A PROPOSAL FOR MAPPING THE SKY AT DEKA-HECTOMETER WAVELENGTHS: THE LFSA

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ABSTRACT. The concept is developed for a scientific space mission to survey the entire sky and to image individual sources at frequencies between 1.5 and 26.3 MHz, a frequency range over which the Earth's ionosphere transmits poorly or not at all. The required technology already exists and there are many important scientific goals which can be attained with high sensitivity, high resolution space observations at the lowest frequencies available to astronomy from within the absorbing interstellar plasma of our own Galaxy.

1. INTRODUCTION

The opening of a new spectral window for astronomical investigations has always resulted in major discoveries, significant insights into astrophysical processes, and an enrichment of our understanding of the universe. A recent example is the extremely successful Infrared Astronomy Satellite (IRAS) which surveyed the sky in the far infrared and yielded such important discoveries as galactic cirrus emission and proto-planetary systems.

Our proposal is directed towards imaging the entire sky at frequencies below 30 MHz, which are totally inaccessible or extremely difficult to observe from the ground due to ionospheric absorption and scattering. This frequency range represents a region of the electromagnetic spectrum that is essentially unexplored by astronomy but which, at ~10^6 Hz, is likely to display phenomena as different from those at centimeter radio wavelengths (~10^9 Hz) as centimeter radio phenomena are from infrared (~10^{12} Hz), or infrared are from the ultraviolet (~10^{15} Hz), or ultraviolet are from the x-ray (~10^{18} Hz). Because of this large gap in our knowledge, even though many worthwhile projects can already be defined for a new instrument, the likelihood of discovering new processes and objects is great. An improvement in sensitivity to the few Jansky level and in resolution to the sub-minute-of-arc level will be as much of an advance for the field as was the Einstein satellite for x-ray astronomy or the IRAS for infrared astronomy. Also, observing at frequencies as low as ~1 MHz extends

S. Débarbat et al. (eds.), Mapping the Sky, 483–486.

astronomy to the lowest practicable physical limit for studying electromagnetic radiation from within our Galaxy. At still lower frequencies the diffuse interstellar ionized hydrogen gives a very high optical depth due to free-free absorption over relatively short path lengths.

In order to work at such low frequencies, however, ionospheric disturbances dictate that observations must be taken from space. We propose, therefore, construction of a Low Frequency Space Array (LFSA) to form a space based synthesis interferometer which can carry out high resolution, high sensitivity sky surveying and source imaging over the frequency range from 1.5 to 26.3 MHz where ground based observations are difficult (at 26.3 MHz) to impossible (at 1.5 MHz). Even without considering the serendipitous discoveries which have always accompanied the opening of a new realm of frequency, resolution, or sensitivity in astronomy, a low frequency telescope in space can:

a. map the entire sky, with emphasis on the galactic background non-thermal emission, with high resolution and sensitivity;
b. determine the distribution of galactic diffuse ionized hydrogen by surveying its absorption to discrete background sources;
c. study the interstellar plasma by investigating the origin, distribution, and magnitude of its scattering and refraction;
d. study individual source spectra for energy production mechanisms and such processes as synchrotron self-absorption, Razin-Tsytovich effect, HII absorption, inverse Compton scattering, and synchrotron losses;
e. study the origin of the correlation between low frequency steep spectrum clusters of galaxies and their enhanced x-ray emission;
f. search for "fossil" radio components in "radio quiet" objects and extend the counts of sources to the low frequencies where synchrotron lifetimes approach the age of the universe;
g. image individual sources with high resolution (~10′ at ~1 MHz to ~5" at ~30 MHz) to investigate spectral index changes across source components and to search for extended halos;
h. study the impulsive emission from Jupiter and the Sun and search for similar radiation from other Solar System bodies; and
i. search for the coherent radiation found from Solar System bodies but undetected so far in larger systems.

2. SYNOPSIS OF PROPOSED MISSION

The preliminary instrumental concept is illustrated in Figure 1. A single spacecraft bus places four free-flying antennas (array elements) into a circular orbit at inclination 30° - 60° with semi-major axis of 10,000 - 12,000 km. The bus itself plays no role other than providing final orbit injection. The four array elements are all identical spacecraft with gravity gradient stabilized, outwardly pointing, broad beam, wide bandwidth antennas and full polarization capability. The receivers are near 1.5, 4.4, 13.1, and 26.3 MHz with individual bandwidths of 50 kHz. The full signal received, after suitable digitization and the addition of monitor and control information, is recorded and then transmitted periodically to the ground from each array element for archiving, correlation, and analysis. Clock stability aboard each array element is such that full array coherence is maintained at all times.

The orbits for the four array elements are chosen such that differential dynamical forces cause the array to expand, without active adjustment, from an initial element separation of <1 km to a final separation of >300 km while the orbital revolution and precession sweep out a survey of the sky. This means that after a period of ~1 year of coherent integration with varying baseline lengths and orientations, a complete synthesis of the sky with high resolution and sensitivity at all 4 frequencies will be available (Figure 2). Since each array element will have minor orbit adjustment capability (micro-thrusters), at the end of a complete synthesis it will be possible to compress the array for repeating the process and obtaining the error and consistency checks necessary for all surveys.

The estimated capability of the LFSA with one possible antenna design is given in Table 1.

Table 1: Estimated LFSA Capability

Freq. (MHz)	T_s (K)	t (sec)	A_e (m^2)	σ (Jy)	N_{det}	Appx. Resol.[a]
1.5	3×10^7	7.5×10^6	2400	40	1300	~ 0°.1
4.4	5×10^6	3.8×10^6	1000	9	5000	~ 1′
13.1	3×10^5	1.5×10^6	400	3	6000	~ 0′.3
26.3	3×10^4	$\sim10^6$	175	1.5	10000	~10″

[a]The maximum resolution is generally limited by the interstellar scattering.

T_s = Effective system temperature (determined by galactic background)

t = Integration time = (0.5 data loss factor) x 1 year/directivity

A_e = Total effective array aperture = 4 x effective aperture per antenna

σ = Rms error (assuming 2 polarization channels, 50 kHz bandwidth per channel, and a sensitivity constant of 2)

N_{det} = Estimated number of detectable sources

3. SUMMARY

We have carried out a preliminary investigation of the scientific justification for and technical feasibility of constructing a Low Frequency Space Array (LFSA) which can map the entire sky and image individual sources between 1.5 and 26.3 MHz with high resolution and high sensitivity. The conclusion is that there are many high quality astronomical programs to which such an instrument can be applied and that the necessary space technology, while novel, is already available. Thus, it appears that further development and planning for such a space mission is a worthwhile program at the present time.

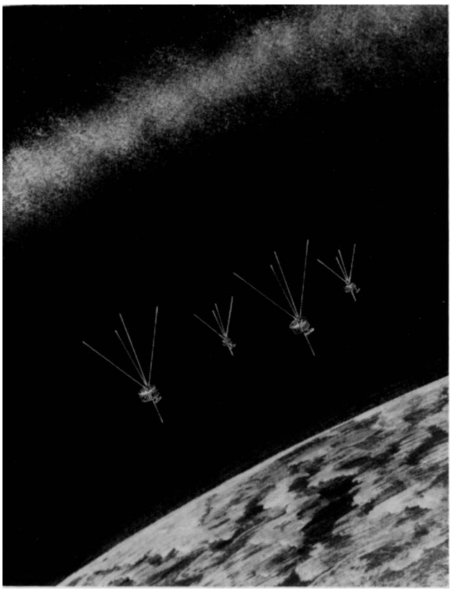

Figure 1: Artist's conception of the Low Frequency Space Array (LFSA) with four array elements.

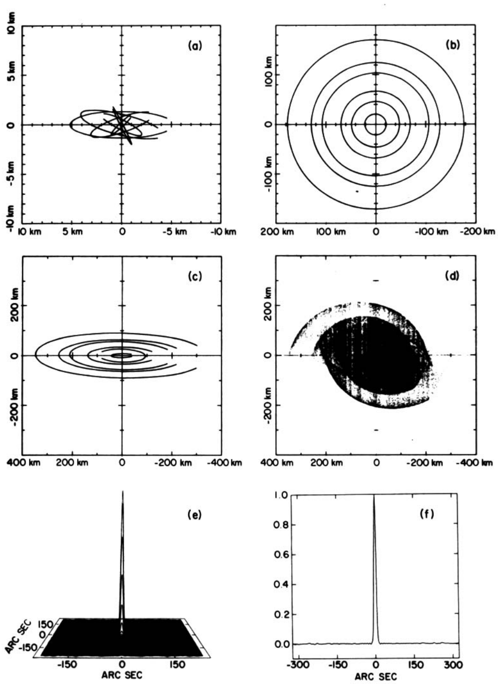

Figure 2: Aperture (Fourier) plane coverage by a 4 element array for a source at RA = 6^h, Dec = 45^o for one orbit on (a) Day 1, (b) Day 180, and (c) Day 360. The total coverage during 1 year is given in (d) and the resulting point spread function (beam pattern) in (e). For a cross cut through the beam pattern better illustrating the sidelobe levels see (f).

https://doi.org/10.1017/S0074180900140070 Published online by Cambridge University Press