National Aeronautics and Space Administration

Detection of Earth in the Presence of Starspot Noise

Joseph Catanzarite, section 383D
Michael Shao, Nick Law, section 3020

Project Objective

Do starspots interfere with the indirect detection of an Earth orbiting a Sunlike star at 1 AU? We estimate the contribution of sunspots to noise in the Sun's astrometric and radial velocity (RV) signature, and the impact on the detectability of the Earth-Sun system by the astrometric and RV methods.

Starspot model

Assumptions:

- ***The Sun's visible flux variation is due to sunspots.***
- ***The birth of starspots is a Poisson process in time.***

Adjustable parameters:

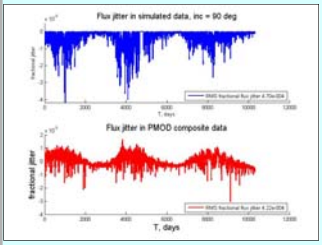
- ***Lognormal distribution of starspot lifetimes***
- ***Starspot area***

Model includes:

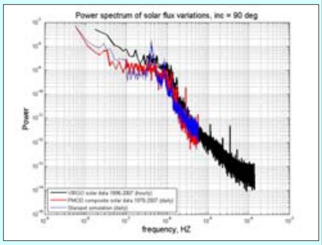
- ***Area projection and limb-darkening***
- ***Systematic starspot latitude drift "Butterfly pattern"***
- ***Inclination of stellar rotation axis***

The simulation nearly matches observed solar flux variations in time and frequency

Time series



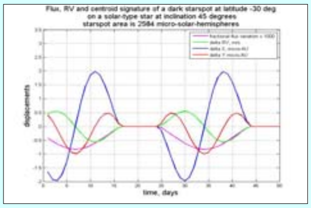
Power Spectral Density



In the simulation, the total daily starspot area is driven by the 30-year record of sunspot numbers

Starspots introduce noise in astrometric and RV measurements

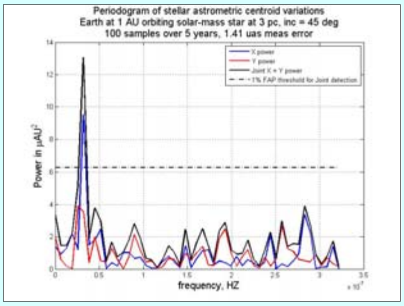
- ***As the star rotates, spots move across its surface, perturbing its astrometric centroid and its radial velocity signal.***
- ***Sunspot lifetimes are typically ~ a week*. So starspot noise is correlated in measurements within ~ a week of each other.***



**The starspot represented in the figure above is persistent, for illustration.*

Result: Sunspots don't interfere with the astrometric detection of Earth, but they are problematic for the radial velocity technique

- ***SIM PlanetQuest detects Earth at 3 pc with 100 2-D astrometric measurements at 1.4 µas differential accuracy, with SNR=7 (See the periodogram of simulated measurements at right).***
- ***With 10x more measurements, SIM PlanetQuest can detect planets down to 0.3 Mearth at the mid-habitable zone at a Sun-like star at 3 pc.***
- ***RV detection of Earth at SNR=7***
  - ***Requires over 2,000 independent measurements, even at precision of 0 m/s***
  - ***The observing cadence must be slower than once per week, to avoid correlated starspot noise, so the observing campaign would take over 40 years.***



Earth-Sun signal vs. noise

Astrometric case

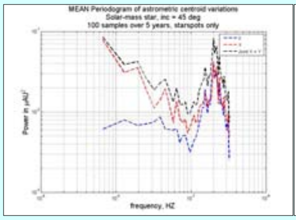
- ***Semi-amplitude of 3 µAU, is over 4X larger than sunspot noise of 0.7 µAU***
- ***Instrument noise of 1 µas is 1 µAU*D where D is star distance in pc; it dominates starspot noise for all but the closest stars.***
- ***Correlations in starspot noise are not a significant problem.***

RV case

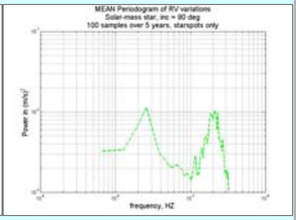
- ***Semi-amplitude of 9 cm/s is 8X smaller than sunspot noise of 60 cm/s.***

Starspot noise is non-white

The power spectral density (PSD) captures the starspot noise per measurement vs. frequency



σ_{spot} = 0.7 µAU at 1 yr period



σ_{spot} = 60 cm/s at 1 yr period

Above plots are for a 5-year observing campaign with 100 uniformly spaced measurements

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