A Survey of Chromospheric Activity in the Solar-Type Stars in M67

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Abstract

We discuss our program to measure the level of chromospheric activity in the solar-type stars in the galactic cluster M67. We describe the observational approach and the data reduction methods adopted, and the selection criteria for the stellar sample.

1 Introduction

We have initiated a survey to measure the level of chromospheric Ca II H&K emission in ~ 100 solar analogs in the galactic cluster M67. The primary objective of this program is to begin a long-term investigation of the nature of *solar* variability. M67 is an especially appropriate target of observation since it is approximately the same age (about 5 Gyr $\pm$ 1 Gyr; Demarque et al. 1992) and of the same metallicity as the Sun (Barry & Cromwell 1974). Our working hypothesis is that a single 'snap-shot' of a large sample of solar analogs will reveal the potential range of *solar* chromospheric activity. In this way, we immediately obtain information on the potential *long-term* variability of the Sun that would not otherwise be possible (or practically feasible) with the modern solar Ca II data-base of only two decades (e.g., White & Livingston 1978; Livingston 1994). This is especially important given that the amplitude of long-term, solar and stellar variations in *brightness* are correlated with cycle variations in *chromospheric* emission (Hudson 1988; Radick 1991). In view of the fact that the Sun is the engine that drives climate on the Earth, any variation in the solar 'constant' must be taken into account in the investigation of the long-term behavior of the global climate.

The final results of this survey are expected to reveal the range of Ca II H+K emission observed in the sun-like stars in M67. We will interpret this range as indicative of the potential cycle-related variability that can occur in solar-type stars and the Sun. For example, is the range in chromospheric activity among the 'Suns' in M67 similar to the 11% excursion in Ca II emission levels seen thus far between the minimum and the maximum in the solar cycle? Those stars that exhibit Ca II emission levels that are less than that seen at solar minimum will confirm, as suggested by Baliunas & Jastrow (1990), the occurrence of exceptionally quiescent phases of magnetic activity analogous to the so-called 'Maunder-minimum' episode of the Sun during A. D. 1645 - 1715 when visible manifestations of solar activity vanished. This period corresponds to a time of reduced average global temperatures on the earth known as the "Little Ice Age" (Foukal & Lean 1990).

An additional objective of the survey is to determine if the solar-age stars in M67 conform to the proposed empirical relationships between age and activity (that have been inferred mainly from young clusters of known ages), and the extent to which activity cycle-related variability among stars of the same age contribute to the scatter in age-activity calibrations.

2 Observational Approach

We are utilizing the 3.5-m WIYN telescope in conjunction with the Hydra multi-fiber positioner to perform multi-object spectroscopy over a 1 degree field. We use a bench-mounted spectrograph with the T2KC CCD, Simmons camera and the 1200 l mm^{-1} grating in second order. Two blocking filters (BG38 & BG39) must be employed to suppress red leak at the sacrifice of some throughput; these filters will soon be replaced in this program by a single $CuSO_4$ filter, thus increasing our throughput. This configuration yields a spectral resolution of about 0.80 Å in the 3950 Å region between the Ca II K and H lines, as measured by the FWHMs of the CuAr comparison lines.

[1]The NOAO is operated for the National Science Foundation by the Association of Universities for Research in Astronomy.

We display in Figure 1 a diagram from the Hydra simulator illustrating the placement of the fiber positioner for target stars in the M67 field. While 100 blue fiber cables are available, only about half of them can be positioned at targets because of the disallowed proximity of fibers that inevitably occurs (i.e., fiber-fiber interactions) in centrally condensed fields. Thus multiple Hydra configurations are required to obtain spectra of the entire sample. At approximately a distance of 870 pc (Montgomery et al. 1993), solar-type stars in M67 are relatively faint with V $\approx$ 14.5. It is really the advent of the Hydra multi-object spectrograph on a 4-m class telescope that enables the efficient conduct of a survey of $\sim$ 100 solar-type stars based on K-line spectroscopy. Nevertheless, spectroscopy of cool stars in the blue is still challenging even with a relatively large-aperture telescope such as the WIYN telescope. A raw Hydra frame comprised of the sum of 4 $\times$ 3600 sec frames is displayed in Figure 2. Differences in intensity are due both to differences in V-magnitude and to variations in fiber throughput which can change by up to a factor of $\sim$ 3 from one fiber to the next.

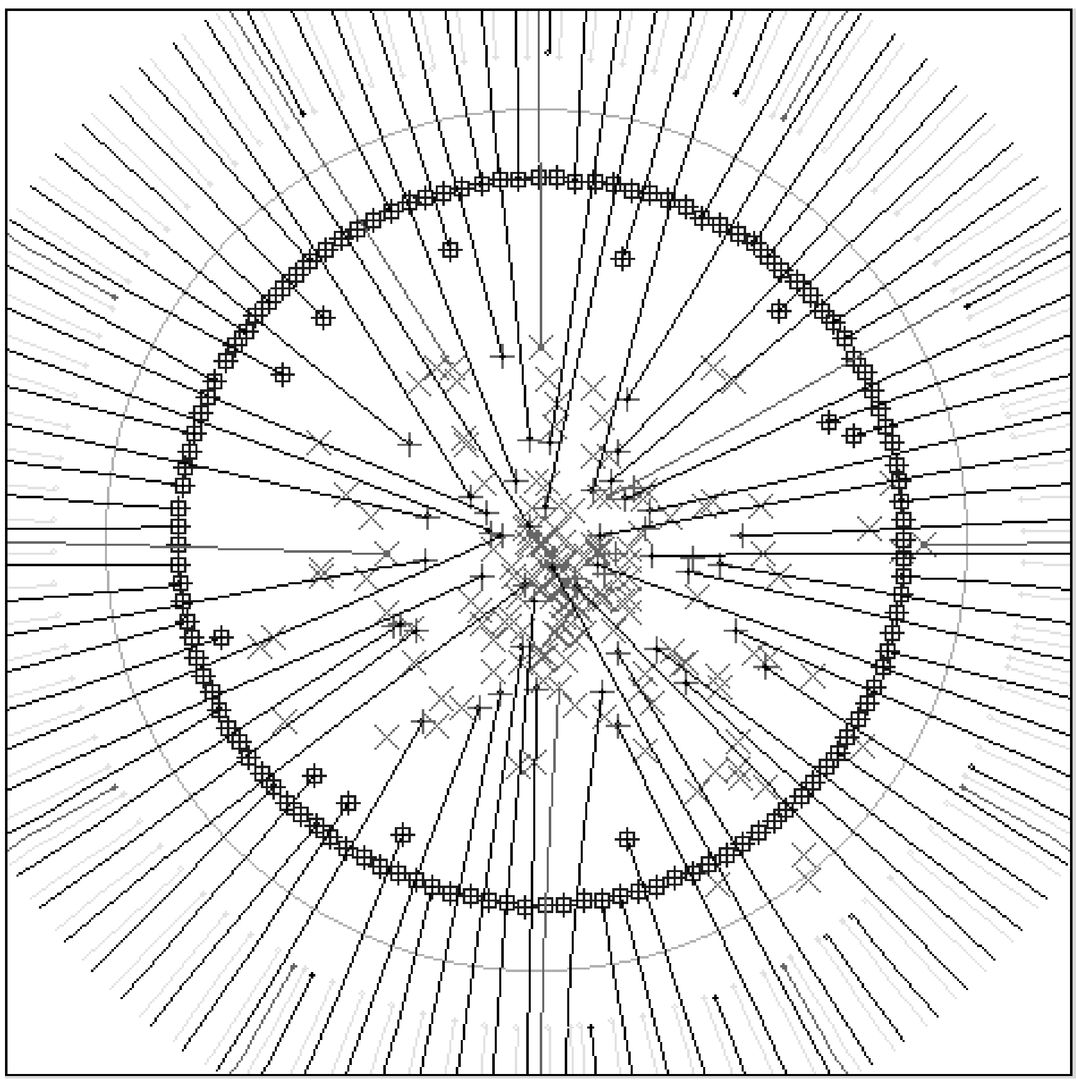

Figure 1: Hydra simulator showing the positioning of fibers for a target field in M67.

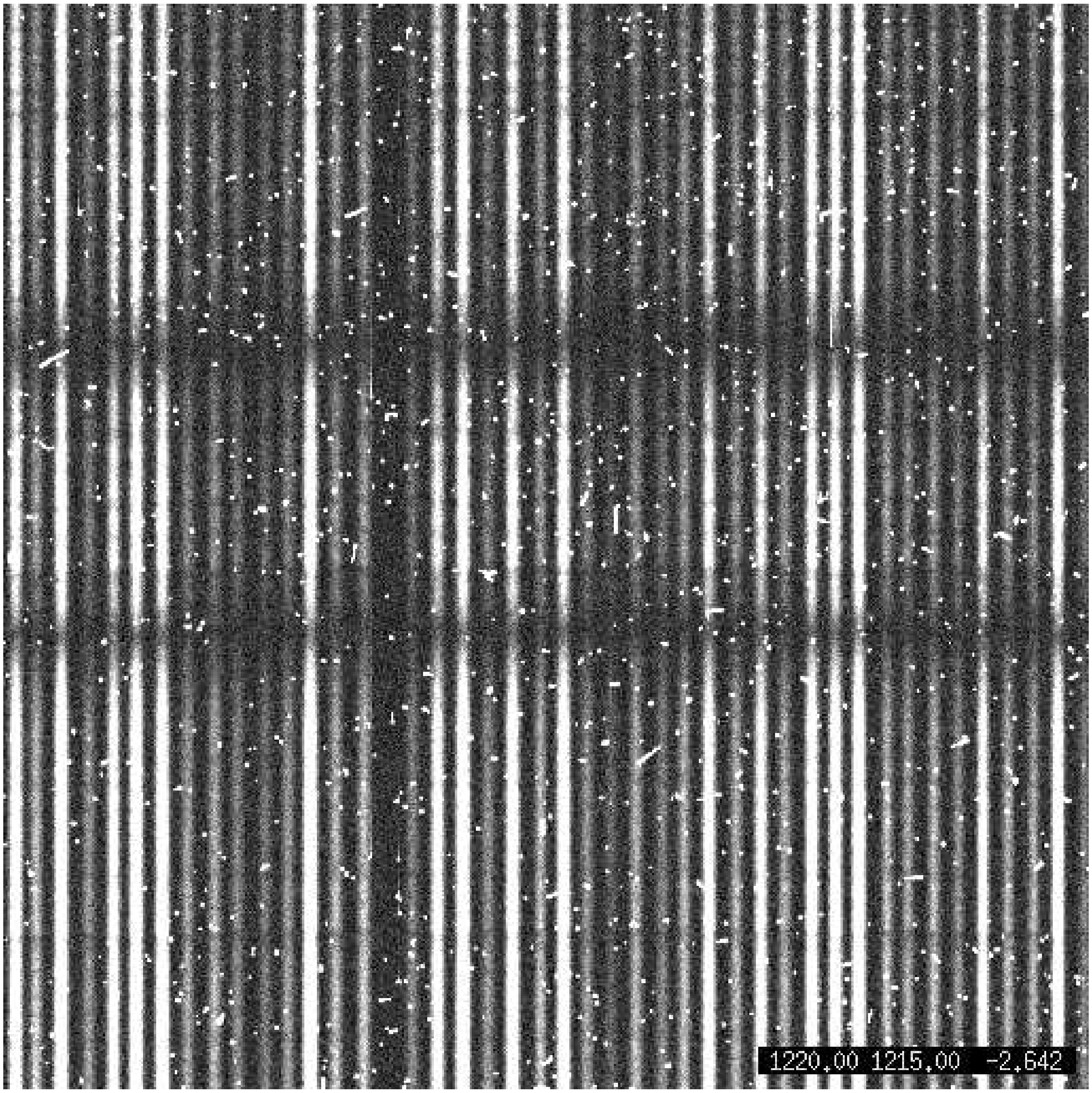

Figure 2: An example of a raw Hydra frame consisting of the sum of 4 $\times$ 3600 sec individual frames for solar-type stars in M67. The dispersion direction is vertical in the figure. The Ca II H and K lines are evident as prominent dark bands in the frame.

2.1 Stellar Sample

The stars are selected from the Girard et al. (1989) proper motion study combined with the CCD photometry given by Montgomery et al. (1993). For those objects from the Girard et al. study where photometry from Montgomery et al. is not available, we adopt the photometry given by Sanders (1977). We include only stars that have a membership probability of $\geq 90\%$ as given by Girard et al. (1989). Our photometric criteria include stars in the range of apparent brightness of $14 \leq V \leq 15$ and intrinsic color of $+0.55 \leq (B-V) \leq +0.78$, where we adopt a value of $E(B-V) = 0.05$ for the color excess in M67 (Montgomery et al. 1993). The resulting spectral range of the sample is $\sim$ F8 - K0. A histogram in intrinsic $(B-V)$ color of the sample is given in Figure 3. In this way, we can ensure that we are observing stars that are very close to the Sun in their photospheric properties.

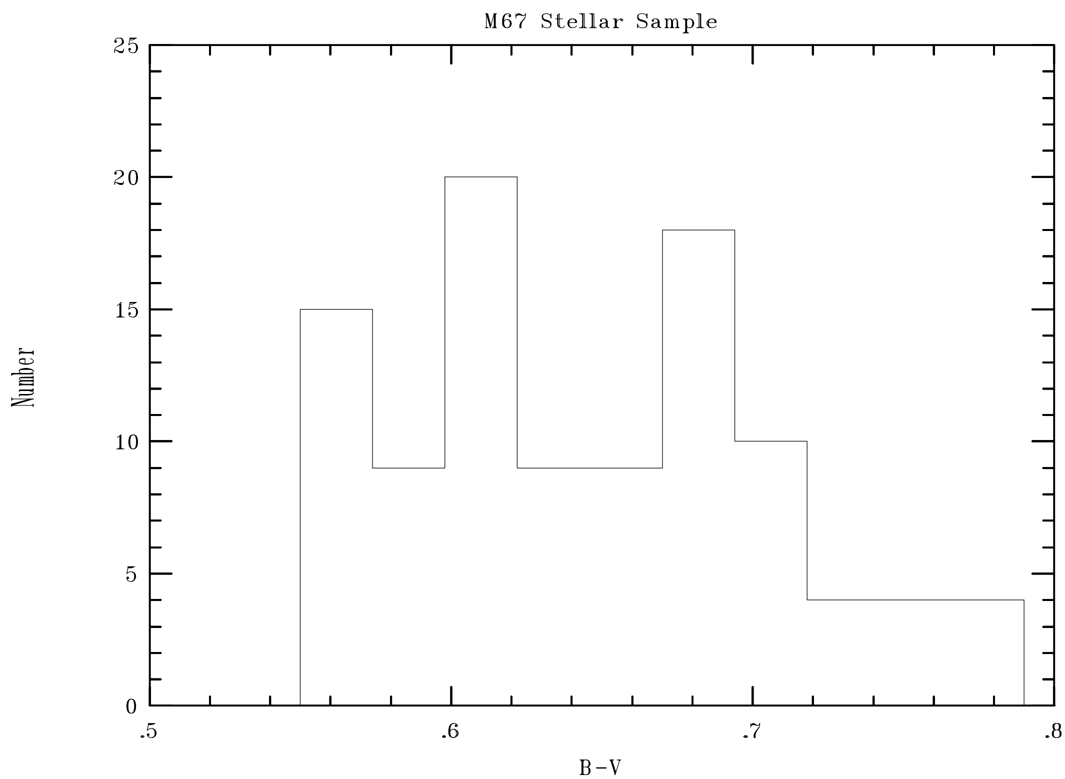

Figure 3: A histogram in $(B-V)$ color of the stars observed in this program. The stellar sample emphasizes solar analogs where we adopt $(B-V) = +0.65$ for the Sun.

3 Data Analysis

The reduction and analysis is not yet complete at the time of writing. Therefore, preliminary results are not presented in these proceedings. However, we will indicate herein our calibration procedure. This procedure is critical in order to achieve a reliable comparison between the results of these stellar observations with those for the Sun seen as a star using completely different instrumentation.

The calibration of the Hydra spectra to residual intensity and flux follows the relations given by Hall & Lockwood (1995) and Hall (1996), initially as functions of $(B-V)$ color. These relations give the residual intensities at pseudocontinuum points at 3912 Å and 4000 Å, respectively, along with the continuum flux at 3950 Å, each as a function of $(B-V)$ color. We apply a correction to the relations for the 3912 and

4000 Å points in order to account for the somewhat lower resolution of our Hydra spectra. The quantitative values of the correction factors are determined from the NSO solar atlas flux spectrum (Kurucz et al. 1984), degraded to match the resolution of the stellar spectra. The result of this procedure is illustrated in Figure 4 where the WIYN/Hydra spectrum of a solar-type star in M67 (S1423; V=14.38, $B-V=+0.65$) and the integrated spectrum of the Sun as a star are given.

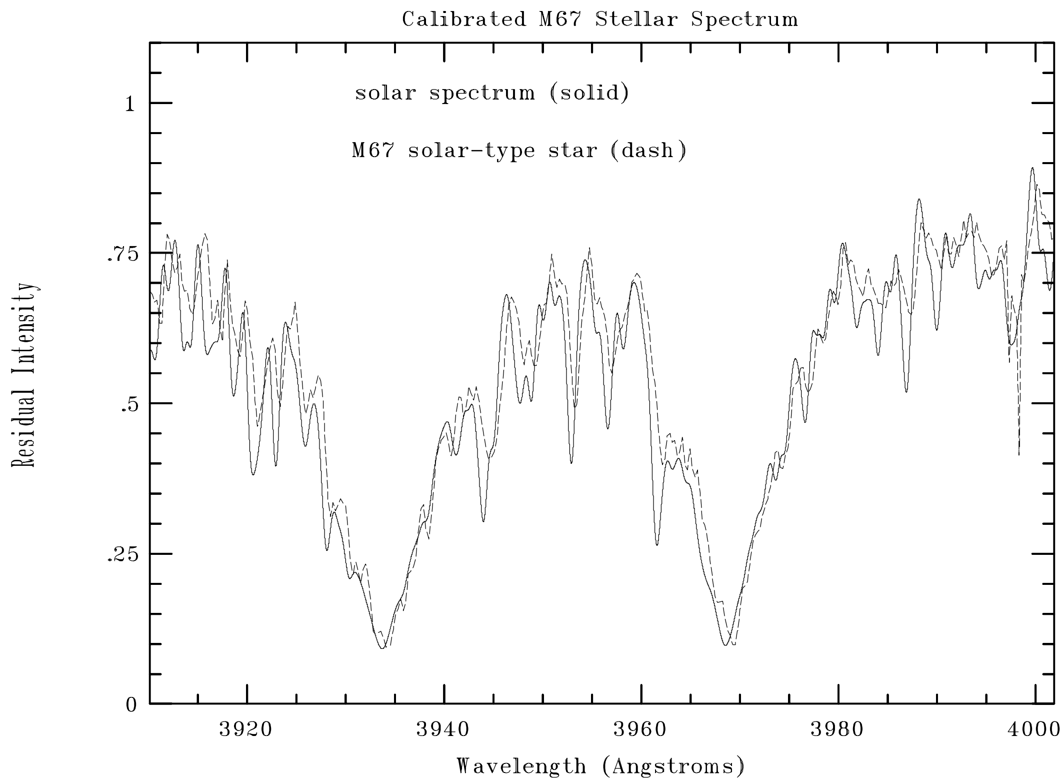

Figure 4: The spectrum of the Sun as a star from the NSO solar flux atlas is shown along with a Hydra spectrum of a solar-type star in M67. The solar spectrum has been degraded in resolution to more closely match the Hydra spectrum. The stellar spectrum is shifted in wavelength relative to the solar spectrum due to the stellar radial velocity.

We also present in Figure 5 a comparison between this same Hydra spectrum and that of a solar analog, 16 Cyg A, as observed with the Lowell Observatory SSS instrument and kindly provided by J. Hall. In both cases, the reduction and calibration procedures yield results that are in very good agreement.

4 Summary

The Ca II H and K survey of solar analogs in M67 is expected to be completed by the conclusion of the Spring 1998 semester. Following reduction and calibration, as outlined above, we will measure the total H and K line emission strengths in 1 Å bandpasses intended to be centered at the respective line cores. In fact, we will fix the bandpasses at the cluster radial velocity thus ensuring that the results can be examined and reproduced by other investigators. The total H+K flux, and the H+K flux normalized to the stellar bolometric flux, will be computed and compared to the corresponding values for the Sun ranging from solar minimum to solar maximum. We will also compute the K-index utilized at NSO/Kitt Peak for observing the Sun as a star as well as the Mt. Wilson S-index. Multiple frames that have been obtained since the implementation of this project in 1996 will be compared to search for possible binary systems. Binaries may

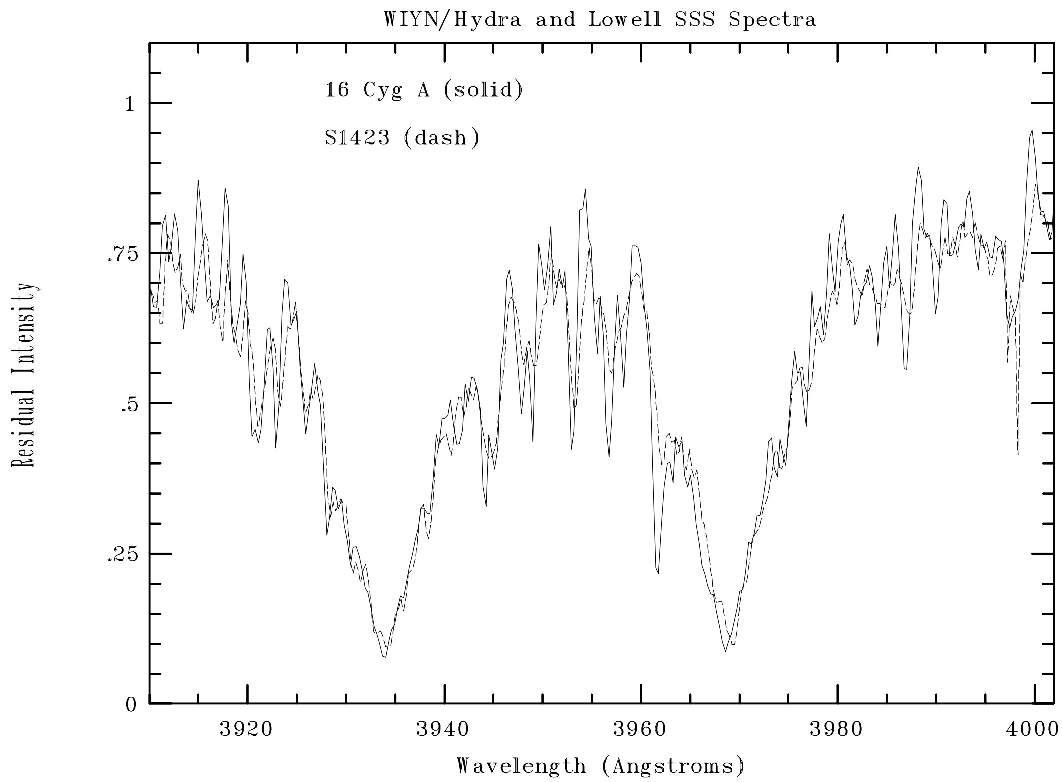

Figure 5: A spectrum from SSS of the solar analog 16 Cyg A, as obtained by J. Hall, is displayed along with the Hydra spectrum of a solar analog in M67. The SSS spectrum has higher spectral resolution. The spectra are slightly shifted relative to each other as a result of the differences in radial velocity. The calibration procedure yields spectra in residual flux that are in very good agreement despite the different instrumentation utilized.

exhibit a somewhat greater level of chromospheric emission and thereby give an inaccurate impression of the potential excursion in solar activity at the high-activity end.

While the survey is expected to yield insights on the range of amplitudes of the solar cycle, a monitoring program of solar analogs in M67 must be implemented in order to fully understand the possible modes of the solar cycle. This survey is a necessary prelude to such a long-term program.

Acknowledgments

We wish to thank the NOAO/KPNO Galactic TAC for its continuing support of this program. The author also acknowledges many useful discussions with Dr. Jeff Hall concerning reduction and calibration issues.

References

Baliunas, S. L. & Jastrow, R. 1990, Nature, 348, 520.
Barry, D. C. & Cromwell, R. 1974, ApJ, 187, 107.
Demarque, P. et al. 1992, AJ, 103, 151.
Foukal, P. & Lean, J. 1990, Science, 247, 504.
Hall, J. C. & Lockwood, G. W. 1995, ApJ, 438, 404.
Hall, J. C. 1996, PASP, 108, 313.
Hudson, H. 1988, ARAA, 26, 473.
Kurucz, R. L. et al. 1984, "Solar Flux Atlas From 296 to 1300 nm", NSO Atlas No. 1.
Livingston, W. C. 1994, "Surrogates for total irradiance", in The Solar Engine and its Influence on the Terrestrial Atmosphere and Climate (Review), ed. E. Ribes, p. 145.
Radick, R. R. 1991, in The Sun in Time (Review), eds. C. P. Sonett, M. S. Giampapa and M. S. Matthews, p. 787.
White, O. R. & Livingston, W. C. 1978, ApJ, 226, 679.

Discussion following Mark Giampapa's talk

Soderblom: I have a question for the solar people. If I want to observe changes in stars like this, I can get signal-to-noise a *lot* faster at Hα than I can at Ca H&K. What is the contrast of the solar cycle in the core of Hα? Do I have a chance of seeing it?

White: Yes. Bill Livingston and I have plots of that. We have about half a solar cycle of measurements in Hα.

Giampapa: The amplitude is about a factor of two less than that in H and K.

Soderblom: So if it's only a factor of two, it seems like it might be more productive to go to Hα than to stay with the calcium lines.

Giampapa: For an initial survey, I chose H and K because of the large body of data that exists for the Sun for these lines. For a monitoring program, Hα might indeed be a good choice for very faint stars.

Friel: In regard to the possible contamination of your sample by binaries, have you looked at the positions of the stars on a color-magnitude diagram and checked them for any correlations with activity level?

Giampapa: I have not looked at their CMD positions, but I did show the one viewgraph that showed four known binaries lying near the top of the observed activity envelope. And Montgomery et al. claim that there does appear to be a photometric binary sequence in M67.

Lockwood: Well, Mark, good luck on the next 10 years [laughter].

Giampapa: Yes, the real challenge there is getting 3.5 or four-meter telescope time on a regular basis!