

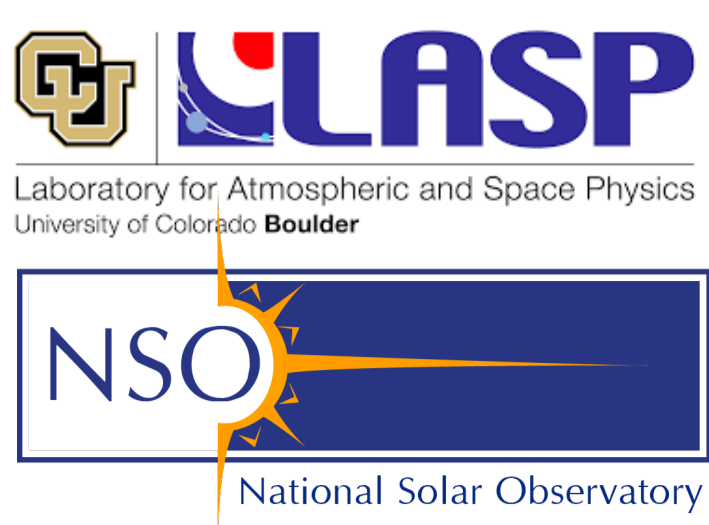
Blue asymmetries in Balmer lines during mid M dwarf flares



Yuta Notsu^{1,2} (Email: Yuta.Notsu@colorado.edu @astronomy_stars),

Adam Kowalski^{1,2}, Hiroyuki Maehara³, Kosuke Namekata⁴, Satoshi Honda⁵, Teruaki Enoto⁶, Kenji Hamaguchi^{7,8}, Isaiah Tristan^{1,2}, Suzanne Hawley⁹, James Davenport⁹, Soshi Okamoto⁴, Kai Ikuta⁴, Daisaku Nogami⁴, and Kazunari Shibata⁴

¹ CU Boulder (LASP), ² NSO, ³ NAOJ, ⁴ Kyoto Univ., ⁵ Univ. of Hyogo, ⁶RIKEN, ⁷NASA/GSFC, ⁸UMBC, ⁹Univ. of Washington,



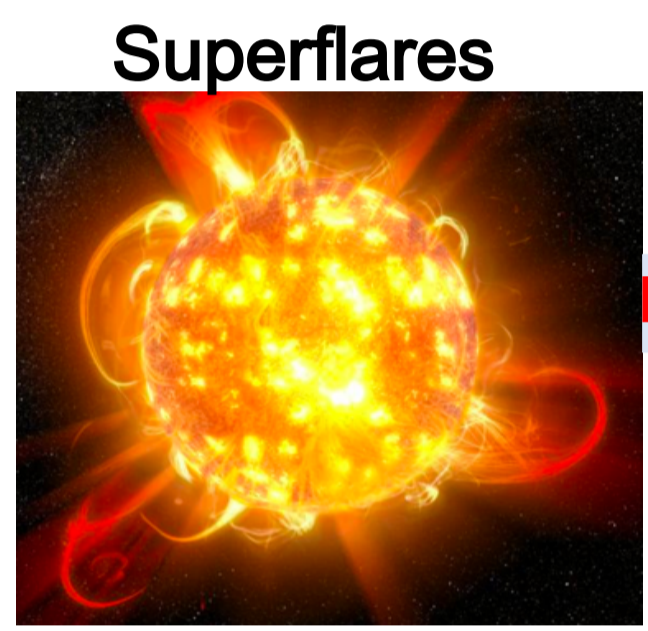
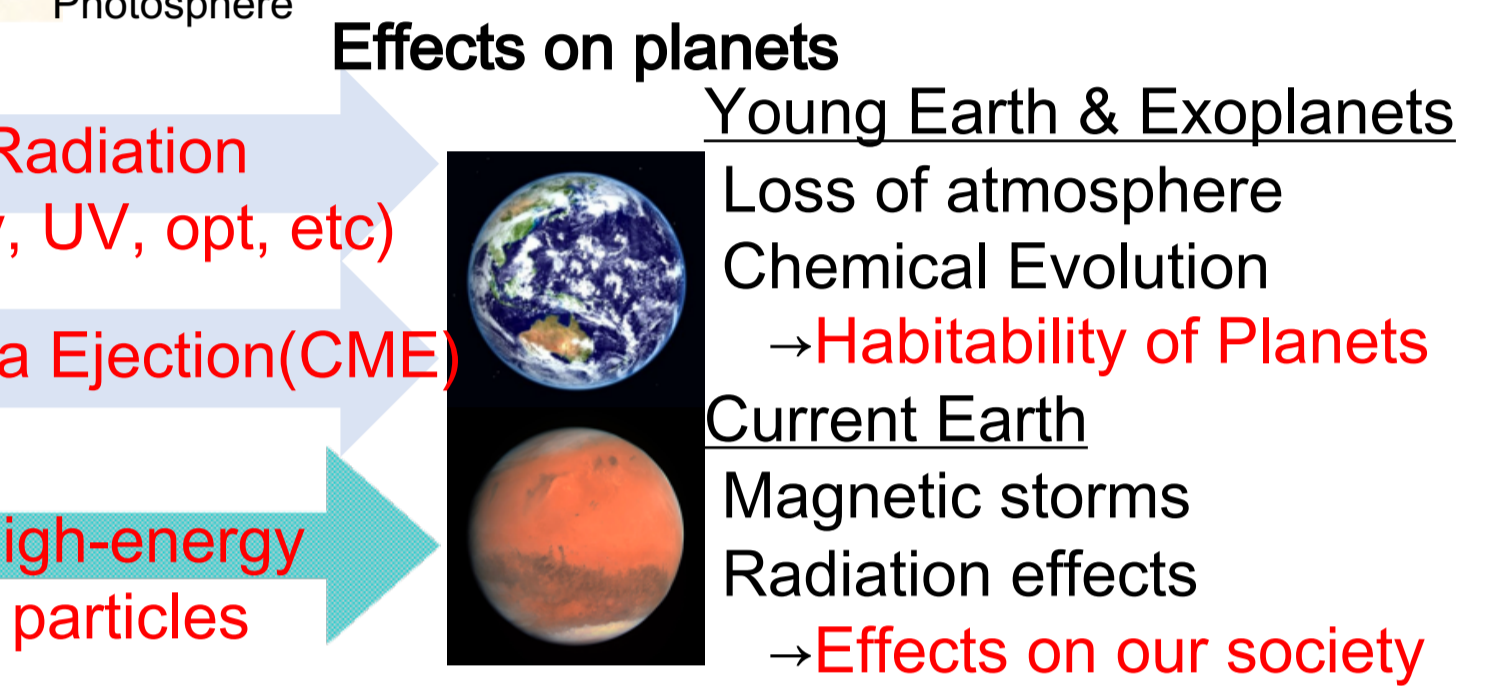
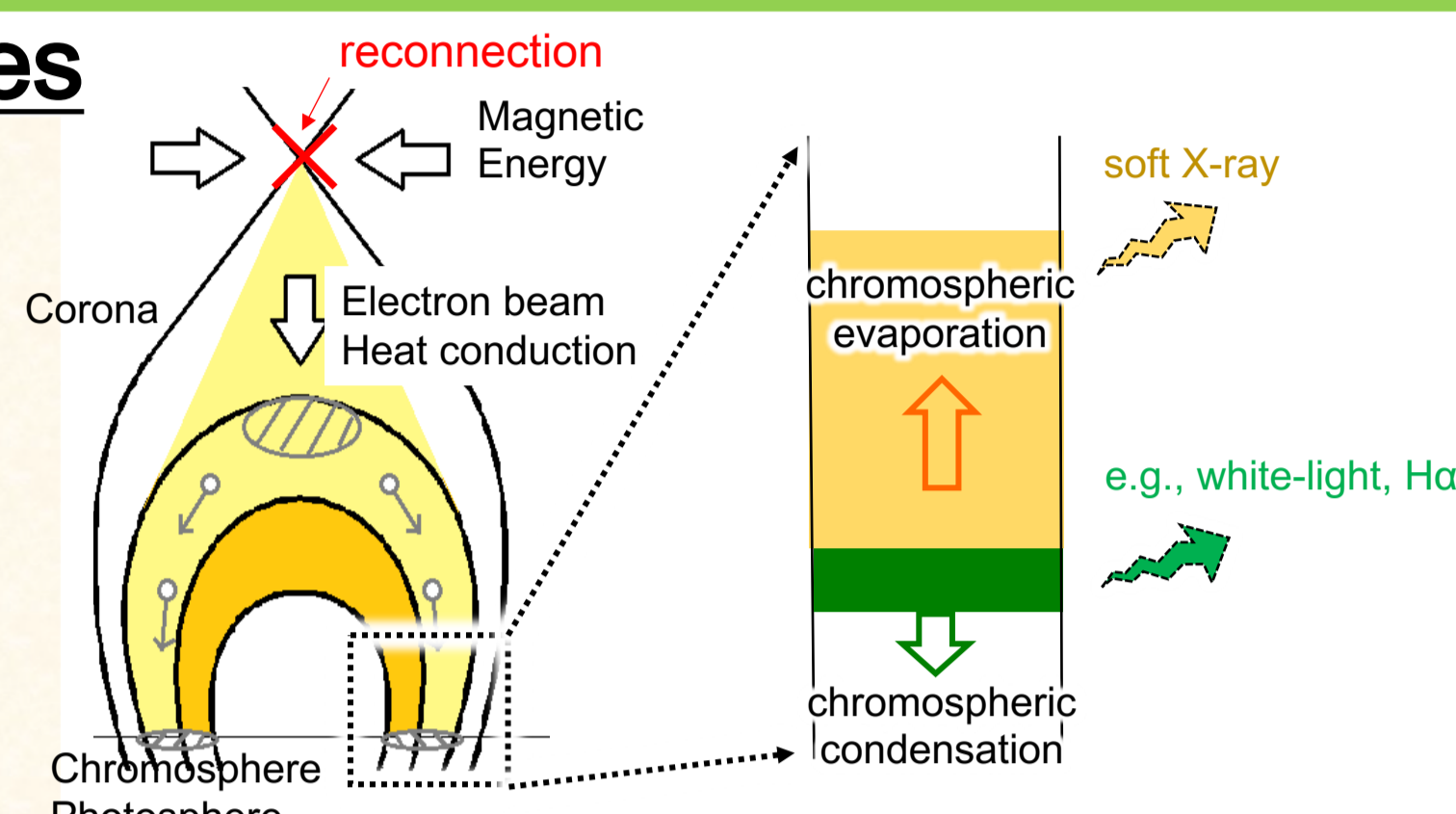
Flares are releases of magnetic energy in the solar/stellar atmosphere, and they have strong emissions from radio to X-rays. During some M dwarf flares, chromospheric line profiles show blue asymmetries (Eason et al. 1992; Honda et al. 2018), although red asymmetries are more commonly observed in solar 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. The latter is helpful for estimating the impact on planets from flares.

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 48 flares in Balmer lines (e.g. H α). Among them, at least 7 flare events show clear blue asymmetries. Blue asymmetry durations are different among the 7 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 (cf. Poster by Okamoto+)

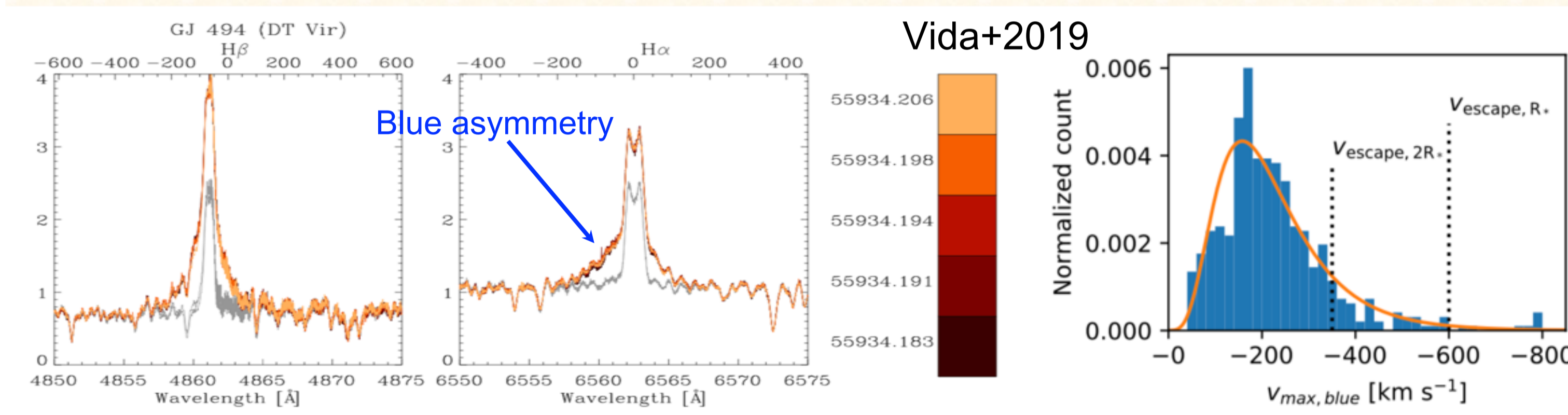


Effects of superflares on planets (cf. Airapetian et al. 2020)

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

A lot of "snapshot" data of Balmer lines (H α , H β , ...) thanks to recent exoplanet surveys. \rightarrow 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??"



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)



~34 night observations (2019Jan - 2021Feb)

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



48 flares in H α line \rightarrow At least 7 events show clear Blue Asymmetries

[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)

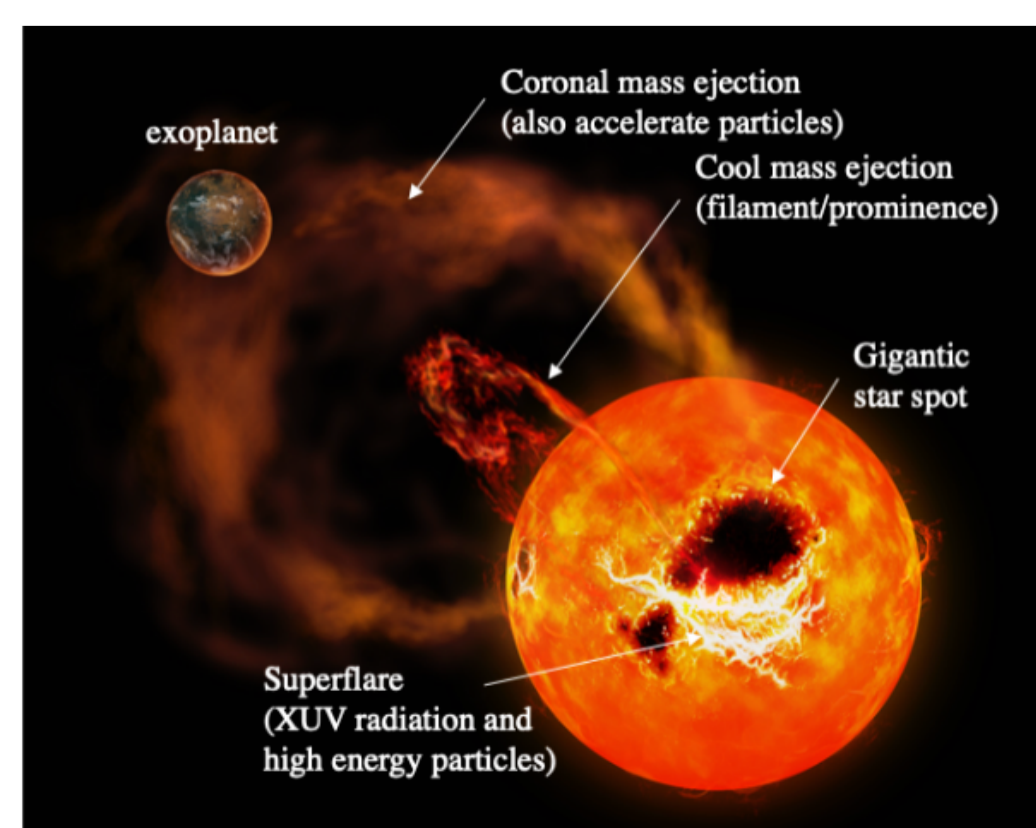
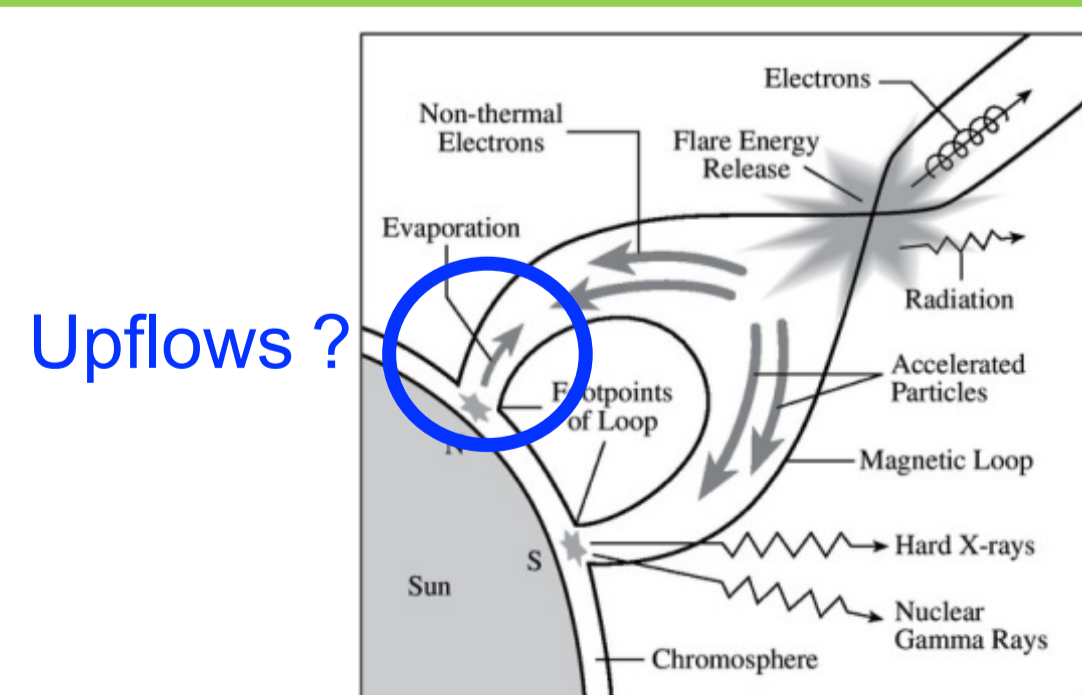


One event already reported in Maehara,Notsu+2021 PASJ (see also Poster by Maehara+) Other 6 events: Notsu+2021 in prep

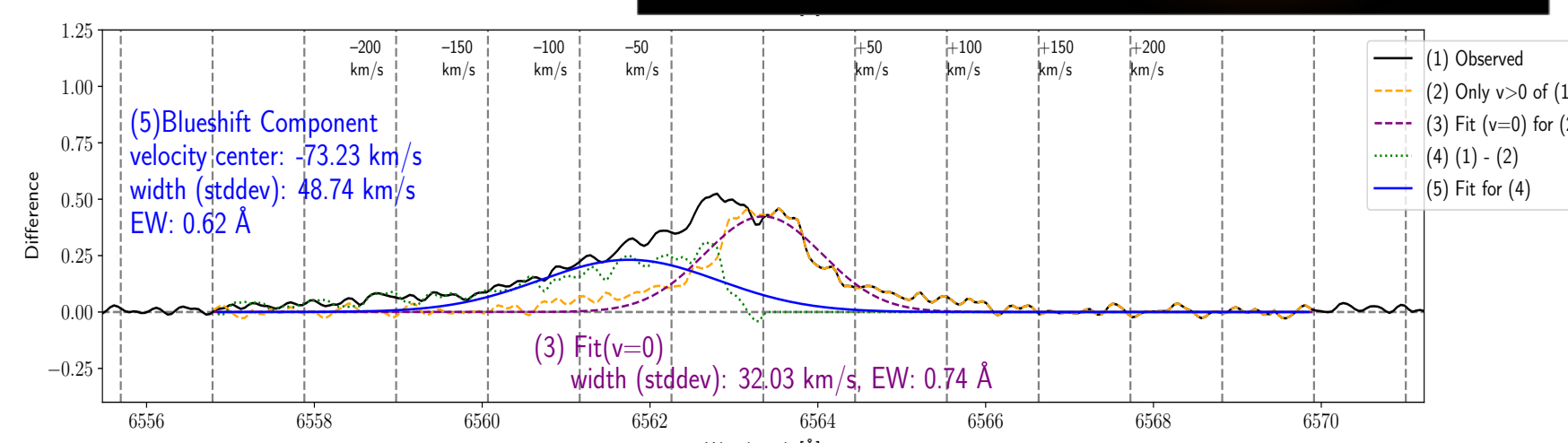
5. Blue asymmetry \rightarrow Mass ejection ??

Blue Asymmetry of Balmer lines can be commonly seen during mid M-dwarf (M3-M5) flares. (7 blue asymmetry events among 48 flares)

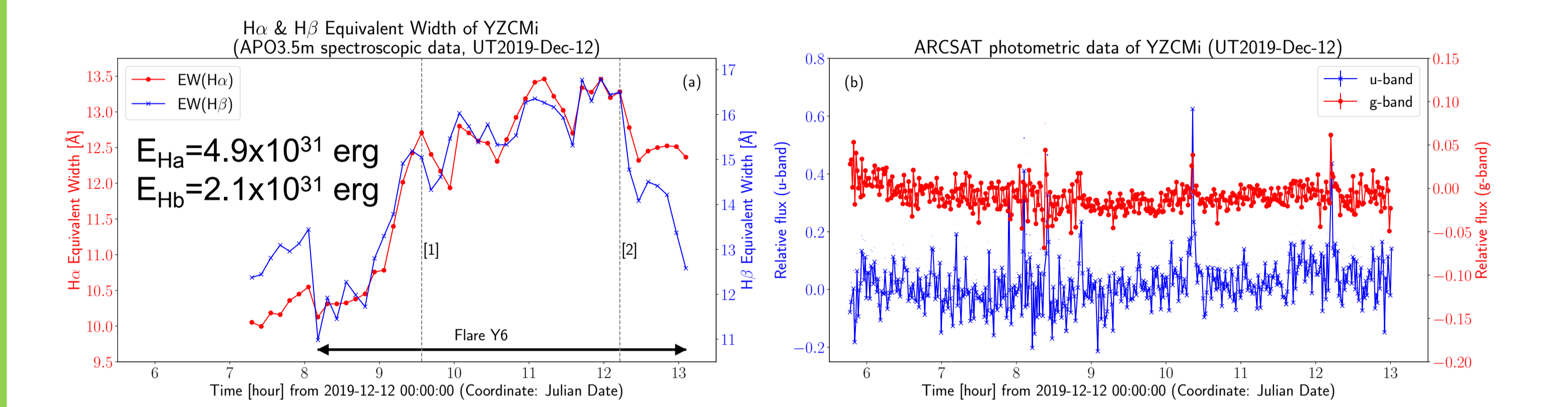
- Cause of Blue Asymmetry in Balmer (e.g., H α) lines?
 - Cool upflows in flaring chromosphere?
 - Cool mass ejections (Prominence Eruption)?
- \rightarrow More detailed studies are needed!



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



4. [Event example] A non (week?) white light flare with shift from blue to red asymmetry



(a) A flare ("Flare Y6") in Balmer lines with duration > 4 hour

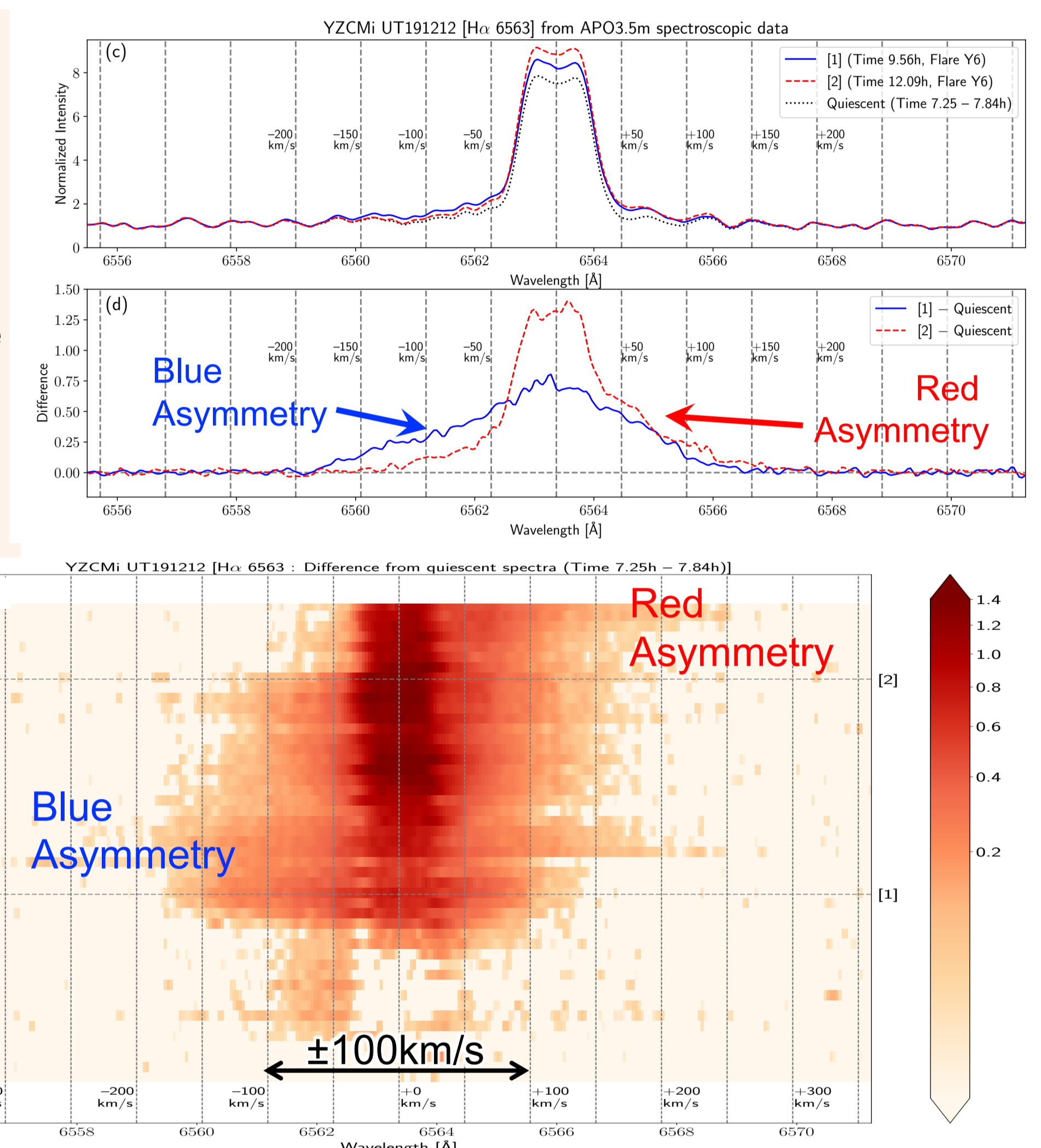
(b) u & g-band photometric data covering the time of "Flare Y6"

(c)&(d) H α spectra of the early/late phases of Flare Y6 (time [1],[2] in (a)).

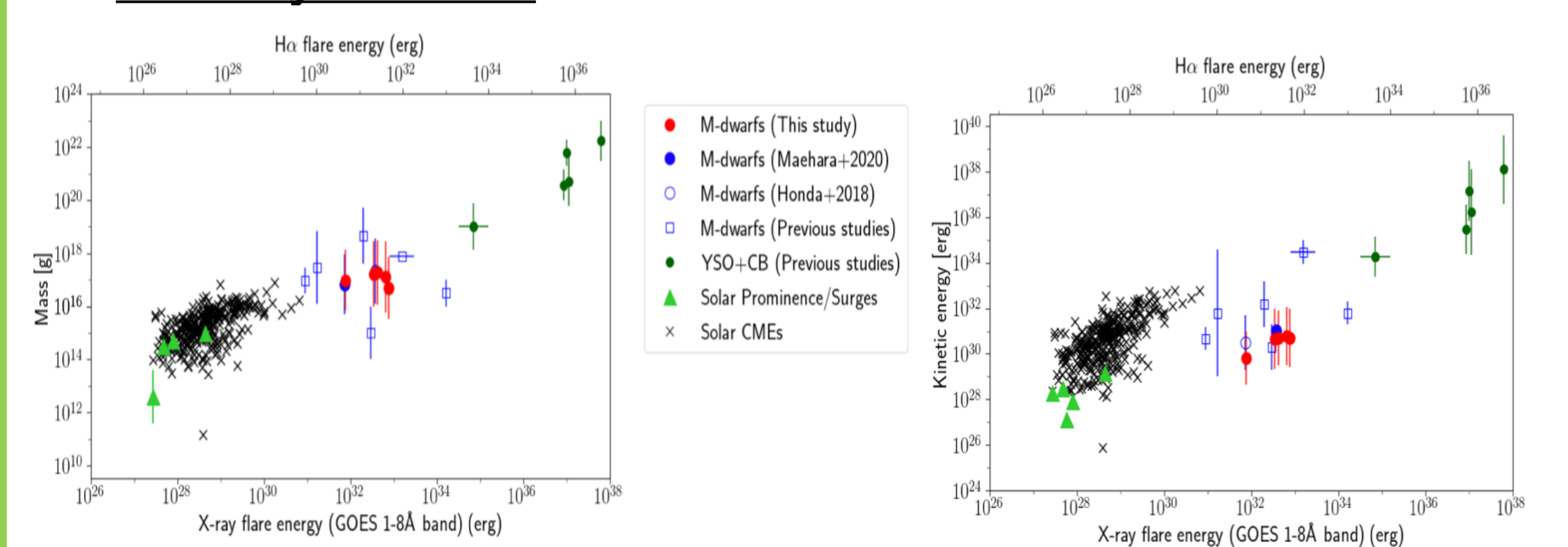
(e) H α difference profile (cf. (d)) color map

Blue Asymmetry continues over 2 hours

Late phase: Red Asymmetry



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)

7. Summary

- Blue Asymmetry of Balmer lines can be commonly seen during mid M-dwarf (M3-M5) flares. (7 blue asymmetry events among 43 flares)
- However, it is still not clear how blue asymmetries occur.

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

- Future
 - More observations for statistical studies
 - Comparison with other wavelengths (UV, X-ray)
 - Effects on planets

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

