Stellar activity in Blanco-1

A search for stellar mass ejections

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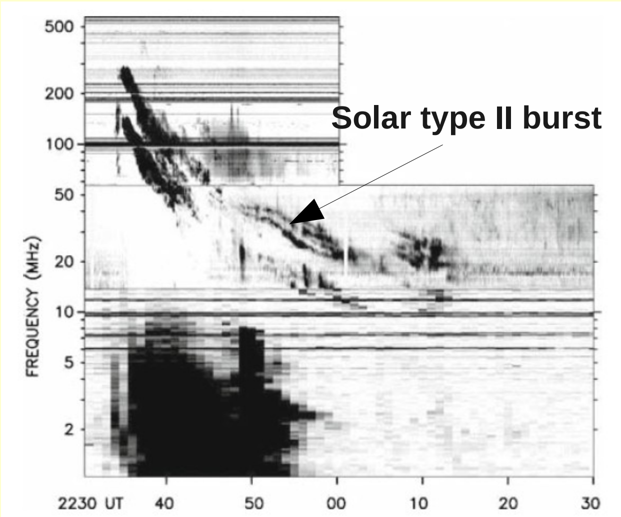
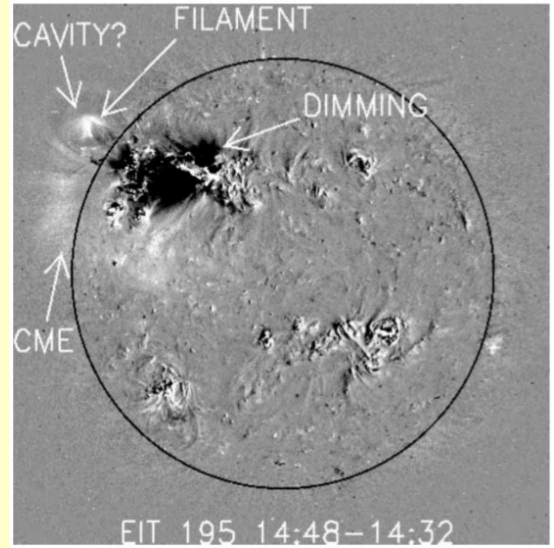
Why search for stellar CMEs?

- Play a signifciant role in planetary atmospheric mass loss for weakly magnetized close-in orbiting planets
- Which fraction of stellar mass and angular momentum loss is caused by CMEs? – stellar spin-down
- Characterizing stellar CME parameters – What were the parameters of CMEs on the young Sun? Verifying models that relate stellar flare rates/energies to parameter distributions of solar CMEs
- Is there a relation of flares to CMEs on stars as we know it for the Sun, at least for the most energetic events?
- Stellar CME parameters are poorly constrained, only single detections of fast and energetic events are reported so far

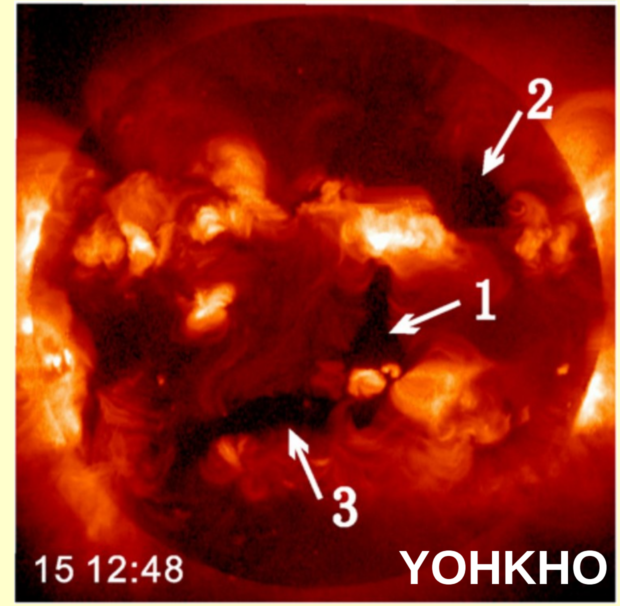
I. How to characterize stellar CMEs?



Cane & Erickson, 2005, "*Solar Type II Radio Bursts and IP Type II Events*" ApJ, **623**, 1180-1194



Gopalswamy & Thompson, 2000, "*Early life of coronal mass ejections*", JASTP, **62**, 1457-1469



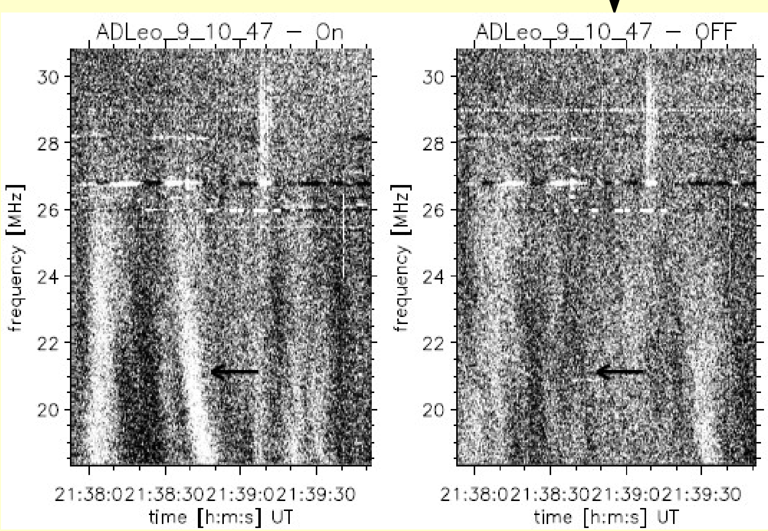
Wang & Zhang., 2007, "*Kuafu and the studies of CME initiation*", AdSpR, **40**, 1770-1779

Radio type II bursts as signature of a shockfront driven by a CME

Using signatures known from the Sun

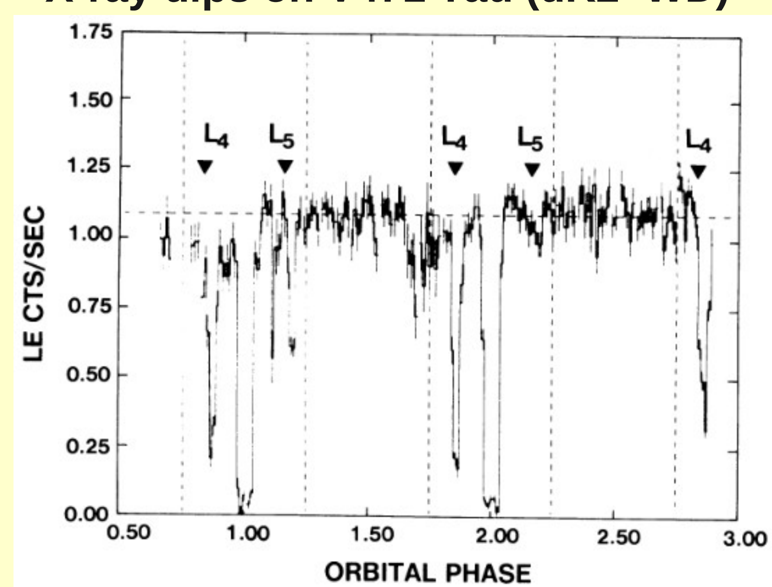
X-ray/EUV dimmings correlated with CMEs (Bewsher et al. 2008)

X-ray dips on V471 Tau (dK2+WD)



Konovalenko et al., 2012, "*Analysis of the flare stars radio bursts parameters at the decameter wavelengths*", EPSC, 902

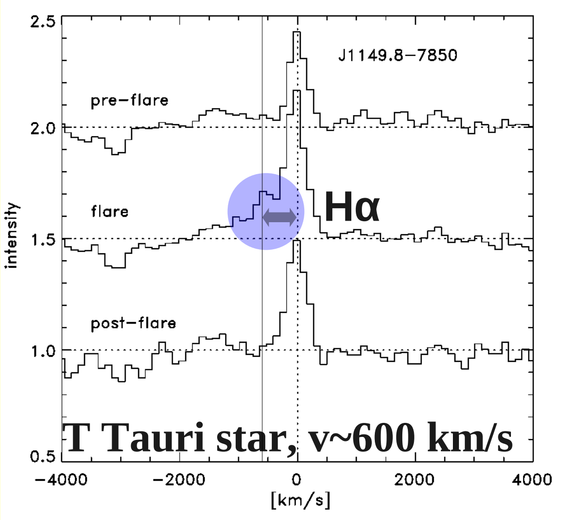
Bewsher et al., 2008, "*The relationship between EUV dimming and coronal mass ejections. I. Statistical study and probability model*", A&A, **478**, 897-906



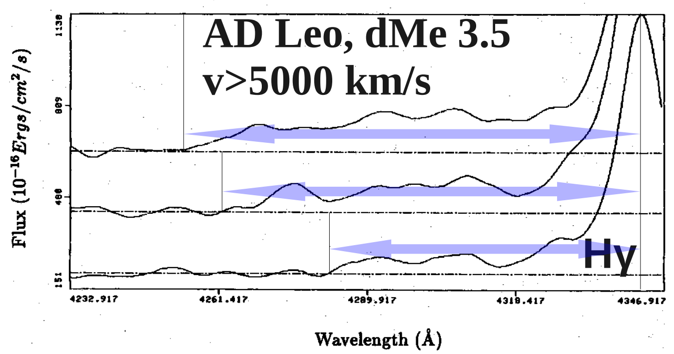
Jensen et al., 1986, "*EXOSAT observations of V471 Tauri - A 9.25 minute white dwarf pulsation and orbital phase dependent X-ray dips*", ApJ, **309**, L27-L31

II. How to characterize stellar CMEs?

Using the signature of moving plasma - Doppler shifted emission/absorption

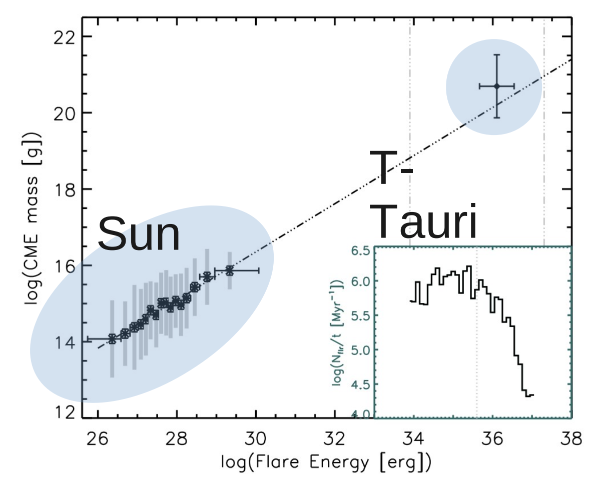


Guenther & Emerson, 1997, "*Spectrophotometry of flares and short time scale variations in weak line, and classical T Tauri stars in Chamaeleon.*", A&A, **321**, 803-810



Houdebine et al., 1990, "*Dynamics of flares on late-type dMe stars. I - Flare mass ejections and stellar evolution*", A&A, **238**, 249-255

Application of distributions of solar CME parameters to stars



Aarnio et al., 2012, "*Mass Loss in Pre-main-sequence Stars via Coronal Mass Ejections and Implications for Angular Momentum Loss*", ApJ, **760**, 9

- **Which method yields a relatively high statistical significance?**
- **Which method has the least observing and target restrictions?**

Multi-object spectroscopic observations of coeval cluster stars using the method of Doppler-shifted emission

What do we further need to characterize stellar CMEs from observations?

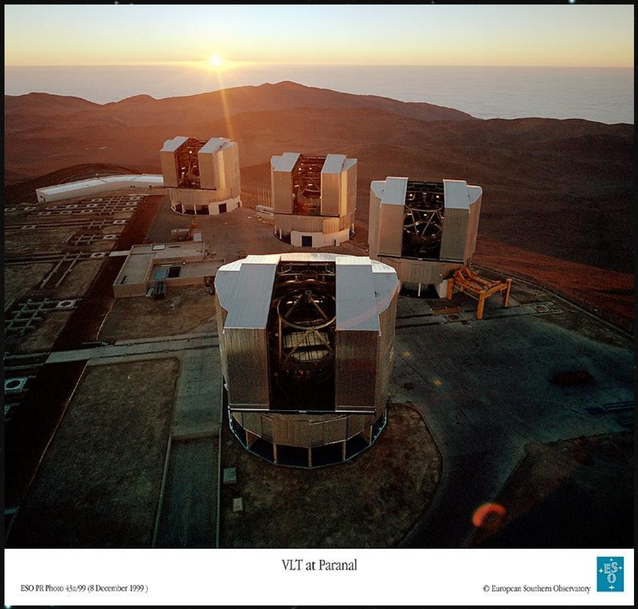
1. A target

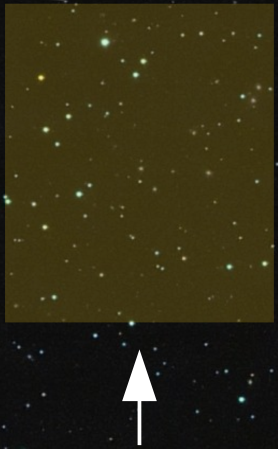
   - **Blanco-1** is a relatively young (~100Myr) and well studied open cluster of high galactic latitude with several hundreds of known members (down to M dwarfs)

2. A suitable observing facility

   - ESO offers several multi-object spectrographs (Paranal: VLT/FLAMES, VLT/VIMOS, VLT/KMOS; LaSilla: NTT/EFOSC2)
   - regarding FoV, wavelength coverage, and resolving power **VLT/VIMOS** turned out to be a suitable instrument

3. Clear skies and active target stars :-)





FoV of VIMOS covered by the 4 quadrants

The target stars

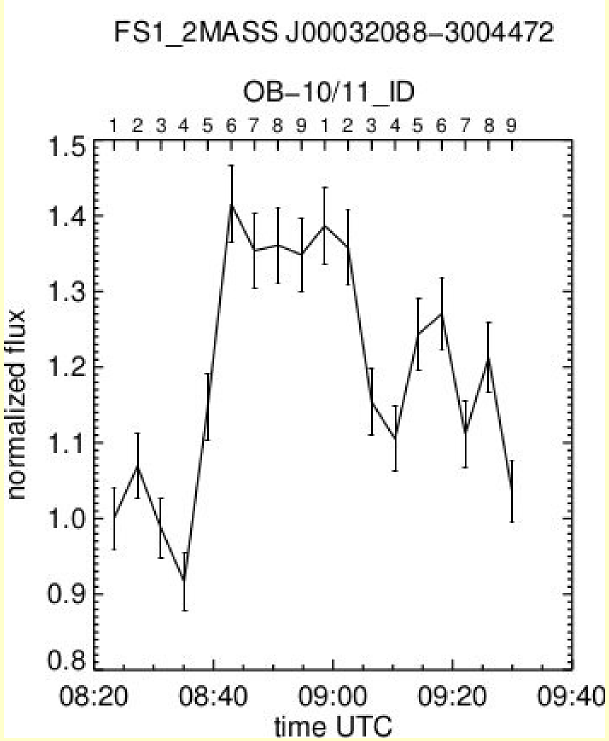
2MASS ID	J [mag]	K_S [mag]	NUV [mag]	V [mag]	$(B-V)_0$ [mag]	$\log L_X$ [erg s^{-1}]	mem [%]	spectral type	luminosity class	Hα	flare
quadrant 1											
00032088-3004472	13.901	13.075	-	18.16	-	28.71	3	M4-5	V	em	1 (FS1)
00032107-3004040[a]	13.093	12.456	-	14.91	-	-	0	K5	V	abs	0
00030027-3003215	11.162	10.555	19.59	12.89	0.91	29.62	93	K4-7	V	abs	0
00033082-3003091[a]	14.379	14.088	20.18	15.56	-	-	0	K3-4	III/V	abs	0
00030351-3002024[a]	14.453	14.211	18.45	15.46	-	-	0	K3-4	III/V	abs	0
quadrant 2											
00031154-2958103	14.299	13.473	-	18.51	1.50	29.16	23	M4-5	V	em	1 (FS2)
00032417-2956229	12.493	11.727	-	14.95	1.30	28.77	91	K7-M0	V	no Hα	0
00032466-2955146	12.172	11.480	21.74	14.18	1.12	29.32	92	K5-7	V	abs-weak	0
00032273-2953505	12.976	12.148	-	16.62	-	28.40	26	M3-4	V	em	1 (FS4)
00032487-2953151	12.766	11.932	-	15.34	-	-	0	K7-M0	V	abs	0
00025965-2952522	12.363	11.534	-	15.85	-	-	0	M1-3	V	abs	0
quadrant 3											
00024178-2958531	12.441	11.598	-	15.60	1.34	28.51	0	M0-1	V	no Hα	0
00021672-2957256[a]	14.712	14.279	20.08	15.77	-	-	0	K2-4	III/V	abs	0
00022848-2956218	13.632	12.832	22.42	17.28	-	-	0	M1-3	V	abs-weak	0
00021972-2956074	11.852	11.047	21.41	14.26	1.17	29.46	81	M0-1	V	em-weak	0
00022589-2952392	13.268	12.386	-	16.44	1.45	29.08	73	M3-4	V	em	0
quadrant 4											
00023679-3007108	12.894	12.487	19.94	14.30	0.81	-	0	K3-5	III/V	abs	0
00023545-3007019	11.040	10.561	18.57	12.52	0.75	29.46	89	K4-5	V	abs	0
00021455-3006443	13.672	12.836	-	17.16	-	-	0	M1-3	V	abs-weak	0
00024292-3006323[a]	14.998	14.579	21.14	16.20	-	-	0	K3-5	III/V	abs	0
00022427-3006170[a]	15.276	14.806	21.70	16.39	-	-	0	K4-5	III/V	abs	0
00022853-3005457	14.164	13.430	-	17.52	-	-	1	M1-3	V	abs-weak	0
00023482-3005255	11.800	11.155	20.73	13.80	0.9	30.00	85	K5-7	V	em-weak	0
00022819-3004435	11.140	10.510	20.20	13.04	0.96	29.76	76	K4-5	V	abs-weak	0
00022512-3004235	14.431	13.473	-	18.86	-	28.63	32	M3-5	V	em	0
00022289-3002532	12.989	12.169	22.07	16.32	-	29.11	68	M3-4	V	em	0
00024051-3001598[a]	12.925	12.587	19.50	14.15	-	-	0	K0-3	III/V	abs	1 (FS3)
00021456-3001115	12.233	11.467	22.04	14.60	1.24	-	0	K4-7	V	abs	0

[a] In a colour magnitude diagram ($V-J$, J) these stars are significantly below the cluster sequence and therefore confirm the non-membership as given in Platais et al. (2011).

Hα variability

<u>X-ray flare rates above 10^{32}erg</u>
<u>Audard et al., 2000</u>

FS1: logLx=28.71 ~ 3.6 fl/d ~ 0.2 fph
FS2: logLx=29.16 ~ 9.6 fl/d ~ 0.4 fph
FS4: logLx=28.40 ~ 1.8 fl/d ~ 0.1 fph

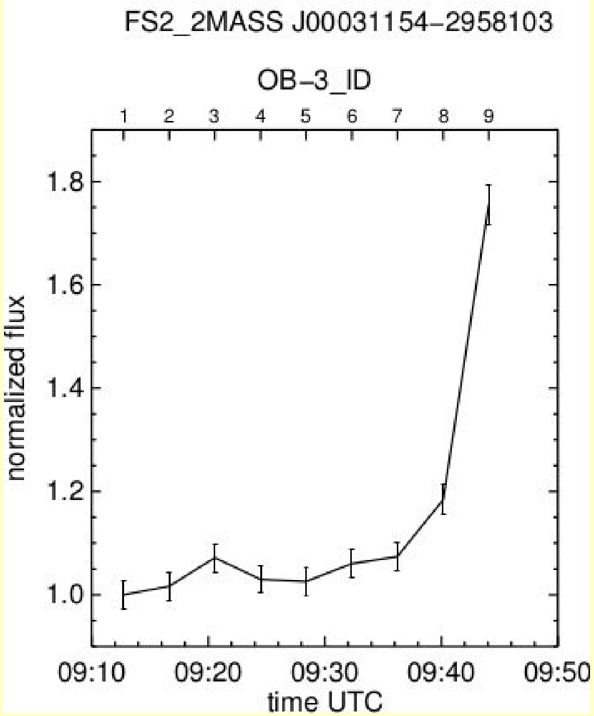


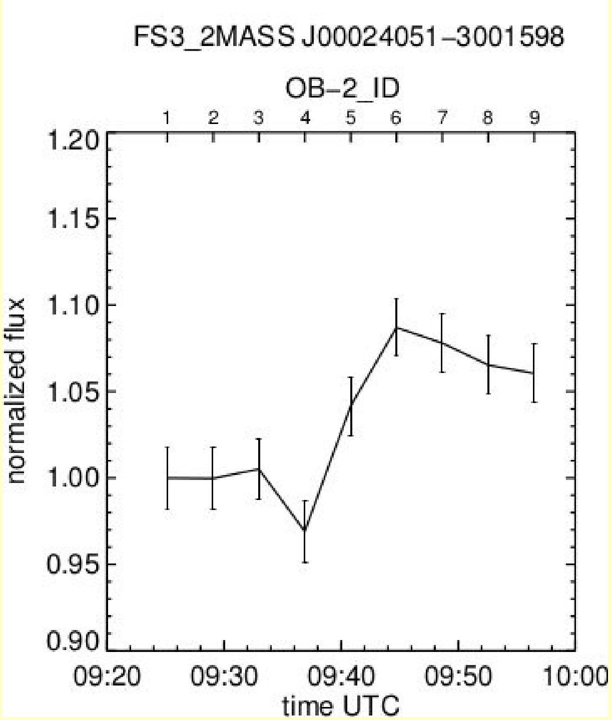
- 4 flares on 4 stars out of 28 – flare rate of 0.2 flares/h (fph) for the flaring stars
- Flare energies of 9×10^{28}-9×10^{29} erg

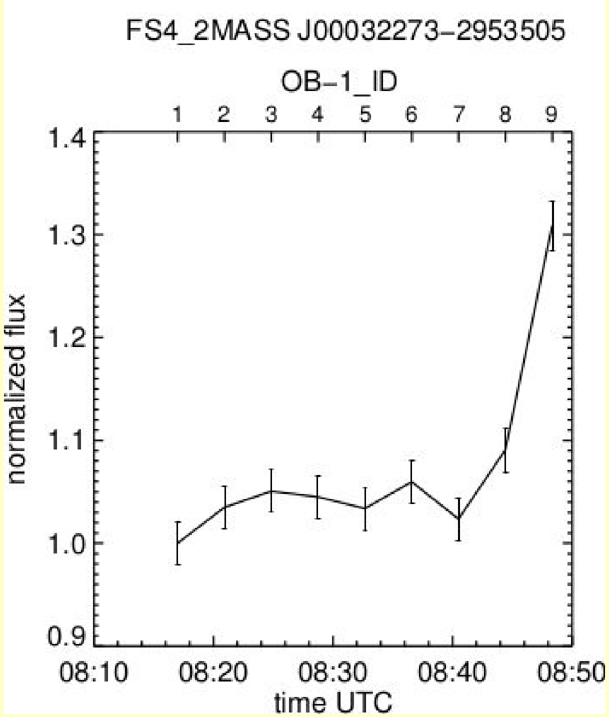
Fit rather well to the Blanco-1 Hα flare rates

Flares on young dMe and weak-line T-Tauri stars showed Hα energies of 10^{31-32}-10^{35} erg (Guenther&Emerson, 1997; Gunn et al., 1994), simultaneously detected with extra emissions related to mass ejections

But why did we detect no flares on the X-ray luminous stars in the sample (logLX=30 ~ 60fl/d ~2.5 fph)?







Audard et al., 2000, "*Extreme-Ultraviolet Flare Activity in Late-Type Stars*", ApJ, **541**, 396-409
Gunn et al., 1994, "*High-velocity evaporation during a flare on AT Microscopii*", A&A, **285**, 489-496

An example: The spectral sequence of FS1

Pre-flare (1 – 4): the individual spectra have less flux than the average one – dip before impulsive phase originates from an Hα blue wing absorptions

Impulsive (5 – 6): increase in flux comes from Hα red wing enhancements

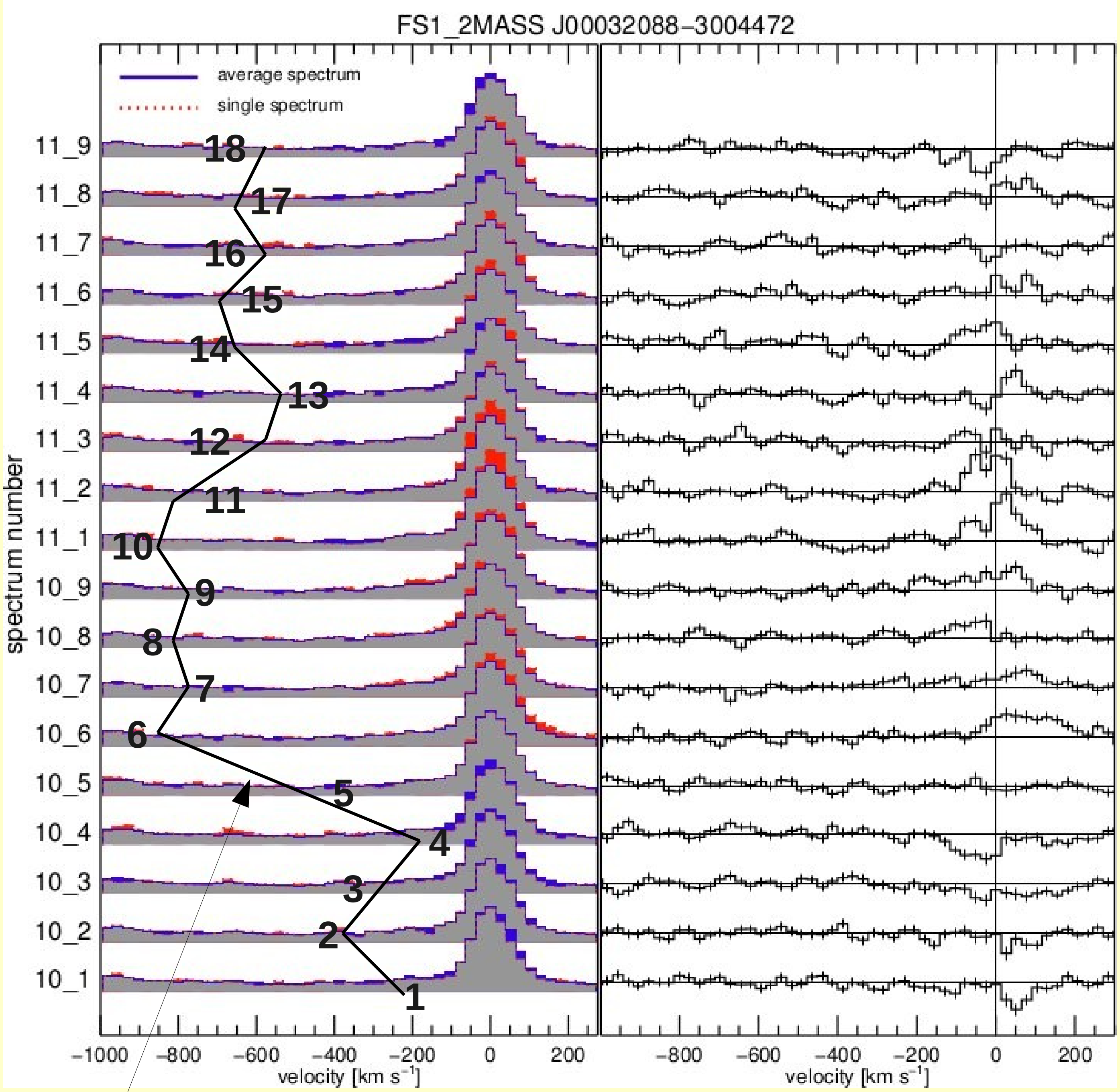
Gradual-Decay(7 -18): up to spectrum 11 we see enhancements in the line center and in spectrum 8+9 also in the blue wing. From spectrum no.12-18 we see weak enhancements in both wings of Hα

No signatures of CMEs, weak enhancements either in the blue and/or the red wing of Hα

Gray area: area covered by both average and individual spectrum

Red area: area belonging to individual spectrum only

Blue area: area belonging to average spectrum only



Spectral time series

Series of residuals

Flare lightcurve

Why were there no signatures of CMEs in the spectra?

- A matter of the rather short observing time of ~5hours, but according to estimated flare rates (Audard et al., 2000) we should have detected 2.5 fph ($E>10^{32}$erg) for the most X-ray luminous stars in the sample
- Projection effects - only CMEs which propagate in the line of sight to the observer show their real unprojected velocity
- S/N of the spectra was too low to allow the detection of even less massive CMEs
- Inclination of the rotation axis; if it lies in the line to the observer we will not see CMEs which are ejected around the stellar equator

  and

- Stars are in "stellar minimum" (activity cycle) therefore less activity, but for young stars the amplitudes of the cycles are lower than for the Sun

To partly shed light on the question why we did not detect CMEs (only upper limit of ~5 CMEs/day) we are using solar distributions of CME mass and velocity and relations of solar flares and CMEs.

Estimation of CME rates

1. The distribution of solar and stellar flares according to their energy follows a power-law

$$\frac{\mathrm{d}N}{\mathrm{d}E} = kE^{-\alpha}$$

Cumulative distribution

$$N(E > E_C) = \frac{k}{\alpha - 1} E_C^{-\alpha+1} = \tilde{k} E_C^{-\alpha+1}$$

Stellar flare scaling law (Audard et al. 2000)

$$\log N(E > 10^{32}) = (-26.7 \pm 2.9) + (0.95 \pm 0.1) \log L_X$$

2. Correlation of solar CME mass and X-ray energy of flares and

$$\left\{ \begin{array}{l} M_{\mathrm{CME}} = \mu E_f^{\beta} \\ M = \mu \left(\frac{E}{C_{GX}} \right)^{\beta} = \tilde{\mu} E^{\beta} \end{array} \right.$$

taken from Drake et al., 2013 fit applied to data from Yashiro &Gopalswamy, 2009

α is a flare index, **μ** and **β** are fitting parameters taken from Drake et al., 2013

Putting 1 and 2 together:

$$N(M > M_C) = \int_{M_C}^{\infty} \frac{\mathrm{d}N}{\mathrm{d}M} \mathrm{d}M = \int_{M_C}^{\infty} \frac{\mathrm{d}N}{\mathrm{d}E} \frac{\mathrm{d}E}{\mathrm{d}M} \mathrm{d}M = \tilde{k} \tilde{\mu}^{\gamma} M_C^{-\gamma}$$

$$\gamma = (\alpha - 1)/\beta$$

Solar CME mass -flare energy relation holds for stars within an order of magnitude comparable to the spread of solar CME masses for a given flare energy

3. Number of CMEs above a certain CME mass (M_C)

4. Projection: by adopting a solar distribution of CME velocities (Wu&Chen,2011) and a randomly distributed projection angle.

Drake et al., 2013, "*Implications of Mass and Energy Loss due to Coronal Mass Ejections on Magnetically Active Stars*", ApJ, **764**, 170, 7

Wu & Chen, 2011, "*The inversion of the real kinematic properties of coronal mass ejections by forward modeling*", RAA, **11**, 237-244

Yashiro & Gopalswamy, 2009, "*Statistical relationship between solar flares and coronal mass ejections*", IAUS, **257**, 233-243

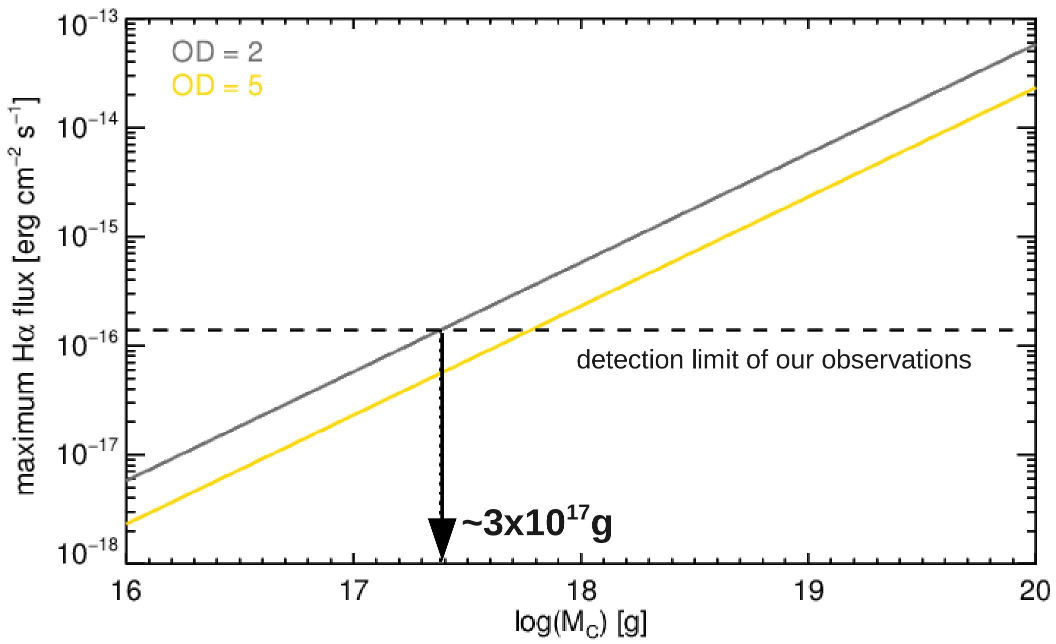
Expected CMEs and their Hα flux

OD: opacity damping parameter, as defined in Houdebine et al. 1990 as the ratio of optical thin to real flux (e.g. OD=2 means that 50% of the radiation escapes from the plasma.

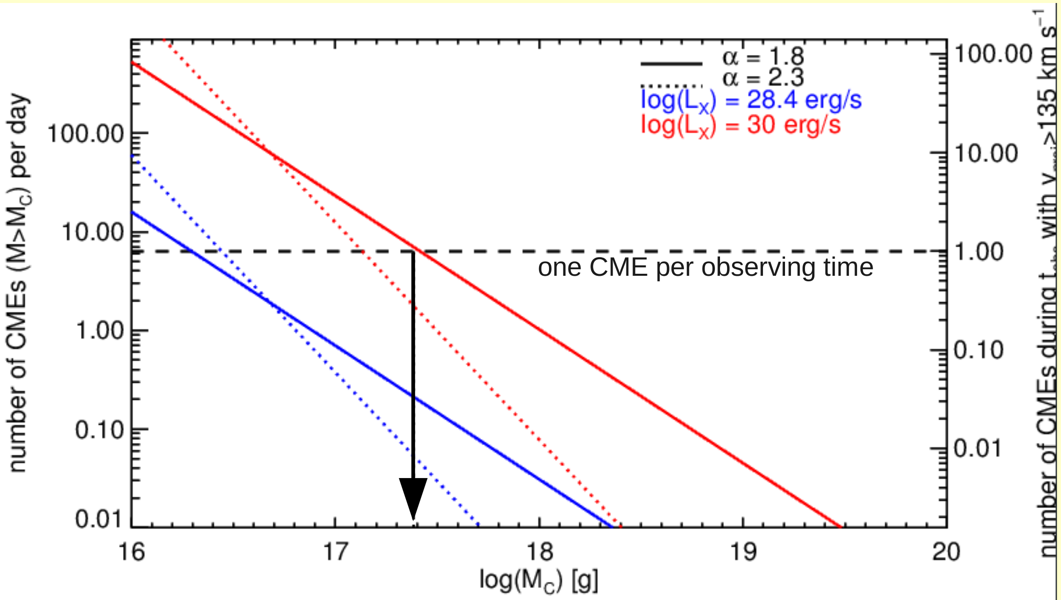
α: power law flare index – for both, solar and stellar flares, an index in the range of 1.5-2.5 has been found

Lower panel: cumulative distribution of number of CMEs with M>Mc – within our observing time only CMEs with masses ≤ 3×10^{17}g could have been detected for the X-ray luminous stars in the sample

Upper panel: maximum Hα flux vs. CME mass for two different OD values. The dashed horizontal line denotes the detection limit of our observations. CMEs associated with Hα flux above this threshold could have been detected with our observational settings. For OD=2 this corresponds to a CME mass of 3×10^{17}g (see vertical dotted lines) which is at the limit of detection for our data.



$$F_{\mathrm{H}\gamma,\mathrm{obs}} = F_{\mathrm{H}\gamma}/OD \qquad F_{\mathrm{H}\alpha} = 3F_{\mathrm{H}\gamma,\mathrm{obs}}$$



The maximum flux can be determined according to Houdebine et al., 1990

$$F_{\mathrm{H}\gamma} \leqslant \frac{N_5 h\nu_{5-2} A_{5-2}}{4\pi d^2} = \frac{h\nu_{5-2} A_{5-2}}{4\pi d^2} \frac{M_C}{(N_{\mathrm{tot}}/N_5)\bar{m}}$$

Conclusions

- No signatures of CMEs in ~5 hours of simultaneous spectroscopic monitoring of 13 members of the young and open cluster Blanco-1

- According to the expected CME rates which are based on distributions of solar CME parameters it has been shown that with our observational detection limit (S/N) we could not have detected Hα flux associated with CME masses of $\leq 3x10^{17}$g

- We conclude that velocity projection effects play not an as important role as the mass of stellar CMEs. For future observations it will be necessary to achieve a higher S/N either with longer exposure times or brighter targets.

Outlook

- more available data sets of young open clusters (IC2391, NGC2516, NGC3532 – ESO/NTT, h Per, IC348, NGC1662 – ENO/NOT), and three fast rotating young stars (HK Aqr, PZ Tel, LOPeg, ESO/2.2.m MPG, TLS/2mSchmidt Telescope), analysis ongoing

- spectroscopic monitoring of young and bright solar analogue stars at Observatory Lustbühel which belongs to our institute, planned task