The X-ray properties of λ Cep, a true twin of ζ Pup?

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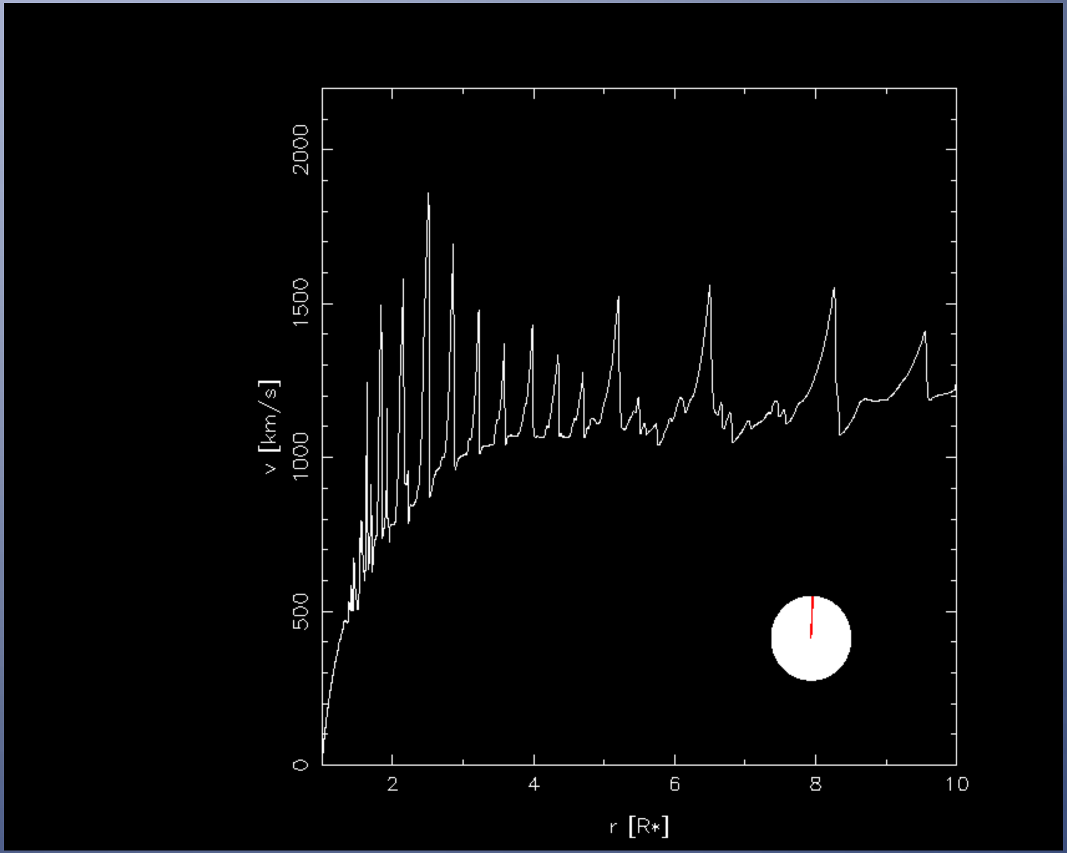
Overview

- Context: X-ray emission from single O-type stars.
- Why λ Cep?
- Goals of this campaign.
- The X-ray emission of λ Cep.
- Simultaneous optical spectroscopy.
- Conclusions and future work.

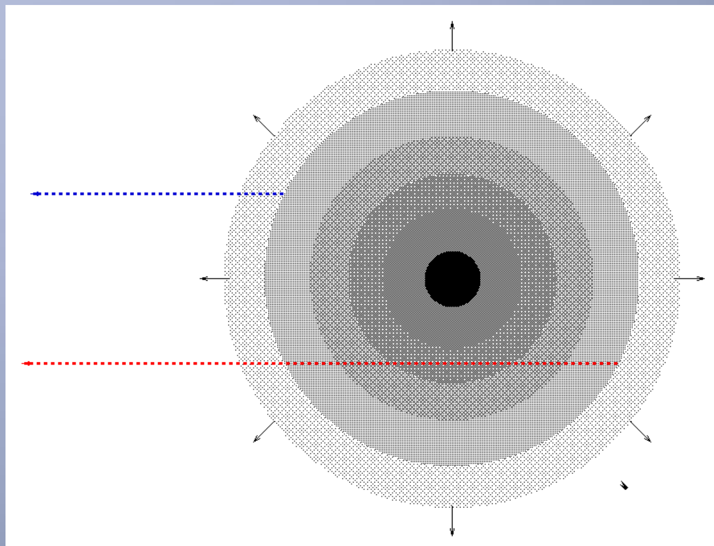
Context: X-ray emission from single O-type stars

- "Standard scenario": instabilities of radiation-driven stellar winds lead to pockets of hot plasma embedded in an otherwise cool wind.



Feldmeier et al. 1997, A&A 322, 878

- X-ray line profiles expected to be broad, blue-shifted and skewed (MacFarlane et al. 1991, ApJ 380, 564; Owocki & Cohen 2001,ApJ 559, 1108).



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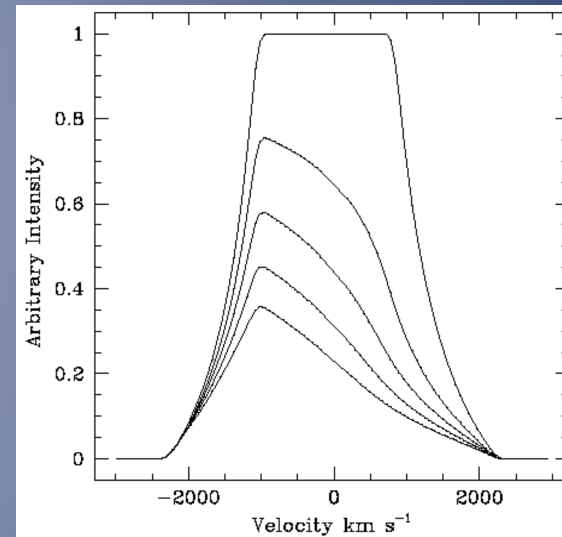
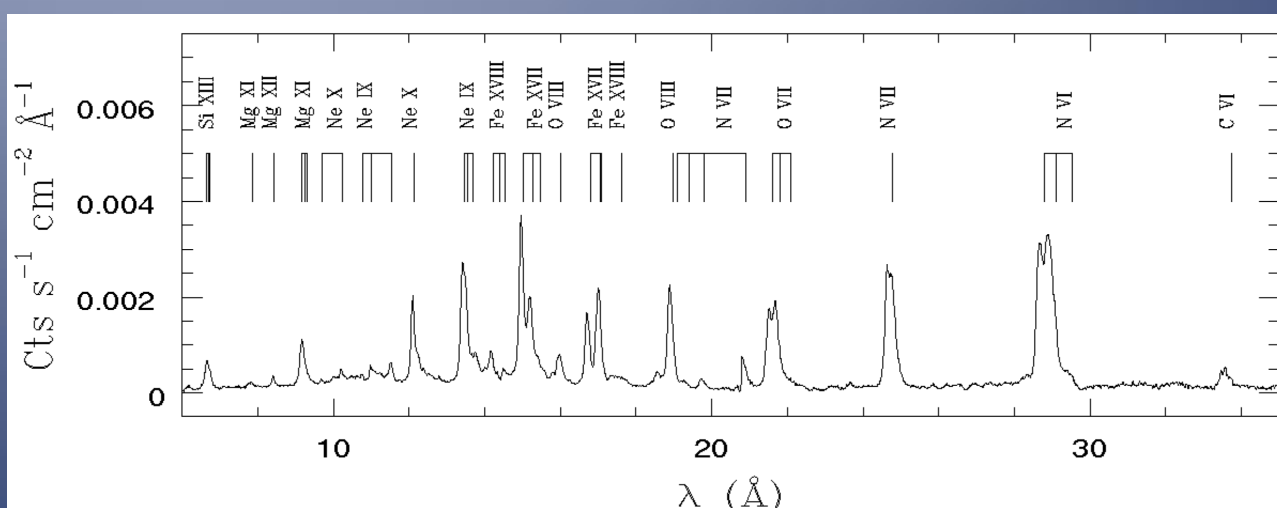
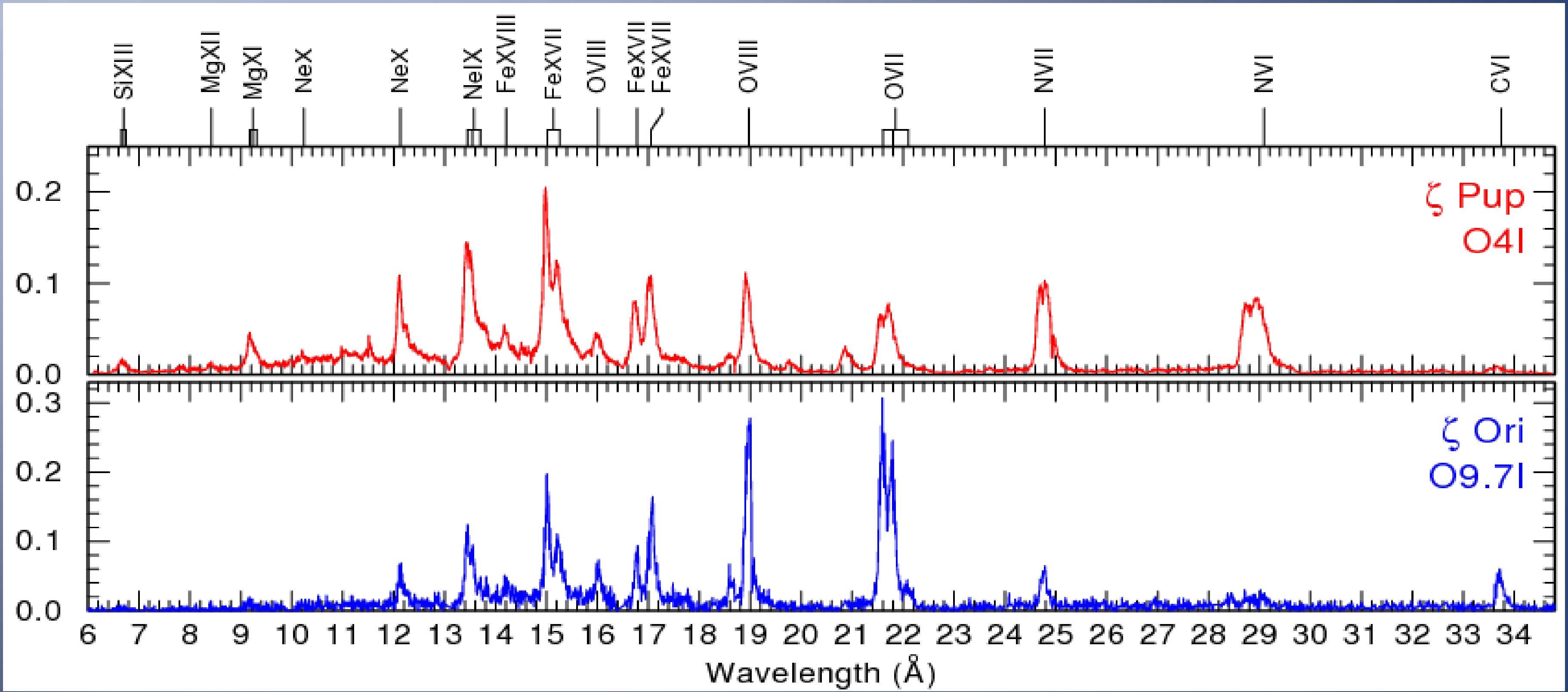


- Observed on HETG and RGS spectra of ζ Pup (O4Ief) (Cohen et al. 2010, MNRAS 405, 2391; Nazé et al. 2012, A&A 538, A22)



- But not all single, non-magnetic O-stars observed so far comply with this picture. The majority have rather narrow, symmetric lines (Oskinova et al. 2006, MNRAS 372, 313).



- Are stellar winds porous? Are the mass-loss rates lower than determined from other wavelength ranges? Is ζ Pup an exception after all?

Why λ Cep?

	ζ Pup	**λ Cep**
Spectral type	O4Ief	O6Ief
v sin(i) (km/s)	210	210
$\log(\dot{M})$ (M_{sun}/yr)	-5.70	-5.85
Multiplicity?	Single, runaway	Single, runaway
B-field	No detection	No detection
f_X(erg cm^{-2} s^{-1})	160 10^{-13}	7 10^{-13}

- λ Cep is the closest cousin of ζ Pup.
- We have obtained 4 *XMM-Newton* observations of λ Cep

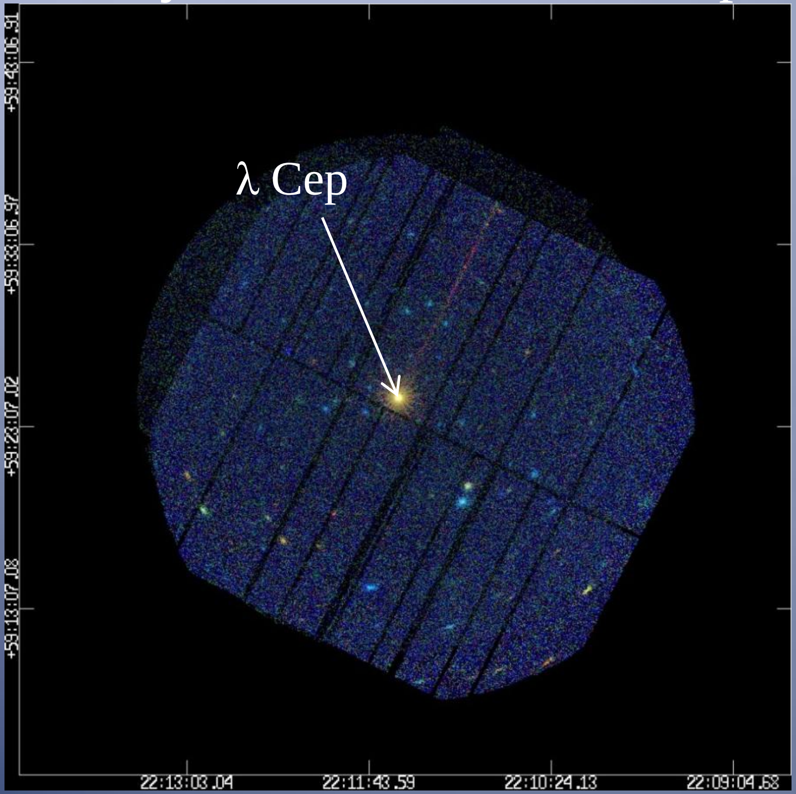
Obs	Date JD–2450000	Exposure time (ks)
I	6456.677	82.5
II	6508.319	75.8
III	6510.473	94.9
IV	6514.317	70.7

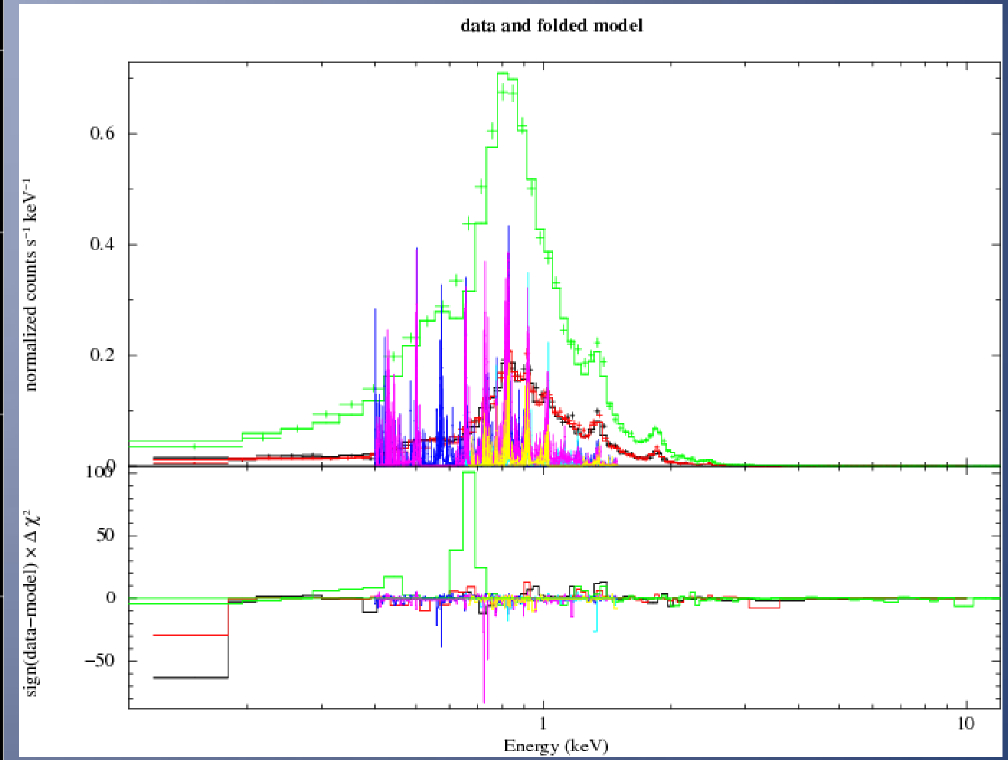
Goals of this campaign

1. Collect RGS data of λ Cep to check whether its lines are broad, blue-shifted as is the case for ζ Pup.
2. Perform a simultaneous X-ray and optical variability study and search for correlations.
3. Achieve a global fit of the RGS spectrum as we did for ζ Pup (Hervé et al. 2013, A&A 551, A83).

X-ray emission of λ Cep

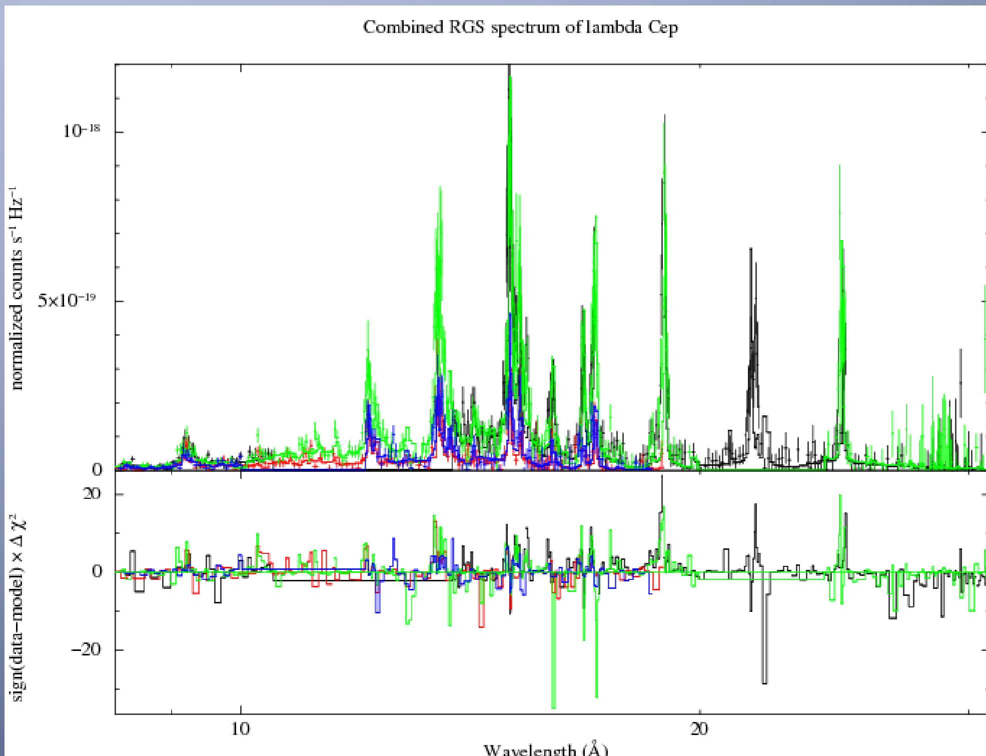
- λ Cep displays a rather soft thermal spectrum that can be represented by a combination of two plasma components @ 0.28 and 0.86 keV.

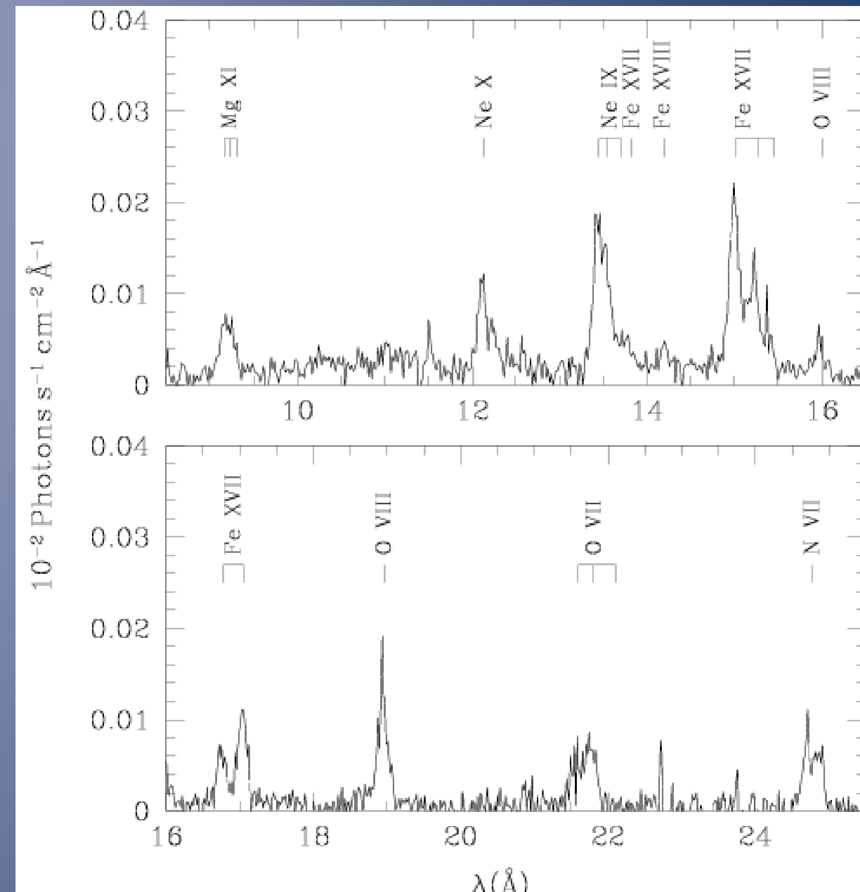




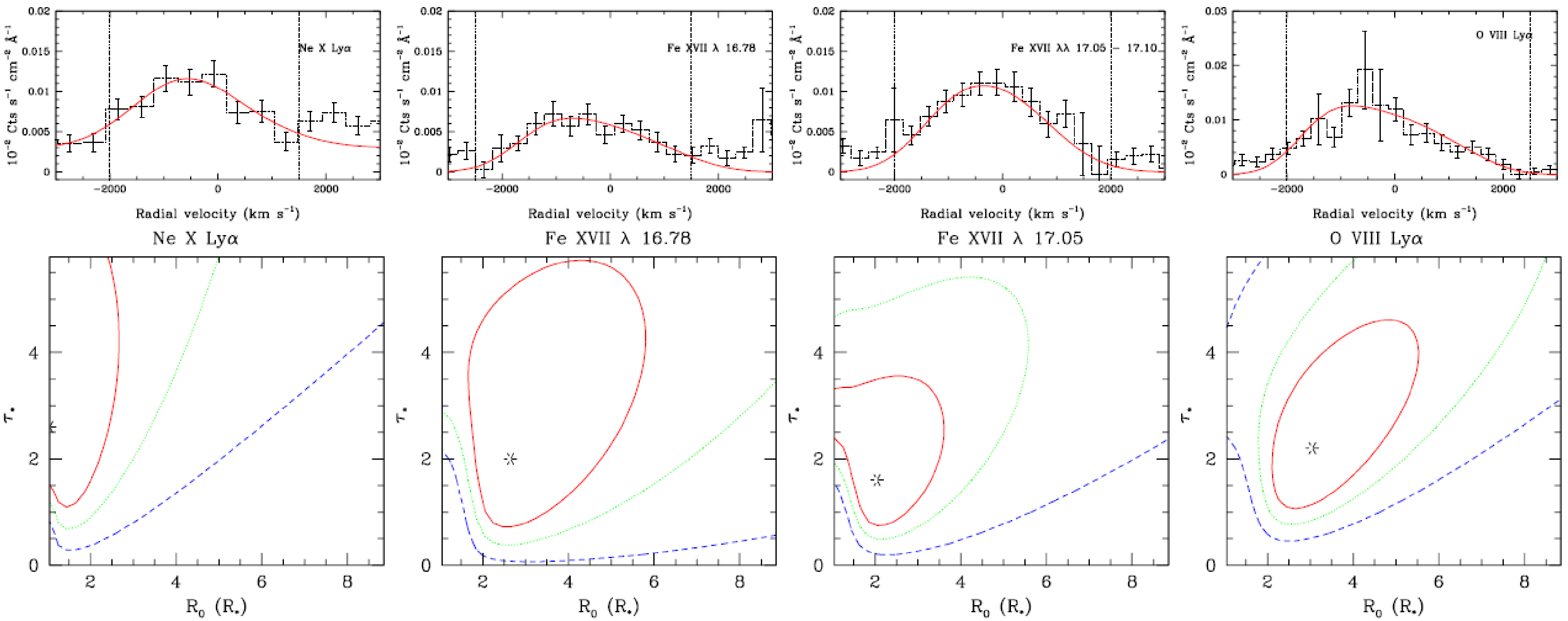
Obs.	$\log N_{\rm wind}$ ($\rm cm^{-2}$)	kT_1 (keV)	norm$_1$	kT_2 (keV)	norm$_2$	$\epsilon(N)/\epsilon(N)_\odot$	χ^2_ν (d.o.f)	$f_X^{\rm obs}$ (10^{-13} erg cm^{-2} s^{-1})	$f_X^{\rm int}$ (10^{-13} erg cm^{-2} s^{-1})
I	$21.71^{+.03}_{-.02}$	$0.276^{+.004}_{-.004}$	$(3.50^{+.20}_{-.20})\ 10^{-3}$	$0.85^{+.04}_{-.03}$	$(5.21^{+.43}_{-.42})\ 10^{-4}$	$3.78^{+.56}_{-.68}$	1.66 (1253)	6.90 ± 0.10	16.8
II	$21.74^{+.02}_{-.02}$	$0.279^{+.003}_{-.003}$	$(4.46^{+.37}_{-.34})\ 10^{-3}$	$0.86^{+.01}_{-.02}$	$(4.68^{+.34}_{-.20})\ 10^{-4}$	$2.84^{+.51}_{-.48}$	1.76 (1265)	7.24 ± 0.09	17.9
III	$21.72^{+.02}_{-.01}$	$0.279^{+.003}_{-.004}$	$(4.05^{+.42}_{-.22})\ 10^{-3}$	$0.86^{+.02}_{-.03}$	$(5.01^{+.43}_{-.23})\ 10^{-4}$	$2.99^{+.44}_{-.53}$	1.74 (1370)	7.33 ± 0.10	17.9
IV	$21.71^{+.03}_{-.02}$	$0.286^{+.005}_{-.004}$	$(3.86^{+.46}_{-.33})\ 10^{-3}$	$0.86^{+.02}_{-.02}$	$(4.79^{+.35}_{-.27})\ 10^{-4}$	$3.91^{+.78}_{-.82}$	1.33 (1179)	7.50 ± 0.10	18.3

- The combined RGS spectrum displays lines of Mg XI, Ne X, Ne IX, Fe XVII, Fe XVIII, O VII, O VIII and N VII

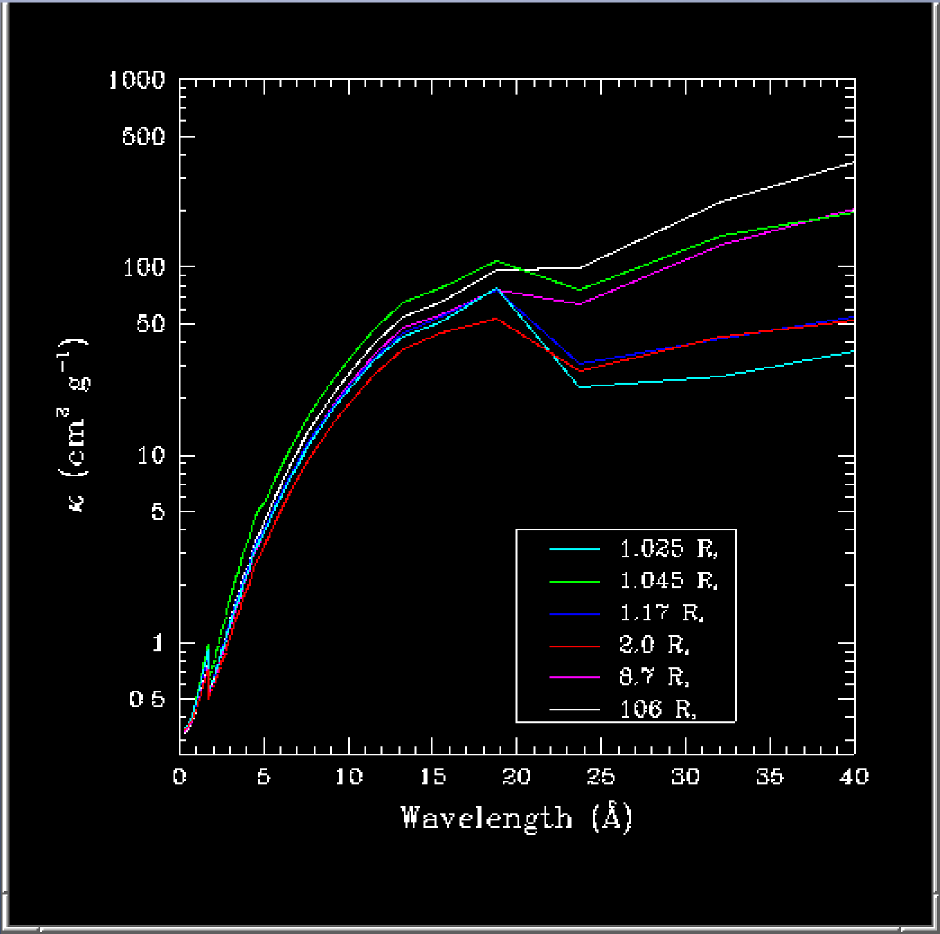


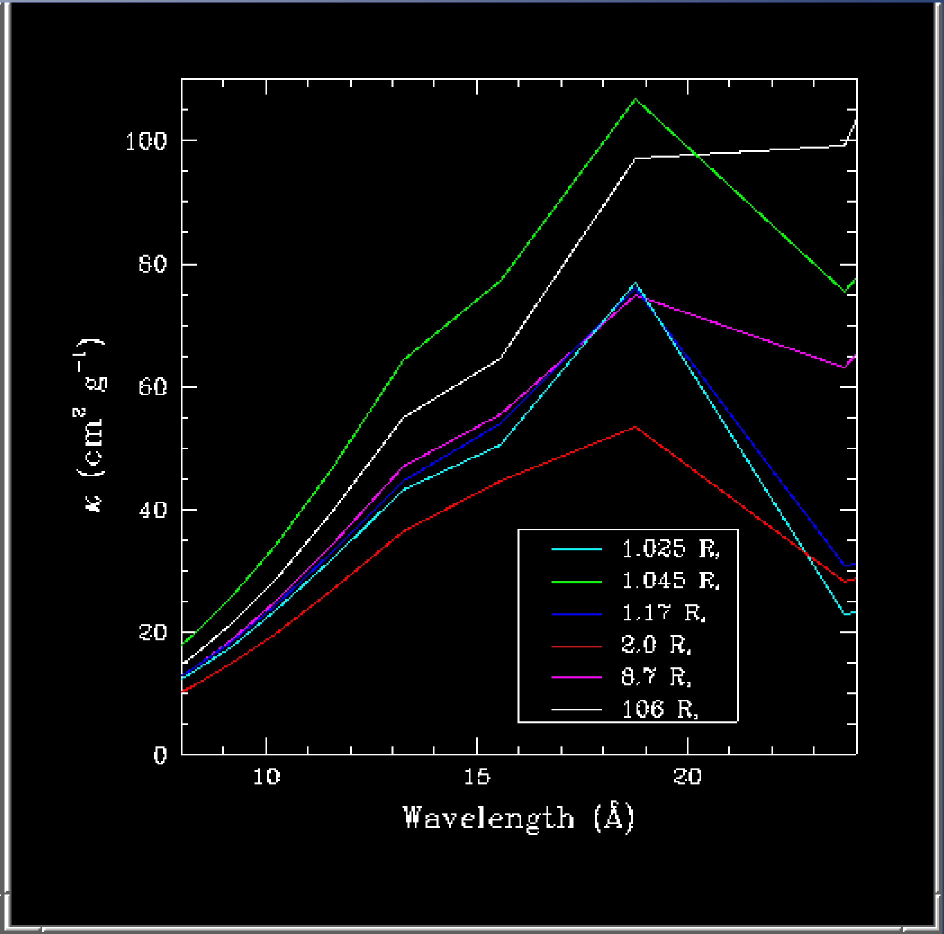


- Individual lines were fitted with the standard model assuming a homogeneous wind with no porosity. The only free parameters are the onset radius of the emission region R_0 and the typical optical depth of the wind $\tau_* = \kappa \dot{M}/(4\pi R_* v_\infty)$
- Error bars on R_0 and τ_* are quite large, but the lines are clearly broad and blue-shifted.

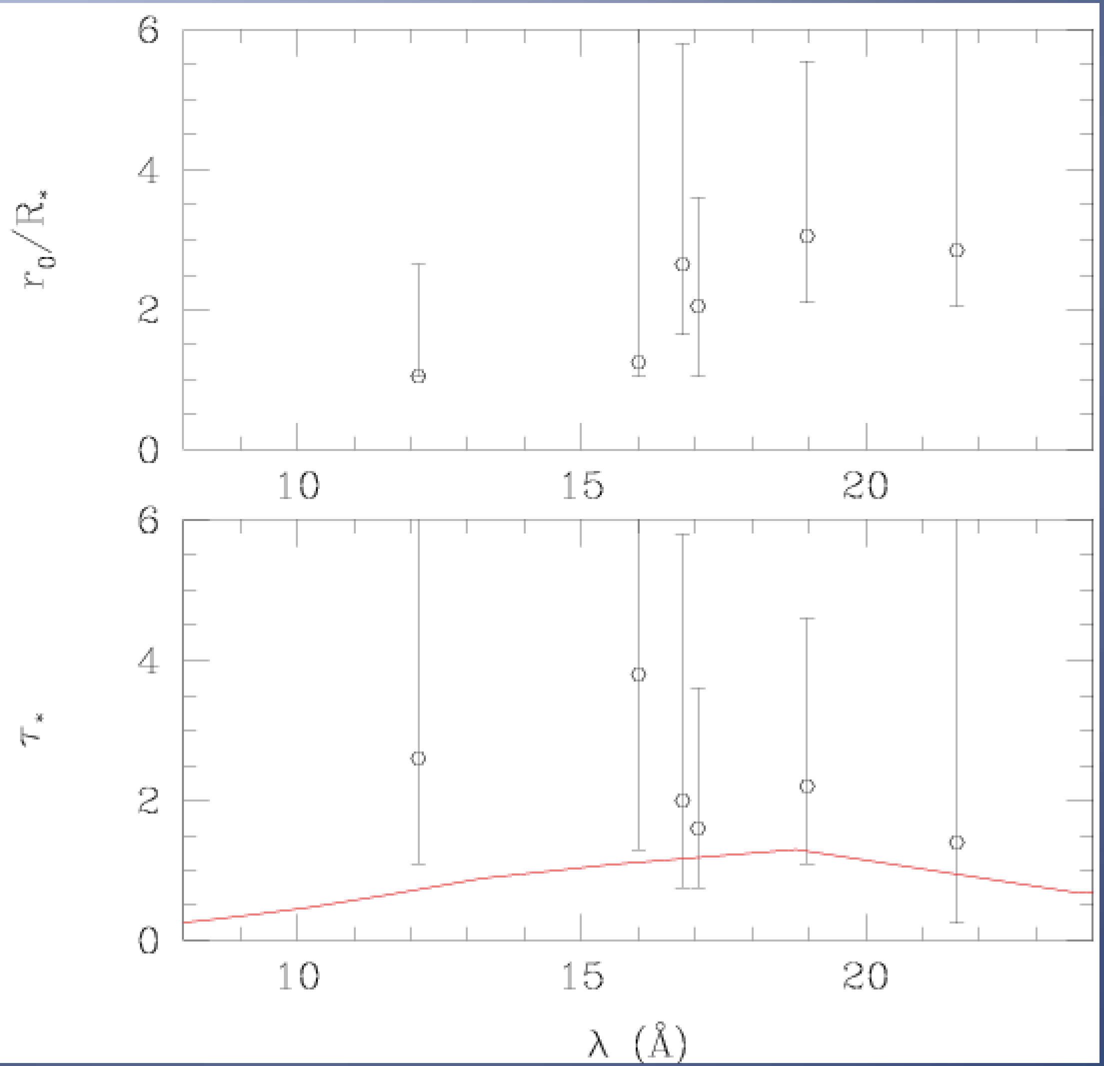


- $\tau_*(\lambda)$ should reflect $\kappa(\lambda)$ and could be used to infer $\dot{M}$ (Cohen et al. 2014, MNRAS 439, 908).
- But $\kappa(\lambda)$ also depends on the position in the wind!
- Coherent treatment done in the fit of entire spectrum (underway).



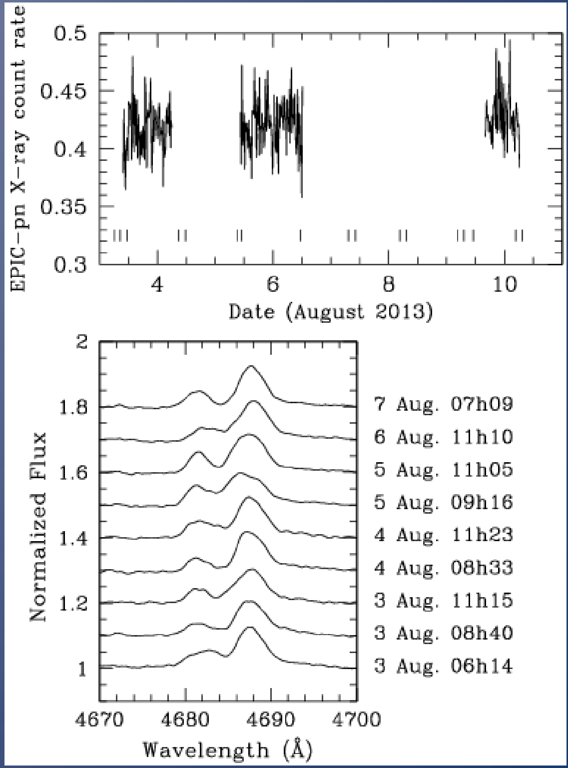


- No clear $\tau_*(\lambda)$ trend seen in our results.
- Results are consistent with mass-loss rate proposed by Bouret et al. (2012, A&A 544, A67)

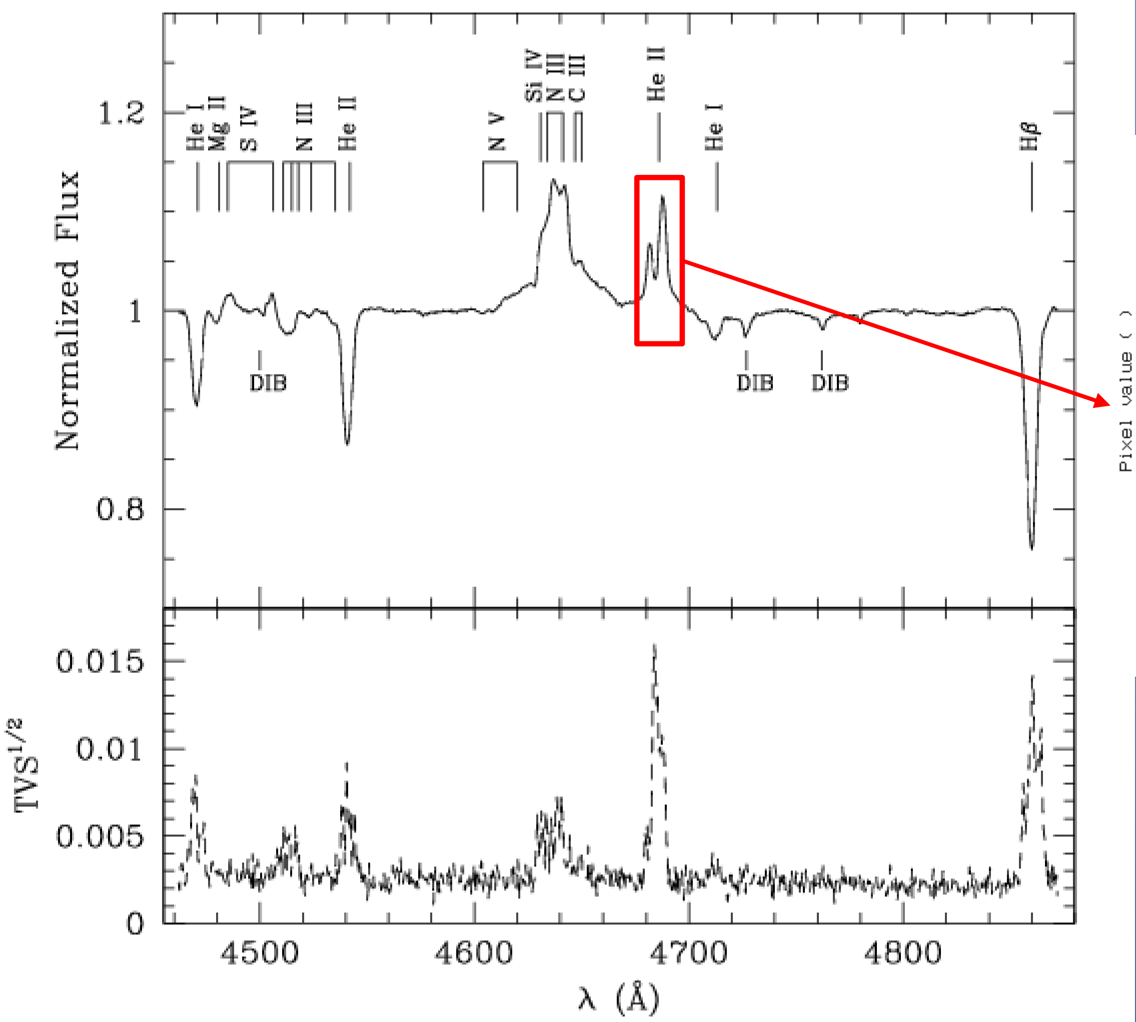


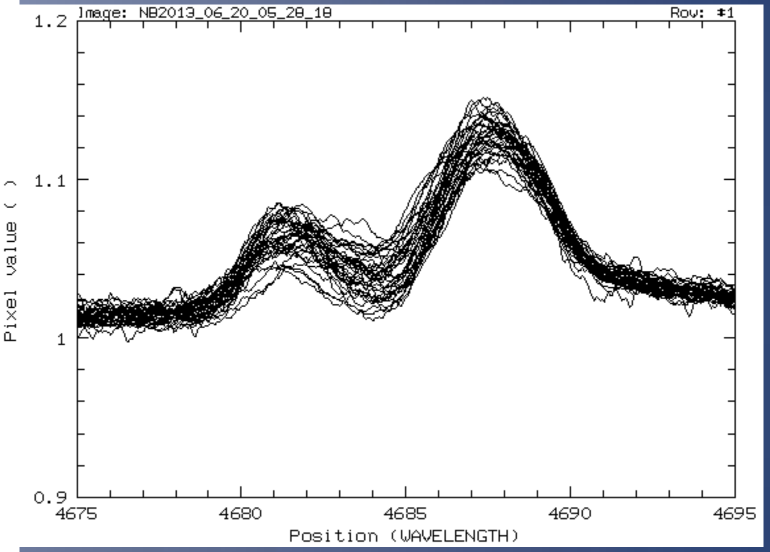
Simultaneous optical spectroscopy

- λ Cep displays optical spectroscopic variability on various time-scales (e.g. Uuh-Sonda et al. 2014, RevMexAA 50, 67).
- No stable periodicity, but recurrent variations possibly due to transient prominences (Henrichs & Sudnik 2014, IAUS 302) rotating with the star.
- Optical spectra were collected at OHP and with the TIGRE simultaneously with the *XMM-Newton* observations.

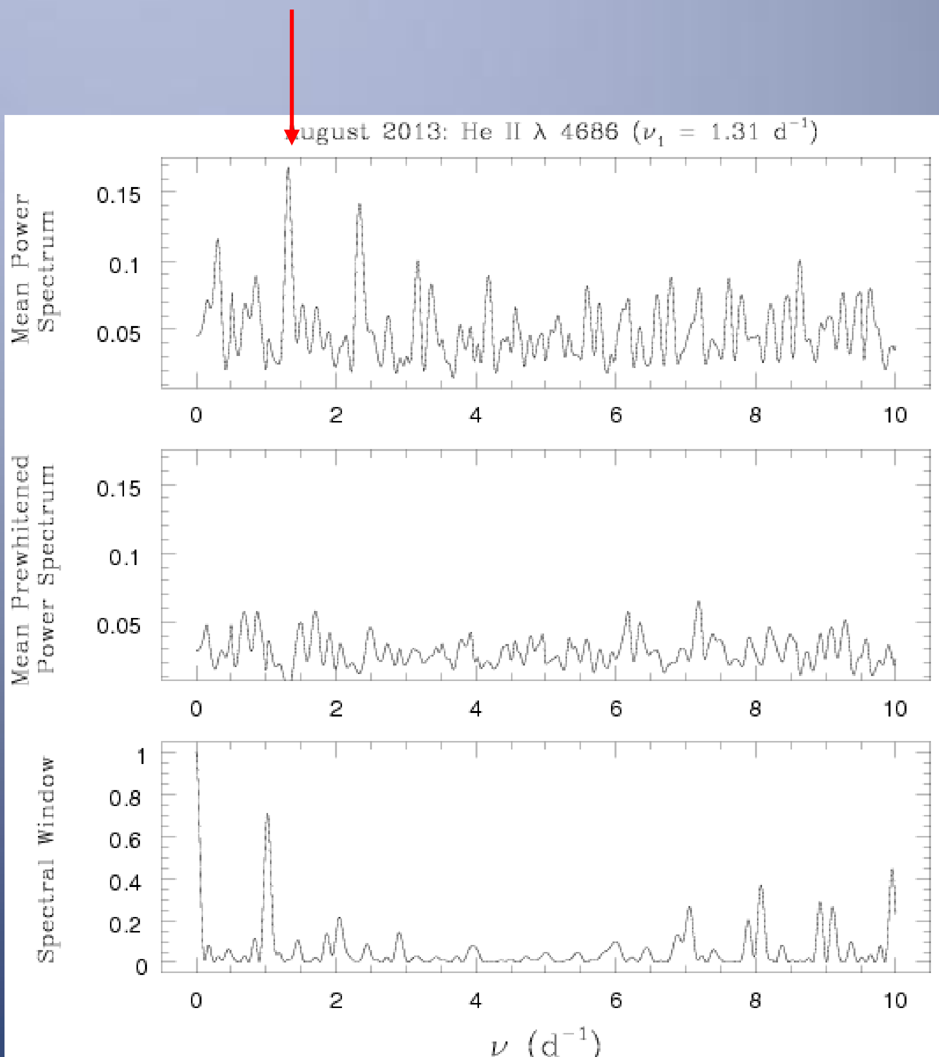


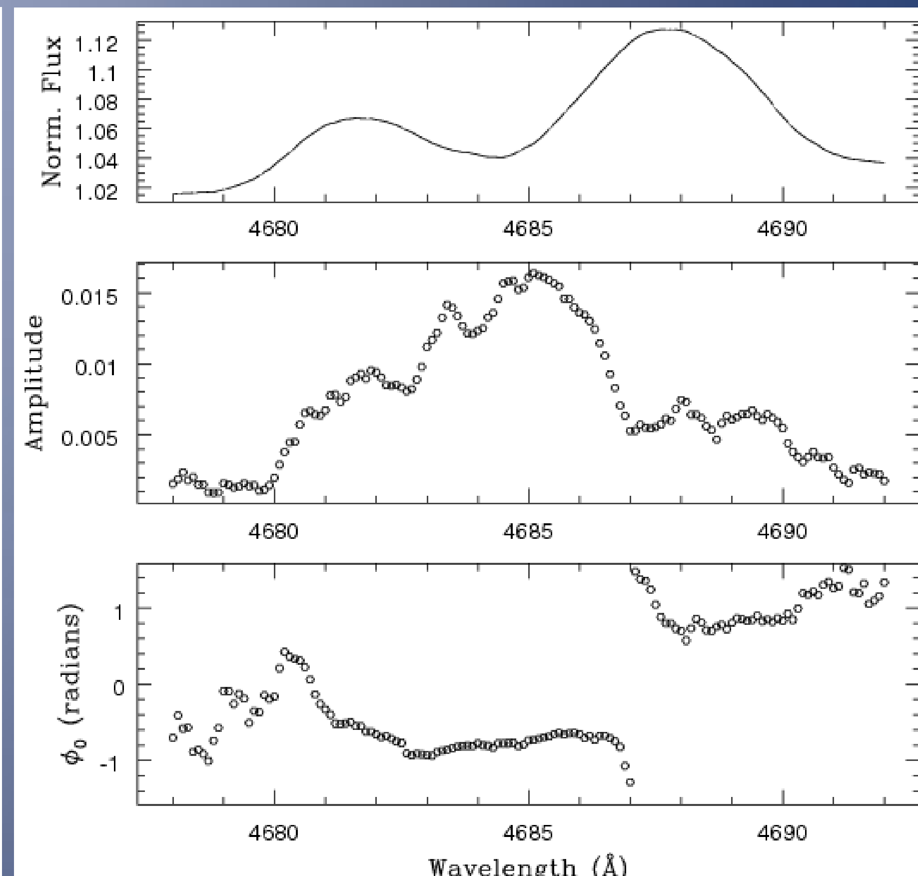
- Double-peaked He II λ 4686 line, distinctive feature of Oef stars with large variations:



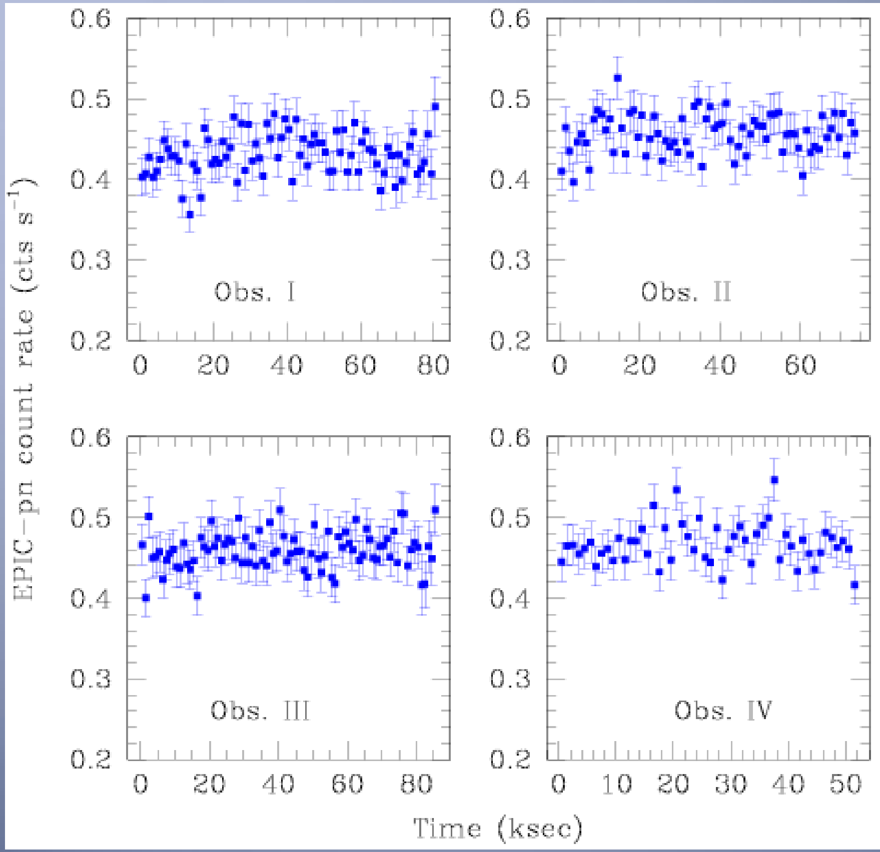


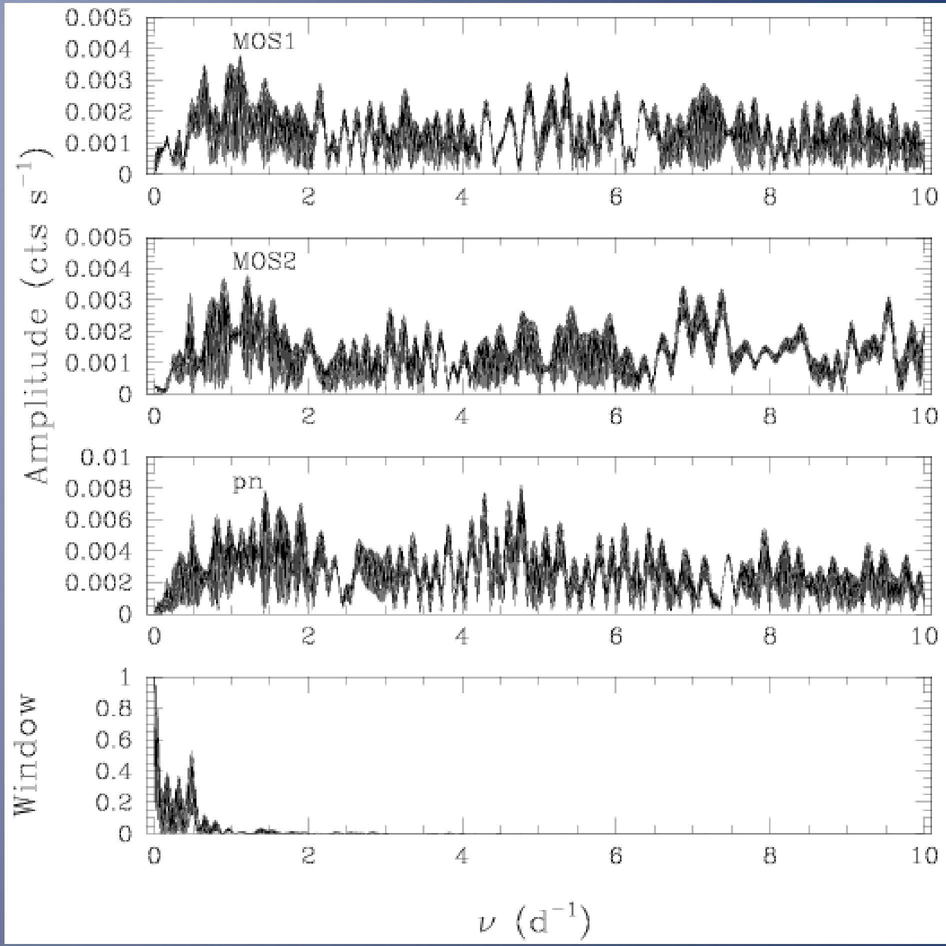
- Fourier analysis yields peak at a frequency of 1.315 d^{-1} (18.3 hrs = 66 ksec)





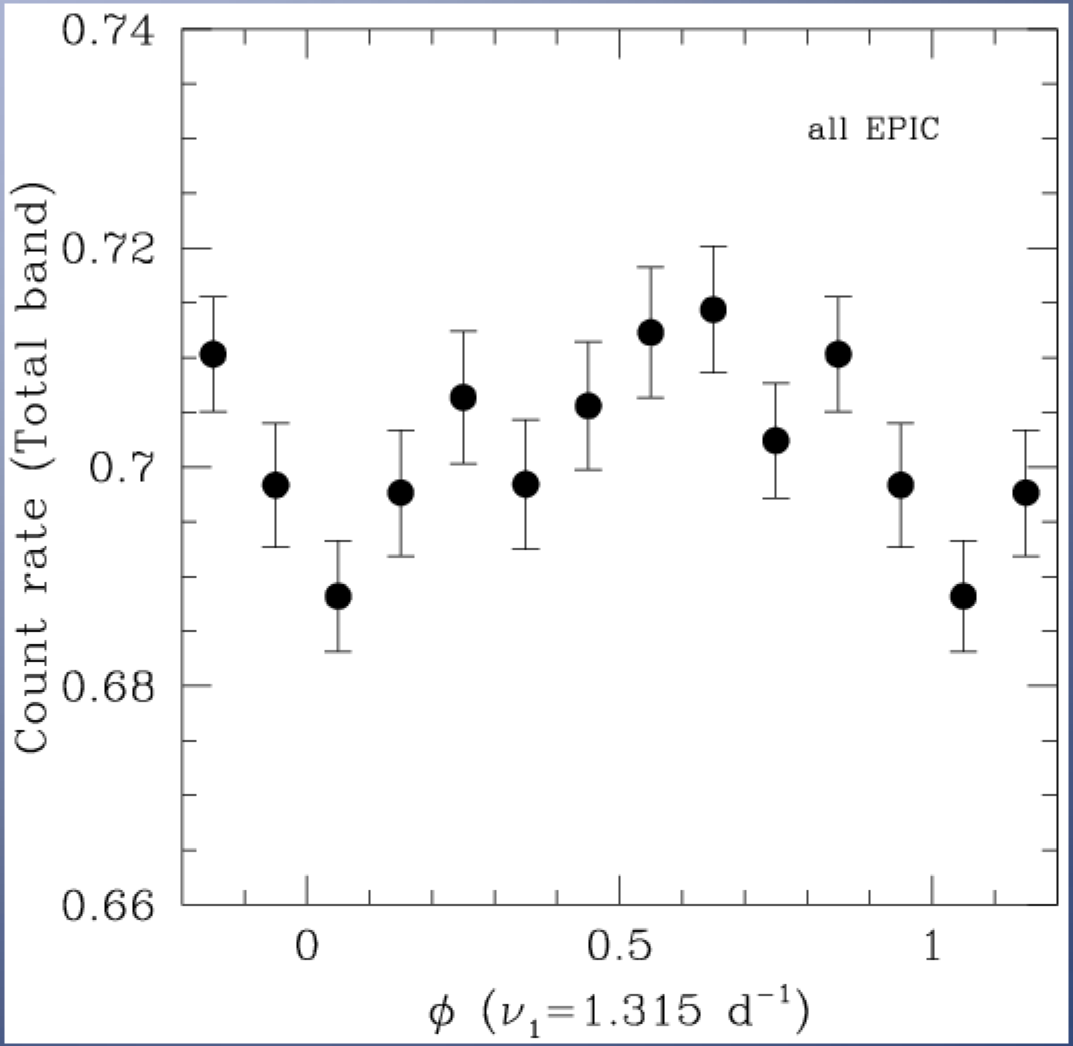
Do we see something similar in X-rays???





Obs.	Count rates (cts s^{-1})		
	MOS1	MOS2	pn
I	.117 ± .001	.119 ± .001	.430 ± .003
II	.124 ± .001	.124 ± .001	.455 ± .003
III	.125 ± .001	.126 ± .001	.459 ± .003
IV	.126 ± .002	.129 ± .002	.466 ± .003

- No significant variations on time-scales from hours to a few days, but variations on longer timescales exist.
- Folding the de-trended X-ray light curve with the 1.315 d^{-1} optical frequency reveals a modulation of ~4%, i.e. significant at 2σ.



Conclusions and future work

- λ Cep displays broad, blue-shifted X-ray spectral lines in agreement with what is expected for its $\dot{M}$
- The optical spectrum displays variability, especially in the He II λ 4686 line on timescales of hours to a few days. Variations, if any, of the X-ray flux on these timescales are limited to a few %.
- There is no indication of X-ray emission from a magnetically confined wind co-rotating with the star.
- X-rays must arise from farther out than the formation region of the He II λ 4686 line.
- A fit of the full RGS spectrum is underway to constrain the radial distribution of the hot plasma in the wind.