Colliding winds in Wolf-Rayet binaries: The γ-ray perspective

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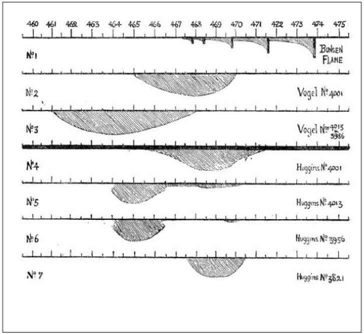
Outline

Introduction: Wolf-Rayet (WR) stars

- Discovered by Charles Wolf and Georges Rayet in 1867 using the 40cm Foucault telescope at the Paris Observatory
- Show broad emission lines of He, N, O and C
- Classification into subtypes depending on:
  - strong spectral lines i.e. WN, WC/WO
  - their evolutionary state (early/late) i.e WNL, WCE
  - ...
- 227 known WR stars in our galaxy

Introduction: Wolf-Rayet (WR) stars



[Huggins; 1890]

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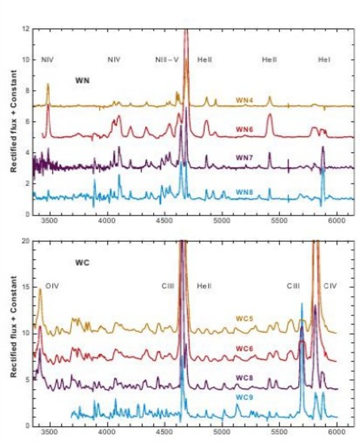

[P.A.Crowther; 2007]

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Introduction: WR stars

Lifetime cycle

$M_O \gtrsim 75\ M_\odot$:

O $\rightarrow$ WN(H-rich) $\rightarrow$ LBV $\rightarrow$ WN(H-poor) $\rightarrow$ WC $\rightarrow$ SN Ic

$M_O \sim 40\text{-}75\ M_\odot$:

O $\rightarrow$ LBV $\rightarrow$ WN(H-poor) $\rightarrow$ WC $\rightarrow$ SN Ic

$M_O \sim 25\text{-}40\ M_\odot$:

O $\rightarrow$ LBV/RSG $\rightarrow$ WN(H-poor) $\rightarrow$ SN Ib

- Stage in the evolution of massive O-type stars
- Lifetime: $\sim 10^5$ yrs
- Physical properties:
  - $M_{wr} \sim$ 10-25 $M_\odot$
  - $T \sim 3 \cdot 10^4$-10^5 K
  - $L \sim 2 \cdot 10^5$-10^6 $L_\odot$
  - $B \sim 10 - 10^2$ G
- Observed binary fraction: 40%

Introduction: Stellar winds of WR-stars

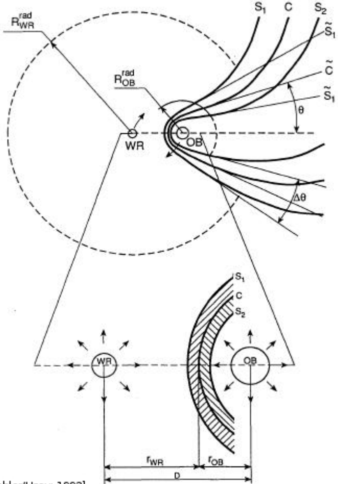
Line driven winds in WR Stars

- Abundance He and "metals" (O, C, N etc.)
  $\rightarrow$ absorption of UV photons
- Doppler-shift of absorption lines
  $\rightarrow$ absorption of undiminished continuum photons
- Extreme flux of E-UV radiation
  $\Rightarrow$ intense line driven winds

- Strong line driven winds
- High terminal velocities
  $v_\infty \sim 3 \cdot 10^2$-$6 \cdot 10^3$ km s^{-1}
- High mass loss rates
  $\dot{M} \sim 10^{-5}$-10^{-4} M$_\odot$
- Energy $\sim 10^{31}$ $\frac{\text{J}}{\text{s}}$
- Colliding winds in WR-binaries
  $\rightarrow$ shock front
  $\rightarrow$ particle acceleration
  $\rightarrow$ IC scattering on photon fields
  $\rightarrow$ ...

$\Rightarrow$ γ-ray emission?

Theory: Geometry



[Eichler/Usov; 1993]

Location of shock front

$$p_{wr} = \rho\left(r_{wr}\right)\left(v_{\infty}^{wr}\right)^2 = \rho\left(r_{ob}\right)\left(v_{\infty}^{ob}\right)^2 = p_{ob}$$

Assuming a spherical stationary wind

$$\Rightarrow \rho\left(r\right) = \frac{\dot{M}}{4\pi r^2 v\left(r\right)}$$

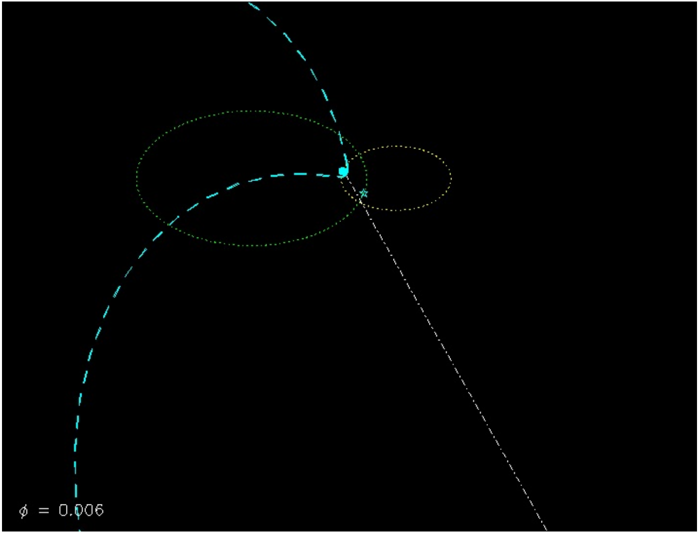
Resulting distances

$$r_{wr} = \frac{1}{1+\sqrt{\eta}}D, \quad r_{ob} = \frac{\sqrt{\eta}}{1+\sqrt{\eta}}D$$

with

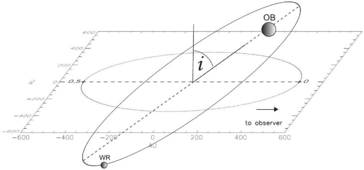
$$\eta = \frac{\dot{M}_{ob} v_{\infty}^{ob}}{\dot{M}_{wr} v_{\infty}^{wr}}$$

Theory: Geometry

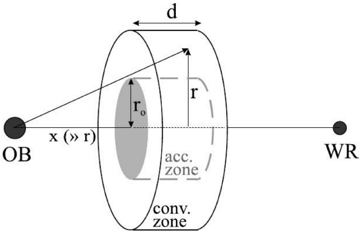


Animation of WR140 orbital motion

Theory: Model for γ-ray emission



[A./O. Reimer; 2009]



[A./O. Reimer, Pohl; 2006]

- Simplifying assumptions
  - uniform wind,
  - cylindrical emission region
  - target photon field monochromatic
  - ...

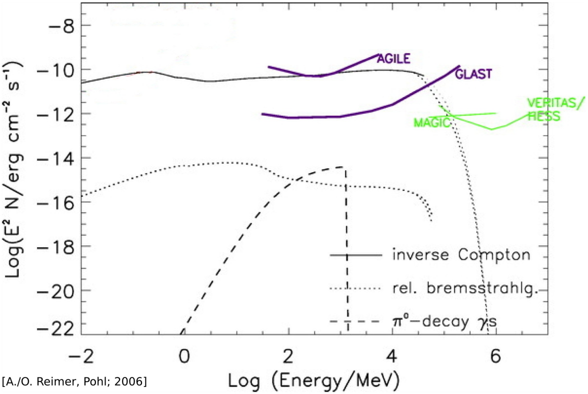
  $\Rightarrow$ allows analytical treatment
- Solution of continuity equations
  $\Rightarrow$ emitting particle spectrum
- mechanisms for γ-ray production:
  - IC scattering
  - relativistic bremsstrahlung
  - π^0-decay

Theory: Model for γ-ray emission

γ-ray flux is determined by:

- Photospheric luminosity
- Temperature
- Mass and momentum loss rates
- Stellar separation
- Distance

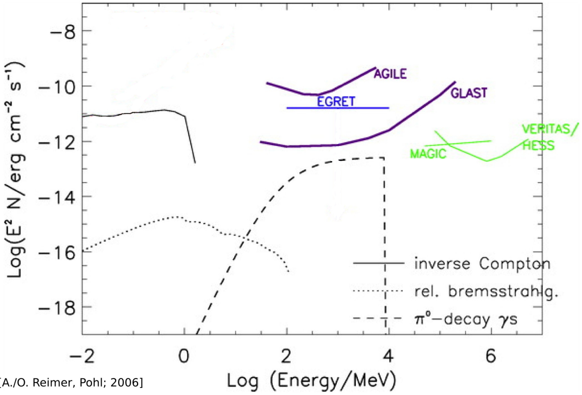
Theory: Flux modeling



[A./O. Reimer, Pohl; 2006]

Spectral energy distribution of WR140 $[\phi = 0.671]$

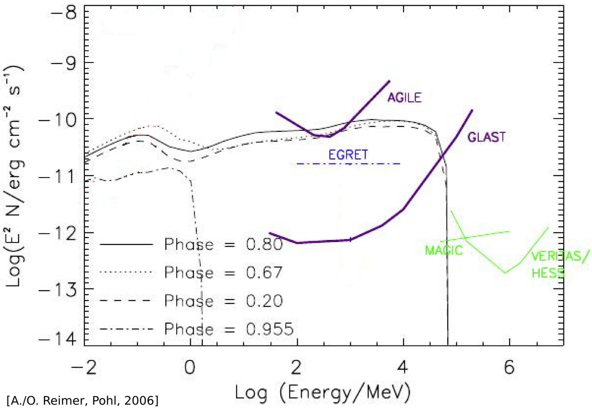
Theory: Flux modeling



[A./O. Reimer, Pohl; 2006]

Spectral energy distribution of WR140 $[\phi = 0.955]$

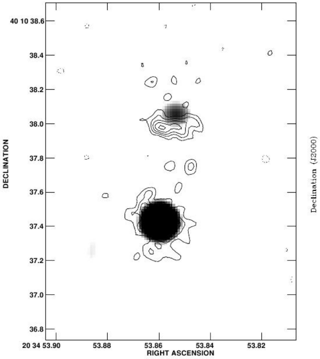
Theory: Flux modeling



[A./O. Reimer, Pohl, 2006]

IC spectra of WR140 depending on ϕ

Indicators: Multi-spectral observations



[Dougherty; 2002]

- Some WR-binaries show strong non-thermal radio emission
  - spectral index ≤ 0
  - high brightness temperature $T_B \sim 10^6 - 10^8$

$\Rightarrow$ synchrotron radiation of relativistic e^-

- X-ray emission of WR147
  - 1-2 keV emission region corresponds with Colliding Wind Region
  - information about physical conditions of hot plasma behind shock

$\Rightarrow$ may give constraints on model parameters

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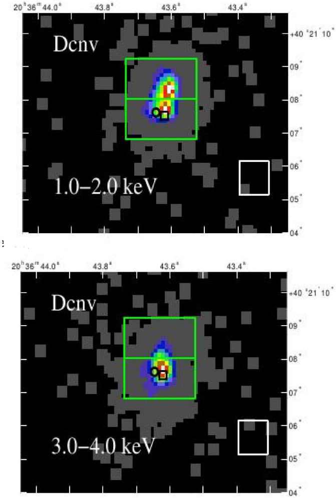

[Zhekov, Park; 2009]

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Summary

- Colliding stellar winds in WR-binaries offer conditions to study physical processes, i.e first order Fermi acceleration etc.
- Radio and X-ray observations are strong evidence of non-thermal particles and hot plasma in the Colliding Wind Region
  - $\Rightarrow$ conditions for γ-ray emission
- *Fermi* data will (hopefully) answer the question of γ-ray emission from colliding wind Wolf-Rayet binaries

Questions?