1. The old game: data precision vs. model accuracy

2. Inversion tests with synthetic light-curves

3. Warm and cool „spots“ from white light?

4. Differential rotation vs. spot changes and faculae
First time-series optical photometry from Antarctica

sIRAIT monitoring of the RS CVn binary V841 Centauri and the δ-Scuti star V1034 Centauri

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25cm telescope
243 hours continuous @ 98%
K. G. Strassmeier, Surface features from high-precision photometry, IAU GA2012, Special Session 13, August, 2012

-83°C
1. The old game: precision vs. accuracy

- Ground-based automatic photoelectric telescopes (APTs) 
  \( \sigma_{\text{ext}} \approx 1-5 \text{ mmag} \ (V \approx 0^m-10^m) \).

- CoRoT \( \sigma \approx 0.25 \text{ mmag} \ (\approx 10^m-14^m) \),

- KEPLER \( \sigma \approx 0.03 \text{ mmag} \ (10^m) - 0.06 (12^m) - 0.12 (14^m) \)
The old game: data precision vs. model accuracy

- Astrophysical accuracy depends on the ratio

\[ \delta = \frac{\text{signal amplitude}}{\text{signal precision}} \]
17 years of BVI 
σ=5mmag 
photometry of HD208472 

vs.

145 nights of CoRoT 
photometry with 
σ=0.24 mmag 
of CoRoT-6

HD208472 – APT: 
Özdarcan et al. 2010, AN 331, 794

CoRoT-6 – CoRoT: 
Lanza et al. 2010, A&A 525, A14
The old game: precision vs. accuracy

- Achievable astrophysical accuracy depends on the ratio
  \[ \delta = \frac{\text{signal amplitude}}{\text{signal precision}} \]
- e.g. HD208472 (V=7.3\,m): \( \delta = 20 \ldots 80 \)
- e.g. CoRoT-6 (V=13.9\,m): \( \delta = 12 \ldots 83 \)
- Notice that time coverage, phase gaps etc. became nearly negligible for ground-based robotic telescopes …
- … for space anyway.
2. **LC-tests**: $\delta \approx 10\text{-}20$ single-rotation inversions

1. S/N=\infty $V$-band data are generated by forward computations from an input spot model.

2. Random noise added to reach $\delta \approx 10\text{-}20$.


**Assumptions:**

Spot model of form

$$I = \int \int (f I_{phot} + (1 - f) I_{spot}) \cos \theta \, dM$$

Fluxes from Kurucz (2000)

Limb-darkening from Diaz-Cordoves et al. (1995)

Johnson V-band
Single-rotation test-light-curve inversions

From Savanov & Strassmeier (2008): Data w/ \( \sigma(V) = 5\)mmag, \( f \)-fractional surface area (0<\( f \)<1); \( T_{\text{phot}} = 5000\)K, \( \Delta T_{\text{spot}} = 1000\)K

As above but "peppered star" without concentrated spots.
More test inversions with V-band data but ...

a) $T_{\text{phot}}$ and $T_{\text{spot}}$ lowered by 250K

b) log $g$ lowered by -0.5dex (3.5 instead of 4.0)

c) Increased $\sigma = 20$ mmag ($\delta=5$)

d) Inclination lowered by 15° (45 instead of 60). Shown with $\sigma = 0$ mmag „data“.

e) $V_{\text{unspotted}}$ brighter by 0.2mag (6.8$m$ instead of 7.0$m$)
Reconstructions for V1355 Ori from V-band ...
\[ \Delta (V-I) (P_{\text{rot}}) \] constrains \( T_{\text{phot}} - T_{\text{spot}} \)

... but also for different bandpasses

Real data: 
- \( V \)-band
- \( I \)-band
However, $(V-I)_0$ may also be variable

HD123351: Strassmeier et al. (2011), A&A
A comparison with Doppler images: V1355 Ori

Doppler images  Light-curve images
A comparison with Doppler images: V1355 Ori

Doppler images

Light-curve images
A comparison with Doppler images: V889 Her

Observed Doppler image

Forward light curve

Reconstructed LC image

Jeffers et al. (2011), MNRAS 411, 1301
3. Warm and cool „spots“ from white light?

- **Plages/faculae** $\Delta T = +1000K$
- **Spots** $\Delta T = -1000K$

**Typical QE at -100C**

[Graph showing QE (%)](image)

- **DD astro-Broadband**
- **DD standard-midband**
- **Std Si astro broadband**

K. G. Strassmeier, Surface features from high-precision photometry., IAU GA2012, Special Session 13, August, 2012
The Sun in photospheric and chromospheric light

Red light

Ca II H&K

Jones et al. (2008), SP 248, 323

Intensity images of the full-disk Sun (CSUN/SFO)
The Sun as a star: ACRIM data = bolometric

Willson R. C. (2003), www.acrim.com
The Sun as a star: reconstructions of $P(\text{rot})$ from spots

Strassmeier & Olah (2003), in 2nd Eddington workshop, ESA SP538

All data
The cause: warm „spots“

- Do stellar plages or other „bright points“ exist?
- Solar plages have different lifetimes than sunspots.
- This demodulates a (white)light curve based on spot transits.
4. Differential surface rotation

Simulation

Fig. 6. The effect of differential rotation. Two spots are positioned at equal longitudes but different latitudes ($\theta = 0$ and $60^\circ$). Only the spot at $60^\circ$ latitude is affected by differential rotation. With the differential rotation parameter $\alpha$ set to 0.1, this spot’s angular velocity is approximately half that of the other spot.

Time series from the ground

HD 17433, K3-4 IV, P=16.4 days

Strassmeier & Bopp (1992)
Differential rotation of ε Eri with MOST: $\frac{\Delta \Omega}{\Omega} = 0.11$

Best two spot model fit with $P = 11.35$ & 11.55 d

Croll, Walker et al. (2006)
CoRoT-6: differential rotation vs. „facular“ component

\[ Q = \frac{\text{faculae area}}{\text{spotted area}} \]

Lanza et al. (2011)
CoRoT-6: differential rotation vs. „facular“ component

\[ Q = 1.5: \quad \frac{\Delta \Omega}{\Omega} = 0.12 \pm 0.02 \]

\[ Q = 4: \quad \frac{\Delta \Omega}{\Omega} = 0.09 \pm 0.02 \]

( \( Q_{\text{Sun}} = 9 \) )

Lanza et al. (2011)
Summary and conclusions

- **Model accuracy** depends on ratio $\delta \equiv \Delta/\sigma$, not just on $\sigma$.
- Typically, $\delta_{\text{Space}} \approx \delta_{\text{Ground}}$ (because $\Delta_{\text{Ground}} \gg \Delta_{\text{Space}}$).
- Light curves are one-dimensional data, a stellar surface is *per se* two-dimensional → **ill-posed problem** even if $S/N=\infty$ or, say, $\delta>100$.
- **Starspots**, chromospheric **network** and **plages** contribute differently at different wavelengths.
- Photometric time-series are most affected by the **different variability time scales** of these three phenomena.
- Best possible solution: employ **bandpasses** in space photometry, e.g. $UBVRI$.
- **Ultimate solution.** Doppler imaging in space with absolute continuum calibration.