Shocking Truth about Massive Stars

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ACIS Raw Detector Image of O-type supergiant ζ Puppis, CXO archive

Chandra’s First Decade of Discovery
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Massive Stars and Stellar Winds

Initial mass $M_\ast > 15M_\odot$

Main Sequence: OB-type

Fast evolution (~Myr) $\rightarrow$ trace star formation

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

Photon momentum $\rightarrow$ acceleration of matter

Radiative acceleration larger than gravitation $\rightarrow$ supersonic STELLAR WIND
OB stars are X-ray active (Einstein observatory 1978)

Hot stars: radiatively driven stellar winds

Supersonic stellar winds are intrinsically unstable

Shocks also result from:
- Collision of streams in magnetically confined wind
- Collision of winds in binaries
X-Ray Spectroscopy of Massive Stars

Prediction of hydrodynamic models

Models predict:
- X-ray emitting plasma \((T_X = 1\ldots10 \text{ MK})\) permeated with warm \((T = 10 \text{ kK})\) absorbing wind
- X-rays originate at few \(R_*\) from the core

X-ray spectroscopy is needed!
Chandra is in Orbit!!!

Cheering crowd ➔

Photo: G. Emerson, E.E. Barnard Observatory

First grating x-ray Sp of OB stars
O-type stars
Analyses of the HETGS spectra

Temperature
- Range from 2 MK to 10 MK

Emission line profiles
- Broad; width scales with wind speed
- Line formation: deep in the wind
- Similar across the spectrum
- Clumped wind treatment is needed

FIR line ratios
- Formed close to the photosphere
- Temperature decreases outward

Abundances
- Agree with wind abundances
Wind-shock Theory has Predictive Power

UV and X-ray spectra
UV and X-ray spectra
PV resonance doublet →
Mass-loss rates!

X-ray line profiles
X-ray spectra

DEM distribution

Krticka et al. 2009

Oskinova et al. 2007

Oskinova et al. 2007
Chandra observations of $\alpha$ Cru

- X-ray brightest massive star on sky
- B0.5IV+BV at d=98 pc
- Companion B1V
- Soft spectrum $T_X = 1..3$ MK

Oskinova et al. in prep.
Stationary plasma in B-stars

- Wind speed is 1500 km/s
- But lines are narrow Comparable to instrumental profile!
- He-like ions: f/i line ratio probes distance to stellar photosphere

X-ray plasma in B-stars

- Close to the photosphere
- Stationary
  Different from shocks in O-type winds
  Pulsations? Coronae?
The evolution of (very) massive stars

Mass removal by wind drives the evolution

- OB $\rightarrow$ (short LBV) $\rightarrow$ WR
- Winds are getting dense and more enriched
- Wolf–Rayet (WR) stars

WN $\rightarrow$ WC $\rightarrow$ WO $\rightarrow$ SN

Credit: NASA/CXC/SAO/F.Seward et al
WR124
WN8-type
Observed serendipitously by Chandra
WN8 stars are X-ray quiet

Image courtesy of D.Ducros and ESA
X-ray view on Wolf-Rayet Stars

- Not all WN-type stars emit X-rays. Lack of X-rays cannot be attributed only to the wind opacity (Oskinova et al. '06)

- X-ray spectra of single WN stars are harder than spectra of O-stars (Ignace et al. 2003)

- Single WC stars are X-ray quiet (Oskinova et al. 2003)

- X-ray bright WR stars are binaries (Oskinova & Hamann 2008)
Closest WO-type Star WR142 in the Star Cluster Berkeley 87

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

- Only three WO stars are known in the MW
- WO is the latest possible evolutionary stage of massive star
- Core-collapse within 10 000 yr
- Strongly influence their environment

Oskinova et al. in prep.
Glimpse at the pre core-collapse star

- Requires state-of-the-art non-LTE models to fit observed optical and UV spectra. Such as PoWR code (Hamann et al. 2006)
- $T_\ast = 160 \text{ kK}, \quad R_\ast = 0.5R_\odot$, wind speed $v = 6000 \text{ km/s}$
- Our analysis indicates that star may be a **FAST ROTATOR** $V_{\text{rot}} \sin i = 4000 \text{ km/s}$. **Current mass $\sim 10 \, M_\odot$**
Discovery of X-ray emission from a WO-type star

- Strong enhancement by CO winds should be very opaque for the X-rays
- X-rays are too hard to be explained by wind shocks
- Hint on the presence of magnetic field $B(r=2R_*) > 7$ kG
- Chandra detects hard X-rays from another compact fast rotator WR2 (WN2)

Oskinova et al. (2009)
Mystery of X-rays from WR stars: Connection With Collapsars (?)

**Abstract**

The optical afterglow of the gamma-ray burst GRB 970508 ($z = 0.835$) was a few hundred times more than any supernova. Therefore, the name “hypernova” is proposed for the whole GRB/afterglow.

A very energetic explosion of a massive star is likely to create a... fireball.... the inner core of a massive, rapidly rotating star collapses into a $\sim 10 \, M_\odot$ Kerr black hole ... A superstrong $\sim 10^{15}$ G magnetic field is needed to make the object ... a microquasar. Such events must be vary rare...to account for the ... GRBs”

Do we indeed observe in our Galaxy massive, magnetic, rapidly rotating stars on latest stages of their evolution?
Shocking truth?

- O-stars: X-rays are generated by wind shocks
- B-stars: not clear: magnetic fields, pulsation, winds.
- WR-stars: no hi-res spectrum exists! Magnetic field, rotation.

- X-rays are sensitive probe of stellar winds
- Generation of X-rays in stellar winds is important physical problem
- X-rays provide insights in stellar structure and evolution