Radio Astronomy Laboratory
University of California, Berkeley
601 Campbell Hall
Berkeley CA 94720

July 8, 2002

Federal Communications Commission

Comment on FCC ET Docket No. 02-135

This letter is written to comment on the general and specific issues raised by questions and comments contained in the Spectrum Policy Task Force document ET Docket No. 02-135.

The writers represent a consortium that operates the Berkeley-Illinois-Maryland Association (BIMA) array, a millimeter wavelength radio astronomy (RA) observatory located in Hat Creek, CA. The BIMA array is currently planned to merge with the Owens Valley Radio Observatory (OVRO) to form the Combined Array for Research in Millimeter Astronomy (CARMA), which will be located in the White Mountains in Southern California. The writers are also involved in design and construction of a new centimeter wavelength RA observatory, the Allen Telescope Array (ATA), which will also be built in Hat Creek, CA. These telescopes are unique scientific instruments which are at the forefront of research in RA.

Below, we describe the economic, cultural, educational and scientific value of RA and our instruments, in particular. These rewards to society are possible because of the primary RA spectrum allocations that currently exist. We discuss the value for RA of electromagnetic national parks, both in terms of spectrum and geographical allocations. We also discuss the progress and limitations in radio frequency interference (RFI) measurement and mitigation and the impact that research should have on spectrum policy. Finally, we discuss specific questions raised in the docket.

Radio Astronomy in Society

Radio astronomers and their supporting institutions cannot afford to buy the spectrum that is allocated to them. But RA repays society for this investment in a variety of ways.

RA seeks to understand physical processes in the Universe through the passive reception of radio waves at frequencies that range from $<$ 10 MHz to $>$ 1 THz. RA is part of a continuum of fields of astronomy which offer distinct and complementary views of the Universe. Much of new science derives from the combination of observations that range from radio to infrared to optical to X-ray to gamma-ray wavelengths.

Nevertheless, RA holds a unique place in the history and future of scientific exploration of space. Nobel Prizes have been earned for the RA discovery of the cosmic microwave background, which placed the Big Bang theory on experimental footing; the RA discovery of pulsars, which are the rapidly spinning ends of the stellar lifecycle; and the RA discovery of effects in the binary pulsar, which confirm important aspects of Einstein's theory of general relativity.

RA promises important future discoveries in many fields. BIMA and CARMA investigate the formation of stars, the evolution of galaxies and the chemistry of the universe, among other things. The ATA will be used to study distant hydrogen, violent transient phenomena and SETI, the search for extraterrestrial intelligence. As has happened in the past, the most stunning discoveries have been made where they are least expected.

The contribution that RA makes to society can be seen in a variety of ways. The ideas and discoveries of RA are found widely throughout our culture — they inform the way we see ourselves and in our place in the universe. Economic value cannot be placed on these ideas. However, popular culture successes such as the movie *Contact* indicate the cultural appeal and consequent economic value that ideas found in RA produce.

More directly, RA contributes to the economy through the education and training of technicians, engineers and scientists, many of whom go on to work outside of an academic or research environment. Observatories are themselves large employers in remote and sometimes economically-depressed regions.

RA also contributes through development of techniques and specialized engineering. For example, the technique of interferometry, which was first developed for RA in the 1950s and also was recognized by the Nobel Prize, is now used in radar, telecommunications, and medical imaging. Currently, research into low noise millimeter wavelength amplifiers may lead to important devices for use in imaging and communications.

Radio Astronomy Spectrum Allocations

The primary RA allocations in the spectrum are crucial to its continued success. These are equivalent to the national parks in the value they provide to RA. They protect crucial parts of the spectrum from any interference.

These allocations represent less than 1% of the total spectrum below 10 GHz. They are chosen to protect the unique spectral signatures of atoms and molecules as well as to provide regular sampling of the spectrum from low to high frequencies. Loss of the 1400 to 1427 MHz allocation, for example, would prevent observation of the most abundant form of matter in the Milky Way, atomic hydrogen.

Protection is necessary because of the intrinsic weakness of RA signals. Many RA observations involve detection of sources that are 50 to 100 dB below the noise of the receiver and sky. This requires integration of hours in wide bandwidths without interference.

Astronomers are interested in observation outside of the protected bands, however. These provide access to wider bandwidths for greater sensitivity and to spectral lines which have been shifted out of the protected RA bands because of their high velocity. One of the highly anticipated RA goals of the next decade is the discovery of the era in which the first stars and quasars where formed. A critical marker for this event is a dramatic change in the spectrum of atomic hydrogen. But rather than occurring in the 1400 to 1427 MHz band, this spectral change probably occurs around 200 MHz.

Electromagnetic National Parks

Most RA observatories are located in remote, radio-quiet regions. Hat Creek, the home to BIMA and the ATA, is located in north-eastern California, several hundred kilometers from San Francisco. The observatory is located in a valley surrounded by high mountains which provide 100 dB of interference protection.

Some formalized protection outside of the primary bands exists for RA near observatories. These protect spectral lines which have been defined to have secondary importance.

We favor broadened support for radio-quiet or coordination zones in the vicinity of RA observatories. Such zones recognize the unique requirements of RA without interfering with the commercialization of the spectrum. These zones should allow for observations outside of the protected RA bands as well as extending sensitivity limits within the bands beyond current limits.

Radio Frequency Interference Mitigation and Its Limitations

Extensive research has been conducted into the measurement of the interference environment and the use of interference mitigation techniques. At Berkeley, we are conducting active investigation into new techniques and testing them on actual interference data. These techniques are being placed into the design of the ATA, which will make it the most advanced observatory in terms of RFI mitigation. We have demonstrated success in eliminating certain kinds of interferers at levels of approximately 30 dB.

However, these techniques are not a panacea for the problems of interference. First, no technique is capable of dealing with all types of interference. Multiple techniques must be developed for multiple problems. One cannot eliminate radar with the same techniques that eliminate a geostationary communications satellite. Second, all of these techniques require compromises in performance of the telescope. These may include loss of sensitivity, resolution or availability. Finally, few of these techniques have been field-tested at a level that is convincing of their general applicability.

We are also implementing a robust receiver in the ATA design. This receiver provides 20 dB of headroom over the system noise, preventing against nonlinear effects due to interference. However, this is still not sufficient if satellites pass through the primary beam of the antenna.

Discussion of Specific Questions in ET Docket No. 02-135

Market-Oriented Allocation and Assignment Policies

In general, we favor rules that are geographically variable. As mentioned above, we are interested in the designation of areas in the vicinity of observatories as electromagnetic national parks. The more restrictive rules in place in such an area would not be appropriate to an urban environment, for instance.

We do not view the establishment of such preserves as a trade for spectrum allocations outside of the preserve. Smaller observatories and educational institutions will still require protection at the primary RA frequencies.

We emphasize again the economic and cultural value of RA. Market-oriented allocation should not lead to the auctioning of the RA allocations.

We note the problematic nature of unlicensed devices for RA. An accumulation of interference from multiple unlicensed devices will be essentially impossible to remove through interference mitigation techniques. They will effectively form a noise floor below which faint sources can no longer be detected. Single-point sources of interference are substantially easier to mitigate.

Interference Protection

We refer the commission to the discussion above regarding the possibilities and limitations of interference mitigation techniques under development for RA. We also note the significant difference between the RA service and other services: RA signals are inherently weak and cannot be manipulated to increase their signal level or be encoded in such a way that improves reception. This makes RA signals especially sensitive to out-of-band and spurious emissions.

We note that many RA receivers cannot be made robust easily. State of the art millimeter wavelength mixers are inherently sensitive to saturation, for example. Furthermore, many legacy systems would require expensive retrofitting to make them robust in an era of relaxed regulation.

Spectral Efficiency

We emphasize again the harmful damage that out-of-band and spurious emissions can have on RA. Any definition of spectral efficiency must include strict limits on these emissions.

We doubt that a single definition of spectral efficiency is sufficient to encompass the variety of uses of the spectrum. In the case of RA use of the spectrum, the scientific impact of the use of the spectrum is not necessarily reflected in the frequency with which observations are made. Such impact cannot be easily predicted given the surprising nature of scientific discovery.

International Issues

RA is an international enterprise. Future large-scale observatories will almost certainly be the result of international collaboration (as the current Atacama Large Millimeter Array and the Square Kilometer Array projects are). Coordination between the United States and other national and international bodies will be essential in creating electromagnetic national parks and other regulations that affect these observatories.

Summary

RA provides a unique cultural and economic contribution through the passive use of the radio spectrum. The primary spectrum allocations for RA are fundamental to the capability to study the universe. Along with geographic protection these allocations create the equivalent of an electromagnetic national park.

We request that the commission take into full account the needs of the RA community in its considerations of these issues.

Sincerely,

Prof. Leo Blitz
Director, Radio Astronomy Laboratory

Dr. Geoffrey C. Bower