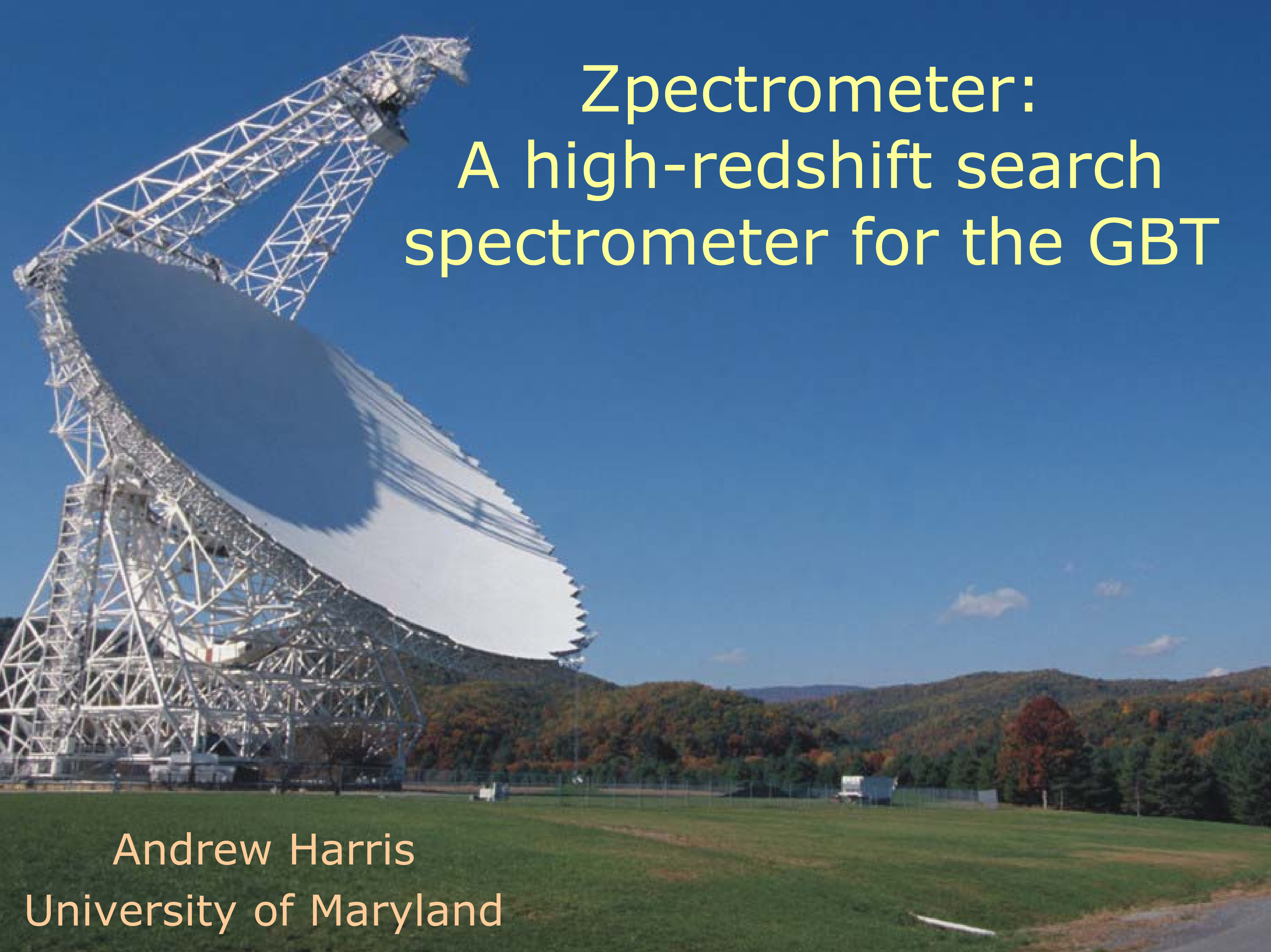


Zpectrometer: A high-redshift search spectrometer for the GBT

Andrew Harris
University of Maryland

Workshop question and talk outline

- What unique science can the GBT do *now*?
  - Explore the high redshift universe
  - *Find redshifts of young galaxies*
- Outline:
  - Quick view of spectroscopic search strategy
  - Straightforward GBT redshift coverage
  - WASP: wideband microwave spectrometer
    - Principle of operation
    - Performance
  - System architecture
  - Minimum WASPs' nest for the GBT

A practical, targeted project with a execution timescale of about one year.

Galaxies in the formation era: a plausible search scheme

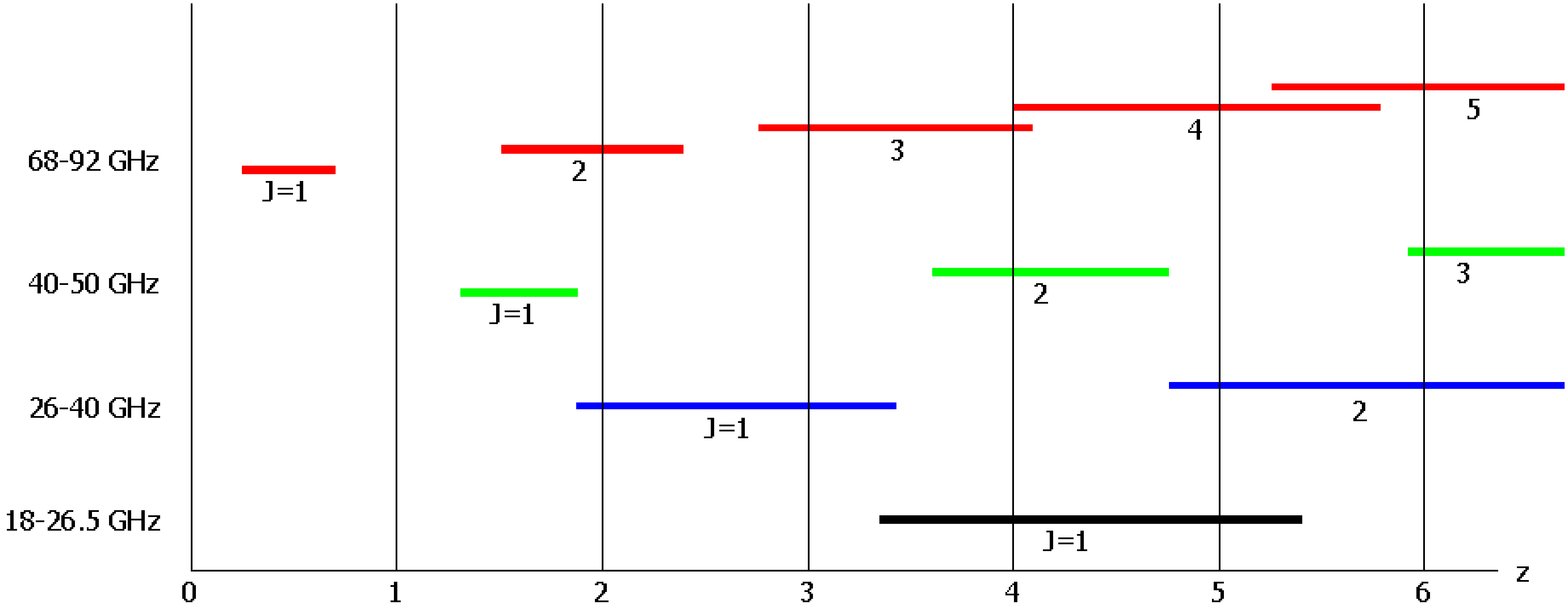
1) Find targets in dust continuum
   - UPenn camera at GBT, BoloCam on CSO or LMT, MAMBO bolometer at 30 m, SCUBA at JCMT, Herschel …
   - Large area-bandwidth product
2) Find line velocity with spectroscopy – search over very broad band
   - Search at target wavelength
   - Large area-bandwidth product
3) Then use interferometers to get spatial detail
   - Large area, high spatial and spectral resolution

Science goals for single-dish observations

- Find very weak sources
- Find precise redshifts through the peak of star formation and beyond
- Get first-cut information on dynamics

None of these require many spectral resolution elements across the line

z-coverage for GBT front-ends



Low-J CO transitions:

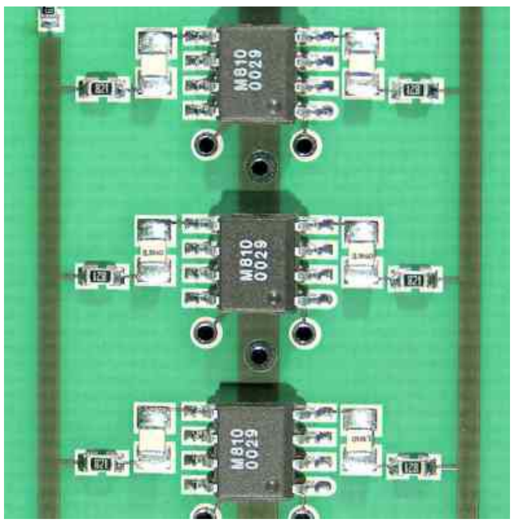
- Excitation conditions show disks, nuclei, everything
- Receivers, telescopes, atmosphere better at lower frequencies

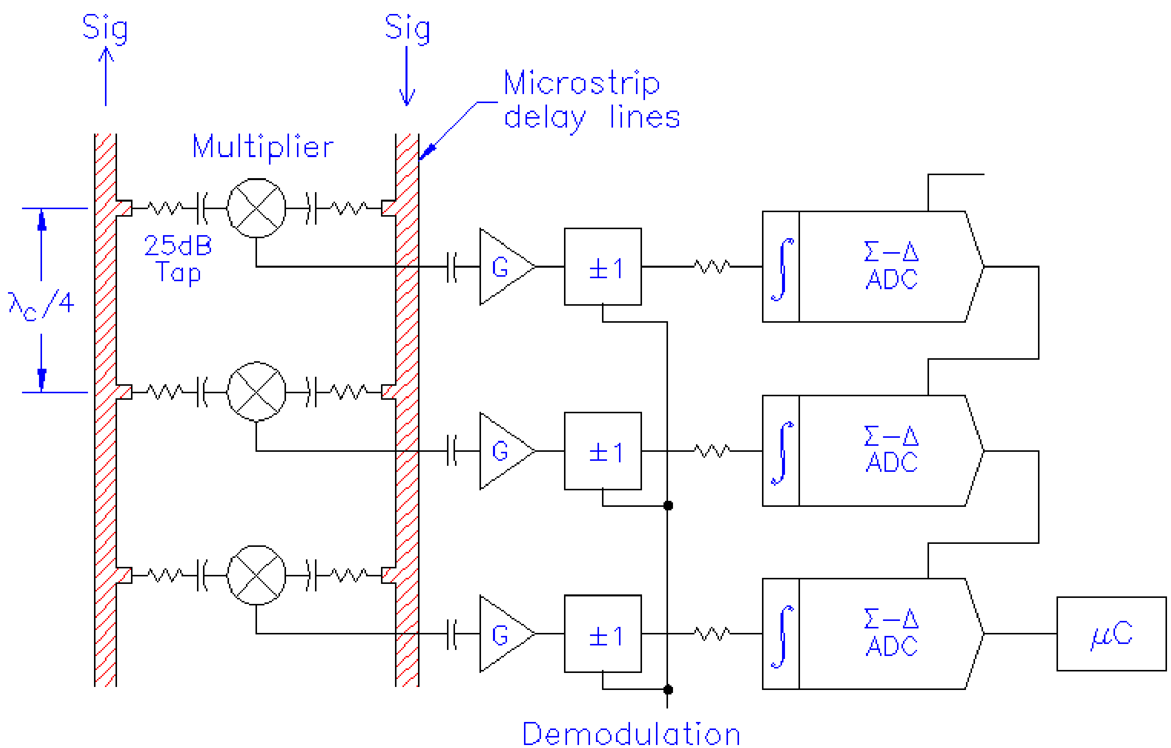
Band summary:

- No one front-end covers all important redshifts
- A combination of Ka- and W-bands covers z > 1.5

WASP2 analog correlator

$$S_{xy}(f) \leftrightarrow R_{xy}(\tau) \qquad R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} V_x(t) \times V_y(t+\tau)\, dt$$

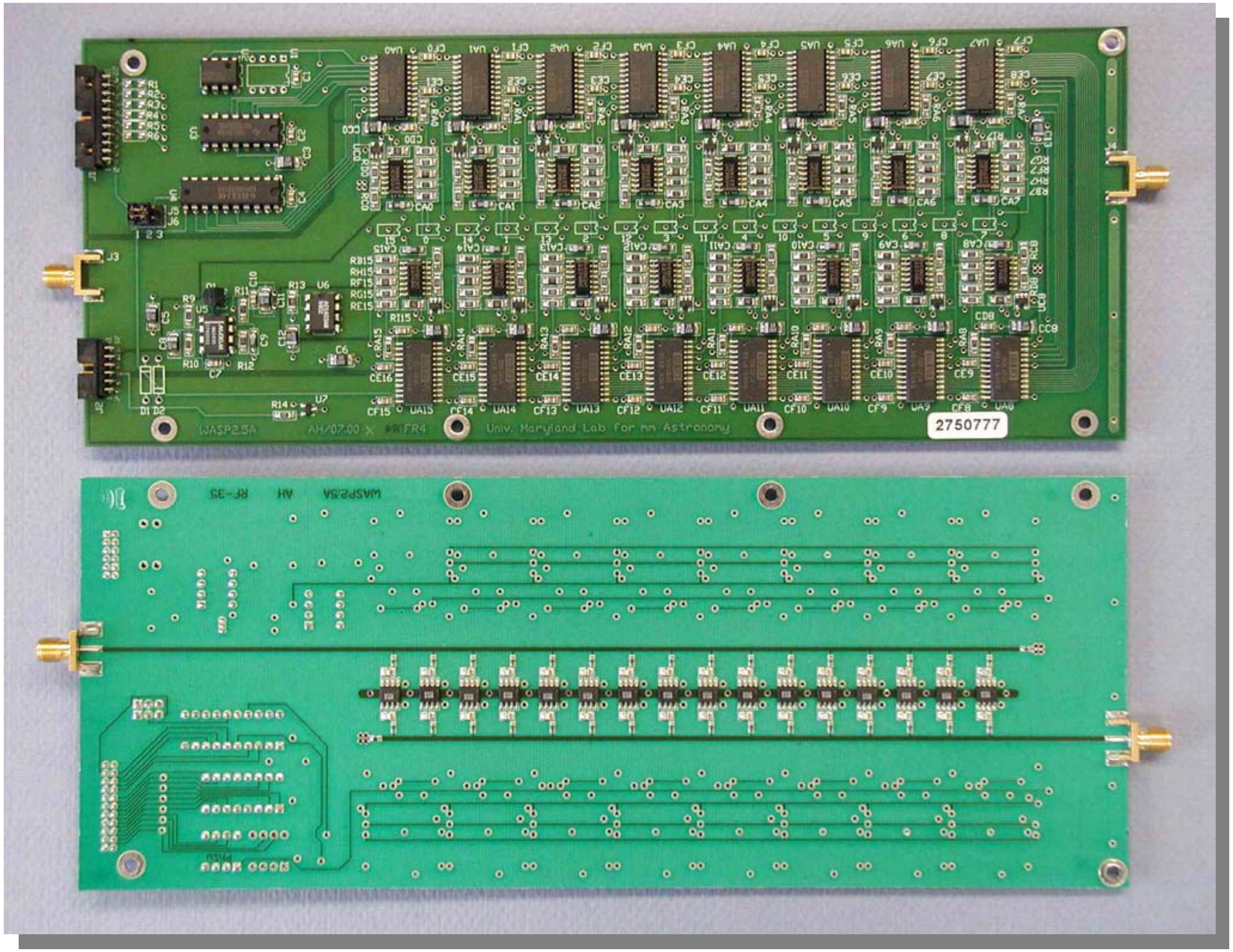




Wideband, simple electronics: low-speed digitization
after high frequency delay and multiplication

WASP2
4 GHz, 16-lag correlator cards

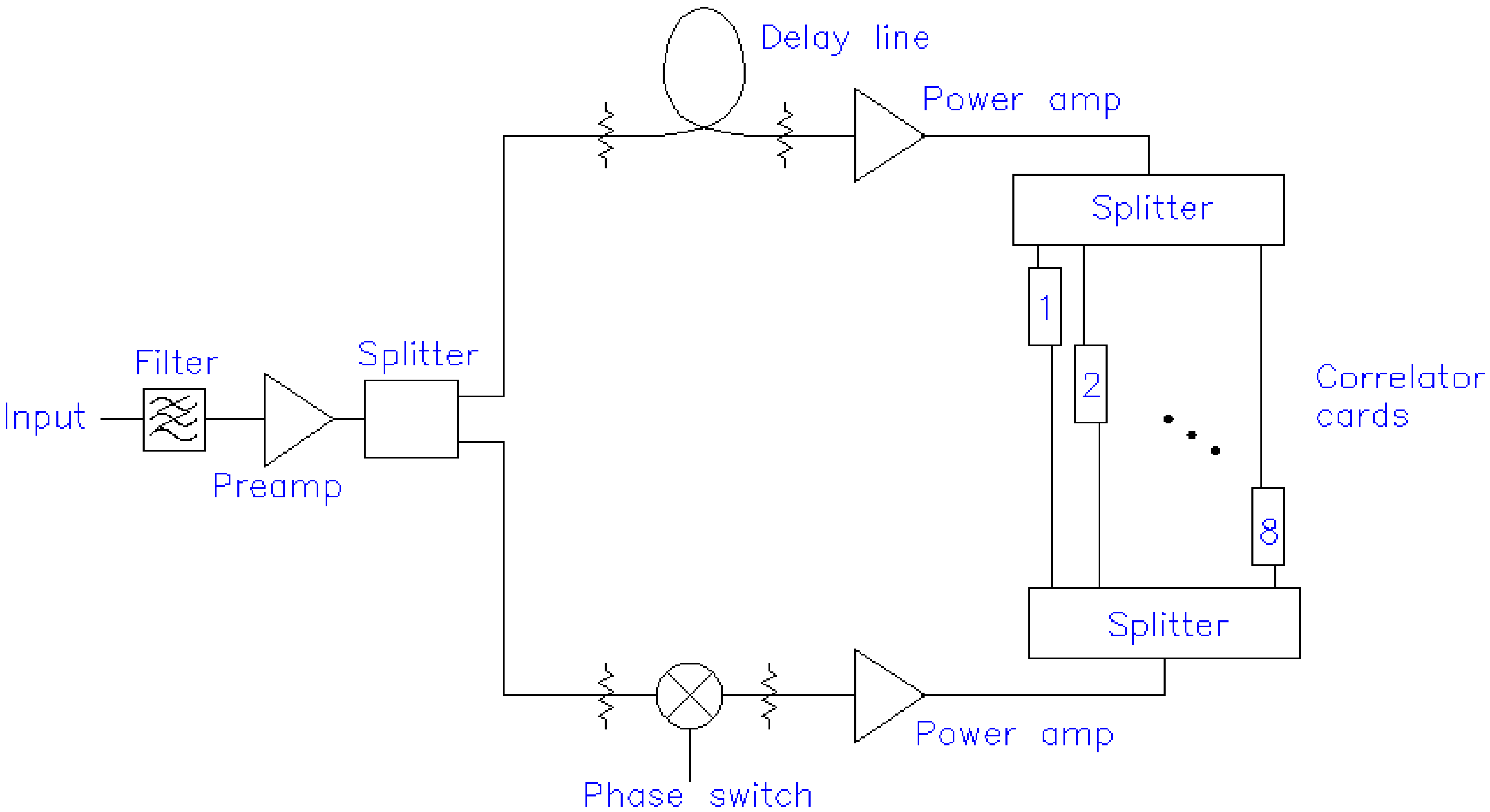
- 100 mm by 10 inch 4-layer hybrid circuit board, FR-4 and Taconic RF-35



Preamps, ADCs, interface

Delay lines, multipliers

WASP2 block diagram

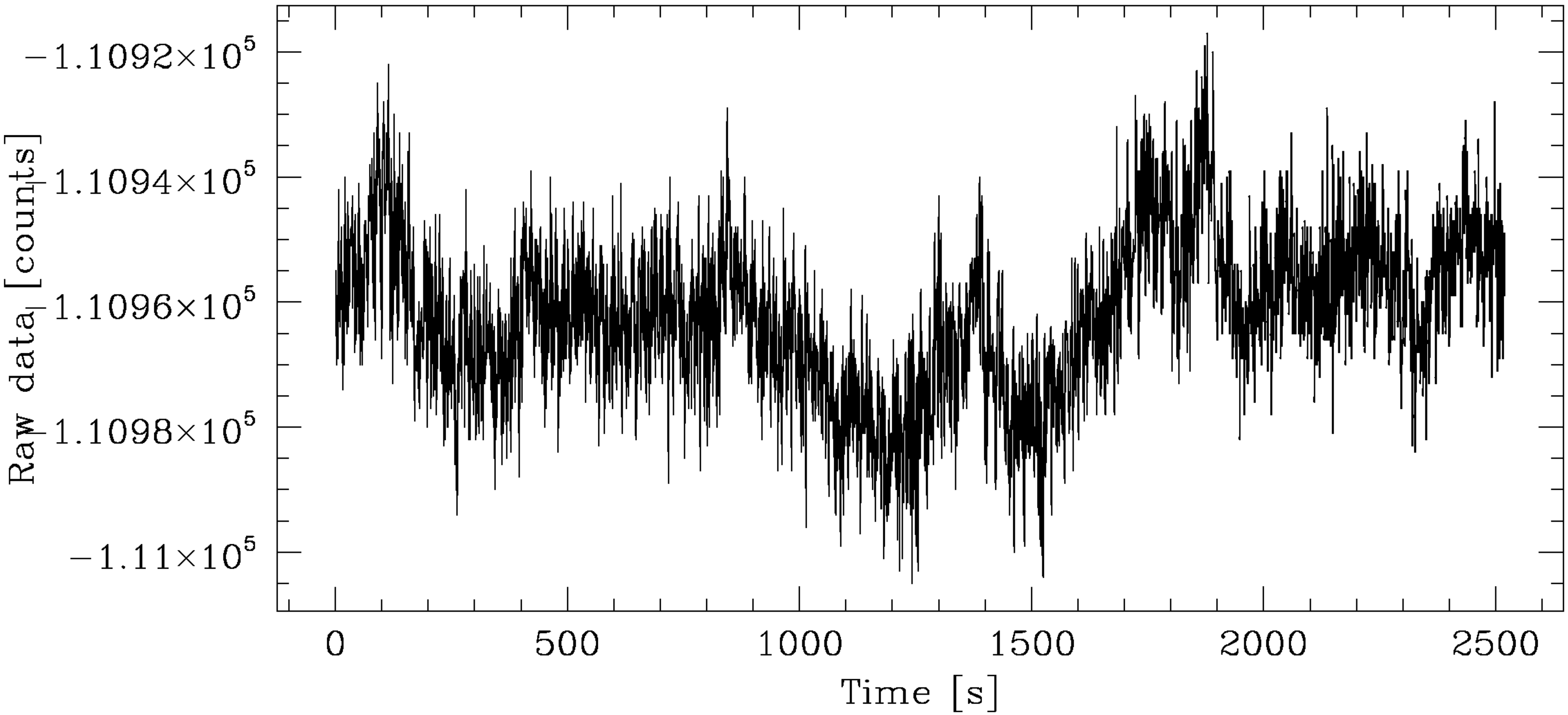


Eight 16-lag correlator cards, cable delays

WASP2 power supply and correlator

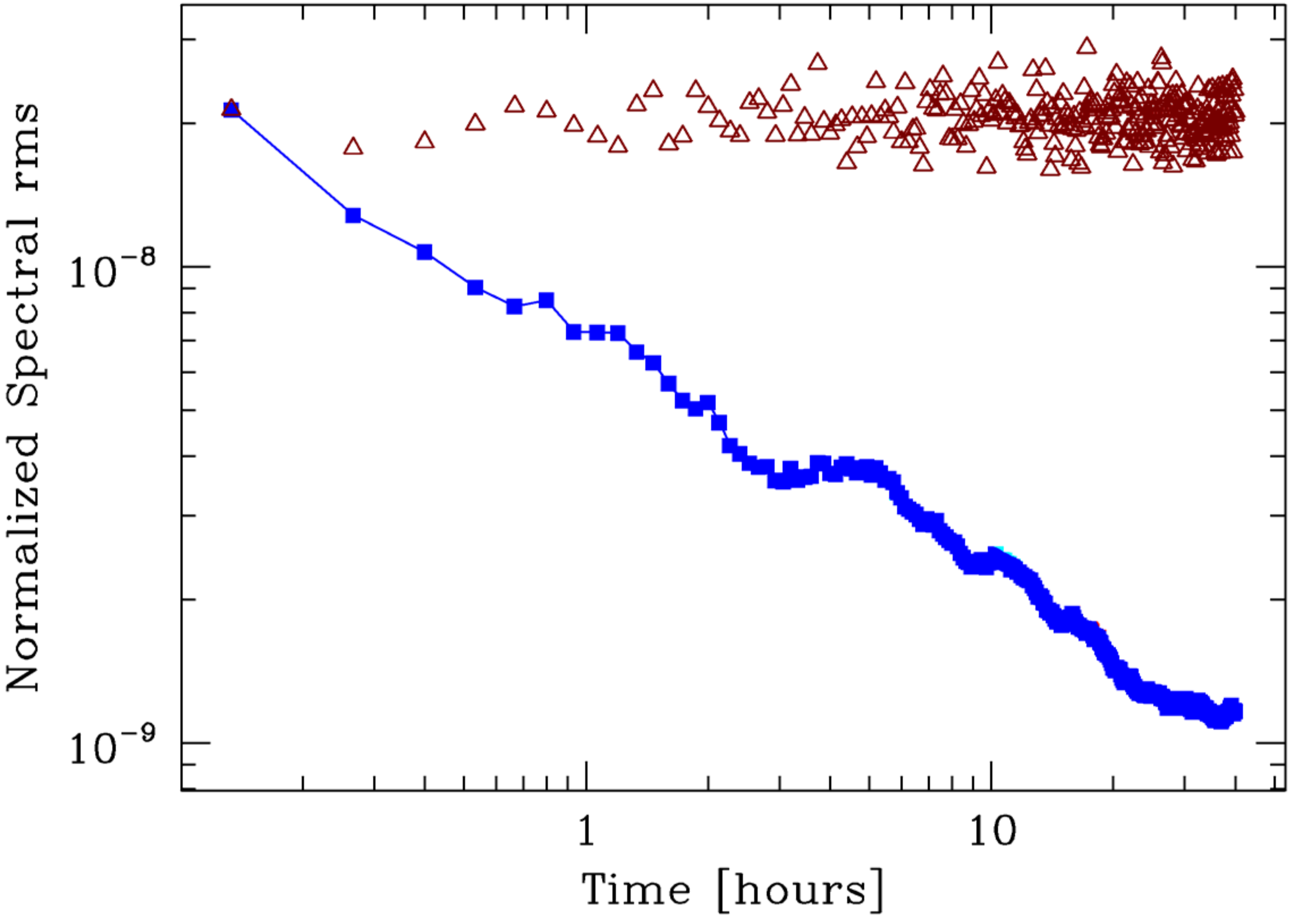
4U chassis (180 mm high); ~50 W/spectrometer

Autocorrelator stability: Time series, zero lag (total power)



$$\frac{1.1099}{1.1093} = 1 + 5.4\times10^{-4} = 2.3\times10^{-3} \text{ dB, pk-pk over 42 minutes}$$

rms noise as a function of time: 40 hour integration (autocorrelator)

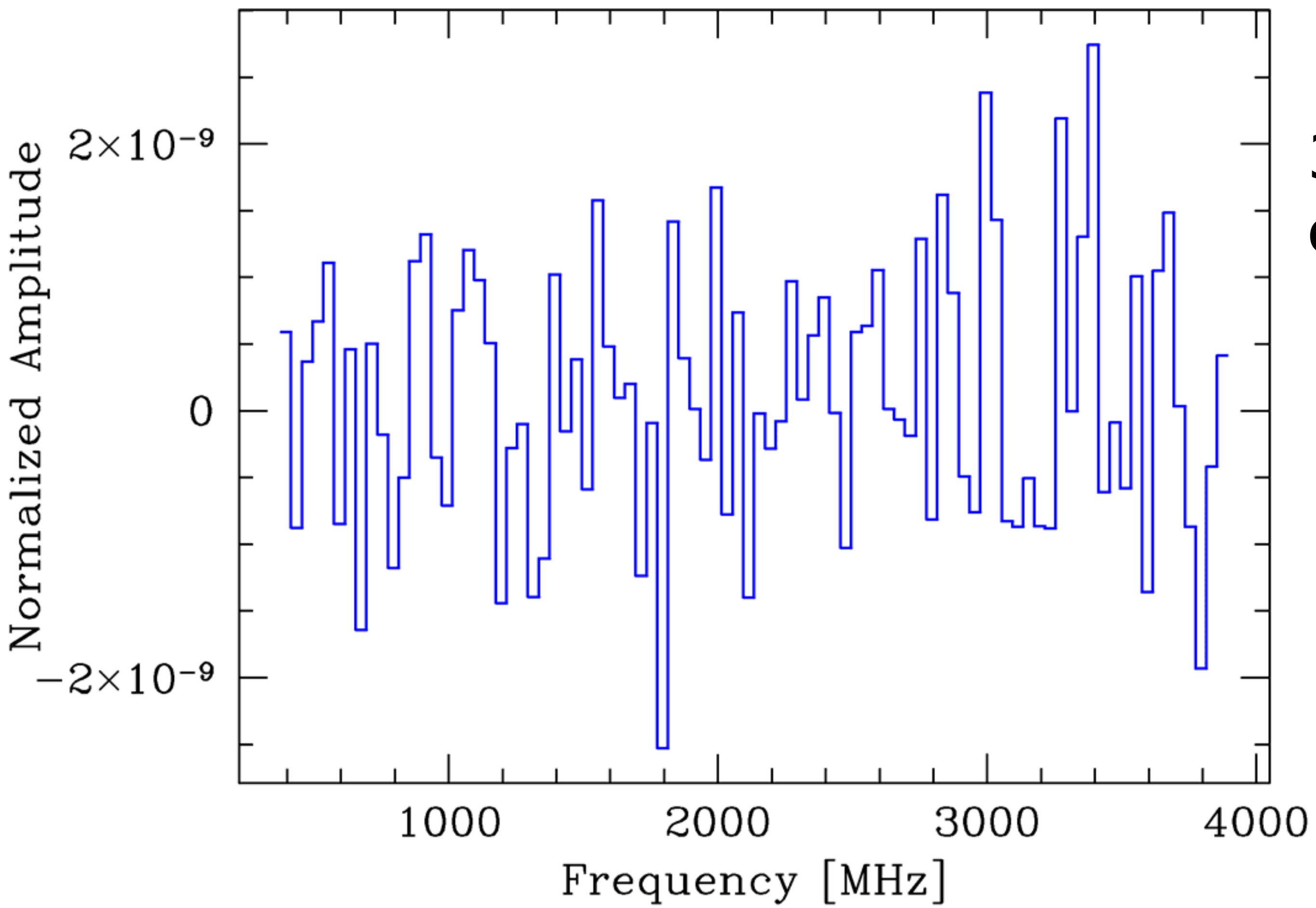


Blue: cumulative

Brown: individual

Noise integrates down as $t^{-0.5}$ for at least 40 hr

Average spectrum after 40 hour integration (autocorrelator mode)

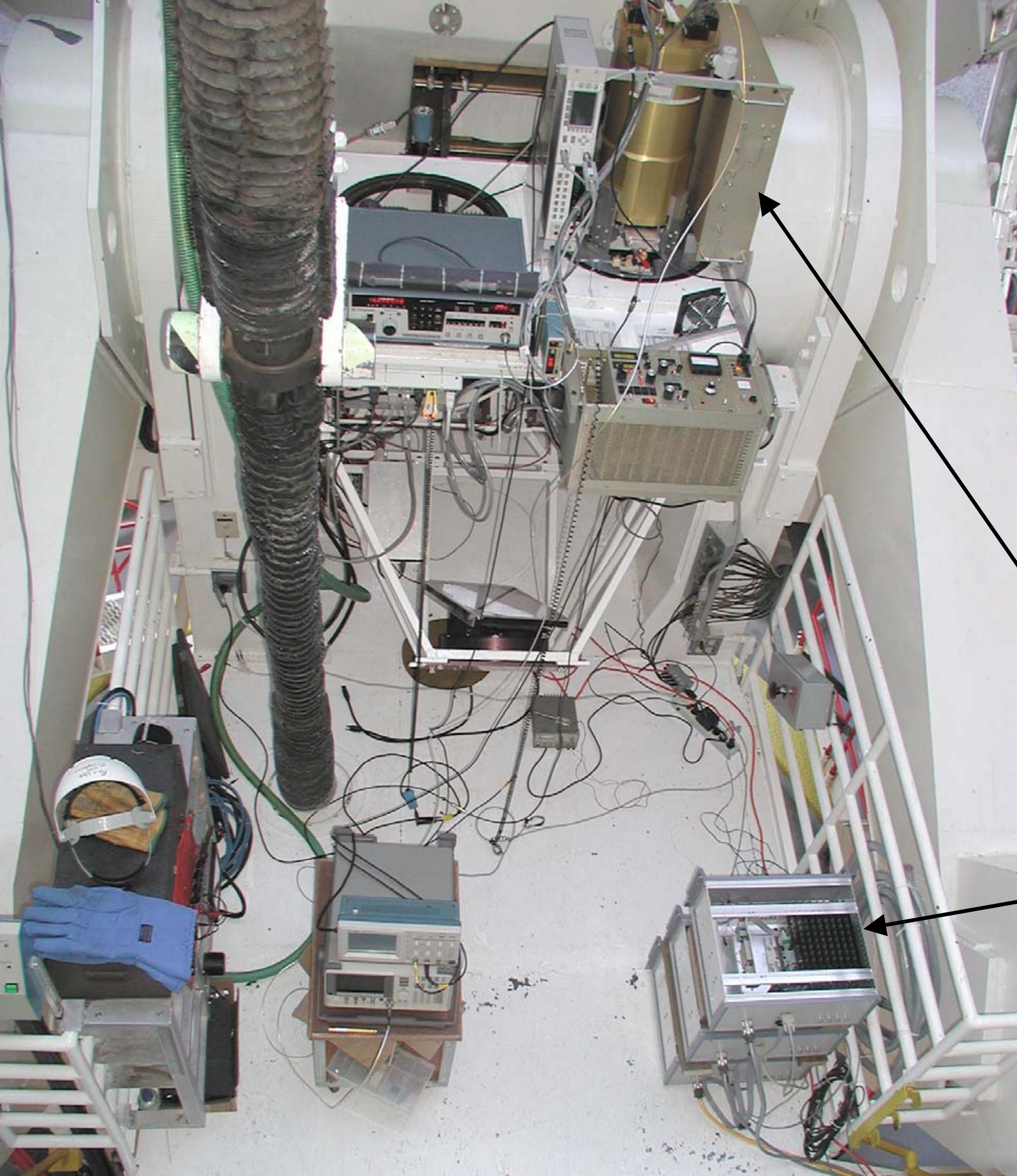


33 MHz channels

Absolutely *no* trace of bandpass shape after 40 hours

Z-Rx and WASPs at the CSO

August 2003



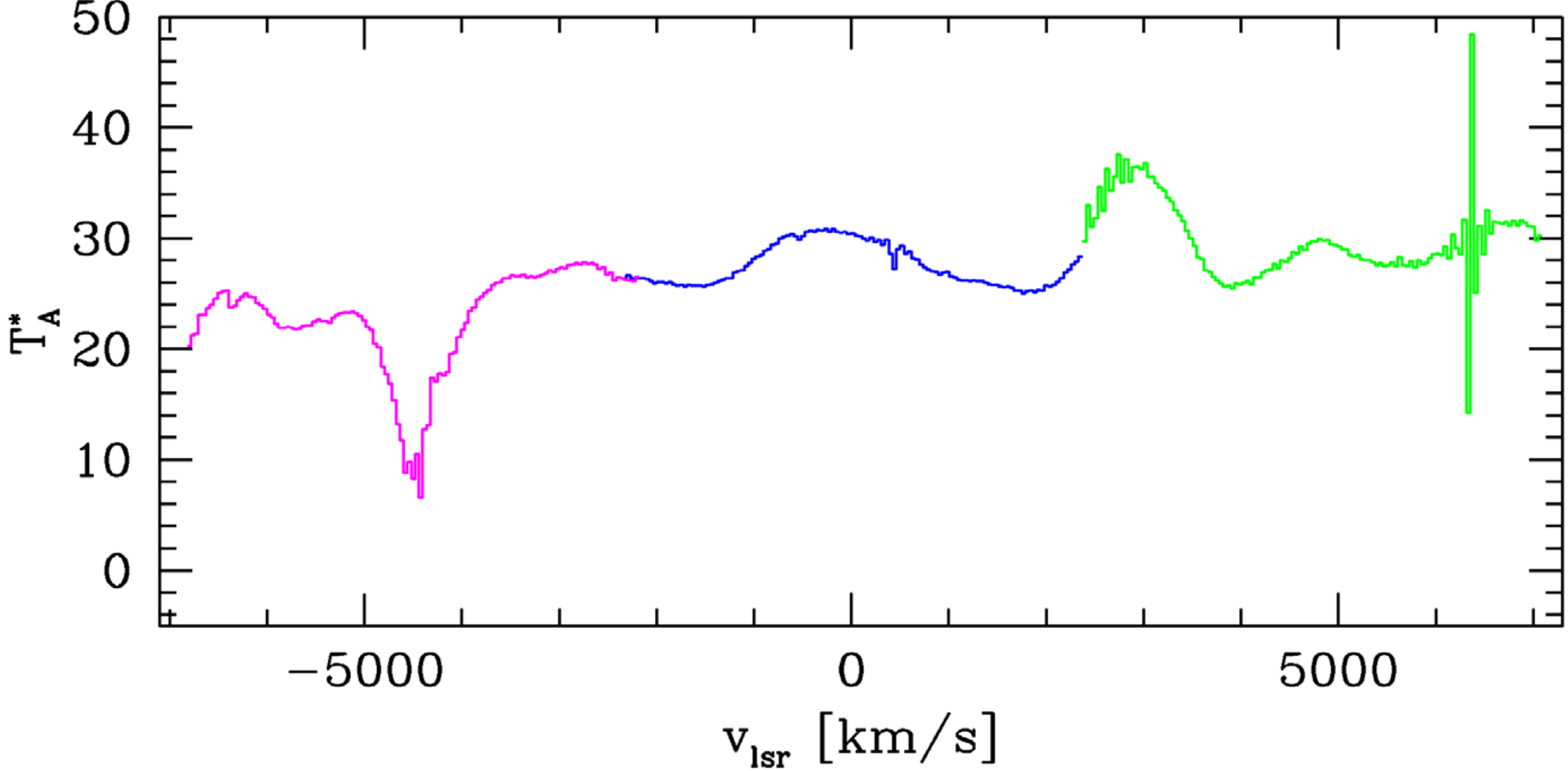
Front-end:
RF: 200-300 GHz
IF: 6-20 GHz

Downconverter splits IF into four sub-bands

WASPs' nest with three 3.5 GHz WASPs

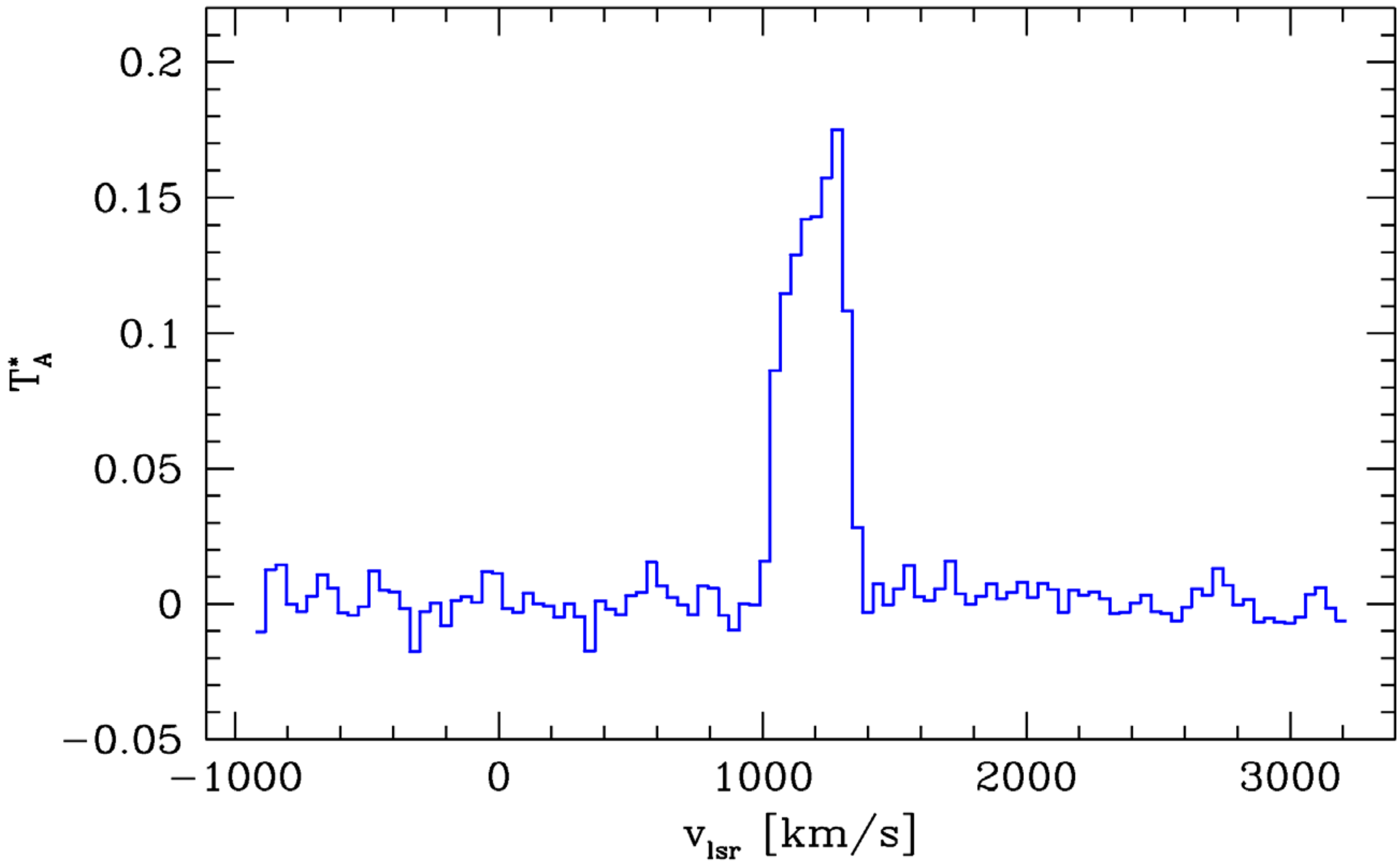
Rice, Sumner, Zmuidzinas, Blain, Harris

Spectrum of Mars with three WASPs (10.5 GHz; 21 GHz DSB)



Aug. 30, CSO; no corrections; interesting ripples and spikes from SIS mixer saturation and LO spurs.

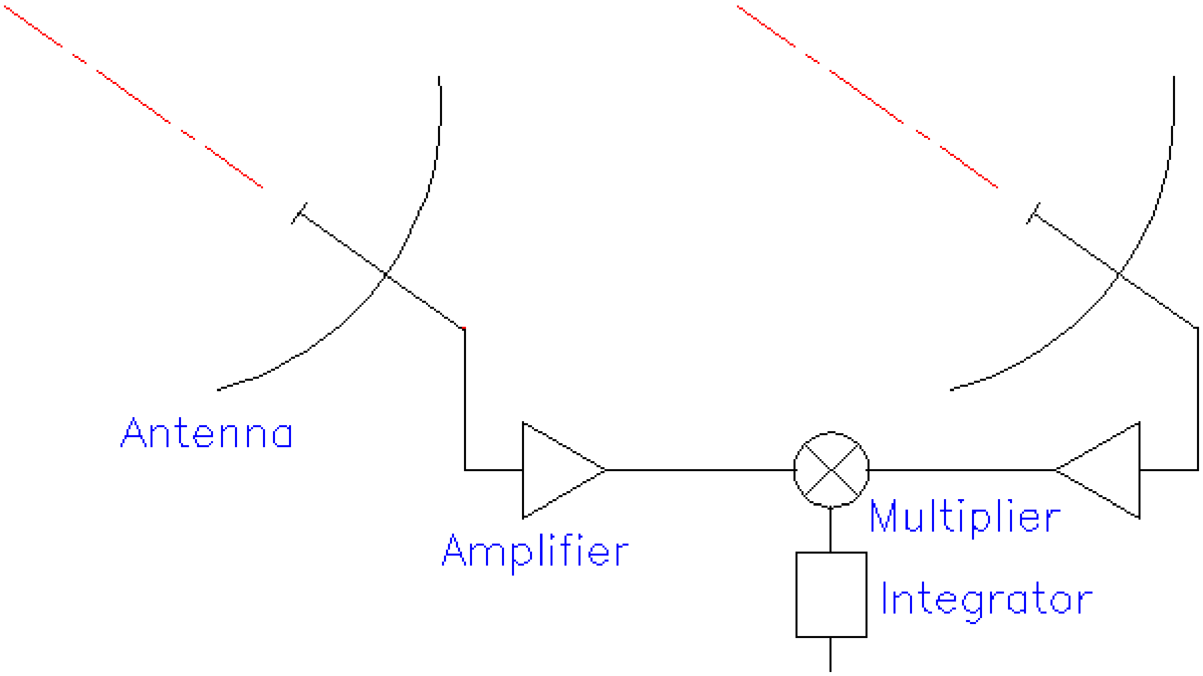
First-night Z-Rx and WASP spectrum NGC1068



CSO, Aug. 30, no corrections

Rice, Sumner, Zmuidzinas, Blain, Harris

Two-element inteferometers and stability



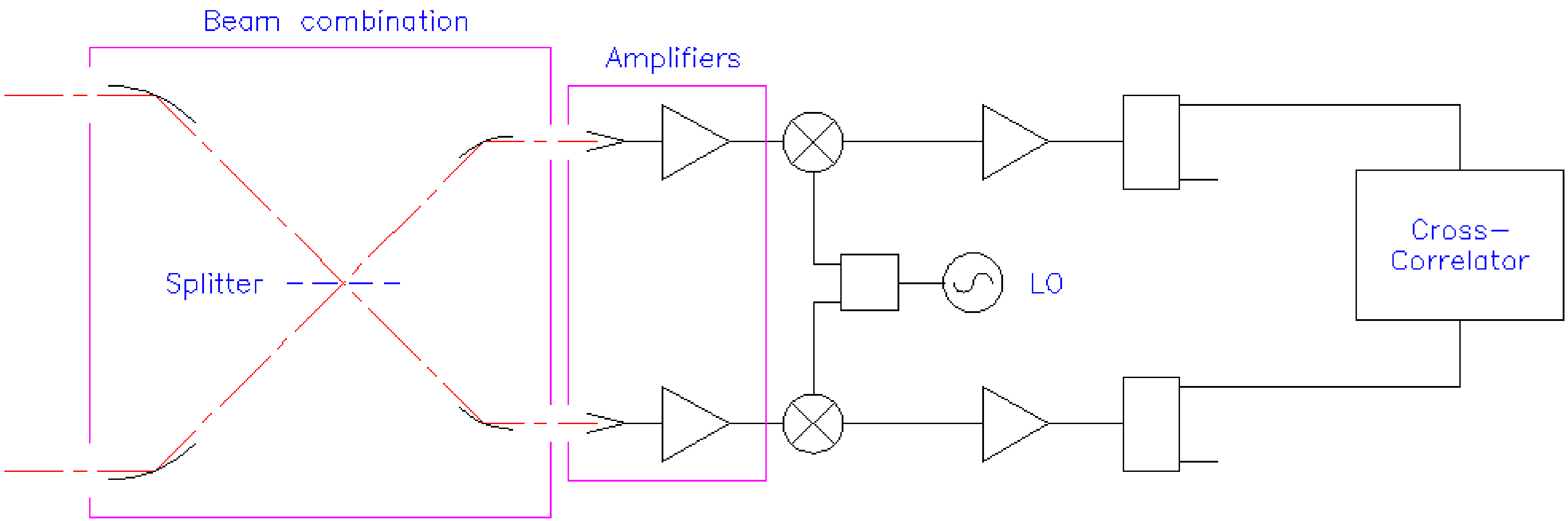
Cross-correlation, interferometer:

$$V_{out} \propto \left\langle (V_1 + N_1) \times (V_2 + N_2) \right\rangle = \left\langle V_1 \times V_2 \right\rangle + \cancel{\left\langle N_1 \times N_2 \right\rangle} + \cancel{\left\langle V_1 \times N_2 \right\rangle} + \cancel{\left\langle N_1 \times V_2 \right\rangle}$$

Total power, single antenna:

$$V_{out} \propto \left\langle (V + N)^2 \right\rangle = \left\langle V^2 \right\rangle + \left\langle N^2 \right\rangle + \cancel{2 \left\langle V \times N \right\rangle}$$

Correlation (continuous comparison) radiometer for a single dish



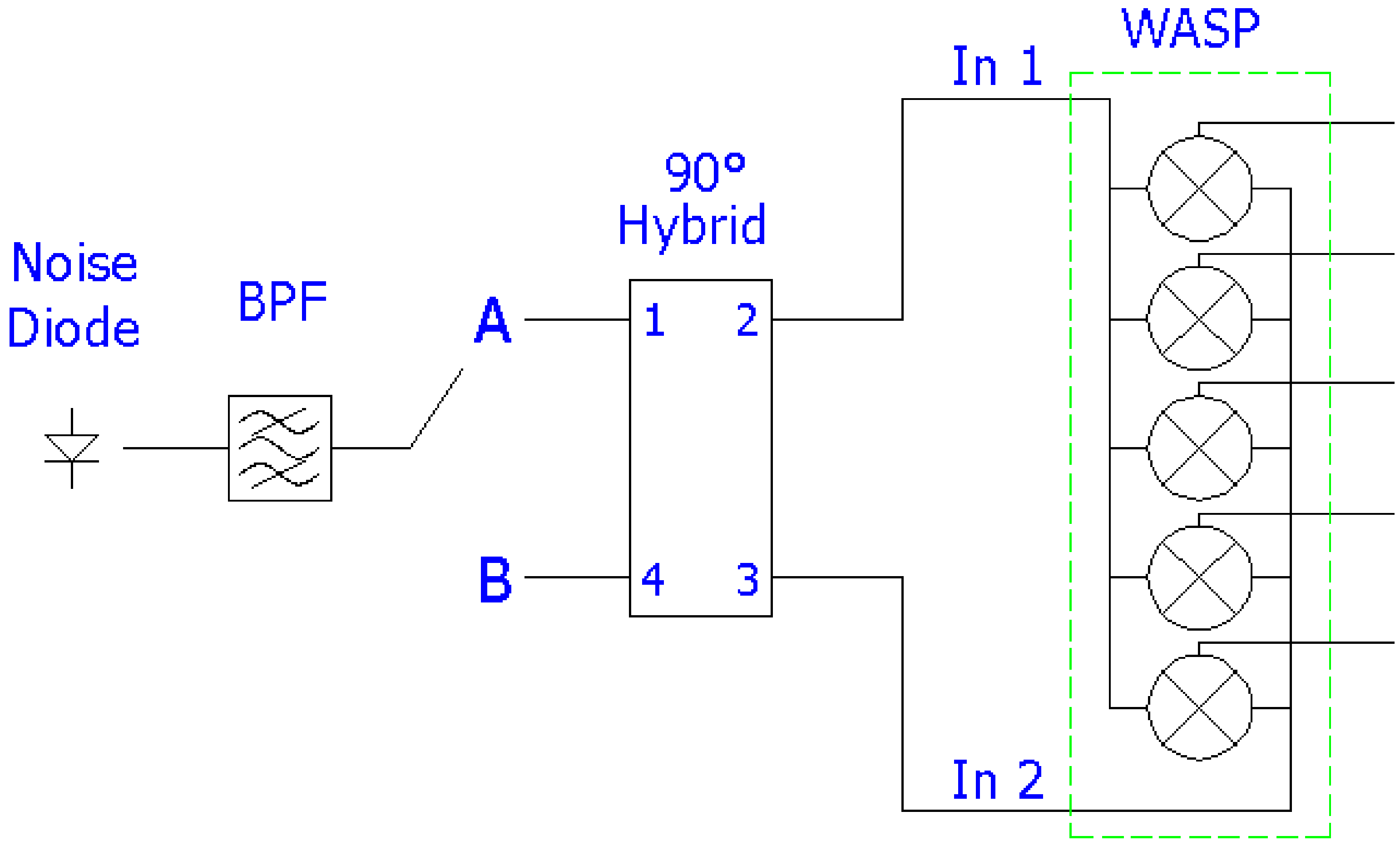
This is the single-dish complement of the two-element spatial interferometer.

- Combine signals from two positions in focal plane
- As much common signal processing as possible
- The "*uncorrelated*" signal is source minus reference
- Continuous comparison for two sky positions

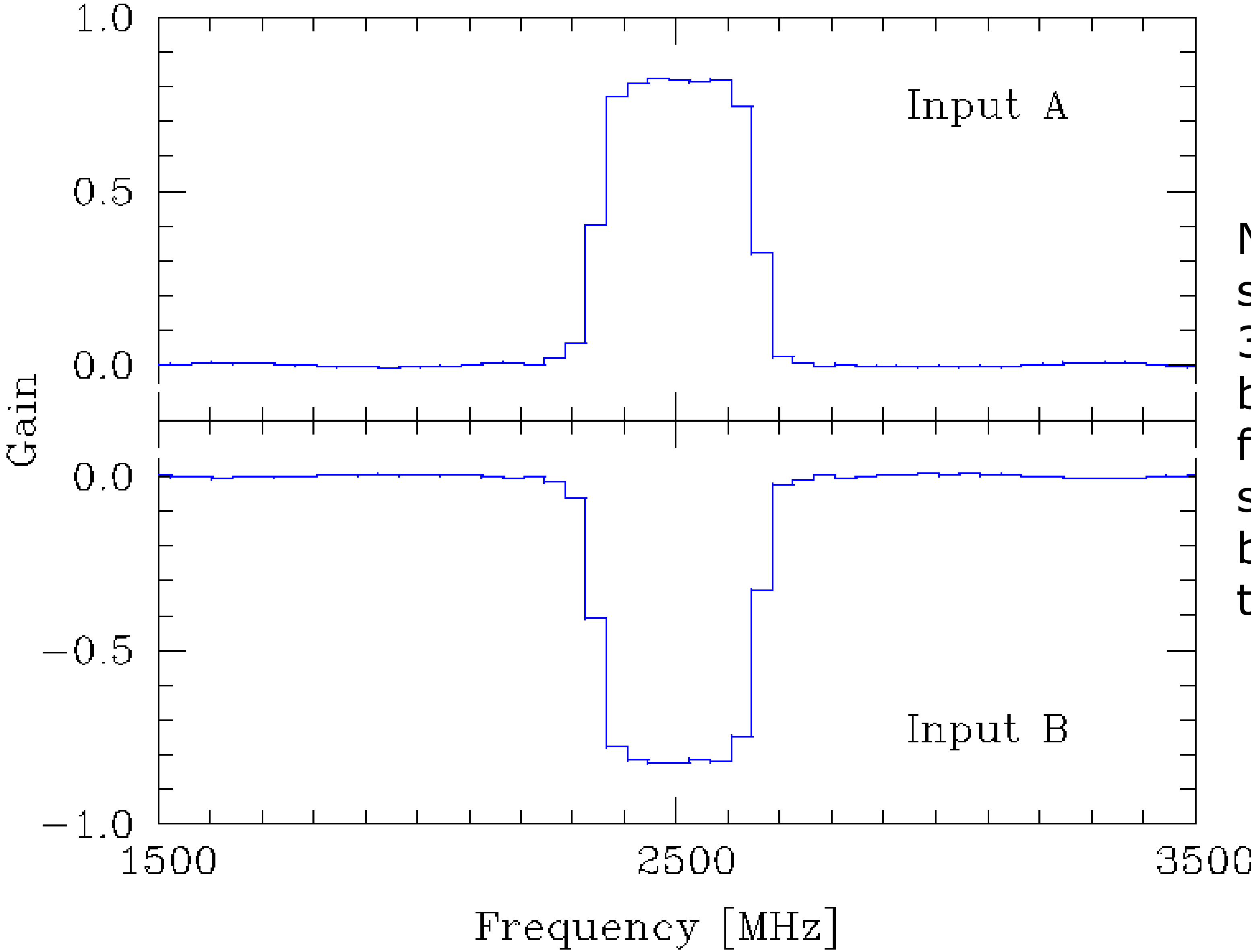
Correlation radiometer advantages

- Dual beam observations
  - Measure signal and reference positions simultaneously
  - Factor of two improvement in time over single-beam system
- Stability
  - Continuously difference signal and reference positions
- Cost
  - Single cross-correlator for two beams rather than one spectrometer per beam for conventional radiometer

Correlation (differential) multi-channel radiometer demonstration

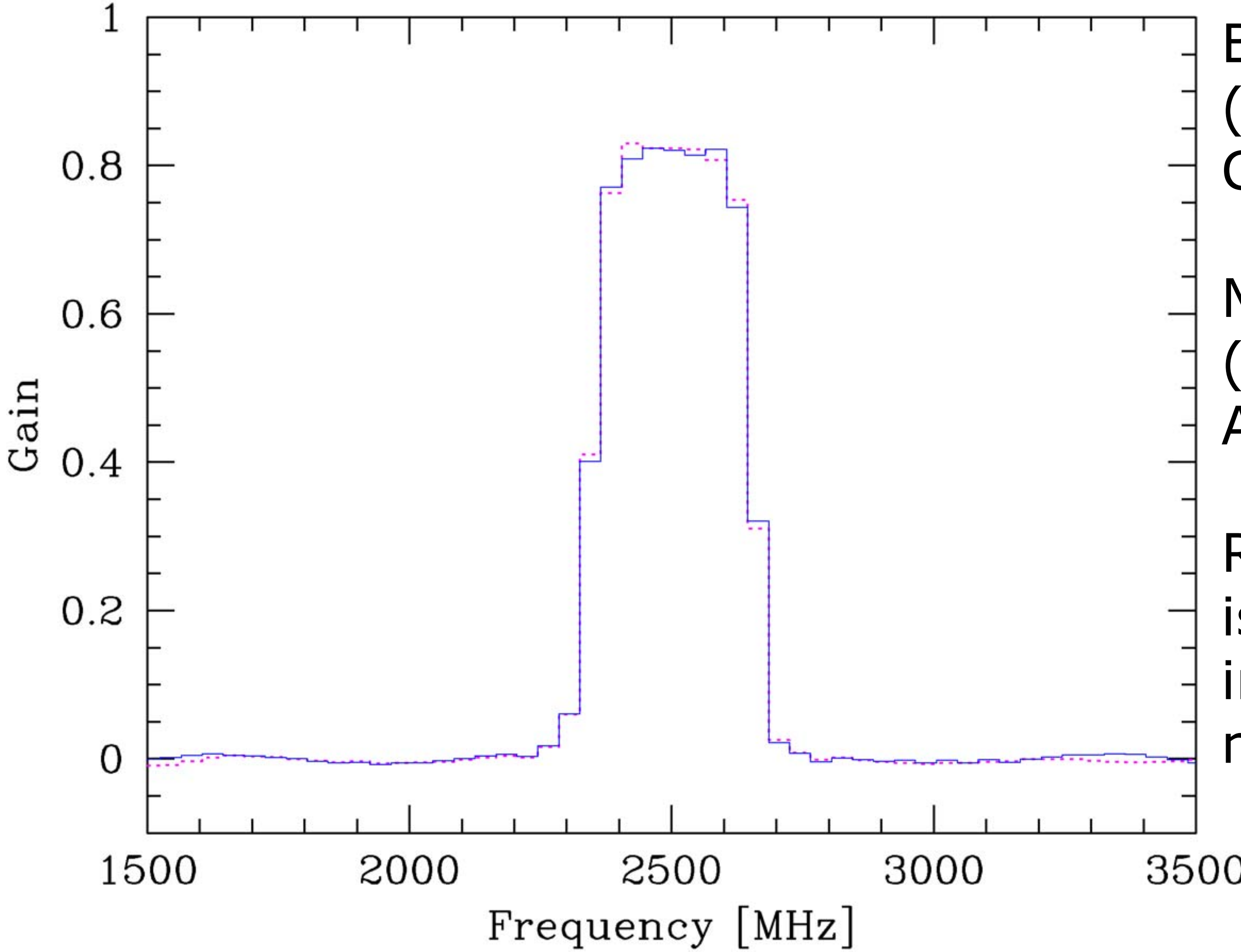


Correlation radiometer spectra



Noise source and 300 MHz bandwidth filter, switch between two inputs

Resolution: auto-correlator and cross-correlator calibrated at input

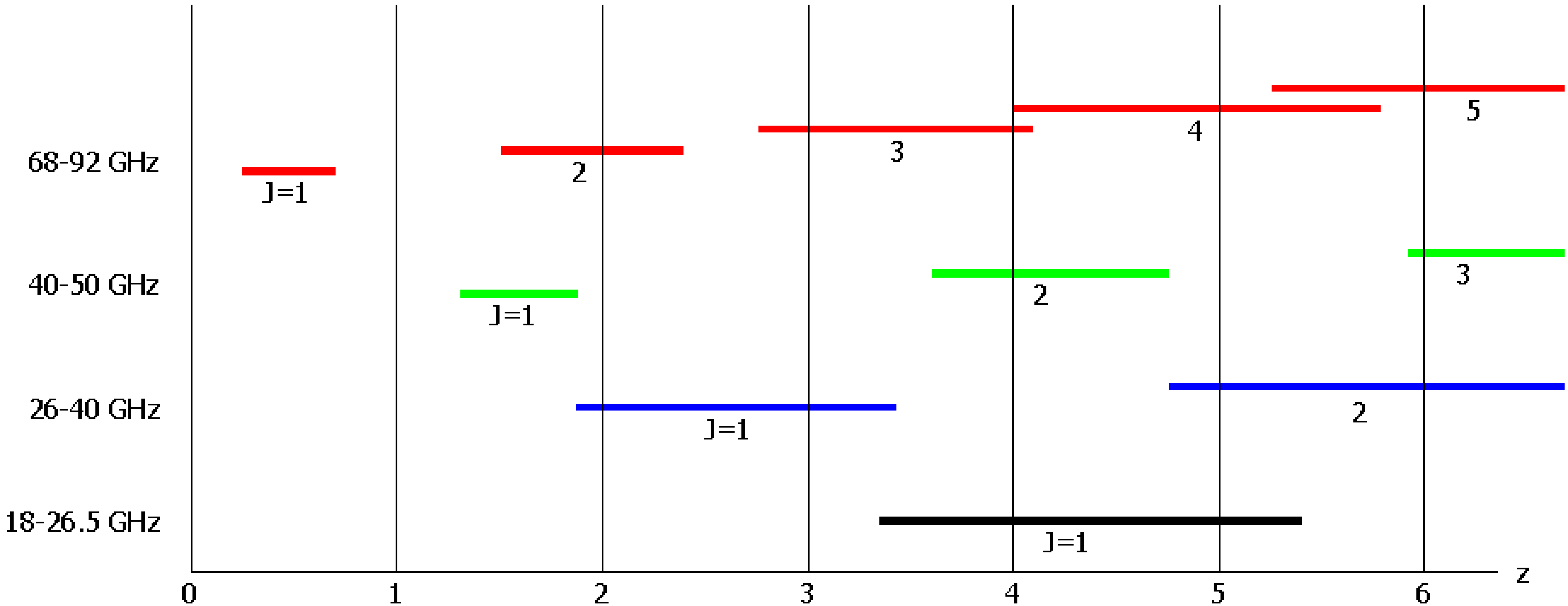


Blue (solid): Cross-corr.

Magena (dashed): Auto-corr.

Resolution is the same in both modes

z-coverage for GBT front-ends



A combination of W-band and Ka-band covers z > 1.5

A concrete proposal for a minimum WASPs' nest in the Ka- and W-bands

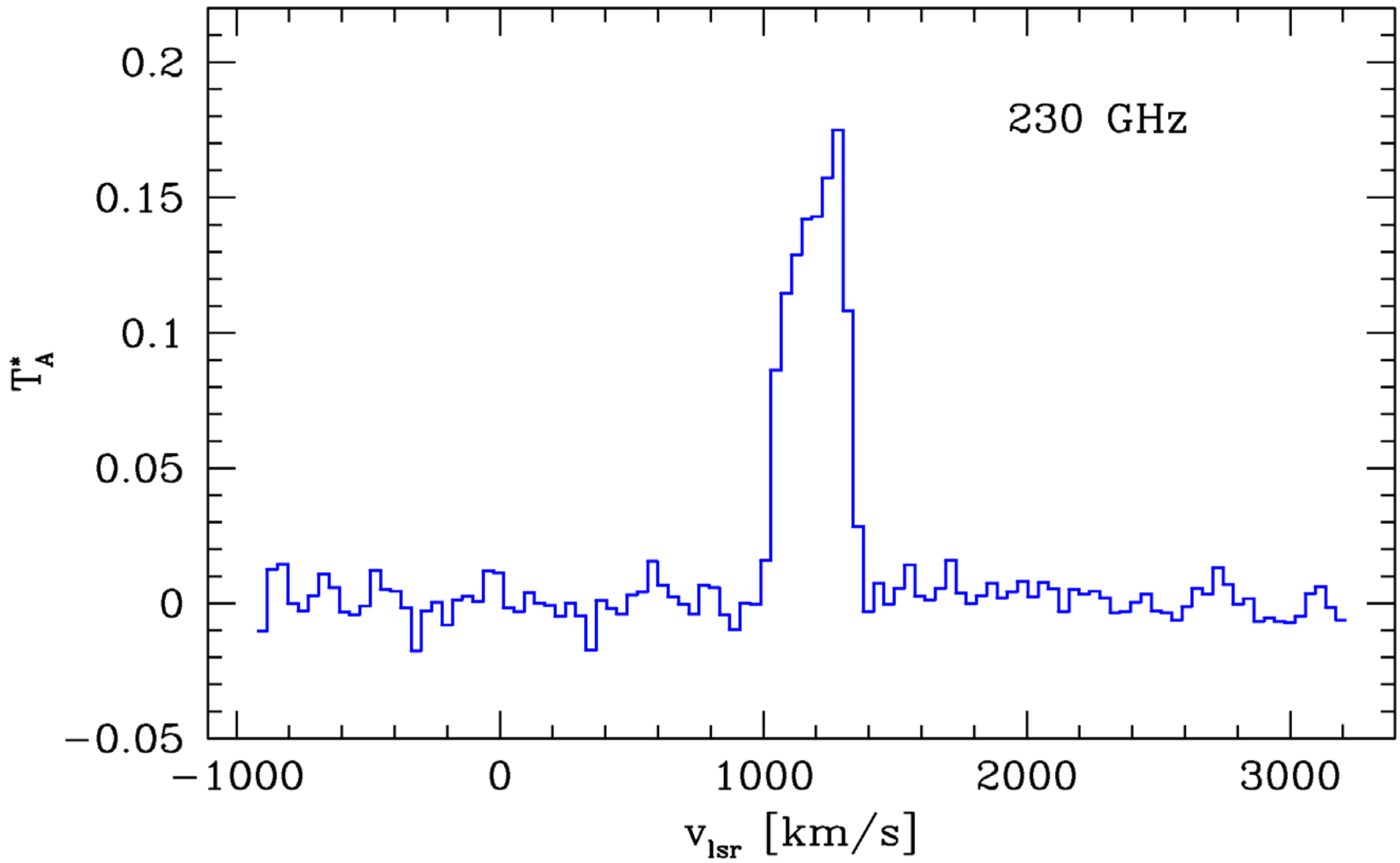
Eight cross-correlating WASPs, each with 3.5 GHz bandwidth and 128 lags (1024 lags total)

Two configurations:

1. Eight WASPs stacked in frequency (W-band)
2. Four pairs of WASPs stacked in frequency with doubled spectral resolution (Ka-band)

Band	Ka		W	
Bandwidth [GHz]	14		24	
Fractional BW	0.42		0.30	
Band edges [GHz]	26	40	68	92
Velocity resolution [km/s]	190	123	145	108

Simulate observations in GBT bands with WASP NGC1068 data



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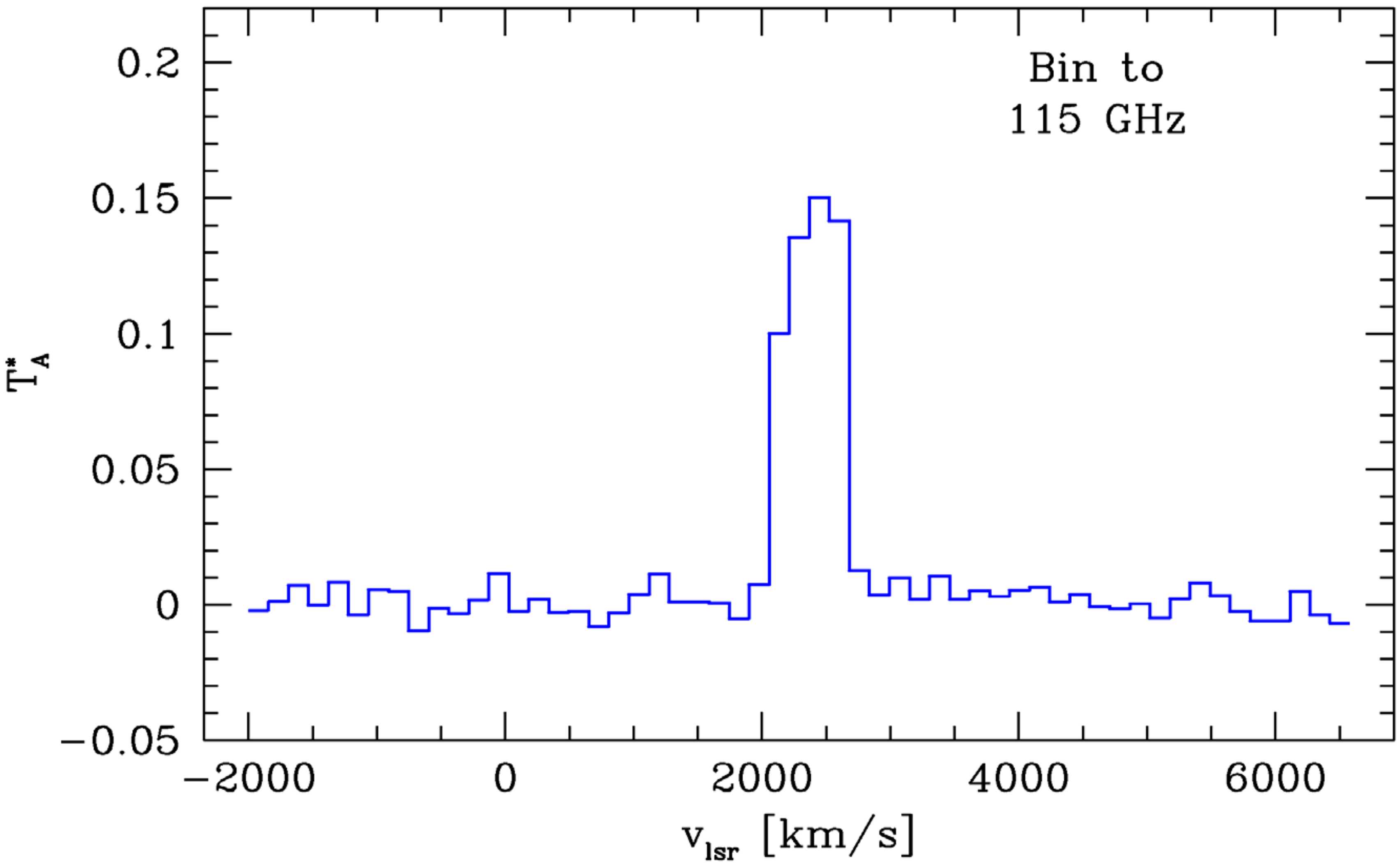
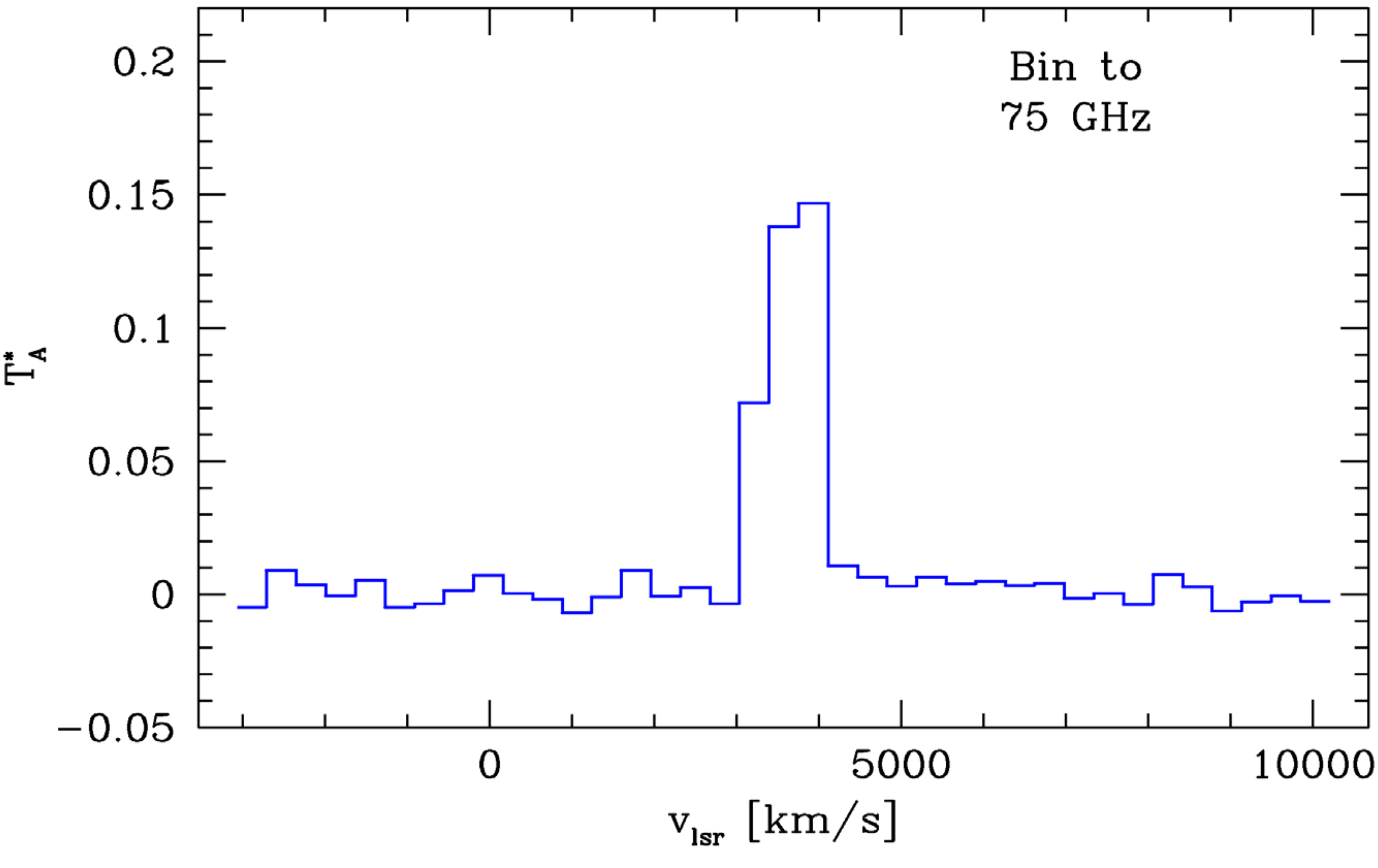
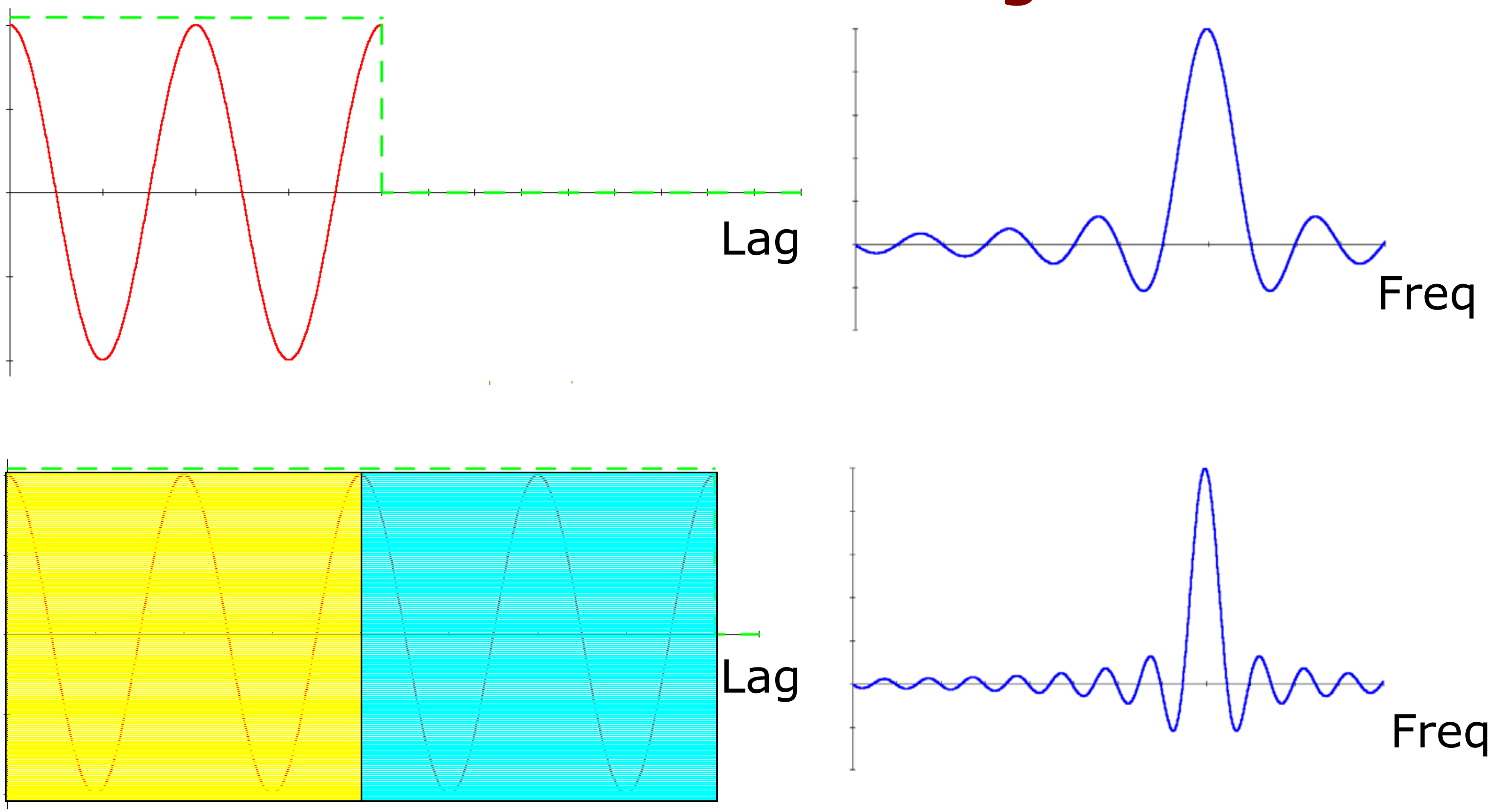


Simulate observations in GBT bands with WASP NGC1068 data

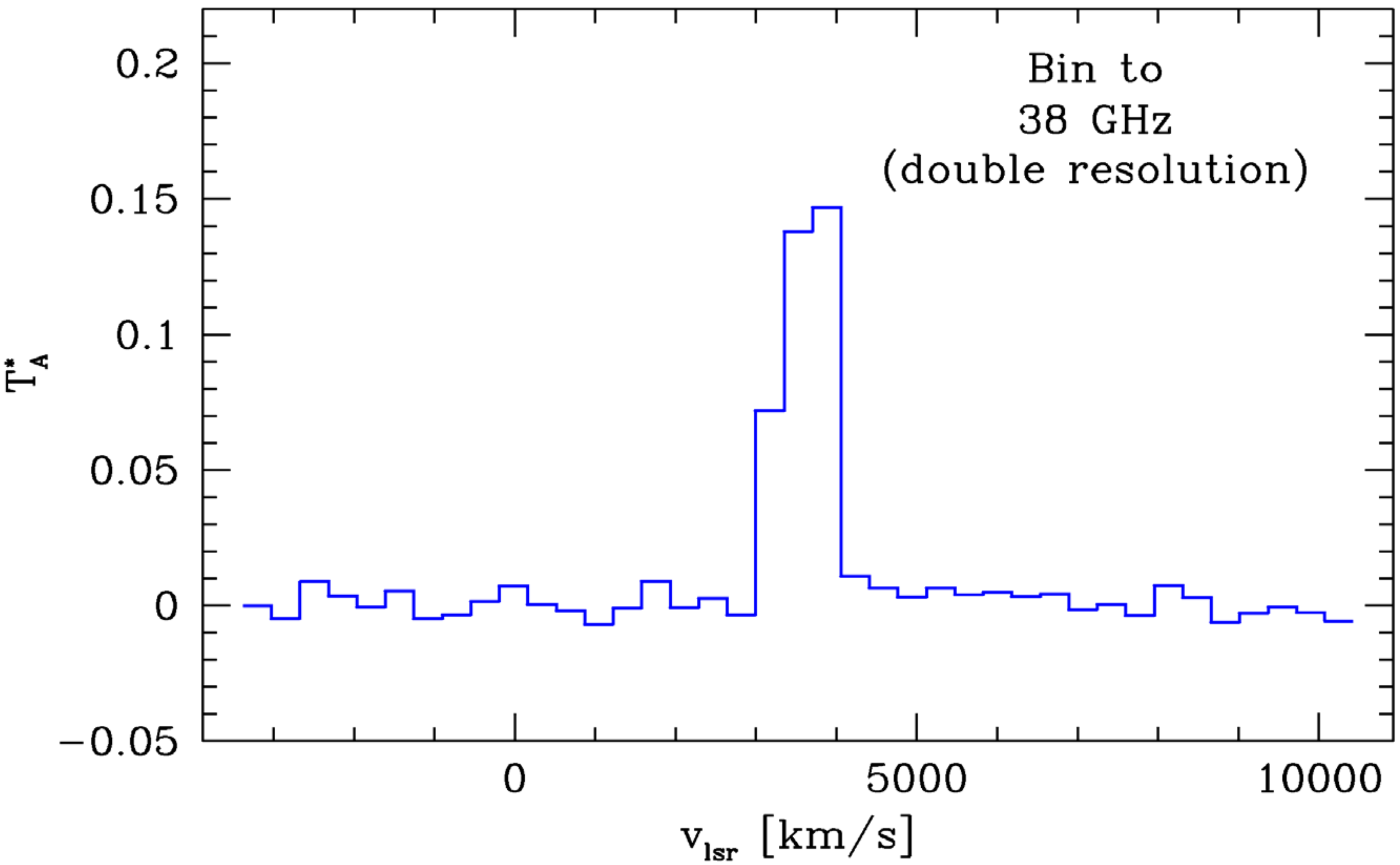


Resolution, bandwidth, sampling, and correlator length



Bandwidth: sampling interval (between lags, $\lambda_{min}/2$)
Resolution: spectrometer length ($\propto$ number of lags)

Simulate observations in GBT bands with WASP NGC1068 data



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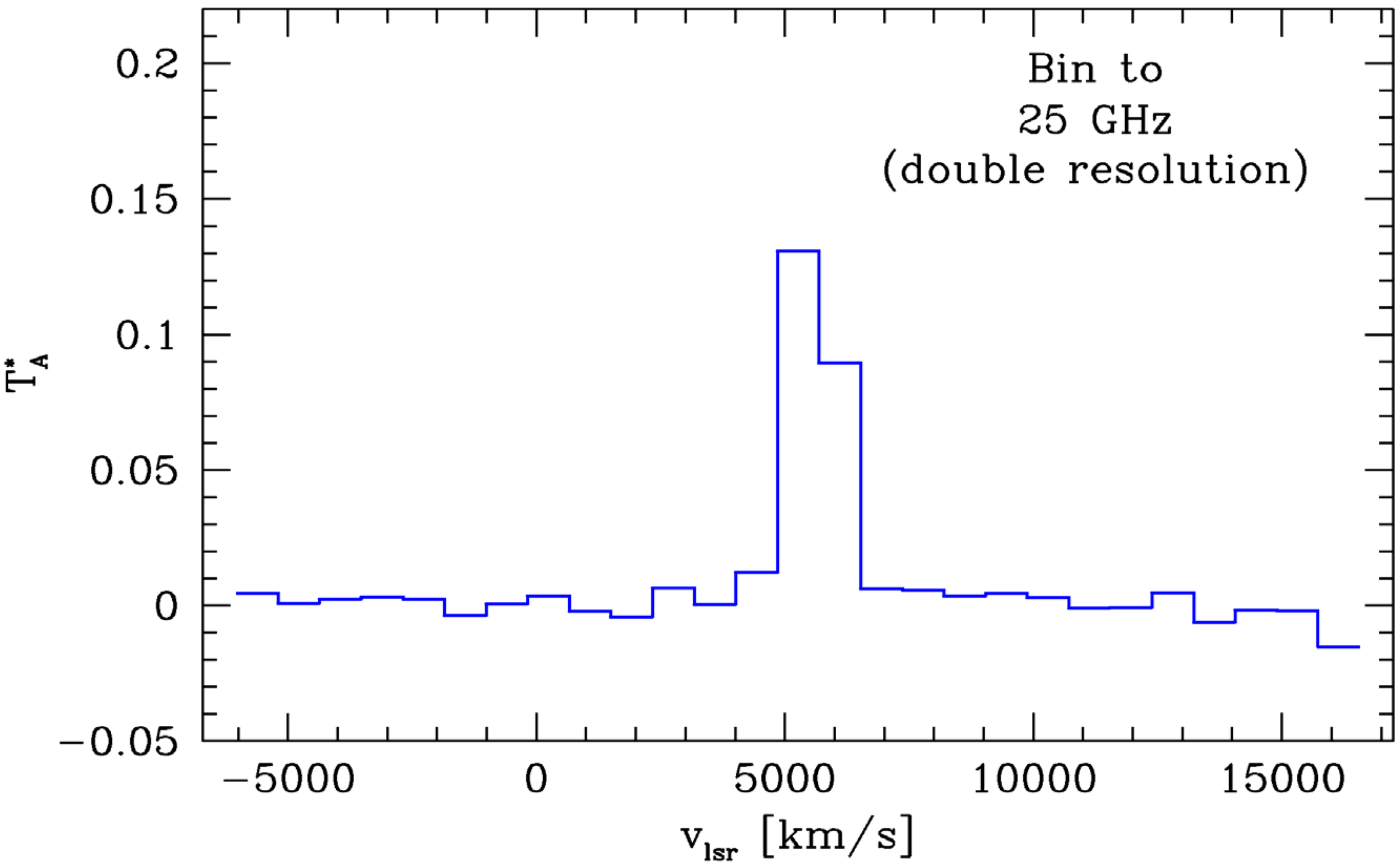

Summary

- The technology exists for wideband CO searches with the GBT in the near-term future
  - Start at Ka band, with advantages of covering the important z = 1.8 to 3.4 range with high aperture efficiency and good pointing
  - Continue at W band to fill in lower-z coverage, get continuous coverage for $z > 2.8$
- A natural approach is to use the (almost) existing correlation radiometers and WASP cross-correlators
- Science:
  - Measure precise redshifts to map star formation peak and beyond
  - Get first-cut dynamical information

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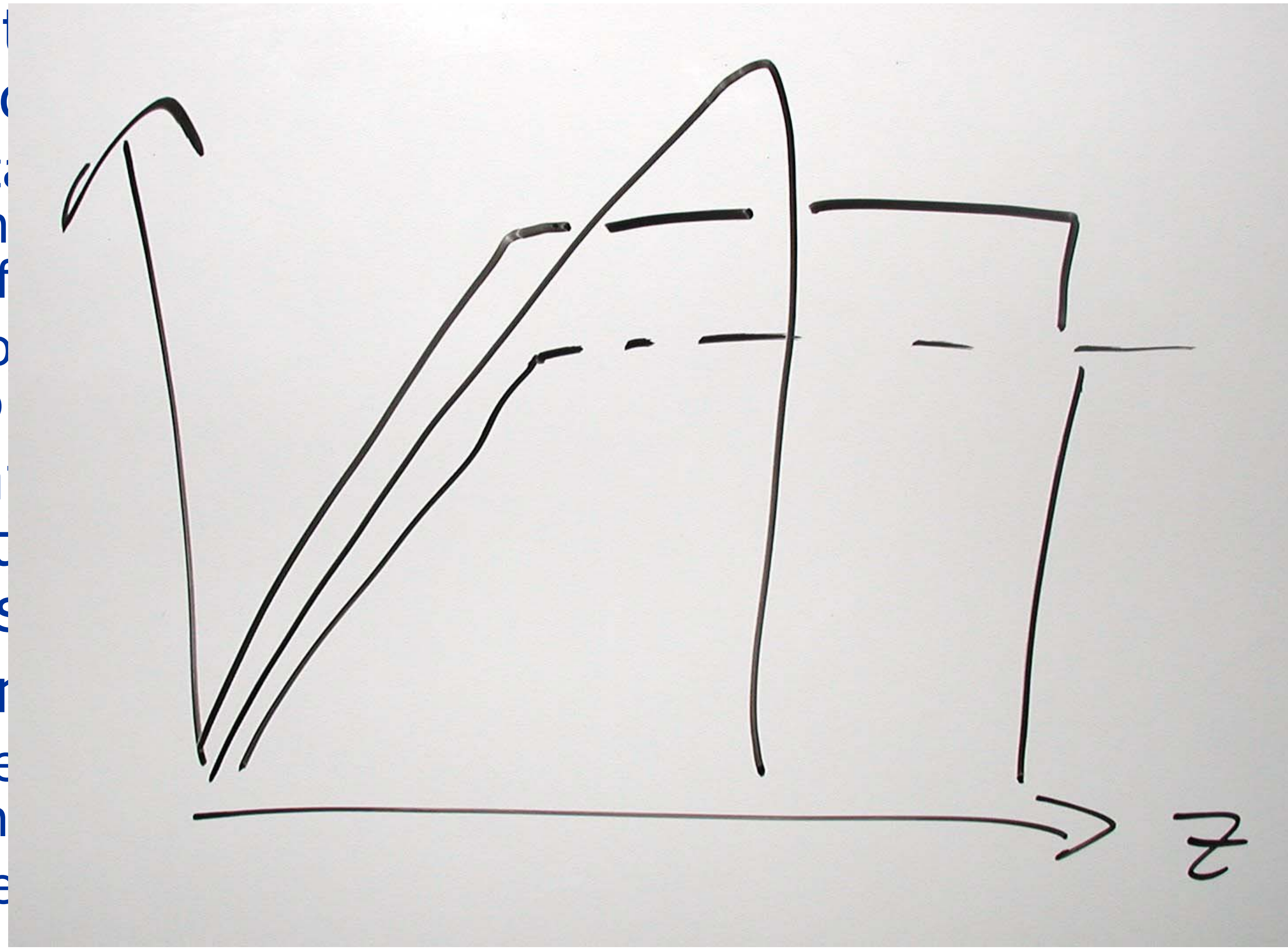

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Blain, yesterday

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