The Green Bank Telescope

K. O’Neil

GREEN BANK OBSERVATORY

The Green Bank Telescope

Outline

- A very brief history
- Overview of the GBT
- Key Characteristics:
  - Optics
  - Frequency coverage
  - Signal Processing
  - Radio Quiet Zones
- Looking to the Future

Why are we here?

January 1954 – Conference in Washington sponsored by NSF, Cal Tech, Carnegie Institute of Washington

If the United States is to keep abreast of developments in radio astronomy, our scientists must have at their disposal larger and more powerful research equipment than is now available to them… there are no instruments in this country comparable with the large steerable paraboloid under construction in England, nor with the large interferometer arrays in Australia and England. The cost of such equipment places it beyond the likely means of any single institution. An observatory available to all qualified scientists is an obvious solution for the problem of inadequate research facilities.

(R. Emberson, AUI, 1954)

Why are we here?

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The level of radio noise or interference … must be extraordinarily low.

To avoid noise the following conditions are necessary:

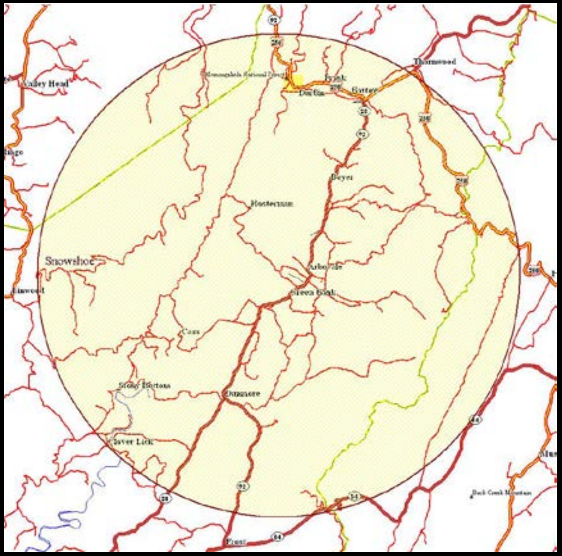
1. The telescopes should be within the view of the smallest possible number of close-by inhabitants who might generate noise in the course of their daily work.
2. The telescopes should not view high tension power lines that radiate radio noise through corona discharges or otherwise.
3. The site should be in a valley surrounded by as many ranges of high mountains in as many directions as possible, to attenuate direct radio propagation from neighboring radio stations and to reduce diffraction of tropospheric propagation into the valley.
4. The site should be at least 50 miles distant from any city or other concentration of people or industries, and should be separated from more distant concentrations by surrounding mountain ranges.

A brief History

Two radio quiet zones

WV Radio Astronomy Zone

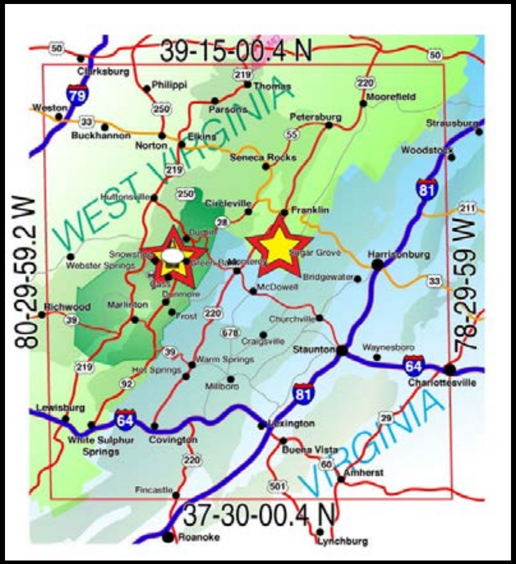
WV Legislature (1956)



Protection within ten miles of the Observatory

National Radio Quiet Zone

FCC &NTIA (1957)

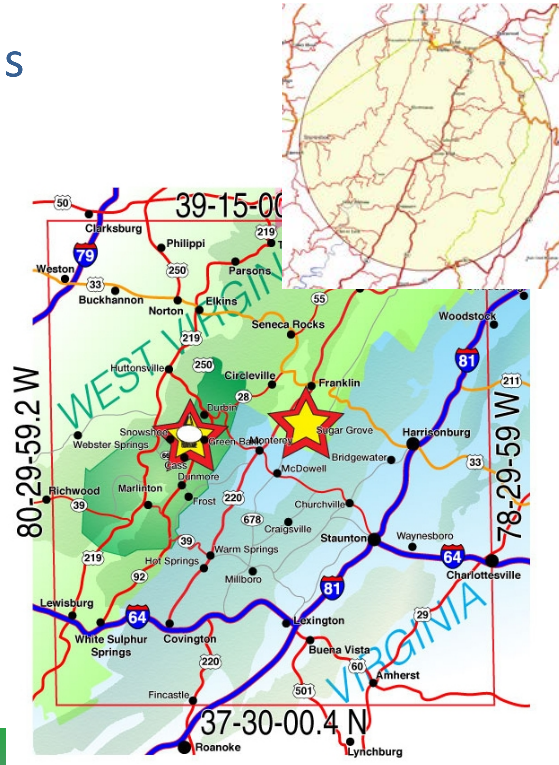


13,000 Square Miles

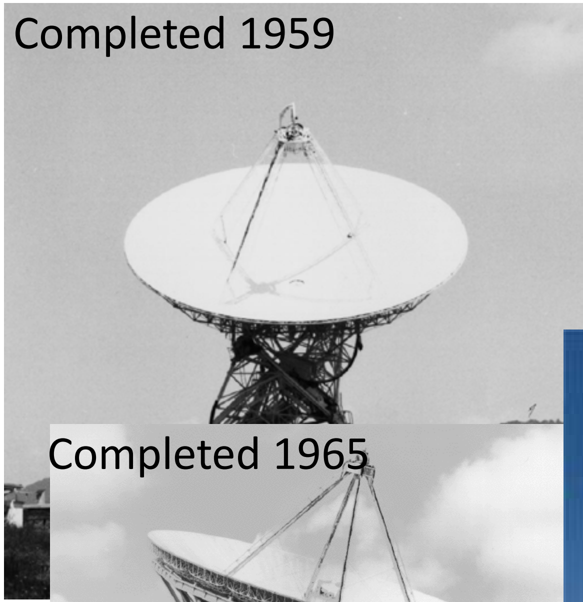
A brief History

Two radio quiet zones

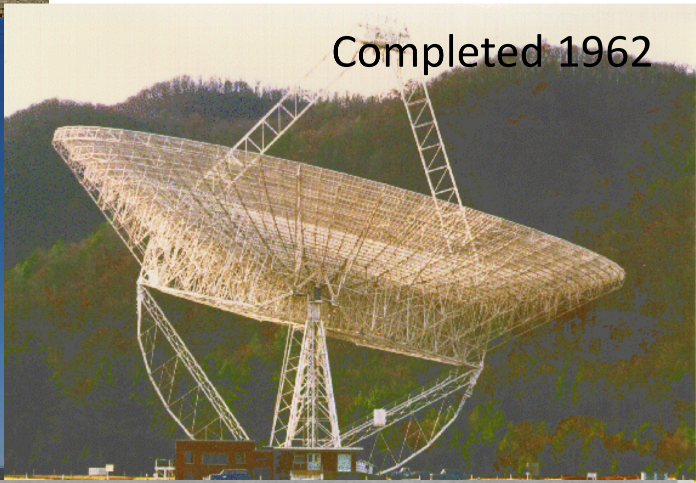
- West Virginia Radio Astronomy Zone
  - 10 miles radius around the Observatory
  - Protects against any electrical equipment that causes harmful interference
  - State based protection with a fine for infractions
- National Radio Quiet Zone
  - 13,000 sq. mile region centered between
    Green Bank and Sugar Grove
  - Coordination: all fixed, licensed transmitters
  - Proved recommendation to NTIA/FCC

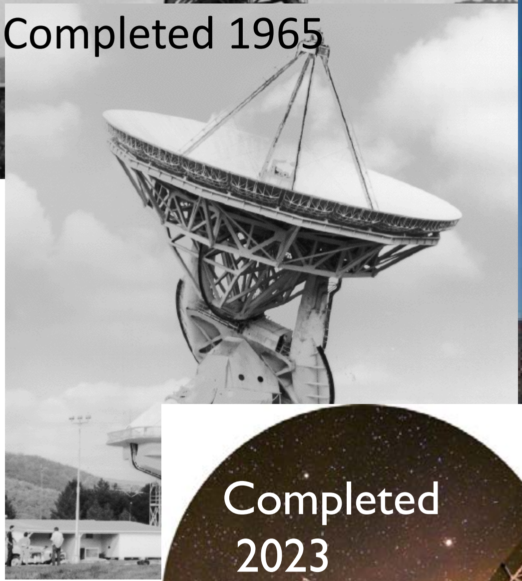


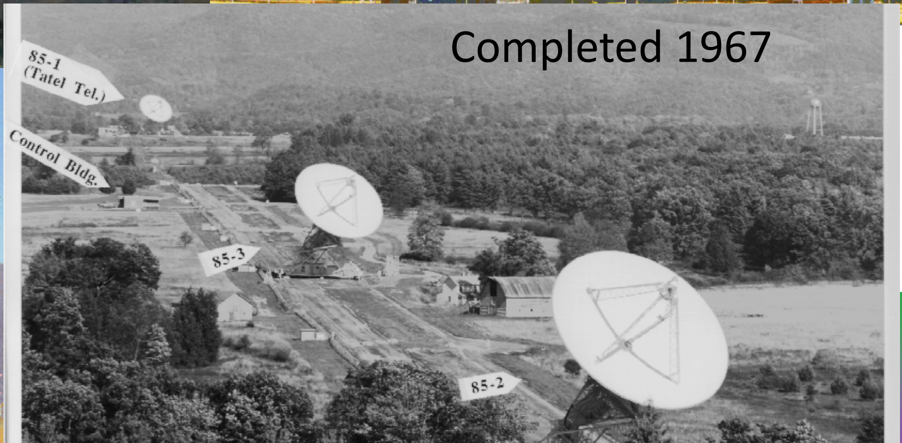
Original National Radio Astronomy Observatory, with world class telescopes for 60 years



Completed 1962







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The GBT: Overview

At 100 m, the GBT is the largest *fully steerable* telescope (and the largest movable structure) in the world.

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Phenomenal sensitivity

Often measure signals in units of 10^{-32} W/m^2/Hz

0.00000000000000000000000000000001 W/m^2/Hz

A cell phone on Mars is 1,000,000 times louder than most astronomical signals

(and yours, here, would be <u>far</u> worse…)

The GBT: Overview

A World Class Facility for Science Research

- 85% sky coverage
- 0.3 – 116 GHz range
- Unblocked aperture
- Phenomenal sensitivity (μJy)
- 30% aperture eff. at 100 GHz
- 6800 hours available annually

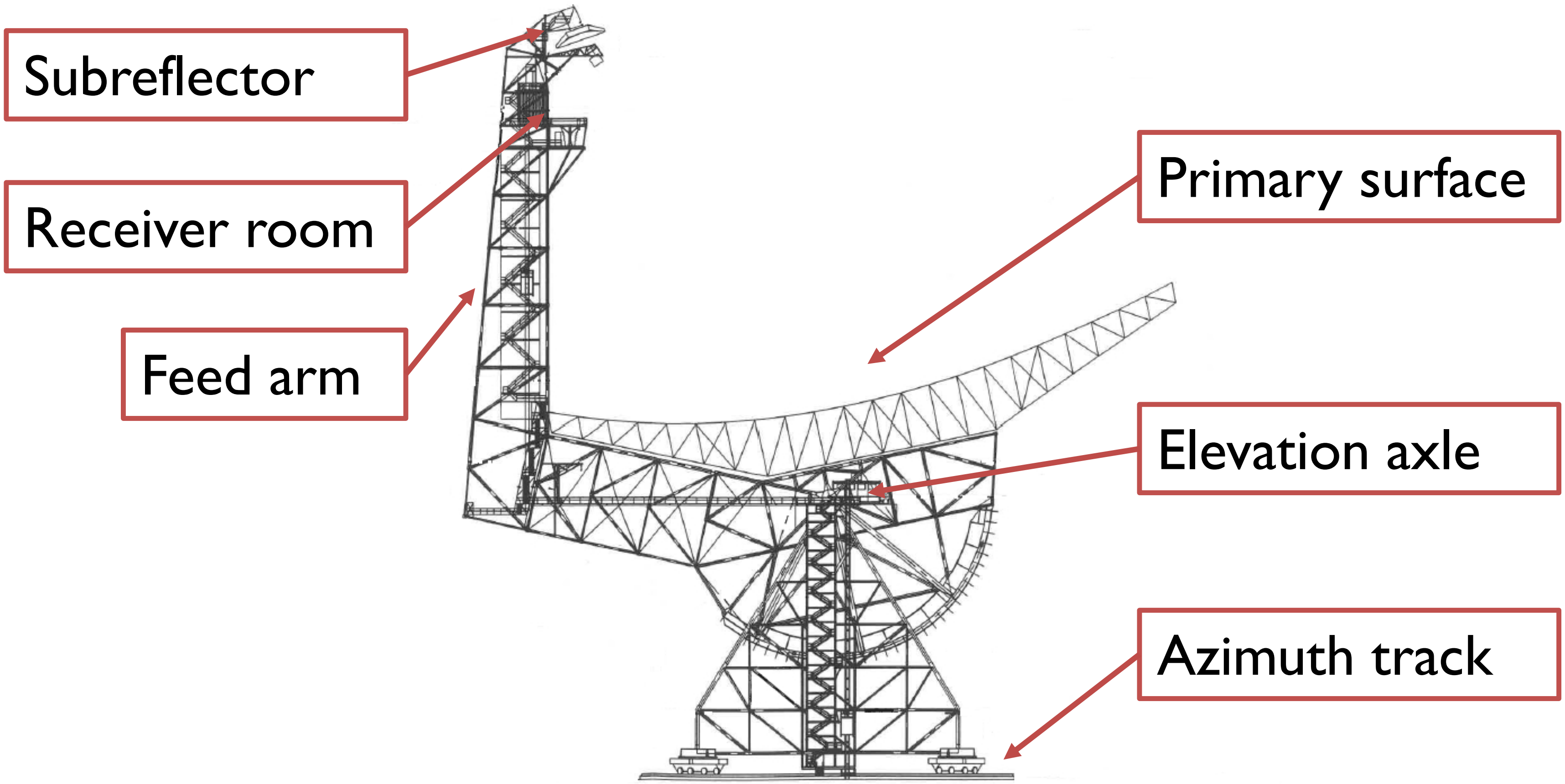
User Community :

- >3000 individual scientists proposed to use the GBT in past 5 years*
- Span range of disciplines from planetary science to chemistry and physics
- Roughly 20% of proposers are new each semester

*Based on number of individual email addresses

GBT Primary Components

Overview



GBT Primary Components

Overview

- Fully Steerable
  - Elevation Limit: 5º
  - Can observe 85% of the entire Celestial Sphere
- Slew Rates: Azimuth - 40º/min; Elevation - 20º/min

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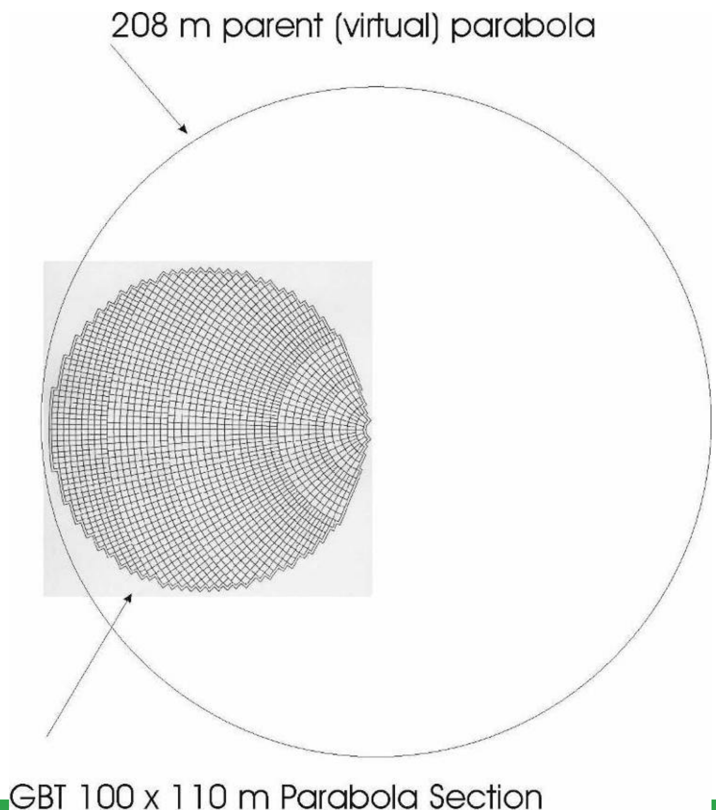
GBT Key Characteristics:

Optics

- Effective diameter= 100m
- (100mx110m section of 208m parent parabola)



GBT Key Characteristics

Optics

- Off axis design: Unblocked Optics, High Dynamic Range

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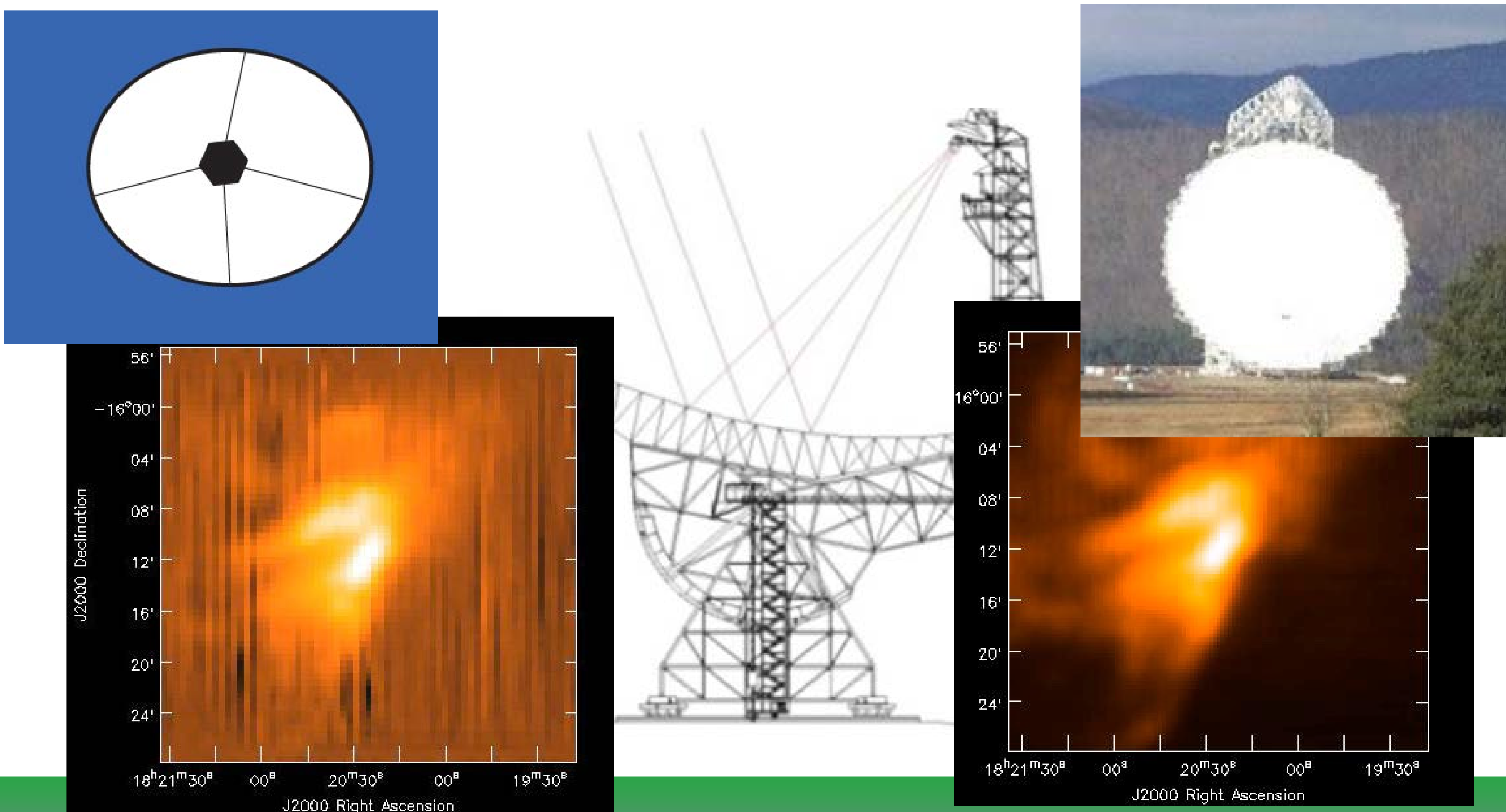


GBT Key Characteristics

Optics

- Gregorian Focus: 8-m subreflector - 6-degrees of freedom
- Prime Focus: Retractable boom

GBT Key Characteristics:

Active Surface

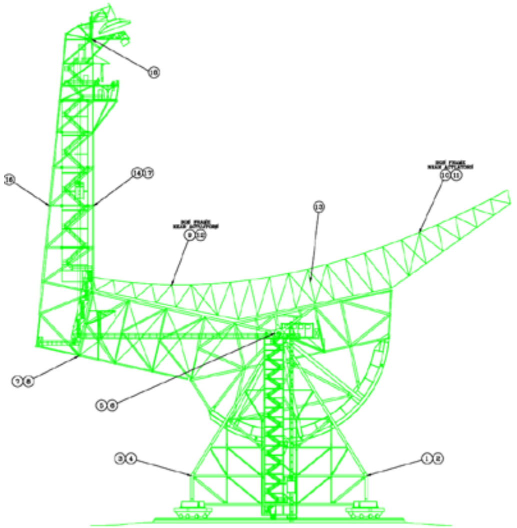
- Makes the GBT the largest single-dish operating efficiently at 3mm in the world

Telescope	Surface RMS/Diameter
GBT	2.3e-6
ALMA	2.0e-6
VLA VLBA NGVLA	2.0e-5 1.4e-5 ~1.0e-5

GBT Key Characteristics:

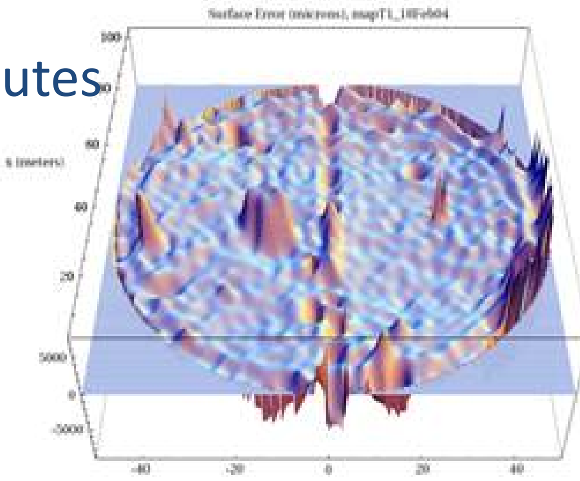
Active Surface

- Uses temperature sensors, holography



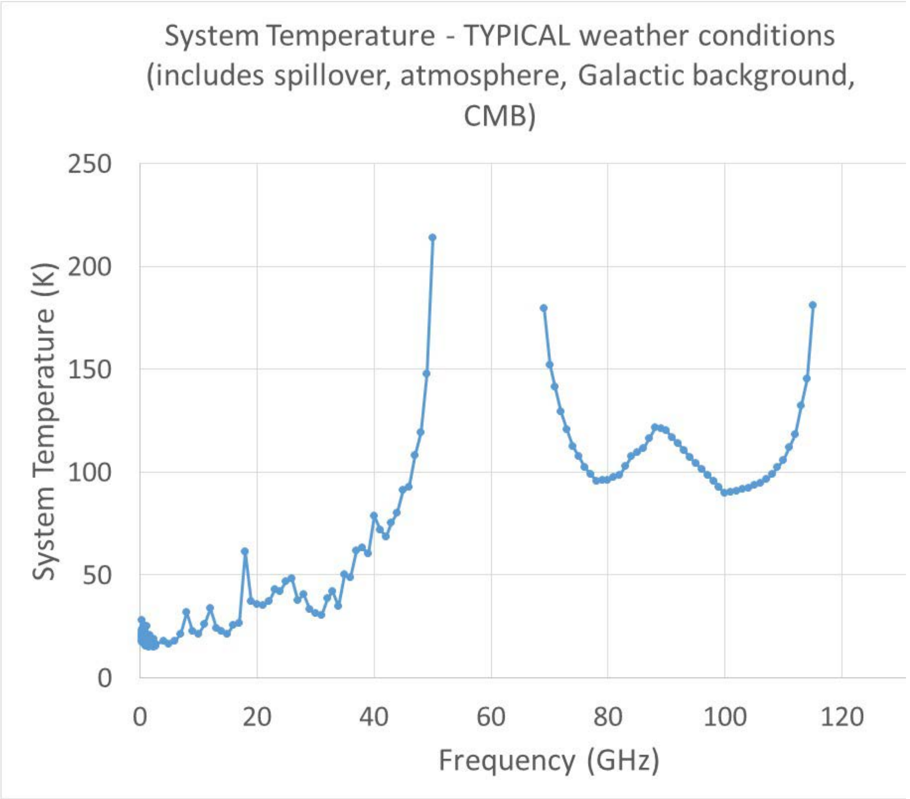
- Temperature sensors:
  - Placed around the telescope;
  - Use in open loop system for surface corrections

- Holography
  - Method to create rough image of the surface
  - Used to provide corrections every 30-120 minutes



GBT Key Characteristics:

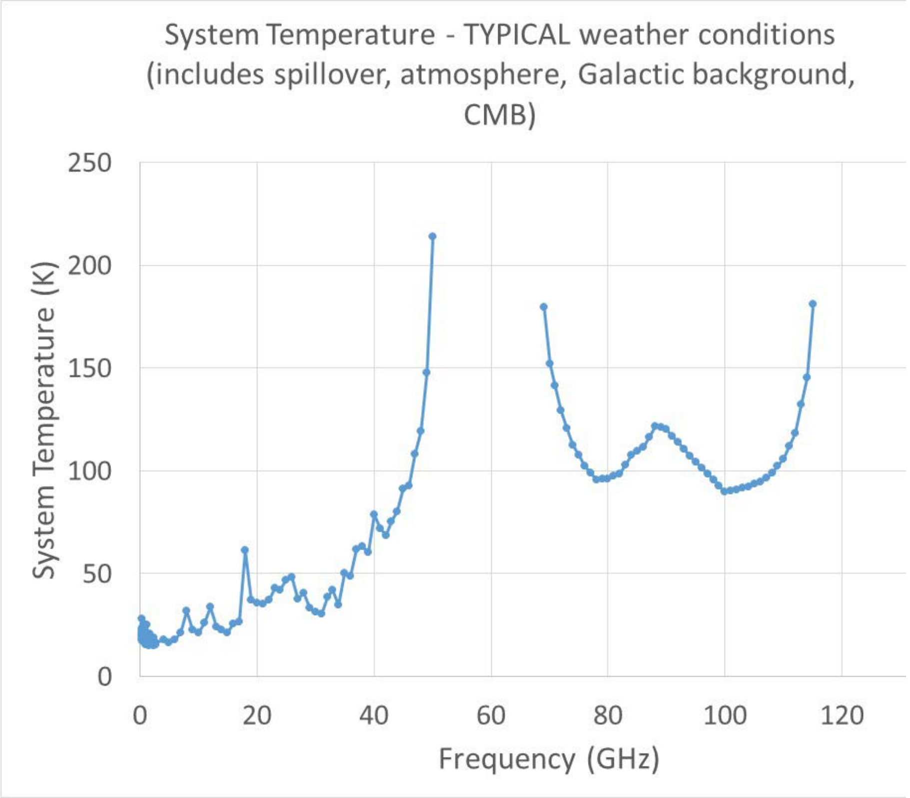
Frequency Coverage from 0.3-116 GHz



GBT Key Characteristics:

Frequency Coverage from 0.3-116 GHz

- Most receivers are single/dual pixel, however…
  - Three multi-pixel ‘cameras’ now available on the GBT



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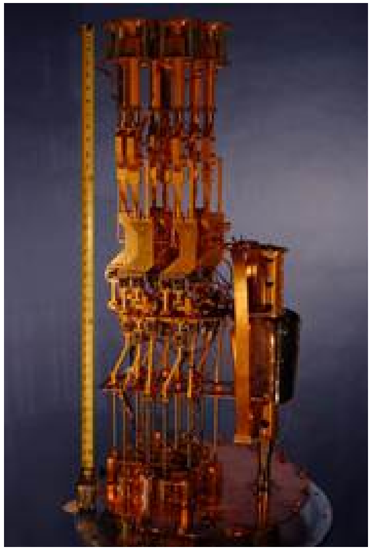
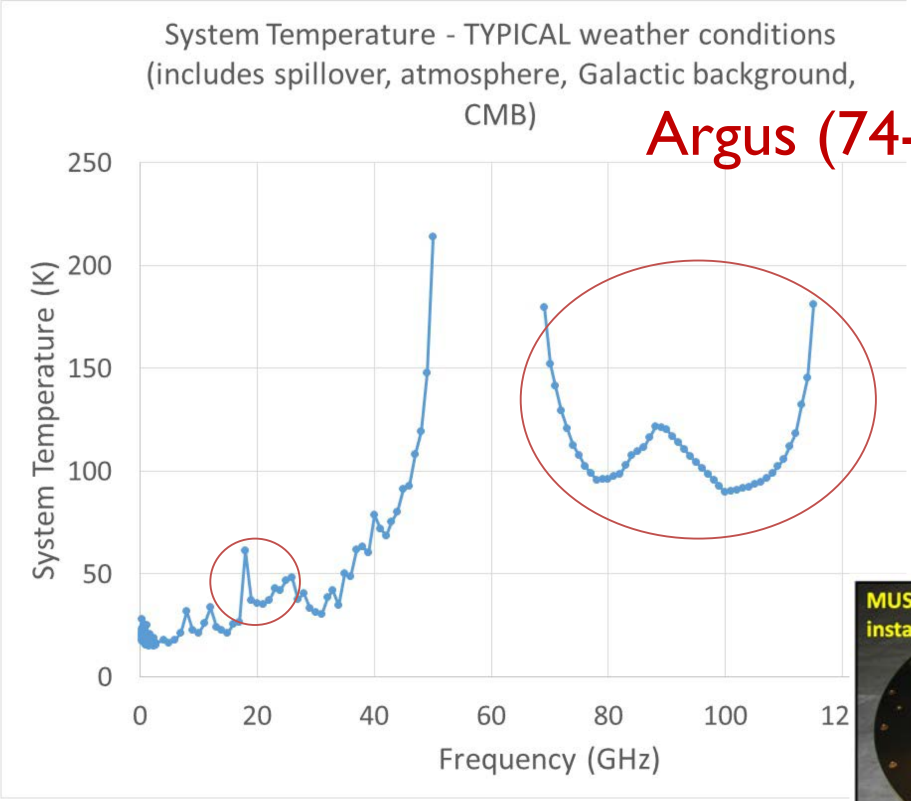
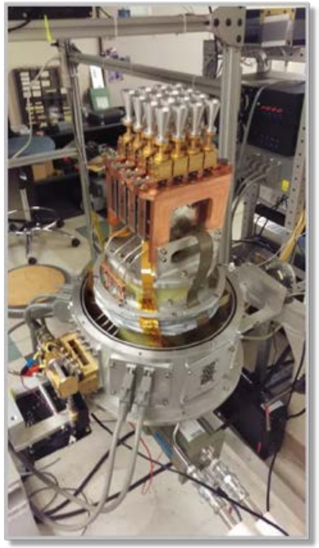
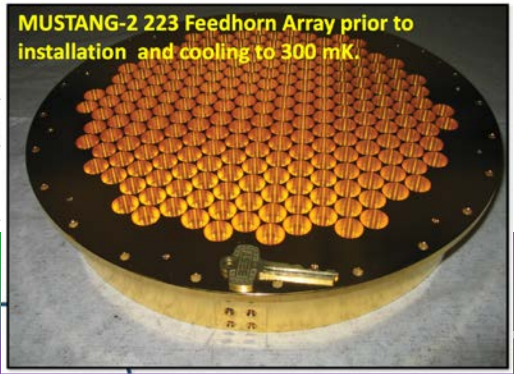


KFPA (18-27.5)



Argus (74-116)





MUSTANG2 (75-105)

GBT Key Characteristics:

Frequency Coverage from 0.3-116 GHz

- Receivers:

    Rotating turret with 8 receiver holes

    (11 receivers, all using the subreflector)

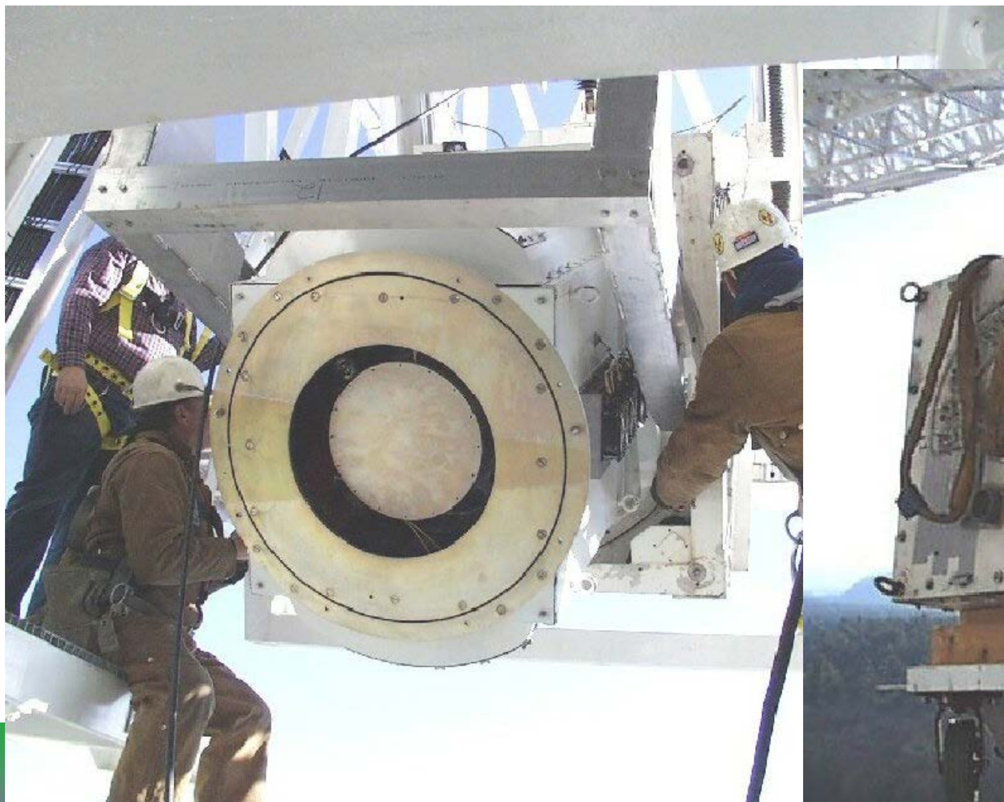
GBT Key Characteristics:

Frequency Coverage from 0.3-116 GHz

- Receivers:

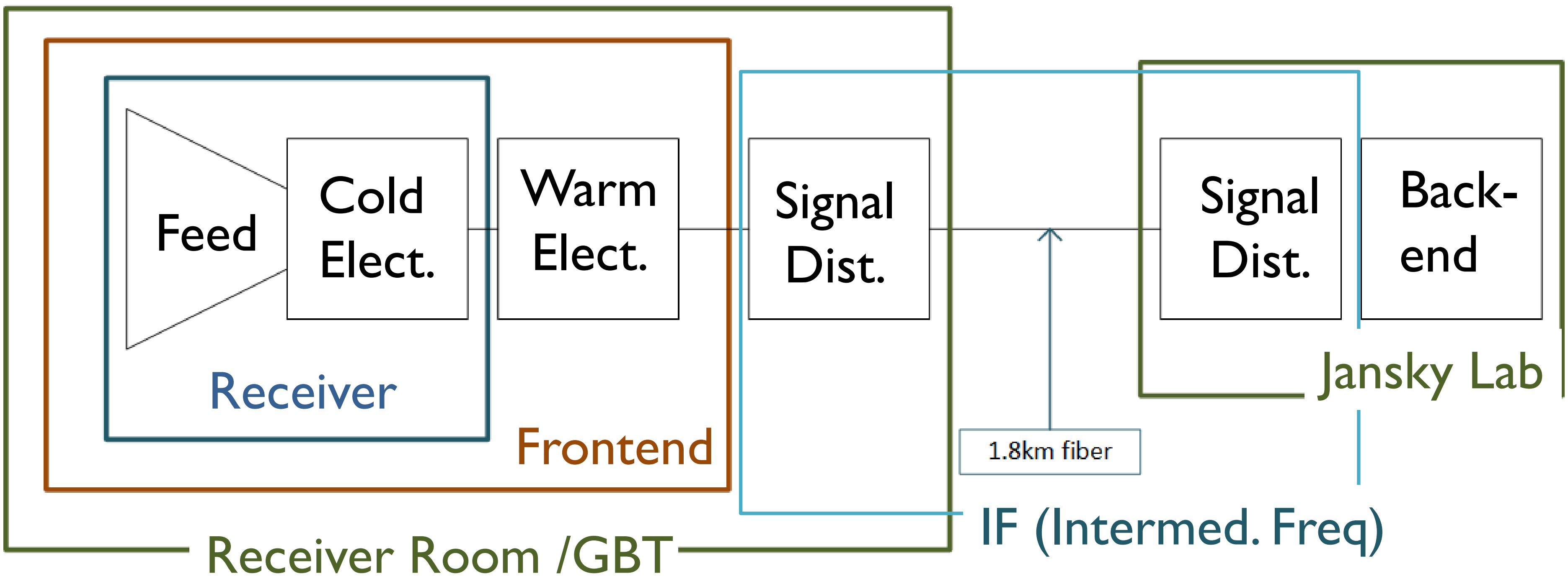
  Only one prime focus receiver at a time

  (4 receivers currently; Do not use subreflector)



GBT Key Characteristics:
Signal Processing

Basic signal chain, for most instruments



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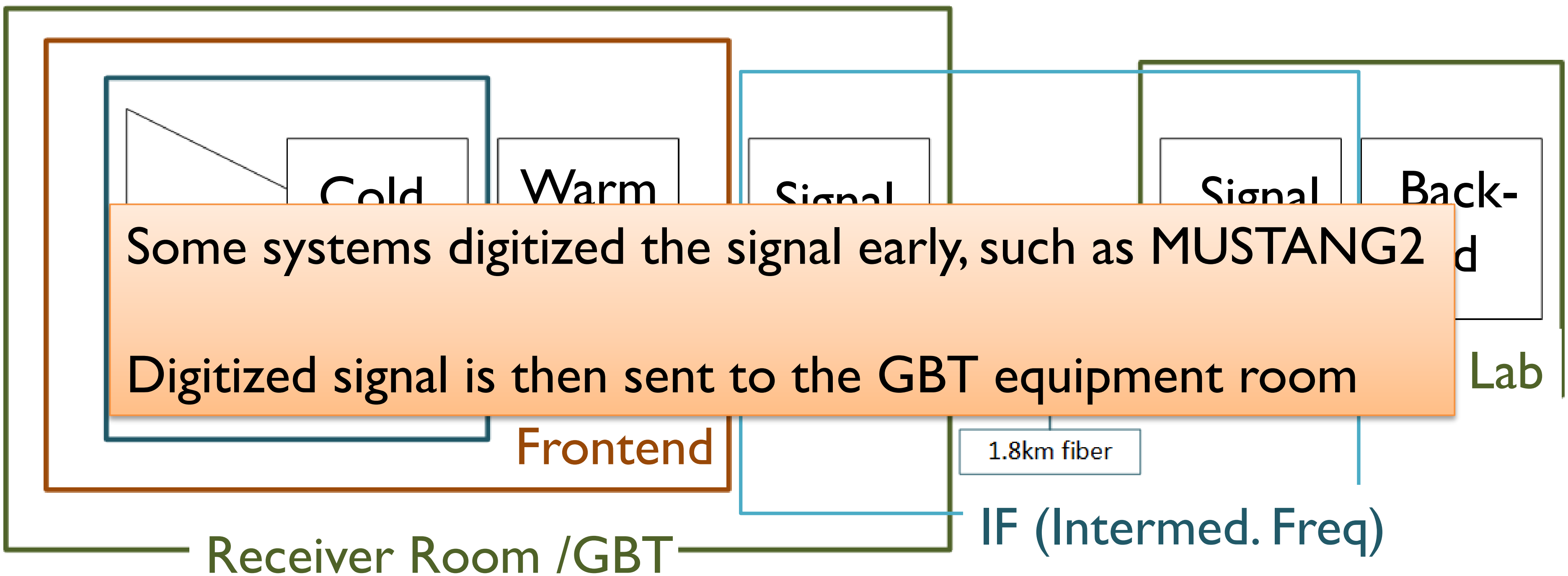

Some systems digitized the signal early, such as MUSTANG2

Digitized signal is then sent to the GBT equipment room

GBT Key Characteristics:

Signal Processing - Backends

GBT Key Characteristics:

Signal Processing

- Primary backend:

VEGAS: Versitile GBT Astronomical Spectrometer

Primary pulsar and spectral line backend

Many, many modes to choose from for:

Time resolution (≥0.34 μs)
Spectral resolution (0.26-1465 kHz)
Total bandwidth (16.875 – 1250 MHz) x8
Many spectral windows (1-8) x8

GBT Key Characteristics:

Signal Processing

- Secondary backends

DCR: Digital Continuum Receiver

Used for most pointing and focus observations

Also available for continuum (total power) observations

Mark 6

Disk-based VLBI recording system

Disk correlation is done at Socorro, not Green Bank

GBT Key Characteristics:

Signal Processing

- Three main backends: VEGAS, DCR, Mark 6

- Other backends include:
  - CCB (Caltech Continuum Backend):
    - Use primarily for holography observations
    - Only works with the Ks receiver
  - JPL Radar backend:
    - Used exclusively when the GBT is receiver radar signals from, e.g. JPL
  - Breakthrough Listen:
    - Used by the Breakthrough Listen team
    - Also available for (limited) use by others

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Looking to the future

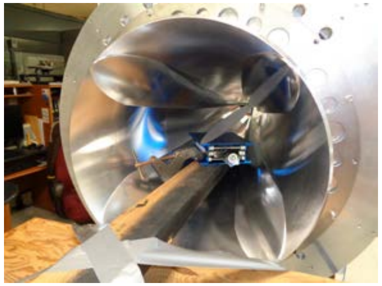
New Instruments , New Possibilities

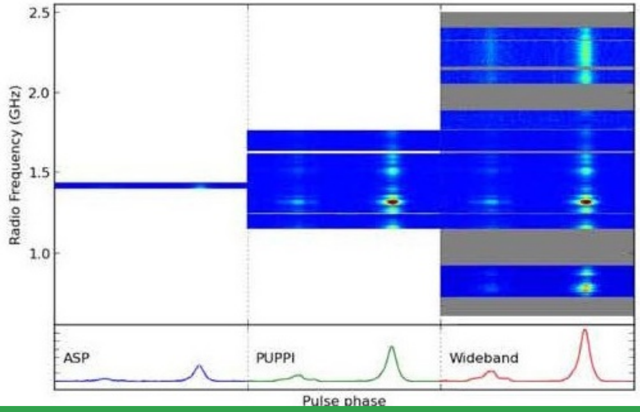
Looking to the future

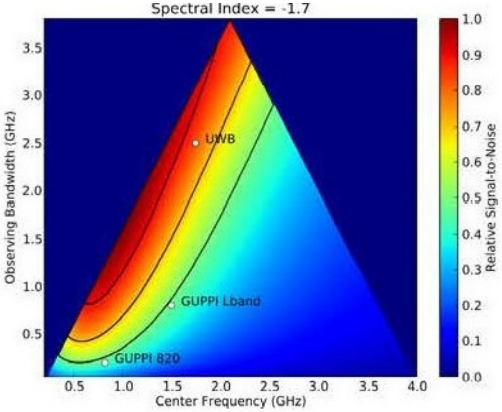
Ultra Wideband Feed

Moore Foundation award (PI: Ransom – NRAO/NANOGrav)

- 0.7 – 4.0 GHz feed optimized for pulsar work
- Aim is T_{sys} ~30 K
- Doubles the sensitivity for most pulsar timing observations
- Also doubles the available bandwidth
- Commissioning right now







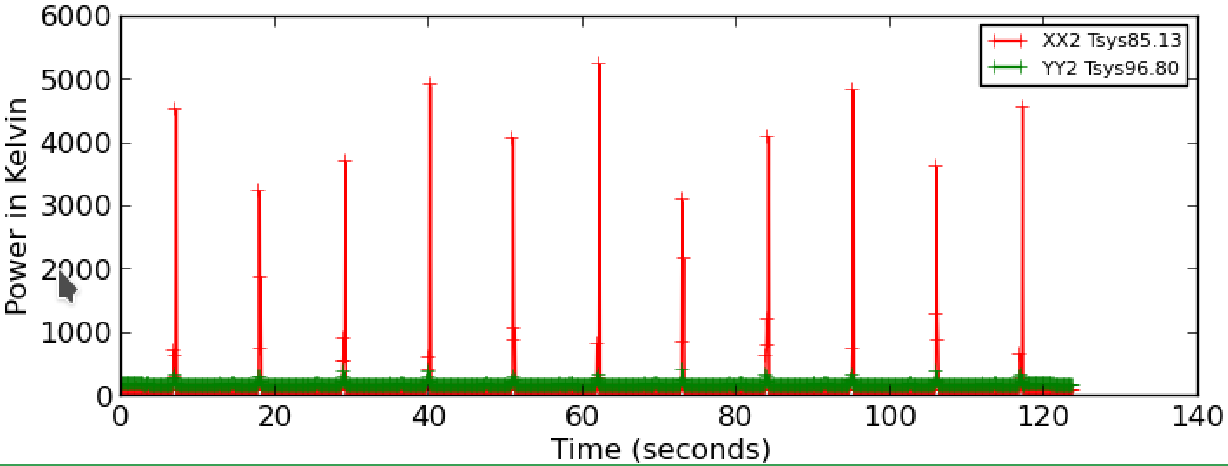
Left: Pulse profile versus frequency for J2214+ 3000 as observed by ASP, PUPPI, planned UWB
Right: Relative SNR as a function of observing bandwidth and center frequency for uniformly-weighted data and a typical pulsar spectral index of -1. 7

Looking to the future

Digitizing the RF

NSF ATI award (R.Lynch, PI)

- Designed for wide-band digital systems
- Increase the range of frequencies detected at any instant
- Allows for active RFI mitigation;
- Improves dynamic range, baselines
- Development underway; Goal is to deploy on UWBR

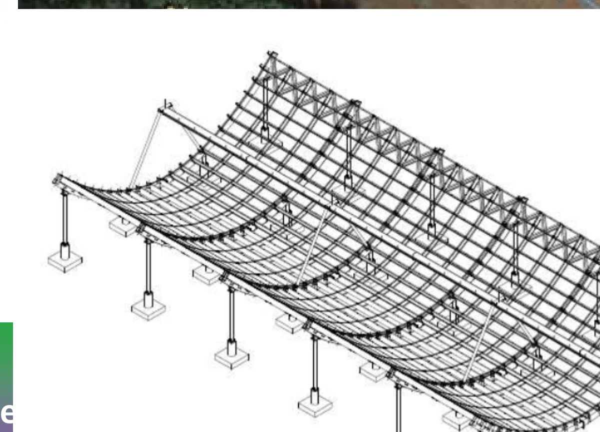


Data from the GBO 20-m telescope demonstrating our new, real-time robust recursive power estimation excision technique.

Looking to the future

CHIME Outrigger

- CHIME outrigger antenna on site
- Plans to build 64 additional (small) antenna; Not yet funded



Looking to the future

The GBT – Radio Cameras

ALPACA (partially funded)

- 69-element phased array feed
- 40 simultaneous dual polarized beams
- 305 MHz of instantaneous BW @ 1.4
- Led by BYU/Cornell

MUSTANG3 (not funded)

- Bolometer array
- 600 dual-linear feeds
- 75-105 GHz in three bands
- Led by UVa, UPenn

ARGUS 144 (not funded)

- Traditional feed horn array
- 10 x 10 pixels; 85-116 GHz
- Pixel spacing 26.7” ; Footprint: 4’x4’

KPAF (not funded)

- Phased array feed
- 225 beams; 20-28 GHz

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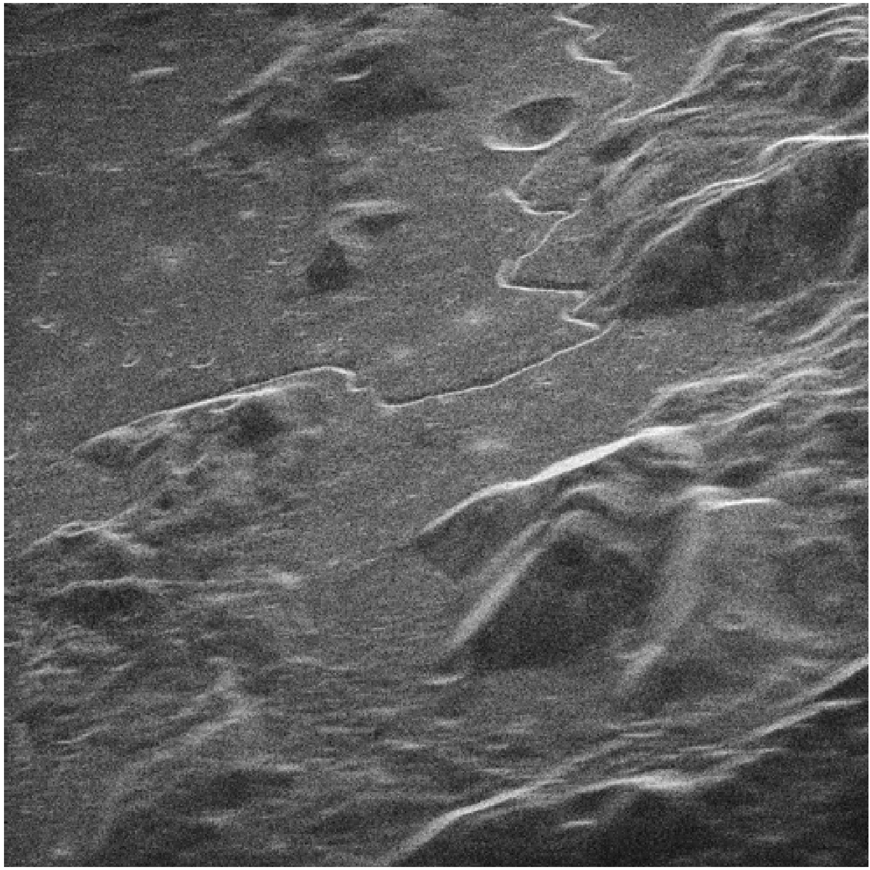
Looking to the future

Radar Systems

Planning for new high power radar system on GBT

Phase I: low power demonstration

- Test system: 700W, 14 GHz
- Images Apollo 15 landing site
- Observations are conintuing



Phase II: high power system

- 50-100s kW transmit on GBT
- VLBA then ngVLA as receive
- Project planning underway
- Not yet funded

Questions?

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