Flares and coronal mass ejections on different stars

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- According to observation. the number of flares on different stars almost does not change from dwarf to hot stars.
- It is known from the Sun observations. the flares may be followed by the coronal mass ejection events (CME).
- The estimates of a magnetic field strength in tubes in photospheres of O-M stars were made.
- We use simple formulas with a clear physical meaning. which give results for the Sun that differ by no more than a factor of 2–3 from the observed ones.
- The main motivation for such approach is as follows: our knowledge of the stars' medium is at approximately the same level as our knowledge of the Sun in the 1950s. Moreover. such simple models allow a complete picture of the processes in the system to be obtained without knowing any details of the stellar activity.
- Basing on the obtained values and parameters of different objects we made estimates of flare energies and estimates of CME's masses and made some assumptions on the minimum and maximum limits for different types of stars and compare them with flares energies. stars luminosities and temperatures.

Necessary Formulars

Equating the magnetic field on the star to the thermal plasma pressure and using the mean free path as a characteristic length. obtain

$$\frac{B^2}{8\pi} = nkT = \frac{\rho G M}{R^2} H, \quad H = \lambda = \frac{1}{n\sigma_T}$$

and the photospheric magnetic field is equal to

$$B_{ph} = \frac{B}{R}\left(\frac{8\pi G m_p M}{\sigma_T}\right)^{1/2} = B_{0\odot}\frac{R_\odot}{R}\left(\frac{M}{M_\odot}\right)^{1/2}$$

So the flare energy is (hear α. β ≪ 1 characteristic values about 0.1)

$$E_{fl} = \beta^2\alpha^3 \frac{R}{R_\odot}\frac{M}{M_\odot}\frac{R_\odot G m_p M_\odot}{\sigma_T} = \beta^2\alpha^3 \frac{R}{R_\odot}\frac{M}{M_\odot} 2.3\times 10^{37} \text{ erg}$$

Necessary Formulars (continuing)

The maximum coronal temperature is

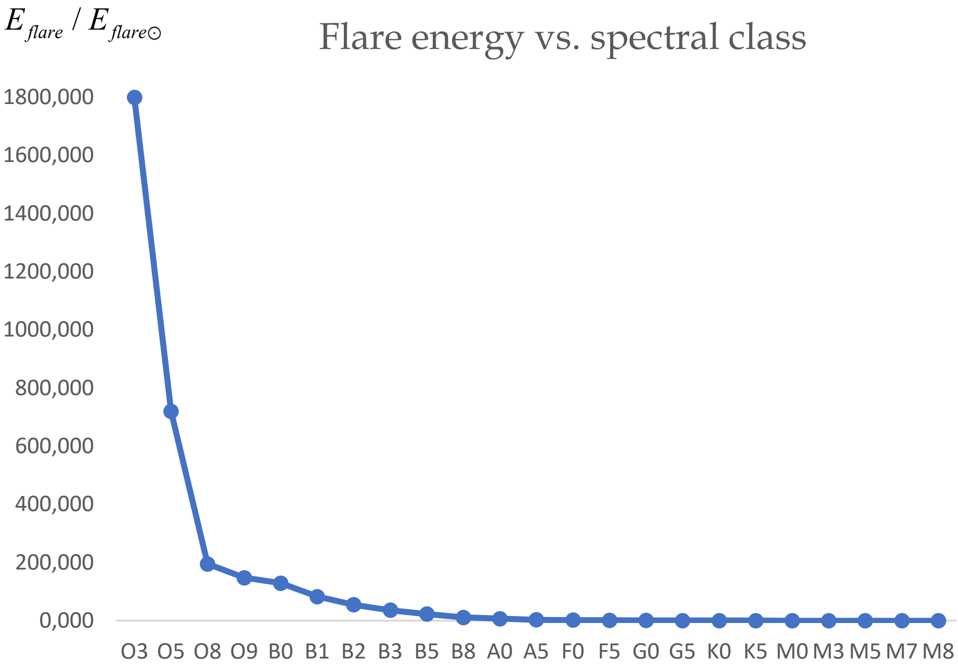
$$T_{cor\max} = G\frac{Mm_p}{4Rk_B} = 5.77\times10^6\left(\frac{M}{M_\odot}\frac{R_\odot}{R}\right)\text{K}=\gamma T_{cor}$$

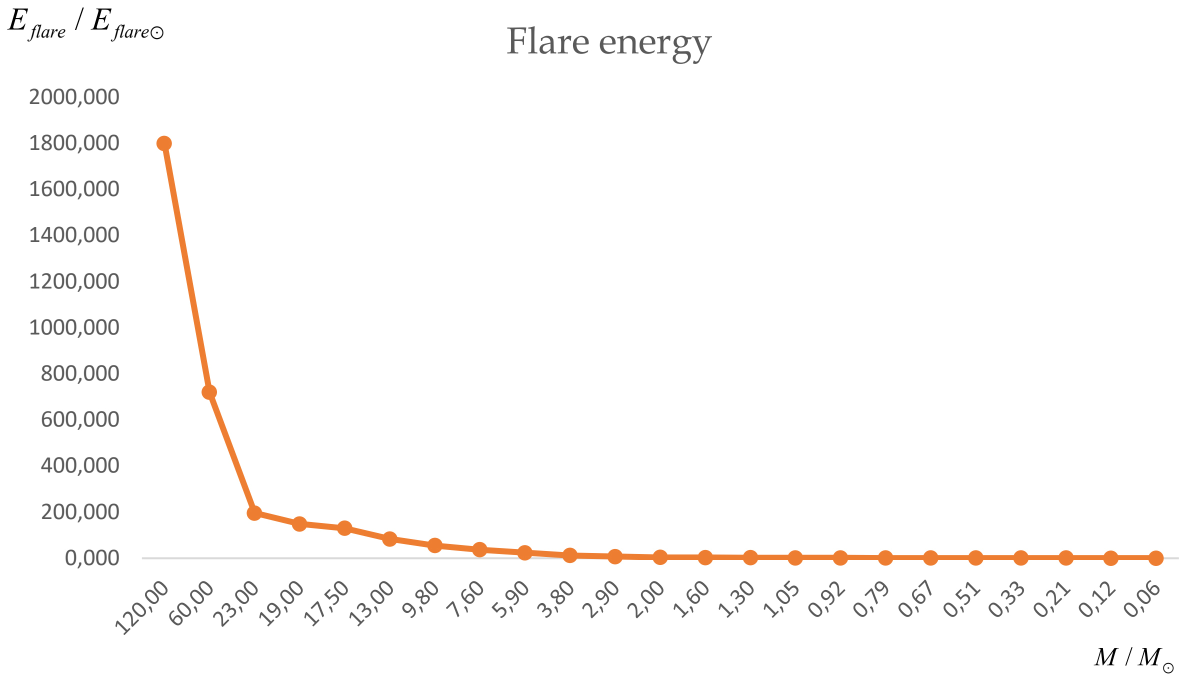
The Coronal Mass Ejection (CME) mass is

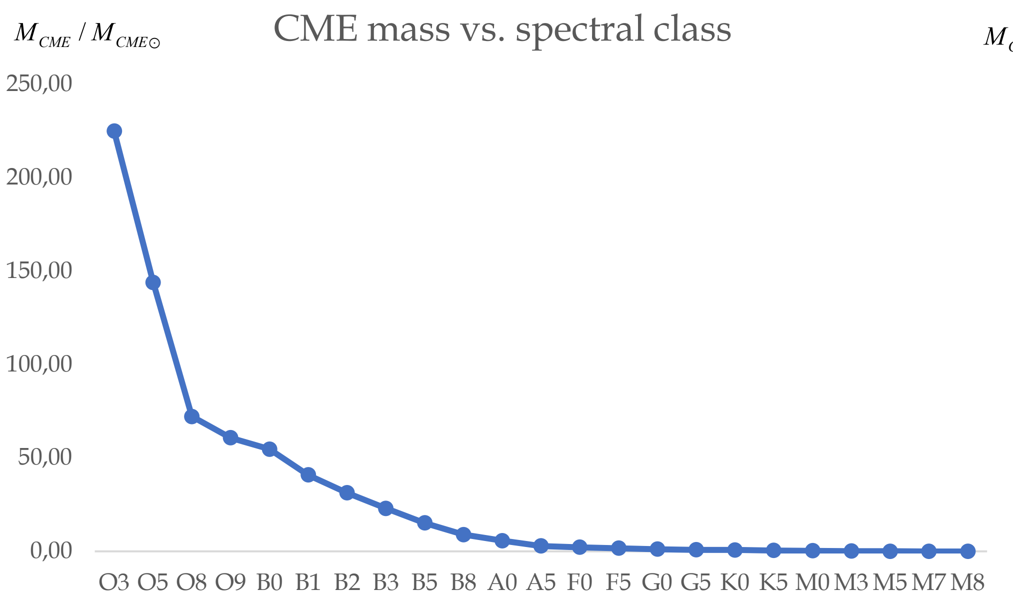
$$M_{\text{CME}} = \frac{\alpha^3\beta^2}{\gamma}\frac{4m_p}{\sigma_T}R^2 = 4.87\times10^{22}\frac{\alpha^3\beta^2}{\gamma}\left(\frac{R}{R_\odot}\right)^2 \text{ g}$$

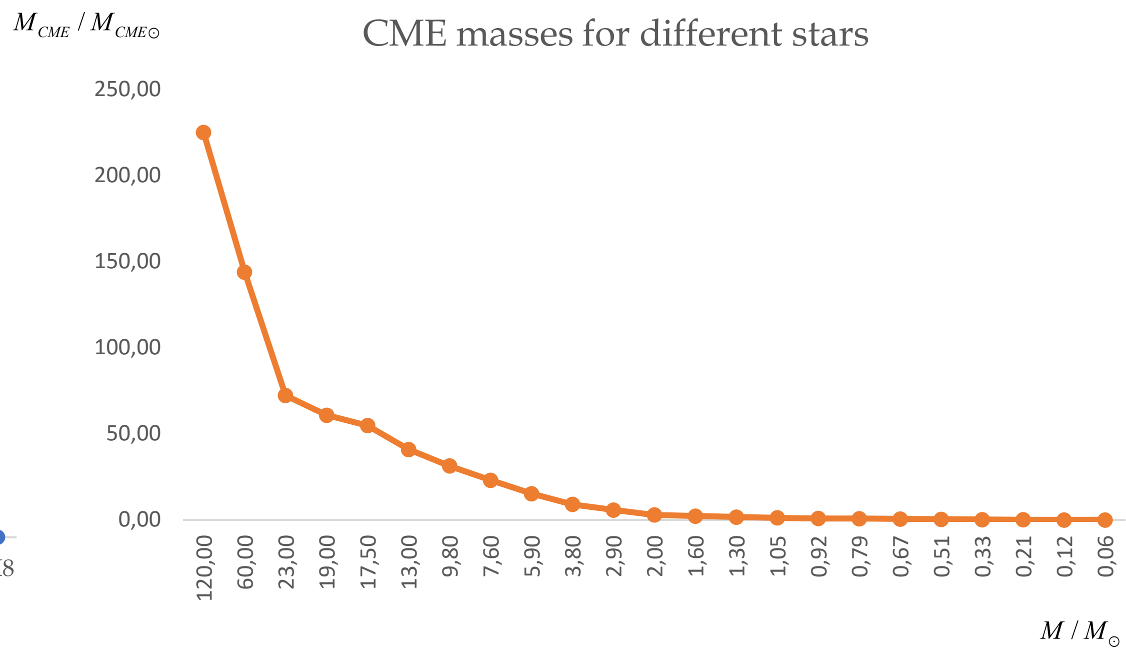
Average parameters for different stars classes

Class	$M/M_\odot$	$R/R_\odot$	T_{star}, K	T_{cor}, 10^6 K	$E_{flare}/E_{flare\odot}$	$M_{CME}/M_{CME\odot}$	$L_{star}/L_\odot$	B_{ph}, G	n_0, 10^{13} cm^{-3}
O3	120.00	15.00	52 500	46.10	1 800.000	225.00	1400000.000	936.9707	0.576
O5	60.00	12.00	44 500	28.80	720.000	144.00	790000.000	828.1729	0.719
O8	23.00	8.50	35 800	15.60	195.500	72.25	170000.000	723.8885	1.02
O9	19.00	7.80	33 000	14.00	148.200	60.84	97000.000	716.983	1.11
B0	17.50	7.40	30 000	13.60	129.500	54.76	52000.000	725.2938	1.17
B1	13.00	6.40	25 400	11.70	83.200	40.96	16000.000	722.8004	1.35
B2	9.80	5.60	22 000	10.10	54.880	31.36	5700.000	717.2188	1.54
B3	7.60	4.80	18 700	9.13	36.480	23.04	1900.000	736.8723	1.80
B5	5.90	3.90	15 400	8.72	23.010	15.21	830.000	799.0759	2.21
B8	3.80	3.00	11 900	7.30	11.400	9.00	180.000	833.6758	2.88
A0	2.90	2.40	9 520	6.97	6.960	5.76	54.000	910.3626	3.60
A5	2.00	1.70	8 200	6.78	3.400	2.89	14.000	1067.315	5.08
F0	1.60	1.50	7 200	6.15	2.400	2.25	6.500	1081.921	5.76
F5	1.30	1.30	6 440	5.77	1.690	1.69	3.200	1125.265	6.64
G0	1.05	1.10	6 030	5.50	1.155	1.21	1.500	1195.167	7.85
G5	0.92	0.92	5 770	5.77	0.846	0.85	0.790	1337.62	9.38
K0	0.79	0.85	5 250	5.36	0.672	0.72	0.420	1341.595	10.2
K5	0.67	0.72	4 350	5.37	0.482	0.52	0.150	1458.584	12.0
M0	0.51	0.60	3 850	4.90	0.306	0.36	0.077	1527.075	14.4
M3	0.33	0.45	3 470	4.23	0.149	0.20	0.036	1637.839	19.2
M5	0.21	0.27	3 240	4.49	0.057	0.07	0.011	2177.572	32.0
M7	0.12	0.18	2 940	3.84	0.022	0.03	0.003	2469.135	48.0
M8	0.06	0.10	2 640	3.46	0.006	0.01	0.001	3142.695	86.3


$E_{flare} / E_{flare\odot}$
Flare energy vs. spectral class
1800,000
1600,000
1400,000
1200,000
1000,000
800,000
600,000
400,000
200,000
0,000
O3 O5 O8 O9 B0 B1 B2 B3 B5 B8 A0 A5 F0 F5 G0 G5 K0 K5 M0 M3 M5 M7 M8


$E_{flare} / E_{flare\odot}$
Flare energy
2000,000
1800,000
1600,000
1400,000
1200,000
1000,000
800,000
600,000
400,000
200,000
0,000
120,00 60,00 23,00 19,00 17,50 13,00 9,80 7,60 5,90 3,80 2,90 2,00 1,60 1,30 1,05 0,92 0,79 0,67 0,51 0,33 0,21 0,12 0,06
$M / M_\odot$


$M_{CME} / M_{CME\odot}$
CME mass vs. spectral class
250,00
200,00
150,00
100,00
50,00
0,00
O3 O5 O8 O9 B0 B1 B2 B3 B5 B8 A0 A5 F0 F5 G0 G5 K0 K5 M0 M3 M5 M7 M8


$M_{CME} / M_{CME\odot}$
CME masses for different stars
250,00
200,00
150,00
100,00
50,00
0,00
120,00 60,00 23,00 19,00 17,50 13,00 9,80 7,60 5,90 3,80 2,90 2,00 1,60 1,30 1,05 0,92 0,79 0,67 0,51 0,33 0,21 0,12 0,06
$M / M_\odot$

Conclusions

- We obtained estimates of the magnetic field energy in the photospheres of O-M stars and used these data to estimate the flares energy and values of coronal mass ejections.
- The values obtained for the Sun coincide with the observed values on the order of magnitude, thus justifying the possibility of such consideration for other stars.
- The magnetic field in the magnetic force tube differs by less than 5 orders of magnitude for flares in O and M stars (900 and 3500 Gs), but for O stars the flare energy appears to be about 5 orders of magnitude higher.
- The masses of CME differ about 5 oders of magnitudes for different classes.