

Stories told by stellar brightness

Mapping stellar active regions based on photometry

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With the team: T. Hackman, A. Haris, G. Henry, et al.

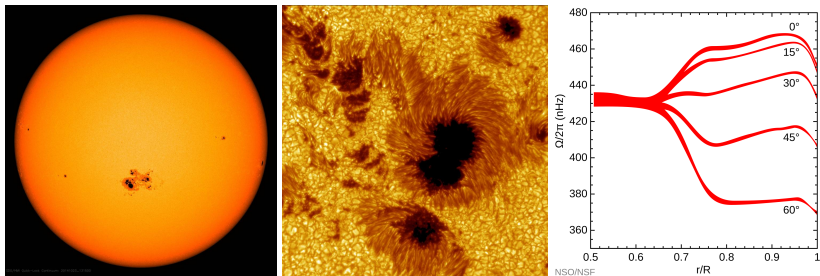
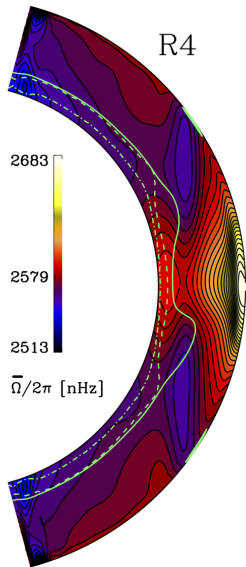


Figure: Sunspots from far (Solar Dynamics Observatory) and in a close-up image (Swedish Solar Telescope).

Why study stellar surfaces?

- Stellar surface phenomena encode information on stellar rotation, activity, magnetic fields, and more.
- Differential rotation (DR) is a consequence of physical properties and the behaviour of magnetic dynamos.
- Stellar dynamos can normally only be studied with complex magnetohydrodynamic simulations.
- Movement of starspots can provide observational constraints for DR.



Typical patterns in stellar DR imply Solar-type profiles.

- Observational constraints are lacking.
- Can we study differential rotation photometrically?

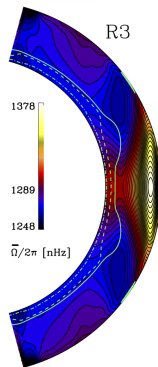
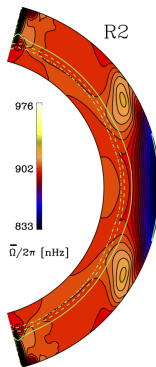
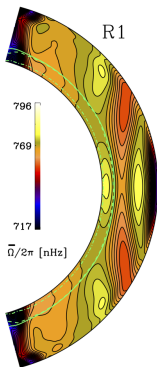
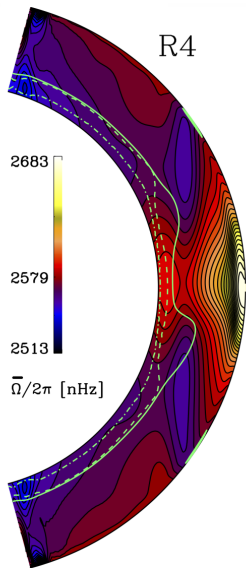


Figure: Simulated DR profiles for various Sun-like stars (Viviani & Käpylä, 2019, A&A 645, A141).



Studying stellar DR is hard with photometry.

- We can identify spot signals in short-baseline data subsets.

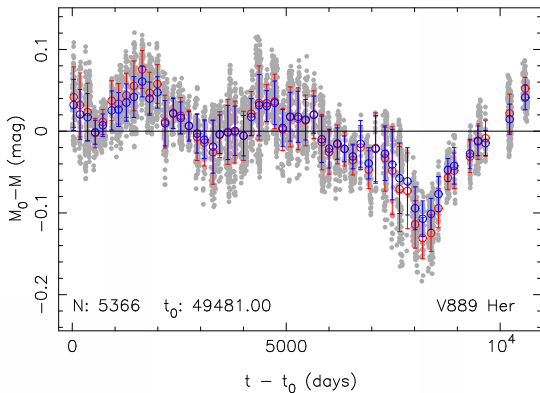
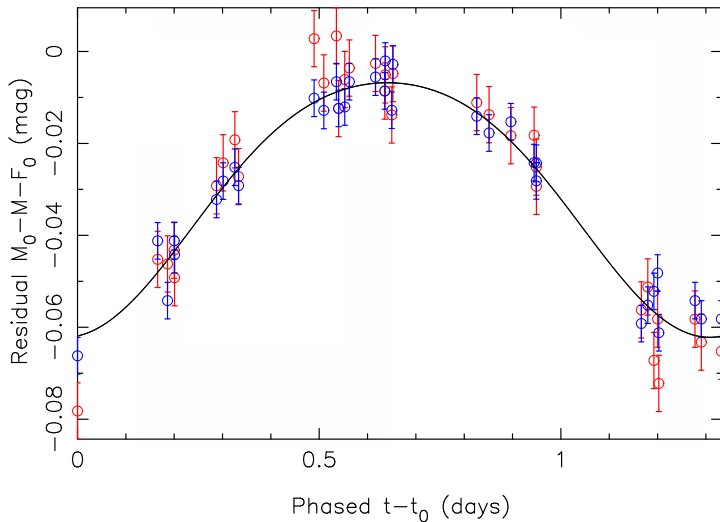


Figure: Differential photometry of V889 Her on V and B bands (Tuomi et al. 2024, A&A, 689, A262).

Figure: Simulated DR profile for a rapidly rotating Sun-like star (Viviani & Käpylä, 2019, A&A 645, A141).

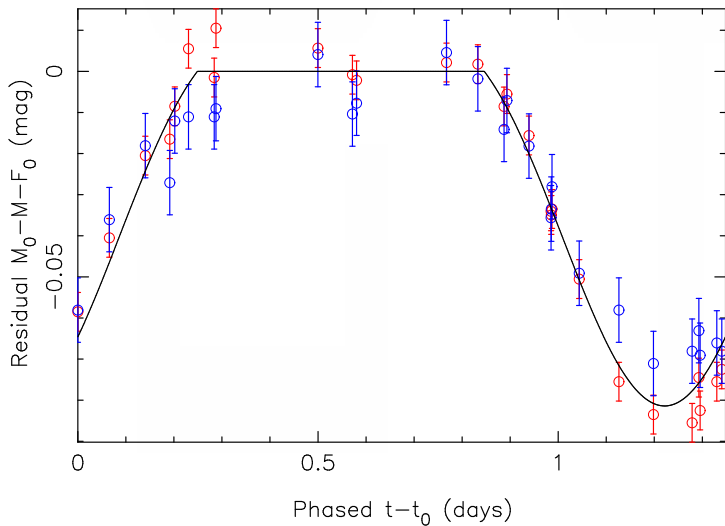


A constantly visible spot.



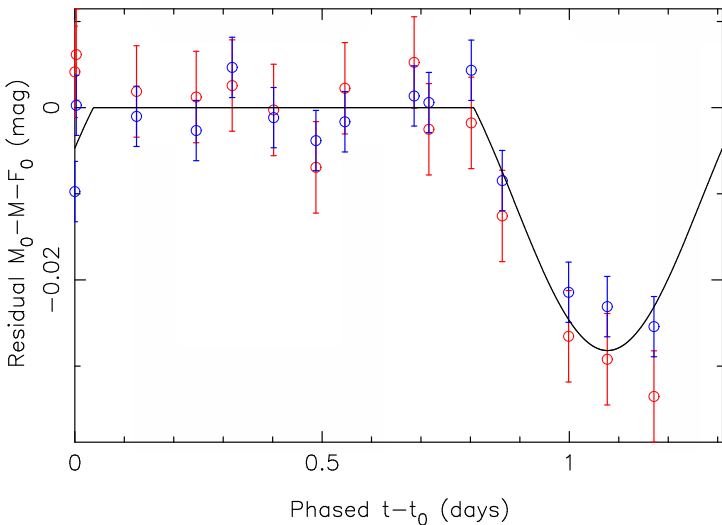


A spot visible roughly half the time.





A spot visible less than half of the time.



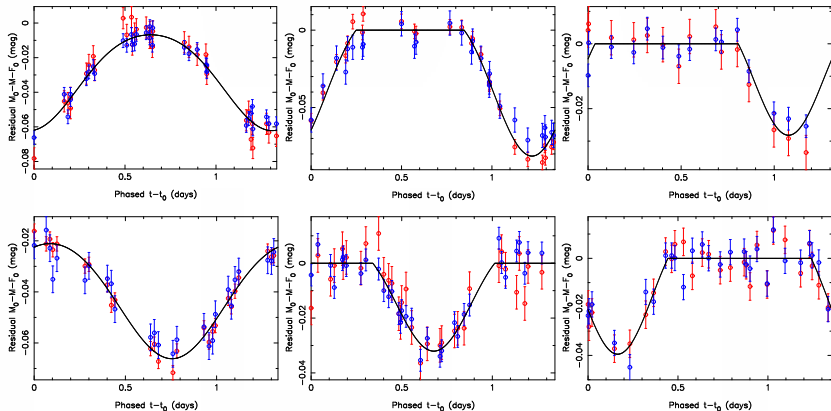
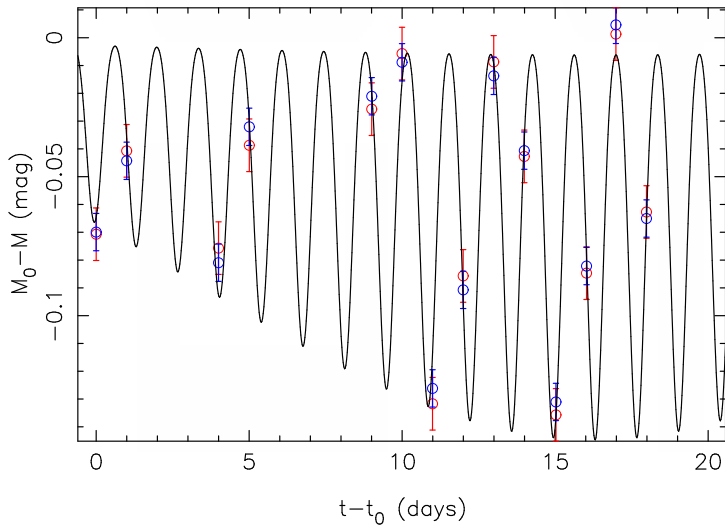


Figure: Detected spot-induced signals in ground-based differential photometry of V889 Her (Tuomi et al. 2026, A&A, submitted).

- Obtaining information on spot properties based on photometry corresponds to a highly ill-posed statistical problem.
- Variations still clearly reveal information on period, amplitude, and spot visibility.

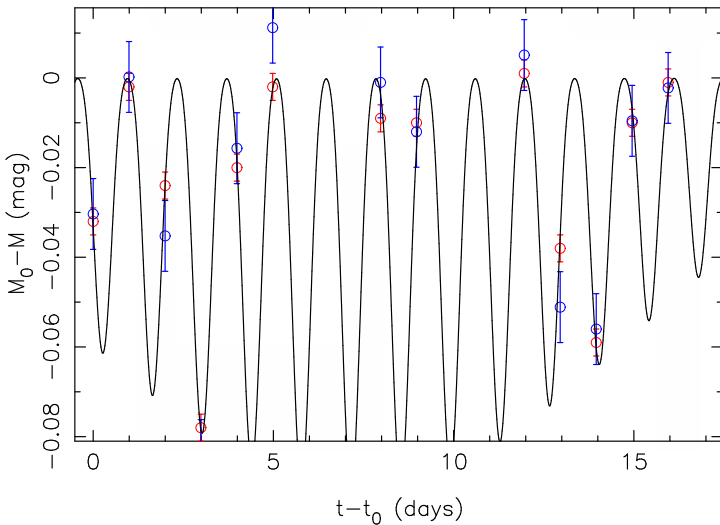


A growing spot.



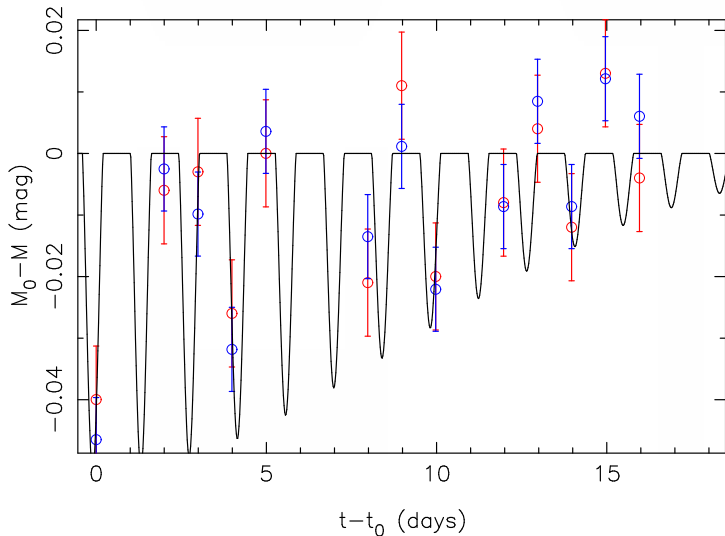


A peaking spot





A disappearing spot.



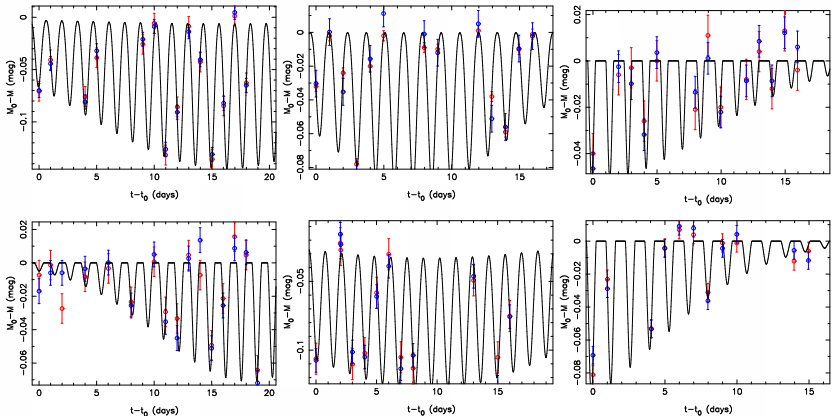
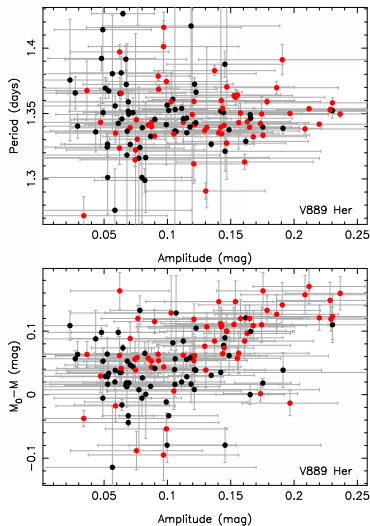


Figure: Detected spot-induced signals in ground-based differential photometry of V889 Her (Tuomi et al. 2026, A&A, submitted).

- The largest spots dominate the variations in the light curve.
- Spots can evolve and have limited lifetimes, appear and disappear, but latitudinal movements are assumed negligible.



A population of starspots



- Larger spots are concentrated at a narrower range of rotation periods .
- When the star is at its brightest (lower spot-coverage) the visible spots are larger and concentrated at polar regions.
- Is this evidence for an extra-solar butterfly diagram?!

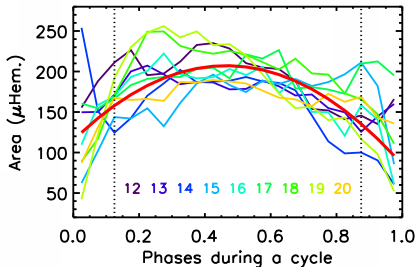


Figure: Mean sunspot group area for cycles 12–20 (Jiang et al. 2011, A&A, 528, A82).

Figure: Spots detected in the photometry of V889 Her (Tuomi et al. 2026, A&A, submitted).



Model for the spot distribution

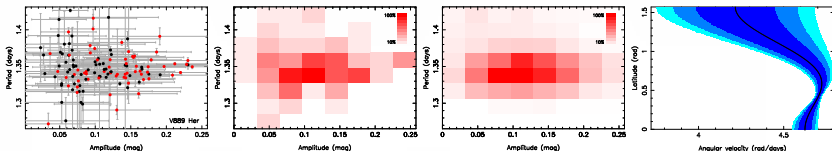


Figure: Observed and modelled spot distribution for V889 Her (Tuomi et al. 2026, A&A, submitted).

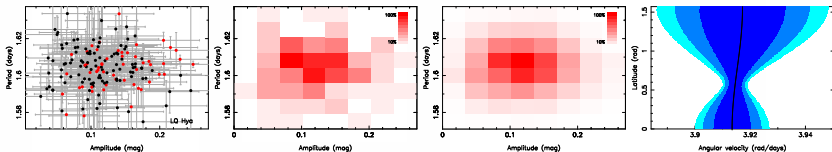


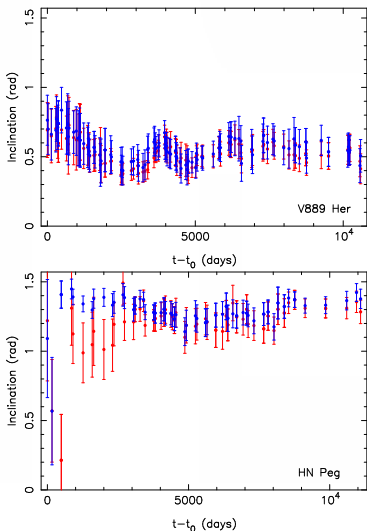
Figure: Observed and modelled spot distribution for LQ Hya (Tuomi et al. 2024, A&A, 689, A262).

- A model* with non-monotonic DR profile best explains the distribution of spots for V889 her. LQ Hya appears to show no evidence for DR.

*) Accounting for projection effects, inclination, limb darkening, and DR as well as stochastic variations in spot angular velocity, amplitude, and in the observed distribution.



What about spot latitudes?



Spot models contain the spot latitude but the view is obscured by uncertainties in stellar inclination.

Information on inclination:

- Some spots move behind the stellar visible surface: star is not close to pole-on orientation.
- Some spots are constantly visible: Star is not edge-on either.
- Limb darkening helps differentiate between spots near stellar limb.

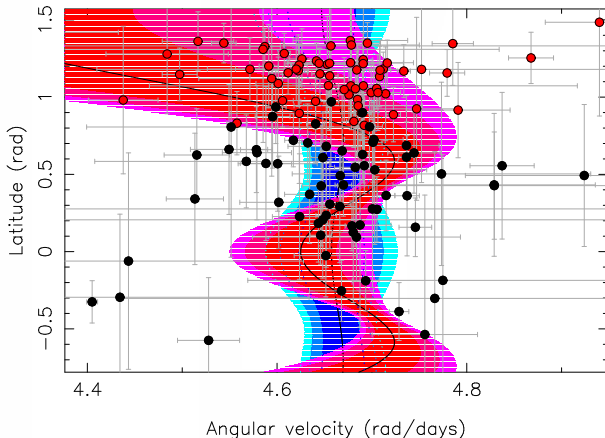
Bayesian updating helps determine inclinations by enabling to collect inclination information from a large number of spot signals.

$$\pi(\theta|m_1, \dots, m_N) \propto l(m_N|\theta)\pi(\theta|m_1, \dots, m_{N-1})$$

Figure: Bayesian updating of inclination for V889 Her and HN Peg (Tuomi et al. 2024, A&A, 689, A262; Tuomi et al. 2026, A&A, submitted).



What about spot latitudes?



Direct spot latitudes

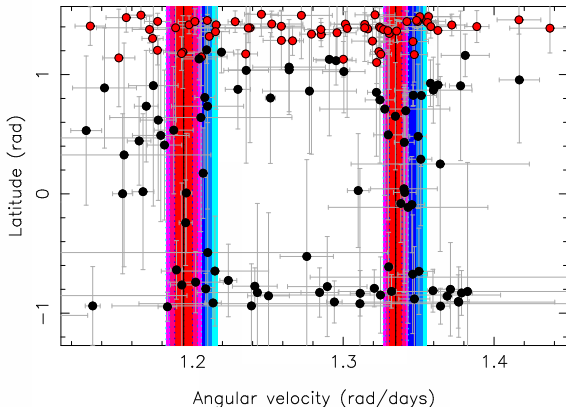
- Latitudes are very uncertain.
- **But we get something!**
- Results are consistent with literature work.
- Photometry can be used to set constraints for stellar DR.

The DR profile of V889 Her obtained by modelling spot visibility distribution (**red**) is consistent with the curve obtained directly from the angular velocities and latitudes (**blue**).

Figure: Tuomi et al. 2026, A&A, submitted.



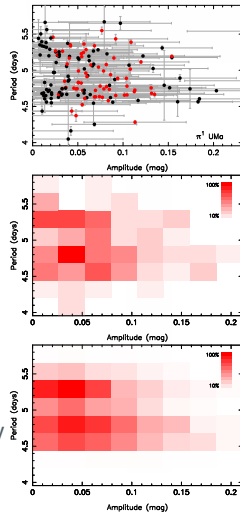
We also find something weird



The DR profile of π^1 UMa obtained by modelling spot visibility distribution (red) and angular velocities and latitudes (blue).

A bimodal distribution!

Figure: Tuomi et al. 2026, A&A, submitted.





Conclusions

- Photometry from small, robotic ground-based telescopes can reveal new information on the spots and DR of nearby stars.
- We can constrain DR profiles with photometry.
- There is evidence for butterfly diagrams of young, nearby, Solar-type stars.
- Bimodal angular velocity distributions lack astrophysical explanations.

Thank You!