Big Chill in the Solar Atmosphere

Earth intercepts only a minuscule fraction of the light and heat radiated by the sun, but it's enough to sustain life on the planet. How the sun's energy, originating in nuclear fusion reactions at its core, gets to the sun's surface and through its atmosphere into space has long interested solar astronomers.

New data now suggest that the chromosphere — that portion of the sun's atmosphere between its surface, or photosphere, and its corona — contains a large component of gas much colder than many researchers had supposed in their traditional models of energy transfer in the atmosphere.

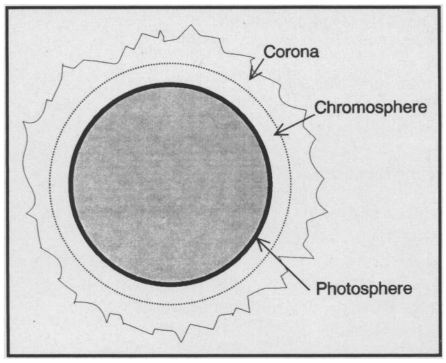
"This really changes our whole picture of what the chromosphere is all about," says astronomer Thomas R. Ayres of the University of Colorado at Boulder.

Ayres, William C. Livingston of the National Optical Astronomy Observatories in Tucson, Ariz., and S.K. Solanki of the Swiss Federal Institute of Technology in Zürich report their findings in the Jan. 7 SCIENCE.

Astronomers had viewed the chromosphere as a relatively uniform blanket of gas with a temperature of between 5,000 and 7,000 kelvins. Starting at roughly 6,000 kelvins at the sun's surface, the solar atmosphere's temperature falls to nearly 4,300 kelvins at an altitude of 500 kilometers before rising to typical chromospheric temperatures. At 2,000 km, near the chromosphere's upper boundary, the temperature again rises steeply, eventually reaching coronal temperatures as high as 1 million kelvins.

Models based on this picture successfully predict the intensity and color of light emitted by a variety of atoms in the sun's chromosphere. But they cannot readily match measurements of the intensity of certain wavelengths of infrared light emitted by carbon monoxide molecules. The carbon monoxide emissions appear to come from gas that is significantly colder than 6,000 or 7,000 kelvins, perhaps as cold as 3,500 kelvins.

Because carbon monoxide molecules form only at temperatures lower than 5,000 kelvins, researchers can use the presence and characteristics of carbon monoxide emissions to map low-temperature features in the solar atmosphere.



This diagram, not drawn to scale, shows the principal components of the solar atmosphere.

In April 1993, astronomers using new equipment at Kitt Peak, near Tucson, Ariz., for the first time obtained high-resolution measurements of infrared emissions from the sun's edge, or limb, where emissions from the photosphere can't muddle the observations.

Because carbon monoxide emissions could be seen above the sun's limb, Ayres contends that cold gas exists at fairly high altitudes in the chromosphere. Moreover, the atmosphere's minimum temperature may occur at roughly 1,100 km above the sun's surface rather than at 500 km, he argues.

Ayres suspects that this cold gas forms a patchy layer, punctuated by hot filaments of gas, in the lower part of the chromosphere. But his suggestion remains controversial.

"The last word isn't in yet," says Robert W. Noyes of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. For example, the clouds of cold carbon monoxide molecules may result from transitory, local phenomena — sharp temperature drops caused when blobs of gas, perhaps ejected from the photosphere, expand rapidly.

"We know a great deal about the structure of the photosphere and its dynamical behavior, and we know very little about the structure of the region a few hundred kilometers up, where the temperature minimum is," Noyes says. "This is an important region of the atmosphere to understand."

New spectrographic equipment and cameras at Kitt Peak will allow researchers to make high-resolution, two-dimensional infrared images of the sun's disk to determine how pervasive the cold carbon monoxide clouds are and how they change over time. "Over the next couple of years, various groups will be making these kinds of observations, and they will likely lay this problem to rest," Noyes says. — *I. Peterson*

Crystal holography with a single beam

Making a hologram — like the rainbow-hued, three-dimensional image that appears in the silvery patch found on a credit card — normally requires the overlap of two separate light beams. One wave carries the image information and the other acts as a reference. When the waves overlap, they create an interference pattern of bright and dark regions, which can be recorded on a photographic plate or some other medium.

Now, Gregory J. Salamo of the University of Arkansas in Fayetteville and his collaborators have demonstrated the possibility of creating holographic images using only one light beam and a crystal of barium titanate sprinkled with cobalt atoms. The researchers describe their technique in the Dec. 27, 1993, PHYSICAL REVIEW LETTERS.

Salamo and his co-workers start with a polarized light beam, about 1.5 millimeters wide, from a helium-neon laser. When it enters the crystal at an oblique angle, the beam splits into two components, which travel in slightly different directions through the crystal.

However, the two separate internal beams are wide enough to partially overlap, and the overlapping light waves interfere with each other to create a pattern of alternating bright and dark stripes inside the crystal. Interactions between the laser light and the cobalt impurities shunt electrons from the bright to the dark areas, creating an electric field that rises and falls in step with the bright and dark stripes.

The periodically varying electric field slightly distorts the crystal structure — in effect imprinting the interference pattern on the crystal. This particular pattern acts like a grating of closely spaced lines that diffracts light. The hologram can persist for days after the original light beam entering the crystal is turned off. The stored pattern can then be "read" or erased at any time using a uniformly bright beam.

"Normally, when you 'write' with two beams, any perturbation in one of the beams can hurt what you're doing," Salamo says. "In this case, there aren't two beams until you get inside the crystal." Users of the new technique would no longer have to worry about achieving proper alignment of the signal and reference laser beams.

The researchers are now looking into the possibility of using their method to store more complex holographic images than simple gratings. "We do this all the time using two light beams," Salamo says. "But if we could use a single beam, that would be a clear demonstration of the technique's potential." — *I. Peterson*