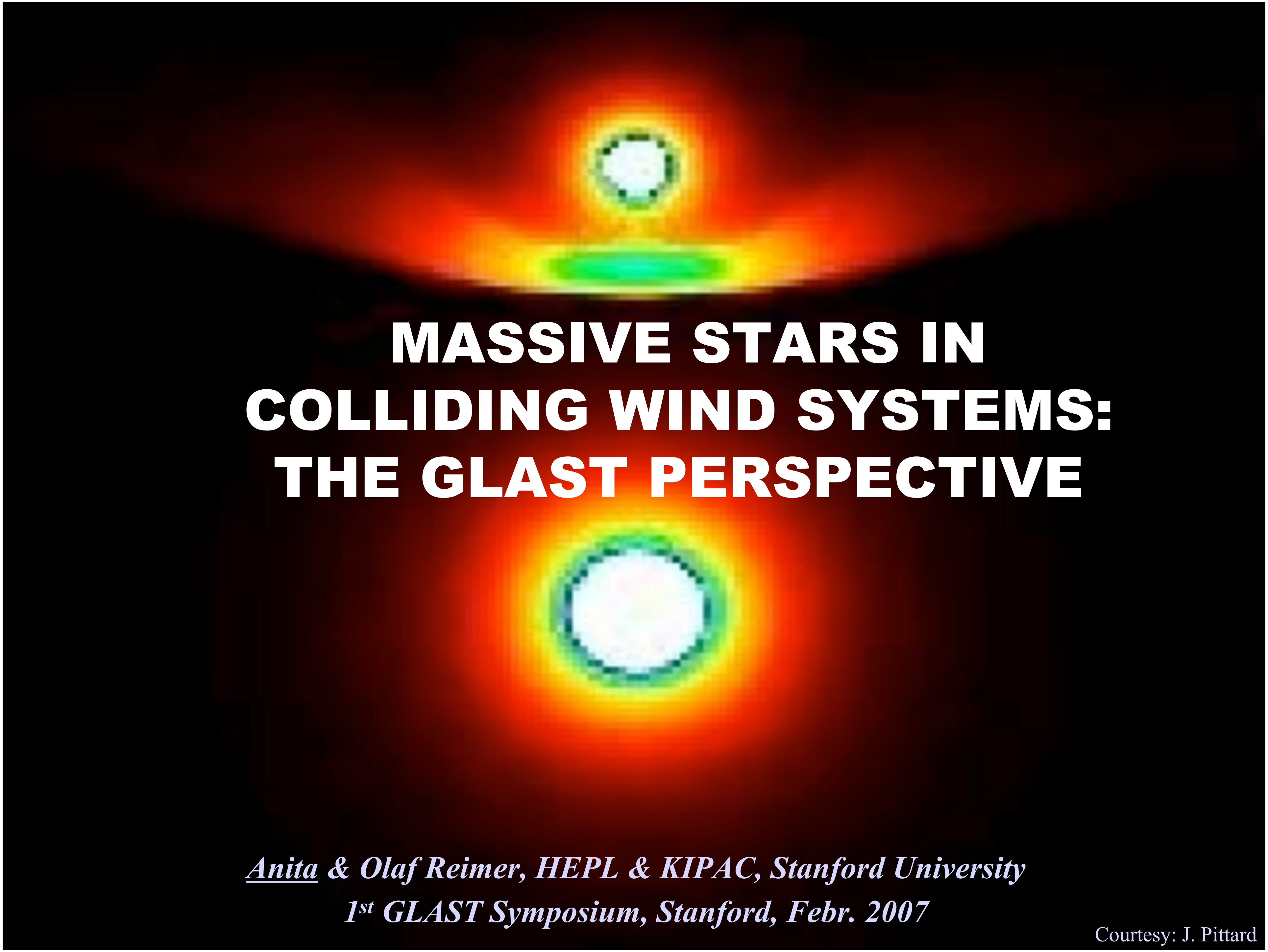

# MASSIVE STARS IN COLLIDING WIND SYSTEMS: THE GLAST PERSPECTIVE

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*1st GLAST Symposium, Stanford, Febr. 2007*

Courtesy: J. Pittard

# Massive Stars ...

... are **hot** (T~3...6 $10^4$K), **massive** ($M \sim 20...80\ M_o$) & **luminous** ($L \sim 10^{6\text{-}5} L_o$)

... show **large mass loss rates in stellar winds:** $\dot{M} \sim 10^{-6...-4}\ M_o/yr$

... possess **supersonic winds:** $V(x) \approx V_\infty(1-R_\star/x)$, $V_\infty \sim 1...5 \times 10^3$ km/s

⇨ **various kinds of shocks/instabilities:**

- **Intra-Wind interactions:**

  „clumps", shocks from line-driven instabilities („chaotic wind model")

- **Wind-ISM collisions**
- **Wind-Wind collisions**
- **Collective effects of stellar winds:**

  large scale shocks at core of association (e.g. Bykov et al. 1992)

# Motivation

***Gamma-rays ⇒ non-thermal relativistic particle distribution required***

• **R**adio **synchrotron radiation** from collision region

„proof“ for: existence of **relativistic e$^-$ &** B-**field**

⇒ **inverse Compton (IC) scattering in photosph. radiation field & relativistic e$^-$-bremsstrahlung are garantueed HE processes !**

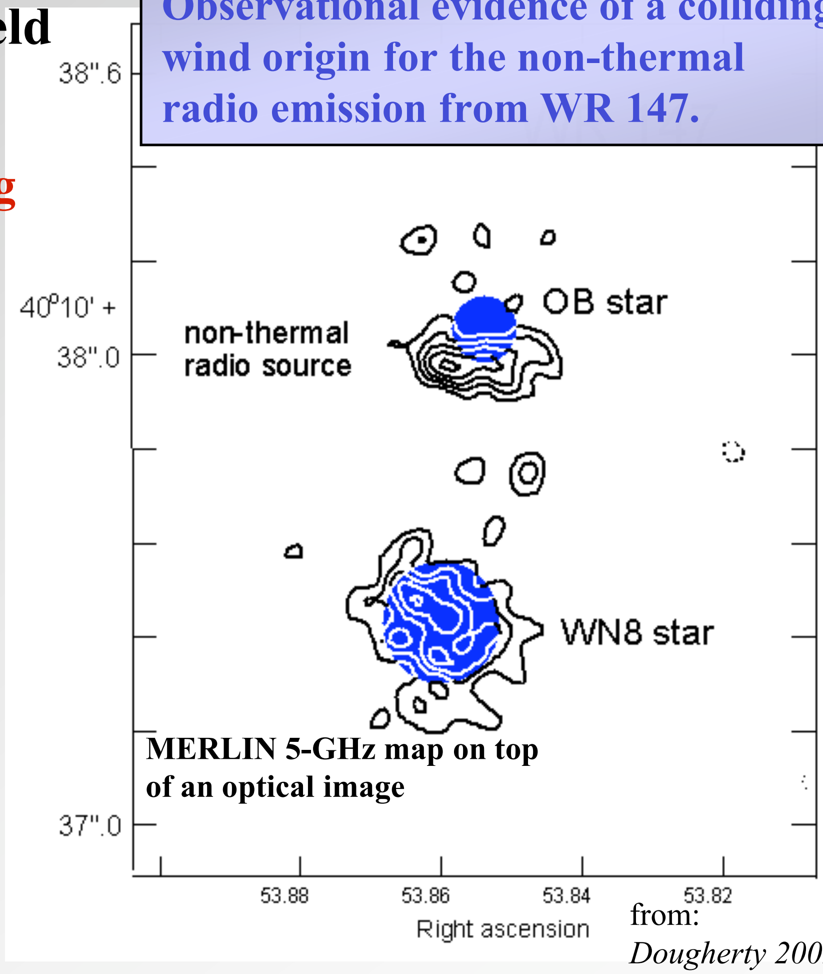
**>14 galactic NT radio emitting WRs known**

$\alpha_{radio} \sim +0.3\ldots-1.3, \quad F_\nu \sim \nu^{-\alpha}$

• Population studies imply **correlation of some still unidentified γ-ray sources (Unids) with massive star populations** (OB-associations, WR-, Of-stars, SNRs)

*[Montmerle 1979, Esposito et al. 1996, Romero et al. 1999, …]*

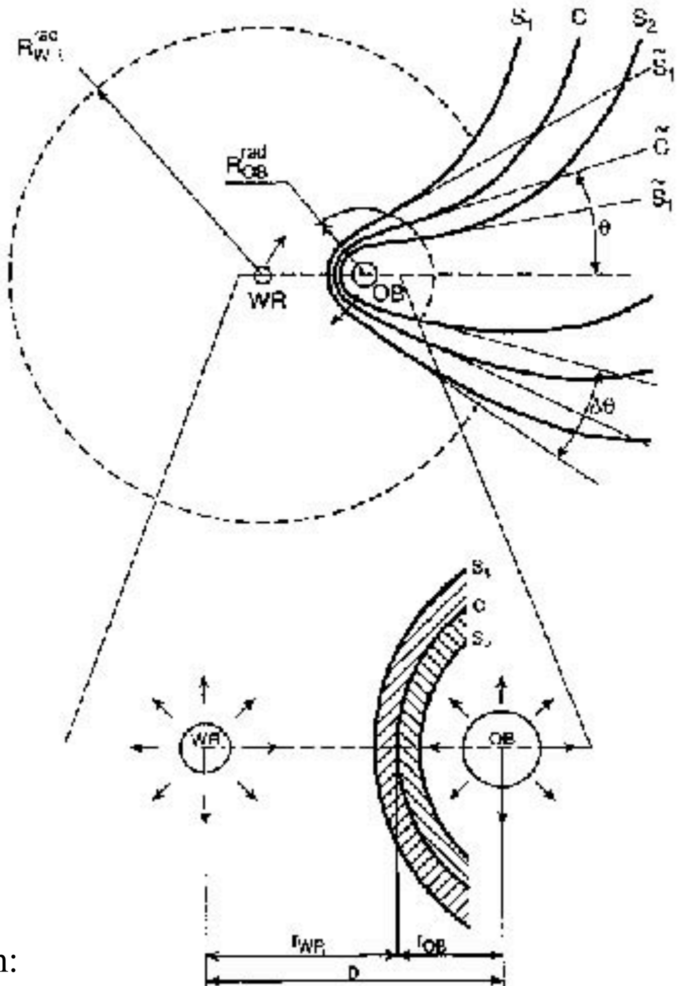
**Observational evidence of a colliding wind origin for the non-thermal radio emission from WR 147.**




**MERLIN 5-GHz map on top of an optical image**

from: *Dougherty 2002*

# A schematic view on a COLLIDING WIND REGION




from:
*Eichler & Usov 1993*

Wolf–Rayet period characterization and distribution

| Period (d) | Characterization | $N_{WN}$ | $N_{WC}$ |
|---|---|---|---|
| $P<1$ | very-short-period binary | 3 | 1 |
| $1<P<10$ | short-period binary | 15 | 9 |
| $10<P<100$ | medium-period binary | 8 | 5 |
| $100<P<1000$ | long-period binary | 3 | 3 |
| $1000<P<10000$ | very-long-period binary | 2 | 7 |
| $10000<P$ | extremely-long-period binary | 1 | 1 |

**$D \sim 3 \ldots 10^5 R_o$**

**Stagnation point** (ram pressure balance):

$$r_{OB} = x = \frac{\sqrt{\eta}}{1+\sqrt{\eta}} D \qquad \text{with} \quad \eta = \frac{\dot{M}_{OB} V_{\infty,OB}}{\dot{M}_{WR} V_{\infty,WR}}$$

→ **$\eta \ll 1$** for WR-binaries

**Magnetic field:**

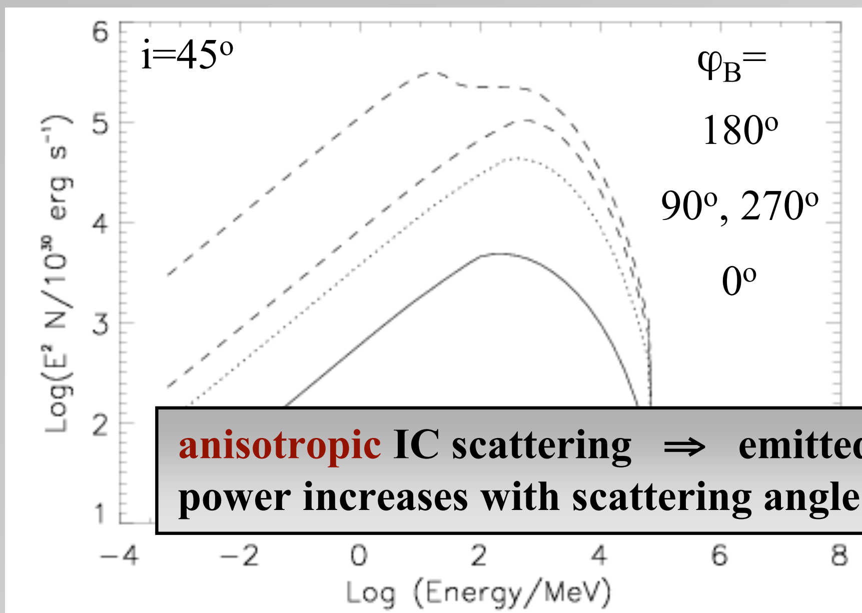
**estimated surface magnetic field: $B_S \sim 10\text{-}10^4$G**

*[Ignace et al. 1998; Mathys 1999; Donati et al. 2001,2002]*

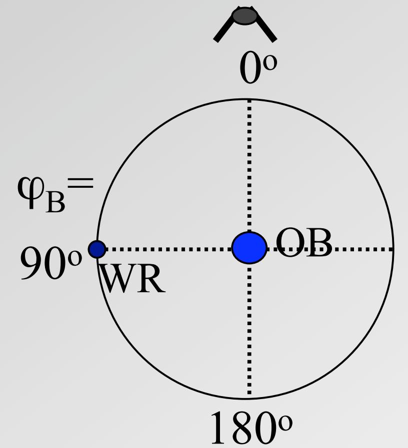
→ **> mG-fields at tenths of pc**

# Constituting the γ-ray output: Operating processes

- **Inverse Compton scattering of stellar photons (anisotropic!, KN-effects?)**




**anisotropic IC scattering ⇒ emitted power increases with scattering angle !**

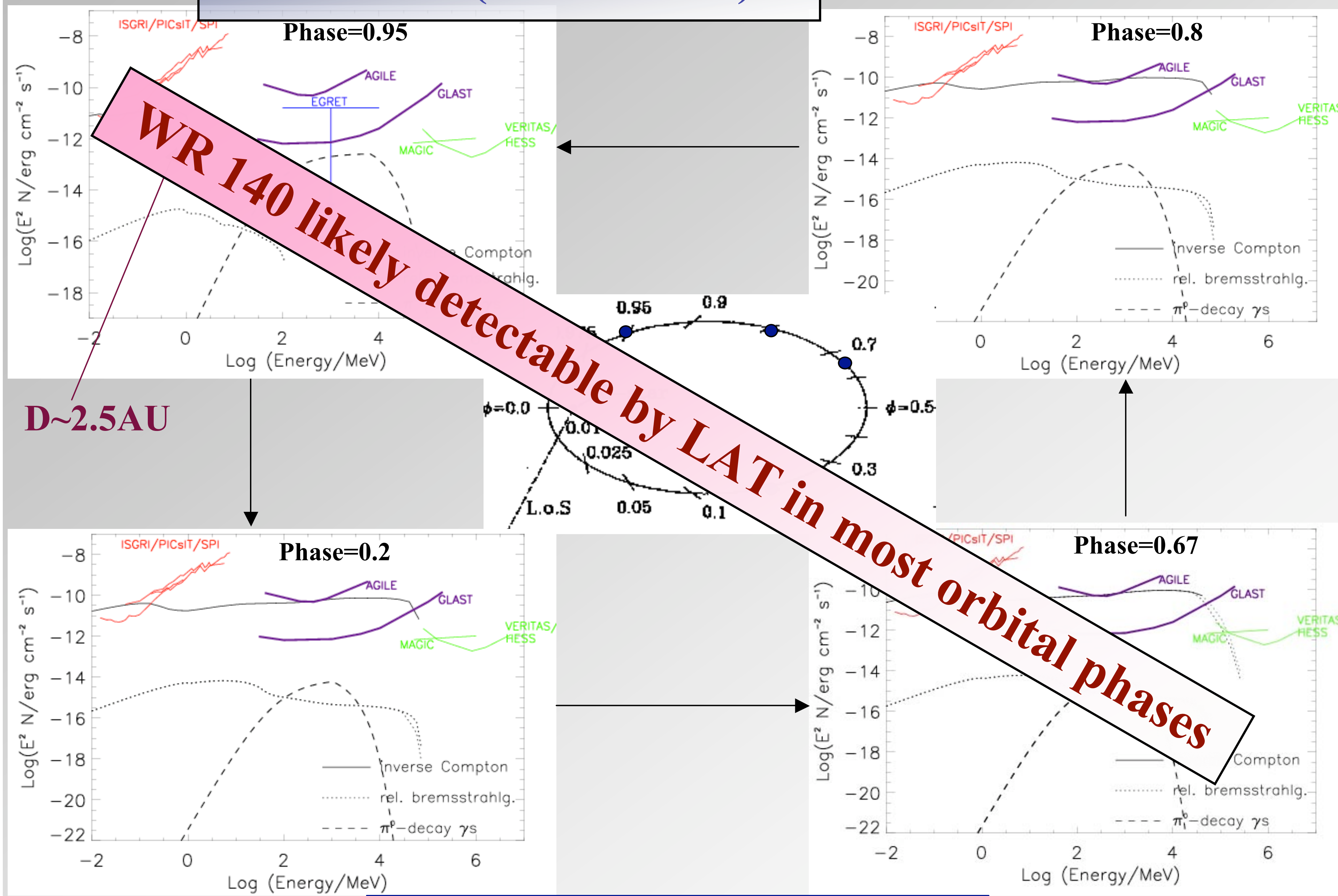



**⇒ orbital variation of IC radiation expected from wide WR-binaries**

- **Relativistic bremsstrahlung**
- **NN/pp inelastic scattering**
- **γ-ray absorption due to γγ pair product.:** $E_{\gamma,cr}$*~66 (*$T_4$*/K)*$^{-1}$*GeV,* $T_4$*=T/(5 10*$^4$*K)*
- **propagation effects** (convection, diffusion): ***spectral softening in post-shock flow***
- **cascade models operate if ions reach sufficient high E** *[e.g. Bednarek 2005,…]*

# WR 140 (WC7+O4-5V)

*[from: Reimer et al. 2006, ApJ, 644, 1118]*



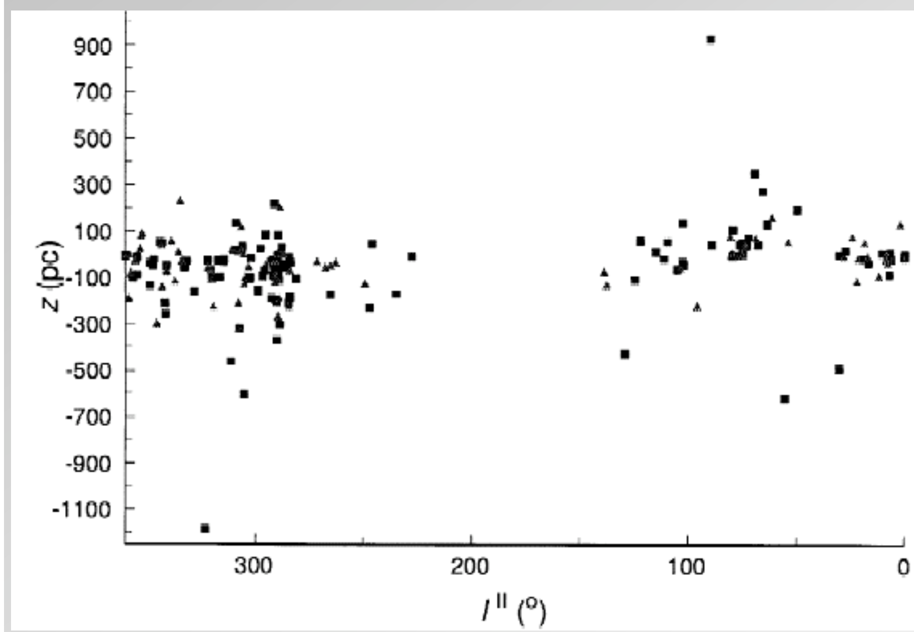
# The massive star population in our Galaxy

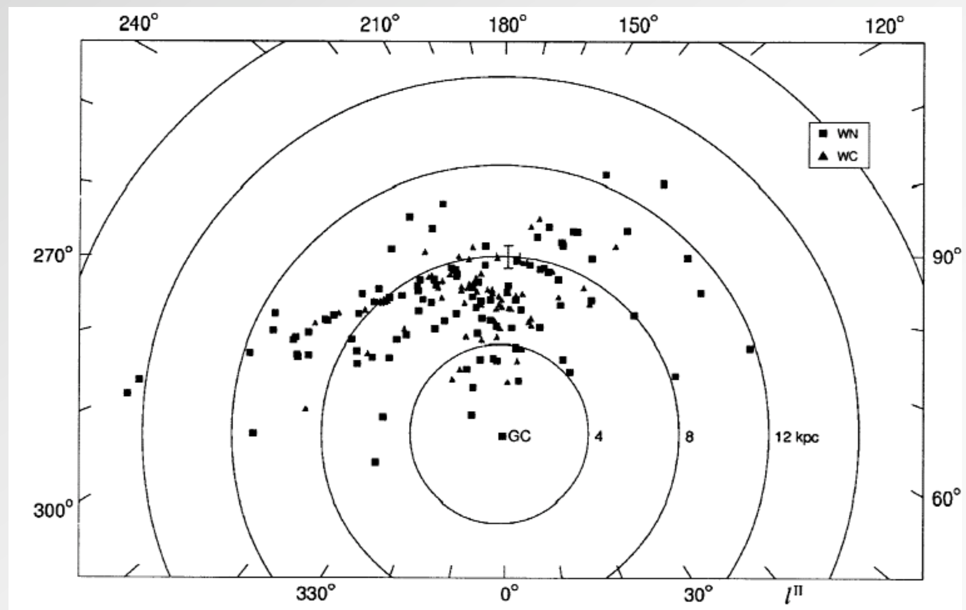
• **227 WR-stars, 378 O-stars detected in the Milky Way**

*[ v.d. Hucht ´01+´06: 7th cat. gal. WR-star +extens., Maiz-Appelaniz et al.04: Gal. O-star cat]*

• **WR-binary frequency (incl. probable binaries) ~ 40-50 %**

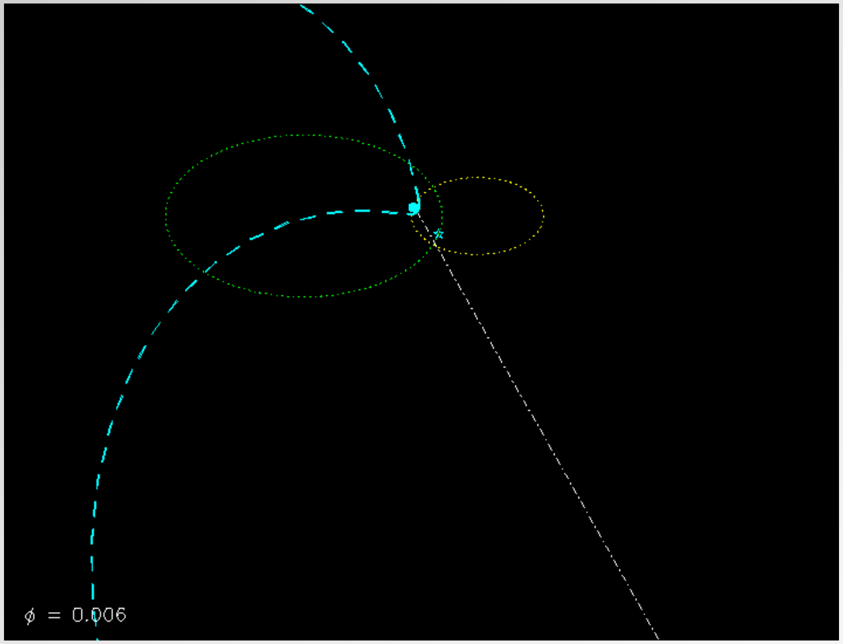
**(*indications:* photometric periodicity, absorption lines/dilution of emission lines, dust form. X-ray excess, radio imaging,...)**




. The galactic Wolf–Rayet star distribution ($l^{II}$, $d$) projected on the galactic plane. The Sun is indicated by +. The distance

# How many massive stellar binary systems (here: WR-binaries) will GLAST's LAT be detecting at most?



# Sample selection

- **gal. WR-binaries → 88 systems**

  **[ *from: van der Hucht ´01+´06:* 7th catalog of gal. WR-stars + extension]**

- **distance ≤ 4 kpc → excludes 42 systems**

  **[*γ-ray flux dilution factor ~ distance²* ]**

- **shock location above star's photosph. → excludes 14 systems**

  **( $x > R_*$ )**

  **[*shock location determined by winds' ram pressure balance*]**

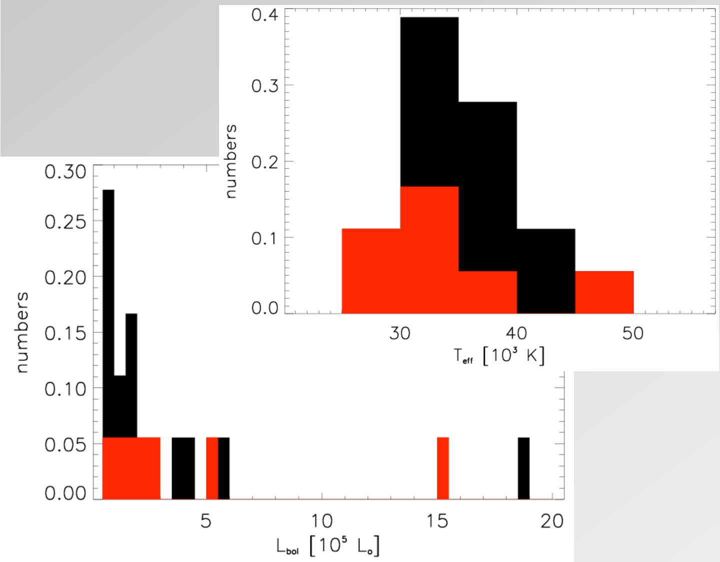
- **orbital period/stellar separation known → excludes 11 systems**

  **[*required to determine shock location and environment*]**

**⇒ consider 21 WR-binary systems for potential LAT-detectibility**

# Parameters & Assumptions

- **IC component only** **[very likely dominant; Reimer et al. 2006 model used]**
- **max. possible acceleration rate** **[mechanism not specified]**
- **system parameters** **[$L_{bol}$, $\dot{M}_{OB,WR}$, $M_{OB,WR}$, $V_{\infty,OB,WR}$, $T_{eff}$, $D_{WR-OB}$, $d_L$]:**
  *van der Hucht `01, Markova et al `05, Nugi & Lamers `00, Schaerer & Maeder `92, Cherepashchuk `01*
- **e=0 assumed** **[$\langle e \rangle_{obs}$ low, $e_{max}$~0.9], $i=90^o$ for unknown systems inclination**
- **$B_*$=100G + magnetic rotator model** ***[Weber & Davis 1967]***
- **energy (particles) injection: (a) particle number conservation:**
  **rel. particle flux ≤ wind particle flux enter acc.zone**
  **(b) energy conservation: $L_{inj} \leq L_{wind}$**




→ $\varepsilon_{target} \sim T_{eff}$, $u_{target} \sim L_{OB}/x^2$, $x=D_{WR-OB}\sqrt{\eta}/1+\sqrt{\eta}$, $\eta=(\dot{M}_{OB}V_{OB})/(\dot{M}_{WR}V_{WR})$

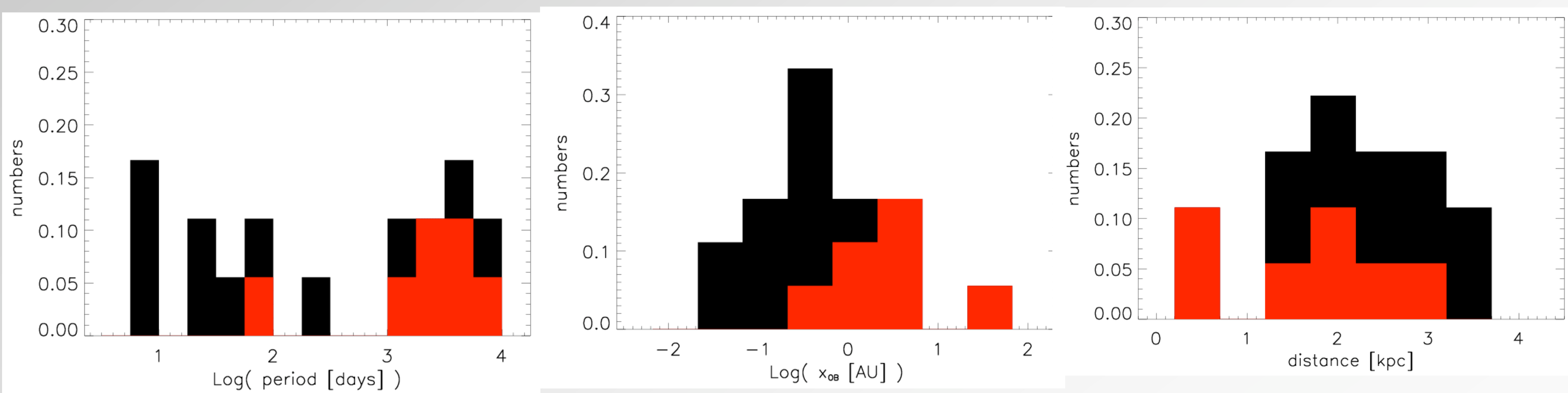
→ $S_{0.1-100GeV}$

# Results

LAT-source, if:
- $E_{IC,max} > E_{LAT,\,min}$
- $F_{IC(>100MeV)} > F_{min,\,LAT,(>100MeV)}$ [used here: $2 \times 10^{-8}$ cm$^{-2}$s$^{-1}$ at $|b| < 0.5$]

⇨ **6-7 WR-binaries likely detectable by the LAT**

- **tend to be very-long-period binaries** [otherwise the severe IC-losses cause low E cutoff of $e^-$spectr. → inhibition of GeV-photon prod. in shorter-period binaries], $x > 10^{12}$cm
- **all but one are non-thermal radio emitters**
- **only most nearby (< 1kpc) WR-systems safely LAT-detectable**



# Uncertainties

- **$D_{stellar}$ : ~ 0.06…3 × D** [ΔP ~ 0.5…2 × P, e=0 assumpt.→ ~ 0.1…1.9 × $D_{stellar}$]
  → × 1.2 more/6 less systems LAT-detectable
- **$B_*$-field: 0.1...10 × $B_*$** → × 1.2 more/1.5 less systems LAT-detectable
- **$\dot{M}_{WR}$ : 0.1...10 × $\dot{M}_{WR}$** [wind clumping] → no signif. change
- **$V_\infty$ : 0.5...2 × $V_\infty$** → × 1.2 more/6 less systems LAT-detectable
- **$L_{bol}$ : 0.5...2 × $L_{bol}$** → × 1 more/3 less systems LAT-detectable
- **$T_{eff}$ : 10-20%** → no signif. change
- **$d_L$ : 0.5...2 × $d_L$** → × 1.3 more/6 less systems LAT-detectable

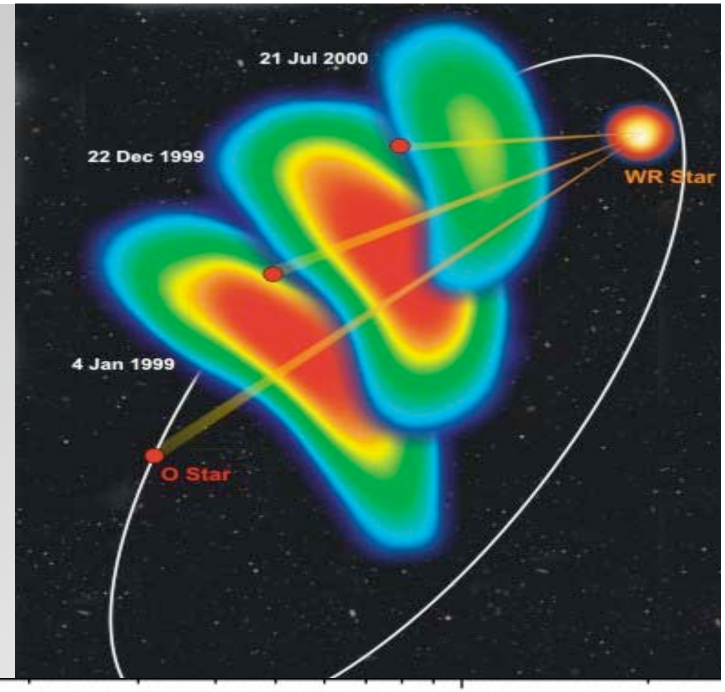
**$6 \pm^{2}_{5}$ WR-binaries may be detectable by the LAT**

# Characteristics of observables

| | Massive binary systems |
|---|---|
| # population members | ~ (several) 100 catalogued |
| Spatial distr. | rather low gal. latitude, conc. towards spiral arms |
| Extension? | NO |
| Variability? | orbital variations expected (more or less pronounced) |
| γ-ray spectrum | softer than synchrotron |
| MWL signature | NT radio in long-P binaries; $F_{lim,GHz}$ < mJy |
| Most promising candidates | WR 11, 70, 125, 137, 140, 146, 147 |

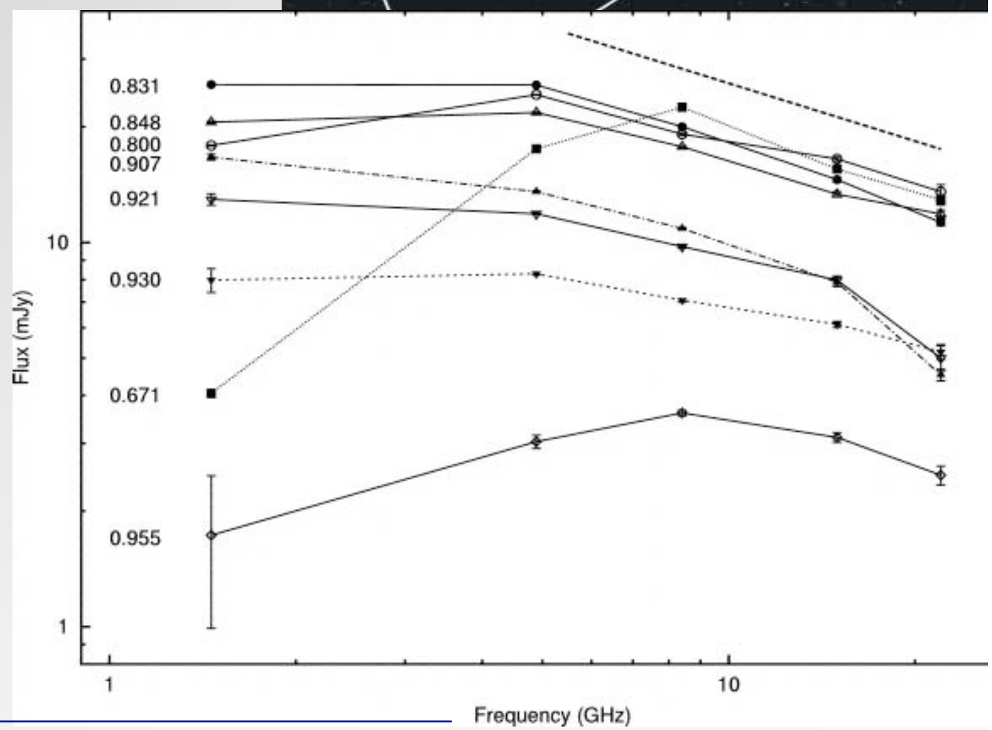
# Prototype: WR 140 (WC7+O4-5V)

- distance ~ 1.85 kpc
- period ~ 2899±10 days
- $L_O$ ~ 6 $10^{39}$ erg/s
- $T_{eff}$ ~ 47400 K
- WC: V~2860 km/s, M~4.3 $10^{-5}$ $M_o$/yr
- O: V~3100 km/s, M~8.7 $10^{-6}$ $M_o$/yr
- e ~ 0.88±0.04, i ~ 122°±5°, ω~47°
- D ~ 0.3…5 $10^{14}$ cm
- 3EG J2022+4317 ?

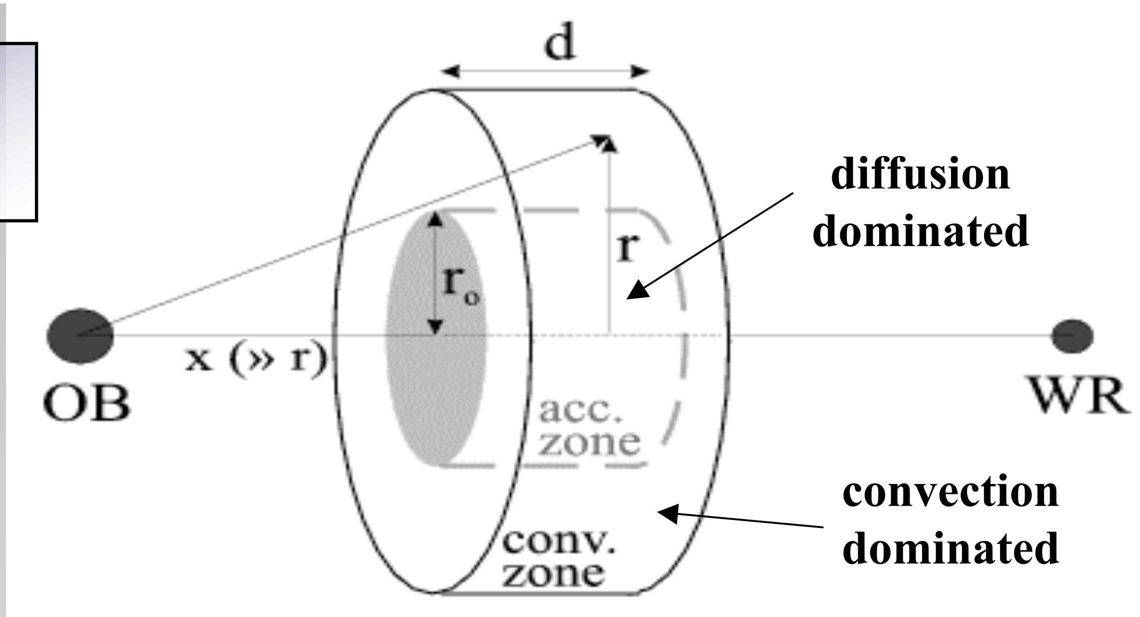



**Parameter values:**

$B_\star = 100\,\mathrm{G}, E_{in} = 3\cdot10^{32} - 3\cdot10^{33}\mathrm{erg/s}$,
$\kappa_{acc} = 2\cdot10^{19}\mathrm{cm^2s^{-1}}$
$\Rightarrow x \approx 0.32\,D,\ n_H \approx 4\cdot10^6 - 9\cdot10^8\mathrm{cm^{-3}}$,
$B \approx 0.2 - 3.5\,\mathrm{G},\ V \approx 1410 - 1540\ \mathrm{km/s}$,
$T_0 \approx 1.6 - 1.9\,\mathrm{ks},\ r_0 \approx 2.4 - 2.6\cdot10^{11}\mathrm{cm}$,
emission volume = $(1\text{-}2.4\,\mathrm{AU})^3$.



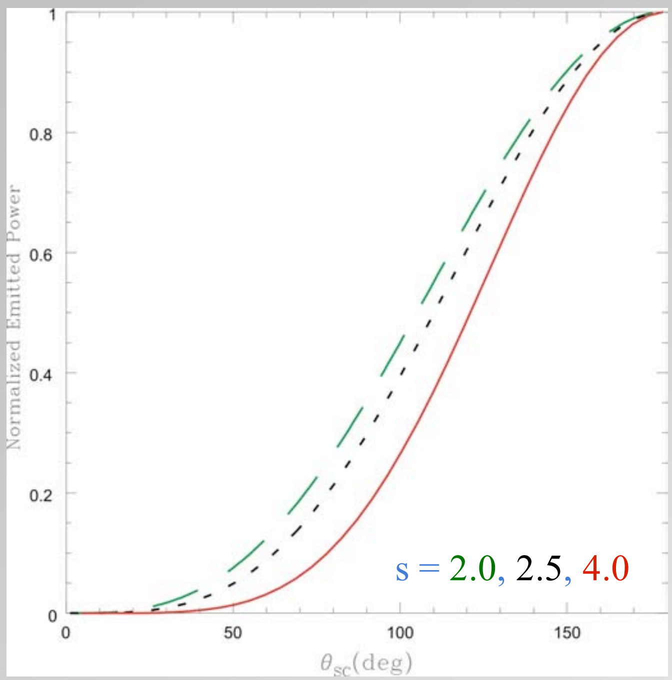
# The Model



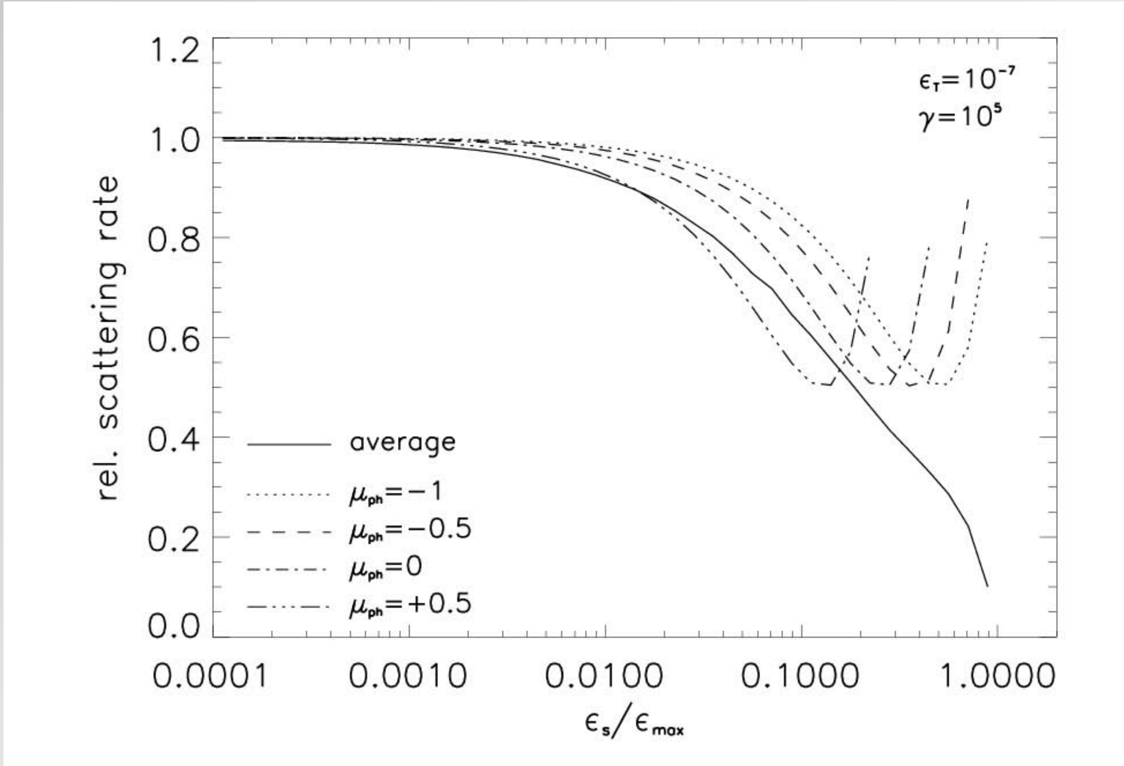

- **uniform wind**
- neglect interaction of stellar radiat. field on wind structure

  ⇒ restrict to **wide binaries**
- **cylinder-like** emission region (x >> r, emission from large r negligible)
- radiation field from WR-star negligible (**D >> x**)
- **photon field** of OB-comp. **monochromatic**: $n(\varepsilon) \sim \delta(\varepsilon - \varepsilon_T)$ , $\varepsilon_T \approx 10$ eV
  **electron** distribution **isotropically**
- convection velocity **V = const.**
- magnetic field **B = const.** throughout emission region

# Anisotropic inverse Compton scattering




from: *Brunetti 1998*




⇒ **more power is emitted at large scattering angles**

⇒ **scattered photon energy decreases with scattering angle**