Revealing colliding wind binaries with radio interferometry: WR 11 & WR 133

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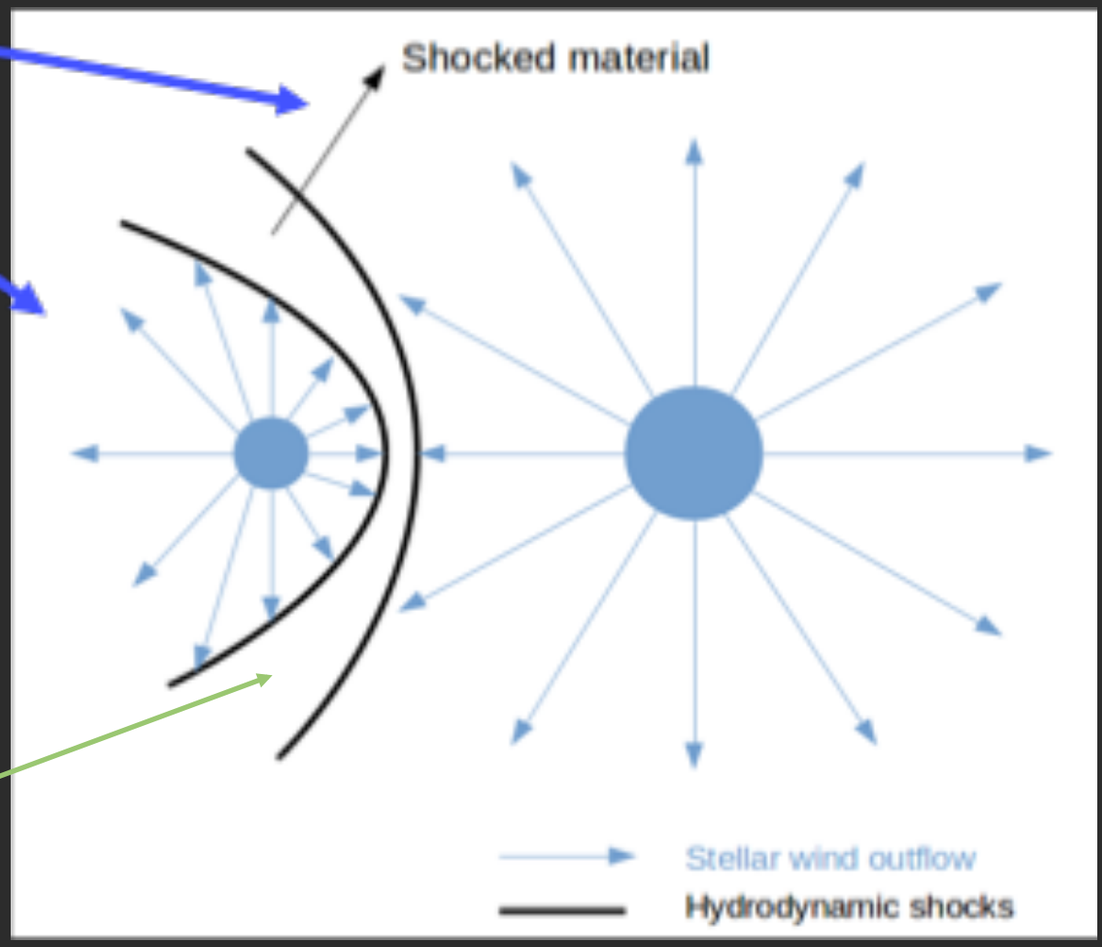
WHAT DO WE EXPECT TO SEE IN RADIO WAVES

Thermal radio emission

Synchrotron radio emission



$$S_\nu^{\rm obs} = S_\nu^{\rm th} + S_\nu^{\rm syn} {\rm e}^{-\tau_\nu^{\rm ff}}$$

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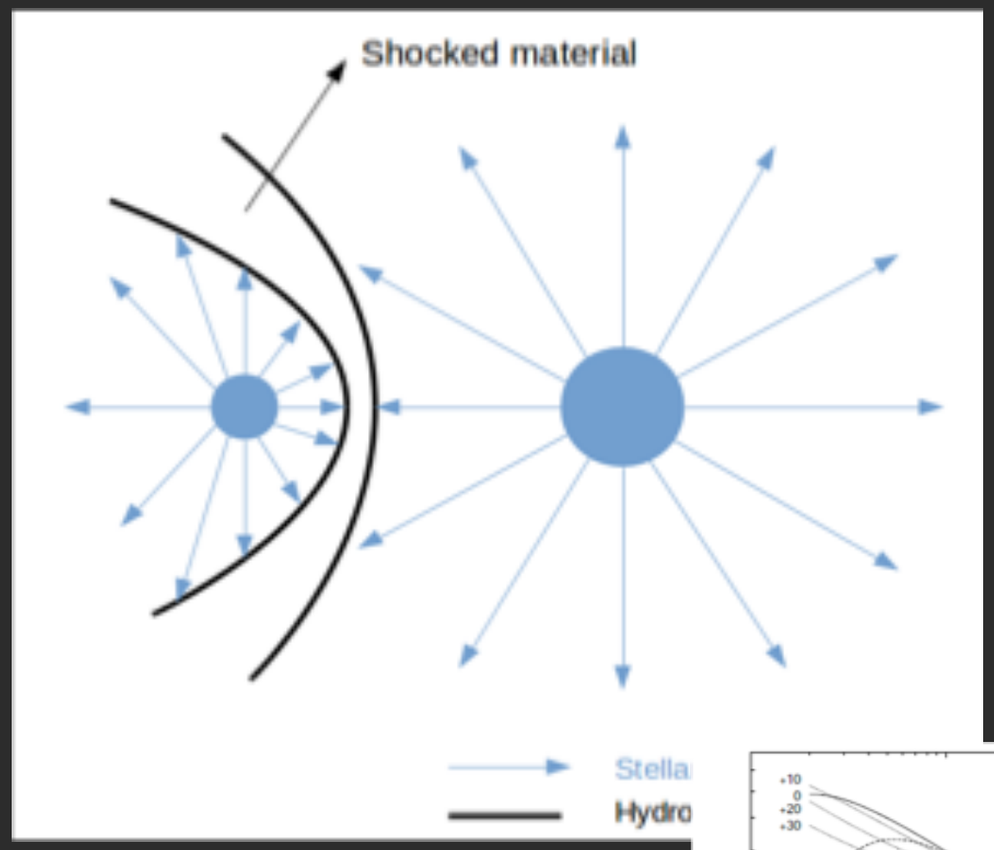
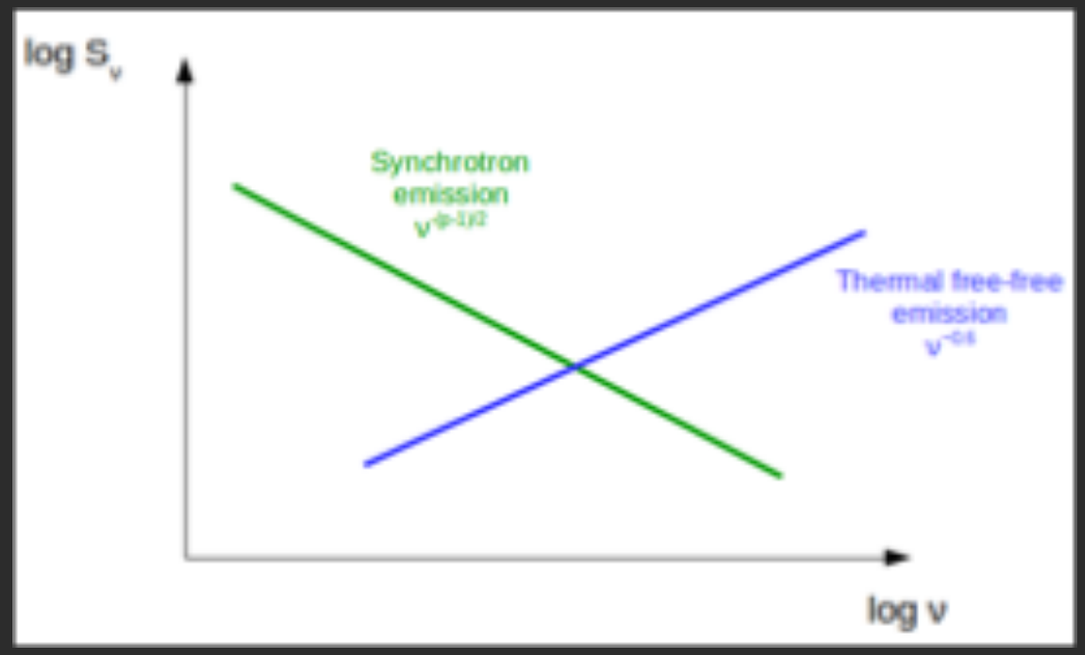
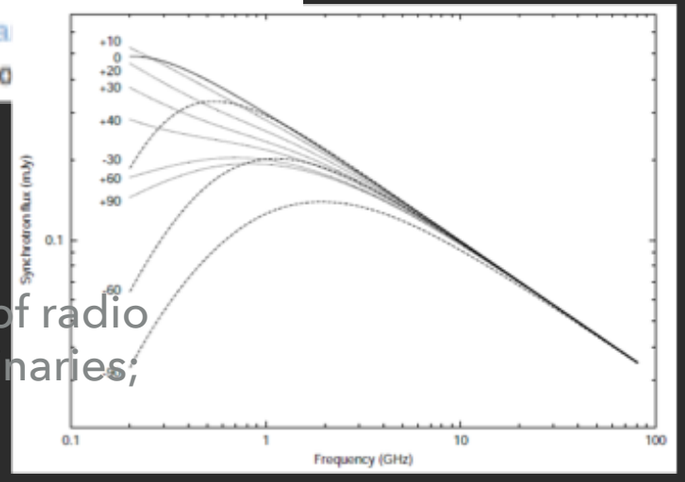
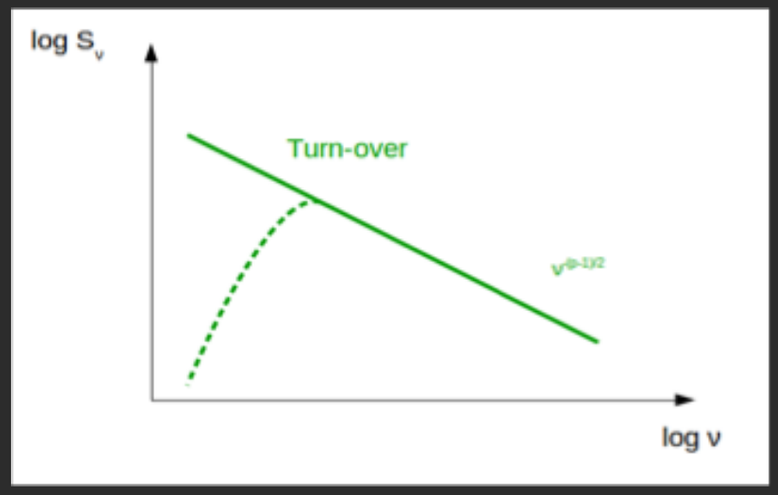








Dougherty+2003: Simulations of radio emission from colliding-wind binaries; inclination vs radio flux

SOME PROBLEMS . . .

- Sensitivity
- Angular resolution
- Source declination

→ System structure: multiplicity, spectral types

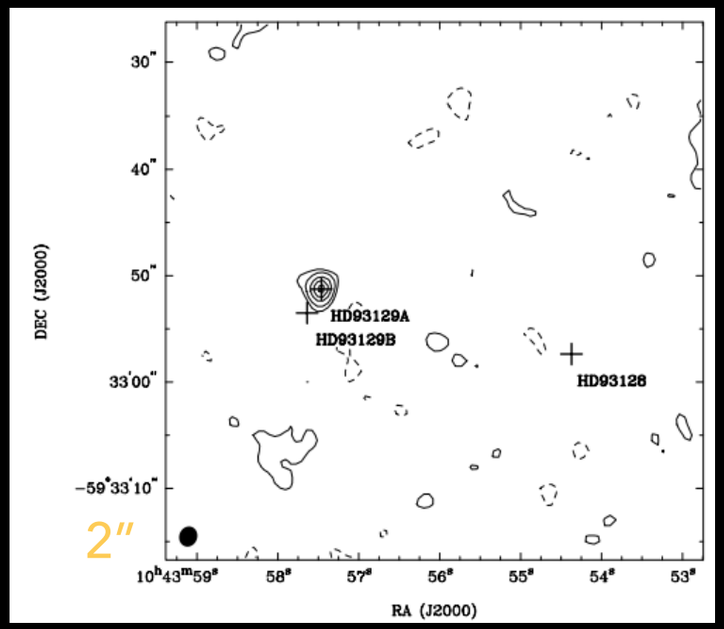
→ Orbit: inclination, period, separation

- System unknowns
- Field bright sources
- Nearby diffuse emission

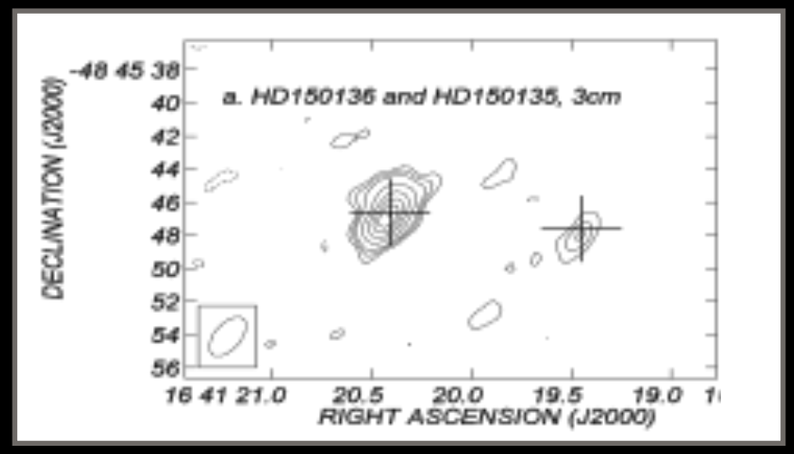
→ Simultaneous multi band observations

Radio interferometry up to VLBI

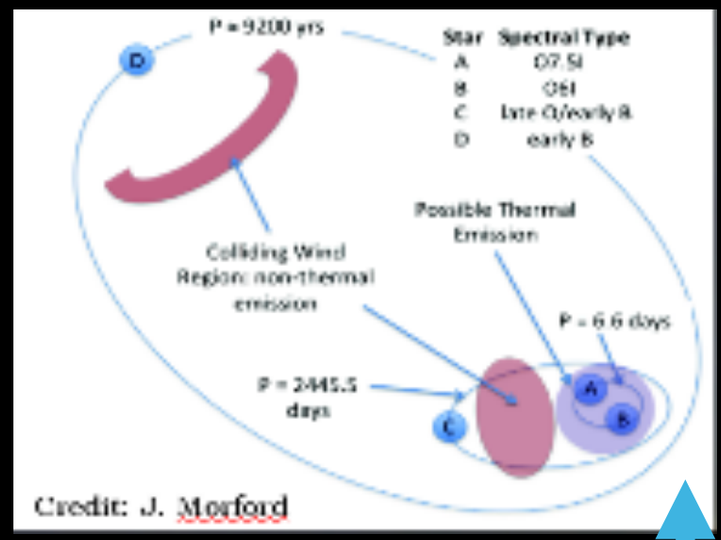
WHY RADIO OBSERVATIONS OF MASSIVE BINARIES



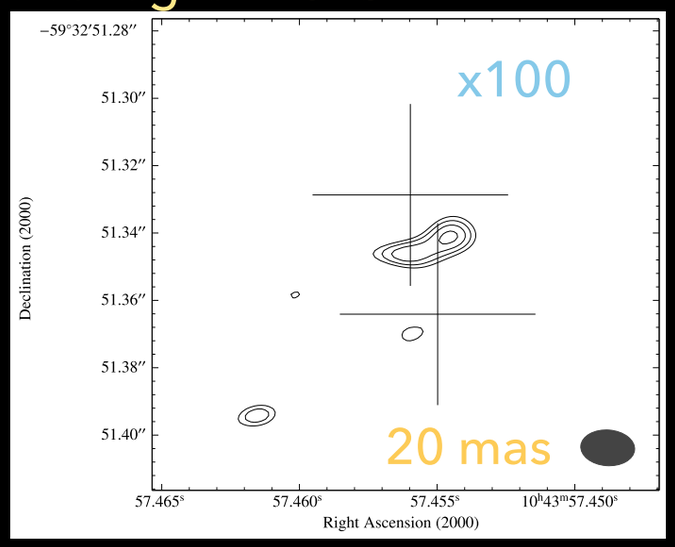
HD 93129A, O2If* (Walborn+02)
Benaglia+Koribalski 04

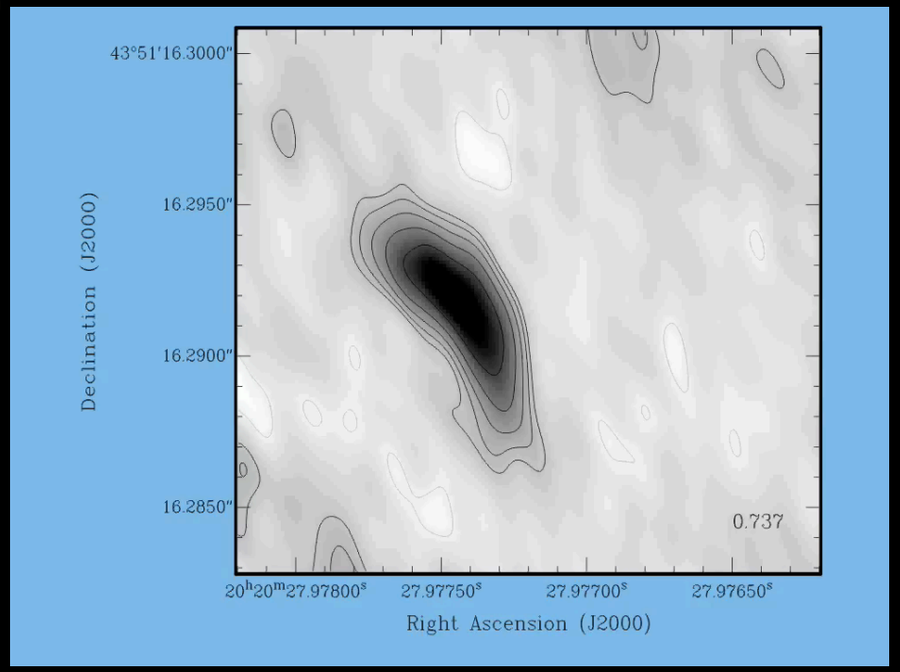


HD 150135, O6.5 V((f))z (Arias+2016)
HD 150136, (O3V+O6V)+O7V, Benaglia+06)

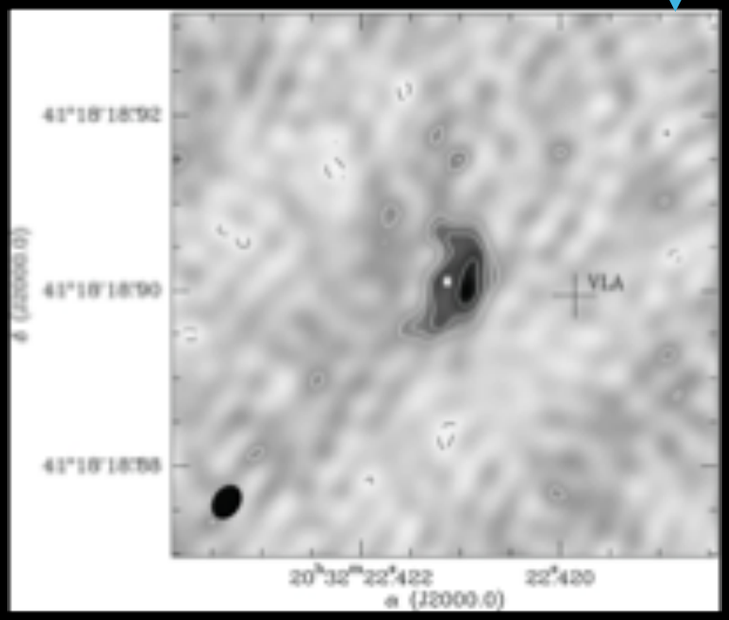


Benaglia+2015



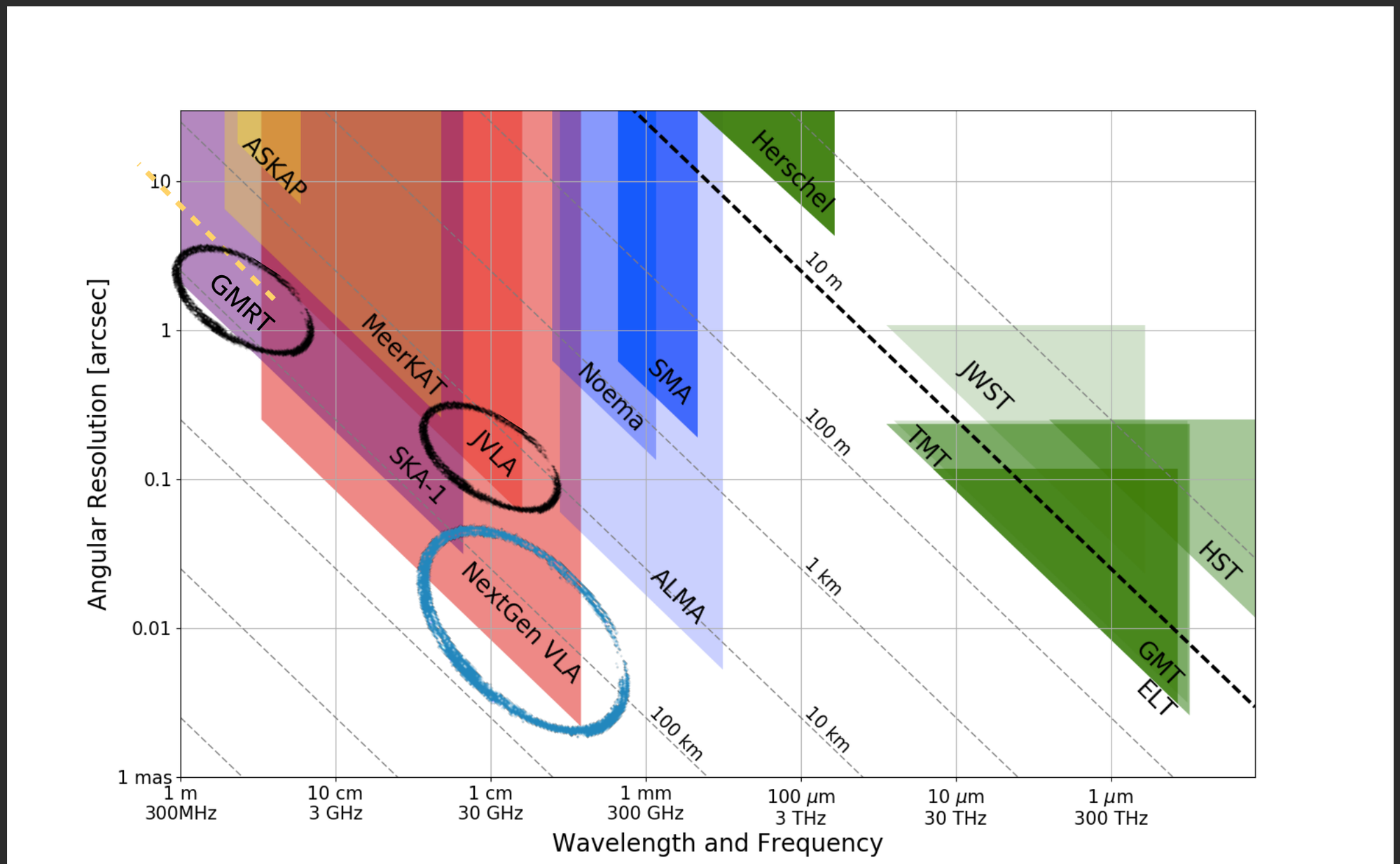


WR 140, Dougherty+2005 WC7+ O5.5fc

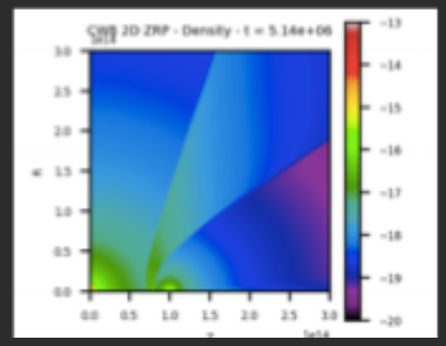


CygOB2#5 Contreras +Ortiz-León+Dzib+COBRaS

ANGULAR RESOLUTIONS IN COMPARISON



CATALOGUES: "PACWB"



PACWBs: *Particle-Accelerating Colliding-Wind Binaries**

De Becker & Raucq 2013: 40 systems → Several to confirm ...

- Membership, multiplicity, spectral types, periods, information of non-thermal emission (soft X-rays, hard X-rays, gamma rays)
- Mass loss rate, terminal velocities, kinetic power, radio flux, radio luminosity

NT emission signatures:

- Spectral index
- High brightness temperature
- Flux variability
- Polarization (?) (talk by S. del Palacio)

Study of stellar winds

↓

astrophysical processes

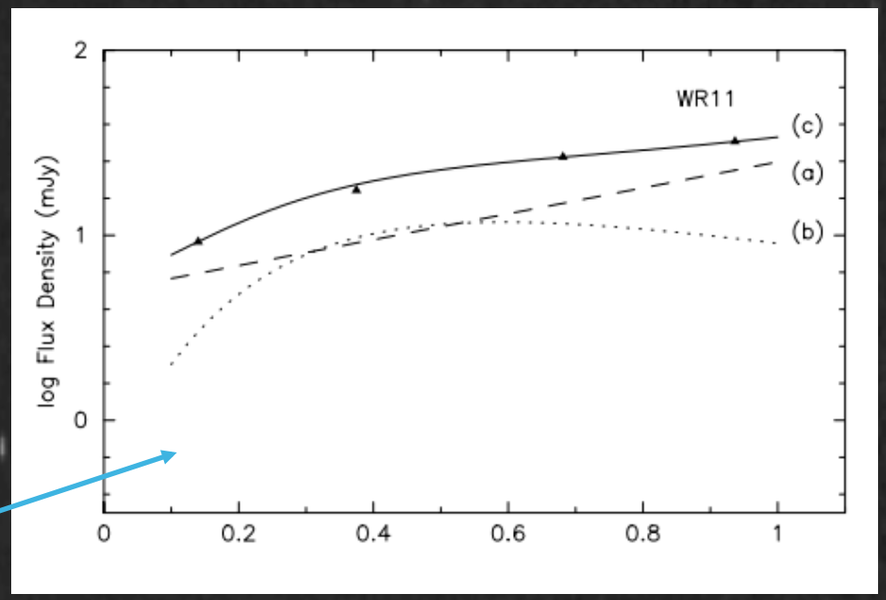
↓

mass loss, stellar evolution

* Predecesors: Wendker 1995, Dougherty & Williams 2000, Benaglia 2010

WR 11: GAMMA ^{2} VELORUM

- The nearest stellar massive binary system (340pc)
- WC8 + O7.5; decl =-47.3º
- 79 days period, 1.2 AU semi major axis
- ATCA observations @ 1.4 - 9 GHz (Chapman+1999)



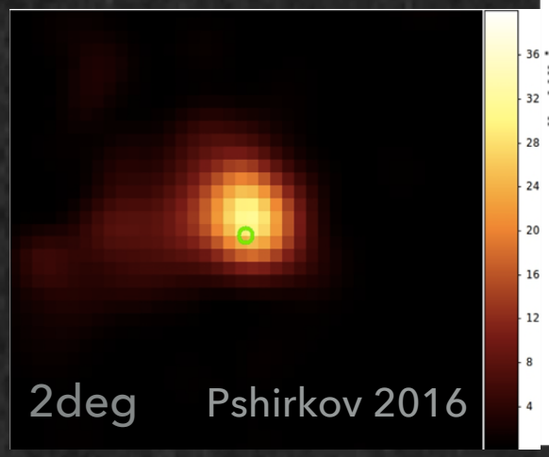
(1) Counterpart of a Fermi source?

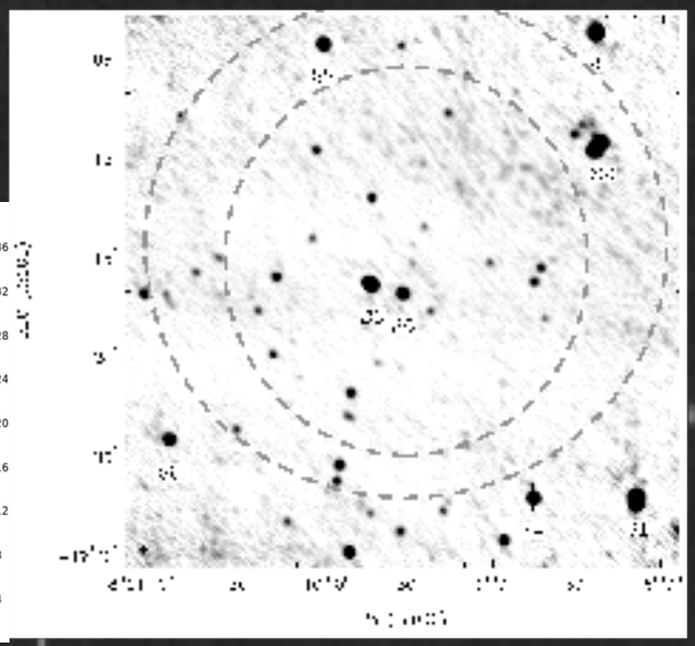
(2) Effects below turn over

GMRT observations at low (centimeter) frequencies

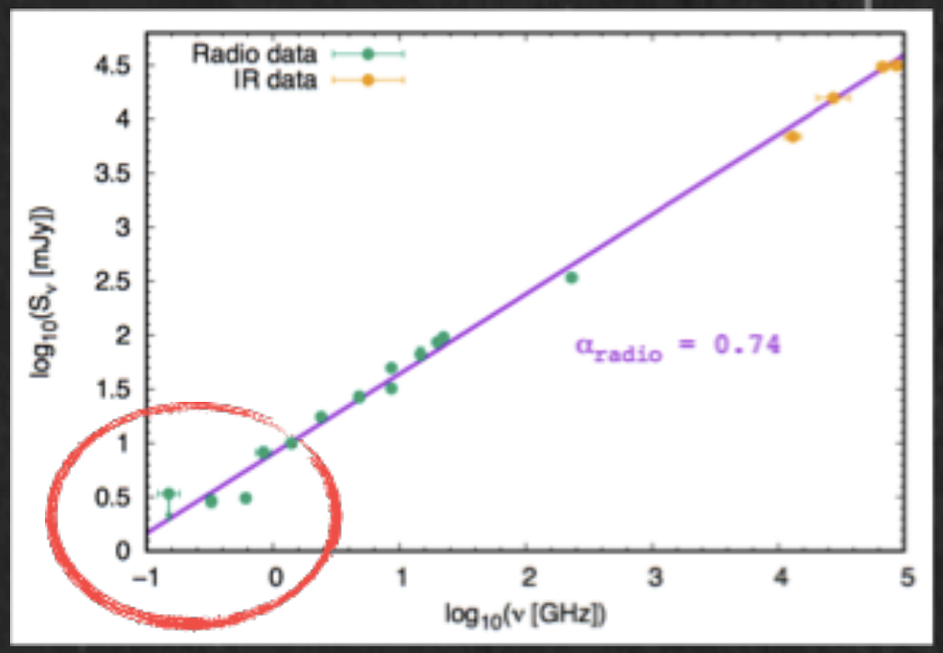
Frequency bands (MHz)	150	325	610	1390
Phase calibrators	0837−187	0837−187	0837−187	0828−375
Observing dates	21/Jan, 11/Feb/2017 241	28/May/2016	23/Jul/2016	03/Oct/2016
Time on source (min)	241	171	120	209
Field of view† (arcmin)	186±6	81±4	43±3	24±2
Synthesized beam	59.6" × 14.0", 2.5°	22.6" × 6.4", 8.2°	12.1" × 3.2", 12.5°	5.4" × 2.1", −175.9°
Center image rms (mJy/beam)	1	1.25	1	0.15

WR 11





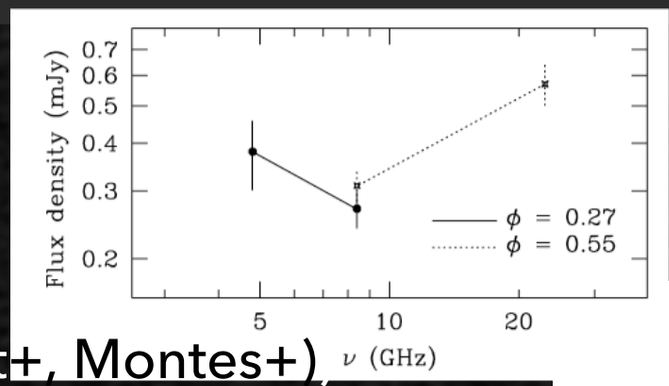
Fermi excess 1.4GHz central field (Benaglia 2016)



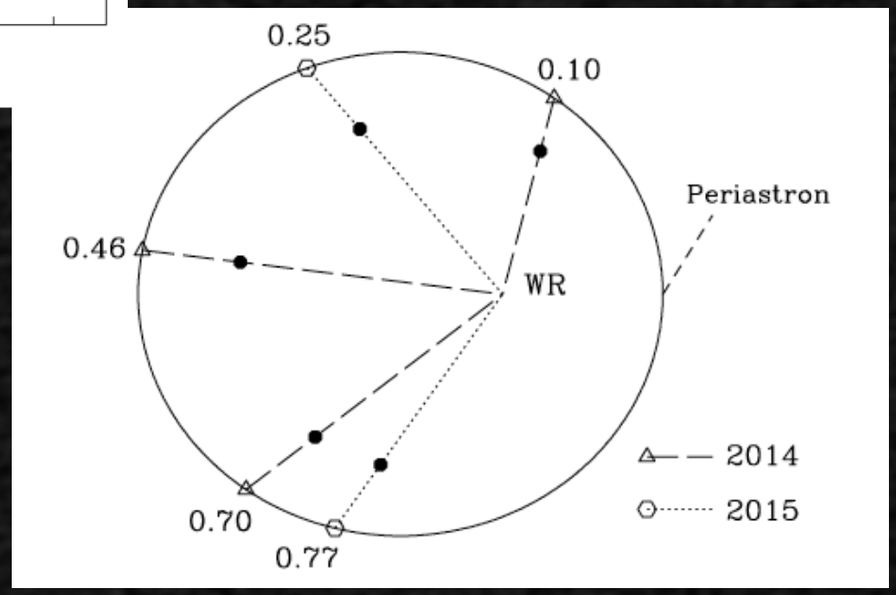
- There are promising non-thermal sources in the field that can contribute to the Fermi excess;
- The radio fluxes from 1 to 230 GHz are consistent with thermal emission;
- However, at lower frequencies more observing time is required to explain the spectrum.

Frequency [GHz]	Flux [mJy]	Synth.beam [arcsec^2, deg]	Reference
0.150	<3.4	59.6 × 14.0, +12.5	this work
0.325	2.9±0.4	22.6 × 6.4, +8.2	this work
0.610	3.1±0.3	12.1 × 3.2, +12.5	this work
0.843	8.2±1	43 × 43	J85
1.4	10±1	6.3 × 2.3, −174.2	this work
2.4	17.5 ±0.1	12 × 8	Ch99
4.8	26.5±0.28	~ 3 × 3	LCK97
4.8	27±3	8.3 × 12.8	AT20G
8.64	50±3	4.6 × 7.13	AT20G
8.64	32.2±0.63	1 × 1?	LCK97
14.7	67±10	2.3 × 2.3	MW78
19.9	86±4	10.8 × 10.8	AT20G
22.3	96±3	0.77 × 0.36, −14	BenPV
230	342±27	25 × 25	L&R91

WR 133



- VLA 1986, 1993, 2004 obs (Abbott+, Montes+),
- WN5 + O9I; 112.4-d orbit; semi major axes of 35 (O) and 70 (WR) R_o
- Phase-lock variations to WCR emission?

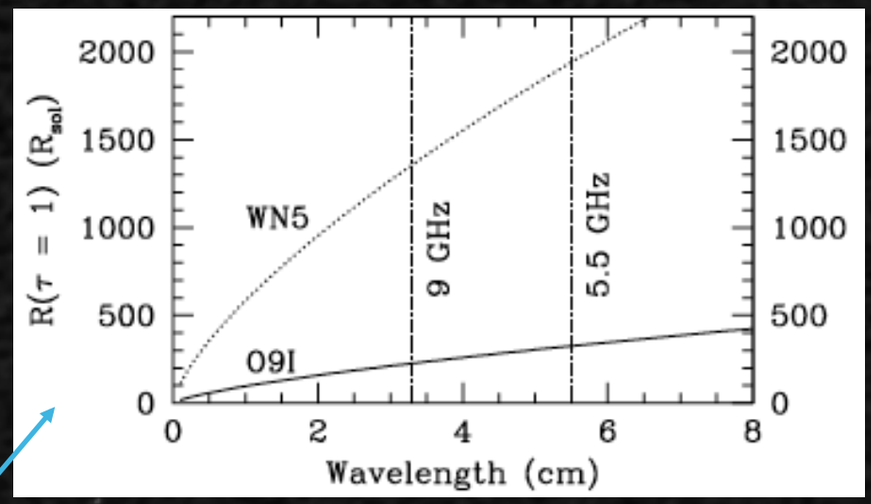


→ JVLA observations along the orbital phases

Epoch	Julian date	Orb.phase (ϕ)	Band ν (GHz)	Synth.beam (",",deg)	rms (mJy/beam)	S_ν (mJy)	α
27 Feb 2014	2456716.5	0.70	5.5	$0.63 \times 0.33, -64.4$	0.02	0.21 ± 0.02	–
28 Feb 2014	2456717.5	0.71	5.5	$0.65 \times 0.31, -66.2$	0.02	0.23 ± 0.02	–
13 Apr 2014	2456761.5	0.10	5.5	$0.67 \times 0.33, -65.3$	0.02	0.21 ± 0.02	–
23 May 2014	2456801.5	0.46	5.5	$0.63 \times 0.37, -63.7$	0.02	0.21 ± 0.03	–
24 Jul 2015	2457227.6	0.25	5.5	$0.52 \times 0.31, -79.1$	0.01	0.19 ± 0.02	
			9.0	$0.28 \times 0.19, -82.2$	0.01	0.27 ± 0.02	$+0.71 \pm 0.26$
20 Sep 2015	2457285.6	0.77	5.5	$0.34 \times 0.33, +41.8$	0.01	0.21 ± 0.02	
			9.0	$0.20 \times 0.19, -51.9$	0.01	0.27 ± 0.02	$+0.51 \pm 0.30$

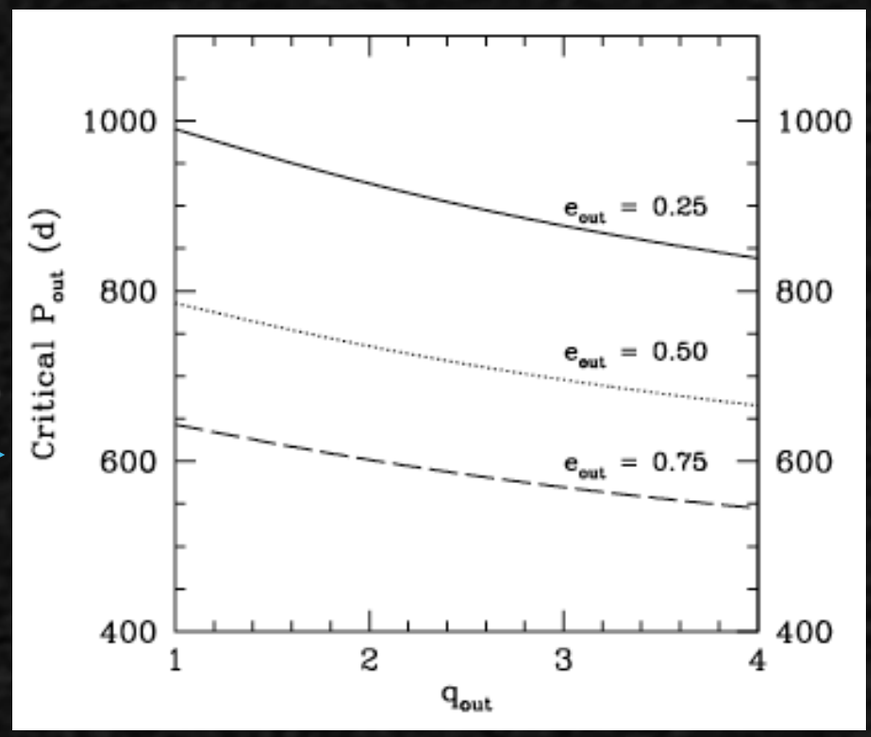
WR 133 ... Steady and thermal emission spectrum along two orbits

- No clear detection of synchrotron emission or variability along the orbit, consistent with the system dimensions and the size of a putative colliding-wind region;
- A triple system, with an inner and an outer orbits, can explain non-detection of NT emission in 2015.



Radio photosphere radius as a function of wavelength for both star winds (Leitherer+ 1995 expressions). Vertical lines are located at wavelengths that correspond to our two observation bands.

Estimate of the critical minimum outer period of WR 133 allowing for a dynamical stability of a hierarchical triple system (Eggleton & Kiseleva 1995 formulas). The critical period is plotted as function of the outer mass ratio, assuming three values for the outer orbit eccentricity.



THANK YOU!