CHEETAH: Modeling Starspots from Kepler Lightcurves

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advised by

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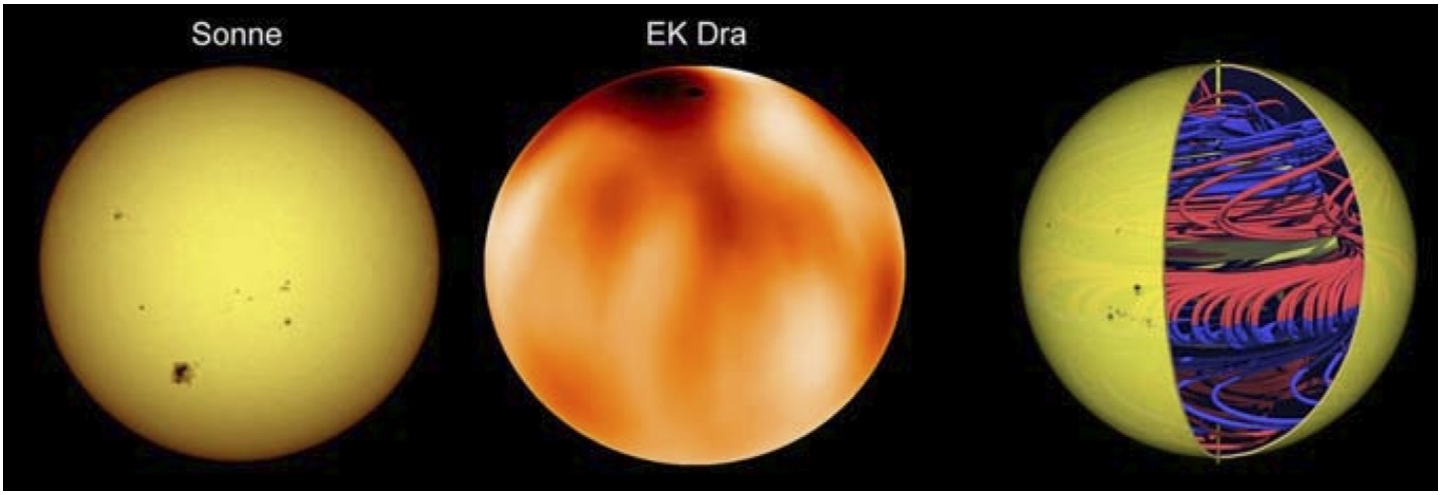
What are starspots?

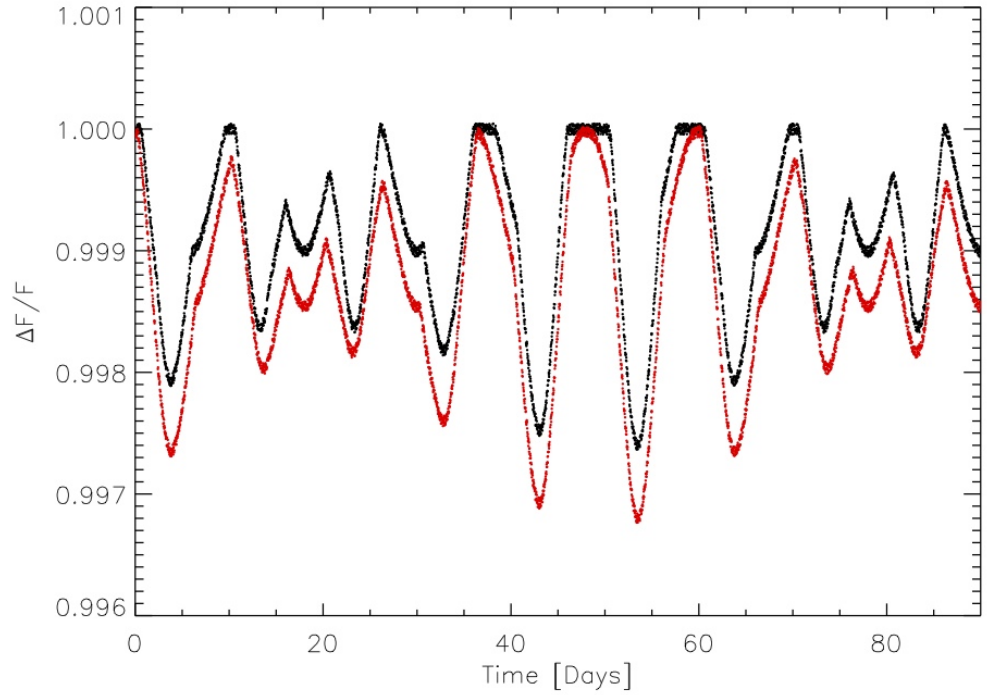
- Cooler areas on the "surface" (photosphere) of a star
- Caused by internal magnetic field penetrating surface
- Solar activity (e.g. flares) tends to occur at or near spots
- Internal magnetic fields of stars not fully understood
- In general, most stellar data comes from the Sun
- Starspots could provide info about MF of other stars



Strassmeier 2009, "Starspots," *Astron Astrophys Rev*

Kepler Data

- Stars (except Sun) generally too far away to see spots
- Kepler measures light intensity of many stars
- Brief periodic dimming used to infer planet revolution
- Gradual variation (lightcurve) used to infer spots



Walkowicz 2012 (see references)

Eker Model

- Assume circular spots
- Integrate specific intensity over visible area
- Gives "loss of light" due to spot
- Parameters:
  - Stellar inclination
  - Spot radius, latitude, longitude
  - Spot contrast, limb-darkening coefficients (fixed)

Single Spot Fitting

Algorithms used:

- Levenberg-Marquardt (LM) algorithm – numerical optimization for nonlinear least squares problems
- K-means – simple clustering algorithm

Procedure:

choose evenly spaced initial points throughout parameter space
for each point in initial points:
    run LM for small number `initsteps` of iterations
cluster results into `nclusters` using K-means
select point with lowest sum squared error (SSE) from each cluster
for each point in reduced list:
    run LM algorithm to convergence
sort output points by SSE, find
keep all points with SSE < `threshratio` * best SSE

(`initsteps`=20, `nclusters`=20, `threshratio`=2 seems to work well)

Multi-Spot Fitting

Sequential fitting:

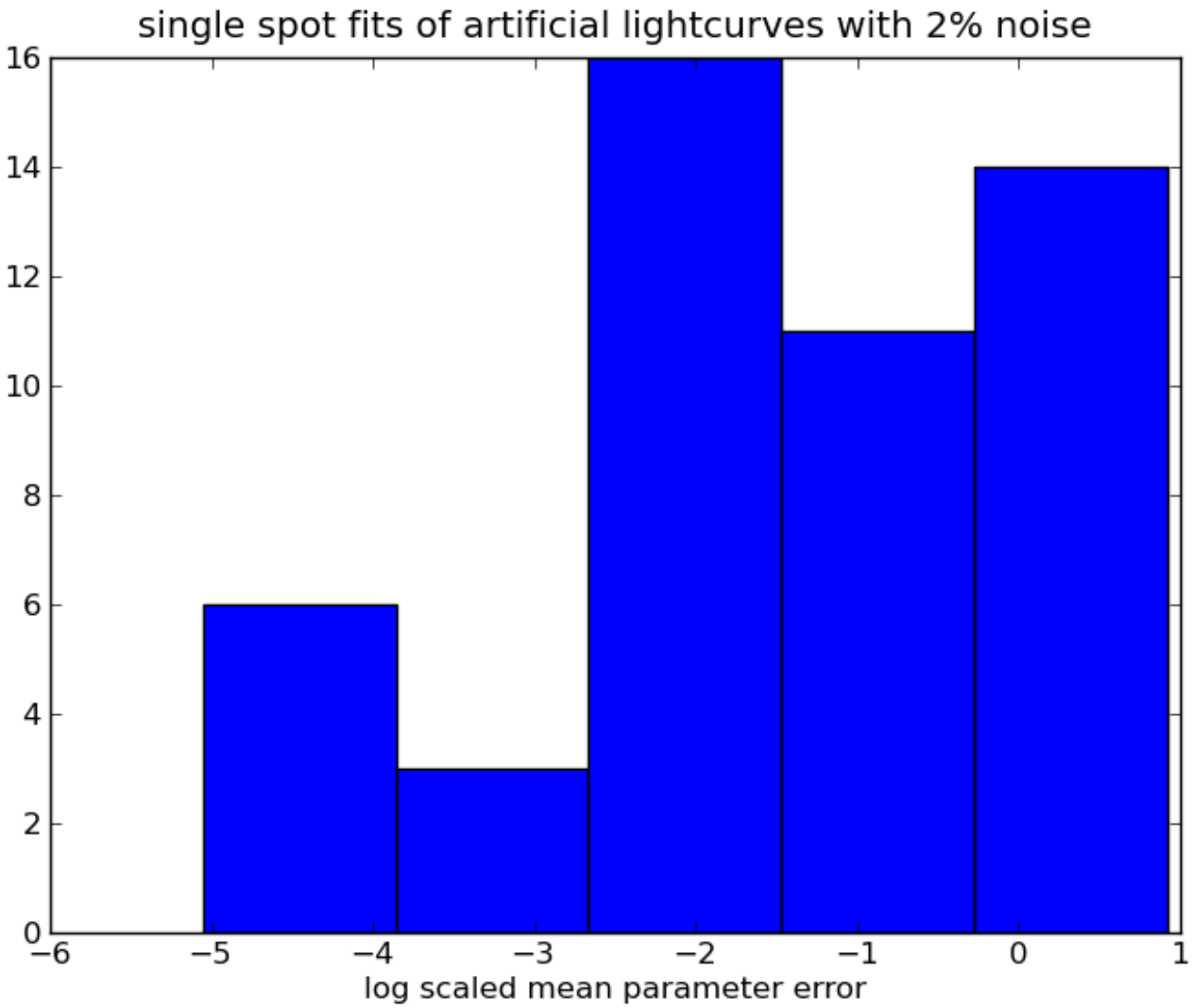
- fit as single spot curve to get inclination and first spot
- for each additional spot:
  - subtract generated lightcurve from data, fit with fixed inclination

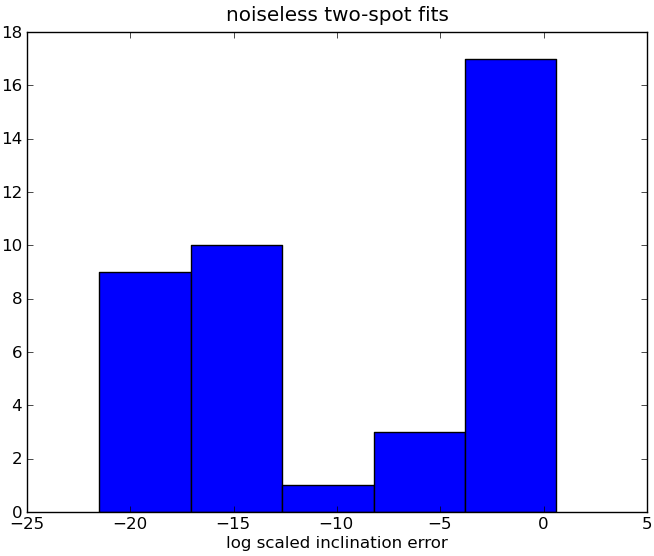
Simultaneous fitting:

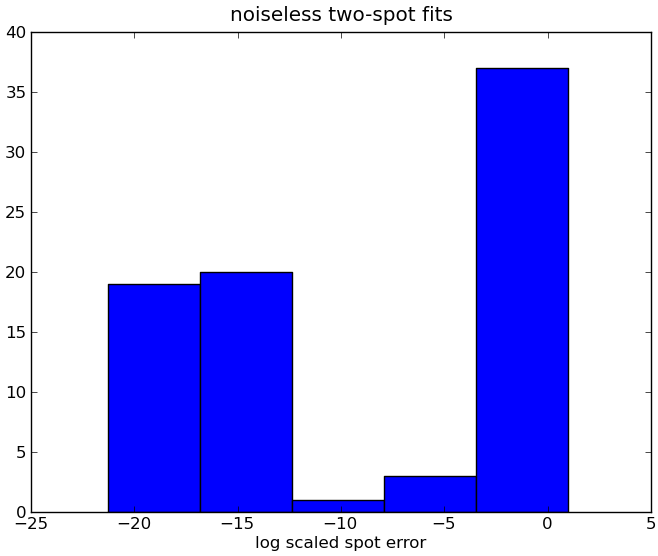
- fit with LM allowing inclination and all spot params to vary simultaneously

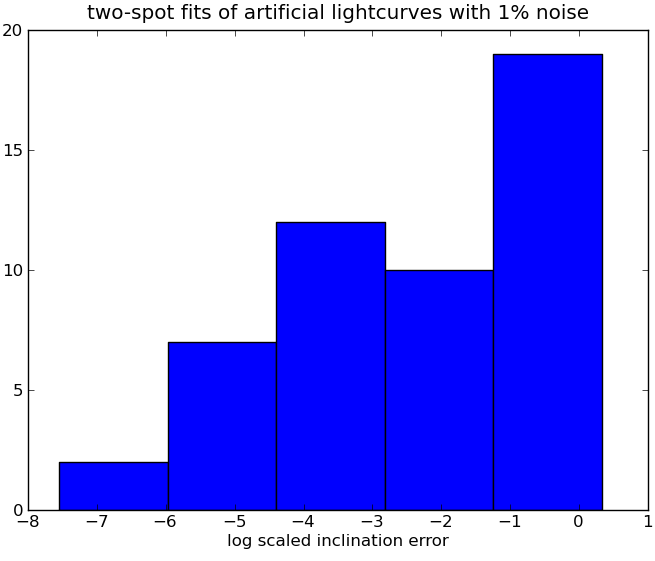
"Ratchet" fitting:

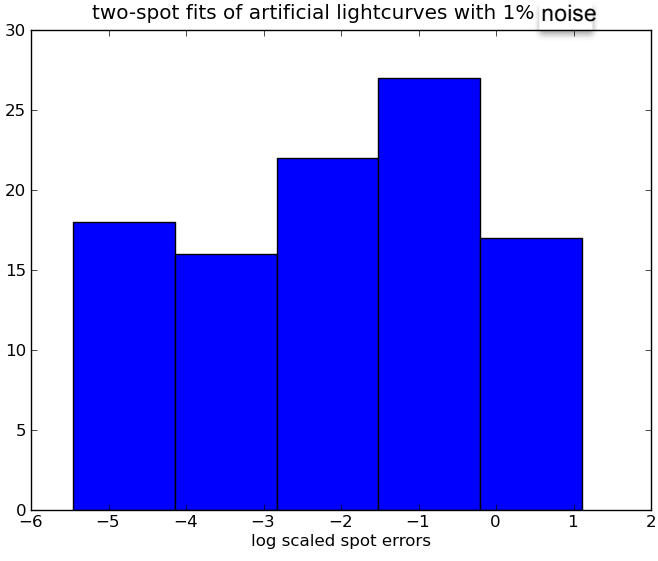
- fit first and second spot sequentially
- use sequential fit output as initial points for simultaneous 2-spot fit
- for each additional spot:
  - subtract generated lightcurve from data, fit next spot sequentially
  - use output as initial points for simultaneous n-spot fit


single spot fits of artificial lightcurves with 2% noise
16
14
12
10
8
6
4
2
0
−6
−5
−4
−3
−2
−1
0
1
log scaled mean parameter error


noiseless two-spot fits
log scaled inclination error


noiseless two-spot fits
log scaled spot error


two-spot fits of artificial lightcurves with 1% noise
log scaled inclination error


two-spot fits of artificial lightcurves with 1% noise
log scaled spot errors

Important References

- Eker 1994, "Modeling light curves of spotted stars," *ApJ*
- Walkowicz et al. 2012, "The information content in analytic spot models of broadband precision lightcurves," *ApJ Supplement Series*