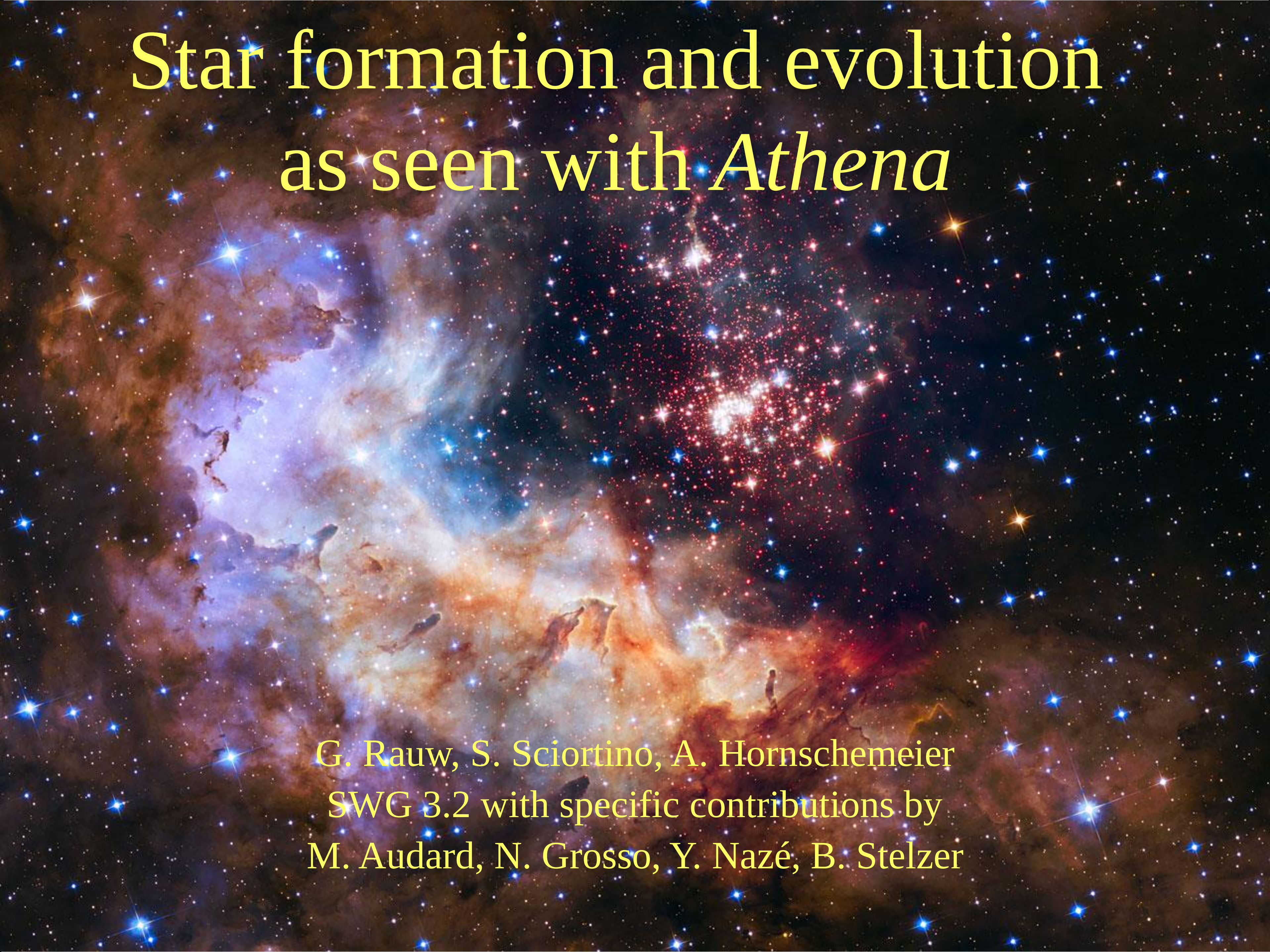


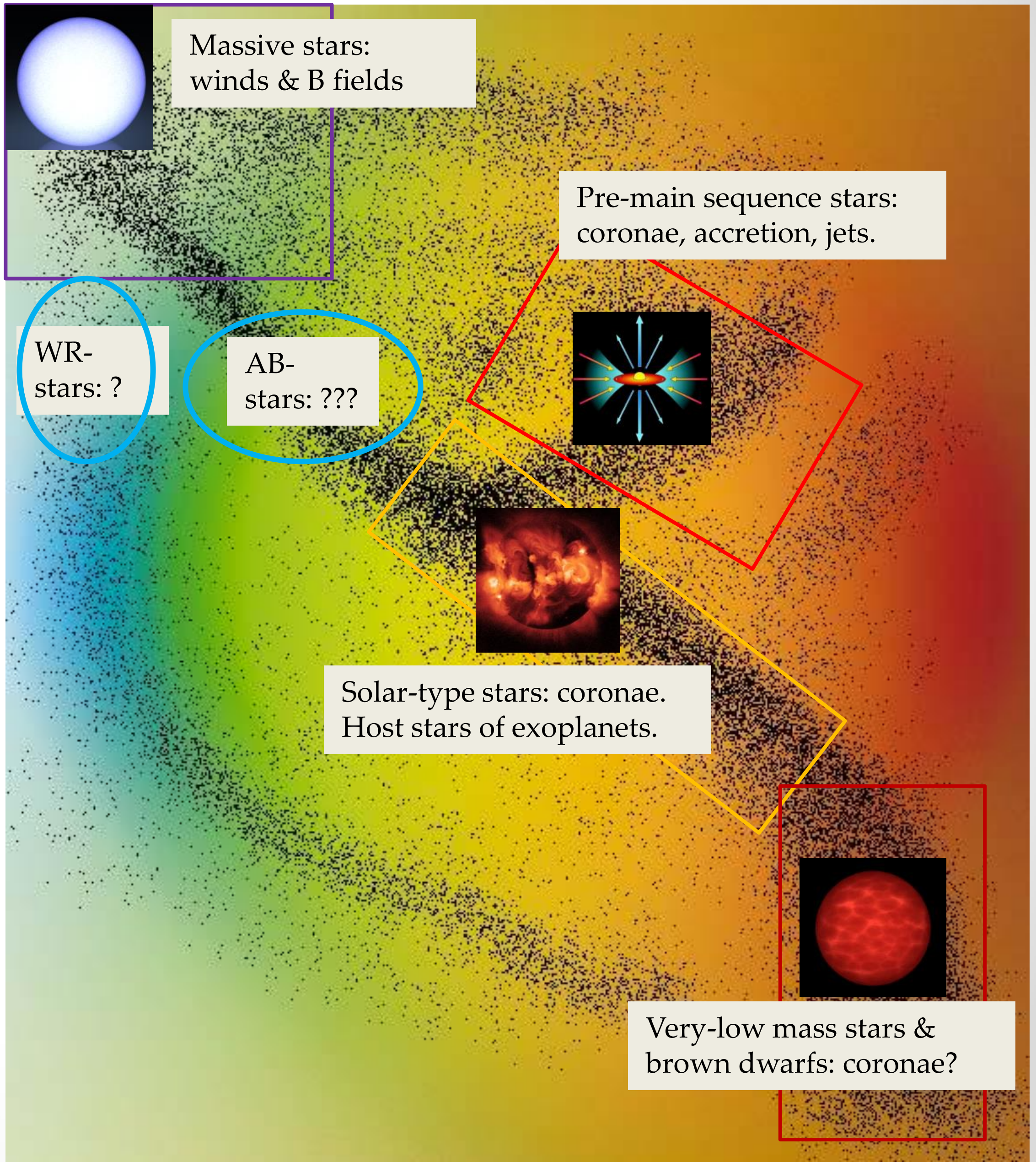
Star formation and evolution as seen with *Athena*

G. Rauw, S. Sciortino, A. Hornschemeier
SWG 3.2 with specific contributions by
M. Audard, N. Grosso, Y. Nazé, B. Stelzer

X-ray emission from normal stars

X-ray emission is observed over wide parts of the HRD.

The mechanisms at work are different for massive and low-mass stars.



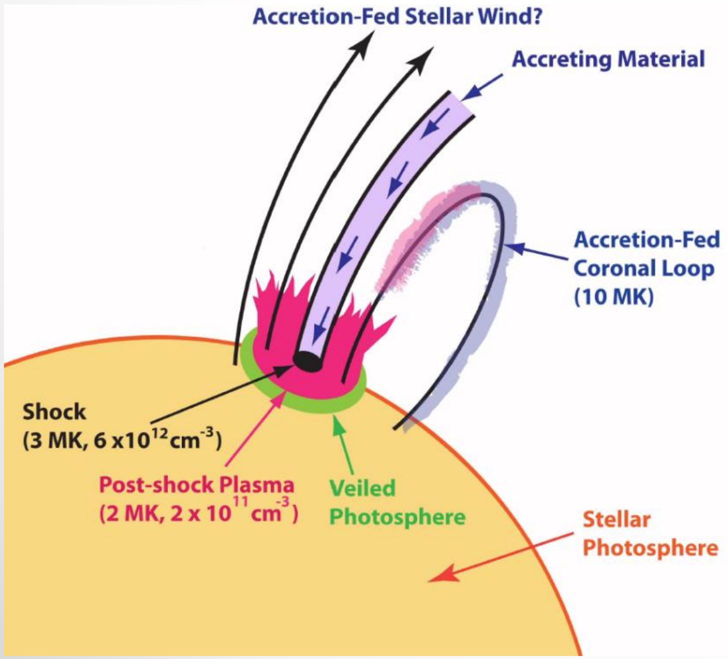
X-ray emission from low-mass stars

In young stellar objects, matter accretes episodically from a warped circumstellar disk (see also poster 8.02 by Schneider et al.).

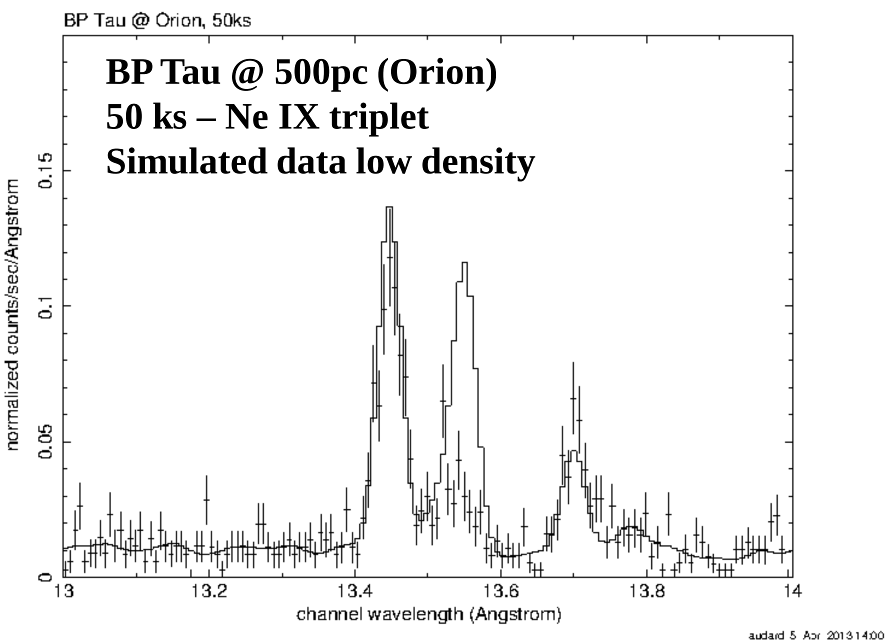
High-resolution spectroscopy has so far been obtained for 7 YSOs only.

4 objects display He-like triplets indicating high plasma densities (soft X-ray emission from material behind accretion shock) .

Athena X-IFU will enlarge the sample, provide measures of density stratification via simultaneous observations of several triplets, provide estimates of optical depths and Doppler shifts.



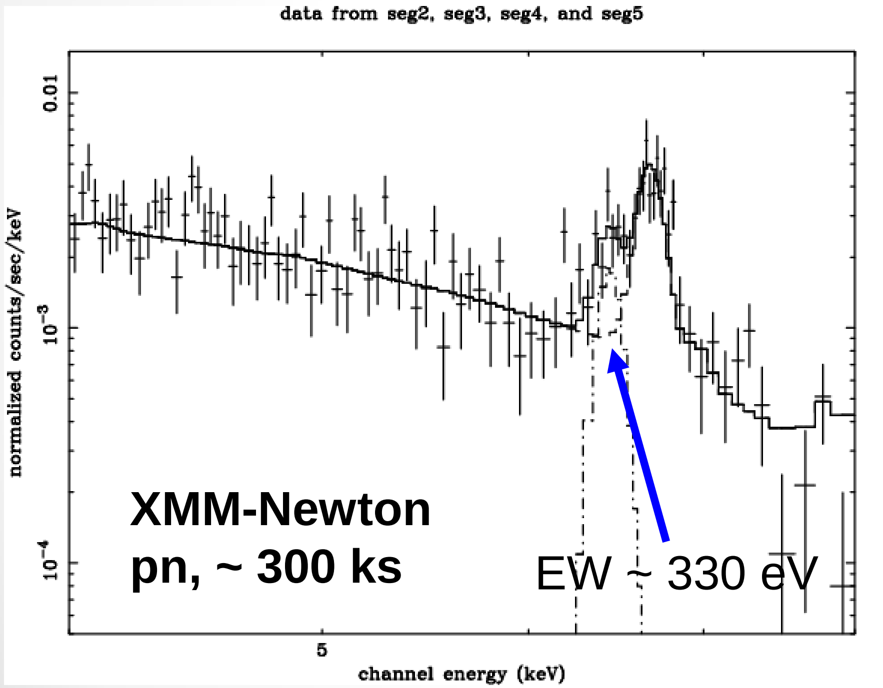
Brickhouse et al. 2010, ApJ 710, 1835



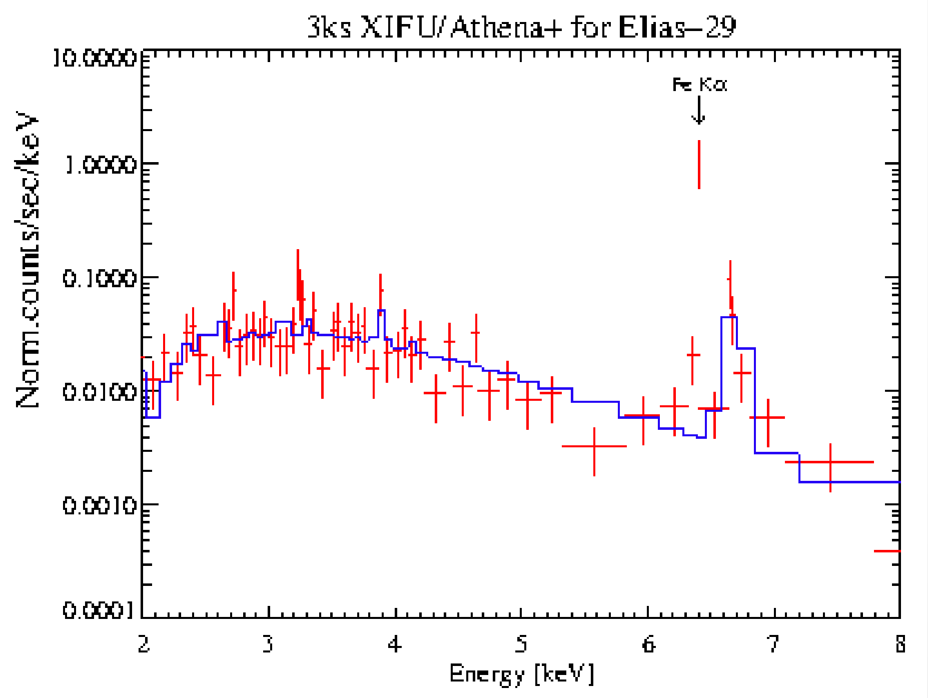
Sciortino et al. 2013, arXiv1306.2333

The Fe Kα 6.4 keV fluorescent line was detected in a dozen objects with EWs indicating an origin in the disk rather than the photosphere, but the link to X-ray flares is unclear (Czesla & Schmitt 2007, A&A 470, L13; Giardino et al. 2007, A&A 475, 891) possibly suggesting collisional ionization by non-thermal electrons.

Time resolved spectroscopy with Athena can give a handle on the process at work. E.g. Elias 29 ($f_X \sim 10^{-12}$ erg cm^{-2} s^{-1}) in ρ Oph



Giardino et al. 2007, A&A 475, 891

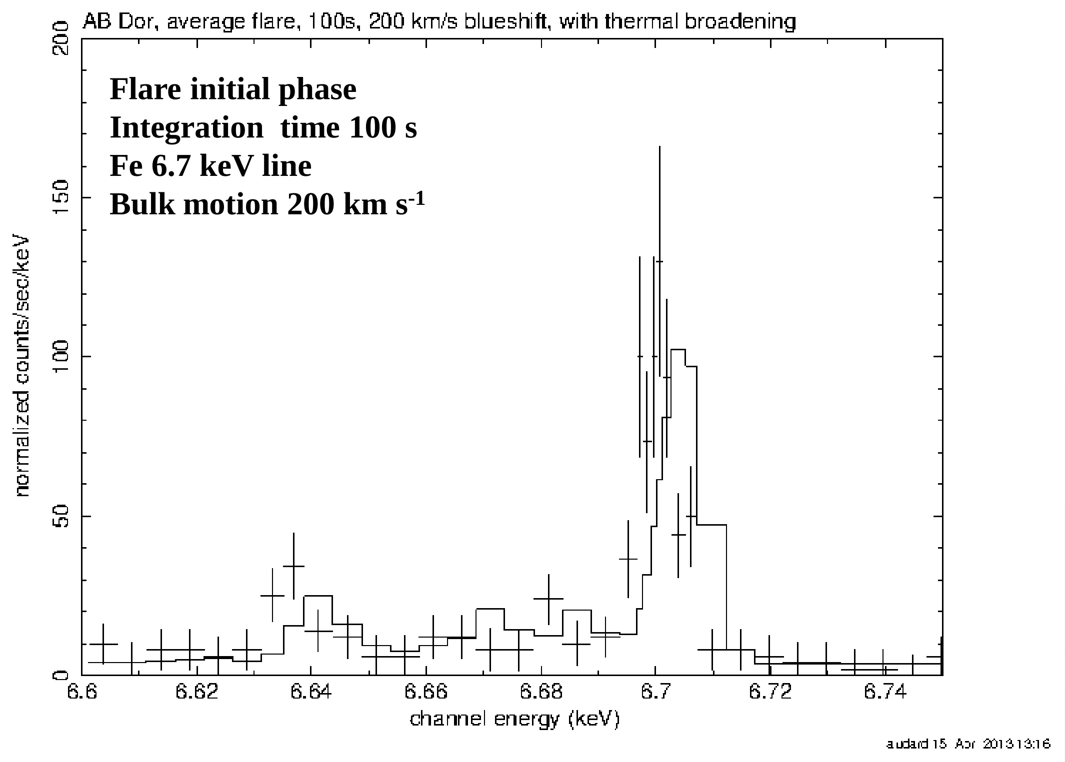


Sciortino et al. 2013, arXiv1306.2333

Extreme flares occur in some classical T Tauri stars, dMe or very active late-type stars. Huge flares in cTTs (peak L_X ~ 10^{32} erg s^{-1}, peak T ~ 200 MK) likely arise in magnetic structures connecting the star and the circumstellar disk at corotation radius. Effect of energy release on disk need to be fully assessed, bulk motion of heated disk material expected.

Athena offers the possibility to measure the bulk motion of the plasma in the early flare phases on short timescales. See also poster 8.01 by Argiroffi et al.

E.g. simulation of 100 s X-IFU integration on the nearby active star AB Dor:



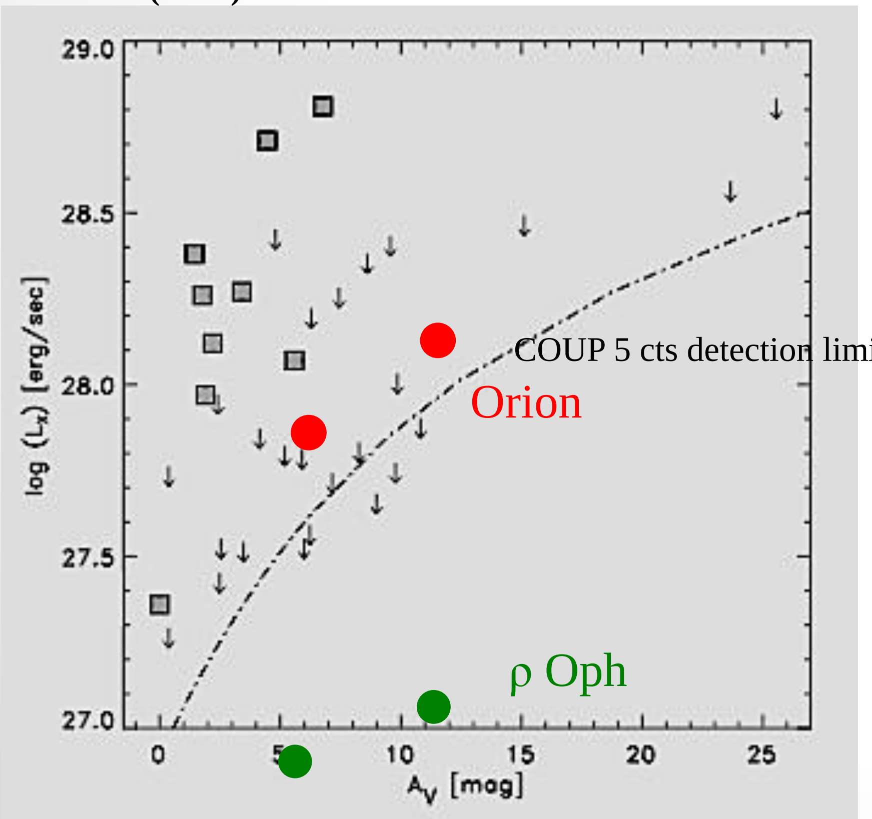
Sciortino et al. 2013, arXiv1306.2333

Are there differences in the L_X/L_{bol} ratio of accreting vs. non-accreting YSOs (Stelzer et al. 2012, A&A 537, A135)? Currently too low a number of low L_X sources are detected for a firm conclusion. Assume a strongly absorbed young BD: $f_{X,abs} \sim 5\ 10^{-17}$ erg cm^{-2} s^{-1} (0.5 – 2 keV) with kT = 1 keV

Intrinsic $L_X = 10^{28.0}$ erg s^{-1} A_V = 10 mag @ 450 pc

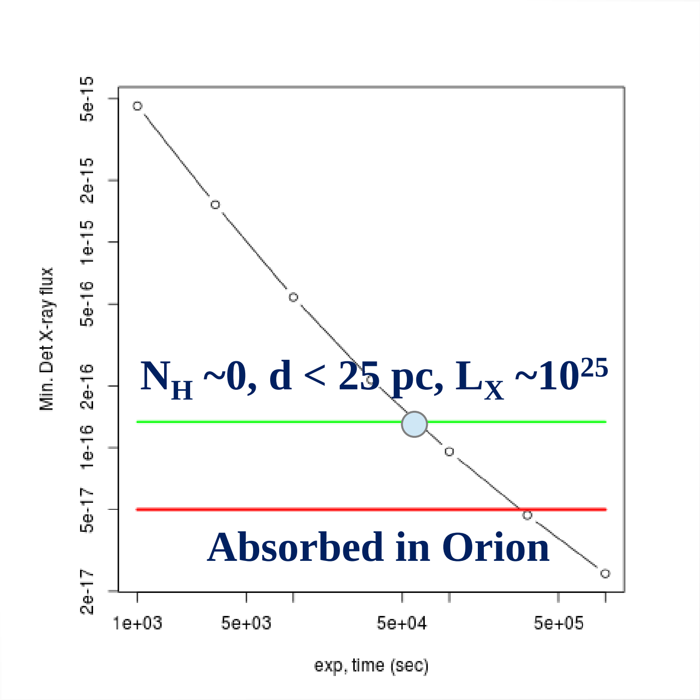
Intrinsic $L_X = 10^{27.8}$ erg s^{-1} A_V = 5 mag @ 450 pc

COUP (ONC) - 1 field for 850ks Chandra



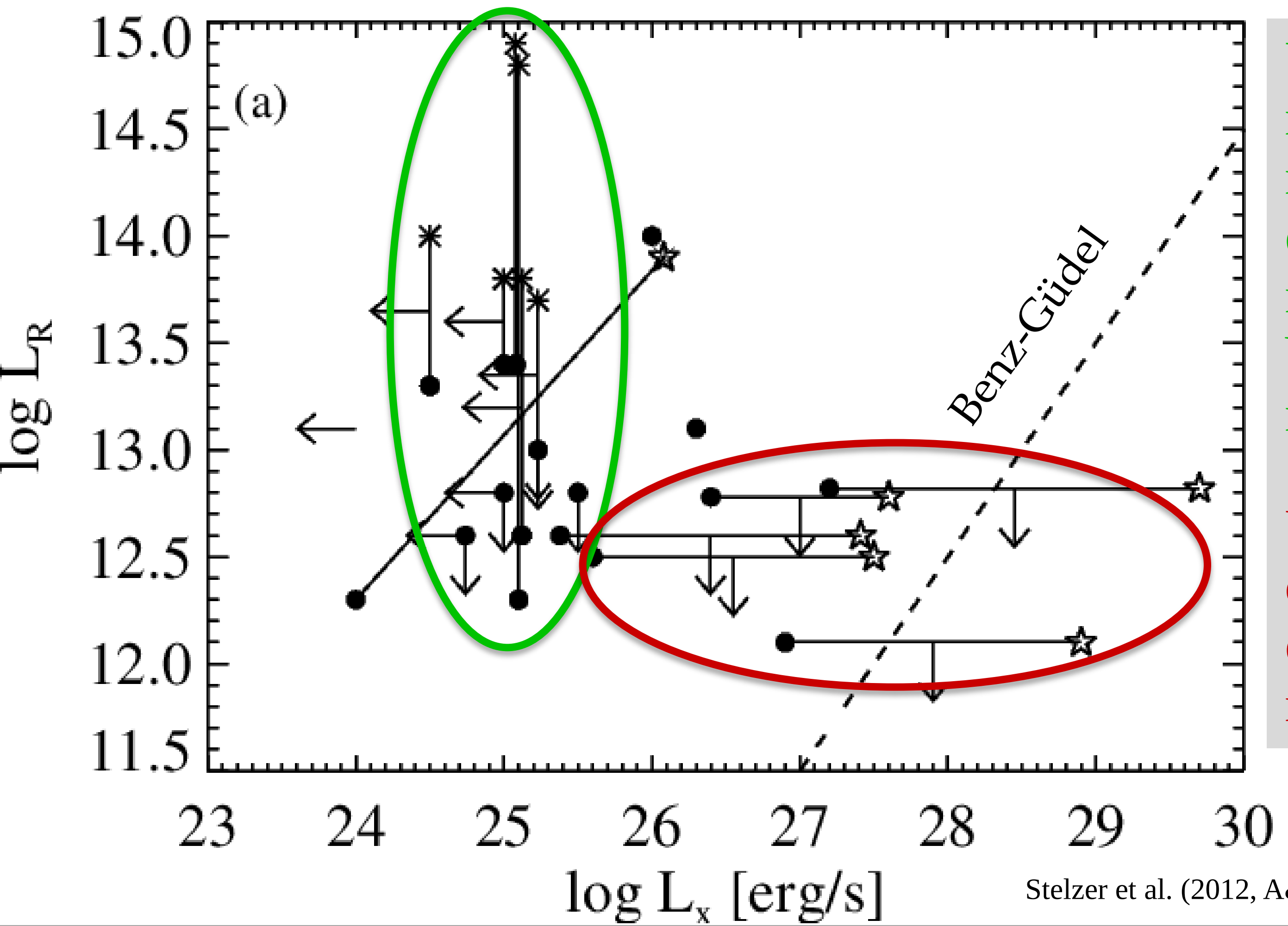
Preibisch et al. 2005, ApJS 160, 582

Deep (~ 400 ks) observations with Athena will detect these objects at the 5 σ level.



What is the X-ray emission mechanism of ultra cool dwarfs (spectral types M7 and later)? Some UCDs violate the Güdel-Benz relation between X-ray and radio luminosity.

Athena can detect nearby UCDs with log L_X ~ 25 in less than 50 ks.



UCDs with bright radio emission show radio bursts → electron cyclotron maser (Hallinan et al. 2006; 2008) but no or very weak X-rays

UCDs without detectable radio emission but with X-ray flares

Stelzer et al. (2012, A&A 537A, 94)

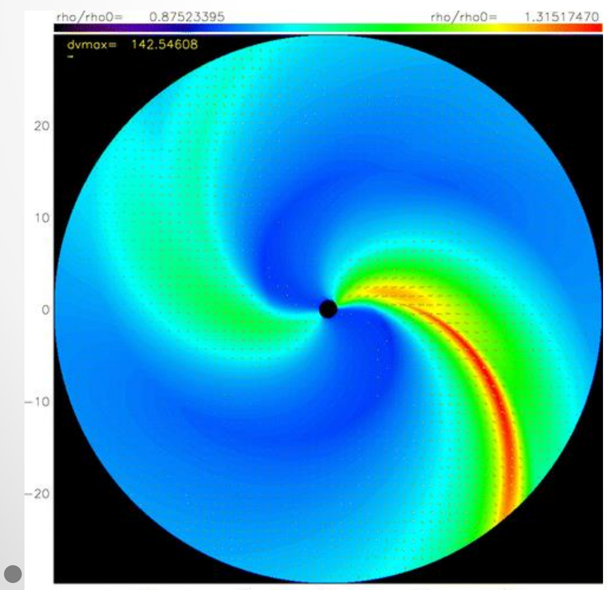
Time-resolved X-ray spectroscopy of massive stars

The standard model for X-ray emission from single, non-magnetic massive stars assumes shock-heated plasma in highly fragmented stellar winds.

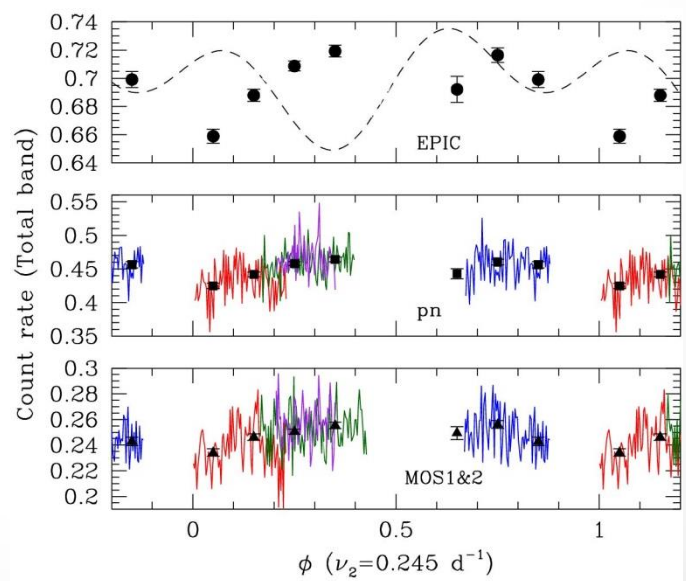
Nazé et al. 2013, ApJ 763, 143

Modulations due to (co-rotating) large-scale wind structures are observed in the UV and optical spectra.

What is the role of these structures in the X-ray emission/absorption?



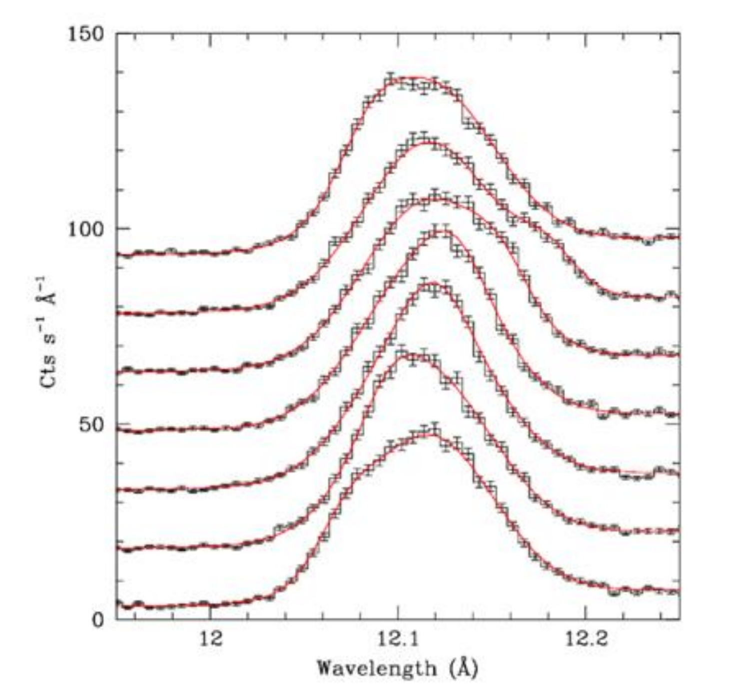
Lobel & Blomme 2008, ApJ 678, 408

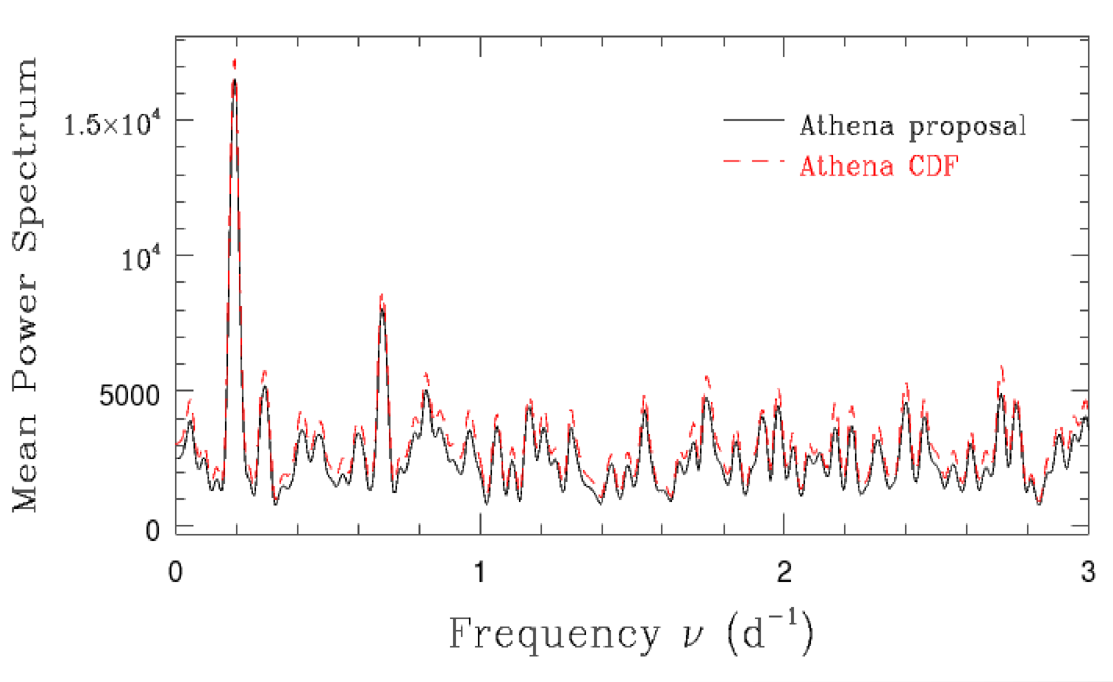


Rauw et al. 2015, A&A 580, A59

With X-IFU, we will be able to investigate variations of individual spectral lines on the relevant time scales (Sciortino et al. 2013, arXiv1306.2333).

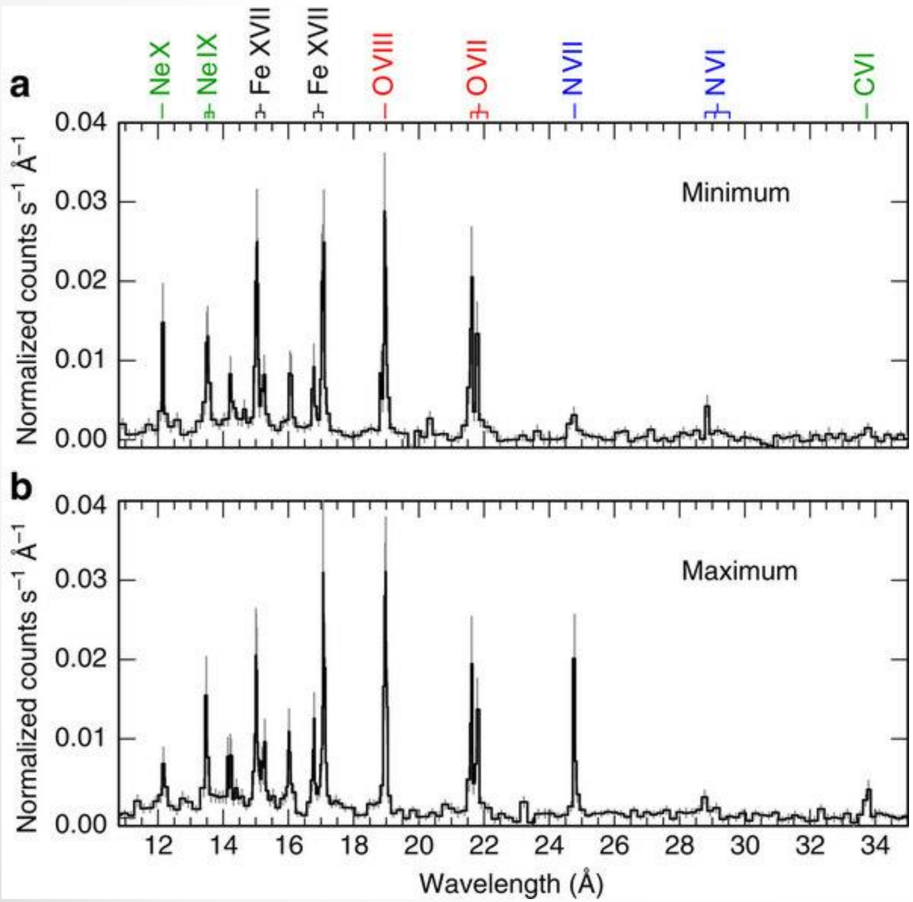
E.g. Fourier power spectrum of a series of 110 simulated 1.8 ksec X-IFU exposures of the Ne X Ly α line of ζ Pup assuming a 5% modulation on a 5 days period:

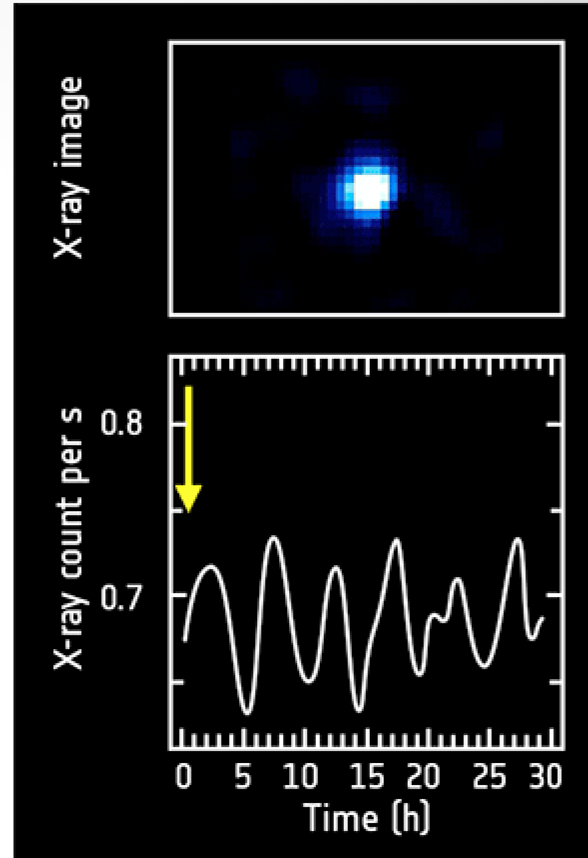


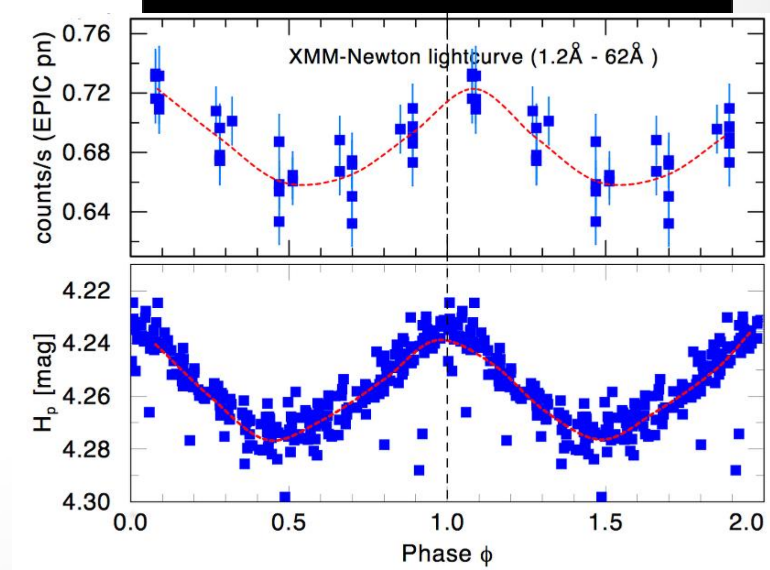


Sciortino et al. 2013, arXiv1306.2333

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 (β Cep-like) pulsations + possible modulation of the N VII Ly α line.



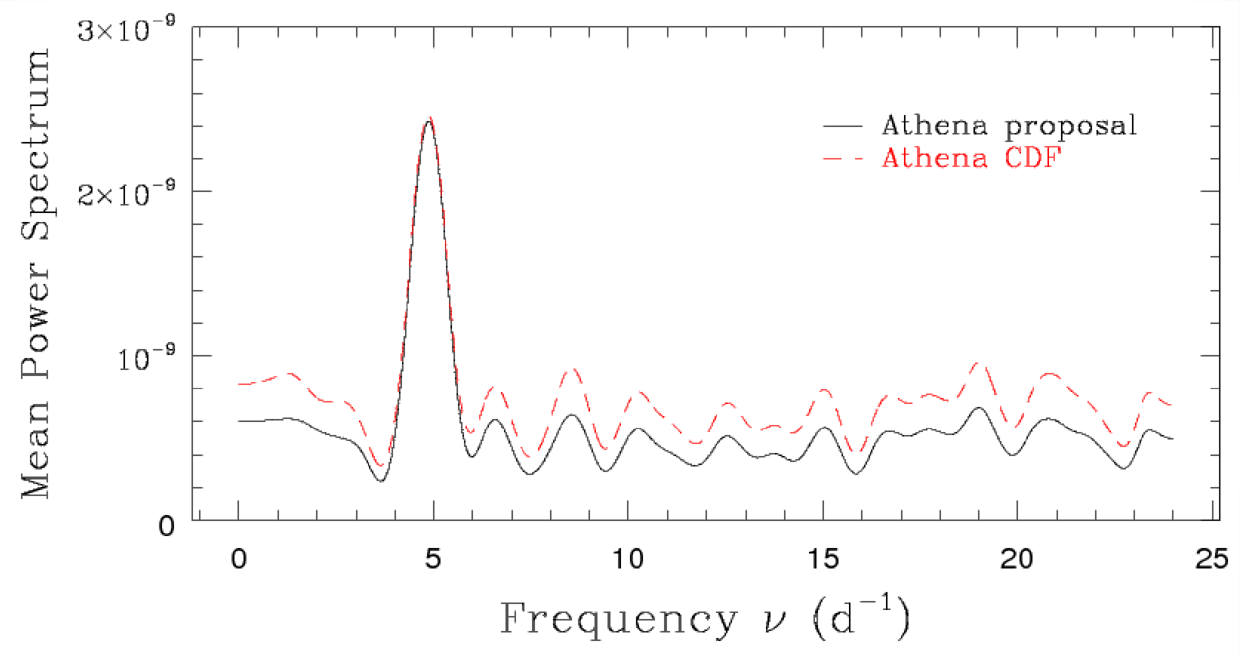




Oskinova et al. 2014, Nat. Comm. 5, 4024

With X-IFU, we will be able to investigate the frequency content of the line profile variations of the N VII Ly α line of ξ^1 CMa.

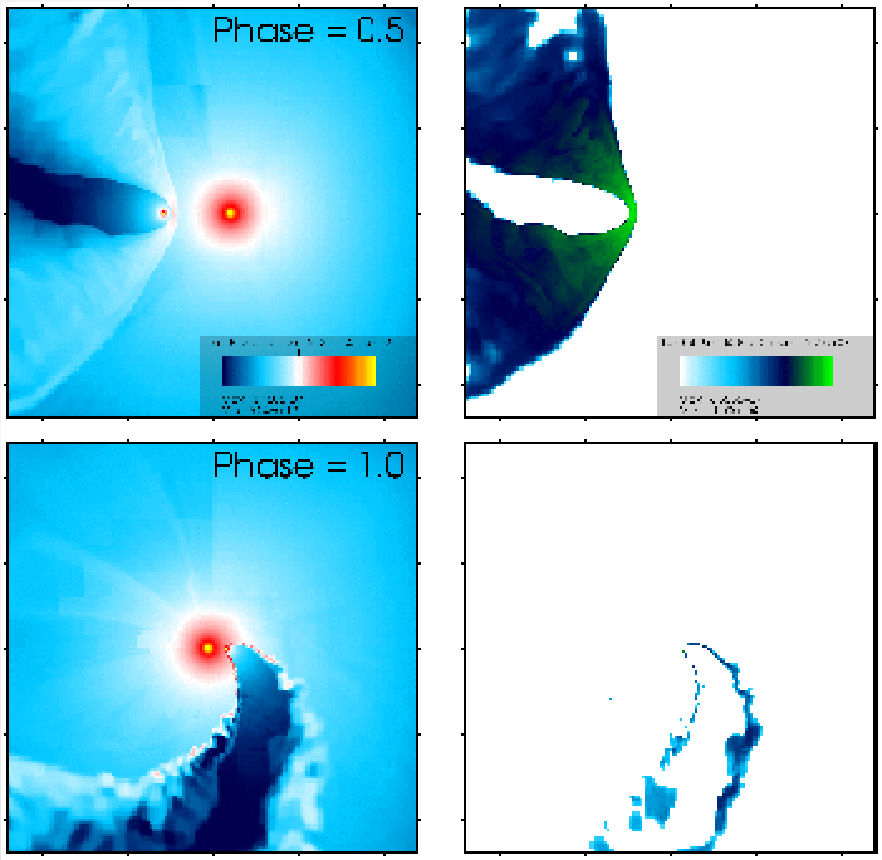
E.g. Fourier power spectrum of a series of 40 simulated 1.8 ksec X-IFU exposures of the N VII Ly α line of ξ^1 CMa assuming variations in the line strength of relative amplitude 35%:



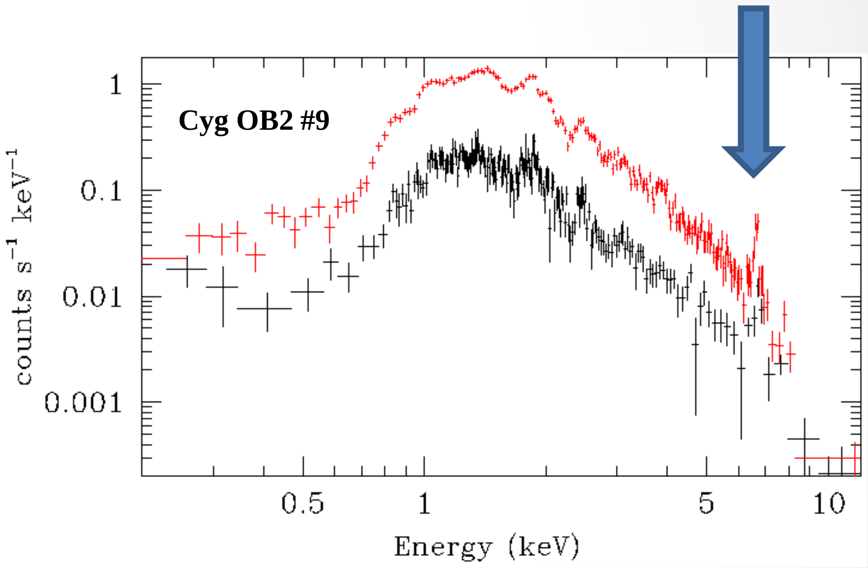
Massive binary systems host a wind interaction region that produces additional X-ray emission.

The observed emission varies with orbital phase due to changing line-of-sight optical depth and/or changing orbital separation (eccentric systems).

Some colliding wind systems exhibit a strong Fe xxv line near 6.7 keV which is solely formed in the wind interaction zone.



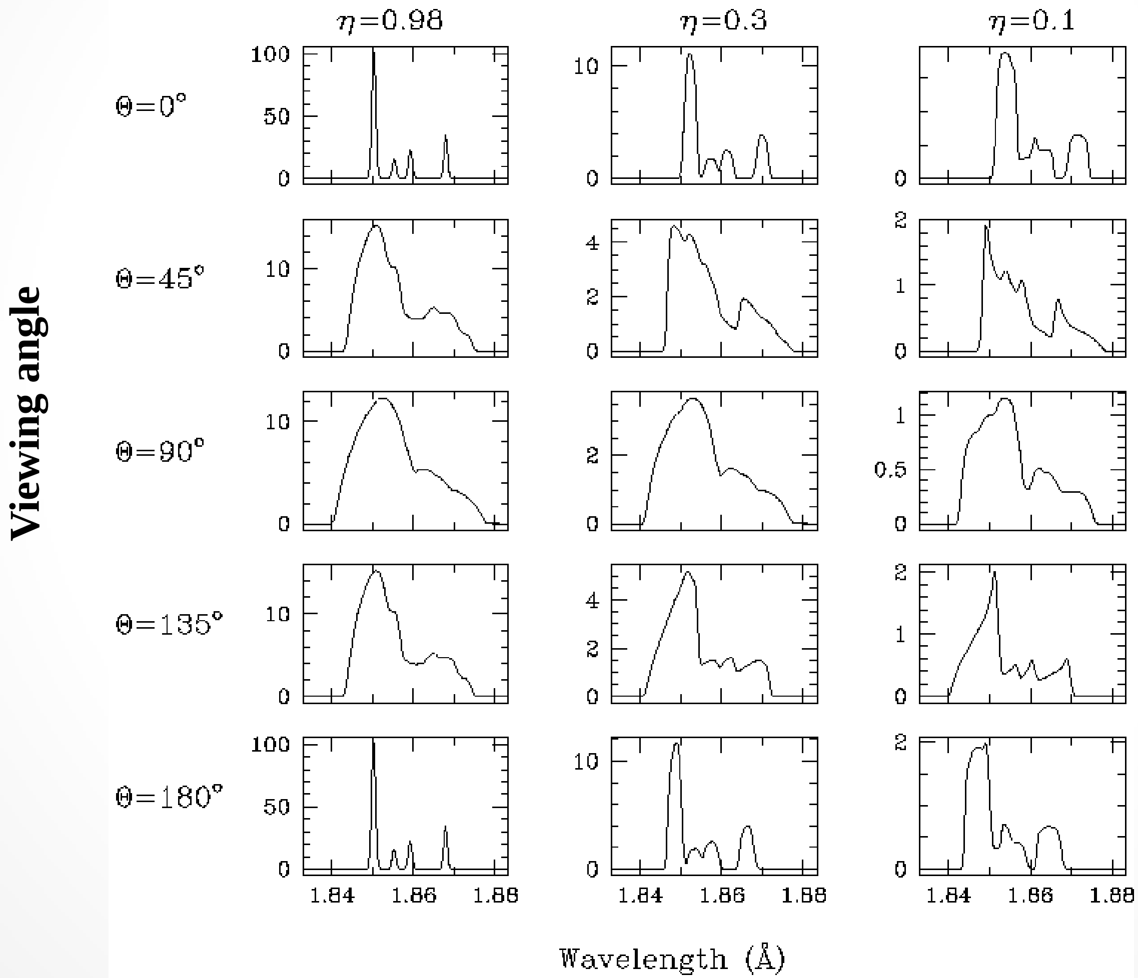
Parkin & Gosset 2011, A&A 530, A119



Rauw & Nazé, ASR, in press

With X-IFU, the Fe K line can be used as a diagnostic for the conditions in the wind-wind interaction zone (Sciortino et al. 2013, arXiv1306.2333; Rauw et al. 2016, New Astronomy 43, 70, arXiv1508.04965).

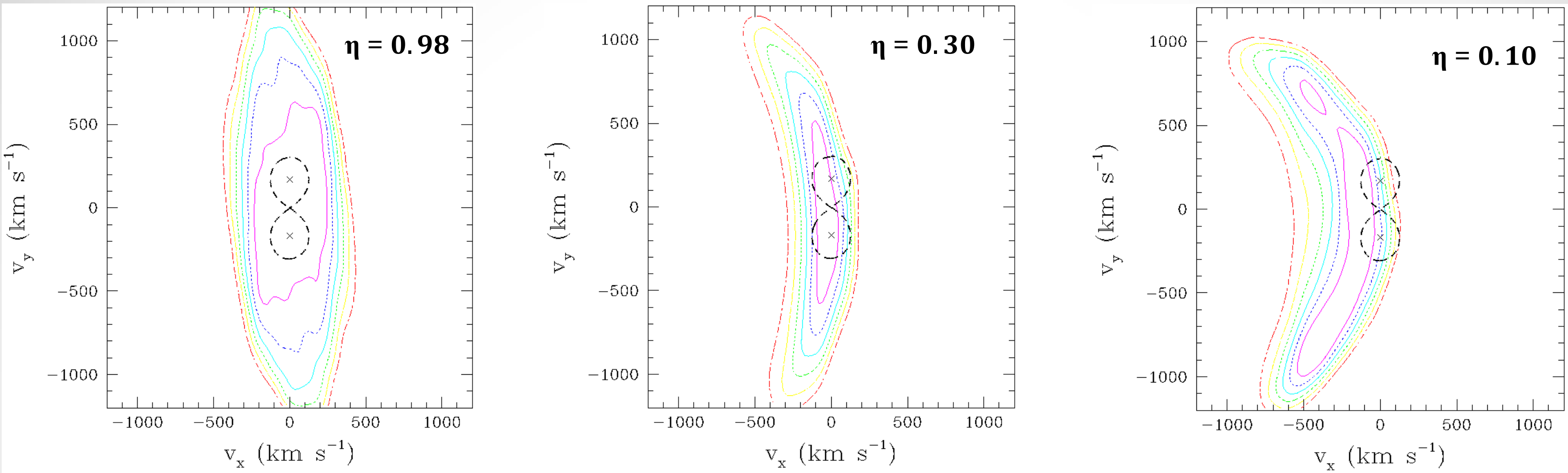
Fe xxv consists of four components → need for least square deconvolution



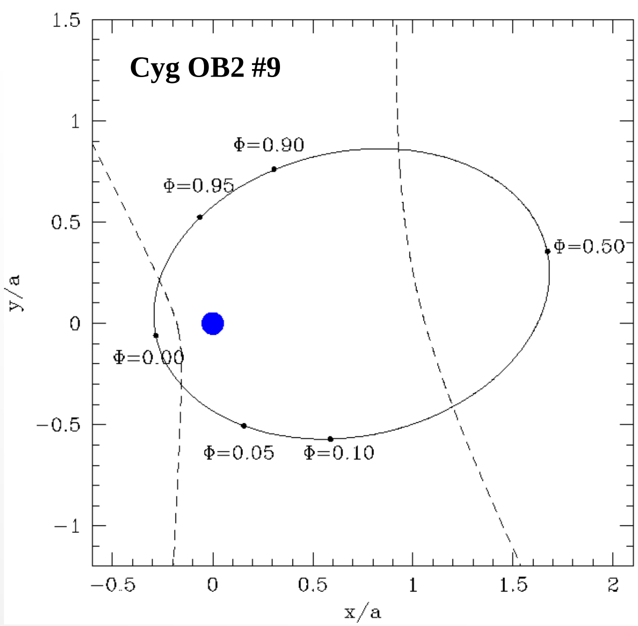
$$\eta = \frac{\dot{M}_2\, v_{\infty 2}}{\dot{M}_1\, v_{\infty 1}}$$

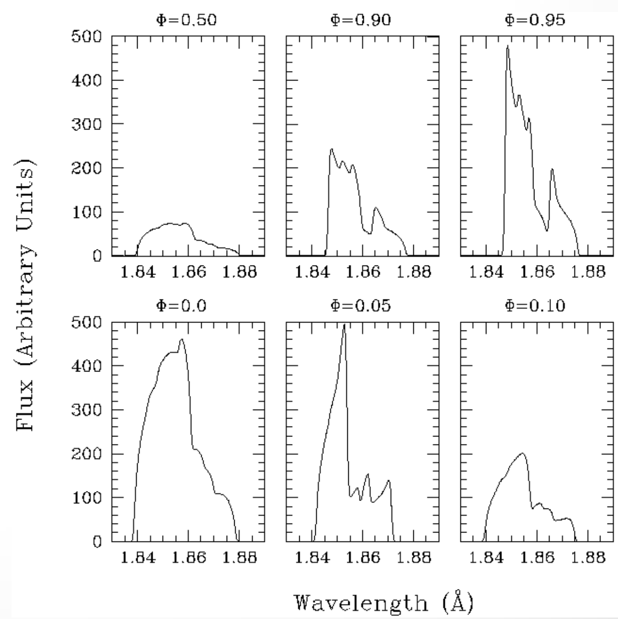
Rauw et al. 2016, New Astronomy 43, 70
(arXiv1508.04965)

Systems with circular orbits observed with X-IFU can be studied with the Doppler tomography technique (Rauw et al. 2016, New Astronomy 43, 70, arXiv1508.04965).



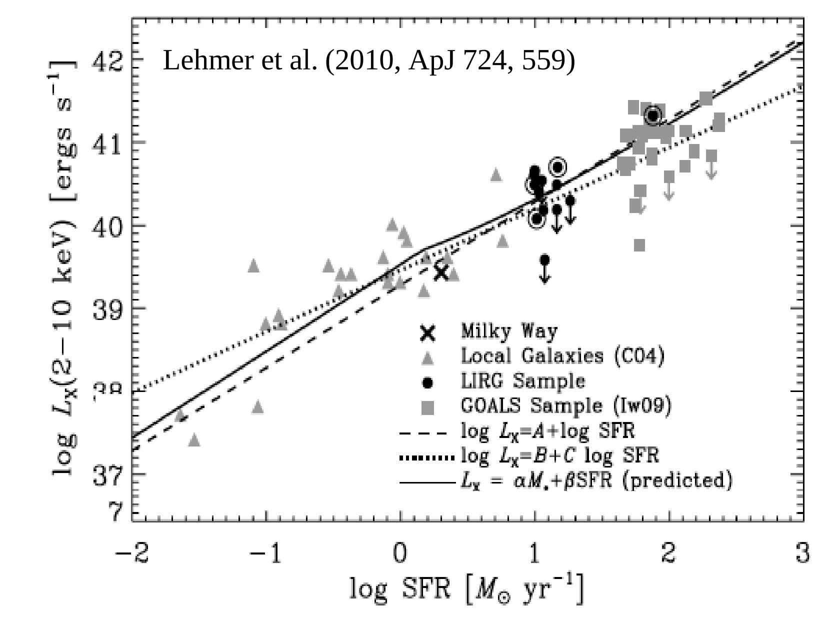
Eccentric systems are expected to display Fe K lines with variable strength and shape.





X-rays from starburst galaxies over Cosmic times

Local galaxies:



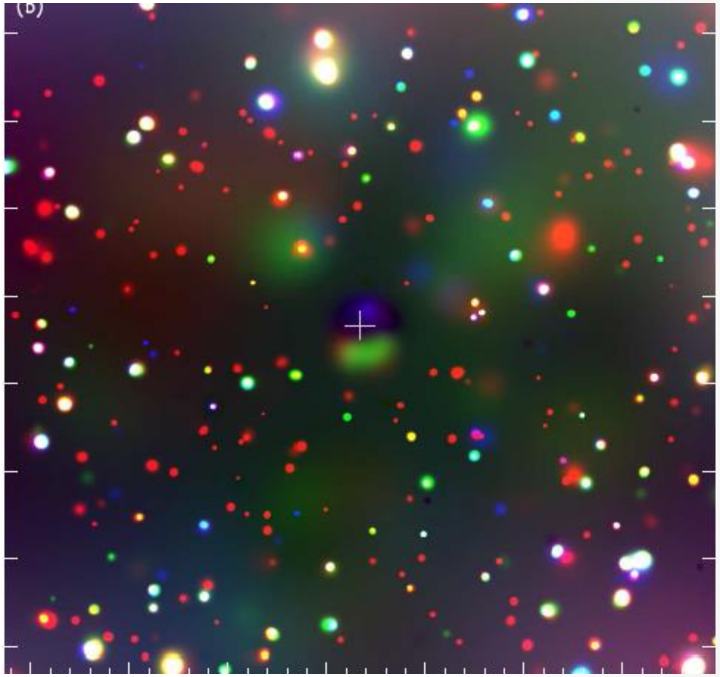
$L_X = L_X(\text{LMXBs}) + L_X(\text{HMXBs})$

$L_X = \alpha\, M_* + \beta\, \text{SFR}$

$L_X/\text{SFR} = \alpha\, (\text{SFR}/M_*)^{-1} + \beta$

Distant (high-z) galaxies:

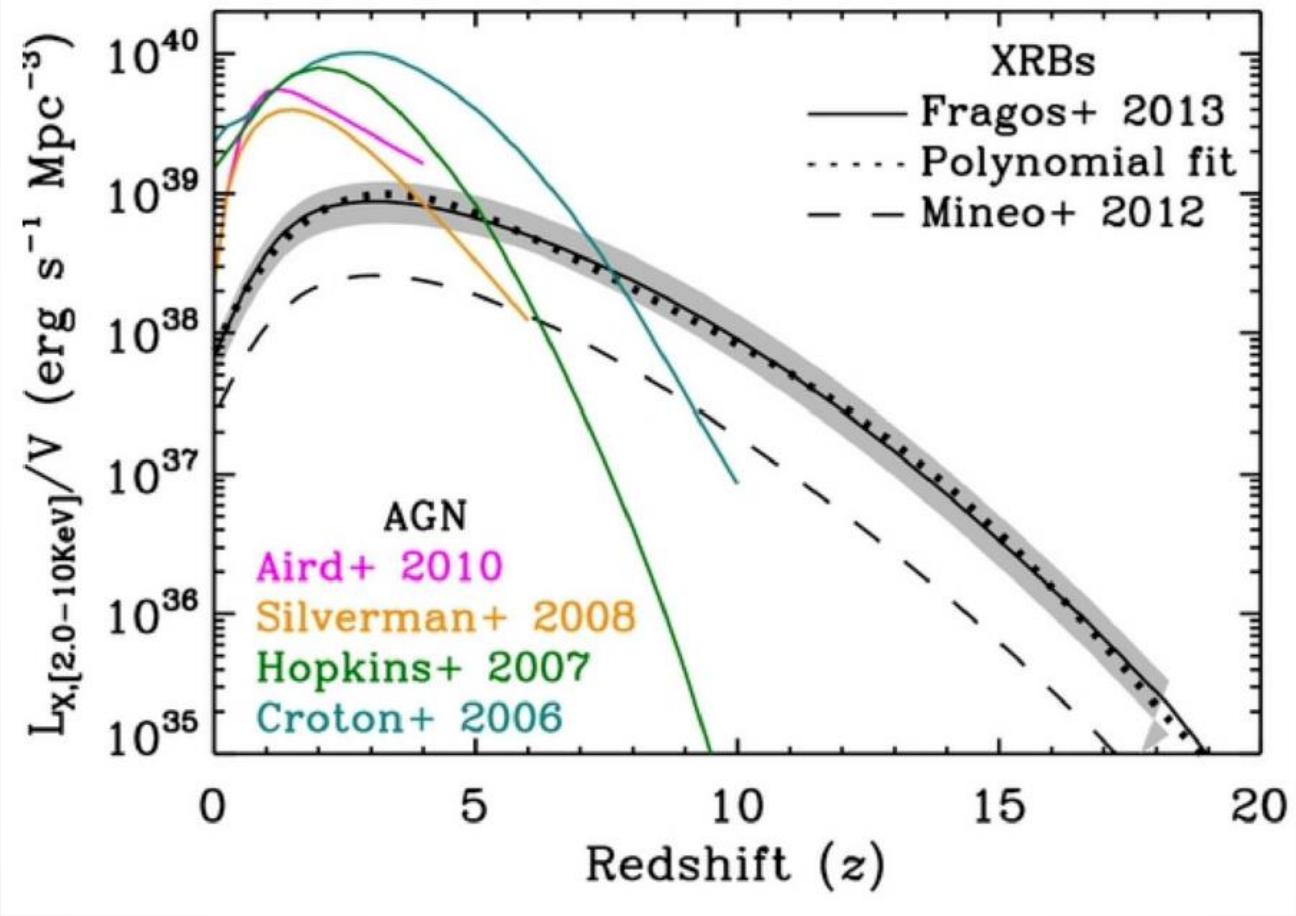
The Chandra Deep Field – South
(6 Ms, Luo et al 2016)



0.5-2.0 keV 2.0-4.0 keV 4.0-8.0 keV

$$L_X = \alpha_0(1+z)^3 M_* + \beta_0(1+z)^{0.92}\text{SFR}$$ (Lehmer et al. 2015, in prep.)

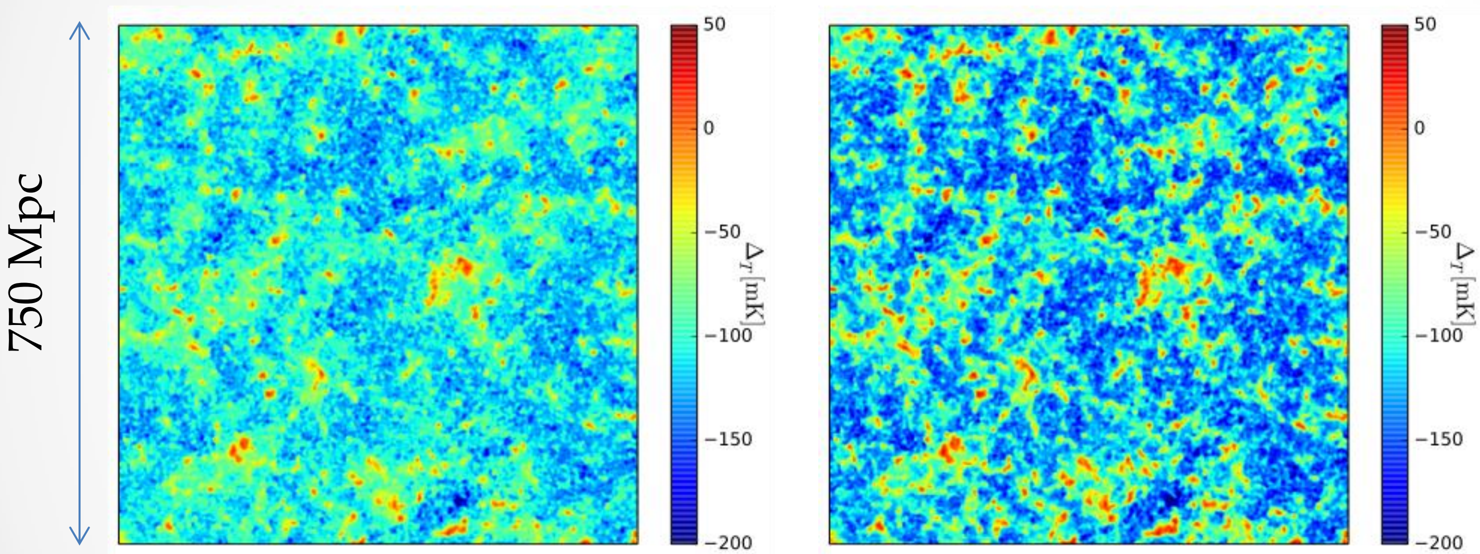
The X-ray output of X-ray binaries exceeds that of AGN @ z > ~ 6 (see also poster 12.03 by Basu-Zych et al.).



The X-ray emission from star forming galaxies is very important in heating the IGM as the first galaxies form.

The X-ray SED directly impacts the 21 cm brightness temperatures @ z = 10 – 20 that will be measured with facilities such as SKA.

Athena WFI will probe the X-ray SEDs of galaxies directly to higher redshifts (z ~6 –10) than ever before .



Hard X-ray SED: z_{peak}=16.7 Soft X-ray SED: z_{peak}=16.3

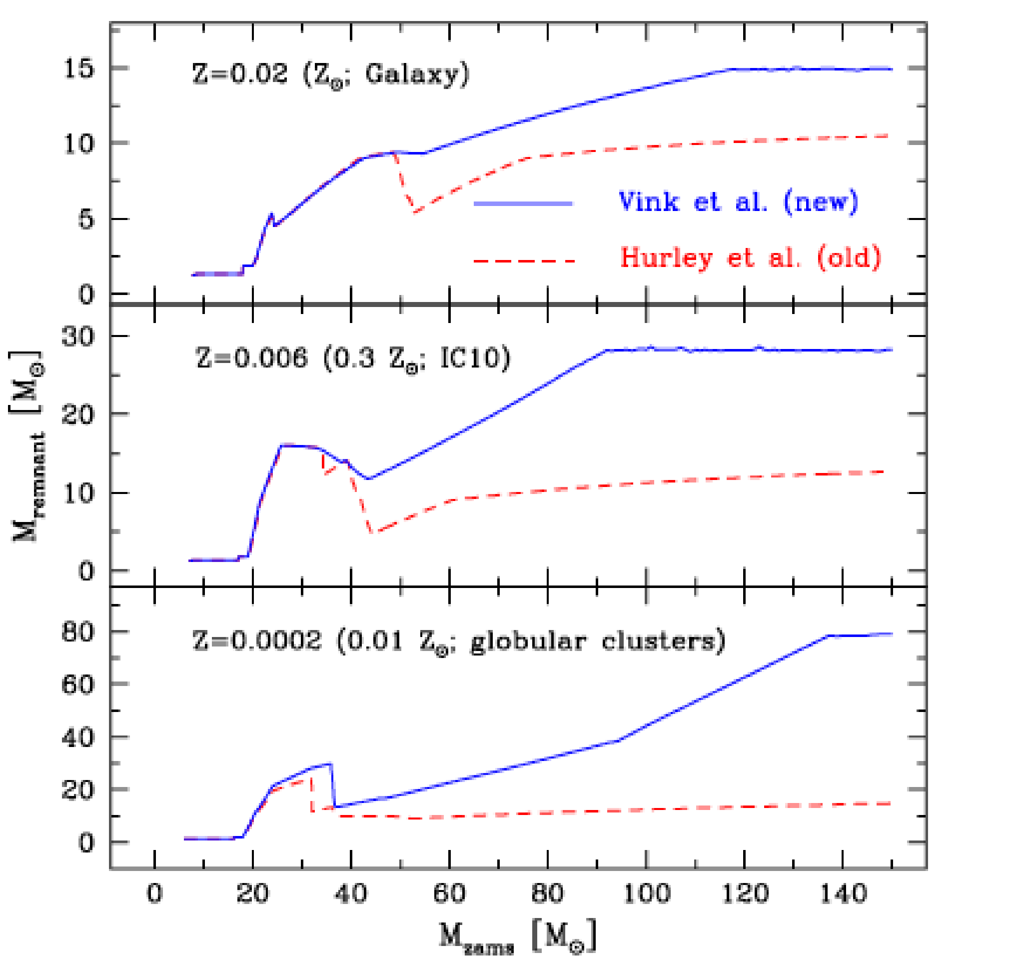
(Pacucci et al. 2014, MNRAS 443, 678)

The Square Kilometer Array (www.skatelescope.org)

The first BH binaries produce enough X-ray emission to heat the gas of the IGM.

But, uncertainties on stellar wind prescriptions affect predictions on the remnant (BH/NS) mass.

Athena-WFI will probe the relation between metallicity and X-ray emission of massive stars via observations of super-massive star clusters in the Local Group.



(Belczynski et al. 2010, ApJ 714, 1217

Conclusions

Athena will allow tremendous progress in numerous questions related to the subject of star formation and evolution in the nearby as well as the more distant Universe.

The topics presented here provide a non-exhaustive overview.

Additional examples include:

- understanding the X-ray emission of hot subdwarfs,
- understanding the intrinsic X-ray emission of Wolf-Rayet stars and tepid stars,
- study the X-ray emission from planetary nebulae,
- …