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The Astronomical Low Frequency Array (ALFA): Imaging from Space

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Abstract

The ALFA mission is a proposed astronomical observatory in space to make high resolution radio images at frequencies below the ionospheric cutoff (∼ 20 MHz). This multi-satellite interferometric array will image solar as well as non-solar phenomena in the frequency range 0.03 - 30 MHz. In this paper, we provide an overview of the ALFA mission, with particular emphasis on solar studies to be undertaken.

Key words: Sun: CMEs — Sun: Prominence Eruptions — Sun: Radio bursts

1. Science Objectives

Radio imaging of cosmic objects by the ground based radio arrays is limited to frequencies above the ionospheric cutoff (∼ 20 MHz to 5 MHz, see Erickson, 1996) because the intervening ionosphere is opaque to lower frequencies. One has to go to space to make observations at frequencies below the ionospheric cutoff. Low frequency imaging from ground based observations has revealed a number of interesting solar phenomena which are expected to continue into the interplanetary medium: Coronal mass ejections (CMEs), magneto hydrodynamic shocks, hot plasmoids from solar eruptions, and relativistic electron beams (see e.g., Gopalswamy and Kundu, 1990; 1995). In the past, there were several space missions that carried radio instruments which made observations that resulted in important and serendipitous discoveries, even though these instruments did not have any spatial resolution (see e.g., Kaiser 1990 for a review). Even with single elements, it was possible to map the topology of the interplanetary magnetic field by remote sensing the radio emission produced by mildly relativistic electrons propagating along these magnetic fields (Bougeret et al. 1984; Reiner et al, 1998).

Spatial information is needed to understand the origin and propagation of transient solar disturbances such as CMEs. Low frequency radio imaging is well suited for studying the CMEs and the associated phenomena from a number of view points.

(i) The radio waves can be detected both from the solar disk as well a from above the limb. This is a major advantage for collecting information on Earth-directed CMEs over the white light coronagraphs which are biased towards limb events.

(ii) Thermal emission: The ambient corona up to an extent of several solar radii can be directly imaged via the thermal free-free emission from the corona. A CME is an excess mass over this ambient corona resulting in an additional contribution to the coronal free-free emission. This has been demonstrated using ground based radioheliographs which imaged CME-related changes in the ambient corona and the CME itself (Sheridan et al, 1978; Gopalswamy and Kundu, 1992). Unlike Thomson-scattered photospheric light, the free-free emission from CMEs does not depend on the location of the CME with respect to the plane of the sky.

(iii) Nonthermal emission originates from shocks, plasmoids and electron beams, in addition to trapped particles in stationary structures attached to the Sun. These structures can be distinguished in an eruptive event and hence imaging them in radio provides valuable information on the CME substructures that could not be obtained from white light observations. In radio terminology, type II and moving type IV bursts correspond to shock waves and

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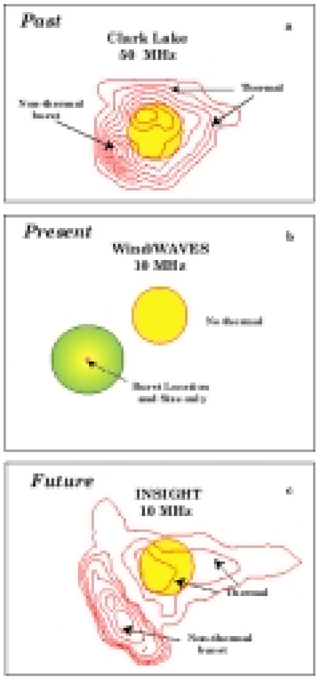

Fig. 1.. (a) A low frequency contour image of the Sun obtained by the Clark Lake Radio Telescope which imaged both thermal and nonthermal radio emissions. This telescope was an interferometric array which ceased operation in 1987. (b) Location of a nonthermal burst and its size derived from Wind/WAVES experiment which is not an interferometer. This represents the current capability of space based solar radio observations. (c) Schematic of a future radio image that could be obtained by a space based array such as ALFA (both thermal and nonthermal emissions could be imaged simultaneously).

plasmoids while type III bursts correspond to electron beams. In Figure. 1 we have shown how imaging can change our view of the outer corona and interplanetary medium as compared to single element radio observations.

There is also a large number of non-solar phenomena that can be probed using a low frequency imager in space: Search for fossil radio galaxies, galaxies with extremely high red shifts revealing conditions of the early universe (Silk and Rees, 1998), physical conditions in the interstellar medium including turbulence, origin of cosmic ray electrons, particle acceleration in supernova remnants and even detection of extrasolar planets (Jones, 1998). In figure 2, we have shown an all-sky image from a single element and a simulation from an interferometric array with a spatial resolution of a few arc minutes. The improvement will be unprecedented and dramatic. Low frequency imaging also can help us understand Earth's magnetosphere by providing spatially resolved images of the sources of continuum and discrete components of auroral kilometric radiation (Desch et al, 1996). We provide an overview of a proposed interferometric array called the Astronomical Low Frequency Array (ALFA) capable of imaging solar, magnetospheric and astrophysical phenomena.

2. Overview of the Mission

The ALFA mission is guided by two basic requirements: (i) we need an aperture synthesis instrument to obtain spatially resolved observations, and (ii) we need to place the array in space to observe at frequencies below the ionospheric cut-off. The array outputs visibility data which need to be calibrated and Fourier transformed to get the images of the sky. The overall spatial resolution achievable using ALFA is shown in Fig. 3, which is a large improvement on what is available so far. It must be pointed out that the corona, the interplanetary medium and the interstellar medium all have a significant scattering effect on the radio sources, thus limiting the spatial resolution. This is not a major problem for the solar bursts and CMEs because their size scales are enormous in the interplanetary medium; this may however present a challenge in studying microscopic plasma processes.

To meet the science objectives described in the previous section, we need a 16-element interferometer that provides 120 baselines. i.e., 120 Fourier components will be measured during each time step of observation (integration time).

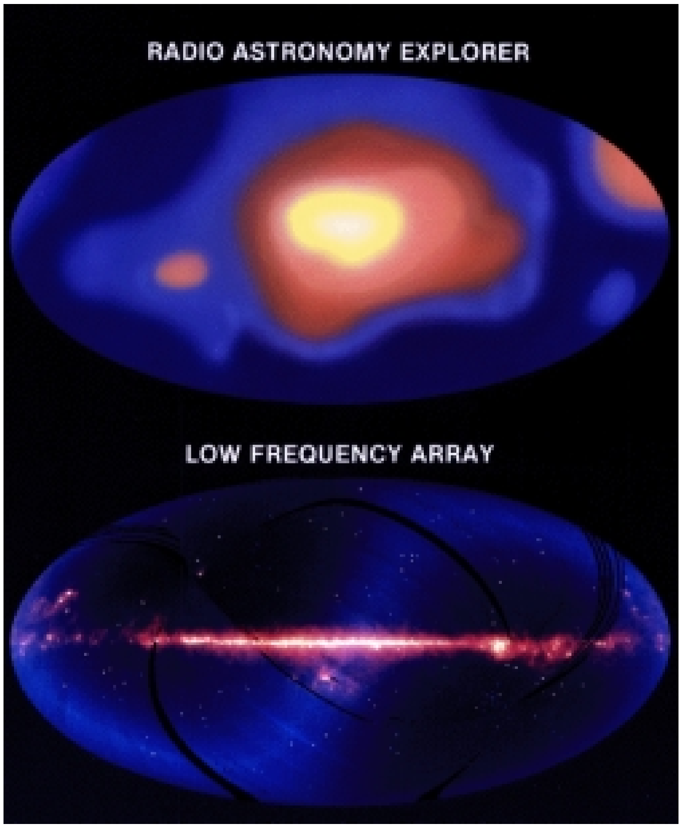

Fig. 2.. Comparing all-sky images from a single spacecraft mission (Radio Astronomy Explorer) with a simulated image with spatial resolution of a few arc minutes obtainable with a low frequency imaging array such as ALFA.

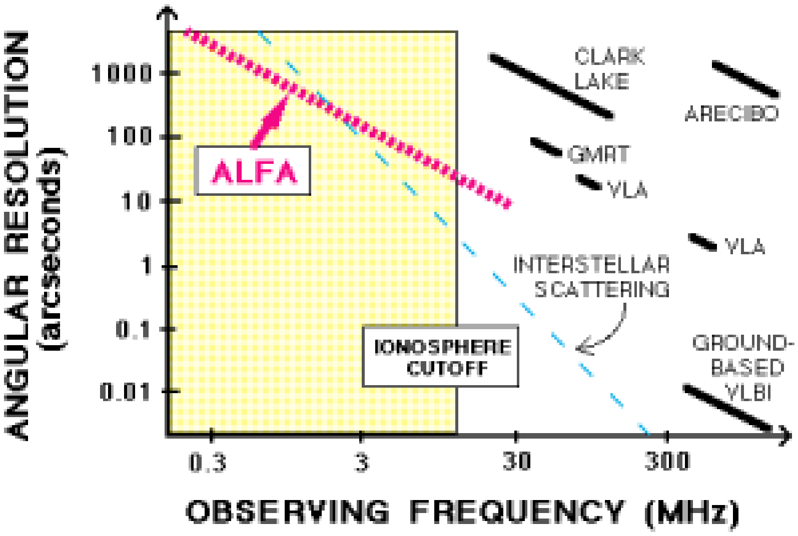

Fig. 3.. Angular resolution of the ALFA array as a function of observing frequency. Angular resolutions of a number of ground based synthesis instruments are also included for comparison. Limitation due to interstellar scattering is shown by the dashed line. There will be additional limitation on the angular resolution due to coronal and interplanetary scattering.

Each element is a single small satellite (called subsat) containing a pair of dipoles (size 10 m) with corresponding low frequency receivers. The receiver output will be sent to ground stations directly from each satellite.

The distribution of the subsats will be made on an imaginary sphere of $\sim$ 100 km diameter (called the Unwin sphere) and the whole array will be allowed to rotate slowly to enhance the visibility coverage. The array will be placed in a distant retrograde orbit (DRO) about the Earth-Moon barycenter (see Fig. 4) in the ecliptic plane. The orbit is chosen such that the radio frequency interference from Earth is minimized. The largest baseline (100 km) determines the angular resolution of the instrument and the shortest baseline determines the largest structure in the sky that can be imaged by the proposed array.

The array will be operated in two basic modes: snapshot imaging for transient solar bursts and all-sky imaging. The snapshot imaging is necessary to study the time variability of transient radio sources and for space weather prediction purposes. Simulations have shown that visibility coverage with high degree of uniformity could be obtained from the proposed configuration even at short spacings. The resulting synthesized beam is of high quality, with side lobe levels generally below 1% of the peak.

The output data from each array element will be time-stamped using X-band carrier signals, sent to the ground stations where they will be recorded on tapes and then transported to the correlation computer to obtain the final product of the mission, viz., images. The array will be launched using a Delta II 7425 launch vehicle. The carrier spacecraft will be slowed into the DRO nine months after the launch to establish the array configuration. The array elements will be deployed sequentially by springs to positions about 50 km from the carrier spacecraft. The baselines will be maintained to an accuracy of less than 3 m using cold gas thrusters.

3. Summary

Getting into space is the next logical step for low frequency radio astronomy and the ALFA mission will accomplish that. The tremendous achievements in communication and satellite technology and the decades of experience in aperture synthesis on Earth will be fully exploited to implement the ALFA mission. Such a telescope is of universal utility for almost all of the astronomical and geomagnetic studies. The mission also represents coordinated efforts from researchers of wide ranging fields and from many nations of the world. The ALFA mission also will be a pioneering mission that can provide important support to the space weather programs which will be more and more relevant as the space based technology advances.

The principal investigator of the ALFA mission is D. L. Jones; the Science Team is: R. J. Allen (STSI), J. P. Basart

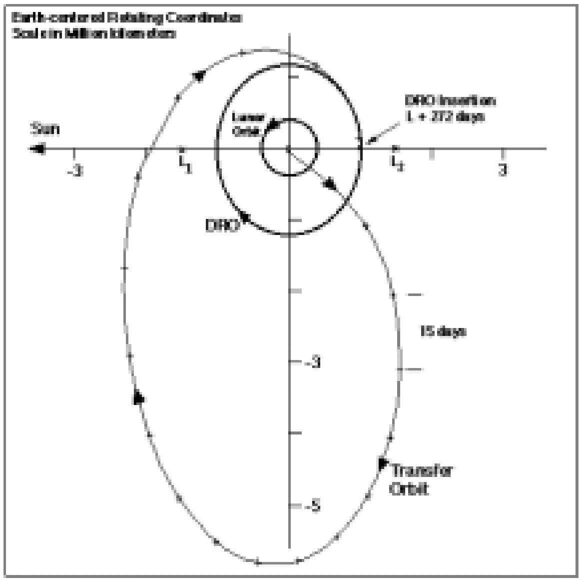

Fig. 4.. Transfer and final Distant Retrograde Orbit (DRO) of the ALFA cluster. The ALFA array will be established 9 months after the initial launch.

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