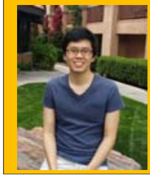
Flare and Starspot-induced Variabilities of Red Dwarf Stars in the Open Cluster M37: Photometric Study on Stellar Magnetic Activity



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Abstract

- We investigate the statistical properties of flare and starspot-induced variabilities of red dwarf stars in the open cluster M37, particularly **(1) understanding magnetic activity phenomena that are seen in groups of stars (with the same age and mass)** and **(2) the correlations among activity indicators**.
- We recalibrate the archival imaging data of the M37 obtained by one-month observing run with MMT/Megacam camera (**Deep, High-cadence & Long-term monitoring**). To detect any significant variability from cool stars, **forced photometry with our multi-aperture indexing technique** is applied to the entire sets (Chang et al. 2015a).
- In this poster, we present an update on flare and rotational statistics of this cluster and further strong evidences that support the classical age-rotation-activity paradigm.

Two photometric tracers of stellar activity

The use of both tracers (flare + starspot) is particularly useful for statistical studies since it can provide more homogeneous information about target star's activity behavior. We developed variability detection algorithms to identify unique features from the light curves (Chang et al. 2015b).

- Among 2500 M dwarfs within our selection criteria, we found 420 flare events from 312 stars and 401 slow/fast rotators with quasi-sinusoidal variations in brightness.
- For further statistical analysis, we considered stars with $P_{mem} \geq 0.2$ (membership prob.) to be candidate cluster members since the effect of field star contamination will not be great on rotation-activity analysis of this aged cluster (Núñez et al. 2015).

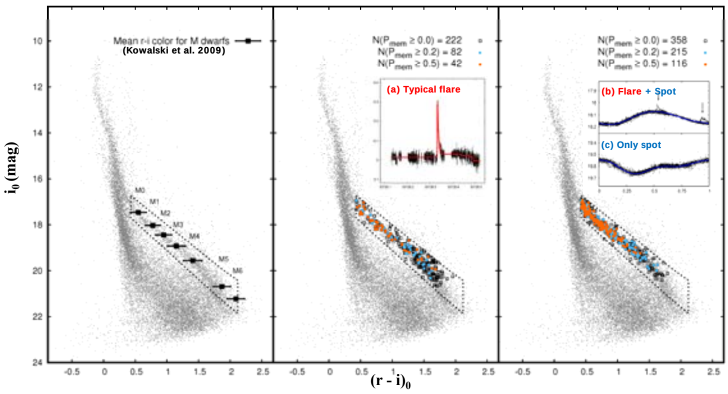

Figure 1. *De-reddened r − i vs. i color-magnitude diagram for sample selection (Left). The CMD positions of stars that flare with P_{mem} (Middle) and those of rotating stars (Right) are indicated by different colors, respectively.*

Ensemble statistics for flare parameters

We follow the ergodic hypothesis for which the number statistics of flares on *n* stars of similar brightness over the time *T* is the same as those of the same star over the time *nT*. In a large sample of stars of similar spectral types, this statistical approach is useful to understand their flaring nature.

- We found that there are no statistical differences in the distributions of flare timescales, estimated energies, and frequencies among stars of the same mass group.
- Our ensemble sample tend to have longer rise ($t_{0,rise}$) and decay ($t_{0,decay}$) timescales compared to those seen in field flare stars of the same spectral type and be more energetic.

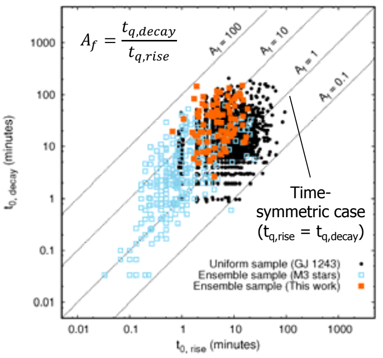

Figure 2. *Direct comparison of flare timescales between uniform sample of flares from a single star (GJ 1243; Davenport 2014) and ensemble flare samples from many stars (M3 stars: Dal & Evren 2010; Chang et al. 2015c).*

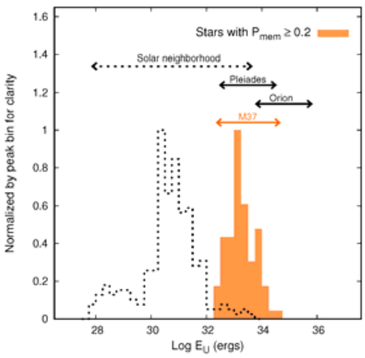

Figure 3. *Estimated U-band flare energy for three clusters (Pleiades, Orion, & M37) and Solar neighborhood. Flares on M dwarfs in clusters are more energetic than field M dwarfs.*

- For the groups of stars with similar brightness, the flare frequency distributions can be approximated by a power-law form $\nu(E) \sim E^{-\beta}$ with $\beta \sim$ 0.52-0.97 for stars with membership information, which are in agreement with previous studies on other open clusters ($\beta \sim$ 0.73-1.18) and active field stars ($\beta \sim$ 0.53-0.73).

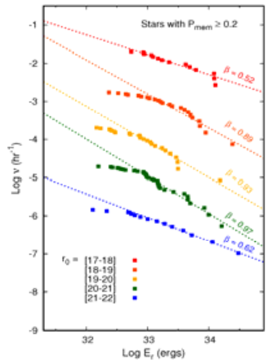

Figure 4. *Upper limit for cumulative flare frequency distributions (FFD) ν(E) vs. r-band flare energy (vertically shifted for each magnitude bin, in order of stellar magnitude down to r = 21-22).*

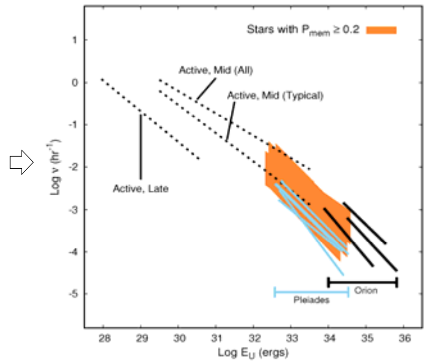

Figure 5. *Cumulative FFDs vs. U-band flare energy for the M37 (shaded region) and those for other statistical studies. Our sample falls nicely between the young open clusters and nearby field stars.*

Spots on M dwarfs with & without detected flares

We searched for differences in the observational properties of the stars with and without detected flares. The rotation periods (P_{rot}), modulation amplitudes, and positions in CMDs for the two samples show no significant differences.

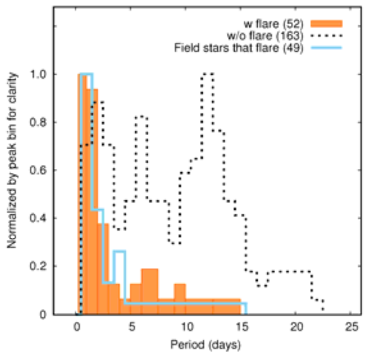

Figure 6. *Rotational periods for samples of stars with (orange) and without (dashed line) detected flares. For a comparison purpose, the periods of field flare stars are also shown (skyblue). Stars that flare may be at least more easily observed among fast rotators.*

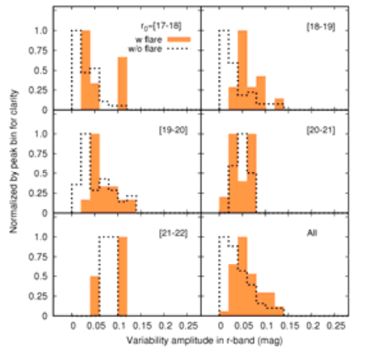

Figure 7. *Variability amplitude histogram of same stars as in Figure 6 across different magnitude regimes. We found no significant difference between the two subsamples, but most stars that flared tend to have a slightly larger variability amplitude.*

We also show the relationship between the rotation periods and the flare parameters:

- The flare energy observed in a given period bin does not correlate with the P_{rot}.
- We confirmed again that rapidly rotating stars can cause more frequent flares than the relatively slower ones (e.g., Notsu et al. 2013; Cadelaresi et al. 2014).

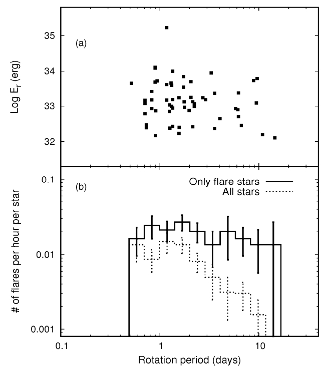

Figure 8. *Relation between the rotation periods and the flare parameters (Top: flare energy; Bottom: flare frequency).*

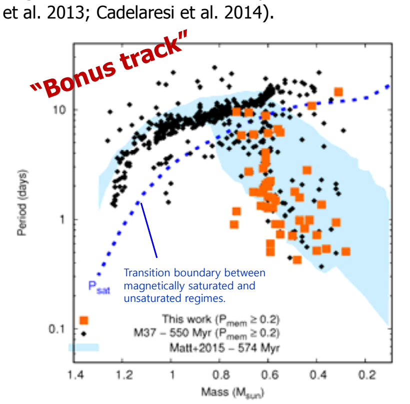

Figure 9. *Mass-period distribution for M37 (black) and flare stars (orange), compared to Matt et al. (2015) model data for 574-Myr-dol (skyblue). The model explains the existence of rapidly rotating active stars.*

References

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