STELLAR MAGNETIC ACTIVITY (PAP351)

Lecture 3, January 31,2024

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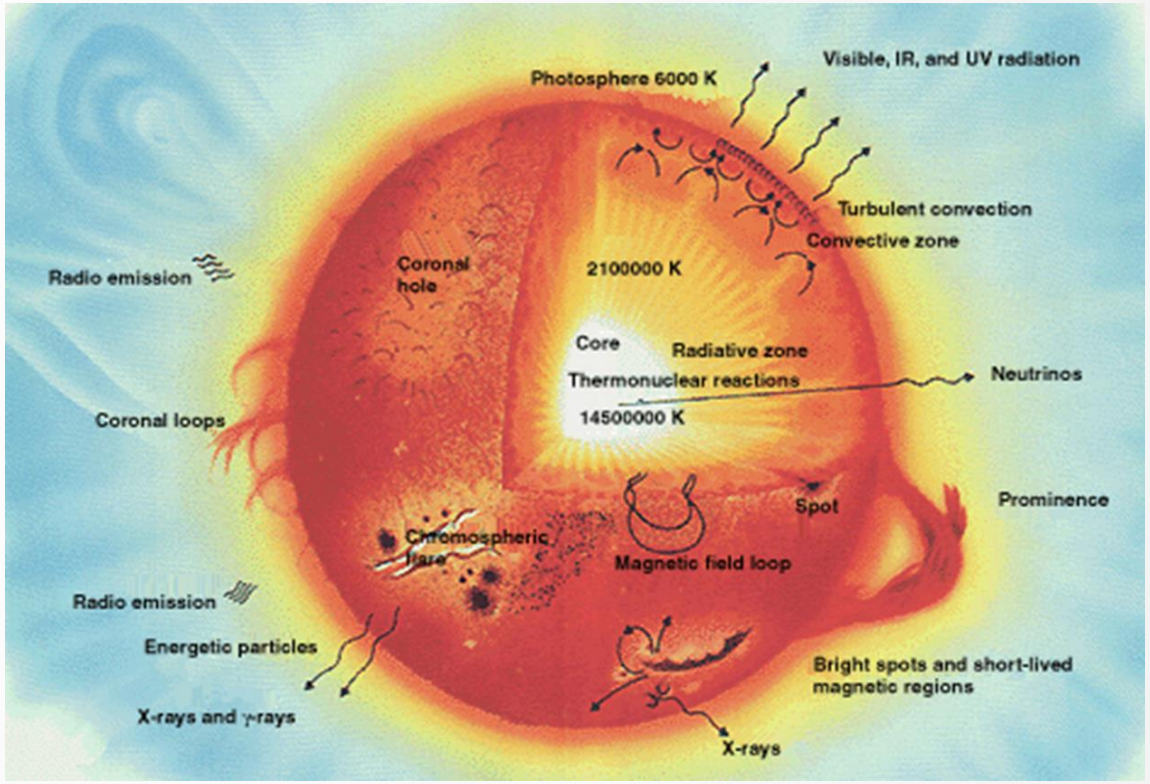
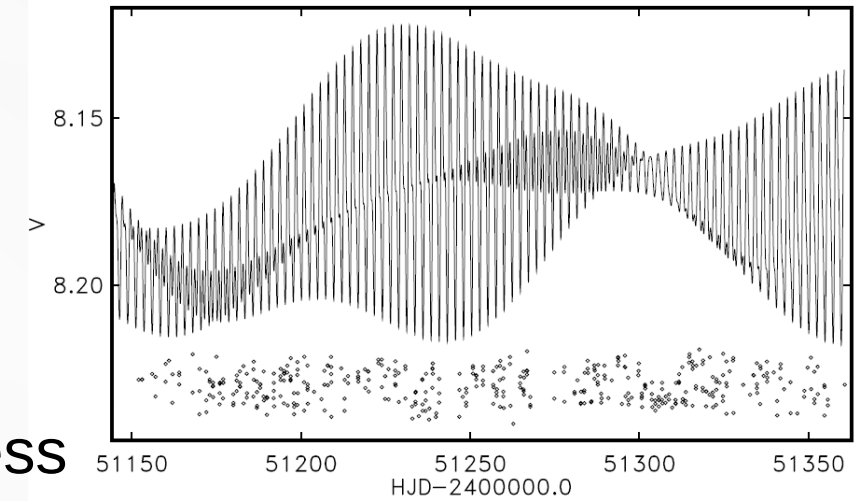
4. MANIFESTATIONS OF STELLAR MAGNETIC ACTIVITY

- Spots
- Bright surface phenomena: Faculae …
- Ca II H&K, Hα -emission (chromosphere)
- UV-radiation (transition region, corona)
- X-rays (corona)
- Eruptions: Prominences, flare, CMEs

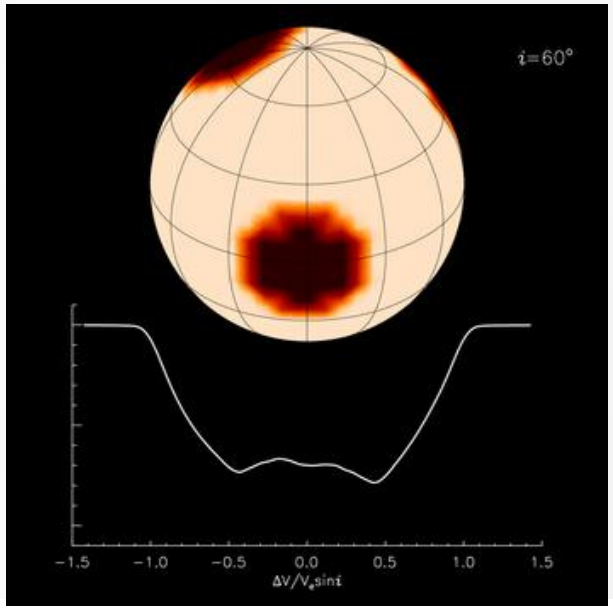


4.1 STARSPOTS

- Believed to be analogues to sunspots
- Two regimes depending on effect on total brightness
  - Spot dominated <= more active stars (e.g. young solar-type stars)
  - Faculae dominated <= less active stars (e.g. the Sun)
- Spot dominated case => as star rotates spots will cause the light to change:
  - Brightness => periodic light curve
  - Spectral lines => periodic “bump”



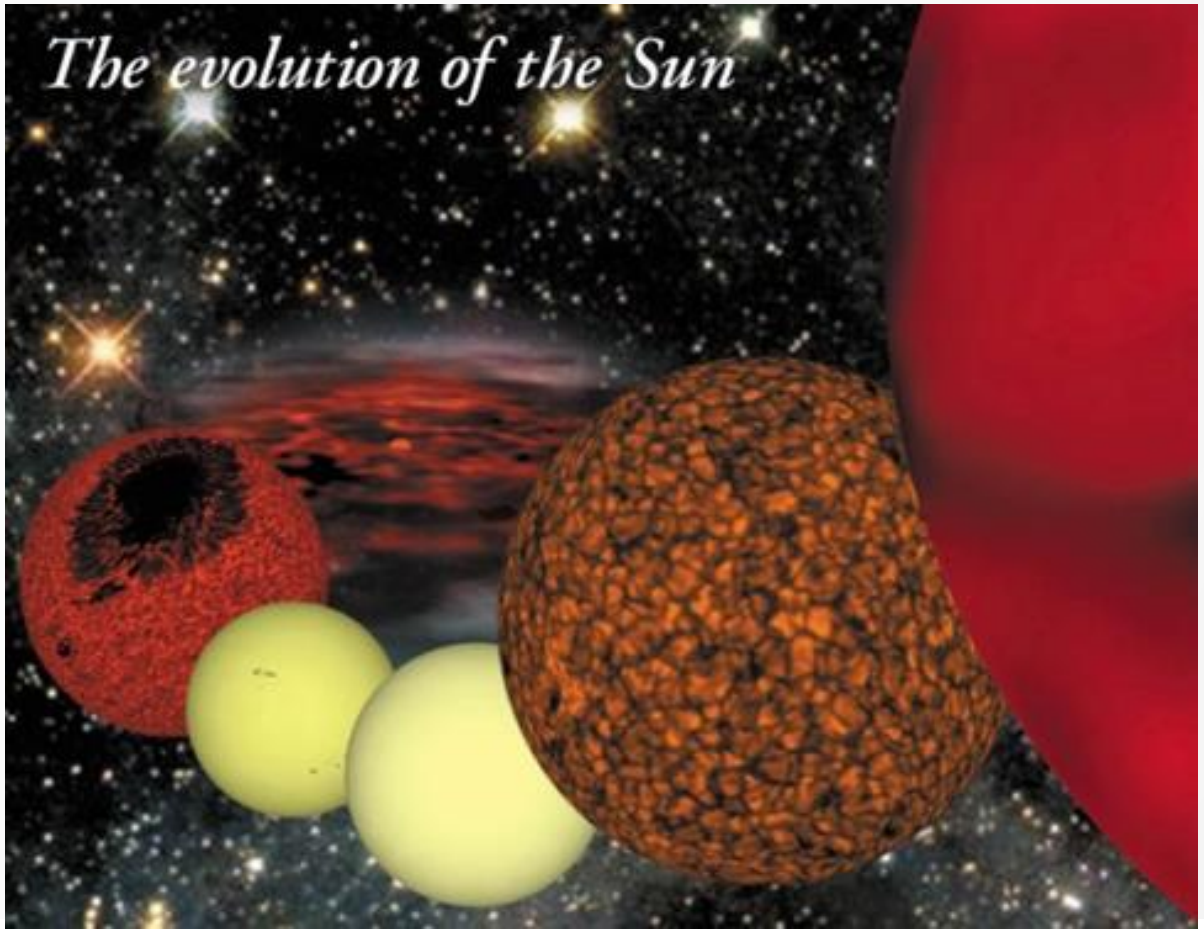
Light curve of FK Com



Animation by O. Kochukhov

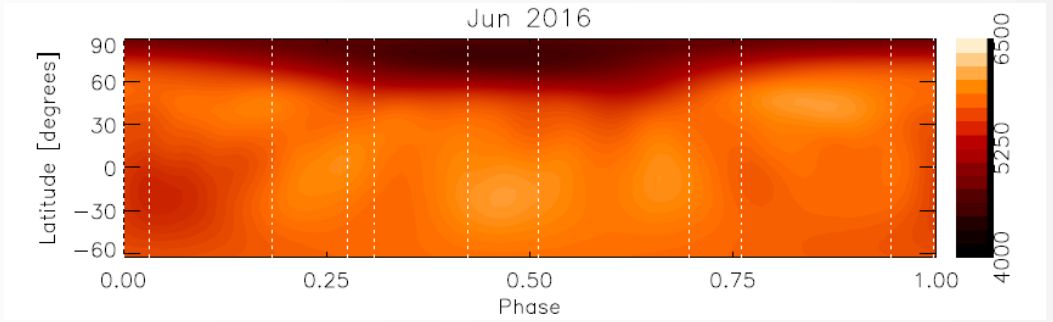
4.1.1 STELLAR EVOLUTION IN TERMS OF SPOTS

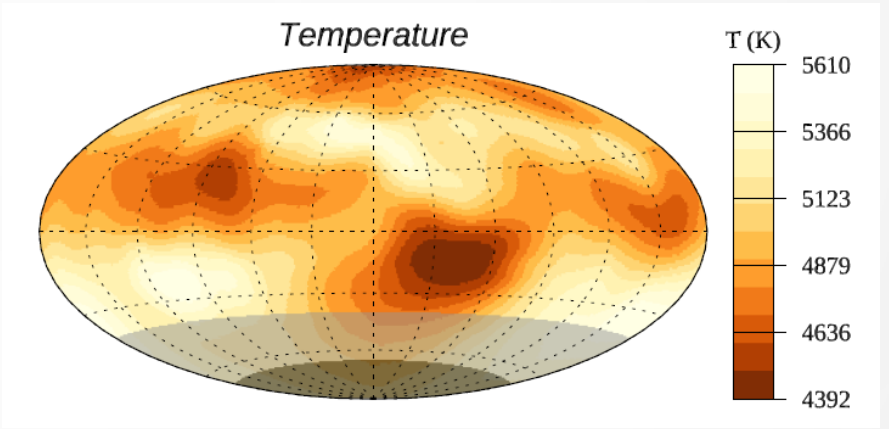
- Young active stars have large spot structures often at high latitudes.
- Magnetic breaking => older stars have smaller spots and nearer equator
- Post-main sequence subgiants and giants => surface inhomogeneities caused by convection.



4.1.2 LATITUDINAL TENDENCIES OF SPOTS

- Rapid rotation => high latitude/polar spots.
- Explanations:
  - Coriolis force acts on rising magnetic flux tubes
  - Meridional flow transports magnetic field towards poles
  - Dynamo generates high latitude spots
- Exceptions: Rapidly rotating stars with both high and mid latitude spots.

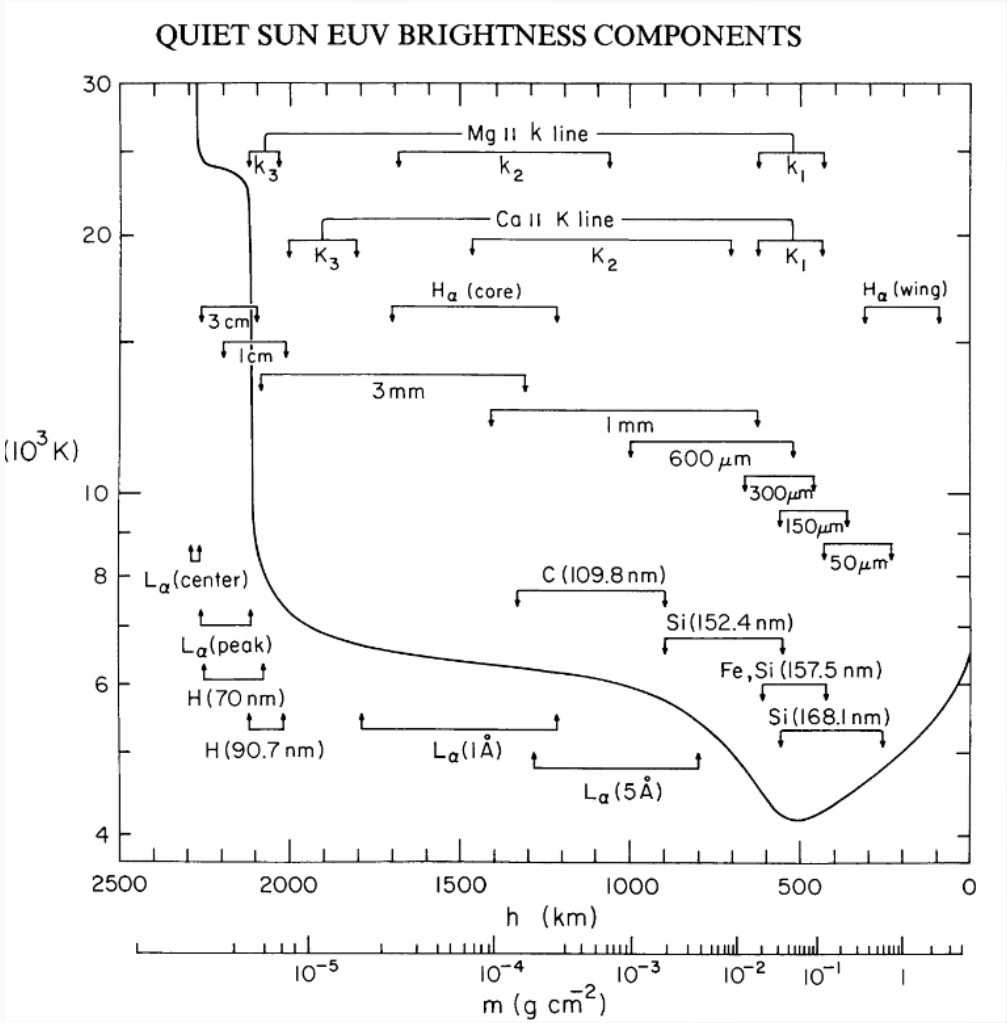




Surface temperature maps of V889 Her (Willamo et al. 2019) and LQ Hya (Kochukhov et al. 2023).

4.2 CHROMOSPHERIC ACTIVITY

- Chromosphere: Thin hot layer above the photosphere.
- Heating mechanism under debate.
- Useful indicators of chromospheric activity: Ca II H&K lines (3968.5 & 3933.7 Å).
- Other possible lines: Mg II h&k (2802.7 & 2795.5 Å), Hα (6564.6 Å), Ca II triplet (~8500 Å).



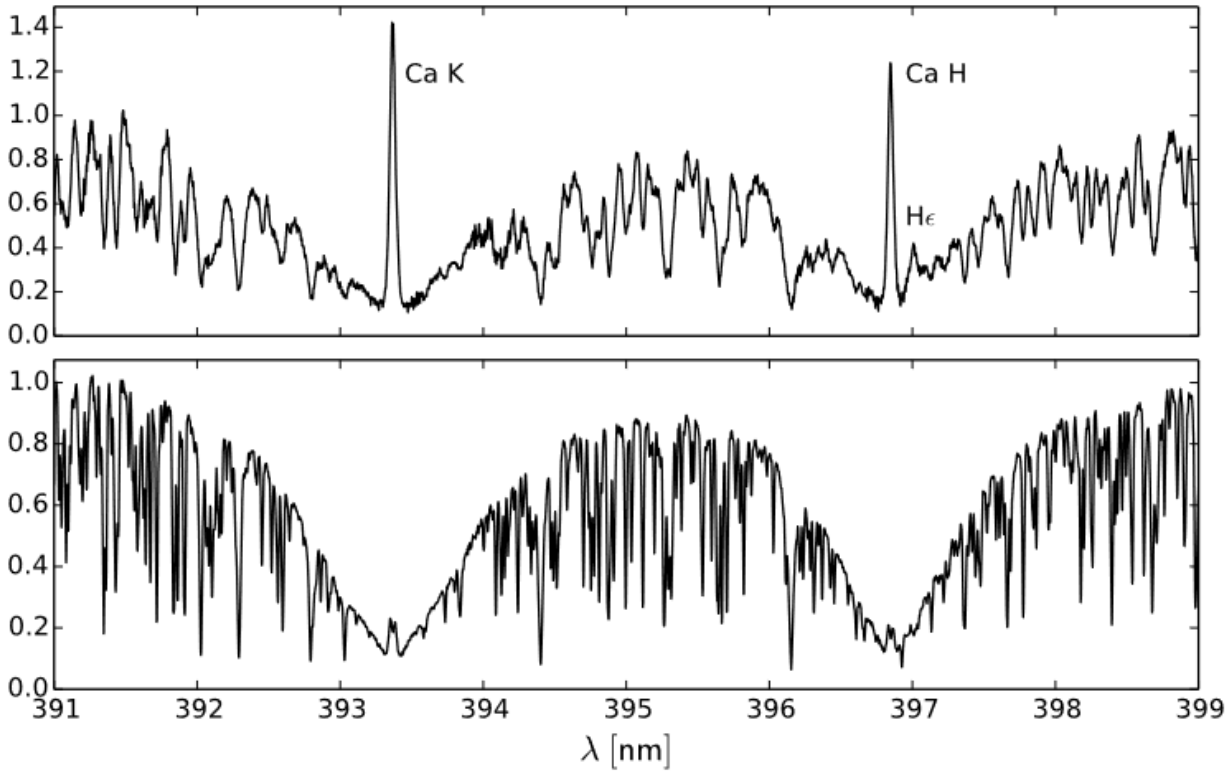
Semi-empirical solar atmosphere model (Vernazza et al. 1981).

4.2.1 CHROMOSPHERIC S INDEX

- Mount Wilson S-index (Vaughan et al. 1978)

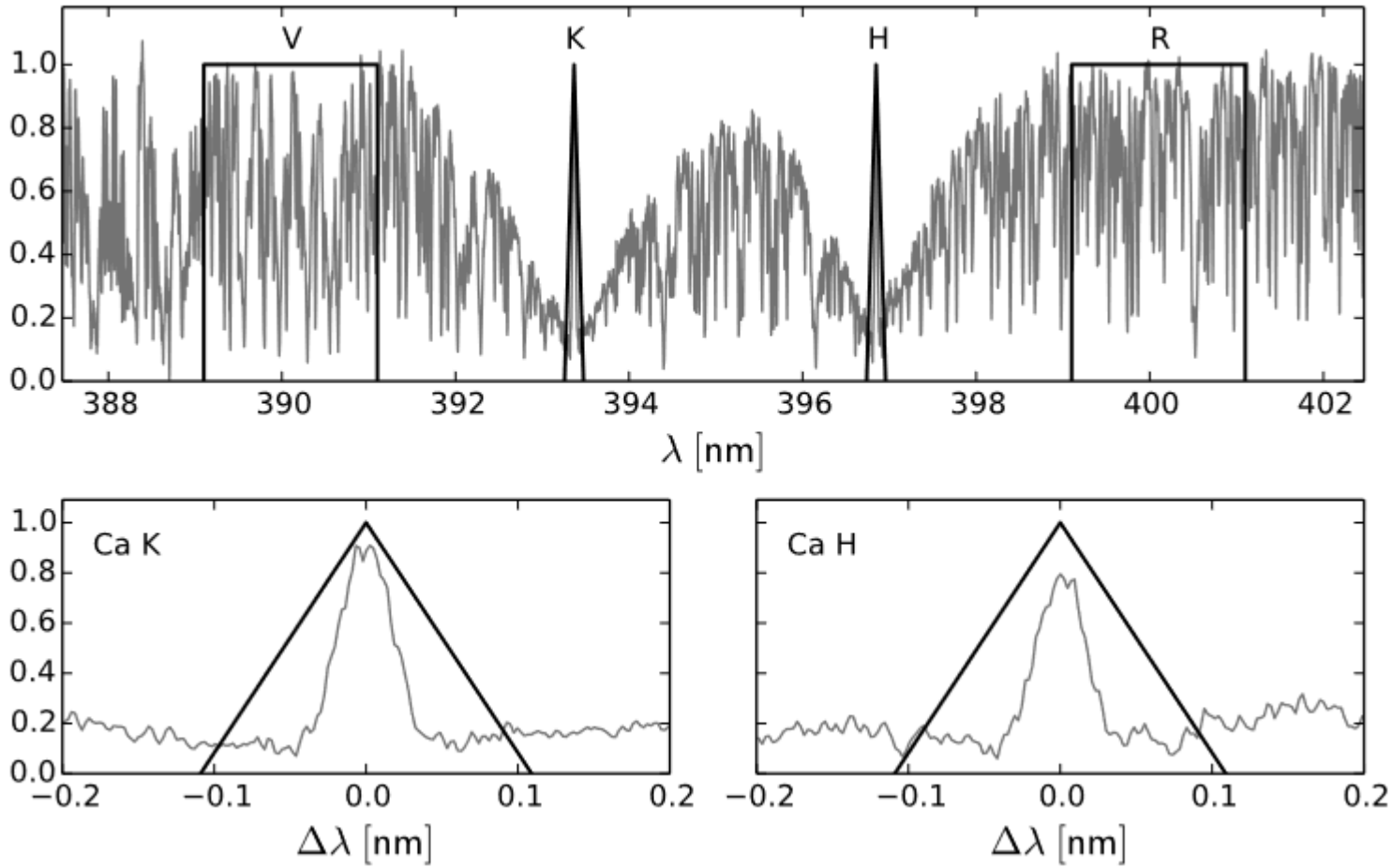
$$S = \alpha \frac{H + K}{R + V}$$

  - H, K, R and V are fluxes measured at the cores of the Ca II H&K lines and continuums on both sides
  - α instrumental calibration constant.



Ca II H&K lines of the stars V383 Lac and V774 Tau (Lehtinen 2016).

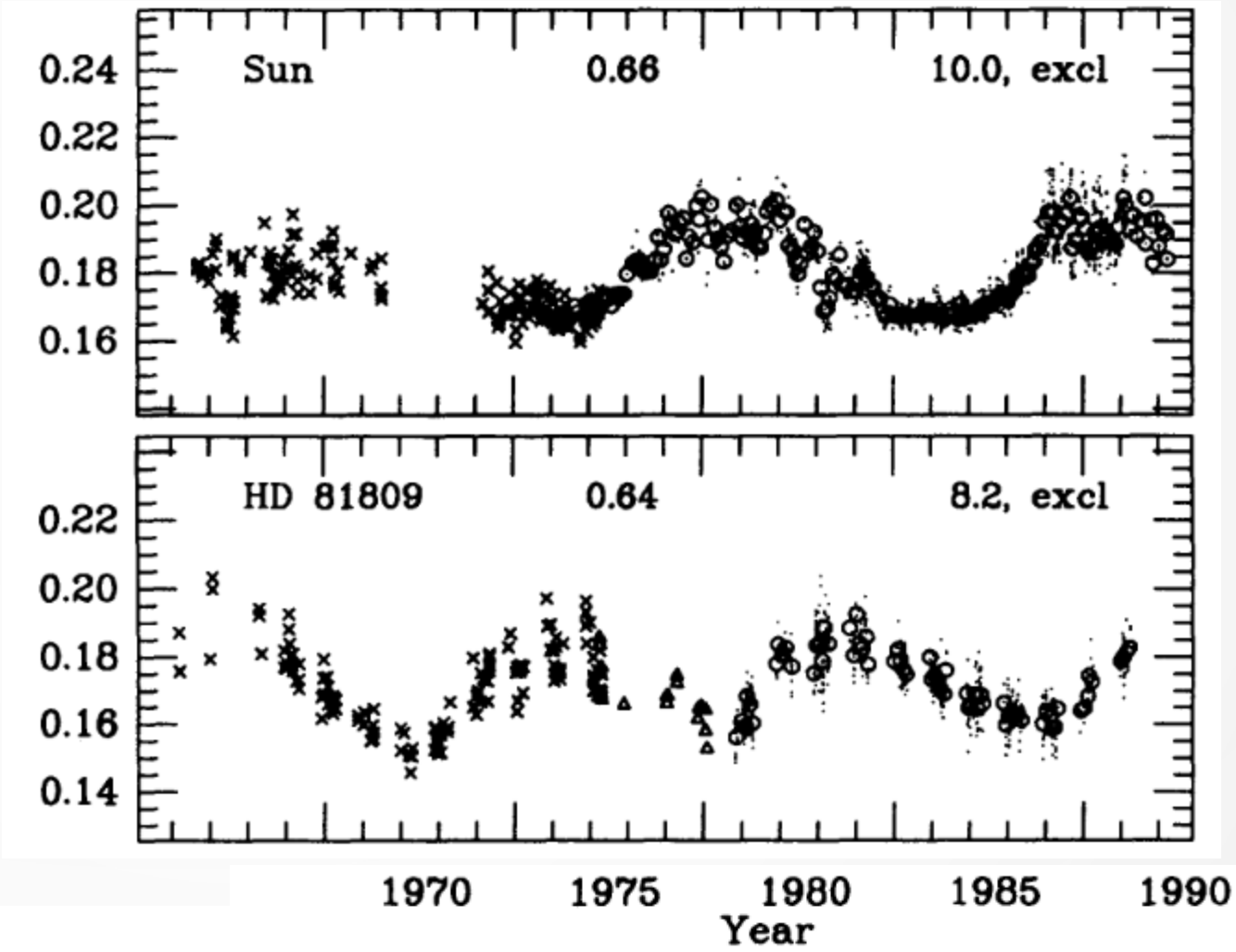
4.2.2 MEASURING S-INDEX



The spectral integration windows H, K, V, and R displayed on the spectrum of DX Leo (Lehtinen 2015).

4.2.3 LONG-TERM VARIATION OF S-INDEX

S-index measurements of the Sun and HD 81809 (Baliunas et al. 1995).



4.2.4 FRACTIONAL EMISSION FLUX R'_{HK}

- Usually, the level of chromospheric activity is given as fractional emission flux R'_{HK}.
- Transformation from S to R'_{HK} for **main sequence stars** (Middlekoop 1982; Noyes 1984; Rutten 1984):
  - We define $R_{\rm HK} = F_{\rm HK}/\sigma T_{\rm eff}^4$, where $R_{\rm HK} = 1.34 \cdot 10^{-4} C_{\rm cf} S$

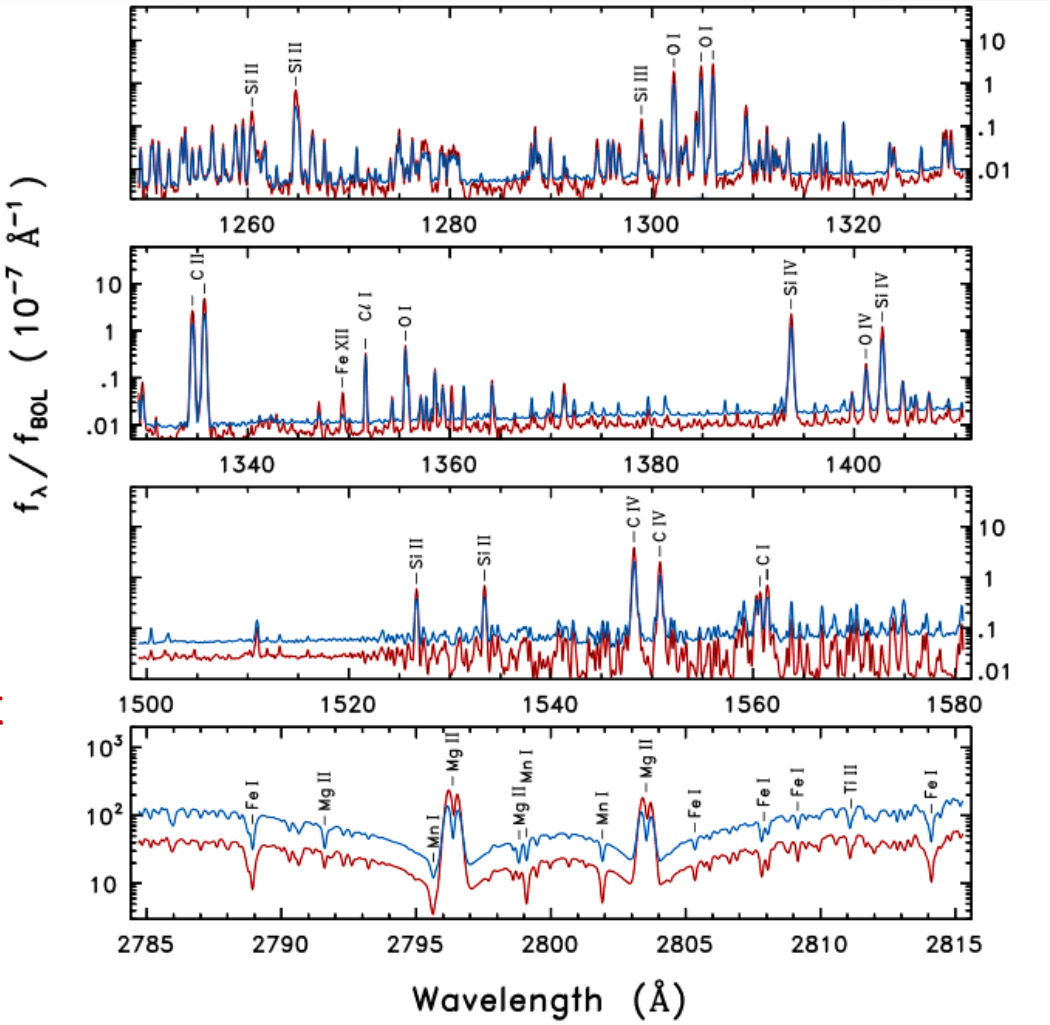
$\log C_{\rm cf} = 0.25\,(B-V)^3 - 1.33\,(B-V)^2 + 0.43\,(B-V) + 0.24$, when $0.3 \leq B-V \leq 1.6$

- To get R'_{HK} the photospheric contribution $R_{\rm phot}$ has to be subtracted:

$R'_{\rm HK} = R_{\rm HK} - R_{\rm phot}$, where

$\log R_{\rm phot} = -4.898 + 1.918\,(B-V)^2 - 2.893\,(B-V)^3$

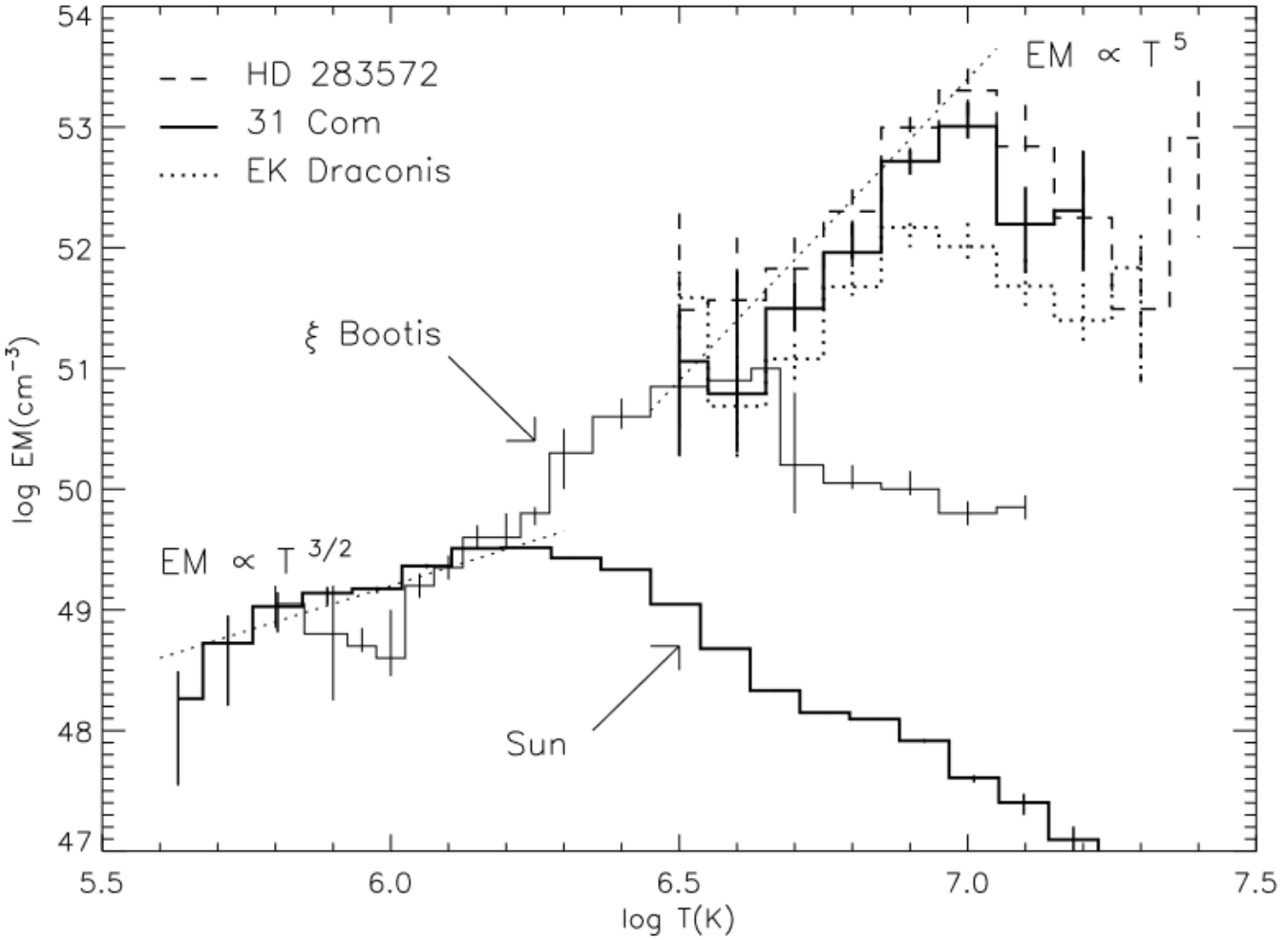
4.3 TRANSITION REGION UV RADIATION



UV-spectra of α Cen A (blue) and B (red). Most emission lines are from the transition region (Ayres 2020).

4.4 X-RAY RADIATION FROM THE CORONA

Emission measure distributions of the coronal plasma of the quiet Sun (G2V), ξ Bootis (G7V) , EK Dra (G5V), 31 Com (G0III) and HD 283572 (G5IV) from Scelsi et al. (2005).



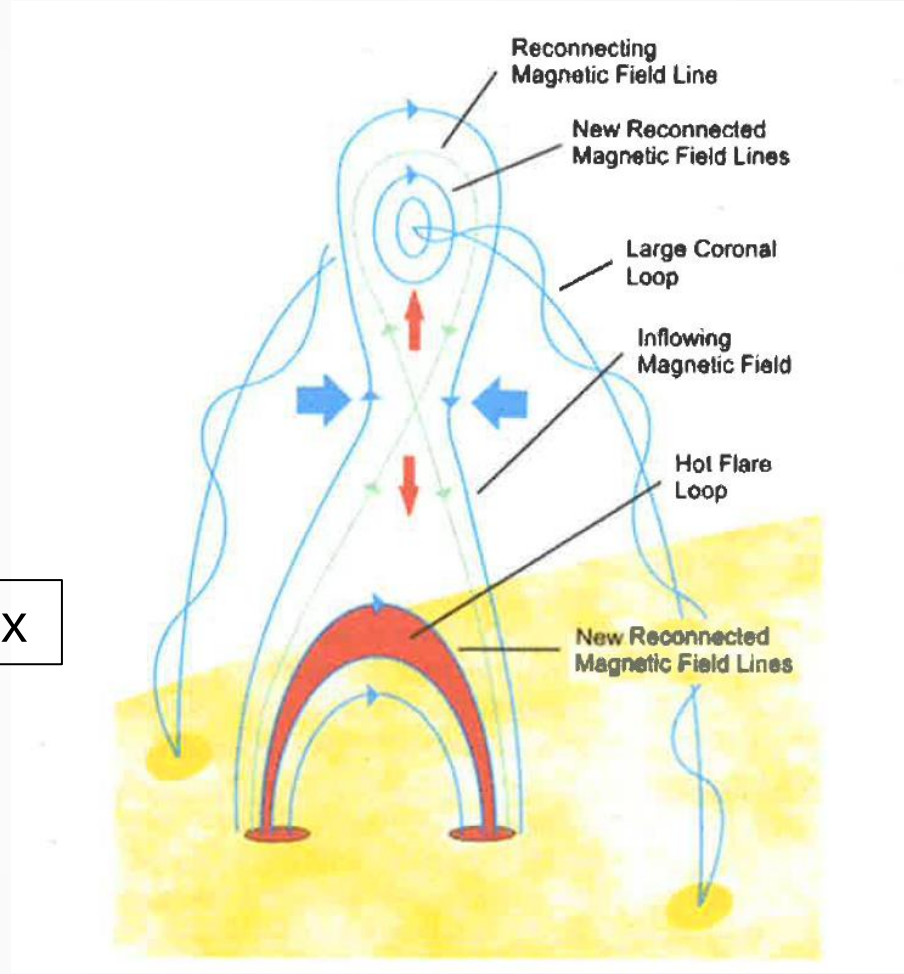
4.5 STELLAR FLARES

- Flares arise from magnetic reconnection.
- In the Sun often asociated with coronal mass ejections (CME).
- Flares seem to follow a general power law:

Frequency

power-law index

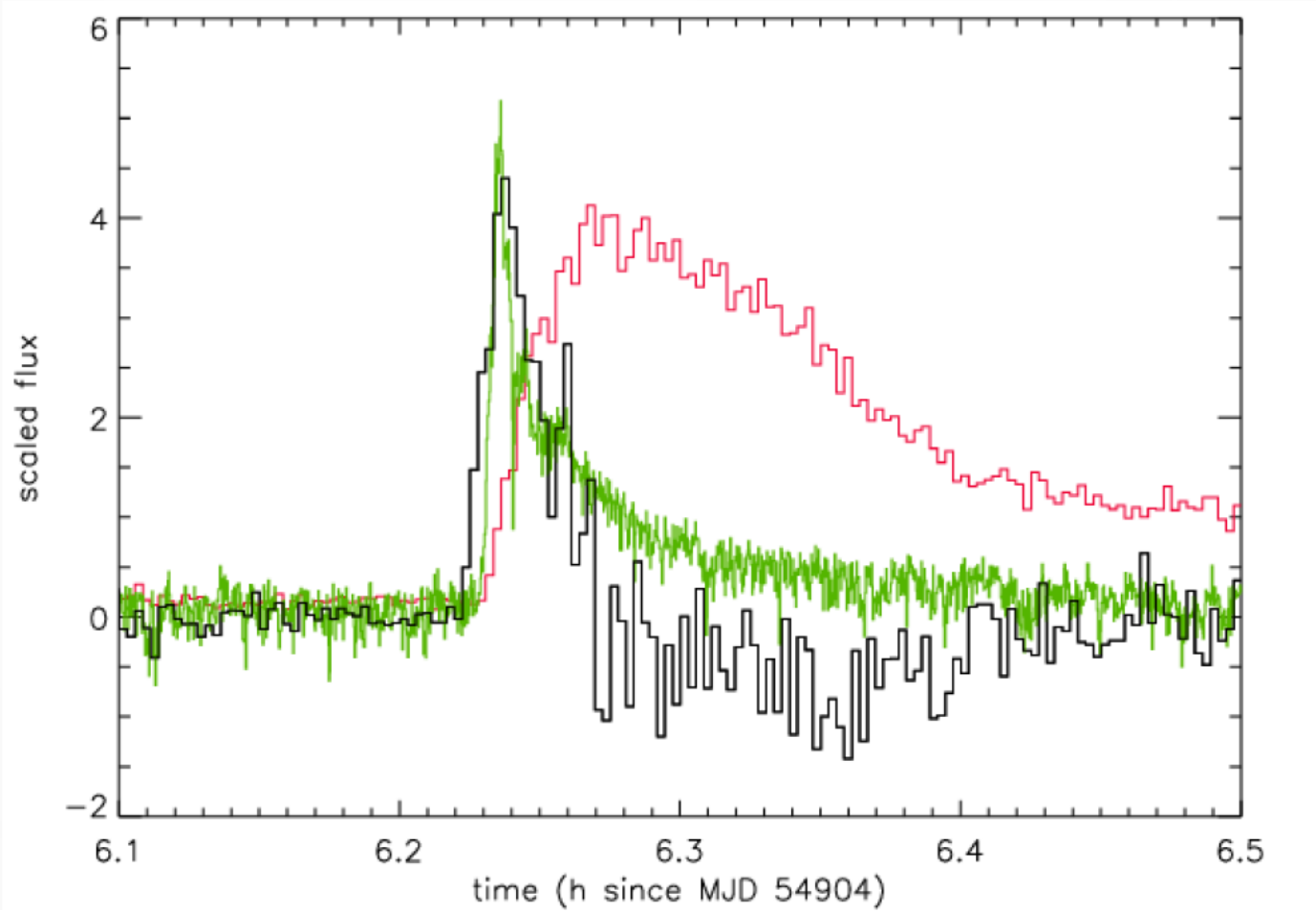
$$\frac{df(E)}{dE} \approx f_0 E^{-\alpha}$$



Flare model (GB, Fig. 4.12).

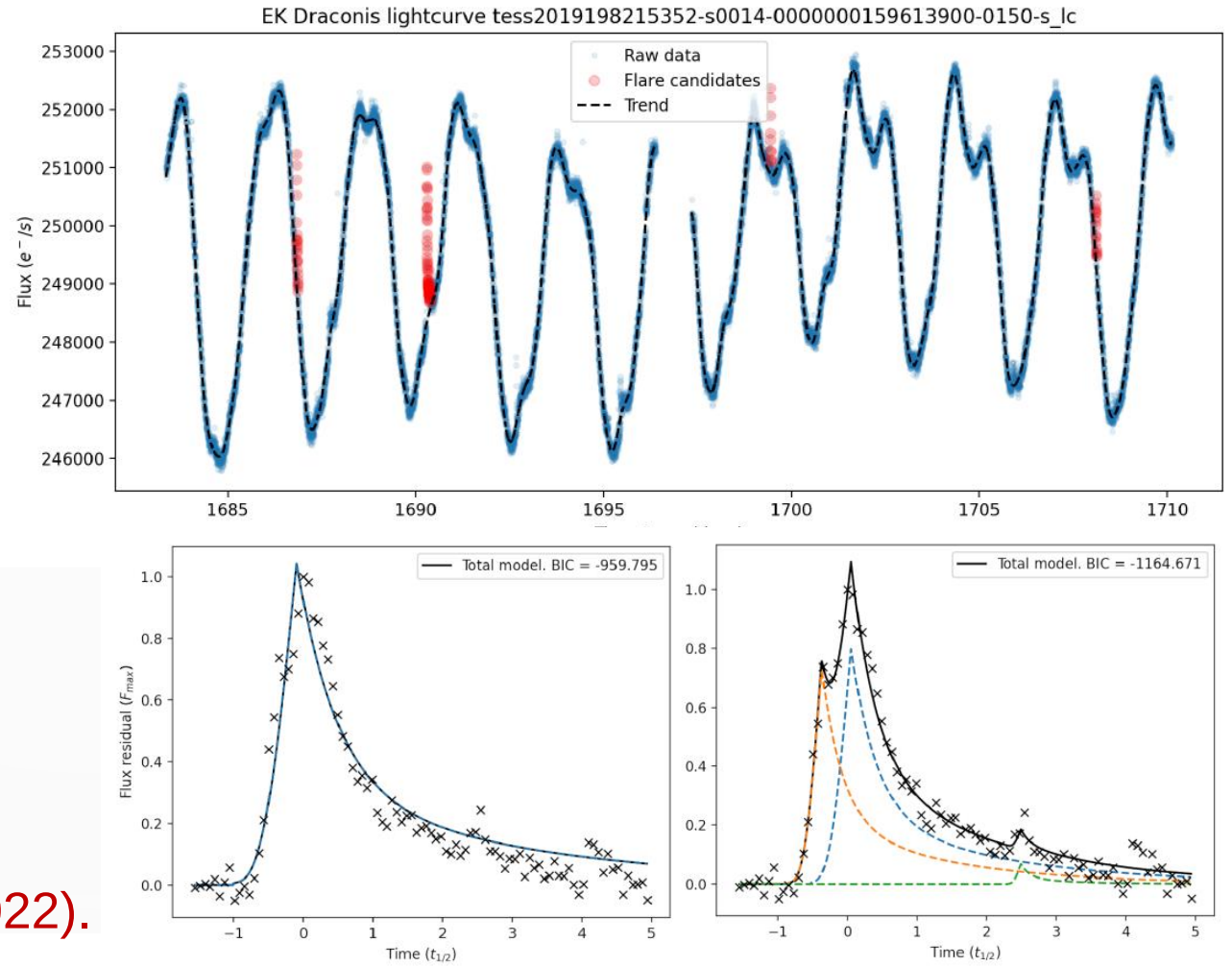
4.5.1 FLARES IN DIFFERENT WAVELENGTHS

Large flare of Proxima Centauri: X-ray (red), its time derivative (black) and the optical (green) light curve (Fuhrmeister et al. 2011).



4.5.2 WHITE-LIGHT FLARE

- Heating of photosphere => white-light flare.
- Significant increase in visual fluxes.
- Characteristic fast rise and slow exponential decay.

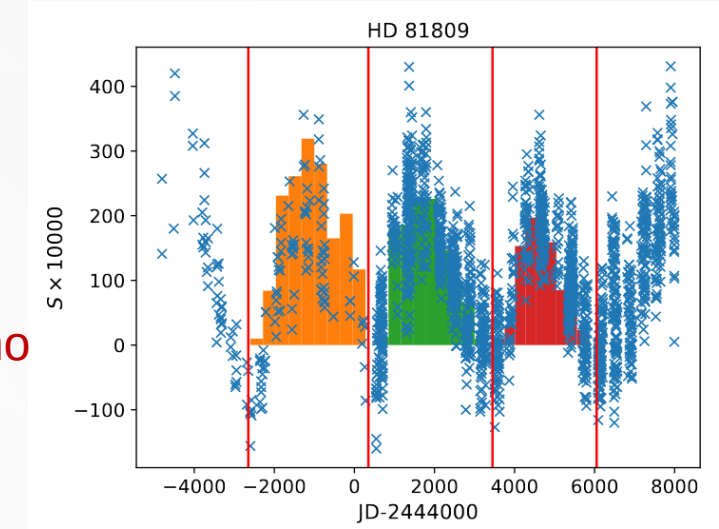


TESS light curve of EK Dra showing flares (Korhonen 2022).

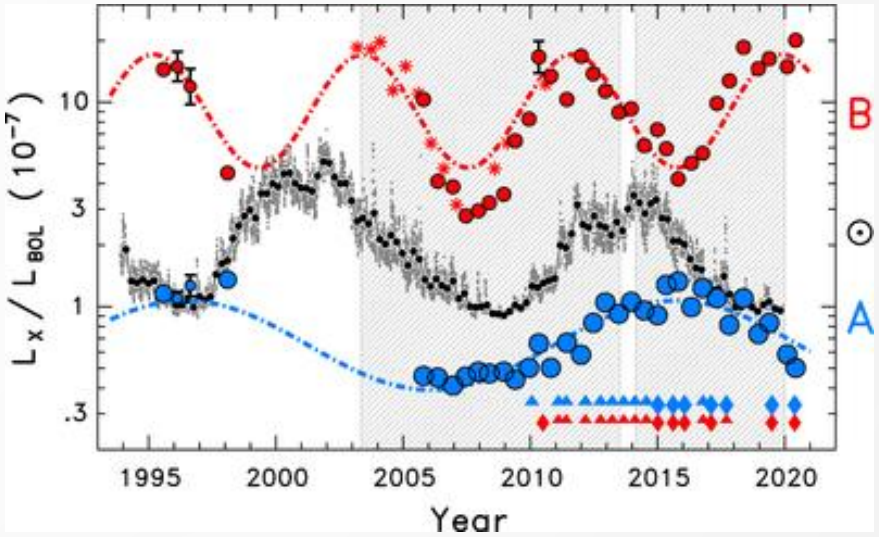
4.6 STELLAR CYCLES

Same cycles

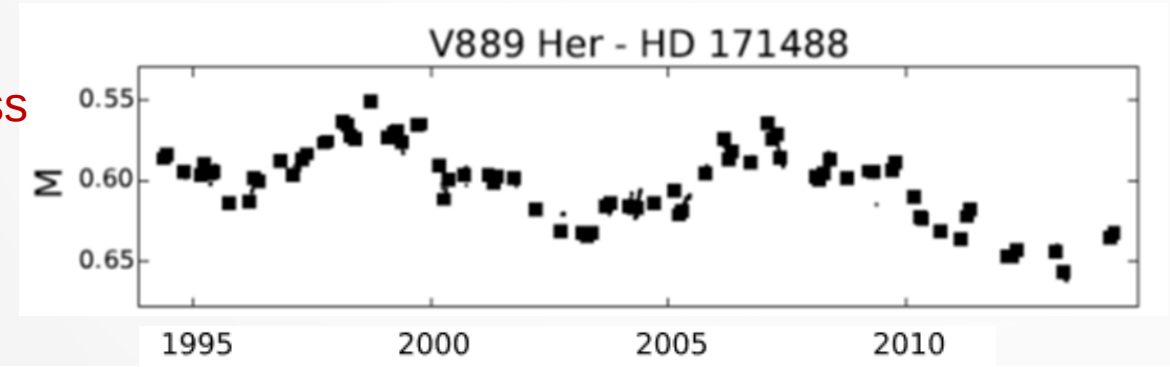
- Spot cycles.
- Cycles of chromospheric activity.
- Cycles of coronal activity.
- Magnetic cycles.



S-index of HD 81809 (Willamo et al. 2020).



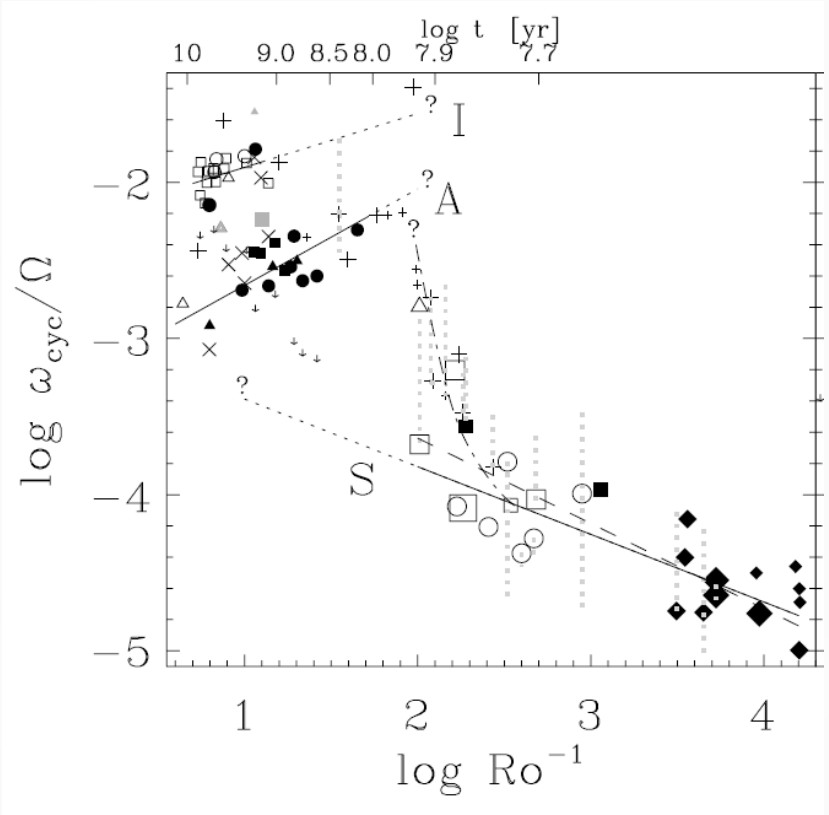
Relative X-ray luminosities of the Sun, α Cen A and , α Cen B (Ayers 2020).

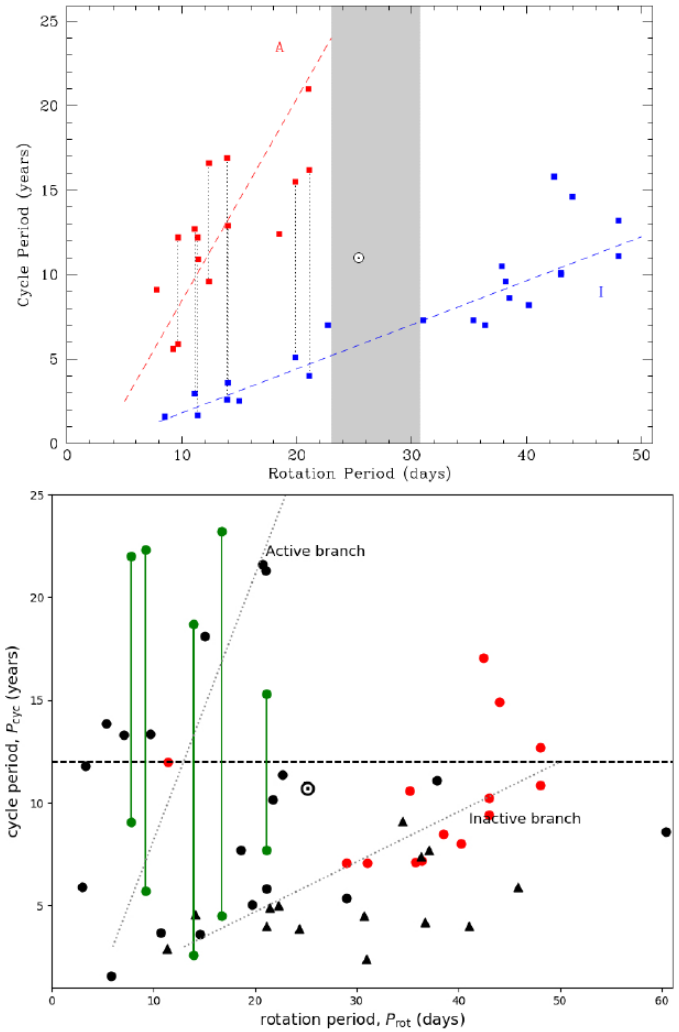


Mean brightness of V889 Her (Lehtinen et al. 2016).

4.7 BRANCHES OF ACTIVITY

- Stellar activity branches:
  - I = inactive
  - A = active
  - S = superactive

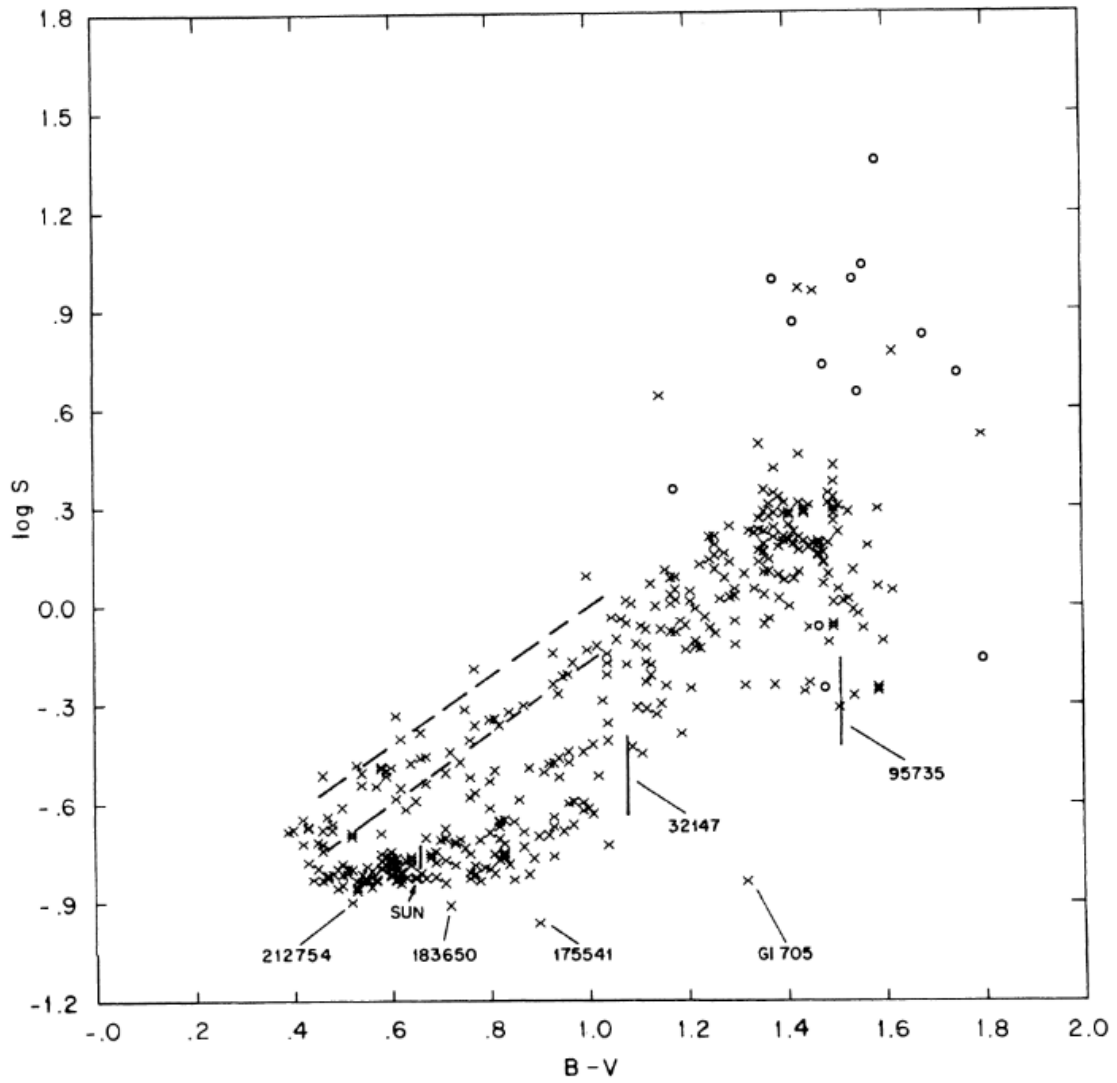




Saar & Brandenburg (1999), Metcalfe et al. (2016) and Boro Saikia et al. (2018).

4.8 VAUGHAN-PRESTON GAP

Gap in the magnetic activity between active and inactive stars (Vaughan & Preston 1980).



5. CLASSIFICATION OF ACTIVE STARS

- In general:
  - Classification by prototypes $\mapsto$ not accurate
  - Often original classification $\mapsto$ later revised/expanded definition
  - Depending on the observation method, the same star can be classified differently
  - Each star has individual peculiarities

5.1 CLASSIFICATION BY D.S. HALL

- Hall (1991) lists the following classes of stars with dynamo action:
  - RS CVn binaries
  - BY Draconis variables (single and binary stars)
  - FK Comae stars (single)
  - Other rapidly rotating G-K single giants
  - UV Ceti type flare stars (single and binary)
  - Solar type single main sequence stars
  - T Tauri variables
  - W Uma binaries
  - Cool secondaries of Algol type contact binaries
  - Cool secondaries of cataclysmic variables

5.2 RS CVn BINARIES

- Detached binaries
- Primary component F-G V-IV (later extended to III)
- 2:ndary can also be magn. active
- Rotation period $1\ \mathrm{d} < P < 30\ \mathrm{d}$
- Strong Ca II H&K emission
- Original definition by Hall (1976)

5.3 BY DRACONIS STARS

- Spectral class: K-M V (later extended to G V)
- Rotation period ~ 1 d – ”a few” days
- Low amplitude light curve
- Ca II H&K emission
- Definition by Bopp & Fekel (1977)

5.4 FK COMAE STARS

- Spectral class: G-K III-IV
- Single
- Rapid rotation: $v \sin i > 40$ km/s
- Possibly coalesced W UMa -binaries
- Strong Ca II H&K emission
- Strong chromospheric and transition region UV-emission
- Definition by Bopp & Rucinski (1981)

5.5 T TAURI STARS

- Rapid & irregular changes in brightness
- Spectral class F5 – G5, low luminosity
- Ca II H&K emission + other chromospheric emission lines
- Strong Li absorption lines $\mapsto$ young stars
- Connected to interstellar clouds
- Sub-groups: Classical = CTTS, weak emission = WTTS, naked = NTTS
- Original definition: Joy 1945
- Newer review article: Petrov 2003 (Astrophysics 46, 506)