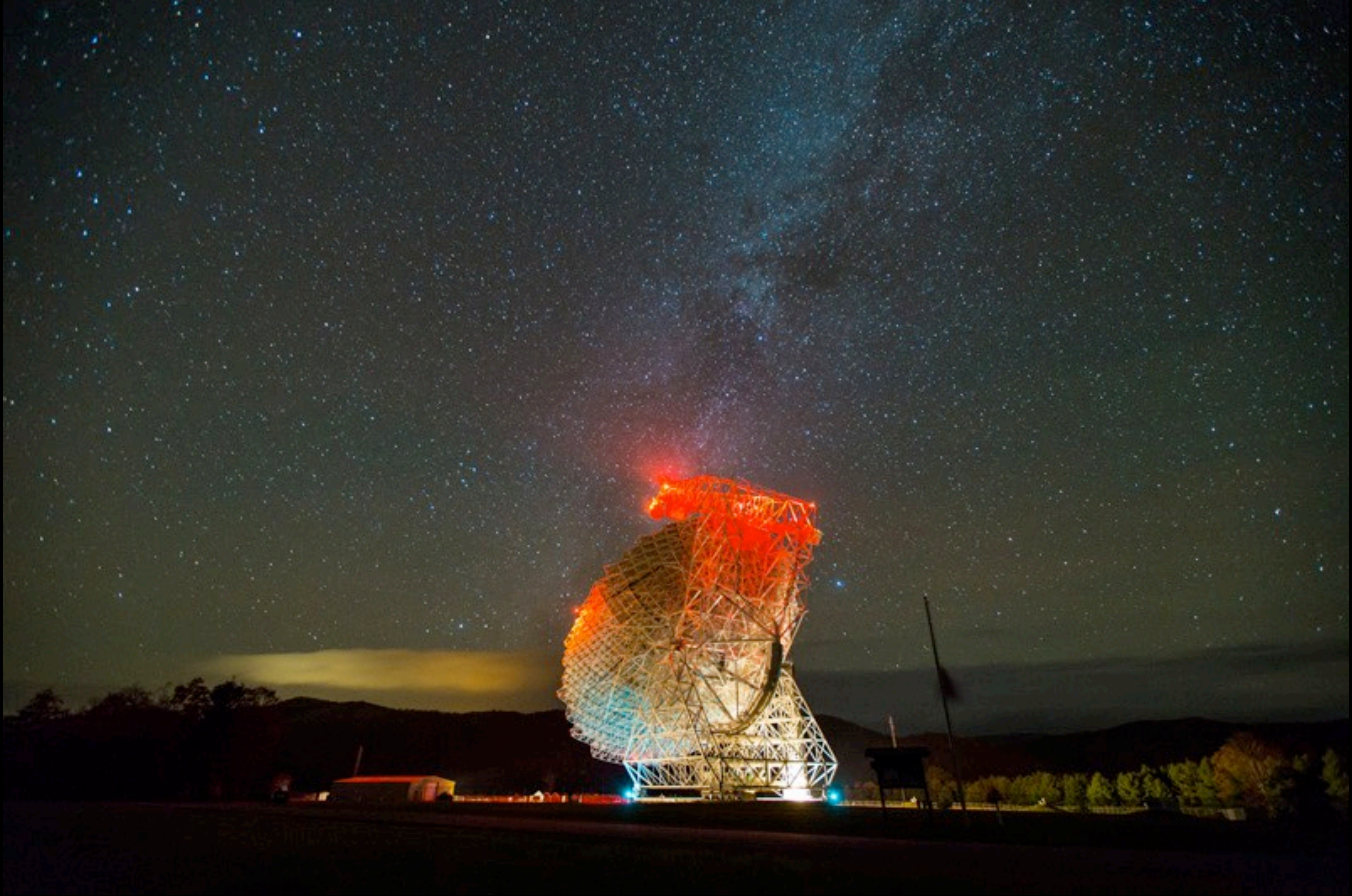
Green Bank Telescope Science Program

Felix "Jay" Lockman
NRAO, Green Bank WV

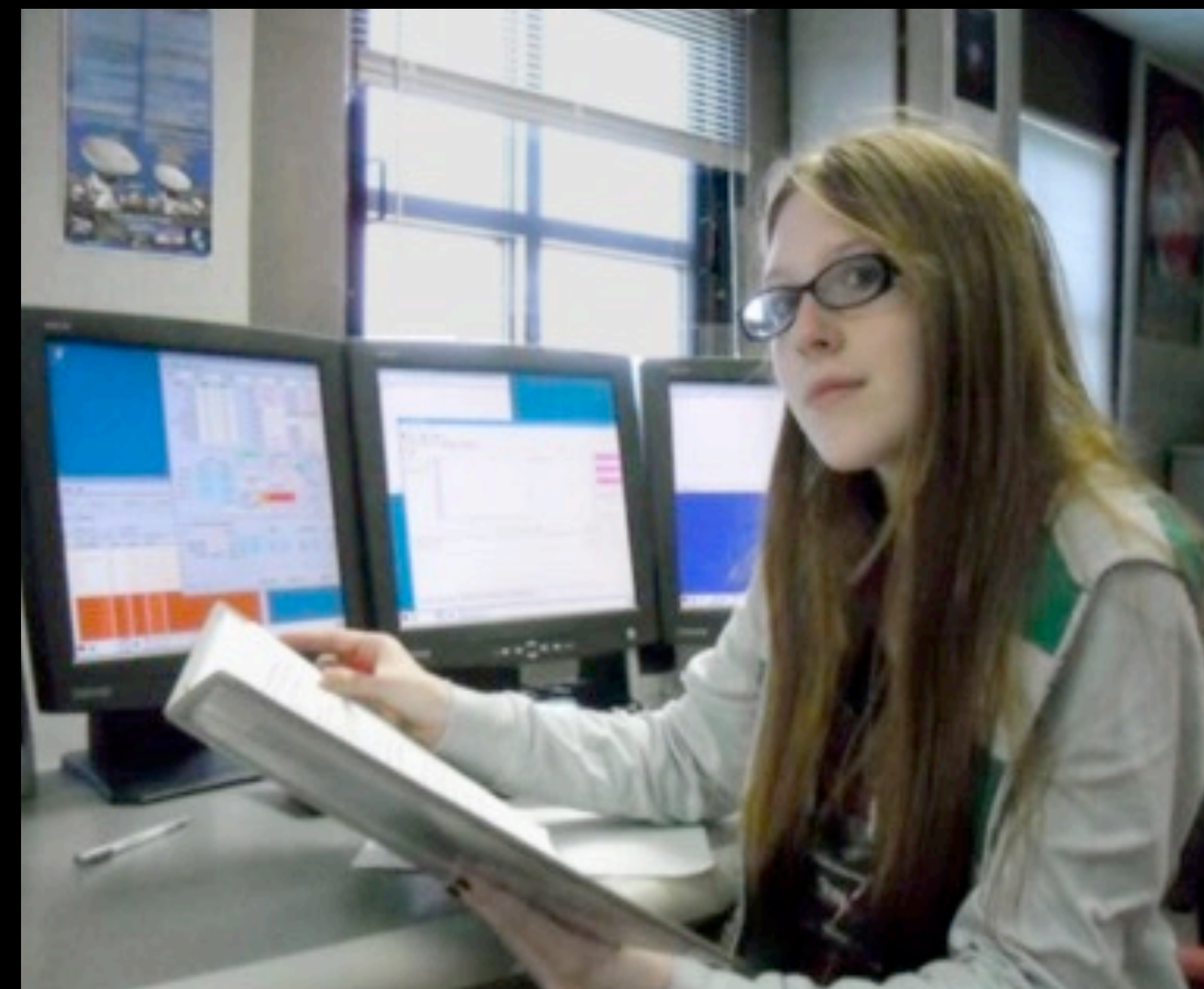
The Green Bank Observatory
A Showcase for the NSF

40,000 – 50,000 visitors each year



NOAA *Weather in Focus* Photo Contest
First Place: Mike Zorger, GBT at night

The Green Bank Observatory
A Force in STEM Education



The Green Bank Observatory
A Showcase for NSF Research

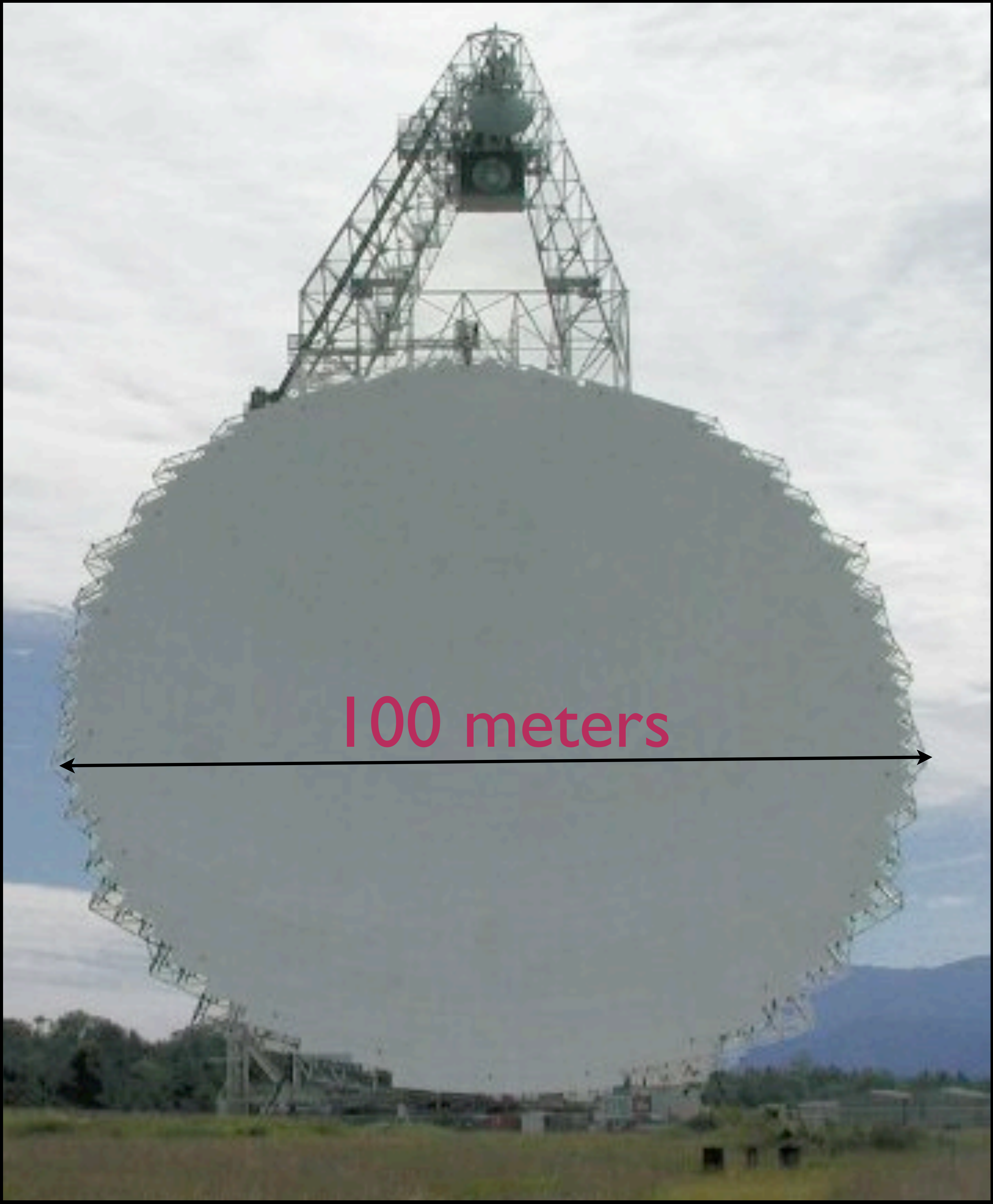
1–2 distinct media pieces a week

NBC, CBS, CNN, Yahoo, Discovery, BBC, Time, The Atlantic, NPR, The Economist, N.Y Times, A(ust)BC...

The GBT

Sensitivity
Location
Radio Quiet Zone

In 2014
6220^h for science
~⅓ at $\nu \geq 18$ GHz



The GBT

- Point source sensitivity of a ~120m telescope

With its state-of-the art receivers it has

- Point source sensitivity √2 better than VLA at ≲2 GHZ

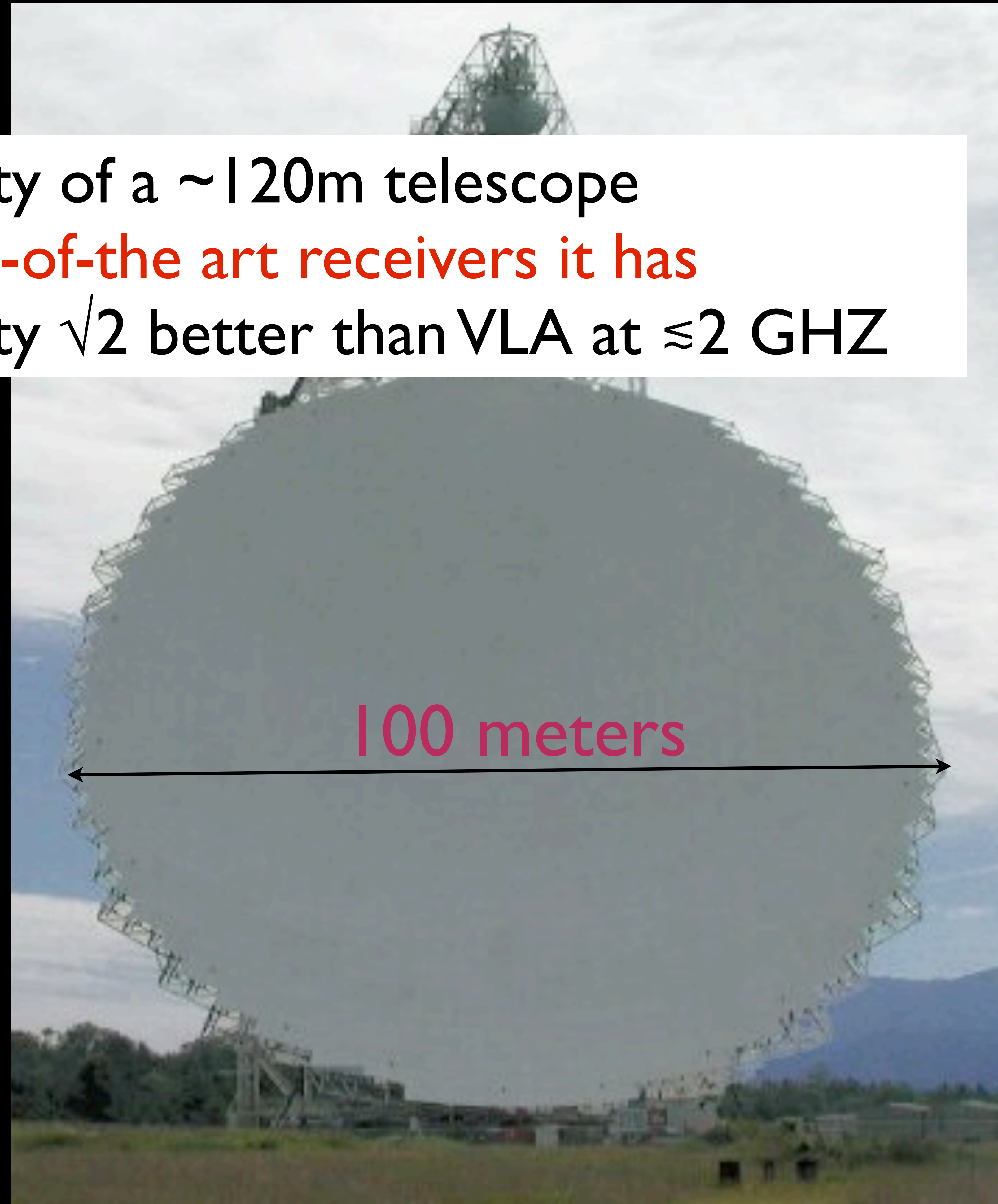
Location

Radio Quiet Zone

In 2014

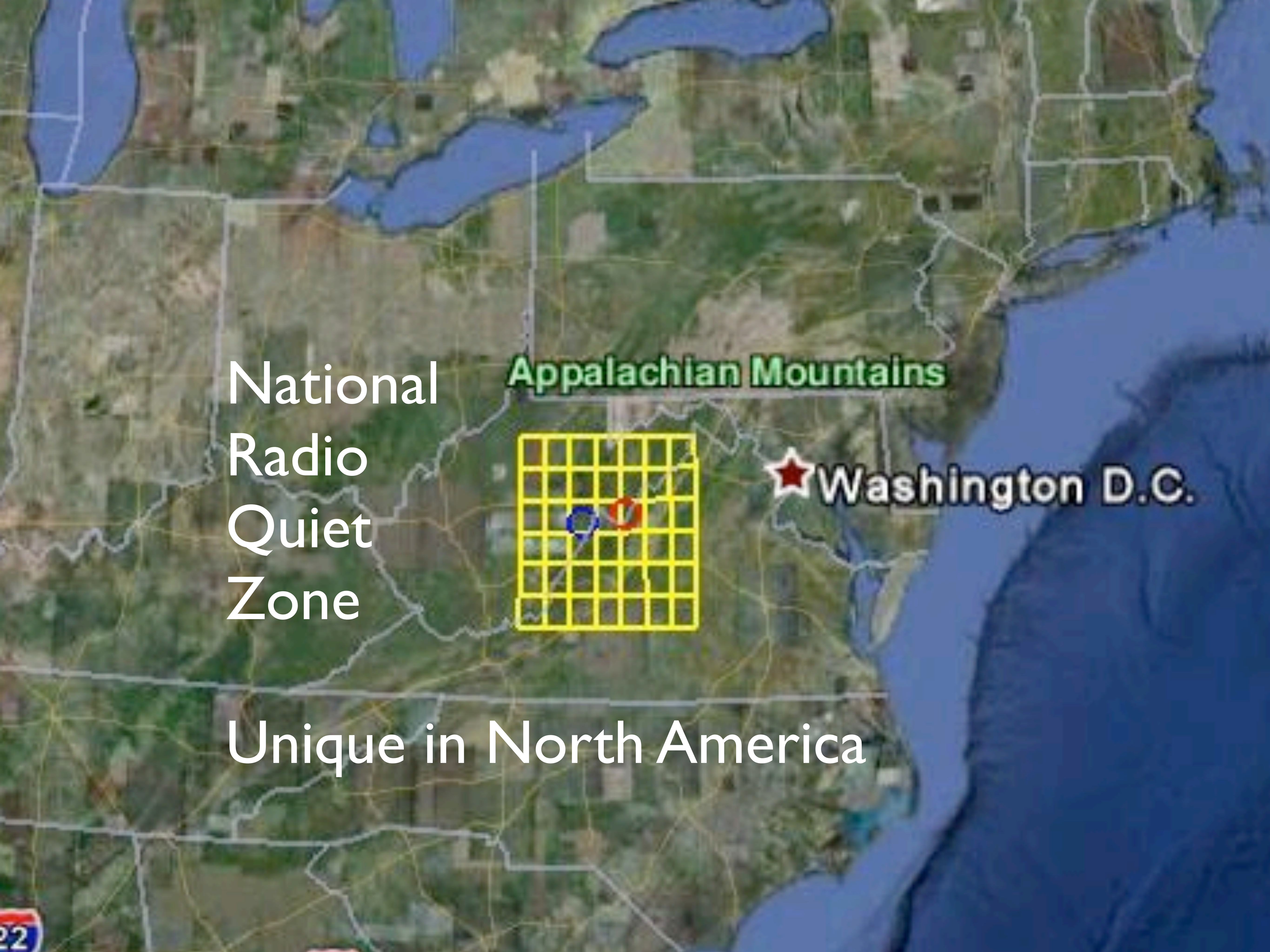
6220^{h} for science

~⅓ at $\nu \geq 18$ GHz

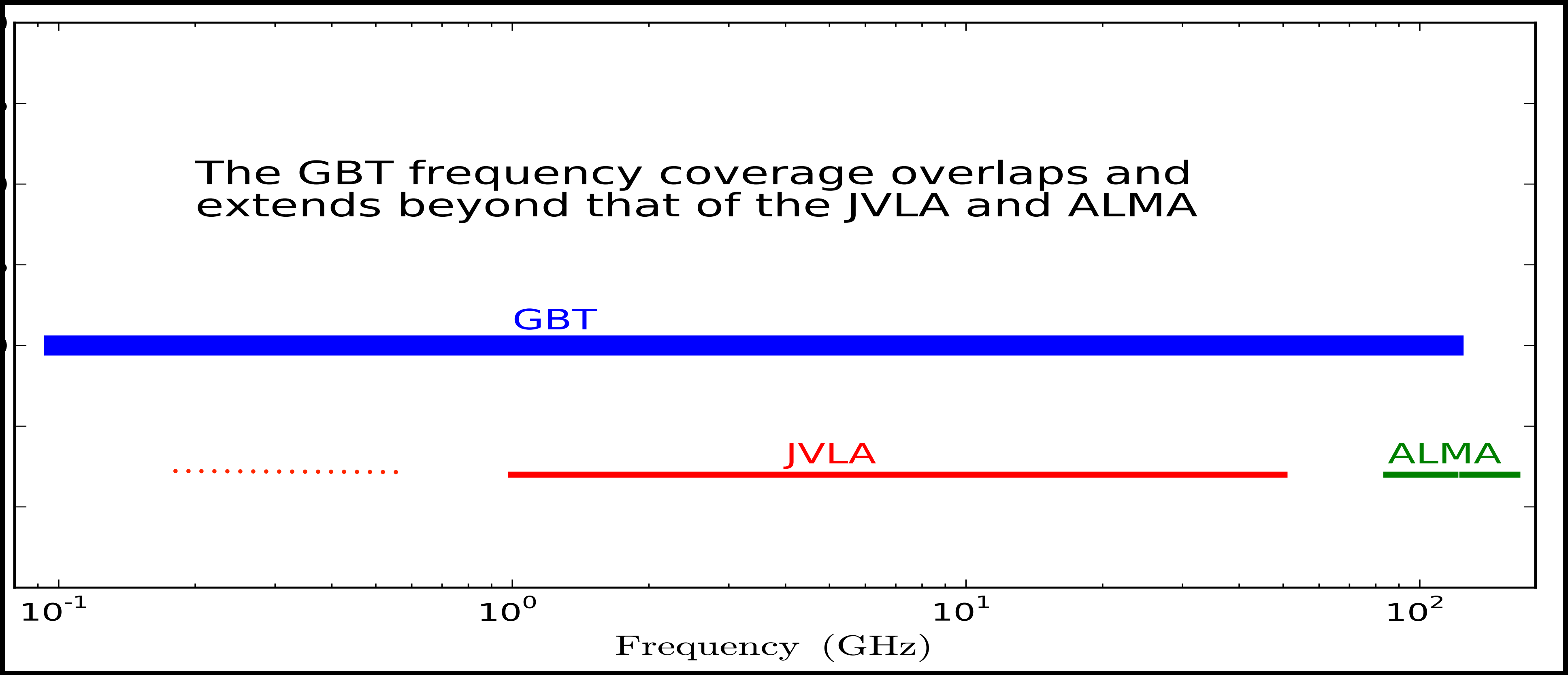


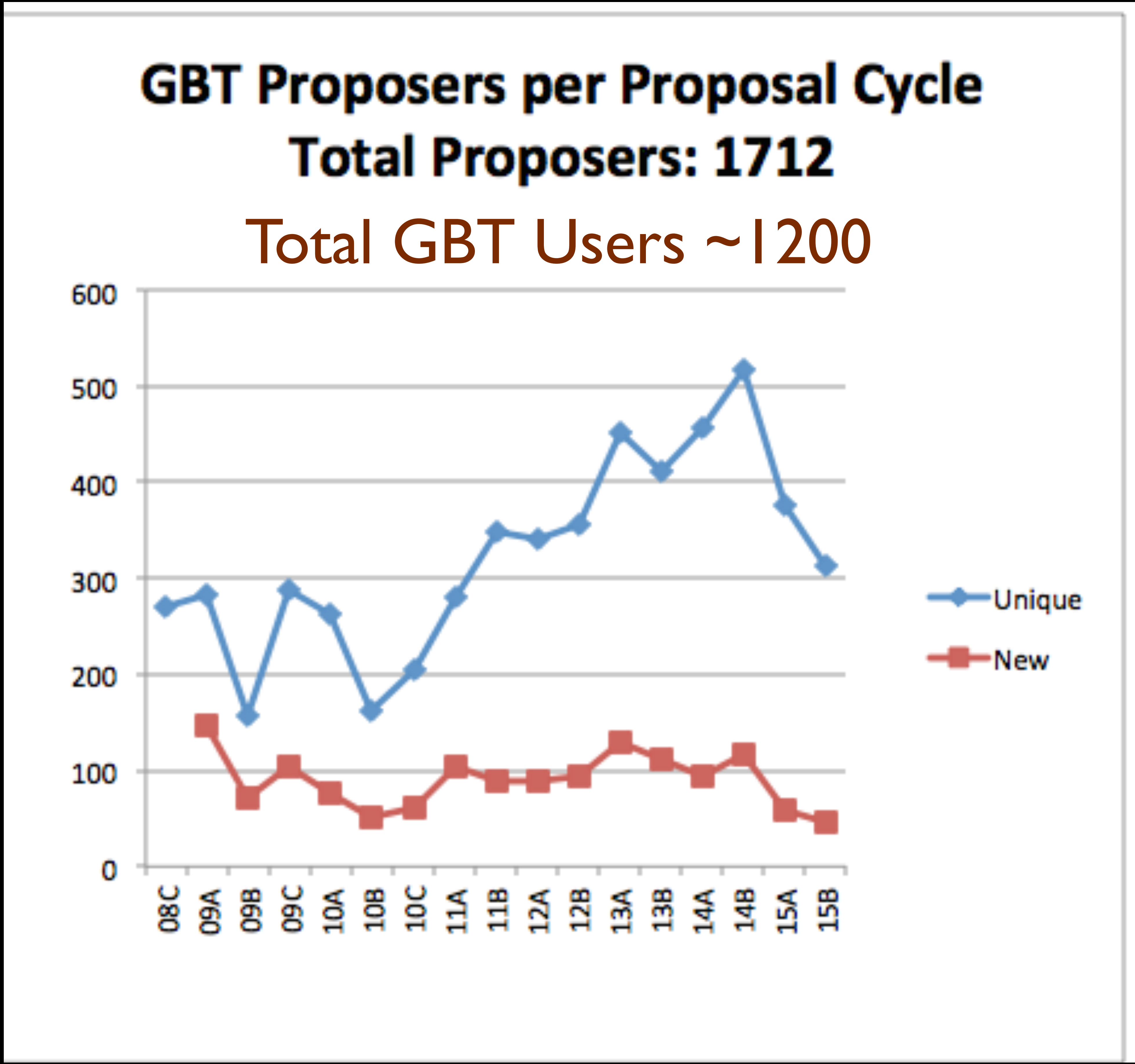
National Radio Quiet Zone

Unique in North America



- Receivers cover 0.1 to >100 GHz
- >85% of total sky covered $\delta \geq -46°$
- National Radio Quiet Zone
- Competitively Scheduled




GBT Proposers per Proposal Cycle
Total Proposers: 1712
Total GBT Users ~1200
600
500
400
300
200
100
0
08C
09A
09B
09C
10A
10B
10C
11A
11B
12A
12B
13A
13B
14A
14B
15A
15B
Unique
New

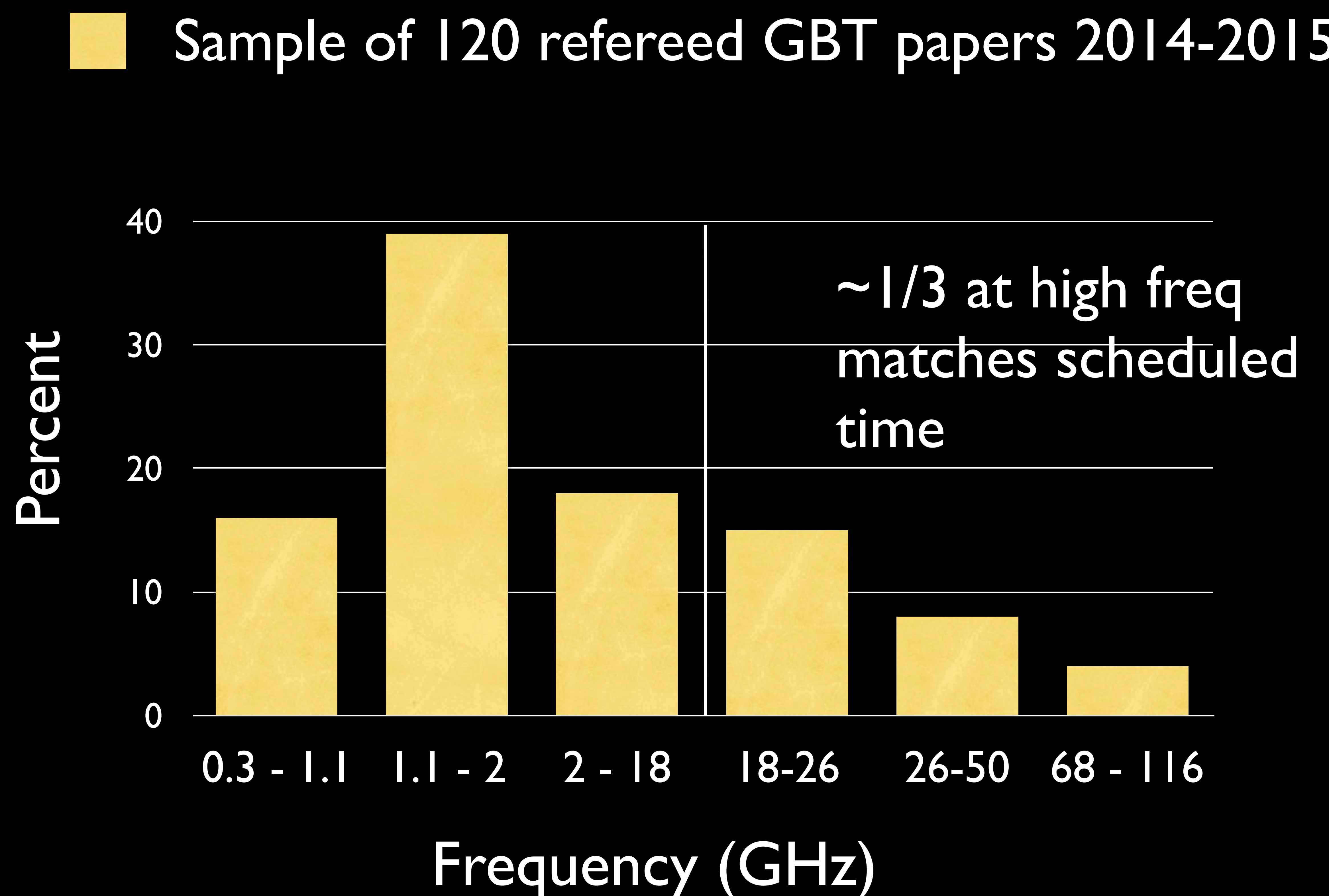
Semester 15B

Statistics by Proposal Count

Proposals	GBT	VLBA	VLA	NRAO
Submitted	64	40	172	276
Approved	25	24	56	105
Filler	10	3	58	71
Rejected	29	13	58	100
Oversubscription	2.6	1.7	3.1	2.6

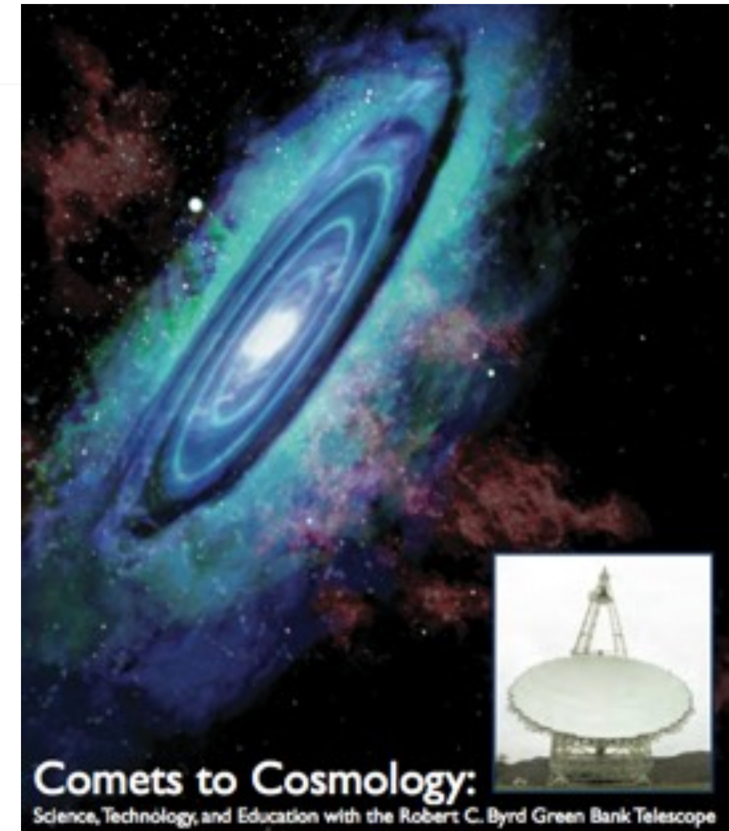
Statistics by Proposal Hours

Proposals	GBT	VLBA	VLA (D)	VLA (DnC)	VLA (Total)	NRAO
Requested	3964	1246	3829	394	4223	9433
Available	2678	945	1408	310	1718	5341
Approved	1254	797	903	148	1051	3102
Filler	439	198	1396	133	1529	2166
Rejected	2271	251	1530	113	1643	4165
Pressure	1.5	1.3	2.7	1.3	2.5	1.8


Sample of 120 refereed GBT papers 2014-2015
40
30
20
10
0
Percent
~1/3 at high freq matches scheduled time
0.3 - 1.1
1.1 - 2
2 - 18
18-26
26-50
68 - 116
Frequency (GHz)

Research areas of most-cited GBT publications

(November 2014)



Pulsars and compact objects
Gravity and General Relativity
Galactic Hydrogen surveys
Interstellar Chemistry
The internal structure of Mercury
Evolution of spiral galaxies
Star formation & pre-stellar objects
Studies of a binary black hole
Hydrogen content of galaxies
Molecules in highly redshifted galaxies
Anisotropies in the cosmic Infrared background

Research areas of most-cited GBT publications

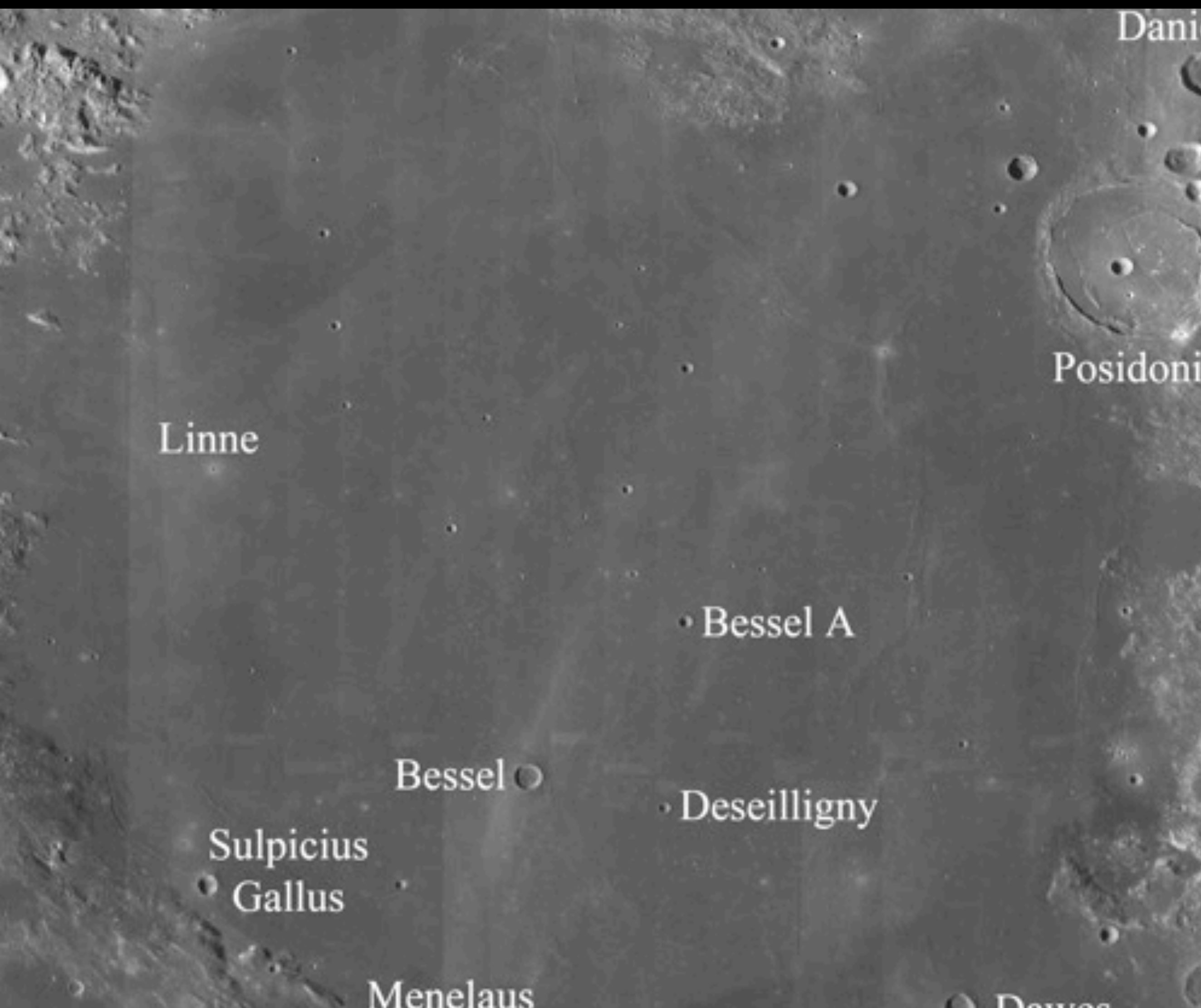
(November 2014)

Pulsars and compact objects (Fermi, Chandra, SWIFT)
Gravity and General Relativity
Galactic Hydrogen surveys (VLA)
Interstellar Chemistry
The internal structure of Mercury (radar)
Evolution of spiral galaxies
Star formation & pre-stellar objects
Studies of a binary black hole (VLBI)
Hydrogen content of galaxies
Molecules in highly redshifted galaxies
The cosmic Infrared background (Planck)

Integrated with the broader community

NRAO

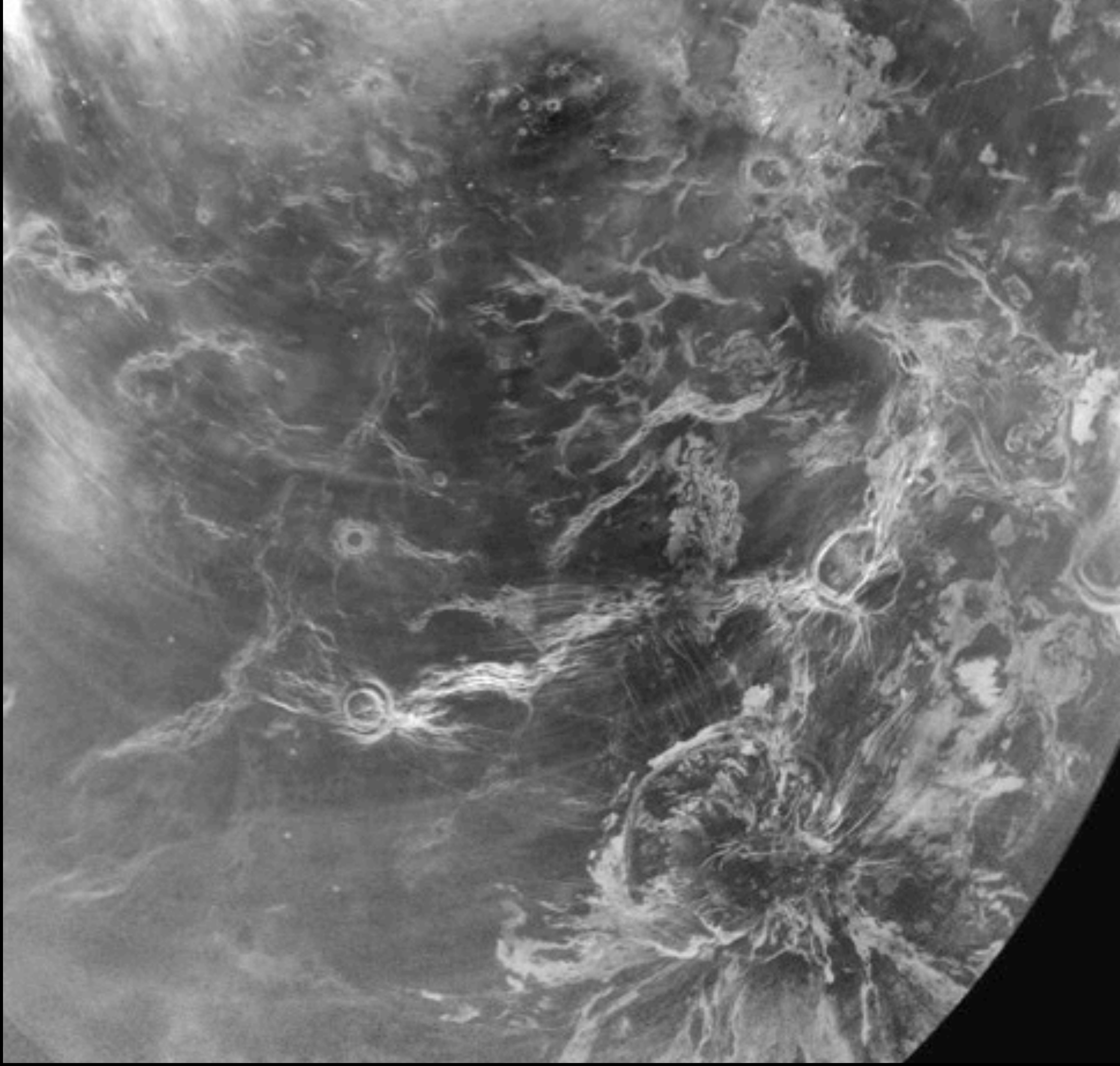
Bi-static radar studies with Arecibo



OPTICAL

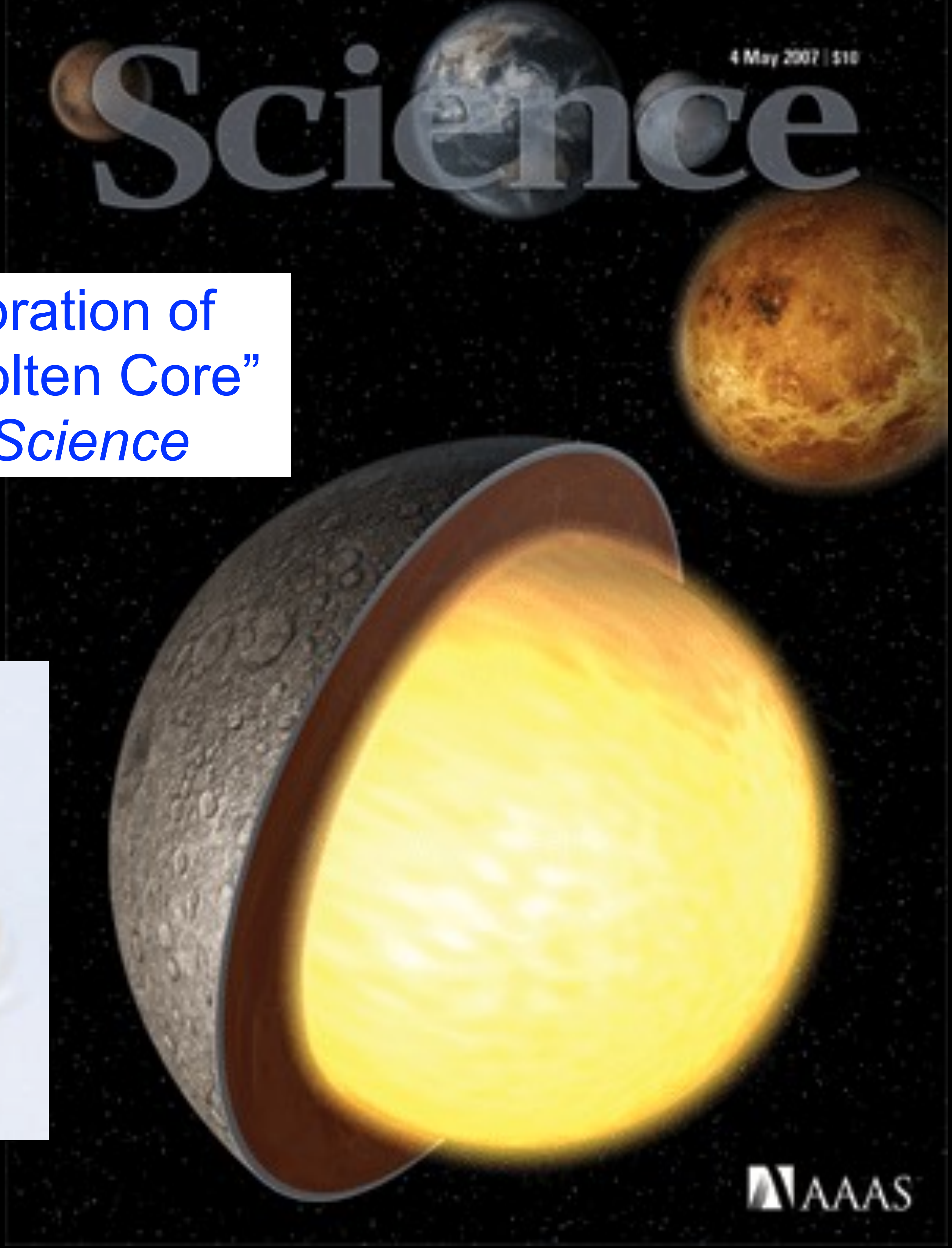
70cm RADAR

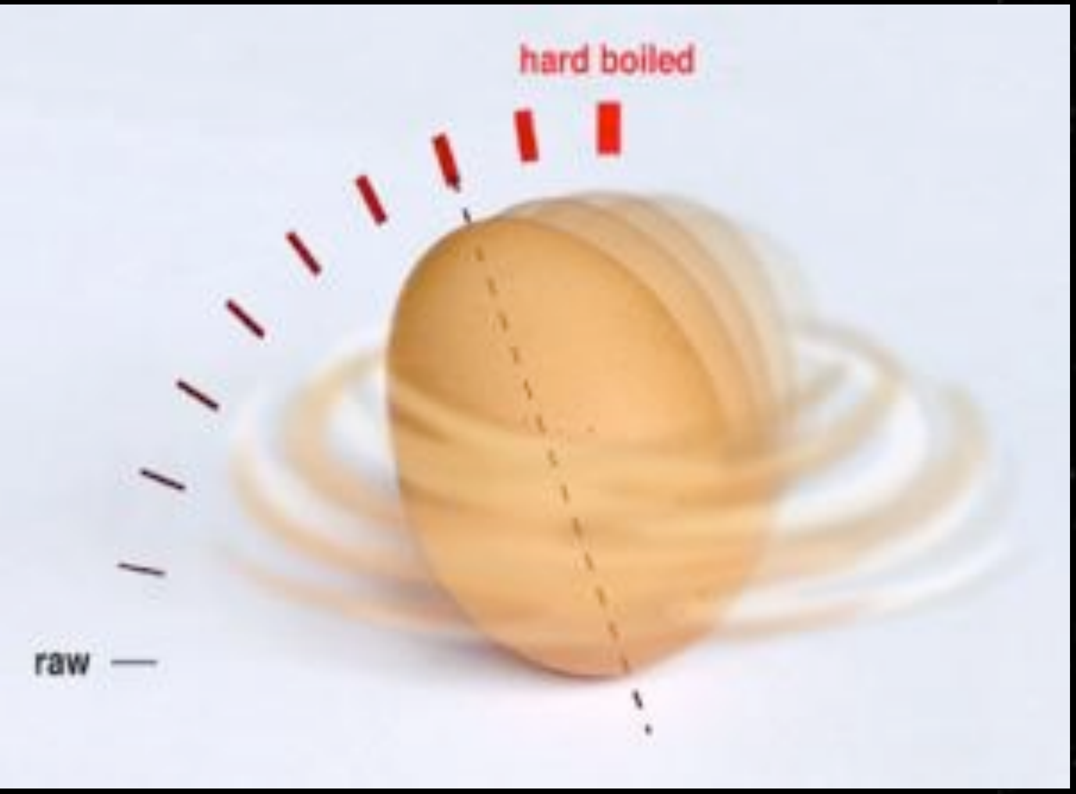
VENUS
Arecibo
+
GBT



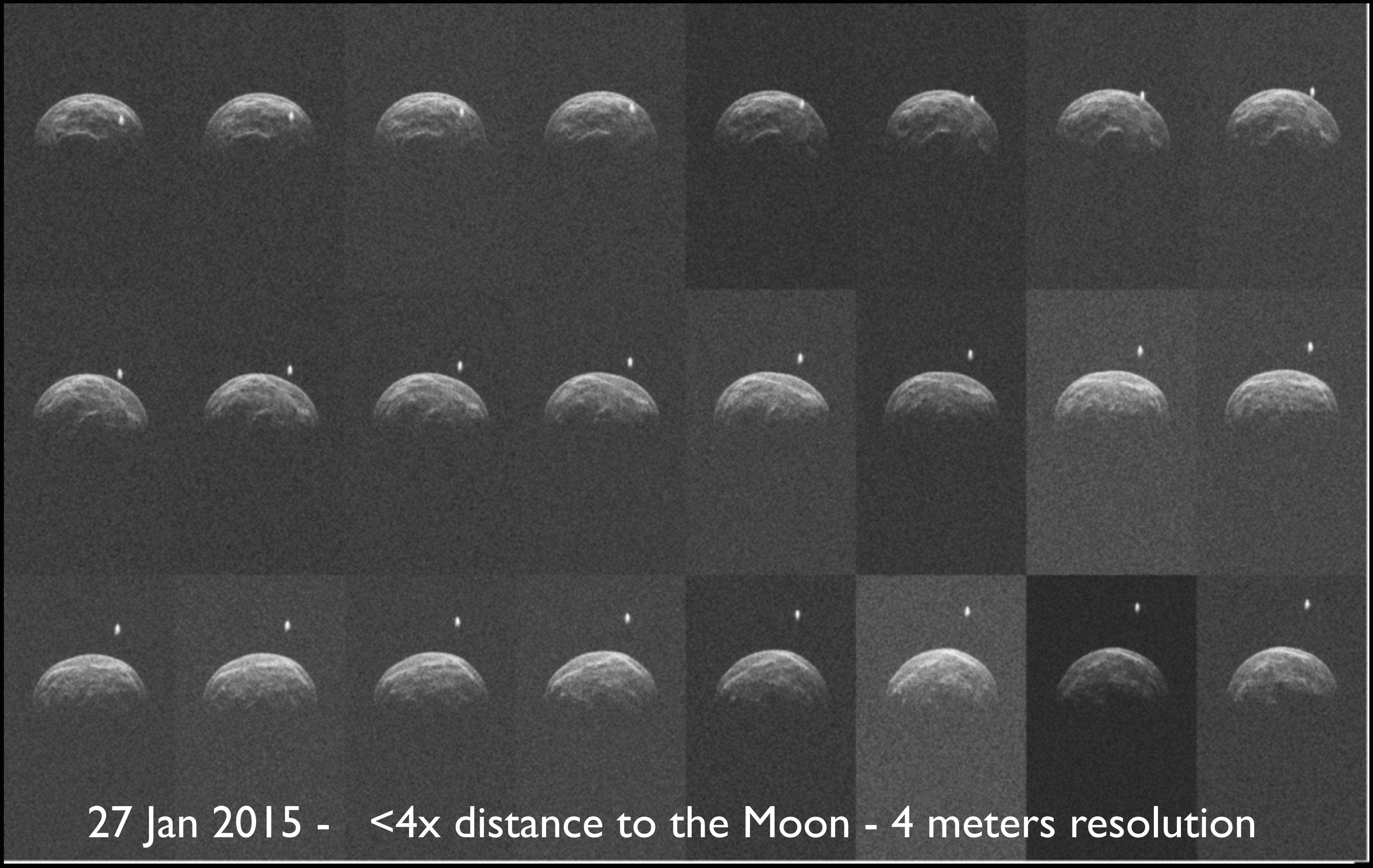
B. Campbell

“Large Longitude Libration of Mercury Reveals a Molten Core”
Margot et al. 2007 Science

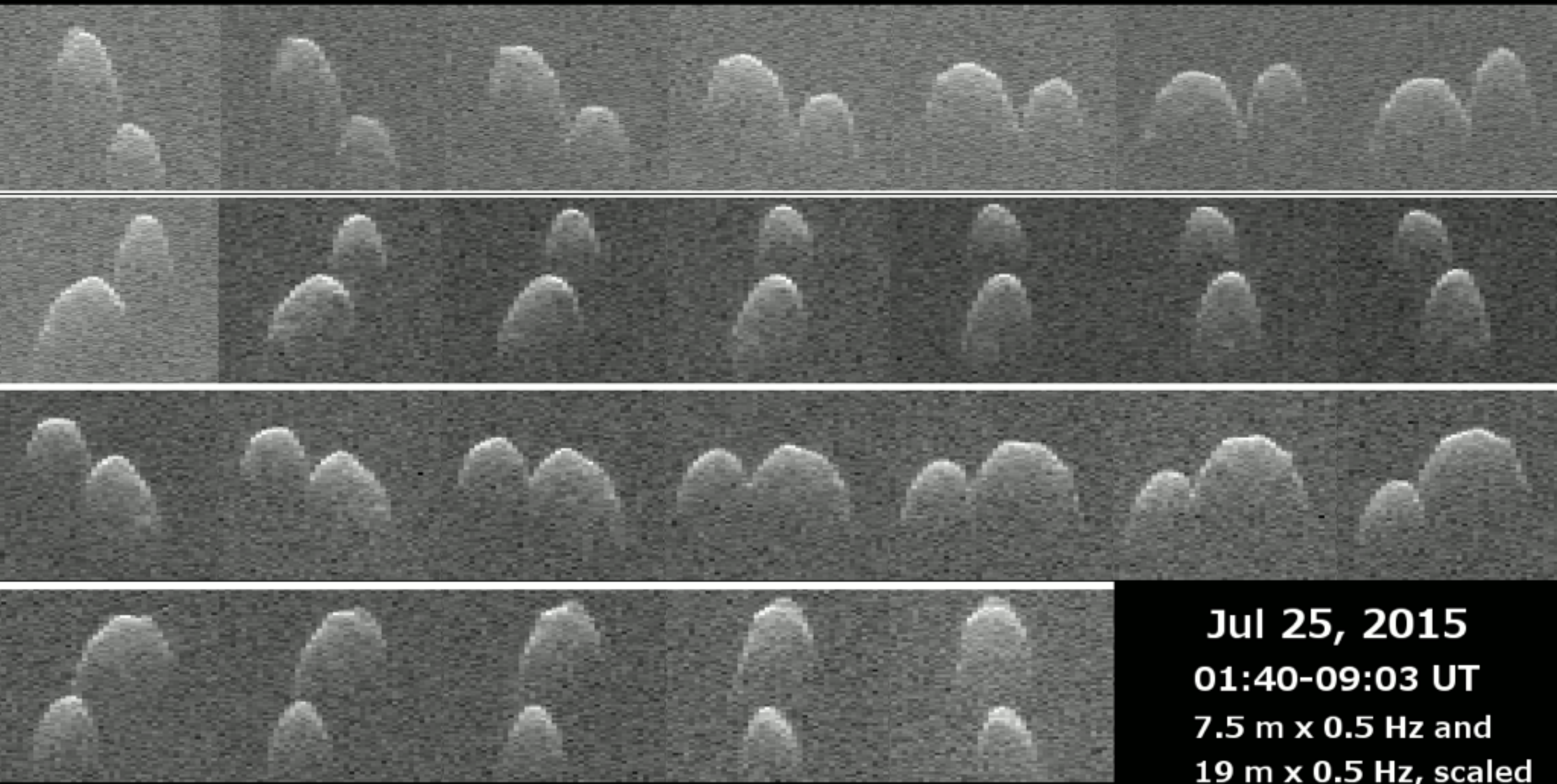




Asteroid 2004 BL86
DSS/Goldstone - GBT Radar



(85989) 1999 JD6



Goldstone-GBT bistatic radar images

~18x the distance to the Moon

GBT -- The Premier Pulsar Telescope

Fastest Pulsar

Most Massive Pulsar

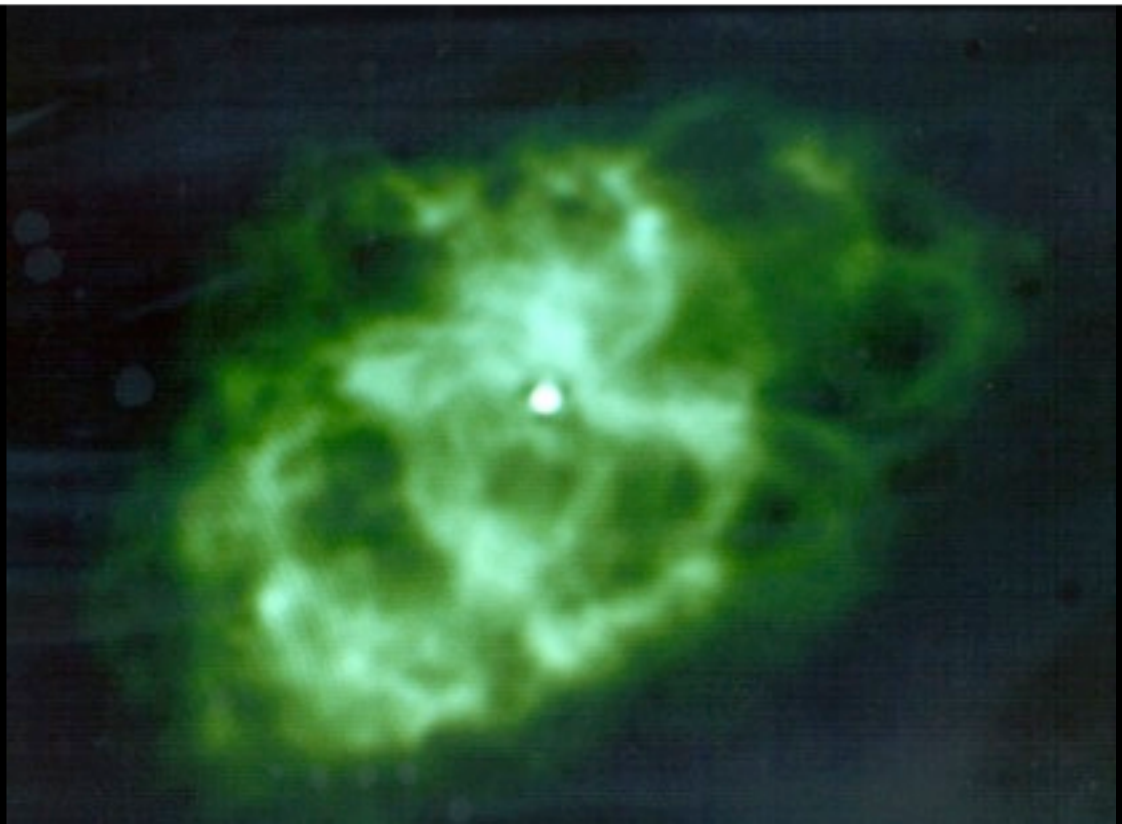
Pulsars in Globular Clusters

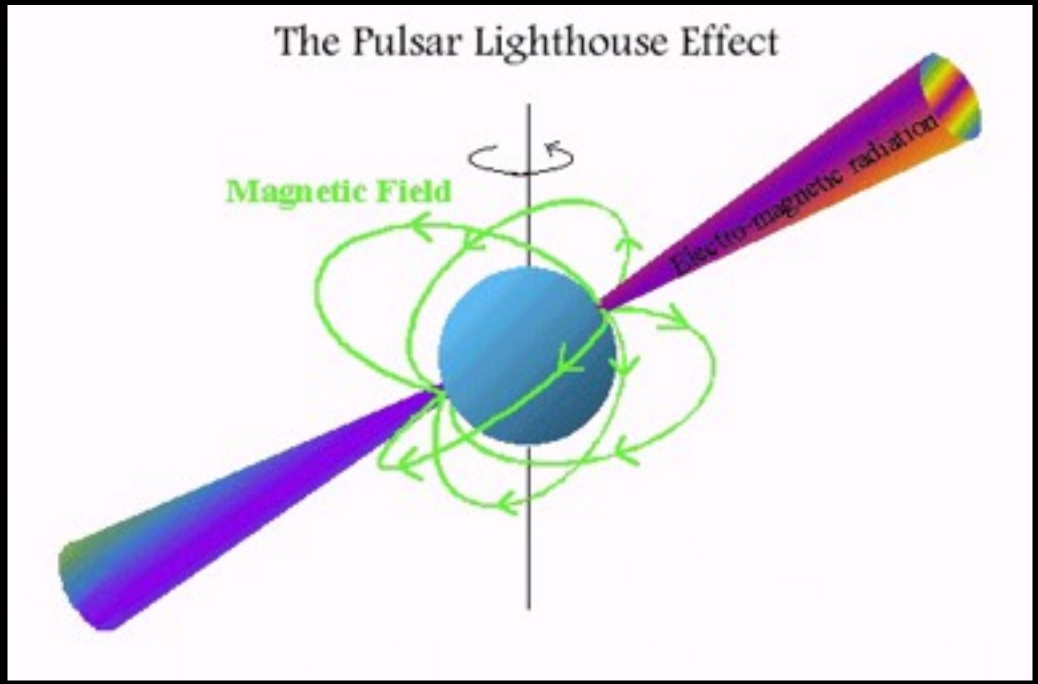
Tests of General Relativity

Relativistic Spin Precession

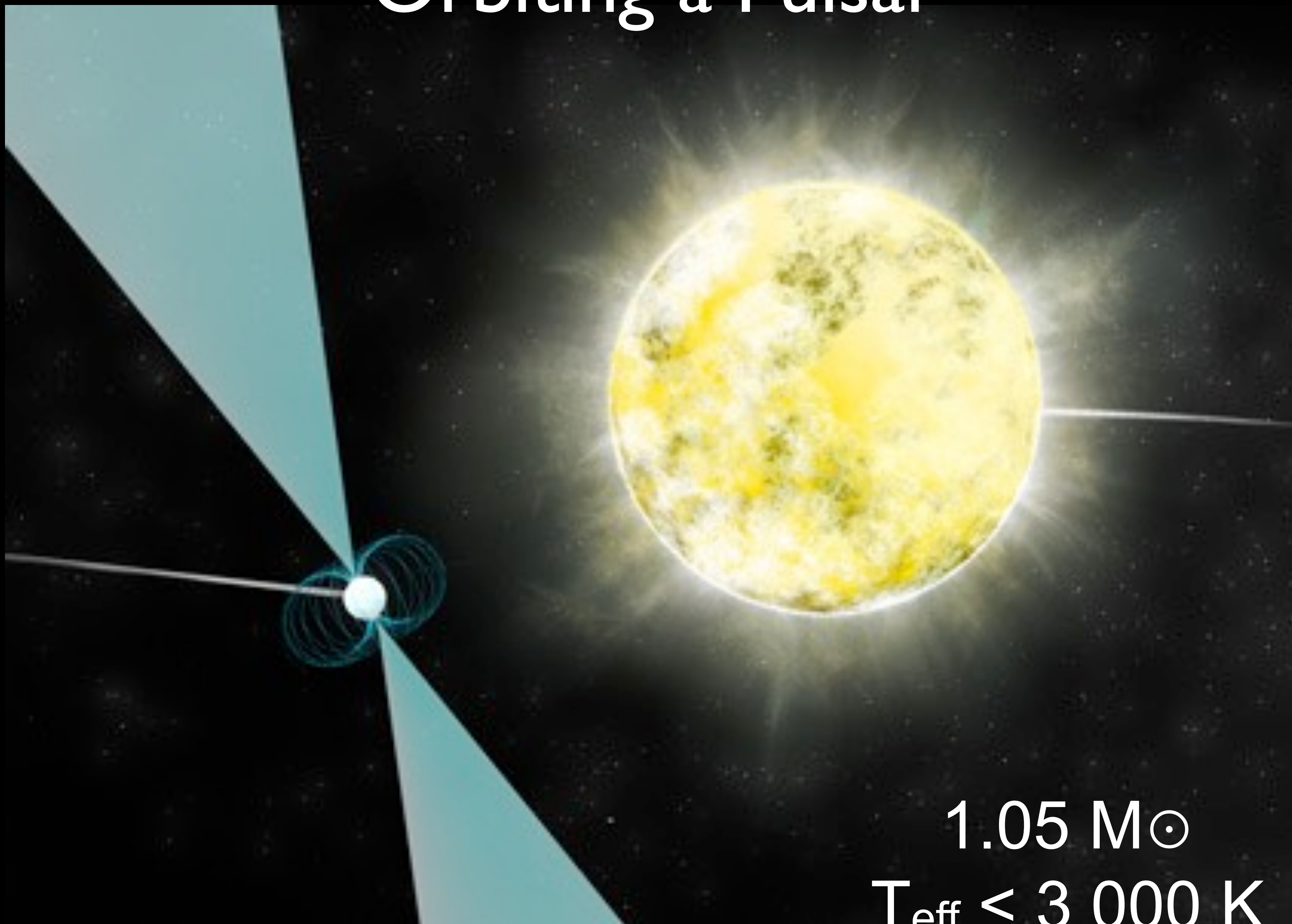
Pulsar in a three-body system

Coolest white dwarf star (a diamond as big as the Ritz)





A Solid Carbon "Diamond" Star Orbiting a Pulsar



1.05 $M_\odot$

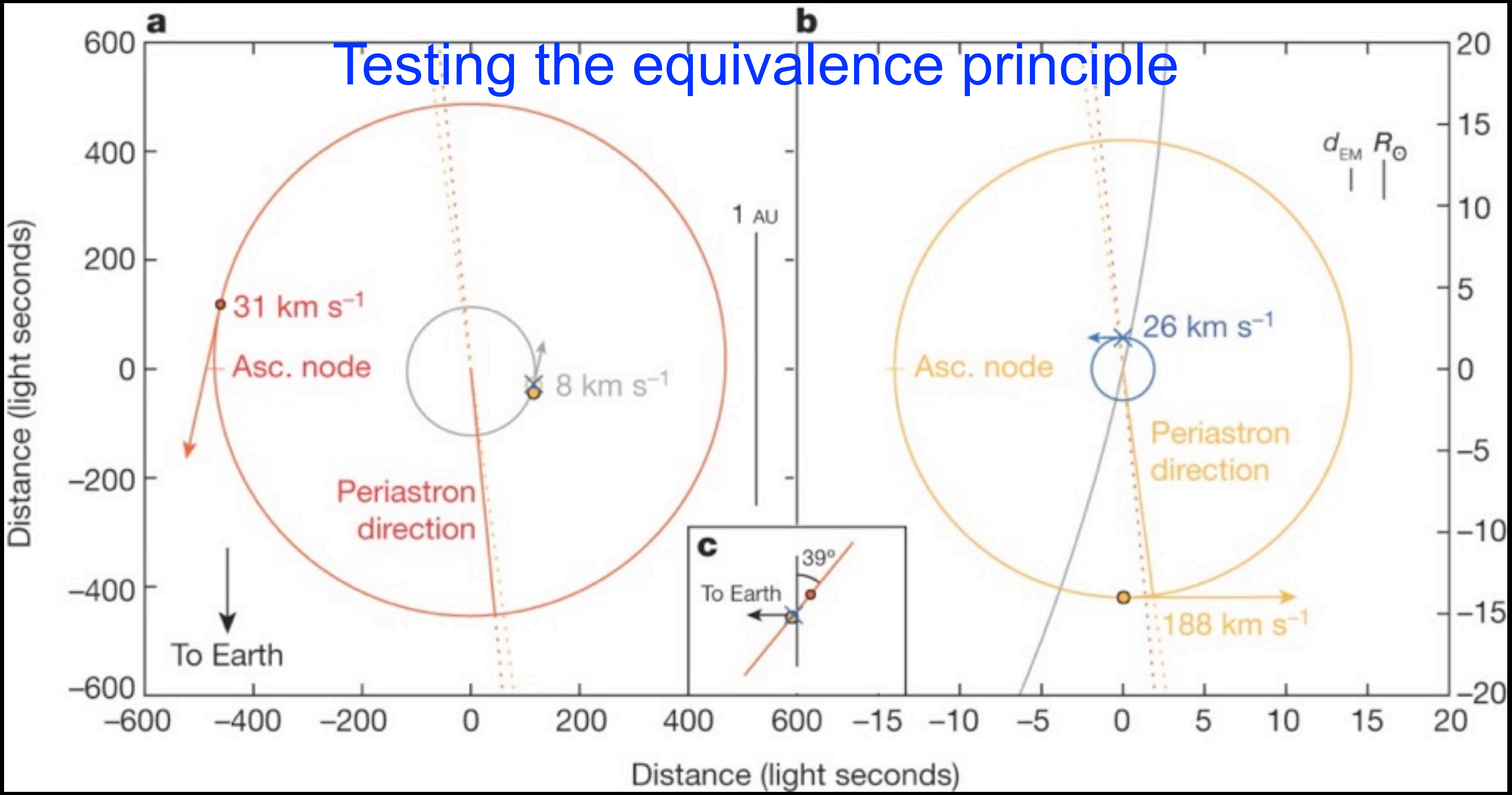
$T_{eff} < 3\,000$ K

age ~ 10 Gyr

Kaplan et al. (2014)

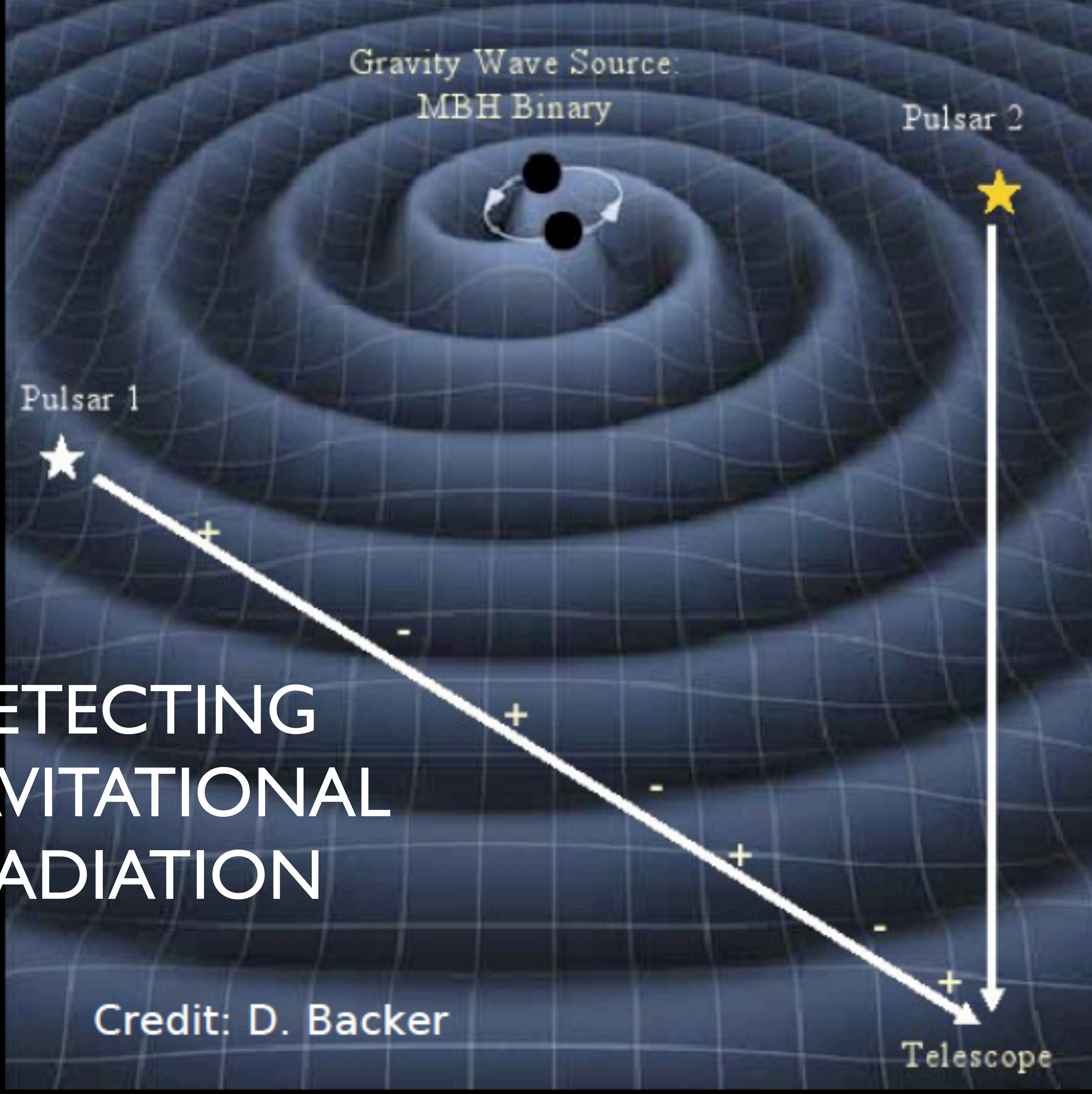
A Pulsar in a Triple System
ARECIBO+ GBT

Ransom et al. (2014) Nature



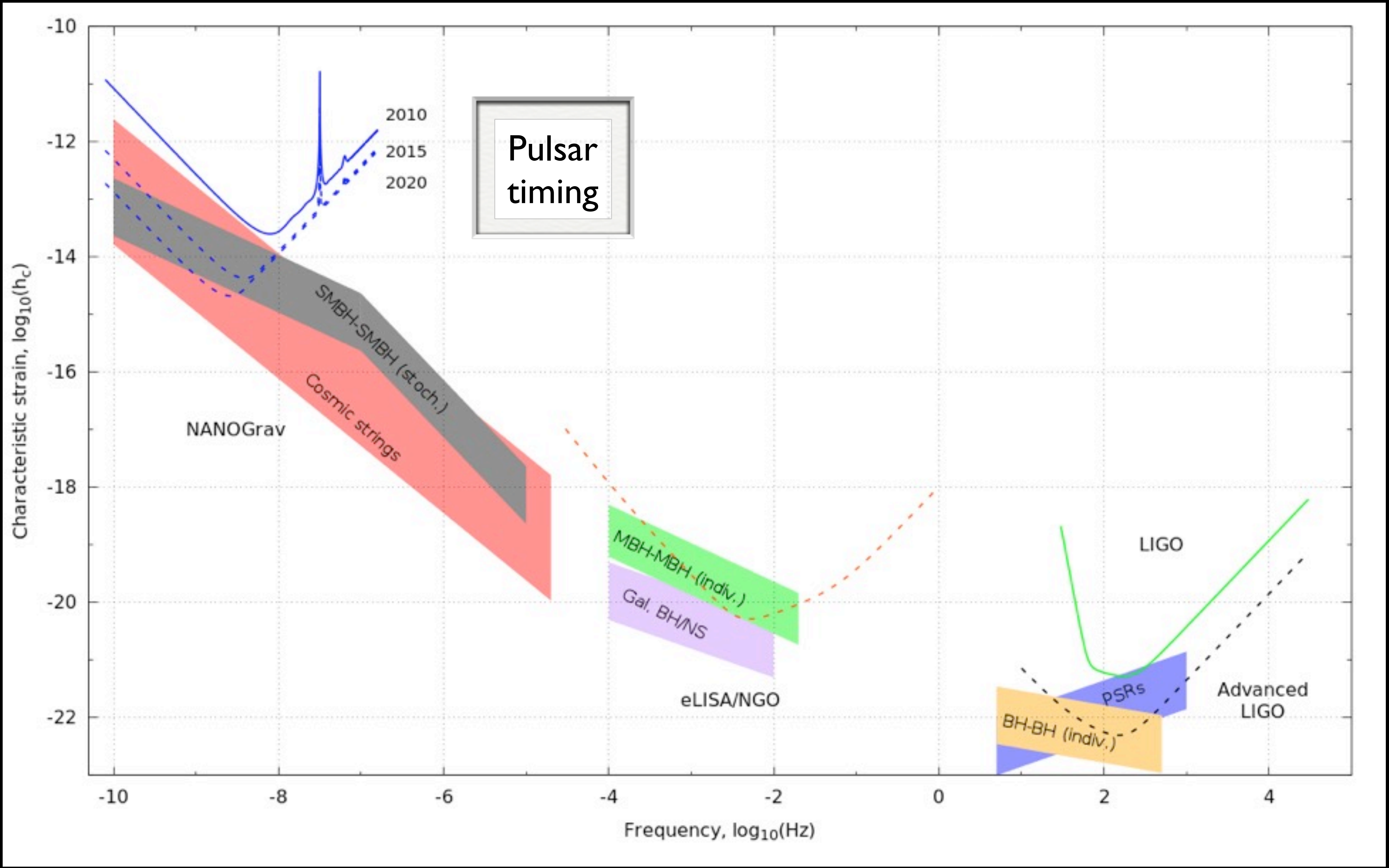
F = ma = GmM/r^2 ???

DETECTING GRAVITATIONAL RADIATION



Credit: D. Backer

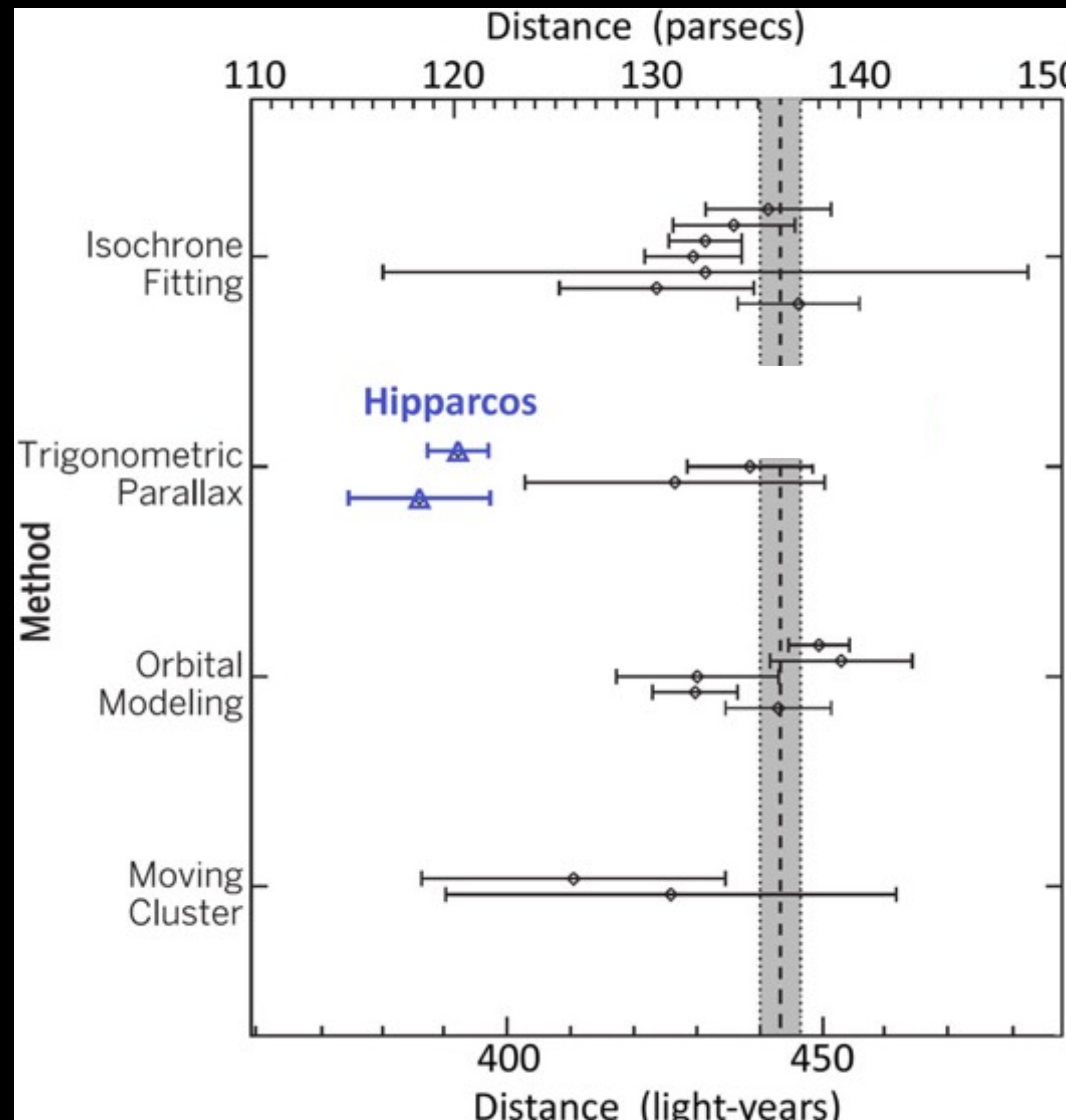
Predicted Power in Gravitational Radiation



see Arzoumanian et al (2015) arXiv: 150803024A

A VLBI Resolution of the Pleiades distance controversy

Melis et al. (2014)



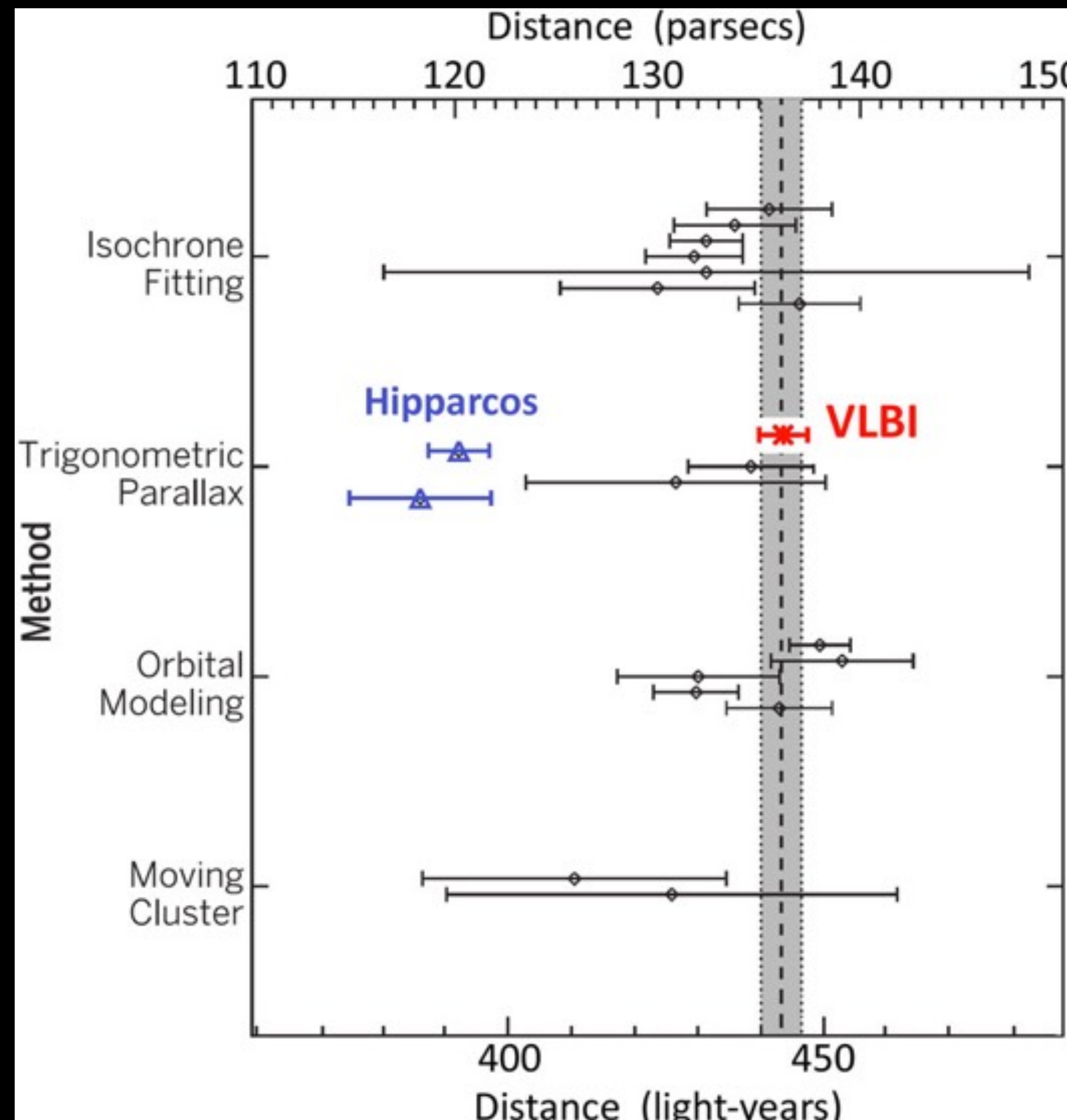
VLBA + GBT + Effelsberg + Arecibo

errors < 0.0001″

134.8 ± 0.5 pc
138.4 ± 1.1 pc
135.5 ± 0.6 pc
136.6 ± 0.6 pc
errors < 1%

A VLBI Resolution of the Pleiades distance controversy

Melis et al. (2014)



Megamaser cosmology project

Braatz, Kuo et al.

Discovered by the GBT
Monitored by the GBT
Imaged by the VLBA + GBT

A digression on the sensitivity of radio telescopes

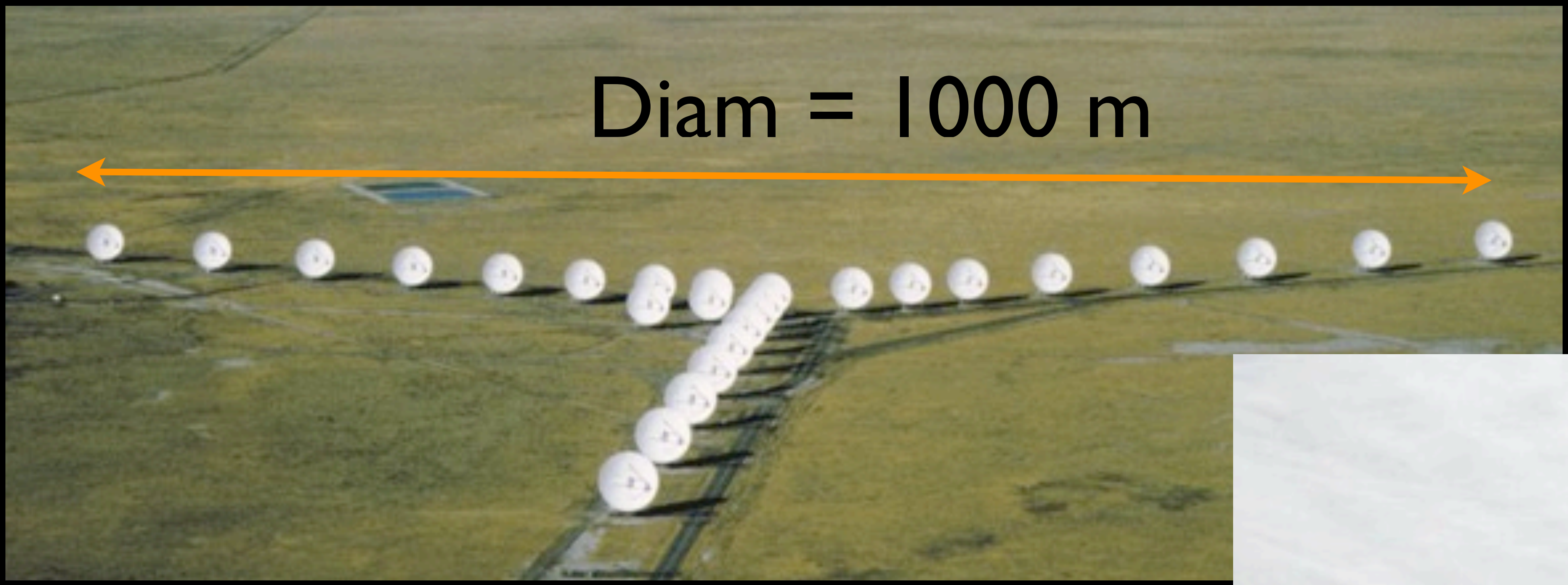
point source

$$t \propto \frac{1}{A_e^2}$$

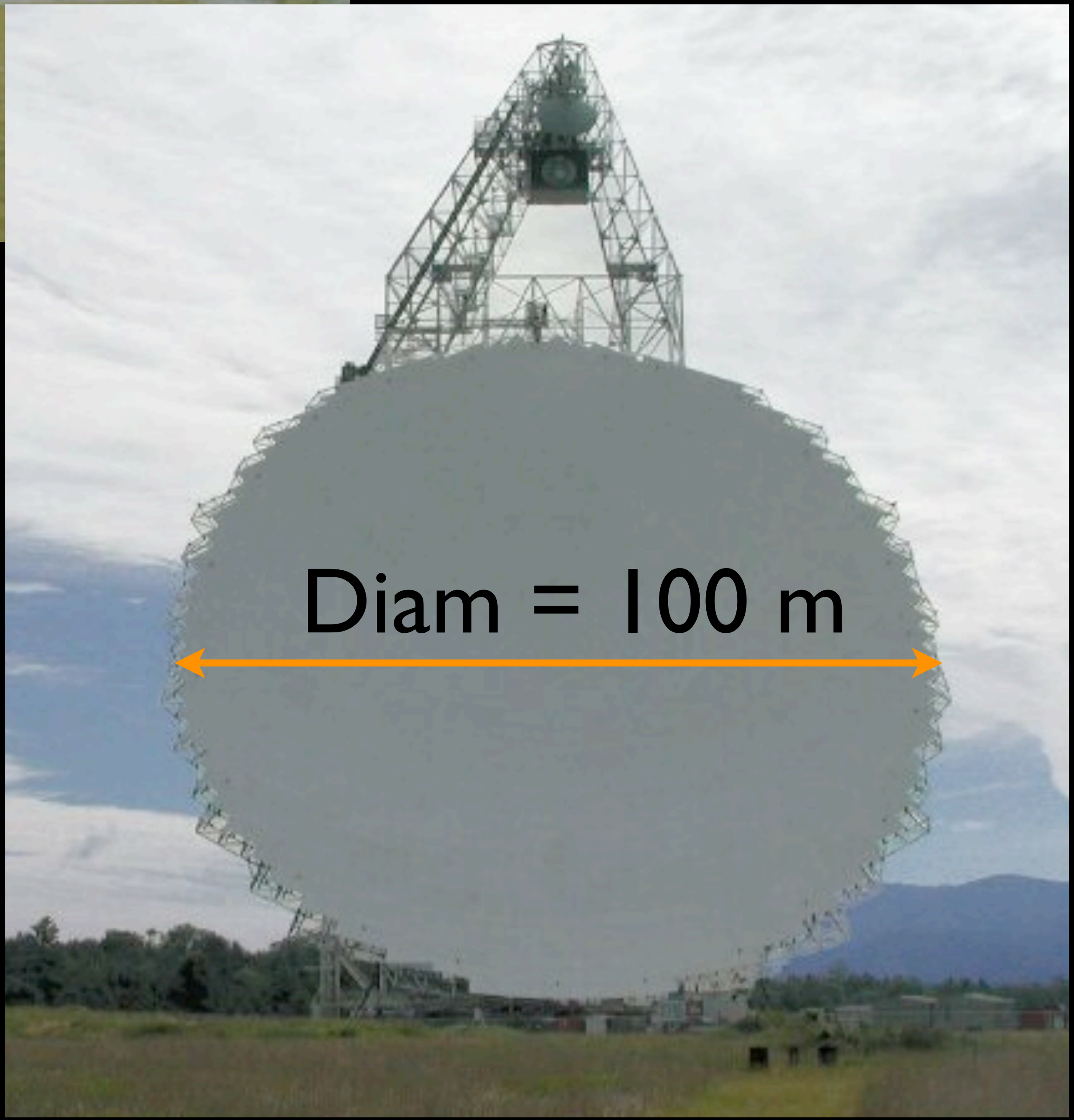
extended source

$$t \propto f^2 \propto \frac{Diam^4}{A_e^2}$$

A digression on the sensitivity of radio telescopes



$$t \;\propto f^2 \propto \frac{Diam^4}{A_e^2}$$



A digression on the sensitivity of radio telescopes

Instrument	f^2	21cm HPBW
GBT	1	9.1’
Arecibo	1	3.2’
VLA-D	$\sim 10^4$	46”
VLA-C	$\sim 10^6$	14”
VLA-B	$\sim 10^8$	4.3”
ASKAP	$\sim 10^6$	

$$t \propto f^2 \propto \frac{Diam^4}{A_e^2}$$

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For a given collecting area, the brightness sensitivity is always greatest for a filled aperture

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A digression on the sensitivity of radio telescopes

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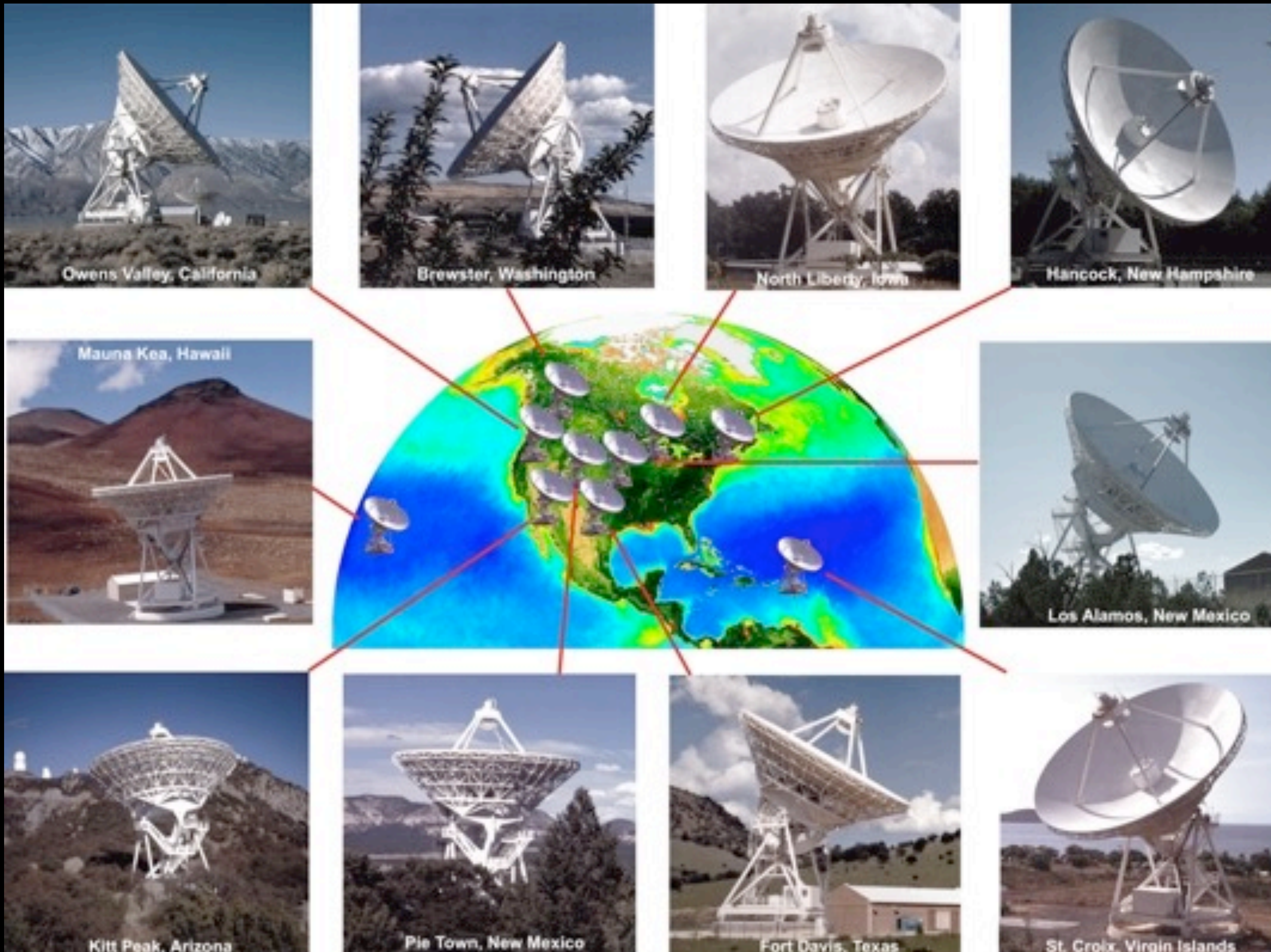
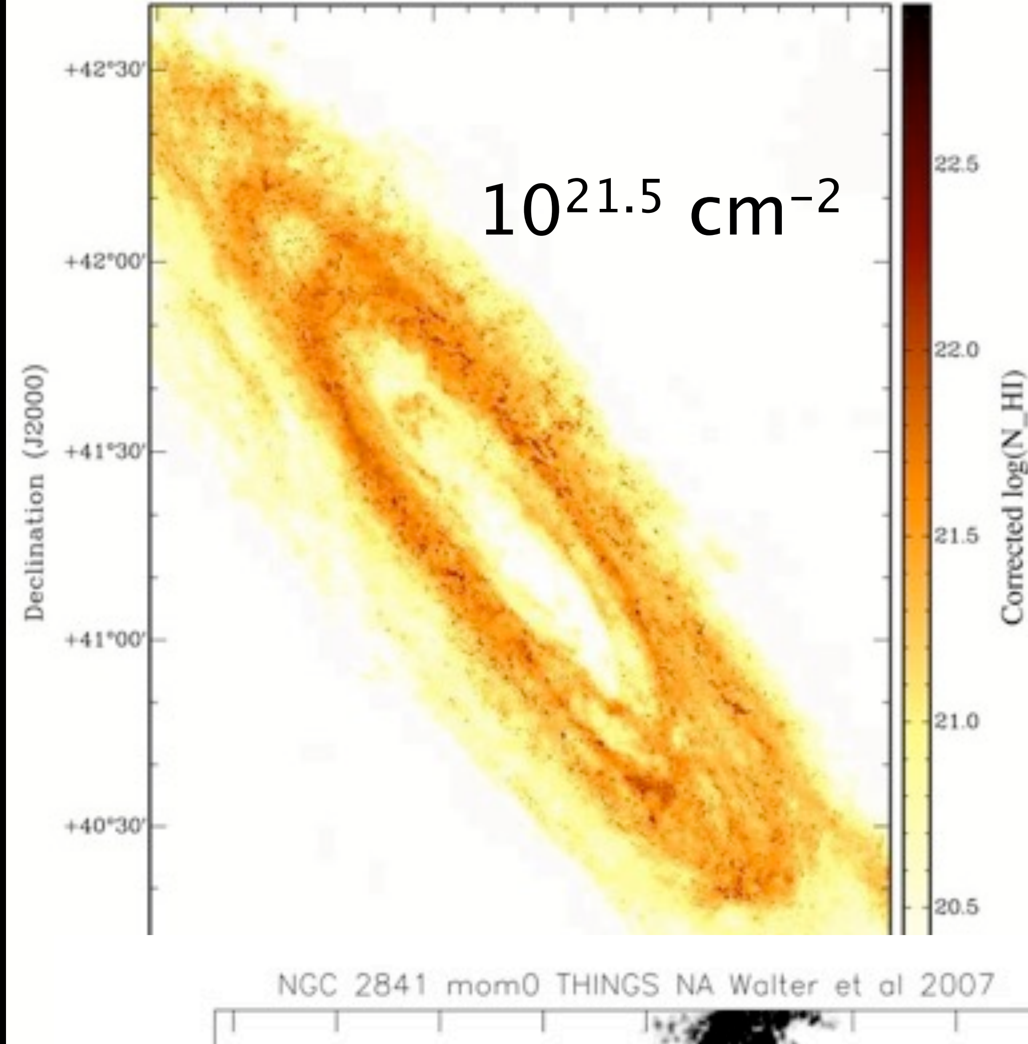
VLA-B	10^8	4.3”

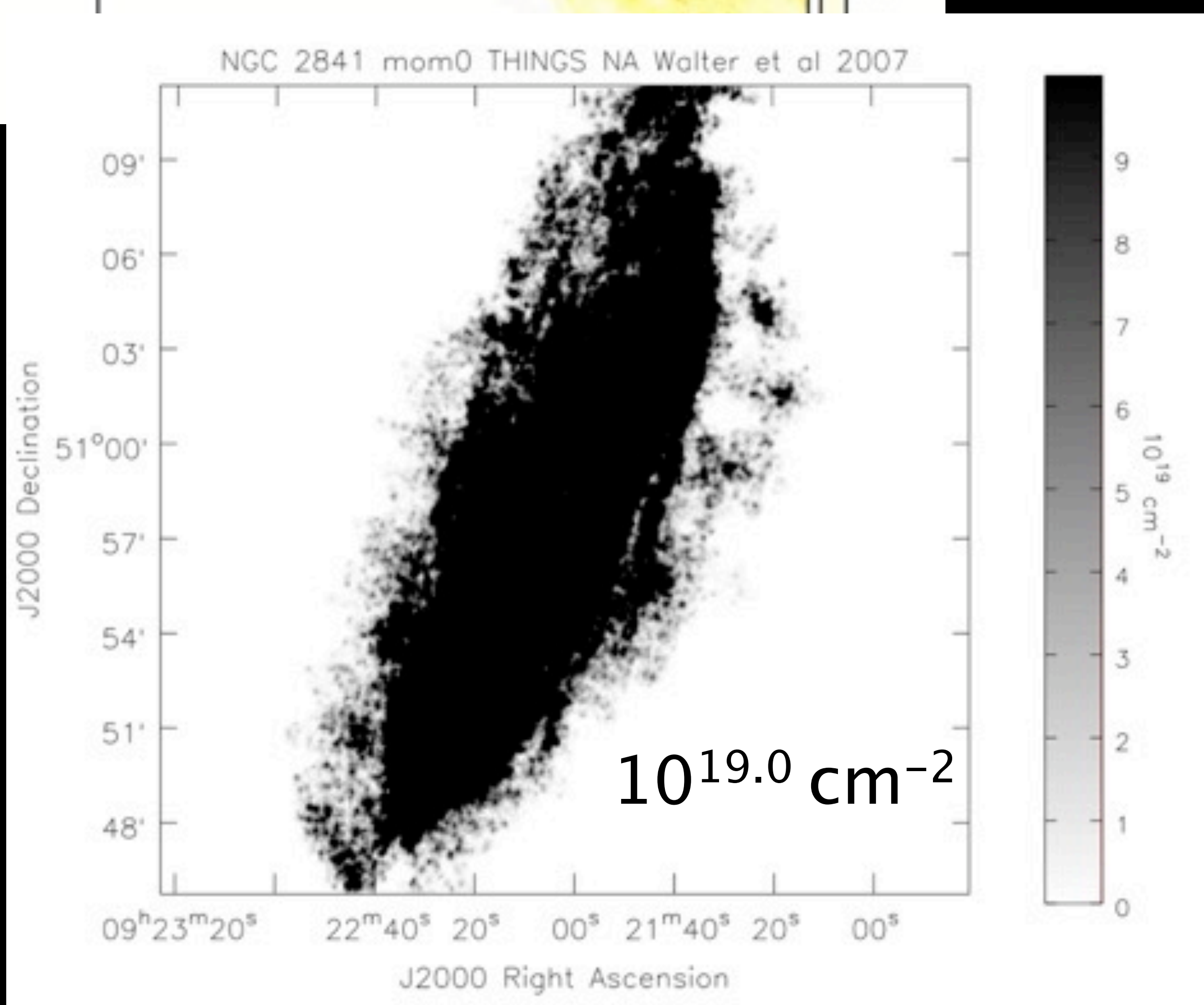
For a given collecting area, the brightness sensitivity is always greatest for a filled aperture

This is not related to the issue of missing short spacings

VLBA Limited to $T_b > 10^5$ K







THINGS VLA Survey

Walter et al. 2008

30″ $3\sigma = 10^{19.5}$ cm^{-2}

6″ $3\sigma = 10^{20.5}$ cm^{-2}

HALOGAS WSRT Survey

Heald et al. 2011

15″ to N_{HI} limit $\sim 10^{19.0}$

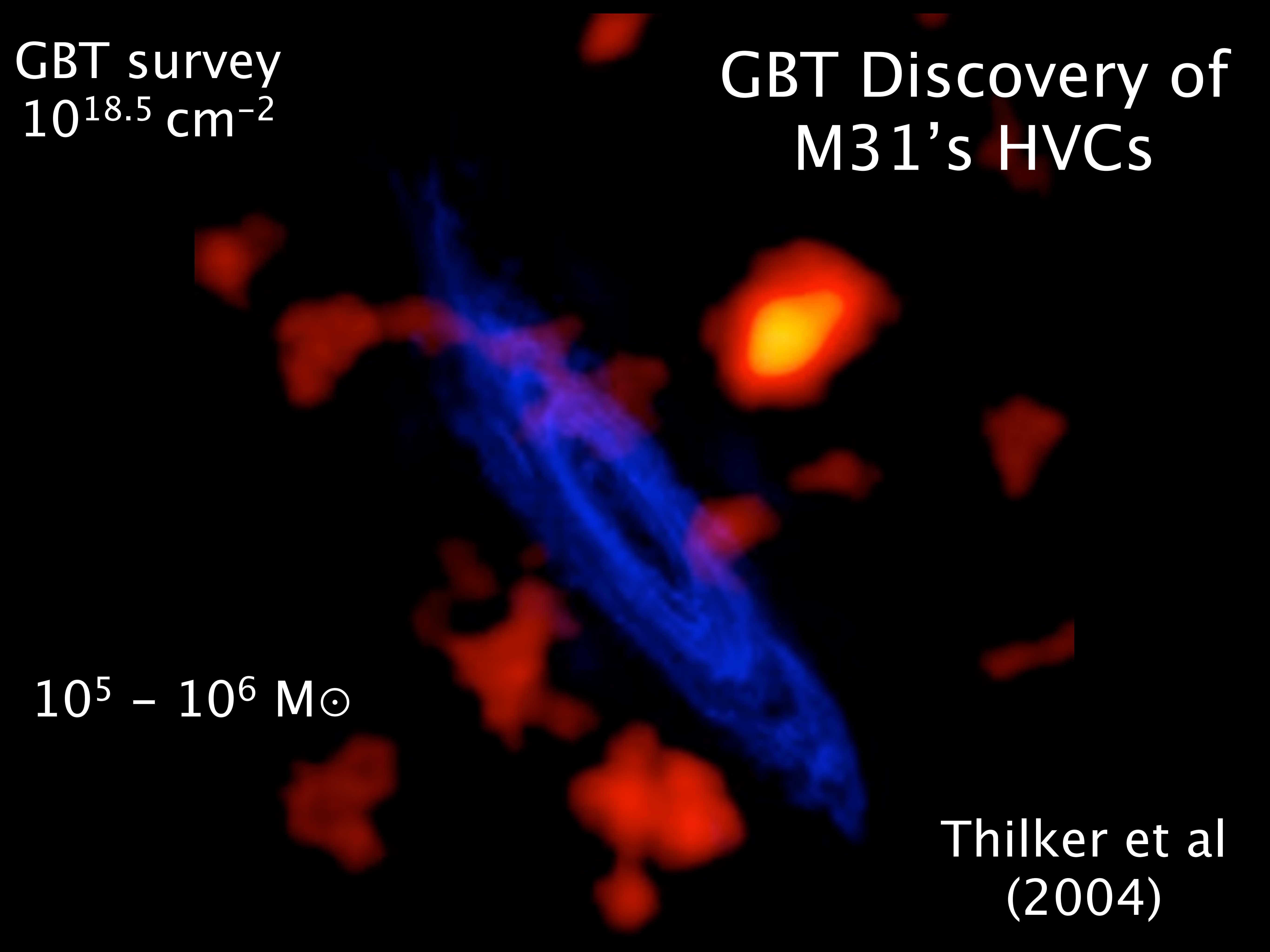
120 hours per galaxy

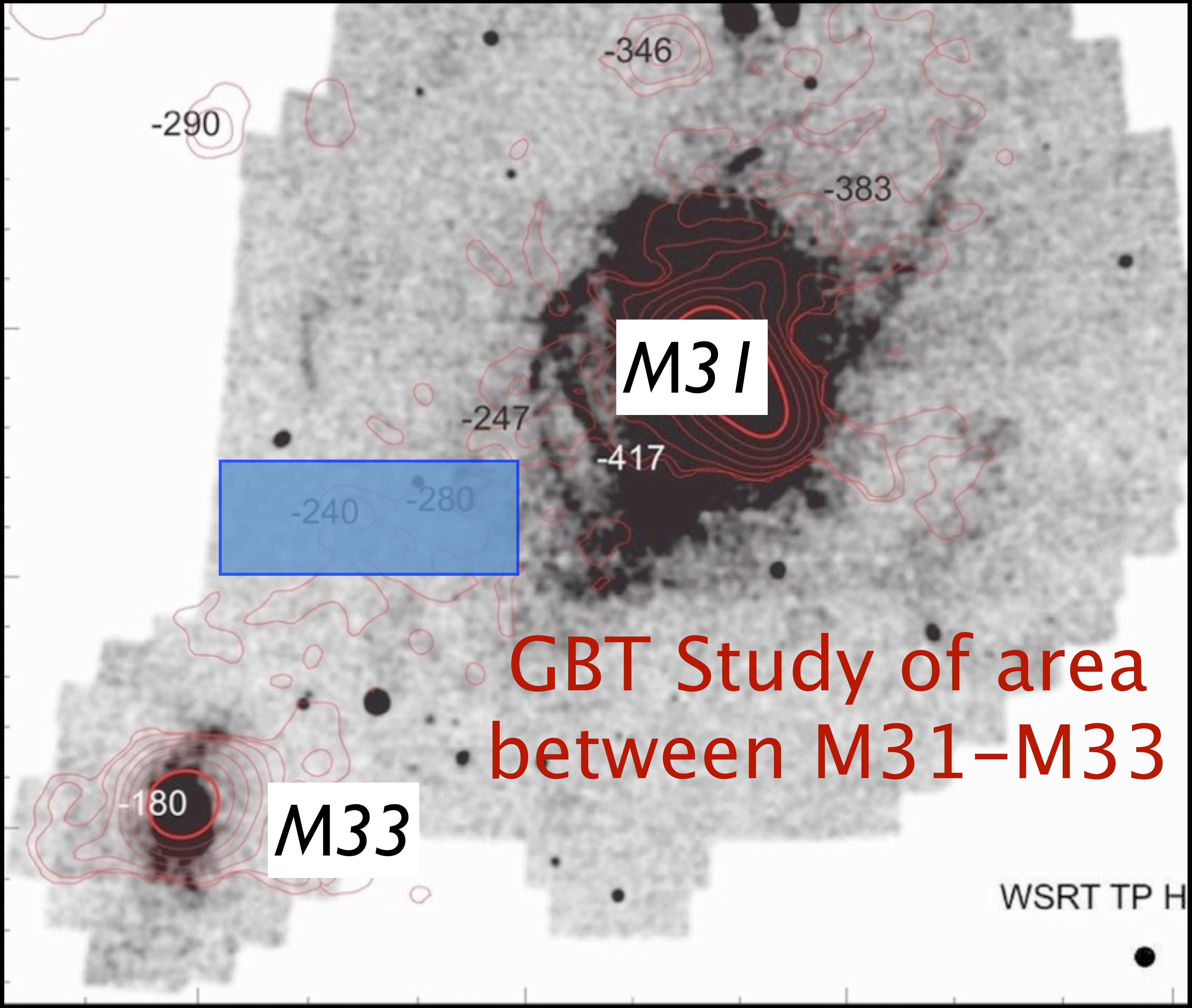
The GBT can detect the very low surface-brightness Universe

No Hydrogen in the Milky Way's Dwarf Galaxies

Galaxy	L ($L_\odot$)	M_{HI} ($M_\odot$)
Segue I	340	<11
UMa II	41,000	<74
Bootes II	1,000	<38
Coma Ber	3,700	<62
Ursa Mi	280,000	<63
Draco	280,000	<133
Spitzer Cloud		400
Hydra II		<200*

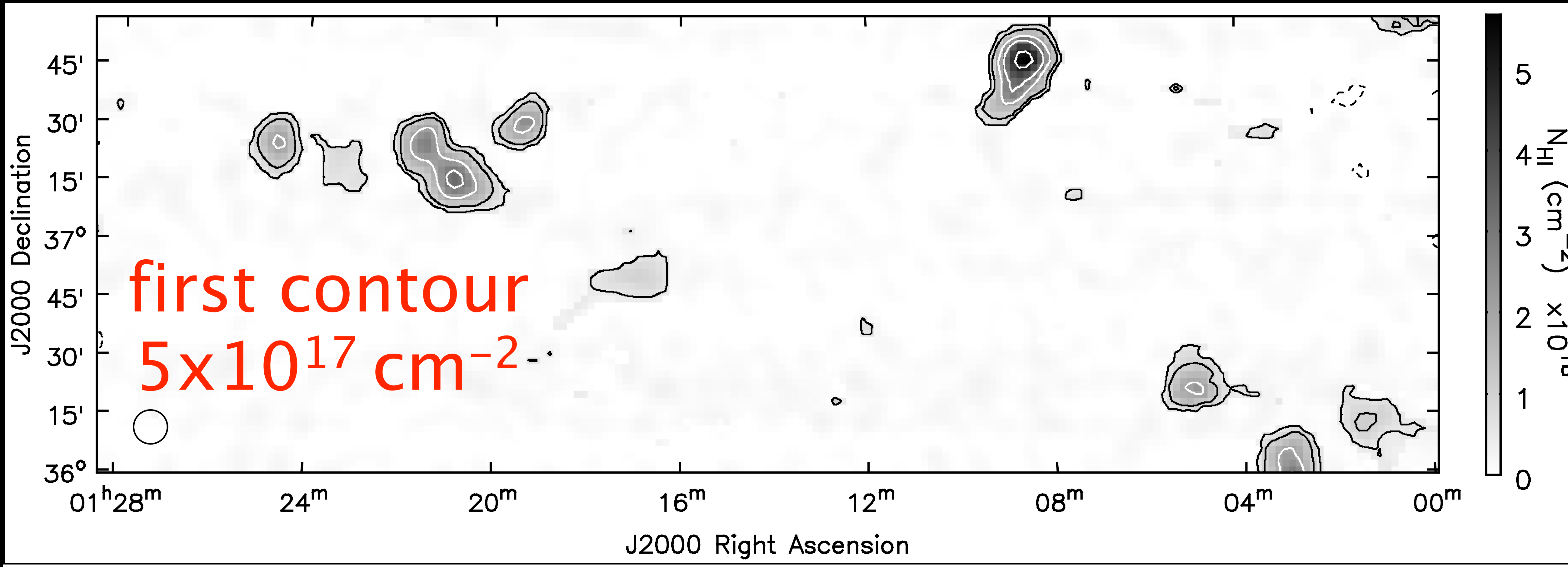
GBT results from Spekkens et al. 2014

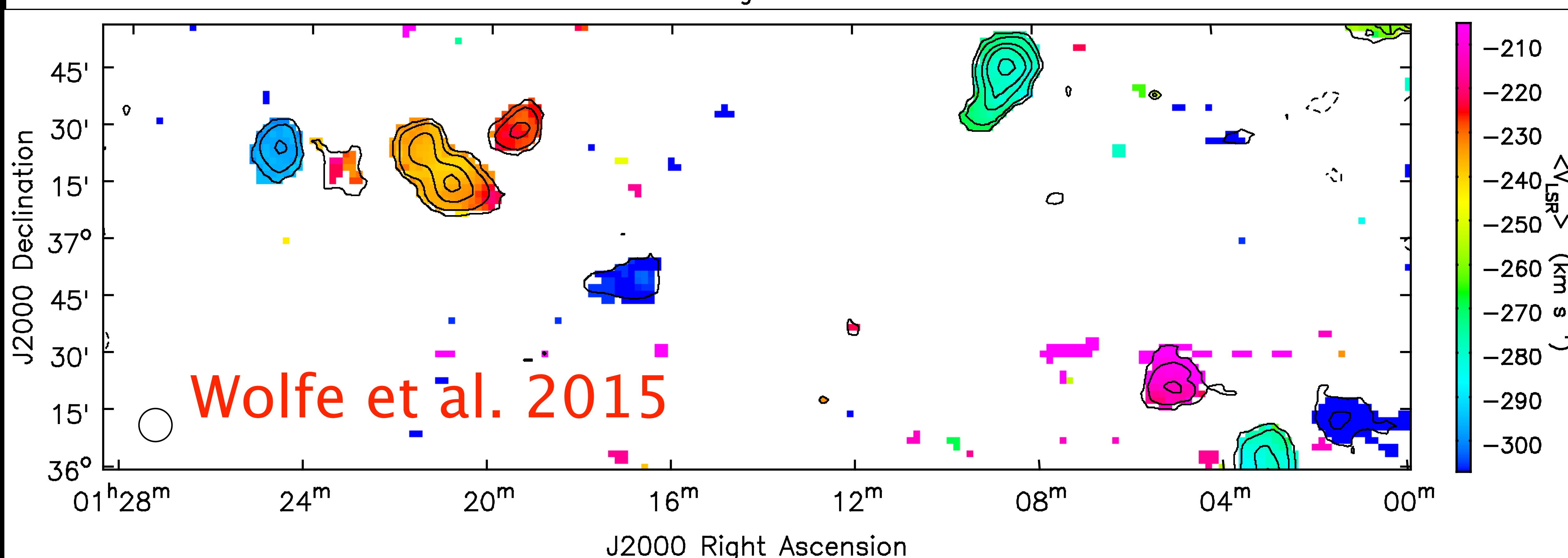

GBT survey
$10^{18.5}$ cm^{-2}
GBT Discovery of M31's HVCs
10^5 – 10^6 M$\odot$
Thilker et al (2004)



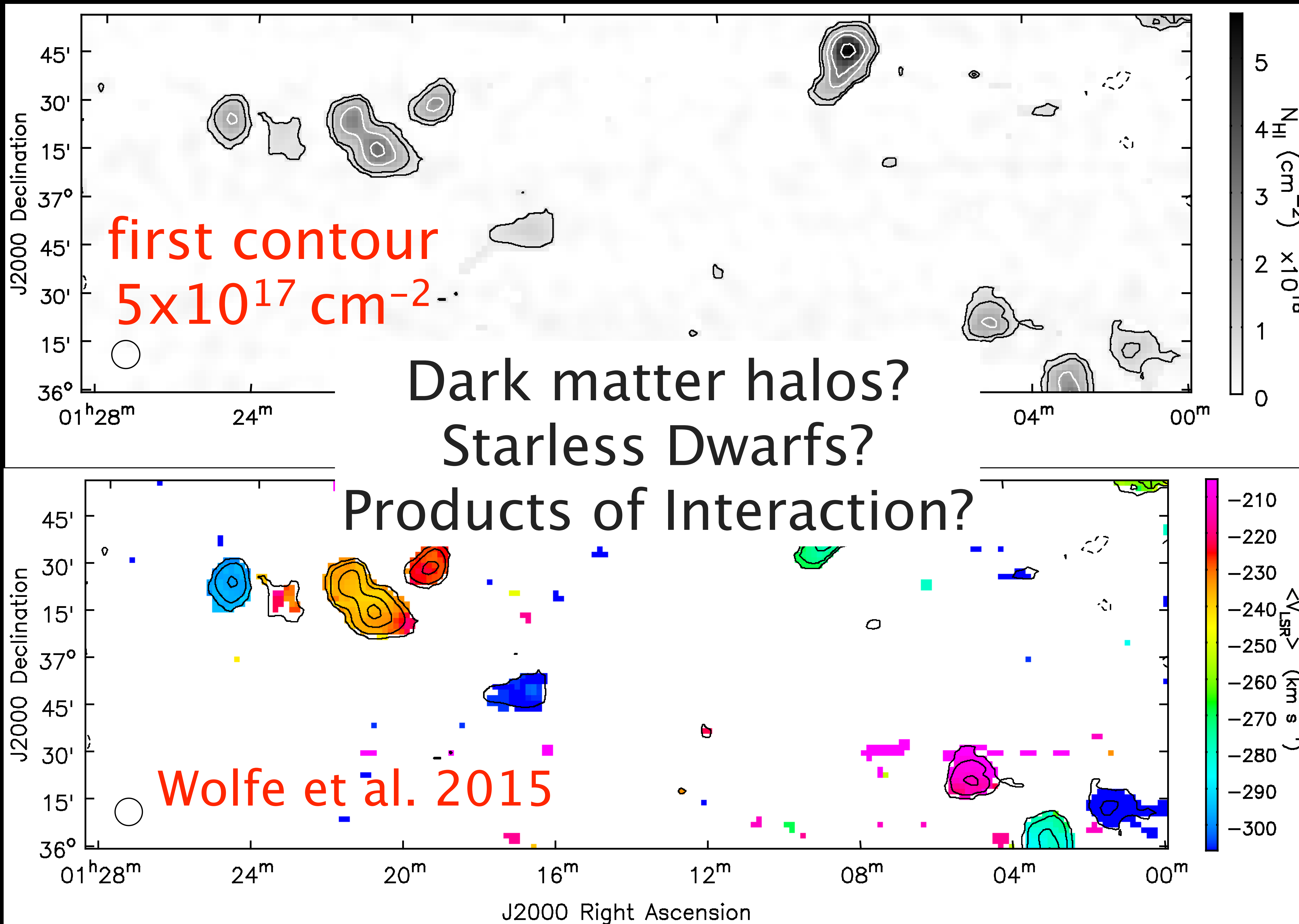
-346
-290
-383
M31
-247
-417
-240
-280
GBT Study of area between M31–M33
-180
M33
WSRT TP H

M31-M33 Clouds





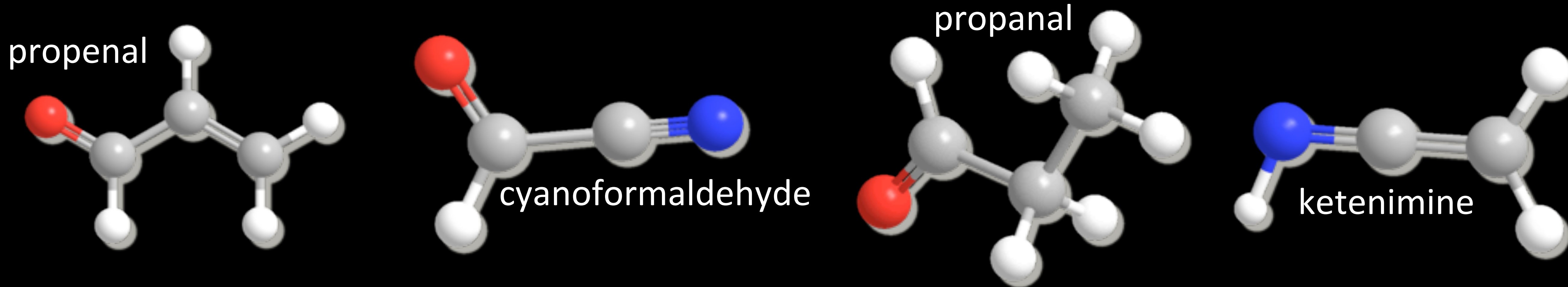
M31-M33 Clouds



GBT Science at High Frequencies

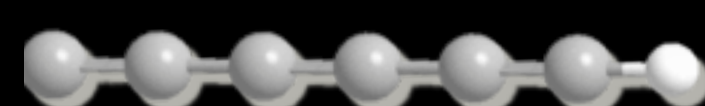
A very brief introduction
to the rest of the Workshop

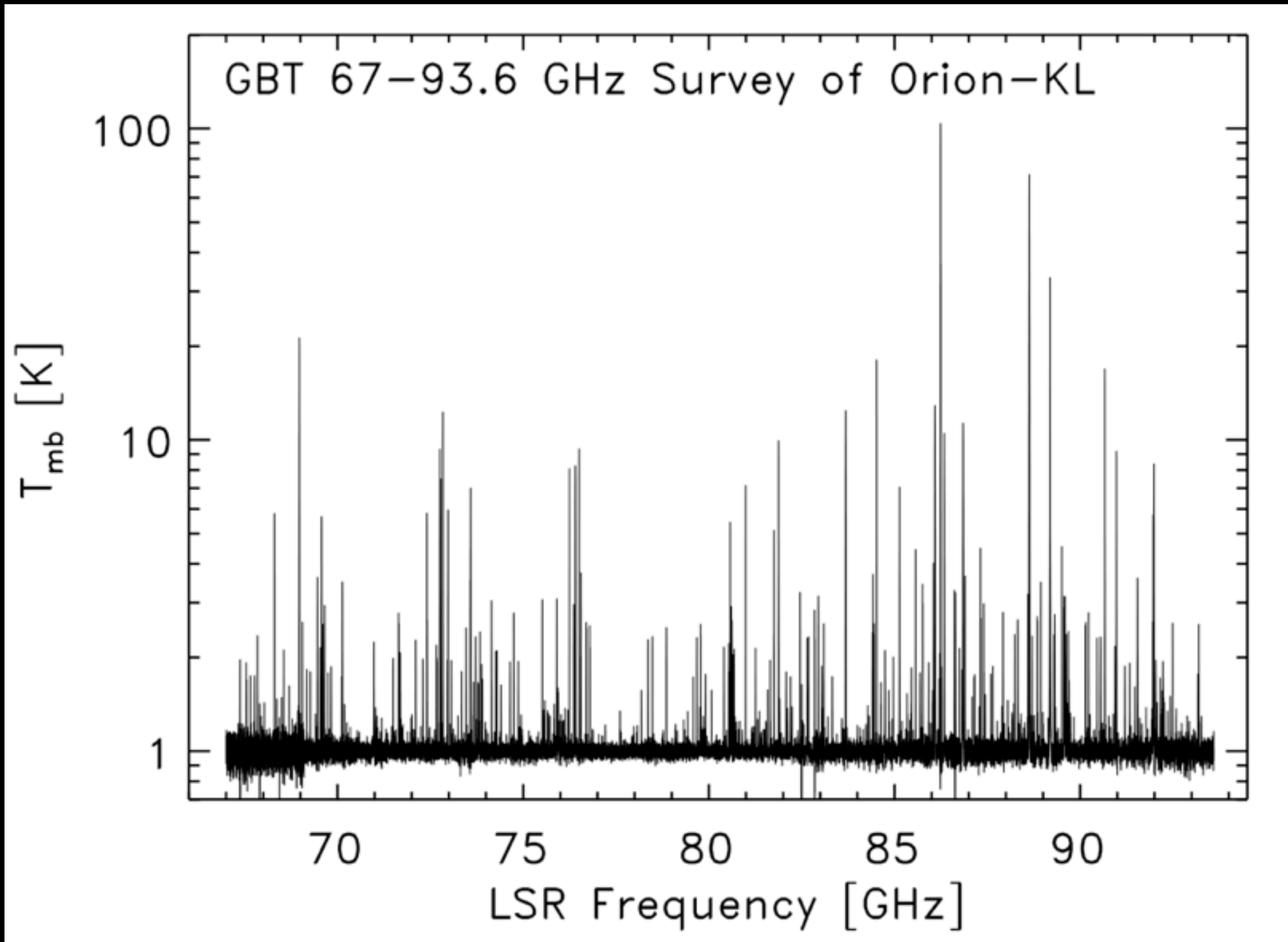
The Chemistry of Interstellar Space



Some (of the 17+) New GBT Molecule Detections

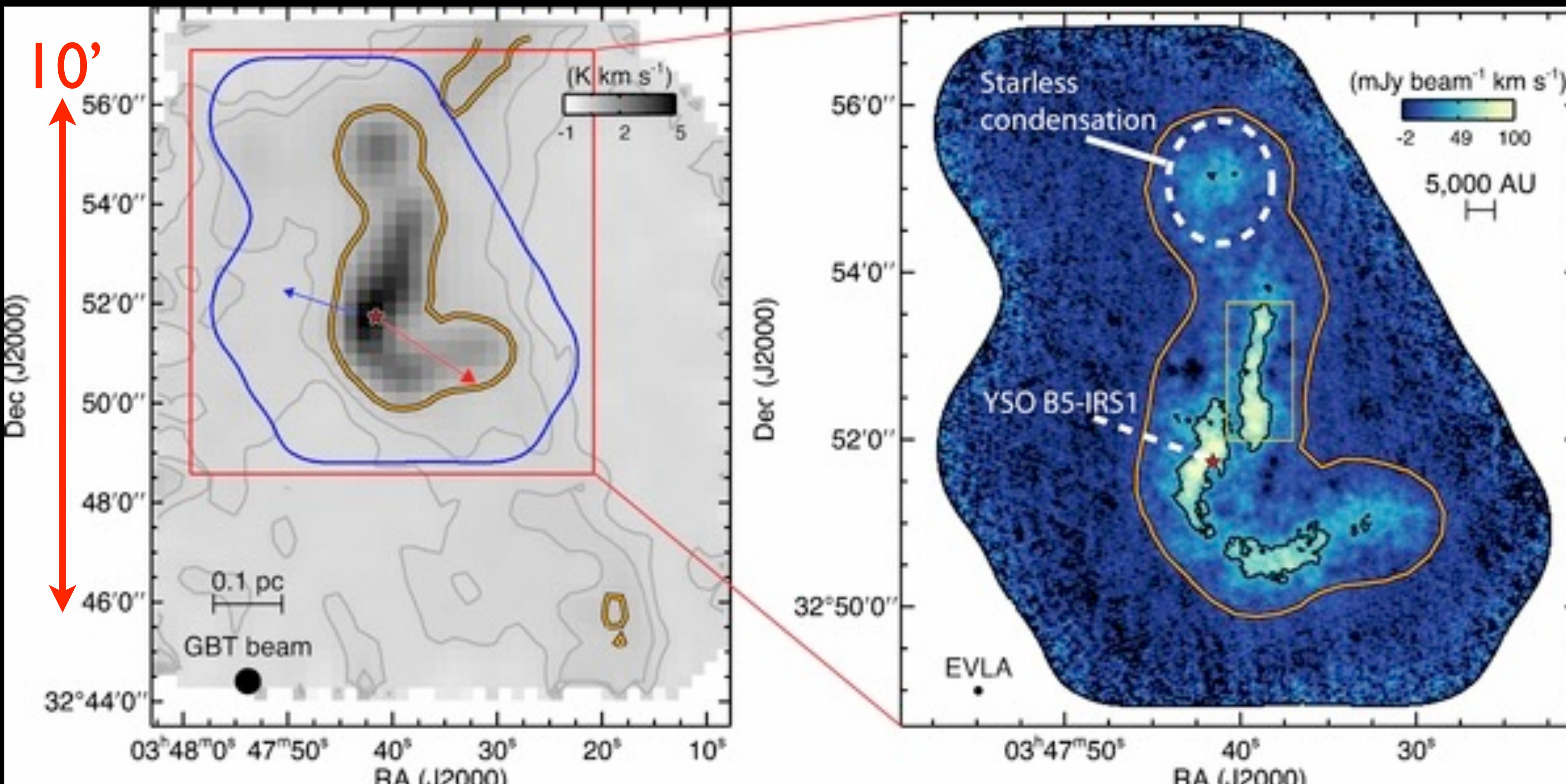
C_6H^-





Frayer et al. 2015

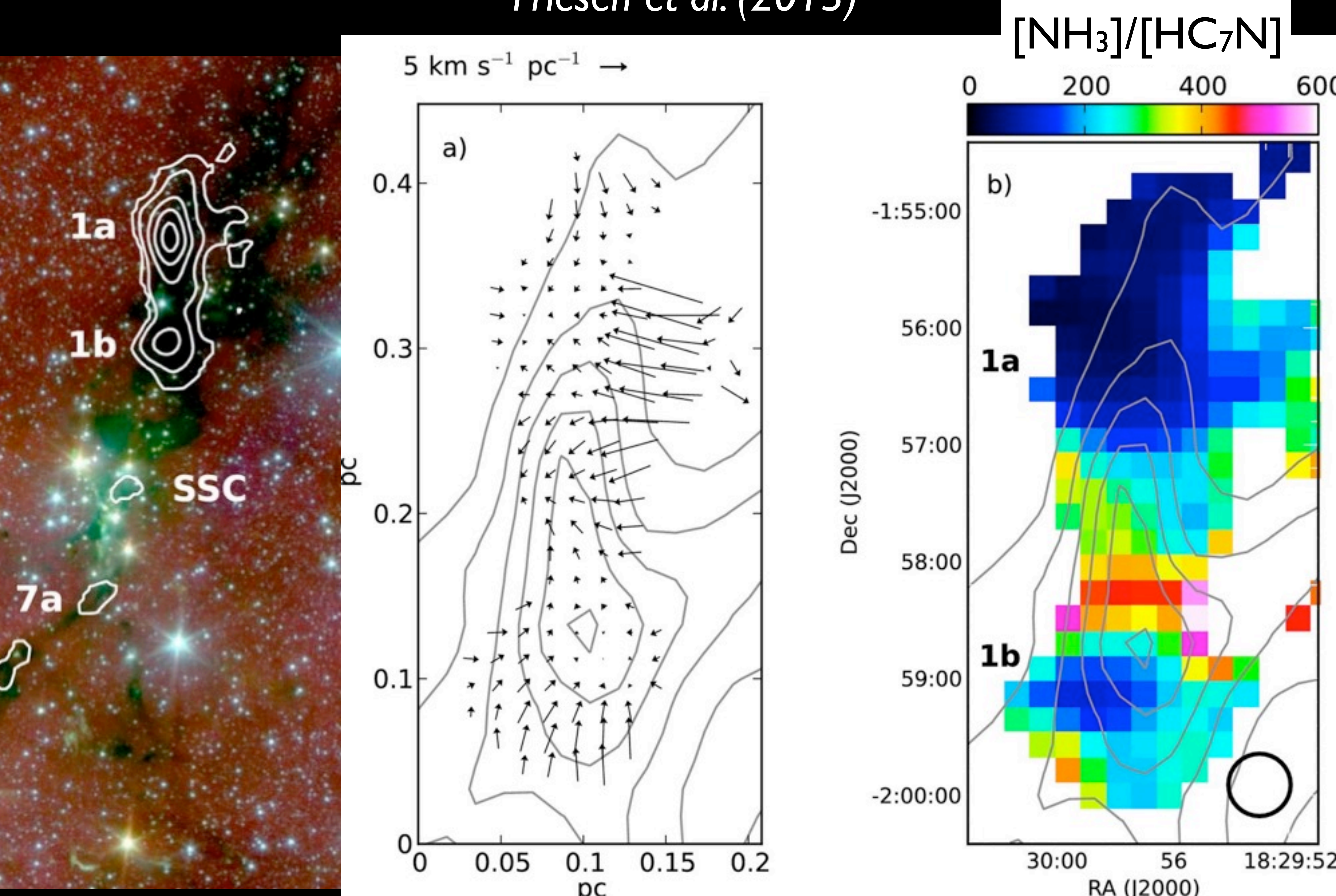
GBT map of NH_3 VLA map of NH_3



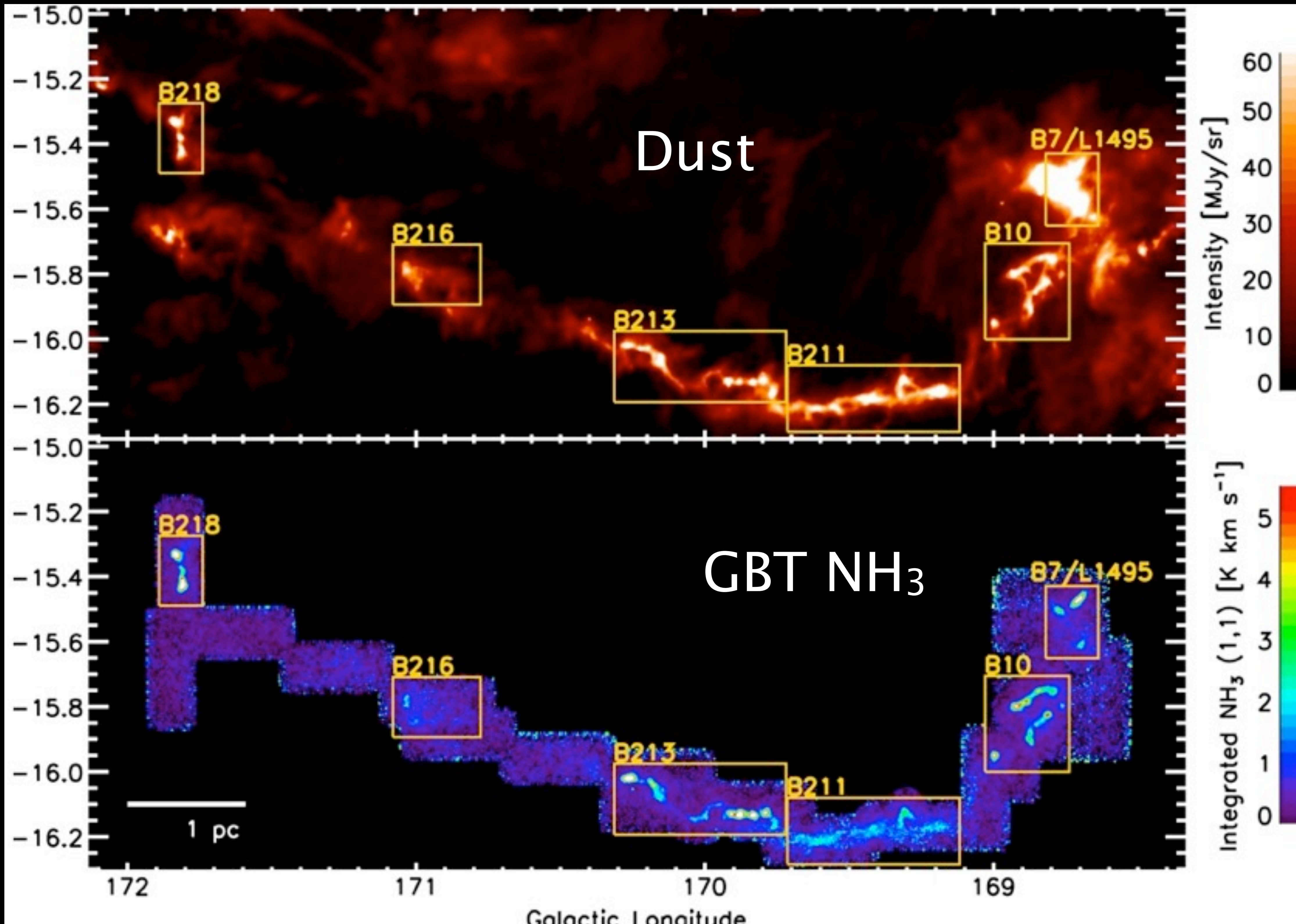
Pineda et al. 2011

HC_7N: A Chemical "Clock" in a Molecular Cloud?

Friesen et al. (2013)



Star Formation in a Filament in Taurus



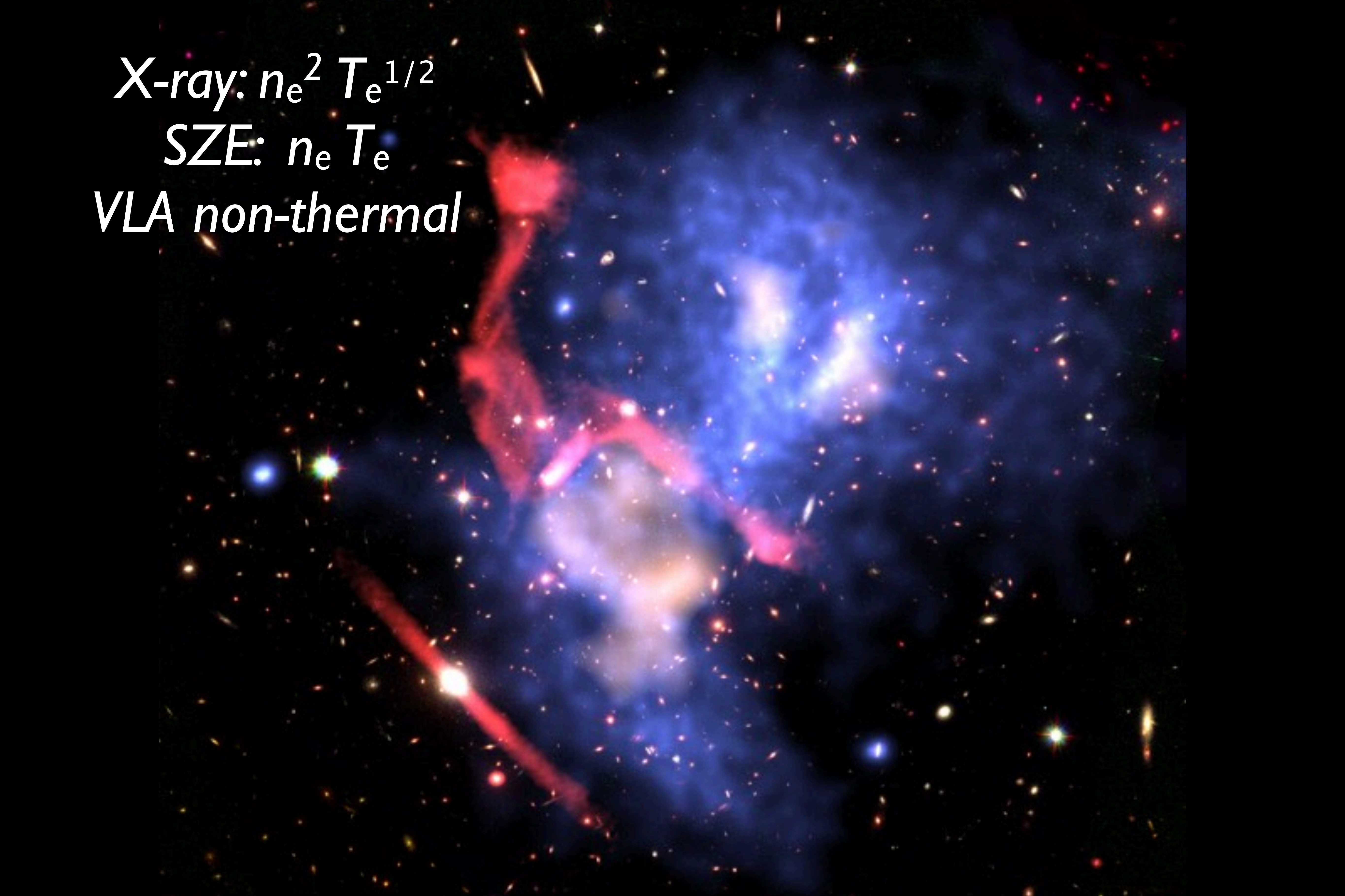
Seo et al. 2015 ApJ 805, 185

GBT detection of mm-cm sized “dust” in star-forming clouds

MUSTANG
Bolometer Array
3.3mm
81–96 GHz

Schnee et al. (2014)

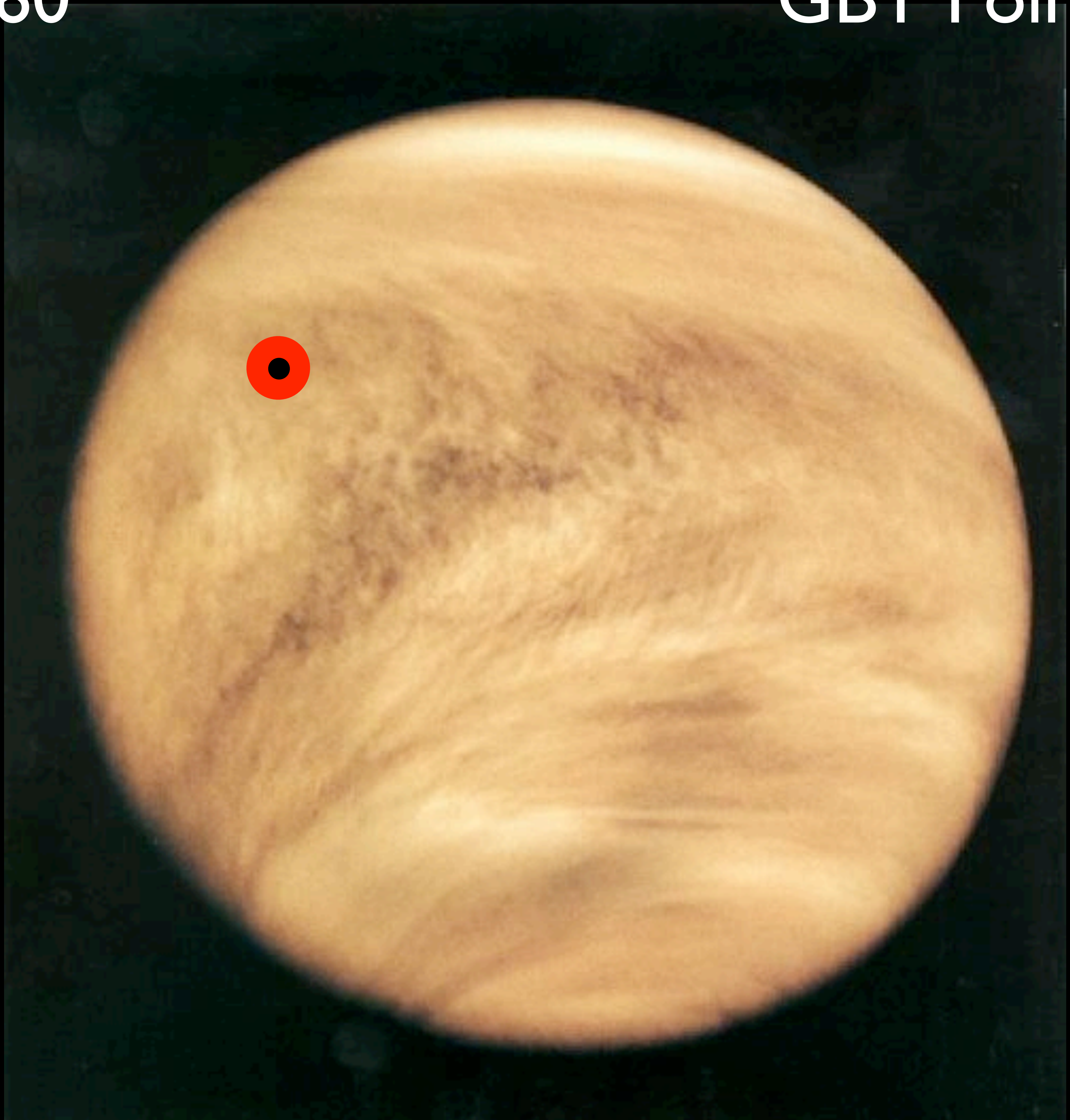
GBT High-Resolution 3mm SZE in a Cluster




GBT Pointing
σ≈2″

Venus 60”

GBT Pointing 2”



The GBT

Powerful

Flexible

Accessible to the U.S Community

The GBT in 2016+

Potential Cameras

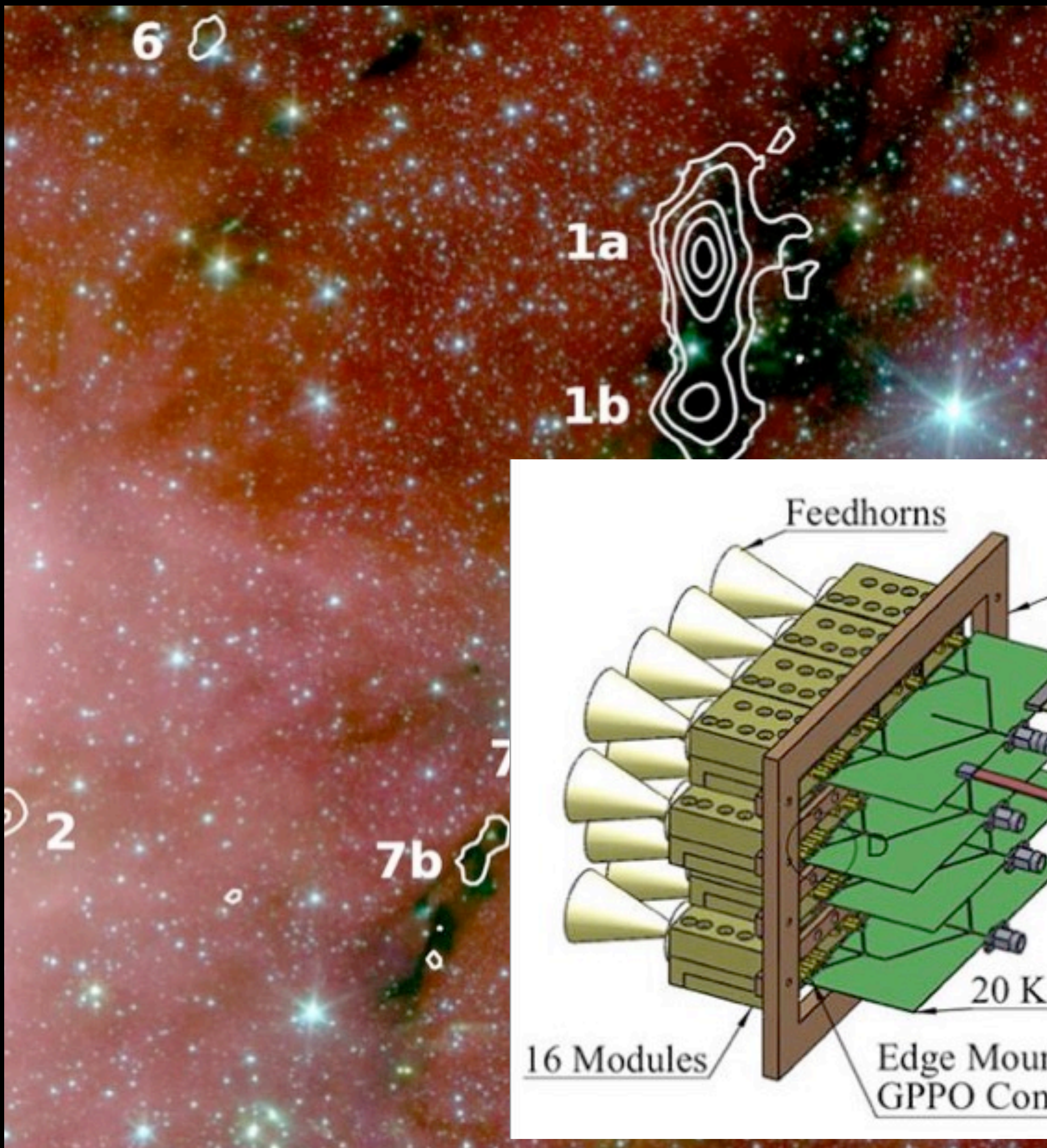
The GBT in 2016+

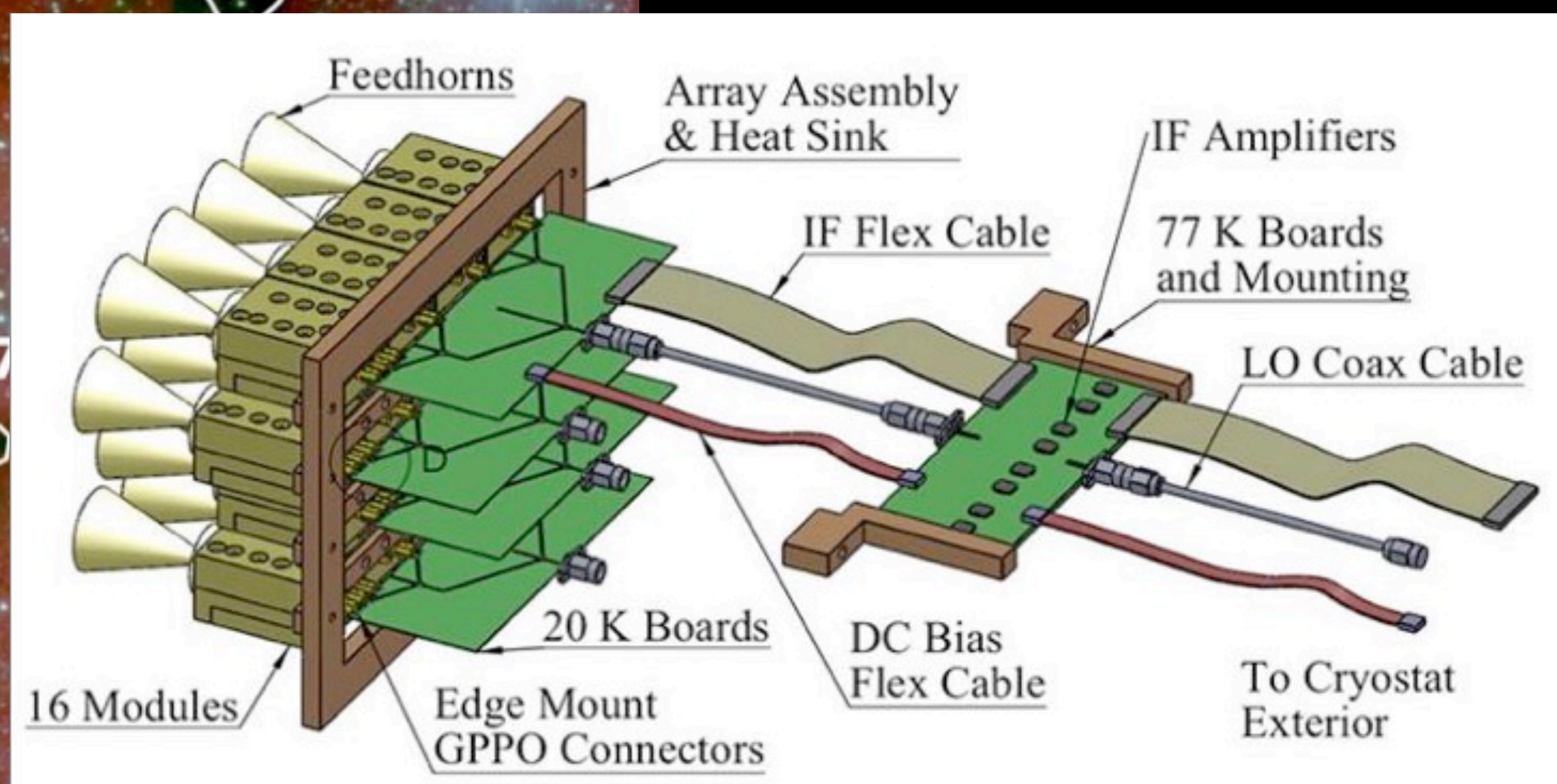
Potential Cameras

Freq	Feed horns	Footprint	HPBW	Highest Coma
22	91	15.8'	35"	-20dB
46	500	18.1'	16"	-15dB
90	800	12.0'	8.3"	-15dB

ARGUS -- 8″ GBT spectroscopy at 3mm

- 16 element scalable 75-115 GHz FPA
- Stanford/CIT-JPL/UMd/ Miami/NRAO
  (NSF grant to Stanford)



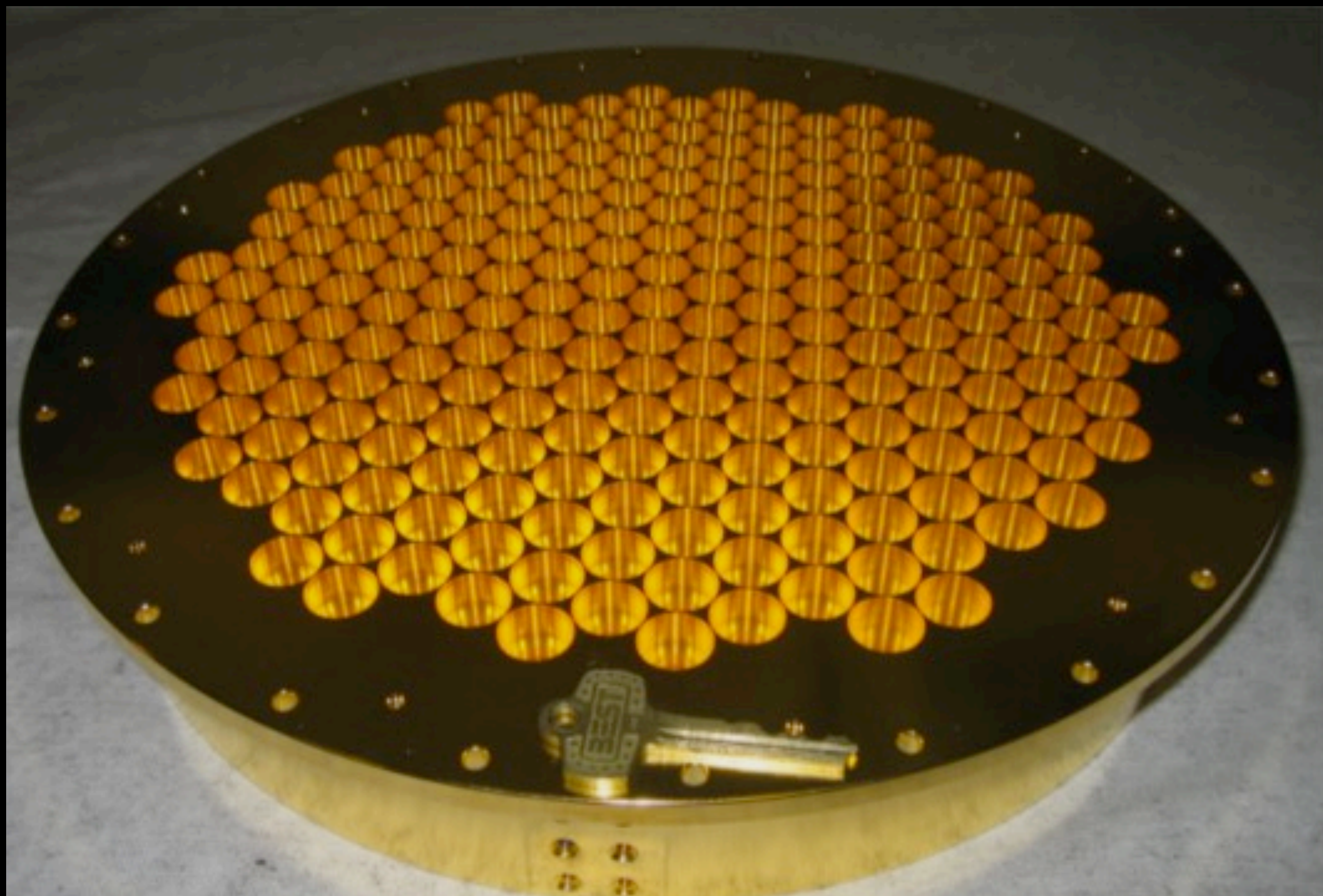


GBT and ALMA at 86 GHz
Mapping a 100 km/s line over a 3’x3’ field

RMS noise	GBT 9” 16 pixel	GBT 9” 100 pixel	ALMA 1” 50x12m	ALMA 5” 50X12m	ACA 23” 12X7m	ALMA-TP 70” 4X12m
1 mJy / beam	2 hr	21 min	1 hr	1 hr	800 hr	600 hr
2 mK / beam	2 hr	21 min	6000 hr	9 hr	17 hr	9 min

ARGUS

GBT MUSTANG - 2 *(NSF grant to Univ Penn)*



223 pixels

>4' FOV

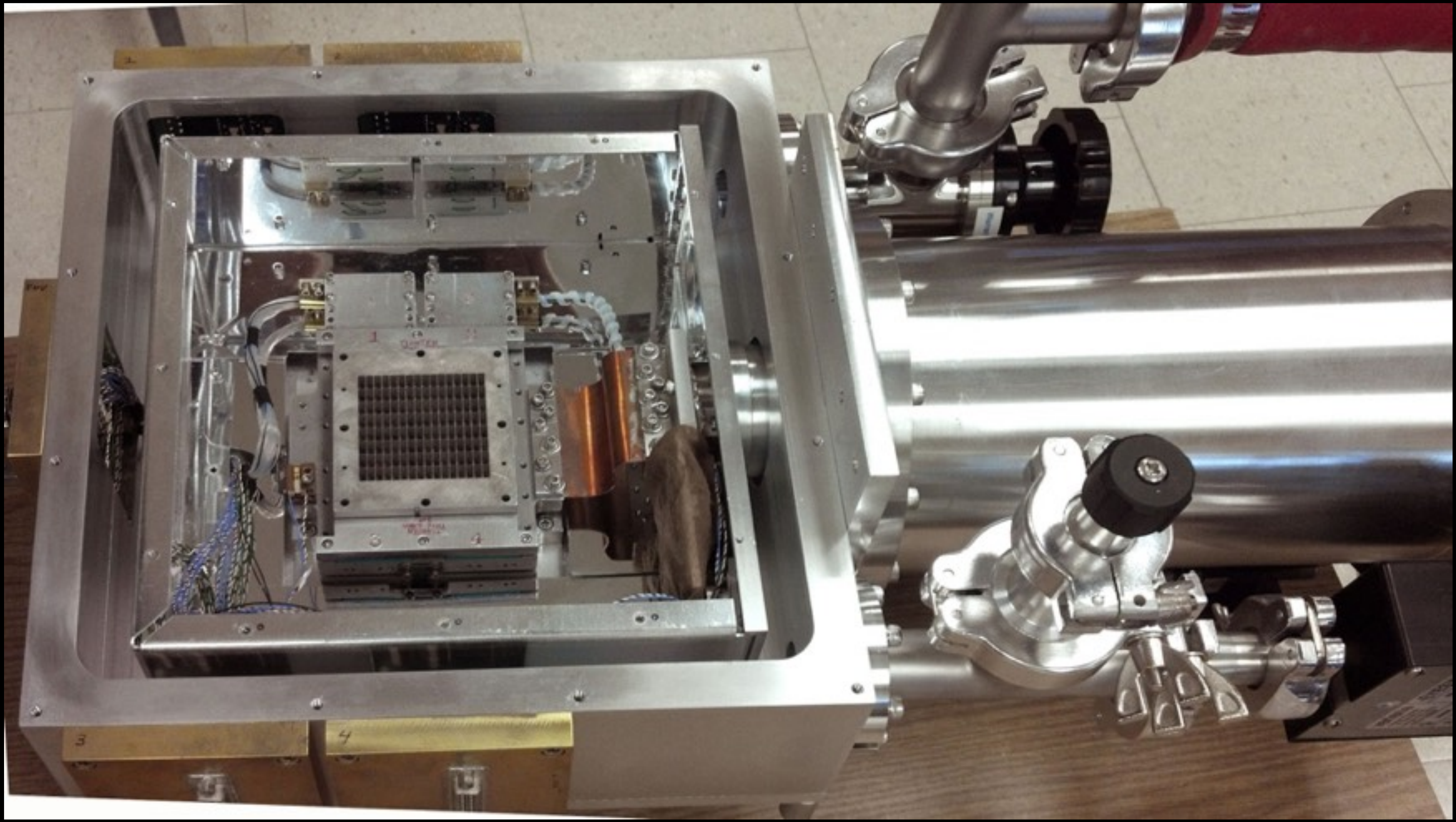
35x faster than MUSTANG

FLAG 21cm *(NSF grant to BYU,WVU)*

The wave of the future

(NSF grant to UMass)

Scalable 75-115 GHz PAF




The GBT in 2016+?