

Space VLBI at Low Frequencies

D.L. JONES¹, R. ALLEN², J. BASART³, T. BASTIAN⁴,
W. BLUME¹, J.-L. BOUGERET⁵, B. DENNISON⁶, M. DESCH⁷,
K. DWARAKANATH⁸, W. ERICKSON⁹, W. FARRELL⁷, D. FINLEY⁴,
N. GOPALSWAMY⁷, R. HOWARD¹⁰, M. KAISER⁷, N. KASSIM¹¹,
T. KUIPER¹, R. MACDOWALL⁷, M. MAHONEY¹, R. PERLEY⁴,
R. PRESTON¹, M. REINER⁷, P. RODRIGUEZ¹¹, R. STONE⁷,
S. UNWIN¹, K. WEILER¹¹, G. WOAN¹² & R. WOO¹

¹ *Jet Propulsion Laboratory, California Institute of Technology, USA*

² *Space Telescope Science Institute, USA*

³ *Iowa State University, USA*

⁴ *National Radio Astronomy Observatory, USA*

⁵ *Observatoire de Paris, France*

⁶ *Virginia Polytechnic Institute, USA*

⁷ *Goddard Space Flight Center, USA*

⁸ *Raman Research Institute, India*

⁹ *University of Maryland, USA, & University of Tasmania, Australia*

¹⁰ *Orbital Sciences Corp., USA*

¹¹ *Naval Research Laboratory, USA*

¹² *University of Glasgow, UK*

Abstract

At sufficiently low frequencies, no ground-based radio array will be able to produce high resolution images while looking through the ionosphere. A space-based array will be needed to explore the objects and processes which dominate the sky at the lowest radio frequencies. An imaging radio interferometer based on a large number of small, inexpensive satellites would be able to track solar radio bursts associated with coronal mass ejections out to the distance of Earth, determine the frequency and duration of early epochs of nonthermal activity in galaxies, and provide unique information about the interstellar medium. This would be a “space-space” VLBI mission, as only baselines between satellites would be used. Angular resolution would be limited only by interstellar and interplanetary scattering.

1 Introduction

Ground-based radio interferometers are able to produce images of the sky at frequencies down to a few tens of MHz. Some important scientific

goals, however, require imaging at even lower frequencies. Absorption and refraction by the ionosphere prevents imaging from the ground at frequencies of a few MHz and lower, so an interferometer array composed of inexpensive satellites will be needed. Suitable locations for a space-based array include very high Earth orbits, halo orbits about the Sun-Earth Lagrange points, Earth-trailing heliocentric orbits, the far side of the Moon, and (perhaps) lunar orbit. The optimal choice depends on financial considerations and the unavoidable tradeoff between a benign environment in which to maintain a multi-satellite array and the difficulty of getting enough data from the array to Earth.

2 Science Goals

What unique science can be done only at frequencies below ~ 10 MHz? There are two general areas where very low frequency observations are critical: First, sources of emission which are intrinsically limited to low frequencies (e.g., plasma oscillations and electron cyclotron masers), and second, observations of strongly frequency-dependent absorption (e.g., free-free absorption by diffuse ionized interstellar hydrogen). Type II radio bursts from interplanetary shocks driven by coronal mass ejections provide a good example of the first case. These intrinsically narrow-band emissions decrease in frequency as the shock propagates farther from the Sun into regions of lower plasma density. In order to image and track type II bursts as they approach 1 AU from the Sun, observations at frequencies below 1 MHz are necessary. This would allow us to predict the arrival at Earth of coronal mass ejections, which can trigger severe geomagnetic storms. If located far enough from Earth, a low frequency array would also be able to image Earth's magnetosphere from the outside and observe how it changes in response to solar disturbances.

A sensitive map of the radio sky with arcminute angular resolution at a few MHz would be especially effective at detecting coherent emission from disks, jets, and possibly gas giant planets orbiting close to nearby stars. Most coherent processes have sharp upper-frequency limits, and can only be detected at low frequencies.

All-sky surveys at low frequencies would map the galactic distribution of low energy cosmic ray electrons and would likely discover large numbers of high redshift galaxies, "fossil" radio lobes, and large-scale interstellar shocks and shells from old galactic supernovae and γ -ray bursts. In addition, diffuse ionized hydrogen could be detected via its

absorption of radiation from extragalactic radio sources across the sky. These observations would complement H α emission maps, which predict large variations in free-free optical depth on angular scales of a few degrees.

3 Requirements for a Low Frequency Array in Space

Any space-based array for very low frequency imaging will need to meet three fundamental requirements: 1) the array must be located far enough from Earth to avoid terrestrial interference and the extended ionosphere, 2) there must be a large enough number of individual antennas in the array to produce dense, uniform (u, v) coverage in all directions simultaneously, and 3) the observing bandwidth must be sufficient to provide useful sensitivity for short snapshot observations. The second and third requirements result from the nearly omnidirectional nature of reasonably sized antennas at very low frequencies. Strong variable radio sources anywhere on the sky will affect the observed total power levels, and unless such sources are imaged on short time scales their time-variable sidelobes will limit the dynamic range of observations in other directions. Simulations show that a minimum of 12 satellites will be needed, with at least 16 satellites preferred (see Figure 1 on the next page).

The maximum useful baseline length is set by interstellar and interplanetary scattering. These effects are proportional to ν^{-2} and thus are much stronger at low frequencies. For frequencies of a few MHz, maximum baselines of a few hundred km are appropriate. The degree of scattering at any given frequency is a strong function of direction on the sky. Consequently, it is important to have a wide range of baseline lengths in the array. Short projected baselines are needed in any case to allow angularly large structures in solar radio bursts and the galactic synchrotron background to be imaged.

Imaging the entire sky is a daunting task, but it can be made tractable by dividing the sky into $\sim 10^3$ fields of view and relying on parallel processing. Each field will require only a 16-bit Fourier transform in the radial direction to account for sky curvature, and ≈ 100 deconvolving beams (see Frail et al. 1994). During deconvolution, model components from all fields must be subtracted from the full 3-D visibility data set to remove sidelobes from other fields during the next iteration of residual image production. The total computing rate required is large by current standards, but will be readily available within a few years.

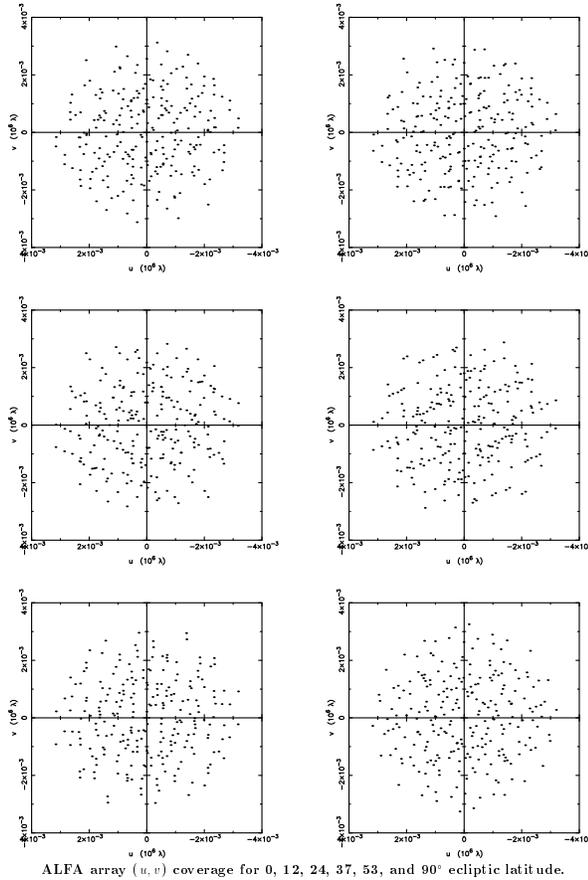


Figure 1: Snapshot (instantaneous) u, v coverage at 10 MHz from a 16 satellite spherical array over a wide range of directions simultaneously.

Acknowledgements. Part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the US National Aeronautics and Space Administration.

References

Frail, D., Kassim, N. & Weiler, K. 1994, *AJ*, **107**, 1120