Stellar X-ray Astrophysics, a.k.a“Normal Stars”

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we have a taste of high spectral resolution observations (R>1000) of stars with Chandra, XMM-Newton, but A_{eff} constraints limit # of stars accessible in moderate (<few hundred ks) exposures

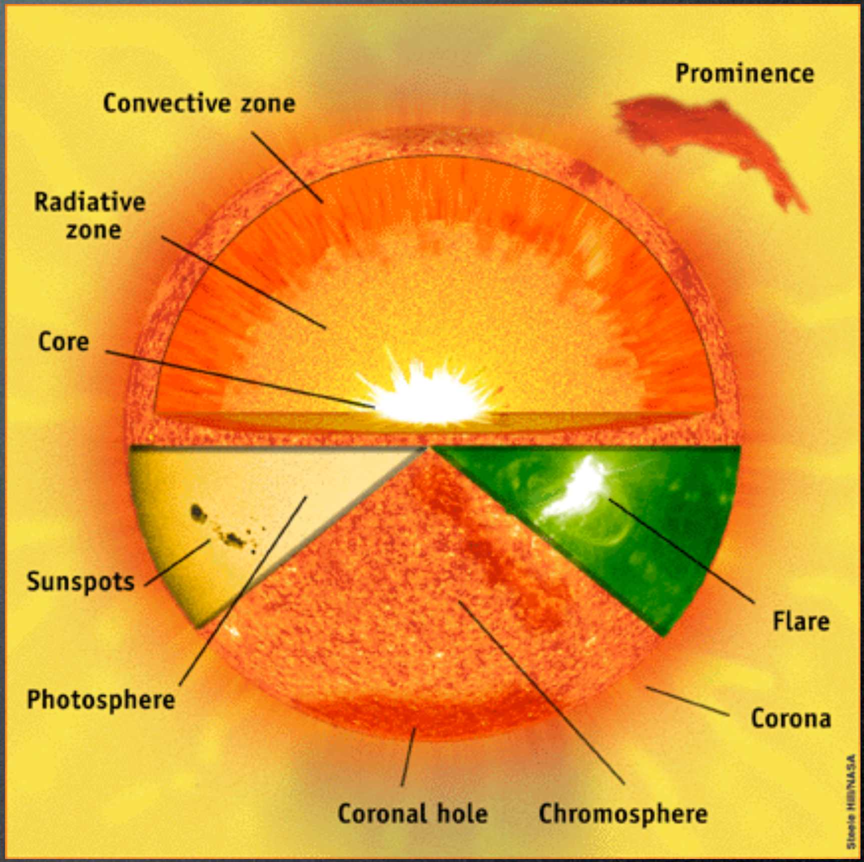
this limits the results to the X-ray brightest stars
(bright=unusual?)

key unanswered questions about how stars interact with and influence their surroundings

requirements for next generation X-ray observatory are high A_{eff}, resolving power

In solar-like stars, "activity" correlates with . . .

- **Convection**
- **Mass**
- Age
- Rotation
- Magnetic filling factor



"Activity" = chromosphere (10^4K), transition region (10^5K), corona (10^6K), radio (NT), flares

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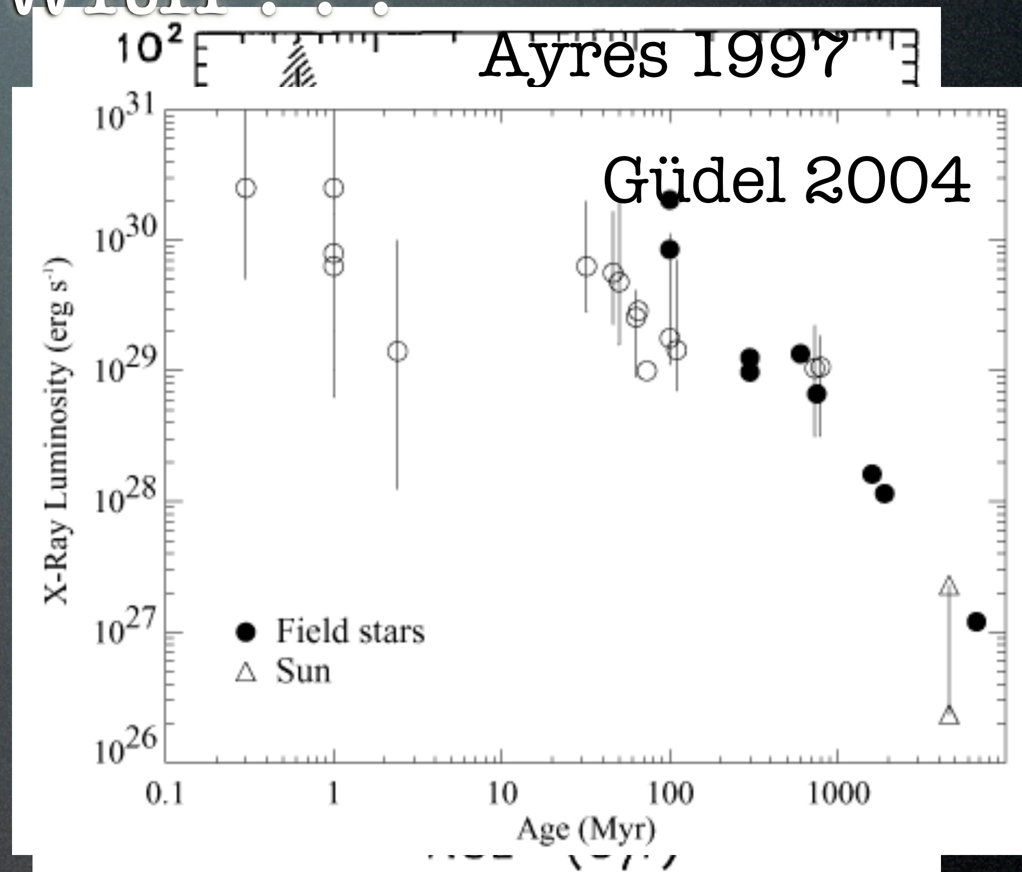

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Saar 1988

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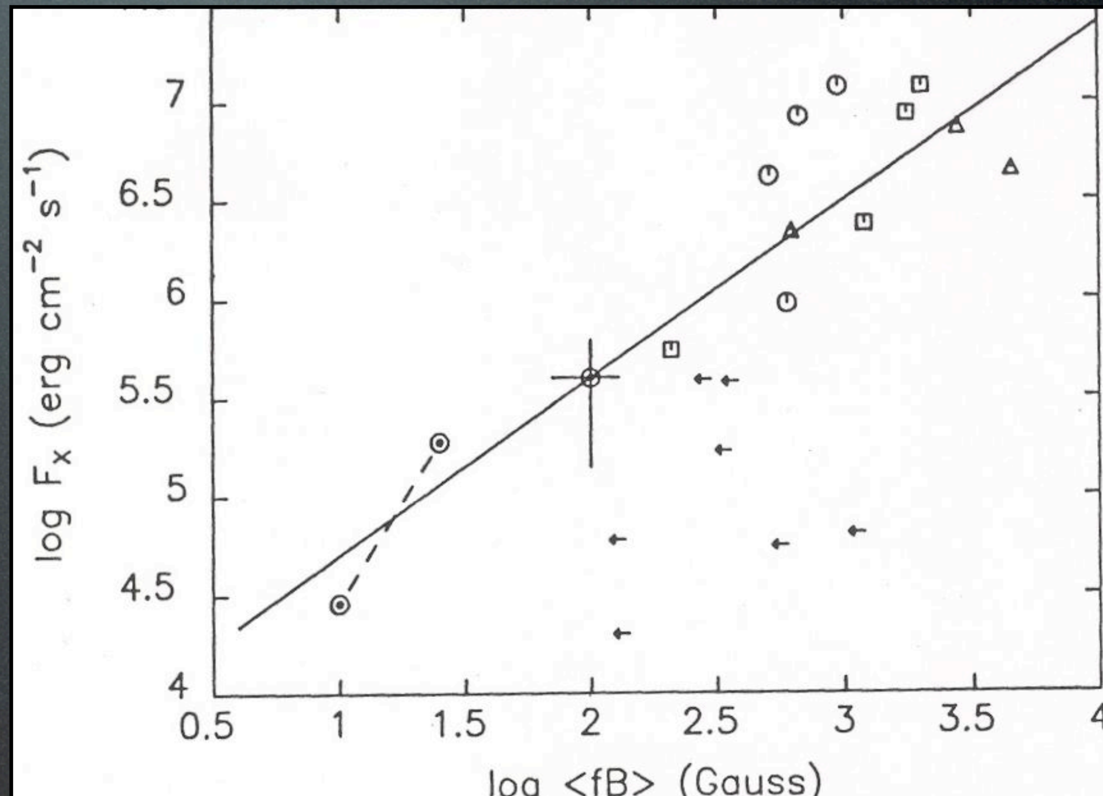

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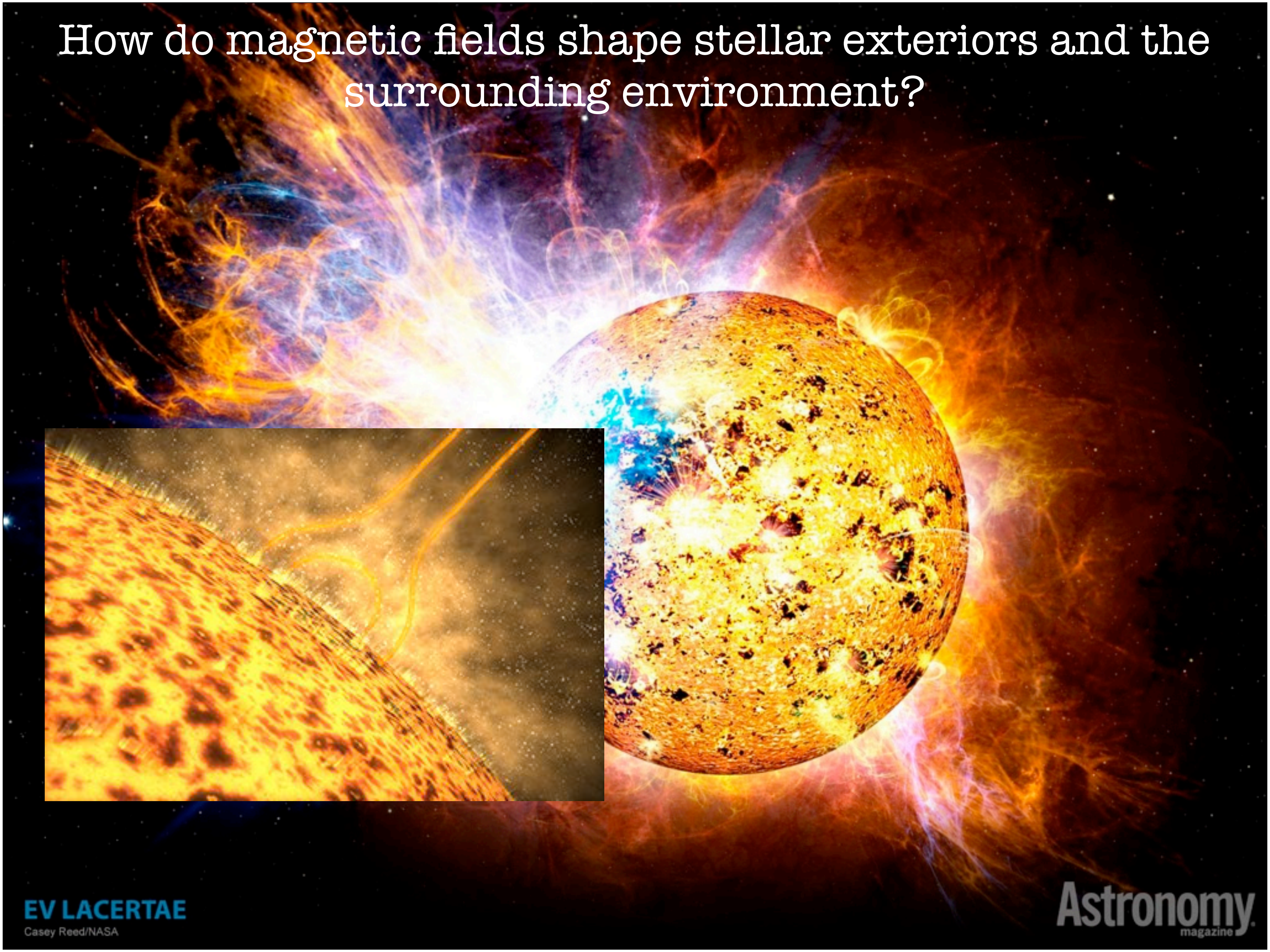
Magnetic fields are dynamic, changing stellar outer atmospheres on a variety of timescales:

Reconnection flares: minutes - hours
Rotation: hours - days
Activity cycles: months - years - decades
Evolutionary timescales

spectroscopic observations are the key to unlocking these activity correlations, gaining a deeper understanding of the dynamo processes

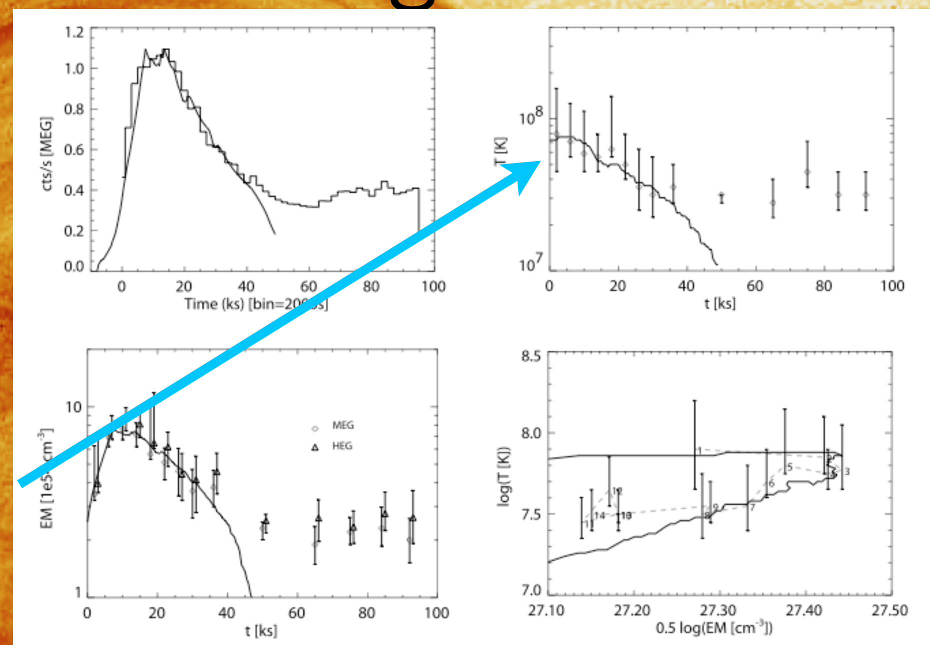
important not just for understanding the star, but also influences planet formation, planet habitability

How do magnetic fields shape stellar exteriors and the surrounding environment?



Stellar soft X-ray flares appear to behave like Solar flares, even in extreme environments: single active giant stars

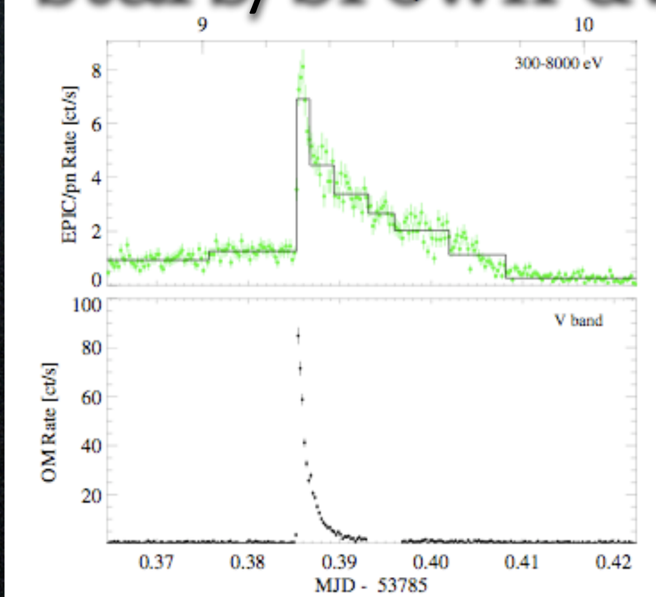
HR 9024 giant flare: R_{star}~14 R_{sun}, M_{star}~3 M_{sun}
larger radius →lower gravity (~0.01 g_{sun}), possibly very extended corona
scale height near 30 R_{star} for T near 100 MK

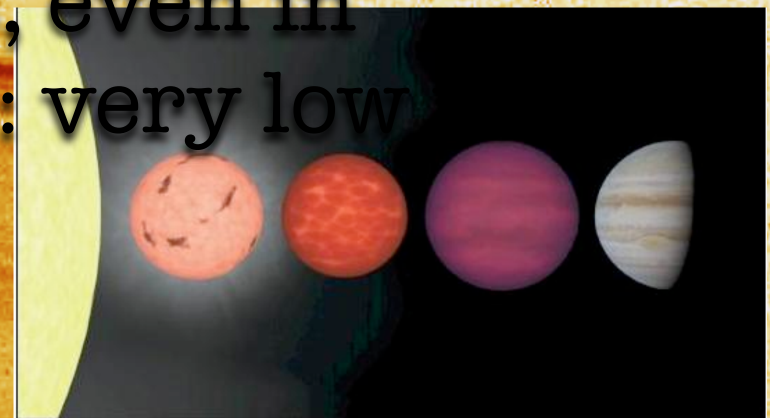


HR 9024 flare seen with Chandra (Testa et al. 2007)

Hydrodynamic modelling of stellar flaring loops applies 1D models of Reale et al. (1997) developed for solar flares,
loop sizes ~ 0.1 R_{star}, typical for solar flares

Stellar soft X-ray flares appear to behave like Solar flares, even in extreme environments: very low stars/brown dwarfs

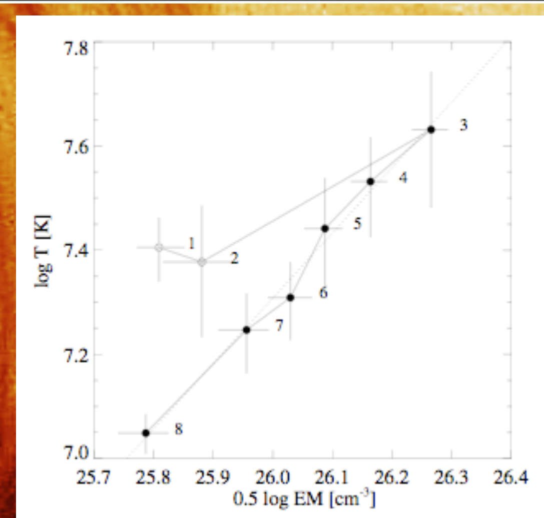




M~0.1 M_{sun}, R~0.1 R_{sun}, so

g~10 g_{sun}

expect coronal scale height to be much smaller

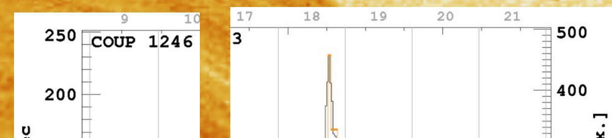


LP412-31 (M8 V) observed with XMM-Newton; Stelzer et al. (2006)

- flare optical delta V=6 magnitudes, among the largest stellar optical flare enhancements
- total flare energy 10^{32} ergs, typical of the largest solar flares

loop modelling using 1D HD solar flare loop models gives scale size for flaring X-ray emission ≥R_{star}, where R_{star} ~0.1 R_{sun}

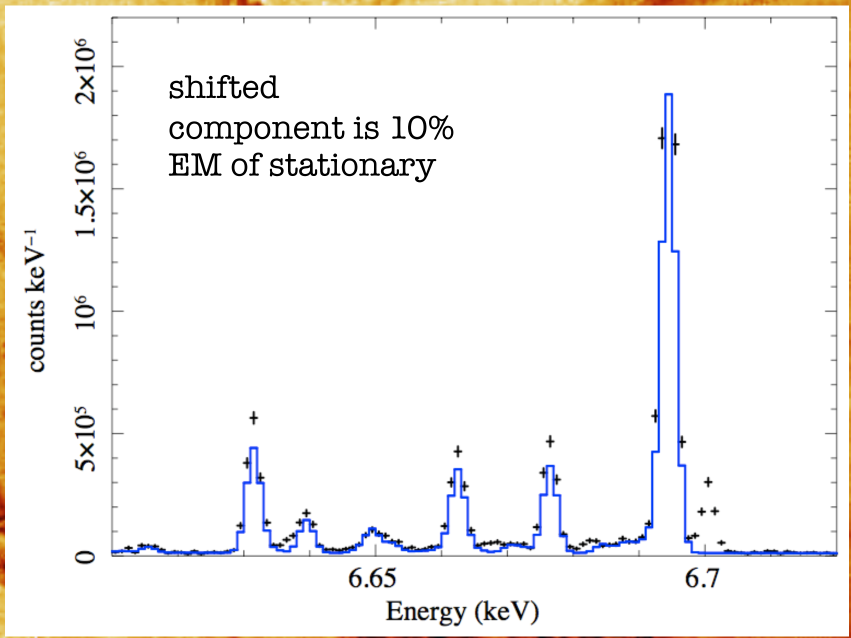
Flares on young stars & the star-disk connection



stellar activity affects protoplanetary disks & planet formation processes:
heating disk outer layers,
inducing disk turbulence via ionization

Favata et al. (2005) evidence for star-disk interaction in large stellar X-ray flares: HD modelling implies large scale sizes for flaring X-ray emission **(up to 55 R_{star})**

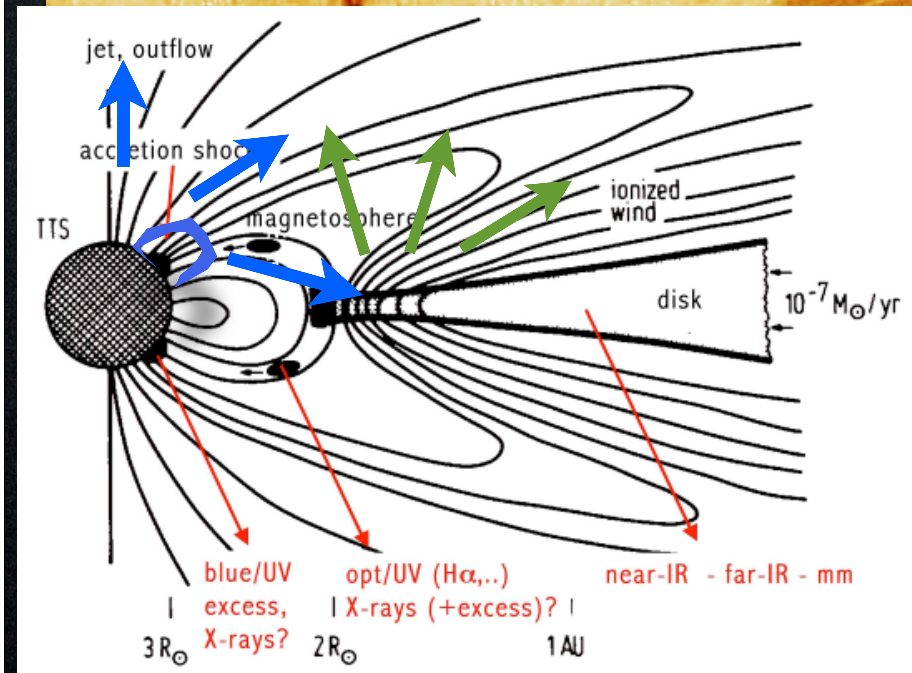
Measuring Flare Velocities is a Key Advance



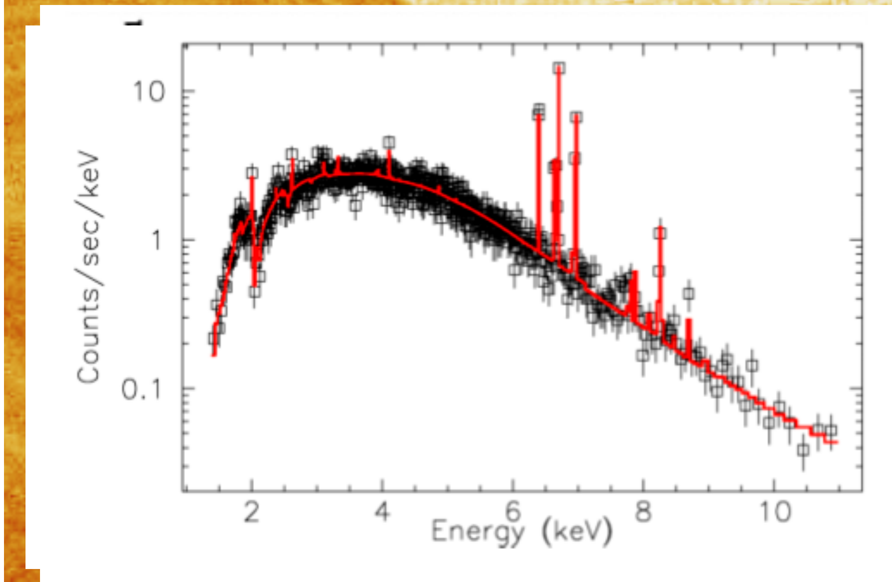
during flares, need to measure: T, n_e, EM, A, **and their changes** to determine energy budget, timescales of heated coronal plasma

XMS 2 ks from a coronal flare; 200 ks each on about 5 stars based on flare statistics, total of 1 Ms

The Fe Kα emission line at 6.4 keV is a relatively newly used diagnostic for stellar flares



Geometry for young stars with disks (from Camenzind 1990); 6.4 keV fluorescent line seen during some X-ray flares implies a geometry due to reflection of stellar X-rays off disk material



2ks of a simulated microcalorimeter spectrum of YSO flare showing 6.4 keV feature

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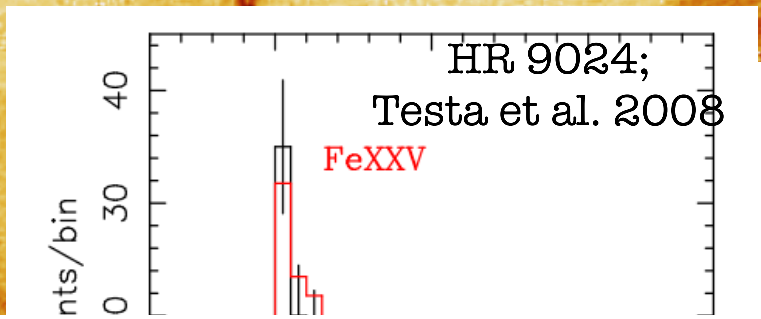
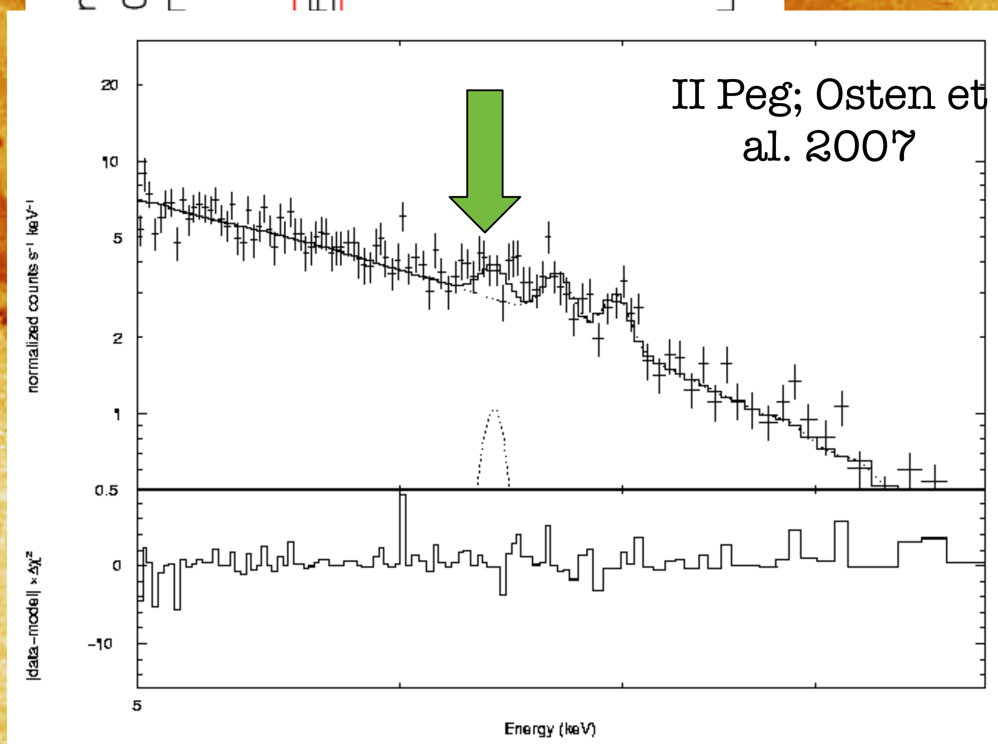
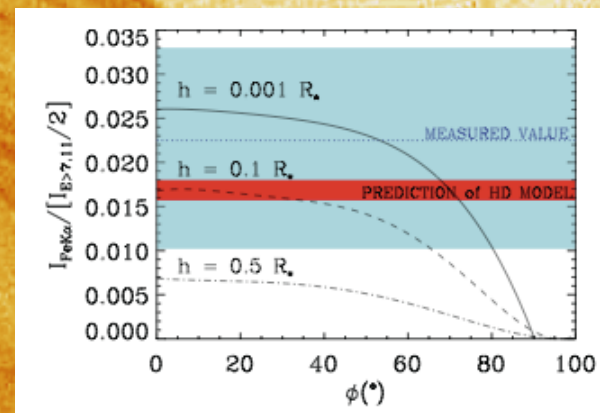
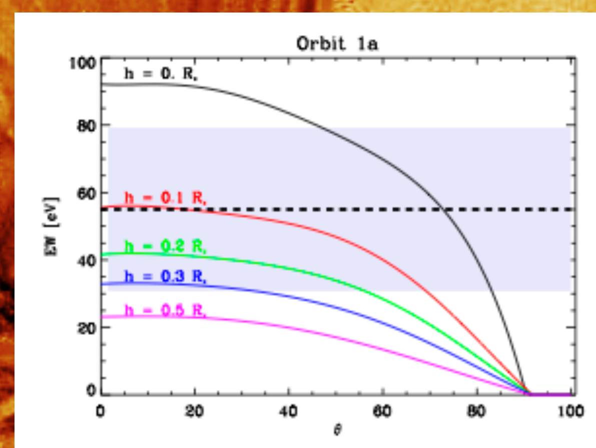


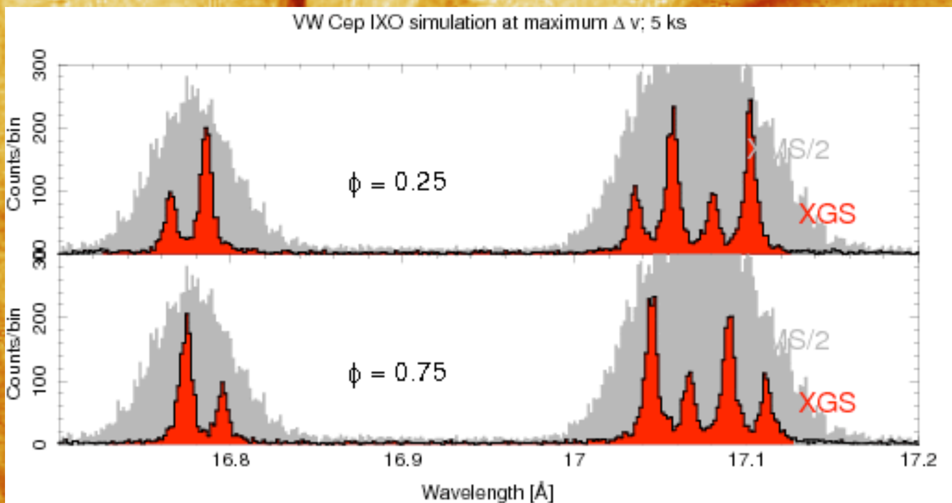


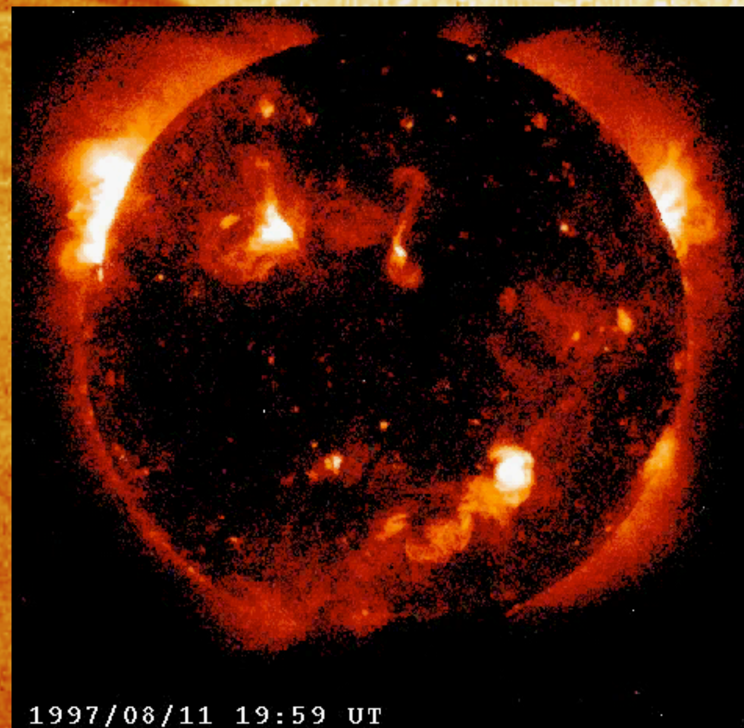




Ercolano et al. 2008

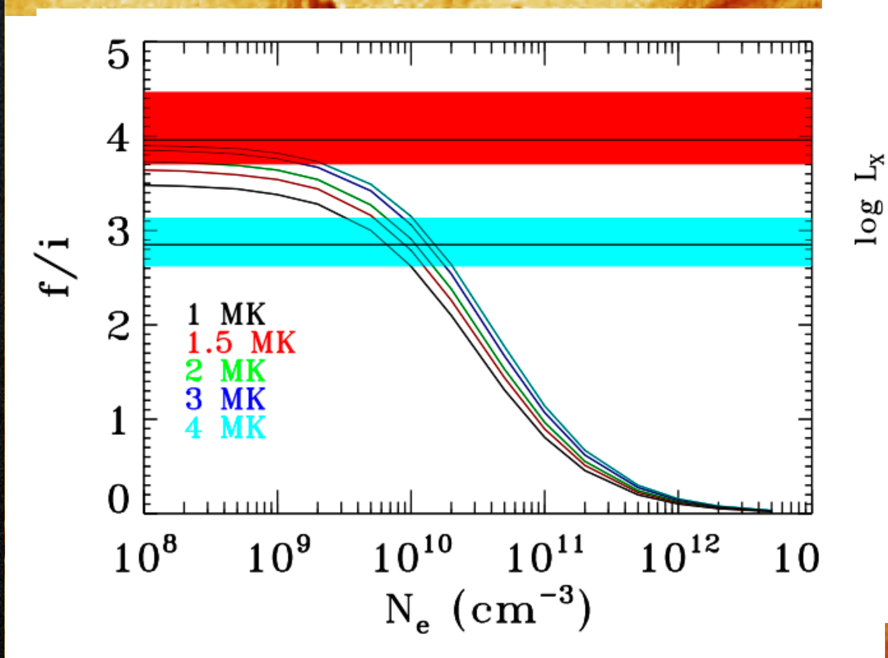
The Sun in Time(s): The Many Faces of a Star

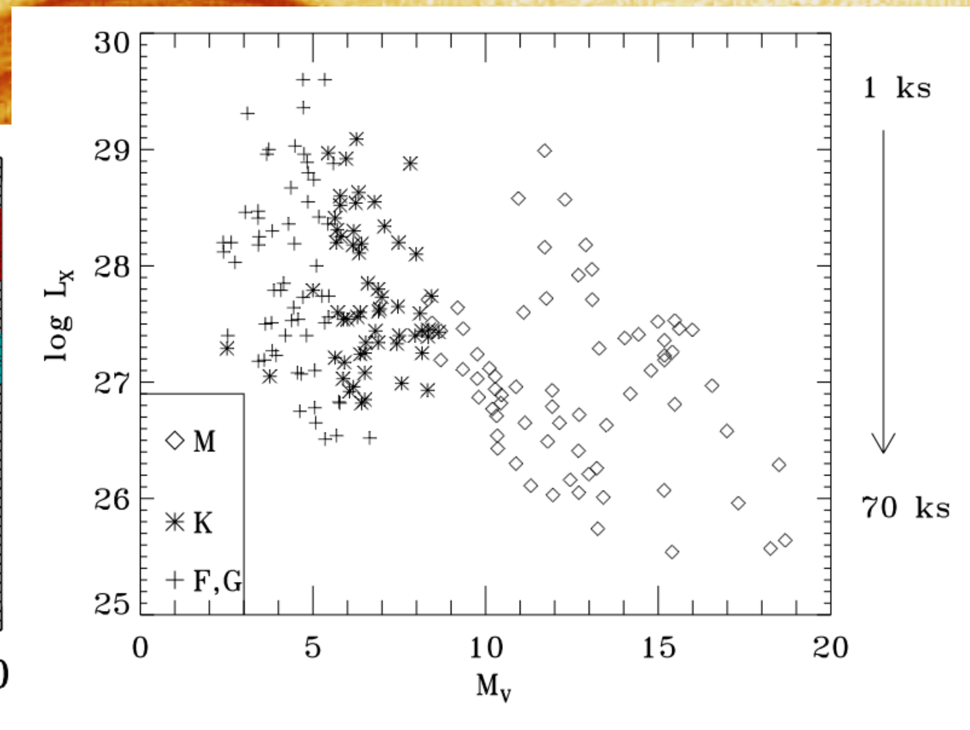




XGS observations needed to spectrally resolve components, determine T, VEM, n_e, A, l_x as a function of orbital/rotational phase

Coronal Spectroscopy of Solar Minimum Stars



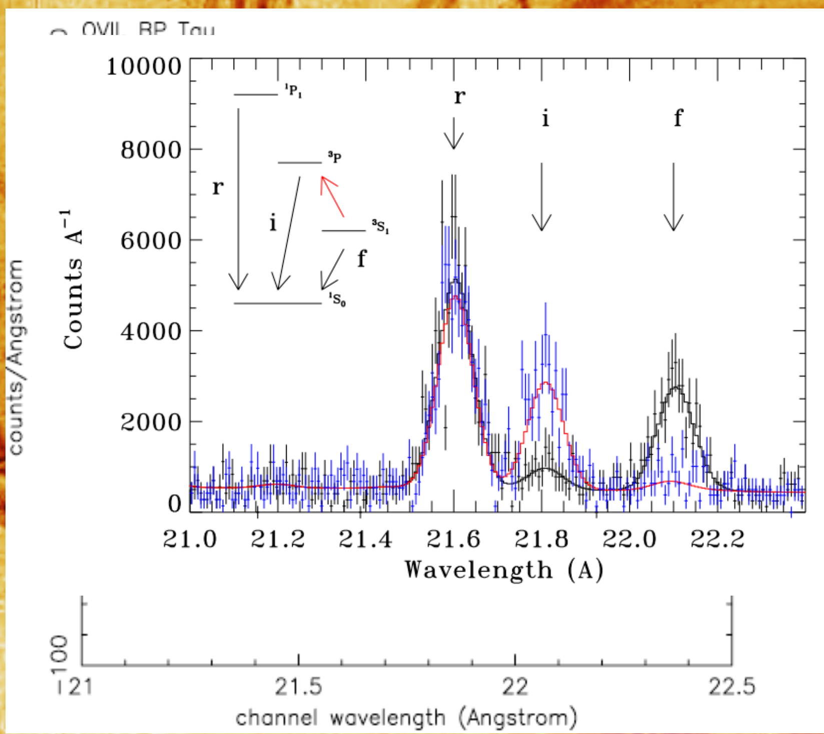


using XMS, constrain n_e from O VII f/i for a solar minimum star (L_x=2x10^{26} erg s^{-1}) at 5 pc in 70 ks; 20 stars in 1.4 Ms to span L_x, T_x, fB

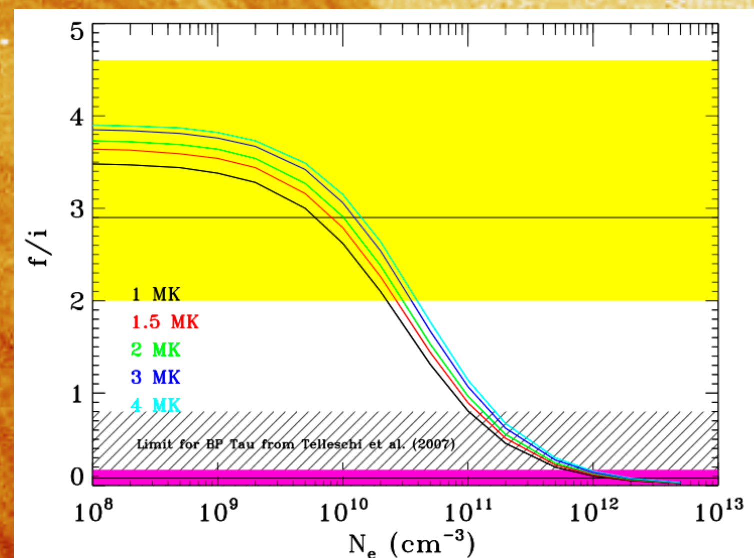
ROSAT FGKM stars out to 14 pc; Schmitt & Liefke 2004

How does magnetic activity in YSOs differ from main sequence stars?

spectra show contribution of accretion processes and coronal emission



10 ks calorimeter observation of BP Tau

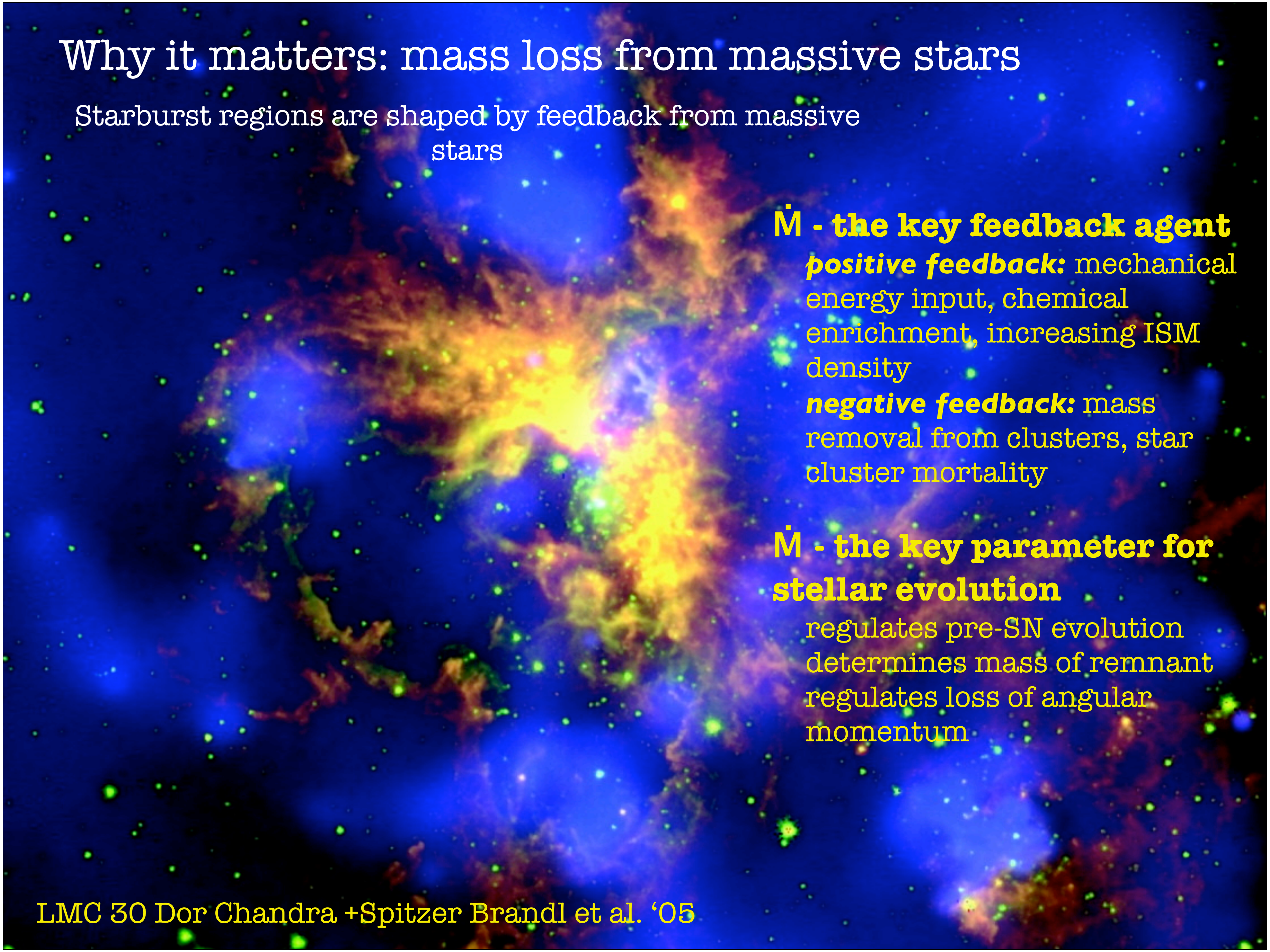


density surveys of uncrowded star-forming regions

need gratings to disentangle Ne IX

Why it matters: mass loss from massive stars

Starburst regions are shaped by feedback from massive stars



$\dot{M}$ - the key feedback agent

positive feedback: mechanical energy input, chemical enrichment, increasing ISM density

negative feedback: mass removal from clusters, star cluster mortality

$\dot{M}$ - the key parameter for stellar evolution

regulates pre-SN evolution
determines mass of remnant
regulates loss of angular momentum

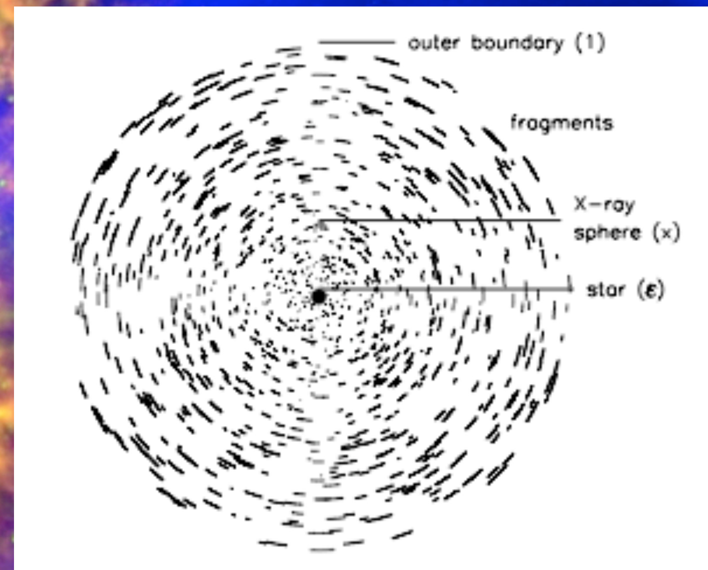
LMC 30 Dor Chandra +Spitzer Brandl et al. ‘05

How rapidly do stars lose mass and angular momentum, and how do environment and mass loss feed back on each other?

X-ray emission probes wind opacity, He-like f/i ratios locate X-ray-emitting shocks

measurements of mass loss via different methods are needed for consistency

-radio free-free, Hα $\propto n_e^2$ -> need degree of clumping
-UV resonance lines: uncertainties in ionization balance can affect determination
- X-rays sensitive to optical depth, clumping



schematic clumpy wind; Feldmeier et al. (2003)

need high SNR spectral line profiles: currently only a handful of stars are bright enough for such observations with Chandra, XMM-Newton

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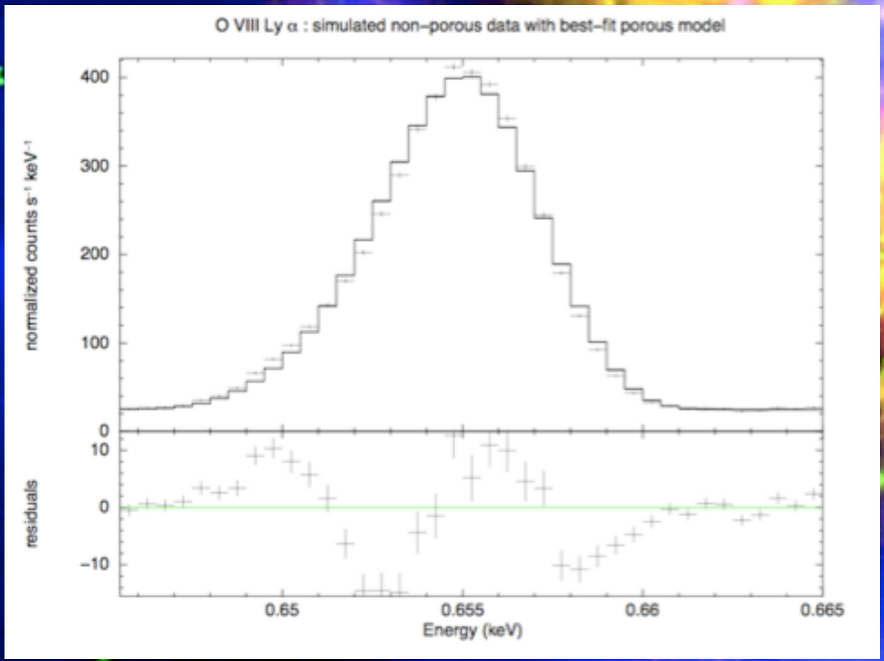


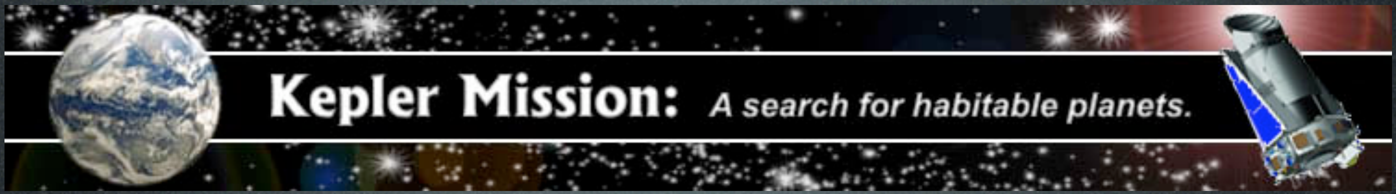
residuals detected in 50 ks IXO XMS observation are due to clumps in stellar wind; can do this analysis for ~36 stars

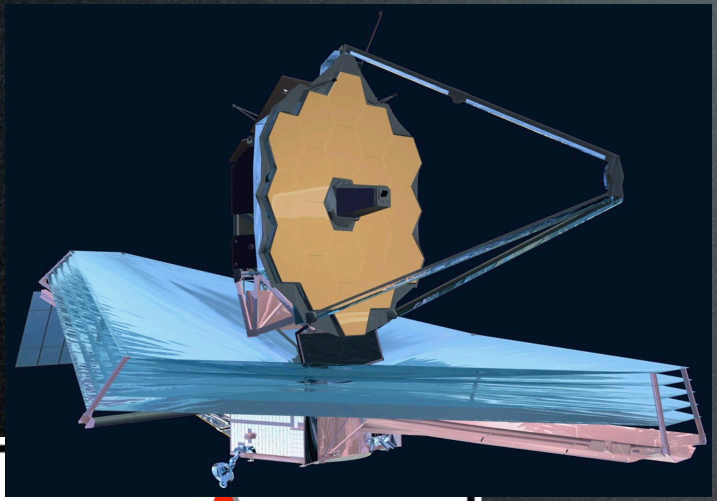
Emission line Doppler widths are ~ 1000 km/s: need large A_{eff} primarily

IXO will expand the results of Chandra, XMM-Newton high resolution spectroscopy of massive stars to a larger sample:

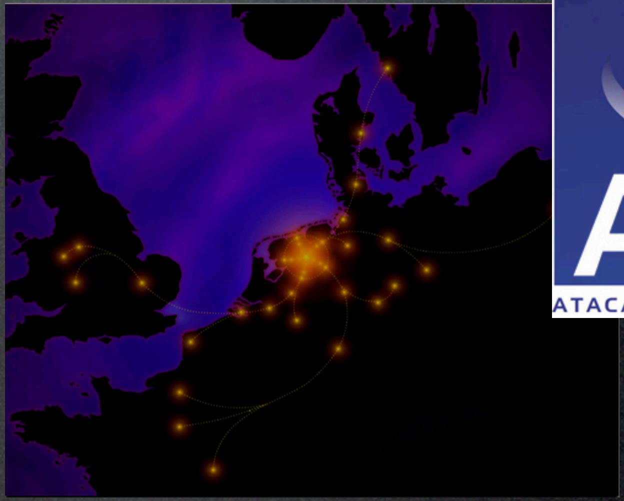
+ Survey mass loss in different Galactic environments +LMC, SMC
+ Explore X-ray production mechanism in OB stars
+ Use colliding-wind binaries as shock physics laboratories
+probe influence of magnetic fields, rotation on angular momentum & mass loss

Complementarity





Expanded
Very Large Array



ALMA
ATACAMA LARGE MILLIMETER ARRAY