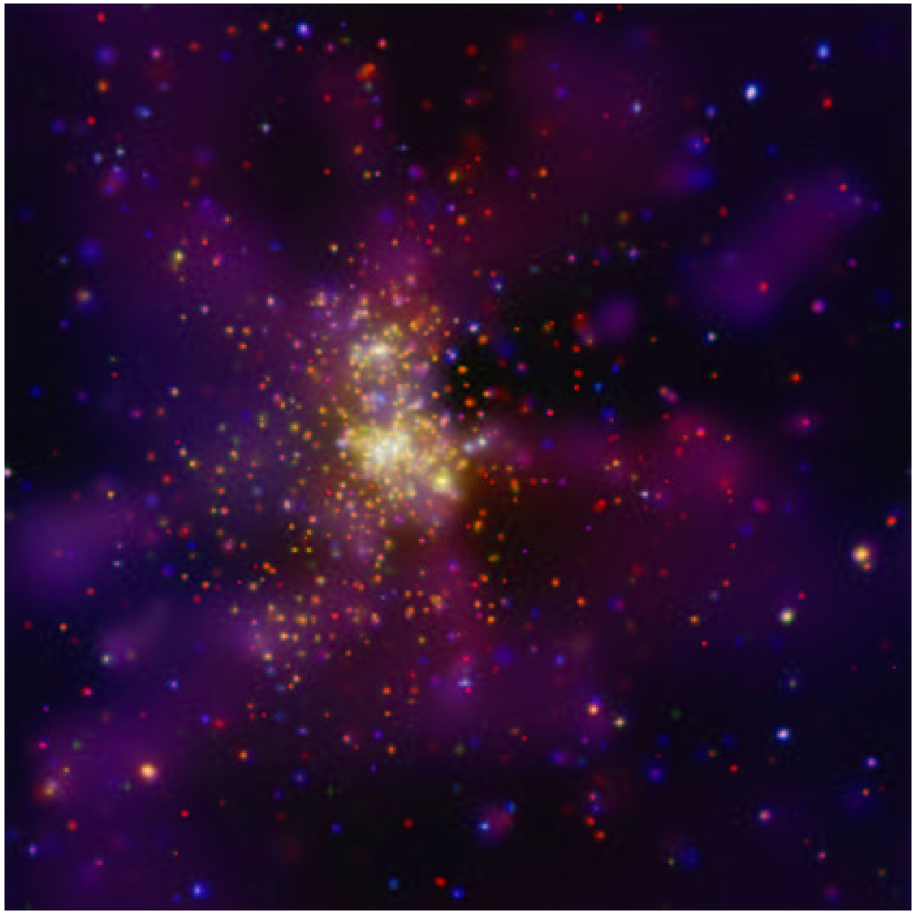
The X-Ray Universe

Potsdam University

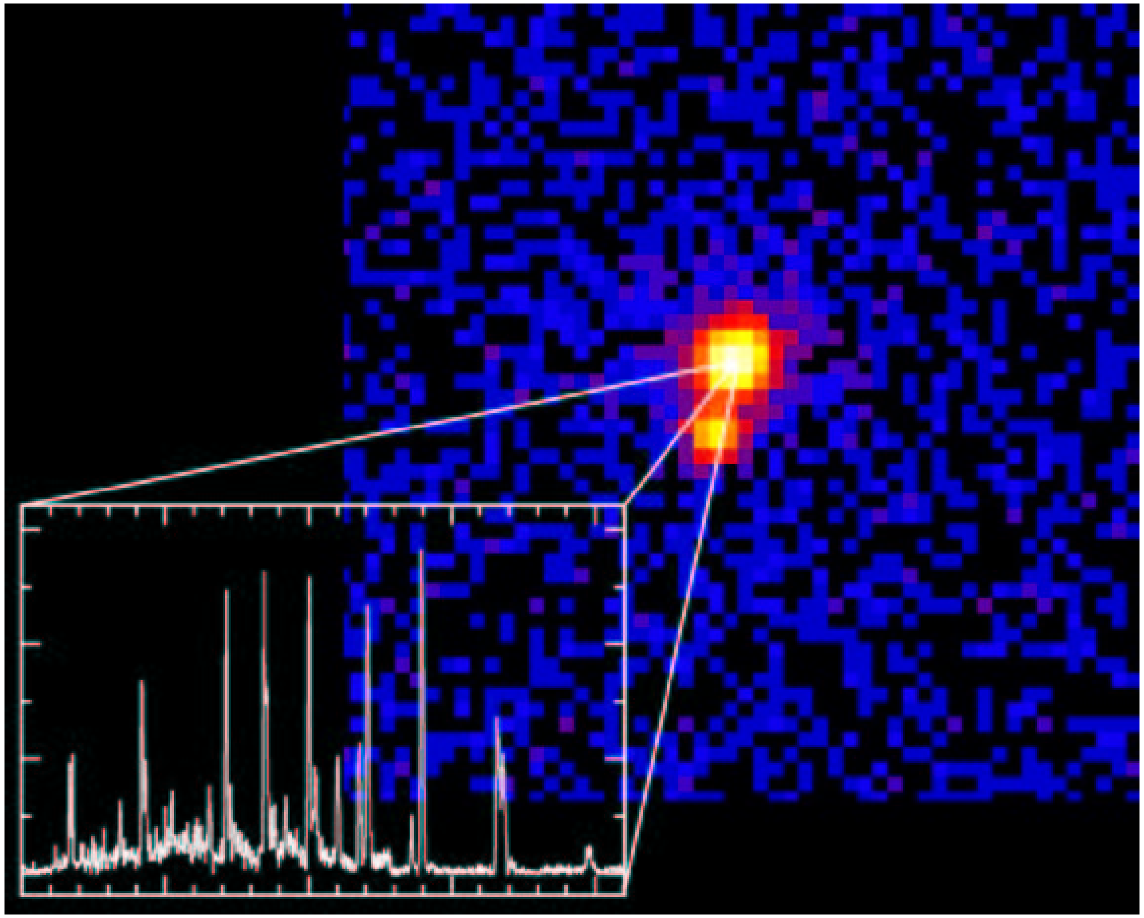
Dr. Lidia Oskinova
Wintersemester 2008/09

lida@astro.physik.uni-potsdam.de
www.astro.physik.uni-potsdam.de/~lida/theormech.html



Chandra X-ray Observatory
Westerlund 2 - a young star cluster
d= 2×10^4 ly

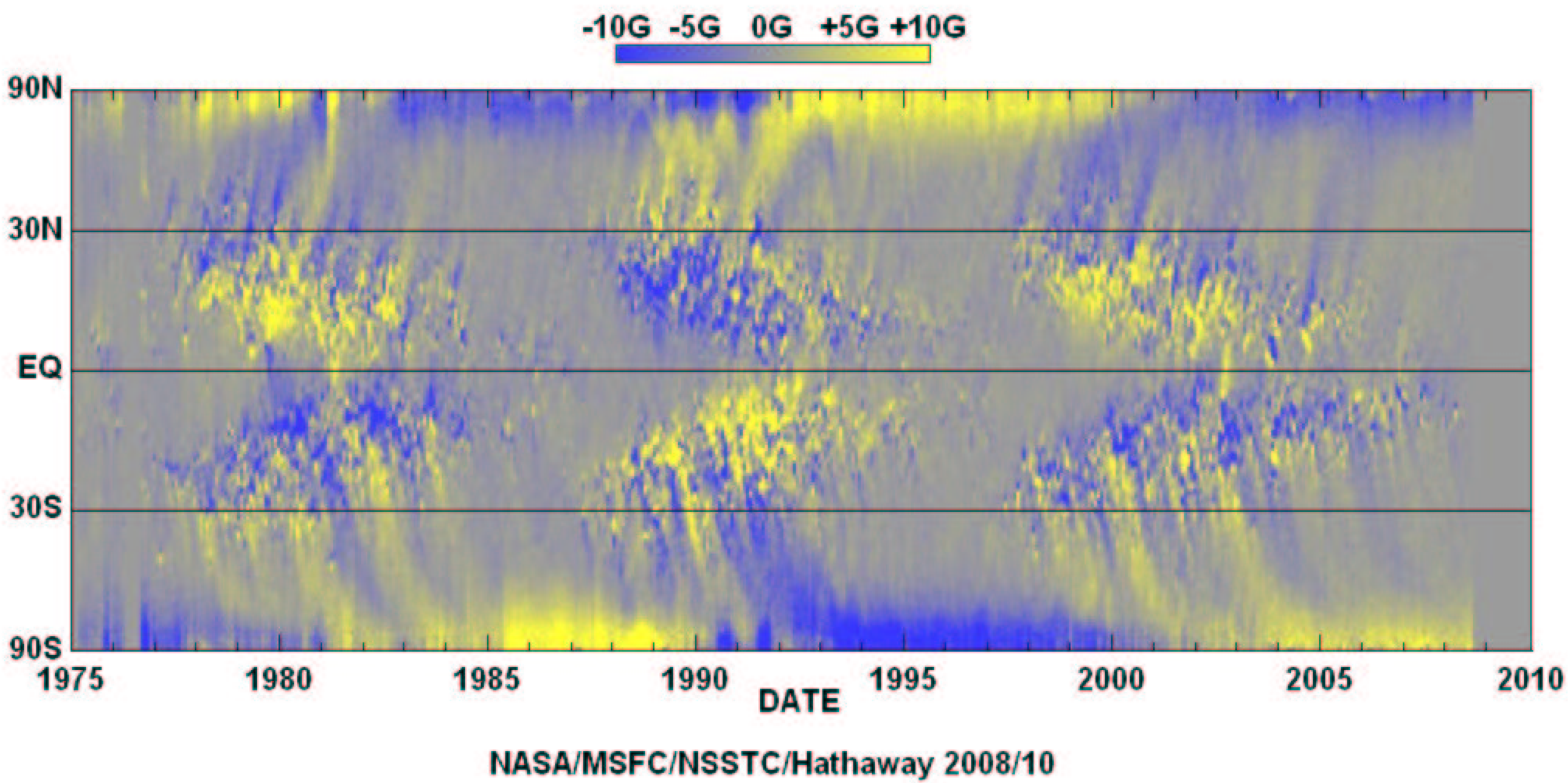
VI. X-rays from Normal Stars



NASA/EIT/W.Waldron, J.Cassinelli

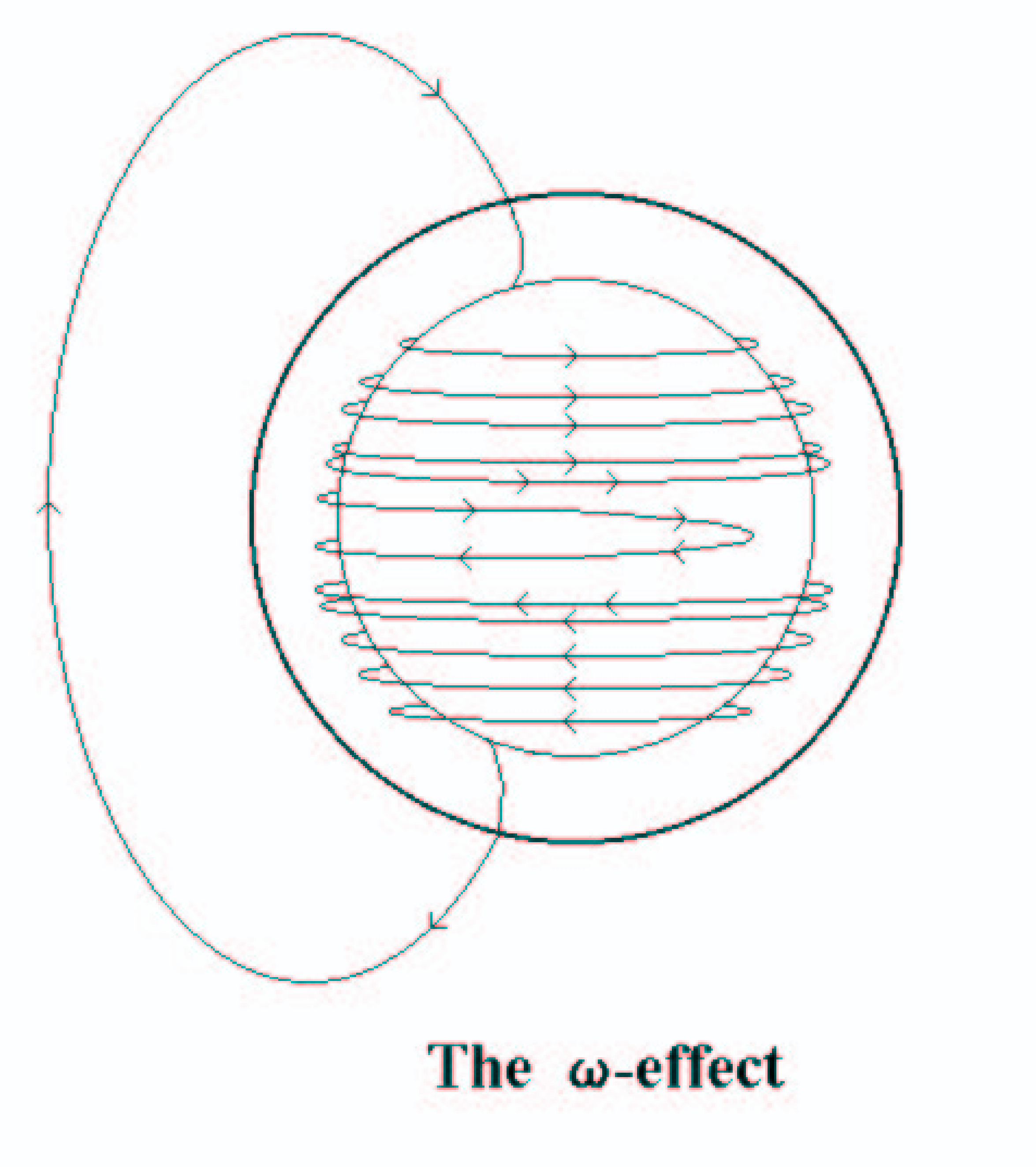
Or not totaly abnormal

VI. Solar dynamo



Observational laws: 1) 11-year period; 2) butterfly diagram; 3) tilt of sunspot group; 4) 22-year magnetic cycle

VI. Ω-effect



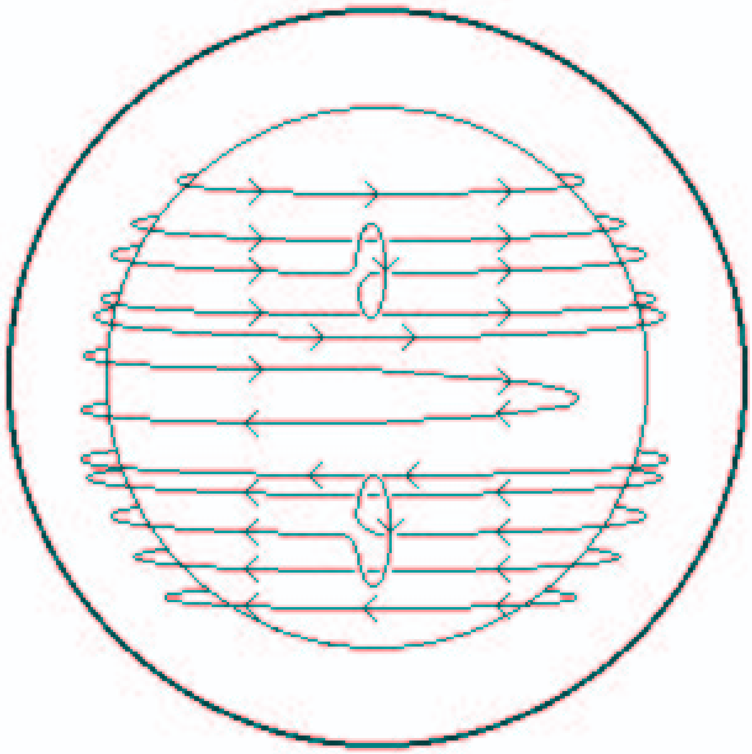
Differential rotation - the change in rotation rate as a function of latitude and radius within the Sun.

Magnetic filed is stretched out and wound around the Sun

Latitudal differential rotation can wrap magnetic field line around the Sun in about 8 months.

http://solarscience.msfc.nasa.gov/

VI. α-effect



The α-effect

Effect of rotation on the rising "tubes" of magnetic field- loops look like letter α

α-effect governs tilt of spot groups and polarity reversal

Similar effects are observed in solar type stars, so Sun is an average star.

Dynamo operates in all low- and solar-mass stars. Activity scales with rotation rate.

http://solarscience.msfc.nasa.gov/

VI. High-Resolution X-ray spectroscopy

CIE plasma: I^{q}/I^{q-1} depends on T

collisional ionization is balanced by radiative recombination

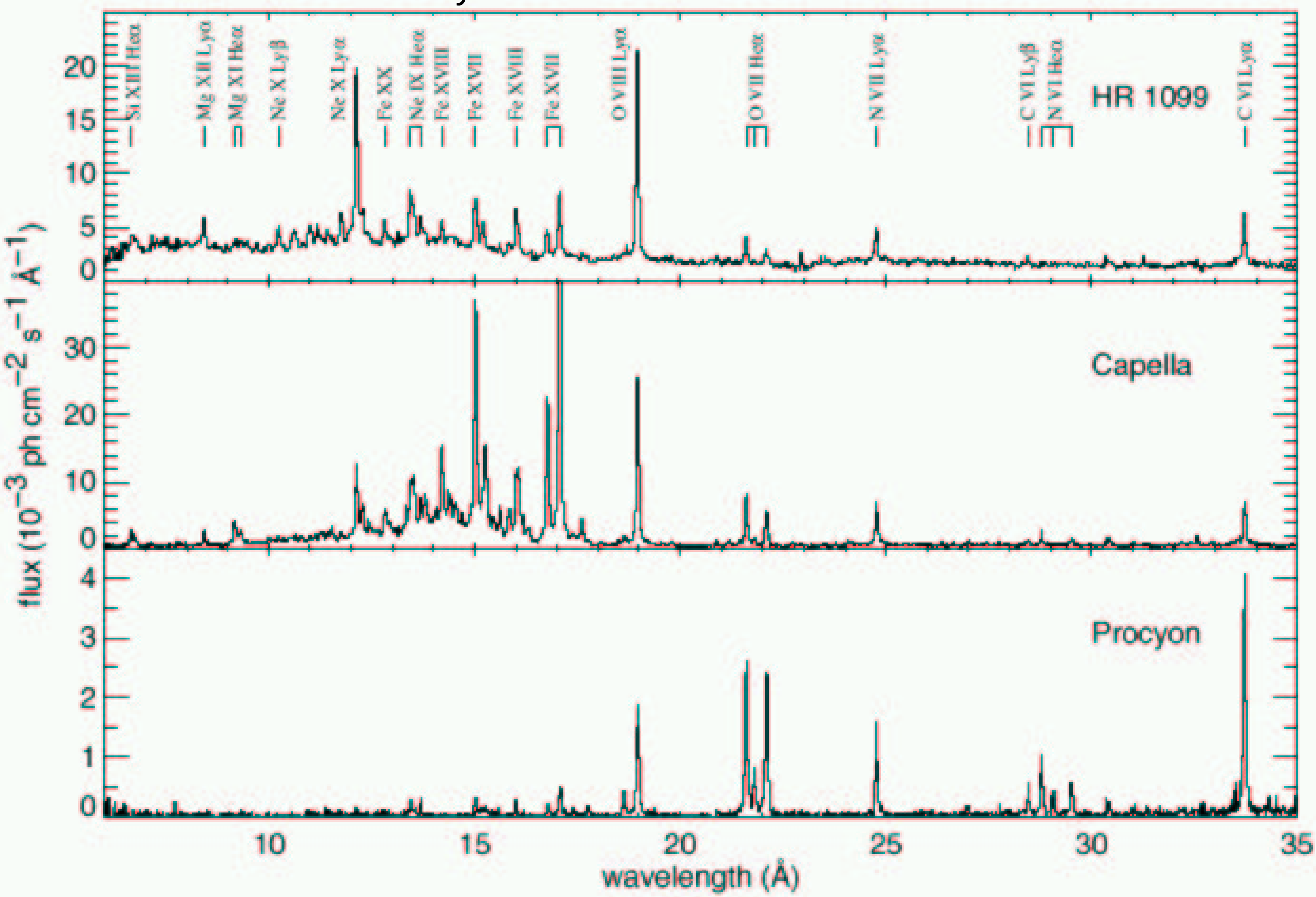
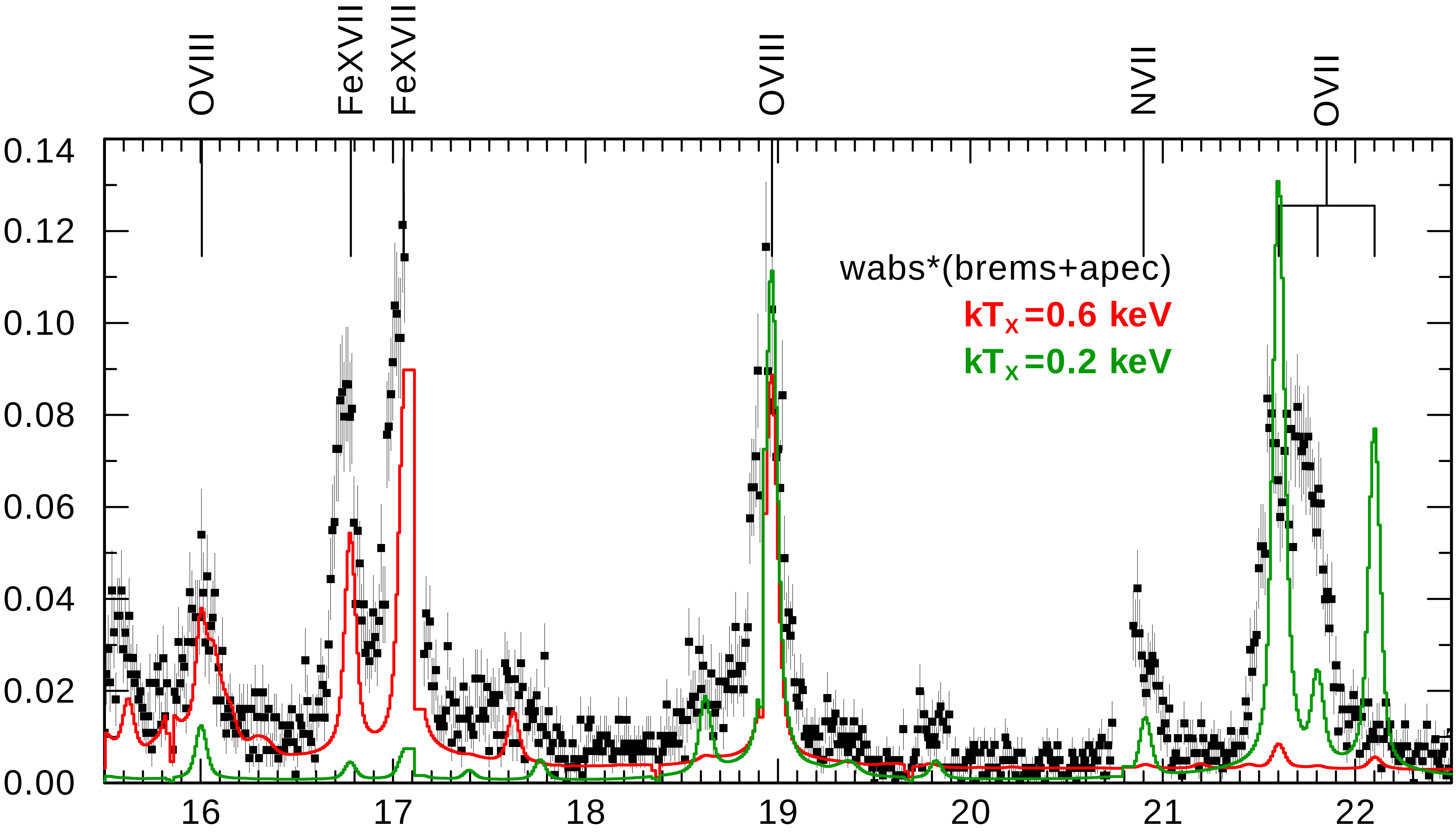


Fig. 6. Three high-resolution X-ray spectra of stars with largely differing activity levels: HR 1099, Capella, and Procyon. Data from *XMM-Newton* RGS

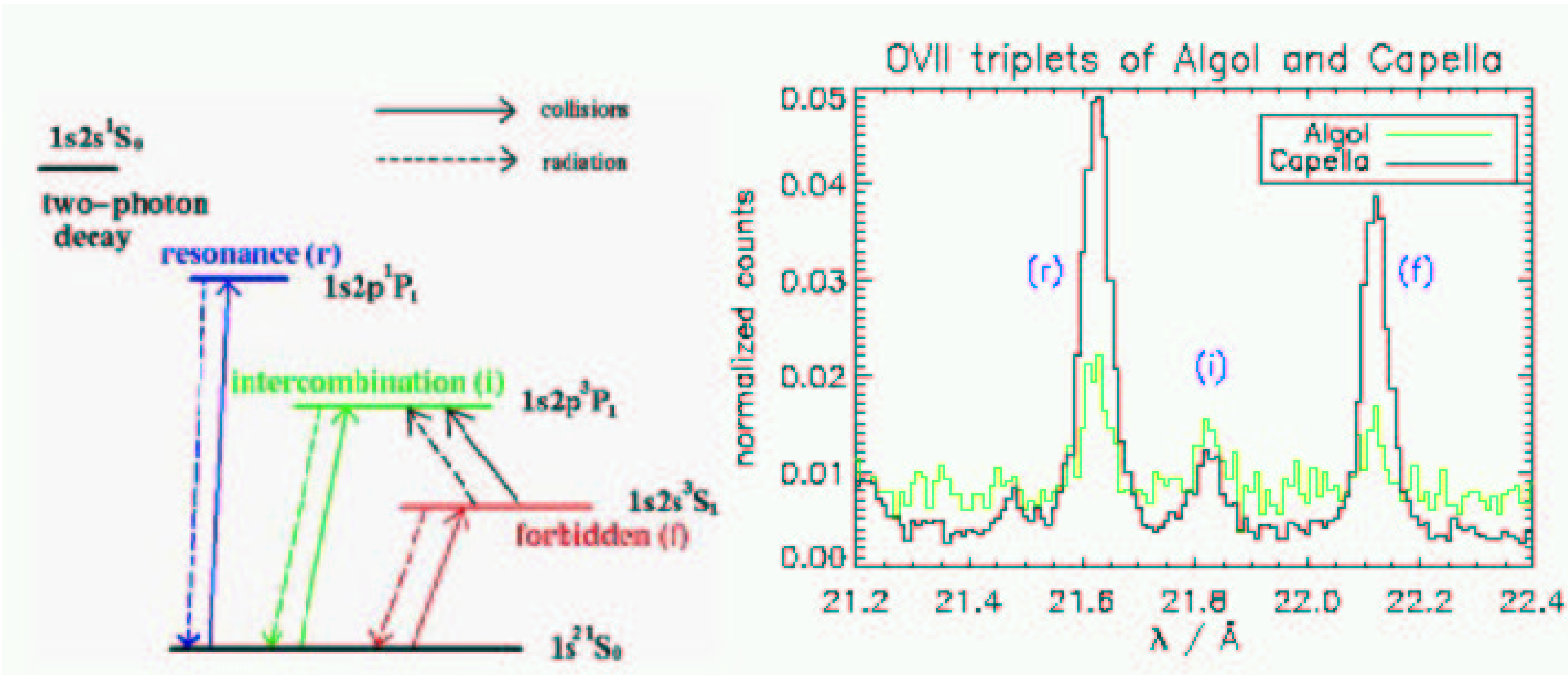
from Güdel 2004, A&AR, 12, 71

Model the data: E.g. spectrum non-isothermal CIE



- Continuum: Free-free continuum (Kahn+'01, Oskinova+'06)
- spectral fits: EM of continuum model $\approx$ EM of line model
- NB! OVII

VI. Electron densities in stellar coronae



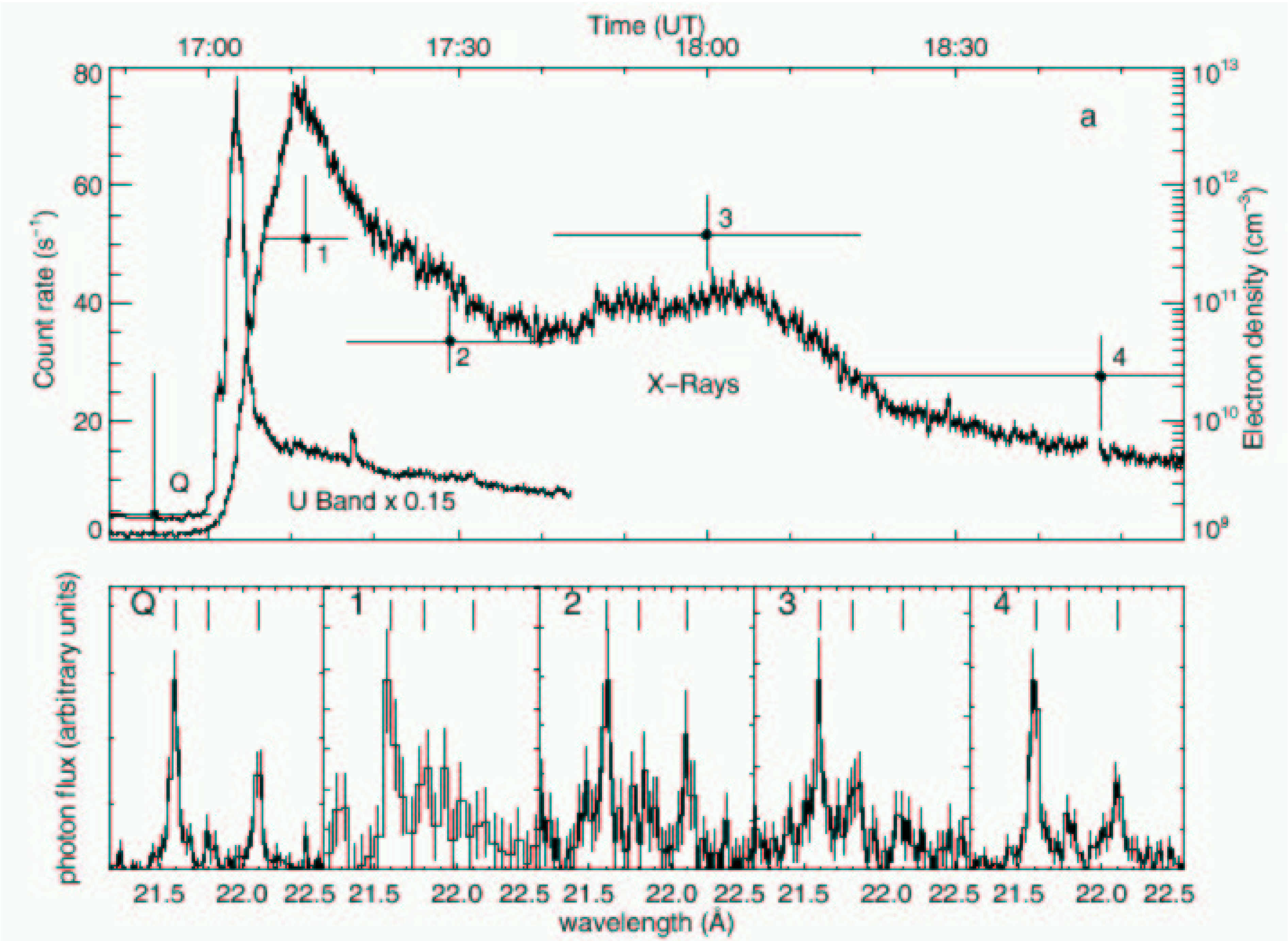
from Güdel 2004, A&AR, 12, 71

He-like ions allow to measure density

Interpretation is not strightforward, because coronae are not homogeneous

VI. Stellar flares

Flare on Proxima Centauri,observed with XMM-Newton

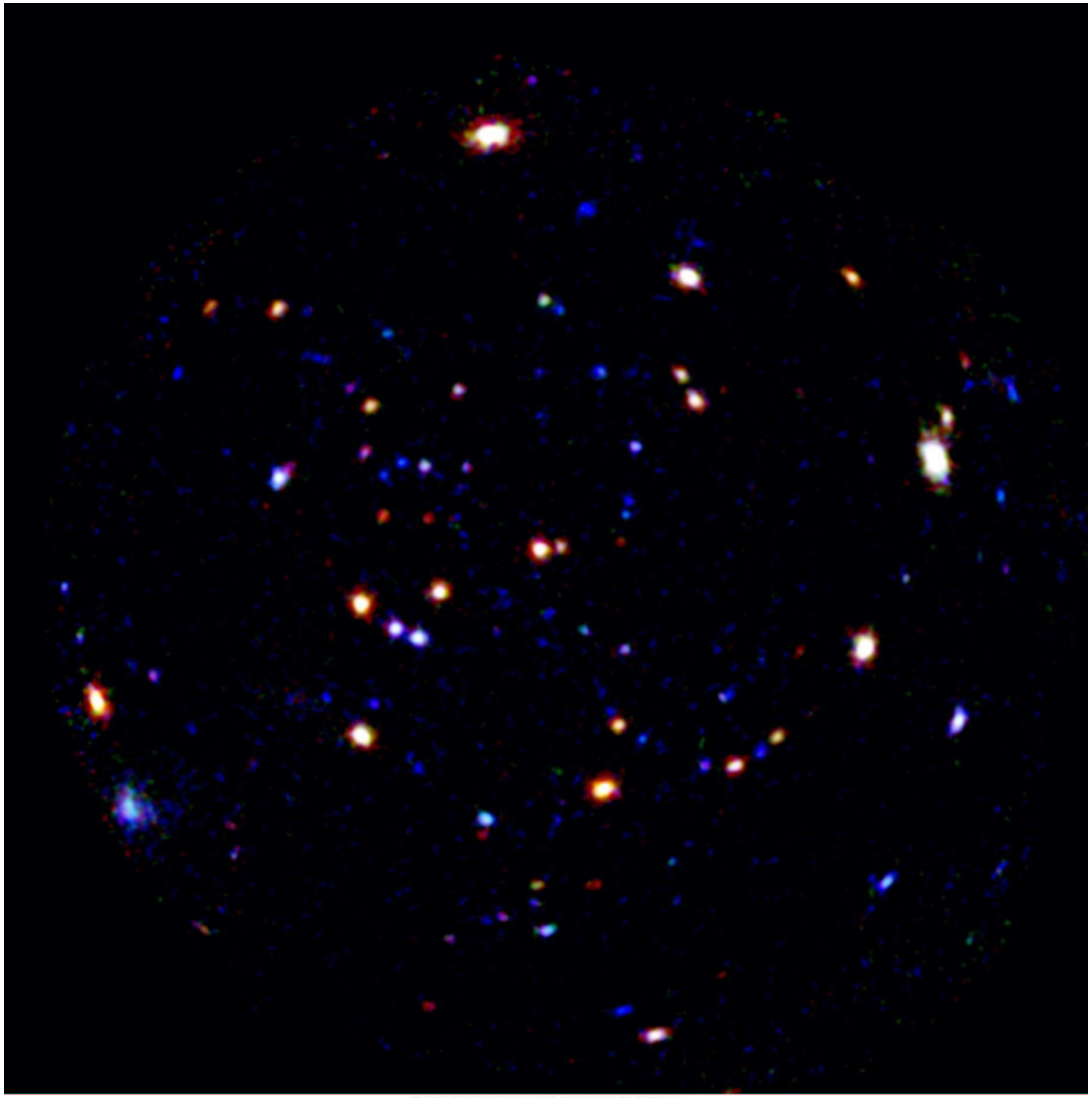


from Güdel et al.2002

VI. Stellar flares: common properites

* Flares are universaly observed
* Theoretically: When the flare energy release evaporates plasma into the corona, heating and cooling effects compete determining the density and temperature profiles in a given flare.
* Obsevrationslly: correlation between flare EM and T: larger flares are hotter.
* The distibution is similar to the Sun: → $\frac{dN}{dE} \propto E^{-\alpha}$. But it apperas that later stars are flaring more

VI. General properties



The Pleiades open (galactic) stellar cluster seen by XMM-Newton

Image courtesy of Rosemary Willatt, Pedro Rodriguez (ESAC)

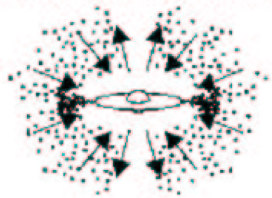
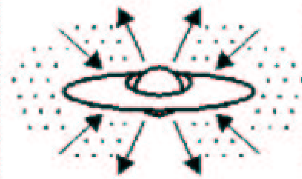
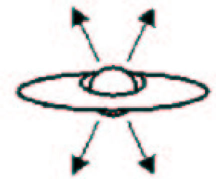
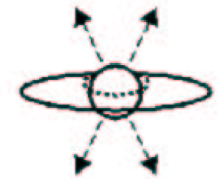
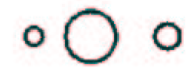
European Space Agency

http://xmm.esac.esa.int/external/xmm_science/gallery/

- Age-luminosity correlation for M~1Msun $L_X \approx 3 \times 10^{28} t^{-1.5}$ erg/s, [t]=Gyr
- Sun and its near-twin α Cen A behave very much alike → Sun is a star !
- Low-mass stars stay active for a longer time.
- Saturation limit of $L_X/L_{bol}=10^{-3}$
- **Dynamo rules it all!**

Pleiades (100 Myr), an open stellar cluster. The image is false-coloured: soft (0.2 - 1 keV), medium (1 - 1.3 keV), hard (1.3 - 10 keV).

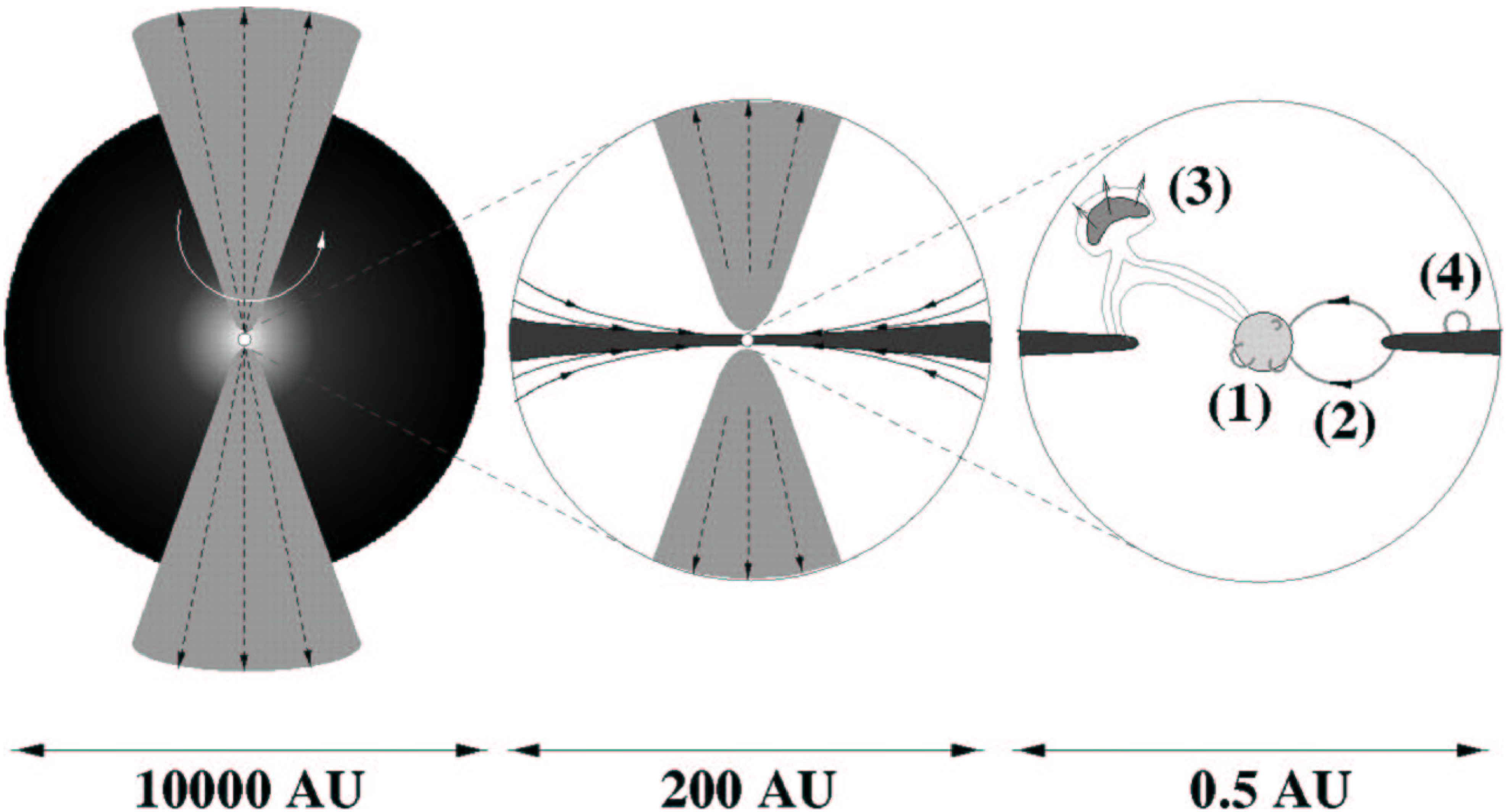
VI. Young stars (solar type)

PROPERTIES	*Infalling Protostar*	*Evolved Protostar*	*Classical T Tauri Star*	*Weak-lined T Tauri Star*	*Main Sequence Star*
SKETCH					
AGE (YEARS)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	$> 10^7$
mm/INFRARED CLASS	Class 0	Class I	Class II	Class III	(Class III)
DISK	Yes	Thick	Thick	Thin or Non-existent	Possible Planetary System
X-RAY	?	Yes	Strong	Strong	Weak
THERMAL RADIO	Yes	Yes	Yes	No	No
NON-THERMAL RADIO	No	Yes	No ?	Yes	Yes

Feigelson & Montmerle ARAÄ 37, 363

VI. Possible sites of X-ray generation

X-rays from collapsing extended envelope	X-rays from inner disk and outflow	X-rays from star-disk magnetic-interaction region

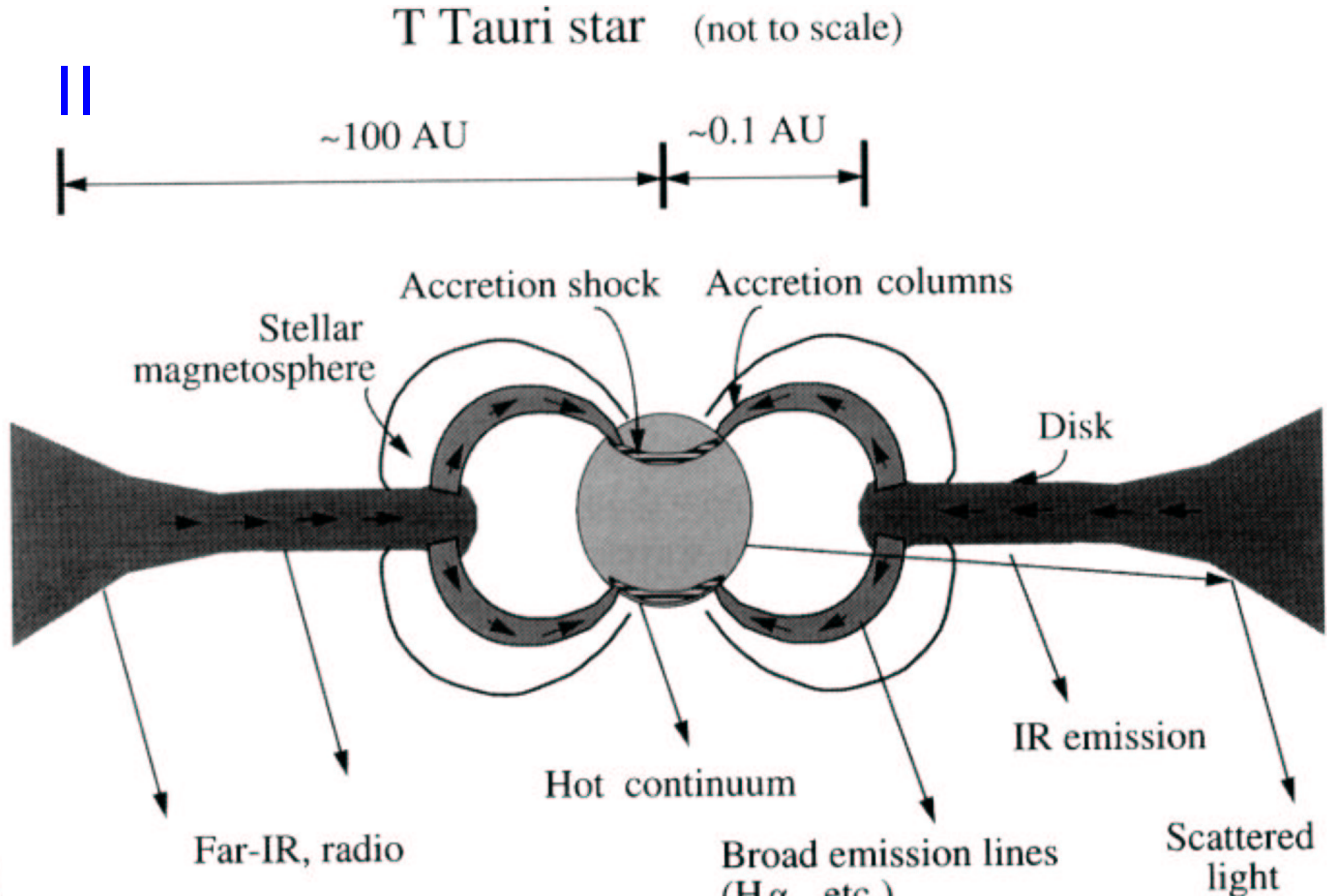


Feigelson & Montmerle ARA&A 37, 363

VI. Qualitative Models

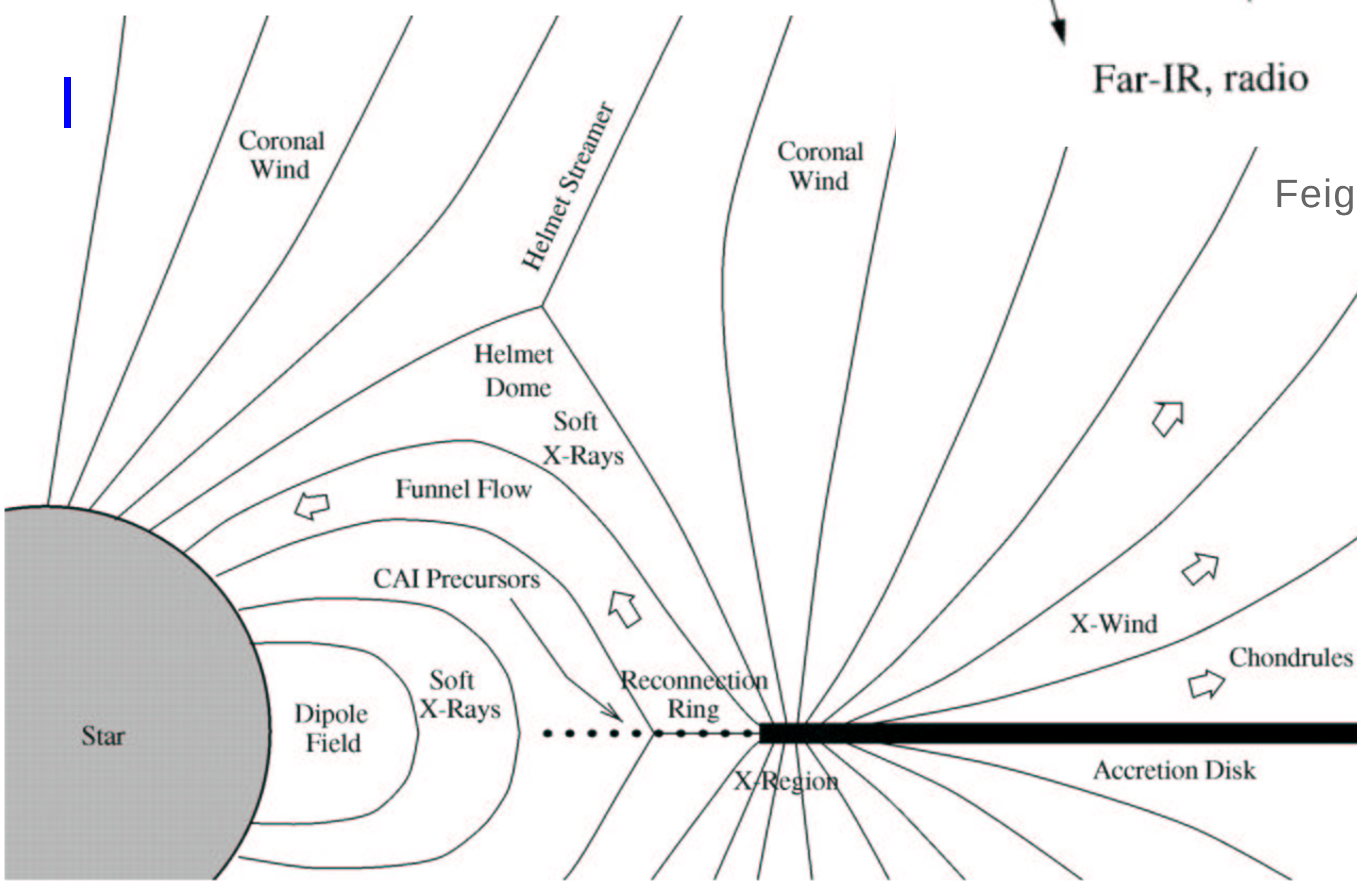
I. the x-wind model of YSOs showing magnetically collimated accretion and outflows with irradiated meteoritic solids (Shu et al 1997)

II



Feigelson & Montmerle ARA&A 37, 363

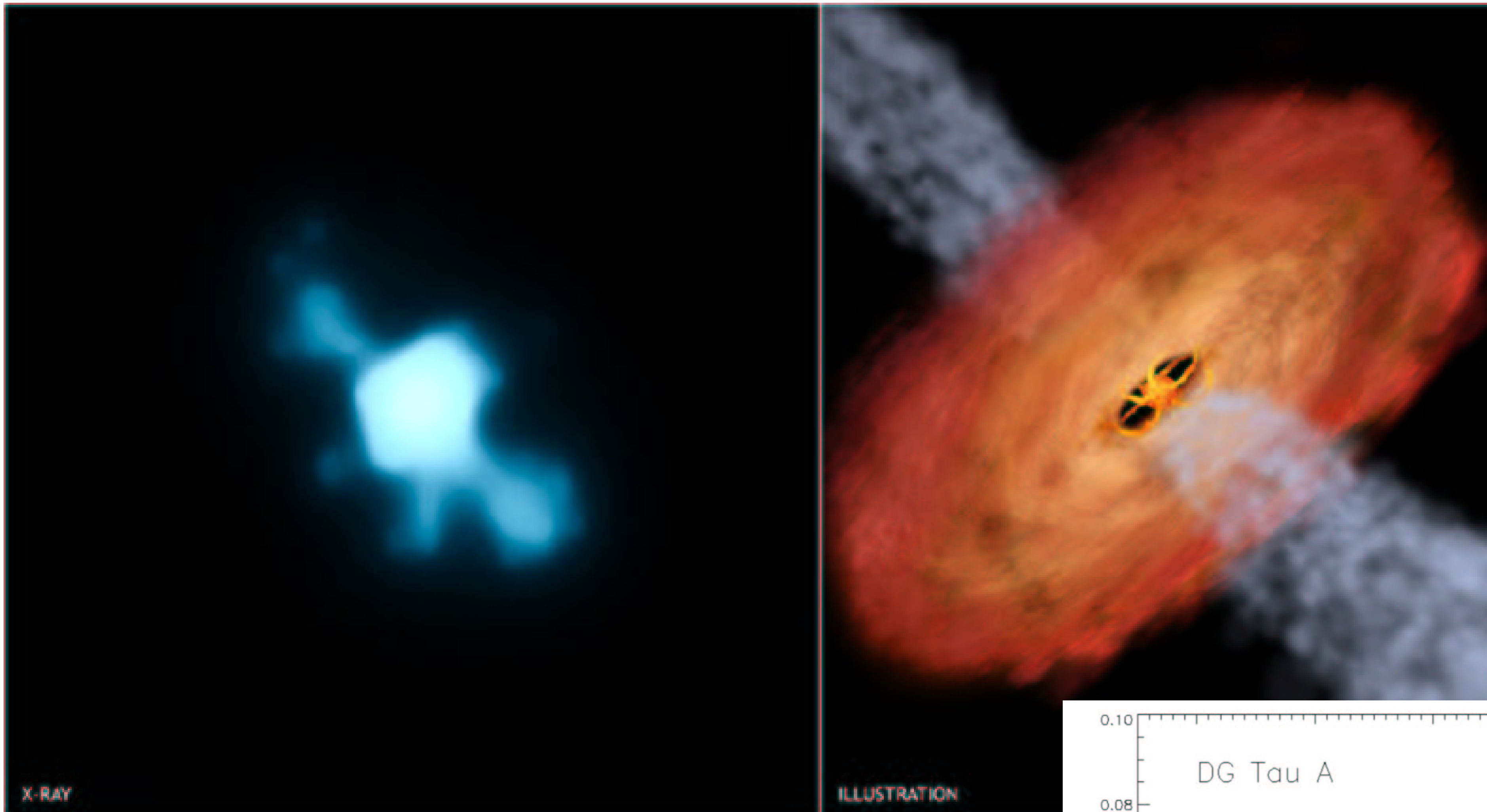
I

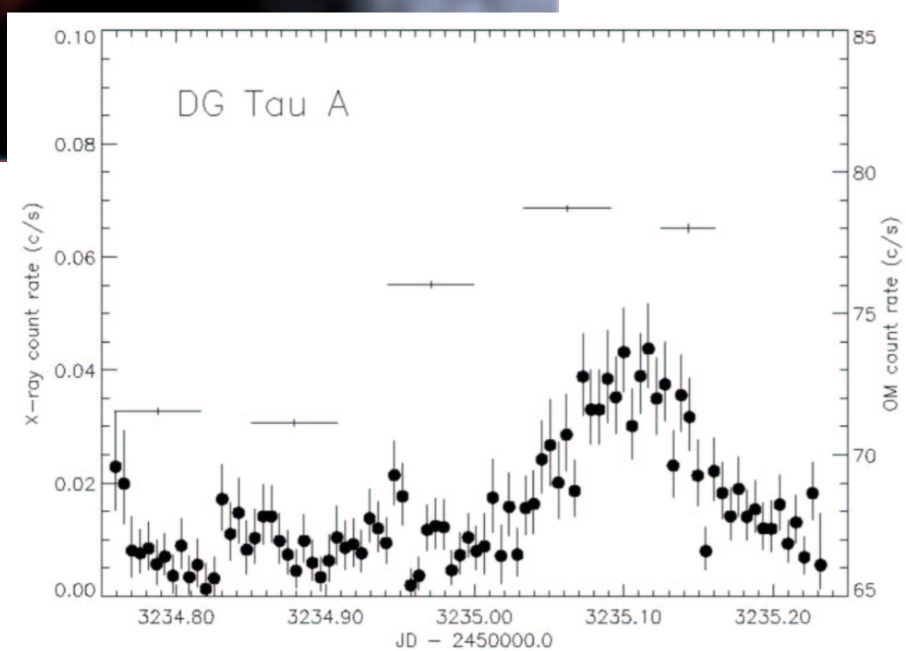


II. magnetically funneled accretion streams

→ broad emission lines (Hartmann 1998)

VI. Observations





http://chandra.harvard.edu/photo/2008/dgtau/

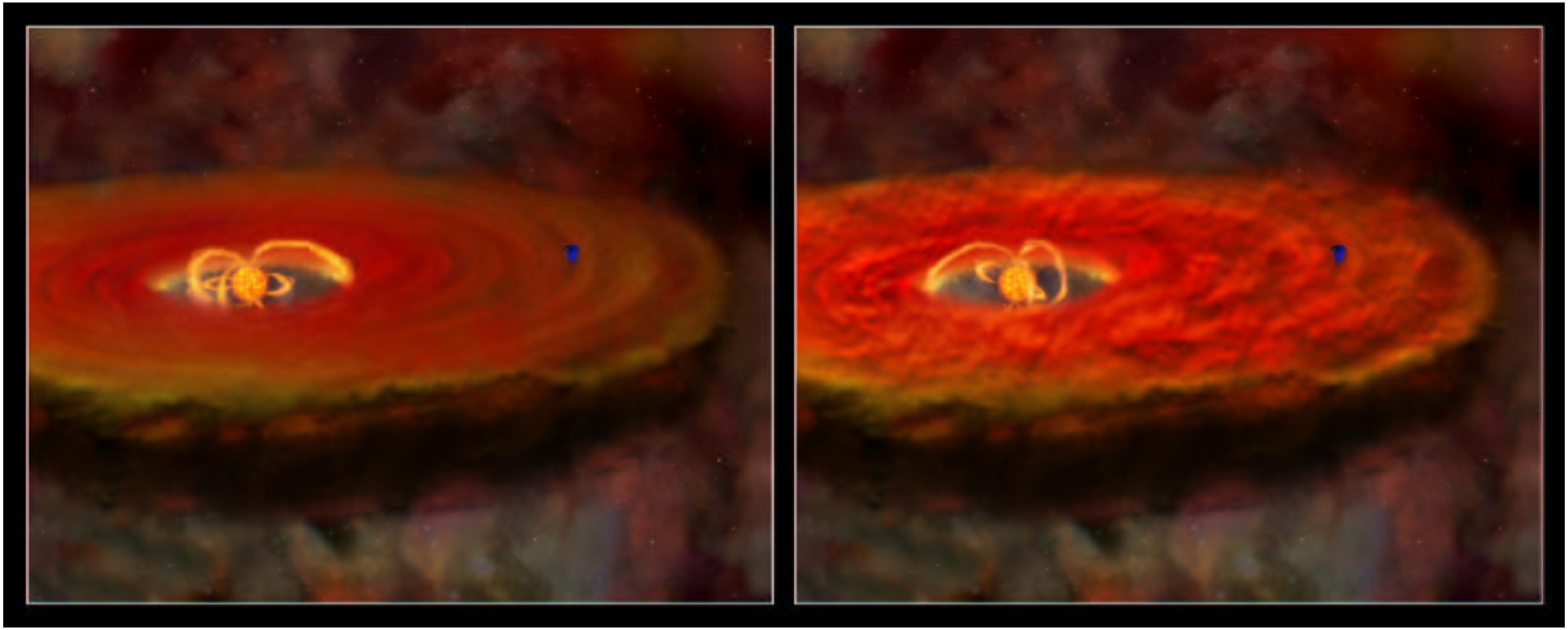
DG Tau $M=1M_{sun}$, Age=1Myr

Jets, disk absorption, flares

Accretion **and** corona (?)

Importance for planet formation

VI. Accretion disks



http://chandra.harvard.edu/photo/2005/orion

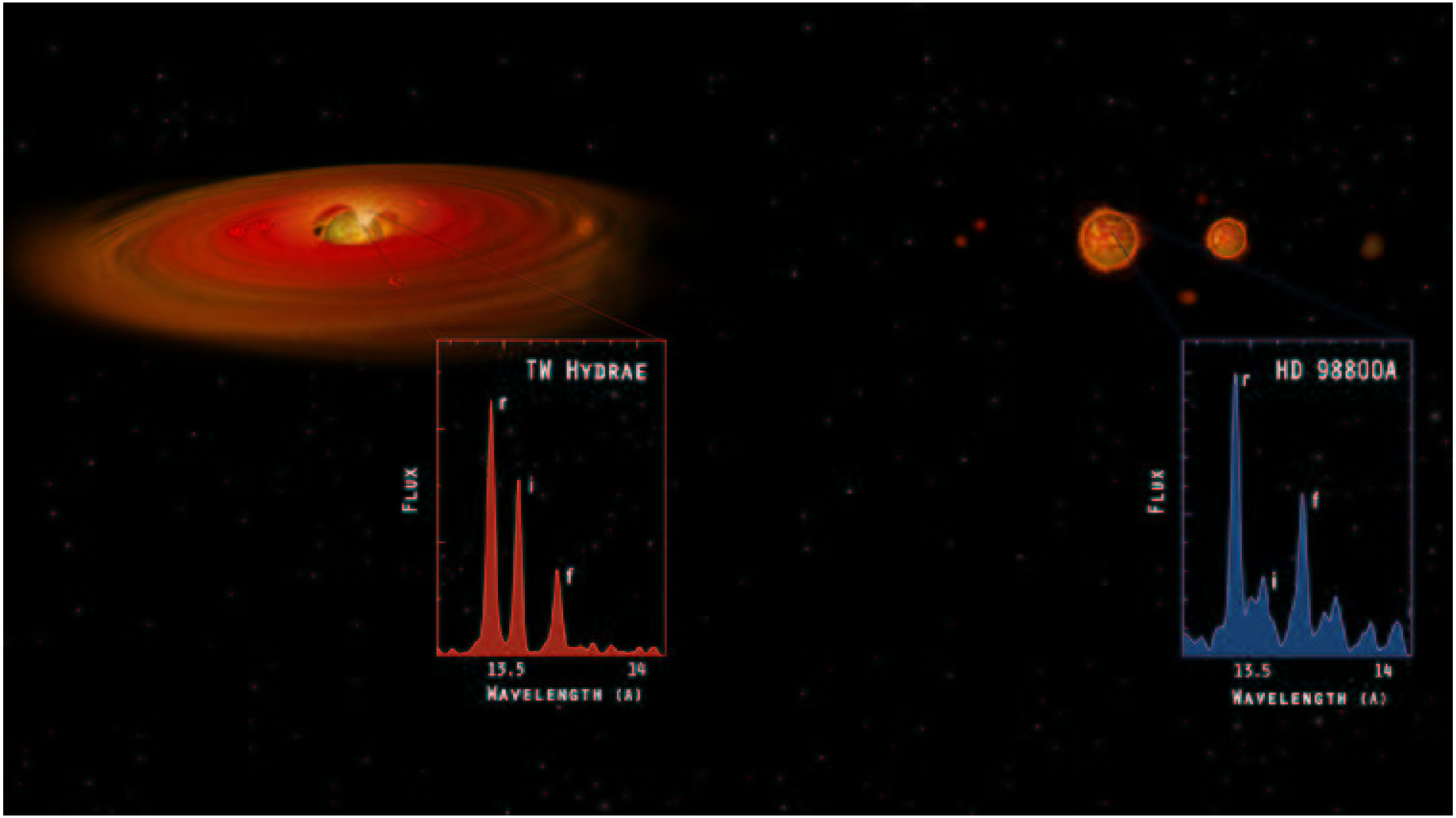
T Tau star flares are importnat to induce turbulens in the disks

MHD simulation turbulent disks prevent planet infall to the central star

X-rays may be needed to initiate chemical reaction neccesasry for planet formation

X-ray activity declines with age

VI. FIR diagnostic of accretion



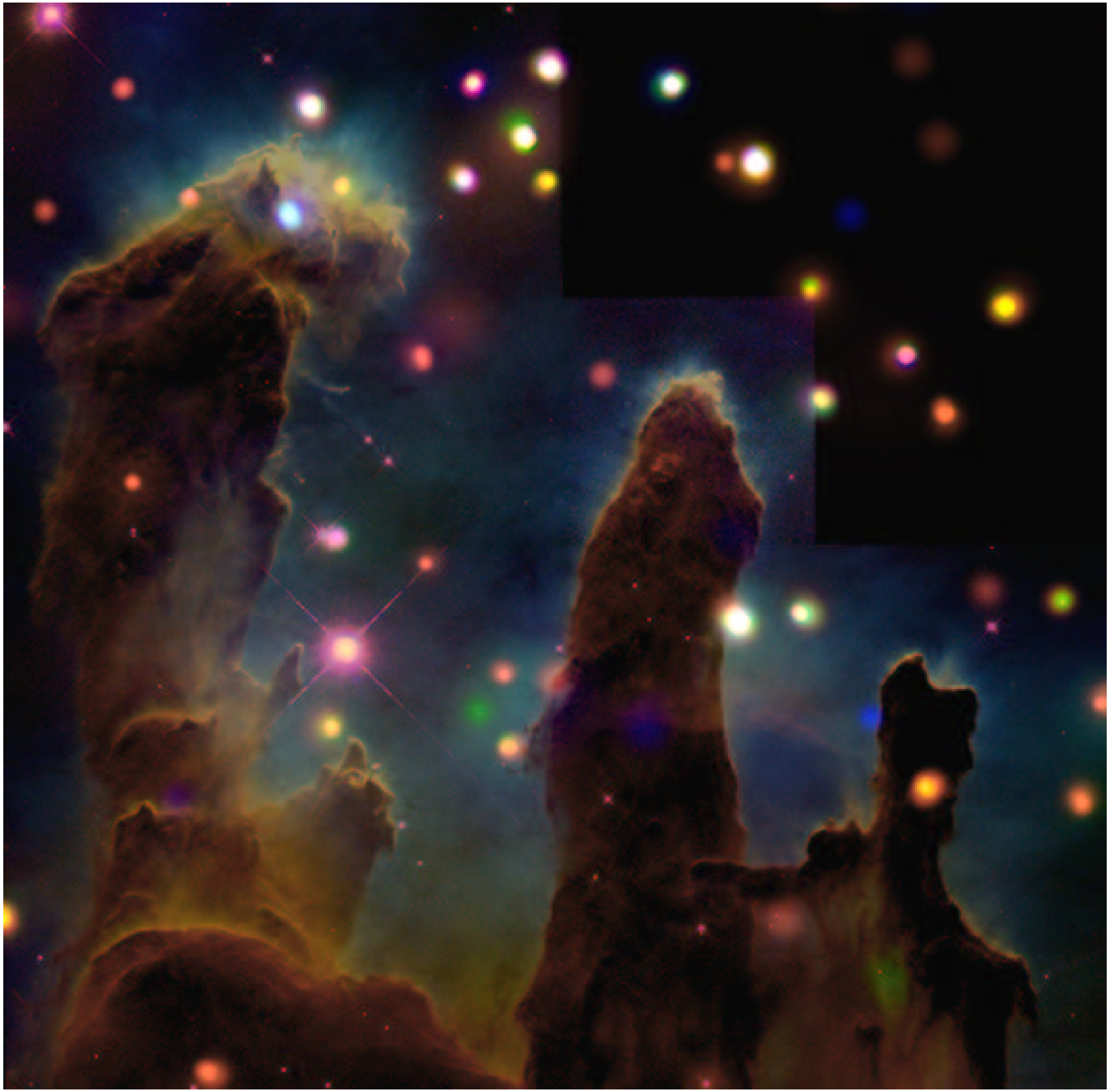
http://chandra.harvard.edu/photo/2003/twhy/

Higher densities in younger stars: accretion column

Older stars: disk dissipates, planet formation

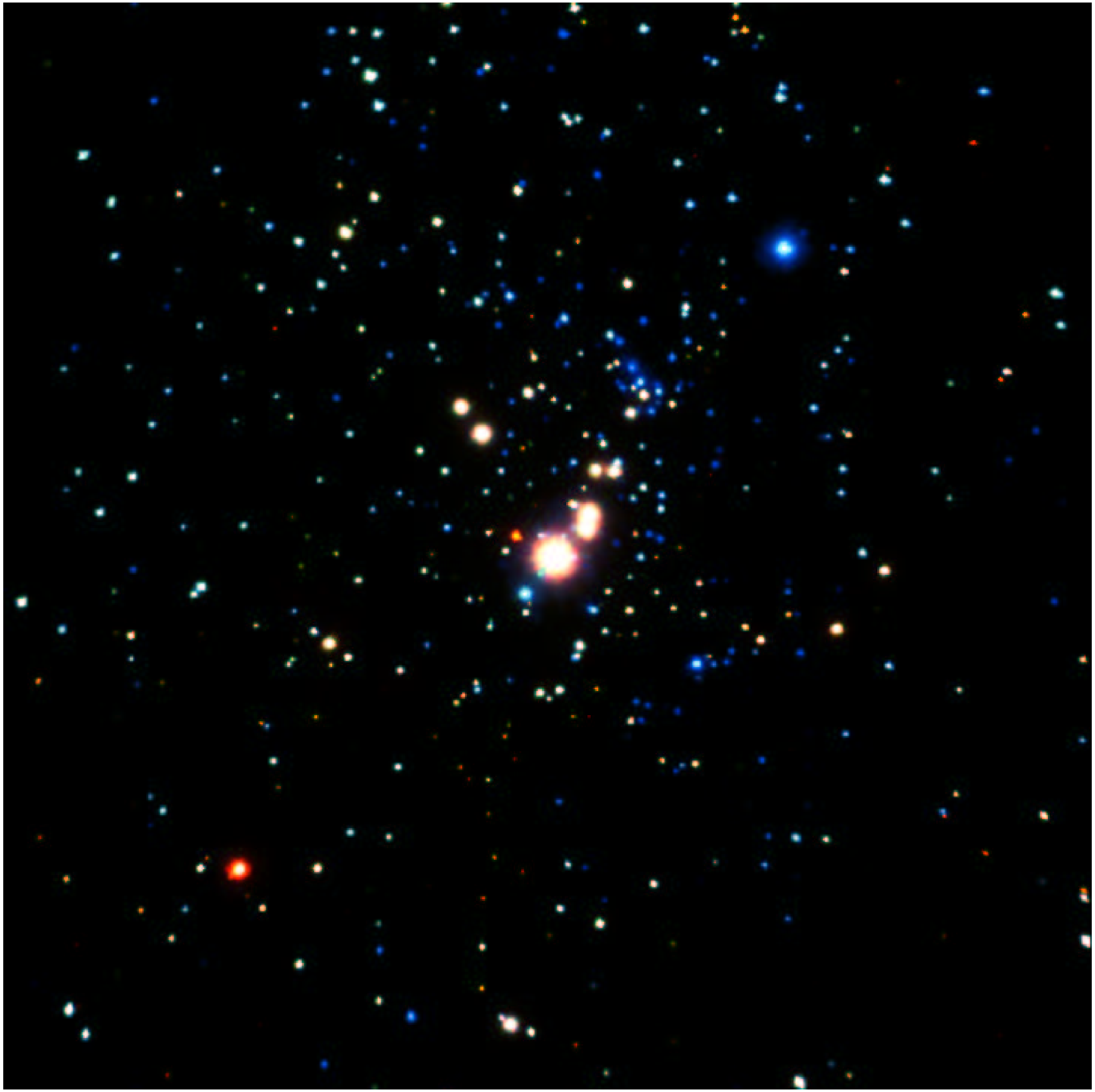
X-ray observations are good tool to search for YSOs

VI. HST & Chandra: Pillars of Creation in M16



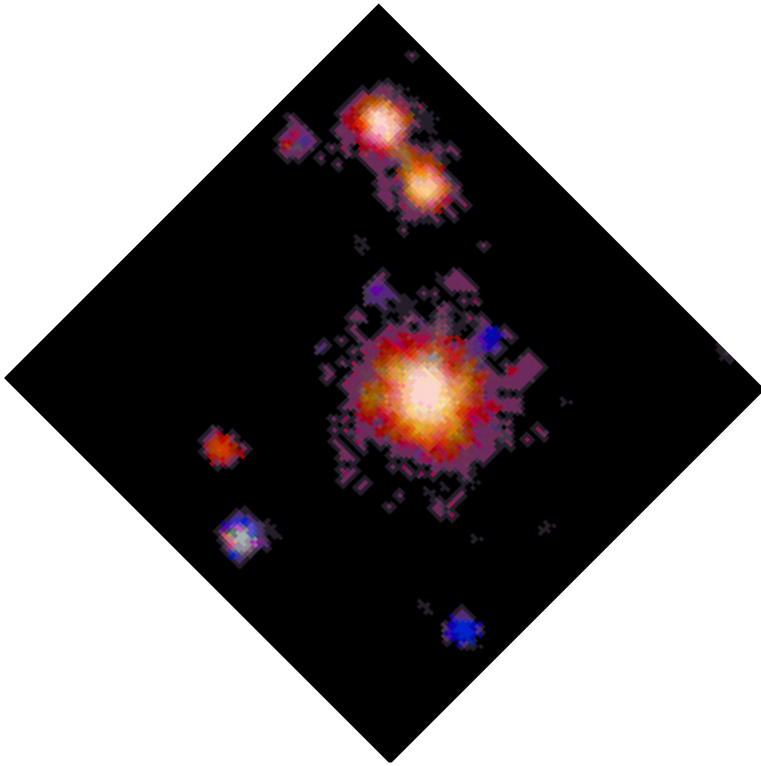
http://chandra.harvard.edu/2007/m16/

VI. Chandra's Orion Nebula



http://chandra.harvard.edu/2005/orion/ see twinkling version

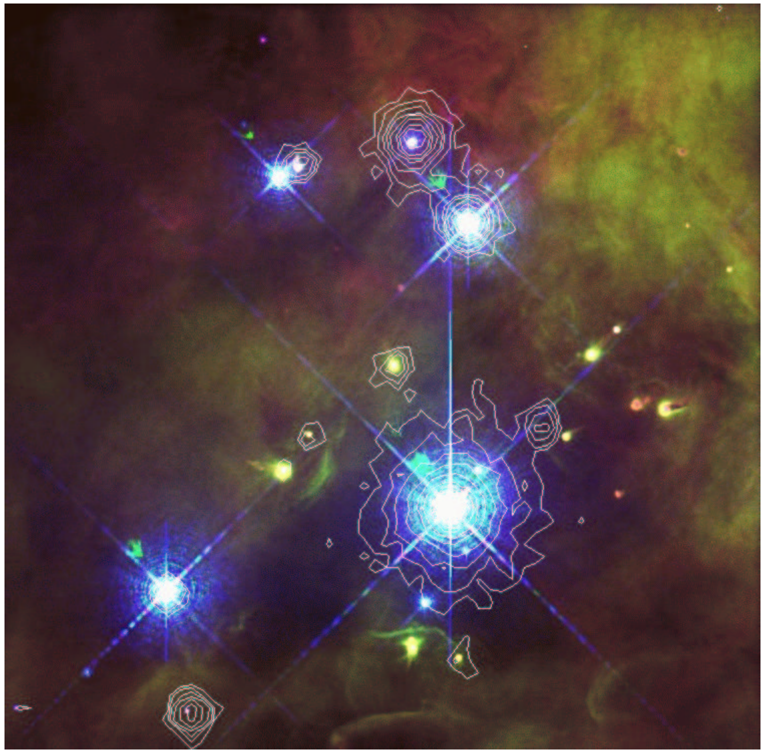
VI. Chandra’s Orion Trapezium



Massive stars in the center of Orion nebula

Young (1Myr) O type stars that ionize the nebula

… Are X-ray sources and they are hard



Massive stars (earlier than A-type)

are fully radiative

Solar type coronae powered by $\alpha\Omega$-dynamo

cannot operate there

Massive stars posses strong stellar winds

http://chandra.harvard.edu/press/00_releases/press_110900.html

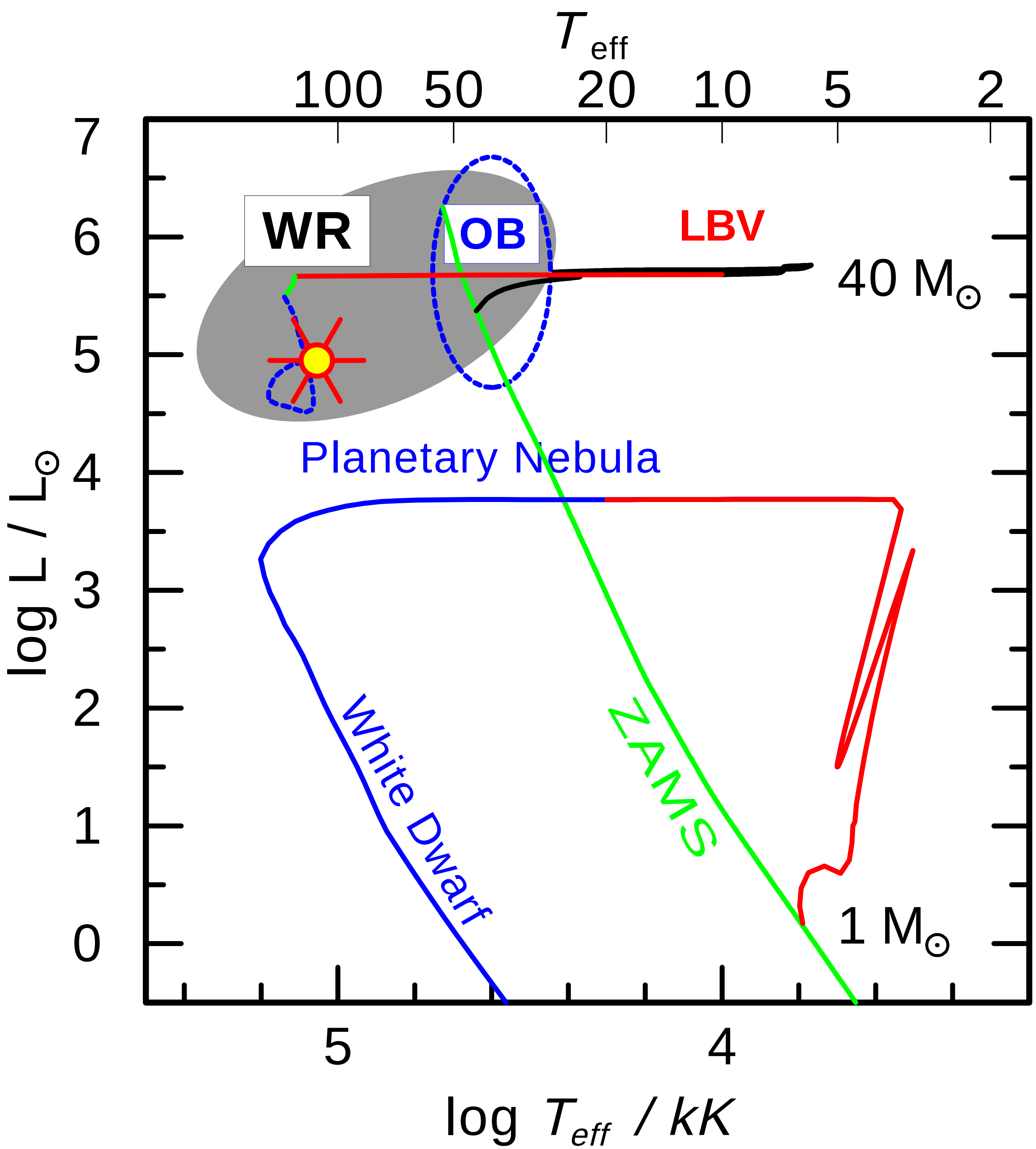
Massive Stars and Stellar Winds

$$M_* > 8M_\odot$$

Live Fast, Die Young (~ few Myr)

- $T_{\rm eff} > 10\,000$ K $\rightarrow$ high surface brightness
- Light: momentum (+ energy) $\rightarrow$ force to the scattering atoms
- Light force > gravitational force $\rightarrow$ **STELLAR WIND**
- Radiative driving is by line scattering
- Moving media: Doppler: line width $\Delta\nu \propto v$
- Feedback: radiative driving force depends on acceleration

The evolution of (very) massive stars



Evolution ← stellar wind (!)

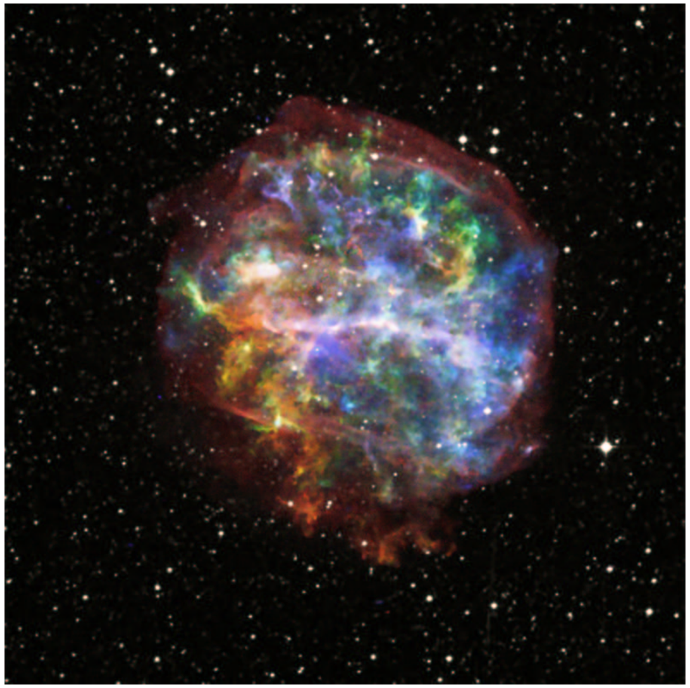
- O and B type stars
- Luminous Blue Variables
- Wolf-Rayet (WR) stars

According to dominant spectral lines

WN (nitrogen) →

WC (carbon) →

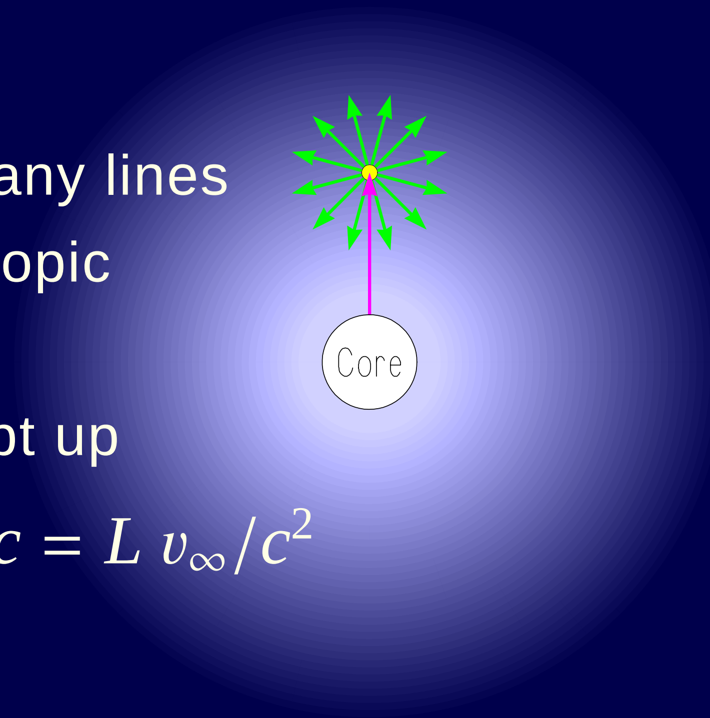
WO (oxygen) →



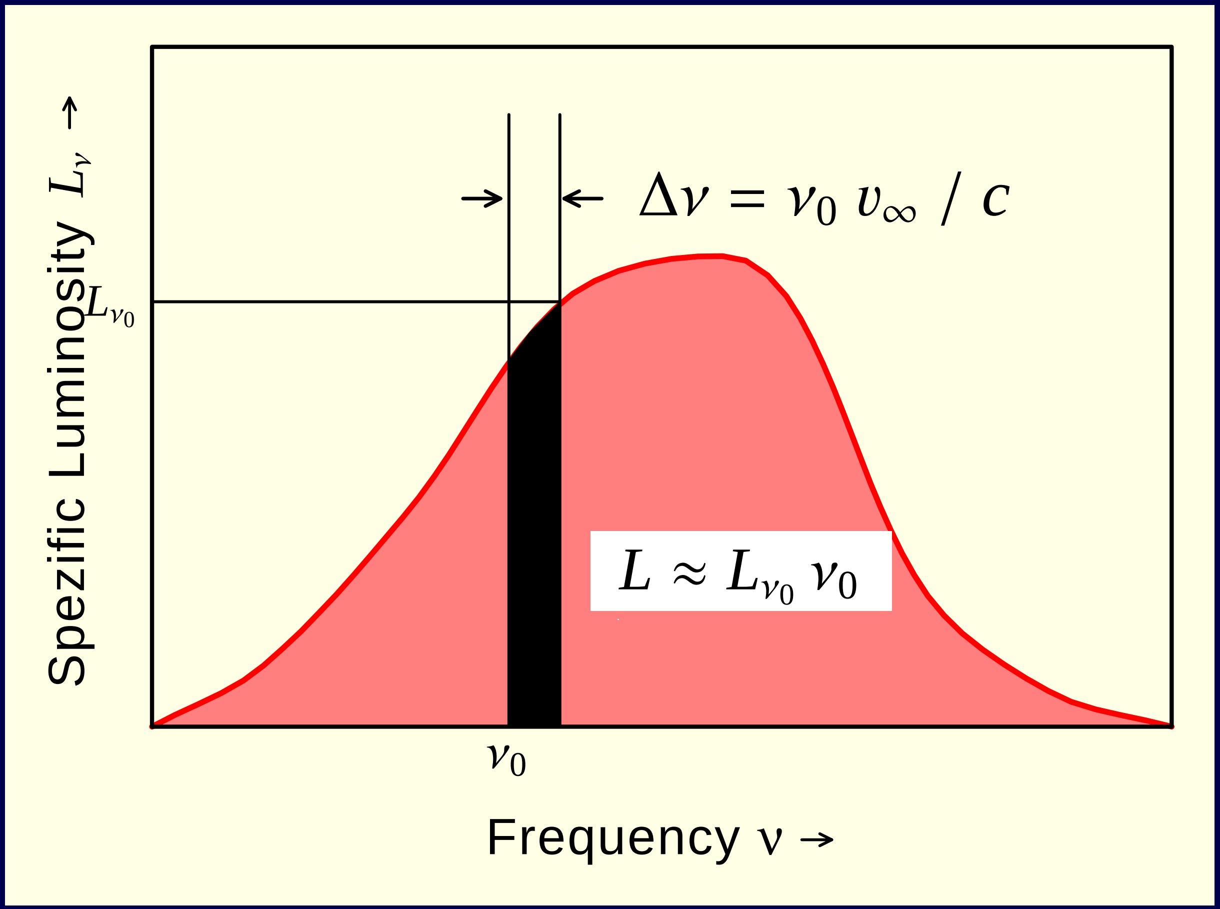
Line-driven stellar winds

(Castor, Abbott & Klein 1975)

- Stellar wind transparent in continuum, opaque in many lines
- Absorption from ~ radial direction; re-emission isotropic
- Acceleration → velocity → Doppler shift of the line
- Photons from a whole frequency band $\Delta\nu$ are swept up



In *one* line intercepted momentum per time: $L_{\nu_0}\,\Delta\nu/c = L\,v_\infty/c^2$



Wind momentum per time: $\dot{M}\,v_\infty$

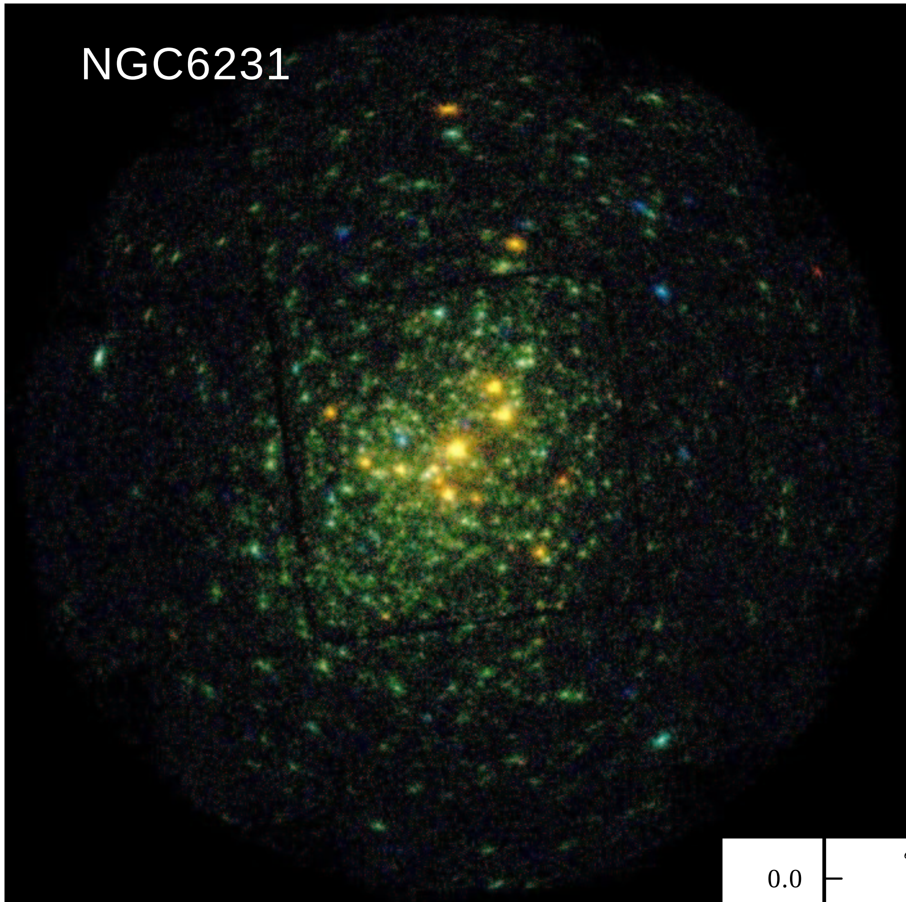
Mass loss driven by *one* line:

$$\dot{M} = \frac{L}{c^2}$$

= mass loss by nuclear burning

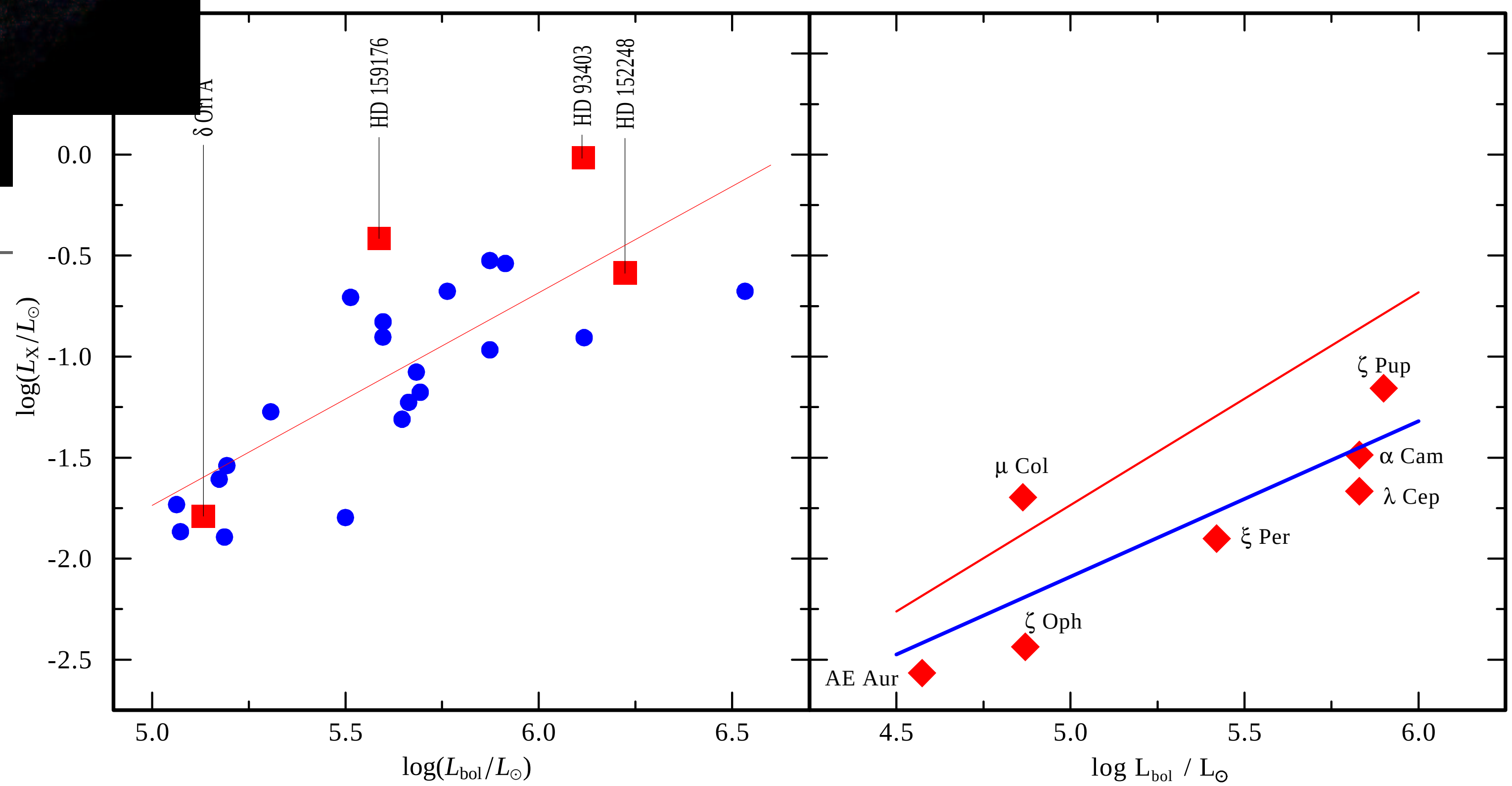
! $L = \frac{dE}{dt} = \frac{d}{dt}(Mc^2)$

VI. All O stars emit X-rays



http://xmm.esac.esa.int/external/xmm_

- 0.01MK<T_{eff}<0.06MK, $L_{bol}=10^{4..6} L_{sun}$
- Clumped wind $\dot{M} = 10^{-6..-8}$ M_{sun}/yr, $v_{wind}>10^3$ km/s
- Einstein, Rosat: $L_X \sim 10^{-7} L_{bol}$ (Seward etal. '79, Berghoever etal. '97)



Oskinova 2005

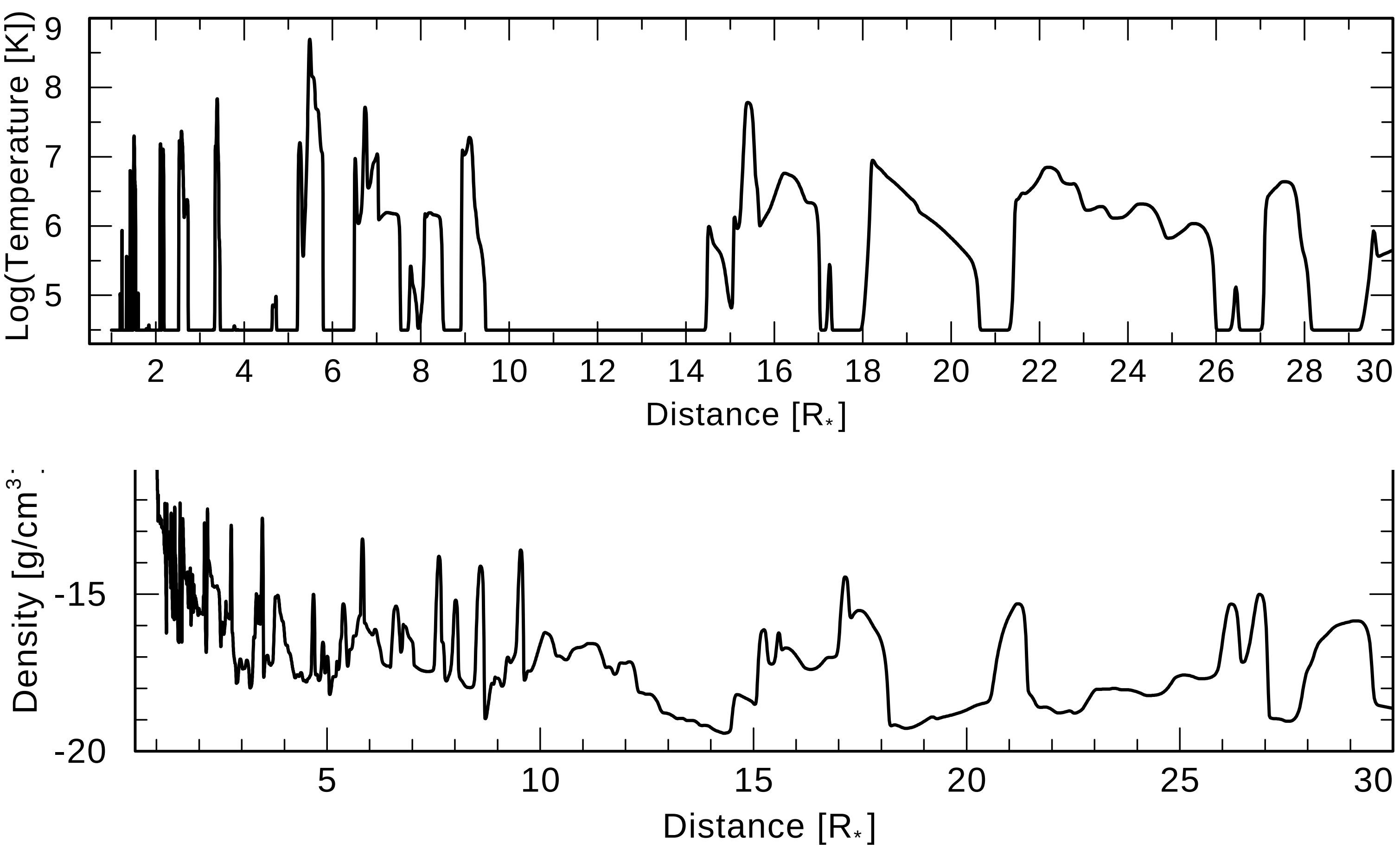
There are no coronae

$L_X \propto L_{bol}$

remains unexplained

How X-rays are generated in O stars? Leading theories.

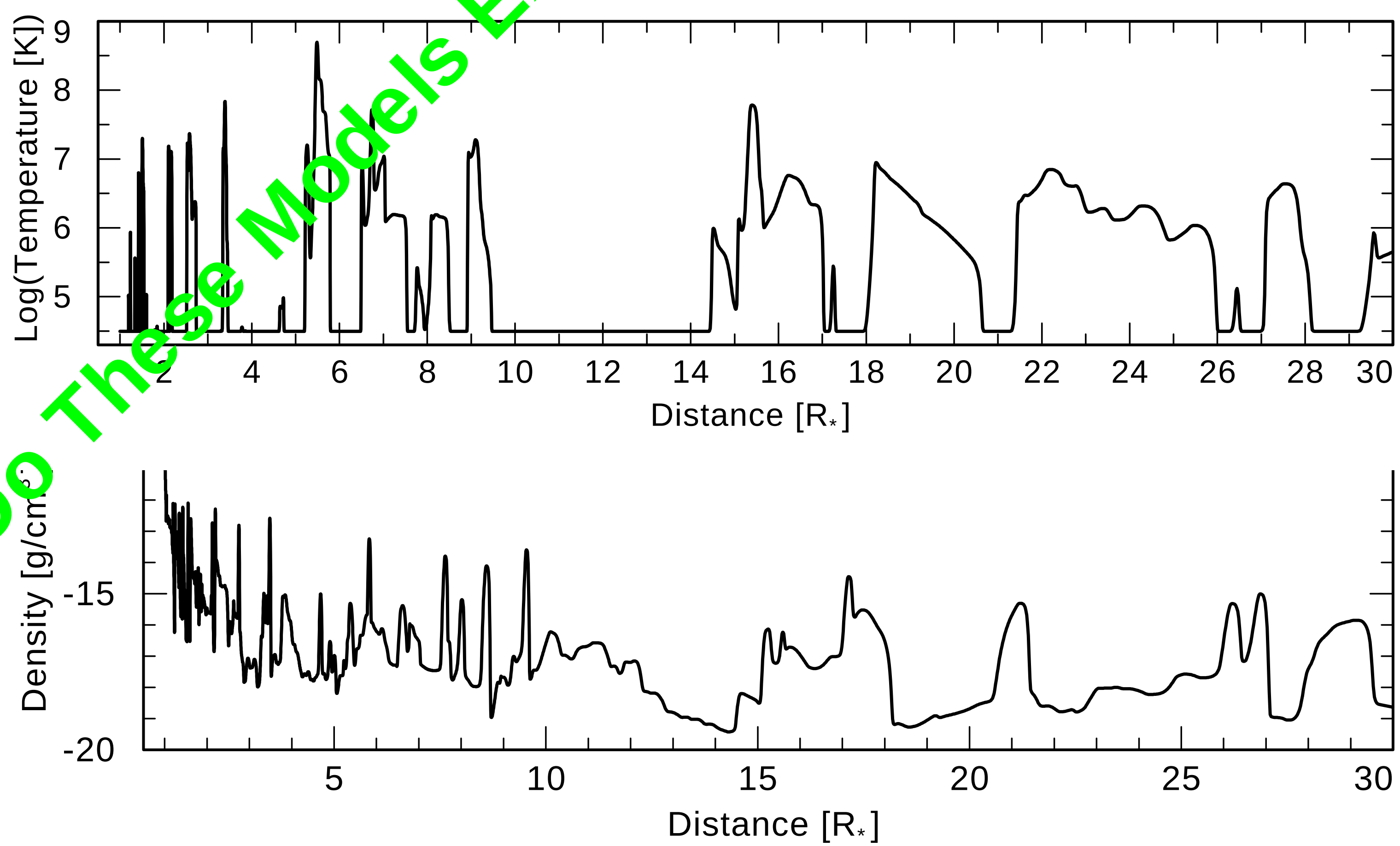
- Bow shocks around blobs (Lucy & White ’80, Cassinelli etal. ’08)
- Magnetically confined loops at the stellar base (Cassinelli & Swank ’83)
- Wind shocks from the instabilities of radiation driving (Owocki etal. ’83)
- Collisions of dense shells in deep wind regions (Feldmeier etal. ’97)



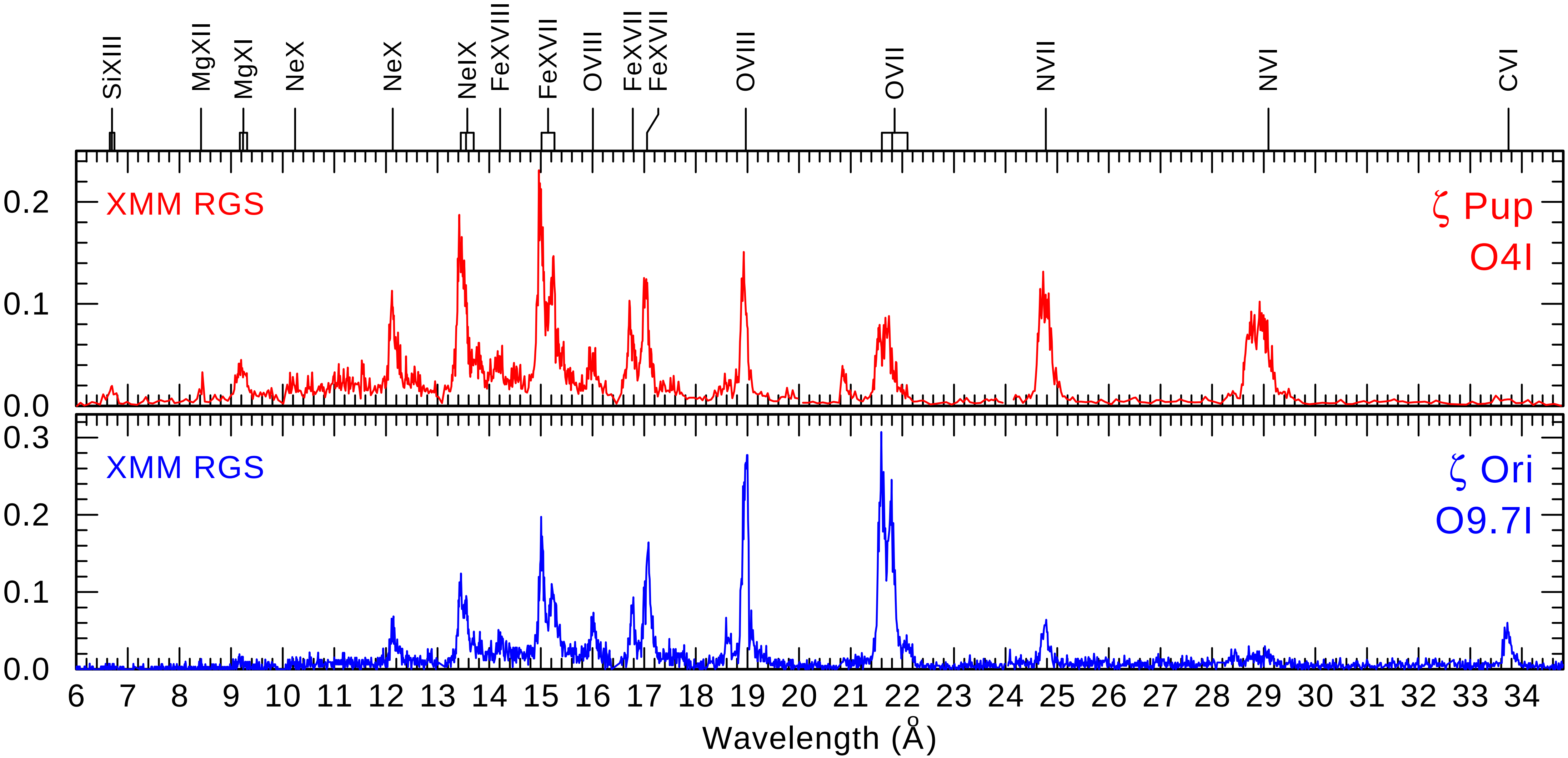
How X-rays are generated in O stars? Leading theories.

- Bow shocks around blobs (Lucy & White '80, Cassinelli etal. '08)
- Magnetically confined loops at the stellar base (Cassinelli & Swank '83)
- Wind shocks from the instabilities of radiation driving (Owocki etal. '83)
- Collisions of dense shells in deep wind regions (Feldmeier etal. '97)

Do These Models Exclude Each Other?



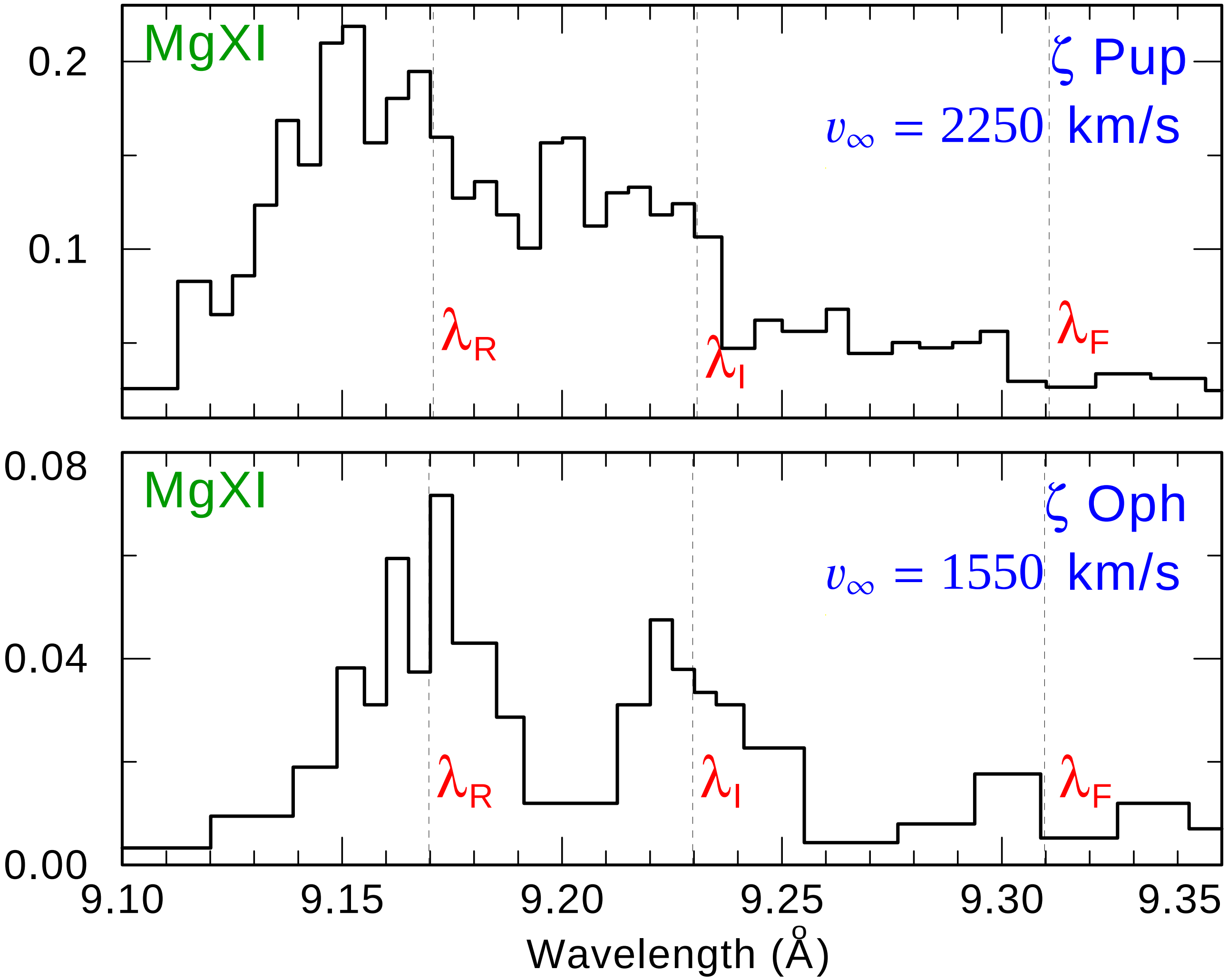
High-Resolution X-ray Spectra



* Overall spectral fitting → plasma model, abundunces
* Line ratios → $T_X(r)$, spatial distribution
* Line profiles → velocity field, wind opacity

Line Ratios of He-Like Ions: Location and Temperature

- Strong UV field $\Rightarrow$ radiative de-population of metastable level ^3S
- Weakening the forbidden (F) line in favor of the interrecombination (I) line
- f/i is diagnostic of UV field. UV field dilutes with radius

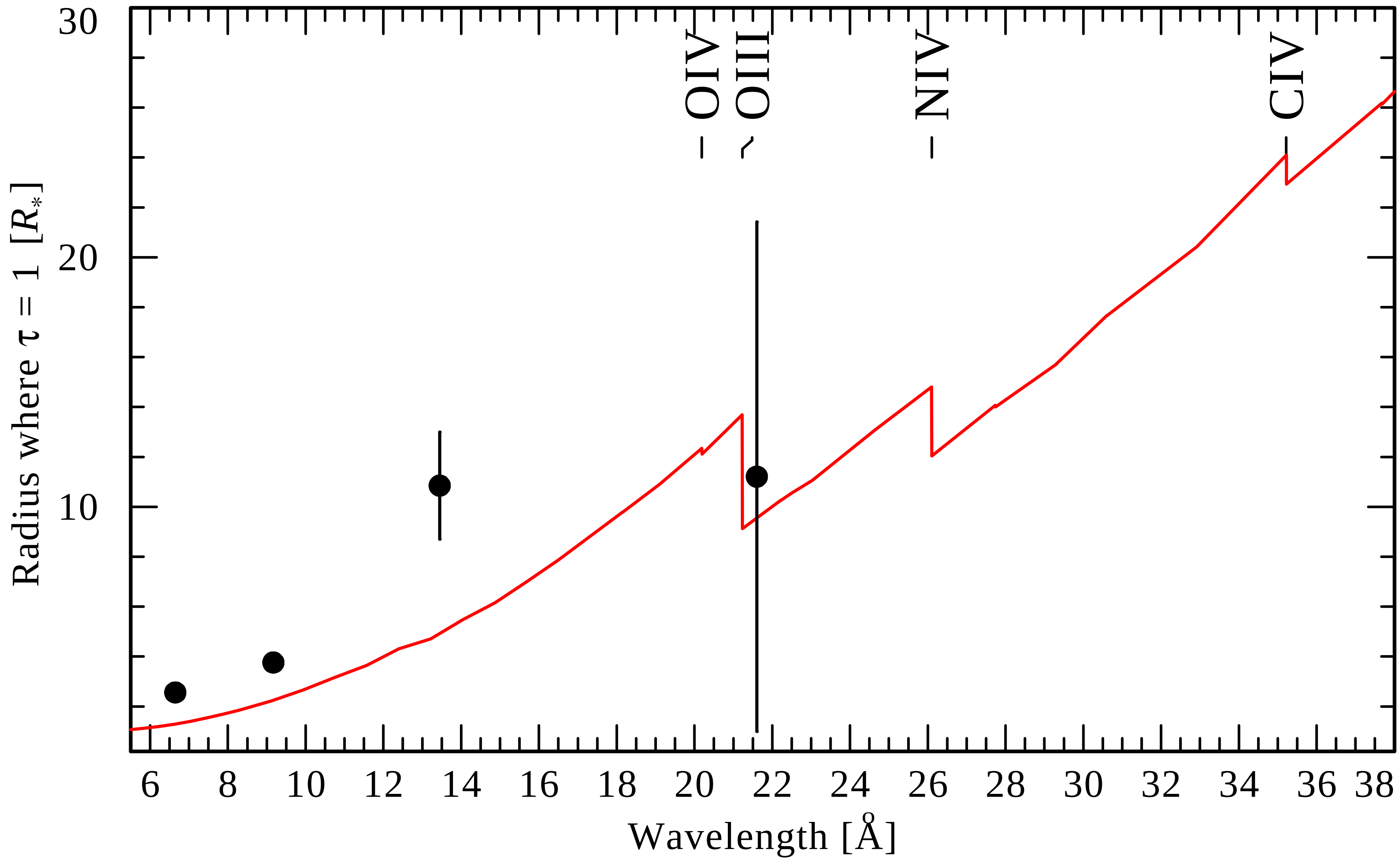


Similar trends for different stars

Oskinova+'06

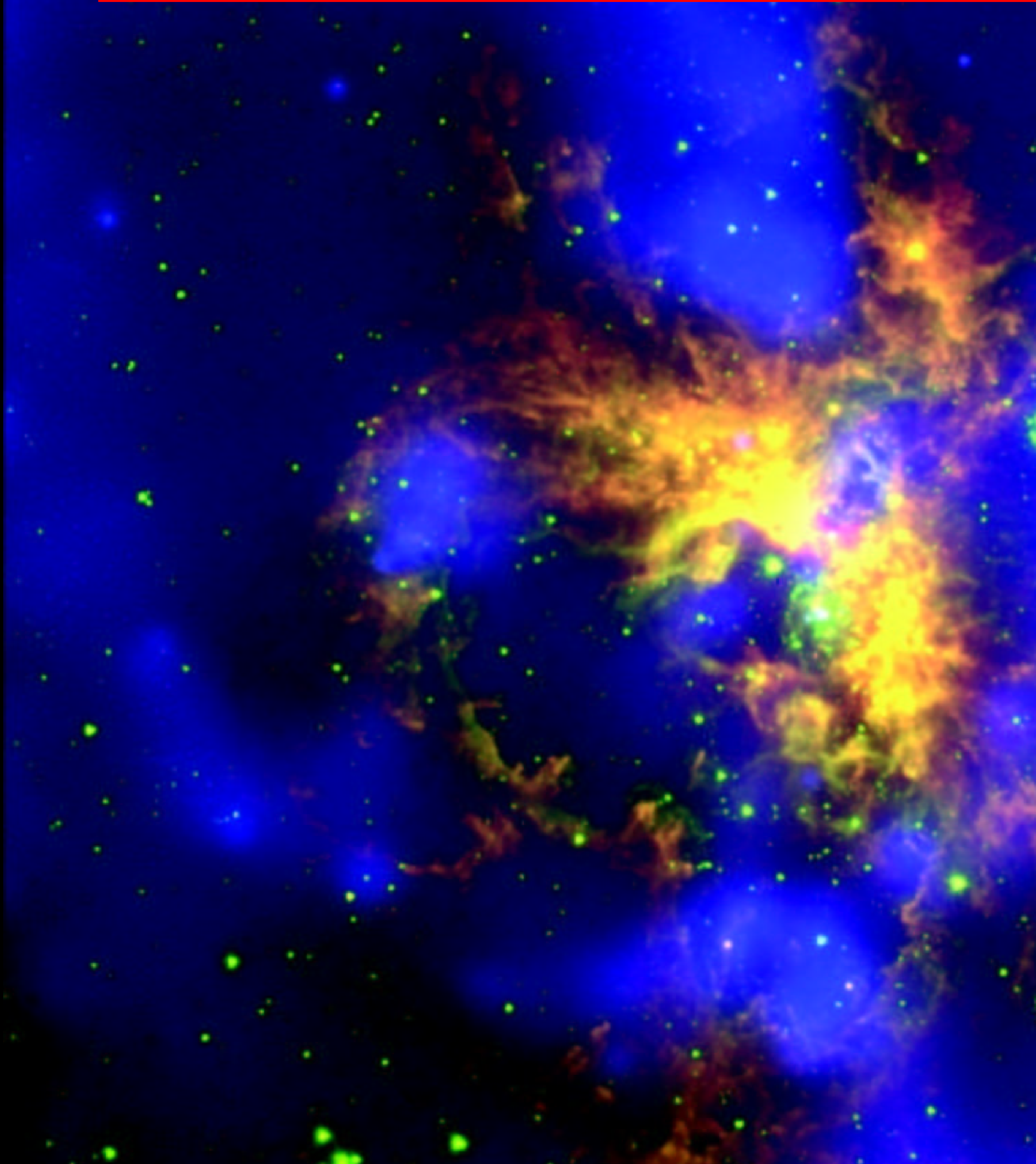
Wind opacity for X-rays

Using modern atmosphere model ζ Pup $\dot{M} = 8.7 \times 10^{-6}\, M_{\odot}/\mathrm{yr}^{-1}$



Agreement between wind-opacity and radii of line formation from fir analisis

Why it matters: mass-loss from massive stars



LMC 30 Dor Chandra+Spitzer Brandl etal. ’05

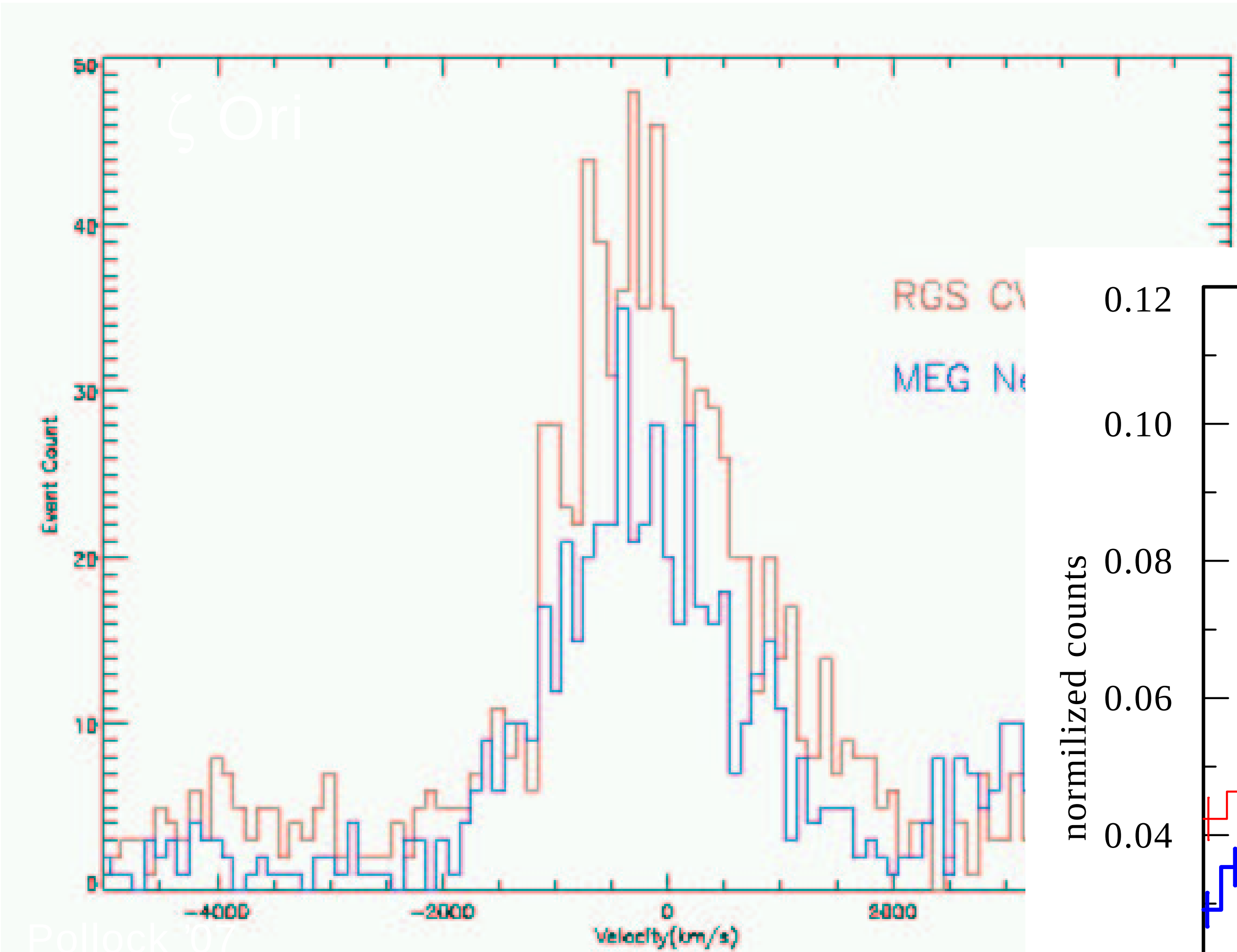
- $\dot{M}$ - key feedback agent
- $\dot{M}$ - key parameter of stellar evolution

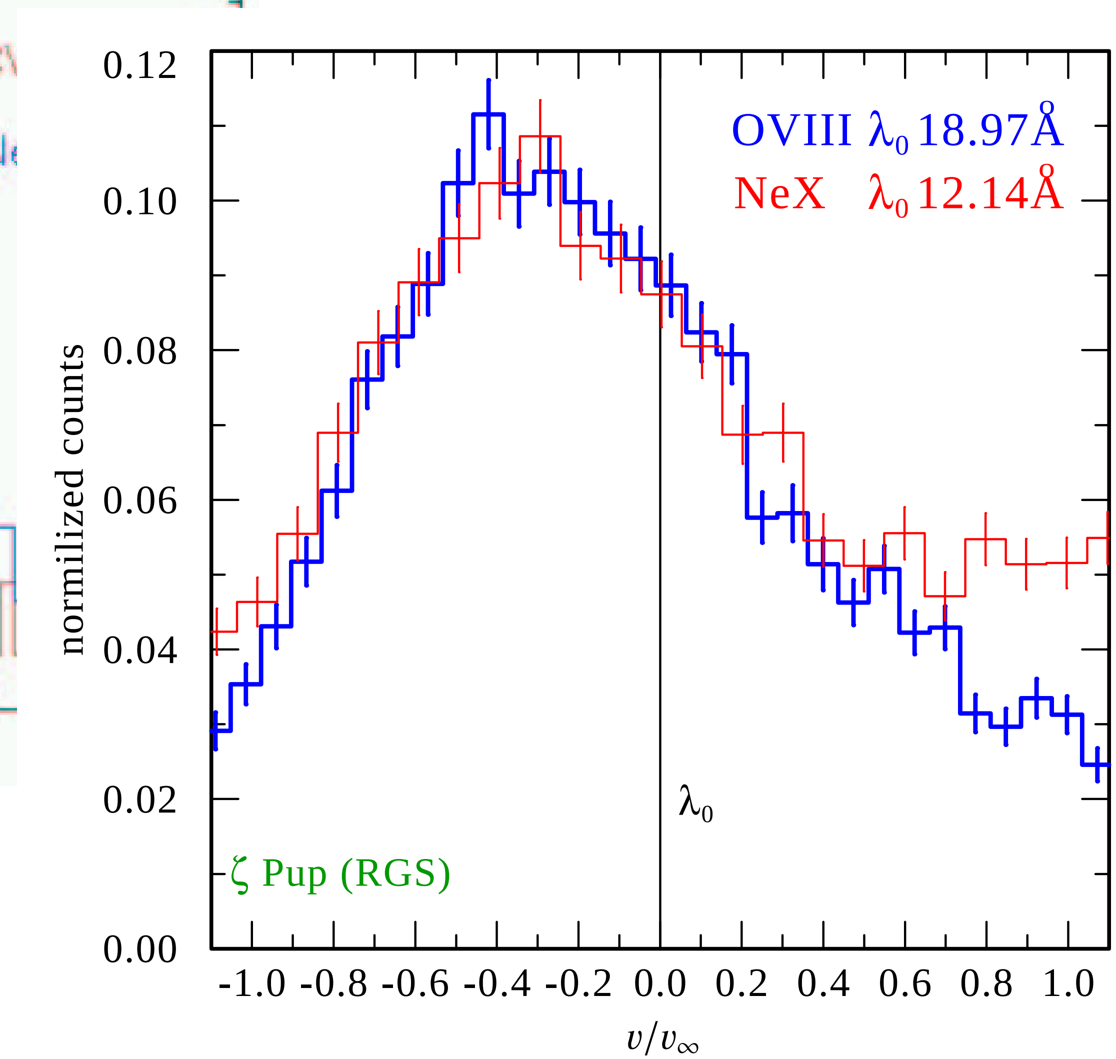
- Empirical determinations are model dependant
- Spectral analisis is hampered by unknown degree of wind clumping
- Literature values differ by 100 times
- X- rays measure wind opacity -> $\dot{M}$

Observed lines are broad

Observed emission line profiles are similar

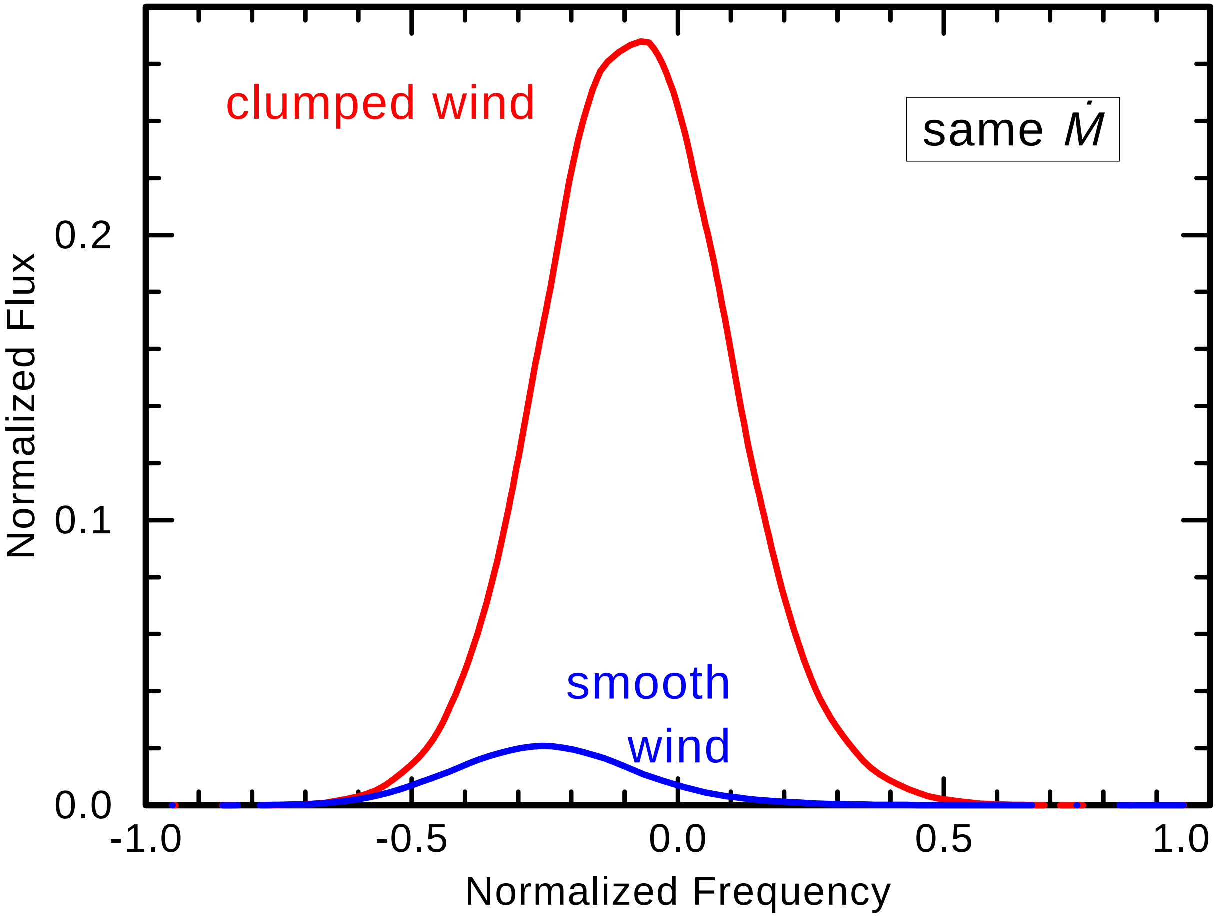
Lines are formed in the wind





X-rays are produced in wind shocks

WInd structure from X-ray lines



Wind opacity for X-ray drastically reduced by clumping

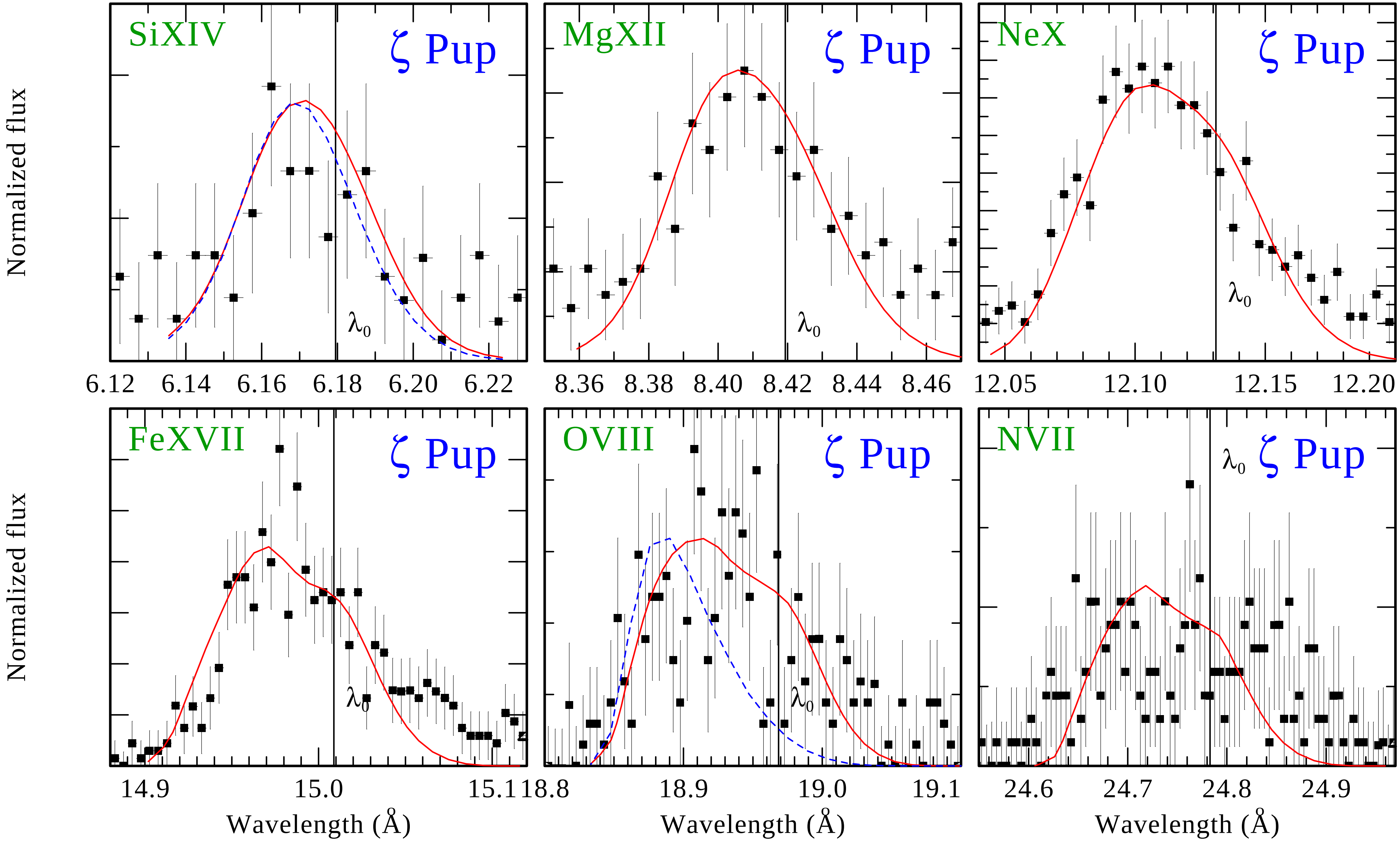
Clumps are rather large - optically thick

⇓

Similar line profiles accross the spectrum

Clumps are flattened

Observed and model lines of ζ Puppis (no fitting!)



Conclusions: Intrinsic wind emission from O stars

- X-rays originate close to the stellar core. Hot plasma fills some space between clumps.
- There are some indications that hottest plasma located close to the core.
- "Hybrid" model? Loop-like structures at the surface, shocks around blobs due to the wind instability?
- Stellar wind is clumped untill proven otherwise. RT in clumped wind is not the same
- Clumping explains shape of X-ray emission line profiles.
- Consitent $\dot{M}$ estimates ranging from radio to X-ray