Inclination and metallicity dependence of the near-UV Ca II H & K emissions

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Theodosios Chatzistergos, Kok Leng Yeo, Natalie A. Krivova, Sami K. Solanki

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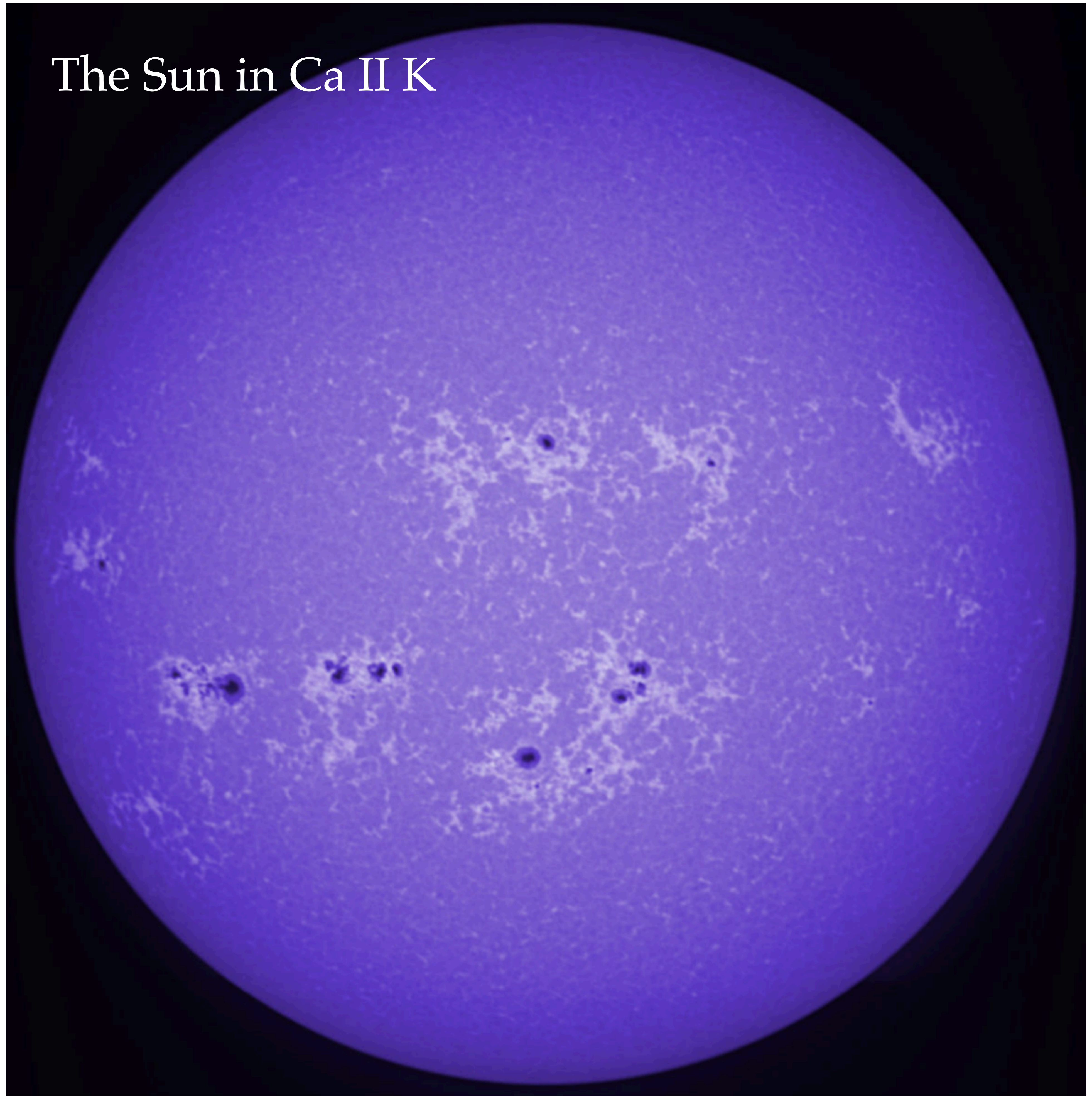
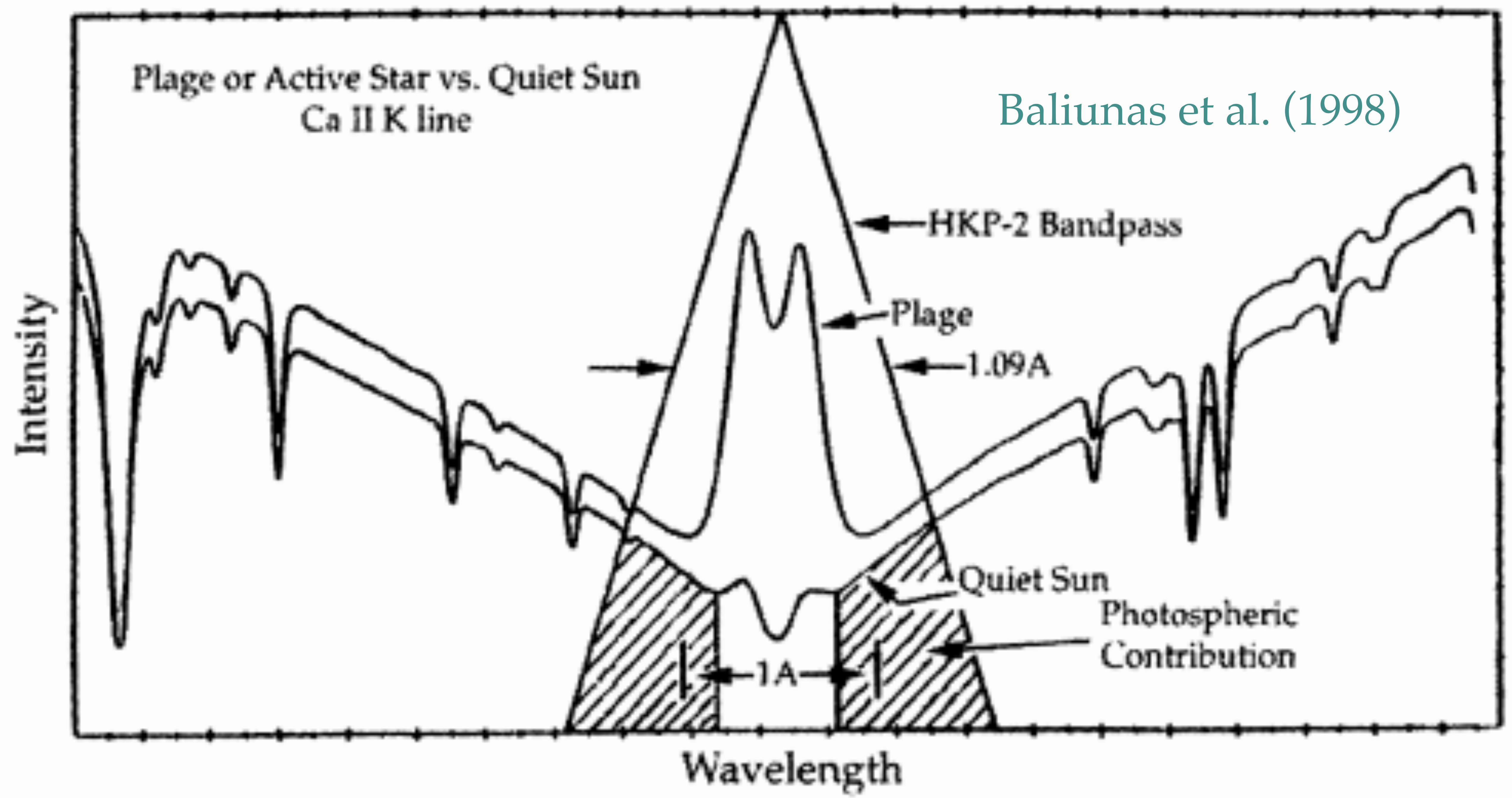
Magnetism in Ca II H & K

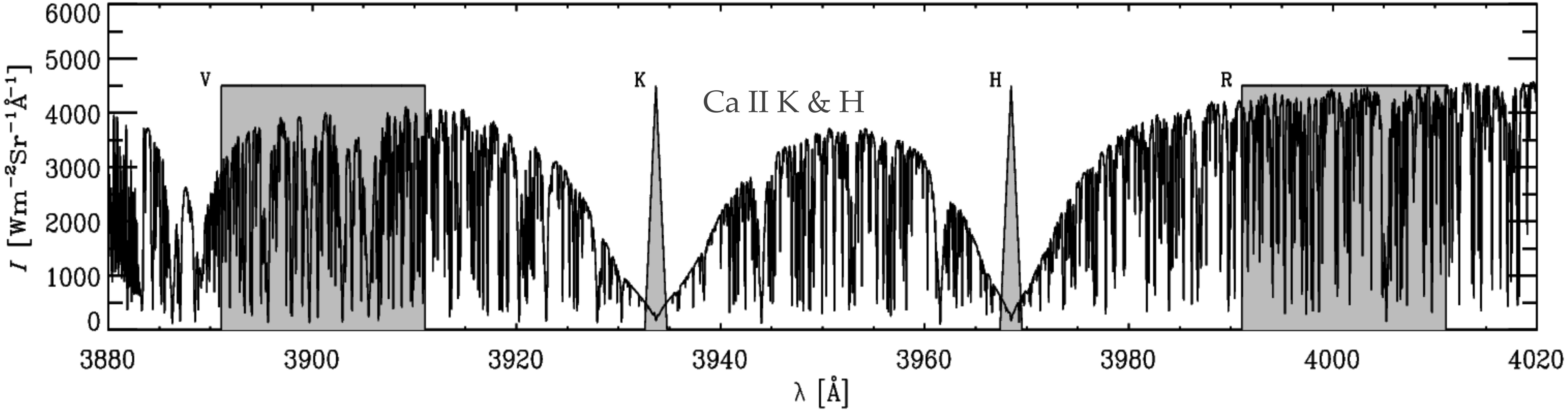


Source: An Introduction to Stellar Magnetic Activity by Gibor Basri

Non-thermal heating by the magnetic fields leads to an increased emission in the Ca II H & K line cores



S-index



$$S(t) = \alpha_c \frac{N_H(t) + N_K(t)}{N_R(t) + N_V(t)}$$

Vaughan et al. (1978)

S-index is one of the main proxies for stellar magnetic activity

Many aspects of the complex relation between stellar magnetism and *S*-index remain largely unexplored (e.g. dependence on the inclination, stellar metallicity)

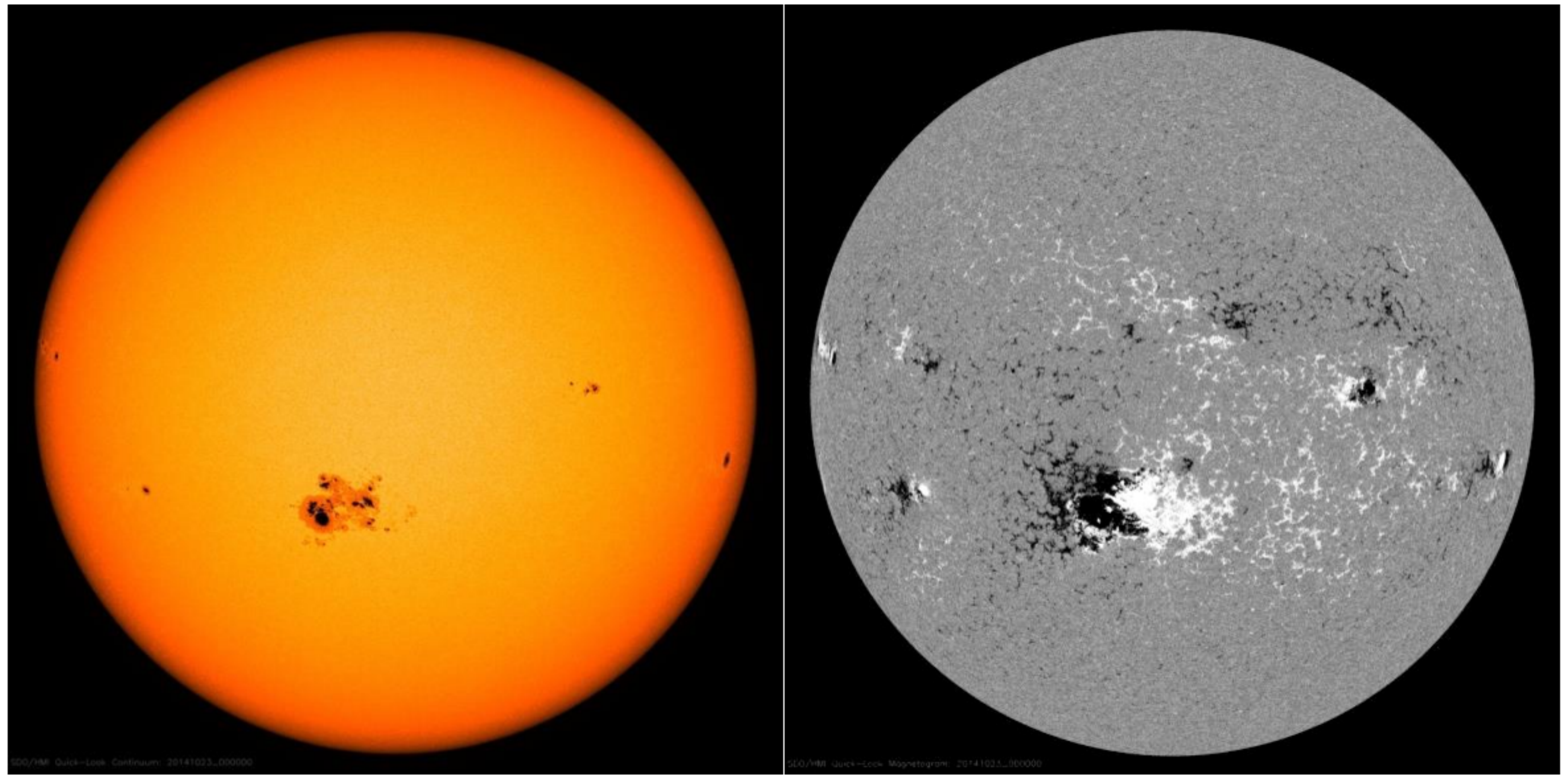
Outline

Development of the model to compute *S*-index and its validation using solar *S*-index data

Exploration of the effect of inclination and metallicity on the *S*-index for solar-stellar comparison studies

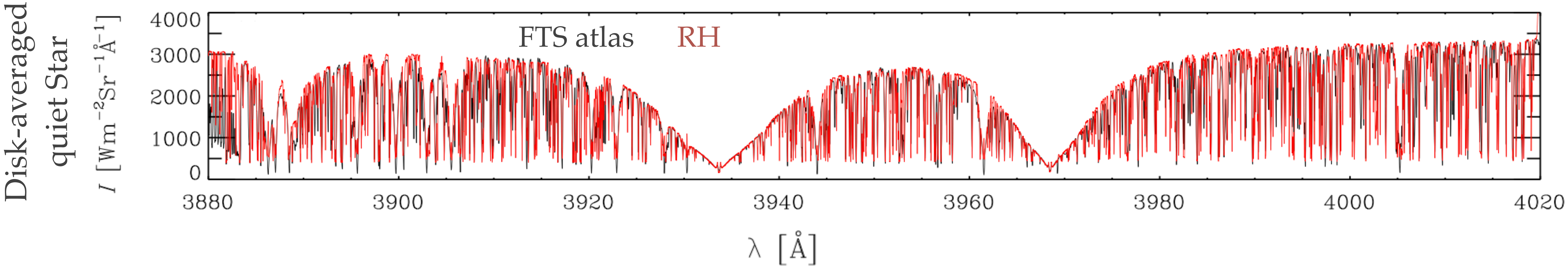
Our approach*

Disk coverage of magnetic features



computed from the observed intensity images and magnetograms (Yeo et al. 2014)

Non-LTE spectra of the quiet Star and faculae



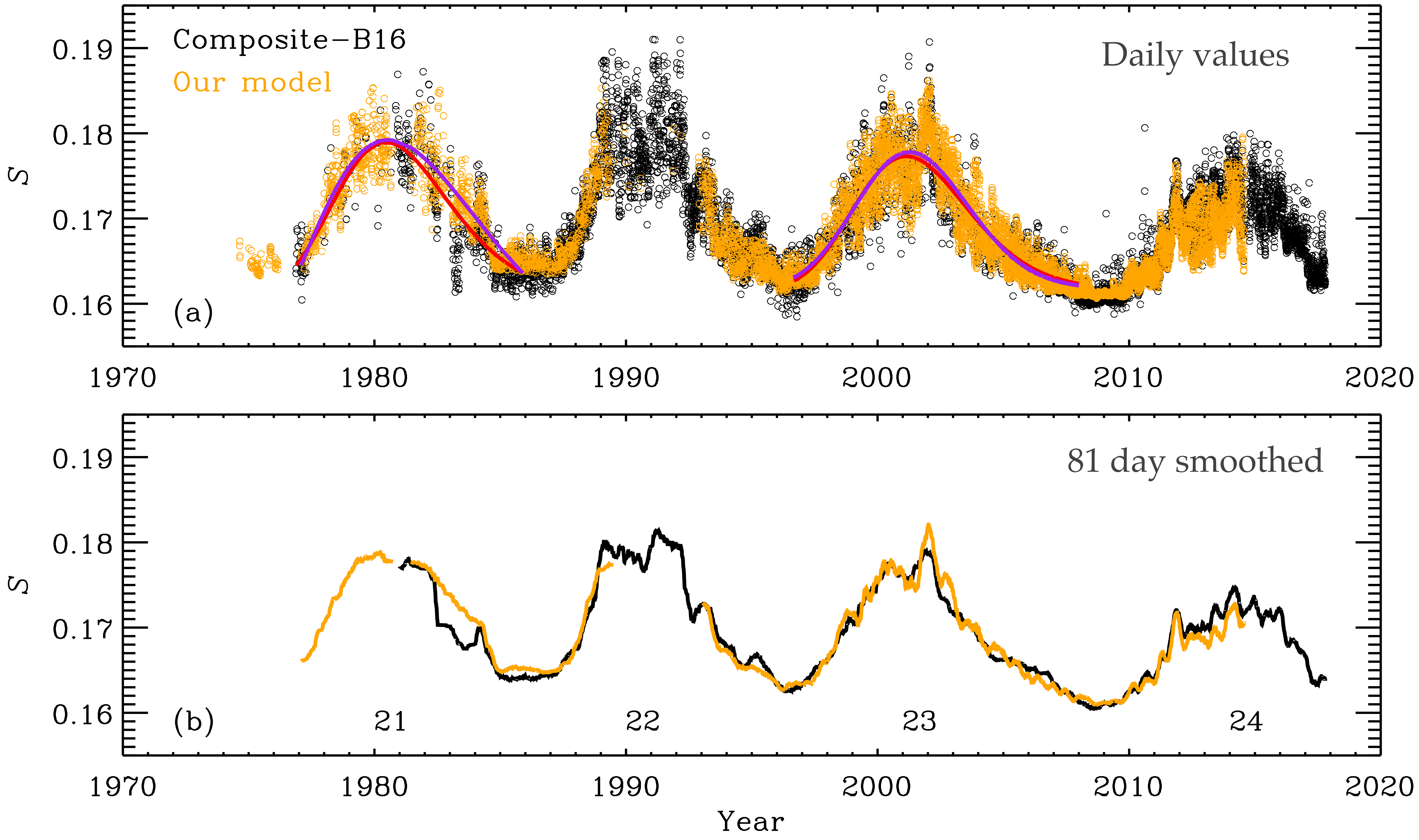
Radiative transfer code **RH** (Uitenbroek 2001)

1D semi-empirical model atmospheres from Fontenla et al. (1999) + MPS-ATLAS

Neglect the contribution from spots

*Based on Spectral And Total Irradiance REconstruction model (Fligge et al. 2000; Krivova et al. 2003)

Solar *S*-index time series



Composite B-16 is derived from Bertello et al. (2016)

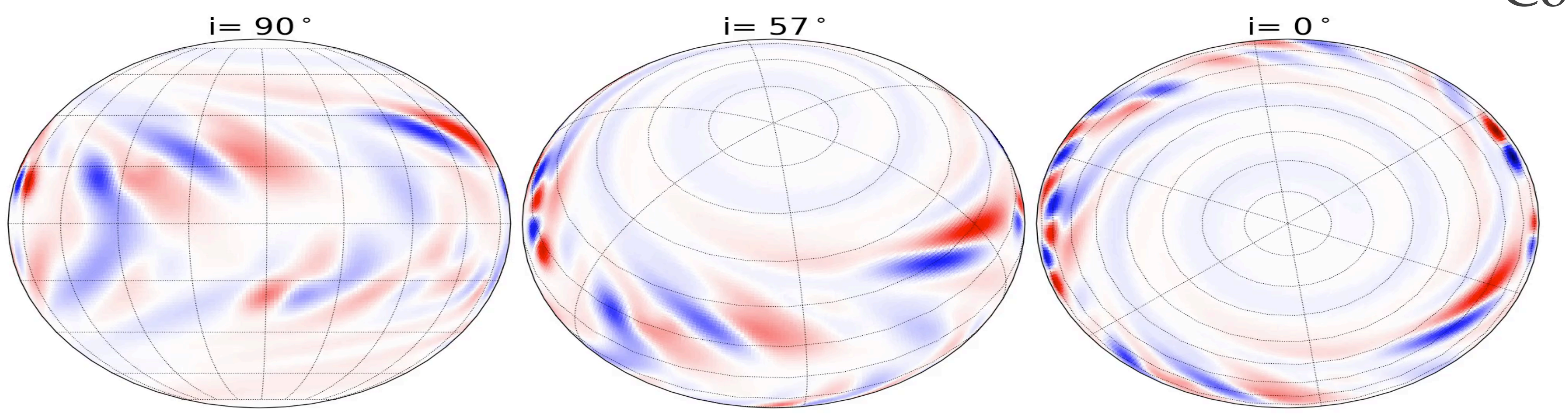
Sowmya et al. (2021)

Effect of stellar inclination ‘i’ on the S-index

Our approach*

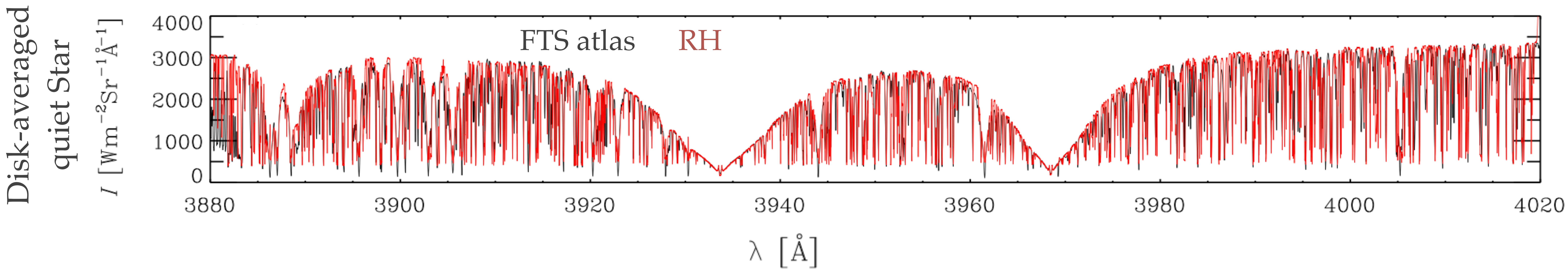
Disk coverage of magnetic features

Courtesy of Nina Nèmec



obtained using the magnetograms synthesised from surface flux transport model (Cameron et al. 2010; Nèmec et al. 2020)

Non-LTE spectra of the quiet Star and faculae



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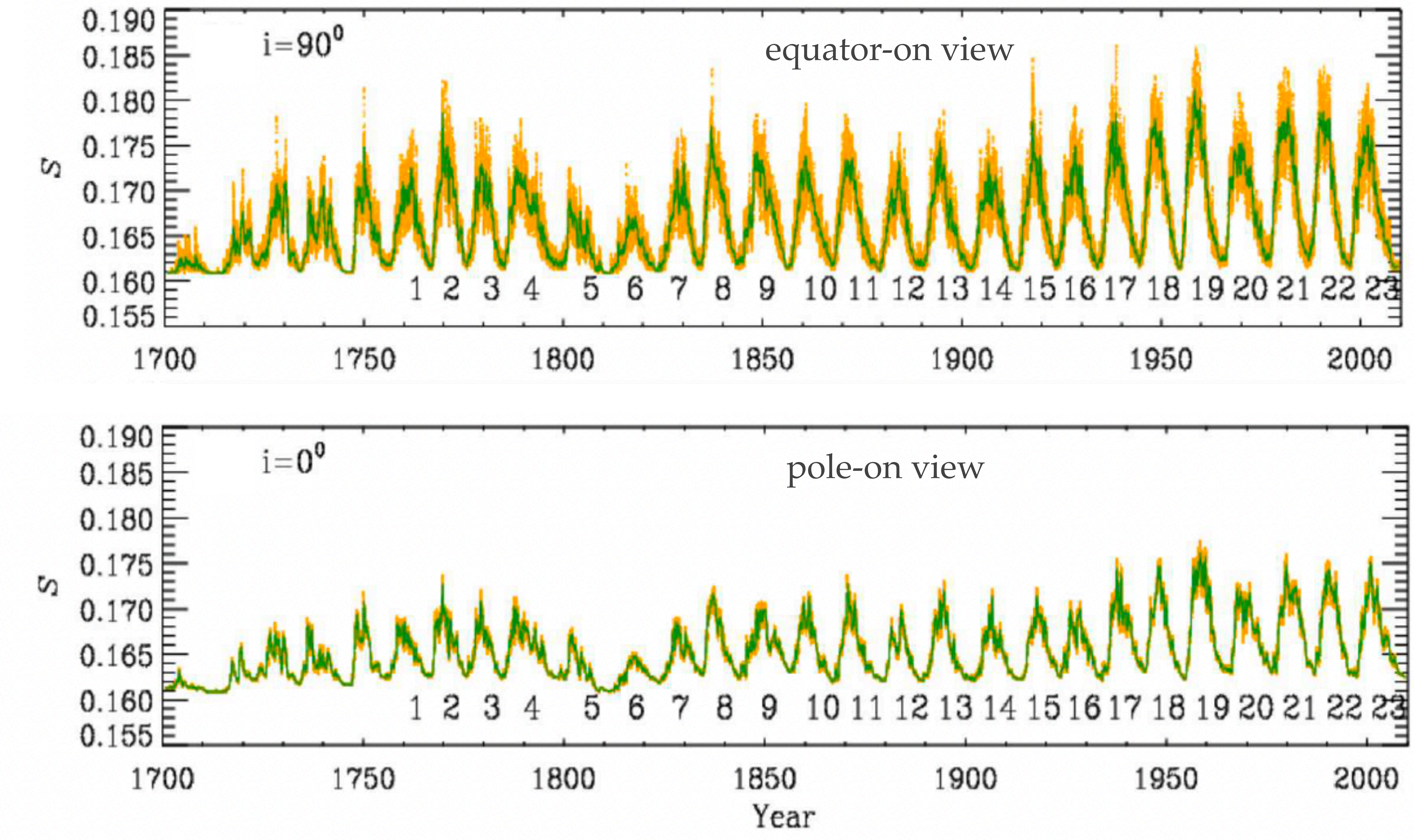
Effect of inclination

Amplitude of S-index variations decreases with decreasing inclination both on the activity cycle and rotational timescales

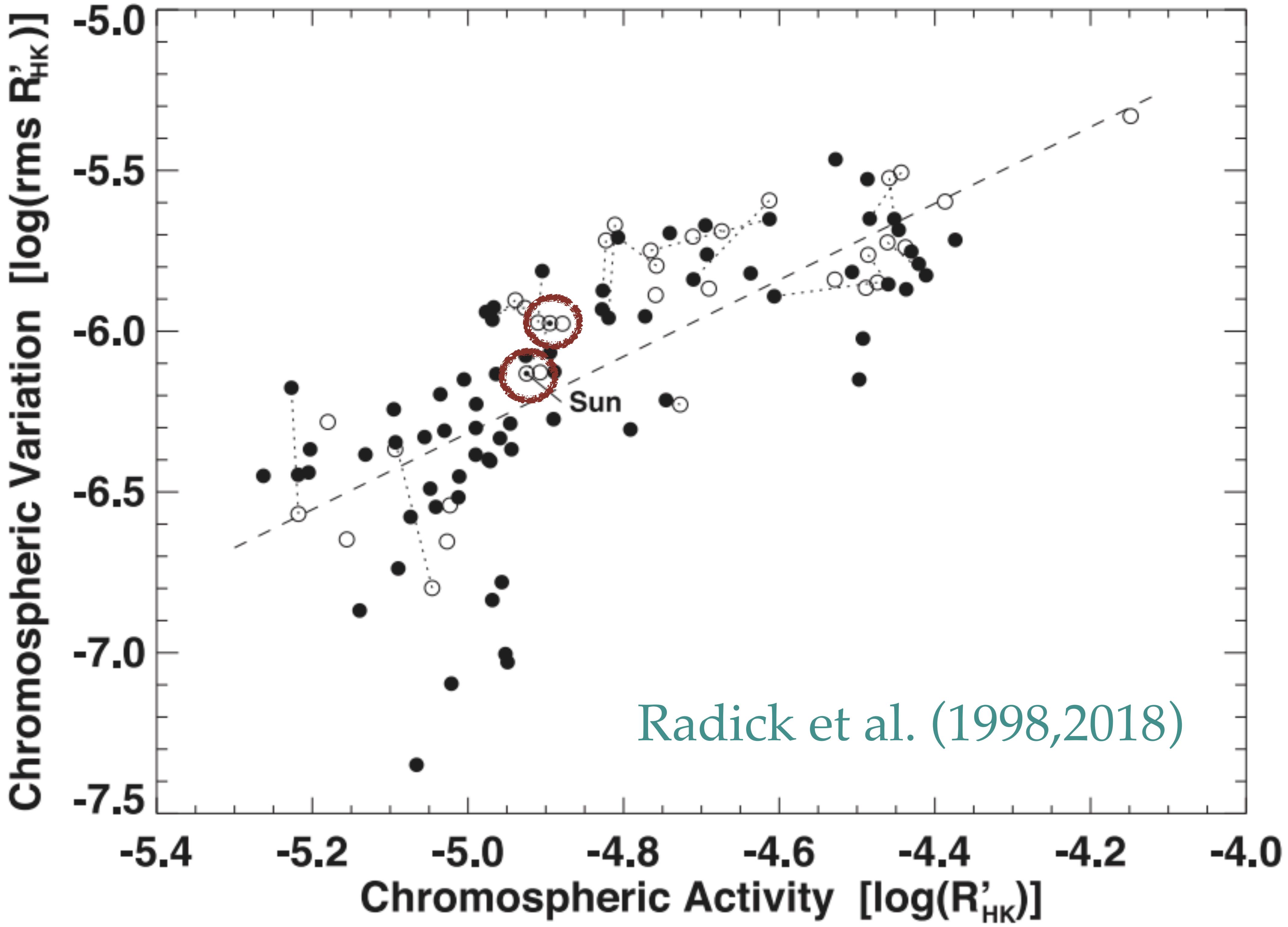


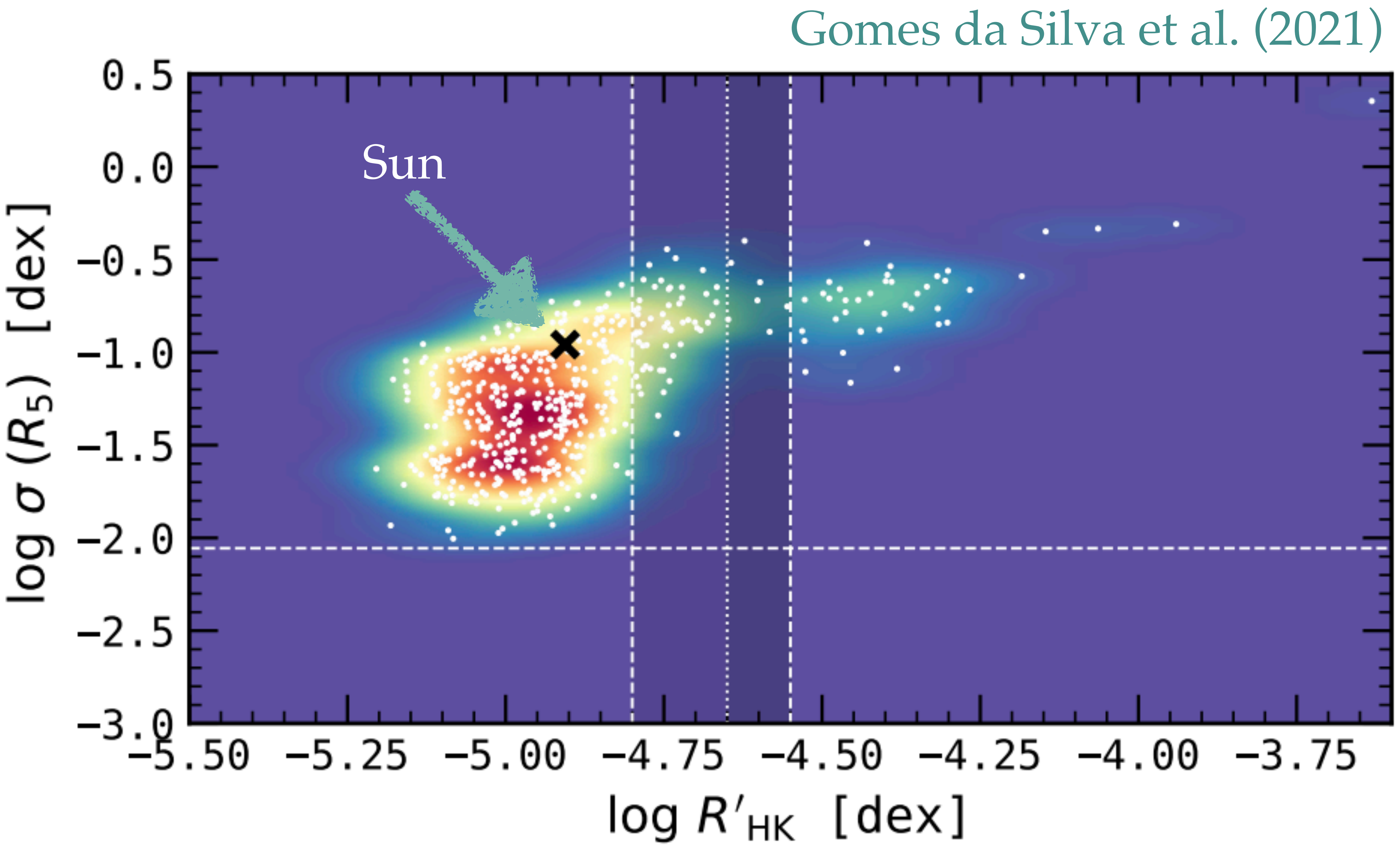
Daily values

81 day smoothed

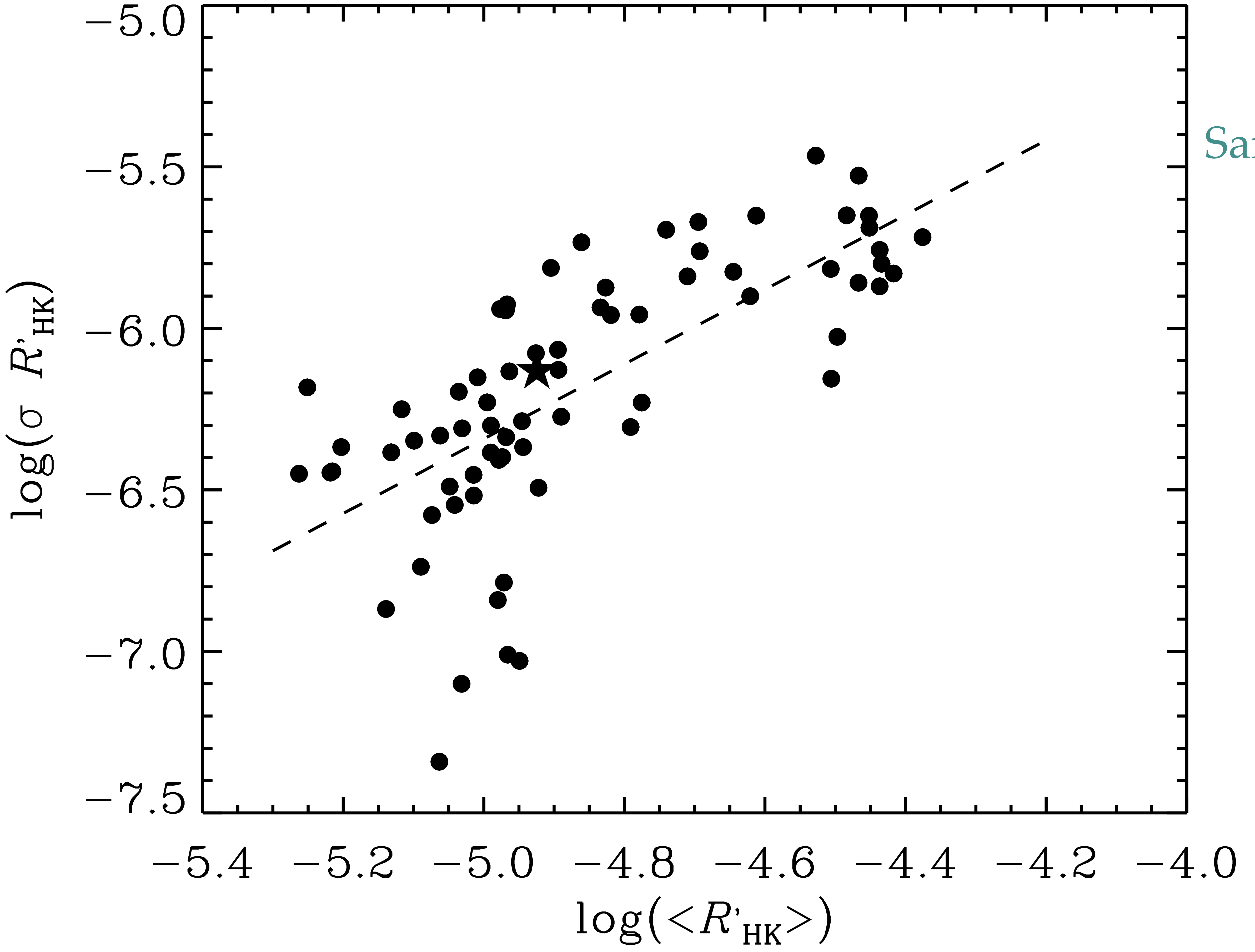
Sowmya et al. (2021)

Is the Ca II variability of the Sun too strong?





Is the Ca II variability of the Sun too strong?



Chromospheric variation

Mean activity

Sample from Radick et al. (2018)

Sowmya et al. (2021)

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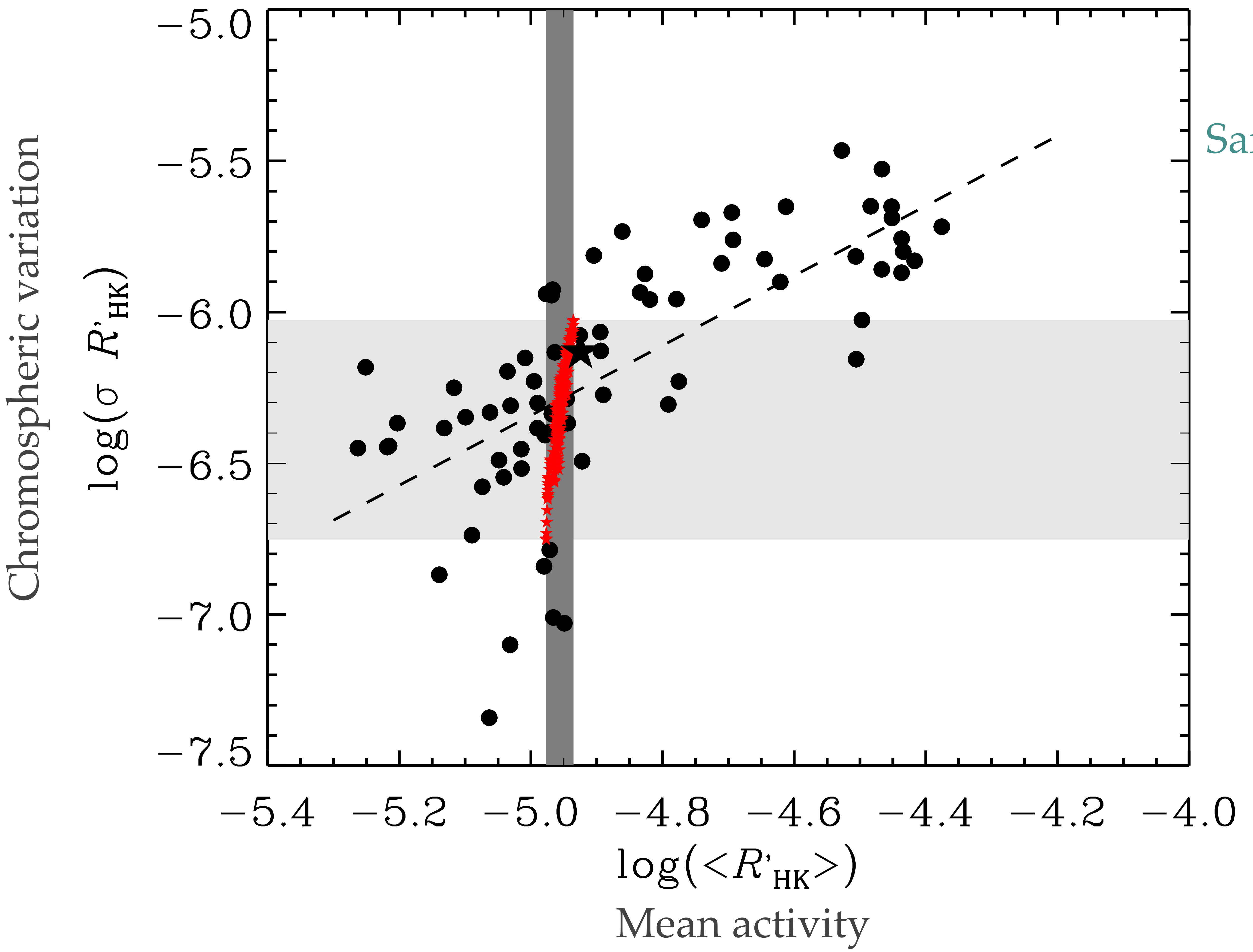


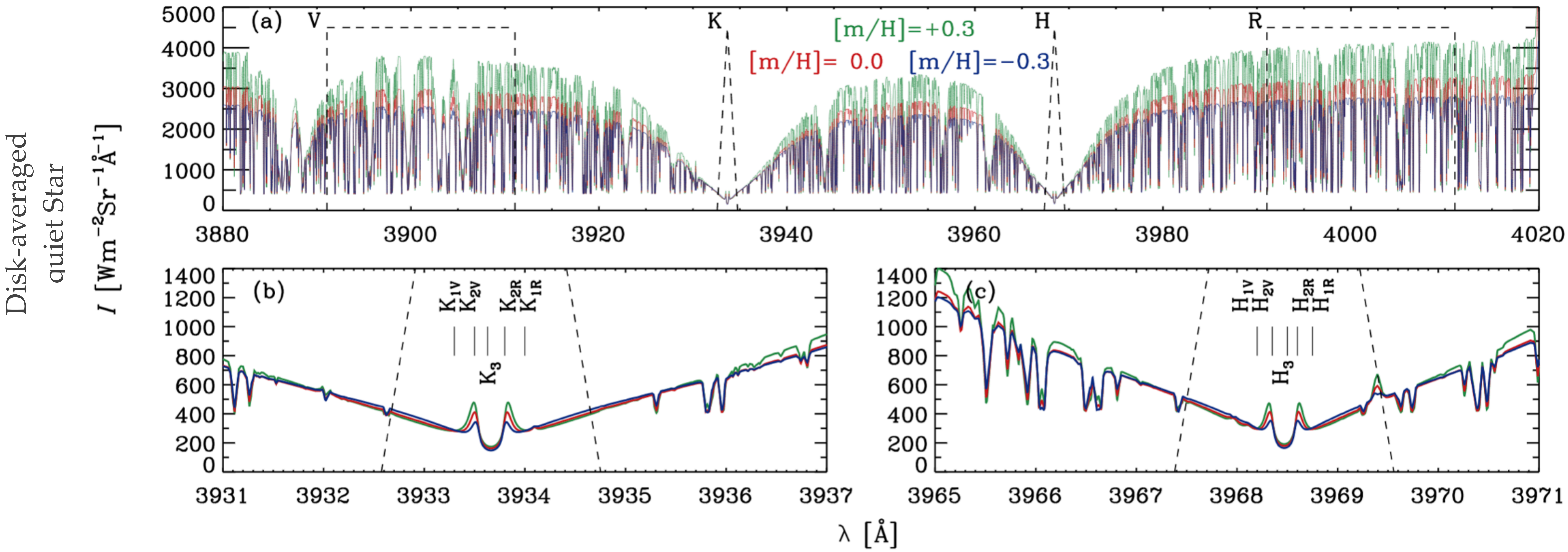
Sample from Radick et al. (2018)

Solar Ca II H & K emission variation is absolutely normal in comparison to stars with near-solar magnetic activity

Sowmya et al. (2021)

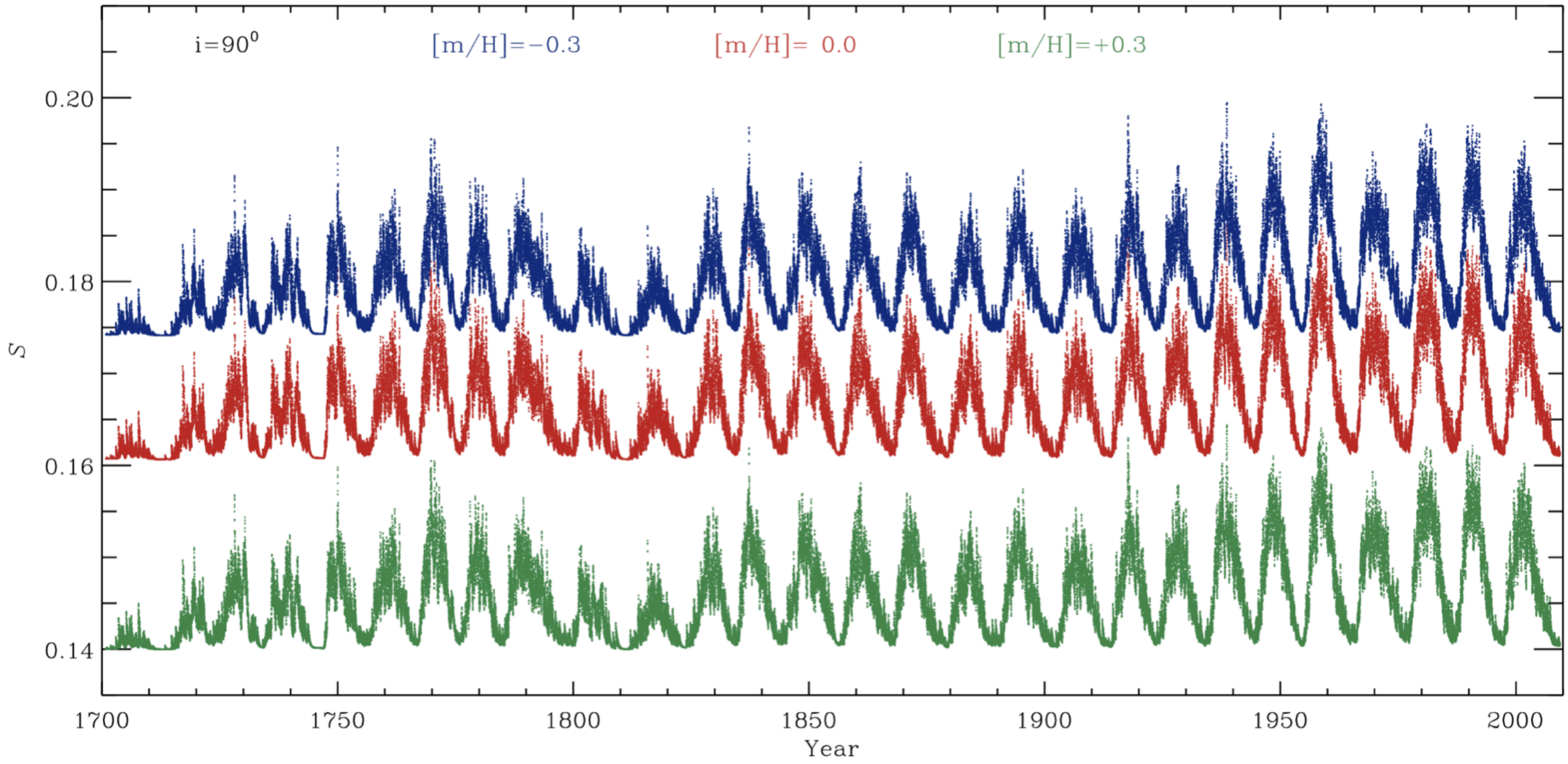
Effect of stellar metallicity ‘[m/H]’ on the *S*-index

Spectra for different [m/H]



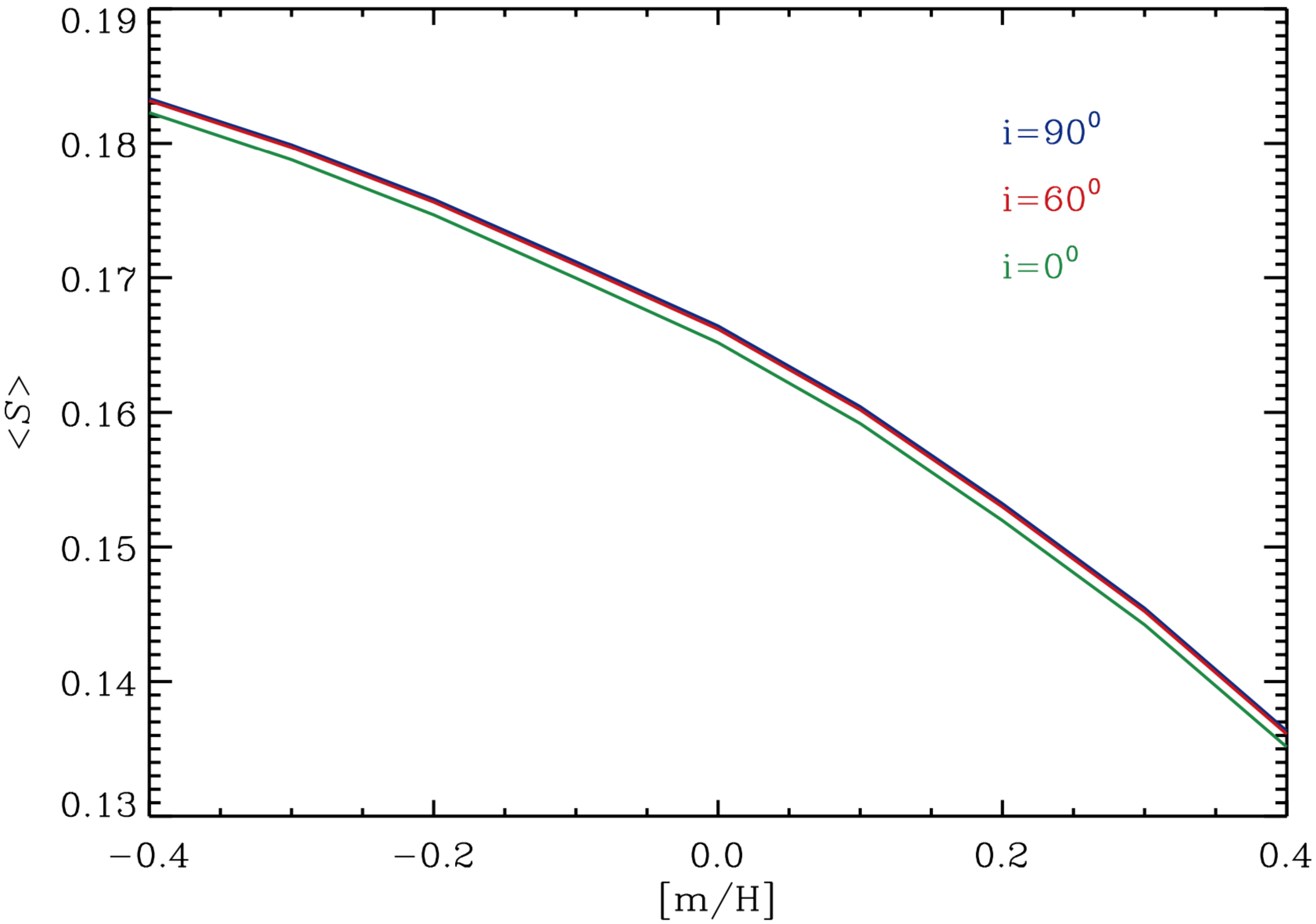
Sowmya et al., in prep.

S-index time series



Sowmya et al., in prep.

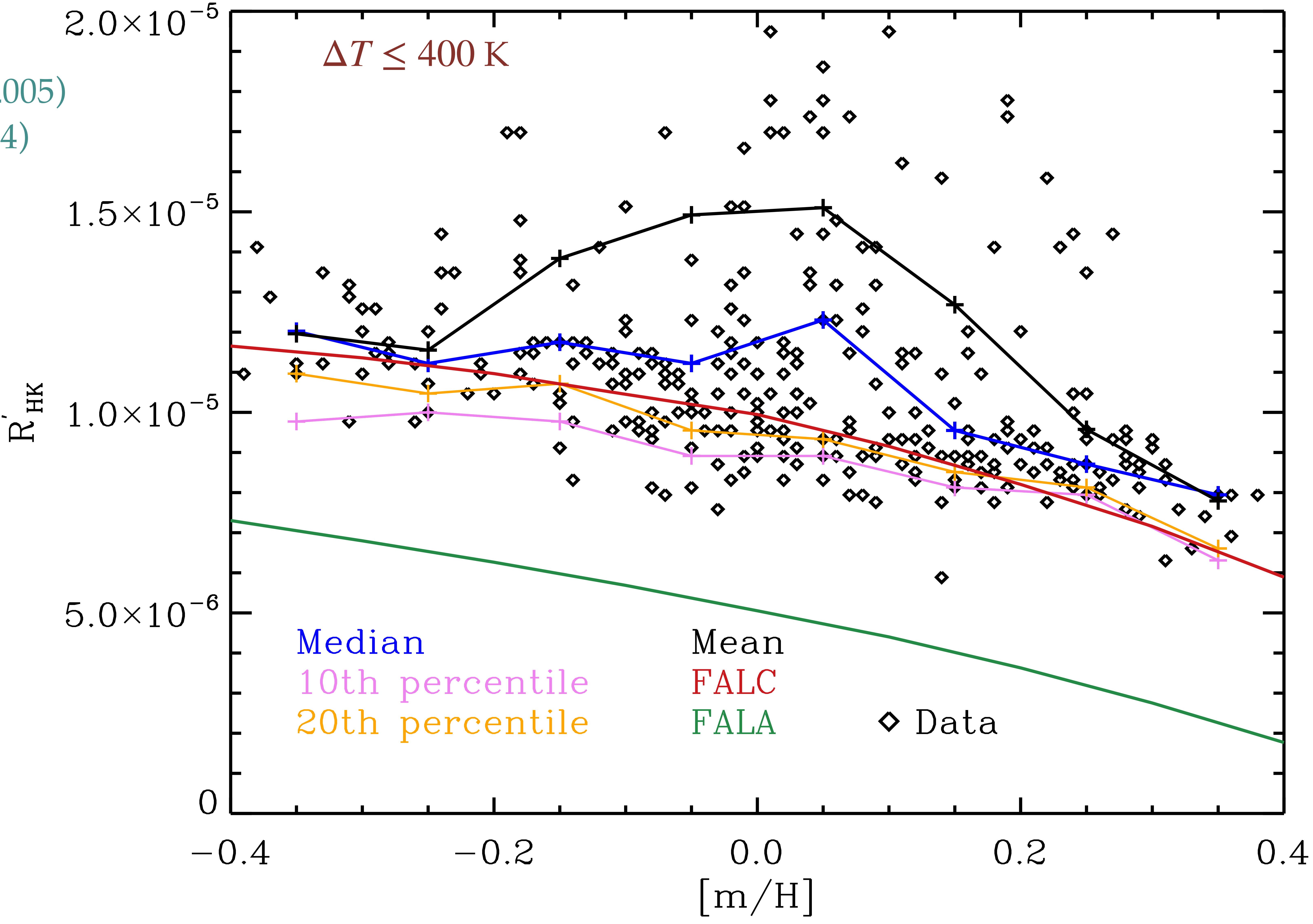
Mean *S* vs [m/H] for different inclinations



Sowmya et al., in prep.

Comparison to observations

Sample from
Valenti & Fischer (2005)
Wright et al. (2004)



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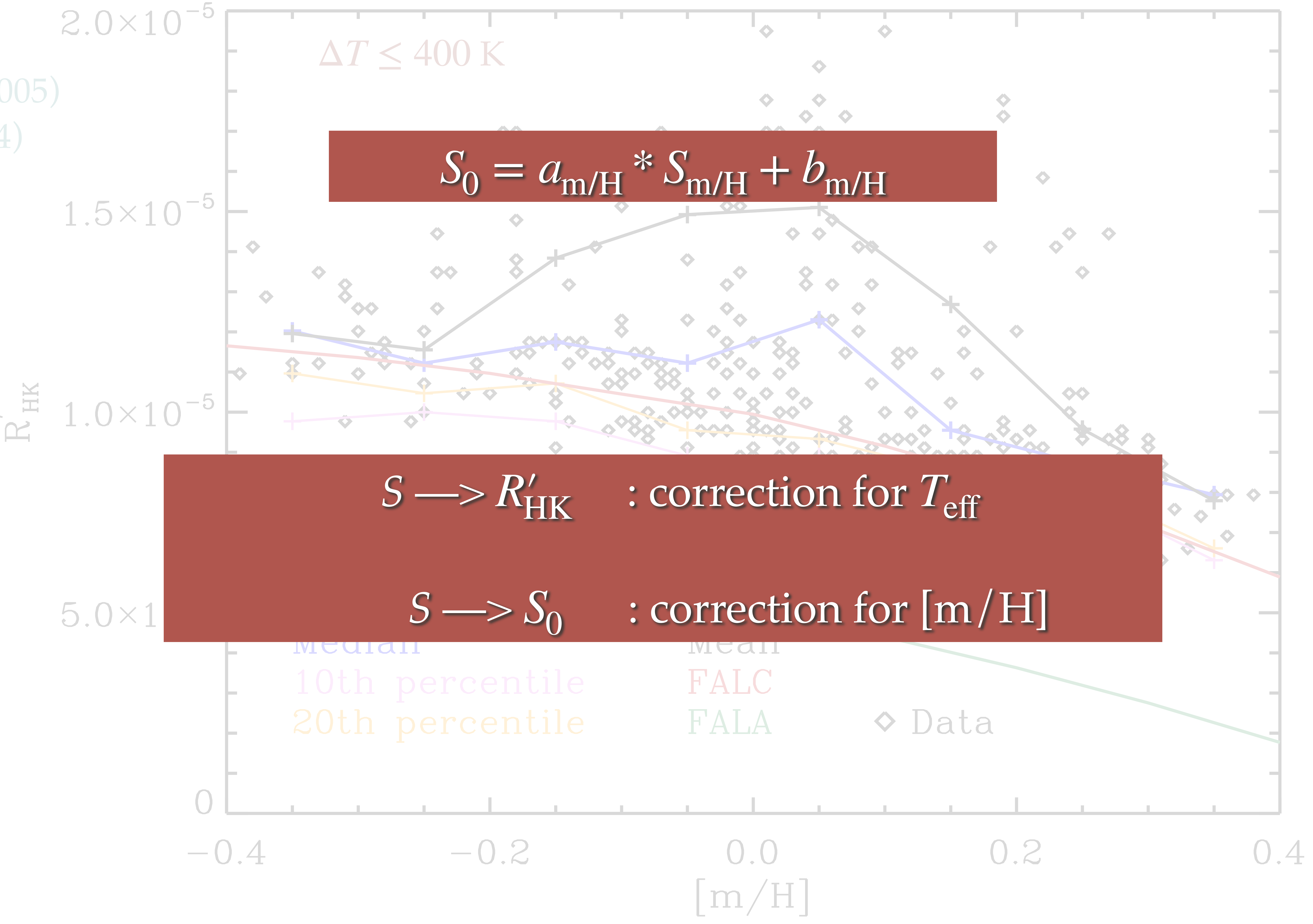

$S_0 = a_{m/H} * S_{m/H} + b_{m/H}$

$S \longrightarrow R'_{HK}$: correction for T_{eff}

$S \longrightarrow S_0$: correction for [m/H]

Sowmya et al., in prep.

Summary

- *S*-index not only depends on the stellar intrinsic properties such as metallicity but also on the stellar inclination
- With decreasing inclination, the amplitude of *S*-index variations decreases
- We find that the Sun has a completely normal level of *S*-index variability
- *S*-index decreases with increasing metallicity

Thank you for your attention!

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Summary

- *S*-index not only depends on the stellar intrinsic properties such as metallicity, surface gravity etc. but also on the stellar inclination
- We developed a model capable of calculating *S*-index variations and used it to study the effect of inclination and metallicity on the *S*-index
- With decreasing inclination, the amplitude of *S*-index variations decreases
- We find that the Sun has a completely normal level of *S*-index variability
- *S*-index decreases with increasing metallicity

Thank you for your attention!

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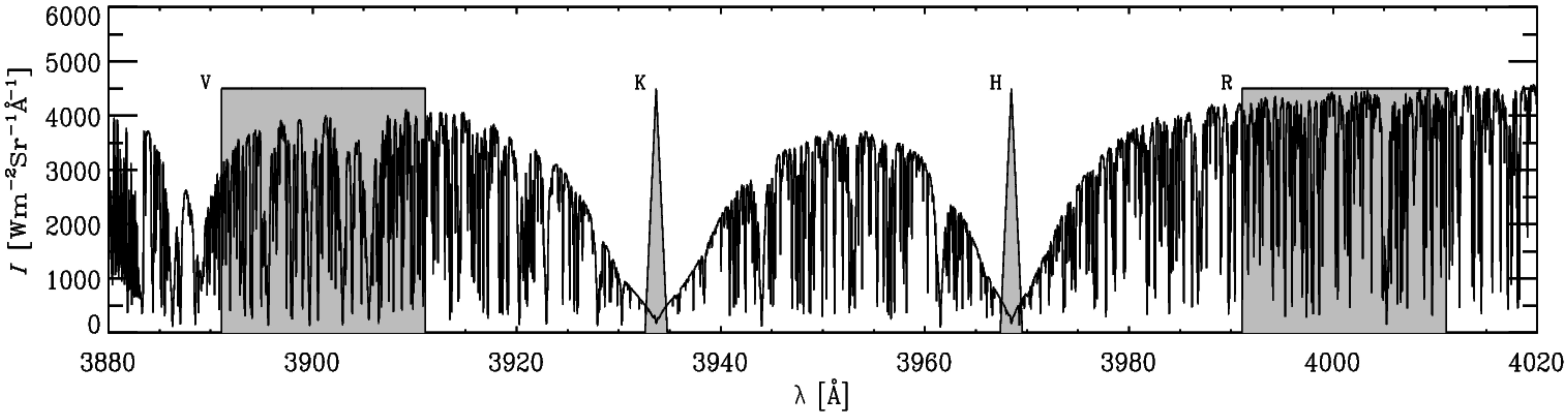
MWO S - index



- Original definition of S - index by Vaughan et al. (1978)

$$S(t) = 8 \quad \alpha_c \quad \frac{N_H(t) + N_K(t)}{N_R(t) + N_V(t)}$$

- t - time
- α_c - calibration constant (= 2.4)
- N_H, N_K, N_R, N_V - flux in the passbands H, K, R, V
- Factor of 8 is to account for the different duty cycles

- K and H - triangular passbands with FWHM 1.09 Å centred at Ca II K (3933.66 Å) and H (3968.47 Å)
- R and V - 20 Å wide rectangular reference passbands
- V (3891.06 Å - 3911.06 Å)
- R (3991.06 Å - 4011.06 Å)

SATIRE-S filling factors

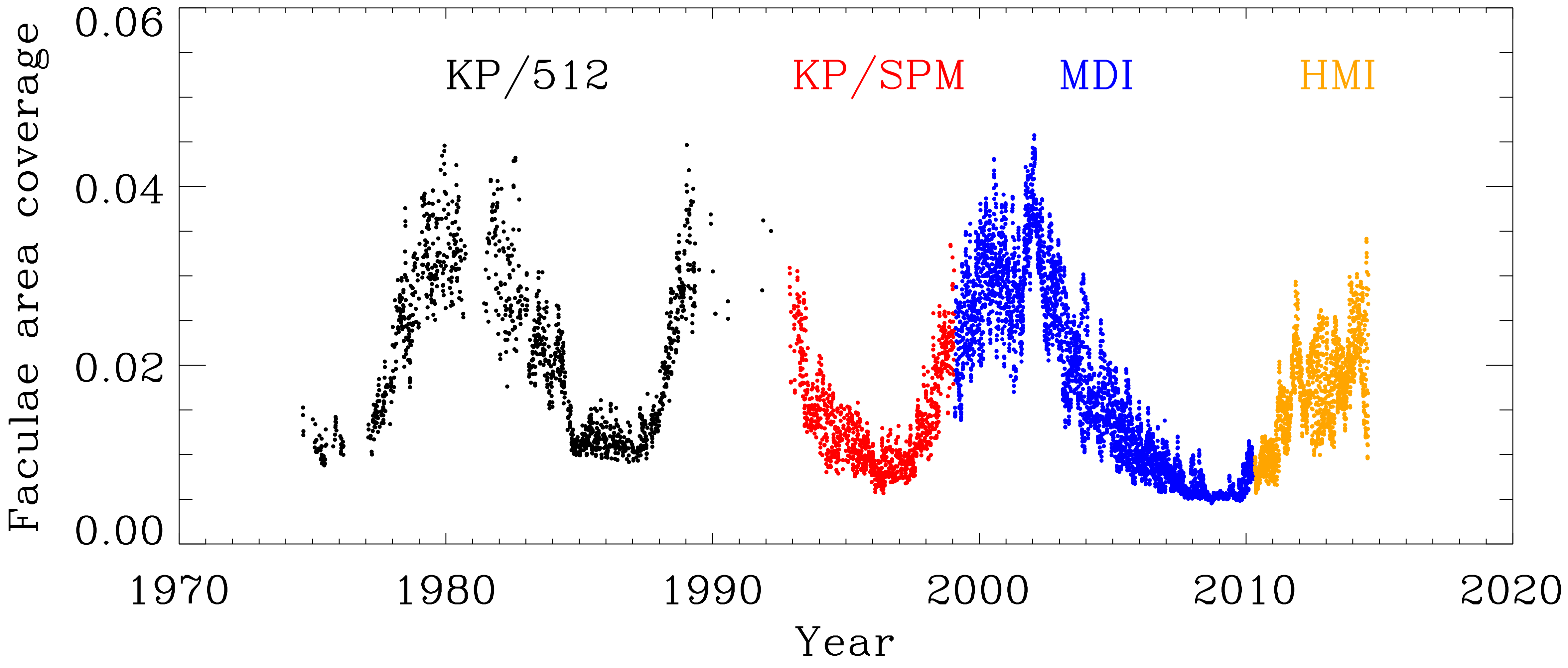
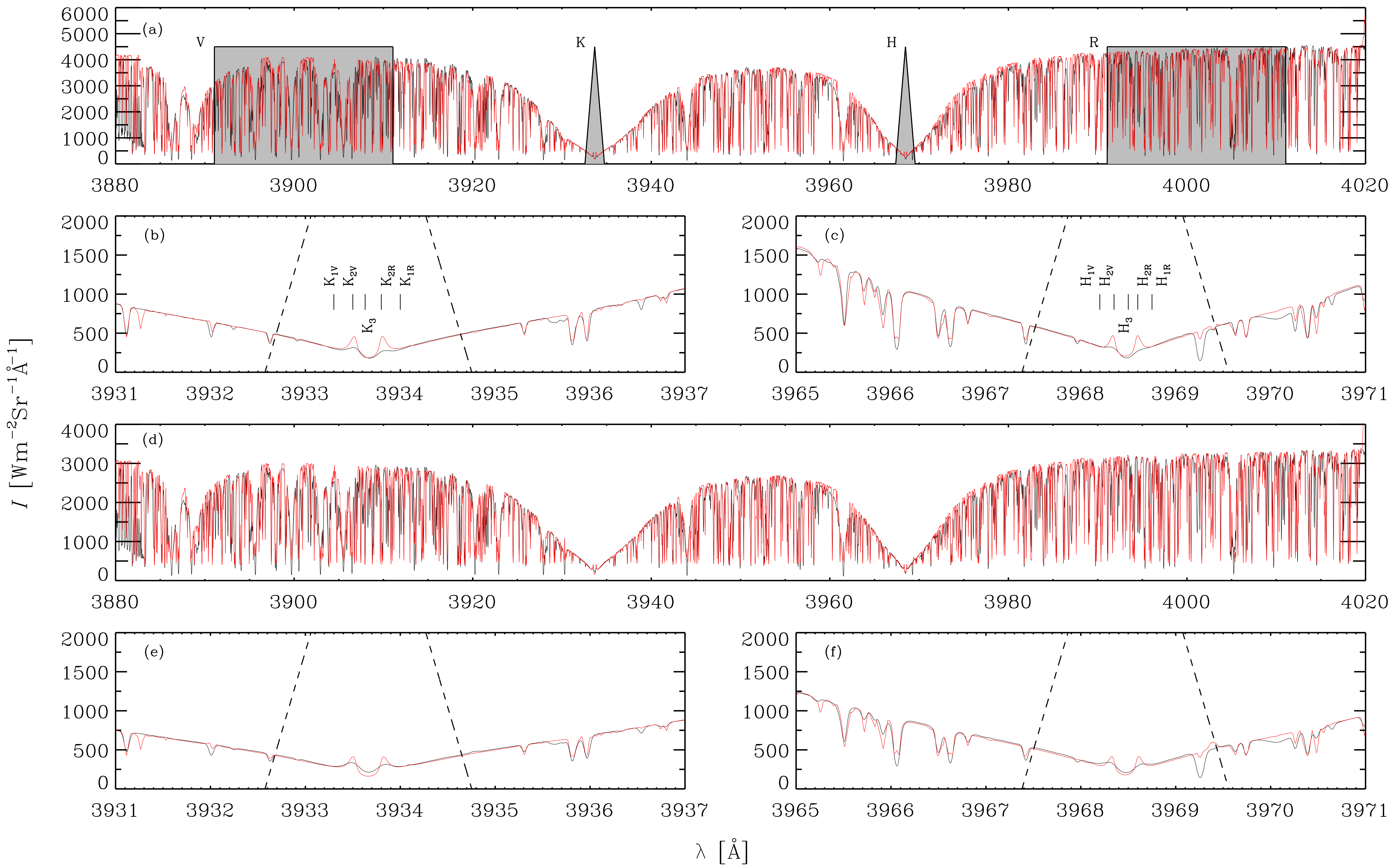


Fig. 2. Area coverage of the facular component for solar cycles 21–24. The colors correspond to observations from different instruments as indicated.

Quiet Sun spectra



Black - observed spectra*

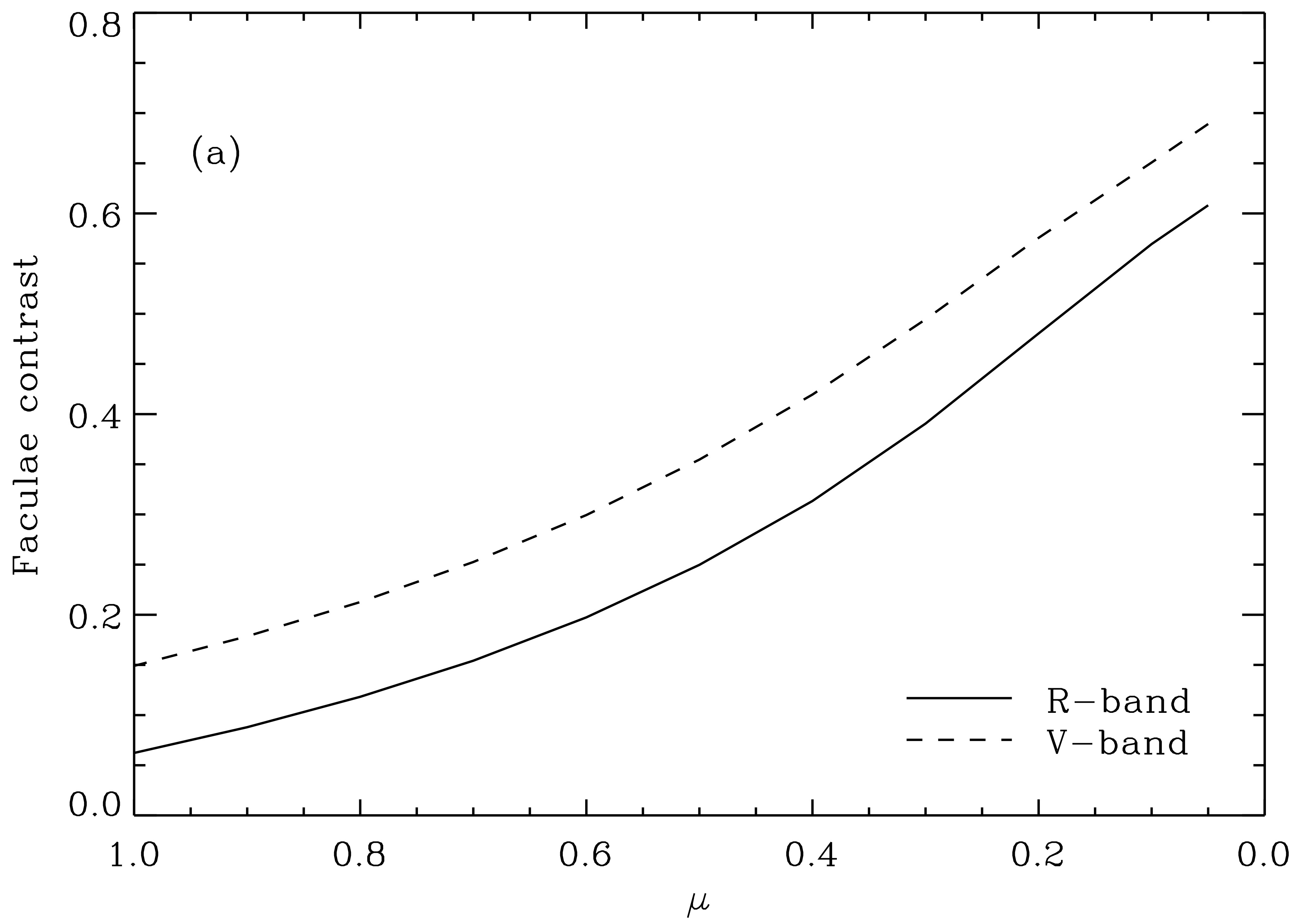
Red - RH spectra

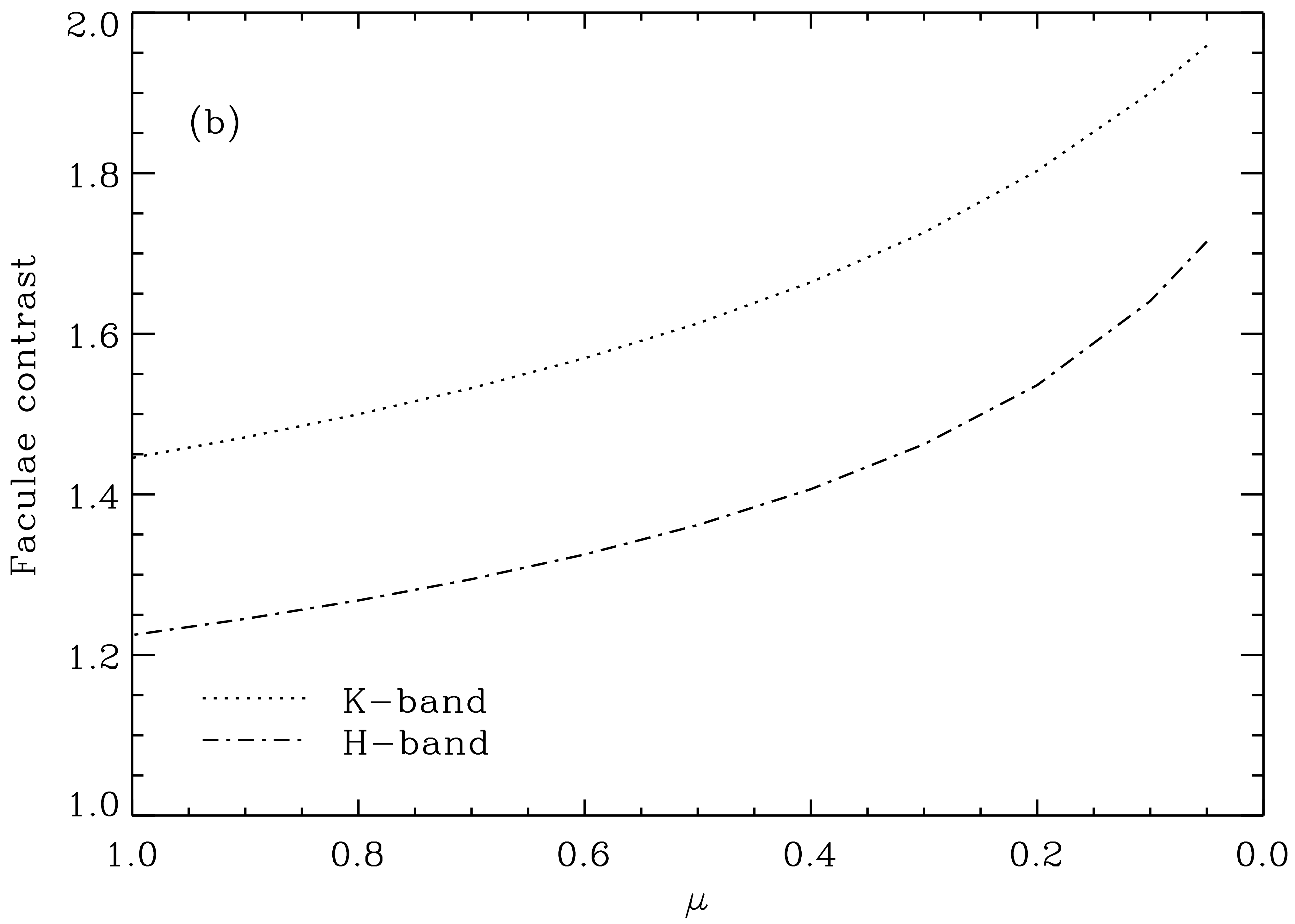
(a), (b), (c) - disk center

(d), (e), (f) - disk integrated

*Hamburg atlas (Doerr et al. 2016)

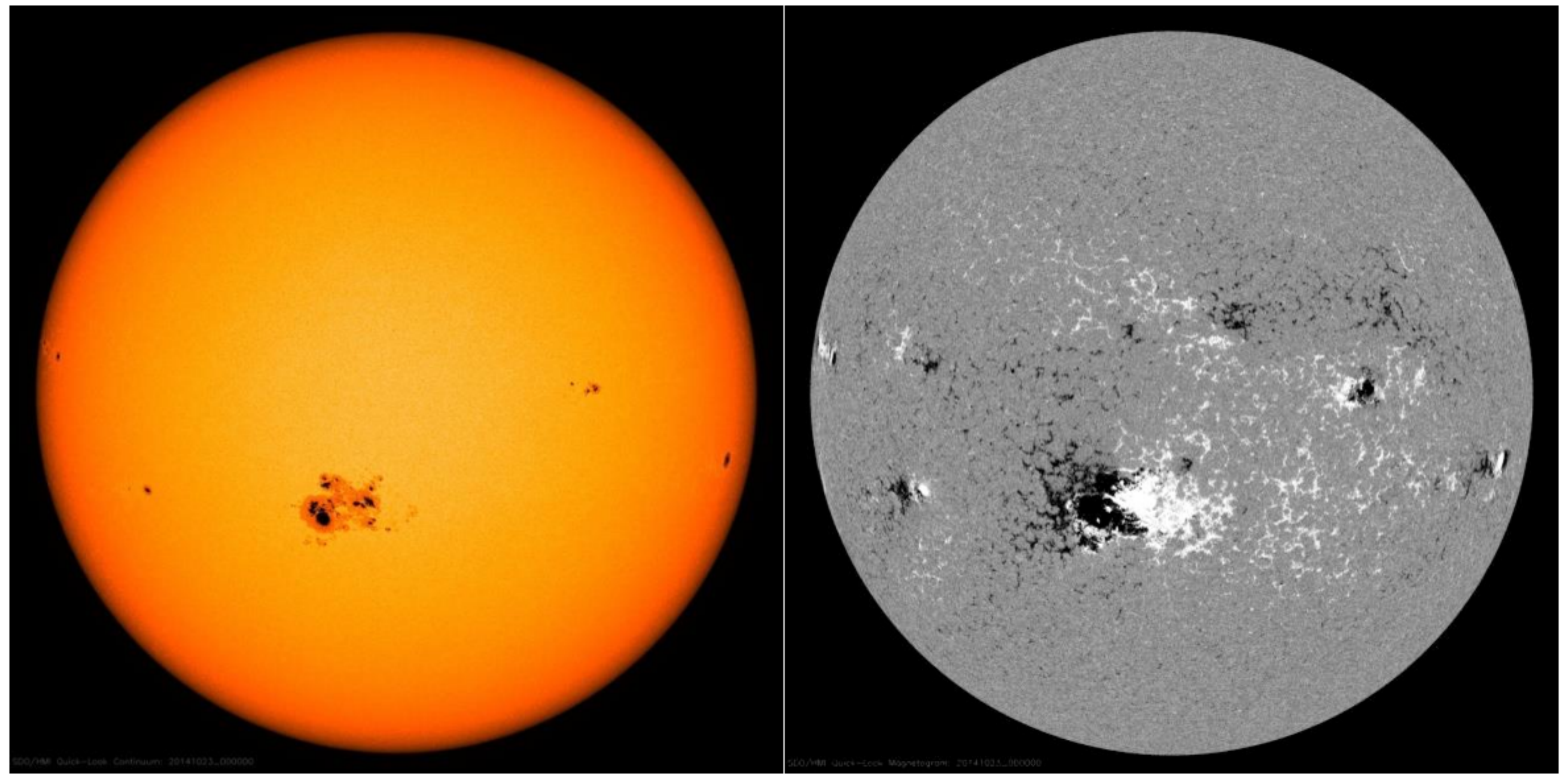
Facular contrast





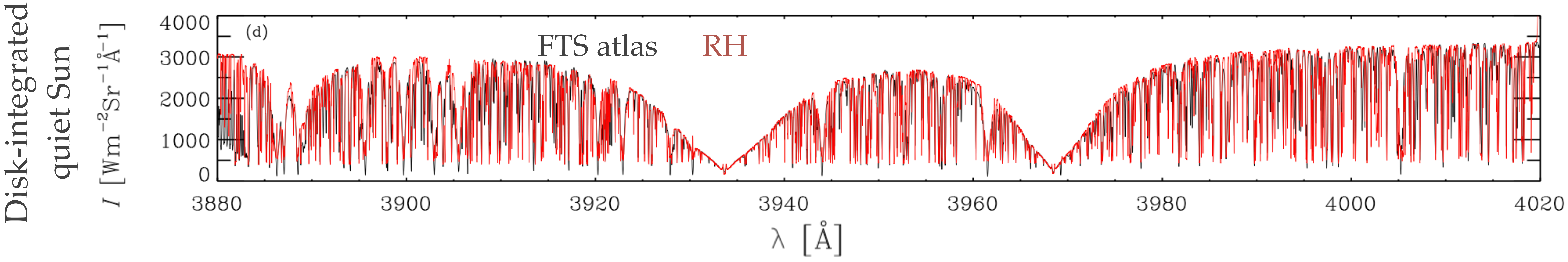
Our model (based on SATIRE*)

Disk coverage of magnetic features



computed from the observed intensity images and magnetograms (Yeo et al. 2014)

Non-LTE spectra of the quiet Sun and magnetic features



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Neglect the contribution from spots

*Spectral And Total Irradiance REconstruction (Fligge et al. 2000; Krivova et al. 2003)

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l concentric rings

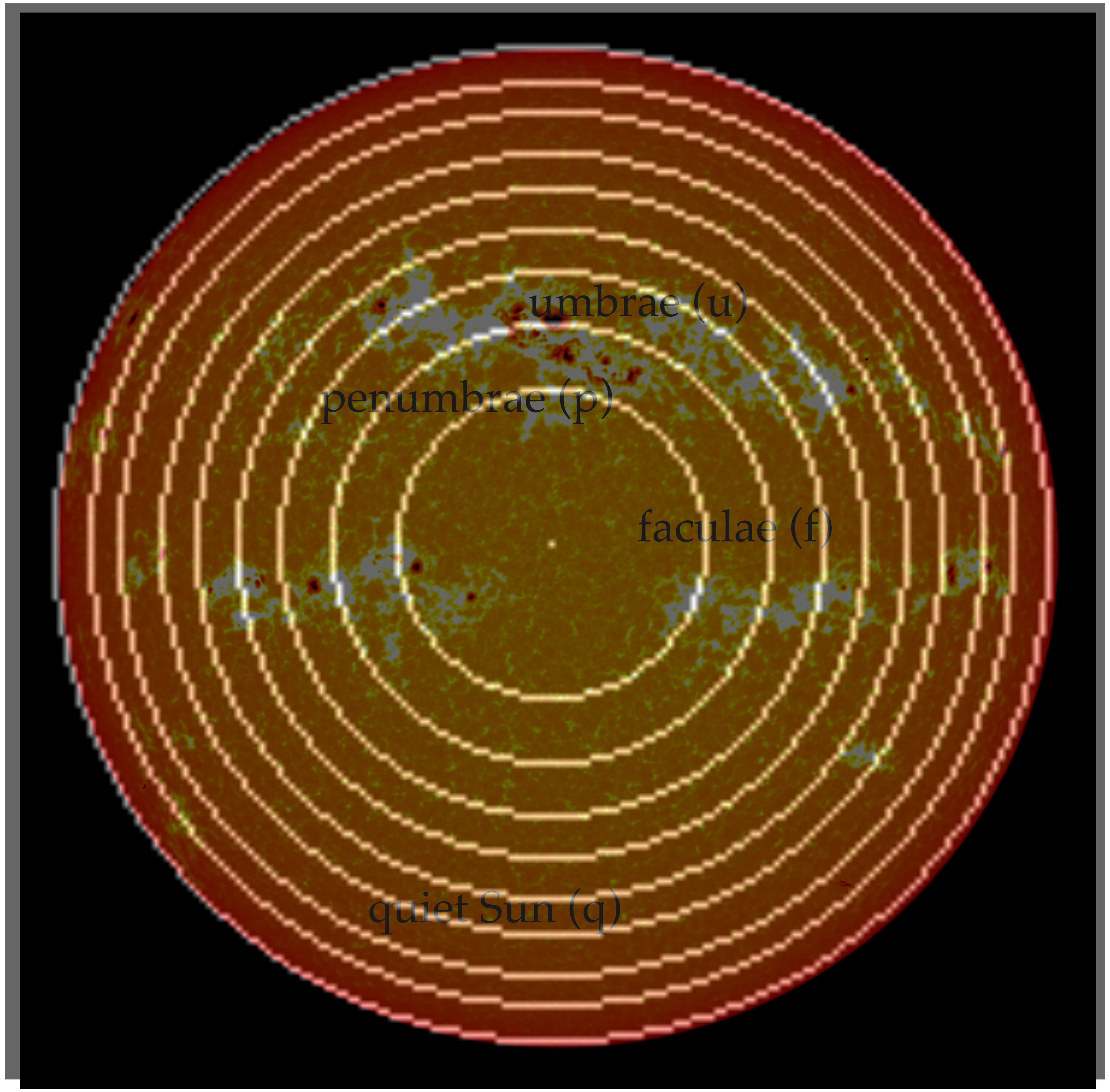


image credit: svs.gsfc.nasa.gov

$$N_m(t) = \int_m F(t, \lambda_m)\ T(\lambda_m)\ \ d\lambda_m$$

Transmission profile of the passband m

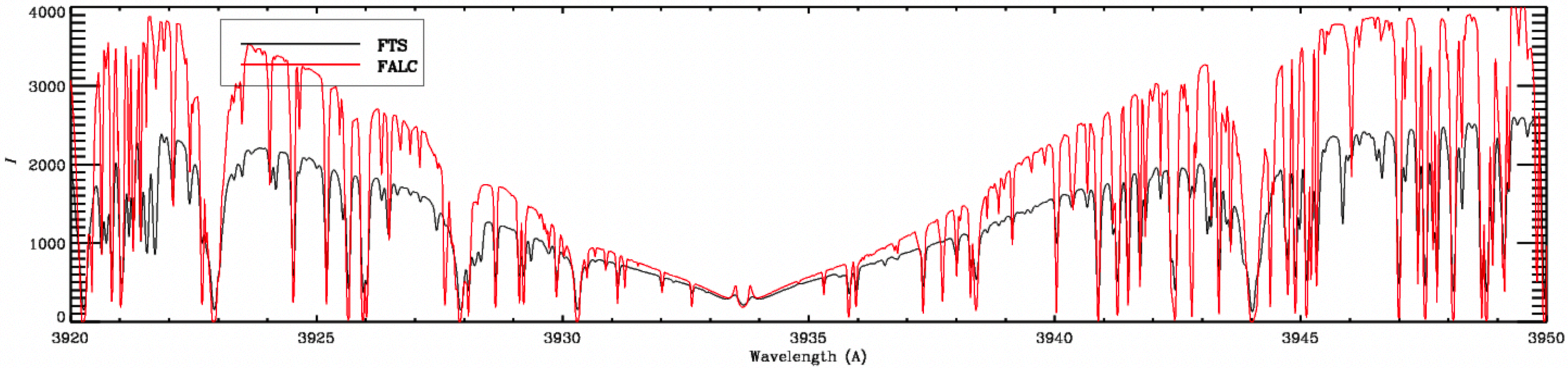
$$F(t, \lambda) = \sum_l \left\{ I_q(\lambda, \mu_l) + \sum_j \alpha_{jl}(t)\ [I_j(\lambda, \mu_l) - I_q(\lambda, \mu_l)] \right\}\ \Delta\Omega_l$$

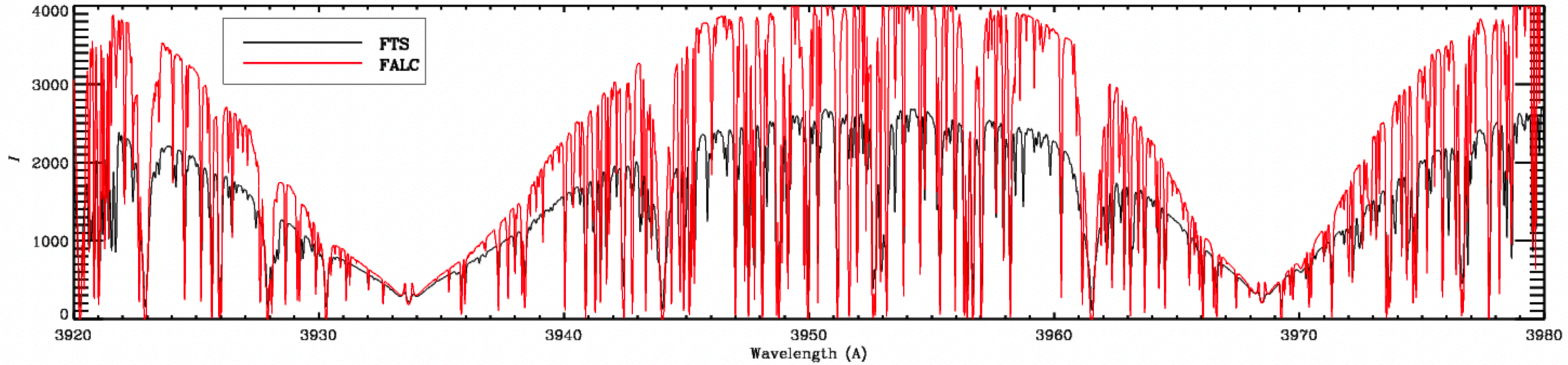
$j = \{f, u, p\}$

disk coverages of magnetic features

*Spectral And Total Irradiance REconstruction (Fligge et al. 2000; Krivova et al. 2003)

Opacity fudging

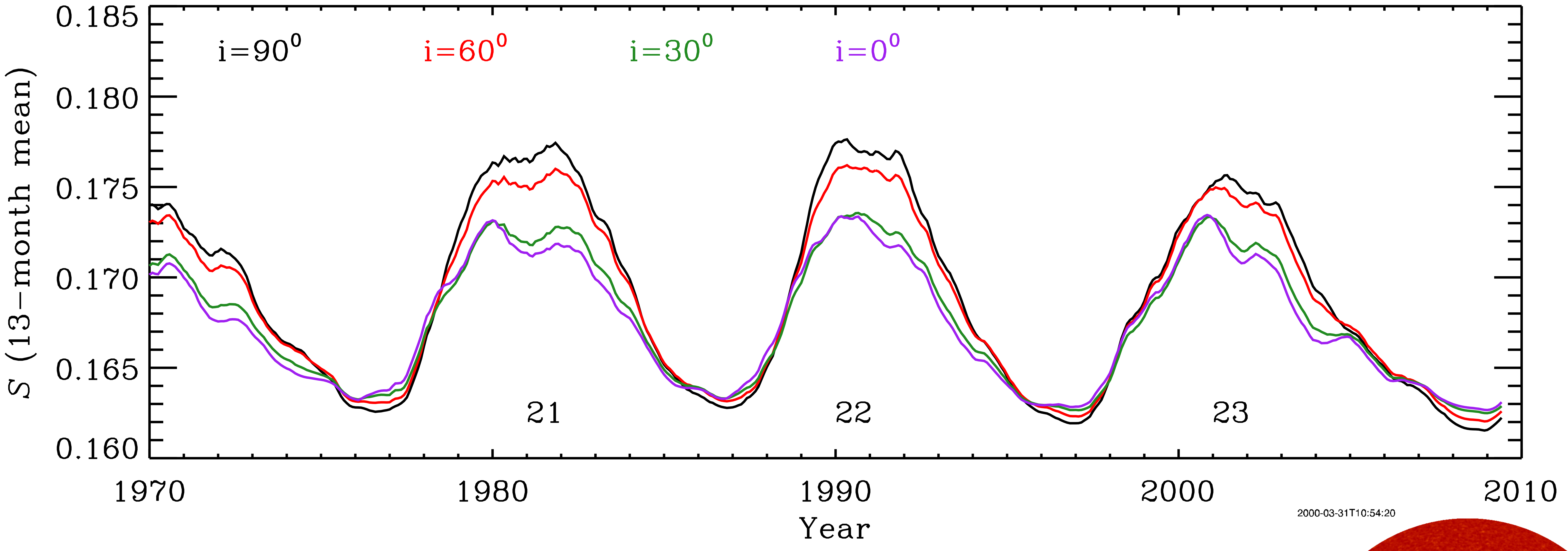


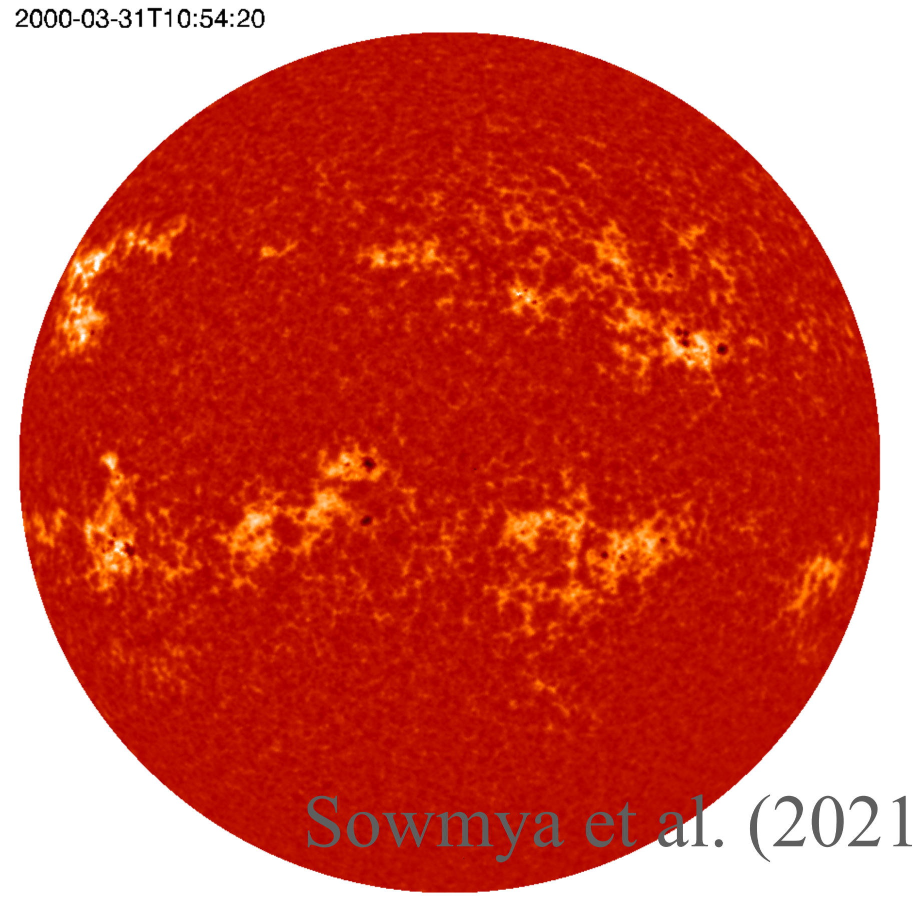


Effect of inclination

i = 90° : equator-on view

i = 0° : pole-on view





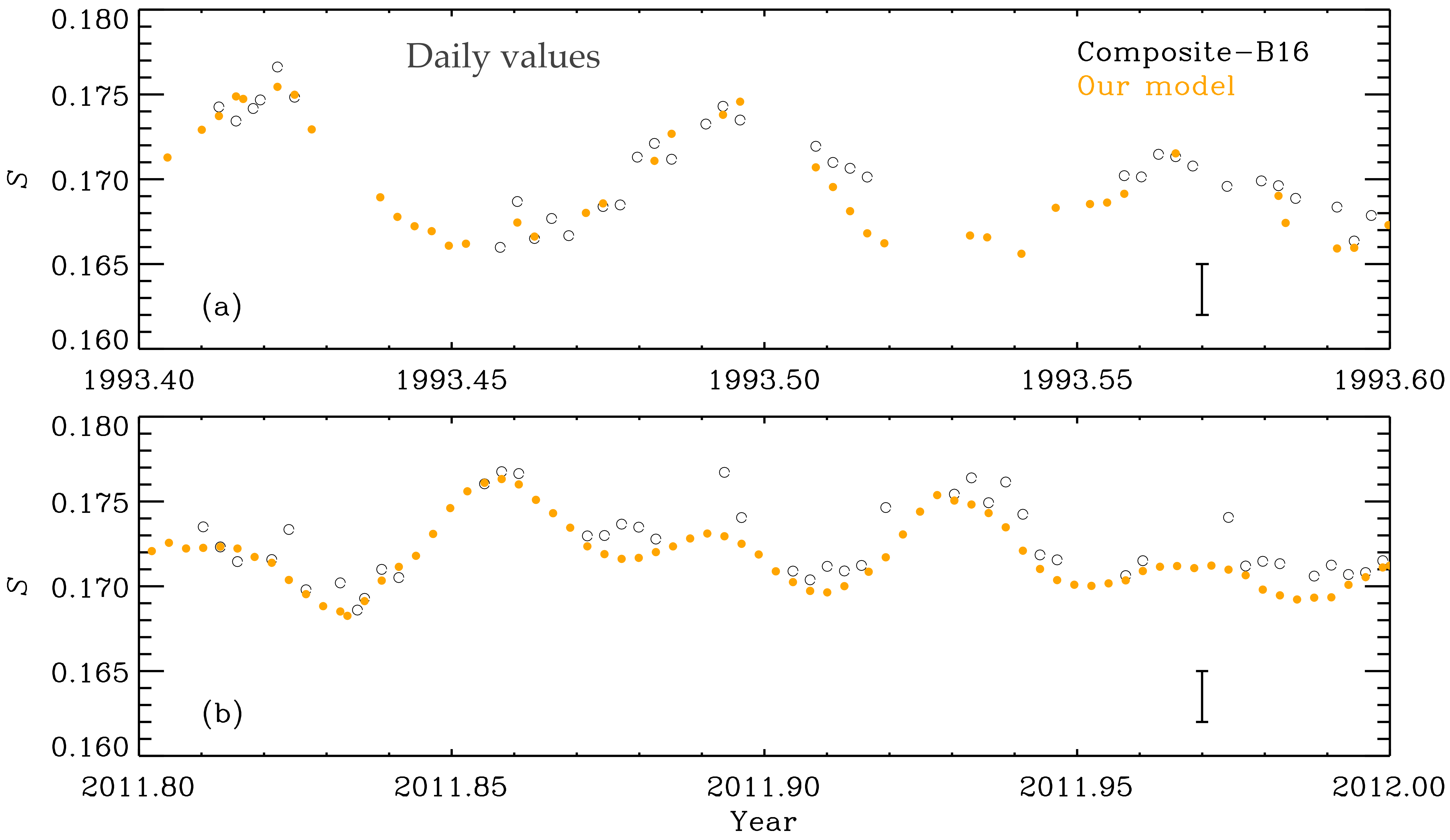
Courtesy: Theodosis Chatzistergos

Driven by the changes in the fractional disk area coverages of faculae and center-to-limb variation of facular contrast

Reconstruction of the *S* - index variations

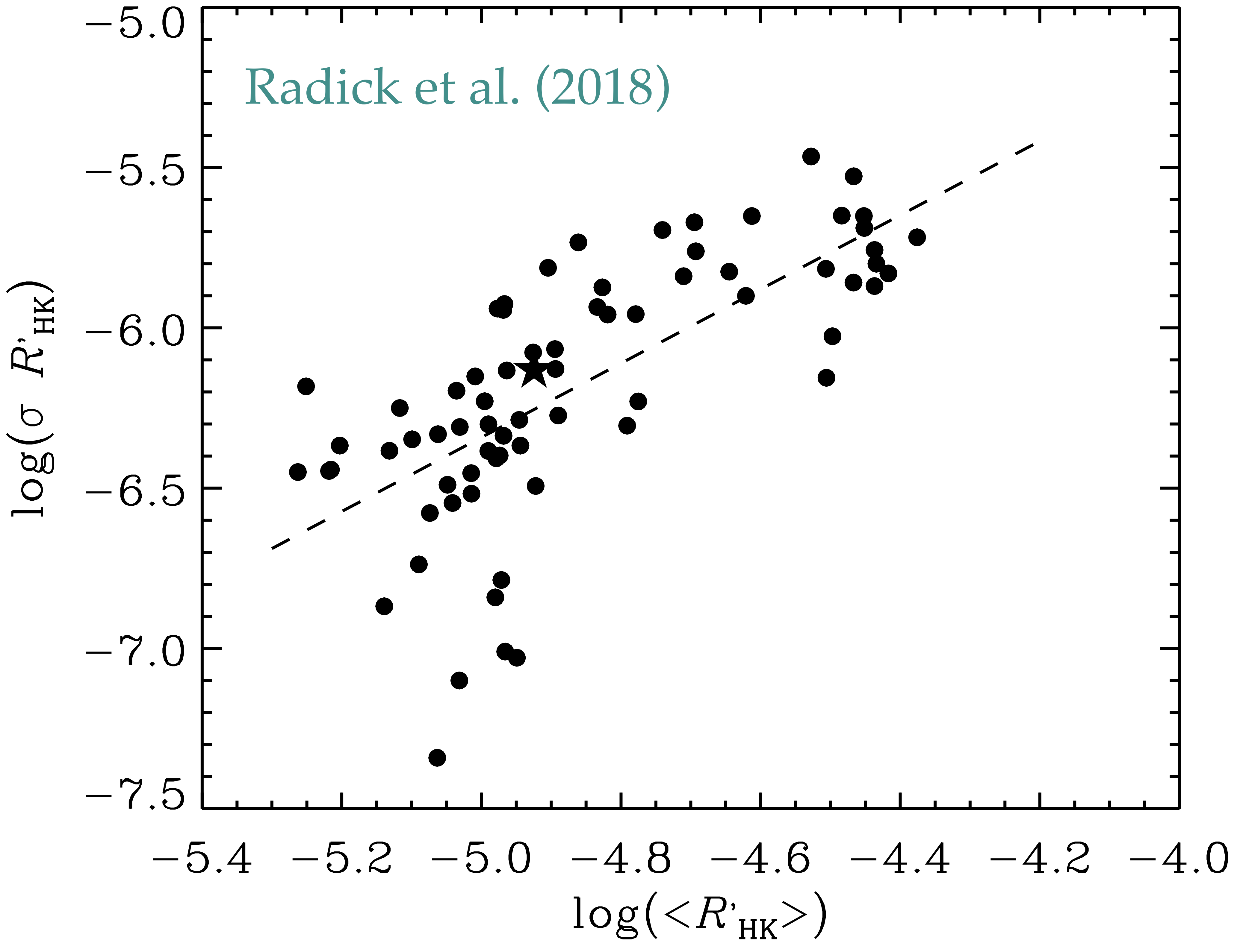
Rotational timescale

Composite-B16 : data from Bertello et al. (2016)

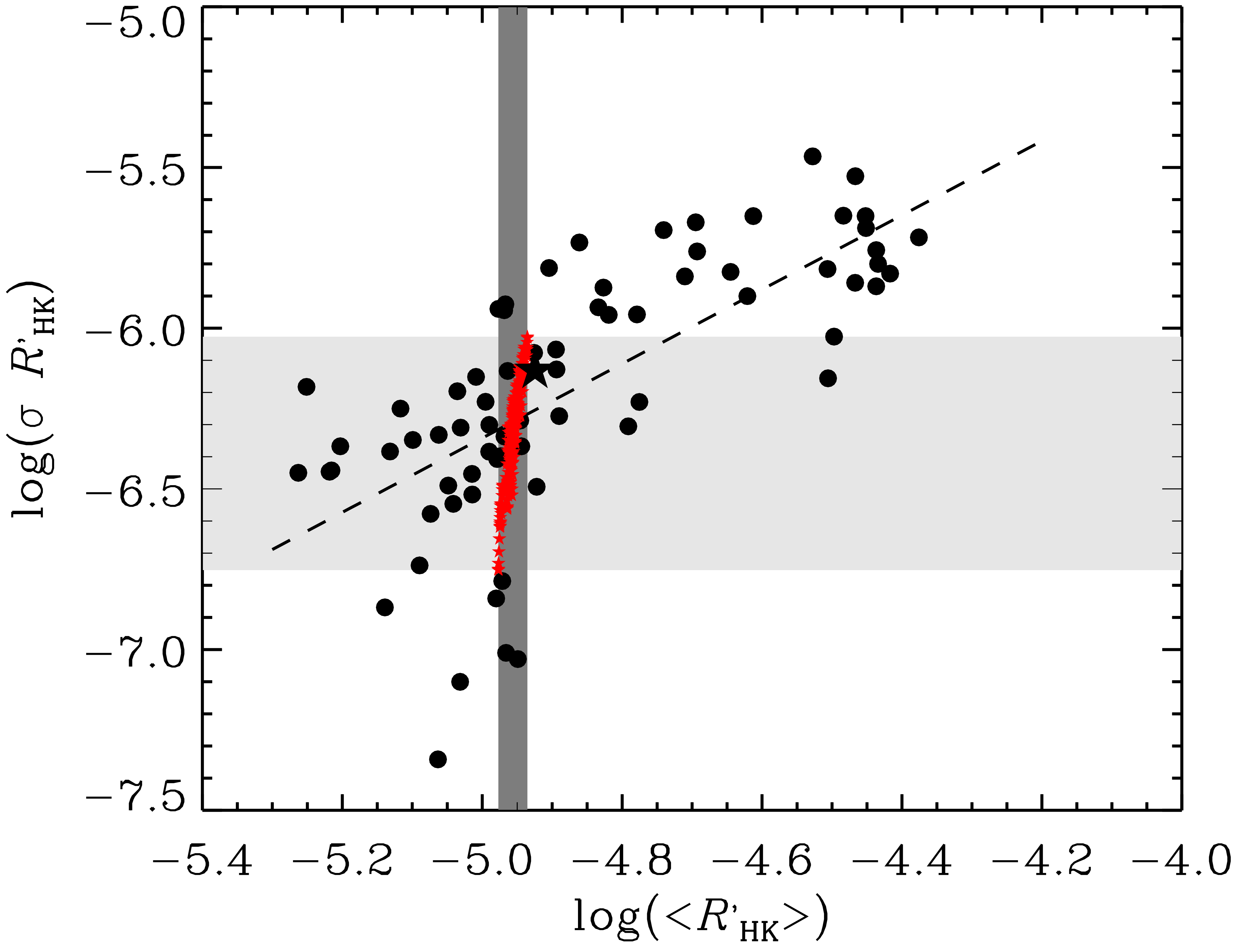


Is the Sun anomalous in its chromospheric activity?

Cycle amplitude



Activity



Solar Ca II H & K emission variation is absolutely normal in comparison to stars with near-solar magnetic activity

Sowmya et al. (2021), ApJ, 914, p21

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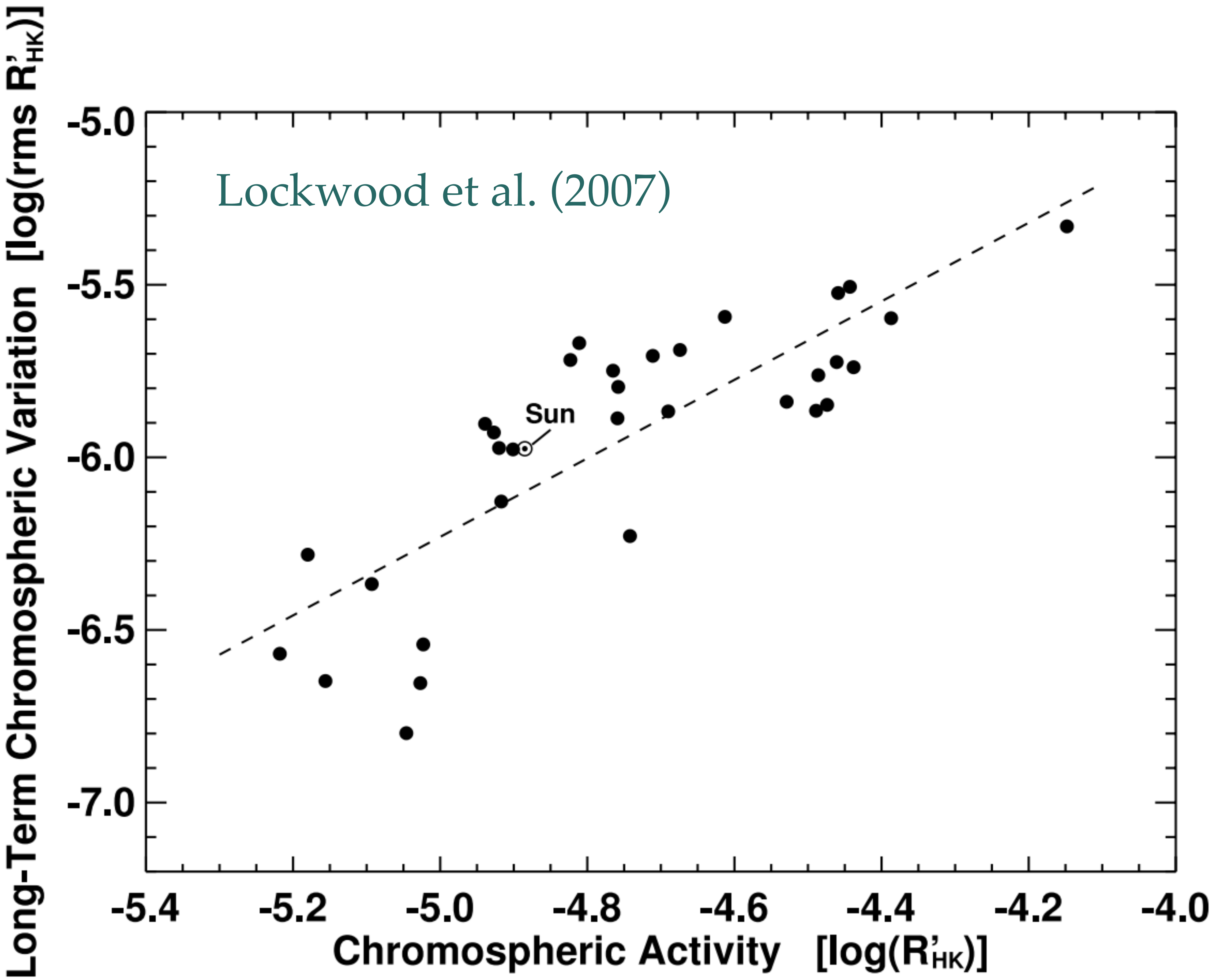

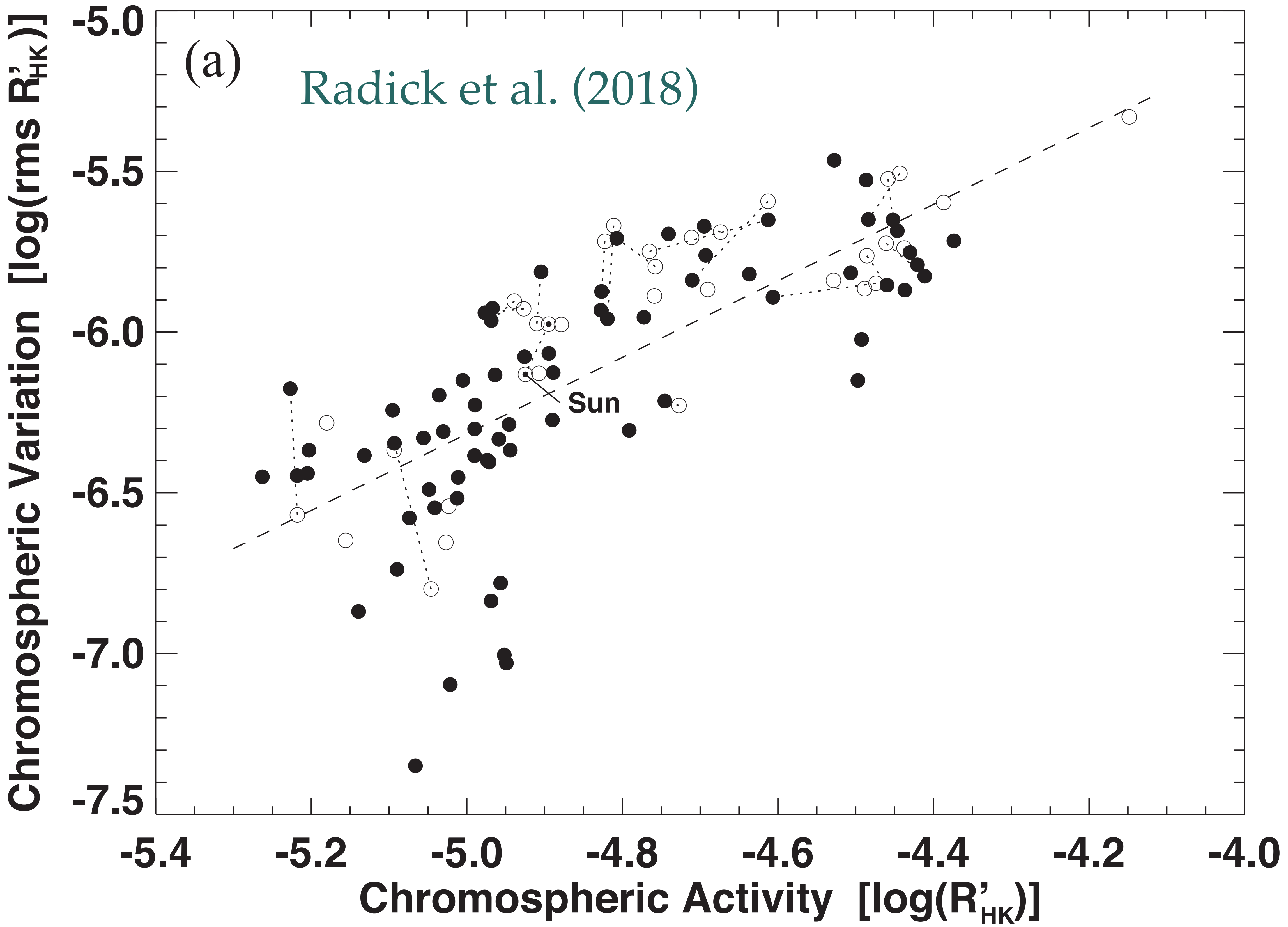

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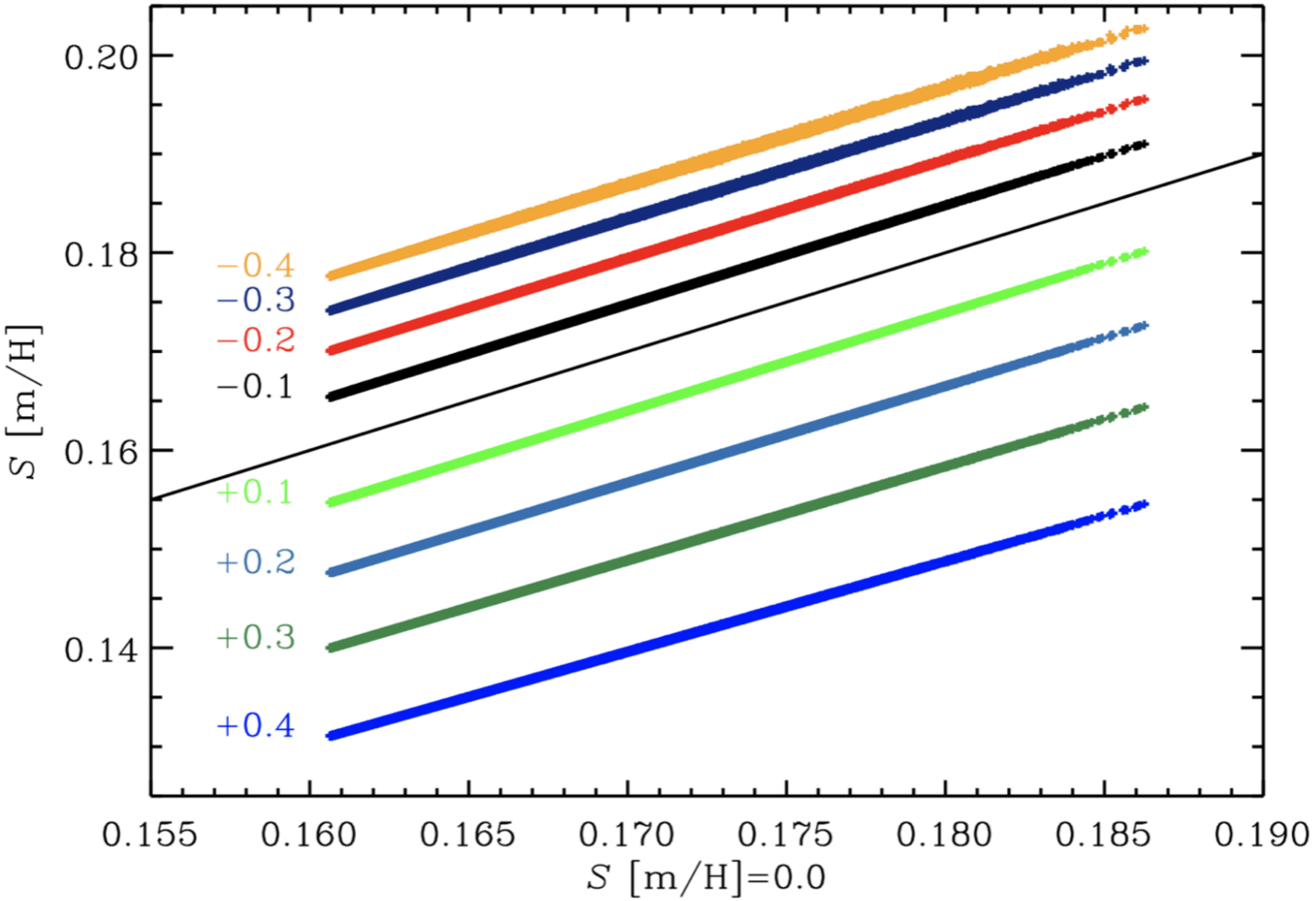
Sowmya et al. (2021), ApJ, 914, p21

Correcting for [m/H] dependence



S-index at a given [m/H] scales linearly with the *S*-index at solar metallicity

$$S_0 = a_{\mathrm{m/H}} * S_{\mathrm{m/H}} + b_{\mathrm{m/H}}$$

Sowmya et al., in prep.

Surface flux transport model

1. SFTM (Cameron et al. 2010; Jiang et al. 2011) is a advective diffusive model describing the passive transport of radial component of the magnetic flux on the stellar surface under the influence of differential rotation and meridional flow

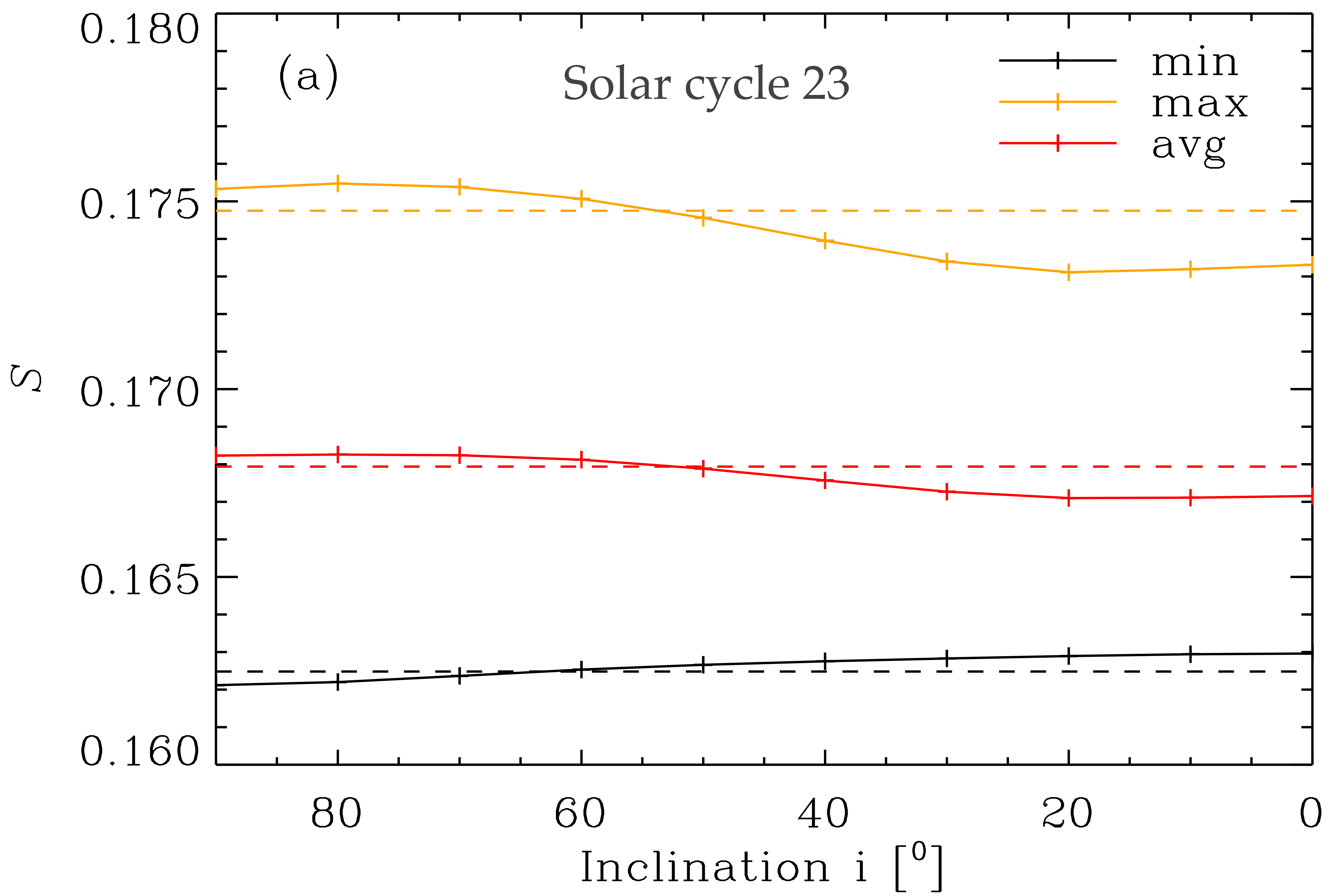
2. The magnetic field emerges as bipolar active regions

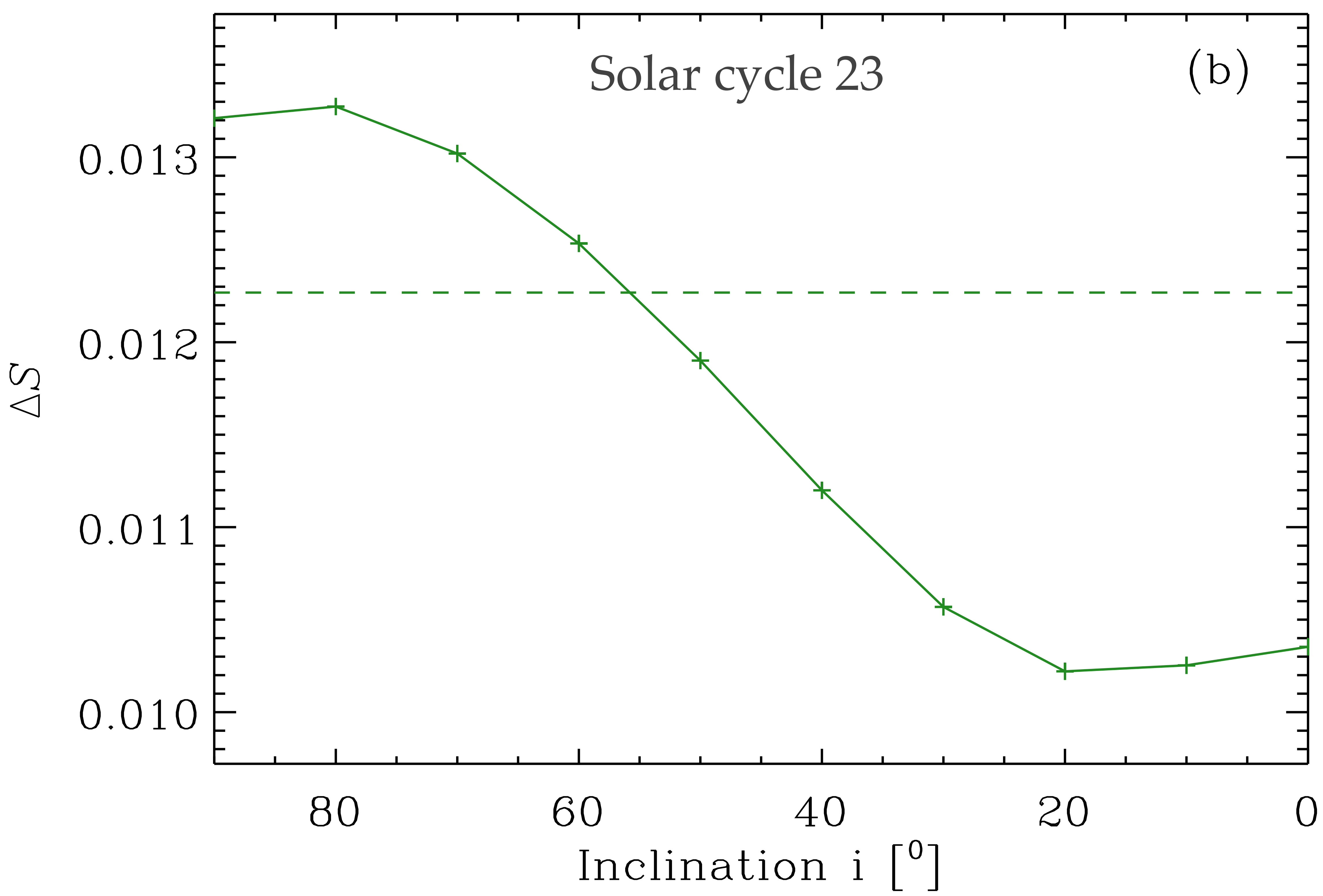
3. The emergence characteristics of these regions are determined using the semi-empirical sunspot group record of Jiang et al. (2011) for the period 1700-2010

4. Statistical properties of sunspots in this record reflect those of the sunspot record of the Royal Greenwich Observatory

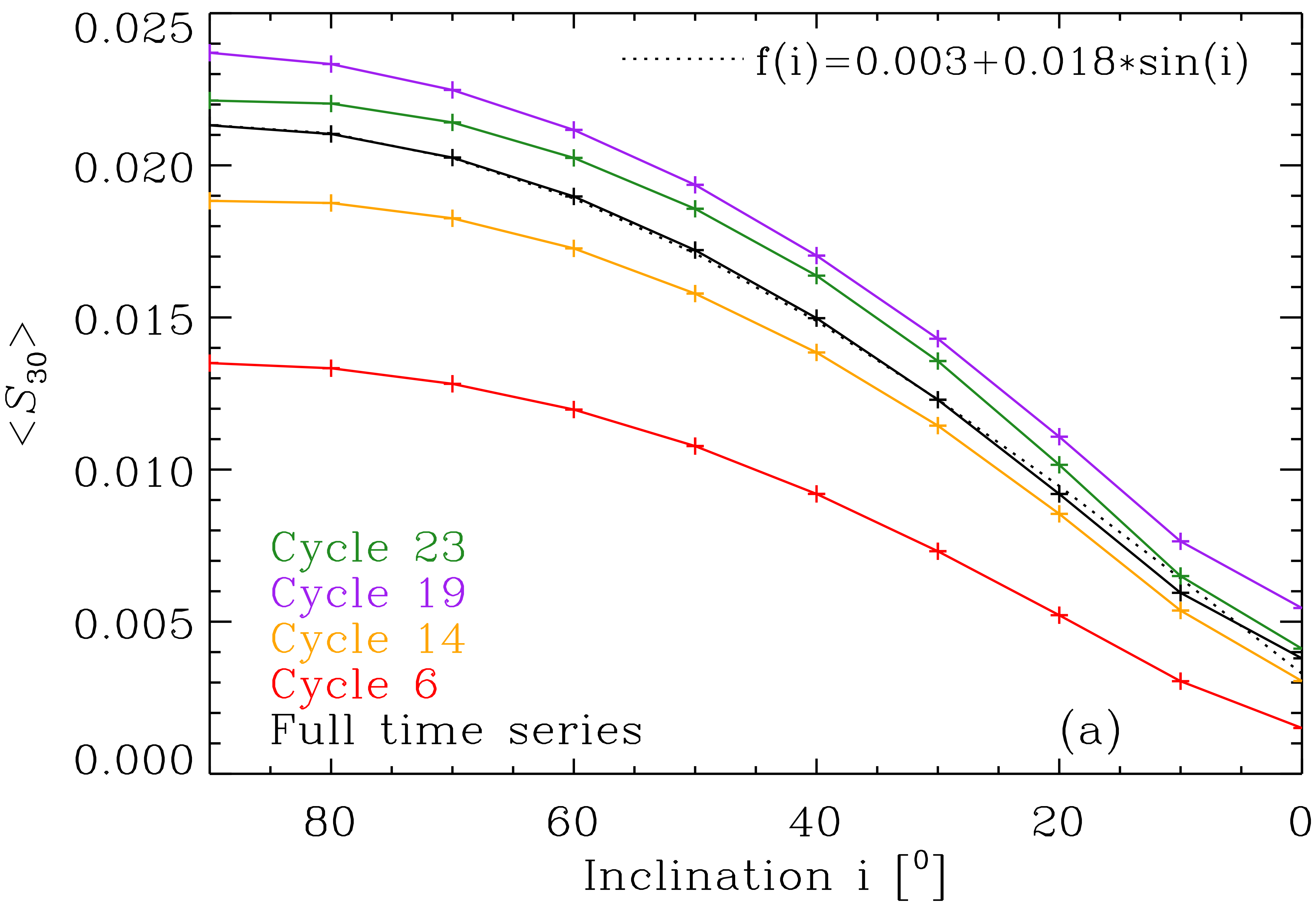
5. Active regions emerge at random longitudes - essential for inclination studies

Variations on activity cycle timescale



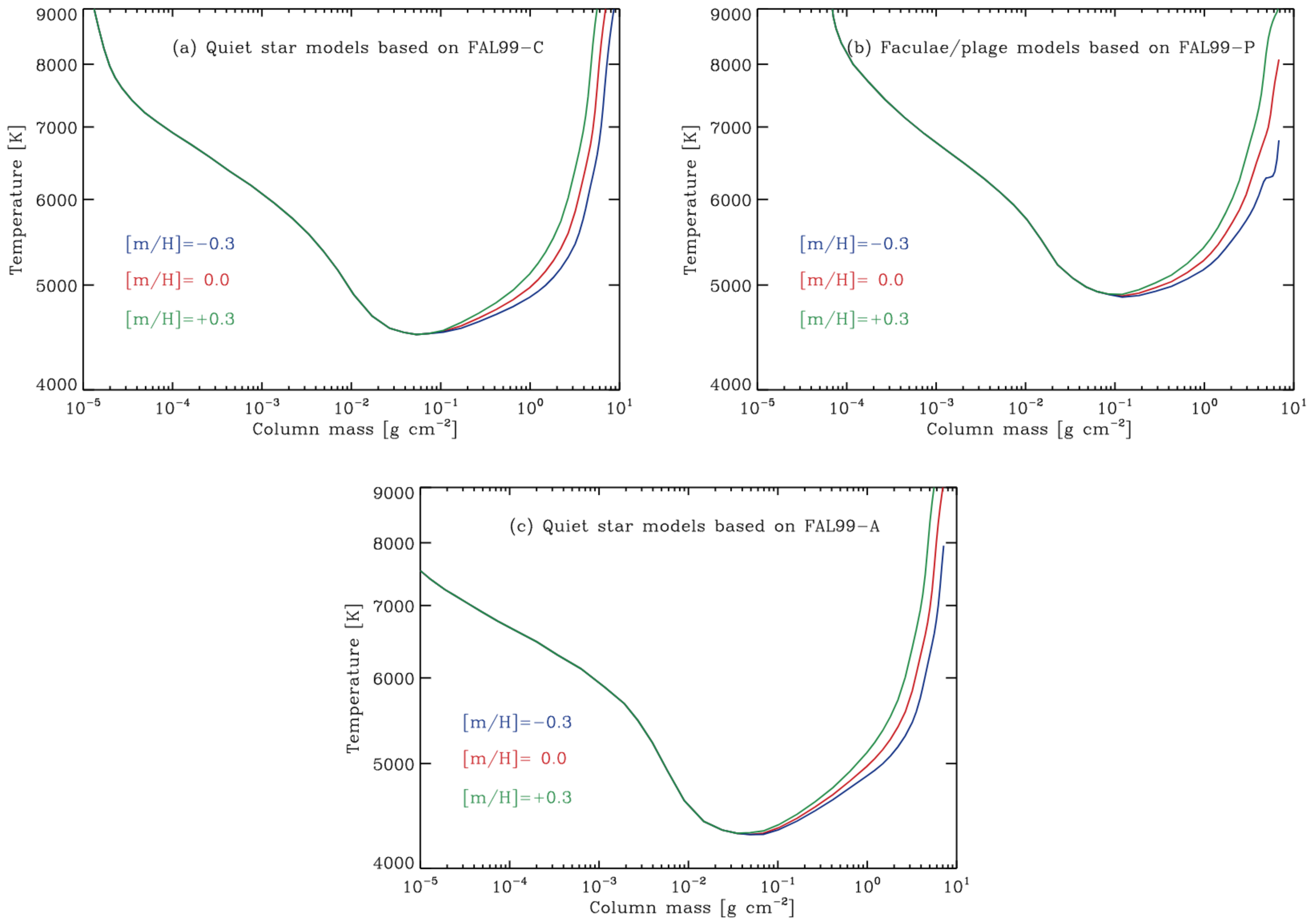


Inclination dependence of rotational variability



can be well approximated by a simple function of the type $< S_{30} > (\mathrm{i}) = c1 + c2 * \sin \mathrm{i}$

Models for different [m/H]

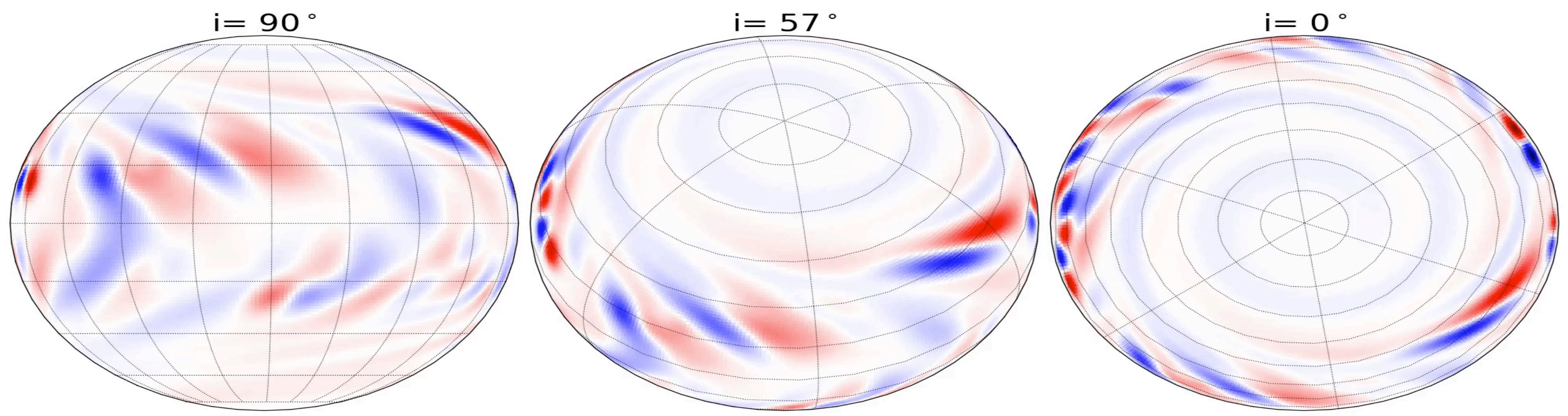


Our approach (for metallicity)

Disk coverage of magnetic features

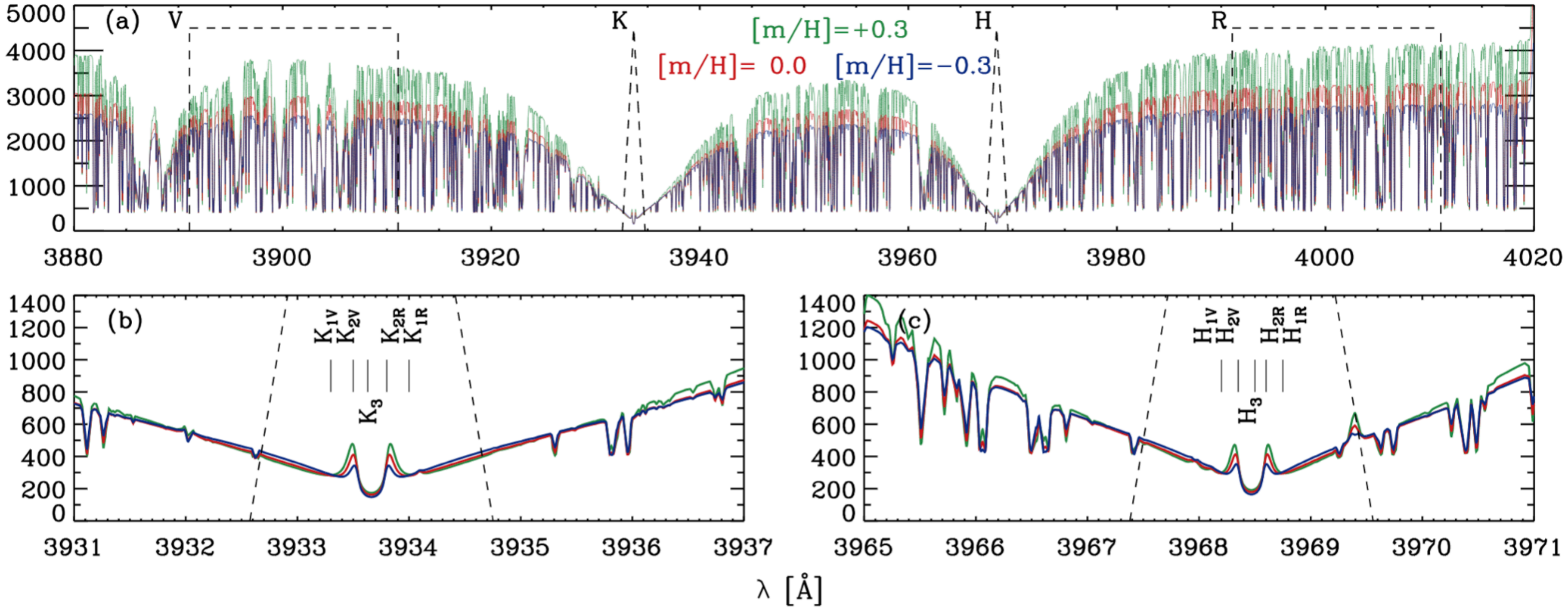
Courtesy of Nina Nèmec

magnetograms synthesised from surface flux transport model (Cameron et al. 2010; Nèmec et al. 2020)

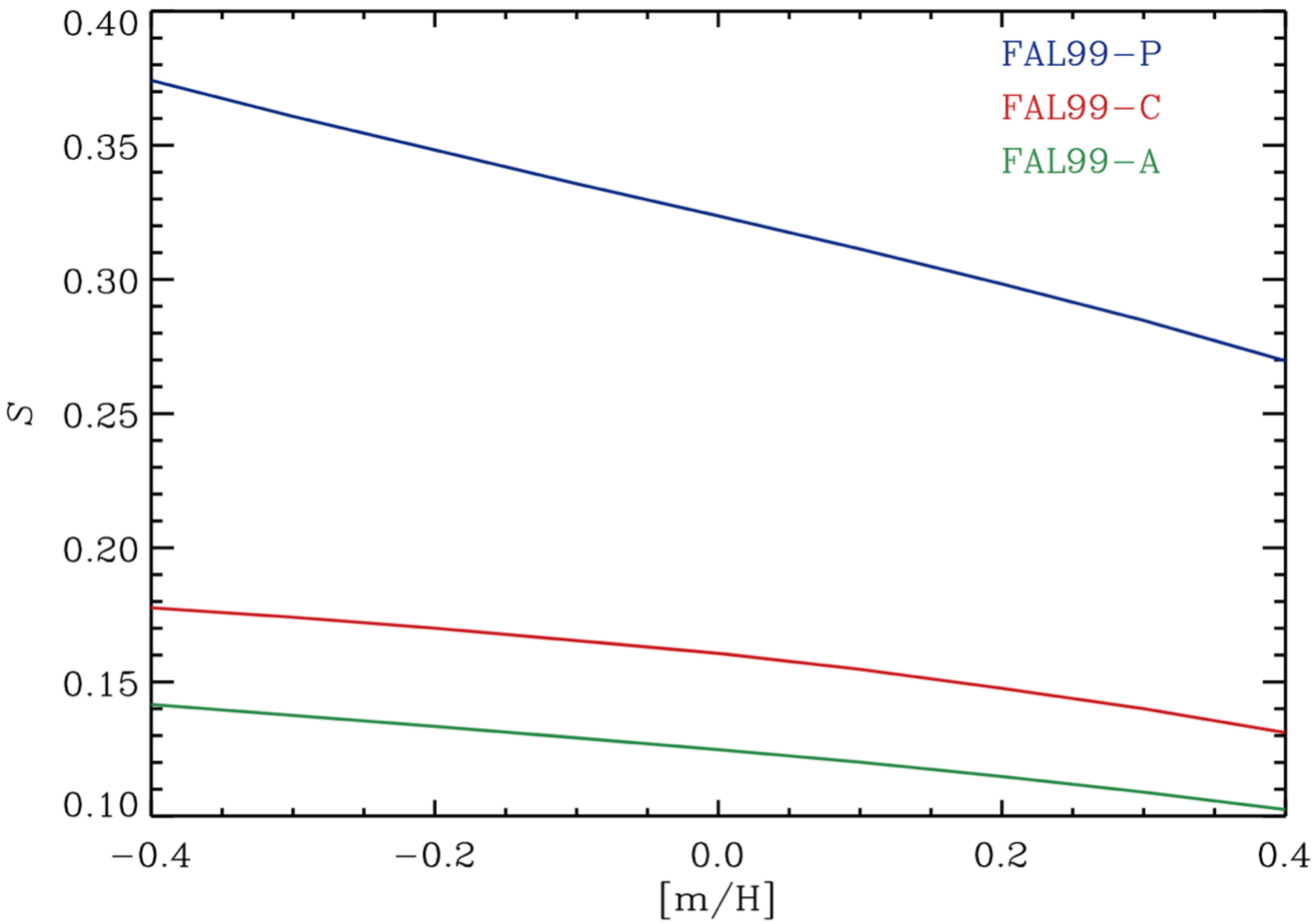


Non-LTE spectra of the quiet Star and faculae

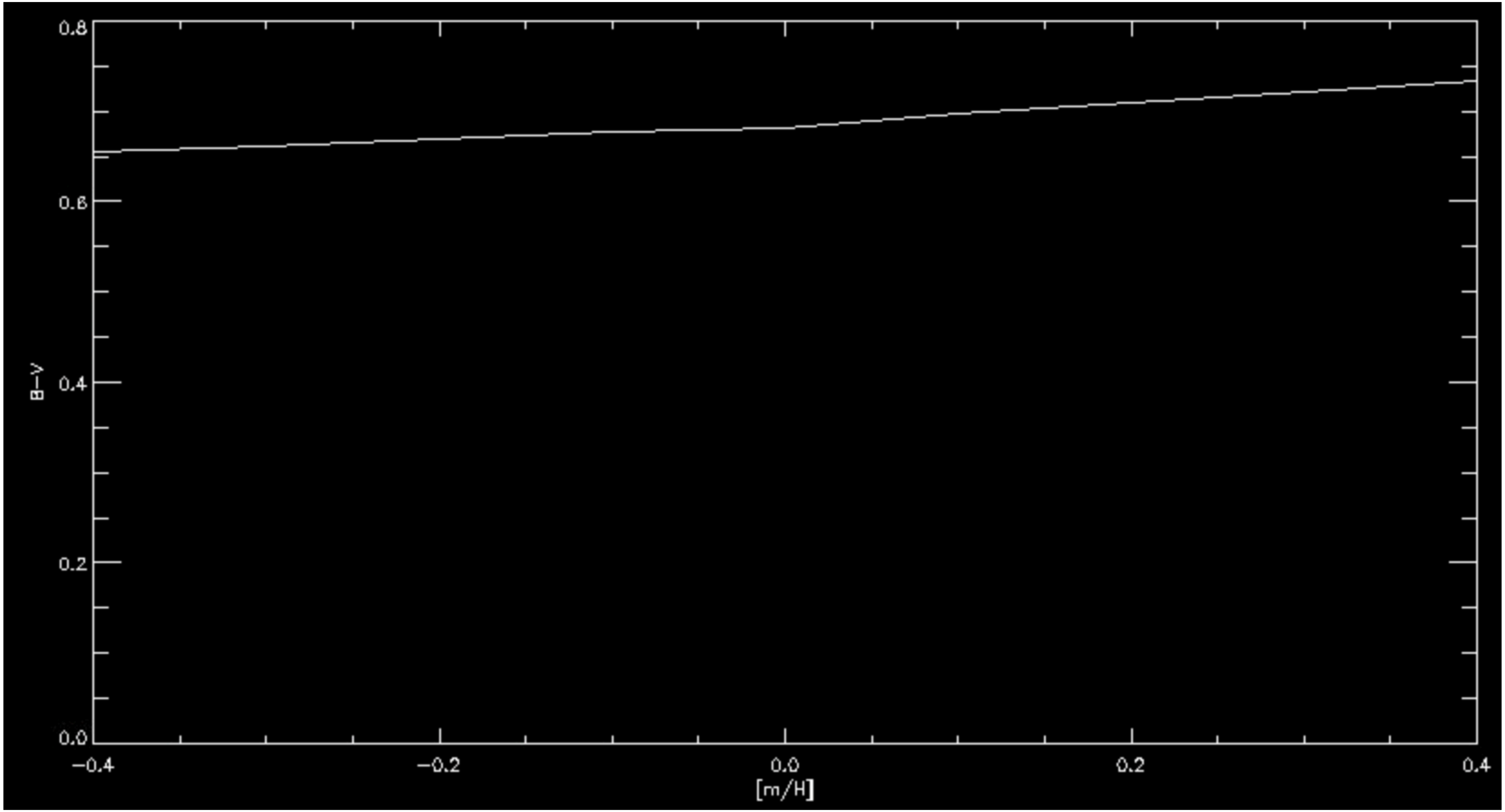
Disk-integrated quiet Star



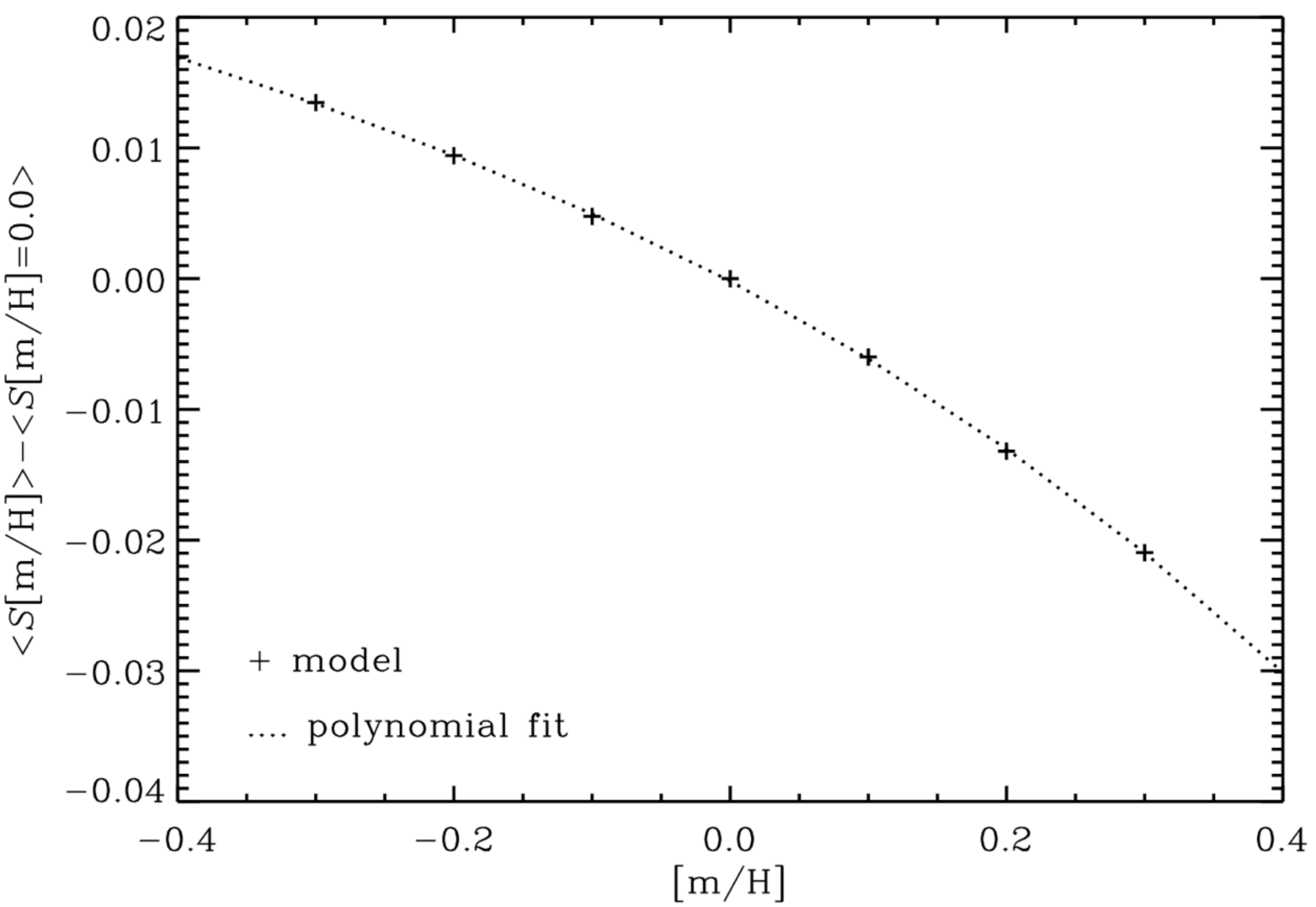
Standard 1D models



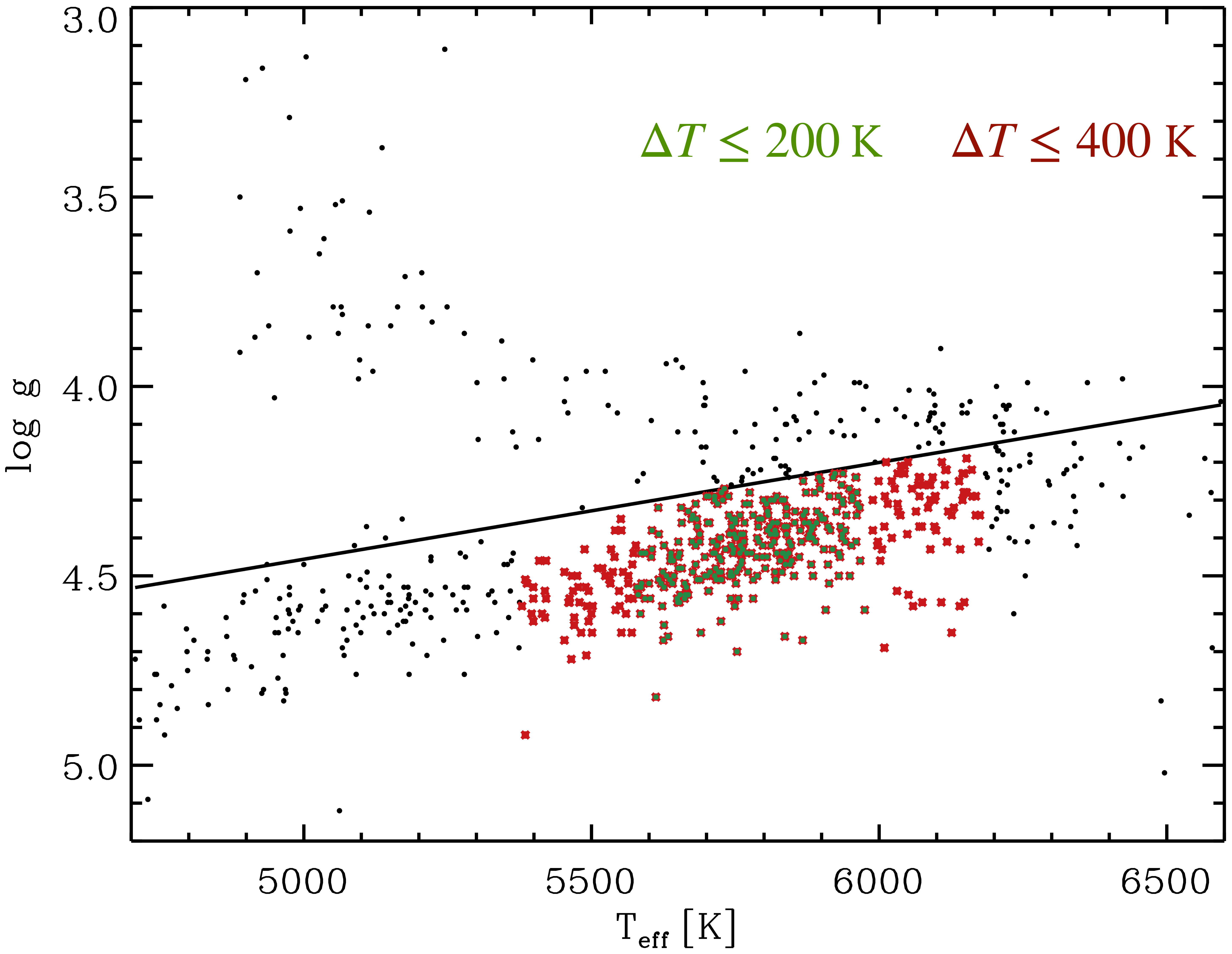
B-V vs metallicity



Polynomial fit



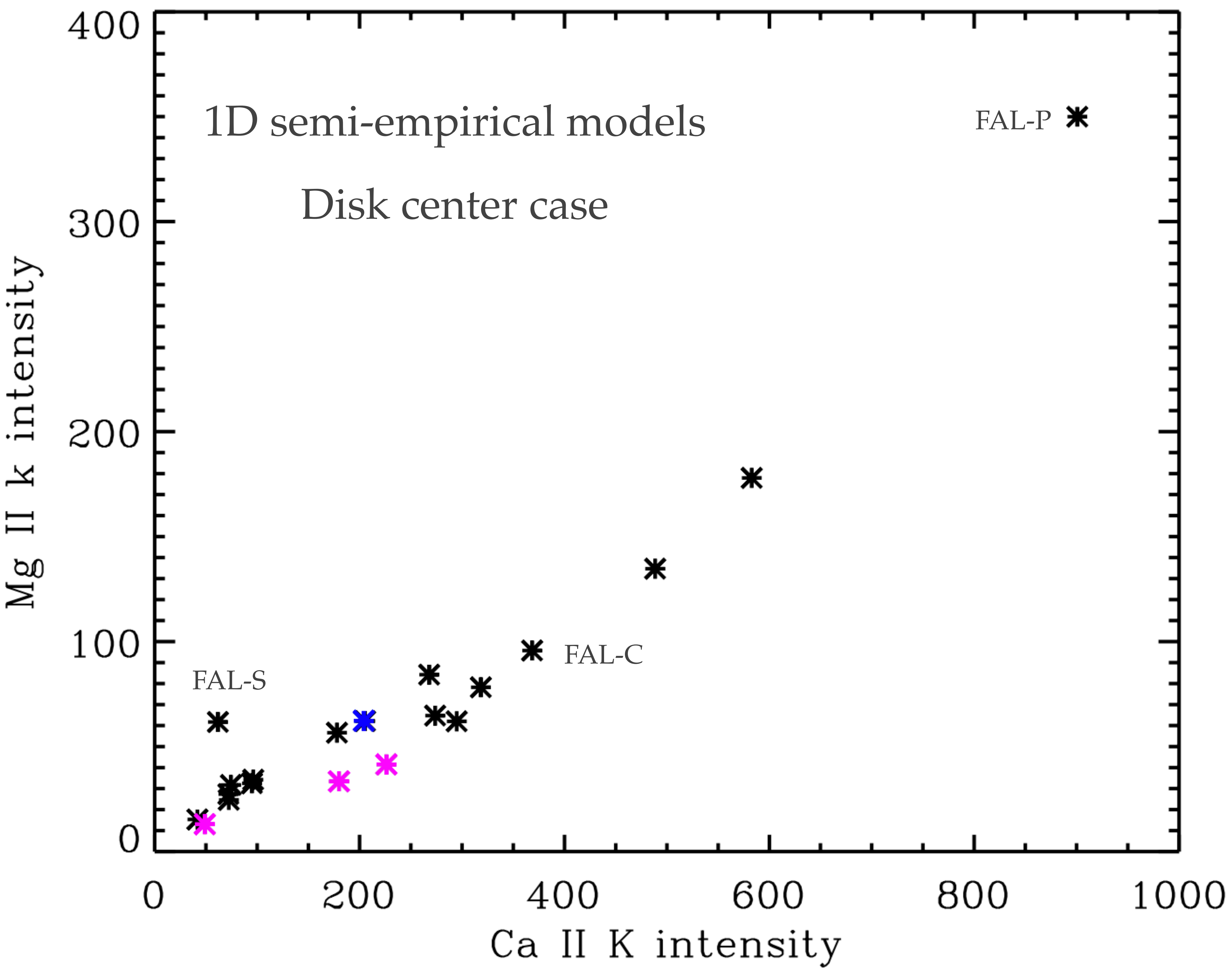
Stellar sample



Wright et al. (2004)

Valenti & Fischer (2005)

Correlation between Mg II & Ca II



Does Ca II flux correlate with the Mg II flux?

Can we use the correlation to get Ca II images of sunspots from IRIS data in Mg II?

Can we learn something about effect of spots on the *S* - index?

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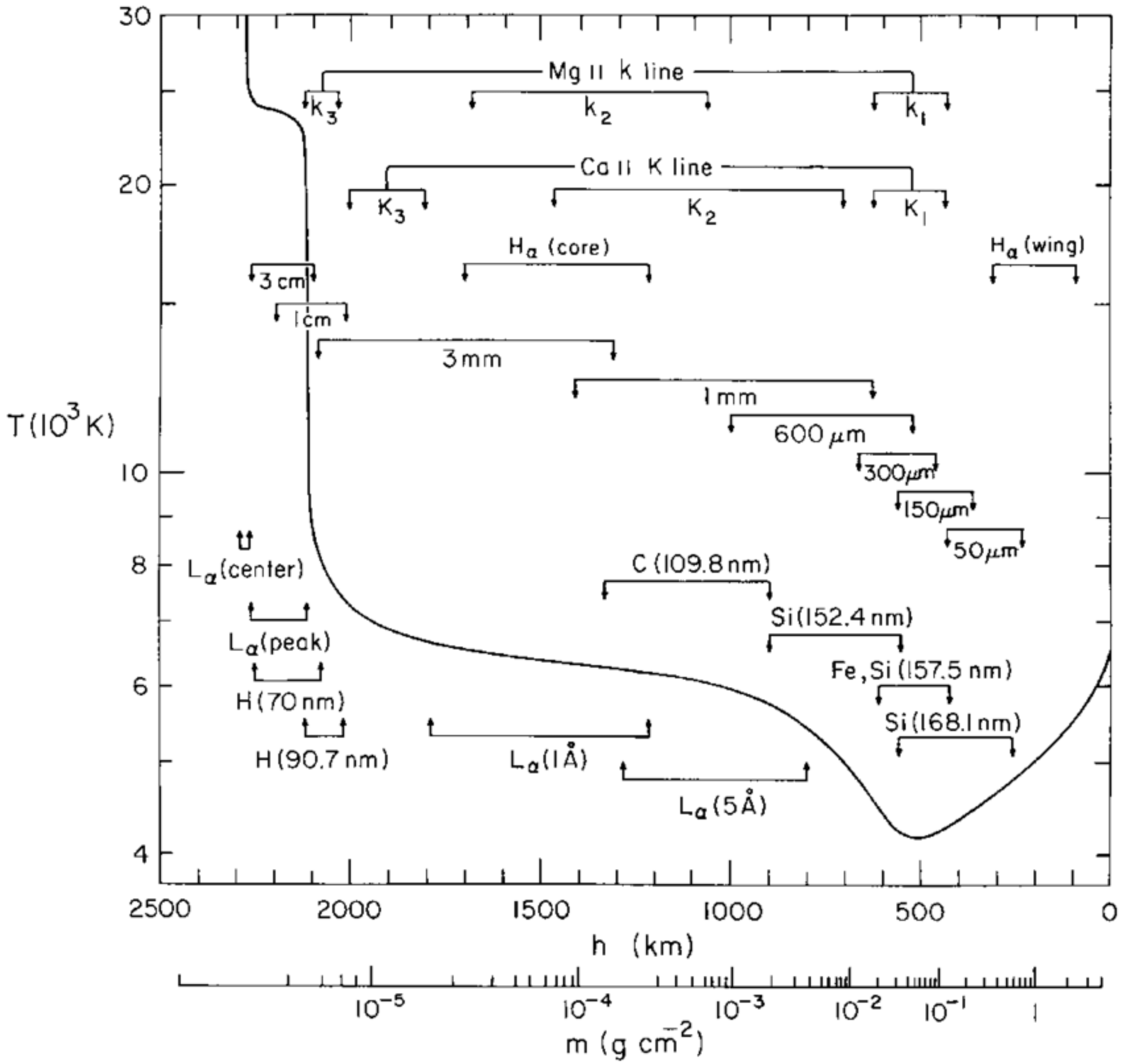
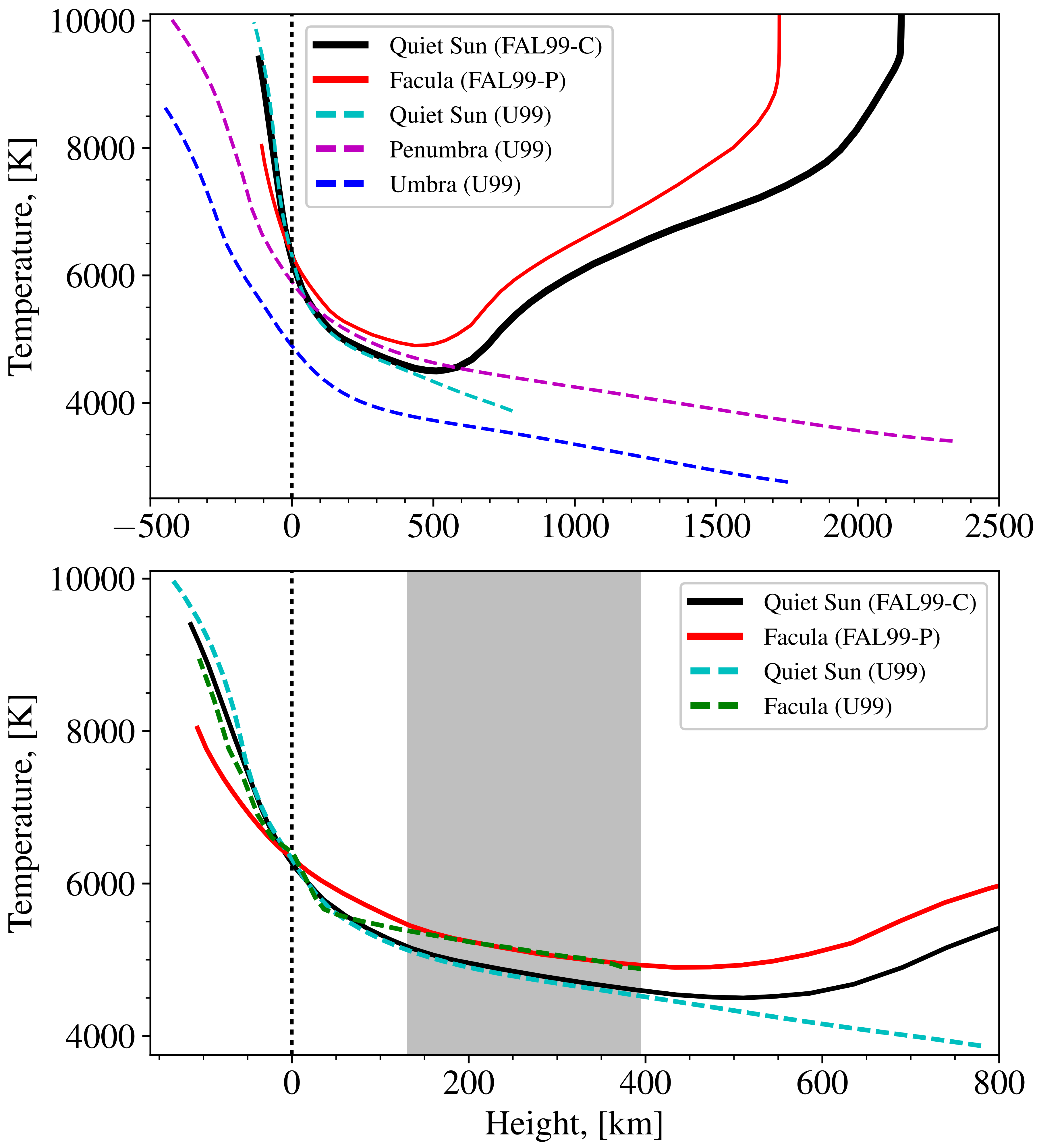
Vernazza et al. (1981)

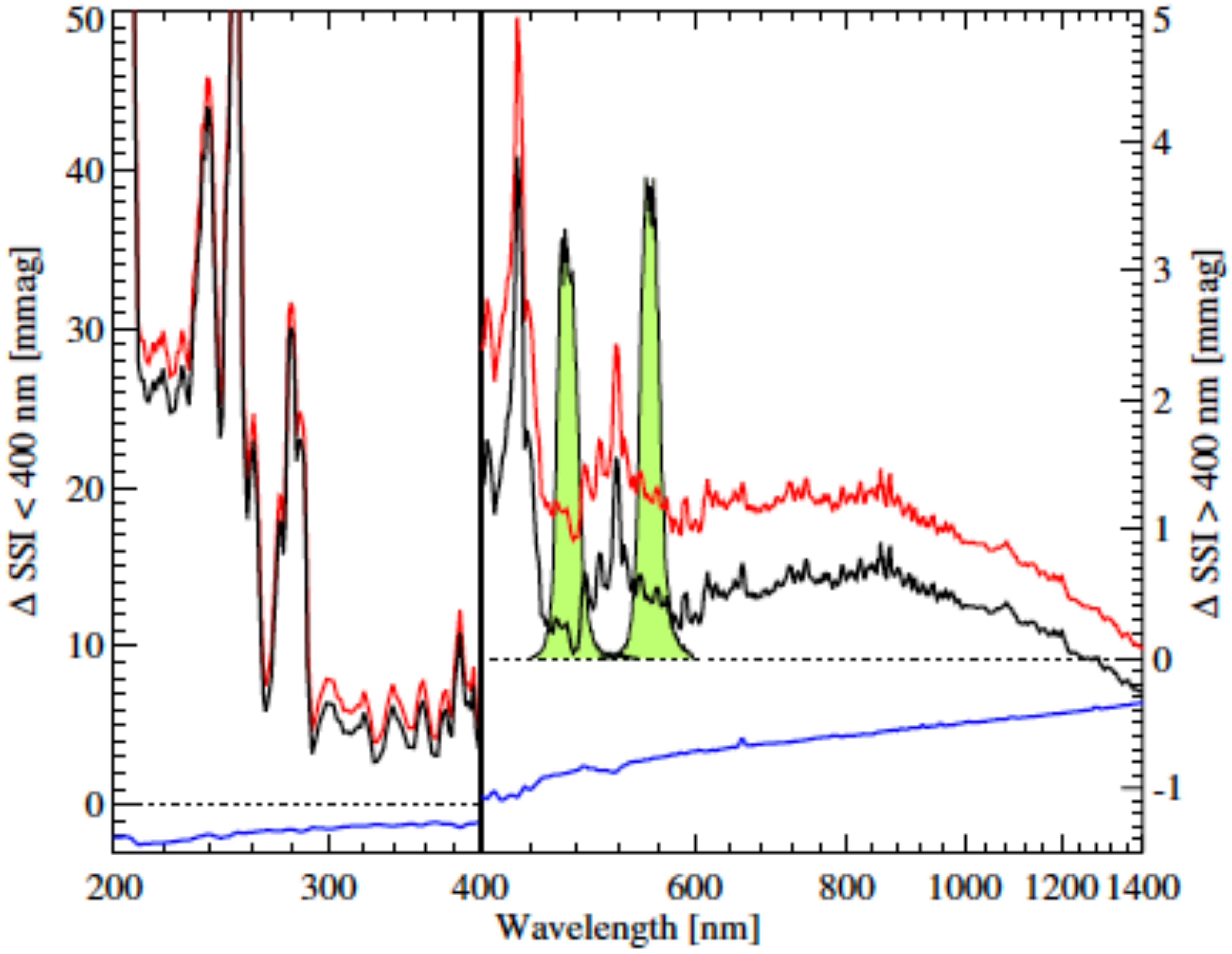


Model atmospheres

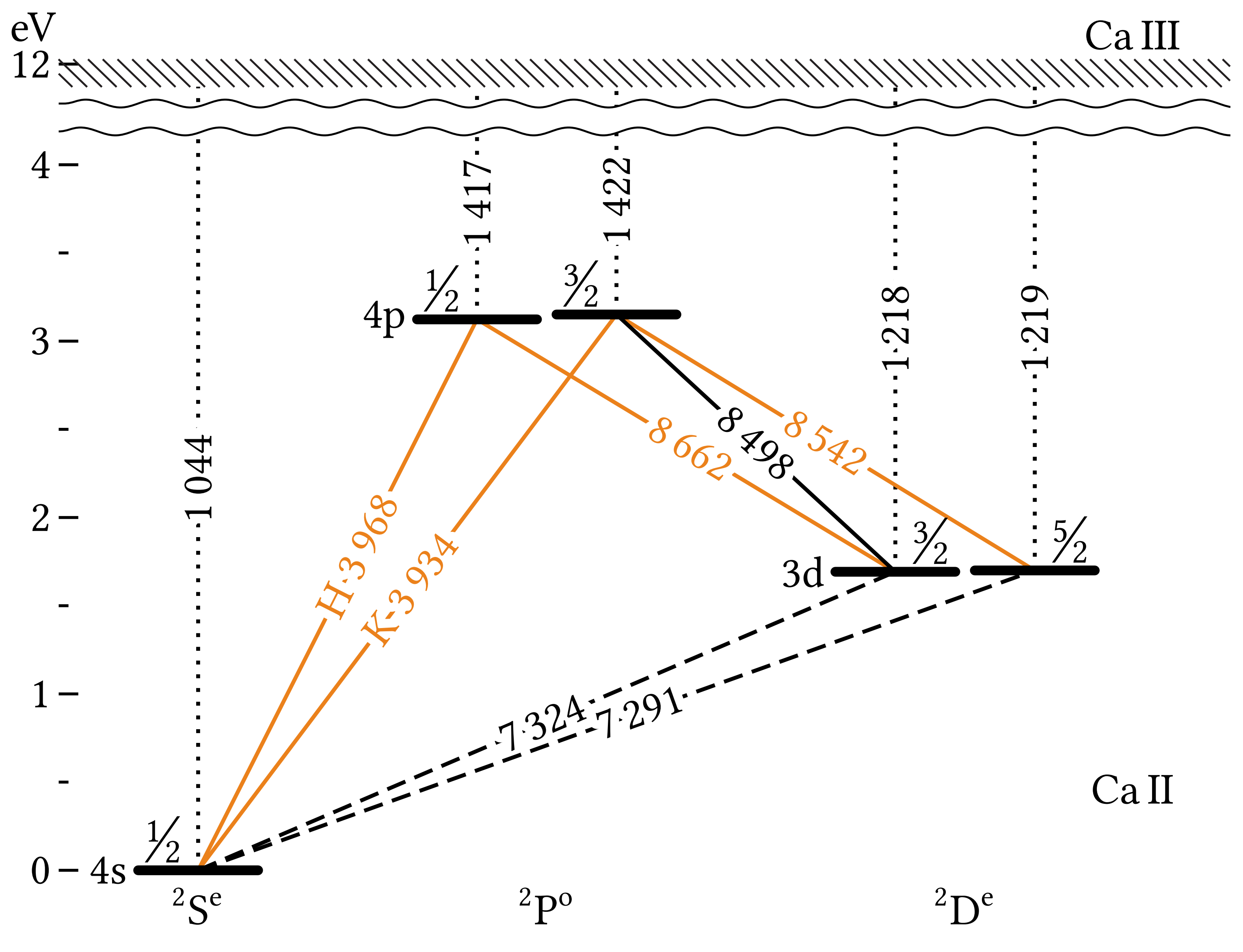


Tagirov et al. (2019)

Shapiro et al. (2016)



Bjorgen et al. (2017)



As model atmospheres we used three snapshots from three different radiation-magnetohydrodynamic (R-MHD) numerical simulations carried out with the Bifrost code (Gudiksen et al. 2011). All three runs simulated a bipolar magnetic region, which consists of two magnetic polarity patches separated by 8 Mm (illustrated for Model 2 in Fig. 3). The region is similar to an enhanced network with an unsigned magnetic field strength of 50 G in the photosphere. In all three cases, the simulation box has the same physical size of 24 Mm × 24 Mm × 16.9 Mm spanning from the top of the convection zone up to the corona. The models differ in the spatial resolutions of their coordinate grids and in the equations of state (EoS) used for the initial R-MHD setup.

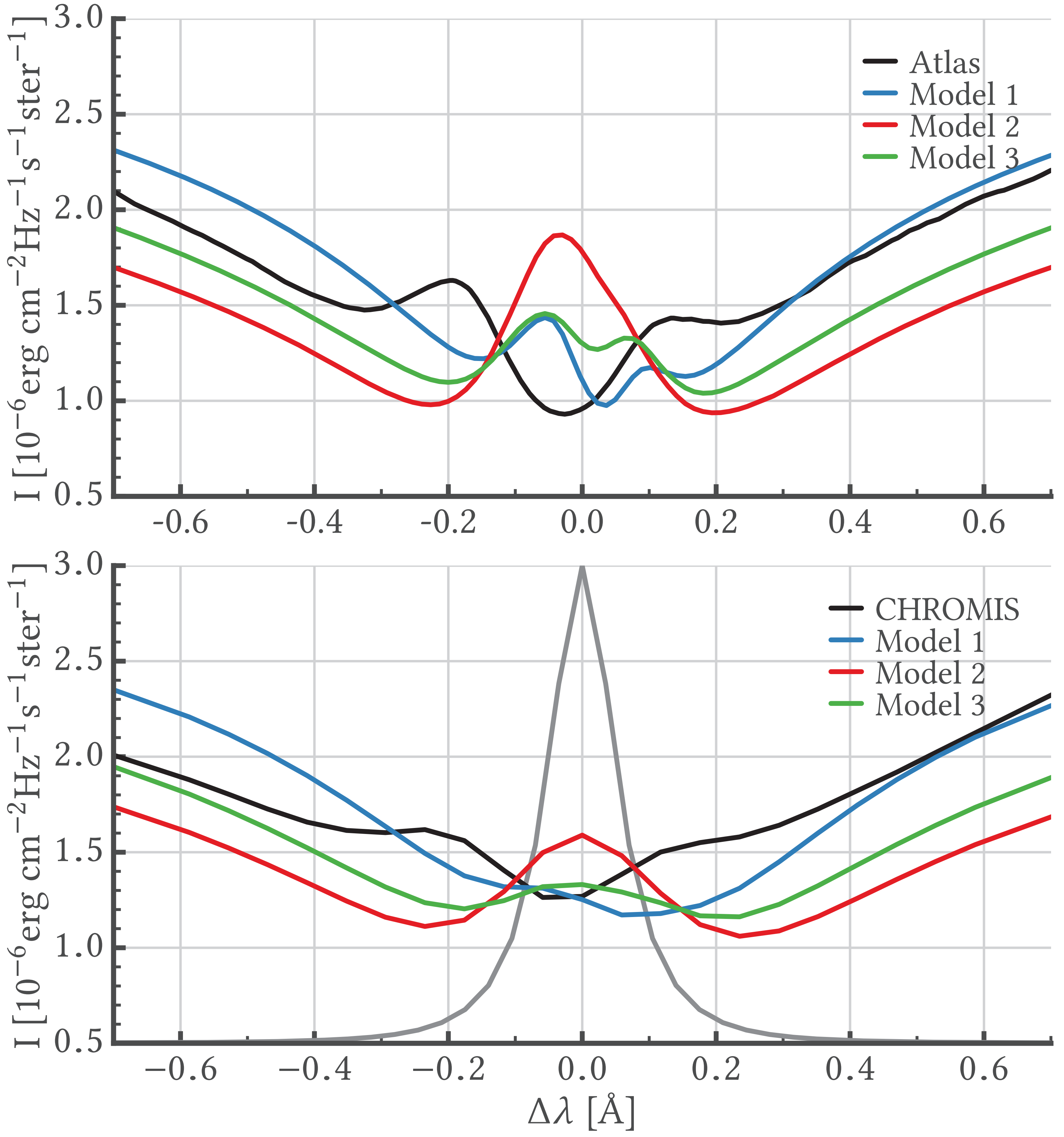


Fig. 10. Spatially averaged intensity profiles of the Ca II K line at $\mu = 1$. *Upper panel*: undegraded synthetic profiles for Model 1, 2, and 3 (blue, red, and green) are compared with the Hamburg atlas profile (black). *Lower panel*: degraded synthetic profiles (same notation) are compared with the SST/CHROMIS profile from our observations (black). The gray curve indicates the assumed CHROMIS spectral transmission profile.