Galaxies and Their Constituents at the Highest Angular Resolutions
IAU Symposium, Vol. 205, 2001
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Prospects for High Angular Resolution at Low Frequencies

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Abstract. High angular resolution imaging at low frequencies (below $\sim$ 10 MHz) requires observations from above the ionosphere. A radio interferometer array in space will be able to open new vistas in solar, terrestrial, galactic, and extragalactic astrophysics. A space-based interferometer could image and track transient disturbances in the solar corona and interplanetary medium - a new capability which is crucial for understanding many aspects of solar-terrestrial interaction and space weather. It could also produce the first sensitive, high-angular-resolution radio surveys of the entire sky at low frequencies. The radio sky will look entirely different below 10-30 MHz because new emission and absorption processes become dominant at these frequencies. As a result, low frequency surveys from space will provide a fundamentally new view of the universe and an extraordinarily large and varied science return.

1. Introduction

The scientific promise of high resolution radio observations at low frequencies, and the need to make such observations from space, has been recognized for many years. Concepts for low frequency radio arrays in Earth orbit, solar orbit, and on the lunar surface have been developed at several institutions. One mission concept, the Astronomical Low Frequency Array (ALFA), was proposed to NASA as a medium-class Explorer mission in 1998. Although the proposal was not selected for funding by NASA in 1999, the scientific peer reviews in both solar and astrophysics areas were favorable. Sooner or later a low frequency array in space will be created. The scientific goals of such an array, which are largely independent of any specific array design or location, are compelling.

2. Scientific Goals

A low-frequency interferometry mission will produce high resolution radio images of the solar corona and interplanetary disturbances such as shocks driven by coronal mass ejections (CMEs). Equally important, for the first time we will be able to image and track these solar disturbances from the vicinity of the Sun all the way to 1 AU, which requires observing frequencies from tens of MHz to tens of kHz. Since Earth's ionosphere severely limits radio interferometry from the ground at frequencies below $\sim$ 30 MHz, these measurements must be made from space.

A low-frequency interferometry mission will also produce the first sensitive, high resolution radio images of the entire sky at frequencies below 30 MHz – the last region of the spectrum that remains unexplored with high angular resolution. Many physical processes involved in the emission and absorption of radiation are only observable at low radio frequencies. For example, the coherent emission associated with electron cyclotron masers, as seen from the giant planets, Earth, and several nearby stars, is not only expected to occur and be detectable elsewhere in the galaxy but to be ubiquitous. The appearance of the galactic plane will be dramatically different than at higher frequencies because of free-free absorption by ionized interstellar gas. It is also very likely that unexpected objects and processes will be discovered.

3. Constraints on Low-Frequency Interferometry

The useful size of a low-frequency array is limited by angular broadening caused by interstellar and interplanetary scattering. However, this scattering limit is a strong function of direction and observing frequency. To allow for this, it will be desirable to vary the size of the array during the mission to increase or decrease the maximum angular resolution. Maximum baseline lengths will vary between a few tens of km to a few hundred km.

Among the challenges of imaging the sky at low radio frequencies is the need to image the entire sky at the same time. This is necessary because individual radio antennas of reasonable size have very low directivity at these frequencies (which, of course, is the reason for using an interferometer array in the first place). Consequently very strong radio sources will create sidelobes in directions far from their positions, and high dynamic range imaging will require that the effects of strong sources be removed from all sky directions, not just from the region immediately adjacent to the sources. This in turn requires an array geometry which produces highly uniform aperture plane (u, v) coverage in all directions simultaneously, a requirement that no previous interferometer array has had to meet. A quasi-random distribution of antennas on a single spherical surface has been shown to provide excellent aperture plane coverage in all directions with a minimum number of antennas.

The number of detectable sources will be limited not by thermal noise (mainly from the Galactic background) but by confusion noise and dynamic range. Confusion effects will be minimized by imaging all strong sources on the sky simultaneously so their flux can be taken into account for each field of view. Dynamic range is determined mainly by the number and distribution of visibility samples, the data signal-to-noise ratio, the quality of calibration, and the complexity of the sources being imaged. Based on our imaging simulations, we expect a spherical array of 16 antennas to provide a dynamic range of $10^2 - 10^3$ for relatively compact sources ($<$100 beams in size), depending on frequency. For very extended sources or the lowest observing frequencies the dynamic range will still be a few tens, which is entirely adequate for imaging strong, rapidly evolving sources such as solar radio bursts.

Acknowledgments. Portions of this research have been carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.