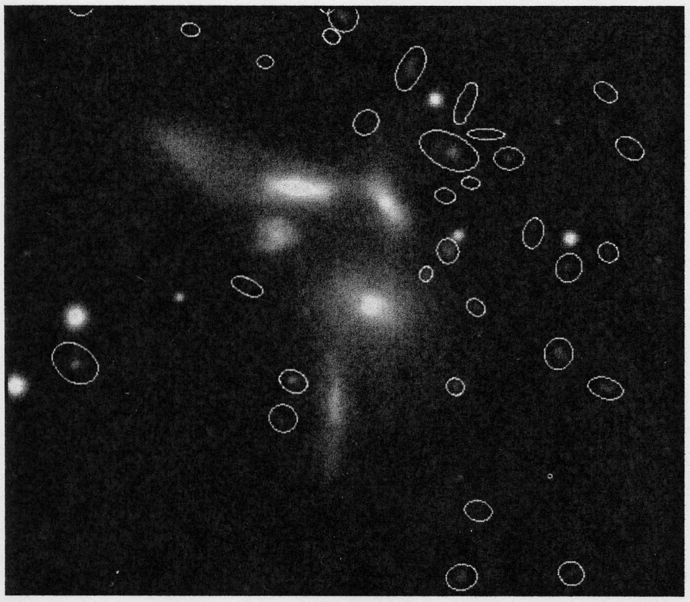

This is another Hickson Compact Group which is also known as Seyfert's Sextet. The sixth "galaxy" in the upper left corner of this very compact configuration is actually not a giant galaxy, but a very luminous tidal tail emanating from the nearby bright spiral. This group may also have extended x-ray emission, which indicates previous interactions.

interesting results. If it turns out that tidal dwarfs contribute significantly to the population of dwarf galaxies, our views of galaxy and group evolution will be profoundly changed. ★

Sally Hunsberger

(Sally Hunsberger is a recipient of the Lowell Postdoctoral Fellowship. Other researchers on this project include Jane Charlton of Penn State University and Dennis Zaritsky of the University of Arizona.)

Gauging the Sun

Measuring the amount of solar radiation received by the Earth, the so-called "solar constant", is astonishingly difficult. Observations from mountain locations beginning at the turn of the century were thwarted by the difficulty of correcting for the amount of radiation absorbed by the Earth's atmosphere. It was not until spacecraft began measuring the Sun 20 years ago that we got a good fix on the true value – about 1,366 watts per square meter at the top of the Earth's atmosphere. Even that value remains uncertain by 1-2 watts owing to the difficulty of calibrating a radiometer in space. The spacecraft measurements also showed for the first time that the Sun's output varies slightly, dropping by just under 0.1% from the 1980 solar sunspot maximum to the 1986 solar minimum.

After decades of speculation, we now know that the Sun is indeed a "variable star", a designation applied by astronomers to stars with brightnesses that change over time. The variations of the Sun arise from the cyclic competition between sunspots, which dim the Sun slightly, and the slightly more powerful accompanying bright faculae, which brighten it. Paradoxically, the Sun is on average slightly brighter when its visible disk shows dark sunspots.

During the second half of the 17th century, sunspot activity ceased for a while and the accompanying "Little Ice Age" of cool European temperatures points to the Sun as the cause. More detailed studies of paleoclimate "proxy data" show other anomalies intimately tied to past solar activity variations. From this evidence, a 1994 National Academy of Sciences panel published a report on "Solar Influences on Global Change" which called for comprehensive solar measurements. Around that time, the National Science Foundation earmarked funding for a grant program called RISE (Radiative Inputs from the Sun to Earth). RISE funds sponsor a Lowell Observatory project to measure the brightness variations of stars similar to the Sun.

What can a study of sunlike stars tell us about the Sun? We would like to be able to estimate future solar variations, a tough assignment in view of the not-quite-regular pattern of the solar cycle. By studying a sample of stars like the Sun, we hope to describe their average behavior and to catch some in possibly unusual states of variation that will allow us to make more reliable estimates of what the Sun is capable of doing.

Since 1984, observer Brian Skiff has been measuring the brightness variations of 40 sunlike stars using the 21-inch telescope on Mars Hill. Each observation takes about 30 minutes and a dozen or more data points are needed per year to record variability. To date, Skiff has made over 8,000 of these measurements! On the basis of the first 11 years' observations, we recently published two papers in *The Astrophysical Journal*. Next year we will wrap up the program with a final summary paper covering the entire 16 years.

Fig. 1 shows a typical data product for one of our stars. The upper graph, called a light curve, shows how one particular star's brightness changes over time. The lower graph shows the magnetic activity of that star – a measure of its spottiness – recorded since 1967 at Mount Wilson Observatory. Similar measurements made by Lowell's Solar Stellar Spectrograph project also record magnetic activity, but only since about 1994. Each point represents a single brightness measurement. Note for this star, which has a clearly defined activity cycle of about ten years, the brightness and magnetic activity change in perfect synchrony. The amplitude of light variation, however, is about 1%, ten times greater than that of the Sun. At Lowell, we can measure long-term variations as small as about 0.2%, a level of precision that was long thought to be unattainable.

Magnetic activity refers to the surface manifestations of stellar magnetic fields. In the Sun, these are most visibly revealed by sunspots. For other stars, which are too far away for us to see such detail, we record the intensity of emission from a particular spectrum line of ionized Calcium (Ca II), the so-called "K line". This line originates in the star's hot, thin chromosphere. Its strength indirectly records the amount of magnetic activity associated with spots.

For comparison with the Sun, we derive a single statistic from each light curve – the amount of year-to-year variation shown on Fig. 2. The horizontal axis is a measure of activity, and also age, expressed on a logarithmic scale with younger stars lying on the right and older stars on the left. The vertical axis shows the amount of variability. We see that compared with the stars nearest it on the graph, the Sun is relatively quiescent, having much less variation than its neighbors.

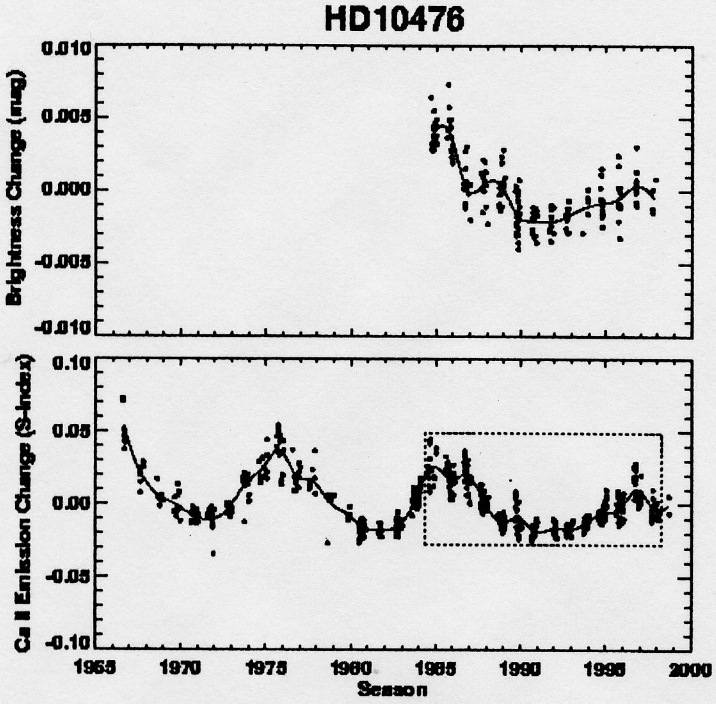

Fig. 1. Photometric brightness (upper graph) and chromospheric Ca II K-line emission (lower graph) time series for the star HD 10476. The dashed-line box in the lower graph encloses the portion of the chromospheric emission time series during which the photometric measurements were also being made. Brighter is upward in both graphs. Fig. supplied by R. Radick.

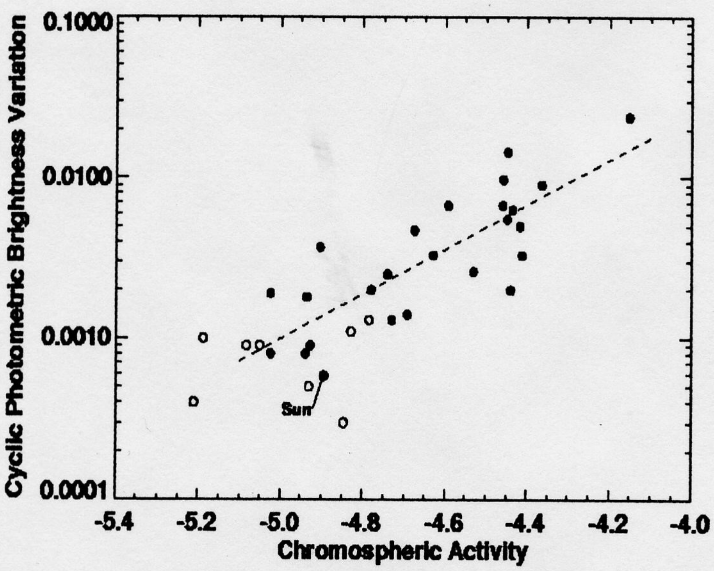

Fig. 2. The relationship between long-term photometric brightness variation and average chromospheric activity as measured by Ca II emission. The trend line was fitted using only stars that are clearly variable, represented by filled symbols. Open symbols may be considered to represent upper limits. Fig. supplied by R. Radick.

This is a surprising result. Why should the Sun be less variable than stars of similar age? Do we live in a golden age of minimal solar variability or is the Sun just somehow different? The question has no simple answer and much more research may be required to answer it.

Programs like this one are relatively rare in astronomy where quick results are often crucial to continued funding. But in this case, 11 years was the minimum acceptable interval needed to see the full cyclic amplitude of a star exactly like the Sun, and twice that would not be unreasonable. This project has been ideal for Lowell Observatory where access to the telescope could be guaranteed for the necessary long haul. The other key components of this program include the willingness of Brian Skiff to sign up for such a long hitch, and for continuing sponsorship of the program by the RISE program of the Division of Atmospheric Sciences of the National Science Foundation. ★

Wes Lockwood

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The Lowell Observer

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