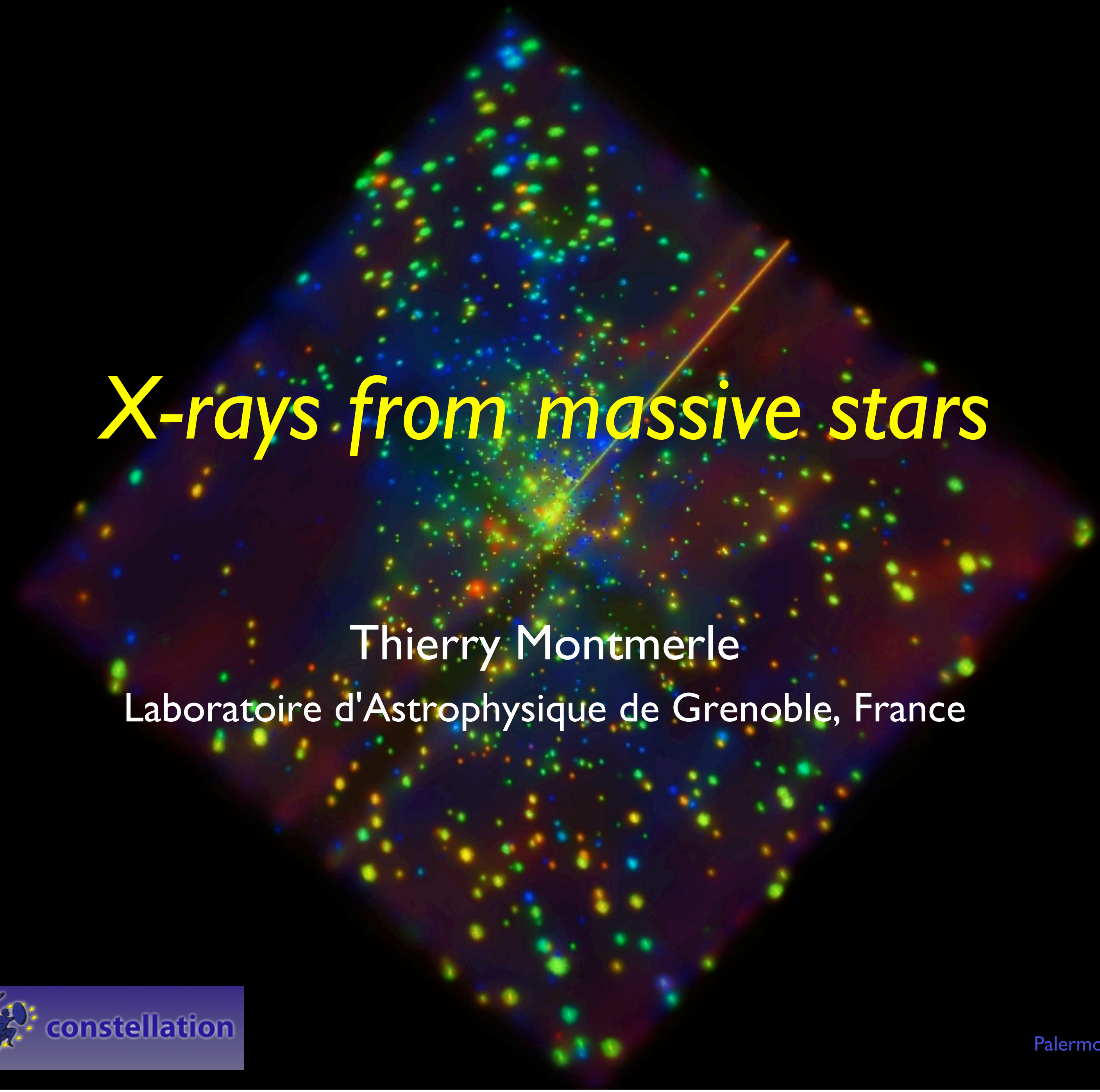

X-rays from massive stars

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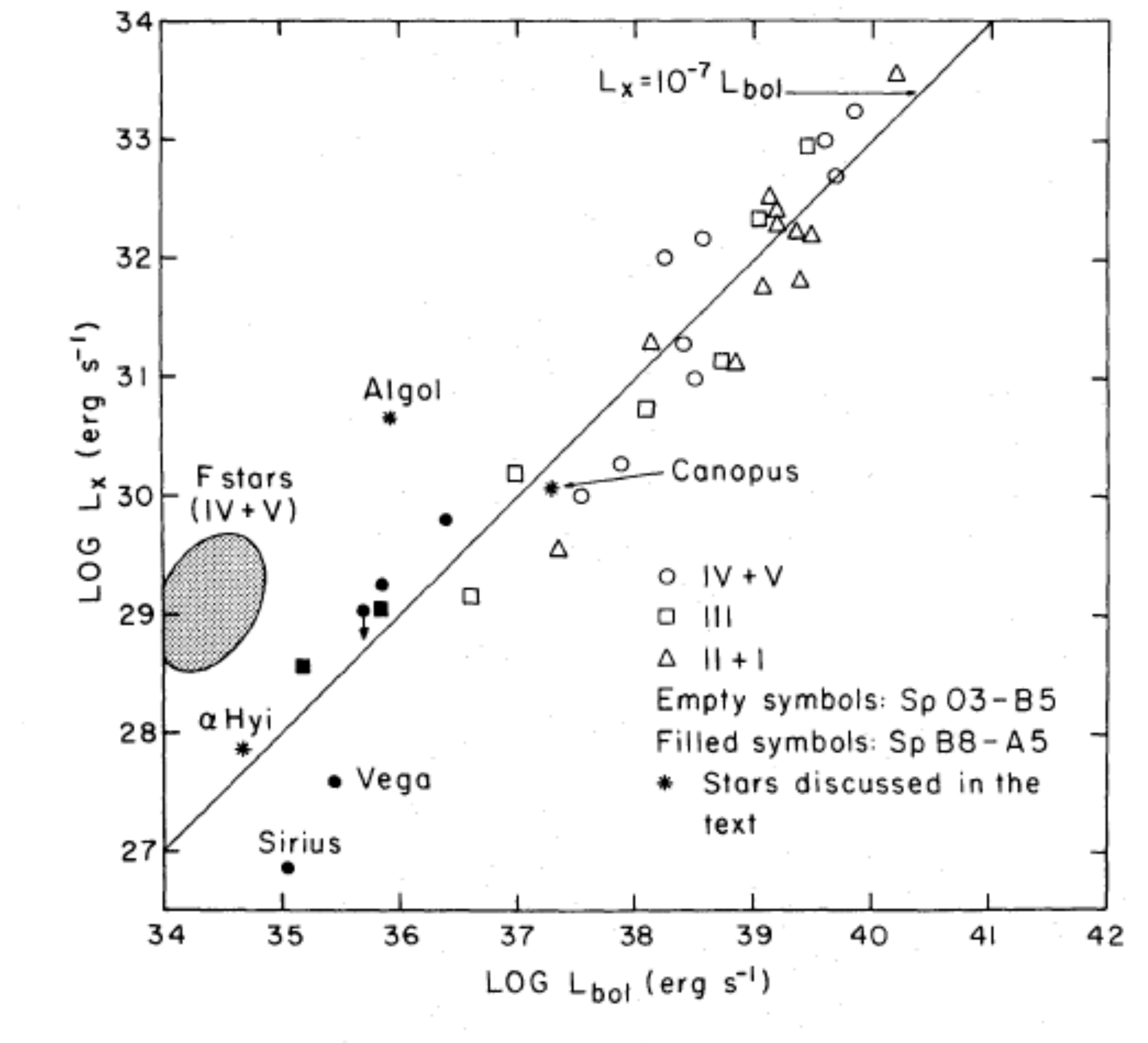
Outline

- 1. Introduction: successes and problems
- 2. Magnetically confined winds
- 3. The case of A stars
- 4. Follow-up: search for magnetic fields in X-ray emitting OB stars
- 5. Conclusions

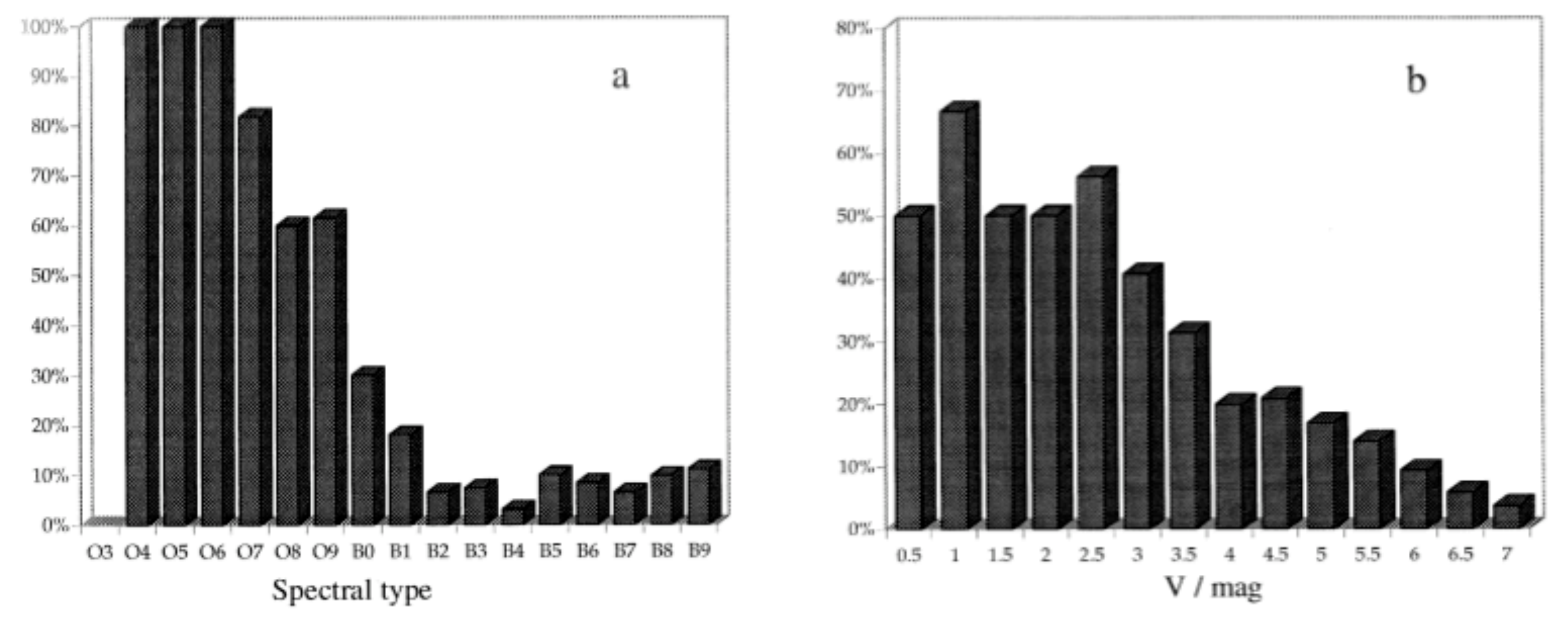
1. Introduction

A long and confusing story…

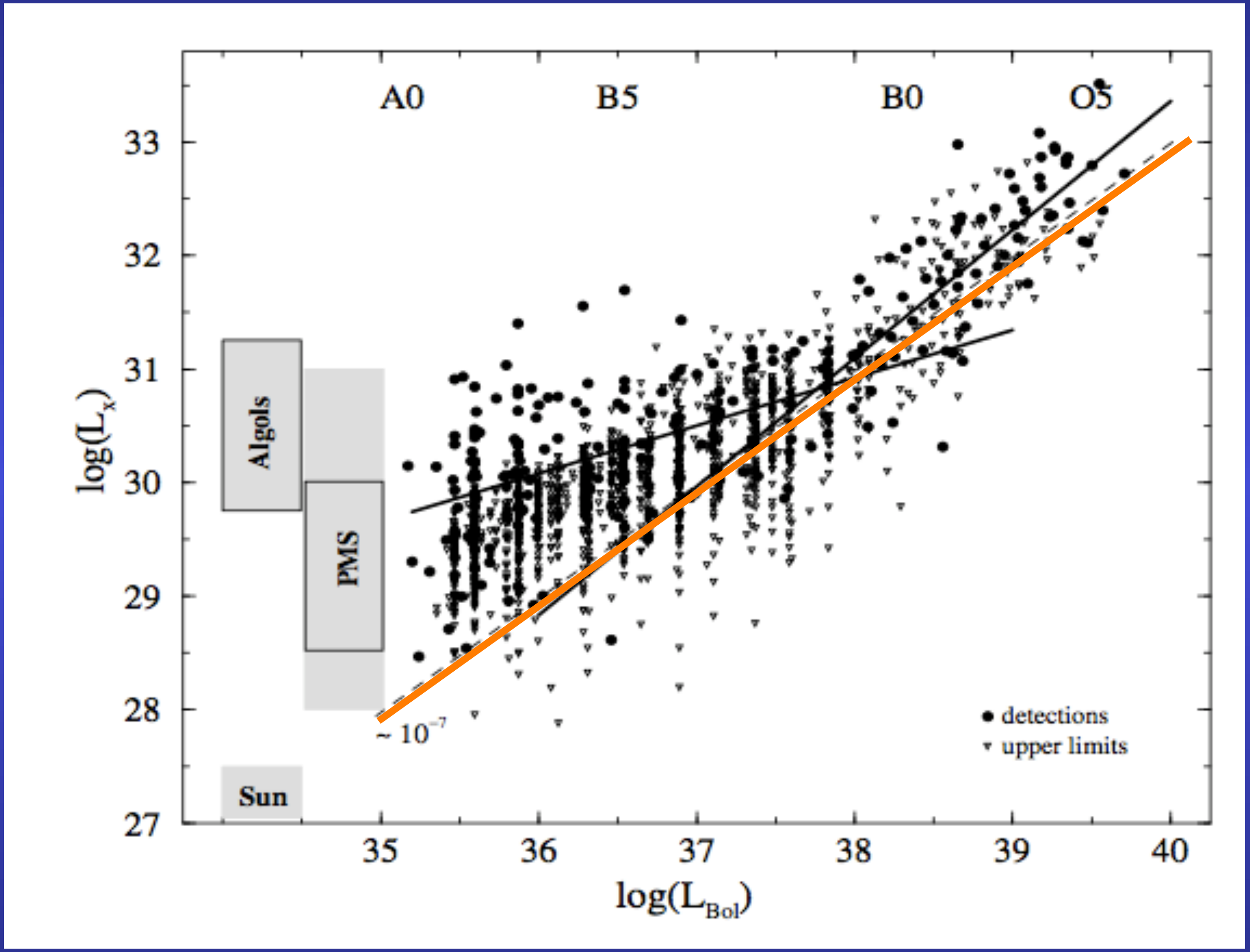
- “Massive” = OBA sp. types, ~ main sequence, $M > 2\ M_a$
- “strong winds” regime ($v_\infty > 1000$ km/s): ~ B3 ($> 8\ M_a$) to O3 ($> 80\ M_a$)
  - Discovery of stellar winds from OB stars by Copernicus (UV lines) in the mid-70’s
  - Stars with outer radiative envelope
  - Mechanism: UV radiation from star: Castor et al. 1975, Lucy
- Observed since the ’80s: *Einstein* survey (35 stars)
  - Famous $L_X/L_{bol} \sim 10^{-7}$ relation
- *ROSAT* surveys
  - Excess luminosities/*Einstein*
  - The late B/A star problem



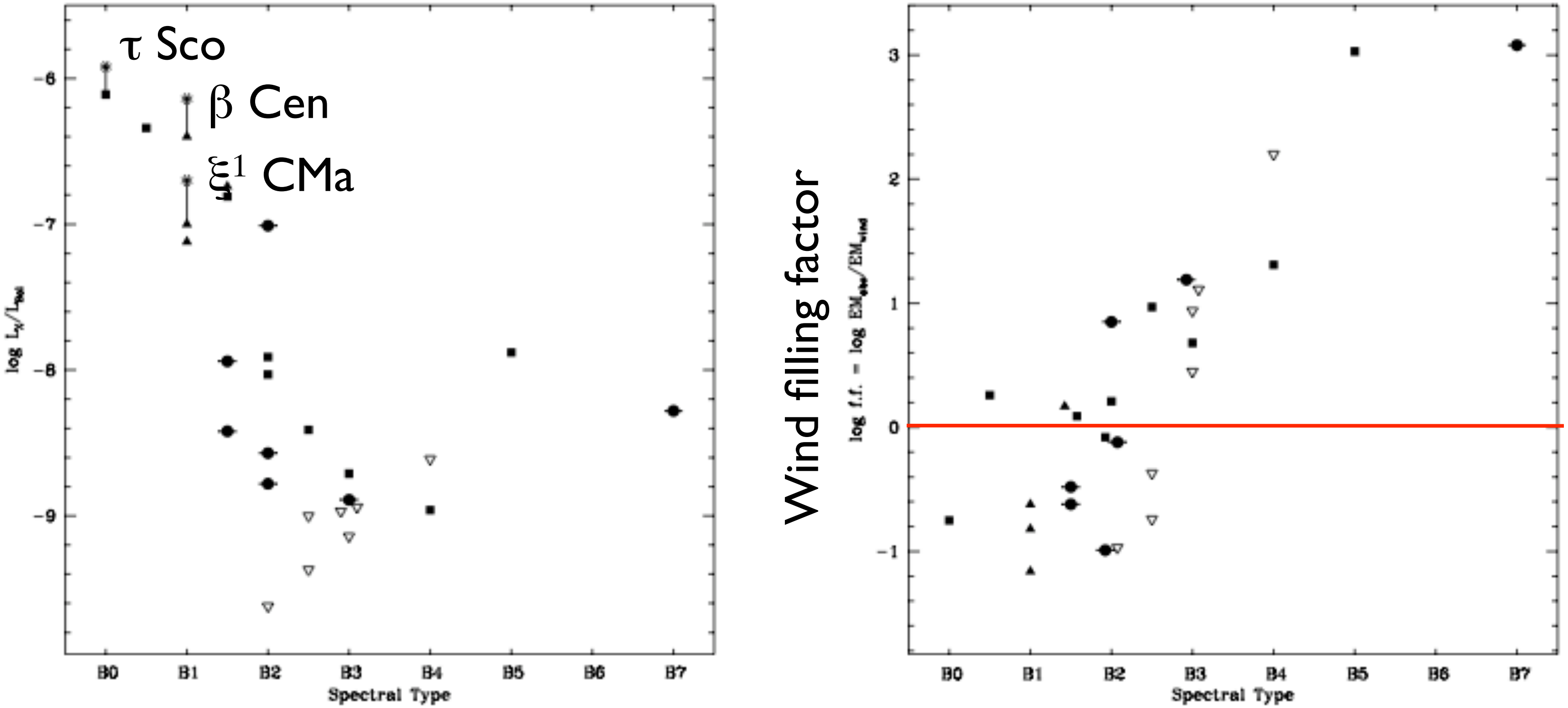
Pallavicini et al. 1981, 35 stars



ROSAT detection rate, 97 stars (Yale BSC, Berghofer et al. 1997)



Excess: low-mass companions ? Variability



20 MS B stars (Cohen et al. 1997)

The Chandra Ultradeep Orion survey (~ 800 ksec eff.)

Detection fraction as a function of spectral type

COUP:	100%	84%	71%	100%	80%	94%	92%
ROSAT:	56 %	30%	10%	70%	75%	75%	70%

BUT:

most of the missing objects are due to confusion with nearby X-ray sources

Detection fraction as a function of spectral type

COUP:	100%	84%	83%	100%	80%	98%	97%

„really undetected“ ($L_X \leq 10^{28}$ erg/sec) are:

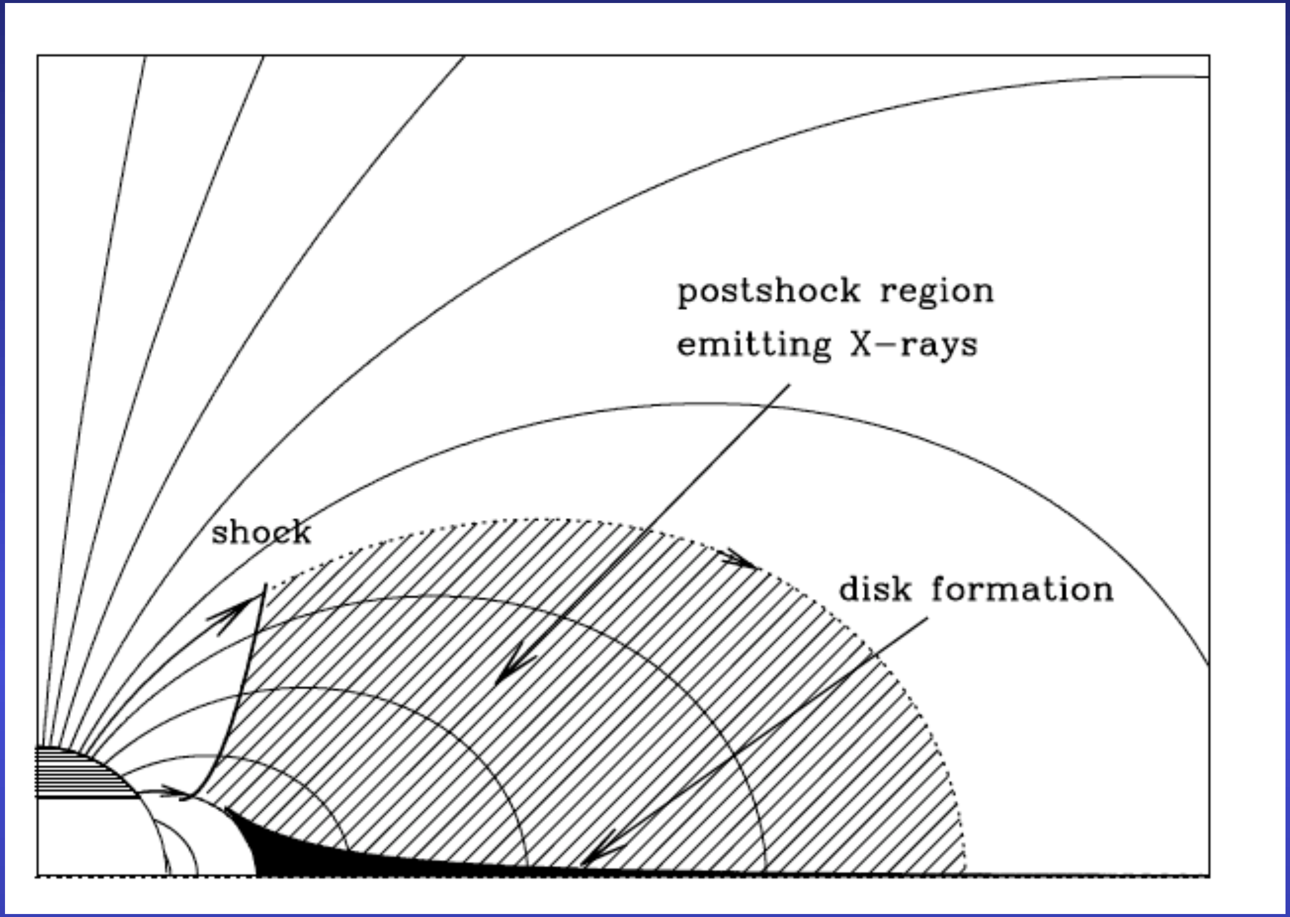
	0	2	1	0	2	3	13
out of	1	13	6	1	10	142	448

(Preibisch 2005)

X-ray mechanisms

- For the majority of OB(< B3) stars, shocks in radiatively unstable winds (clumps) explain most of the X-ray characteristics
- However, a number of OB stars are "X-ray overluminous", either because $L_X/L_{bol} >> 10^{-7}$ ("canonical" value), or because they seem not to have enough hot wind material; A stars should be X-ray dark
- Clues given by some X-ray overluminous "magnetic stars" (Ap-Bp types; He-rich or other abundance anomalies; B measured: few kG)

2. *Magnetically Confined/Channelled/Colliding Wind Shock model*



Key idea: *magnetic confinement of the wind => equatorial shock*

Original model: IQ Aur (A0p Si star, $B_* = 4$ kG;

radiative wind model => Mdot ~ 10^{-10} M_a/yr) (Babel & Montmerle 1997a)

Almost immediate application to θ^1 Ori C (periodic X-ray emission) (BM 1997b)

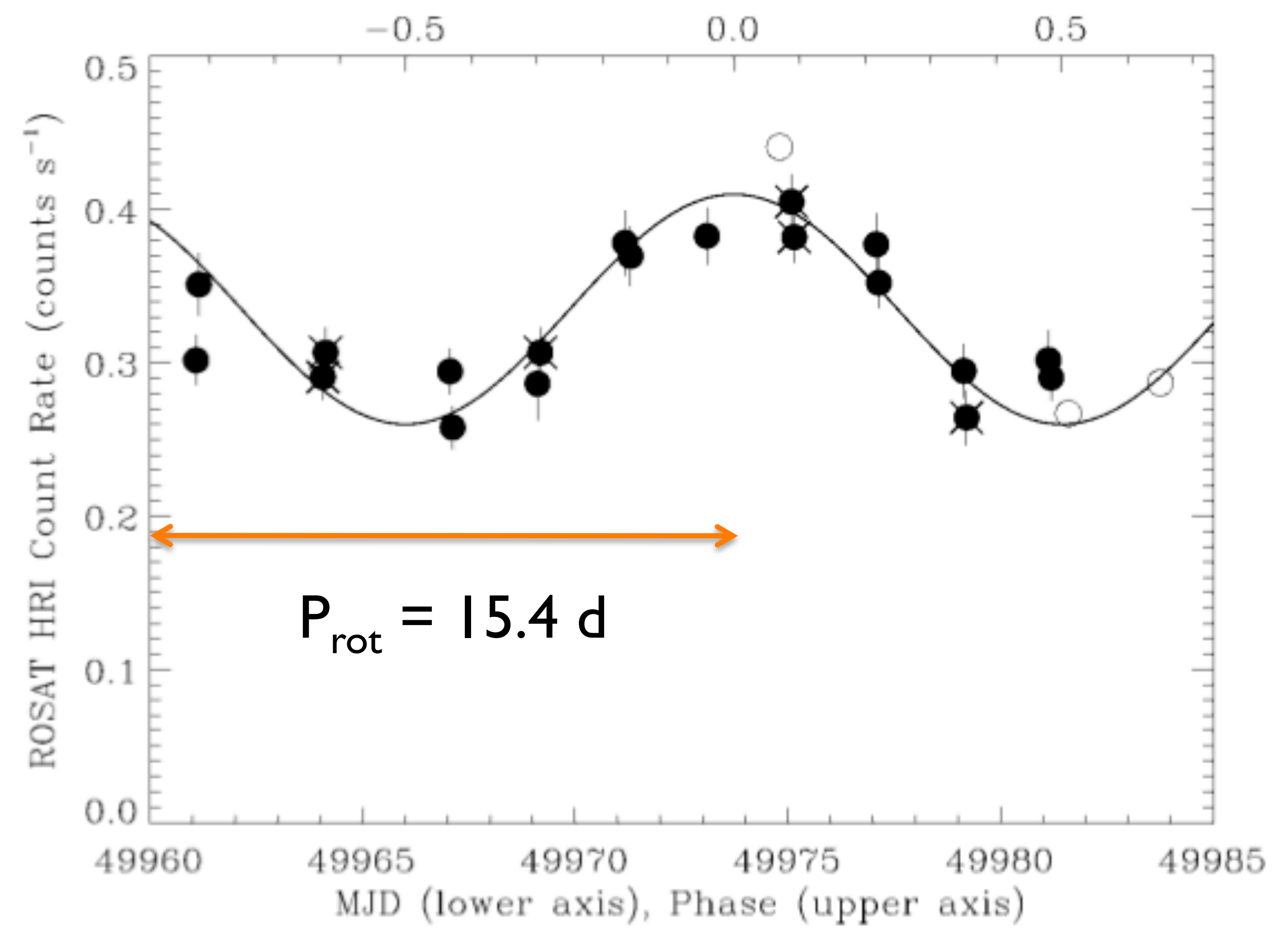
- Magnetic confinement criterion:

$$\eta = \frac{\text{magnetic pressure}}{\text{wind pressure}}$$

$$\eta = \frac{B^2 R_*^2}{\text{Mdot } v_\infty}$$

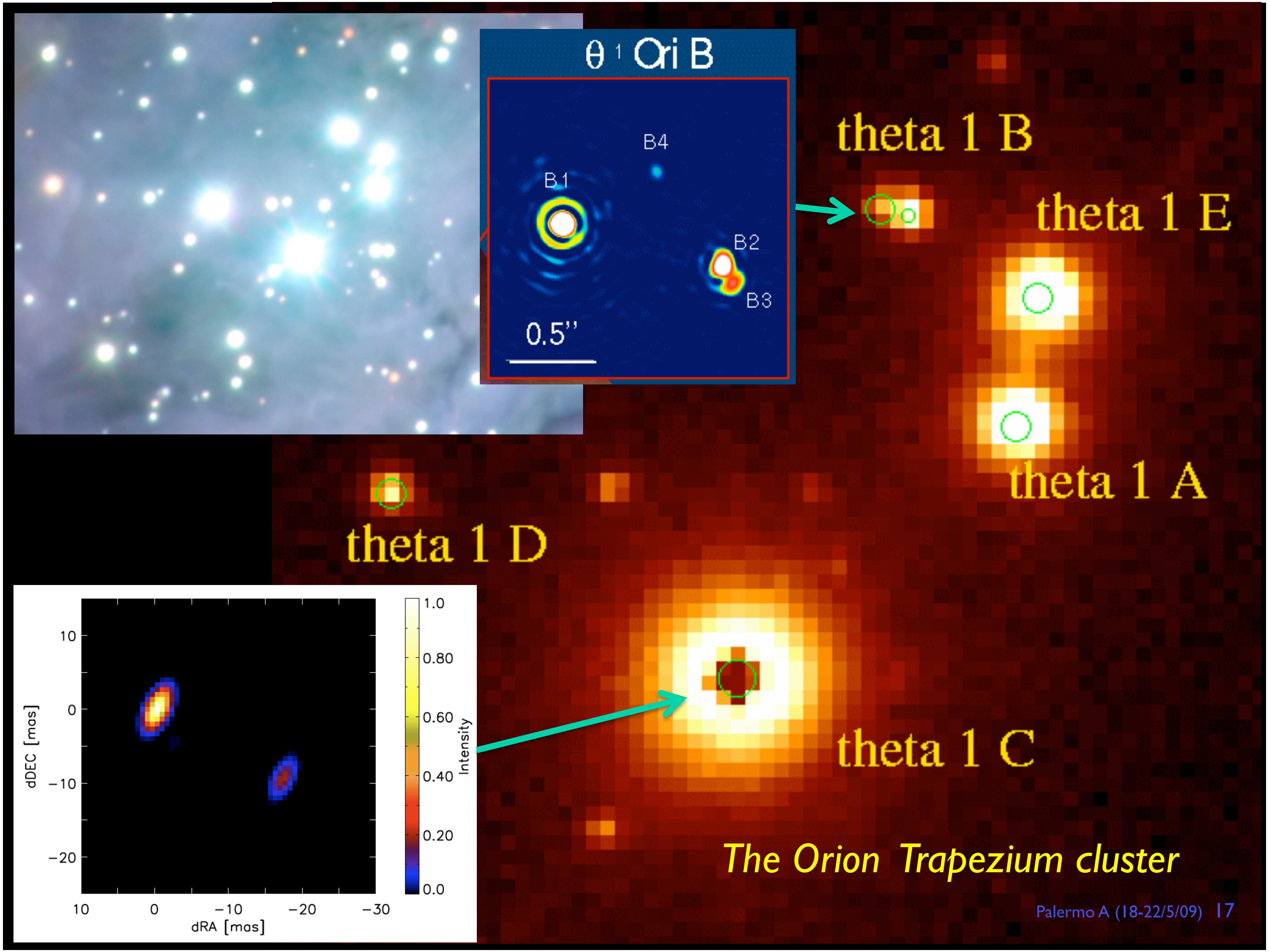
- Some values:

η (θ^1 Ori C) ~ 10; η (σ Ori E) ~ 100



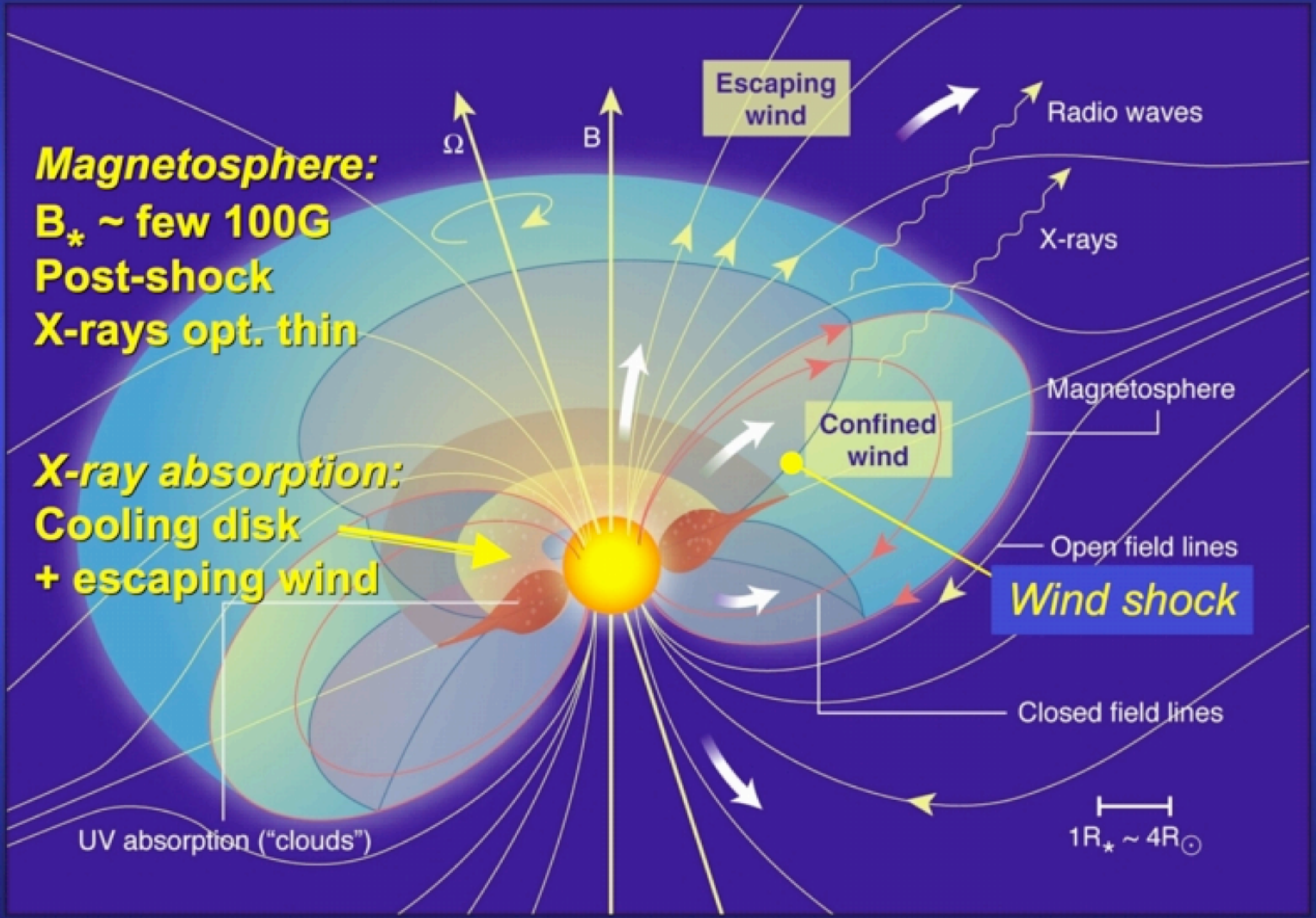
ROSAT, Gagné et al. (1997)

BM97 => *prediction* of B



The Orion Trapezium cluster

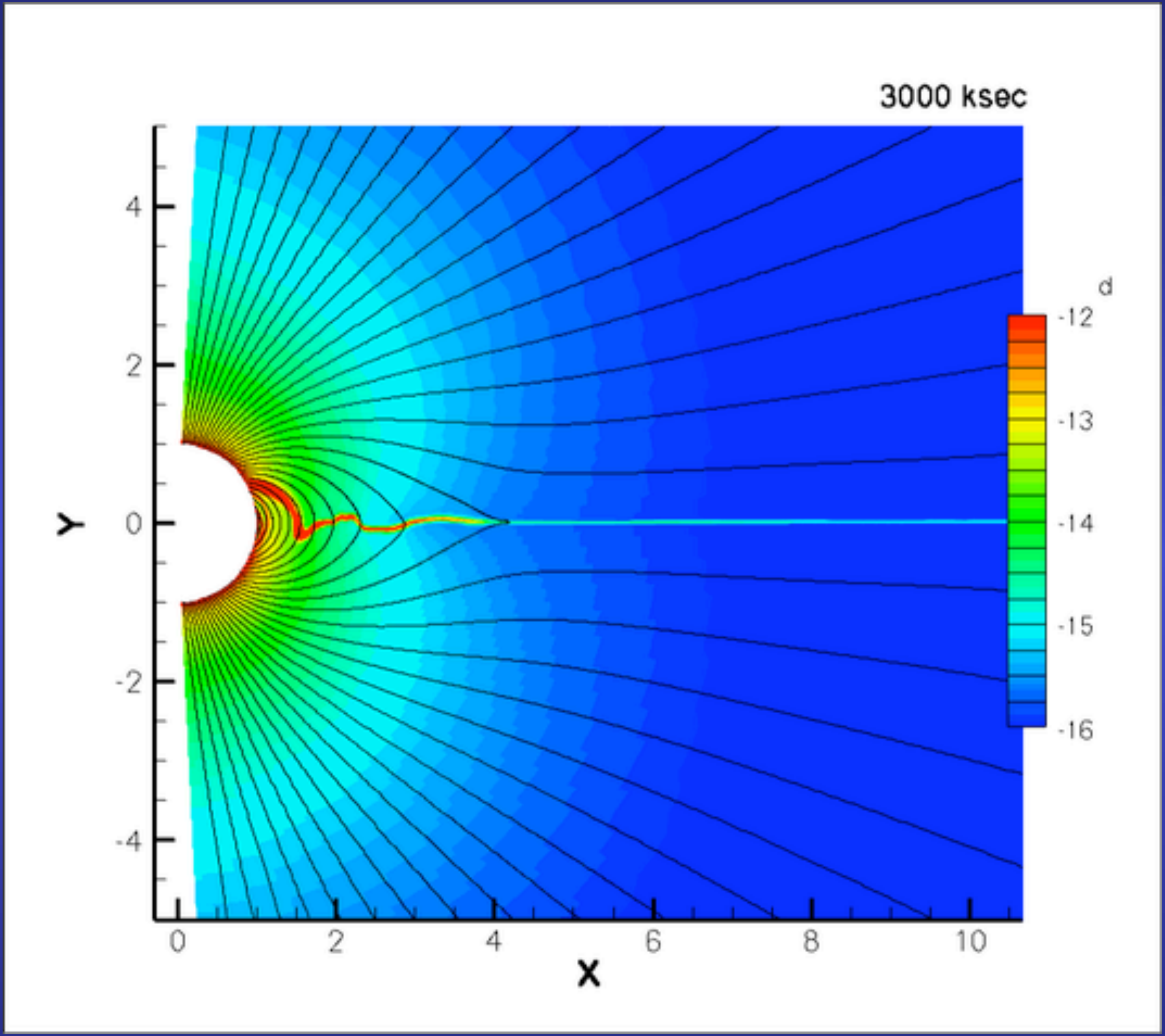
*The **Magnetically Channeled Wind Shock** (MCWS) model*



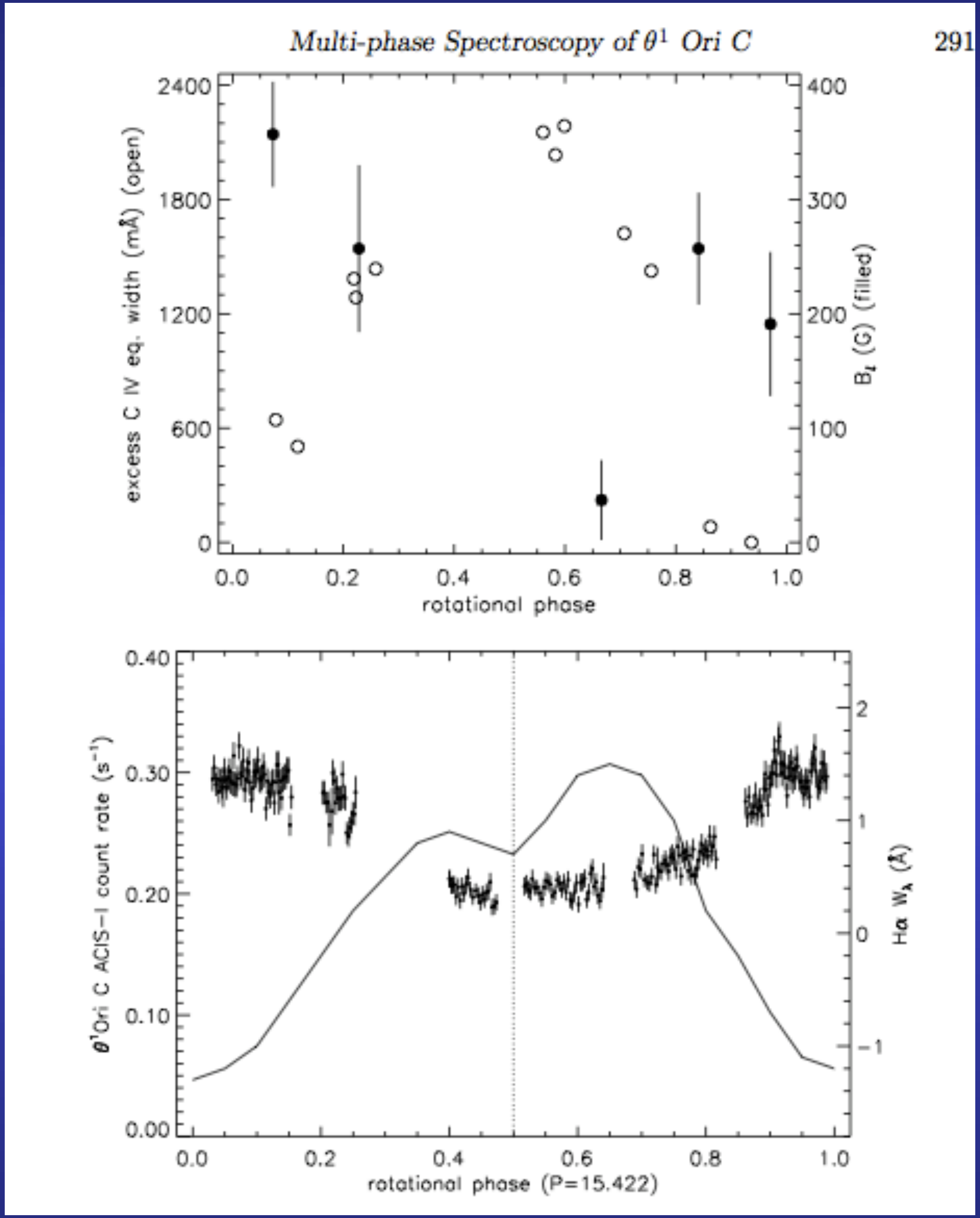
Magnetosphere:
B_* ~ few 100G
Post-shock
X-rays opt. thin

X-ray absorption:
Cooling disk
+ escaping wind

Montmerle 2001, Science *(after Babel & Montmerle 1997)*



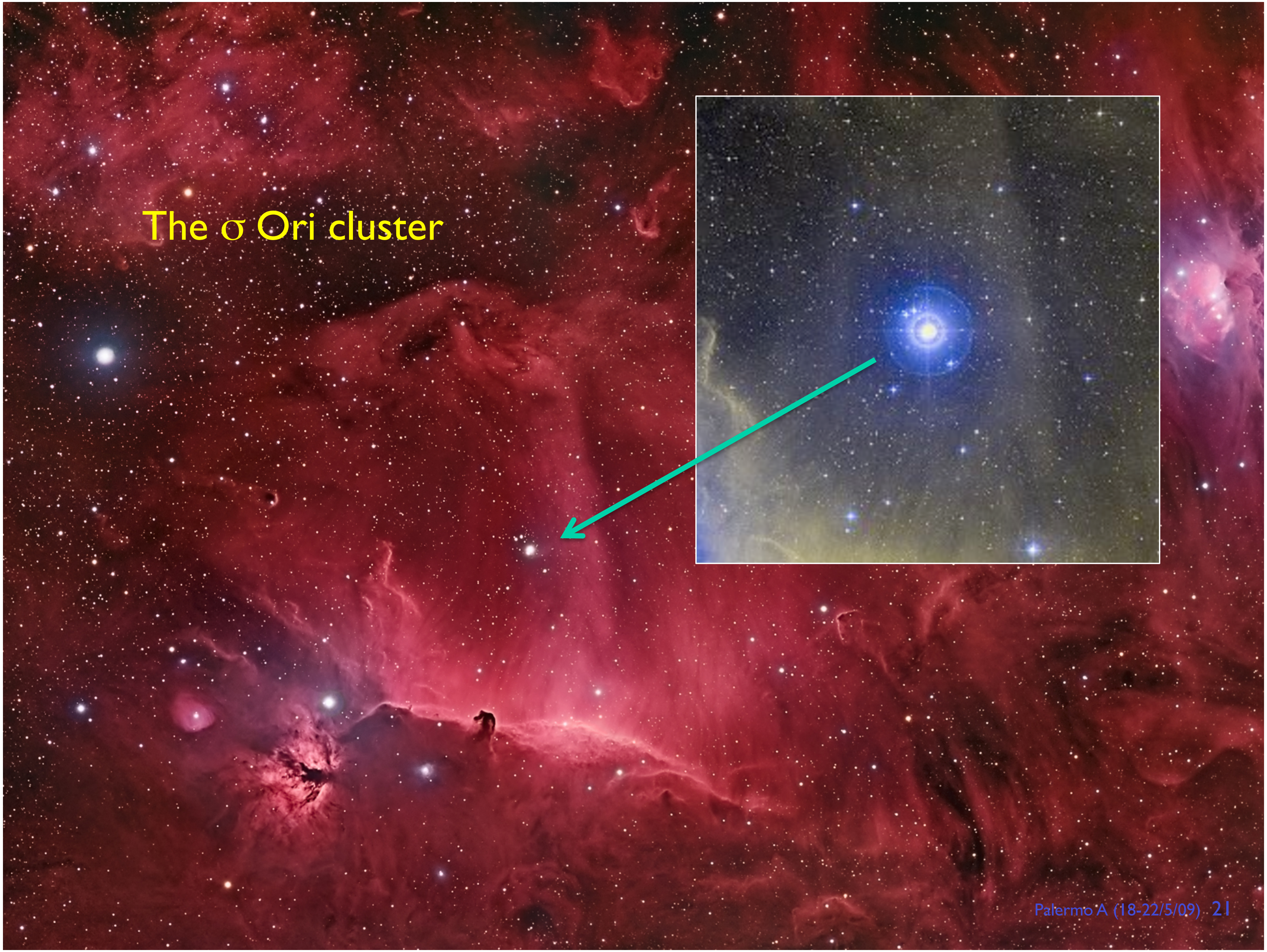
Owocki & Ud-Doula 2005



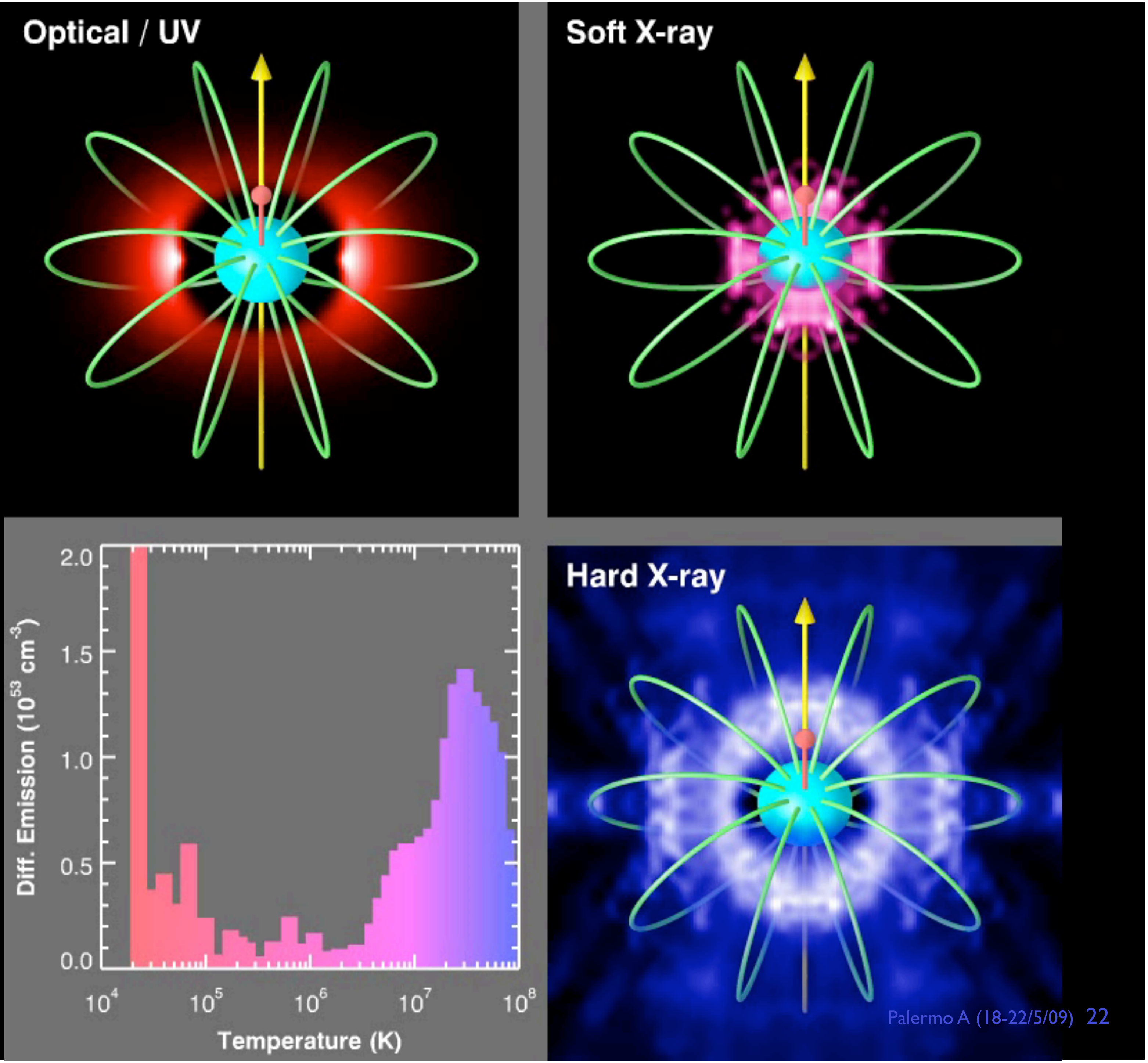
Multi-phase Spectroscopy of θ^1 Ori C 291

Oksala et al. 2005

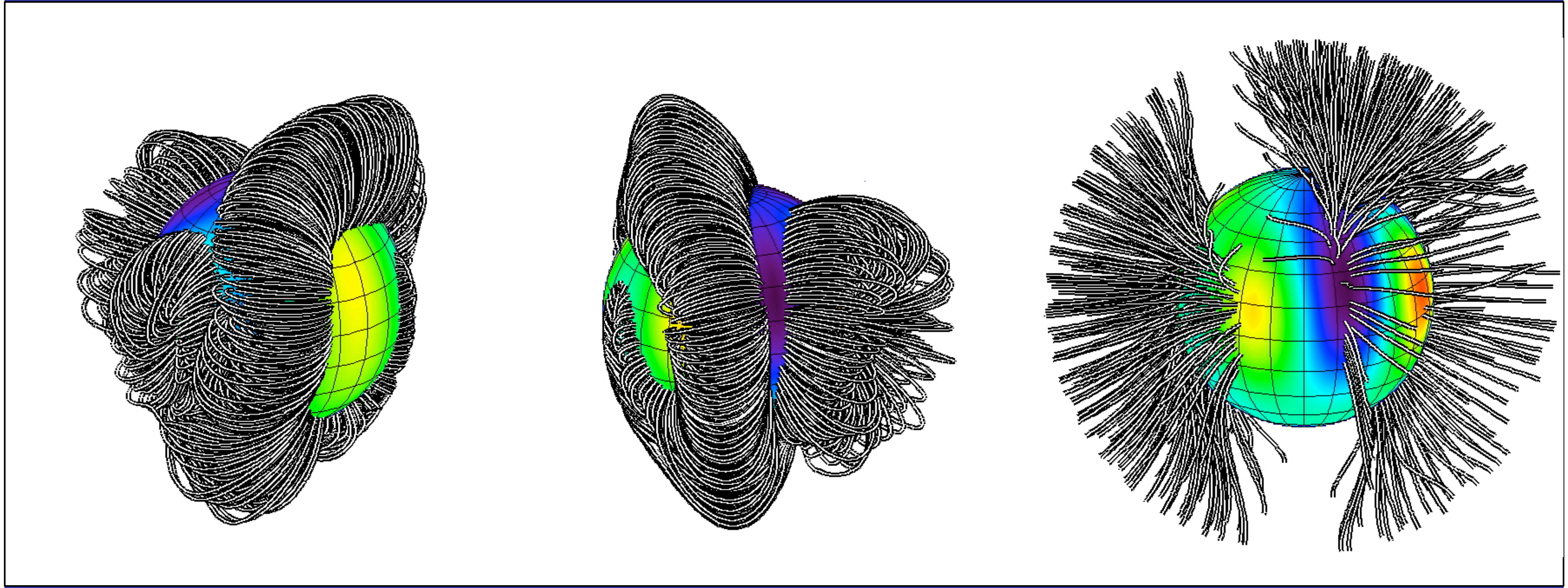
The σ Ori cluster



σ Ori E



RRM model
R. Townsend

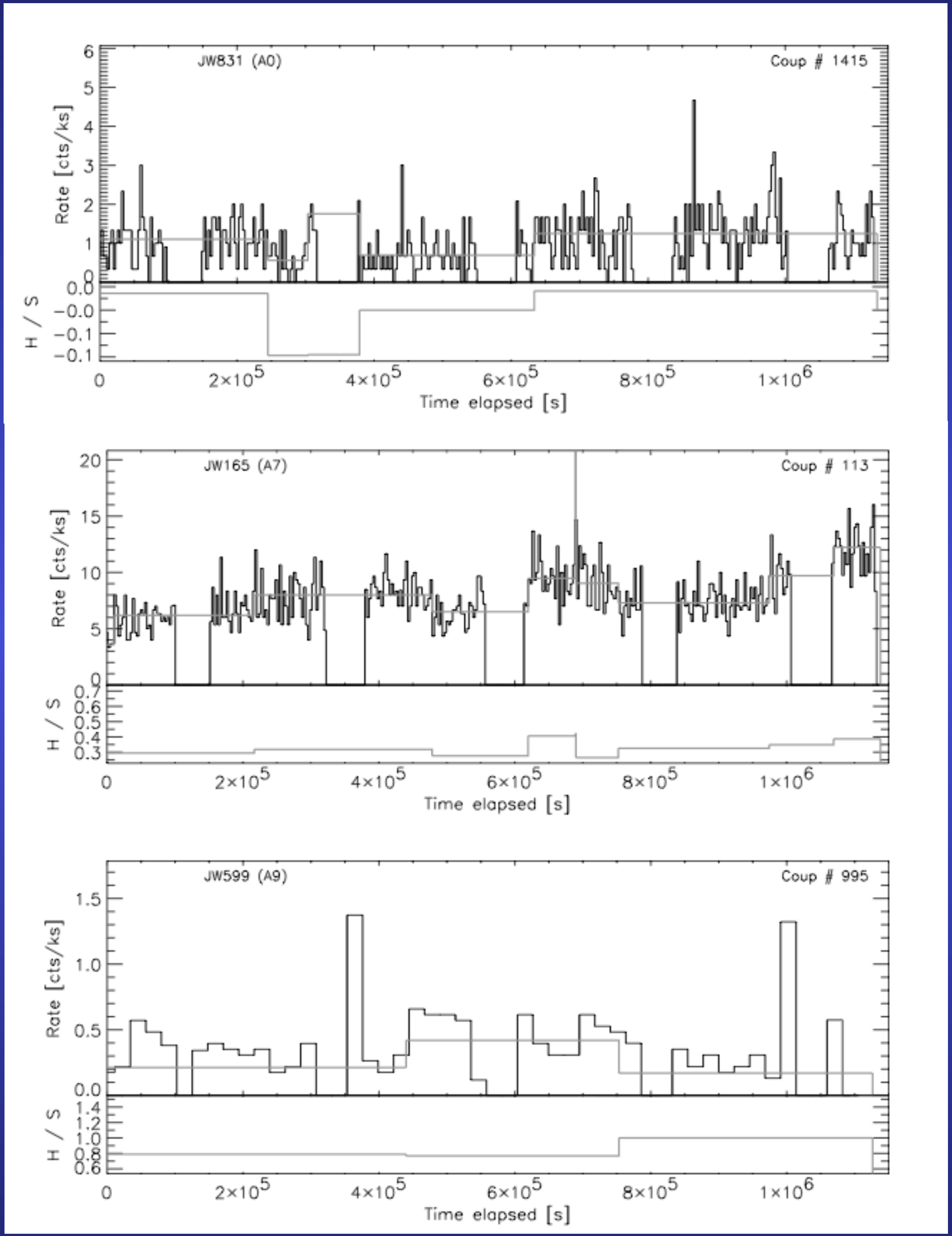


τ Sco, B0p, Donati et al. 2006

3. The case of A stars

- “Normal” A stars are have no convection zone (very small at best) + very weak, slow winds (actually, undetectable) => should be X-ray dark
- Never possible to find very close companion (even with Chandra: 0.1” @ 450 pc = 45 AU)
- Solution: variability (flares) compared with the same population of low-mass stars. Statistical arguments (Stelzer et al. 2005) show that COUP “flaring” A stars have the same varibility as T Tauri stars
- Note: recent detection of B (Narval@Pic du Midi) in Vega (A star): B ~ 1 G

=> Case closed.



(Stelzer et al. 2005)

4. Search for magnetic fields in X-ray emitting stars

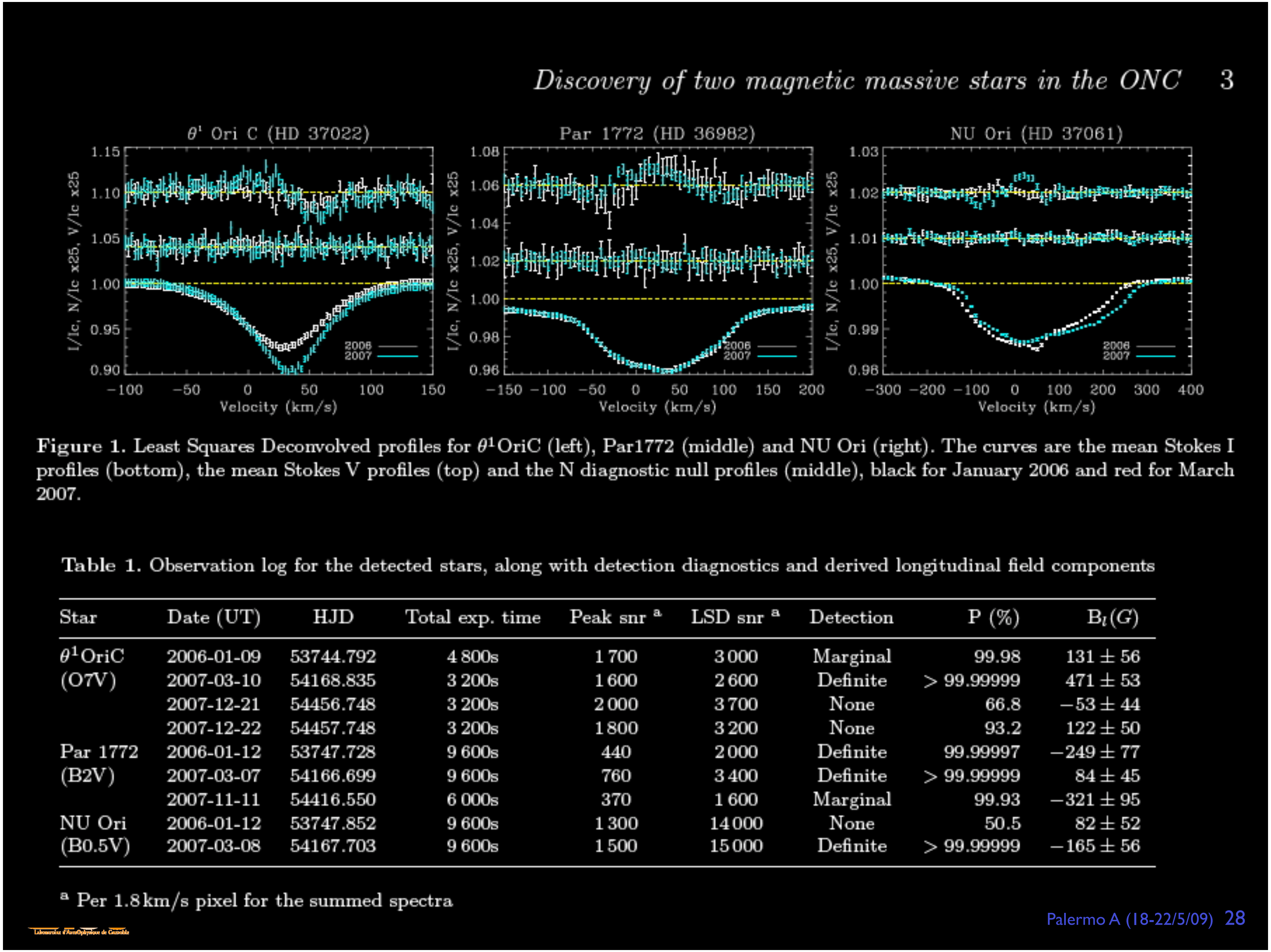


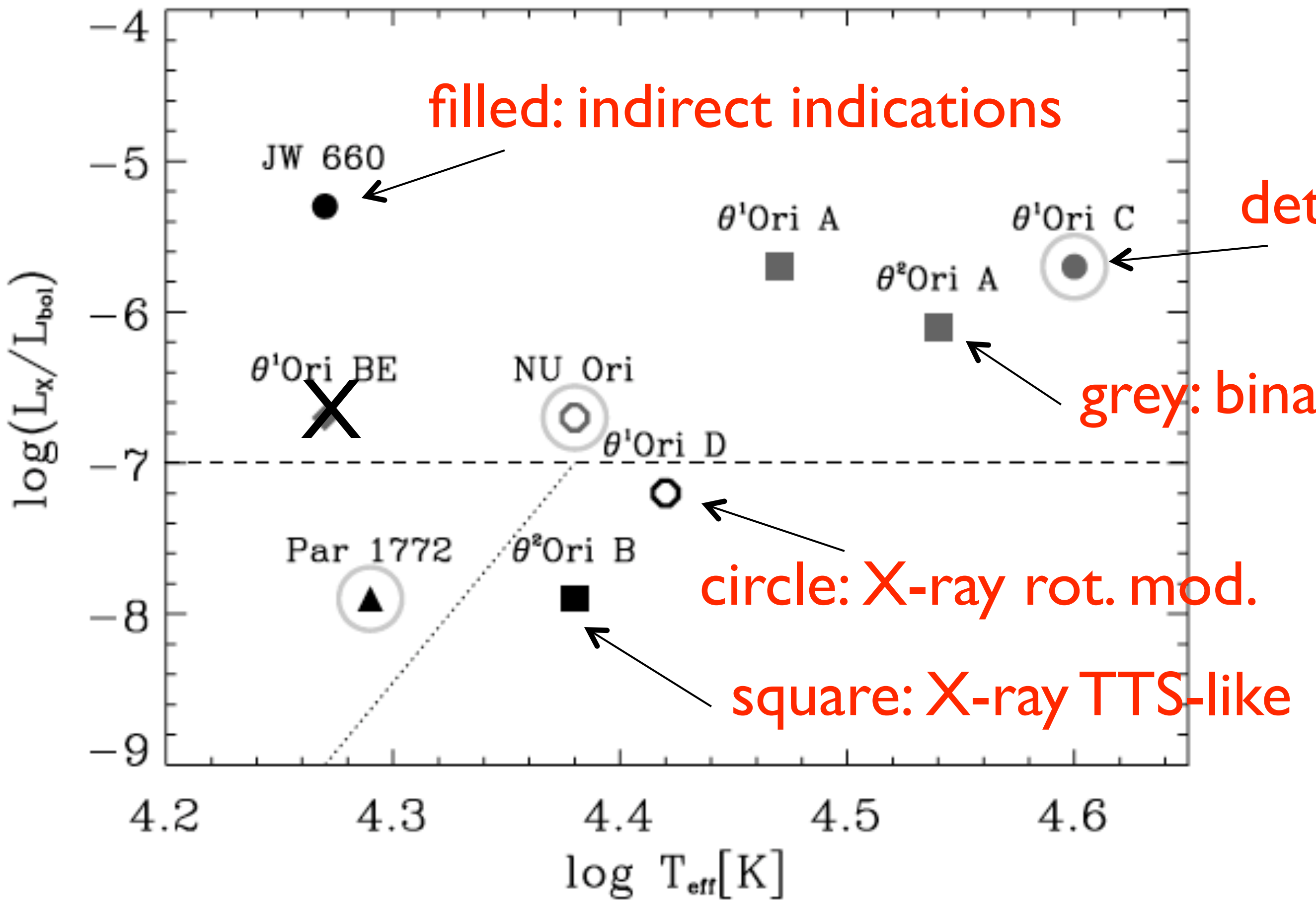
Figure 1. Least Squares Deconvolved profiles for θ^1OriC (left), Par1772 (middle) and NU Ori (right). The curves are the mean Stokes I profiles (bottom), the mean Stokes V profiles (top) and the N diagnostic null profiles (middle), black for January 2006 and red for March 2007.

Table 1. Observation log for the detected stars, along with detection diagnostics and derived longitudinal field components

Star	Date (UT)	HJD	Total exp. time	Peak snr [a]	LSD snr [a]	Detection	P (%)	$B_l (G)$
θ^1OriC	2006-01-09	53744.792	4 800s	1 700	3 000	Marginal	99.98	131 ± 56
(O7V)	2007-03-10	54168.835	3 200s	1 600	2 600	Definite	> 99.99999	471 ± 53
	2007-12-21	54456.748	3 200s	2 000	3 700	None	66.8	-53 ± 44
	2007-12-22	54457.748	3 200s	1 800	3 200	None	93.2	122 ± 50
Par 1772	2006-01-12	53747.728	9 600s	440	2 000	Definite	99.99997	-249 ± 77
(B2V)	2007-03-07	54166.699	9 600s	760	3 400	Definite	> 99.99999	84 ± 45
	2007-11-11	54416.550	6 000s	370	1 600	Marginal	99.93	-321 ± 95
NU Ori	2006-01-12	53747.852	9 600s	1 300	14 000	None	50.5	82 ± 52
(B0.5V)	2007-03-08	54167.703	9 600s	1 500	15 000	Definite	> 99.99999	-165 ± 56

[a] Per 1.8 km/s pixel for the summed spectra

120 V. Petit, G. A. Wade, L. Drissen, T. Montmerle, E. Alecian (2009)



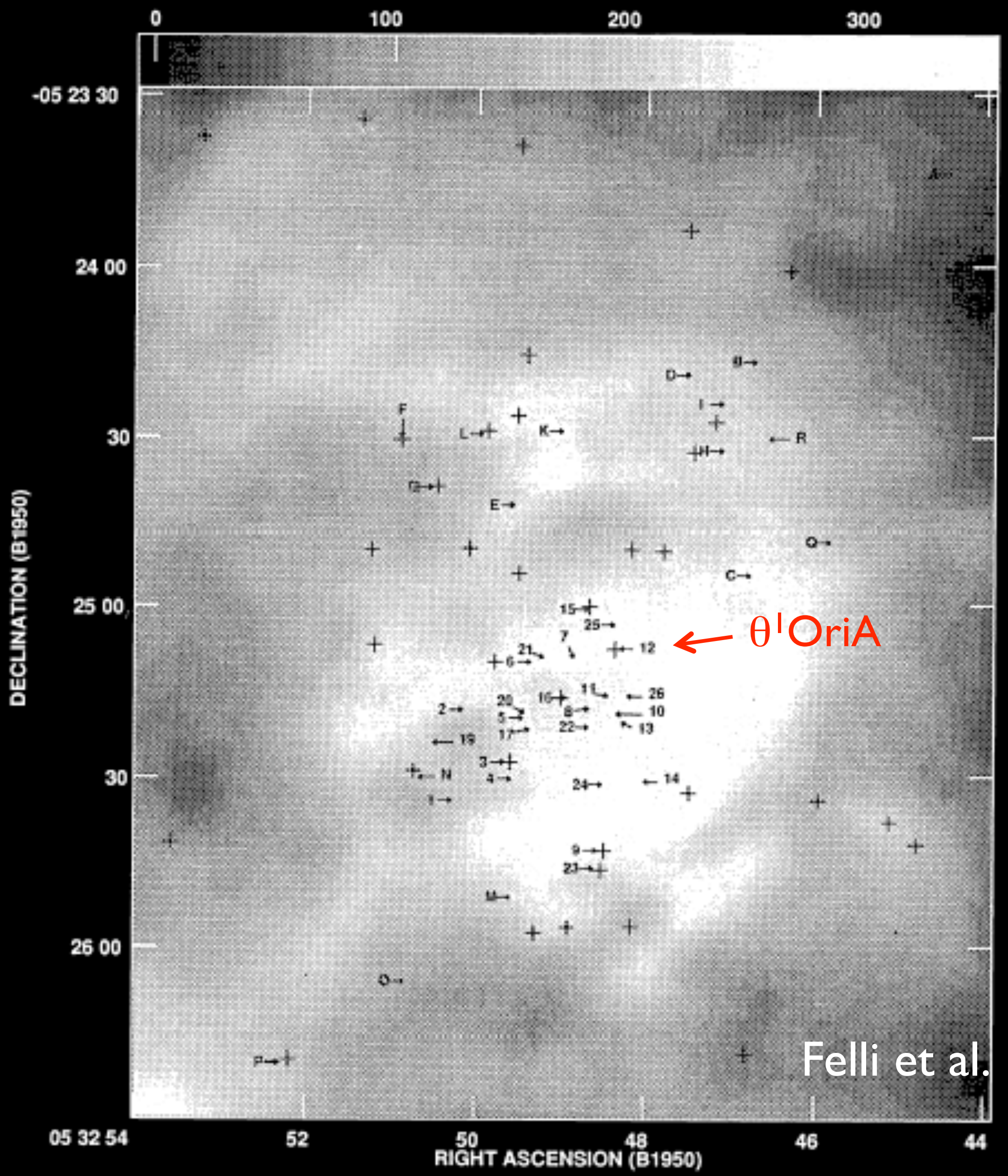
filled: indirect indications

detected

grey: binary ?

circle: X-ray rot. mod.

square: X-ray TTS-like



θ^1OriA

Felli et al. 1992

Fig. 1. A finding chart for the small diameter sources in Table 1. The position of each one is indicated with an arrow and labeled with the name in Table 1. Crosses mark the positions of bright stars in the Orion Nebula, from Strand (1958). The gray scale image is a 1.4 GHz surface brightness distribution of the central core of the HII region, from the VLA B-configuration observations of Felli et al. (1992)

- In all so far 6 O stars have detected magnetic fields (100 – 1500 G) (~ 50% in Orion)
- 24 B stars detected (~ 50%)
- Ap-Bp stars ~ 5% of AB stars
- Herbig AeBe stars: see talk by E. Alecian
- Origin of B still debated; probably fossil and depending on formation conditions

5. Conclusions

- X-ray modelling of winds from massive stars difficult
- Well-established (but still few) cases of « magnetically confined » winds; accurate modelling requires MHD (instabilities), unless η >>> 1: magnetospheric configuration stille problematic (mapping possible with Espadons@CFHT)
- More generally, connection between X-rays and (mesurable) magnetic fields not straightforward
- High-resolution X-ray spectroscopy gives strong constraints on wind parameters (triplet ratios, etc.)