Solar brightness variations as they would be observed by the *Kepler* telescope

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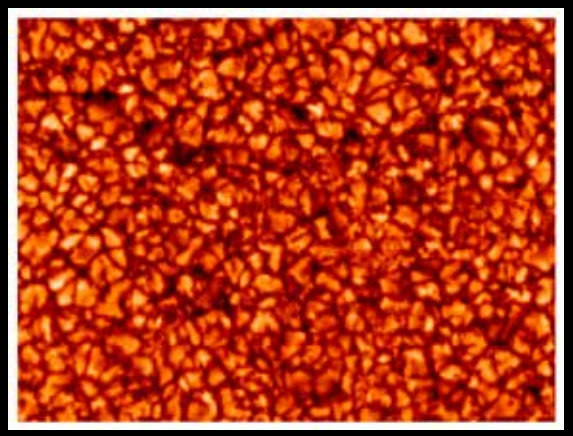
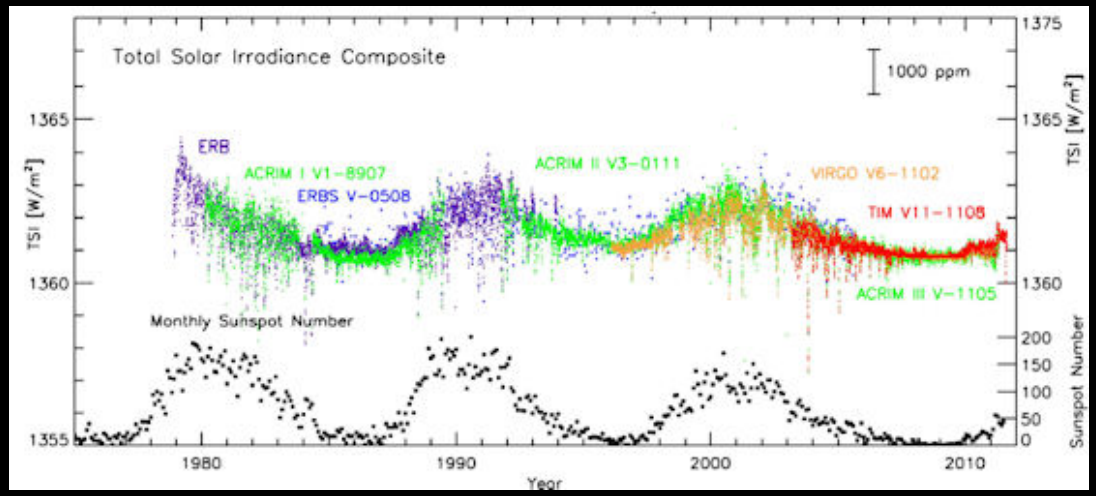
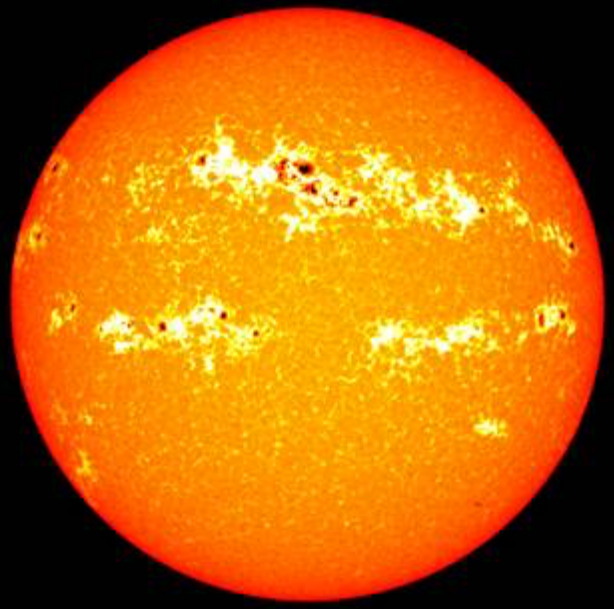
Sun is variable on all time scales

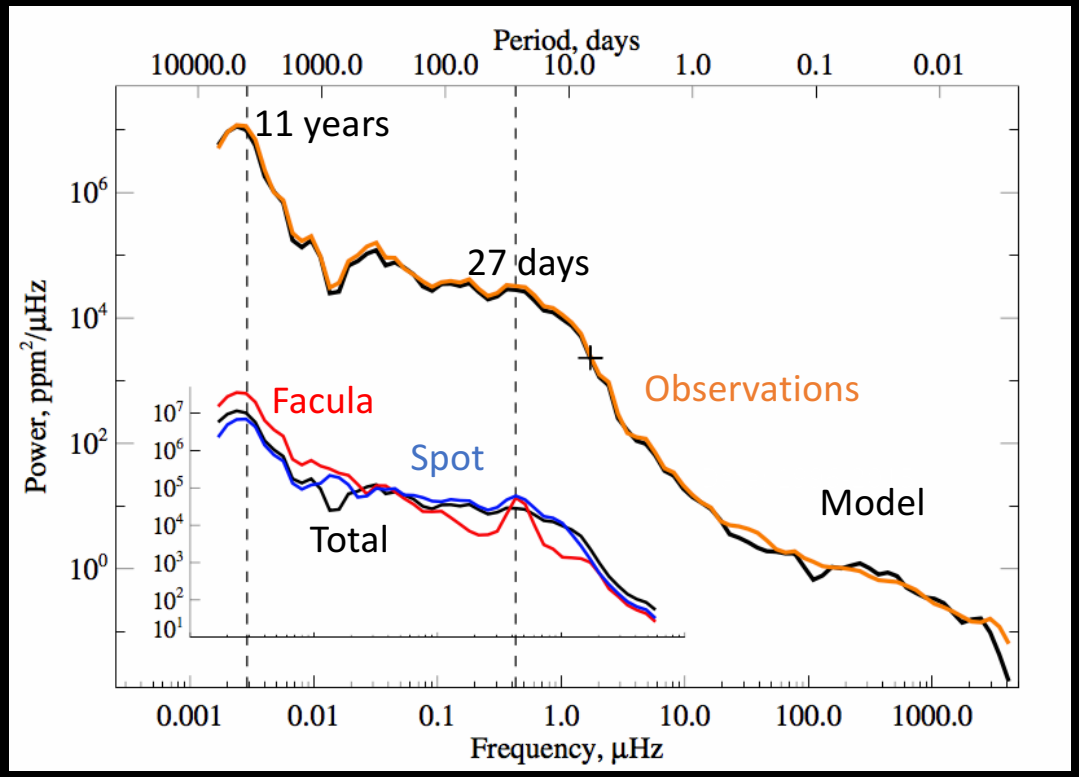
- Minutes – days: oscillation, granulation
- Days – month: evolution of magnetic features, rotation
- Decades – Millenia: solar activity
- Mega– Gigayears: stellar evolution







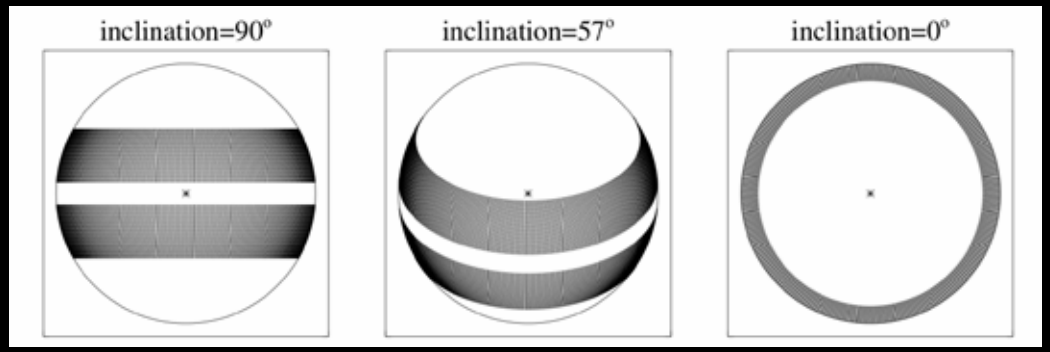
Solar and stellar variability on rotational timescale



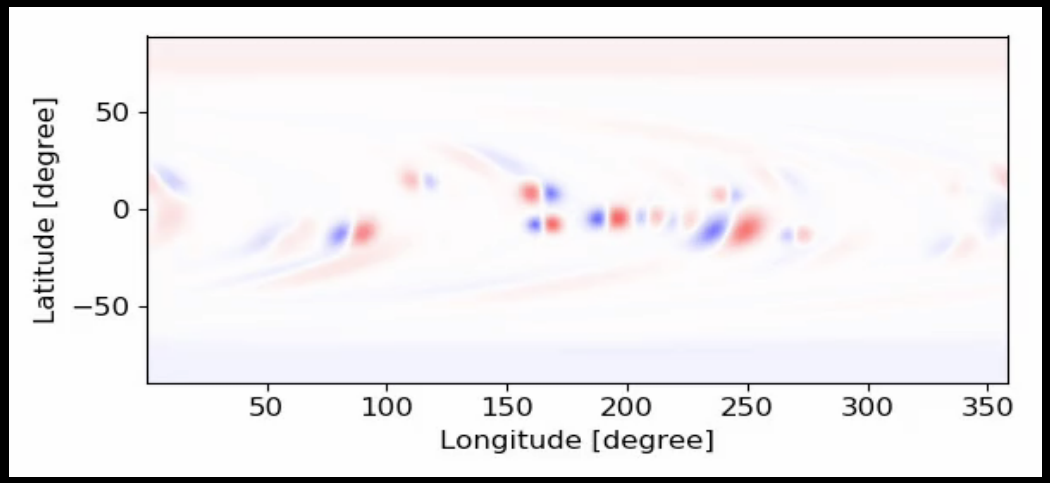
Shapiro et al., 2017

- Sun: on rotational timescales spots are dominant
- *Rotation period not detectable!*
- *Kepler*: observe stars with different inclinations and rotation periods
- Stars might be spot or faculae dominated (inclination, metallicity, temperature,…)

Our aims



Shapiro et al. 2014



Studies on cycle timescale → activity bands

BUT: we want to study day-to-day variations

Need information on day-to-day basis

For inclination studies: distribution on the far side

How? – Surface Flux Transport Model

(Cameron et al. 2010)

$$\frac{\partial B}{\partial t}(\lambda, \phi, R, v(\lambda), \Omega(\lambda), \eta_H, D(\eta_r), B^{\pm}(\lambda, \phi, t)\ )$$

How? – Surface Flux Transport Model

(Cameron et al. 2010)

longitude mer. flow surface diffusivity source term

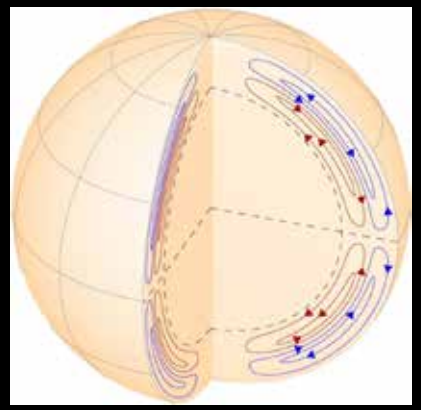
$$\frac{\partial B}{\partial t}(\lambda, \phi, R, v(\lambda), \Omega(\lambda), \eta_H, D(\eta_r), B^{\pm}(\lambda, \phi, t))$$

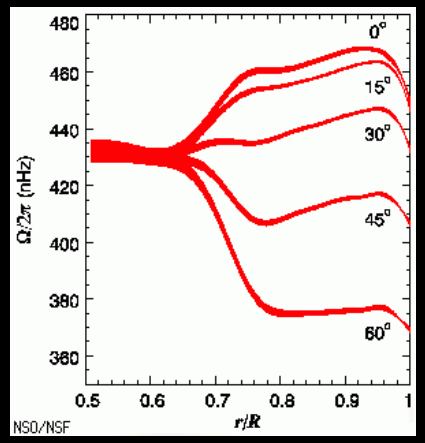
latitude radius diff. rot lin. operator

$$v(\lambda) = \begin{cases} 11 \cdot \sin(2.4 \cdot \lambda) & \lambda \leq 75° \\ 0 & elsewhere \end{cases} \quad \text{m/s}$$

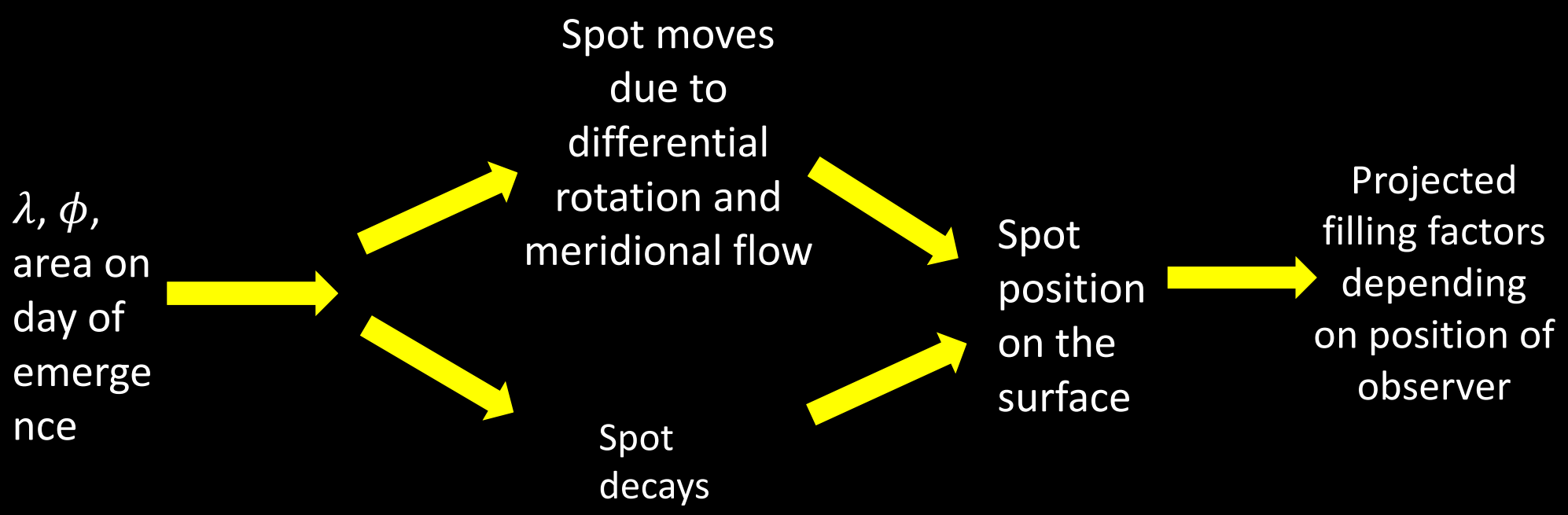
$$\Omega(\lambda) = 13.37 - 2.3 \cdot \sin(\lambda)^2 - 1.6 \cdot \sin(\lambda)^4 \quad \text{degree/day}$$

$$B^{\pm}(\lambda, \phi) = B_{max} \frac{0.16\, \Delta\beta^2}{\delta^2} \exp\left(-\frac{2\left[1 - \cos\left(\beta_{\pm}(\lambda, \phi)\right)\right]}{\delta^2}\right)$$





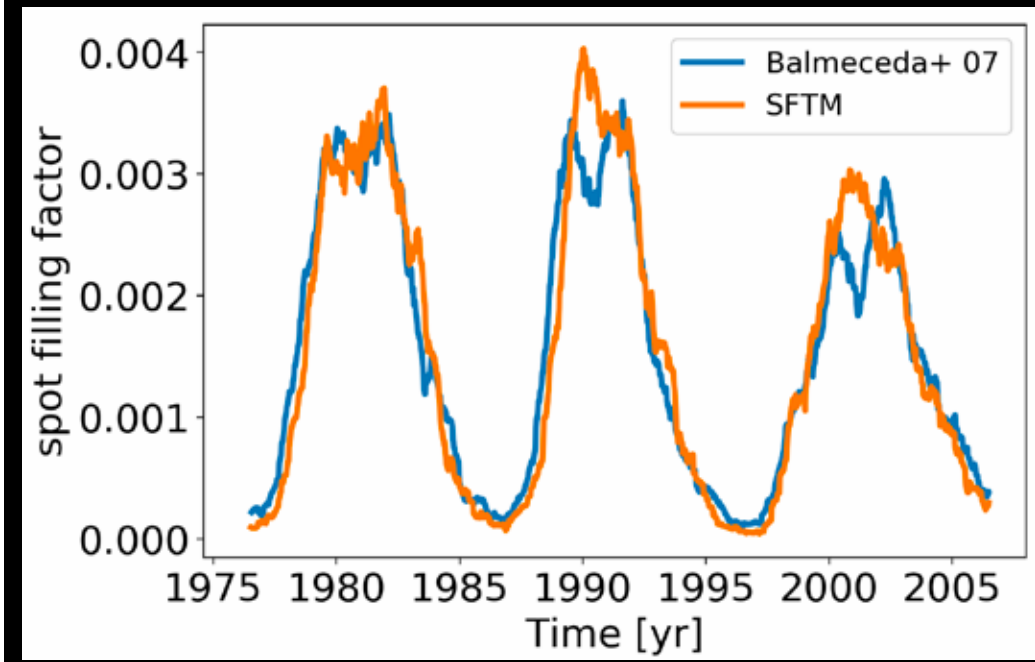
Defining spot filling factors



SFTM output is on a non-rotating surface → add solar rotation!

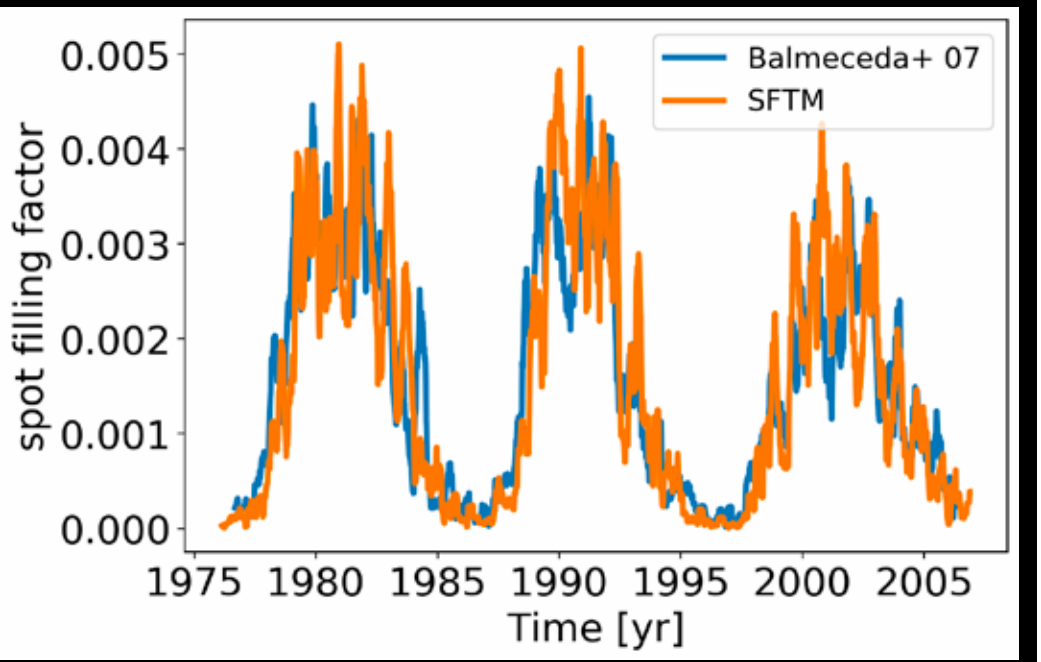
Comparisons with observations

365-day smoothed data



Average:
Balmeceda: **0.00159**
SFTM: **0.00156**

81-day smoothed data



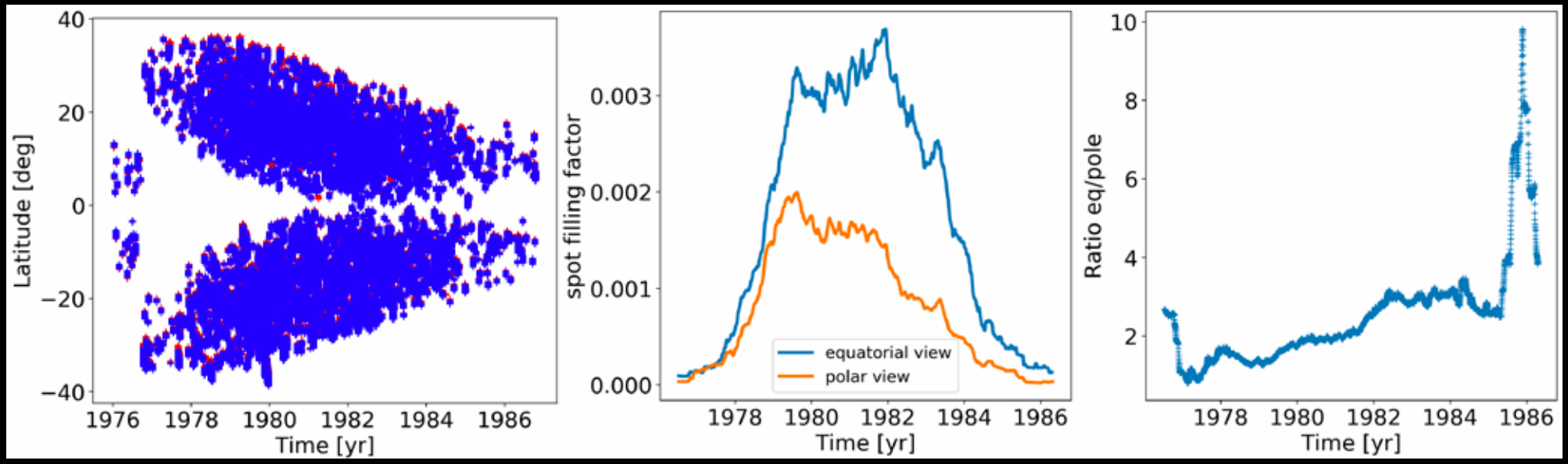
RMS:
Balmeceda: **1.33e-08**
SFTM: **1.64e-08**

Changing the inclination

Butterfly diagram

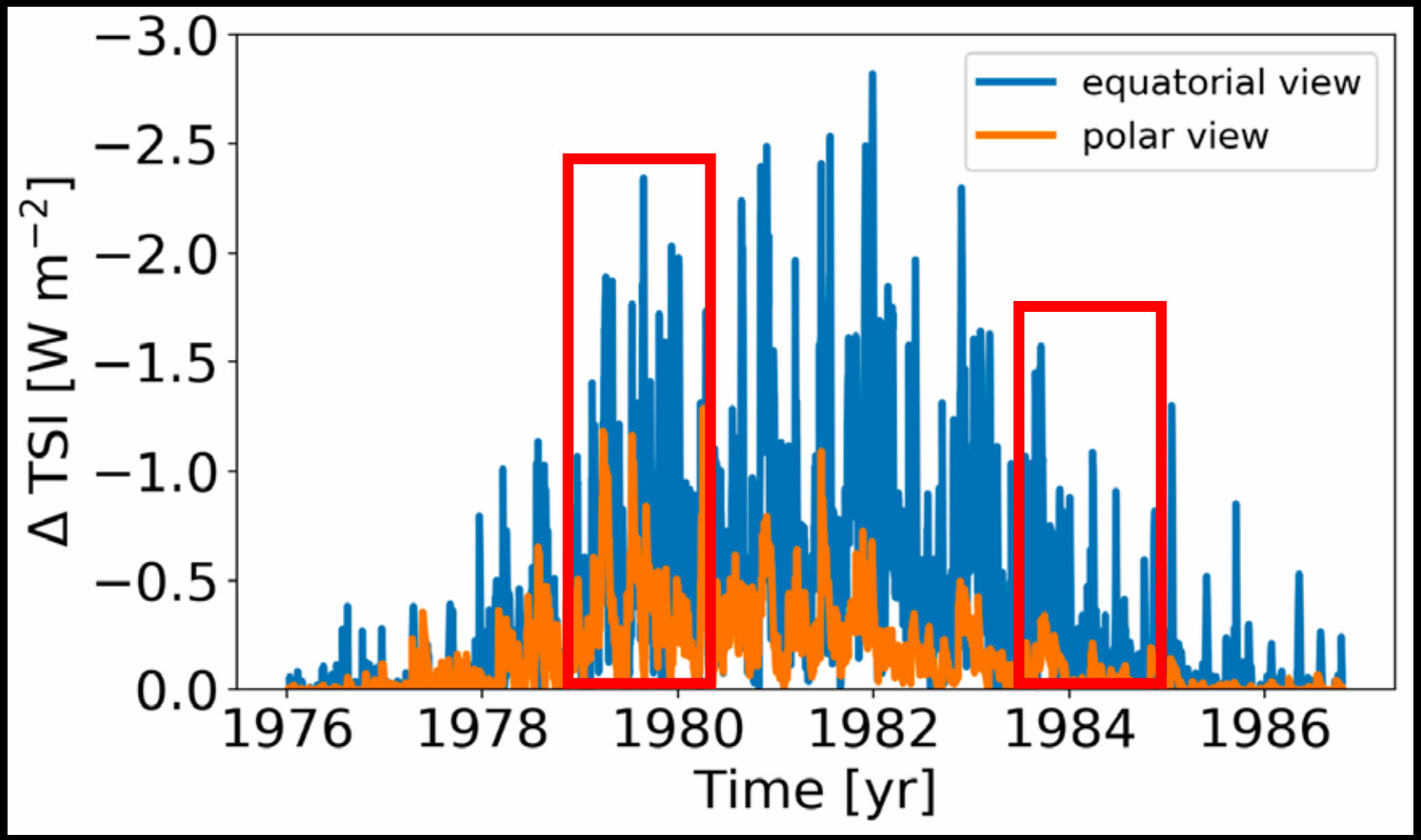
365- day smoothed data

Ratio of equatorial and polar view

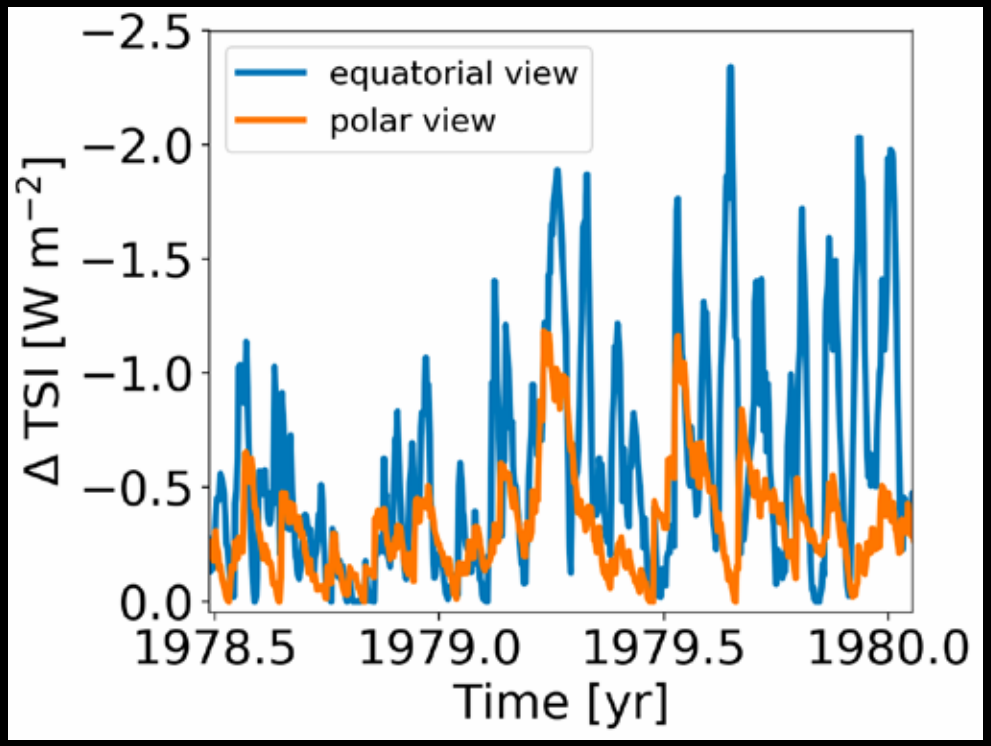


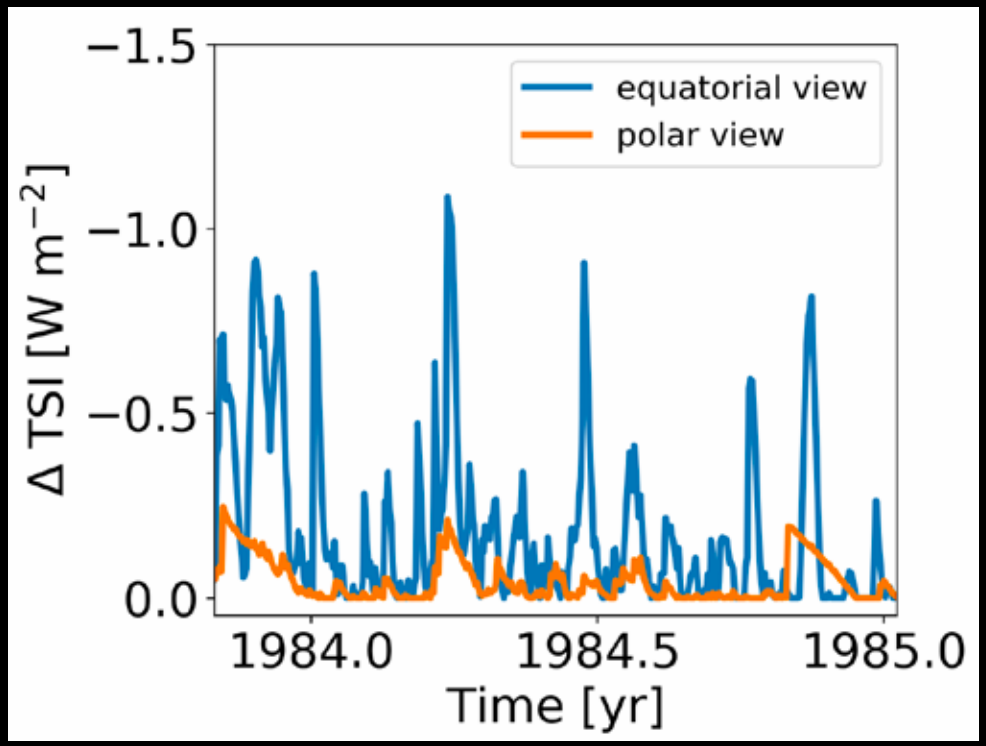
Peak of cycle shifts with lower inclinations towards the beginning to the cycle due to the shape of the butterfly diagram

TSI variability due to spots I



TSI variability due to spots II





Conclusion and Outlook

- Solar-stellar comparison: need to understand how the Sun would be observed from arbitrary locations
- SFTM statistically reproduces observed spot filling factors
- We calculated spot component of TSI variability from arbitrary vantage point

Thank you for your attention!

- Future plans:
  - Include facular component
  - SFTM: faster rotators → higher activity (Emre Isik)