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TECHNICAL COMMENTS

Stellar Variability and Global Warming

Stellar observations (*1*, *2*) suggest that the sun is less variable in its total light output than other stars of comparable magnetic activity. In his report (*3*), Peter Foukal offers an interpretation of this result in terms of a model for solar variability. It appears, however, that this model does not account completely and correctly for the stellar observations.

Foukal argues that the broadband variability of a star like the sun is explainable in terms of two types of discrete magnetic features on its surface, namely bright faculae (in both active regions and the magnetic network) and dark sunspots. A central feature of his interpretation of the stellar observations is the expectation that the variation in total light must be dominated by the dark (spot) component when the average activity exceeds some level.

This model can, indeed, explain the high amplitude brightness variability of stars that are considerably younger than the sun. Such stars have time-averaged magnetic activity several times greater than that of the present-day sun. Their total light output also characteristically varies inversely with their emission in the resonance lines of ionized calcium (widely accepted as a proxy for the bright faculae), a fact implying that their net broadband variability is driven by the dark (that is, spot) component, consistent with Foukal's expectation.

Stars similar in age to the sun, however, have time-averaged magnetic activity comparable to that of the present-day sun (*4*). They show calcium emission variations on the time scale of the 11-year solar activity cycle ranging from about one-half to twice that of the corresponding solar variation. Their broadband variability ranges from 0.1%, which is characteristic of the sun, to values as much as ten times larger. The broadband cyclic variation of the sun seems to be a factor of 3 or 4 below what one would expect for a star with this average magnetic activity, despite the fact that the amplitude of the sun's calcium emission variation appears to be fairly typical.

These stars, including the sun, characteristically share a property that clearly distinguishes them from younger stars: Their total light output varies directly with their calcium emission, rather than inversely. In terms of the two-component model, this means that, regardless of its amplitude, the net broadband variability of these stars is dominated by the bright (facular) component. Thus, Foukal's argument that the dark (spot) component is driving the net broadband variability of some of these stars (the more strongly varying, in particular) is not correct. Accordingly, his interpretation does not explain, in a fundamental, qualitative way, the behavior of those stars he is most concerned with, namely, stars with average magnetic activity comparable to that of the present sun, but with broadband variability amplitudes that are several times larger.

Furthermore, the behavior of some of these solar analogs appears to pose quantitative difficulties for the two-component model of solar and stellar variability itself. Consider, for example, the star HD 10476. Its average magnetic activity is only 6% greater than that of the sun. The decadal variation of its calcium emission, however, exceeds that from the sun by a factor of almost two. If the proportionality between calcium emission and the bright (facular) component is similar for both the sun and its stellar analogs (*5*), then the contribution to HD 10476's broadband variation from the bright component must also be about twice the corresponding solar value, or 0.4%. Photometric measurements show that its net broadband variation, which reflects the contribution from the dark as well as the bright component, is about 0.6%, six times the solar value. In conjunction, these two measured relations imply that the "dark" component must make a *positive* contribution of 0.2% to the decadal variation of this star, which is, of course, contradictory.

In total, somewhat more than one-third (5 of 13) of the observed sample of close solar analogs pose similar difficulties. If we include stars that are clearly less active than the sun, the situation remains about the same: 8 of 21 stars in the augmented sample are discordant. Perhaps solar-stellar variability does involve "other mechanisms than modulation by photospheric magnetism . . ." (*3*, p. 239). For example, there may be some large-scale phenomenon going on that is not accounted for by a two-component model that views variability as the sum of contributions from small-scale features alone (*6*).

In any case, it seems evident that such problems in explaining the behavior of solar analog stars must also cast doubt on conclusions about the range of possible solar variability and the consequent implications for studies of global warming. I disagree with the suggestion that the observation of relatively large amplitude variability among sun-like stars is not particularly relevant to "the explanation or prediction of Earth's climate anomalies in the immediate past or future" (*3*, p. 238). Were the sun simply to regress to the mean defined by its stellar analogs, it would experience variations in its total light output several times larger than those measured during the past 15 years, without any accompanying change in its average magnetic activity. Until we have a consistent explanation for the observed behavior of solar analog stars, it would seem imprudent to dismiss the clues that stellar observations are providing us about the range of possible solar behavior.

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