Star formation and evolution with ATHENA

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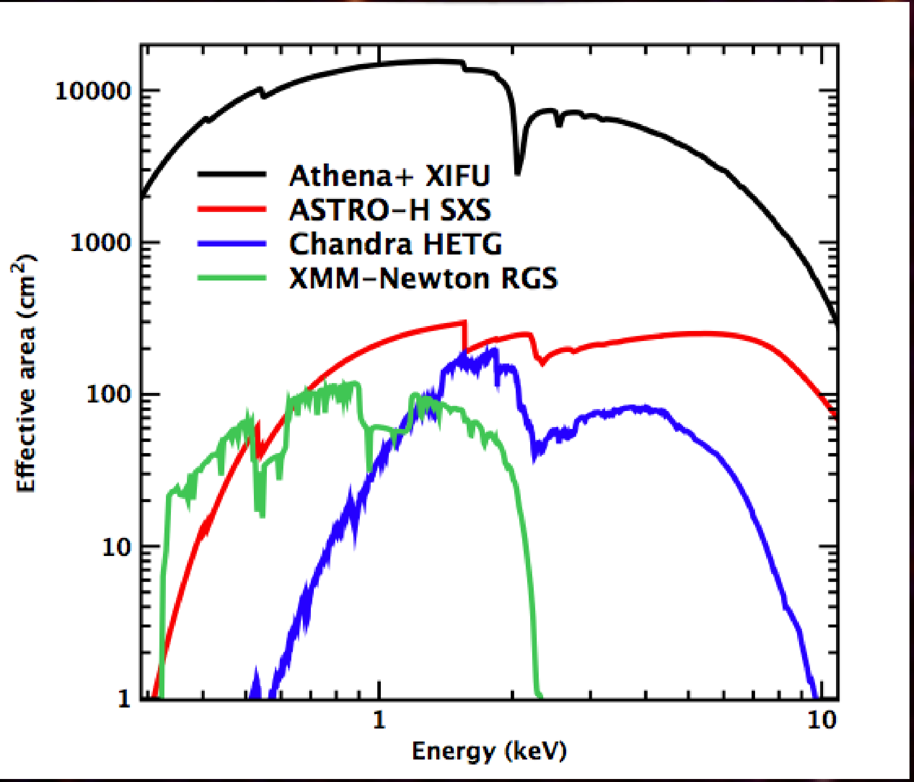
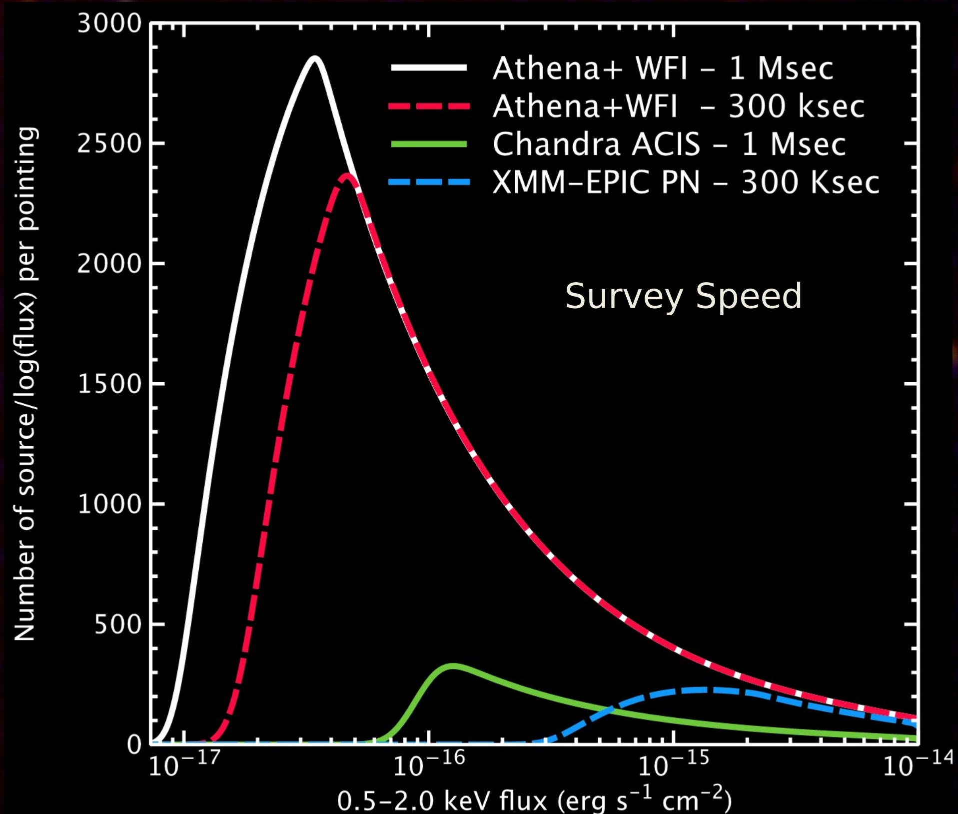
and the whole ATHENA team

The next generation X-ray Observatory

Athena has vastly improved capabilities compared to current or planned facilities, and will impact on virtually all areas of astrophysics

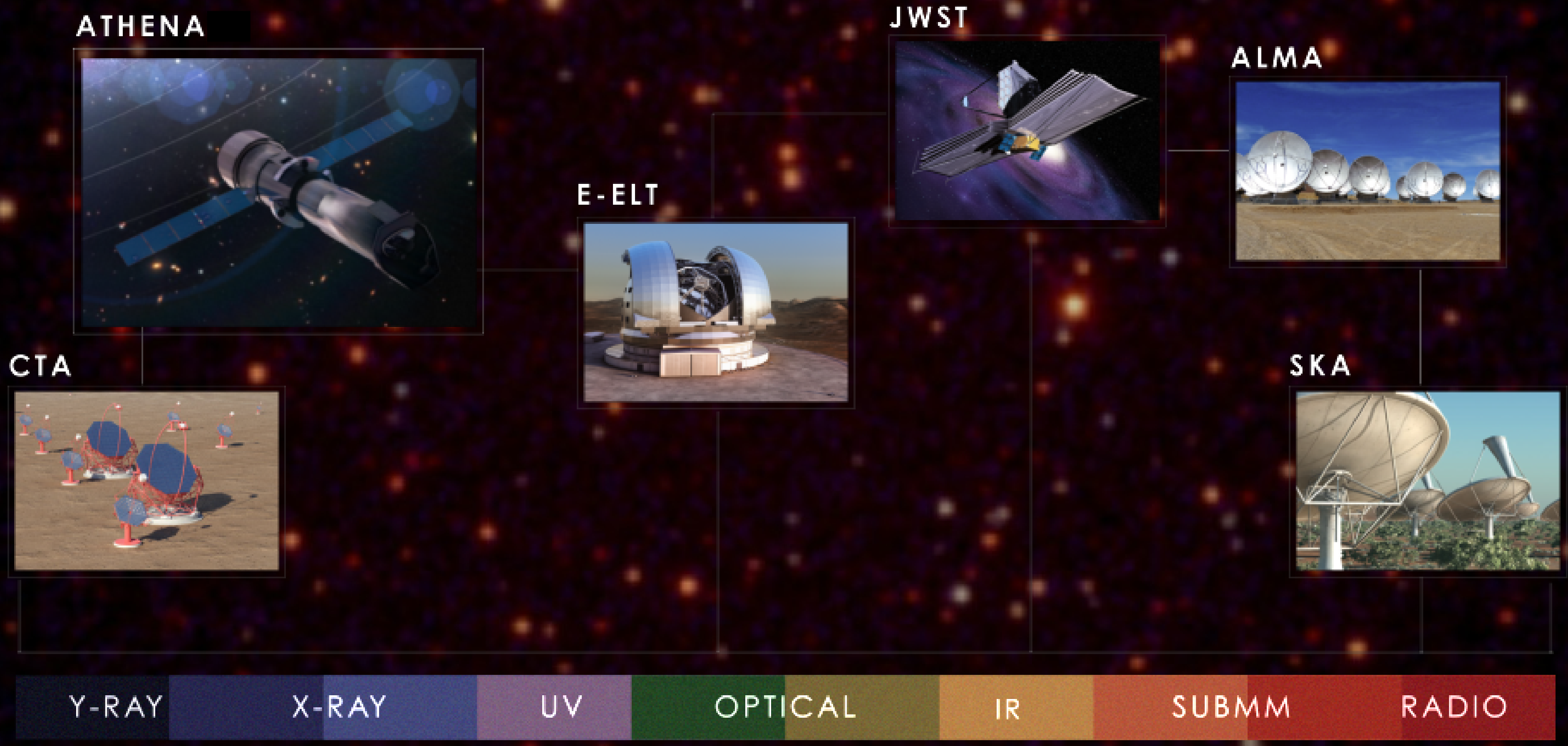


Two order of magnitudes improved X-ray spectroscopy → Time resolved X-ray spectroscopy for > 2 10^4 sources



Deep survey capability of near and far Universe

Athena science in context



Athena is a crucial part of the suite of large observatories needed to reach the science objectives of astronomy in the coming decades

Wide Field Imager (WFI)

WFI consortium lead: Germany

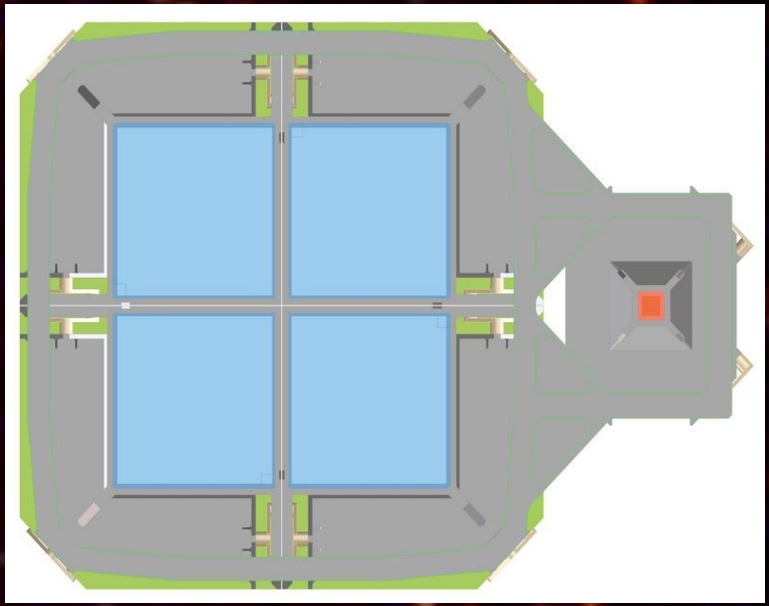
FoV = 40 arcmin ↔ Size = 140 mm

4 large DEPFET sensor chips

512 x 512 pixels with 130 µm x 130 µm

sensitive area → 67 x 67 mm^2

Time resolution: **(1.28) 5 ms**



1 fast timing DEPFET sensor

64 x 64 pixels with 130 µm x 130 µm

sensitive area → 8.3 x 8.3 mm^2

Time resolution: **160 µs** (or **80 µs** with 2-line readout option)

Window mode: 8+8 lines (36 arcsec ≈ 7 x PSF): **20 µs** (or **10 µs** with 2-line readout option)

X-Ray Integral Field Unit (XIFU)

XIFU consortium lead: France (PI), Italy & Holland (CoPI)

Transition Edge Sensor microcalorimeter in cryo (50 mK)   4-kpixel array

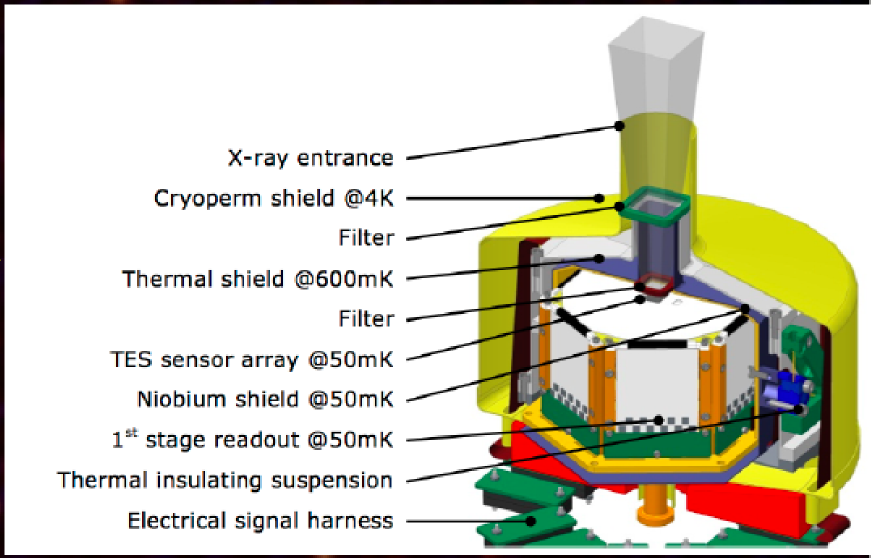
Large TES-based CryoAC for Low instrumental background

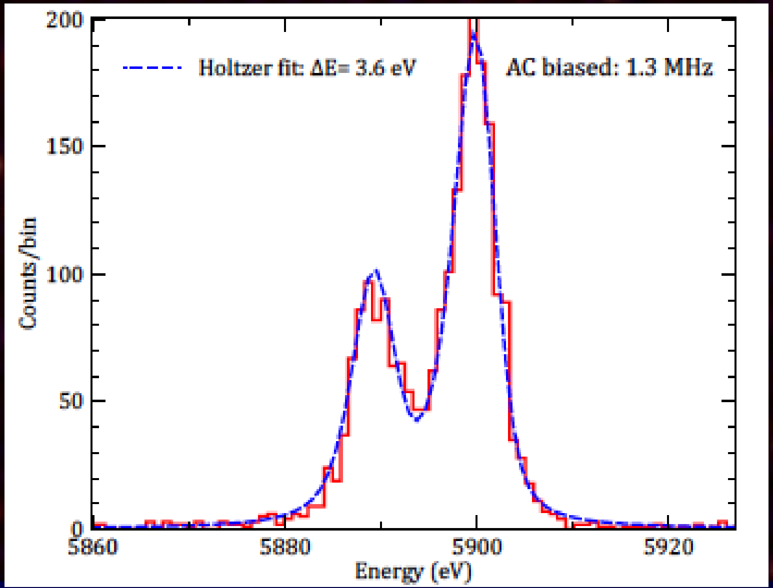
Read-out: FDM multiplexing

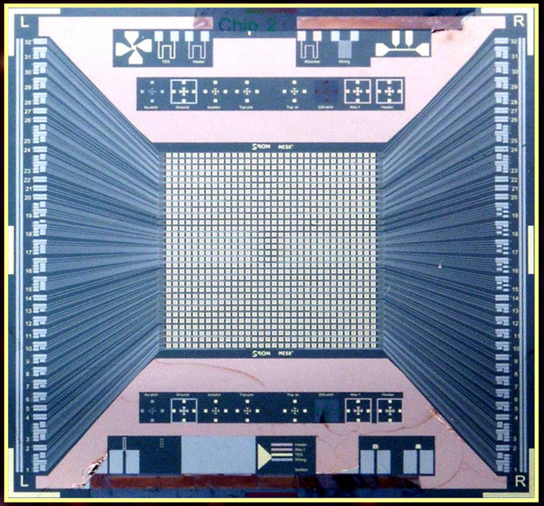
2.5 eV resolution @ 0.3-7.0 keV

R= 230 @OVII triplet (0.57 keV)

R= 2700 @FeXXV &XXVI lines (~6.7 keV)







Italy in ATHENA

- Science, Mission and Instruments with a leading role of Italian scientists and industry.

 XIFU CoPI + synergical participation to WFI

- Roles & Community: 1 in the ESA Study Team, 9 Italian co-chairs of Mission & Science WGs + 160 Italian members

 Italian Key institutions are:

INAF: IAPS(RM), IASF-MI, IASF-Bo, IASF-Pa, OABrera, OABo, OATo, OAPa, OaTs, OAArcetri, OARM, OANa

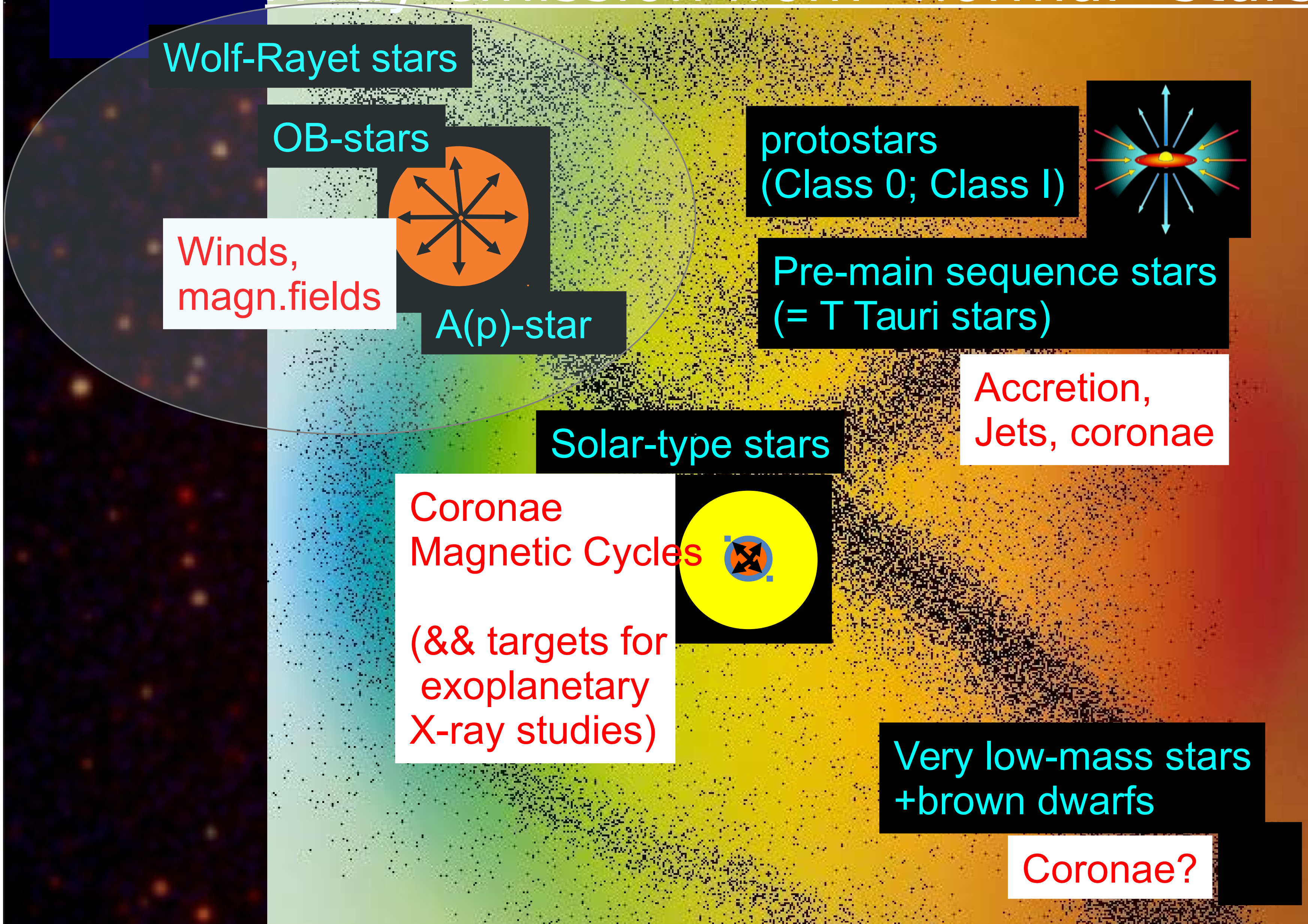
Uni &INFN Genova, Uni Rm1,Rm2,Rm3, Uni Bo, Uni Pa, Uni Mi

CNR, IFN-RM

- Industrial role from mission prime-ship, subsystems, instrument cutting-edge technologies, mirror assembly (TAS,CGS,FBK, Mediolario,..)

- Italian contributions formalized at the ESA-Leading Funding Agencies meeting in Oct. 2014

X-ray emission from "normal" stars



X-ray Integral Field Unit (X-IFU): Time dependent high-spectral resolution of stars and planetary nebulae

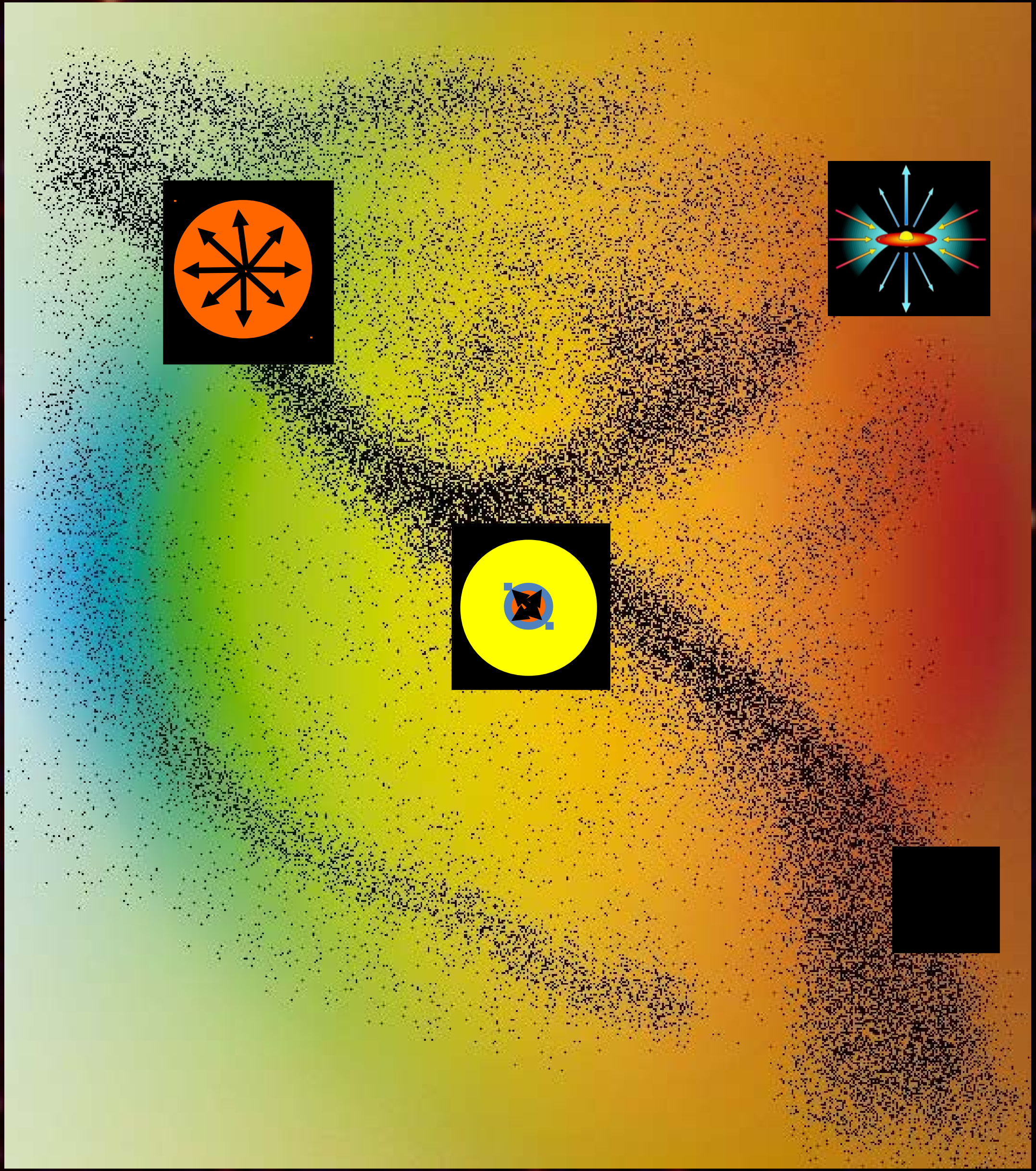
Wide Field Imager (WFI): Detailed study of star formation regions

Key Stellar Studies with ATHENA

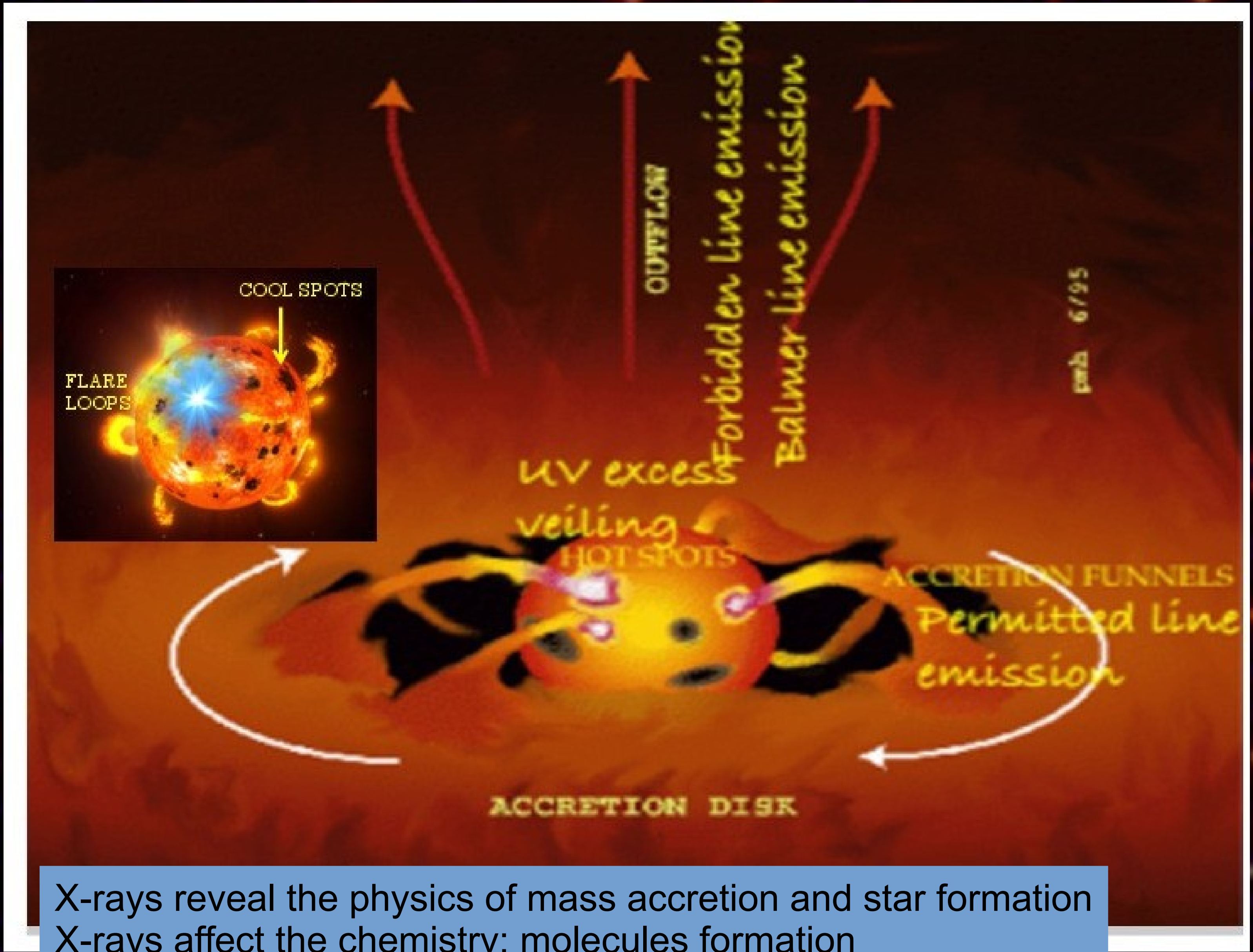
-> High res. **time resolved** X-ray spectroscopy:
- Accretion onto YSOs (+ young BDs)
- Extreme flare dynamics
- Nature of the Fe Kα emission in YSOs
- Wind and Mass Loss in Massive stars (OB-stars, WR-stars)

-> Detection & MW coordinated observations
- Do Class 0 YSOs are X-ray emitters ?

-> Origin of the X-ray emission from UCDs

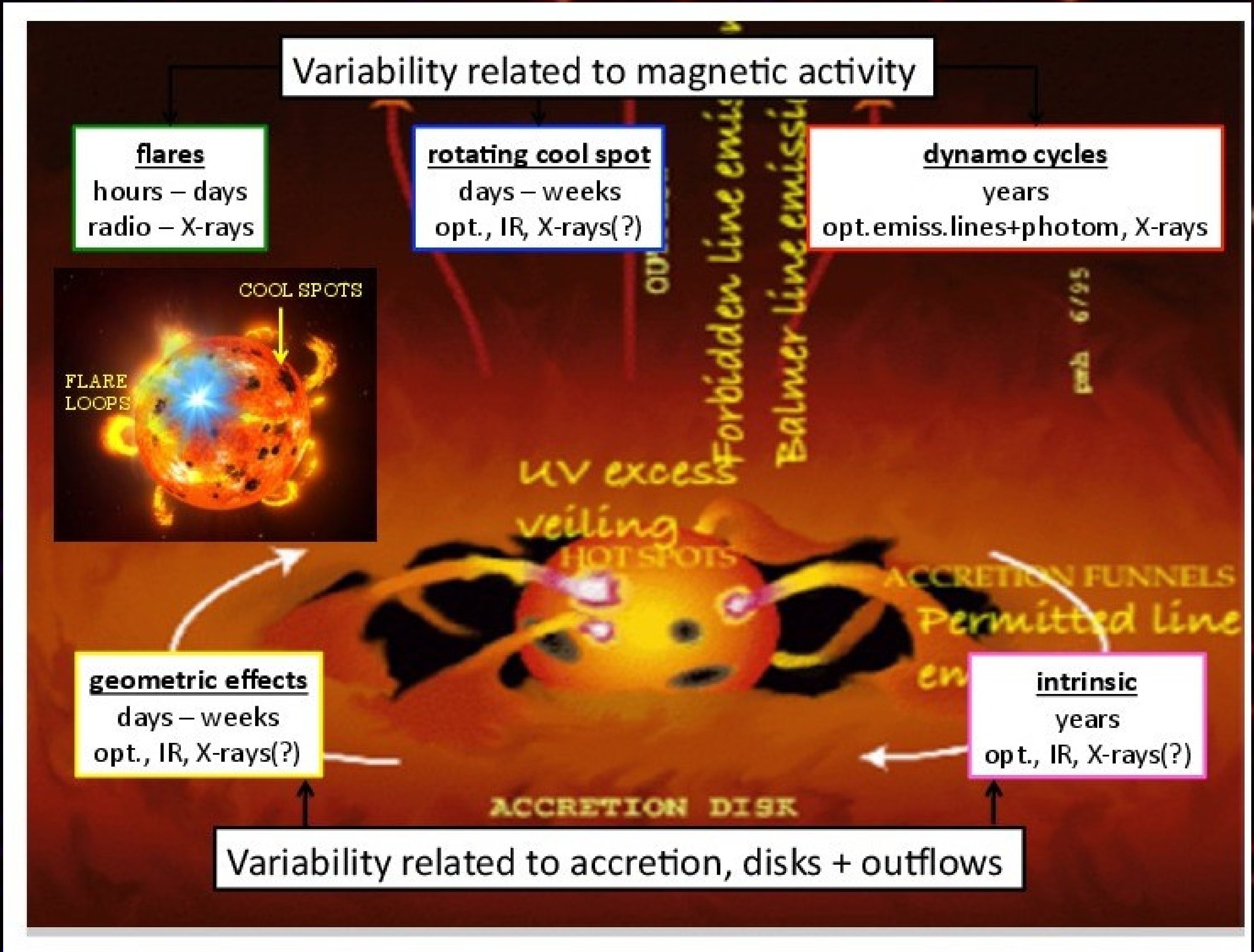


X-rays and YSO physics



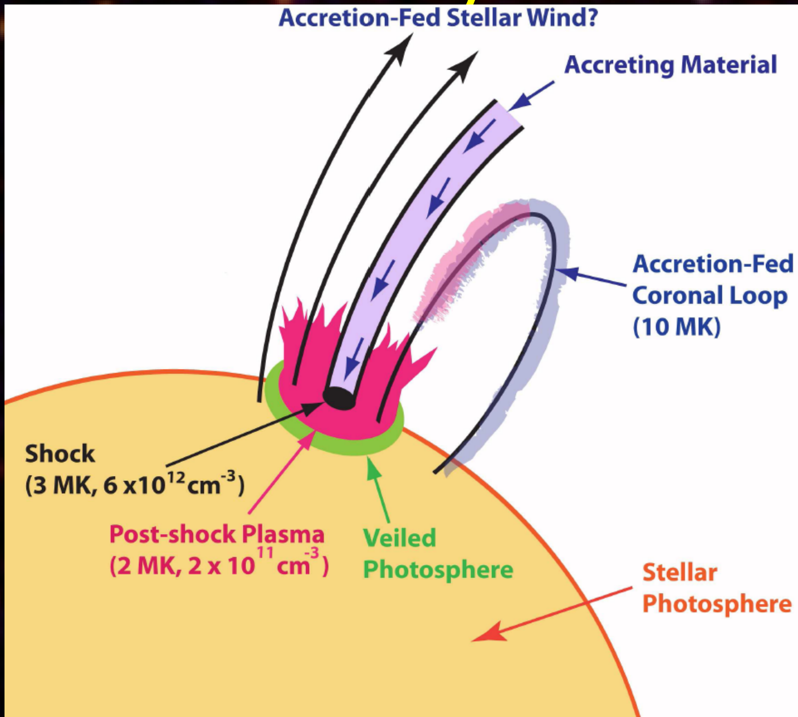
X-rays reveal the physics of mass accretion and star formation
X-rays affect the chemistry: molecules formation
X-rays ionize and heat circumstellar disks
X-rays affect planet formation and migration

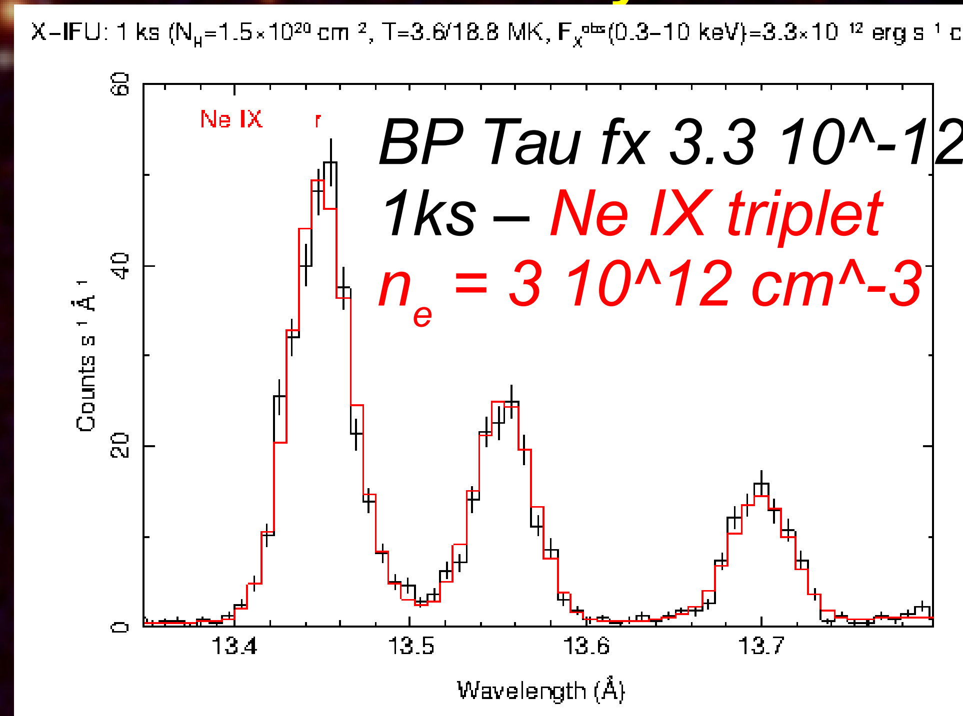
YSO Variability on several time scales



Accretion on YSO

only 7 CTTS can be studied as today





Matter accretes from warped circumstellar disk, in many accretion episodes → variability. Shocks heat stellar surface at the base of accreting funnel → soft X-ray (O, Ne triplets → high density plasma).

Soft emission only from stellar shocked matter ? =>> Density stratification → Simultaneous observations of many triplets // Coordinated MW observations

Emission optically thin ? =>> Optical depth from OVI & OII Lyman series

Disk warping ==> variable Nh → modulated X-ray emission

Doppler shift from shock-heated plasma or other YSO emitting structures?

Accretion on YSO

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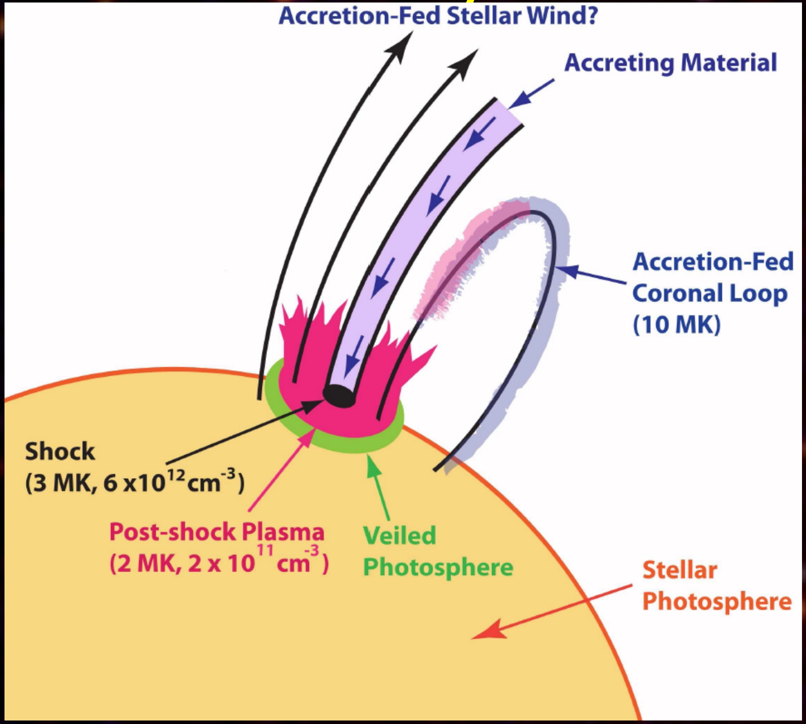

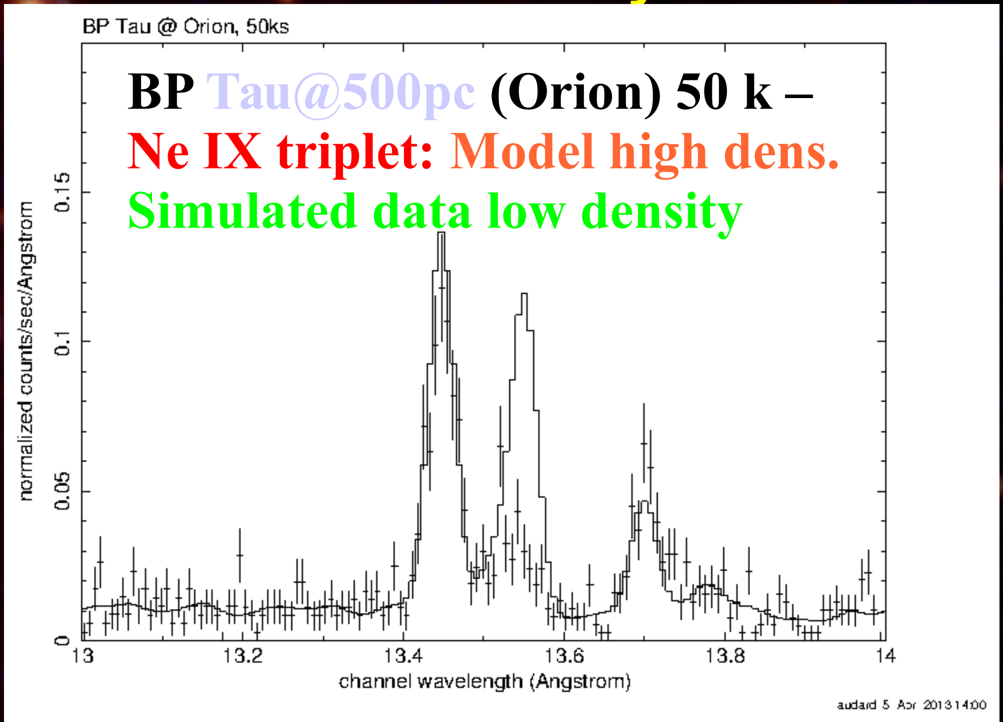

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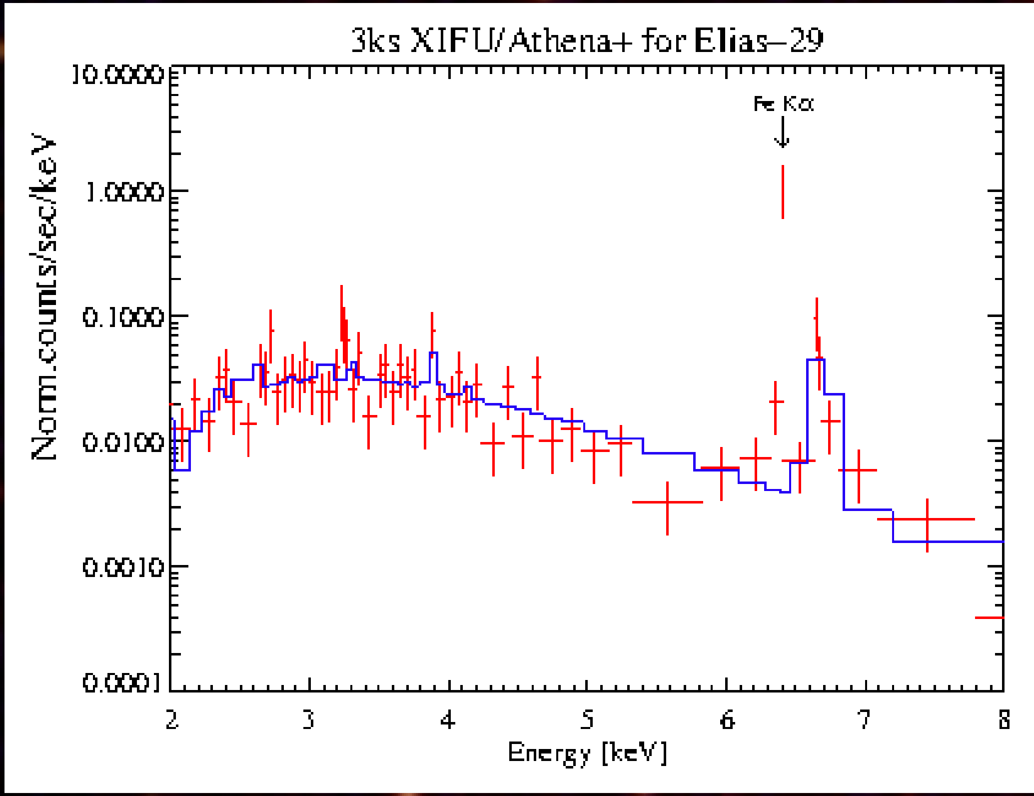
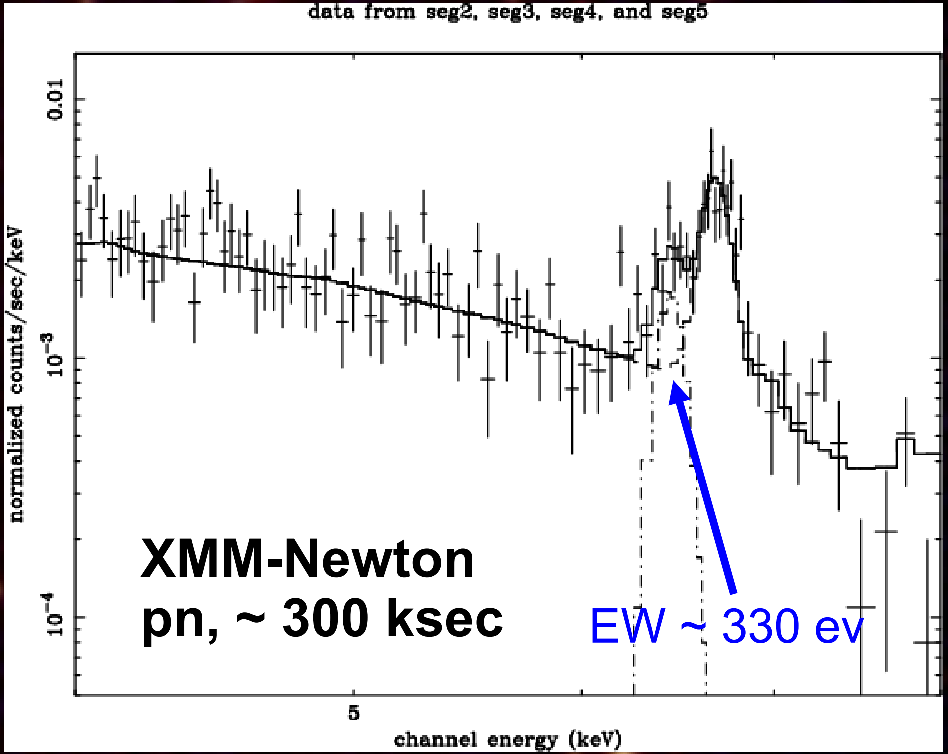
Fe ~ 6.4 keV Kα line(s) in YSOs



X-rays very likely the major ionization source of circumstellar disk gas in initial few Myrs, key effect on disk evolution and planet formation

El29 in rho Oph, an intense (log Lx~ 30.3, fx ~ 1e-12) strongly absorbed CTTS with Fe 6.4 kev line



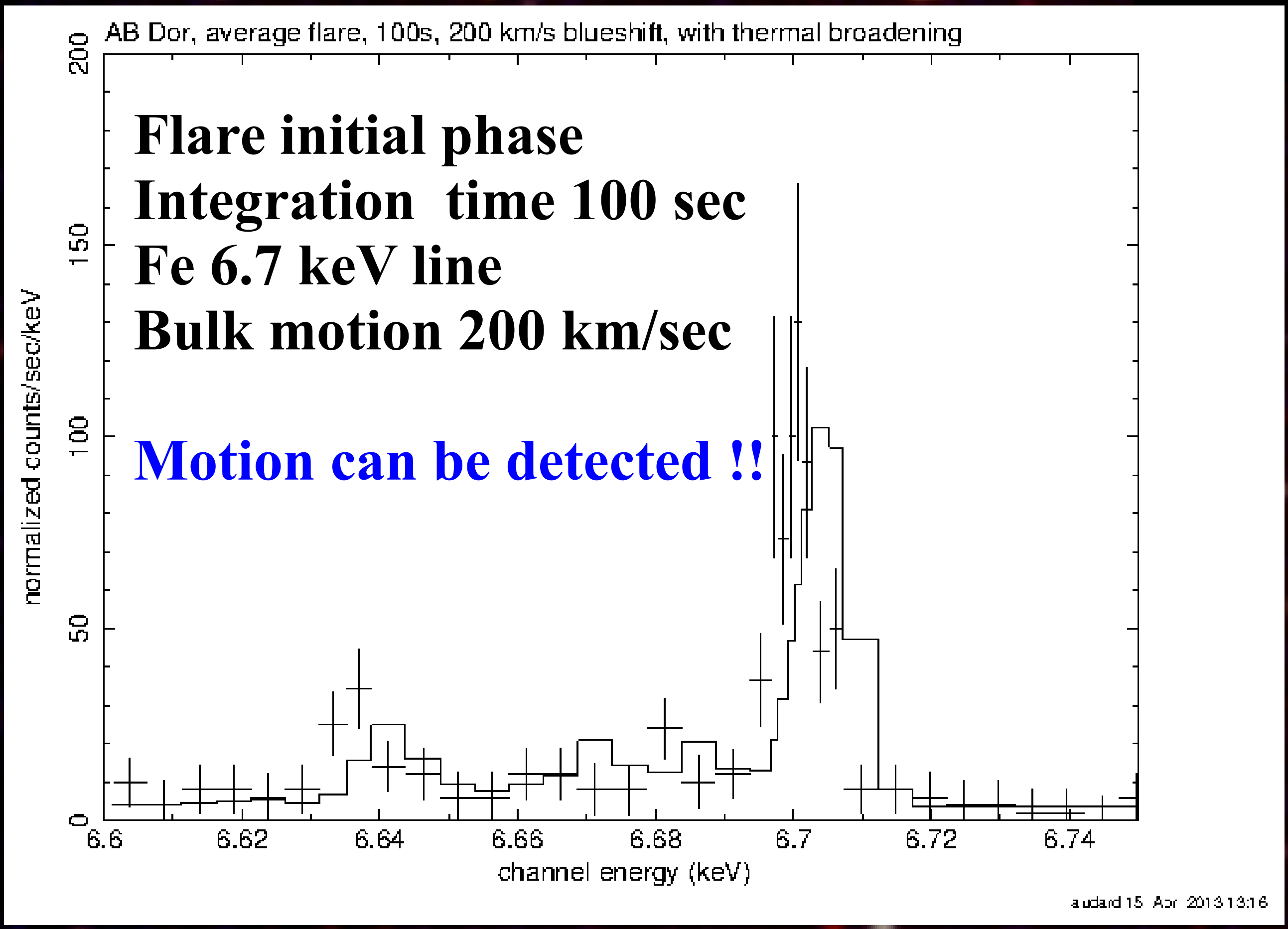
Photosphere max EW ~90-150 eV ->
Emission from disk material
X-ray (> 7.1 keV) ionization, but no clear relation with flare occurrence ->
Collis. ionisation by non-thermal electrons ?
Open question →
Time resolved spectroscopy needed

Extreme Flares

AB DOR: Nearby (14.9 pc) Active star

fx_quite ~ 4 e-11, Lx ~ 10^30

3T (0.11, 0.62, 1.90 keV; 16.1, 57.3, 19.6 10^51 cm^-3)



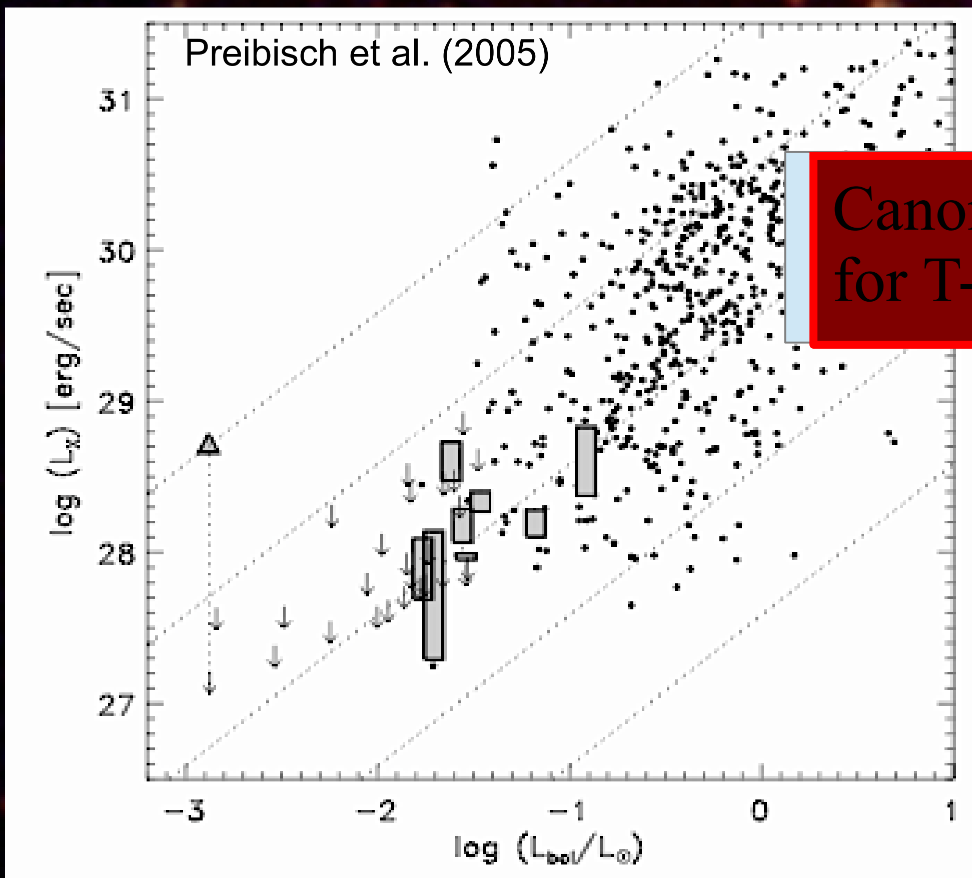
Huge flares on some CTTS
Peak Lx ~ 10^32 erg/sec
Peak T ~ 200 MK
Big magnetic structures thought to connect the star surface and the circumestallar disk at corotation radius.

Effect of energy release on disk need to be fully assessed, bulk motion of heated disk material expected.

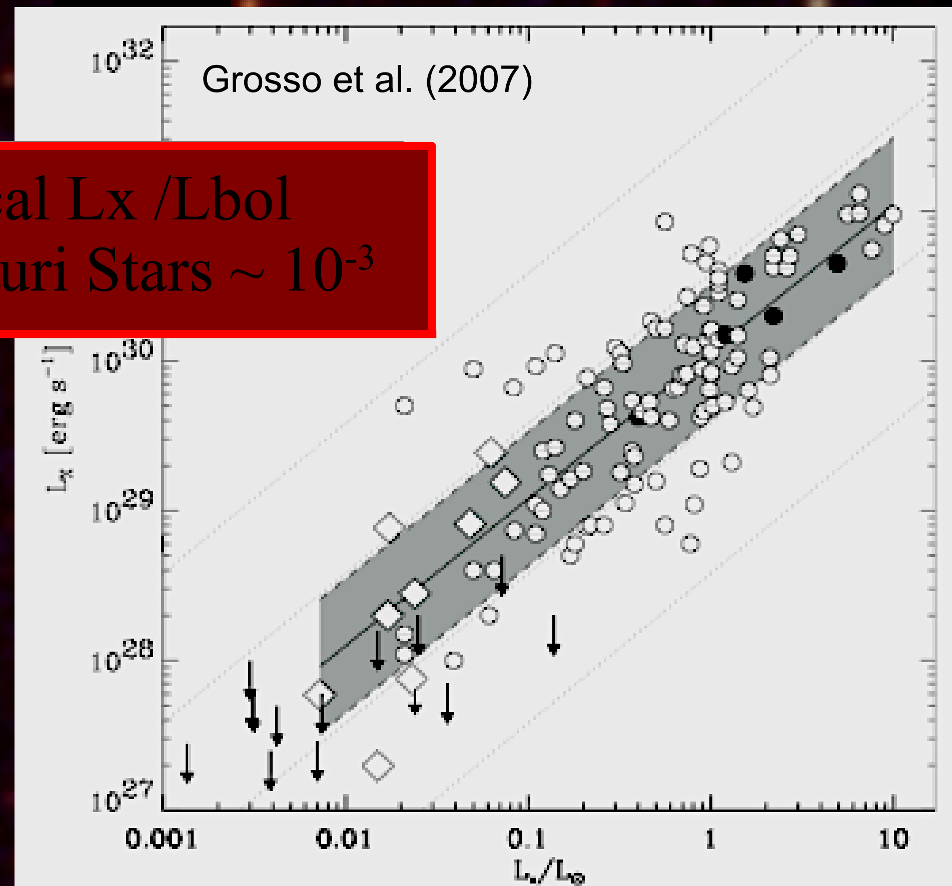
Ultra Cool Dwarfs

Dynamo in the substellar regime compared to T-Tauri Stars?
From a coronal to a planetary-like emission ? At what mass (age) ?

COUP (ONC) -- 1 field for 850ks Chandra XEST (TMC) -- 19 fields for 30 ks XMM

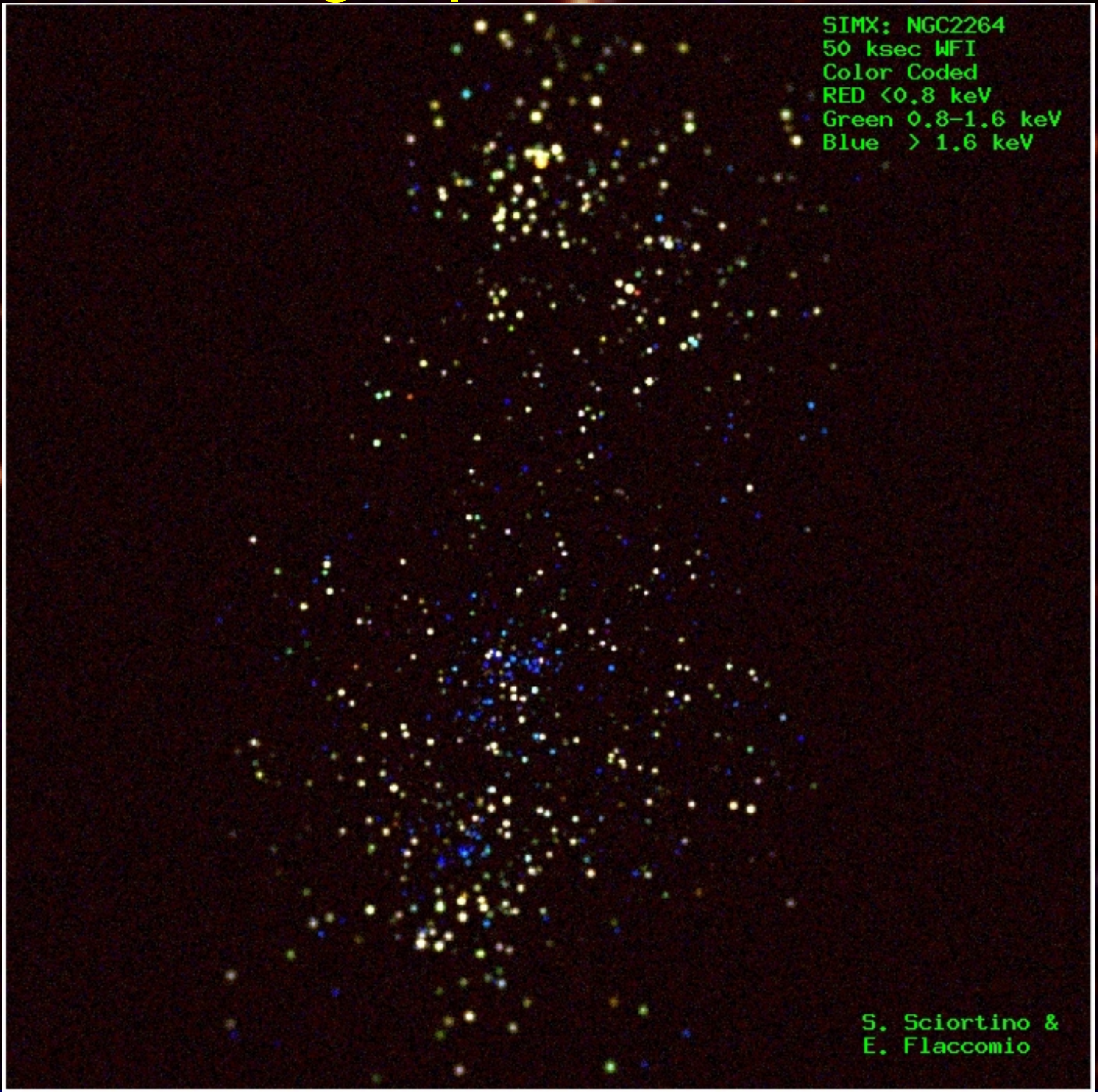


Canonical Lx /Lbol
for T-Tauri Stars ~ 10^{-3}



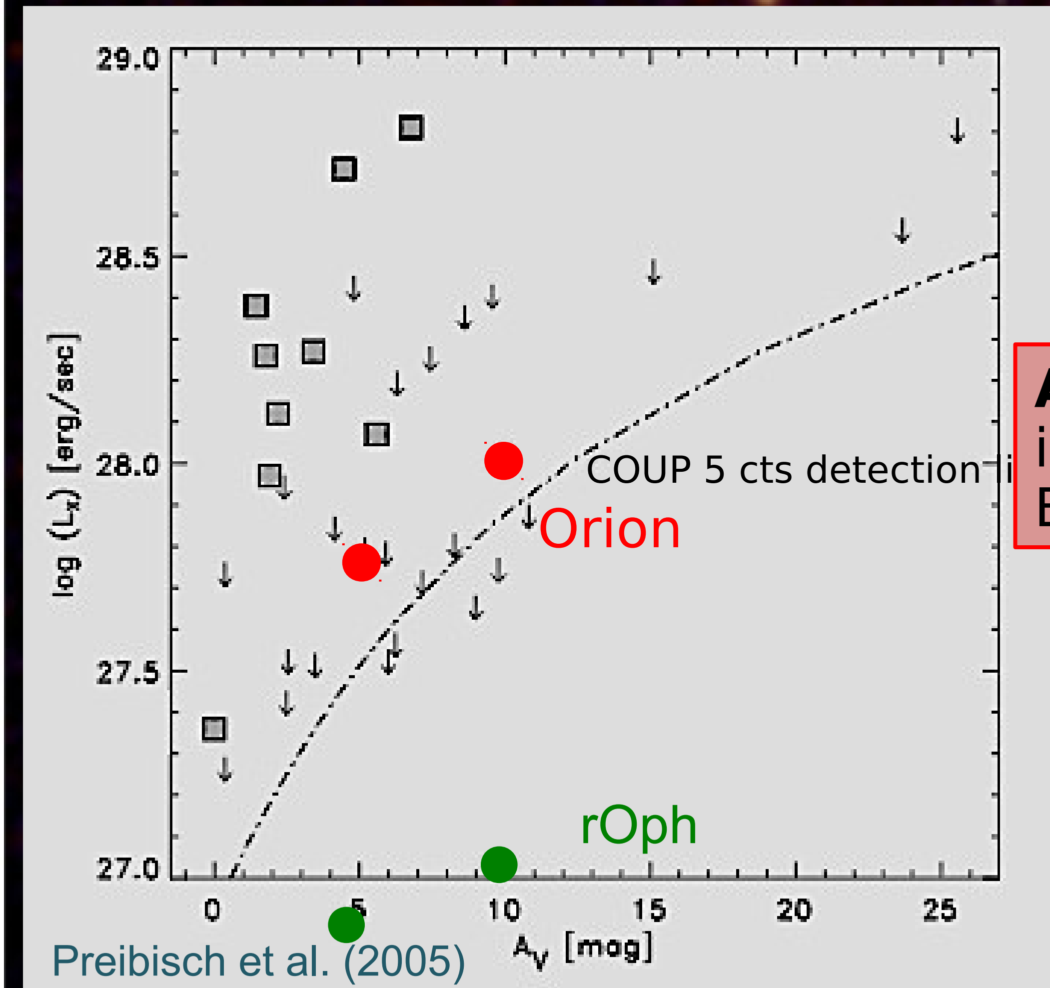
Is Lx / Lbol of BDs in star forming regions comparable to higher-mass stars or lower ?
Too few detected Bds for a firm conclusion

ATHENA will detect UCD in nearby SFR & Young Open Cluster



Detecting Ultra Cool Dwarfs with ATHENA

COUP: 850ks Chandra in Orion
Only weakly absorbed BDs detected



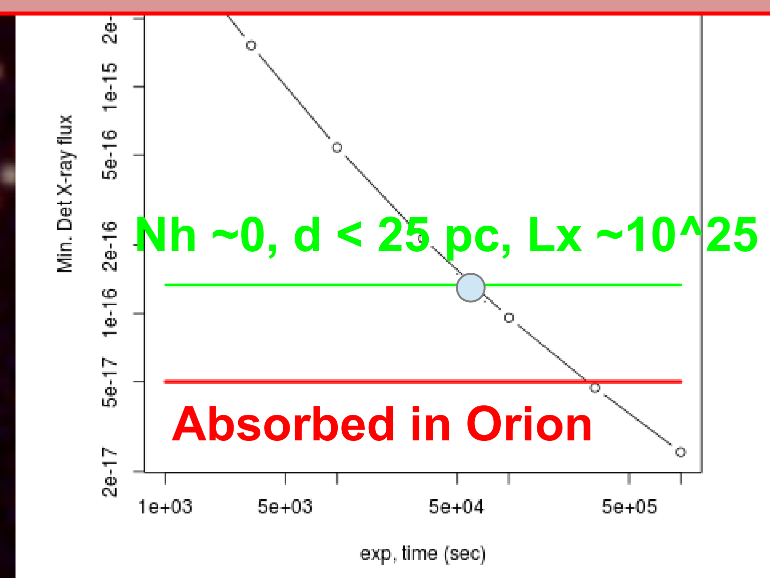
Assume a strongly absorbed BD in ONC:

1) Intrinsic Lx = $10^{28.0}$ erg/s Av = 10 mag
Intrinsic Lx = $10^{27.8}$ erg/s Av = 5 mag

@ 450 pc

(fx)abs ~ 5 10^-17 erg/cm2/s
@ 0.5-2 keV for kT = 1 keV

ATHENA: can detect these objects in deep obs (~ 400 ks), Nearby old BD log Lx ~ 25 in less than 50 ksec



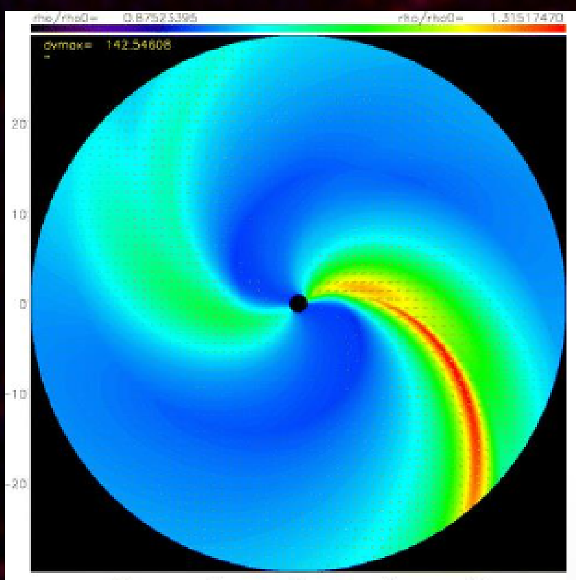
Time-resolved X-ray spectroscopy of massive stars

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

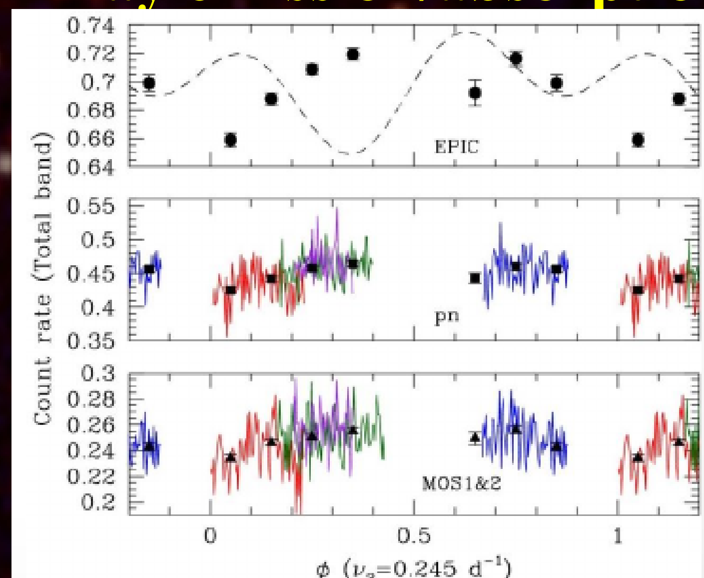
Nazé et al. 2013, ApJ 763, 143

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

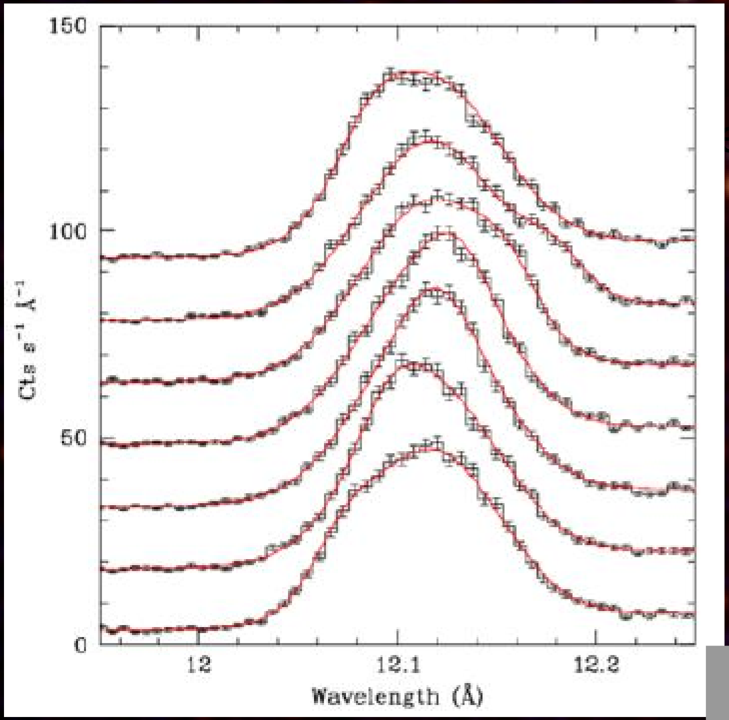


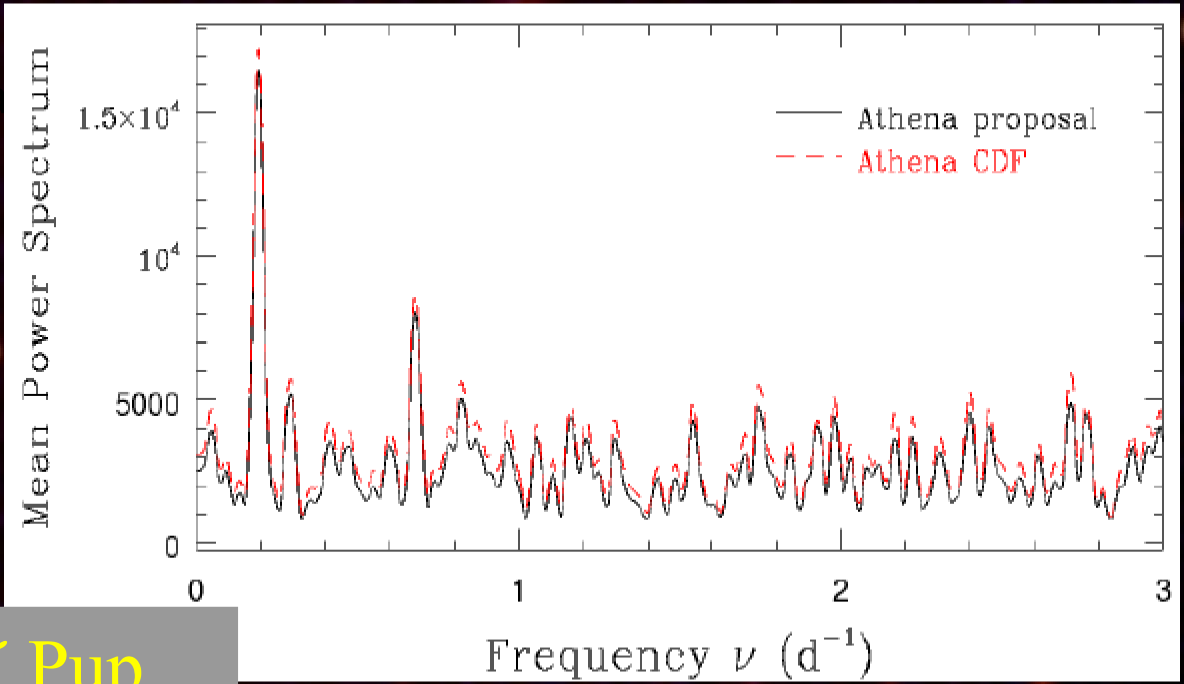
Rauw et al. 2015, A&A 580, A59

Time-resolved X-ray spectroscopy of massive stars

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).

Fourier power spectrum of a series of 110 simulated 1.8 ksec X-IFU exposures of the Ne X Ly α line for a 5% modulation on a 5 days period
==> Wind velocities: a few 1000 km/s, Wind flow time: ~ 1 hr





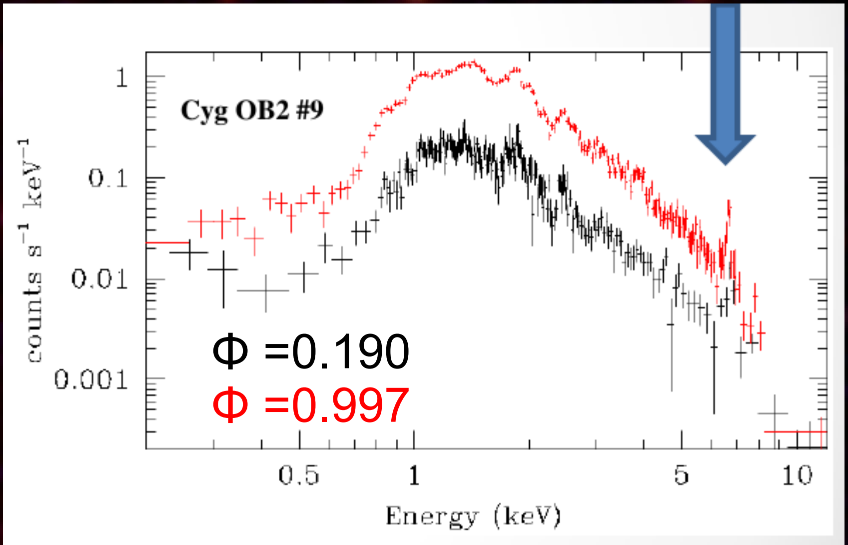
ζ Pup

Wind Interaction in massive binaries

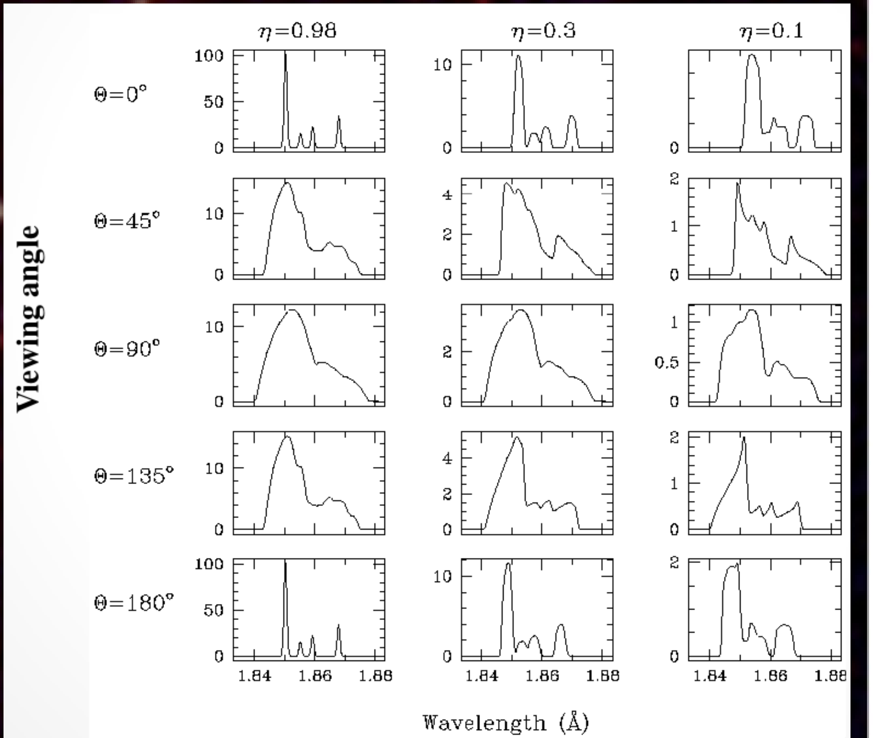
Some colliding wind systems exhibit a strong Fe xxv line near 6.7 keV which is solely formed in the wind interaction zone.

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

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; Rauw et al. 2015, arXiv1508.04965). Fe xxv (K line) consists of four components. Shapes depend on η and viewing angle



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



Rauw et al. 2015, arXiv1508.04965

Conclusions

ATHENA will offer great opportunities for the stellar physics studies, e.g.

Accretion, outflow and magnetic phenomena physics in YSOs

Origin of the high energy emission in Ultra Cool Dwarfs

Origin of high energy emission in single massive stars

Characterizing the wind interaction of massive binaries

But there is a lot more:

Star-Planet Interaction studies

Exoplanetary transit in X-ray domain: Planetary Atmosphere and Stadowgraph of Stellar Coronae

Variability <==> simultanesous observations from Ground & Space (e.g. PLATO)

Long term magnetic cycle studies

Characterizing the emission of Planetary Nebulae (our Sun future)

Origin of the emission of magnetic massive stars

Large scale star formation studies in the Local Group …..