EDGES Recombination Line Foregrounds

3rd Global 21cm Workshop

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Motivation

- Are C and H RRLs at high Galactic latitudes a foreground for 21cm power spectrum measurements (MWA, HERA, LOFAR)?
  - RRLs are bright on the Galactic plane
  - Observed also in nebulae
  - But how bright in diffuse ISM off the plane? Poorly quantified at high galactic latitudes.
- Also provides an opportunity to check EDGES systematics with faint (narrow-band) signals

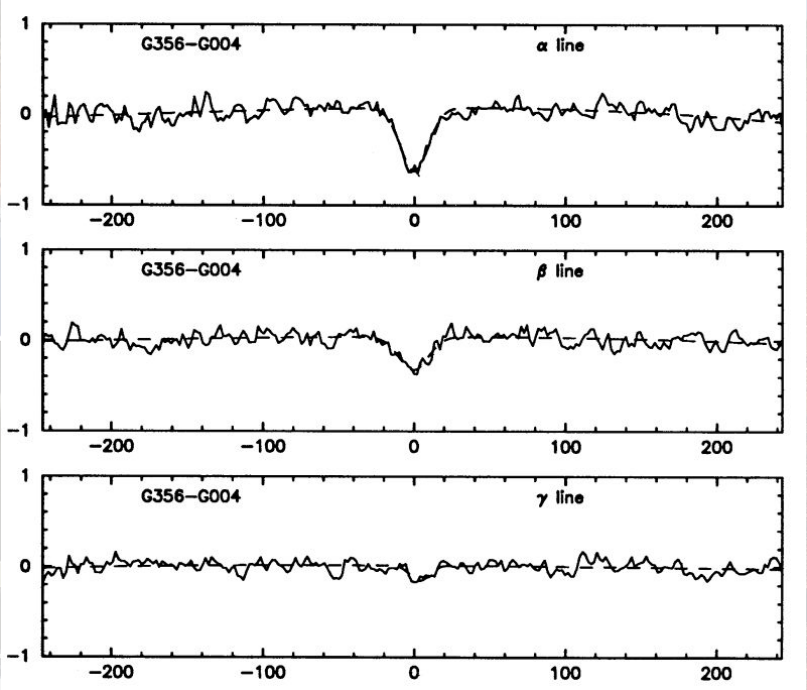
Motivation

- We can use EDGES to place an upper limit
- Simply flagging RRL freqs may interfere with power spectra
- Seek to determine strength, see if flags needed for power spectra

Plan: We will use EDGES drift scan to see RRL amplitude averaged over EDGES large beam at all LSTs

Recombination Lines

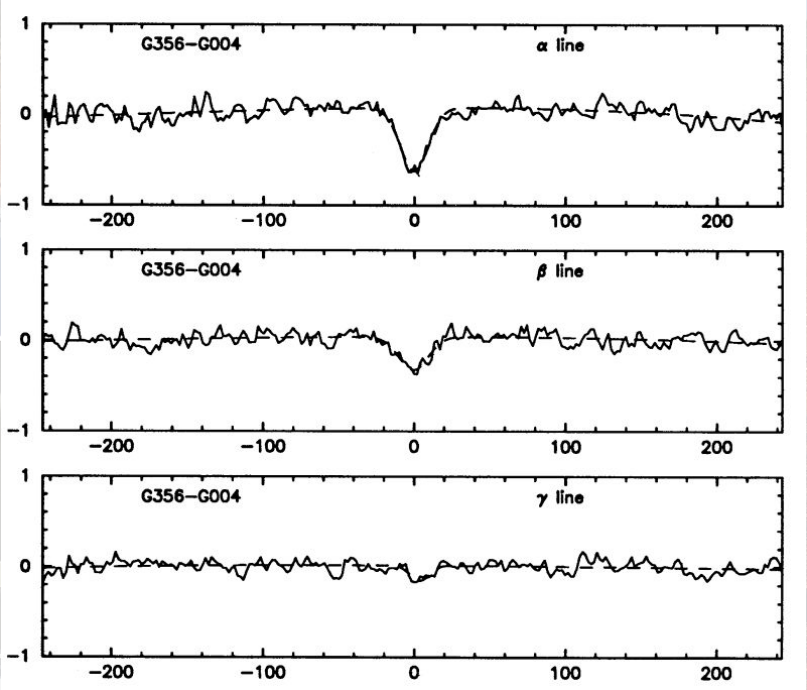
- Created by change in electron energy level
- C found in ionized CII regions,
- Carbon expected in absorption below 115 MHz
- Hydrogen expected in emission from 50-200 MHz
- Low-Frequency “Diffuse” RRLs typically from diffuse neutral ISM
    - Coexist to cold, diffuse HI regions



Above: Alpha, Beta, and gamma carbon RRL profiles seen near Galactic center.
Erickson et al 1995

Recombination Lines

- C amplitude typically 0.1% of background brightness (in absorption)
- Line depth depends on electron temperature Te, density ne
- CO maps can act as a tracer for molecular clouds, and therefore possible CII regions
- HI maps trace neutral hydrogen



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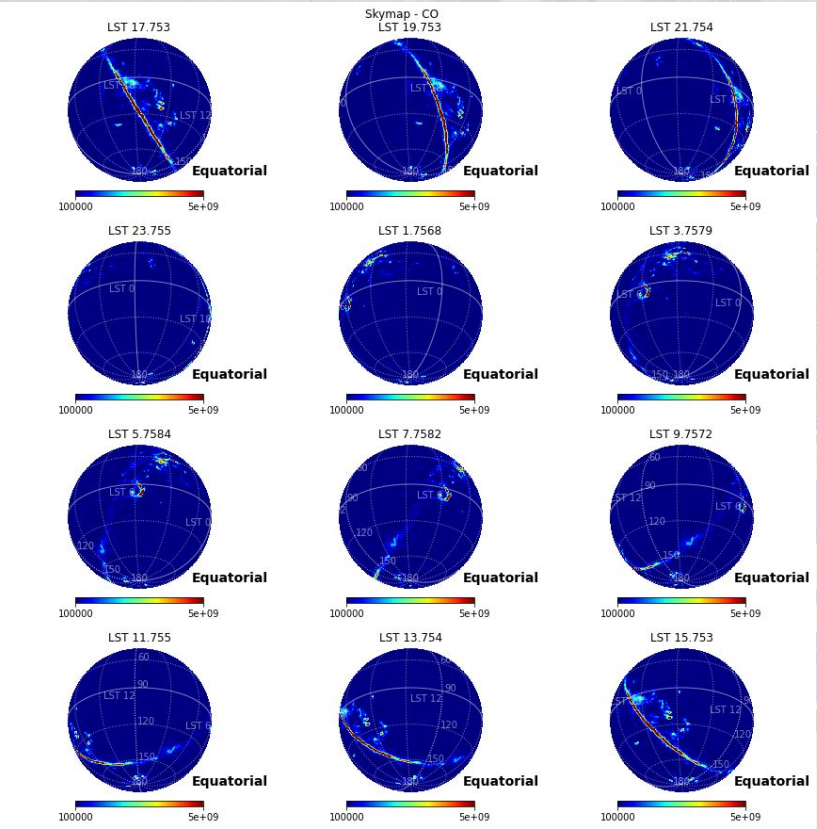
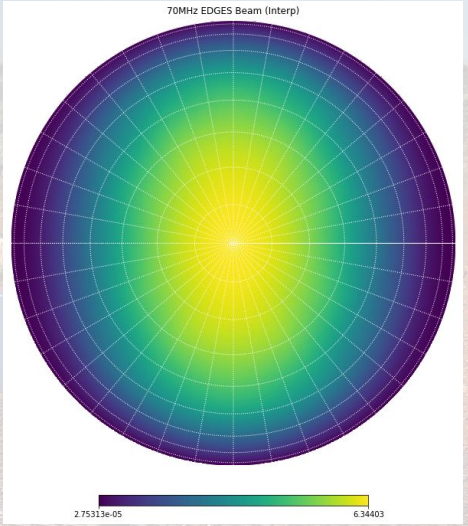
CO and 21cm as a proxy for gas

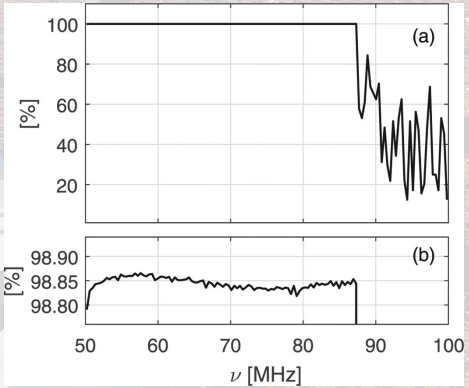


- CO common in molecular clouds (H_2), excitation occurs on borders of clouds and diffuse ISM regions
- For CO data we use the PLANCK 2015 CO Map
- 21cm traces HI regions, where CII can be found diffused within
- For 21cm data we use the HI4PI Sky Survey

Data

- EDGES Low-1 (50-100 MHz)
- 384 Days spanning October 2015 to April 2017
- Beam @ 78 MHz: 71deg NS 108deg EW
- 32768 Channels, 6.1kHz spacing
  - Effective resolution 12.2kHz due to B-H window function
- Ignoring FM band, only analyzing 50-87 MHz
- Very little RFI in band



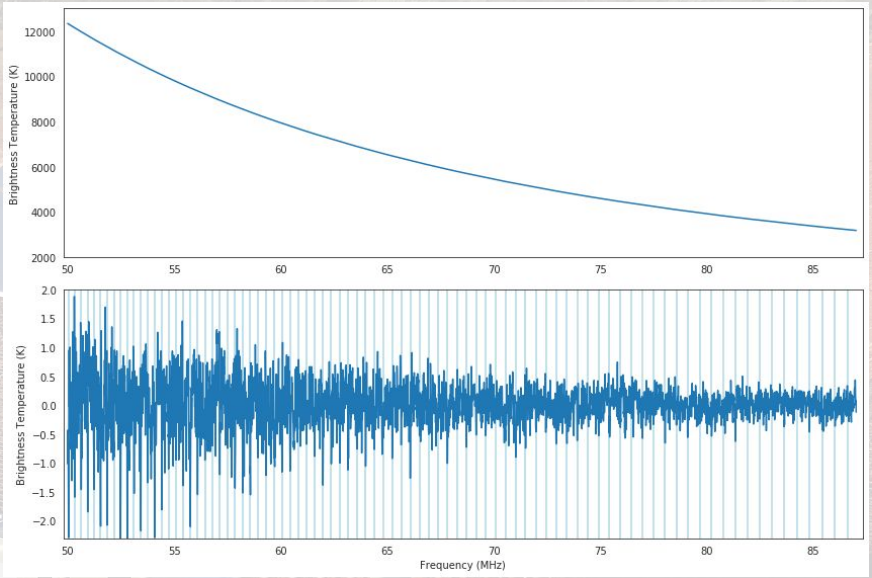


Top Right: EDGES beam at 78MHz
Bottom Right: RFI cutoff, Bowman et al 2018

Processing

- Calibrated, RFI filtered
- Two hour bins in LST centered on even hours
- Spectra trimmed to 50-87 MHz to avoid FM band
- Each spectrum fitted with 9 term polynomial, which is subtracted
- Outlier spectra removed from analysis
- Residuals then averaged across all days

LST = 18 hr



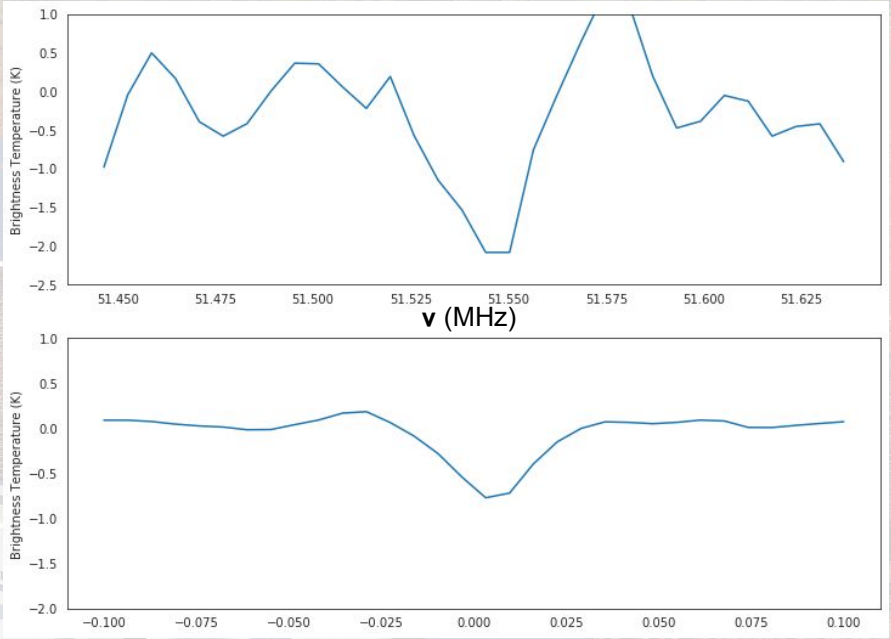
LST = 18 hr
Top: total integration
Bottom: residuals after polynomial, vertical show expected RRLs

Lewis et al. (in prep)

Processing

- Extract windows around Carbon α RRLs
  - 32 frequency channels per window
  - 85 windowed spectra
- Windows stacked for average line profile
- Stacking (unweighted) improves the amplitude SNR to a range from ~5 to ~23

LST = 18 hr



Top: Single line window
Bottom: Average profile across all windows

Lewis et al. (in prep)

Broadening

<u>Sources of broadening</u>
Instrumental:

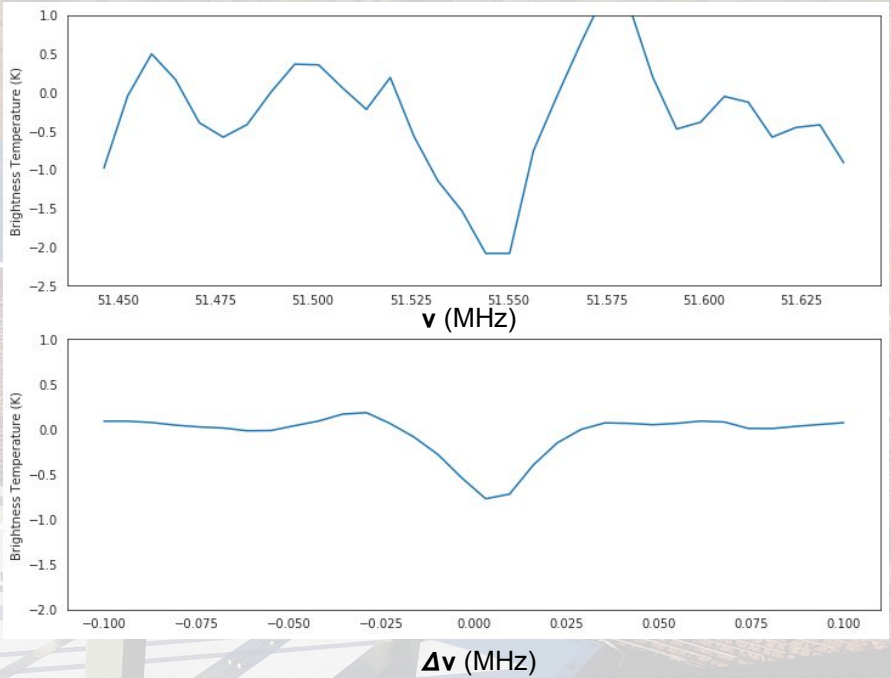
- spectral resolution (12.2 kHz),
- stacking in frequency

Intrinsic:

- Thermal temperature (Doppler broadening): ~2 kHz
- galactic rotation (Doppler shift): ~10 kHz
- Other sources of broadening not significant

At 50 MHz, 1 kHz = 6 km/s
At 50 MHz, 1 channel = 36 km/s
At 87 MHz, 1 chanel = 21 km/s

LST = 18 hr

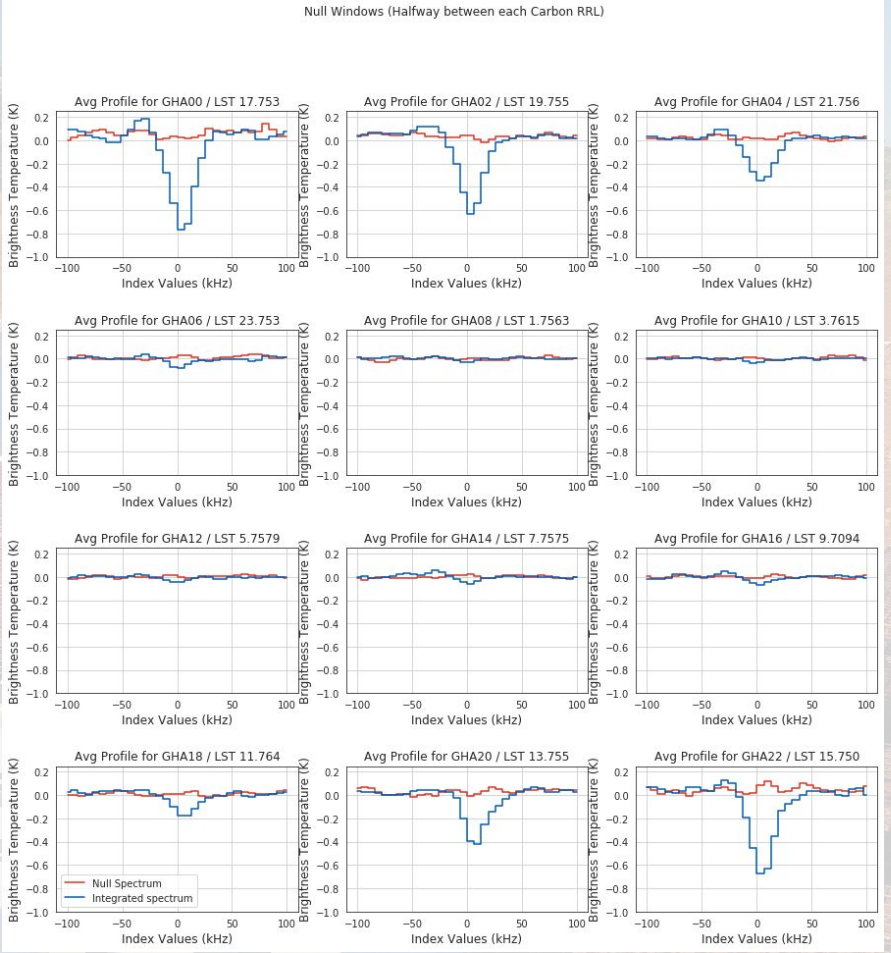


Top: Single line window
Bottom: Average profile across all windows

Lewis et al. (in prep)

Line Profiles

- Process repeated for each LST period
- As a check, we also do a null test in windows centered between C RRLs
- Carbon is main absorption line, smaller emission peak 35 kHz below matches hydrogen line offset
- As expected, we see increased absorption as Galactic Plane transits at LST=18 hr (top left plot)



Blue: stacking on lines centers
Red: stacking off line centers

Profile Fits

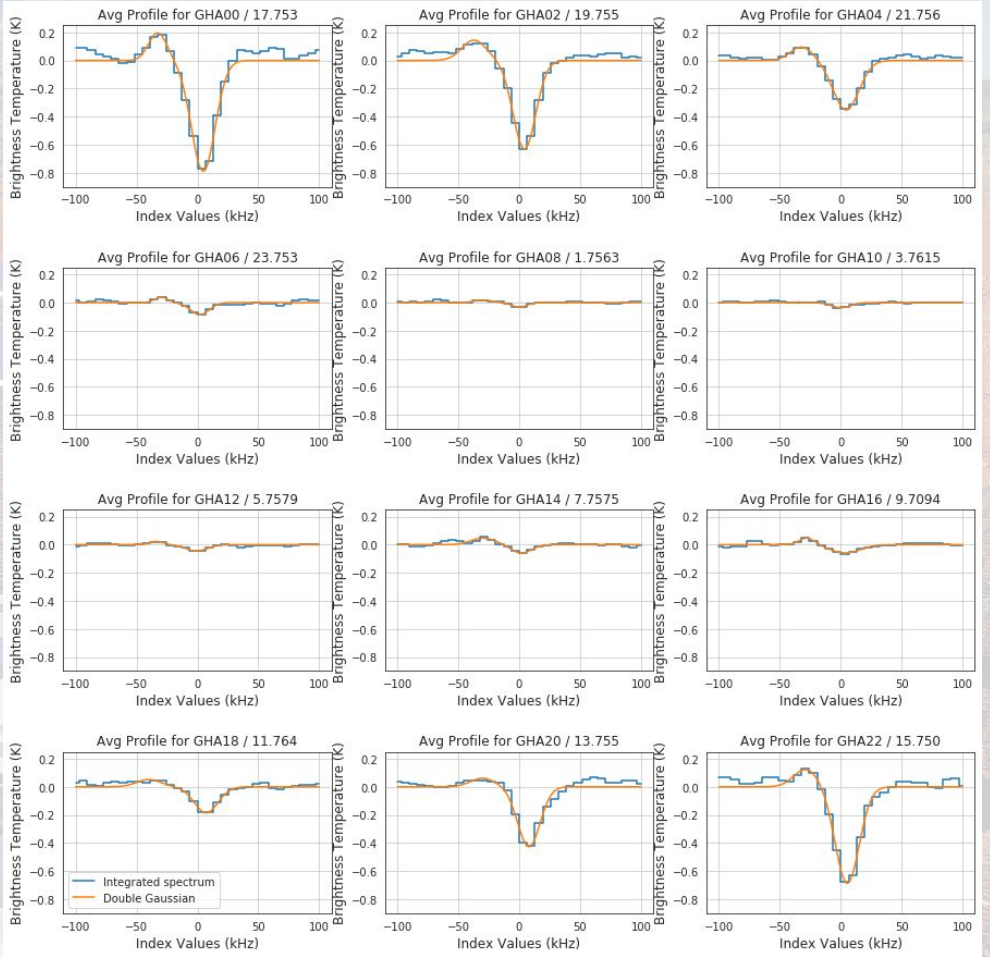
Carbon and hydrogen fit simultaneously
Model: Gaussian for each
Constraints:
Ca, Cnu0, Csigma,Ha, Hnu0, Hsigma
Upper bounds: [0, 0.01, inf, inf, -0.02, 0.010]
Lower bounds: [-inf, -0.01, 0, 0, -0.04, 0]

Carbon absorption:

- Amplitude: 33 < |A| < 789 mK
- Average FWHM: ~21 kHz

Hydrogen emission:

- Amplitude: 6 < |A| < 197 mK
- Average FWHM: ~18 kHz



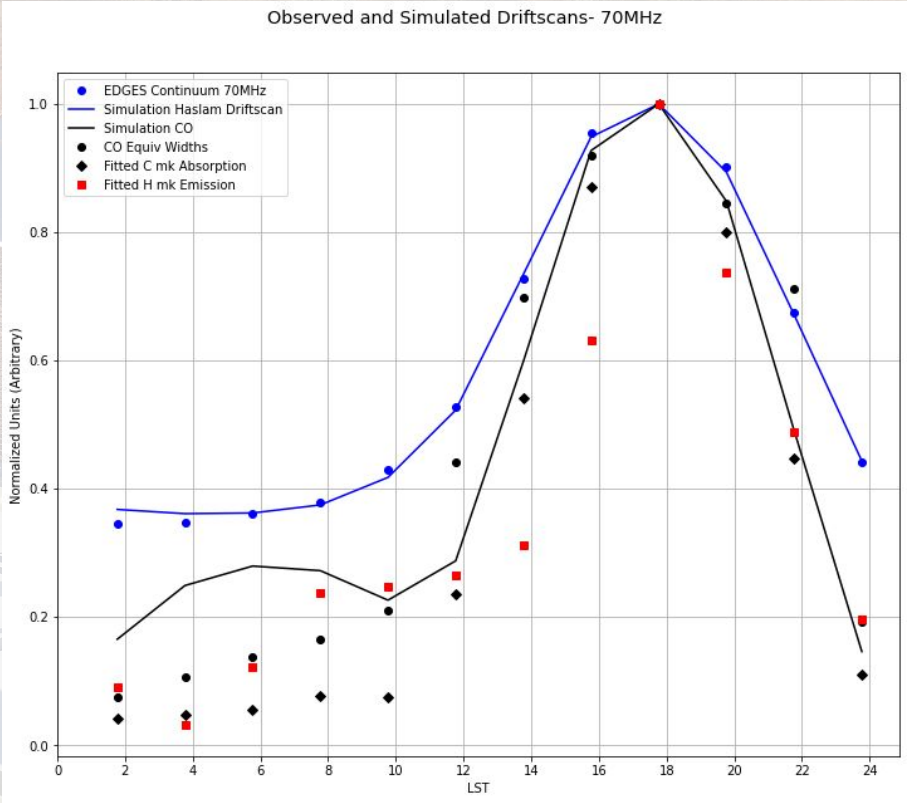
Lewis et al. (in prep)

Measured vs. simulated drift scans

We used CO and HI sky maps to simulate drift scans

Here drift scans and observed intensities are overlapped in LST with normalized scale

Error bars coming soon



Lewis et al. (in prep)

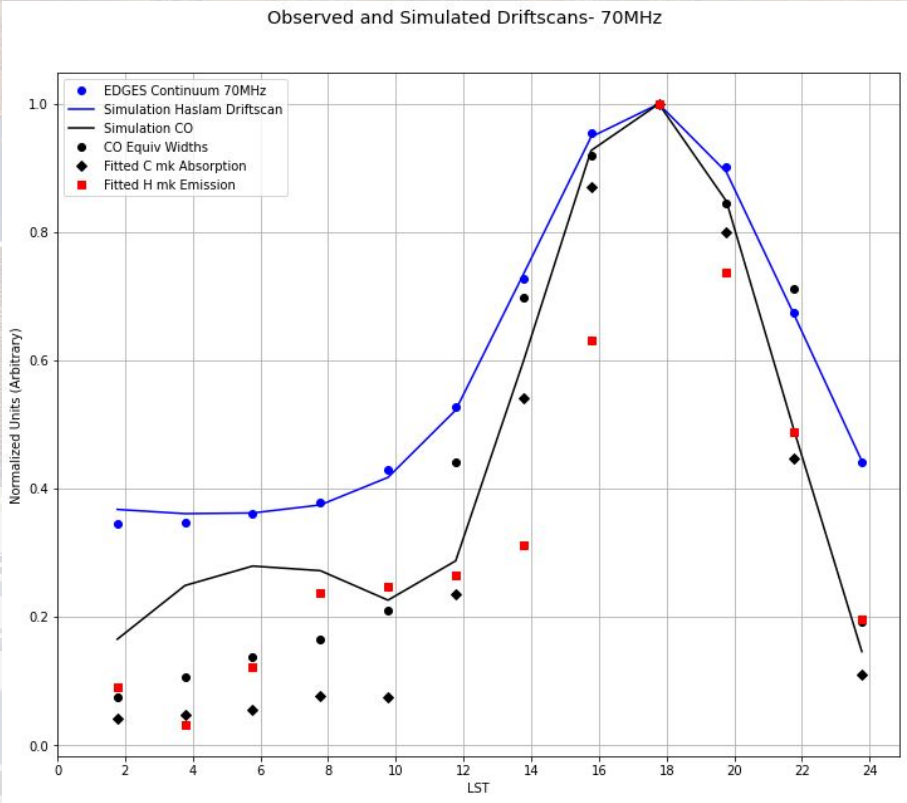
Measured vs. simulated drift scans

Broad agreement of trends between data and CO, HI templates

Differences

- Data lower at low LST than tracers
- Haslam traces synchrotron, which remains bright off the Galactic plane, leading to wider peak in drift scan compared to RRL measurements
- HI distribution highly concentrated in plane, not sure why specifically narrower from LST 14-20
- CO map traces Carbon α , has large excited regions that extend off the plane. Leads to bump at low LST

CO map traces specific excitation transition, not necessarily representative of total gas content



Lewis et al. (in prep)

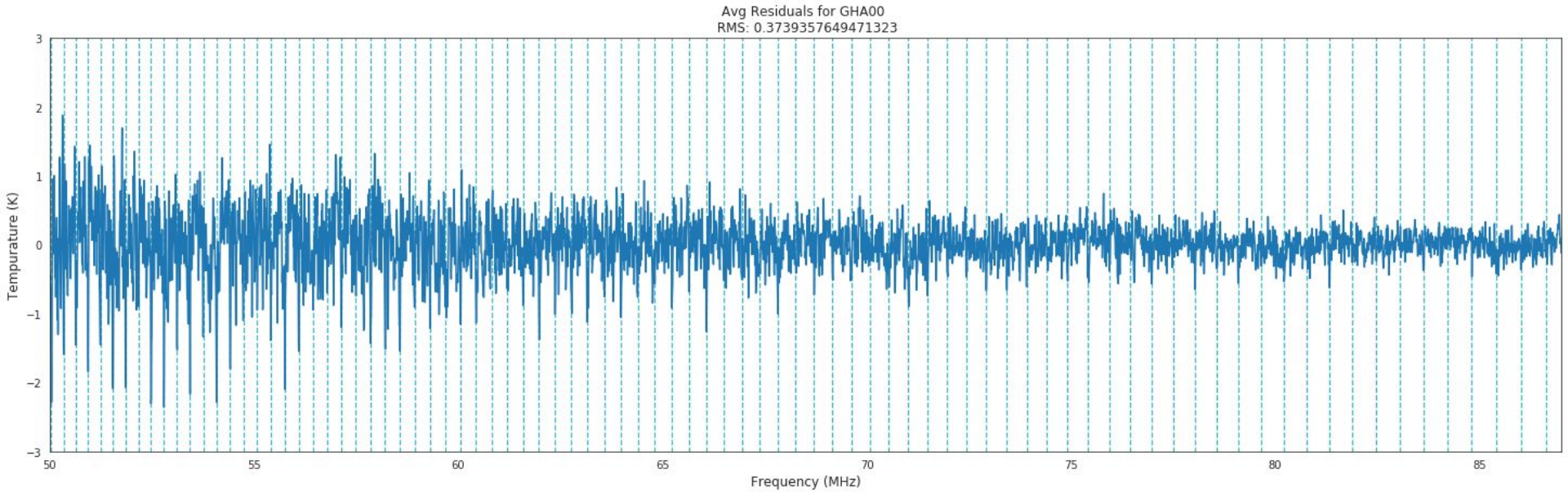
Constraints on high-latitude RRLs

- Both C and H beam-averaged RRLs are <45 mK at high Galactic latitudes (LST 2-4 hr)
  - Carbon minimum at 2 LST is: 33 mK
  - Hydrogen minimum at 4 LST is: 6mK

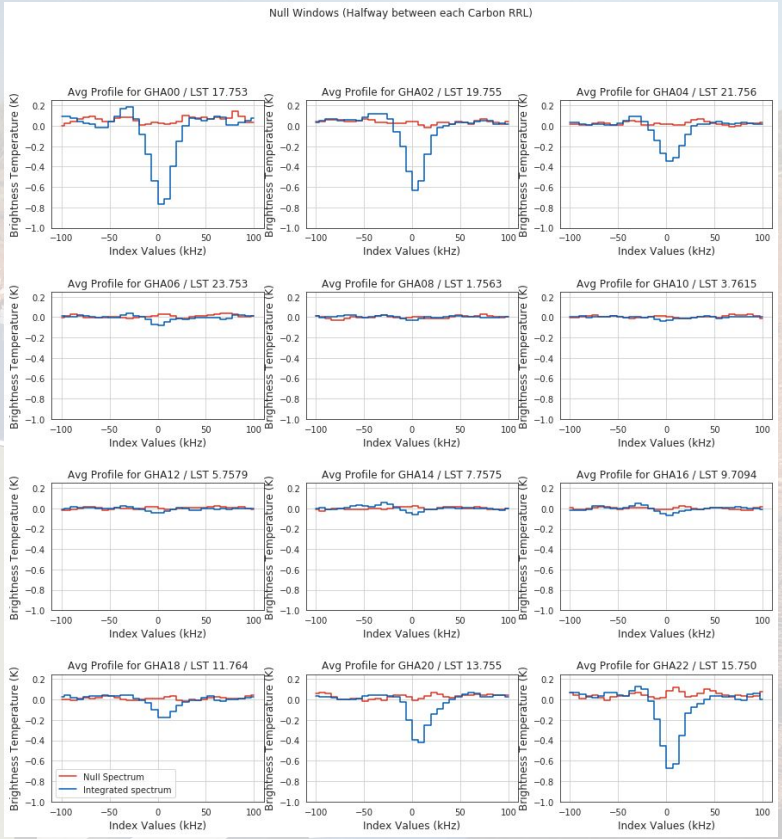
- Comparison to 21cm signal:
  - 21cm signal is ~10 mK
  - MWA observes at Dec. -27 deg:
    - EoR0 - RA 0.00 h (C 86 mK)
    - EoR1 - RA 4.00 h (C 37 mK)
    - EoR2 - RA 11.33 h (C 59-186 mK)
  - HERA observes in drift scan across all LST with a ~10 deg wide track centered at Dec. -27deg
  -
- If lines are truly diffuse and evenly distributed across beam, then HERA and MWA will likely ultimately need to flag these channels

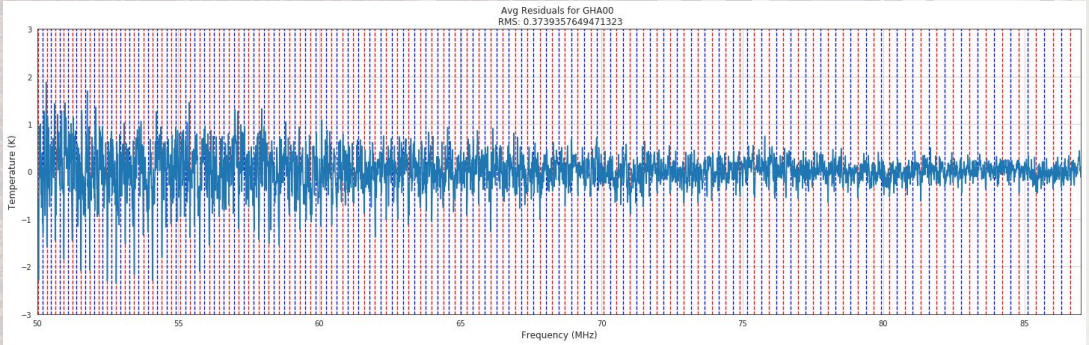
Conclusion

- RRLS remain visible in EDGES beam-averaged spectra at high Galactic latitudes (LST 0-4 hr):
  - Beam-averaged Carbon amplitude >33 mK
  - Beam-averaged Hydrogen amplitude <24 mK
- RRLs will likely have small impact on MWA and HERA 21cm searches currently, but will likely need to be flagged when reach full sensitivity
- Future work: finish analysis and see if we can use the template maps to estimate the RRL strength at any given RA, Dec.


Avg Residuals for GHA00
RMS: 0.3739357649471323
Tempurature (K)
3
2
1
0
−1
−2
−3
50
55
60
65
70
75
80
85
Frequency (MHz)

Null Profile Check





Experiment to Detect the Global EoR Signal

Located at MRO

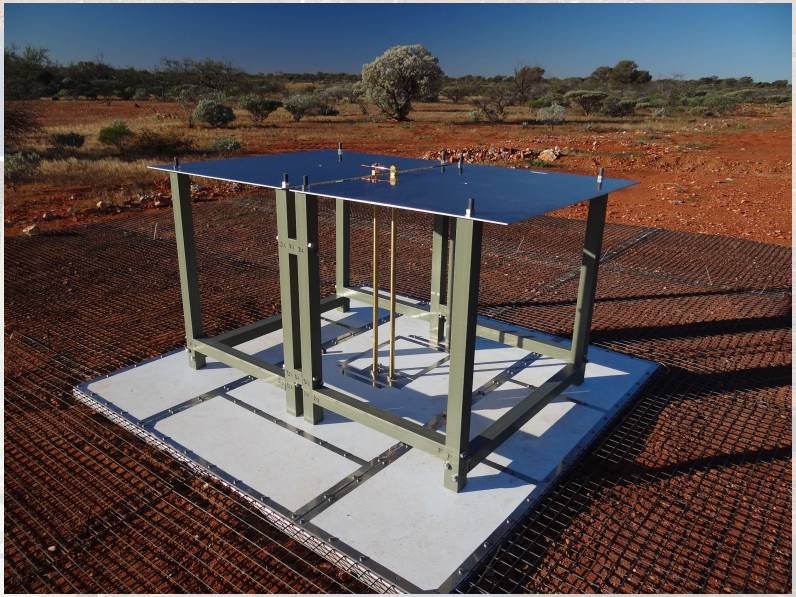
Multiple instruments, 50-200 MHz Range

Lowband 50-100 MHz

Beam @78 MHz:

71 parallel - 108 perpendicular

Fixed at zenith



Expected RRL driftscan should follow normal trend