Predicting and Measuring the Effect of RFI on 21-cm Epoch of Reionization Power Spectrum Measurements

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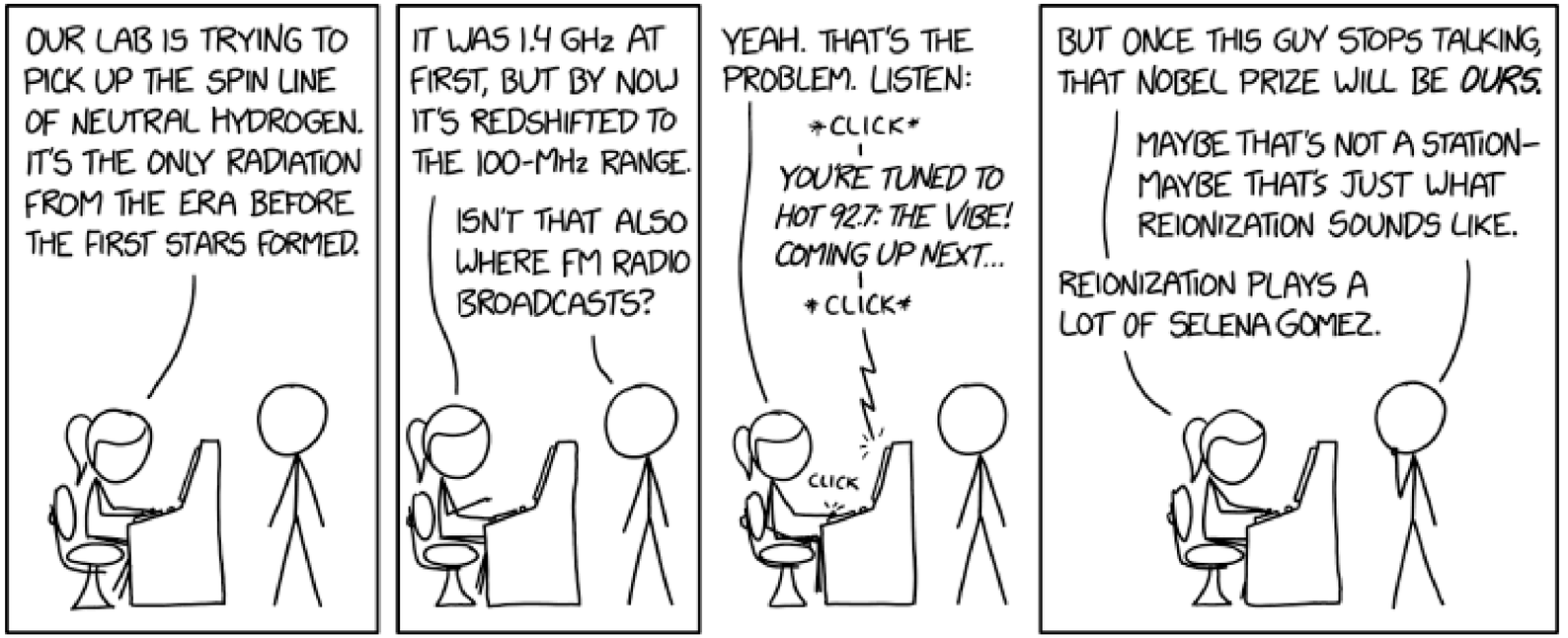
Strangely accurate XKCD depiction of my life



Talk Outline

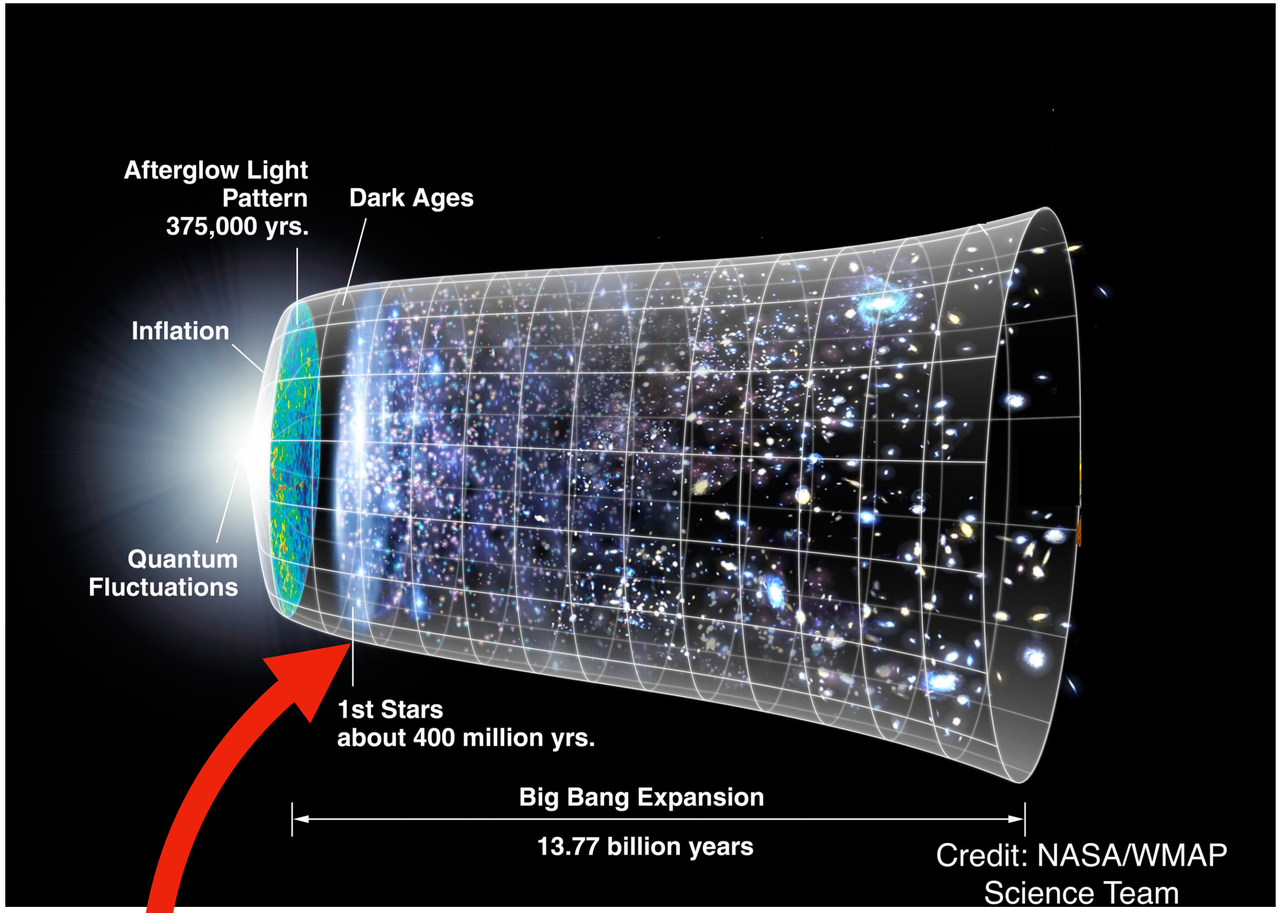
Motivation: Introduce the Epoch of Reionization (EoR) and MWA.

Predictions: Show theoretical assessment of RFI on our power spectrum measurement.

Mitigation: Briefly describe SSINS (RFI flagging software)

Observational Verification: Show observational evidence of RFI contamination in power spectrum measurements and improvements from mitigation

The Expanding Universe



Approximate beginning of reionization

- The expanding universe is cooling, and undergoes phase transitions
- Epoch of Reionization (EoR) is a transition from neutral to ionized Hydrogen on a universal scale
- The EoR will tell us about interesting cosmological processes such as structure formation
- Exact time period of reionization is unknown

The Murchison Widefield Array (MWA)

Photo Credit: Dr. Natasha Hurley-Walker (Curtin/ICRAR)

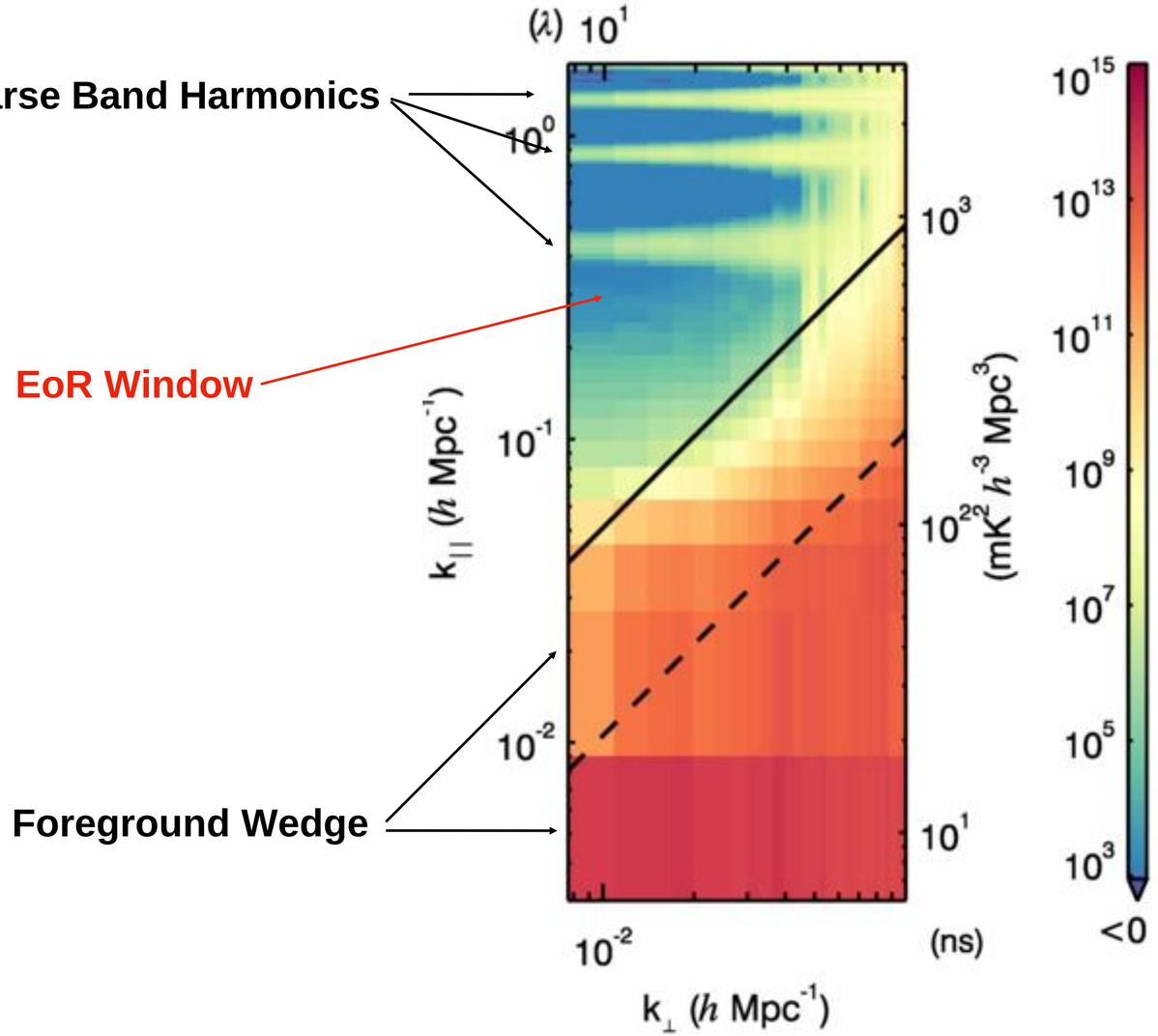
Photo Credit: Greg Rowbotham, ICRAR (2016)

- Very remote site in Murchison Radio Observatory
- Each receiving element is actually a 4x4 tile of crossed dipole antennas
- Can electronically point a tile using delays in the beamformer
- Current correlator takes 128 inputs
- Sensitive from 80-300 MHz
- Correlator outputs 30.72 MHz of visibility data in two-minute chunks

Observation Parameters

Cadence	Length	Band-width	Freq. Res.	Base-lines
2 s	2 min	30.72 MHz	40 kHz	8128

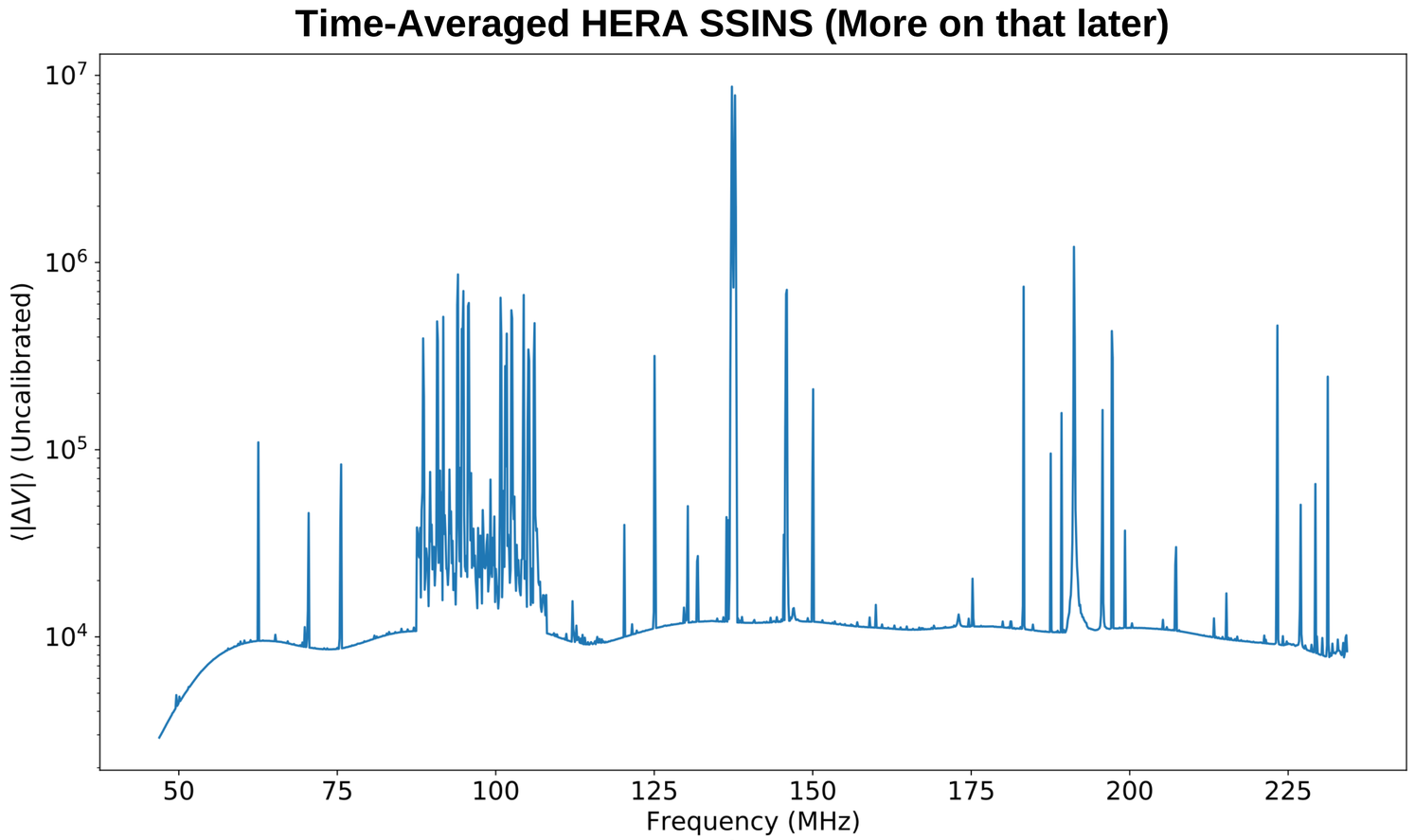
Anatomy of a 2d Power Spectrum



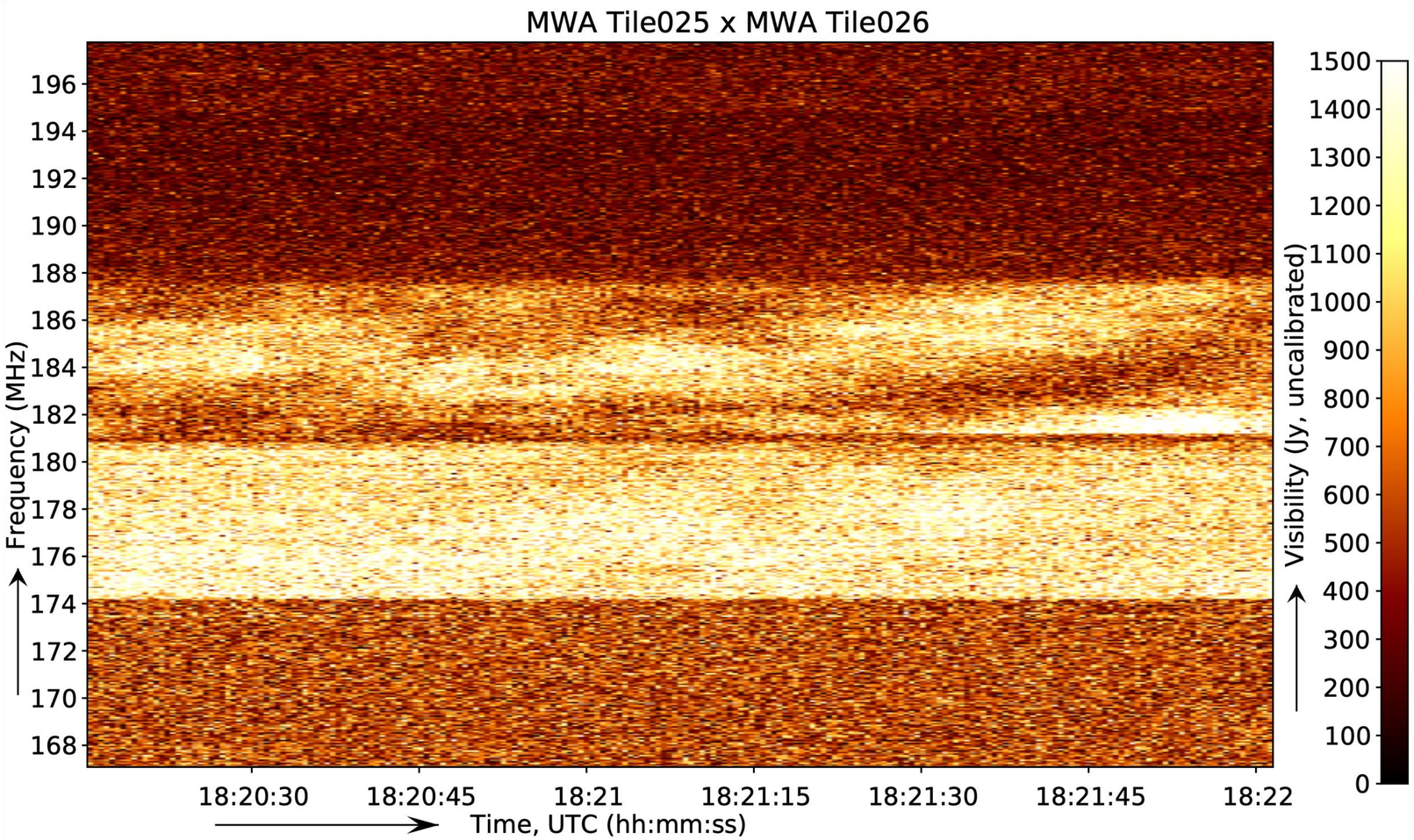
- Colorbar spans 12 orders of magnitude
- Bottom contaminated by foregrounds
- Wedge is a result of chromatic instrumental effects
- Upper left is the “EoR window”
- Horizontal streaks in window from filter
- Goal for now is to clean out the window as much as possible

RFI Puts Power in the EoR Window

- It has sharp spectral variations
- This means it can block our measurement of the signal we're interested in

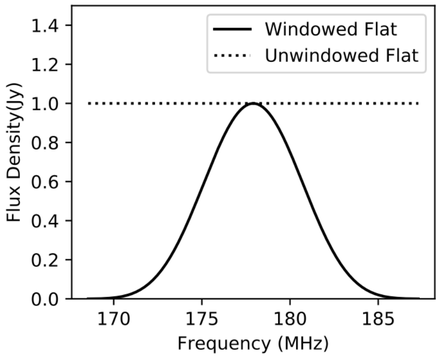


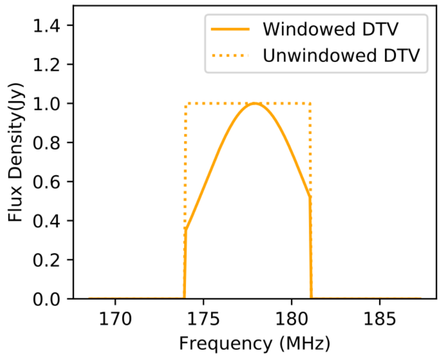
Digital TV in MWA Data

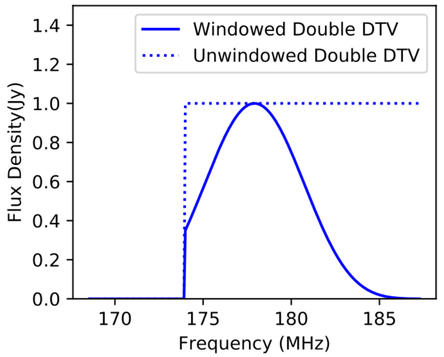


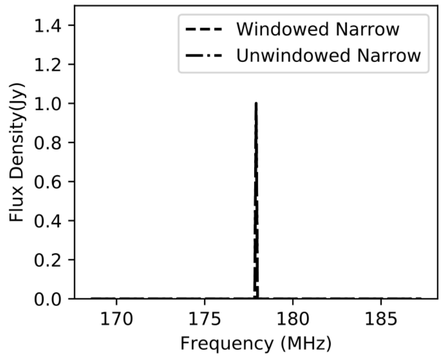
Source: https://arxiv.org/abs/1501.03946

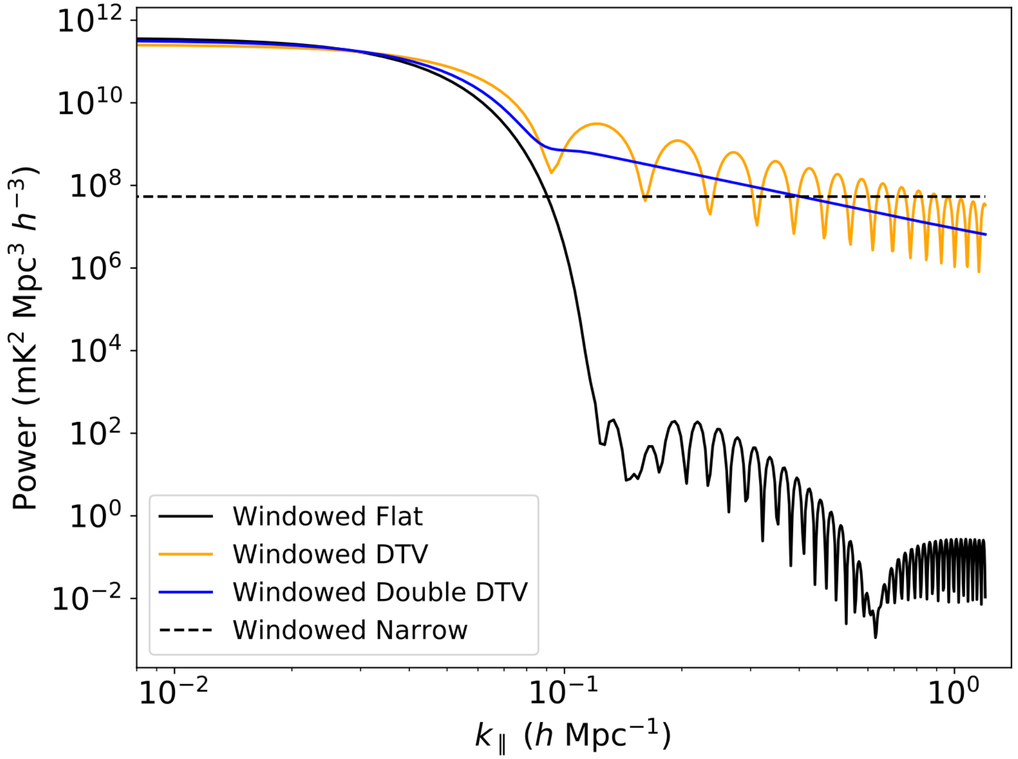
Semi-analytic Calculation of RFI Power Spectra

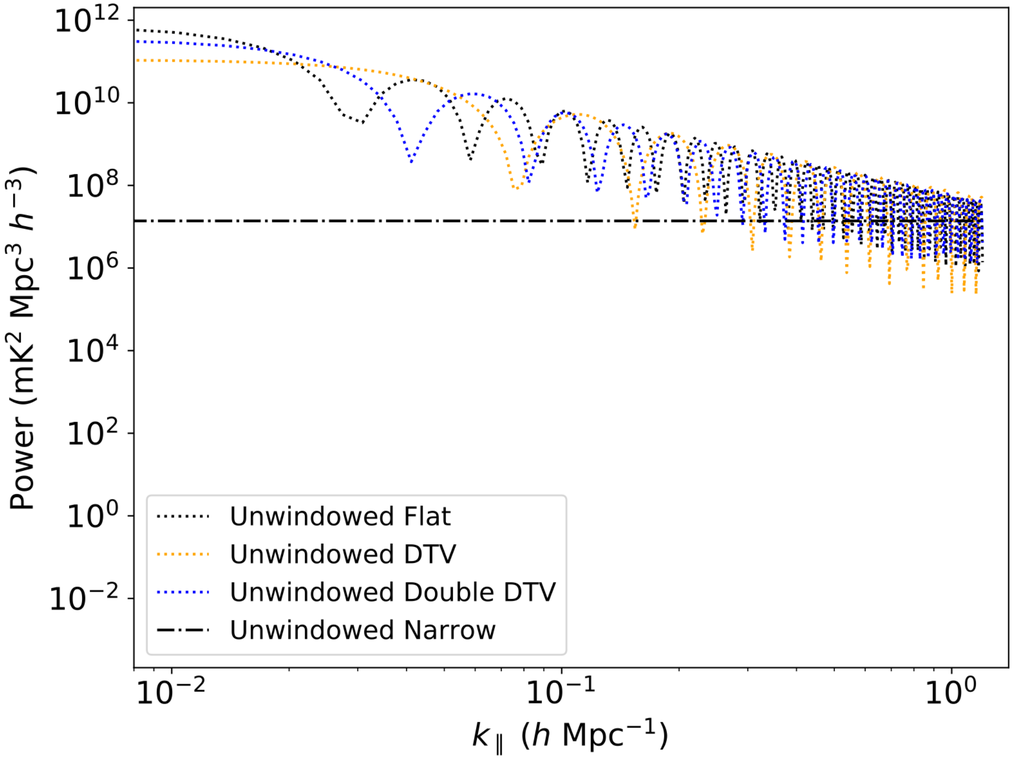




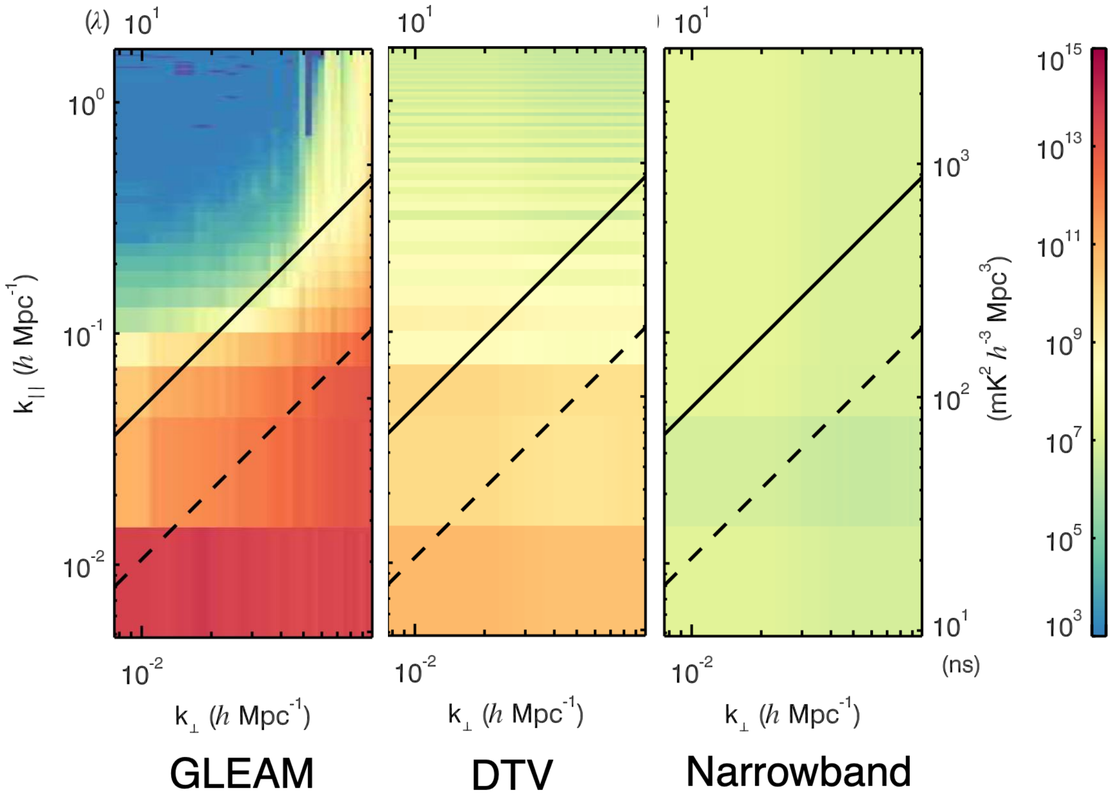


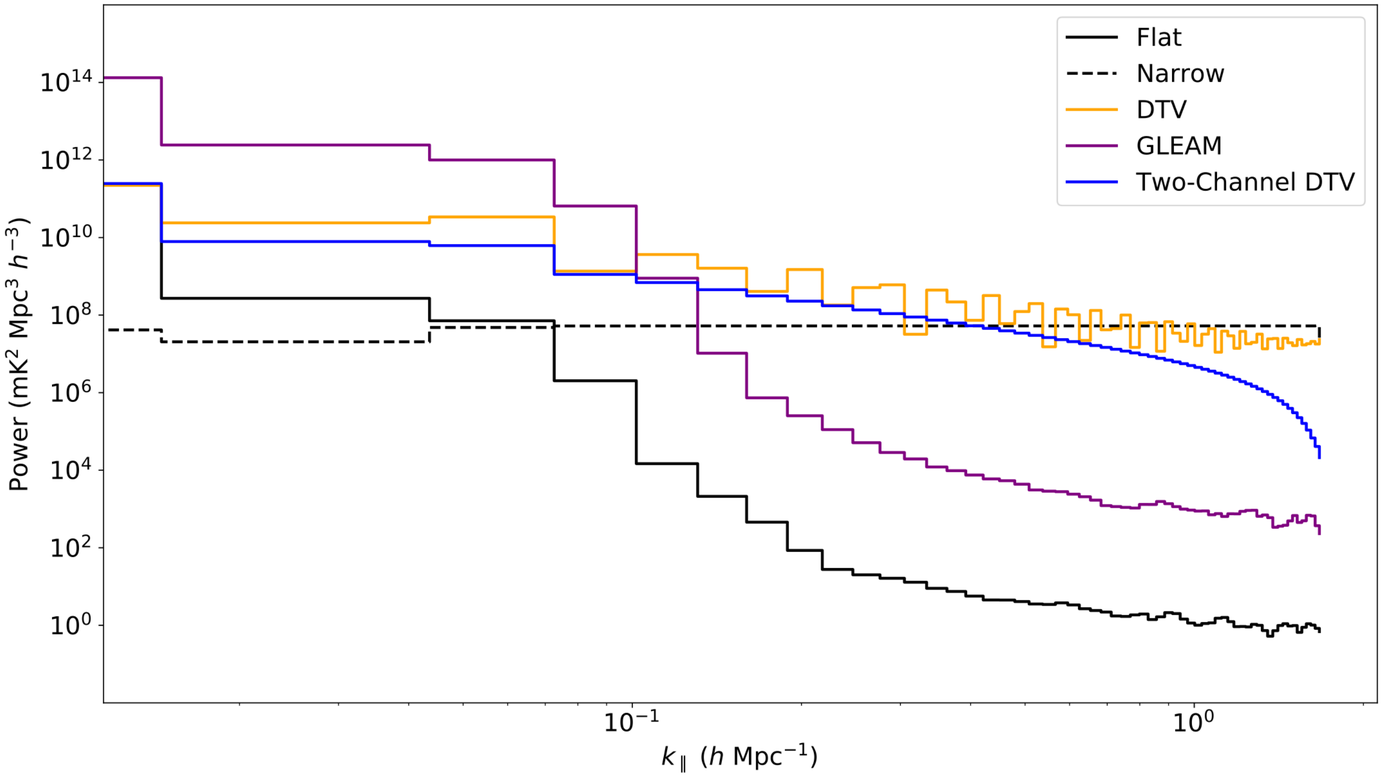






In-situ Simulation of RFI Power Spectra



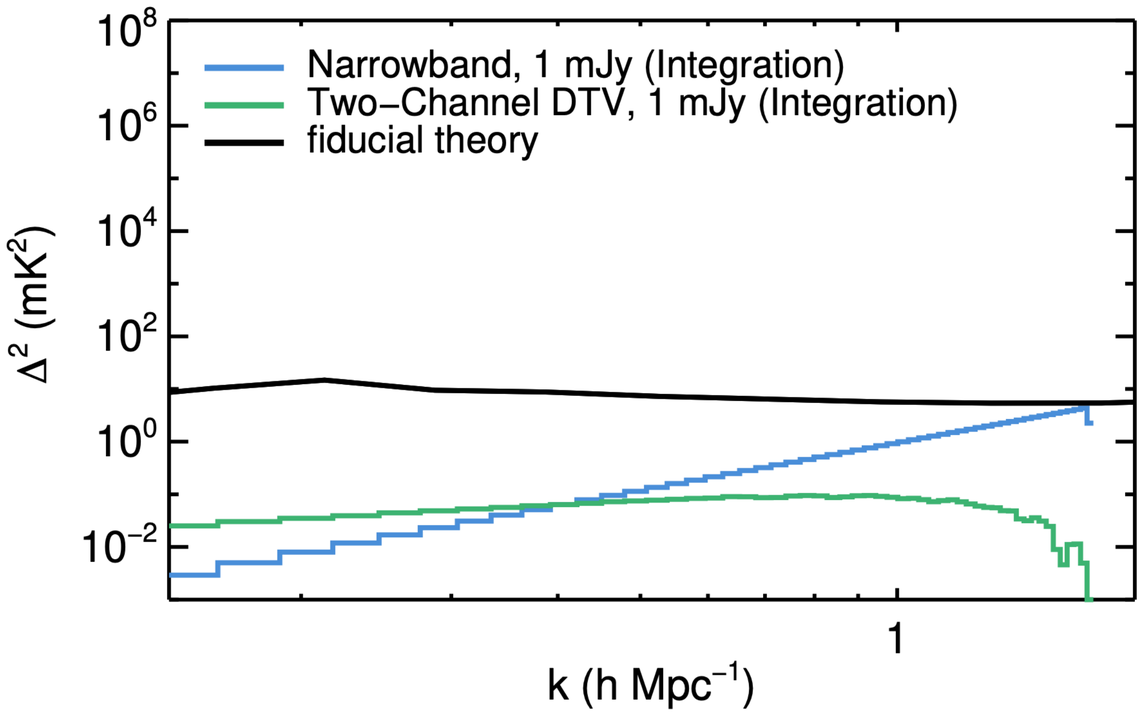


Most point sources on the sky

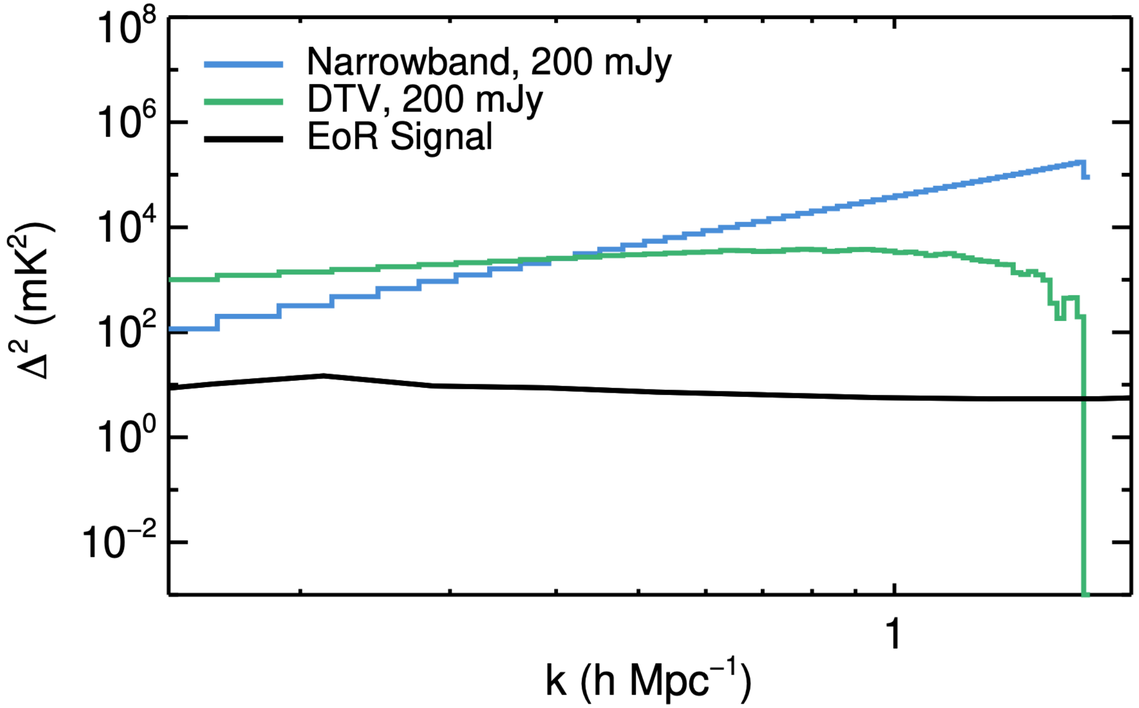
Single RFI source of moderate brightness provides substantially more contamination than entire sky of point sources

RFI Budget and Current Projection

Where we might need to get



Upper bound on where we are



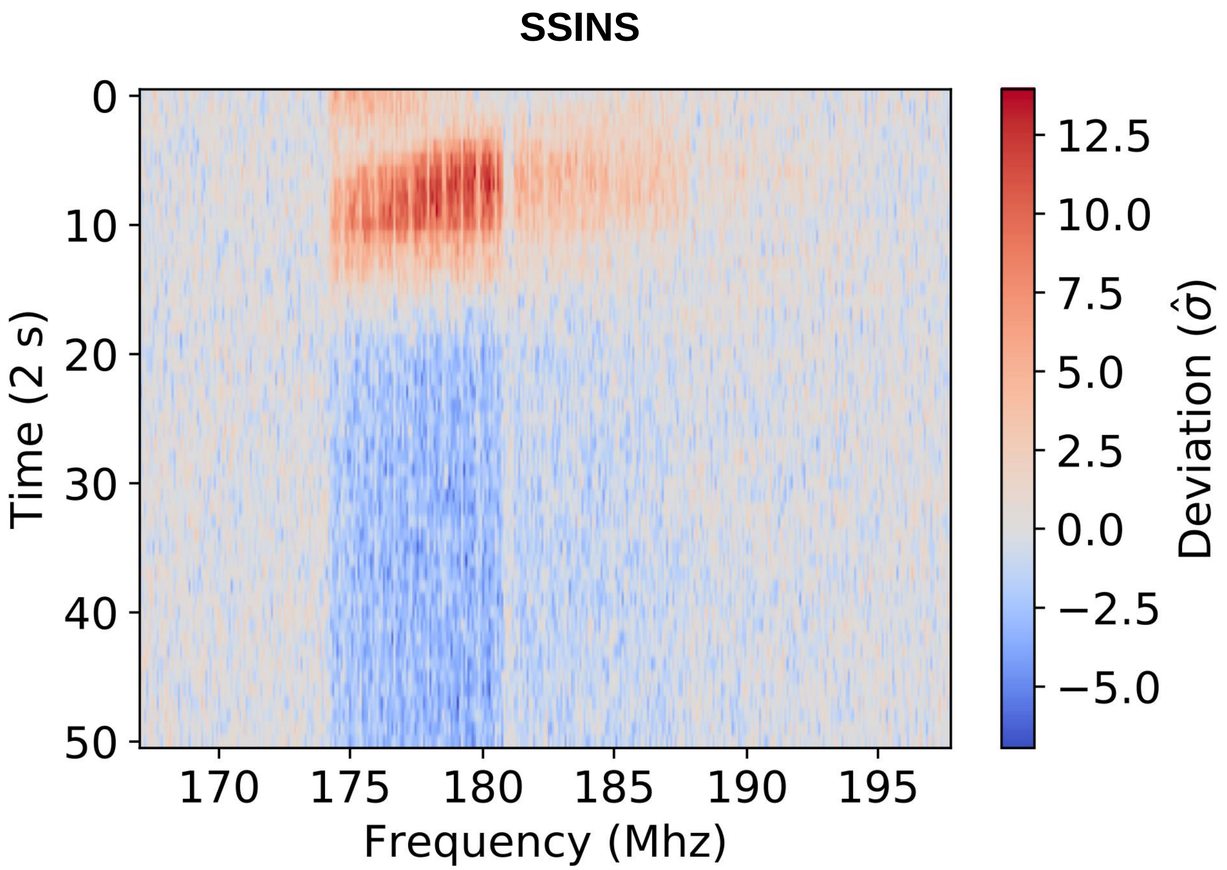
Budget is affected by a few other items:

1. Duty cycle of RFI emitters
2. Spatial distribution of sources
3. Presence of other systematics
4. Which EoR theory is actually right

We are likely to still need significant improvements to RFI mitigation techniques

Paper: https://arxiv.org/abs/2004.07819

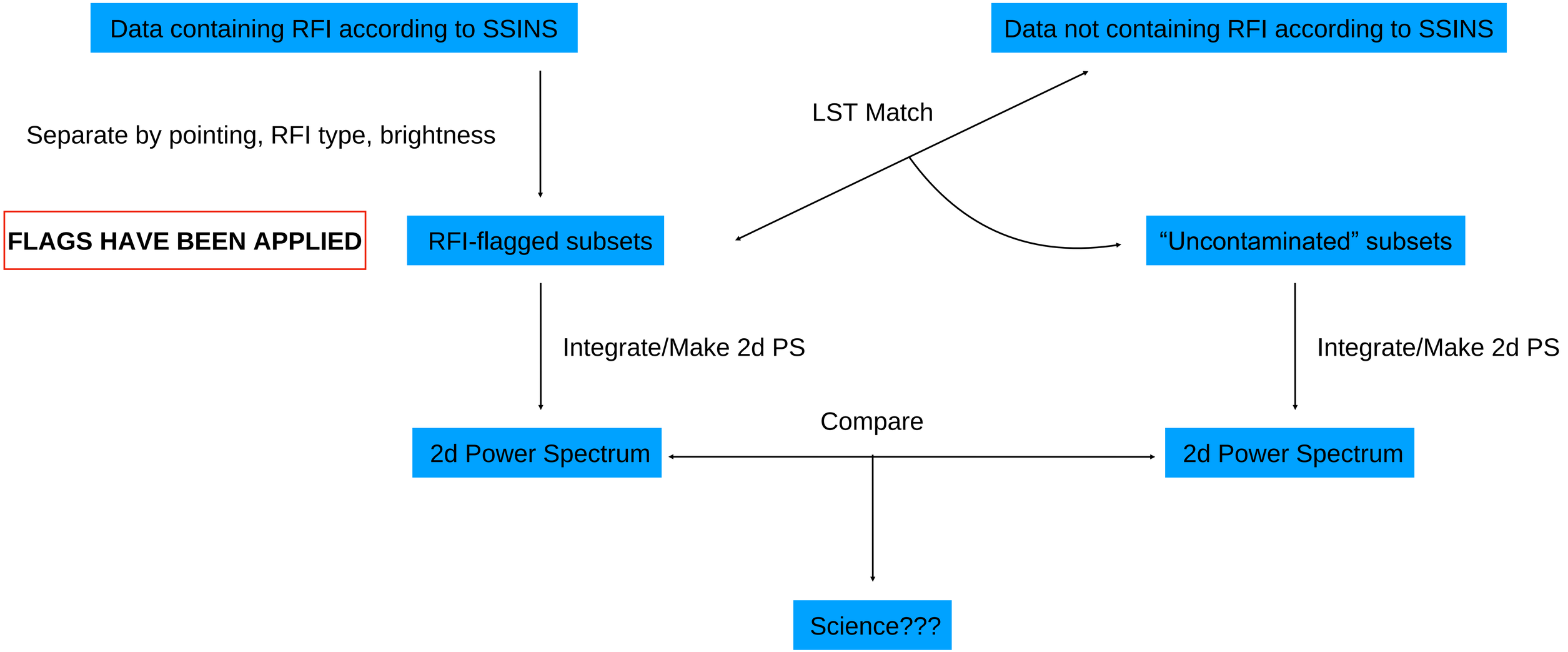
SSINS: Sky-Subtracted Incoherent Noise Spectra



https://arxiv.org/abs/1906.01093

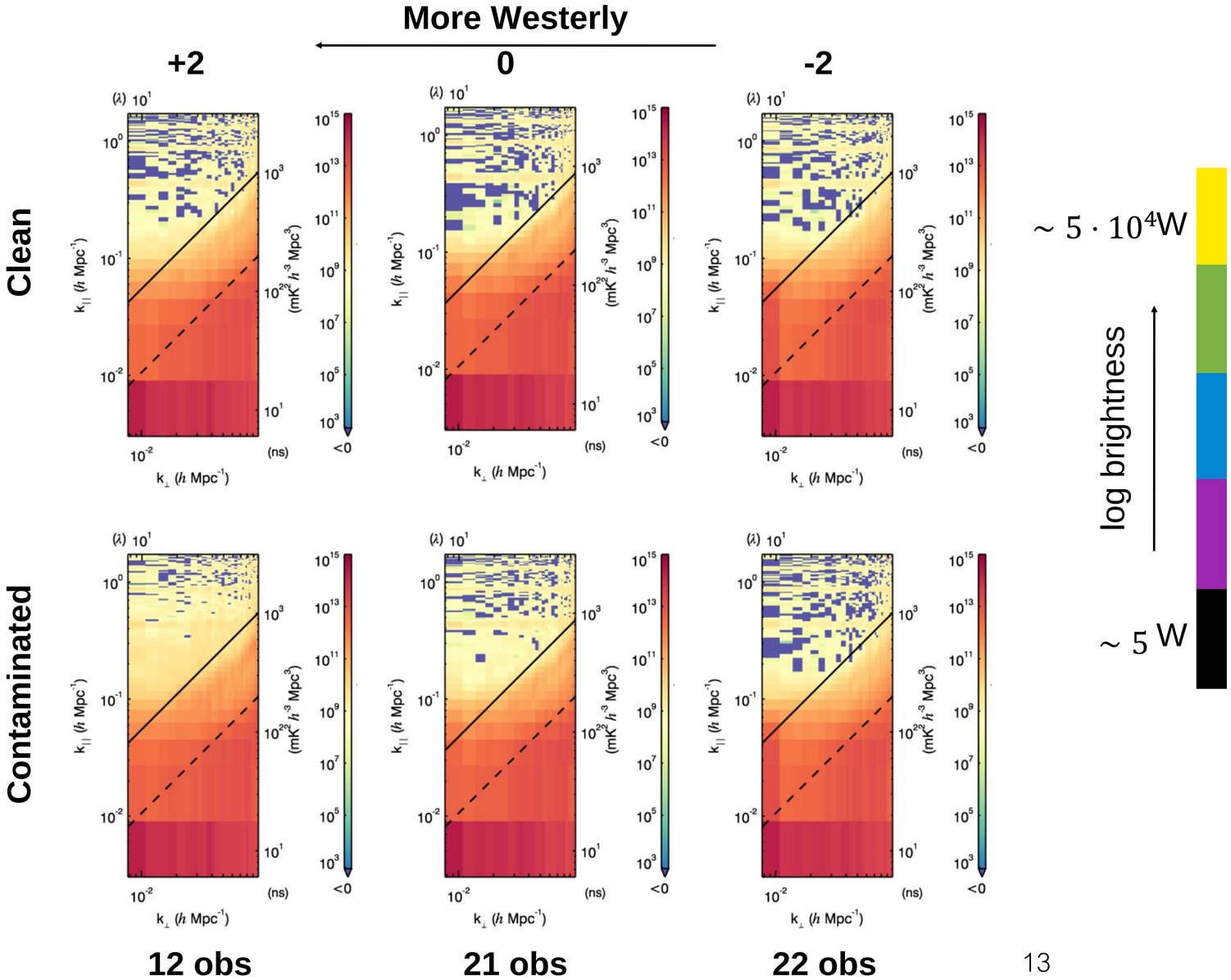
- Ultra-faint RFI: looks for RFI fainter than single-baseline thermal noise
- GitHub link here: https://github.com/mwilensky768/SSINS
- Time-difference neighboring visibilities, take amplitude (subtract sky, leave noise/RFI)
- Surpass single-baseline sensitivity by averaging amplitudes over baselines
- Boost contrast with mean-subtraction: estimate mean/standard deviation with time average to find sample z-scores
- Can find z-score of a sub-band by summing over the sub-band (detailed in paper)

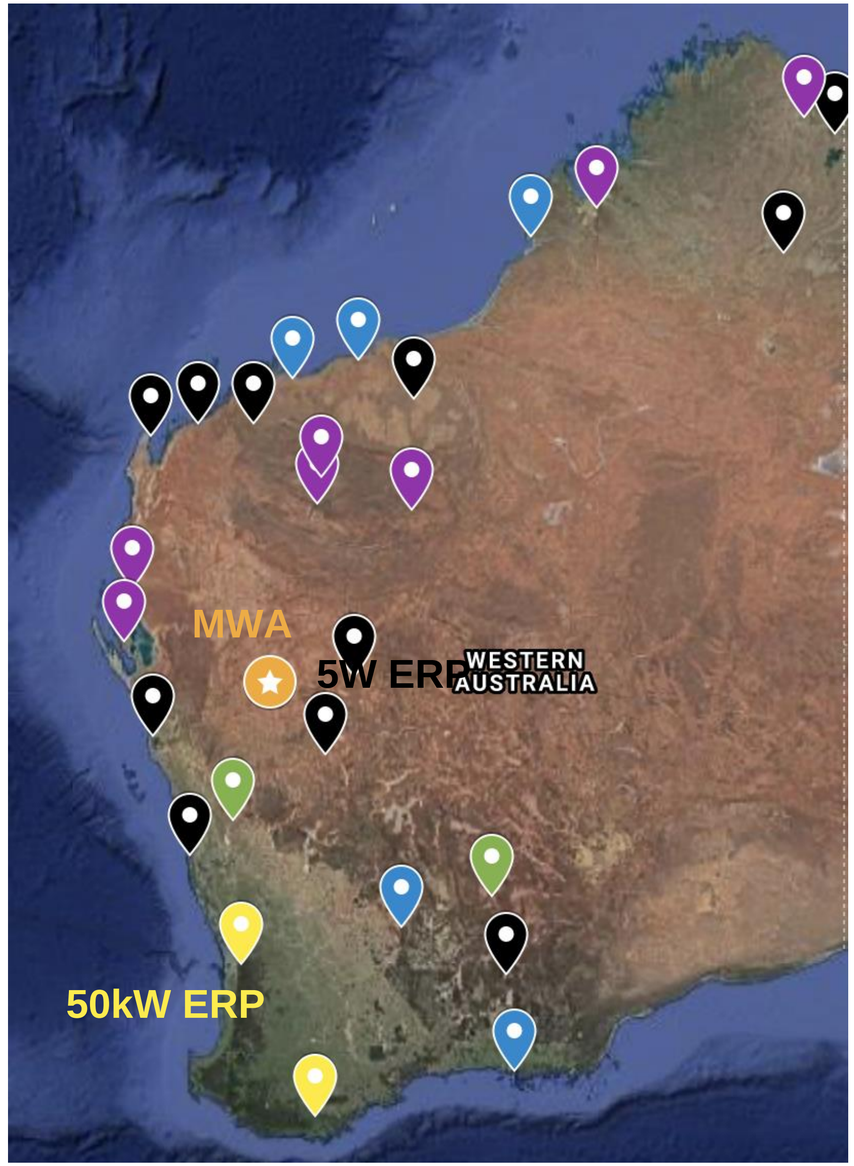
Jackknife Test



(Is there a difference and is it likely to be due to RFI?)

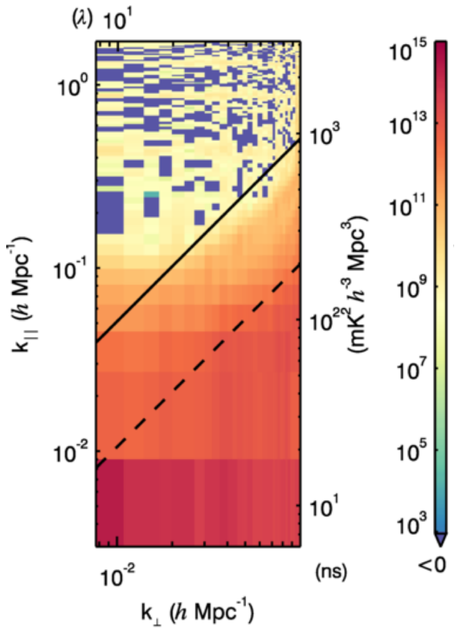
Western Pointings more Contaminated



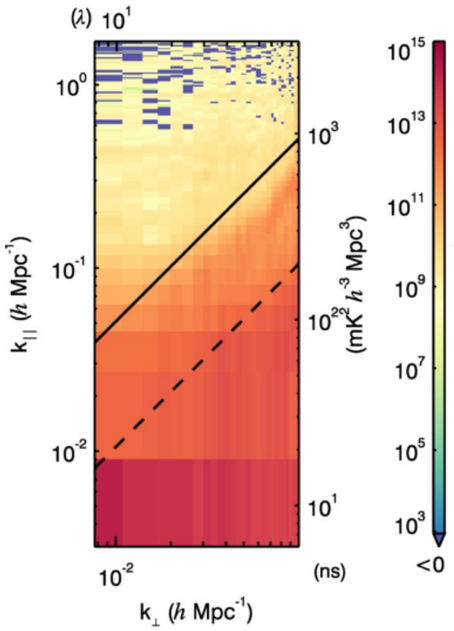


Applying SSINS Flags Removes Window Power

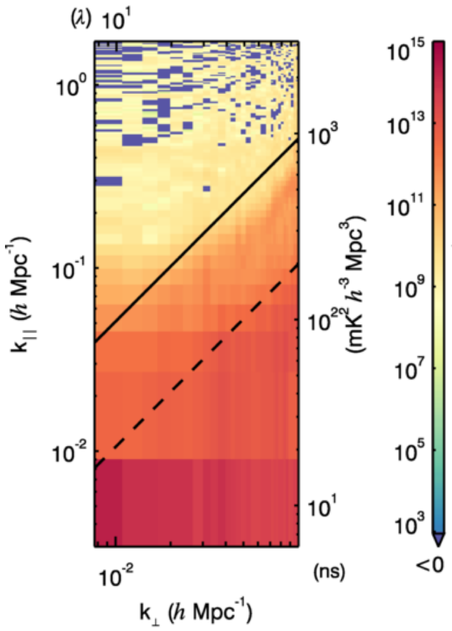
Clean LST-match



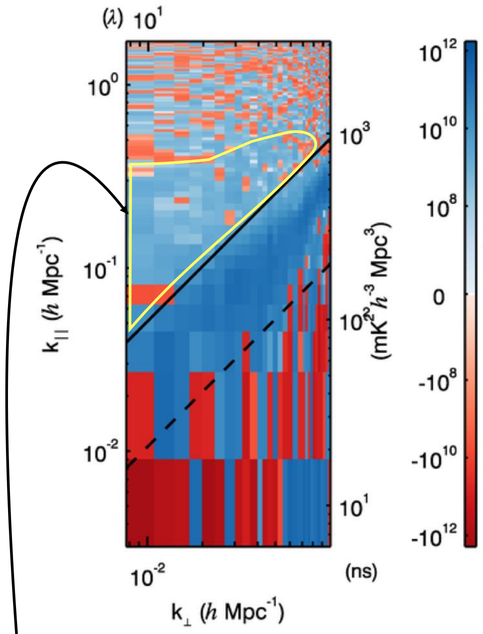
No Flags Applied



SSINS Flags Applied



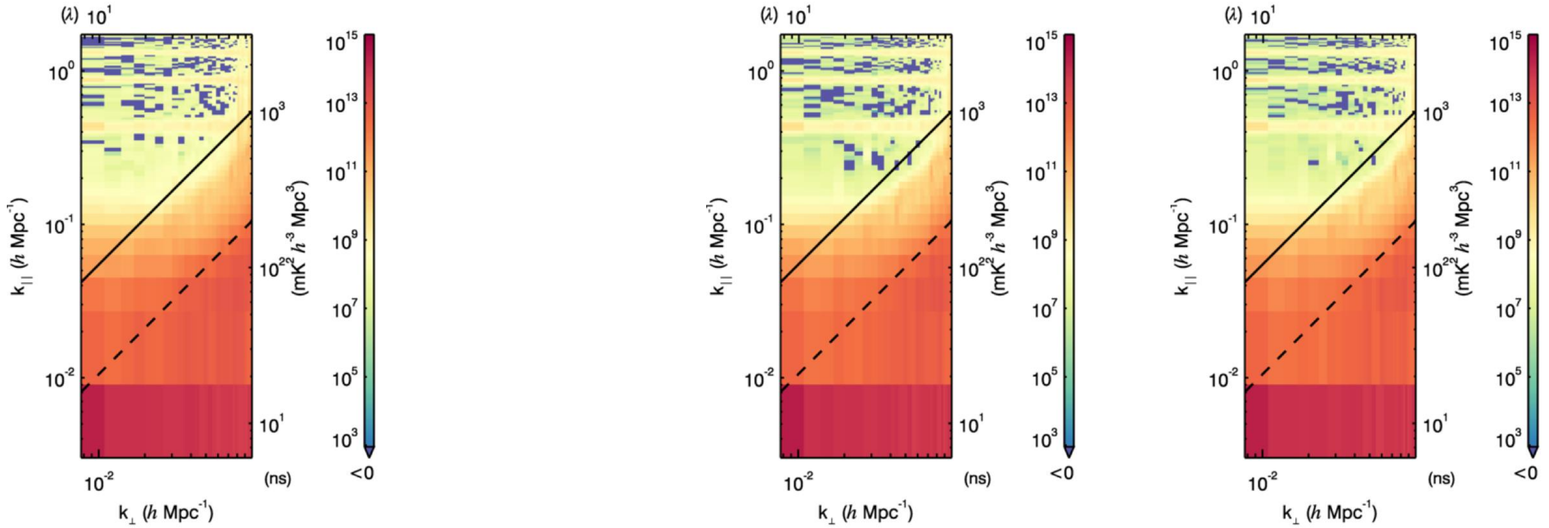
Difference



Characteristic RFI footprint in EoR window

Some Deep Power Spectra

E-W

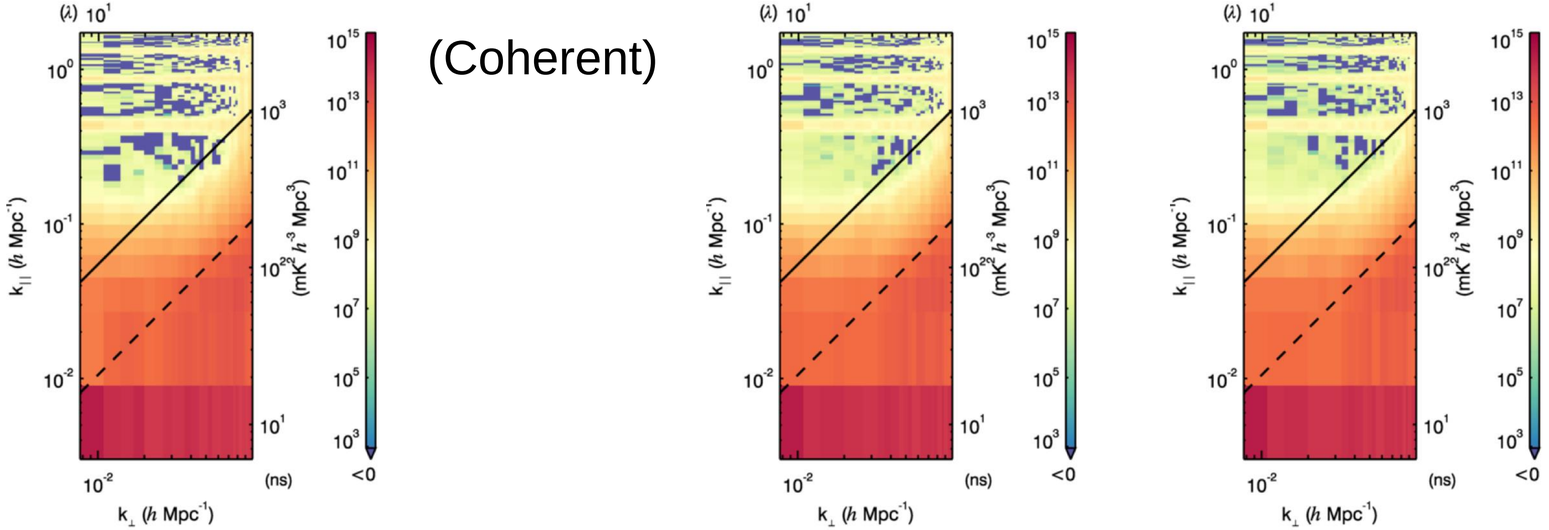


+

(Coherent)

=

N-S



Wall of Shame

Limit Set

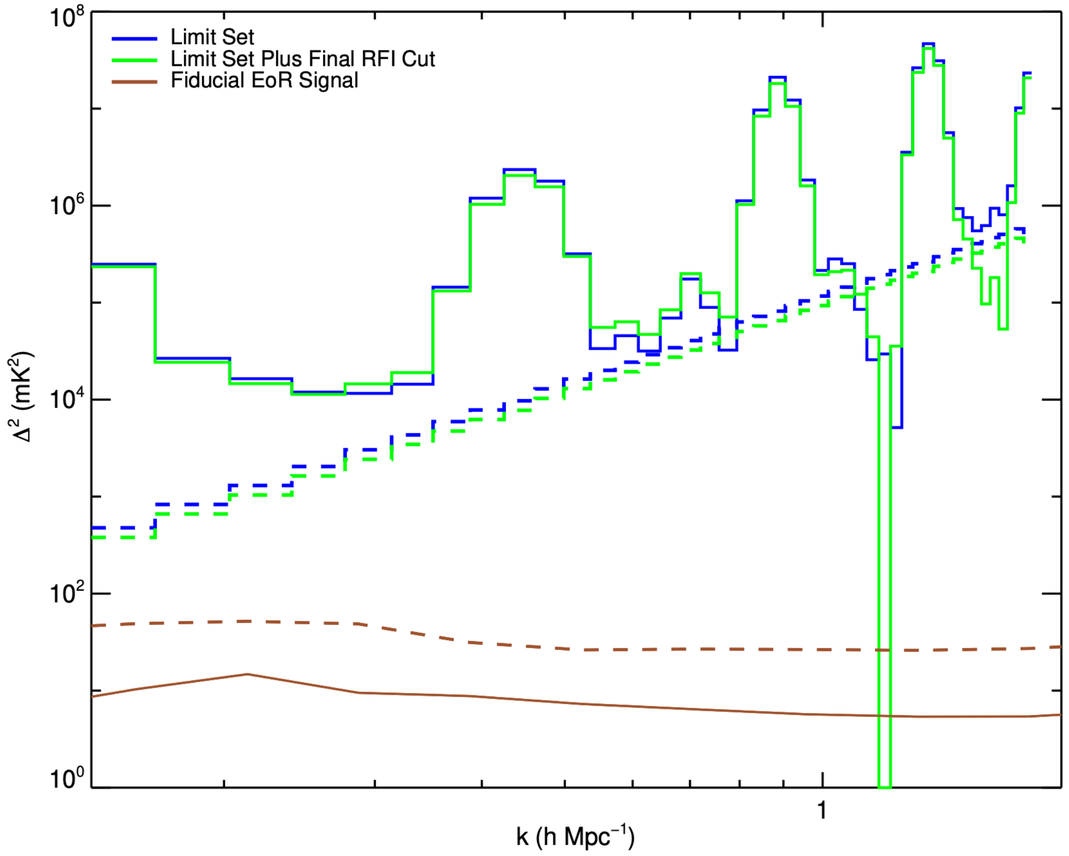
All

- E-W wall of shame appears RFI-limited in E-W but not N-S
- Limit set appears systematically limited in both polarizations
- Total set looks RFI-dominated in E-W, and possibly differently systematically limited in N-S

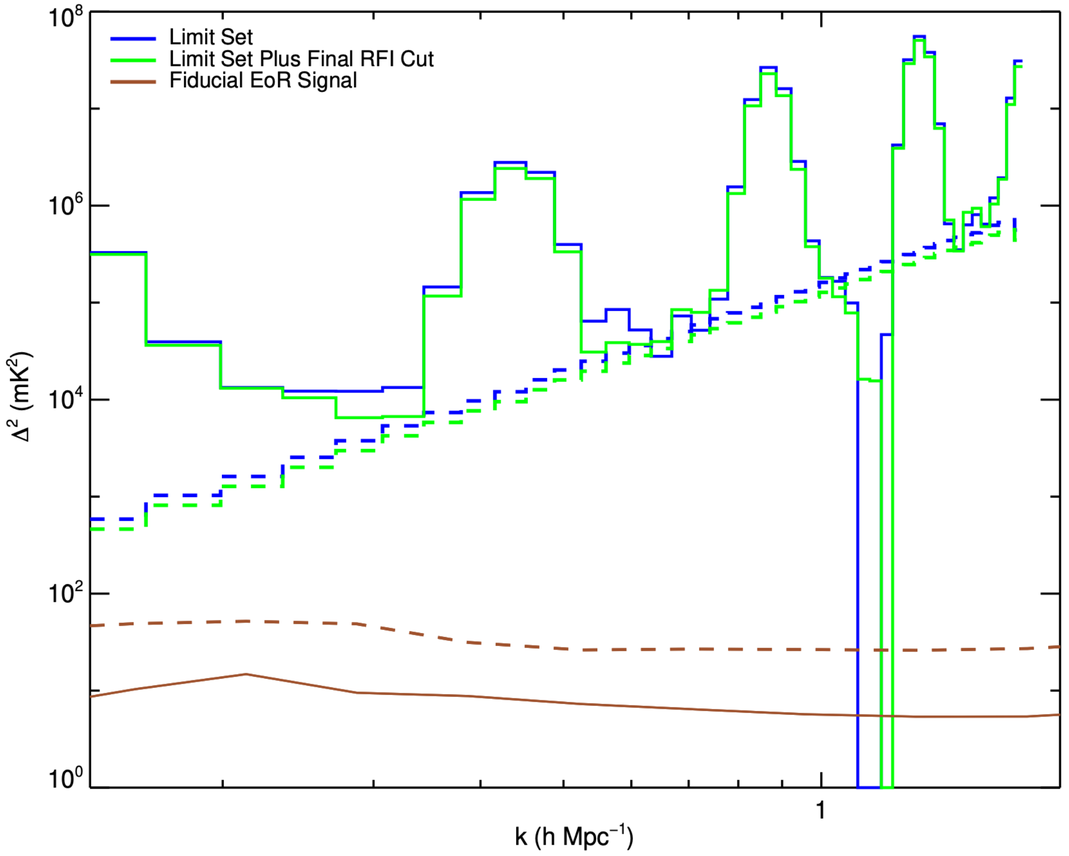
Preliminary Upper Limit on 21-cm EoR PS

Including RFI set degrades E-W limit b/w 1st and 2nd harmonic

E-W, z=6.5



N-S, z=6.5



Conclusion

•RFI mitigation efforts likely need improvement.

•However its effect on deeper power spectrum integrations needs to be investigated

•Mechanism for becoming subdominant on deeper integration is “dilution” during coherent averaging of power spectra as well as incoherent averaging.