

star forming region in the SMC (Optical/X-ray): Henault-Brunet, Oskinova+ 11, Oskinova+ 13

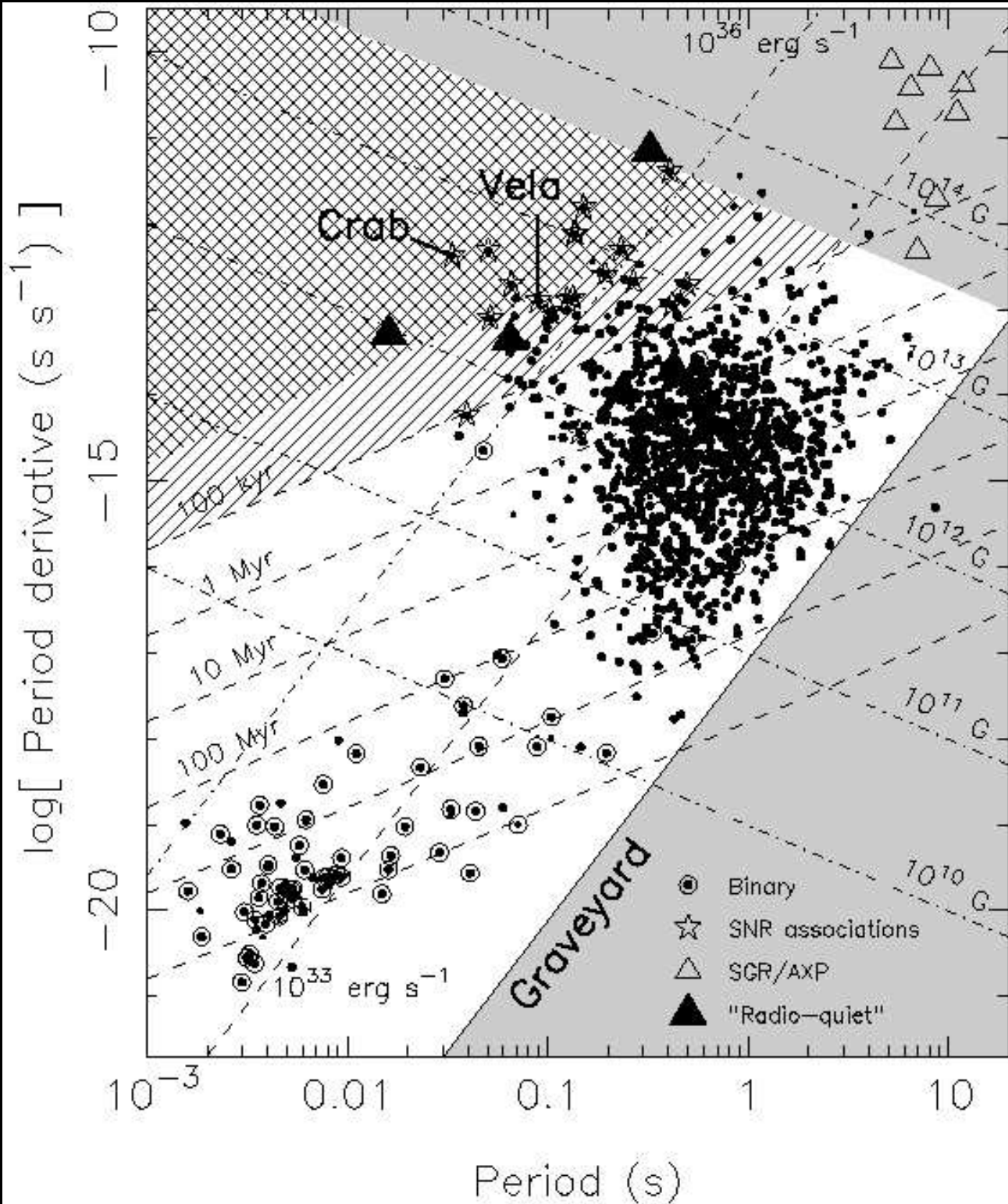
EM observational constraints on BHs and NSs

- Astrophysical GW channels: agreement with EM obs. HMXBs?
- Are existing excuses sufficiently good?
- Side branches of GW channels: agreement with EM observations?
- Are **co** in GWs stem from the same progenitor pool as HMXBs?

Lidia (Lida) Oskinova

The P-Pdot diagram

02



Taken from "Handbook of Pulsar Astronomy" by Lorimer & Kramer

The **pulsar HRD**: the exact evolution paths?

- young pulsars in SNRs
- fast spinning low-B pulsars in binaries
- high-B magnetars

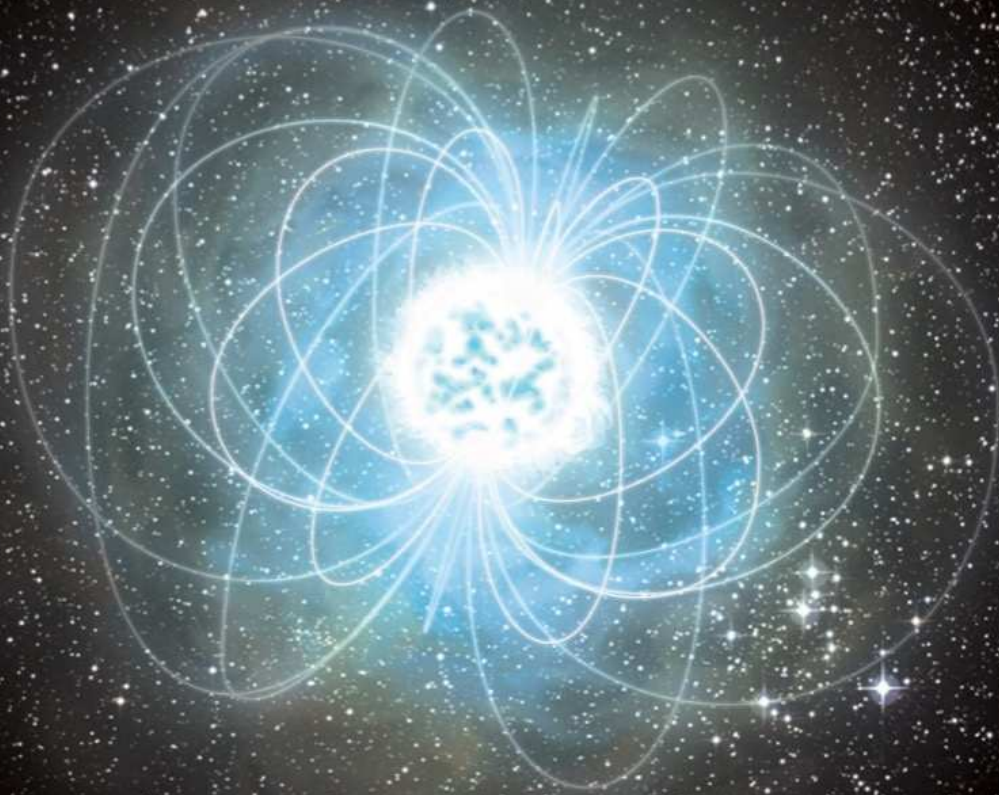
age $\tau = P/2\dot{P}$

- Keane & Kramer 08: Galactic SN rate → NS overproduction.

NS evolution?

Magnetars

03



NS with $B > 10^{15}$ G

- Duncan & Thompson'92: helical dynamo action
- fossile fields (?)
7% of massive stars are strongly magnetic
- Phenomena related to magnetar birth:
 - Cosmic Rays
 - L-GRBs
 - SL-SNe
 - FRBs
 - S-GRBs
 - direct GWs

Kasen & Bildsten 10 (SNe), Woosley 10, 17 (SNe), Metzger+ 11, 17 (SL-SNe, GRBs, FRB), Inserra+ 13 (SL-Ic), Keane+ 12 (FRB), Kaspi, Victoria & Beloborodov 17 (ARA&A), Stella+ 05 (GW NS shape); Zhong&Dai&Li 19 (GW at formation)...

LIGO 2019ApJ...874..163 - search for GW associated with magnetar bursts - negative (O3)

Magnetars in Binaries? ⁴

Astronomers have finally discovered a potential partner for a magnetar found in the Westerlund 1 star cluster. It might even solve the mystery behind the formation of these strange stars.

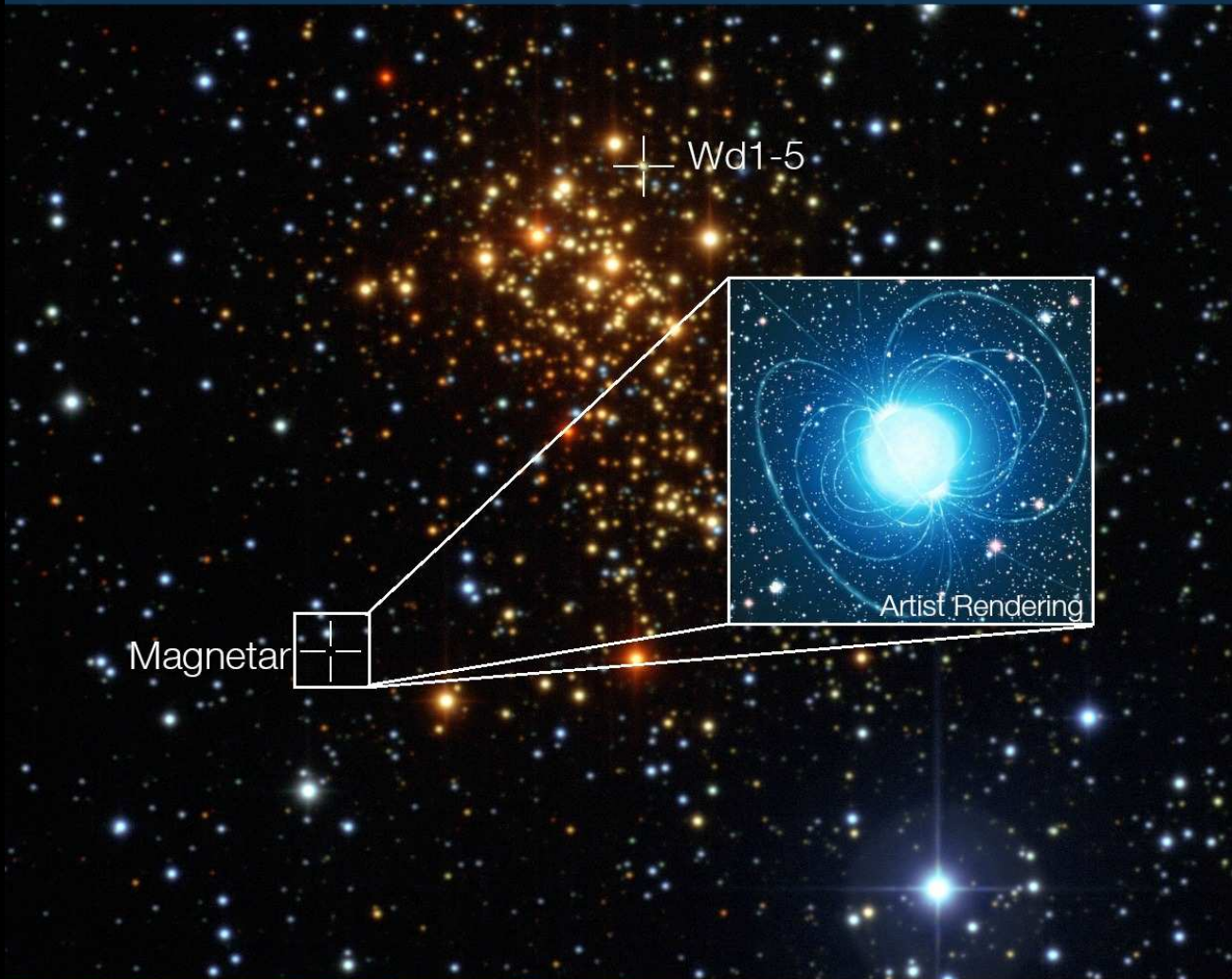


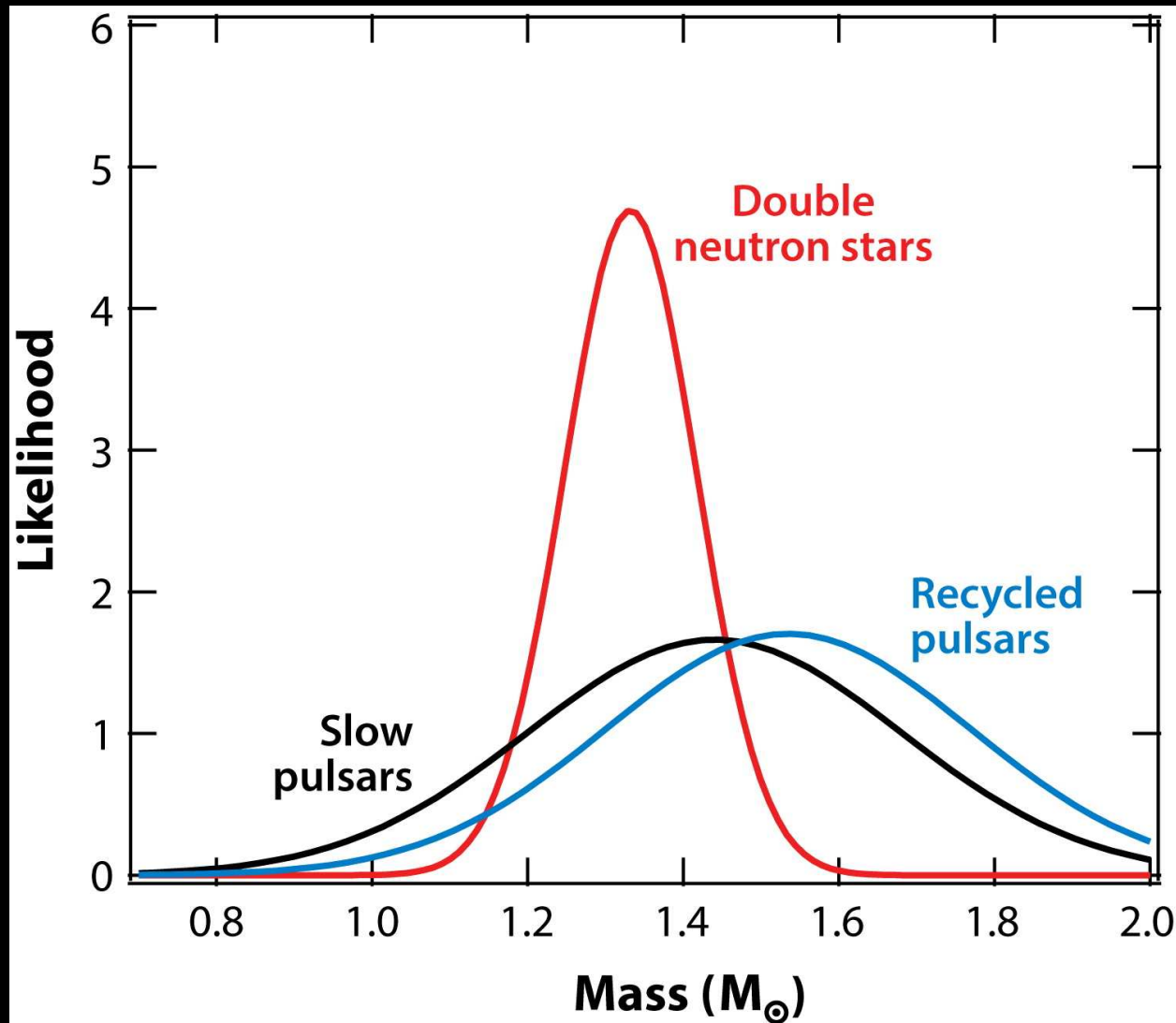
Image Credit: ESO/L. Calçada

- Paucity of magnetars in binaries. Kicks during birth? (Clark+ 14)
- Paucity of binary magnetic massive stars. Mergers?
- If mergers → how rates compare to GWs?
- S-GRBs rate in the Galaxy?
- Accreting magnetar candidate - 4U0114+65, $P_{\text{spin}} = 9350 \text{ s}$ (Sanjurjo-Ferrin+ 17)

The maximum NS mass measured is $2.14M_{\odot}$ (Cromartie+ 19)

05

Most massive NS are in binaries - not surprising? Different mass functions BNS and recycled - constrain on formation channels?



GW 190425: was it a He-star (WR) + NS? (LIGO 19)

Statistics? are all millisecond pulsars in LMXBs?

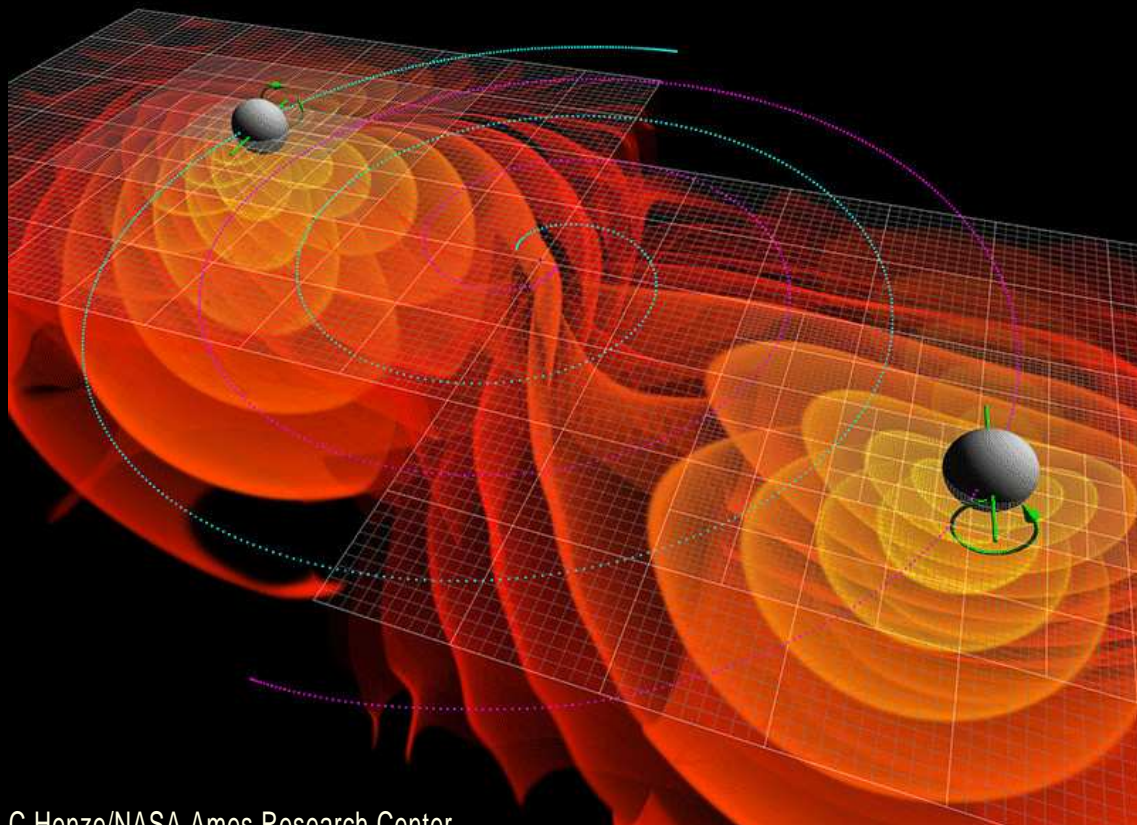
Systematics with NS mass measurements in HMXBs

AR

Özel F, Freire P. 2016.

Annu. Rev. Astron. Astrophys. 54:401–40

Commonly-cited channels for the GW BH merger's progenitors

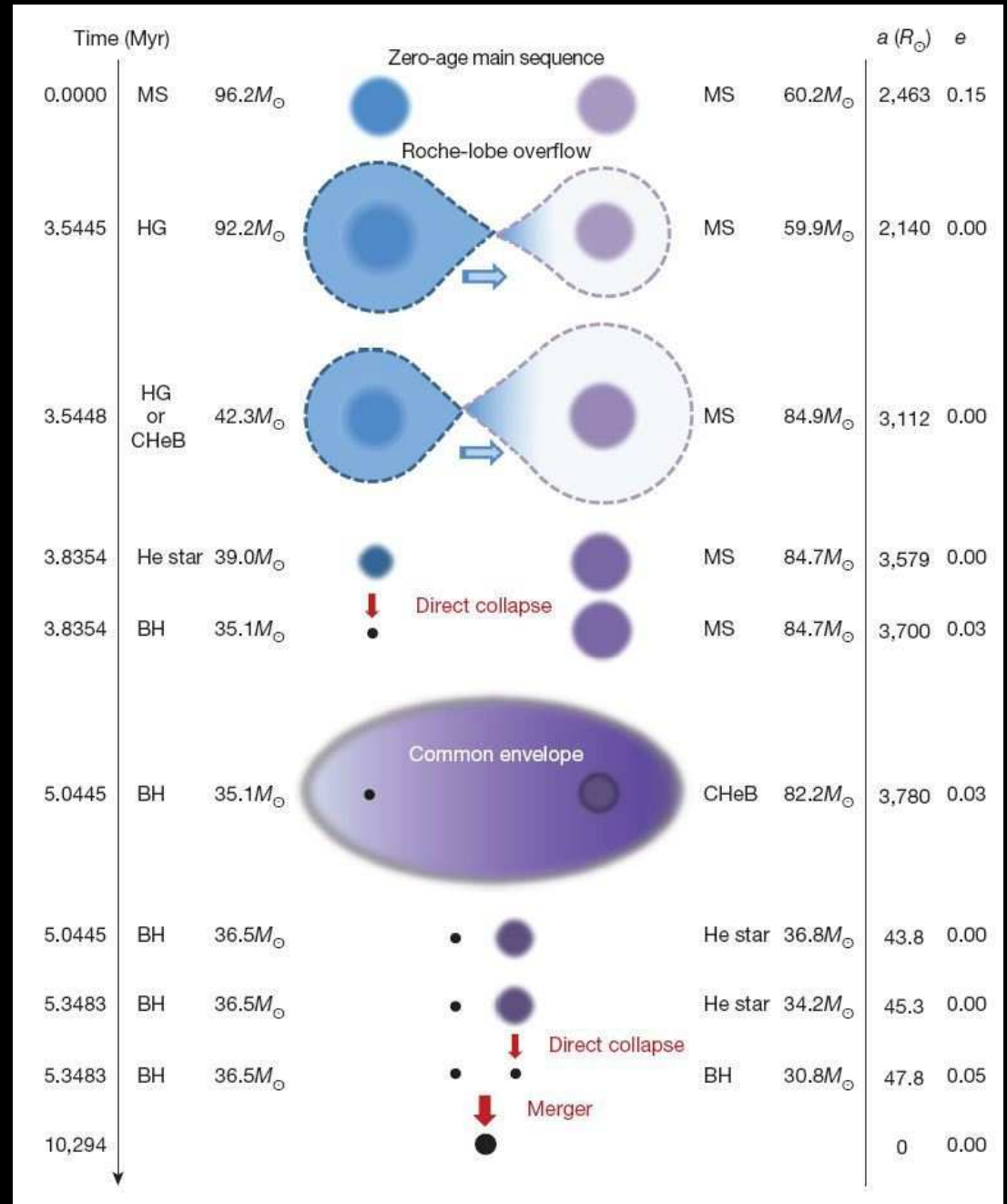
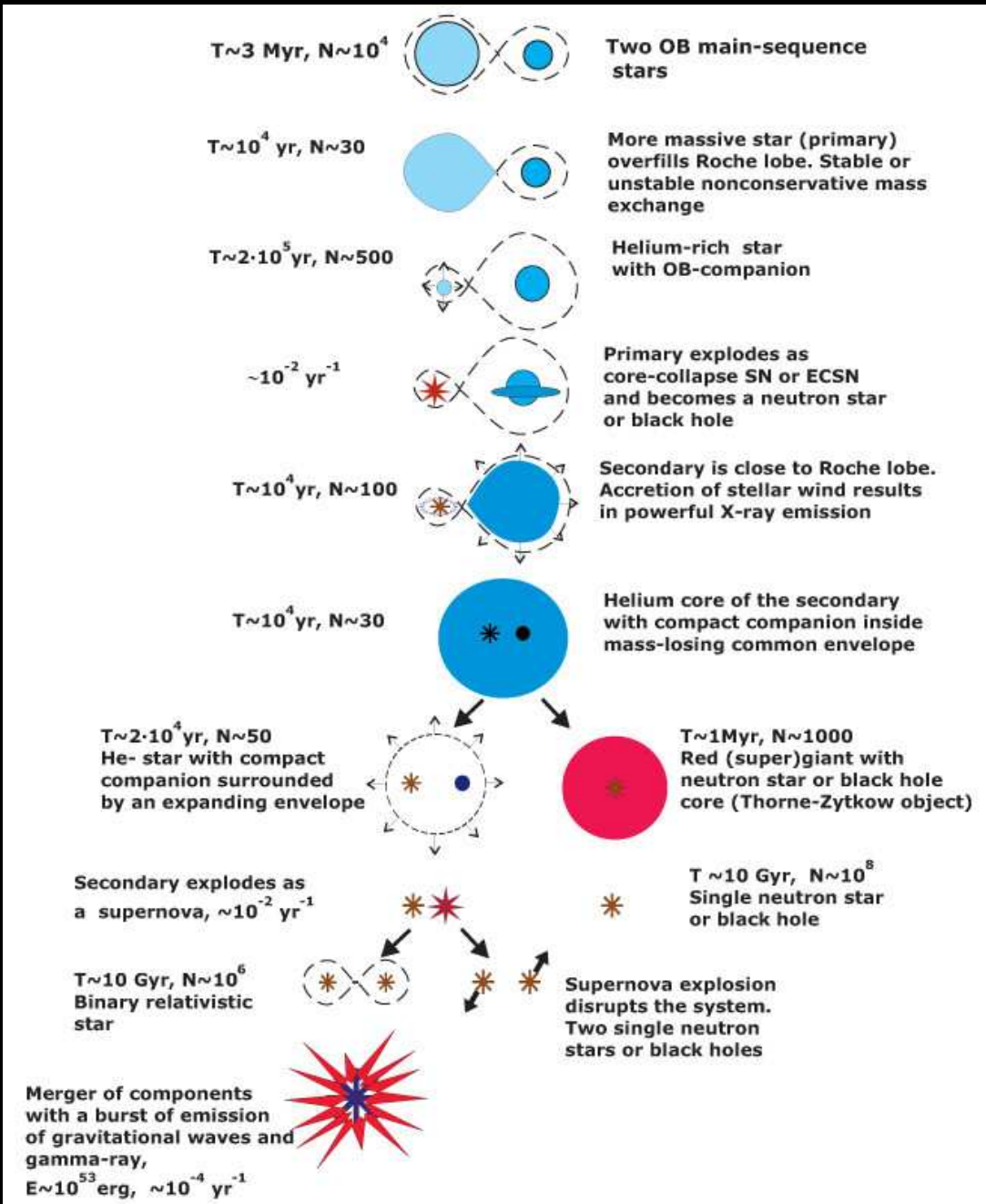


C. Henze/NASA Ames Research Center

- **Field massive binaries**
 - Standard scenario
 - CH evolution
- **Dynamic interactions in dense clusters**
- **Hybrid models**
- **Primordial BHs**

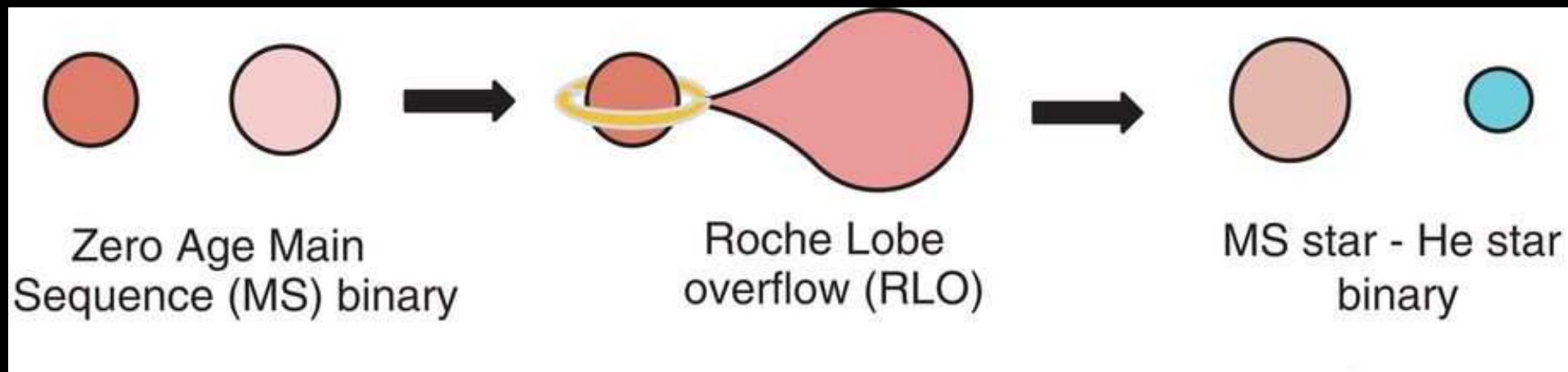
Successful model needs to explain - masses, spins, merger rates, distributions ...

can any of the channels be excluded? Spins.



Two classic ways to form Wolf-Rayet stars

I. Stripped He-cores from mass exchange in binaries (Paczynski 67)

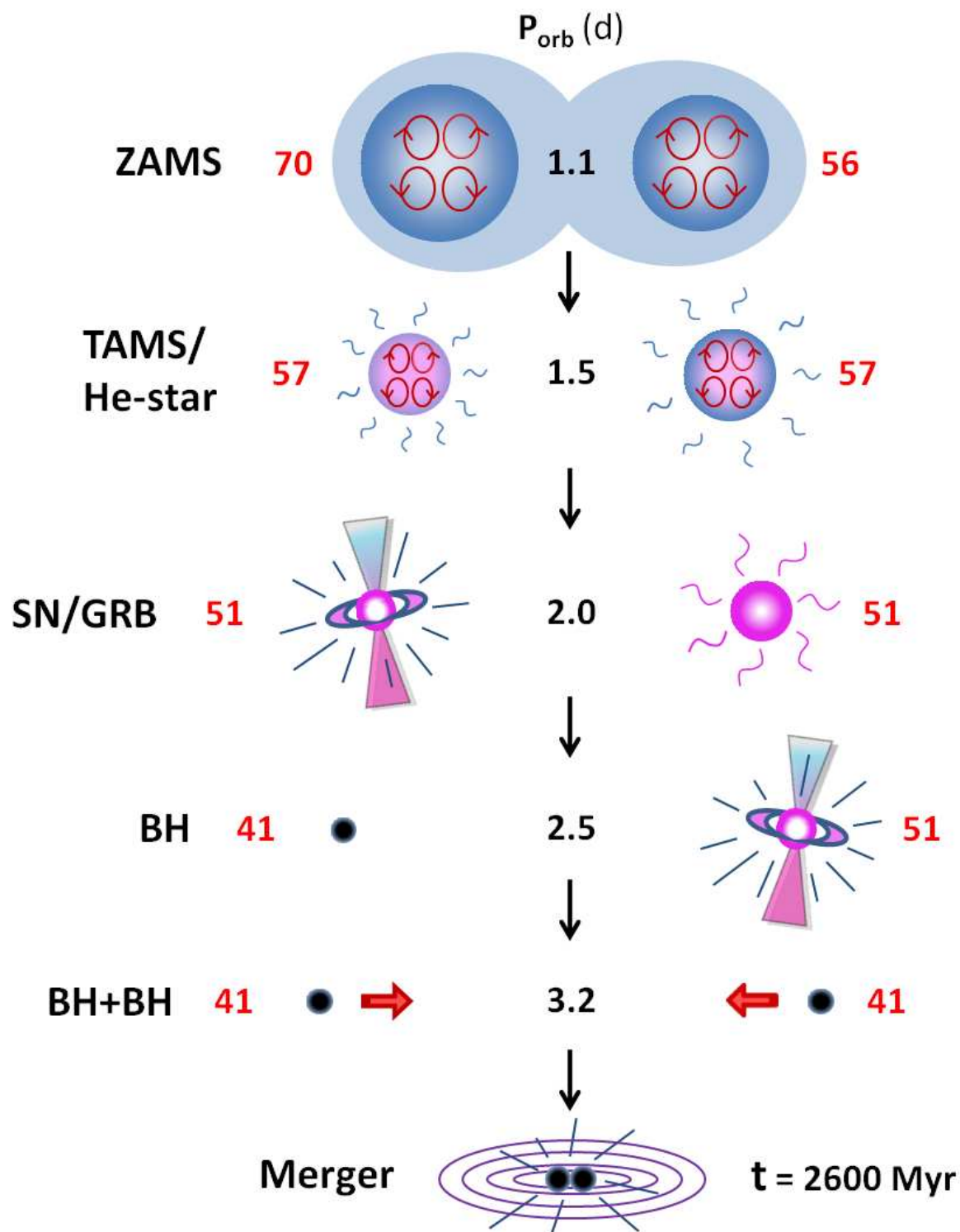


II. Stripped He-cores as a result of stellar wind in single stars (Conti 75)



Unique channel does not explain **WRs in the SMC & LMC** (Shenar+)

Do heavy BH progenitors exist in local BCD galaxies?



Maeder 87, Mandel deMink 16; Marchant+ 16

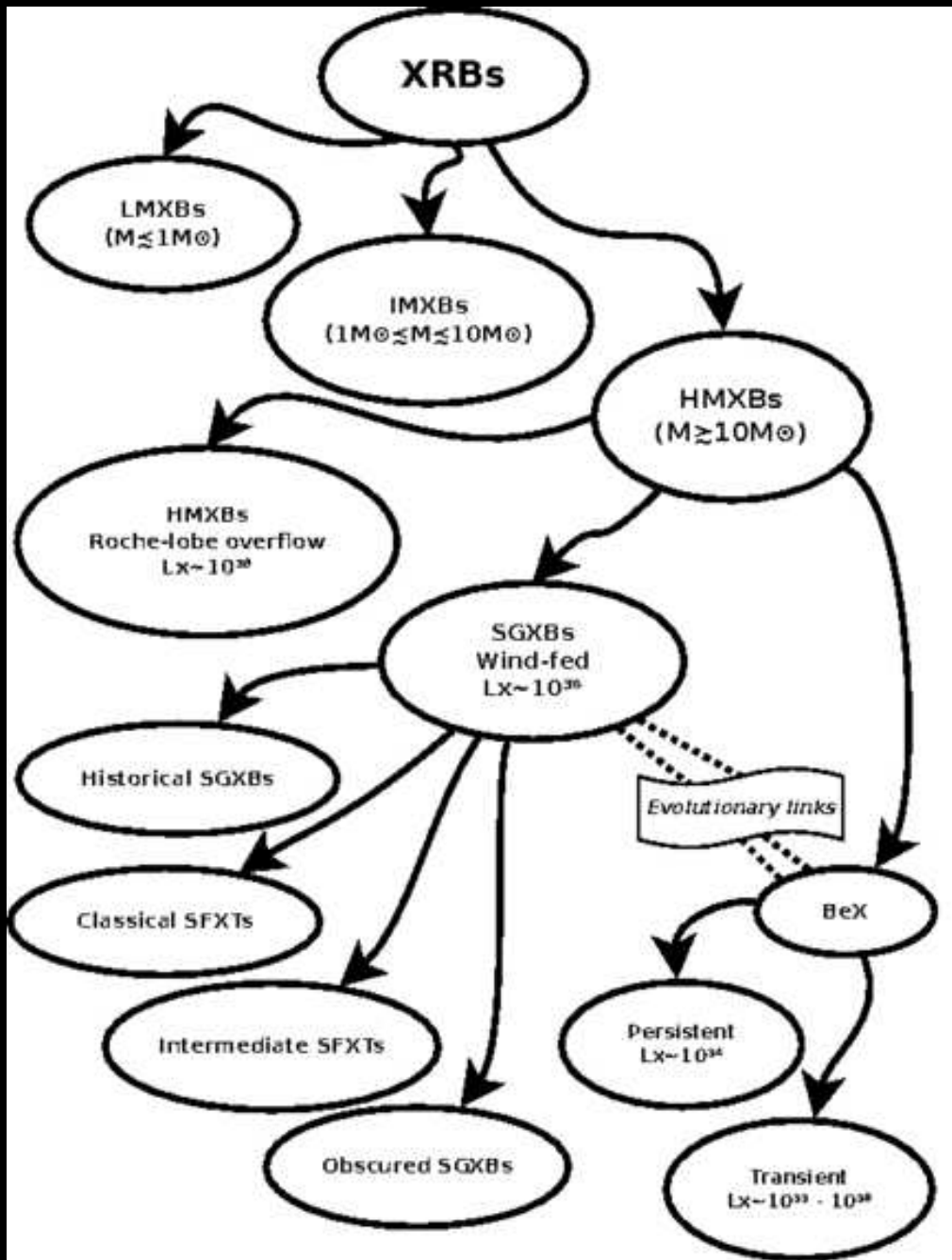
WR stars in the SMC - nearly qCH evolution (Martins+ 06, Hainich+ 10, 14)

Ramachandran+ 19: at SMC $Z \rightarrow M^* > 30M_{\odot} \rightarrow \text{qCHE}$

The answer is - **likely**

No RLOF fed BH HMXBs with massive SGs at low-Z, i.e. no SG BH ULX (?)

The Taxonomy of X-ray Binaries ¹⁰

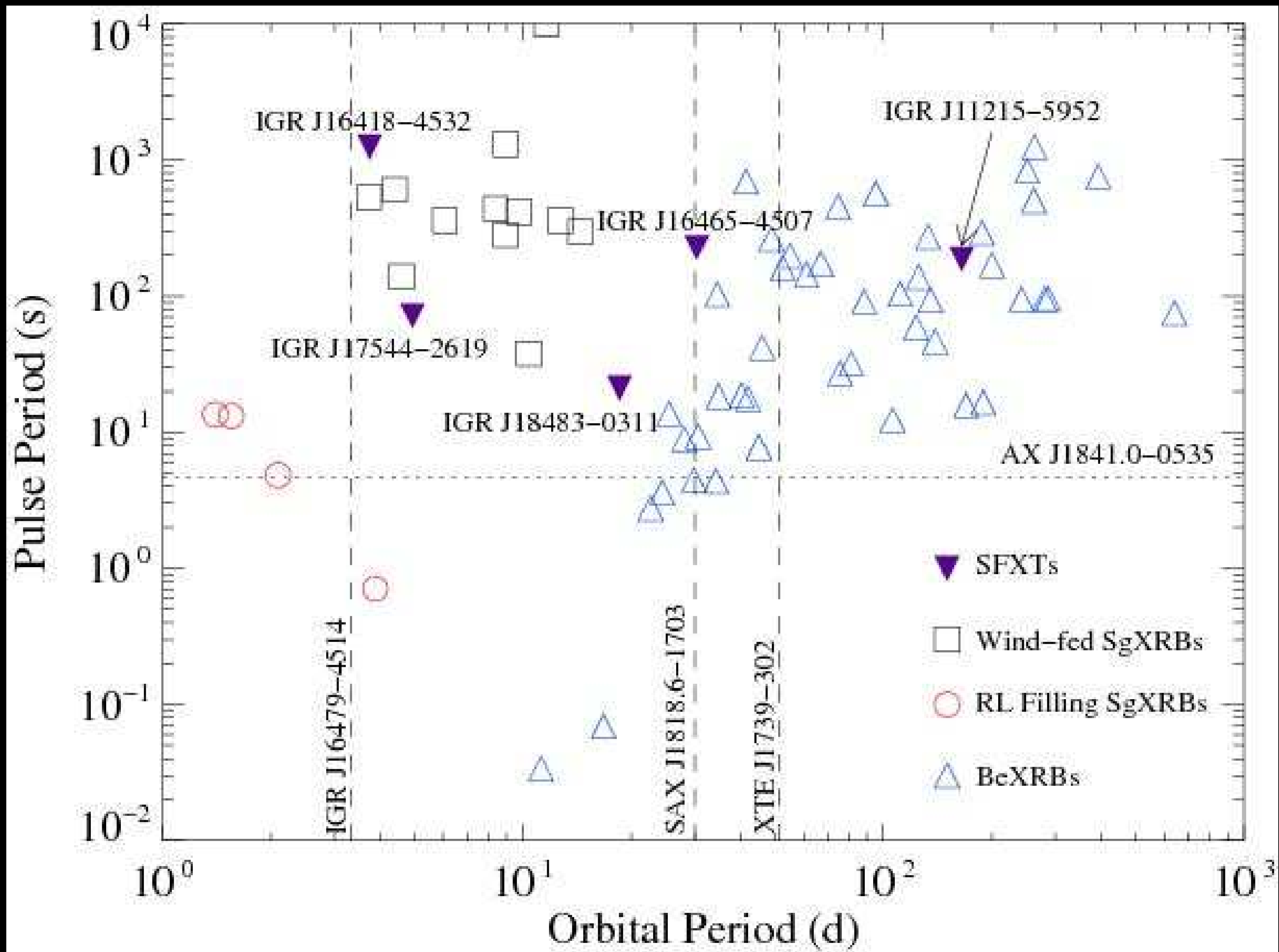


- The side branches of GW channels should go through one of these bins. Is it true?

Links with transients: e.g. CE and HMXB formation (LO, TB, + 19).

- The majority of persistent HMXBs have BSG donor and ~identical orbital properties - signature of CE? (in prep.)
- Donor types: Be (!), BSG (!), WR+BH (?), WR+NS (?), 1 MS, 1-2 AI-type (ULX), RSG (ULX), 1 B[e]-CE?, 1 LBV (?)

Corbet diagram: Orbital vs. X-ray pulsar period (Corbet 96) ¹¹



SFXPs: majority of HMXBs is in quiescence. Interplay between B , P_{NS} , \dot{M}_{acc} (Bozzo+, Shakura+)

star forming region in the SMC (Optical/X-ray): Henault-Brunet, Oskinova+ 11, Oskinova+ 13

Metallicity effects

Higher HMXBs production rate at low-Z (Brorby+ 14)

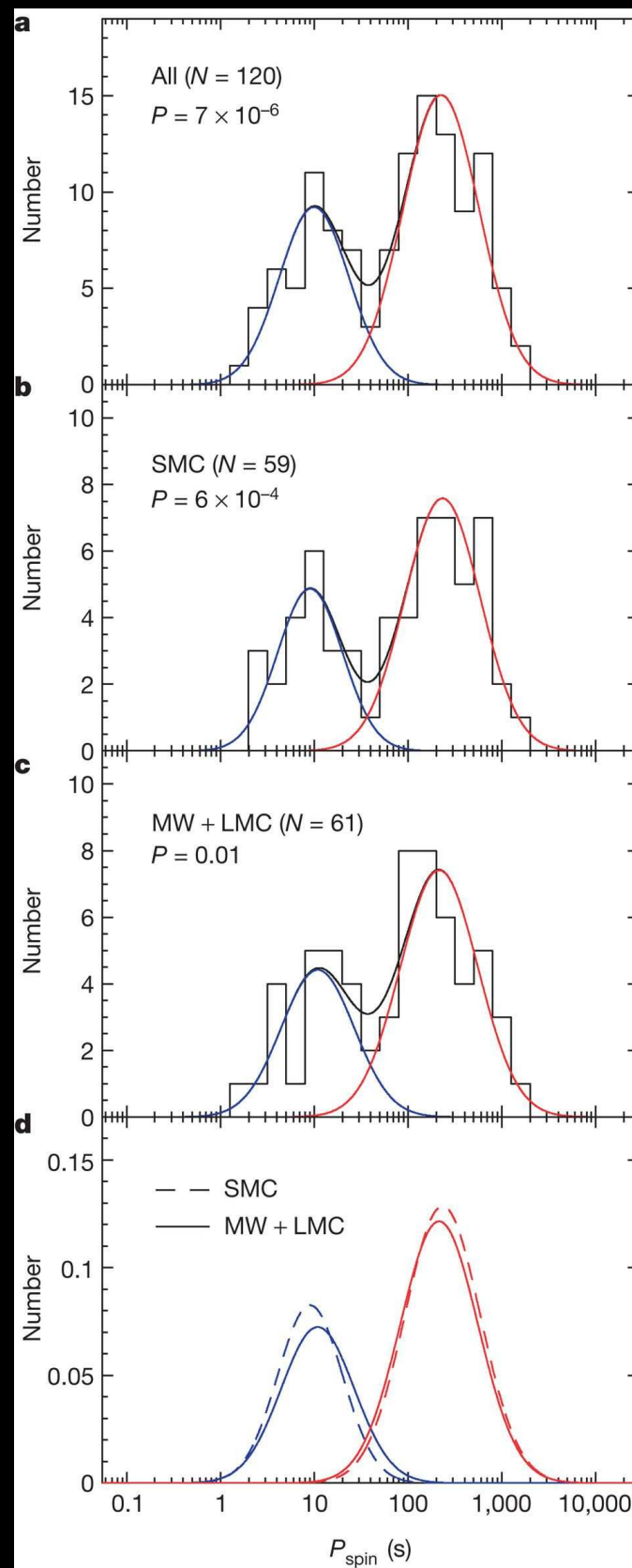
SMC: all but 2 are BeXRB - Z-effect or SF history (Antoniou+ 19)?

Does Z affects the ratio of wind-fed vs RLOF systems (Linden+ 10)?

No BH, no LMXBs in the SMC (recent catalog Lazzarini+ 19)

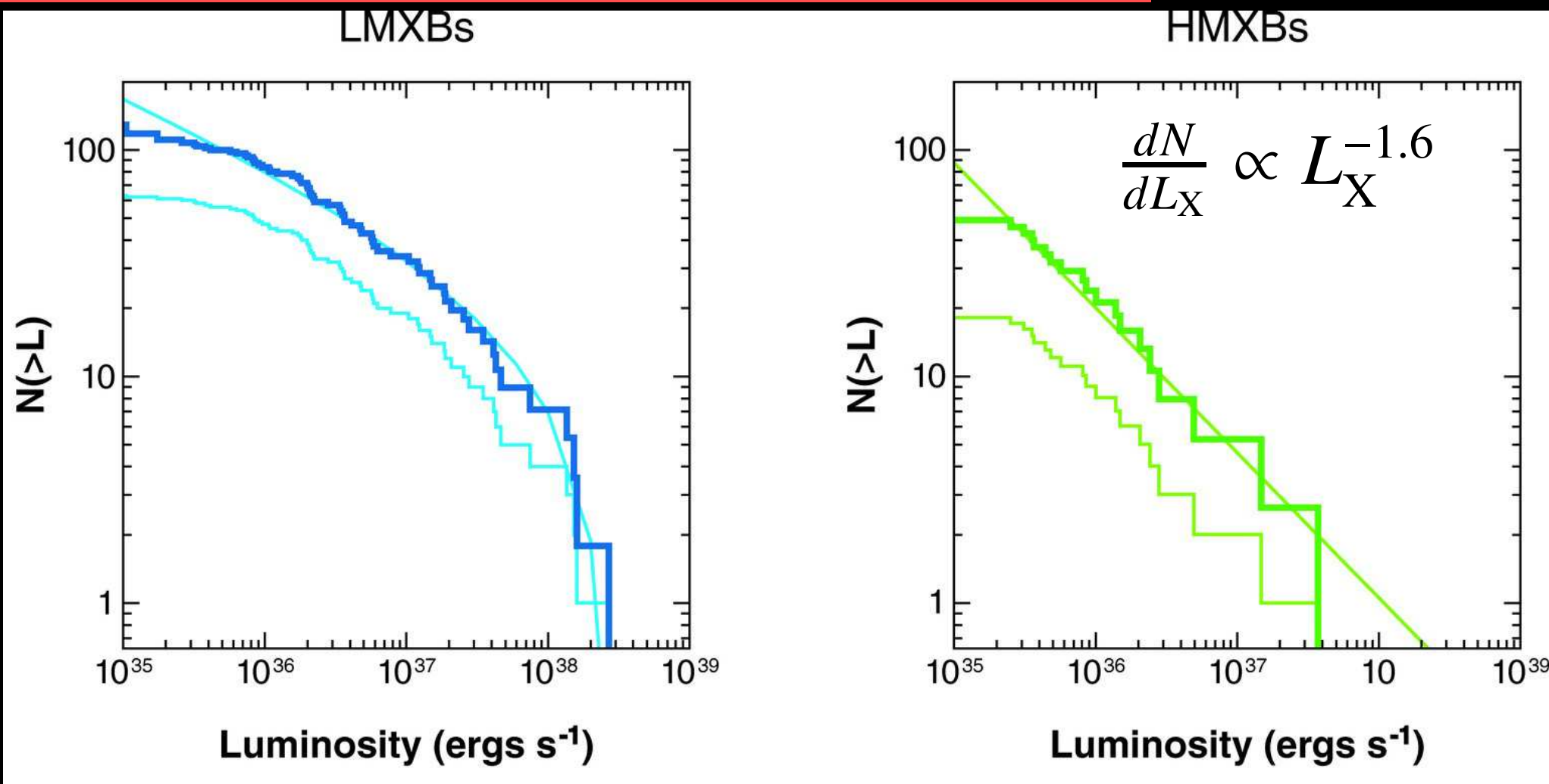
Long period pulsars within SNR (Henault-Brunet+ 11, Gvaramdze+ 19).

SNe mechanisms?



The universal X-ray luminosity function (Grimm+ 03)

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LMXBs and HMXBs: different slopes

No breaks - no first mass gap between NS and BH, no cut off.

At low-Z the normalization is different but the slope remains

Implication - the same BH mass spectrum at low and high-Z?

Can the BH mass spectrum be pulled out of the XLF?

Accretion mechanisms determine the slope, low M-dependence (?)

WR HMXBs

WR+NS - not detected

do no survive CE? (van den Heuvel+ 18)
NSs are hidden in WR winds? (Toala+ 18)

WR + NS merger - GRB?

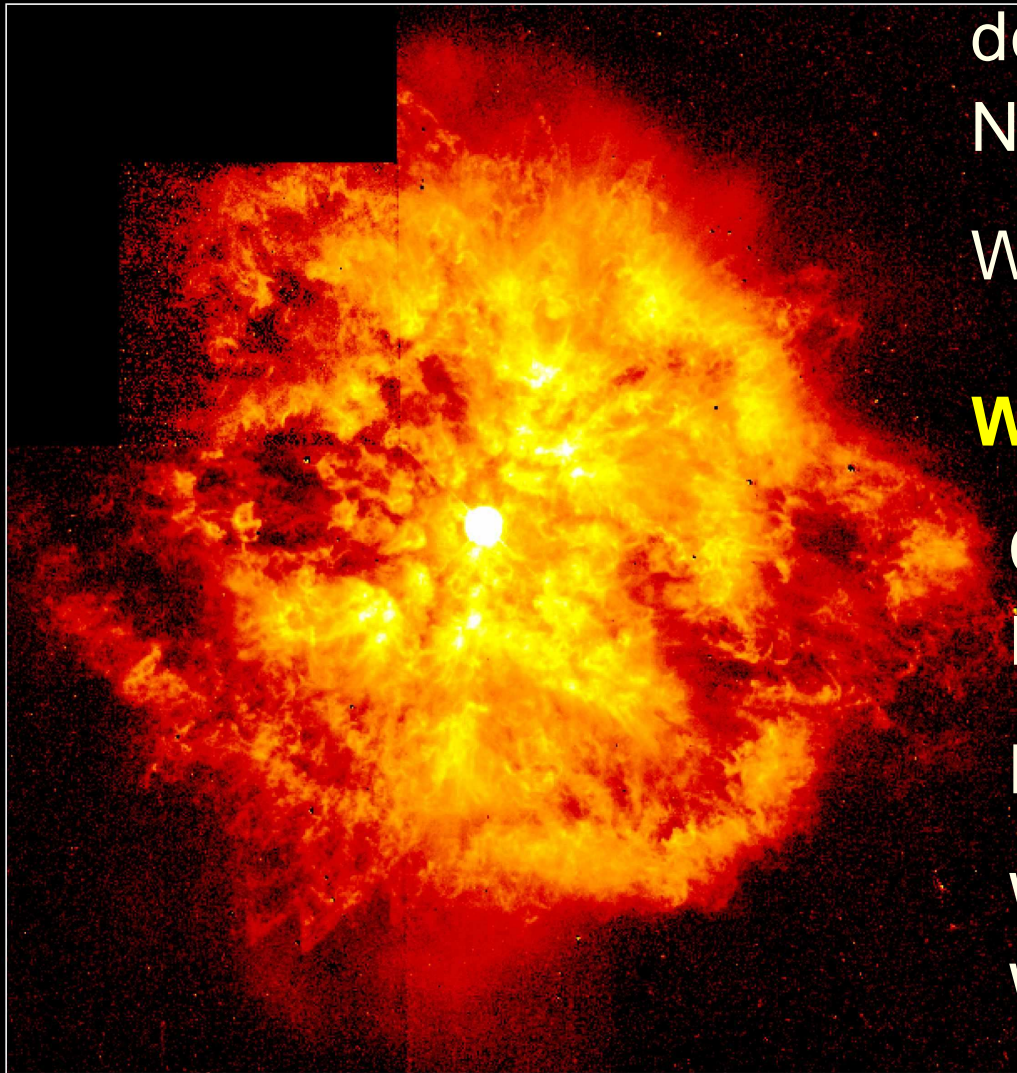
WR+BH - a handful of candidates

Cyg X-3: $10.4M_{\odot}$ WR + $2.4M_{\odot}$ BH/NS
P=4.8 hr (Zdziarski+ 13)

How secure are other WR+BHs?

WR star direct collapses: rates of
WR HMXB?

WR -binaries/ WR HMXBs/ GRBs/
and SNe

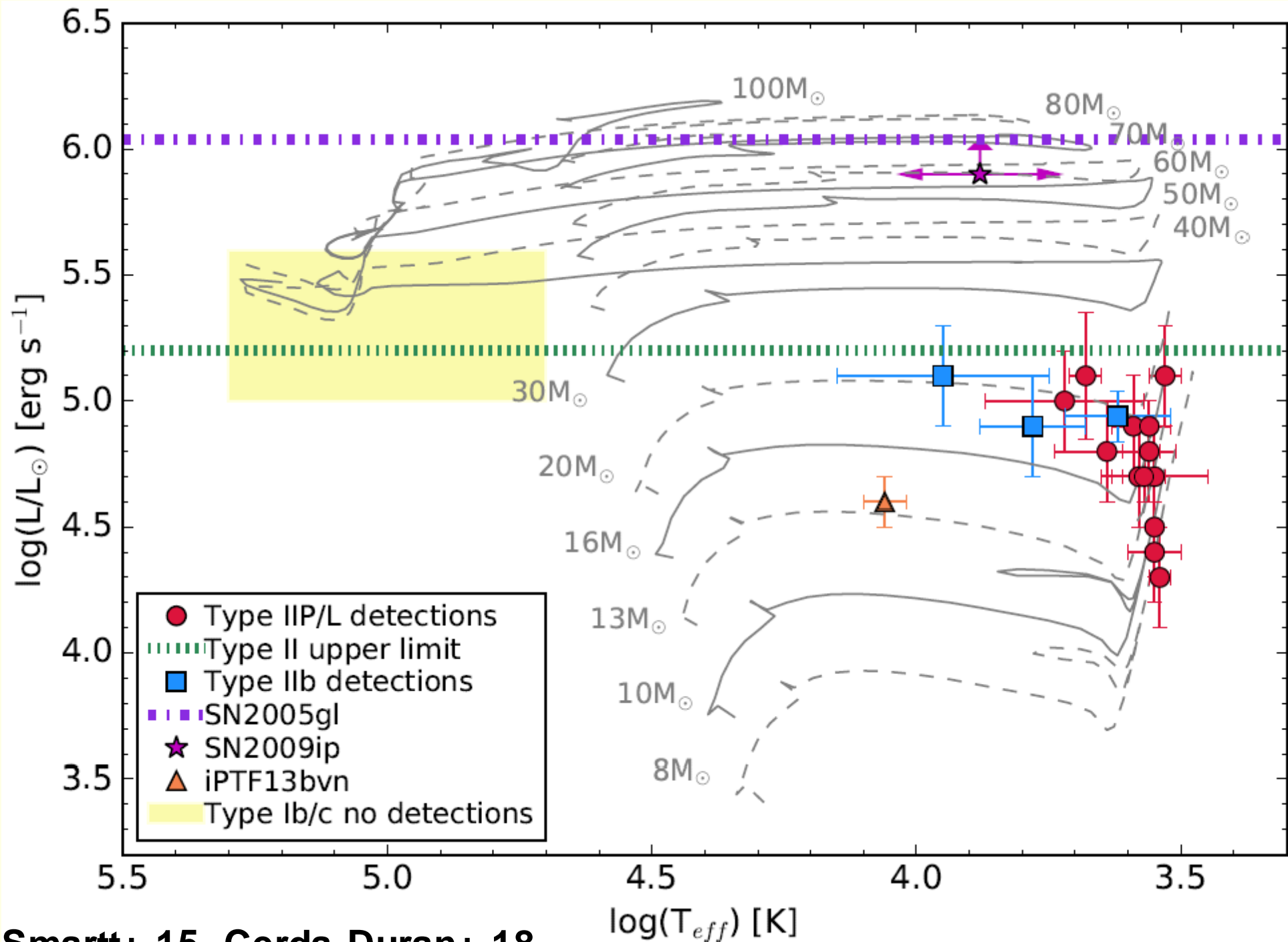


Nebula M1-67 around Star WR124
Hubble Space Telescope • WFPC2

PRC98-38 • STScI OPO • Y. Grosdidier and A. Moffat (University of Montreal) • NASA

IC 10 X-1 co - $2M_{\odot}$ (Laycock+ 15); NGC 300 X-1 (LMXB? Binder2015);

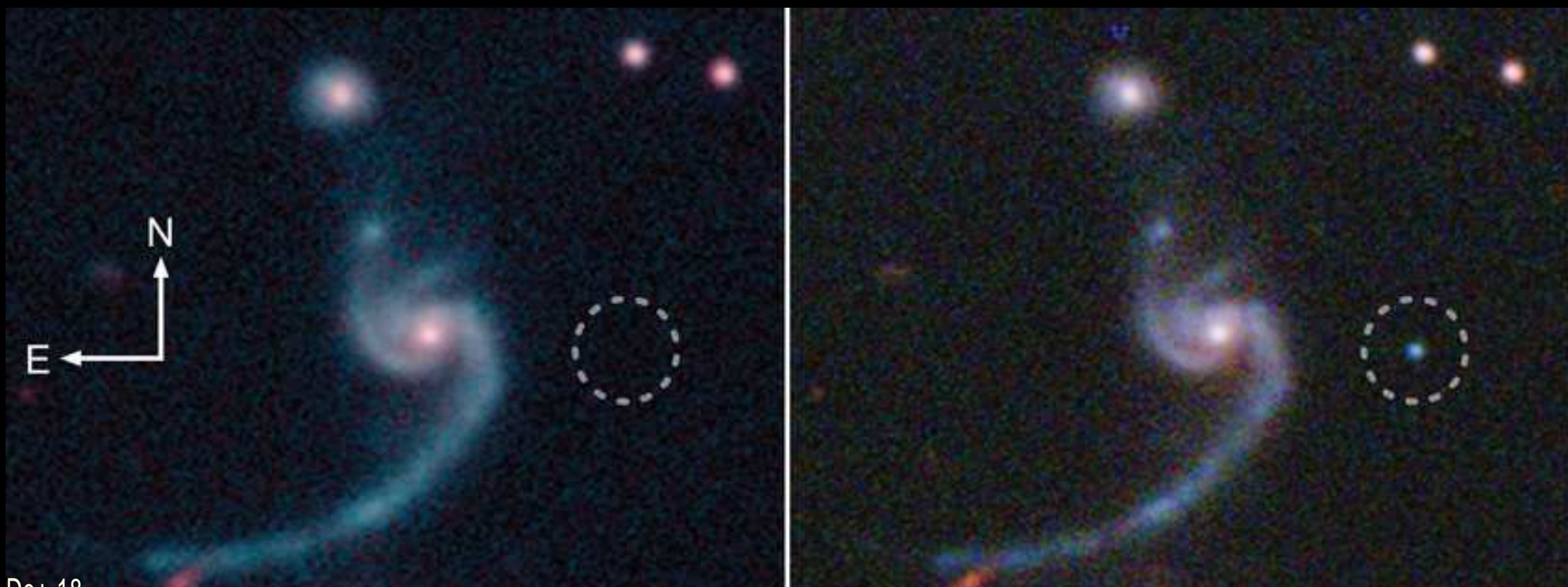
Testing stellar evolution with SNe progenitors and their absence



Smartt+ 15, Cerda-Duran+ 18

Are stripped SNe Ibc products of binary evolution (?)

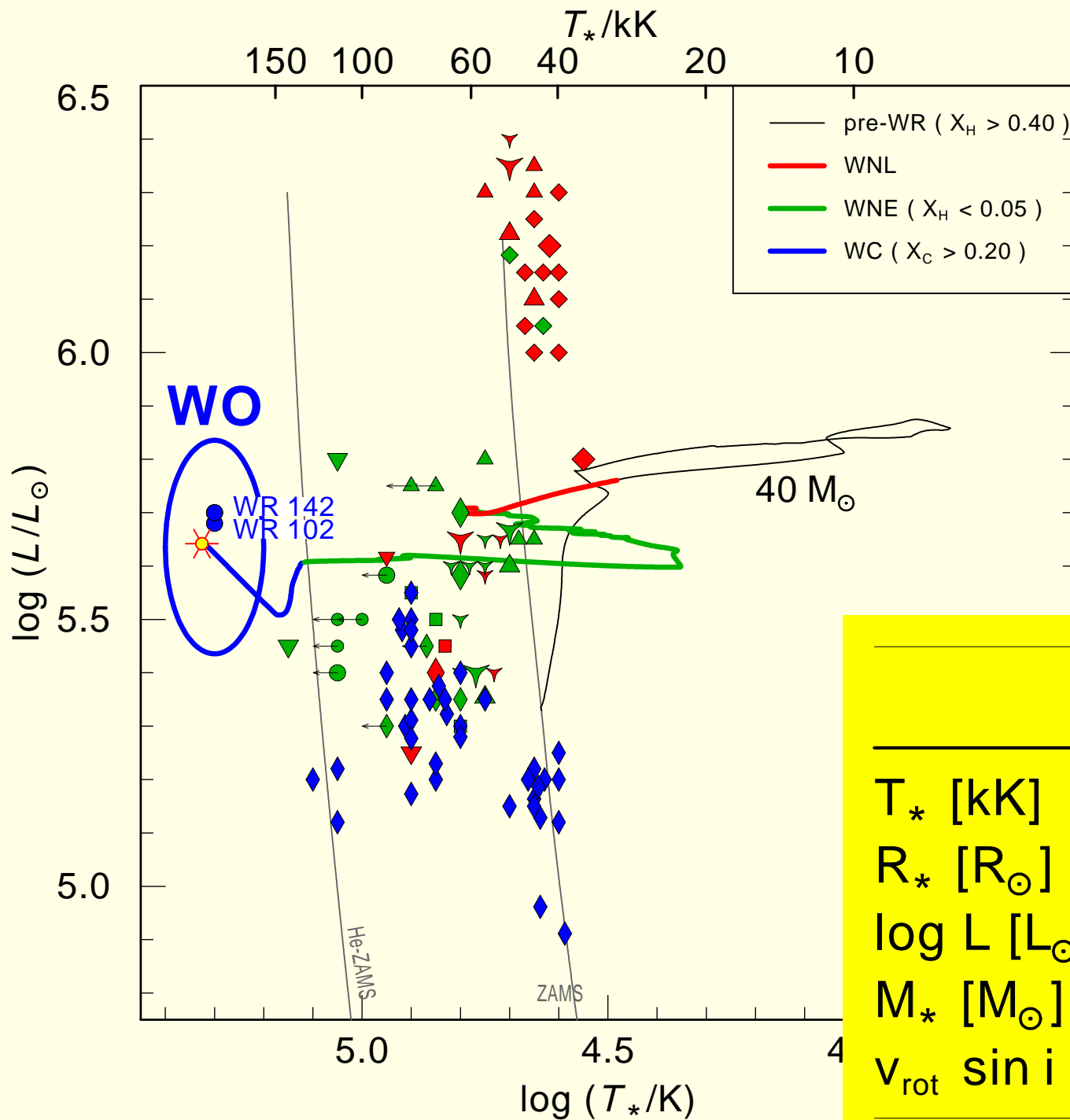
- SE-SNe progenitors $M < 5M_{\odot}$, i.e. initial mass $< 25M_{\odot}$ (Prentice+ 18)
- Low-mass H-free ejecta and low explosion energies
- Binary evolution products and double-NS progenitors
- The progenitors are low-mass stripped WC/WO stars
- Massive binary progenitor SNIc 2017ein (Kilpatrick+ 18)



De+ 18

SNIc iPTF 14gqr $M(\text{ejecta})=0.2M_{\odot}$; $E=1e50$ erg

What do we know about real WO stars?



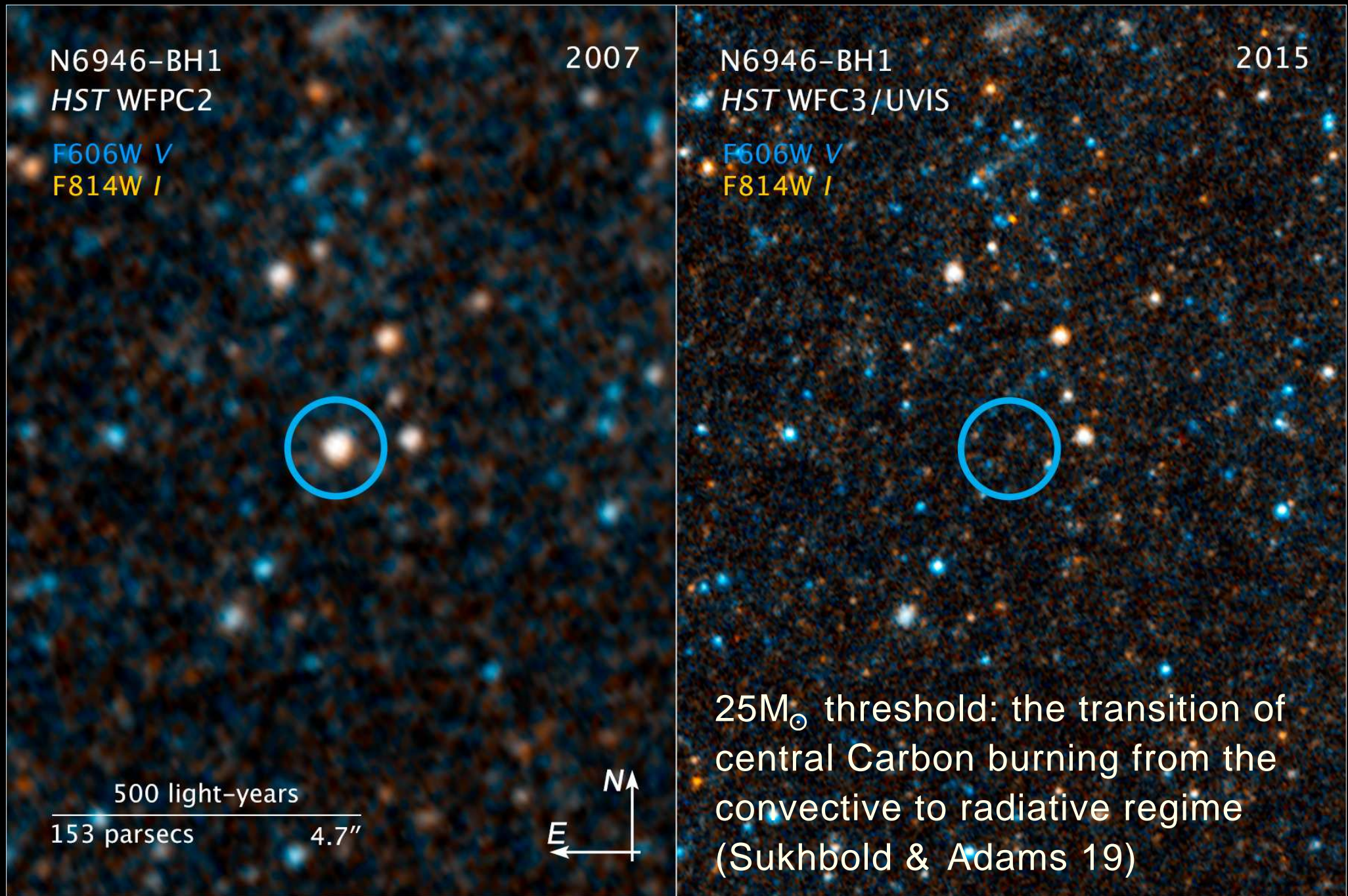
Five WOs
in the Local Group
(LO+ 11; Sander+ 12, Tramper+ 14)

Great agreement with
evolutionary tracks
for single stars

Close to carbon MS

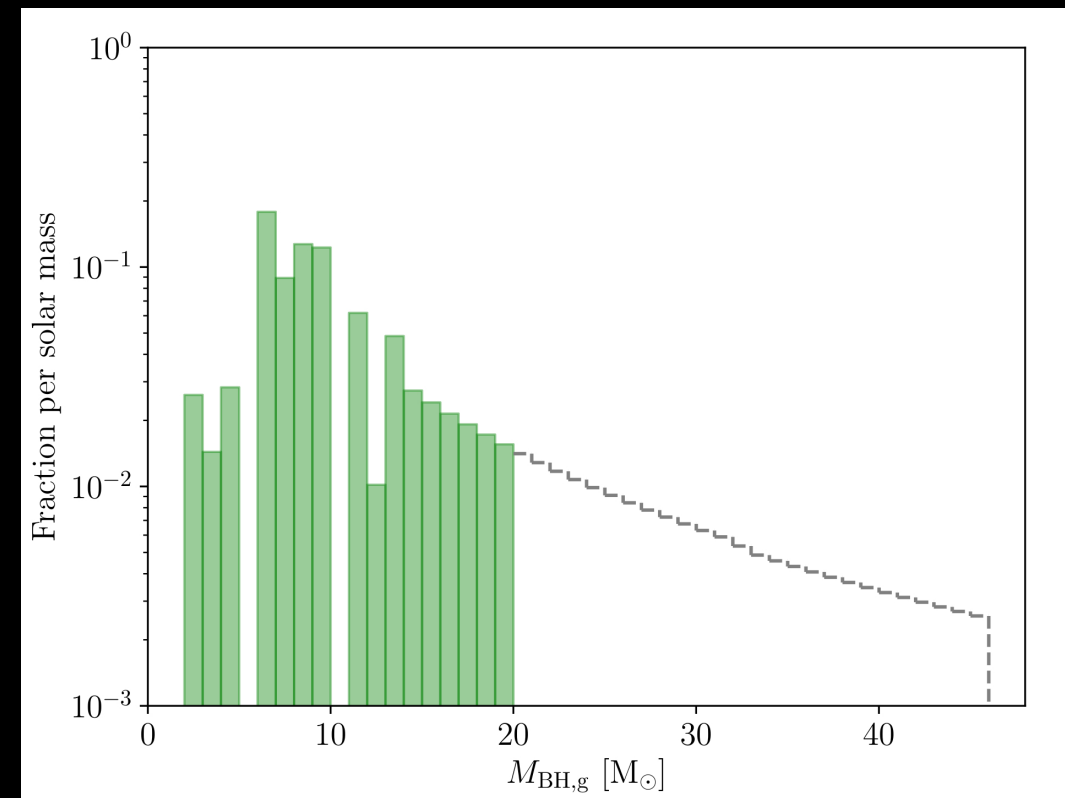
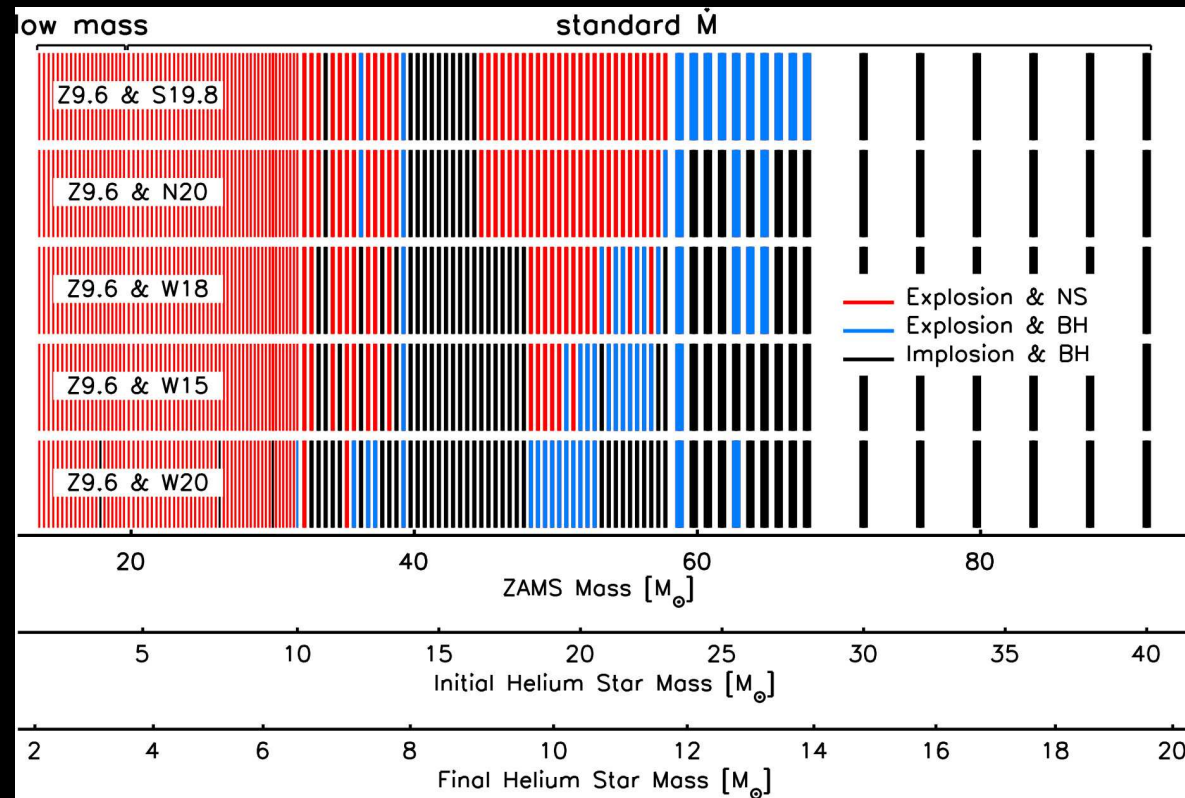
	WR102	WR142
T_* [kK]	200	200
R_* [R_\odot]	0.6	0.6
$\log L$ [L_\odot]	5.7	5.7
M_* [M_\odot]	19	20
$v_{\text{rot}} \sin i$ [km/s]	~1000	~1000

N6946-BH1 - disappearance of a $25M_{\odot}$ RSG (Adams+ 2017)



July 8, 2007 vs. October 8, 2015 HST>WFPC2, WFC3/UVIS

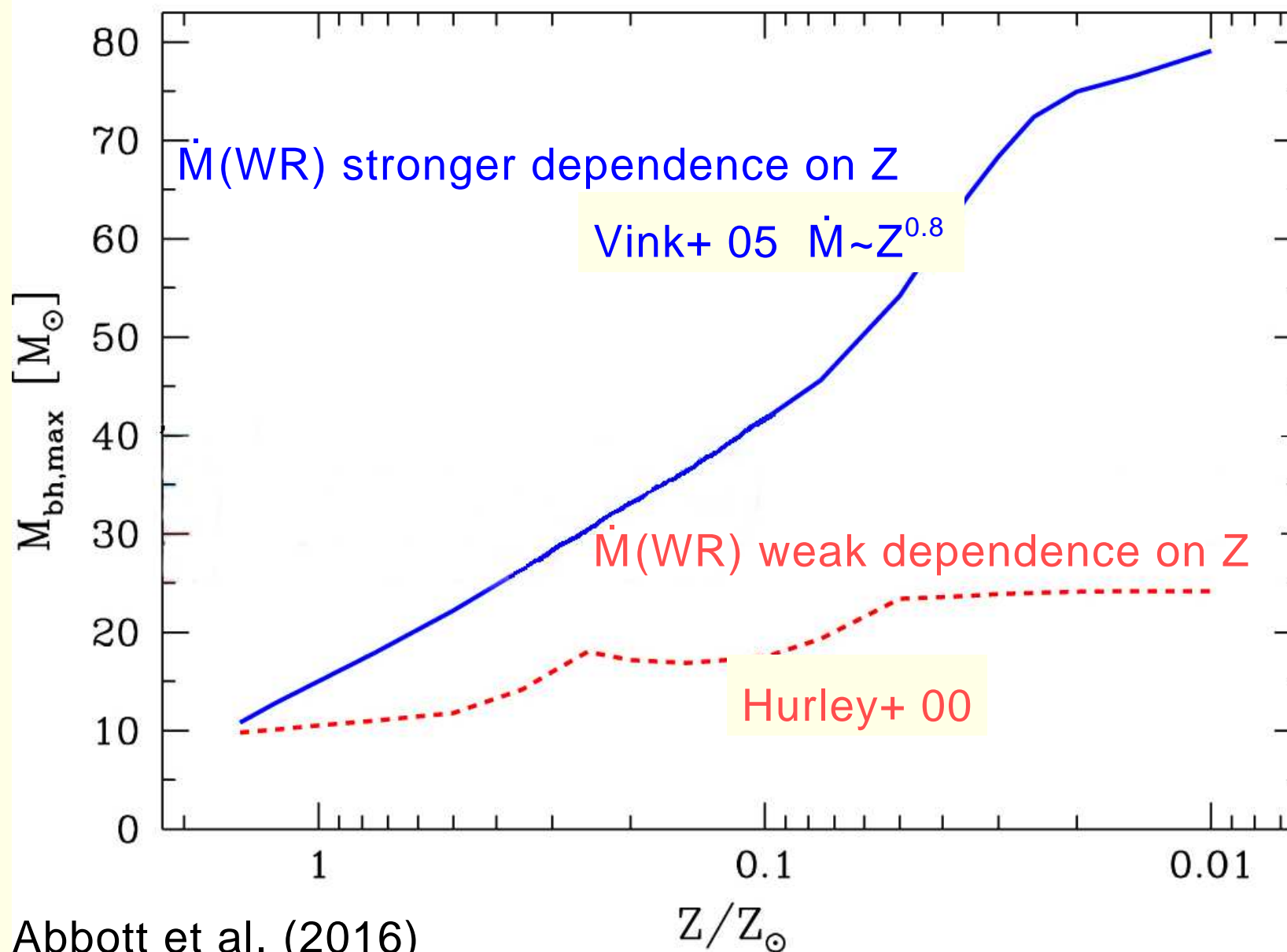
The median NS mass - 1.35-1.38 M_{\odot} and
The median BH mass 8.6 M_{\odot}



No mass gap between NS and BH
Sensitive to mass-loss on the WR stage

Astrophysical implications of GW detections

max. BH mass in dependence on metallicity for different \dot{M}

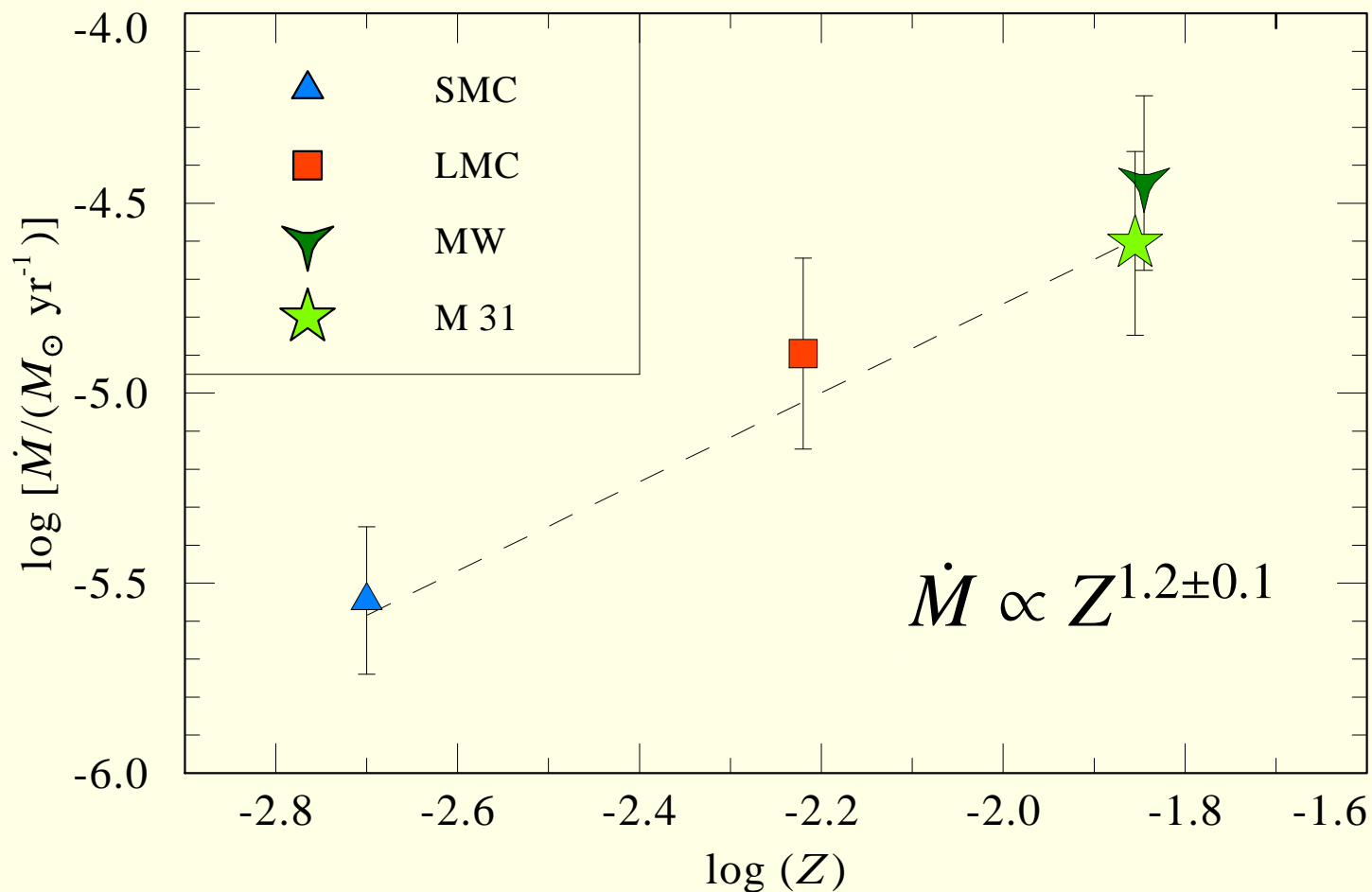


Metallicity dependence of WR mass-loss rates

Large samples of WN stars from

- Small Magellanic Cloud (SMC)
- Large Magellanic Cloud (LMC)
- Milky Way
- Andromeda Galaxy (M31)

$$\dot{M}_{\text{WR}} = f(L, T_*, X_{\text{He}}, Z)$$

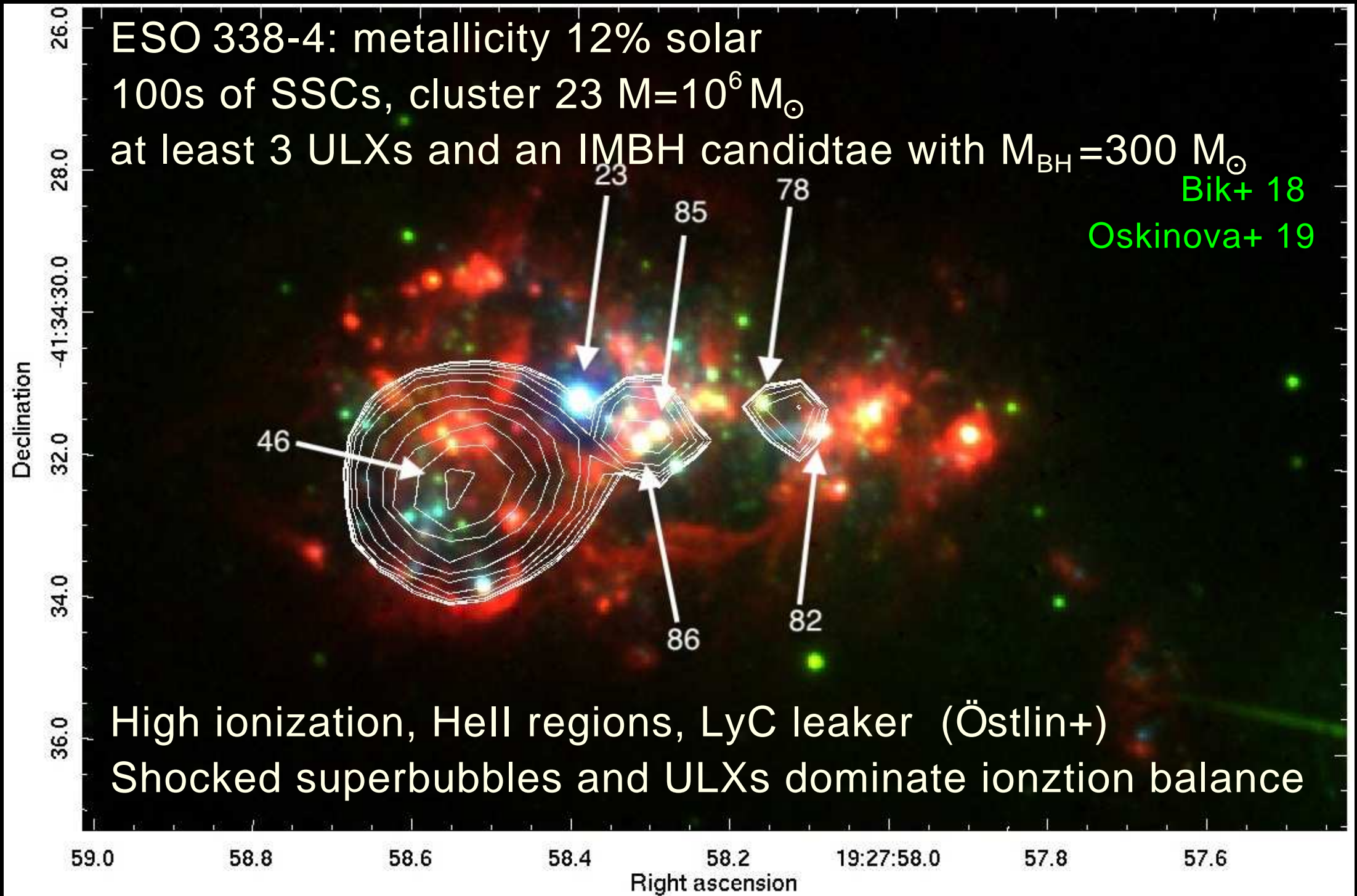


Hainich+ 15

→ Z-dependence
much steeper than
assumed in
population
synthesis!

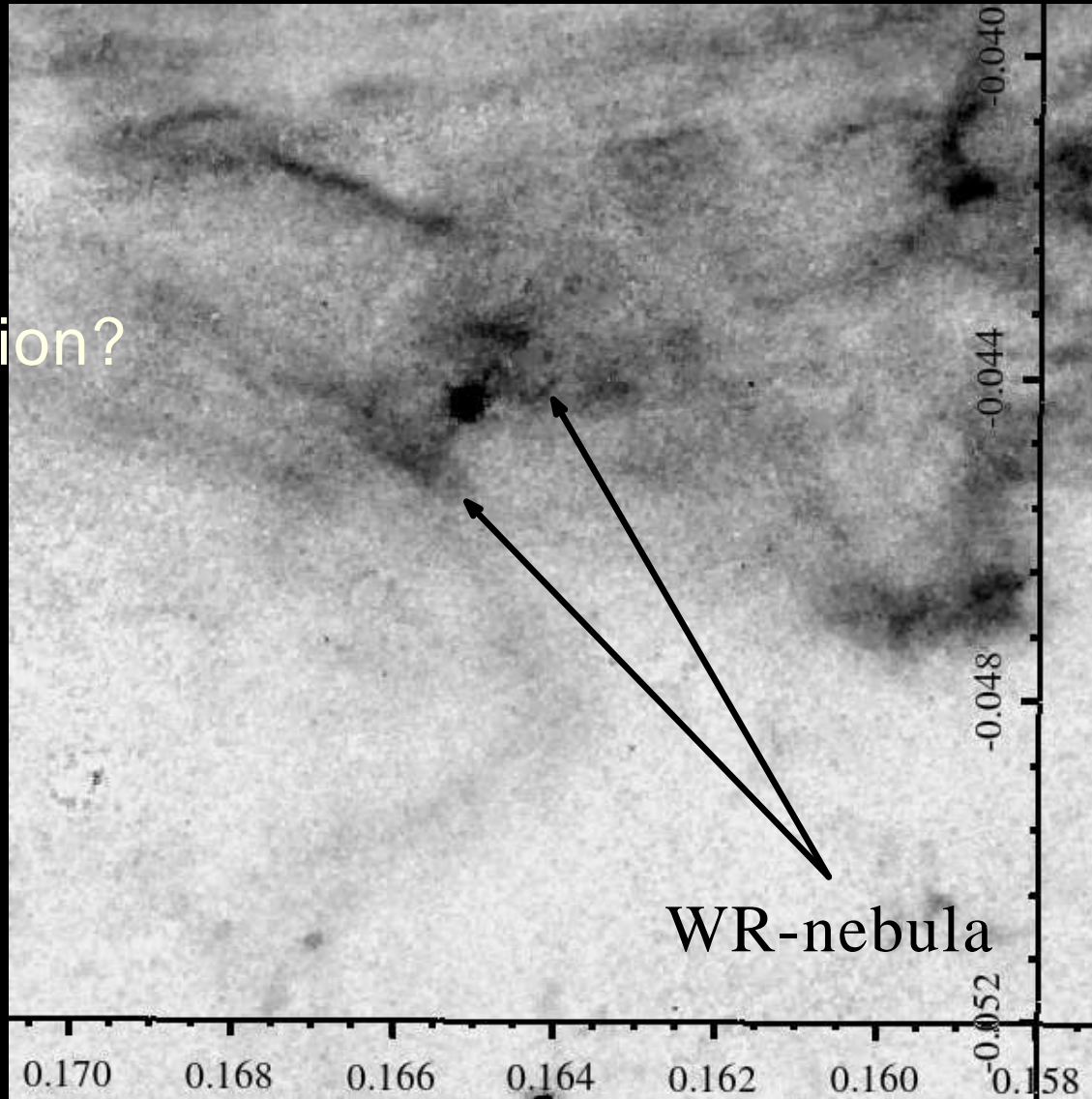
$$\dot{M} \sim Z^{1.2}$$

WR HMXBs are natural ULXs (Hainich+ 19, Marchant+ 18)



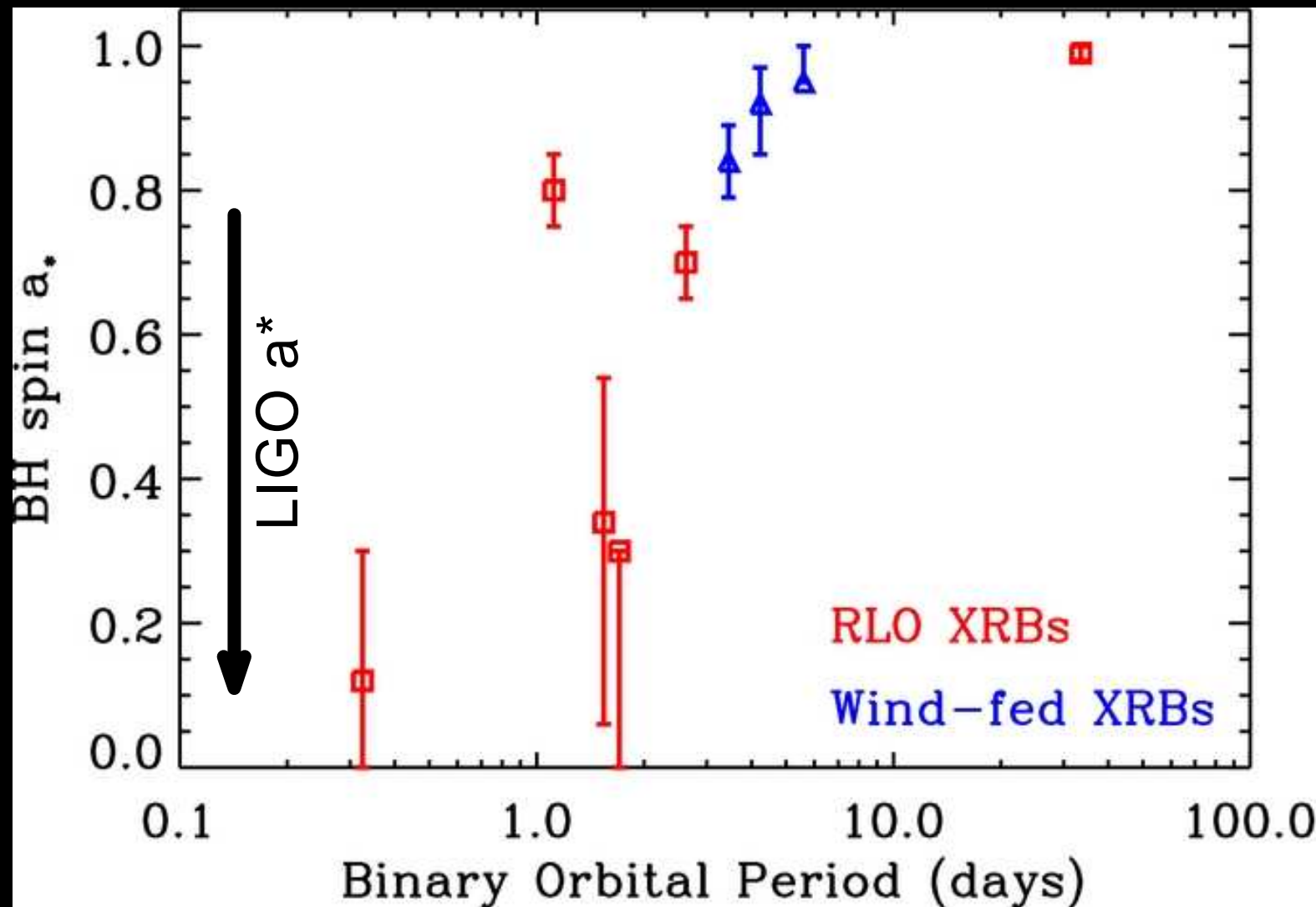
X-ray quiet BH binaries

Inhibited accretion?
Wide orbits?
Be+BH (?)



WR102c (Lau+ 16, Steinke+ 16)

Binary channel and spin discrepancy - how bad is it?



Fragos+ '15

9 BH systems with measured spin.

Six LMXB

Three wind HMXB

$a_* < 0.8$

Even in binary channel time delay could be 10^{10} yr (Eldridge+ 16)

Penrose process: extracting energy from spinning BH

Banados+ 09: Kerr Black Holes as Particle Accelerators to Arbitrarily High Energy

Blandford-Znajek mechanism - jet acceleration

Kerr BH interaction with DM

star forming region in the SMC (Optical/X-ray): Henault-Brunet, Oskinova+ 11, Oskinova+ 13

EM observational constraints on BHs and NSs

- EM observations of BH/NS - are they in line with the GW channels?
- Are the excuses for the discrepancies sufficiently good? spins
- Side branches of GW channels: agreement with EM observations?
- Are **co** in GWs stem from the same progenitor pool as HMXBs?
- GW channels: how to constrain contributions of various channels?

The only WO star in the SMC is a binary

Shenar+ 16: analysis of complete set of WR binaries in the SMC

AB 8: WO+O4V, $20M_{\odot}$ + $60M_{\odot}$

Do WRs collapse to BH directly or as LGRBs at $Z \ll Z_{\odot}$?

supergiant shell - 600 pc diameter
 $H\alpha + [OIII] + X\text{-ray}$