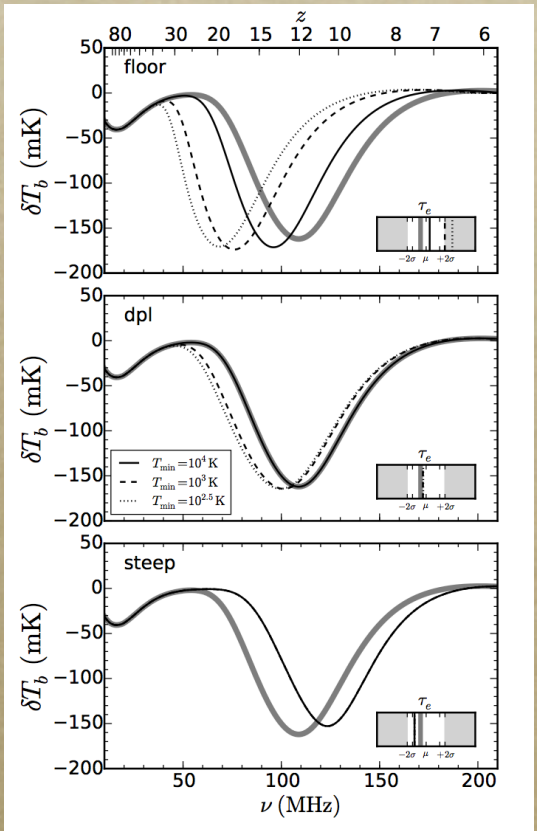
# Current Status

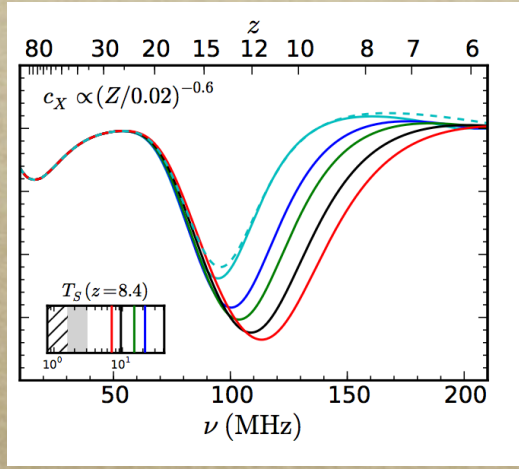



**Mirocha et al. (2016)**

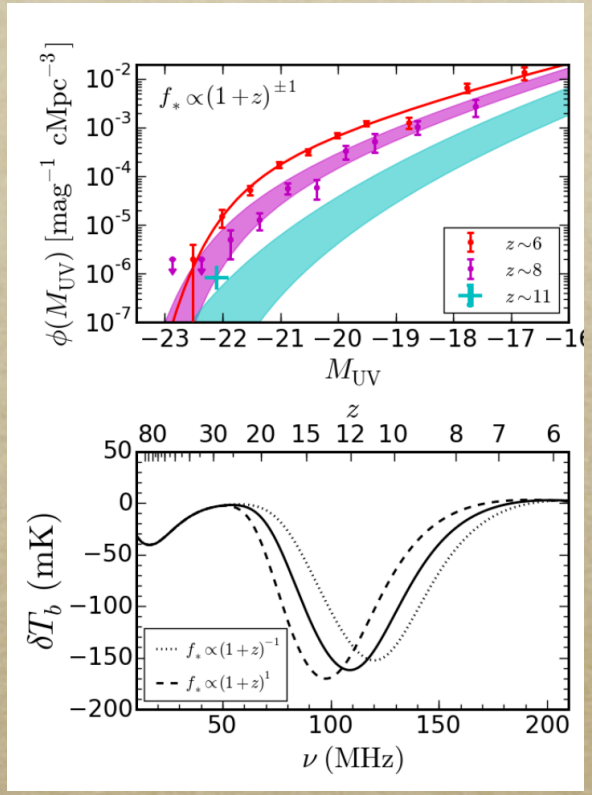
- *Extrapolation of existing galaxy observations + "vanilla" assumptions is changing our conservative models!*
- *Later (higher frequency) features*
- *Mixing heating and reionization eras*

# Uncertainties in the “Vanilla” Global Signal



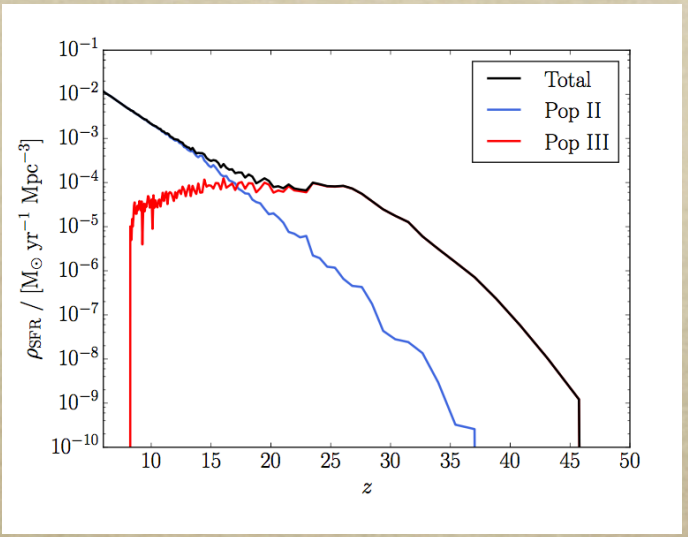

**Mirocha et al. (2016)**

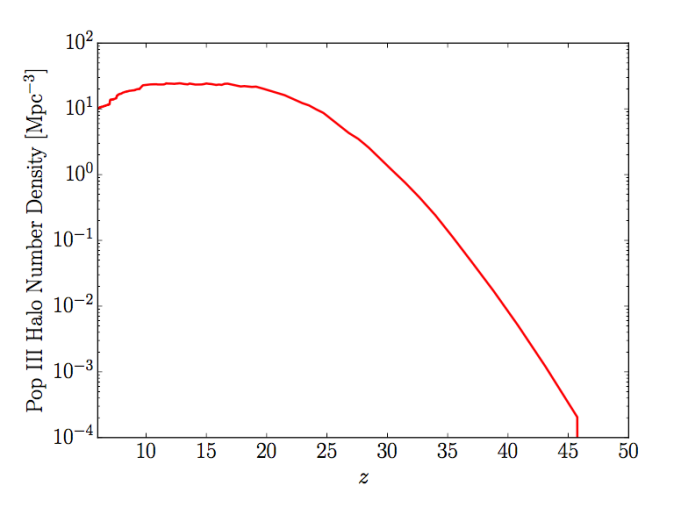



- *Lots of unknown parameters - spin-flip will help to focus models!*
- *Unclear so far how well interferometers can do on their own*

# What about exotic populations?

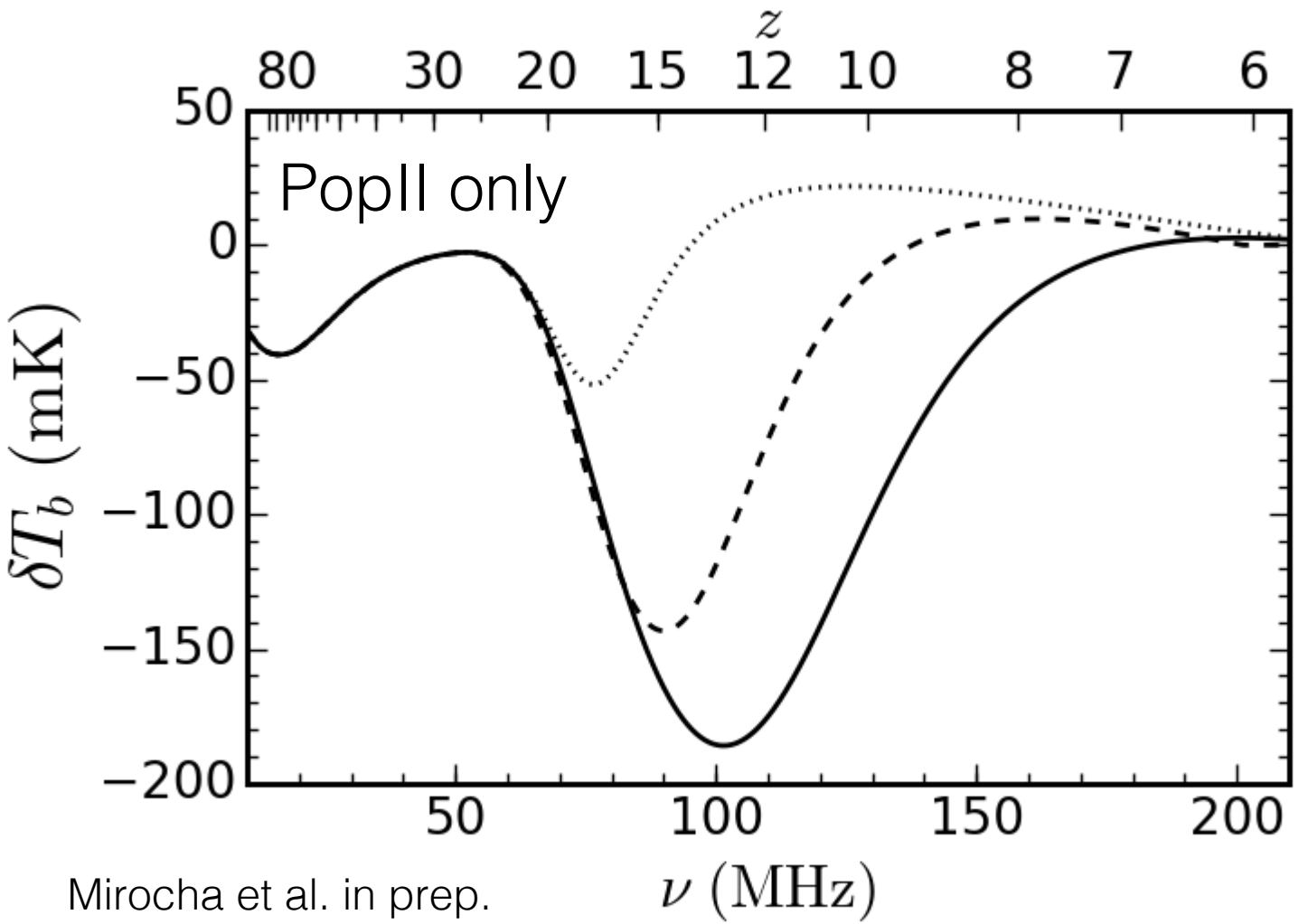
- *Pop III stars*
  - *Form in metal-free gas: higher masses?*
  - *Form in fragile halos: bursty mode?*
- *Find a "plateau" in Pop III SFRD*
- *If more massive AND binary, may cause very strong X-ray heating!*




**Mebane et al. (in prep)**

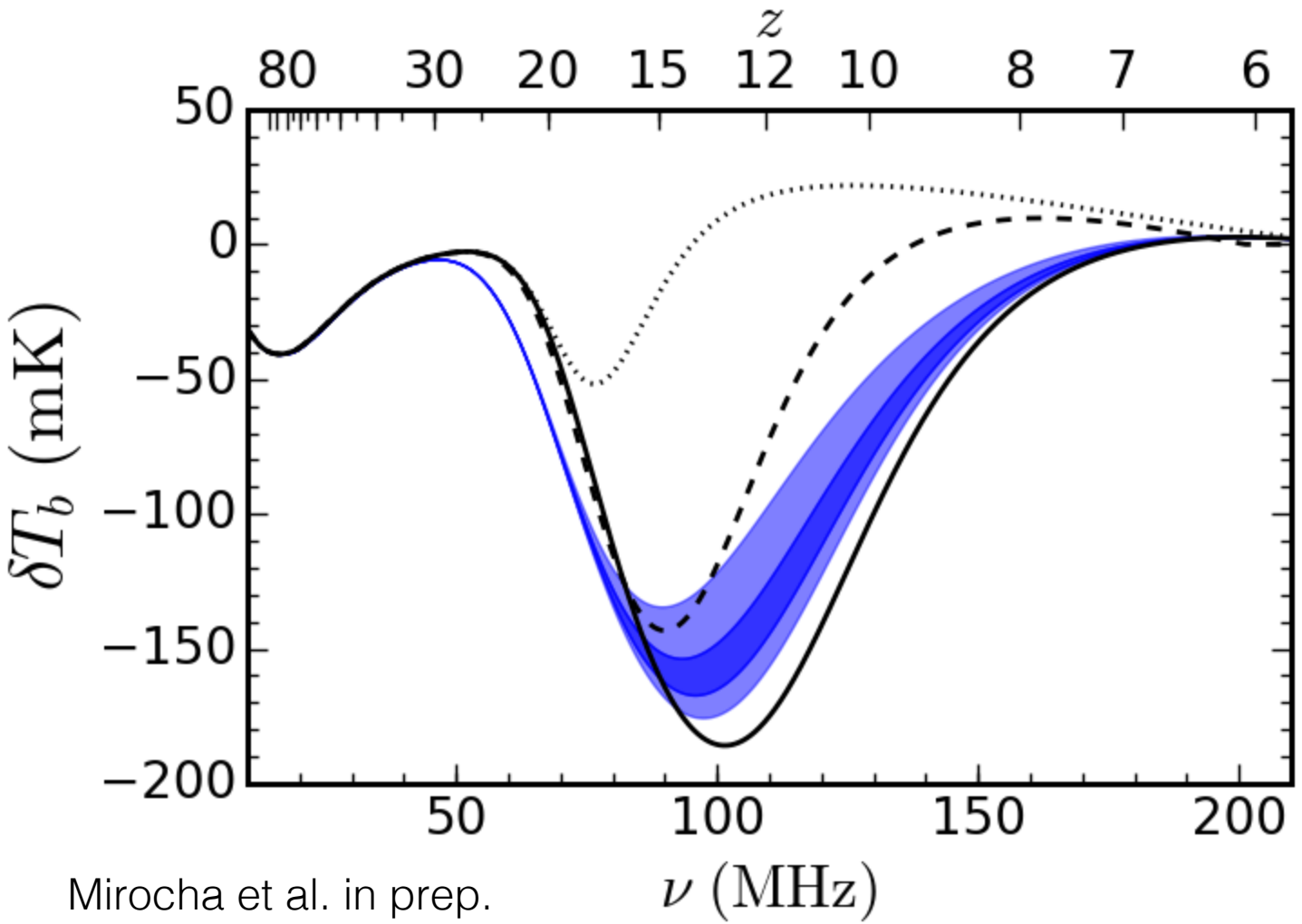
# How discernible is PopIII?



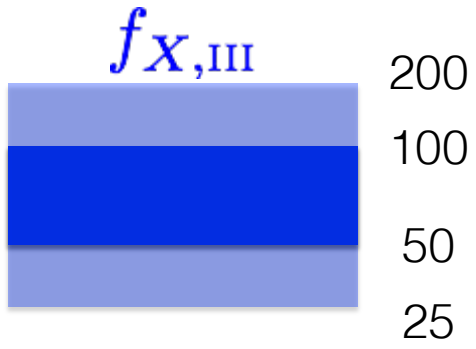

Mirocha et al. in prep.

Shallow troughs = stronger emission peaks

# How discernible is PopIII?




PopIII not so resilient




Mirocha et al. in prep.

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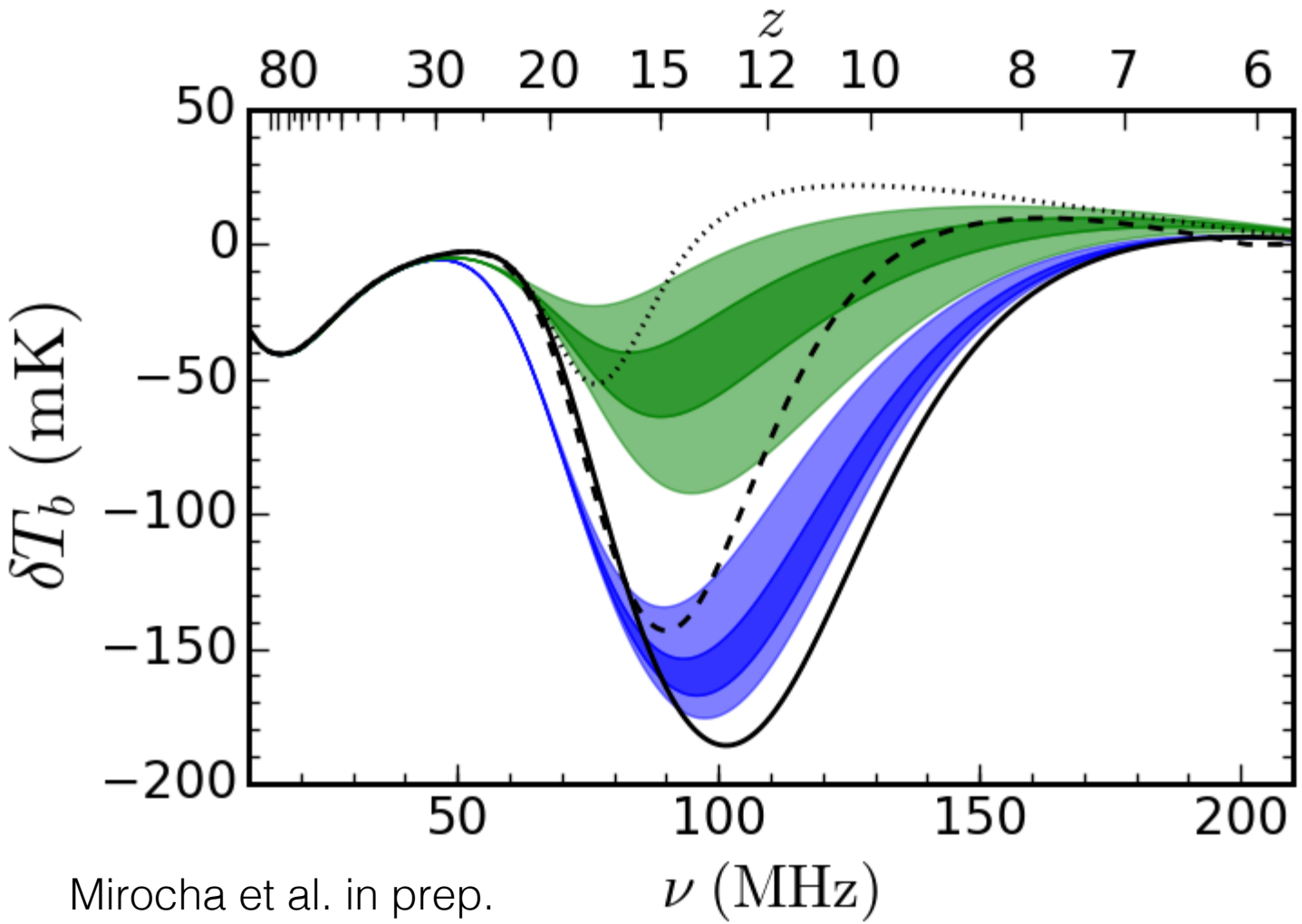
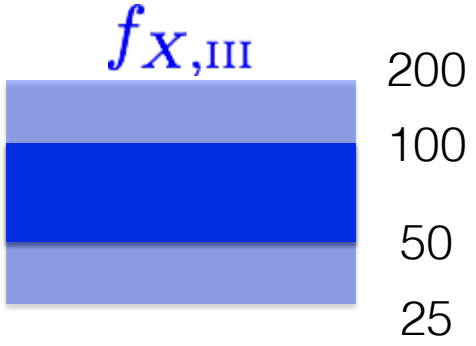
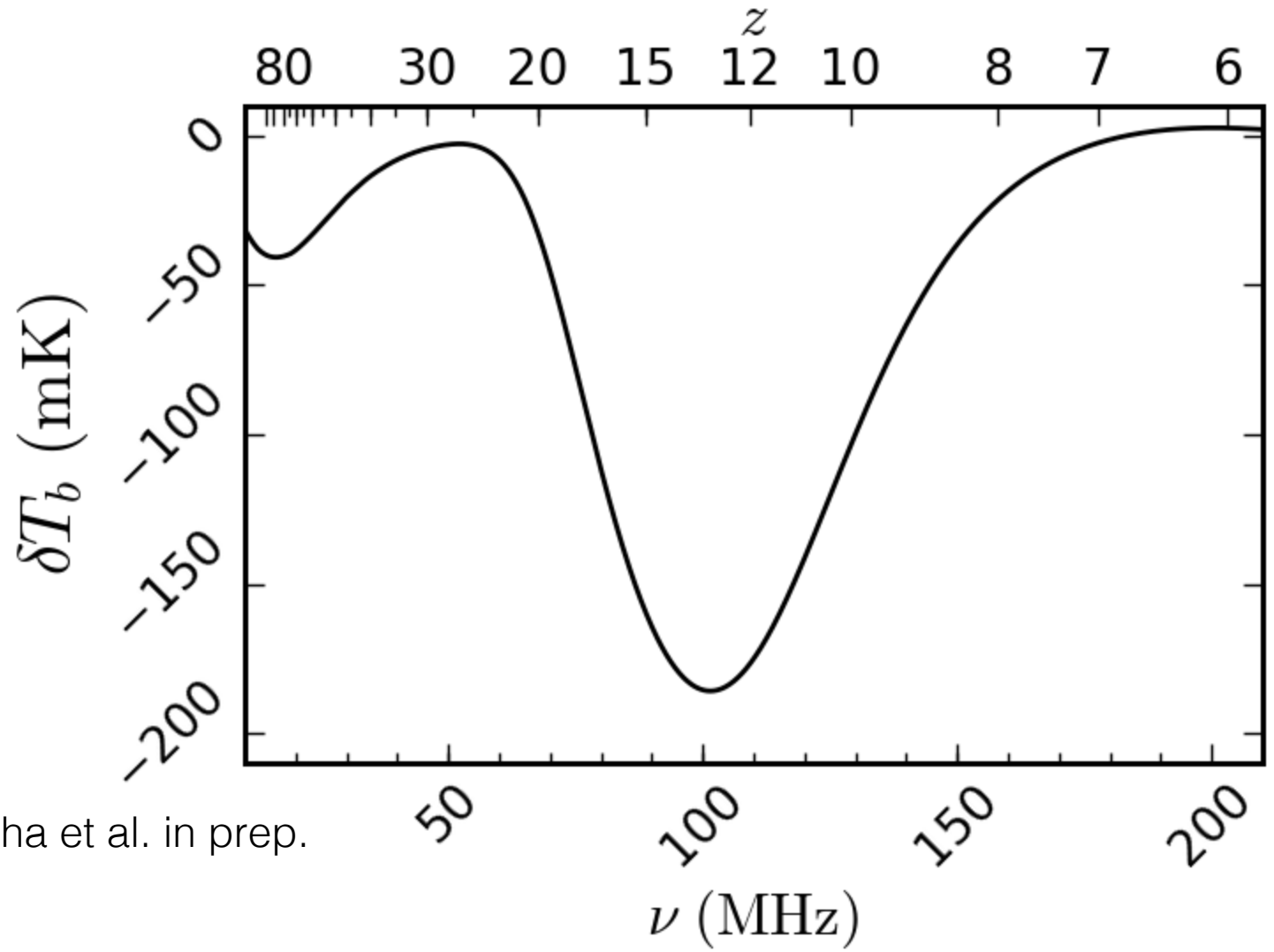



PopIII more resilient




Mirocha et al. in prep.

# Unique Signature?




Mirocha et al. in prep.

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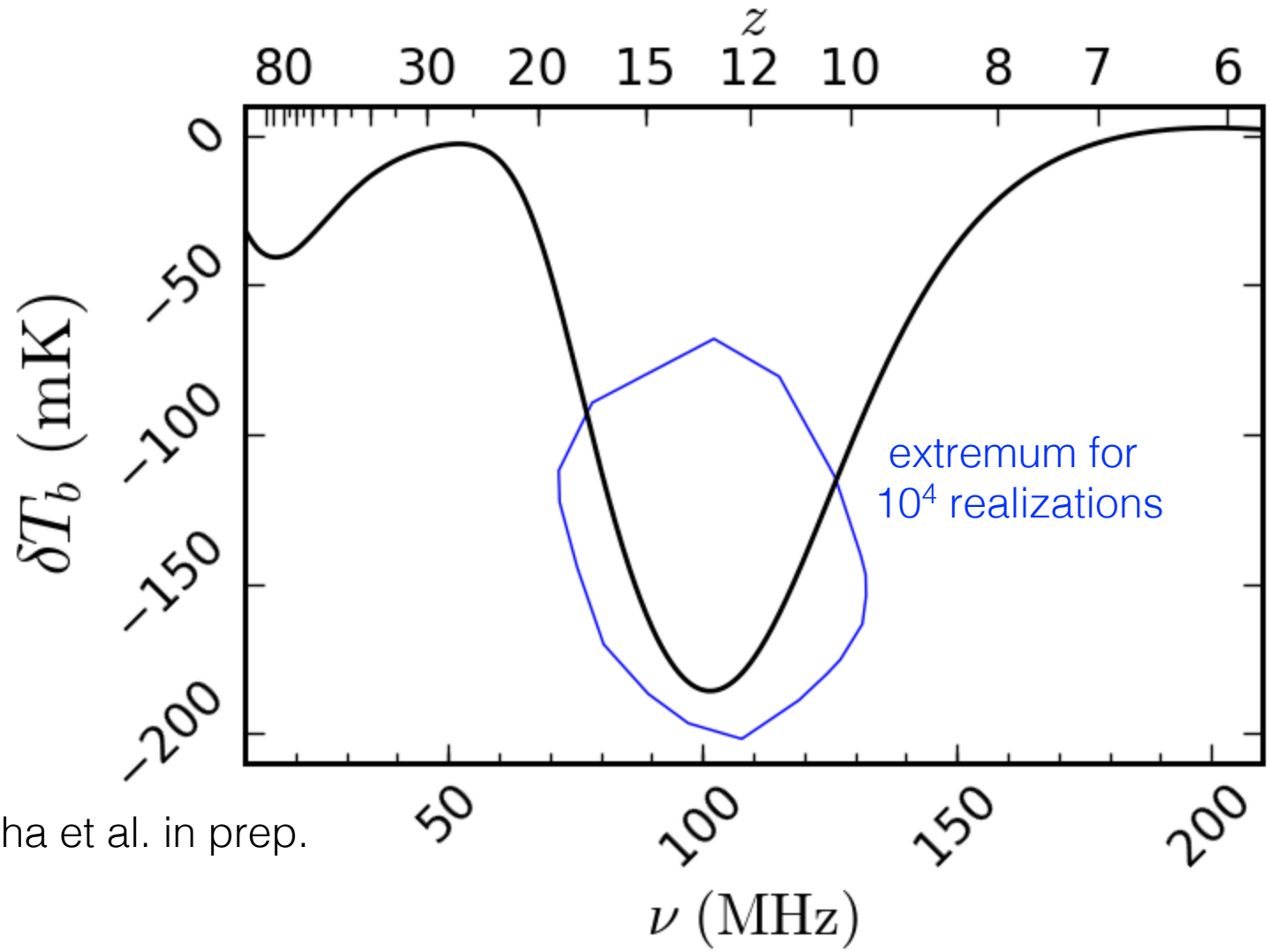


Mirocha et al. in prep.

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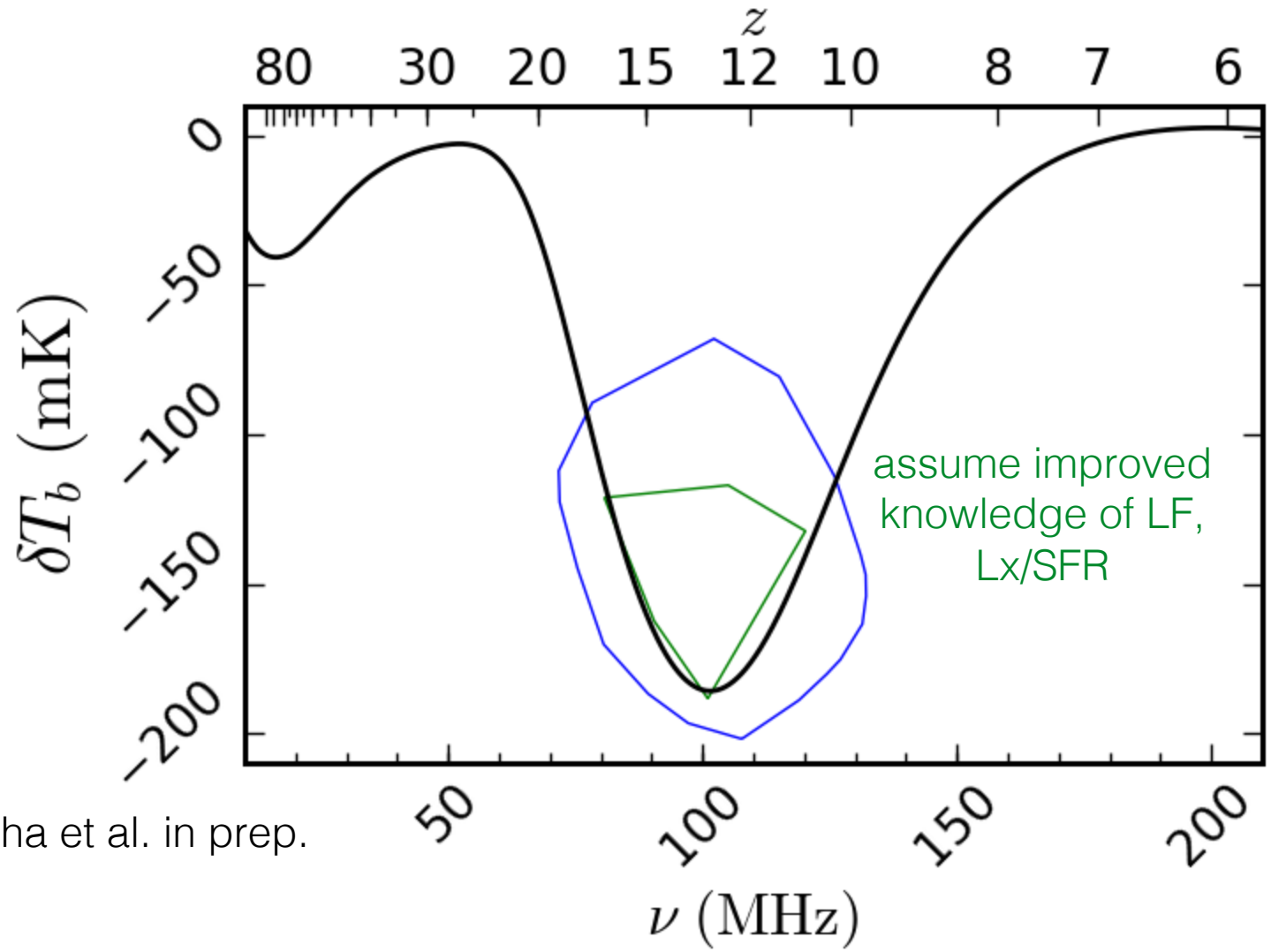


Mirocha et al. in prep.

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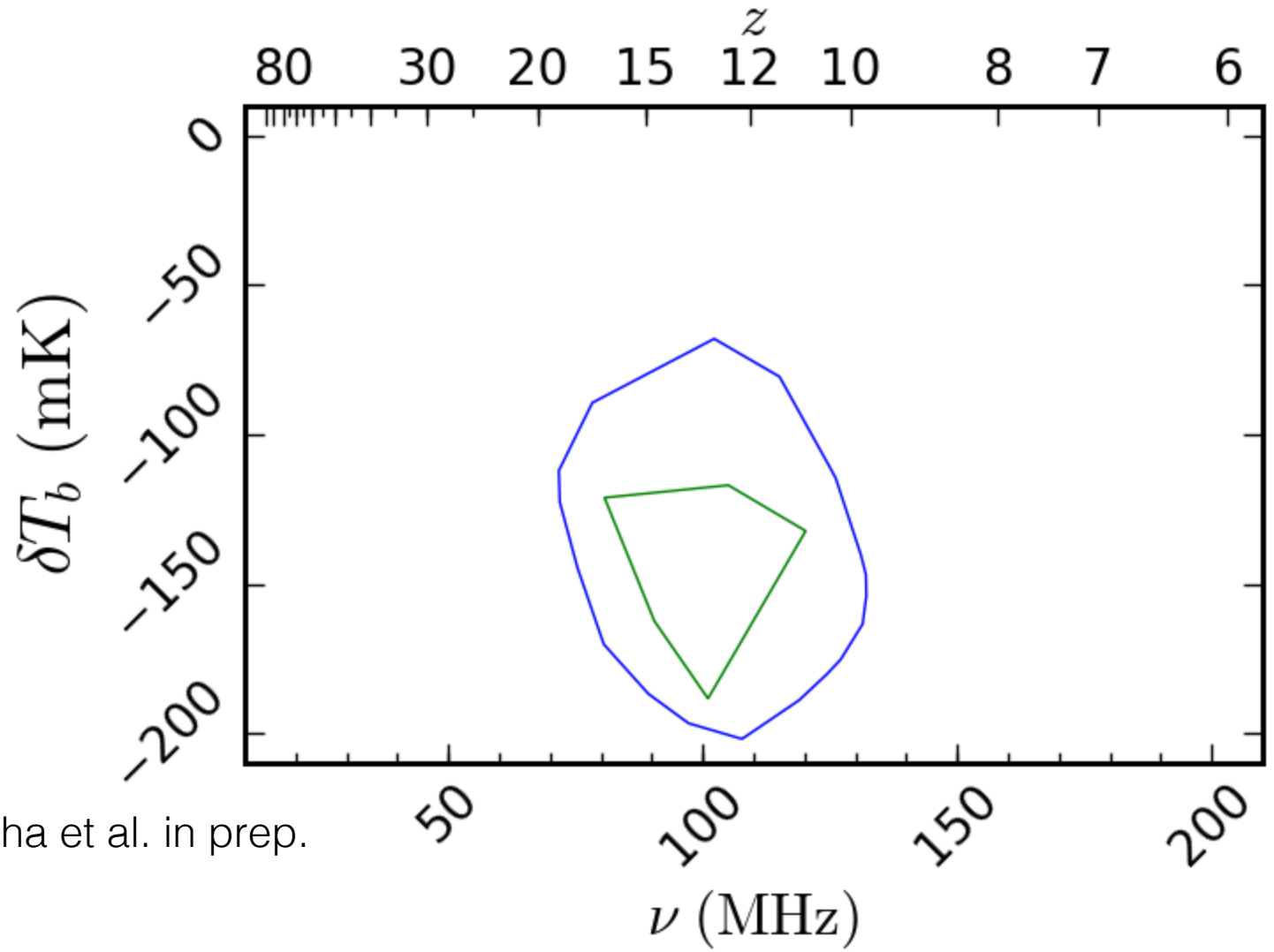


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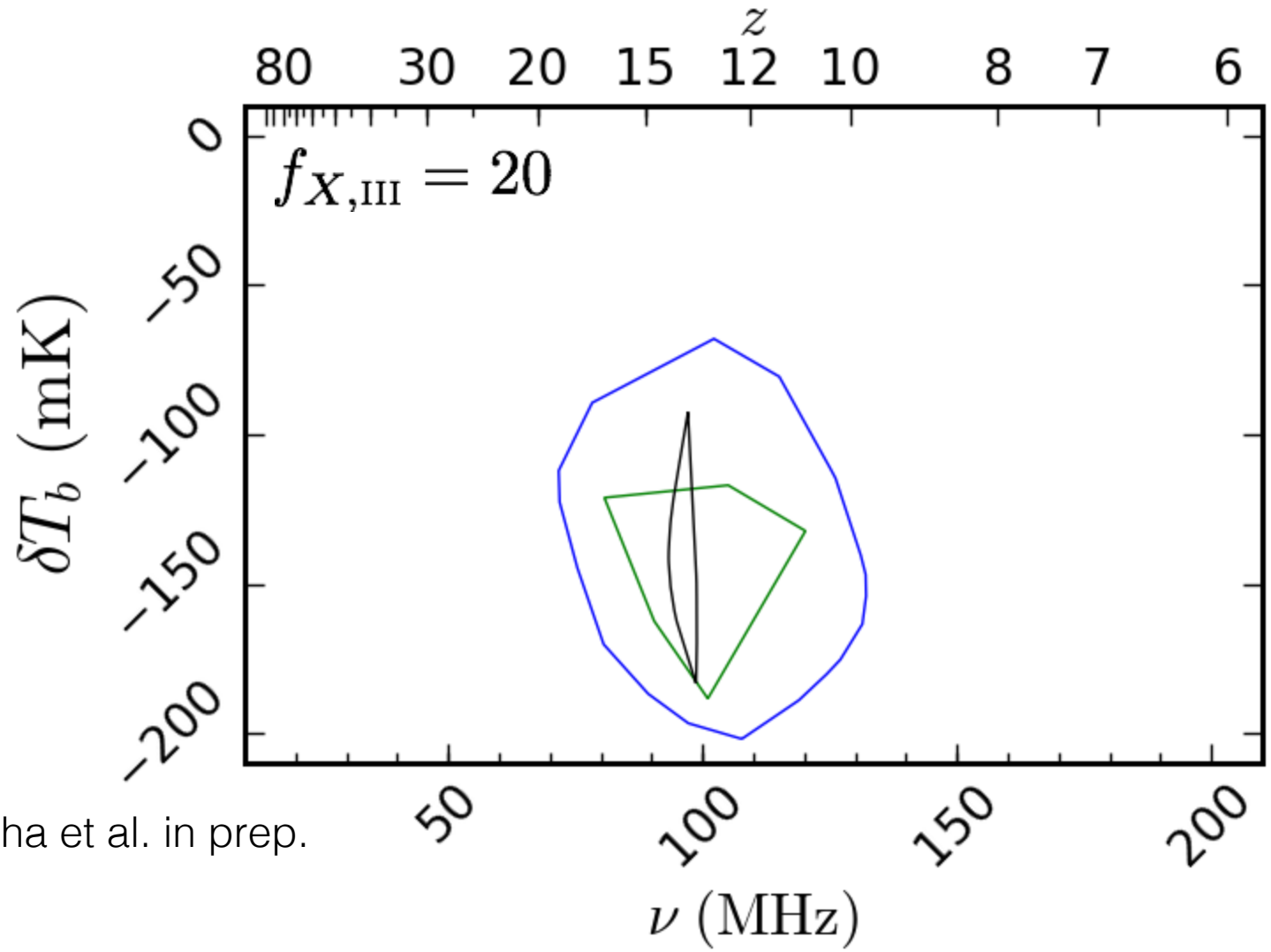


Mirocha et al. in prep.

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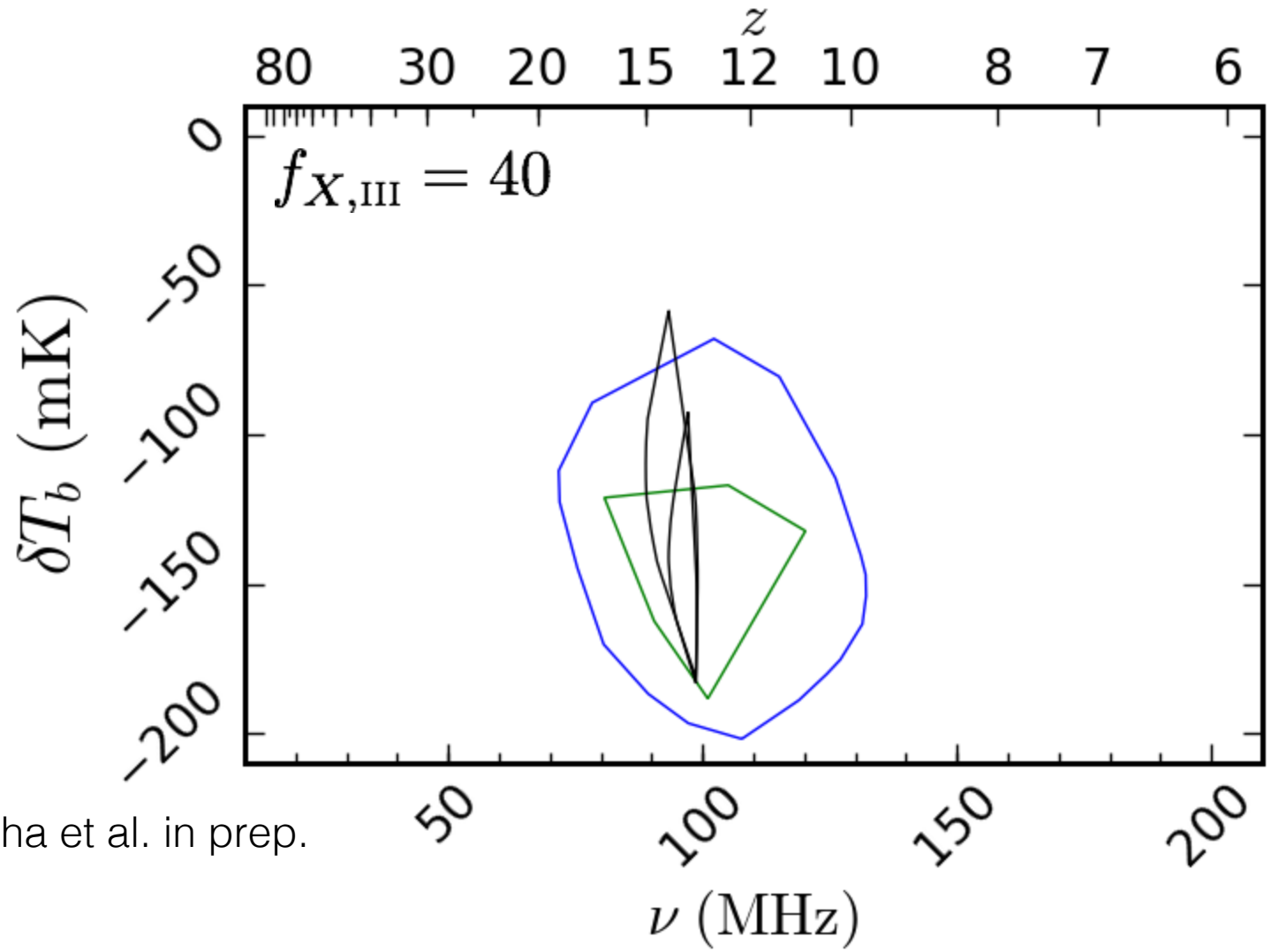


Mirocha et al. in prep.

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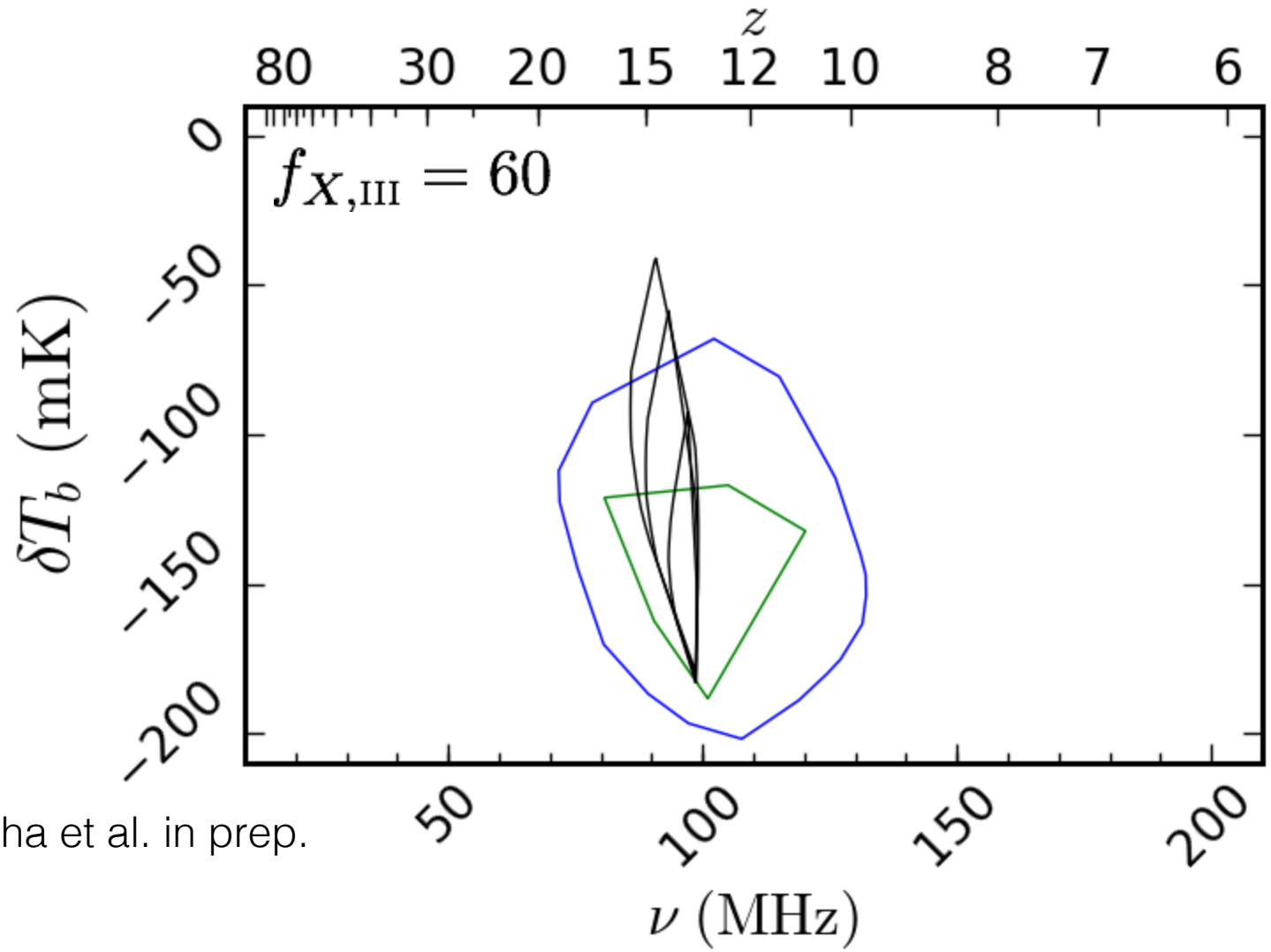


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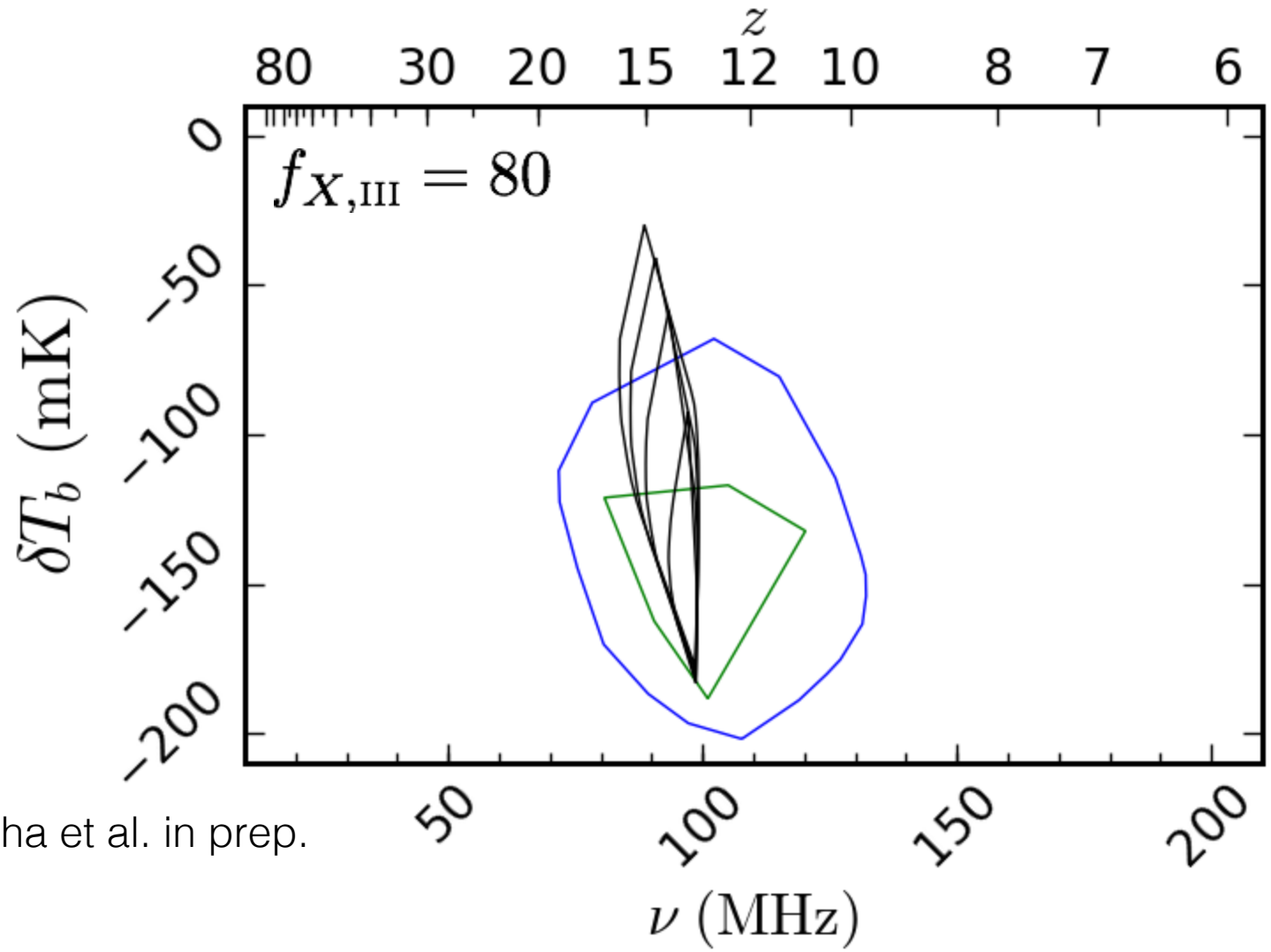


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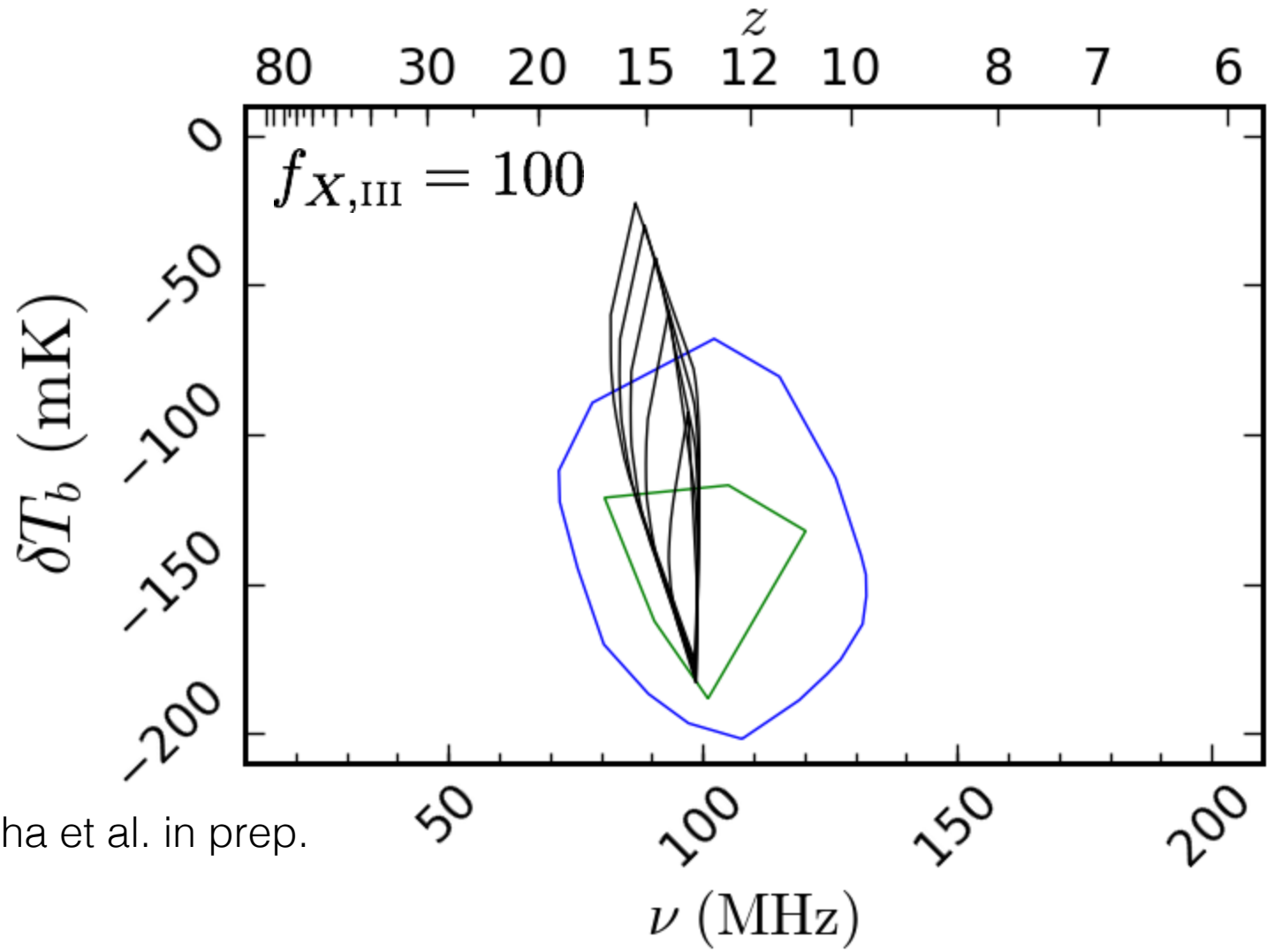


Mirocha et al. in prep.

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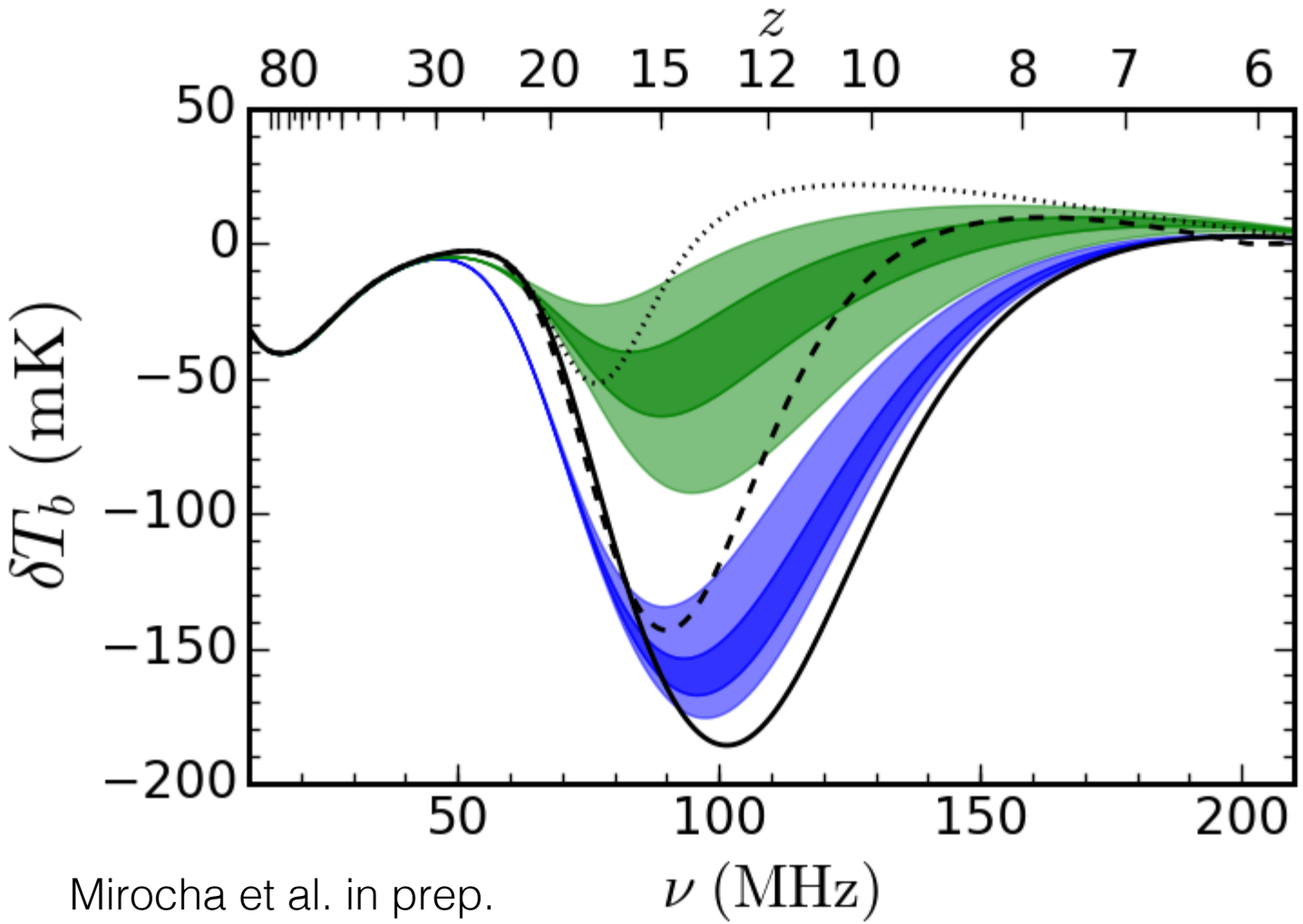
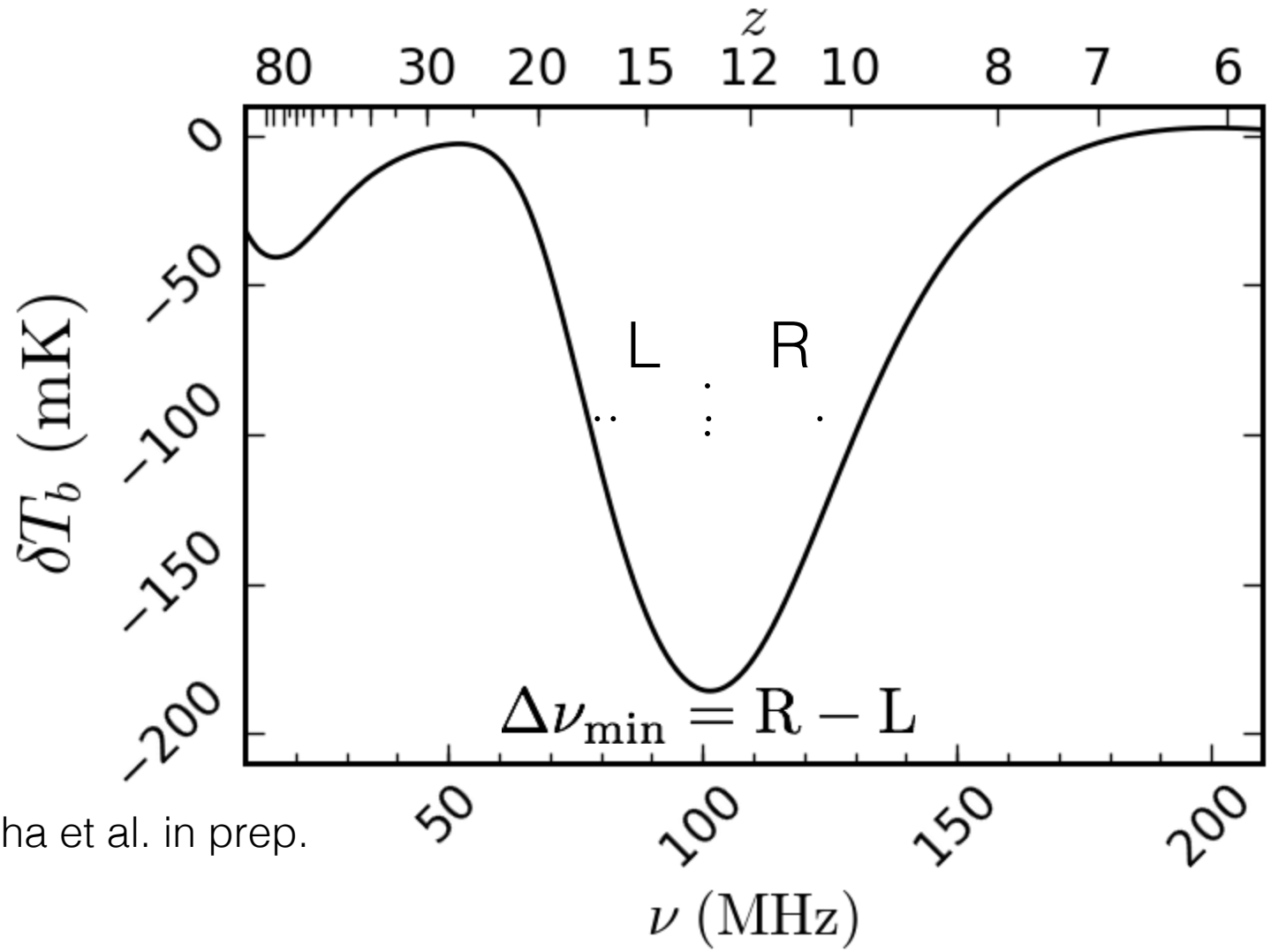



Mirocha et al. in prep.

Remember it's really that the ***shape*** is different, not just the amplitude.

# Shape Diagnostic

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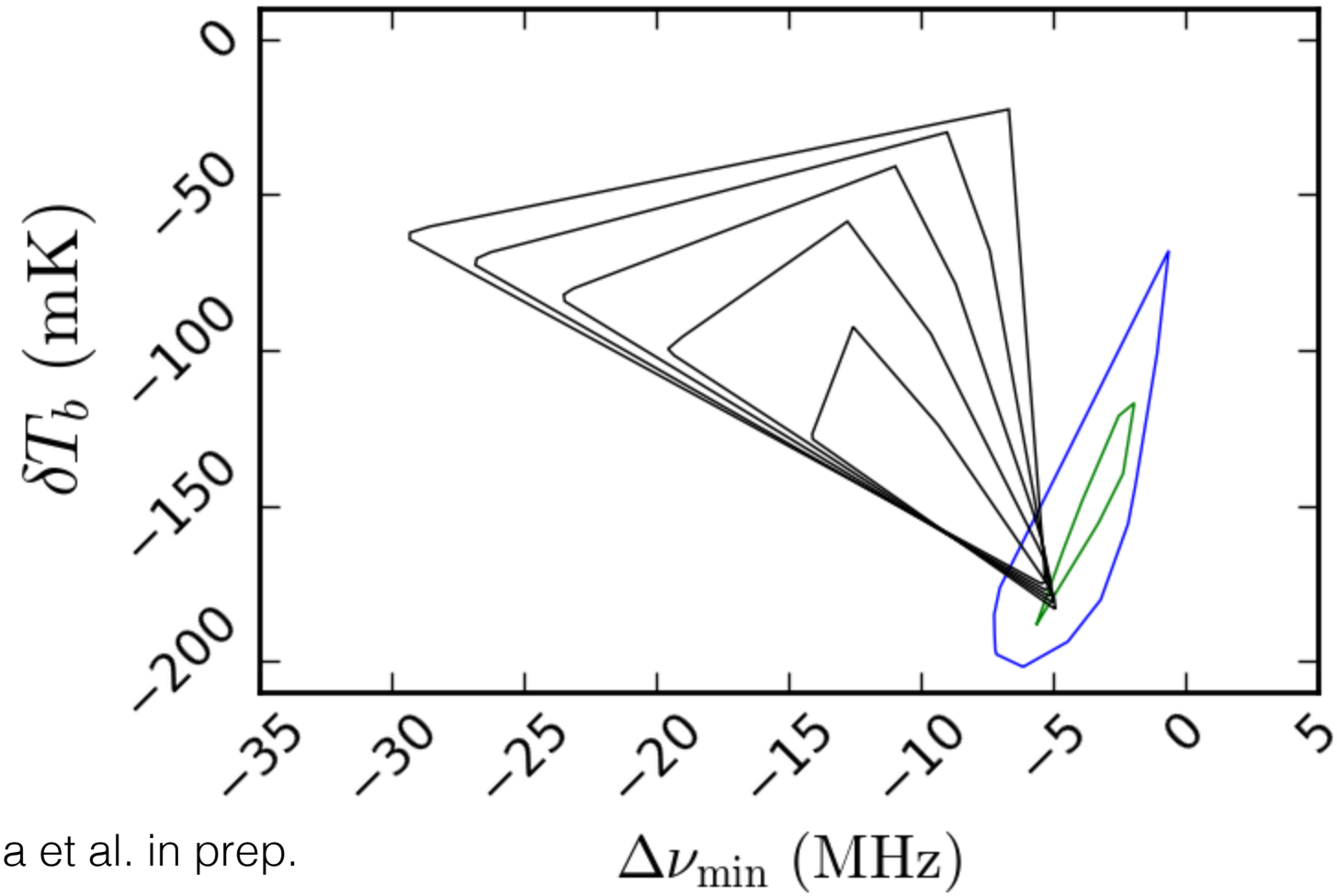
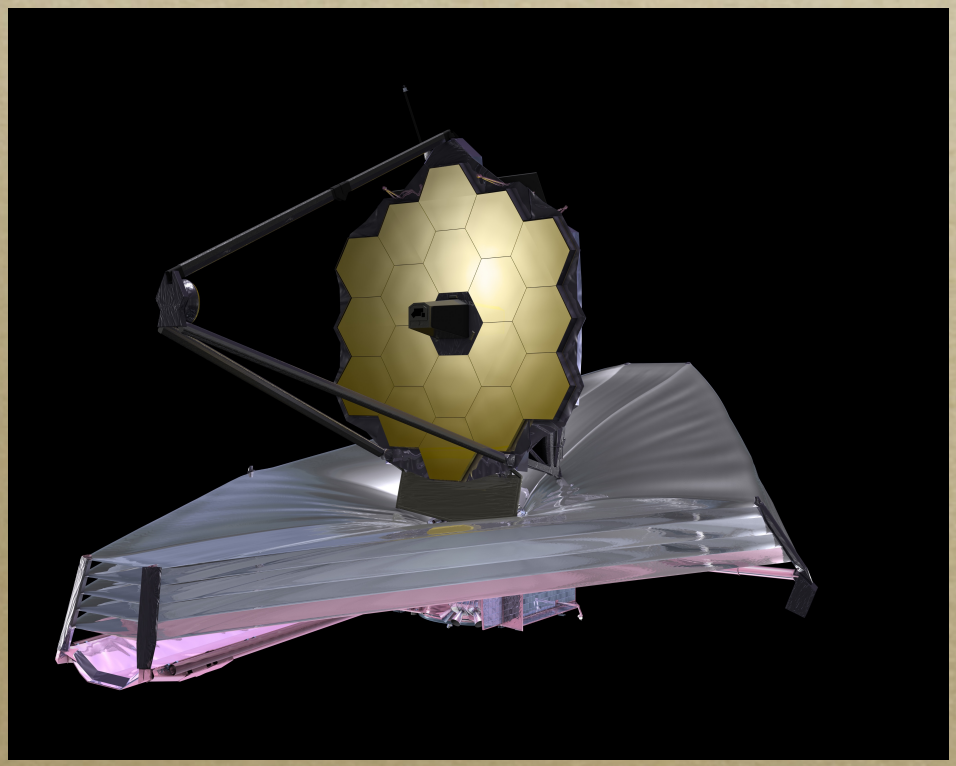


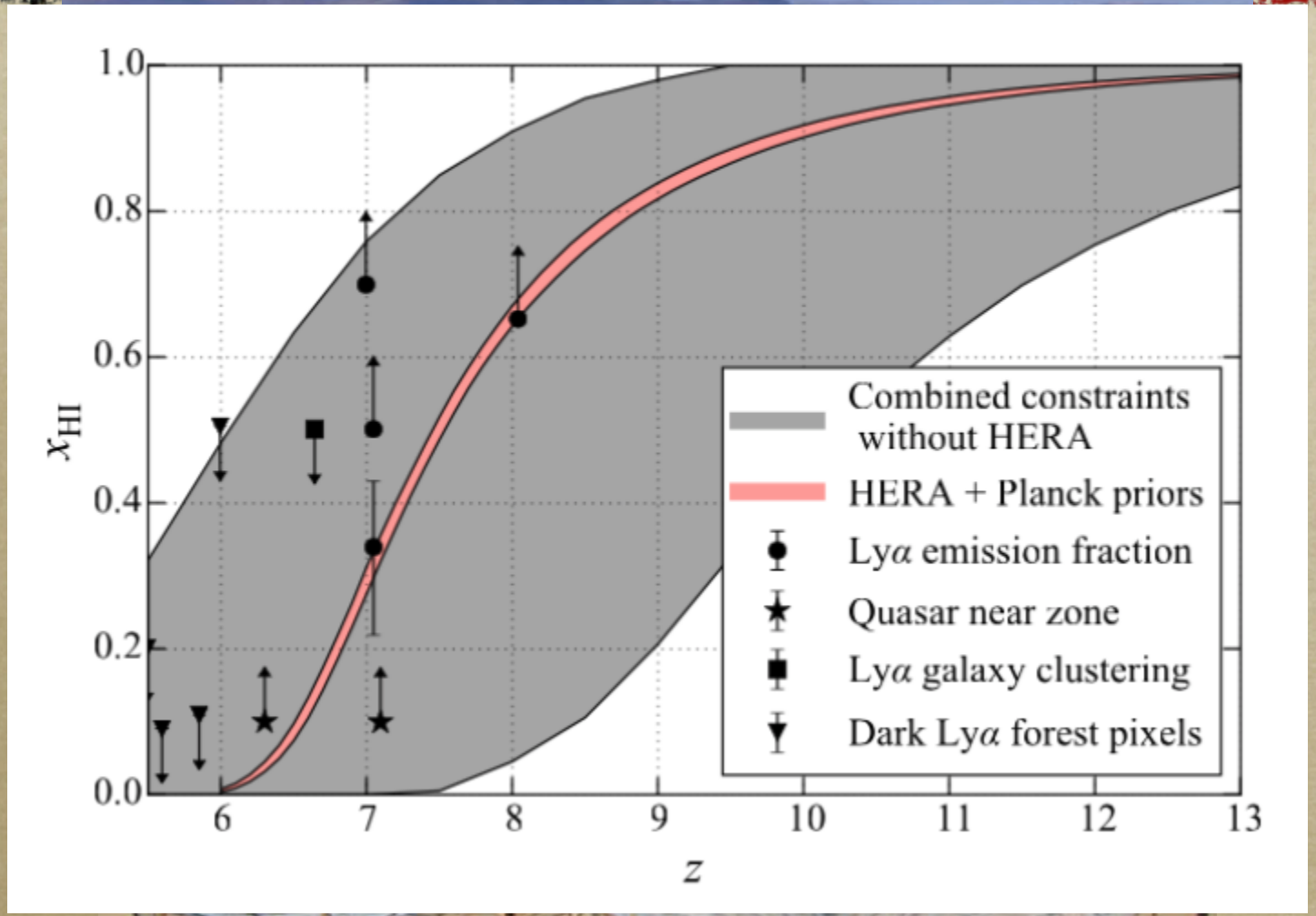

Mirocha et al. in prep.

# The 21-cm Signal and Future Instruments



- *Continuing improvement in galaxy observations*
  - *HST Frontier Fields*
  - *Quasar surveys*
  - *ALMA*
  - *JWST (2018+)*
  - *Thirty-meter class telescopes*
- *How do these inform spin-flip measurements, and vice versa?*

# The Hydrogen Epoch of Reionization Array




# Year 1 Plans - UCLA

- *Project #1: Complete models of Pop III star formation (Mebane)*
- *Project #2: Complete quantification of Pop III signatures in global signal (Mirocha)*
  - *Run through DARE pipeline for detectability estimate?*
- *Project #3: Combine global signal, interferometer, galaxy, and CMB constraints into one framework (Mirocha)*