X-rays from low and intermediate mass stars

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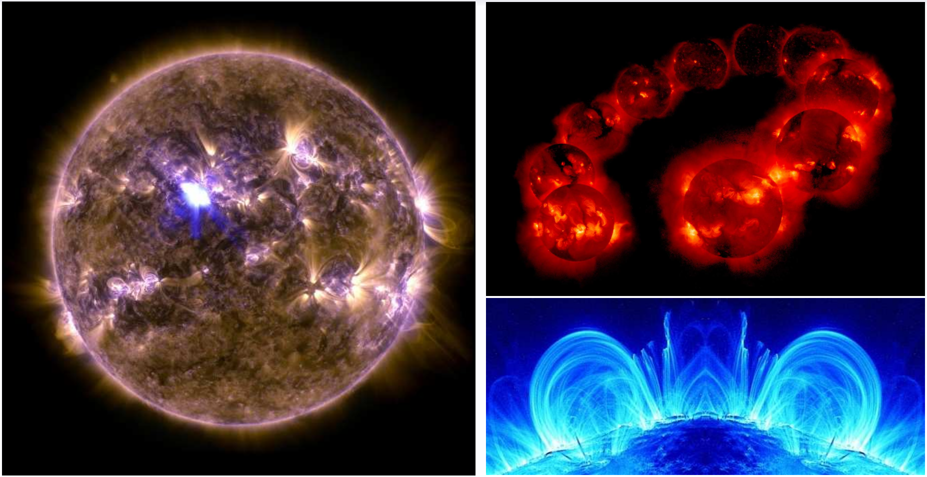
Hamburger Sternwarte

X-ray Universe, Dublin, 16 - 19 June 2014

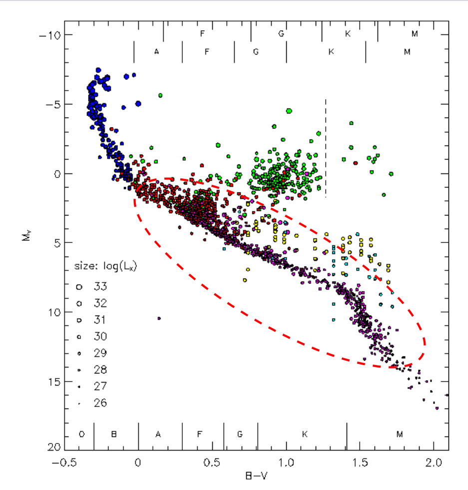
The solar corona



Sun in X-rays: *SDO*, *Yohkoh*, *TRACE*

Solar corona is highly structured and dynamic

Stellar X-ray emission



'The X-ray HRD' (Güdel 2004)

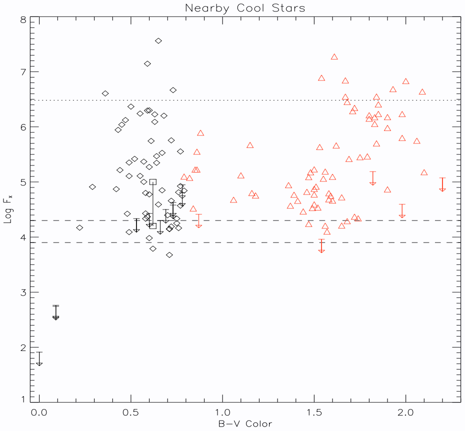
This talk:

Low and intermediate mass stars

- X-ray generation mechanisms
- Time evolution of X-ray emission

X-ray stars are (virtually) everywhere!

Cool stars in X-rays

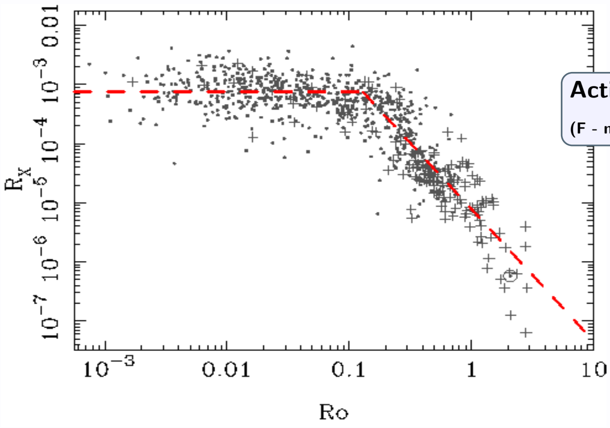


The solar neighborhood: volume limited

(Schmitt 1997)

- X-ray surface flux varies by orders of magnitude at given B-V
- Sun weakly active, coronal holes describe lower limit
- X-ray activity declines towards hotter stars

Cool stars in X-rays

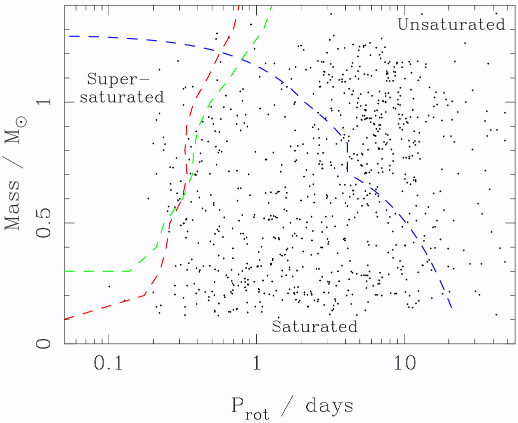


Activity-dynamo relation

(F - mid M) (Wright+ 2011)

- X-rays from magnetic activity, $\log L_X/L_{bol} \approx -3 \ldots -7$
- $L_X \propto$ dynamo power; $\mathrm{Ro} = P/\tau_c$
- powerlaw (slope?) - saturation (level, breakpoint ?) - supersaturation (?)

Coronal dynamo regimes



Activity regimes of stars (blue: Ro = 0.13, red: $R_c/R_* = 3$, green: $G_X = 0.01$) (Wright+ 2011)

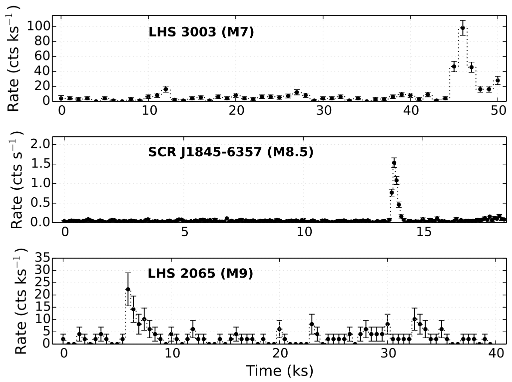
(also: Jeffries+ 2011)

- dynamo regimes depend on mass and rotation
- supersaturation: excess polar updraft vs. centrifugal stripping

X-ray activity at very low masses

Very red dwarfs are faint...
...and fully convective!

Ultracool Dwarfs - magnetic activity at low masses



mod. active stars

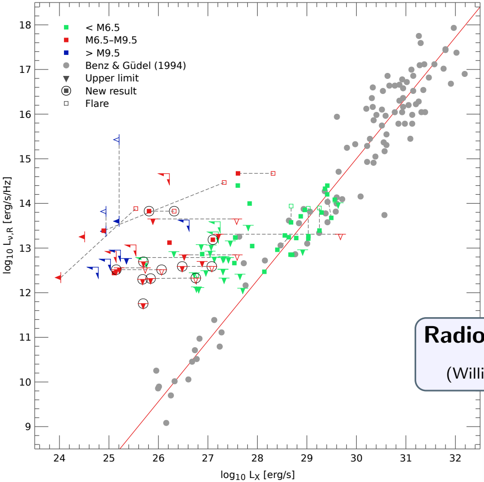
$\log L_X/L_{bol} \approx -4$,

$T_{Xqq} = 1 - 5$ MK

X-ray light curves of very low mass stars (XMM-Newton, Chandra)

- quasi-quiescent X-ray emission, $\log L_X/L_{bol} \approx -3.0 \cdots -5.0$
- strong flares with hot plasma ($\gtrsim 10$ MK) frequent

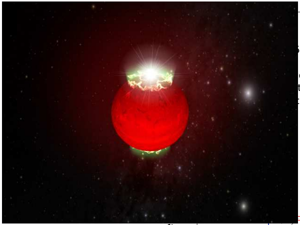
Ultracool Dwarfs - X-ray/radio connection



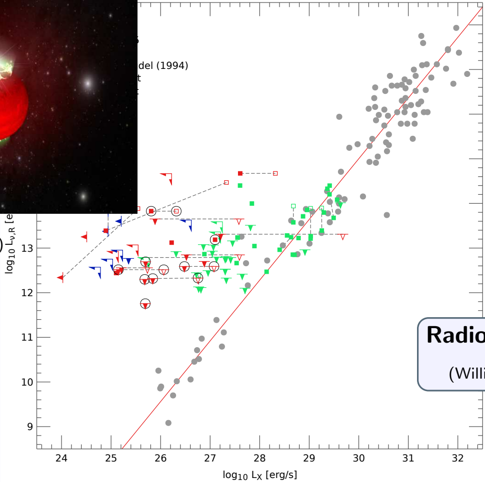
Radio vs. X-ray luminosity

(Williams+ 2014)

- X-ray bright and radio bright group (also Stelzer+ 2012)
- UCDs violate Güdel-Benz relation



(image by G. Hallinan)



Radio vs. X-ray luminosity

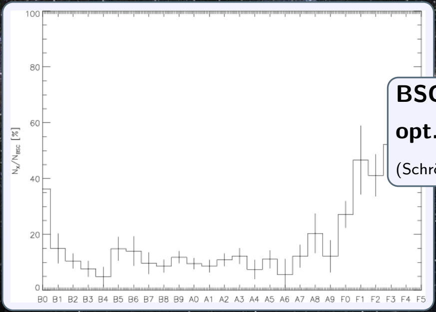
(Williams+ 2014)

- changing/bimodal dynamo mechanism, increasingly neutral atmospheres (e.g. Mohanty & Basri 2003, Reiners & Basri 2010)
- radio bright objects, fast rotators: ECME, aurorae (Hallinan+ 2007/08)

X-ray activity at higher masses - A stars

A stars are optically bright...
but what about X-rays?

X-ray activity at higher masses - A stars

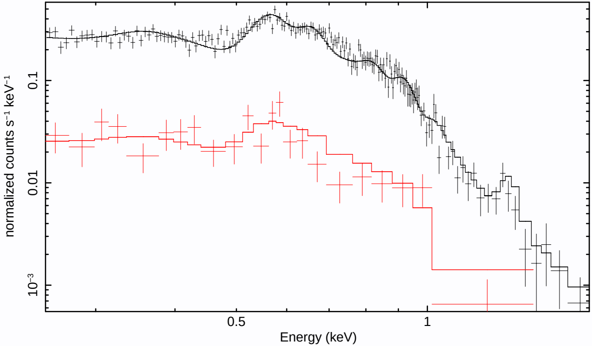


BSC sample:

opt. brightness limited

(Schröder & Schmitt 2007)

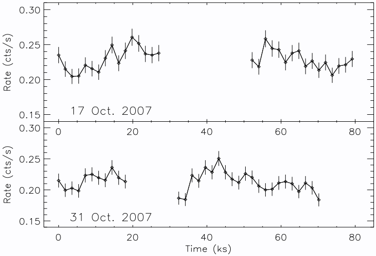
X-ray activity at higher masses

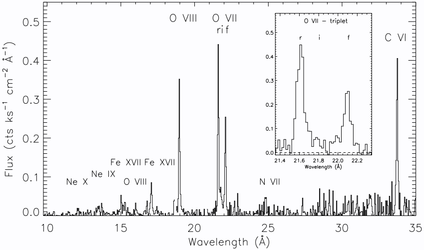


XMM spectra of Altair and Alderamin

- A7 IV-V, $M = 1.8/2.0\ M_{\odot}$, age: 1.2/0.8 Gyr
- ultra-fast rotators, $Vsini \approx 220/280$ km/s, 60/80 % break-up
- virtual identical X-ray properties

X-ray activity at higher masses

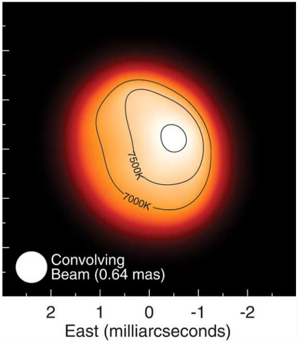


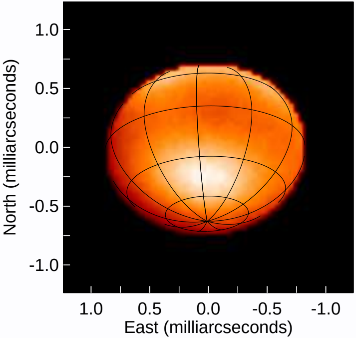


X-ray light curve and high-res spectrum of Altair (A7) (Robrade & Schmitt, 2009)

- $L_X = 1.4 \times 10^{27}$ erg/s, $\log L_X/L_{bol} = -7.4$
- minor activity, rotational modulation, long-term stable corona
- coronal properties similar to inactive Sun
  - dominated by cool 1–4 MK plasma
  - solar-like abundance pattern (FIP effect, Ne/O ratio)
  - O VII f/i-ratio high (UV sensitive)

X-ray activity at higher masses

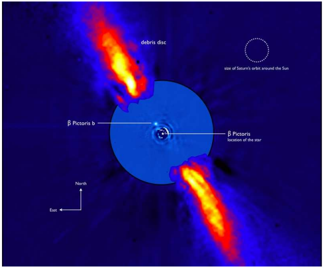


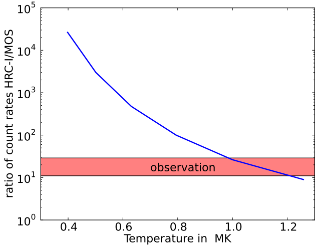


Surface images of Altair & Alderamin, CHARA (Monnier+ 2007, Zhao+09)

- oblate, gravity darkening $\Rightarrow T_{\rm eff} \approx 6800\,\mathrm{K}$ - $8500\,\mathrm{K}$
- X-ray surface features at $T_{\rm eff} \lesssim 7400$ K
- 'equatorial bulge corona'

The fading of X-ray activity





β Pictoris (ESO, Günther+ 2012)

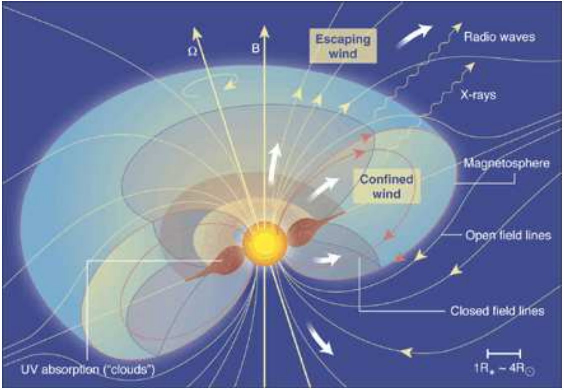
- β Pictoris - A6, young, debris disk (Hempel et al. 2005, Günther et al. 2012)
    - X-rays: very soft ($T_X \approx 1$ MK), very faint ($\log L_X \approx 26.5$)

$\Longrightarrow$ No significant magnetic activity around A5 (or earlier)

...tight upper limits on Fomalhaut (A3) and Vega (A0) ($\log L_X < 25.5$)

- X-ray detections likely companions (e.g. VAST survey; De Rosa et al., 2011)

Ap/Bp stars – X-rays and the MCWS model



Ap/Bp stars: magnetic intermediate mass stars, chemically peculiar, slow rotators

fields: large-scale, stable, uncorrelated, rare ($< 10\,\%$), fossil

MCWS model

(Babel & Montmerle, 1997)

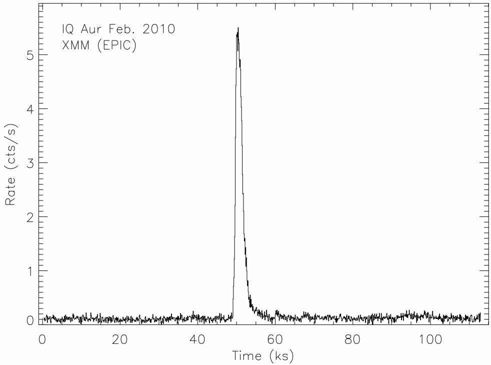
MHD/RFHD advancements:

(ud-Doula, Owocki, Townsend)

rigid disks, dynamic phenomena

- IQ Aurigae: A0p, ($T_{\rm eff} \approx 14500$ K, $M = 4.0\,M_\odot$, age ≈ 60 Myr)
- ROSAT detection: X-ray bright, soft spectrum
- X-rays via magnetically confined wind-shocks (MCWS)

Ap/Bp stars – X-rays and the MCWS model



XMM-Newton lightcurve of IQ Aur (Robrade & Schmitt, 2011)

MCWS model

(Babel & Montmerle, 1997)

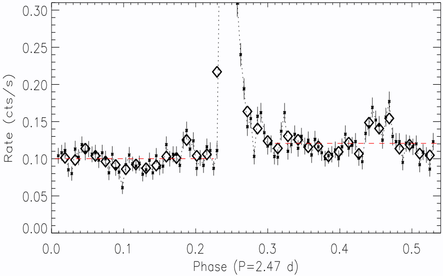
MHD/RFHD advancements:

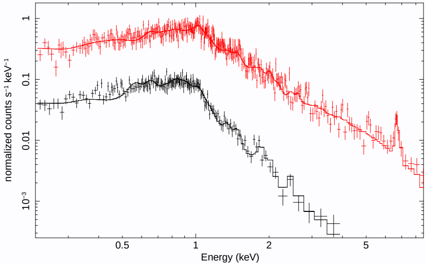
(ud-Doula, Owocki, Townsend)

rigid disks, dynamic phenomena

- hot plasma in quasi-quiescence & large flare
- strong soft X-ray component
- magnetic activity + wind shocks

Ap/Bp stars – IQ Aurigae

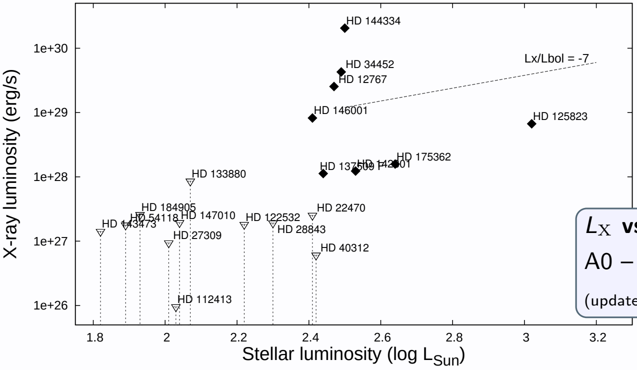




Quasi-quiescent lightcurve & X-ray spectra - XMM (Robrade & Schmitt, 2011)

- $\log L_{\rm X\,qq} = 29.6$ erg s^{-1}, $\log L_{\rm X}/L_{\rm bol} \approx -6.5$
- X-rays from well above the stellar surface (O VII $f/i \approx 1$, d $\gtrsim 7$ R$_*$)
- **flare**: $L_{\rm Xpeak} = 3 \times 10^{31}$ erg s^{-1}, very hot plasma: $T_{\rm X} \lesssim 100$ MK
- metallicity increase, moderately sized structure, $L \lesssim 0.2\,R_*$

Ap/Bp stars in X-rays



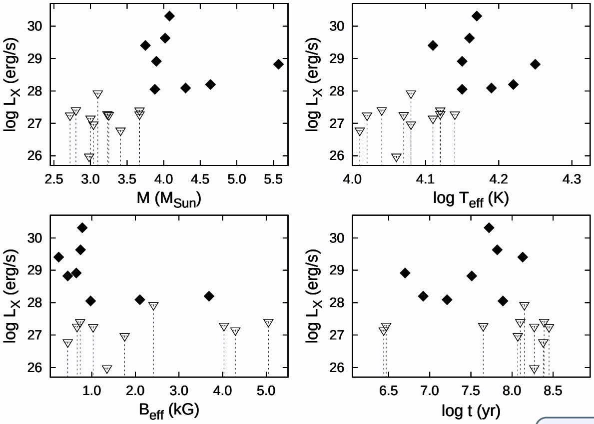
L_X **vs.** $L_{\rm bol}$

A0 – B7, magnetic CP stars

(updated from Robrade & Schmitt (2011)

- X-rays predominantly in more luminous Ap/Bp stars ($L_* \gtrsim 200 L_\odot$)
- sufficient mass loss & wind speed, strong magnetic confinement ($\eta_* \gg 1$)
- weak trend with opt. brightness ...but large scatter
- X-ray / Radio relation violated in all cases, radio-overluminous

Ap/Bp stars in X-rays

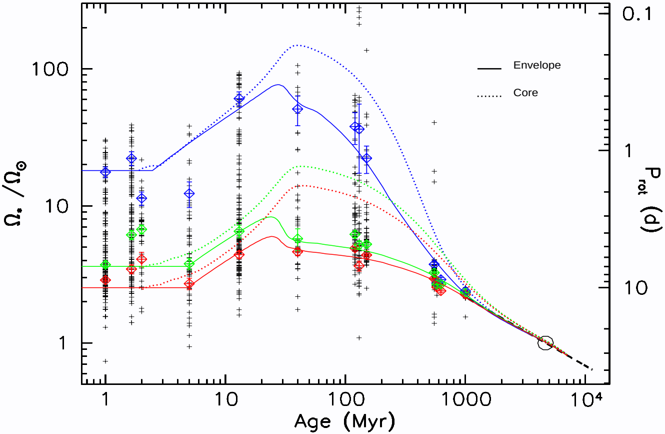


L_X vs. stellar parameter

- no correlation of L_X with age or $B_{\rm eff}$
- unexplained scatter: magnetic field geometry, time variability, companions...

The temporal evolution of solar-like activity

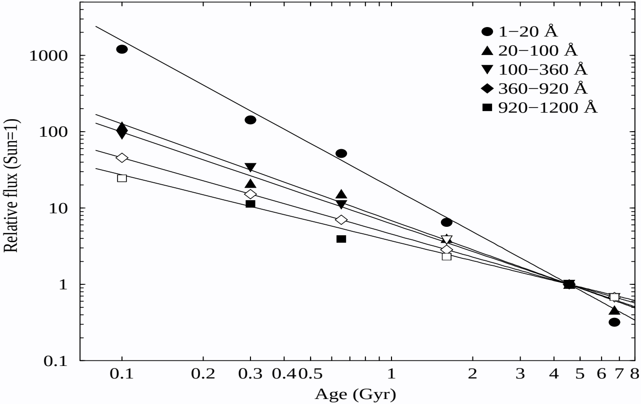
The evolution of stellar rotation



Rotation vs. age for solar-like stars in open clusters (Gallet & Bouvier 2013)

- large spread of initial rotation periods
- rotation is function of age and mass ($T_{\rm eff}$, color)

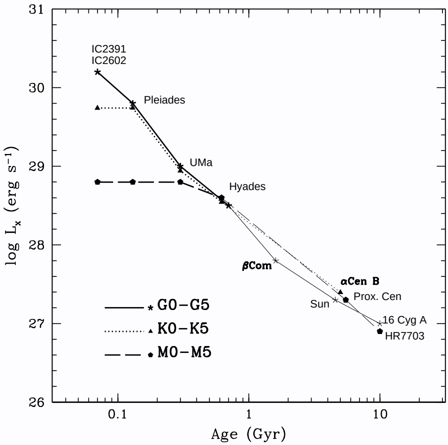
X-ray activity as age indicator



X-ray/UV flux vs. age - 'Sun in time' (Ribas+ 2005)

- activity age: rotation ⇒ dynamo processes/magnetic field ⇒ activity
- steep decline, wavelength dependent

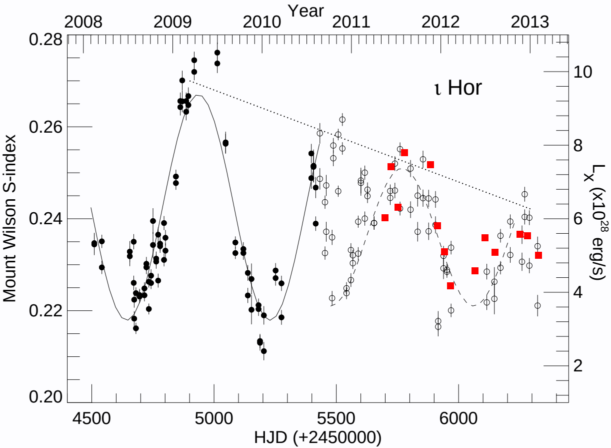
X-ray activity as age indicator



X-rays vs. age (Garces+ 2011)

- well suited to identify young stars
- scatter in young stars - age ok for ensembles like groups/clusters
- poorly calibrated beyond 1 Gyr, activity cycles in older stars

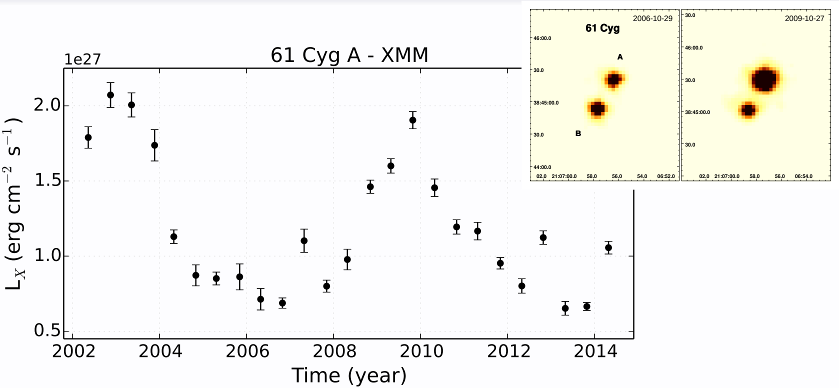
Activity cycles in X-rays



***ι* Hor (F8)**, age: 600 Myr; Ca II (black), X-rays (red) (Sanz-Forzada+ 2013)

- cycles in more active stars often irregular
- multiple periods present

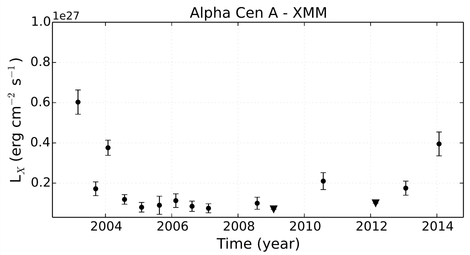
Activity cycles in X-rays

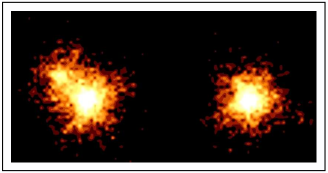


61 Cyg A (K5), age: 4 – 6 Gyr (Robrade+ 2012)

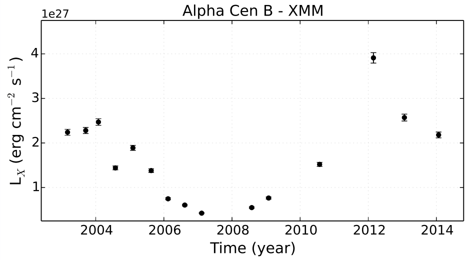
- cyclic X-ray activity in older solar-like stars, likely common
- diverse periods and amplitudes, coronal changes are solar-like
- var. more pronounced for hotter plasma/active regions

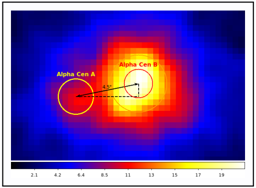
Activity cycles in X-rays





MOS1: α Centauri A/B: 2003/2005





MOS1: α Centauri A/B: 2014

α Cen A (G2) and α Cen B (K1), age: 5 − 7 Gyr (Robrade+ 2012)

SUMMARY so far

Low mass stars:

Magnetic activity omnipresent in stars with surface convection

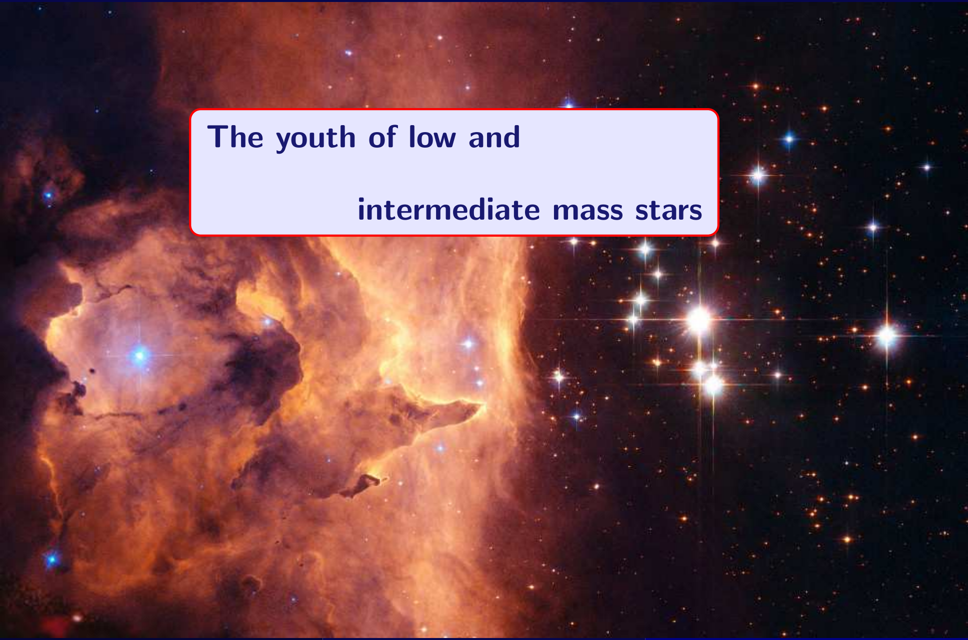
- **dynamo power related to rotation and internal structure**
- **strong evolution with time, appearance of activity cycles**
- **deviations from solar type dynamo at low and high mass end**

Intermediate mass stars:

X-ray emission generated by MCWS phenomena

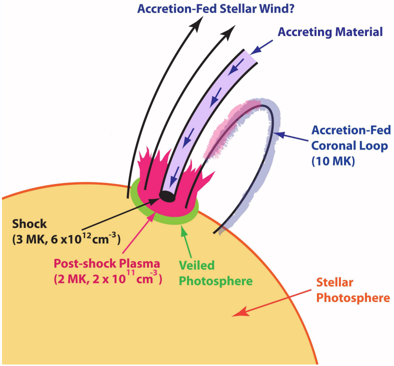
- **sufficiently fast and strong winds required**
- **magnetic activity needed to explain X-ray phenomena in IQ Aur**
- **several details open**

X-rays from YSOs

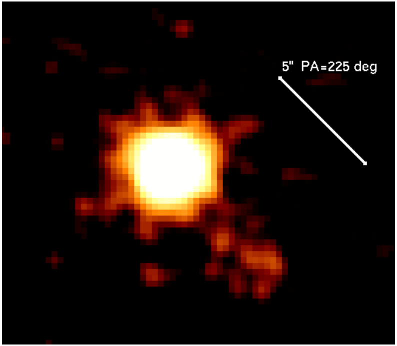


The youth of low and intermediate mass stars

Young low-mass stars: classical T Tauri stars



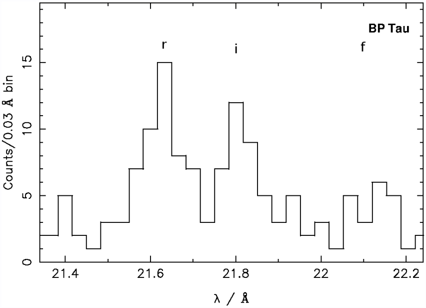
TW Hya (0.5 Ms *Chandra*, Brickhouse+ 2010)

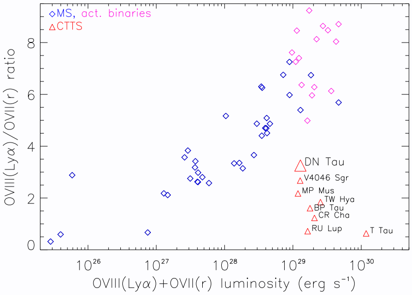


DG Tau (ACIS, Güdel+ 2011)

- magnetic activity omnipresent and strong
- X-rays from accretion shocks common (high density plasma + soft excess)
- stellar X-ray jets

Young low-mass stars: classical T Tauri stars





BP Tau RGS, O VII-triplet (Schmitt+ 2005)

soft excess O VIII/O VII ratio (Robrade+ 2014)

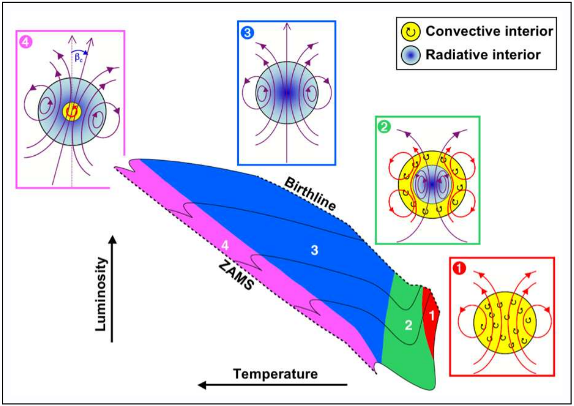
BP Tau (Schmitt+ 2005), DN Tau (Robrade+ 2014), MP Mus (Argiroffi+ 2007), RU Lup (Robrade & Schmitt 2007), TW Hya (Kaster+ 2002, Stelzer & Schmitt 2004, Brickhouse+ 2010, 2012), V4046 Sgr (Günther+ 2005, Argiroffi+ 2012)...

soft excess: Güdel &Telleschi 2007, Robrade & Schmitt 2007, Telleschi+ 2007...

jets: Güdel+ 2007, 2011, Schneider & Schmitt 2008...+ sample studies like COUP, XEST...

See talks at: Stellar parallel session

HAeBe stars – young intermediate mass stars

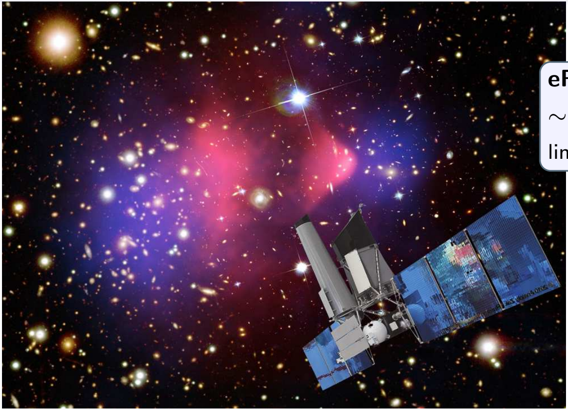


(1.5 – 15 $M_\odot$
Alecian+ 2013)

- X-rays from jets, coronae (AB Aur, HD 163296...)
- large spread in $\log L_{\mathrm{X}}/L_{\mathrm{bol}}$, companions? (Stelzer+ 2009)
- IMTTS at lower masses/younger age (RY Tau, SU Aur, T Tau...)

AB Aur (Telleschi+ 2007), HD 163296 (Swartz+ 2005, Günther & Schmitt 2009), SU Aur (Robrade & Schmitt 2006), RY Tau (Skinner+ 2011), T Tau (Güdel+ 2007)...

Into the future...



eRASS

$\sim$ 0.7 Mio. X-ray stars

lim. $F_X \approx 1 \times 10^{-14}$ erg cm^{-2} s^{-1}

- 2015 – ASTRO-H (JAXA+): calorimeter, resolution 7 eV, 0.3 – 12.0 keV
- 2016 – eROSITA/SRG (D/Ru): all-sky survey, 0.3 – 10.0 keV

Talks on Thursday morning: Predehl, Guainazzi...