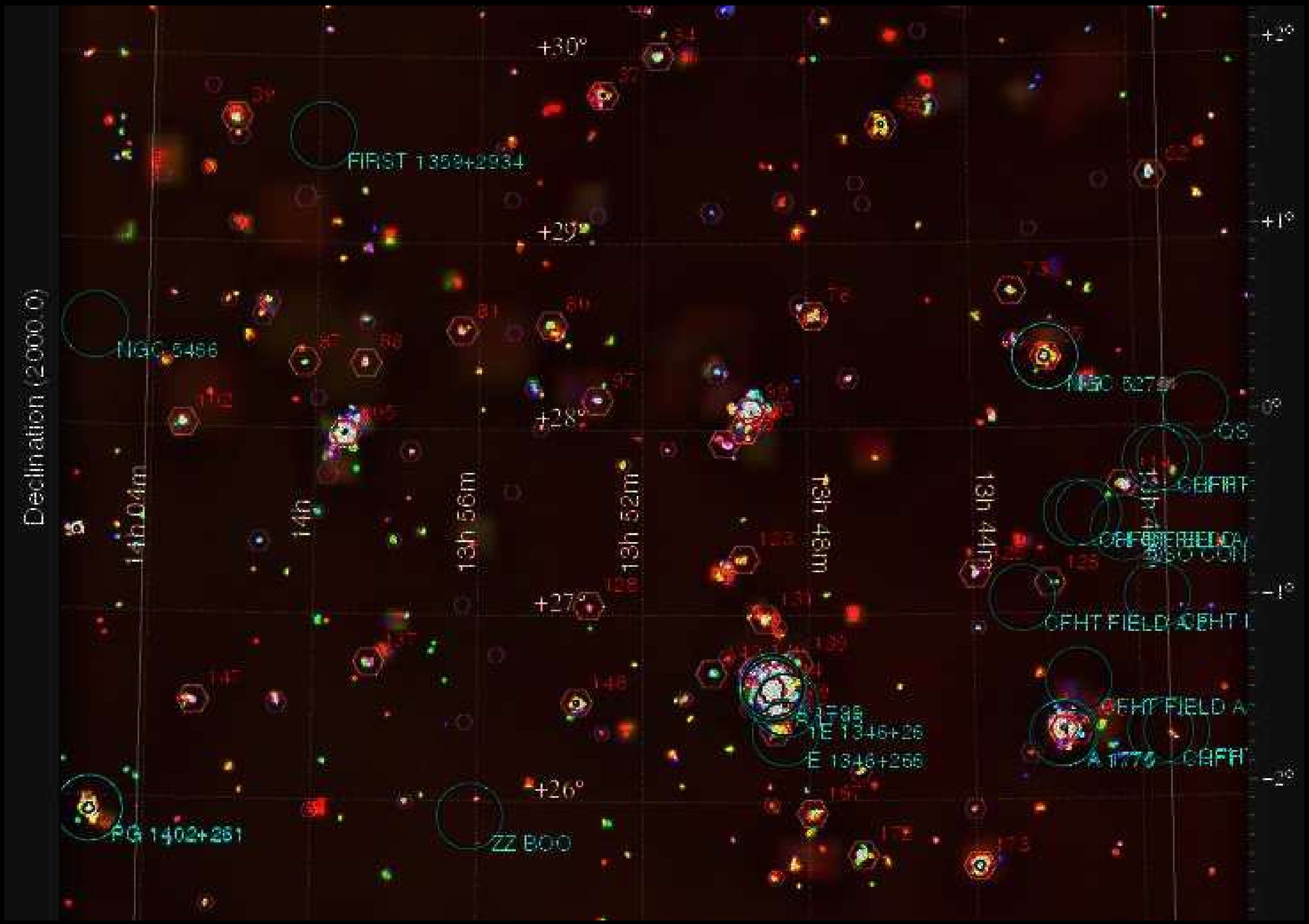
X-rays from massive stars and clusters



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1st eROSITA International Conference 2011

Massive Stars and Stellar Winds

Initial mass $M_* > 8M_\odot$

Fast evolution (~Myr) →
trace star formation

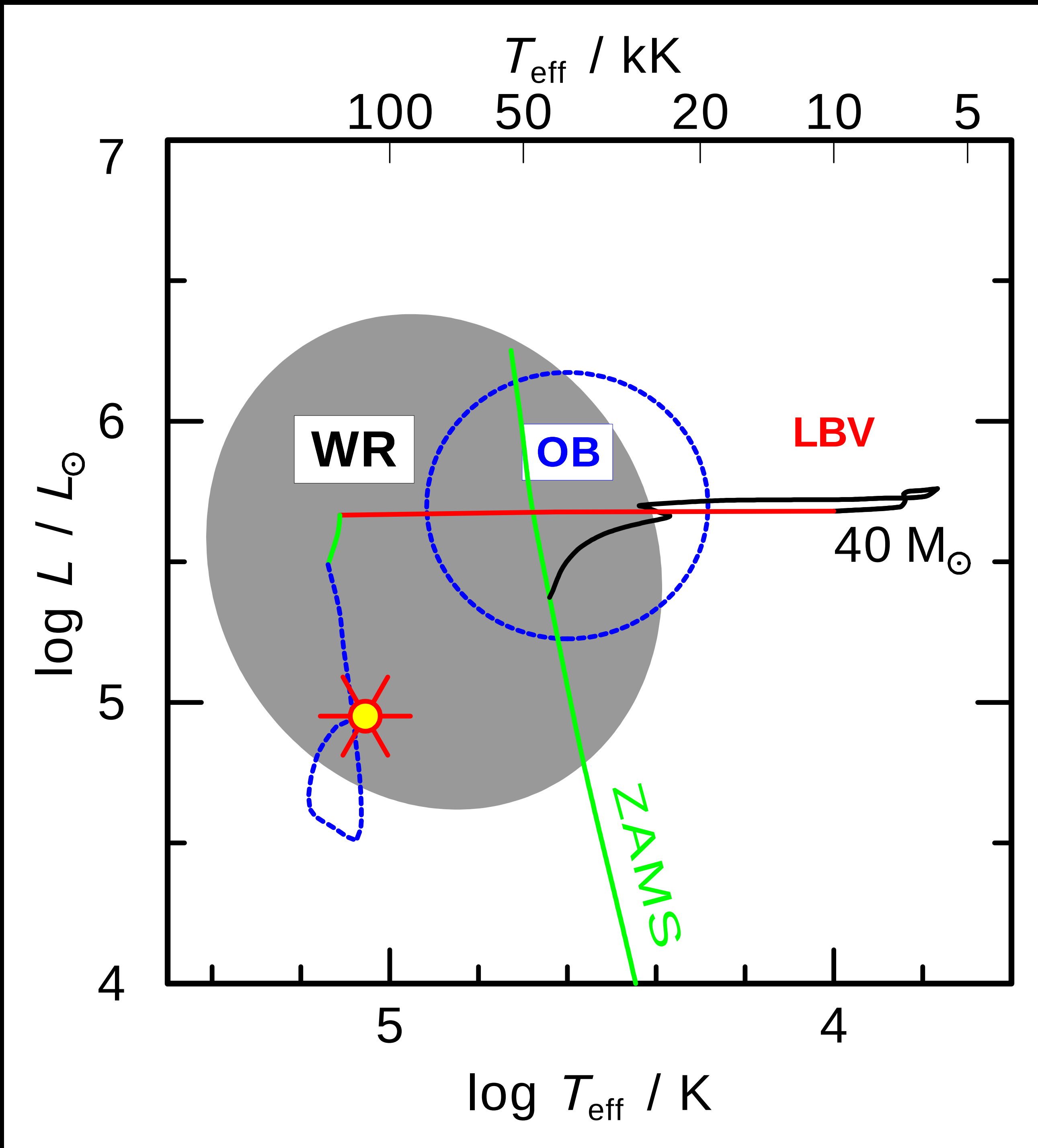
Hot. $T_{\text{eff}} > 10\,000$ K →
high surface brightness

Photon momentum →
acceleration of matter

Radiative acceleration > than gravitation →
supersonic **STELLAR WIND**

Spitzer IRAC image of ζ Oph

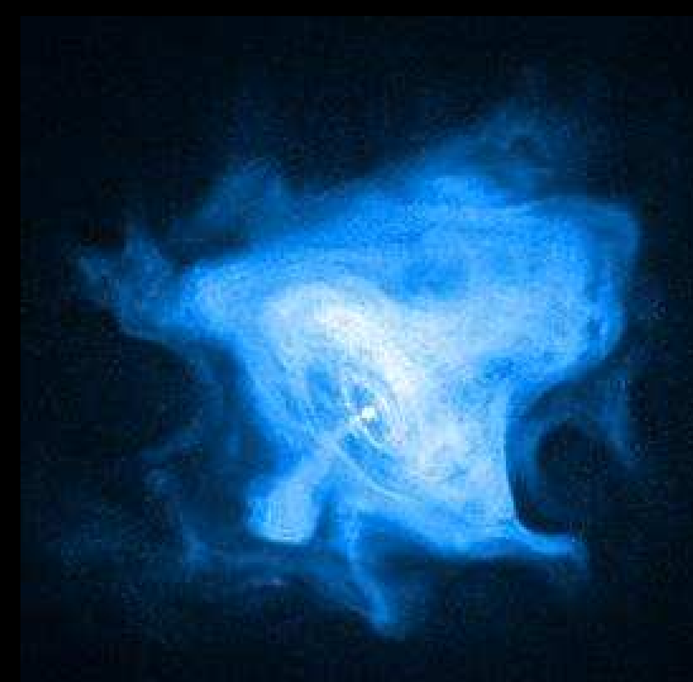
The evolution of (very) massive stars



Mass removal by wind drives the evolution

- OB → (short LBV) → WR
- Winds are getting dense and more enriched
- Wolf-Rayet (WR)

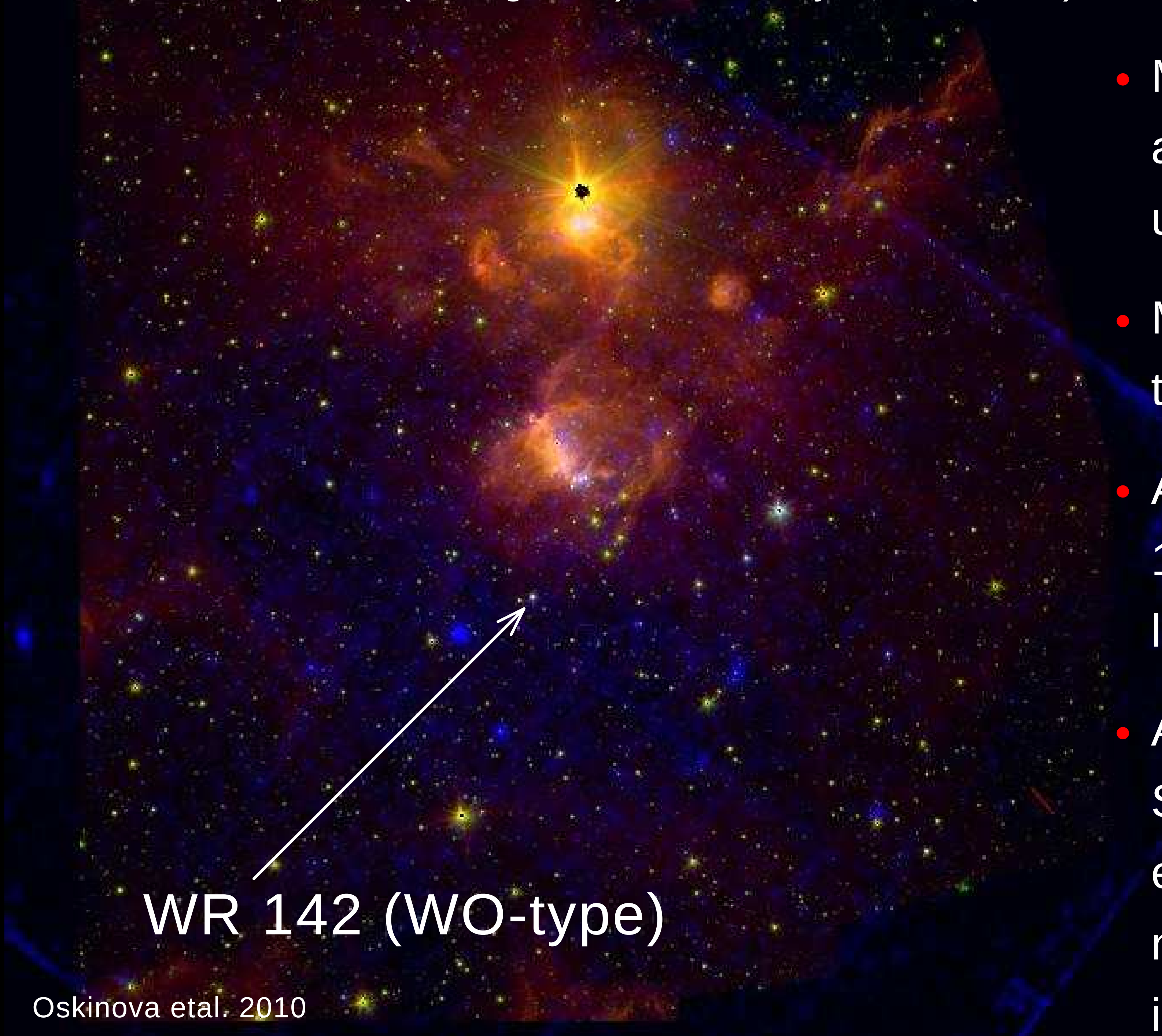
WN → WC → WO → SN



Credit: NASA/CXC/SAO/F.Seward et al

Massive star feedback in the ISM and IGM cannot be neglected

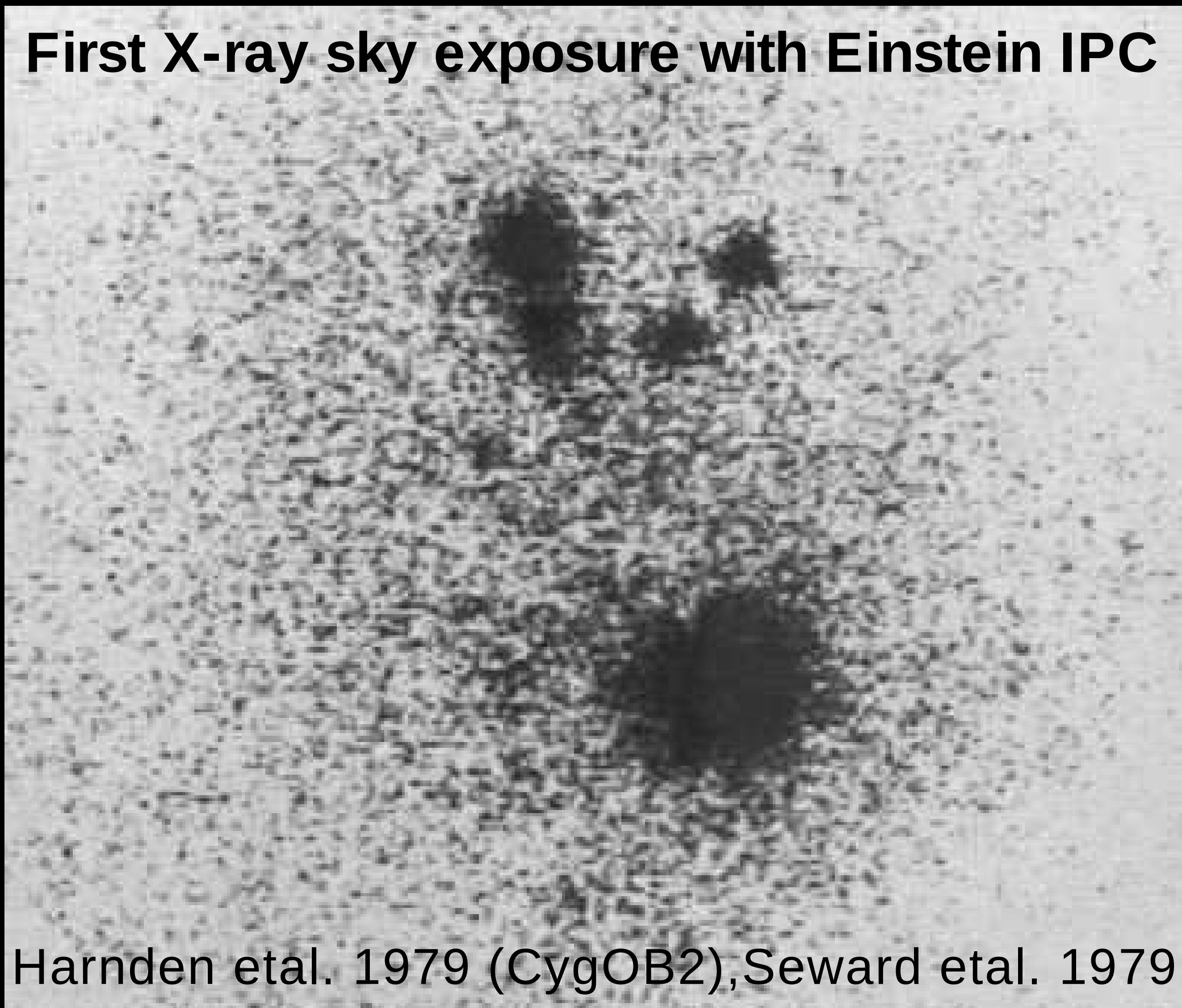
Combined Spitzer (red+green) and X-ray EPIC (blue) image of the SFR ON 2



Oskinova etal. 2010

- Mechanic energy of a massive star wind: up to 10^{38} erg/s
- Massive star life-time: few Myr
- A star deposits up to 10^{53} erg during its life time!
- Accounting only for SNe in galactic energy budget: missing 50% of income

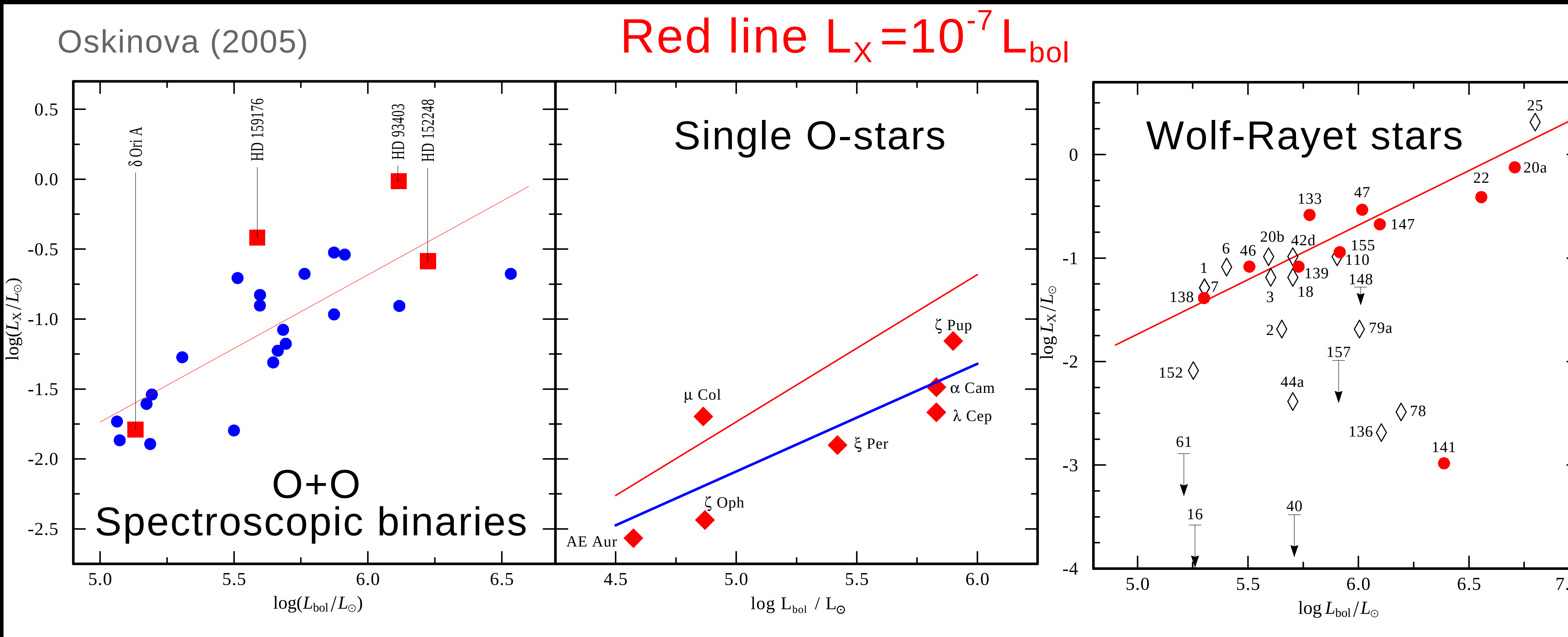
Massive stars emit X-rays (Einstein observatory 1978)



- X-rays were predicted by Hoare (1975), Cassinelly & Olson (1978)
- Seminal study Pallavicini etal. (1981): O and early B stars → Correlation $L_X = 10^{-7} L_{bol}$ but no correlation with $v \sin i$
- The spectra are soft, peculiar stars have harder spectra.

- Important confirmation: RASS (Berghoefer etal. 1997)
- Chandra and XMM-Newton observations (e.g. Moffat etal 2002, Sana etal 2006, Wolk etal. 2008)

Examples of $L_X = 10^{-7} L_{bol}$ correlation



- The correlation is approximate
- It holds for O and early B stars, single and binaries
- Wolf-Rayet stars do not follow this correlation
- Stars later than B1-spectral type do not follow this correlation

WHY massive stars emit X-rays ?

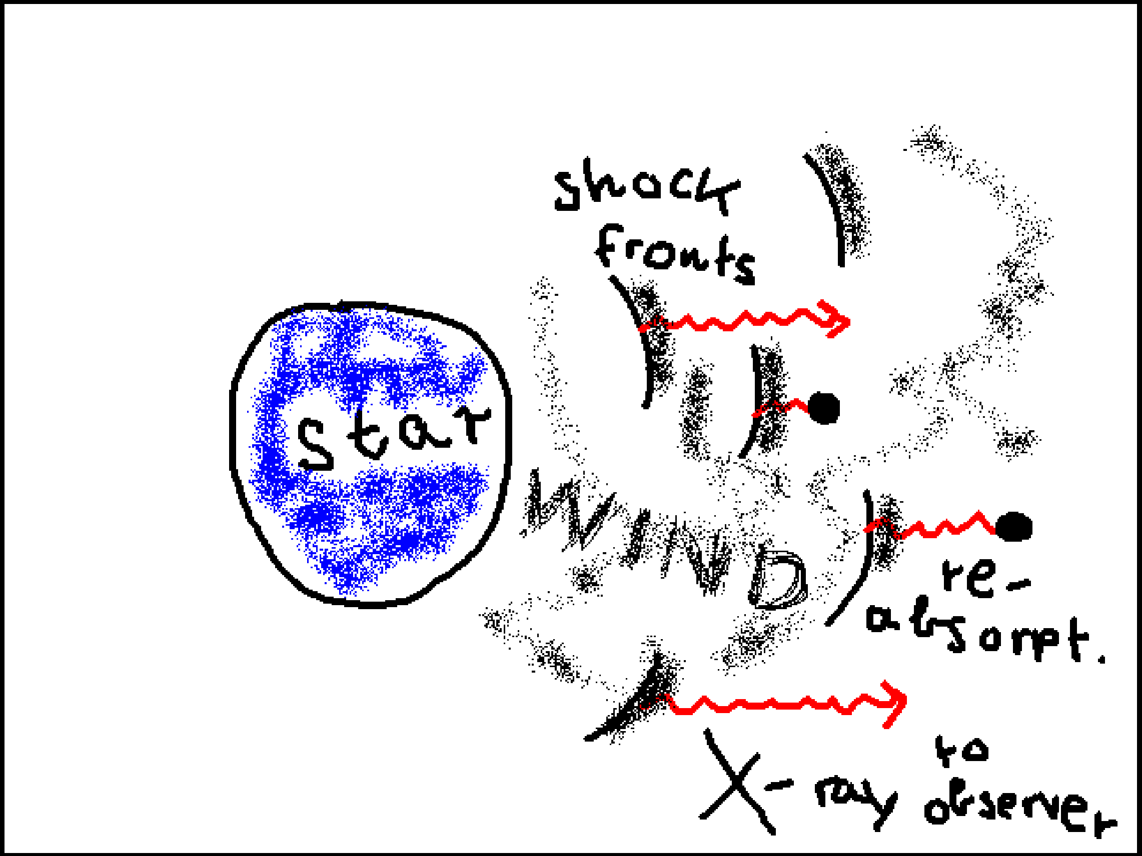
Two leading theories

- Shocked stellar winds
- Hot coronae associated with surface magnetic field

Succesful model shall explain the $L_X = 10^{-7} L_{bol}$ correlation

Radiatively driven stellar winds are intrinsically unstable

Lucy & Solomon (1970), Radiative hydrodinamic X-ray: Feldmeier etal (1997)



Shocks

Heating

X-Rays

Shocks also result from:

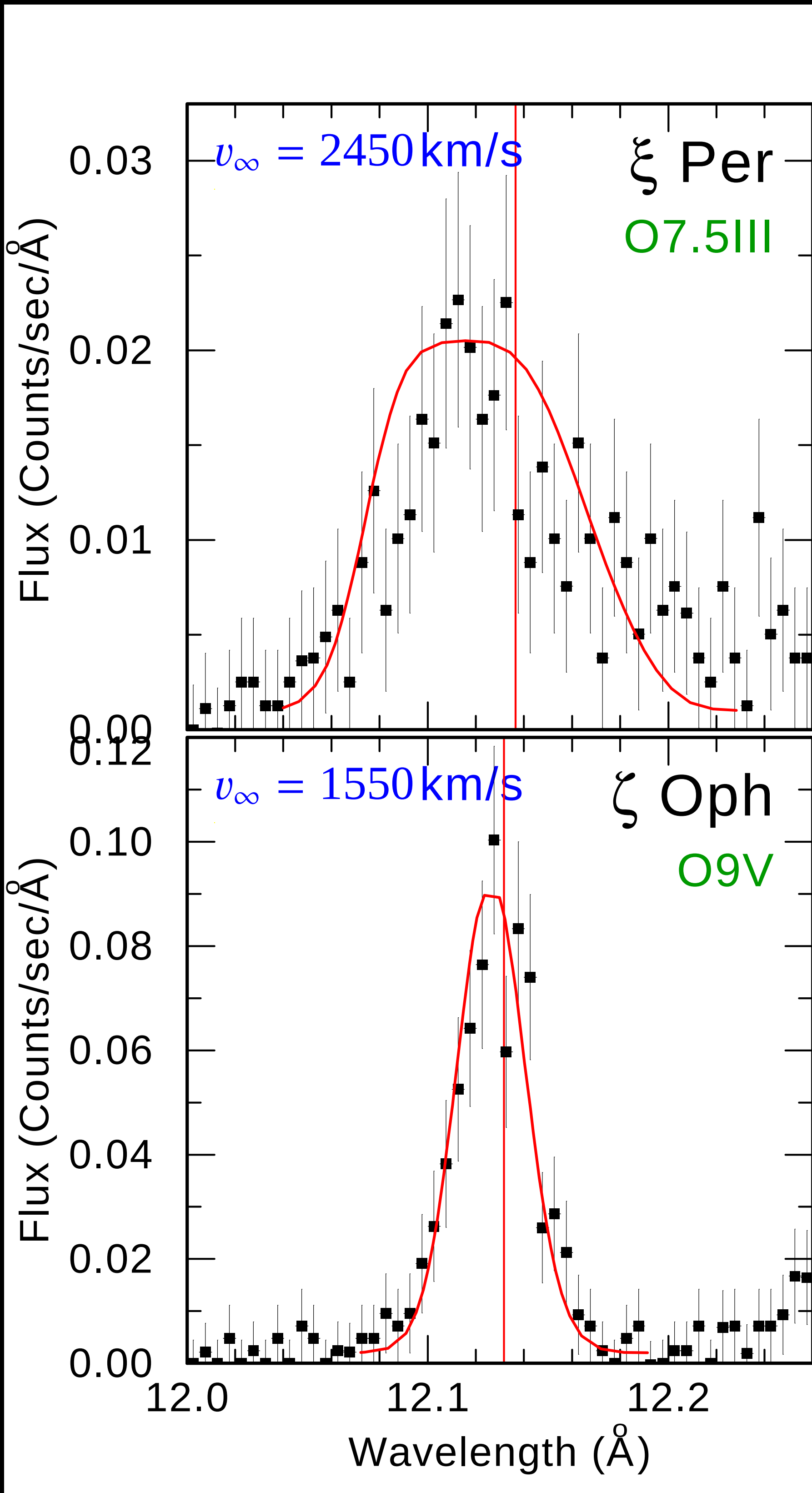
- **Collision of streams in magnetically confined wind**
- **Collision of winds in binaries**

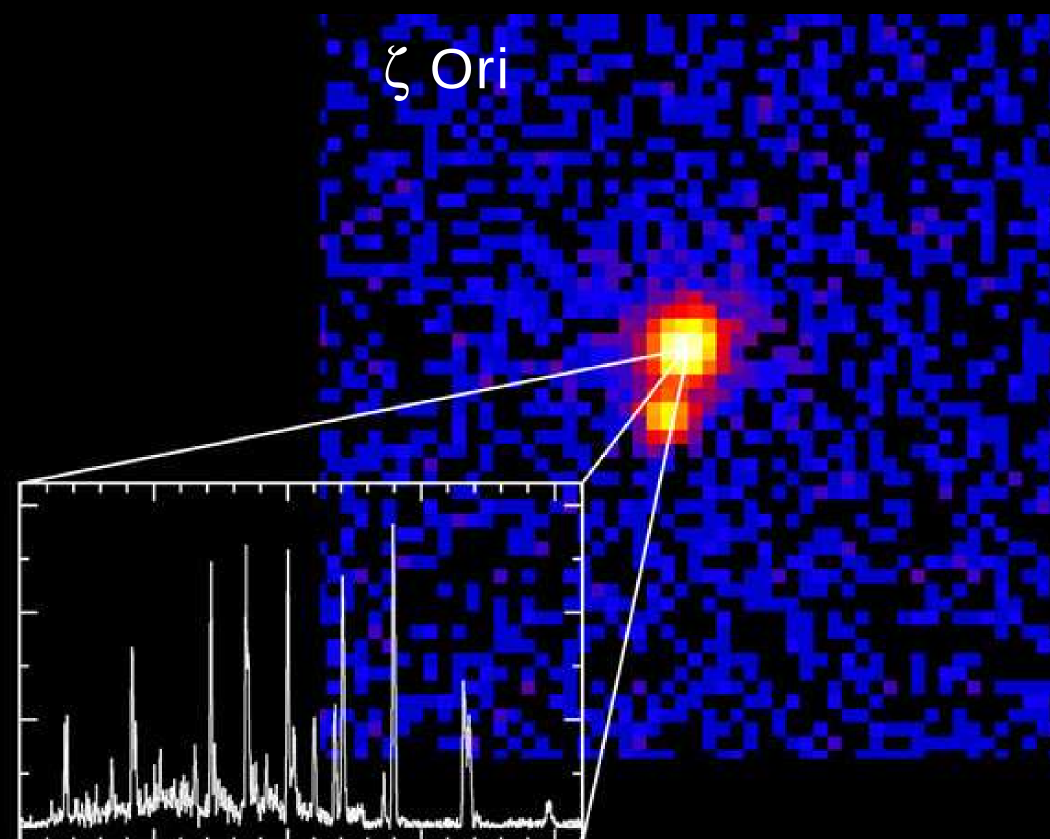
Wind shock model explains:

broad and blueshifted X-ray emission lines

(Cassinelli etal 2001, Kramer etal 2003, Oskinova etal 2006)

The model does not predict the correlation between L_X and L_{bol}

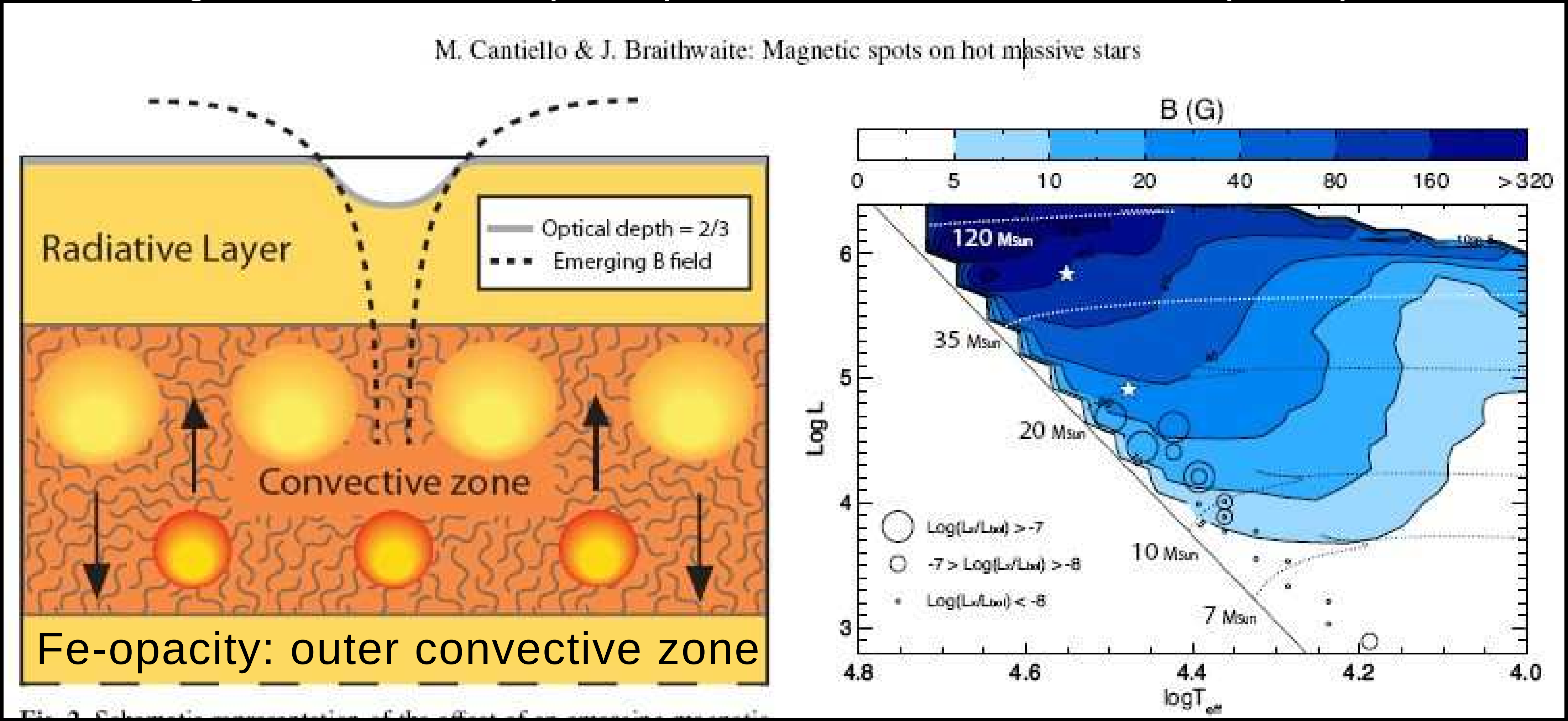




NASA/EIT/W.Waldron, J.Cassinelli

Surface magnetic field

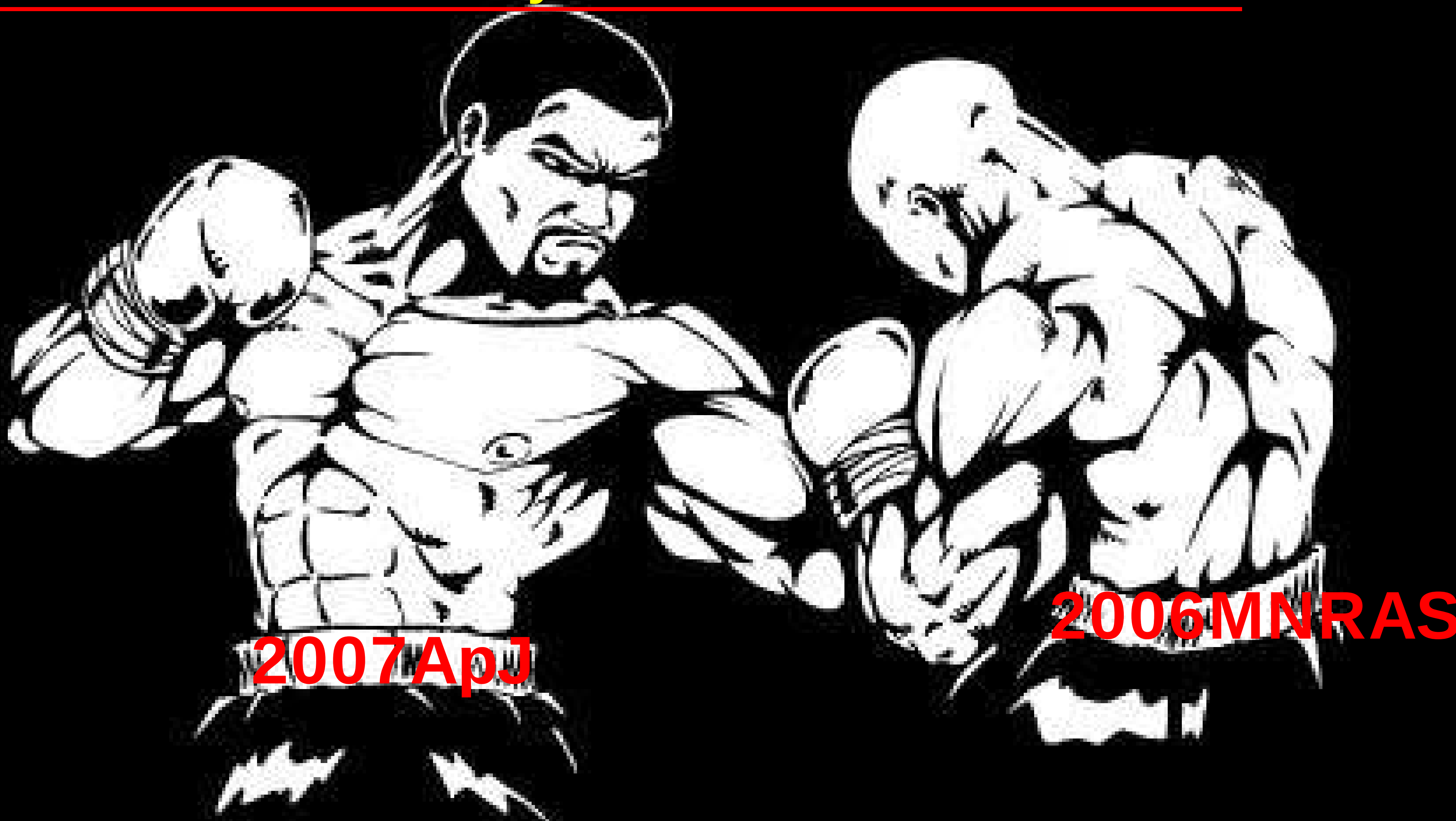
MacGregor & Cassinelli (2005), Cantiello & Braithwaite (2011)



The model:

- Explains why the hottest X-ray plasma is close to the photosphere
- It predicts the dependence of **B**-field strength on $\mathbf{L_{bol}}$
- It may explain $\mathbf{L_X = 10^{-7} L_{bol}}$

Two rival models of X-ray emission in massive stars

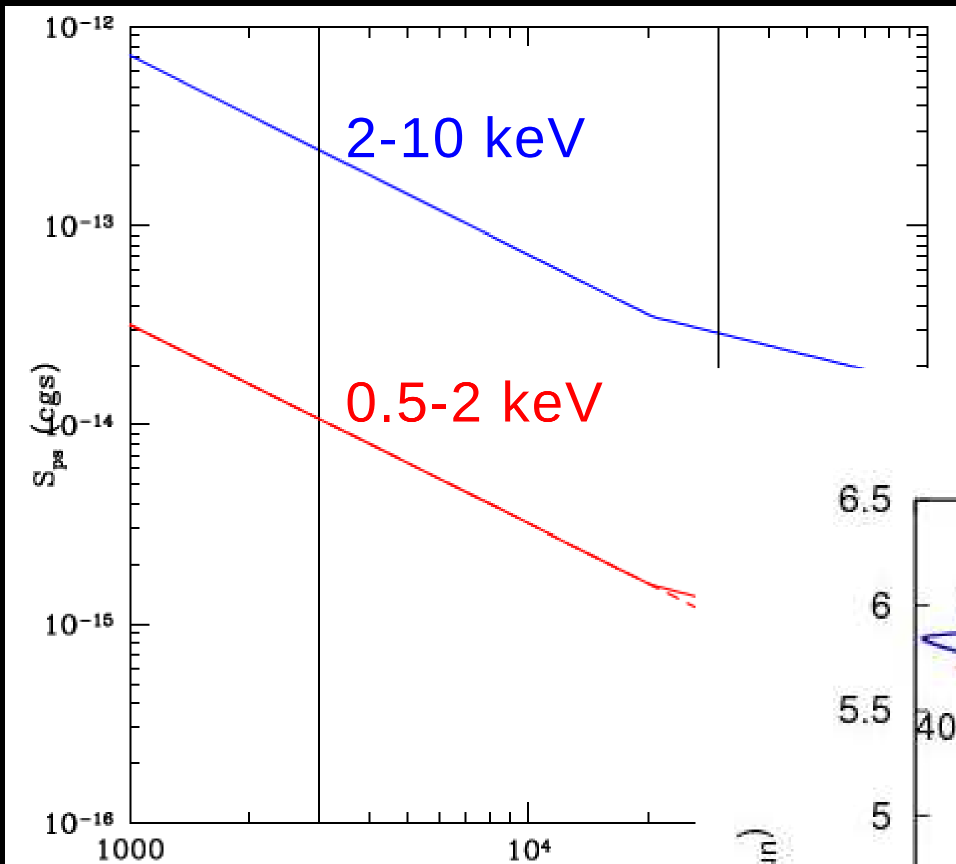


New data are needed to decide among the models:

- High-resolution spectra (XMM-Newton and Chandra)
- Comprehensive sample of stars across the HRD (**eROSITA**)

eROSITA and the evolution of massive stars

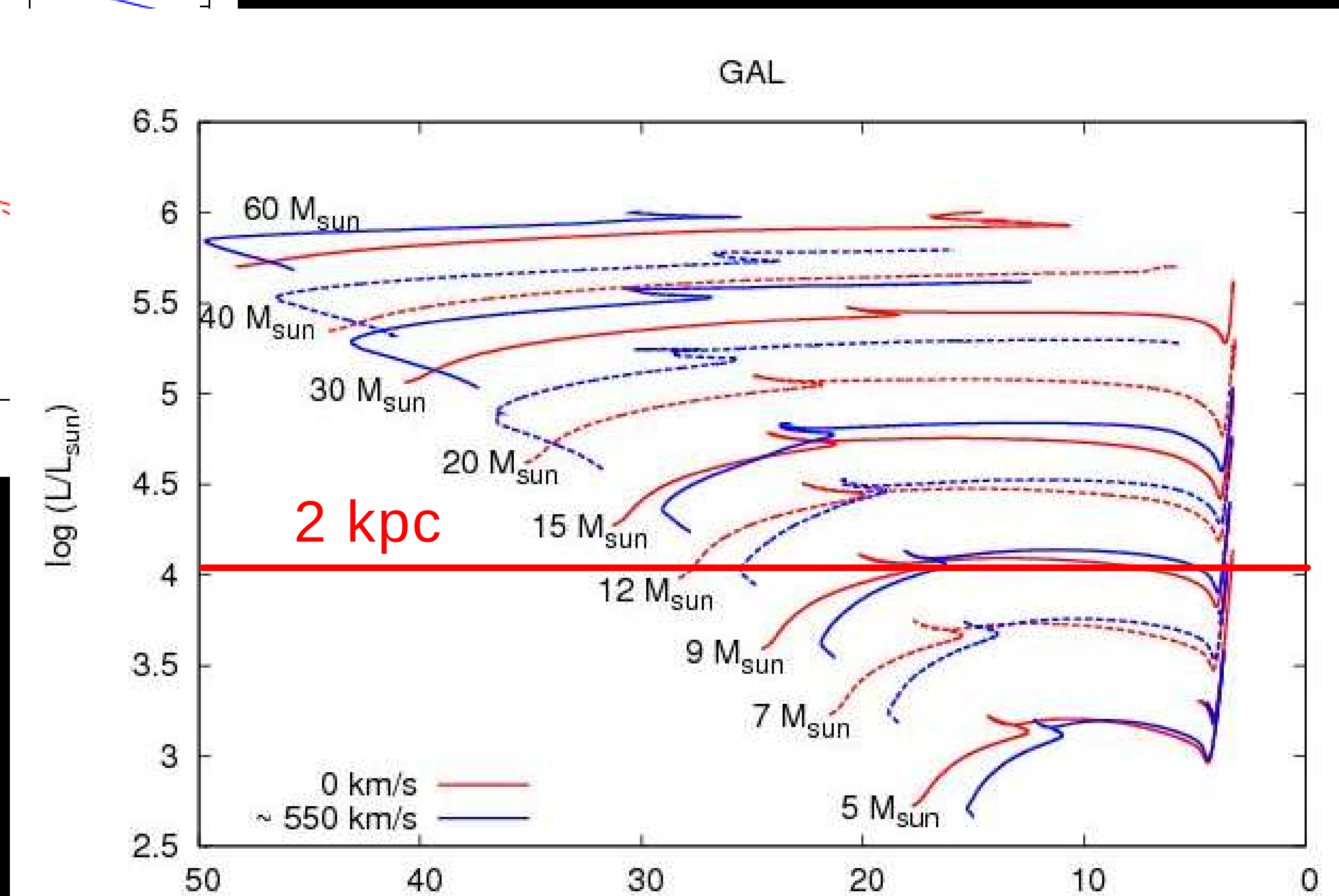
5σ point-source sensitivity vs exp.time



Predehl etal. (2010)

Complete sample within 2 kpc

HRD of massive stars



Brott etal. (2011)

eROSITA survey

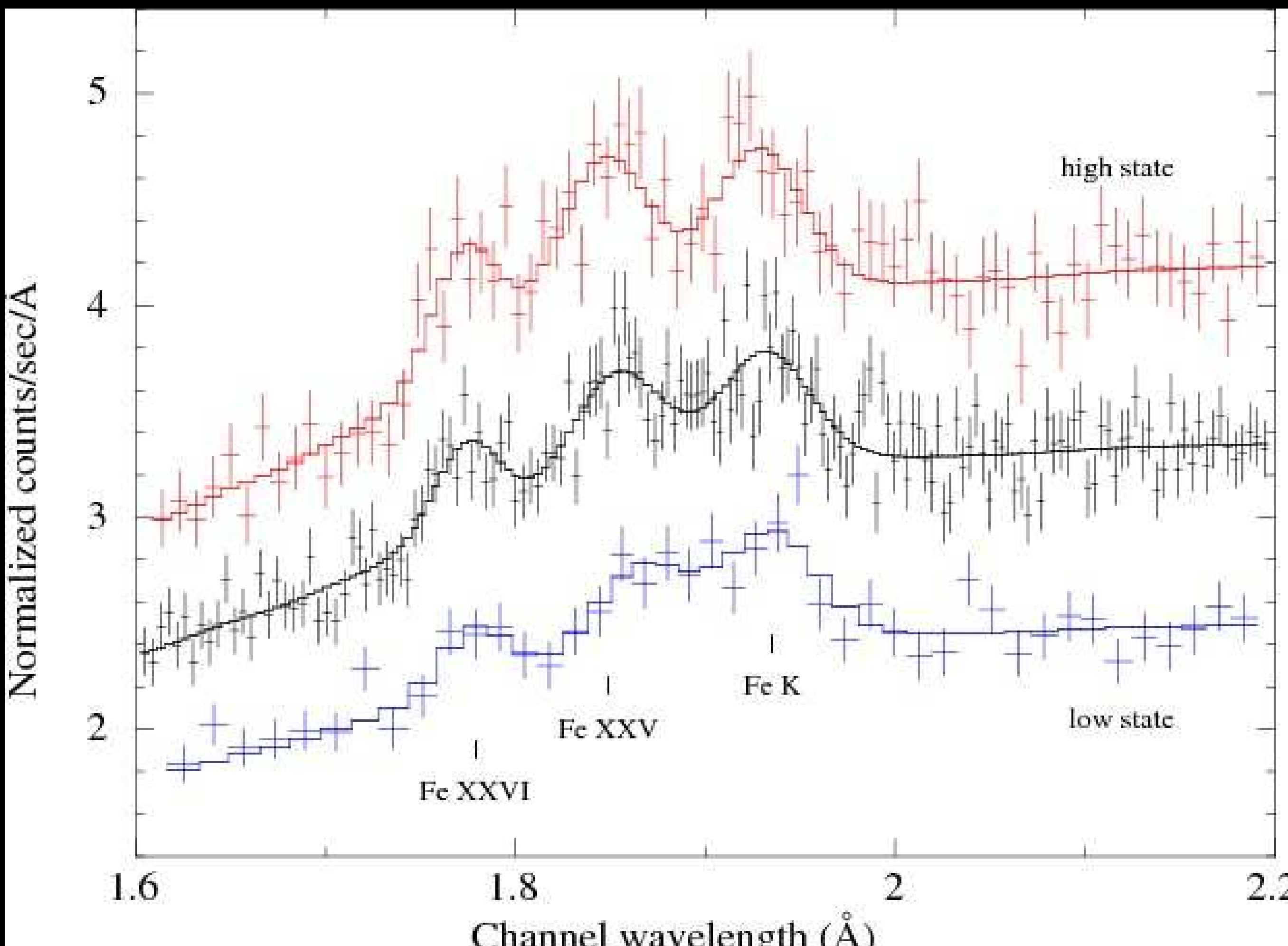
10^{-14} erg s^{-1} cm^{-2}

4 10^{-12} erg s^{-1} cm^{-2}

Look for the surprises in the hard band

eROSITA survey not only 2 dex deeper than RASS.
All-sky survey in hard X-ray band

Variability in Fe complex γ Cas



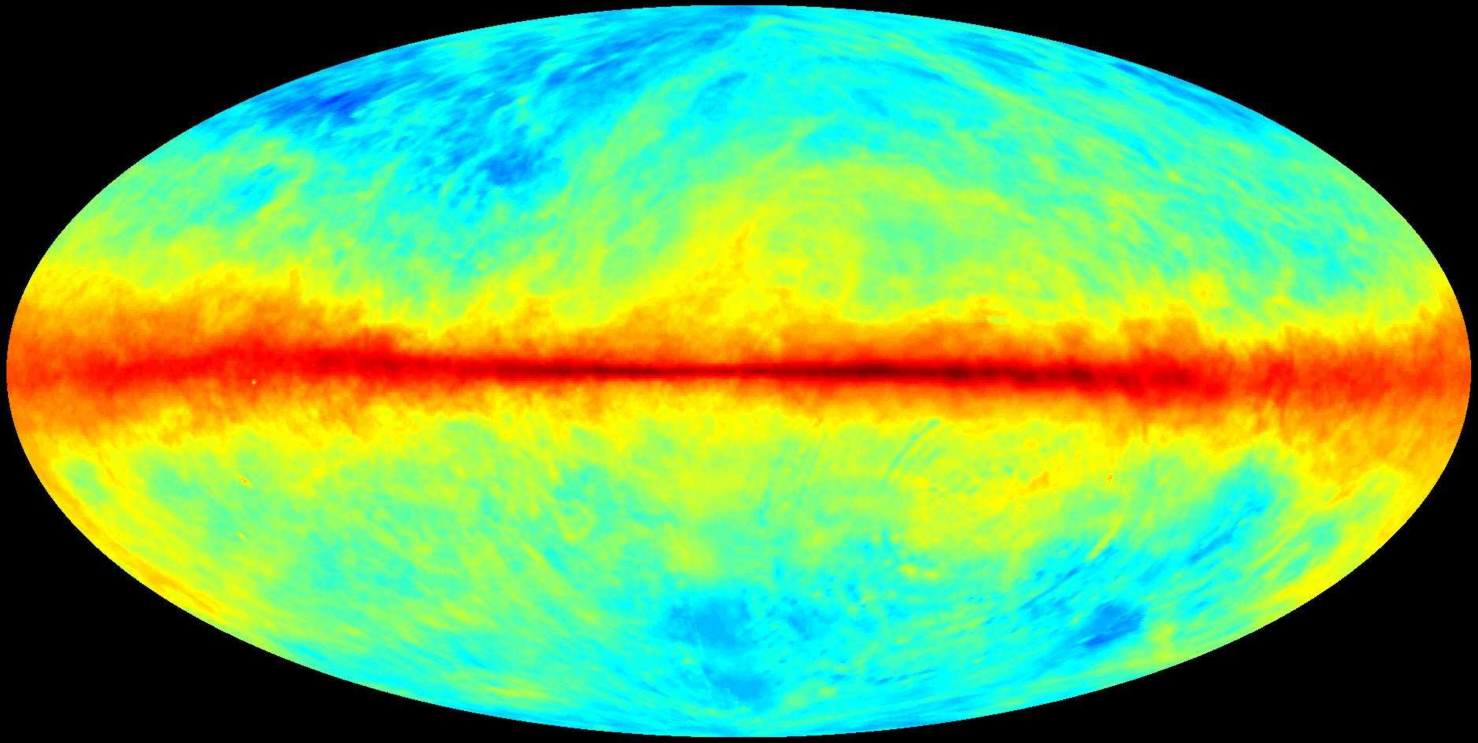
Lopes de Oliveira etal (2010)

- Magnetic stars and colliding wind binaries
- Some massive stars are hard in X-rays, but physical mechanisms are not known e.g:
  - γ Cas type objects
  - WR46, WR48a
  - τ Sco analogs
  - θ^2 Ori A stars
  - ...

Galactic plane absorption

Massive stars concentrate in galactic plane

Leiden-Dwingeloo 21 cm at δ>-30; Dickey-Lockman 21 cm at δ>-30



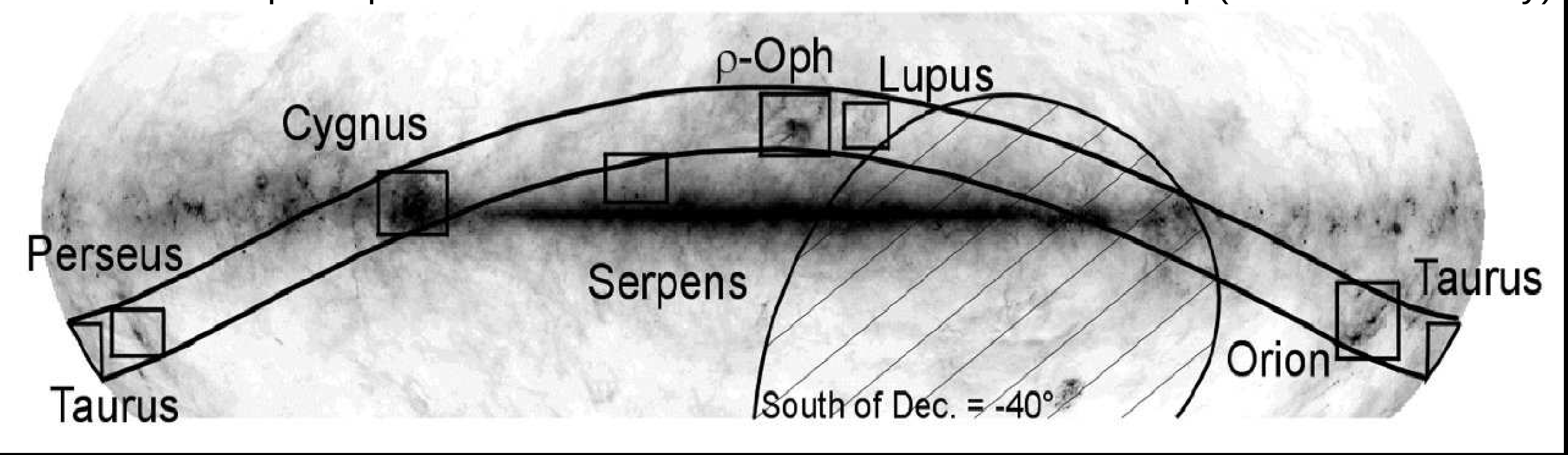
Even in the most obscured regions, eROSITA will reach F_X=6 10^{-13} erg s^{-1} cm^{-2}. Sensitive to detect 'normal' massive star within 1.5 kpc.

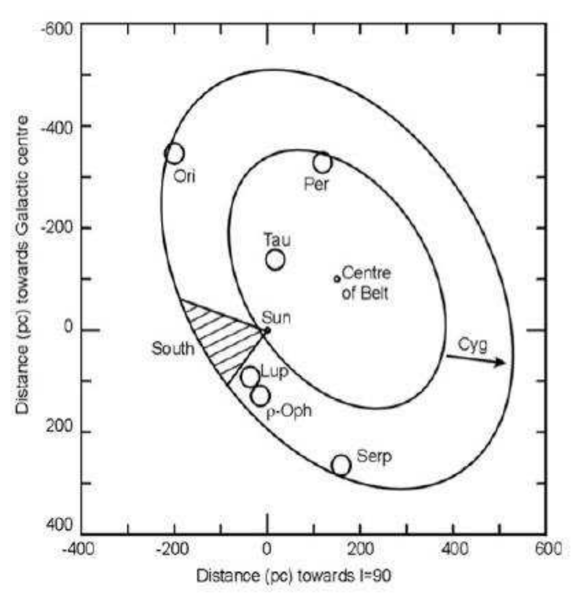
Important: X-ray spectra and hardness ratios **(Poster G. Rauw)**

Local Star Formation: Gould's Belt

- Most star formation within 0.5 kpc lies in **Gould's Belt.**
- Ring centred on a point 200 pc from the Sun and tilted at 20 degrees to the Galactic Plane.

Gould's Belt superimposed on to an IRAS 100 micron emission map (JCMT mm survey)

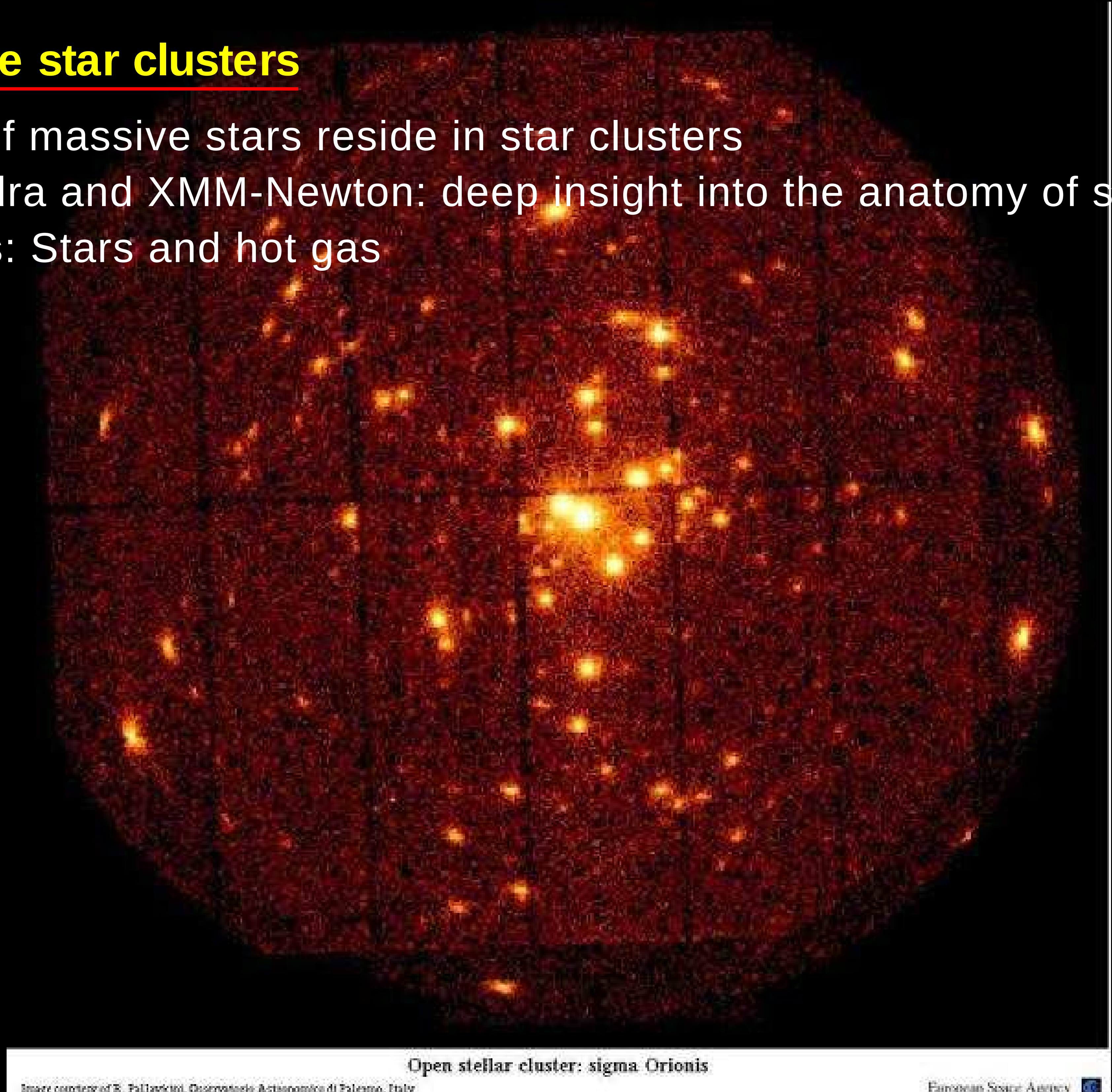




- eROSITA will provide a very significant high-energy picture of solar neighbourhod
- eROSITA combined with IR and mm surveys: unravel **the local star formation history**

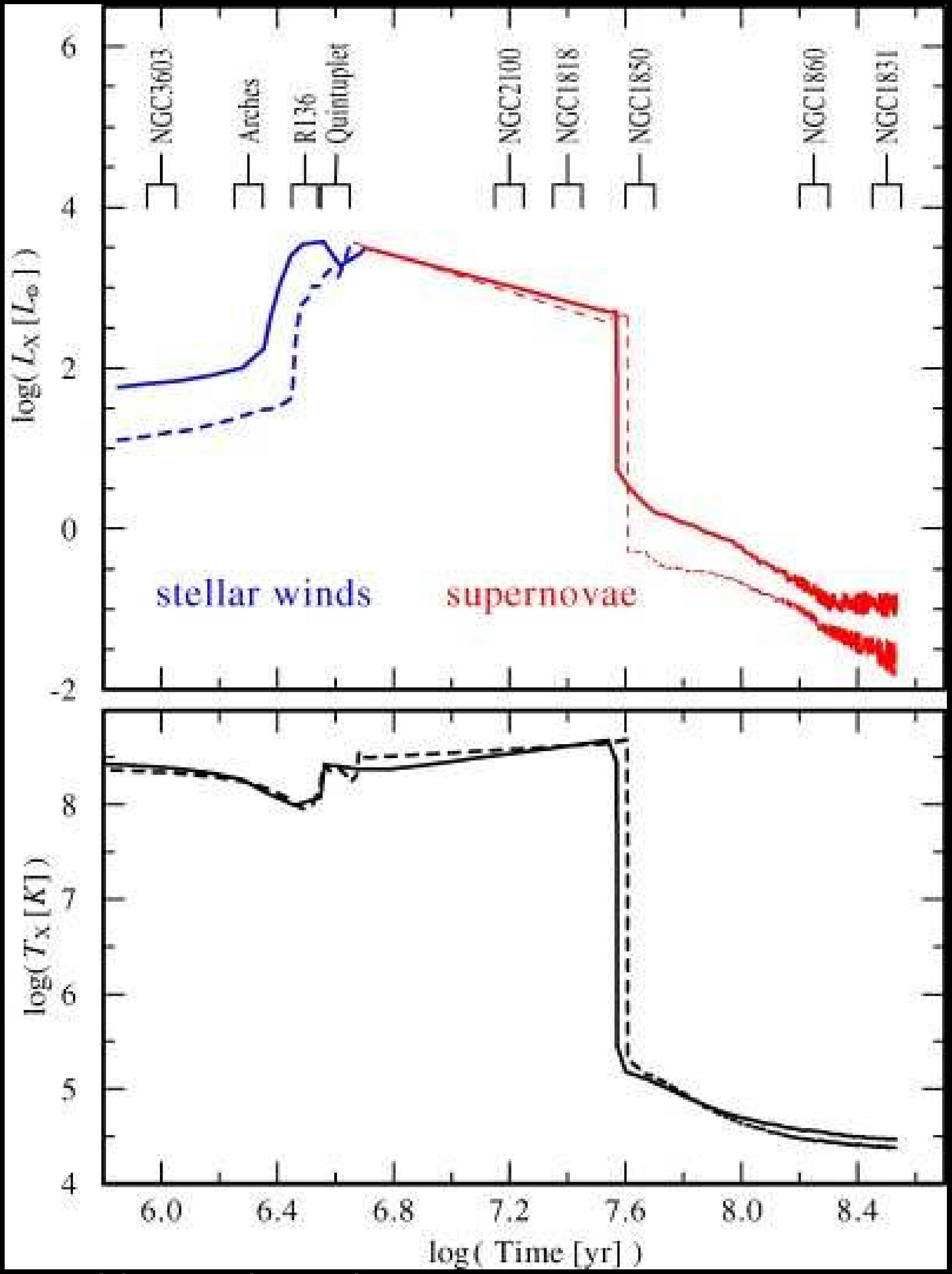
Massive star clusters

- 70% of massive stars reside in star clusters
- Chandra and XMM-Newton: deep insight into the anatomy of star clusters: Stars and hot gas



Evolution of X-ray emission from massive star clusters

- Models predict that L_X from star cluster depends on its age and mass

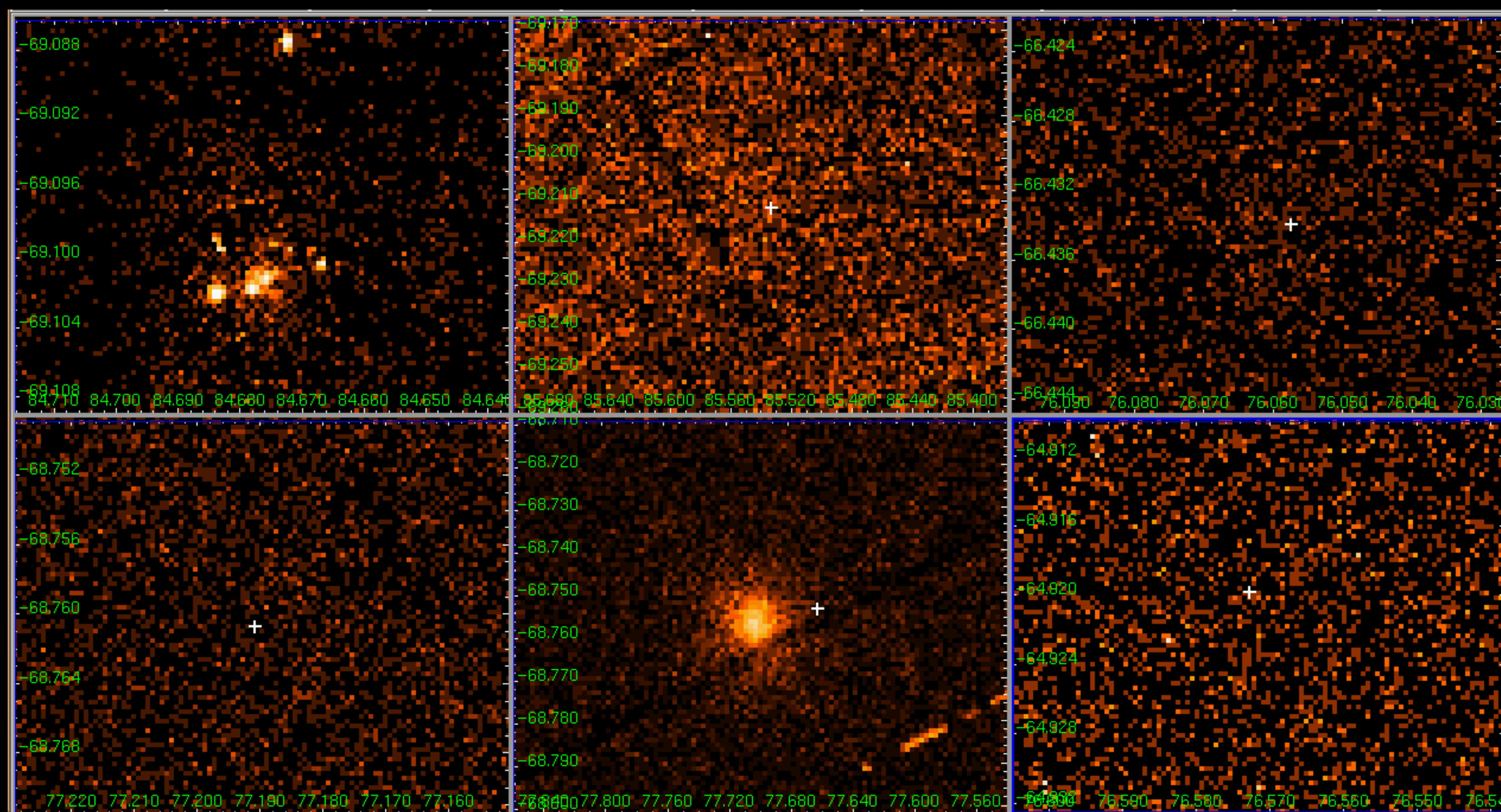


Oskinova (2005)

- Typical size of a cluster: 2 pc → 20" at d=20kpc
- The X-rays from clusters shall be hard
- eROSITA will detect most massive star clusters within 6Mpc
- eROSITA will provide importnat X-ray snapshot of star cluster formation and evolution

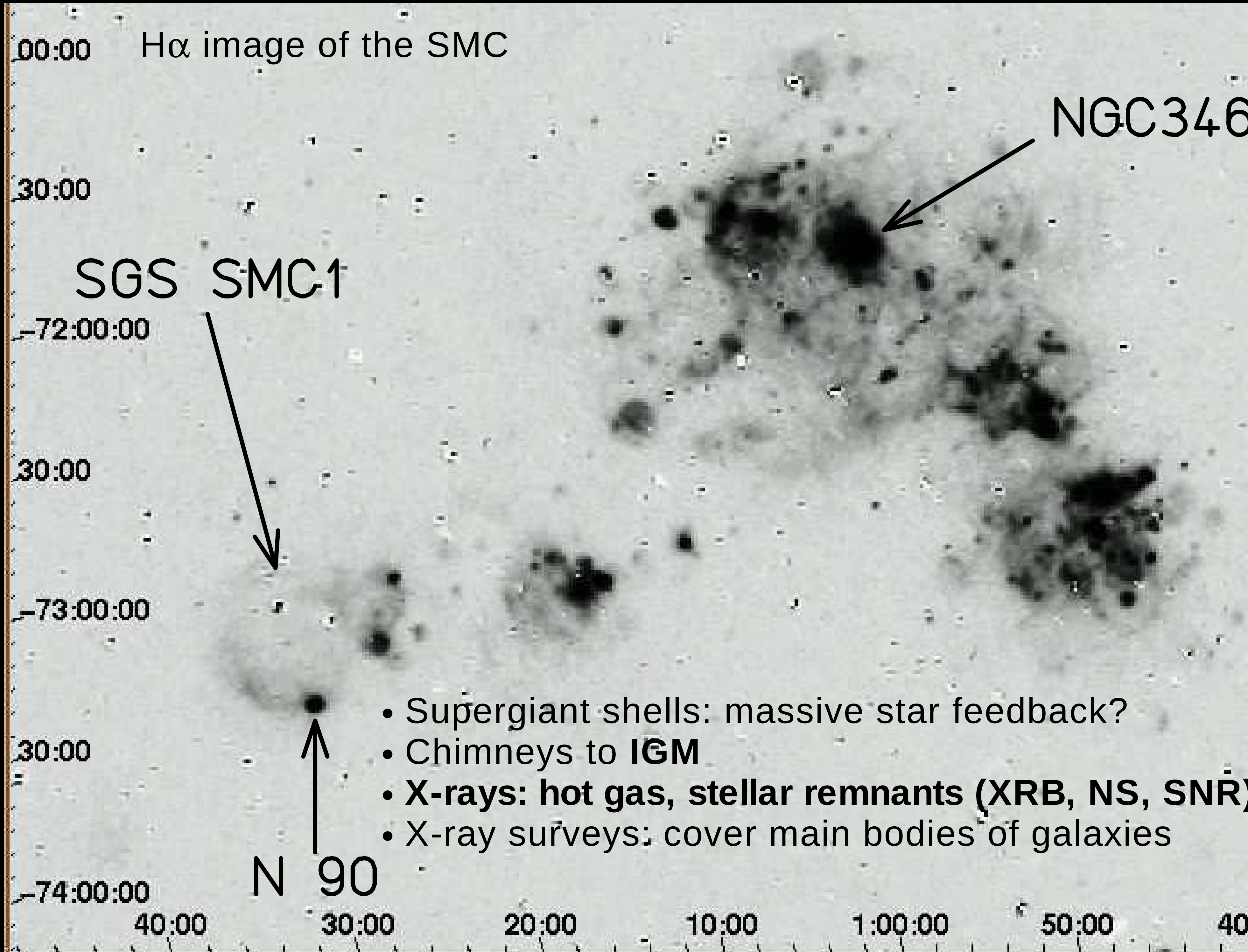
Sample of massive star clusters in the LMC

- LMC, SMC important sample of clusters differemt M and Age
- There is evolution of X-ray emission from clusters
- Well studied in optical/IR: cluster parameters are known



eROSITA: variability, transients, bubbles, XRBs location

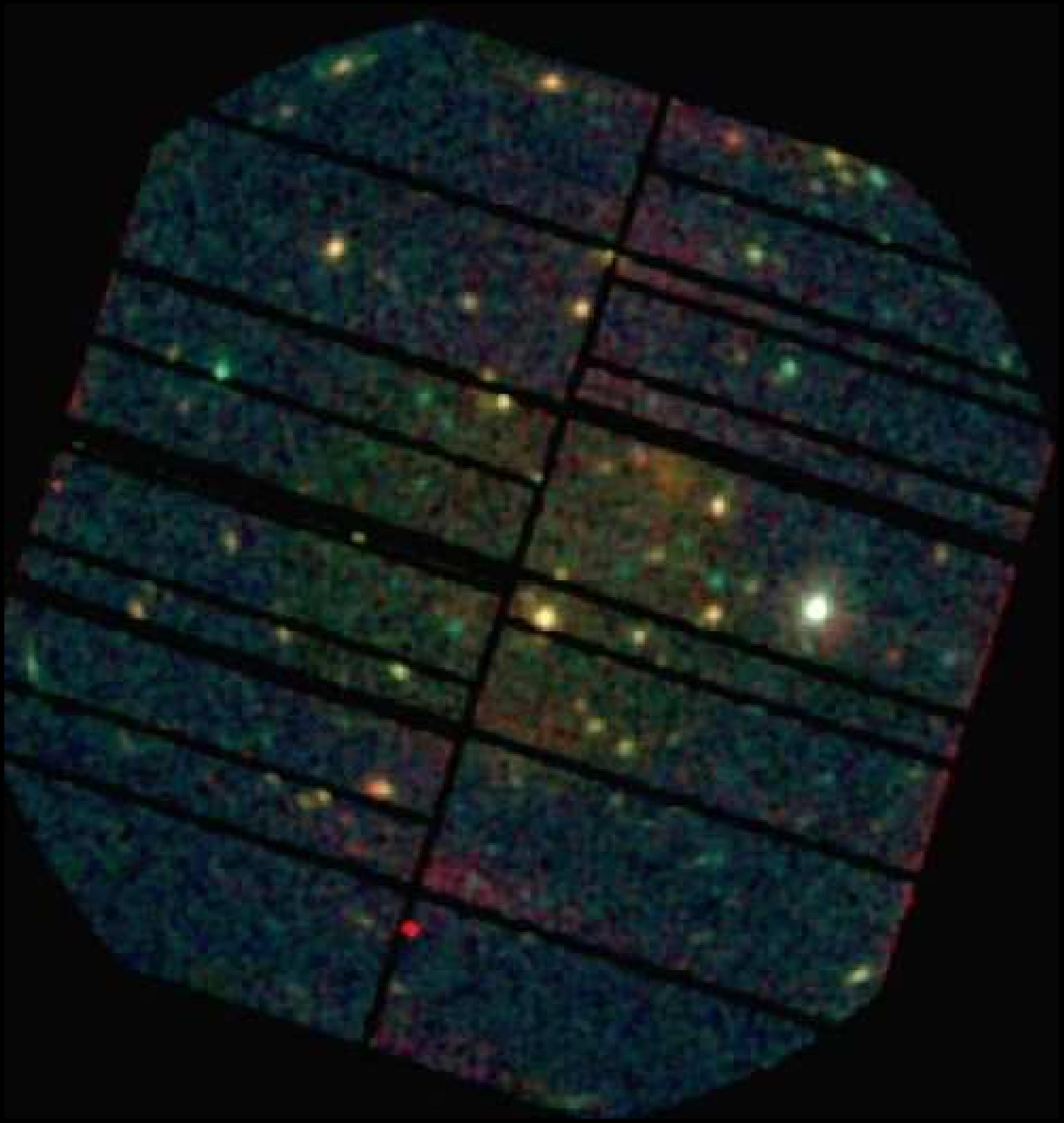
Massive stars and clusters: structuring galaxies



- Supergiant shells: massive star feedback?
- Chimneys to **IGM**
- **X-rays: hot gas, stellar remnants (XRB, NS, SNR)**
- X-ray surveys: cover main bodies of galaxies

Part of the SMC Wing in X-rays

EPIC PN 3 colour



Henault-Brunet etal. (2011), Oskinova etal (2012)

The periferal part of the SMC Wing: low ρ and Z

Star formation: new XRBs are detected

eROSITA: galactic suburbs - starformation in province

LMC: 20ks survey. Excellent to study the SMC Wing, the Bar, the galaxy interactions

XRB with $L_X > 10^{32}$ erg s^{-1} will be identified

Diffuse X-ray emission: heated gas

Optical/IR/radio follow up are important

Summary

eROSITA: large uniform sample of massive stars accross the HRD

Dependence of X-ray on fundamental stellar parameters: elucidate the stellar physics

X-ray evolution of massive star clusters and feedback

Galaxies and their interaction: connection between SF and XRBs