GONE WITH THE WIND

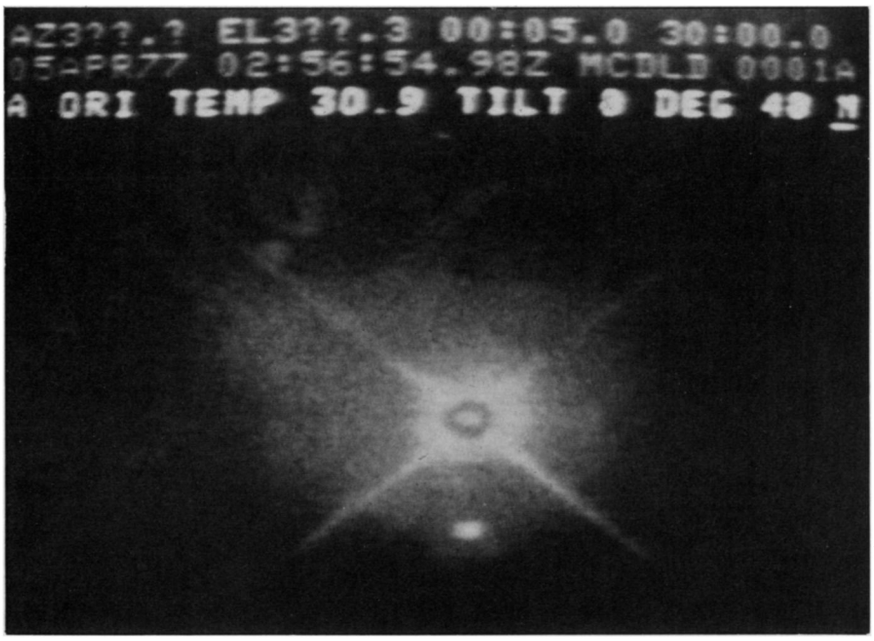
Stars continuously lose a lot of matter to the interstellar medium, some of them at 'hurricane' speeds

BY DIETRICK E. THOMSEN

One of the early and very significant discoveries of the first space vehicles was the existence of the solar wind, a constant flow of gaseous material away from the sun that proceeds past the inner planets to the outer reaches of the solar system, where it disappears into the general stock of interstellar matter. It would be unusual if the sun, which is a fairly representative star, possessed a feature that a lot of other stars didn't share, and in fact, observations pioneered by the late Armin Deutsch of the Hale Observatories, have found evidence that such stellar winds are a fairly widespread phenomenon. As Ray Weymann of the University of Arizona puts it, mass loss by such a mechanism is fairly strong for stars with luminosity greater than that of the sun.

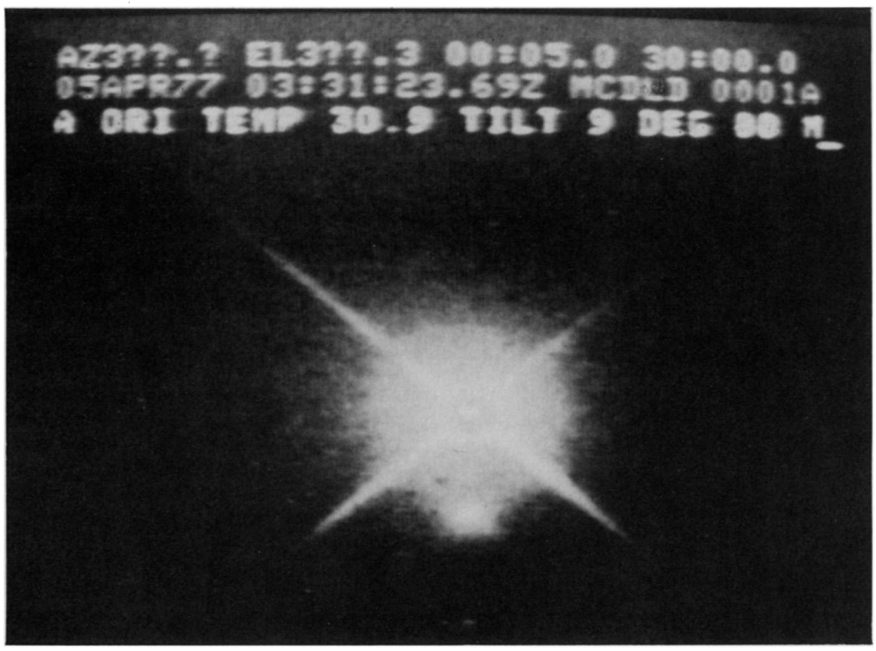
Stellar winds are thus important contributors to the stock of interstellar matter and as such they have a double effect on the physical evolution of stars. First, they affect the stars from which they blow away mass. Second, they affect the stars that form out of the interstellar matter to which they contribute. In any galaxy where star formation and evolution have been going on for some time—and in our galaxy they have been going on for a few billion years—new stars are formed mainly from material that is not primordial but has been processed through one or more generations of old stars. This material gets to the interstellar clouds that condense into new stars partly through stellar explosions—novas and supernovas—but mainly, it seems, through the steady processes of stellar winds.

The sun is a star fairly well along its evolutionary course. According to the generally accepted theory, stars are born bright and bluish-white, and as they age, they get dimmer, and their color gradually changes toward the red. If a graph is made that shows the relation between luminosity and spectral class or color (called a Hertzsprung-Russell diagram), the majority of known stars, which are seen in different stages of evolution, fall on a curve called the main sequence that starts high on the left with the bright blue-white stars and curves over to dimmer red ones at the lower right. Life is not entirely simple, however. The Hertzsprung-Russell diagram also has a horizontal branch that leads off the main sequence, and two groups of stars, the bright red giants in the upper right corner and the dim white dwarfs in the lower left that lack a continuous connection to the main sequence. Presumably stars reach these states by rapid evolutionary jumps.



Photos: LASL

A shell of potassium gas leaving Betelgeuse is 400 times the size of the solar system.



Betelgeuse's cloud also includes dust. This is an image of light reflected from the dust.

If the stellar wind is considered in relation to a star's position on the Hertzsprung-Russell diagram, Weymann says, it turns out to be a "very general phenomenon." It extends from class O (the bluest) through classes B, A, F, G, K to M, the reddest, dimmest stars. (The sun belongs to class G.)

The observational evidence for stellar winds is generally contained in the spectra of the stars. The pattern of resonance lines of particular elements can be seen superimposed on the spectrum of the star. The lines exhibit a shift from their rest values that indicate that the elements concerned have a velocity away

from the star. The conclusion then is that gaseous matter is flowing out of the star. Velocities can be calculated from the line shifts and, Weymann says, average velocities tend to decline from early (blue) stars to later (reddish) ones while the strengths of the observed lines tend to increase. This, Weymann says, is probably just an effect of being able to see farther down into the later class stars to the regions where the stuff is denser and just being accelerated.

In recent months there has been an important addition to the spectral evidence, a success in actually photographing a large cloud of matter on its way out of a star. The star in question is one of the most prominent in the sky, the bright red giant Betelgeuse, or Alpha Orionis. The work was done at the University of Texas McDonald Observatory in Ft. Davis, Tex., by Maxwell Sandford and Charles Gow of the Los Alamos Scientific Laboratory. They managed to photograph a large shell surrounding Betelgeuse in the light of neutral potassium atoms and in starlight reflected presumably from dust grains. The cloud of matter thus photographed leaving Betelgeuse is 400 times as large as our solar system (1,200 times the size of the star), or about 1.6 trillion miles in radius.

The photographs were made using a special infrared sensitive television tube (an intensified silicon-intensified vidicon) that was made for Los Alamos by RCA and is the only one of its kind in existence. (The light of potassium is in the infrared at 0.77 microns wavelengths.) Thirty-minute exposures were necessary to get prints of the faint light from the cloud. And to prevent the star's bright image from washing out the faint surrounding image the star was blocked by an occulting disk. As a result of the technique a ghost image of the star appears below the middle of each photograph. The observers found some evidence for a similar cloud around R Leonis, but have so far failed to detect shells around two other red giants, Antares and Alpha Herculis.

Another piece of evidence about Betelgeuse, which Weymann, who was giving a review of stellar winds at the June meeting of the American Astronomical Society in Atlanta, described as "a bulletin just handed me," comes from the radio astronomer Benjamin Zuckerman of the University of Maryland. Zuckerman finds from the radio emanations of hydrogen that hydrogen is flowing from Betelgeuse at the rate of a millionth of the sun's mass every year.

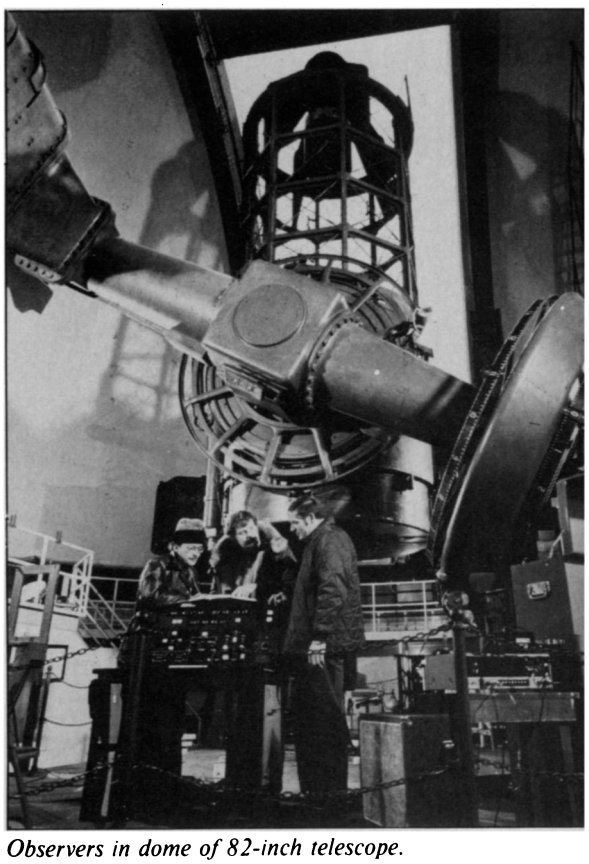
How to explain these phenomena? Theoretically it seems necessary to make a distinction between cool and hot stars. In cool stars like Betelgeuse, the flow has to be fairly cool, so a simple model like heating and thermal flow, which seems to fit the sun, won't do. In fact what Weymann calls the establishment model for cool stars seems to fit fairly well to the circumstances of Betelgeuse. It involves dust and radiation pressure.

According to modern physics, light comes in little particulate bundles of energy called quanta, and when a quantum strikes something small, like an atom or one of the dust grains in question here, it imparts some momentum to its target. In a star like Betelgeuse, the sum of a large number of such hits adds up to a significant amount of radiation pressure. The dust drags gases along with it, and Sun Kwok of the University of Minnesota, Neville Woolf of the University of Arizona and Robert Gilman, formerly of the University of Minnesota, have calculated that this pressure can drive the outward flow at transsonic velocities. There also seems to be a lot of microscopic turbulent motion.

Of course one of the critical points in this analysis is how close to the central parts of the star dust can exist without vaporizing. Specifically, can dust exist in the stellar chromospheres? Critics of the model object that the dust should not exist there, but mass loss does occur there. Weymann points out that "it is by no means obvious that the dust cannot exist in chromospheres. These are cool chromospheres." In Kwok's model, Weymann adds, the dust begins in the chromosphere.

A second objection is that this kind of stellar-wind mass loss is observed in metal-deficient stars, where dust grains should be hard to find. But Weymann says with lower mass stars, the escape velocity is lower so maybe the mechanism doesn't have to be as strong. Finally, a third objection is that the macroturbulent motion doesn't exist. But Weymann answers, "It seems to me it does," basing his belief on the wide spectral lines observed, which would indicate a lot of widely different velocities, one of the main features of turbulent motion.

Much hotter stars must be treated differently. Evidence for mass flow from these, stemming from observations pioneered by Donald Morton of Princeton University, indicates a vigor and intensity that Weymann calls "stellar hurricanes." Prominent data include those taken from Zeta Ophiuci and Zeta Puppi. Velocities here go to 3,000 to 3,500 kilometers per second compared with 10 to 20 kilometers per second for the cool stars. Here, too, the total luminosity seems to be the key to what happens, and also indicates that radiation pressure may be an important factor.



Observers in dome of 82-inch telescope.

Leon Lucy of Columbia University and Philip Solomon of the State University of New York at Stony Brook have suggested a mechanism again involving radiation pressure, but using radiation directly absorbed by atoms of gas rather than by dust particles. Each atom of the outflowing gas absorbs quanta corresponding to its resonant frequencies, and these absorptions give it kicks of momentum. One problem with this is that inner atoms will shadow outer ones so that the outer ones get no momentum this way unless there is some way for them to get "out of their own shadow." One way would be a velocity difference between inner and outer atoms so that the outer ones absorb at slightly shifted frequencies. All in all, however, Weymann comments that this method seems to fail by a factor of about 2 1/2 to provide the necessary momentum. Still, agreement within 2 1/2 should be a spur to further efforts.

And so the work goes on. Observers seek more and better evidence, especially regarding the classes of stars, A, F and G supergiants, for example, for which there is little theoretical understanding of stellar-wind flow. Theorists seek improved models. Perhaps some of the models proposed will be dropped, some changed or new ones proposed. There can be more than one detailed mechanism operating. Over the years it will take much more work by observers and theorists to paint a comprehensive picture of how stars from all over the Hertzsprung-Russell diagram contribute mass to the interstellar medium. □