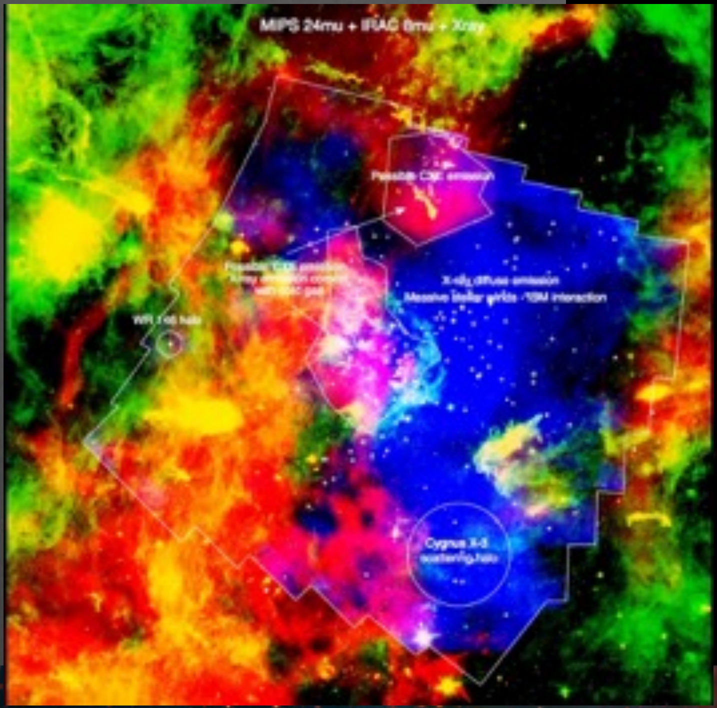
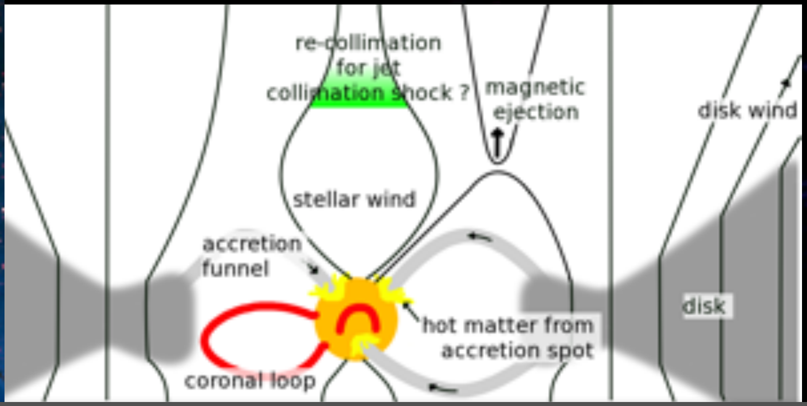
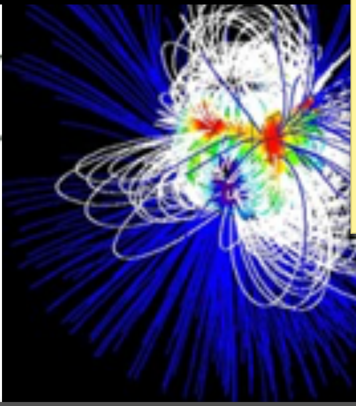
How X-rays changed the way we understand Star Forming Regions







Uno de los grande prejuicios que la comunidad astronómica ha manifestado hasta hace un par de décadas fue la de considerar que la mayoría de la radiación de rayos-X observada en el Universo esta asociada a objetos compactos (NS, BG), fenómenos de interacción entre estrellas evolucionadas, y/o eventos explosivos del tipo SNs, SNRs.
Durante décadas, se ha ignorado la existencia, o al menos la relevancia de los procesos de emisión de rayos-X en escenario jóvenes, SFR y/o estrellas en formación.
Aquí se expondrán brevemente los diversos escenarios astrofísicos vinculados a la emisión de rayos-x en objetos estelares jóvenes y su impacto en las condiciones astrofísicas del ISM de la region en la que se forman las estrellas.

Una muestra de esto ha sido que fue dificultoso determinar dentro del esquema de clasificaciones de la reunion, si esta charla correspondía a:

[OCPAE]: Objetos Compactos y Procesos de Altas Energías / Compact Objetcs and High-Energy Processes

[MI]: Medio Interestelar / Interstellar Medium.

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1- Star - ISM connection

ISM properties are directly connected to the stellar evolution (Burbridge et al 1957) —> *feedback* effects between stellar evolution and generation of new stars.

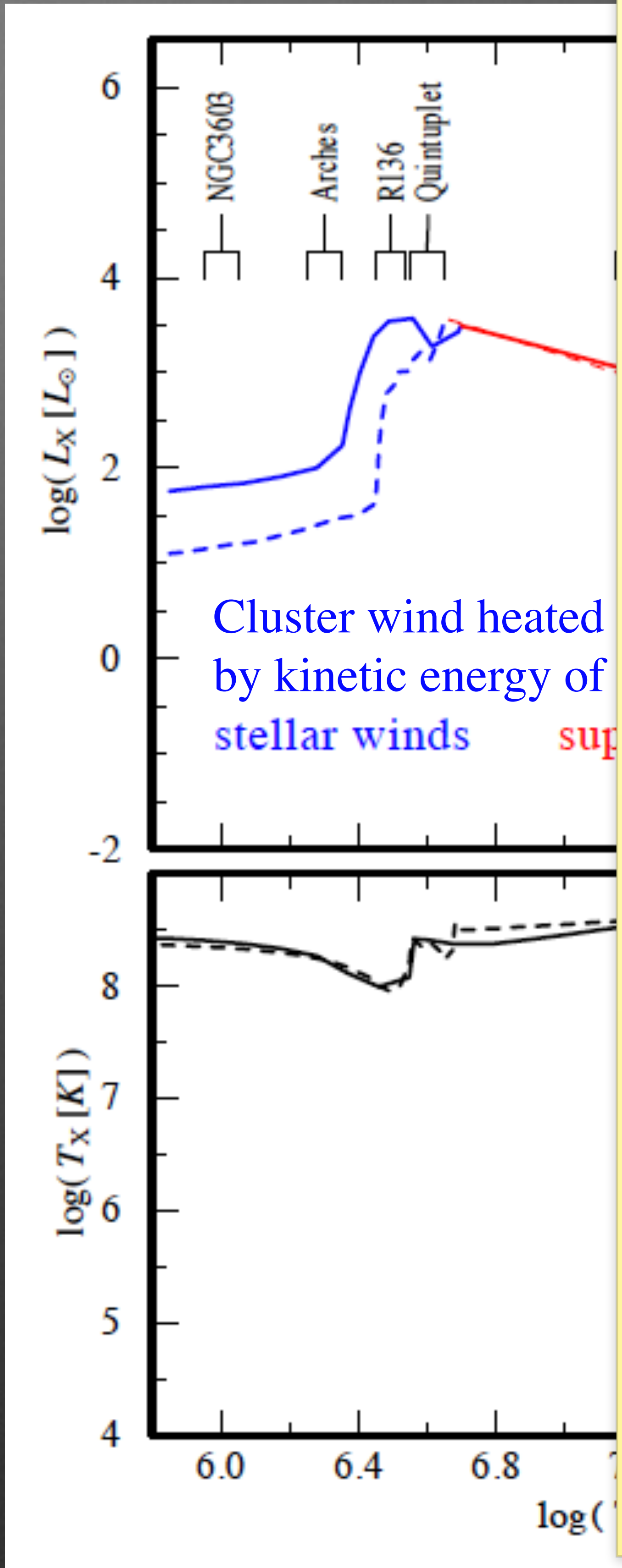
Mass loss from massive stars ($M > 20M_{\odot}$) enrich ISM during its life, even more during the final stages (e.g. SN explosions)

—> ISM is enriched by nucleosynthesis and their properties and abundances change in time.

10 K Temperature 10^7 K

Molecular Clouds —> HI clouds —> Warm HI —> Warm HII —> HII regions

>10000 cm^{-3} Density 10^{-3} cm^{-3}



Desde un punto de vista teórico Burbidge etal 1957 fue quien abordo la interacción estrella-SFR a través de incluir los efectos de perdida de masa en estrellas masivas, sobretodo en sus fases finales de vida, antes de su explosion como SN.

De esta manera somos capaces de conocer una relación entre la temperatura y la densidad del ISM en SFR, la cual es dependiente de la edad de la region.

Mucho mas recientemente Oskinova 2008, realizo un modelo hidrodinámica sobre la interacción estrellas-SIM, considerando la energía cinética de los vientos estelares de las estrellas, en sus fases de evolución, PMS, MS, post-MS, finalmente como SN.

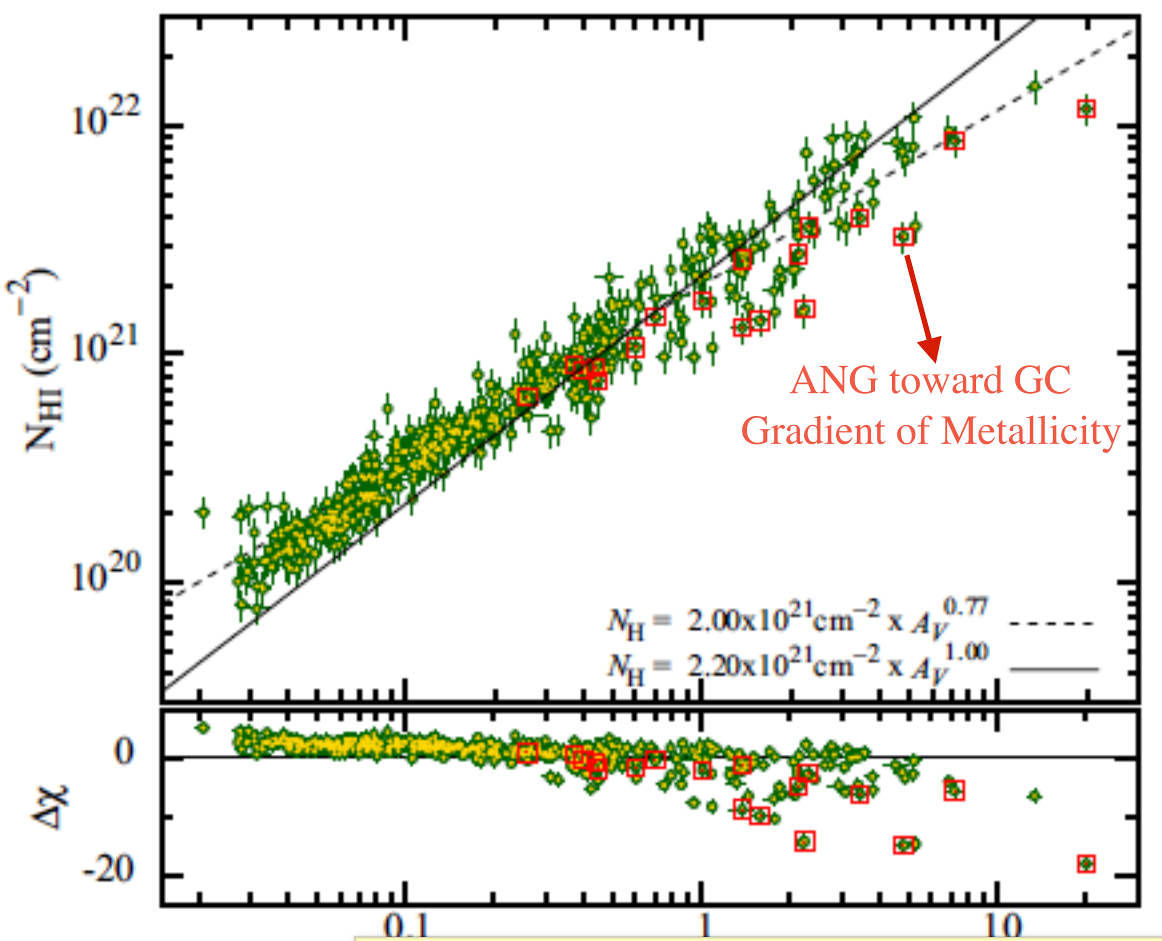
Dicho estudio estimo que en cluster muy jóvenes (edades < 2.5E6 años) , solo con estrellas PMS o MS, la luminosidad de rayos-X del cluster es baja (no ha habido tiempo suficiente para calentar el ISM via la acción de los SW).
Posteriormente, entre 2.5 - 5.0 E6 años, cuando aparecen estrellas del tipo WR o tipo-O de clases I, II, III), la Lx del cluster aumenta por acción de los fuertes vientos que calientas el ISM vas shocks.
Subsecuentemente, luego de 6E6 años, las explosiones de SN dominan la emission de X observadas en el cluster, la cual tiene una componente principal en la emisión difusa de rayos-X, y en mucho menos medida de la que proviene de las estrellas de la región.

A todo esto, uno de los puntos mas importantes a considerar es el efecto que tiene el ISM sobre la radiación-X.

Images courtesy Dra L. Oskinova (MNRAS 2008)

2- Why X-rays ?

- Typical ISM gas density is low (10^{-20} the Earth atmosphere)
- Abundance (A_z) in ISM is crucial to estimates absorbed material as the equivalent HI column density ($N_H \sim 10^{Az-12}$).
  —> In the Galactic Center $N_H \sim 10^{22}$ cm^{-2}.
- Typically accepted for Galactic observations
  —> NH/Av ~ 1.7x10^{21} cm^{-2}. (R_v=4) (Vrba et al. 1993)
  —> NH/Av ~ 1.9x10^{21} cm^{-2}. (R_v=6) (Vuong et al. 2003)
  —> NH/Av ~ 2.1x10^{21} cm^{-2}. (SNRs) (Guber & Ozel, 2009)
- Av ~ 10 to 20 mag is not a problem, X-ray observations can penetrate to Av ~200 !!!
- At X-rays energies, absorption cross section is similar to that the millimetric [mm] wavelengths !
- In X-rays [0.1-15 keV], absorption K and L edges are easily observed from most of elements
- —> X-rays observations are crucial to understand ISM properties in SFR
- —> Unveil most of stars, almost, all over the mass range… Why ?



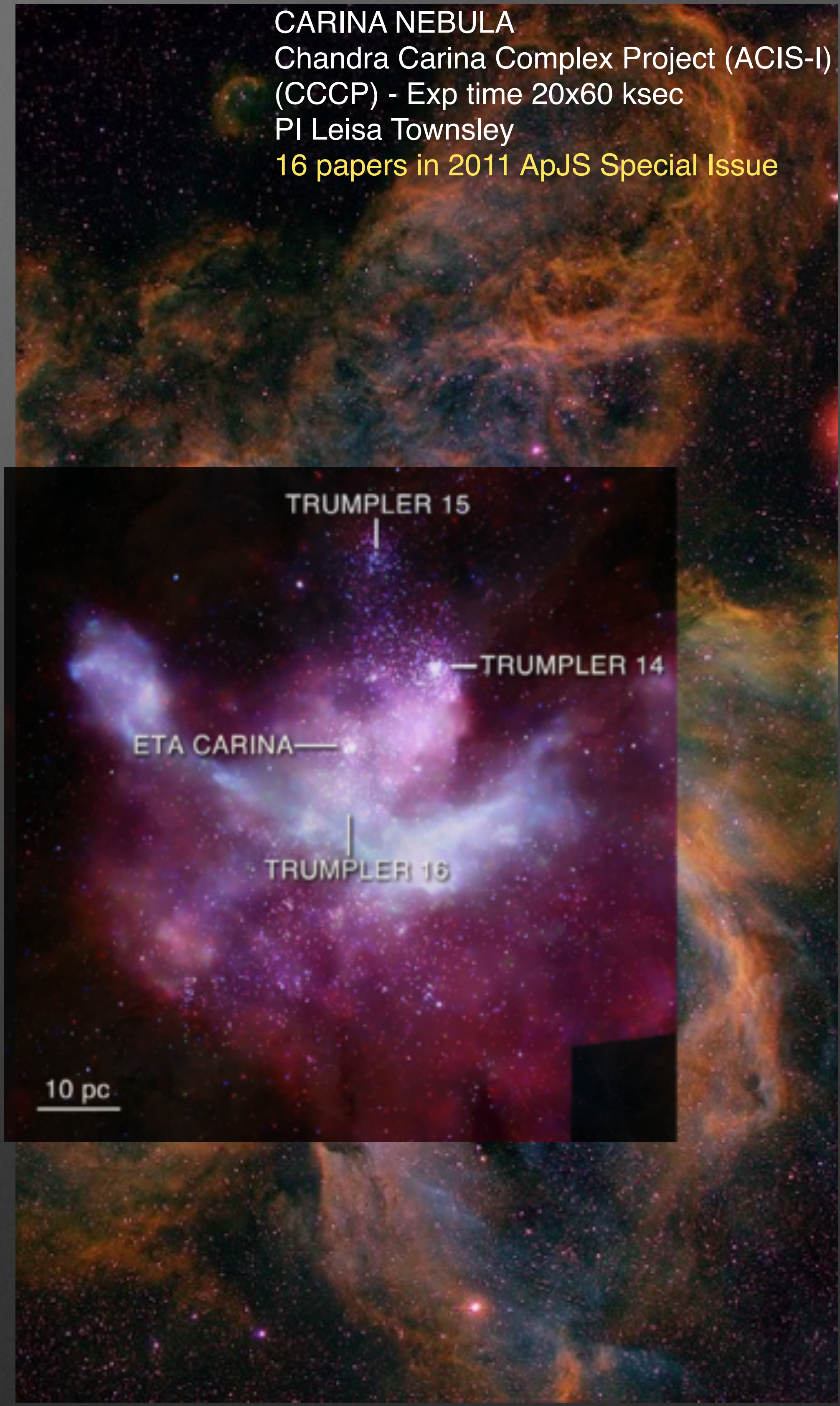
La primer consideración a tener en cuenta es que la densidad columna de HI que absorbe rayos-X depende de abundancia de los elementos Z.

Esto implica una relación NH/Av la cual dependiendo de el coeficiente de extinción visual R del ISM dará diversas (no tanto) correlaciones.

Un gran beneficio de estudiar abundancias en espectros X es que las transmisiones K y L de las lineas de absorción se observan para casi todos lo elementos.
Por lo cual,, las observaciones X son especialmente importantes para determinas las propiedades del ISM.
A su ves los rayos X son transparentes al ISM, permitiendo revelar la gran mayoría de la población estelar de una region.

2- Why X-rays ?

ORION NEBULA
Chandra Orion Ultradeep Project (ACIS-I)
(COUP) - Exp time 1x850 ksec
PI E. Feigelson
13 papers in 2005 ApJS Special Issue

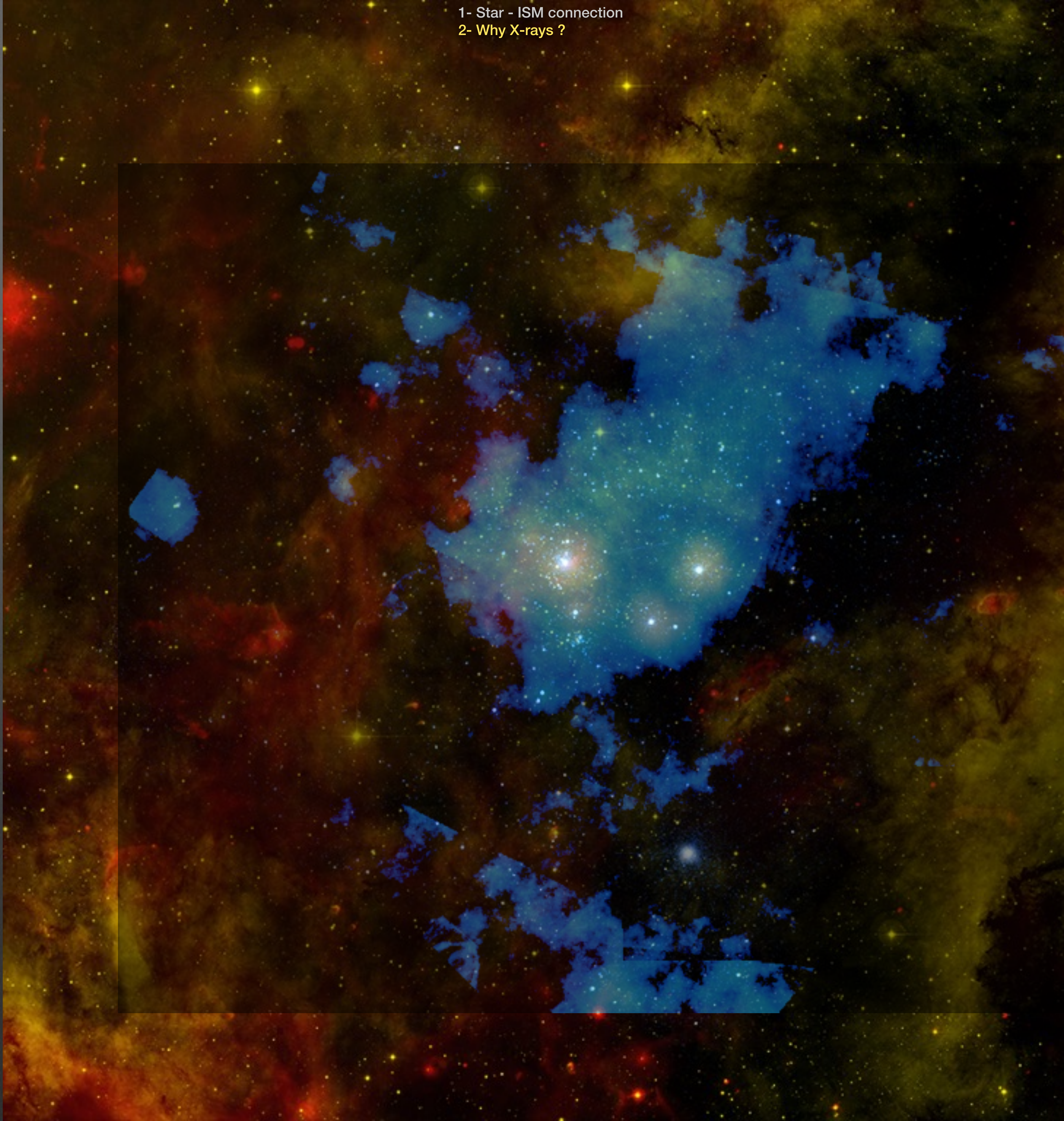


CARINA NEBULA
Chandra Carina Complex Project (ACIS-I)
(CCCP) - Exp time 20x60 ksec
PI Leisa Townsley
16 papers in 2011 ApJS Special Issue

El uso de observaciones IR, ópticas combinadas con rayos-X ha sido una de las mas exitosas combinaciones para estudiar SFR. Actualmente entre mas de una lista de 200 publicaciones a diversas regiones, destacan las campañas realizadas en large projects Chandra (2005) en Orion (350 pc), como también (2011) en Carina (2250 pc).

2- Why X-rays ?

CYGNUS OB2 ASSOCIATION
PI. Drake et.al - Exp time 36x50 ksec
FOV 1 sq.deg.
17 papers in 2017-2018
ApJS Special Issue



Recientemente, en una de las mas ambiciosas investigaciones (2016 - 2017), hemos realizado 36 apuntados Chandra de 50 sec (1.1 Msec) en Cygnus OB2, una de la asociaciones estelares masivas mas importantes de la Galaxia.

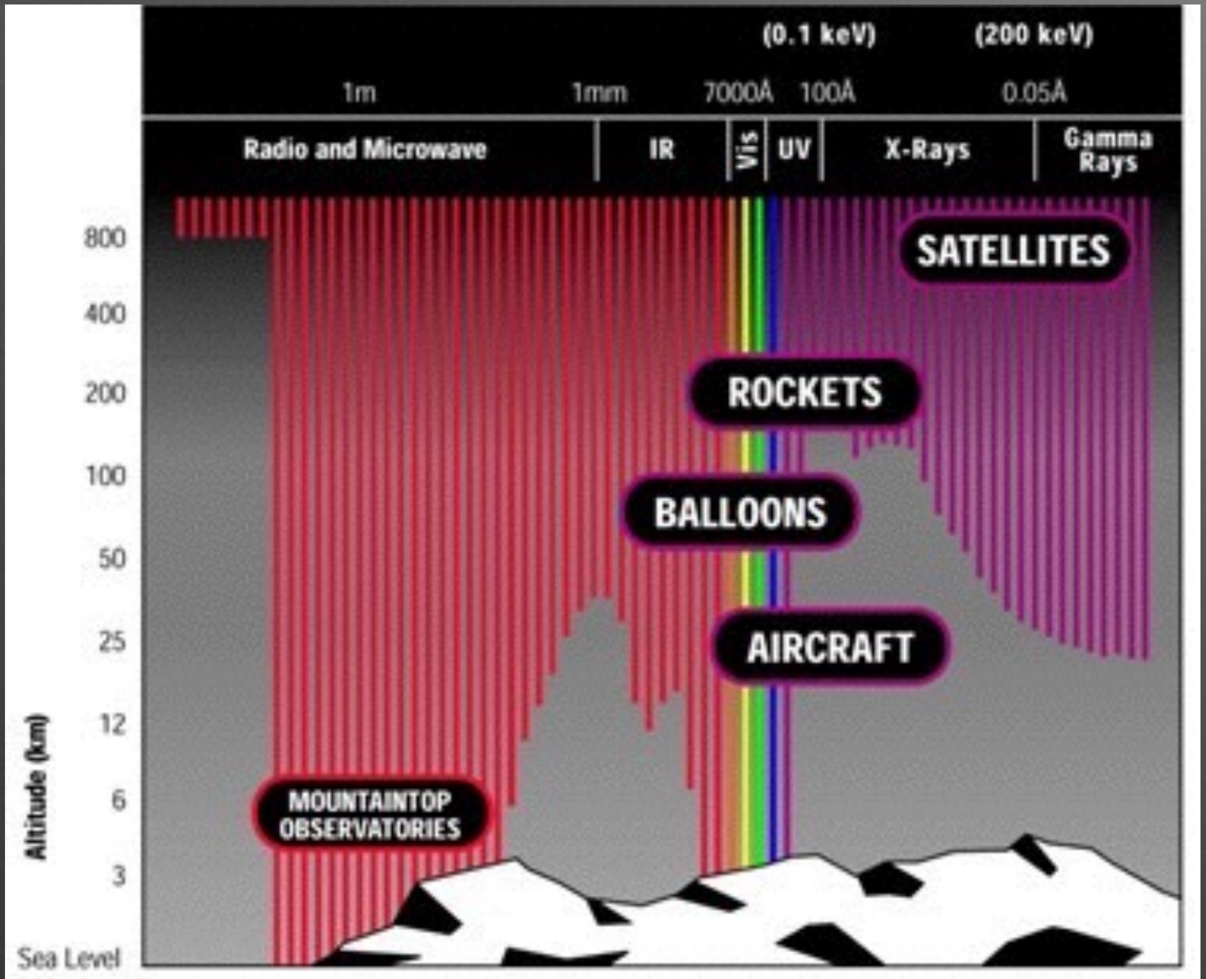
La imagen muestra la combinación de tres mosaicos de 1x1 grados en las bandas SI (rojo) OIII (verde) y X-ray (azul)

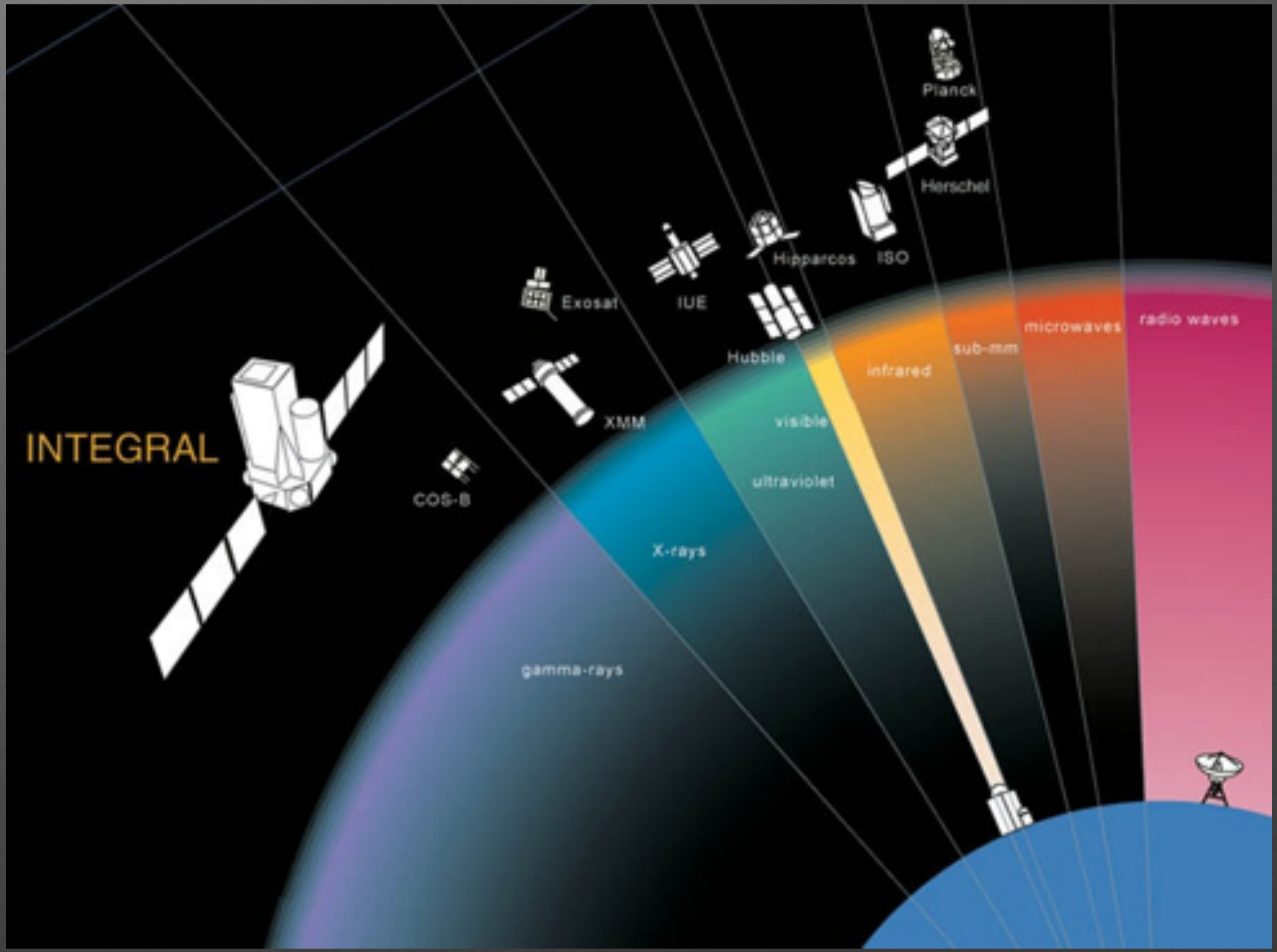
Entre varios de los resultados, solo basta destacar que por primera ves estamos en grado de revelar los procesos de emisión de rayos-X que se produce por la acción de la interacción viento estelar - ISM.

Esta nueva perspectiva ha surgido luego de una basta serie de misiones satelitales de rayos-X.

3- How to observe in X-rays ?

- Fortunately, X-rays are absorbed by Earth’s atmosphere !!!
(X-ray photon passing through atmosphere encounters as many atoms as in a 5-meter thick wall of concrete !!!)





T
I
M
E

Uhuru (1970 - 1973) in [2 - 20 keV] in T+I modes
Einstein (1978 - 1981) in [0.2 - 20 keV] in T+S+I modes
Exosat (1983 - 1986) in [0.05 - 50 keV] in T+S+I modes
Rosat (1990 - 1999) in [0.1 - 2.5 keV] in T+S+I modes
RXTE (1995 - Now) in [2.0 - 250 keV] in T+S modes
Integral (2002 - 2008) in [15 keV - 10 MeV] in T+S modes
XMM-Newton (1999 - Now) in [0.1 - 15 keV] in T+S+I modes
Chandra (2000 - Now) in [0.1 - 10 keV] in T+S+I modes
NuStar (2013 - Now) in [3 - 79 keV] in T+S+I modes

Over 380 years, optical telescopes improved sensitivity by 100 million times from Galileo's telescope to HST.
Chandra X-ray Observatory represents a comparable leap in sensitivity over Giacconi's 1963 X-ray telescope,… but in only 36 years!

4- First X-rays sources

- First extrasolar detection of X-rays (Giacconi et al. 1962) was LMXB Scorpius X-1 (9 kpc)

- Limited sensitivity of the X-ray telescopes in 60’ and early 70’ just detects at $L_x \sim 0.1 - 2\times10^{38}$ [cgs].

- Some sources appears in the sky and remain bright for a few weeks —> (X-ray transients). In burst phase $L_x \sim 10^{39-40}$ [cgs].

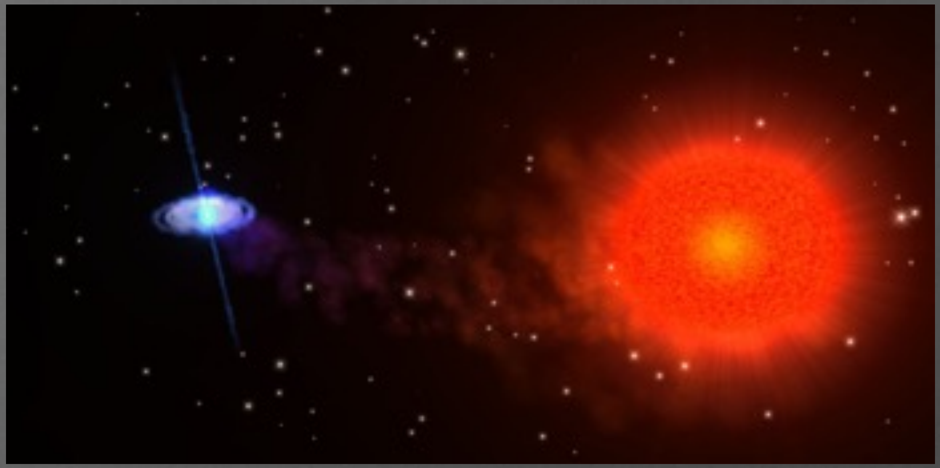
- Improved sensitivity of X-ray satellites in the 80’ —> new horizons for variety of different astrophysical sources (Einstein X-ray sat).

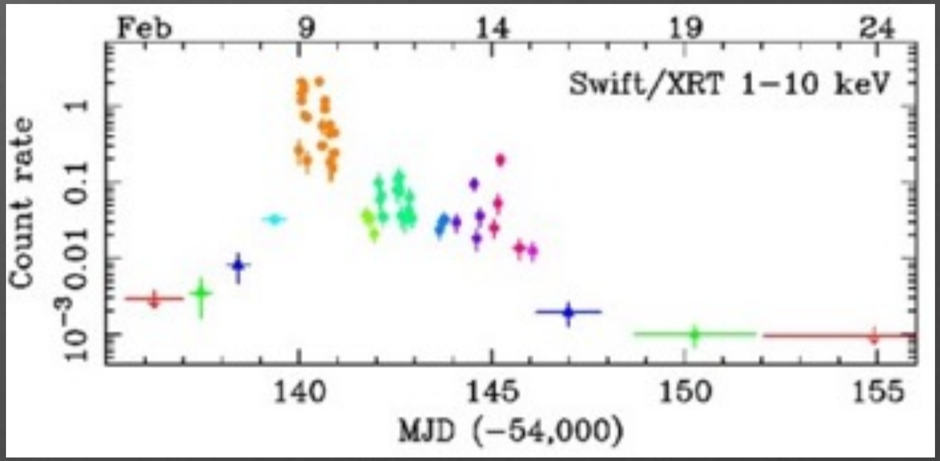
- Xray from O-type stars:
  Hoare (1975)
  Cassinelli & Olson (1978)
  —> Carina Nebula (Seward et.al 1979)
  —> Cyg OB2 (Harnden et.al 1979).

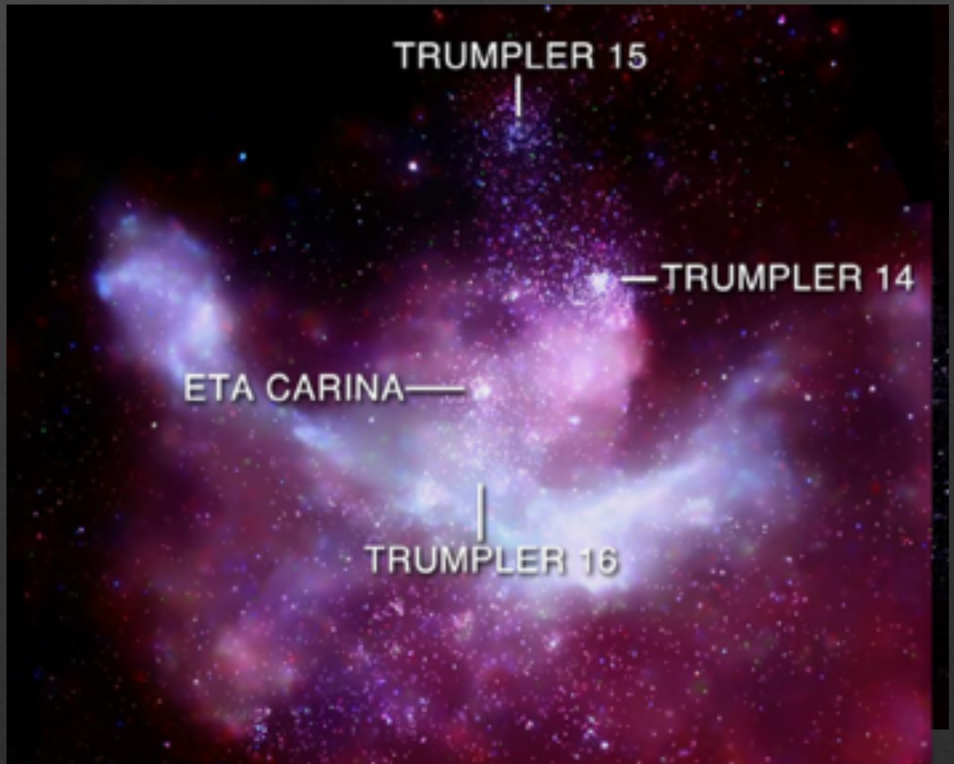
- Not much variability in the observed X-ray emission:
  Berghofer & Schmitt (1994, 1996)
  —> phase locked colliding wind binaries (Corcoran 1996)

- Young (PMS) and/or MS stars were also observed in X-rays.
  ($L_x \sim 10^{31}$ x 10^{34}) [cgs]

Non compact (Young) stars emits a vast amount of X-rays radiation !!!



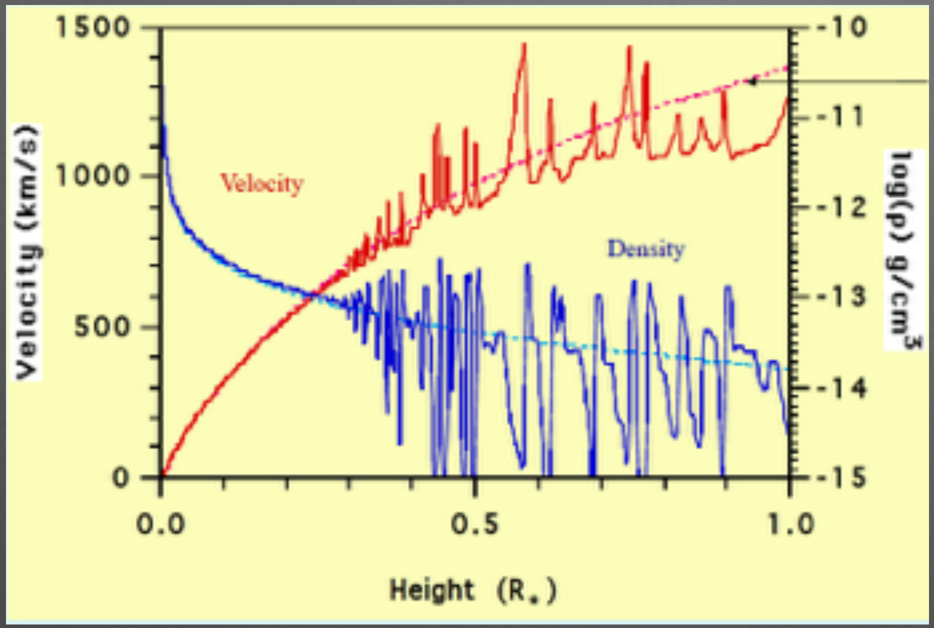




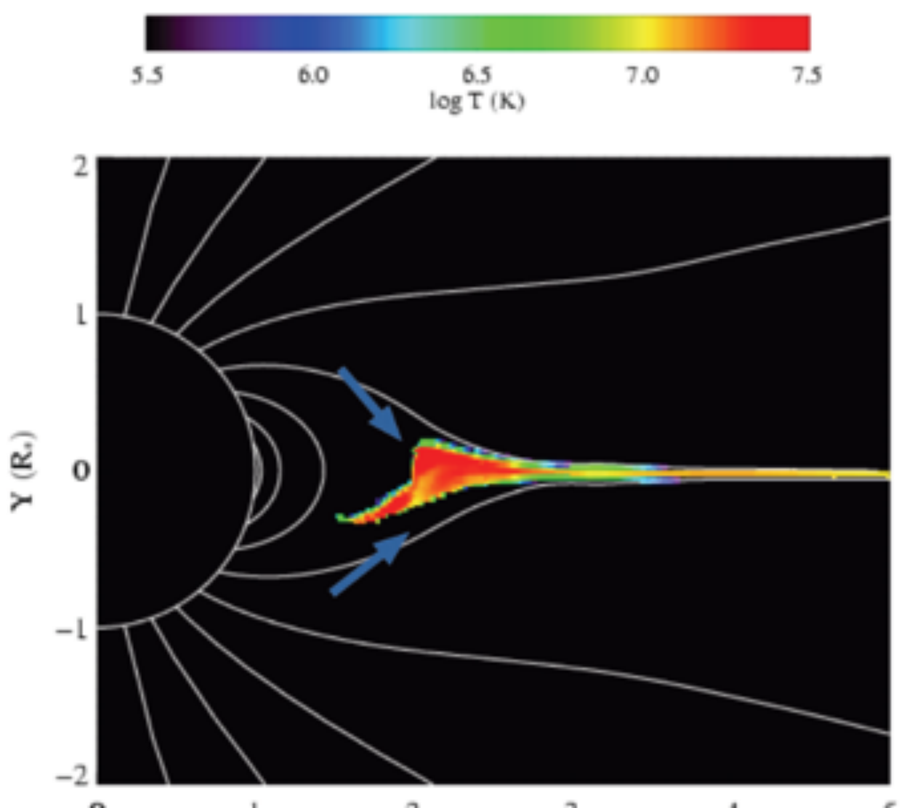
5- X-ray emission from early O-type stars

There are three MAIN X-ray thermal mechanisms acting in early massive stars:

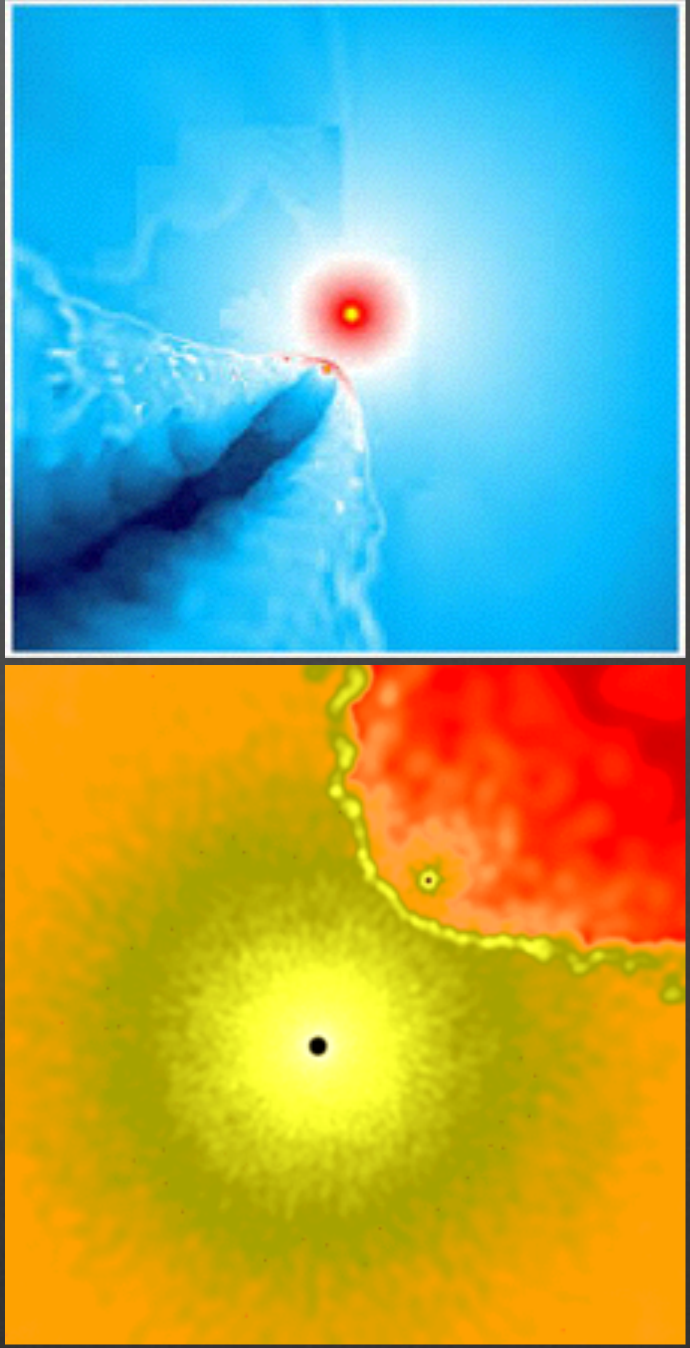
1- Instability-generated Embedded Wind Shocks
—> Soft (< 1 keV) X-rays



2- Magnetically Confined Wind Shocks (MCWS)
—> Usually Harder (~1-2 keV) thermal X-rays



3- Colliding Wind Shocks (CWS) in Binaries
—> Hardest (1-10 keV) thermal X-rays



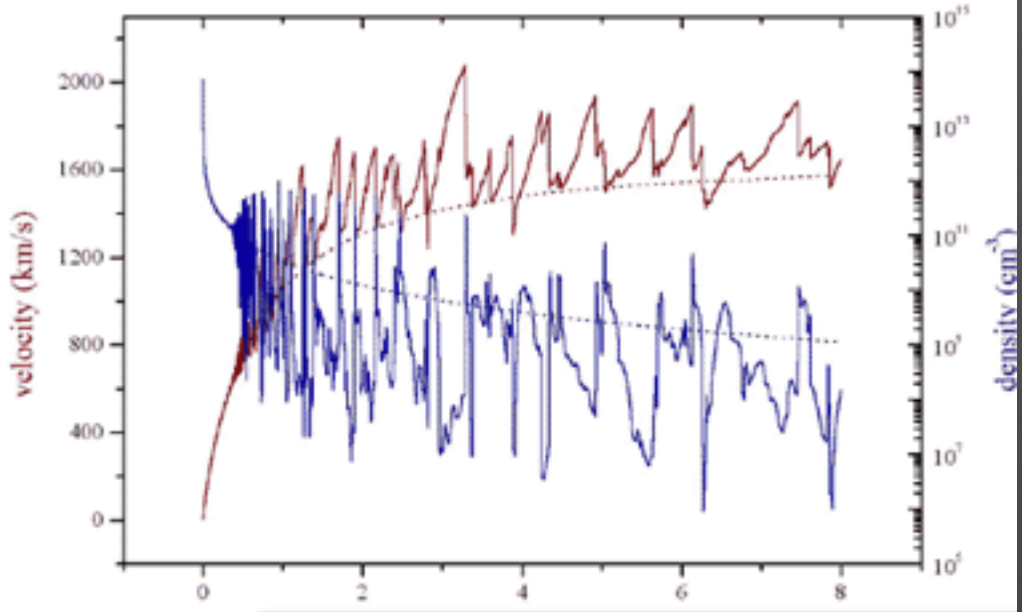
Images courtesy Dr. David H. Cohen and Dr. Stan Owocki

5- X-ray emission from early O-type stars

5.1 - Embedded Wind Shocks

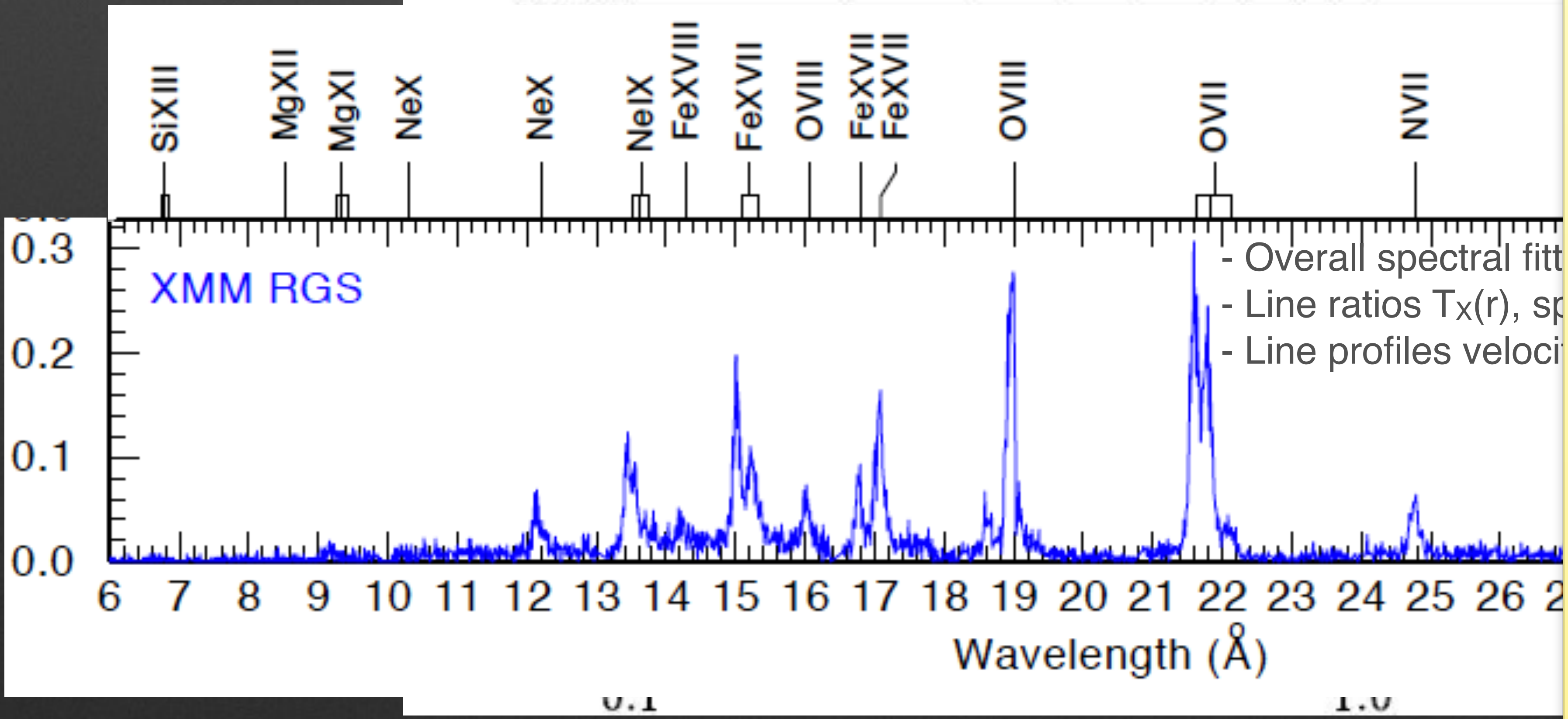
- Hot stars have radiative flux ~ sT^4 —> through spectral lines (unstable process) —> Instabilities —> collisions —> Powerful winds (dM/dt ~10^{-5} -10^{-6} M_o/yr & v_∞~2500 to 3000 km/s)
- Small internal shocks generates X-ray emission (Lucy & White 1980; 1982, Owocki & Rybicki 1984)
- Instabilities along the wind structure —> reverse shocks (Owocki et.al 1988) —> compatible with cooling zones behind the shocks (Feldmeier et.al 1997) —> X-ray spectroscopy is a sensitive probe of stellar winds.

r ~ 1.5 R★ numerous shock structures above 1.5 R★



Best quality Zeta-Orionis X-ray spectra before year 2001 (

Best quality Zeta-Orionis X-ray spectra with XMM-Newt



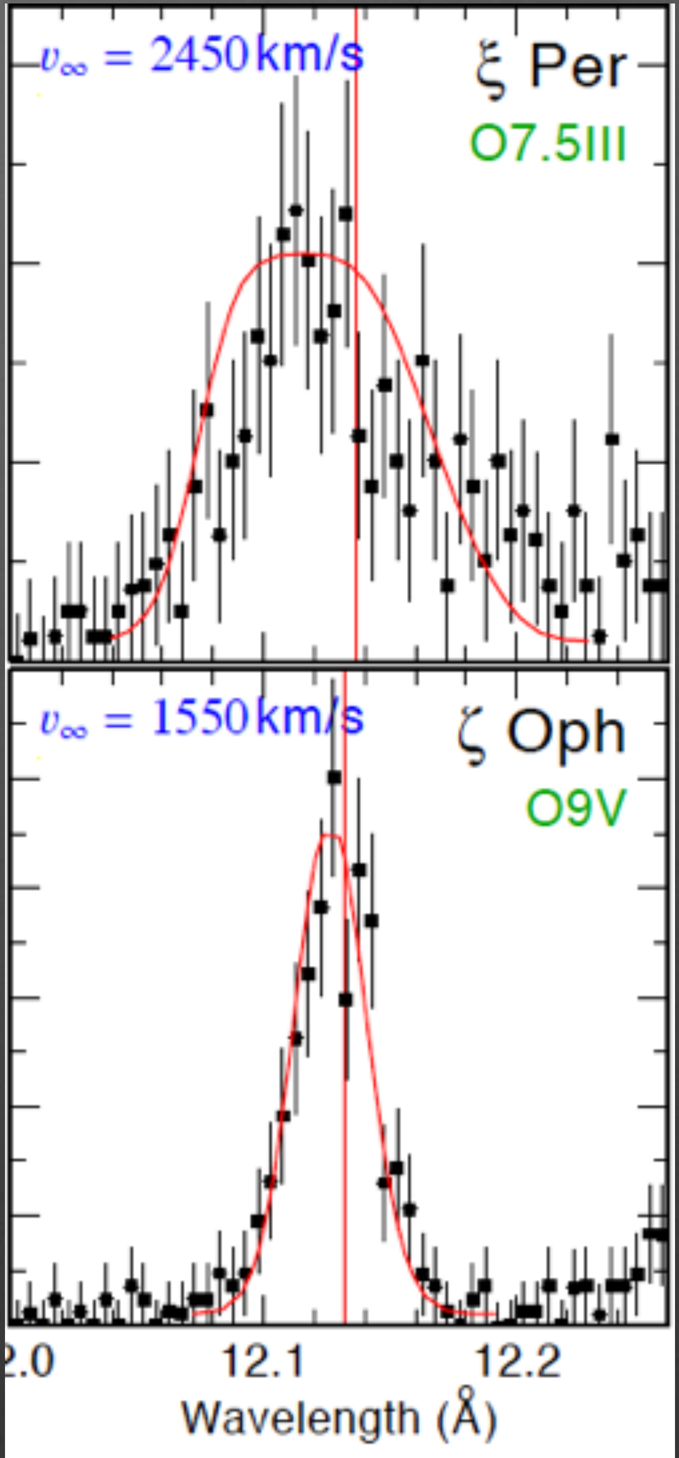
- Overall spectral fitt
- Line ratios T_X(r), sp
- Line profiles veloci

Partiendo de la base que la estrellas de alta masa (M>15 Mo) no poseen envoltura convectiva, su flujo es enteramente radiativo y prop a Teff^4. Dado que tenemos temperaturas fotosfericas por encima de 10000 K, la presion de radiacion es lo suf. alta como para transferir el momento dinamico y acoplarse con viento estelar que llega a velocidades de 3000 km/s.
Durante la expansión se producen numerosos shocks internos responsables de variabilidad de corto duración.

5- X-ray emission from early O-type stars

5.1 - Embedded Wind Shocks

- Temperature :
  - Range from 2 MK to 10 MK where $kT = 1.35\ (v_{wind}/1000)^2$ (Muno 2006).
- Emission line profiles
  - Broad width lines scales with wind speed
  - Similar across the spectrum
  - Clumped wind (Feldmeier et.al 2003)
  - Plasma is not in CIE (Pollock 2007)
- Line ratios (f-i-r) in He-like ions
  - Stellar wind density via forbidden-intercombination-resonance ratios
  - Formed close to the photosphere
  - Temperature decreases outward



Images courtesy Dra Lidia Oskinova

Soft X-rays can be explained by wind shocks ?

… More than 100 papers based only on XMM data:
Kahn et.al (2001), Sana et.al (2004), Raassen et.al (2005), Rakowski et.al (2006), Leutenegger et.al (2007), Naze et.al (2010)

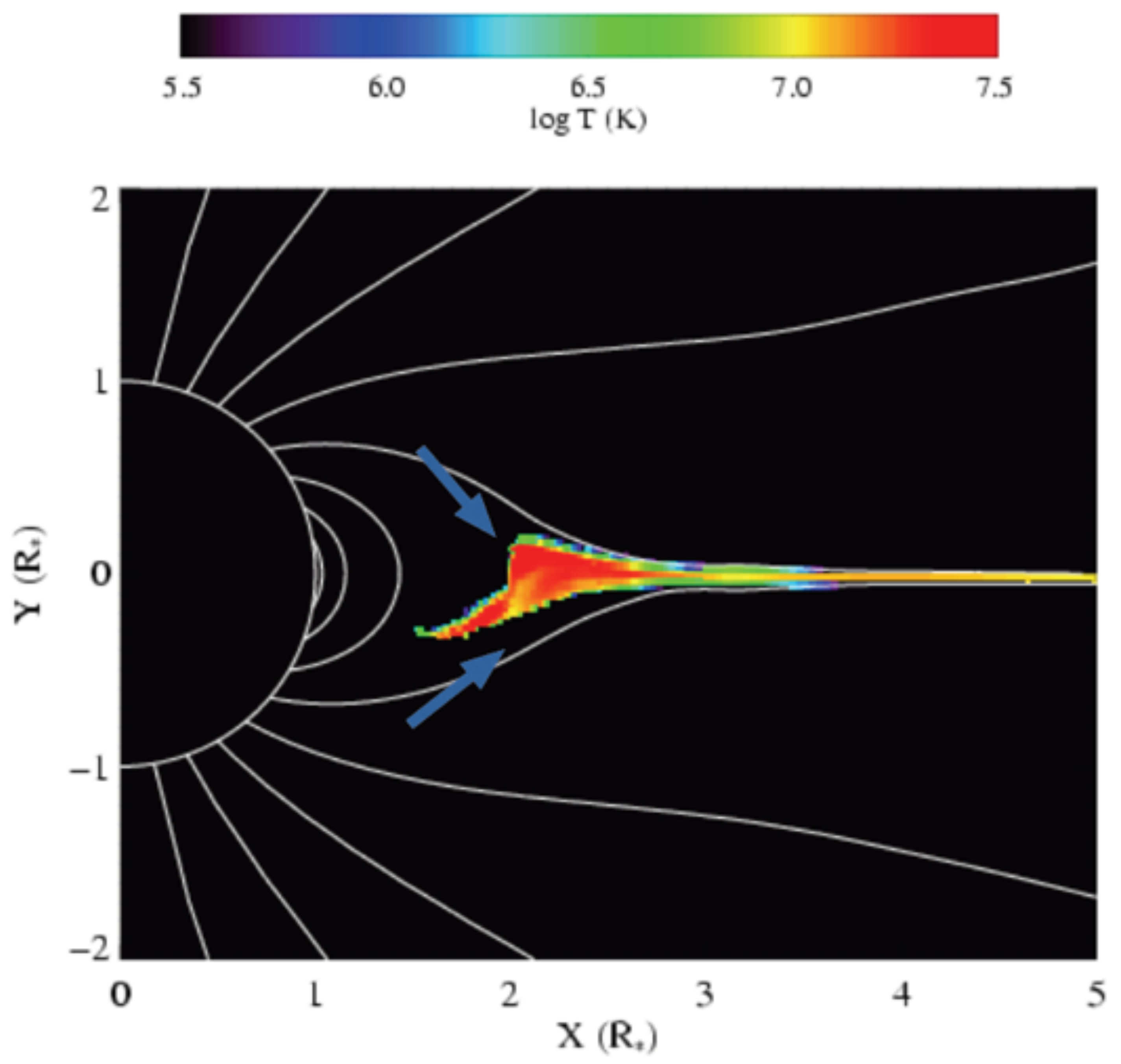
Typical $L_x \sim 10^{31}$ to 10^{33} erg/s and kT~0.5 to 0.8 keV
Hard X-rays from O-type stars are difficult to be explained by the Embedded Wind Shock model !!!

5- X-ray emission from early O-type stars

5.2 - Magnetically Confined Wind Shock (MCWS)

- Magnetic fields are not expected for massive stars (Fully radiative stars),…
- About 10% of massive stars present strong (mostly dipolar) magnetic fields !
- MS (Diez & Mathis 2010) and even for PMS (Alecian et al. 2013) observed fossil B fields as simple dipoles.
- Trap and channels their stellar winds in closed magnetic loops (Babel & Montmerle 1997ab, Gagne et al. , 2005a).
- Interplay between Stellar wind and Magnetic field —> efficiency of confinement (ud-Doula & Owocki 2002)

$$\eta(r,\theta) \equiv \frac{B^2/8\pi}{\rho v^2/2} \approx \frac{B^2 r^2}{\dot{M} v(r)}$$



Images courtesy Dr David Cohen

5- X-ray emission from early O-type stars

5.2 - Magnetically Confined Wind Shock (MCWS)

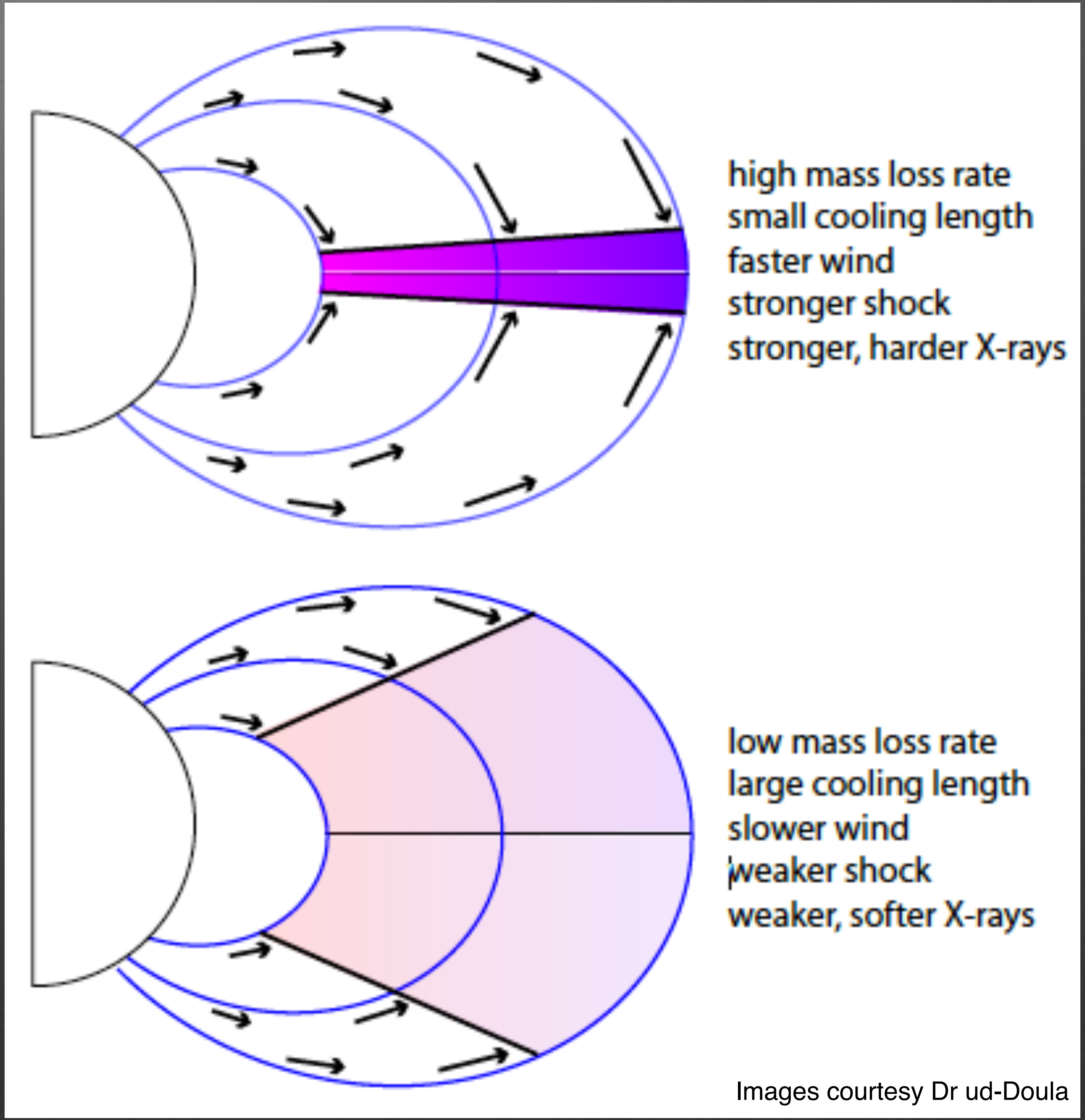
- MCWS X-ray emission geometry strongly depends B and dM/dt of the star
- There is a secondary element that affects the L_x but also the Hardness of X-ray radiation (cooling parameter)

$$\chi_\infty \propto V_\infty^4/\dot{M}$$

Babel & Montmerle (1997)
find an observational trend
$L_x = dM/dt \,.\, v_\infty \,.\, B^{0.4}$

However,…
Survey of 11 magnetic O-type stars
(Oskinova et.al 2011) found no link between
individual level of L_x, B, P_{rot}, v_∞ , L_{bol}.

Typical L_x ~10^{33} to 10^{34} erg/s and kT~2 to 3 keV
No correlation was found between hardness and magnetic field intensity or stellar parameters (Naze et.al 2014).



Images courtesy Dr ud-Doula

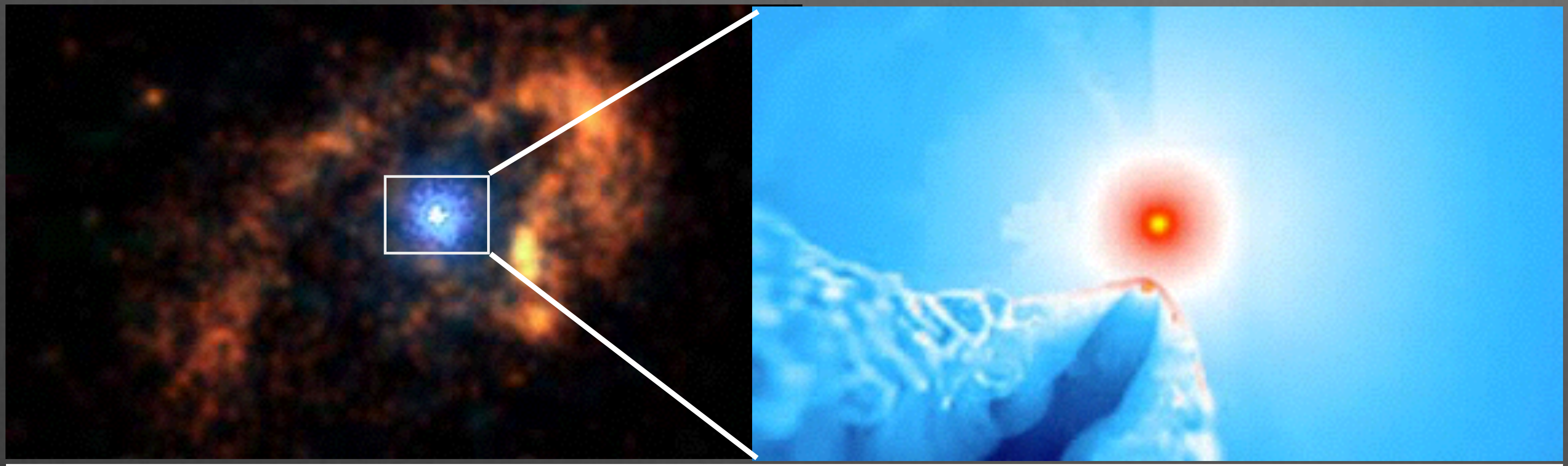
5- X-ray emission from early O-type stars

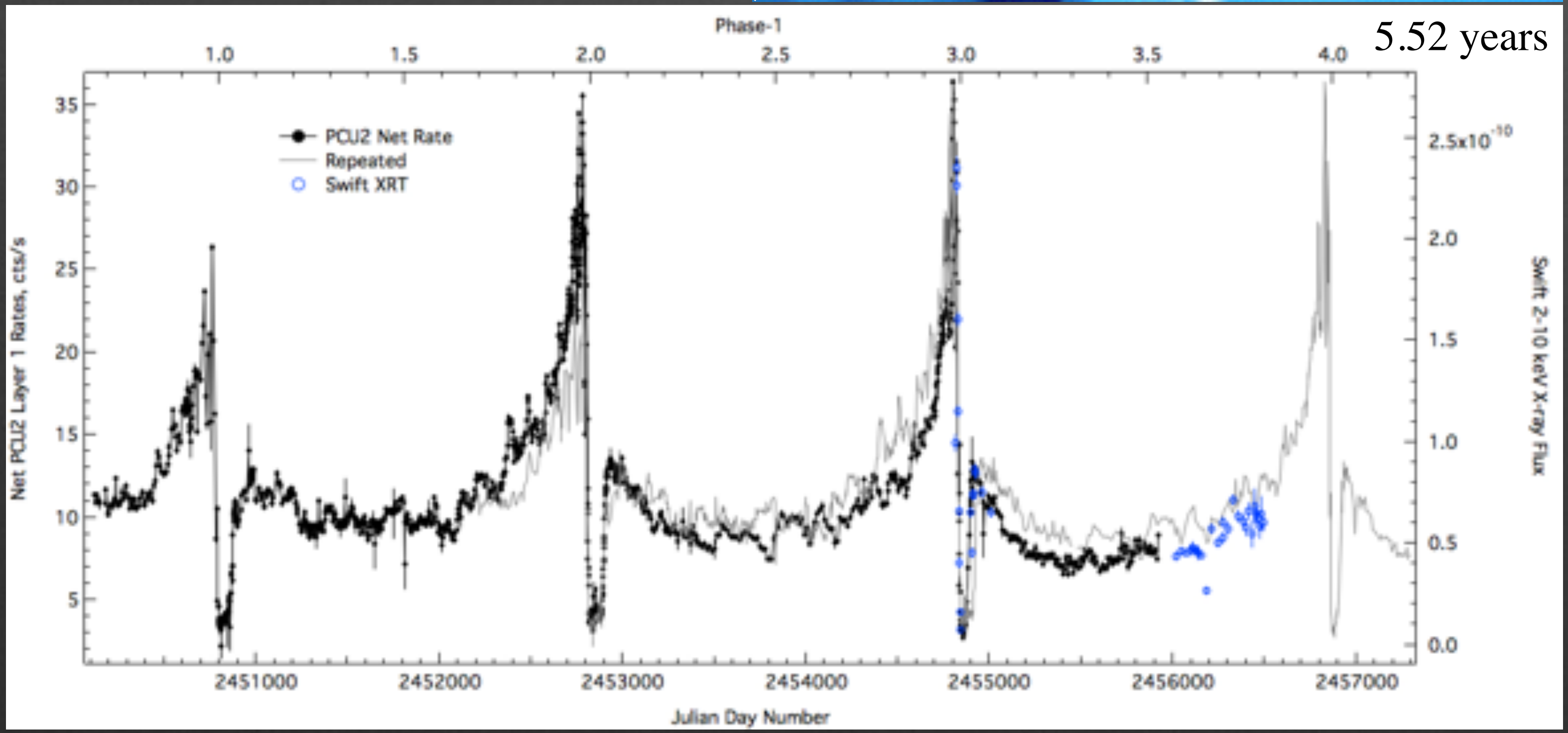
5.3 - Colliding Wind Shocks (CWS)

- CWS was early recognized for the extra X-ray production (Prilutskii & Usov, 1976).

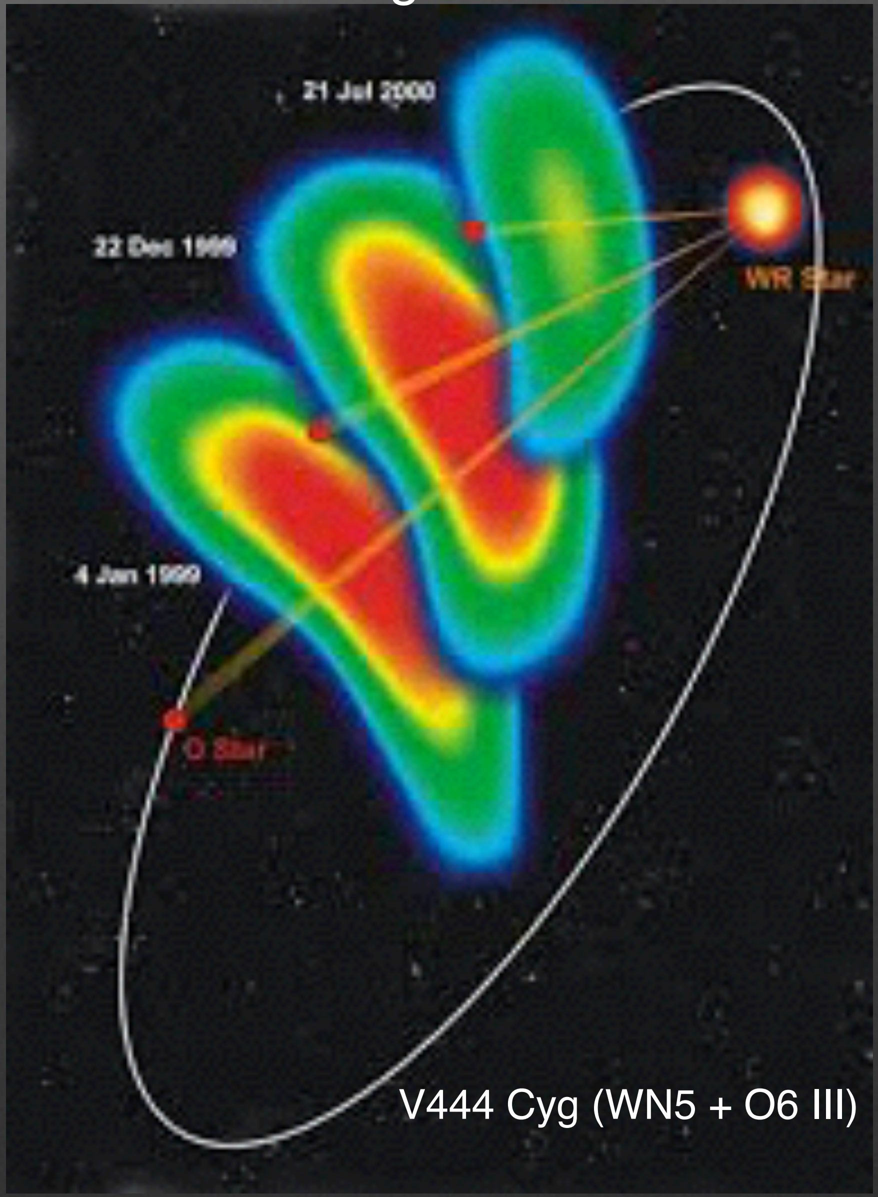
- Pollock (1987), through WR find binaries are X-ray over luminous respect to single ones

- Eta Carina as CWS binary (LBV + O?) (Mehrner et.al 2010)





WR + O colliding



V444 Cyg (WN5 + O6 III)

Astrophysical parameters affects the way CWS are produced —> stellar parameters of the stars, binary separation, eccentricity of the orbit, etc. —> changes on variability patterns and L_x excesses.

5- X-ray emission from early O-type stars

5.3 - Colliding Wind Shocks (CWS)

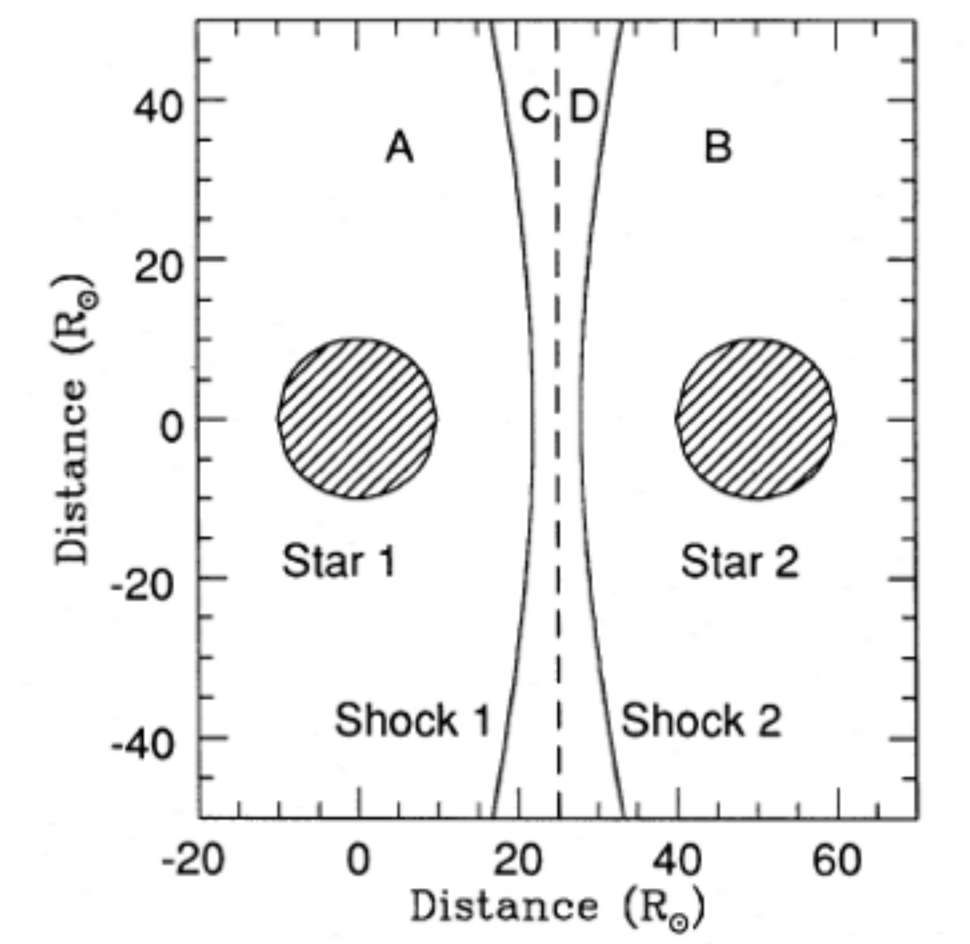
- The Colliding Wind Zone (CWZ) is defined by the ratio of wind momenta (Stevens & Pollock, 1994).

- O+O and WR+O systems are most relevant scenarios —> different scenarios

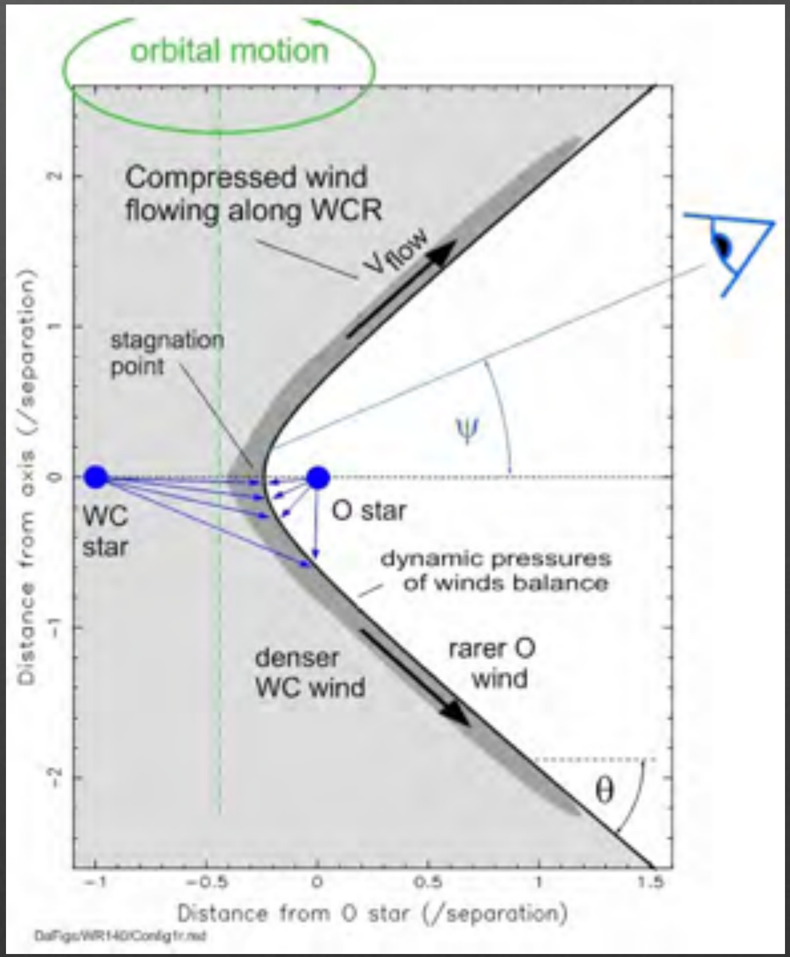
-Ingredients:
Otype —> dM/dt ~ 10^{-6}~ to 10^{-7} M_o/yr
WR —> dM/dt ~10^{-4} to 10^{-5} M_o/yr
Wind velocities ~ 1-3x10^3 km/s
Orbital separations
Excentricity

$$\mathscr{R} \equiv \left(\frac{\dot{M}_1 v_1}{\dot{M}_2 v_2} \right)^{1/2} = \frac{d_1}{d_2} .$$

O+O equal winds



WR+O unequal winds



5- X-ray emission from early O-type stars

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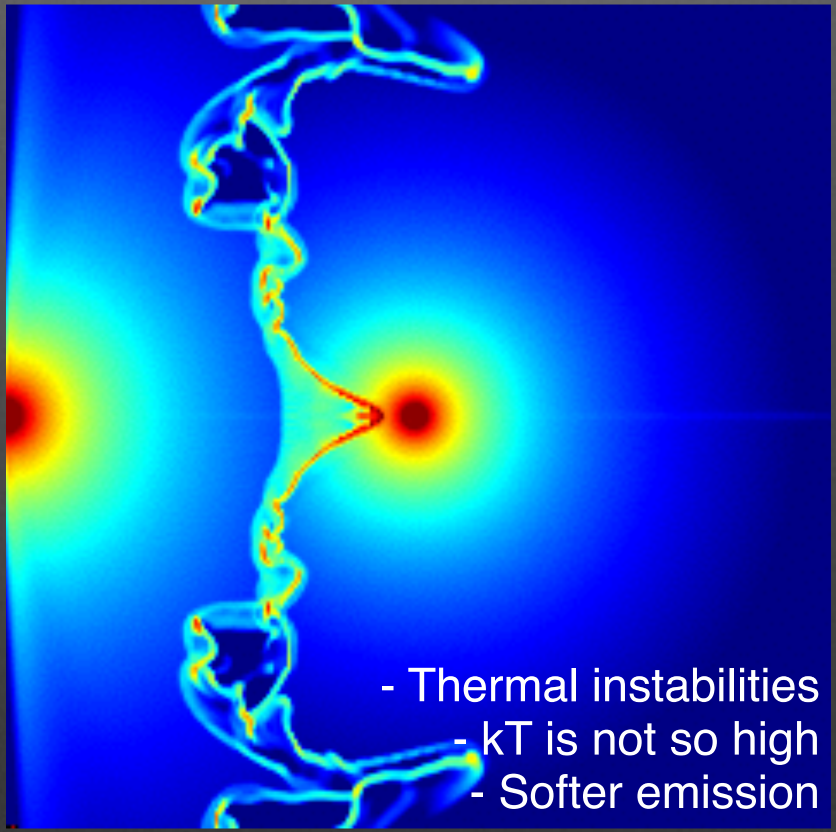
$$\mathscr{R} \equiv \left(\frac{\dot{M}_1 v_1}{\dot{M}_2 v_2}\right)^{1/2} = \frac{d_1}{d_2} \, .$$

Close binaries
v=v(r)
Radiative limit

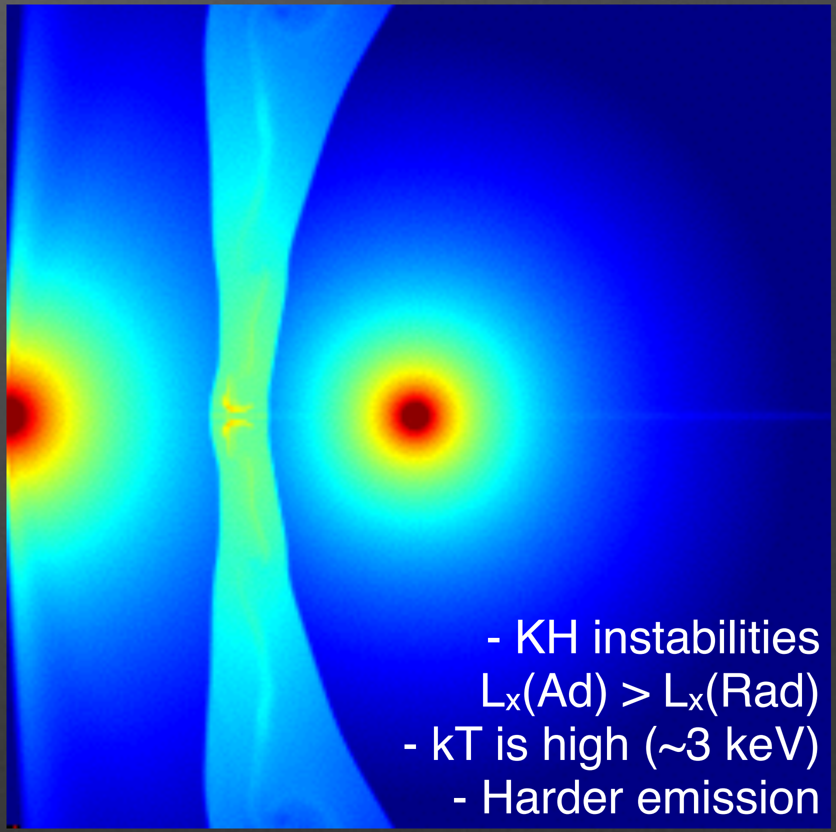
Separated binaries
v=v∞ (terminal)
Adiabatic limit

Radiative limit (X<<1)



- Thermal instabilities
- kT is not so high
- Softer emission

Adiabatic limit (X>>1)



- KH instabilities
L_x(Ad) > L_x(Rad)
- kT is high (~3 keV)
- Harder emission

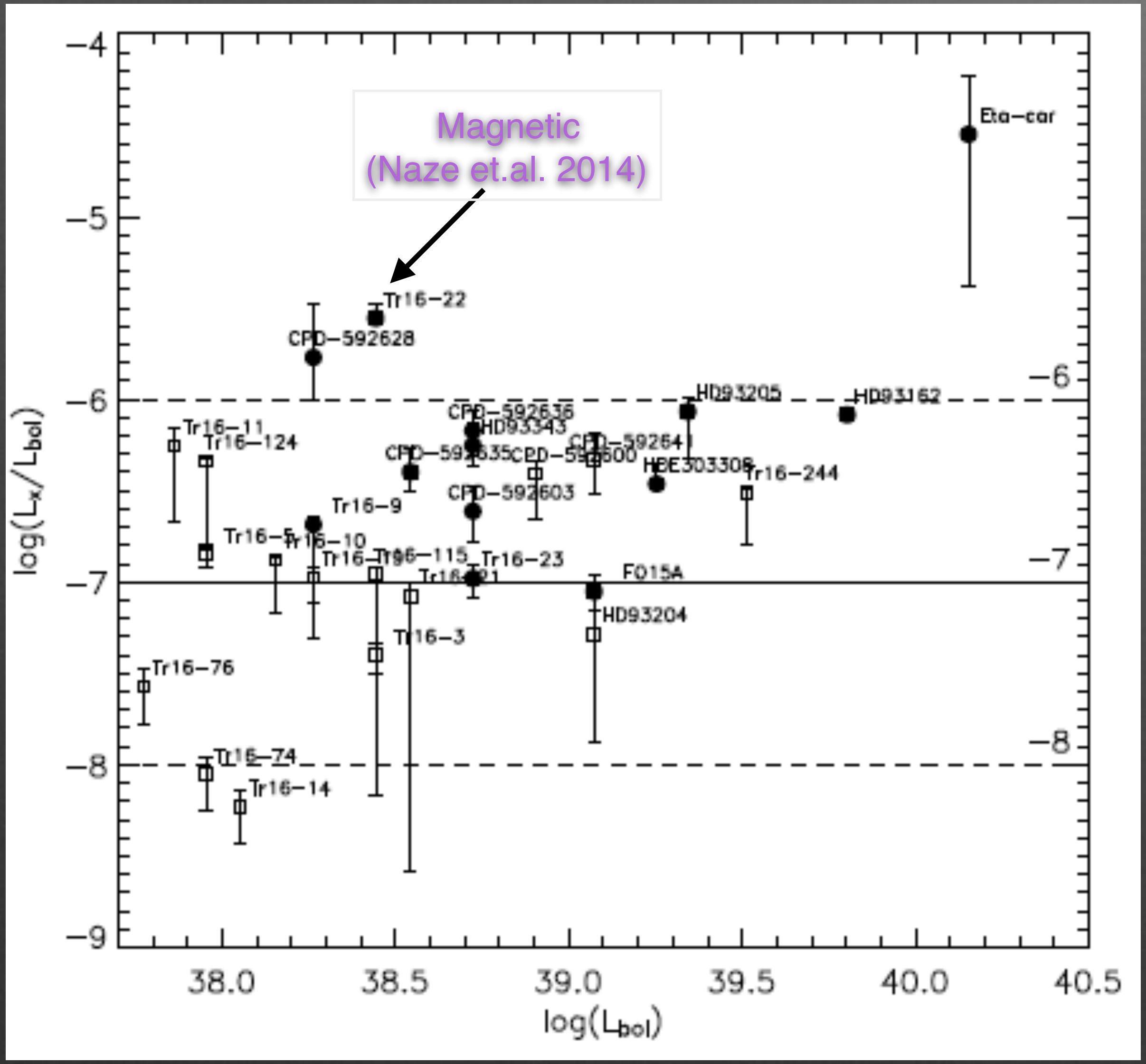
$$\chi = \frac{t_{\rm cool}}{t_{\rm esc}} \approx \frac{v_8^4 d_{12}}{\dot{M}_{-7}} \, ,$$

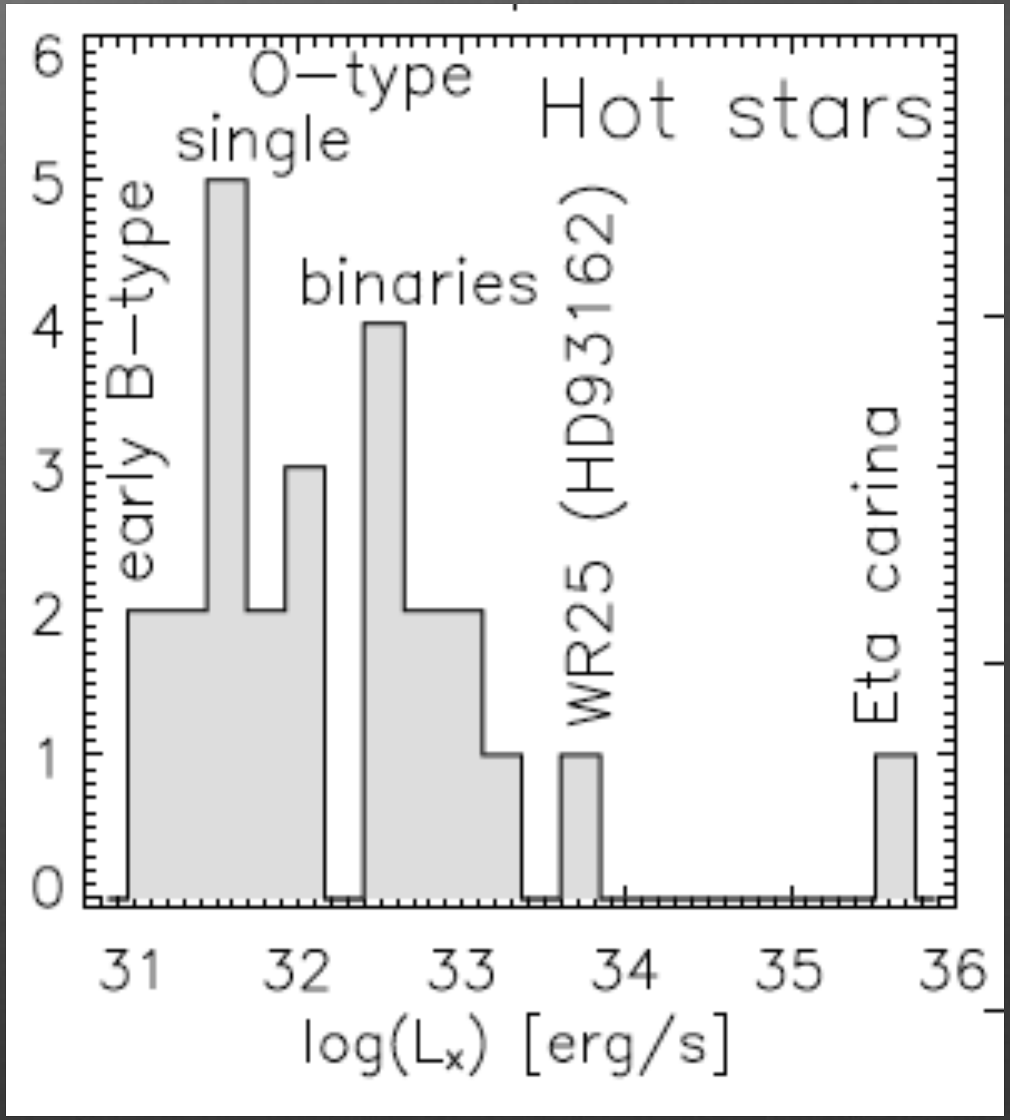
- Cooling change also with geometry (Radiative + Adiabatic) regimes.
- L_x ~ $(dM/dt)^2$ / D —> eccentric binaries decrease L_x with D.
- L_x ~ f_x(dM/dt).v^2 for radiative limits.

5- X-ray emission from early O-type stars

5.3 - Colliding Wind Shocks (CWS)

- The L_x/L_{bol} relationship (In Carina - Albacete Colombo et.al. 2008).
- In Cygnus OB2, Albacete Colombo et.al. 2007 , Rauw et.al. 2016).



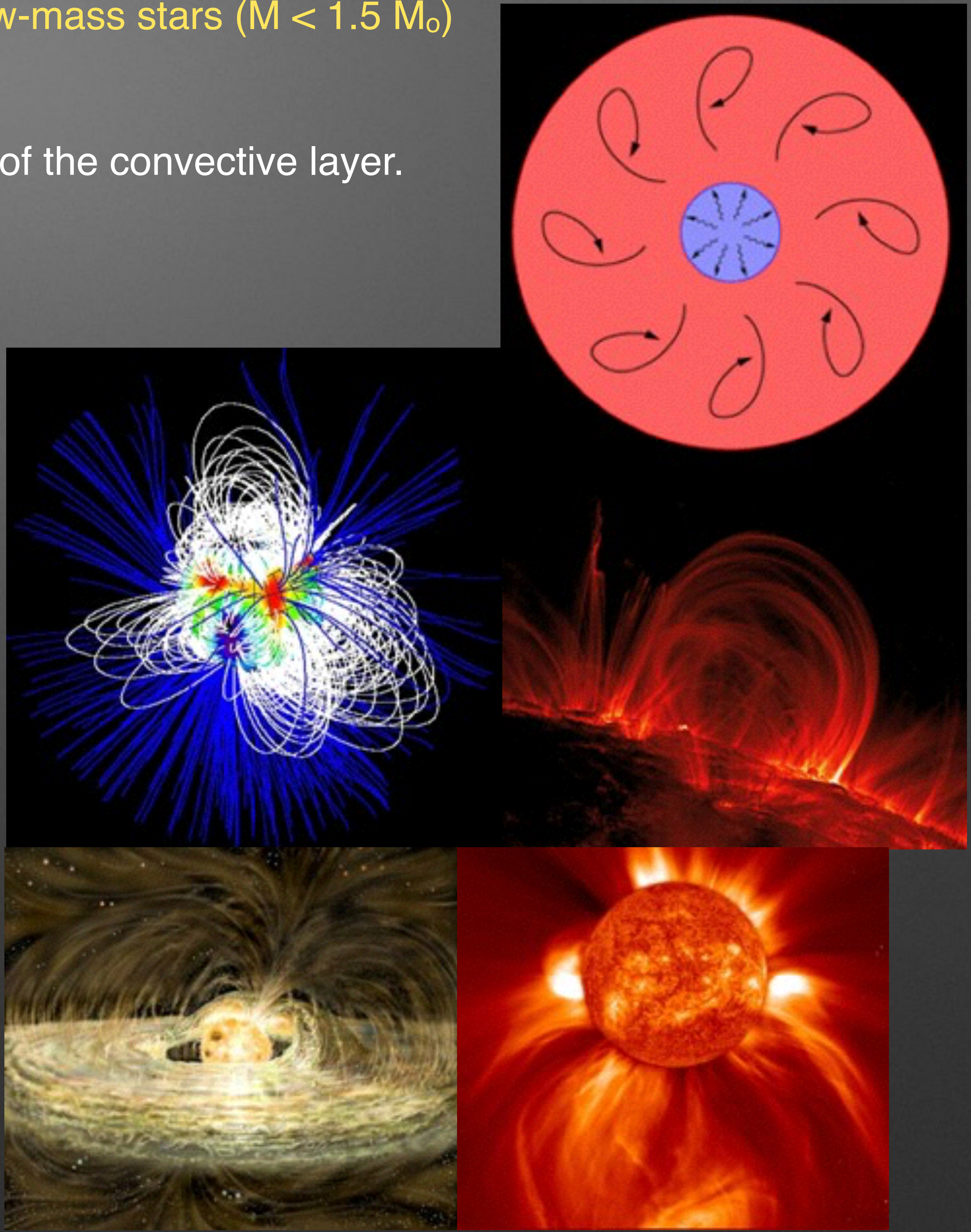


- Binaries O+O o WR+O show an X-ray excess respect to their single counterparts, but in some cases with hard X-ray emission.
- How massive stellar contents affect ISM and further evolution of low-mass stars ?

6- Young stellar objects (T-Tauri vs MS)

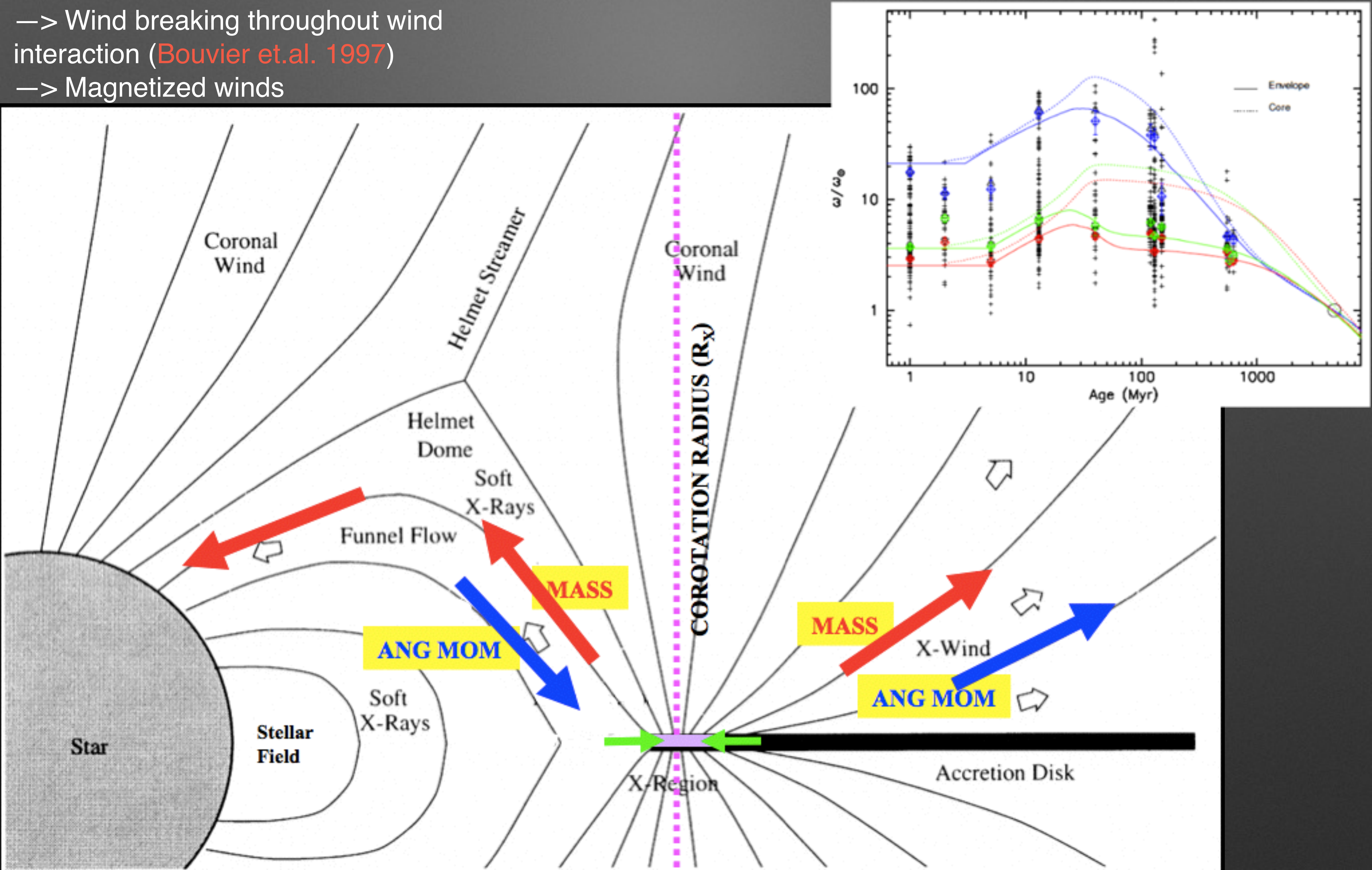
Oppositely to Massive stars, production of X-rays in low-mass stars ($M < 1.5\ M_{\odot}$) are strictly related to surface B.

- B is linked to the star rotation rate and the depth of the convective layer.
- A complex configuration (not dipolar)
- Evolution of surface rotation from PMS to late-MS (1 Myr - 10 Gyr)



6- Young stellar objects (T-Tauri vs MS)

—> Wind breaking throughout wind interaction (Bouvier et.al. 1997)
—> Magnetized winds



6- Young stellar objects (T-Tauri vs MS)

6.1 - X-ray emission level in MS stars

Pallavicini et.al. (1981) based on dynamo theory ($B \sim \Omega_{rot}$) —> $L_x \sim (v_{rot} \sin i)^2$

Vidotto et.al. (2014) —> $L_x \sim B^2$ (scale with the magnetic density)

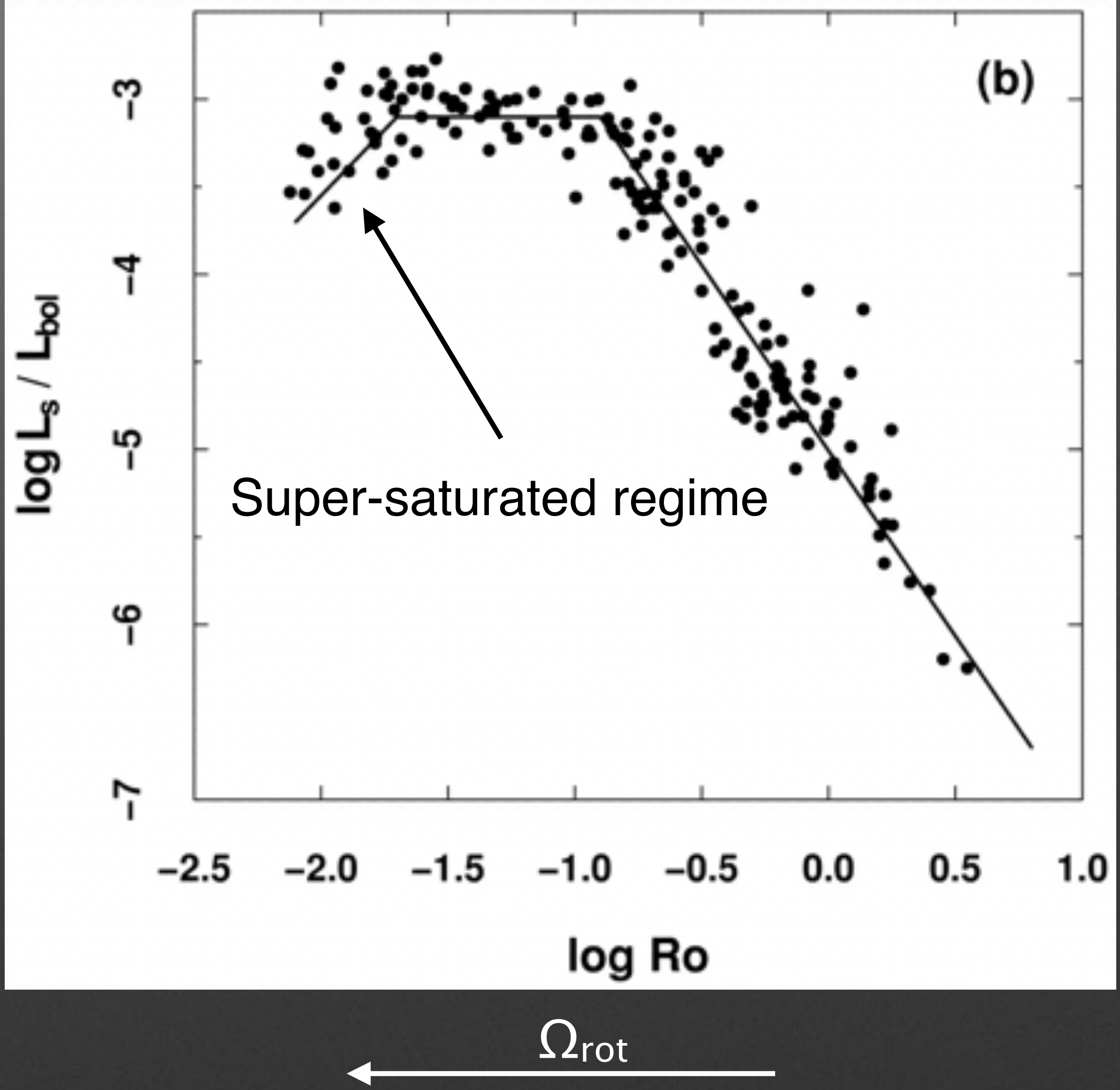
X-ray emission from MS stars does not increase ad infinitum (as R contracts) with increasing rotation Ω_{rot} —> Rapidly rotating stars L_x/L_{bol} saturate $\sim 10^{-3}$.
—> Saturation is independent of spectral types

This is known as the Rotation-Activity relationship for MS stars (Noyes et.al. 1984)

Bugs in the plot:

- Tau is model dependent
- Rotational modulation in saturated regime (for PMS)
- Low efficiency in dynamo at higher Ω_{rot}
- Centrifugal stripping of the corona

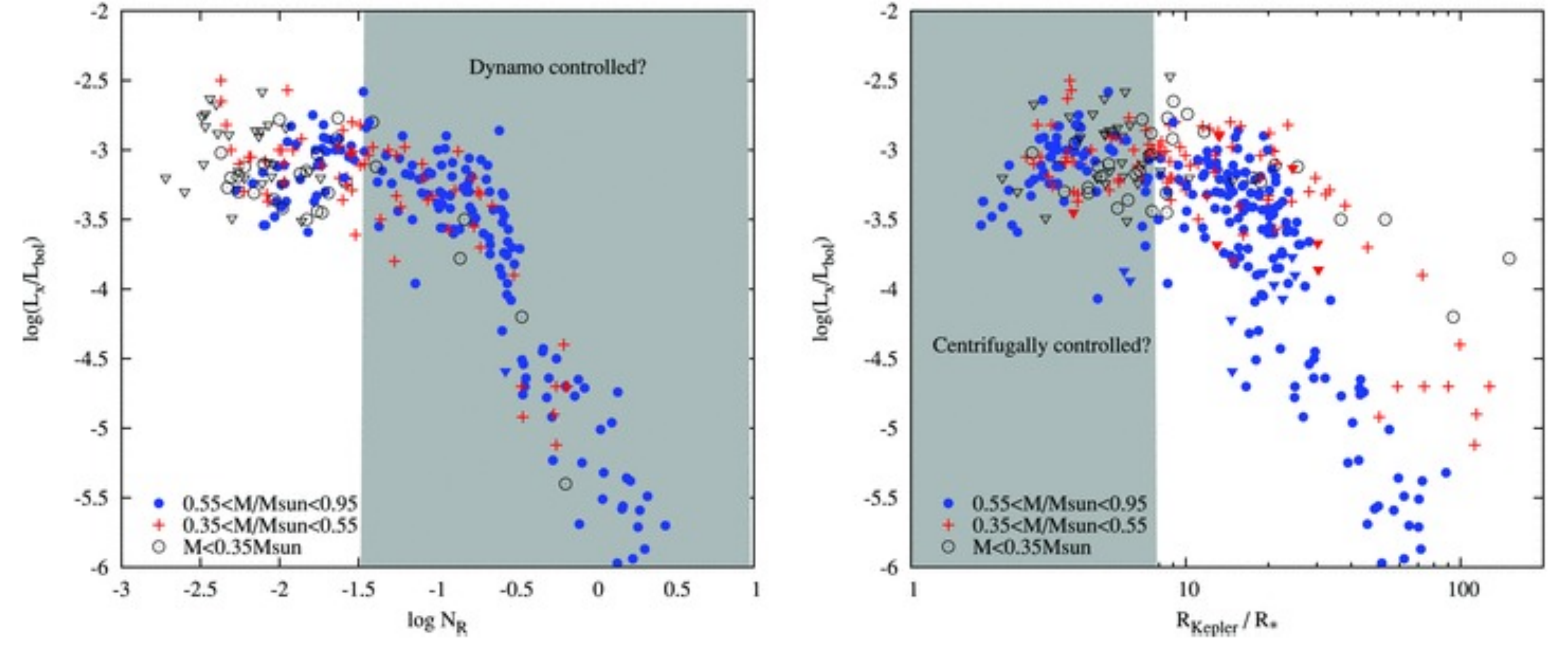
(Flaccomio et.al. 2005, Jardine & Unruh 1999, etc)



rate.

6- Young stellar objects (T-Tauri vs MS)

6.1 - X-ray emission of MS stars



Bugs in the plot:

- Tau is model dependent
- Rotational modulation in saturated regime (for PMS)
- Low efficiency in dynamo at higher Ω_{rot}
- Centrifugal stripping of the corona

(Flaccomio et.al. 2005, Jardine & Unruh 1999, etc)

rate.

6- Young stellar objects (T-Tauri vs MS)

6.2 - X-ray emission of Pre-MS stars

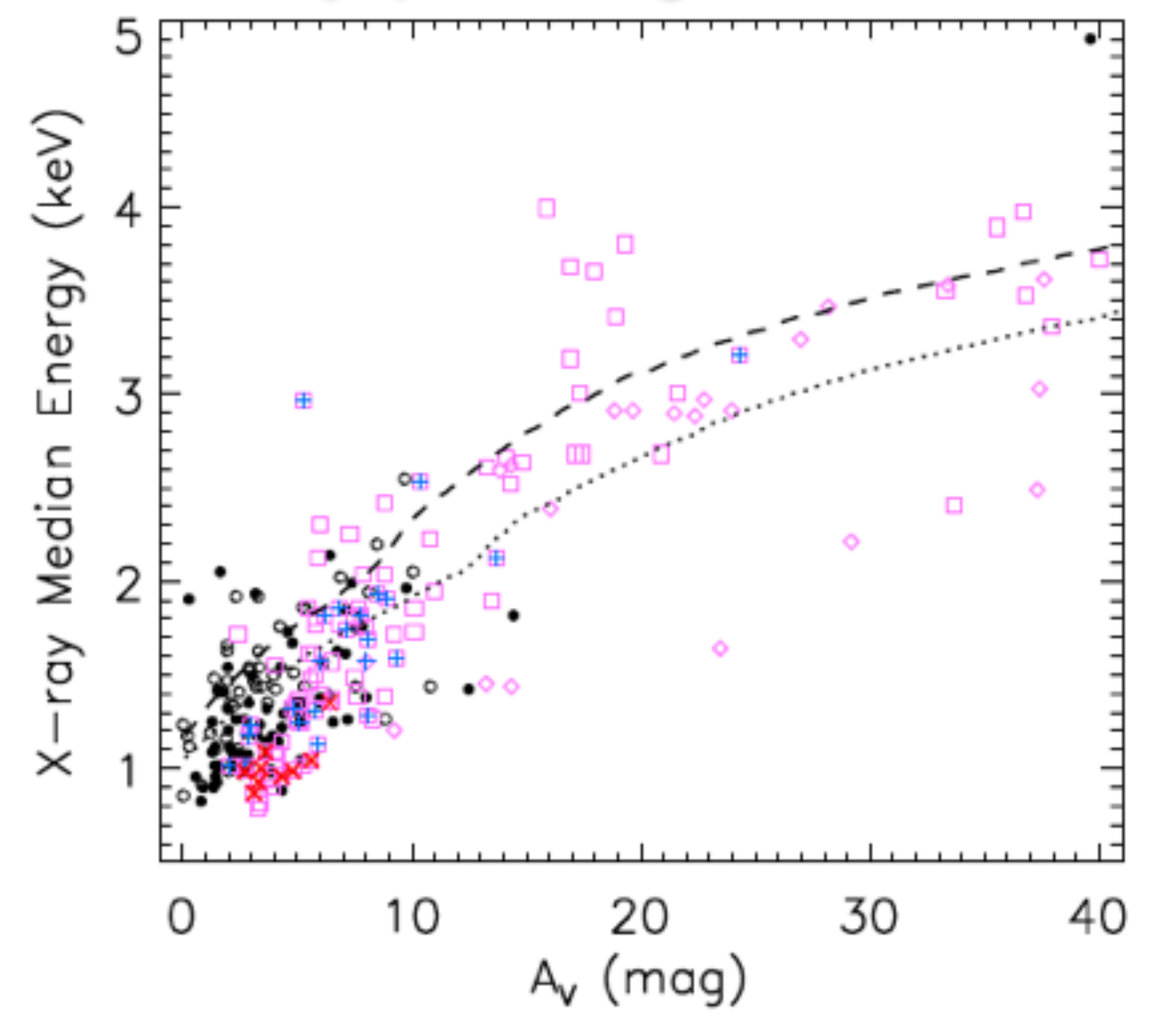
For PMSs the Rotation-Activity relationship with high scatter !!!

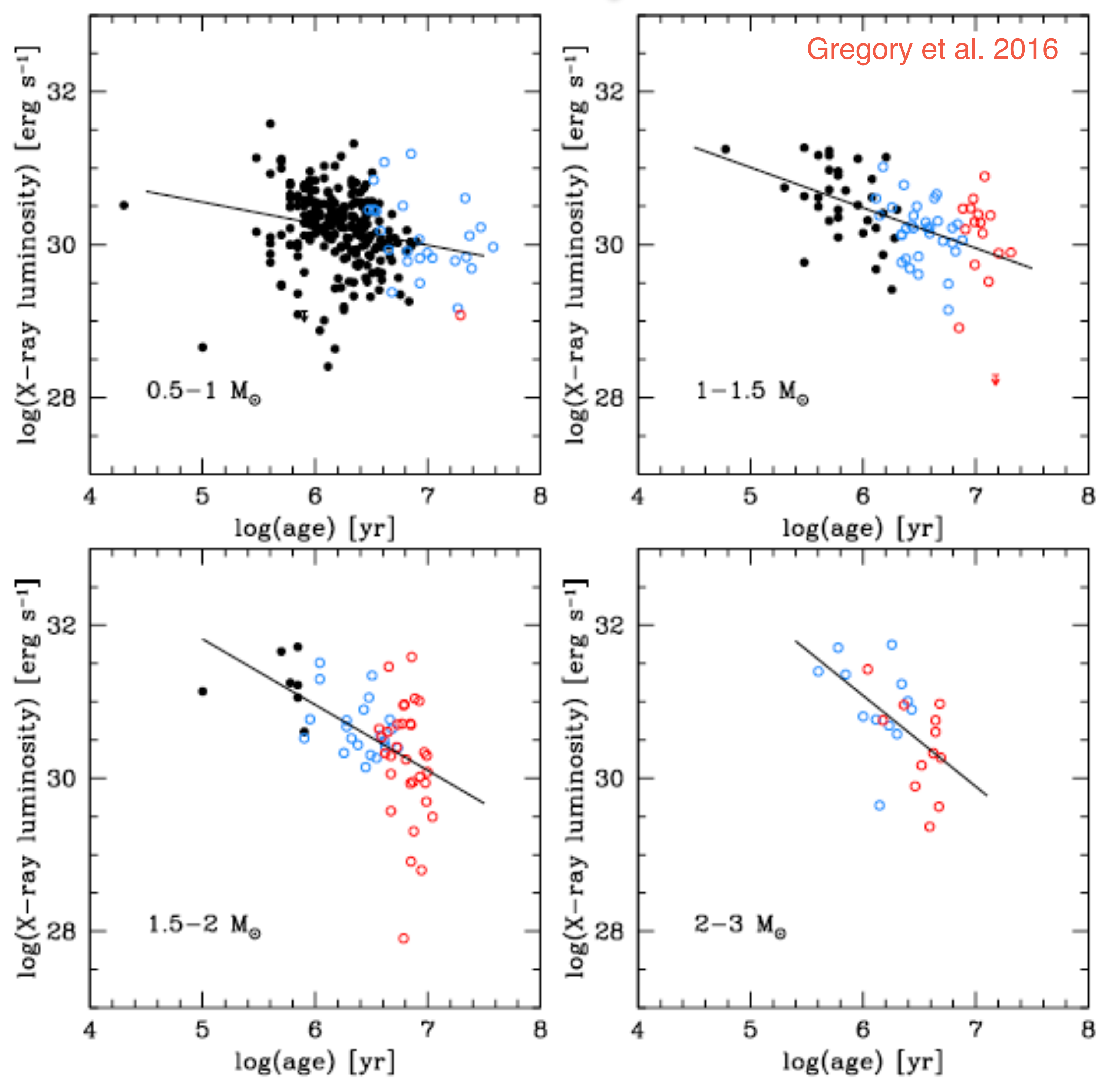
Argiroffi et.al. (2016) reported PMS stars ($M > 1M_{\odot}$) in a 13 Myr cluster display activity regimes like MS stars.

Non-members are faints in X-rays

PMSs are 10 to 10^4 X-ray luminous than Sun

- X-rays pass through dense ISM !

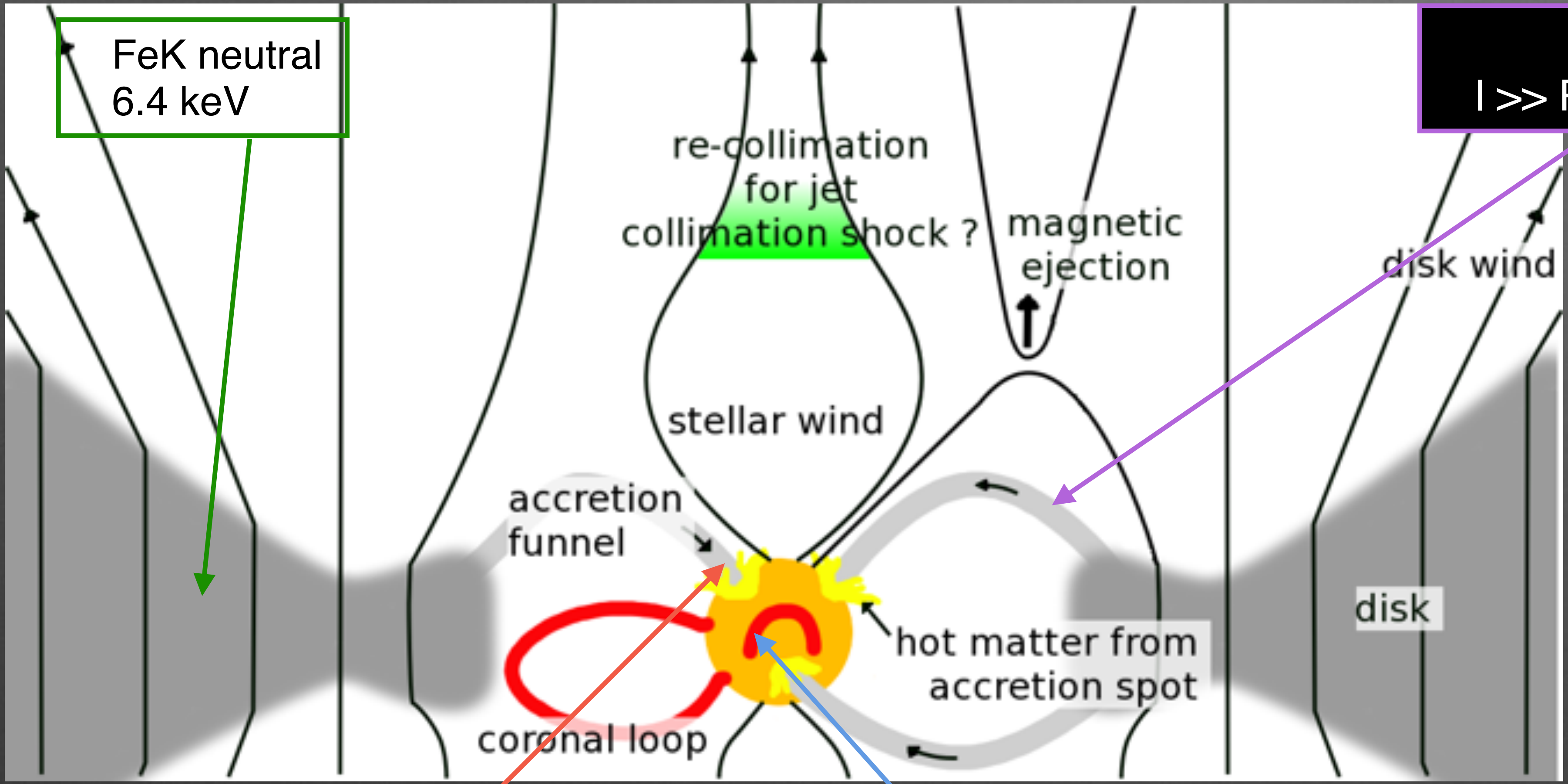




7- YSOs - disk interaction

T-Tauri Stars are strong X-ray emitters : $L_x \sim 10^{28}$ to 10^{31} erg/s (10^3 L_x Sun)

$T_x \sim 10$ to 30 MK (10 T_x Sun)



FeK neutral
6.4 keV

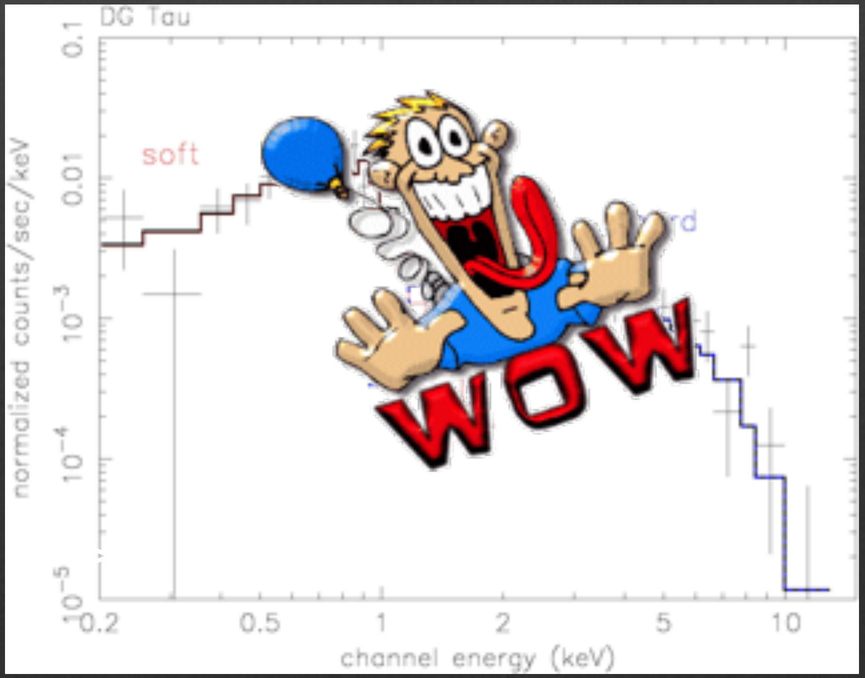
Extended loops
l >> R & FeK 6.7 keV emission line

Magnetospheric Accretion shocks
(only in accreting CTTSs not for WTTSs)

v < 300 km/s —> $T_x \sim 1\text{-}3\times10^6$ K
e.g. TW Hydra (Kastner et.al. 2002)

“Normal” Solar-like coronal loops
(L < R_{inner}) —> scaled up Sun activity.

Coronal component is by far dominant



HOWEVER, X-ray observations (Neuheauser et.al 1998,~ 20 cites)

—> L_x in CTTSs EVEN in acreting phase < L_x for non-acreting WTTSs

7- YSOs - disk interaction

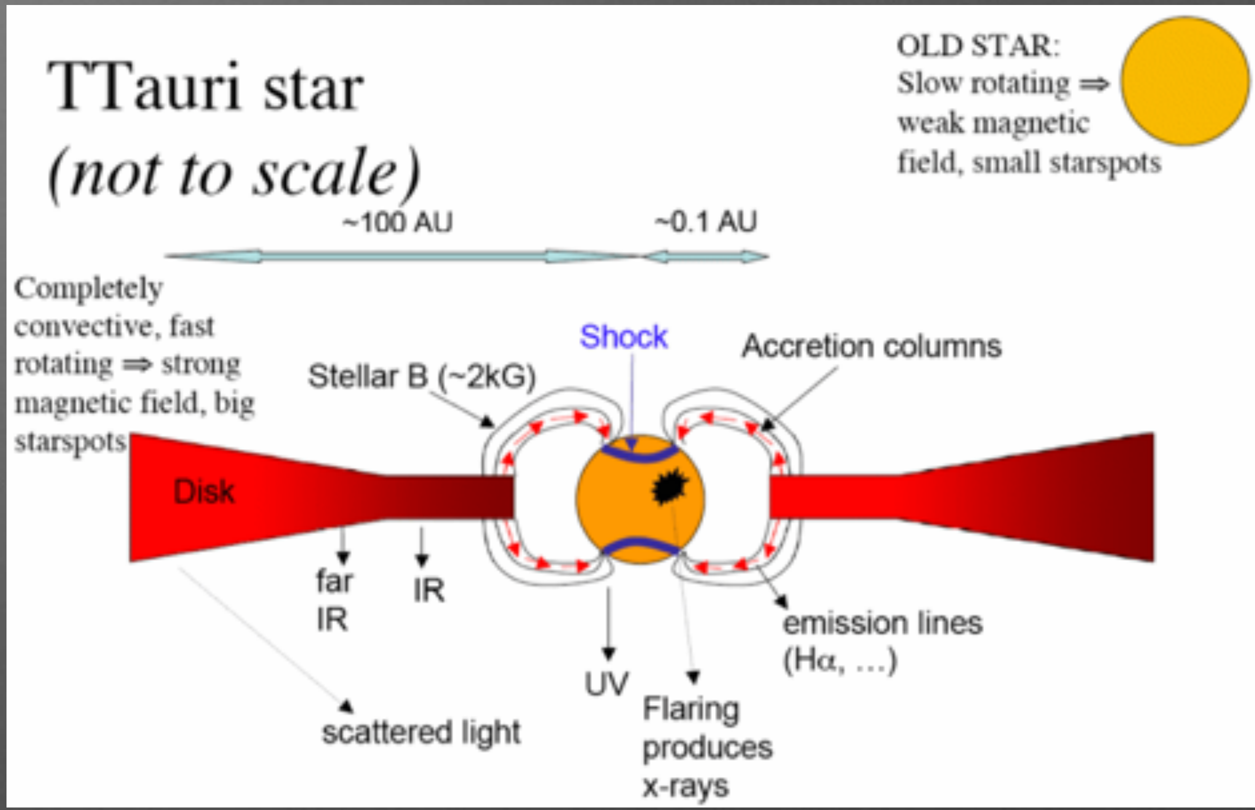
7.1- X-ray deficiency in CTTSs

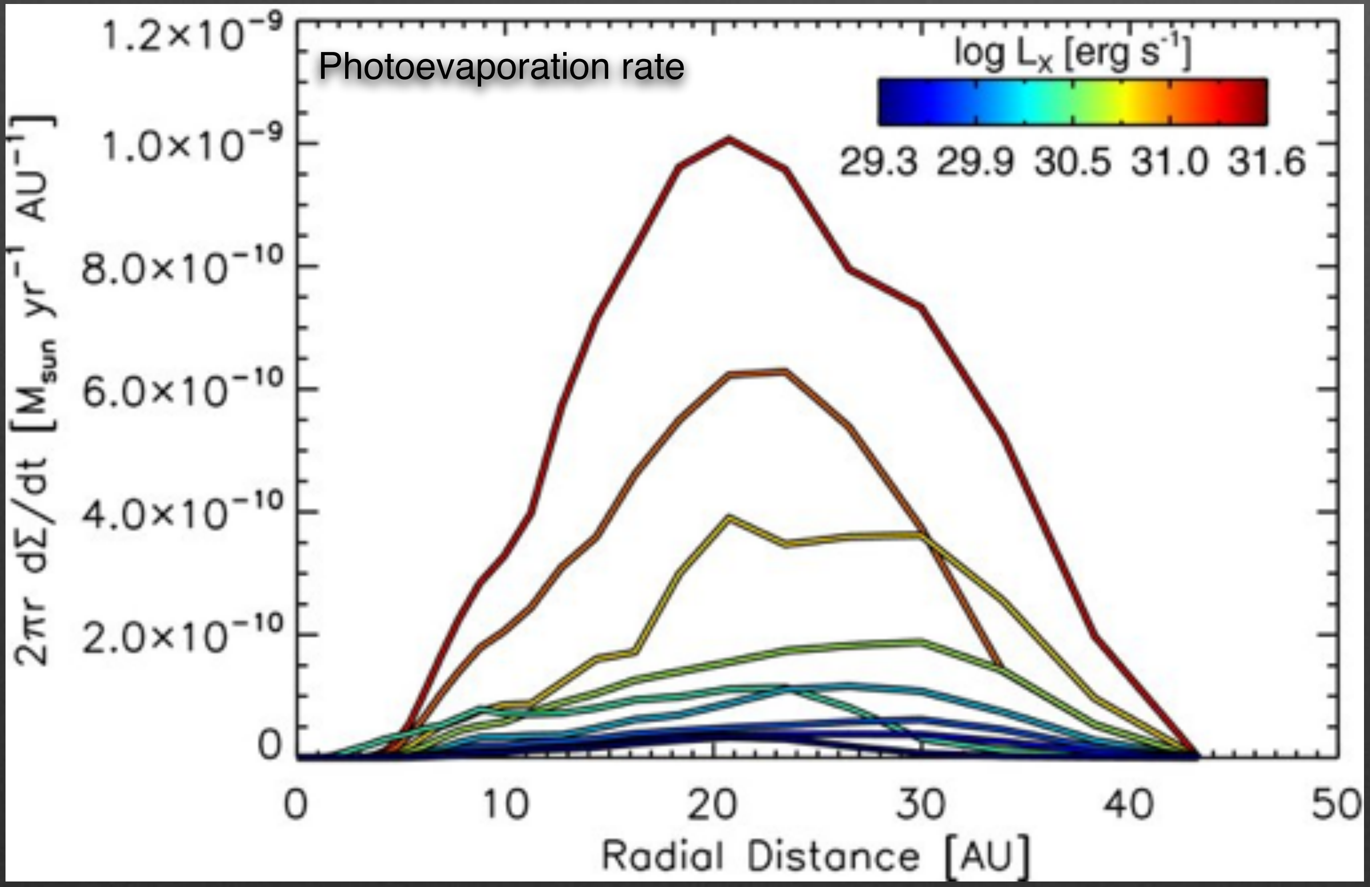
1) Suppression of X-rays as a consequence of accretion:

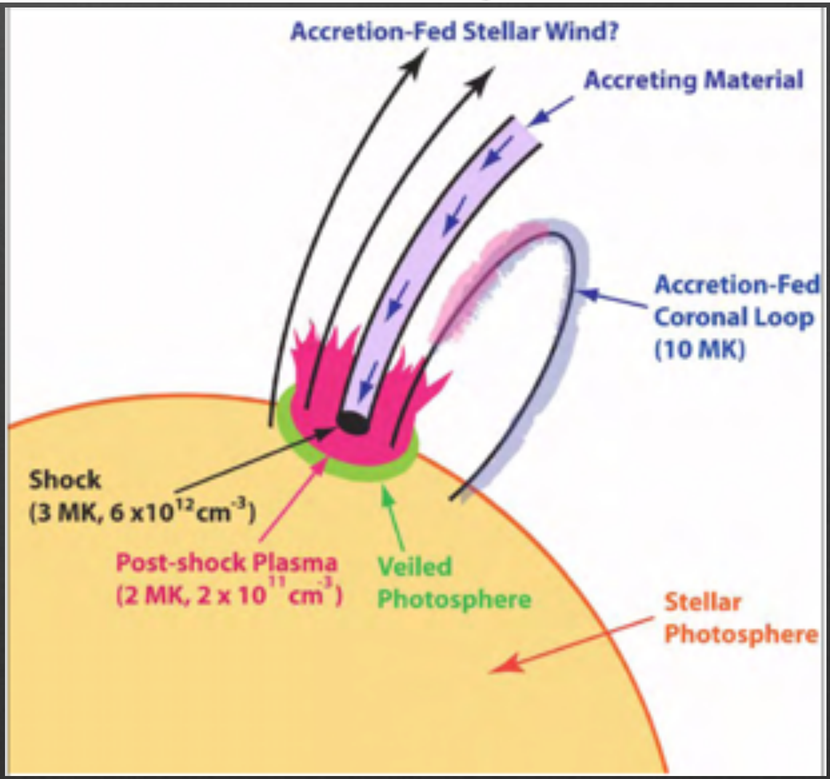
- disruption of magnetic corona (Stassun et.al 2004)
- suppression of convection through the accreted gas (Preibisch et.al. 2005)
- reduction of differential rotation via star-disk interactions (Gudel et.al. 2007)

2) X-ray emission drives the accretion (Drake et.al. 2009)

- disk mass lose rate proportional to the X-ray luminosity
- higher X-ray luminosity —> lower mass accretion rate.





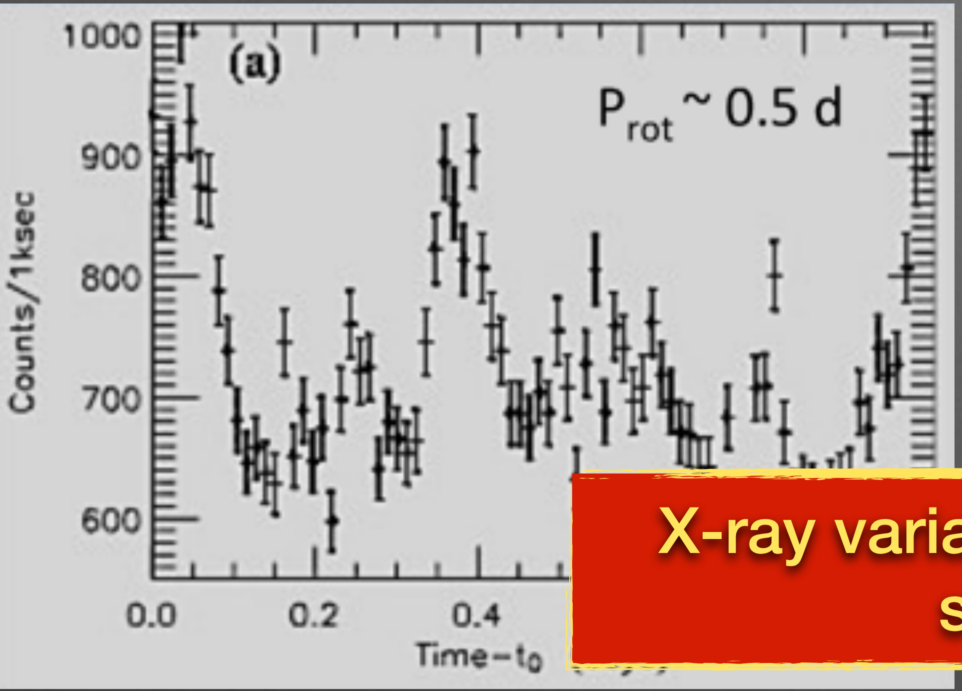


How X-ray luminosity change in time ?

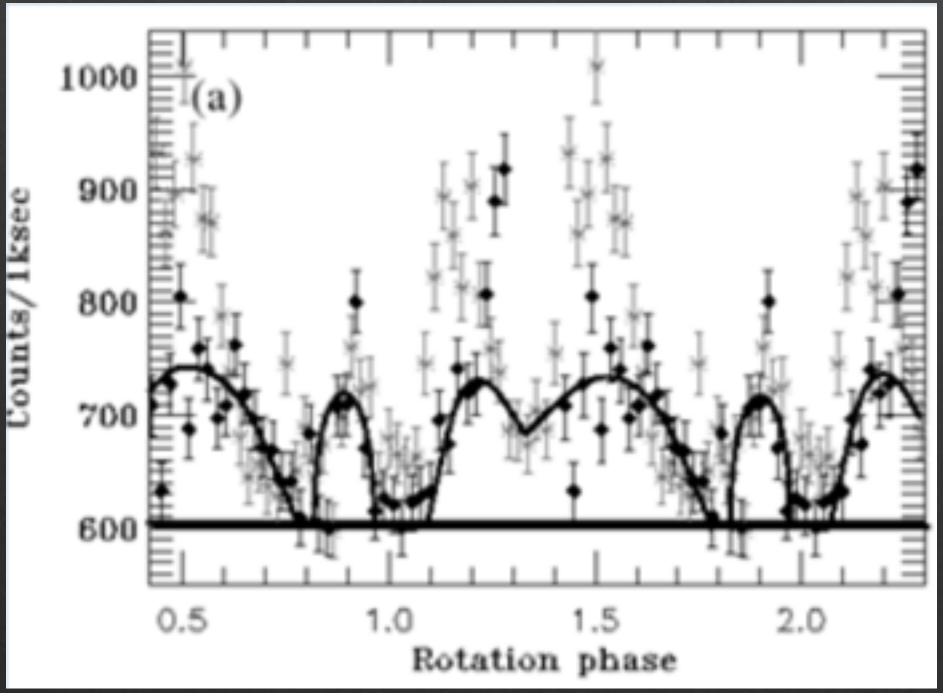
7- YSOs - disk interaction

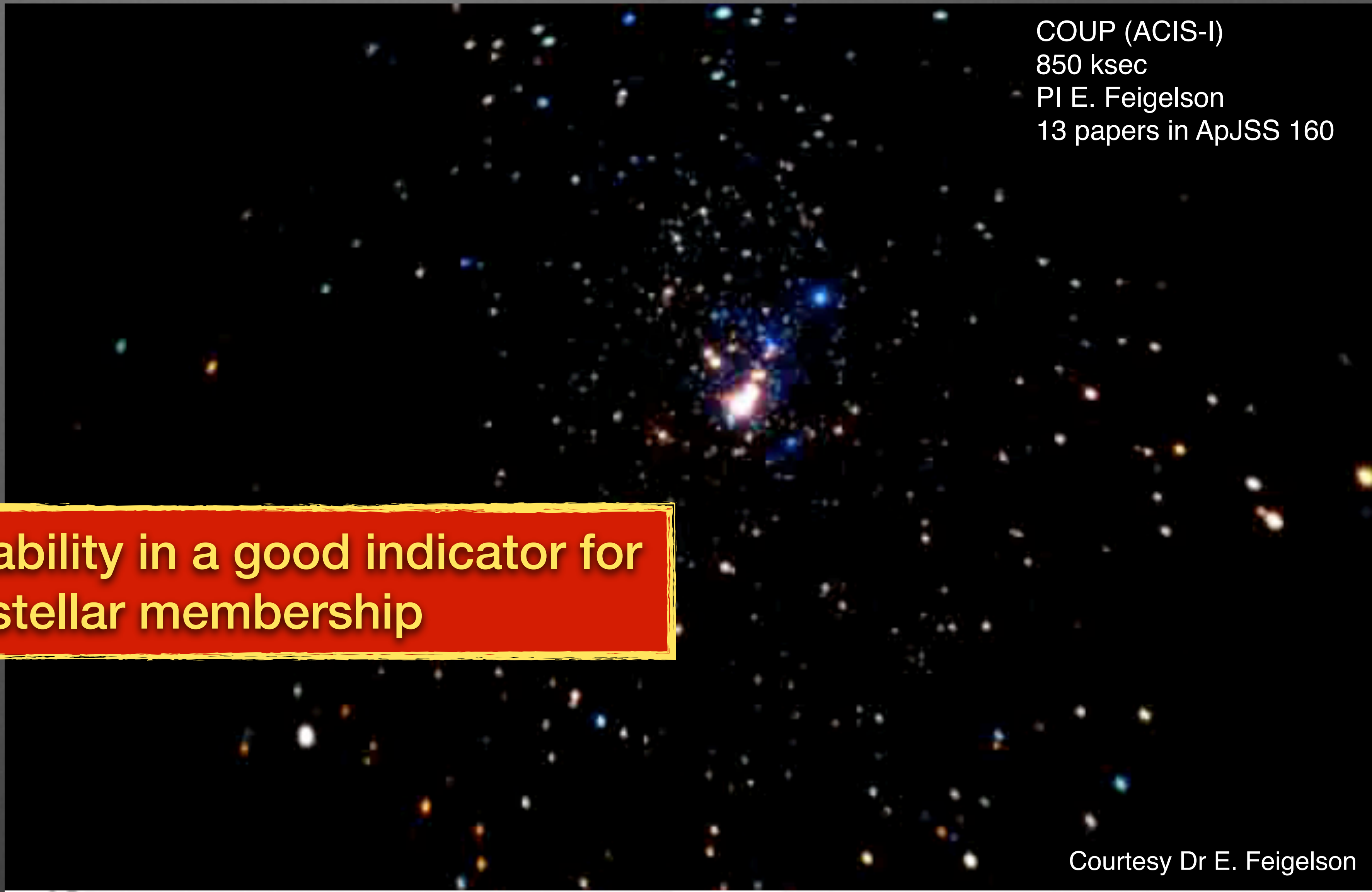
7.2- X-ray variability

Rotational modulation
(Husain et.al. 2007)



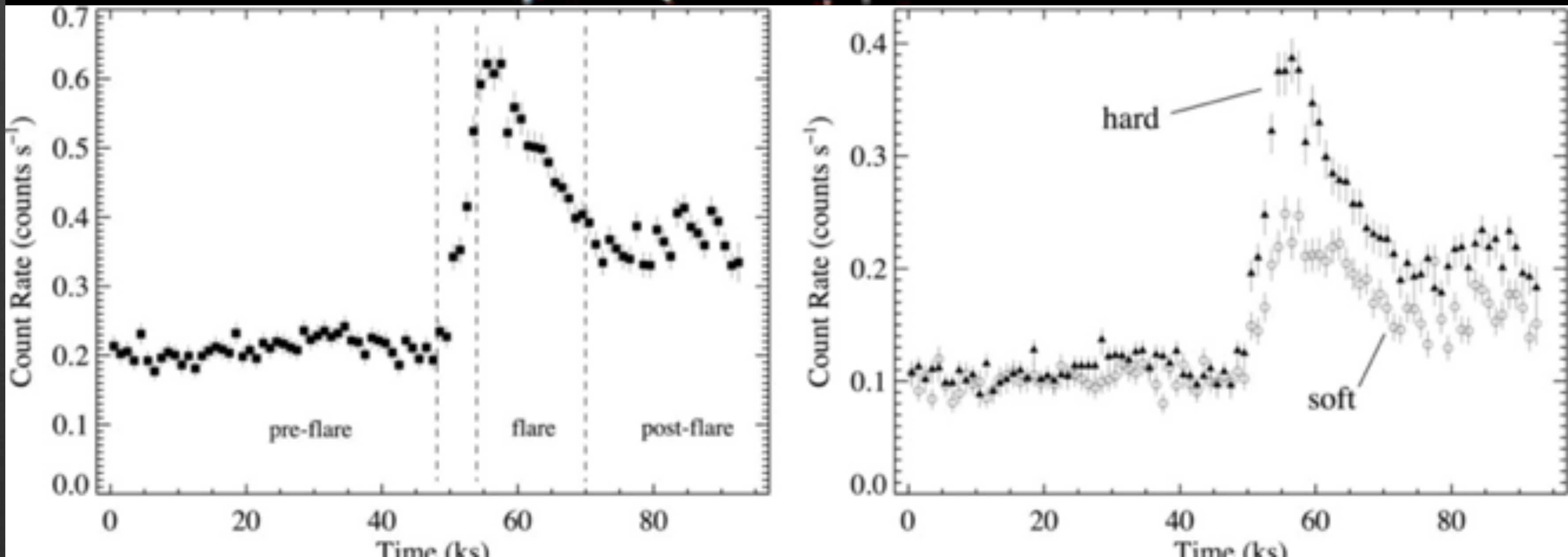
—> Modeling of X-ray emitting loops
—> reconstruction of X-ray lightcurve





COUP (ACIS-I)
850 ksec
PI E. Feigelson
13 papers in ApJSS 160

Courtesy Dr E. Feigelson



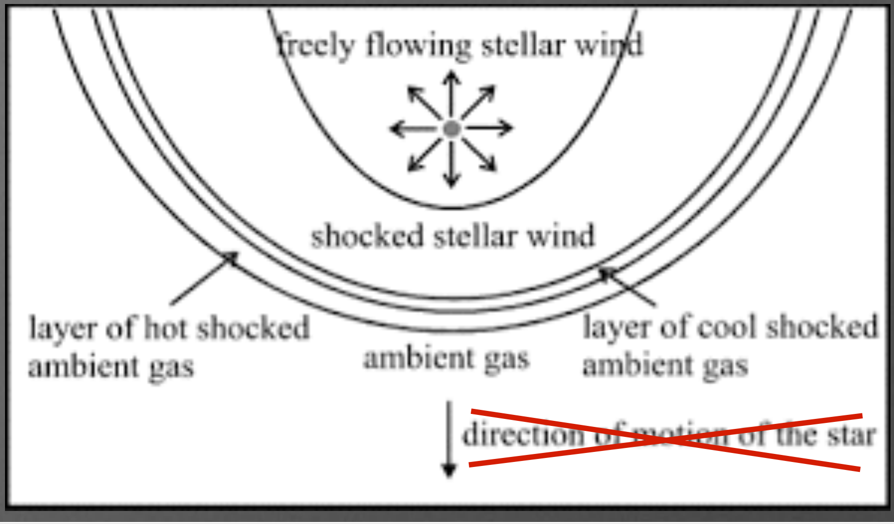
X-ray variability in a good indicator for stellar membership

8- Diffuse X-ray emission in SFRs

Theoretically expected:

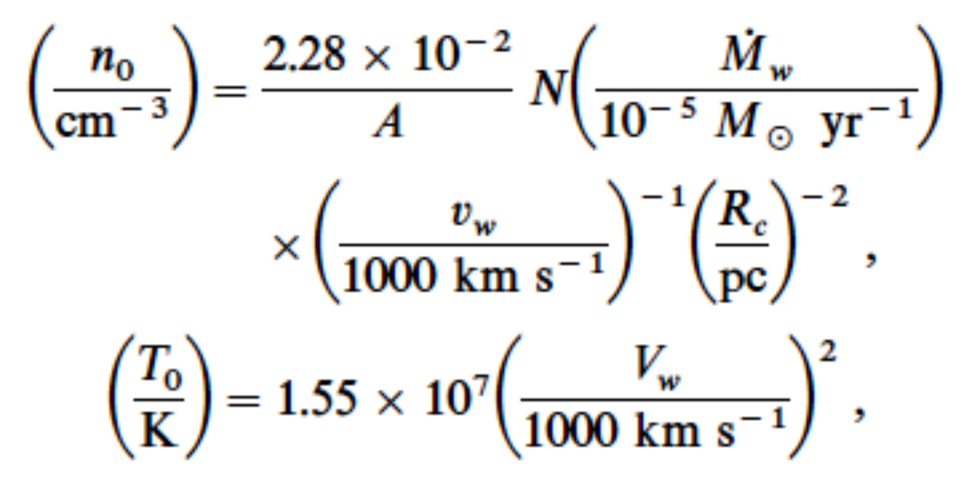
- Supersonic stellar winds from massive stars —> dissipative shock waves in the local ISM (Polcaro et.al. 1991)

- Thermal and/or Non-thermal emission is expected via:
  - Thermal bremsstrahlung
  - Synchrotron radiation from ISM-winds shocks
  - Charge exchange (CXE) mechanism
  - Inverse Compton



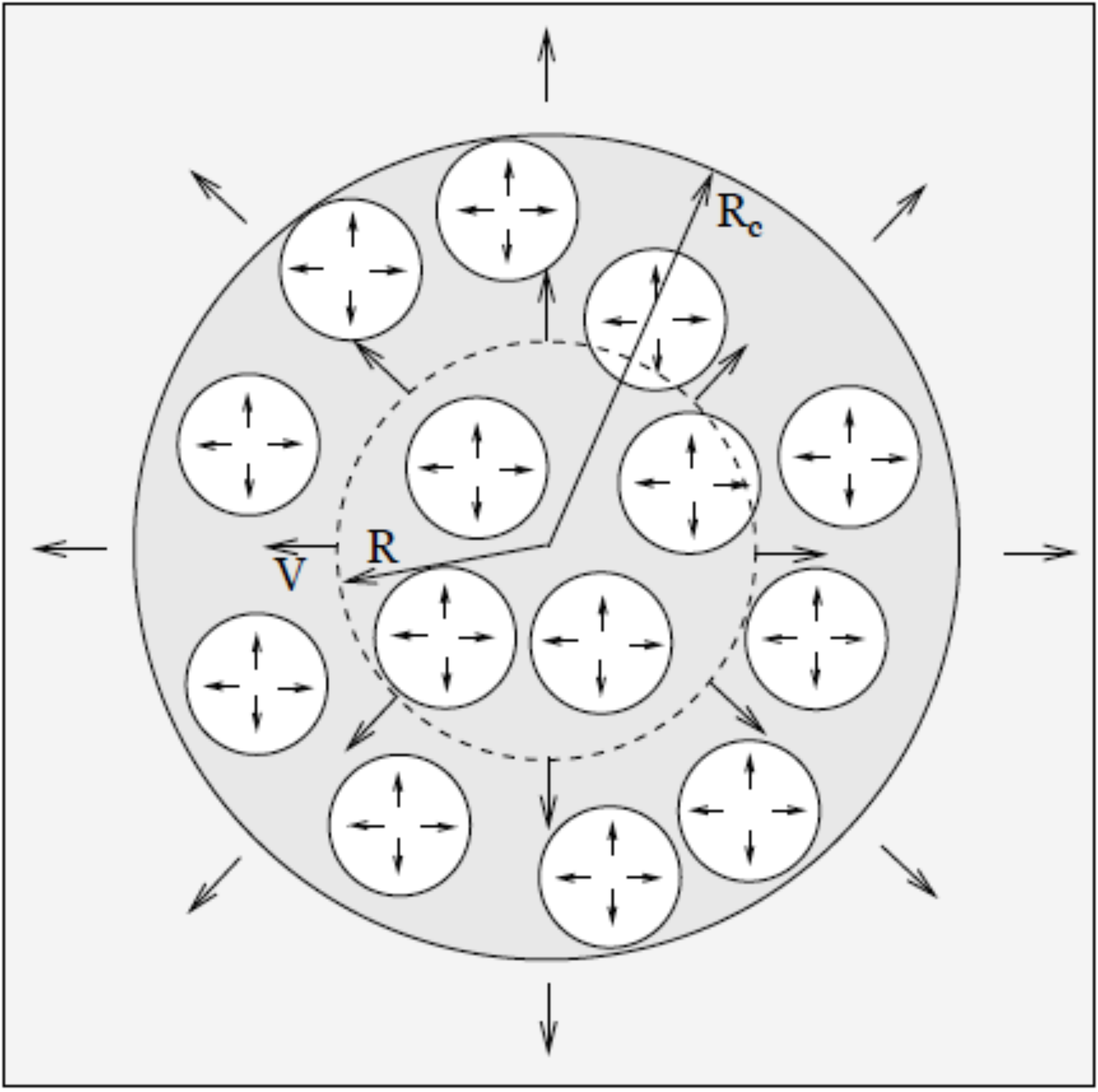
Wind-blown bubbles around massive O and WR stars

Superbubbles from OB associations (Strickland & Stevens 1998) from ROSAT [0.1-2.4 keV] —> Clumped Wind Model (CWM) (Canto 2000)



$$\left(\frac{n_0}{\mathrm{cm}^{-3}}\right) = \frac{2.28 \times 10^{-2}}{A} N \left(\frac{\dot{M}_w}{10^{-5}\, M_\odot\ \mathrm{yr}^{-1}}\right) \times \left(\frac{v_w}{1000\ \mathrm{km\ s}^{-1}}\right)^{-1} \left(\frac{R_c}{\mathrm{pc}}\right)^{-2},$$

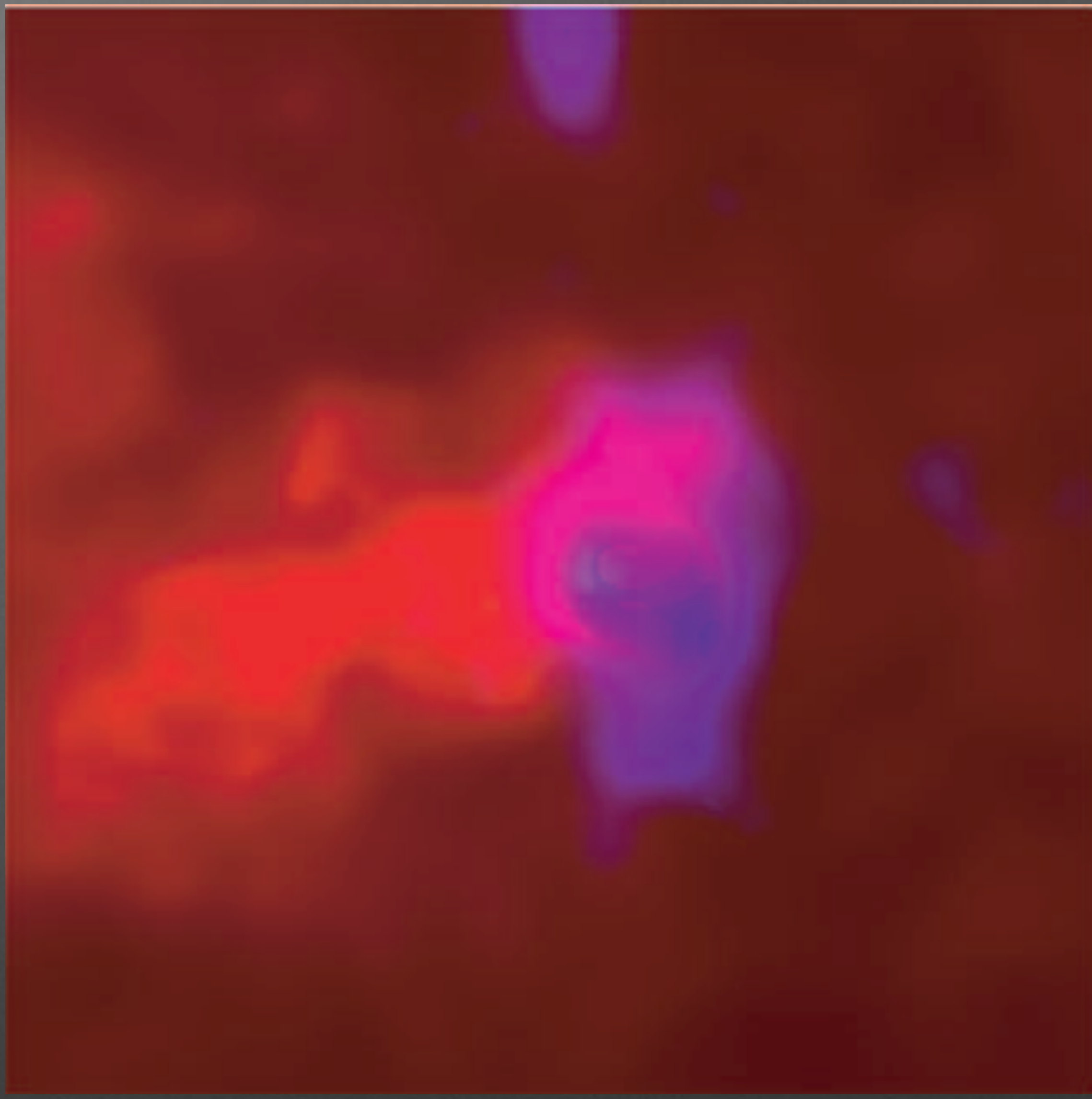
$$\left(\frac{T_0}{\mathrm{K}}\right) = 1.55 \times 10^{7} \left(\frac{V_w}{1000\ \mathrm{km\ s}^{-1}}\right)^{2},$$

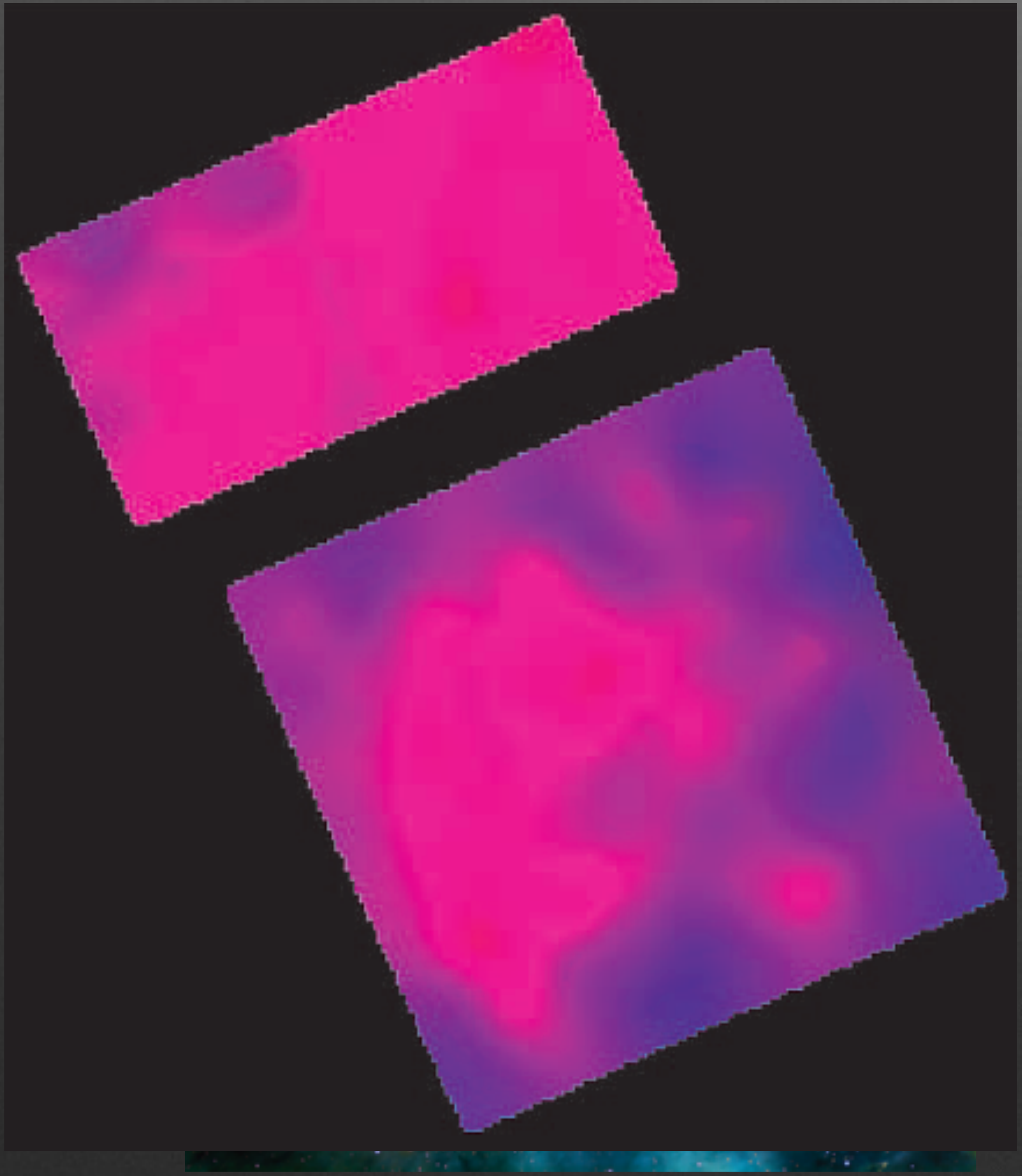


HOWEVER, it is FAINT ! (low surface brightness)

8- Diffuse X-ray emission in SFRs

- Townsley et.al. (2003) first serious (ACIS-I) study reveals 10 MK gas on massive SFRs Omega Nebula (M17) → and Rosette (NGC 2237-2246). ↓





$T_X \sim 1$ to 10 MK
$L_X \sim 6\times10^{32}$ (Rosette)
$L_X \sim 3.4\times10^{33}$ (M17)

8- Diffuse X-ray emission in SFRs

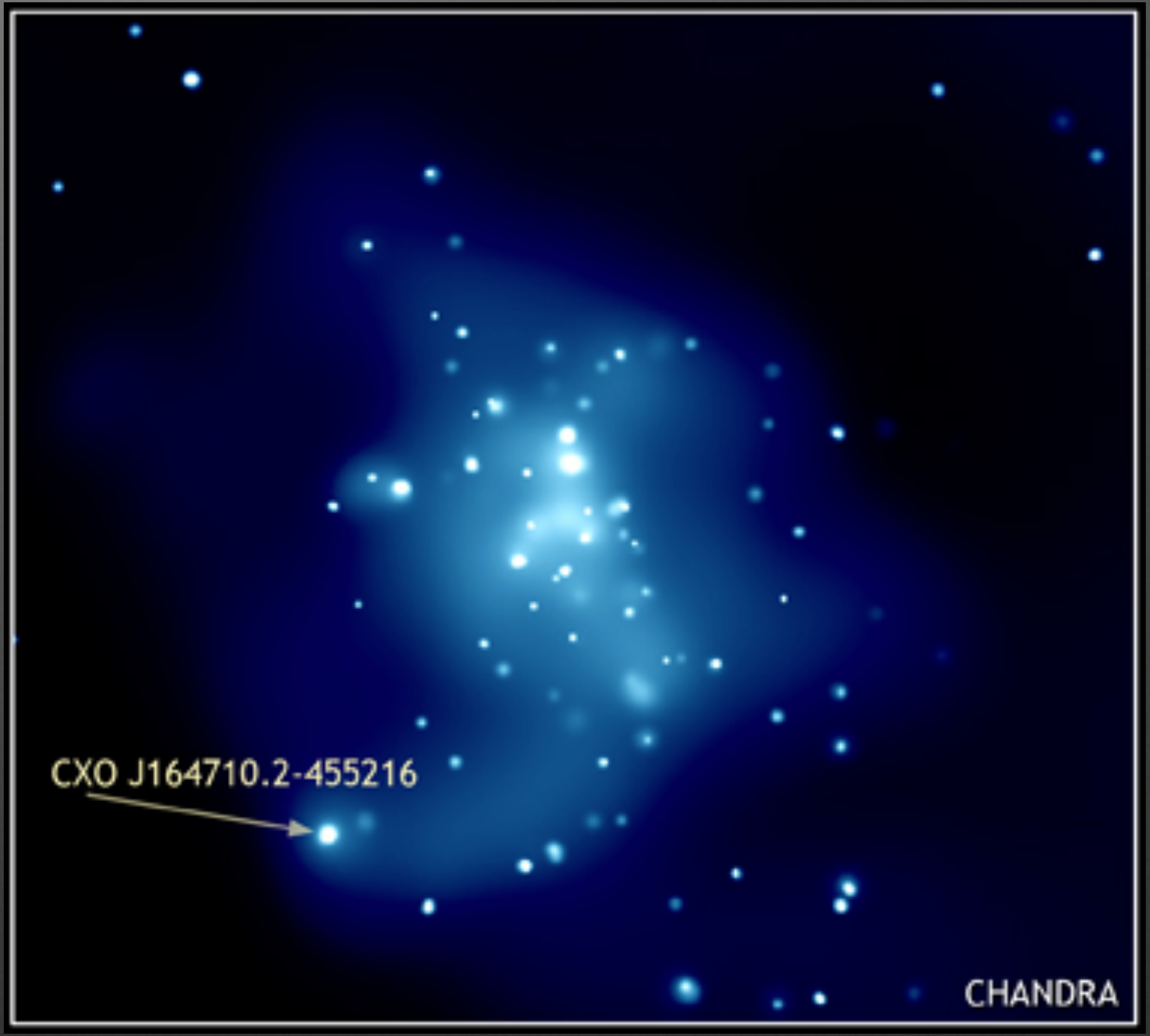
Muno et.al. (2008) detects diffuse X-ray emission at Westerlund 1 Massive SRT

Optical: VRI (MPG/ESO)
X-ray: Chandra (ACIS-S)

CLUSTER
- Distance ~5 kpc
- Age ~ 3 Myrs
- Extent ~ 6 pc

STELLAR CONTENTS
- 25 WR stars
- 1 LBV
- Several red supergiants
- 5 yellow hypergigants
- ~ 80 OB supergiants
- MS early O-type

(Next Chandra Large Project)
PI: Guarcello, M.

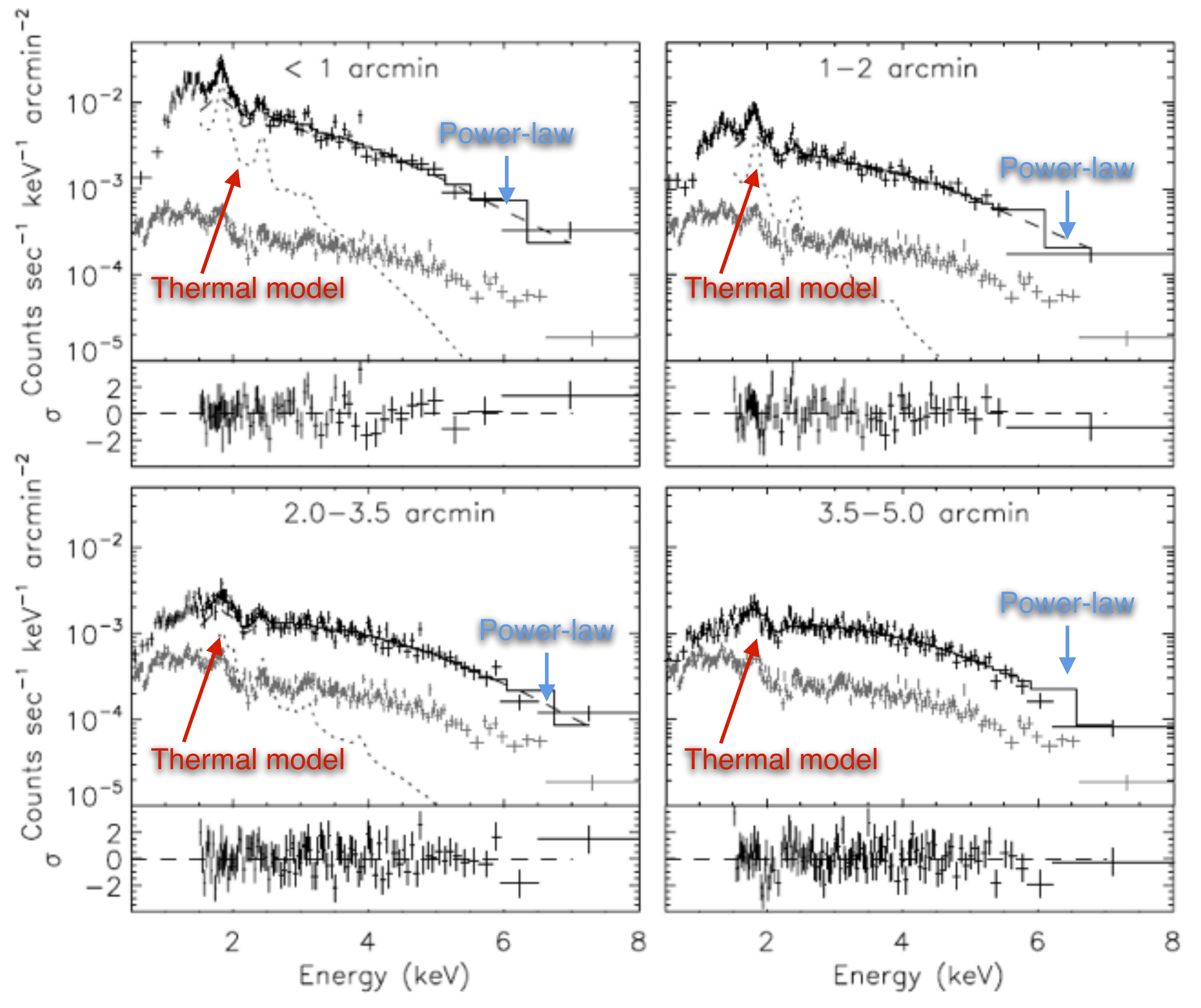


8- Diffuse X-ray emission in SFRs

Muno et.al. (2008) detects diffuse X-ray emission at Westerlund 1 Massive SRT

L_X [2.0 - 8 keV] ~ 3×10^{34} (erg/s) above CWM (Rc < 4 pc), so:
- Unresolved low-mass PMS (~30%)
- No FeK alpha (6.7 keV)
- Abundances ~ 0.4
- O+WR stellar winds
- Heat conduction near the ISM
- kT_X ~ 0.7 keV

Non-thermal emission is not considered in CWM:
- non thermal particles (SNR, CW) (Eichler & Usov, 1993)
- If produced —> IC >> Synch (Rybick et.al 1979)

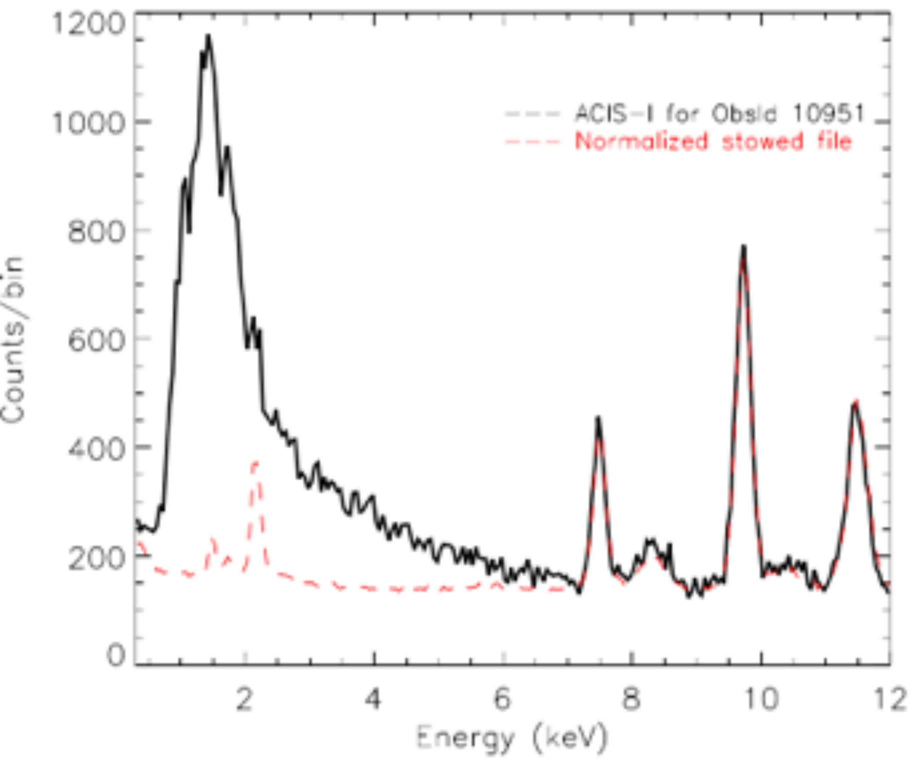


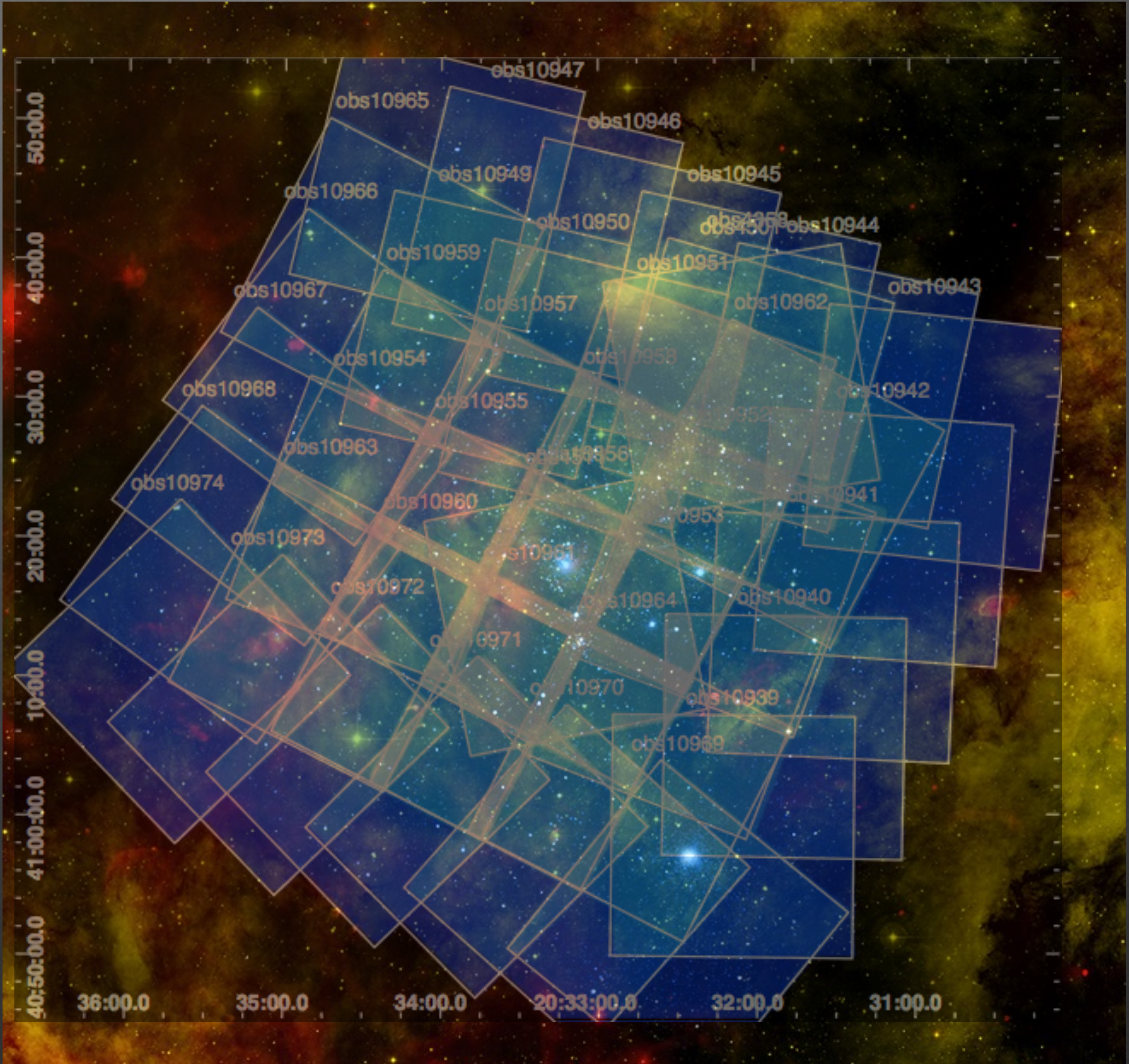
More sophisticated analysis is needed for reliable results !!!

8- Diffuse X-ray emission in SFRs

8.1- Cygnus OB2 large project

- PI (J. Drake)
- 36+4 Chandra ACIS-I (Wright 2012)
- source PSF 99% excluded (ACIS-Extract, Broos et.al. 2012)
- detailed bkg analysis
- Energy range [0.5-7.0] keV

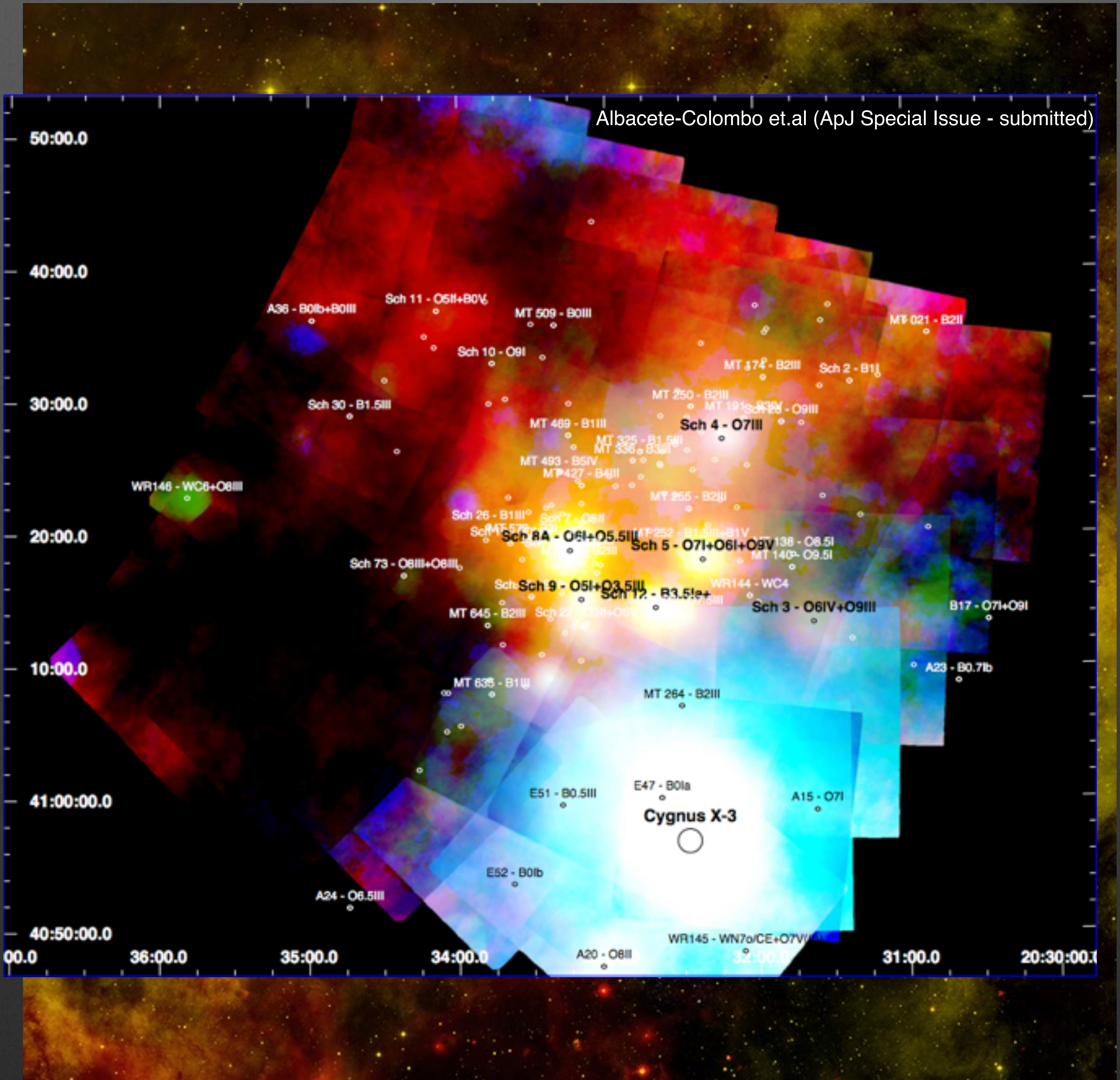




Images courtesy Dr Nick Wright

8- Diffuse X-ray emission in SFRs

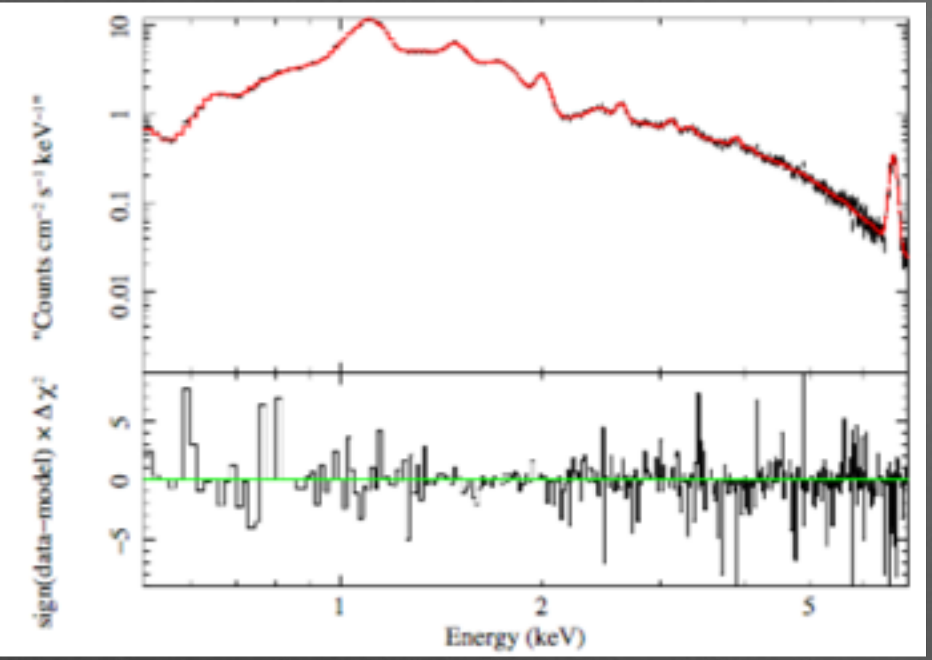
8.1- Cygnus OB2 large project



Albacete-Colombo et.al (ApJ Special Issue - submitted)

8- Diffuse X-ray emission in SFRs

8.1- Cygnus OB2 large project

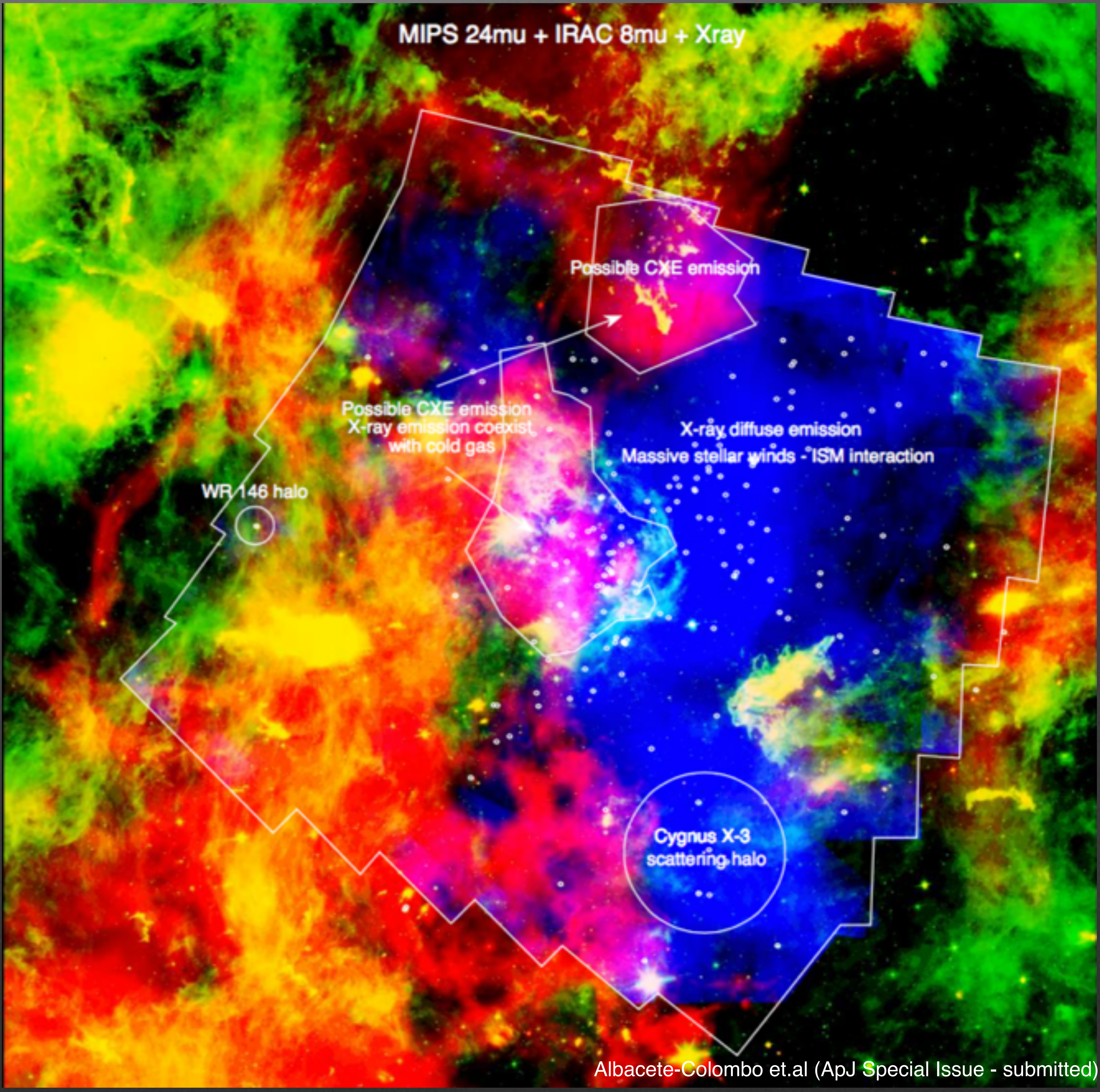


$kT_X \sim 0.8\text{-}1.1$ keV
$f_X \sim 10^{-15}$ erg/cm²/s
$L_X \sim 2.3 \times 10^{34}$

Emission IC (<0.2 pc) >> Sync (>5 pc)
—> Non thermal emission is absent

This kind of sophisticated studies are the only way to understand diffuse X-ray emission in SFRs (Galactic).

Next X-ray missions ATHENA are crucial for further extragalactic studies.

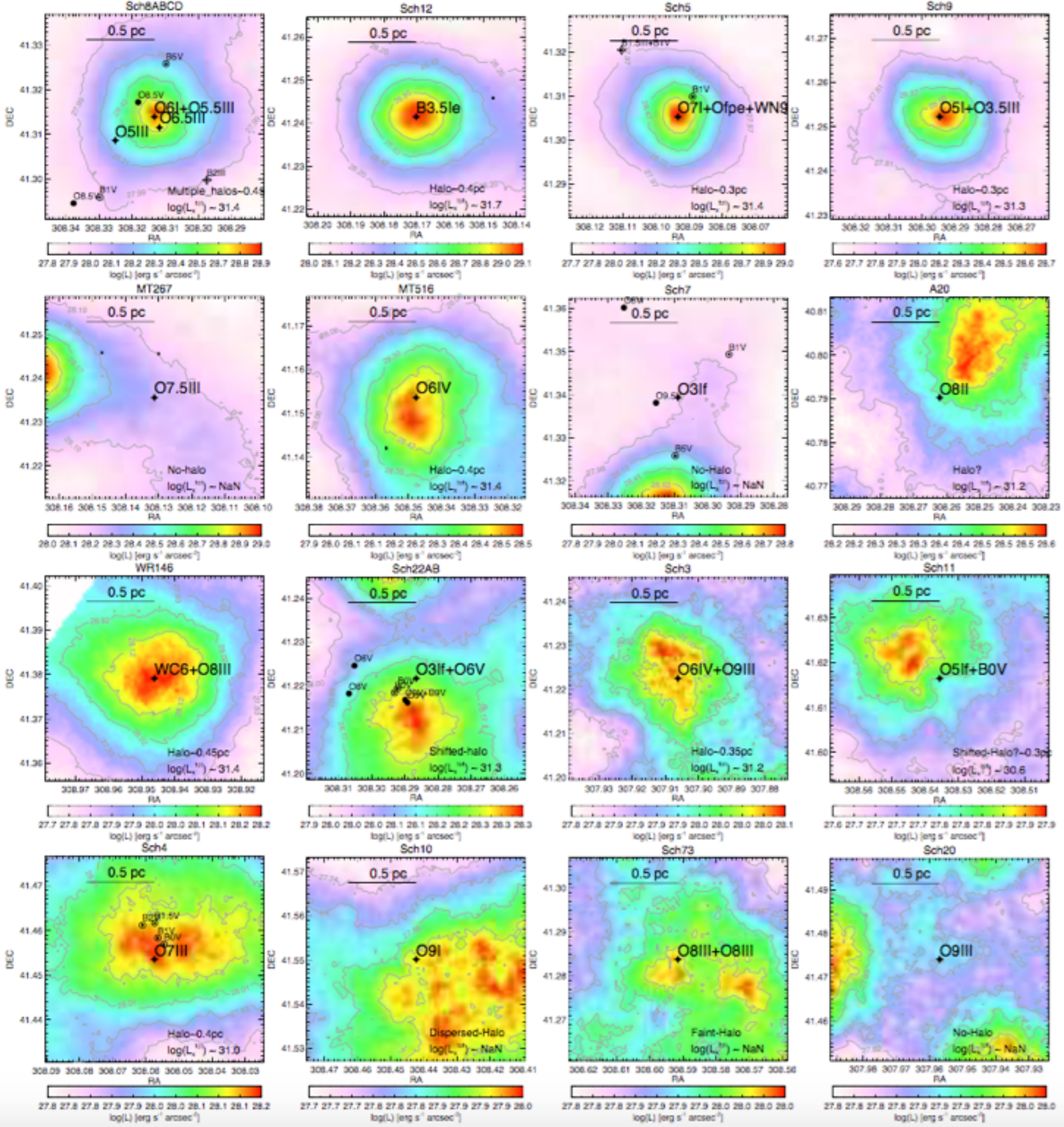

MIPS 24mu + IRAC 8mu + Xray

Albacete-Colombo et.al (ApJ Special Issue - submitted)

8- Diffuse X-ray emission in SFRs

8.2- X-ray haloes around massive stars ?

X-ray flux is at the limit of delectability !!



http://www.the-athena-x-ray-observatory.eu

The Athena X-ray Observatory: Community Support Portal

The Hot and Energetic Universe

Athena is a mission proposed to address the Science Theme "The Hot and Energetic Universe", which has been selected by ESA in its Cosmic Vision program. In particular, it undertakes three key scientific objectives:

1) Determine how and when large-scale hot gas structures formed in the Universe and track their evolution from the formation epoch to the present day.

2) Perform a complete census of black hole growth in the Universe, determine the physical processes responsible for that growth and its influence on larger scales, and trace these and other energetic and transient phenomena to the earliest cosmic epochs.

3) Provide a unique contribution to astrophysics in the 2030s by exploring high energy phenomena in all astrophysical contexts, including those yet to be discovered.

From the unique perspective endowed to Athena by its unprecedented spectroscopic and imaging capabilities in the 0.5-12keV range, this mission will lead the quest into solving these questions from its launch in 2028.

9- SUMMARY

Thank you !!!

If interested, further questions, discussions, and suggestions at:
albacete.facundo@conicet.gov.ar

- X-rays studies of PMS are crucial to understand ISM properties and star formation all over de mass ranges.

- X-rays emission is expected to be dominant for SFR with ages less than 3 millions of years.

- With different mechanisms, low-mass (magnetic-dynamo) or high-mass (shock winds, magnetic confinement, colliding winds), X-ray emission leads into a vast knowledge of the astrophysical processes occurring in the atmospheres, but also in the interior, of the stars all over the mass range !!!.

- X-ray can penetrate dense gas and dust structures

—> Unveiling a huge fraction of stars, missed with optical or near IR observations.
—> X-ray observations are “mandatory” for serious optical and near-IR studies of SFRs.

- L_x of PMSs are larger (10-1000 times) respect to L_x of MS stars

—> unbiased true stellar membership.
—> they are scaled-up scenarios of flare activity of MS.

- Rigorous data-analysis is needed for reliable diffuse X-ray emission studies

—> hot gas co-exist with cold gas, so changing our understanding about condition in which stars forms.
—> We are at the limits the capabilities of the last major mission XMM-Newton, but specially for Chandra.

- Next mission ATHENA (~2028) would be the starting point for these kind of studies out of our Galaxy !!!