Massive "widowed" stars

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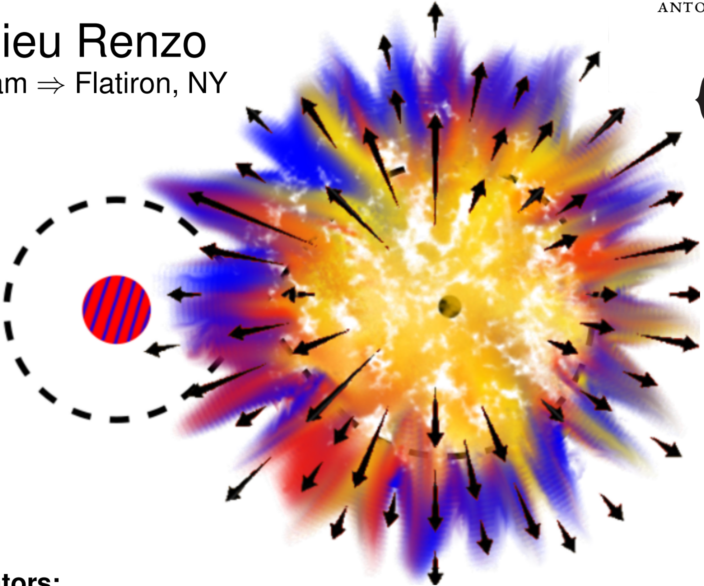
BinCosmos

Mathieu Renzo

Amsterdam ⇒ Flatiron, NY



Collaborators:

E. Zapartas, S. E. de Mink, Y. Götberg, S. Justham, R. Farmer, R. G. Izzard, S. Toonen, D. J. Lennon, H. Sana, E. Laplace, S. N. Shore, V. van der Meij, ...

Outline

The most common massive binary evolution path

Natal kicks and black holes

Spatial velocity distribution

Runaway binaries with a compact object

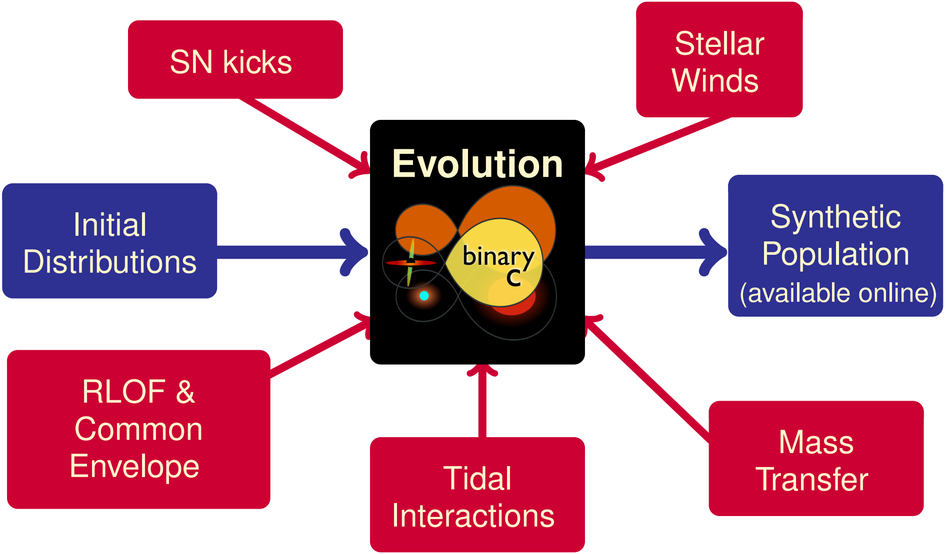
The case of 4U1700-37

Massive runaway origins ...

... is there a problem ?

Methods: Population Synthesis

Fast ⇒ Allows statistical tests of the inputs & assumptions



Izzard *et al.* 04, 06, 09, 18; de Mink *et al.* 13; Schneider *et al* 15

SNe typically break binaries

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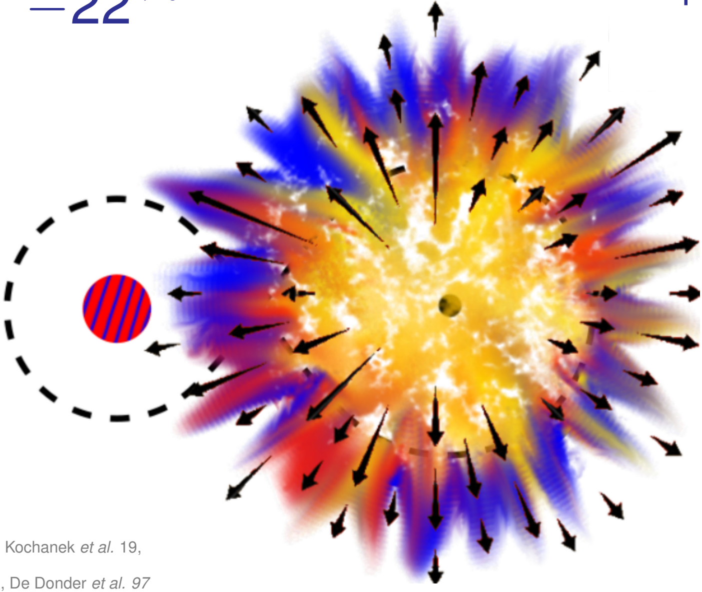
$86^{+11}_{-22}\%$ of massive binaries are disrupted



Renzo *et al.* 19b, Kochanek *et al.* 19,

Eldridge *et al.* 11, De Donder *et al.* 97

Most common massive binary evolution

Credits: ESO, L. Calçada, M. Kornmesser, S.E. de Mink

Spin up, pollution, and rejuvenation

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The binary disruption shoots out the accretor

Spin up: Packet ’81, Cantiello *et al.* ’07, de Mink *et al.* ’13
Pollution: Blaauw ’93
Rejuvenation: Hellings ’83, Schneider *et al.* ’15

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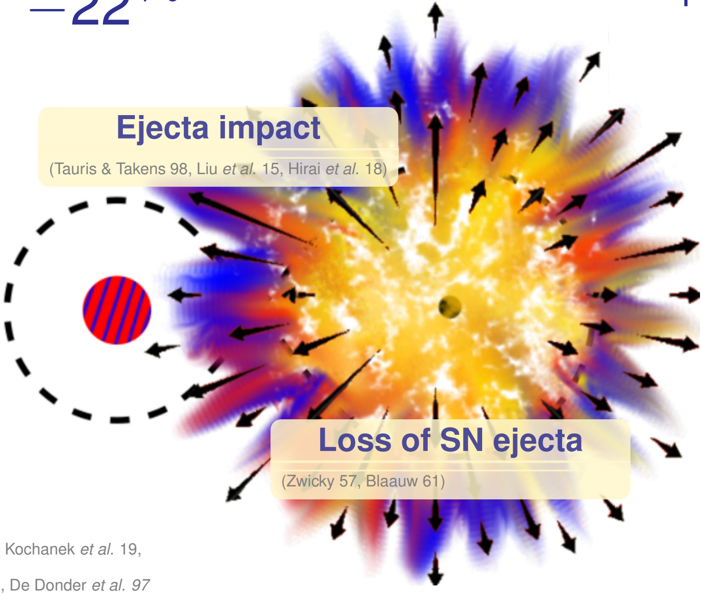

Renzo *et al.* 19b, Kochanek *et al.* 19,

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What exactly disrupts the binary?

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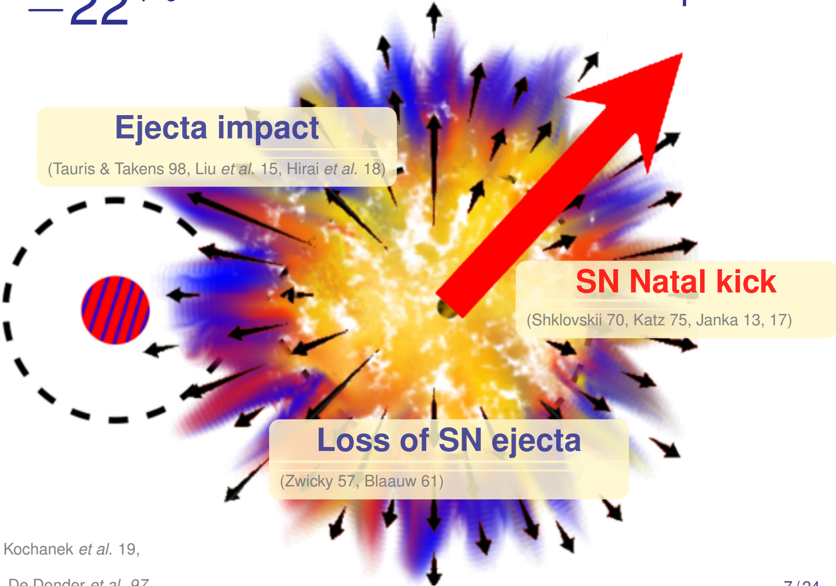

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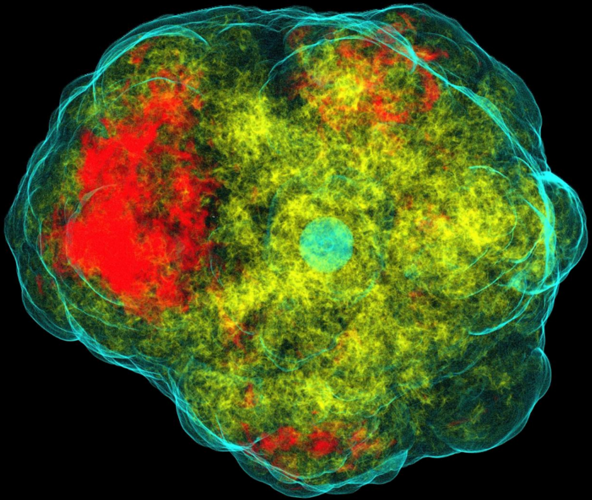
SN natal kick

Observationally: $v_{\mathrm{pulsar}} \gg v_{\mathrm{OB-stars}}$

Physically: ν emission and/or ejecta anisotropies



Credits: C. D. Ott, S. Drasco

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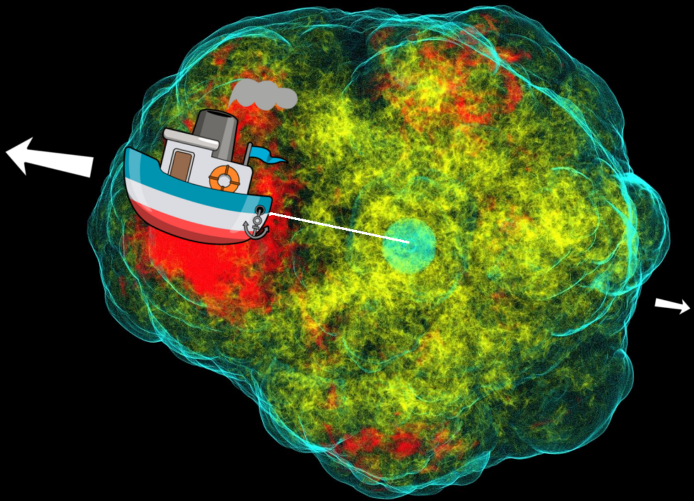

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Do BHs receive kicks?

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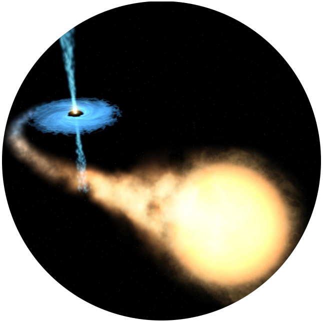
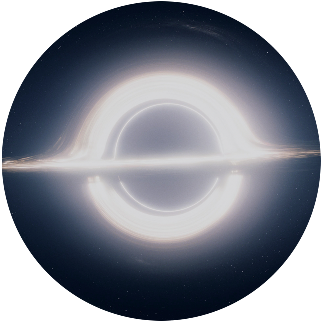
NO

⇒ most remain together with their widowed companion

YES

⇒ most are single and we can't see them...





e.g., Repetto *et al.* 12, Mandel 16, O'Shaugnessy *et al.* 17, Janka 17, Renzo *et al.* 19b, Atri *et al.* 19

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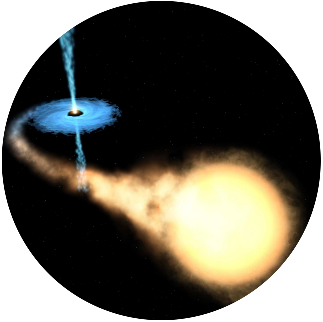

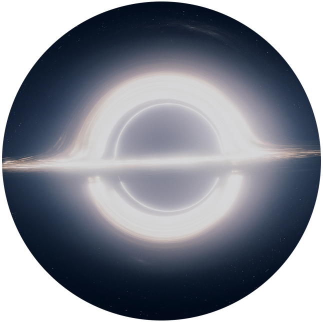

...but we can see the widowed companion

e.g., Repetto *et al.* 12, Mandel 16, O'Shaugnessy *et al.* 17, Janka 17, Renzo *et al.* 19b, Atri *et al.* 19

A way to constrain BH kicks with Gaia

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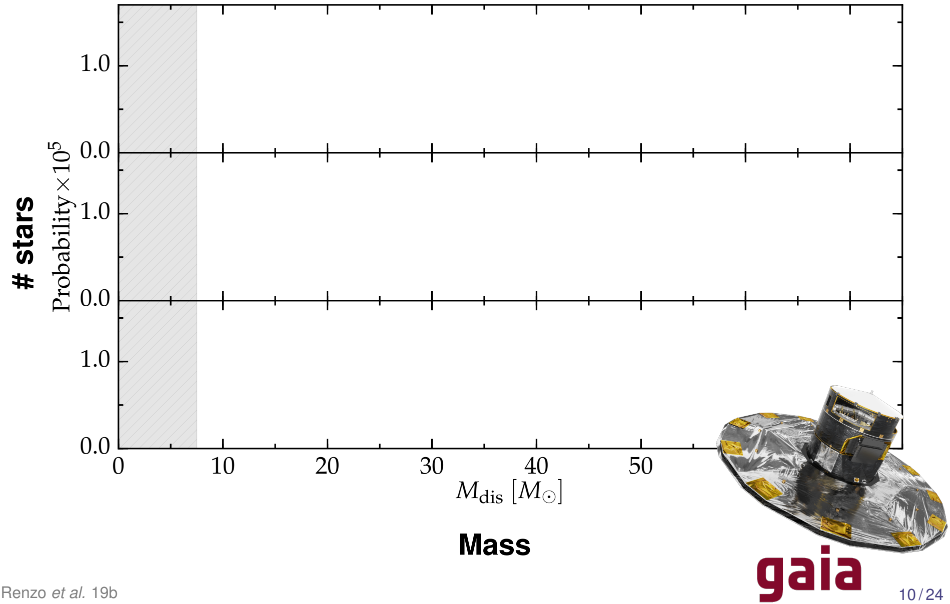
Massive runaways mass function ($v \geq 30\,\mathrm{km\ s^{-1}}$, $M \geq 7.5\,M_\odot$)



Renzo *et al.* 19b

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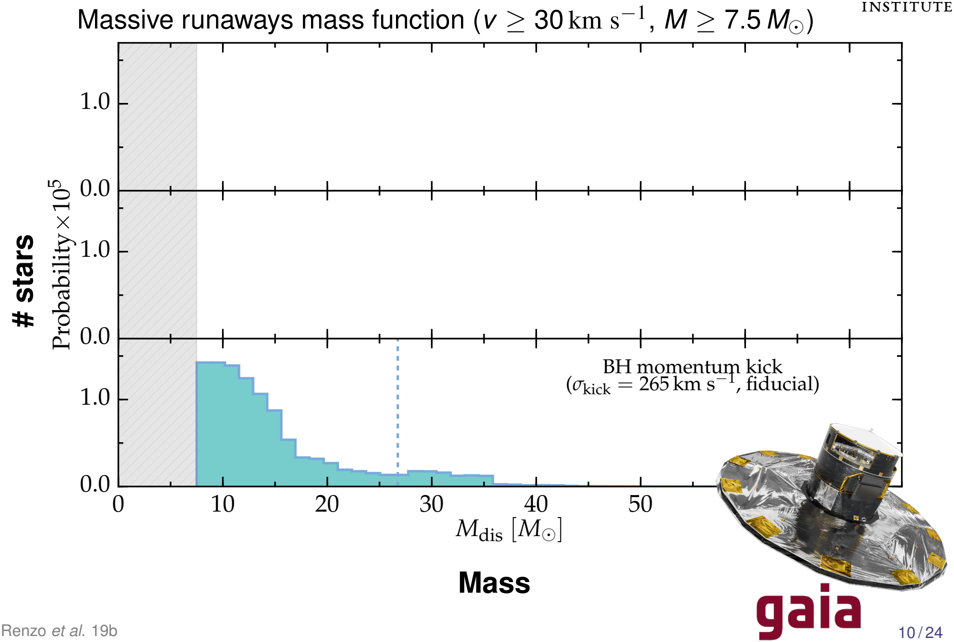

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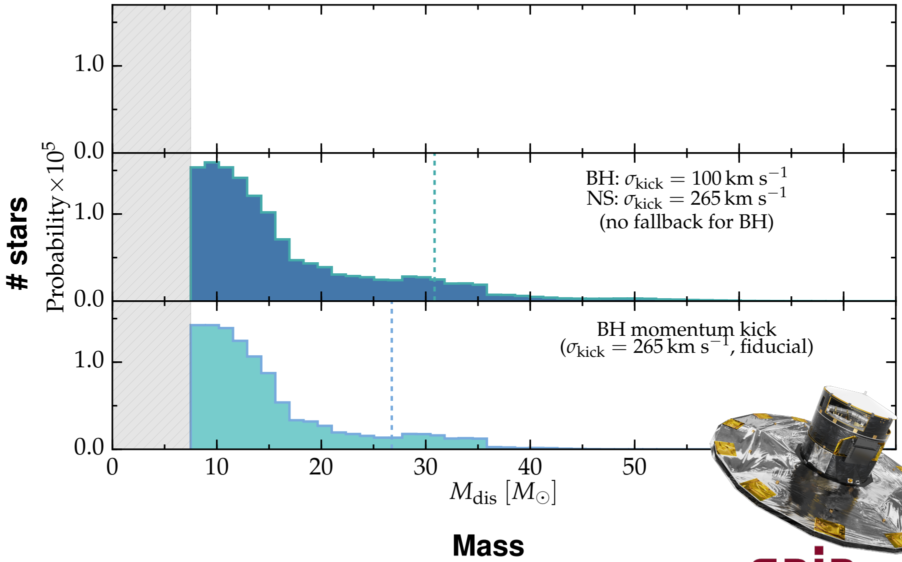

gaia

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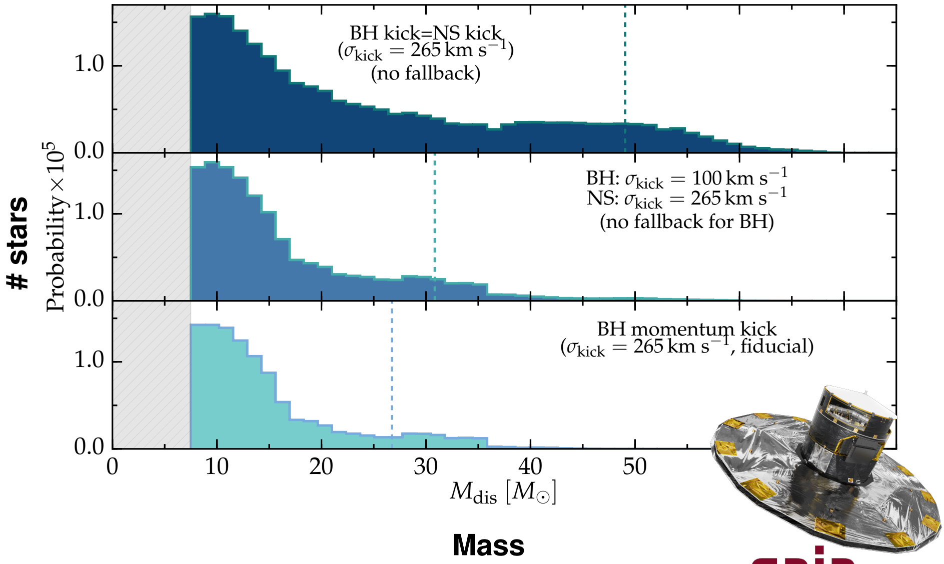

gaia

Renzo *et al.* 19b

Contamination from dynamical ejections

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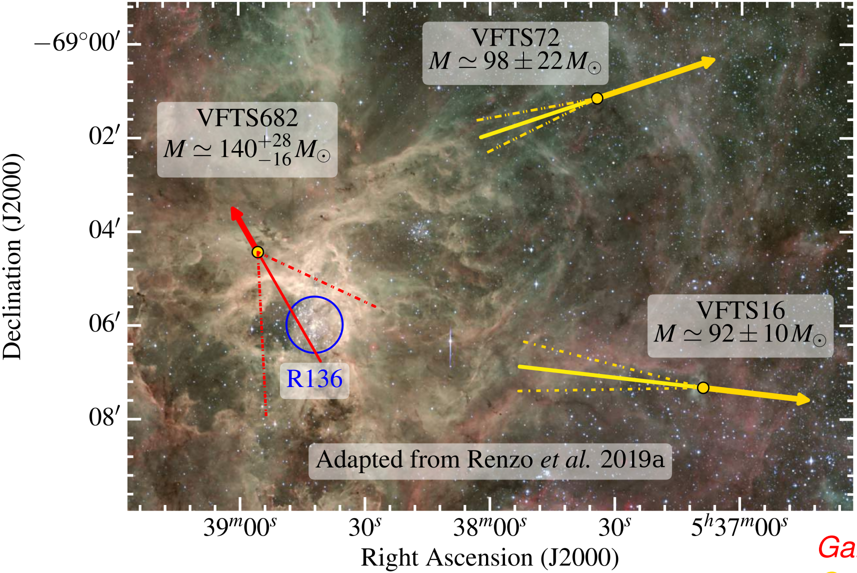
Proper motions relative to the cluster R136



Gaia+HST
Gaia

see also Lennon *el al.* (incl. MR) 18, Drew *et al.* 18, Kalari *et al.* 19

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The most common massive binary evolution path

Natal kicks and black holes

Spatial velocity distribution

Runaway binaries with a compact object

The case of 4U1700-37

Massive runaway origins ...

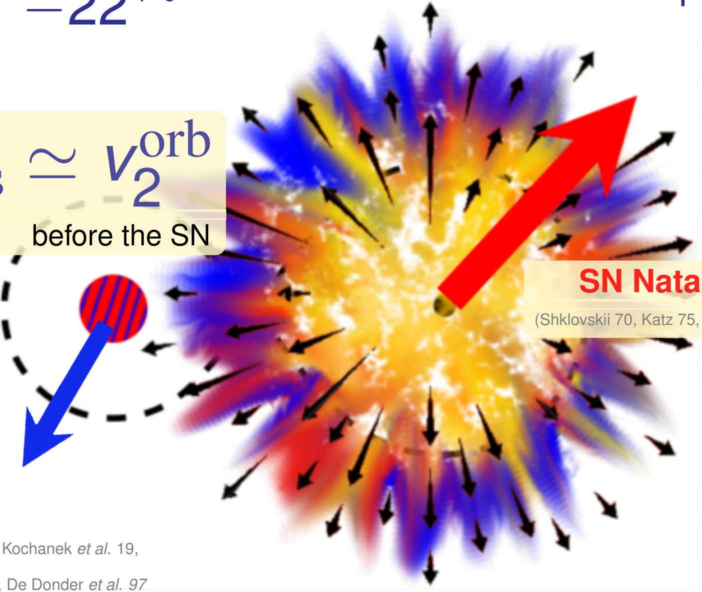
... is there a problem ?

Kicks do not change companion velocity

$86^{+11}_{-22}\%$ of massive binaries are disrupted

$$v_{\mathrm{dis}} \simeq v_2^{\mathrm{orb}}$$

before the SN



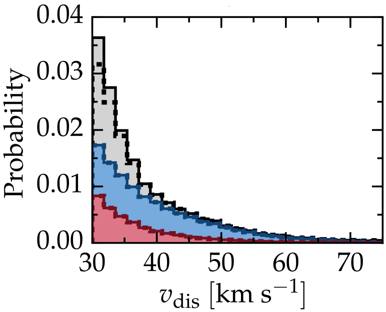
SN Natal kick

(Shklovskii 70, Katz 75, Janka 13, 17)

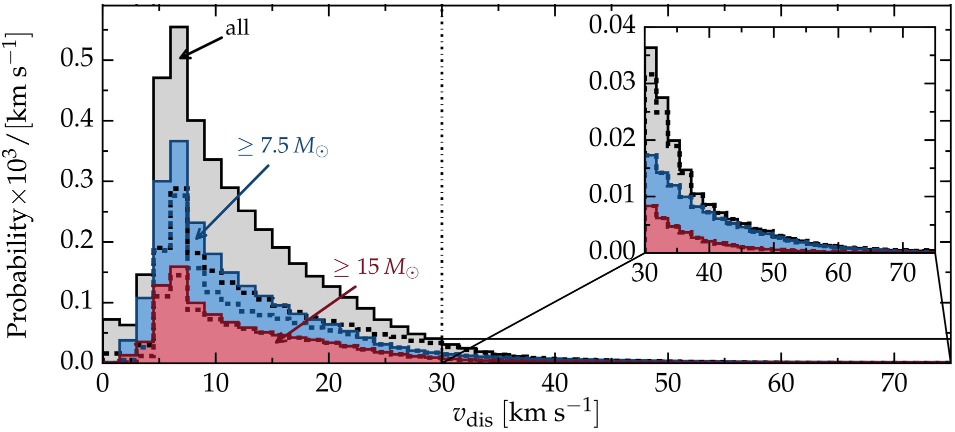
Renzo *et al.* 19b, Kochanek *et al.* 19,

Eldridge *et al.* 11, De Donder *et al.* 97

Velocity distribution: **Runaways**



Velocity distribution: **Walkaways**



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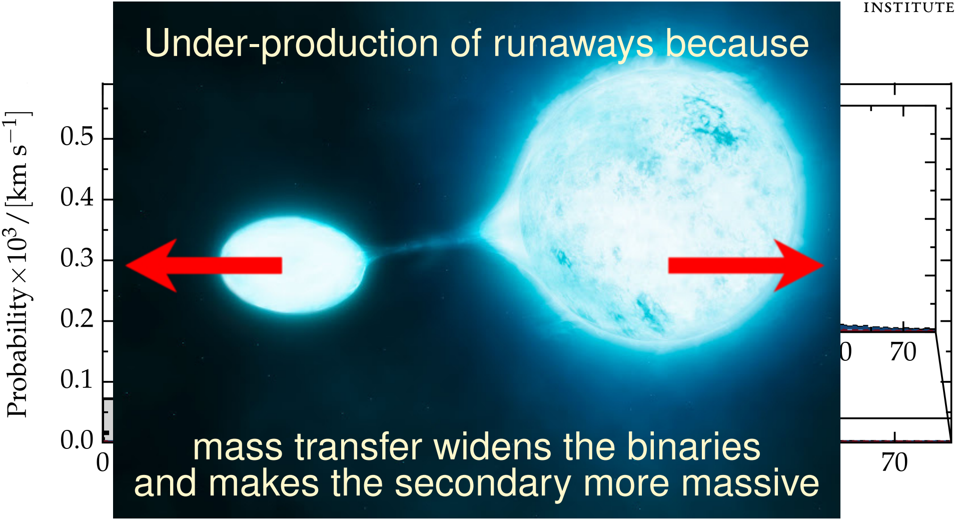

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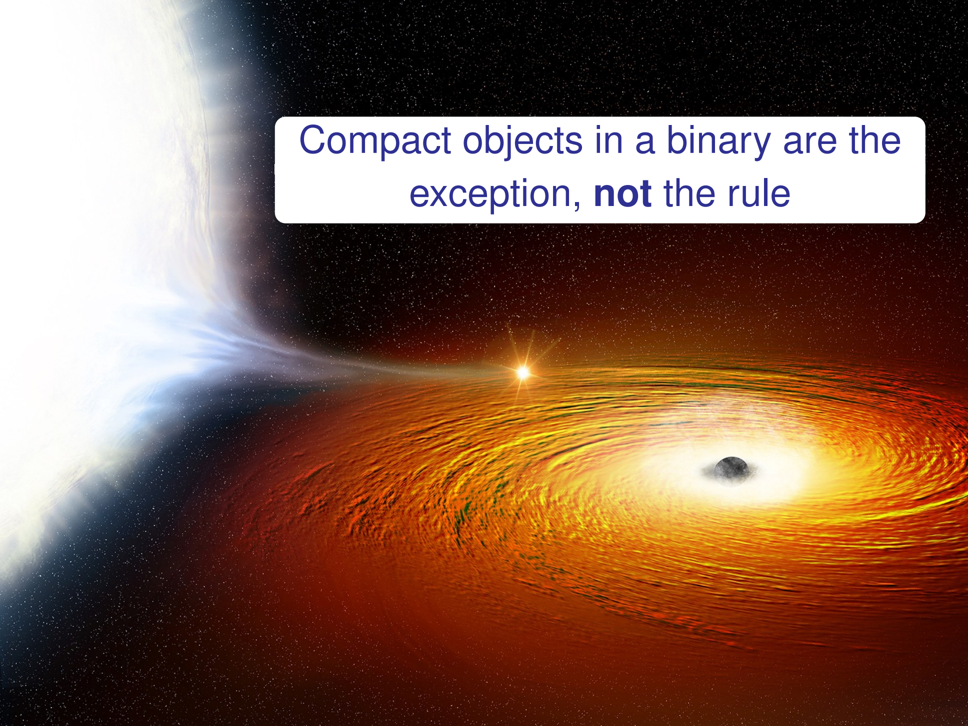
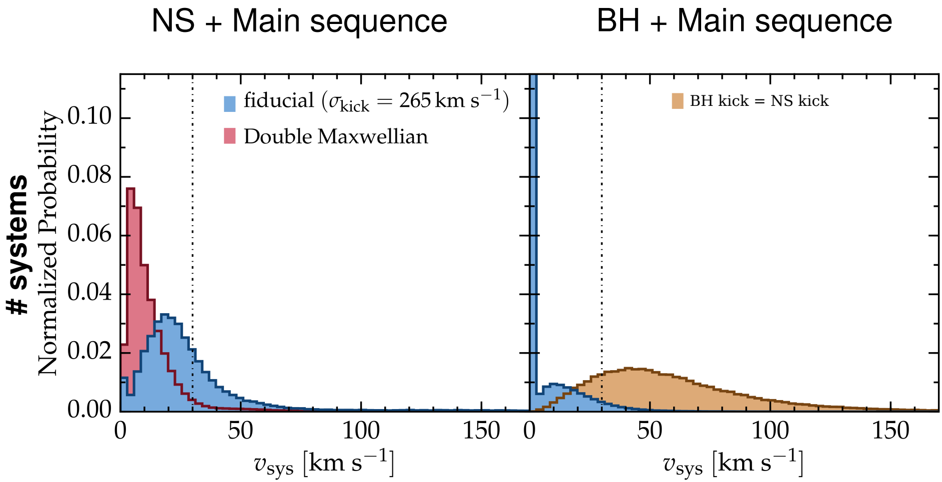


Compact objects in a binary are the exception, **not** the rule

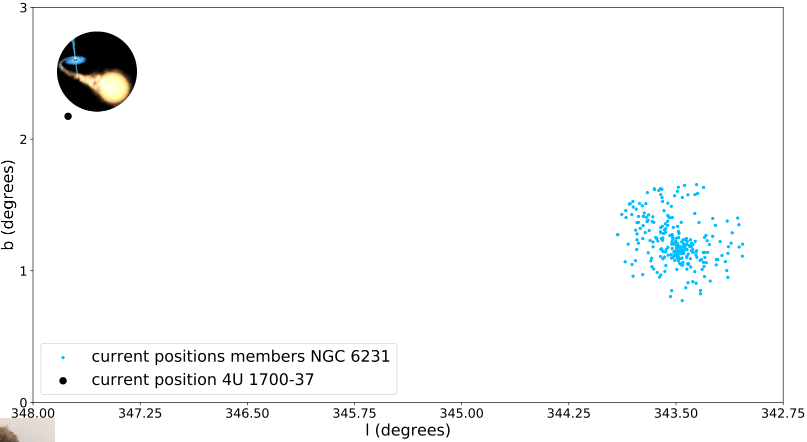


Velocity respect to the pre-explosion binary center of mass

Renzo *et al.* 19b

Preliminary: The case of 4U1700-37

Galactic longitude



Galactic latitude

Preliminary: The case of 4U1700-37

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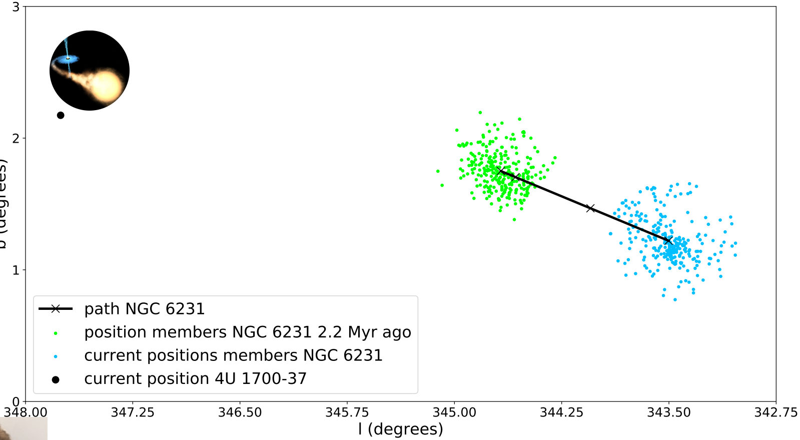
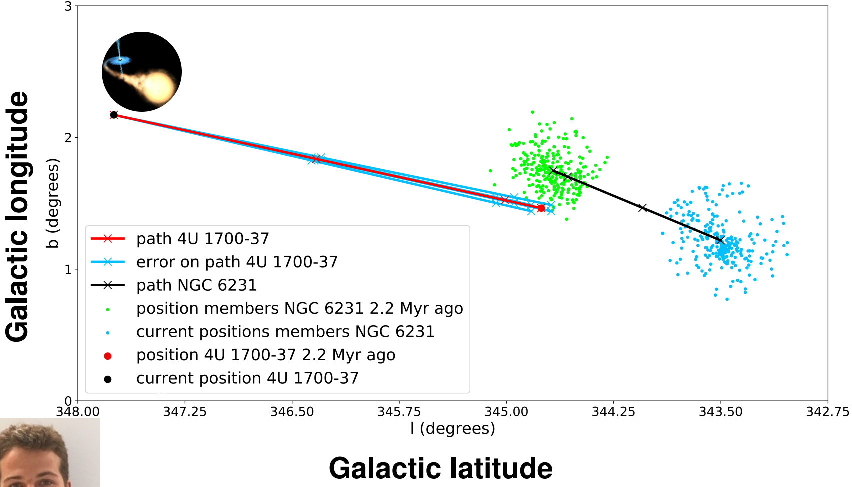


Galactic latitude

van der Meij *et al.* (incl. MR), in prep.

Preliminary: The case of 4U1700-37



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Known ejection mechanisms

Cluster ejections

- Happen before SNe
- Can produce high v
- Least massive thrown out
- *Gaia* hint: high efficiency

...Binaries are still important! but might not leave signature

Binary SN disruption

- Most binaries are disrupted
- Determined by SN kick
- Ejects accretor
- $v \simeq v_2^{\rm orb}$ typically slow
- Leaves binary signature

spin up, pollution, rejuvenation

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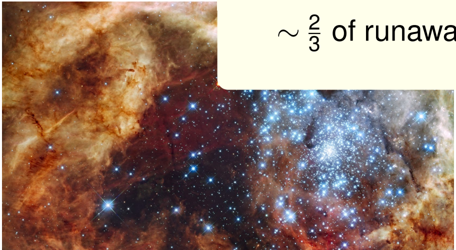
  spin up, pollution, rejuvenation

Relative efficiency ?

$\sim \frac{2}{3}$ of runaways from binaries

Hoogerwerf *et al.* 01



O type stars runaway fraction

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$$\frac{\#\ \text{runaways}}{\#\ \text{all stars}} \simeq$$

Observational claims: (regardless of origin)

$$\sim\ 10\%$$

$\sim \frac{2}{3}$ from binaries

Hoogerwerf *et al.* 01

Theoretical consensus from binaries:

$$0.5^{+2.1}_{-0.5}\%$$

Renzo *et al.* 19b, De Donder *et al.* 97, Eldridge *et al.* 11, Kochanek *et al.* 19

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Jilinski *et al.* 10
see also A. Bhat talk!

~~Hoogerwerf *et al.* 01~~

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Renzo *et al.* 19b, De Donder *et al.* 97, Eldridge *et al.* 11, Kochanek *et al.* 19

Is it really a problem?

- **Frame of reference to measure *v***
- Biases in favor of runaways
- *Gaia* hint: high efficiency dynamical ejection
- Binary prediction sensitive to SFH

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Conclusions

Take home points: Binary SN scenario

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- $86^{+11}_{-22}\%$ of massive binaries are disrupted

$\Rightarrow$ NS/BHs w/ companion are the exception, rather than the rule

- SN kicks are responsible but don't change the companion velocity

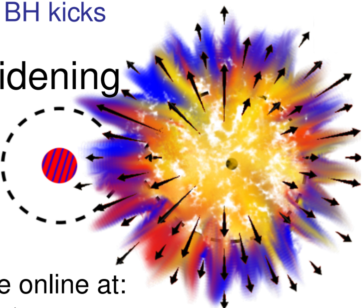
$\Rightarrow$ How fast a "widowed" star is tells how close to the exploding star it was

$\Rightarrow$ Mass distribution of runaways can constrain BH kicks

- Mass transfer causes orbital widening

$\Rightarrow$ Walkaways outnumber Runaways by $\sim 10\times$

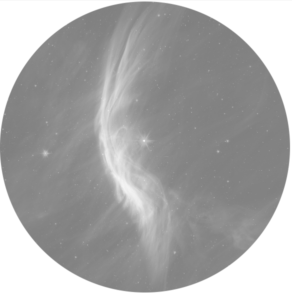
$\Rightarrow$ Is there a "runaway origin problem"?



All synthetic populations are online at:
`https://sandbox.zenodo.org/record/262858#.XJoMiEMo9hH`

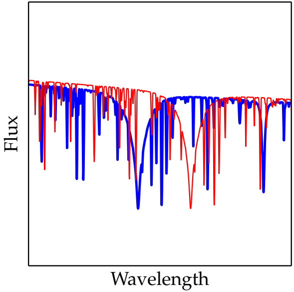
Backup slides

Observations of stellar velocities



⇐ Bow shocks

Doppler shifts ⇒



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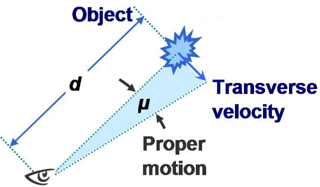


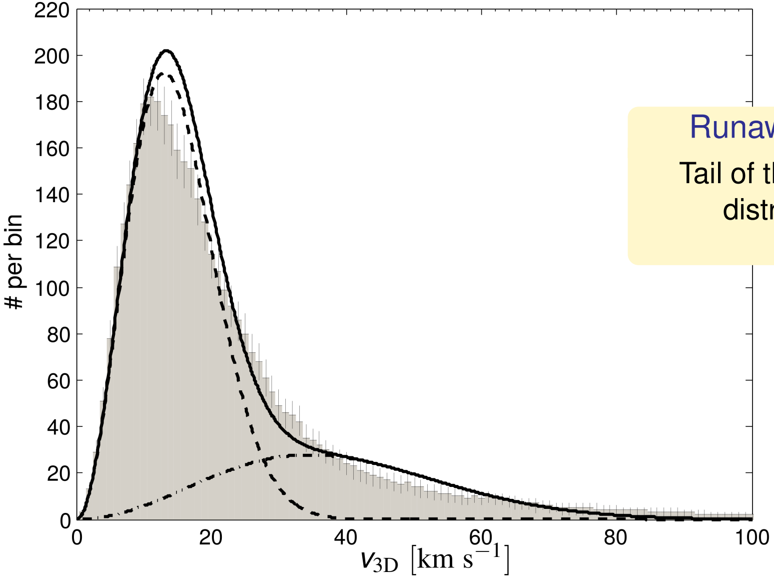
⇐ Proper motions

(if distance known)

=

$v_{3\mathrm{D}}$

What is a runaway star?



Runaway stars

Tail of the velocity distribution

Blaauw 61

Hipparcos velocity distribution for young ($\lesssim$ 50 Myr) stars, Tetzlaff *et al.* 11,

see also Zwicky 57, Blaauw, 93, Gies & Bolton 86, Leonard 91, Renzo *et al.* 19a, 19b

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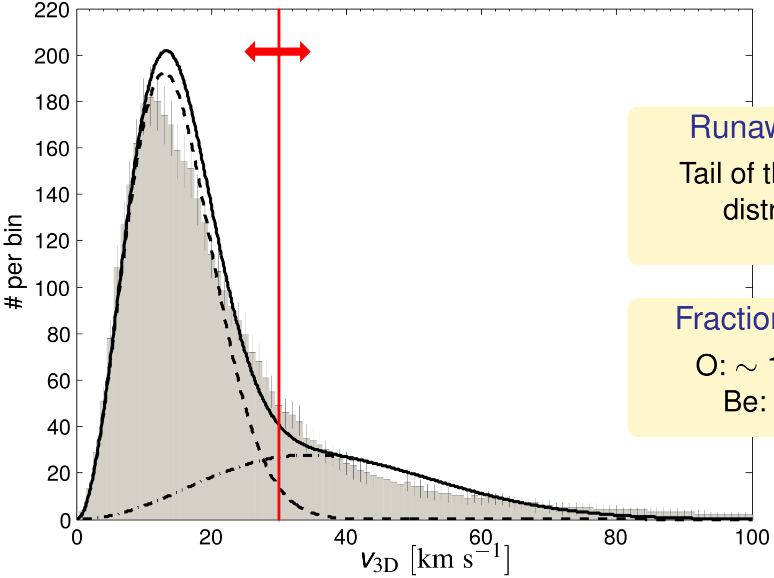

Runaway stars

Tail of the velocity distribution

Blaauw 61

Fraction per type

O: $\sim 10-20\%$

Be: $\sim 13\%$

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VFTS682: Concordant Picture?

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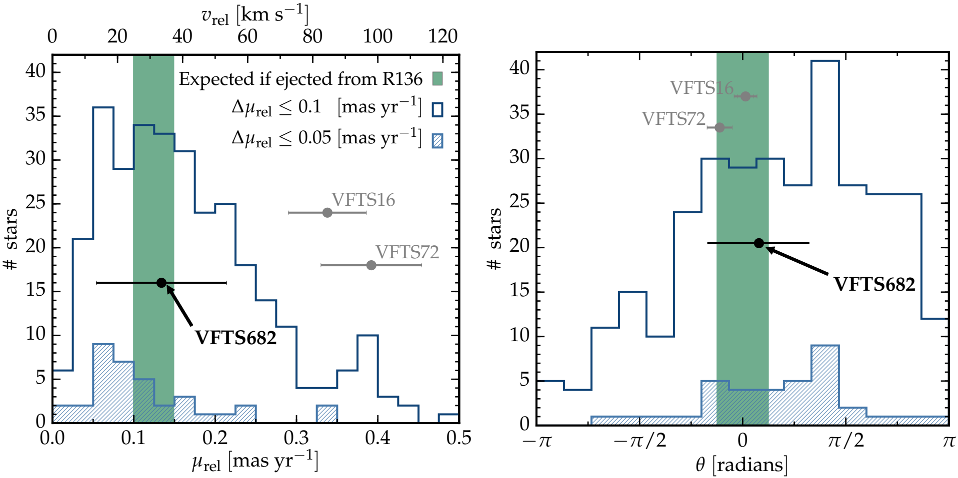
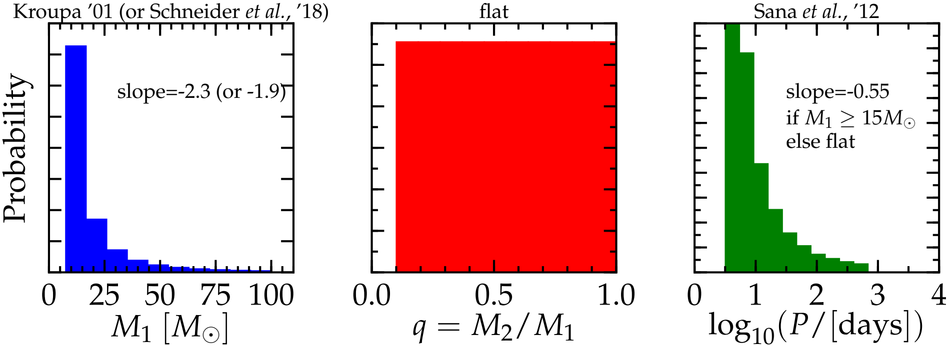
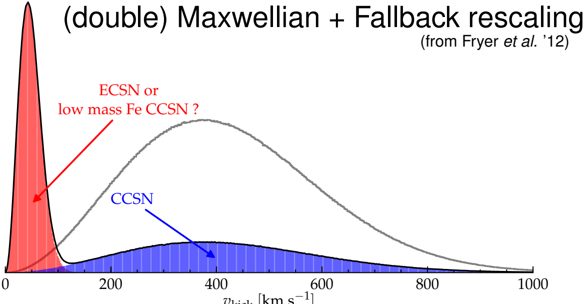


Large error bars compatible with no motion, but
best values fit with expectations for dynamical ejection

Renzo *et al.* 19a

Initial Distributions





Runaway fraction for O-type too low!

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Physical Assumptions	Parameter	value	$\mathcal{D}$ [%]	f_{15}^{RW} [%]	f_{15}^{WA} [%]
Fiducial population		see Sec. 2	86	0.5	10.1
Mass transfer efficiency	β_{RLOF}	0	86	0.3	1.5
		0.5	87	1.2	8.6
		1	87	0.7	14.7
Angular momentum loss	γ_{RLOF}	γ_{disk}	85	0.2	7.3
		1	86	0.6	9.9
Common envelope efficiency	α_{CE}	0.1	86	0.5	10.1
		10	84	0.5	10.0
Mass ratio for case A merger	$q_{crit,\ A}$	0.80	86	0.5	10.2
		0.25	86	0.6	9.4
Mass ratio for case B merger	$q_{crit,\ B}$	1.0	89	0.0	5.0
		0.0	85	0.6	10.1
Natal kick velocity	σ_{kick}	0	16	–	0.0
		300	87	0.6	10.3
		1000	91	1.2	11.2
Natal kick amplitude	(σ_{kick}, f_b)	(100, 0)	84	0.3	8.7
Double maxwellian with $\sigma_{kick} = 30\,\mathrm{km\,s^{-1}}$		for $M_{NS} \leq 1.35$	65	0.5	4.9
Restricted kick directions		$\alpha < 10\,\mathrm{deg}$	87	0.6	10.3
		$\frac{\pi}{2} - \alpha < 45\,\mathrm{deg}$	86	0.5	10.0
Fallback fraction	f_b	0	97	1.5	12.1
Metallicity	Z	0.0002	77	2.6	7.7
		0.0047	84	1.2	10.3
		0.03	88	0.5	10.0

Robust outcome
(but less bad at low Z)

$$f_{15}^{RW} \stackrel{\text{def}}{=} \frac{\#\ \text{runaways}}{\#\ \text{stars}}$$

Observed:

$$f_{15}^{RW} \simeq 10 - 20\%$$

$\sim\frac{2}{3}$ of runaways from binaries

Hoogerwerf *et al.* 01

(but see also Jilinski *et al.* 10)

Renzo *et al.* 19b

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		10	84	0.5	10.0
Mass ratio for case A merger	$q_{crit,\ A}$	0.80	86	0.5	10.2
		0.25	86	0.6	9.4
Mass ratio for case B merger	$q_{crit,\ B}$	1.0	89	0.0	5.0
		0.0	85	0.6	10.1
Natal kick velocity	σ_{kick}	0	16	–	0.0
		300	87	0.6	10.3
		1000	91	1.2	11.2
Natal kick amplitude	(σ_{kick}, f_b)	(100, 0)	84	0.3	8.7
Double maxwellian with $\sigma_{kick} = 30\,\mathrm{km\,s^{-1}}$		for $M_{NS} \leq 1.35$	65	0.5	4.9
Restricted kick directions		$\alpha < 10\,\mathrm{deg}$	87	0.6	10.3
		$\frac{\pi}{2} - \alpha < 45\,\mathrm{deg}$	86	0.5	10.0
Fallback fraction	f_b	0	97	1.5	12.1
Metallicity	Z	0.0002	77	2.6	7.7
		0.0047	84	1.2	10.3
		0.03	88	0.5	10.0

Robust outcome
(but less bad at low Z)

$$f_{15}^{RW} \stackrel{\mathrm{def}}{=} \frac{\#\ \text{runaways}}{\#\ \text{stars}}$$

Observed:

$$f_{15}^{RW} \simeq 10 - 20\%$$

$\sim\frac{2}{3}$ of runaways from binaries

Hoogerwerf *et al.* 01

(but see also Jilinski *et al.* 10)

Renzo *et al.* 19b

Runaway fraction for O-type too low!

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Physical Assumptions	Parameter	value	$\mathcal{D}$ [%]	f_{15}^{RW} [%]	f_{15}^{WA} [%]
Fiducial population		see Sec. 2	86	0.5	10.1
Mass transfer efficiency	β_{RLOF}	0	86	0.3	1.5
		0.5	87	1.2	8.6
		1	87	0.7	14.7
Angular momentum loss	γ_{RLOF}	γ_{disk}	85	0.2	7.3
		1	86	0.6	9.9
Common envelope efficiency	α_{CE}	0.1	86	0.5	10.1
		10	84	0.5	10.0
Mass ratio for case A merger	$q_{\mathrm{crit,\,A}}$	0.80	86	0.5	10.2
		0.25	86	0.6	9.4
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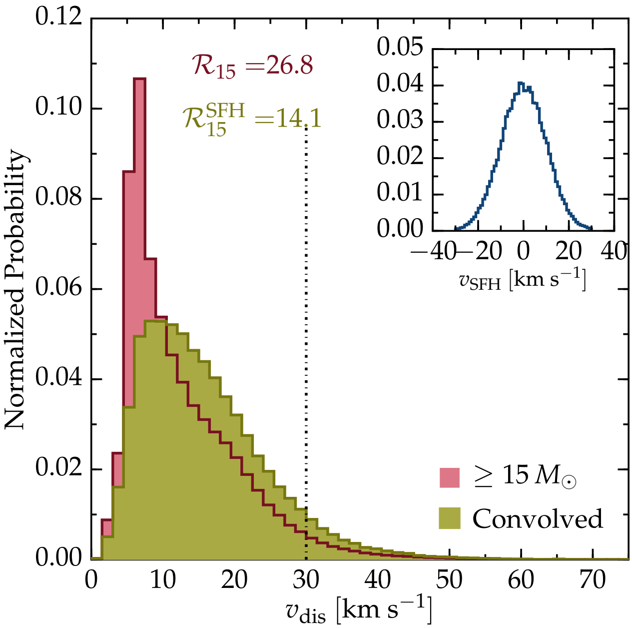
Hoogerwerf *et al.* 01

(but see also Jilinski *et al.* 10)

Renzo *et al.* 19b

Star forming region velocity dispersion



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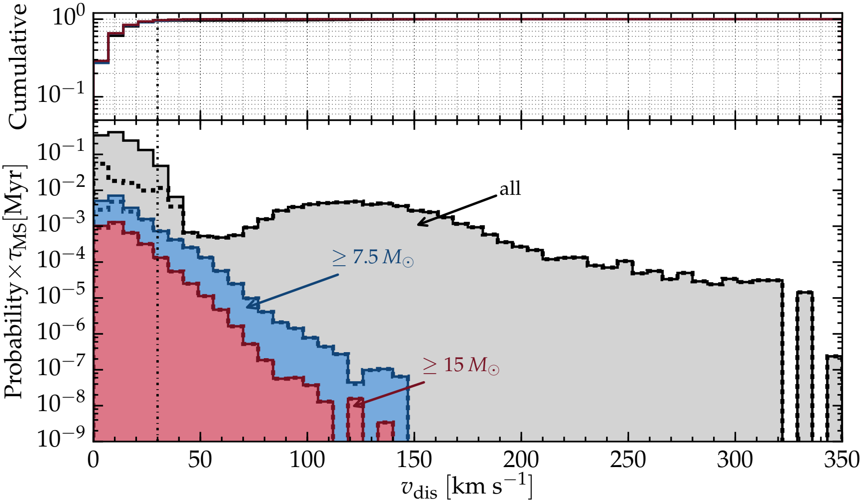
Velocity distribution with lifetimes



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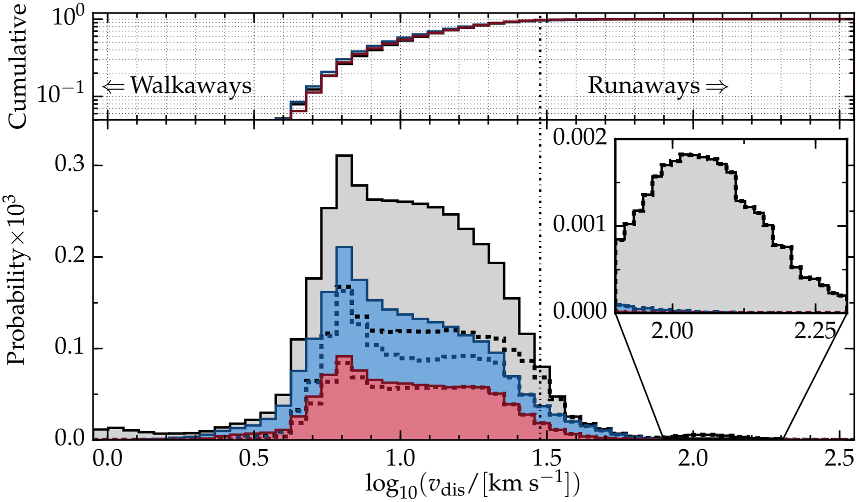
Velocity distribution log-scale



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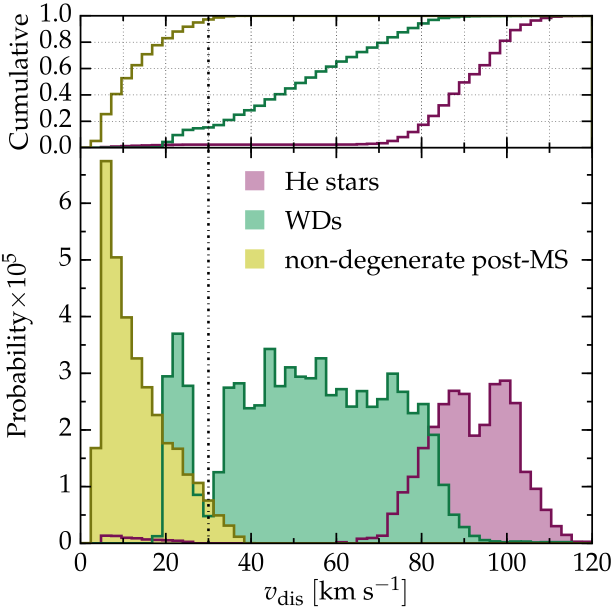
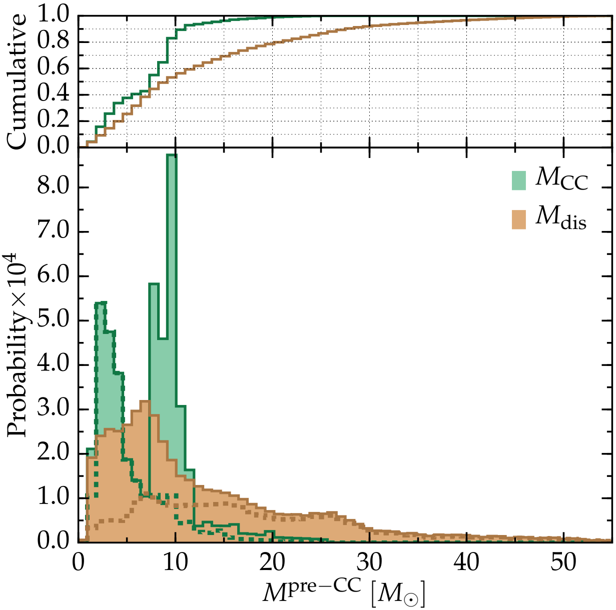
Velocity post-main sequence stars



pre-CC mass distribution



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pre-CC separation distribution

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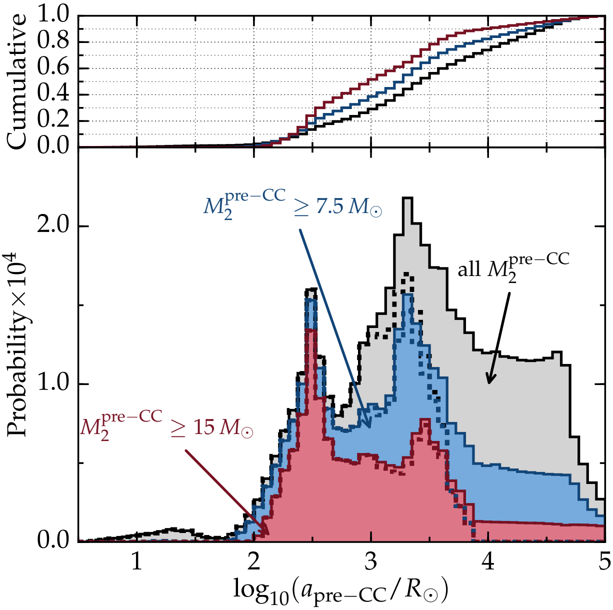

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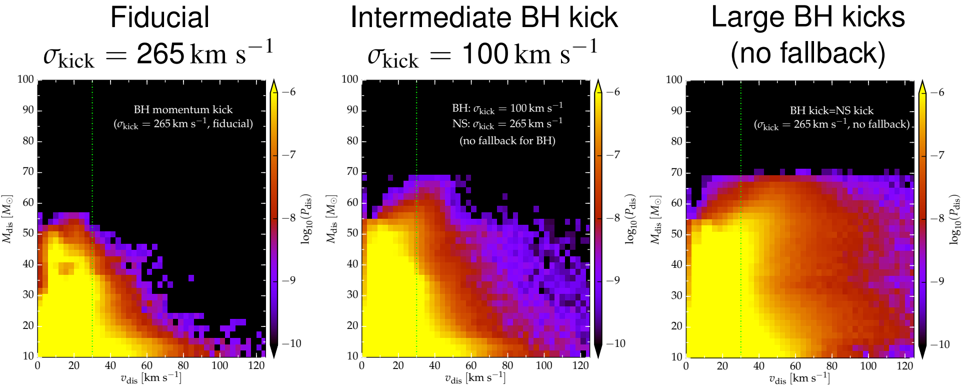
Mass-velocity varying the natal kick



Massive “widowed” stars:

Probes for explosions physics and binary evolution

Mathieu Renzo

Amsterdam ⇒ Flatiron, NY

Collaborators:
E. Zapartas, S. E. de Mink, Y. Götberg, S. Justham, R. J. Farmer, R. G. Izzard, S. Toonen, D. J. Lennon, H. Sana, E. Laplace, S. N. Shore, V. van der Meij, ...

NASA, JPL-Caltech, Spitzer Space Telescope

Why are massive stars important?

Nucleosynthesis & Chemical Evolution

Star Formation

Ionizing Radiation

Supernovae

GW Astronomy

NASA, JPL-Caltech, Spitzer Space Telescope

Why are massive stars important?

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- Nucleosynthesis & Chemical Evolution
- Star Formation
- Ionizing Radiation
- Supernovae
- GW Astronomy

~70% of O type stars are born in close binaries

(e.g., Mason *et al.* '09, Sana & Evans '11, Sana *et al.* '12, Kiminki & Kobulnicky '12, Kobulnicky *et al.* '14, Almeida *et al.* '16)

~10% **of O type stars are runaways**

(e.g., Blaauw '61, Gies '87, Stone '91)

NASA, JPL-Caltech, Spitzer Space Telescope

How far do they get?

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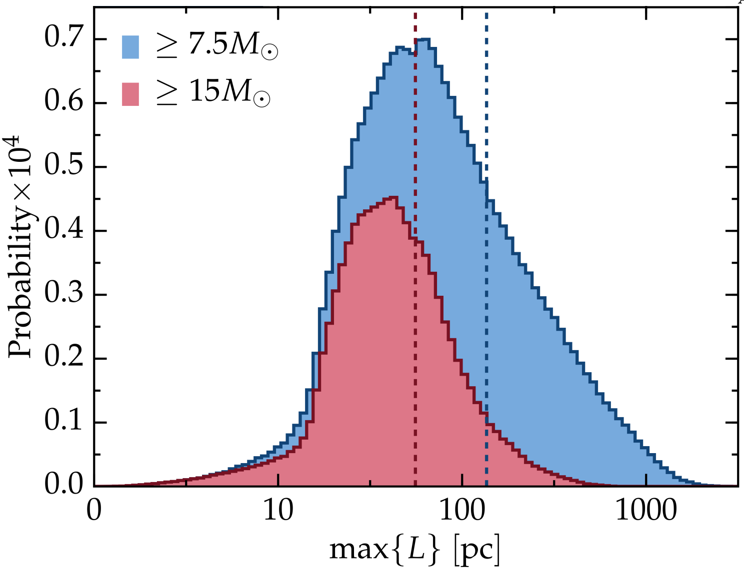

"Distance traveled"

(No potential well)

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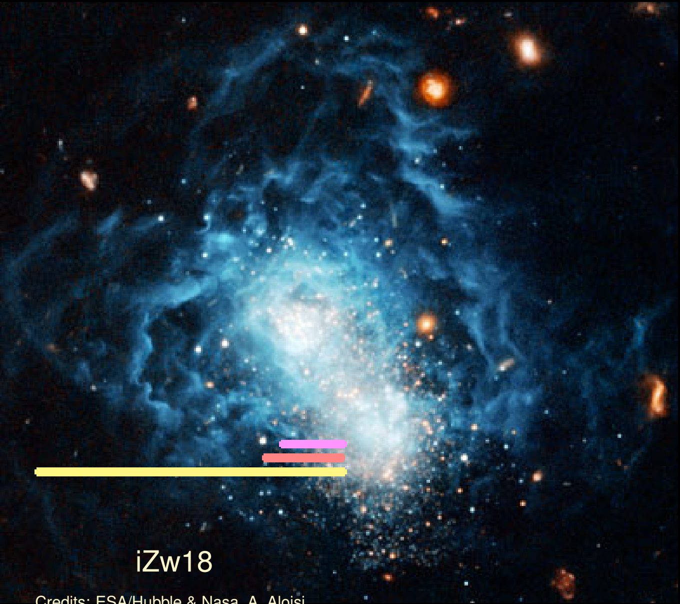
Where do they die?



Credits: ESA/Hubble & Nasa, A. Aloisi

for $M \geq 7.5\,M_{\odot}$:

$\langle D \rangle$ = 128 pc

$\langle D_{\rm run} \rangle$ = 525 pc

$\langle D_{\rm walk} \rangle$ = 103 pc