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Early Magnetic B-Type Stars: X-ray Emission and Wind Properties

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Early magnetic B-type stars

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X-Ray Universe 2011

Massive Stars and Stellar Winds

Initial mass $M_* > 8M_\odot$

Main Sequence: OB-type

Fast evolution (~Myr) → trace star formation

Hot. $T_{\mathrm{eff}} > 10\,000$ K $\longrightarrow$ high surface brightness

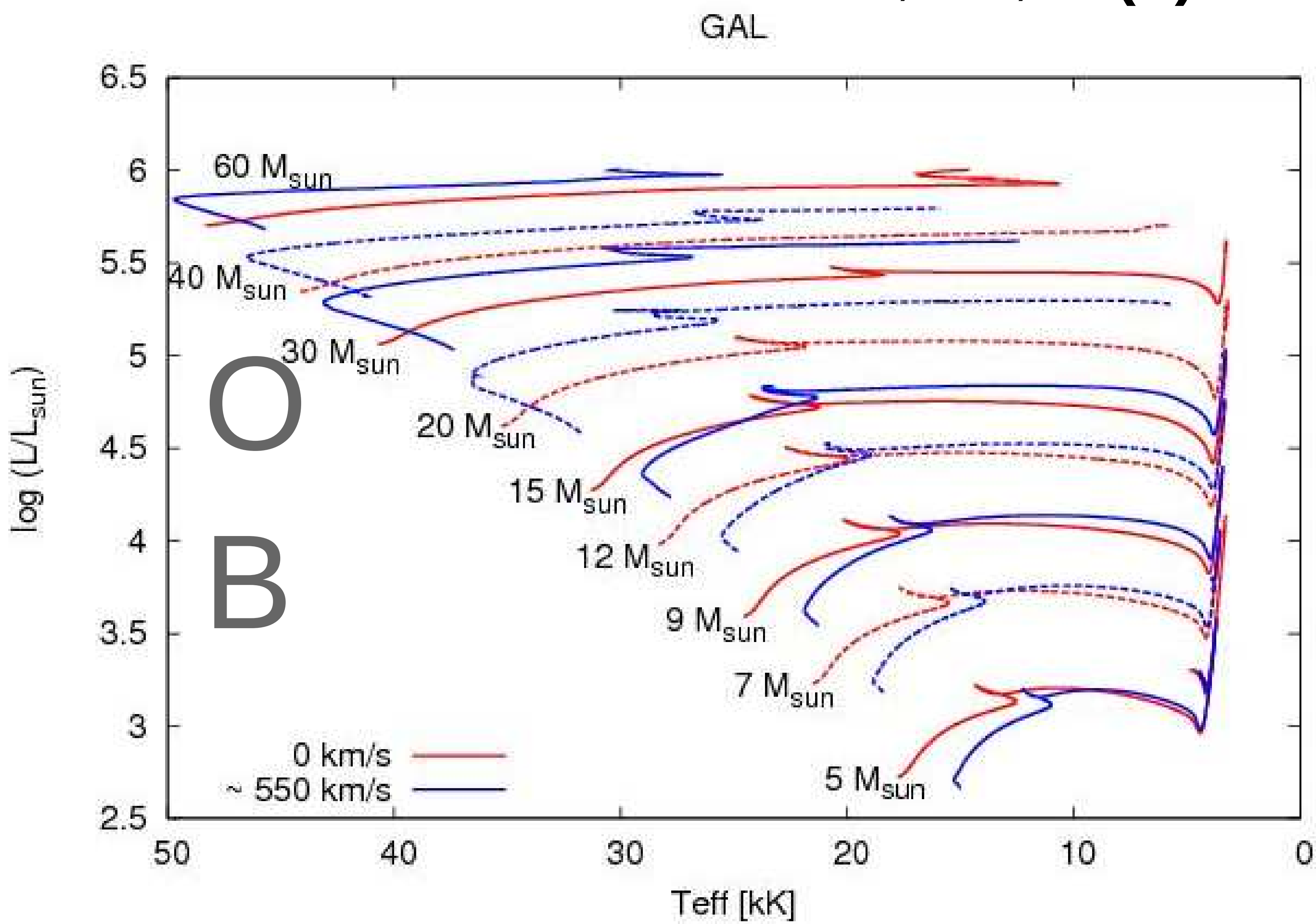
Photon momentum $\longrightarrow$ acceleration of matter

Radiative acceleration larger than gravitation $\longrightarrow$ supersonic **STELLAR WIND**

nasaimages.org

The evolution of massive stars

Evolution ← stellar wind, rot, **B (?)**



Stellar structure: no outer convective zone **(no dynamo)**

Chemically Peculiar (classical) magnetic ApBp stars

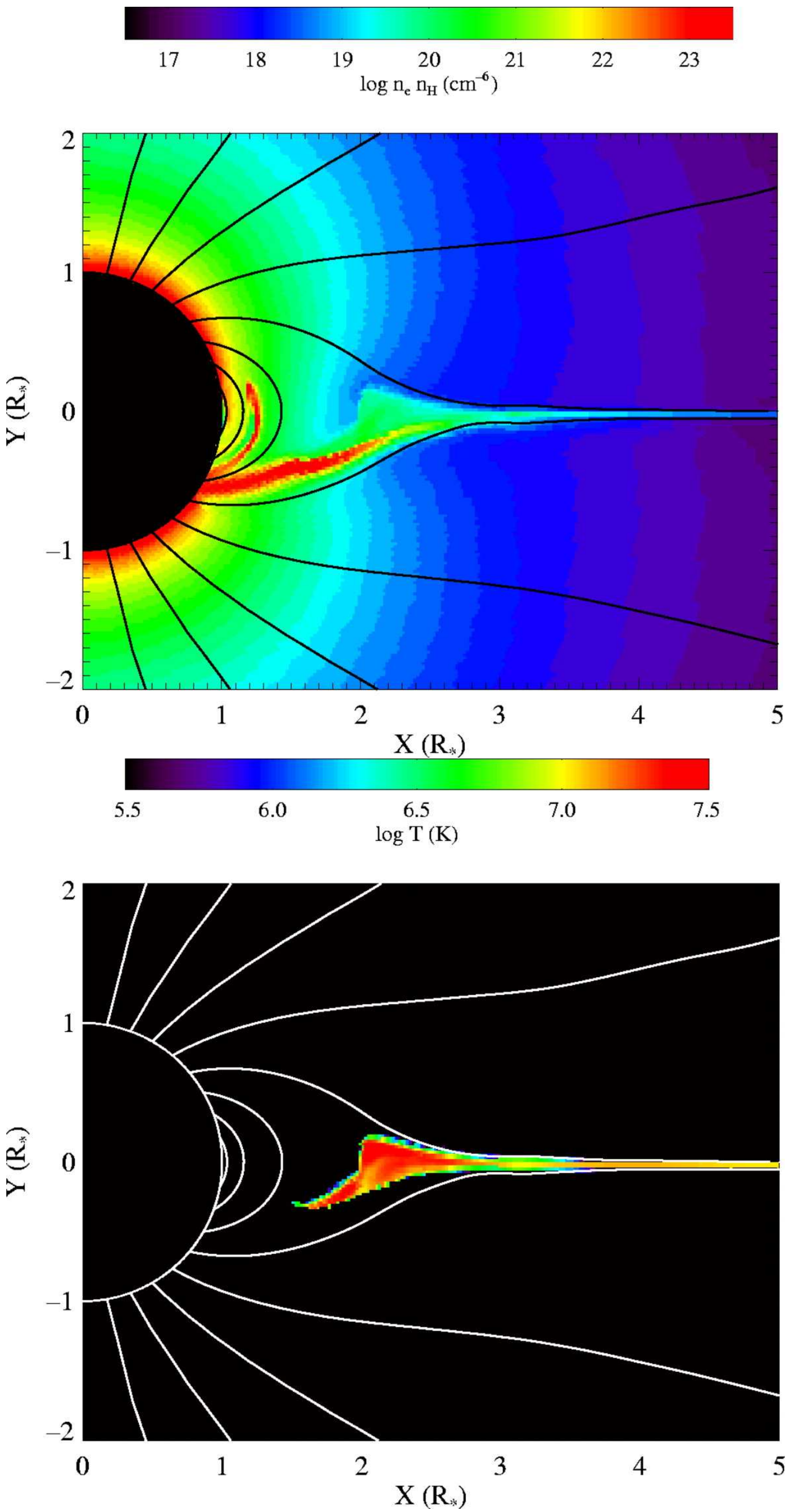
Wide range of spectral types. Dipole kG-strong magnetic fields

σ Ori E - cartoon from D. Groote homepage

Winds $\rightarrow$ Low Plasma- β $\rightarrow$

Stellar wind dynamics is dominated by B

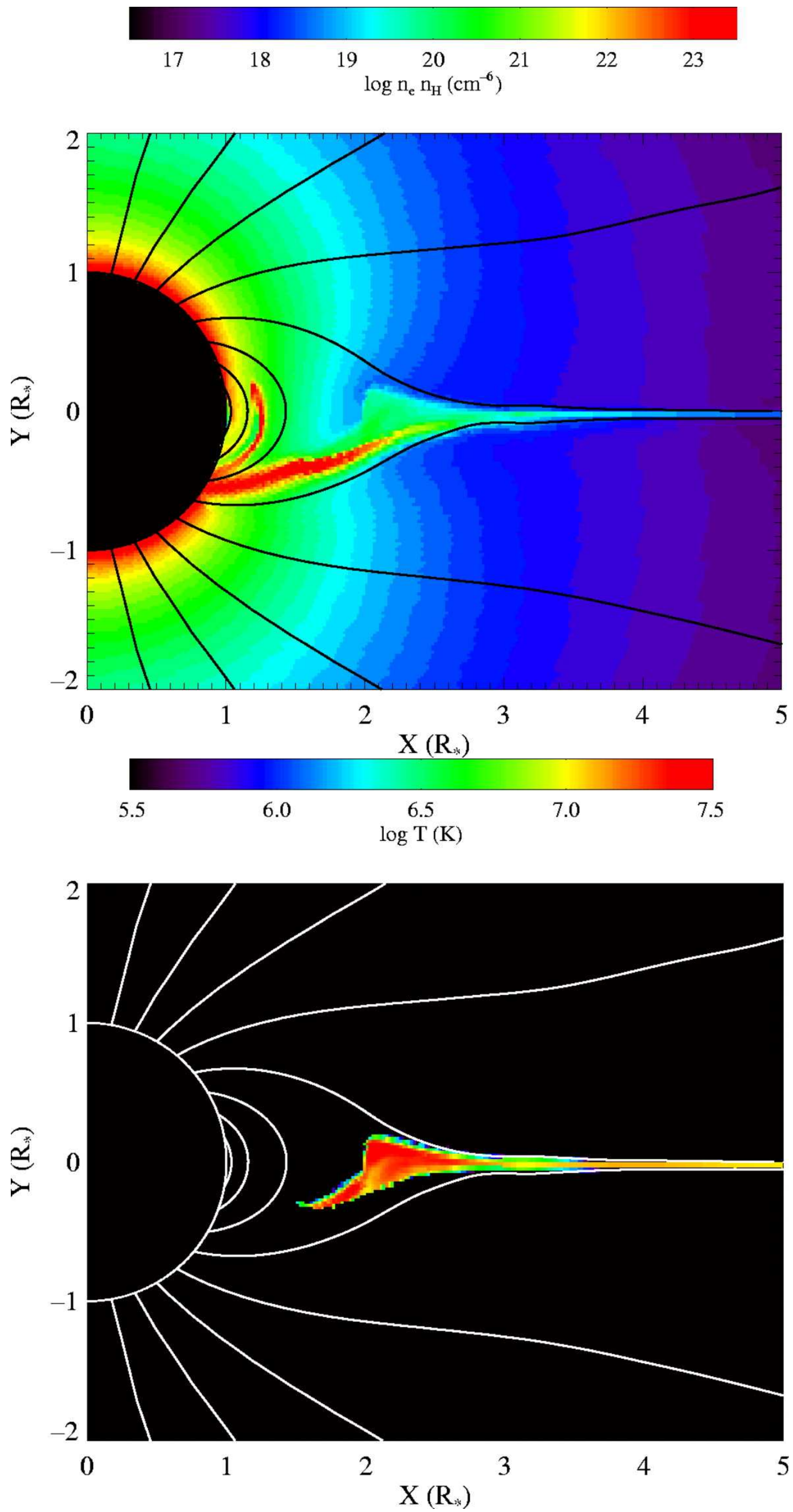
Magnetically Confined Wind Shock (MCWS) model (Babel & Montmerle 1997ab)



- θ^1 Ori C : a story of success
- Babel & Montmerle 97; Stahl etal 96,08; Weigelt etal 99; Donati & Wade 99; Schulz etal 00, 02; Donati etal 02; **Ud-Doula etal 02, 06,08,09;** Naze etal 10.
- Dipole kG magnetic field - oblique magnetic rotator
- Multiwavelength properties are well explained and confirmed by MHD simulations
- **An accepted template of a magnetic OB star**

adopted from Gagné etal 05

MCWS model predictions



MCWS: well defined model predictions:

- $L_X/L_{bol} >> 10^{-7}$
- **DEM peaking at 20 MK**
- Narrow X-ray line profiles
- X-ray periodic variability
- X-ray formation at few R_*

Can X-rays be used as a diagnostic tool to reveal magnetic massive stars?

adopted from Gagné etal 05

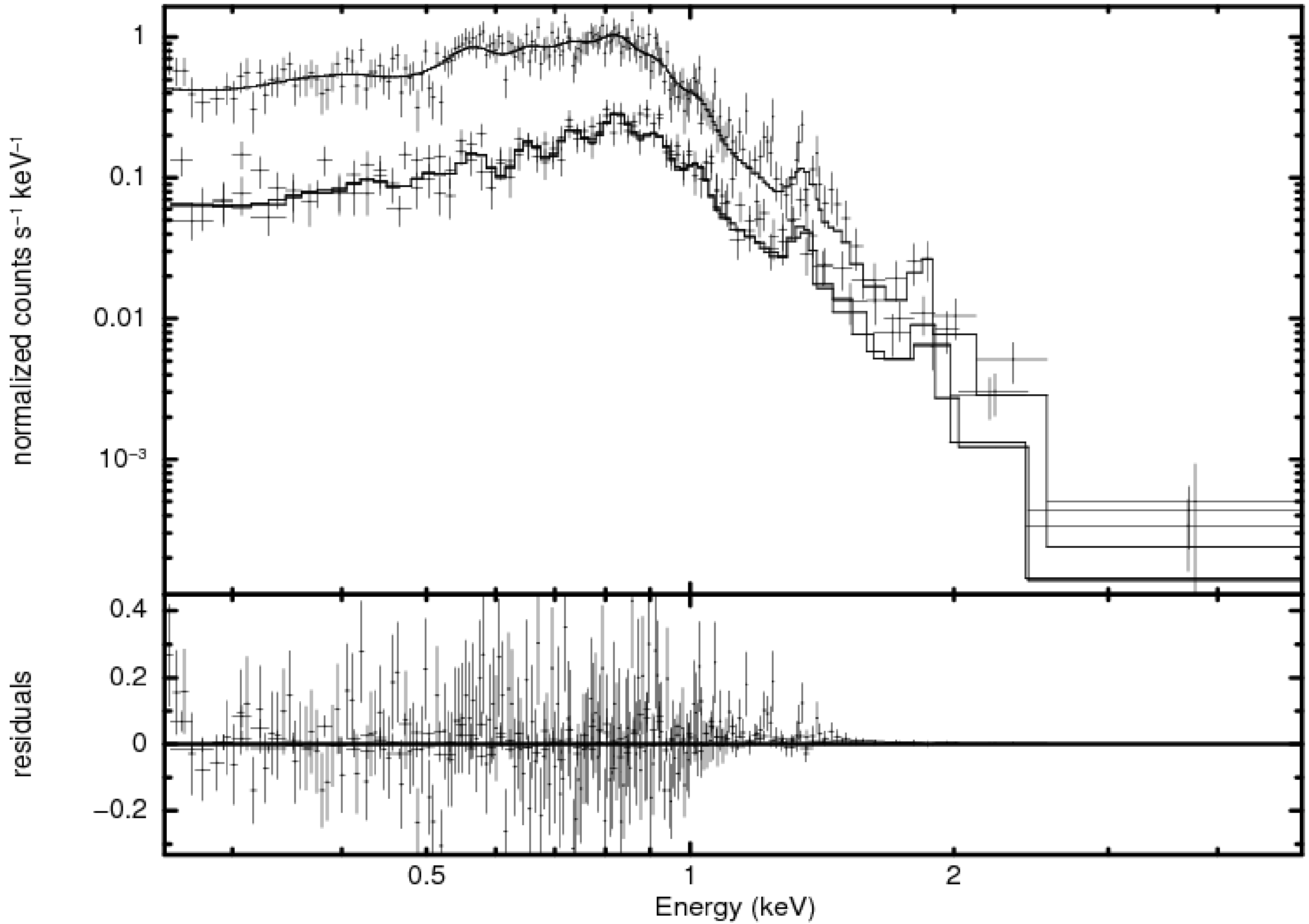
X-ray emission and stellar winds

Last decade: **boom** in the detections of magnetic fields on massive stars (Donati & Landstreet 2009)

- Collect all exisiting X-ray data on early type (earlier than B2) B-stars. Dedicated XMM-Newton observations for three stars, ξ1 CMa, ζ Cas, V2052 Oph: two are detected for the first time
- **The complete sample of early B-type stars with detected magnetic fields and existing X-ray observations to date.** (Oskinova etal. 2011)
- To obtain quantitative information on stellar winds: model UV lines using state-of-the-art stellar atmosphere code PoWR.

X-ray spectra of magnetic B-stars

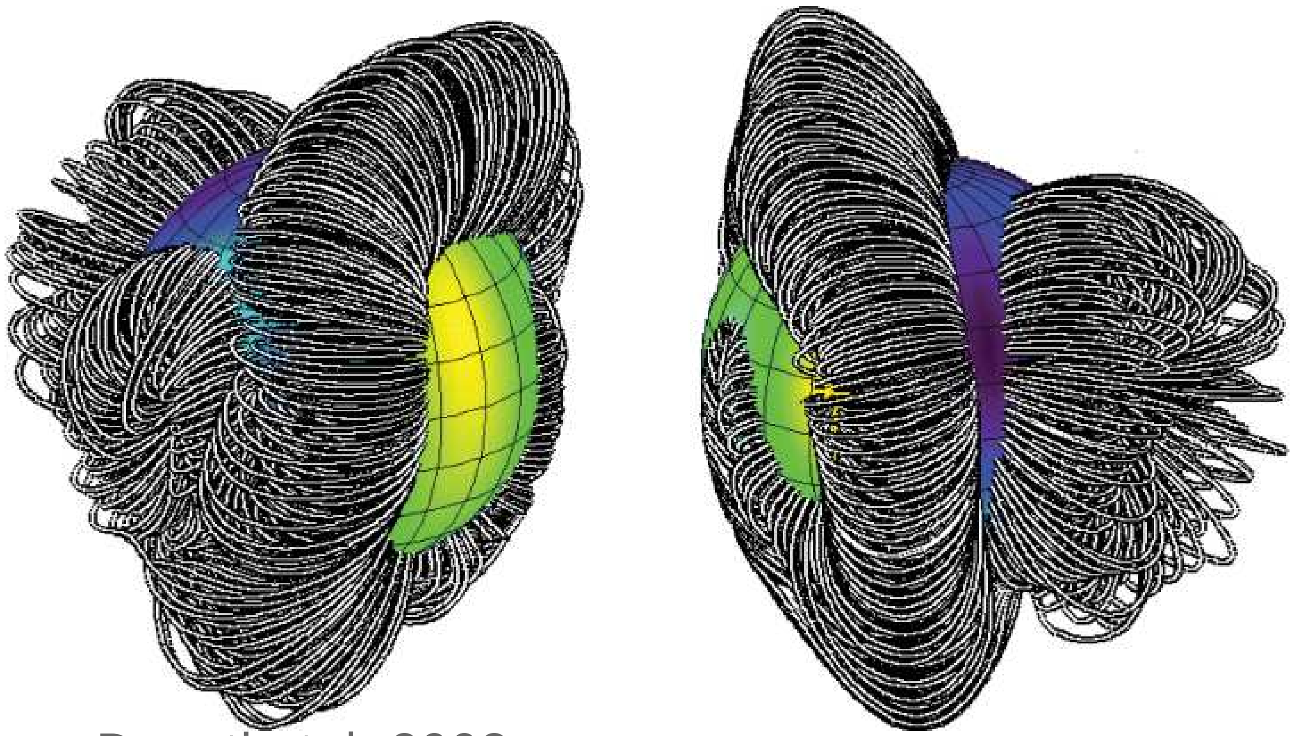
Example: XMM-Newton observations of ξ^1 CMa : $\mathbf{B_{pol} = 5.3\ kG}$



- The bulk of hot gas T_X=1 MK (except τ Sco, σ Ori E)
- The $\log(L_X/L_{bol})$ ratio in the range -5.6 … -8.5

X-ray variability

- Magnetic configuration of τ Sco
- Strongly assymetric, not dipole
- Correlation of X-ray flux with B:
  - Wind confined models
  - coronal loop models
- **Observe at different rotational phases**



Donati etal. 2003

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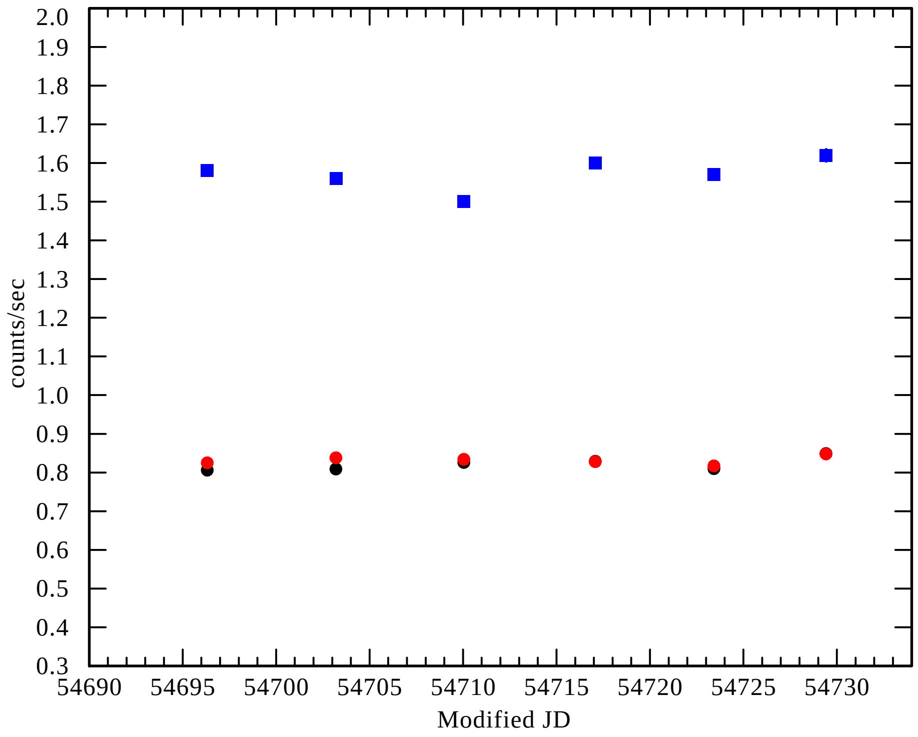
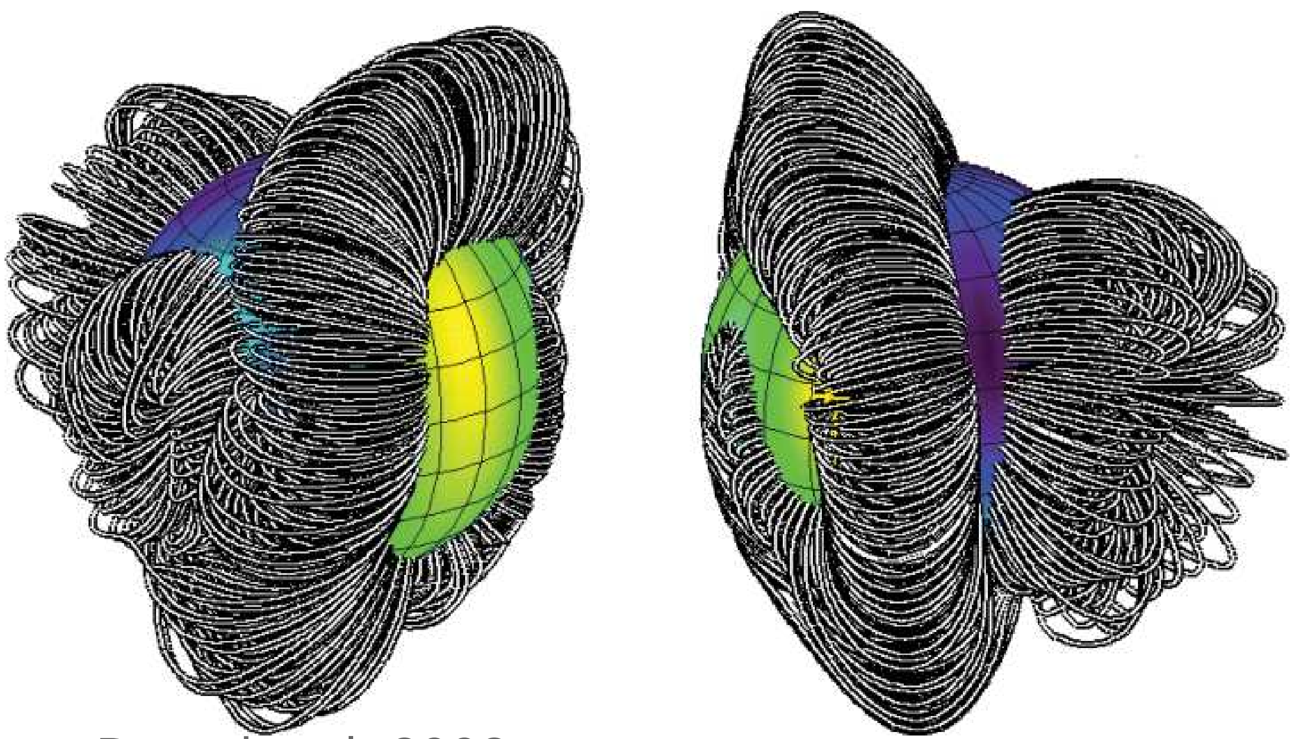
- **No X-ray variability**



Ignace etal 2010



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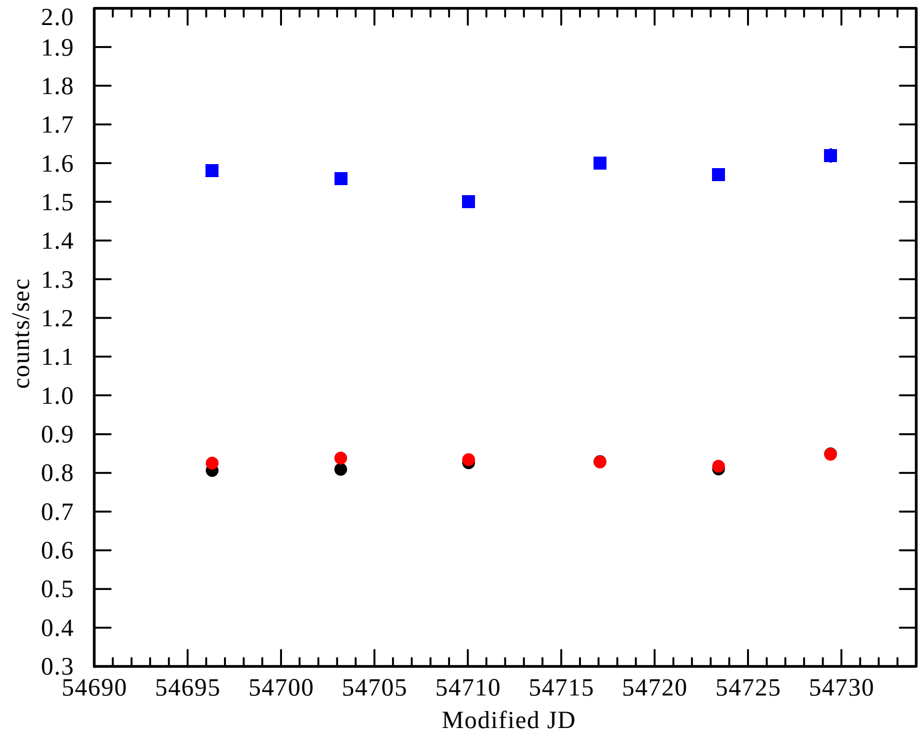
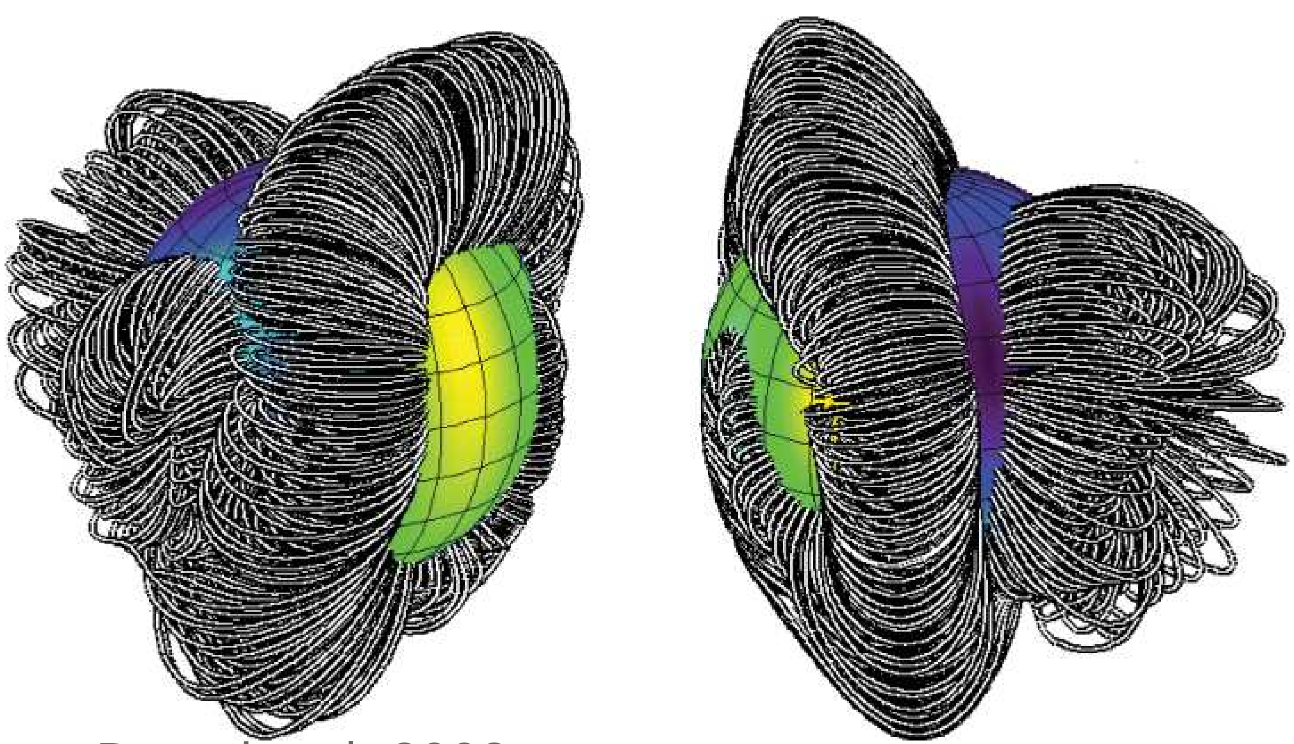


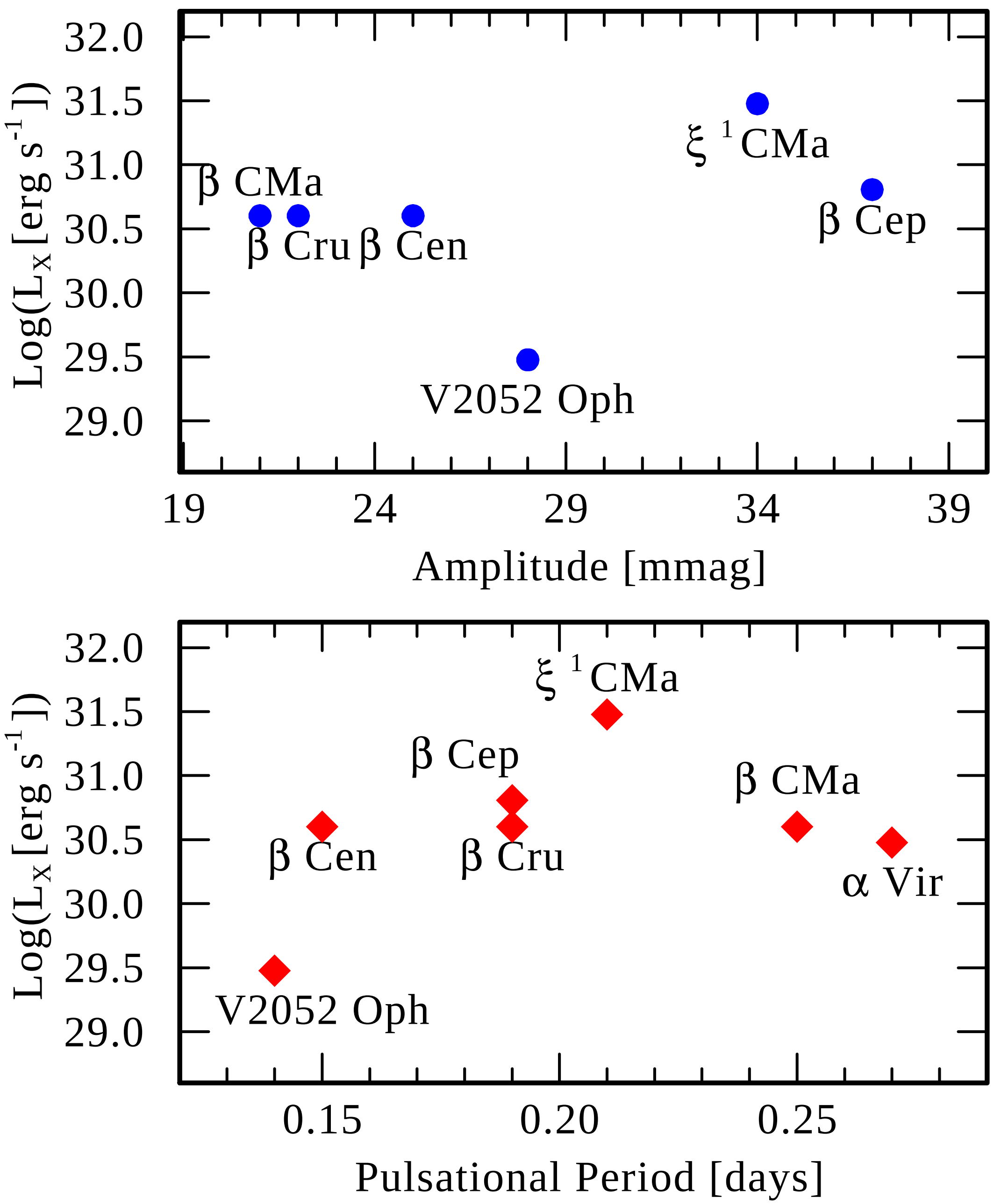


Donati etal. 2003

- β Cep soft spectrum, no variability, narrow lines (Favata etal 09)
- σ Ori E hard spectrum, flare (?) (Groote etal 04, Sanz-Forcada etal 2004)
- θ^1 Ori C hard spectrum, periodic X-ray variability (Gagne 1998, +)

Correlation with stellar parameters

L_X of β Cep-type stars vs. magnitude of pulsation (upper panel) and pulsational period (lower panel)

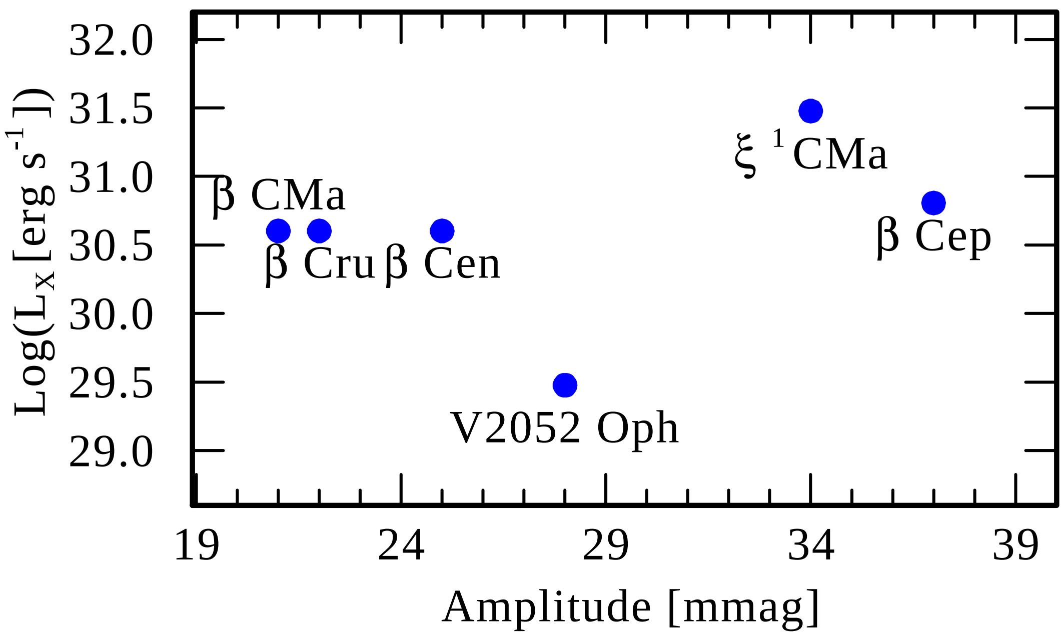


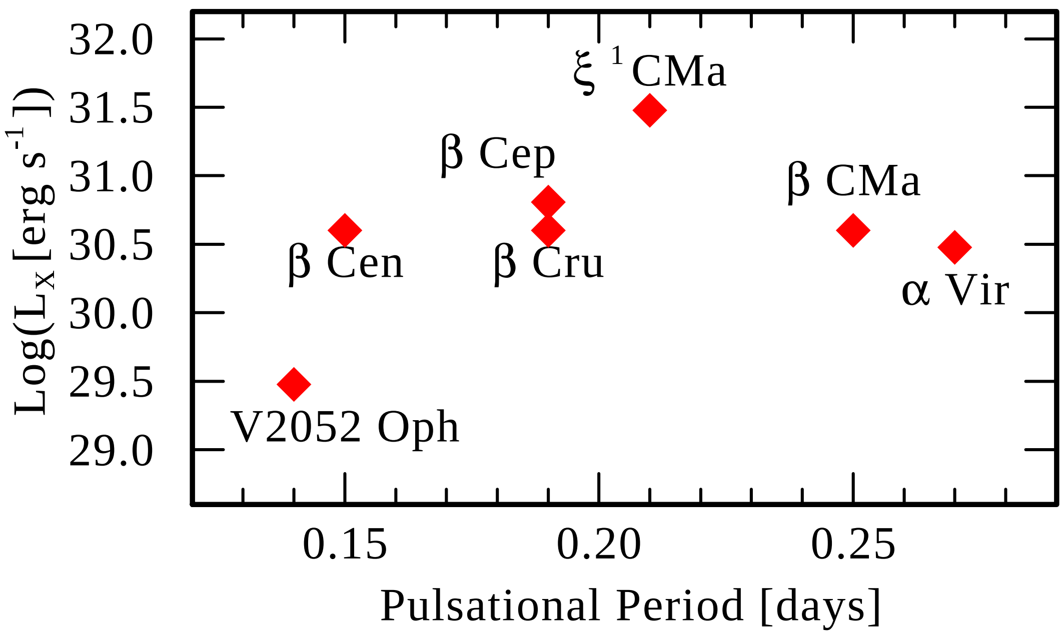
Our sample is small (11)

- No correlation with P_{rot}
- No correlation with **B**
- No correlation with P_{puls}
- No tight correlation with L_{bol}

Correlation with stellar parameters

L_X of β Cep-type stars vs. magnitude of pulsation (upper panel) and pulsational period (lower panel)





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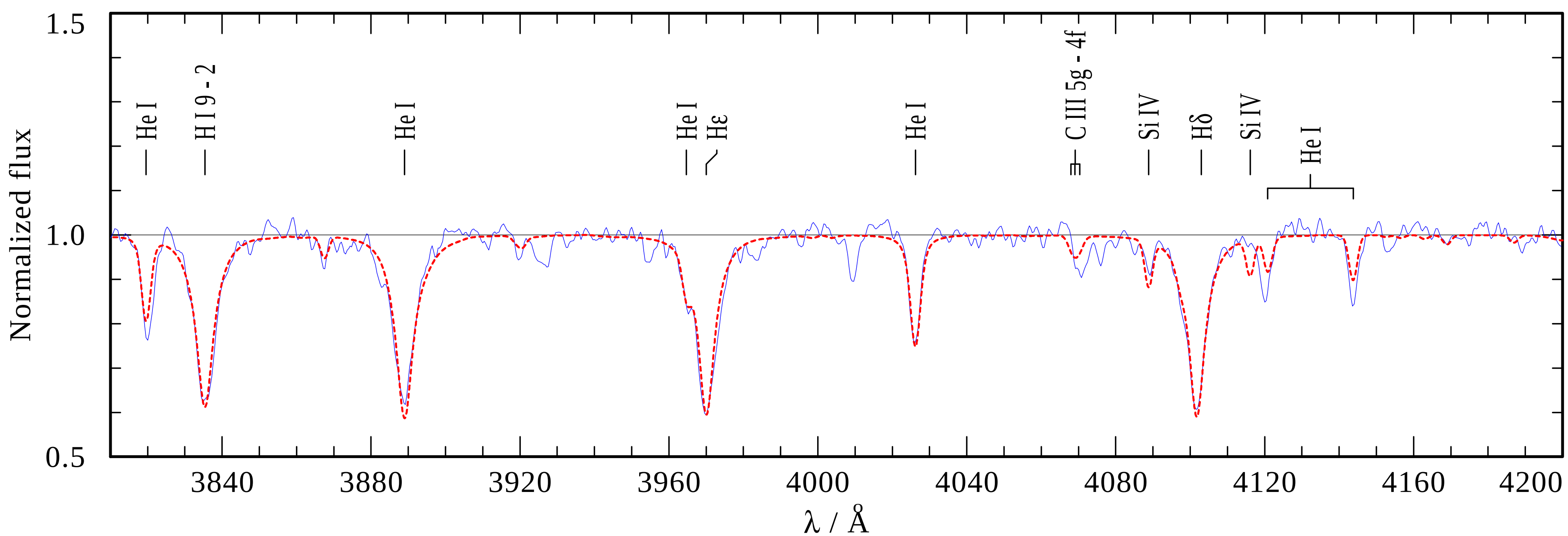
What about stellar winds?

Stellar Wind Analysis

- PoWR NLTE stellar atmospheres
- Iron Line blanketing
- Co-moving frame RT
- Complex atomic data
- Expanding atmospheres
- Photosphere + wind
- X-Rays

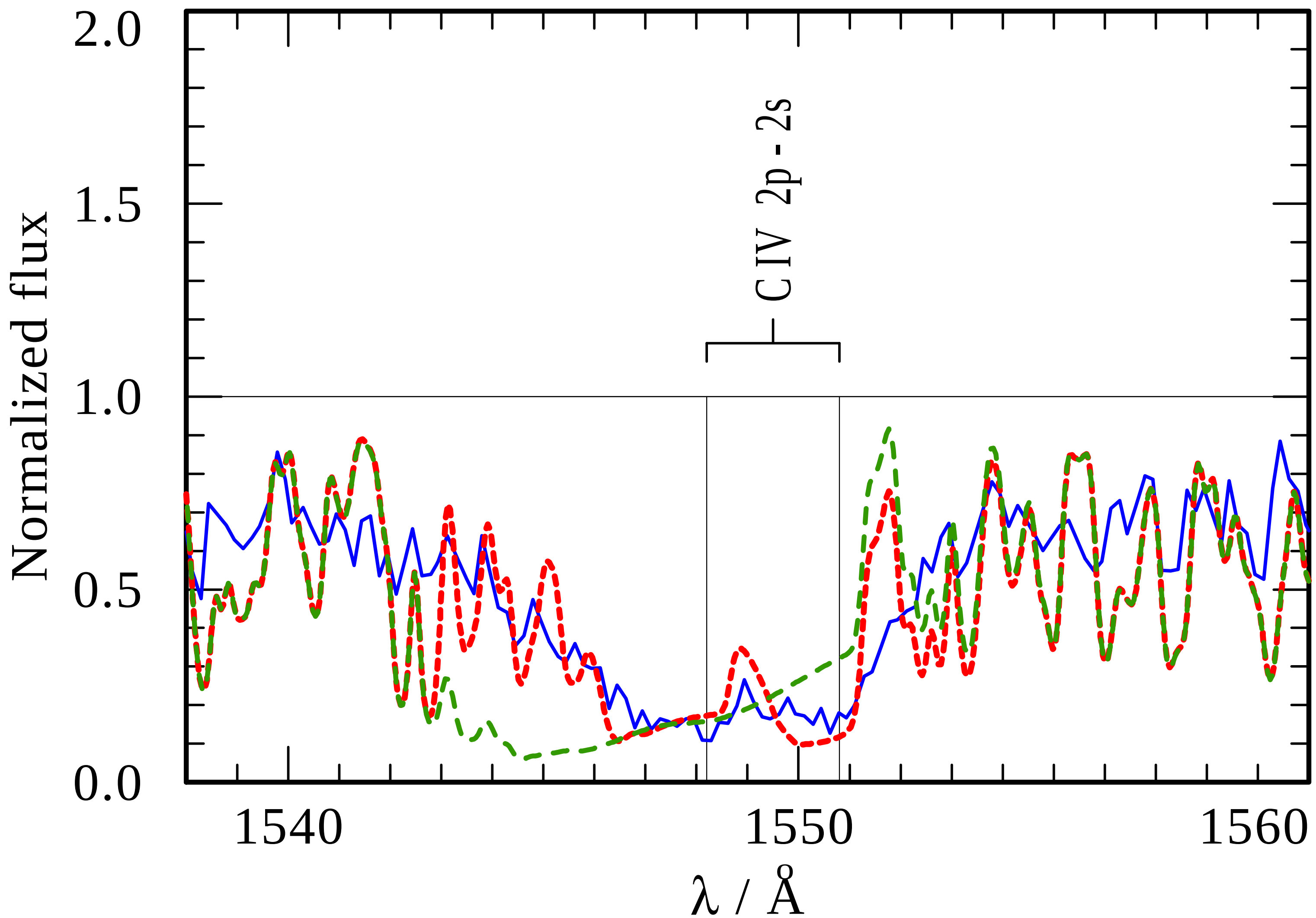
Optical spectrum of ξ^1 CMa (blue) vs. PoWR model (red)



X-rays are important for correct mass-loss rate diagnostics

The effect of ionization by X-rays on CIV line

The IUE spectrum of τ Sco (detail)



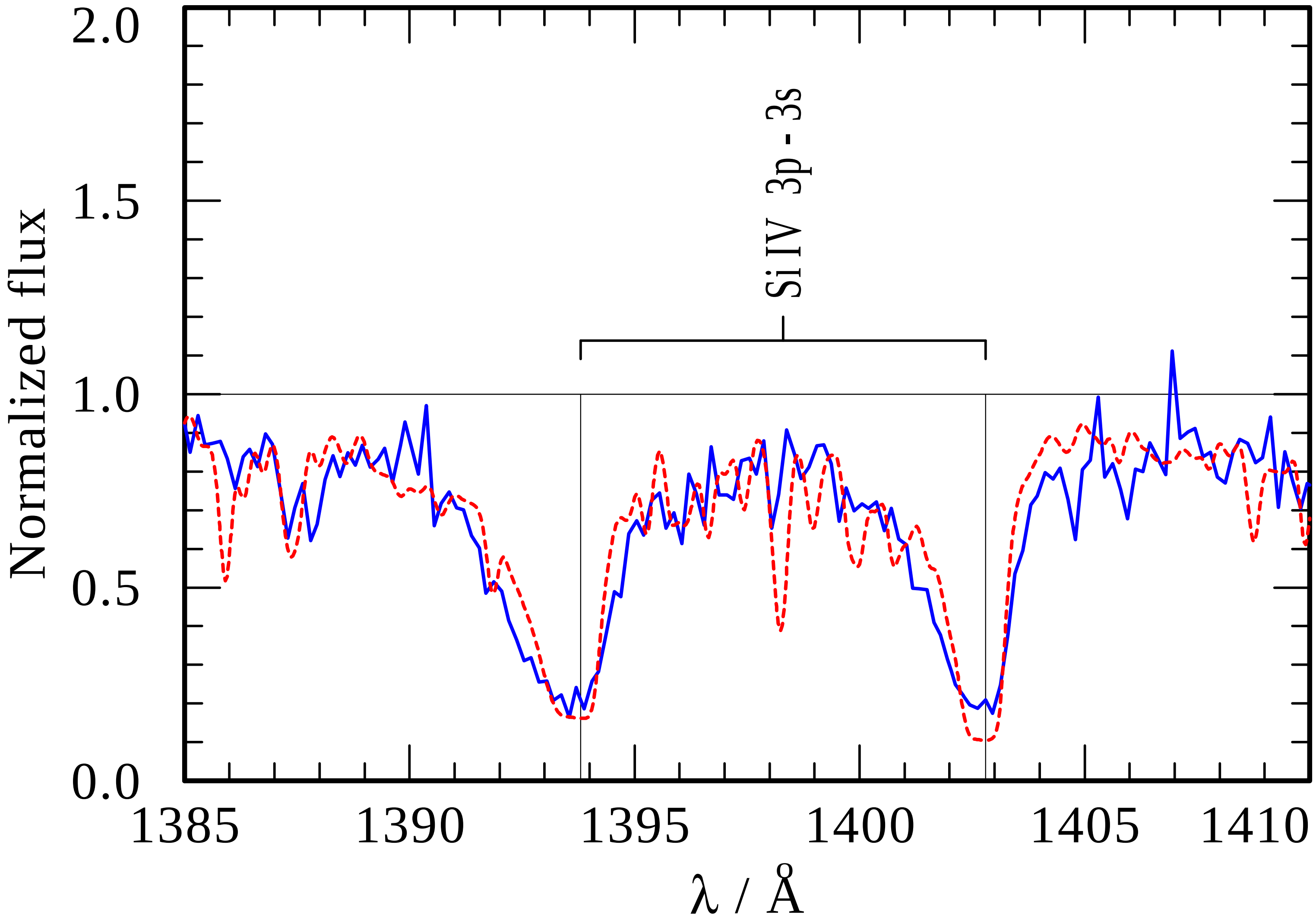
Blue observations

Model without X-rays; with X-rays; $\log(\dot{M}) = 10^{-9.3}$ **$M_\odot$/yr**

X-rays are important for correct mass-loss rate diagnostics

The effect of ionization by X-rays on SiIV line

The IUE spectrum of β Cep (detail)



Blue observations

Model with X-rays; $\log(\dot{M}) = 10^{-9.1}$ $M_\odot$/yr

The results of the wind analysis diagnostics

- The wind velocities are low (approx. 700 km/s)
- The mass-loss rates are low $\log(\dot{M}) \sim -10$
- The radiative pressure is capable of driving the winds a factor of few stronger: **"Weak Winds"**
- The emission measure of hot X-ray emitting gas is much higher than the emission measure of cool gas we see in the UV: **the hot plasma is very dence or has large volume**
- Low-β plasma: the wind motion is dominated by **B**

Comparing with the observations diagnostics

- We know **B** strength and configuration from other groups
- We know X-rays emission ($L_{X\&M,\ kTX}$) from observations
- Plug it in the PoWR model, compute UV spectra, obtain stellar wind parameters
- Use **B**, $\dot{M}$, v_{wind} as parameters for MCWS model.
- Compare predicted L_X, kT_X, DEM with the obsered.
- How well does MCWS model works? Check alternative models.

Conclusions (followed up by open questions)

Based on our comprehensive study of the complete (present) sample of massive B-stars with **B**

- MCWS model can explain observed ”normal” L_X: the stellar winds are weaker than theoretically predicted by the stellar wind theory.
- MCWS doesn’t seem be able to explain the DEM as obtained from the observations (too low temperatures)
- X-ray properties of magnetic B-stars are diverse: no tight L_X-L_{bol} correlation: some sources are hard some sources are soft.
- Soft and intrinsically faint X-ray stars can be magnetic.
- X-rays must be incorporated in stellar spectral analysis to obtain the correct ionization structure and mass-loss rate.

Open Questions

- Why B-stars have weak winds?
- Origin, incidence, and structure of **B ?**
- How X-rays are generated: MCWS model is not be a unique possibility ?
- Many further questions....

Thank you!