Binary evolution and supernova kicks

Mathieu Renzo
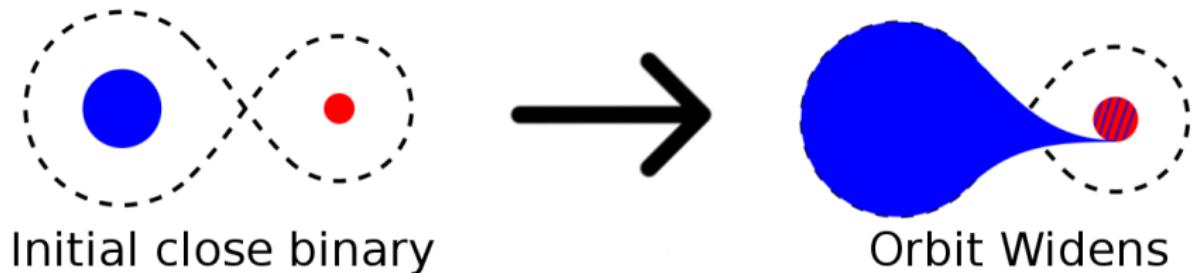
SF
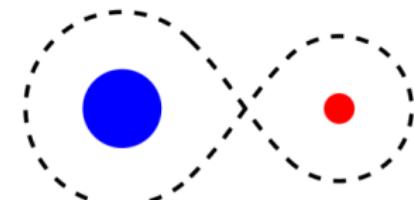
Initial close binary

The most common binary evolution path
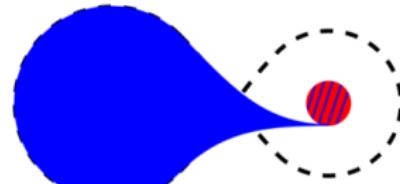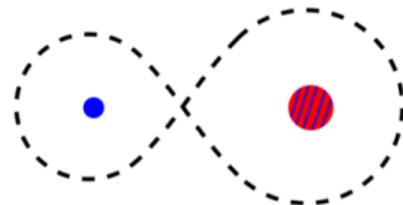
Initial close binary

Orbit Widens

The most common binary evolution path
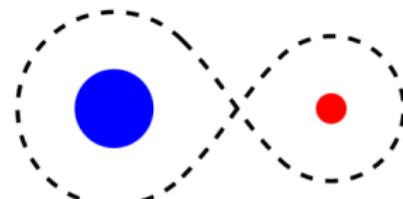
Initial close binary
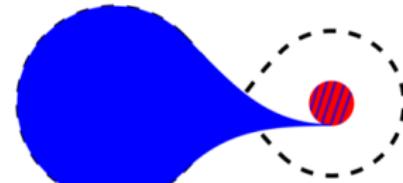
Orbit Widens

Stripped star + Accretor
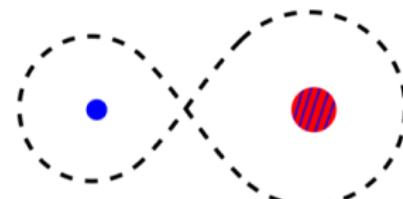
The most common binary evolution path
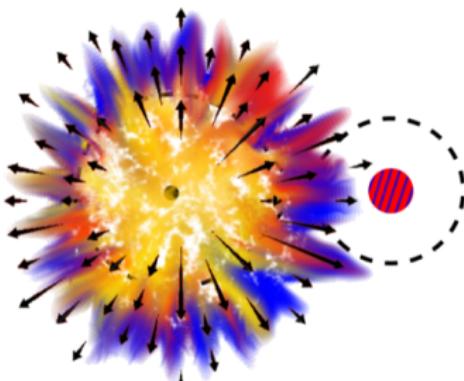
Initial close binary

Orbit Widens

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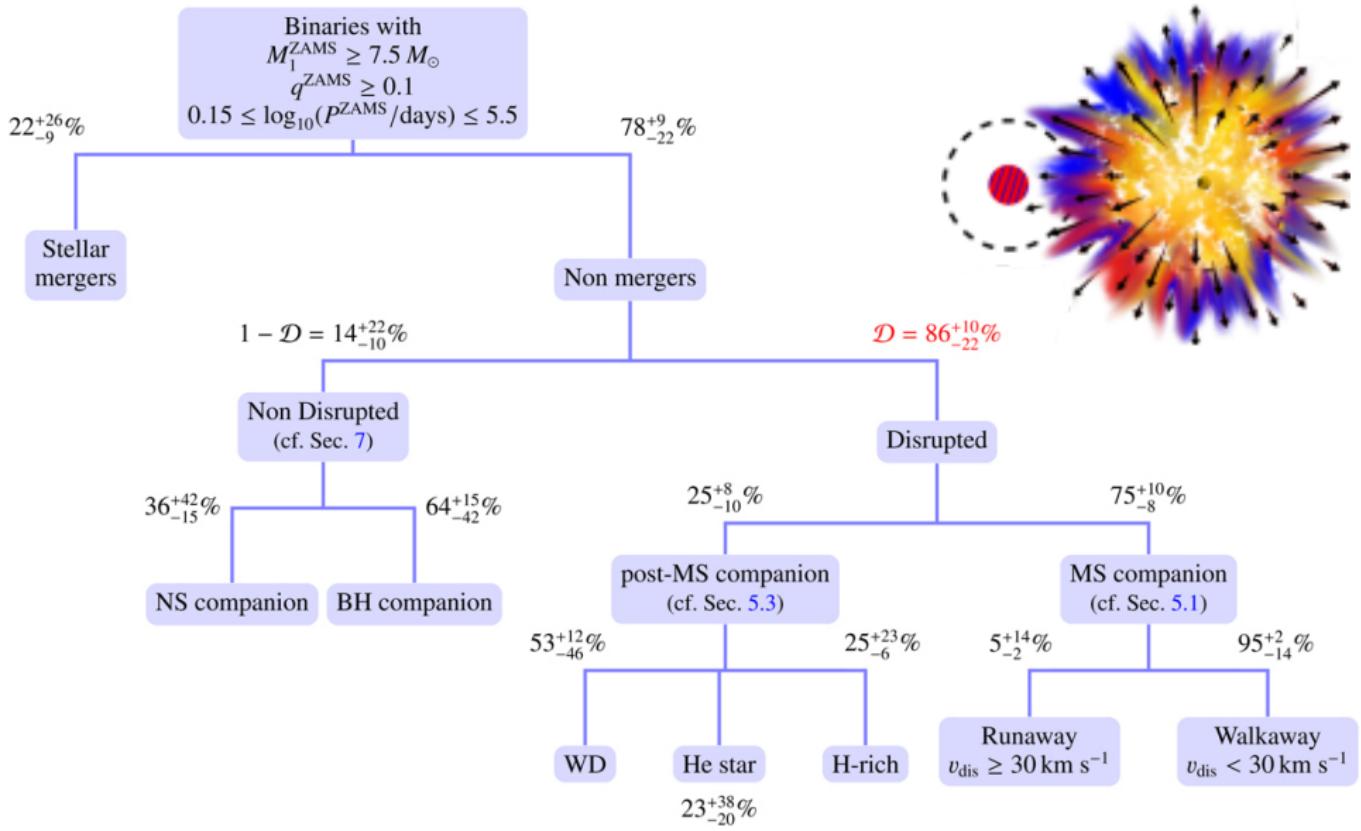
Core Collapse & Disruption

see outreach movie at
https://www.youtube.com/watch?v=qmfJNI0PXbo
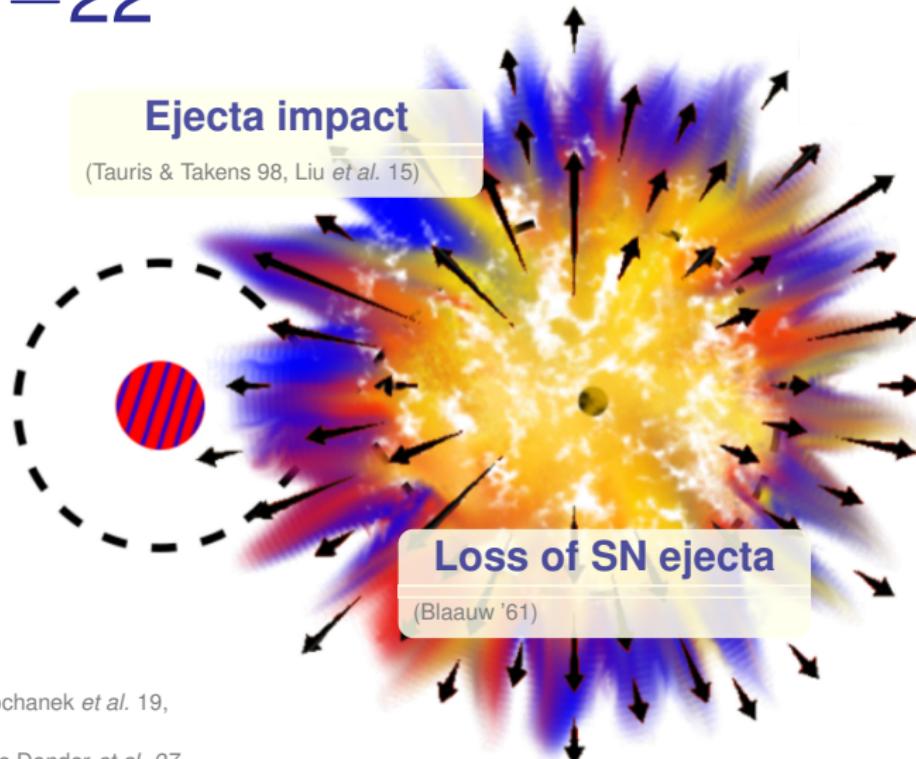
How common is "common"?

Binaries with
$M_1^{ZAMS} \geq 7.5\,M_\odot$
$q^{ZAMS} \geq 0.1$
$0.15 \leq \log_{10}(P^{ZAMS}/\text{days}) \leq 5.5$

$22^{+26}_{-9}\%$ — Stellar mergers

$78^{+9}_{-22}\%$ — Non mergers

$1 - \mathcal{D} = 14^{+22}_{-10}\%$ — Non Disrupted (cf. Sec. 7)

$\mathcal{D} = 86^{+10}_{-22}\%$ — Disrupted

$36^{+42}_{-15}\%$ — NS companion

$64^{+15}_{-42}\%$ — BH companion

$25^{+8}_{-10}\%$ — post-MS companion (cf. Sec. 5.3)

$75^{+10}_{-8}\%$ — MS companion (cf. Sec. 5.1)

$53^{+12}_{-46}\%$ — WD

$23^{+38}_{-20}\%$ — He star

$25^{+23}_{-6}\%$ — H-rich

$5^{+14}_{-2}\%$ — Runaway $v_{dis} \geq 30$ km s^{-1}

$95^{+2}_{-14}\%$ — Walkaway $v_{dis} < 30$ km s^{-1}

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Renzo *et al.* 19b

What exactly disrupts the binary?

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

Ejecta impact
(Tauris & Takens 98, Liu *et al*. 15)

Loss of SN ejecta
(Blaauw '61)
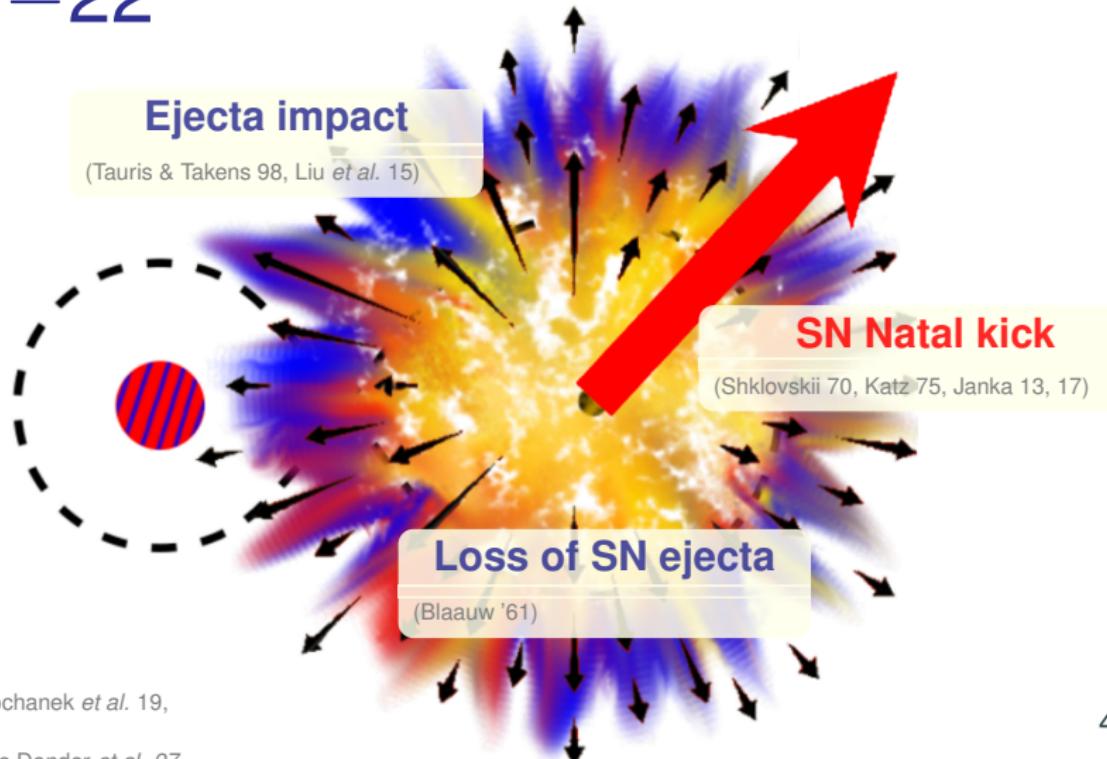
Renzo *et al*. 19b, Kochanek *et al*. 19,

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

What exactly disrupts the binary?

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


Ejecta impact
(Tauris & Takens 98, Liu *et al.* 15)

SN Natal kick
(Shklovskii 70, Katz 75, Janka 13, 17)

Loss of SN ejecta
(Blaauw '61)

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

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

Kicks do not change companion velocity
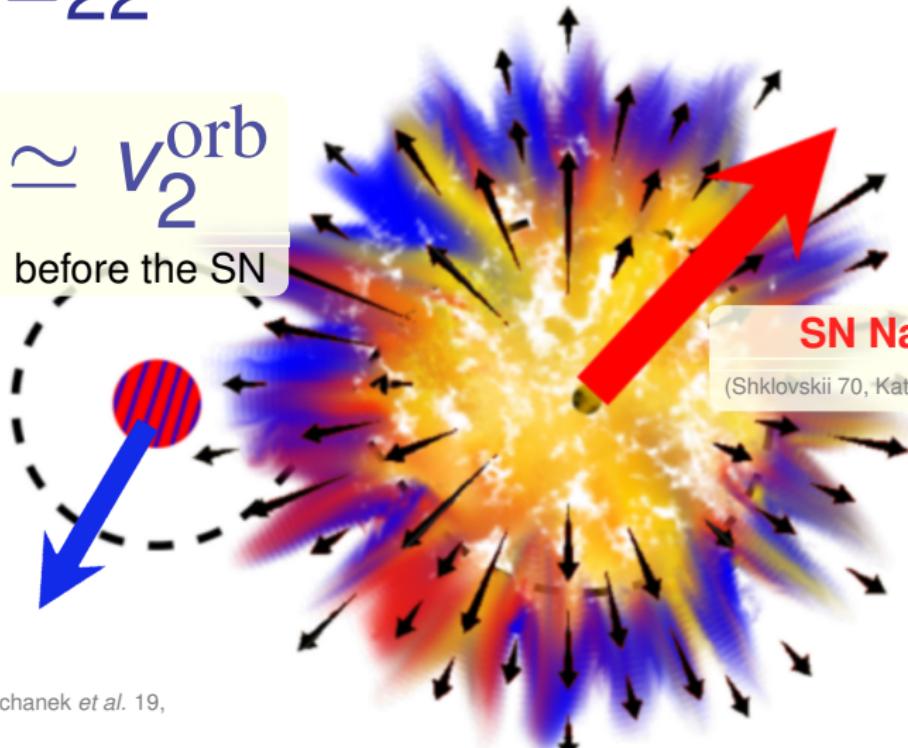
$86^{+11}_{-22}\%$ of massive binaries are disrupted

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

before the SN

SN Natal kick

(Shklovskii 70, Katz 75, Janka 13, 17)
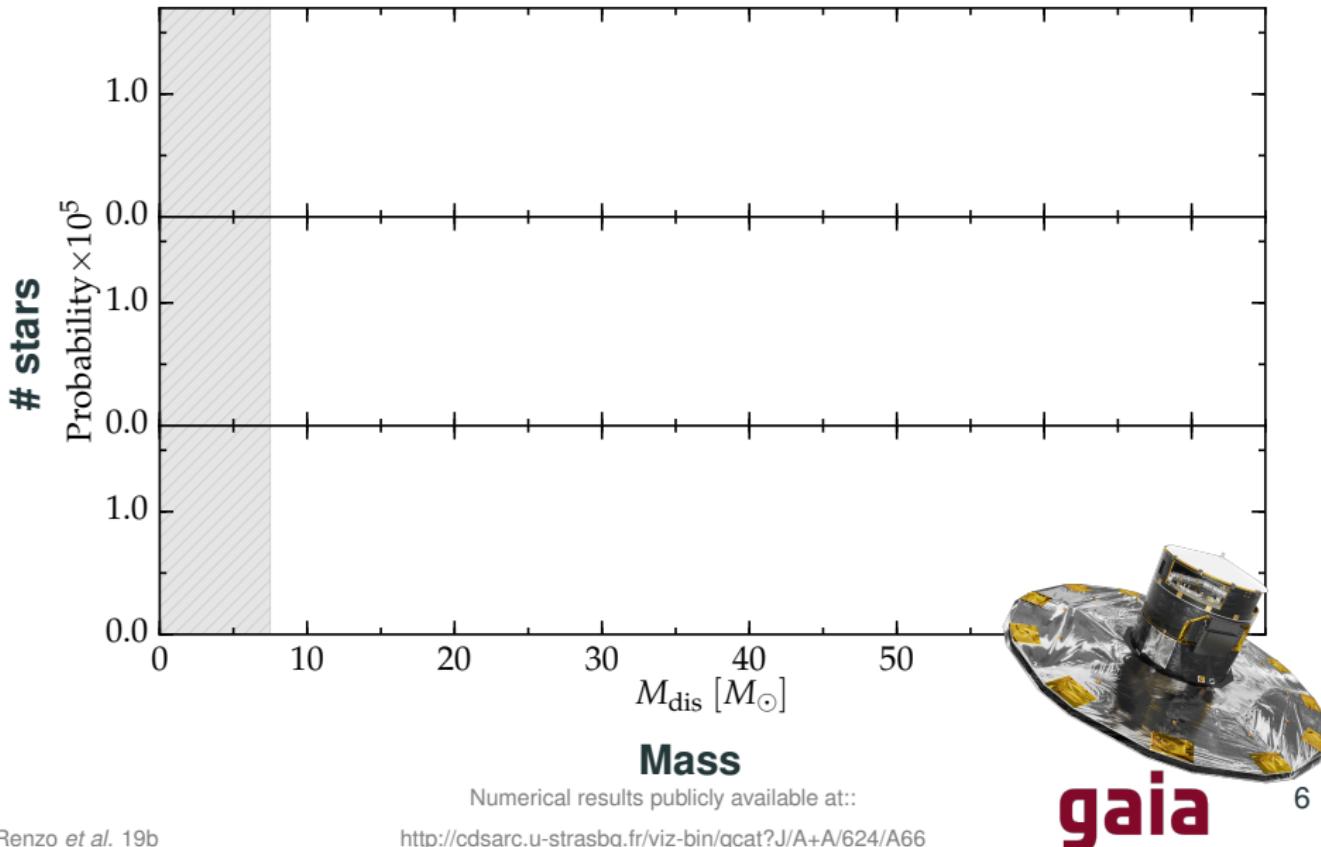
Renzo *et al.* 19b, Kochanek *et al.* 19,

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

BH kicks from the mass of runaways
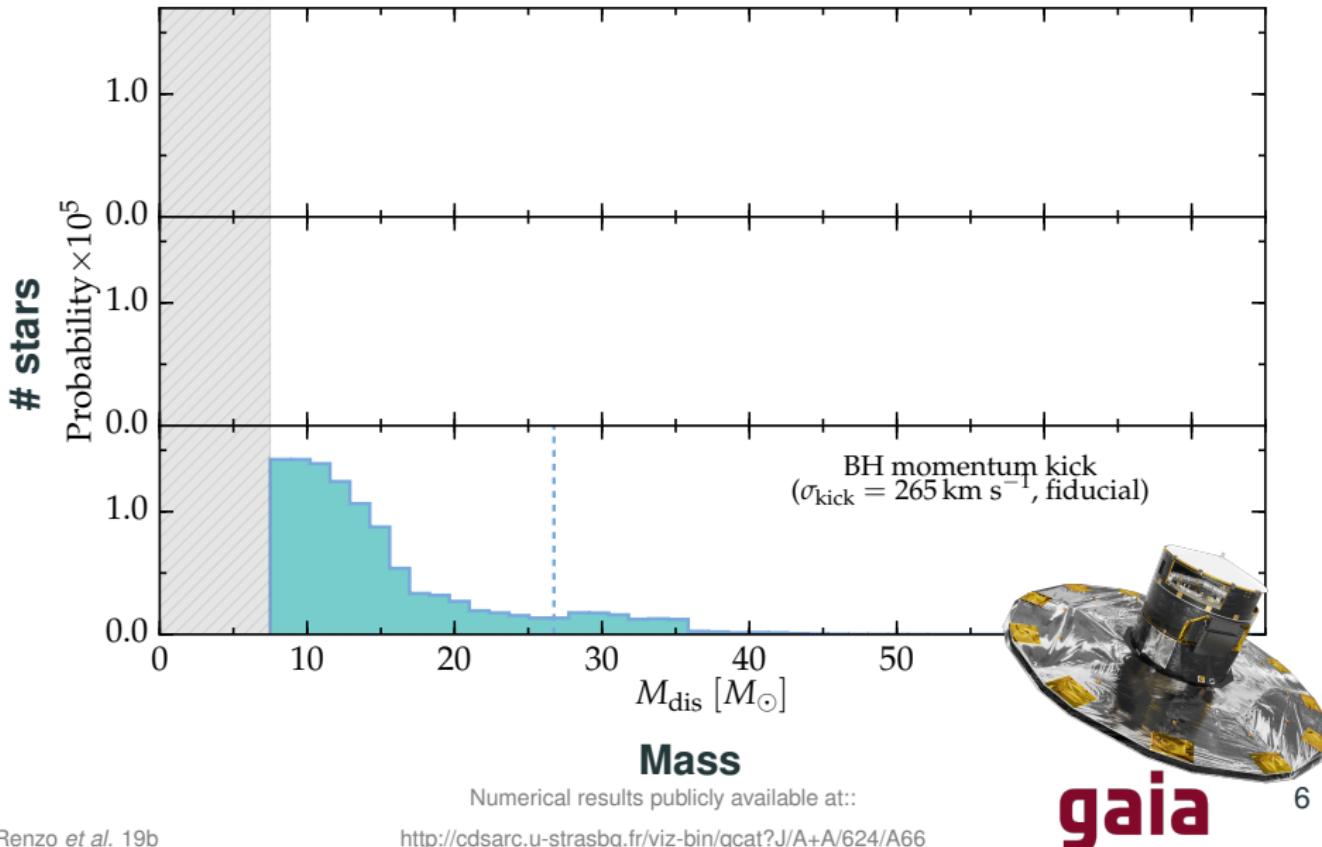
A way to constrain BH kicks with Gaia
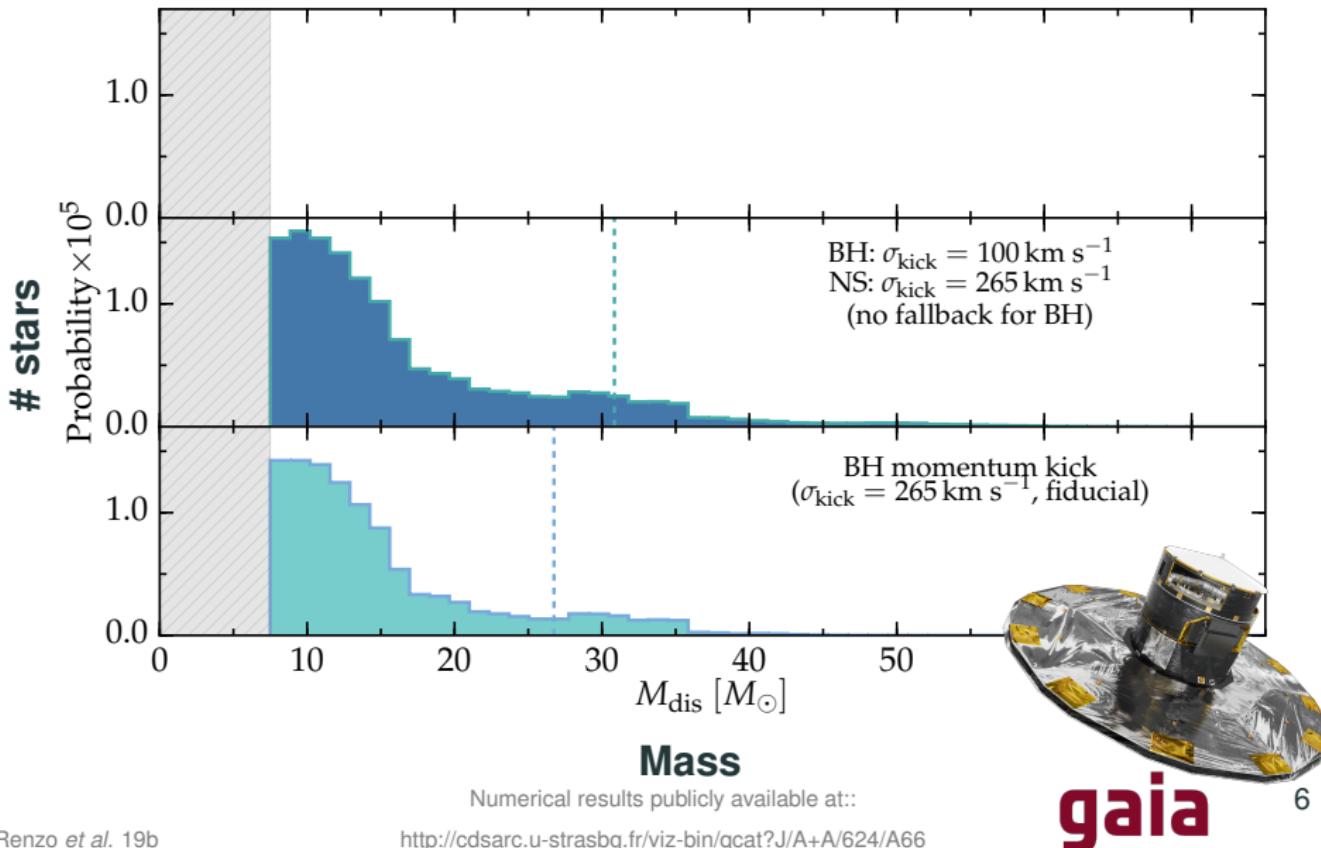
Massive runaways mass function ($v \geq 30\,\mathrm{km\,s^{-1}}$, $M \geq 7.5\,M_\odot$)

 # stars

Probability $\times 10^5$

$M_{\mathrm{dis}}\,[M_\odot]$

Mass

Numerical results publicly available at::

http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

Renzo *et al.* 19b

gaia

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

BH momentum kick
($\sigma_{\mathrm{kick}} = 265\,\mathrm{km\,s^{-1}}$, fiducial)

 # stars

Probability $\times 10^5$

$M_{\mathrm{dis}}\,[M_\odot]$
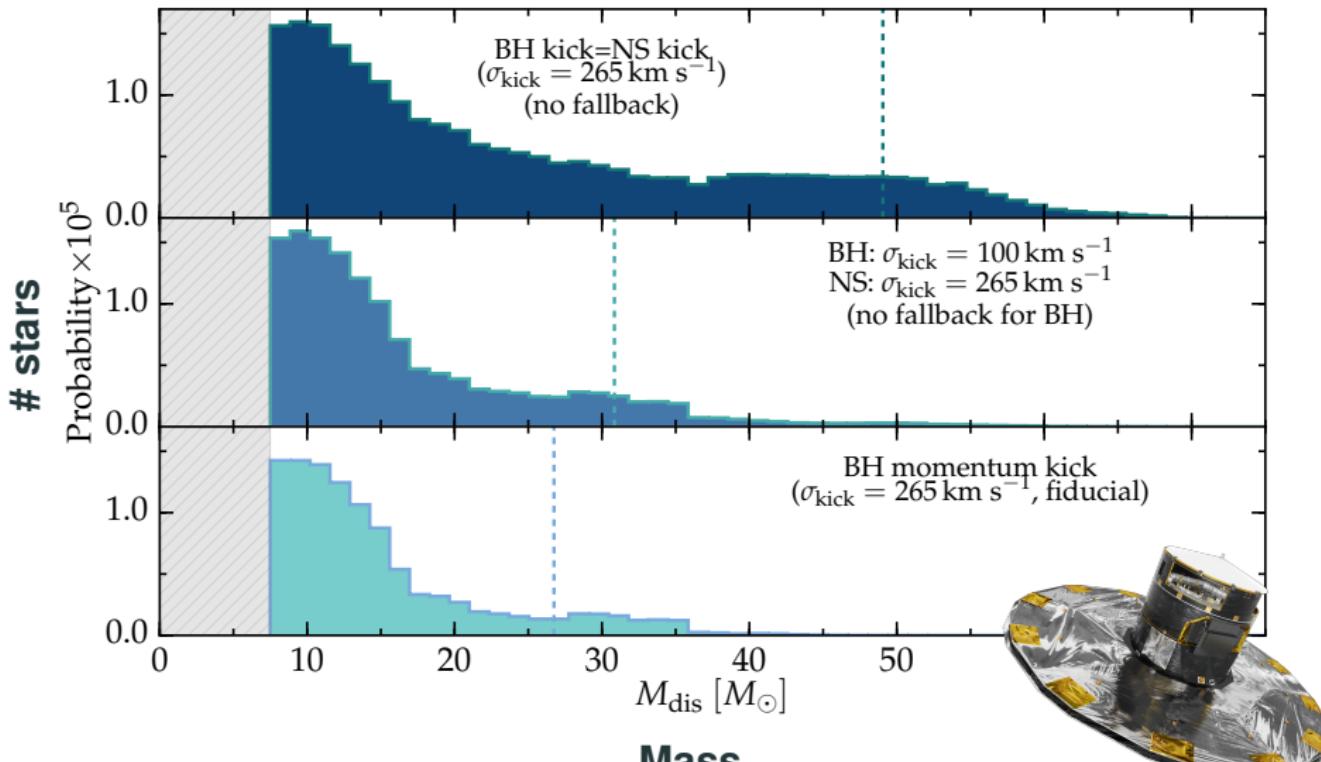
Mass

Numerical results publicly available at::

gaia

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

BH: $\sigma_{\mathrm{kick}} = 100\,\mathrm{km\,s^{-1}}$
NS: $\sigma_{\mathrm{kick}} = 265\,\mathrm{km\,s^{-1}}$
(no fallback for BH)

BH momentum kick
($\sigma_{\mathrm{kick}} = 265\,\mathrm{km\,s^{-1}}$, fiducial)

stars

Probability $\times 10^5$

$M_{\mathrm{dis}}\ [M_\odot]$

Mass

Numerical results publicly available at::

Renzo *et al*. 19b   http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

gaia

6

A way to constrain BH kicks with Gaia

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

stars
Probability $\times 10^5$

BH kick=NS kick
($\sigma_{\mathrm{kick}} = 265\,\mathrm{km\,s^{-1}}$)
(no fallback)

BH: $\sigma_{\mathrm{kick}} = 100\,\mathrm{km\,s^{-1}}$
NS: $\sigma_{\mathrm{kick}} = 265\,\mathrm{km\,s^{-1}}$
(no fallback for BH)

BH momentum kick
($\sigma_{\mathrm{kick}} = 265\,\mathrm{km\,s^{-1}}$, fiducial)

$M_{\mathrm{dis}}\ [M_\odot]$

Mass

Numerical results publicly available at::

http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

gaia

6
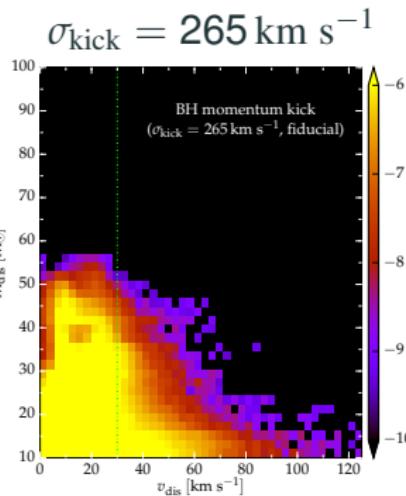
Renzo *et al.* 19b

Mass-velocity varying the natal kick

Renzo *et al.* 19b, (see also Dray *et al.* 2006 for WR runaways)
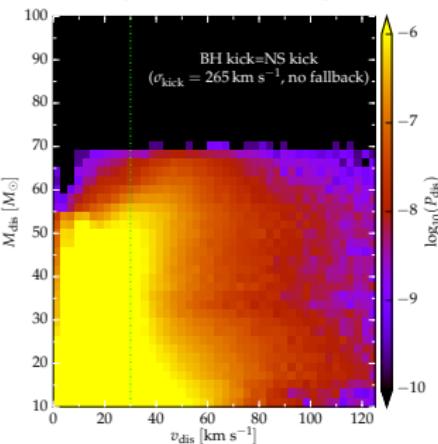
Fiducial
$\sigma_{\rm kick} = 265\,{\rm km\,s^{-1}}$

Intermediate BH kick
$\sigma_{\rm kick} = 100\,{\rm km\,s^{-1}}$

Large BH kicks
(no fallback)

Numerical results publicly available at:

http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66
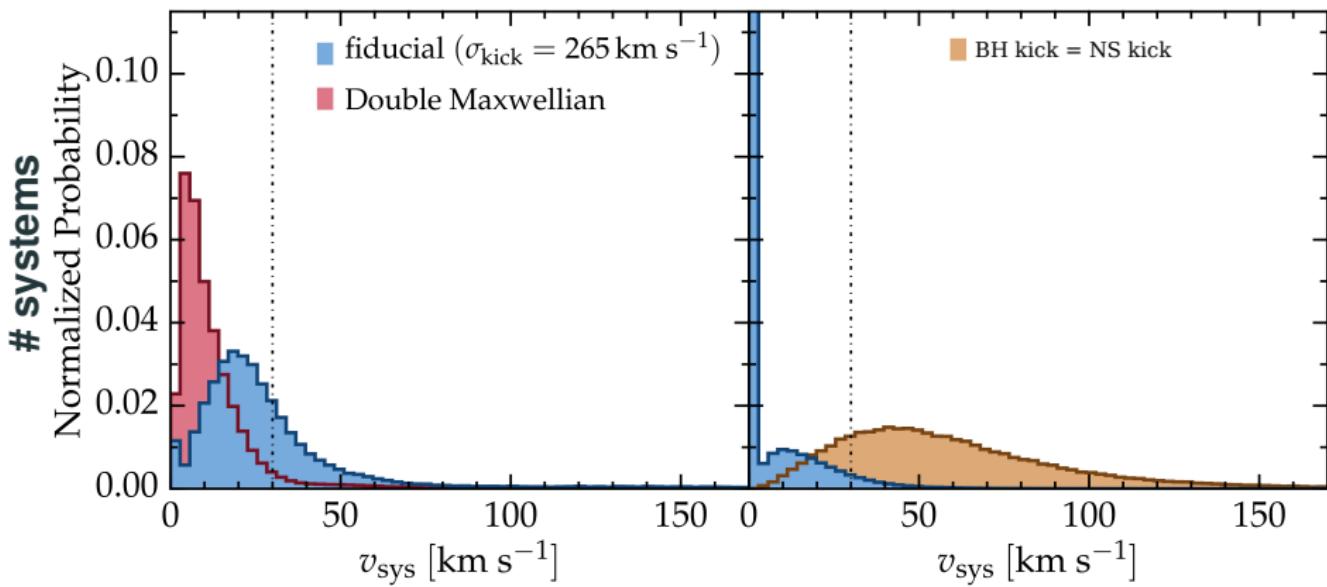
Kicks constraints from XRBs astrometry

Post-SN velocity of surviving binaries

Velocity respect to the pre-explosion binary center of mass

Preliminary: The case of 4U1700-37

$M \simeq 2.5\,M_\odot$, $M_* \simeq 60 \pm 10\,M_\odot$, $P \simeq 3.4\,\text{days}$, $e \simeq 0.22$, $v \simeq 60\,\text{km s}^{-1}$


- current positions members NGC 6231
- current position 4U 1700-37

Galactic longitude

b (degrees)

Galactic latitude

l (degrees)

van der Meij, D.-F. Guo, *et al.* (incl. MR), in prep.

gaia

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van der Meij, D.-F. Guo, *et al.* (incl. MR), in prep.

$M \simeq 2.5 \, M_\odot$, $M_* \simeq 60 \pm 10 \, M_\odot$, $P \simeq 3.4 \, \mathrm{days}$, $e \simeq 0.22$, $v \simeq 60 \, \mathrm{km \, s^{-1}}$

- path 4U 1700-37
- error on path 4U 1700-37
- path NGC 6231
- position members NGC 6231 2.2 Myr ago
- current positions members NGC 6231
- position 4U 1700-37 2.2 Myr ago
- current position 4U 1700-37

Galactic longitude
b (degrees)

Galactic latitude
l (degrees)

347.25 346.50 345.75 345.00 344.25

van der Meij, D.-F. Guo, *et al.* (incl. MR), in prep.
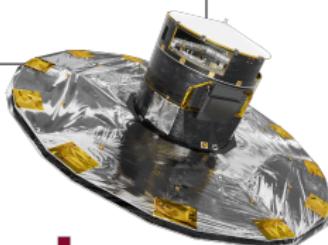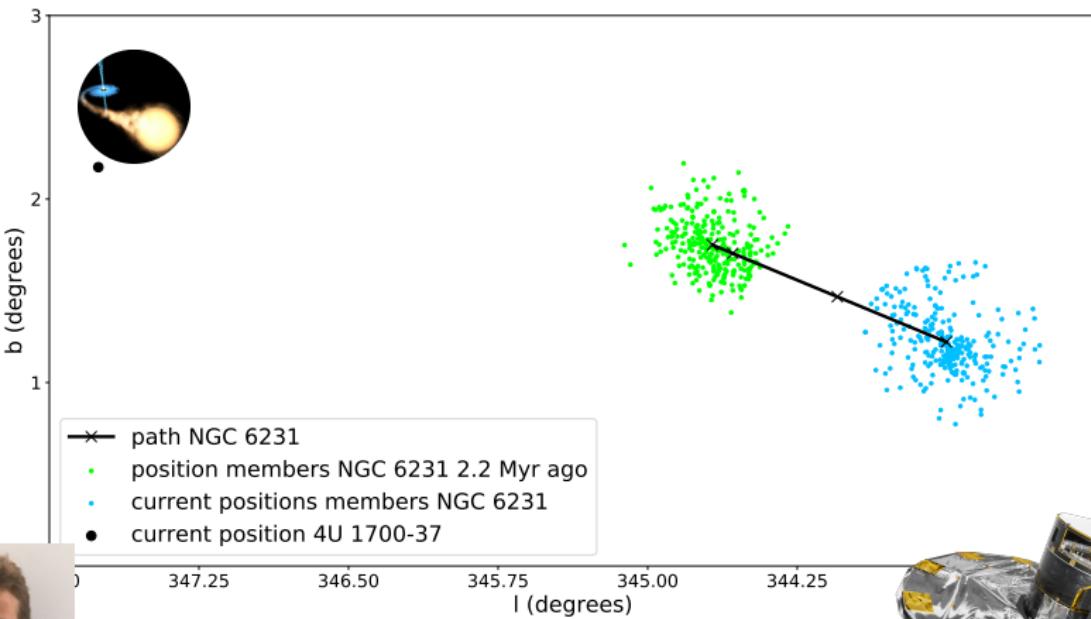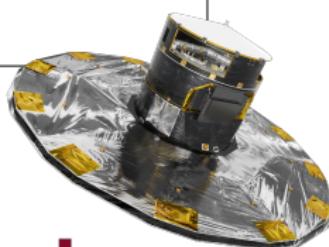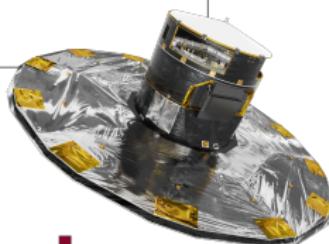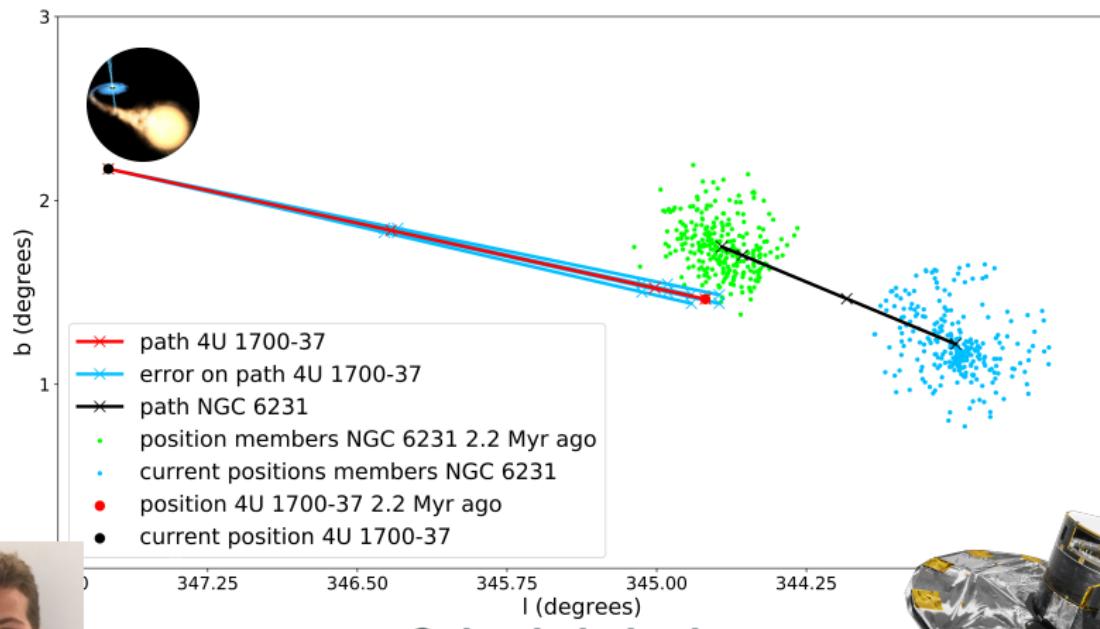
gaia

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Conclusions

Take home points

Natal kicks cause the disruption of $86^{+11}_{-22}\%$ of massive binaries

For disrupted binaries the kick acts only on compact object
$\Rightarrow$ walkaways outnumber the runaways;
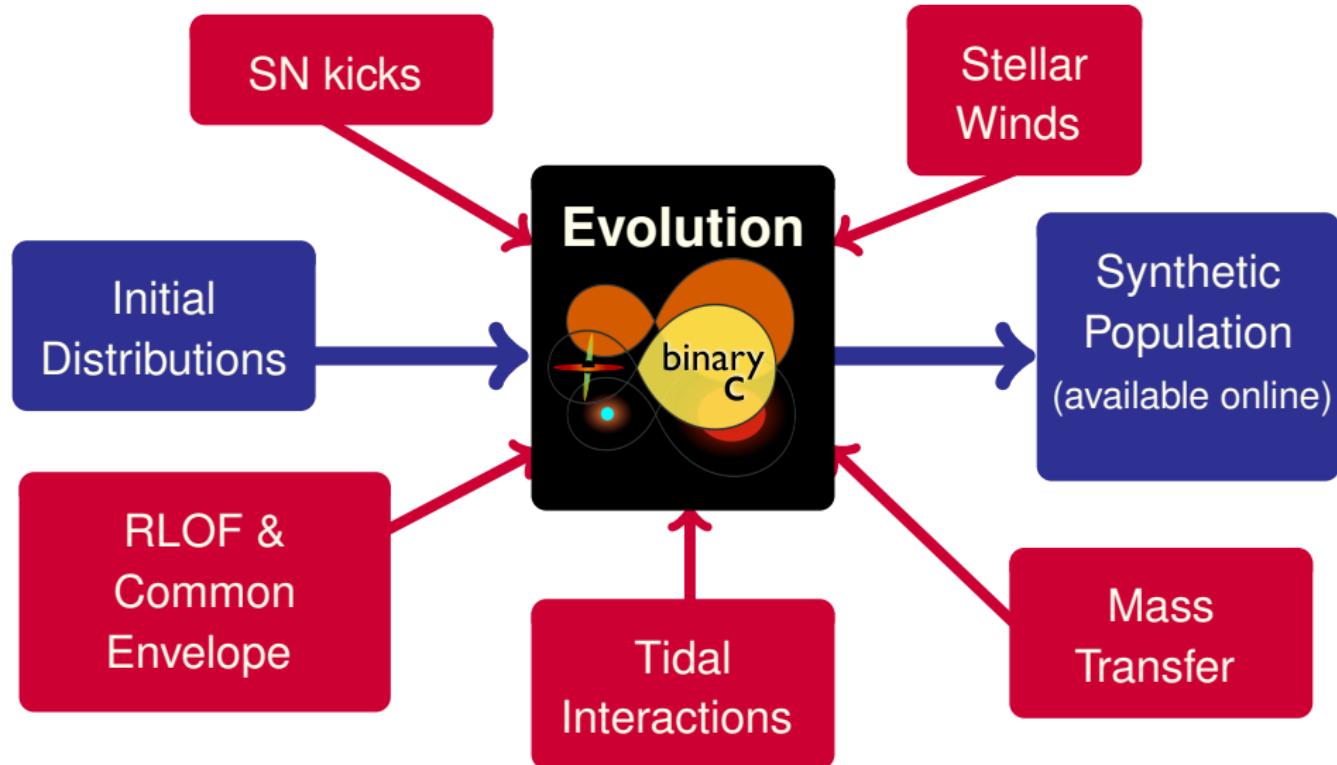
If binary remains bound the kick changes the kinematics of the whole system;

Runaway mass distribution $\Rightarrow$ constraints on BH kicks without seeing the collapse nor the BH.

Backup slides

Methods: Population Synthesis
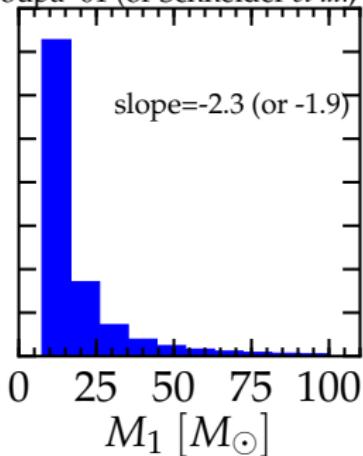
Fast $\Rightarrow$ Allows statistical tests of the inputs & assumptions
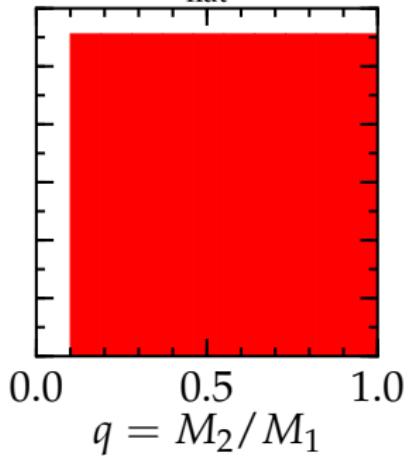
Initial Distributions
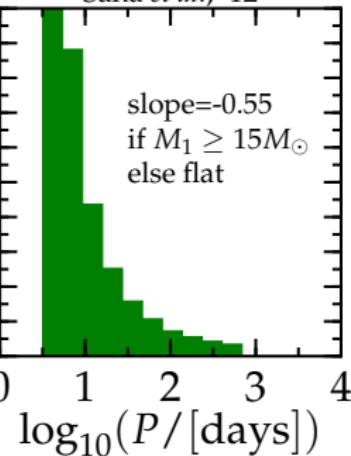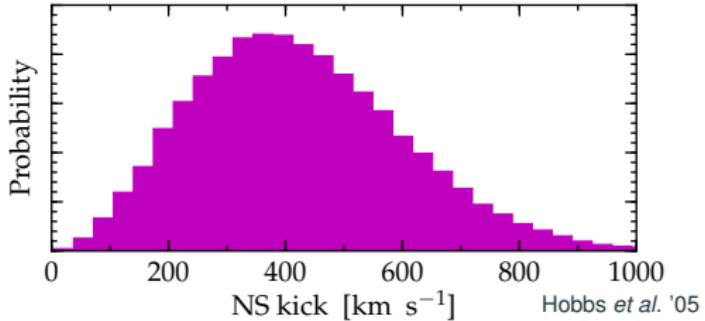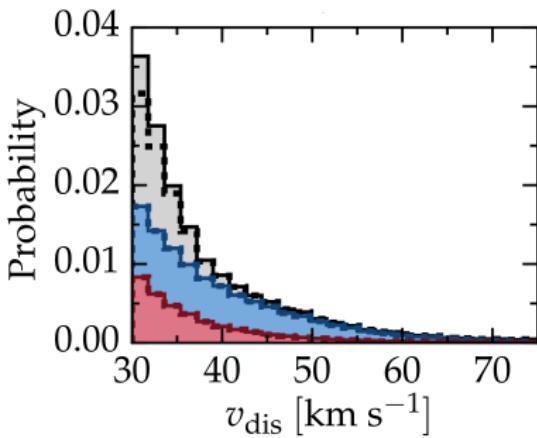
Maxwellian $\sigma_{v_{\text{kick}}} = 265 \, \text{km s}^{-1}$ + Fallback rescaling
(from Fryer *et al.* '12)

Velocity distribution: Runaways
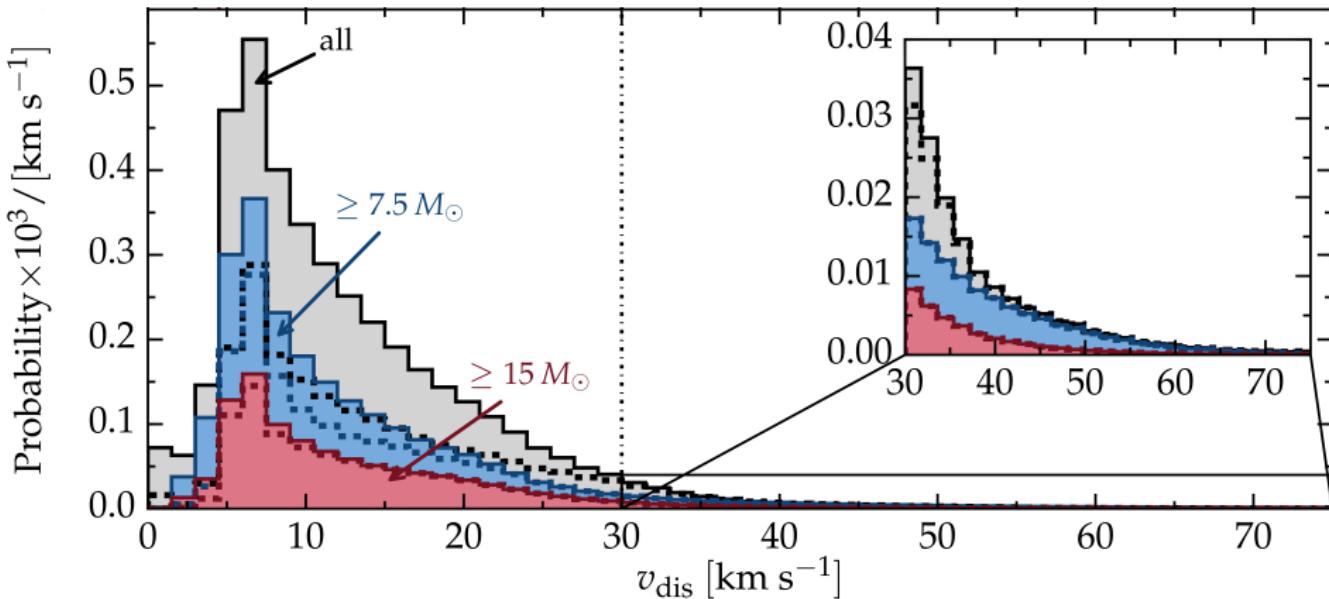
Velocity respect to the pre-explosion binary center of mass

Numerical results publicly available at:

Velocity distribution: Walkaways


Velocity respect to the pre-explosion binary center of mass

Numerical results publicly available at:
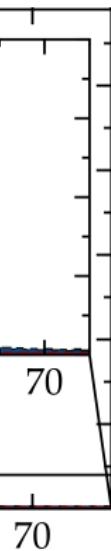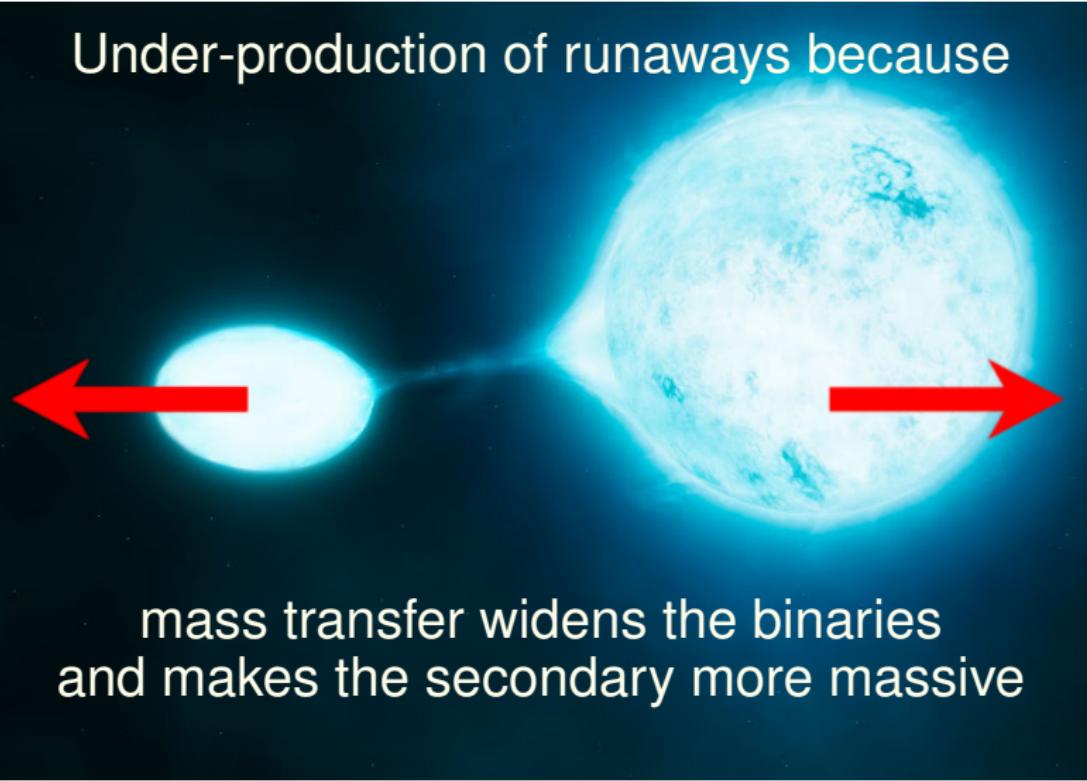
Velocity distribution: Walkaways

Under-production of runaways because
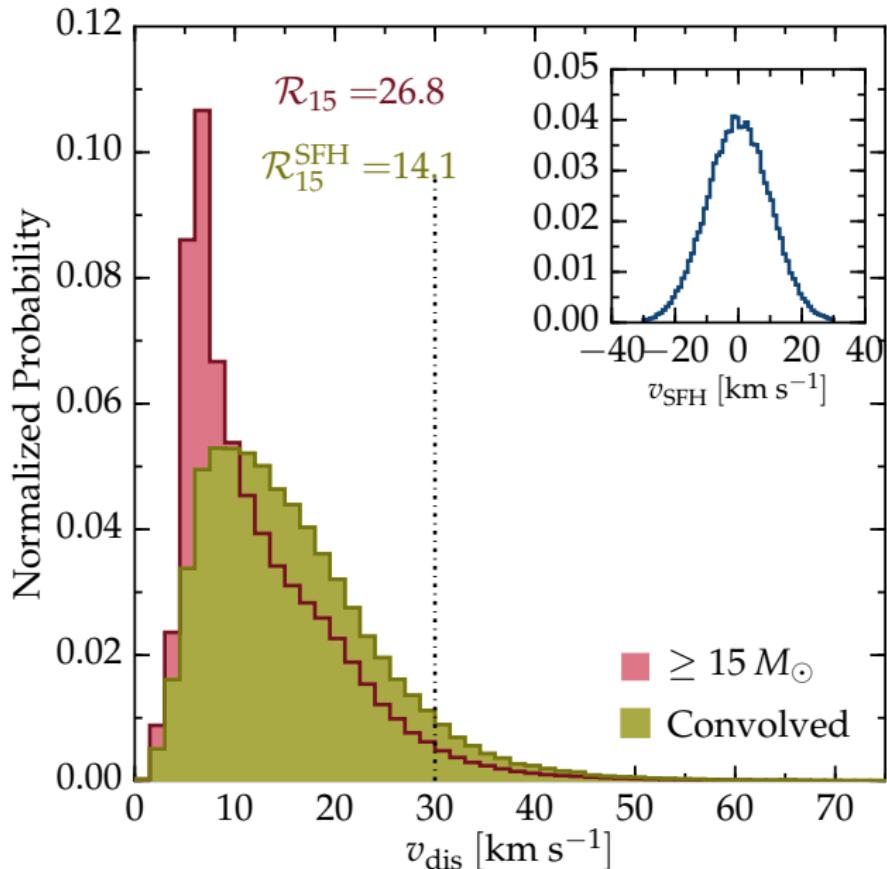
mass transfer widens the binaries
and makes the secondary more massive

Velocity respect to the pre-explosion binary center of mass

Numerical results publicly available at:

Renzo *et al.* 19b   http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66
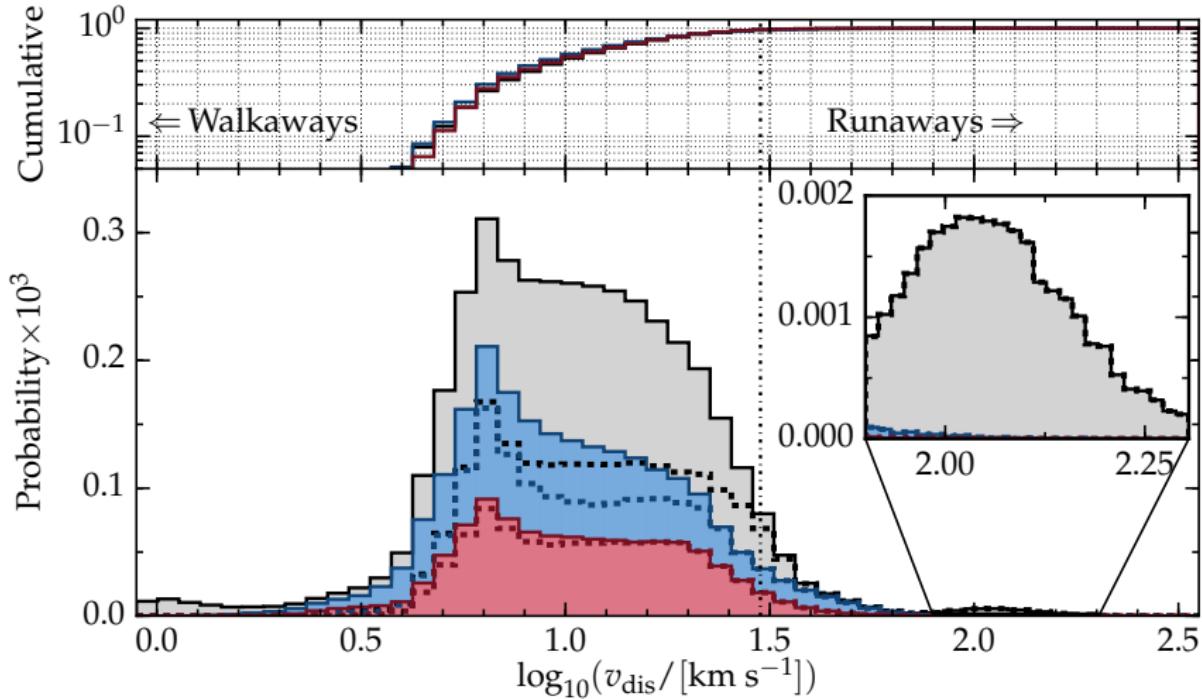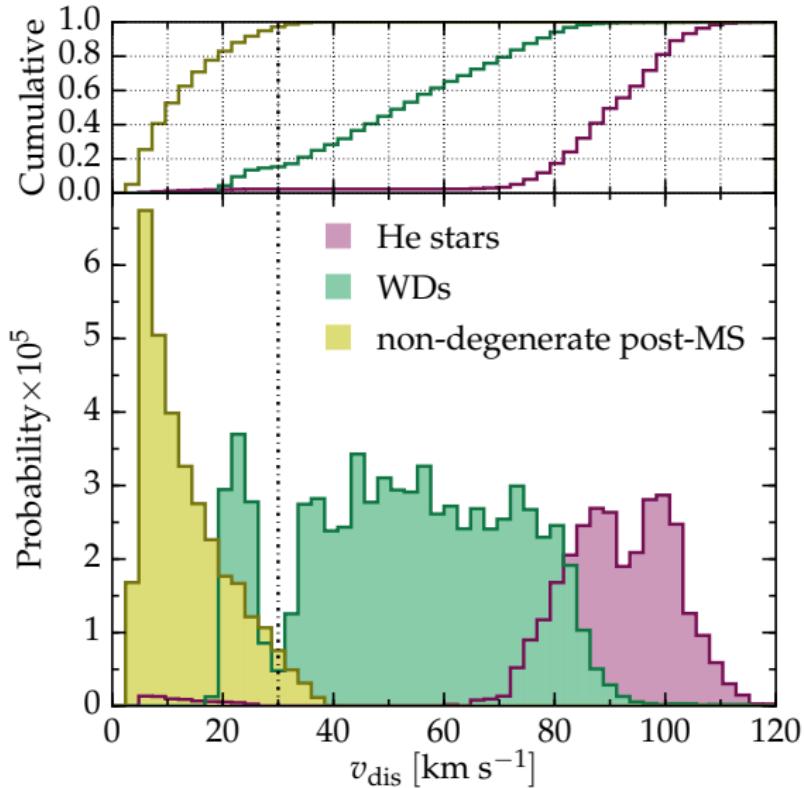
# Star forming region velocity dispersion
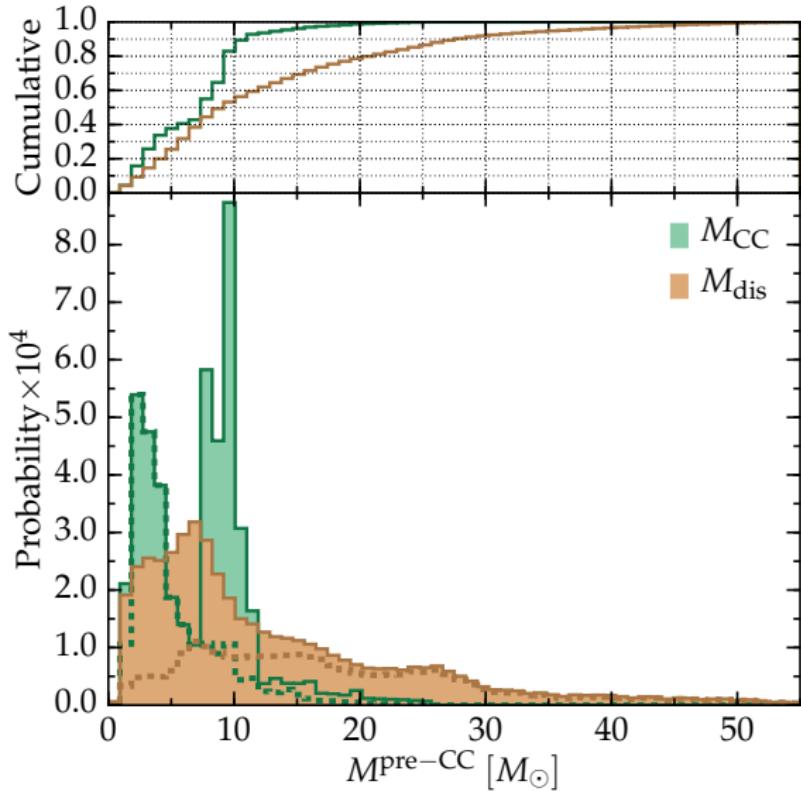
## Velocity distribution log-scale
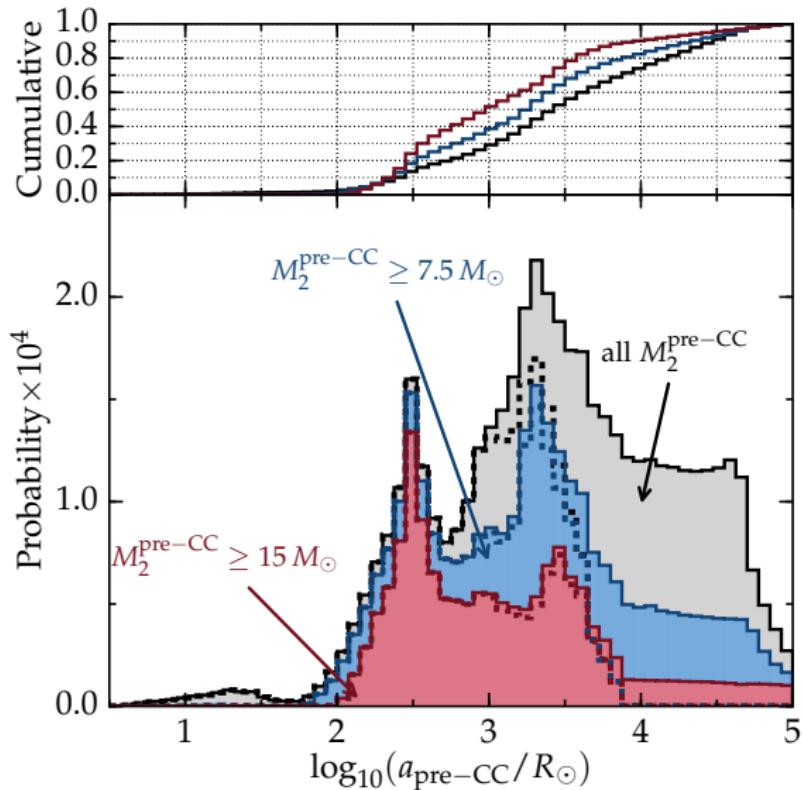
Velocity post-main sequence stars
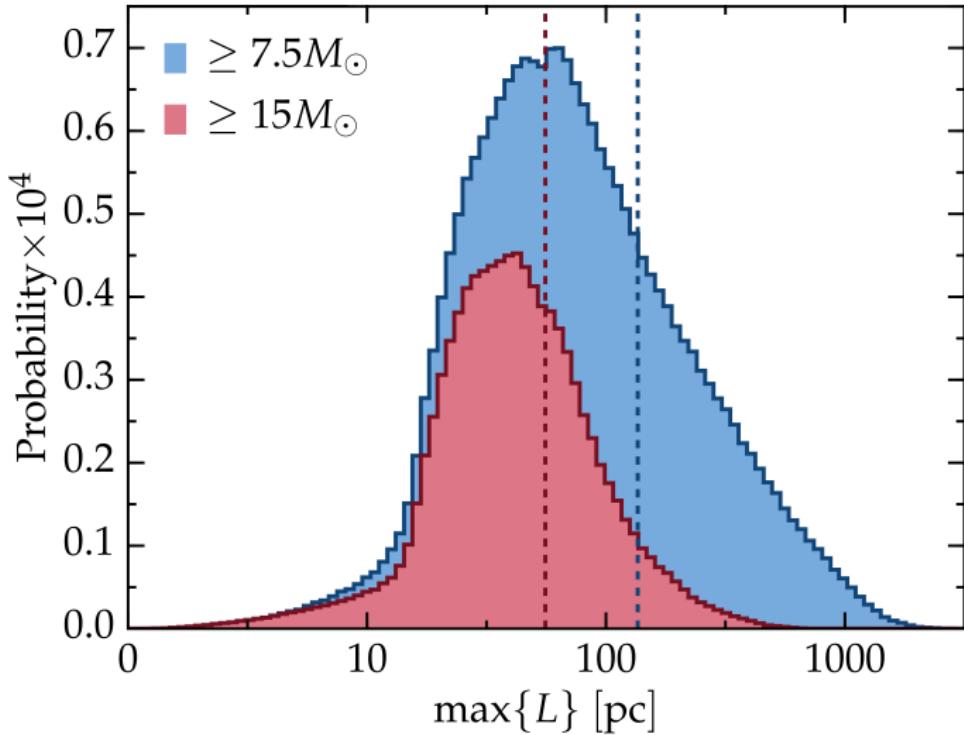
pre-CC mass distribution

# pre-CC separation distribution

How far do they get?

"Distance traveled"
(No potential well)