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Starspot mapping with parallel tempering for M-dwarf flare stars

Kai Ikuta [1] (ikuta@kusastro.kyoto-u.ac.jp), Hiroyuki Maehara [2], Yuta Notsu [3,4,5], Kosuke Namekata [2], Taichi Kato [1], Soshi Okamoto [1], Shota Notsu [6], Satoshi Honda [7], Daisaku Nogami [1], Kazunari Shibata [1]

1. Kyoto University 2. NAOJ 3. University of Colorado Boulder 4. NSO 5. Tokyo Tech 6. RIKEN 7. University of Hyogo

Ikuta et al. 2020, ApJ, 902, 73 (Paper I); Ikuta et al. 2021, to be submitted (Paper II)

Introduction to Starspot

Apparent indicator of stellar magnetic activity on the surface

Superflares are reported on M-, K- G-dwarf stars (cf. Notsu's poster)

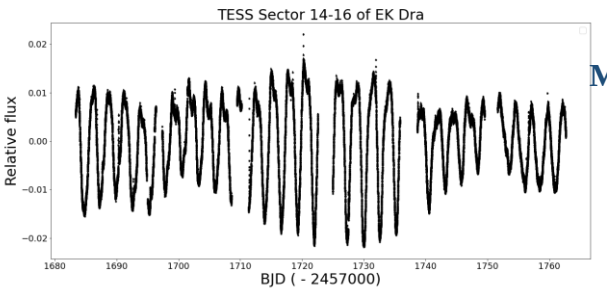
Size: < 10 % of the hemisphere (10^4 times larger than sunspot)
Location: some ones are on pole (equator to mid-latitude for sunspot)
Lifetime: < a few years (dozens of days for sunspot)

Kepler facilitated starspot studies with long-term and high precision
→ **Light curves exhibit modulations ascribed to spots**

Flares are NOT correlated with the light curve phase (cf. Hawley+14)

More spots exist than the number of periodicities (cf. Namekata+20a)

Purpose



How does the surface of flare stars look like ?

→To what extent are spot location and size ?
→How many spots ?

Rotation period,
Differential rotation,
Spot location, size,
emergence/decay rates

We conduct starspot mapping with stellar/spot parameters

Implementation of Code (Paper I)

Setup

Input: Kepler/TESS-like synthetic light curve produced with three spots (25 parameters)

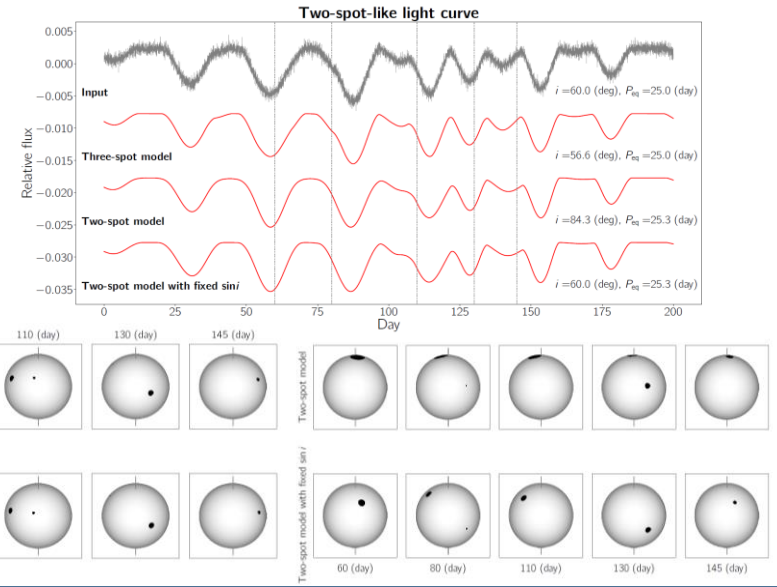
Optimize the light curve by three-, two-, and four-spot models with **parallel tempering**
Compute the model evidence to compare models (the number of spots)

Result

Output: Unimodal posteriors are deduced for three- and two-spot models
Multimodal one are deduced for four-spot model

Three-spot model is preferable than two- and four-spot models
→The number of spots can be determined for synthetic light curve

Parameter degeneracies are also discussed in Ikuta+20



Application to M-dwarf flare stars (Paper II)

Background & Setup

AU Mic (Sector 1&27), **YZ CMi (Sector 7&34),** and EV Lac (Sector 16)
→ Their flares have been spectroscopically observed (Notsu & Maehara's poster)

Starspot modeling with two-spot models (the spot size is stable)
Flares are detected utilizing *stella* code (Feinstein+20)

Result for YZ CMi

Deduced differential rotation ≒ 0 → **Phase-folded light curve**

The amplitude of light curve and flare frequency decreased in two Cycles
→The decrease in spot size (spot decay)

The structure of light curve has varied from one periodic to two periodic
→ Almost same latitudes (within 20 deg) are deduced for Sector 7 and 34
→ The differential rotation or spot emergence/decay in two Cycles

Flares are NOT correlated with phases → Either spot is always visible

Remarks & Prospects

Starspot studies are significant for exoplanet characterization

- Multi-wavelength (Hα and X-ray) modeling (cf. Namekata+20b; Toriumi+20)
- Analyze anomalies in spot-crossing events (cf. Bruno&Deleuil 21)
- Compare a result by Gaussian process (Luger+21a&b)
- Classify light curves with unsupervised machine learning