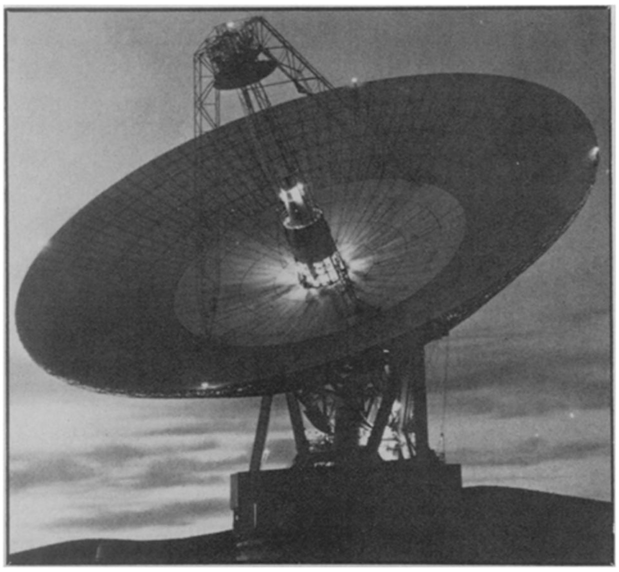
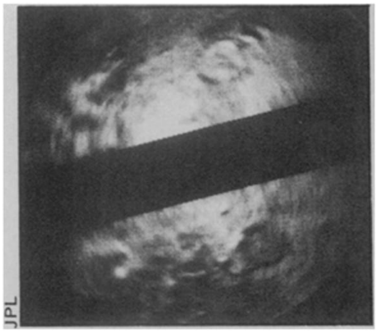
RADAR PROBES OF THE PLANETS

Mars' rilles, Mercury's craters, Venus' hills and Saturn's rings are all being studied by radar

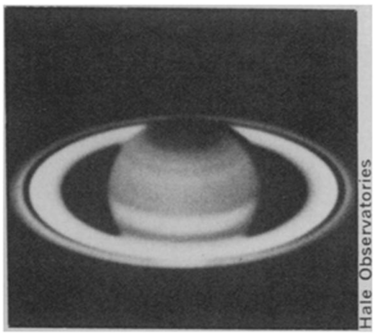


JPL's 64-meter antenna at Goldstone.



JPL

Radar map of craters on Venus.



Hale Observatories

Saturn's rings: Why so bright?

Astronomy is a passive science. In general astronomers cannot experiment with the objects of their observation; they can only record the radiations emitted by celestial objects and deduce what they can from such records.

The one branch of astronomy that is more active than most is radar astronomy. It does not wait for celestial objects to emit radiation or to reflect radiation emitted by other celestial bodies. Radar astronomy sends radiation for them to reflect and thereby derives information that passive watching cannot.

By its nature radar astronomy is limited to the solar system and to the nearer reaches of that. It is a project that piggybacks more or less on NASA's program for tracking its deep-space probes. "Our major goal is to improve the technology of the deep space network," says Richard Goldstein of the Jet Propulsion Laboratory, who has been a leader in radar astronomy since its beginning. A radar system that can track the rings of Saturn is certainly a large step toward that goal. On the way to it, the program has contributed a good deal of information about various members of the solar system. The work is done mainly with the 64-meter antenna at Goldstone, Calif.

It started in 1961 with the first radar echo from Venus. Venus comes nearer to the earth than any other planet so it was a logical place to start. (Some years before that radar echoes had been obtained from the moon, marking the first extension of radar beyond the earth.) Venus was also something of a mystery planet: The dense cloud cover of its atmosphere made visual knowledge of its surface impossible. Astronomers believed—based on assumption as much as observation—that its rotational period was locked in synchrony with its orbital period.

The radar work that Goldstein did with Howard Rumsey showed that the surface of Venus is rough and caterous, a characteristic shared by the moon and all the terrestrial planets but the earth. Radar also turned up the surprising datum that the rotation of Venus is retrograde—in the opposite sense from most rotary motions in the solar system—and in synchrony with the motion of the earth.

Observations were then extended to Mars and Mercury. In the Mercury work S. Zohar collaborated with Goldstein; the Mars work was done with George Downs, Paul Reichley and others. It was radar that first found evidence of craters on Mercury, the existence of which was confirmed by the photographs of Mariner 10. For both Mars and Mercury the radar work is a complement to the photographic work of flybys and orbiters. Differences in elevation do not show up well on the photographs, and such things as an overall slope on the surface or even a raised dome would not be seen, says Goldstein. The radar can measure differences in elevation—down to 100 meters in the case of Mars—and, says Goldstein, the plan is to "use radar as benchmarks for altitude measurement."

Indeed one can take a radar profile across a part of Mars and compare it with Mariner photographs and see how the radar picks out the craters and rilles.

For Mars the plan is to develop a radar profile of the entire surface of the planet. In any one observation the radar "sees" only a small circle on the disk of the planet, but over weeks and months as the planet's aspect changes, the circles moves up and down.

Periodically the observers keep returning to Venus too. During the past winter abundant Venus data were taken. Goldstein hoped for a dozen pictures across the planet. Unfortunately the spacecraft people needed the antenna for part of the time that Goldstein had planned on so only about three pictures will come out of the data.

The biggest and most recent success, in which Goldstein worked with George Morris, was the successful reflection of a radar beam from the rings of Saturn. Oddly enough, the bulk of the planet shows little reflection that can be distinguished from background noise. On the other hand the rings are very bright.

For most celestial objects the radar reflectivity is quite low. This is one of the things that makes successful radar studies of planets so amazing from a purely technological point of view.

Compared with the reflectivity of a silver sphere, the usual standard of comparison, Venus has a reflectivity of about 1.5 percent. The moon's is 5 percent and Mars' 8 percent. The rings of Saturn give a whopping 60 percent.

And that's not the worst of it. One can see through the rings of Saturn. Therefore they cannot be closely packed. If the volume is half filled with whatever the rings are made of, the reflectivity of the material becomes 120 percent of that of a silver sphere. If it's one-quarter filled, the reflectivity is 240 percent. "You can't have amplification," says Goldstein. There are no little green or purple men sitting in the rings with radio receivers and transmitters. "It becomes a problem to figure out what can reflect that well."

Two possibilities come to mind: jagged chunks one meter across or larger or ice spheres as small as six centimeters. In ice there would be repeated internal reflection that would enhance the reflectivity. But for that the spheres have to be perfect, and, Goldstein asks, how do you get perfect spheres out there?

They want to take another look in December and use a variety of wavelengths from the 12.6-centimeter S-band that they have been using to the 3.5-centimeter X-band in the hope of getting some fix on what the substance of the rings is. Over a 7.5-year period the tilt of Saturn changes so that our view of the rings goes from nearly broadside to edge-on. Annual observations over that period, as the angle of view changes, could help tell something about the packing of the rings.

Saturn is about as far out as the radar can probe. Saturn's nearest approach to earth is 8.4 astronomical units. (One a.u. is the radius of the earth's orbit.) It takes 2 hours and 15 minutes for the signal to reach Saturn and return. So they broadcast for 2 hours and 15 minutes and then listen for 2 hours and 15 minutes. Uranus, the next planet out, comes no nearer to earth than 17.4 a.u. This would require twice the broadcasting and listening time, and the observational day just isn't long enough. Also there's a possible difficulty with transmitter power.

Within the orbit of Saturn lie five planets, about which much is yet to be learned, and the asteroids. The asteroids, considering their tiny size, represent perhaps the neatest radar trick of all. Goldstein has gotten readable echos from Toro and Icarus, and he hopes to try Eros in January when it comes within 14 million miles of the earth. Radar can tell something about the sizes, shapes, rotation and surface composition of the asteroids. "I expect to cause more controversies than I can settle," he says. □

INFRARED IMAGES FROM THE STARS

One of astronomy's newest branches analyzes infrared emissions of stars, dust clouds and gases

Astronomical objects emit radiation over a wide range of the electromagnetic spectrum. Yet until recently astronomy has been confined to a small portion of the spectrum, the visible range, even though as Charles H. Townes of the University of California at Berkeley remarks, excluding the sun, there is more radiation in the infrared and microwave than in the visible range. For many centuries astronomers were totally ignorant of the existence of the nonvisible emanations. Once they were discovered, special equipment had to be built to observe them.

Infrared astronomy is thus a relatively new branch of the science. Reception and processing of this radiation have made substantial progress in the last four years, says Townes. "Infrared has increased in sophistication" in recent years, says David M. Rank of the Lick Observatory, "but it still has a long way to go to be on a par with other branches" of astronomy.

Townes, who shared in the 1964 Nobel Prize in physics for his contributions to the development of the maser, has lately become interested in celestial masers and other quantum electronic effects in astronomy.

A main intellectual reason for pursuing infrared observations is that infrared looks at considerably different things than visible-light astronomy. The wavelengths a body emits generally depend on its temperature. The temperatures of stars are typically in the thousands of degrees, the range appropriate to emitting visible light. Infrared comes from much cooler bodies. Ten microns is one of the wavelengths at which a lot of observing is done. This is emitted at a temperature of 300 degrees K.

Infrared astronomy thus studies cool objects, those that don't emit appreciable visible light. This includes the cosmic dust, interstellar gases (the vibrations of atoms in gas molecules is a typical mechanism for producing infrared), cool layers in stellar atmospheres, planetary atmospheres, and the strange newly discovered infrared sources in the centers of galaxies. "Some galaxies emit the bulk of their energy in the infrared," says Rank.

Three hundred degrees K. is the value that physicists usually mean when they refer to room temperature. It is equal to 27 degrees C. or about 81 degrees F. This means that a room that is visually totally dark can be very bright in the infrared. The walls, the furniture and human bodies all contribute.

Infrared observations thus suffer severe problems in sorting the signal from the noise. "It's like doing optical astronomy in the daytime," says Rank. For really faint sources the equipment must be refrigerated—in some cases down to liquid helium temperature (a few degrees K.). On the other hand the same kind of telescopes as are used for optical astronomy can be used to reflect infrared. Most metals become even better reflectors at long wavelengths than they are for visible light, and the "figure" of the mirror, its exact shape, doesn't matter as much.

Getting information out of the infrared calls for some complex equipment. Every astronomer always wants to do spectroscopy on any object he studies. Separating the individual wavelengths in the signal can tell him a great deal about the chemical substances present in the object and the physical conditions prevailing there. Infrared spectroscopy, Rank points out, is more difficult than visible spectroscopy. There one disperses the light with a diffraction grating and takes a photograph of the spectrum. In the infrared one must build a linear array of photoconductors to disperse the light and use multiple detectors to take the spectra.

An ideal instrument for infrared studies, Townes says, would be an "up converter" that would take an infrared signal and multiply its wavelengths by some common factor so that it would come out as visible wavelengths. One could then be able to take a picture of what the infrared "sees."

Something rather similar to this does exist. Townes calls it a heterodyne receiver for infrared. The principle is to take the incoming infrared signal and mix it with the light from a carbon dioxide laser. The mix is accomplished in a special crystal. The output is a wave in the radio range that can be detected with a radio receiver. The

Continued on p. 138