Interfering at One Millimeter

New telescopes promise high-resolution studies of the places where ordinary stuff is turned into stars

Illustrations: Caltech

BY DIETRICK E. THOMSEN

Astronomers used to think that molecular physics and chemistry belonged generally to planets. Stars are much too hot for it, and before stars existed there was no way to make the atomic nuclei on which atoms and molecules are formed.

The discovery that the space between stars is nevertheless full of clouds of molecules, some of them quite complicated, came as a surprise. The molecules have to be made in interstellar space — stars being still too hot for it — and chemists have not yet quite made up their minds how. The presence of all this interstellar junk, as it has been called, reacts on theories of stellar formation because it seems that young stars are forming in these clouds. At the same time, the stuff out of which the young stars are forming is originally debris that came from existing stars one way or another. There is nowhere else the atomic nuclei could have been made. To put it another way: Fire thou wert and to fire shalt thou return. Ashes and dust are an intermediate stage.

To study this cosmic recycling bin is a delicate job for astronomers. The radiation emitted by molecules is not very bright. It comes mostly from thermal excitation which is not as efficient as the processes available in other parts of the universe, and it tends to fall in the border region between the radio and the infrared, a region to which very little observing equipment is specifically dedicated.

The clouds are extensive and the regions where interesting things such as star formation, natural masers or planetary nebula formation are going on tend to be small. High resolution for mapping and for pinpointing the details of the small active regions is necessary to know what is really going on. A mirror ten meters across that was built specifically for this part of the spectrum and recently installed at the California Institute of Technology's Owens Valley Radio Observatory has achieved a resolution of 27 seconds of arc at a wavelength of 1.3 millimeters.

The reflector operating now is one of several that are being built at the Caltech campus in Pasadena by what almost amounts to assembly line methods. Two others will be brought to Owens Valley to form an interferometer with the one already there. The interferometer arrangement will increase the resolution, giving the equivalent resolution of a single telescope as wide as the distance between members of the interferometer. The fourth telescope will be shipped to Hawaii and installed on Mauna Kea.

The construction of the telescopes uses prefabricated and interchangeable parts, and these factors have made construction of two at a time much less costly than it might have been, says Robert B. Leighton, the leader of the project. The reflector support consists of prefabricated units built of spidery interlockings of light metal struts. The mirror blank consists of matching hexagonal pieces of honeycomb material that is ground to shape by a tool that runs over its surface, and then coated with aluminum. So successful are the techniques that they may be used repeatedly in the future. There was a proposal to build one of these reflectors for use in the Southern Hemisphere and install it at the Cerro Tololo Inter-American Observatory in Chile, but it seems that CTIO, which is an optical observatory, did not want to get into radio astronomy, and radio observatories approached as prospective managers did not want to get onto someone else's grounds. A prominent Indian astronomer approached Leighton about building one of these telescopes for him to use in India. He was told that by the time Caltech's four were built he could build one himself, and they showed him how.

The operation of the one telescope now at Owens Valley indicates that interferometric operation will be possible at quite short wavelengths, Leighton says, at least down to one millimeter and under certain conditions something may even be possible to three-quarters of a millimeter. This will put astronomers in the way of studying certain particular rotational energy transitions of the carbon monoxide molecule that can tell them much about the behavior of energy in the interstellar clouds. They should be able to study carbon monoxide made with different isotopes of carbon, say carbon 13 instead of carbon 12, to learn about the nuclear chemistry of interstellar matter and of the stars that produce it as well as the stars into which the different isotopes go. In all, there should be a wealth of information about temperature gradients in the clouds, about the formation of new stars, about the structure of shell stars, a par-

Support for ten-meter mirror for millimeter-wave astronomy is provided by prefabricated metal trusses.

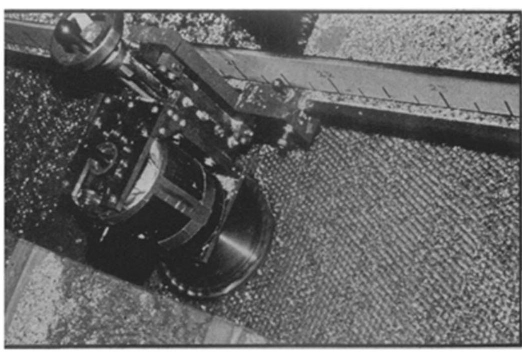
Photos: Caltech

ticular kind of infrared stars that have shells around them, and about planetary nebulae.

This is truly the borderland between radio and infrared, and in fact, Leighton says, the working telescope is instrumented by groups interested in broadband measurements, who use bolometers, essentially an infrared recording technique, and those wanting to chart particular spectral lines, who use radio receivers.

The interferometric detail is of interest not only to the stellar astronomers and cosmologists studying the interstellar clouds, but also to those whose territory is closer to home. The planets do enjoy a similar chemical and temperature regime to that of the interstellar clouds, and much of their emanations come in the millimeter wave range. This instrument could resolve such details as the satellites of Jupiter and Saturn and some of the asteroids. Planetary astronomers from the Jet Propulsion Laboratory, where a lot of NASA's planetary work has been located, are interested.

There is also a remote possibility of some interferometry at Mauna Kea, where the telescope will suffer less from atmospheric absorption of the incoming radiation than at Owens Valley (Mauna Kea being a much higher elevation). The National Radio Astronomy Observatory has wanted to build a 25-meter radio tele-



Honeycomb material is ground to mirror surface then coated with aluminum.

scope on Mauna Kea, and if it ever does that telescope could serve as a fixed-baseline interferometer with the 10-meter one that Caltech will have there.

And ultimately there is the not-impossible question of very long baseline interferometry (VLBI). VLBI is a technique much used at longer radio wavelengths in which observations made of the same object at the same time by widely separated telescopes are recorded on tape and combined in a computer and thereby simulate an interferometer as big as the space between the telescopes. With this technique radio astronomers have simulated the resolution of a telescope as wide as the earth. Leighton says he was talking about this project to Marshall Cohen, one of the prominent practitioners of VLBI. "I said: 'Someday you're going to want to use the millimeter waves for VLBI'; and he said: 'Don't think we aren't thinking of it.'" □

gument has largely disappeared, and the redshifts are now referred to some phenomenon of nature yet unknown.

However, there is an interesting relation between the numbers of observed quasars and their redshifts: the higher the redshift, the more quasars. If one takes the redshifts to be representative of distance in time and space, this means the quasars belong mostly to the distant past. That is what is done by Maarten Schmidt, the recently appointed director of the Hale Observatories. Schmidt does volume counts of quasars, seeking to determine the space densities of quasars in different past epochs. His work takes account of the expansion of the universe, but finds nevertheless that quasars were much more thickly packed in space in long past epochs than they are now. At very large distances, he says, say four-fifths of the age of the universe (16 billion years ago), the space density goes up by a thousand.

Schmidt concludes that quasars are therefore a phenomenon of the early universe. It was somehow easier for them to form in early times when matter and energy were more closely packed. Gradually most of them evolved to something else or burned out. There's no law against a quasar forming now, but it's unlikely. "Suddenly you realize that we seem to be living at the end of the fireworks," he says. "The show is just about over."

But as the captains and the kings depart, they need a candle to light their way offstage. As the cosmologists contemplate the end of the show they want a standard candle, a way of making sure, among other things, that the redshift-distance relation is exact enough to be a measure of what the expansion of the universe has done and is doing and will do.

The question of the quasar redshifts could be solved by finding an independent way of determining quasar distances. This is where the standard candle comes in. A light made to have a known intrinsic luminosity can be used to measure distances. The farther away it is, the dimmer it will look. Comparing its apparent luminosity at any location with its standard intrinsic luminosity will yield the distance.

Are there any quasars that can serve as standard candles? Not quite. But recent work reported from the Lick Observatory (in the June 8 NATURE) promises to provide almost exactly this means. It will enable astronomers to use a measurable physical characteristic of a quasar to determine that quasar's intrinsic luminosity, which amounts to the same thing as having a standard candle out there.

Jack A. Baldwin of the Institute of Astronomy in Cambridge, England, postulated that the intrinsic brightness of a quasar should be related to the width of a particular line in the quasar's spectrum. (The line width depends on the amount of motion of atoms in the object, and that should be related to the amount of energy being generated.) Baldwin tried this idea on a selection of quasar spectra, but with less than convincing results.

"Jack's data were taken from an inhomogeneous sample," says Joseph Wampler of Lick, one of those who collaborated on the later effort. It was a group of quasars chosen for another purpose plus some others added on. It was open to the objection that it favored optically faint quasars, in whose spectra the lines show up stronger than they do in the spectra of bright ones, and that it included quasars of widely varying redshift, which meant that assumptions about the meaning of the redshift had to be added in.

Baldwin, William L. Burke, C. Martin Gaskell and Wampler proceeded to take a group of quasars that would be free of these objections. The quasars were selected on radio criteria (a flat radio spectrum) so that characteristics of their optical spectra would not influence the selection. They were all between redshift 1.1 and 1.4 so that cosmological models based on redshift would not matter. "The hypothesis was confirmed beautifully," Wampler says.

The group thought so well of the result that they made a Hubble diagram, a graph of velocity versus distance, from which one should be able to determine the curvature of the universe and conclude that someday the universe will stop expanding and begin to collapse. This answer to one of cosmology's fundamental questions is the diametrical opposite to the conclusion in favor of a universe that is not only expanding forever, but expanding with an acceleration, repeated a few weeks before by Beatrice Tinsley of Yale University (See p. 141). Wampler remarks that to reach that conclusion she puts in evolutionary effects, the proposition that the objects studied change with time and therefore are not physically the same at all redshifts. Somehow the disparate conclusions will someday have to be reconciled.

Somehow a lot of other disparities will have to be resolved. We can return to the galaxies where Hubble and his contemporaries began. It is difficult to make a galaxy into a standard candle. They are too various physically, and too many factors affect their luminosity. But just by taking a lot of factors and defining a class of galaxies very narrowly, it may be possible to get them to have the same or nearly the same intrinsic brightness. This was tried by Vera Rubin of the Carnegie Institution of Washington and Kent Ford of Kitt Peak National Observatory. They studied the distribution of redshifts of a narrow class of galaxies (Scl) over the southern sky and found an anisotropy that could be interpreted as a velocity of our cluster toward a point in the sky (SN: 8/18/73, p. 114). But it's a different velocity and a different point from those indicated by the studies of the blackbody radiation. That's another thing that will have to be reconciled, Smoot says. □