fleck: Fast approximate light curves for starspot rotational modulation

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Software

- Review
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Summary

Stars are born rapidly rotating, and dappled with dark starspots in their photospheres. Starspots are regions of intense magnetic fields which dominate over local convective motions to produce dim, cool regions in stellar photospheres. Starspot coverage shrinks from stellar youth into middle age.

In the associated paper submitted to AAS Journals, we show that *ensembles* of light curves of stars in young clusters can be used to constrain their spot distributions. One can imagine that photometric surveys of young clusters are essentially observing the same star at many different inclinations, allowing us to marginalize over the unknown inclinations of the individual stars if we model their light curves as a population.

`fleck` is a pure Python software package for simulating rotational modulation of stars due to starspots, which we use to overcome the degeneracies and determine starspot coverages accurately for a sample of young stars. `fleck` simulates starspots as circular dark regions on the surfaces of rotating stars, accounting for foreshortening towards the limb, and limb darkening. The software is an efficient, vectorized iteration of earlier codes used in Morris, Agol, Davenport, & Hawley (2018) and Morris et al. (2019).

The user supplies the latitudes, longitudes and radii of spots, and the stellar inclinations from which each star is viewed, and `fleck` takes advantage of efficient array broadcasting with `numpy` to return approximate light curves (van der Walt, Colbert, & Varoquaux, 2011). For example, the present algorithm can compute rotational modulation curves sampled at ten points throughout the rotation of each star for one million stars, with two unique spots each, all viewed at unique inclinations, in about 10 seconds on a 2.5 GHz Intel Core i7 processor. This rapid computation of light curves en masse makes it possible to measure starspot distributions with Approximate Bayesian Computation.

While `fleck` is intended to model ensembles of light curves, we also include some examples of fitting light curves of individual spotted stars. Other methods exist which are more efficient for modeling individual systems, such as `starry` (Luger et al., 2019) and `spotrod` (Béky, Kipping, & Holman, 2014), and we encourage users to explore whether those packages might be ideal for modeling individual systems.

The mathematical formalism of the `fleck` algorithm is detailed in the software's documentation. The `fleck` package is built on the `astropy` package template (Astropy Collaboration et al., 2018).

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