

Insights into the First Stars from Low- Frequency Radio Observations:

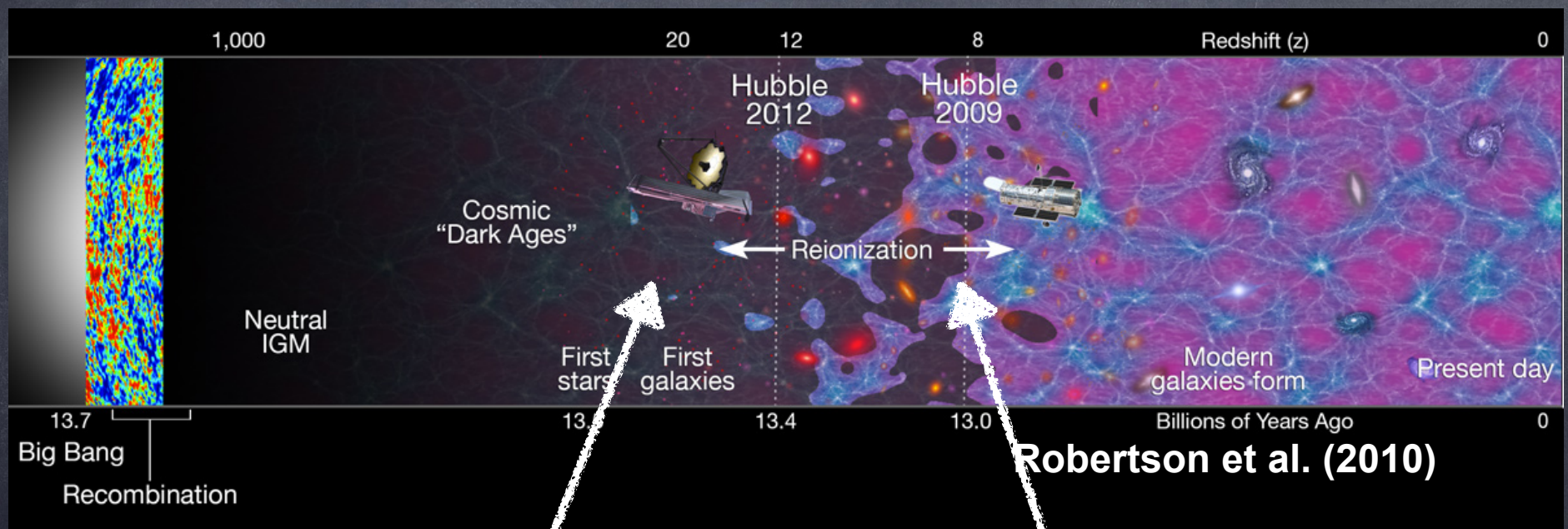
The Lunar Environment as an
Astrophysics Platform

Steve Furlanetto, Rick Mebane, and Jordan Mirocha
July 24, 2019

Outline

- The Cosmic Dawn and the 21-cm Signal
- The EDGES measurement: an example of new astrophysics
- The Moon as a next step

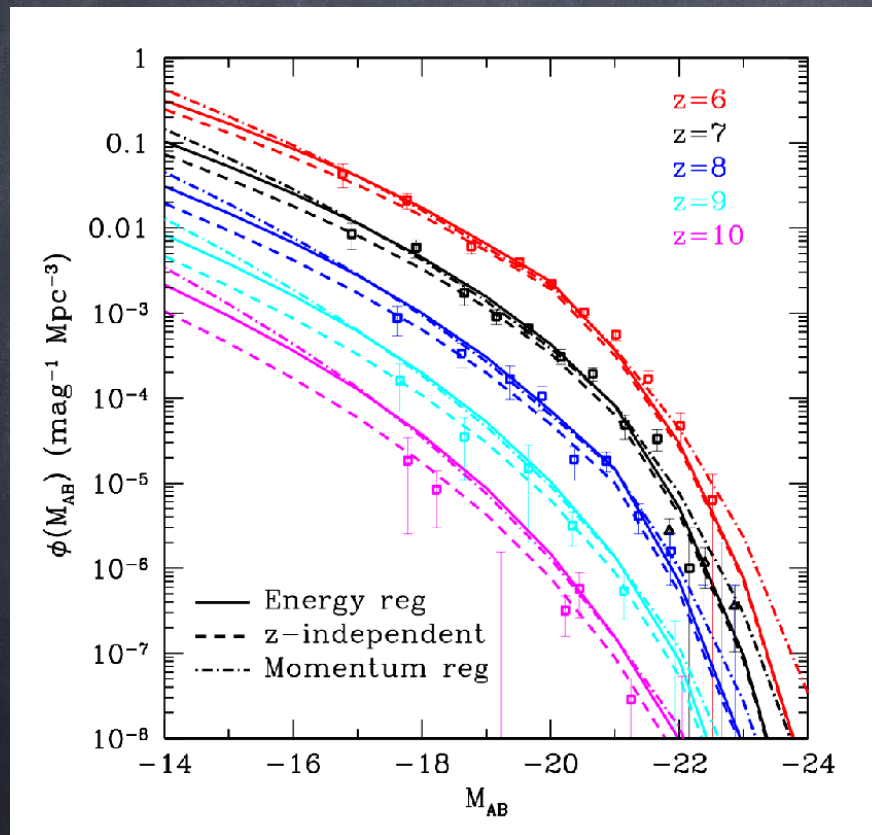
Some Context: The Cosmic Dawn and Reionization



"Cosmic Dawn"

Reionization

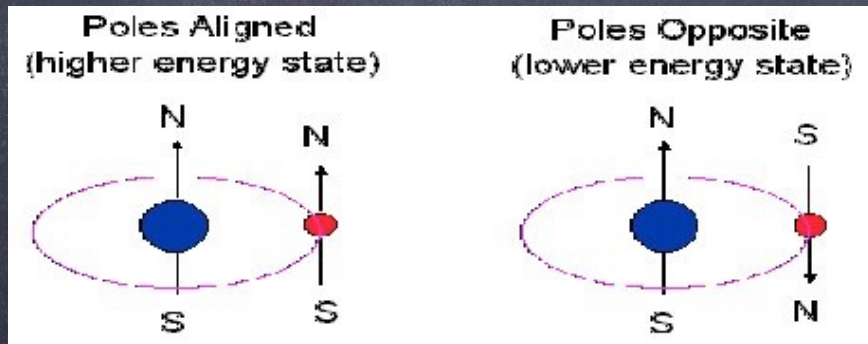
The State-of-the-Art: Galaxy Abundances



Furlanetto et al. (2017)

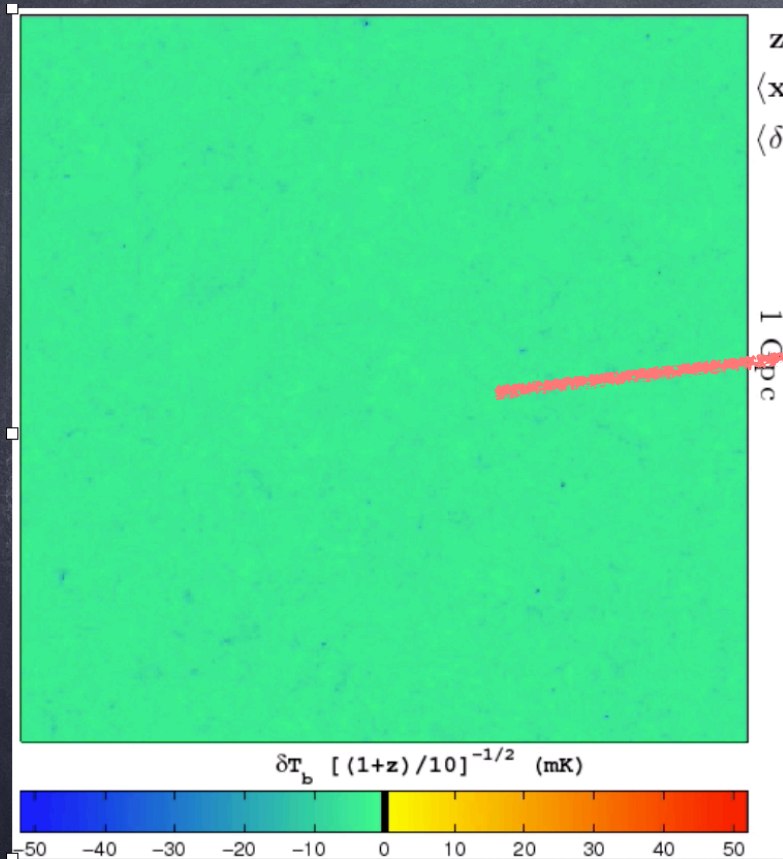
- Deep surveys have measured the bright end of the galaxy luminosity function with some precision to $z \sim 10$
 - Probes of fainter end are more controversial
- This observed LF has no particular surprises: simple galaxy models fit without any real trouble

The 21-cm/Spin-Flip Transition

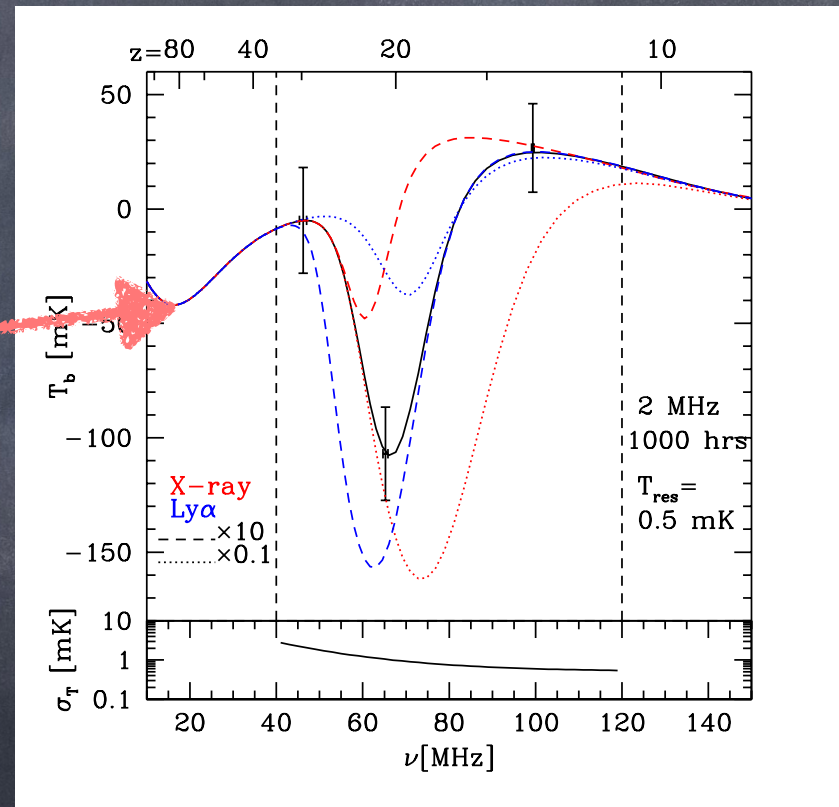


- Hyperfine transition of neutral hydrogen
- Rest wavelength = 21-cm BUT redshifted by $\sim 10x$!
- Rest frequency = 1420 MHz BUT observed frequencies 20-200 MHz

The 21-cm Signal

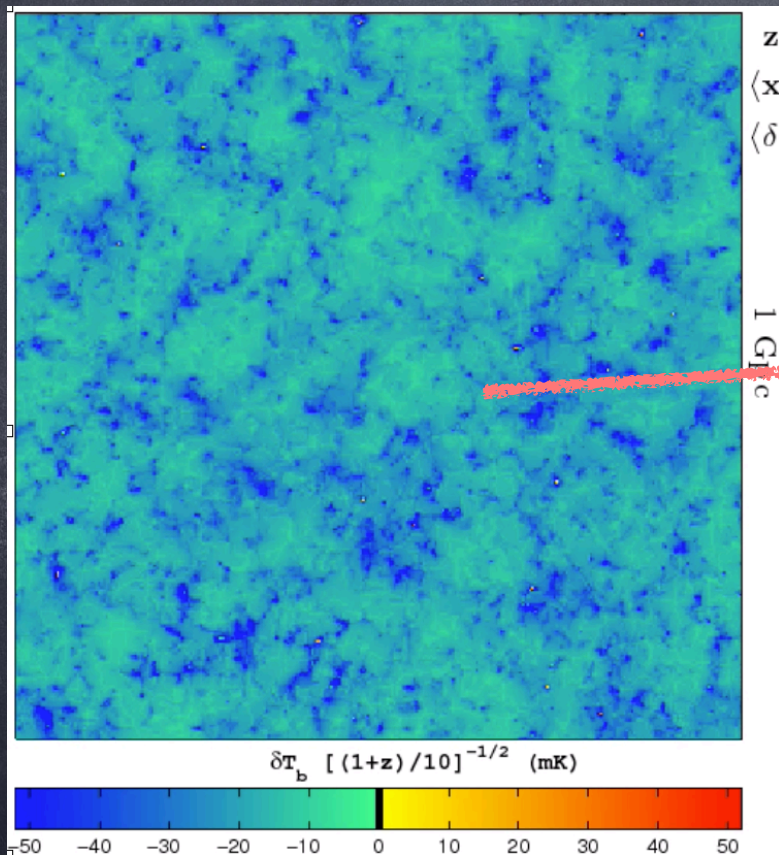


Mesinger, Furlanetto, & Cen (2011)

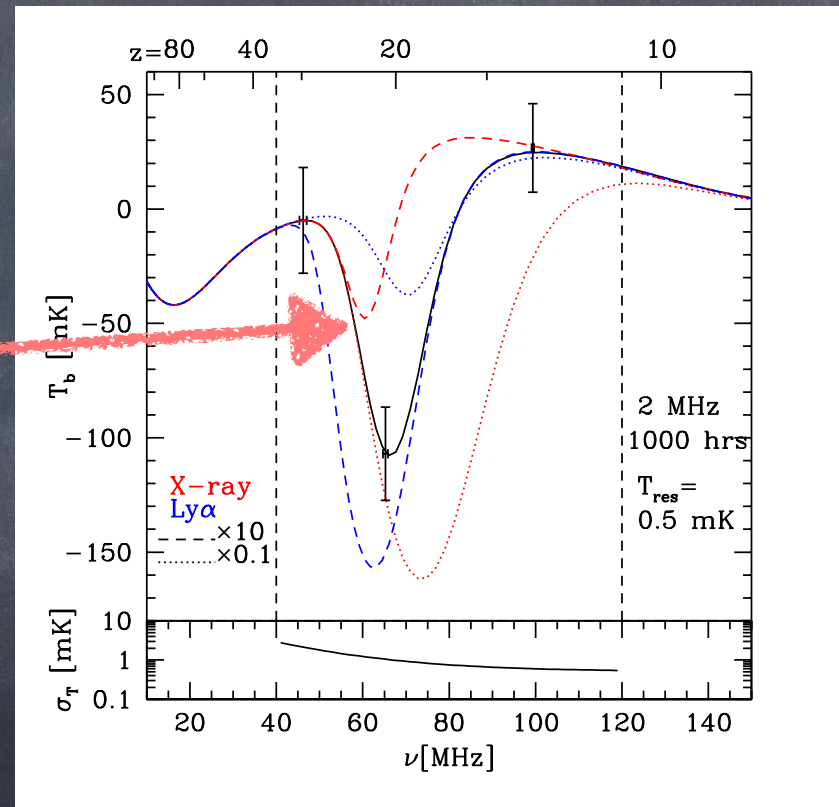


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The 21-cm Signal

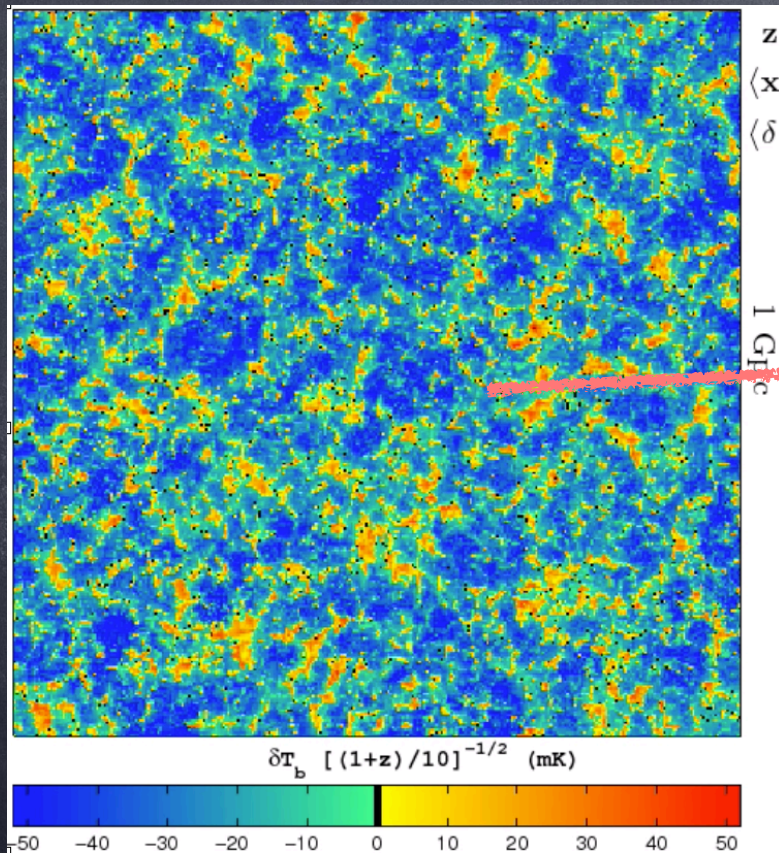


Mesinger, Furlanetto, & Cen (2011)

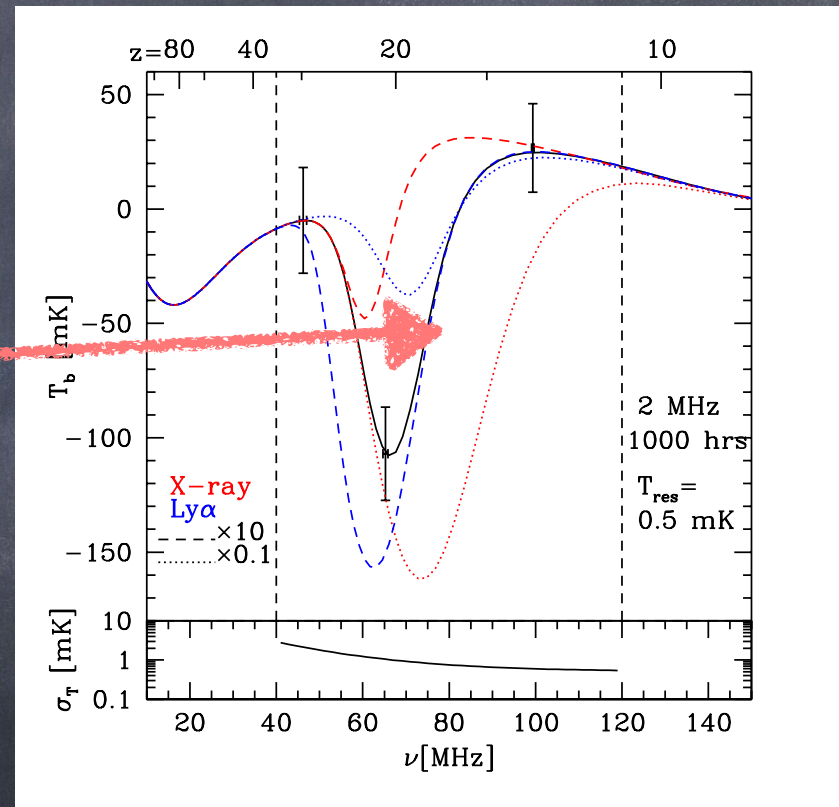


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The 21-cm Signal

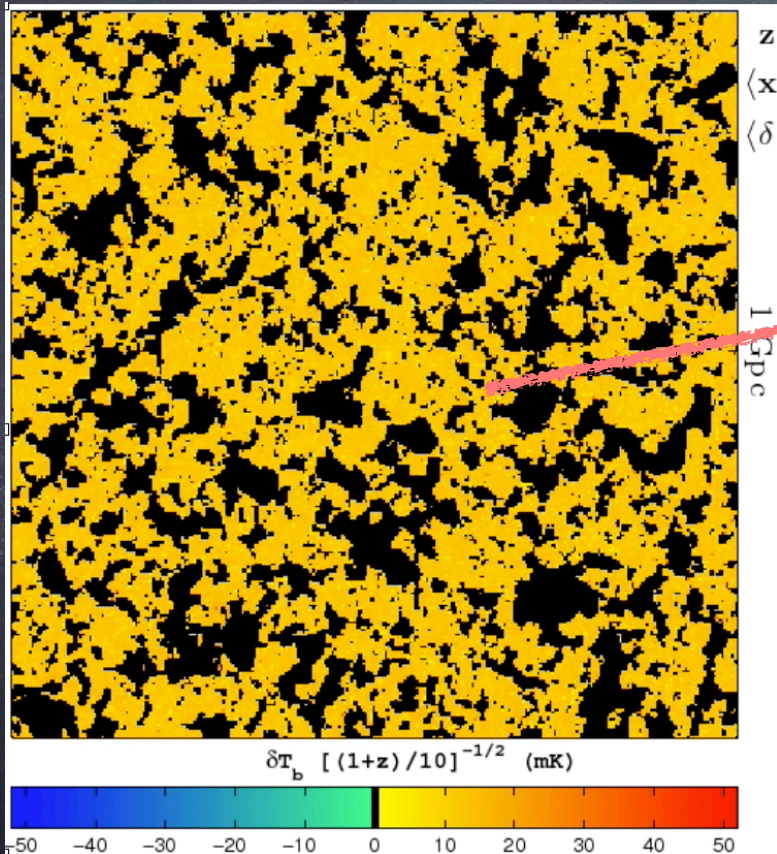


Mesinger, Furlanetto, & Cen (2011)

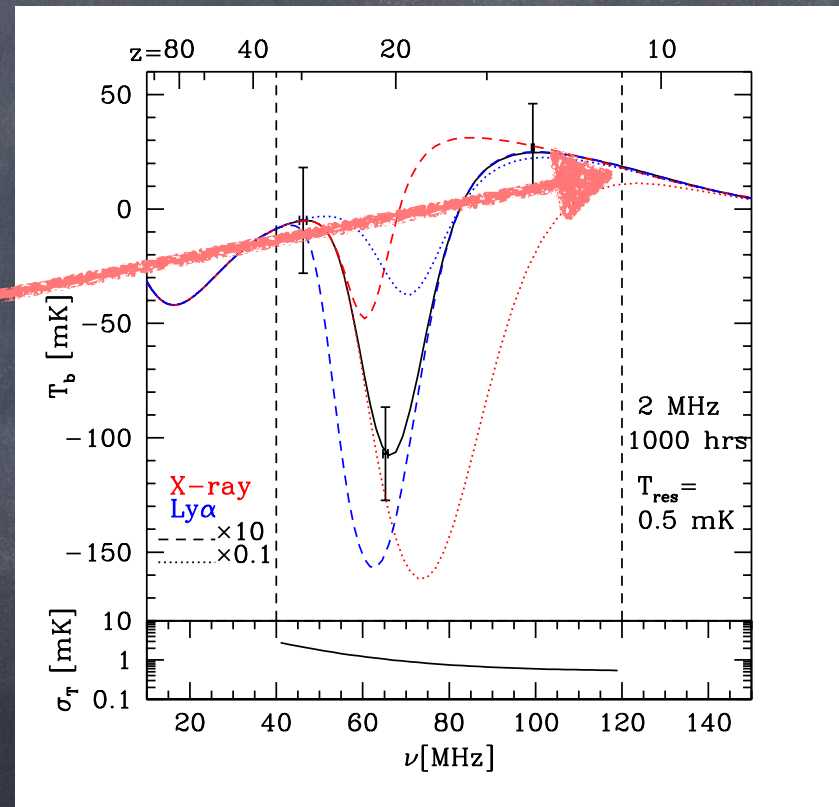


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The 21-cm Signal



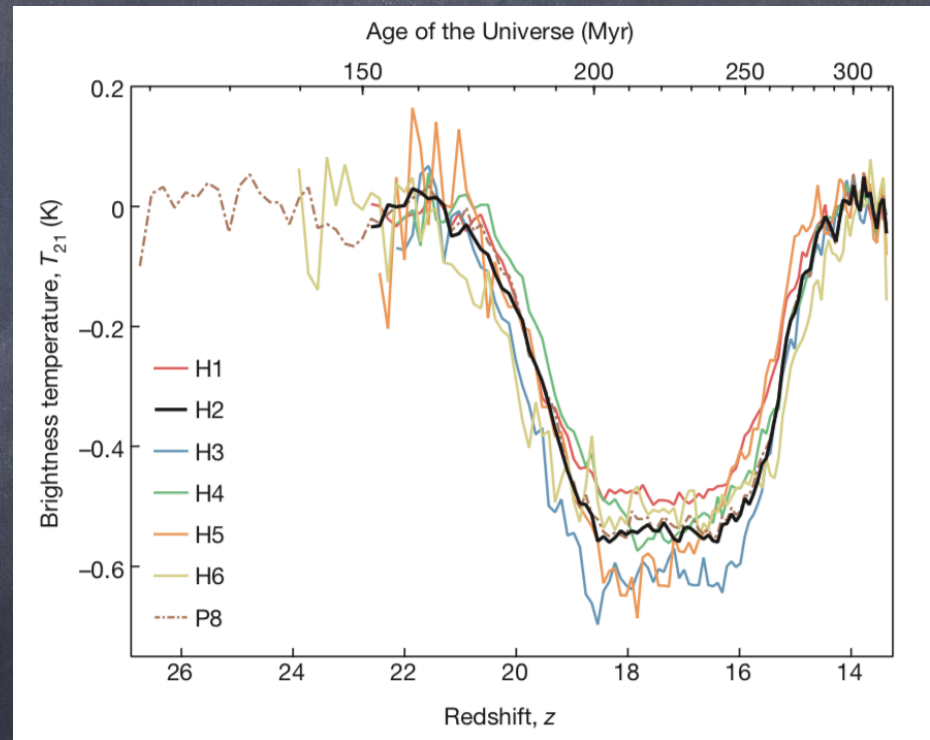
Mesinger, Furlanetto, & Cen (2011)



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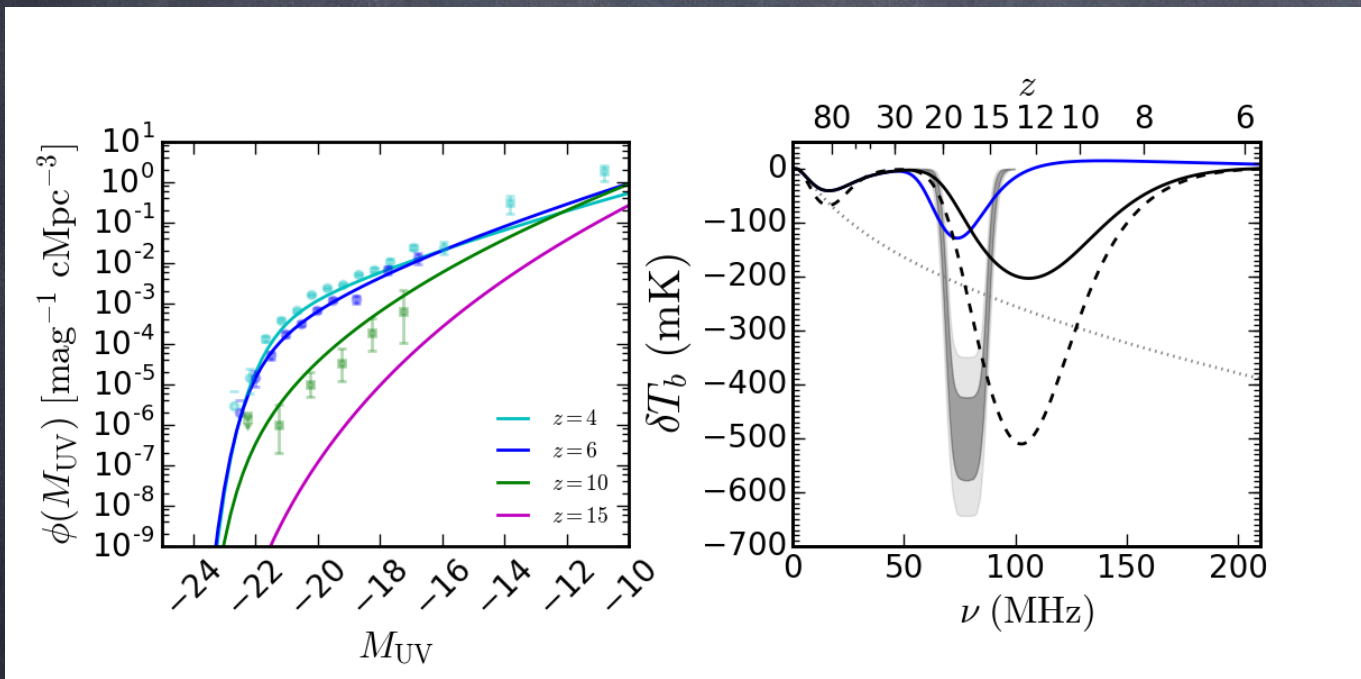
The EDGES Detection

- In Feb. 2018, Bowman et al. announced the first detection of the 21-cm signal!
- The claim is very controversial - but it is **AT LEAST** an example of what we can learn from the 21-cm signal



Bowman et al. (2018)

EDGES and Galaxies

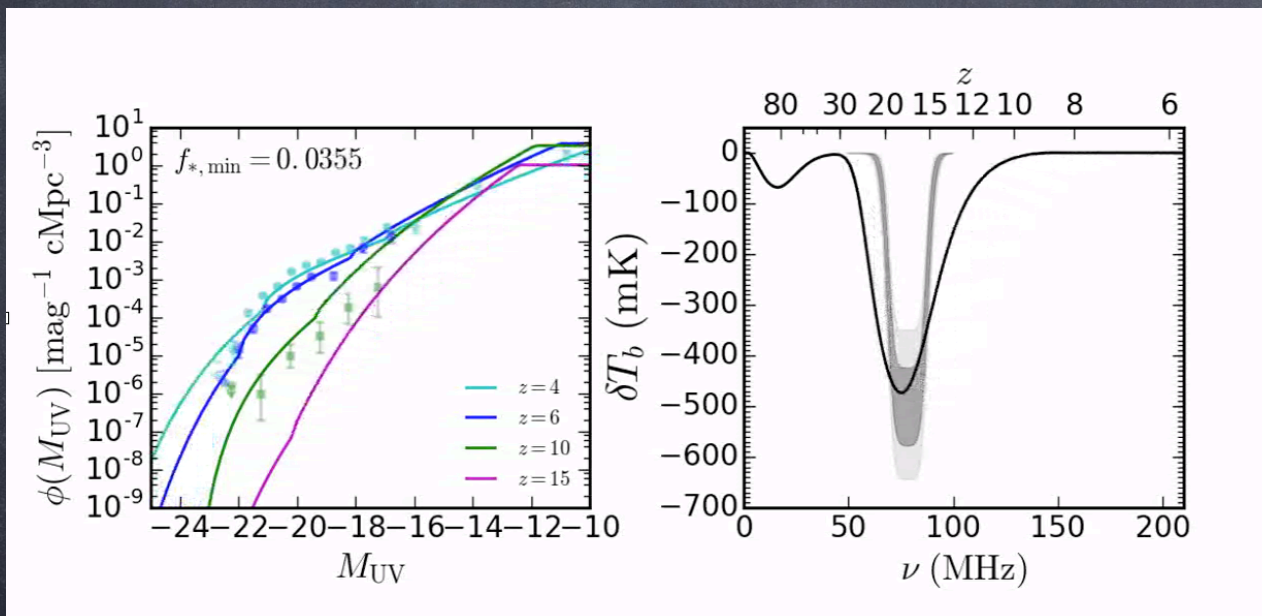


Mirocha & Furlanetto (2018)

With a "vanilla" calibration to UV LFs, EDGES signal is weird in three ways...

- Depth
- Shape
- Timing

EDGES and Galaxies



Mirocha & Furlanetto (2018)

- Timing is most important for galaxy formation
- Early signal requires EITHER
 - More efficient star formation at higher redshifts
 - More efficient star formation in (very) small halos
 - (Or both)

A Solution - The First Stars?

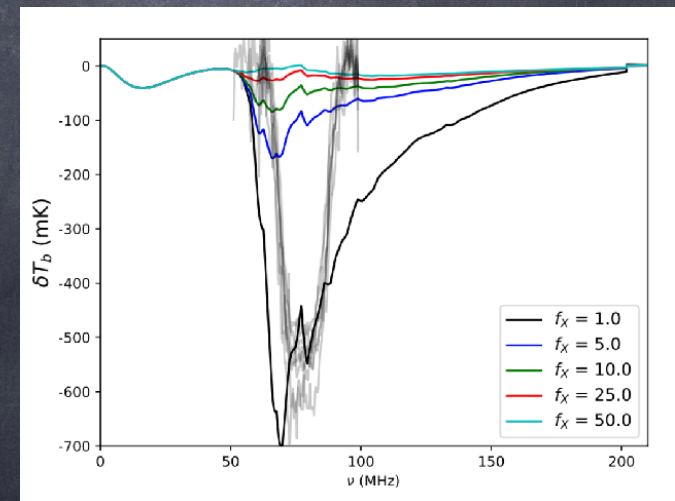
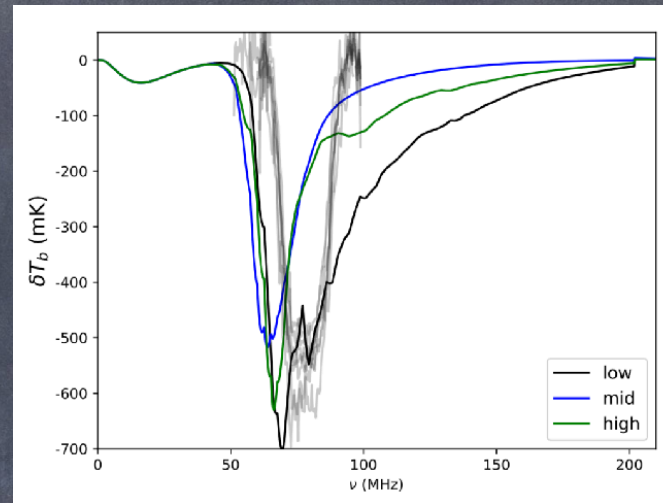
- The first "Population III" stars form in tiny dark matter clumps through an entirely different mode
- Transition to "normal" star formation as heavy elements form and halos grow
- Can these Pop III stars provide the extra UV background?



R. Hurt

A Solution - The First Stars?

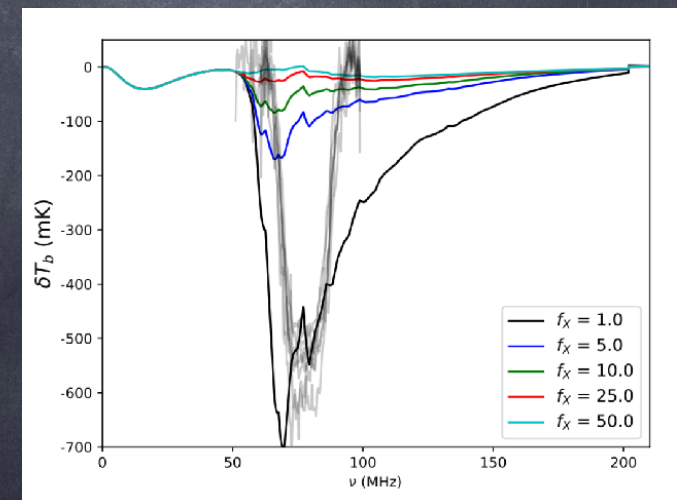
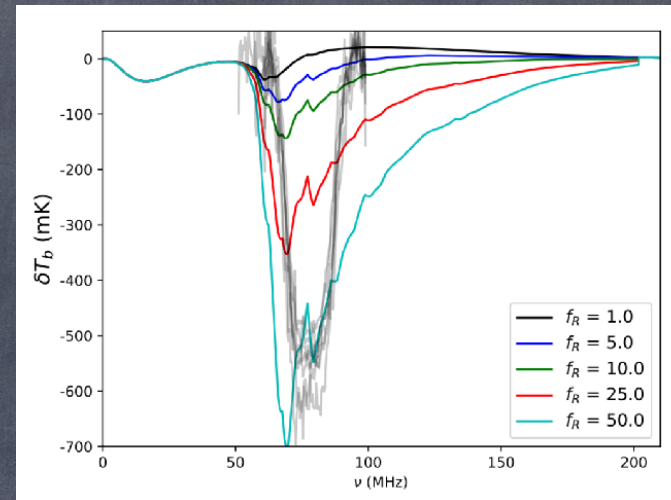
- Shown are a variety of Pop III models that all reproduce the rough timing of EDGES
- This provides a "natural" solution to the timing - but it is also not a guarantee!



Mebane et al. (in prep)

What about the amplitude?

- The biggest problem with EDGES: the huge amplitude
- Requires either:
 - Excess cooling of intergalactic gas (exotic physics - study with DAPPER!)
 - Excess radio background - either exotic physics or self-generated by these sources?
- An entirely Pop III solution is POSSIBLE but NOT EASY



Mebane et al. (in prep)

To the Moon!

- The Moon enables us to explore lower frequencies and obtain a purer signal
 - Use Dark Ages signal to separate exotic physics and astrophysics
 - And study the Cosmic Dawn signal with much cleaner systematics - the crucial step in the interpretation!
- DAPPER/DARE: study global frequency to very low frequencies (early times)
- FARSIDE and lunar arrays: begin to study fluctuations in signal - even richer in astrophysics

Summary

- The spin-flip signal is a powerful and complementary probe of the first generations of galaxies
- The recent EDGES detection provides the first evidence for a new kind of star formation in the Cosmic Dawn - and fits reasonably well with expectations for the first stars
- The Moon provides a powerful platform for turning these hints into detailed science!