WHAT IS FASR?

The Frequency-Agile Solar Radiotelescope (FASR) is the next-generation solar-dedicated radio telescope which has now been recommended as a priority (one of 7 mid-sized ground-based projects) by the 2000 NAS Astronomy & Astrophysics Survey Committee (the McKee-Taylor decadal review). The goals for FASR are

- to achieve an image quality superior to that of the VLA over the frequency range 0.3 - 20 GHz simultaneously

- to achieve 1 arcsecond resolution at 20 GHz (resolution at other frequencies scales linearly with wavelength)

- full-disk imaging over a wide frequency range in two circular polarizations

- solar-dedicated: FASR will observe every day, all day, regardless of cloud cover

- to achieve a large value for the product of (number of frequencies per image set) x (number of image sets per second)

- absolute (astrometric) positional accuracy, sensitive enough to monitor brighter sidereal sources at night

A concensus was reached at an international workshop held in 1995 that these goals represent the logical next step for solar radioastronomy. They can be achieved at modest cost using current technology. A major emphasis will be placed on making FASR data as widely and as easily accessible as possible in processed image form. Because of this we expect that the user-base for FASR will include everyone in the solar and solar-terrestrial communities.

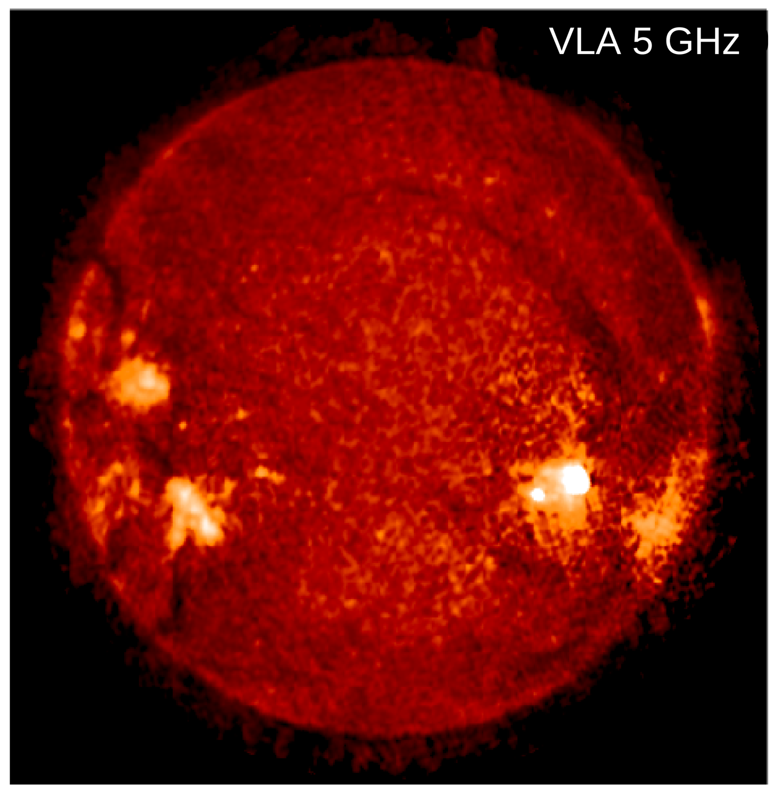


Figure 1. A 14-hour-synthesis full-disk image of the Sun at 4.6 GHz made with the VLA by imaging 26 different fields and combining the data as a mosaicked image. The brightest features are gyroresonant sources over sunspots where strong magnetic fields make the corona optically thick; there the brightness temperatures reach 2 million K. At the other extreme are the filaments seen near the east limb, where the temperature drops to 5000 K. FASR will make full-disk images with much better dynamic range and up to 10 times better spatial resolution at a range of frequencies every second.

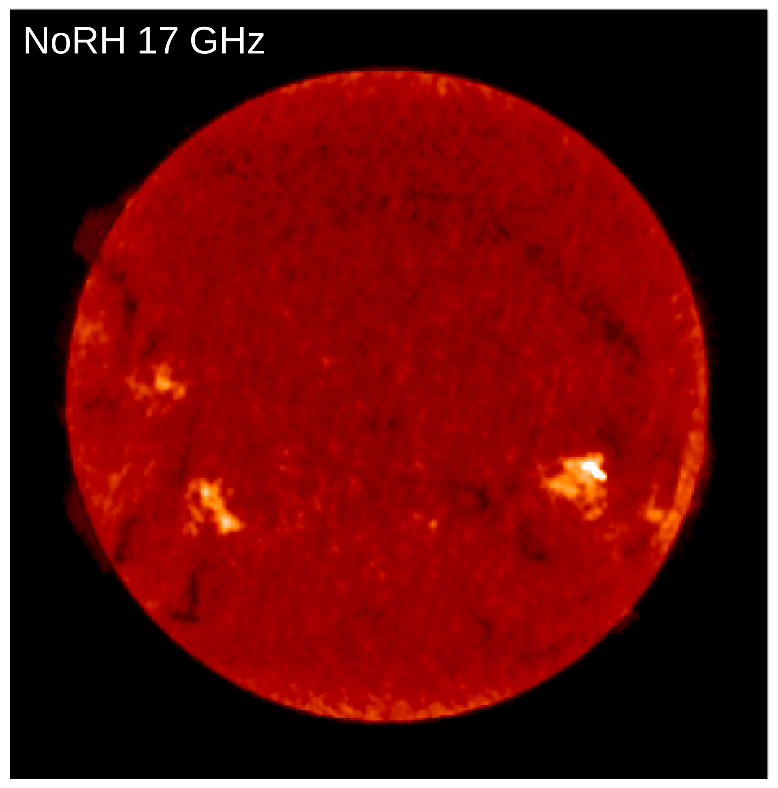


Figure 2. An 8-hour synthesis map of the Sun at 17 GHz made using the 84-element Nobeyama Radioheliograph; the time of this image is about 7 hours later than Figure 1. The resolution is similar (12"). In quiet Sun regions this frequency penetrates lower into the chromosphere, to the 10000 K level, whereas at 5 GHz (Fig. 1) the optically thick level is at 30000 K. At this high frequency the sunspots in the southwest no longer show sources at coronal temperatures because the maximum coronal magnetic field strength is not sufficient (2000 G) for optically thick gyroresonance emission.

SOLAR RADIO EMISSION

Solar radio emission has powerful diagnostic value because it is dominated by two emission mechanisms which we understand very well, and which allow us to see features in the solar atmosphere ranging in temperature from several thousand K up to 10^8 K and higher. It is the only wavelength range with such a wide range of energy coverage. The dominant emission mechanisms are (Figures 1, 2, 3)

- bremsstrahlung, which favors cool dense plasma: at radio wavelengths the solar atmosphere is optically thick due to bremsstrahlung at a height which increases with wavelength, so that by changing wavelength we probe different layers of the atmosphere; and

- gyromagnetic emission. In active regions the low harmonics of this mechanism make the corona optically thick where there are sufficiently strong magnetic fields, which allows us to measure magnetic fields in the corona; and during flares energetic electrons radiate via this mechanism at high harmonics, allowing us to see electrons with energies from tens of keV up to more than 1 MeV.

An important aspect of being optically thick at long wavelengths (the Rayleigh-Jeans limit) is that the observed emission is simply proportional to the brightness temperature of the source: in other words, radio observations of the solar atmosphere act as a pure thermometer measuring temperatures in the atmosphere. No atomic physics and ionization balance calculations are needed to determine temperatures.

SCIENCE GOALS

CORONAL MAGNETIC FIELDS

- Radio emission from active regions at a fixed frequency arises from a very narrow layer of constant magnetic field strength in the corona (Figure 4)
- By observing at different frequencies we peel away the corona in different isogauss layers
- The FASR frequency range corresponds exactly to the range of magnetic field strengths of interest in the corona, 200 - 2500 G
- This is the only technique which allows quantitative mapping of the magnetic field in the corona
- Effects of coronal currents may be seen directly in the radio images

ENERGY RELEASE SITE

- Energy release in solar flares occurs in the corona
- Observations such as Fig. 5 show energetic electrons at a single height
- Broad frequency coverage will show the distribution of emission at all heights in such a flaring loop
- Powerful radio diagnostics resulting from combining spatial and spectral data allow us to pinpoint the energy release site

FLARING LOOPS AND ENERGY DISTRIBUTIONS

- Flare images at different frequencies see different energies and magnetic fields in a flare site (Figures 6, 7)
- Radio spectral information gives a direct measure of the nonthermal electron energy distribution
- Radio-emitting electrons are trapped in the coronal magnetic loops: morphologies of the radio emission can be used to model both the magnetic field distribution and the electron energy and pitch-angle distributions
- Radio timing information, like hard X-ray timing, adds yet another diagnostic dimension

ADDITIONAL SOLAR STUDIES

- Coronal heating: FASR is ideal for quiet-Sun and microflare studies thanks to excellent snapshot imaging ability
- Coronal mass ejections: thermal emission from CMEs may be detected against the disk in the frequency range 0.5 - 1 GHz. No imaging data currently exist in this range to test this possibility
- Characterization of the three-dimensional thermal structure of the atmosphere
- Synoptic measurements over the whole solar disk

NON-SOLAR OBSERVATIONS

- Night-time monitoring of brighter variable stellar (e.g., Cygnus X-3, RS CVn systems) and planetary (e.g., Jupiter) sources

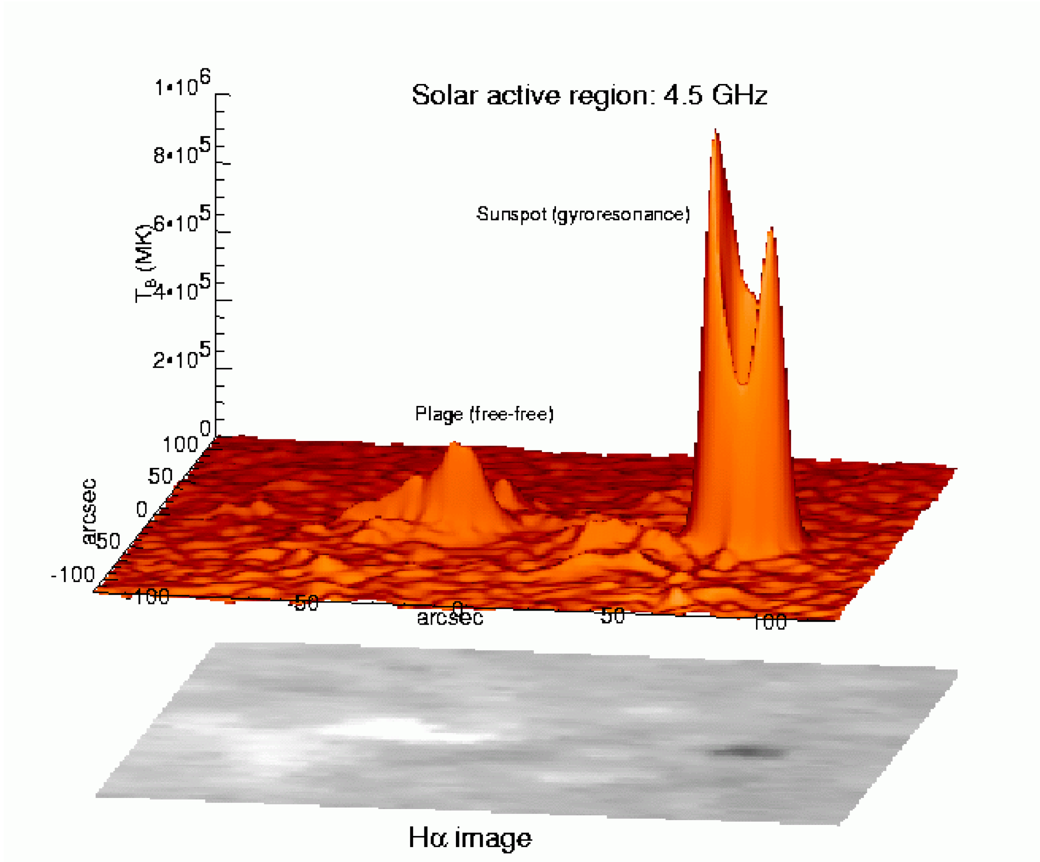


Figure 3. A VLA 5 GHz observation of a solar active region (upper plot) over an H-alpha image. The upper plot shows the relative brightness temperatures of gyroresonance sources (over the sunspot) and bremsstrahlung emission (over plage in the trailing part of the region) typical at 5 GHz: bremsstrahlung from hot dense soft-X-ray-emitting plasma is not optically thick at this frequency and contributes atmost several hundred K of brightness temperature. Over the sunspot coronal temperatures are measured; over the umbra the brightness temperature drops where the optically thick layer drops lower into cooler layers of the umbral atmosphere. (From Zlotnik et al. 1999)

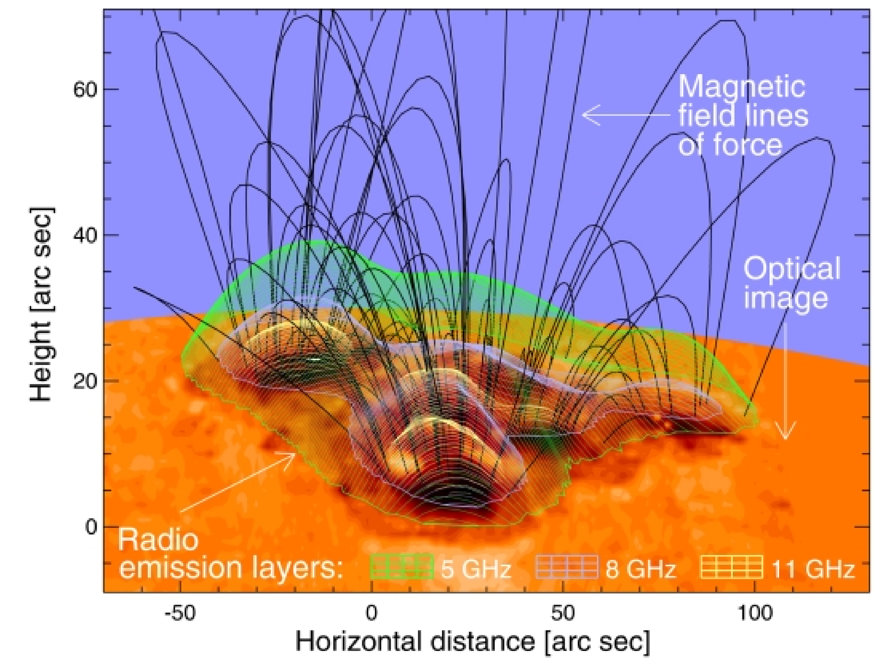


Figure 4. A perspective view of a complex sunspot group (7 May 1991) in optical continuum is shown with field lines extrapolated into the corona. The three surfaces are the calculated gyroresonant surfaces in the corona that will dominate the radio opacity at each of three radio frequencies: 5 GHz (B = 600 G), 8 GHz (B = 950 G) and 11 GHz (B = 1300 G). The measured radio brightness temperatures are a direct measure of the temperature in the corona in very narrow layers of constant magnetic field strength. This figure illustrates the way in which radio studies pick out discrete narrow layers in the corona and thus do not suffer from line-of-sight integration effects. (Produced by Jeongwoo Lee/NJIT.)

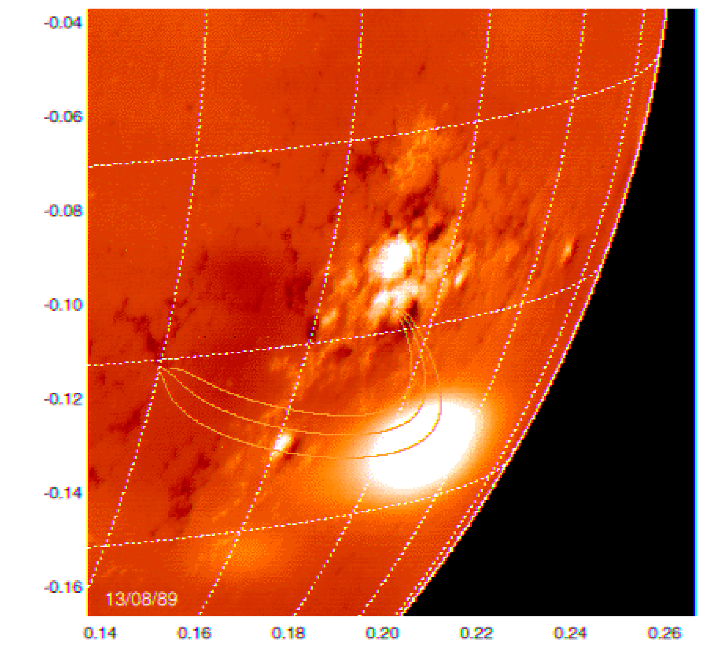


Figure 5. An example of a type U burst observed by the VLA. A type U burst is a type III burst in a closed magnetic loop. Spectrographic records from the PHOENIX spectrometer (ETH/ Zurich) show that the VLA, imaging the burst at 1446 MHz on 13 August 1989, sampled the frequency corresponding to the apex of a magnetic loop anchored in the active region. The magnetic field lines shown are the result of a potential field extrapolation using the magnetogram (color) as a boundary condition (from Aschwanden et al. 1992).

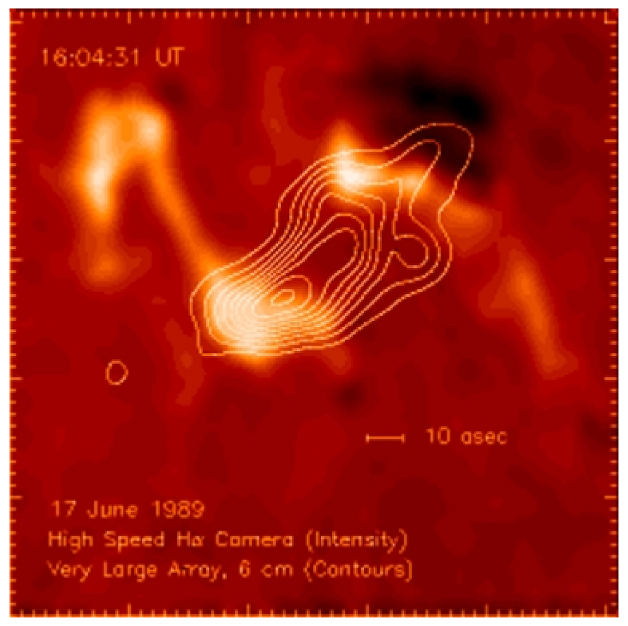


Figure 6. The contours represent 4.9 GHz VLA observations of the M8.7 flare in AR 5528 studied by Bastian & Kiplinger (1991). The greyscale image shows the H-alpha emission, characterized by two ribbons. The entire 4.9 GHz source is optically thick near the time of the flare maximum and the location of maximum radio brightness lies between the magnetic footpoints.

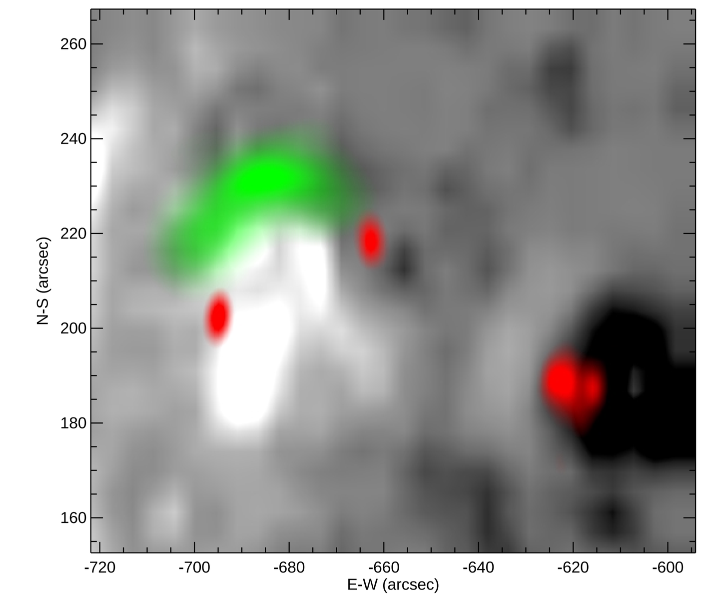


Figure 7. A VLA observation of a flare in which the emission at two frequencies can be seen simultaneously. Green represents 5 GHz emission while red represents 15 GHz emission. The underlying greyscale image is the Kitt Peak magnetogram (white = upgoing fields, black = downgoing). At 5 GHz the whole loop is optically thick, as in Figure 5; at 15 GHz only the footpoints are bright (together with a quiescent gyroresonance source over the leading sunspot at right). Multifrequency images contain a wealth of information on the coronal magnetic field and on the particle distribution function. (From Nindos et al. 1999)

WHAT WILL FASR PRODUCE?

FASR is designed to be flexible enough to operate as both a forefront research tool like the Vacuum Tower Telescope or AST, and as a synoptic instrument producing standard data products routinely, like SOLIS. The required flexibility will be built into the correlator and frequency-selection system, which will permit FASR to vary the number and nature of frequencies at which it makes images and the rate at which images are acquired. Specific research projects, such as studying fine frequency structure in flare emission or enhancing sensitivity to thermal emission from CMEs against the disk, can be designed by choosing particular correlator setups.

Routine DAILY data products will include:

- full-disk images at a number of frequencies, absolutely calibrated, which may be used to estimate accurately the solar irradiance

- coronal magnetograms: at a minimum, maps of the magnetic field strength at the base of the corona

- measures of coronal activity such as strong vertical coronal magnetic field gradients or rapid evolution of coronal magnetic fields

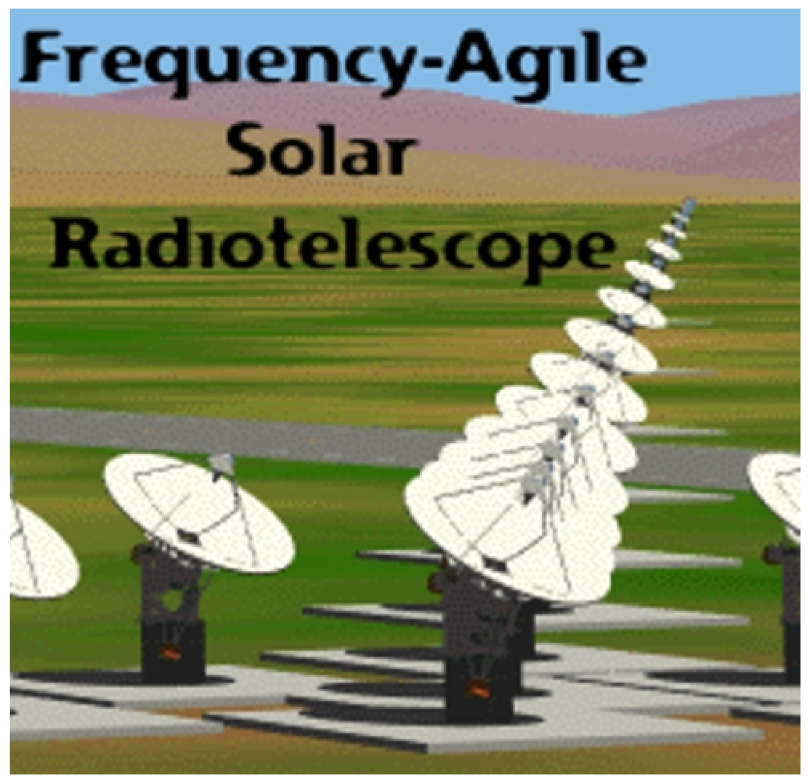
- database of flares, erupting prominences and CMEs, including spectral properties.

- flare-patrol movie sequences

All FASR data will be available via Web-based interface; users will be able to request data in final processed and calibrated image form. The aim is to make FASR data widely used beyond the traditional solar radio community.

THE TELESCOPE

- Antenna size 3 - 5 m
- Of order 100 antennas, necessary to achieve excellent snapshot dynamic range
- Frequency range 0.3 - 30 GHz desired, 0.5 - 20 GHz essential
- Frequency resolution of order several percent above 3 GHz and 1% below 3 GHz
- Dual circular polarization
- Angular resolution 1" at 20 GHz, 20" at 1 GHz (array size 3 km)
- Field of view (HPBW) in excess of a solar diameter at least up to 10 GHz
- Fiber-optic transmission, 20 GHz instantaneous bandwidth, large correlator
- Time resolution would be flexible, depending on correlator mode and number of frequencies acquired simultaneously, but at least subsecond-capable
- Cost: estimated to be $15-20 million. Small dishes are cheap, a large correlator and wideband data transmission are expensive



CURRENT STATUS

FASR is presently conceived to be a joint project between NJIT (Dale Gary), NRAO (Tim Bastian), and Lucent Technologies (formerly Bell Labs), with additional participation from U. Maryland (Stephen White), UCB (Gordon Hurford) and others. Possible international partners have also expressed interest and will be pursued. Lucent is interested in FASR as a source of tangential research collaborations leading to innovative ideas in broadband fiberoptic communications and microelectronics, and is interested in solar impacts on modern communications. FASR will require the same technological developments anticipated by other major radio telescope projects currently being worked on: low-cost antennas, broadband RF transmission, and digital signal processing including wide bandwidth correlators. A work plan is in preparation.

The scientific case for FASR has now been presented to two major review panels commissioned to make recommendations on the future of solar astronomy, and both have endorsed the scientific goals and listed FASR amongst their priorities for the future:

- The NRC Task Group on Groundbased Solar Research (the "Parker" committee) in 1999 recommended "exploratory development of a high-resolution frequency-agile solar radiotelescope".

-The NAS 2000 Astronomy and Astrophysics Survey Committee (the "Decade Report" chaired by Chris McKee and Joe Taylor) listed FASR (as well as the optical Advanced Solar Telescope project) as one of seven priorities for medium-sized projects amongst ground-based telescopes presented to the committee. They note that FASR will "apply modern technology to provide unique data on the Sun at radio wavelengths.....will follow the dynamic nature of solar variability at radio wavelengths and probe a range of solar surface layers from the chromosphere to the corona."