DESIGN REVIEW OF BRAZILIAN DECIMETER ARRAY (BDA)

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Background of the Project

In 1997, I was requested by Prof. C.N.R. Rao to attend the General Assembly of the Third World Academy of Science held in August 1997 in Brazil. I decided to spend 10 days at INPE near Sao Paulo (equivalent to ISRO) at the invitation of Dr. Hanumant Sawant, a senior scientist at INPE, who had visited GMRT earlier and wanted India to help them for a radio astronomy project in Brazil. I suggested to him to build a solar array described in the proposal, since they had been carrying solar research for more than a decade.. I visited them again in September 1999 and made a detailed review as described in this report. Comments by members of NCRA would be valuable.

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ABSTRACT

The Brazilian scientists are planning to set up a radio interferometric array for observations of the Sun at decimetric and centimeter wavelengths and which will also be valuable for galactic and extragalactic radio astronomical studies. The array consists of 30 low cost parabolic dishes of 4 meter diameter and six antennas of 7 meter diameter. During the first phase over the next 3 years it is proposed to construct a TEE array with 19 antennas in an eas -west array of about 240 m length and a north-south array of 11 antennas of about 150 m length. The design of the array is optimised for making two-dimensional maps of the radio Sun at frequencies of 1.4, 2.7 and 5 GHz over a period of seconds or minutes.

The possibility of constructing a 30-element array consisting of three perturbed Reuleaux curves in a triangle of about 160 m diameter (Keto, 1997) is also being considered but the TEE array may give a higher dynamic range by using the principle of redundancy for short term observations of the radio Sun. The above design is being proposed considering the limited resources of the group at INPE and also the size of the available terrain of the selected site.

In the second phase of the project, it is proposed to place additional six antennas of 7 or 10 m diameter in an east-west array of about 2 km length with the TEE array near its centre for obtaining higher resolution. About two years ago it was proposed to operate the array in the frequency range of about 1200-1700 MHz for not only making maps of the Quiet and Active Sun, but also for studying structure of decimetric Type III bursts. In this review, it is proposed to add capability of observing also in the radio astronomy bands of 2690-2700 MHz and 4990-5000MHz which will allow tomography of the solar active regions by combining the above data with data from the X-ray satellite maps, the Japanese mm and cm maps, the proposed sub-mm maps by Brazilian and Argentina scientists and the French observations being made at Nancy at meter wavelengths.

The radio maps at 1.4, 2.7 and 5 GHz are likely to be very important for understanding the evolution of active regions in the upper chromosphere and lower corona regions through studies of the thermal and gyro-synchrotron emission.

In this design review report are given comments regarding various scientific and technical aspects of the proposed Brazilian Decimetric Array (BDA).

1.0 INTRODUCTION

In early 1997, a solar radio astronomy group at the Instituto Nacional de Pesquisas Espacias (INPE) had proposed construction of a radio interferometer consisting of six 5-meter antennas and four 9-meter antennas for observations of the Sun and other galactic and extra-galactic radio sources. The design was reviewed with the INPE scientists and Prof. E. Ludke of the Federal University of Santa Maria during the visit of G. Swarup to INPE, from 12-19 September, 1997. It was proposed to construct a closely spaced TEE array consisting of low cost 4-m parabolic dishes which are mass produced in Brazil for satellite communication. The design of the array was chosen to allow making high quality maps of the Sun at 1420 MHz on a daily basis and also to make a survey of Galactic HI emission at 21 cm, etc. A suitable site was selected by the INPE group during the visit G. Swarup at the INPE's facilities at Cachoeira Paulista (about 10 km^2 area, though mostly hilly) which is located about 110 km away from the INPE's headquarters at São José dos Campos and which is about 220 km away from São Paulo towards Rio de Janeiro.

Details of the basic design developed for the antenna and receiver system for the BDA by the INPE group are given in a report dated 2nd June, 1999. In Section 2 of this report is summarised the science case for the proposed BDA. In Section 3 are given discussions concerning the antenna configuration. Comments on the antenna and receiver systems are given in Sections 3 and 4. Discussions and Conclusions are given in Sections 5.

2.0 SCIENCE CASE

2.1 STUDIES OF THE RADIO SUN

The main objectives of the proposed BDA are to make radio images of the Sun at several frequencies in real time. INPE's group has proposed observations in the frequency range of about 1200 to 1700 MHz for "spectral tomography of solar active regions". The solar group at INPE has made detailed studies of the dcm type III bursts in the frequency range of about 1 to 2.5 GHz which are associated with acceleration of electrons during flares in the active regions.

Bastian et al. (1998) have highlighted the importance of high spatial and time resolutions studies of decimeter wave bursts for understanding acceleration mechanisms of electrons giving rise to energetic flares. These may be discussed with currently active workers in the field. ***Obviously two-dimensional maps of the Sun in the Radio Astronomy Bands of 1.4 GHz, 2.7 GHz and 5 GHz will permit application of the spectral tomographic techniques for prediction of the solar perturbances such as flare and occurrences of CME's which will enable space weather prediction and possible observations of galactic and extra-galactic radio sources. Thus, BDA is a low cost versatile equipment.***

As discussed in the next section, it should be possible to make two-dimensional maps of the Sun not only at 1.4 GHz ,but also at 2.7 and 5 GHz by a relatively small modification of the feeds and electronics of the 4m antennas. The spacing of the antennas has been chosen to ensure minimum aliasing of the radio Sun by the grating responses of the TEE array at 1.4 GHz. The images at 2.7 and 5 GHz would have effects of aliasing but could be cleaned to a fair extent, particularly for studying active regions.

Studies of the two-dimensional radio maps made at several frequencies in Brazil and elsewhere (Japan, Nancay, etc.) and their comparison with X-ray maps would allow studies of the evolution of active regions and determination of their physical parameters, such as electron density, temperature and magnetic fields. It may be noted that radio maps are particularly important for estimating magnetic fields in upper levels of chromosphere and lower solar corona where takes place energy release due to reconnection of magnetic fields and, therefore, multi-frequency radio maps are likely to be quite important for prediction of solar transient events (Gary and Hurford, 1994; Bastian et al., 1998).

HIGH RESOLUTION ONE DIMENSIONAL MAPS AND EAST-WEST SYNTHESIS ARRAY

It is proposed to add six antennas in an east-west array of about 2 km length during the second phase of the project of BDA for obtaining resolution of about 20 arcsec at 1.4 GHz and about 4 arcsec at 5 GHz. This will allow to study fine structure of active regions, dcm Type III bursts and microwave bursts associated with the X-ray transient events (Bastian et al., 1998).

2.2 GALACTIC STUDIES

BDA will be a valuable instrument for studies of extended sources such as supernovae remnants and HII regions in our Galaxy. Since the proposed correlator for mapping of the radio Sun has a bandwidth of 2 MHz with no spectral resolution, BDA can not be used for making HI surveys of the Galactic plane. However, it is proposed that the correlator to be built by the Indian Institute of Astrophysics, Bangalore should allow phased-array operation of the 30 antennas of the BDA. Hence, by adding a simple 256 channel digital spectrometer to the phased array output, a frequency resolution of 8 kHz can be obtained for a radio source covered by the 4 x 4 arcmin beam of the phased array. This may allow HI studies in specific directions of our Galaxy (e.g. high velocity clouds).

2.3 EXTRA-GALACTIC STUDIES

BDA may be used for a survey of the Southern Sky at 1.4, 2.7 and 5 GHz in order to supplement radio surveys done by the Molonglo and Australia telescopes, particularly for the regions of the sky not accessible to the VLA. As described in Section 1, BDA will have rms sensitivity of about 3 mJy at 21 cm for a system temperature of 50 K using a low-noise RF amplifier. BDA can also be used for studying variability of radio sources.

In the phased array mode, BDA can be used as a VLBI antenna of about 20 m diameter in order to provide a good north-south resolution to the VLBA network with USA.

3.0 SITE

Considering Brazilian economy and logistics, group of INPE has proposed the location of the BDA at the INPE's site at Cachoeira Paulista (latitude 22° 40', longitude 44° 30') which is located about 110 km Northeast of INPE's main laboratories at São José dos Campos which is also the headquarters of INPE. São José dos Campos is about 110 km Northeast of São Paulo. Rio de Janeiro is about 300 km east of Cachoeira Paulista (Figure 1).

INPE owns an area of about 3 km x 2 km at Cachoeira Paulista. Some of the main activities at this site are (a) processing of the remote sensing satellite data using a large computer facility, (b) meteorological Research and wealthier and prediction and (c) a digital ionosonde sweeping in the range of 1-30 MHz.

The INPE's site at Cachoeira Paulista is mostly hilly and various facilities are connected by a network of roads (Figure 2). There exists a flat valley of approximately 300 m x 300 m in east-west and north-south directions. This valley has a small creek running on the western and southern directions. There are hills between this flat site and various facilities mentioned above (Figures 3 and 4). A tarred road passes on the eastern border of this flat site.

About 200 persons are working at the INPE's campus at Cachoeira Paulista including administrative and other support personnel. A daily bus runs between INPE's camp at São José dos Campos and Cachoeira Paulista. All the civil and other infra-structure facilities for the BDA are to be executed by the technical group at Cachoeira Paulista which has considerable experience and facilities.

4.0 CONFIGURATION

During the visit of G. Swarup in 1997, it was decided to select a TEE array for the BDA with 16 antennas placed along an east-west array and 10 antennas along the north-south array. Separations of 16 m was selected between adjacent antennas of both the arrays.

The TEE configuration was selected for the purpose of calibration of the amplitude and phase of the array using the principle of redundancy as demonstrated by Nakajima et al. (1994) for the Nobeyama radio-heliograph and by Ramesh et al. (1998) for the Gauribidanur radio-heliograph. However, a periodic TEE array produces grating responses which could give rise to aliasing or overlapping of parts of the solar images. It may also be worthwhile to investigate whether a Y-array with periodic spacing for obtaining redundancy would give similar calibration capability or rather than increasing spacing between the antennas with distance from the centre as is the case for the VLA. It would desirable to undertake analytical and simulation studies for optimising the configuration of the BDA.

Keto (1997) has proposed and demonstrated that a 24-element array placed along perturbed "Reuleaux triangle" provides a much more uniform coverage of the (u,v) visibility plane than the Y-array or the circular array. However, it is not clear whether the principle of redundancy can be used for the "Reuleaux triangle". It may be stressed that a good self-calibration procedure is important for the BDA in order to obtain sufficiently high dynamic range for making radio maps every few minutes or hours to allow studies of the evolution of the solar active regions, identifying coronal holes and possibly also detecting CME's.

The spacing between antennas is determined by the size of the radio Sun. At a wavelength of 21 cm, a spacing of 16 m between adjacent antennas seems to be a good compromise between the resolution of the two-dimensional array and separation of the grating lobes, being about 4 x 4 arcmin and 45 arcmin, respectively. The resolution of the fan-beam of the east-west array is about 2.5 arcmin at 21 cm. The resolution of the array at 2.7 GHz and 5 GHz will be about half and one-third, respectively. It is proposed to add 4 antennas of 4-m diameter at 8 m spacing for obtaining data at low spatial frequencies so as not to resolve the disc of the Sun at the high frequencies.

Thus, the proposed BDA to be built during the first phase will consist of 30 antennas of 4 m diameter arranged in a 240 m long east-west array (19 antennas) and 152 m long north-south array (11 antennas) (Figure 5).

Relative merits of TEE, "Reuleaux triangle" and Y arrays should be investigated during the proto-type phase. However, the cost of all the three configurations, considering civil works and transmission lines is likely to be almost the same.

5.0 ANTENNAS

It is proposed to use 30 nos. of low cost 4 m diameter parabolic dishes which are mass produced for satellite reception in Brazil. The surface consists of 9 mm x 5 mm stretched al diamond mesh. The quoted gain of the dishes is 41.3 dB at 4 GHz using an open-ended waveguide feed with three outer chokes.

Considering an efficiency of 70 % for the aperture iluminance by the feed, it is estimated that the rms accuracy of the surface is likely to be lower than 3 mm, (i.e. ± 6 mm from the mean parabola or peak to peak error of about 12 mm). A Brazilian firm has quoted rms accuracy of 2 mm but the firm is not a direct manufacturer. It is strongly recommended that the selected vendor should provide a rotating template along with the dishes so that the surface error can be checked, and adjusted if required, by using a suitable assembly procedure to ensure rms error to be less than 3 mm (2 mm may be achievable with some care).

During discussions with one of the suppliers, it was told that each of the multiple radial parabolic frames forming the dish are quite accurate to about a mm but longer errors arise during the assembly of the frames perhaps due to tolerances of holes in the circumferential members etc. These errors can perhaps be minimised by using a rotating template along with a suitable assembly procedure. Any case, even for a rms error of 3 mm, the efficiency of the 4 m antenna will be about 0.35 at 5 GHz and 0.5 at 1.4 GHz for the open-ended circular waveguide feed and somewhat lower for the crossed log-periodic array using such antennas, BDA should provide sufficiently high signal to noise ratio for solar observations even at 5 or 6 GHz.

A Brazilian firm (TechnoCAD) has prepared detailed drawings for the mount and the drive system of the 4 m dishes using an X-Y mount concept as is used widely for satellite-TV dishes. This type of mount provides rather limited coverage of the sky for sources outside the solar declination range of ± 23 degrees. The estimated cost is U$10 k per antenna including electronics and installation according to the above design. In order to provide a better sky coverage and also for reducing the cost appreciatively, INPE has placed a order with SK, M/S engineering of Mumbai, India to produce detailed drawings of either HA-DEC or Alt-Az mounts within 3 or 4 months in consultation with myself (Prof. Govind Swarup).

6.0 RECEIVER SYSTEM

6.1 GENERAL COMMENTS

Prof. Everton Lüdke of the Federal University of Santa Maria (RS) is designing the receiver system of BDA (Project Report in Preparation, June 1999). He will be assisted by others. I had detailed discussions with him at INPE during his visit from 31st August to 4th September, 1999 on the basis of the original proposal for BDA's operation from 1200 to 1700 MHz. Mainly, I stressed to him that one need not plan to put a synthesiser at each of the 30 antennas considering that the array size (240 m x 152 m) is rather small and the LO reference signal can be easily and reliably distributed using low-loss coaxial lines and multiplied or amplified as required. The development of phase coherent synthesisers is likely to be time consuming and costly.

The receiver system for the BDA is described briefly below considering my suggestion for its operation at 1.4, 2.7 and 5 GHz (not simultaneously but operation on a switching basis).

6.2 FEEDS AND FRONT-END AMPLIFIER

It is suggested to use a crossed log-periodic antenna (LPA) with a broad-band amplifier covering 1.4 to 5 GHz. DAS-INPE is already using this concept on a 9-m dish for a dynamic solar-spectral receiver operating from 200 MHz to 2500 MHz. The crossed dipole array could be developed on a fibre-glass board. The phase centre of the LPA at 5 GHz will coincide with the focus of the dish but will be about one wavelength away along the dish axis for 1.4 and 2.7 GHz. Thus, the 4-m dish may have an efficiency of only 0.35 or so at all the three frequencies. Using FETs broad band amplifier is likely to have noise figure of about 2 dB (system temperature of about 200 K) with negligible intermodulation products for radio interference signals of about -50 dBm expected at the Cachoeira Paulista site. A system temperature of less than 200 K is desirable for calibration of the array using several strong radio sources, although the expected antenna temperature of the 4-m dishes in the direction of the Sun is > 1400 K at 1.4, 2.7 and 5 GHz.

It may be noted that a group led by Dr. Sandy Weinberg of JPL, SETI institute and Berkeley University is planning to develop a broad band feed and a low-noise amplifier (less than 50 K) with high dynamic range for operation from 1 to 10 GHz or 1 to 22 GHz for a proposed dedicated array for SETI consisting of 500 dishes of 5 m diameter with f/d of about 0.7. It may be possible to borrow some of their concepts for the required feed and RF amplifier of the BDA.

6.3. LO AND IF SYSTEM INCLUDING TRANSMISSION LINES

The LO system should provide coherent signals of about mW power at each of the 30 antennas. The phase of the LO signals should not vary by more than about 5 degrees at 1.4 GHz due to length variations of the buried transmission lines with temperature. One may tolerate higher phase variation at 2.7 and 5 GHz where one may not aim solar radio maps with very high dynamic range.

The length variations of low-loss helical transmission lines and standard optical fibre cable are about 1 part in 80,000 per degree centigrade. Assuming a daily temperature variation of only 2 degree centigrade at a depth of 1 m, the phase variation at 1.4 GHz for a length of 150 m for a helical cable will be about (taking propagation constant of (1/0.8) for the cable):

$$\delta\Phi = (150/0.8)(2/80{,}000)(360/0.21) = 8^\circ$$

at 1.4 GHz and 24 degrees at 5 GHz. However, this could be easily measured and compensated by using round-trip phase measurements technique from the centre to the three ends of the TEE array (Swarup and Yang, 1961; Thompson et al., 1986). Another possibility is to install a second line and feed a small RF signal before the RF amplifiers using a 30 dB directional coupler and thus calibrate the entire electronics in amplitude and phase periodically or continuously using the correlated outputs.

Lüdke has proposed sending a 10 MHz reference signal and a synthesiser at each antenna for the generation of the LO at each antenna. However, this may be costly and difficult to maintain over a long period. He had also suggested running a long low-loss helical-coaxial line along each of the three arms and placing a directional coupler at each of the antenna locations for tapping the required LO power for the mixers. For 10 antennas along each arm and 10 mW at each mixer, we require to send 100 mW for losses coaxial lines and directional couplers. The loss of the transmission lines could be compensated by using a 1 Watt amplifier at the input of each of the three lines (see Figure 6 for one of the possible schemes).

One may consider using optical fiber cable which has quite a low loss of less than 0.5 dB/km at 1300 nm. However, directional couplers of varying coupling as required for coupling equal power to each of the 10 antennas are not easy to make. Also receivers are costly. One may consider sending LO to each antenna separately on 10 core fiber cable along each arm but the system is unnecessarily complex and costly. The same remarks hold for bringing RF from each antenna. Thus, it seems that the choice of helical coaxial cables of 1/2 or 7/8 inch diameter seems to be suitable for the TEE array of BDA. Directional couplers can be easily made using strip line technique.

The choice of the LO frequency and IF depends upon the required frequency agility of the observing bands. In particular it may be required to cover 1400-1700 MHz for observing dcm type III bursts. In that case, IF frequency should be greater than 300 MHz. There are many possibilities; the choice depends on: (a) specifications, (b) readily available components and (c) designers convenience.

Lüdke has proposed using an IF of 710 MHz with 20 MHz bandwidth and then using a second LO at 720 MHz for bringing the second IF at 10 ± 1 MHz to the central building. It will be desirable to make all incoming cables to be equal in length. For the required suppression of the image frequency signal at 730 ± 1 MHz, it would be desirable that the 710 MHz filter has 35 or 40 dB suppression, in order to ensure high dynamic range of the solar radio maps.

An alternative is to bring the second IF at 70 ± 10 MHz (where low cost filters are available) and to reduce the bandwidth to 2 MHz in the base band system in the central building. This would allow possible widening of the bandwidth of BDA to 10 or 20 MHz in future. One may also consider using the first IF at 480 MHz as used for the Ku band satellite receivers if suitable filters are readily available. However, for the sake of economy one may restrict to 2 MHz band and bring digitised BB signal to the central building using weaver scheme being developed by Dutch group (Smolders, 1999, Fig. 3.3.7 b and Ref. 3).

As mentioned above, the choice of the LO, IF and Baseband system depends upon the designer. I understand that Lüdke is developing proto-type cards and a final design can then be selected based on the results obtained.

6.4 CORRELATOR

A one-bit correlator system will be built using the chips designed for the Nobeyama Radio Telescope and used in 1024 channel digital correlator system for the Gauribidanur telescope with 1 MHz bandwidth (16 east-west x 16 north-south groups with all 32 antenna groups cross-correlated including self-correlation and 2 polarisation's). Dr. K. R. Subramanian and Mr. Sundarajan (IIA, Bangalore) have indicated their willingness to get it developed at Bangalore for an estimated cost of U$ 12,000. It is advisable to built it for 32 antennas. A detailed description and block diagrams of the samplers, delay lines, multipliers and integrators including interfaces, software, test cards etc, as required for BDA needs to be written with the firm estimates of costs. It would be valuable if the delay steps are made small enough or digital phase-shifters are introduced for allowing phased array operation of the BDA.

7.0 SYSTEM PARAMETERS

We calculated the sensitivities of the BDA for: (a) observations of the Sun (including its contribution to the antenna temperature) for different times of integration and (b) for galactic and extra-galactic studies assuming two different system temperatures. Values are also given for narrow bandwidths as may be obtained with phased array for HI studies. Detailed values of sensitivity are given the plots attached. It is seen that the BDA will have a high sensitivity for a variety of astronomical studies.

8.0 RFI SURVEY

It is important to make detailed RFI surveys at various locations at Cachoeira Paulista, particularly near the radio astronomy bands of 1400-1427 MHz, 2690-2700 MHz and 4690-4700 MHz. A resolution bandwidth of 100 kHz may be used and observations made for 10 or 20 minutes.

Additionally survey should be made from 100 MHz to 5 GHz using a bandwidth so as to cover 400 MHz in each step to identify any strong signals.

The survey is to be made using a spectrum analyser with a log-periodic antenna placed at a height of about 5 or 6 m, possibly attached to a van. A patrol generator with an AC regulator is required. The survey should be made with the log-periodic antenna pointed in four different directions. The survey is to be made at a distance of about 100 m from the computer building and ionosonde.

Finally, detailed survey may be made on 2 or 3 occasions in a day on the edge of the road of the selected site for the BDA.

9.0 PROTO-TYPE ARRAY

It is suggested that a proto-type Array consisting of 5 antennas placed in an east-west array be constructed in a period of about 12 to 18 months after the approval of the project for constructing 30 antennas of phase 1. The proposed array configuration is sketched in Figure 5.

10.0 CONCLUSION

BDA will be a valuable instrument not only for solar studies but also for certain galactic and extra-galactic studies in radio astronomy. It can be built at a relatively modest cost but would require careful manpower development and training.

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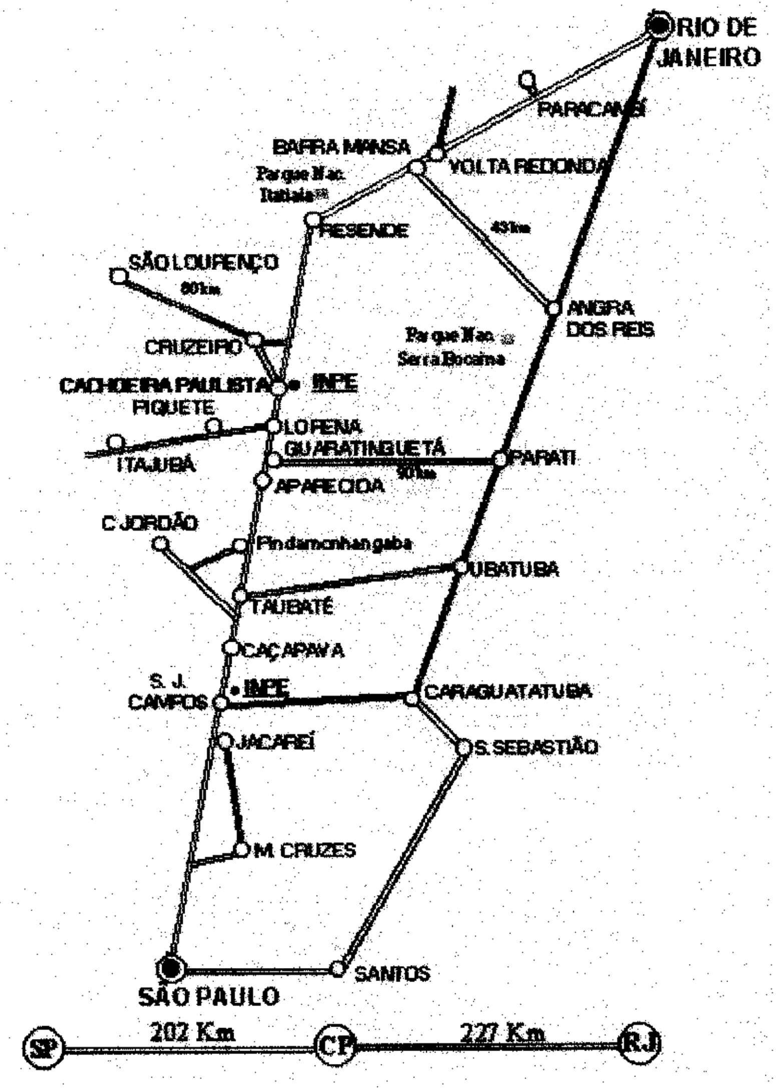

Fig. 1 – Location of Cachoeira Paulista and São José dos Campos.

Fig. 2 – Layout of INPE Campus at Cachoeira Paulista which also shows T-array and the 2 km east-west array.

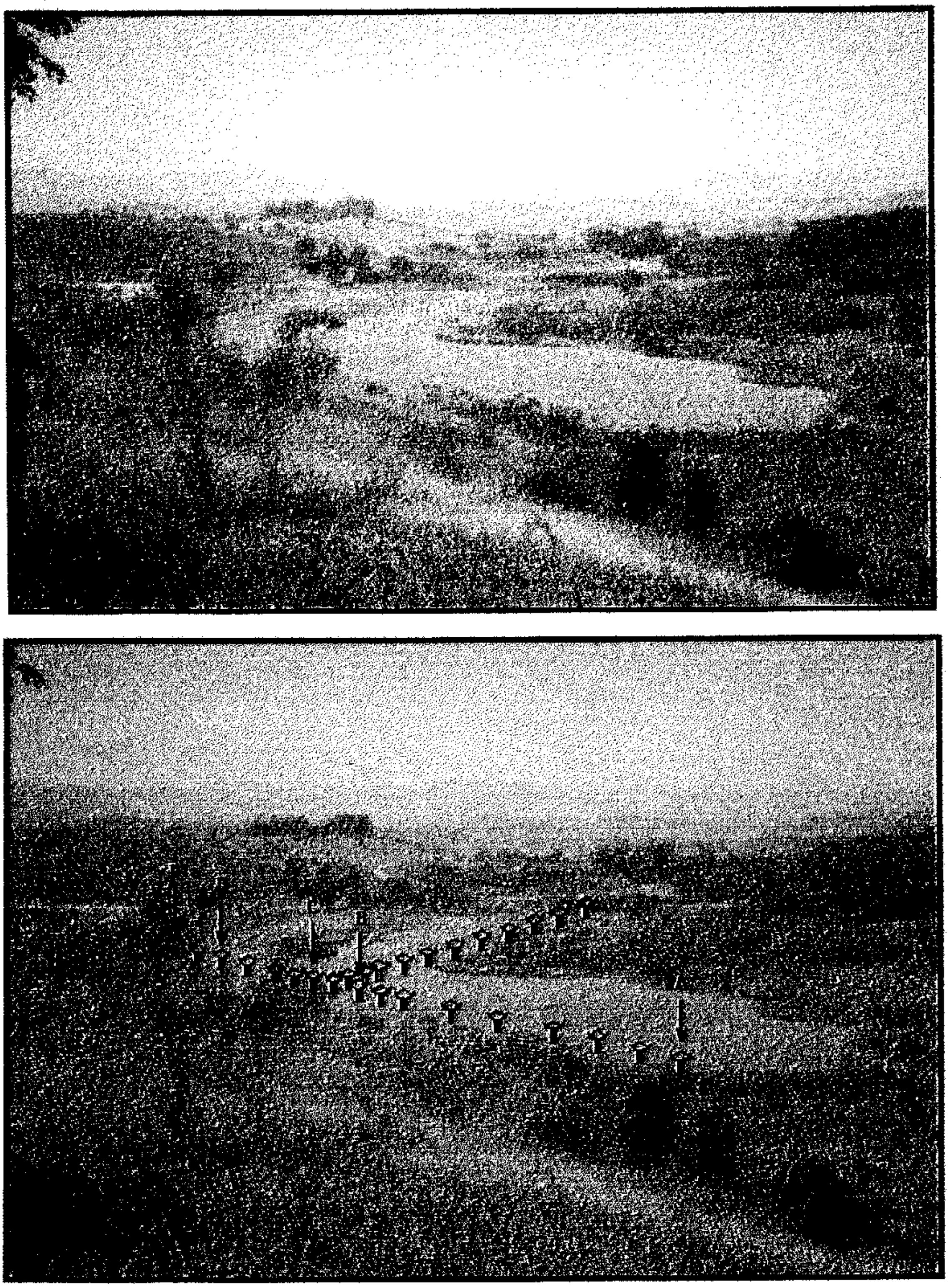

Fig. 3 – (top) Picture of the valley (INPE - Cachoeira paulista) where the TEE-array will be installed. (bottom) Same picture showing the sketched locations of array configuration. Letters A, B, C, D, and E, represent the antennas of the proto-type array.

Fig. 4 – Picture of the valley (TEE-array site) approximately in the east-west direction (top). Prof. Swarup, Dr. Sawant and Dr. Vats discussing with civil engineer (bottom).

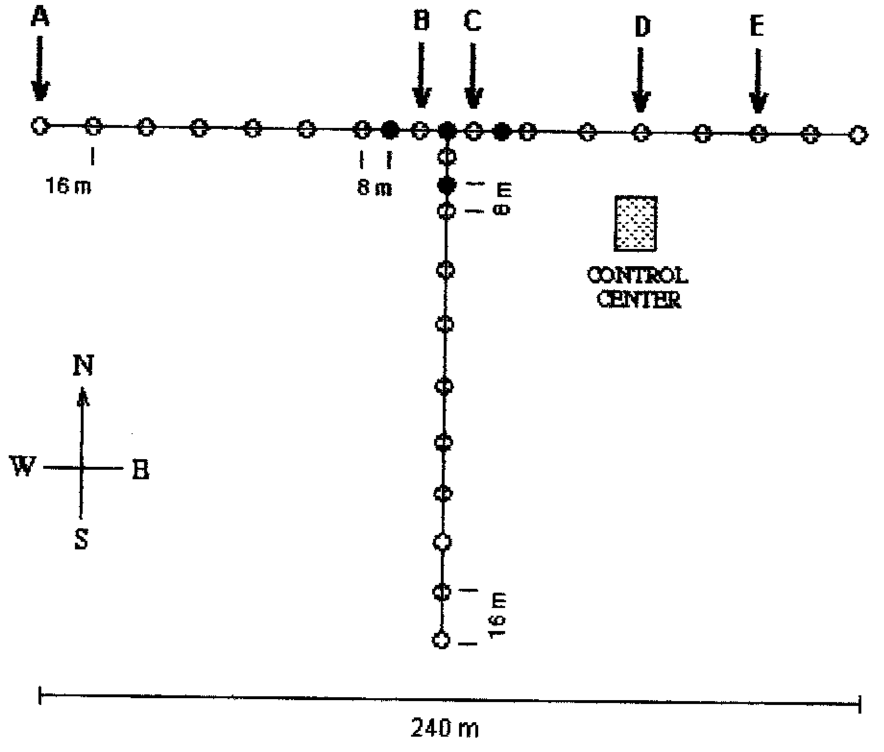

Fig. 5 – "T"-Array configuration of BDA, consisting of 30 antennas of 4-m diameter: (a) the two dimensional grating array is shown by open circles; (b) 4 antennas shown by filled circles will provide coverage to low (U,V) spatial frequencies for the broad features of solar disk; (c) arrows signed by letters A, B, C, D e E, show proposed location of 5 antennas for the proto-type phase which will provide spatial frequencies of 1, 2, 3, 4, 5, 6, 7, 8, 11, and 13 times of (16 m/wavelength) in units of cycles/radians.

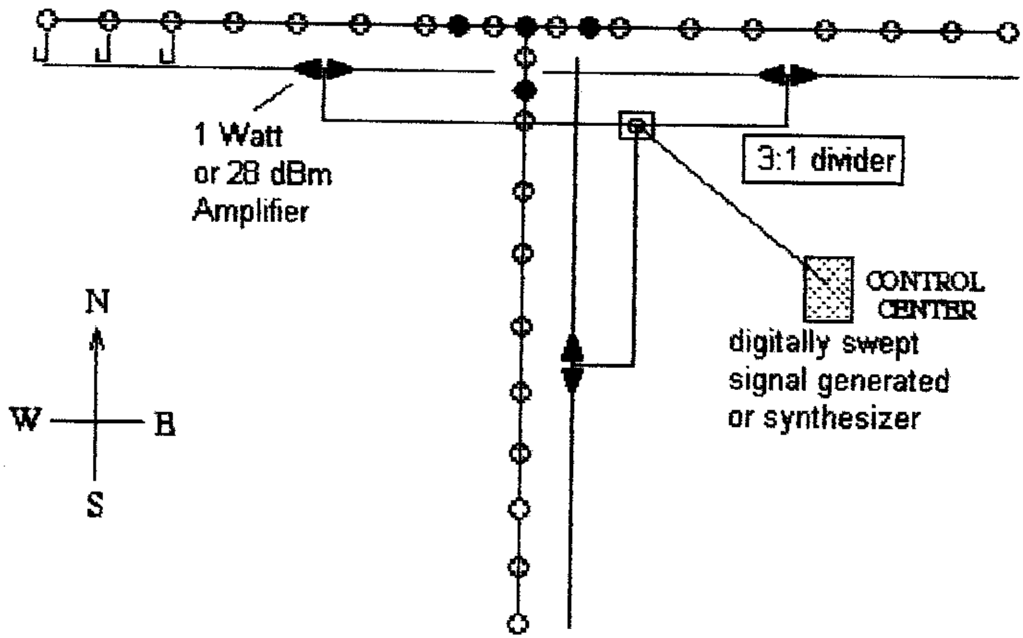

Fig. 6 – Scheme of a possible system of transmission lines using a divider 3:1.

FORMULAE TO ESTIMATE BDA SENSITIVITY IN FLUX DENSITY AND TEMPERATURE

The flux density per beam - ΔI_m (mJy/beam) - is given by (eq. 43 - Adornes, PhD. Thesis, 1998):

$$\Delta I_m = \frac{\sqrt{2} k_B T_{sys}}{\eta_a \eta_c A \sqrt{N_b N_{FI} \tau \Delta\nu}}$$

where: k_B is Boltzmann constant, T_{sys} system temperature, η_a antenna efficiency, η_c correlator efficiency, A is the physical area of the antenna, N_b , number of baselines, N_{FI} is number of IF, τ is observing time and $\Delta\nu$ is bandwidth.

To estimate minimum detectable temperature per beam - ΔT (K/beam) - from eq. 1, we use the expression:

$$\Delta T = \frac{\lambda^2 \Delta I_m}{2 k_B \Omega_b}$$

where: λ is wavelength and $\Omega_b = \pi(\frac{\lambda}{D})^2$ is the beam solid angle.

For the Sun we estimate antenna temperature according to:

$$T_A = T_{SUN} \frac{\Omega_{SUN}}{\Omega_A}$$

where: Sun radius $R_{SUN} \simeq 15.5$ arcmin., $\Omega_{SUN} = \pi(\frac{15.5}{3438})^2$, d = 4m and $\Omega_A = \frac{\pi}{4}(\frac{1.2\lambda}{d})^2$.

We estimated the values of ΔI_m and ΔT for following frequencies 1.4, 2.7 and 5.0 GHz, for solar and galactic and extragalctic observations assuming a 2 MHz correlator and also a phased array. Sun temperature (T_{SUN}) at these frequencies was given by Zirin et al. (Ap. J. 370:779, 1991).

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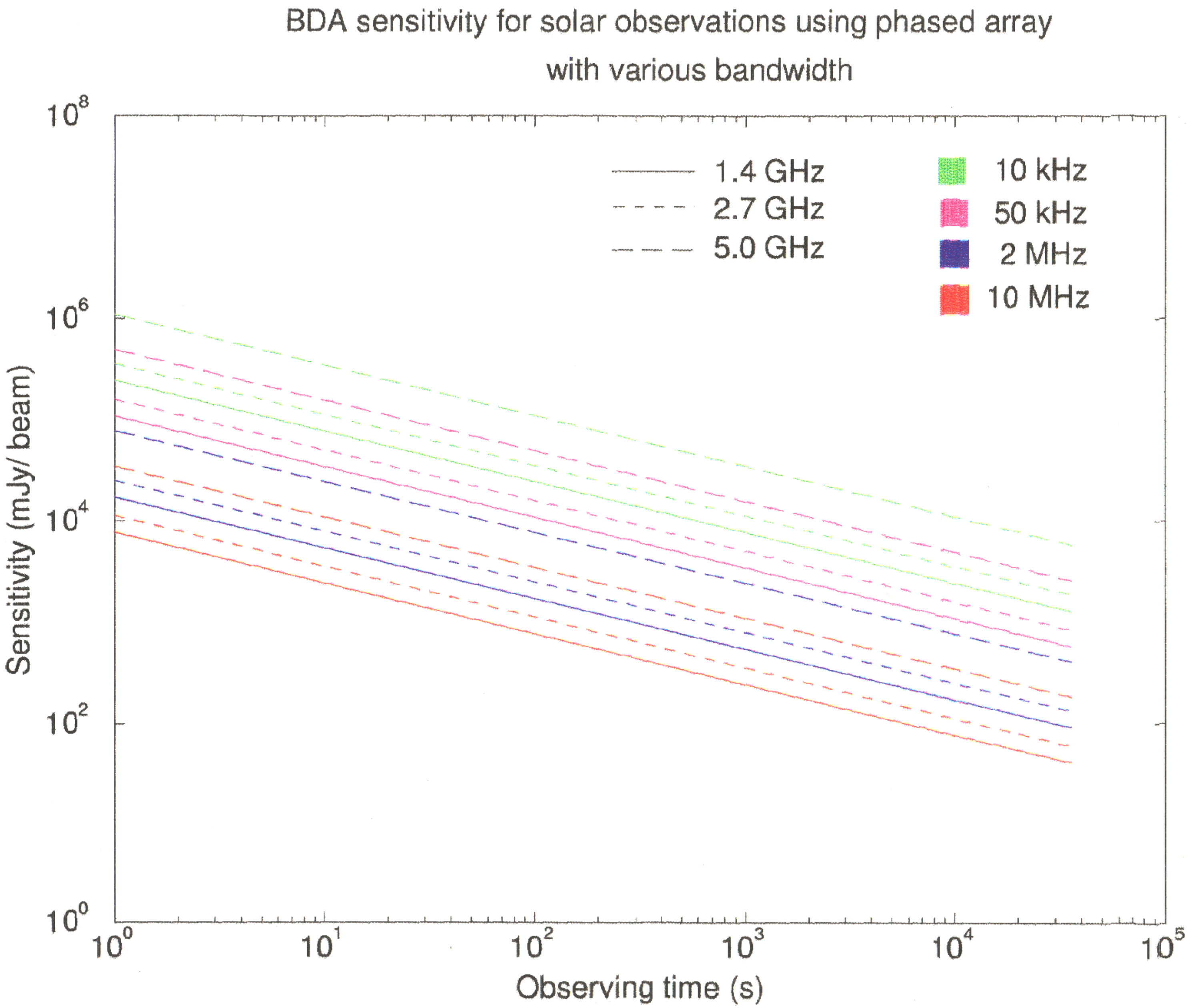
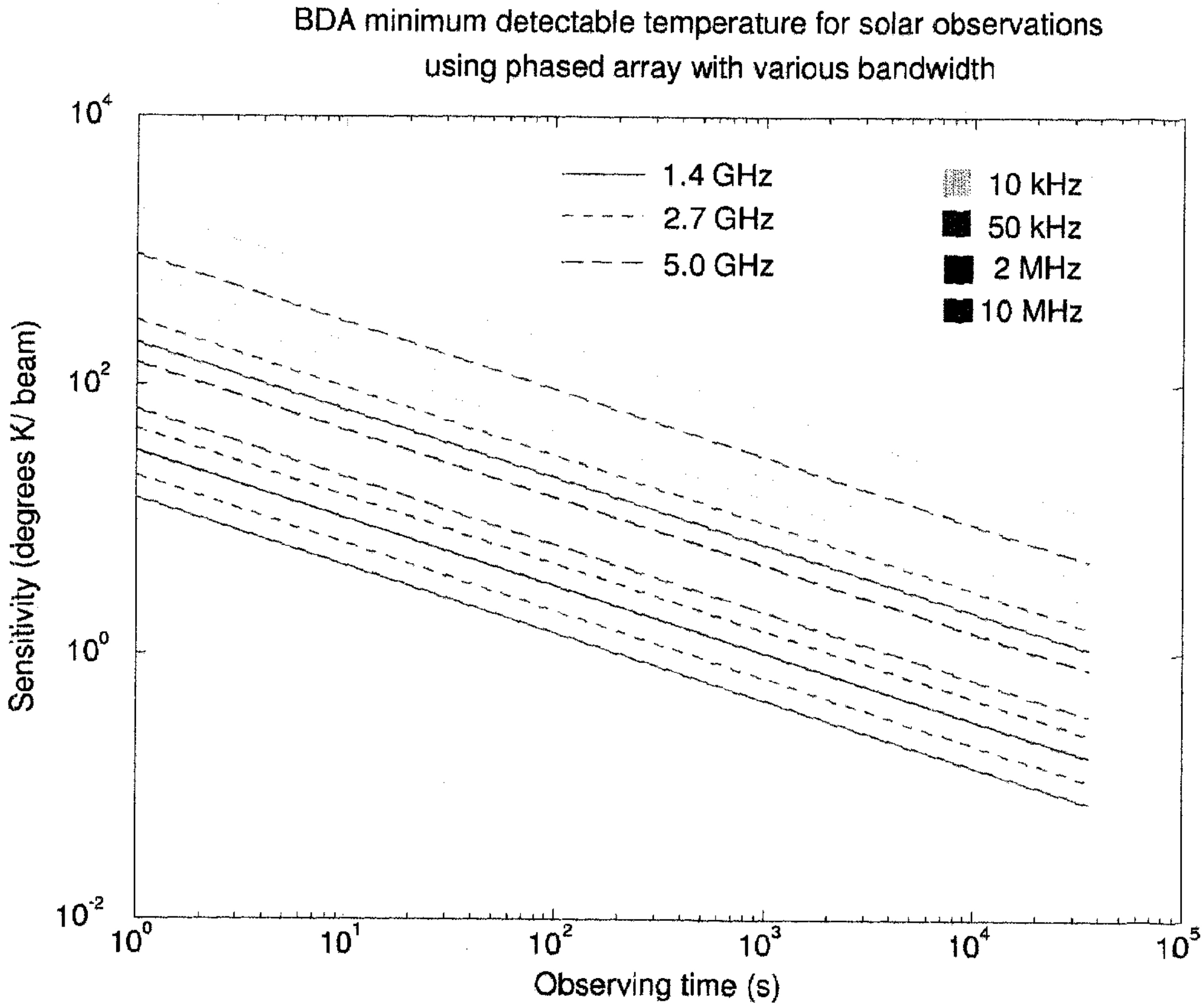
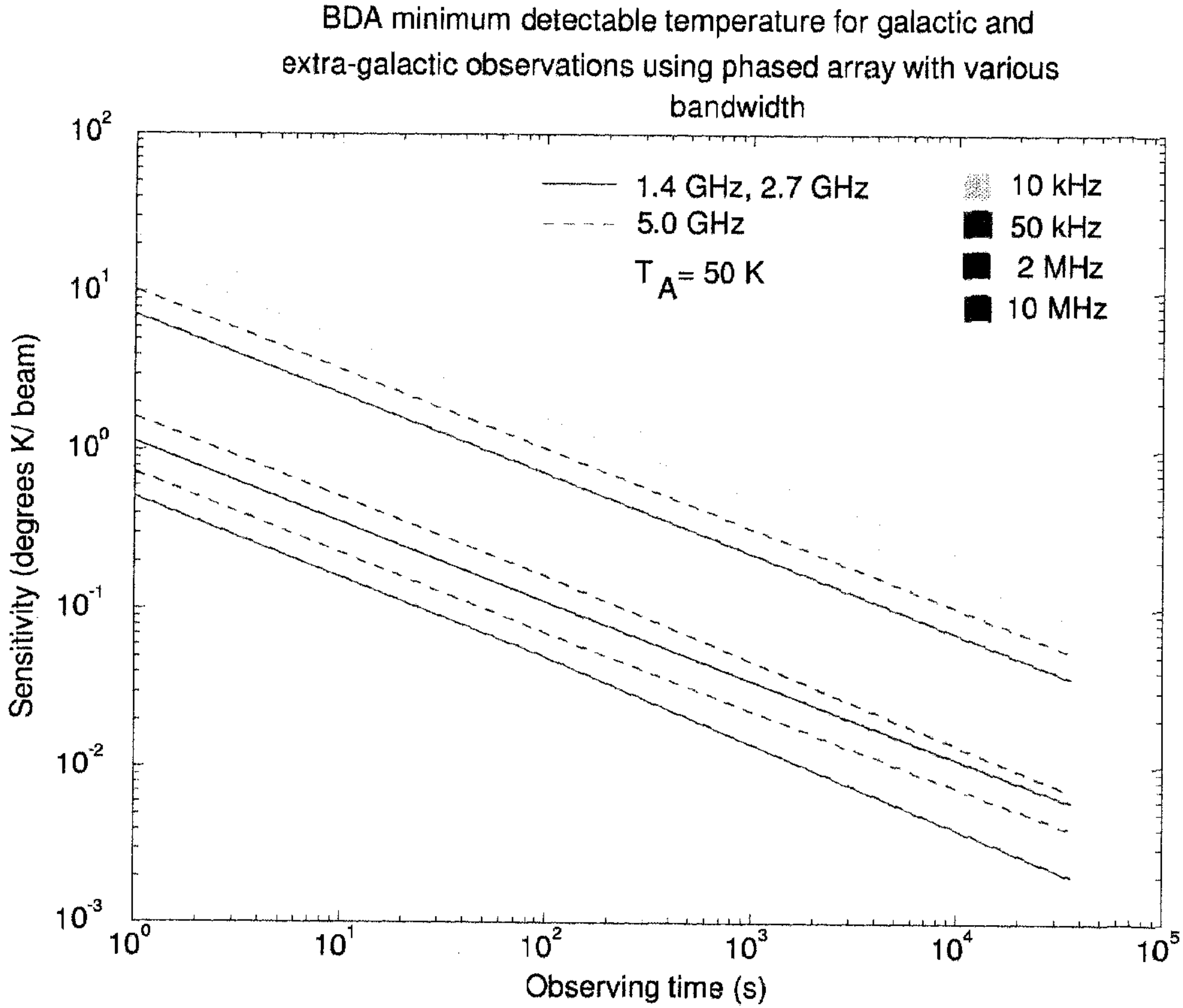
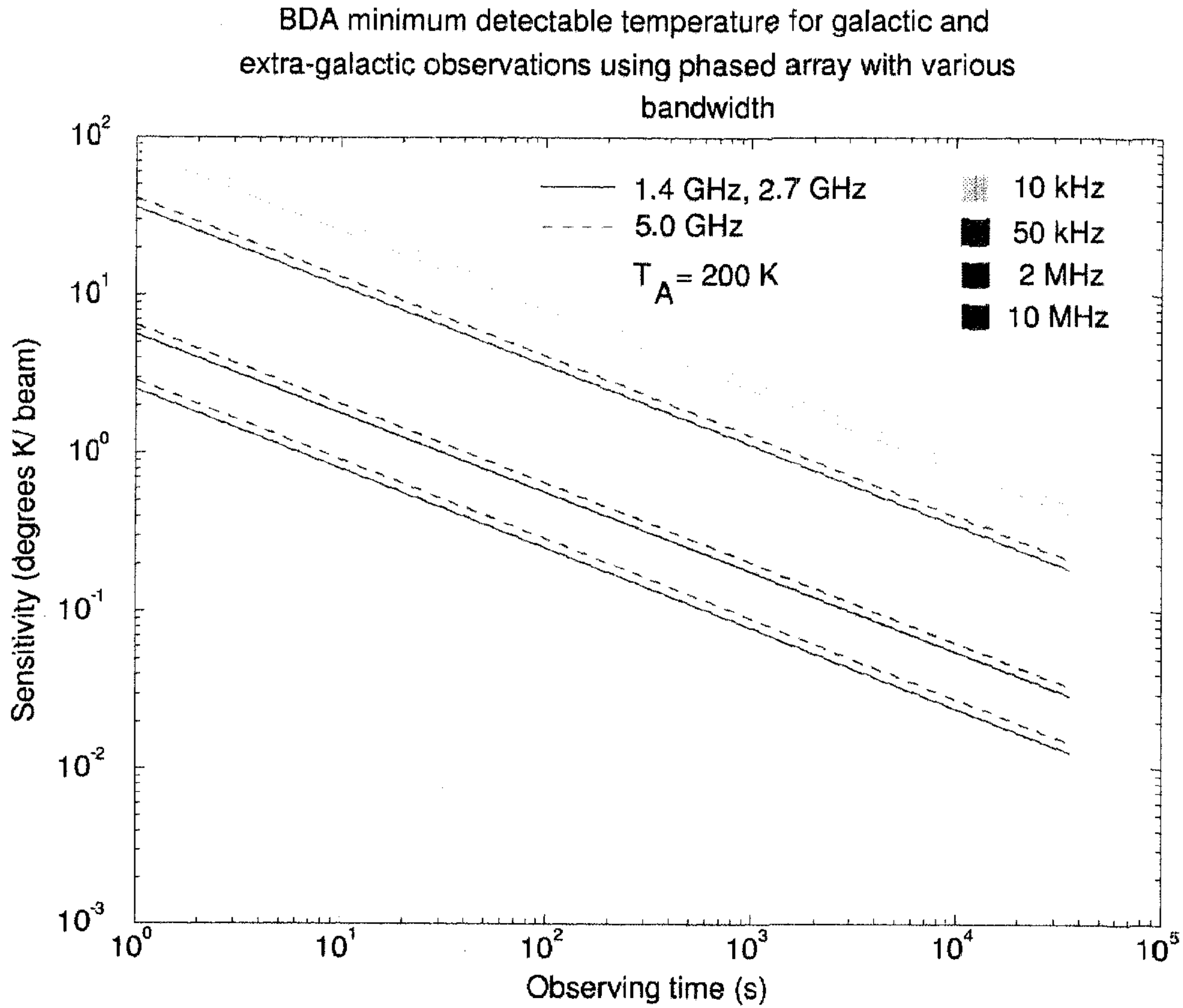
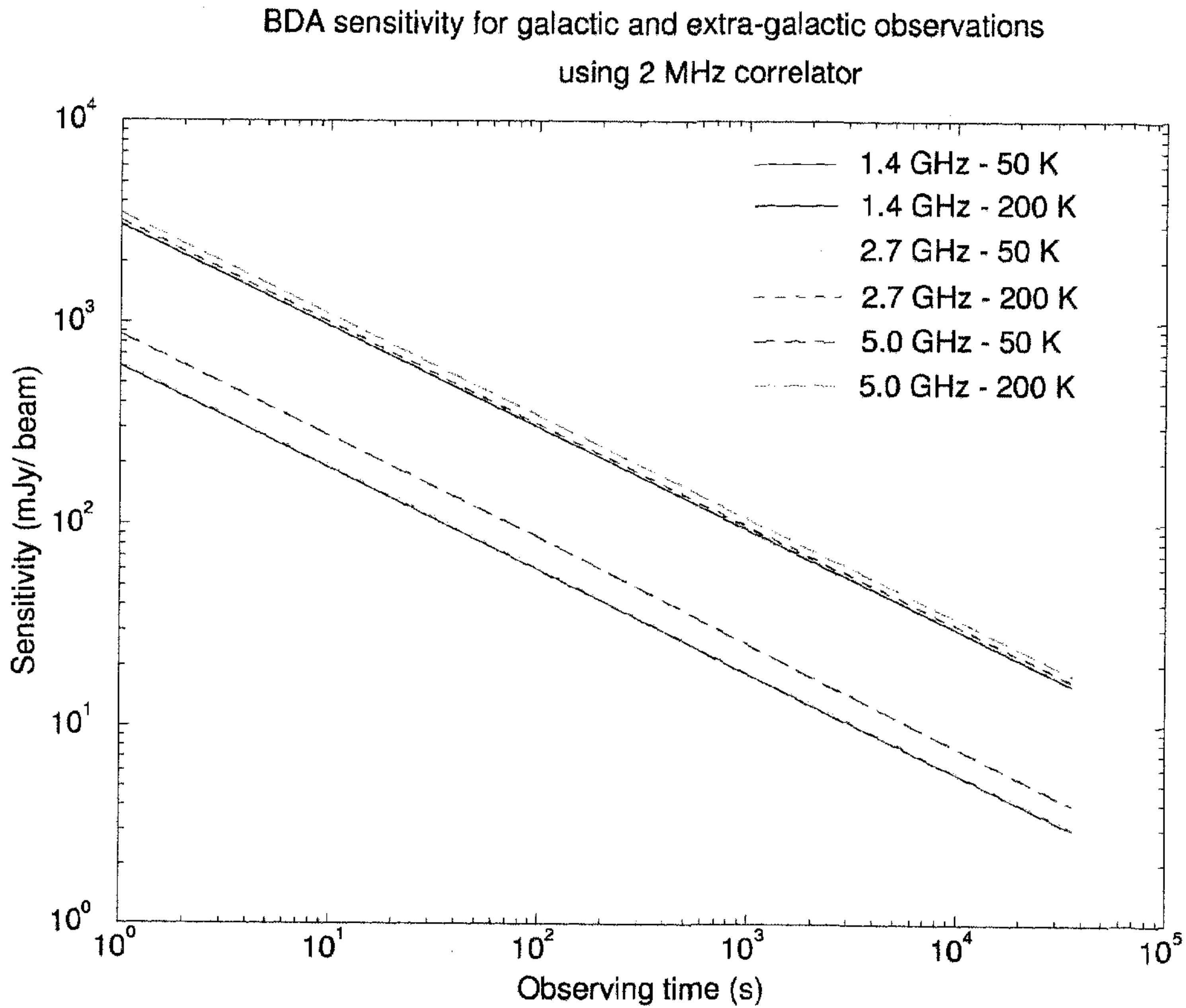


BDA sensitivity for solar observations using phased array
with various bandwidth
1.4 GHz
2.7 GHz
5.0 GHz
10 kHz
50 kHz
2 MHz
10 MHz
Sensitivity (mJy/ beam)
Observing time (s)

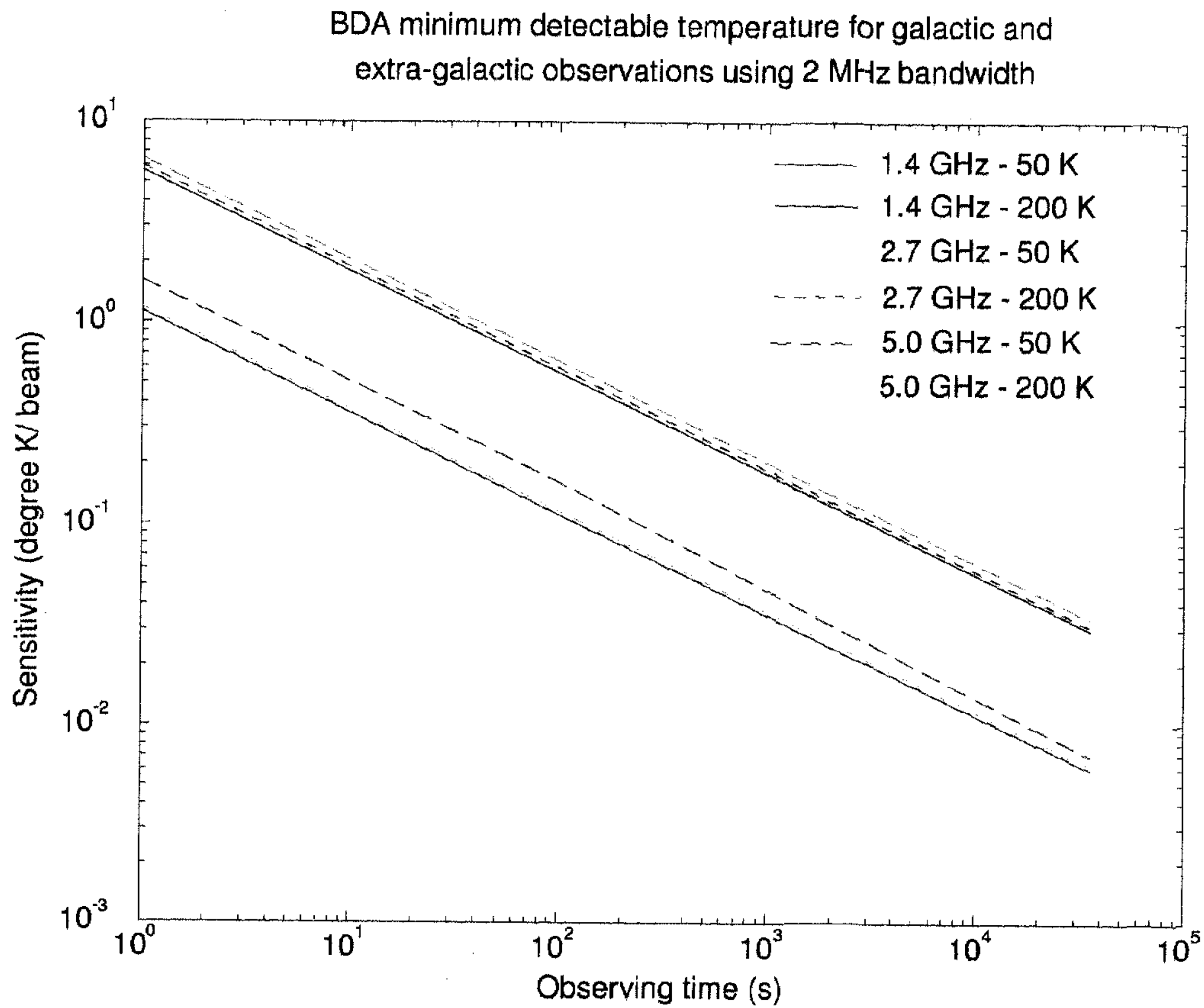

BDA minimum detectable temperature for solar observations
using phased array with various bandwidth
1.4 GHz
2.7 GHz
5.0 GHz
10 kHz
50 kHz
2 MHz
10 MHz
Sensitivity (degrees K/ beam)
Observing time (s)
10^4
10^2
10^0
10^{-2}
10^0
10^1
10^2
10^3
10^4
10^5

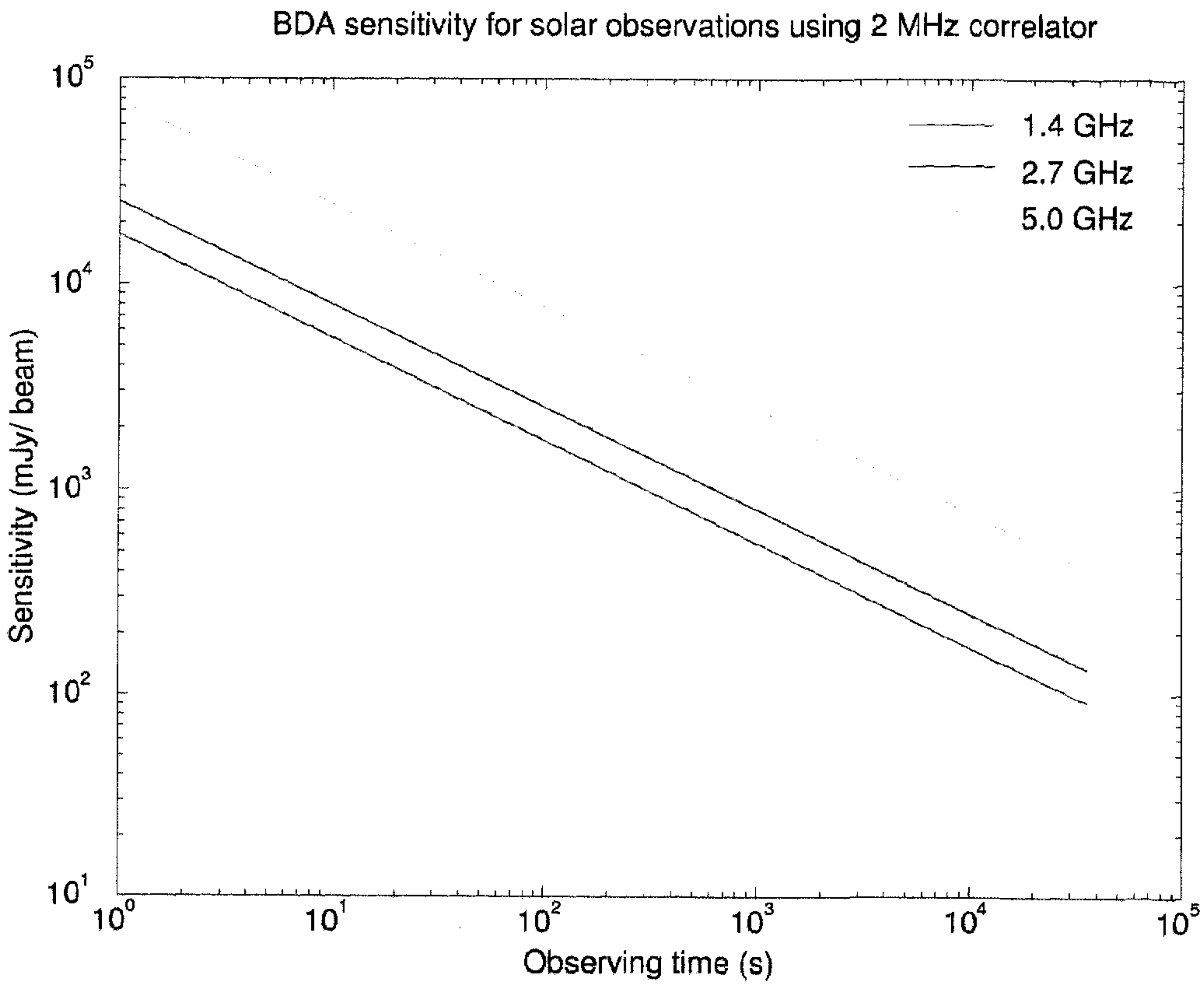

BDA minimum detectable temperature for galactic and extra-galactic observations using phased array with various bandwidth
1.4 GHz, 2.7 GHz
5.0 GHz
T A= 50 K
10 kHz
50 kHz
2 MHz
10 MHz
Sensitivity (degrees K/ beam)
Observing time (s)
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^0
10^1
10^2
10^3
10^4
10^5

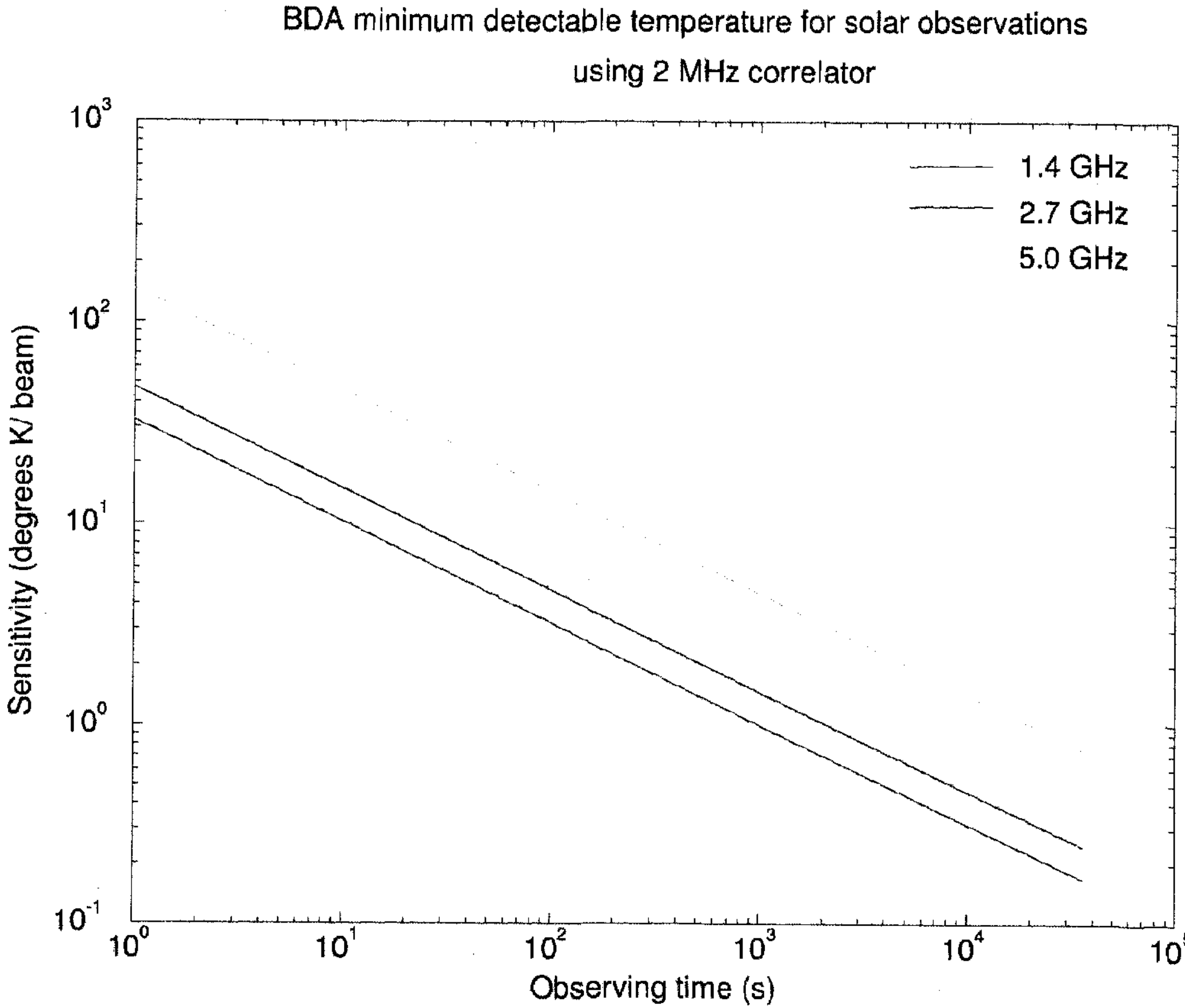

BDA minimum detectable temperature for galactic and extra-galactic observations using phased array with various bandwidth
1.4 GHz, 2.7 GHz
5.0 GHz
T_A = 200 K
10 kHz
50 kHz
2 MHz
10 MHz
Sensitivity (degrees K/ beam)
Observing time (s)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^0
10^1
10^2
10^3
10^4
10^5



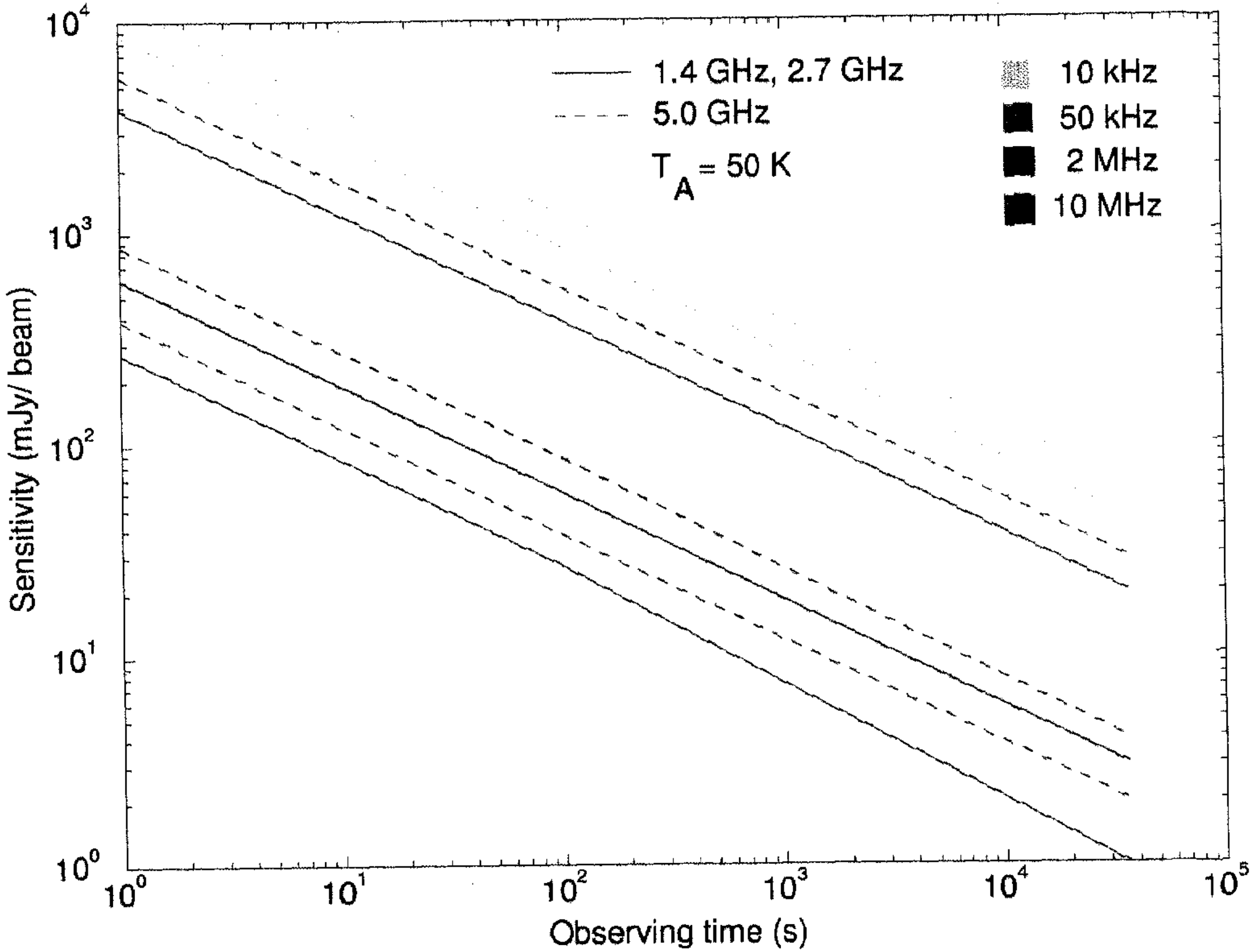
BDA sensitivity for galactic and extra-galactic observations
using 2 MHz correlator
Sensitivity (mJy/ beam)
Observing time (s)
1.4 GHz - 50 K
1.4 GHz - 200 K
2.7 GHz - 50 K
2.7 GHz - 200 K
5.0 GHz - 50 K
5.0 GHz - 200 K

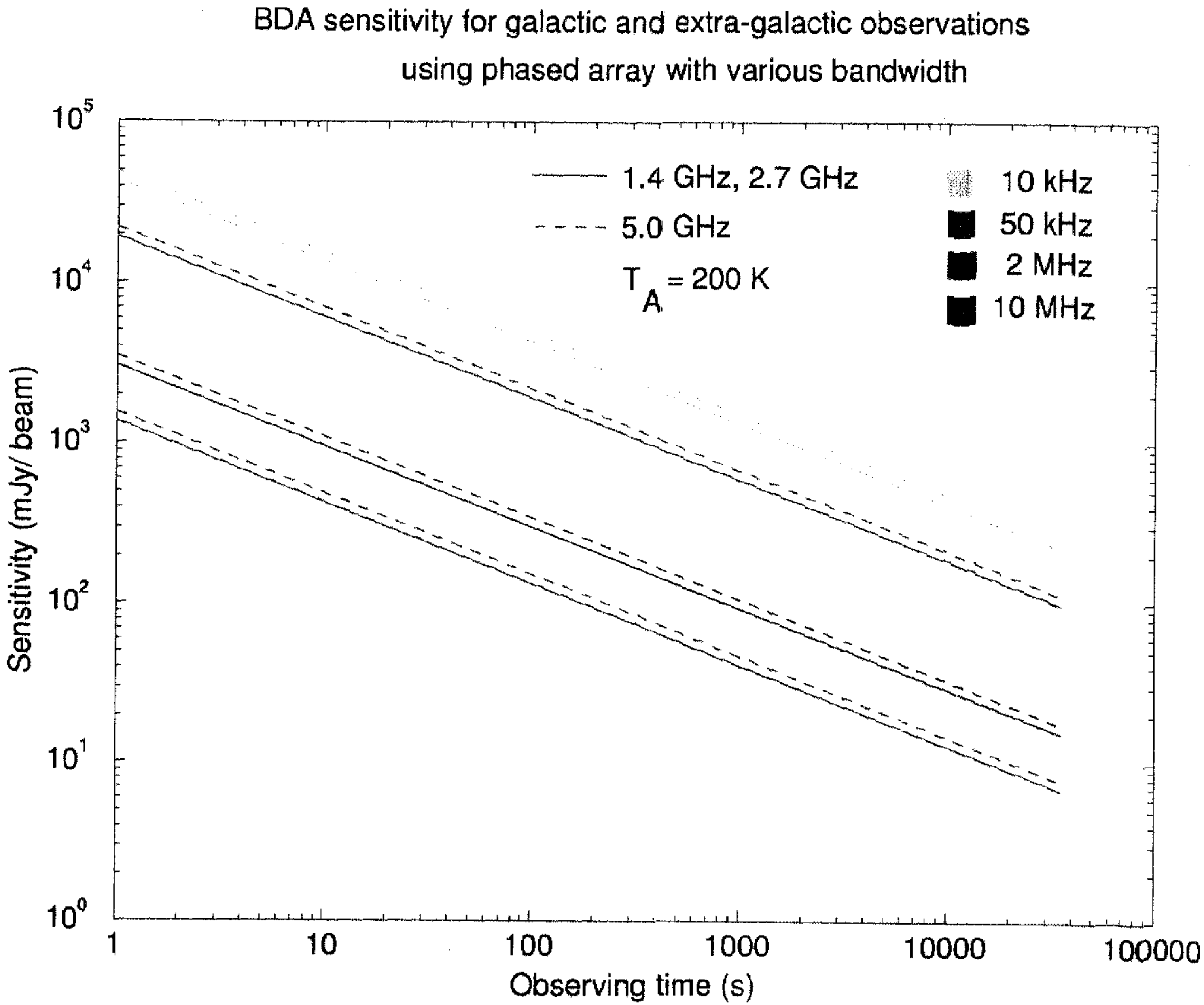

BDA minimum detectable temperature for galactic and
extra-galactic observations using 2 MHz bandwidth
Sensitivity (degree K/ beam)
Observing time (s)
1.4 GHz - 50 K
1.4 GHz - 200 K
2.7 GHz - 50 K
2.7 GHz - 200 K
5.0 GHz - 50 K
5.0 GHz - 200 K
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}


BDA sensitivity for solar observations using 2 MHz correlator
Sensitivity (mJy/ beam)
Observing time (s)
1.4 GHz
2.7 GHz
5.0 GHz
10^1
10^2
10^3
10^4
10^5
10^0


BDA minimum detectable temperature for solar observations
using 2 MHz correlator
Sensitivity (degrees K/ beam)
Observing time (s)
1.4 GHz
2.7 GHz
5.0 GHz
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

BDA sensitivity for galactic and extra-galactic observations using phased array with various bandwidth




BDA sensitivity for galactic and extra-galactic observations
using phased array with various bandwidth
1.4 GHz, 2.7 GHz
5.0 GHz
T_A = 200 K
10 kHz
50 kHz
2 MHz
10 MHz
Sensitivity (mJy/ beam)
Observing time (s)
10^5
10^4
10^3
10^2
10^1
10^0
1
10
100
1000
10000
100000