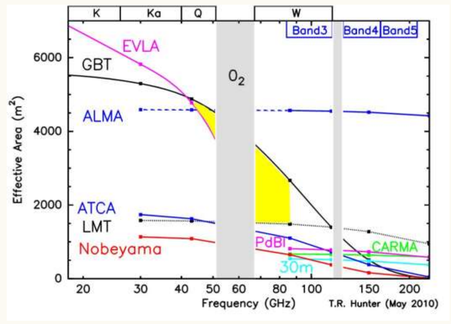
GBT 3mm Observations in the ALMA-Era

David Frayer, Brian Mason, Amanda Kepley, Scott Schnee, & Ron Maddalena
(National Radio Astronomy Observatory)

Summary

We discuss the current capabilities and instrumentation under development covering the 3mm atmospheric window from 67-115.3 GHz for the Robert C. Byrd Green Bank Telescope (GBT). The current GBT 4mm receiver operates from 67 GHz to 93 GHz and has comparable sensitivity to ALMA Cycle-1 at 84-90 GHz. Within the 3mm window below 84 GHz (ALMA has no frequency coverage below 84 GHz), no facility in the world comes close to matching the GBT sensitivity. The development of 3mm multi-pixel cameras such as Argus and Mustang will greatly improve the spectral-line and continuum mapping capabilities of the GBT. Although ALMA will provide excellent sensitivity at sub-arcsec resolution over small areas, multi-pixel cameras on the GBT will greatly improve the available mapping speeds for large areas at 3mm. The GBT surveys will provide targets for detailed follow-up ALMA studies, and the GBT could provide sensitive short-spacing data for GBT+ALMA imaging.

Based on the 2012 portfolio review which was misguided and flawed in its understanding of radio facilities and techniques, the NSF is threatening to close the GBT. If you are interested in keeping the GBT open for astronomical research, voice your concerns to NSF and on the AUI web forum. The GBT is operated by the National Radio Astronomy Observatory and is currently a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.



The GBT has the largest effective collecting area of any telescope on earth operating from 40 –84 GHz (shown in yellow). The GBT is sensitive to extended emission unlike interferometers and can provide important short-spacing data for many VLA and ALMA programs

GBT vs ALMA Sensitivity: Estimated Observing Times

	GBT 1pixel	GBT/ARGUS 16pixel	GBT 100pixel	ALMA 1"	ALMA 5"	ACA (23")	ALMA-TP (70")
Rms=1mJy/beam per point	2.5min	2.5min	2.5min	1.2min	1.2min	5hr	3hr
Rms=2mK per point	2.5min	2.5min	2.5min	122hr	11min	6min	3s
Map 3'x3' with 1mJy/beam	18hr	69min	11min	59min	59min	80hr	27hr
Map 3'x3' with 2mK	18hr	69min	11min	6000hr	9hr	96min	27s

The table above shows the observation time needed to reach 1mJy/beam (point-source sensitivity) and 2mK (extended-source sensitivity) for a 100km/s spectral line at 89 GHz using the GBT (9" resolution) with a different number of W-FPA "pixels" compared with ALMA, ACA, and ALMA-total-power mode. The GBT+ARGUS provides similar mapping speeds as ALMA, and an 100 pixel W-FPA could map 3mm spectral-lines much faster than ALMA.

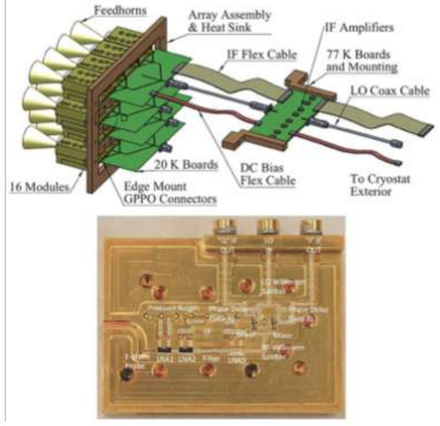
ARGUS

Argus 16 element scalable W-band FPA for the GBT

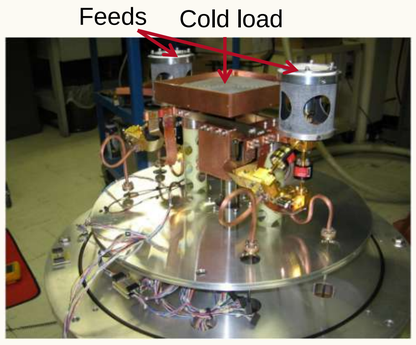
Argus is scheduled to be deployed at the GBT by November 2014 and is a collaboration between Stanford U. (PI Sarah Church), Caltech, JPL, Univ. Maryland, Univ. Miami, and NRAO.

Frequency operation range: 75-115.3 GHz

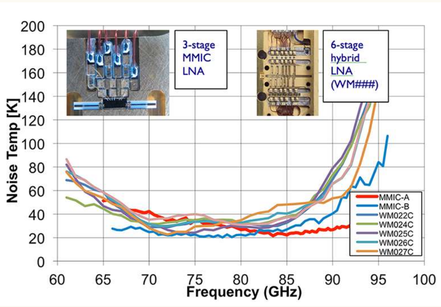
Tsys~75K

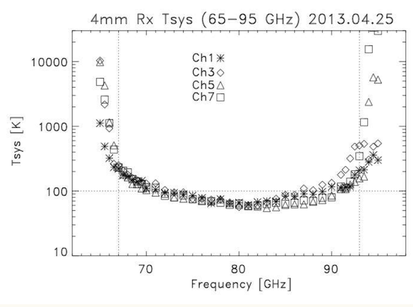


4mm Receiver

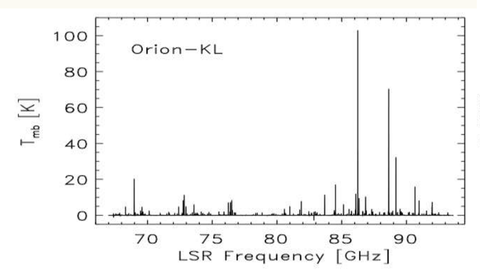


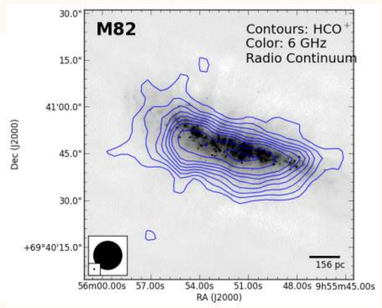
The GBT 4mm receiver is a dual feed, dual linear polarization receiver which operates from 67 – 93 GHz. The science drivers are primarily based on spectroscopic studies, but the receiver also includes a ¼ wave-plate to provide circular polarization for VLB observations.





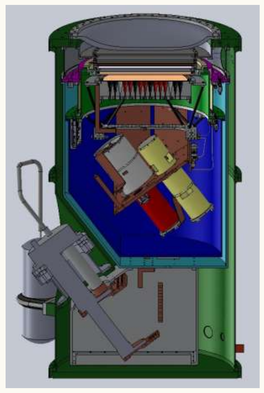
(Left) The performance of different cold amplifier designs measured in the lab. (Right) Recent system temperature measurements on the sky as a function of frequency for each of the 4 channels (2 polarizations and 2 beams, "ch1,3,5,7") shown as symbols for the new amplifiers.



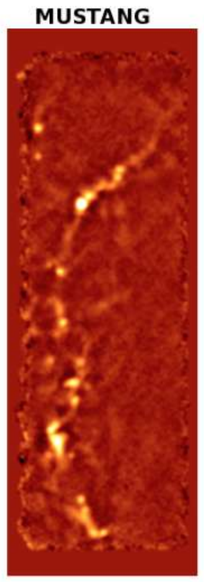


(Left) The GBT 4mm ORION-KL spectral-line survey (Frayer et al.) . (Right) Contours show GBT 4mm HCO+(1-0) map of M82 on top of a VLA 6 GHz continuum image (Kepley et al.). The GBT 4mm receiver opens up the low end of the 3mm atmospheric window with unprecedented sensitivity. The early 4mm science programs have focused on studies of deuterated species in cold pre-stellar cores, dense gas tracers (e.g. HCN, HCO+) in star-forming regions within our galaxy and local galaxies, and the physical processes and complex chemistry within the ISM via molecular lines throughout the band.

Mustang



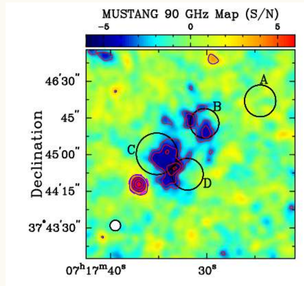
Mustang is a 3mm bolometer camera for the GBT. The detectors for Mustang-1.5 are 3-8x more sensitive than the current Mustang. Mustang-1.5 (available 2013) will provide similar mapping speeds to ALMA, while Mustang-2 with 332 detectors will map more than 10x faster than ALMA.

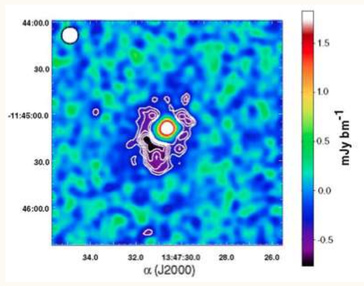


(Right) Mustang image of the Orion complex (Schnee et al.)

MUSTANG-2 Sensitivity

	Detectors	Relative	Relative	Map Integration Time (hrs)		
	#	Sensitivity	Speed	Current	Survey	Deep
Depth				40 μJy	20 μJy	5 μJy
Map size				4'.25 × 4'.25	8' × 8'	8' × 8'
MUSTANG	33	1	1	25	358	5,736
M-1.5 (32)	29	5	22	1.2	16	261
M-1.5 (64)	58	5	44	0.6	8	130
MUSTANG-2	332	5	250	–	1.4	23
ALMA Band 1	-	-	-	0.7	10.0	160
ALMA Band 3	-	-	-	1	15.0	240





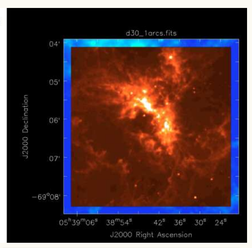
(Left) Mustang SZE image of the triple merget MACSJ0717+3745 (Mroczkowski 2012). (Right) Mustant SZE image of RXJ1347-1145 which shows deviations from equilibrium not previously evident from the x-ray image (Mason et al. 2010).

CASA Simulations

The panels below show CASA simulations comparing GBT, ALMA, ACA, and ALMA+ALMA-TP+ACA images. Using a combination ALMA and GBT data will yield superior results than the combination of ALMA+ACA+ALMA-TP data sets. Ideally for good image reconstruction, one should use short-space data from a single dish that is at least 2 times the size of the shortest interferometric baselines. This points to the usefulness of the GBT for many ALMA 3mm and VLA programs.

CASA Simulations to compare GBT vs ALMA+ACA +ALMA_TP
30dor 8um IRAC image – Rescaled from 2" pixels to 1" pixels.

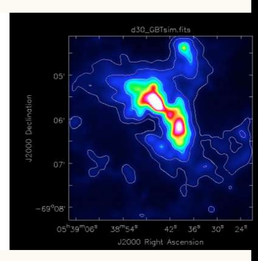
30dor in the LMC is the most luminous star-formation region in the local group of galaxies.



GBT simulated HCN image:

Total flux: 1.25 Jy

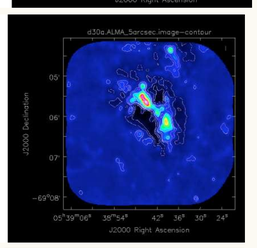
Contours are (0.05, 0.1, 0.2, 0.4, 0.6, 0.8) x peak.



ALMA 5"image (50x12m dishes, full ALMA)

Flux: 0.084 Jy (7% of total flux)

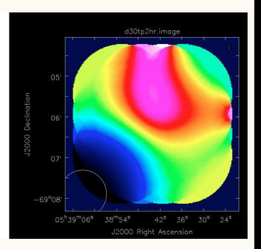
Contours (-0.1, -0.05, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8)xpeak



ALMA in Total-Power Mode (4x12m dishes OTF maps)

Note the lack of spatial information….

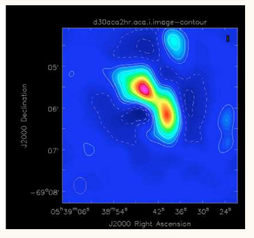
Not very useful for combining with data taken with ALMA's resolution.



ACA image: (9x7m dishes)

Shorter spacing recovers more of the emission.

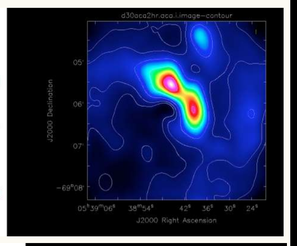
Flux= 0.40 Jy (32% of total flux)

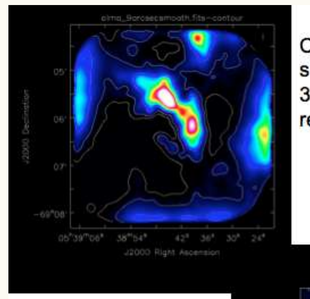


ACA+TP image:

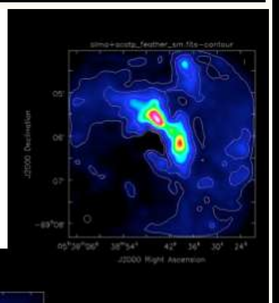
Flux=1.16Jy (93% of total flux)

Note that TP adds significant flux outside of the known emission regions.

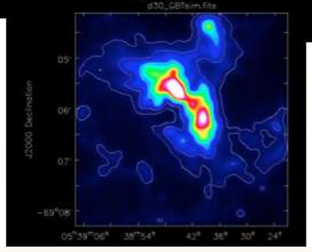




Comparisons of simulations of the 30Dor region (10" resolution).



GBT



Above: ALMA using ACA+TP for clean model does well for bright central regions, but has edge effects and misses extended emission.

Above: ALMA "feathered" with ACA+TP adds in extended emission throughout the map and does not do as good as job with bright central region.