in order to bring the ratio to population 1 to 2500 in 15 years. This ratio is far below that in any Western European country.

The per capita income of the country is less than $300 per year, and the cost to the government for the training of one physician is at least $10,000 U.S. equivalent, taking into consideration both the premedical and medical school years. If two of the 50 graduates per year—a percentage drain less than half that which Grubel views with equanimity—leave to practice in the United States, the country has not only had $20,000 go down the drain, but is deprived of an essential public service. In terms of per capita income relative to that of the United States, this loss is equivalent to more than $200,000.

Were these two physicians to remain in their country, their effect on the wellbeing of the population would far exceed anything they might absorb in social services. In the course of a year each one could convert a hundred persons made invalid by parasitic diseases into productive workers, whose contribution to the national income would be many times the "more than an average value of government services" that Grubel has the skilled professional absorb in an underdeveloped country. The drain of these two brains impoverishes their land by a far greater proportionate amount than the contribution they can make to the United States.

JACOB SACKS
Department of Chemistry, University of Arkansas, Fayetteville 72701

Radio Astronomy: Conflict of Frequencies

On 6 December 1966 a scientific satellite was launched from Florida with one of its carefully designed and important experiments purposely rendered inoperative. This expensive decision, and the events that led to it, simultaneously represent a failure of scientific liaison, furnish an example of generous international cooperation, and illustrate the importance of achieving international agreement on the protection of radio frequencies for space research and for radio astronomy.

On 9 November we learned quite accidentally that NASA scientific satellite, ATS-E, proposed for launching in a year or so, was to carry a radiobeacon transmitter for ionospheric research into a synchronous orbit. The proposed frequency band was centered on 406.8 megahertz. A synchronous satellite is almost stationary with respect to the earth, at an altitude of approximately 22,000 miles. The radio signals can be received over nearly a full hemisphere of the earth's surface.

It happens that a number of the world's most important radio telescopes operate exclusively in the same frequency band. These instruments have extremely great sensitivity, to the degree that they would be interfered with in a very harmful way by radiated power sufficient to accomplish the ionospheric research mission of the satellite. As the satellite is nearly fixed with respect to the telescope, the interference would be continuous for several years.

During discussion of this situation with our colleagues in ionosphere research, we learned that a similar satellite was, in fact, already on the launching pad at Cape Kennedy, to be positioned over the Pacific Ocean in direct view of the new Mills Cross telescope near Canberra, Australia.

An immediate decision was necessary. One can imagine the dilemma in which NASA officials found themselves. On the one hand, the ionospheric experiment was ready to launch. It was part of an expensive complex of experiments. Ground stations were ready. To cut it off at the last minute might cause some unexpected interaction which could jeopardize other experiments on board. Many scientists and engineers had planned and hoped and worked for years to bring the experiment into being. On the other hand, the Mills Cross, a major instrument of the Cornell-Sydney Astronomy Center supported jointly by U.S. government and Australian funds, would probably be put out of action for as long as 5 years. Radio telescopes in other parts of the world could be adversely affected, as well.

The NASA people made a courageous and farsighted decision: expensive and risky and disappointing though the action was, they disconnected the beacon transmitter.

How did this unfortunate situation arise? Radio astronomy, as a latecomer among the users of the radiofrequency spectrum, has never been able to secure adequate frequency protection on either national or international scales. International frequency-allocation practices have been regional rather than worldwide in scope and have led to intercontinental inconsistencies in the frequency bands allocated to radio astronomy. With the advent of man-made radio transmitters in space, the situation has become very serious.

The band 401 to 406 megahertz is allocated by international agreement to "meteorological aids," including radiosondes and weather satellites. The band 406 to 420 megahertz is allocated to the "fixed service," which includes mainly point-to-point communication systems. Historically, radio astronomers have long desired some space in this region of the spectrum, but the most that has been achieved to date is the rather weak footnote in the Final Acts of the Extraordinary Administrative Radio Conference, Geneva, 1963:

> The band 404-410 in Region 2 and the 406-410 in Regions 1 and 3 are also allocated to the Radio Astronomy Service. An appropriate continuous band within these limits shall be designated on a national or area basis. In making assignments to stations of other services to which these bands are allocated, administrations are urged to take all practicable steps to protect Radio Astronomy observations from harmful interference.

In the United States, only the band 404 to 406 megahertz has been so protected.

Thus, radio telescopes operating in this part of the spectrum run the risk of interference from transmitters outside their respective national jurisdictions. Nonetheless, because other suitable frequencies have not been available, and because they have been able to obtain protection on a purely local basis, several radio observatories in Europe and Australia have constructed elaborate radio telescopes operating at or near 406 megahertz.

Technically, the choice of 406.8 megahertz by NASA was perfectly logical. The ionospheric experiment needs two widely separated frequencies with a constant electrical phase relationship. Both ground and satellite instrumentation are greatly simplified if one is a harmonic of the other. In this case, 406.8 megahertz is the third harmonic of the frequency of the existing data-transmission and tracking-beacon transmitter, the latter being chosen in accordance with the international allocations for space research. It is a time-honored practice to transmit on *any* frequency, regardless of allocation, so long as the transmitted power is so low that it will not interfere with any of the *primary* uses of the frequency. In this case the latter criterion was certainly satisfied with respect to the meteorological aids and the fixed services. Nonetheless, the extreme sensitivity of the radio telescope, which radio engineers of other services often appreciate only with difficulty, makes it extremely vulnerable to such transmissions from satellites.

NASA has demonstrated in the most dramatic way possible its desire to cooperate in international protection of radio astronomy observations. Clearly, then, a failure of liaison within both scientific and frequency-management communities was responsible for the last minute cancellation of the experiment. We understand that NASA on 15 September sent a routine announcement of proposed frequency usage, including the experiment in question, to the appropriate governmental agencies in Australia and other countries. The proposed usage was discussed and approved by the cognizant U.S. government committee, but apparently the staff of the National Academy of Sciences Committee on Radio Frequency Requirements for Scientific Research did not become aware of the conflict until too late. Similarly, the Inter-Union Committee on the Allocation of Frequencies for Scientific Research, an international committee of scientists, apparently did not learn of the matter until the last minute (*1*).

Any one of these agencies could have given *timely* warning of the conflict, had they recognized the danger. The lessons are clear: liaison among scientific users of frequencies must be more systematic and intensive; renewed efforts must be made to provide worldwide, exclusive allocations for radio astronomy and space research; radio astronomers must become more alert to frequency protection problems and must cooperate more in resolving them. In particular, agencies proposing transmissions which are potentially harmful to radio astronomy should request information from the International Frequency Registration Board, Palais Wilson, Geneva, Switzerland. Radio astronomers should make certain that their frequencies are on record with the IFRB.

G. W. Swenson Jr.*
National Radio Astronomy Observatory, Charlottesville, Virginia

R. N. Bracewell
Radio Astronomy Institute, Stanford University, California

Reference and Note

1. R. L. Smith-Rose, *Nature* **203**, 7 (1964).
* On leave of absence from the University of Illinois, Urbana.