STAR FEATURES

Astronomers are exploring the chemistry of stellar atmospheres with a technique for finding starspots

By DIETRICK E. THOMSEN

In a telescope, on a photographic plate or on any of the photoelectric sensors now used by astronomers, stars appear as shimmering points of light. Telescopes simply cannot resolve them as disks. Yet astronomers are working on indirect methods to determine and plot surface features on stars. Steven Vogt, Don Penrod and Artie Hatzes of the University of California at Santa Cruz have developed a method for finding starspots, cool spots on a star's surface that are similar to sunspots (SN: 7/17/82, p. 36). Now they are applying that method to plot the chemical structures of stellar atmospheres, to discover the regions in those atmospheres where given chemical elements are more or less abundant and so to learn something about the dynamics and the magnetic activity of those atmospheres.

When you have a method like this for determining starspots, what do you do with it? One possible application is to look at stars of the Ap class, which have long been known to have surface features, even if those features couldn't be mapped. Ap stars are highly magnetic. They are not as ultramagnetic as the multimegagauss white dwarfs that have been breaking records lately, but they are more magnetic than most stars. The magnetism constrains the dynamics of their atmospheres, particularly the distribution of different chemical elements over the surface. The Santa Cruz group's observational work on Ap stars, which Hatzes is leading, will be a test of theories of what happens in the atmospheres of those stars. He gave a report in Ames, Iowa, on some aspects of it at the recent meeting of the American Astronomical Society.

The method depends on an analysis of the profiles of lines in the spectra of the stars. Particular energy transitions in a given atom or molecule emit or absorb fairly precise wavelengths of light. When the star's light is spread out into a spectrum, these sharp quantum jumps appear as bright or dark lines superimposed on the continuous rainbow. In the spectrum of a rotating star, these lines get slightly smeared out. Half the star's surface is always approaching us, and the other half always receding from us, as the star rotates. In the receding half, the Doppler shift, a phenomenon discovered in the early 19th century, stretches the emitted light waves slightly, shifting them a bit toward the red. In the approaching half, the waves are compressed and shifted to the blue.

The resulting spectral line is spread over a very short range of wavelengths, each of which represents a different longitudinal location on the surface of the star. Analyzing the profile of this smeared-out line — that is, charting the variations in brightness over the small spread of wavelengths — finds parts of the surface that happen to be cooler or hotter than others, and these locations can be followed as they move with the star's rotation.

Line profiles can be used to determine chemical abundances as well as temperature. A given spectral line comes from a particular quantum transition in a particular chemical element. Each element identifies itself with a characteristic pattern of lines. Studying the profile of a line or lines from a given element can map the regions of the star's surface where that element is more or less abundant than average.

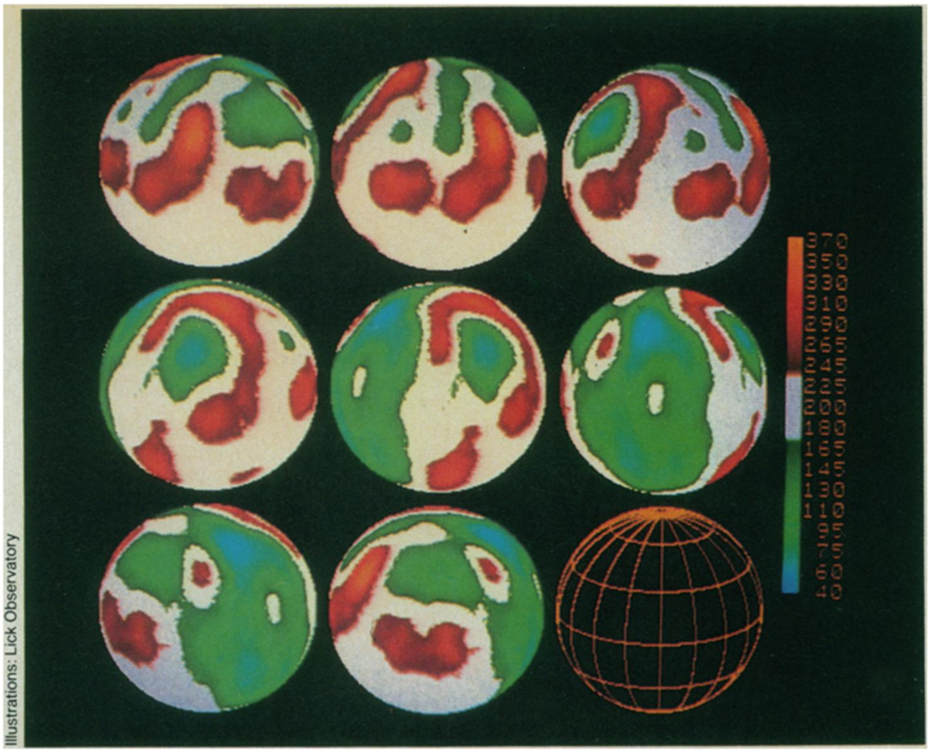
In the abundance work as well as in some of their more recent starspot work, the Santa Cruz group has used a mathematical process known as maximum entropy to solve some of the ambiguities in the simple line profile work. The line profile gives longitudinal information, but the latitude of the spot or the abundance feature is unclear. Determining the star's rotation axis and charting how fast a given feature moves with respect to a pole of the rotation can help solve some of the latitude problem, but ambiguities remain. Although some critics have been dubious, the Santa Cruz group believes that maximum entropy can solve the remaining difficulties.

The problem, as Vogt describes it, involves the link between two mathematical "spaces." The observer has a certain set of data; these can be said to define an abstract mathematical space, the "data space." The data come from physical processes on the surface of the star. The surface is an actual physical space, which they call the image space. The image space produces the data space. The observers, knowing the data space, want to reverse the process and go from it to the image space.

The connection between the image space and the data space consists of 1,200 equations with 1,000 terms apiece to be solved simultaneously. They are represented by a matrix, an ordered array of elements taken from the equations. To get from the data space to the image space, the calculation must invert this matrix, but, Vogt points out, it can't do this because there aren't enough known quantities in the matrix that can be guessed. The alternative is to use a large computer for a numerical solution — making trial after trial until it finally hits the right one.

Maximum entropy enters here. Invented by mathematicians, it is a way of directing the computer's efforts. "We're using a black box," Vogt says. In principle, Vogt says, there are an infinite number of images of the surface of the star that can make the data look a certain way, and the calculation has to pick the one that is correct. Maximum entropy says that there is a unique solution, that one that fits the data and, in terms of information theory, contains the least information. It is thus the leanest solution with the fewest extras.

The computer begins with a guess at the correct image, and starts perturbing it. It checks whether the perturbations seem to be leading to more or less entropy, and so quickly homes in on the appropriate image. All test cases work well.



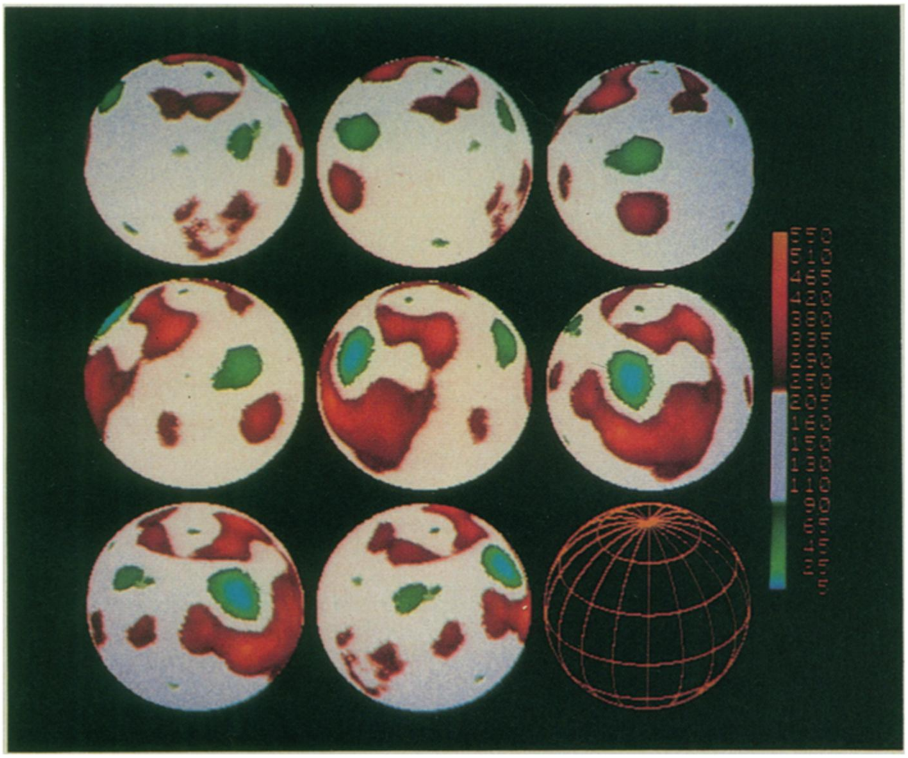
Illustrations: Lick Observatory

Maps of silicon distribution in the atmosphere of 11 Orionis. In red areas silicon is overabundant; in green regions it is underabundant.

"We keep trying to outwit it," says Vogt, "but it still manages to get the right answer."

In fact, he says, the calculation is aided by constraints imposed by the data. Many of the mathematical possibilities are not physical possibilities. Seventy or 80 percent of the solution doesn't use the entropy part. "You are forced into these kinds of images just to fit the data," Vogt says. "Then you start looking at the entropy and start finding those little bumps and wiggles."

During an interview in Santa Cruz, Hatzes displayed on the computer console some of the images he was then working with. The first was a test. They had made up an image of a star, converted it to data and then put the data through the program. One thing the result shows is a ring, an overabundant ring. "Maximum entropy found a solution for that," Vogt says. "Many people believe that rings should be indistinguishable from spots. In maximum entropy there's a difference: A ring comes out as a ring, not a spot."



Spots where silicon is overabundant in the atmosphere of Gamma-2 Arietis are mapped in red; ringlike regions of silicon underabundance appear in green. Features move from frame to frame as the star rotates.

The rings are important because theory expects to find them. Hatzes shows a real star, Gamma Arietis. It shows a spot where ionized silicon is underabundant, surrounded by a ring of overabundance. Vogt says people who have done magnetic measurements have found a pole where the underabundant spot is. It's what people were expecting, he says: There's a theory that magnetically constrained diffusion occurs in these stellar atmospheres. Ionized gases are electrically charged and so have to follow magnetic field lines. Where the field lines are vertical—at poles—the material rises or falls and tends to be underabundant. Where the lines are horizontal, the ionized material is trapped and tends to be overabundant.

Another real star appears on the screen, Iota Cassiopeiae in chromium. People have tried to get magnetic data on this star, Vogt says, but failed.

Here's a spot of grossly underabundant chromium. "It's probably one of the poles," says Hatzes.

Vogt suggests the star's field configuration is a displaced dipole.

"The intensities of the poles are different," Hatzes replies. "You can get that by displacing the dipole or by adding a quadrupole field. One of the guys who's big on diffusion theory says if you add a quadrupole, you get one pole fatter."

Thus, the observations seem to be determining things about the magnetism of these stars that direct magnetic observations do not. Altogether, the observations provide support for the diffusion theory —and that, the observers say, is an important result. ☐