SAMARKAND STATE UNIVERSITY

DEPARTMENT OF PHYSICS

Solar Cycle Variation of Coronal Mass Ejections

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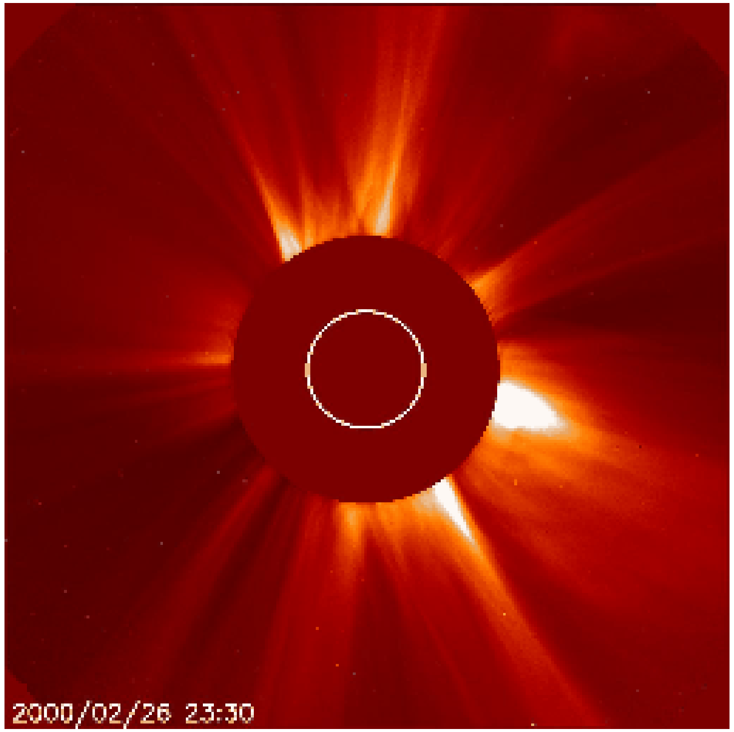
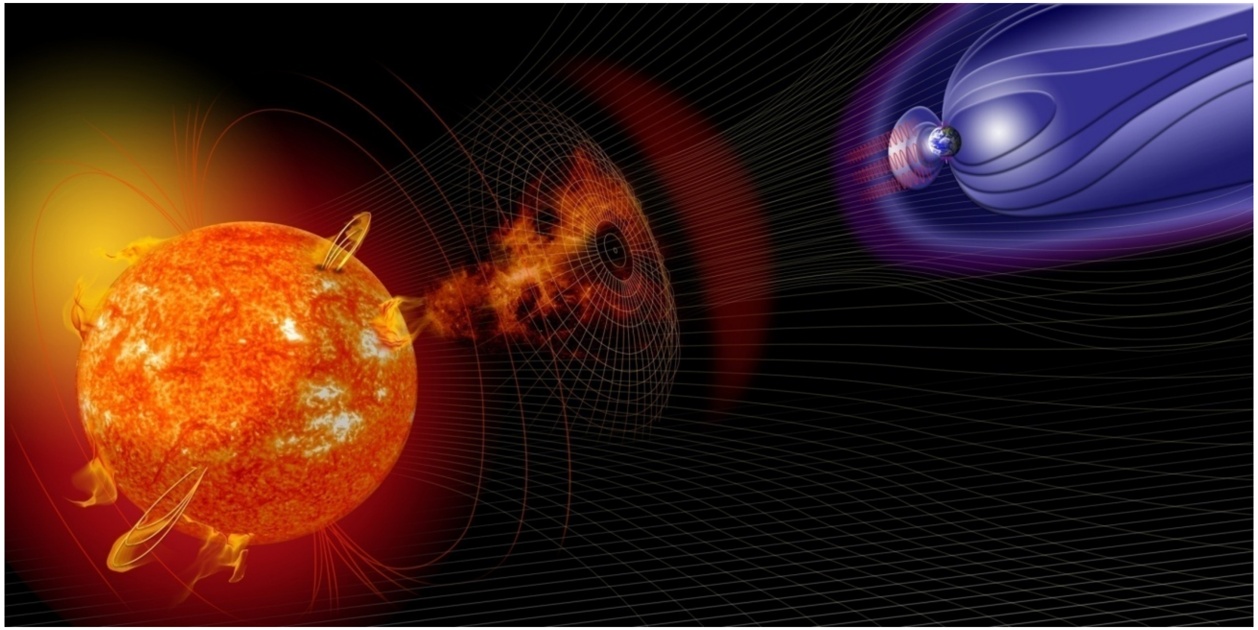
INTRODUCTION

- Similar to the Sun, other stars have also shown the spectroscopic evidence of a quasi-steady wind (i.e. stellar wind) and episodic stellar coronal mass ejections (CMEs) from their corona (de Jager, Nieuwenhuijzen & van der Hucht 1988; Dudley & Jeffery 1992; Kudritzki & Puls 2000; Puls, Vink & Najarro 2008).
- Although several attempts have been made for understanding stellar winds and stellar CMEs, their properties are not yet well understood, both theoretically and observationally (Parker 1960; Lamers & Cassinelli 1999; Matt & Pudritz 2008)

SOLAR CORONAL MASS EJECTIONS (CMEs)

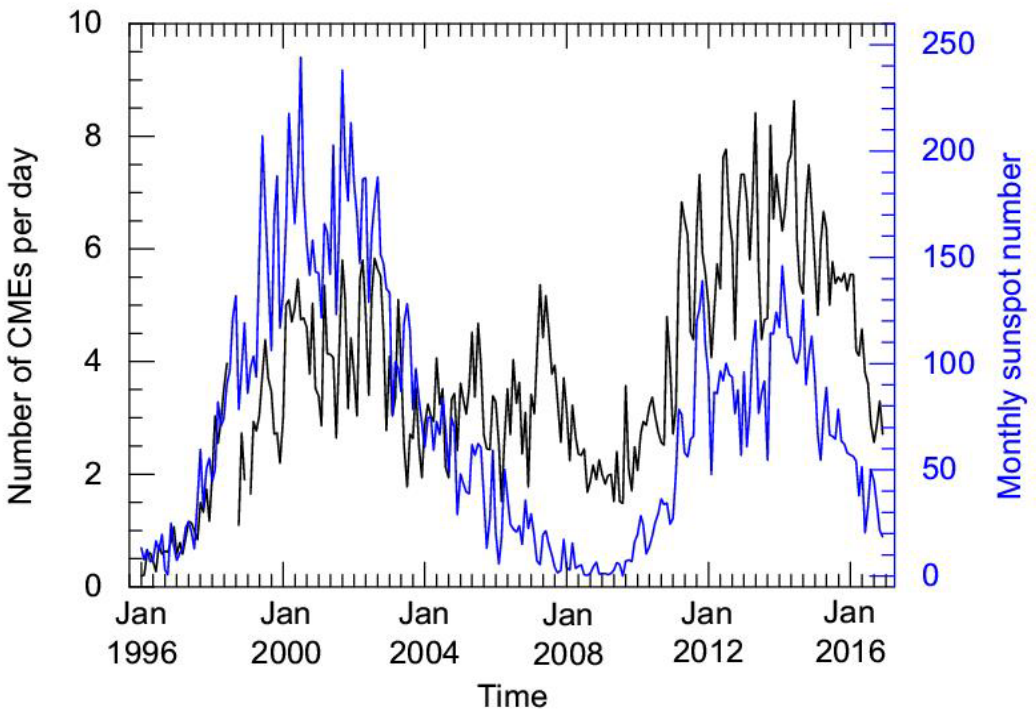
- Mass up to one billion tons (from intensity to n_e from Thomson scattering, from radio and X-ray observations)
- Speed: < 10 to <= 2500 km/s (ranging from < sound speed to >Alfven speed)
- Typical Kinetic Energy: 10^{20}-10^{25} J (similar as large flares)

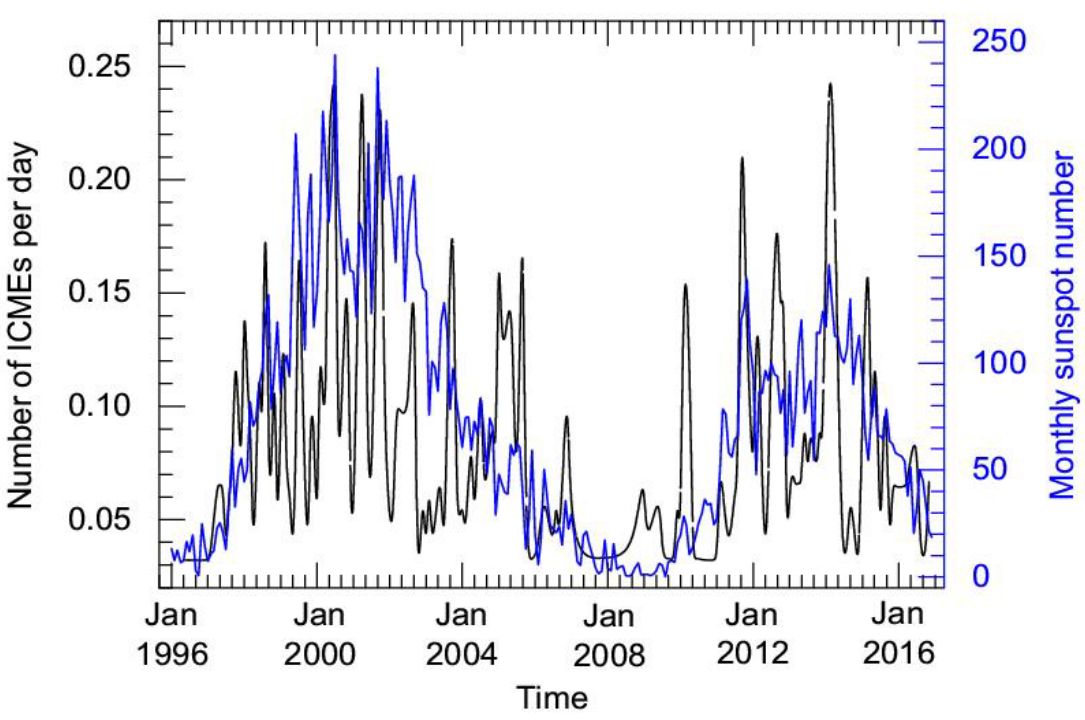




- CME Mass loss rate may have solar cycle dependence

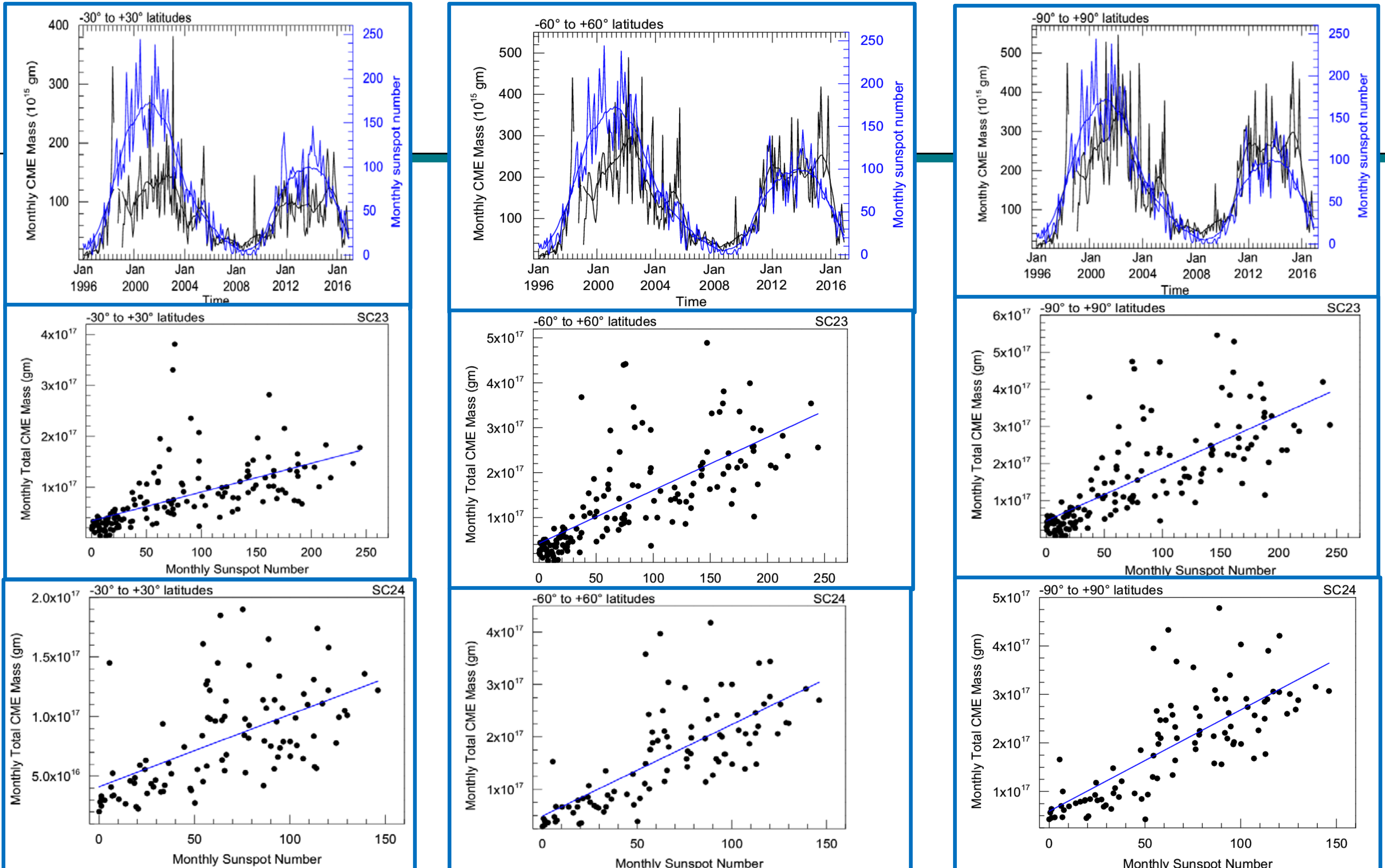
SOLAR CYCLE VARIATION OF CORONAL MASS EJECTIONS





- CMEs rate for the period of 2012-2014 is increased by a factor of ≈1.6 while SN is decreased by a factor of ≈1.7 than that in 2000-2002 years (*Wang & Colaninno 2014; Gopalswamy et al. 2015; Petrie 2015*)
- ICMEs during the first 7 years of SC24 is decreased by 40% of that during the same interval of SC23. Also, during the maximum of SC24, the rate of ICME reaches up to the same value as during the maximum of SC23.

CDAW GSFC NASA CME catalogue (Yashiro et al. 2004)
SIDC website (Clette et al. 2014)
Richardson/Cane ICME List (Cane & Richardson 2003; Richardson & Cane 2010)



-30° to +30° latitudes
Monthly CME Mass (10^{15} gm)
Monthly sunspot number
Jan 1996
Jan 2000
Jan 2004
Jan 2008
Jan 2012
Jan 2016
Time
-60° to +60° latitudes
-90° to +90° latitudes
SC23
SC24
Monthly Total CME Mass (gm)
Monthly Sunspot Number

Cycle	c_1	c_2	r	r^2 (%)
Fitting from Equation (1) (CMEs and sunspot number)				
SC 23 (-30º to 30º)	1.1	67	0.60	36.0
SC 23 (-60º to 60º)	2.4	85	0.72	51.8
SC 23 (-90º to 90º)	2.8	91	0.74	54.8
SC 24 (-30º to 30º)	1.2	82	0.57	32.5
SC 24 (-60º to 60º)	3.4	98	0.74	54.8
SC 24 (-90º to 90º)	4.1	118	0.76	57.8
Fitting from Equation (2) (CMEs and X-ray background luminosity)				
SC 23	2.5×10^{-22}	90	0.78	60.1
SC 24	2.6×10^{-22}	126	0.80	64.0
Fitting from Equation (3) (Solar wind and sunspot number)				
SC 23	-0.2	696	0.1	1
SC 24	-0.1	616	0.03	0.09
Fitting from Equation (4) (Solar wind and X-ray background luminosity)				
SC 23	-1.2×10^{-23}	694	0.09	0.8
SC 24	1.6×10^{-23}	594	0.09	0.8

$$\frac{dM_{CME}}{dt} = 5 \times 10^{14}(c_1 S + c_2) \quad \text{gm month}^{-1} \; (1)$$

$$\frac{dM_{SW}}{dt} = 5 \times 10^{15}(c_1 S + c_2) \quad \text{gm month}^{-1} \; (3)$$

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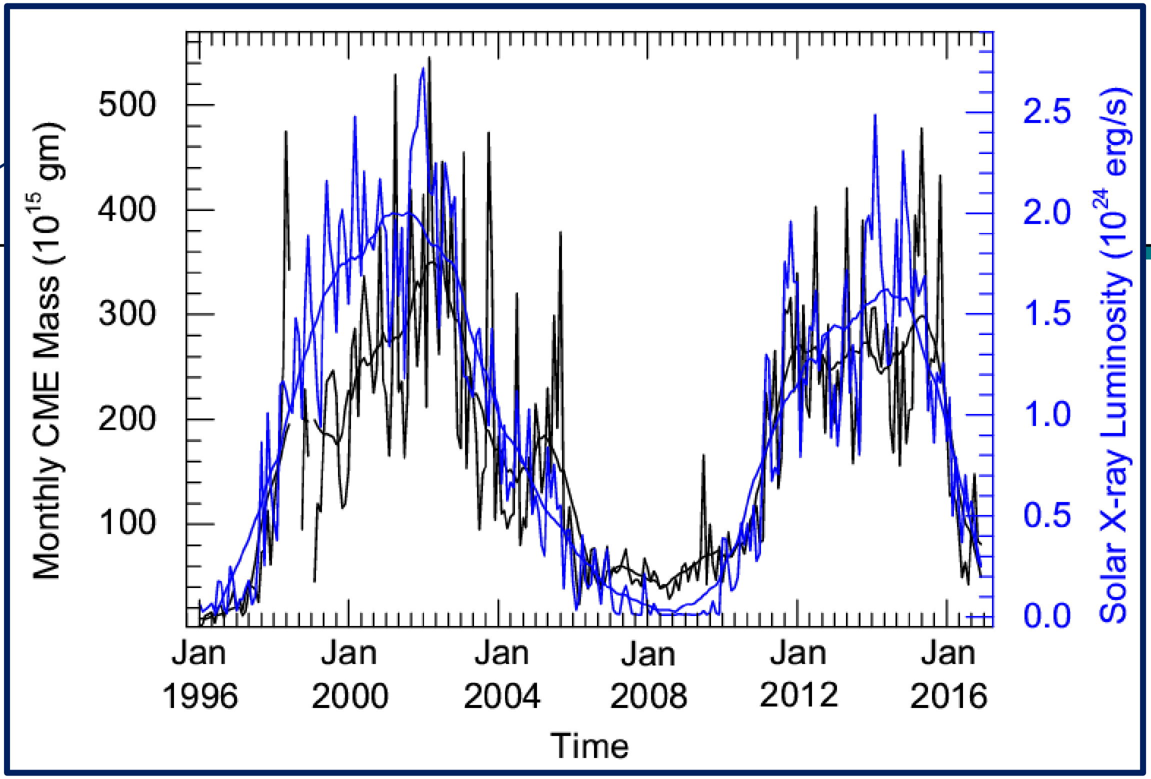

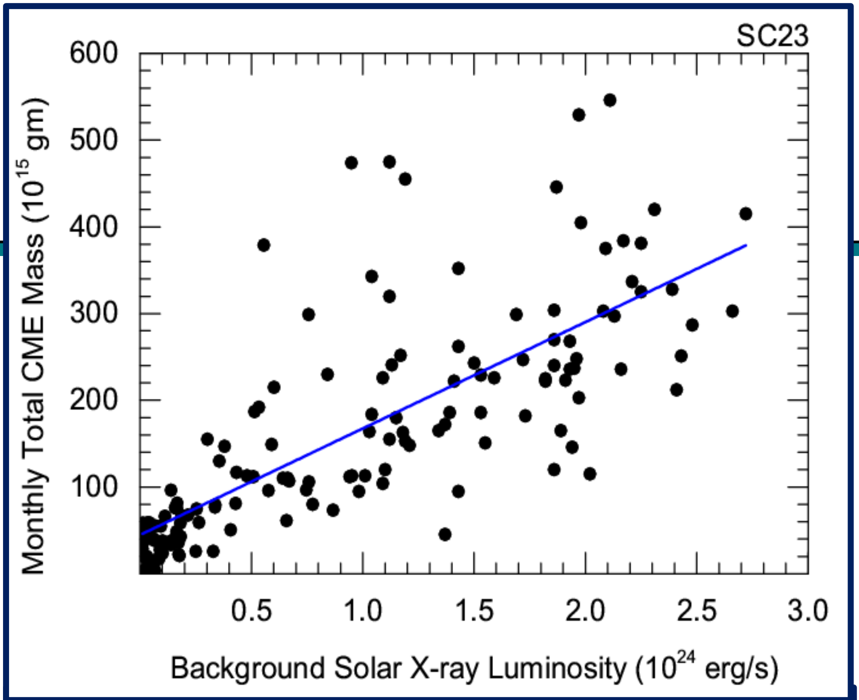

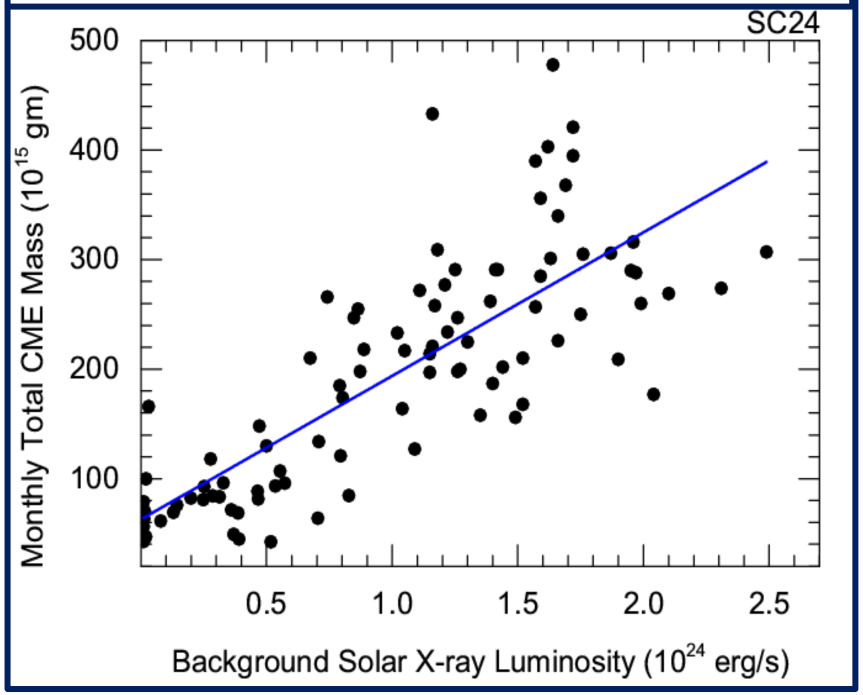

- Around 60% and 64% of the variability in mass loss rate for solar cycle 23 and 24, respectively;
- The variability in mass loss rate explained by X-ray background luminosity is around 5% higher for both the cycles than that using the monthly averaged sunspot number;
- This implies that measured X-ray luminosity is a better proxy for the mass loss activity due to CMEs for the whole Sun.

Mishra, Srivastava, Mirtoshev et al.: 2019, MNRAS

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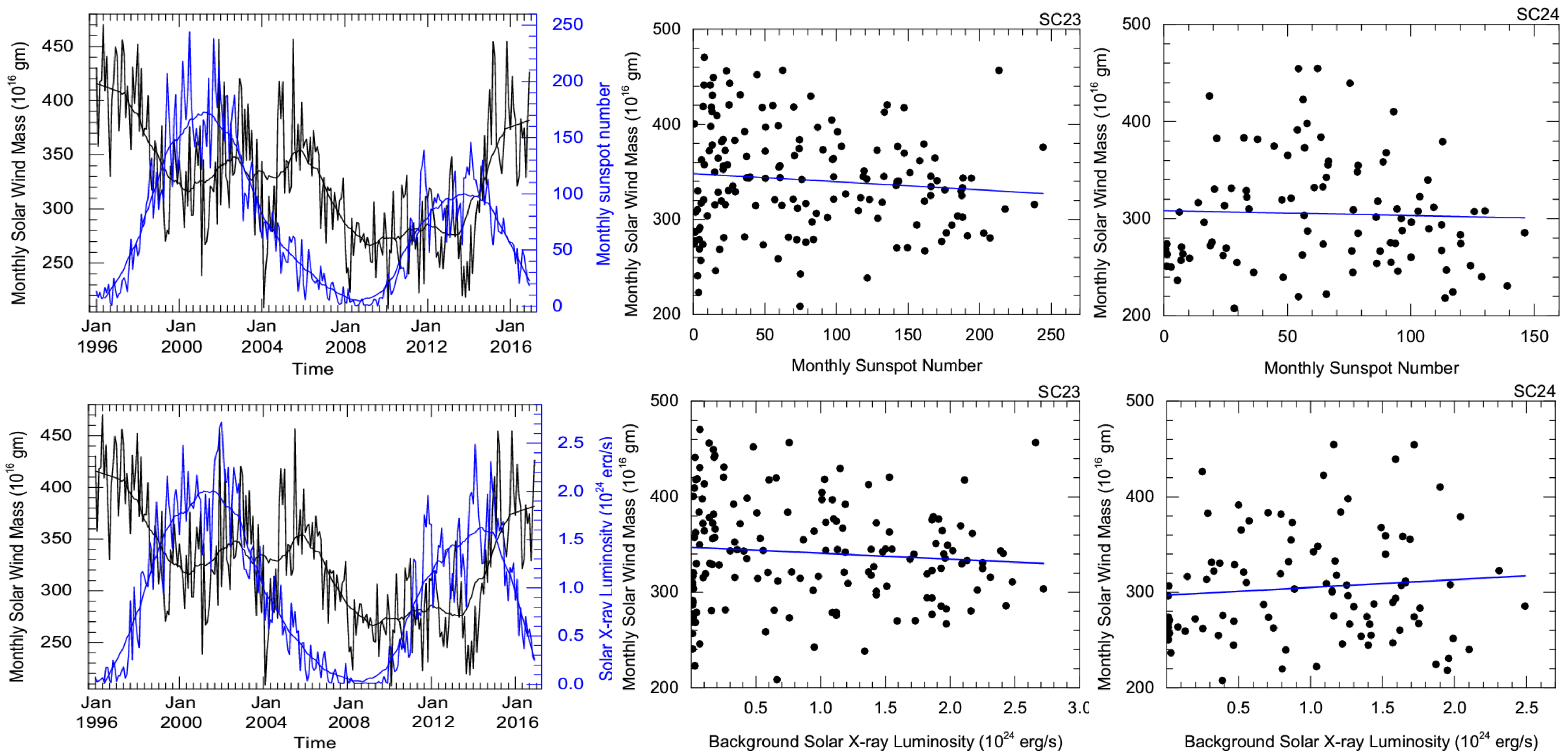

We note that the variability in the mass loss via solar wind could not be properly explained in terms of a linear function of sunspot number and solar X-ray background luminosity

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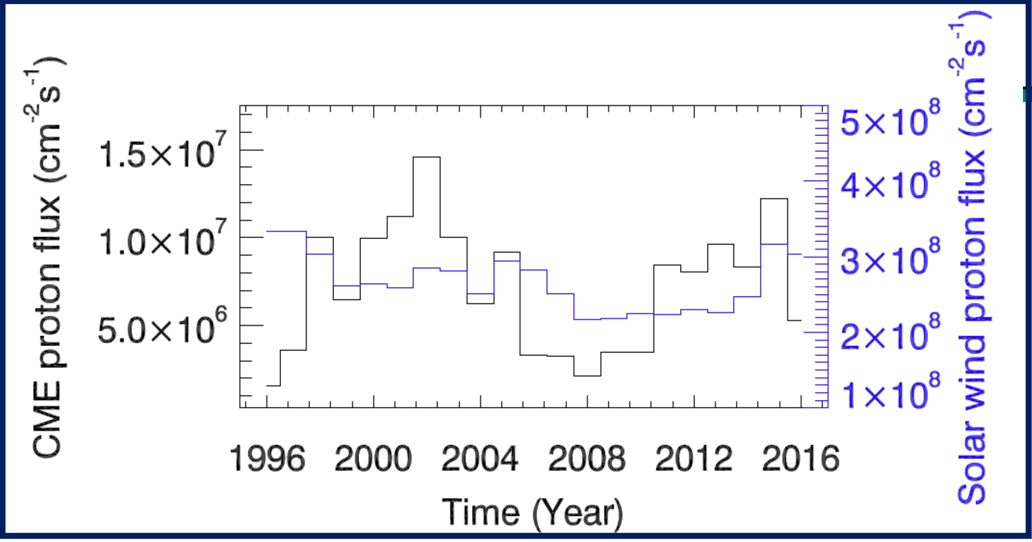
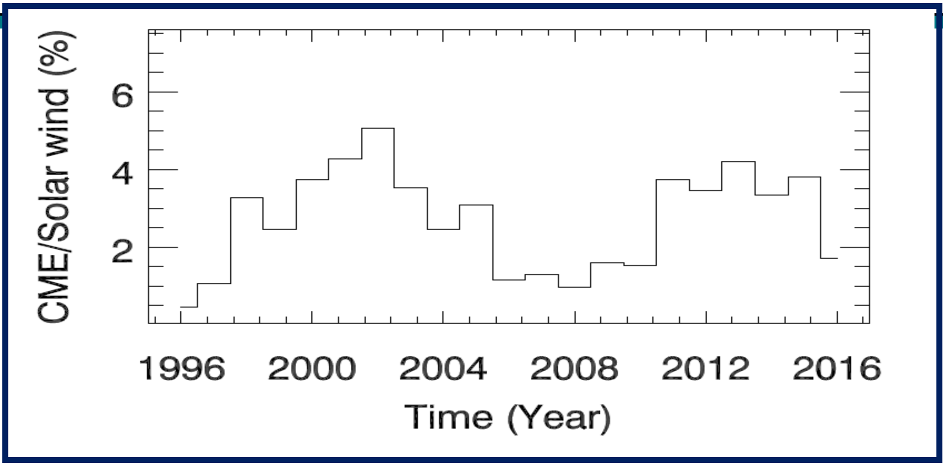
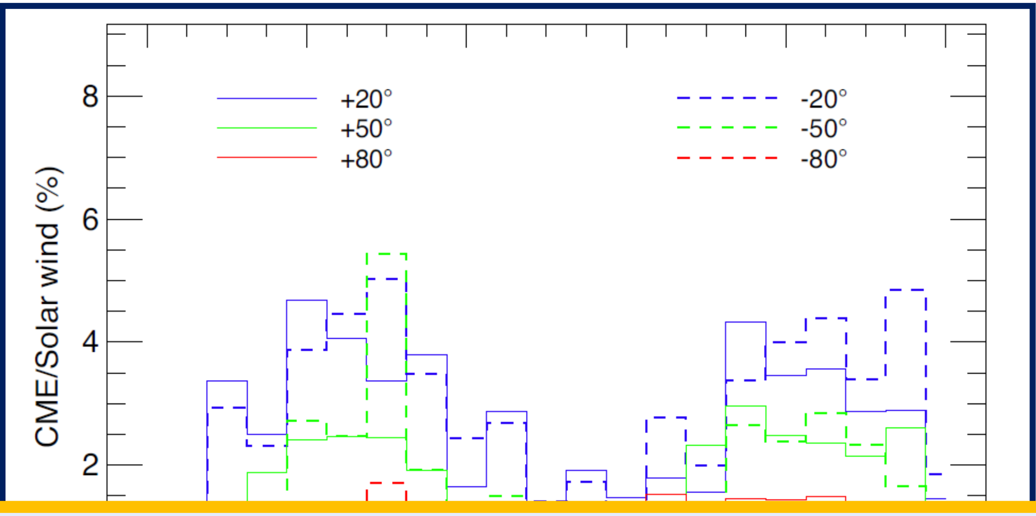
Relative Contribution of CMEs to the Solar Wind







- We note that solar wind mass flux is almost constant over time;
- The contribution of CMEs to the solar wind mass flux is negligibly small during the solar minimum;
- CMEs contribution increased up to ≈ 5% and becomes ≈ 1% along the 80° of heliolatitude at the maximum of the cycles.

Earlier works about contribution of solar CMEs to background solar wind mass flux at 1 AU (Hildner 1977; Howard et al. 1985; Jackson & Howard 1993; Webb & Howard 1994; Lamy et al. 2017). In these studies, the fractional contribution of CMEs to the solar wind was found to be different and it ranged from 5 to 16 percent at the maximum of the solar cycles.

CONCLUSIONS

- We established a relationship for mass loss rate as a linear function of monthly averaged sunspot number and solar X-ray background luminosity. This suggests that X-ray background luminosity is a better proxy for CME mass loss rate over the solar cycle than the sunspot number. However, the solar wind mass loss rate shows no obvious solar cycle dependency.
- The solar wind mass loss rate is roughly an order of magnitude larger than the CME mass loss rate. The fractional contribution of CMEs to solar wind mass flux is around 5 percent during solar maximum in the ecliptic and it is much smaller at higher heliolatitudes and/or during solar minimum.

CONCLUSION

- Since it is more difficult to observe the signatures of stellar CMEs and stellar spots than stellar X-ray flux, we think that the measured stellar X-ray background luminosity can probably be used as prediction tools for determining occurrence rate of CMEs from stars.
- However, the reliability of the extrapolation of the solar observations to other stars with much higher activity remains to be investigated in future studies.


THANK YOU...