Blue asymmetries in Balmer lines during mid M dwarf flares

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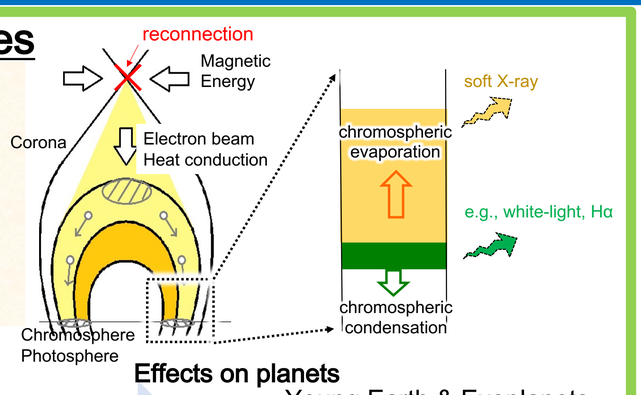
Flares are releases of magnetic energy in the solar/stellar atmosphere, and they have strong emissions from radio to X-rays. During some M dwarf flares, chromospheric line profiles show blue asymmetries (e.g., Honda et al. 2018), although red asymmetries are more commonly observed in solar flares. Similar enhancements of the blue wings of Balmer lines may provide clues for investigating the early phases of stellar coronal mass ejections (CMEs) during flares (cf. Vida et al. 2016&2019), but this is still controversial. Thus, we need more flare spectroscopic observations with high time resolution to understand the relationship between mass ejections and flaring events.

We have conducted several simultaneous spectroscopic and photometric observations of mid M dwarf flare stars using APO 3.5m/ARCES, SMARTS 1.5m/CHIRON, TESS, and ground-based 0.4-1m photometric telescopes. During 34 nights of observations, we detected 46 flares in Balmer lines (e.g. Hα). Among them, at least 8 flare events show clear blue asymmetries. Blue asymmetry durations are different among the 8 events (20min ~ 2hr). These results suggest upward flows of chromospheric plasma during flare events. By assuming that the blue asymmetries were caused by prominence eruptions, we estimate the mass and kinetic energy of the upward-moving material to be 10^{15} - 10^{18} g and 10^{29} - 10^{32} erg, respectively. The estimated masses are comparable to expectations from the empirical relation between the flare X-ray energy and mass of upward-moving material for stellar flares and solar CMEs. In contrast, the estimated kinetic energies for these non-white-light flares are roughly 2-3 orders of magnitude smaller than that expected from the relation between flare X-ray energy and kinetic energy for solar CMEs. This could be understood by the difference in the velocity between CMEs and prominence eruptions.

1. [Introduction] Solar / Stellar flares

Magnetic energy release
in the solar/stellar atmosphere.
Strong emissions from radio to X-rays.

Many updates from
statistical studies of Kepler/TESS data
e.g., age vs flare frequency



Effects of superflares on planets (cf. Airapetian et al. 2020)

Superflares

Radiation (X-ray, UV, opt, etc)

Plasma Ejection(CME)

High-energy particles

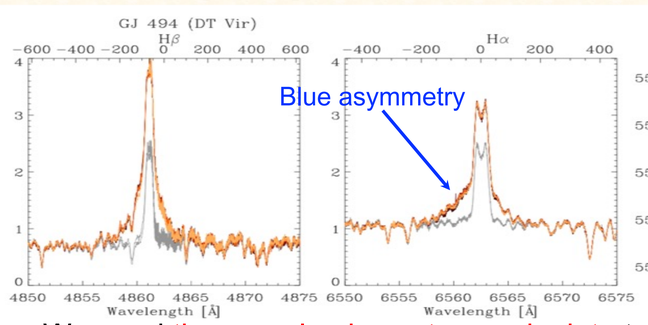
Effects on planets

Young Earth & Exoplanets
Loss of atmosphere
Chemical Evolution
→Habitability of Planets

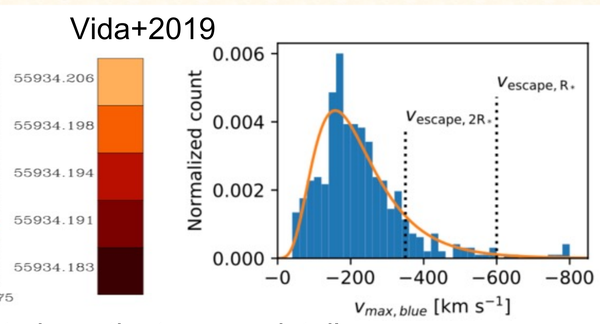
Current Earth
Magnetic storms
Radiation effects
→Effects on our society

2. [Introduction] Blue (excess) asymmetry of flares

A lot of **"snapshot"** data of Balmer lines (Hα, Hβ, ..) thanks to recent exoplanet surveys.
→ There are many asymmetric blue-shifted spectra (Fuhrmeister+18; Vida+19).
- Blue asymmetries are common events of M-dwarf flares ??
- There are growing interests "Are these blue asymmetries related with **stellar CMEs**??"



Vida+2019



We need time-resolved spectroscopic data to investigate more details.

3. Simultaneous spectroscopic and photometric observations

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

[Optical Spectroscopy (λ/Δλ ~ 31,500 & 25,000 & 10,000)]
(US) Apache Point Observatory (APO) 3.5m (ARCES)
(Chile) CTIO SMARTS1.5m telescope (CHIRON)
(Japan) Nayuta 2m (MALLS)

[Photometry (Ground & Space)]
(US) APO 0.5m telescope (u&g-band)
(Chile) LCO 1m/0.4m telescopes (U&V-band)
(Japan) MITSuME 0.5m (g,R&I-band)

TESS (1-band: 6000-10000Å)

~34 night observations
(2019Jan – 2021Feb)

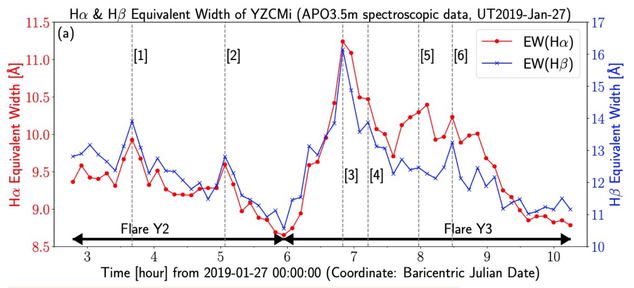
46 flares in Hα line

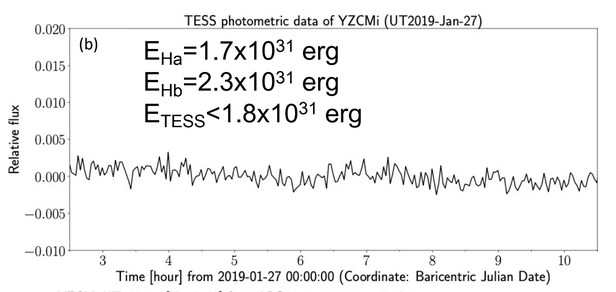
→ At least 8 events show clear Blue Asymmetries

One event already reported in Maehara,Notsu+2021 PASJ
(see also Poster by Maehara+)

Other 7 events:
Notsu+2021 in prep

4. [Event example] A non (weak?) white light flare with blue asymmteries



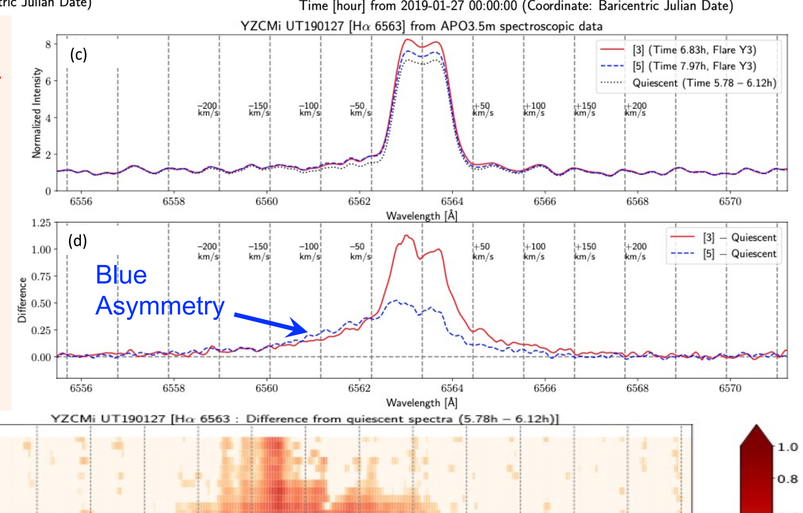


(a) Flare ("Flares Y2 & Y3") in Balmer lines with duration 3-4 hours

(b)TESS photometric data covering Flares Y2&Y3

(c)&(d) Hα spectra of the peak phases of Flare Y3 (time [3],[5] in (a)) .

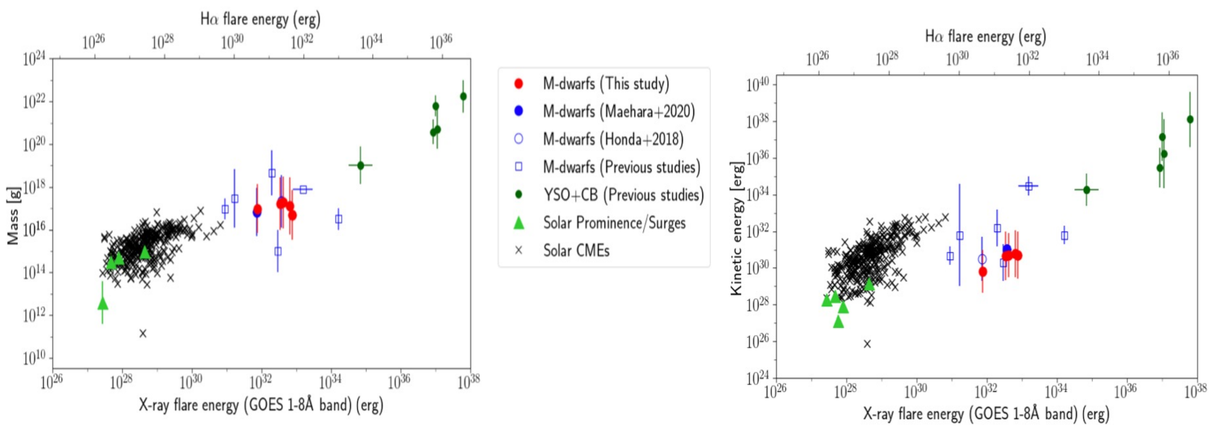
(e) Hα difference profile (cf. (d)) color map



Blue Asymmetries (duration ~20min) twice during Flare Y3

No (weak?)
White light flare

6. Mass & Kinetic energy of mass ejections estimated from blue asymmetries



The estimated masses are comparable to expectations from the empirical relation between the flare X-ray energy and mass of upward-moving material for stellar flares and solar CMEs.

In contrast, the estimated kinetic energies are roughly 2-3 orders of magnitude smaller than that expected from the relation for solar CMEs.

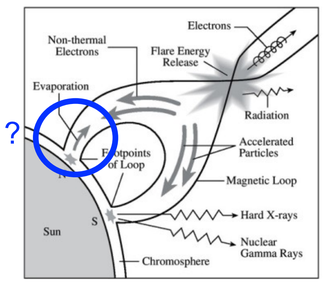
This could be understood by the difference in the velocity between CMEs and cool prominence eruptions (cf. Gopalswamy+2003)

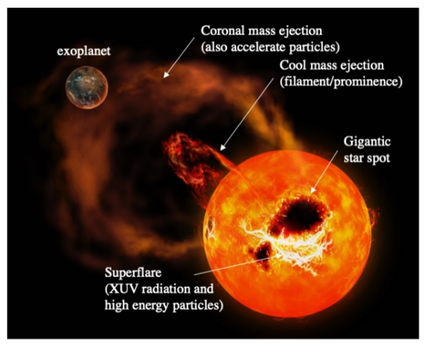
5. Blue asymmetry → Mass ejection ??

- Blue Asymmetry of Balmer lines can be commonly seen during mid M-dwarf (M3-M5) flares.
  (8 blue asymmetry events among 46 flares)

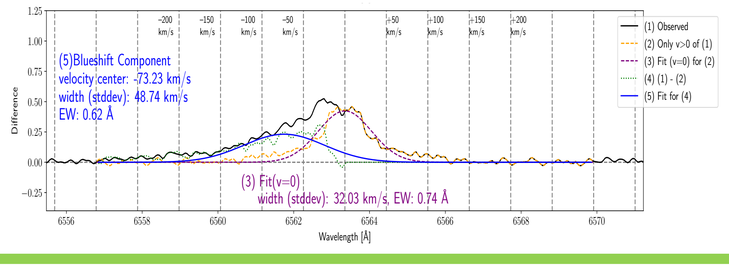
- Cause of Blue Asymmetry in Balmer (e.g., Hα) lines ?
  - Cool upflows in flaring chromosphere ?
  - Cool mass ejections (Prominence Eruption) ?
  → More detailed studies are needed !

Upflows ?





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



7. Summary

Maehara, Notsu+2021 PASJ
(See also Poster by Maehara+)
Notsu+2021 in prep

- Blue Asymmetry of Balmer lines can be commonly seen during mid M-dwarf (M3-M5) flares.
  (8 blue asymmetry events among 46 flares)
- However, it is still not clear how blue asymmetries occur.

- Mass & Kinetic energy of mass ejections estimated from blue asymmetries
  →Consistent with solar relations ??
  (considering the velocity difference between prominence eruptions and CMEs)

- Future
  - More observations including other lines (Ca II, He I)
  - Comparison with other wavelengths (UV, X-ray)
  - Effects on planets

Stellar CME-related EUV dimming observations by future UV mission (ESCAPE) can be also related.