Insights into the First Stars from Low-Frequency Radio Observations: The Lunar Environment as an Astrophysics Platform

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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

Robertson et al. (2010)
The State-of-the-Art: Galaxy Abundances

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

Furlanetto et al. (2017)
The 21-cm/Spin-Flip Transition

- Hyperfine transition of neutral hydrogen

- Rest wavelength = 21-cm BUT redshifted by ~10x!

- Rest frequency = 1420 MHz BUT observed frequencies 20-200 MHz
The 21-cm Signal

Mesinger, Furlanetto, & Cen (2011)
The 21-cm Signal

Mesinger, Furlanetto, & Cen (2011)

J. Pritchard
The 21-cm Signal

Mesinger, Furlanetto, & Cen (2011)
The 21-cm Signal

Mesinger, Furlanetto, & Cen (2011)
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

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

- Depth
- Shape
- Timing

Mirocha & Furlanetto (2018)
EDGES and Galaxies

- 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)

Mirocha & Furlanetto (2018)
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?
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!