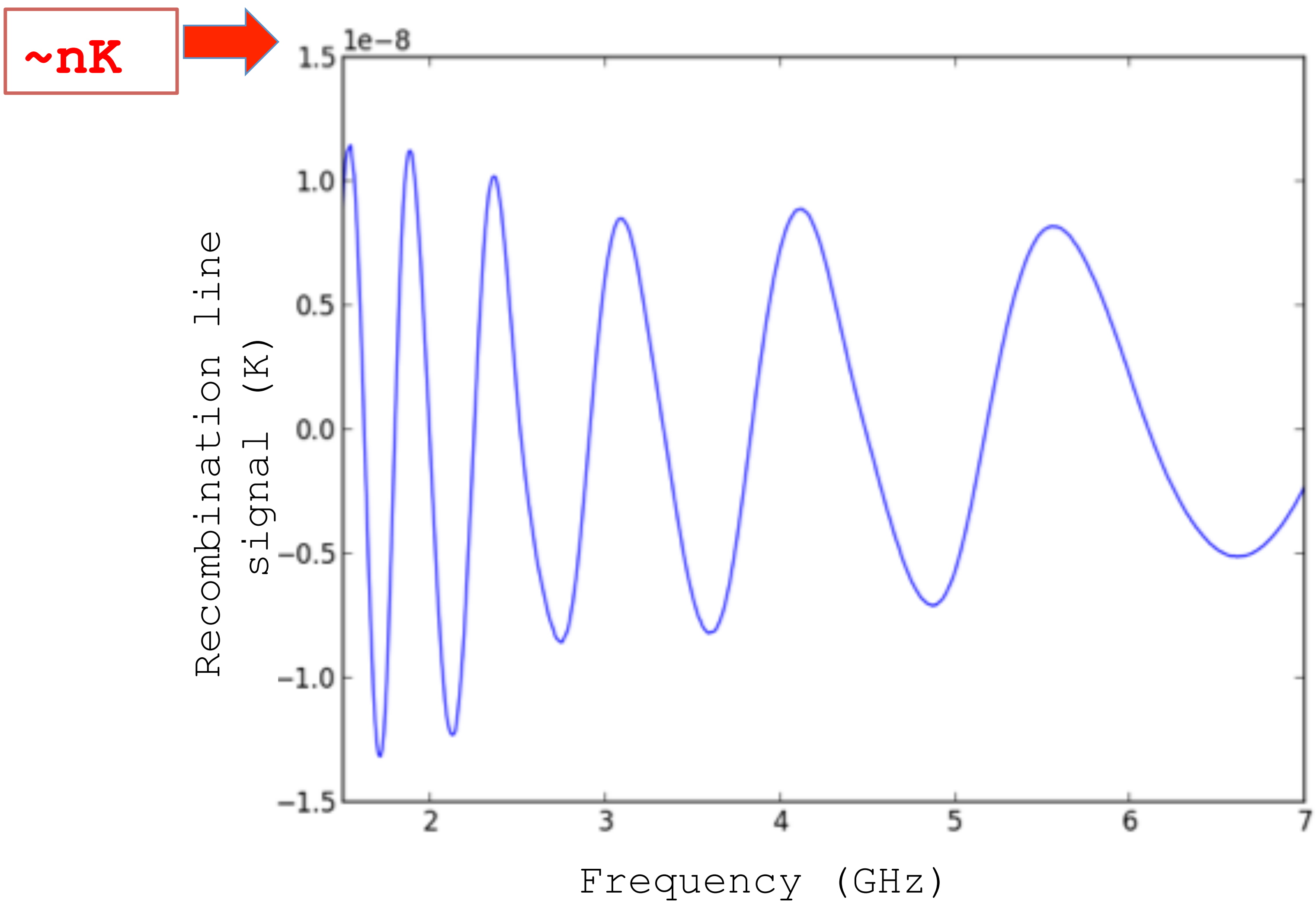
APSERa

Array of Precision Spectrometers for the Epoch of RecombinAtion

Mayuri Sathyanarayana Rao

Raman Research Institute
Bangalore

The signal we are chasing



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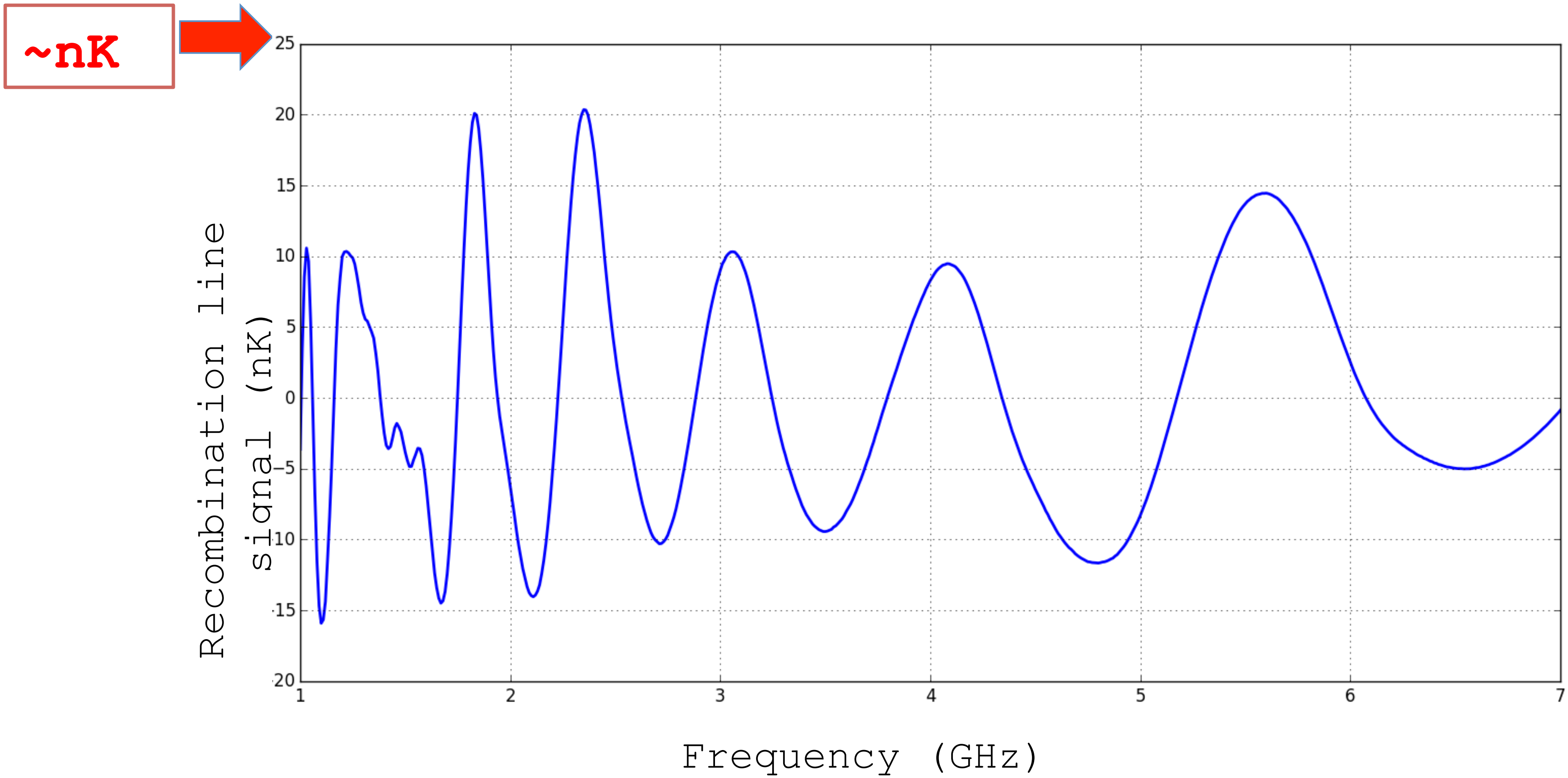


Adapted from: Chluba, J., & Ali-Haimoud, Y.,2016, MNRAS, 456, 3494

Properties

- Signal goes from 100 MHz ~ THz
- GHz: Peak-Peak amplitude ~10s nK
- Almost quasi-periodic, well defined strcuture
- Global Signal
- Unpolarized

A view of the universe

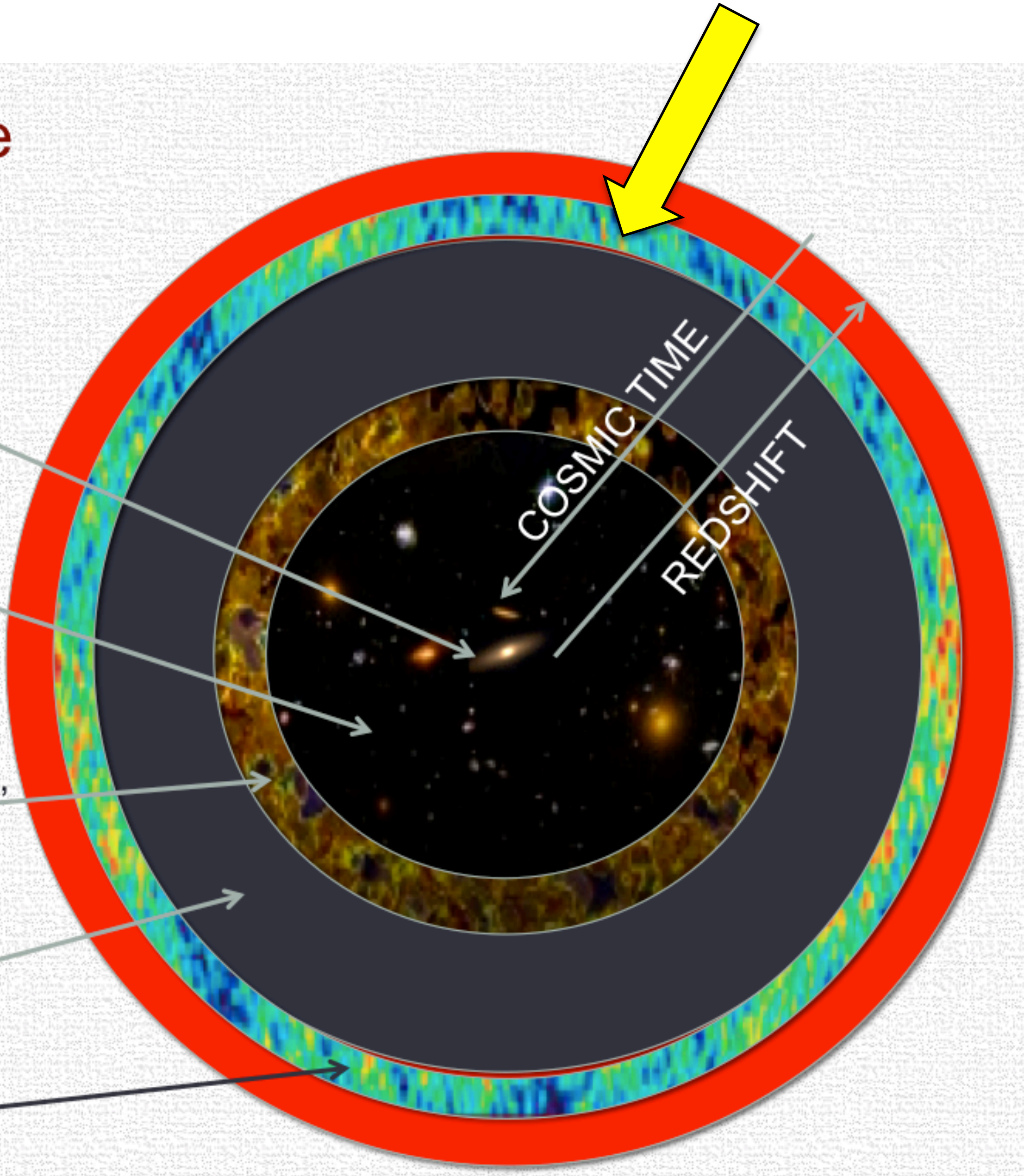
Galactic foreground:
Synchrotron, thermal
(z ~ 0)

Discrete radio sources:
AGNs, Star-forming gal.,
normal gal.
(z ~ 0-7)

21-cm from the cosmic dawn,
re-ionization
(z ~ 6-15)

21-cm from the dark ages
(z ~ 15-150)

CMB from recombination
(z ~ 1090)



The Epoch of Recombination

- What is/was it?
  - $e^- + p^+ \rightarrow H + \gamma$

- When was it?

  - HeIII → HeII $5000 \leq z \leq 8000$
  - HeII → HeI $1600 \leq z \leq 3500$
  - HII → HI $500 \leq z \leq 2000$

- Recombination occurs at redshifts $z < 10^4$
- Thermalization not effective
- There should be some ***small*** spectral distortion due to the photons released during recombination!

Why detect them?

- Confirmation of thermal, ionization history of the Universe
- Independent measure of cosmological parameters
- Experimental measurement of pre-stellar Helium abundance
- Primordial y-type distortions

First step…

We ask the question:

“ Even with an ideal instrument can we detect this signal?”

First step…

We ask the question:

" Even with an ideal instrument can we detect this signal?"

YES

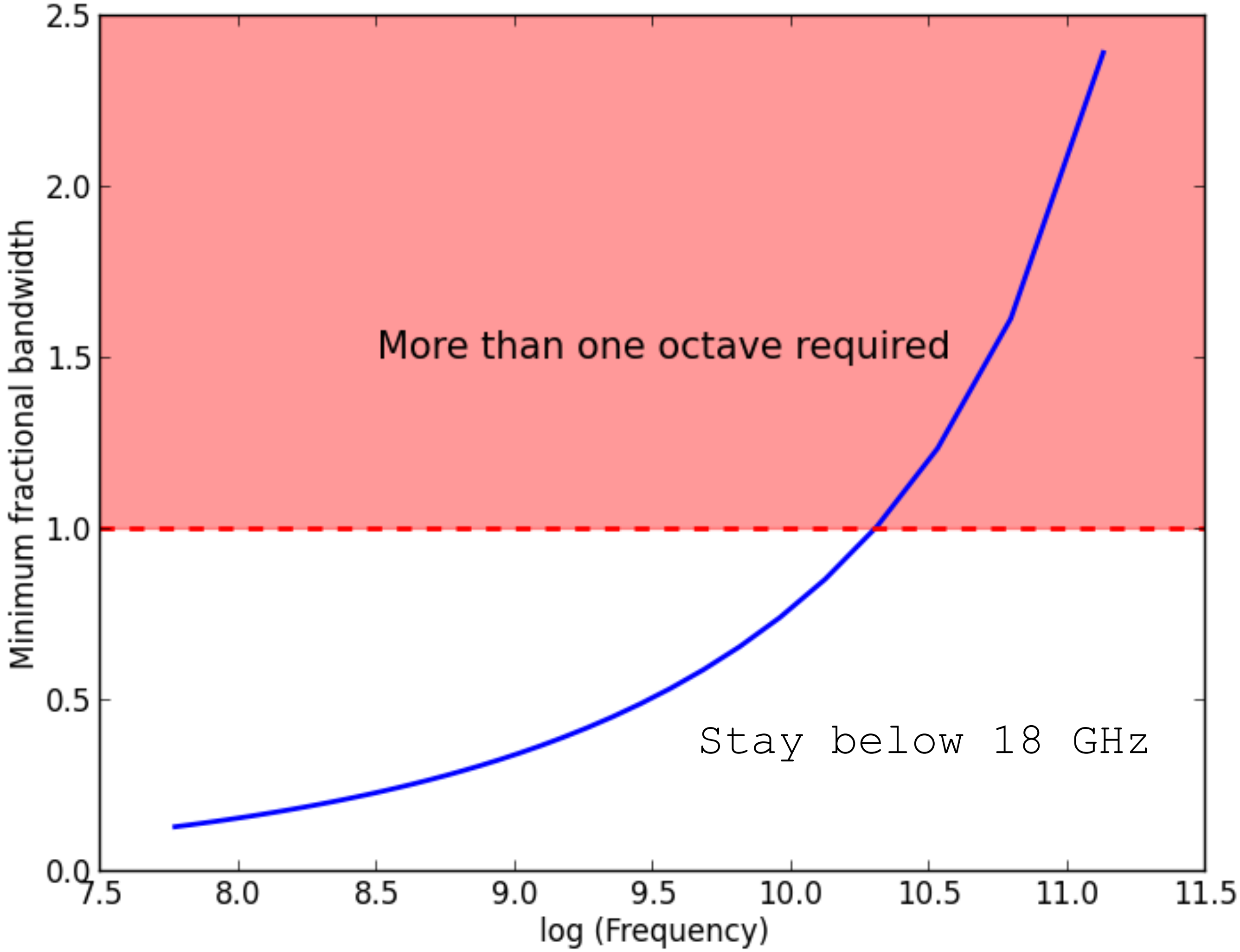
Phew!

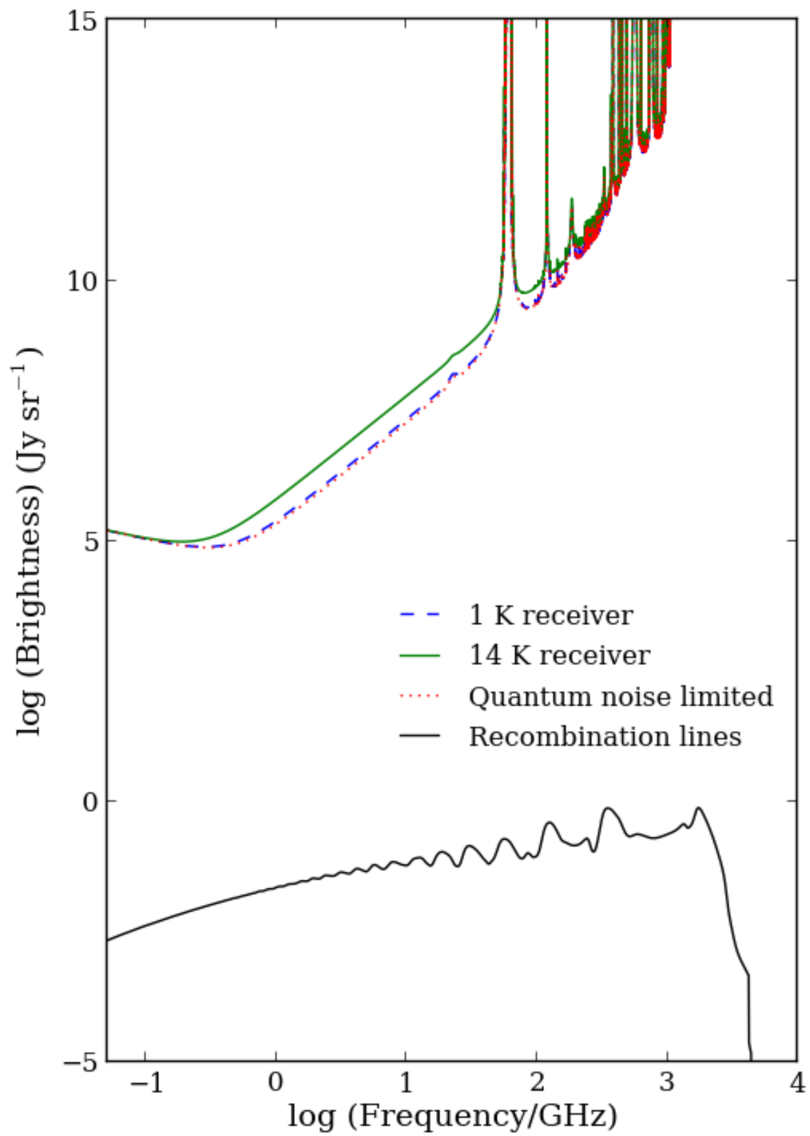
Choose the ideal frequency

Criteria

- Include at least two recombination lines in an octave
- Maximize Signal-to-Noise ratio (Ground)

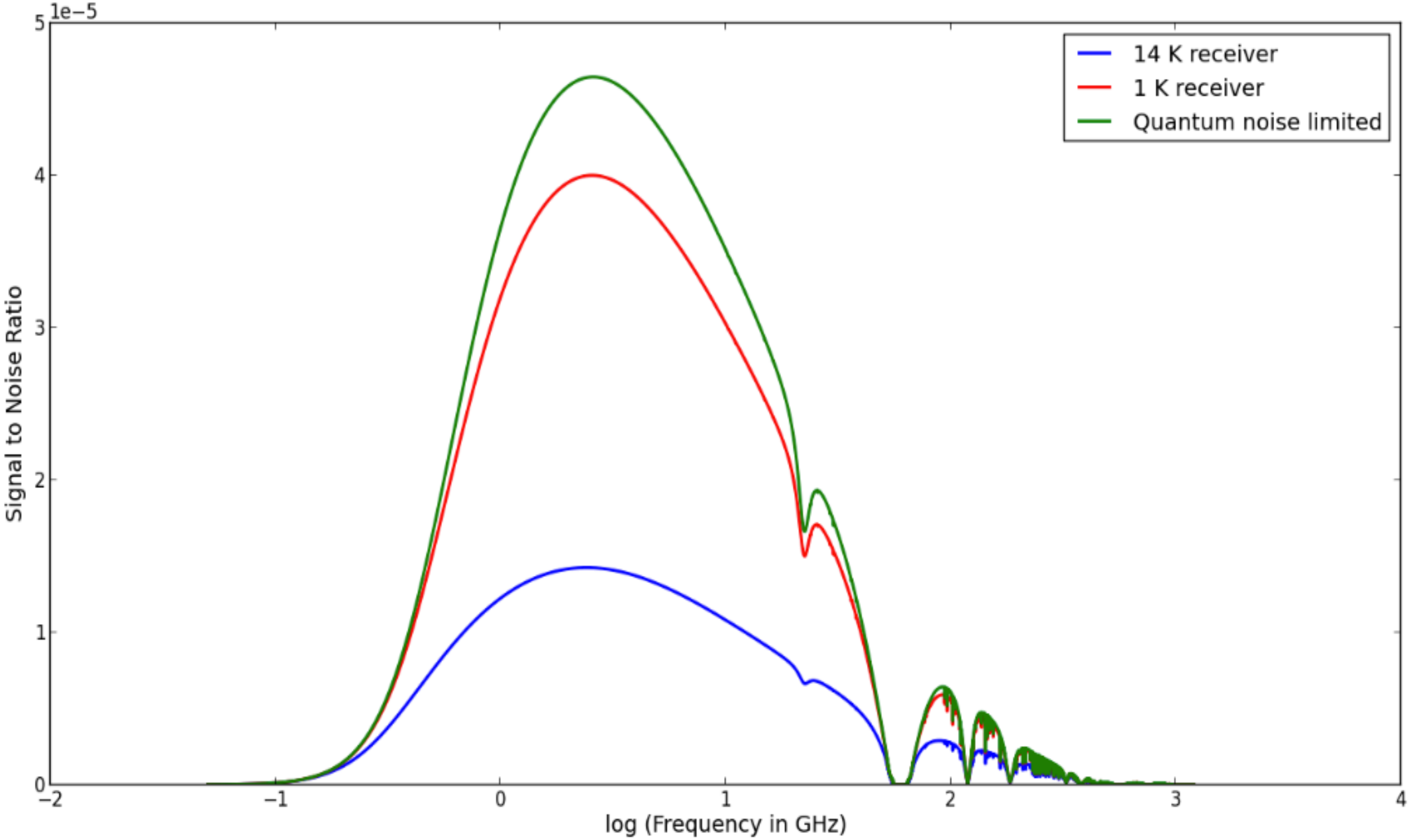
Choose the ideal frequency



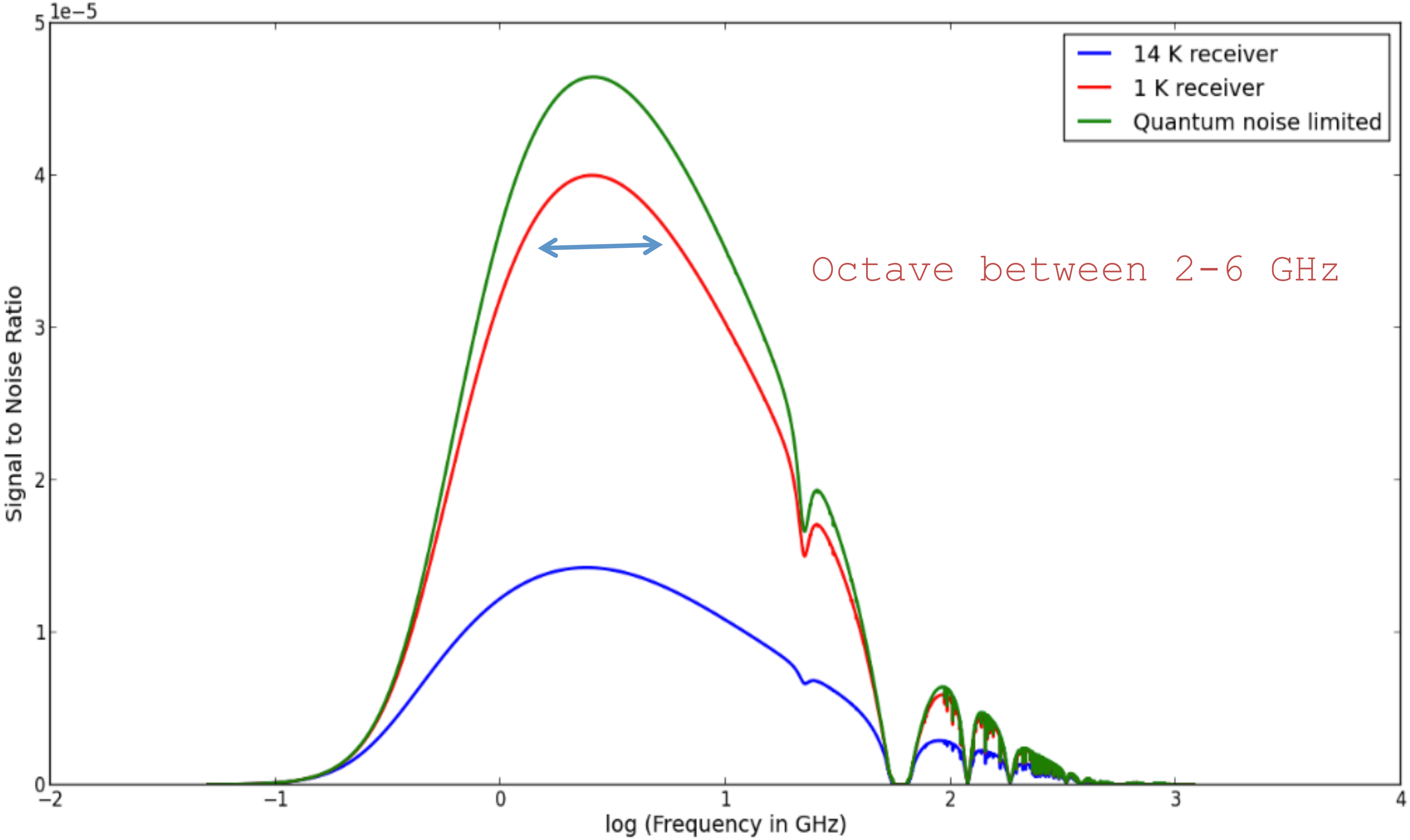


15
10
5
0
−5
−1
0
1
2
3
4
log (Brightness) (Jy sr^{-1})
log (Frequency/GHz)
1 K receiver
14 K receiver
Quantum noise limited
Recombination lines

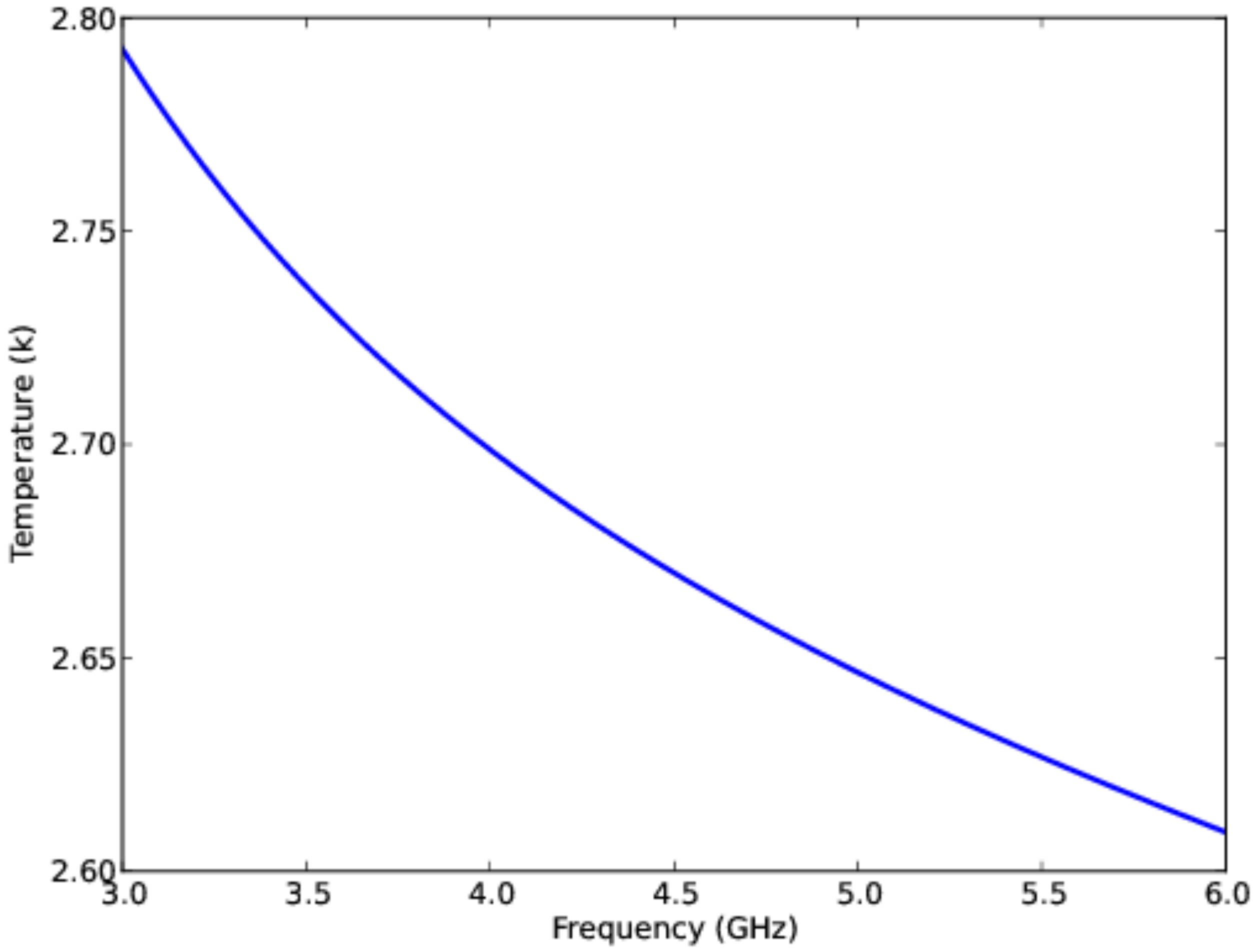
Choose the ideal frequency



Choose the ideal frequency



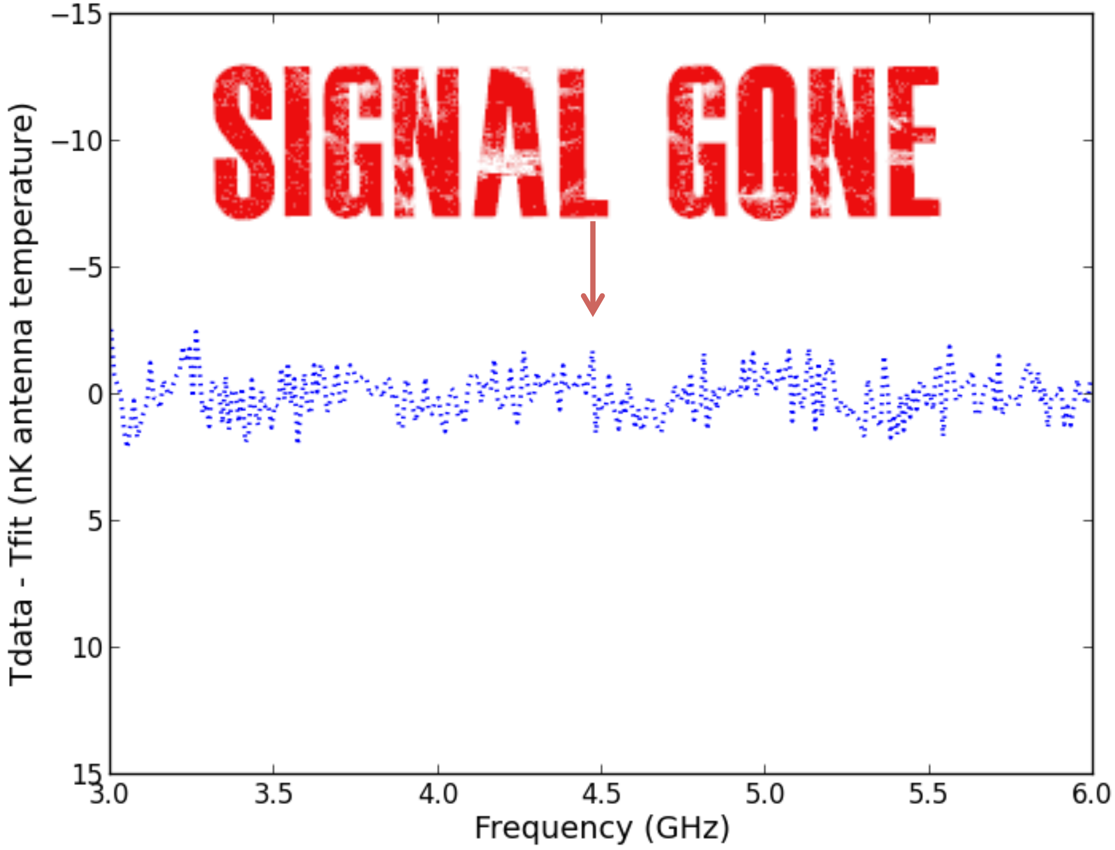
Simulate a sky spectrum



Devise a foreground subtraction method

- Foreground subtraction is a non-trivial problem
- We do not know the functional form of the foreground
- Multiple power laws summed is 'smooth'
- Assumptions:
  - Ideal, frequency independent beam

If we fit with an unconstrained polynomial



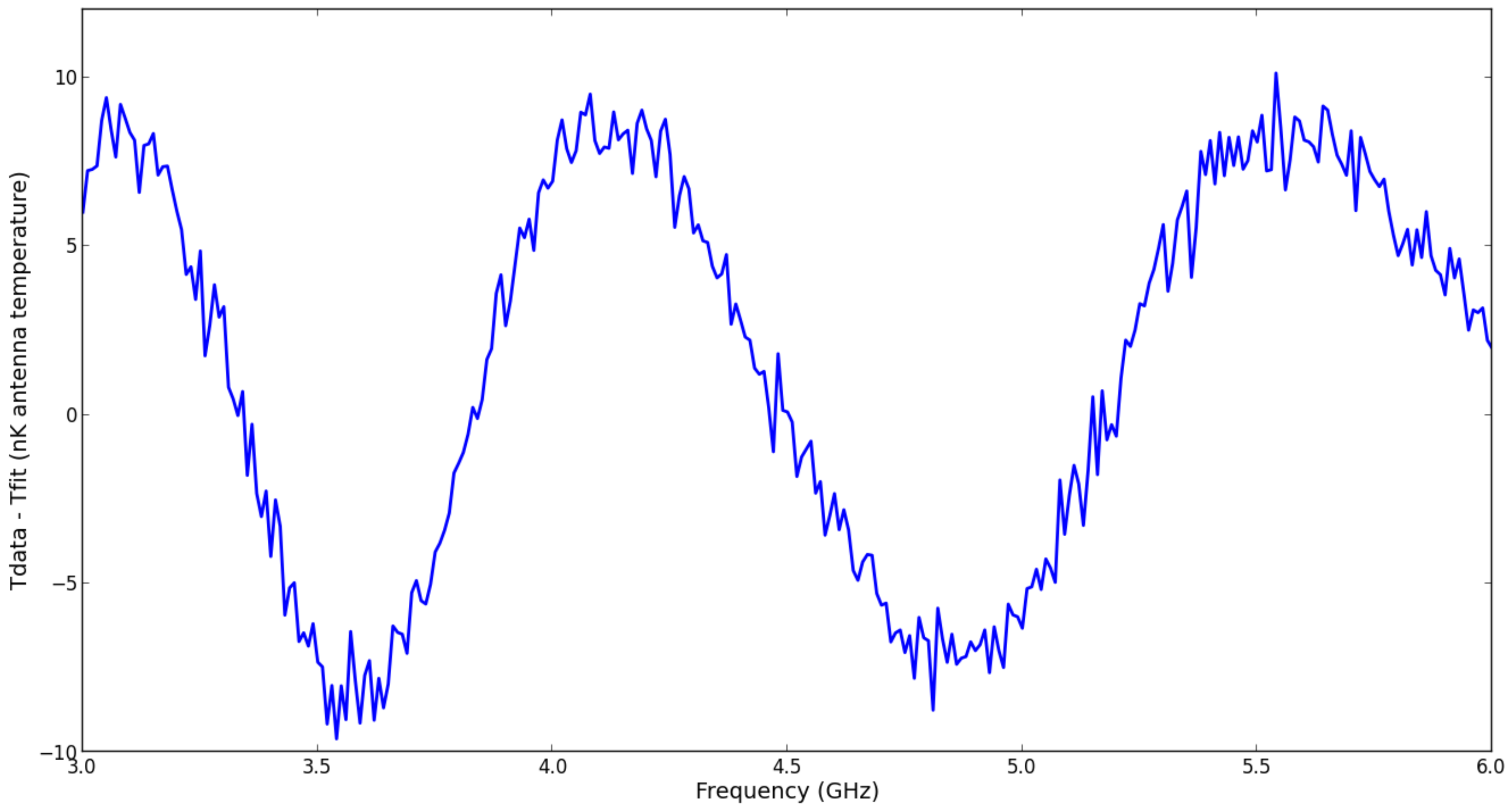
Maximally Smooth function

- Do not allow zero crossings in higher order derivatives
- Polynomial in log(ν) and log(T)space

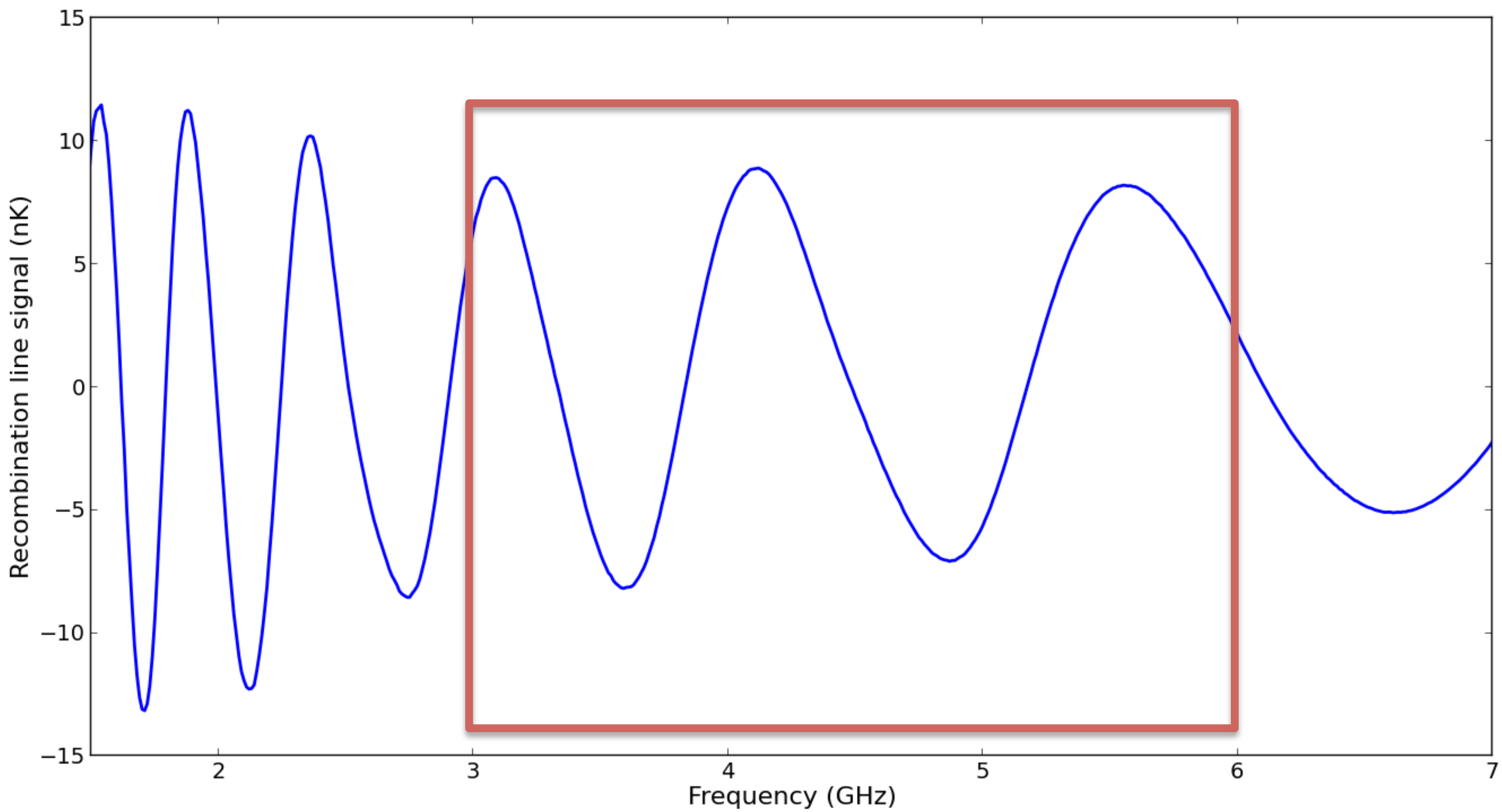
$$10^{\Sigma p[i]*\log(\nu/\nu_0)i}$$

- Taylor expansion about lowest freq. ν_0 in band
- Successive approximation

Residual on fitting with an MS function



What we expect



Statistical tests of confidence

- MCMC : Markov Chain Monte Carlo analysis
- $T(\nu) = BB\ (p[0]) + p[1]*Trec(\nu) + 10^{\Sigma p[i]*\log(\nu/\nu_0)i}$

  $(i = 2,3,\ldots., N)$
- Marginalize over all parameters except p[1], which is the amplitude of the template expected
- Estimate distribution of this parameter for different levels of noise in spectra

Bayes Factor

- Compare two models to explain the same data
- Data D, Models M1 and M2
- $$BF = \frac{P(M1 \mid D)}{P(M2 \mid D)}$$
- Model M1 (Null Hypothesis)

$$T(\nu) = BB(p[0]) + 10^{\Sigma p[i] * \log(\nu/\nu_0) i}$$

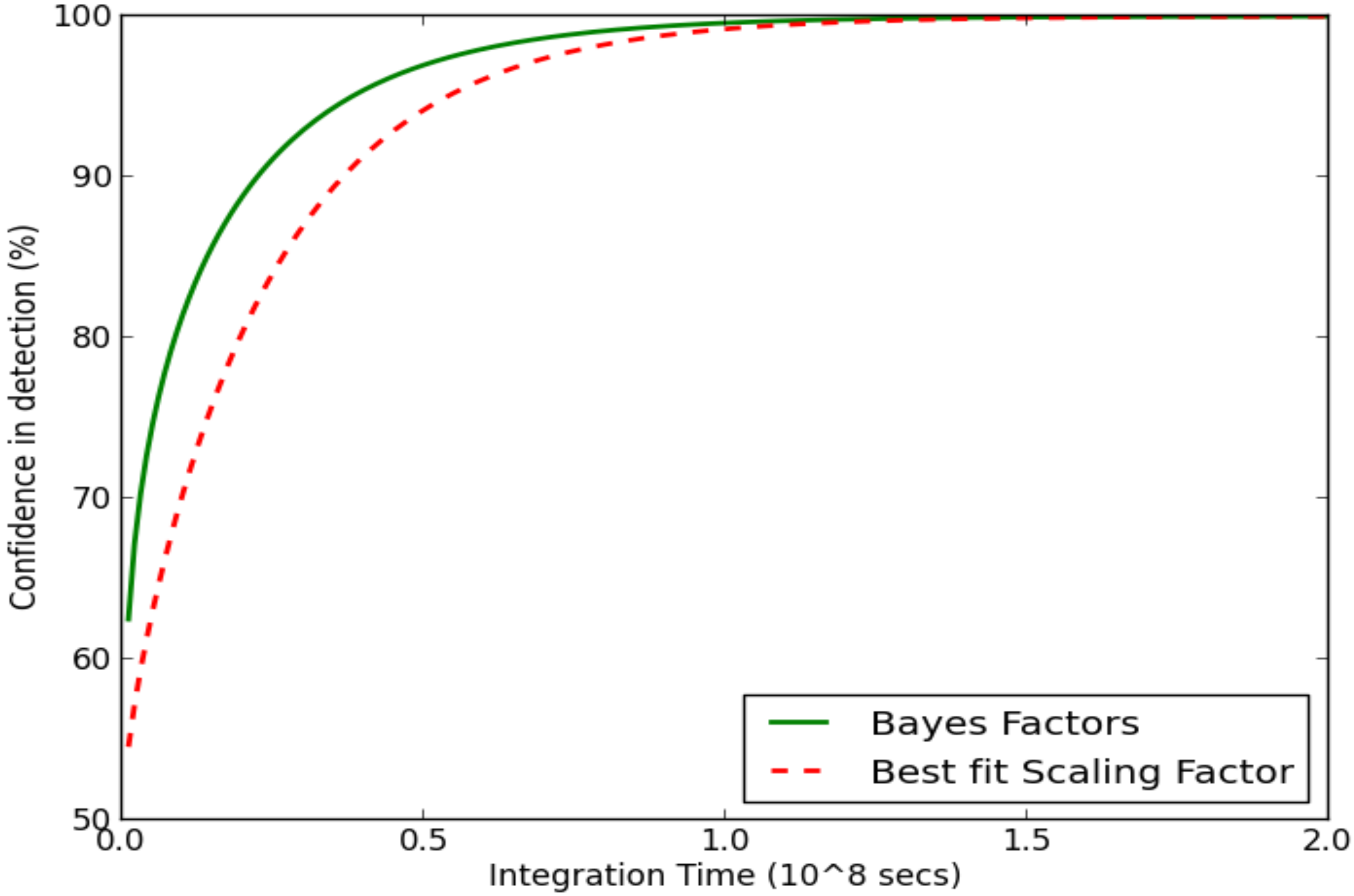
$(i = 1, 2, \ldots, N)$

- Model M2 (Alternative Hypothesis)

$$T(\nu) = BB(p[0]) + Trec(\nu) + 10^{\Sigma p[i] * \log(\nu/\nu_0) i}$$

$(i = 1, 2, \ldots, N)$

And the results are in



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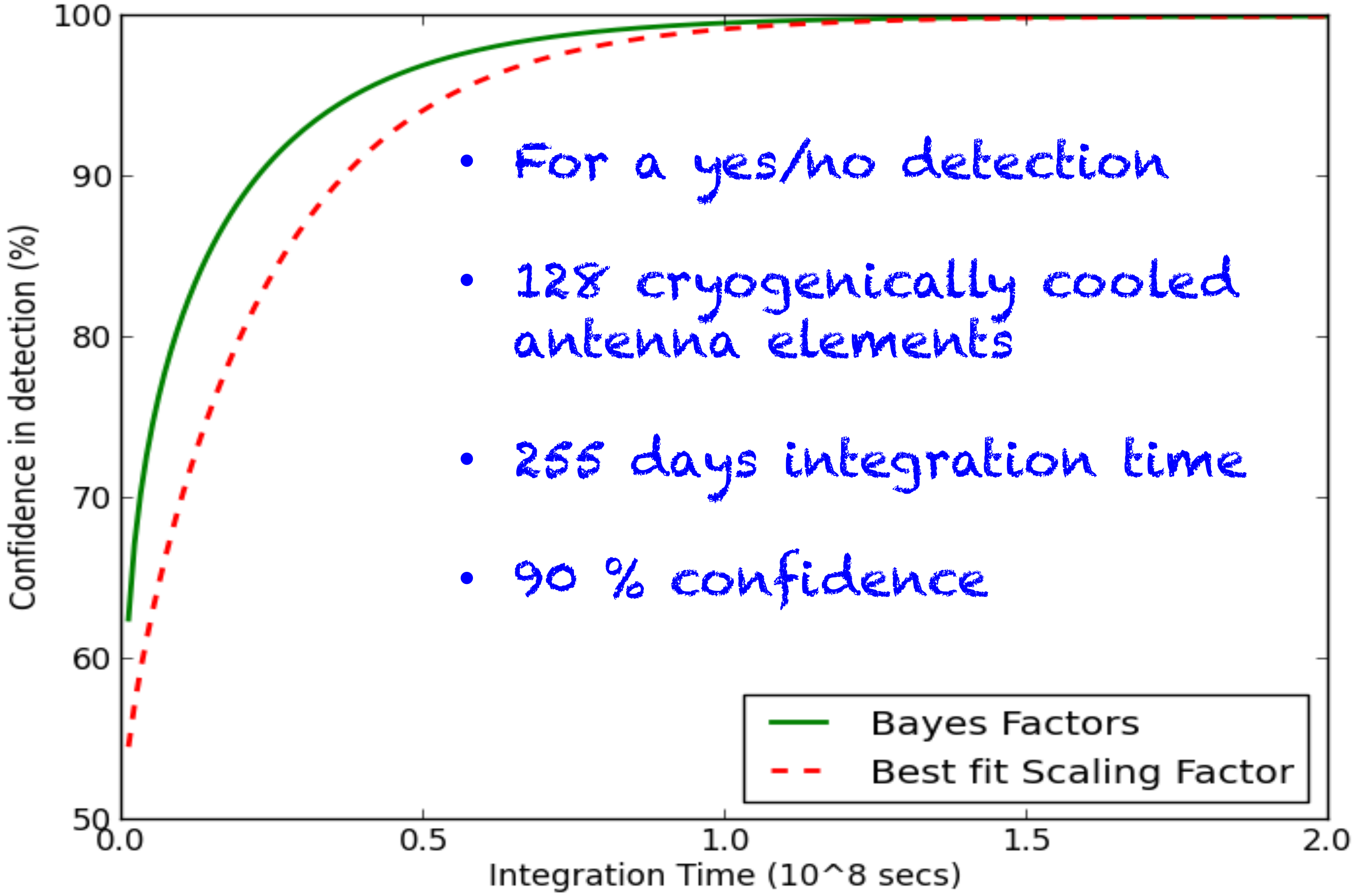

- For a yes/no detection
- 128 cryogenically cooled antenna elements
- 255 days integration time
- 90 % confidence

Take away

- We want to detect signals arising from the epoch of recombination
- We have devised an algorithm to model the intervening foregrounds. This is the Maximally Smooth.
- With an array of 128 cryogenically cooled radio telescopes we can detect the signal with 90% confidence in about one year.

LOTS OF WORK TO BE DONE!!!

Take away

- We want to detect signals arising from the epoch of recombination
- We have devised an algorithm to model the intervening foregrounds. This is the Maximally Smooth.
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IT MAKES SENSE TO DO THE

LOTS OF WORK TO BE DONE!!!

APSERa

Array of Precision Spectrometers for the Epoch of RecombinAtion

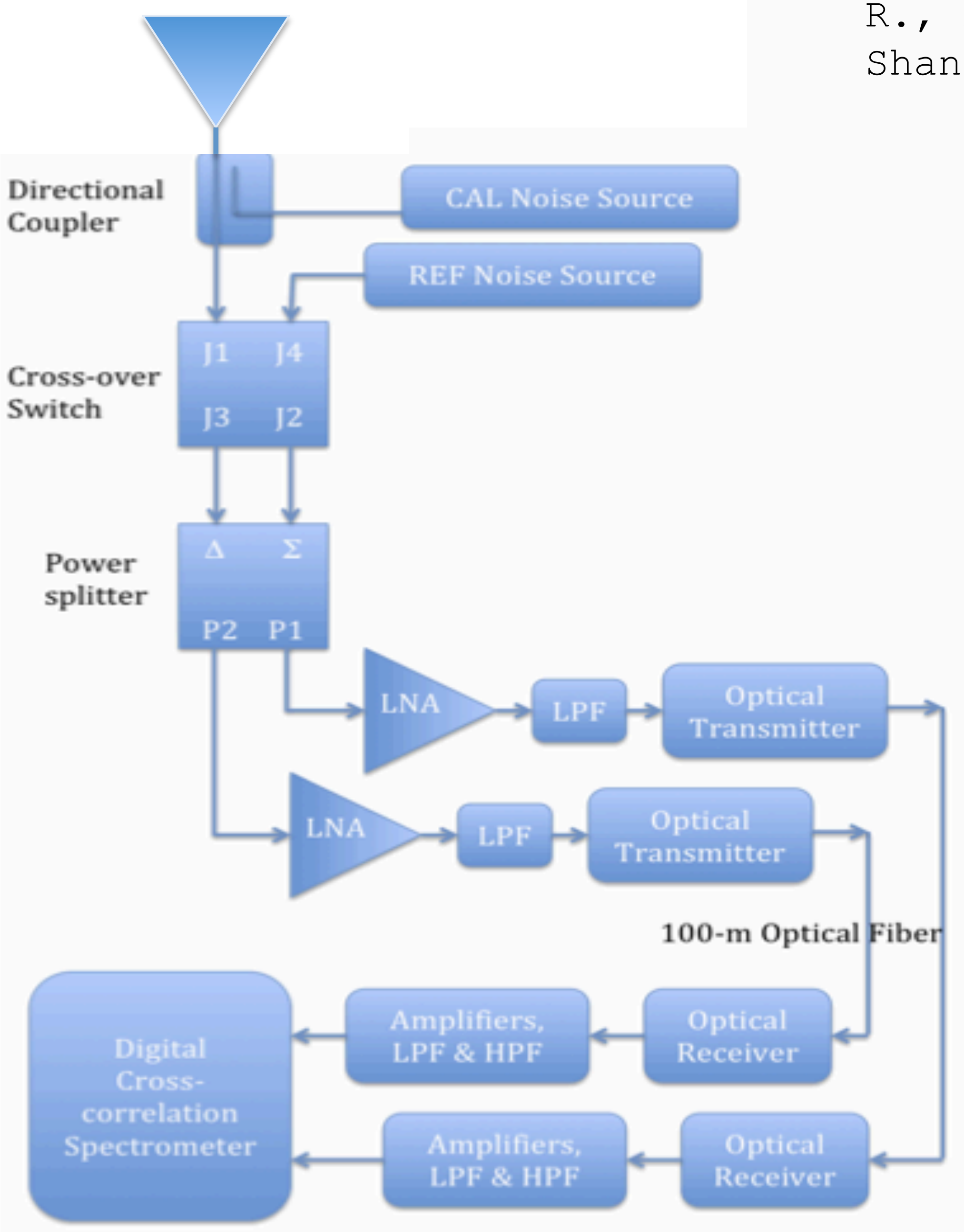
http://www.rri.res.in/DISTORTION/

APSERa

Prototype element of array

- 2 – 4 GHz
- Correlation spectrometer
- Being designed and built at RRI

Courtesy: Patra, N., Subrahmanyan, R., Raghunathan, A., & Udaya Shankar, N. 2013, ExA, 36, 319



- Noise injection to provide bandpass calibration and differential measurement
- Correlation spectrometer removes uncorrelated noise in the signal path
- Subtracting measurements from different switch states removes correlated (noise) power
- FX correlation spectrometer

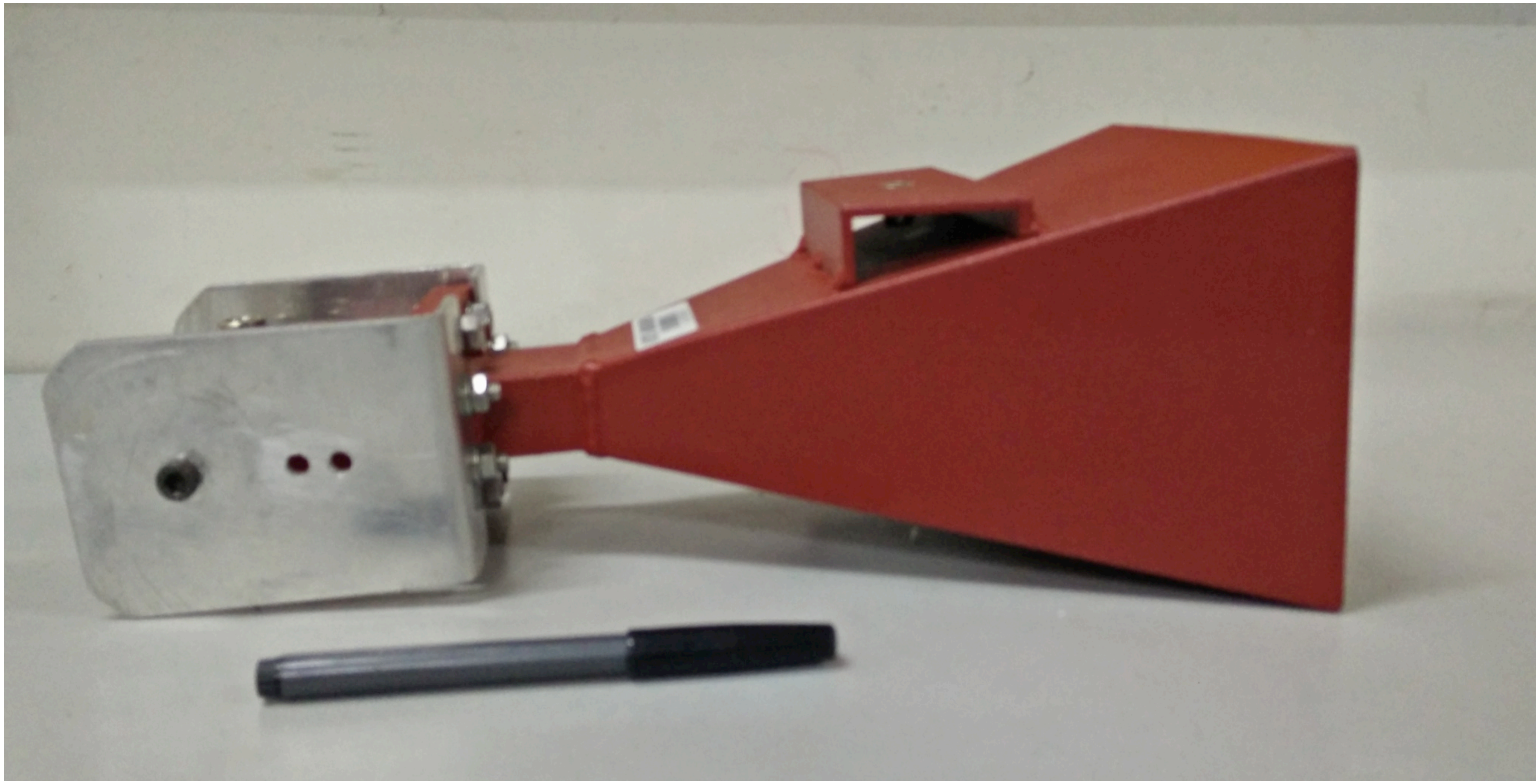
Antenna

Specifications:

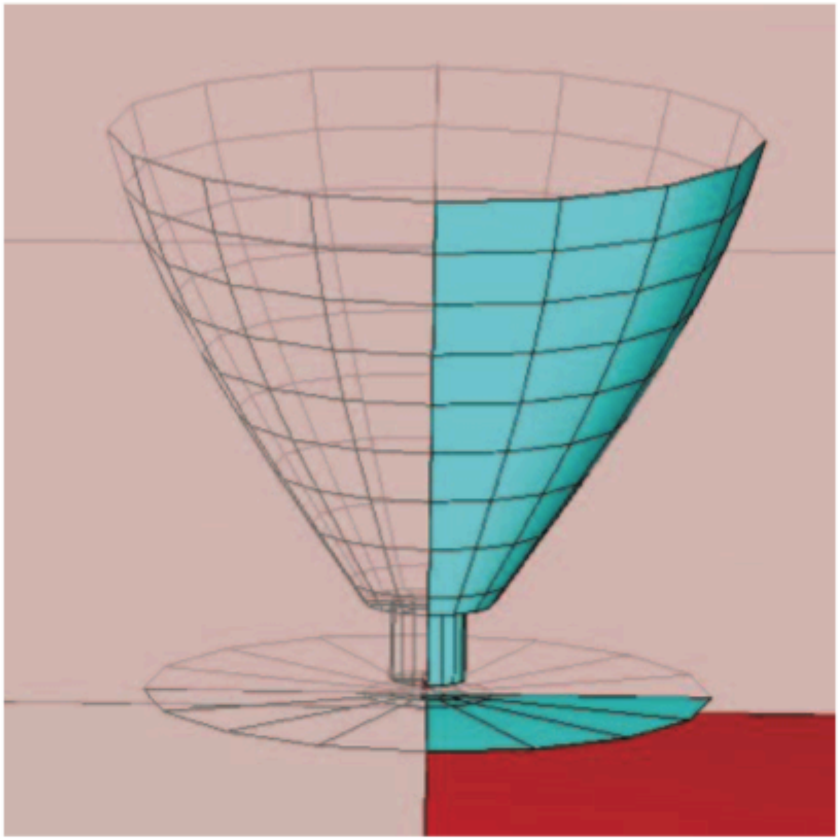
- Frequency independent over 2-4 GHz
- Smooth return loss characteristics

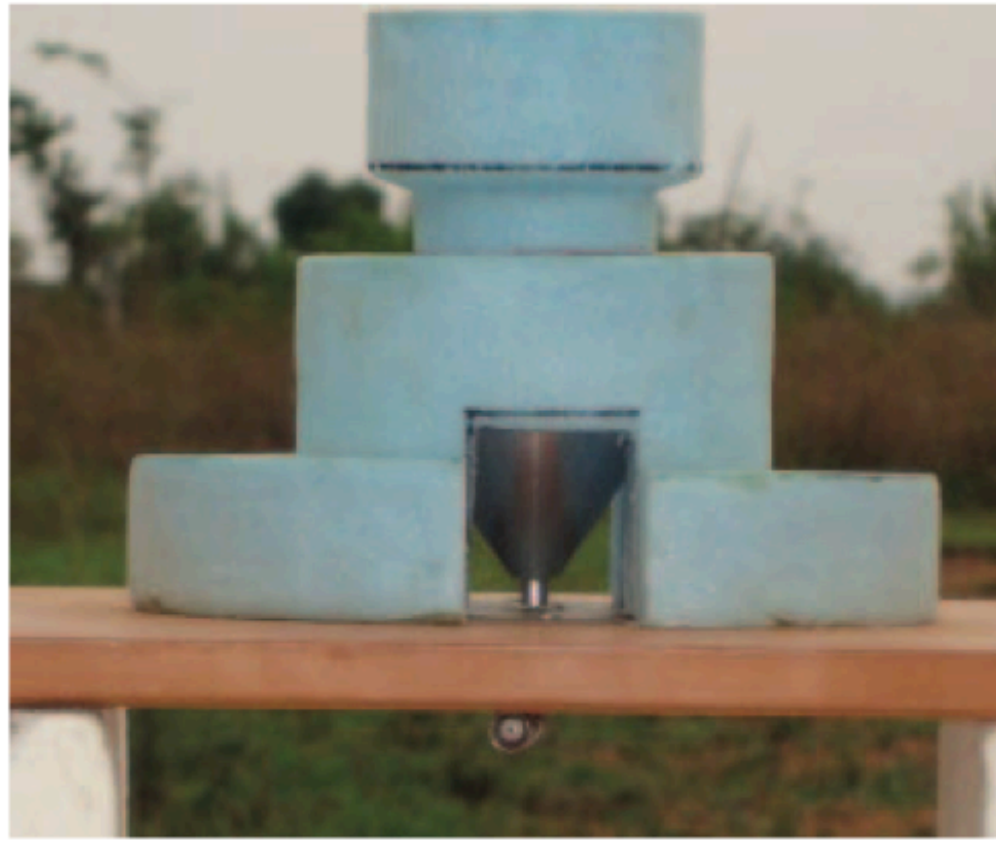
Both these characteristics help in avoiding spurious spectral features

Antenna



Antenna

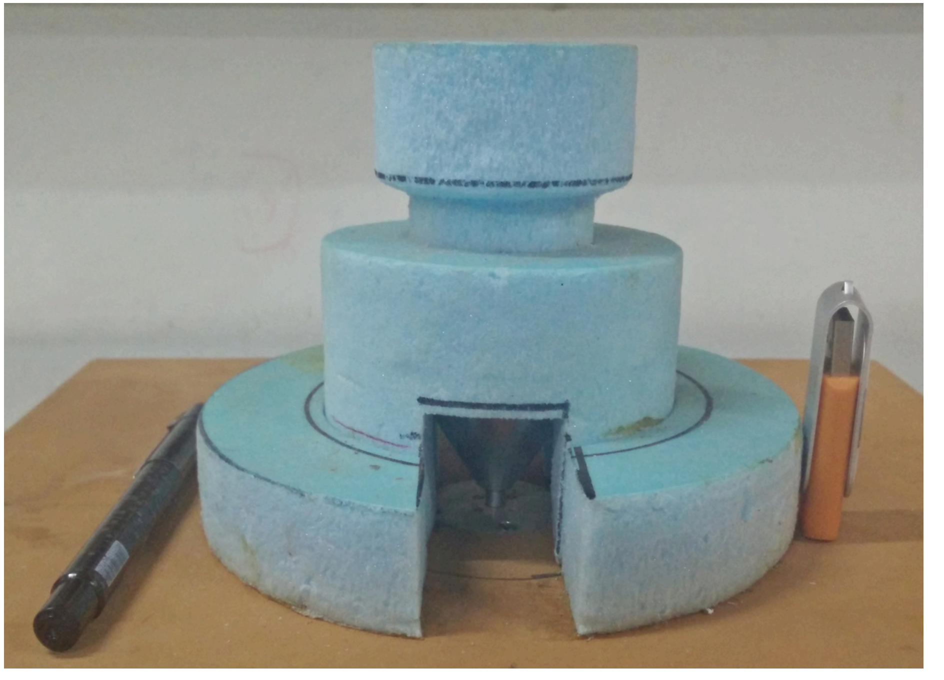




Raghunathan, A. ; Shankar, N.U. ; Rao, M.S. ; Subrahmanyan, R. 2015 Proceedings of the IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), 7-11 Sept. 2015, Turin, Italy. Page 949 - 95

Antenna

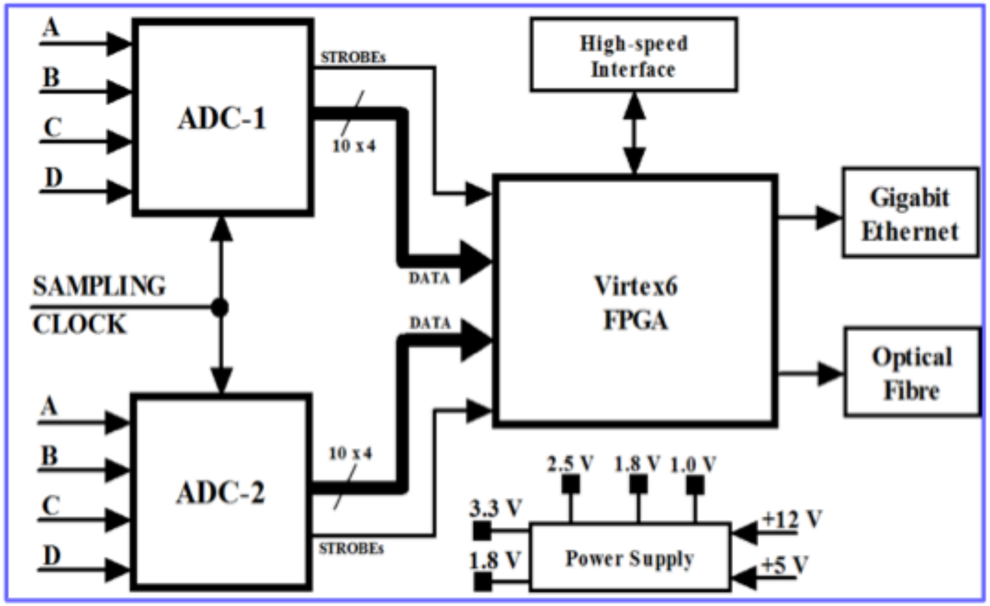
- Short monopole at all frequencies
- Sinusoidal profile helps achieve frequency independence
- Antenna height ~4cm, disc radius ~2cm
- Return loss better than 15 dB and smooth to 1% level
- HPBW has ~10% variation across the band



Correlator


ERA - SPECTROMETER
RF INPUT
TO
ADC-2(I)
ADC-2(Q)
ADC-1(Q)
POWER
GPS
CONTROL

Digital Signal Processing platform (pSPEC) built around multi-GSps ADCs and Virtex 6 FPGA



ADC	FPGA
* EV10AQ190CTPY, Quad ADC,	* XC6VSX315T, High-performance Logic with advanced serial connectivity
* 10-bit, 1.25 GSps per channel	* 1344, advanced DSP48E1 slices
* ABW = 3 GHz, V_{p-p} = 500 mV	* 20, 6.6 Gbps Transceivers
* 1-Ch, 2-Ch & 4-Ch modes of operation	* 413, 36 kb RAMs / 826 18kb RAMs

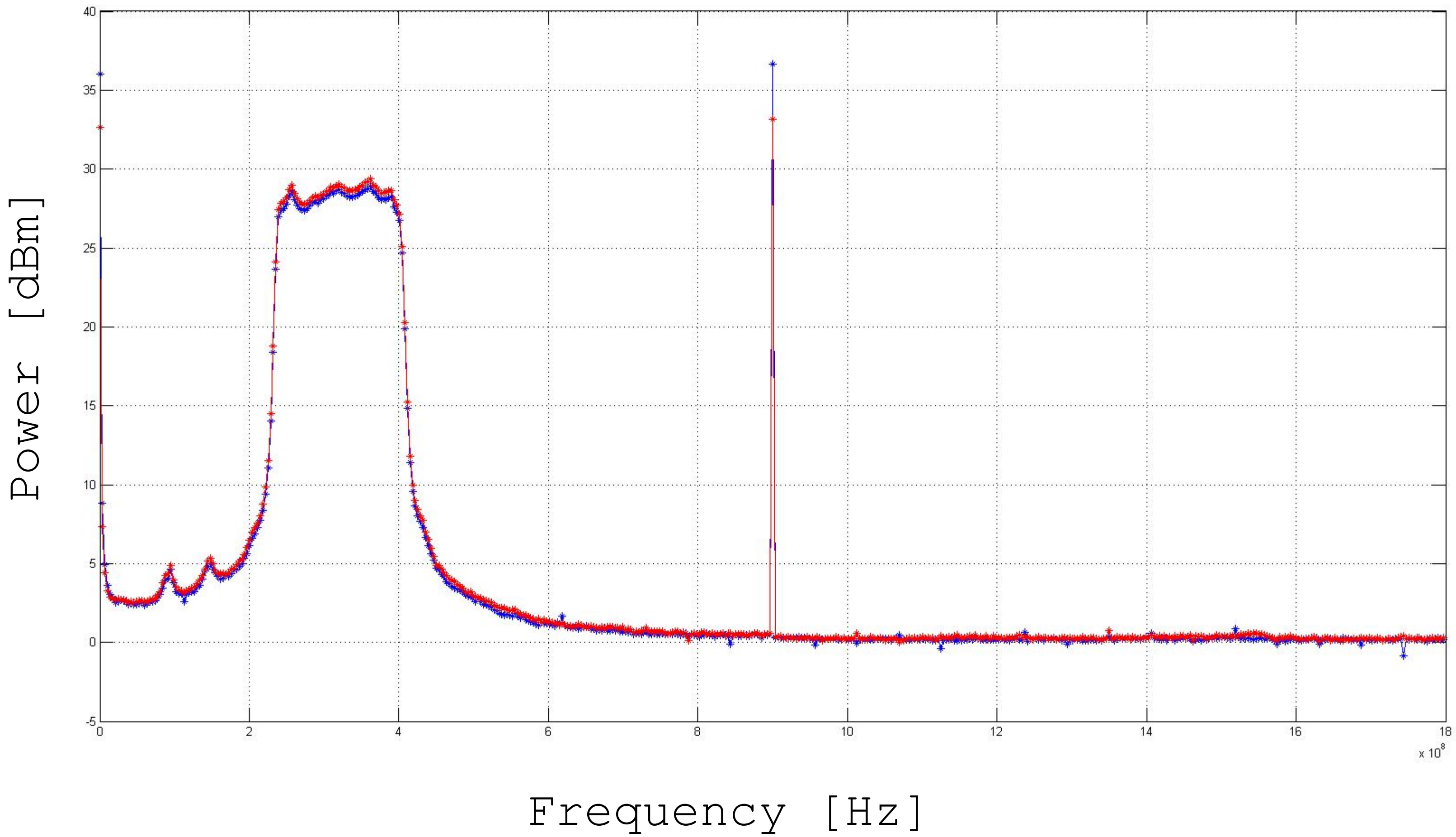
- Processing of 4 analog signals at Fs = 2 GSps (2 ADCs in time- interleaved mode)

Courtesy: B S Girish and Srivani K.S

Correlator

- Achieving perfect I-Q throughout GHz is challenging
- Results in unavoidable image spectral features in spectrum
- Non-IQ scheme places higher demand on samplers to achieve wide bandwidths

Correlator


40
35
30
25
20
15
10
5
0
-5
0
2
4
6
8
10
12
14
16
18
x 10^8
Power [dBm]
Frequency [Hz]

APSERa on its way

- Antenna design being improved upon
- Analog scheme identified, will evolve
- Digital correlator implemented with two architectures. Samplers will be replaced, FPGA chip will be upgraded
- System integration and field tests will begin shortly

We're warmed up for the get set go!

People

- Ravi Subrahmanyan (RRI)
- N Udaya Shankar (RRI)
- Jens Chluba (University of Manchester)
- Saurabh Singh (RRI)
- Srivani K S (RRI)
- Girish B S (RRI)
- Somashekar R (RRI)
- Raghunathan A (RRI)
- Divya J (RRI)
- Nivedita S (RRI)

Thank you