Long-Term Brightness Variability of Sun-like Stars

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72 primarily main-sequence Sun-like stars; Figure from Radick et al. (2018). Solar photometric variability calculated with SATIRE model.
- Time-scales < a day: convection and oscillations [Seleznyov et al. 2011]
- Time-scales > a day: caused by surface magnetic fields [Ermolli et al. 2013, Solanki et al. 2013]
11-years solar cycle driven by magnetic activity; phenomena are spots and faculae

\[ F(\lambda) = F_Q(\lambda) + F_m(\lambda), \]

- Corresponding to the amplitude of solar cycle 23
- Uses solar magnetic feature distribution

Solar brightness in Strömgren b filter; blue lines are the time point of the two upper plots
Delicate balance between faculae and spot contribution
Spot: smooth not much contribution from Fraunhofer lines
Opacity changes with different metallicity values \([M/H]\); contributions from Fraunhofer lines.
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Change of line opacities leads to different effective $T$ (for $M/H=0.3$ results in a $210K < \Delta T_{\text{eff}} < 290K$)

- Photometric variability almost doubles (for $[M/H] = 0.3$) when taking the change in the atmospheric structure into account
- Effective temperature is restored
- Combined effect of Frauenhofer lines and the adjusted atmosphere model

- Dependence of variability integrated over Strömgren b and y filters and Kepler pass-band
Placing a hypothetical Sun with $M/H = 0.4$

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The solar fundamental parameters are close to a local minimum for the brightness changes on the magnetic activity time-scale.

More detailed investigation including the effect of effective temperature and inclination will be soon available (Witzke, V. et al. in prep.).

Observed activity and greater brightness change of the solar analogue HD 173701 can be explained by the two times greater metallicity compared to the Sun (Karoff et al. 2018).

**Future steps:**
- Comparison of stars for which extended and detailed measurements exist
- Large sample of stars, for example from Kepler full-frame images
- Important to take the effect of the changed radiation field on the atmospheric structure into account
- In future 3D-MHD calculations will be employed for more realistic modelling
Effect of Small Effective Temperature Deviations

- Small $T_{\text{eff}}$ changes of $\pm 100$ K, which is of the order of measurement accuracy (Pinsonneault et al. 2012)

- Drop in effective temperature - spot dominated brightness changes

- Note, 1-D models do not capture geometric effects, e.g. from hot faculae walls
Stars of Solar Magnetic Activity

- **HD 224930**: $P_{\text{rot}} = 33$ or $15$ d, $T_{\text{eff}} = 5400$ K, Spot-dominated
- **HD 201092**: $P_{\text{rot}} = 38$ d, $T_{\text{eff}} = 4000$ K
- **HD 197076**: $P_{\text{rot}} = > 18.7$ d, $T_{\text{eff}} = 5770$ K, spot-dominated
- **HD 55575**: $P_{\text{rot}} = \text{---}$, $T_{\text{eff}} = 5850$ K, Spot-dominated
- **HD 6920**: $P_{\text{rot}} = 14$ d, $T_{\text{eff}} = 5900$ K
- **HD 38858**: $P_{\text{rot}} = \text{---}$, $T_{\text{eff}} = 5700$ K
- **HD 146233**: $P_{\text{rot}} = 23.70$ d, $T_{\text{eff}} = 5750$ K
- **HD 159222**: $P_{\text{rot}} = 17.42$ d, $T_{\text{eff}} = 5800$ K
- **Sun**: $P_{\text{rot}} = 24.5$ d, $T_{\text{eff}} = 5770$ K

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