mind, and on the other hand he is a man of action," says Andrei Sher, a Pleistocene expert at the Severtsov Institute of Ecology and Evolution in Moscow.

Zimov also won important allies in the Sakha government. Aware that Sakha could neither rely on subsidies from Moscow nor revenue from its abundant but hard-to-extract nonrenewable resources—gold, diamonds, oil, and natural gas—Sakha President Mikhail Nikolaev has embraced wildlife stewardship as a potential source of meat for the local population and, perhaps, tourist dollars. Although it may be difficult logistically for Russians—let alone foreigners—to get to Cherskii, Zimov predicts that adventure tourists could boost the region's fortunes. "I hope the density of animals in the park in 20 years will be the same as in the Serengeti," he says.

Even if Zimov doesn't manage to create a Siberian Serengeti, the grand ecosystem experiment he is embarking on is likely to keep researchers busy for decades to come. "Scientists are tired of discussing the greenhouse effect," Zimov says with a twinkle in his eye. "Now, maybe it will be interesting for them to discuss ecosystem reconstruction." Sher certainly thinks so: "I am looking forward to the start of this great enterprise." **–RICHARD STONE**

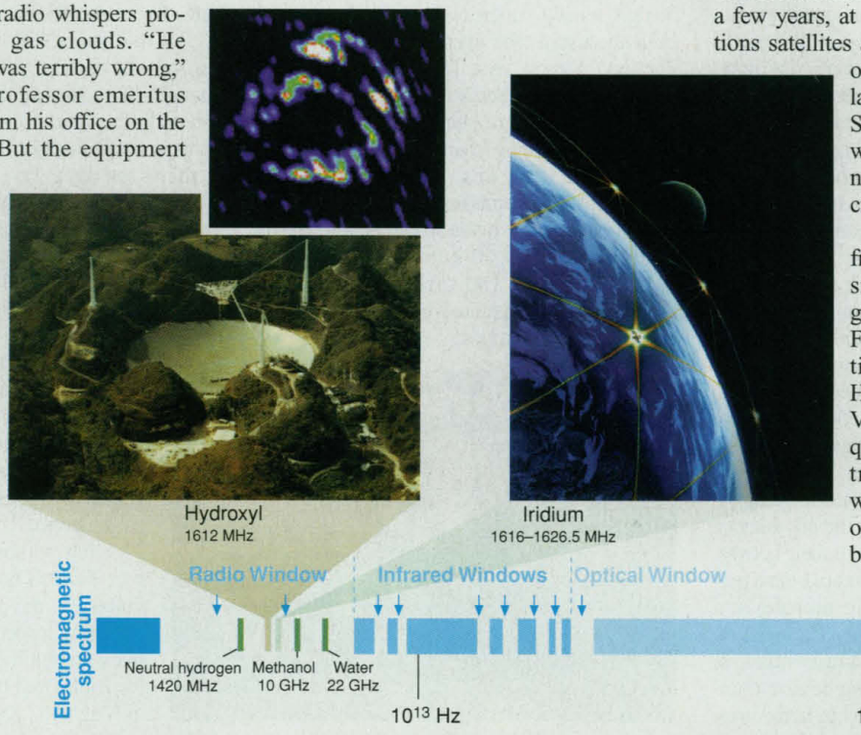
RADIO ASTRONOMY

Iridium Accelerates Squeeze on the Spectrum

A fleet of 66 satellites that will transmit near an important frequency for studies of the cosmos is the latest example of commercial assaults on the radio spectrum

Astronomer Harold Weaver was sound asleep when the phone rang one night in 1963. On the other end of the line was a colleague warning him about strange readings from the University of California's radio telescope in Hat Creek, whose sensitive antennae tracked the natural radio whispers produced by galactic gas clouds. "He thought something was terribly wrong," the 81-year-old professor emeritus recently recalled from his office on the Berkeley campus. But the equipment was working fine: The unexpectedly strong emissions were evidence of the first known natural maser, an intense blast of laserlike, organized radio waves unleashed by molecules excited by cosmic radiation.

Today, Weaver's maser—a signal produced by negatively charged hydroxyl ions composed of hydrogen and oxygen—is one of radio astronomy's most important beacons. The unusually bold spectral line it produces at 1612 megahertz (MHz) on the radio spectrum (see graphic) has led astronomers to new insights into how stars form and die. In particular, the maser's fluctuating intensity allows astronomers to estimate the temperature, composition, and other attributes of galactic gas clouds, including those that serve as stellar nurseries and those ejected by dying red giant stars. Hydroxyl masers are also one of the field's few reliable cosmic yardsticks: By measuring the time delay of the maser's signal between a red star's far and near sides, researchers can estimate the star's diameter and hence its distance from Earth. "The hydroxyl line is a real workhorse that has allowed some spectacular studies," says astronomer James Cohen of the Nuffield Radio Astronomy Laboratories at Jodrell Bank, England.



Electromagnetic smog. Iridium satellites *(right)* produce stray emissions that block important hydroxyl maser signals tracked by radio telescopes, such as the dish in Arecibo, Puerto Rico *(lower left)*. The signals help astronomers understand the gas shells that surround dying stars *(above)*.

Soon, however, astronomers may find that hydroxyl workhorse and other important spectral lines much harder to ride. Celestial signals at a growing number of important points along the radio spectrum are being blocked from Earth-bound telescopes by a blanket of electromagnetic smog laid down by communications satellites. This fall, that blanket will grow thicker when the mobile phone company Iridium LLC turns on a $5 billion, globe-girdling fleet of 66 satellites to serve customers who never want to be out of touch. And Iridium isn't the only threat to parts of the radio spectrum that astronomers once had mostly to themselves. Within a few years, at least 100 other communications satellites are due to be launched, and one firm has designed a flotilla of signal-relaying airships. Some of these new platforms will interfere with stellar signals unless government officials intervene, observers say.

"The demand for radio frequencies is growing explosively, and the spectrum is getting crowded," says Paul Feldman, a telecommunications lawyer with Fletcher, Heald & Hildreth in Rosslyn, Virginia. "Increasingly, the question is whether radio astronomers can keep their windows of discovery clear of interference from neighboring users."

The sound of snowflakes

Astronomers are vulnerable bystanders in the communications revolution because they operate some of the most sensitive passive radio receivers on Earth. Modern radio telescopes can detect distant energy emissions of less than a trillionth of a watt, signals equivalent to the energy ripple generated by a falling snowflake. As a result, some astronomy dishes are notoriously suscepti-

CREDITS: (CLOCKWISE FROM TOP LEFT) CHAPMAN/AAO/ATNF, KILLEEN/ATNF AND VAN LANGEVELDE/JIVE/JODRELL BANK OBSERVATORY, IRIDIUM LLC, NAIC

ble to interference, especially from signals traveling from space to Earth. Indeed, astronomers have estimated that a single cellular phone transmitting from the surface of the moon would be perceived on Earth as one of the strongest radio signals in the universe.

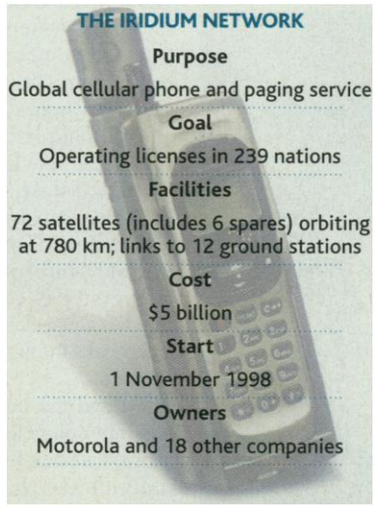
To shield their sensors from unwanted signals, astronomers have waged a 40-year campaign to secure proper access to important frequencies (*Science*, 8 December 1995, p. 1564). There have been some successes. In 1992, for instance, the International Telecommunication Union (ITU), the United Nations body that allocates the spectrum to different users, awarded radio astronomers primary rights to a chunk of the spectrum around the coveted 1612 hydroxyl band, from 1610 to 1613.8 MHz. In a footnote, the ITU said astronomers would be protected from a specified level of "harmful" interference from mobile satellite services.

That policy was quickly put to the test when Iridium won the right to transmit messages from space to Earth in an adjacent band, from 1616 to 1626.5 MHz. Despite early assurances that the downlink signals would stay clear of the hydroxyl frequency, engineers with Iridium's parent company, Motorola, soon admitted that radio emissions would stray into the hydroxyl band at levels that would swamp signals from the cosmos. The news stunned those who had fought for the protective ITU footnote.

The community tried initially to convince Motorola to fix the problem before the satellite system was launched, arguing that the footnote required it to move to another part of the spectrum or redesign the system, an expensive undertaking. But company officials asserted that it was only required to share the sky with the world's dozen major radio observatories. Because those telescopes spend only a portion of their time studying the hydroxyl line, the company said, the problem could be solved by providing researchers with a few unobstructed hours each day. "Did we agree with the radio astronomers' interpretation of that footnote? No, because you can't be that rigid," says Iridium's Jack Wengryniuk, one of the company's lead negotiators.

Then the astronomers tried another tack, winning governmental promises to reject licensing of Iridium unless it made an effort to protect domestic radio observatories. In the United States, this leverage led to a 1994 time-sharing agreement between Iridium and the Charlottesville, Virginia–based National Radio Astronomy Observatory (NRAO), which is funded by the National Science Foundation. The pact required Iridium to provide four observing hours each night—when phone chatter dies down—to the single-dish observatory in Green Bank, West Virginia. Two other multidish arrays, which are less sensitive to Iridium's signals, won less stringent relief. To the disappointment of astronomers outside the United States, the limited NRAO pact became a model for later agreements.

Even so, it took four more years of negotiations for Iridium to work out a similar agreement with the National Astronomy and Ionosphere Center (NAIC), which runs the world's largest single-dish telescope in Arecibo, Puerto Rico. The pact, signed this past March, provided Arecibo with 8 hours a night of observing time, plus up to 20 hours of daylight telescope "passes" to observe special objects such as comets. Even that agreement has its limitations, however. "It is an annoying solution because it imposes a straitjacket on our schedule," says Mike Davis, Arecibo's project manager.



CREDIT: IRIDIUM LLC

In Europe, astronomers unhappy with the restrictions imposed by the U.S. agreements took a different approach. Under the banner of the European Science Foundation, astronomers from across the continent signed a pact in August that puts off difficult time-sharing decisions for a year, an interval when Iridium traffic is expected to be light. The U.S. time restrictions "are unacceptable to us: We are not willing to give up daytime observations," says Peter Spoelstra, an astronomer at Westerbork Observatory in the Netherlands.

The Europeans, however, did extract a promise from Iridium to eliminate the interference problem before launching its next generation of satellites in 2006. But some astronomers doubt the company can meet the technical challenges, even by that deadline, because Iridium's need for light and inexpensive satellites limits the use of heavy filters and rules out some possible solutions. Iridium's Wengryniuk concedes that the pact is "a pretty complicated arrangement that is going to take a lot of work on both sides."

The U.S. and European agreements exerted a strong influence on negotiations with India, which operates the Giant Meterwave Radio Telescope near Pune. "First the American astronomers compromised and the Europeans followed, so we had to soften our stand," says astronomer Govind Swarup, explaining why his National Center for Radio Astronomy agreed in August to a compromise that provides his observatory with six clear hours a night and requires Iridium to pay for filters that remove some of the interference. Swarup also wonders if Iridium can meet the 2006 deadline, and he warns that future battles are possible. "There is no silver bullet," he says. "If they don't respect the agreement, we will approach the government to cancel their [broadcasting] license."

The brutal truth

Wireless industry analysts say that such a threat lacks credibility in the United States. The Federal Communications Commission is likely "to ignore the protests of radio astronomers and side with the communications provider" if Iridium fails to uphold its agreements, says Larry Swasey of Allied Business Intelligence in Oyster Bay, New York. And astronomers should not expect to win over the many companies lining up to launch new wireless systems, he adds: "The brutal truth is that most of these companies have given little thought to what effect their services will have on astronomy." Astronomers are most concerned about a proposal to use bandwidths near an important neutral hydrogen line at 1.4 gigahertz (GHz), as well as a malfunctioning television satellite that is interfering with a methanol line at about 10 GHz.

The next step for astronomers is an ITU allocation conference set for May 2000 in Geneva. The goal is to expand existing allocations where possible and to stake out new claims to key spectrum bands above 75 GHz. That bandwidth has been virtually vacant except for radio astronomers exploiting newly discovered spectral lines, such as one produced by celestial methanol molecules. The conference "may be the last where corrections may be made," predicts Willem Baans of Westerbork Observatory.

Other researchers, however, are preparing for the worst. "There is no way we can fight off the commercial interests and protect all [the bands]," says NRAO's Barry Turner. The result, he predicts, will be "a lot more glum radio astronomers." On the bright side, says Weaver, the hydroxyl line's discoverer, there's at least one region that no company has yet to exploit—the moon's dark side, which is sheltered from Earth's electromagnetic smog. "Last time I looked," says Weaver, "the quiet side was still there, waiting for us." **–DAVID MALAKOFF**

With reporting from Pallava Bagla in New Delhi.