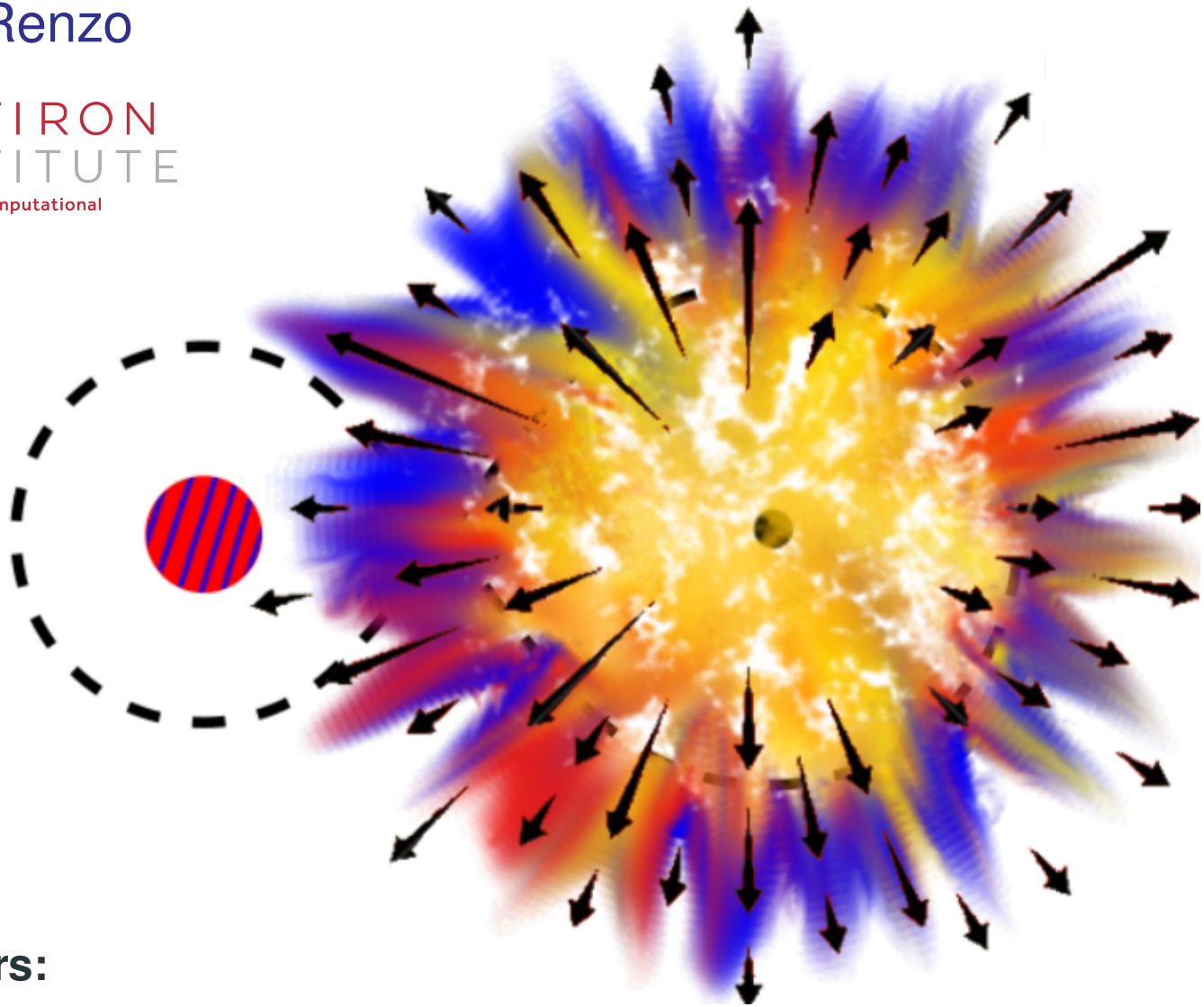
Massive “widowed” stars

Mathieu Renzo

FLATIRON INSTITUTE
Center for Computational Astrophysics

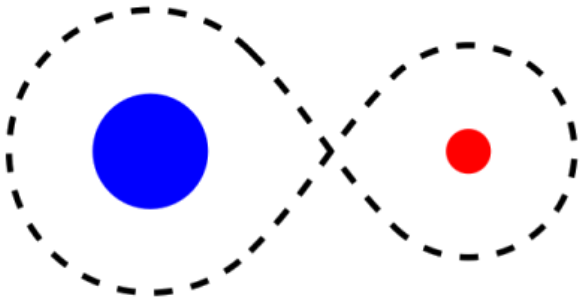


Collaborators:

E. Zapartas, S. E. de Mink, Y. Götberg, S. Justham, R. J. Farmer, R. G. Izzard, H. Sana, S. Toonen, E. Laplace, S. N. Shore, F. Evans, E. M. Rossi, L. Kaper, D.-F. Guo, V. van der Meij, D. J. Lennon, L. van Son, M. Cantiello, B. D. Metzger, ...

The most common massive binary evolution path

The most common binary evolution path

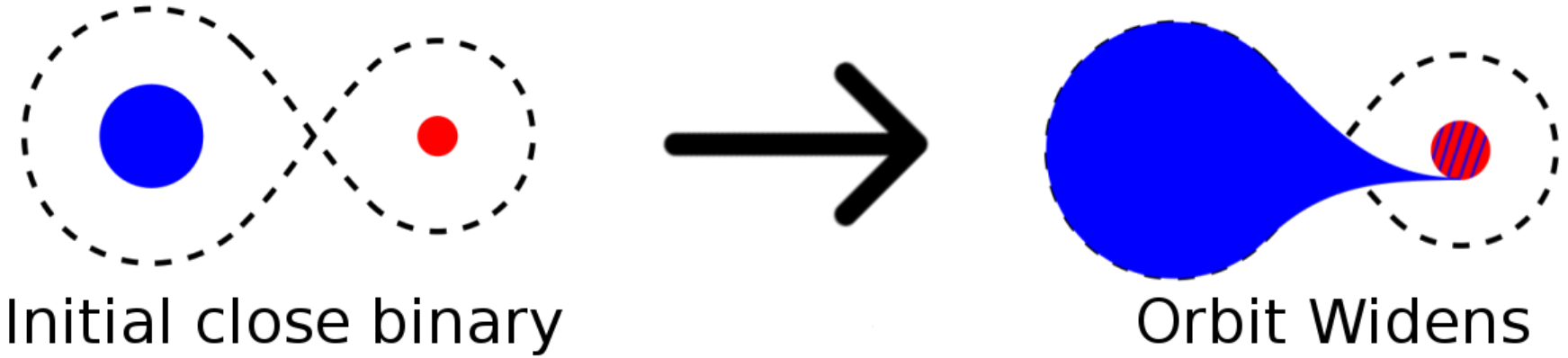


Initial close binary

see outreach movie at

https://www.youtube.com/watch?v=qmfJNI0PXbo

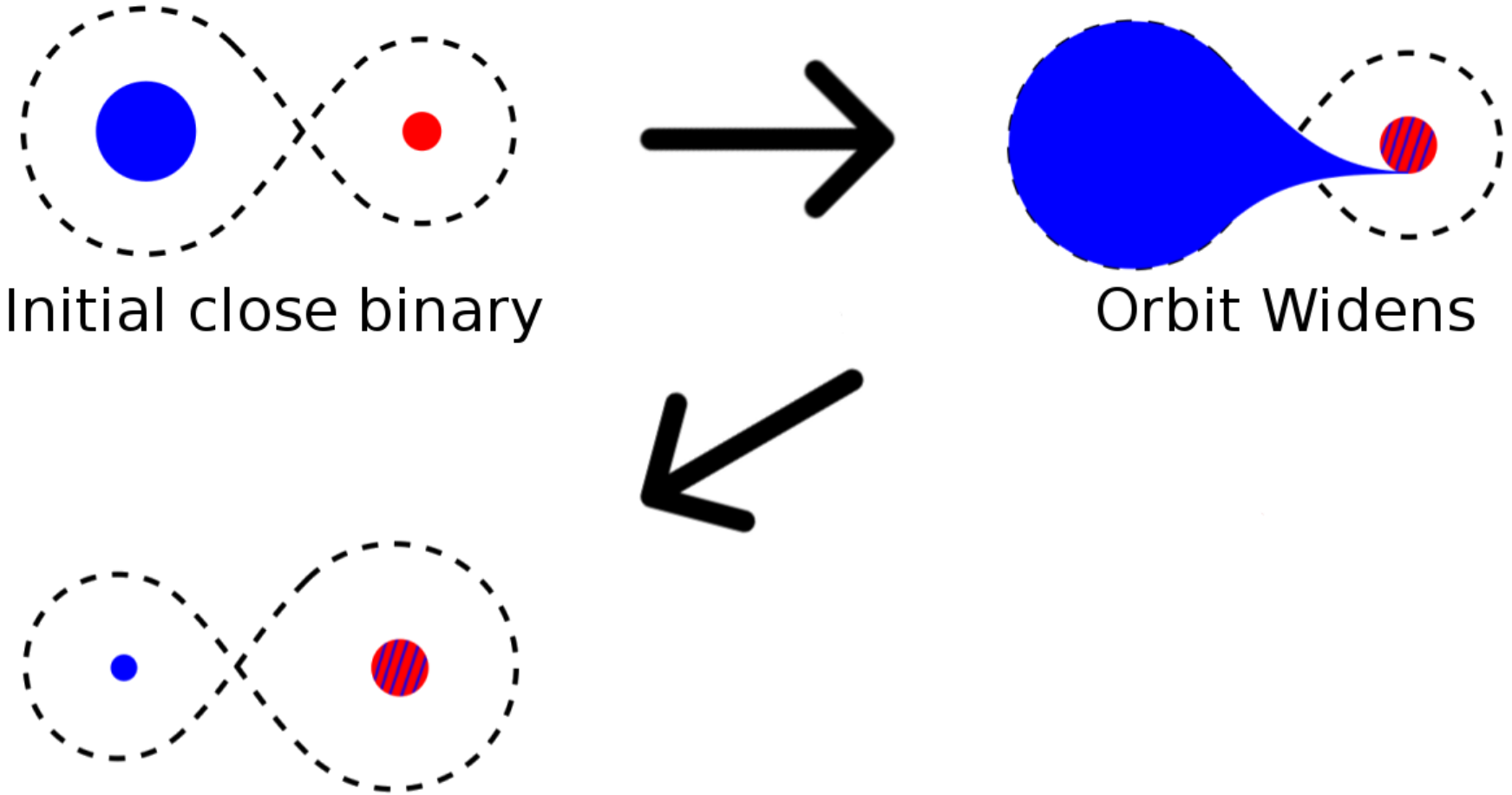
The most common binary evolution path



see outreach movie at

https://www.youtube.com/watch?v=qmfJNI0PXbo

The most common binary evolution path



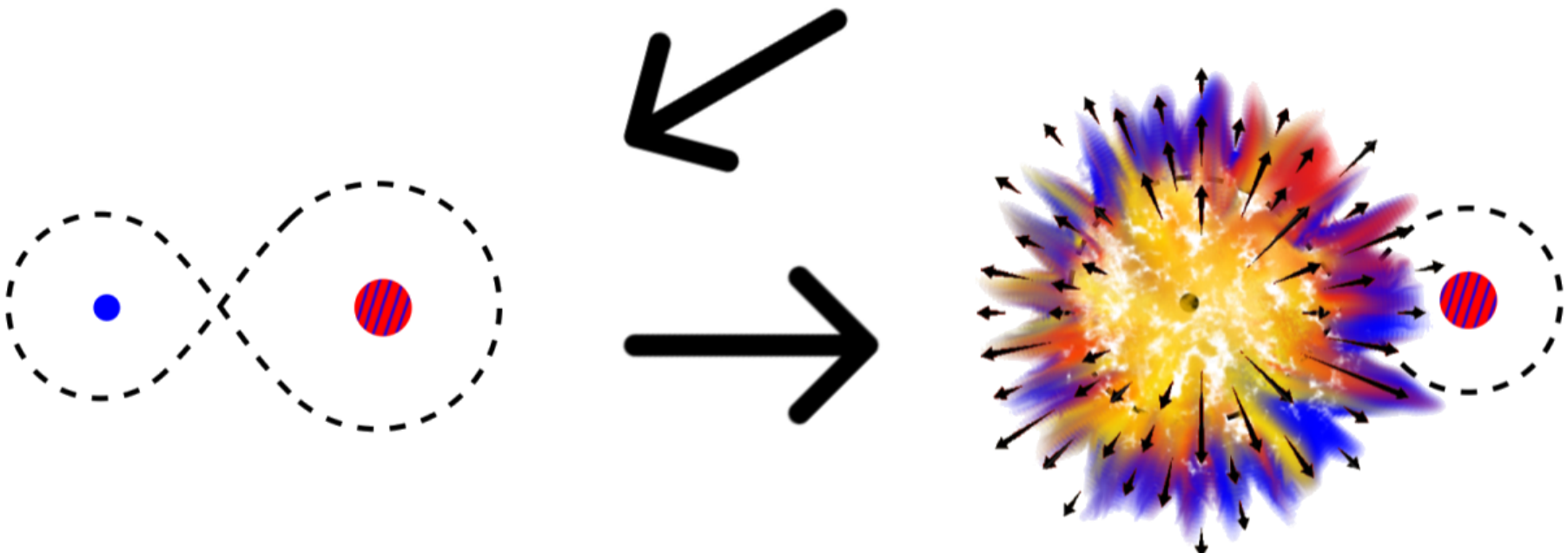
see outreach movie at

https://www.youtube.com/watch?v=qmfJNI0PXbo

The most common binary evolution path

Initial close binary

Orbit Widens



Stripped star + Accretor

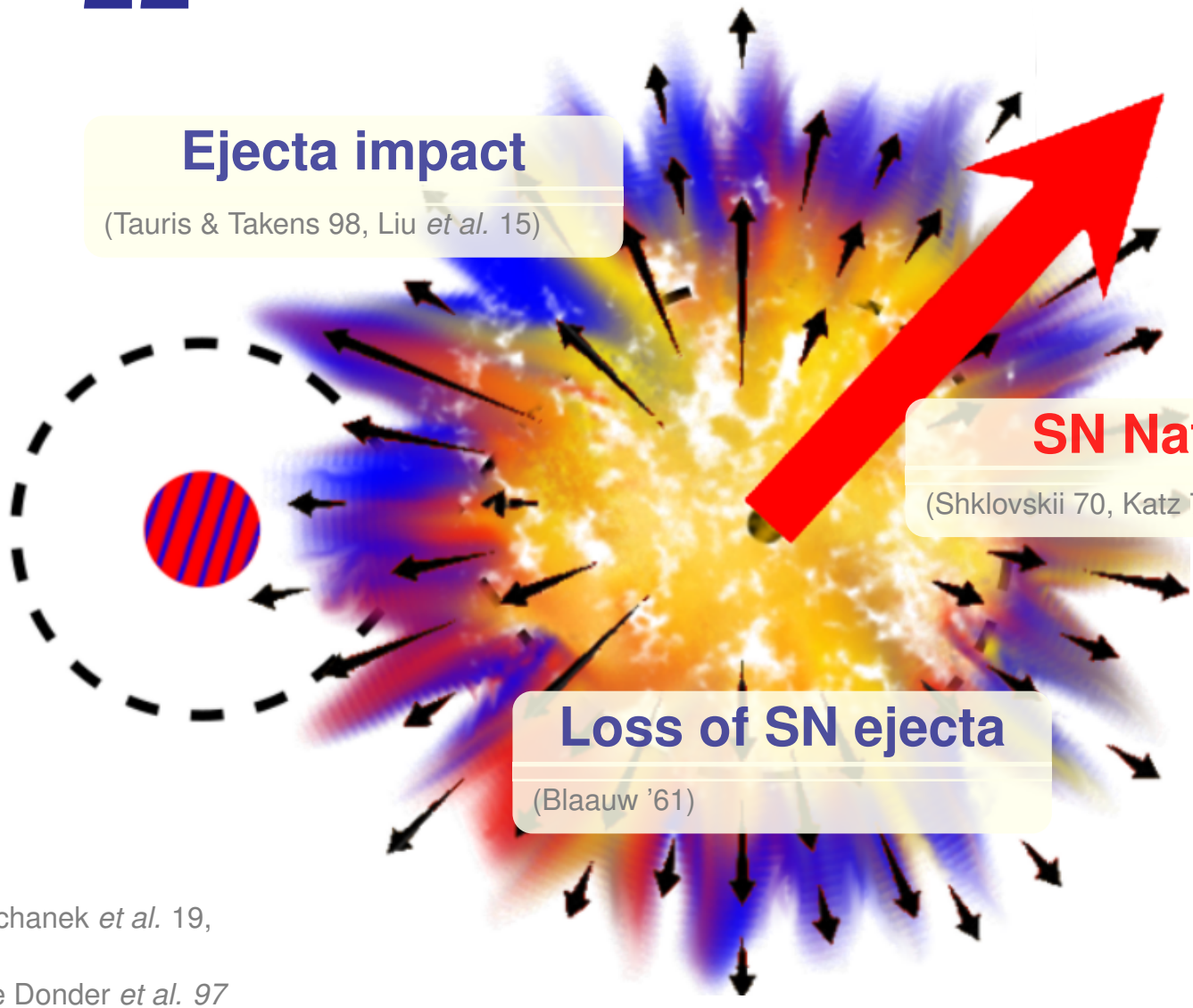
Core Collapse & Disruption

see outreach movie at

https://www.youtube.com/watch?v=qmfJNI0PXbo

SN natal kicks disrupt the binary

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



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

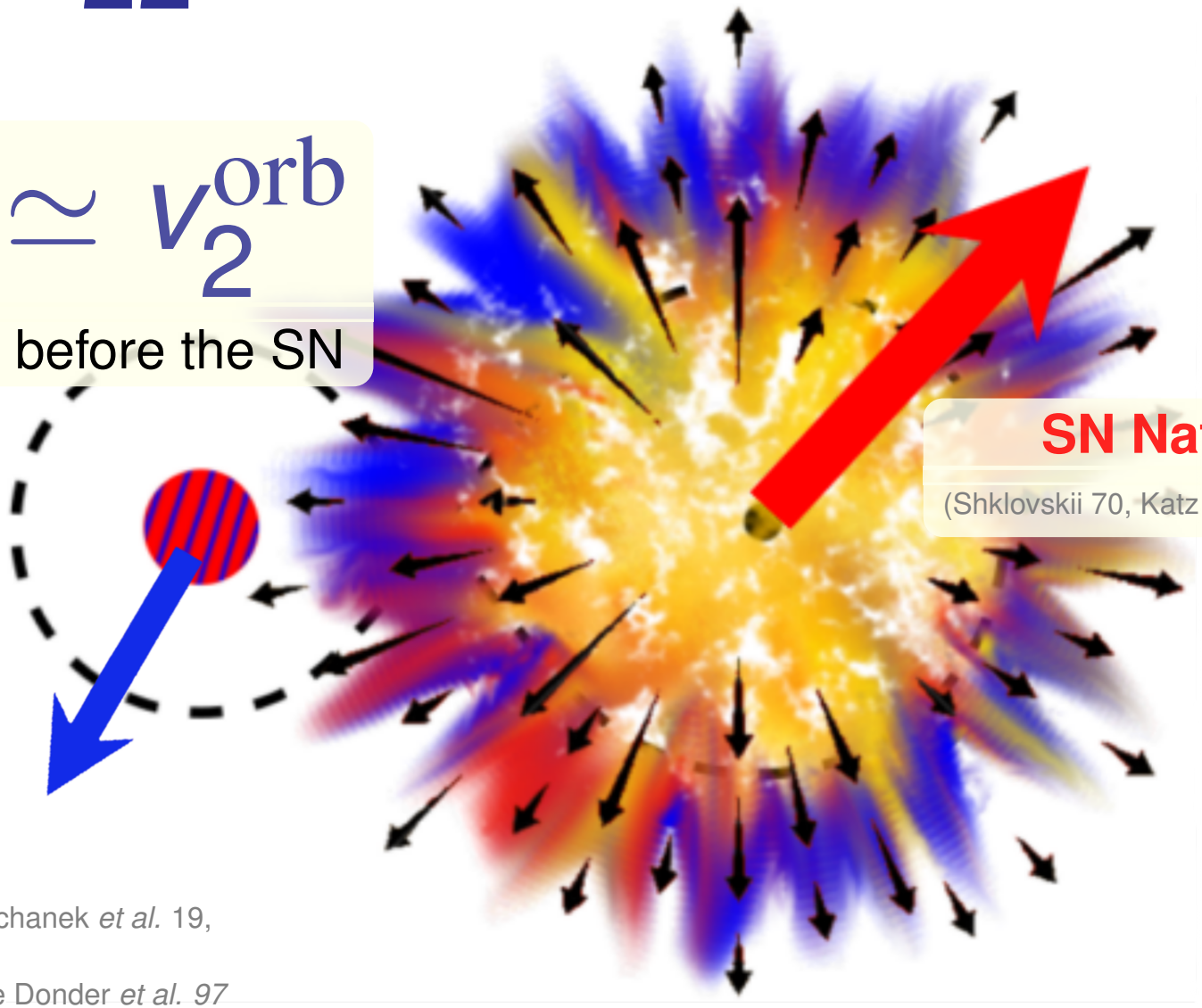
Eldridge *et al.* 11, De Donder *et al. 97*

Kicks do not change the velocity of the widowed star

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

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

before the SN



SN Natal kick

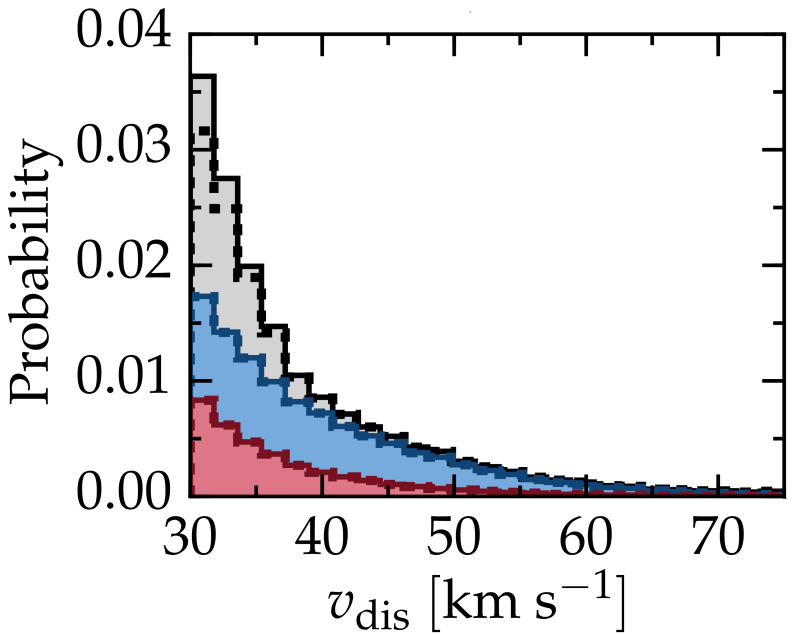
(Shklovskii 70, Katz 75, Janka 13, 17)

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

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

Kinematics of the widowed stars

Widowed stars can be *runaways*...

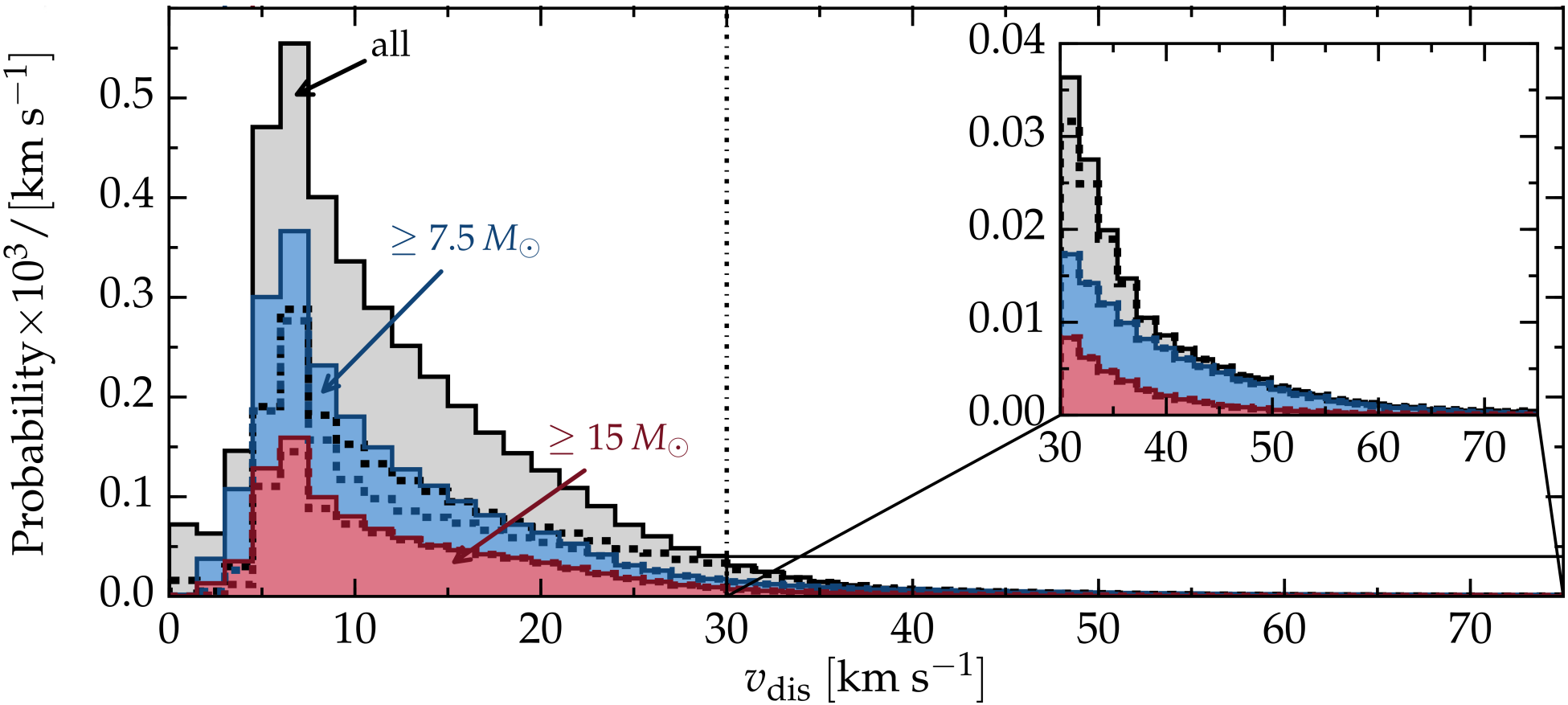


Velocity respect to the pre-explosion binary center of mass

Numerical results publicly available at:

Renzo *et al.* 19b, Renzo & Zapartas 20 http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

...but most widowed stars are only *walkaways*

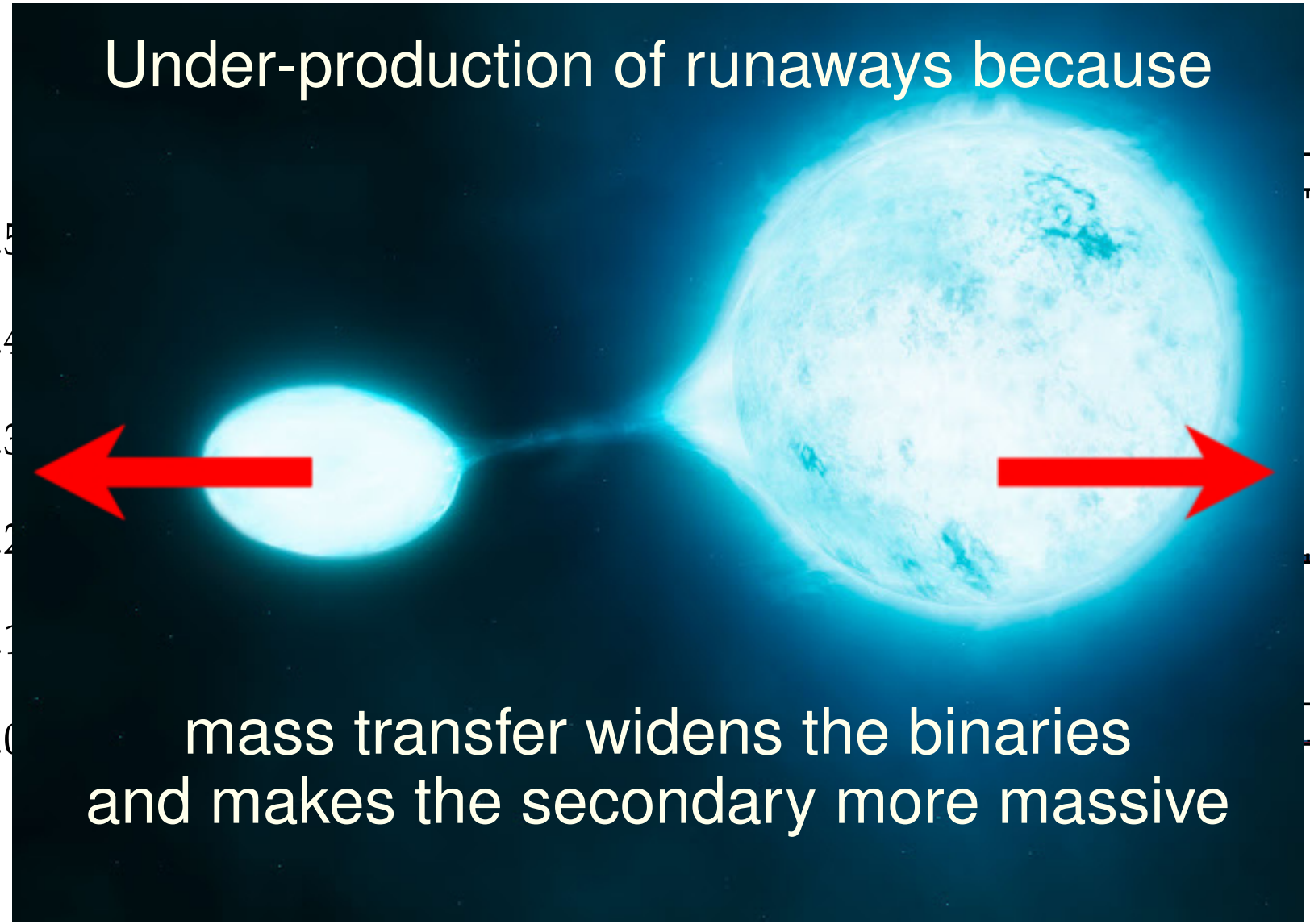


Velocity respect to the pre-explosion binary center of mass

Numerical results publicly available at:

Renzo *et al.* 19b, Renzo & Zapartas 20 http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

...but most widowed stars are only *walkaways*



Probability $\times 10^3$ / [km s^{-1}]

0.5
0.4
0.3
0.2
0.1
0.0

70
70

Velocity respect to the pre-explosion binary center of mass

Numerical results publicly available at:

Renzo *et al.* 19b, Renzo & Zapartas 20 http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

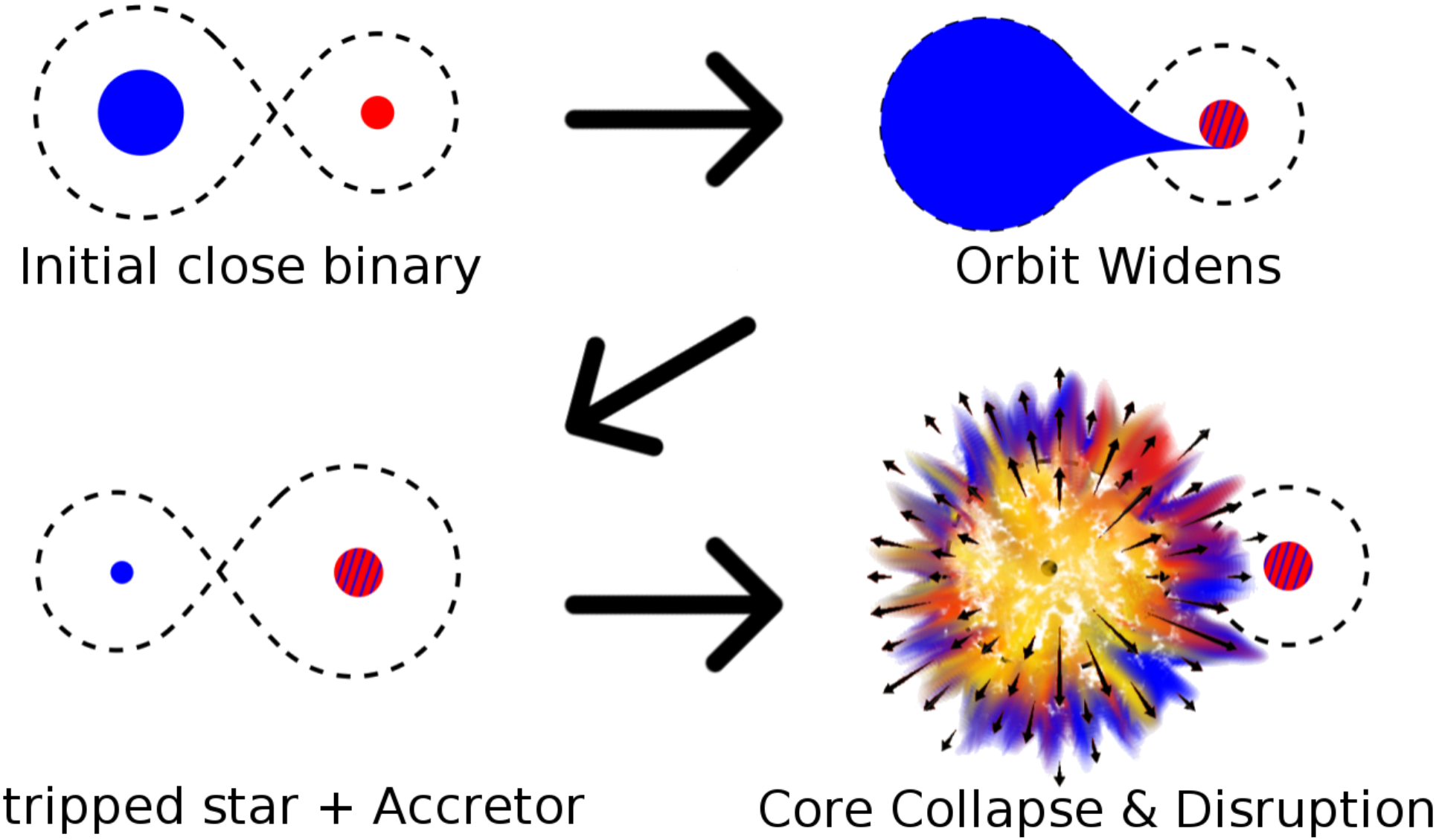
Can widowed stars escape the Galaxy?

Some hyper-velocity stars come from the disk

Effective definition $v_{\rm galactic} \gtrsim 400\,{\rm km\ s^{-1}}$

Hills 1988, Brown *et al.* 2005, Brown *et al.* 2015, Kosopov *et al.* 2019, Evans, MR, Rossi 2020 arXiv:2006.00849

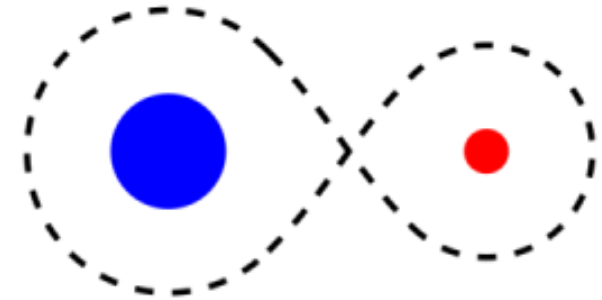
Can massive binaries produce HVS?



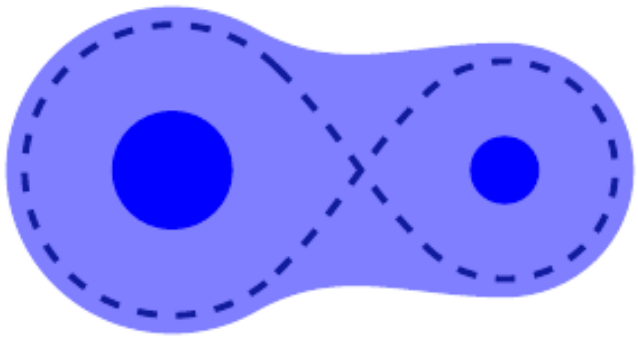
Evans, MR, Rossi 20, arXiv:2006.00849, Renzo *et al.* 2019 see also Przybilla *et al.* 2008b, Eldridge *et al.* 2011, Irrgang *et al.* 2018

Can massive binaries produce HVS? Yes...

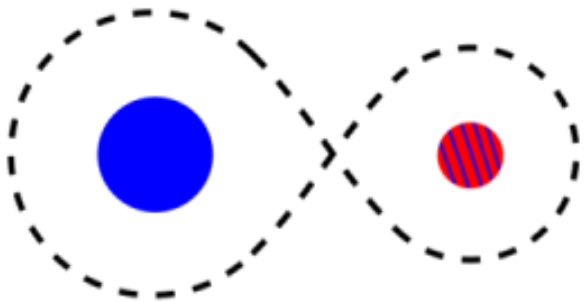
... in a less common evolutionary path

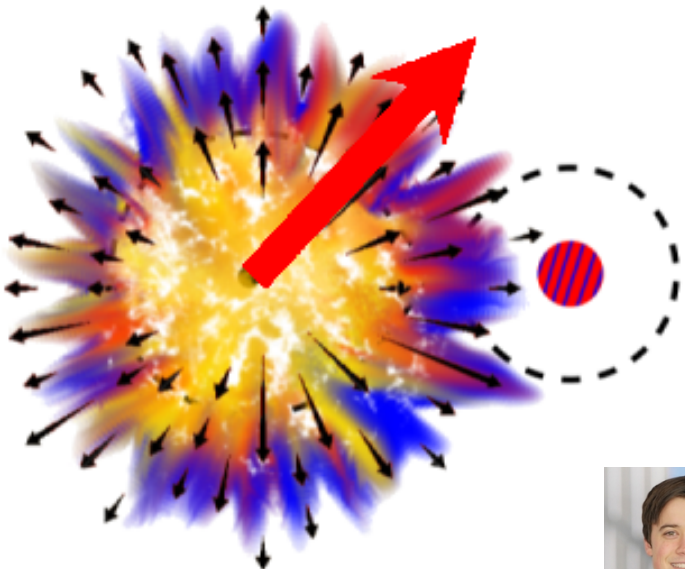


Initial close binary



Orbit shrinks





Large BH kick

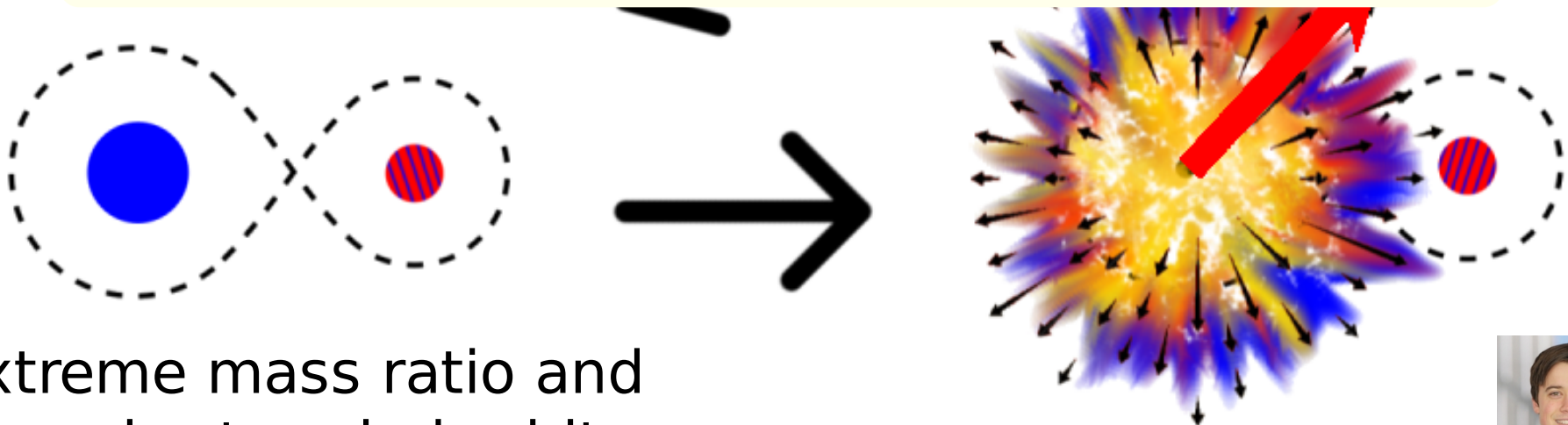
Extreme mass ratio and
very short period orbit

Evans, MR, Rossi 20, arXiv:2006.00849, Renzo *et al.* 2019 see also Przybilla *et al.* 2008b, Eldridge *et al.* 2011, Irrgang *et al.* 2018

Can massive binaries produce HVS? Yes...

... in a less common evolutionary path

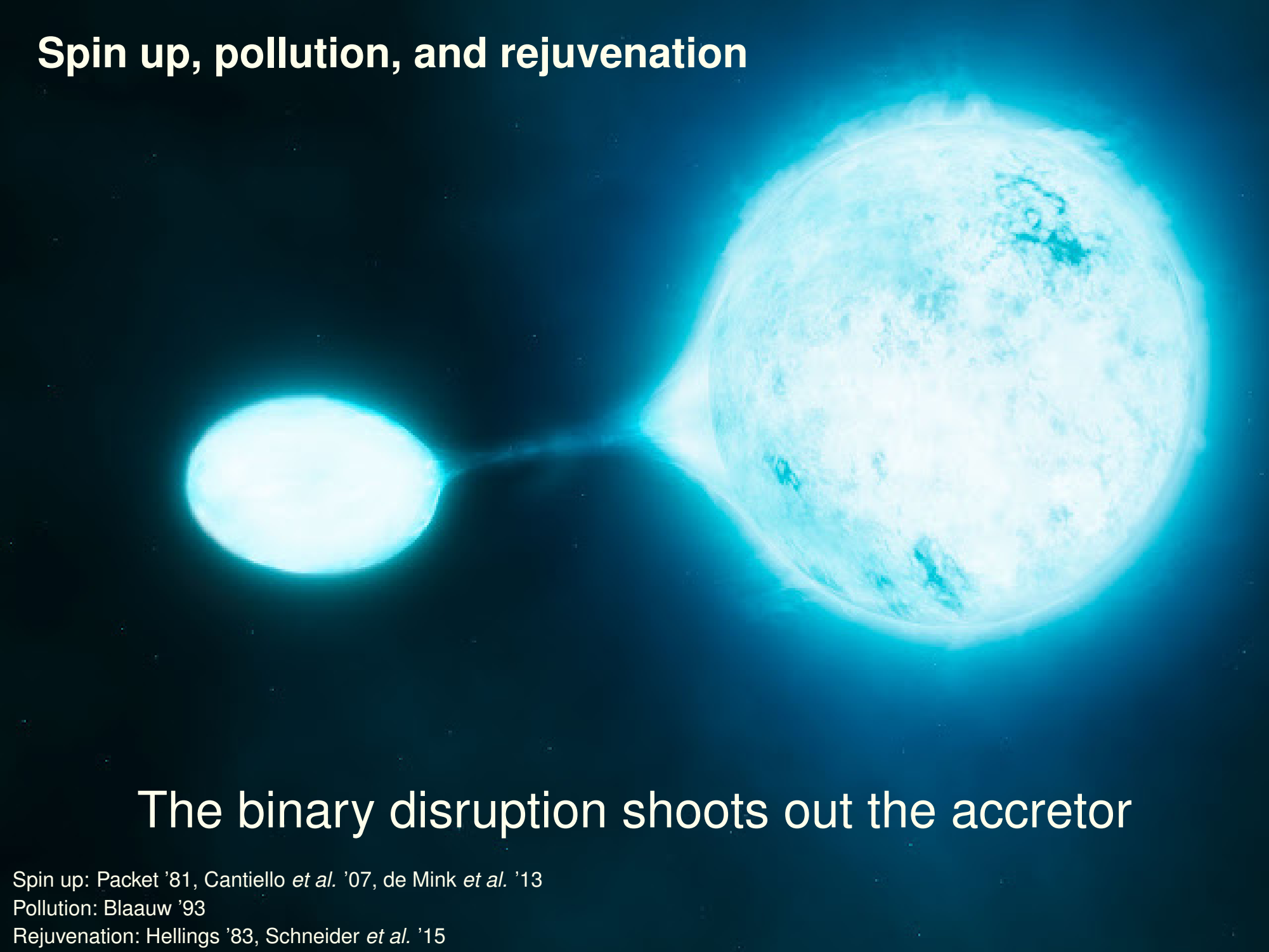
... and only for extreme choices of free parameters for both common envelope *and* BH kicks



Evans, MR, Rossi 20, arXiv:2006.00849, Renzo *et al.* 2019 see also Przybilla *et al.* 2008b, Eldridge *et al.* 2011, Irrgang *et al.* 2018

How do widowed stars look?

Spin up, pollution, and rejuvenation



The binary disruption shoots out the accretor

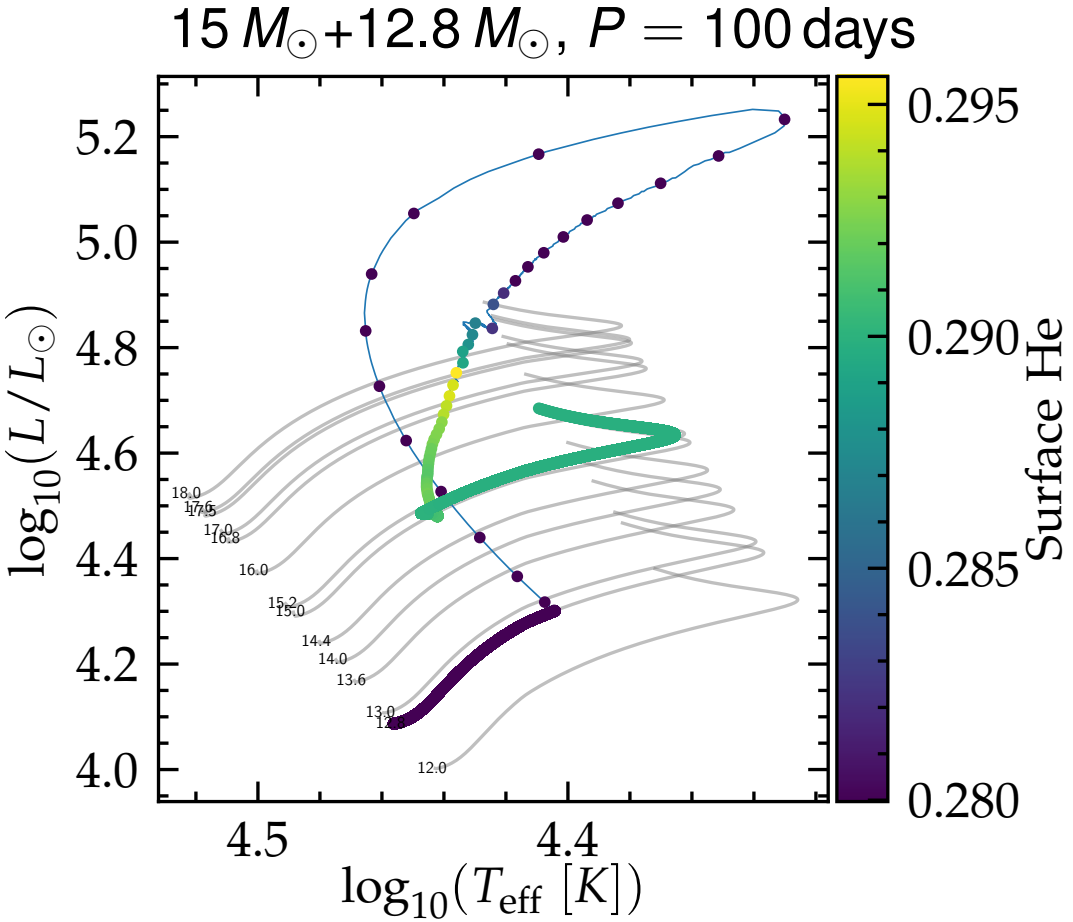
Spin up: Packet ’81, Cantiello *et al.* ’07, de Mink *et al.* ’13
Pollution: Blaauw ’93
Rejuvenation: Hellings ’83, Schneider *et al.* ’15

Work in progress: Modeling the accreting star

Renzo *et al.*, in prep.,

see also Podsiadlowski 2006, Hirai *et al.* 2018

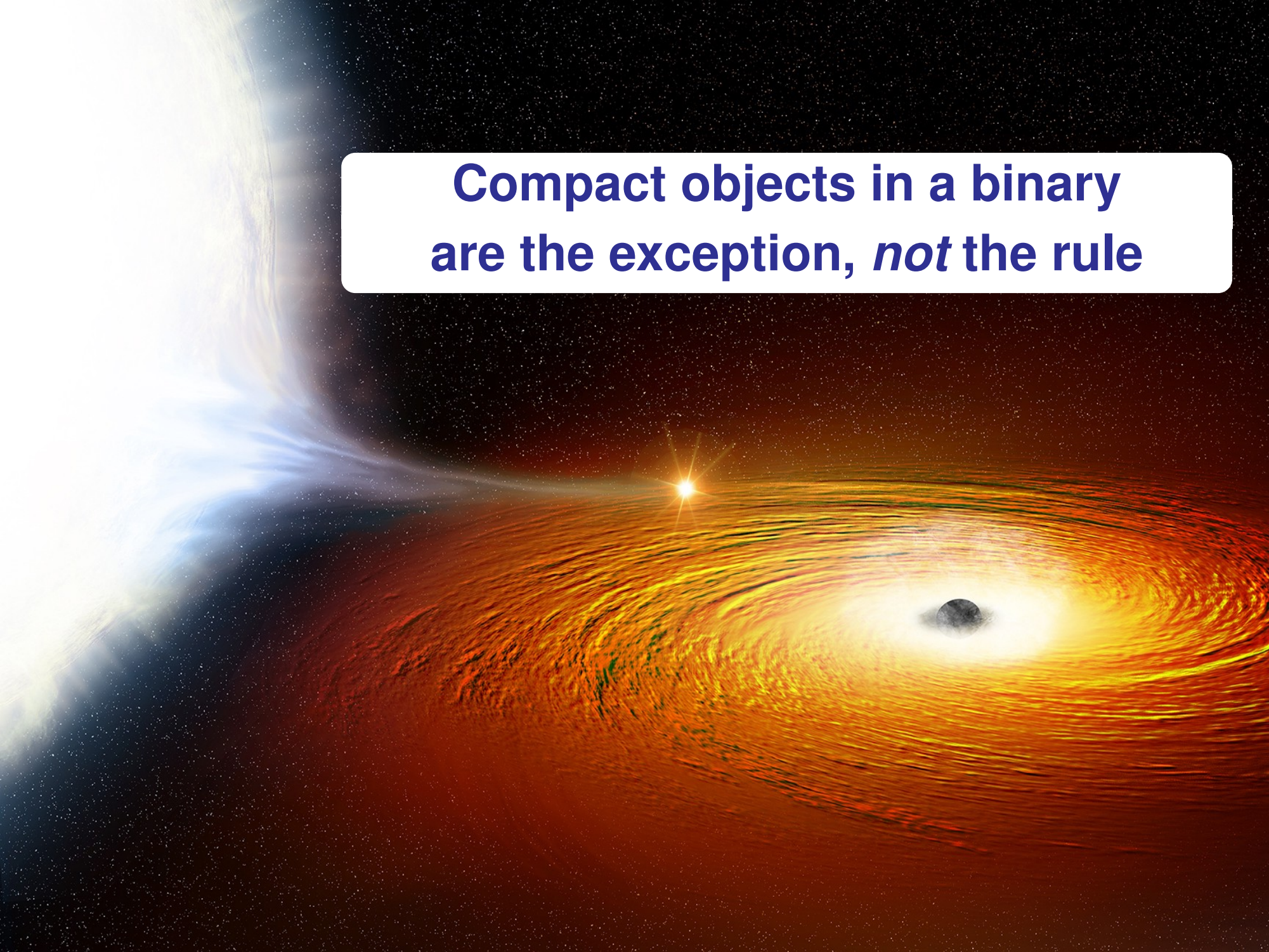
MESA



Challenging numerical stability

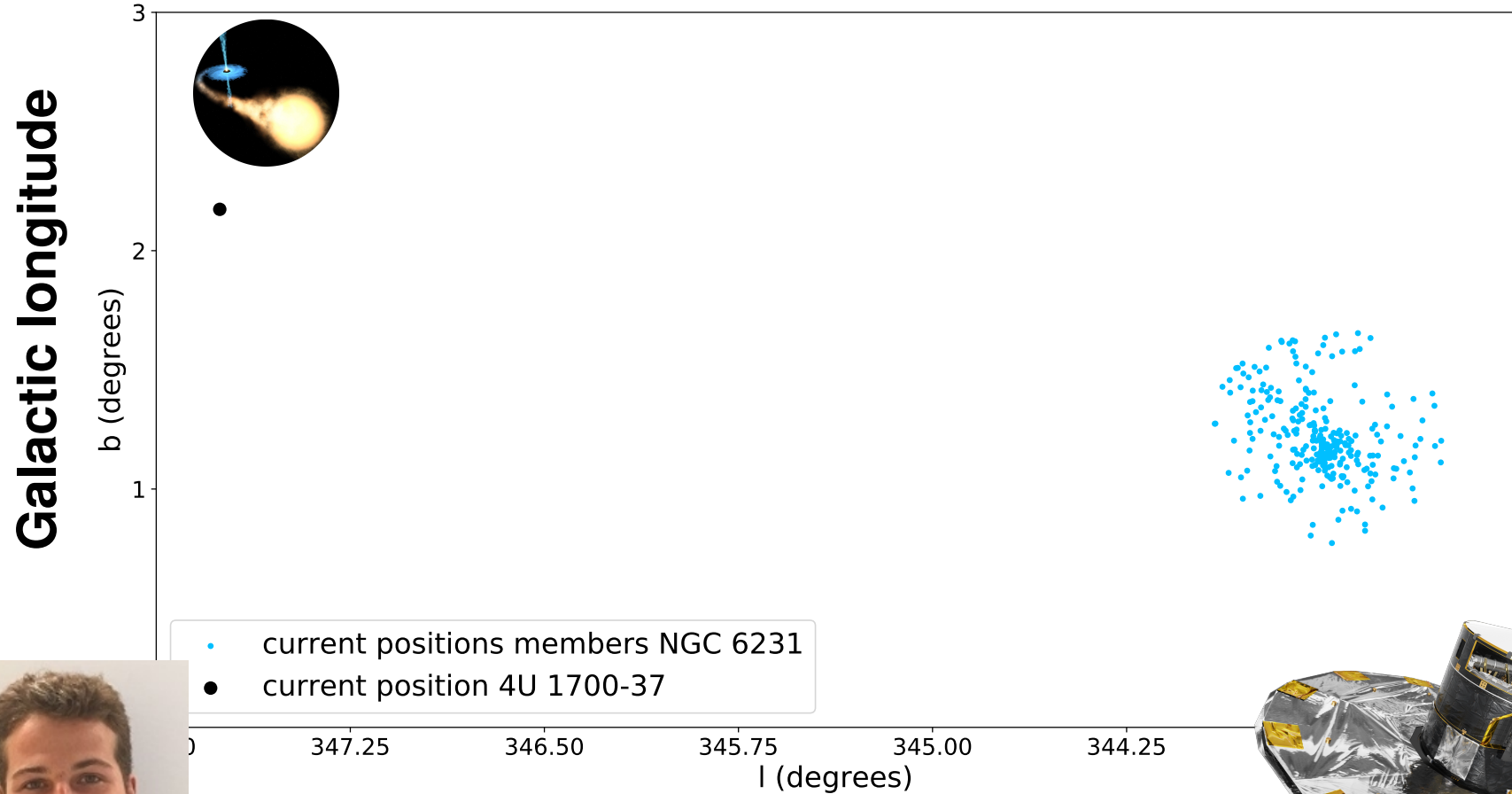
Many physical unknowns

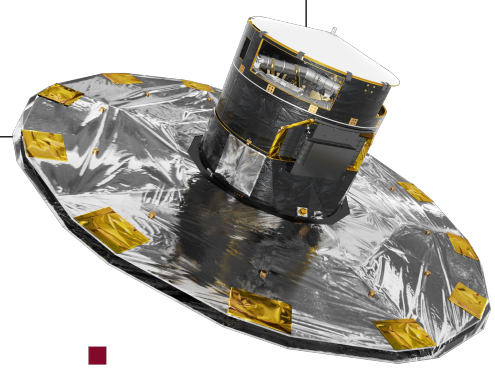
Binaries surviving the SN


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

Preliminary: The case of 4U1700-37

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

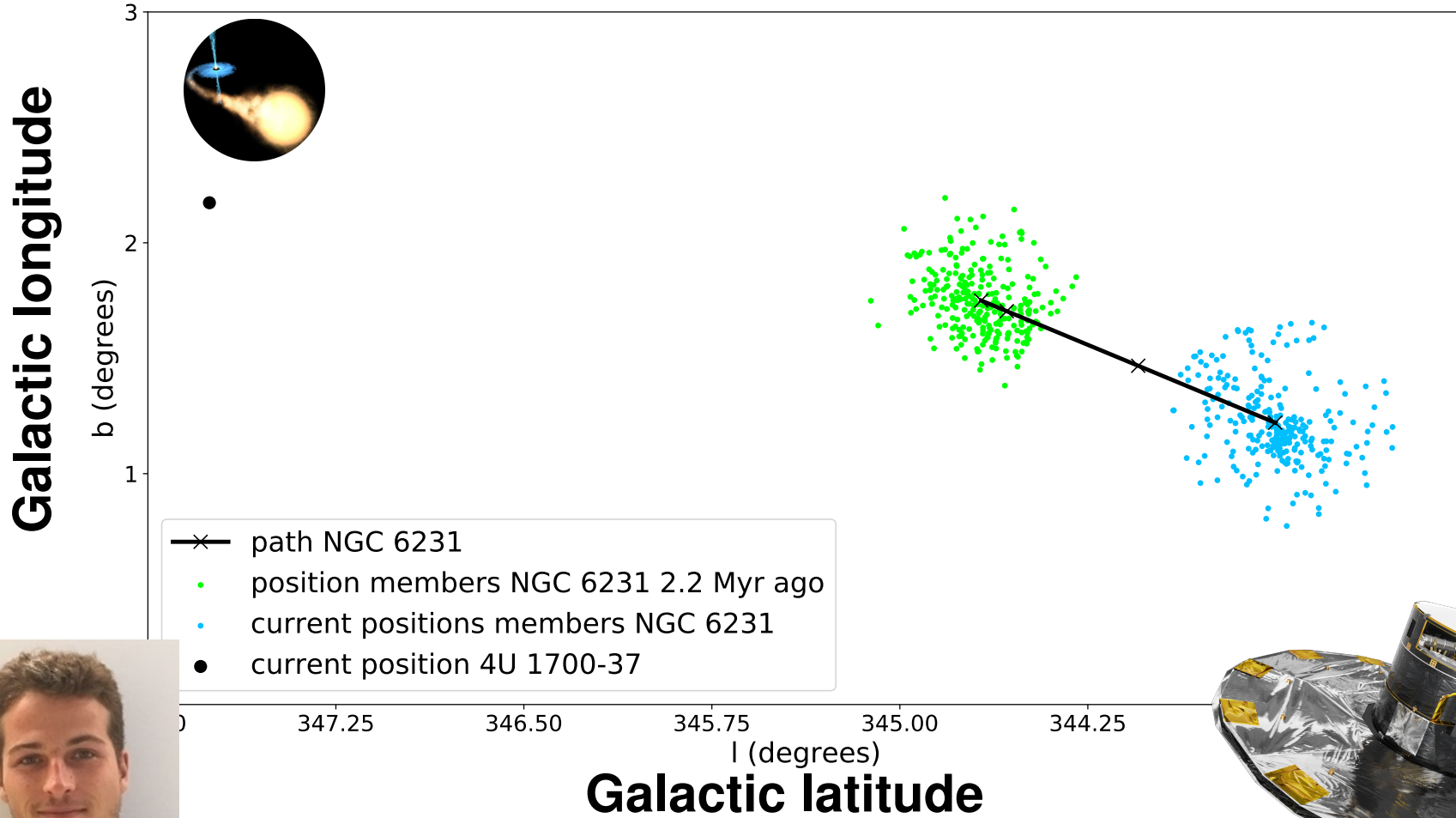


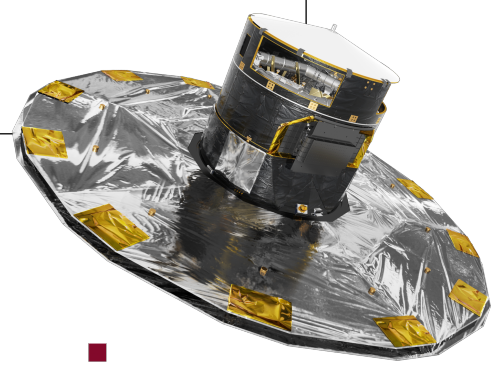


van der Meij, D.-F. Guo, *et al.* (incl. MR), in prep.

Preliminary: *Gaia* corroborates cluster of origin

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

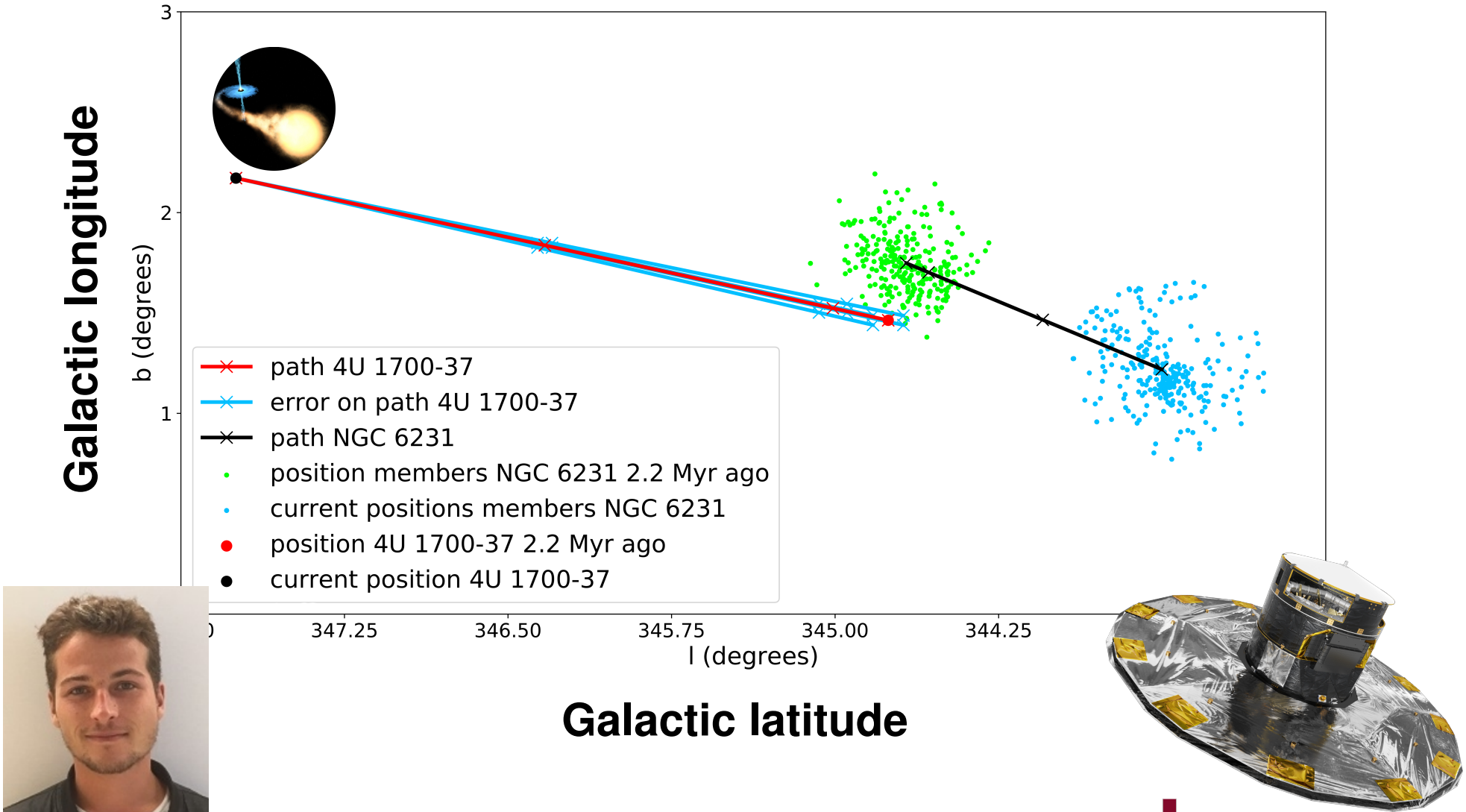




van der Meij, D.-F. Guo, *et al.* (incl. MR), in prep.

Preliminary: Cluster of origin constrains past evolution

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



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

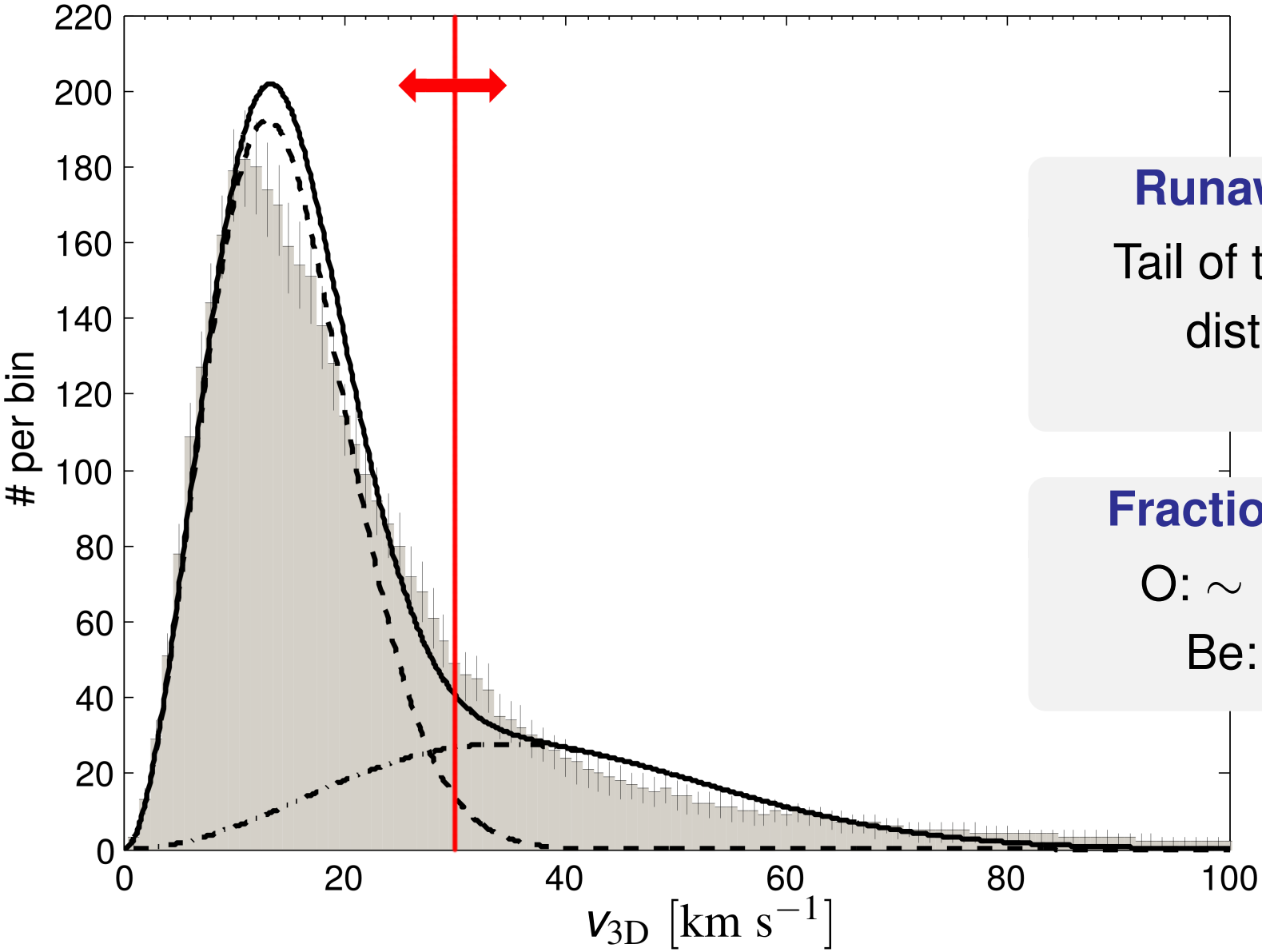
Conclusions

Take home points

- Most massive binaries disrupted at 1st core-collapse
- “Widowed” stars modified by binary interactions
- Most are slow moving walkaway, some are runaway
- Unlikely that they contribute to HVS population

Backup slides

What is a runaway star?



Runaway stars

Tail of the velocity distribution

Blaauw 61

Fraction per type

O: $\sim 10 - 20\%$

Be: $\sim 13\%$

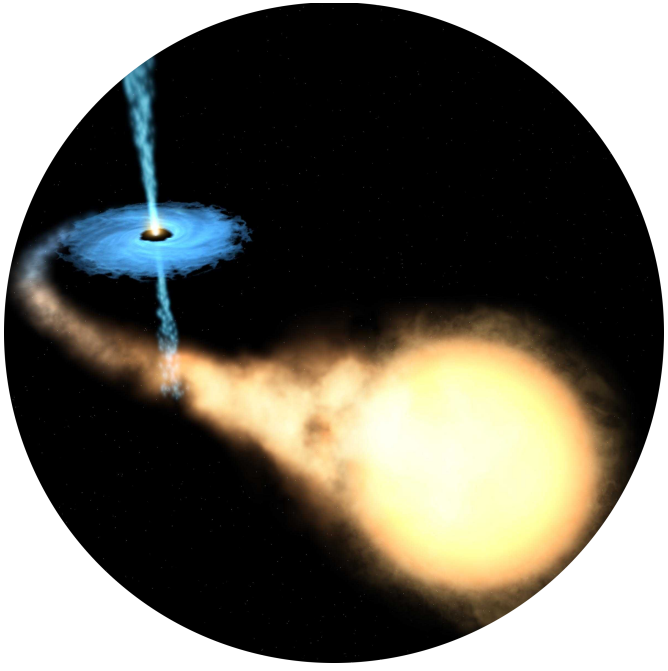
Hipparcos velocity distribution for young ($\lesssim 50$ Myr) stars, Tetzlaff *et al.* 11,

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

Do BHs receive kicks ?

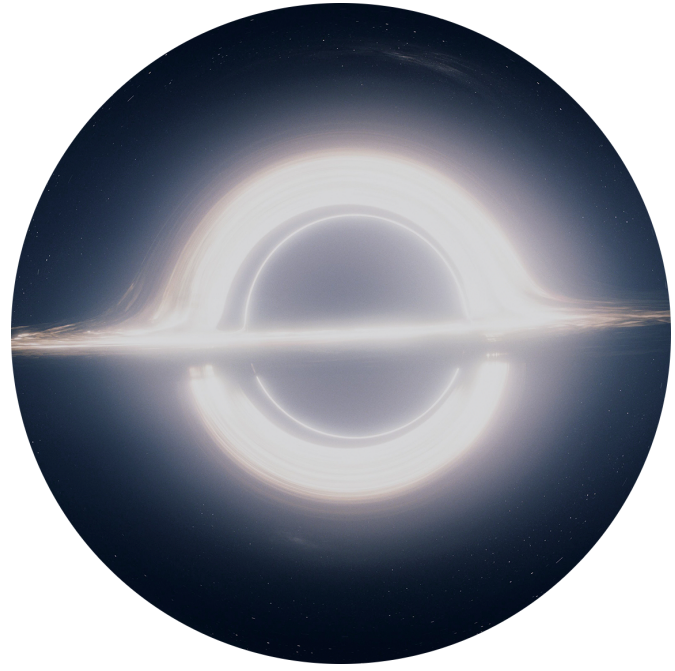
NO

$\Rightarrow$ most remain together with their widowed companion



YES

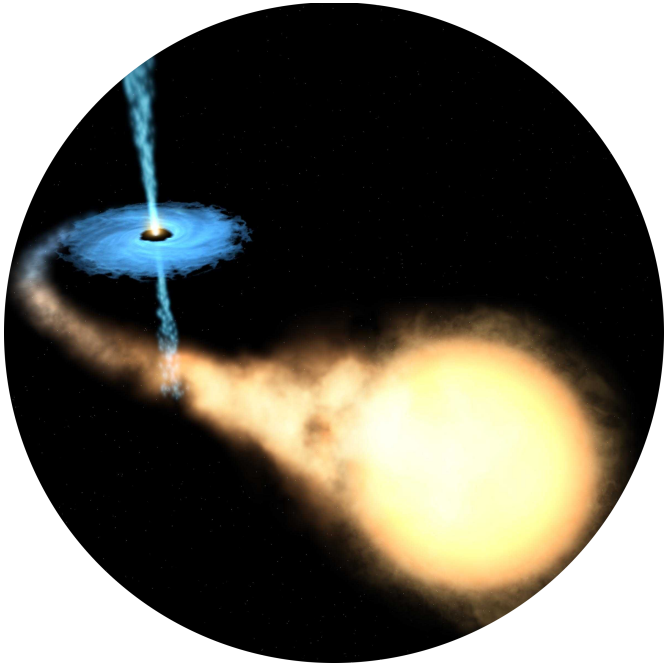
$\Rightarrow$ most are single and we can't see them...



Do BHs receive kicks ?

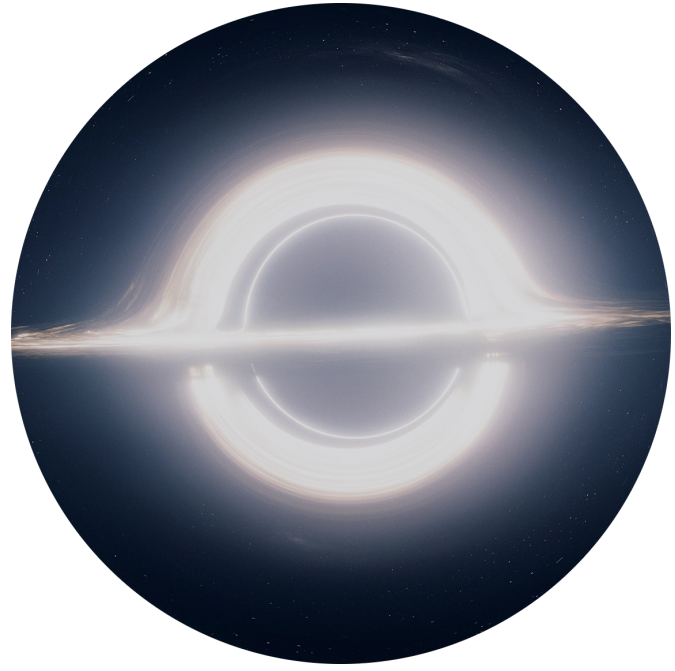
NO

⇒ most remain together with their widowed companion



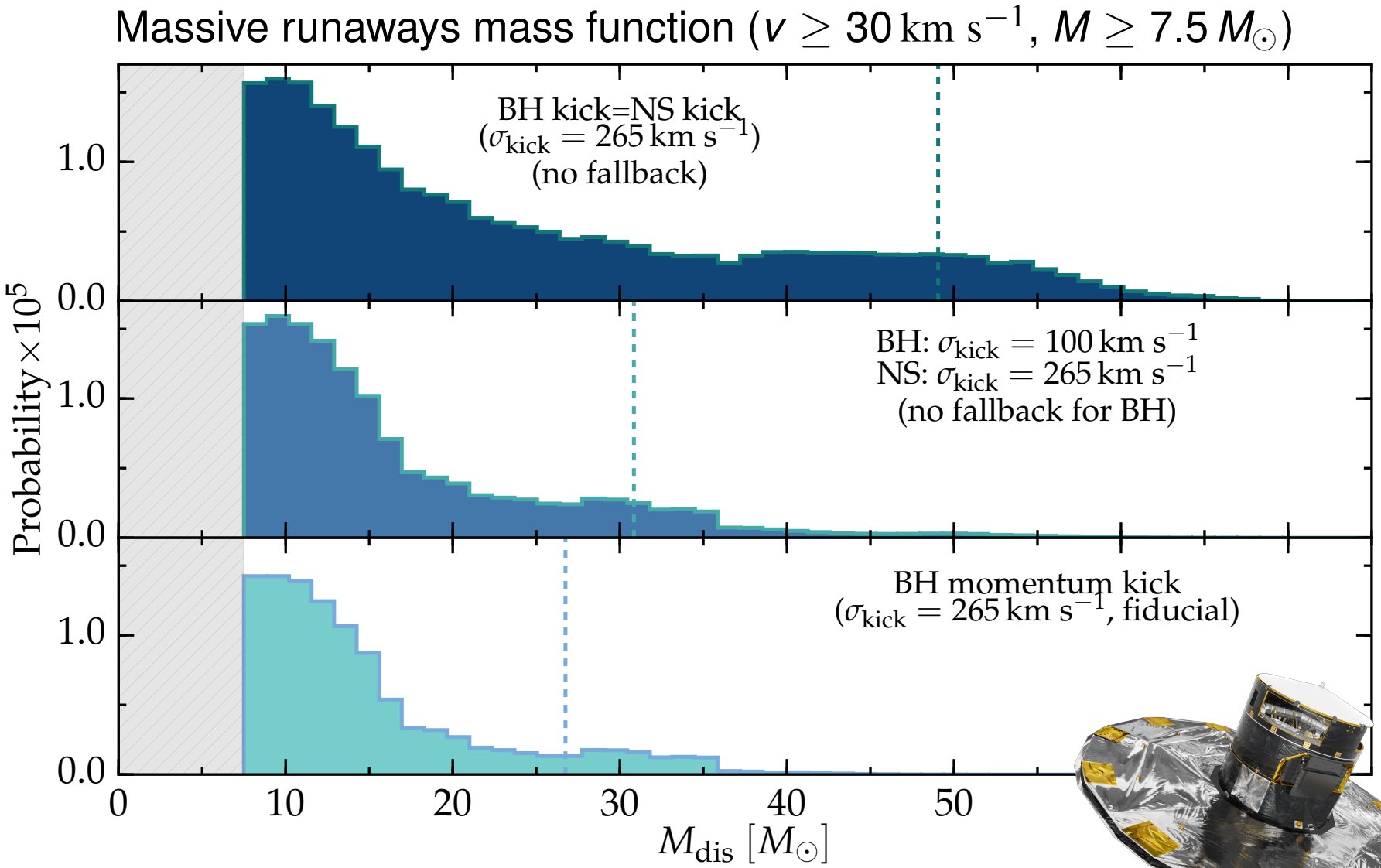
YES

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



...but we can see the "widowed" companions

A way to constrain BH kicks with Gaia



Numerical results publicly available at:

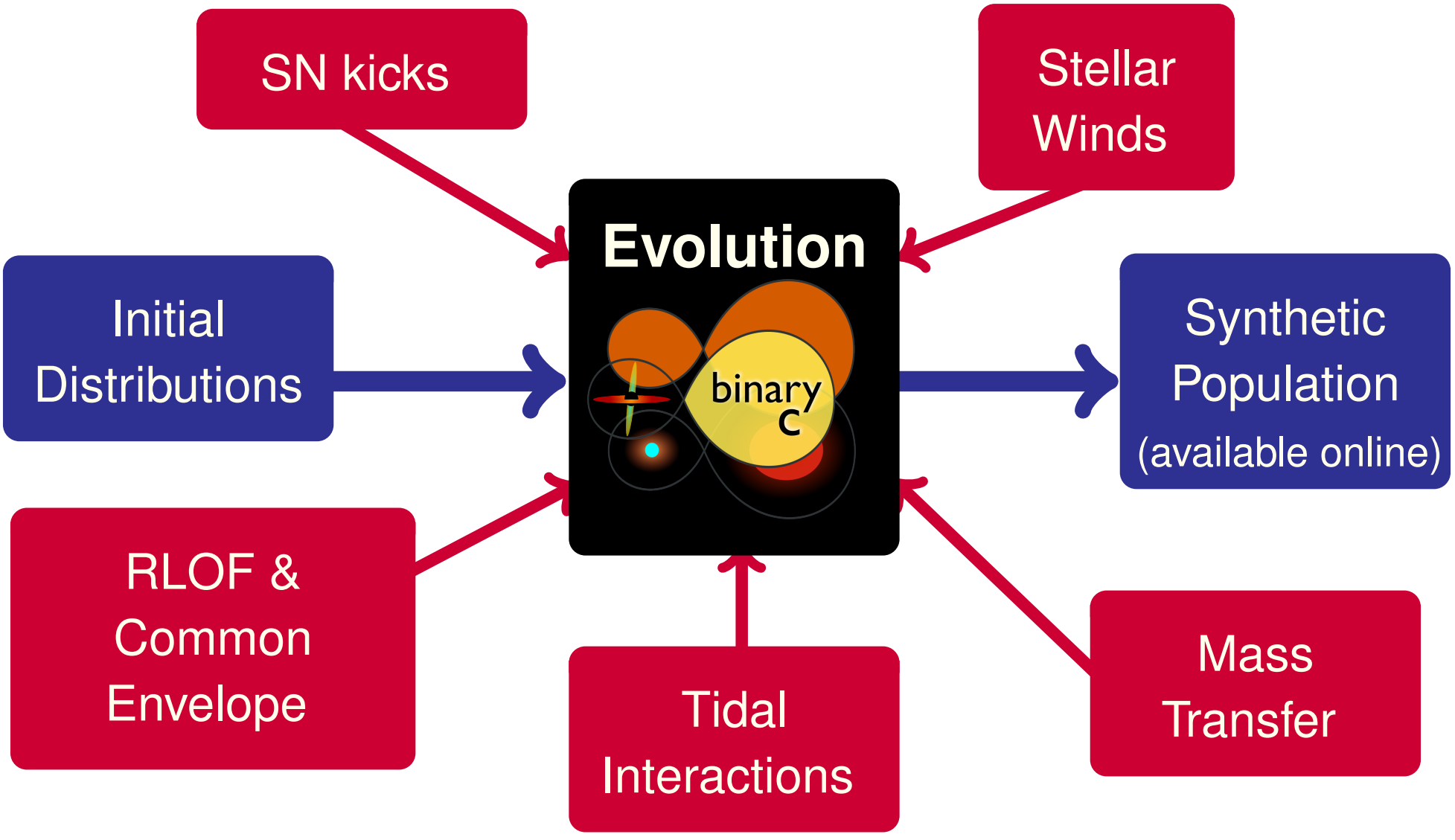
http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

Renzo *et al.* 19b

gaia

Methods: Population Synthesis

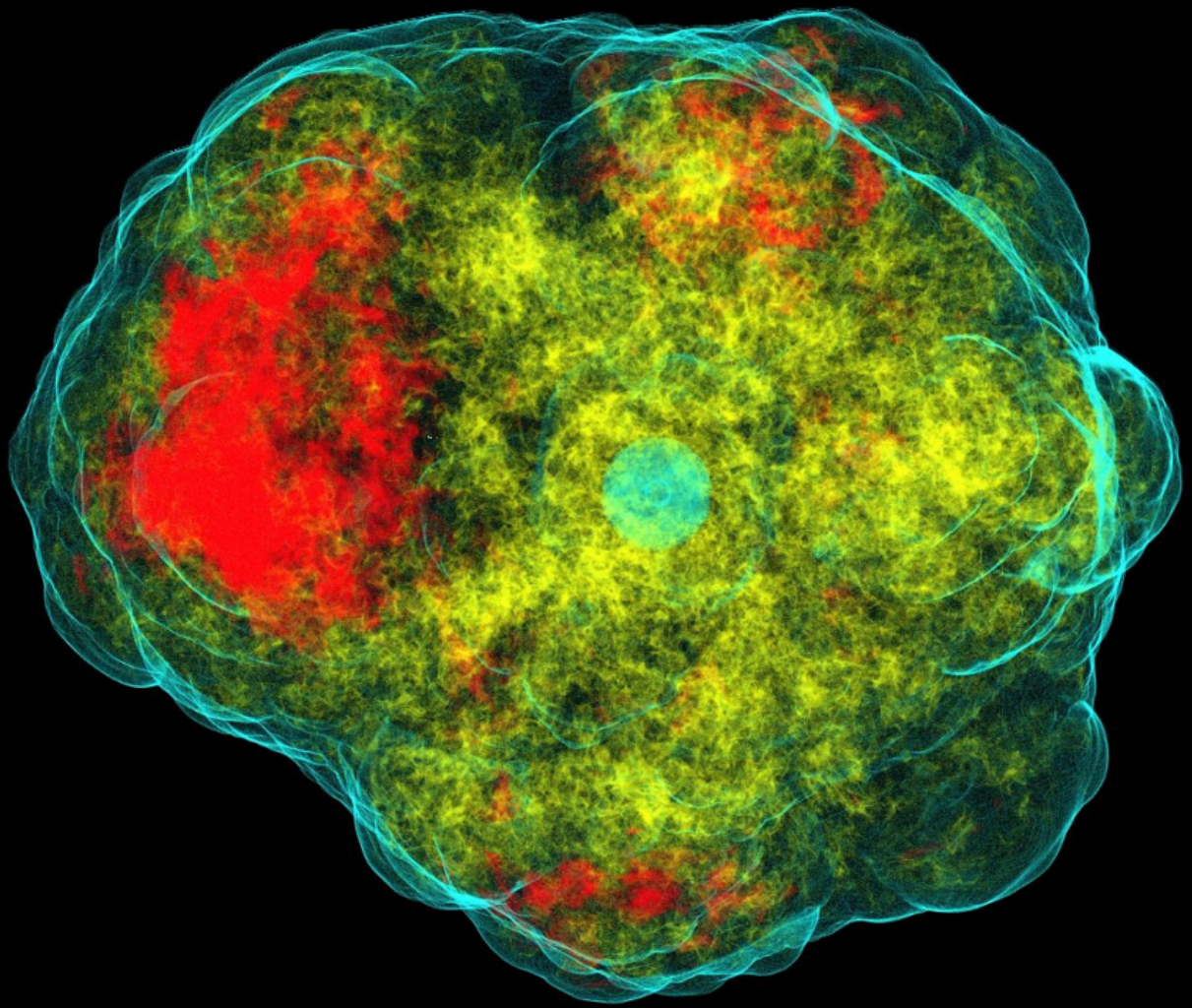
Fast $\Rightarrow$ Allows statistical tests of the inputs & assumptions



SN natal kick

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

Physically: ν emission and/or ejecta anisotropies

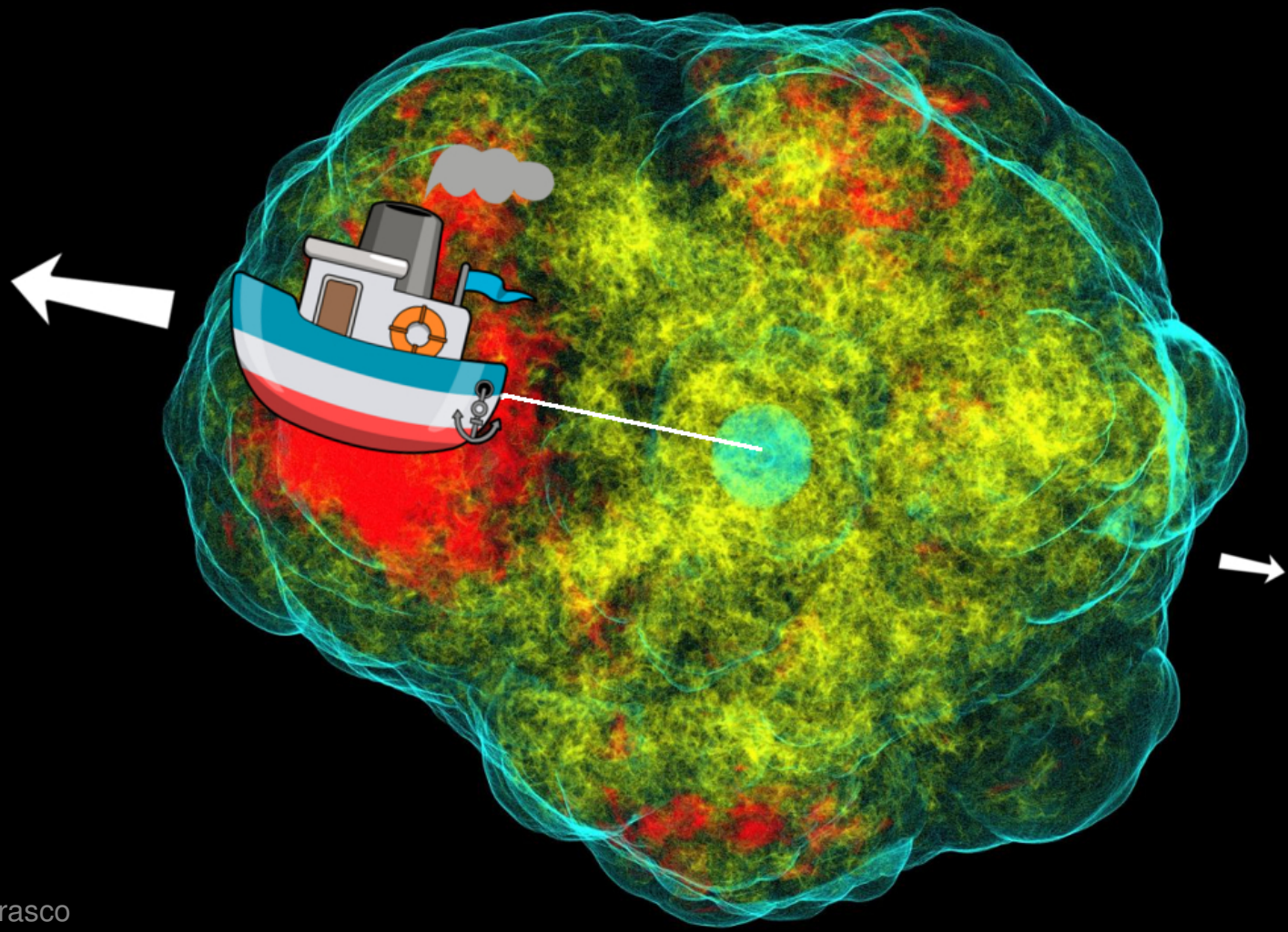


Credits: C. D. Ott, S. Drasco

SN natal kick

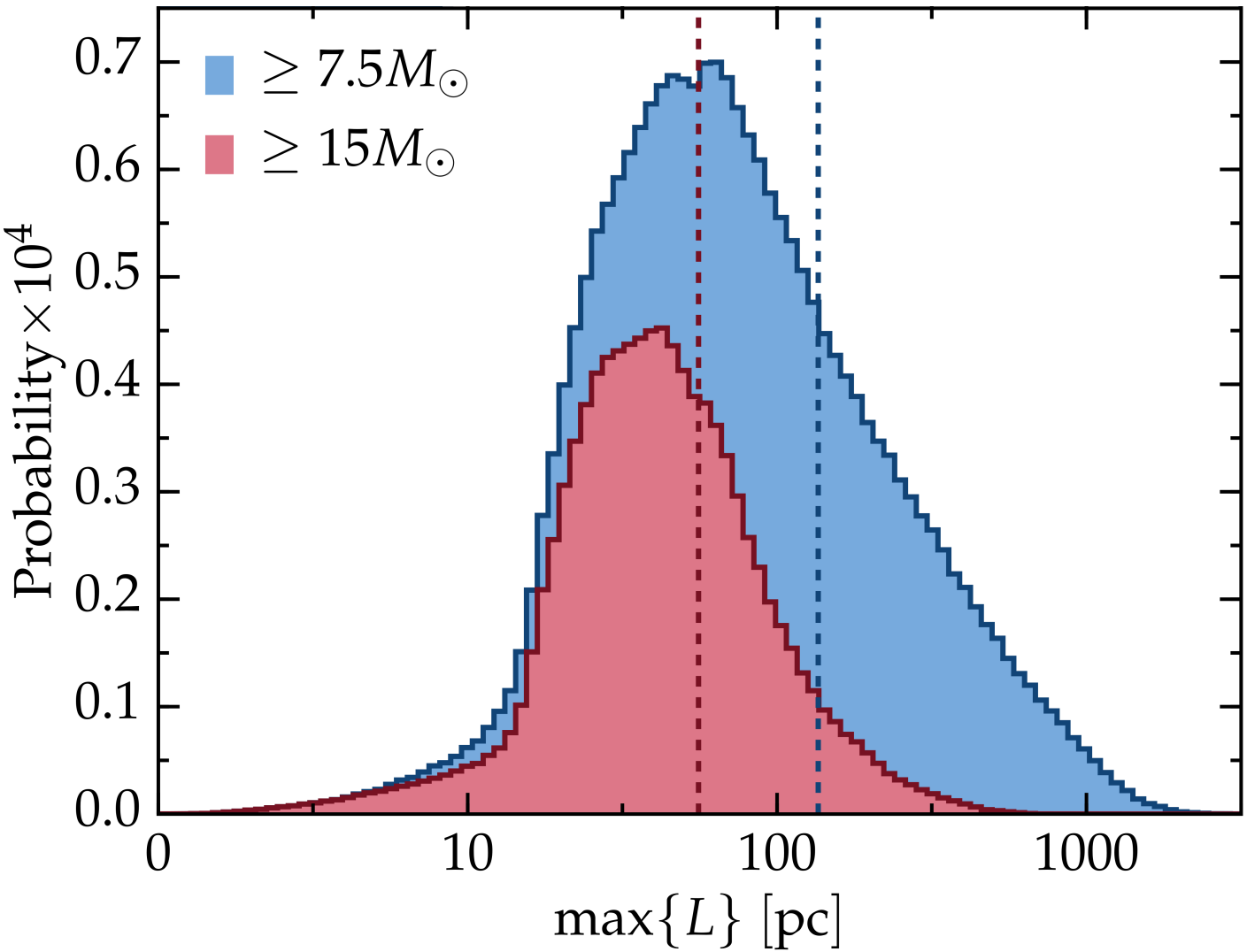
Observationally: $v_{\mathrm{pulsar}} \gg v_{\mathrm{OB-stars}}$

Physically: ν emission and/or ejecta anisotropies



Credits: C. D. Ott, S. Drasco

How far do they get?

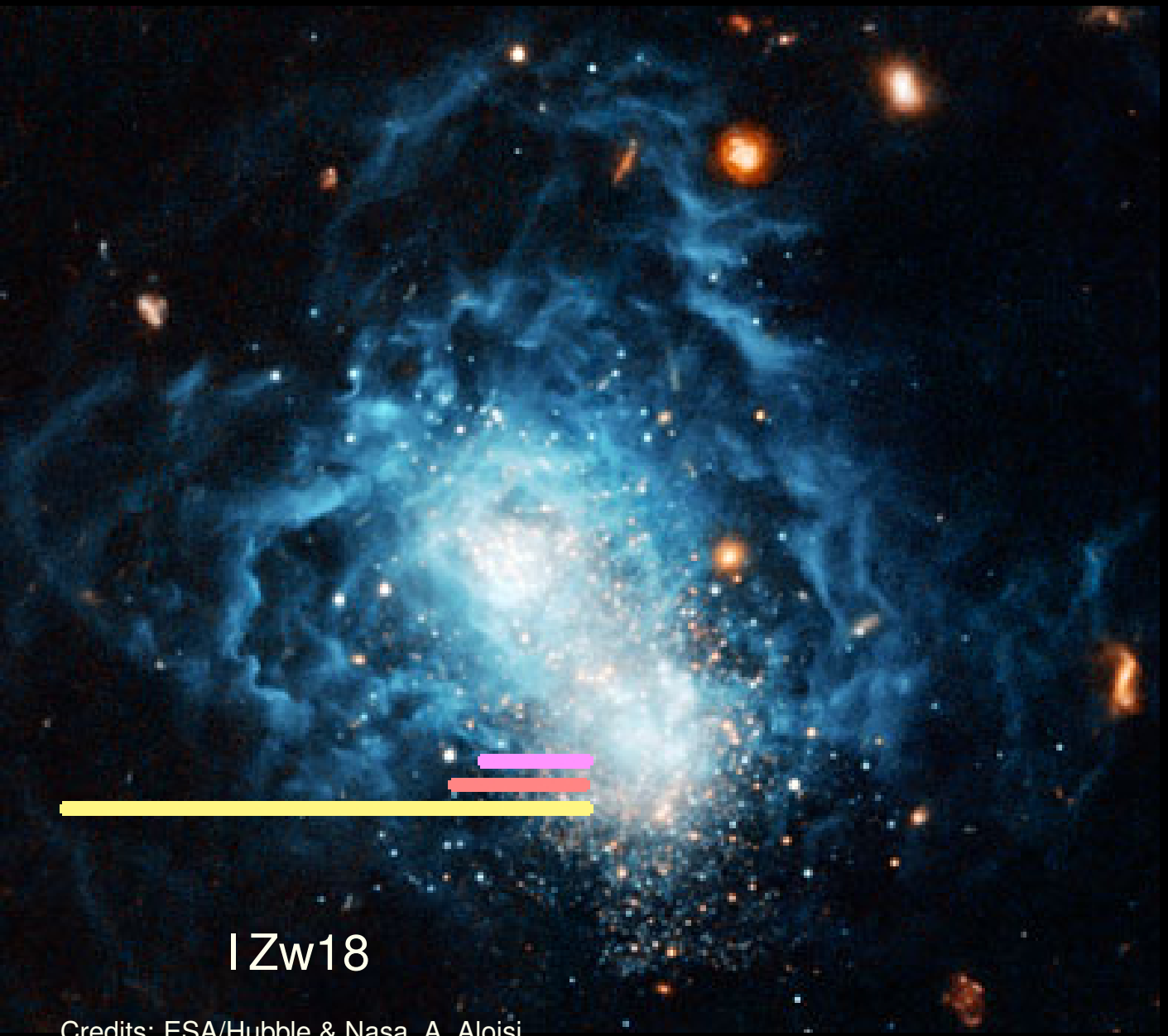


"Distance traveled"

(No potential well)

Renzo *et al.* 19b

Nevertheless: widowed stars can escape local dust clouds



Credits: ESA/Hubble & Nasa, A. Aloisi

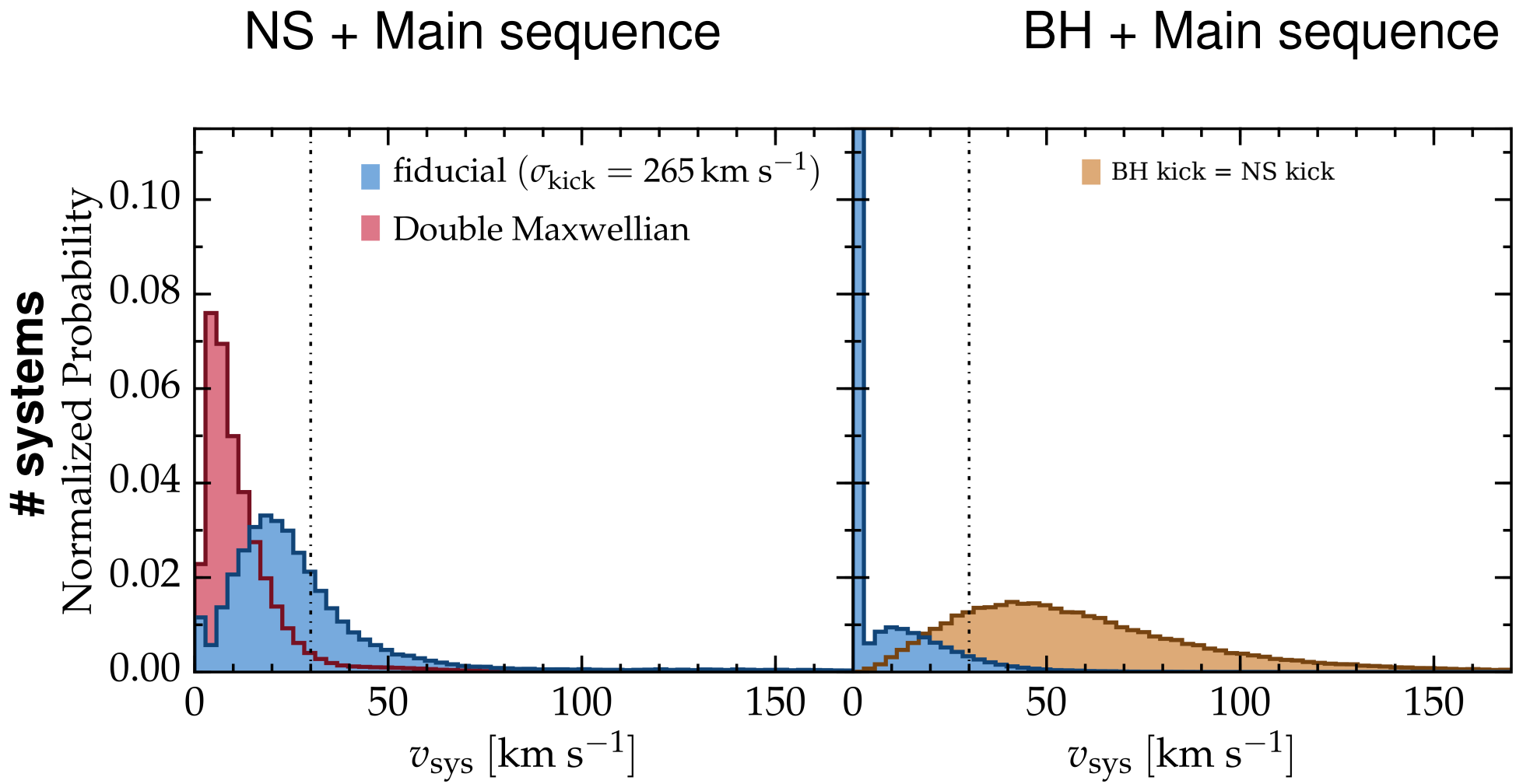
for $M \geq 7.5\,M_\odot$:

$\langle D \rangle$ = 128 pc

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

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

Post-SN velocity of surviving binaries



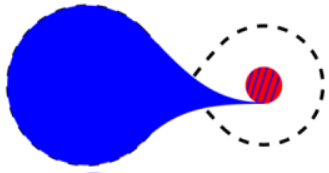
Velocity respect to the pre-explosion binary center of mass

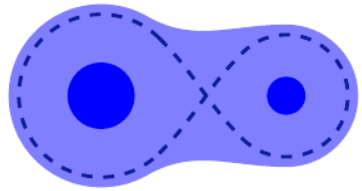
Numerical results publicly available at:

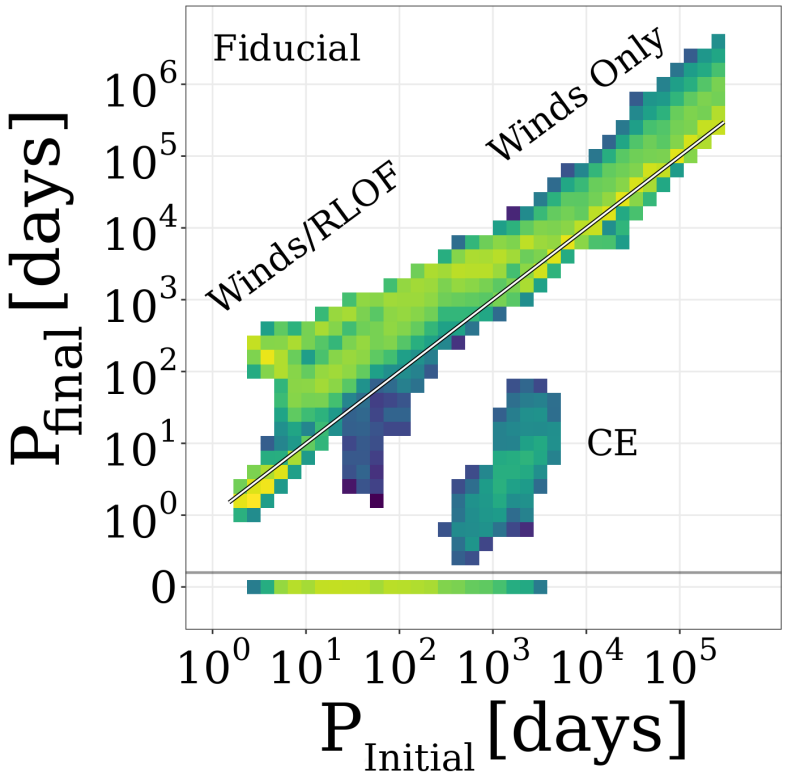
http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A66

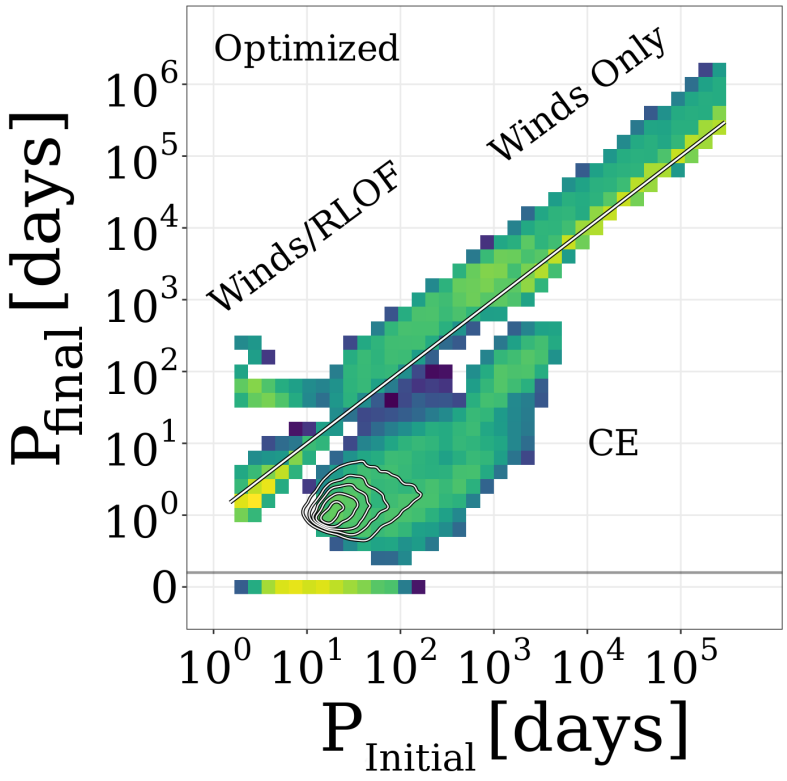
Renzo *et al.* 19b

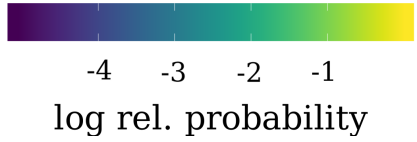
Period evolution depends on uncertain free parameters











Evans, MR, Rossi 20, arXiv:2006.00849