WR25 & WR140 in X-ray relation to η Carinae

with data from
RXTE, Swift XRT, XMM-Newton EPIC-MOS, Chandra HETG

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G2G with WR140
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X-ray bright Wolf-Rayet binaries

WR 25
- η Carinae’s next-door neighbour
- \( V = 7 \) m
- WN6ha+O
- Gamen+ optical radial velocity orbit
  - \( P = 0.569 \) years
  - \( e = 0.595 \)
  - \( \text{asini} = 2.4 \) AU
  - \( T_0, \omega, \text{etc.} \)

WR 140
- \( V = 7 \) m in Cygnus
- WC7+O5
- Marchenko+ optical radial velocity orbit
  - \( P = 7.94 \) years
  - \( e = 0.881 \)
  - \( \text{asini} = 14.1 \) AU
  - \( T_0, \omega, \text{etc.} \)

X-rays from WR 25 & WR 140
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WR 25’s $L_X$-$N_X$ history

XSPEC> model const(\phi) * abs(\phi) * S_x * ISM

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Ingredients for a tractable X-ray model of WR 25

- Gamen+’s optical radial velocity orbit
- orbital inclination
- WN6ha stellar parameters
  - mass-loss rate
  - abundances
  - wind velocity
  - stellar radius
- O stellar parameters
  - mass-loss rate
  - abundances
  - wind velocity
  - stellar radius
- X-ray emitting surface
  - not a point source ⇒ Cantó, Raga & Wilkin (1996)
- Empirical $L_X(D)$
- 50-parameter Xspec local model
  - 77 XMM EPIC-MOS and Swift XRT spectra
    - 3850 parameters
Cantó, Raga and Wilkin (1996) surface

\[ \theta_1 \cot \theta_1 = 1 + \beta(\theta \cot \theta - 1) \]

- 2D ⇒ 3D
- WR-star
  - absorption
  - eclipse
- O-star
  - absorption
  - eclipse
- line velocity profiles

\(\bigcirc\) no Coriolis forces
\(\bigcirc\) not a thin shell

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Change of variable ⇒ $L_X(D)$ (cf CWB 1/D)

XSPEC> model const(φ)*abs(φ)*$S_X*$ISM
CRW-3D eclipse and 1keV absorption in WR 25

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CRW-3D “minimum” radius for WR 25

- \( R_{WN6ha} \geq 49 \, R_\odot \) (50% higher than HGL(2006))
- \( \frac{dM}{dT} = 2.7 \times 10^{-6} \, M_\odot \, yr^{-1} \) (20x lower than HGL(2006))
- inclination fixed at 90°
- Gamen+ orbital parameters relaxed
- C-statistic = 36505.65 using 44139 bins and 44131 degrees of freedom
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

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WR140’s 2-10 keV X-rays with RXTE

\[ T(D) \leftrightarrow P(\rho) \]

X-rays at low resolution

X-rays from WR 25 & WR 140
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WR140 with RXTE through the 2009 event

X-rays at low resolution
Also Swift XRT, Suzaku & XMM

X-rays from WR 25 & WR 140
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WR140 with RXTE through the 2009 event

\[ \text{XSPEC} > \text{model} \ const(\phi) \times \text{abs}(\phi) \times S_x \times \text{ISM} \]

\[ N_x(\text{WR140}) > 50 \ N_x(\text{WR25}) \]

X-rays from WR 25 & WR 140

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Change of variable $\Rightarrow L_X(D)$ (cf CWB 1/D)

XSPEC> model const(ϕ)*abs(ϕ)*S_X*ISM

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Chandra phase-dependent grating spectra of WR140

2006-04-01
(φ,D/a,θ)=(2.649,1.77,-36°)
apastron

2008-08-22
(φ,D/a,θ)=(2.951,0.59,+2°)
O-star

2000-12-29
(φ,D/a,θ)=(1.987,0.23,+44°)
periastron

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Chandra phase-dependent spectra of WR140

- hot electron continuum 80%
- lines 20%
  - no RRCs
- vnp shock WC abundances
  - Ne, O etc.

X-rays at high resolution

X-rays from WR 25 & WR 140

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Chandra normalised spectra of WR140

X-rays at high resolution

X-rays from WR 25 & WR 140

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WR140’s shock and post-shock physics

✧✧✧ Spitzer ⊕ Zel’dovich & Raizer Coulomb-collisional arguments
  ✧✧✧ $I_{\text{ion-ion}} \approx 14(D/a)^2 \text{ AU} \Rightarrow \text{collisionless shocks}$
  ✧✧✧ $I_{\text{ion-electron}} \approx 21(D/a)^2 \text{ AU} \Rightarrow \text{free electron heat up slowly}$
  ✧✧✧ $I_{\text{ionization}} \approx 8(D/a)^2 \text{ AU} \Rightarrow \text{bounds electrons freed slowly}$

✧✧✧ 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

✧✧✧ cf SNR & solar wind ↗ magnetosphere
Chandra X-ray NeX line profiles

cf Henley+ (2003) and CRW-3D

X-rays at high resolution

X-rays from WR 25 & WR 140

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Chandra X-ray mean line profiles

Mean X-ray line profiles

X-rays at high resolution
X-rays from WR 25 & WR 140
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WR140 X-ray implications and complications

- P=2896d?
- X-ray spectra nearly identical in shape at φ=2.649 and φ=2.951
- X-ray eclipse started slowly
  - soon after O-star conjunction
  - well before quadrature
- shocked WC and O5 material mix
- line profiles combine bulk and random components
  - width(IP)
  - affected by stellar eclipses
Interim lessons from WR25 & WR140

- Eclipses of extended CWB X-ray sources
  - WR wind
  - WR star
- Out of eclipse
  - No obvious flares
  - Significant departures from $L_{\times}(D) \propto 1/D$
- Collisionless plasma looks collisional
  - shocked WR and O-star material mix
  - collisionless ionization?