Signals from the epoch of RECOMBINATION

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CAASTRO ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

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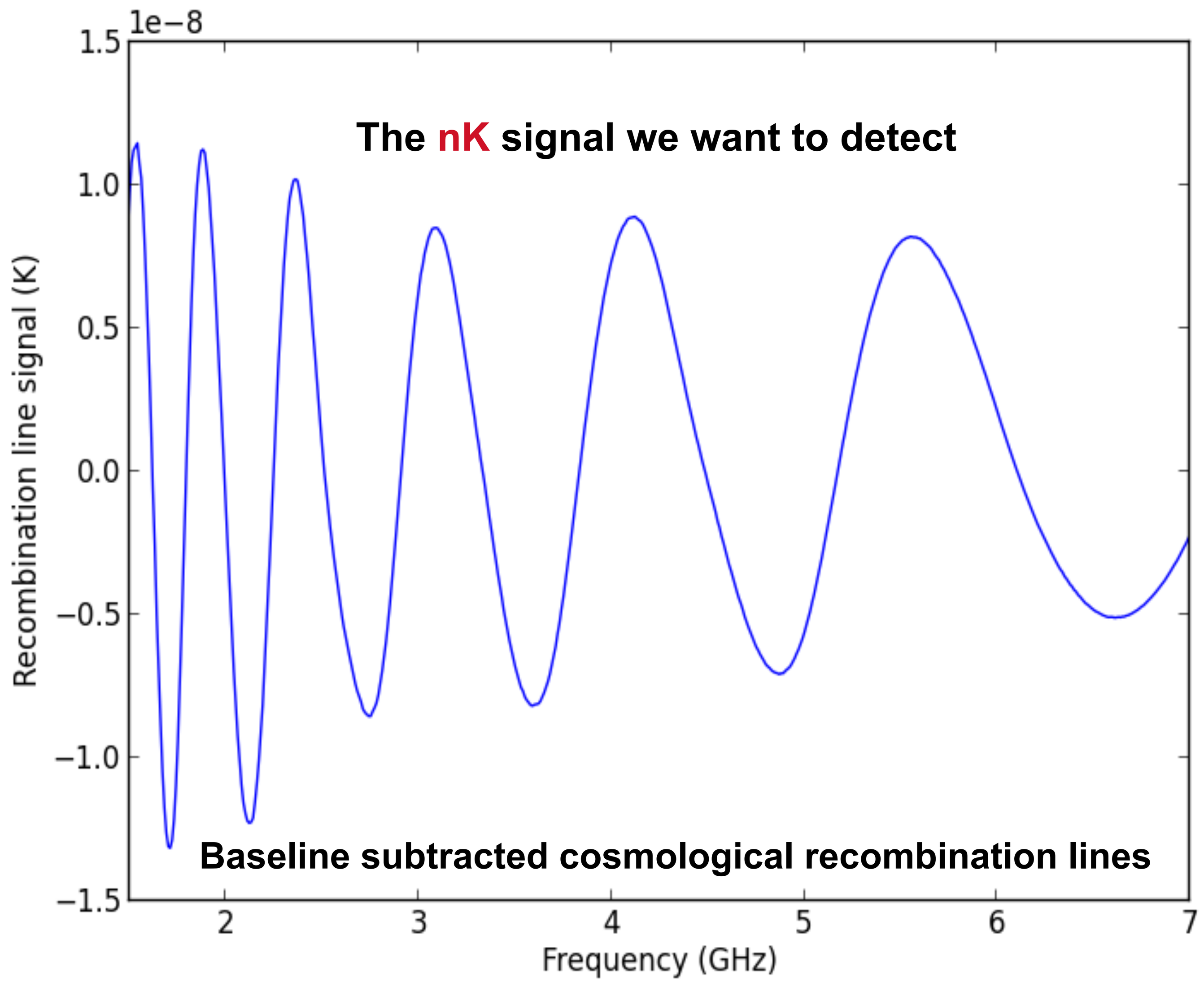
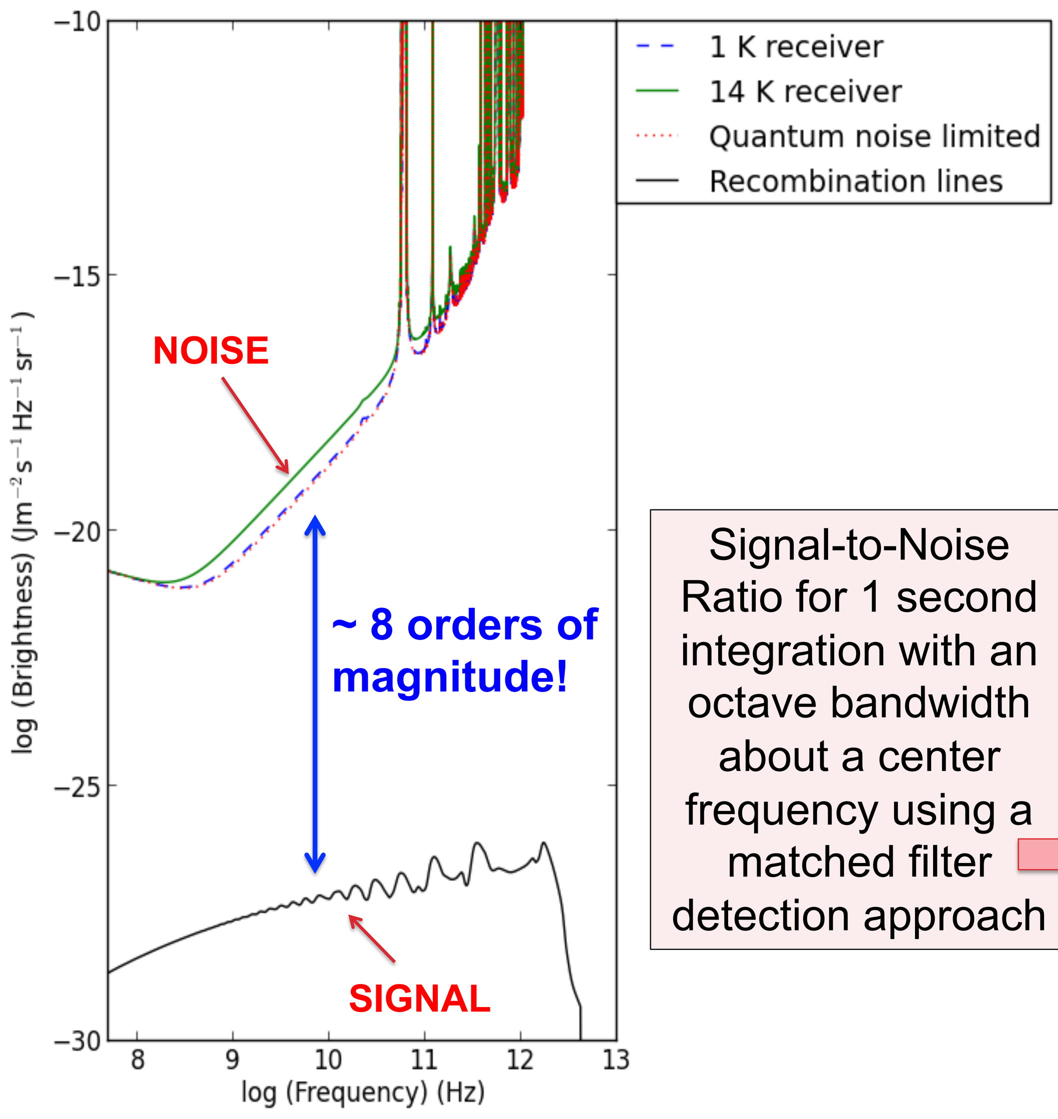
What and Why?

- Spectral distortions in the CMB arise from photons emitted during the epoch of Recombination HII → HI (500 < z < 2000) HeII → HeI (1600 < z < 3500) HeIII → HeII (5000 < z < 8000)
- In cm-wavelengths the signal is a quasi-sinusoidal ripple of amplitude ~8 nK that is buried in the sky spectrum which is 8 orders of magnitude larger
- Motivations for experimentally detecting this broad weak signal
  - Probes physics beyond the Last Scattering Surface (z ~ 1190)
  - A unique method to measure of pre-stellar He abundance
  - Constrains thermal and Ionization history of the Universe
  - Provides an independent measure of cosmological parameters

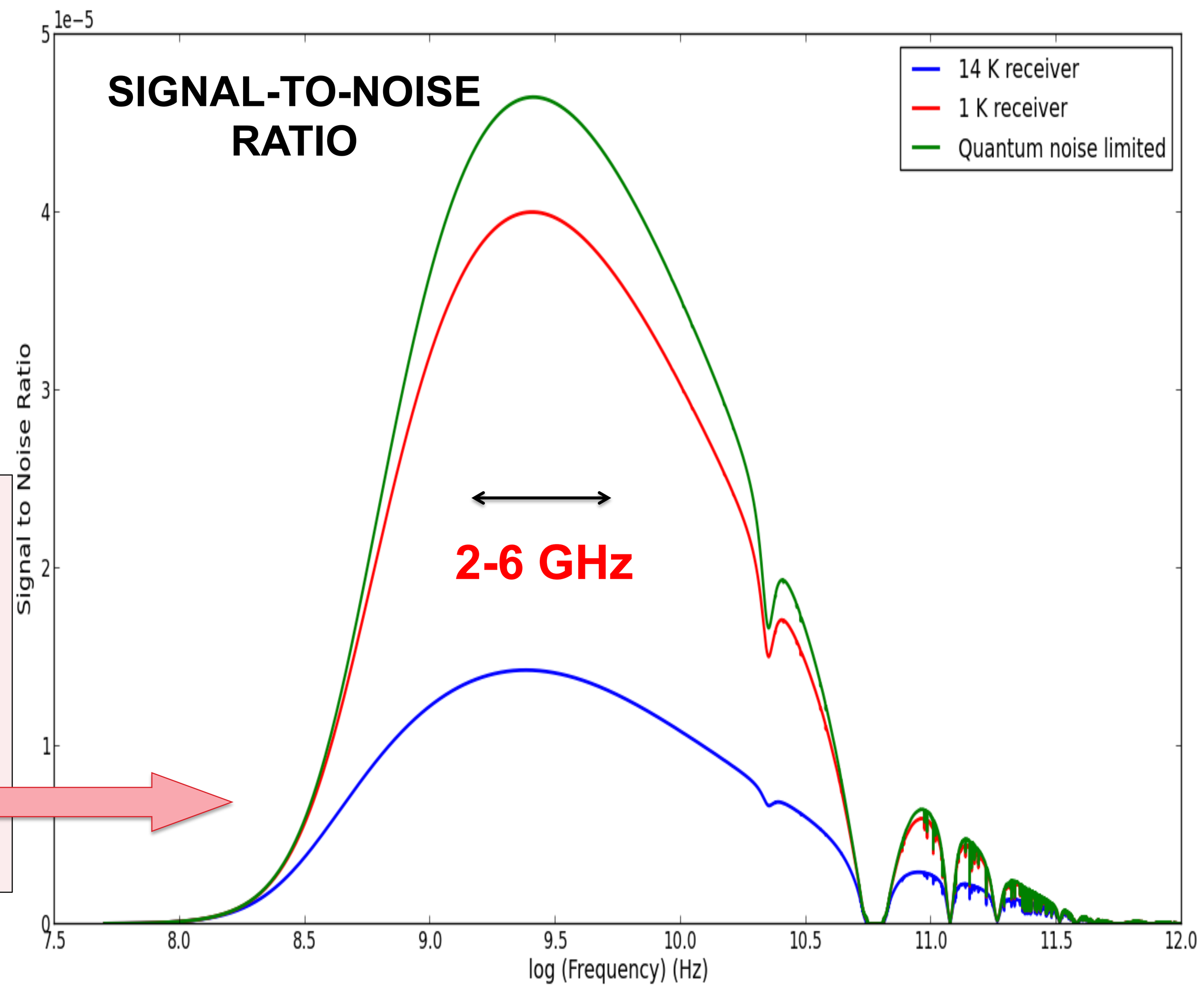
Frequency choice for ground based detection

- Signal-to-noise ratio with typical conditions at Chajnantor favours an octave bandwidth between **2-6 GHz**
- We simulate synthetic sky spectra between 3-6 GHz as recorded by a frequency independent antenna with $\cos^2$(ZA) beam
- Interpolation between all sky maps at 408 MHz, 1420 MHz and 23 GHz including effects of precession, refraction etc. to generate sky spectra
- Pipeline generates mock calibrated spectra over time whose mean temperature varies as the sky and Galactic Plane drift across the telescope beam



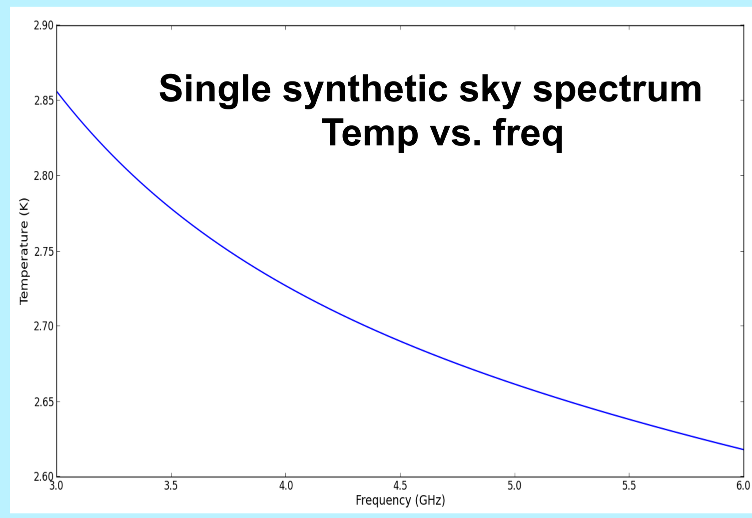


Signal-to-Noise Ratio for 1 second integration with an octave bandwidth about a center frequency using a matched filter detection approach



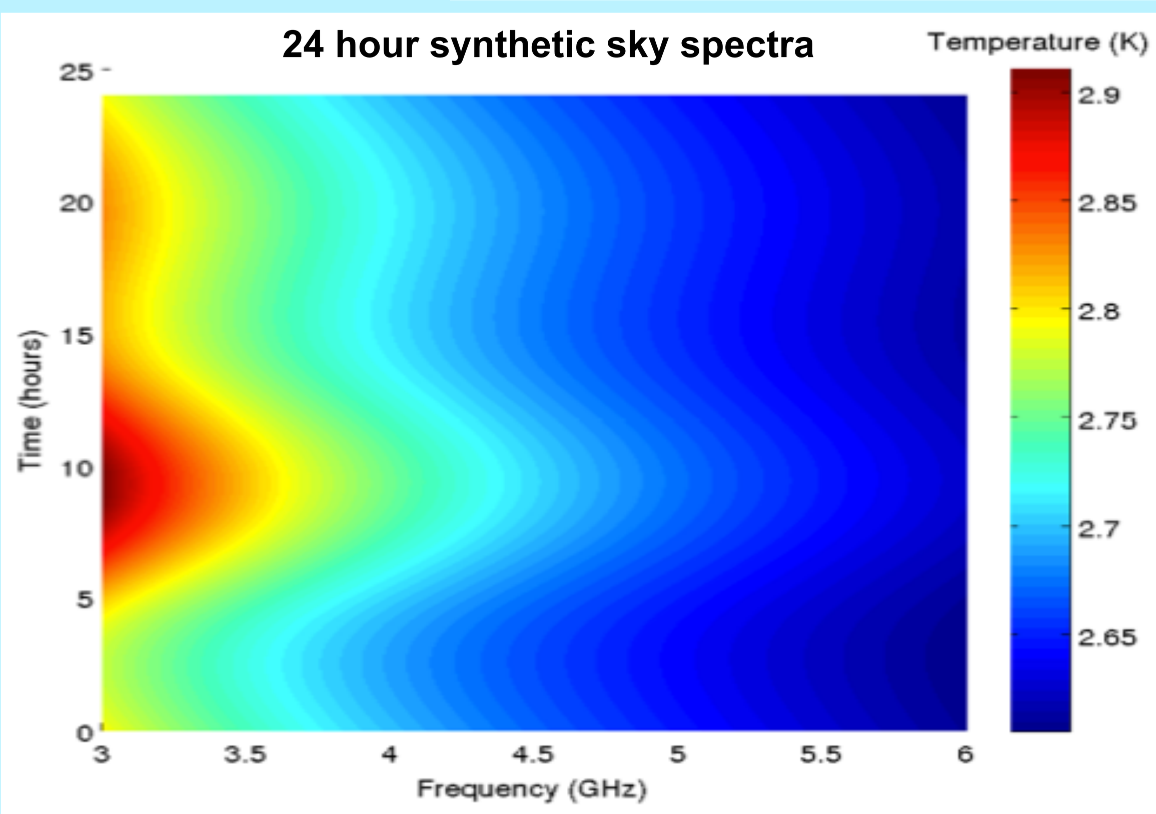
Maximally smooth Polynomial

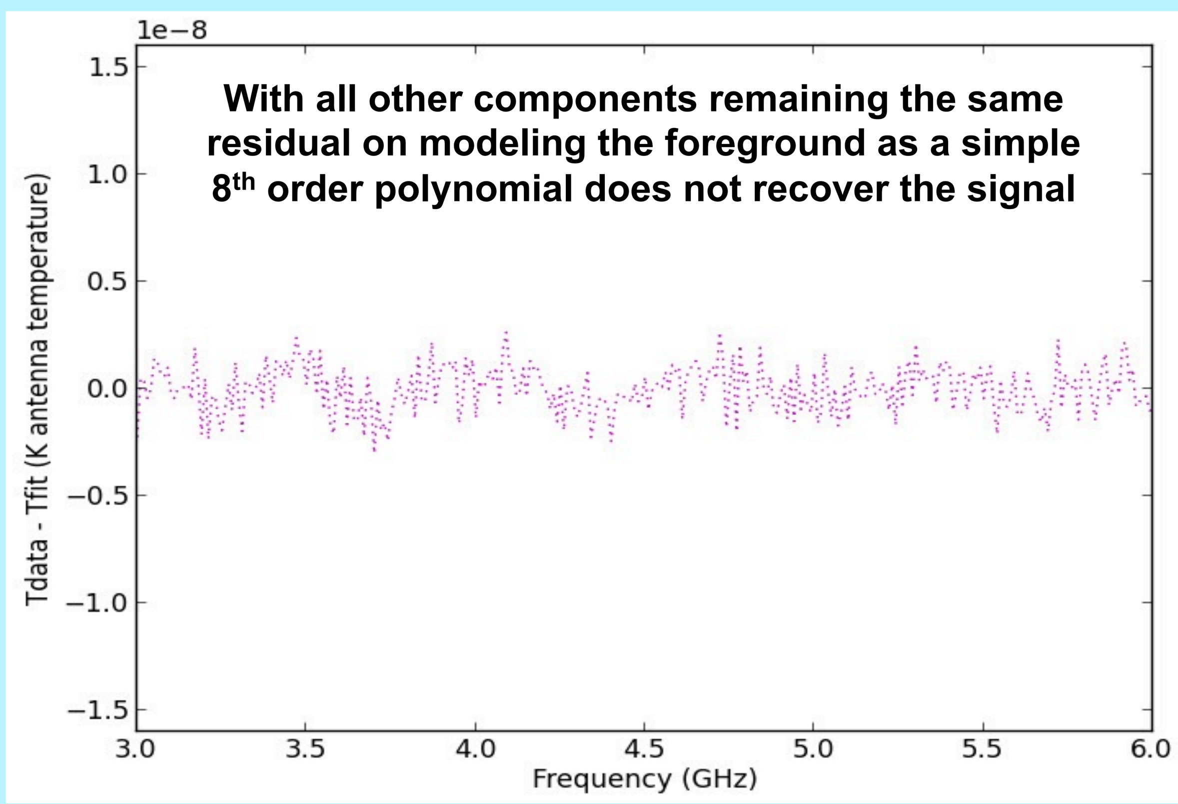
- Foreground is 'smooth'. A low order polynomial will fit out the ripple and signal cannot be recovered
- A 'Maximally smooth' polynomial has no zero crossings of higher order derivatives and does not fit to the ripple
- Modeling spectra as the sum of a blackbody component (CMB), a maximally smooth polynomial (foreground) and a term with the recombination line template multiplied by a scaling factor can successfully recover the buried recombination lines

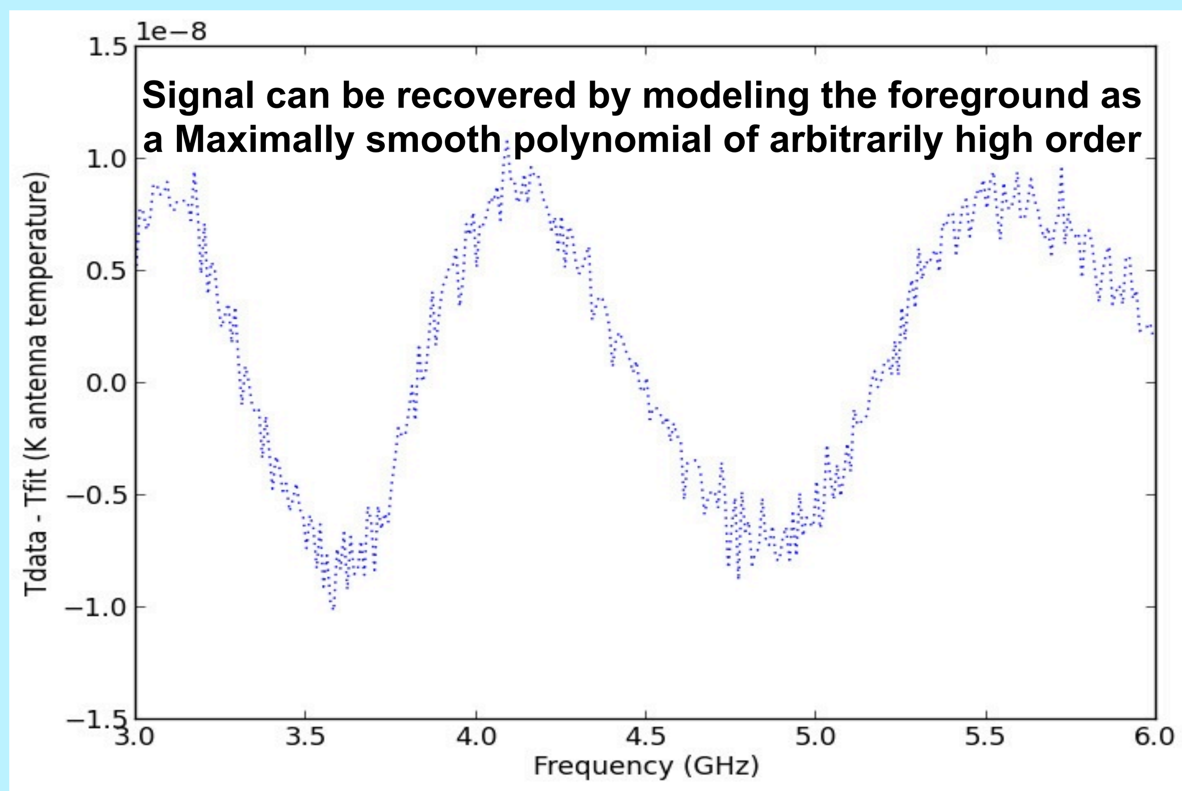


Sky temperature → CMB (Blackbody); Recombination line template weighted by scaling factor; Foreground (Maximally smooth polynomial)

$$T(\nu) = \left(\frac{h\nu}{k}\right) / \left(e^{\frac{h\nu}{kp[0]}} - 1\right) + p[1]y_{rl}(\nu) + 10^{\sum_{i=0}^{n} p[i+2](\log_{10}(\nu) - \log_{10}(\nu_0))^i}$$







Confidence in Detection

- Use Bayes factors to test whether the signal in present or absent in spectra
- Use MCMC modeling of scaling factor parameter to measure amount of cosmological recombination line signal buried in synthetic sky spectra
- The Bayes factor method testing a simpler problem requires lesser integration time compared to the more complex hypothesis tested by the MCMC method to reach the same level of confidence
- Detecting the presence of cosmological recombination lines with 90% confidence with an array of 128 elements using cryo-cooled receivers requires 255 days of integration time

APSERa

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- Array of Precision Spectrometers for the Epoch of RecombinAtion
- Project at the Raman Research Institute with a science goal of experimentally detecting signals from the epoch of Recombination
- On completion APSERa will comprise an array of 128 miniature radio telescopes operating between 3-6 GHz deployed at a radio quiet location

CONCLUSIONS

- It is feasible to experimentally detect spectral distortions in the CMB arising from cosmological Hydrogen and Helium recombination in an octave bandwidth in the 2-6 GHz frequency range
- Fitting the foreground with a Maximally smooth polynomial and using an array of 128 elements with cryo-cooled receivers these cosmological recombination lines can be detected with 90% confidence in 255 days

References: (1) Sunyaev, R. A., & Chluba, J. 2009, Astronomische Nachrichten, 330, 657 (2) Foreman-Mackey, D., Hogg, D. W., Lang, D., & Goodman, J. 2013, PASP, 125, 306 (3) Haslam, C. G. T., Salter, C. J., Stoffel, H., & Wilson, W. E. 1982, A&AS, 47, 1 (4) Reich, P., & Reich, W. 1986, A&AS, 63, 205 (5) Subrahmanyan, R., & Cowsik, R. 2013, ApJ, 776, 42 (6) Paine, S., 2004, The am Atmospheric Model, SMA Tech. Memo 152