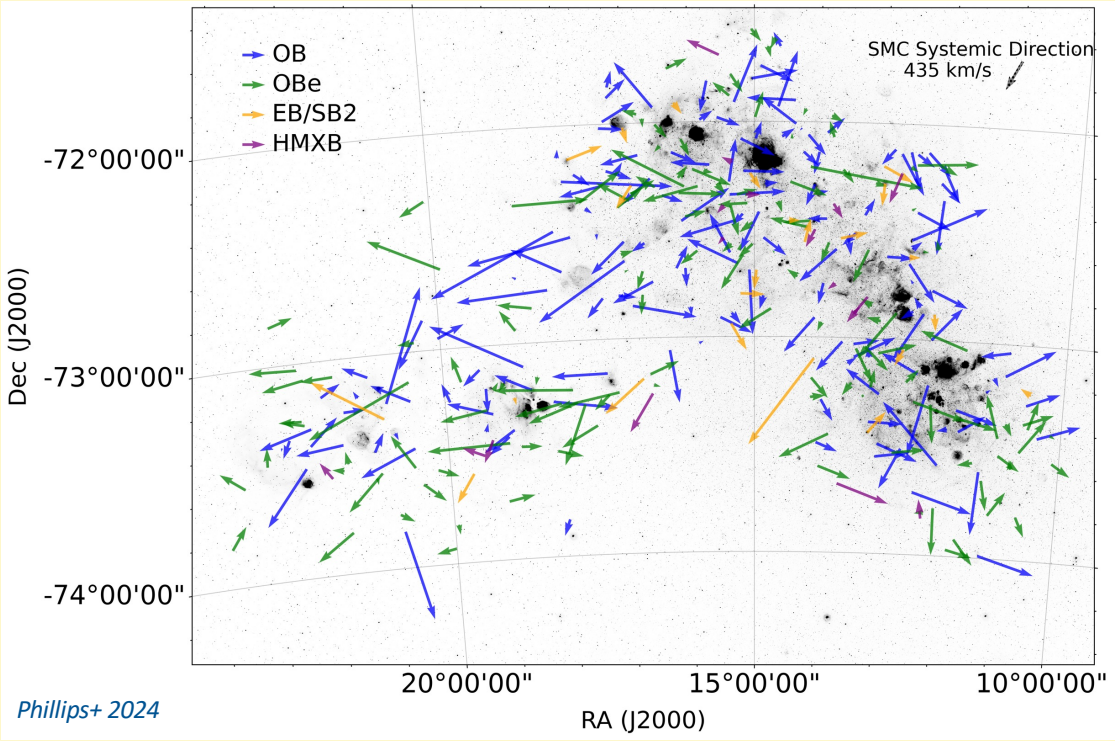
Massive Stars Ejected from Clusters

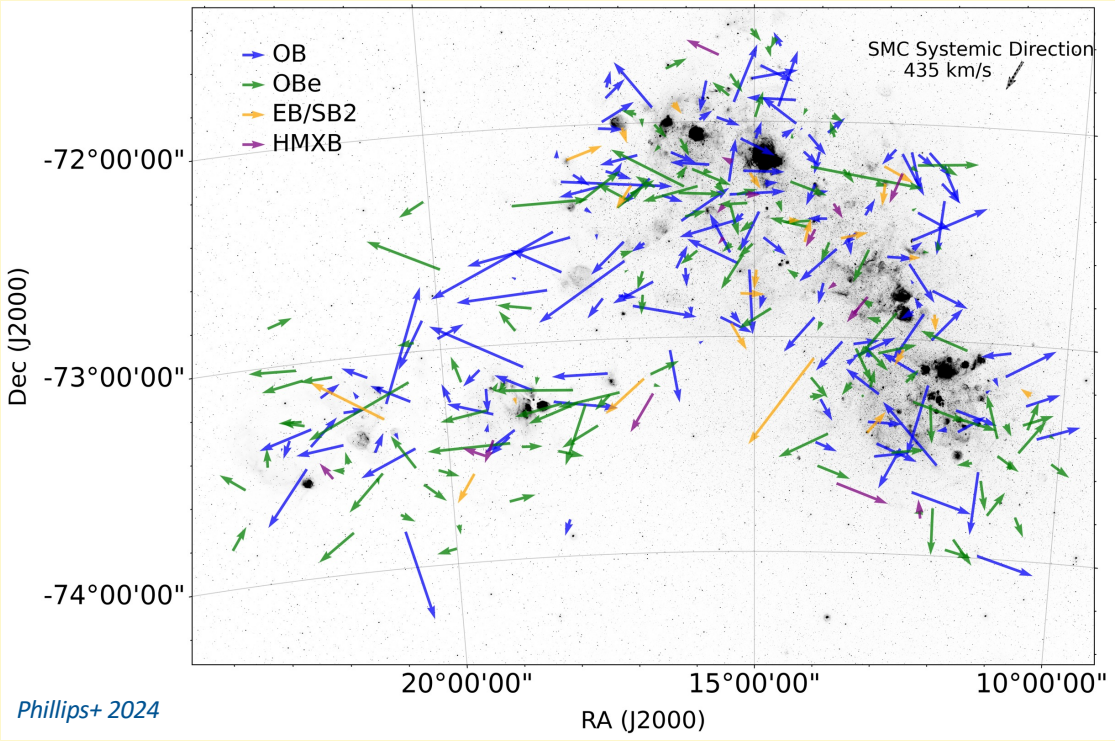
Sally Oey *University of Michigan*



Grant Phillips (UM)
Irene Vargas-Salazar (UM)
Julian Deman (UM)
Caden Burkhardt (UM)
Fiona Han (UM)
Jan Eldridge (Auckland)
Norberto Castro (UM/AIP)
Mathieu Renzo (Flatiron/AZ)
Edmund Hodges-Kluck (NASA/GSFC)
Johnny Dorigo Jones (UM/CO)

LSA ASTRONOMY
UNIVERSITY OF MICHIGAN

The Runaways and Isolated O-Type Star Spectroscopic Survey of the SMC (RIOTS4) *Lamb+ 2016*



Phillips+ 2024

FIELD STARS from Oey+ (2004)

28 pc clustering length

~ 400 stars ~ 30% of OB stars

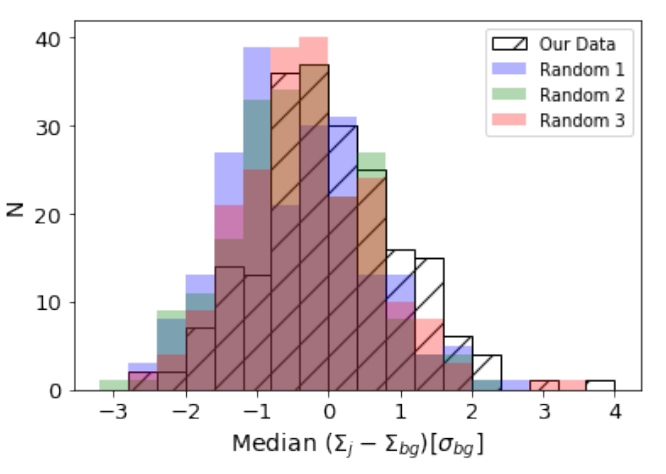
$Q_{UBR} \leq -0.84$

$B \leq 15.21$

from Massey (2002)

≳ 95% of field OB stars are ejected from clusters!

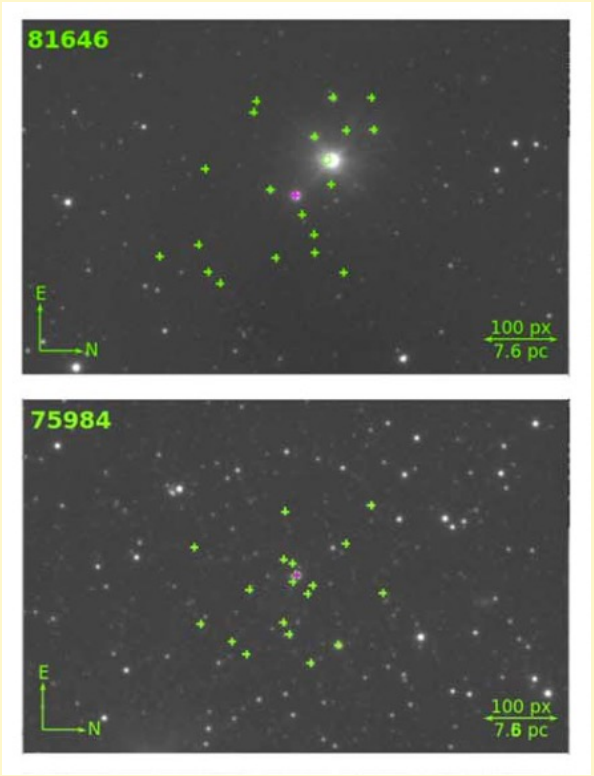
Vargas-Salazar, Oey+ 2020 *cf, e.g., de Wit+ 2004; Gvaramadze+ 2012; Oey+ 2013*



Median overdensities for j=8-10 nearest neighbors

- **Nearest Neighbors**
- **Friends-of-Friends**
- **Stacked fields**

OGLE
I-band

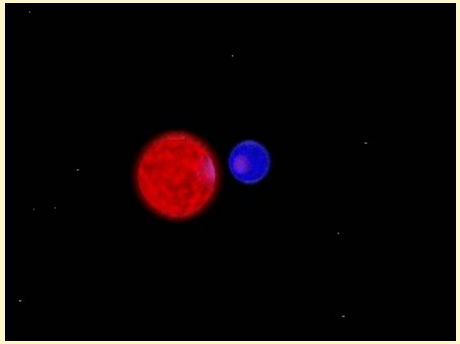


Examples of non-ejected candidates

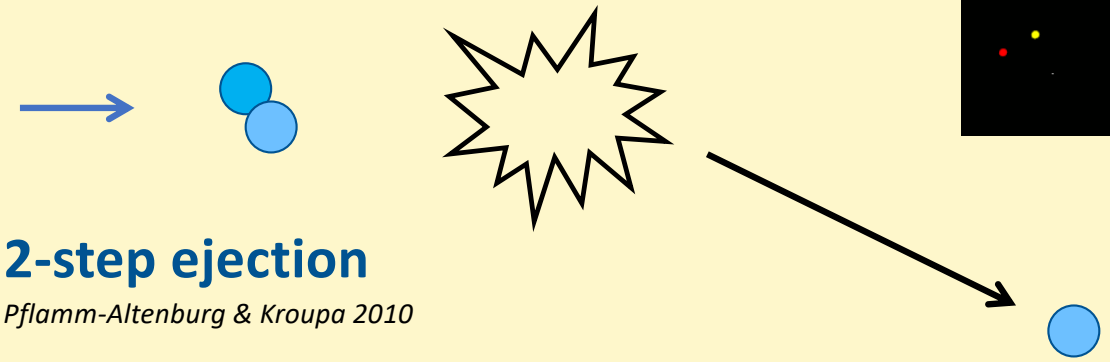
Ejection Mechanisms

Originate from binaries or multiples

Supernova ejection (BSS)



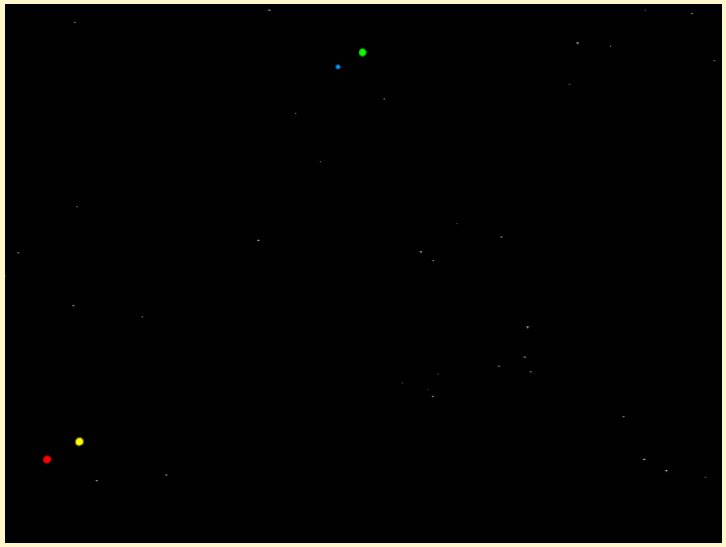
A. Irrgang



2-step ejection

Pflamm-Altenburg & Kroupa 2010

Dynamical ejection (DES)

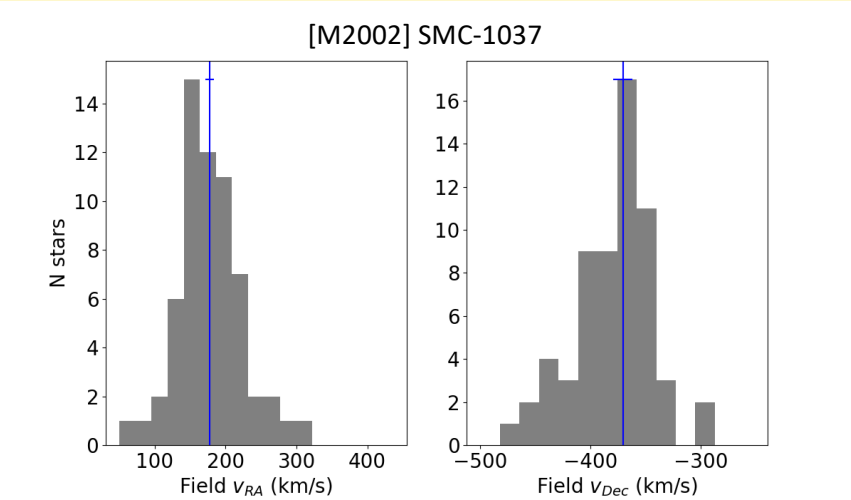


Dynamical (DES) vs SN (BSS) Ejections

Hoogerwerf+ 2001

Faster, more massive stars

Slower, lower mass stars are faster



Phillips, Oey+ 2024

Gaia Proper Motions

Phillips+ 2024; Dorigo Jones+ 2020; Oey+ 2018

DR3: 336 RIOTS4 field OB / OBe stars

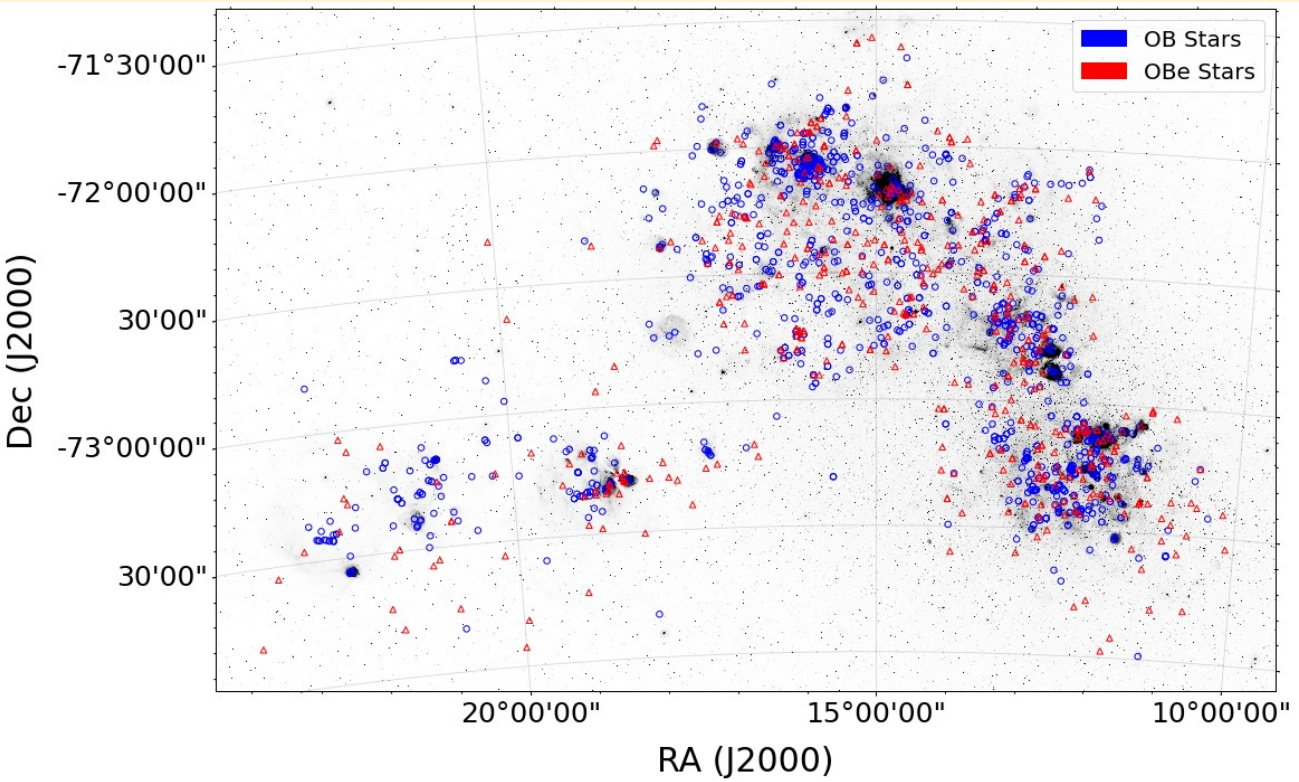
PMs relative to local velocity field
$< 5'$ (90 pc), $G < 18$

median err = 16 km/s

Runaway: $v_\perp \geq 24$ km/s (i.e., 30 km/s space velocity)
Walkaway: $v_\perp < 24$ km/s unbound

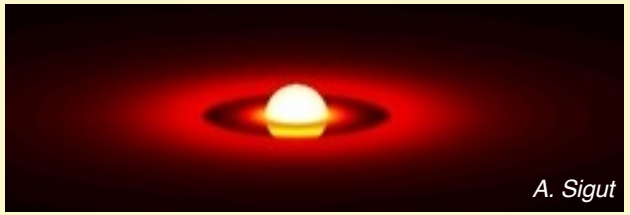
Massive Star classes:
OB – OBe – WR – LBV – sgB[e]

Which types come from binary progenitors?



Classical OBe stars

post-interaction mass gainers?

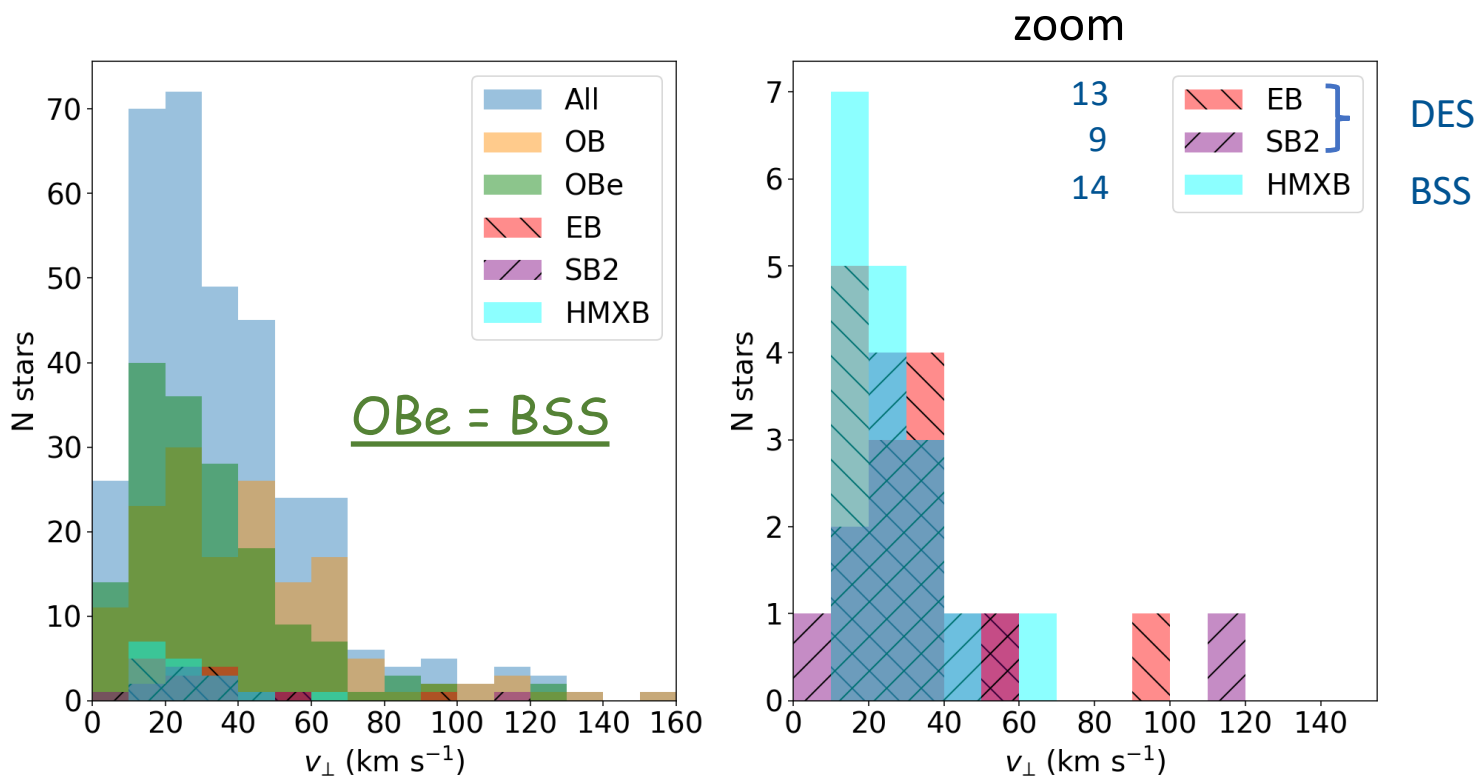


40% of SMC OB pop more isolated

Dallas, Oey & Castro 2022

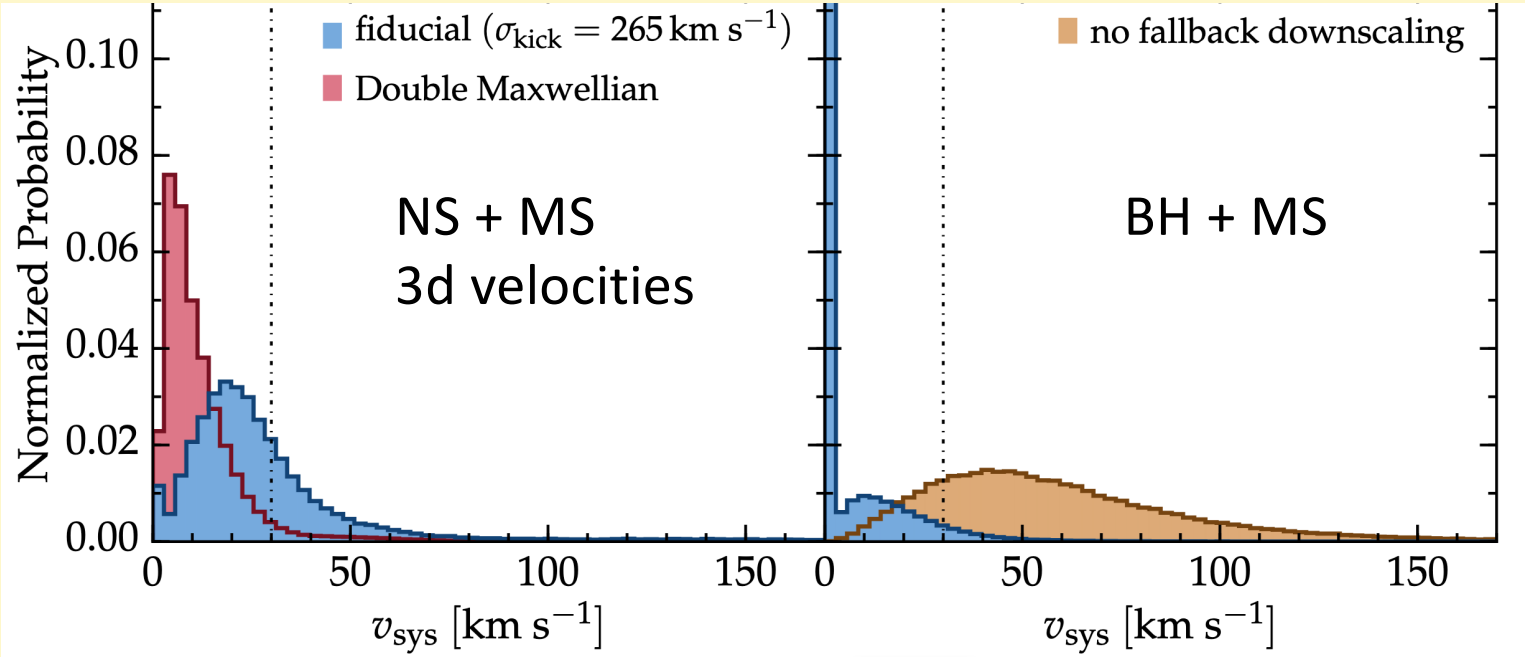
Classical OBe stars

Phillips, Oey+ 2024; Dorigo Jones+ 2020



cf. Sana+ 2022

Classical OBe stars

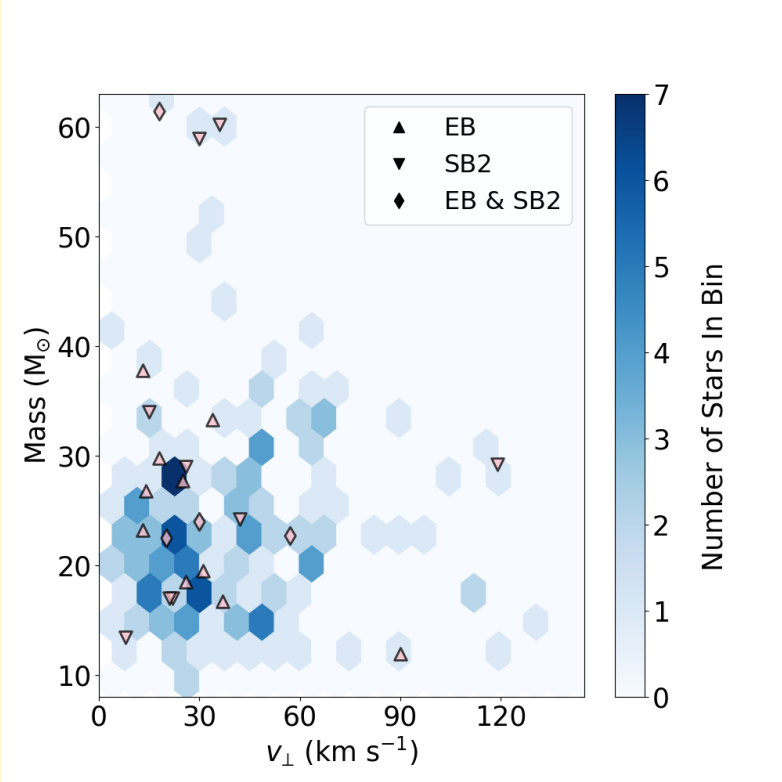


Binary population synthesis models: *Renzo+ 2019*
binary.c

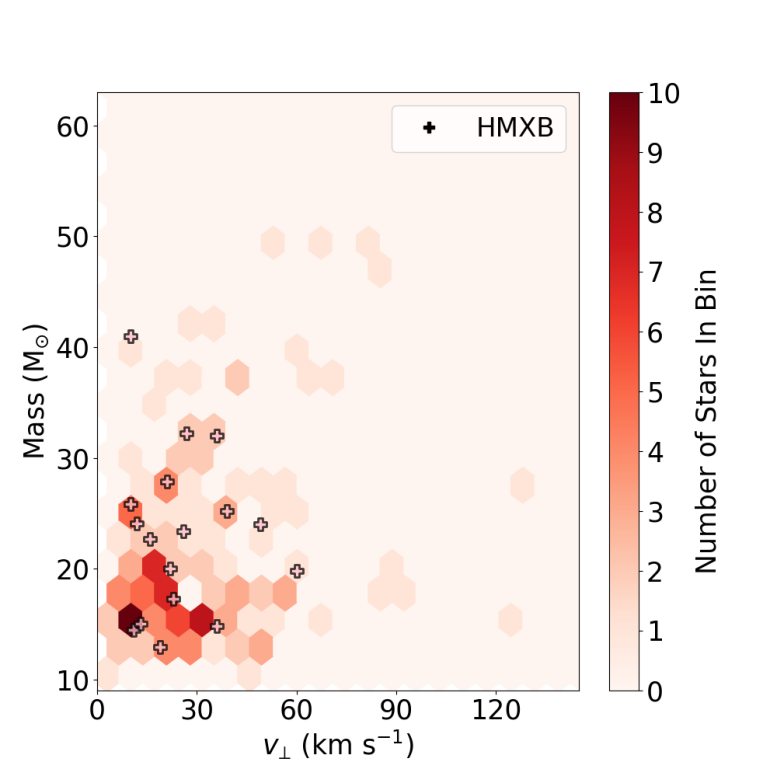
Classical OB and OBe stars

Phillips, Oey+ 2024

OB stars dominated by DES



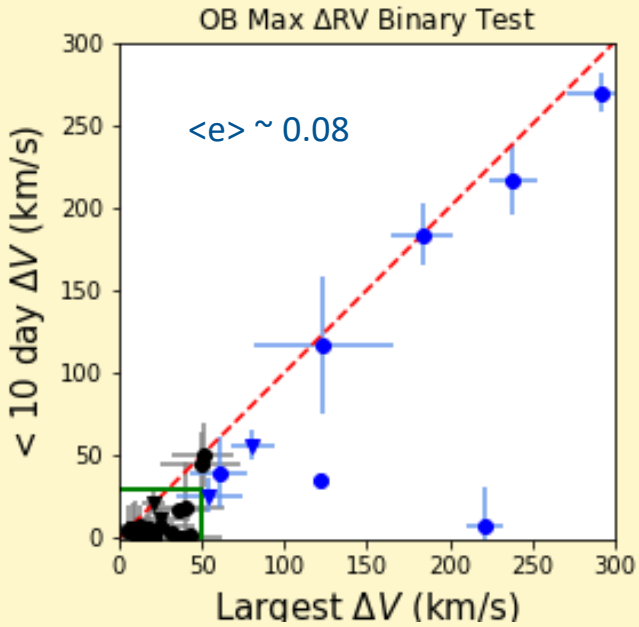
OBe stars dominated by BSS



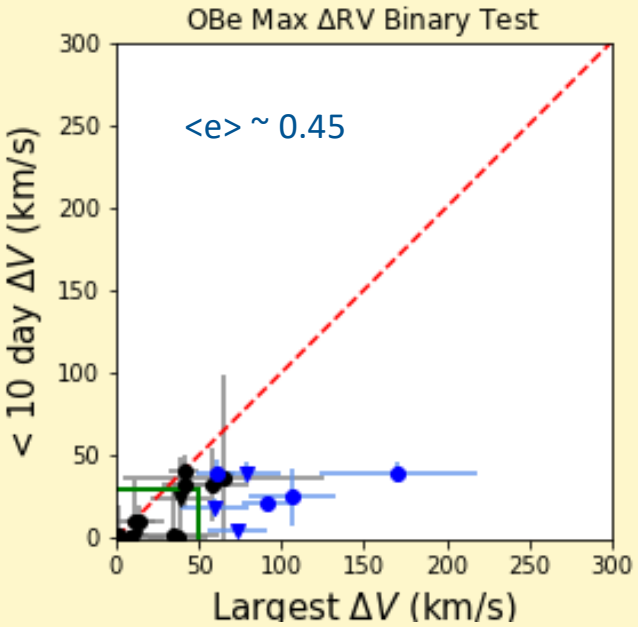
Classical OB and OBe stars

Vargas-Salazar, Oey+ 2024, in prep

OB stars dominated by DES



OBe stars dominated by BSS

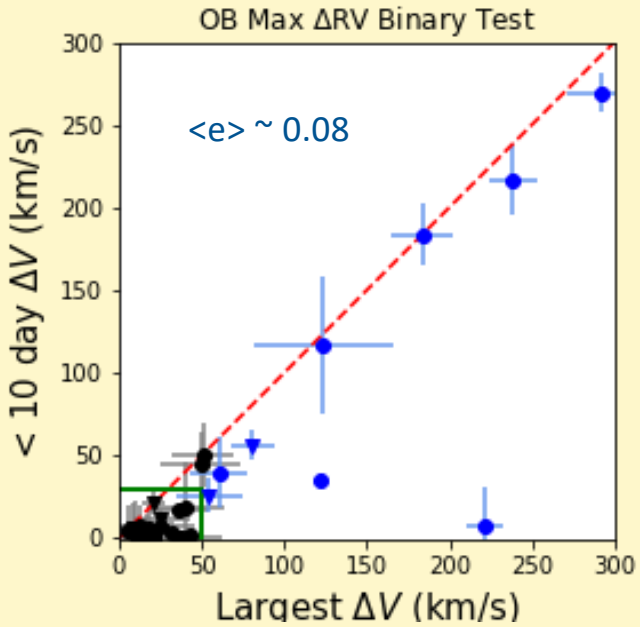


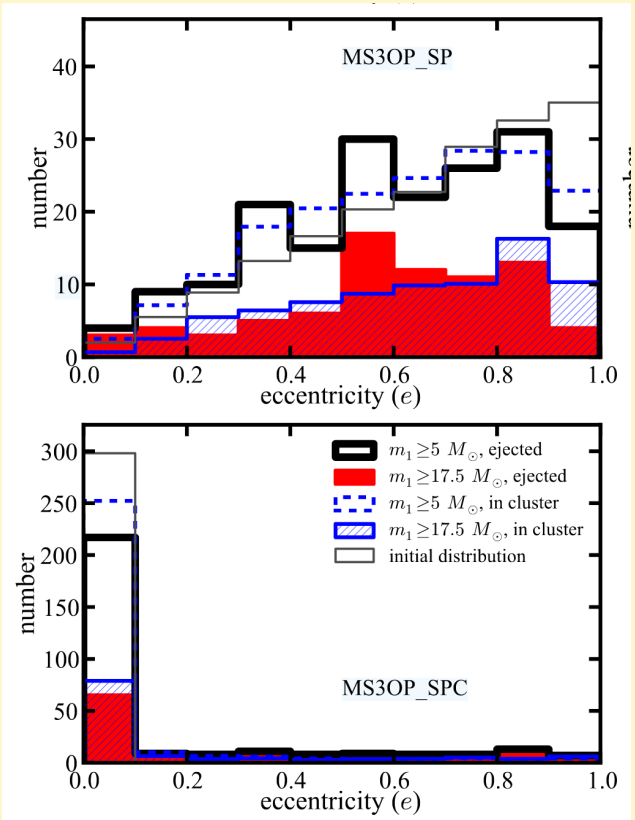
RV binary survey of RIOTS4 field targets in SMC Wing

Classical OB and OBe stars

Vargas-Salazar, Oey+ 2024, in prep

OB stars dominated by DES





non-circular

circular

Primordial binaries = twins in circular orbits

N-body simulations: *Oh & Kroupa 2016*

DES vs BSS

Table 3
Numbers and Ratios of Walkaway and Runaway Field OB Stars

	Numerator[a]	Denominator	Ratio	Model[b]
Runaway DES/BSS	119	82	1.5 ± 0.2	1.7
Total W/R	324	201	1.6 ± 0.1	1.8
BSS W/R	185	82	2.3 ± 0.3	2.3
DES W/R	139	119	1.2 ± 0.1	1.5

Notes.
[a] Numbers of walkaways are corrected by a factor of 2.4 for incompleteness (see Paper II).
[b] See the text and Table 4 for details about the model predictions.

Phillips, Oey+ 2024; Dorigo Jones+ 2020

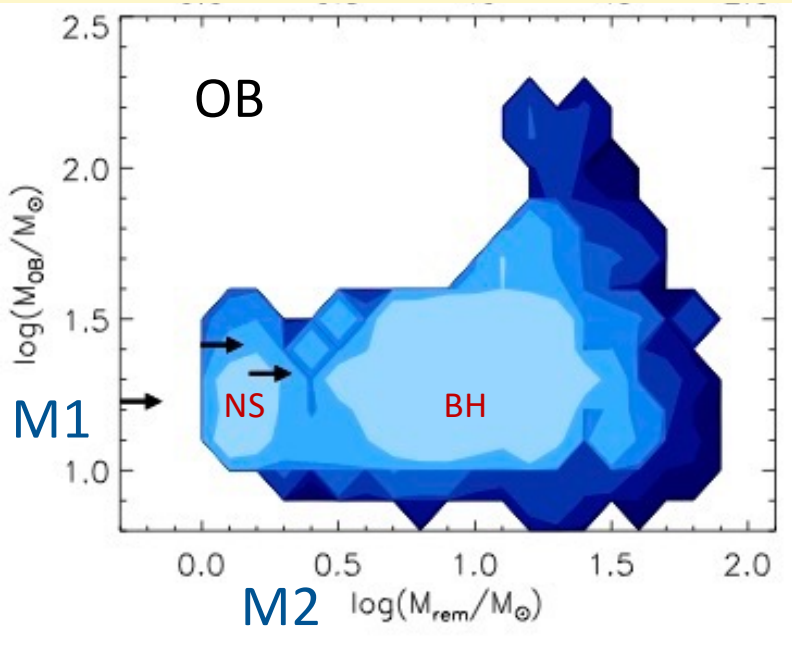
Contrib to SMC OB pop

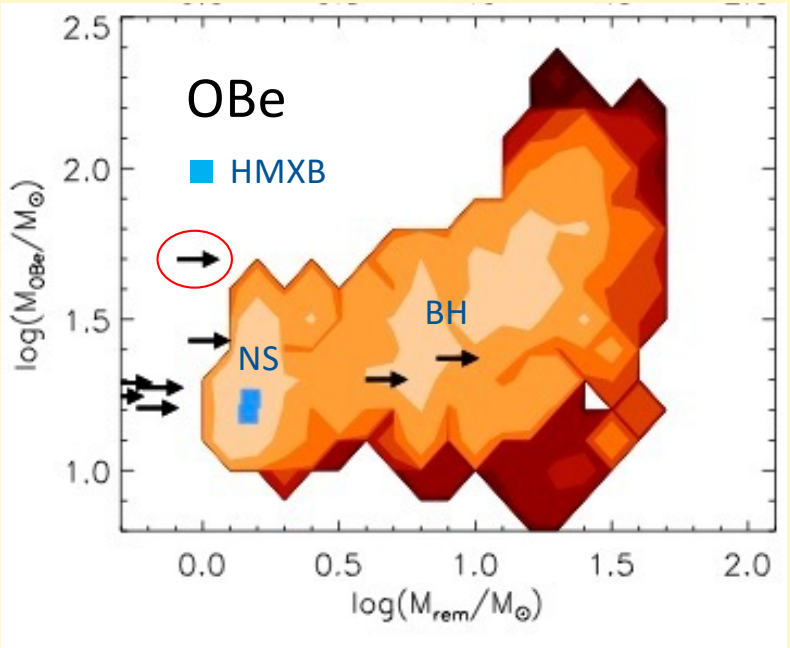
DES model - Oh & Kroupa 2016:
ejection fraction 0.2
walkaway:runaway 60:40
binary fraction 0.8

BSS model - Renzo+ 2019:
assume 50% ejected
assume 2-step runaways = 0.2 post-SN walkaways

BPASS binary population synthesis model: BSS

Vargas-Salazar, Oey+ 2024, in prep





Binary OB and OBe stars in SMC Wing:

- Constraining M2 based on *P*, *M*1, ecc, *i*

<u>OBe systems</u>

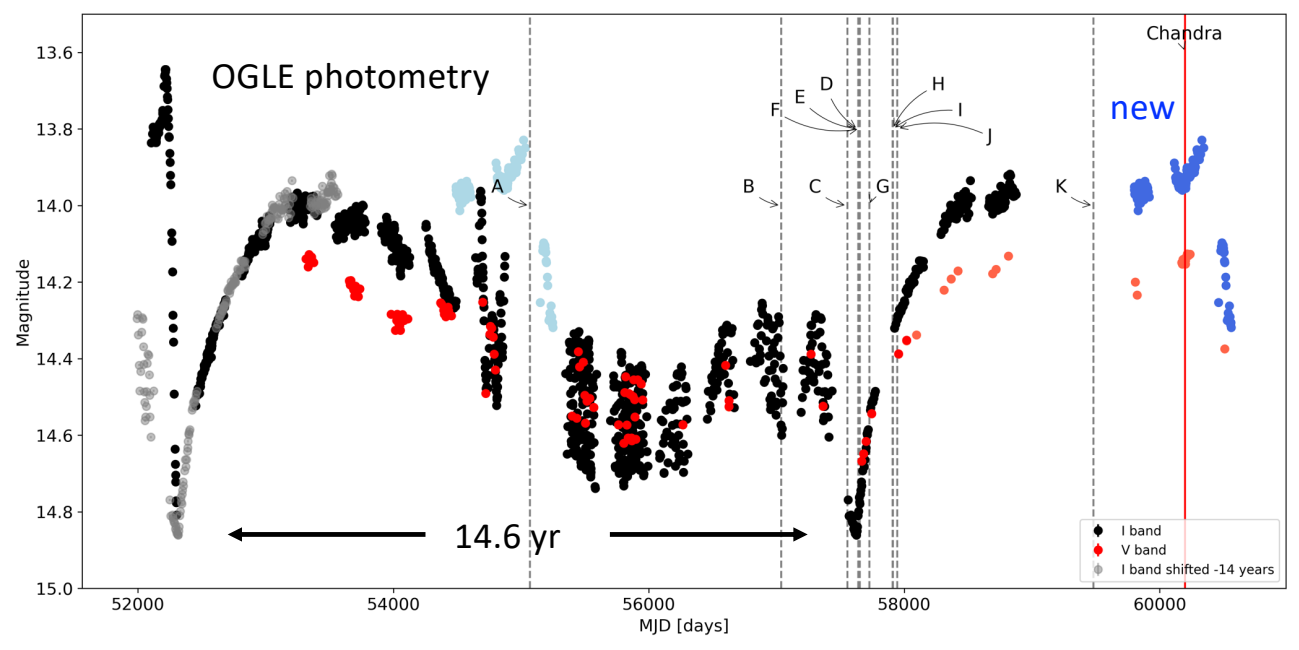
Higher-mass BH systems expect long 1000-d periods

NS : BH = ~ 40 : 60

[M2002] 75061, B1e : M1 = 20 $M_\odot$, M2 > 5 $M_\odot$ - BH

76773, Be : M1 = 24 $M_\odot$, M2 > 9 $M_\odot$ - BH

AzV 493: Hi-ecc, hot, massive Oe star w/BH candidate



gray, light blue = overplotted from 2nd cycle

Oey, Castro, Renzo+ 2023

$M1 = 50 +/- 9\ M_\odot$

$\log L/L_\odot = 5.83$

$T_{eff} = 42{,}000$ K

$e > 0.93$

$P = 7.3$ yr? 14.6 yr?

$v \sin i = 370$ km/s

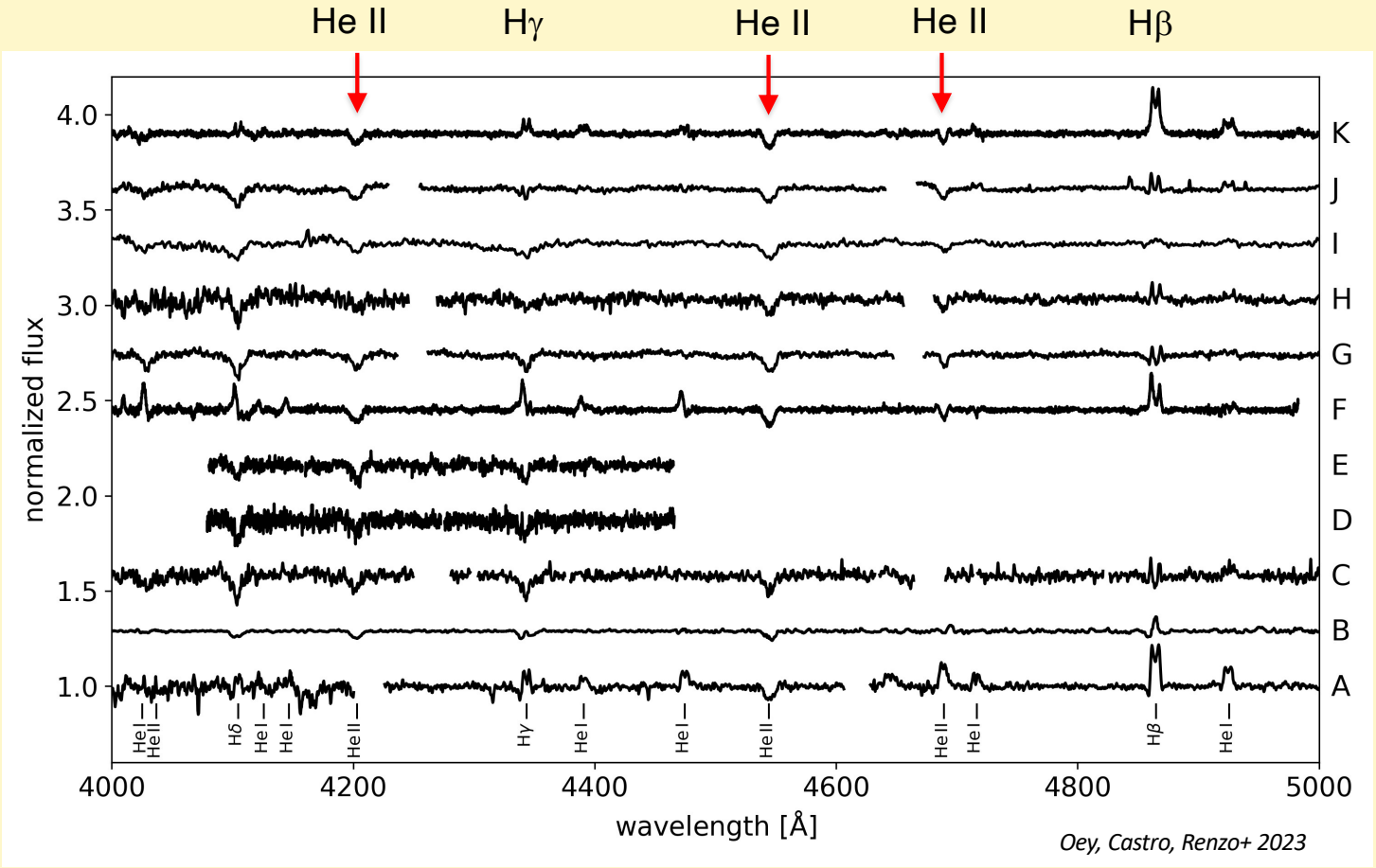
$v_\perp = 54 +/- 11$ km/s

Vargas-Salazar+ in prep

Chandra non-detection 2023-09-11

$L_X < 4 \times 10^{34}$ erg/s

AzV 493: Hi-ecc, hot, massive Oe star w/BH candidate



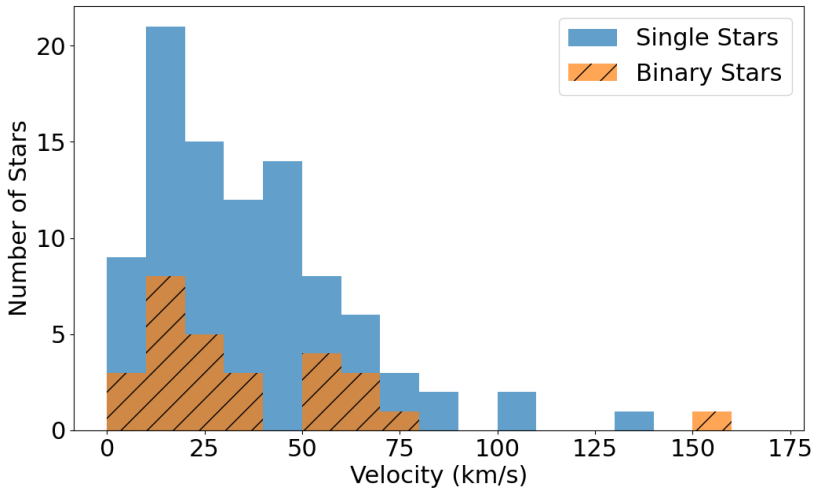
large spec variation!

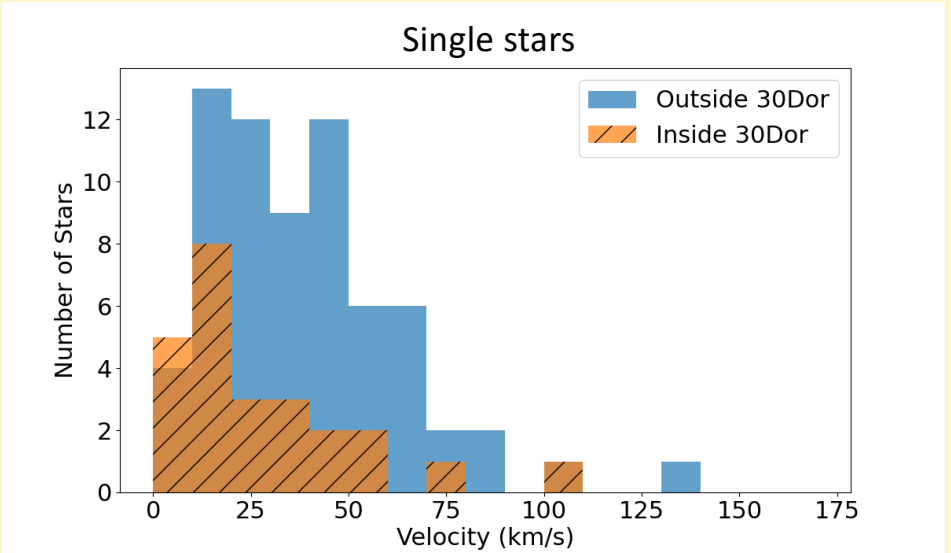
preliminary

Wolf-Rayet stars

Burkhardt, Han, Oey+ in prep
Han, Burkhardt, Oey+ in prep

LMC WR stars with usable Gaia DR3 data
Excludes 12 stars in core of R136 due to crowding





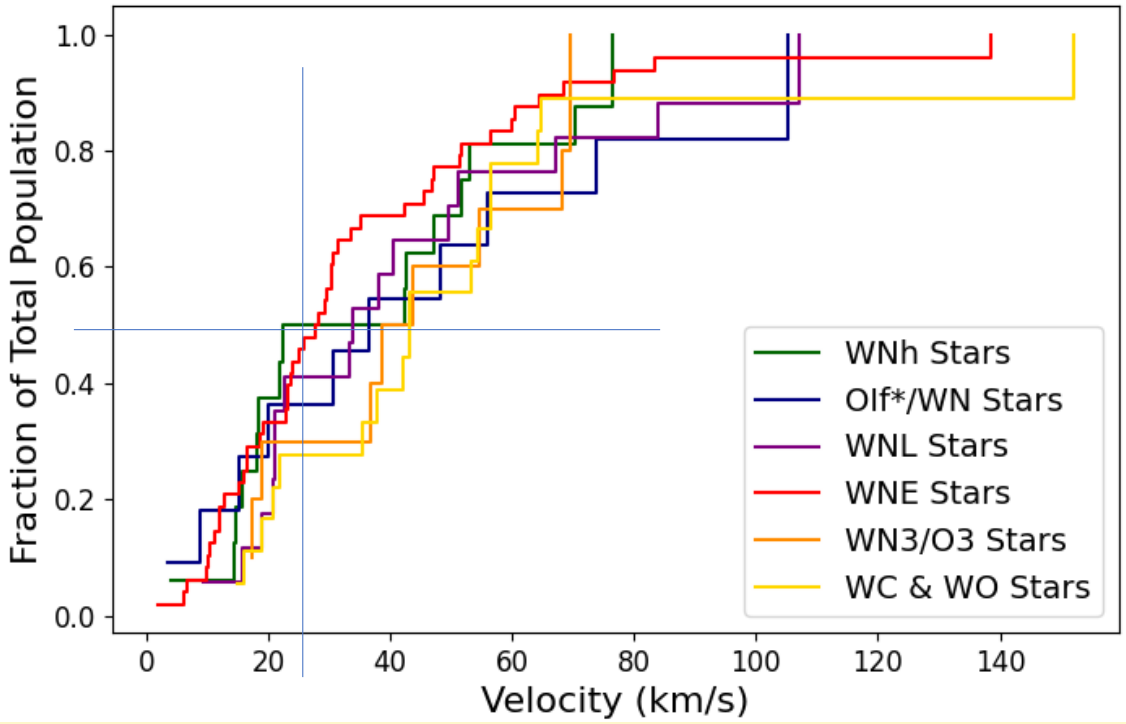
Both DES and BSS ejections among single stars?

preliminary

Wolf-Rayet stars

Burkhardt, Han, Oey+ in prep
Han, Burkhardt, Oey+ in prep

~All classes dominated by runaways!



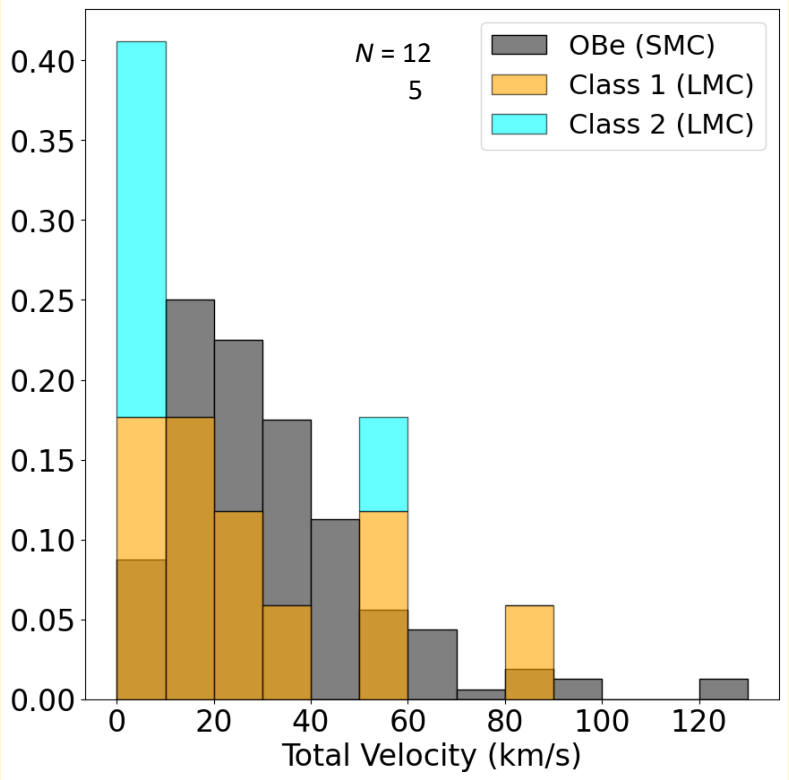
WNh, O If*/WN, WNL
moderately fast
hi-M, H-burning
DES? *cf. Maiz-Apellaniz+ 2018*

WC, WN3/O3
very fast, esp binaries
lower-M
post-MS BSS mass donors?
cf Renzo+ 2019, Pols 1994

WNE
slowest, but still ejected
lower-M, older

Luminous Blue Variables

Deman & Oey 2024



Hot stars with eruptions, circumstellar material

LMC, SMC LBV stars with usable Gaia DR3 data
Catalog and Classes from *Agliozzo+ 2021*

Class 1: Dusty nebula ~ ejecta
Class 2: No dusty nebula. "Stellar" free-free emission

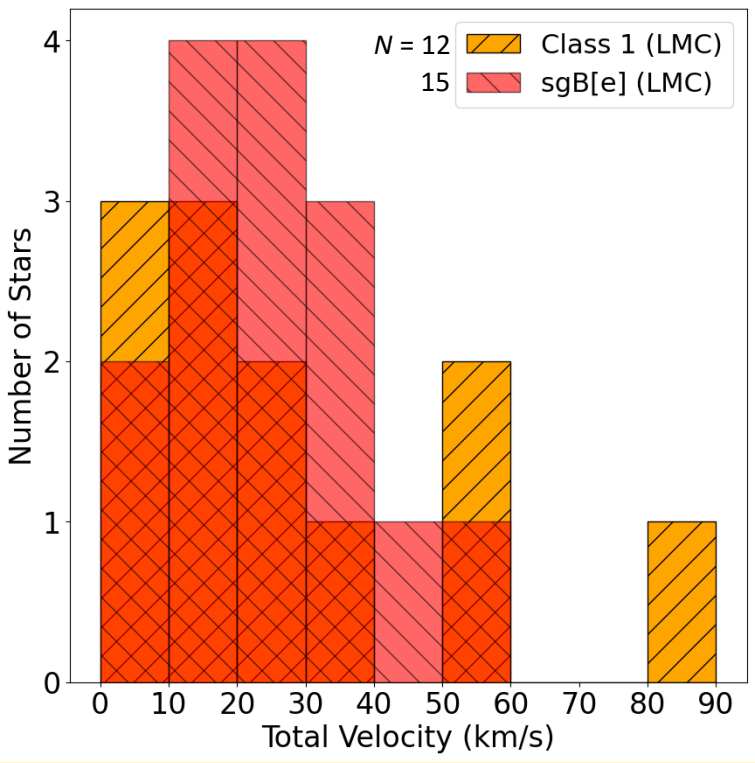
Class 2 (no ejecta) are unaccelerated

Class 1 (with ejecta) are accelerated
- BSS products

cf. Smith & Tombleson 2015; Aghakanloo+ 2017

Classical supergiant B[e] stars

Deman & Oey 2024



Dense, circumstellar disks with hot dust
lower L than LBV

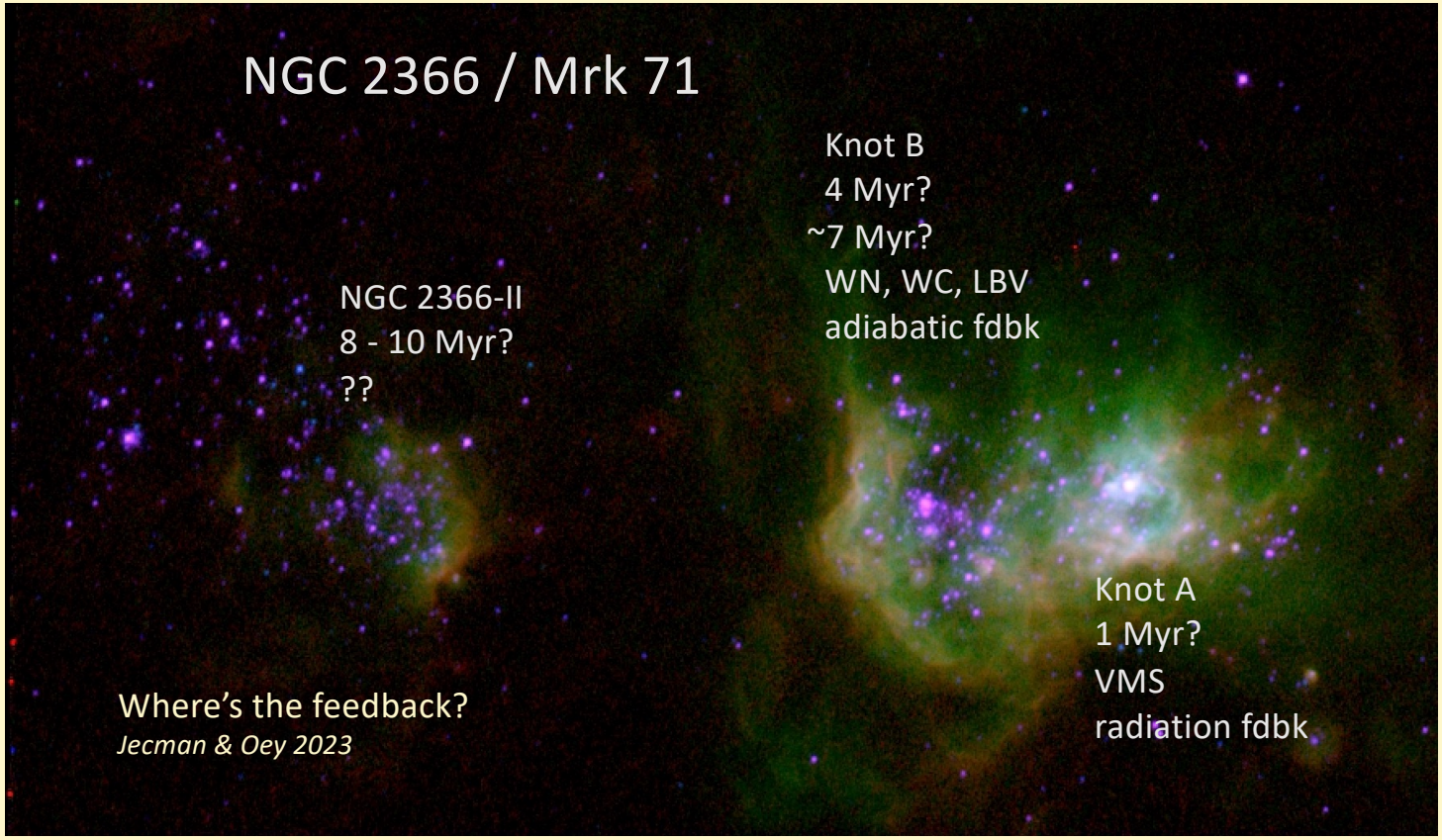
LMC, SMC sgB[e] stars with usable Gaia DR3 data
Catalog from *Kraus 2019*

sgB[e] are faster than LBV
Dominated by BSS?

L - $v_{\perp}$: sgB[e] stars ≠ LBVs

Clusters vs OB associations?

cf. 30 Dor *e.g., Stoop+ 2024*



Summary

- **≳ 95% of Field massive stars are ejected**
  - DES dominate runaways; DES & BSS ~ similar for walkaways?
- **Classical OBe stars : BSS binary mass gainers**
  - Kinematics, binary eccentricities
  - 3 BH candidates, incl AzV 493 = extreme ecc, hot, hi-*L*, variable Oe
- **Most WR are ejected**
  - WC, WN3/O3 : post-MS mass donor BSS?
- **LBVs with dusty nebulae = ejected; without = not ejected**
- **Classical sgB[e] : faster than LBVs - BSS?**