Blue wing asymmetries in Balmer lines and possible mass ejections during mid M dwarf flares

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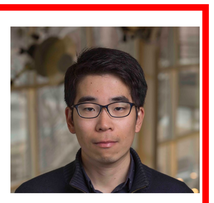
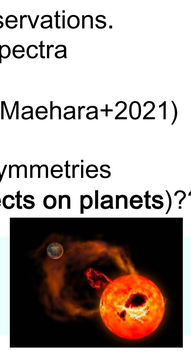


1. Introduction - Blue asymmetries of flares on M-dwarfs

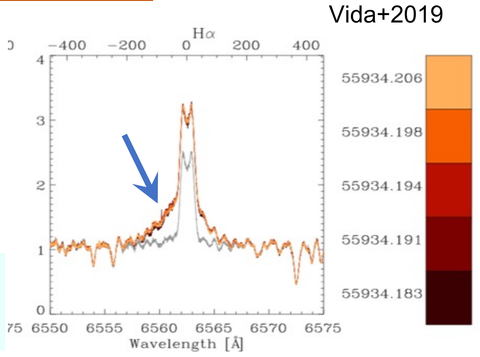
Recent M-dwarf H-alpha line spectroscopic observations.
→ There are many asymmetric blue-shifted spectra (blue asymmetries) during flares.
(e.g., Vida+2016&2019, Honda+2018, Maehara+2021)

There are growing interests "Are these blue asymmetries related with **stellar mass ejections** (**and effects on planets**)??"

However, still many points to be investigated
How blue asymmetries are generated ?
Really related with mass ejections ?



Vida+2019



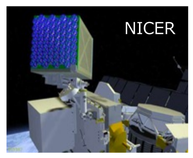
2. Observation – Simultaneous spectroscopic and photometric observations

[Target stars]
YZCMi(M4.5V), EVLac(M4V), ADLeo(M3.5V)

[Optical Spectroscopy (λ/Δλ ~ 31,500 & 25,000)]
(US) Apache Point Observatory (APO) 3.5m (ARCES)
(Chile) CTIO SMARTS1.5m telescope (CHIRON)

[Photometry (Ground & Space)]
(US) APO 0.5m telescope (u&g-band)
(Chile) LCO 1m/0.4m telescopes (U&V-band)
TESS (1-band: 6000-10000Å)

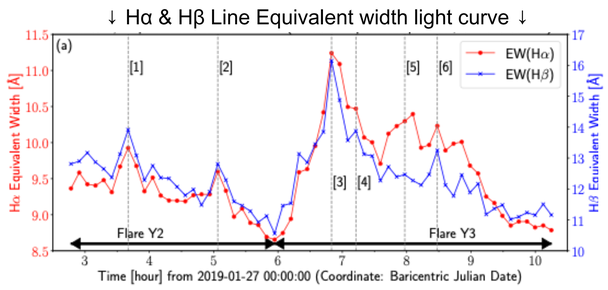
[Soft X-ray spectroscopy] NICER (Only 3 nights)



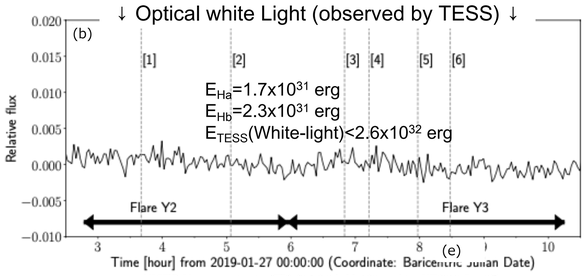
2019Jan – 2021Feb: 31 night observations
(25 nights @ APO)
41 flares in Hα line
→ **At least 7 events show clear blue wing asymmetries**
(Notsu et al. submitted to ApJ)

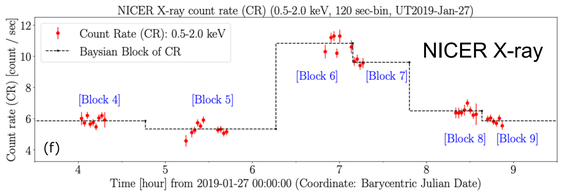
4. [Event 1] A non/weak white-light flare with short-lived blue wing asymmetries

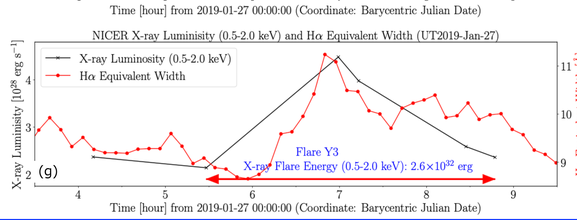
↓ Hα & Hβ Line Equivalent width light curve ↓



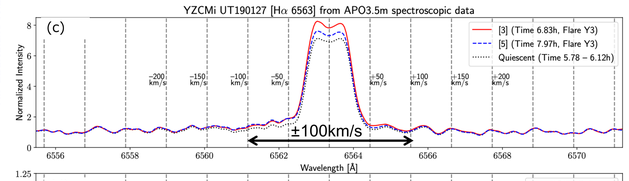
↓ Optical white Light (observed by TESS) ↓

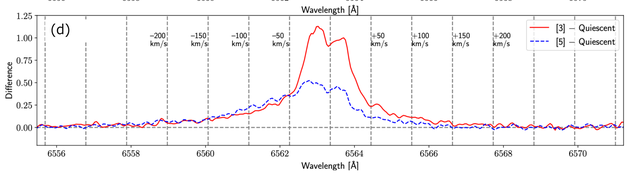


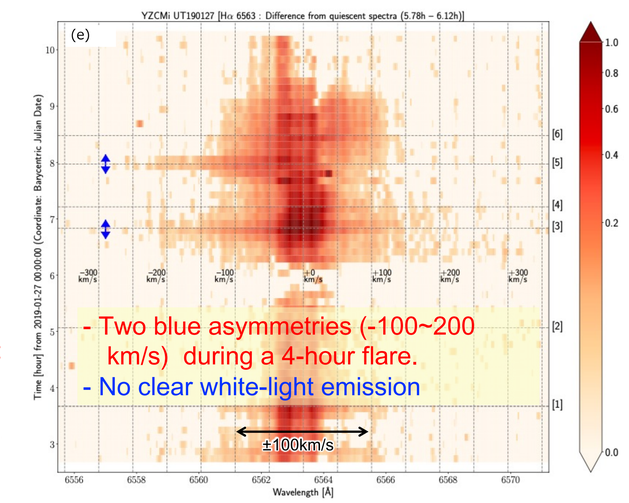




(c) Hα line profiles during a flare (time [3],[5] in (a))
(d) Difference profile from quiescent
(e) Hα difference color map (time evolution)

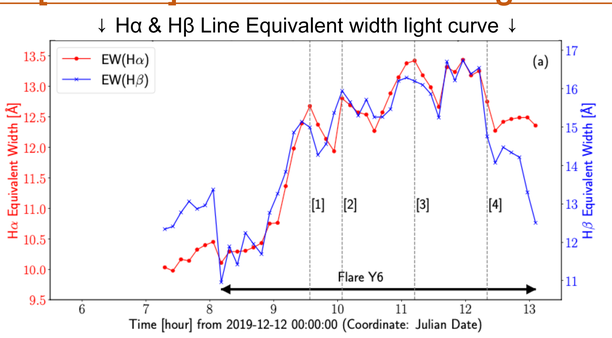




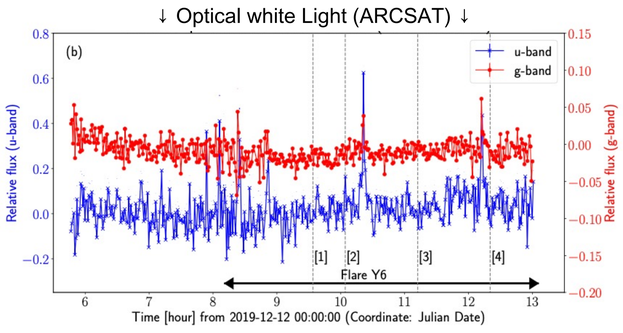


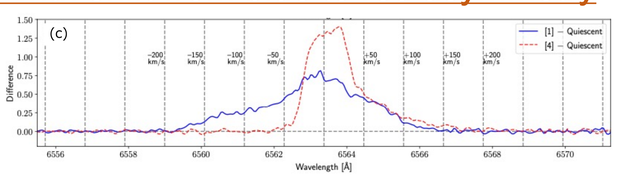
5. [Event 2] A non/weak white-light flare with shift from blue to red asymmetry

↓ Hα & Hβ Line Equivalent width light curve ↓

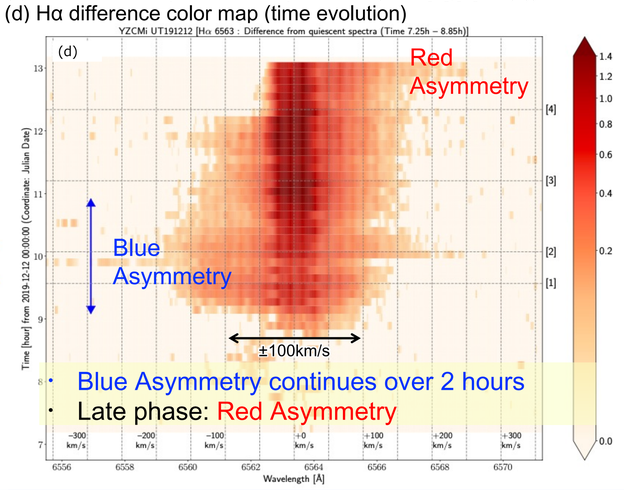


↓ Optical white Light (ARCSAT) ↓





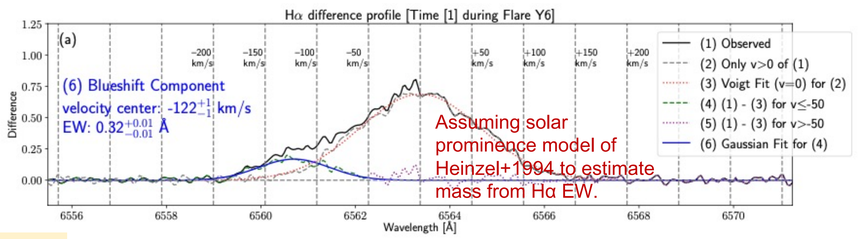
(c) Hα Difference profile from quiescent (time [1],[4] in (a))
(d) Hα difference color map (time evolution)



- Blue Asymmetry continues over 2 hours
- Late phase: Red Asymmetry

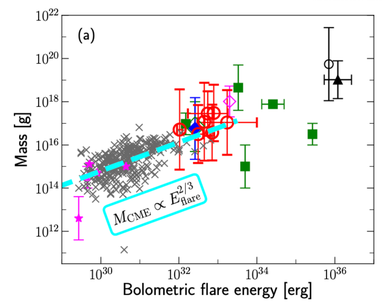
7. Mass, velocity, & kinetic energy estimated from blue wing asymmetries

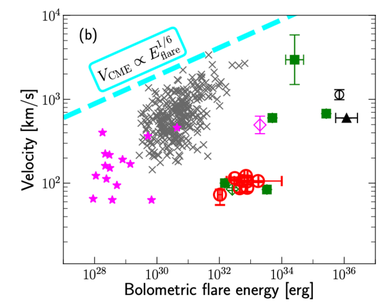
By assuming that the blue asymmetries were caused by prominence eruptions, we estimate the mass, velocity, and kinetic energy of the upward-moving materials.

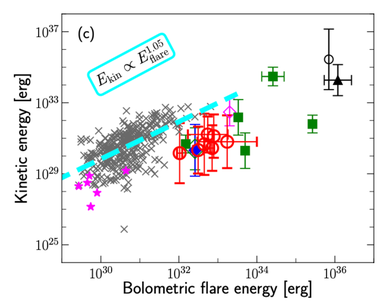


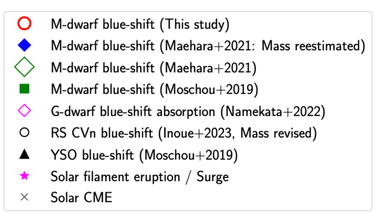
Mass vs. flare energy
The estimated mass is comparable to expectations from the empirical relation between the flare energy and mass of solar CMEs.

Kinetic energy vs. flare energy
The estimated kinetic energy is 1 or 2 orders of magnitude smaller than that expected from the solar CMEs.
(cf. Moschou+2019, Maehara+2021)



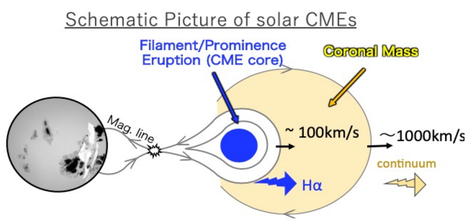


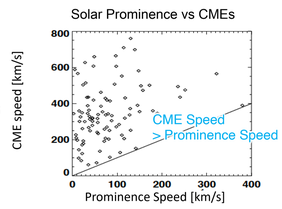




CME suppression ??
(e.g., Alvarado-Gomez+2018; Sun+2021)
Velocity evolution from prominence eruptions to CMEs ??
(e.g., Gopalswamy+2003)
→ More investigations necessary !

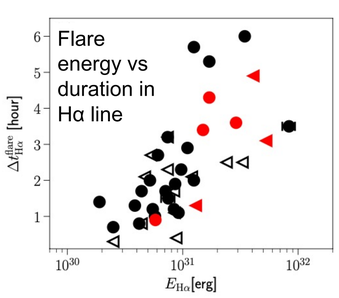
Schematic Picture of solar CMEs





Future : More multi-wavelength observations
e.g., EUV dimming (coronal material) ←→ Hα Blue shifts (prominence/filament)
e.g., magnetic field (ZDI) ←→ mass ejections (CME suppression ??)

6. Properties of flares with blue wing asymmetries



- flares with BWA
- flares with BWA (partially observed)
- flares without BWA
- flares without BWA (partially observed)

← Blue wing asymmetries could be seen both in relatively large/long and small/short flares.

○The duration of the blue wing asymmetries range from 20 min to 2.5 hours.

○Blue wing asymmetries can be observed during both white-light (WL) and candidate non WL flares.

○ All of the seven flares showed blue wing asymmetries also in the Hβ line, but there are large varieties on which other chromospheric lines showed blue wing asymmetries.

8. Conclusion

(Notsu et al. submitted to ApJ)

- Blue wing asymmetry of Balmer lines can be commonly seen during mid M-dwarf (M3-M5) flares. (7 bluewing asymmetry events among 41 flares in this observation campaign)
- Various correspondences in flare properties (e.g., flare & asymmetry durations, WL or non-WL)
- Mass & Kinetic energy of mass ejections estimated from blue asymmetries: can be consistent with solar relations (assuming velocity evolution from prominence eruptions to CMEs).
- Further multiwavength observations (e.g., with EUV dimming) and more modeling studies (e.g., how prominences on M-dwarfs are observed as in Leitzinger+2022) are important.