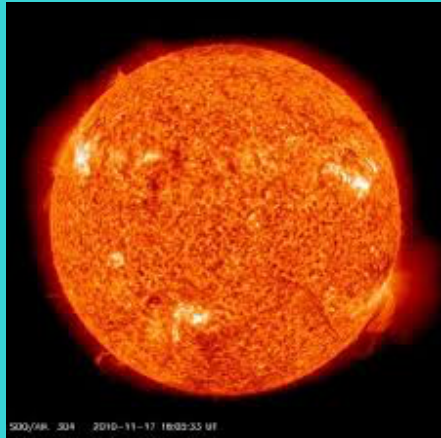


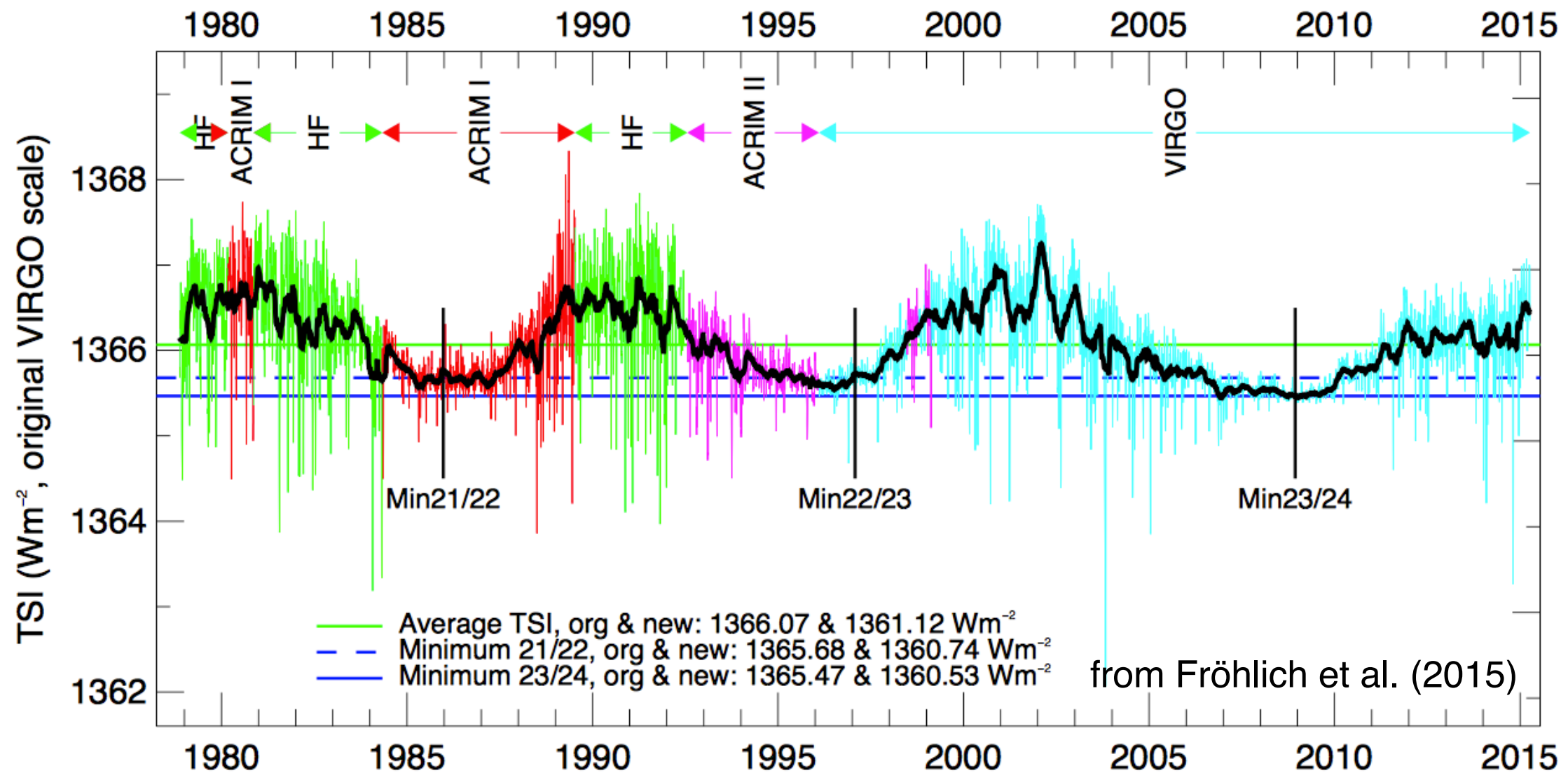
Can we use the Sun to explain the variability of more active stars?

Alexander I. Shapiro, Sami K. Solanki, Natalie A. Krivova



Total Solar Irradiance

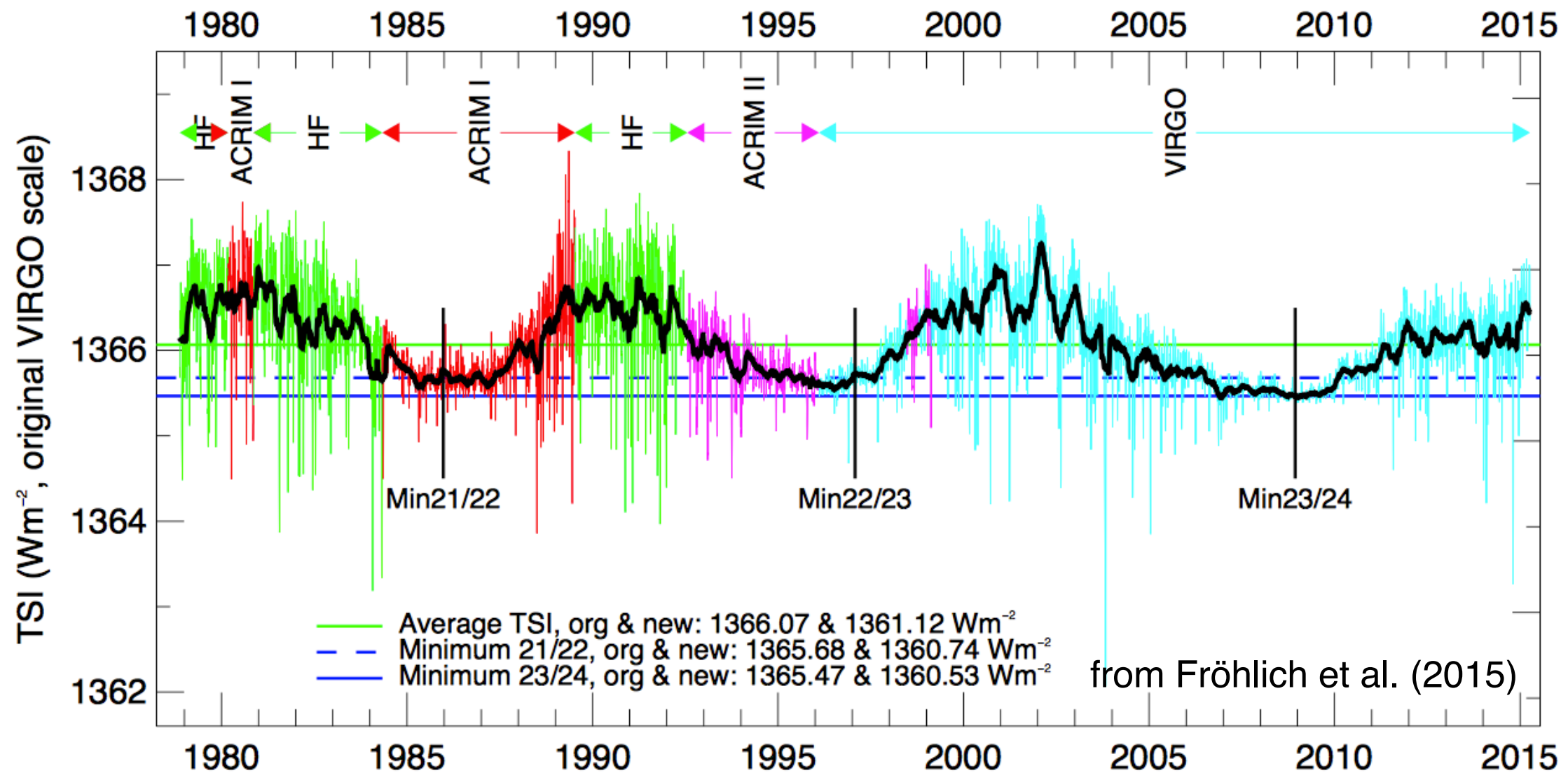
spectrally integrated solar radiative flux at one AU from the Sun



- timescale of solar rotation
- 11-year activity cycle
- centennial timescale

Total Solar Irradiance

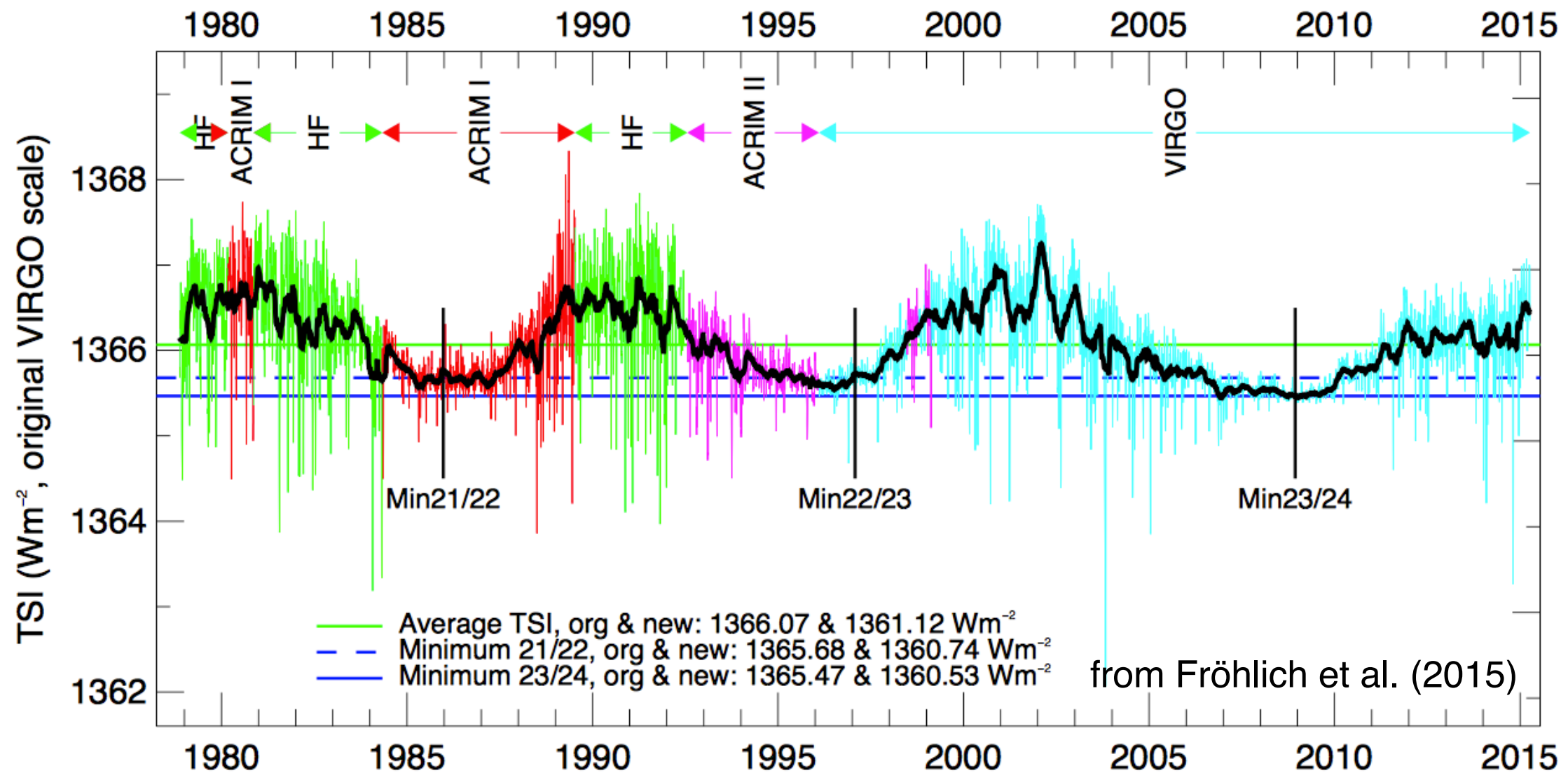
spectrally integrated solar radiative flux at one AU from the Sun



The TSI variability over the last 30 years is relatively well constrained

Total Solar Irradiance

spectrally integrated solar radiative flux at one AU from the Sun

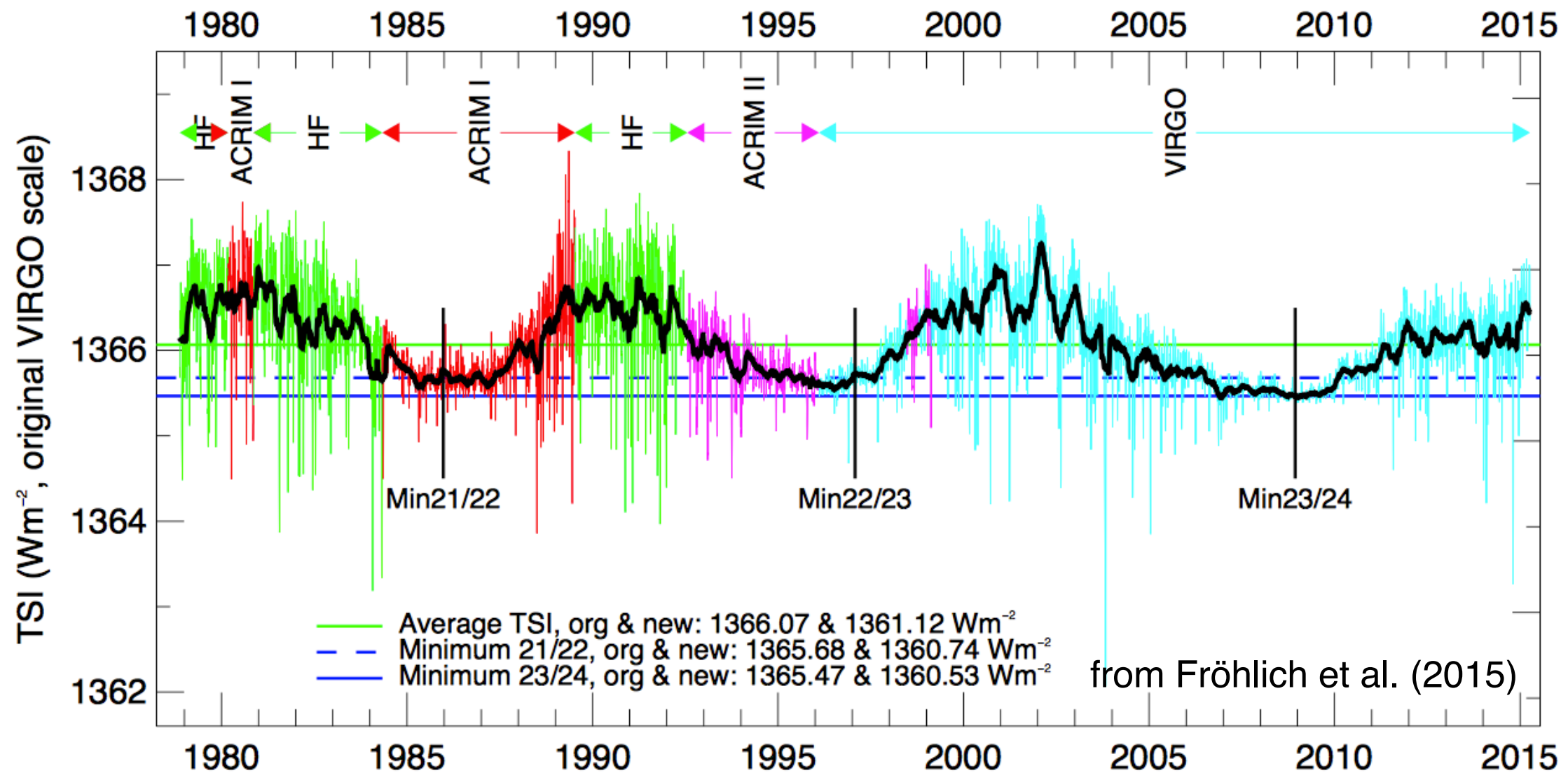


The TSI variability over the last 30 years is relatively well constrained

There is a controversy on how solar spectrum changes
(**400-700 nm** - even the phase is uncertain)

Total Solar Irradiance

spectrally integrated solar radiative flux at one AU from the Sun

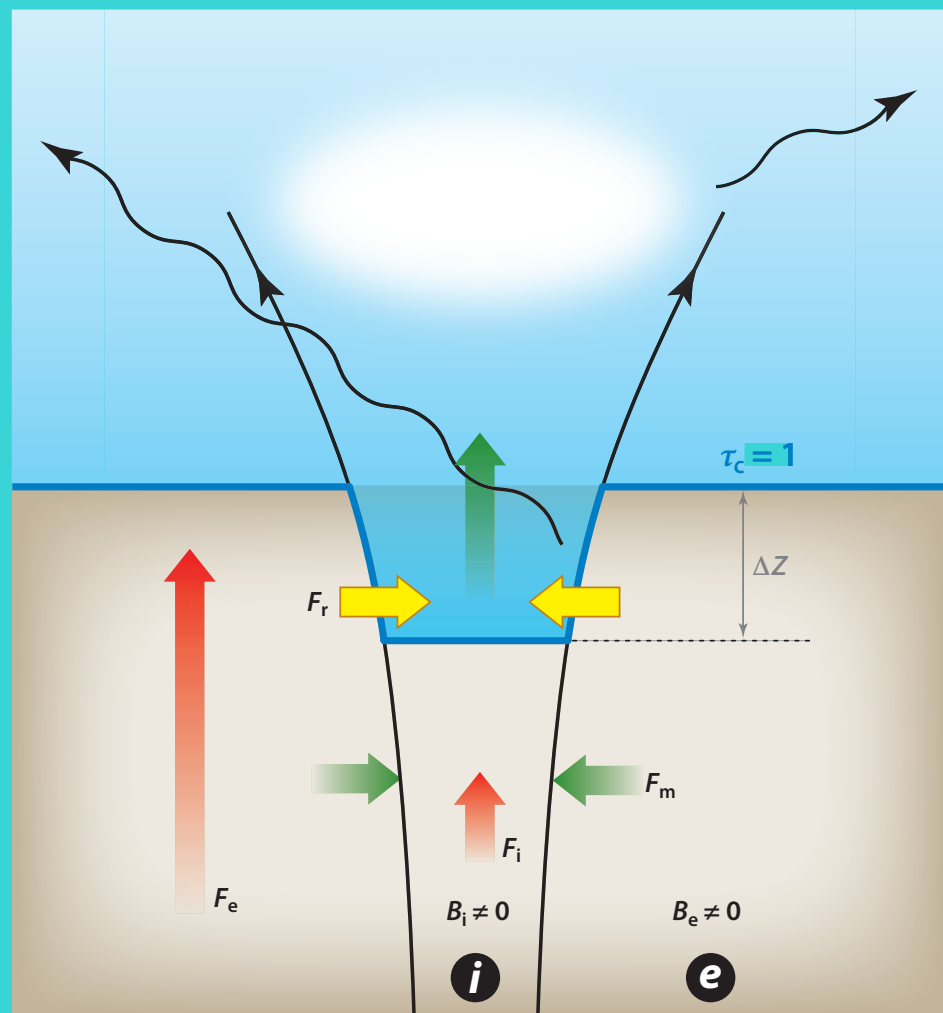


The TSI variability over the last 30 years is relatively well constrained

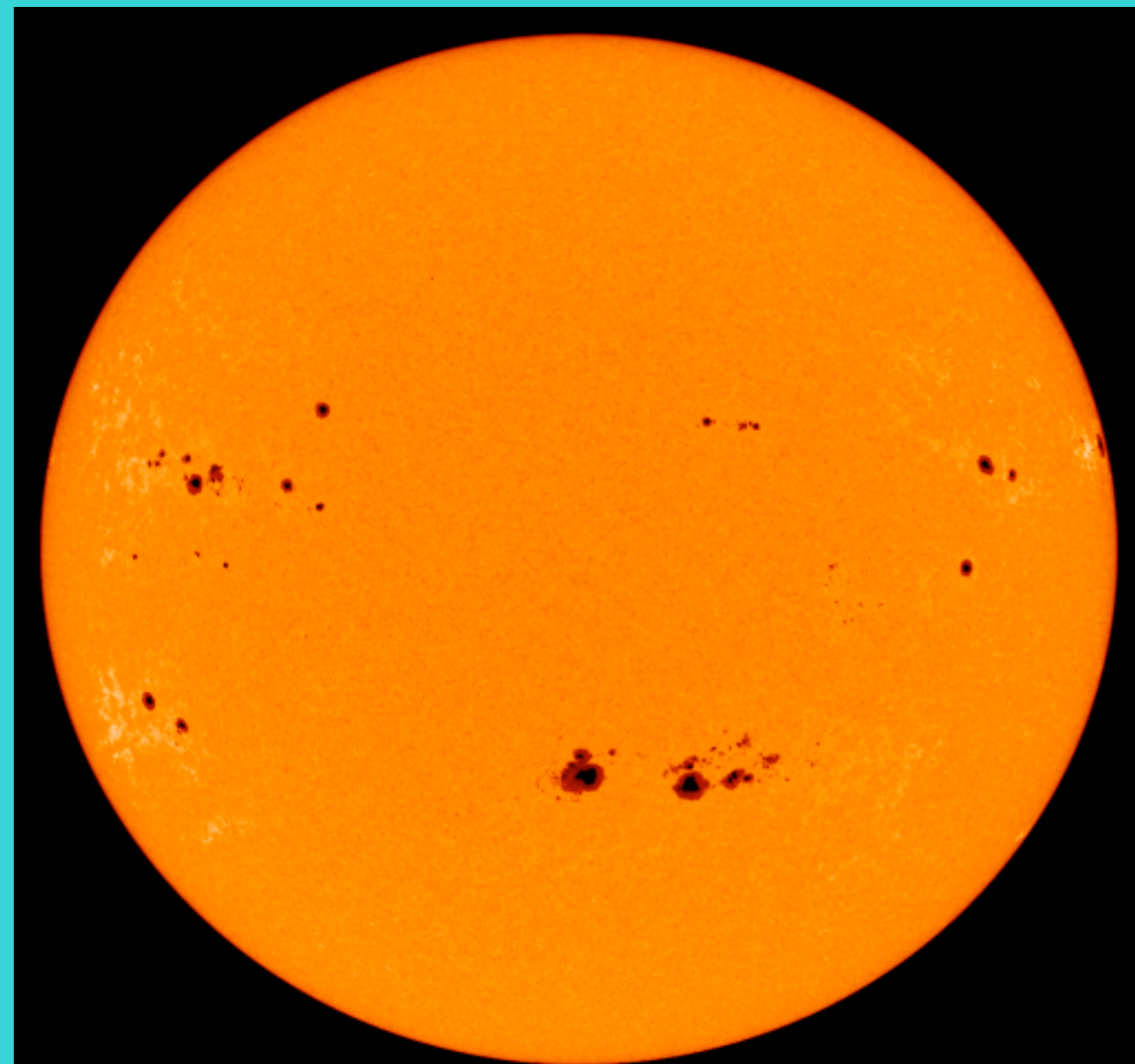
There is a controversy on how solar spectrum changes
(**400-700 nm** - even the phase is uncertain)

The amplitude of the secular TSI changes is heavily debated

Origin of brightness variability



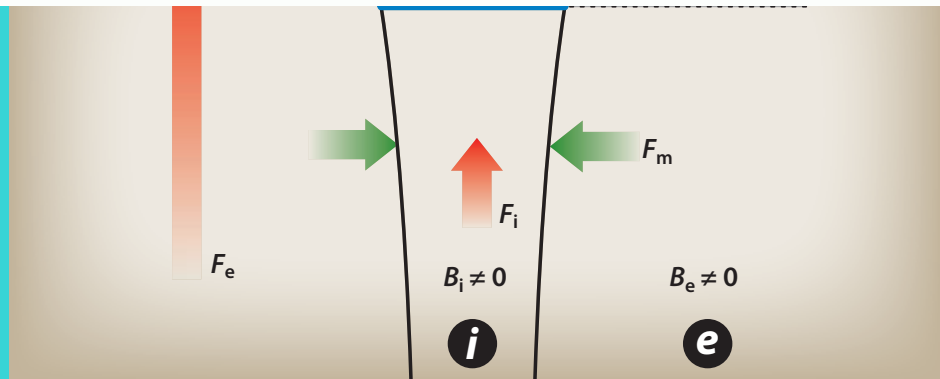
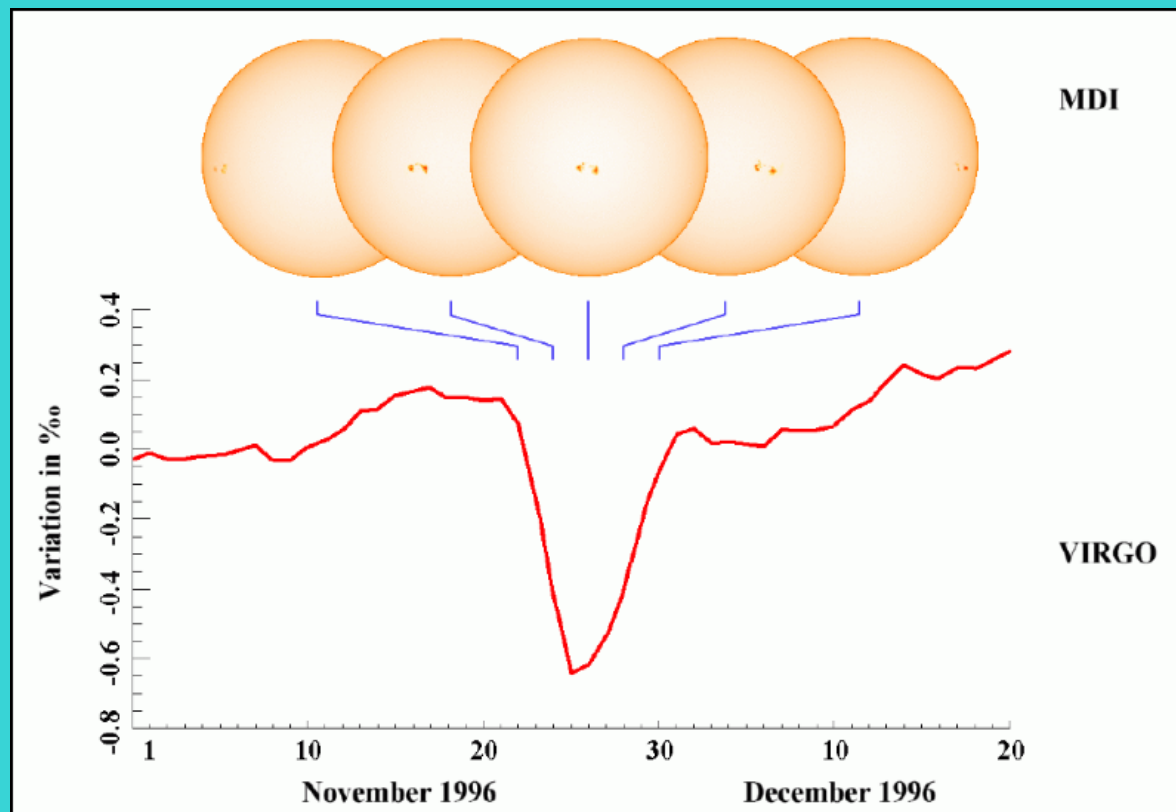
from Solanki et al. 2013



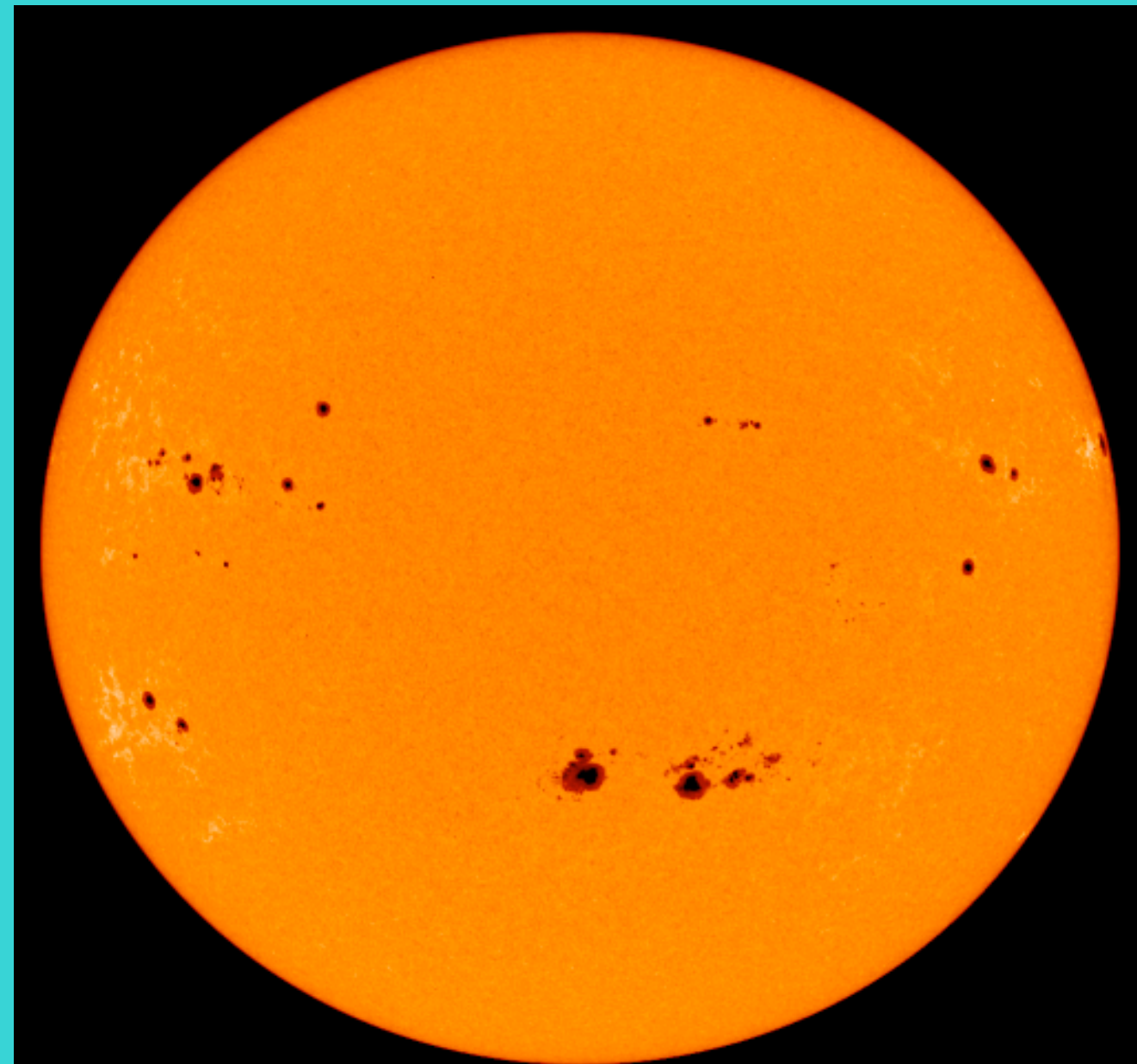
darkening due to **sunspots**
and brightening due to
faculae and the network:

$$\Delta S_{\text{tot}}(t) = \Delta S_s(t) + \Delta S_f(t)$$

Origin of brightness variability



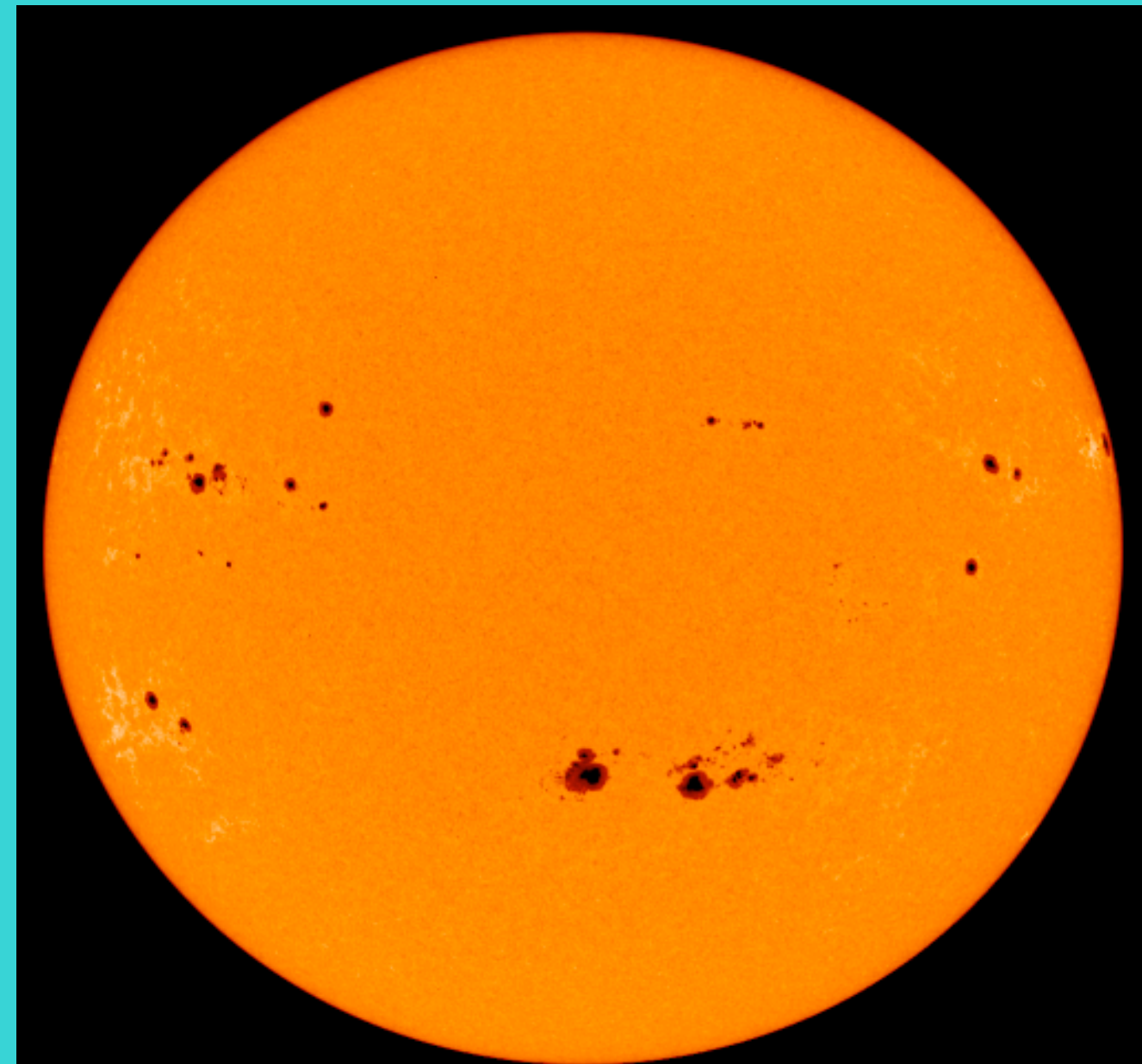
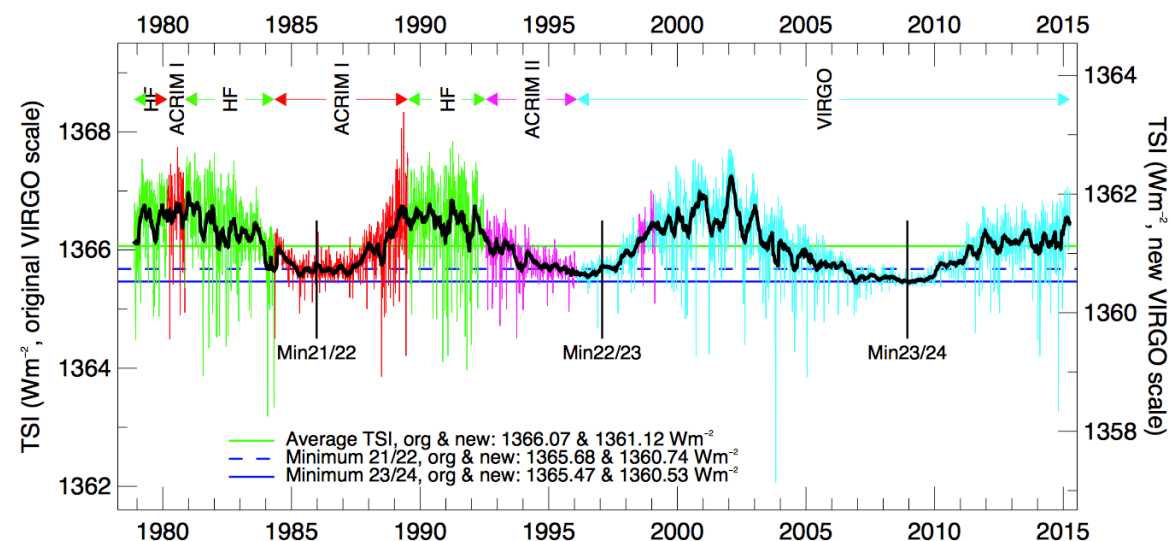
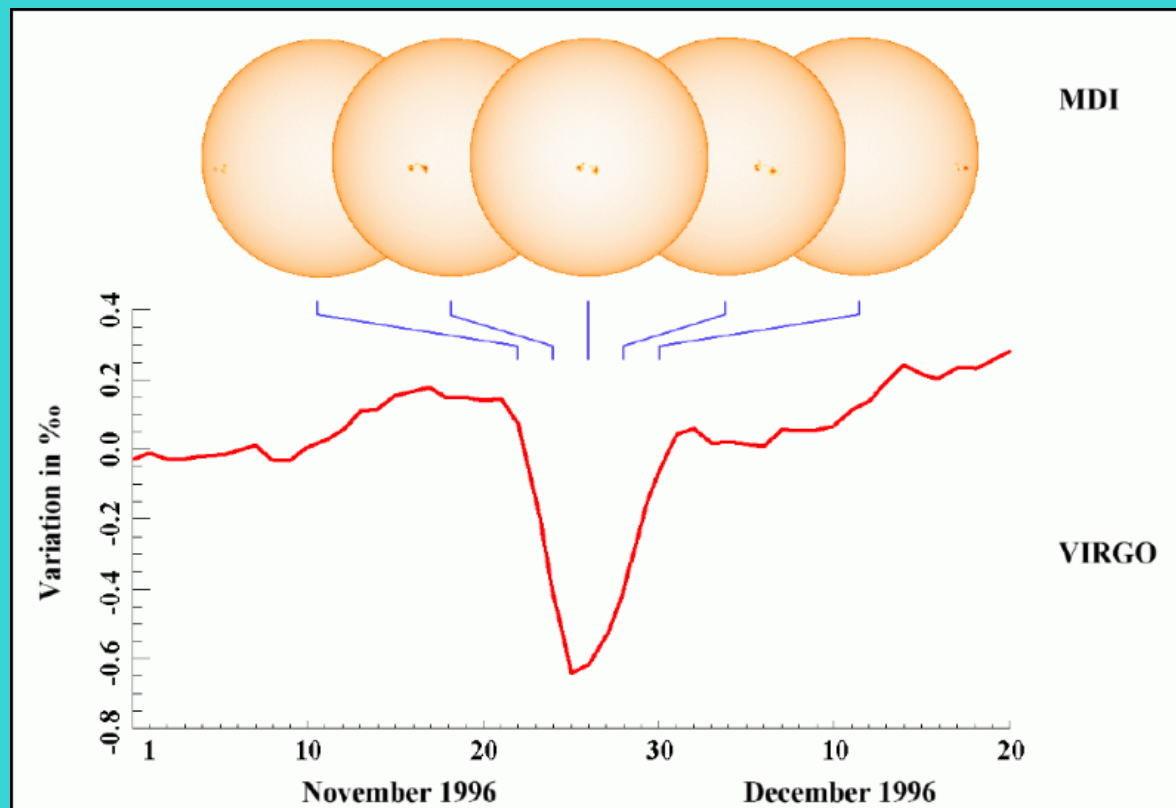
from Solanki et al. 2013



darkening due to **sunspots**
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faculae and the network:

$$\Delta S_{tot}(t) = \Delta S_s(t) + \Delta S_f(t)$$

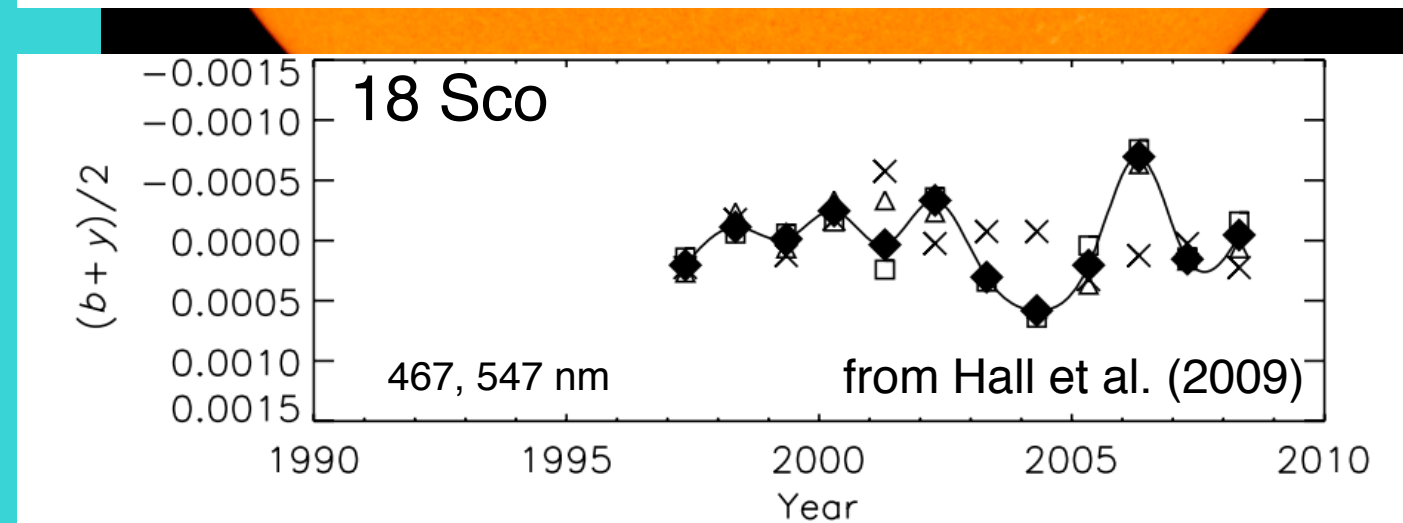
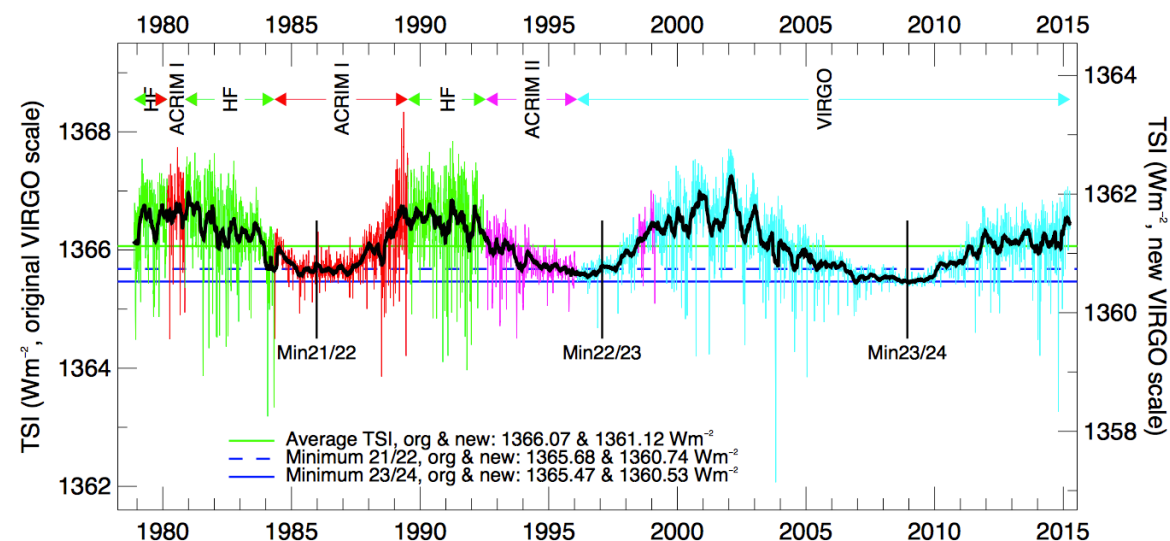
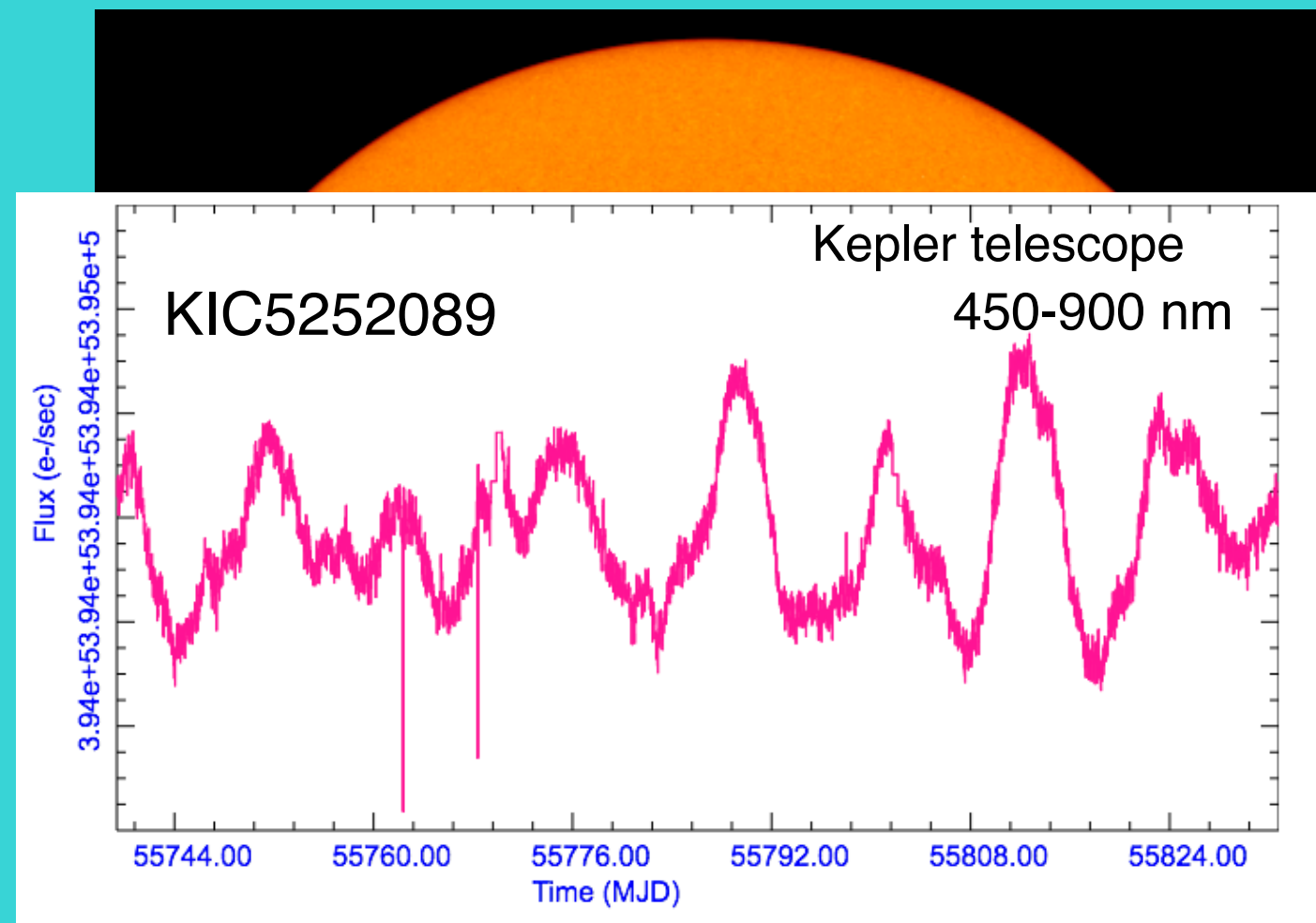
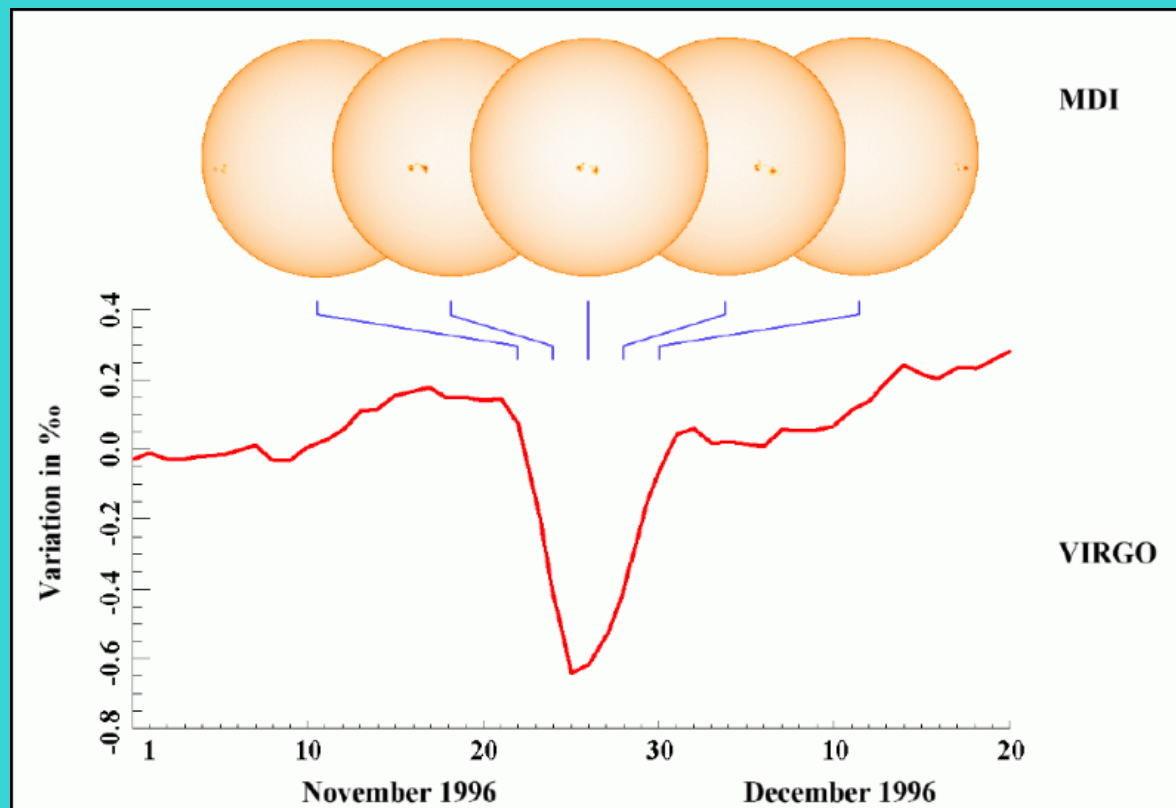
Origin of brightness variability



darkening due to **sunspots**
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$$\Delta S_{tot}(t) = \Delta S_s(t) + \Delta S_f(t)$$

Origin of brightness variability



faculae and the network:

$$\Delta S_{tot}(t) = \Delta S_s(t) + \Delta S_f(t)$$

Ground-based data



21-inch refractor at the
Lowell Observatory



Automatic Photoelectric Telescopes
at the Fairborn Observatory

$\sim 10^2$ stars; ~ 10 -20 years

Spaceborne data



Kepler



CoRoT

$\sim 10^5$ stars; ~ 100 days

Ground-based data



21-inch refractor at the
Lowell Observatory



Automatic Photoelectric Telescopes
at the Fairborn Observatory

$\sim 10^2$ stars; ~ 10 -20 years

activity cycles

Spaceborne data



Kepler



CoRoT

$\sim 10^5$ stars; ~ 100 days

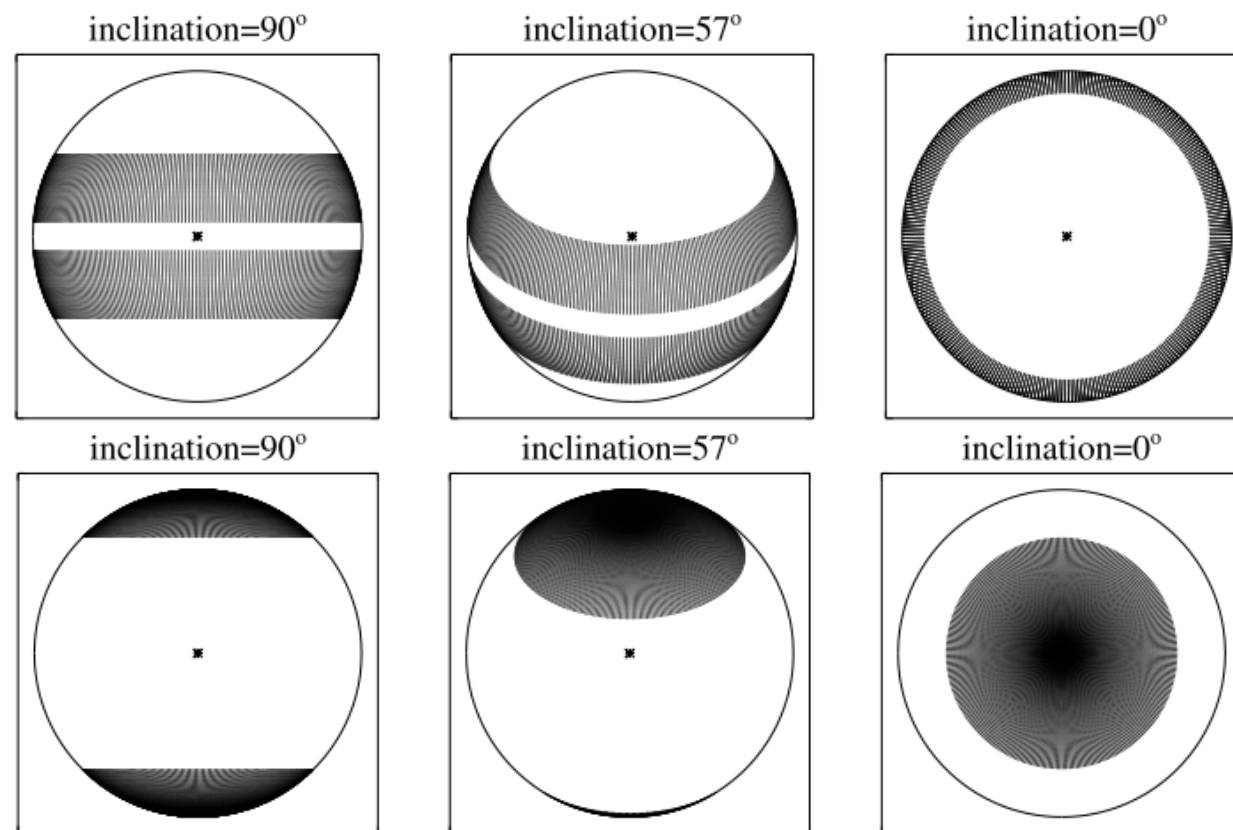
rotational modulation



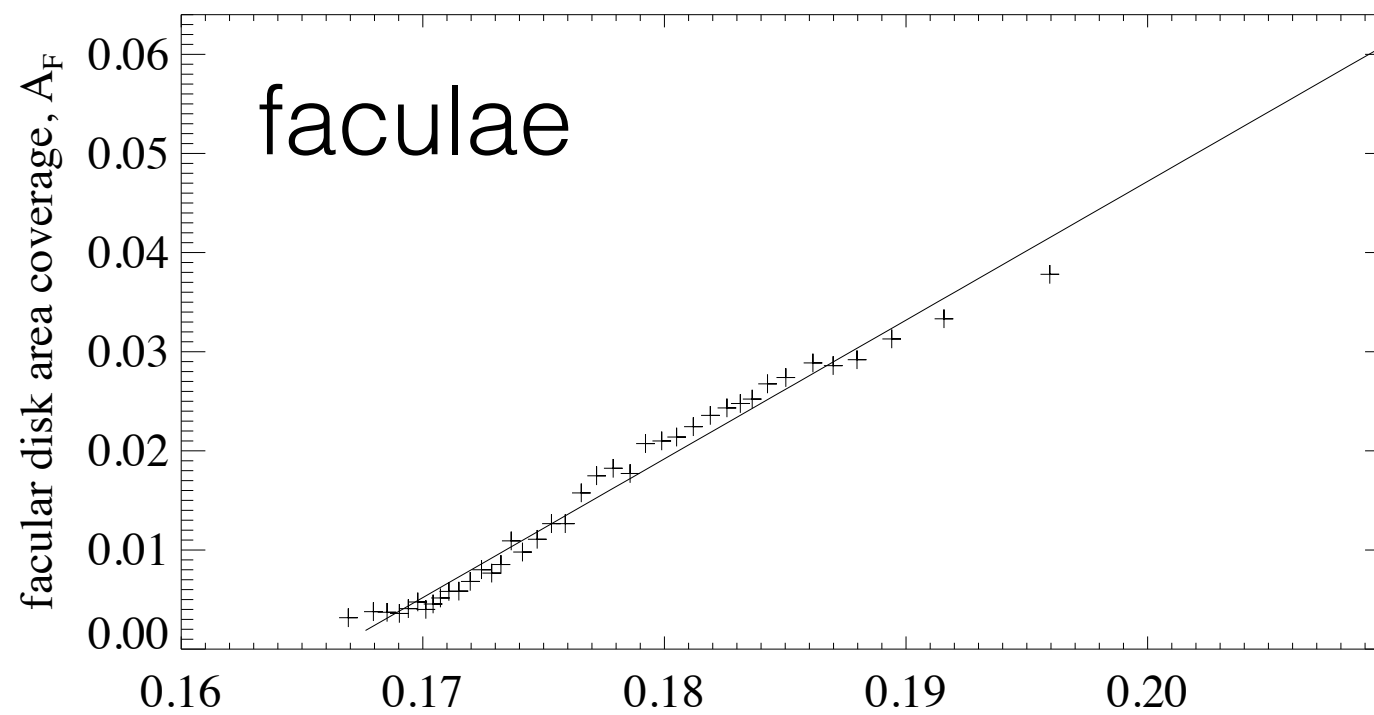
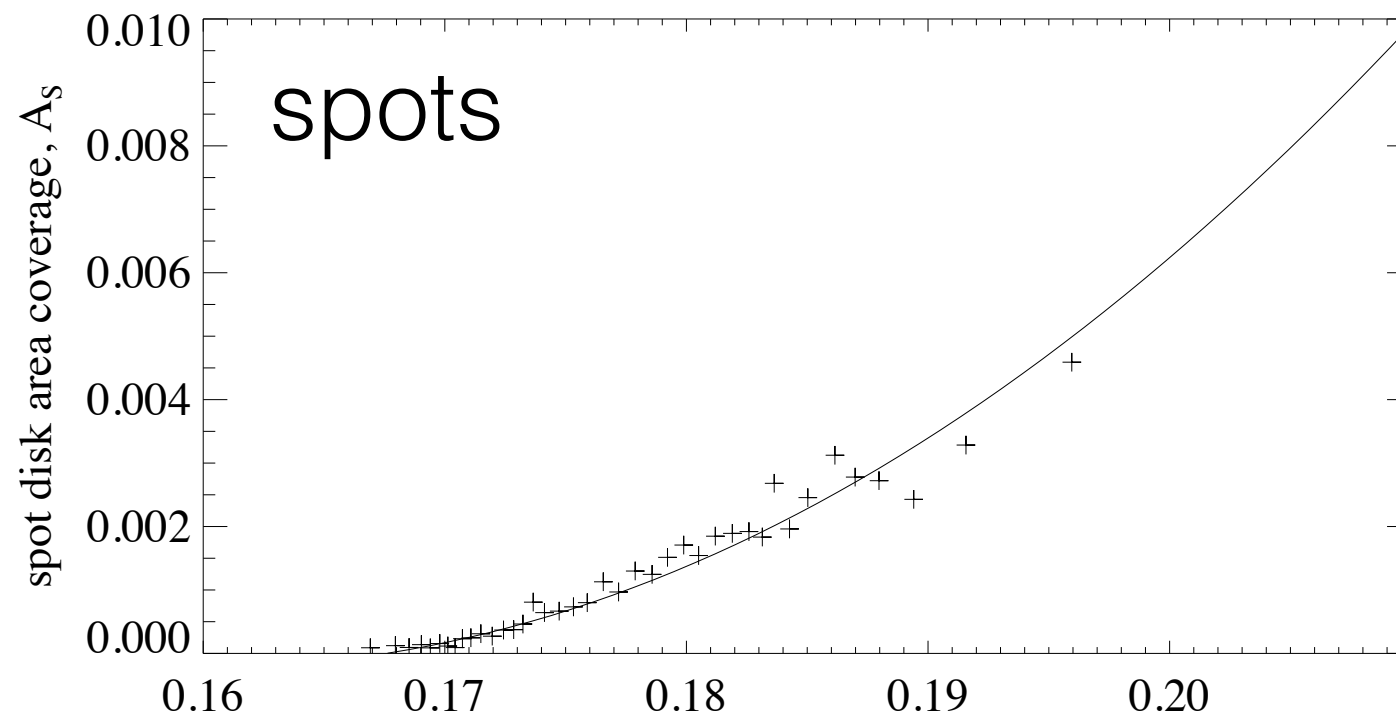


Spectral And Total Irradiance Reconstruction (SATIRE)

extrapolated to stars by treating them as
hypothetical Suns with coverage by magnetic
features different from that of the Sun



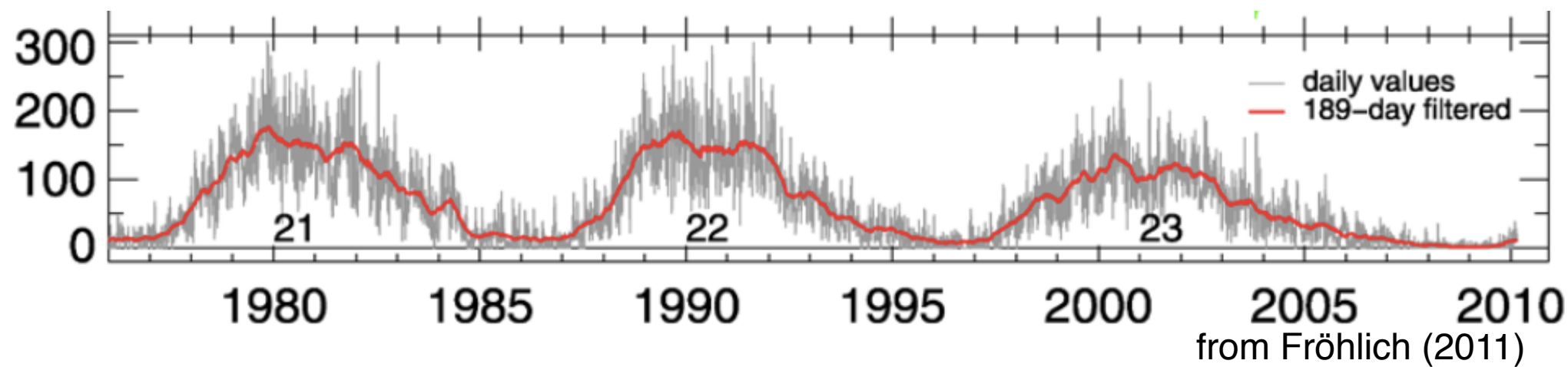
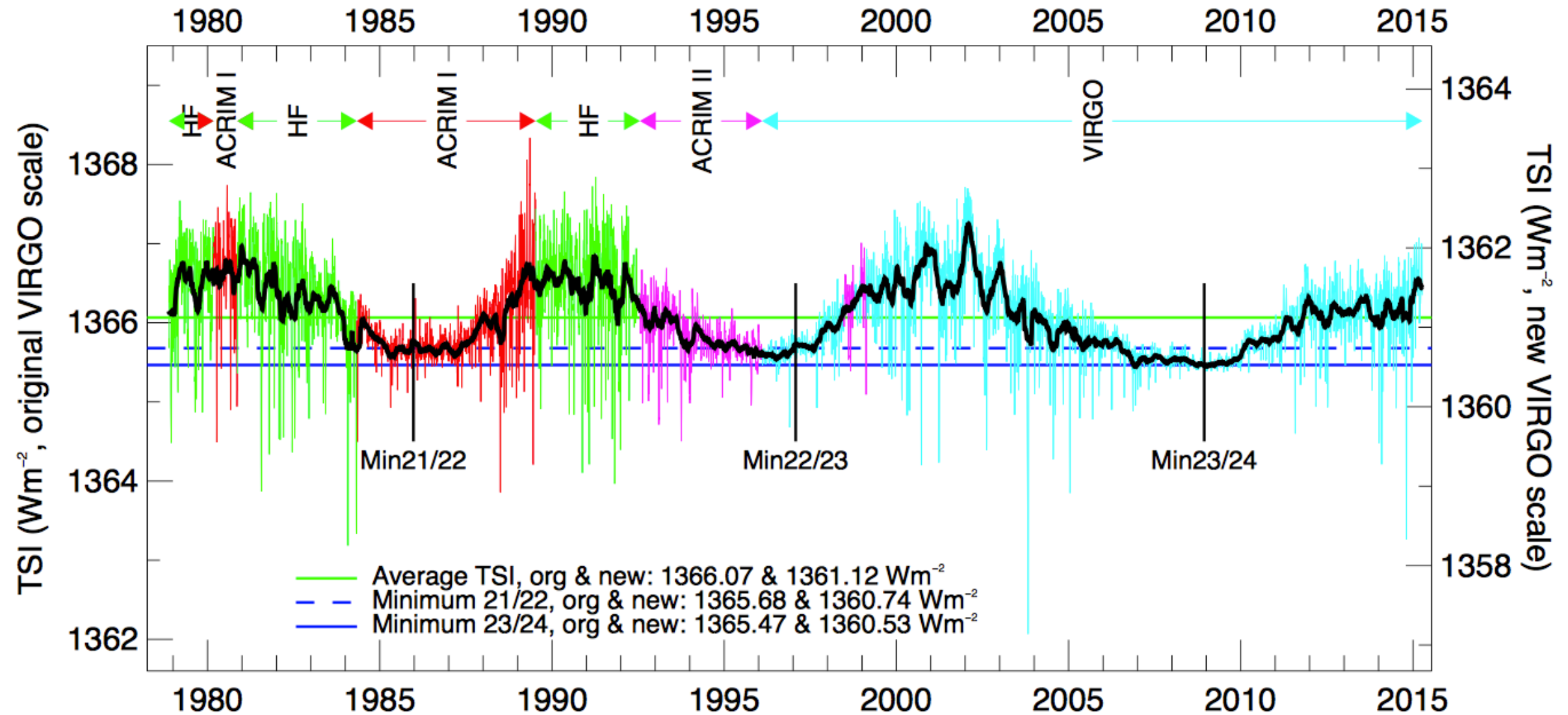
Disk coverage factors



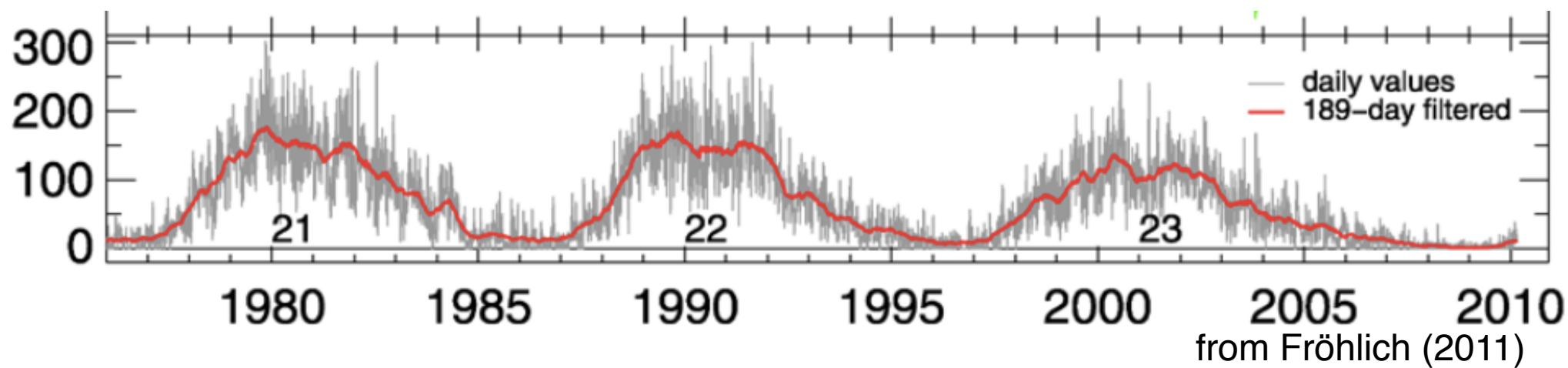
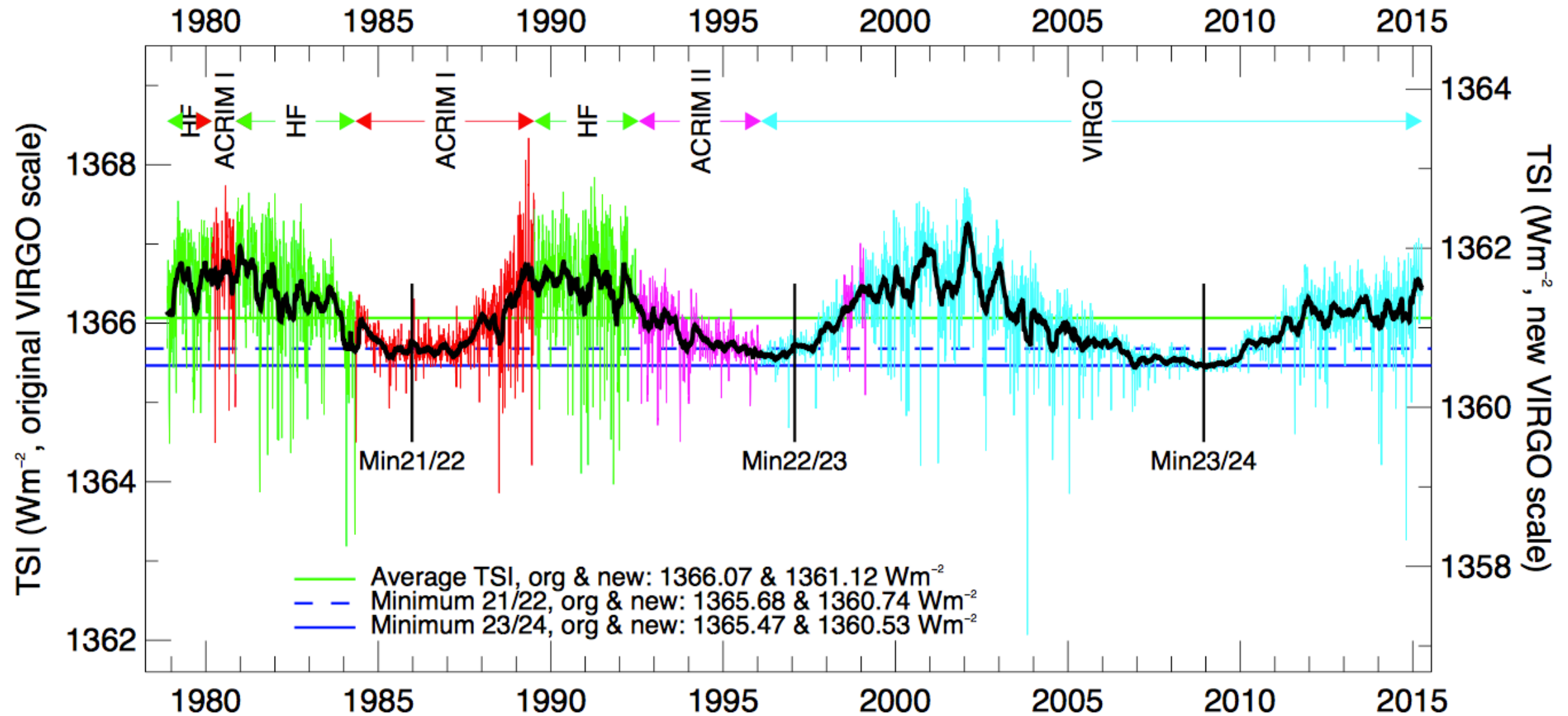
Activity

from Shapiro et al. (2014)

TSI vs. SSN



TSI vs. SSN



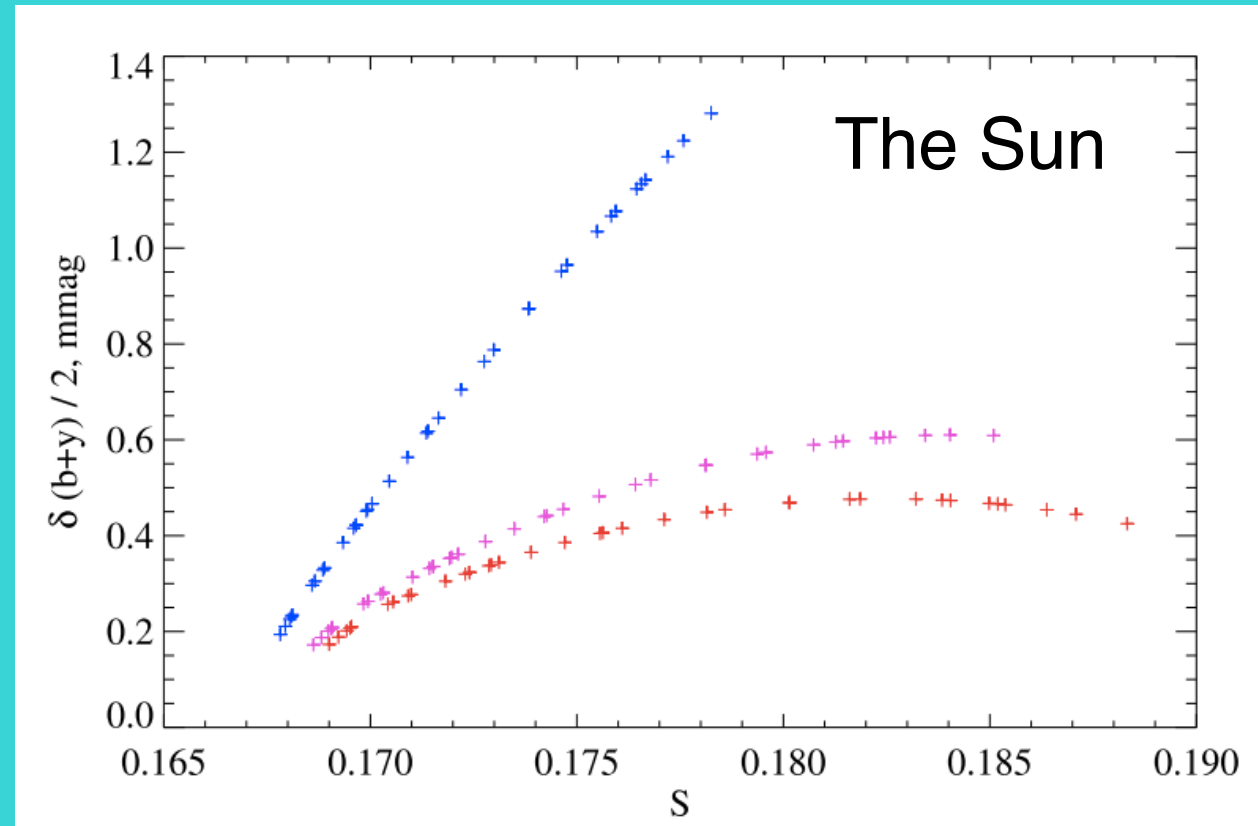
160

160

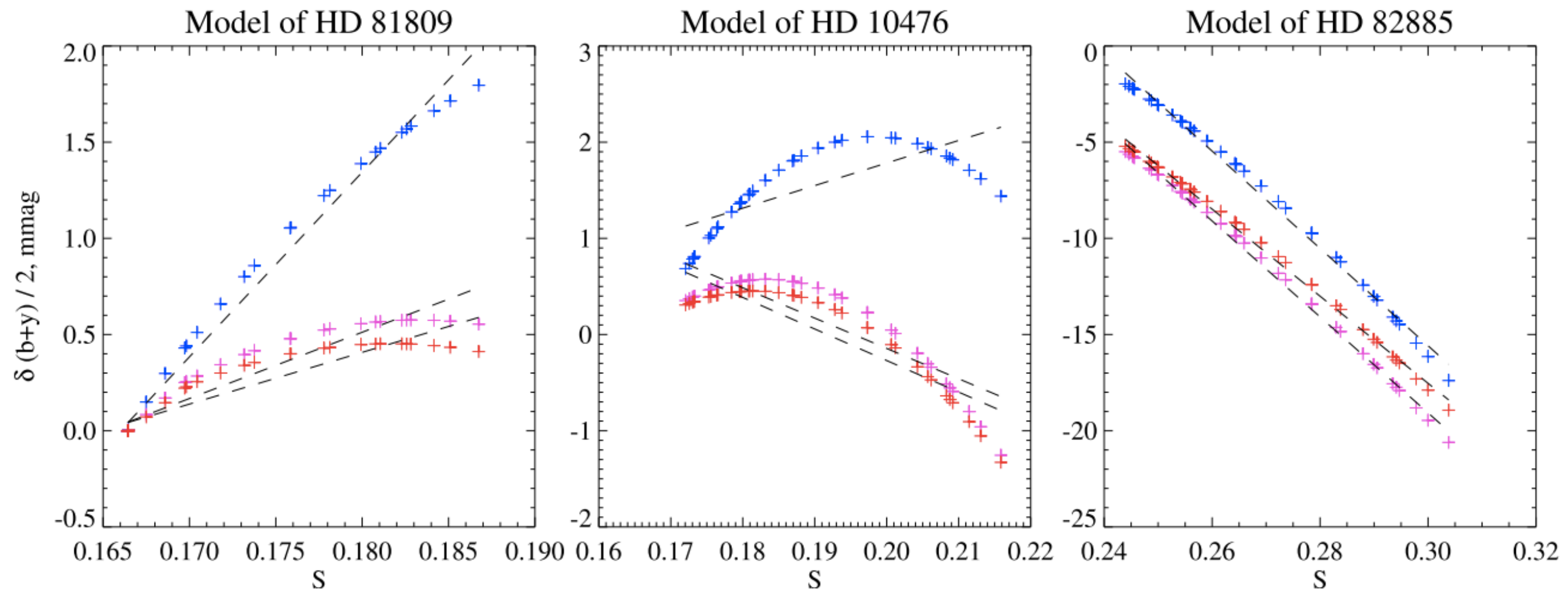
120

SSN

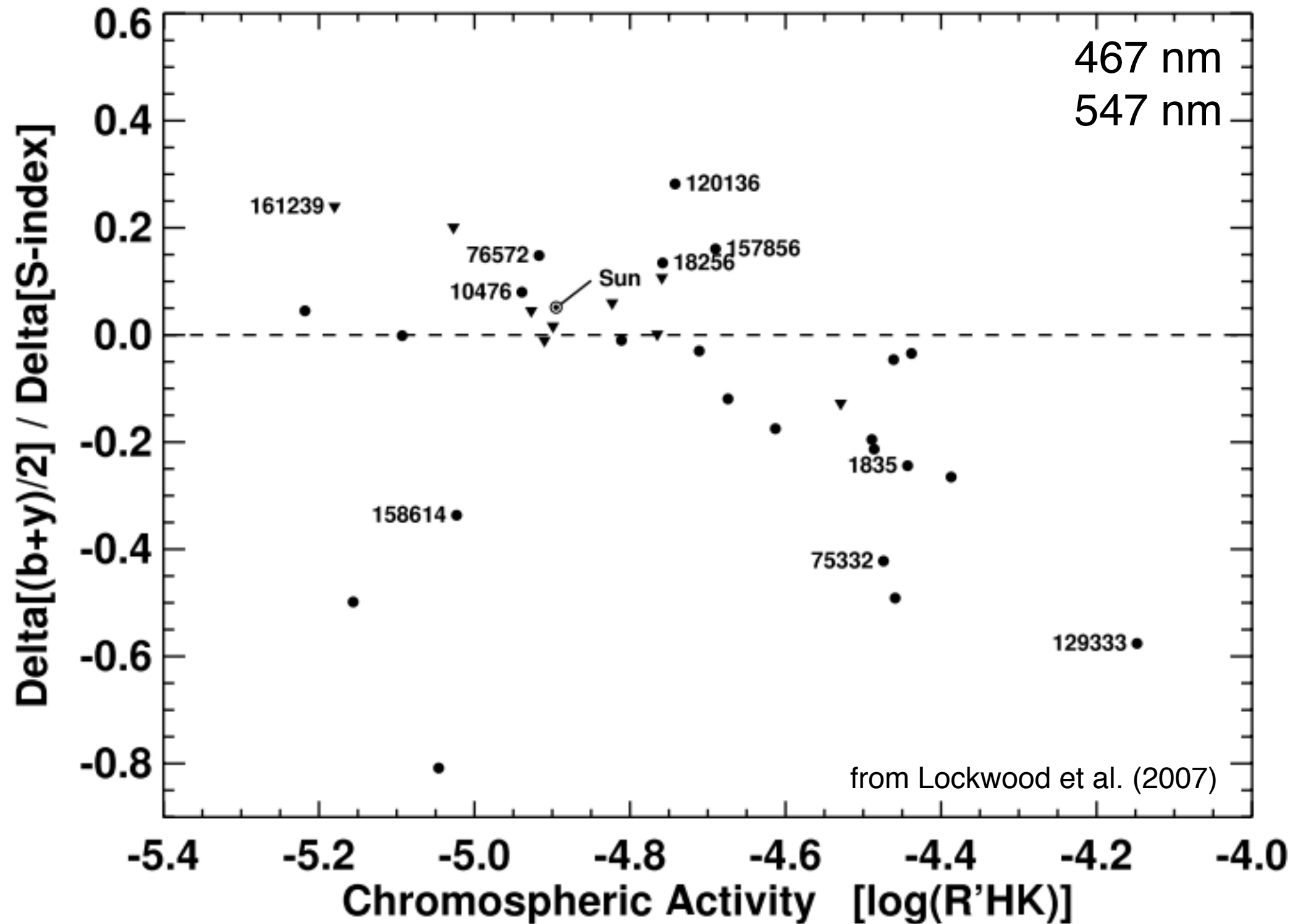
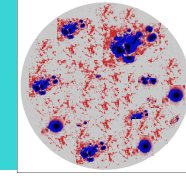
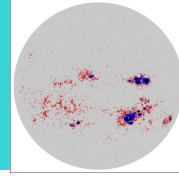
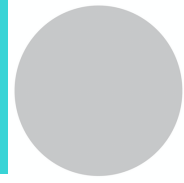
Brightness vs. activity



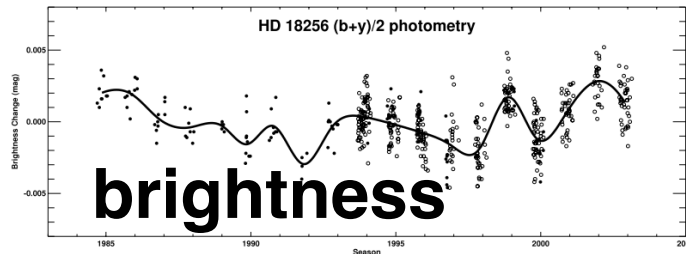
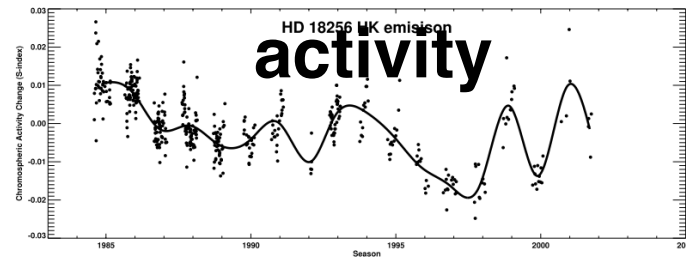
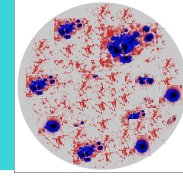
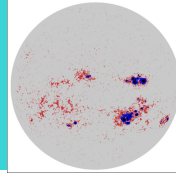
equatorial view
intermediate view
polar view



Faculae- vs spot-dominated variability

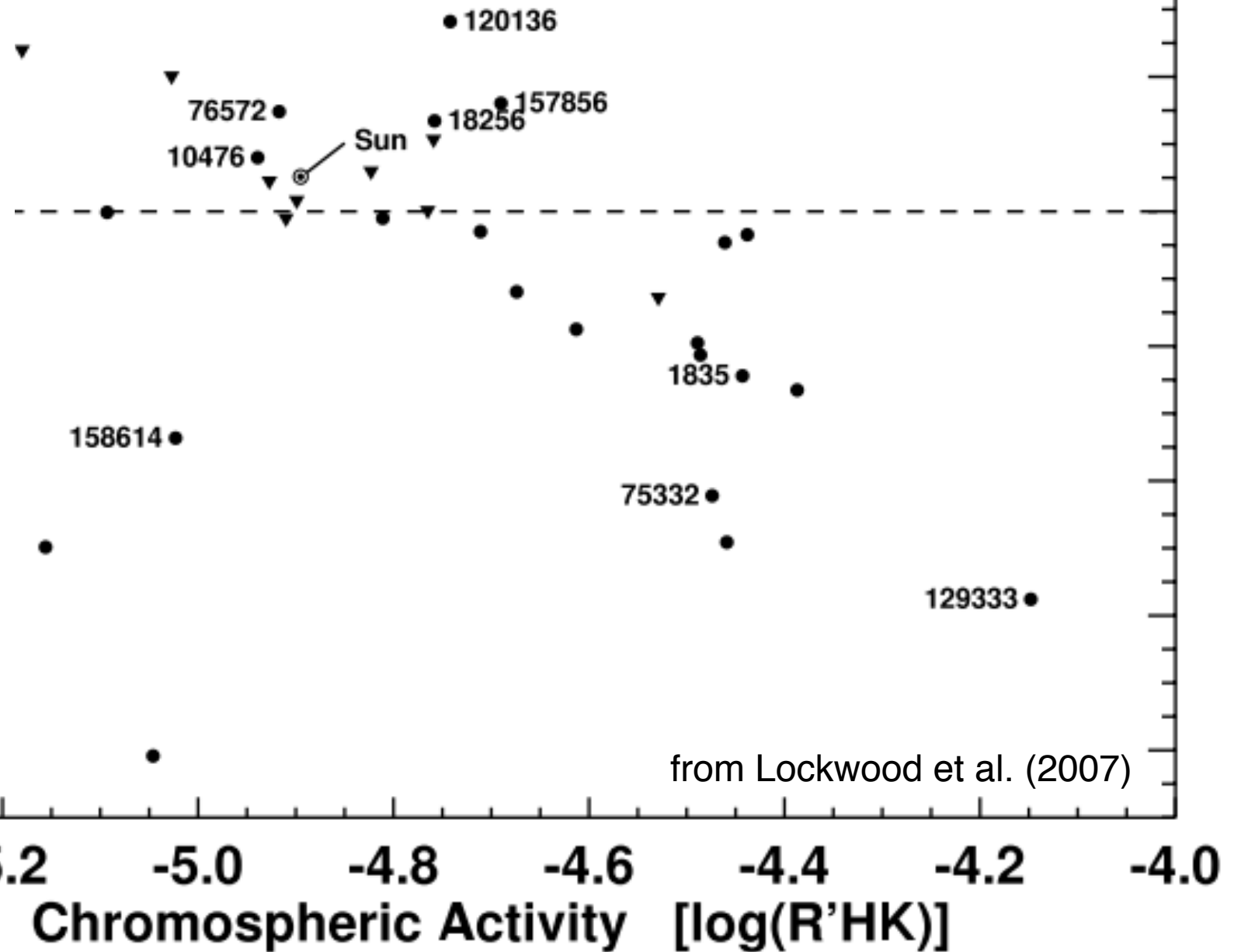


Faculae- vs spot-dominated variability

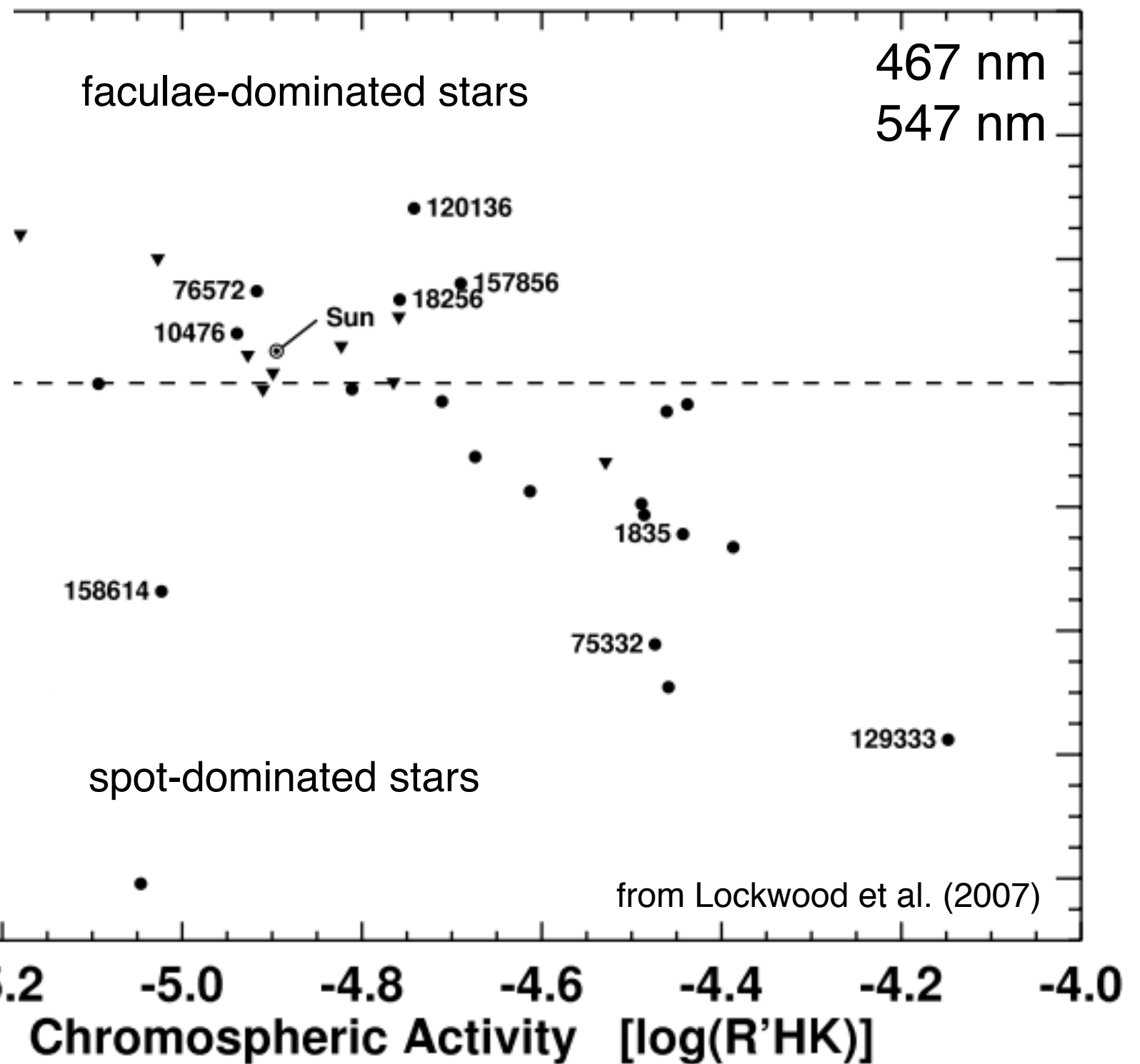
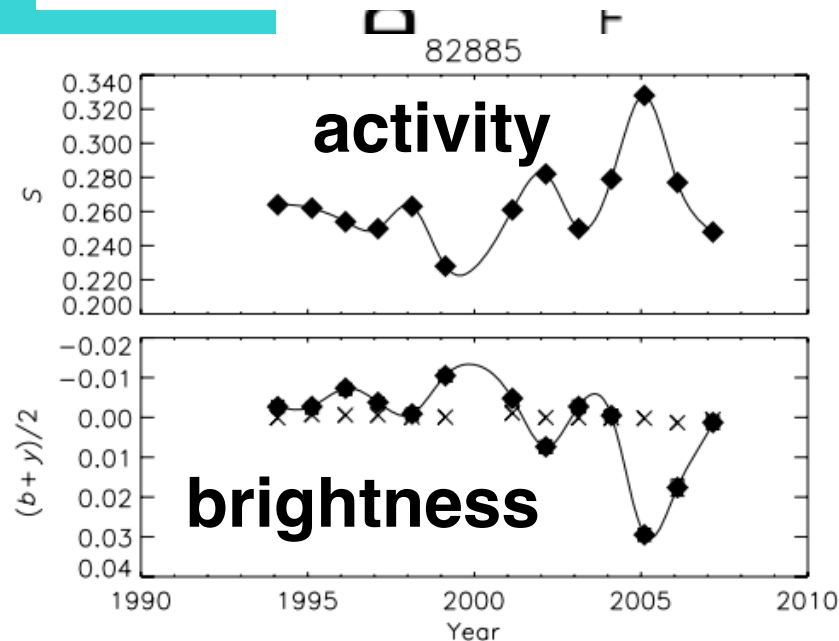
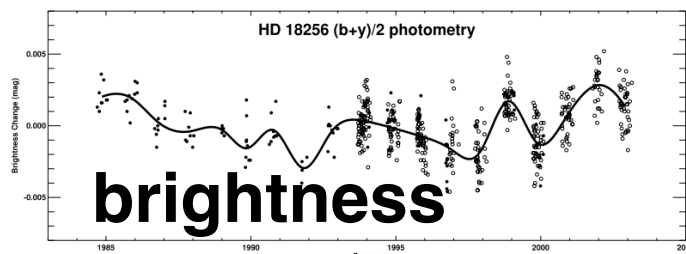
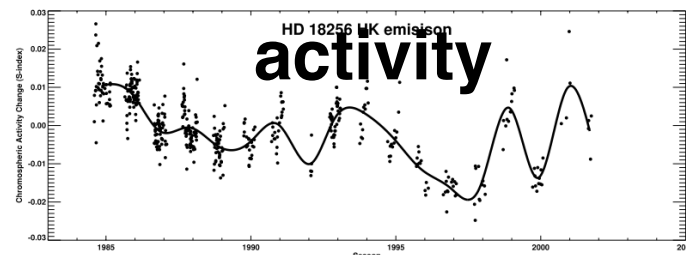
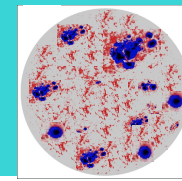
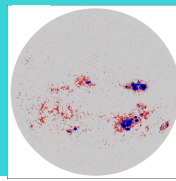
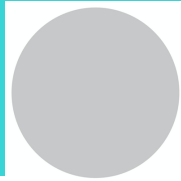


faculae-dominated stars

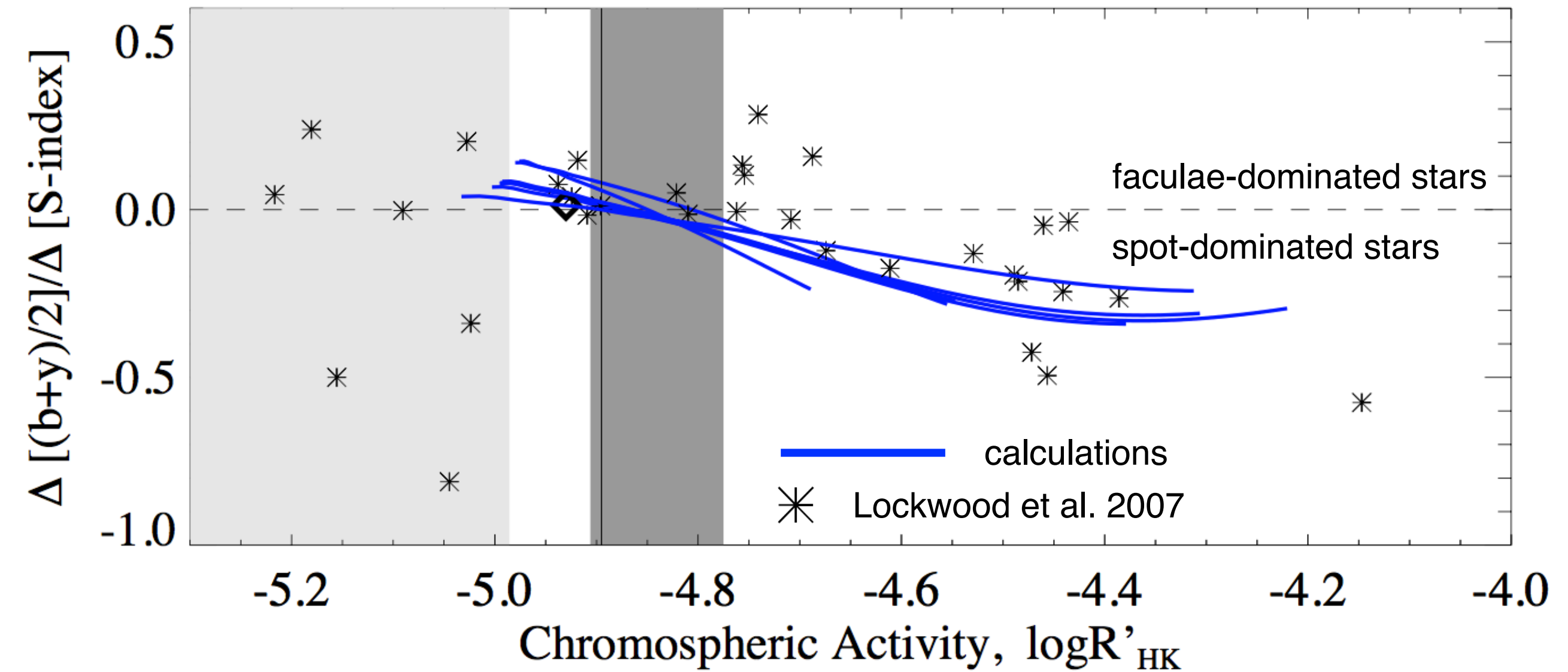
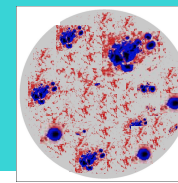
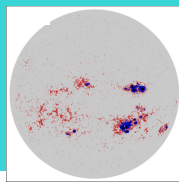
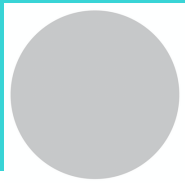
467 nm
547 nm



Faculae- vs spot-dominated variability

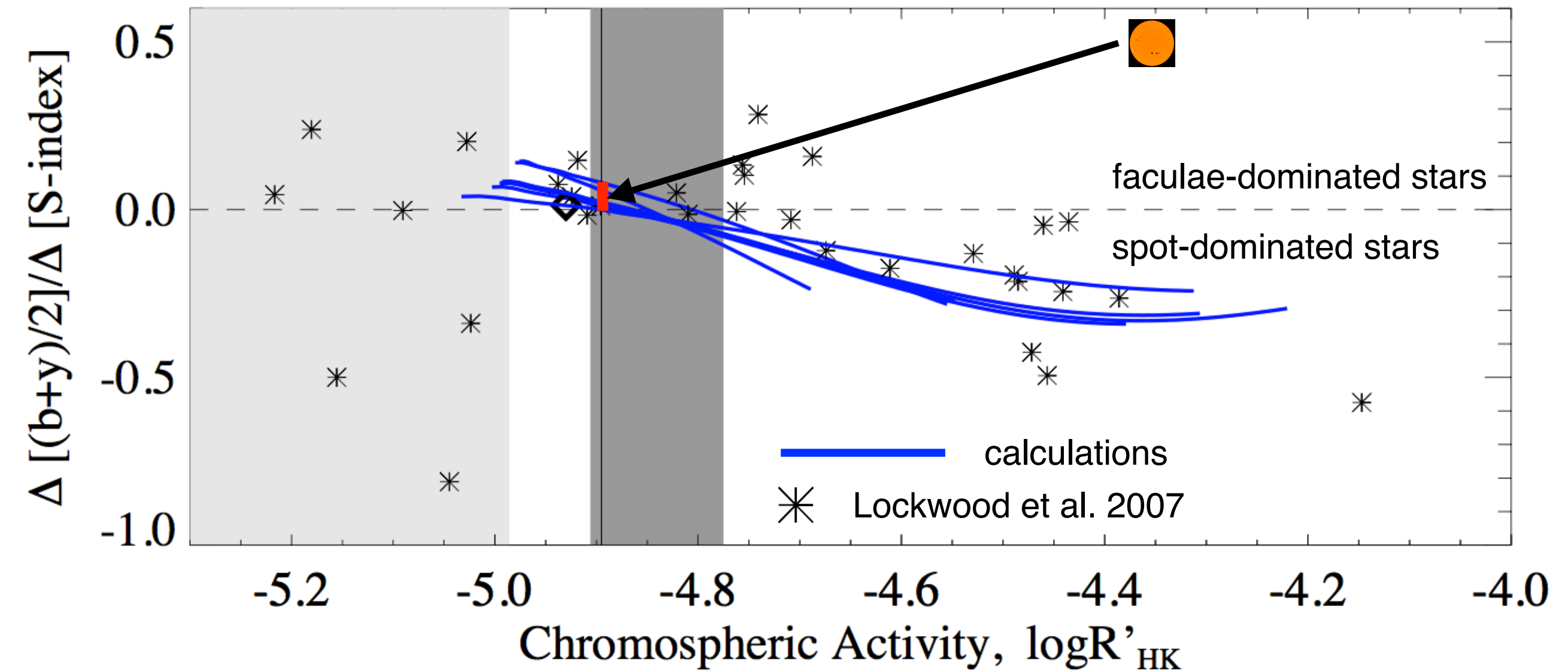
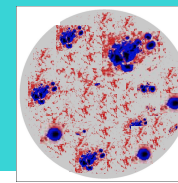
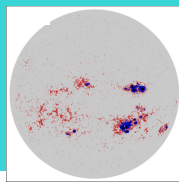
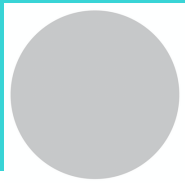


Faculae- vs spot-dominated variability



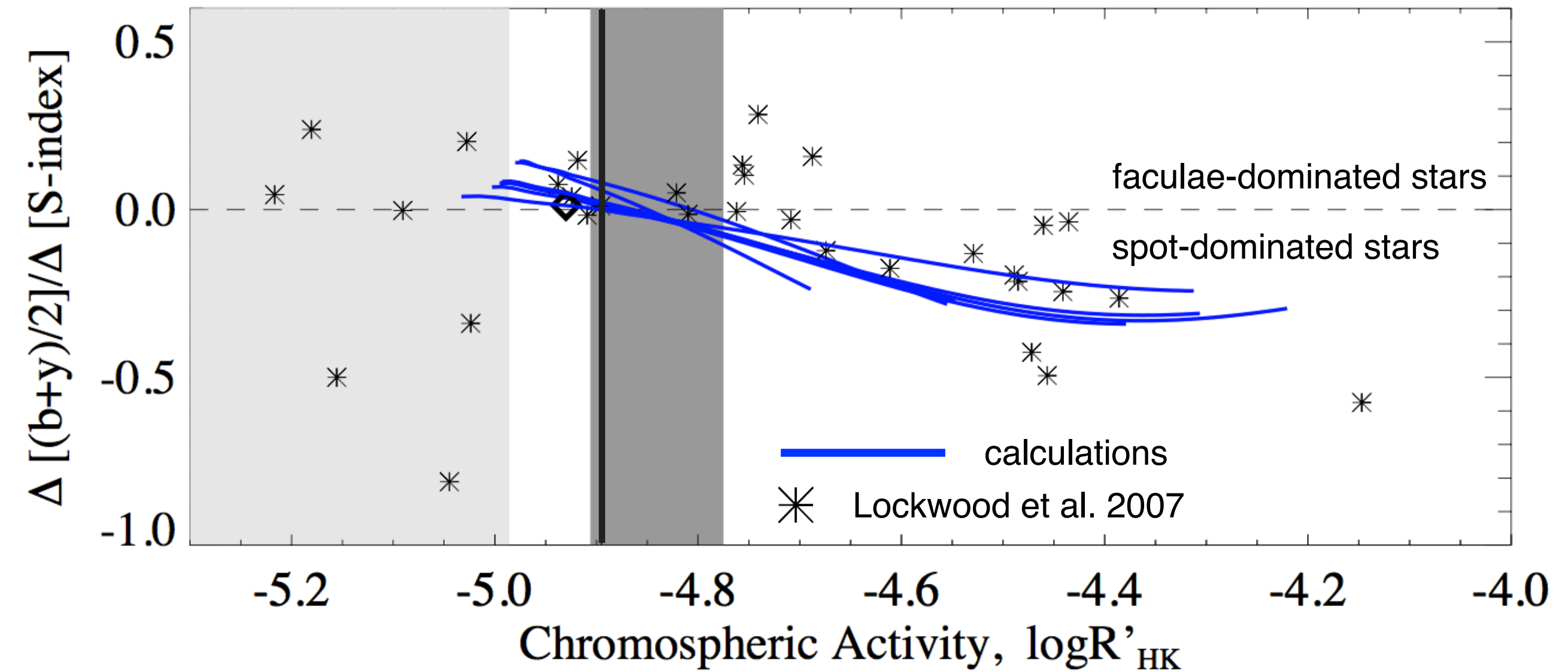
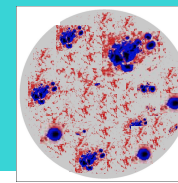
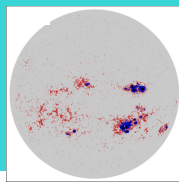
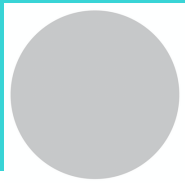
from Shapiro et al. (2014)

Faculae- vs spot-dominated variability

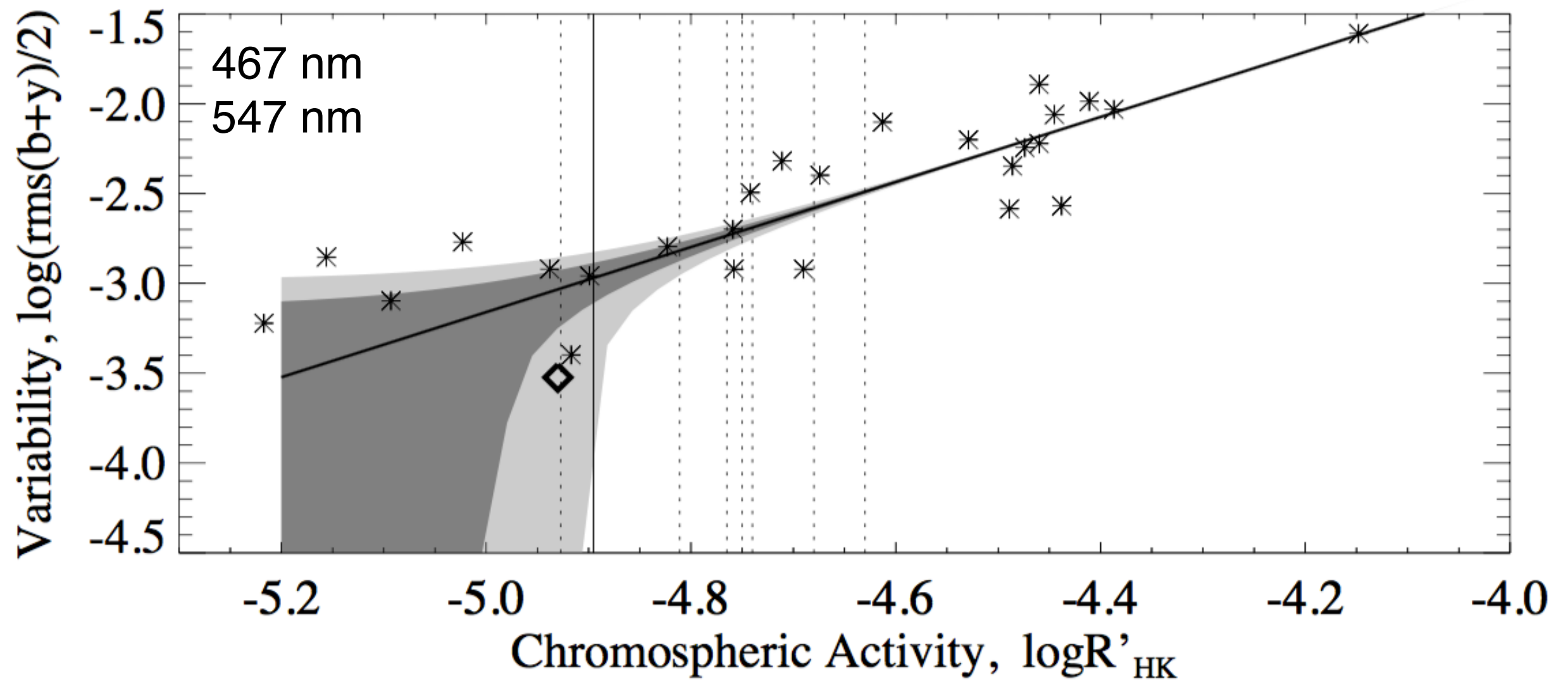
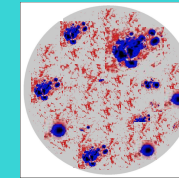
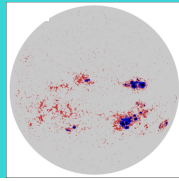
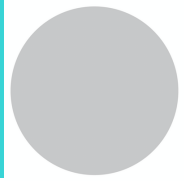


from Shapiro et al. (2014)

Faculae- vs spot-dominated variability

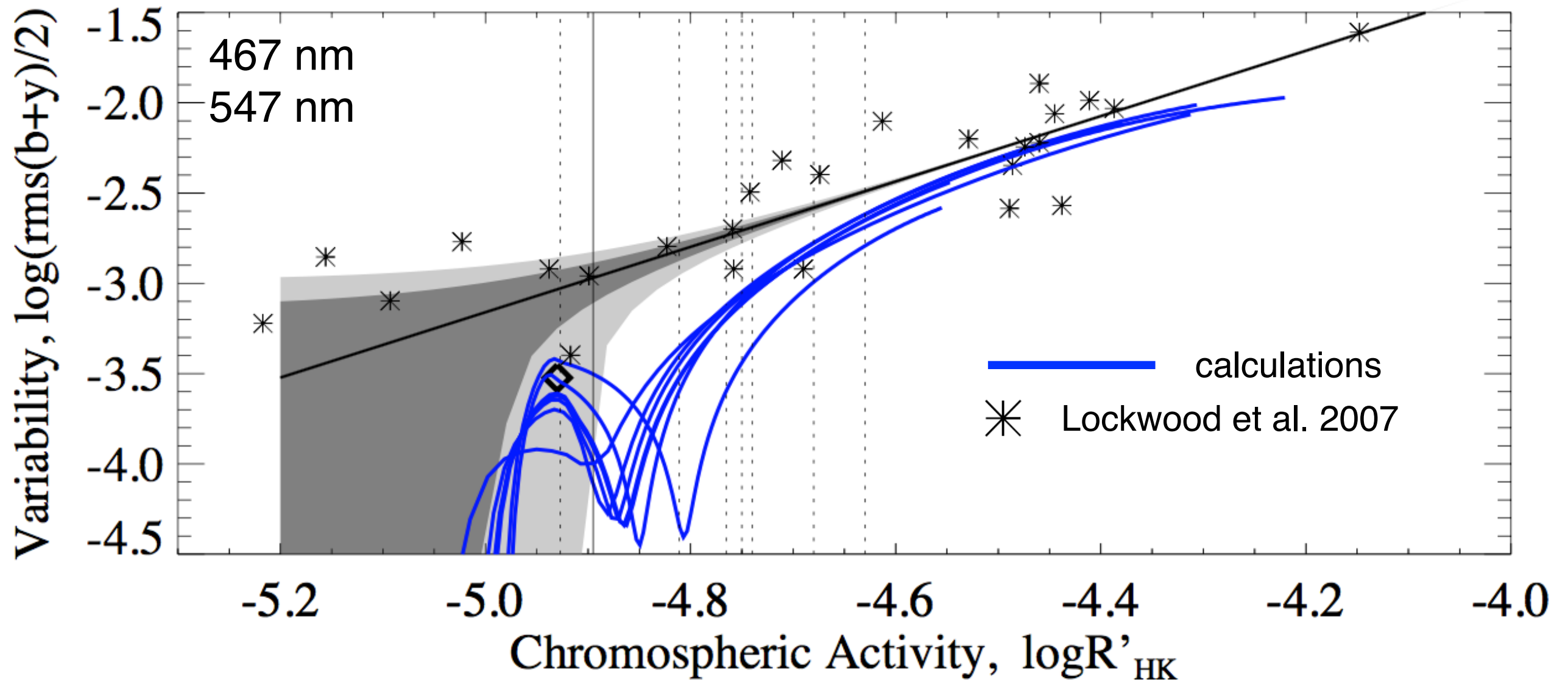
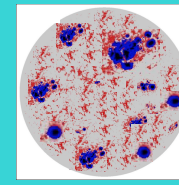
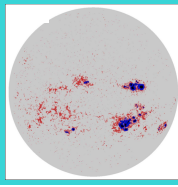
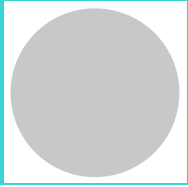


from Shapiro et al. (2014)



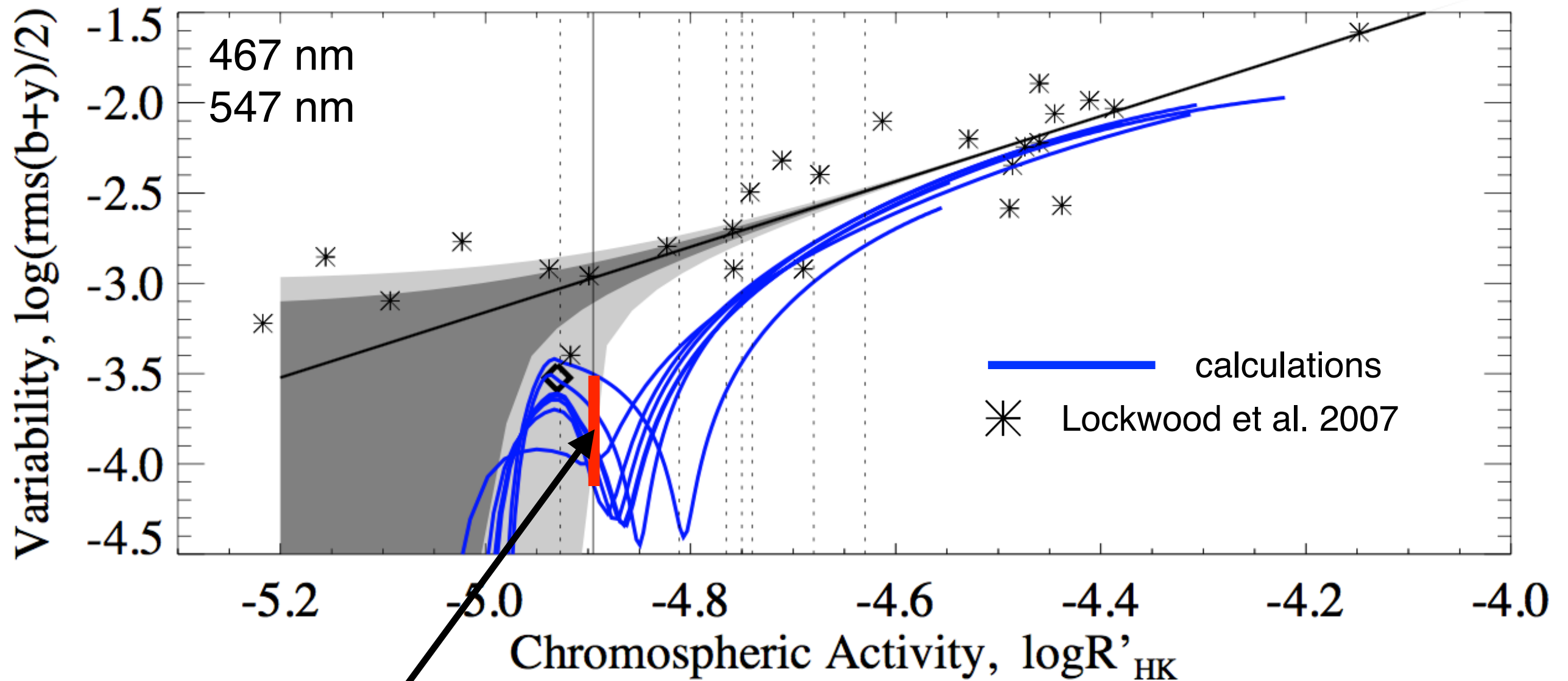
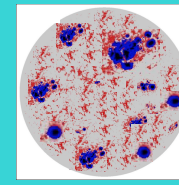
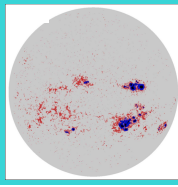
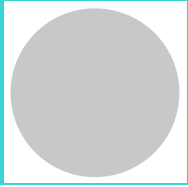
data from Lockwood et al. (2014)

Photometric variability as function of activity



from Shapiro et al. (2014)

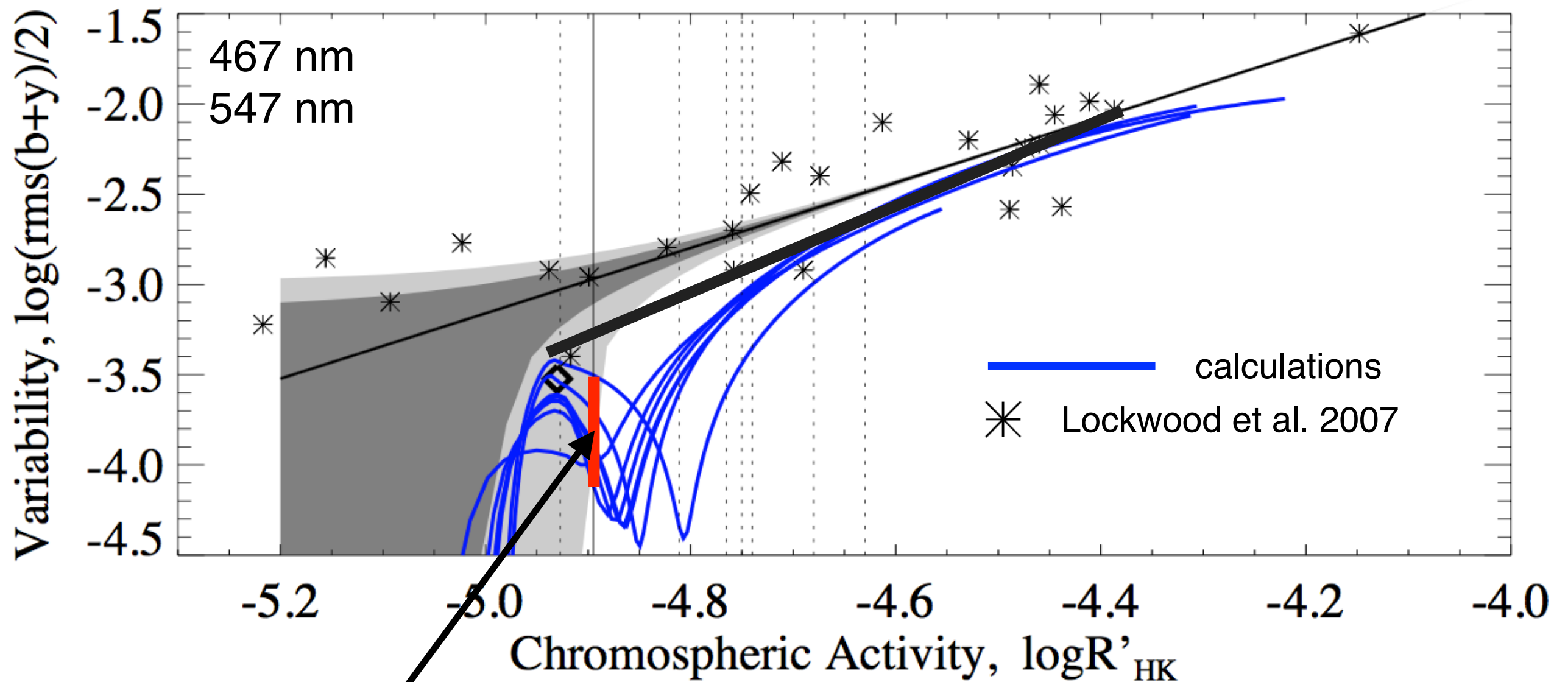
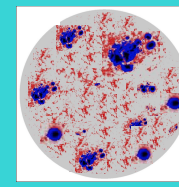
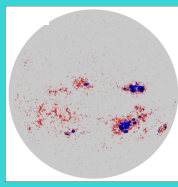
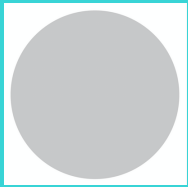
Photometric variability as function of activity



from Shapiro et al. (2014)



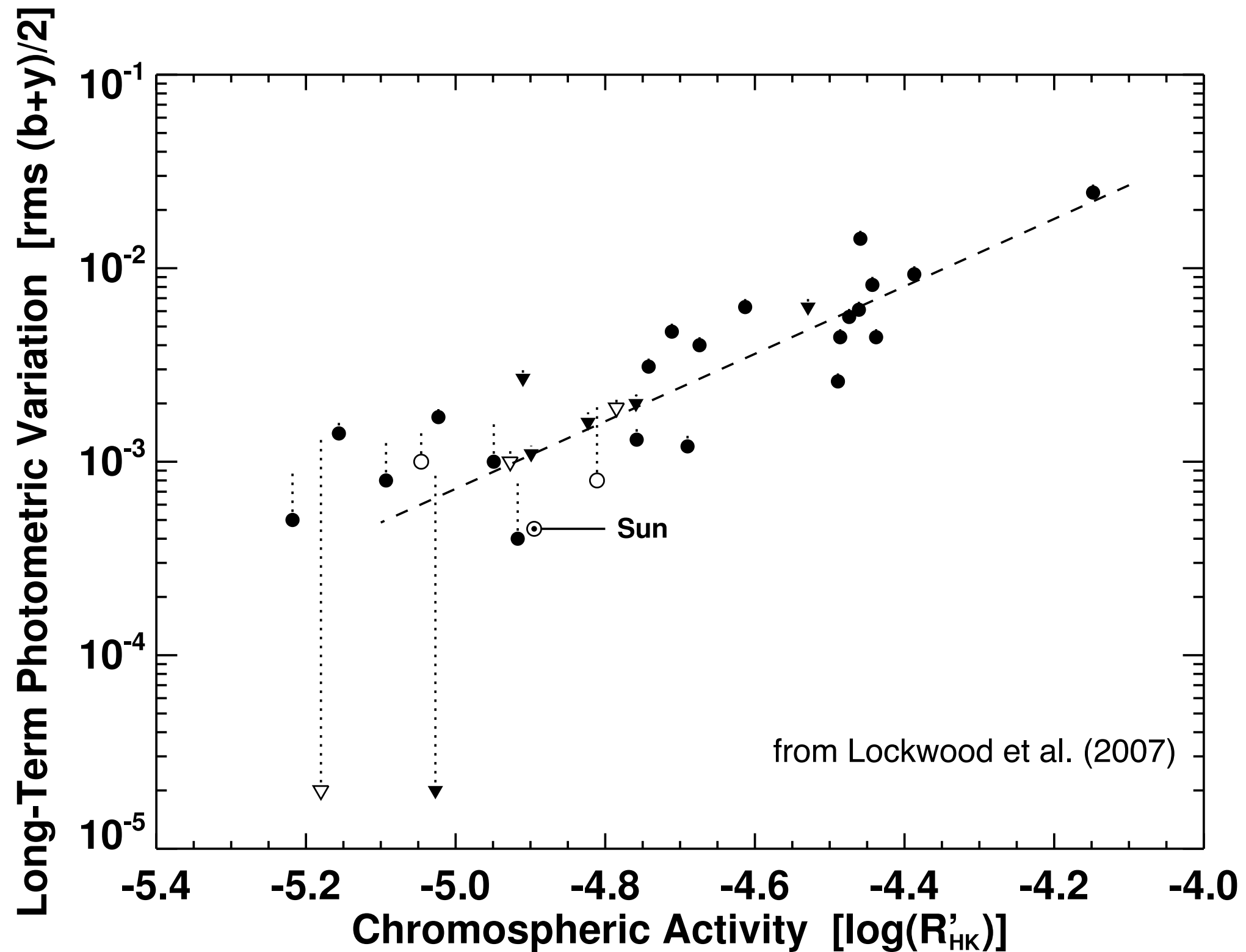
Photometric variability as function of activity



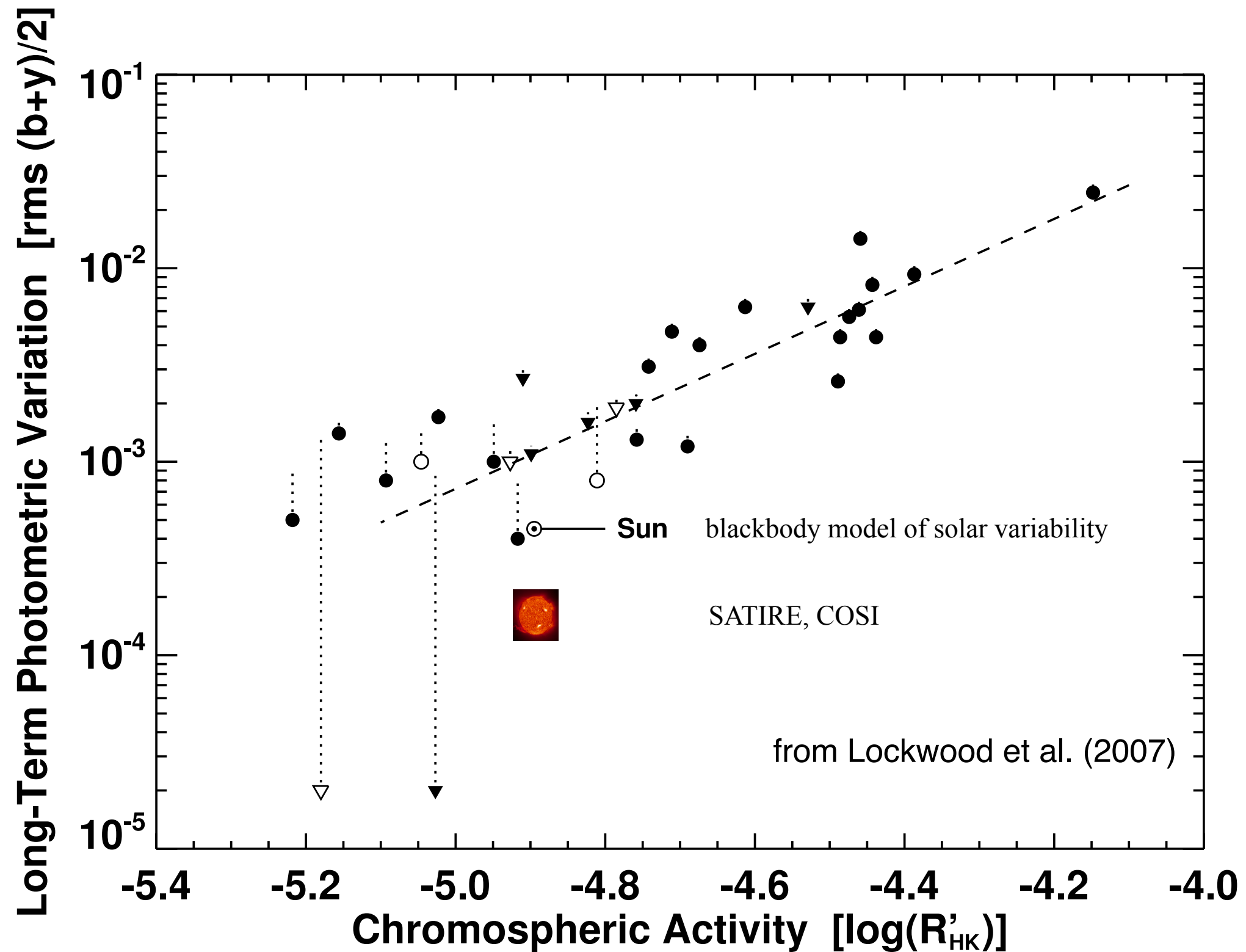
from Shapiro et al. (2014)



Variability as a function of activity



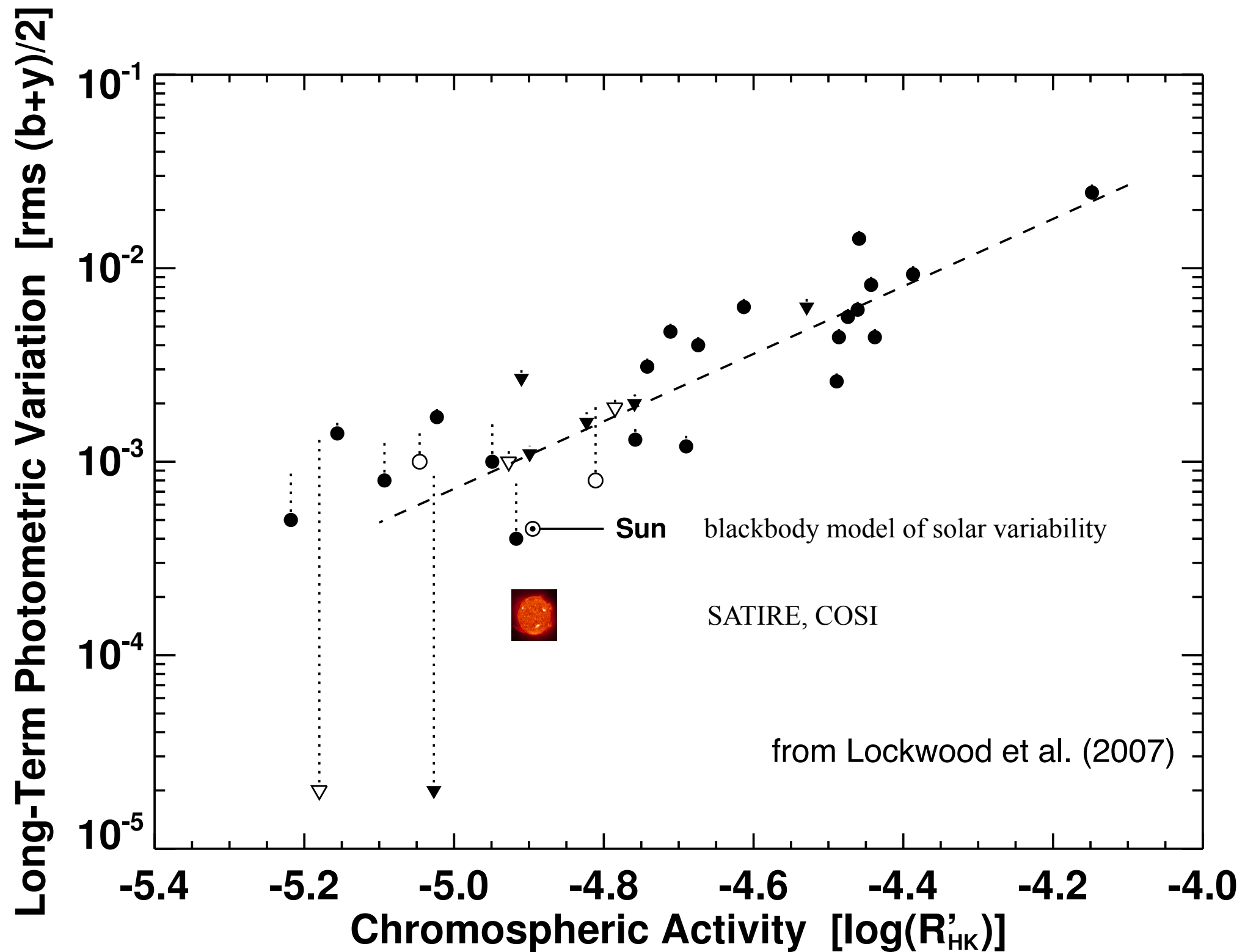
Variability as a function of activity



Variability as a function of activity

Is something wrong with the solar dynamo?

Is the Sun a Sun-like star?

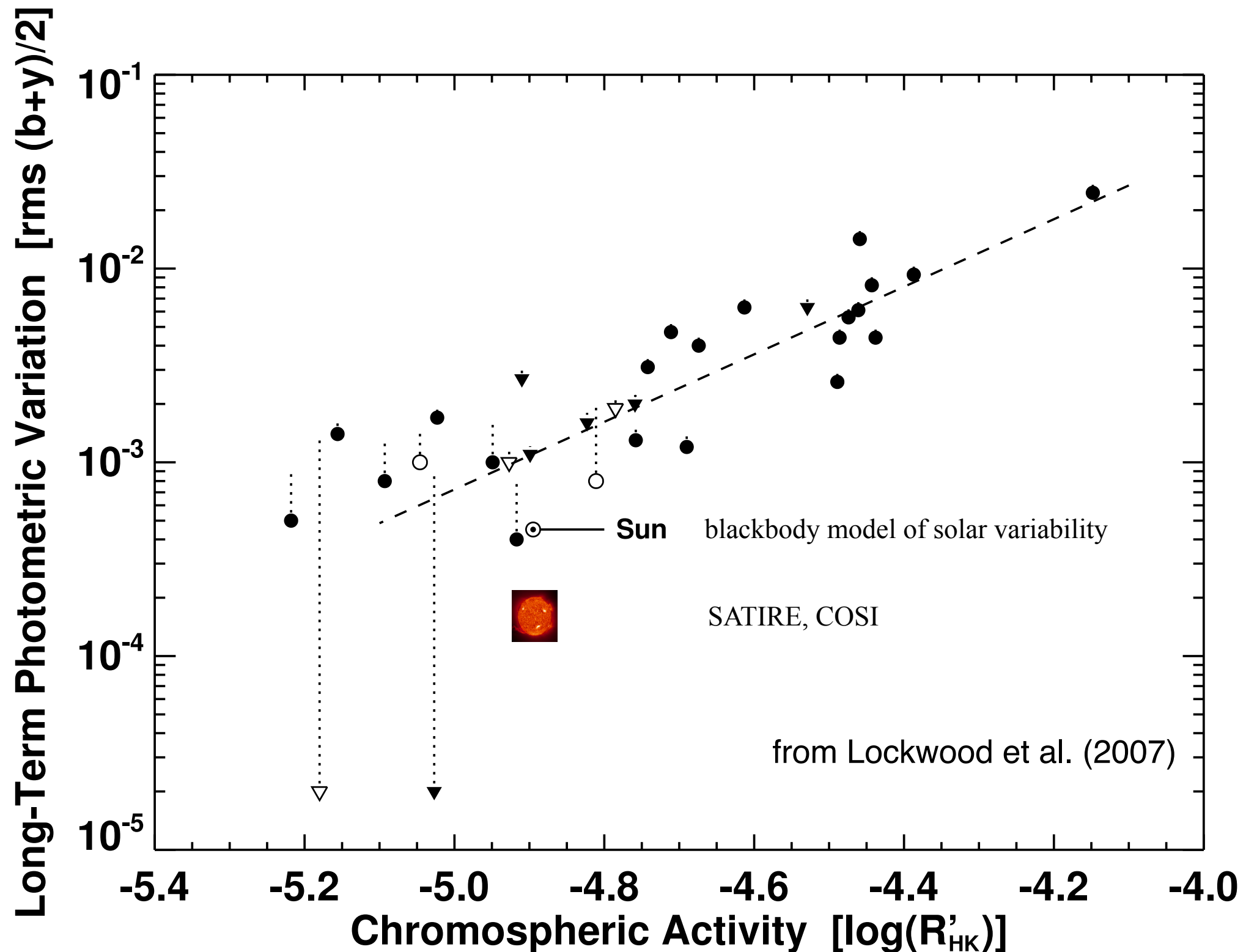


Variability as a function of activity

Is something wrong with the solar dynamo?

Is something wrong with stellar data?

Is the Sun a Sun-like star?



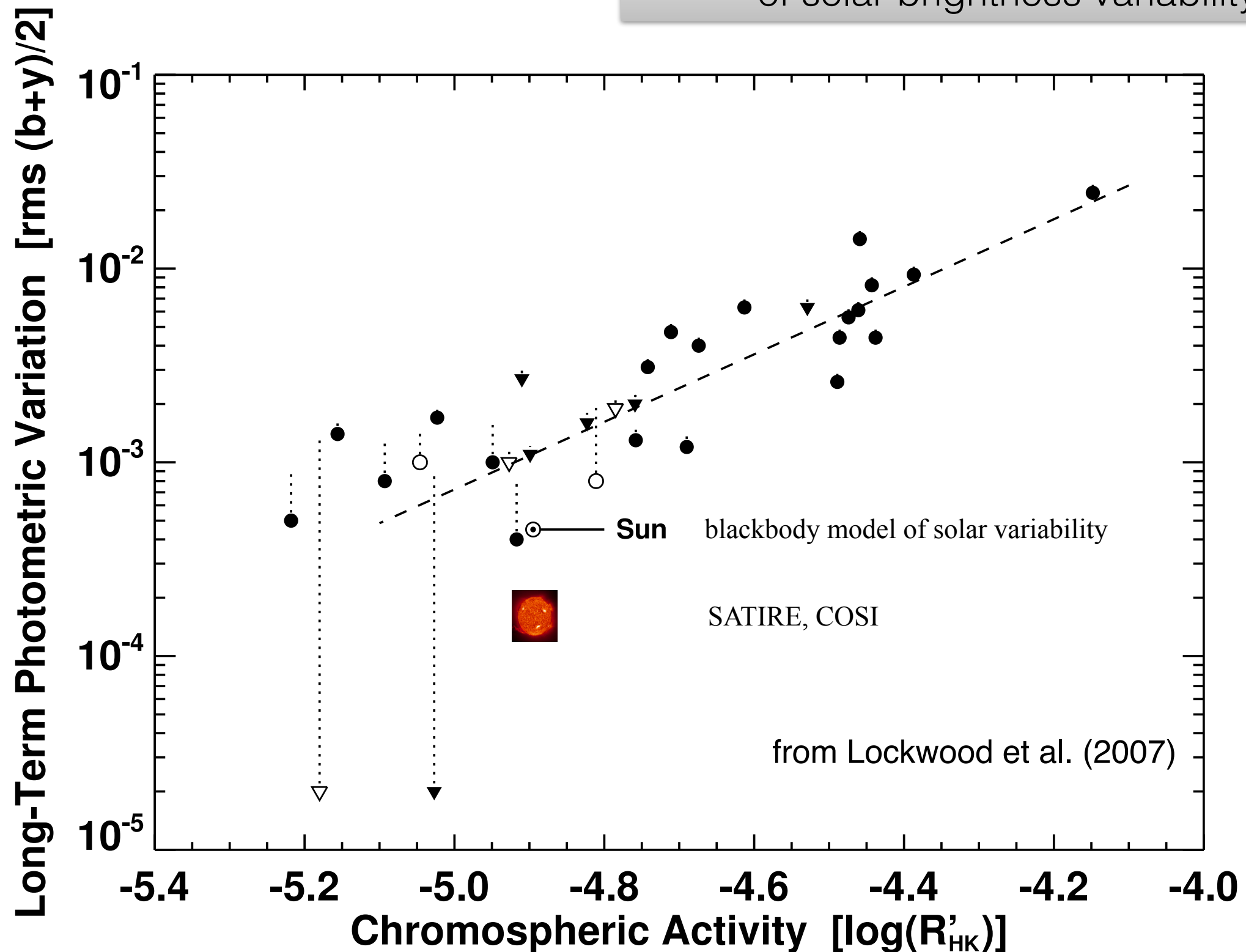
Variability as a function of activity

Is something wrong with the solar dynamo?

Is something wrong with stellar data?

Is the Sun a Sun-like star?

Is something wrong with our understanding of solar brightness variability?



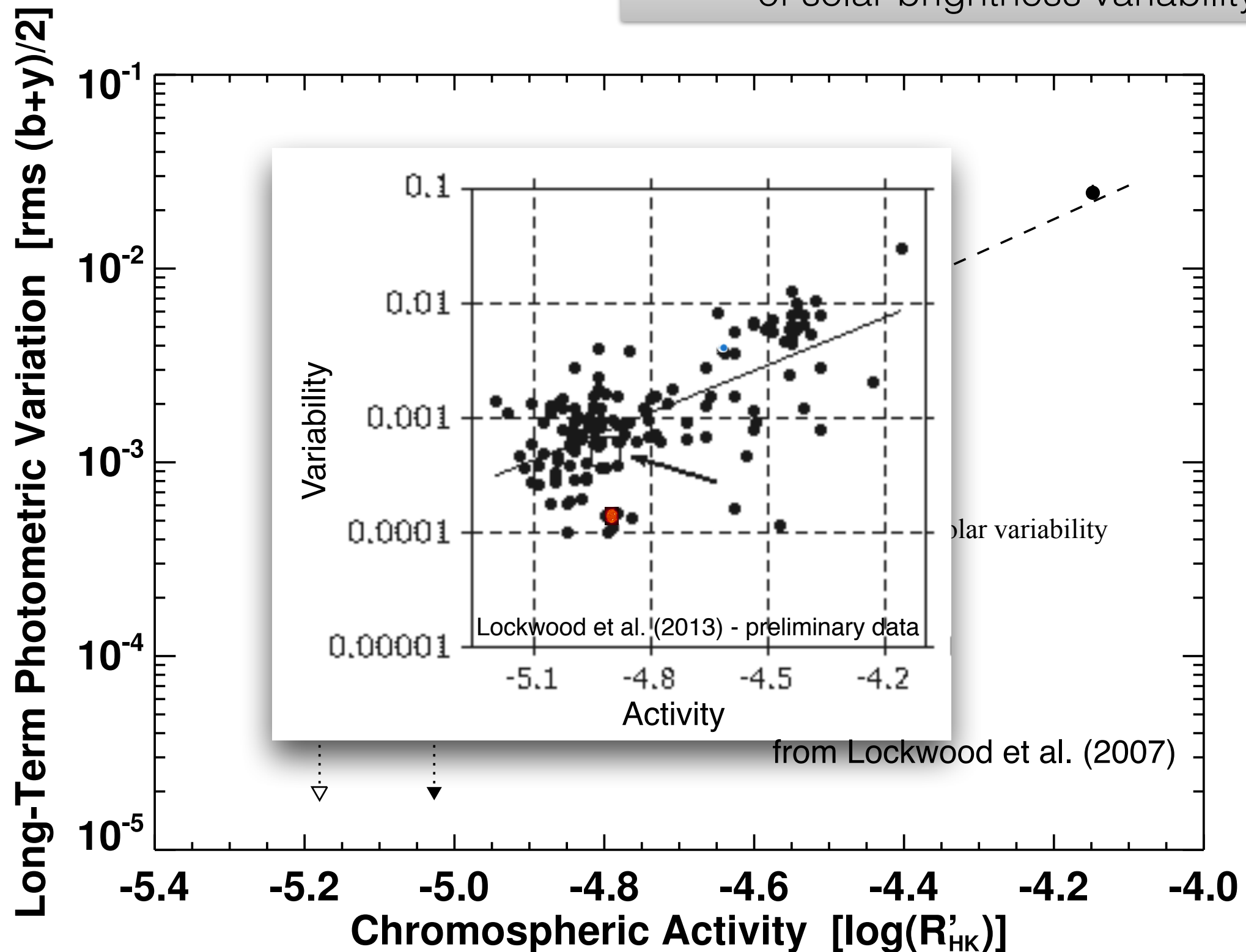
Variability as a function of activity

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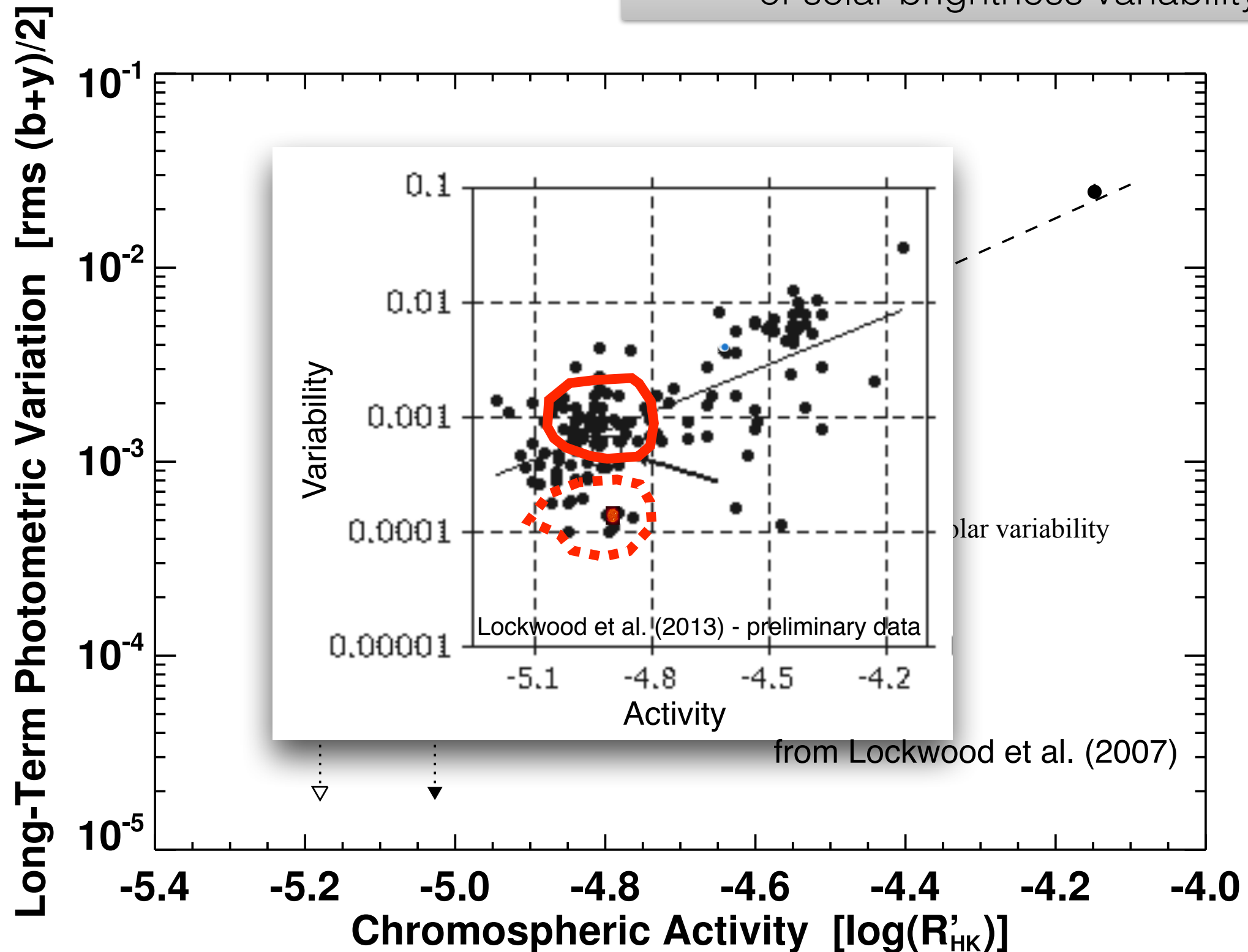
Variability as a function of activity

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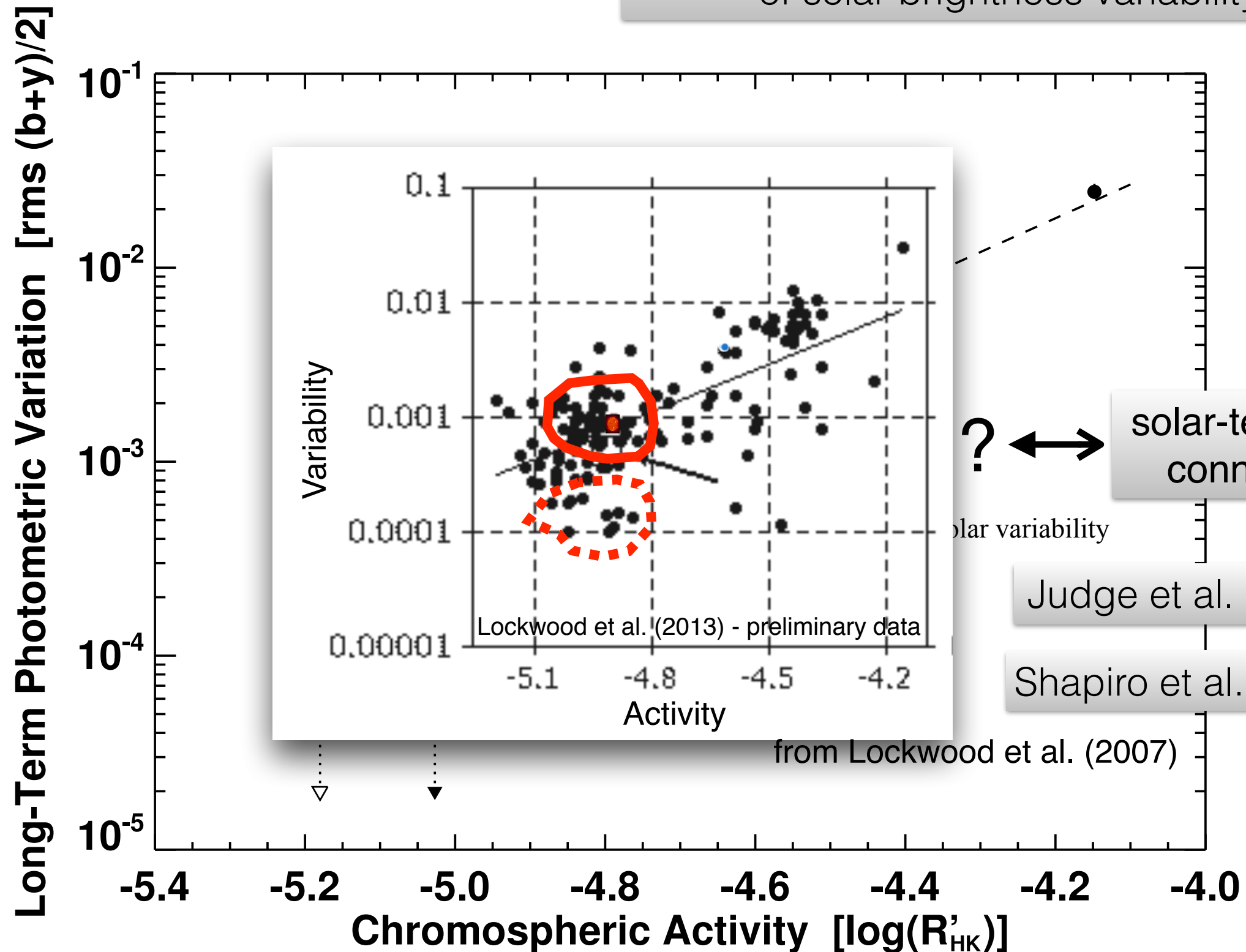
Variability as a function of activity

Is something wrong with the solar dynamo?

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Is the Sun a Sun-like star?

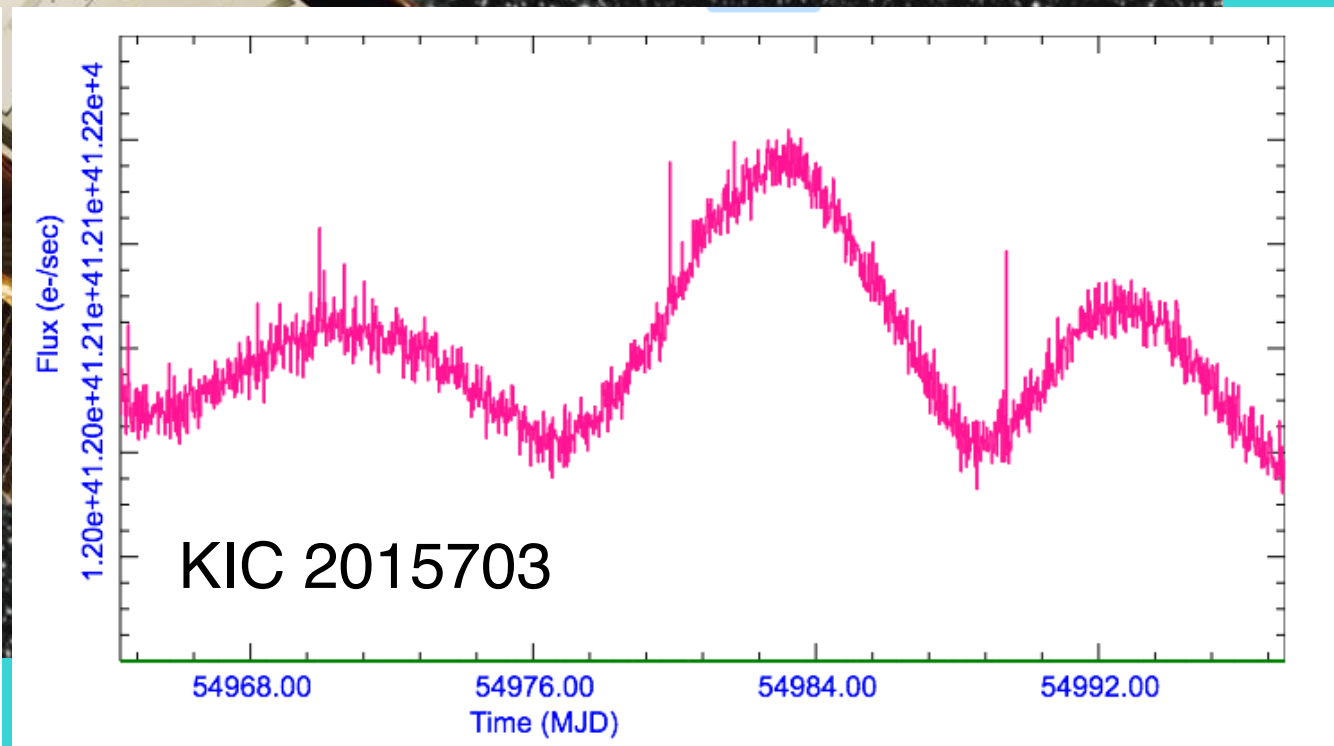
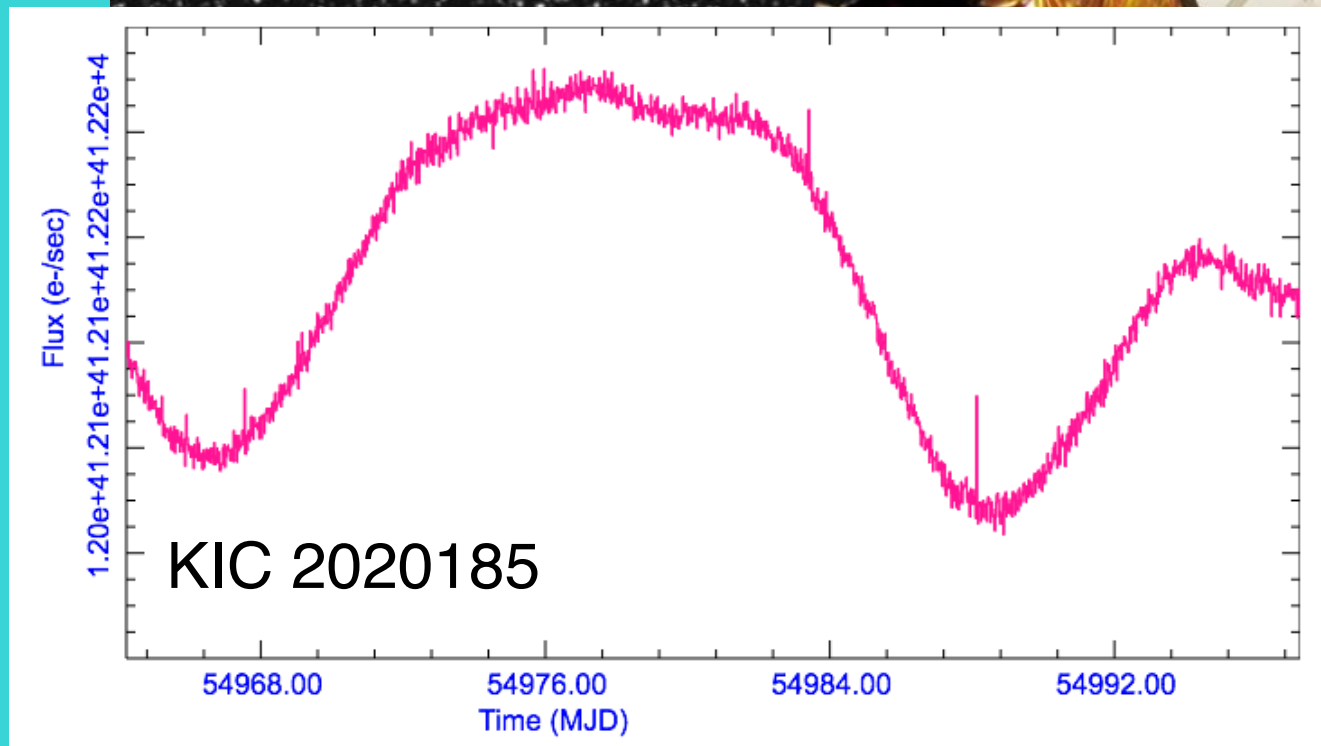
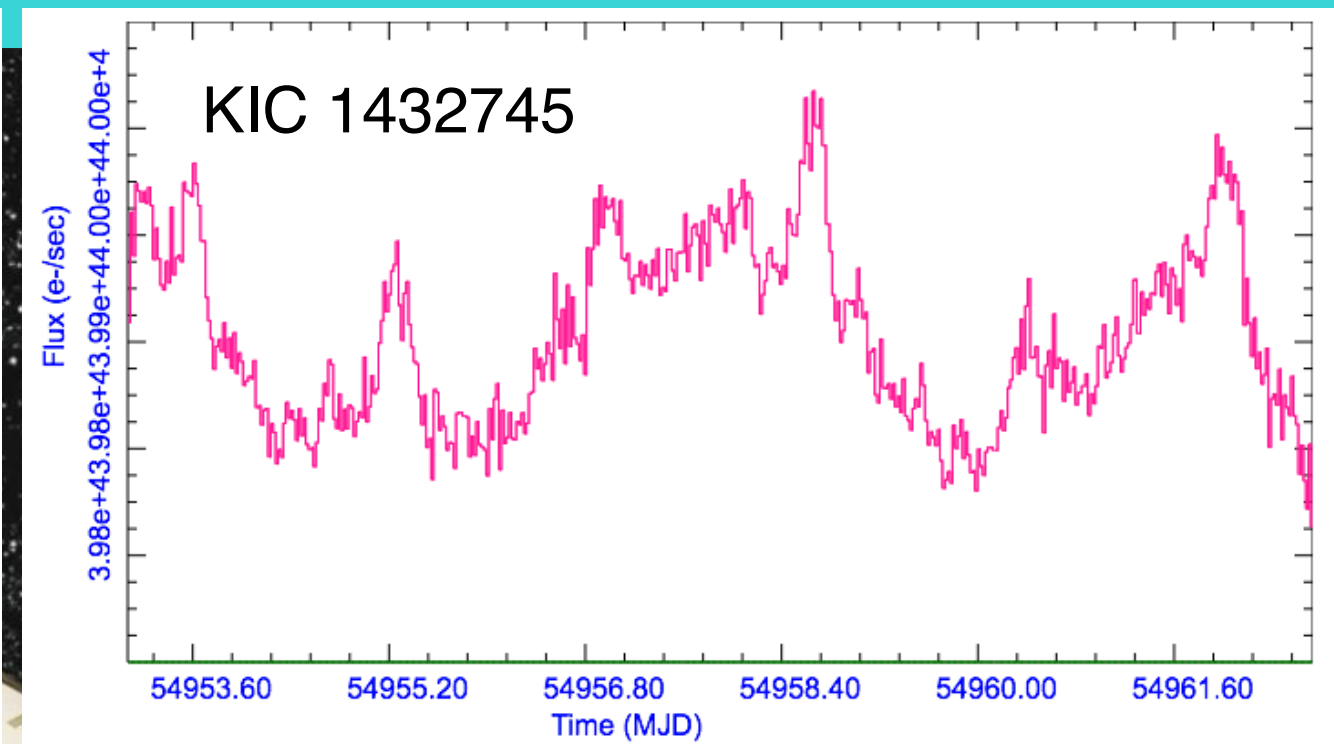
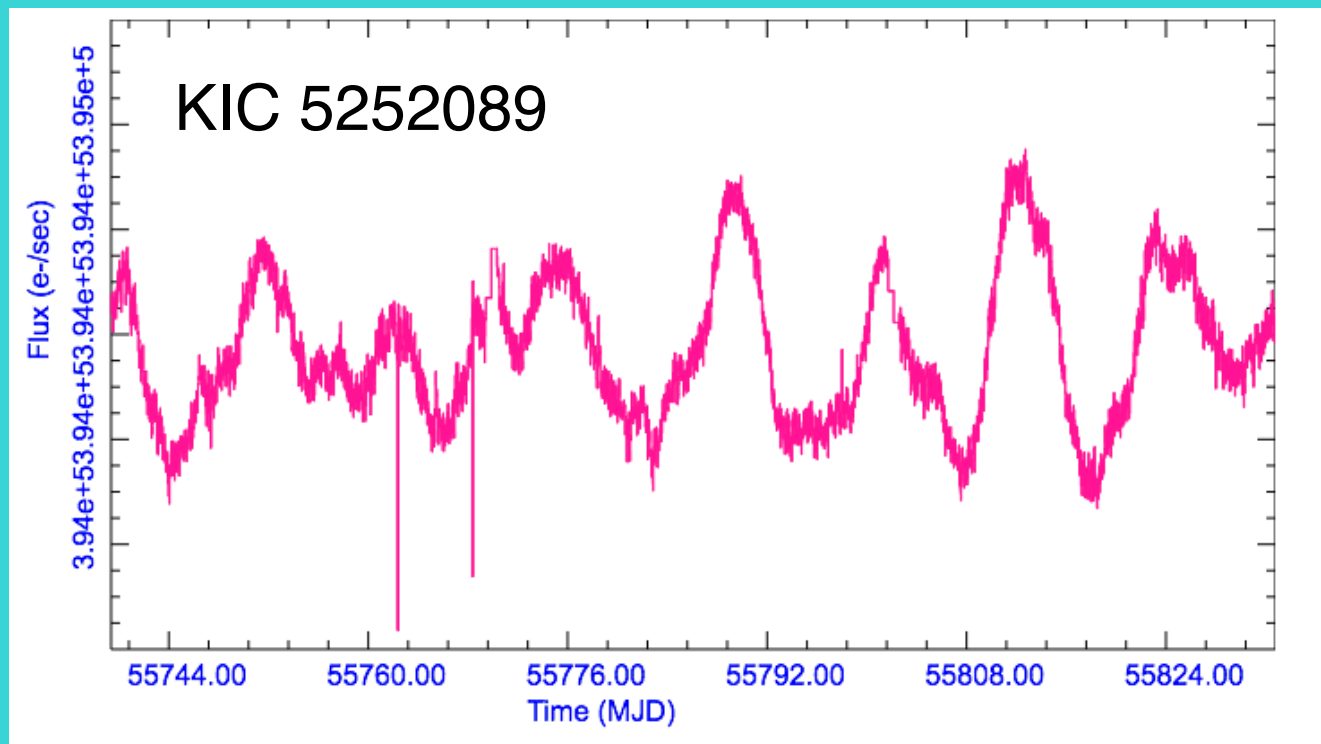
Is something wrong with our understanding of solar brightness variability?

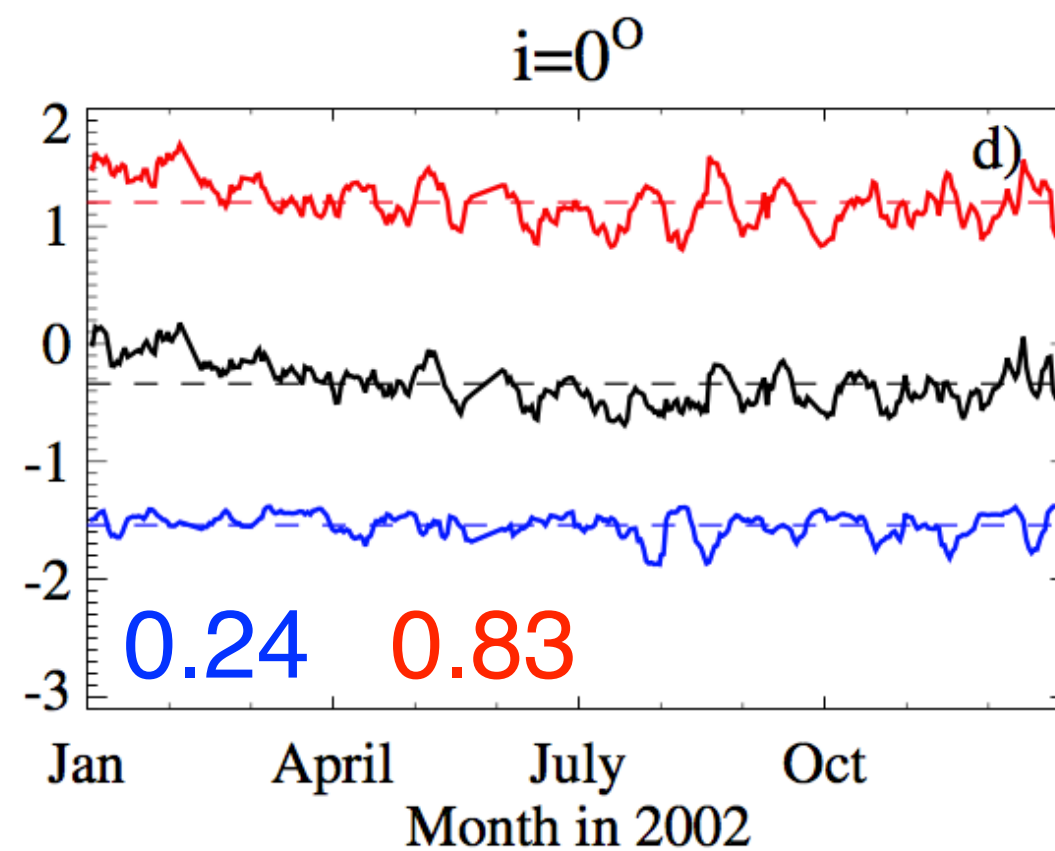
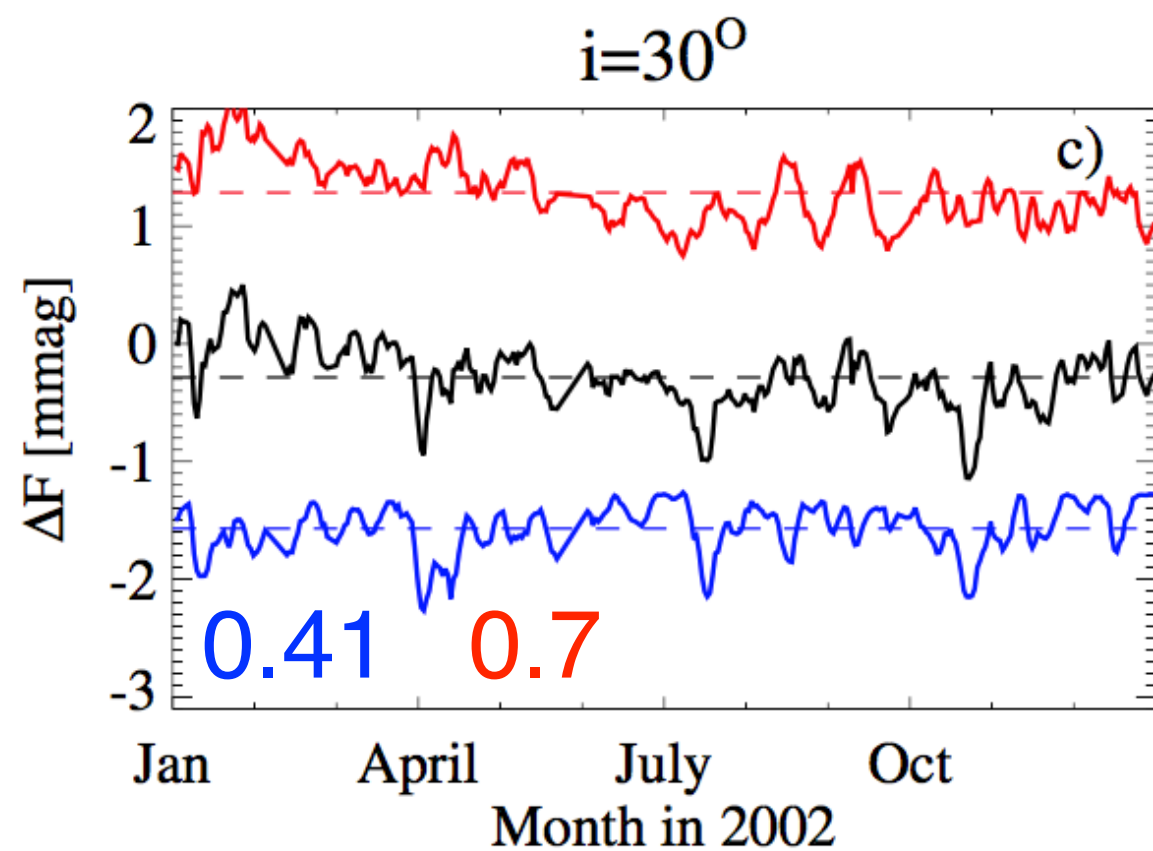
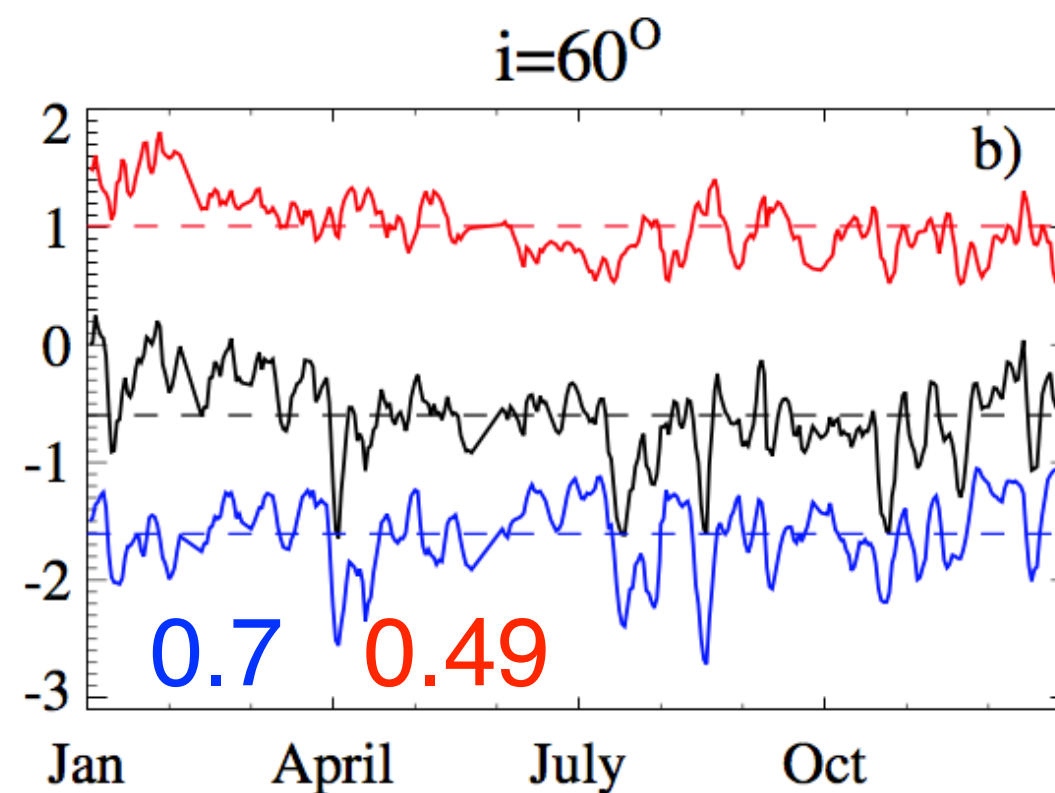
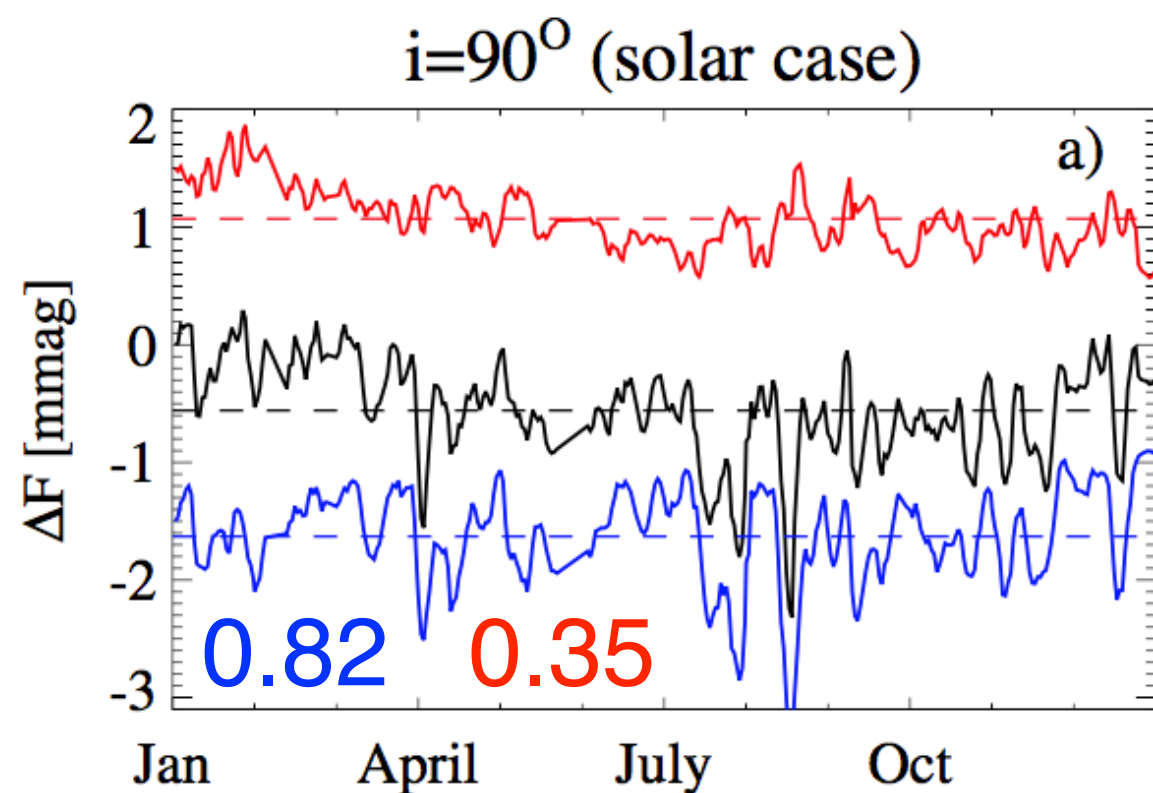


Kepler data



Kepler data





SUMMARY

We have reproduced the transition from direct to inverse brightness-activity correlation

We have shown that the facular signature can be seen in the Kepler light curves of stars identical to the Sun and observed out of their equatorial planes

We *believe* that the Sun is a solar-type variable

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THANK YOU!