Massive close binary puzzles

Dany Vanbeveren

Vrije Universiteit Brussel

Massive stars in Santa Barbara
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Evolution of massive stars

- Evolution of massive stars started as evolution of massive binaries in the late sixties, and seventies.

  - WR stars have lost most of their hydrogen envelope ➔ RLOF was considered as a most plausible process ➔ binaries

    The massive star conference in 1971 in Buenos Aires:
    Kuhi (1971): all WR stars are binary components

  - The observations of X-ray binaries

  - (Paczynski, van den Heuvel, Iben, Tutukov, Yungelson, Brussels, …)

The rise of stellar winds and the Conti scenario (1976) for WR single stars

Is it possible that WR star form via massive single star evolution, single stars that lose their hydrogen envelope by stellar winds?

Yes: Chiosi et al., 1978 massive single star evolution with stellar winds

But do WR single stars exist (remember Kuhi, 1971)?

Yes: Vanbeveren and Conti, 1980: the Kuhi (1971) statistics is biased, the real WR+OB binary frequency is no more than 30-40%

Vanbeveren et al. (1998):

Population synthesis of O-type stars and WR stars

- The WR+OB binary frequency = 30-40%

  A population of massive stars consists of real single stars, un-evolved (=pre-RLOF) binaries, evolved (= post-RLOF) binaries, post-supernova rejuvenated binary mass gainers (mostly single but with binary origin), binary mergers (singles with a binary origin), etc.

- What must be the primordial massive O-type binary frequency ***f*** in order to explain the observed WR+OB binary frequency?

  - Answer: ***f > 0.7*** (a decade later confirmed by H. Sana)

A major theme at massive star meetings in a not very distant past:

1. Did RLOF play a role in the formation of WR+OB binaries ?

Cornelis Troost,
18th century

the closing diner
'Tony Moffat' price
for beating a dead
horse

WR binaries in the Solar Neighbourhood

SALT observations of vrot; Shara, Crawford, Vanbeveren, Moffat, Zurek, Crause, 2016

System	Sp. Type	Period (d)	WR mass	OB mass	vrotsini	vrot	vrot begin WR	
WR21	WN5+O4-6	8,3	19,0	36,9	271,0	355,9	440,0	
WR30	WC6+O6-8	18,8	16,4	34,0	487,0	497,3	520,0	
WR31 !!!	WN4+O8V	4,8	7,6	17,8	221,0	312,5	493,0	
WR42	WC7+O7V	7,9	13,7	22,9	321,0	496,3	574,0	
WR47 !!!	WN6+O5V	6,2	51,6	60,1	76 (?)	82,5		
WR79	WC7+O5-8	8,9	10,6	28,9	124 (?)	224,1	290,0	
WR97 !!!	WN5+O7	12,6	12,2	21,7	272,0	474,1	502,0	
WR113	WC8+O8-9IV	29,7	12,7	26,7	334,0	354,3	360,0	
WR11	WC8+O7.5III-V	78,5	9,6	30,5	200,0	225,0	232,0	
WR127	WN3+09.5V	9,5	16,9	36,4	250,0	305,2	365,0	
WR139	WN5+O6III-V	4,2	9,3	27,9	215,0	219,3	365,0	
WR151	WN4+O5V	2,1	19,9	28,2		340,0		
WR133	WN5+09I	112,4	16,6	34,0				
WR141	WN5+O5III-V	21,7	36,4	26,3				
WR155	WN6+O9II-Ib	1,6	24,1	29,9		360,3		**➔LSS3074**
WR9	WC5+O7	14,3	9,0	32,1				
WR140 !!!	WC7+O4-5	2900,0	23,2	62,2				
	(e=0.85)							

The massive mass-exchange binary LSS 3074*

(Raucq et al., 2017)

O5.5I + O6.5-7I

Period P = 2.2 days

14.6 $M_\odot$ + 17.2 $M_\odot$

7.5 $R_\odot$ + 8.2 $R_\odot$

Conclusions

- Most of the O-type components in WR+O binaries are rejuvenated
- Most of the O-type components in WR+O binaries seem to be fast rotators
- ➔ common envelope evolution did not play an important role in the mass range where the WR+O binaries come from

2. Do WR stars end their life with a SN explosion ?

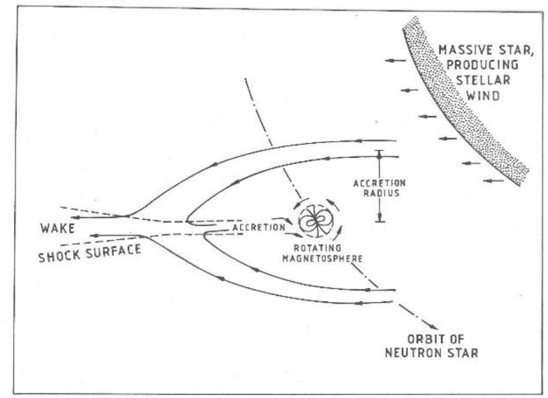
What are the consequences when the WR stars in WR+OB binaries would collapse to form BHs (without a SN explosion)?

- The evolution of WR+OB ➔ BH+OB ➔ BH+WR via stable RLOF (Pavlovskii et al., 2017)

- SS433-like mass loss: mass transfer leads to the formation of a disk around the BH, followed by mass loss from the disk via a disk-wind, which has the specific orbital angular momentum of the BH (van den Heuvel et al, 2017)

- Alternative: ..., which has the specific orbital angular momentom of the BH + the specific rotational angular momentum of the disk (present talk)

System	Sp. Type	BH+WR	Period (d)
WR21	WN5+O4-6	10+15	0,24
WR30	WC6+O6-8	14.5+14.5	2,44
WR31 !!!	WN4+O8V	5+6	merger
WR42	WC7+O7V	11+8	0,73
WR79	WC7+O5-8	8+12	0,19
WR97 !!!	WN5+O7	8+7	0,27
WR113	WC8+O8-9IV	10+11	1,25
WR11	WC8+O7.5III-V	7+12	0,23
WR127	WN3+09.5V	10+15	0,12
WR139	WN5+O6III-V	5+12	merger
WR151	WN4+O5V	11+12	0,14
WR133	WN5+09I	10+15	1,40
WR141	WN5+O5III-V	18+12	7,20
WR155	WN6+O9II-Ib	13+12	0,14
WR9	WC5+O7	7+13,5	merger
WR140 !!!	WC7+O4-5	18+40	(LBV) >4000d
	(e=0.85)		



Davidson & Ostriker, 1973

Formation of X-rays by mass accretion + absorption of X-rays in the stellar wind of the WR star (Vanbeveren, Van Rensbergen & De Loore, 1982)

Too many WR X-ray binaries in the Solar Neighborhood

Possible solutions

- SS433-like mass loss (Fabrika, 2004): disk-wind mass loss + mass loss via L2 ➔ most BH+OB binaries merge

- WR experience a SN explosion at the end of their life ➔ most WR+OB binaries are disrupted

➔ No or few double BH binaries are formed via this scenario

3. The formation channels of binary black holes (BBH) that merge within Hubble time in general, the progenitor of GW150914 in particular

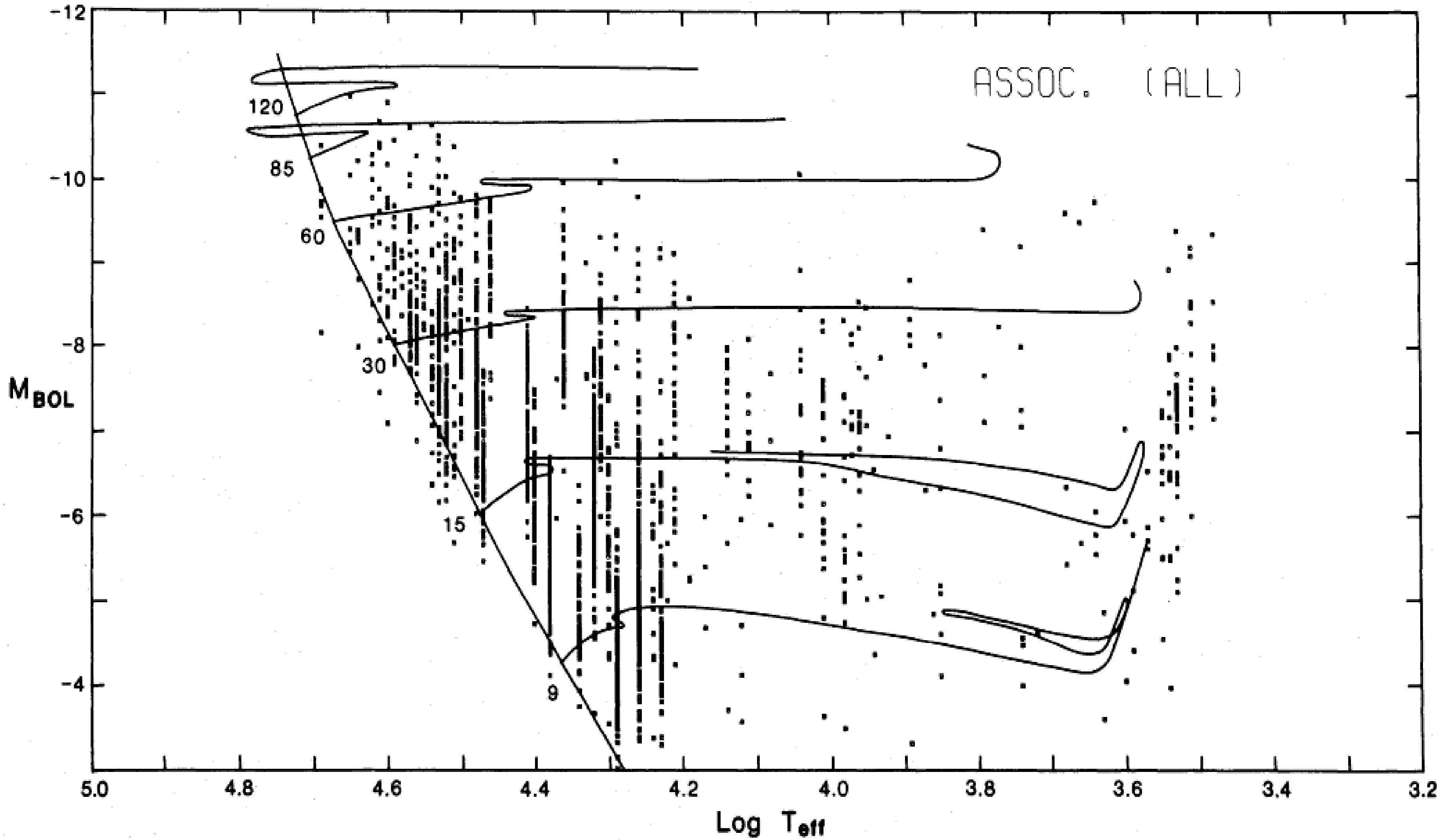
1. The field binary evolution model via common envelope evolution (Dominic et al., 2012)

2. Merger rates of BBH formed by stellar dynamics in Globular Clusters (Rodriguez et al., 2016)

3. Chemically homogeneous evolution of tight massive binaries (Marchant et al., 2016)

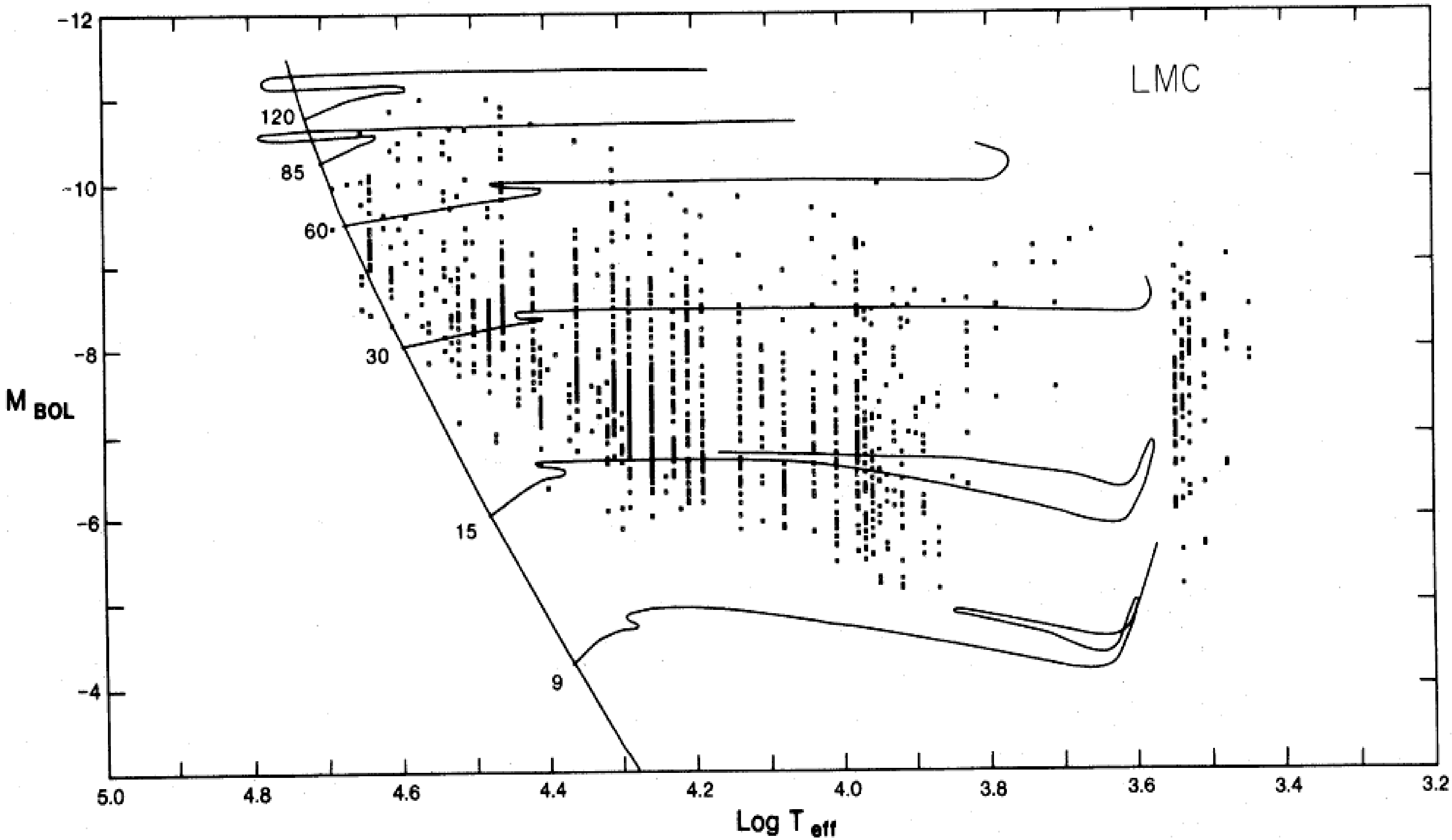
4. More exotic or may be not so exotic: primordial black holes (Bird et al., 2016)

Observational data from Humphreys & McElroy, 1984



2500 stars

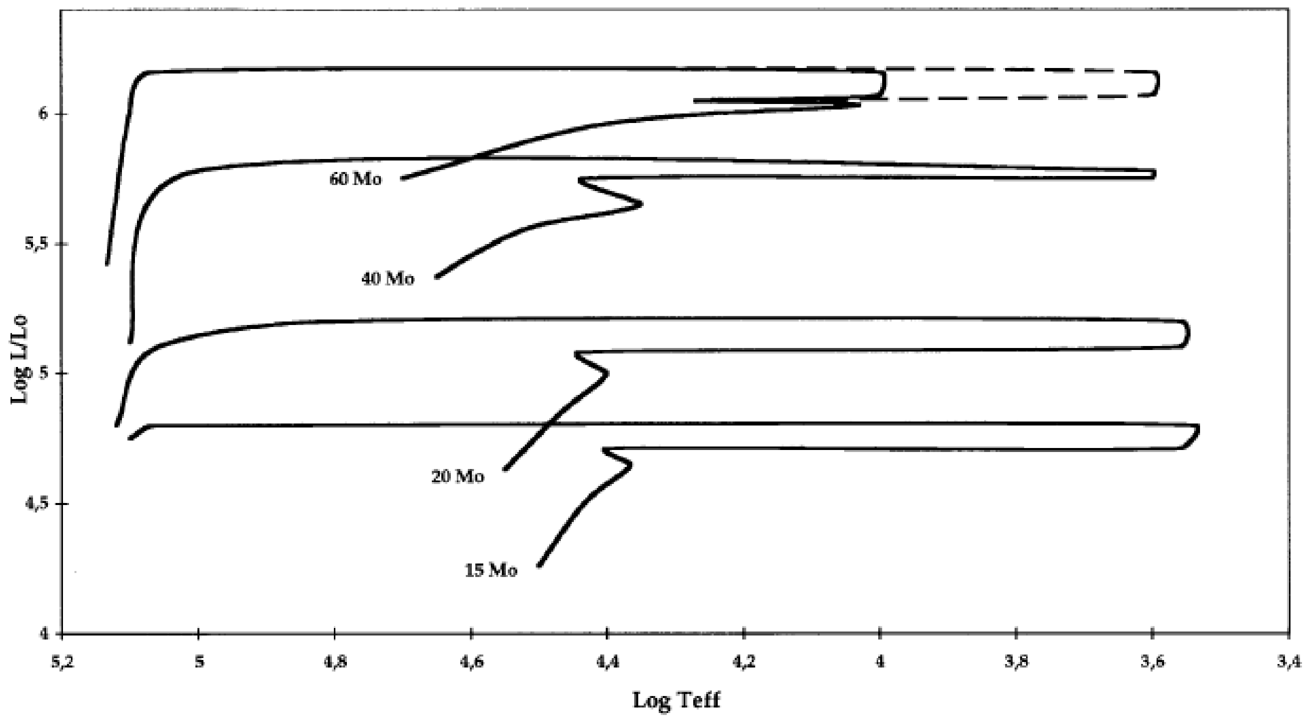
Observational data from Humphreys & McElroy, 1984



1300 stars

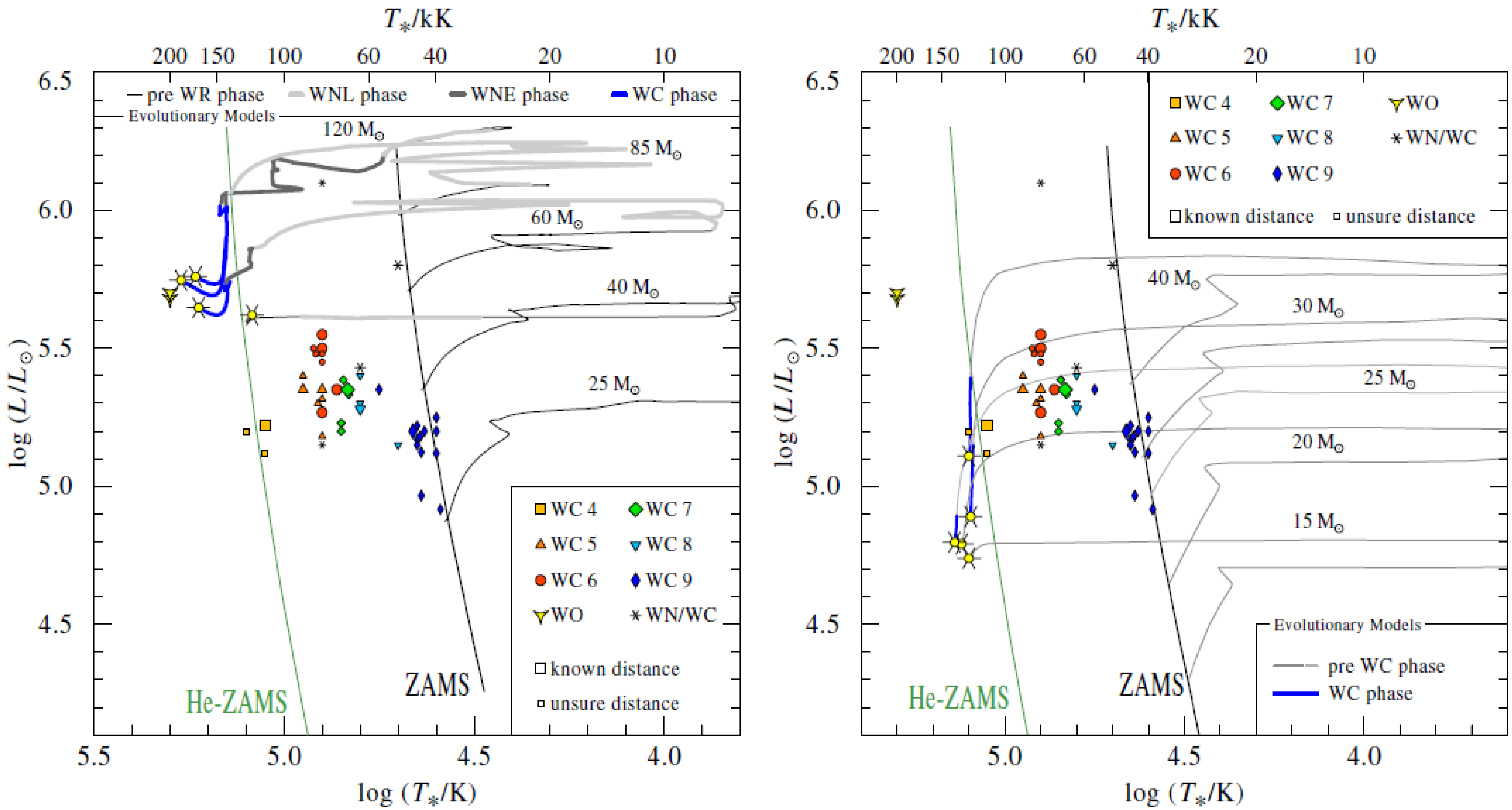
Vanbeveren et al, 1996, 1998

The evolution of single stars with alternative (compared to De Jager et al., 1988)
RSG mass loss rates



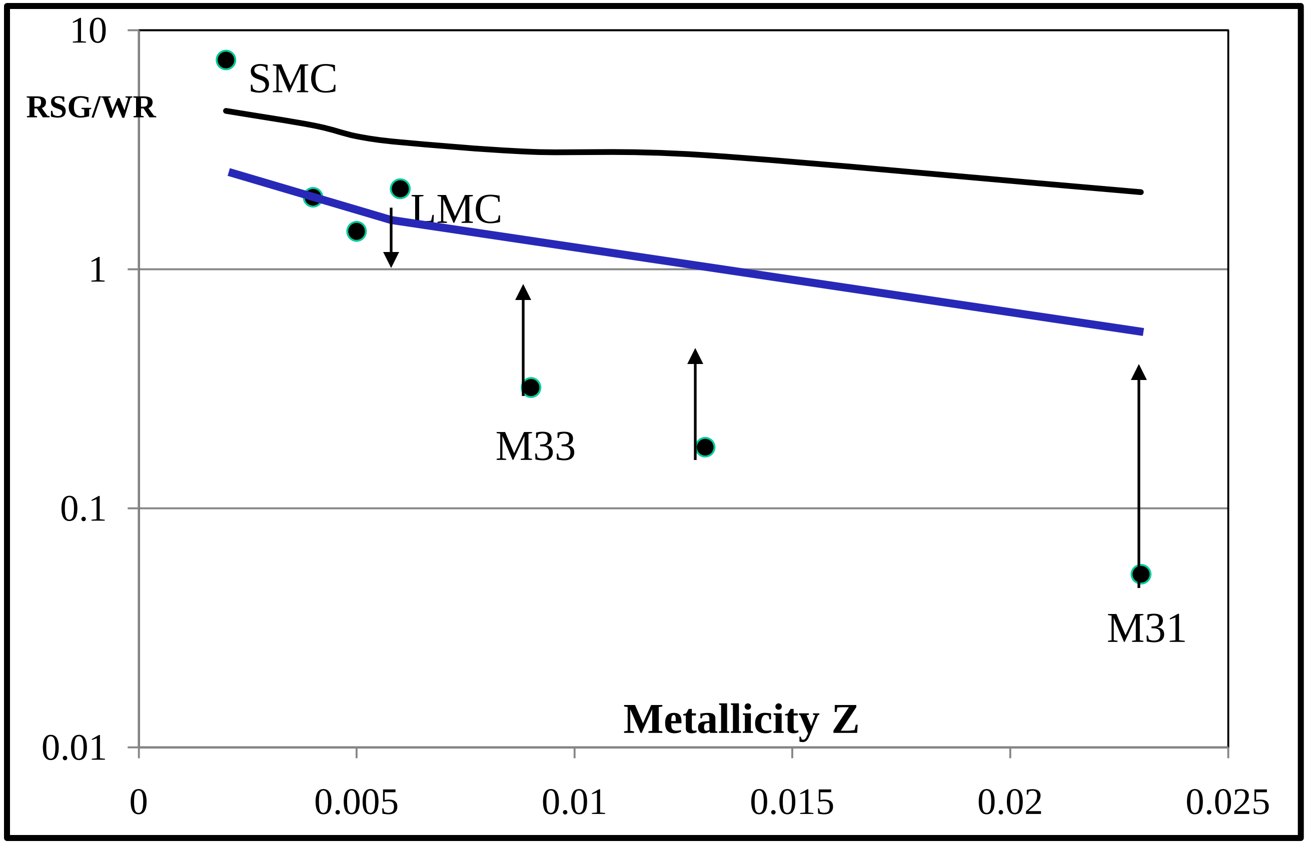
Recently, also the Geneva team implemented higher RSG mass loss rates in their single star evolution (Ekstrom et al., 2012; Georgy et al., 2012, 2013; Meynet et al., 2014)

The HR-Diagram of WC stars



Galactic WC stars: Sander et al., 2012

The number ratio Red Supergiants/WR

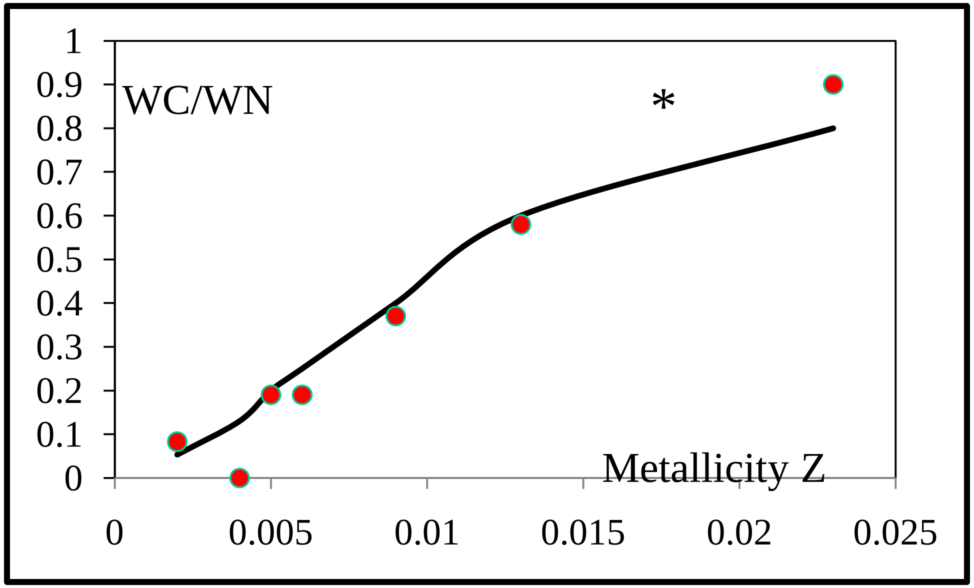


Data: Massey (2003)
Massey et al. (2013)

Black line: prediction with De Jager rates
Blue line: prediction with Brussels tracks (1998)

The WC/WN number ratio

(Vanbeveren et al., 2007)



The WC/WN ratio as a function of Z

L. Smith (1973): argued that metallicity might be responsible for the relative absence of WCs in the Magellanic Clouds, but without understanding the physical mechanism

Vanbeveren and Conti (1980): argued that it is the effect of Z on stellar wind mass loss that causes the differences in WC/WN number ratio

The figure compares observations (Massey, 2003) with theoretical prediction (Vanbeveren et al., 2007; see also Eldridge et al., 2008); 60% binaries, 40% single stars, using our 1998 single star tracks with alternative RSG stellar wind mass loss rates ➔ correspondence is rather satisfactory.

The effect of LBV mass loss on the population of double compact binaries, double compact binary mergers and GW-detection rates (the case GW150914)

Dominik et al. (2012, 2013, etc)

Stellar wind mass loss (LBV?) is not large enough to suppress the RLOF in case B/C binaries with M > 40 Mo

Mennekens and Vanbeveren (2014)

Stellar wind mass loss (LBV?) is large enough to suppress the RLOF in case B/C binaries with M > 40 Mo

If this is true also for small Z the effect on the detection rates is enormous (about a factor 1000); primarily the BH-BH merger rate is affected.

If this is true also for small Z it is possible that a double BH leading to GW150914 cannot be formed via the CE of a field massive binary

Warning: initial final mass relation for binary components
Hurley versus non-Hurley