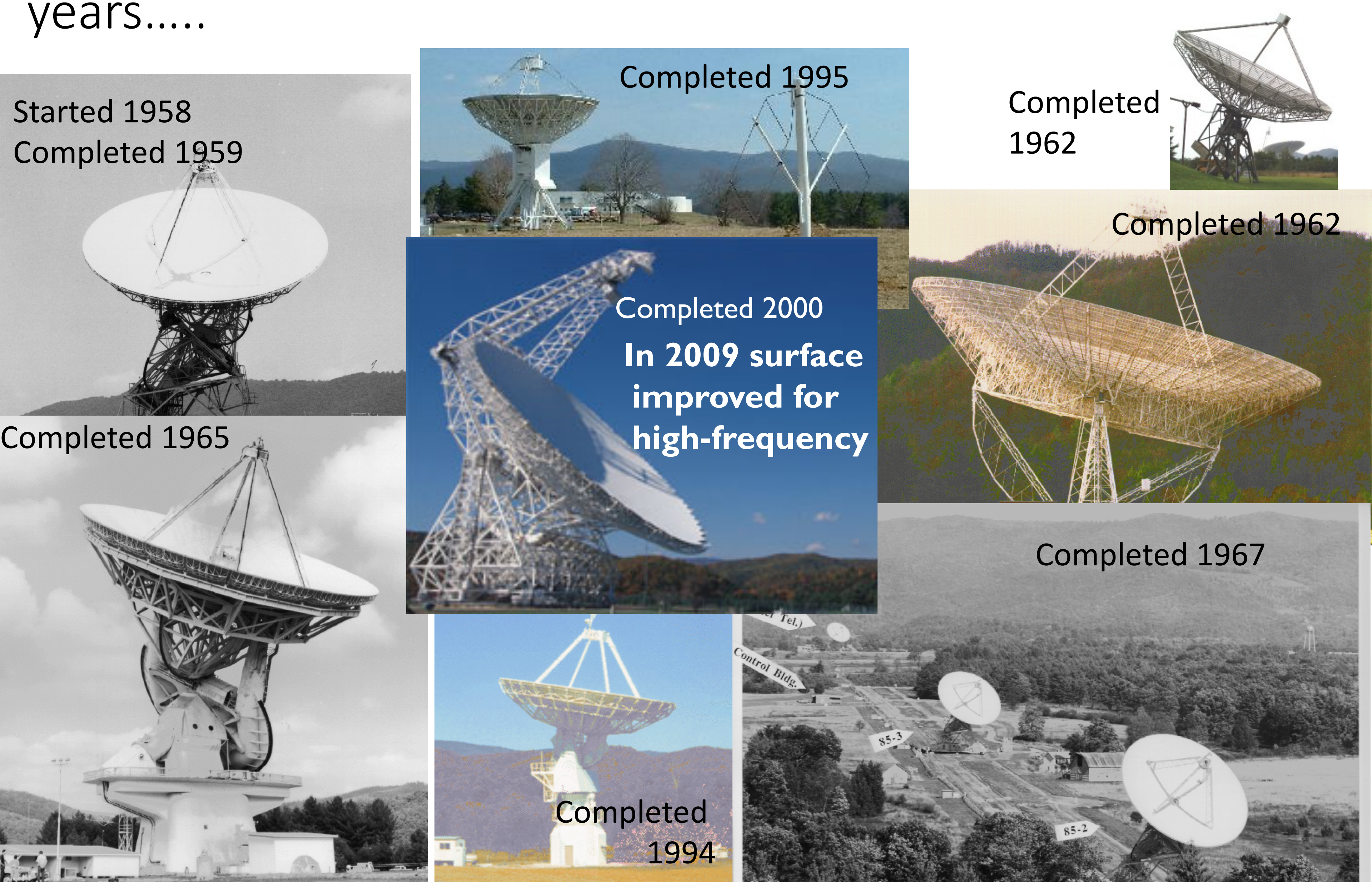
The Green Bank Telescope

David Frayer (GBO)

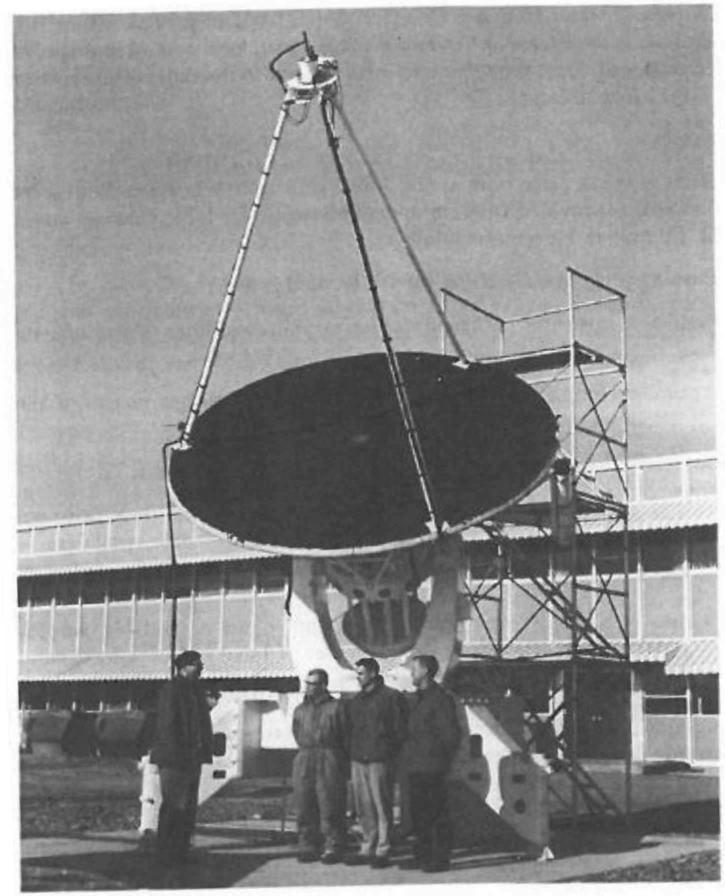
GREEN BANK OBSERVATORY

Green Bank is the original NRAO site and has been operating world-class radio telescopes for nearly 60 years.....



Interestingly, early mm-wavelength astronomy started in Green Bank (1963)

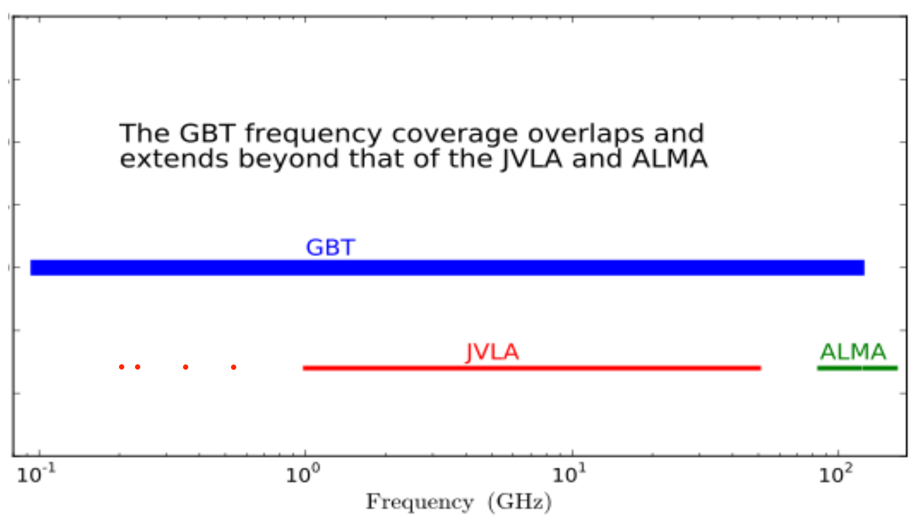
Arnold Davidson next to the 5-foot mm-wave telescope.



The Twelve Foot mm-wave telescope behind the Jansky Lab. Left to right: Frank Low, Tom Carpenter, Arnold Davidson, Omar Bowyer.

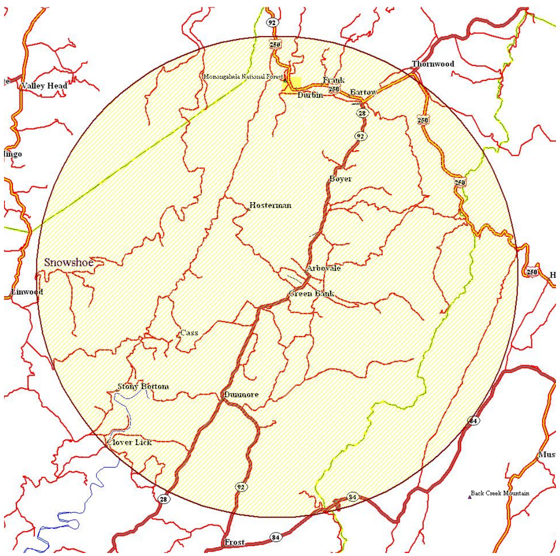
Key Capabilities of the GBT

- 100 meter diameter unblocked
- Receivers cover 0.1 to 116 GHz
- Excellent point-source sensitivity
- Unsurpassed sensitivity for extended objects
- >85% of total sky covered   (δ≥-46°)
- Location in the National Radio Quiet Zone



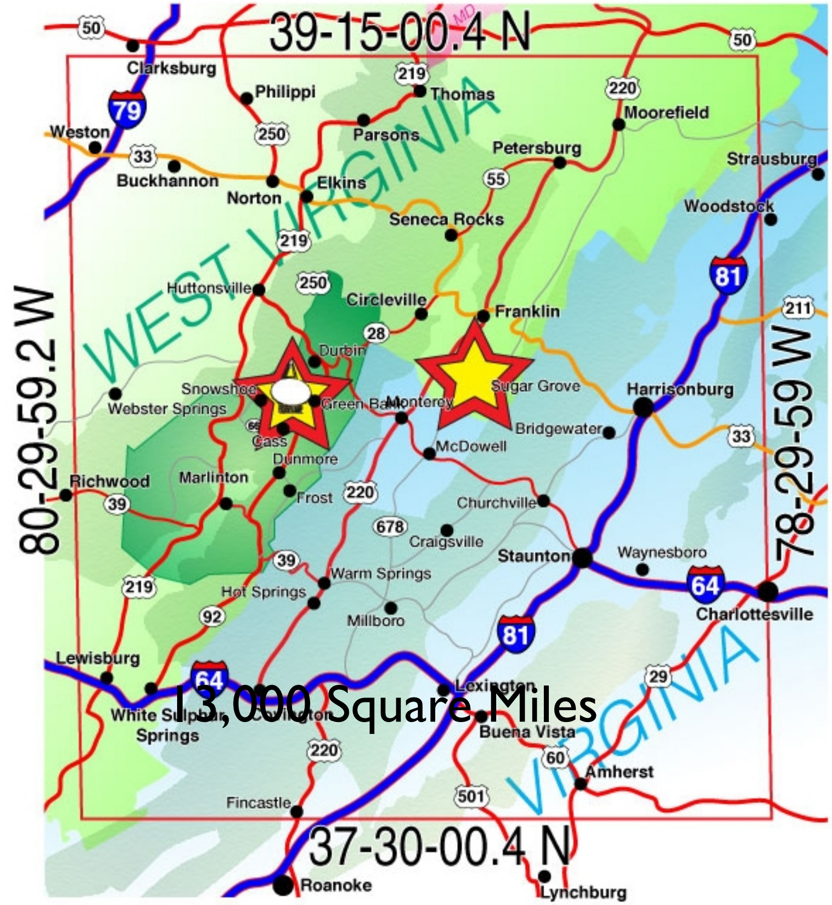
Site protected from Radio Interference

WV Radio Astronomy Zone
Established by the West Virginia Legislature (1956)



Protection within ten miles of the Observatory

National Radio Quiet Zone
Established by the FCC and NTIA (1957)

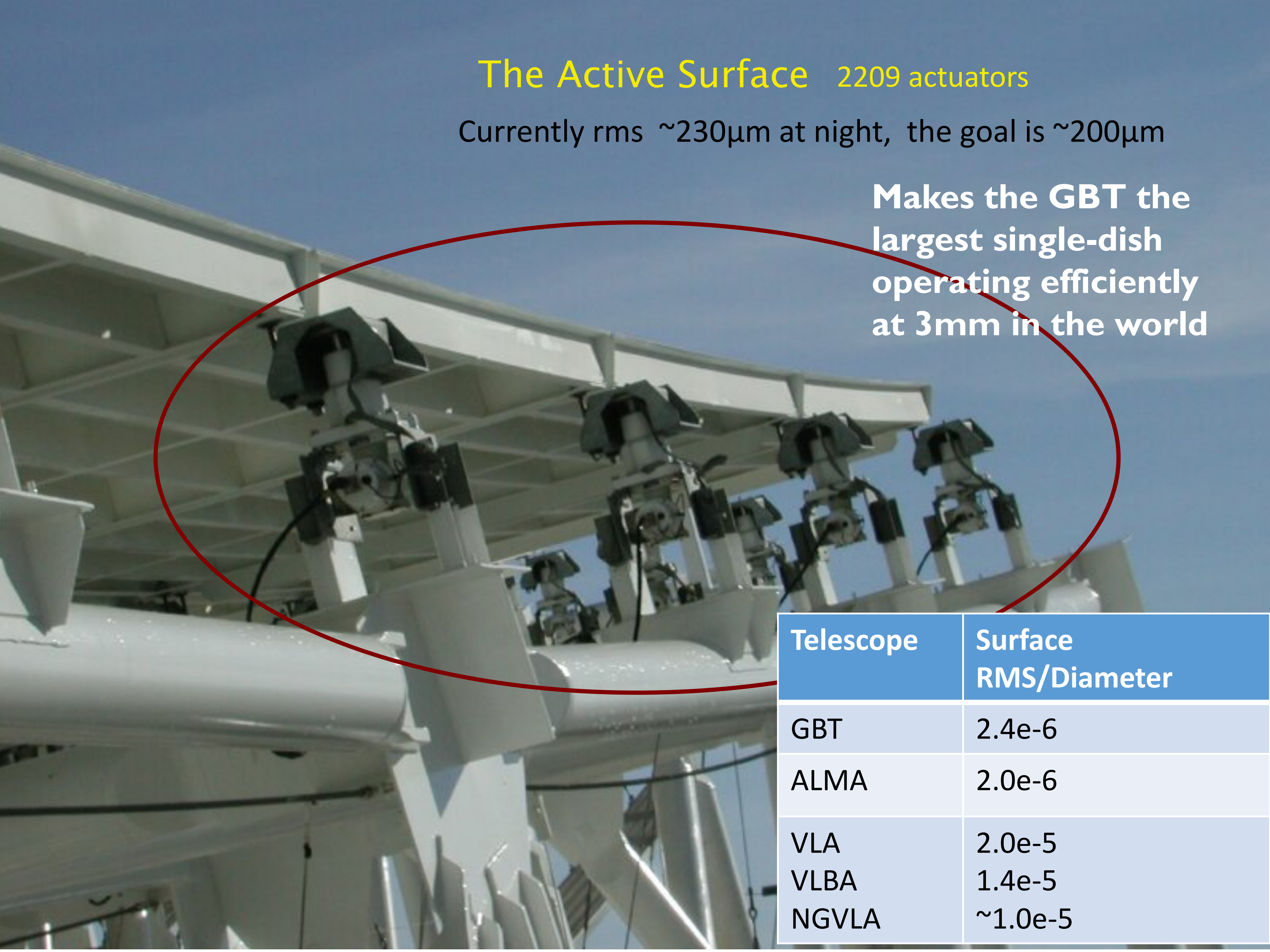


13,000 Square Miles

The Active Surface 2209 actuators

Currently rms ~230μm at night, the goal is ~200μm

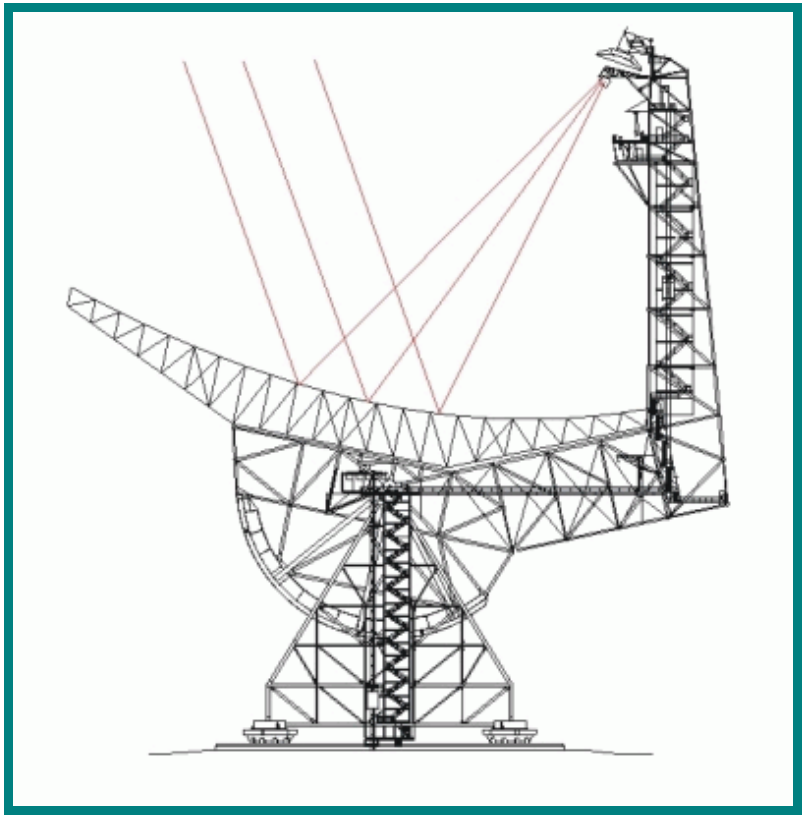
Makes the GBT the largest single-dish operating efficiently at 3mm in the world

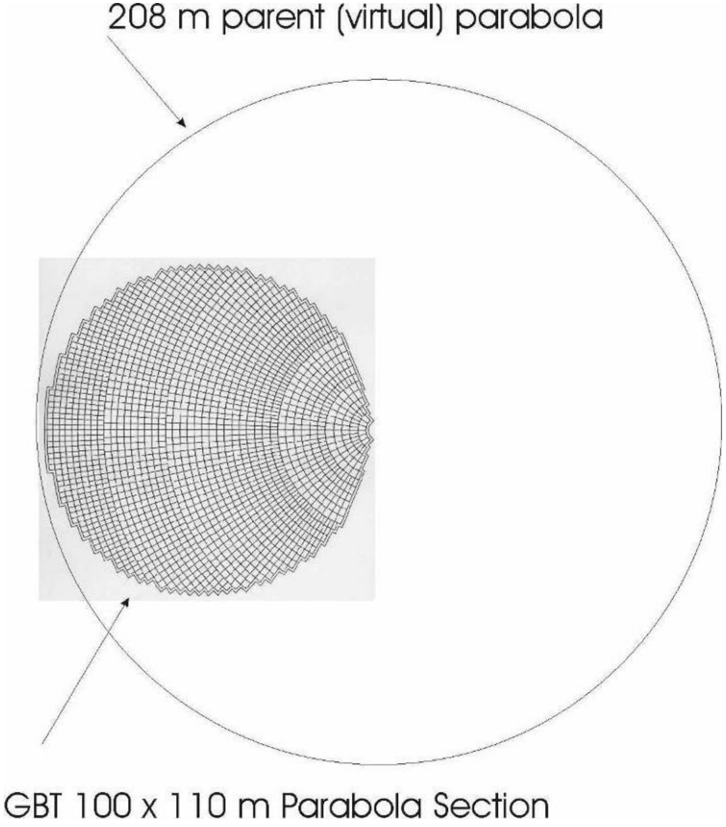


Telescope	Surface RMS/Diameter
GBT	2.4e-6
ALMA	2.0e-6
VLA VLBA NGVLA	2.0e-5 1.4e-5 ~1.0e-5

GBT Telescope Optics

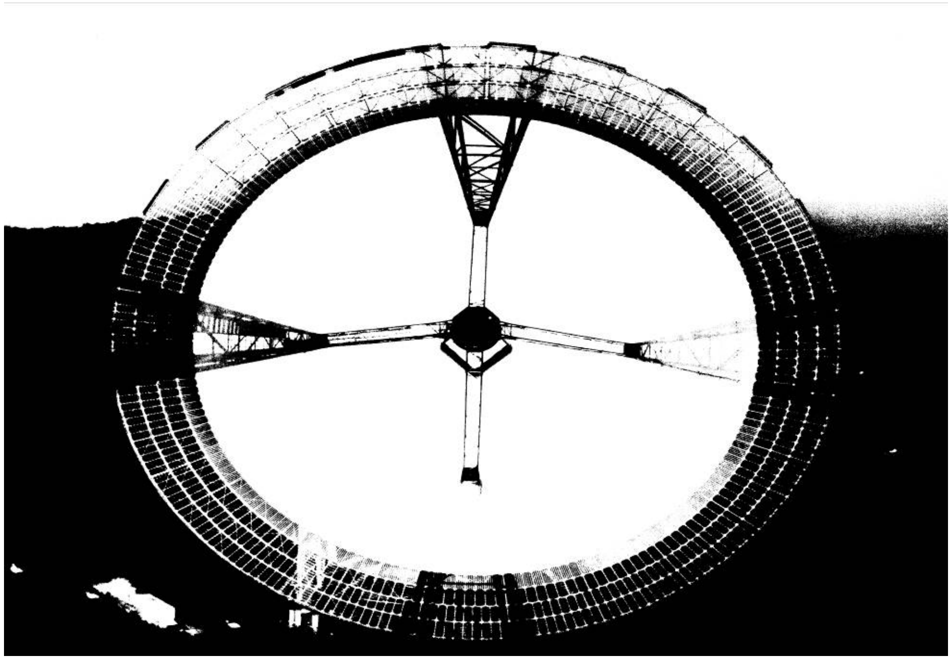
- 110 m x 100 m of a 208 m parent paraboloid
  - Effective diameter: 100 m
  - Off axis - Clear/Unblocked Aperture



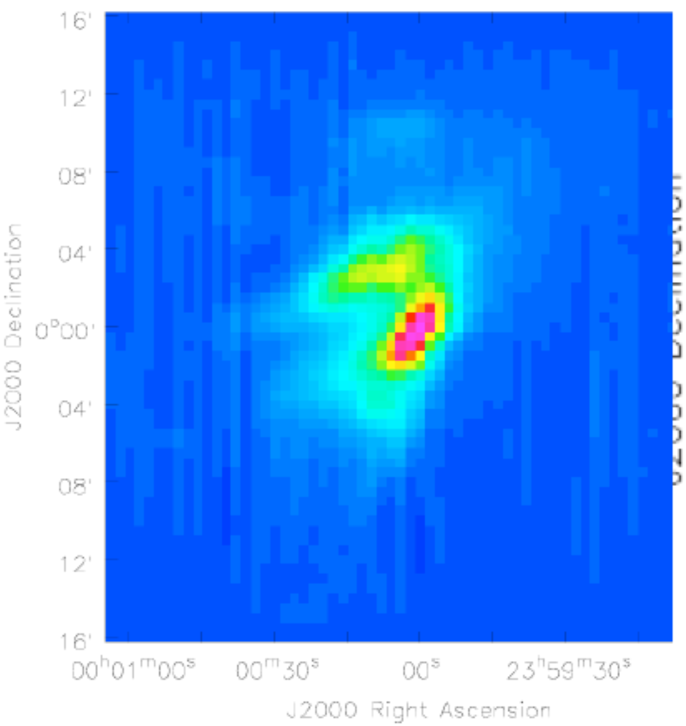


Telescope Optics *-- unblocked aperture*

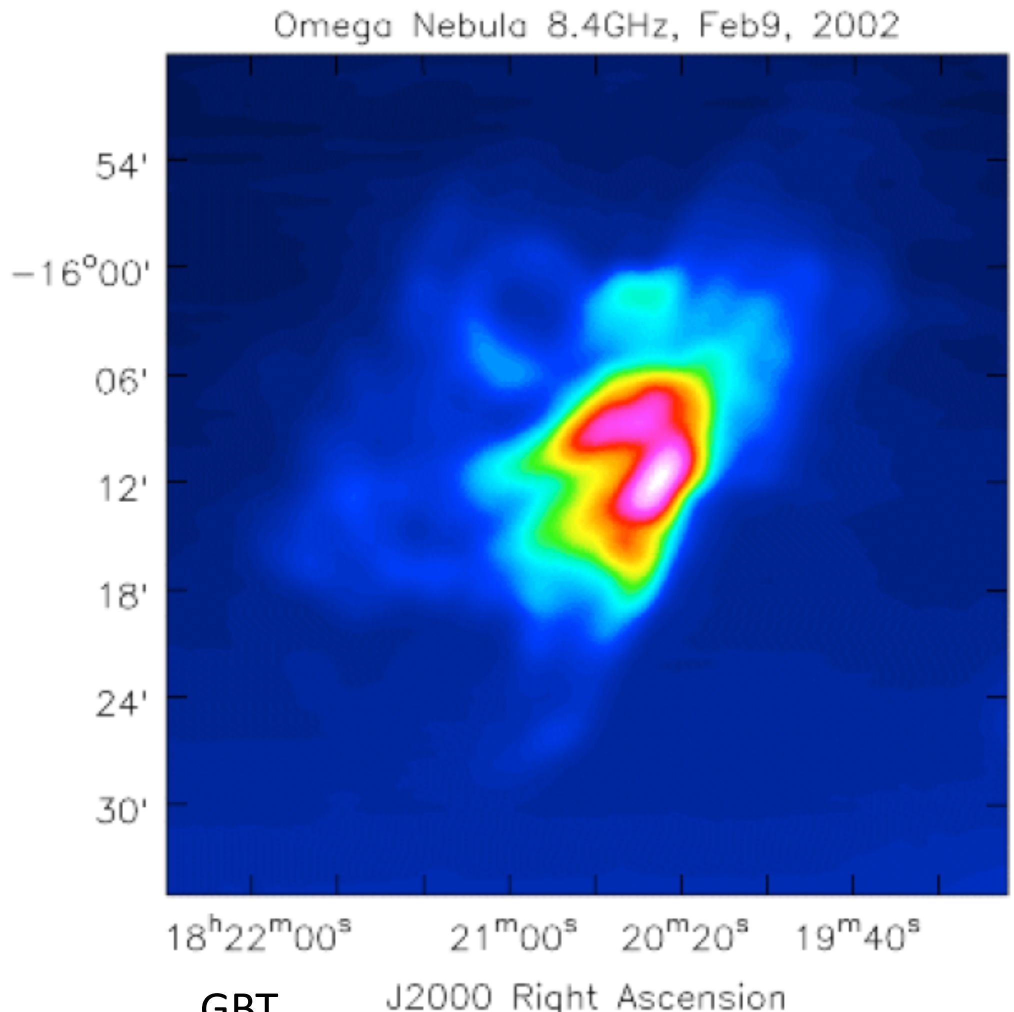
- High Dynamic Range
- High Fidelity Images



Telescope Optics



Bonn



GBT

Telescope Optics

Prime Focus: Retractable boom

Gregorian Focus: 8-m subreflector - 6-degrees of freedom

Telescope Optics

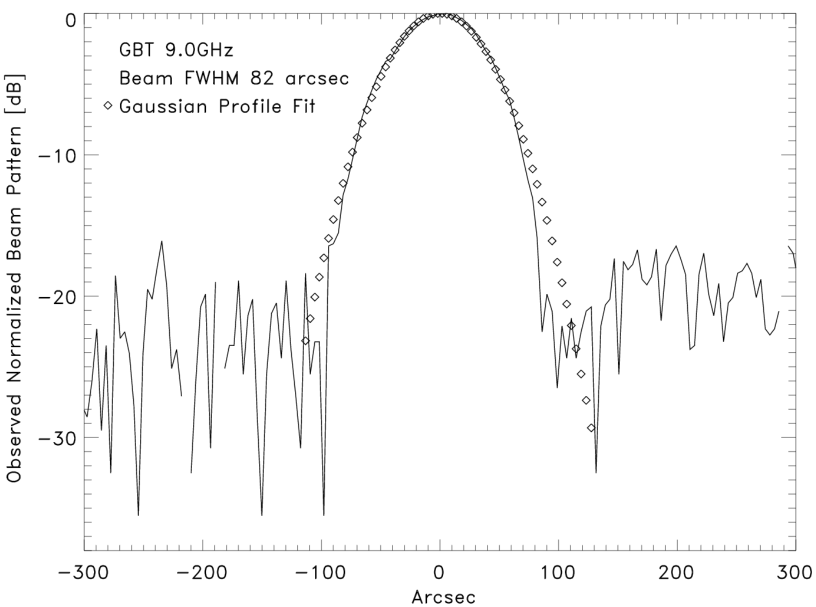
Rotating Turret with 8 receiver bays

Telescope Structure

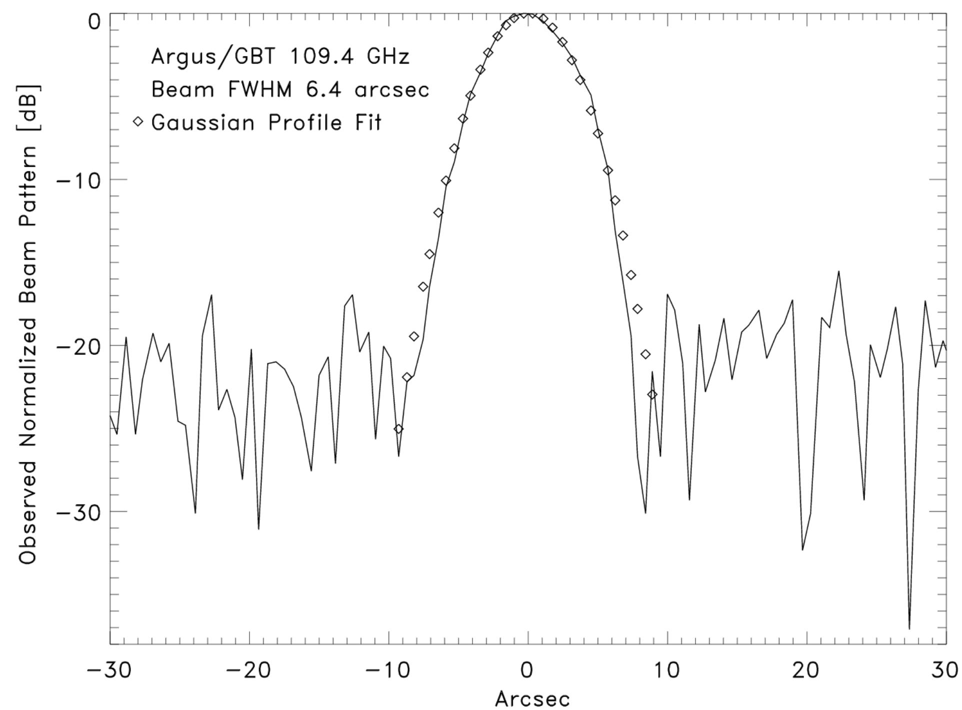
- Fully Steerable
  - Elevation Limit: 5º
  - Can observe 85% of the entire Celestial Sphere
- Slew Rates: Azimuth - 40º/min; Elevation - 20º/min

The GBT Achieves its Theoretical Beam at 110 GHz

2017 GBT memo #296 – demonstrates the success of the pointing-and-control system, the gravity and thermal modeling with active surface corrections – lots of work by many people over the last decade….



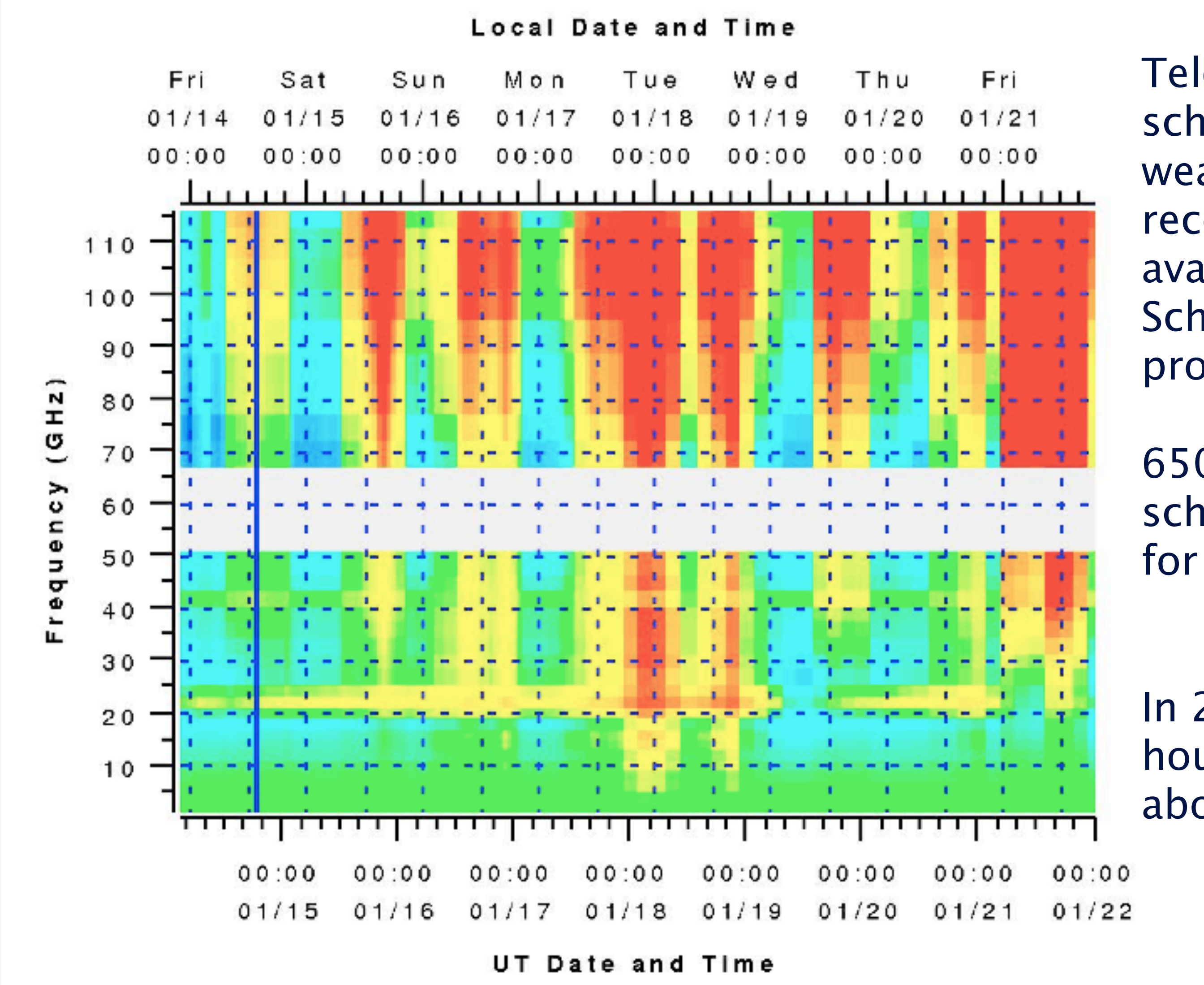
GBT/X-band 9.0 GHz



GBT/Argus 109.4 GHz

Unblock GBT aperture ➔first side-lobe predicted at -27dB

Dynamical Scheduling System allows efficient use of telescope at high frequency – based on weather model predictions that are updated every 6 hrs.

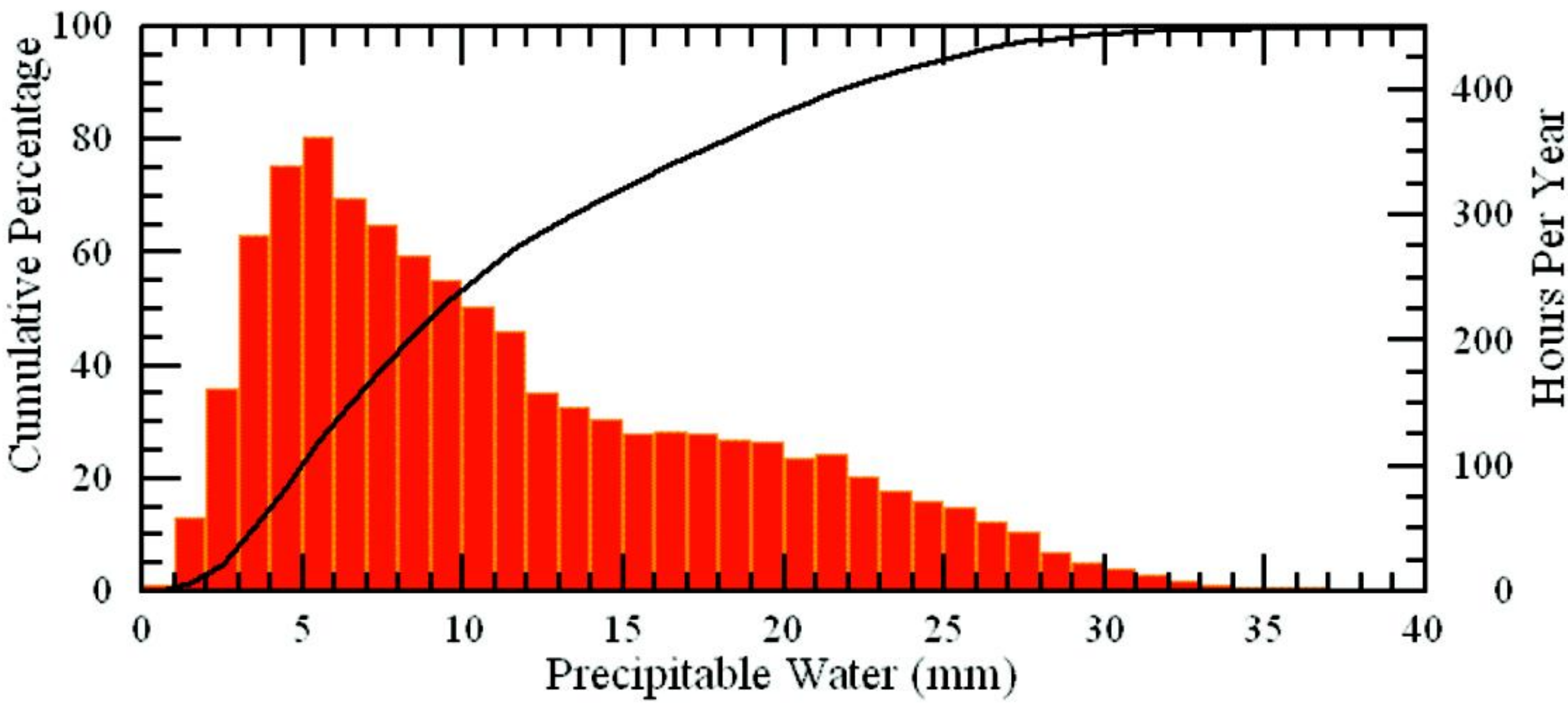


Telescope dynamically scheduled daily based on weather conditions and receiver and observer availability. Dynamic Scheduling matches the project to the weather

6500+ hours a year scheduled
for observations

In 2010 there were ~1800 hours used at frequencies above 18 GHz

~50% of time in Green Bank has less than 10mm of H2O (acceptable for 3mm observations)

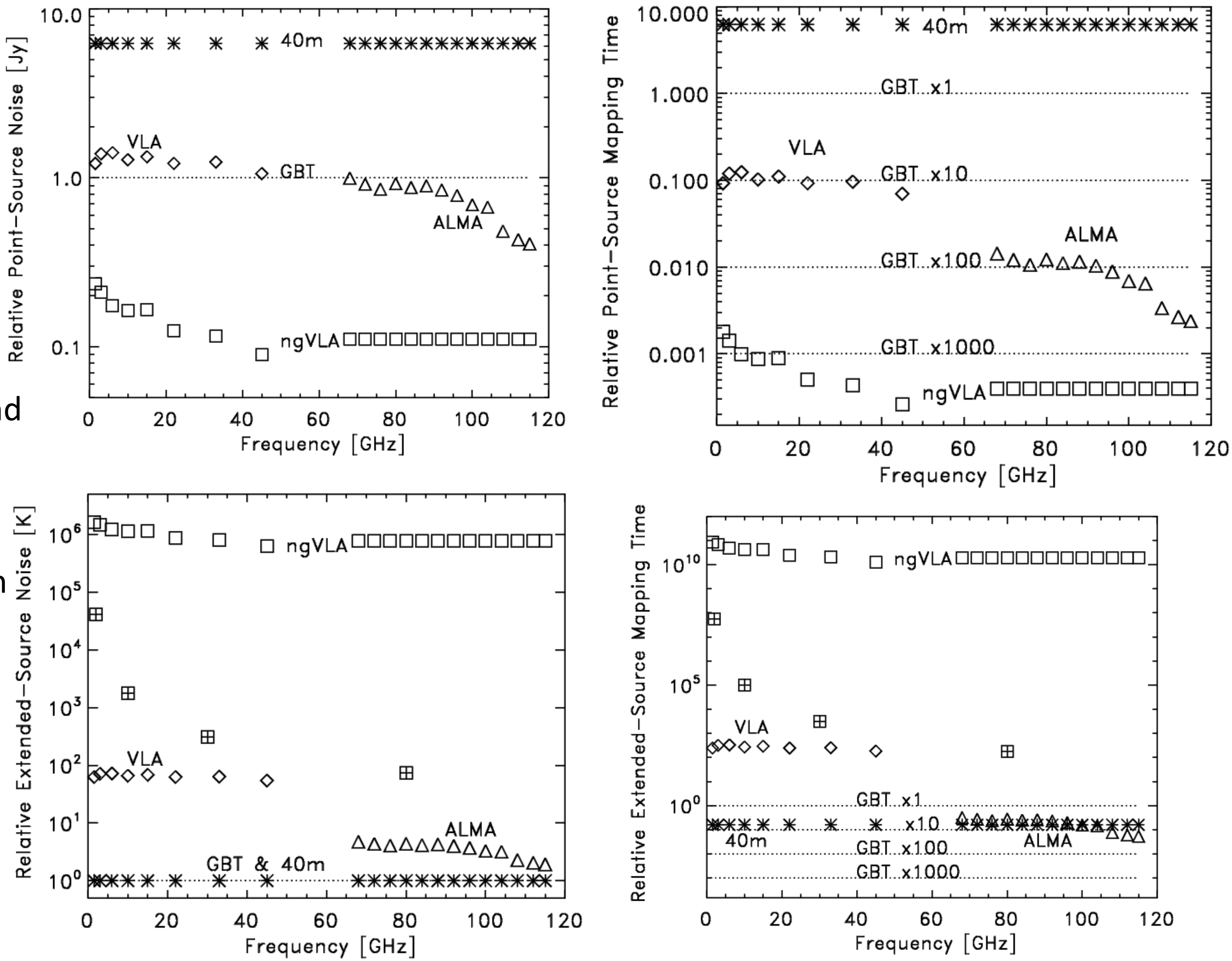


GBT Sensitivity and Mapping Speeds

ngVLA Memo#14

Large single dishes are needed for surface brightness sensitivity and wide-area mapping.

The GBT with multi-pixel cameras can provide unmatched mapping power.



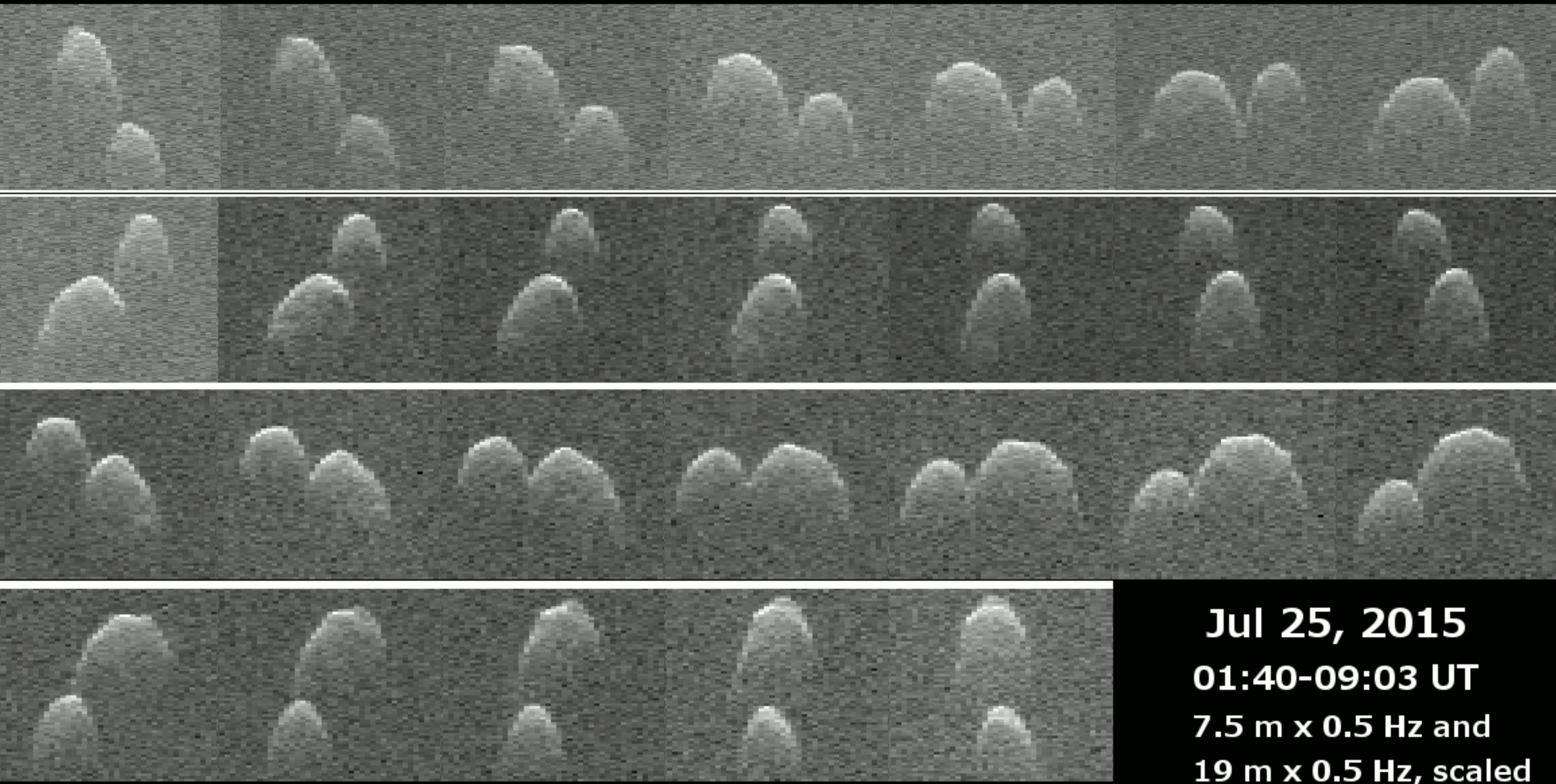
Wide Range of GBT Science Areas:

- Pulsars: Discovery of new pulsars, the most massive pulsar, gravity waves via pulsar timing
- Neutral Hydrogen HI: Masses of local galaxies, Kinematics of galaxy and local group/dark matter
- High-redshift/Cosmology: Galaxy clusters, CO in the early universe, HI intensity mapping at high-redshift
- Interstellar Organic Molecules/Astro-chemisty
- Masers: black hole masses, distances via proper motions and independent measurement of Ho
- Star Formation: NH3 mapping, cold and dense gas tracers at 3-4mm
- Basic Physics: The search for Gravitational Radiation, Limits on Fundamental "constants"
- Solar system astronomy -- planetary radar
- SETI – Breakthrough Listen

Radar: Protecting Planet Earth -- Chelyabinsk, Russia -- Feb. 15, 2013


Goldstone-GBT
27 Jan 2015
Asteroid 2004BL86

(85989) 1999 JD6



Jul 25, 2015

01:40-09:03 UT

7.5 m x 0.5 Hz and

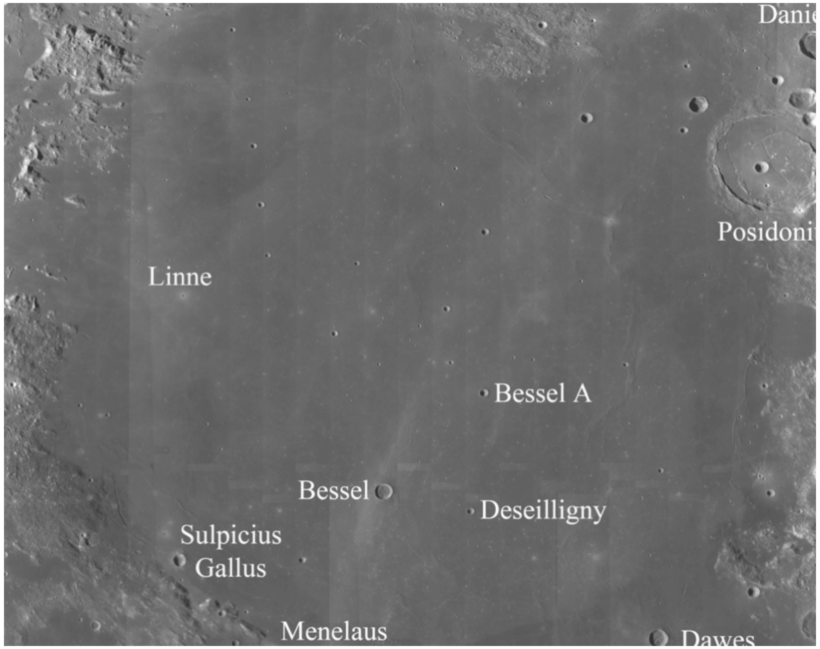
19 m x 0.5 Hz, scaled

Goldstone-GBT bistatic radar images

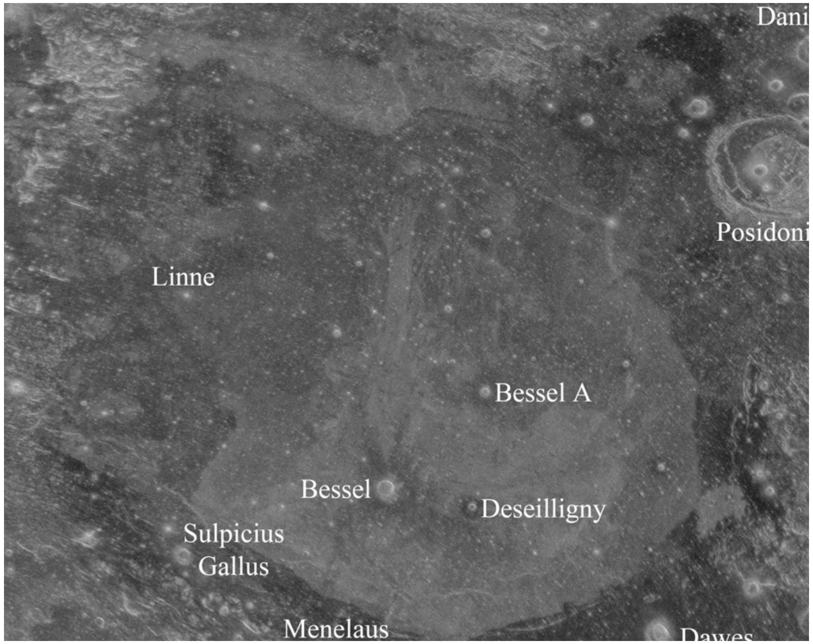
~18x the distance to the Moon

GBT Bi-static radar studies with Arecibo

Radar image of the moon



Optical



70cm radar

"The 70 cm backscatter differences provide a view of mare flow-unit boundaries, channels, and lobes unseen by other remote sensing methods."

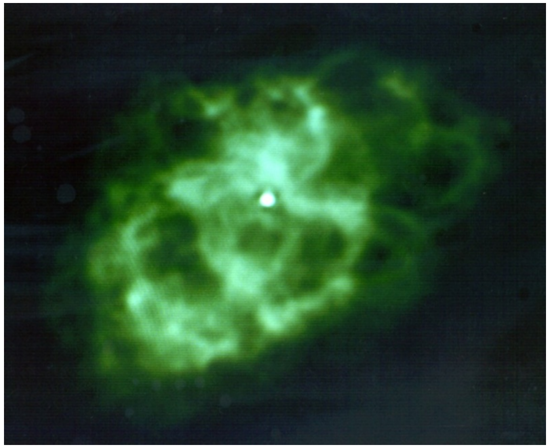
-- Campbell, B.A. et al. JGR-P 2014

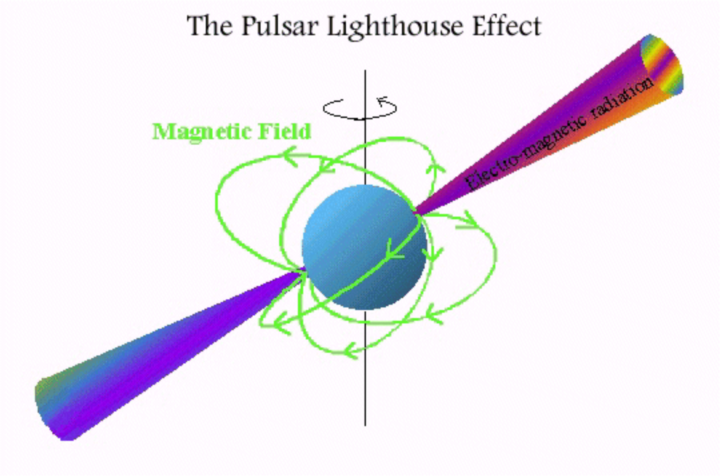
The GBT remains the world's premier pulsar observatory

(Quiet Zone, collecting area, receivers, detectors, sky coverage)

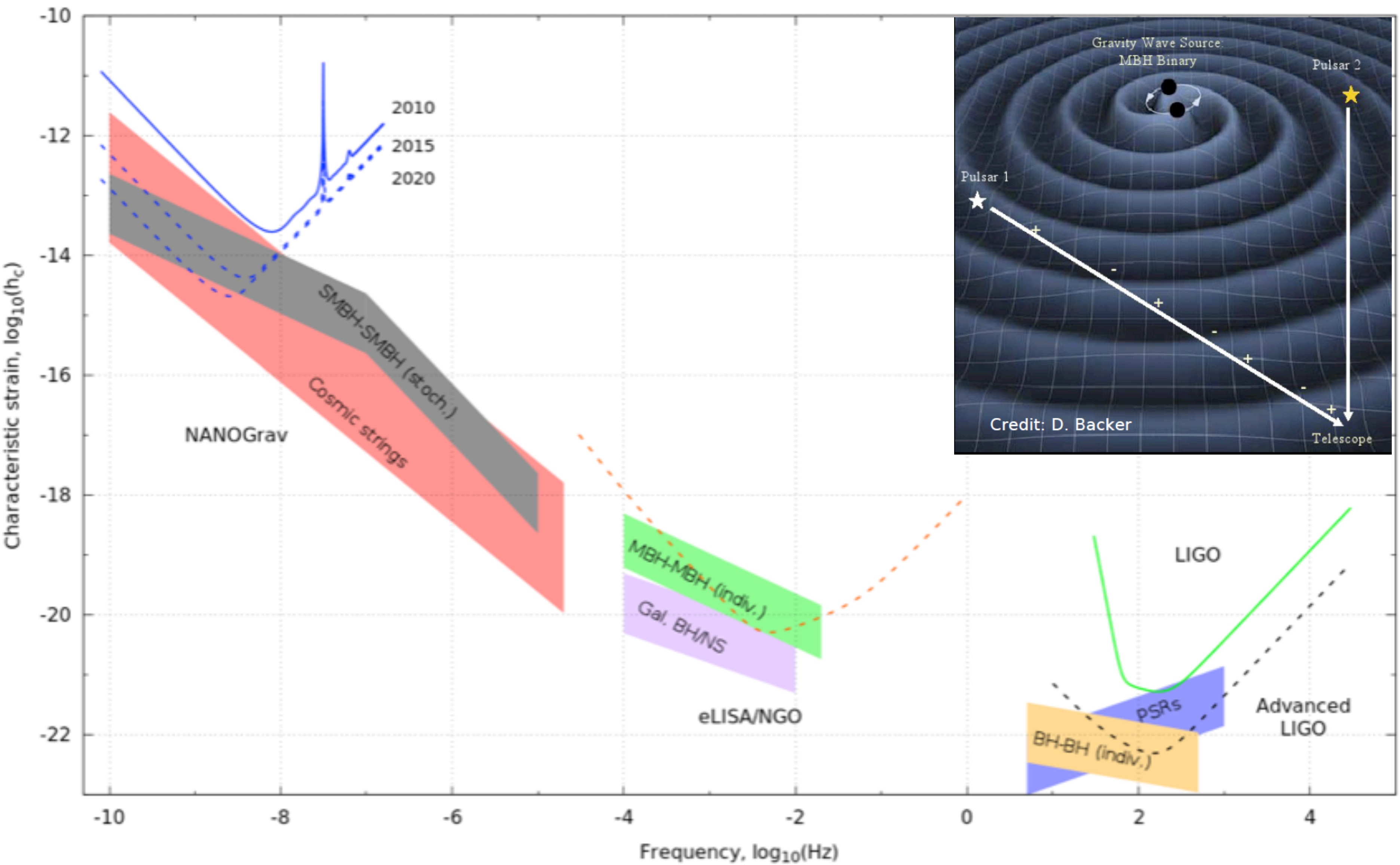
The Pulsar Renaissance:

- Fastest Pulsar
- Most Massive Pulsar (constrains equation of state of matter)
- Pulsars in Globular Clusters
- Tests of General Relativity
- Relativistic Spin Precession
- Pulsar in a three-body system
- Coolest white dwarf star (carbon – diamond star)



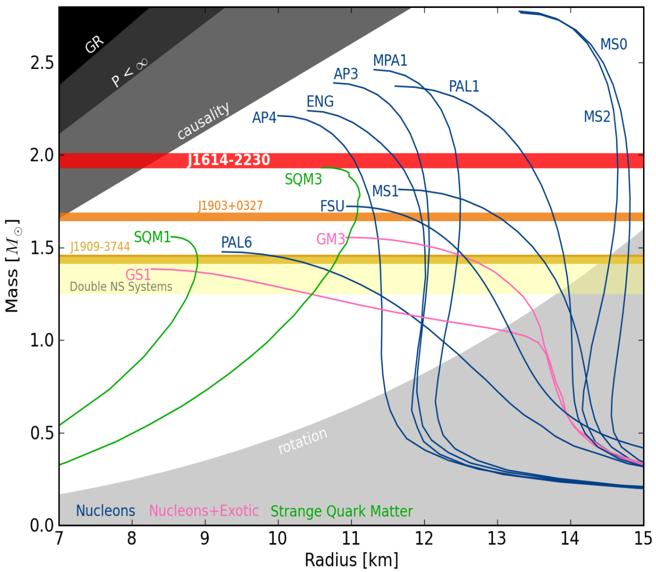


Searching for a detection of Gravitational Waves via Pulsar timing (NANOGrav)



Massive pulsars, M~2M$_\odot$

J1614-2230



The new mass determination for PSG J1614-2230 makes it the most massive pulsar known, and rules out a number of soft equations of state for nuclear matter including many "exotic" hyperon, kaon models.

(Demorest et al. 2010)

PSR J0348+0432 (2.01+/-0.04 Msun)

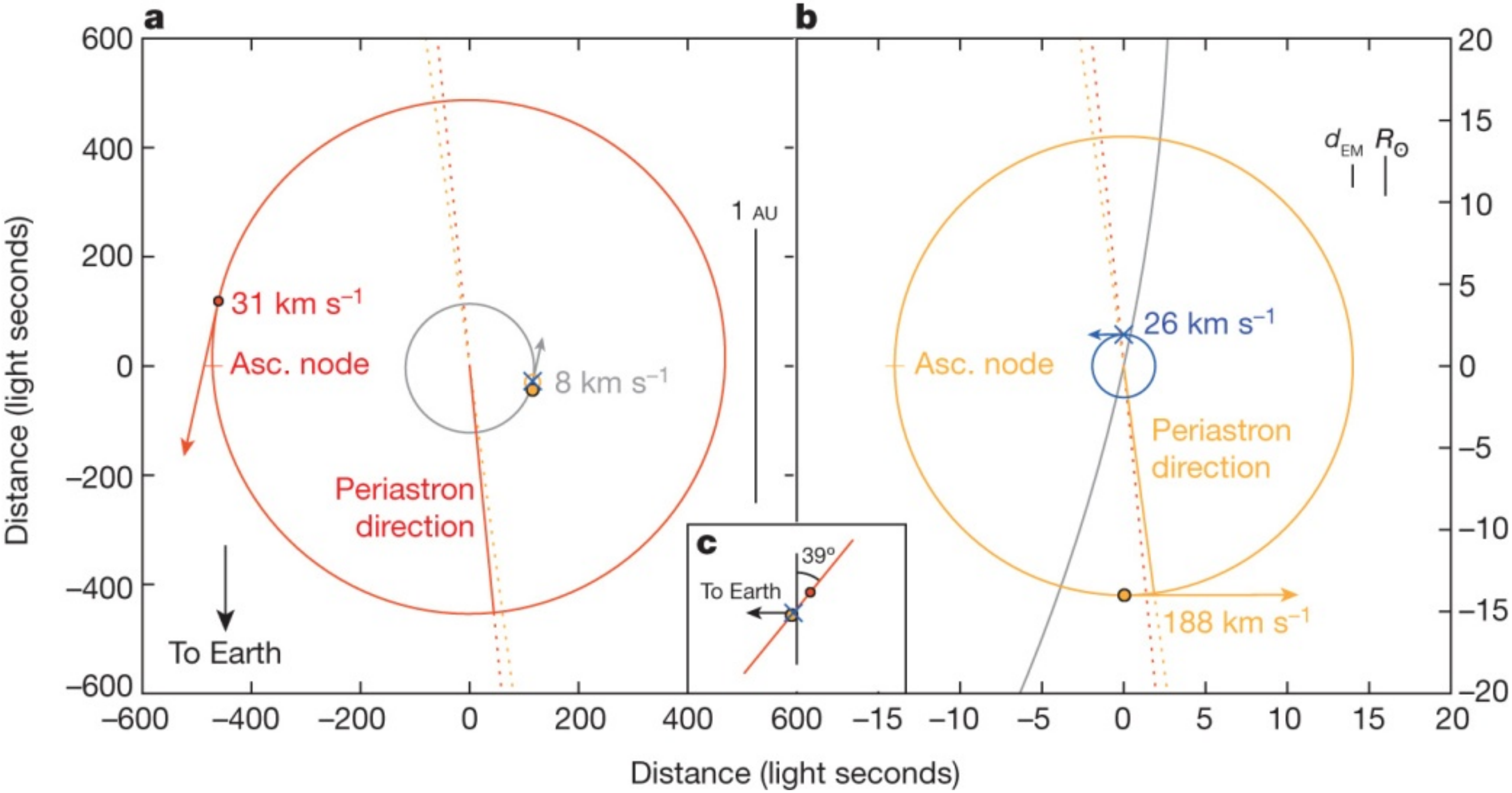
Lynch+2013; Antoniadis+2013

{artist impression of pulsar with WD companion}

NRAO

GBT Discovery of a Pulsar in a Triple System

Ransom et al. Nature (2014)



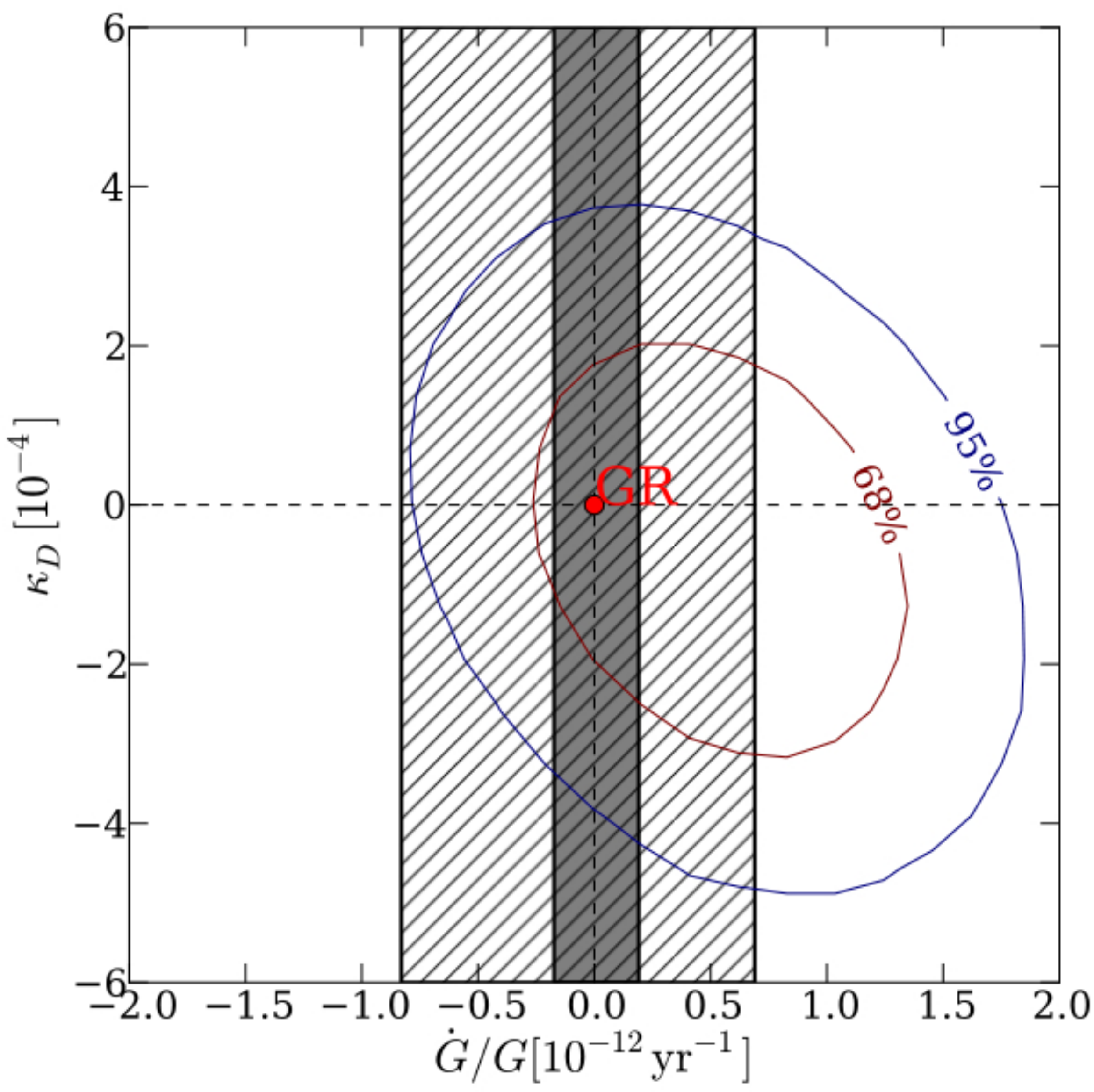
Masses: 1.4378(13), 0.19751(15), 0.4101(3) M☉
Angle between orbital planes: 1.20(17)x10^{-2} deg

Testing the Equivalence Principle (gravitational and inertial mass)
F=ma = GMm/r^2??

Fundamental Physics: Constraining Gravity

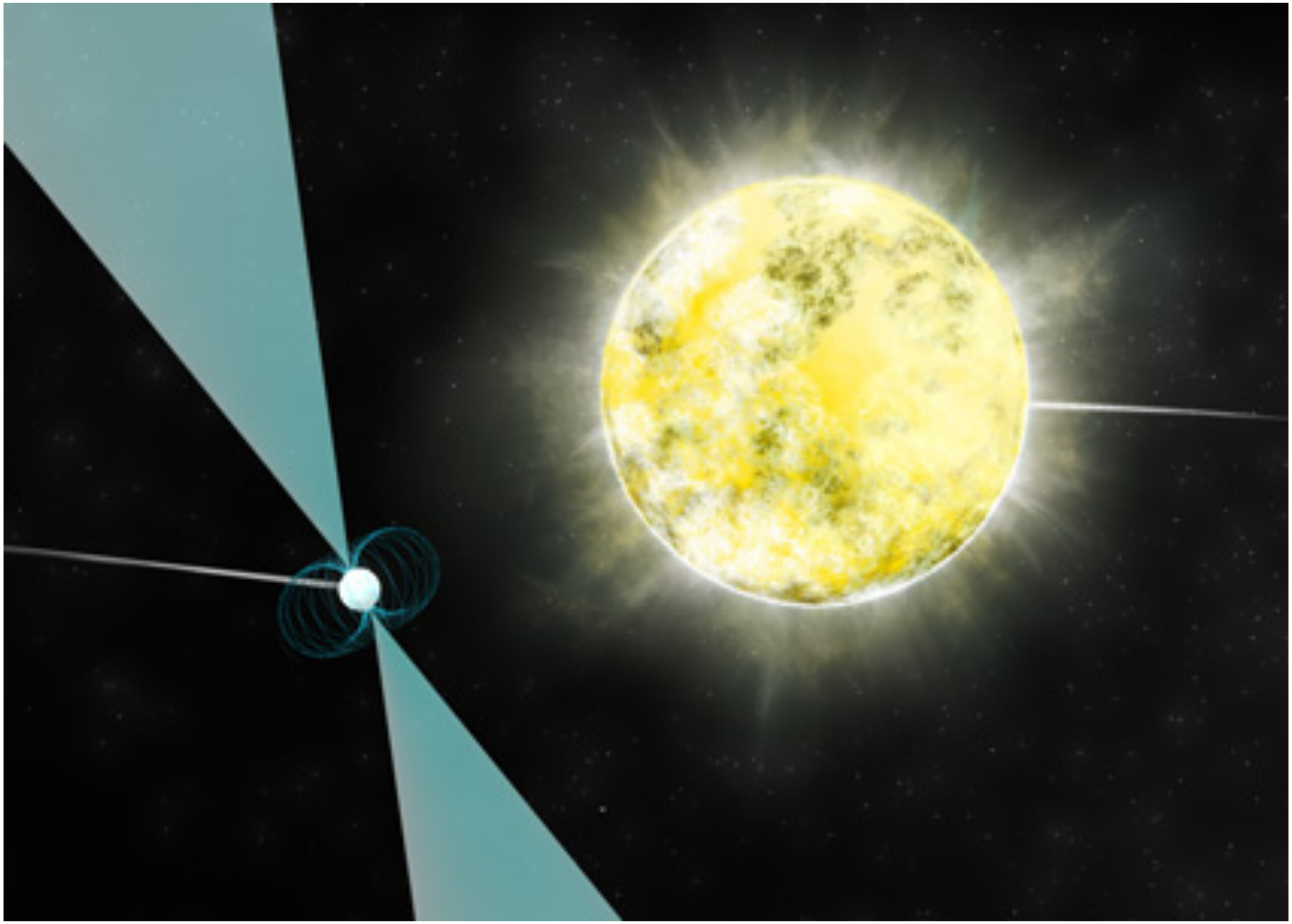
Stringent limits to variation of the Gravitational constant using a pulsar binary, (J1713+0747)

Zhu+2015



A Solid Carbon "Diamond" Star Orbiting a Pulsar

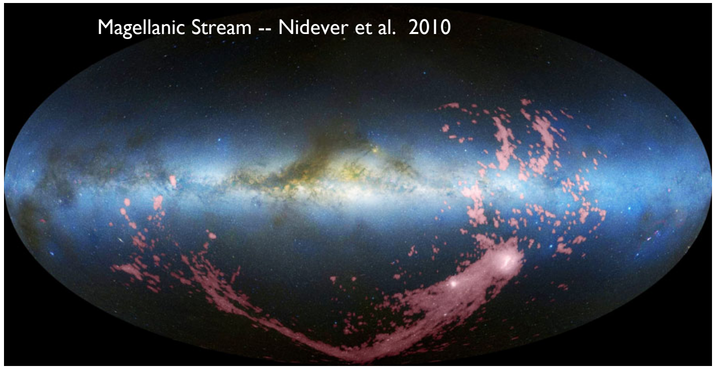
Kaplan et al. (2014)

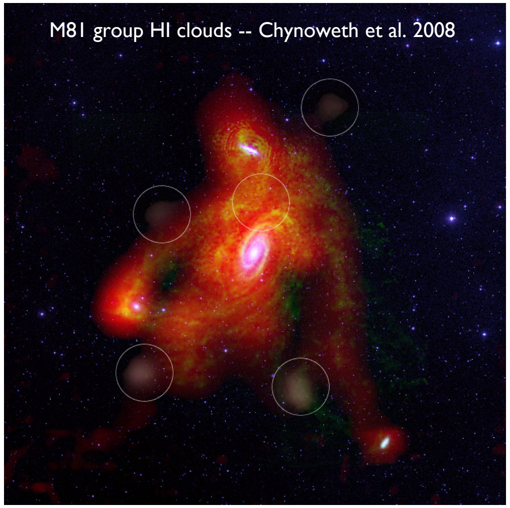


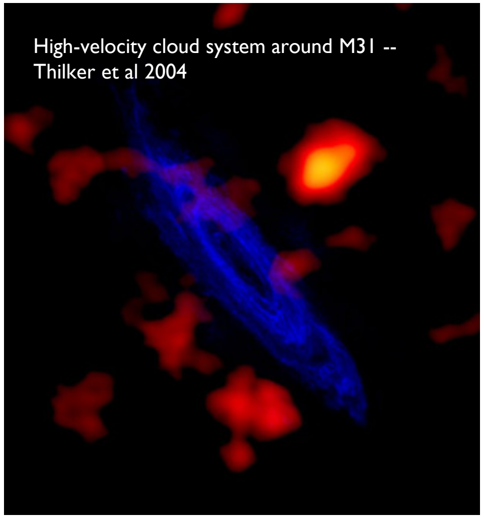
GBT Studies of faint HI -- unequalled sensitivity

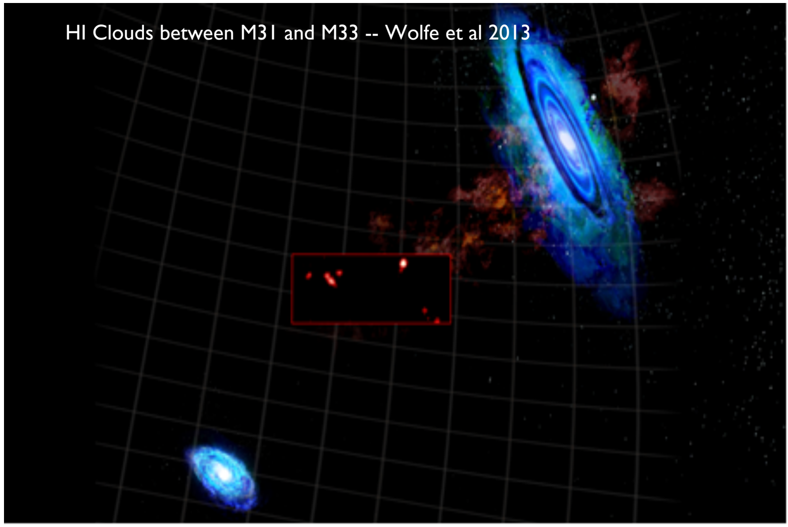
GBT offers ability to detect HI to $N_{HI} \sim 10^{17}$ cm^{-2}

- Interactions
- Outflows from winds and fountains
- Cool gas accretion



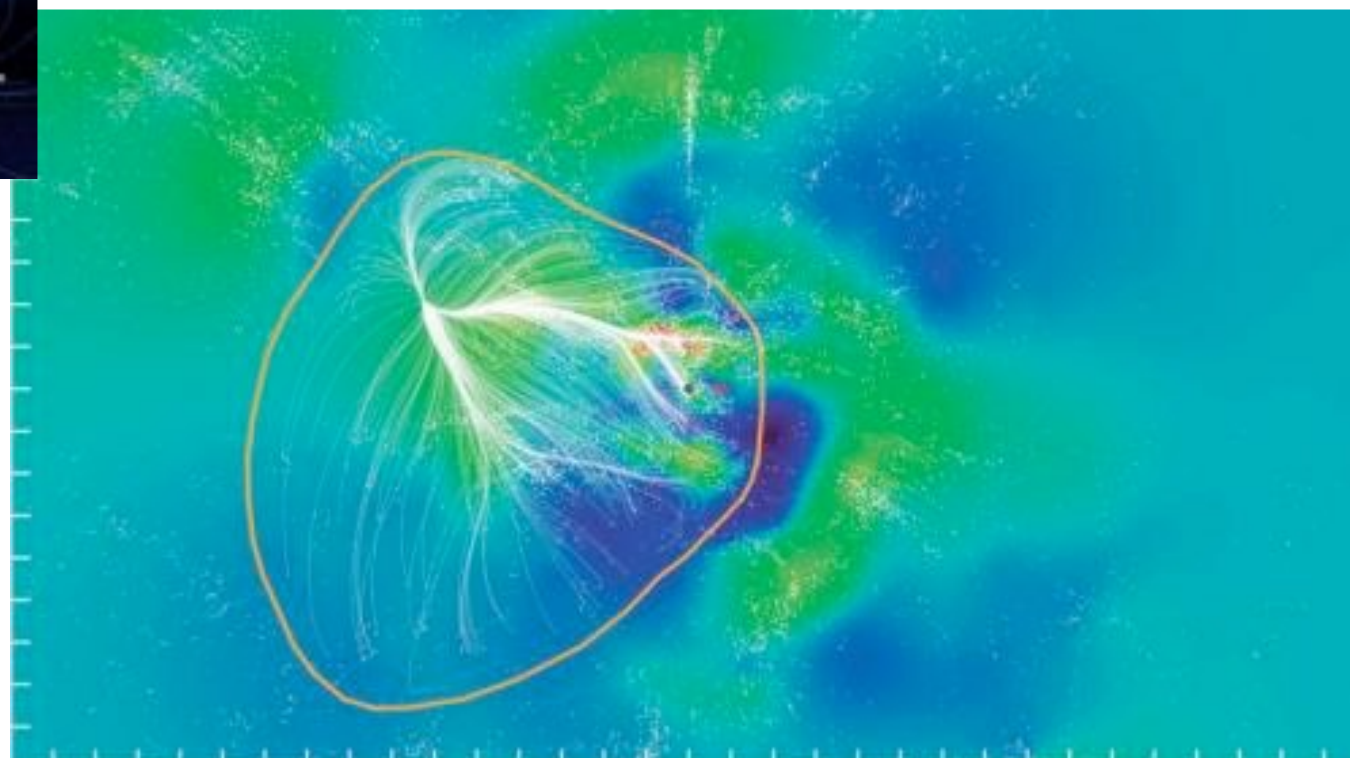






GBT Hydrogen measurements show the structure of the local Universe

(Tully et al. 2014)



Local Super Cluster ($\sim 10^{17}$ Msun)
Laniakea – Hawaiian for immeasurable Heaven

HI "Intensity Mapping"

At large redshift the HI from individual galaxies cannot be seen, but their collective signal is detectable.

This technique was developed on the GBT by **Ui-Le Pen, Jeffrey B. Peterson et al.**

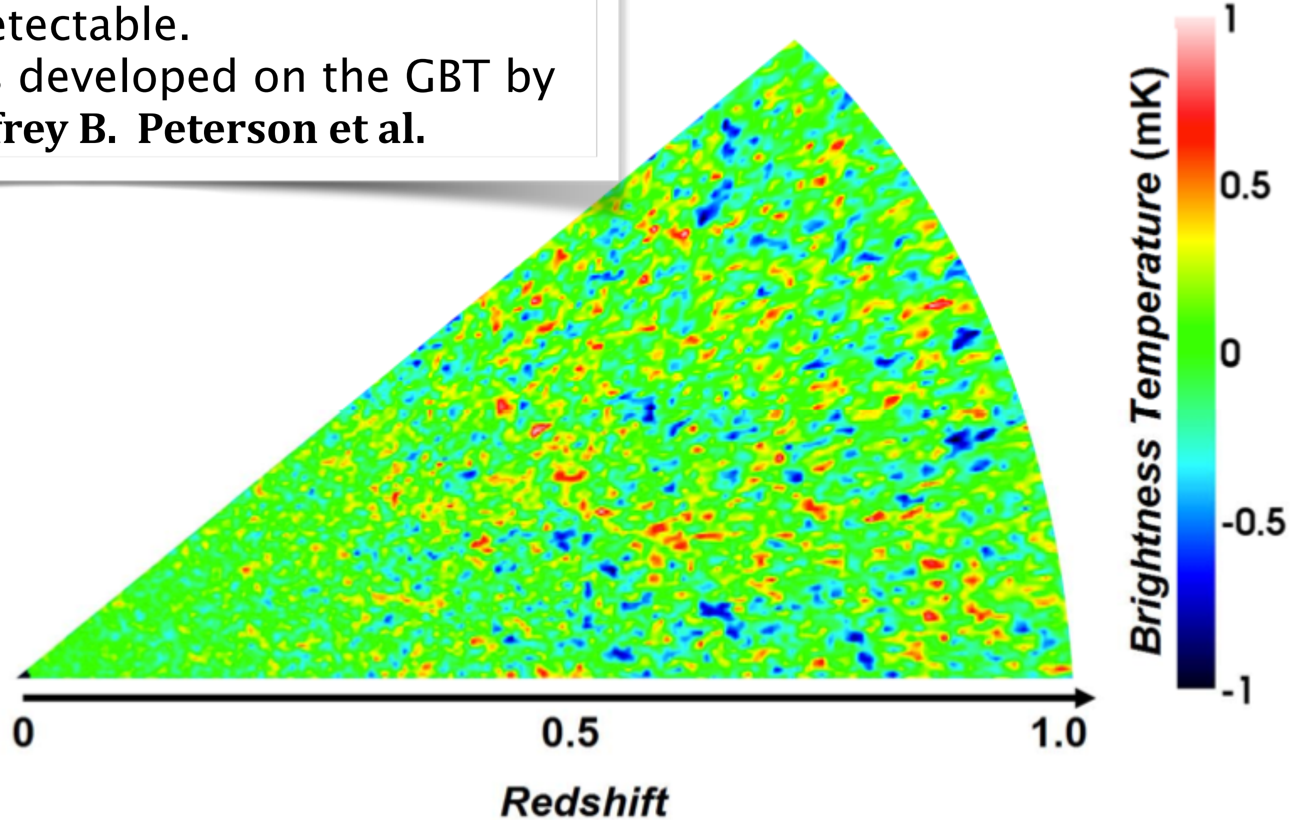


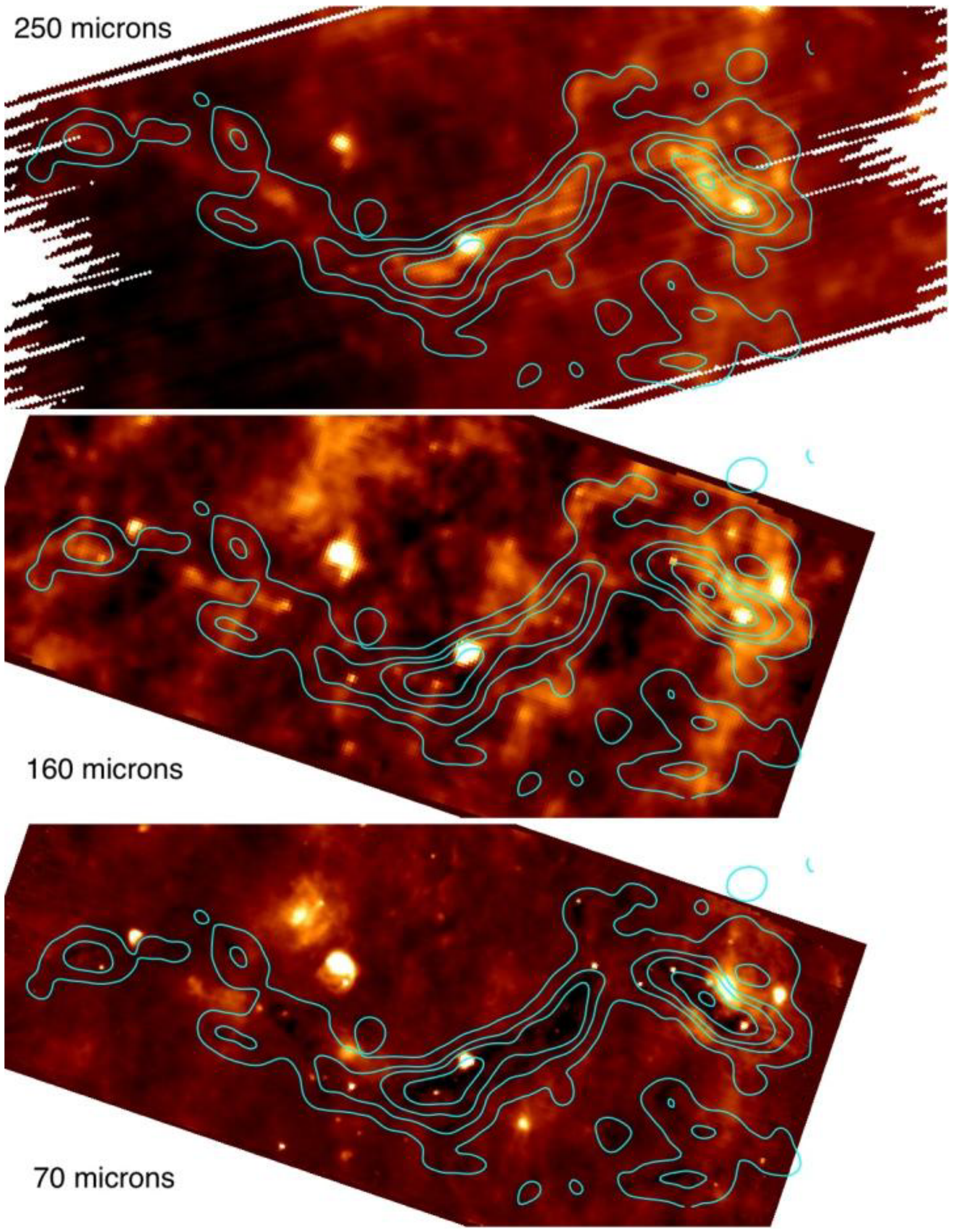
Figure 2: Simulated fluctuations in the brightness temperature of 21cm emission from galaxies in a slice through the universe. The emission is smoothed over 8/h Mpc. The redshift, z, translates to frequency: ν=1.42GHz/(1+z). *Red indicates overdensity and blue underdensity.*

Star Formation

How do star clusters form and evolve?

What is the role of filaments?

Where do high mass stars form?



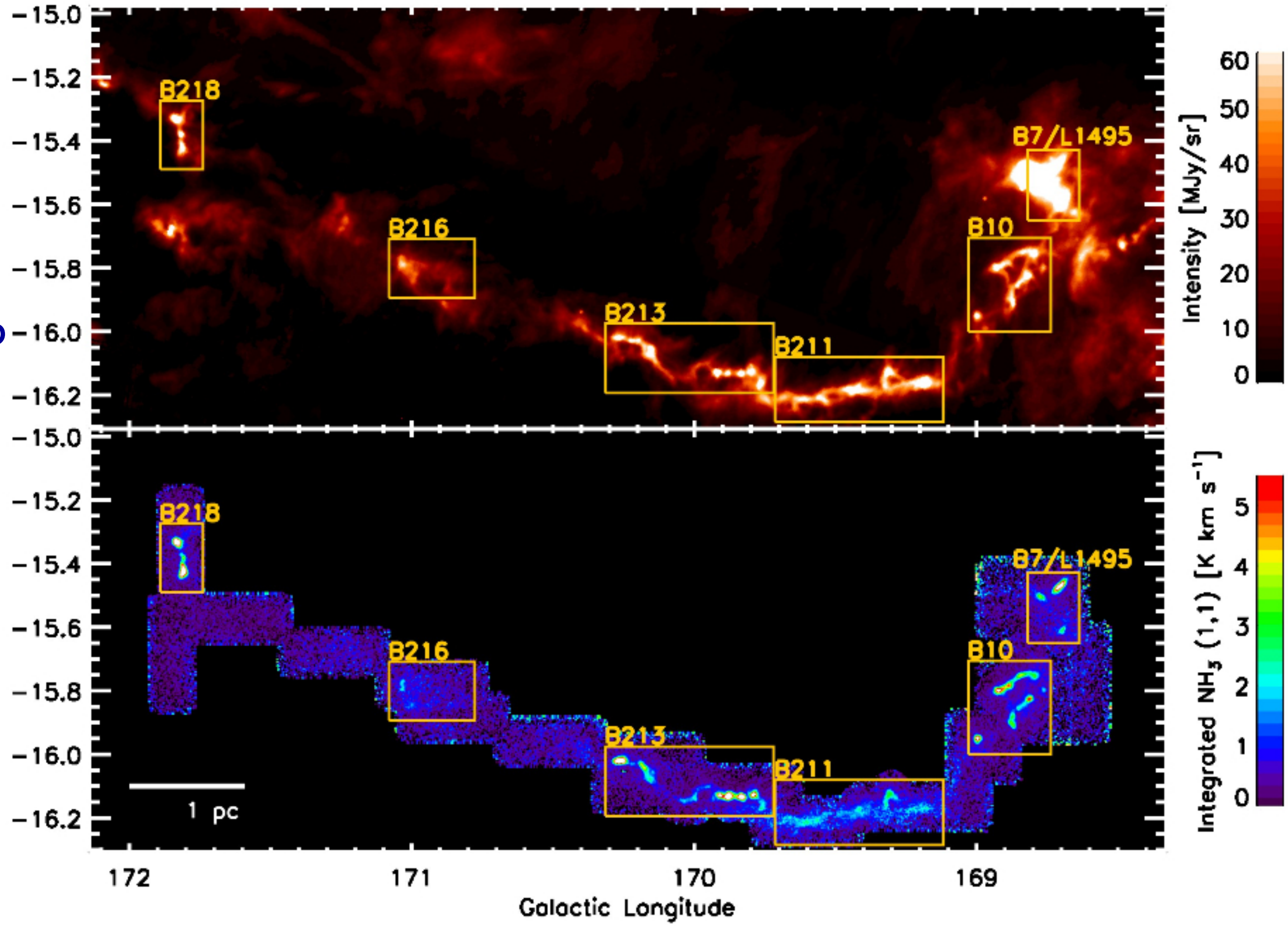
GBT NH3 contours on top Infrared images of IRDC ("The Snake") *Courtesy J. Jackson*

Studies of Star-Forming Filaments via NH_3

Taurus filament.

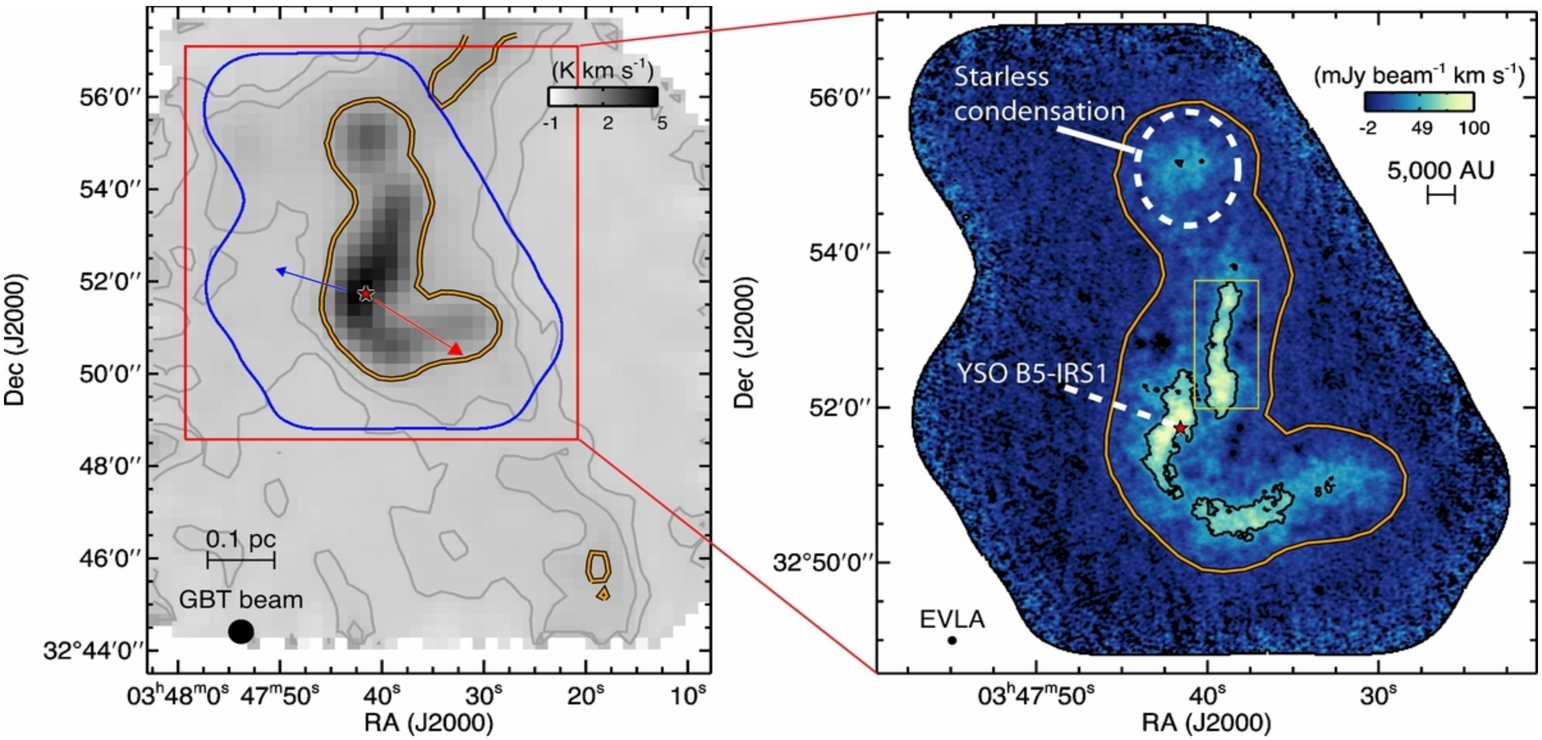
Herschel 500um (top – Dust image) and GBT NH3 (bottom)

Seo+2015



Stellar Birth and Evolution

Yellow contour from the GBT (left) shows where the molecular gas has a subsonic velocity dispersion undergoing large-scale collapse/fragmentation. GBT combined with VLA shows (right) shows starless core and YSO outflow regions



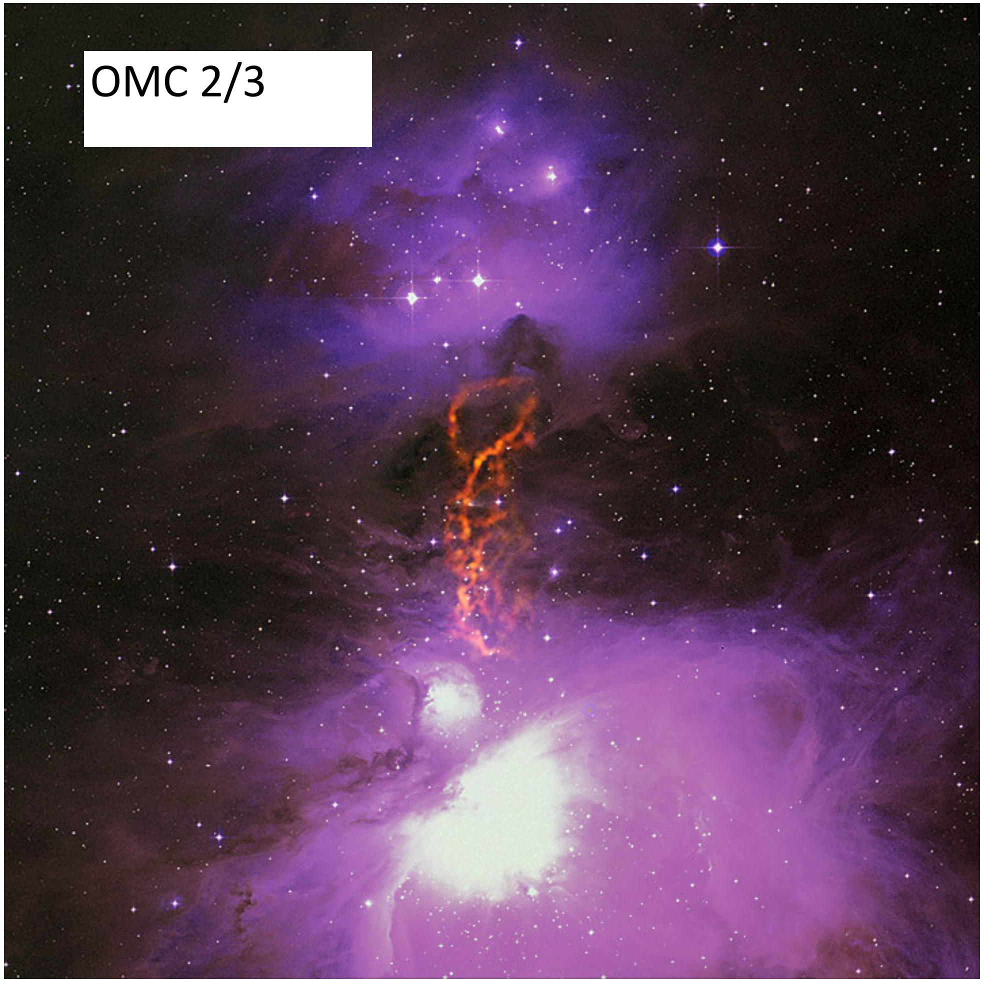
NH_3 intensity of Baranard5 with the GBT (left) and GBT+EVLA (right)

Courtesy Pineda, et al

GBT NH3 image of Orion molecular cloud (red, 1.5deg) with WISE infrared image in blue showing warm dust

GBT Detection of mm-cm sized particles in Orion

Schnee et al. (2014)



← 5 ' →

MUSTANG

- Bolometer Array
- 3.3mm
- 81–96 GHz
- 14 hours

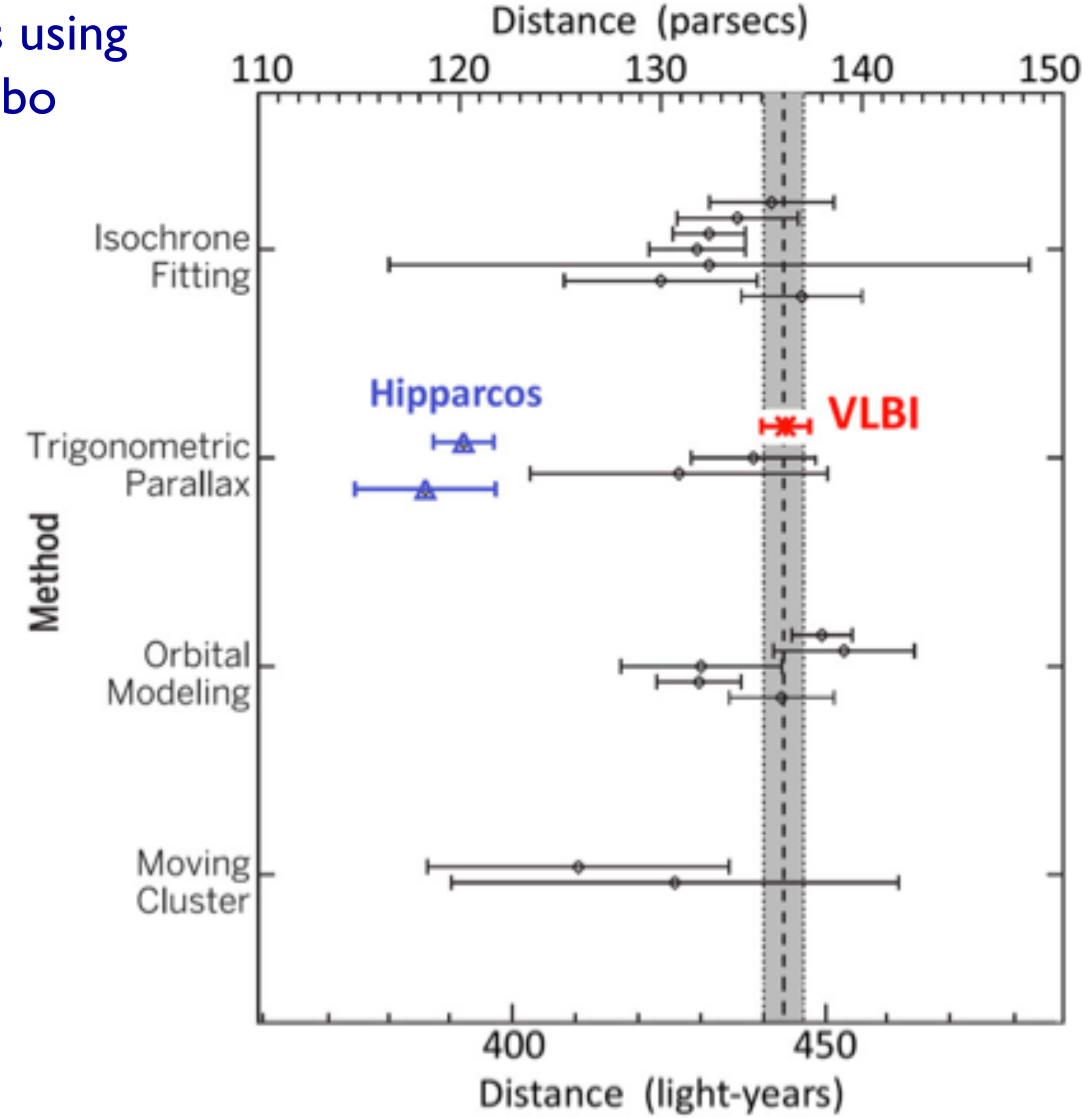
Brighter emission at 3.3mm suggests the existence of "pebbles" which may jump start planet formation {or a new model for dust emissivity}

GBT used with VLBA/HSA/GMVA

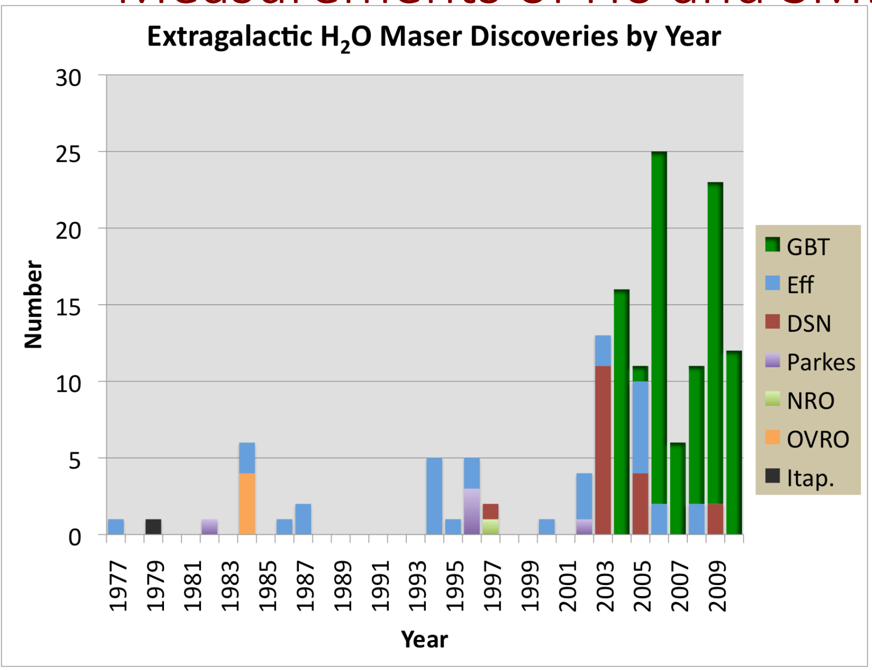
e.g., VLBI Resolution of the Pleiades Distance Controversy

(Melis et al. 2014)

Trigonometric parallax of radio stars using the VLBA +GBT + Effelsberg + Arecibo



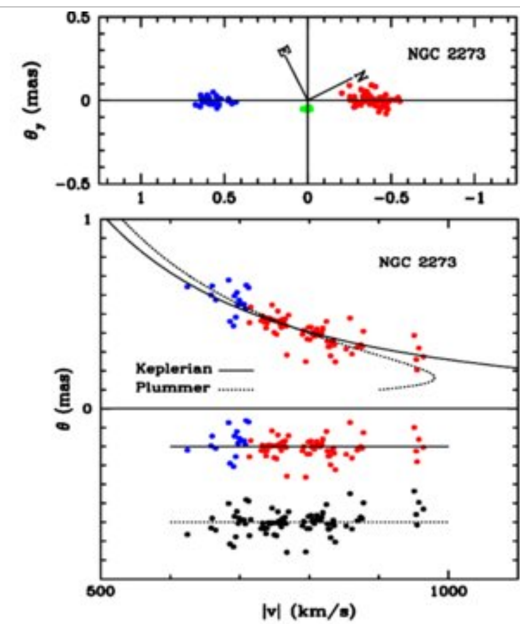
Measurements of Ho and SMBH masses via H20 Masers

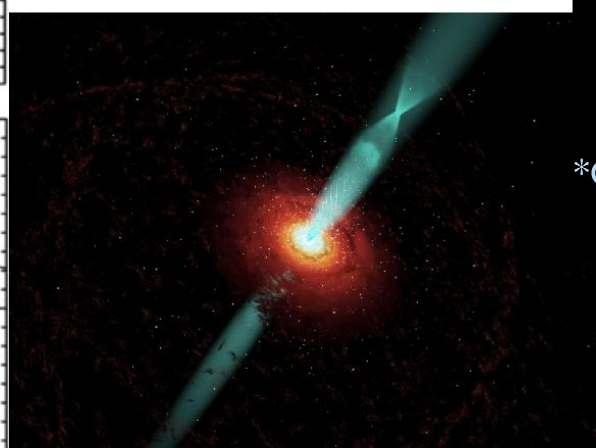


Over 80 masers discovered with the GBT (k-band 22GHz)

Measuring H_0 within 3% precision by obtaining geometric distances to water masers in other galaxies*

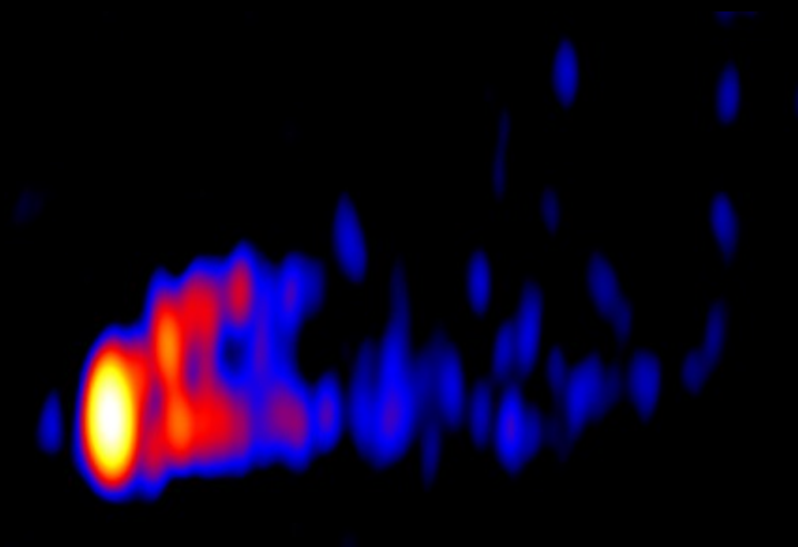
Measuring precise masses of the black holes in megamaser disk galaxies*





*GBT used both for Maser discovery and providing necessary sensitivity to VLBA

M87 3mm VLBI Jet



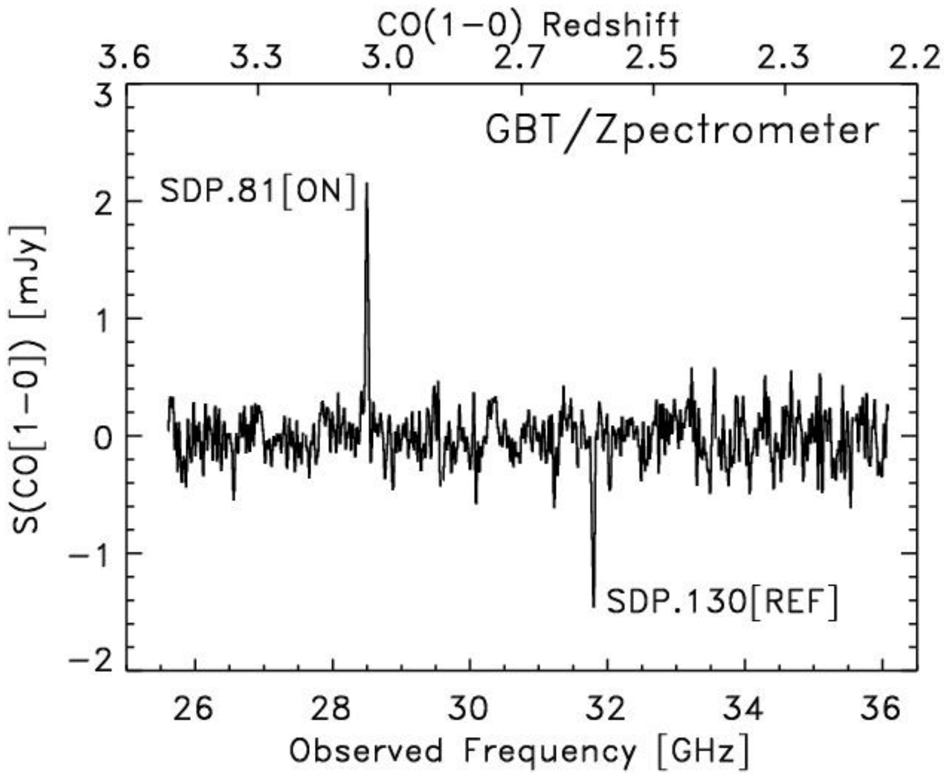
The M87 jet at an angular resolution of 0.25x0.08 mas (~10 Schwarzchild radii) in 3mm VLBI (Hada et al 2016)

GBT High-Redshift Molecular Gas

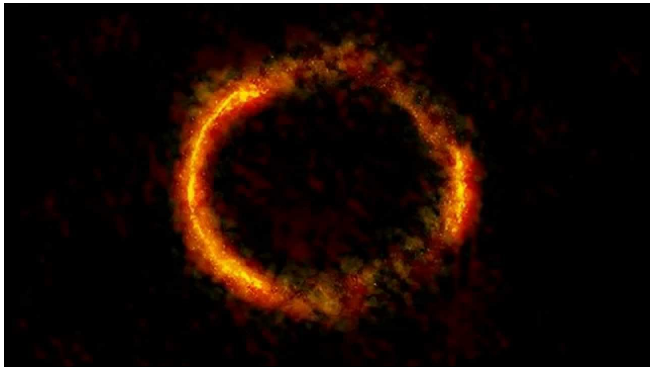
Measurements of molecular gas from young galaxies in formation.

About 30 Herschel sources with GBT CO(1-0) redshifts.

Groups also pursuing CO(3-2) searches at z~7.5 with the GBT in Q-band (40-45GHz) as well as confirming high-redshift sources from the LMT with CO(1-0) on the GBT.



ALMA image of SDP.81 (“ALMA’s ring of fire”)



Galaxy Clusters/SZE – measurements of large-scale structures at 90 GHz that probe the cluster environment in which galaxies form

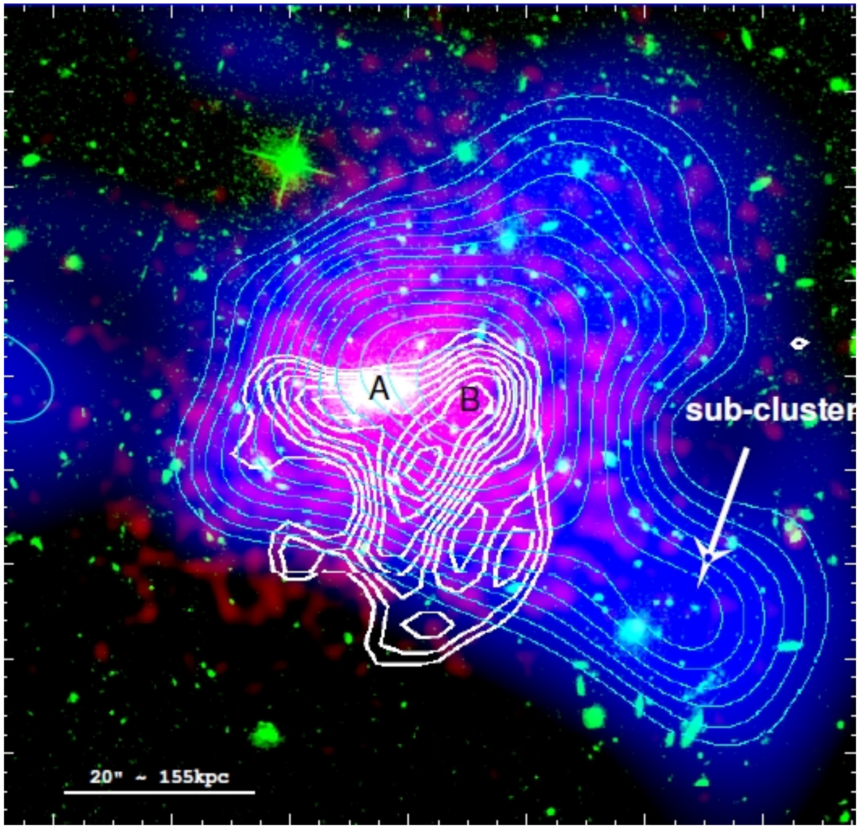
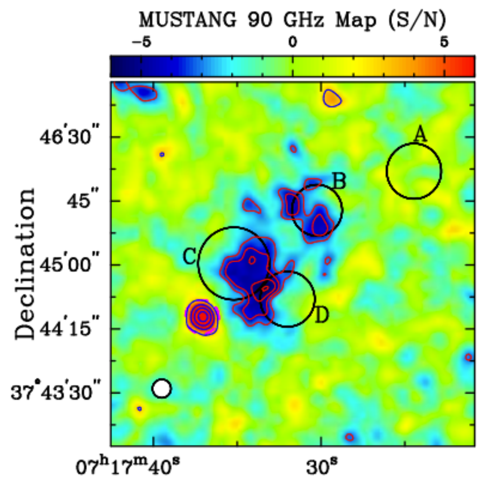
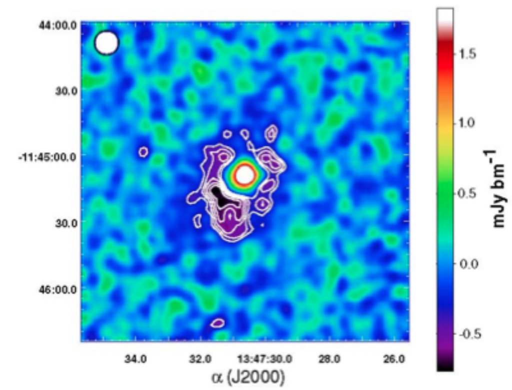


Image of CL1226.9+3332 (z = 0.89); White is MUSTANG; Green is optical (HST); Red is X-ray (Chandra); Blue is mass density (HST) *Courtesy Korngut, et al.*





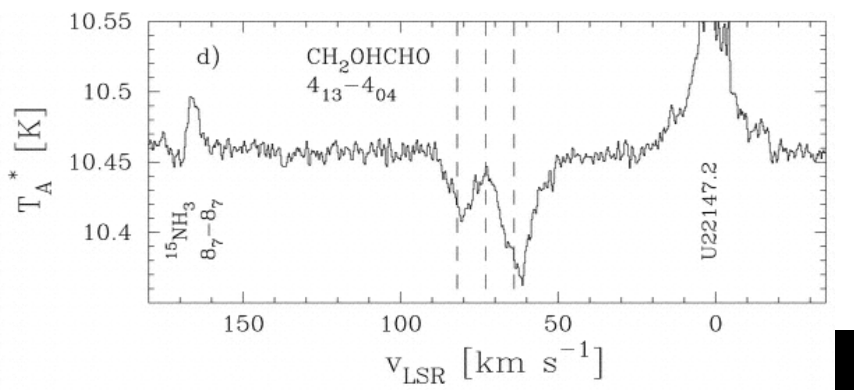
(Left) Mustang SZE image of the triple merger MACSJ0717+3745 (Mroczkowski 2012). (Right) Mustang image of RXJ1347-1145 which shows deviations from equilibrium first shown by high angular resolution SZE measurements (Mason et al. 2010).

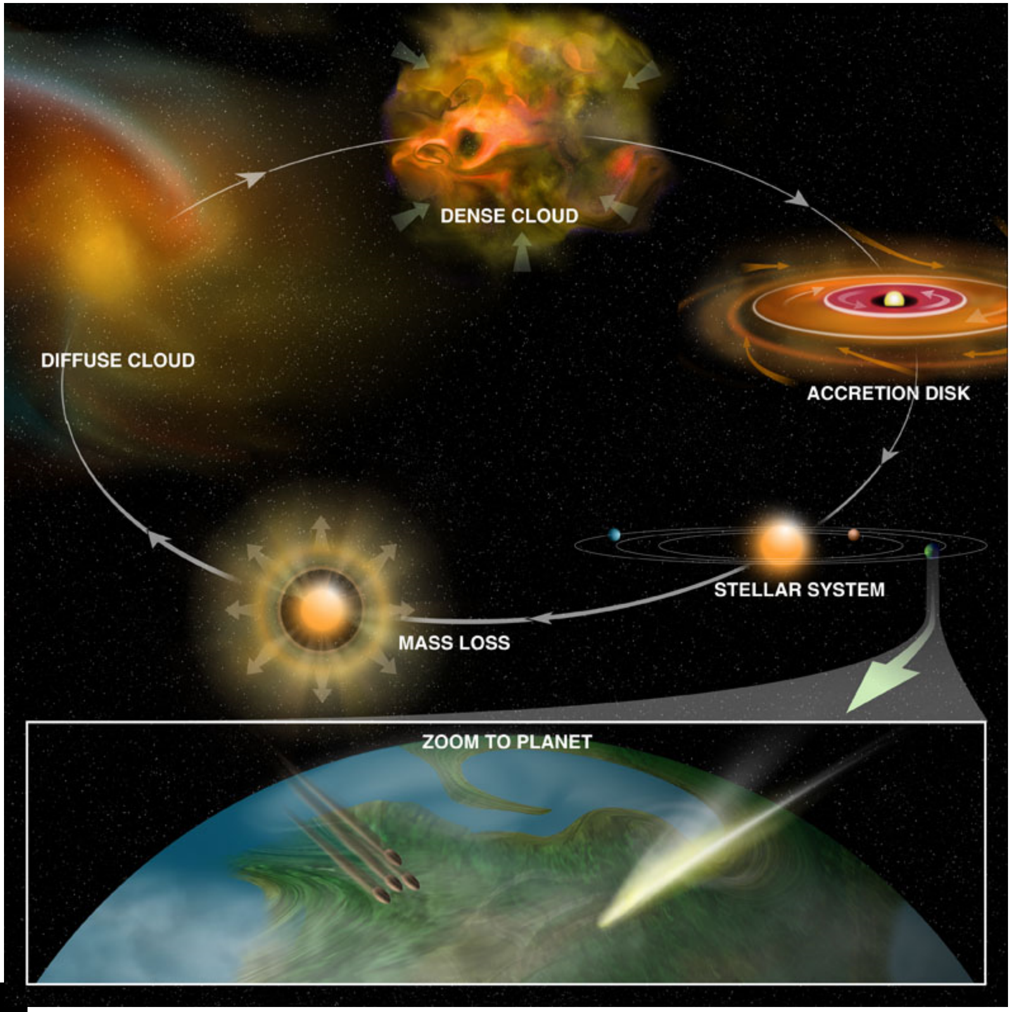
Origin of Life

How did life arrive on Earth?

Connect Organic Chemistry in Space with Life on Earth

Measure interstellar chemical processes to determine the characteristics of pre-biotic chemistry in star-forming regions



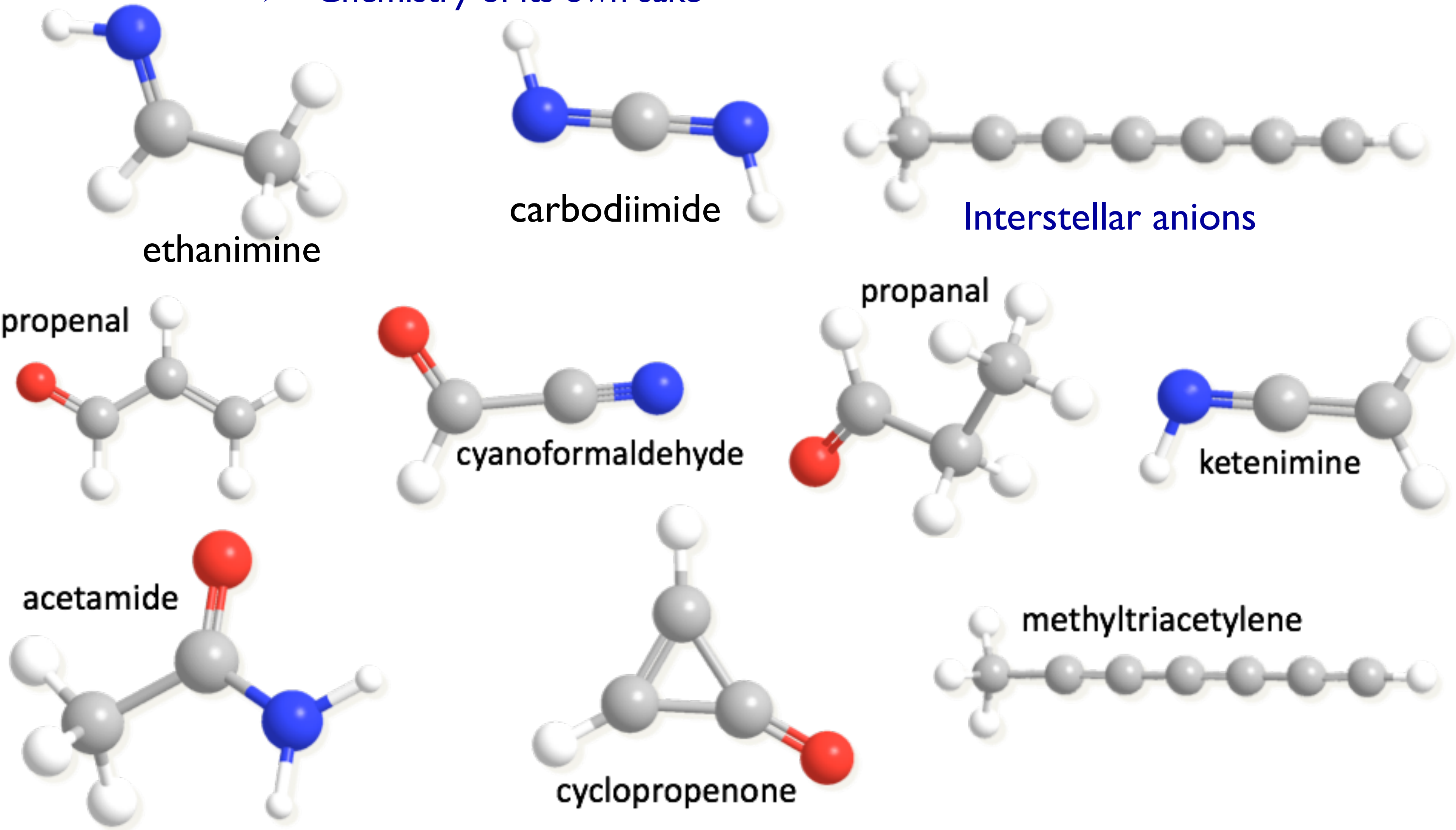


Low temperature sugar-related molecule

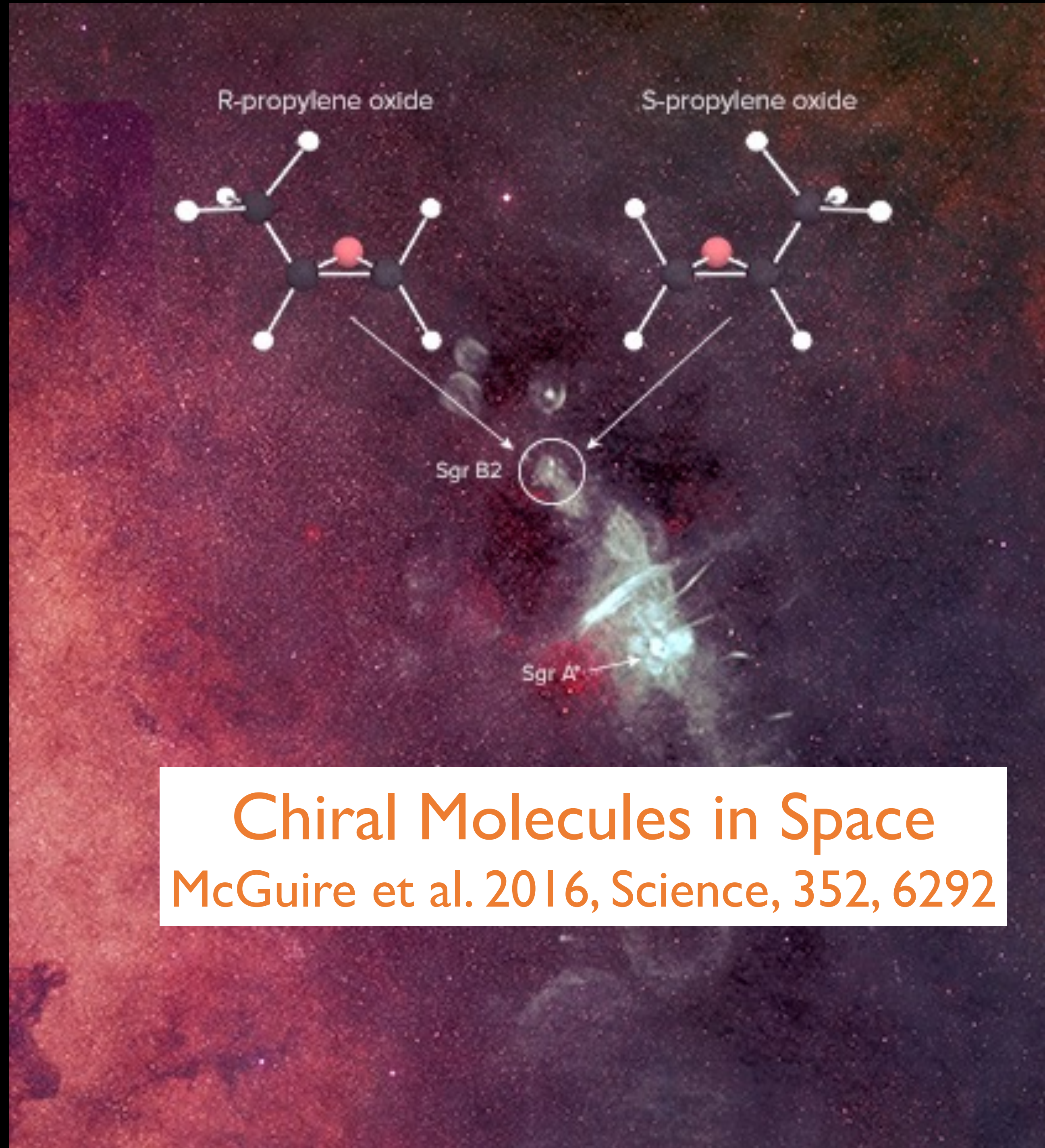
Courtesy Hollis, Jewell, Lovas, Remijan

Some (of the ~20) New GBT Molecules

- Linking ISM chemistry to origin of life
- Chemistry as tool for understanding star-formation
- Chemistry of its own sake



Biochemistry on Earth shows homochirality (e.g., all left-handed amino acids/proteins)



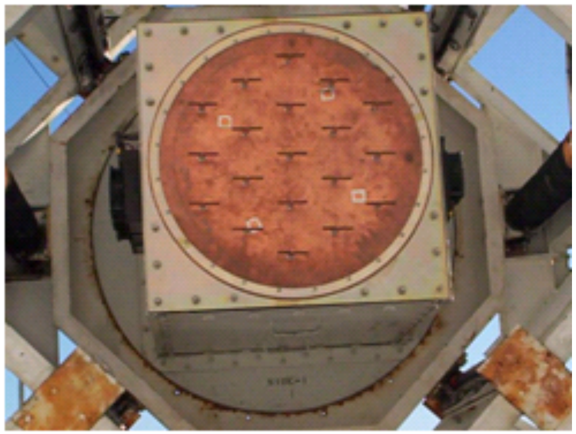
Chiral Molecules in Space

McGuire et al. 2016, Science, 352, 6292

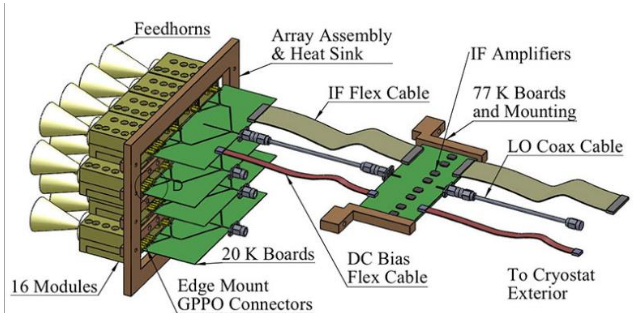
New GBT Instruments

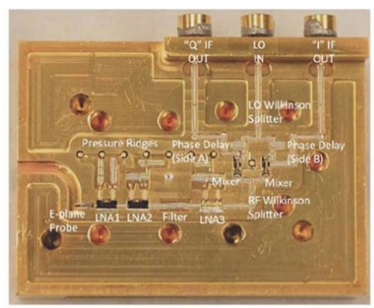
FLAG

19-element phased-array feed [PAF] (7beams) at 21cm BYU/NRAO.

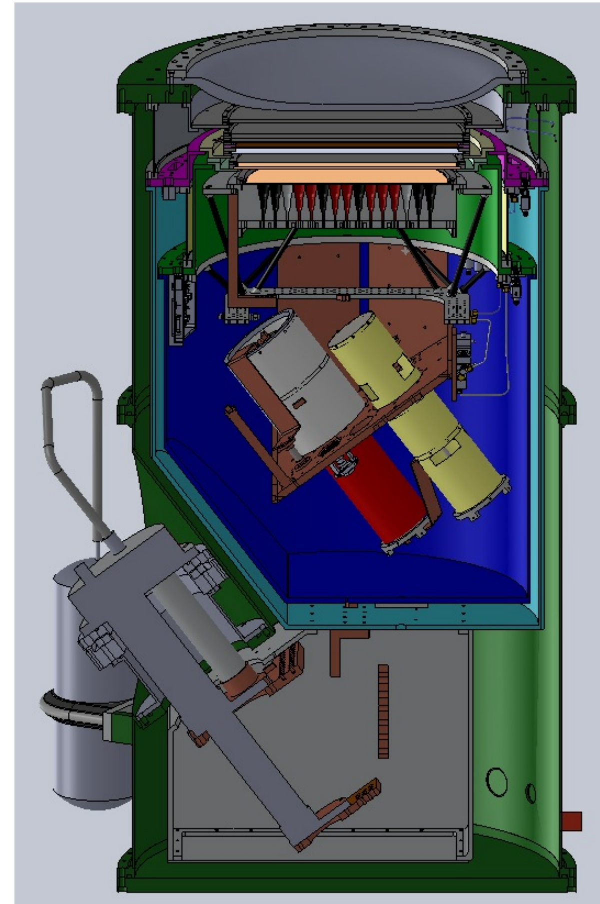


16 element scalable 75-115 GHz FPA [Stanford/CIT-JPL/UMd/Miami/NRAO]





Mustang-2 [Upenn/NRAO] 3mm 223 pixel bolometer camera



VEGAS

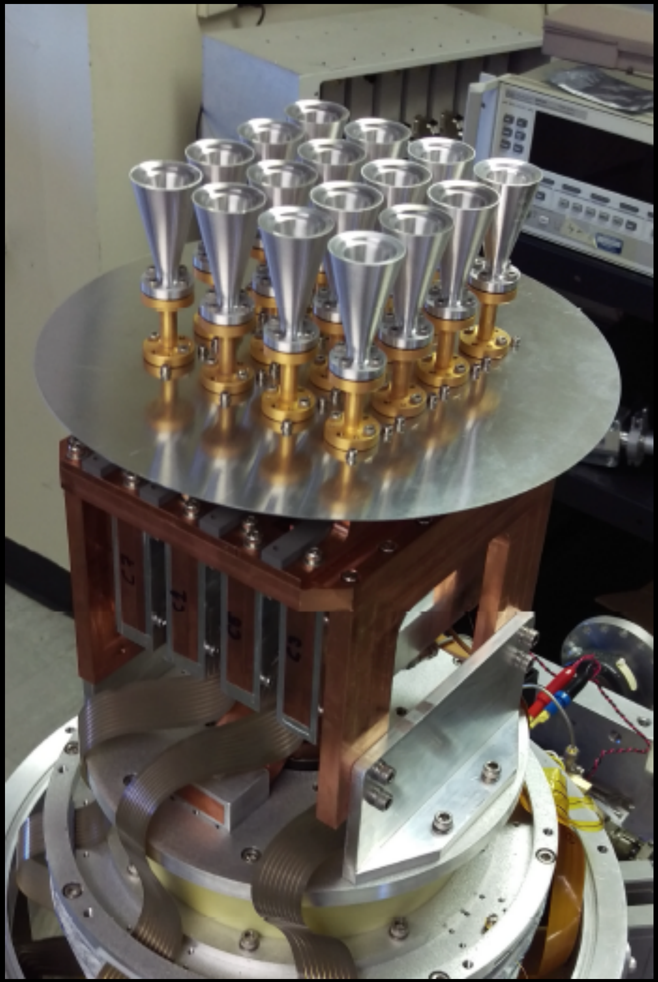
Versatile GBT Astronomical Spectrometer (CASPER, NRAO/GBO). VEGAS has replaced the spectral-processor, the old GBT spectrometer, and will also replace the pulsar GUPPI backend in coming year(s)

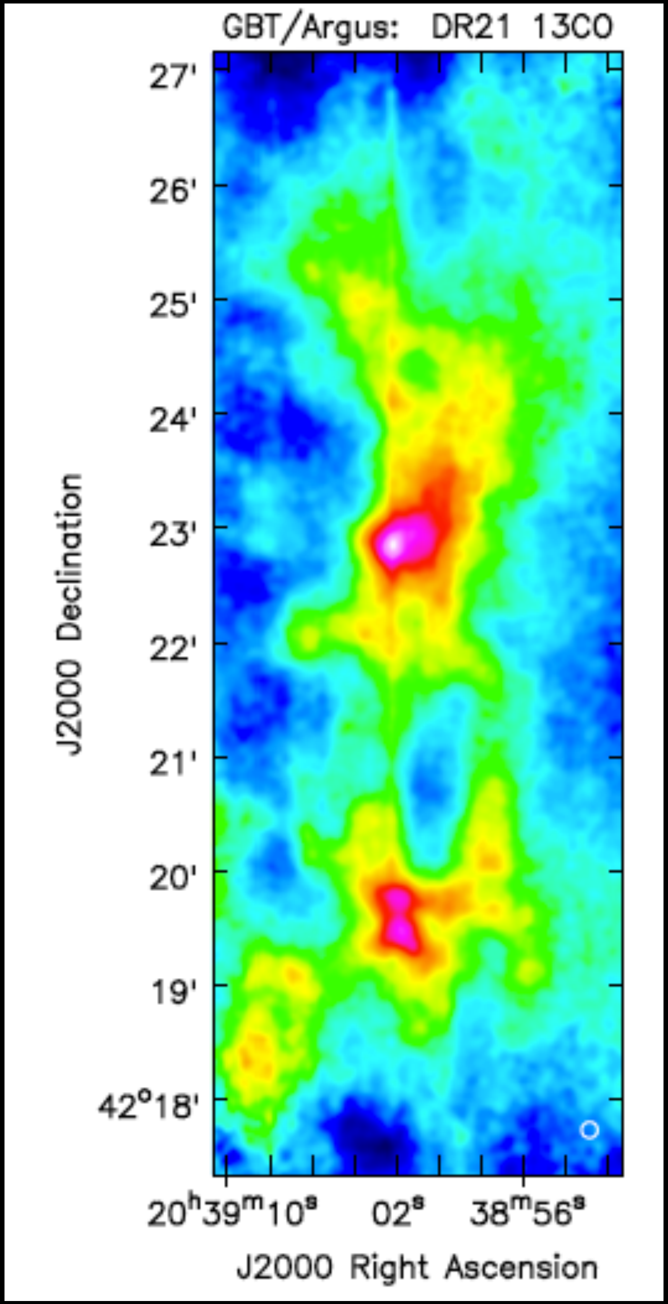
VEGAS, Argus, and Mustang-2 are available for use on the GBT.

Argus

16 pixels

75-116 GHz





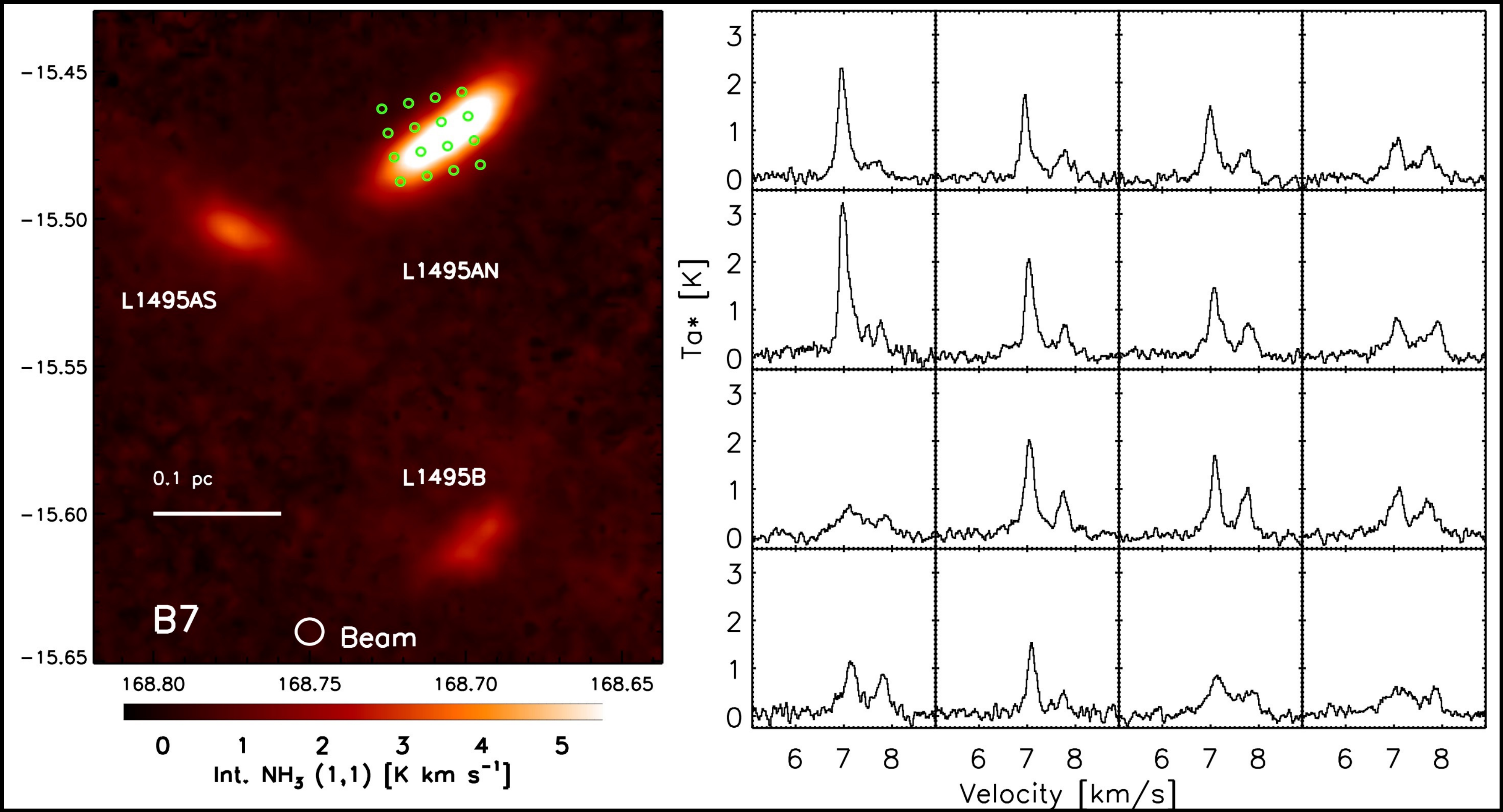
DR 21

^{13}CO

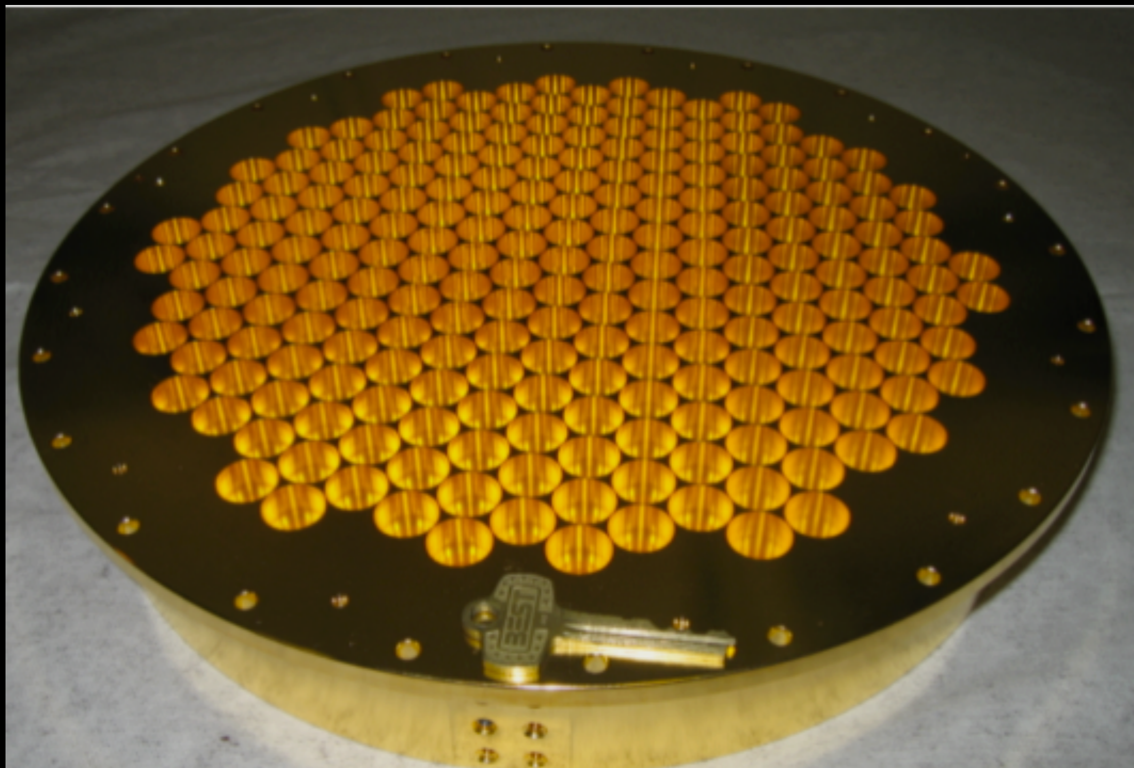
40 min commissioning observations with high-opacity conditions

$\tau_{110} = 0.42$

Seo et al (in prep) 10 min HCO+ snapshot with ARGUS



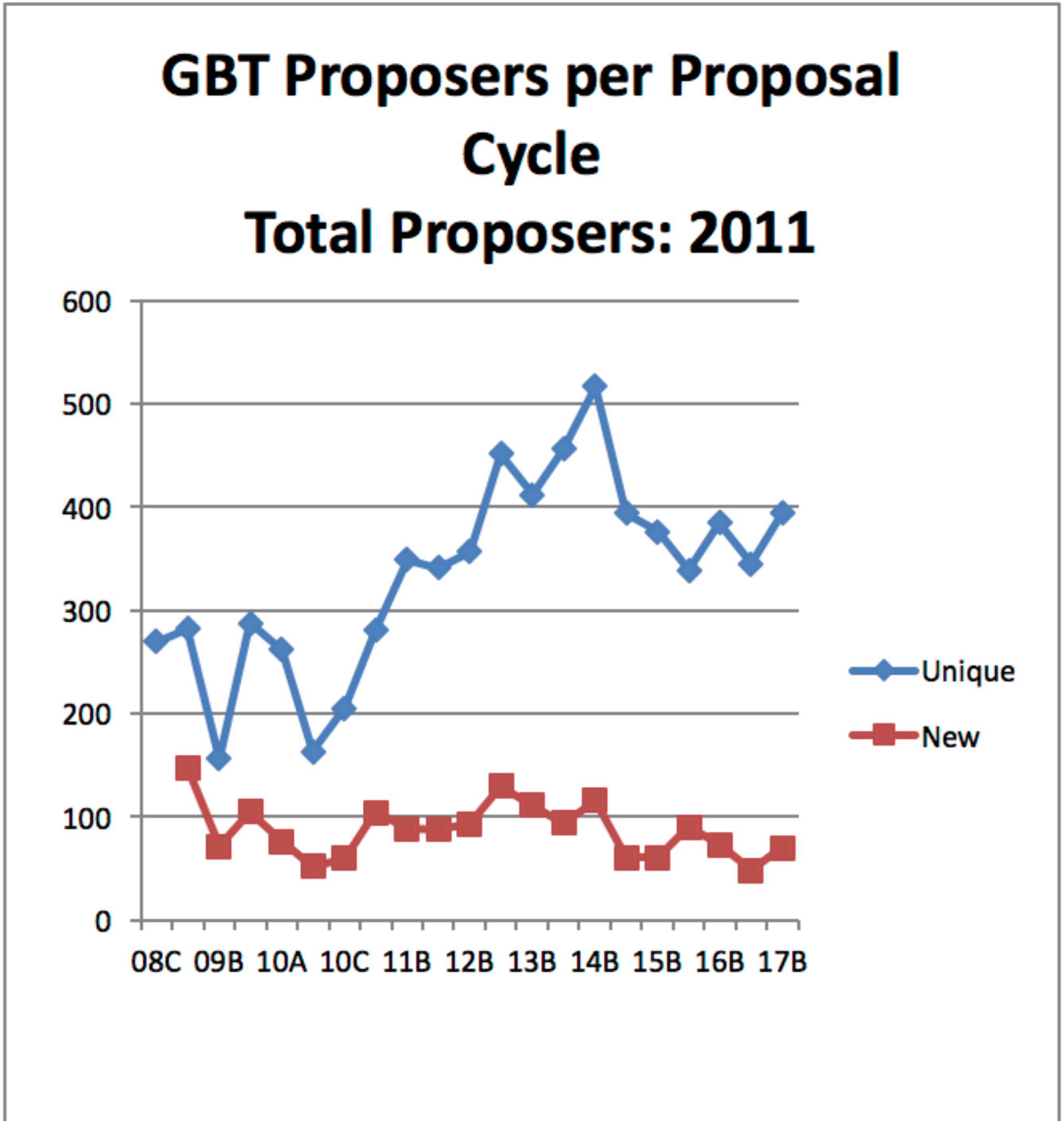
GBT MUSTANG - 2



223 pixels
>4’ FOV
35x faster than MUSTANG

The GBT user-base is growing.

Currently, there are around ~1200 users of the GBT, and there are 282 active GB observer accounts (which are closed every year if inactive).



File Edit View History Bookmarks Tools Help

Green Bank Observator... ×

greenbankobservatory.org/science/partners/

Search

GREEN BANK OBSERVATORY

GBO Partners

ABOUT RESERVATIONS EVENTS NEWS ENGAGE CONTACT

VISIT EDUCATION SCIENCE TELESCOPES SERVICES

National Science Foundation

The NSF built the Green Bank Observatory and funded its operation for more than 50 years. Today the NSF still owns the facility and funds part of the operation of the 100-m GBT for "open skies" science.

Breakthrough Listen

Breakthrough Listen is the largest ever scientific research program aimed at finding evidence of civilizations beyond Earth. The GBT plays a key role in the Breakthrough Listen project, and roughly 20% of the time available on the GBT is dedicated to this research.

NANOGrav

The North American NanoHertz Observatory for Graviational Waves, or NANOGrav, has members drawn from across the United States and Canada. The GBT is a key instrument for the NANOGrav experiment, and it spends roughly 5% of its time monitoring pulsars to look for gravitational waves.

West Virginia University Center for Astrophysics

West Virginia University (WVU) has a rapidly growing research and teaching group within the Department of Physics and Astronomy which explores a wide variety of hot topics in current astrophysics. WVU time on the 100-m Green Bank Telescope is used by professors and students to pursue their own research projects and interests.

Partners

- Breakthrough Listen
- NANOGrav
- NSF Open Skies
- West Virginia University

GBT Observers

Green Bank Scientific Staff

RELATED LINKS

Observing with the GBT

Proposal Calls

The GBT used to be 100% "open-skies" for science, but due to the NSF 2012 divestiture recommendation, the GBT open-skies time is currently ~66% and could decrease to less than 30% in the coming years…..

Concluding Remarks

- The GBT operates up to 116 GHz.
- The flexibility of the GBT makes it a key platform for developing and deploying new instrumentation and technologies.
- The GBT is the only large (100m class) radio telescope that observes efficiently at >20 GHz
- The offset design and low RFI environment enables the deepest possible HI observations
- Multi-pixel cameras such as Mustang-2, Argus and future beam forming arrays can improve the power of the GBT by orders of magnitude**.**
- **The new Argus, Mustang-2, and VEGAS instruments have enabled new science opportunities with the GBT.**
- The GBT user-base is growing, while the amount of available NSF time is decreasing…

The GBT is just beginning to realize

its scientific potential at high frequencies.