Dynamics of the collisionless plasma in WR140

Andy Pollock (ESA-E)

Corcoran (US), Dougherty (CA), Hamaguchi (US), Moffat (CA), Pittard (UK), Williams (UK)

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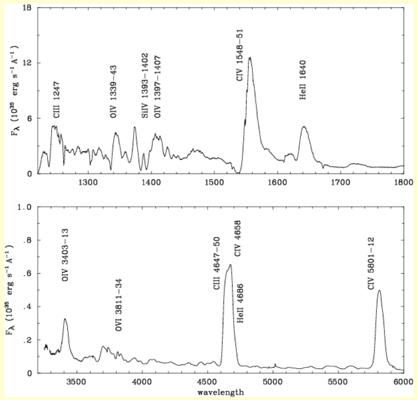
Hot stars ⊂ {OBAFGKMRNS,1-9,V-I}

- ✶ M = 20-100 $M_\odot$
- ✶ T = 30,000-100,000 K
- ☼ radiatively-driven winds
  - ★ O stars (e.g ζ Pup : O4If ∈ 300 in the Galaxy)
    - H burning
    - solar abundances
    - ☼ dM/dt ~ 10^{-6} $M_\odot$/yr
    - ☼ v_∞ ~ 1000-3000 km/s
  - ★ O ⇒ Of ⇒ WNL ⇒ WNE ⇒ WC ⇒ WO ⇒ ✺
  - ★ Wolf-Rayet stars (e.g. WR11 : γ Vel : WC8+ ∈ 200 in the Galaxy)
    - He burning
    - WN
      - He & N
    - WC
      - He, C & O
    - ☼ dM/dt ~ 10^{-5} $M_\odot$/yr
    - ☼ v_∞ ~ 800-5000 km/s

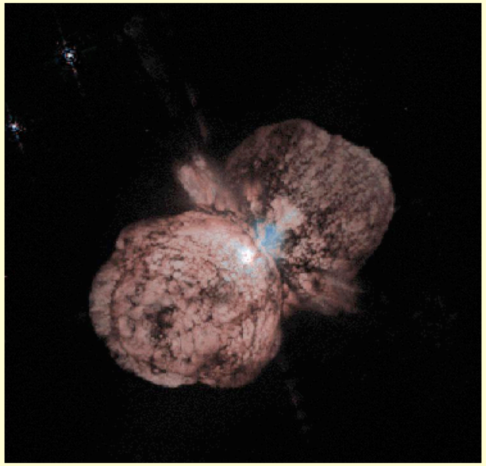


Hot-star binaries ☼+☼

- ☼+☼ binary fraction is high > 50%
- ☼+☼ δ Orionis
  - ☼+☼ V = 2^m
  - ☼+☼ O9.5II+B0.5
  - ☼+☼ P = 5 days
- ☼+☼ η Carinae
  - ☼+☼ 1843 outburst V = -1^m
  - ☼+☼ LBV+?
  - ☼+☼ P = 5.5 years
- ☼+☼ γ Velorum
  - ☼+☼ V = 1^m
  - ☼+☼ WC8+O8III
  - ☼+☼ P = 78.53 days

- ☼+☼ WR140
  - ☼+☼ V = 7^m in Cygnus
  - ☼+☼ WC7+O5
  - ☼+☼ P = 2899 days

η Carinae

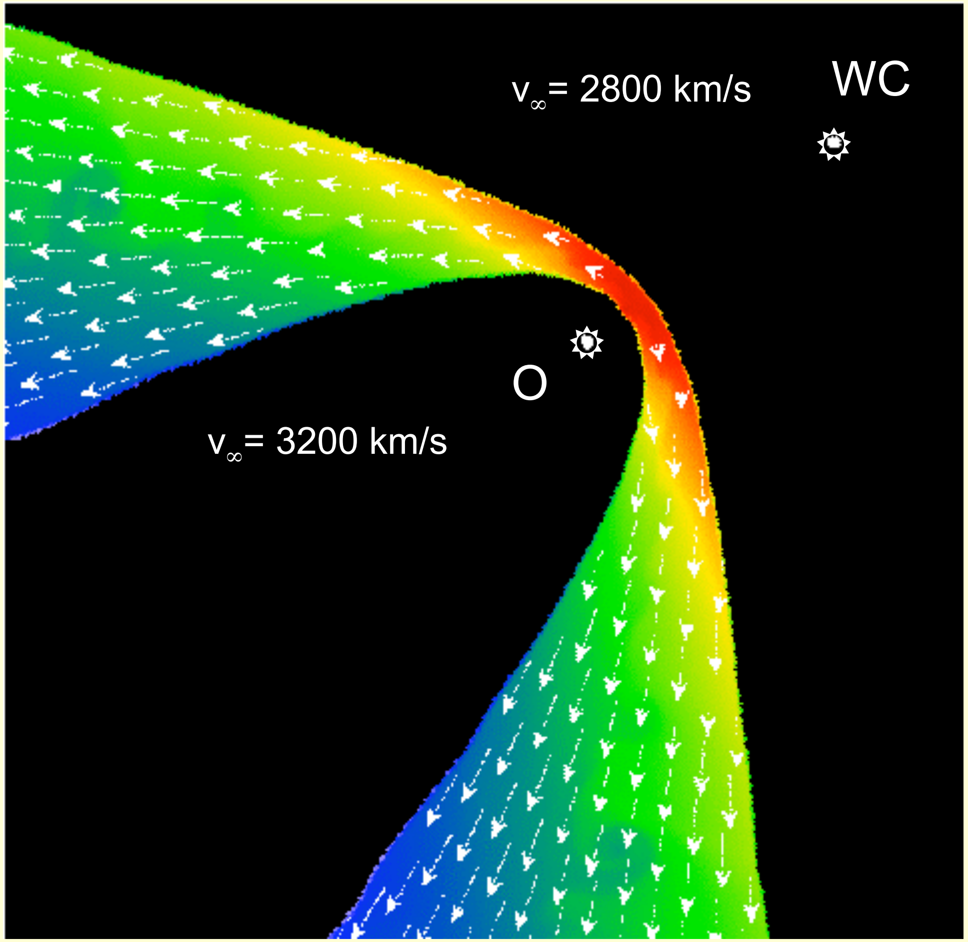


A.M.T. Pollock
XMM-Newton SOC

European Space Astronomy Centre
Villanueva de la Cañada, Madrid, Spain

WR140's colliding-wind shocks

colliding winds ⇔ counter-streaming plasma flows ⇔ well-known boundary conditions {μ,n,v,T}



Stevens, Blondin & Pollock (1992) numerical hydrodynamics

What is it ?

P = 2899±3 days

$a \sin i$ = 14.1±0.5 AU

e = 0.881±0.005

$1-e \leq (D/a) \leq 1+e$

$\rho(1-e)/\rho(1+e) \sim 250$

T0={1985,1993,2001,2009}

What does it do ?

IR outbursts @ T0

non-thermal radio @ !T0

X-rays ∀ T(D,φ)

What's it worth ?

best collisionless shocks in astrophysics

WR140's 2-10 keV X-rays with *RXTE*

D~2AU

D~30AU

D~2AU

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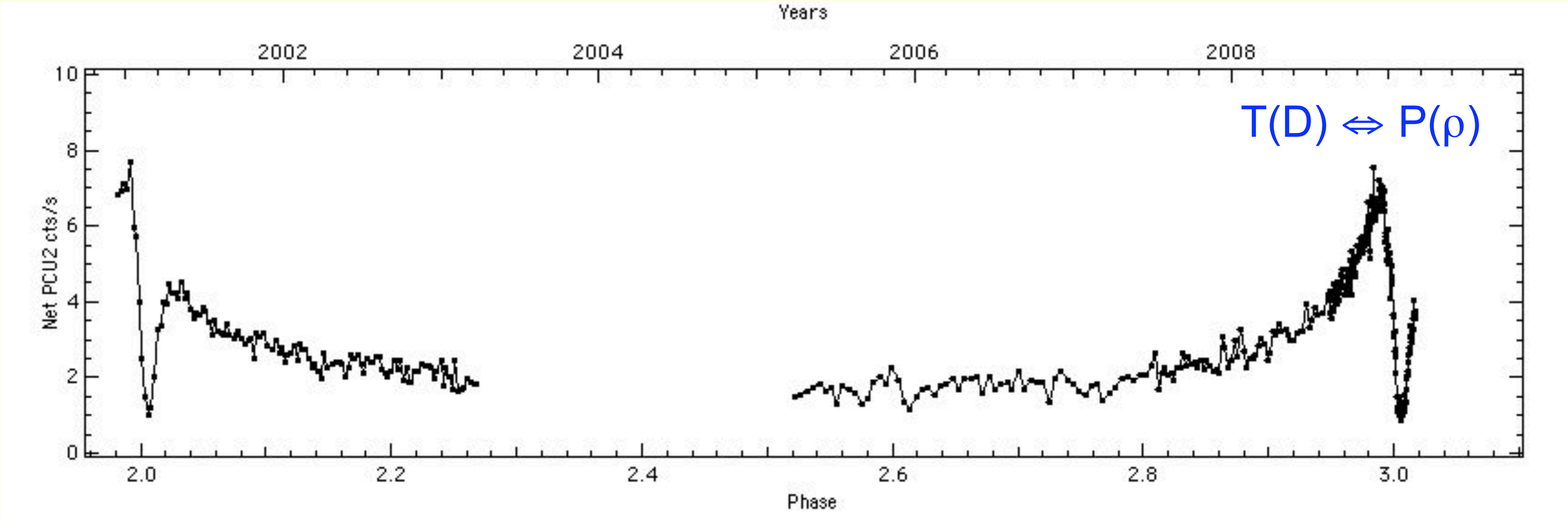


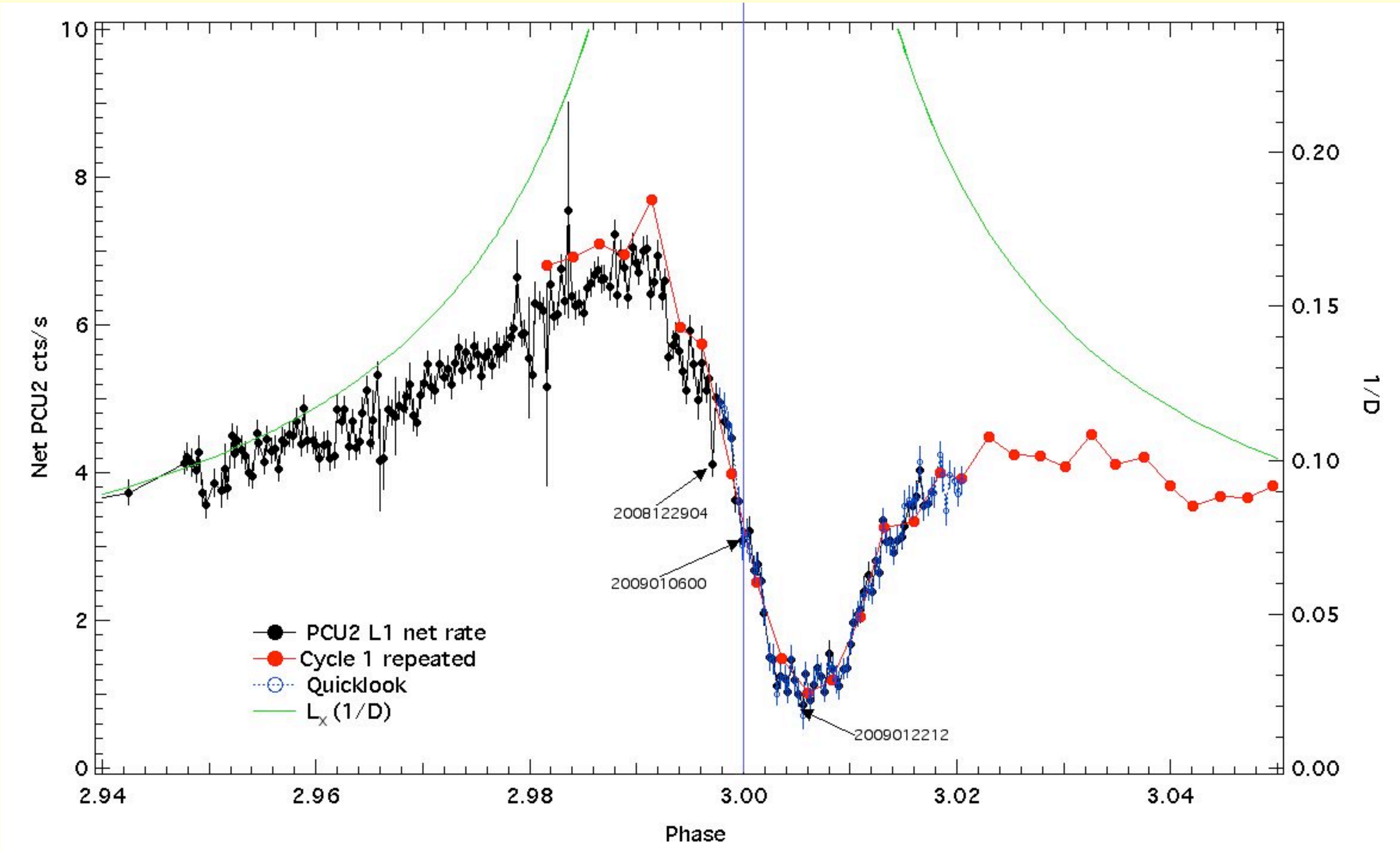
X-rays at low resolution

Plasma dynamics in WR140 et al.

A.M.T. Pollock
XMM-Newton SOC

European Space Astronomy Centre
Villanueva de la Cañada, Madrid, Spain

WR140's 2-10 keV X-rays with *RXTE*



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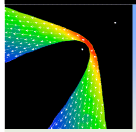
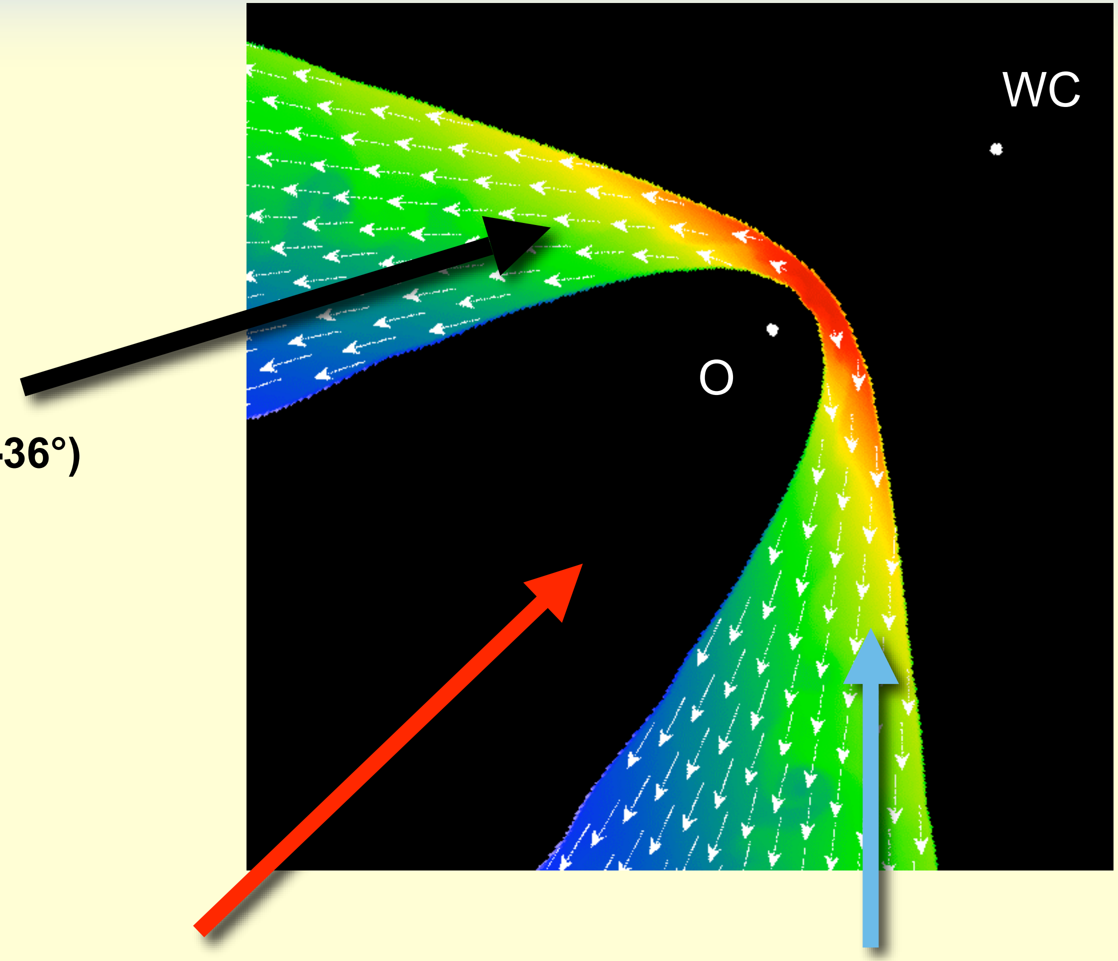


Chandra phase-dependent spectra of WR140



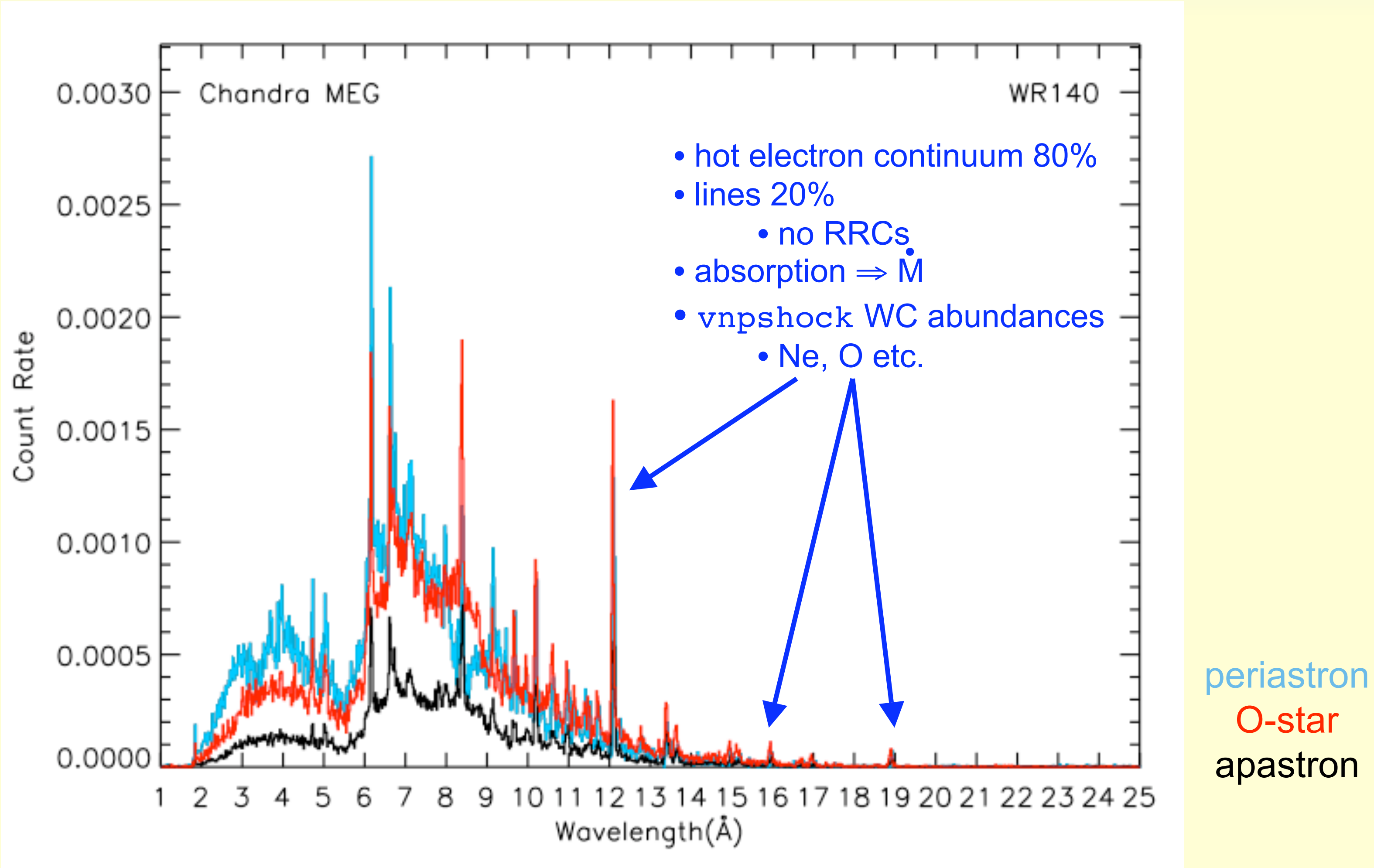
2006-04-01
(φ,D/a,θ)=(2.65,1.77,-36°)
apastron

2008-08-22
(φ,D/a,θ)=(2.95,0.59,+2°)
O-star

2000-12-29
(φ,D/a,θ)=(1.99,0.23,+44°)
periastron

A.M.T. Pollock
XMM-Newton SOC
European Space Astronomy Centre
Villanueva de la Cañada, Madrid, Spain

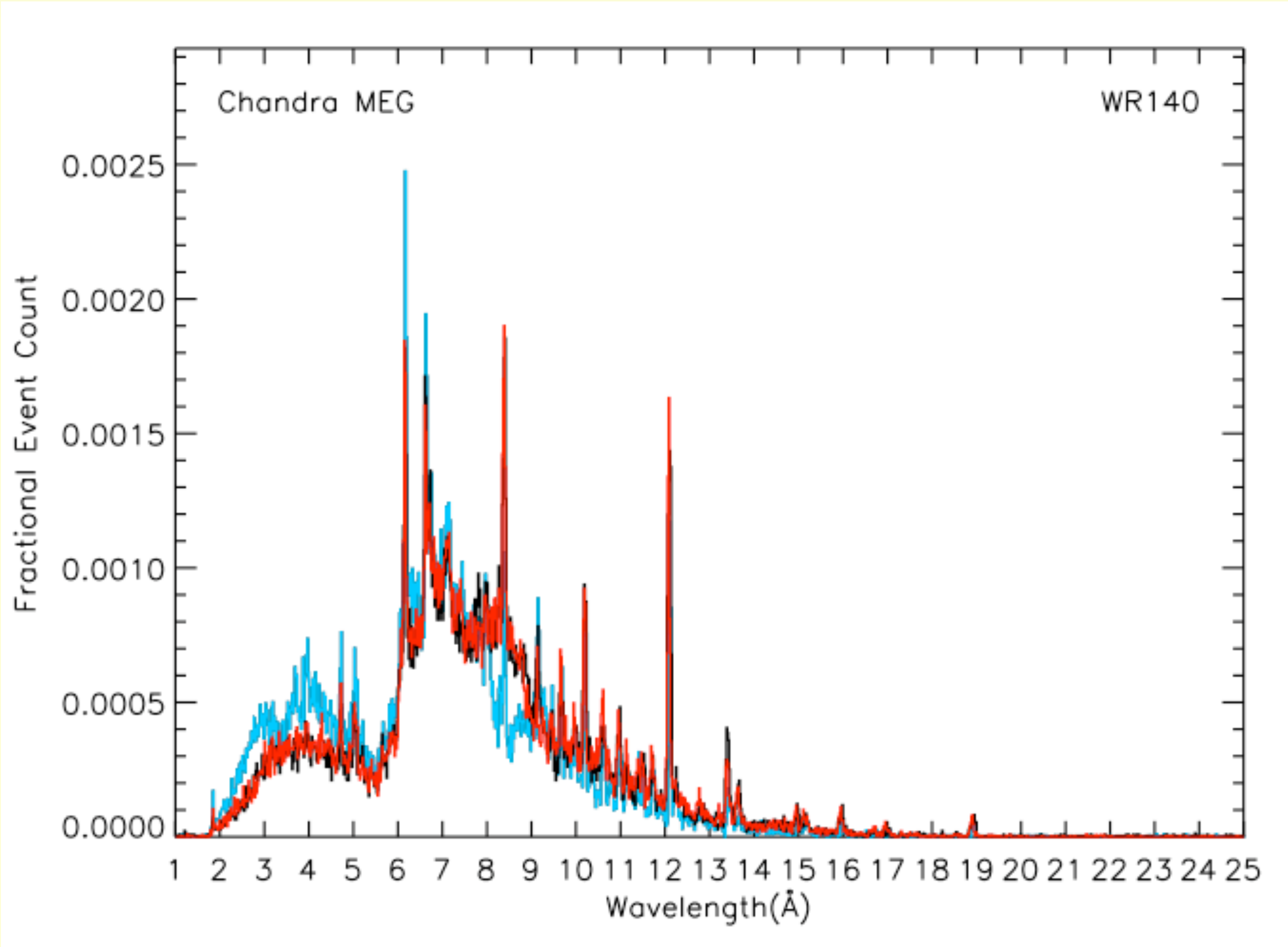
Chandra phase-dependent spectra of WR140



A.M.T. Pollock
XMM-Newton SOC

European Space Astronomy Centre
Villanueva de la Cañada, Madrid, Spain

Chandra normalised spectra of WR140



periastron
O-star
apastron

X-rays at high resolution

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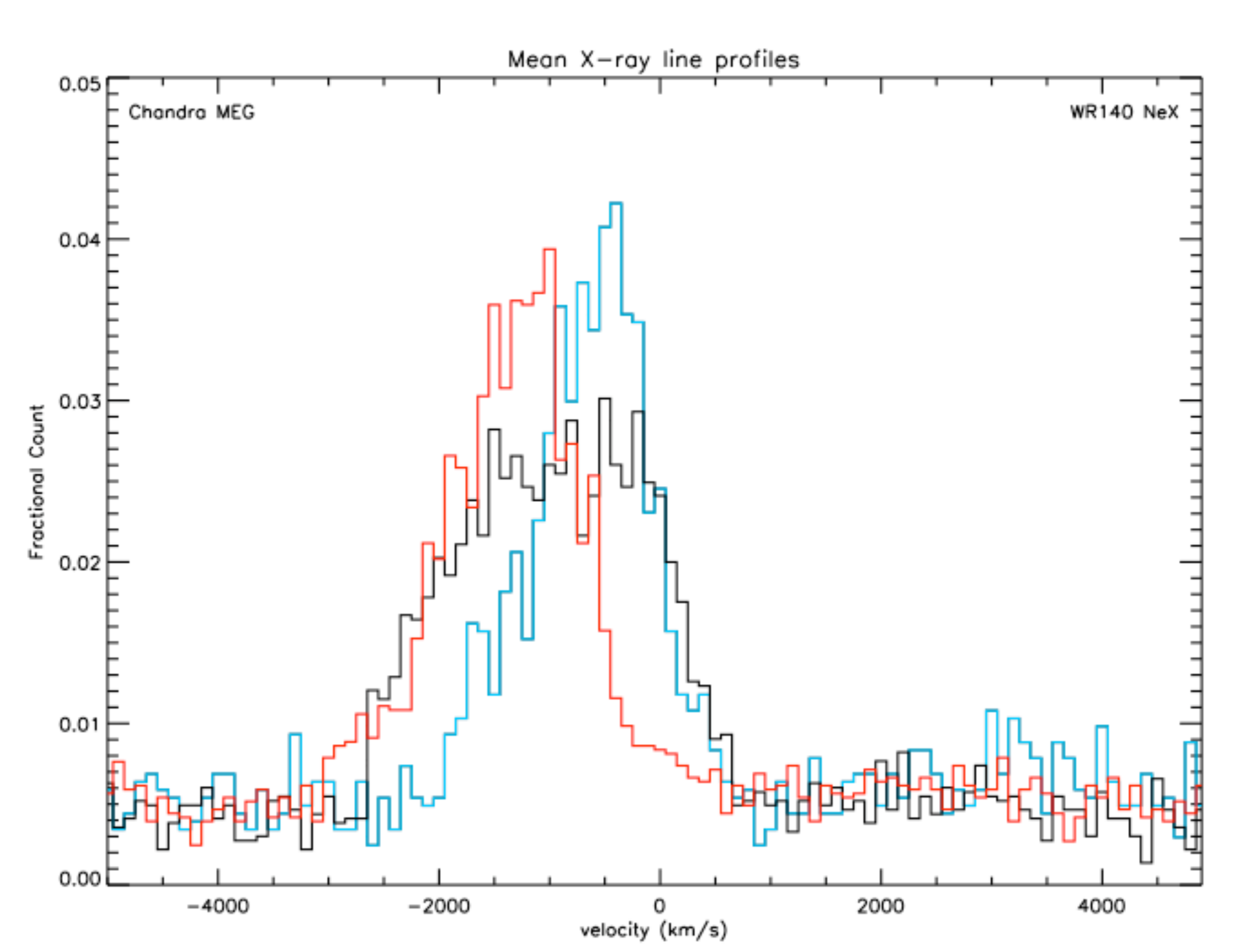
Chandra X-ray NeX line profiles



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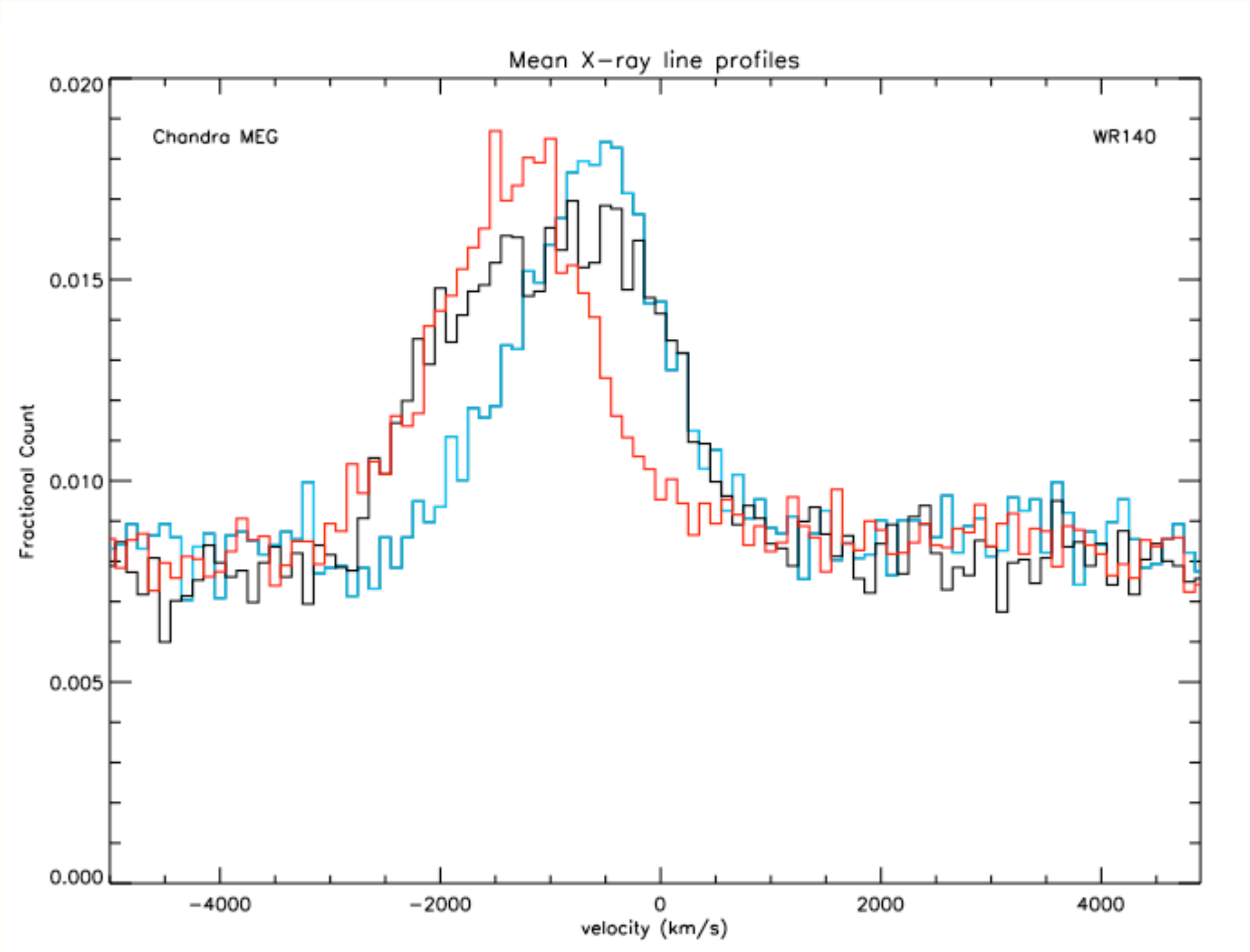
Chandra X-ray mean line profiles



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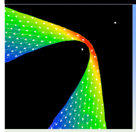


WR140's shocks and post-shocks

☼+☼ Spitzer ⊕ Zel'dovich & Raizer Coulomb-collisional arguments

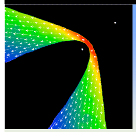
- ☼+☼ $l_{ion\text{-}ion}$ ≈ 14(D/a)^2 AU ⇒ collisionless shocks
- ☼+☼ $l_{ion\text{-}electron}$ ≈ 21(D/a)^2 AU ⇒ free electron heat up slowly
- ☼+☼ $l_{ionization}$ ≈ 8(D/a)^2 AU ⇒ bounds electrons freed slowly

☼+☼ WR140's spectrum looks like a collisional plasma

- ☼+☼ Coulomb collisions are not enough
- ☼+☼ plasma physics ⇔ B
  - ☼+☼ Alfvén waves
  - ☼+☼ wave-particle interactions
  - ☼+☼ Weibel instability
  - ☼+☼ two-stream instability
- ☼+☼ ¬equilibrium
- ☼+☼ charge exchange
- ☼+☼ no ionization precursor

☼+☼ Analogues

- ☼+☼ SNR
- ☼+☼ solar wind ↯ magnetosphere



IXO colliding-wind basic physics manifesto

- X-ray orbits and eclipses
  - WR140, η Carinae, WR25, (γ Velorum)
  - WN
    - WR21a, WR133
  - WC
    - WR79, WR93
- Incorporate collisionless plasma physics
- Scotch hydrodynamical models including the “contact discontinuity”
- Identify the source of electron heating
- Calculate post-shock ionization including charge exchange
  - chemical composition ⇔ stellar evolution
- Reproduce the observed X-ray line velocity profiles
  - *cf* Analytical model of Cantó, Raga & Wilkins 1996, ApJ, 469, 729
- Binary rotation
  - *cf* Athena 3-D numerical model of LeMaster, Stone & Gardiner, 2007, ApJ, 662, 582