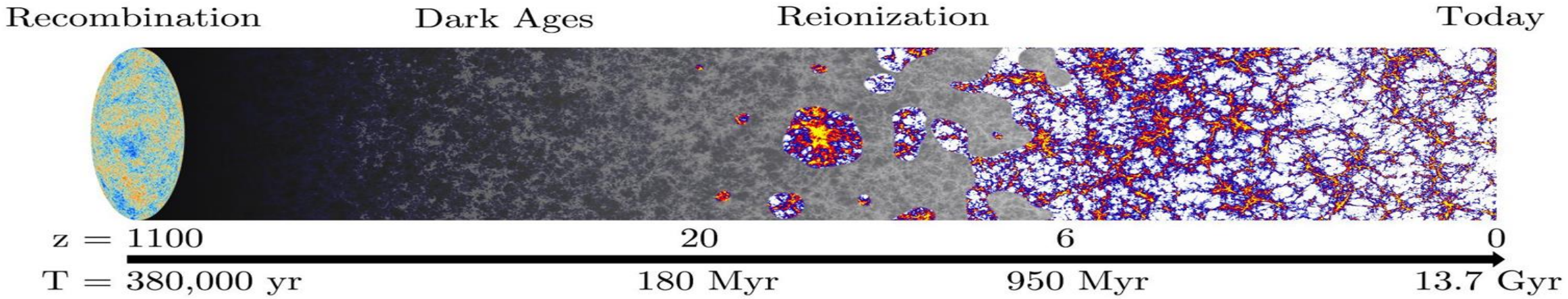
The Cosmic Twilight Polarimeter

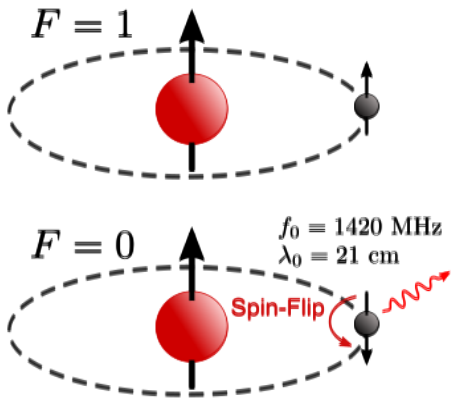
David Bordenave[1,2], Bang Nhan[2], Alec Handy[2], Rich Bradley[2], Jack Burns[3]

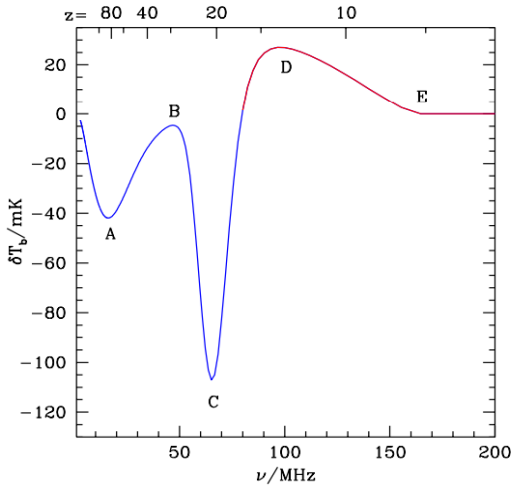
[1] University of Virginia, [2] National Radio Astronomy Observatory, [3] University of Colorado, Boulder

NESS Site Visit 2020

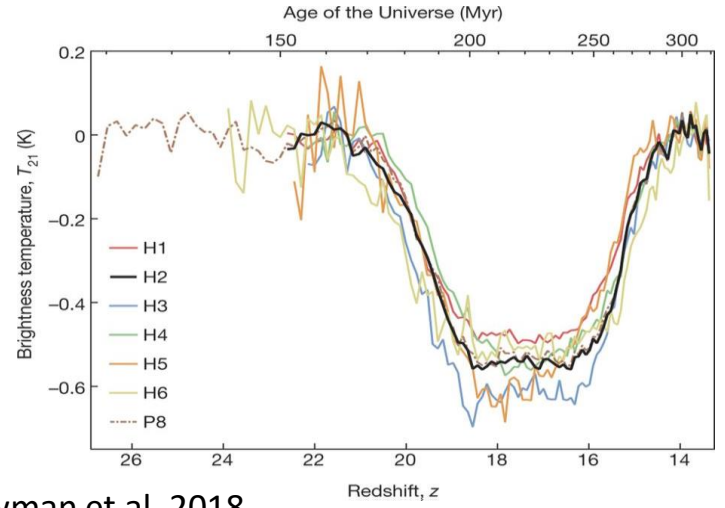
Origin of the Cosmological 21-cm Signal







Harker et al. 2011



Bowman et al. 2018

Key Challenges

- Signal Extraction
  - Galactic Foreground that is 4-6 orders of magnitudes brighter than signal
  - Instrumental and observational systematics
- Antenna
  - Beam Chromaticity
  - Large near-field significantly couples antenna to local environment (e.g. soil)
  - Difficult to measure and characterize in situ
- Environment
  - Terrestrial Radio Interference (RFI)
  - Ionospheric effects: emission, absorption, refraction, and cut-off at low frequencies

What is Induced Polarization?

- It is an artifact of the detector (Polarization leakage) that allows unpolarized light to leak into polarized components and vice versa
- This effect is purely instrumental and is due to the projection of off-boresight sources onto the detector
- We can determine how any arbitrary optical system transforms incoming polarized light with the Mueller matrix (see figure)

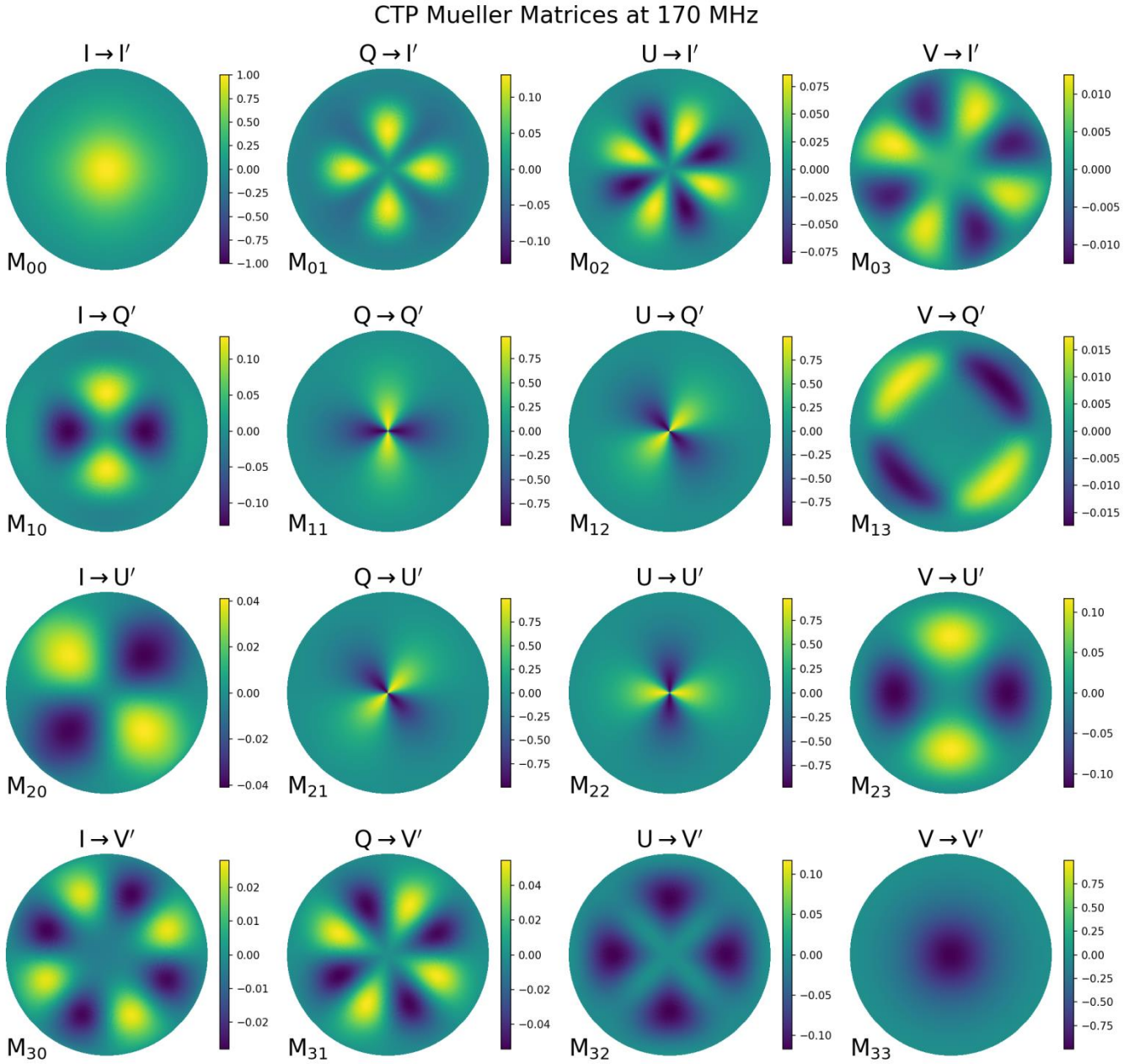
Antenna Jones matrix from EM simulation

$$\mathbf{M}=\mathbf{T}\left(\mathbf{J}\otimes\mathbf{J}^{*}\right)\mathbf{T}^{-1}$$

$$\vec{\mathbf{S}}'=\mathbf{M}\,\vec{\mathbf{S}}$$

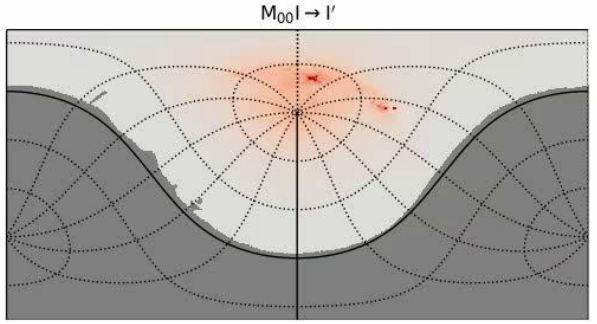
Obs. Stokes vector

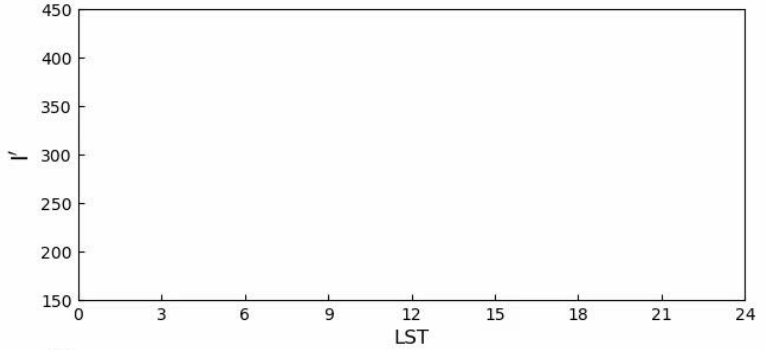
Input Stokes vector

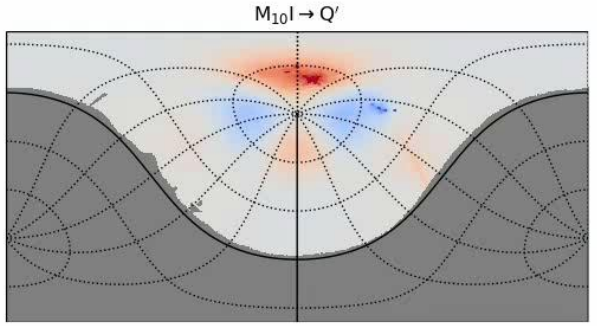


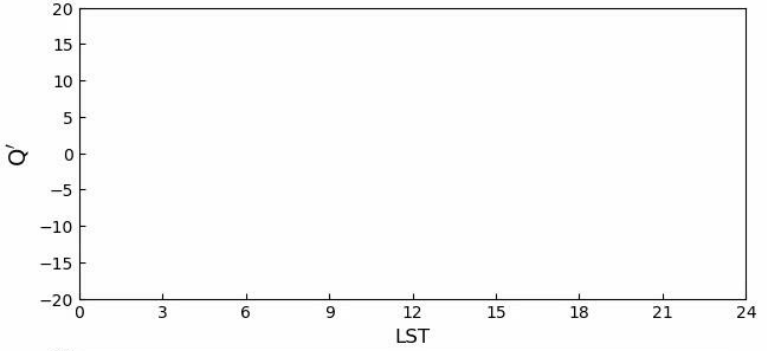
An Illustrated Example

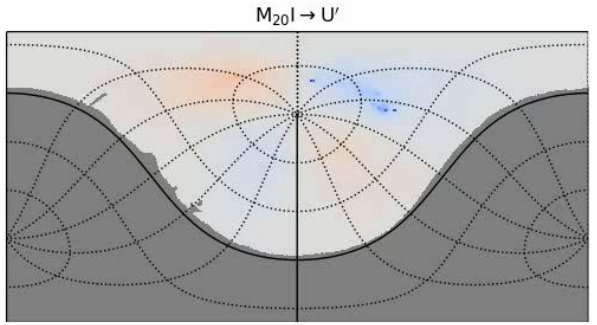
- Anisotropies and large scale structures in the foreground sky can excite polarization modes via the antenna polarization leakage
- Through rotations of the antenna and drift scans the polarization signal will be modulated offering more spatial information of the system can be gained through conventional observations.

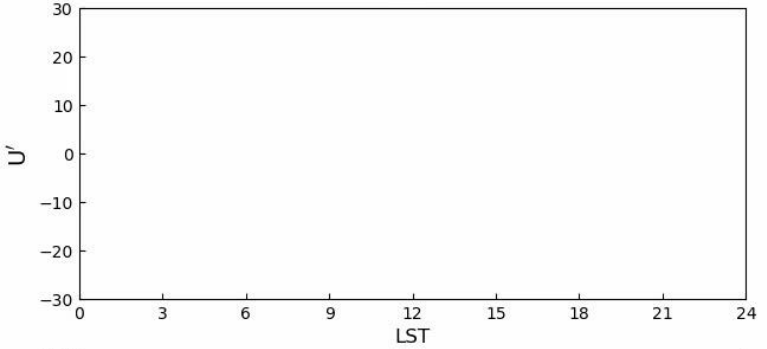


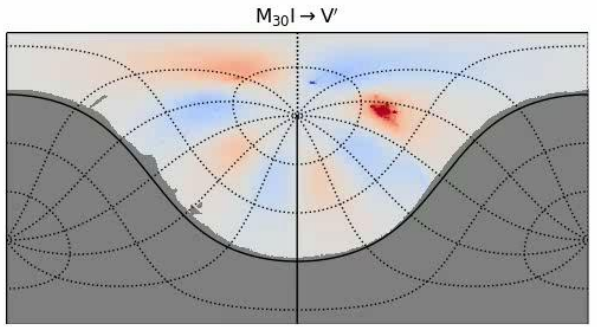


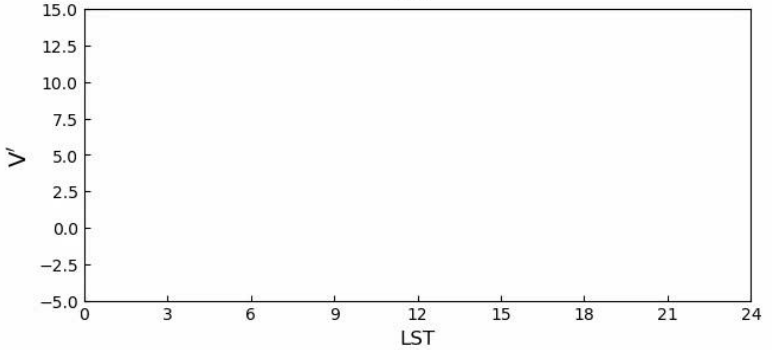








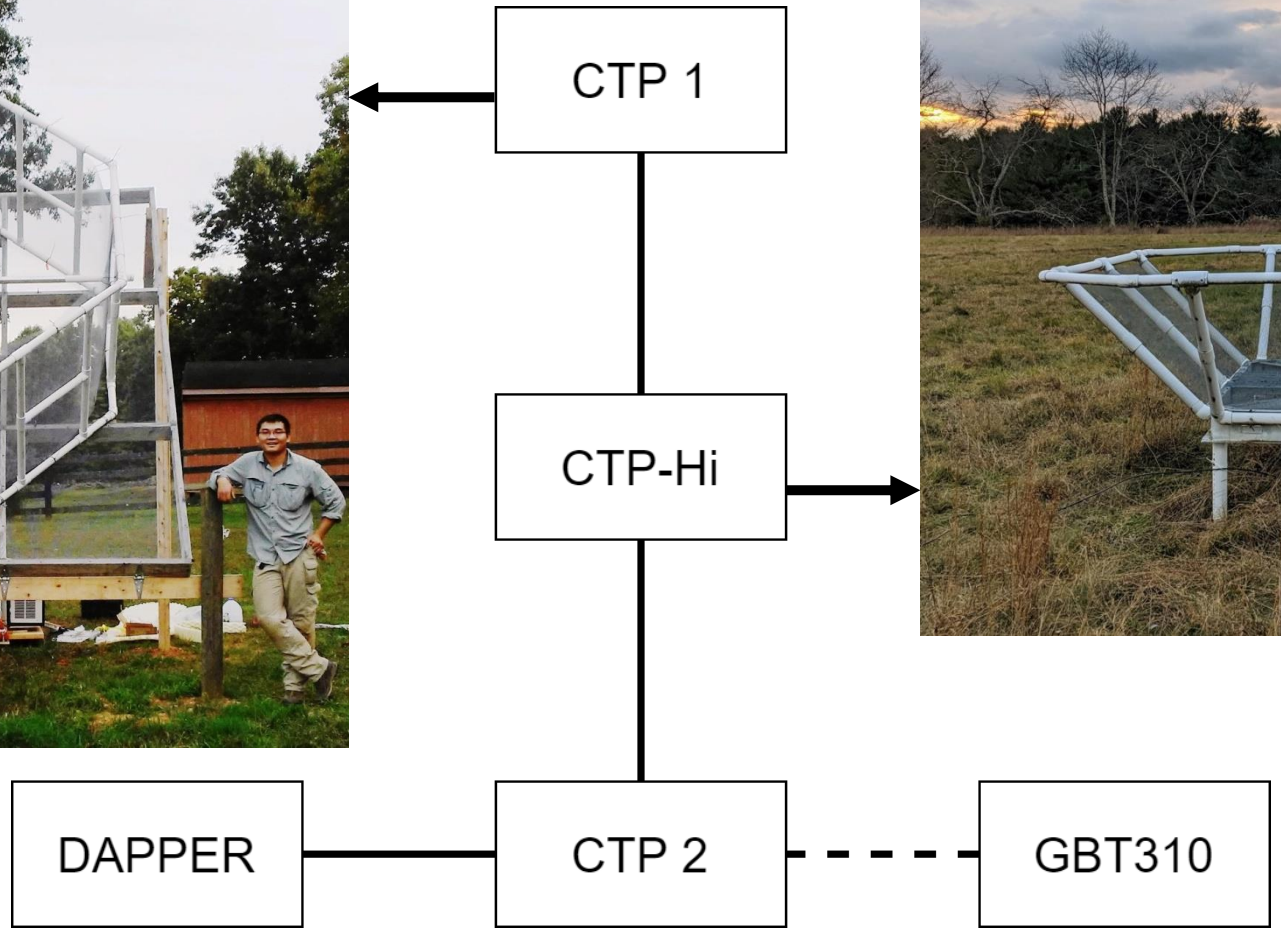




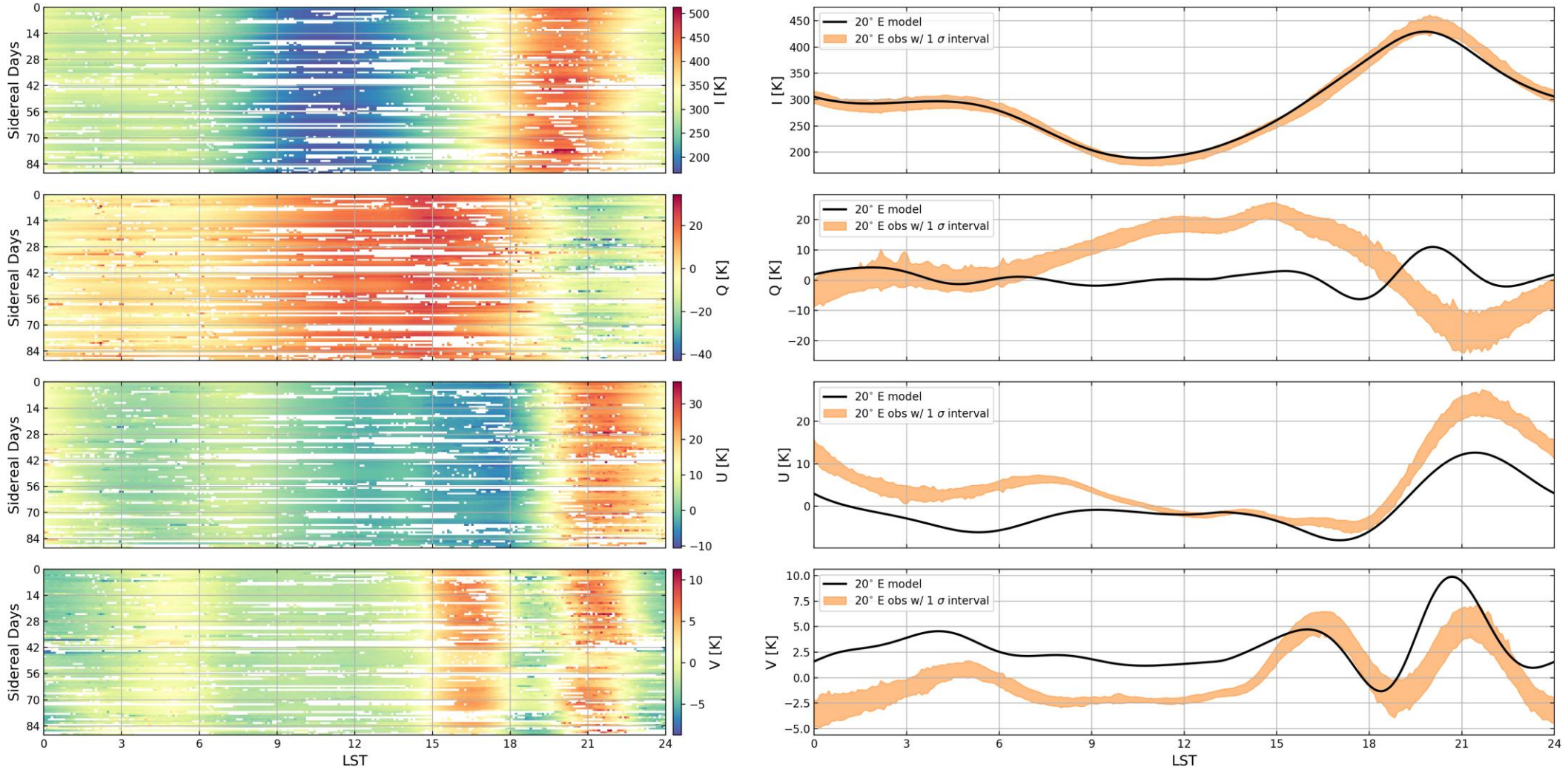
Lineage of the CTP

Fall 2017
Central Virginia

Fall 2019
Green Bank, WV



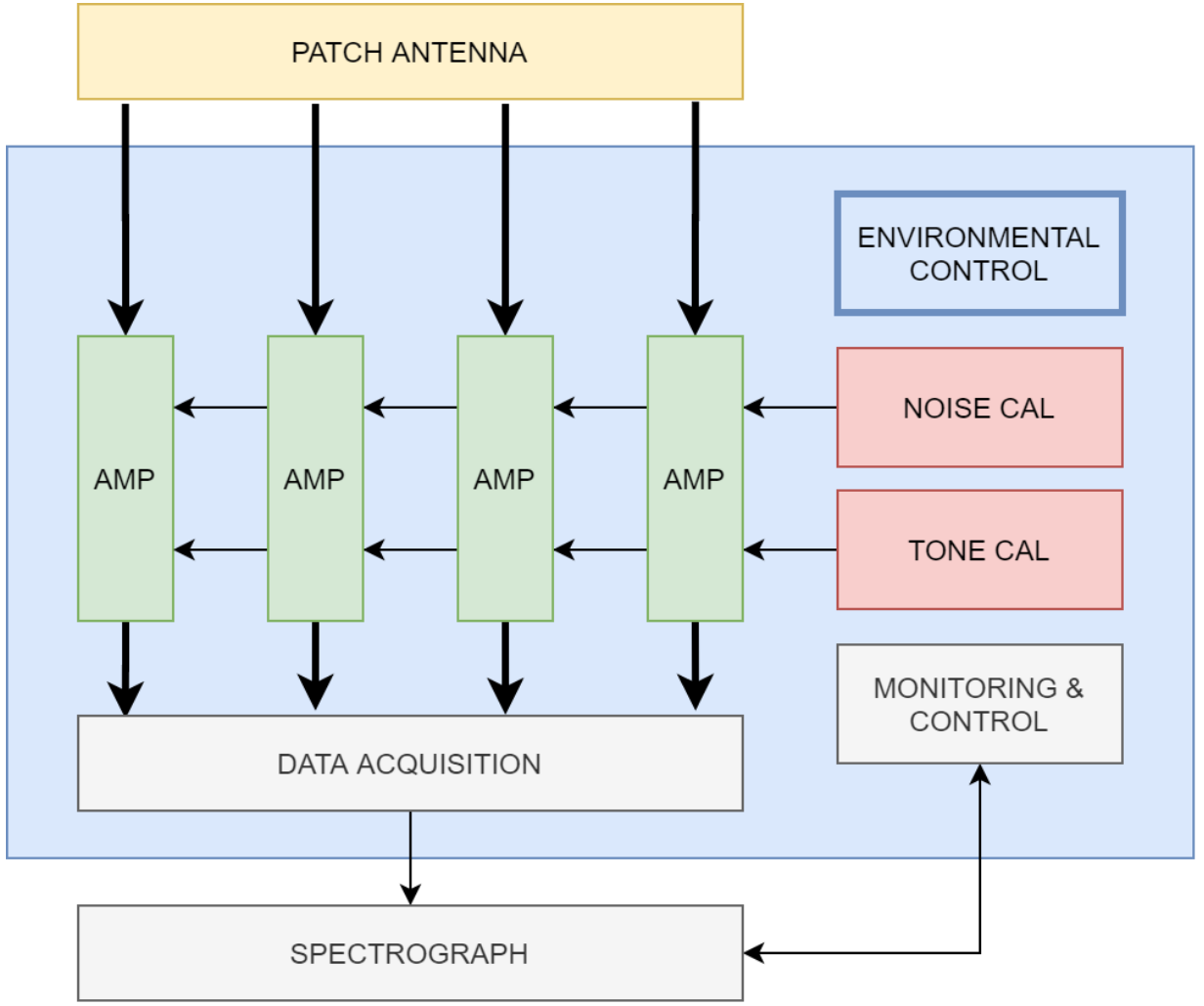
Recent Results: CTP-Hi at 170 MHz



The CTP2 Balanced Correlation Receiver

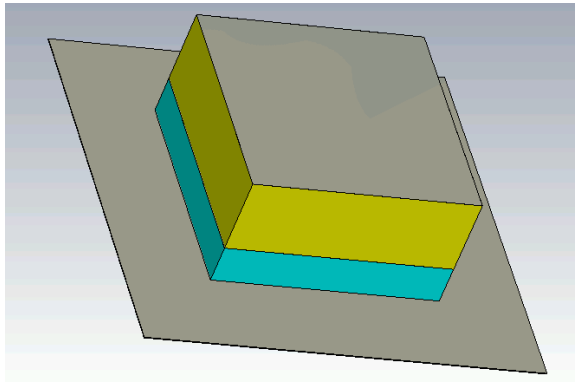
CTP2 will test many new methods and technologies relevant to ground and space based instruments

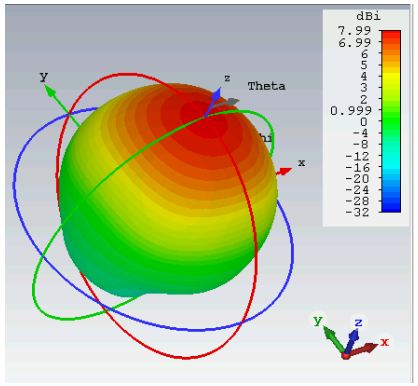
- A broadband ***patch antenna***
- A new ***balanced correlation receiver*** architecture
- ***Tone calibration***
- Use of ***physical circuit modeling*** in calibration process



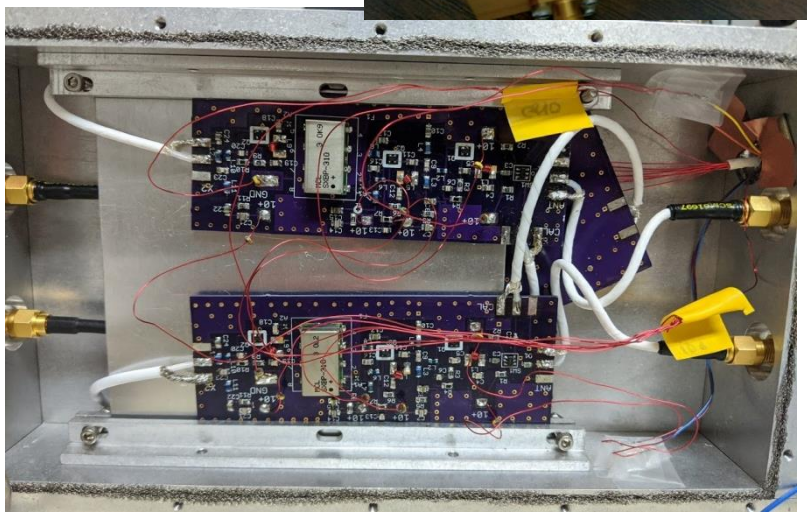
Ongoing Instrument Development

Patch Antenna Modeling

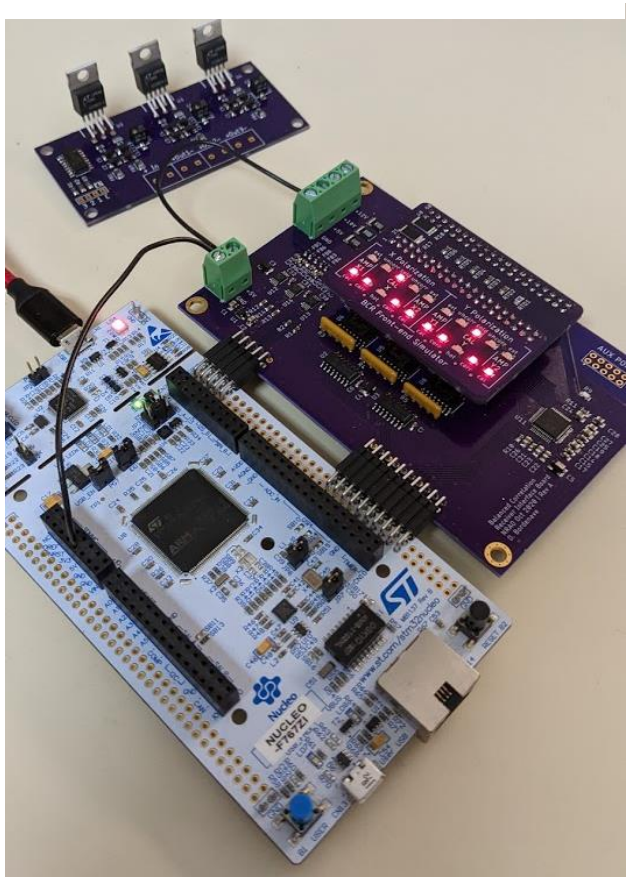




Prototype amplifier and noise calibration boards



Prototype Monitoring and Control boards



Summary

The Cosmic Twilight Polarimeter will be both a full fledged ground based global 21cm experiment and engineering prototype for the ***Dark Ages Polarimeter Pathfinder*** (**DAPPER**) space mission

- Recent observations of **dynamically induced polarization** show promising results
- We are developing several key technologies for the **DAPPER** instrument
- Planned deployment to Green Bank, WV during summer 2021