X-ray emission from Ap/Bp stars

Bridging cool and hot stars

Jan Robrade

Hamburger Sternwarte

The X-Ray Universe 2011, Berlin

Overview

1. **From the 'hottest cool' to the 'coolest hot' stars**

2. **X-rays from Ap/Bp stars**

Classical regimes of stellar X-ray emission

The hot stars regime (O to early B-type)

- X-rays from wind-shocks
- $L_\mathrm{X} \propto L_\mathrm{bol}$, $\log L_\mathrm{X}/L_\mathrm{bol} \approx -7$

The cool stars regime (late A to late M-type)

- X-rays from magnetic activity (coronae)
- $L_\mathrm{X} \propto 1/R_\mathrm{o}^2$ (dynamo efficiency), $\log L_\mathrm{X}/L_\mathrm{bol} \approx -3 \ldots -7$

$\Rightarrow$ X-ray 'dark zone' from mid B to mid A

plus: the young ones (Class 0/I, T Tauri stars, HAeBe stars)

- magnetic activity, accretion-shocks, shocks in outflows/jets

X-rays from A-type stars

The hottest cool stars:

- 'normal' A-type stars
- $T_{\rm eff} \sim 7500 - 10000$ K, M $\sim 1.6 - 2.4\ M_\odot$
- **Altair** (A7) - fast rotator, weakly active ($\log L_{\rm X}/L_{\rm bol} = -7.4$)
  - hottest magnetically active type of star ($L_{\rm X} = 1.4 \times 10^{27}$ erg s^{-1})
  - equatorial bulge corona (Robrade & Schmitt, 2009)
- companions (VAST survey; De Rosa et al., 2011)
- HR 8799 (A5, 'misclassification') (Robrade & Schmitt, 2010)
  - kA5 hF0 mA5 v λ Boo star
- β Pictoris (A5, debris disk) (Hempel et al. 2005)
  - X-rays: very faint, very soft

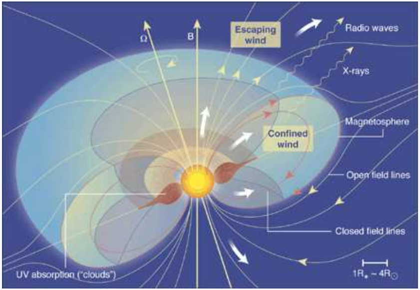
X-rays from late B/early A-stars

The coolest hot stars

- 'peculiar' A-type stars
- $T_{\mathrm{eff}} \sim 7500 - 14000$ K, M $\sim 1.6 - 4.0\ M_{\odot}$
- A0p stars overlap with late B-type stars

- X-rays from **magnetic** Ap/Bp stars
  - **IQ Aur** (A0p) as prototype
  - latest X-ray detected 'hot' star
  - large-scale magnetic structures, slow rotators
  - chemically peculiar, mainly CP2 (Preston, 1974)

Ap/Bp stars – IQ Aur and the MCWS model



X-ray emission from magnetically confined wind-shocks

MCWS model (Babel & Montmerle, 1997)

IQ Aurigae: $T_{\rm eff} \approx 14500$ K, age ≈ 60 Myr, very blue (B-V $= -0.16$)

- X-ray detection with *ROSAT*
- $\log L_{\rm X} = 29.6$ erg s^{-1}, $T_{\rm X} = 0.3$ keV (3.5 MK)
- bright but soft X-ray emission
- $V_\infty = 800$ km s^{-1}, $\dot{M} \approx 10^{-10} \ldots 10^{-11}\ M_\odot\,{\rm yr}^{-1}$

The MCWS model

Advancements of MCWS model by ud-Doula, Owocki, Townsend

- magnetically channeled line driven stellar winds (dynamic models)
- MHD simulations incl. stellar rotation
- strong magnetic confinement: rigid disk structures + centrifugal breakout

⇒ 'Standard model' for magnetic hot stars

invoked to explain: X-ray overluminosity, hard spectral components, flares, rotational modulation... of O and B-type stars:

θ^1 Ori C, O5 (Gagné et al. 2005)

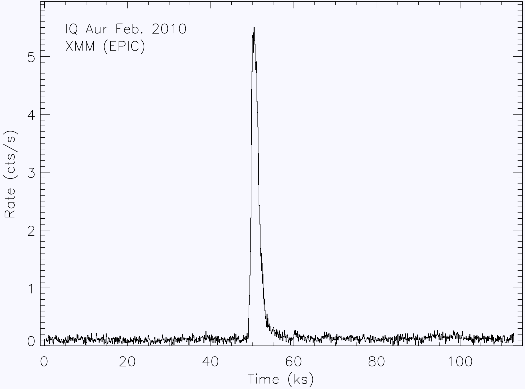
τ Sco, B0.2 (Cohen et al. 2003)

σ Ori E, B2p (Townsend et al. 2005)

β Cep, B2III (Favata et al. 2009)

... time to re-examine the archetype

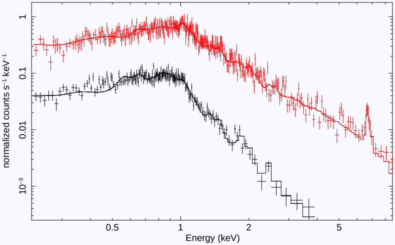
A0p stars - not just wind shocks?!



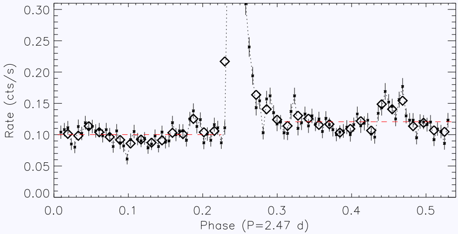
XMM-Newton observation of IQ Aur (Robrade & Schmitt, 2011)

- major differences to *ROSAT*
- hot plasma in quasi-quiescence & large flare detected

IQ Aur I – Global X-ray properties



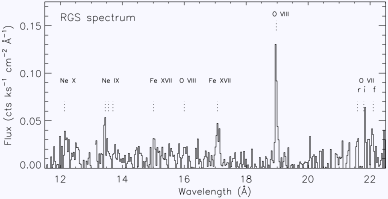
PN spectra: QQ-phase (black) vs. flare (red)



QQ light curve

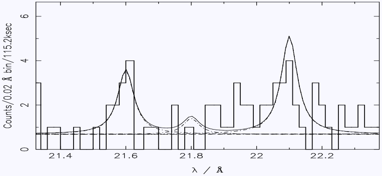
- $\log L_{X\,qq} = 29.6$ erg s^{-1} ($\log L_X/L_{bol} \approx -6.5$)
- strong $\gtrsim$ 10 MK plasma component in quasi-quiescence
- no clear rotational modulation of light curve
- large flare with flux increase of factor ~ 100, very hot plasma

IQ Aur II – High resolution spectrum



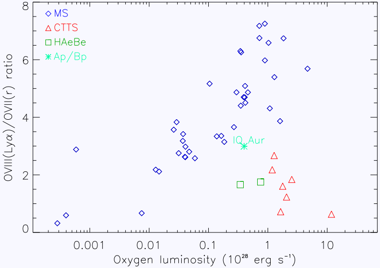
O VII He-like triplet:

tracer of the UV-field



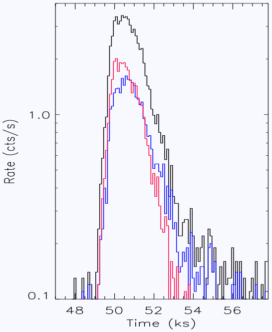
O VIII vs. O VII:

indicator of non-coronal emission

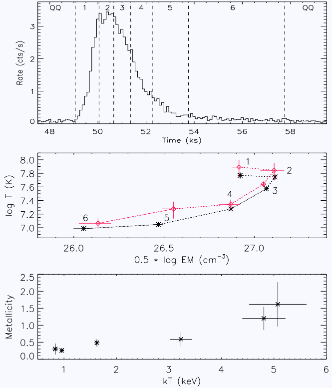


- O VII f/i-ratio high: X-rays from well above the stellar surface ($f/i \approx 1$, d $\gtrsim 7$ R_*)
- O VIII vs. O VII excess of cool plasma only moderate - new regime?

IQ Aur III – The flare



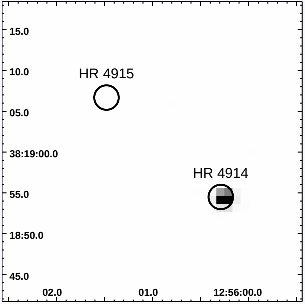
PN: blue: 0.2-1.0 keV, red: 1.0-8.0 keV



- flare peak luminosity $L_{\mathrm{X}} = 3 \times 10^{31}$ erg s^{-1}, $T_{\mathrm{X\,flare}}$ up to $\approx$ 100 MK
- moderately sized flare structure, $L \lesssim 0.2\,R_*$
- metallicity increase during flare

⇒ Magnetic activity required !!!

α^2 CVn



Einstein and *ROSAT* detected - wide binary

ACIS-S image:
prototypical A0p star α^2CVn (HR 4915) is X-ray dark (Robrade & Schmitt, 2011)

F0 star HR 4914 clearly detected at $\log L_{\mathrm{X}} = 28.6$ erg s^{-1}

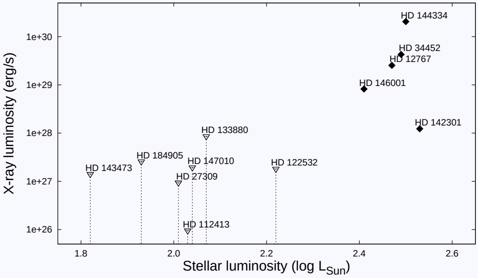
α^2 Canum Venanticorum: 15 ks *Chandra* observation

- not detected, U.L. of $\log L_{\mathrm{X}} \lesssim 26$ erg s^{-1}

optically similar stars differ in X-ray luminosity by factor $\gtrsim 1000$

... but how similar are A0p stars?

Ap/Bp stars – The larger view



B8 – A0, magnetic CP stars

$\sim$ 2.8 – 4.2 $M_{\odot}$

(stellar data from Kochukhov & Bagnulo, 2006)

Chandra + *XMM-Newton* data

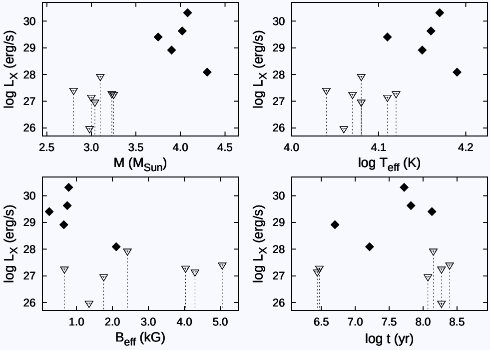
only single or resolved stars

A puzzeling zoo of X-ray detections vs. non-detections was present in the literature.

- IQ Aur is more luminous, massive and hotter than α^2CVn
- **all** brighter stars X-ray detected ...but with large scatter
- **no** fainter star X-ray detected
- X-ray detections are Si and/or He-weak stars

$\Rightarrow$ luminous Ap/Bp stars ($L \gtrsim 200 L_{\odot}$) are X-ray sources

Ap/Bp stars – The larger view II



- age and magnetic field strength not a major player
- time dependent phenomena likely of minor importance
- **companions?** not ruled out, but statistically unlikely
- X-ray / Radio (Güdel-Benz) relation violated in all cases
  - Ap/Bp stars are radio-overluminous by orders of magnitudes (Linsky et al. 1992)

Ap/Bp stars – MCWS models

Theory:

- X-ray luminosity: $L_{\mathrm{X}} \propto \dot{M} V_{\infty} B_{*}^{0.4}$ (BM97)
- X-ray temperature: $T_{\mathrm{X}} \approx 1.15 \times 10^{5}\mathrm{K}\,(\frac{V_{sh}}{100\ \mathrm{km\,s^{-1}}})^{2}$
- magnetic confinement: $\eta_{*} \propto B_{eq}^{2} R_{*}^{2} / \dot{M} V_{\infty}$ (ud-Doula et al. 2002, 2008)

sufficient mass loss: YES

$\Rightarrow$ only in massive/high luminosity objects

sufficient wind speed: YES

strong magnetic confinement ($\eta_{*} \gg 1$): **YES**

effective channeling of stellar wind
build-up of rigid disk: magnetic reconnection + centrifugal breakouts

Caveats:

- models tuned for more massive stars, smaller η_{*}
- unexplained scatter: magnetic field geometry, companions, time variability...

Summary

X-rays from Ap/Bp stars

- X-ray detections concentrate at high luminosities
  strong dependence on stellar properties
- X-ray emission from wind-shocks and magnetic activity
- X-ray properties compatible with MCWS model
  magnetically channeled stellar wind, strong confinement and rigid disk
- importance of other parameters?

Thanks !