Indeed, perhaps the most intriguing thing about the survey so far is what the Canadian team did *not* see: brown dwarfs, starlike objects that just miss being massive enough to ignite by thermonuclear fusion. According to astrophysical theory, the threshold for thermonuclear burning is about 80 Jupiter masses; a brown dwarf of anything approaching that mass would have stood out in the survey like a searchlight. Campbell is therefore willing to make a categorical assertion: "We've ruled out brown dwarfs between 10 and 80 Jupiter masses."

The Canadians' failure to see brown dwarfs is not altogether surprising, since no one else has seen them either despite a considerable amount of searching. But the new results do lend fresh urgency to a larger question. Low-mass stars are far more abundant in the galaxy than high-mass stars, and a naive extrapolation would lead one to expect that brown dwarfs ought to be even more abundant. The fact that brown dwarfs are rare or nonexistent means that there is something about the star formation process that we do not understand.

"One of the things we're trying to trace is the set of pathways to star formation," says Eugene Levy, director of the University of Arizona's Lunar and Planetary Laboratory in Tucson. Astronomers now believe that all stars are born in essentially the same way inside the galaxy's so-called molecular clouds, which are dense regions of interstellar gas and dust. As the clouds contract by their own self-gravity, the very densest clumps become so massive that they collapse and ignite by thermonuclear fusion. But for some reason, says Levy, there is a bifurcation. On one extreme there are (presumably) embryonic planetary systems like ours, where the infalling gas and dust surround the protostar with a thick, viscous disk. This disk, which is where the planets themselves form, has so much dissipation that everything in it settles into a circular orbit. The image of our own sun's primordial disk can still be seen from the fact that the planets all orbit in the same plane, in the same direction, and in near circular orbits.

At the other extreme, says Levy, there are the systems that go on to become binary or multiple stars; in fact, these multiple systems seem to be in the majority. "Two subcomponents detatch themselves from the inward flow and go on to form separate stars," he says. "From there the evolution of the system is no longer viscous, which means that the two stars are no longer closely coupled." Indeed, the very fact that binary stars tend to circle one another in relatively elliptical orbits means that dissipation never had a chance to erase their infall velocity.

Now, are these two cases just two extremes of a continuum, asks Levy? Do binary systems with one very small member merge imperceptibly into planetary systems with one very large Jupiter? The absence of brown dwarfs, which would occupy that intermediate range, suggests that the answer is no.

But that just leads to another question, says Levy: Why the gap? "One of the reasons for wanting to know the answer," he says, "is because it will tell us something about the dynamics of the gas [in the collapsing cloud]." Especially at the low-mass end, star formation involves a delicate and poorly understood interplay between the one force trying to compress the new star—gravity—and the many forces trying to tear it apart, including pressure, turbulence, magnetic fields, and rotation.

"What's amazing to me is that the lower limit for star formation seems to be so close to the lower limit for nuclear burning," he says. "It's not obvious why that should be. But then, in astrophysics there are a lot of coincidences that people still don't understand." ■ M. MITCHELL WALDROP

Monitoring Earth and Sun by Satellite

Researchers attending the spring meeting of the American Geophysical Union held 18 to 21 May in Baltimore have grown familiar with doing geophysical studies by satellite. Here are three current examples discussed at the meeting: gauging the output of the sun, measuring crustal movement, and deciphering the mineral composition of surface rocks.

How the Sun Faded Even as Its Sunspots Did

The sun has been slowly fading during this decade, even as the number of dark sunspots blemishing its face followed its 11-year cycle to a minimum last fall. Peter Foukal of Cambridge Research and Instrumentation, Inc., in Cambridge, Massachusetts, and Judith Lean of Applied Research Corporation in Landover, Maryland, reported that the sun's fading, when it would seem it should brighten, appears to be a result of the decline of more subtle areas of enhanced brightness. This decline has more than compensated for the decrease of sunspots, they say. The sun's brightness is liable to begin increasing as a new cycle begins, but Earth was probably not so lucky during the Little Ice Age of the 17th century.

Although they doubt that the decline of the sun's total output began as early as 1978, as some observations suggest, Foukal and Lean confirm that two different satellite radiometers have measured a decrease of solar irradiance of 0.07% from 1981 to 1984. A decrease as small as 0.1% lasting a decade might change global climate perceptibly. The earlier reported decrease may have been due to an unintended break-in period of the radiometers, they say, but the recent decrease is certainly real. In support of that contention, they cite the consistent response of the two radiometers—called ERB and ACRIM—from 1981 to 1984. In addition, irradiance changes measured by the two instruments over periods of 4 to 9 months correlated with each other as well as with changes in the structure of the sun's surface.

Foukal and Lean believe that they have pinned down just which changes in the sun's surface caused the sun's recent dimming. Sunspots would seem to be the most obvious candidates. They can contrast so much with their hotter, brighter surroundings that the unaided eye can pick out large ones when the sun is near the horizon. Less obvious but more extensive are the bright areas called plage or faculae associated with sunspots.

Both types of features reflect the snaking of ropes of strong magnetic fields through the visible surface. Sunspots appear dark because their large diameters obstruct the convective flow of heat toward the surface more than they uncover the hotter depths and thus increase their radiation into space. The narrower plage tubes enhance radiation without greatly obstructing convection and are thus bright.

Foukal and Lean found a close correlation between changes in irradiance over 4 to 9 months and measures of the influence of

The dark and the bright. *As the sunspot cycle goes into decline, the dark sunspots become scarce, but the extent of bright faculae as well as barely visible bright network radiation also decrease. The net effect is apparently a dimming of the sun.*

sunspots and plage on irradiance. But even the combination of these two features could not explain the long-term decrease between 1981 and 1984. To do that, they include a measure of all bright areas, plage as well as the bright but less contrastive network radiation that is barely visible and is dispersed away from the plage and sunspots. It turns out that about one-half of the effect of bright regions comes from changes in network radiation.

So, as the solar cycle winds down and the decline in sunspots tends to brighten the sun, the parallel decline in plage and network radiation more than compensates, and the sun fades, according to Foukal and Lean. They calculate from archival solar observations made before the satellites went up that irradiance should have increased about 0.12% from the 1975 sunspot minimum to the maximum in 1981. If the sun follows the same form during its new cycle, a similar brightening should be getting under way now.

The direct linking of sunspots and irradiance lends further support to the connection made in 1976 by John Eddy of the National Center for Atmospheric Research between the Maunder Minimum, a near absence of sunspots between about 1645 and 1715, and the coldest excursion of the Little Ice Age, a period of unusual cold in Europe from the 16th through the early 19th century. While cautioning that it can be little more than a guess, Foukal and Lean estimate that such a protracted minimum of solar activity might have been accompanied by an irradiance decrease of 0.14% from present-day maxima. Acting over 70 years, such a brightness dip could clearly affect climate. As Foukal and Lean comment, the sun's prominent dark spots may have received the most study in the past, but its bright areas appear to dominate its output and deserve increased attention.

Geologist's Hammer Is Joined by Spectrometers

Gregg Vane of the Jet Propulsion Laboratory (JPL) can do field geology without going into the field. The trick is his use of the Airborne Visible and Infrared Imaging Spectrometer or AVIRIS. The second-generation instrument in a series of instruments being developed by JPL, AVIRIS looks down on the earth's surface from its perch in a U-2 aircraft and records a high-resolution reflectance spectrum for each of 550 picture elements, one of which covers 20 meters of the surface.

From such spectra, the presence of individual minerals can be determined by comparison with laboratory spectra. Arranging spectral results pixel by pixel yields an aerial photograph–like map of rock composition. Laboratory work and some field verification is required, of course, but sampling every few tens of meters across an 11-kilometer swath that lengthens at the speed of a U-2 makes possible a new way of looking at the land.

Vane reported that AVIRIS, which just became operational in June, has several advantages over its predecessor, the Airborne Imaging Spectrometer (AIS) carried on a C-130. AVIRIS covers the spectrum from 0.4 to 2.5 micrometers, so that distinctive mineral features in both the visible and infrared can be used for identification. AIS covered only the infrared. The AIS swath was only 0.3 kilometer compared to the 11-kilometer swath of AVIRIS. But AVIRIS retains the narrow 10-nanometer sampling interval of AIS which allows it to resolve diagnostic features that can be as narrow as 20 nanometers. "This should make possible the routine identification of a major portion of surface materials," Vane said.

As an example of one new possibility, Vane cites a planned search for signs of rare earth elements, made famous by their role in high-temperature superconducting compounds. Another is the extension of studies of mineral distribution as evidenced in the spectra of vegetation, since plant cover is an obstacle to direct observation of the surface. Spectral imaging can even monitor the health and perhaps the biochemical composition of vegetation. The next step up for imaging spectrometry is a possible flight of an instrument on the shuttle followed by the placement of an upgraded imaging spectrometer on the polar orbiting platform of the mid–1990s.

Precision of Global Positioning Increases

During the past 2 years, geodesists have improved by an order of magnitude the precision with which they can determine positions on the surface of the earth using the satellite-based Global Positioning System (GPS). They can now monitor at low cost and with unprecedented ease the changes being wrought in the earth's crust—changes including sea-floor spreading in Iceland, strain accumulation along the San Andreas fault, bulging above the magma chamber under California's Long Valley, and the subsidence caused by ground-water removal.

Speakers reported that positions are now being determined with precisions of about 1 part per 10 million over distances of up to 480 kilometers. That is an error of 1 centimeter in measuring the distance between markers 100 kilometers apart.

The improvement was attributed to several developments. With experience, researchers are simply getting better at analyzing the positional data derived from the comparison of signals received at different sites from the same GPS satellite. They are also using a new technique for precisely determining the positions of the satellites, which are operated by the U.S. military for the instantaneous but less precise determination of position. In the new geodetic technique, researchers tie several sites to the GPS network whose positions have also been determined by the more precise, but expensive, very long baseline interferometry (VLBI) technique. These fixed sites then act as benchmarks for orbit determination. At some locations, the use of water-vapor radiometers has also improved precision by taking a better account of the effects of a humid atmosphere on the satellite signals.

William Strange of the National Geodetic Survey in Rockville, Maryland, is optimistic about the future of GPS. "The single biggest improvement will be the full constellation" of 18 GPS satellites. "We really don't have much data now," he says. With the present six satellites, any one site typically has two to three or at most four satellites in sight for a few hours a day. When new launches beginning after 1989 bring the system up to strength, six satellites will be in sight at all times from any point on the globe. Then, Strange believes, the relatively inexpensive GPS receivers, which fit in the back of a jeep, will replace mobile VLBI units that require two tractor trailers of equipment, at least when distances to be measured are less than 1000 kilometers. ■

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