A Crash Course In: The First Stars

- **When?** The first generations of stars – called Population III or Pop III - have not yet been observed, but they are believed to have formed ~50 million years after the Big Bang.

- **Where?** The first stars formed inside tiny dark matter clumps, about one million times smaller than the Milky Way. Because their clouds are so fragile, the radiation and supernovae from these stars likely dramatically disrupted the gas clouds.

- **How?** These stars formed from differently than nearby stars, through clouds of molecular hydrogen without heavy elements. As a result, they were likely 10-100 times more massive than the Sun.

- **How long?** When these stars died, they produced heavy elements that changed the mode of star formation. Eventually, their sites transformed into normal Pop II star-forming galaxies.

- **What was left?** Because they were so massive, many of these stars may have left remnant black holes, which could then accrete gas from their surroundings and produce X-ray photons.

The Dark Ages Radio Explorer (DARE), a radio telescope in lunar orbit, is a proposed mission that could observe this signal. The NESS team is also exploring concepts for a radio array on the lunar farside.

A Crash Course In: The Spin-Flip Background

- **Origin:** The spin-flip, or 21-cm, background is generated by the hyperfine transition of neutral hydrogen, which makes up more than 90% of the baryonic matter in the Universe during the epoch of the first stars. When ultraviolet light from the first stars illuminates this hydrogen, the spin-flip signal can be seen in absorption against the cosmic microwave background (which pervades the Universe). Once X-rays from the first black holes heat the matter, the signal transforms into emission, and it vanishes only when the hydrogen is reionized by later generations of stars.

- **Observations:** The hyperfine transition produces photons with wavelengths of 21 cm, which then redshift as they travel through the expanding universe. Today, they are observable at low radio frequencies (40-200 MHz).

The First Stars and the Spin-Flip Background

At left, we show examples of the spin-flip background in our models. The gray curves show examples that ignore Pop III star formation entirely. The green curves include them, with a range of star formation efficiencies (top to bottom panels) and X-ray heating efficiencies (green bands). The addition of Pop III stars does not dramatically shift the extrema of the signals but does affect their shapes.

At right, we show these sets of models in a space defined by two custom statistics: W characterizes the width of the trough relative to its height, while A characterizes its asymmetry. Even when Pop III stars are rare, shape signatures provide a unique, robust way to distinguish them.

Lunar radio telescopes can probe the otherwise unobservable first stars in the universe by measuring the shape of the spin-flip background spectrum.

**REFERENCES**


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