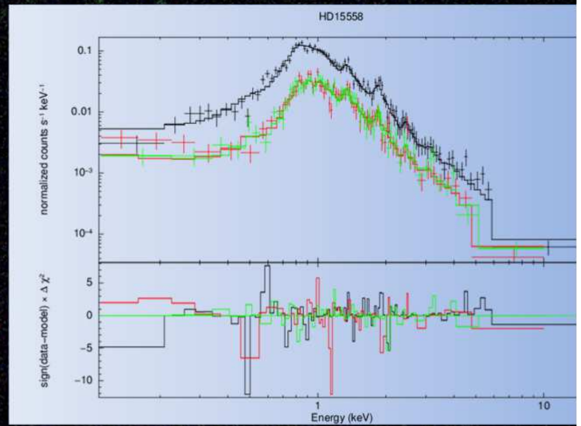
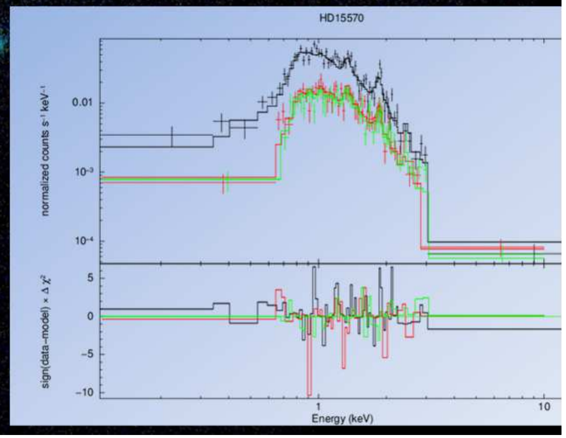
Perspectives for hot stars in the next decade



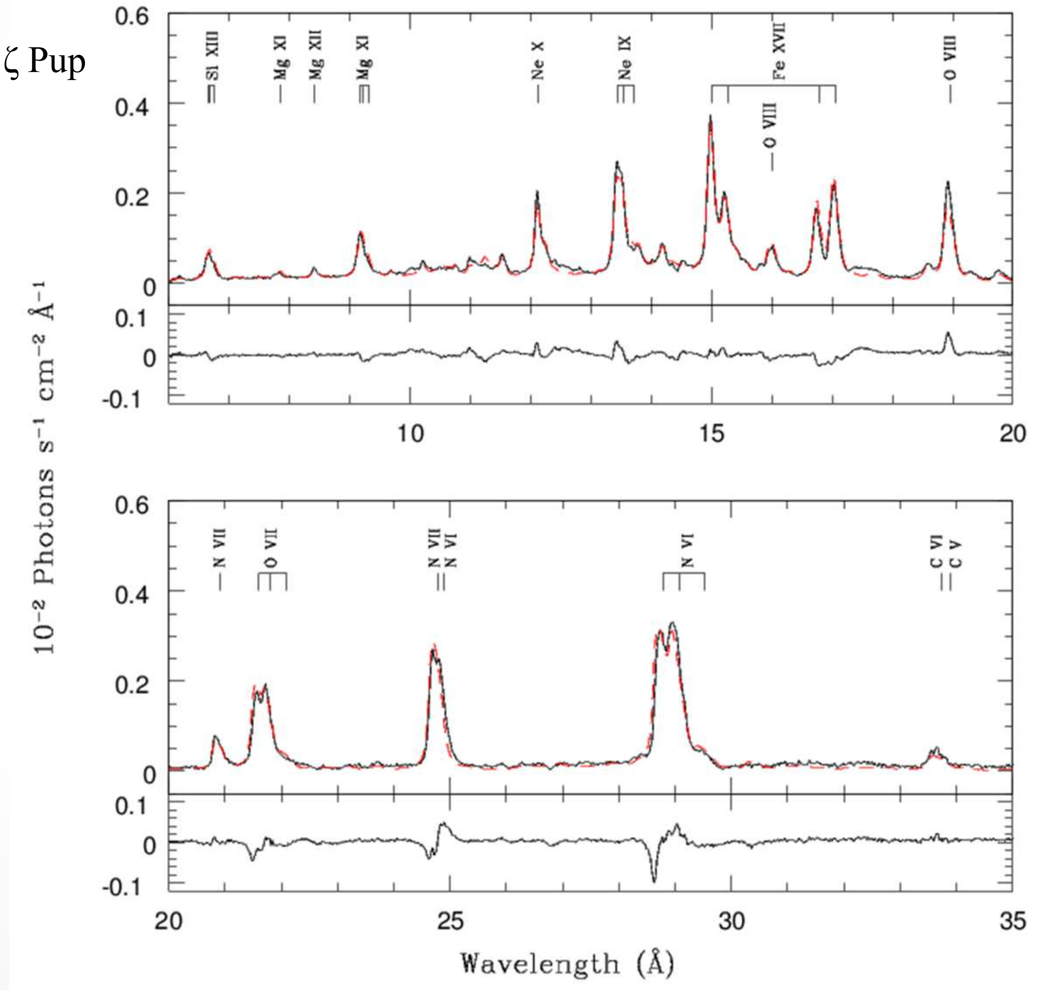


Gregor Rauw
University of Liège, Belgium

What we have learned with XMM-Newton and Chandra …about X-rays from single non-magnetic massive stars

High-resolution spectroscopy of bright O-stars has deeply changed our views:

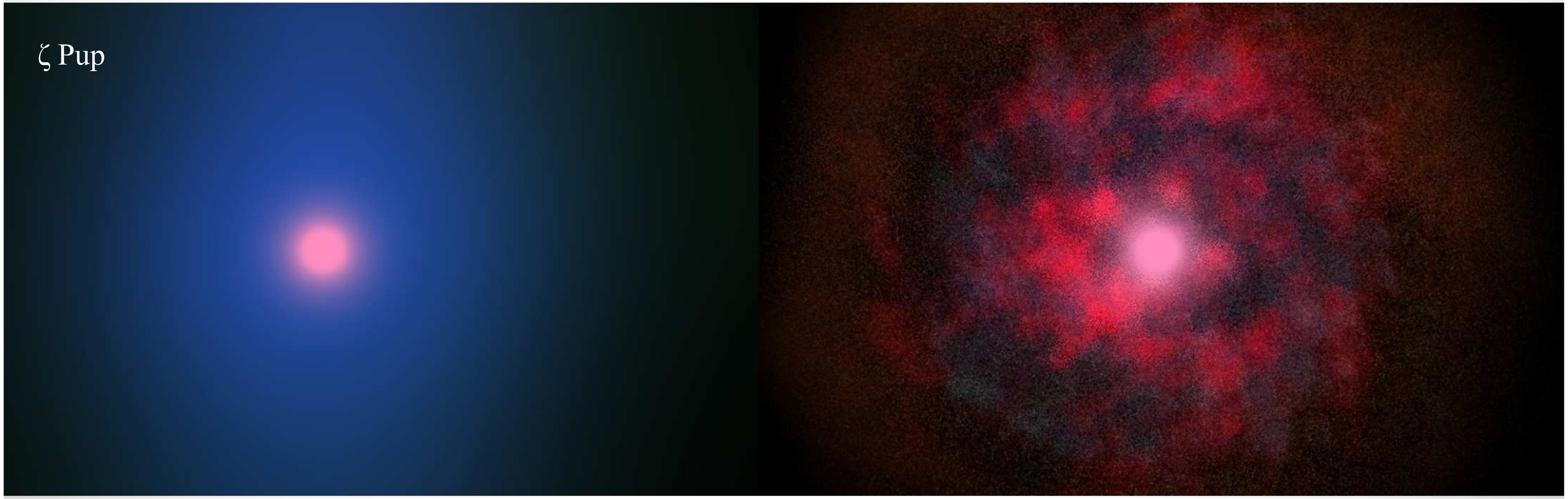
ζ Pup



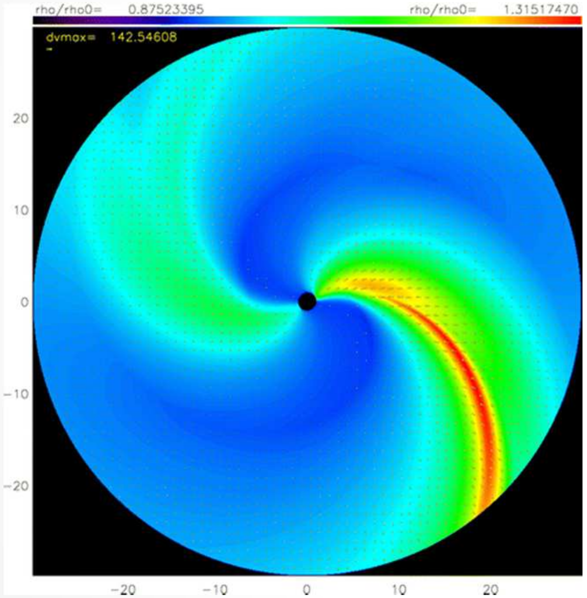
Hervé et al. 2013, A&A 551, A83

The line morphology is essentially consistent with the scenario of shock-heated plasma distributed throughout the wind, but…

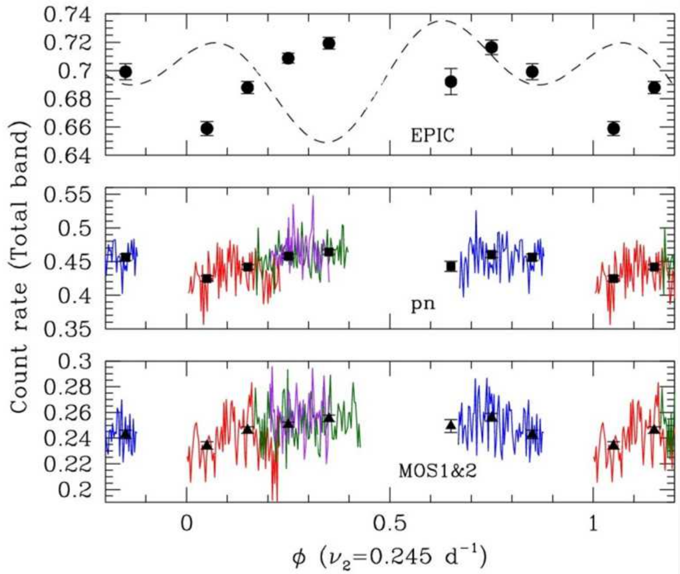
- The X-ray plasma was found to be located much closer to the photosphere than anticipated (down to 1.2 R_*, e.g. Rauw et al. 2015, A&A 580, A59).
- The mass-loss rates inferred from these spectra are lower than previously thought (e.g. Cohen et al. 2014, MNRAS 439, 908).
- The winds of massive stars are highly fragmented, containing at any time more than 10^5 independent clumps (Nazé et al. 2013, ApJ 763, 143).



Long exposures also revealed evidence for rotational modulation of the X-ray emission by so-called co-rotating interaction regions (CIRs) that are well known in the optical and UV domain: ζ Pup (Nazé et al. 2013, ApJ 763, 143), WR6 (Ignace et al. 2013, ApJ 775, 29), ξ Per (Massa et al. 2014, MNRAS 441, 2173), λ Cep (Rauw et al. 2015, A&A 580, A59).

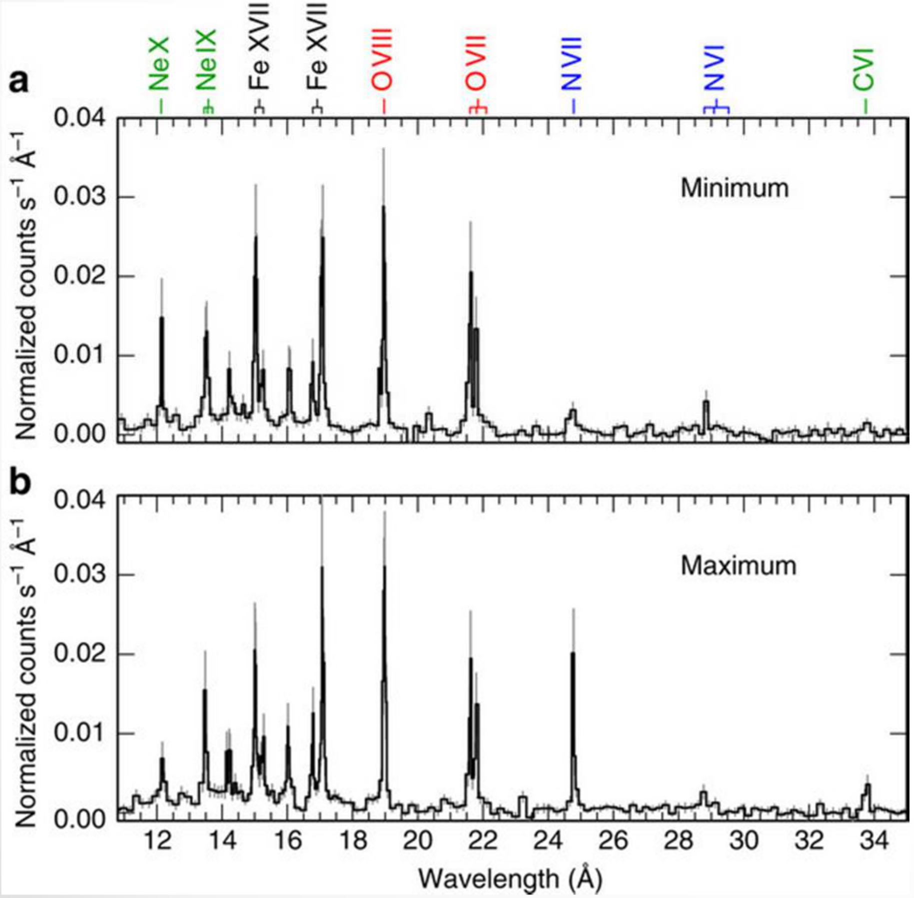


Lobel & Blomme 2008, ApJ 678, 408

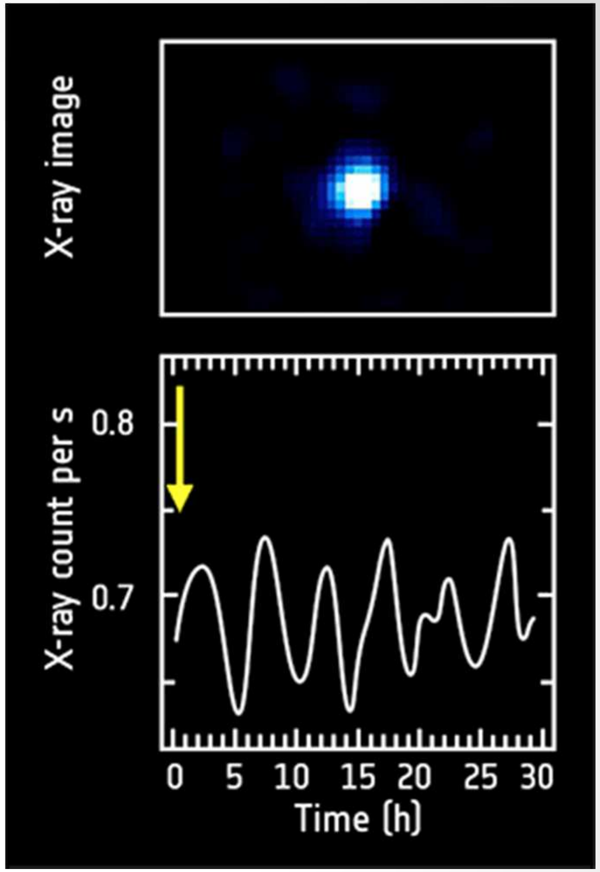


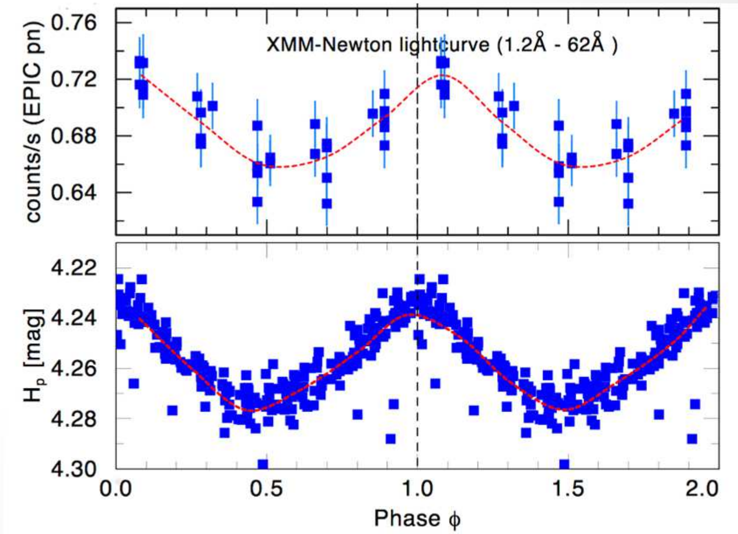
λ Cep

X-ray pulsations were detected in the magnetic B0.5IV star ξ^1 CMa (Oskinova et al. 2014, Nature Comm. 5, 4024): 10% modulation of the broadband X-ray flux on the 4.9 hrs period of its non-radial pulsations + possible modulation of the N VII Ly α line (needs confirmation).



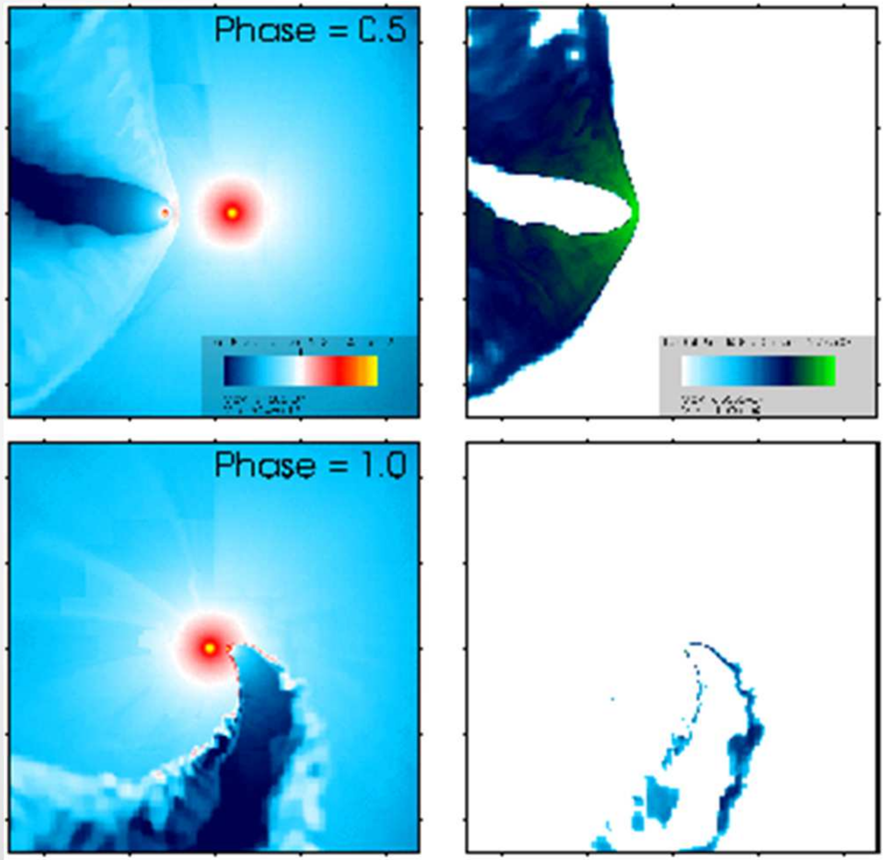
ξ^1 CMa



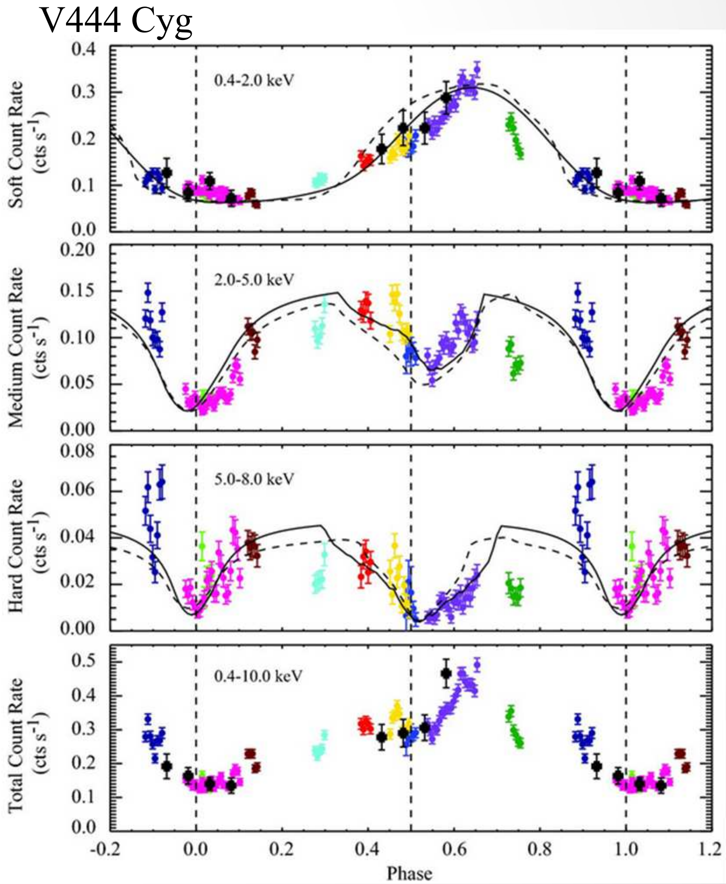


What we have learned with XMM-Newton and Chandra …about colliding winds in binaries

Massive binaries host wind interaction regions producing additional X-ray emission. The observed emission varies with phase due to changing line-of-sight optical depth and/or changing orbital separation (eccentric systems).



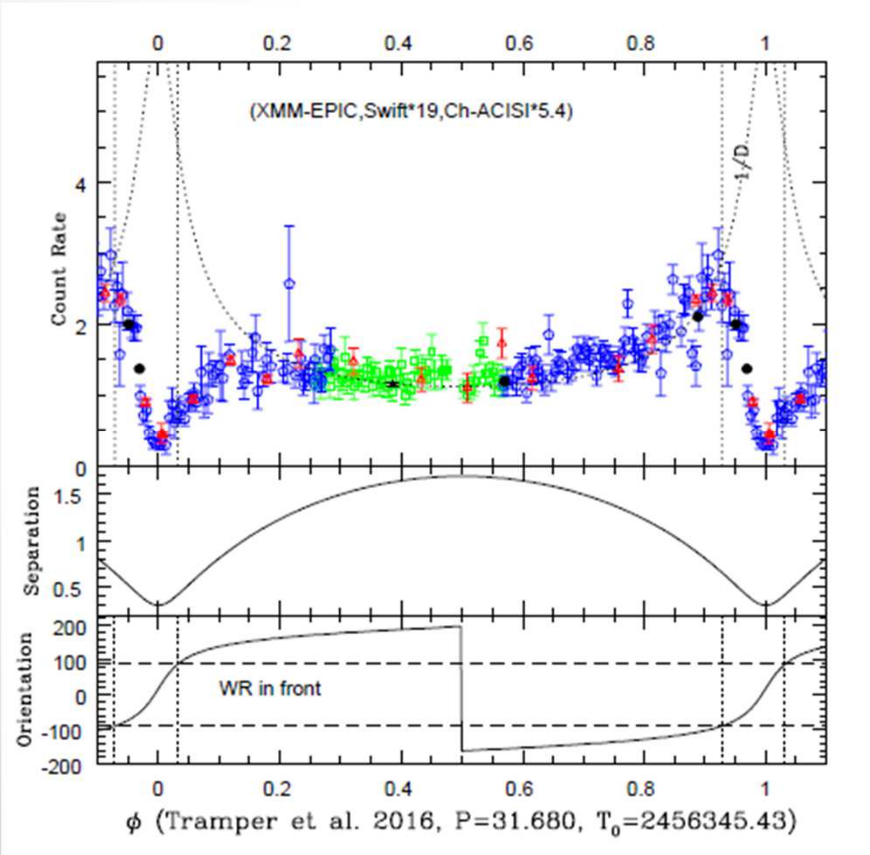
Parkin & Gosset 2011, A&A 530, A119

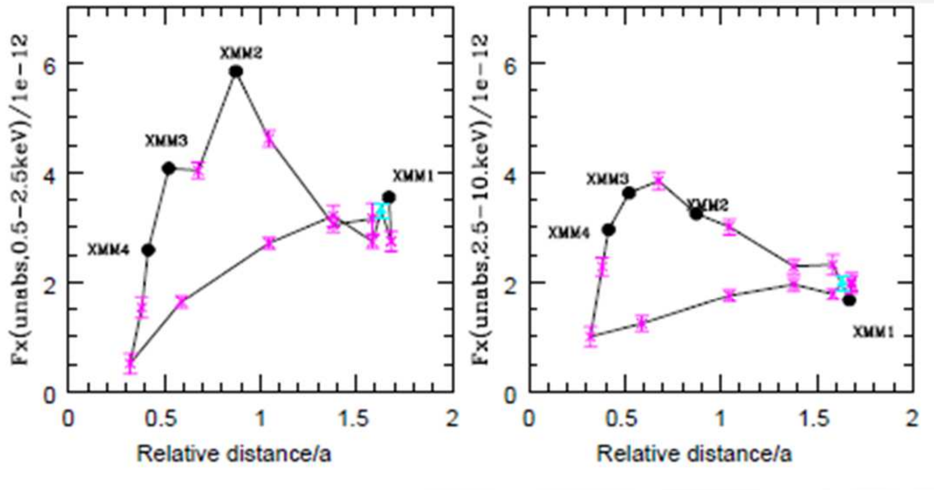


Lomax et al. 2015, A&A 573, A43

Our previous knowledge of colliding wind binaries was very much incomplete. XMM-Newton, Chandra and Swift have shown that:

- Not all massive binaries are X-ray overluminous.
- Monitoring of eccentric systems revealed complex variations with hysteresis-like loops and disruptions of shocks (e.g. Cazorla et al. 2014, A&A 561, A92; Gosset & Nazé 2016, A&A in press, arXiv1604.01536).

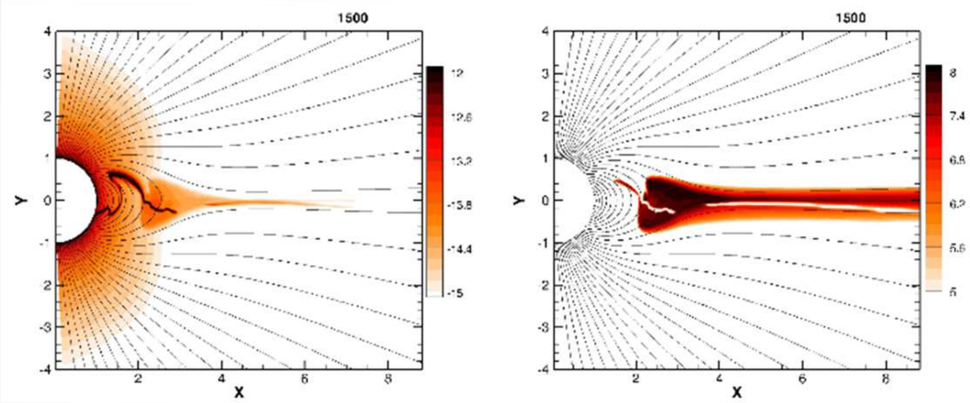




WR21a

What we have learned with XMM-Newton and Chandra …about X-rays from magnetic massive stars

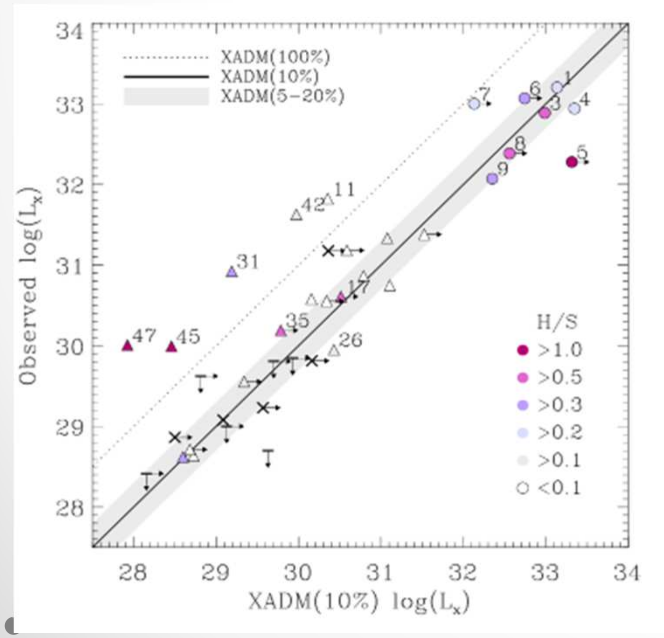
Magnetic OB stars produce X-rays in magnetically confined stellar winds.



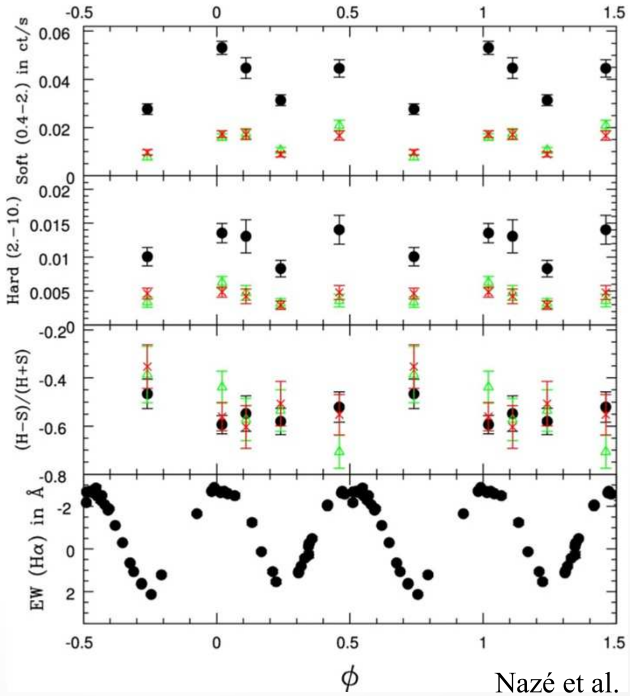
ud-Doula et al. 2014, MNRAS 441, 3600

Observations have shown that:

- L_X scales mostly as predicted (Nazé et al. 2014, ApJS 215, 10)
- Most magnetic OB stars display rotational modulation of f_X (e.g. Petit et al. 2015, MNRAS 453, 3288)



Nazé et al. 2014, ApJS 215, 10



CPD-28° 2561

Nazé et al. 2015, MNRAS 452, 2641

Hot/massive stars in the next decade

1. High-resolution spectroscopy:

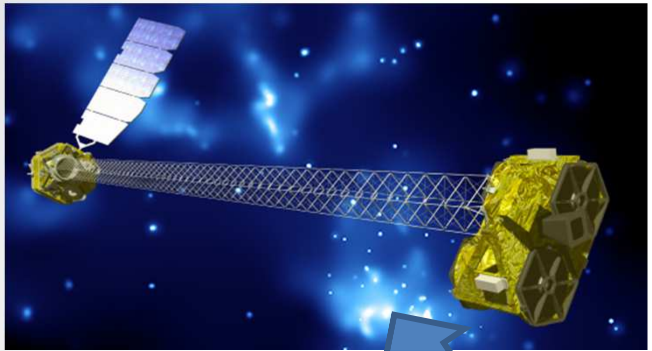
- There is still a handful of massive stars that are within reach of RGS, but these objects require ~ 300 ks exposures to achieve a reasonable S/N.
- Spectral line variability studies for the X-ray brightest O-stars will shed new light on the effect of co-rotating large-scale structures.

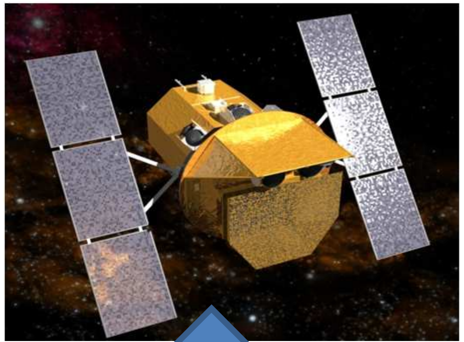
2. XMM-Newton does an excellent job in the time domain (stability of the instruments + simultaneous data from three EPIC cameras):

- Opportunities to study structures in the winds of bright O or WR stars in coordination with ground-based (optical) or space-borne (UV) spectroscopy or photometry.
- Monitor critical phases of colliding wind binary systems to probe the physics of the shocks.
- Monitor rotational modulation of the X-ray emission from hot star magnetospheres.

Hot/massive stars in the next decade

3. Synergies with other X-ray facilities:

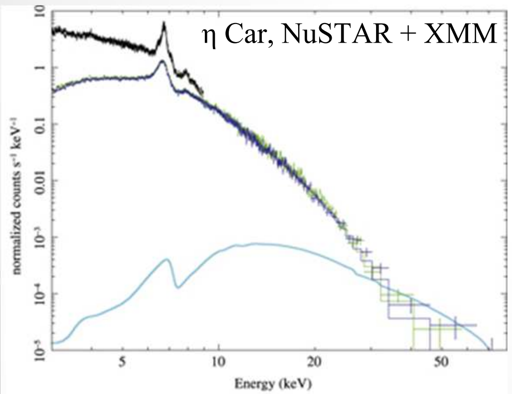




NuSTAR: studies of hard tails of colliding wind systems and γ Cas analogs.

Swift: monitoring of colliding wind systems.

eROSITA: follow-up of interesting sources detected during the survey.



Hamaguchi et al. 2016, ApJ 817, 23

Conclusions

The high spectral resolution and excellent monitoring capabilities of XMM-Newton tremendously improved our view of hot/massive stars and their X-ray emission.

Many questions related to the physics of shocks in stellar winds remain that can be addressed in the coming decade with XMM-Newton.

Important aspects include:

- Studies in the time domain (colliding winds, variability of single stars,…)
- Synergies with other X-ray facilities and with ground-based telescopes (can be private telescopes) or space-borne observatories (e.g. HST, BRITE, MOST,…)

Some of these topics do require substantial amounts of observing time (to cover the relevant time scales and/or to achieve the requested S/N ratios).