Radio Telescope Components

- Reflector(s)
- Feed horn(s)
- Low-noise amplifier
- Filter
- Downconverter
- IF Amplifier
- Spectrometer

Radio Signal Detection

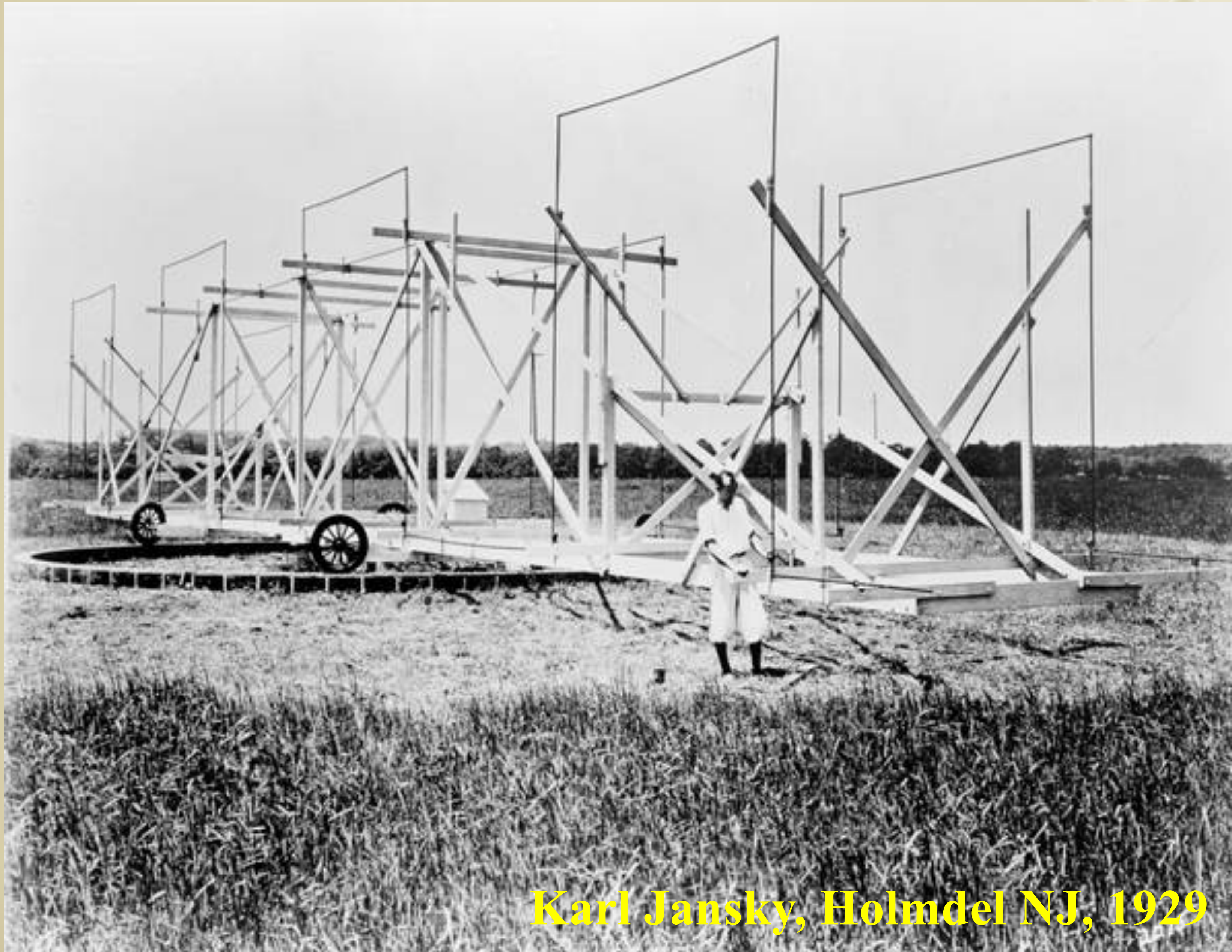
- Signal detected as a wave rather than a photon in contrast with optical
  - The receivers (detectors) are on order the size of incoming waves
- Wave detection preserves phase information:

$$V=V_0\sin(\omega t-\phi)$$

V_0 is amplitude, ϕ is the phase

- Phase info. makes interferometry easy

Radio Telescopes



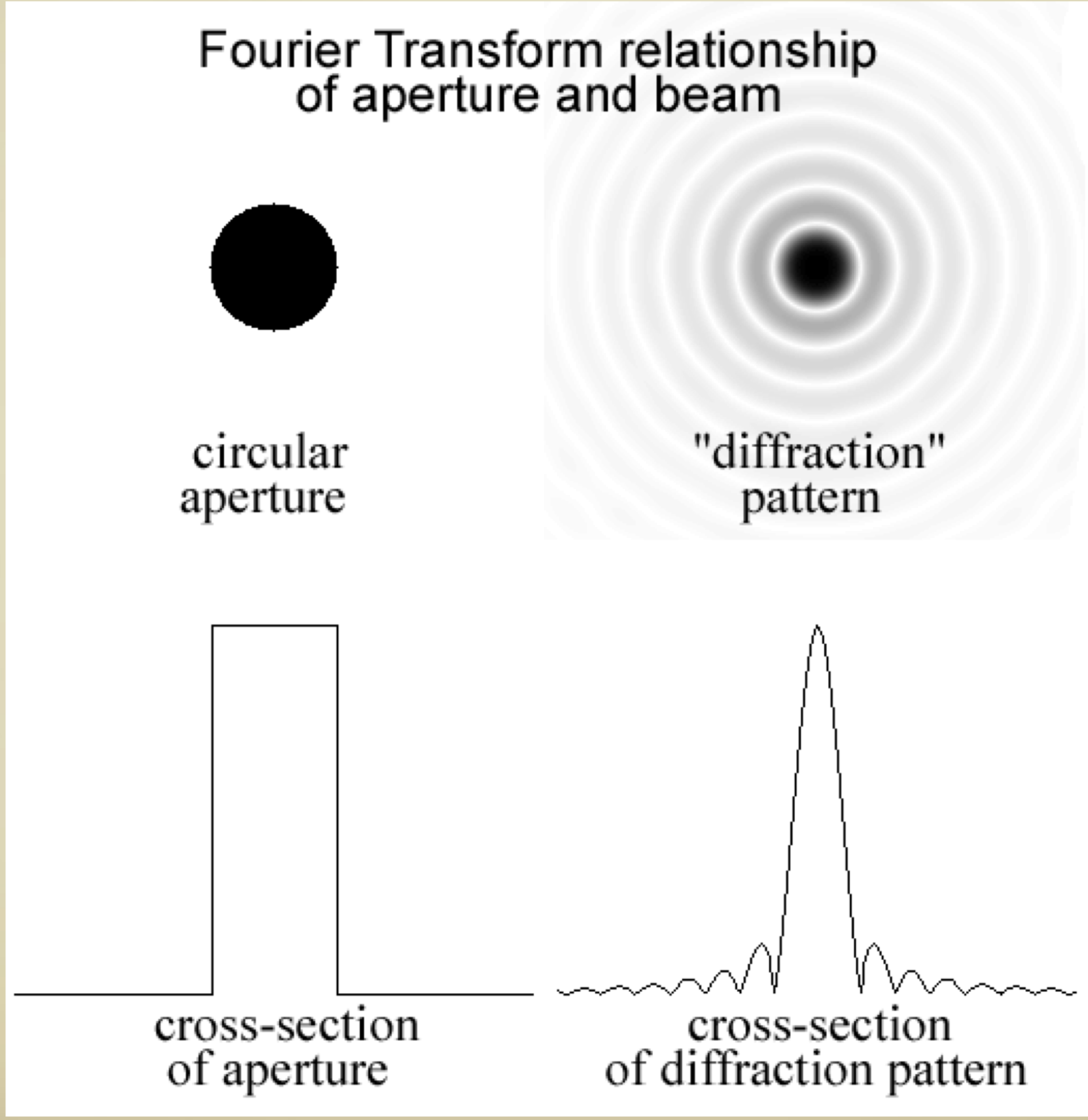
Feedhorn

Hardware that takes the signal from the antenna to the electronics

GBT receivers

Typical cm-wave feedhorn

Fourier Transforms and Beam Patterns

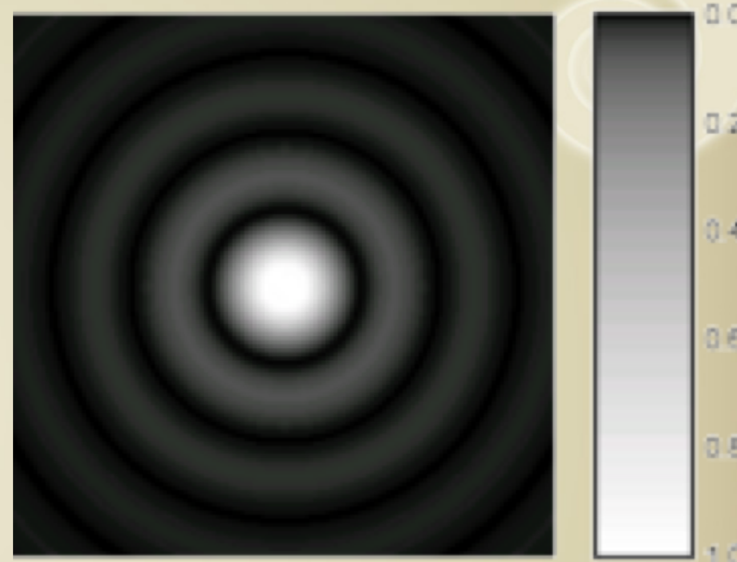


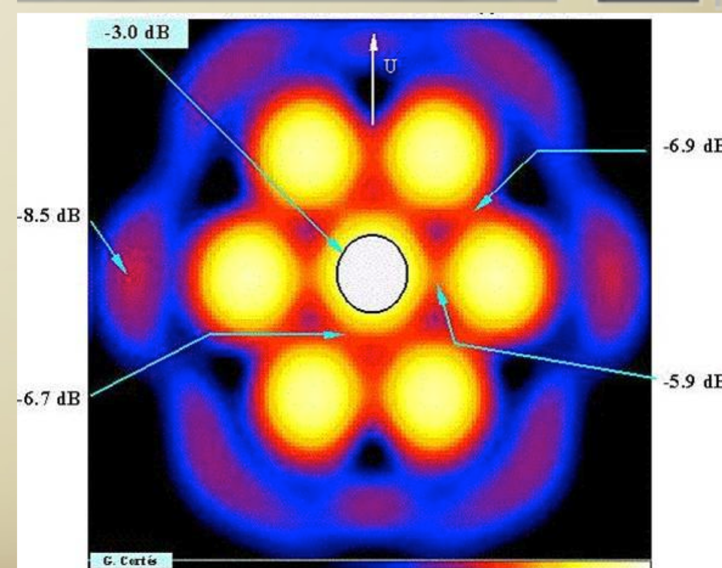
Radio Telescope Characteristics
beam and sidelobes

- Diffraction pattern of telescope

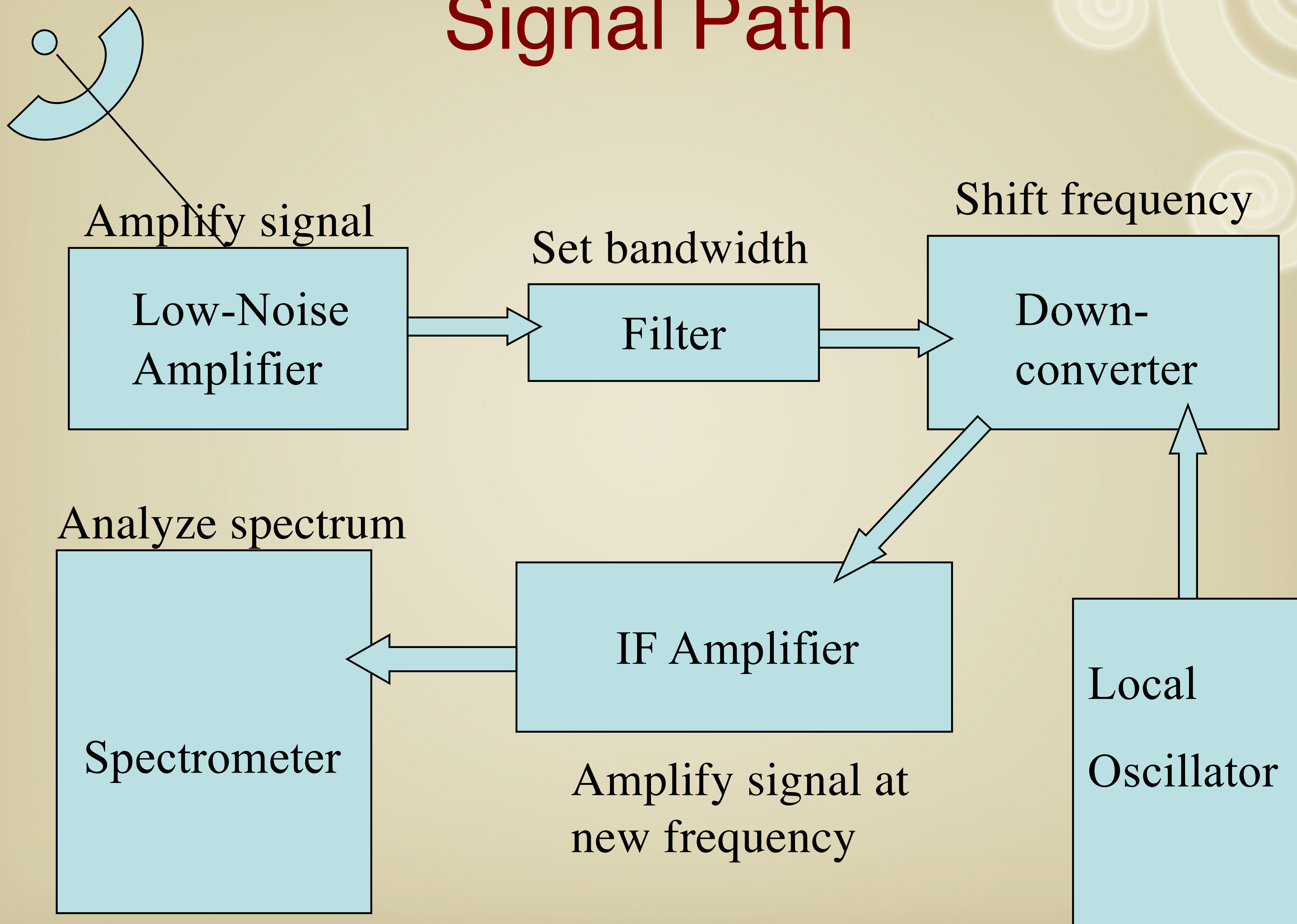
  $\sin\theta = 1.22\ (\lambda/D)$

- Diffraction pattern indicates sensitivity to sources on the sky
- Uniformly illuminated circular aperture: central beam & sidelobe rings
- FWHM of central beam is called the *beamwidth*
- Note that you are sensitive to sources away from beam center



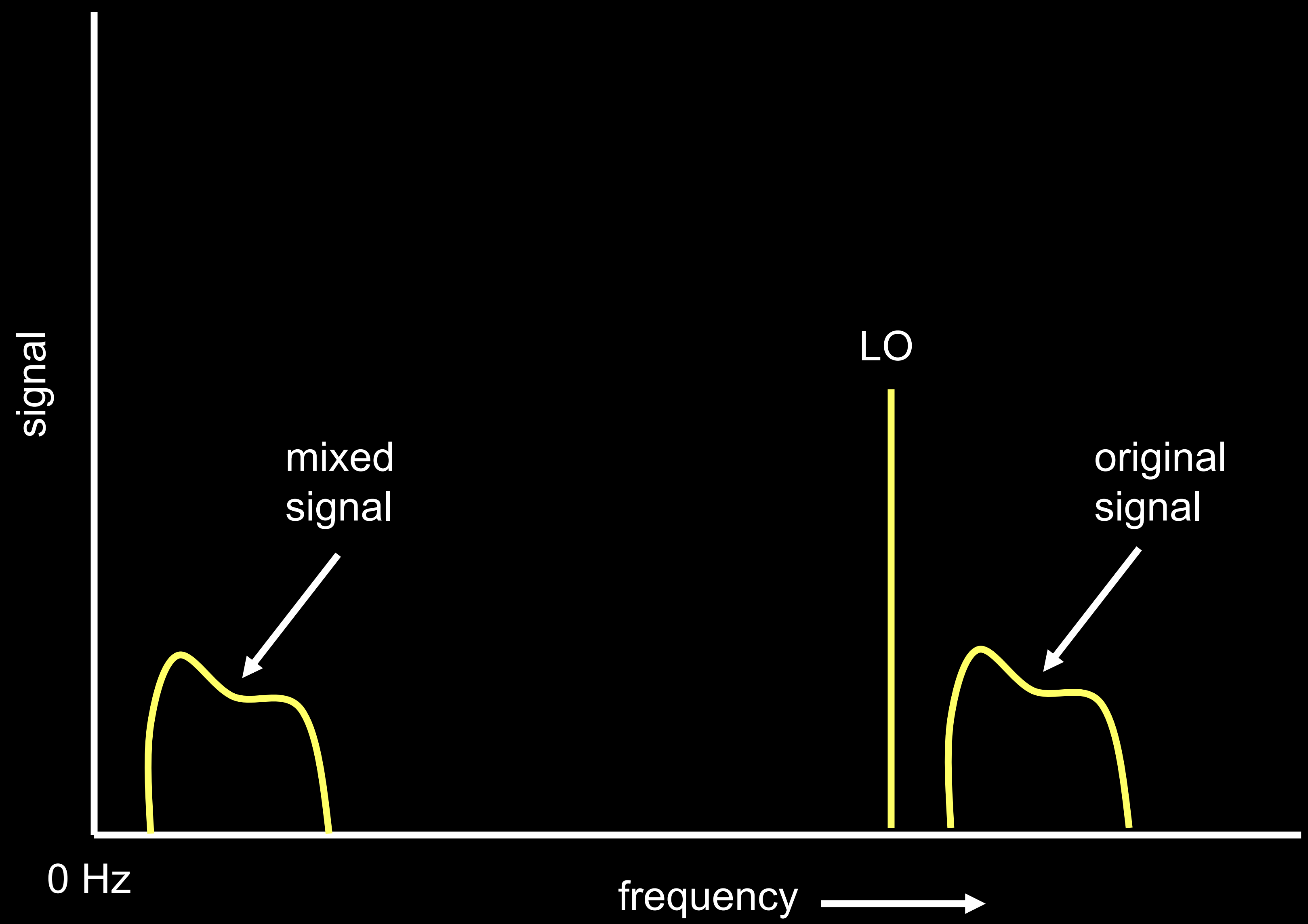


Signal Path



Amplify signal
Low-Noise Amplifier
Set bandwidth
Filter
Shift frequency
Down-converter
Analyze spectrum
Spectrometer
IF Amplifier
Amplify signal at new frequency
Local Oscillator

Mixers



The Signal Path

- Strong amplification and stable receivers needed – signal much smaller than thermal receiver noise.

- Switching techniques monitor and correct for variations in amplifier gain:
  – between sky and reference source
  – between object and “empty” sky
  – between frequency of interest and neighboring passband.

- Downconversion of signal since smaller frequencies are more convenient for the electronics

Autocorrelation Spectrometer

Or how we actually make sense out of the signal

- Measures fourier transform of power spectrum

- Special-purpose hardware computes the correlation of the signal with itself:

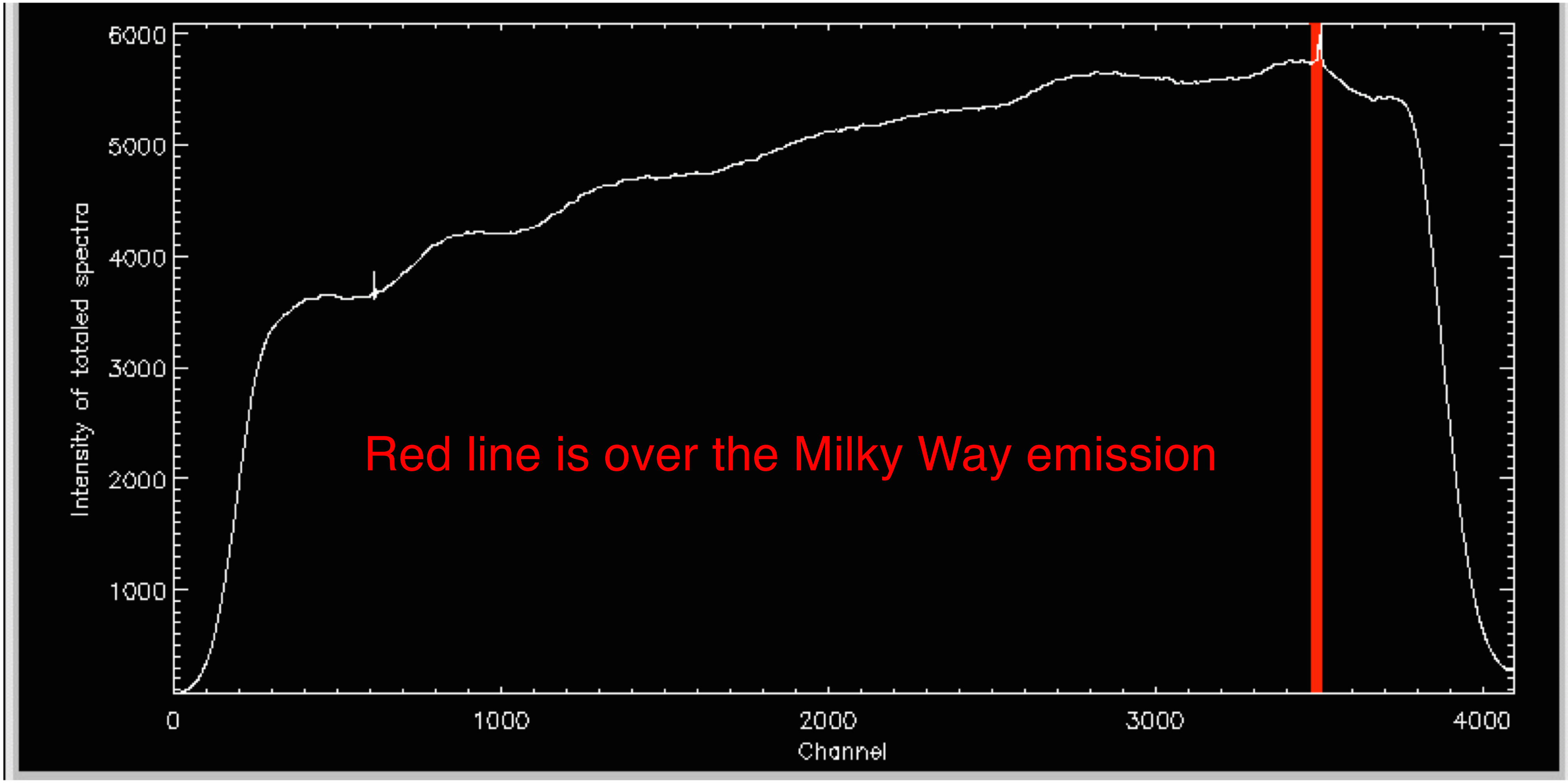
  $$R_n = N^{-1} \Sigma_1^N [\upsilon(t_j)\upsilon(t_j+n\delta t)]$$

  where δt is *lag* and υ is signal voltage; integer n ranges from 0 to $(\delta t\ \delta f)^{-1}$ if frequency channels of width δf are required

- Power spectrum is discrete Fourier transform (FFT) of R_n

Resulting Raw Spectrum

Raw baseline shape for a 21 cm observation with Arecibo



Baselines and Observing Schemes

- Instrumental effects cause variations in the baseline that are often much larger than the signal that we want to measure
- We need to find a way to observe with and without the source but without changing the instrumental effects
- We usually accomplish the above with either beam (position) switching or frequency switching

Observing Techniques:

HI 21 cm Observing in Action

Position switching:

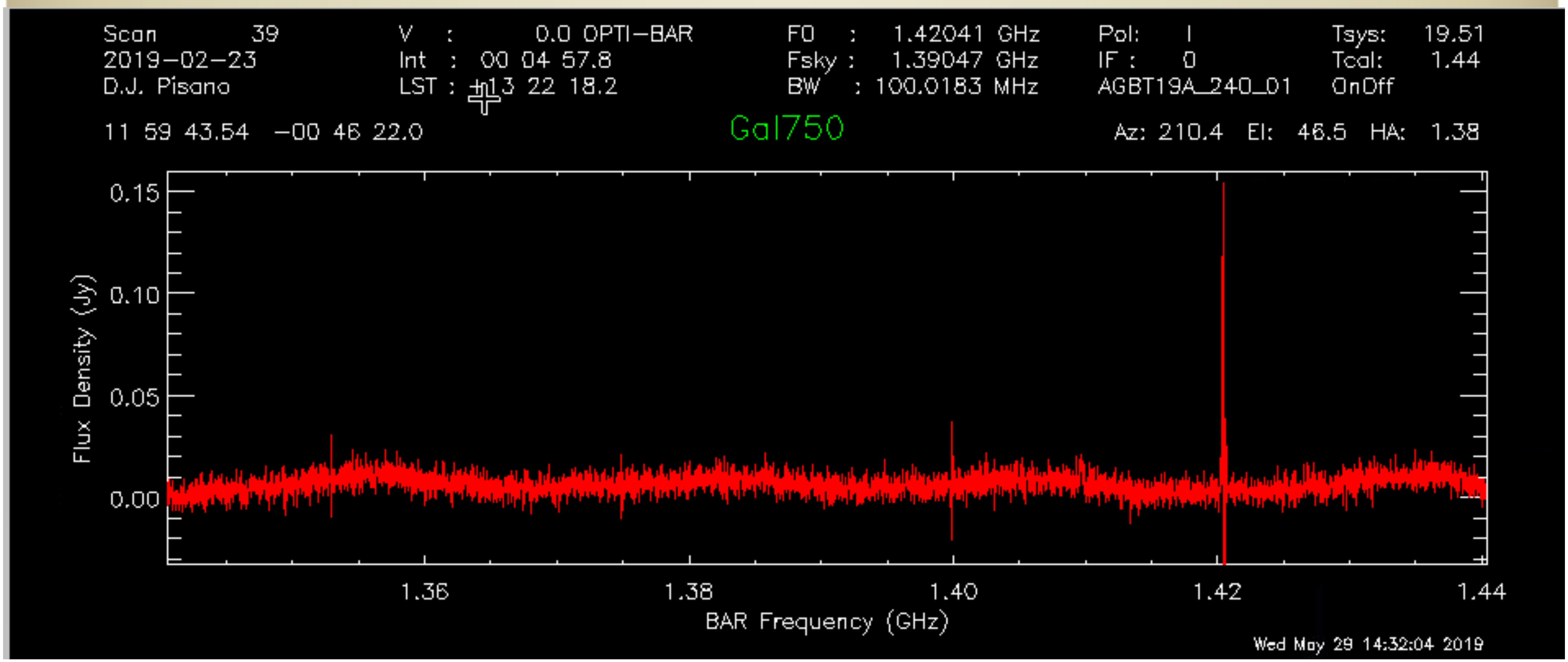
ON: telescope tracks the position of a source for a length of time

OFF: the telescope then returns to the original position on the sky and tracks the same telescope orientation over the same amount of time

- Baseline shape is removed using the off spectrum
- Because the telescope tracks the same position without a source, the systematics of the telescope should be the same

Spectrum Properties

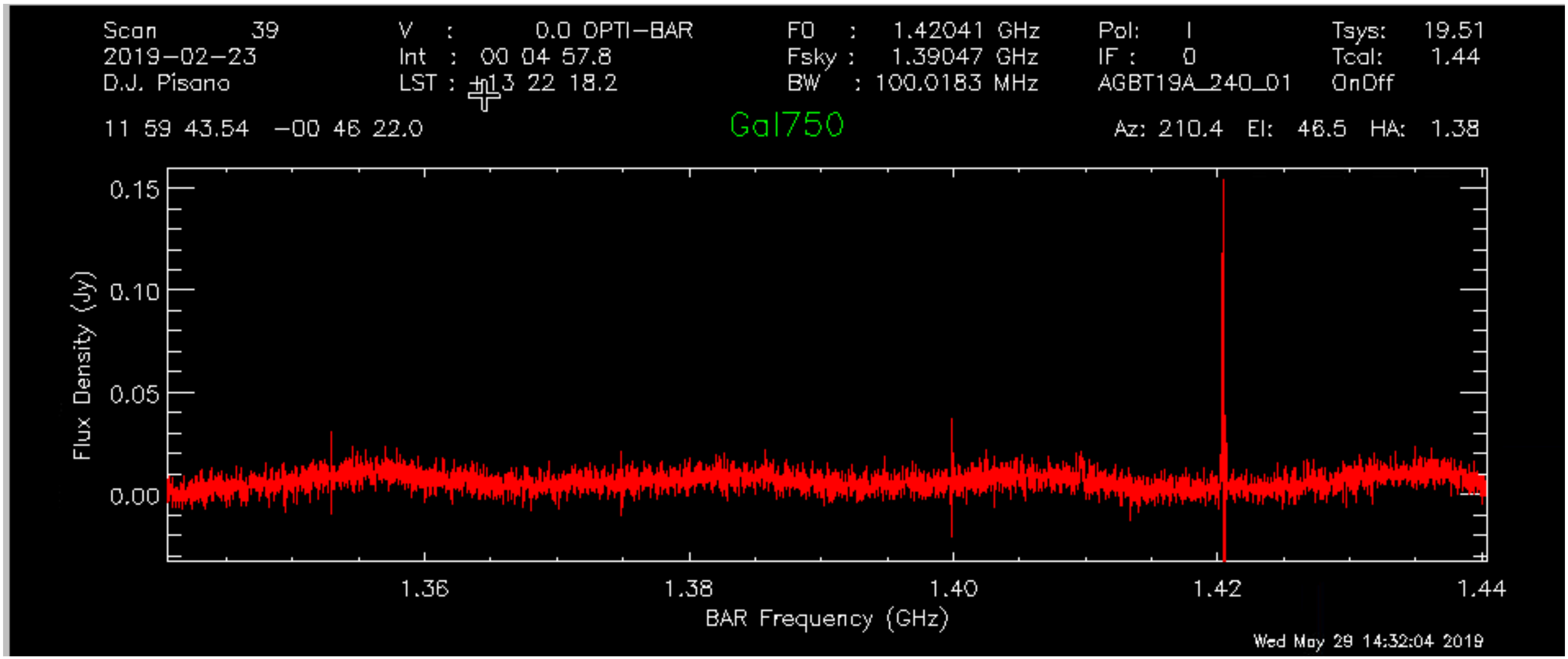
- Bandwidth – The range of frequencies over which the spectrum is measured
- Channel – The frequency separation between flux measurements (each point in the measured spectrum)
- Spectral resolution – The minimum frequency difference at which spectral features can be separated



Resulting Spectrum

$$T_{Source} = \left[\frac{T_{ON} - T_{OFF}}{T_{OFF}}\right] T_{sys}$$

System temperature: temperature of blackbody producing same power as telescope + instrumentation without a source



Spectral Resolution

- The spectral resolution can be limited by:
  - integration time (signal-to-noise)
  - filter bank resolution (if you're using a filter bank to generate a power spectrum in hardware)