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

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find a way to get some useful scientific observations out of the tests."

The enormous weight of the antennas (214 tons each) and their diesel-electric transporters (70 tons) will be distributed across two sets of standard railroad tracks, separated by an 18-foot distance between their centerlines. If it is an irony that the antennas of the most sophisticated radio astronomy observatory in the world will be moved about on railroad tracks, it is further irony that the tracks, and the ties on which they will rest, will be not new, but used. The prices of new timber ties and railway-track steel have skyrocketed in the past year or two. So VLA officials have been scrambling to obtain what they need from no-longer-used railroads on military bases and other government facilities.

The sprawling array will cross ranch property boundaries, one county line and U.S. Highway 60. A standard railroad crossing will be built where the northern arm goes across the highway. When the antennas are moved into various configurations along the array, they'll occasionally have to cross the highway, creeping along at rates of 5 miles per hour. "There's a clear view for 10 miles in either direction so there shouldn't be any problem," says Wells. "But," adds Egler, "I sure bet we see some surprised motorists."

The antennas will make their observations not from the main tracks, but from permanent observing stations, 100 feet off to the side, connected by spurs perpendicular to the main railway. This will leave the main tracks free to carry personnel and maintenance equipment and alleviate the need for access roads. There will be 72 of these observing stations, giving astronomers great flexibility in positioning the 27 antennas. Each station will have three foundations, one for each leg of the antenna. The foundations are meant to prevent overturning of the antennas and to support them in a precisely fixed position.

Every antenna could be moved to a new position within 48 hours, according to Wells. Since only one antenna will be moved at a time, observations can proceed without interruption.

But it will be seven more years before all the construction and testing is completed and astronomers are making full operational use of all antennas at once. The construction is not all that difficult, but the funding is being spread out over a number of years so that the chunks of money required from any given budget year are smaller. Loyal engineers, Wells and Egler fully understand the budgetary realities, but they can't disguise a certain wistfulness about the length of time required. Says Egler: "If we had all the money at once, we could finish this up in two years." □

. . . Seeing *(from p. 133)*

If there are 25 elements in the corrector, there is less than a millisecond to adjust each one since the turbulence changes about every 20 milliseconds. Yet Muller and Buffington think it can be done.

Itek's RTAC is in essence a rubber mirror. The basic element is a piezoelectric crystal. When a voltage is applied to a piezoelectric crystal, it can be made to expand or contract. The crystal has independent electrical connections for each two seconds of arc across its surface. Thus each element of that diameter can be individually squeezed or expanded. The surface of the piezoelectric crystal is covered with a thin layer of aluminized glass to do the actual reflecting.

The deformable RTAC mirror deforms according to instructions given by a shearing interferometer that makes an instantaneous map of the wavefront as it enters the telescope. RTAC is a reimaging device that can be mounted on an existing telescope and will work on the light reflected by it.

A laboratory model of RTAC now exists and has done well in tests on artificially degraded images. Within the year Hardy and collaborators hope to try it out on actual stars. It is expected to be useful for objects as faint as 10th to 12th magnitude.

These are only a few of the projects intended to help astronomers with their seeing difficulties. Success would remove a serious age-old frustration. Astronomers' feeling about it is exemplified in the tone of Stachnik's voice when he says of RTAC: "They show an image of a star distorted. They flip a switch, and the image shrinks to a little dot." □

. . . Infrared *(from p. 135)*

advantage is that radio receivers are more sensitive to amplitude and frequency differences than infrared ones at present. Heterodyne techniques have also been tried in infrared interferometers. Testing with artificial light sources indicates that one can get interference fringes this way. The actual spacing between the two telescopes that would be set up in a working model is still a matter of controversy.

Given the techniques now available, what do you see? Starting near home, infrared can be used to study the atmospheres of the planets. Take Mars for example. Infrared confirms that carbon dioxide is there. Infrared can be used to study the temperature of the Martian atmosphere as a function of height above the surface and pressure. This is one way to measure variations in the height of the surface.

The same can be done for other planets. Work on the pressure and temperature of gases on Jupiter has only recently been done. Among other things it found a lot of ammonia there.

By knowing the detailed structure and activity of other atmospheres planetary scientists can come to understand the earth's better. The atmosphere of Venus is 100 times as heavy as the earth's; that of Mars one hundredth as heavy. Scientists cannot experiment on the earth's atmosphere by, say, heating it up 50 degrees and seeing what happens, but by observing the atmospheres of other planets they can see some of what the possible effects of changes in our own might be.

Further out in the galaxy the beginning and the end of a star's life provide circumstances where infrared observation is especially valuable. Dust clouds appear to be the places where stars are born. "One can see through them in the infrared," says Rank. "It's impossible to see through them in the visible." The temperature of the dust is characteristically anything from 150 to 300 or 400 degrees K.

In the clouds one sees relatively warm objects that are totally invisible optically. These are presumably the spots where dust and gas are condensing into stars. The infrared observers want to study the time scale of star formation and the mechanisms by which it occurs.

Toward the end of its life a star may puff off a cloud of gas which forms a dusty, gassy halo around the star. How the dust gets formed presents astronomers with a chicken-or-egg problem, says Rank. Dust particles don't like to form unless there are other dust particles around, but somehow the process has to get started.

Once the dust forms, infrared astronomy can study its chemical composition. One finds calcium carbonate, silicates (sand), ordinary minerals. The dust is similar to rocks on earth. "It's interesting to know that that's the way it is," says Rank.

To further universalize chemistry—to prove that the far reaches of the universe are made of stuff much like that in our corner of it—one can study the chemistry of distant galaxies. Infrared will prove a useful medium in this endeavor.

Finally there are the now famous—and strange—infrared sources in the centers of galaxies. One question to settle, says Rank, is whether the sources are really in the centers or whether it just looks that way. Of course the big question is: What are they?

And who knows what new species of infrared-emitting object may be discovered next week. The universe, seen and unseen, is full of many more kinds of things than Horatio's philosophy ever dreamed of, and one has to watch closely to keep up with the astronomers as they discover them. □