Variability of the Sun and Sun-like Stars on Different Timescales

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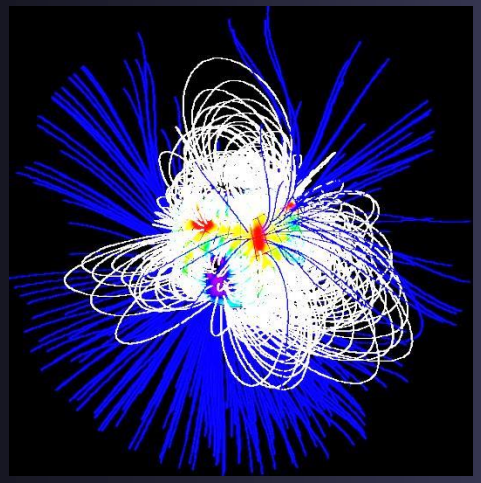

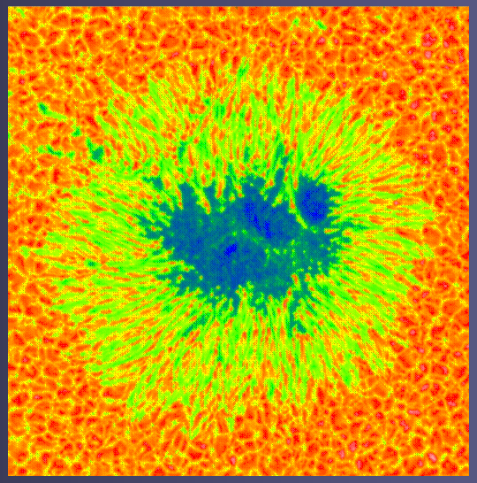

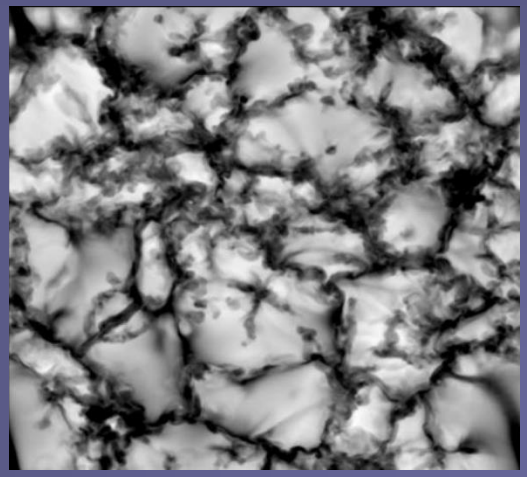

Variations in activity on many timescales

- Minutes – hours:
  Flares, CMEs
- Solar rotation (27 days):
  rotational modulation
- Solar cycle (11 years):
- Gleissberg cycle +
  secular trend (century):
- Grand minima &
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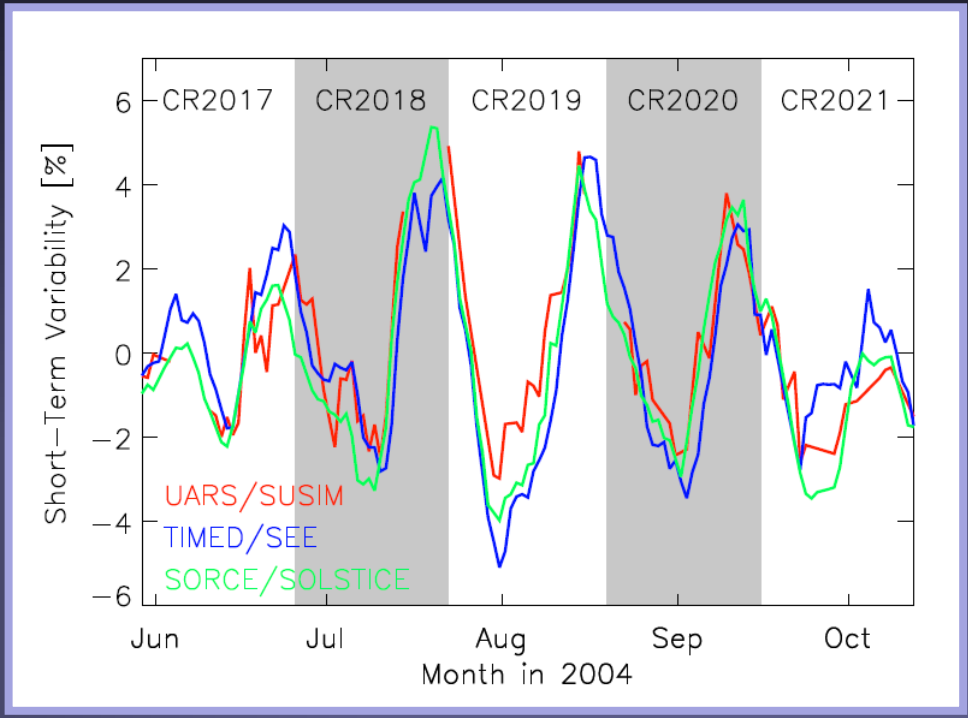

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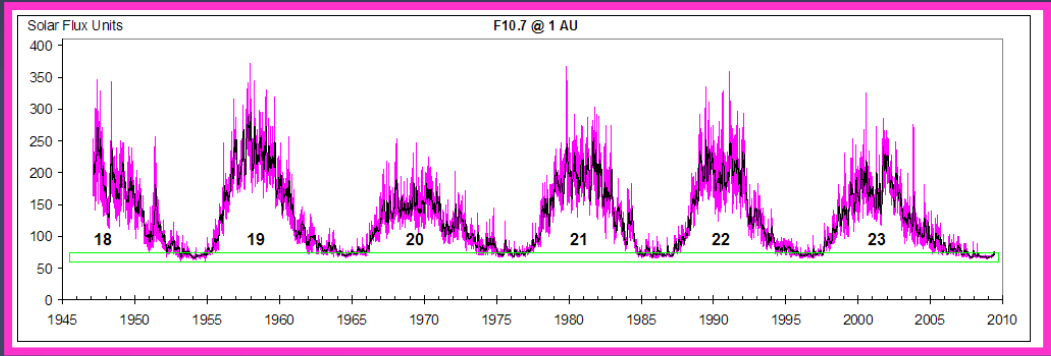

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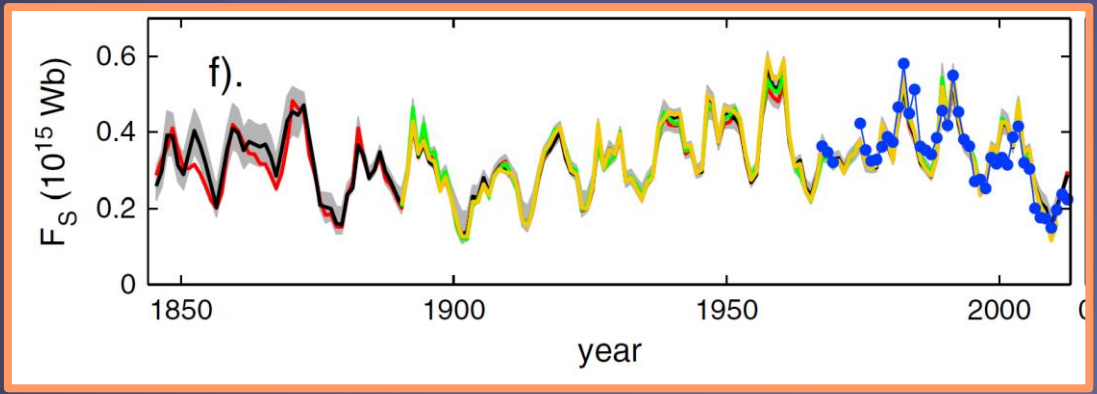

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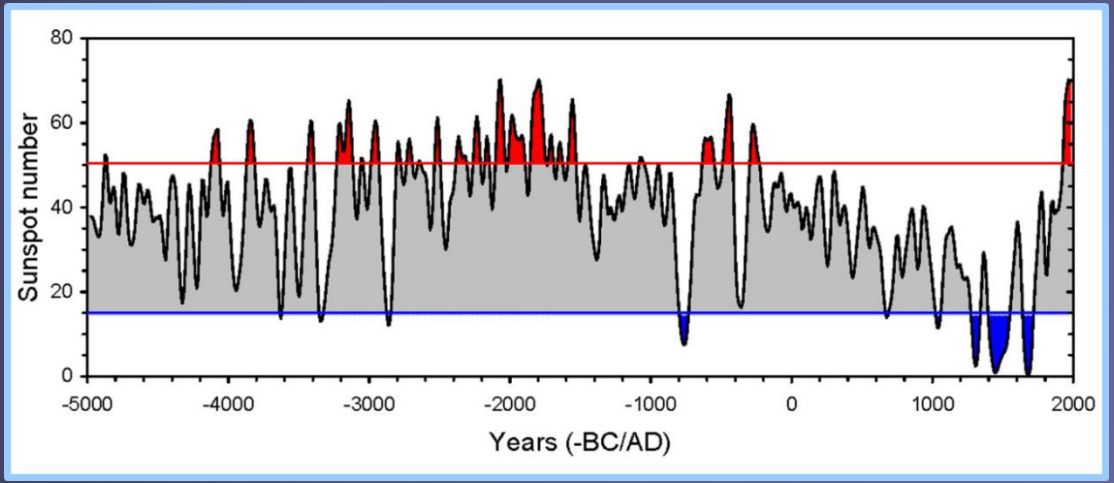
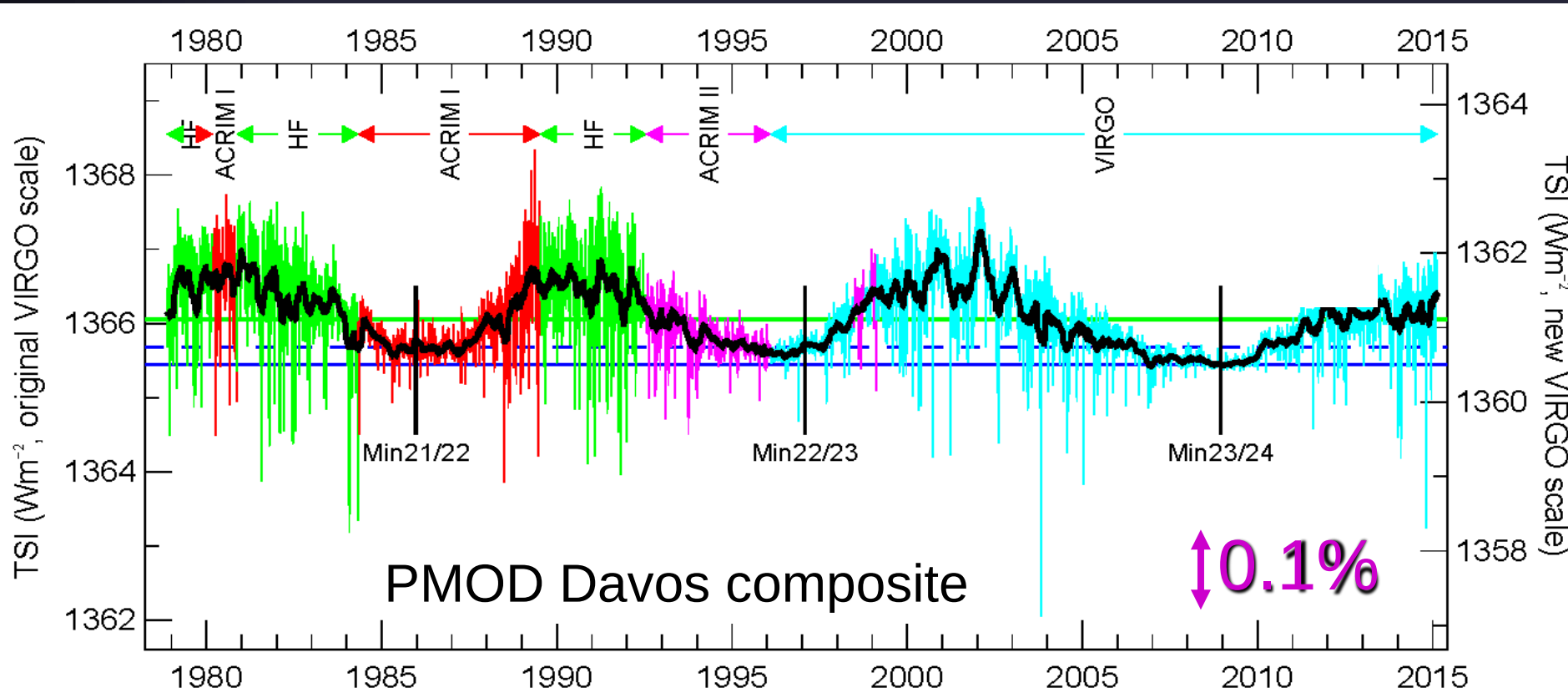


Total Solar Irradiance (TSI)



Composite of TSI constructed by putting together measurements from different instruments

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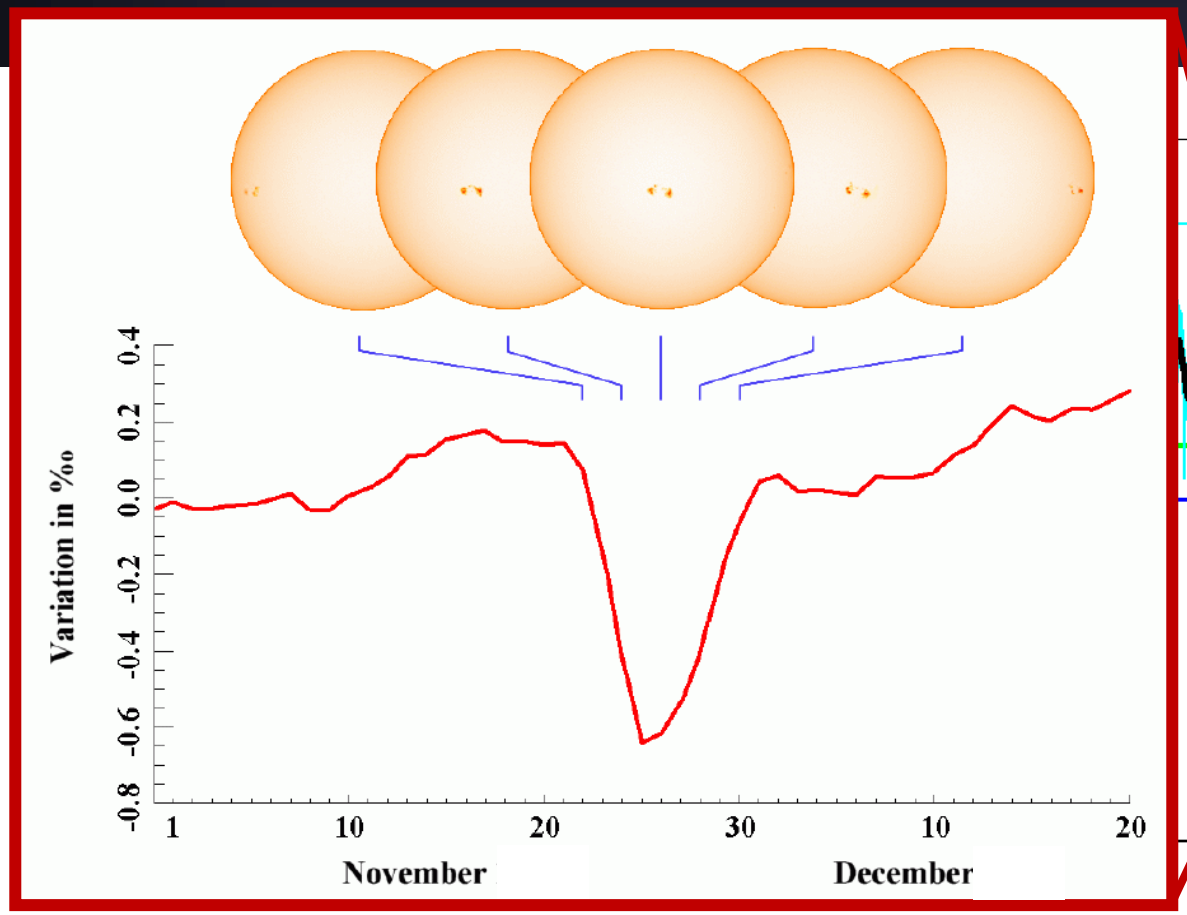

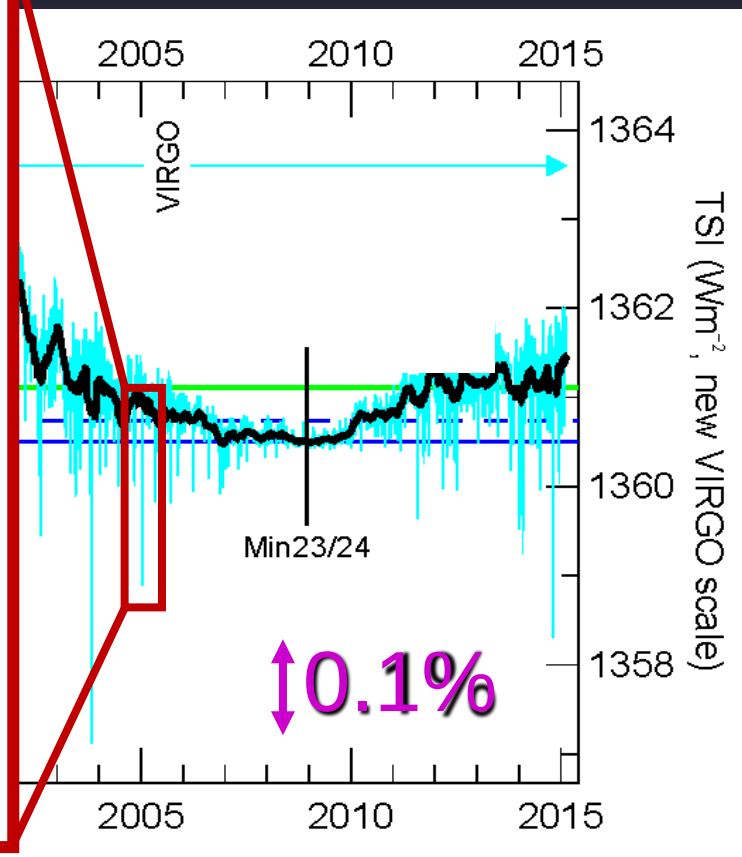

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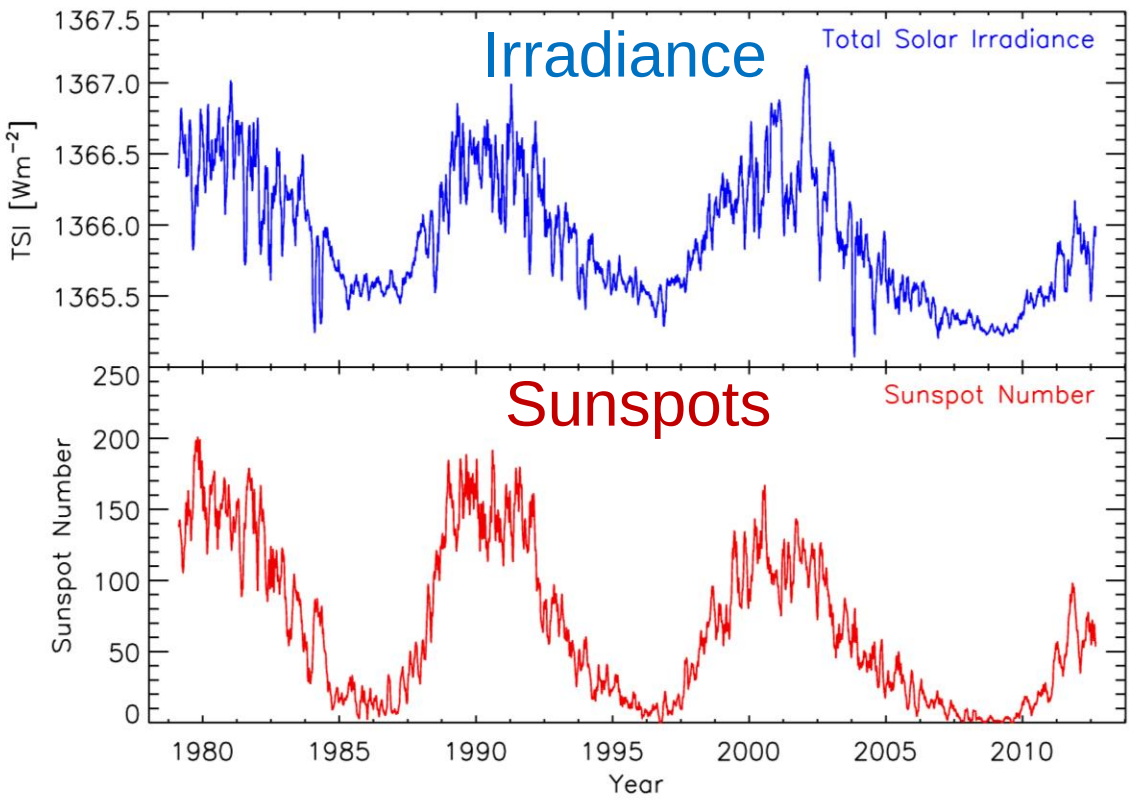
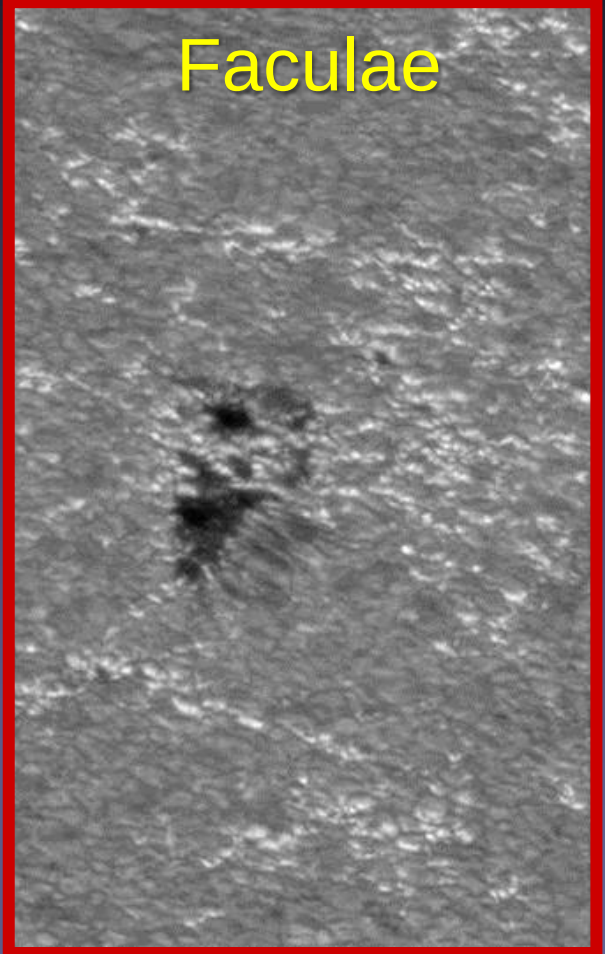
Irradiance and sunspots



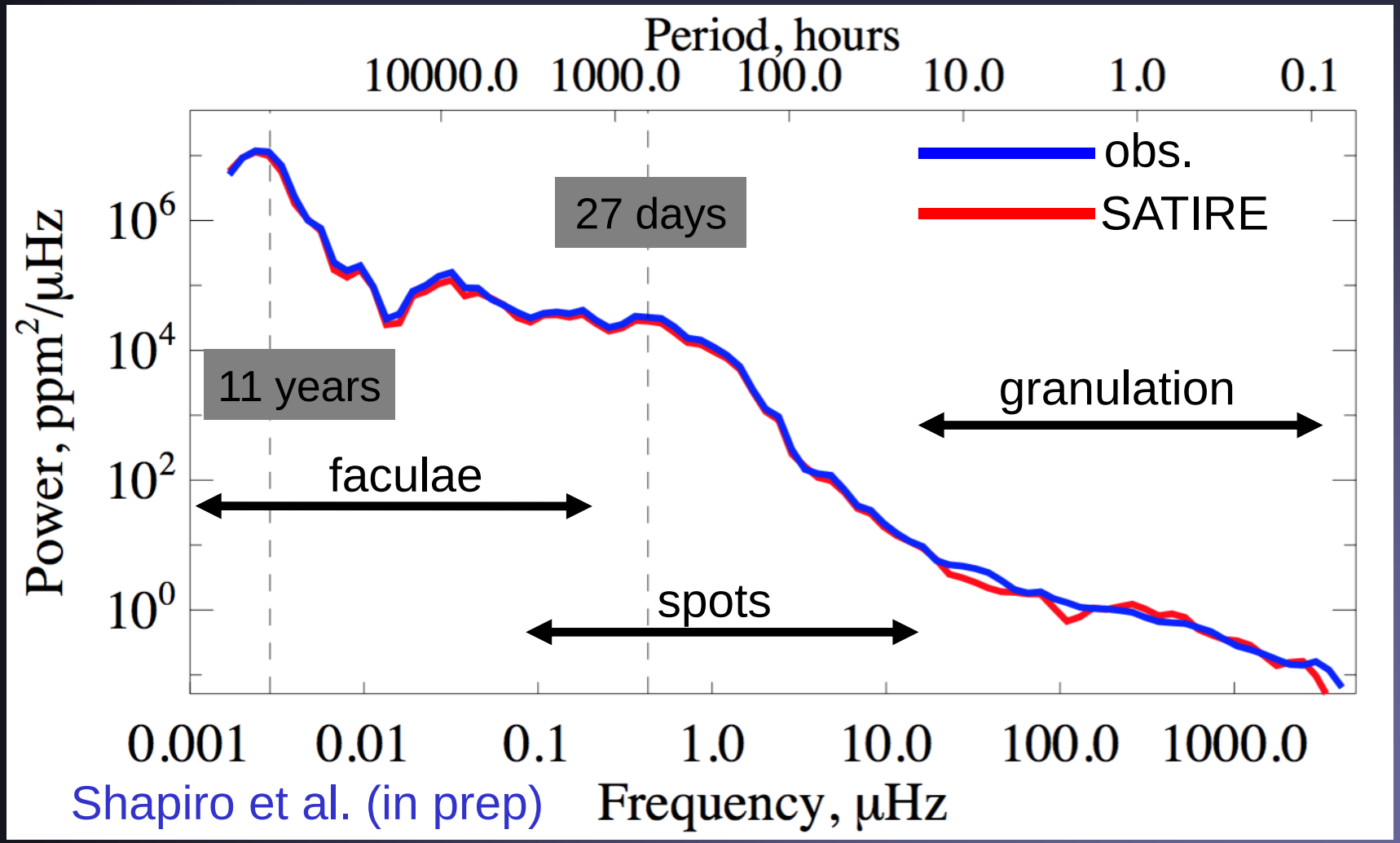
Courtesy K.L. Yeo



The Sun is **brightest** at times of high solar activity, i.e. when the number of **dark** sunspots is largest

Irradiance changes: measured & modelled

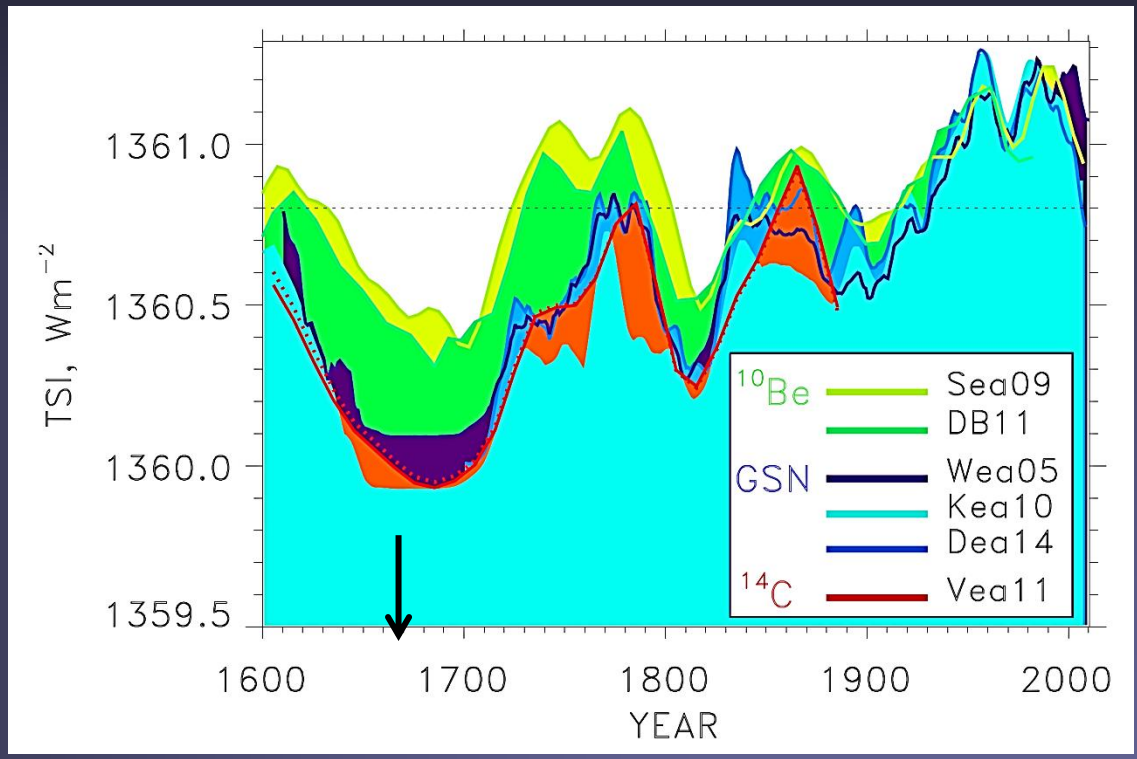
Global wavelet power spectrum of Total Solar Radiative Flux (1996 - 2015)



Solar Irradiance Since 1700: How strong are the variations?

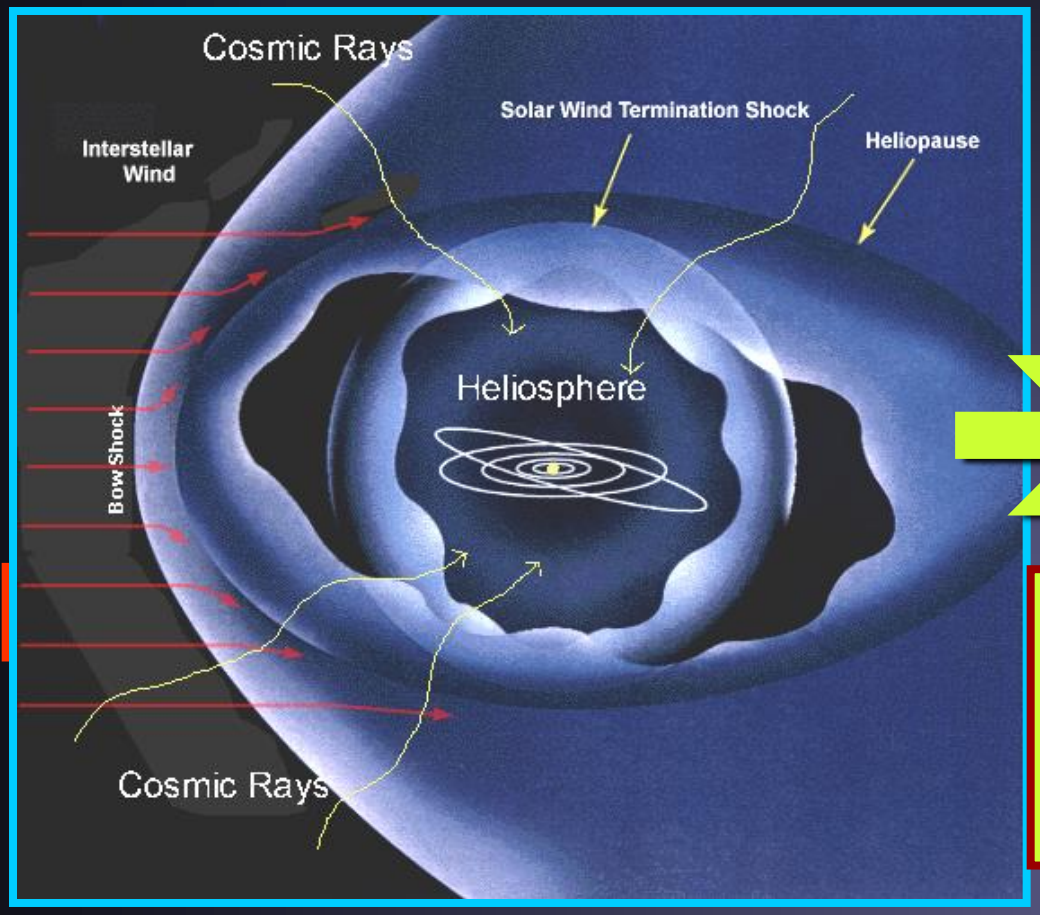
Different models give different increase in total solar irradiance (TSI) since Maunder minimum
0.6 - 3 W/m^2 → Unsatisfactory!

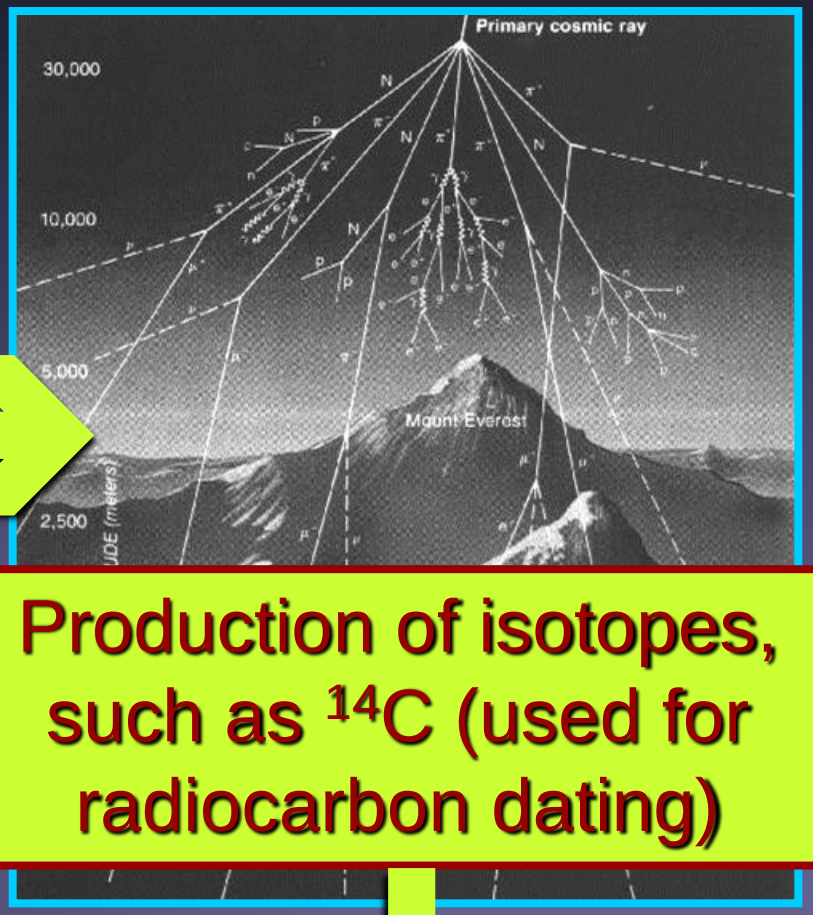
But the shape of profile of TSI with time is relatively similar



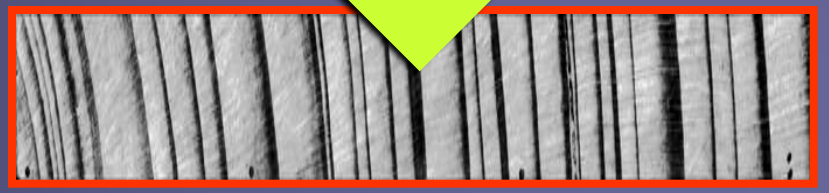
SATIRE: more physics-based model (flux transport simulations)
Reproduce: observed TSI, SSI, total & open magnetic flux.
Gives rise of TSI since Maunder minimum of ~1.2 W/m^2

Cosmic rays, the Sun & tree rings





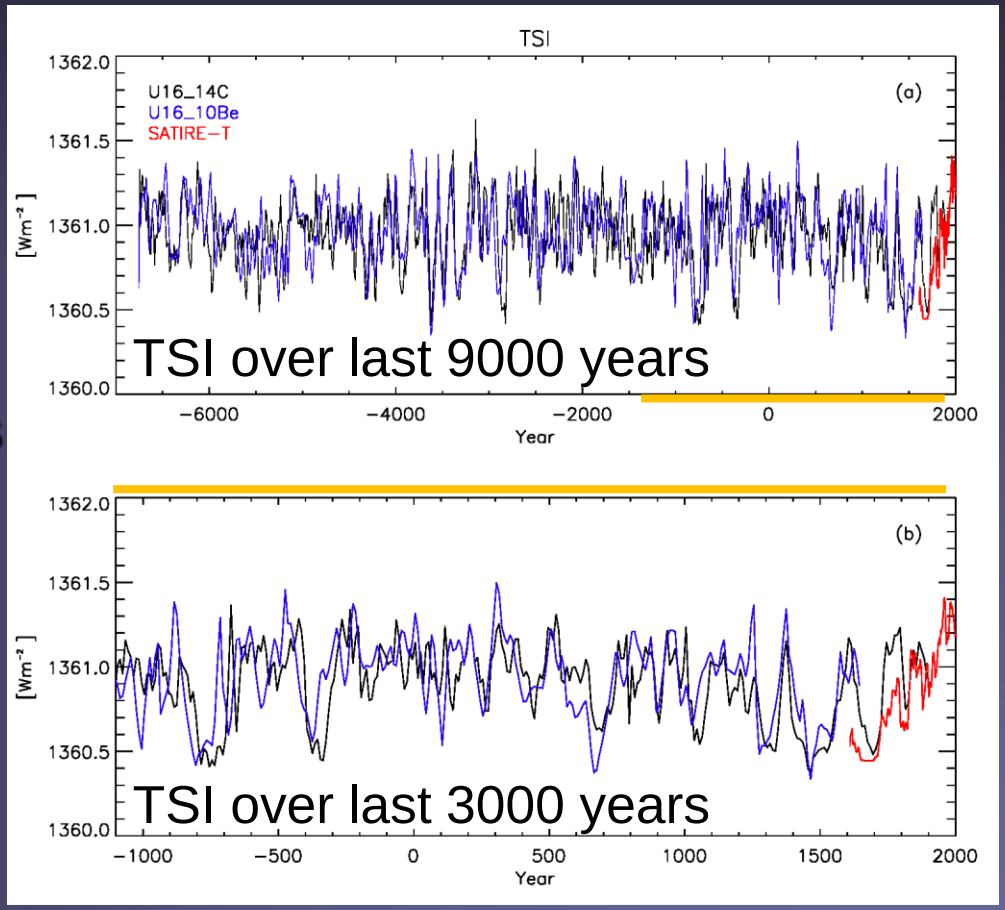
Production of isotopes, such as ^{14}C (used for radiocarbon dating)



Cosmic ray flux is changed by solar activity ➔ get solar activity level from, e.g., ^{14}C in terrestrial archive

Solar irradiance over the holocene

- ^{14}C from trees, ^{10}Be from ice cores ➔ cycle averaged magn. flux for past 9000 yrs (Solanki+04; Usoskin+07...)
- Then using SATIRE model compute TSI over 9000 yrs (Vieira+11; Wu+17)
- There are many periods of high and of low activity, with the TSI following roughly the activity level, but being more regular than activity



Wu, C.-J. et al. in prep.

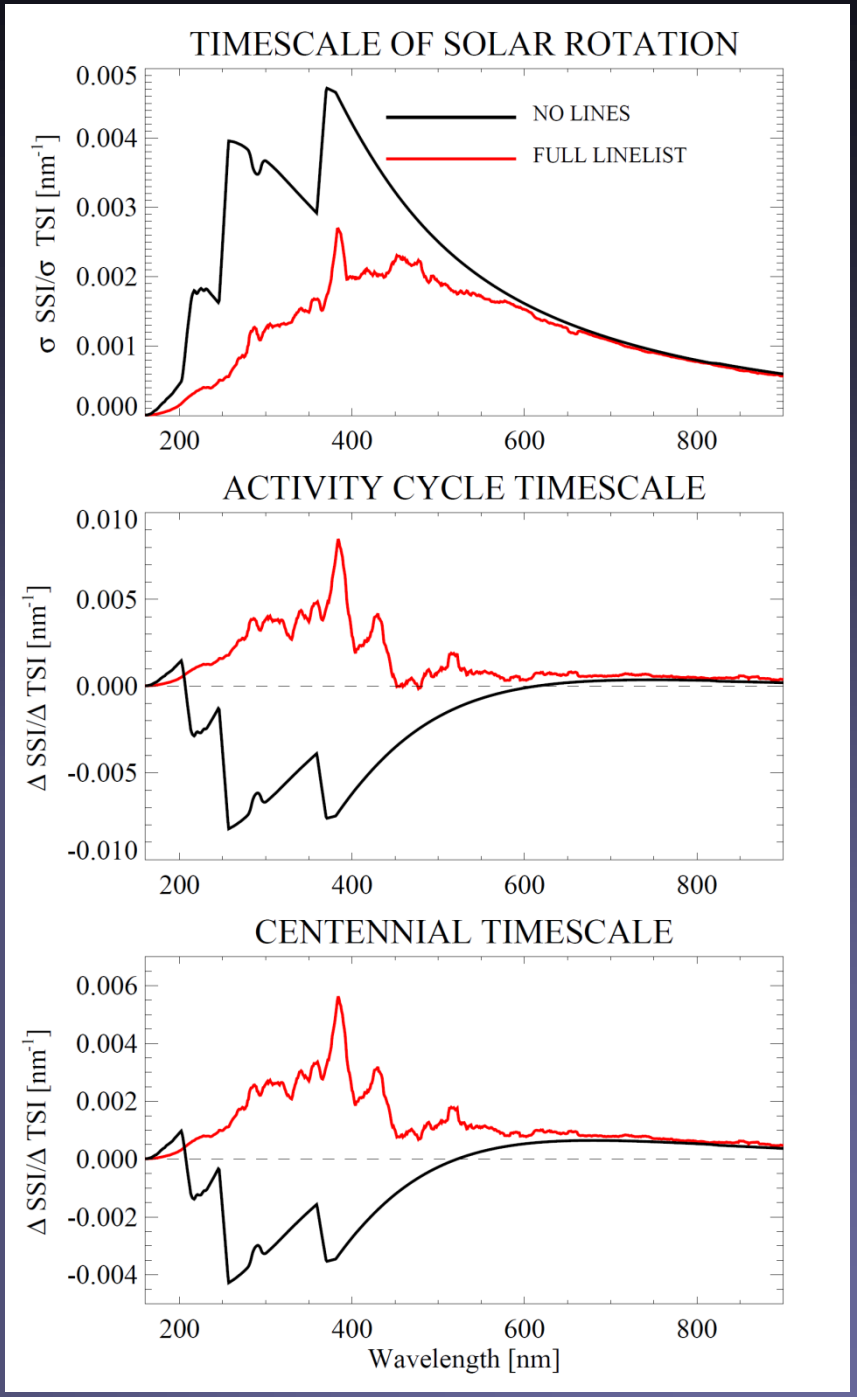
Influence of spectral lines

- Influence of spectral lines depends on timescale. For Sun:
  - rotational timescale: spectral lines decrease the variability
  - activity cycle and longer: spectral lines change sign of variations!

➔ Flux variations of a star depend significantly on metallicity

➔ Metal poor Sun-like stars will have larger rotational variability, and smaller, or even oppositely signed cyclic variability

Shapiro et al. 2015



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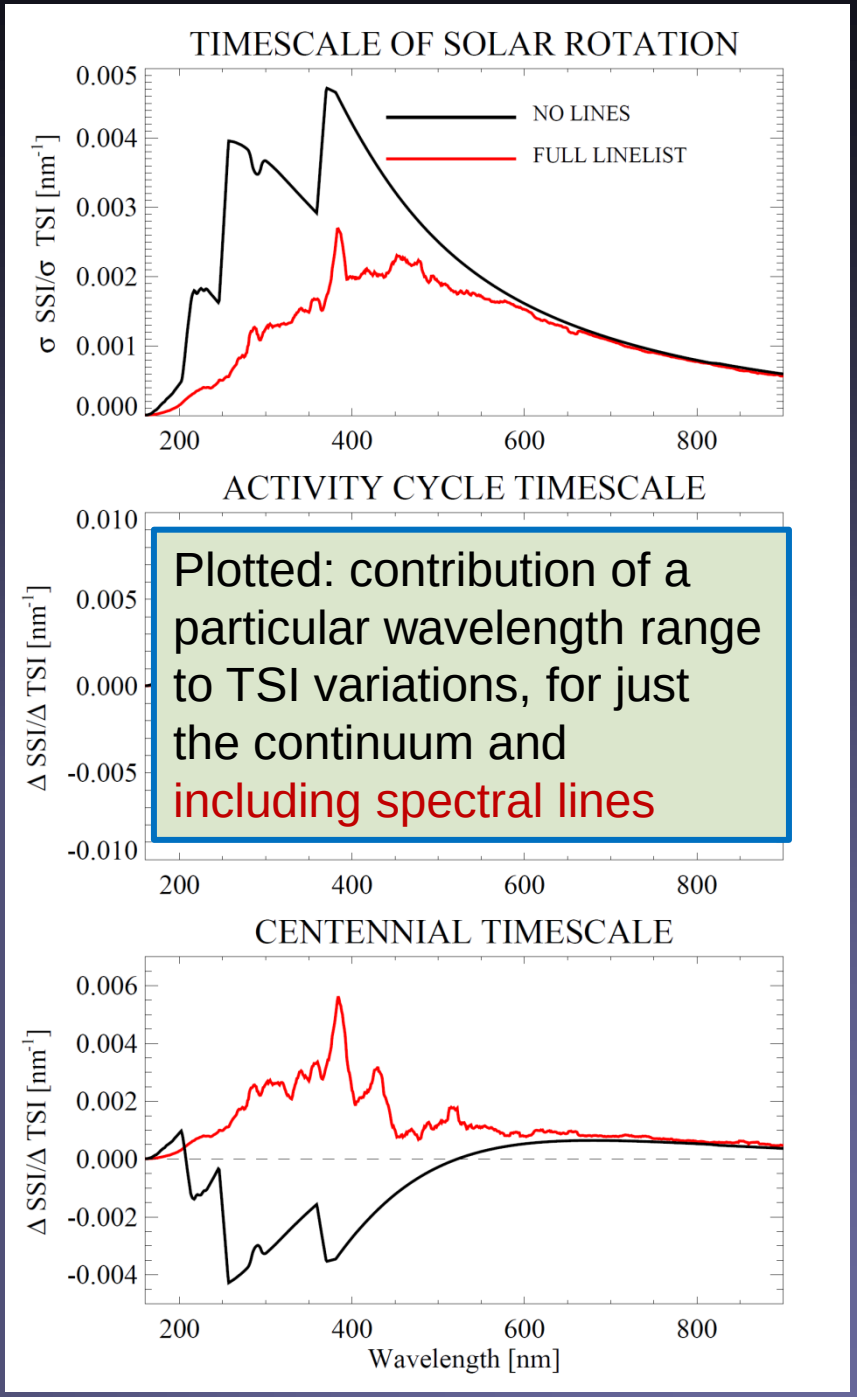
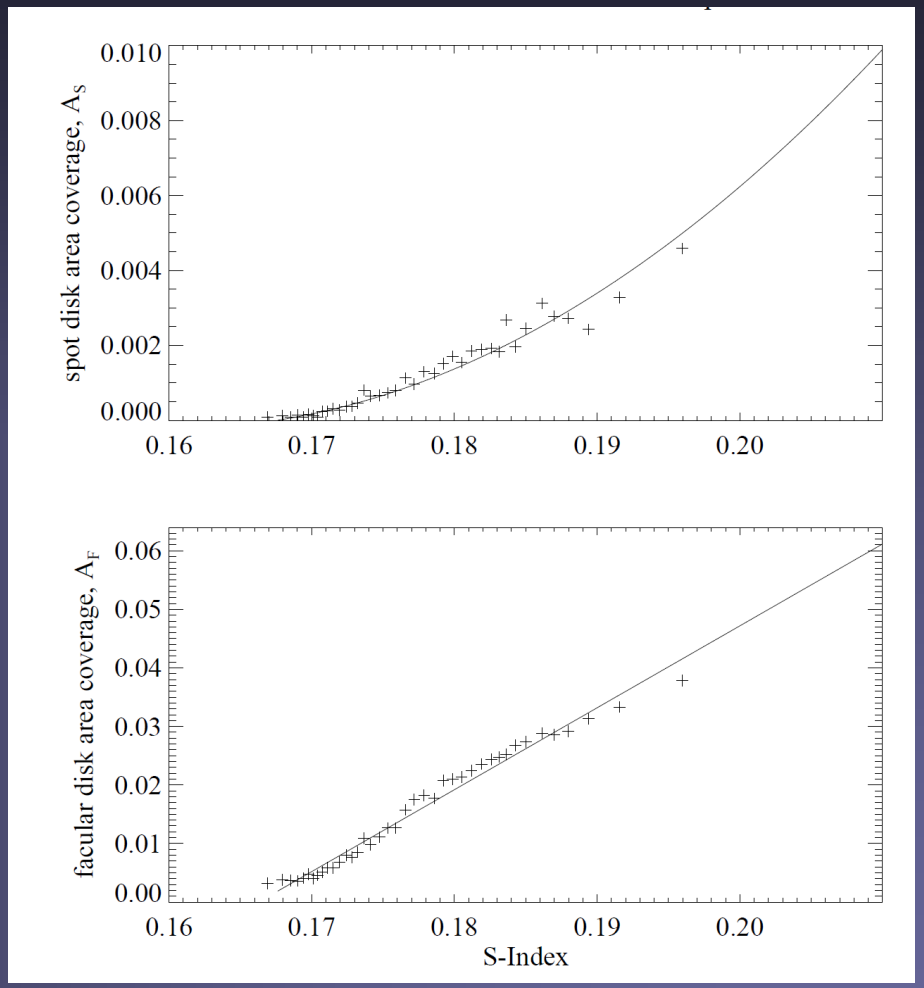


SATIRE modelling of Sun-like stars

- Observations (Lowell obs.): low-activity stars brighten at activity cycle max., while high activity stars darken (Lockwood+ 92, 97, 07)
- The magnitude is such that the solar paradigm was called into question (Raddick+ 89)
- Approach: extrapolate the coverage by spots and plages taken from SATIRE model to higher activity (Ca S-index)
- Key: spot coverage increases quadratically, faculae linearly



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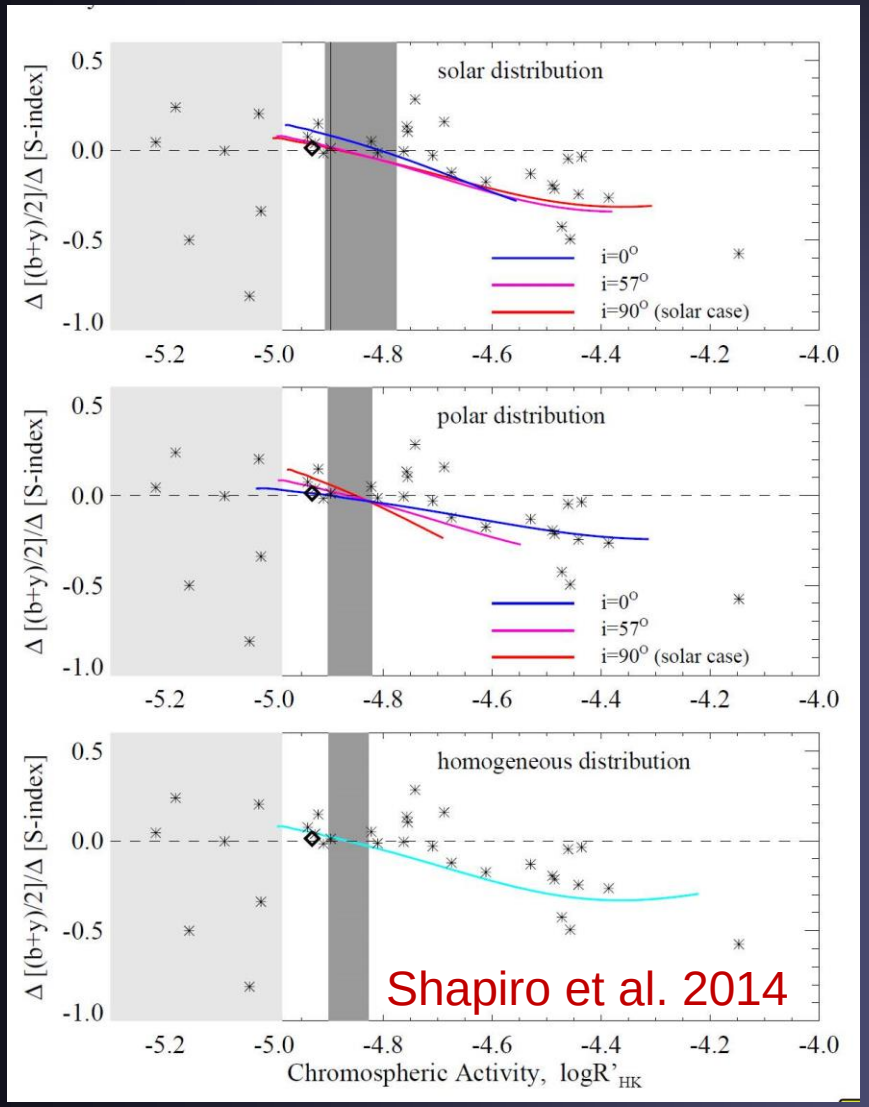


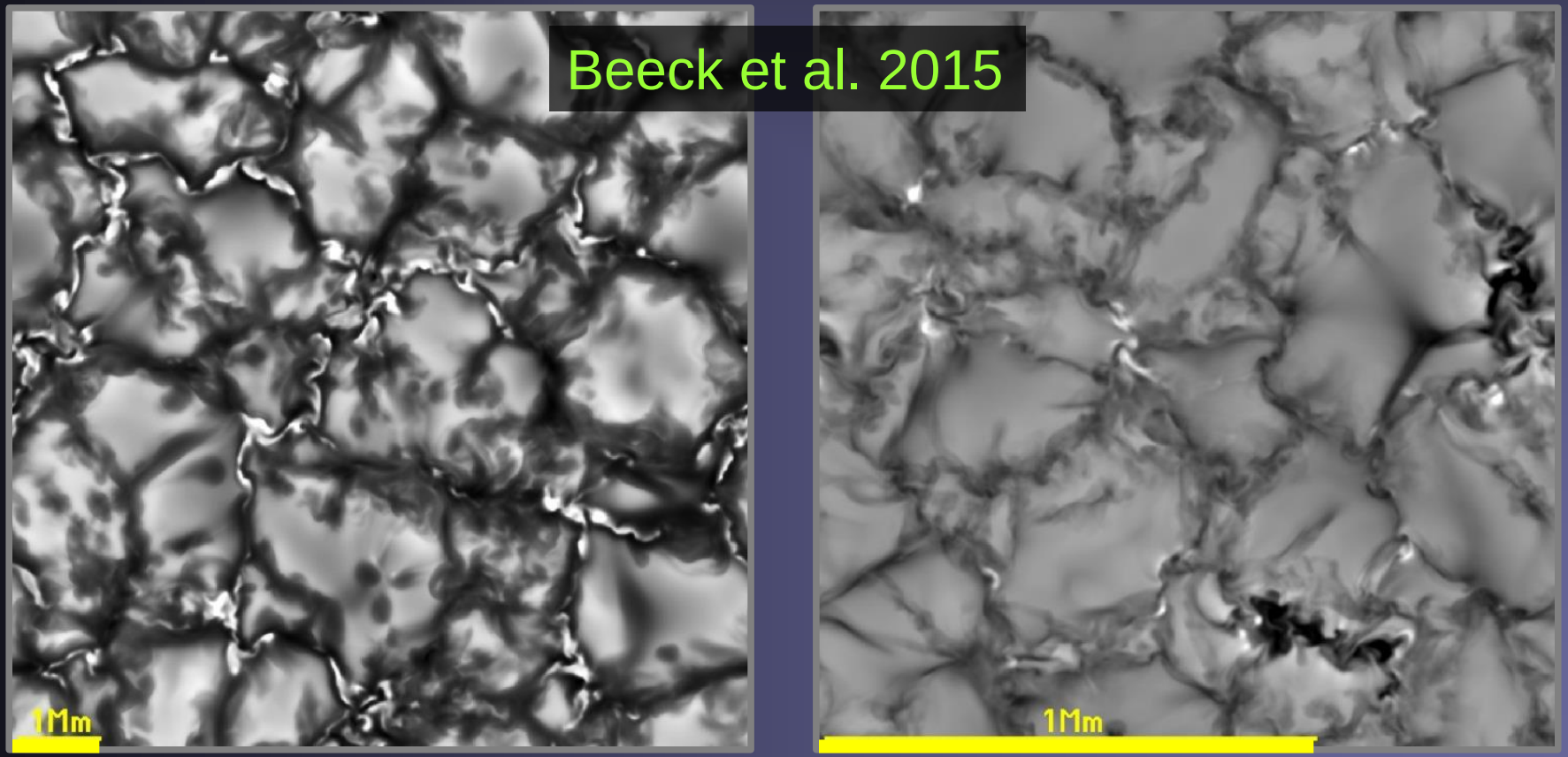
- Use relations from last slide, to compute change in radiative flux over a stellar activity cycle in filters used at Lowell
- Do so for stars with different levels of activity, i.e. different spot and plage coverage
- Plotted:
  Δ brightness / Δ S-index vs. Chromospheric activity
  - Star symbols: observations
  - Lines: models for different view angles relative to rotation axis

Application to other stars

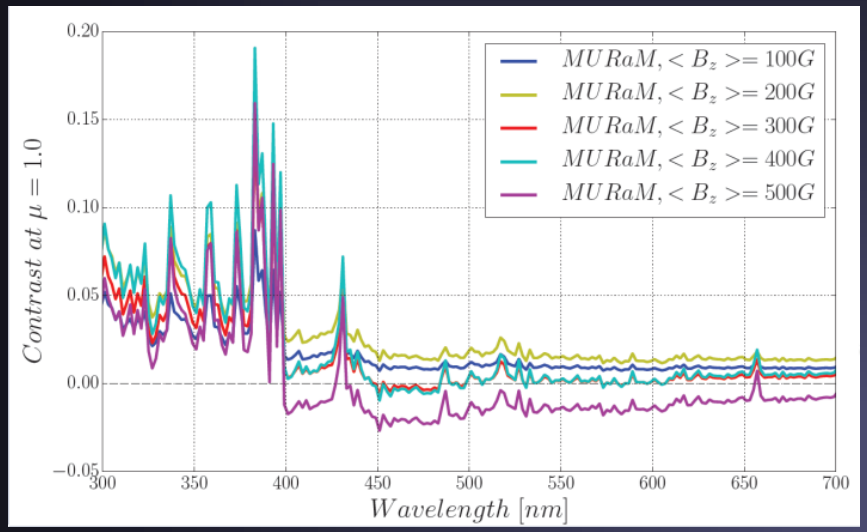
Emergent flux & contrasts show spectral type dependence
Such models can be used to compare with Kepler data

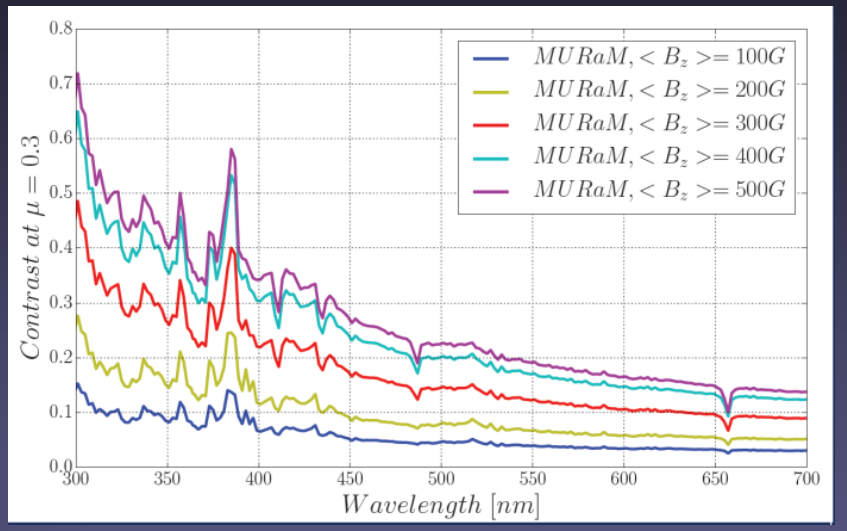
G2 (100 G)

M2 (100G)

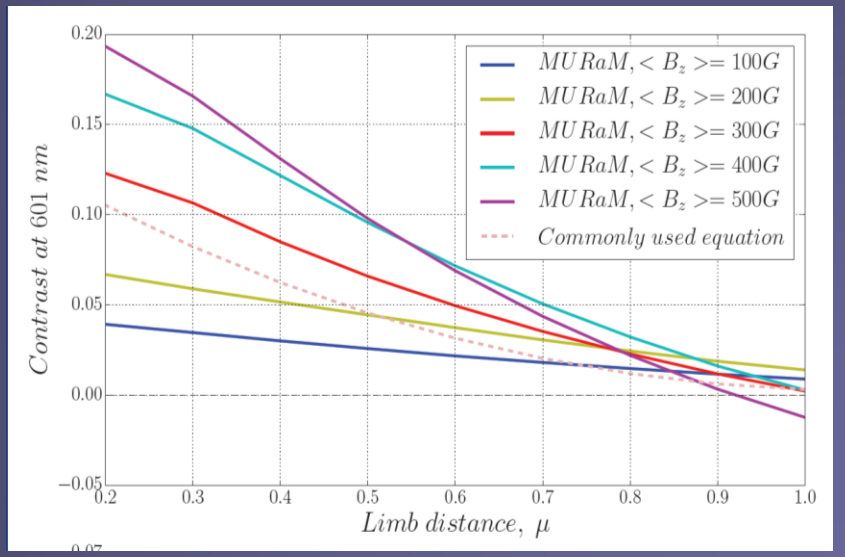


Stellar variations: activity cycle timescale





- Detailed CLV computations agree well with solar obs. (e.g., Yeo et al. 2013)
- Some quantitative differences to simple formulae (e.g., Herrero et al. 2015)
- Now apply to M-F MS stars



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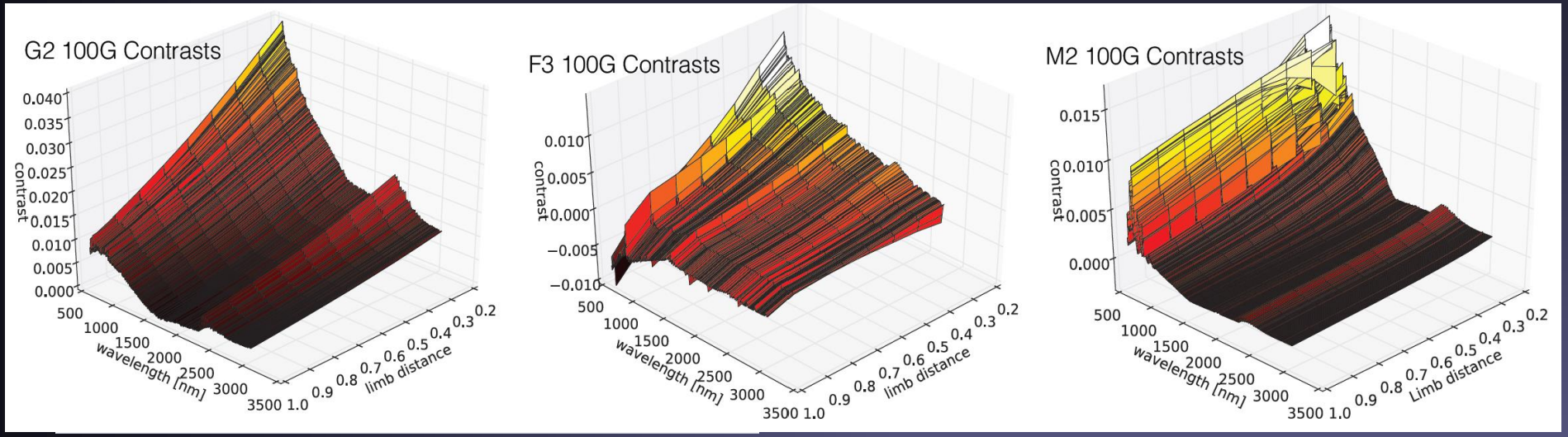

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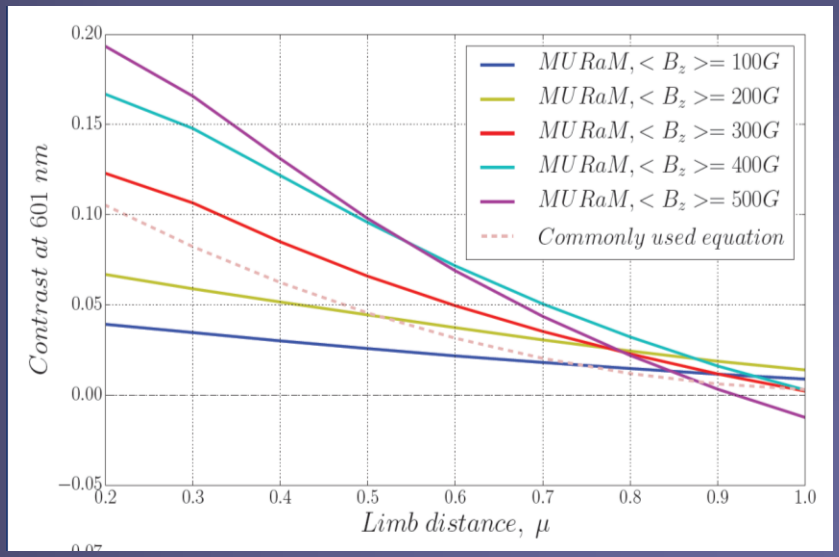
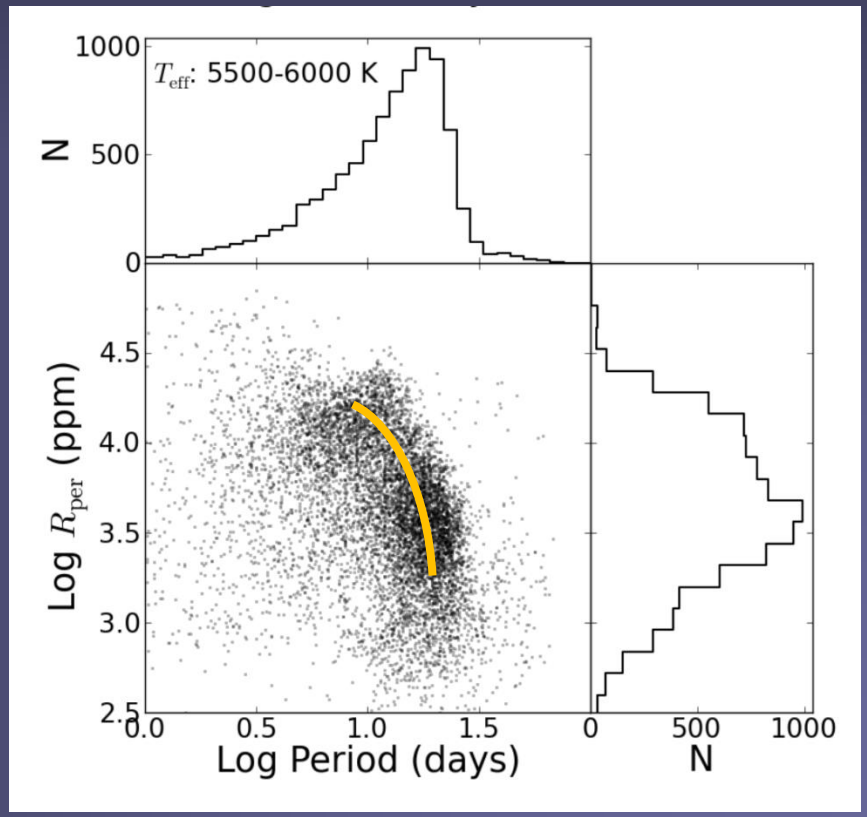


Stellar variations: rotation timescale

- Short term variability of “Sun-like” Kepler stars increases with decreasing rotation period (Walkowicz+13, Reinhold+13, McQuillan+14; no dependence found by Garcia+14)
- Next steps: use a flux transport simulation to evolve surface coverage of spots and faculae on stars
- Change parameters (amount of flux in bipolar regions, placing of magnetic features on solar surface, etc.) and compare with observations aiming to reproduce statistical quantities



Thank you for your attention