

Spectral and Brightness Variations of Cycling and Flat Activity Sun-Like Stars

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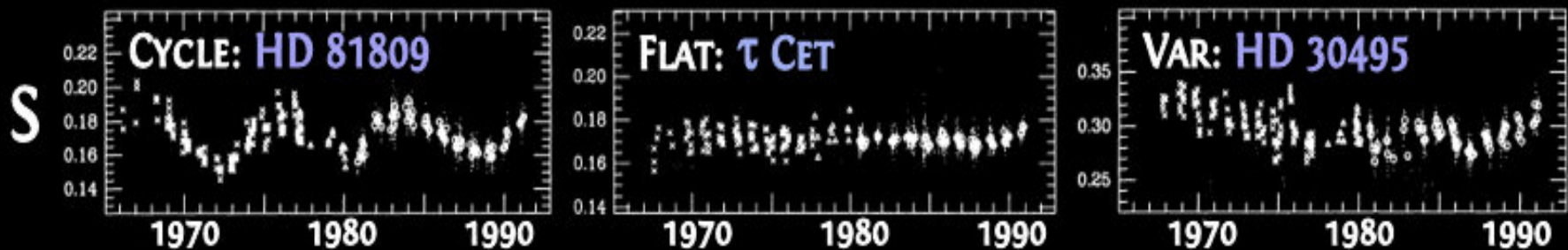
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See also Hall's review in <http://solarphysics.livingreviews.org>

The Mount Wilson HK Project, 1966-2003: Discovering Stellar Activity Cycles

“Does the chromospheric activity of main-sequence stars vary with time, and if so, how?” (O.C. Wilson)

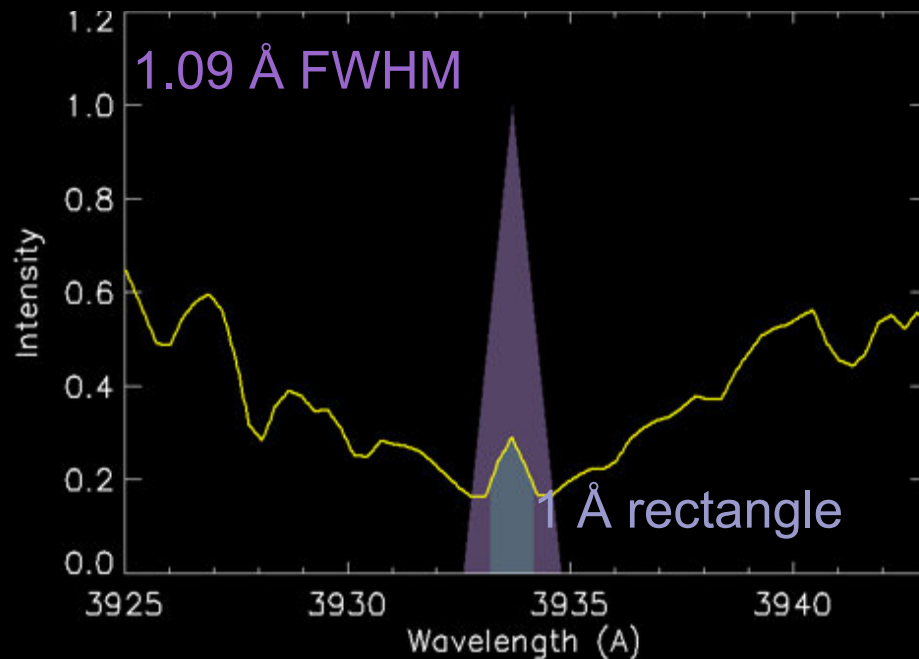
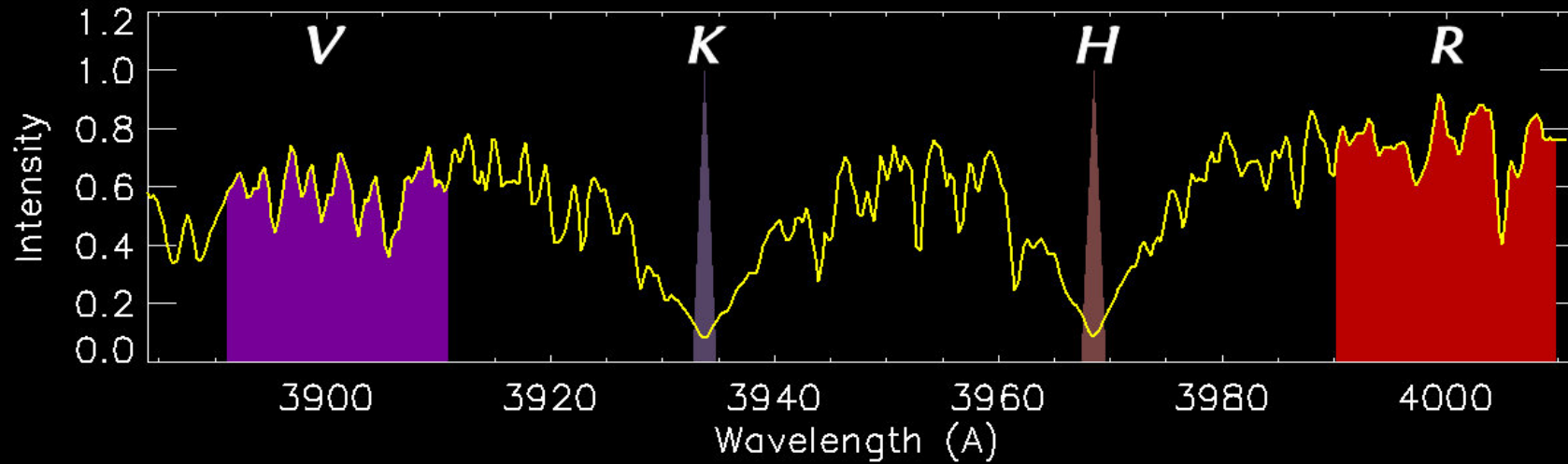


Cycling: 60%

Flat: 15%

Variable: 25%

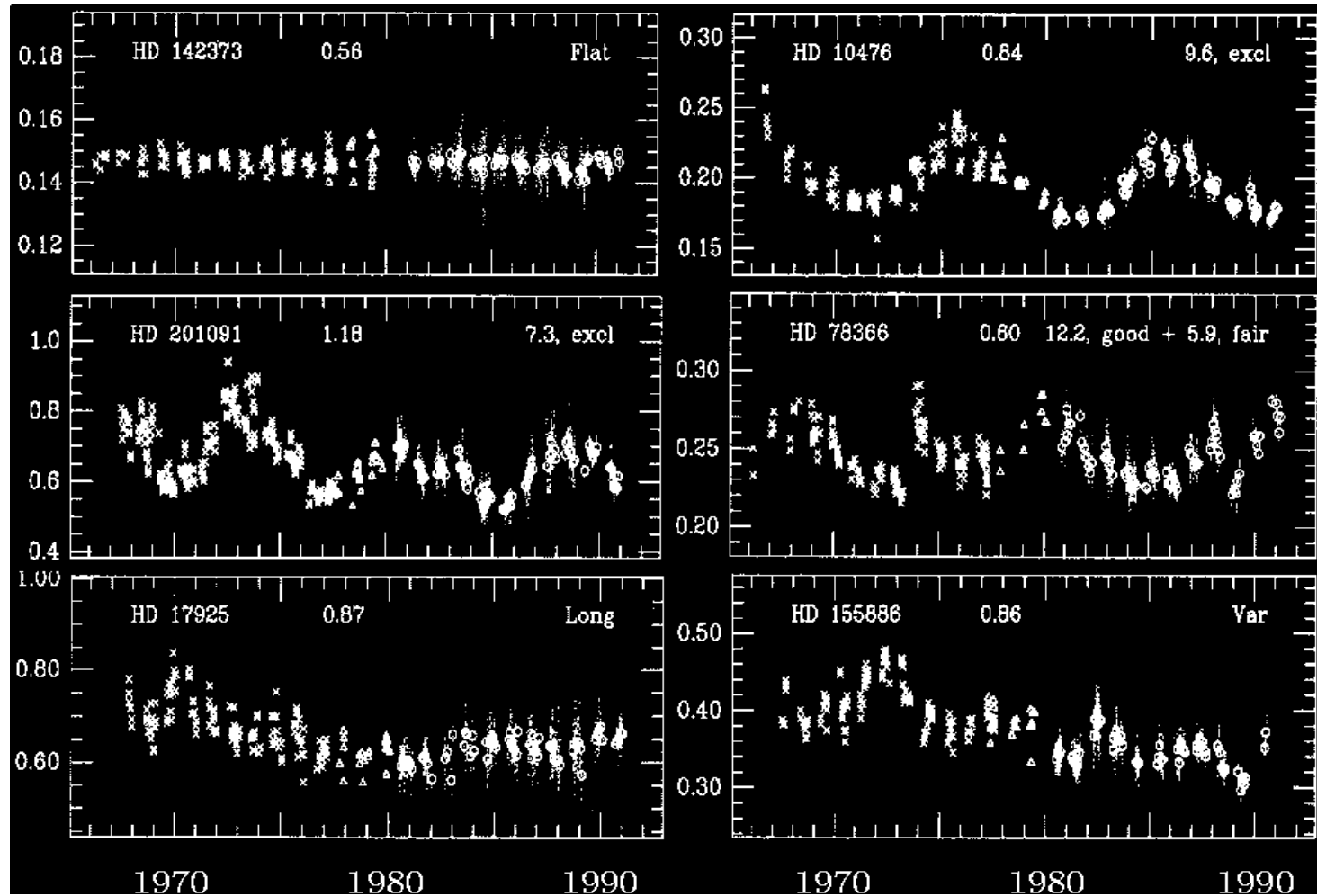
Measuring stellar activity



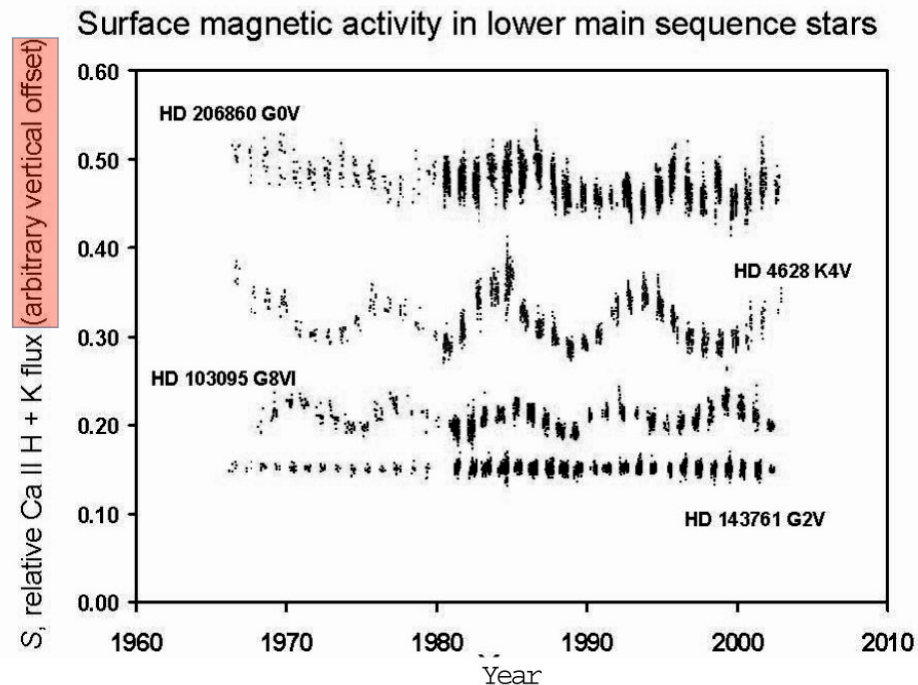
$$S = \alpha \frac{H + K}{R + V}$$

$$R'_{HK} = \frac{F_{HK}}{\sigma T_{eff}^4} - R_{HK, phot}$$

Examples of stellar activity “cycles”

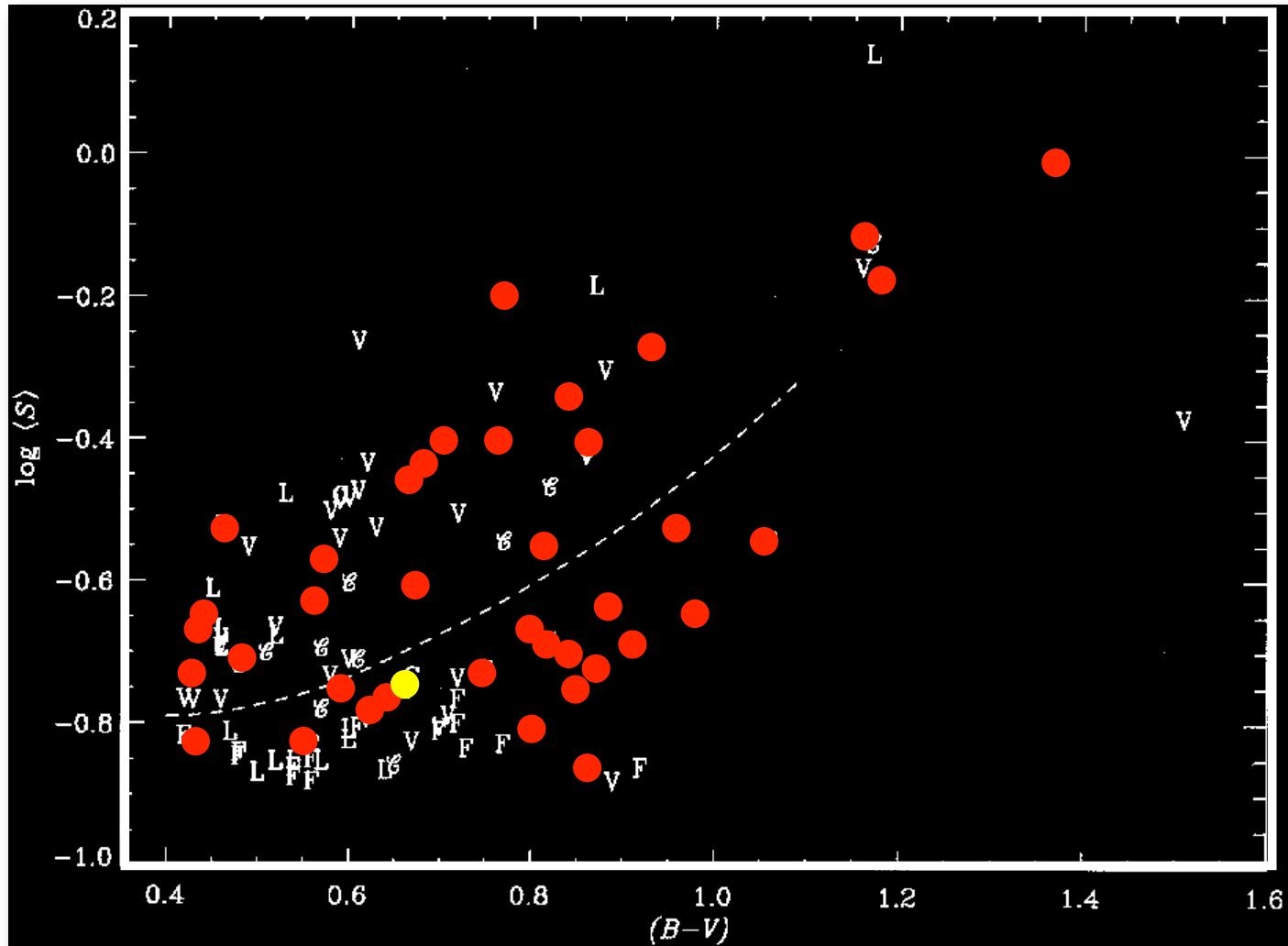


“Sun in time”



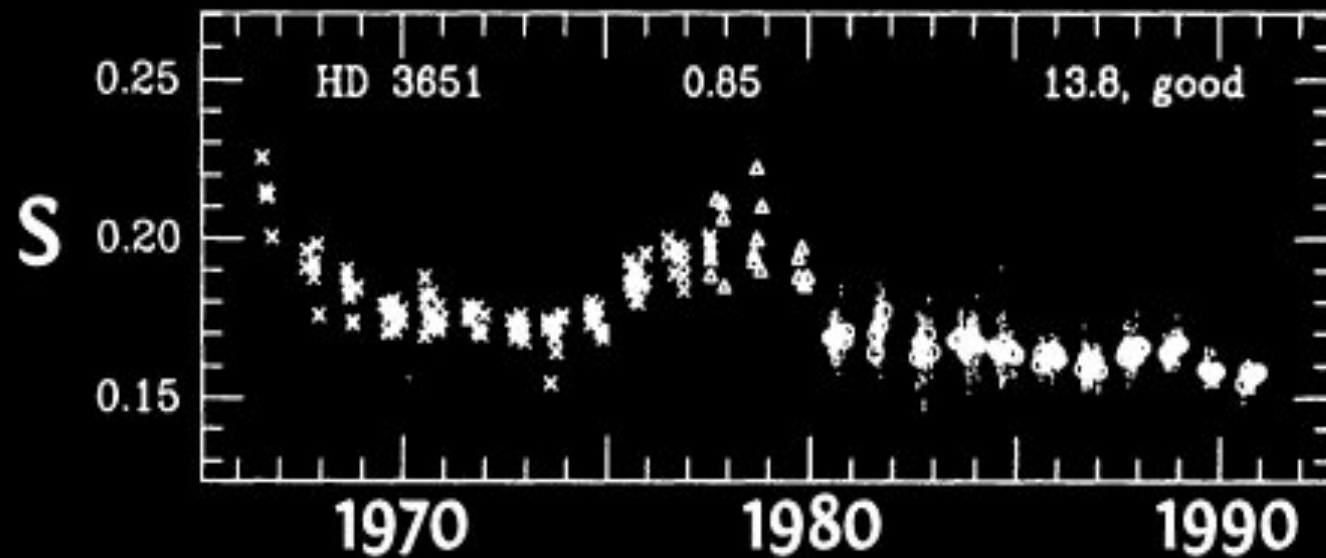
- Top: HD 206860; $P=4.7d$ - a counterpart of the sun approximately 2 billion years ago.
- Lower curves: three Sun-like stars – HD 4628 ($P=38d$), HD 103095 ($P=31d$, or $P=60d$, age ~ 10 Gy) and HD 143761 ($P=21d$). HD 143761 may be in a state like the Sun's Maunder minimum.

Stellar activity “cycles”: common but not dominant



Evidence for Grand Minima

There is some evidence for Maunder Minimum transitions in the Mount Wilson Observatory data set



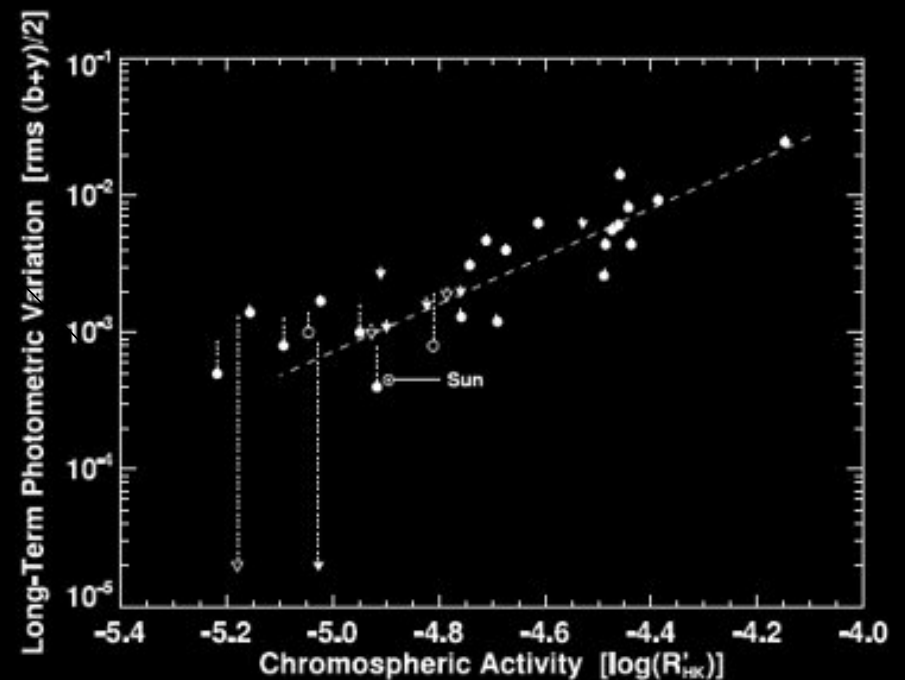
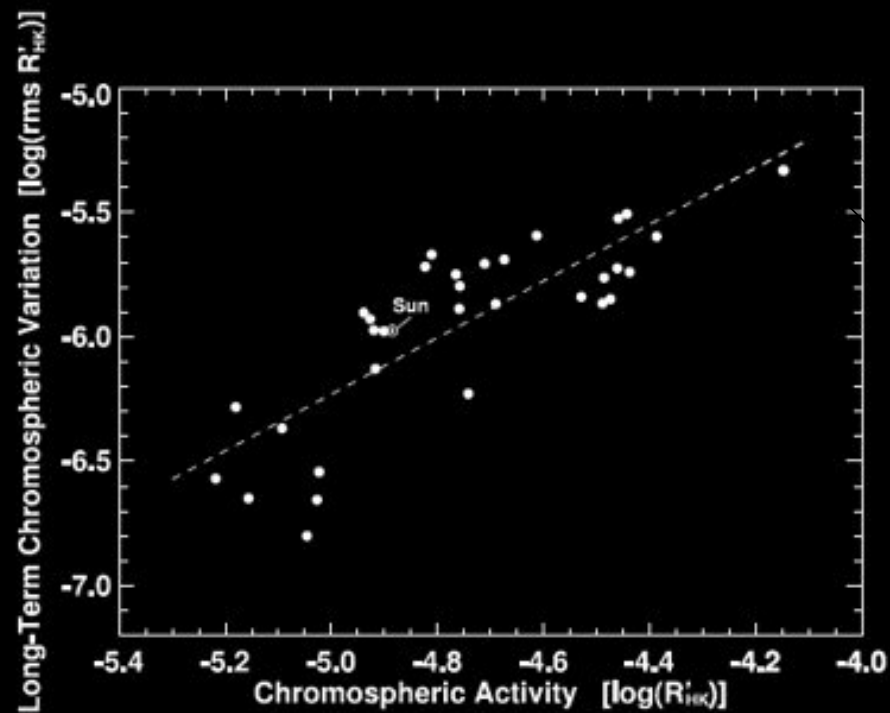
The Solar-Stellar Spectrograph, 1994-present

Activity and Brightness Variations of Solar Analogs



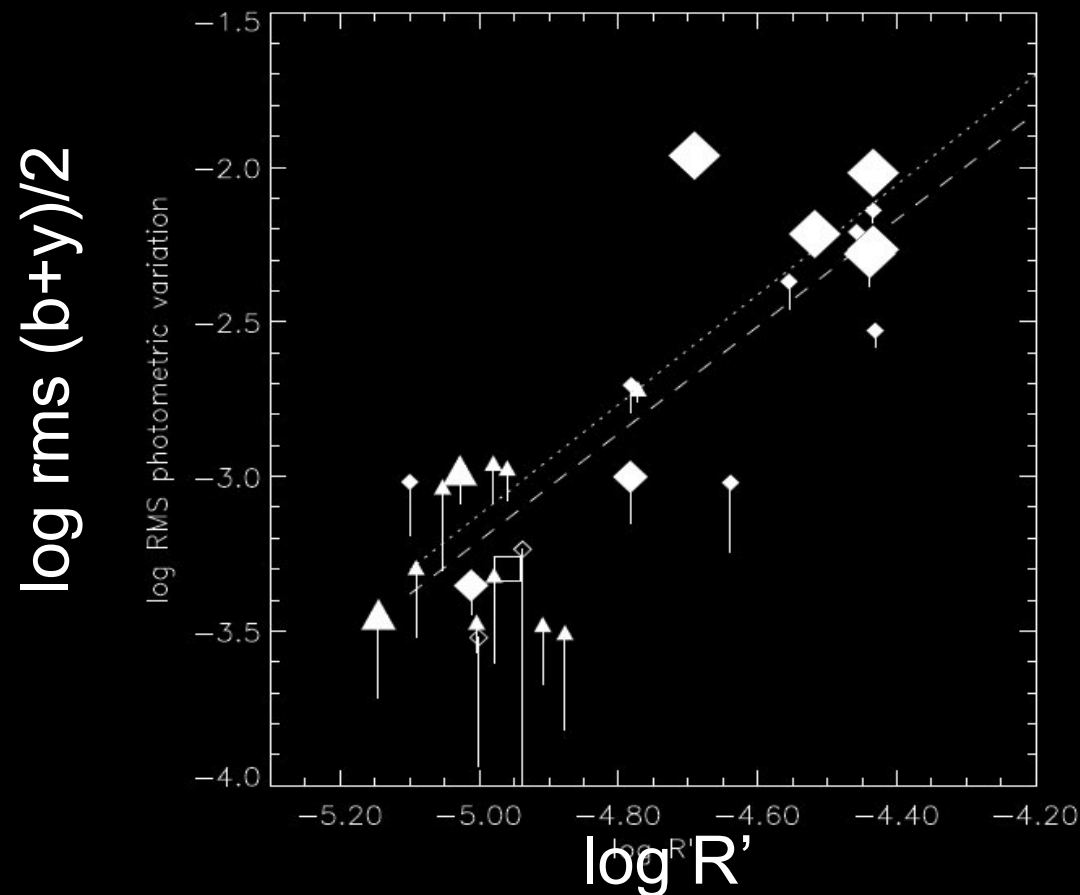
Activity-Brightness Correlations: MWO stars

Mount Wilson – Lowell – Fairborn contemporaneous HK + photometry



Activity-Brightness Correlations: SSS* stars

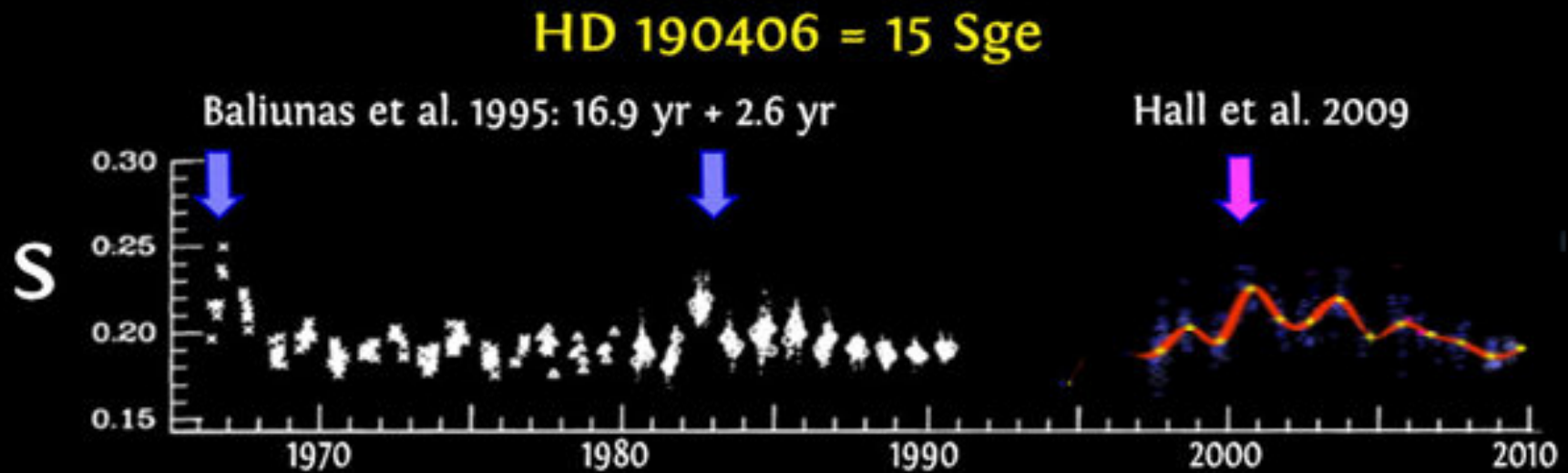
Lowell – Fairborn contemporaneous HK + photometry of close solar analogs



* SSS: Solar-stellar spectrograph

Flat Activity Stars: HD 190406

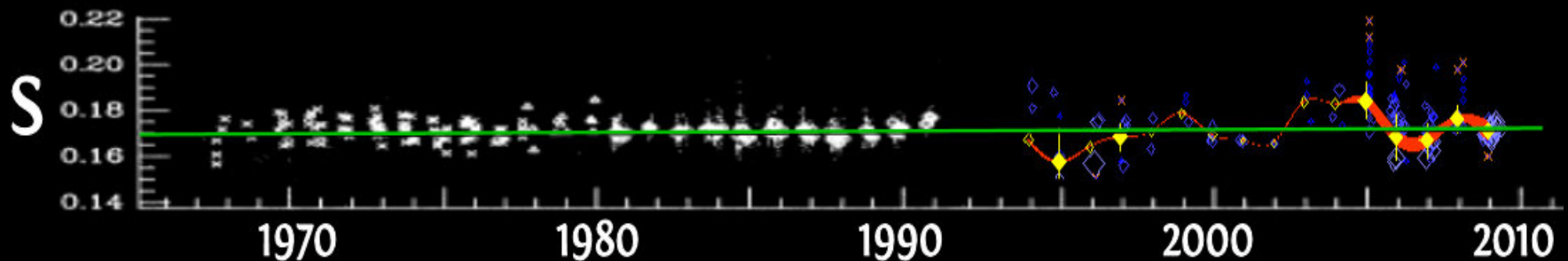
Relatively constant base activity level can show multiply periodic behavior



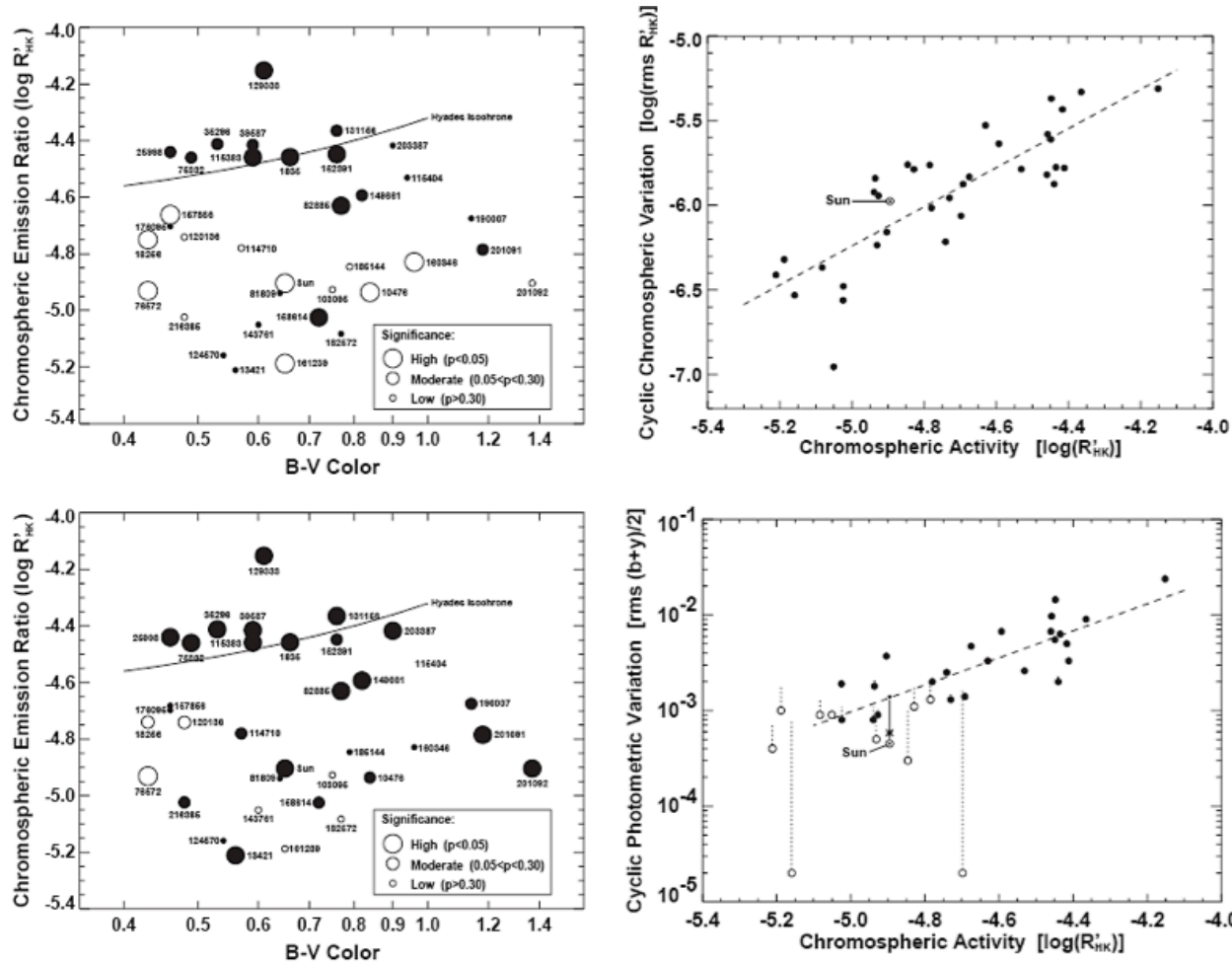
Flat Activity Stars: HD 10700

Coronal observations suggest magnetic activity persists, and is likely not much lower than modern solar minima.

HD 10700 = τ Ceti



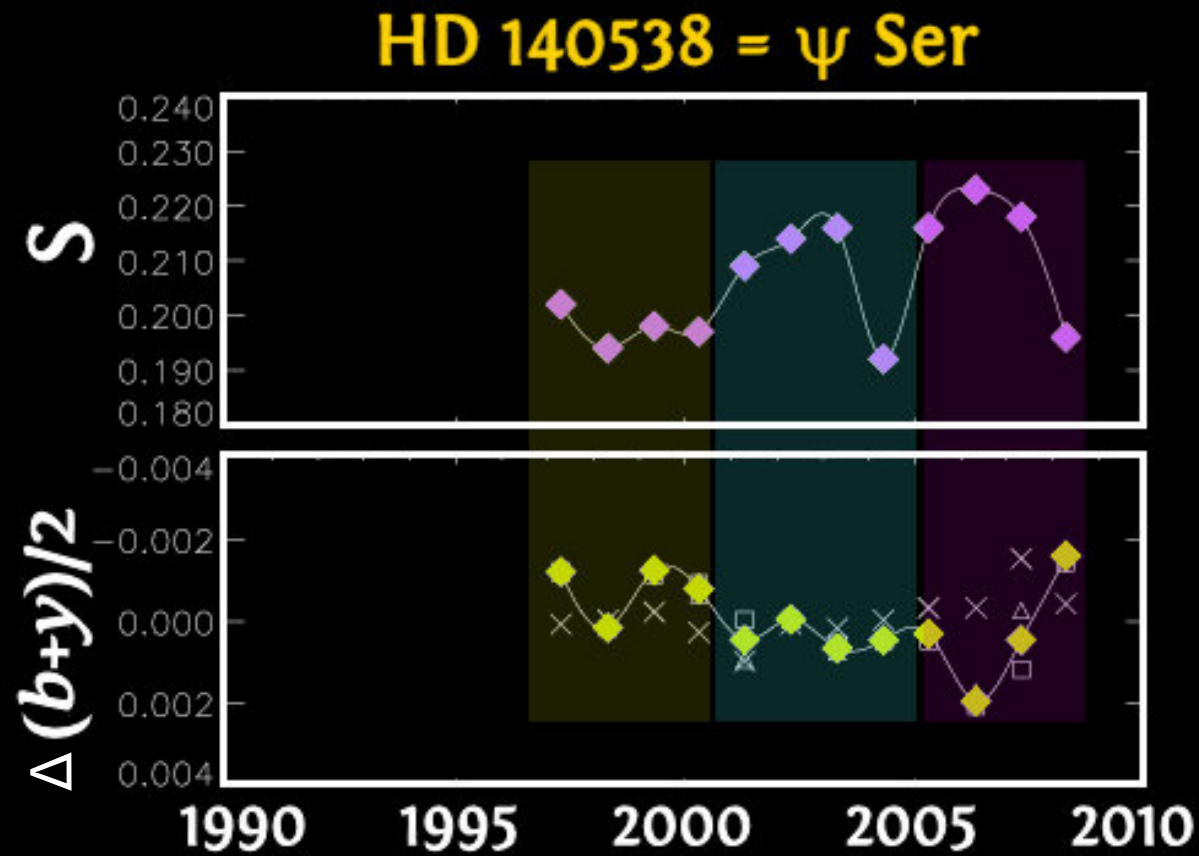
Activity vs. 'brightness'



- Top: long-term correlations. Bottom: short-term correlations.
- Filled symbols: anti-correlation of activity and brightness
- Open symbols: positive correlation of activity and brightness

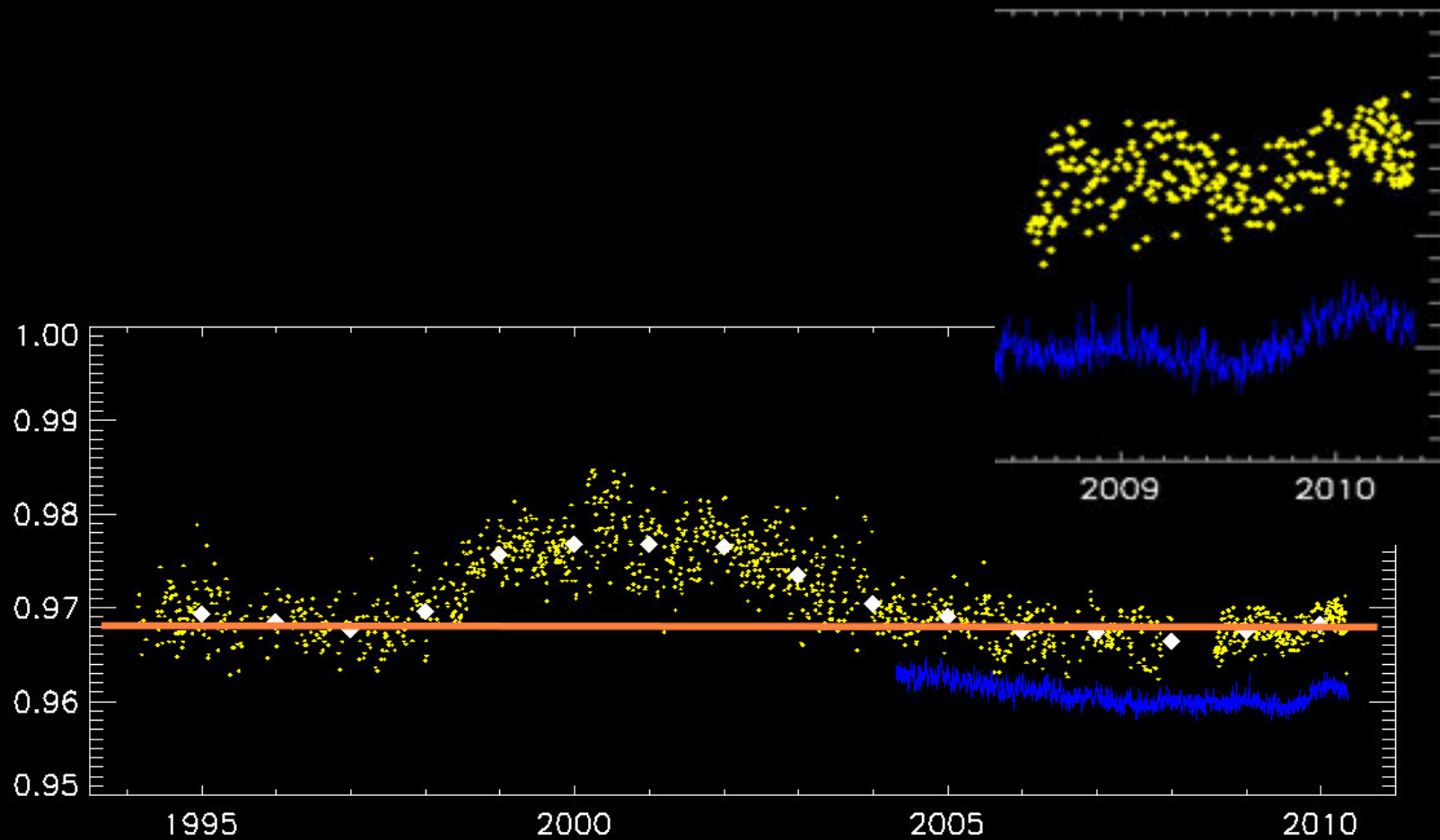
Activity-Brightness relationships

There is evidence for a change in sense of the activity-brightness correlations in HD 140538. The minima lie near the maximum S of modern solar cycles.



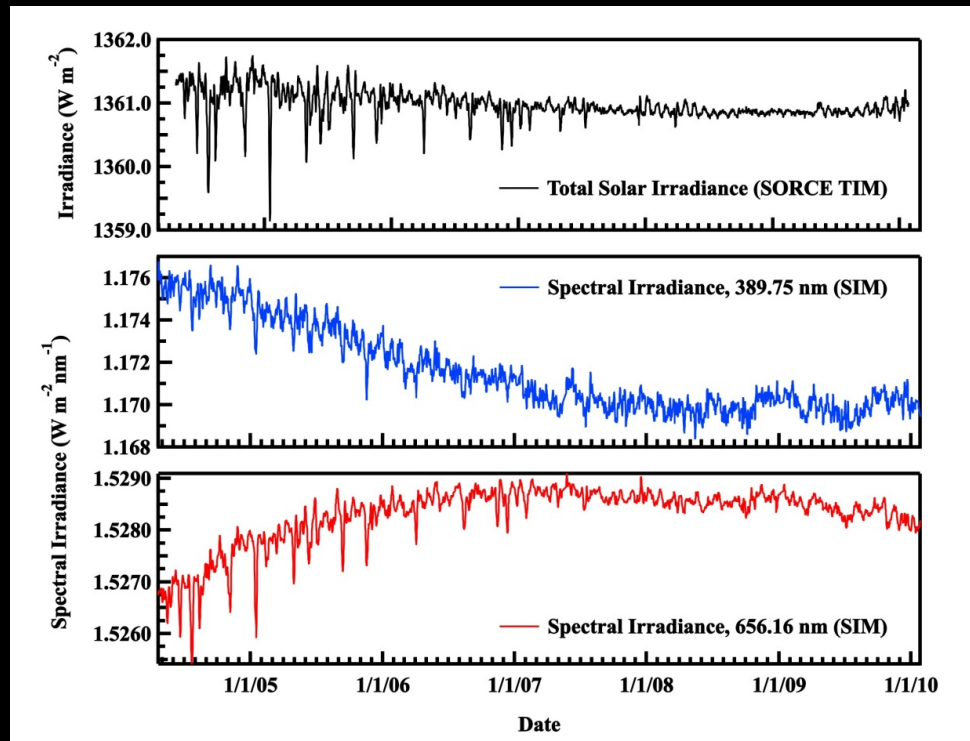
SSS vs. SORCE SIM UV variations

Recent Ca HK data from SSS closely track SORCE SIM time series.



SIM irradiance variations

But the bandpass used to interpret stellar variations (among others) shows an inverse correlation!



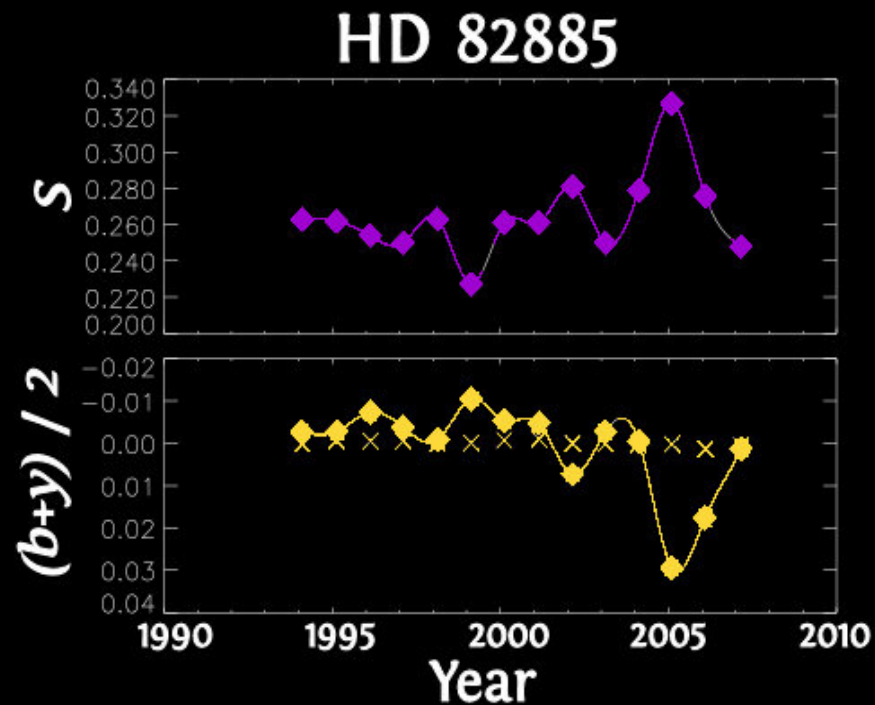
near Ca II H,K 'continua',
blueward of Stromgren b
0.47%

redward of Stromgren γ
1.1%

SIM irradiance variations

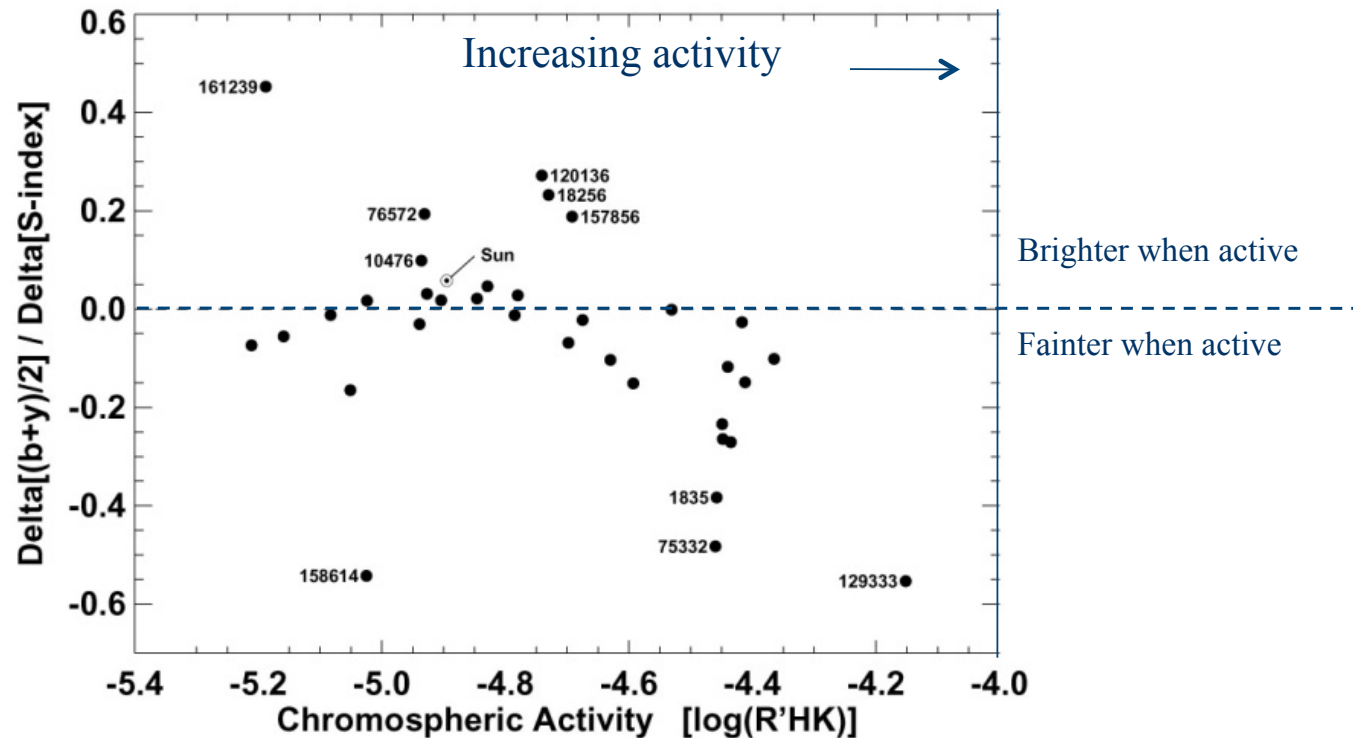
Complications in interpretation:

SIM data show anticorrelation of activity and brightness in the Stromgren b and y bandpasses...but interpretation of these variations in terms of TSI underpin our understanding of stellar variations.



Radiance variations visible wavelengths.

- Hypothesis: with increasing activity, “blocking” by starspots outweighs facular brightening, but at what activity level we find the transition depends on behavior of $(b+y)/2$ with activity, which remains to be established.



Conclusions from bright solar analogs

Transitions between direct and inverse activity-brightness variations may occur at activity levels at or slightly above the modern solar maximum

Long term observations of good solar analogs indicate the 0.1% TSI variation of the solar cycle is not unusual

The frequency of apparent grand minima in our data set is consistent with the solar record of the past millennium, and recent papers present convincing evidence for the end of the “Modern Maximum” of solar activity

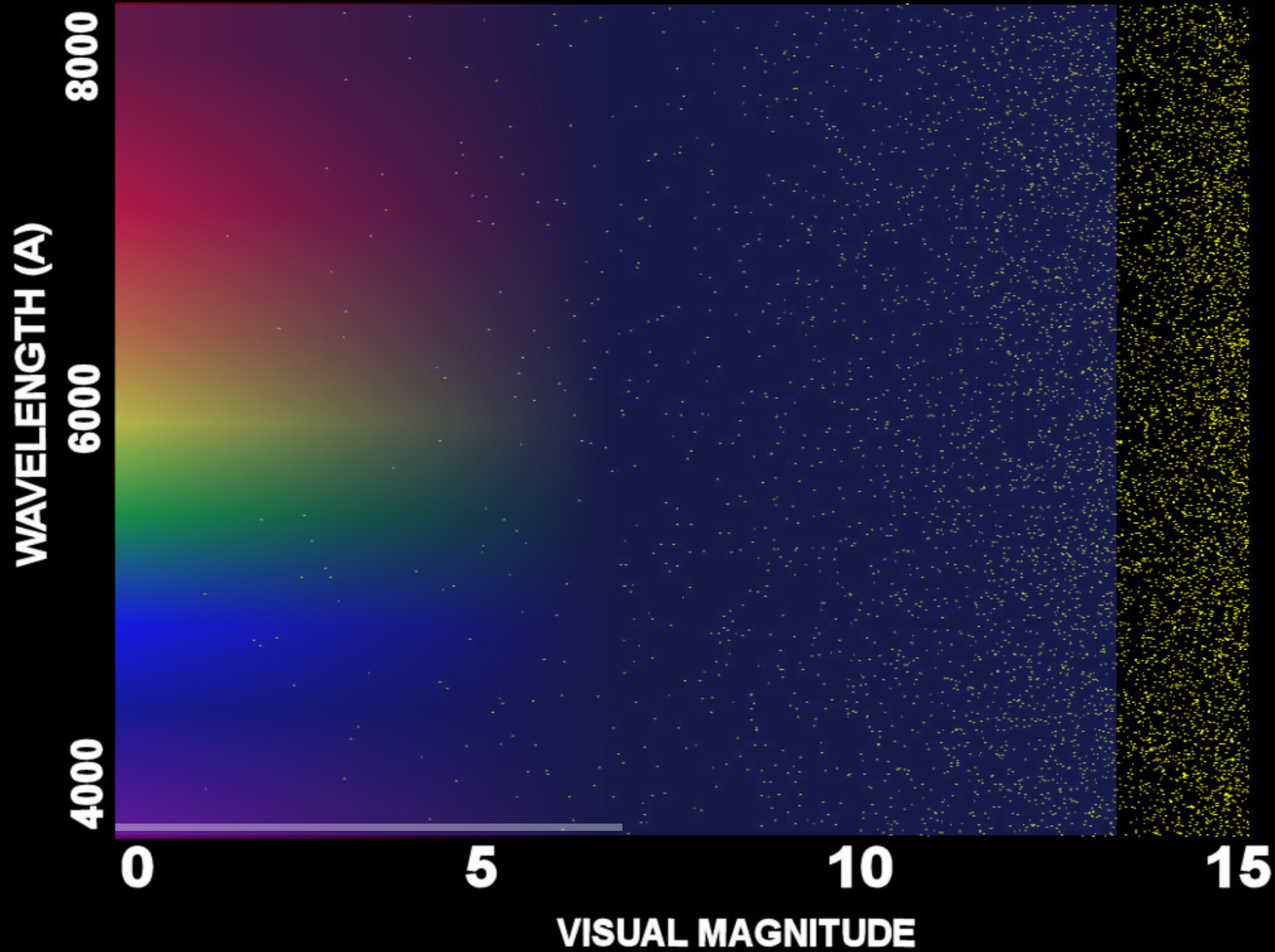
The magnetic state of flat activity stars does not appear to be markedly different than that of the modern solar minimum

Future directions (1)

Expanded proxies and wavelength coverage (e.g. G band at 4300 Å). We have learned much of what we can learn from the HK surveys.

Contemporaneous photometry is essential, especially in light of recent solar spectral irradiance observations

A significant sample of solar twins requires synoptic observing programs to V ~ 11. Current surveys are quite narrowly focused.



Future directions (2)

Future programs can leverage new surveys (e.g., Kepler) to target stars known to have Earth-like planets.