Coronal Variability on Active (RS CVn) Binary Stars

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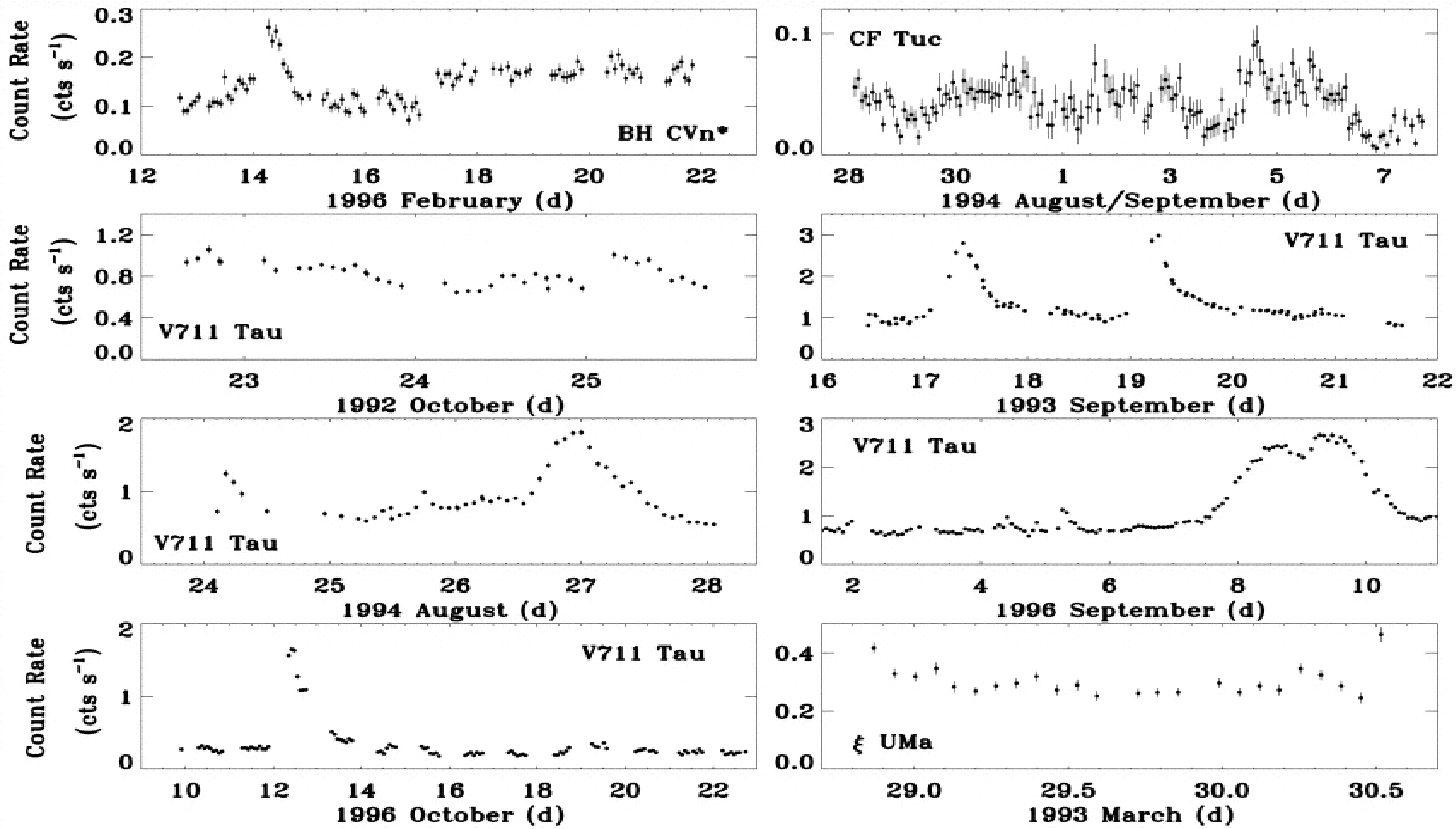
Active binary stars contain rapidly rotating stars that spend much (~ 40%) of the time flaring. Flare outburst time scales and duty cycle are much longer than on the Sun and M dwarfs.

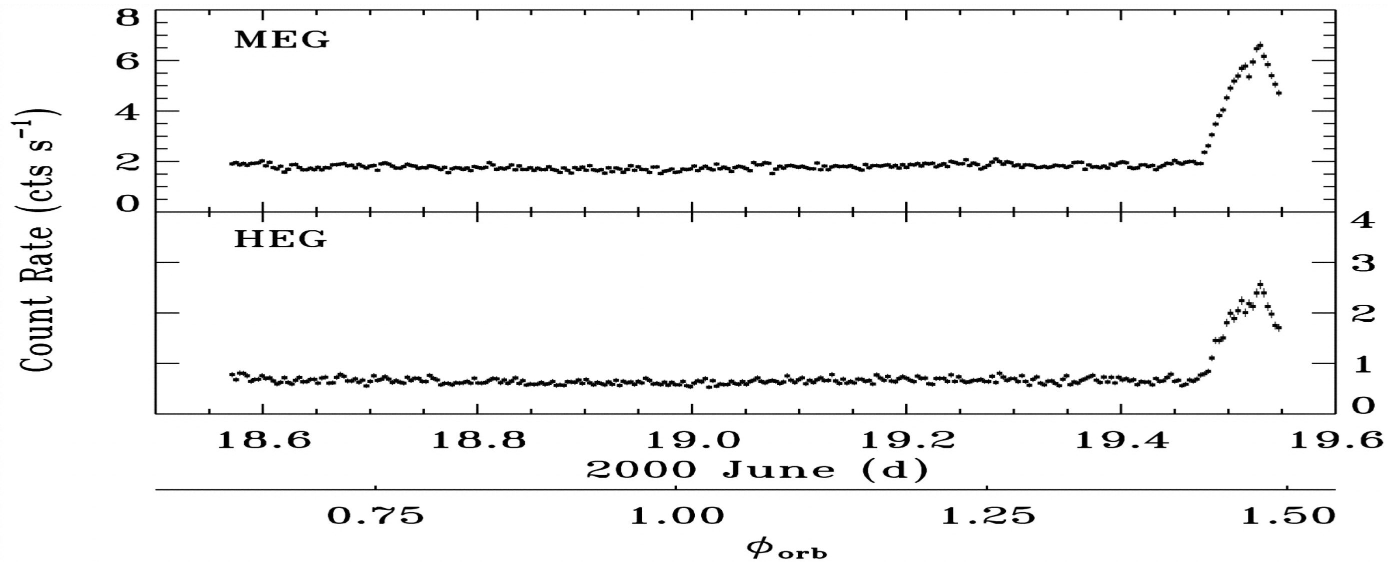


RS CVn Binaries observed by us with Chandra

- Sigma^2 CrB -- Active binary with two dwarf components (F6 V + G0 V) --- solar-like stars but rotating once in just over a day [25 times faster than the Sun]. Orbital period =1.14 days.
- Sigma Gem -- Active binary with a giant primary (K1 III) --- secondary is a dwarf with spectral type G6 or later. Orbital period = 19.604 days.
- HR1099 -- Active binary with a subgiant primary (K1 IV) --- secondary is a G5 dwarf. Orbital period = 2.84 days.

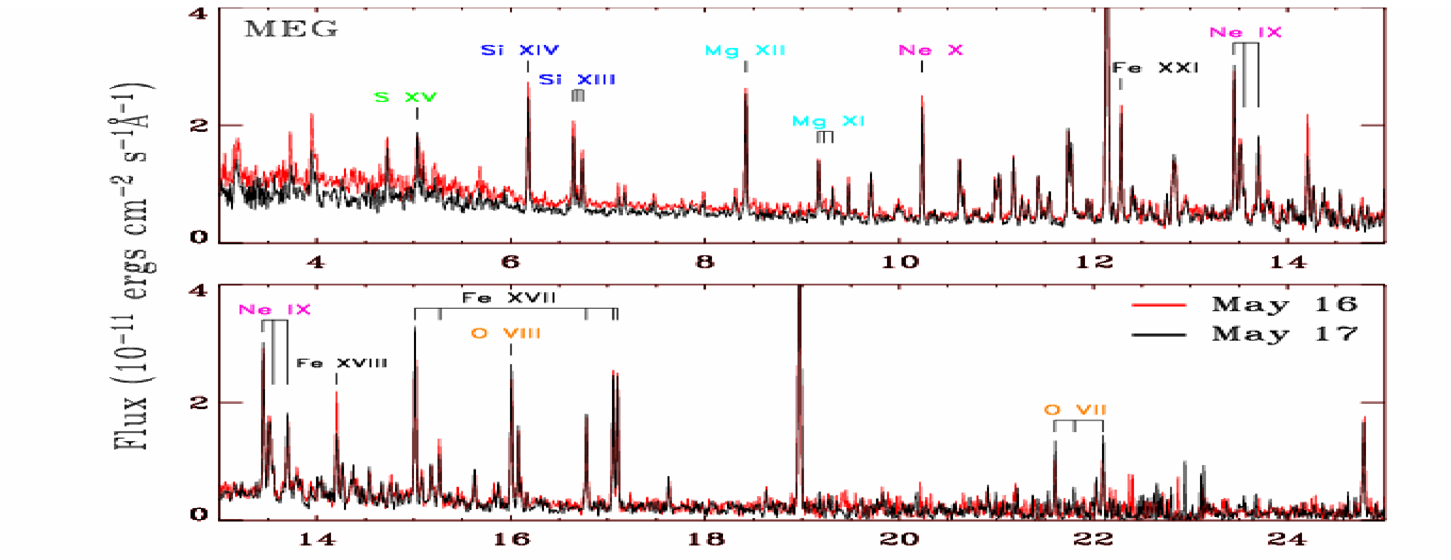
Chandra Observation of σ^2 CrB

(Osten et al. 2003, ApJ, 582, 1073)



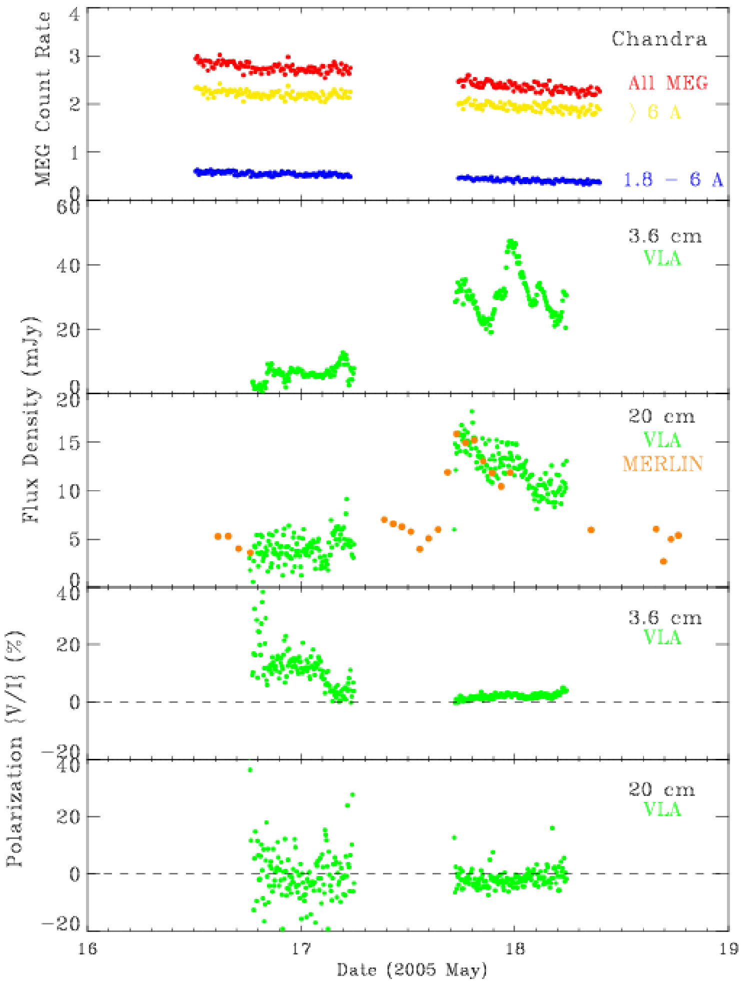
- 86 ks obs. -- on 2000 June 18-19 (First of 5 EUVE flares).
- Long quiescence – typically flare rise faster than decay.
- Overall enhancement x3.5 but x15 for $\lambda < 10$ A.
- Flare T_e 50 MK, cf 30 MK in quiescence, – bulk of plasma at 6-8 MK.
- Fe abundance doubles (0.46 -> 0.91) during flare but other elements changes far less.

Chandra Observation of σ Gem



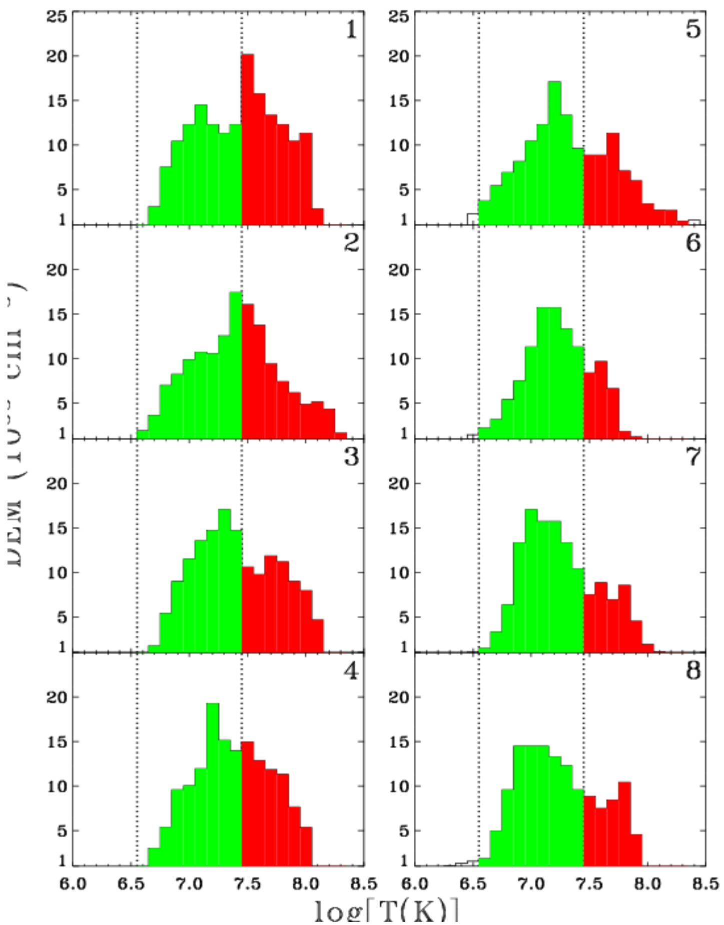
- 120 ks obs. -- 2005 May 16-18 (Two 60 ksec pieces).
- Strong continuum emission that declines throughout the observation.
- Star observed during two days of flare decay, with a starting level at ~ 3 times the expected quiescent level.

Chandra Observation of σ Gem



- Steady flare decay with almost all change at high energy (Data split into 8 or 4 pieces).
- Strong radio flare at 3 + 20 cm WITHOUT any X-ray response ---- no Neupert Effect.
- Significant injection of energetic electrons emitting nonthermal gyrosynchrotron emission but no additional heating of the denser X-ray emitting plasma.

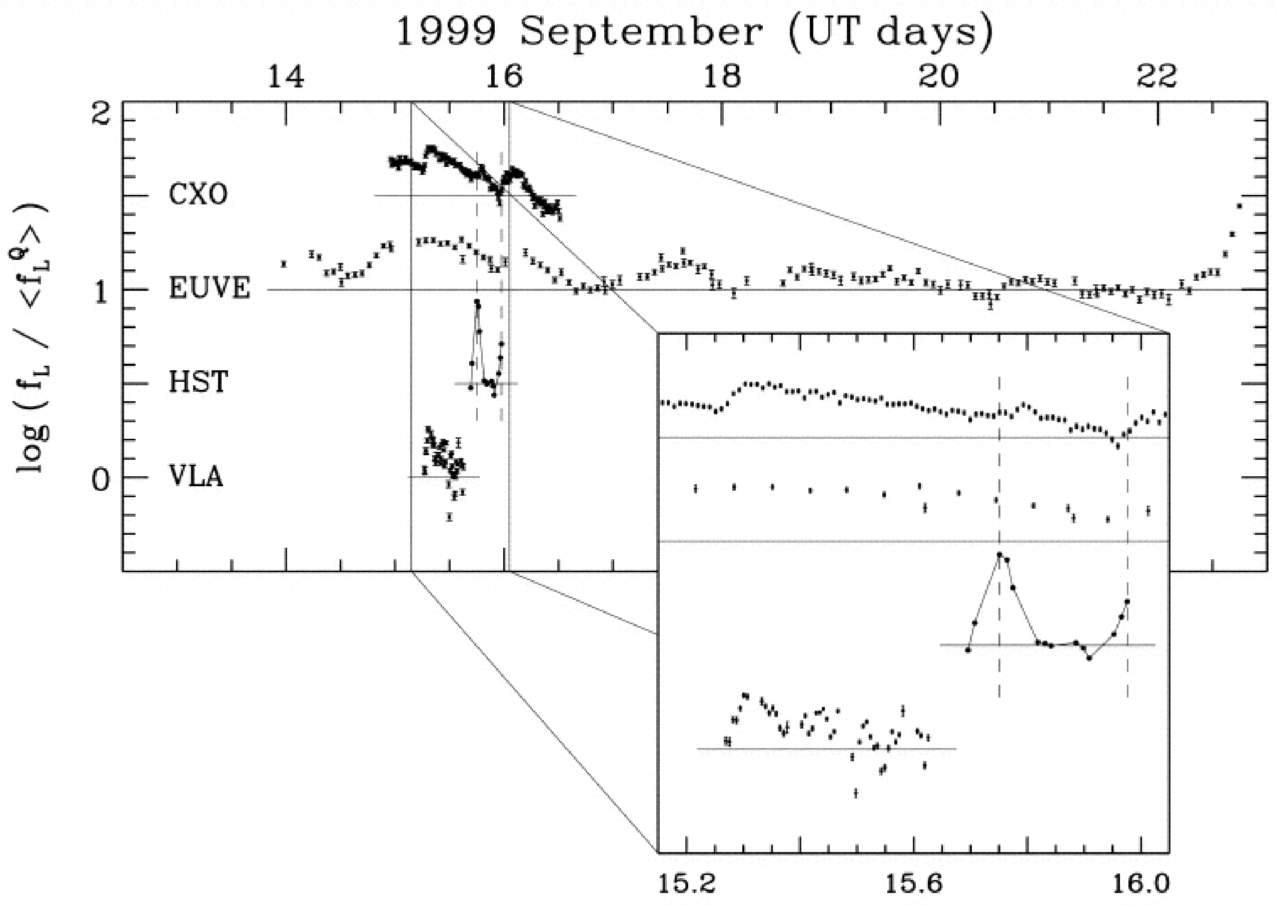
Chandra Observation of σ Gem



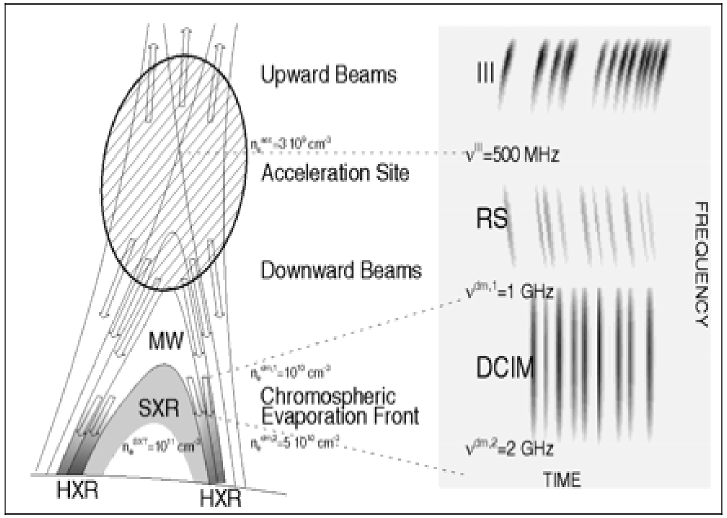
- Steady thermal evolution – systematic decline in peak of DEM, but with persistent hot plasma. NB Peak T_e over 10^8 K.
- Multiple flare components must be present.
- Density evolution at Mg XI (i.e. involving apparently stable log T_e =6.8 plasma) from from 10^{13} cm^{-3} at the start of observation almost to the low density limit of 10^{11} cm^{-3} at the end.
- Almost no change in elemental abundances.

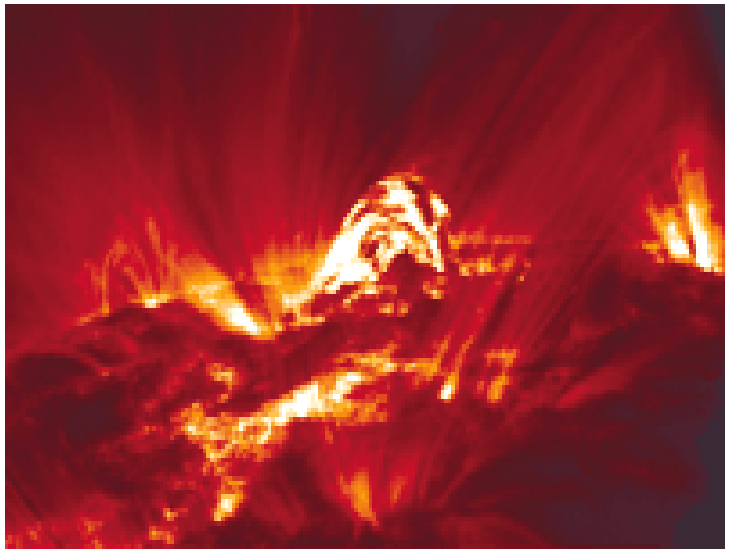
Variability during Chandra HR1099 Observation

- No X-ray flares in Chandra (136 ksec) data.
- Two UV flares without a coronal response –- flare heating does not have to seen in soft X-rays.



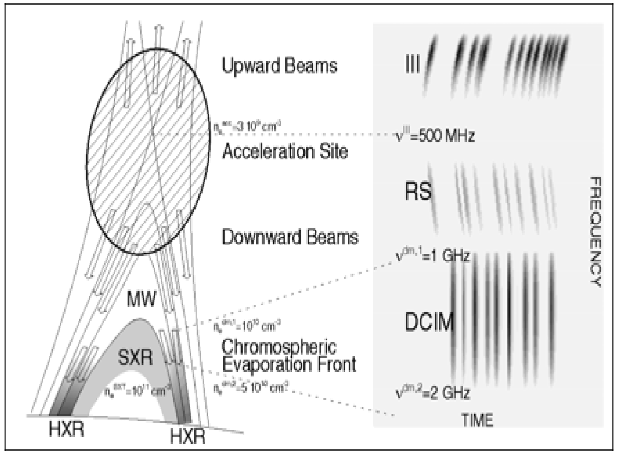
SUMMARY & CONCLUSIONS

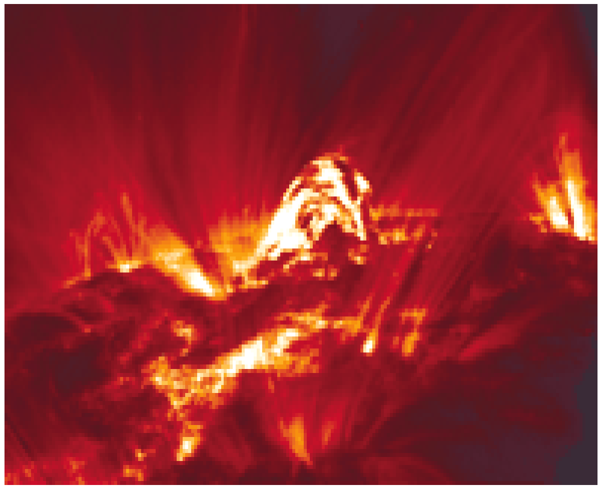




- Are these flare outbursts anything like solar flares?
- How much of the solar flare physics can be transferred to the stellar flare outbursts?

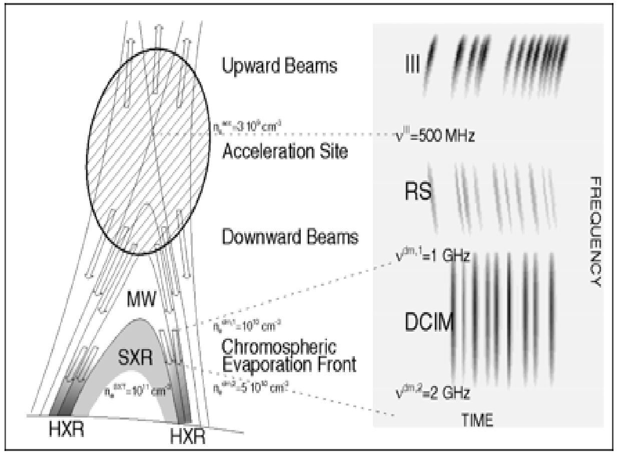
SUMMARY & CONCLUSIONS

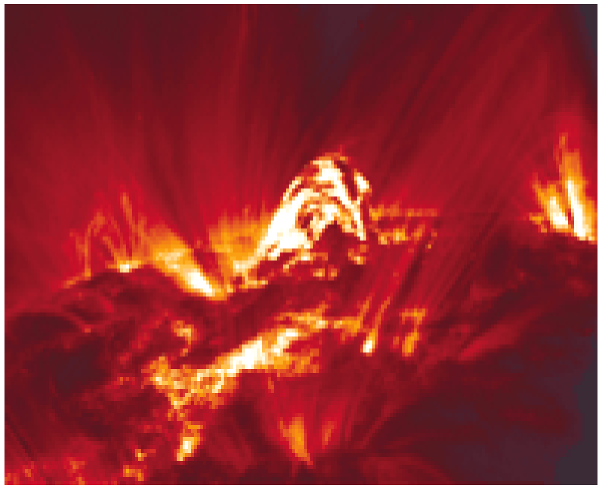




- Basic magnetic reconnection physics undoubtedly the same.
- B similar, but filling factor much larger and field distribution can differ significantly.
- Outbursts involve many coronal loops and significant fraction of stellar corona [No “single loop” models!]. This must be so because of the different time scales seen for distinct plasma components.

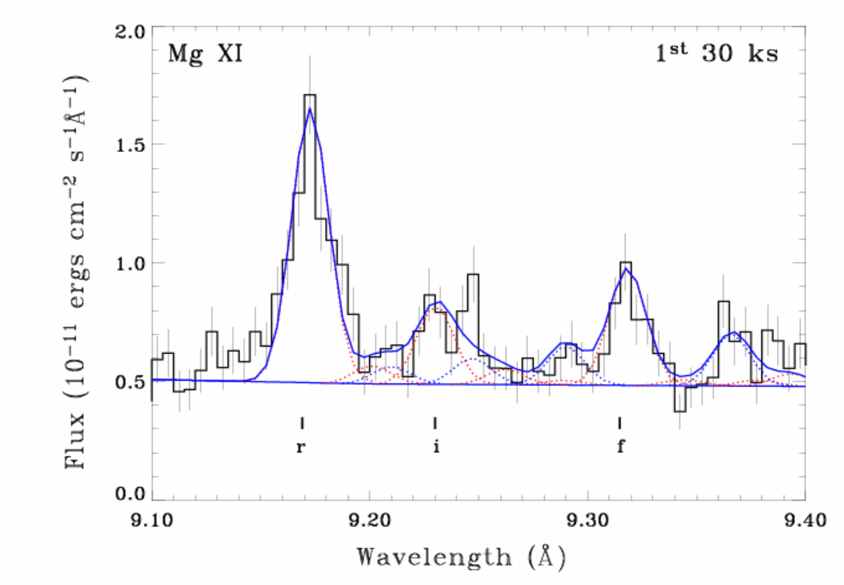
SUMMARY & CONCLUSIONS

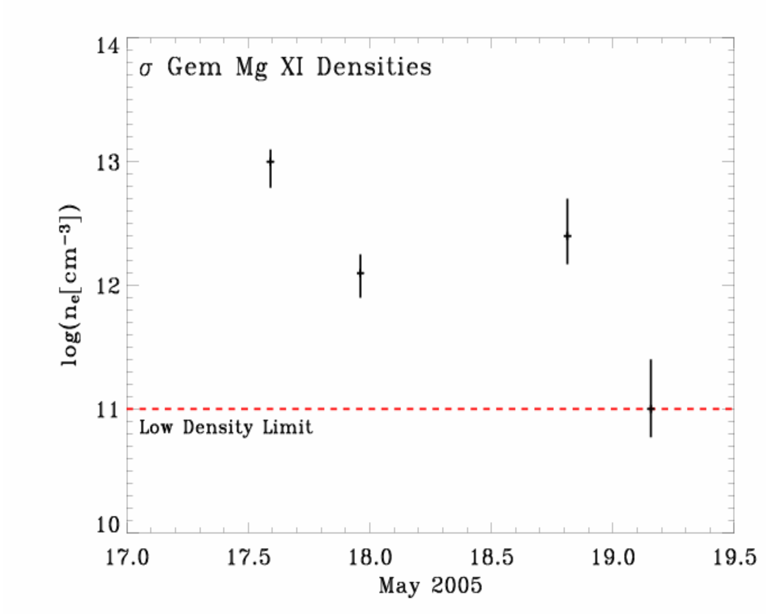




- Behaviour strongly supports chomospheric evaporation filling loops and nonthermal particle acceleration. The particles driving the evaporation can only be firmly characterized by harder (> 10 keV) X-ray data.
- Soft X-ray and radio show how the flare process fills different coronal magnetic loops.
- Long periods of near constant quiescence, even though the activity levels are 10^3 times the solar level, are just as important.
- Outburst duration related to log g .

Chandra Observation of σ Gem



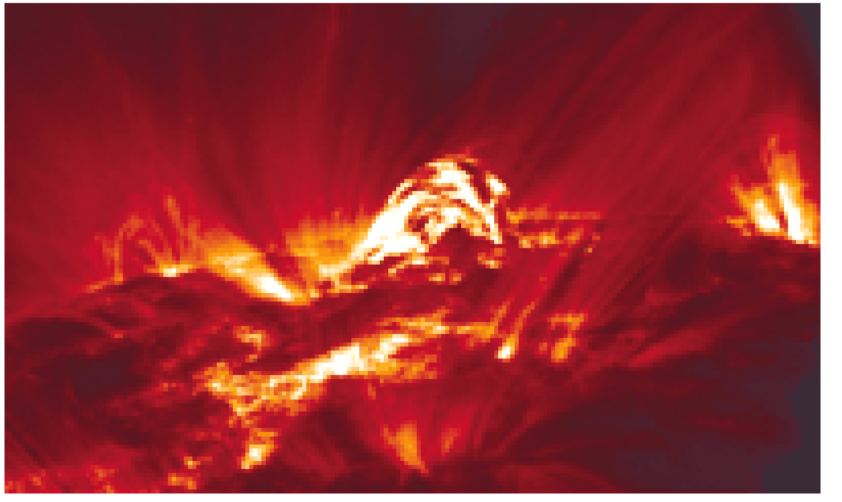


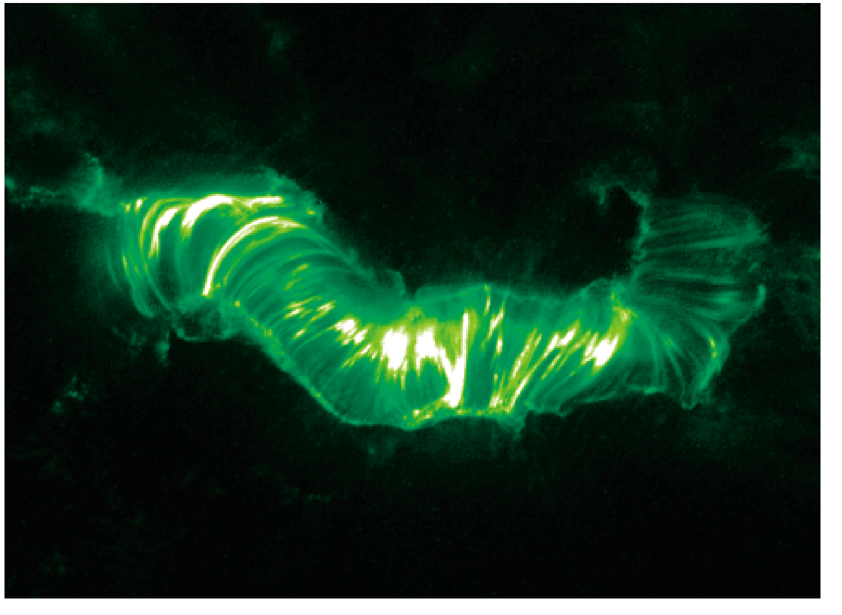
- Mg XI He-like triplet – density diagnostic @ log Te = 6.8
- Electron density declines over time from 10^{13} cm^{-3} at the start of the observation almost to the low density limit of 10^{11} cm^{-3} at the end.

The End

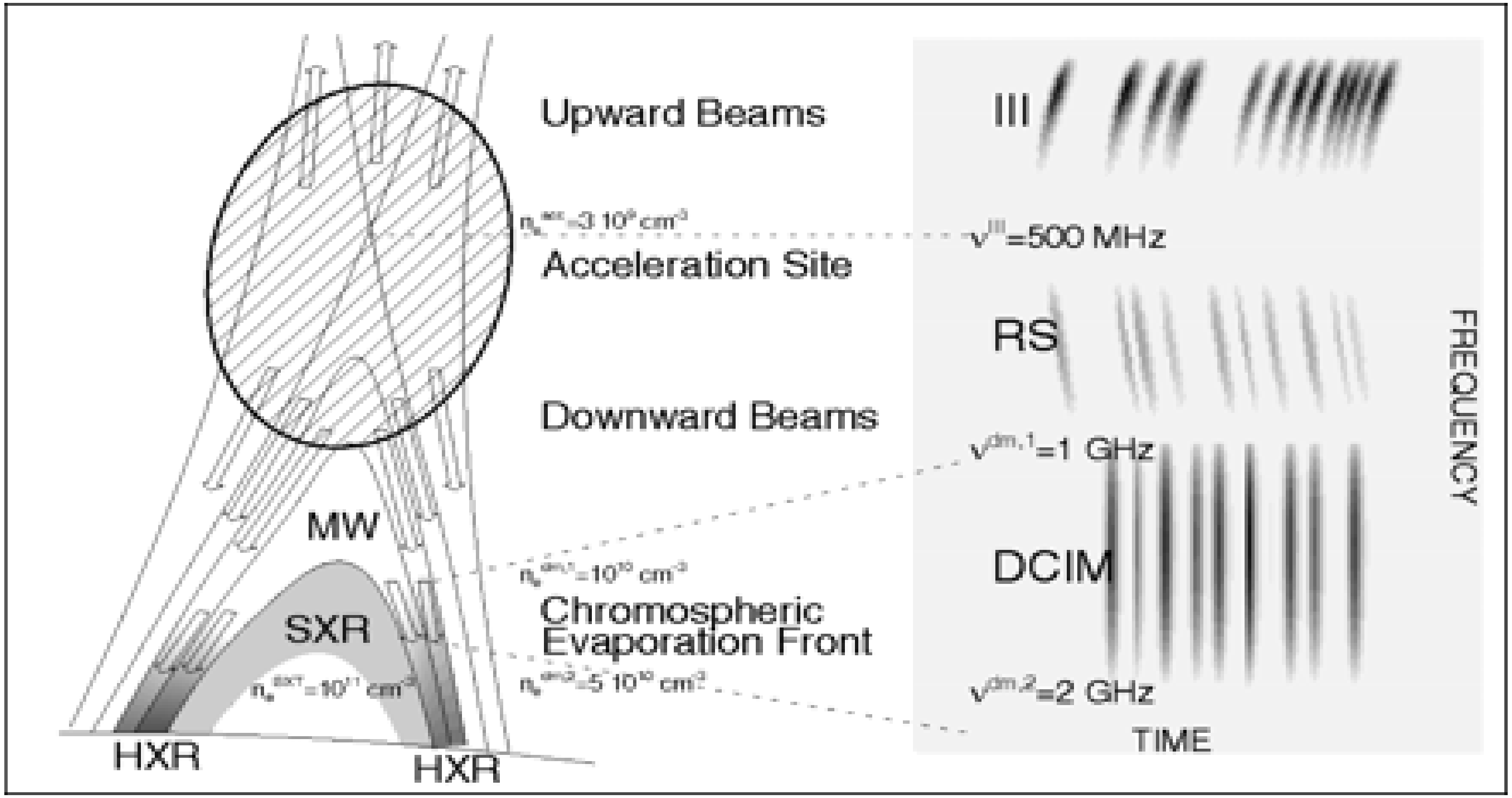
Flare Magnetic Field Geometries are Complex

- Constant interaction between magnetic loops.
- "Two-ribbon flares."
- Stellar situation even more complex – coronal filling factors near unity, EM much larger but densities similar, i.e. coronal volumes and extent larger.

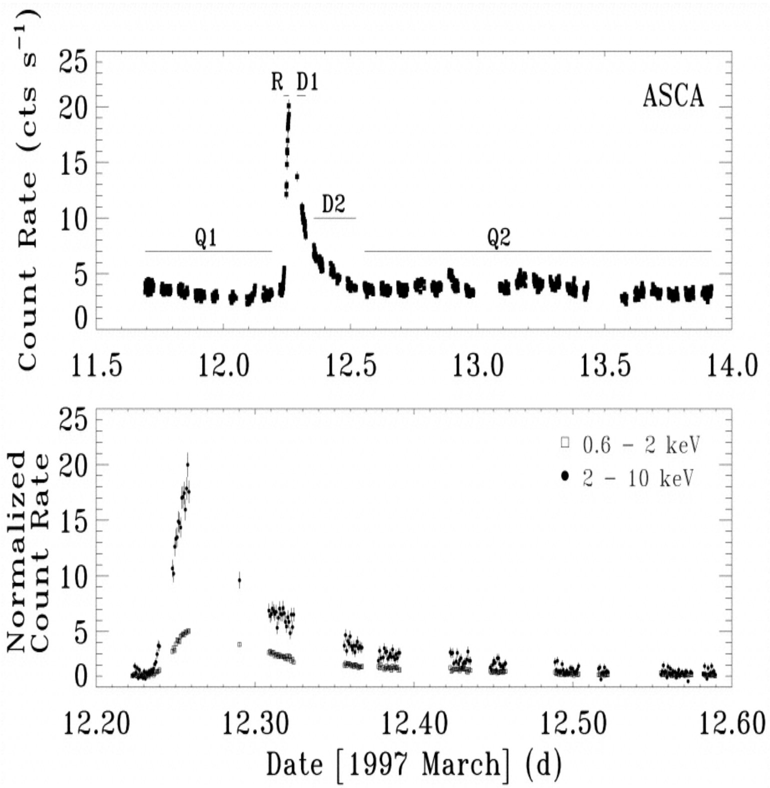


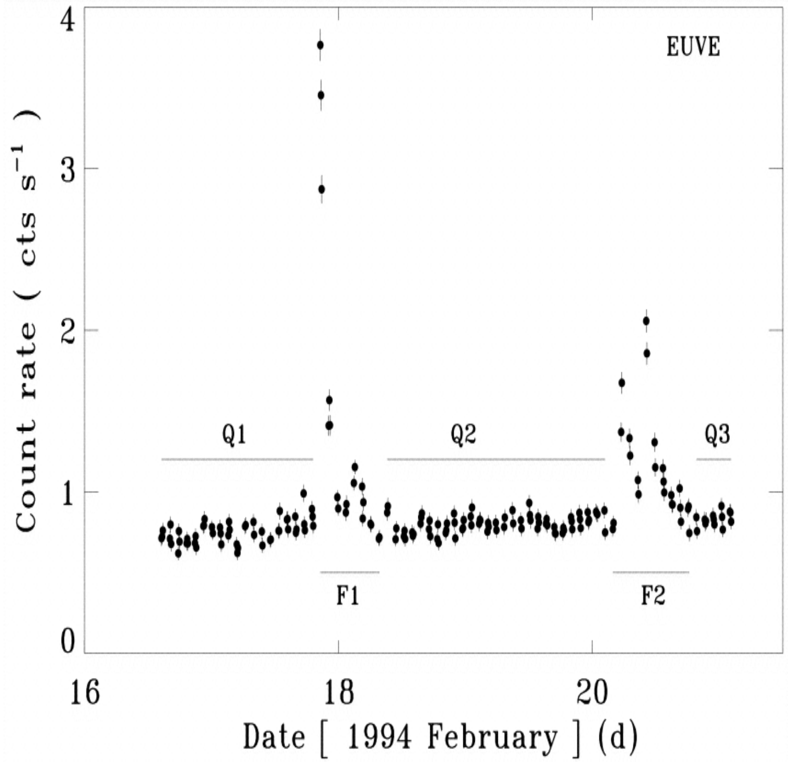


Schematic Flaring Loop Configuration
(X-ray and Radio Emitting Regions)



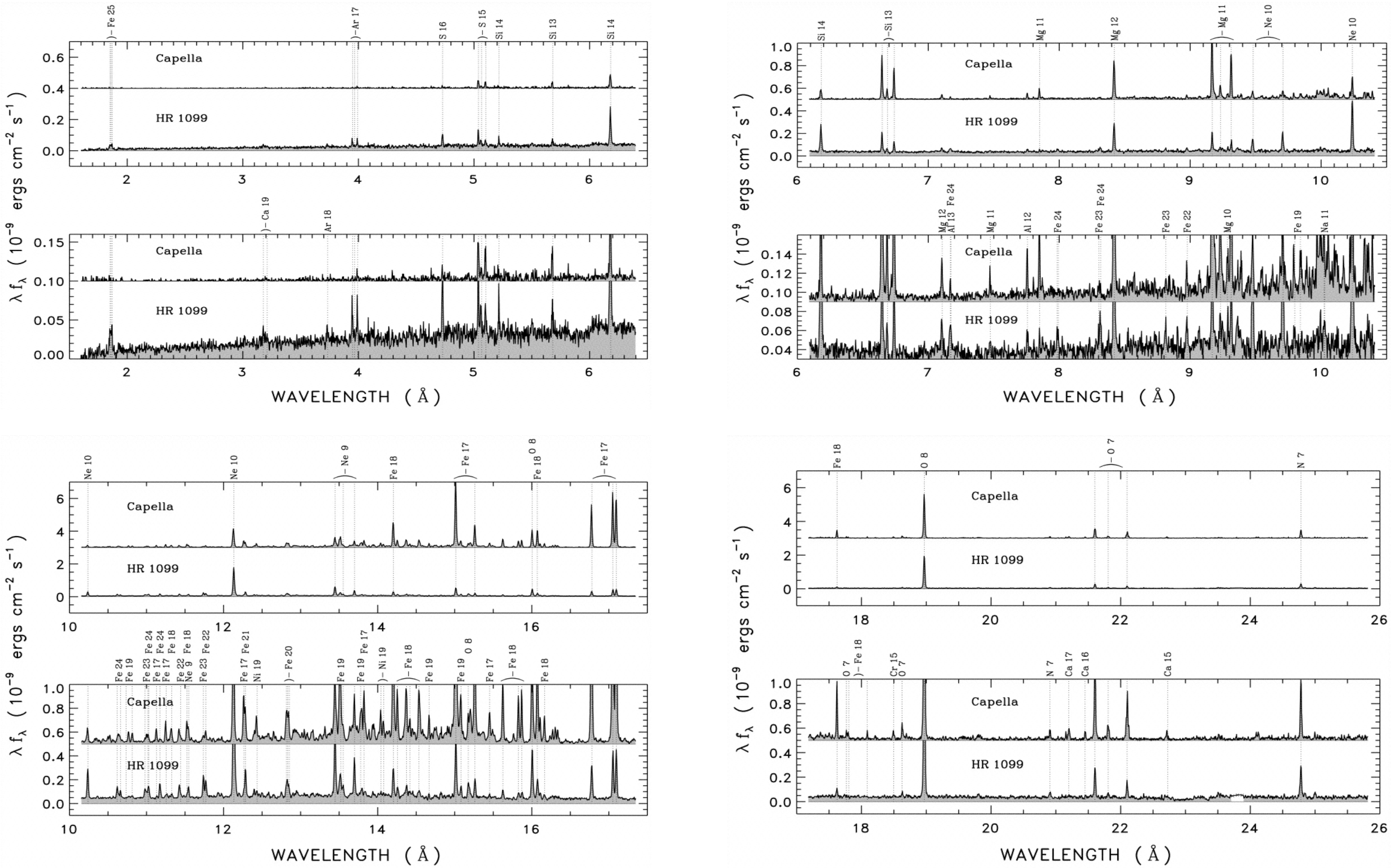
X-ray and EUV Flares on Sigma² CrB





- Higher energy passbands see faster flares

HR1099 Chandra HETG Spectrum



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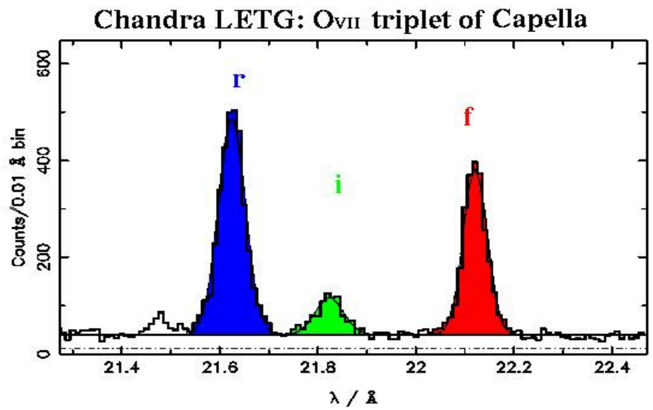
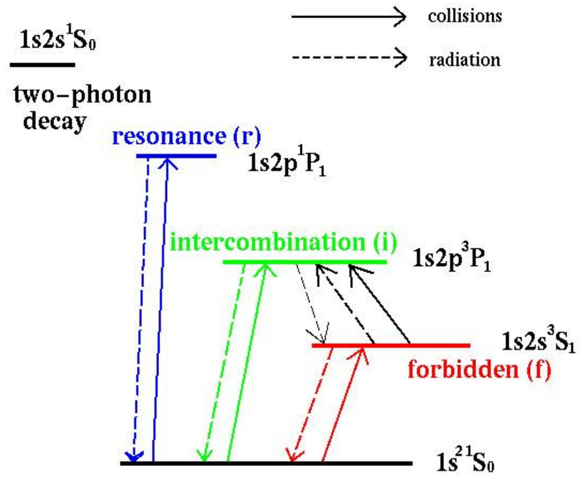
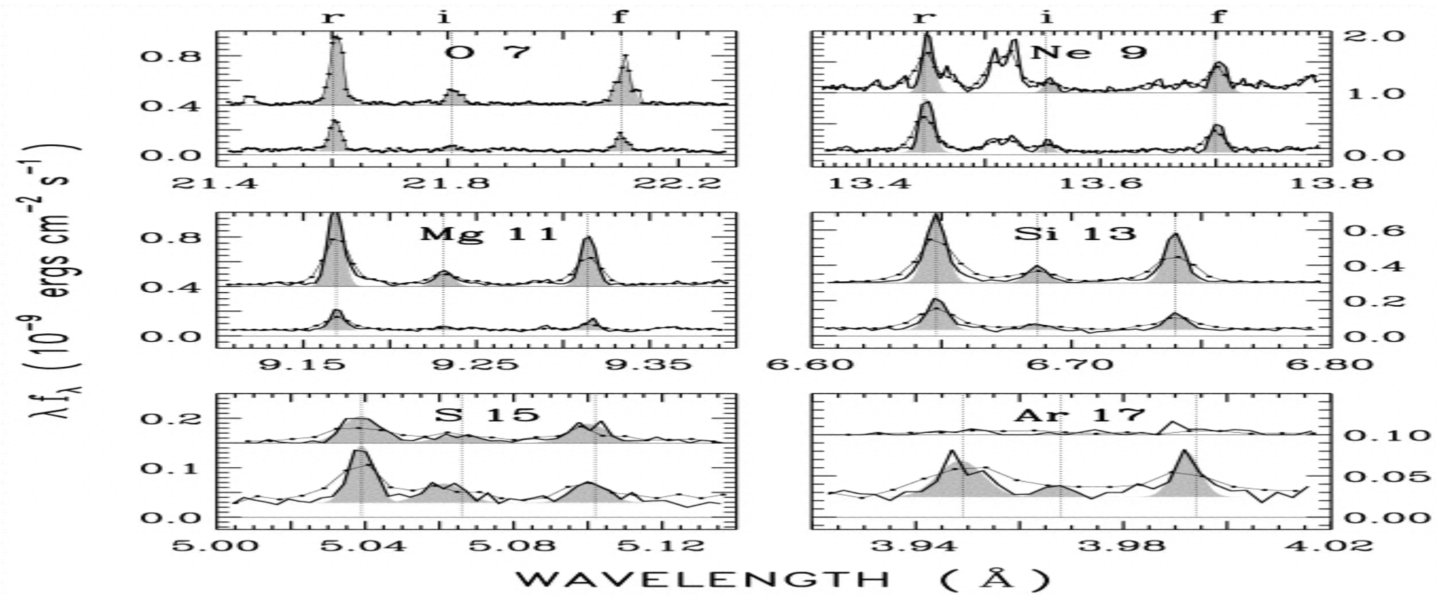




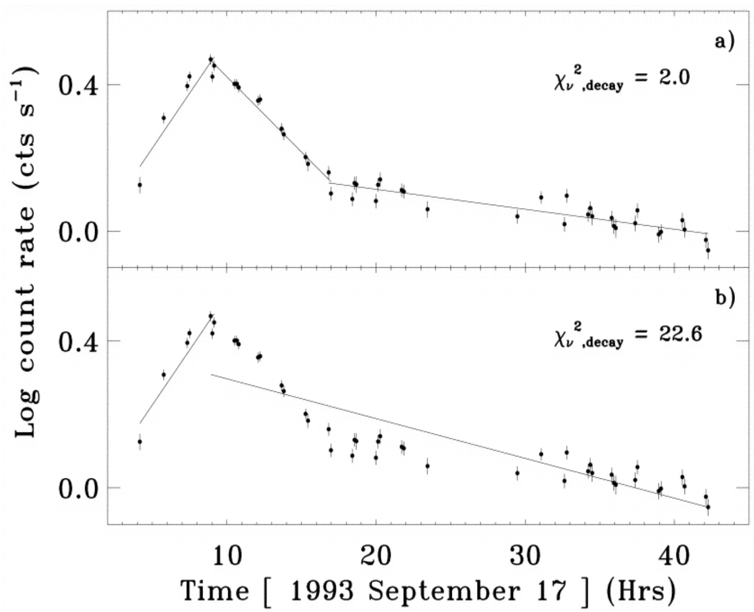


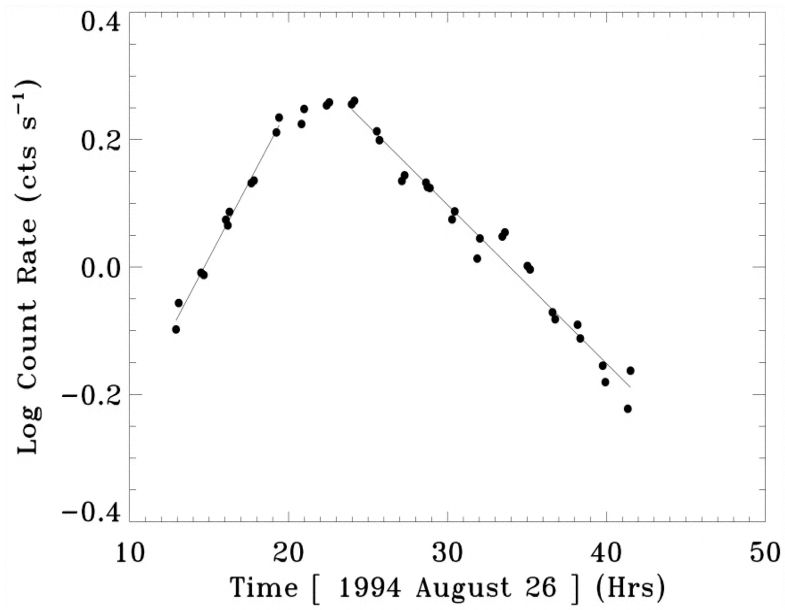
Measuring Coronal Densities

Future Potential

- Significant increases in the number of young stars with well established stellar properties can be made using ground-based optical and IR observations.
- Coronal spectroscopy is limited to the capabilities of Chandra, XMM, and Astro-E2 for the foreseeable future.
- UV spectroscopy is in turmoil with the demise of HST STIS and no way to install the COS spectrograph on HST.
- In contrast, a vast improvement in radio and sub-mm observational capability in just a few years due to the EVLA and e-MERLIN arrays and most notably the construction of ALMA (Chile).
- Measuring chromospheric and transition region flows associated with flares should be relatively easy in the UV but measuring the coronal velocity fields using UV and FUV coronal forbidden lines is challenging.

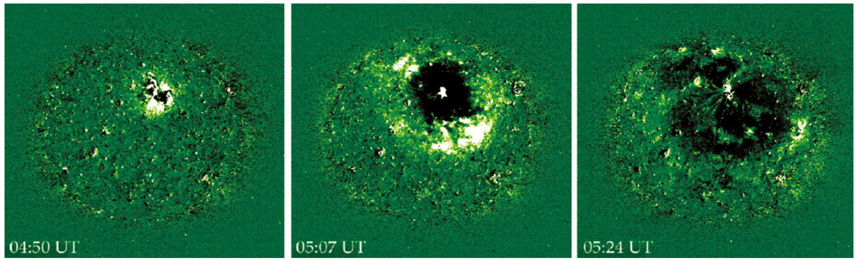
EUV Flare Morphology – Long Duration Flares on HR1099

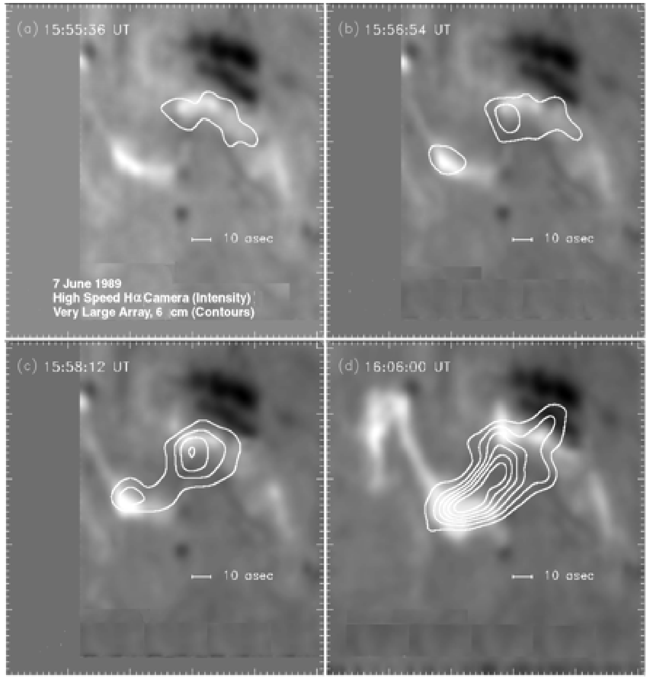


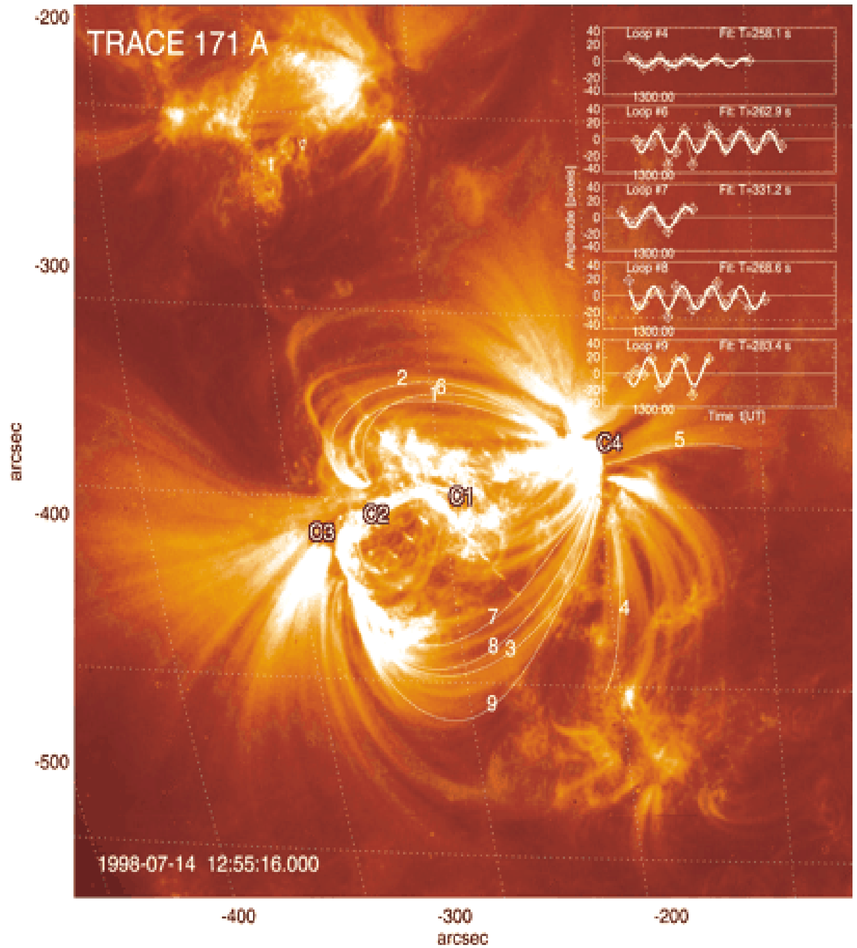


- Flares involving many loops and large volumes
- Multiple decay timescales – flare expansion
- Long timescales imply extensive continued heating
  – no single impulsive reconnection event

Solar Flaring Loops and Flare Propagation







Summary of Current Knowledge

- Long uninterrupted Chandra and XMM observations allow detailed study of changes in coronal temperature, emission measure, and abundances.
- Coronal flare densities can be measured only in the most fortuitous cases.
- Measuring chromospheric and transition region flows associated with flares is relatively easy in the UV but measuring the coronal velocity fields using UV and FUV coronal forbidden lines is challenging.
- "We gotta get lucky" – need a big (factor of 10?) flare and to see all of it in X-rays, UV, and probably radio.

the end