Astronomical Surveys with the Green Bank Earth Station

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Overview

Use of the Green Bank Earth Station (GBES) 45ft telescope for radio astronomy will improve the system reliability and better determine the pointing and gain measurements. This document summarizes characteristics of the GBES 45ft telescope and receivers relevant to astronomical surveys of the sky at 15 and 8.5 GHz. The existing hardware is described, the scientific merits of a survey summarized, a simple survey plan is outlined and possible improvements to the GBES listed. An image obtained with the GBES of the galactic center is presented.

GBES Mission Benefits

The operation of the GBES antenna as a radio telescope provides a continuous test of the GBES readiness for tracking satellites. In addition, experience in previous surveys has shown that antenna pointing and gain characteristics are most completely determined by survey observations (Condon, *personal communication*). In survey mode, all detectable sources are used to check pointing and gain corrections.

Also the scientific results of the high frequency survey, detecting and monitoring high variability sources and identifying Gamma Ray Burster sources are important for orbiting VLBI. These types of sources are exactly the types to be studied by Orbiting VLBI.

Hardware Summary

A detailed description of the hardware and software design for the OVLBI telescope is given in the NRAO document entitled *The Green Bank OVLBI Earth Station: Report On the Detailed Design Phase* by L. D'Addario *et al.* 1992. Here, only the existing (and planned) elements relevant to surveys are itemized.

Antenna: 13.7 meter (45 ft) diameter antenna is expected to have minimum efficiency, $\eta = 0.35$. The effective area, A_e, of the antenna is 51.6 m^2. (This area implies a 53.5 Jy source would increase the receiver temperature by 1 Kelvin.)

Receivers: At both 15 and 8.5 GHz, the GBES will have cooled receivers with estimated total system temperature (receiver + sky) of 67^o K. The continuum dual polarization receivers are sensitive over a wide bandwidth (~1GHz). The 500 MHz bandwidth IF provides both polarizations at both frequencies to the total power detectors.

Detector: Total power detectors provide continuous total power levels to the station computer via the Monitor and Control Bus.

Software: The GBES has VxWorks running on Motorola 68000 family computer, which controls antenna motion and monitors GBES functions such as the received power levels. Software already exists to measure the peak and centroid location of emission, in order to check antenna pointing characteristics. The VxWorks computer is on a local area network where data processing tasks can be given to other work stations.

Surveys

For a survey of the sky to be useful, good sensitivity to large angular areas are required in short times. Given the GBES antenna size and low receiver system temperature, a 1 second observation yields a 0.1 Jy RMS noise level for both 15 and 8.5 GHz observations. At 15 GHz, the antenna beam FWHM is approximately 6 arc minutes, and the angular area of the beam is 2.4×10^{-6} sr.

A reasonable time scale for completing a survey of the northern sky is 10 days. Assuming a 0.25 second integration on each beam, the antenna would need to move at 24 degrees per minute during the survey. (Well below the 40 degrees per minute maximum speed of the 45 ft.) Surveying 2π sr to 0.2 Jy RMS requires $2\pi/4 \times 2.4 \times 10^{-6} = 6.5 \times 10^{5}$ seconds = 8 days. Two days of the 10 day cycle would be reserved for calibration and antenna maintainance. In the same time, the sky is also surveyed at 8.5 GHz with RMS noise level of ~0.08 Jy. At the end of six months, the 15 GHz survey reaches a RMS noise level of 0.05 Jy/beam.

For certain types of research, small angular regions (a few square degrees) may also be repeatedly surveyed. A square degree of sky contains 127 GBES beams at 15 GHz, so that an RMS noise level of ~20 mJy/beam is achieved in 1 hour. (~ 6 mJy/beam at 8.5 GHz) In this survey mode, the GBES will continuously scan a region of the sky.

The calculations above to do not include loss of sensitivity due to the filtering processes required to remove atmospheric variations. However, because the sky is mostly empty at these flux density levels, the adjacent off-source sections of the survey can be used for measurement of the atmospheric variations without significant degredation of the on-source measurements.

Scientific Justification

To date, no complete survey of the sky has been done at either 15 or 8.5 GHz. It is likely that most of the sources detected at the flux density levels accessible to the GBES 45ft have already been detected in earlier surveys, however it is also probable that a complete survey in a new wavelength band will discover new types of objects or shed new light on already detected objects.

The scientific uses of the 45ft survey observations are:

Gamma Ray Bursts: During the last decade, gamma ray burst sources have been detected which are brighter than our entire galaxy for a period of a few milliseconds

(Hudec, R 1993, *Astron. Astrophys. Suppl.*, **97**:49). No optical or radio identification has ever been made of these sources, and the origin of these bursts remains a mystery. Gamma Ray burst sources are believed to be detectable at radio wavelengths for a few days after the bursts (Paczynski and Rhoads 1993, "Radio Transients of Gamma Ray Bursts", *Ap. J.*, Submitted).

Variable Sources: Radio sources are known to show stronger and earlier variation at short wavelengths (Kellerman and Pauliny-Toth 1968, *A.R.A.A.*, **6**: 417). Several groups are monitoring radio source variations, but no complete sample of sources is available for study.

New Objects: Surveys of the sky have detected new and unexpected types of sources (e.g. pulsars, gravitational lenses). Because the 15 GHz band has not yet been surveyed, the new discoveries are possible.

Survey Plan

Our survey plan is to observe the entire northern sky at 10 day intervals, in order to monitor source variability, detect explosive events and average the surveys to produce a high sensitivity, all sky image.

Since only a few hundred sources will be detected with signal-to-noise-ratio (SNR) greater than 10, between surveys, the marginal detections (SNR $\sim$ 7) will be re-observed to bring the number of reliable (SNR $>$ 10) detections up to a few 1000 per survey.

During the surveys, the Gamma-ray Observatories will be monitored for reports of bright gamma-ray detections. The locations of these gamma ray bursts are known only with accuracy of a few degrees, and these areas will be intensively surveyed, searching for new or variable radio emission. When new sources are detected, they will be re-observed with the VLA to determine positions sufficiently accurate for optical identification.

When gamma-ray candidate regions are not visible, the large scale surveys will continue.

Gamma Ray Bursts

The brightest of these gamma rays bursts occur at irregular intervals of a few months (Fichtel *et al.* 1993, *Astron. Astrophys. Suppl.*, **97**:13, (Fishman *et al.* 1993, *Astron. Astrophys. Suppl.*, **97**:17). The exact angular location of origin of these bursts is known only to ± 1 degree, and a survey instrument must be available at critical times for searches of a few square degrees at high frequencies.

OVLBI Improvements

Naturally, since the OVLBI-ES is not primarily designed for Astronomical surveys, there are several changes to the OVLBI-ES that might improve the ability to make astronomical observations. However, since the mission of OVLBI-ES is satellite tracking, all changes must improve OVLBI-ES reliability.

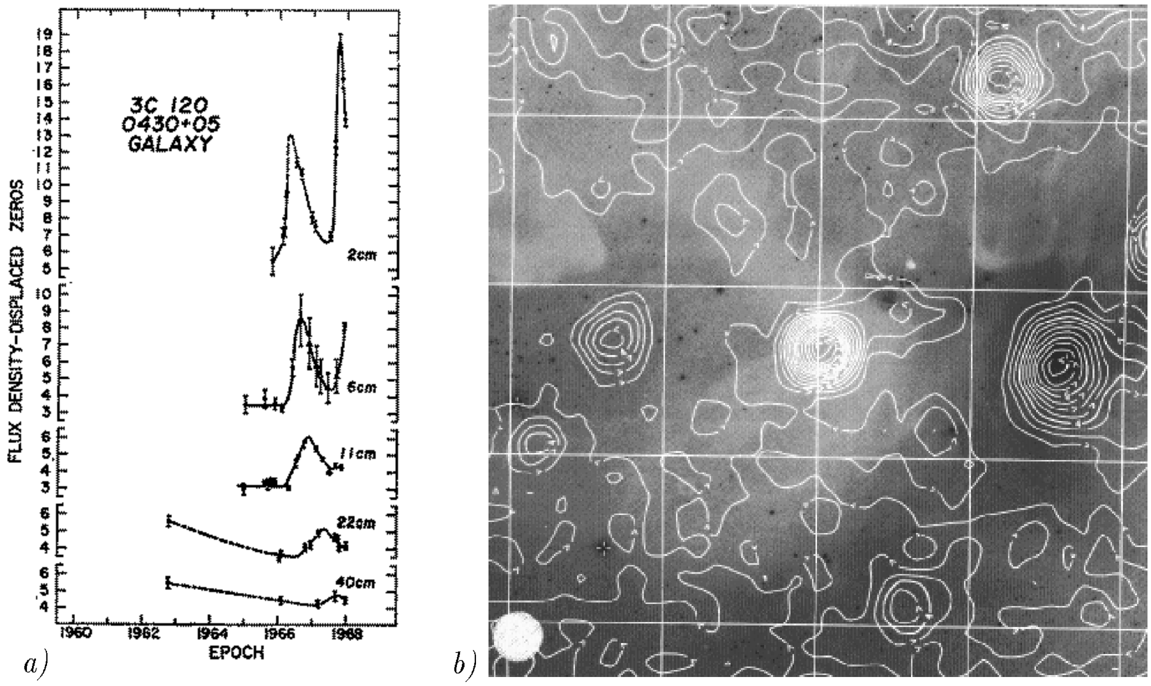

Figure 1: *a)* Variations of radio source flux density as a function of time and wavelength of observation (Kellarmann and Pauliny-Toth 1968). Note much greater variation at 15 GHz (2 cm) than at lower frequencies. *b)* Radio wavelength image contours superimposed on a 1 square degree field containing the *continuous* gamma ray source L1688 (Schlickeiser *et al.* 1989, *Astron. Astrophys.* **216**:197). Radio observations have been used to study star forming regions with gamma ray emission. The 15 GHz survey will have an angular resolution similar to that shown in this figure.

One survey improvement is mounting a second 15 GHz receiver next to the presently planned 15 GHz receiver. If properly done, this receiver can be a "hot" spare for the 15 GHz receiver and allows doubling the survey speed. Clearly this improves the OVLBI-ES reliability and can largely be done with already budgeted spare parts.

An additional improvement for OVLBI-ES is increasing the bandwidth of continuum signal available for detection. Currently, dual polarization channels 500 MHz wide are available, and increasing the channel width to 1 GHz immediately improves the survey sensitivity by a factor of $\sqrt{2}$. Parts of the receiver-backend-detector system are already capable of 1 GHz bandwidth.

Conclusions

Radio surveys of the sky with the GBES are clearly both feasible and valuable. In addition to providing the highest radio frequency survey to date, the GBES surveys are a unique opportunity to contribute to the active field of gamma ray burst studies.

Perhaps most important, the GBES surveys provide a continuous test of the GBES readiness for its most important task, tracking satellites.

Appendix A: Galactic Center Observation

An observation with the Ku band Front End was made on the night of 94 April 26, toward the galactic center. A 10^o by 10^o region was scanned while moving the antenna in elevation at 3 degrees per minute and recording data every 0.25 seconds. Adjacent elevation scans were offset by 3 arc minutes in right ascension. The total observing time was 2.8 hours.

The image was made by median filtering the individual scans to remove the sky background variations. The median filter width was two degrees, so this image is insensitive source structure with angular scale larger than 1 degree. A C^{++} program was written by R. Payne (NRAO) to write the data into FITS format tables. Another program was written to grid the points of observation into an image. The contour plot was produced using the Astronomical Image Processing System.

Note the low declination of this image, showing that high quality images can be made with the GBES at these wavelengths at low elevation.

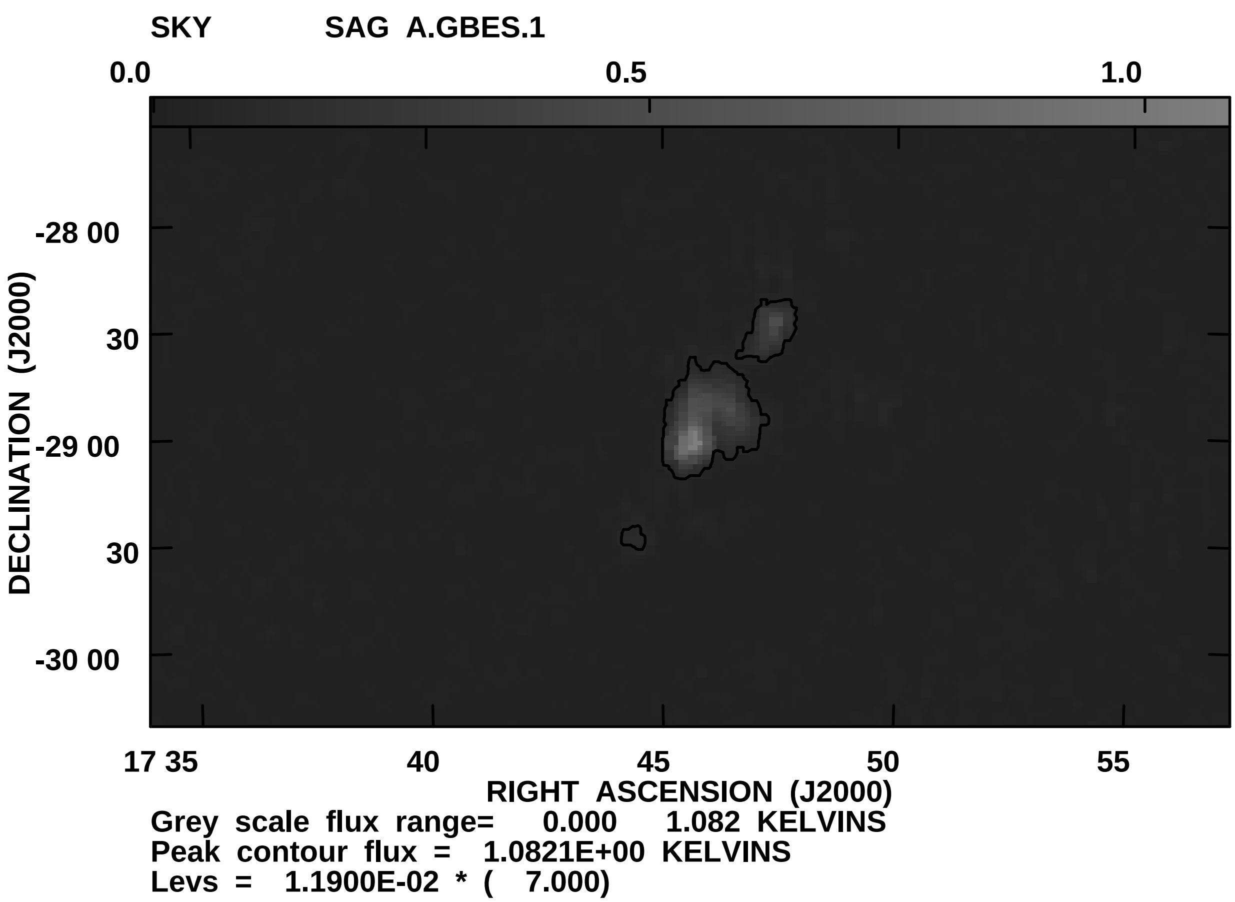

Figure 2: Image of the Galactic center made at 14.1 to 14.6 GHz with the GBES Left and Right circularly polarized Feed. The RMS noise level in the image is 0.012 K, corresponding to 0.64 Jy. The central component is the galactic center, Sagittarius A, the northern component is an H_{II} region, Sagittarius B, and the southern component is Sagittarius C.