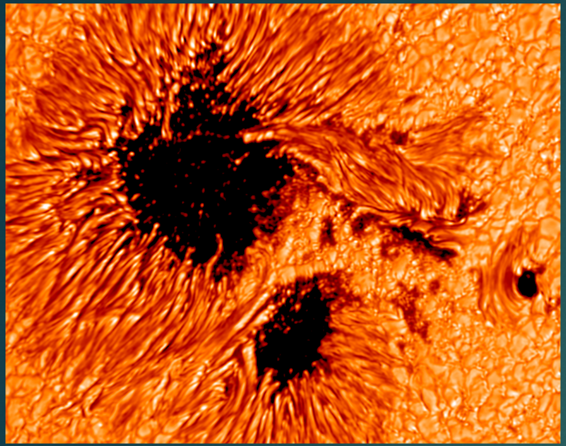

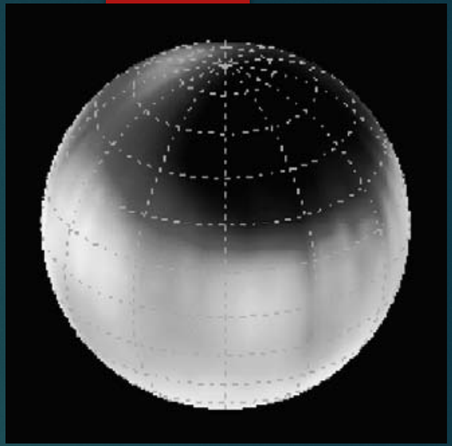

The Sun as a key to interpreting the variability of cool main sequence stars and to characterizing their exoplanets

Sami K. Solanki, Tanayveer Bhatia, Robert Cameron, Emre Isik, Natalie A. Krivova, Timo Reinhold, Alexander Shapiro, K. Sowmya, Veronika Witzke

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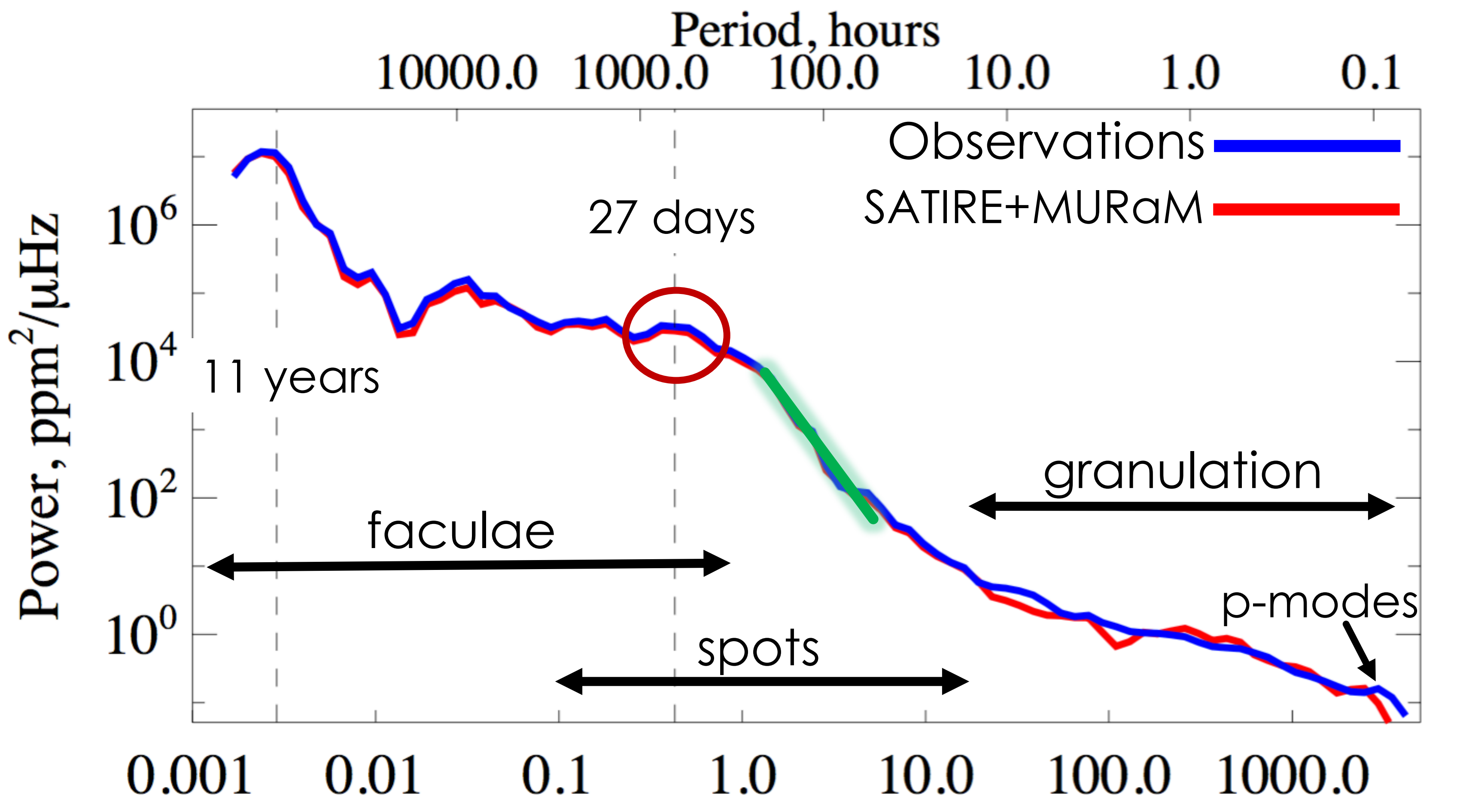
Solar surface B-field drives irradiance changes

- Global wavelet power spectrum of Total Solar Irradiance (1996-2015)
- Well reproduced by MURaM + SATIRE models
- No rotation peak at 27 days! But rotation rate is key for stellar activity
- Rotation gives large gradient in power at ~5x higher frequencies
- ➔ Use Gradient of Power Spectrum (GPS) to get rotation rate of stars

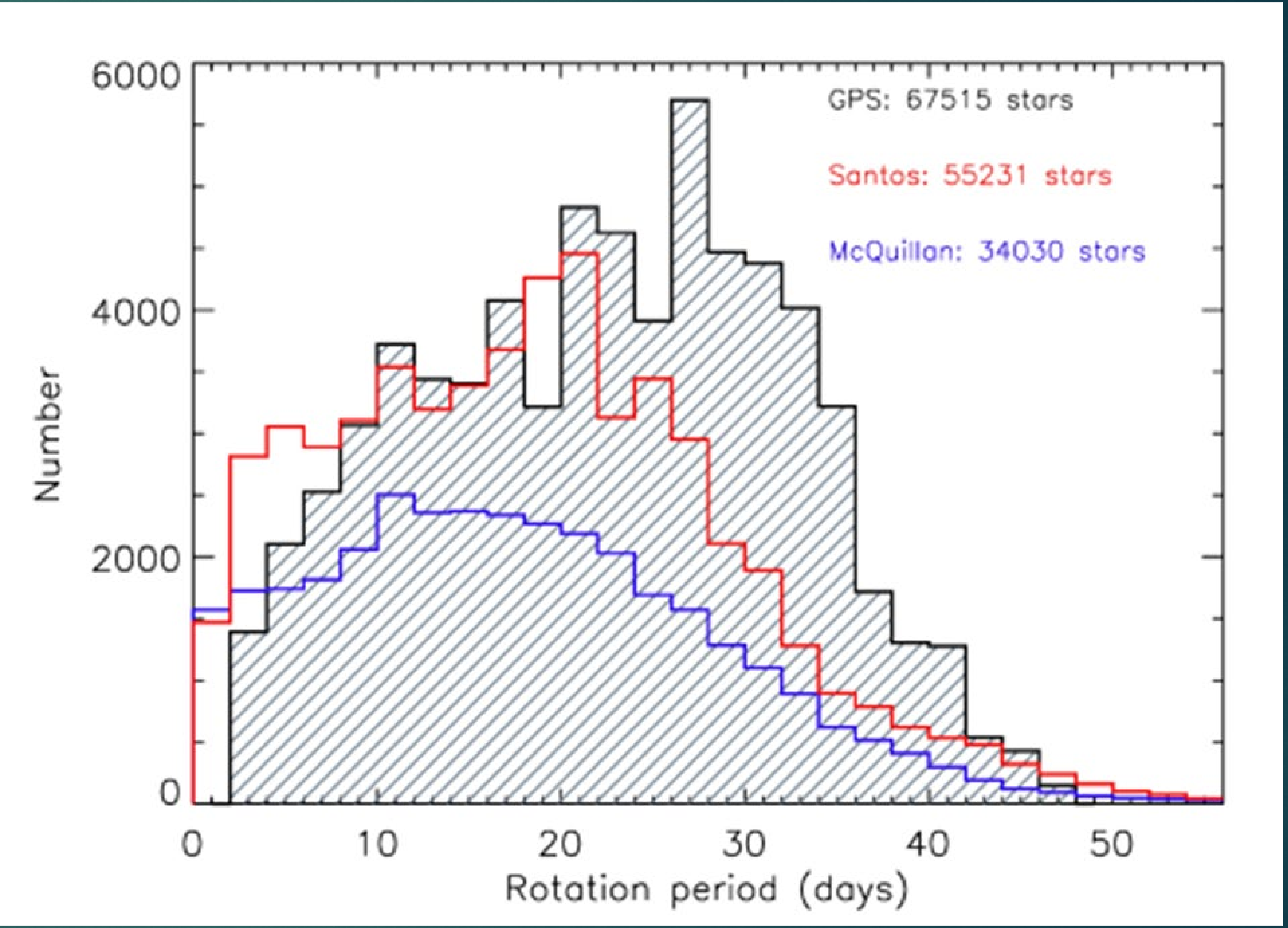
Recall talk by Natalie Krivova on wednesday



Shapiro et al. (2017)

Irradiance changes: measured & modelled

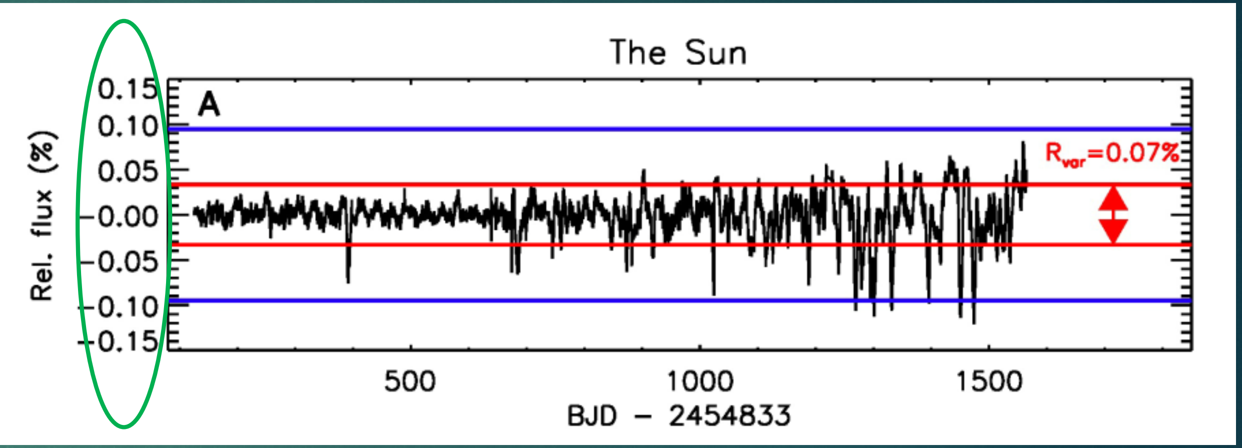
- Method developed & tested by Shapiro+20; Amazo-Gomez+20a,b
- Compared with standard technique, auto-correlation function (ACF):
  - ACF works mainly for periodically variable stars
  - GPS works also for irregularly variable stars (like the Sun) where ACF fails
- ➔ Reinhold+23: rotation rates of 67500 Main Sequence Kepler stars using GPS and ACF. GPS turns out to be the main method for stars with longer periods

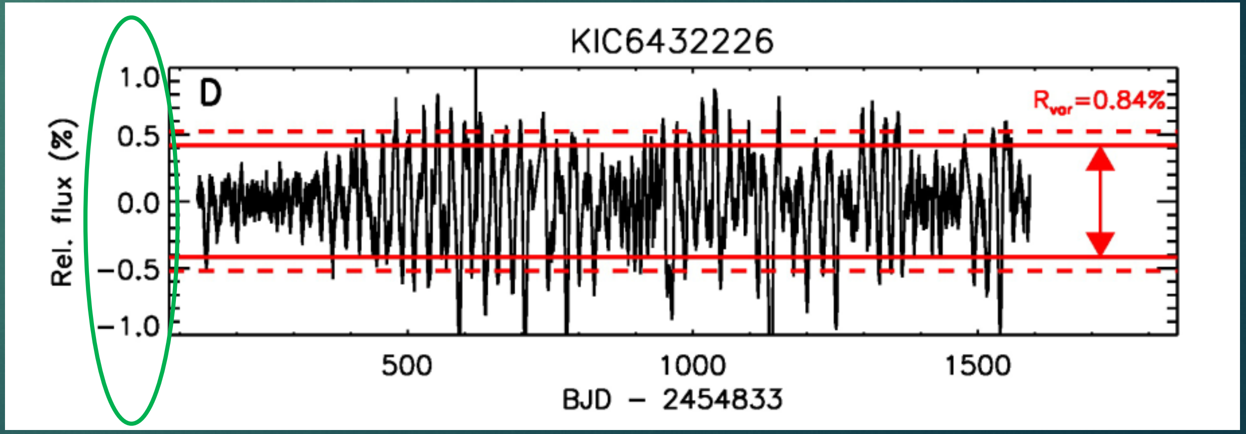


Reinhold et al. 2023 in press

The mystery of monster stellar variability

- Even if stars are selected to be Sun-like:
  - $T_{eff} = 5500\text{-}6000\ K$
  - Age 4-5 Gyr
  - log $g > 4$ (solar: 4.44)
  - Metallicity: -0.8 to 0.3 dex
  - Rotation period (sidereal): 20-30 d
- A large fraction of these ≈ 6000 near-solar-twins displays a variability significantly larger than solar

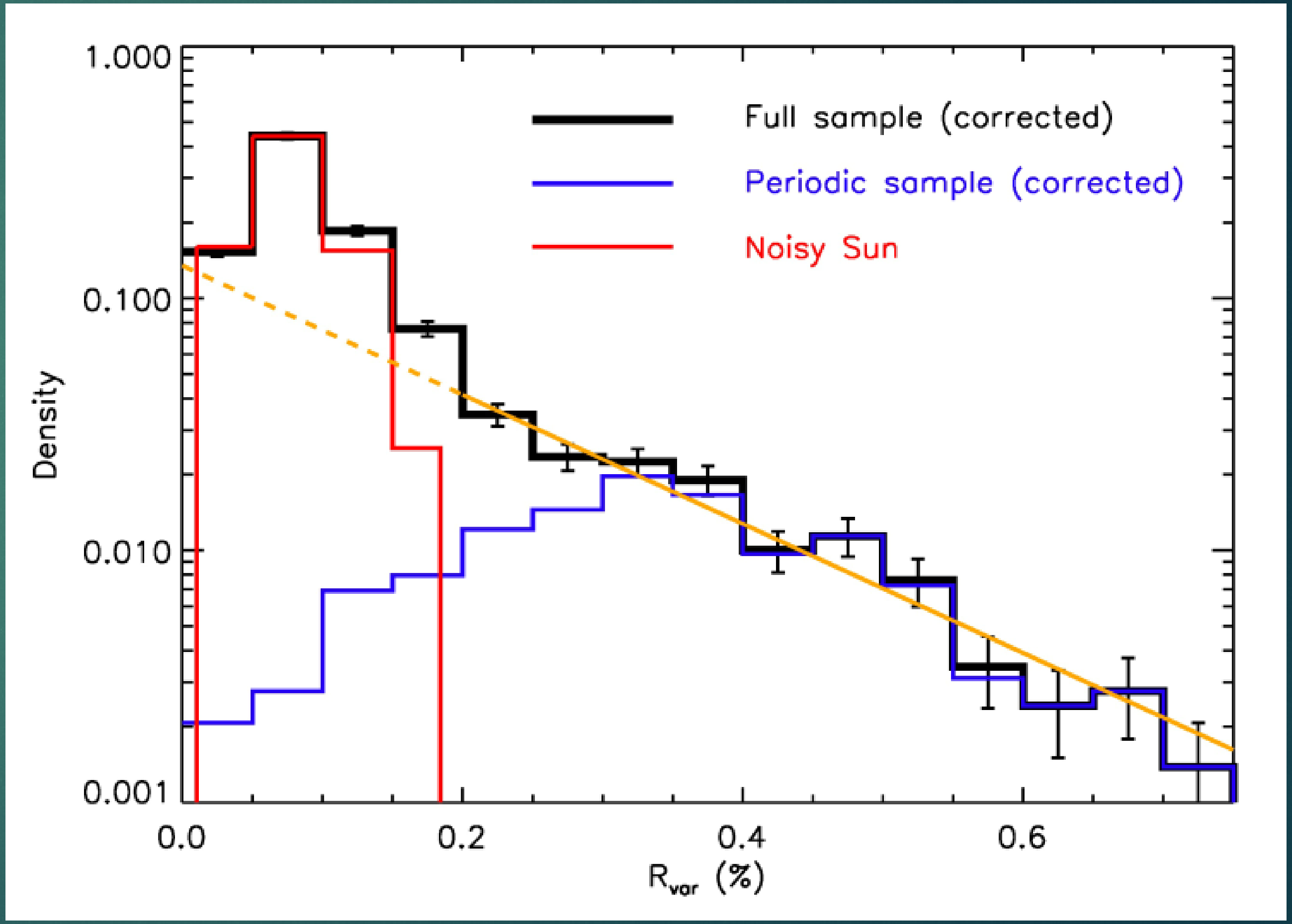




Reinhold+ 2020 Science

The mystery of monster stellar variability

- ≈ 10% of all sun-like stars have variability larger than the Sun
- 1. Either these stars are in some as yet unknown way different from the Sun
- 2. Or the Sun reaches higher variability levels than over the last couple of centuries over ≈10% of the time
- The latter interpretation has consequences for the solar influence on climate

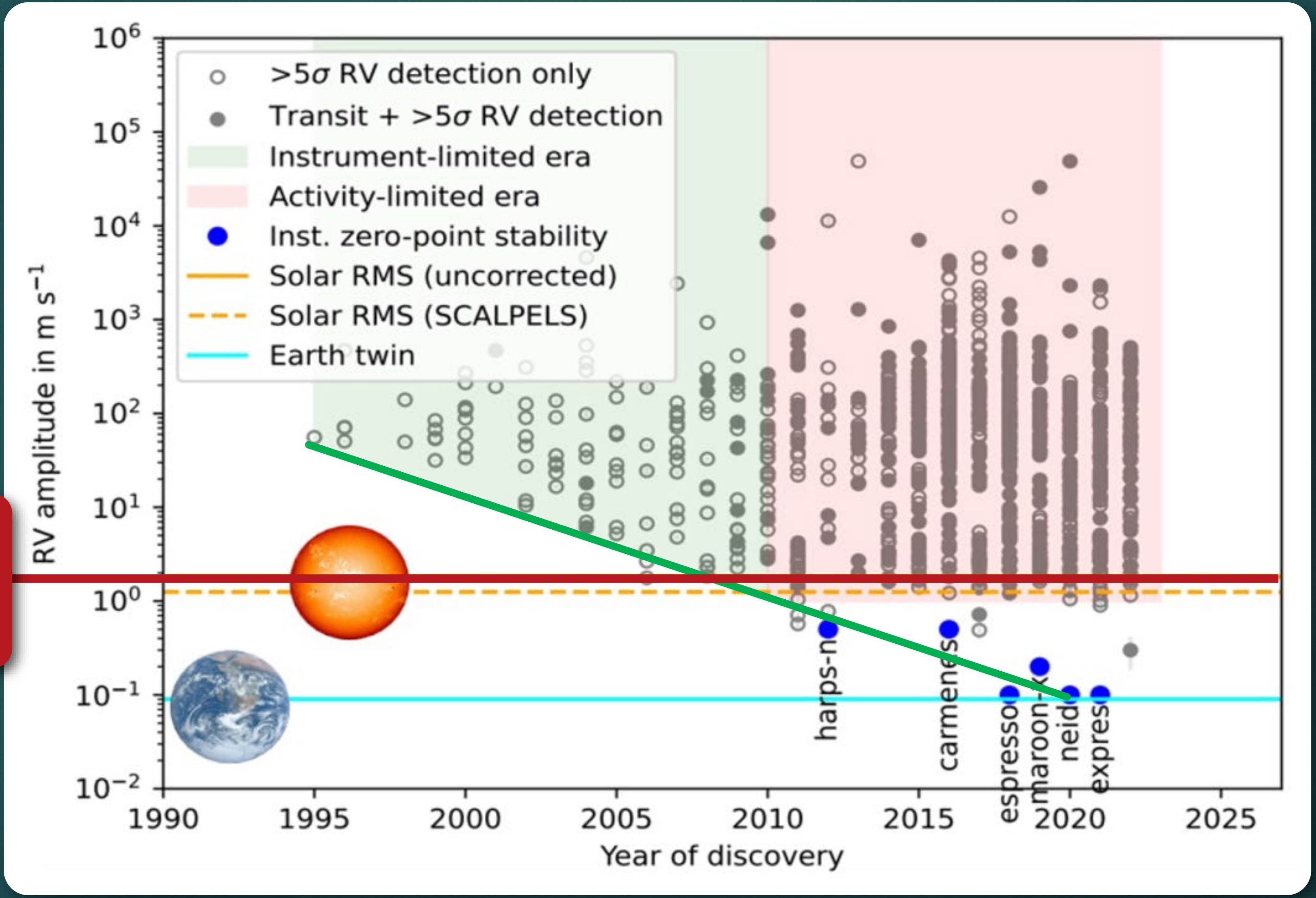


Reinhold+ 2020 Science

Detection of small exoplanets using radial velocity variations

Recall talks by A. Ghedina and Isabella Pagano

STELLAR MAGNETIC VARIABILITY



A. Collier-Camero

Stellar variability turns out to be biggest hinderance to detecting Earth-like exoplanets for nearly every detection technique

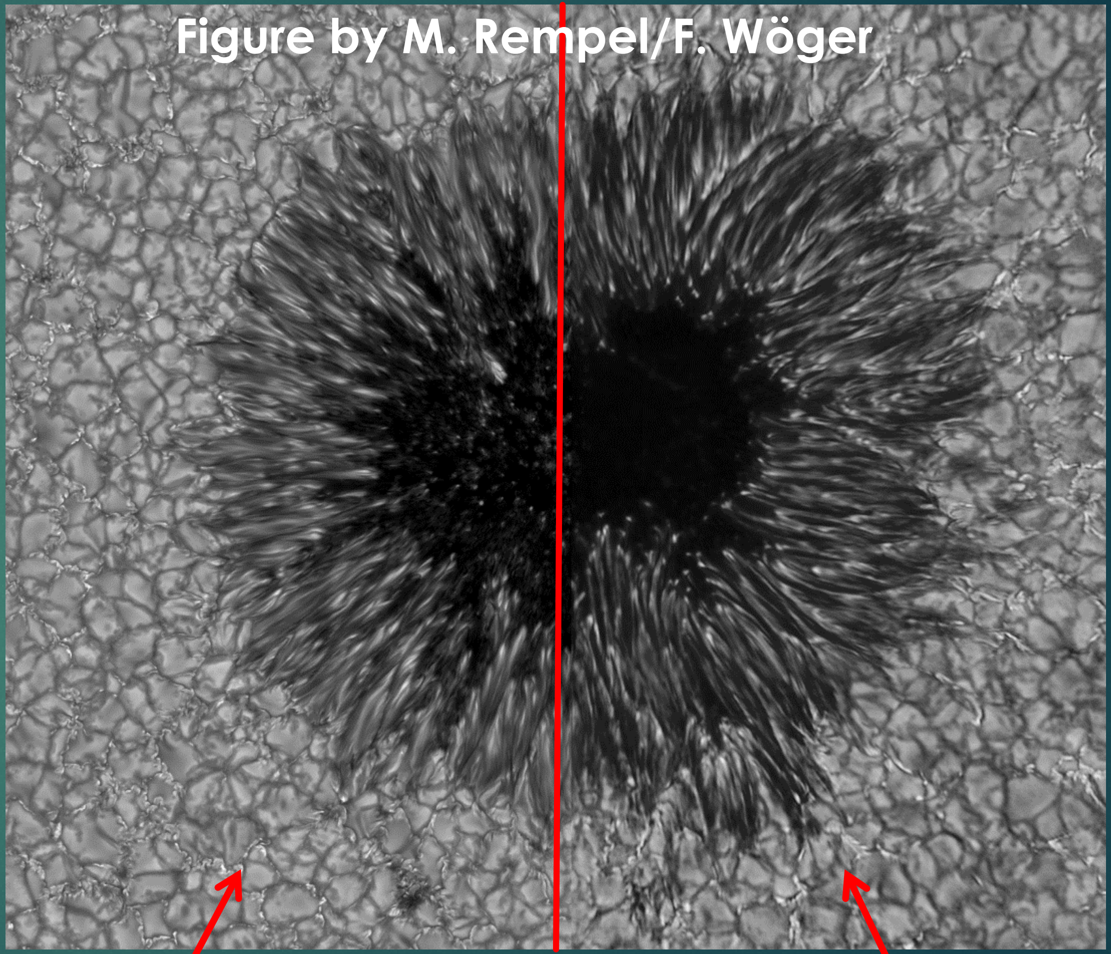
We need techniques to overcome this handicap → use the Sun as a guide

Sunspot simulations

- Radiation MHD simulations of sunspots are maturing fast (e.g., MuRAM code, Rempel+ 09,15; Panja+21)
- Reproduce observations surprisingly well
- Played an important role in identifying the energy transport mechanism in sunspots (e.g., Vögler+Schüssler 06; Heineman+ 07; Rempel+ 09a, b)

Gain new insights into physics

Help interpret observations

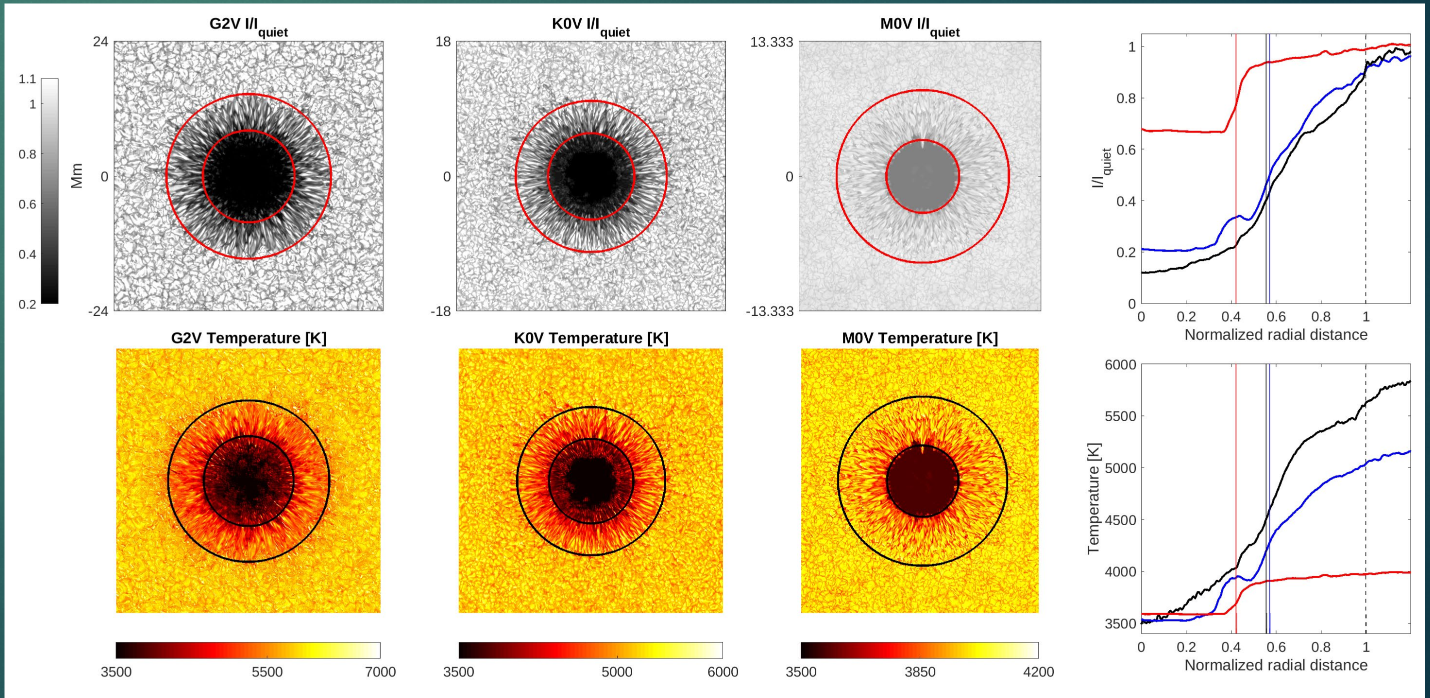


Simulation (M. Rempel/HAO)

G-band observation (F. Wöger/NSO)

Starspot simulations

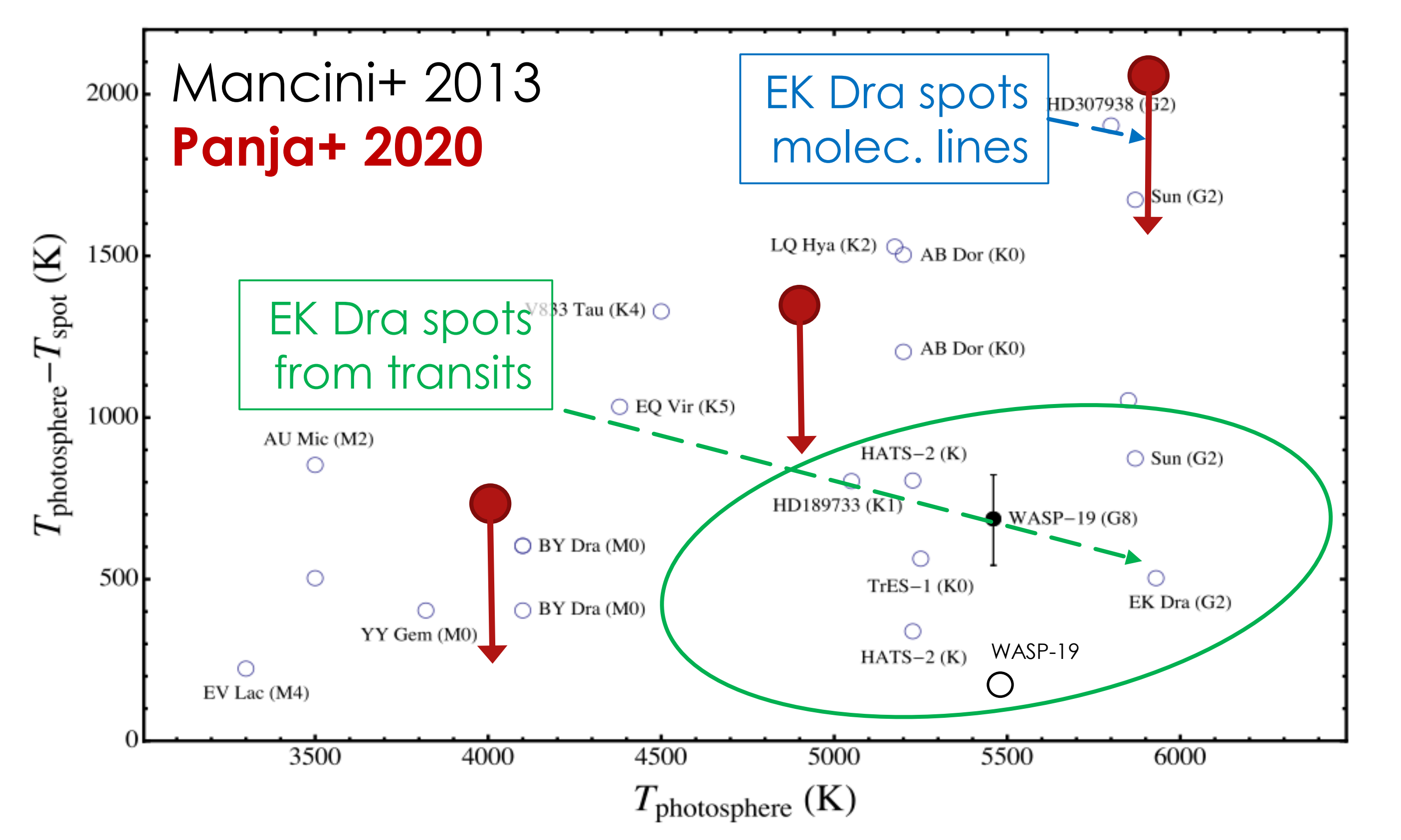
- Radiation MHD simulations of starspots provide their internal properties without problems of obs. → builds on the maturity & realism of sunspot simulations
- Simulation boxes scaled to cover similar number of granules → G-star box has ~10 times larger area than M-star box
- Results:
  - Contrast decreases rapidly from G2 to M0
  - Field strength increases slightly
  - Evershed flow decreases strongly



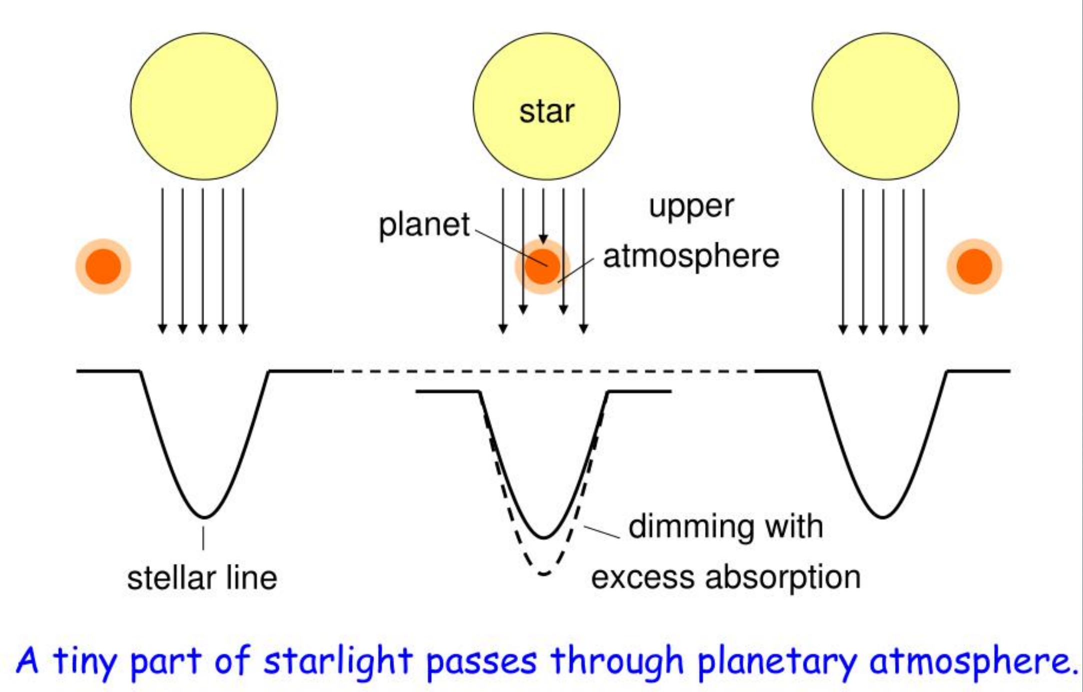
Panja et al. 2023 submitted

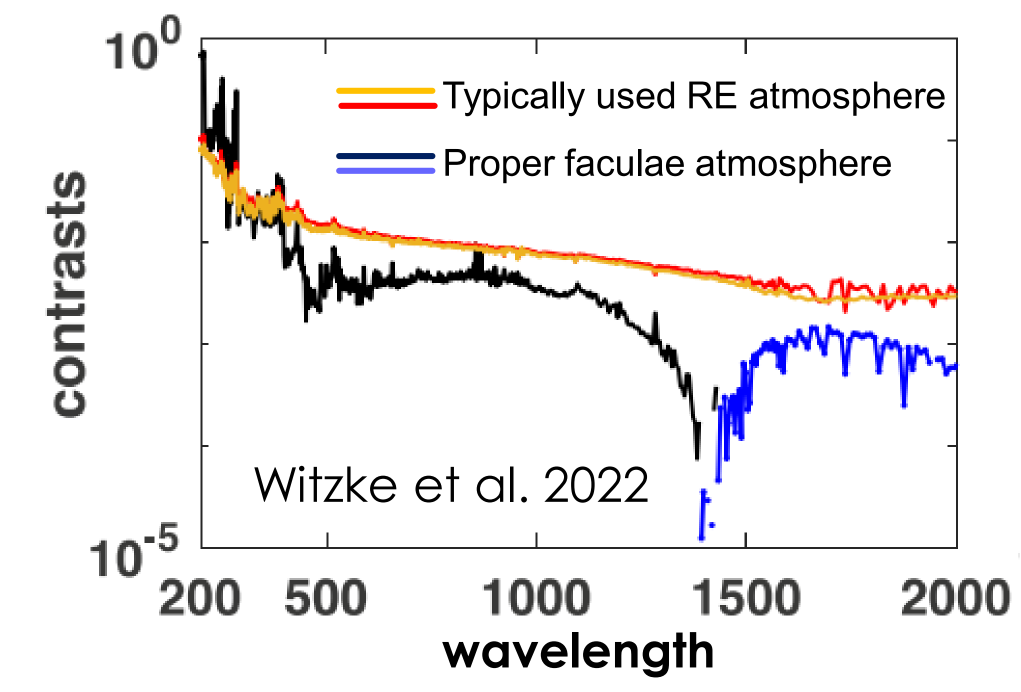
Starspot simulations vs. observations

- Simulated intensity contrast of starspots reproduce measurements collated by Berdyugina 2005
- Transits give lower temperature contrasts than other methods ➔ Due to degeneracy between spot temperature and area?



Transmission spectroscopy





- Difference between stellar spectrum during transit and at other times → info on spectrum of transiting planet's atmosphere
- At wavelengths with excess planetary absorption, planet appears larger (greater transit depth) → composition of planet's atmosphere
- Important: any error due to incorrect stellar atmosphere → error in planet's composition

Conclusions

- Observations, understanding & modelling of solar irradiance → needed to understand variability of cool stars
- Insights from Sun → deeper understanding of variability in Sun-like, but has also provided some surprises
- Extending to other spectral types etc. → Needs MHD simulations of sunspots, faculae & convection
- Exoplanet science: solar input needed to
  - detect Earth-like exoplanets by all widely used technique
  - characterizing Earth-like exoplanets & their atmospheres around M-dwarfs (transmission spectroscopy)
- … and much more. A very rich field!
  - stellar rotation of non-periodic stars
  - true meaning of stellar activity indices (e.g. S-index)

Thank you for your attention