Comparing the Sensitivity of the GBT with other telescopes

Note: The calculations on this page for W-band are outdated. They do not contain the significant improvements to the 43 and 90 GHz efficiency from the 2009 holography campaign!! Also, the low values of efficiency for the Plateau antennas listed below are clearly wrong. - T. Hunter

This page presents a comparison of the GBT with other radio telescopes, both single-dishes and interferometers, at three frequency bands: L-band (1.4 GHz), K-band (24 GHz), and W-band (90 and 115 GHz). These frequencies were chosen for scientific reasons: 1.4 GHz corresponds to studies of Galactic and extra-galactic neutral atomic hydrogen (HI), 24 GHz corresponds to transitions of ammonia (NH_3), and 90 GHz is close to the frequency of SiO and 115 GHz corresponds to carbon monoxide (CO). While there are many other interesting transitions at other frequencies within these bands, the sensitivity of the GBT and other telescopes are similar at other frequencies within these bands (except for 115 GHz which is on the high end of the W-band).

I will compare the telescopes using a number of metrics. These include single-pointing point source sensitivity, single-pointing extended source sensitivity (aka. brightness temperature sensitivity), point source survey speed, and extended source survey speed. The formulae used for these calculations come from Johnston & Gray 2006 and are described below.

Point Source Sensitivity:

$\sigma_s = \frac{T_{sys}}{G\sqrt{Btn_p}}$ [Jy]

where T_{sys} is the system temperature, G is the gain and is defined as $G = \frac{A\eta_a}{2k}$ where A is the total geometrical area of the telescope, η_a is the aperture efficiency, and k is the Boltzman constant (= 1380 $Jy\ K^{-1}\ m^2$), B is the bandwidth or channel width, t is the integration time, and n_p is the number of polarizations. This formula applies when the source is much smaller than beam of the telescope.

Extended Source Sensitivity:

$\sigma_t = \frac{T_{sys}}{\sqrt{Btn_p}}$ [K]

with the same definitions as above. This formula applies when the source is comparable or larger than the telescope beam.

Point Source Survey Speed:

$SS_s = FBn_p(\frac{G\epsilon_c\sigma_s}{T_{sys}})^2$ [square degrees per second]

where F is the field of view and ϵ_c is the correlator efficiency. Note that the gain, G, is for the entire telescope. This is the gain per antenna times the number of antennas for an interferometer (for a large number of antennas).

Extended Source Survey Speed:

For a single-dish: $SS_t = FBn_p(\frac{\epsilon_c\sigma_s}{T_{sys}})^2$ [square degrees per second]

For an interferometer: $SS_t = FBn_p(\frac{\epsilon_c\sigma_s}{T_{sys}})^2 f^2 \epsilon_s^{-2}$ [square degrees per second]

where $f = \frac{A\eta_a N}{\frac{\pi}{4}L^2}$ with L equal to the longest baseline, A is the area of a single antenna, and N is the number of antennas within L; and ϵ_s is the synthesized aperture efficiency and is equal to 1 for uniform weighting and proportional to $(1/\theta)^2$, so for the VLA with natural weighting it is equal to 0.43.

For interferometers, I always assume that the antennas are in their most compact configuration possible, except when otherwise noted.

Comparisons

Comparisons are being made at 1.4, 24, 90, and 115 GHz. The numbers for each telescope typically are taken from their online Users Guides, online sensitivity calculators, or their webpages in general. The sources will be listed below each table, as will status of the project if it is not currently operating. Because of the diverse sources of numbers, they are not always exactly comparable. For example, some telescopes list T(sys) at zenith while others list it at 45 degrees elevation. At high frequencies, the weather conditions are not always directly comparable. Because of the difficulty in obtaining values of opacity, I have not calculated $T_{eff} = T_{sys} e^{-\tau}$, which is used for calculating the signal-to-noise of an observation. At W-band, the difference between T(sys) and T(eff) may be as large as 50%.

I have tried to be as fair as possible and have erred on the side of generosity to telescopes other than the GBT. When comparing different telescopes, I have assumed that the same channel width, B, is the same for both telescopes and that the correlator efficiencies are also the same. These surveys are down to the same limiting sensitivity. For point source and extended source sensitivity the values listed are the relative noise in the same integration time.

In each section, the first table lists the parameters for all single-dish telescopes, the second table is for interferometers and the third table shows the ratio of sensitivities and survey speeds relative to the GBT for all the telescopes.

L-band (1.4 GHz)

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize	FOV	Bandwidth	Note
	GHz				K/Jy	K	Arcmin	sq. deg.	MHz	
GBT	1.15-1.73	1	2	0.70	2.00	20.0	9.2	0.027	650	1
Arecibo	1.225-1.525	7	2	0.40	10.50	30.0	3.5	0.027	200	2
Effelsberg	1.29-1.72	7	2	0.54	1.50	23.0	9.2	0.186	100	3
Parkes	1.23-1.53	13	2	0.57	0.67	23.5	14.0	0.800	64	4
Nancay	1.1-1.8	1	2	0.48	1.40	35.0	9.4	0.028	50	5

Notes:

1. From online Proposer's Guide
2. From online Users Guide
3. From webpage, multibeam is under construction.
4. From online Users Guide
5. From webpage, actual beamsize is 4'x22'; 9.4' is the beam with an equivalent area

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize	FOV	Bandwidth	L

	GHz				K/Jy	K	Arcmin	sq. deg.	MHz	m
EVLA-D	1.0-2.0	1	2	0.55	2.64	26	1.00	0.280	1000	1000
EVLA-E	1.0-2.0	1	2	0.55	2.64	26	3.00	0.280	1000	200
WSRT	1.15-1.75	1	2	0.54	1.34	27	0.22	0.280	160	2928
GMRT	1.000-1.45	1	2	0.38	6.60	76	0.03	0.180	32	3000
GMRT-CS	1.000-1.45	1	2	0.38	3.30	76	1.00	0.180	32	1000
ATCA	1.25-1.78	1	2	0.68	0.46	32	2.17	0.340	64	350
ATA-42	0.5-11.2	1	2	0.63	0.28	44	2.83	7.060	100	300
ATA-350	0.5-11.2	1	2	0.63	2.33	44	1.19	7.060	100	900
ASKAP	0.7-1.8	1	2	0.80	1.48	35	0.36	30.000	300	2000

Notes:

1. From EVLA memo #119, and Observational Status Summary, for D-array
2. As above, for E-array and from EVLA memo #6 (proposed)
3. From online Quick Guide to Observations with the WSRT
4. From Users Manual and GMRT Specifications, for whole array
5. As above, for central square
6. From Users Guide and Guide to Observations
7. From UC-Berkeley webpage, for ATA-42
8. As above, but for ATA-350 (proposed)
9. From Johnston et al. 2007, PASA, 24,174 (proposed)

Telescope	σ_s	σ_t	SS_s	SS_t	*f*
GBT	1.00	1.00	1.0000	1.0000	1.00000
Arecibo	0.29	1.50	12.4107	0.4503	1.00000
Effelsberg	1.53	1.15	2.9773	5.2930	1.00000
Parkes	3.51	1.18	2.4470	21.8046	1.00000
Nancay	2.50	1.75	0.1670	0.3409	1.00000
EVLA-D	0.98	1.30	10.8659	0.0029	0.00928
EVLA-E	0.98	1.30	10.8659	0.3357	0.23203
WSRT	2.01	1.35	2.5959	0.0000	0.00055
GMRT	1.15	3.80	5.1095	0.0000	0.00003
GMRT-CS	2.30	3.80	1.2774	0.0003	0.01154
ATCA	6.96	1.60	0.2644	0.0027	0.01343
ATA-42	15.71	2.20	1.0761	0.0066	0.01094
ATA-350	1.89	2.20	74.5177	0.0056	0.01013
ASKAP	2.36	1.75	201.9096	0.0006	0.00130

At L-band, only Arecibo is dramatically more sensitive to point sources than the GBT. The GBT has similar sensitivity to the EVLA system. For extended sources, the GBT is more sensitive than any other telescope. This does not take into account the excellent dynamic range and clean beam of the GBT that make it even better than these numbers show. Unfortunately, since the GBT has only a single beam on the sky at L-band, it is significantly worse at both point source and extended source surveys than a number of other telescopes.

K-band (24 GHz)

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize
	GHz				K/Jy	K	arcsec
GBT	18-26.5	1	2	0.62	1.50	35.0	33.0
	18-26.5	7	2	0.62	1.50	35.0	33.0
	18-26.5	61	2	0.62	1.50	35.0	33.0
Effelsberg	17.9-26.24	1	2	0.26	0.73	73.0	39.0
Tidbinbilla 70m	19.91-20.51,21.78-22.38,23.61-24.21	1	2	0.48	0.67	40.0	48.0
Nobeyama	20.0-25.0	1	2	0.63	0.36	100.0	73.0
Parkes	16-26	1	2	0.50	0.25	45.0	68.0
Mopra	16-26	1	2	0.49	0.07	40.0	144.0
Sardinia	18-26.5	7	2	0.56	0.65	81.0	48.0
Yebes	21.75-22.85,23.35-24.45	1	2	0.76	0.34	150.0	79.0
Haystack	20-25	1	1	0.38	0.14	120.0	114.0

Notes:

1. From online Proposer's Guide, for current system
2. As above, but for 7-pixel array (under construction)
3. As above, but for 61-pixel array (proposed)
4. From webpage
5. From online Observers Guide (may cease astronomical observations)
6. From online Proposal Guide
7. From online Users Guide, and from Kate Brooks for new receiver (under construction)
8. From Kate Brooks and online technical summary
9. From Sardinia Radio Telescope Project Book (under construction)
10. From Bachiller et al. (2007) and Jose A. Lopez-Perez (director) (under construction)
11. From online technical guide

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize	FOV	Bandwidth	L
	GHz				K/Jy	K	arcsec	sq. arcmin	MHz	m
EVLA-D	18-26.5	1	2	0.51	2.44	47	2.80	3.970	1000	1000
EVLA-E	18-26.5	1	2	0.51	2.44	47	15.00	3.970	1000	200
ATCA	16-26	1	2	0.49	0.08	52	8.00	4.520	2000	350

Notes:

1. From EVLA memo #103, EVLA Project Book and Observational Status Summary, for D-array in excellent

weather

2. As above, for E-array and from EVLA memo #6 (proposed)
3. From Users Guide and Guide to Observations

Telescope	σ_s	σ_t	SS_s	SS_t	*f*
GBT	1.00	1.00	1.0000	1.0000	1.00000
	1.00	1.00	7.0000	7.0000	1.00000
	1.00	1.00	61.0000	61.0000	1.00000
Effelsberg	4.29	2.09	0.0760	0.3211	1.00000
Tidbinbilla 70m	2.56	1.14	0.3232	1.6198	1.00000
Nobeyama	11.90	2.86	0.0345	0.5995	1.00000
Parkes	7.71	1.29	0.0714	2.5686	1.00000
Mopra	25.59	1.14	0.0291	14.5785	1.00000
Sardinia	5.31	2.31	0.5256	2.7651	1.00000
Yebes	18.91	4.29	0.0160	0.3120	1.00000
Haystack	51.95	4.85	0.0044	0.5076	1.00000
EVLA-D	0.83	1.34	17.0421	0.0005	0.00861
EVLA-E	0.83	1.34	17.0421	0.2982	0.21516
ATCA	29.32	1.49	0.0154	0.0017	0.00968

For single pointings, the GBT has better point source sensitivity at 24 GHz than any other telescope except the EVLA. For extended sources, however, the GBT is more sensitive than every other telescope. For surveys of point sources, the current system on the GBT is better than any other telescope except, again, the EVLA. With the 7-pixel K-band focal plane array, the GBT's point source survey speed is about half of the EVLA's, but with the full 61-pixel FPA the GBT would be 3.5 times faster than the EVLA. For extended source surveys, Tidbinbilla, Parkes, Mopra, and Sardinia are all faster than the current system (and Mopra is faster than the GBT with the 7-pixel array), but all of these telescopes have significantly worse resolution than the GBT. As a result, the GBT would be preferable for surveys of extended sources at K-band than these other telescopes when fine detail is important.

W-band

90 GHz:

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize	FOV	Bandwidth	No
	GHz				K/Jy	K	arcsec	sq. arcmin	MHz	
GBT (current)	68-95	1	2	0.09	0.260	100.0	8.0	0.02009	800	1
GBT (PTCS)	68-95	1	2	0.40	1.140	100.0	8.0	0.02009	800	2
GBT (WFPA)	68-95	100	2	0.40	1.140	100.0	8.0	2.00889	800	3
LMT	85-116	16	2	0.70	0.500	85.0	15.0	1.13000	100	4

LMT	75-111	1	2	0.70	0.500	75.0	15.0	0.07063	36000	5
Effelsberg	84.0-95.5	1	2	0.26	0.730	163.0	11.0	0.03798	100	6
Nobeyama	82-116	25	2	0.39	0.220	200.0	14.5	1.64988	512	7
IRAM	72-115.5	1	2	0.62	0.160	118.0	29.0	0.26398	1000	8
Mopra	77-116	1	2	0.49	0.067	180.0	36.0	0.40680	8000	9
Yebes	86-115	1	2	0.76	0.340	200.0	26.0	0.21219	1024	10
Kitt Peak	90-116	1	2	0.51	0.021	220.0	70.0	1.53806	2400	11

Notes

1. For current telescope performance (data from Todd Hunter) using weather data from Ron Maddalena and assuming T(rx)=75K (planned)
2. As above, but for PTCS goals (from Todd Hunter) (planned)
3. As above, but with a 100-pixel focal plane array (proposed)
4. From LMT project book, webpage, SEQUOIA webpage (under construction)
5. As above, but for Redshift Receiver System (under construction)
6. From webpage
7. From NRO webpage and BEARS page
8. From webpage
9. From online Users Guide and Technical Summary
10. From Bachiller et al. (2007) and Jose A. Lopez-Perez (director), T(rx)=100 K, assumes T(sky)=100 K (under construction)
11. From ARO webpage, Users Manual

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize	FOV	Bandwidth	L
	GHz				K/Jy	K	arcsec	sq. arcmin	Mhz	m
ATCA	83.5-106	1	2	0.27	0.380	300	2.4	0.320	2000	21
CARMA	85-116	1	1	0.63	0.180	246	12.0	5.143	1500	14
Plateau de Bure	81-116	1	2	0.12	0.045	100	5.0	0.785	320	13
Nobeyama Array	85-116	1	1	0.67	0.077	400	5.0	1.861	1000	82
ALMA	84-116	1	2	0.79	2.100	67	3.0	1.494	8000	15
ALMA+ACA	84-116	1	2	0.79	2.300	67	3.0	1.494	8000	15
ACA	84-116	1	2	0.79	0.260	67	20.0	3.798	8000	36

Notes

1. From Guide to Observations and Sensitivity Calculator
2. From CARMA webpage, uses effective antenna size
3. From PdBI webpage
4. From NMA Status Report
5. From ALMA sensitivity calculator, ALMA memo 276, brochure, and Al Wooten for 64 element ALMA (under construction)
6. As above plus ALMA memo 538, for ALMA+ACA (under construction)

7. As above, but just for the ACA, using 7m antenna field of view (under construction)

Telescope	σ_s	σ_t	SS_s	SS_t	*f*
GBT (current)	1.00	1.00	1.0000	1.0000	1.00000
GBT (PTCS)	0.23	1.00	19.2249	1.0000	1.00000
GBT (WFPA)	0.23	1.00	1922.4852	100.0000	1.00000
LMT	0.44	0.85	287.9241	77.8547	1.00000
LMT	0.39	0.75	23.1139	6.2500	1.00000
Effelsberg	0.58	1.63	5.6096	0.7116	1.00000
Nobeyama	2.36	2.00	14.7006	20.5322	1.00000
IRAM	1.92	1.18	3.5739	9.4374	1.00000
Mopra	6.99	1.80	0.4150	6.2500	1.00000
Yebes	1.53	2.00	4.5156	2.6406	1.00000
Kitt Peak	27.24	2.20	0.1032	15.8187	1.00000
ATCA	2.05	3.00	3.7807	0.0008	0.01448
CARMA	5.03	3.48	10.1381	0.0678	0.02831
Plateau de Bure	5.78	1.00	1.1706	0.0030	0.00876
Nobeyama Array	19.10	5.66	0.2539	0.0616	0.05979
ALMA	0.08	0.67	10807.7918	17.3468	0.32358
ALMA+ACA	0.08	0.67	12964.4486	21.9545	0.36403
ACA	0.67	0.67	421.1623	207.6819	0.70222

At 90 GHz, the GBT (after the PTCS improvements to the surface) will be more sensitive than any other telescope for observations of point or extended sources, except ALMA. The limited field-of-view, however, means that a number of other telescopes will have better survey speeds than GBT. If the GBT is outfitted with a 100-pixel focal plane array, then the GBT will be the premier survey telescope for point sources; ALMA would still be an order of magnitude faster. For extended sources, only the ACA would be faster by a factor of 2.

115 GHz:

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize	FOV	Bandwidth	N
	GHz				K/Jy	K	arcsec	sq. arcmin	MHz	
GBT (current)	68-116	1	2	0.02	0.068	172.0	6.2	0.01207	800	1
GBT (PTCS)	68-116	1	2	0.27	0.770	172.0	6.2	0.01207	800	2
GBT (WFPA)	68-116	100	2	0.27	0.770	172.0	6.2	1.20659	800	3
LMT	85-116	16	2	0.70	0.500	130.0	15.0	1.13000	100	4
Nobeyama	82-116	25	2	0.26	0.150	300.0	14.5	1.64988	512	5

IRAM	72-115.5	1	2	0.59	0.150	260.0	22.0	0.15192	1000	6
Mopra	77-116	1	2	0.42	0.058	500.0	32.0	0.32142	8000	7
Yebes	86-115	1	2	0.76	0.340	300.0	22.0	0.15192	1024	8
Kitt Peak	90-116	1	2	0.49	0.020	283.0	55.0	0.94951	2400	9

Notes:

1. For current telescope performance (data from Todd Hunter) using weather data from Ron Maddalena and assuming T(rx)=75K (planned)
2. As above, but for PTCS goals (from Todd Hunter) (planned)
3. As above, but with a 100-pixel focal plane array (proposed)
4. From LMT project book, webpage, SEQUOIA webpage (under construction)
5. From NRO webpage and BEARS page
6. From webpage
7. From online Users Guide and Technical Summary
8. From Bachiller et al. (2007) and Jose A. Lopez-Perez (director), T(rx)=100 K, assumes T(sky)=200 K (under construction)
9. From ARO webpage, Users Manual

Telescope	Frequencies	Beams	Polarizations	Aperture Eff.	Gain	T(sys)	Beamsize	FOV	Bandwidth	L
	GHz				K/Jy	K	arcsec	sq. arcmin	MHz	m
CARMA	85-116	1	1	0.63	0.180	461	9.5	3.139	1500	14
Plateau de Bure	81-116	1	2	0.12	0.045	170	5.0	0.785	320	13
Nobeyama Array	85-116	1	1	0.67	0.077	600	5.0	1.207	1000	82
ALMA	84-116	1	2	0.79	2.100	121	3.0	0.915	8000	15
ALMA+ACA	84-116	1	2	0.79	2.300	121	3.0	0.915	8000	15
ACA	84-116	1	2	0.79	0.260	121	20.0	2.326	8000	36

Notes:

1. From CARMA webpage, uses effective antenna size
2. From PdBI webpage
3. From NMA Status Report
4. From ALMA sensitivity calculator, ALMA memo 276, brochure, and Al Wooten for 64 element ALMA (under construction)
5. As above plus ALMA memo 538, for ALMA+ACA (under construction)
6. As above, but just for the ACA, using 7m antenna field of view (under construction)

Telescope	σ_s	σ_t	SS_s	SS_t	*f*
GBT (current)	1.00	1.00	1.0000	1.0000	1.00000
GBT (PTCS)	0.09	1.00	128.2223	1.0000	1.00000
GBT (WFPA)	0.09	1.00	12822.2318	100.0000	1.00000

LMT	0.10	0.76	8863.6275	163.9417	1.00000
Nobeyama	0.79	1.74	218.7115	44.9477	1.00000
IRAM	0.69	1.51	26.8125	5.5103	1.00000
Mopra	3.41	2.91	2.2934	3.1523	1.00000
Yebes	0.35	1.74	103.4705	4.1388	1.00000
Kitt Peak	5.59	1.65	2.5146	29.0687	1.00000
CARMA	1.43	3.79	126.8774	0.0657	0.02831
Plateau de Bure	1.49	0.99	29.1660	0.0051	0.00876
Nobeyama Array	4.36	4.93	5.2703	0.0874	0.05979
ALMA	0.02	0.70	146139.8609	16.0443	0.32358
ALMA+ACA	0.02	0.70	175301.5565	20.3061	0.36403
ACA	0.18	0.70	5694.6287	192.0816	0.70222

At 115 GHz, PTCS improvements for the GBT are absolutely essential for it to be competitve with other instruments. With these improvements, the GBT will have similar point source sensitivity to the LMT (if it attains its specifications) and will be better than all other telescopes, except ALMA. For extended sources, the LMT, Plateau de Bure, ALMA, and the ACA will be up to 25% more sensitive than the GBT. As at 90 GHz the GBT will need a 100-pixel focal plane array to be faster than the LMT, Nobeyama, CARMA, and ACA for point source surveys; ALMA remains an order of magnitude faster. For extended source surveys, the GBT with a FPA will still be 50% slower than the LMT and 92% slower than the ACA.

Plots

* Point Source Sensitivity

* Extended Source Sensitivity

-- DjPisano - 17 Feb 2008

This topic: GBT > WebHome > CurrentCapabilities > GBTSensitivityComparison
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