The explosive life of massive binaries

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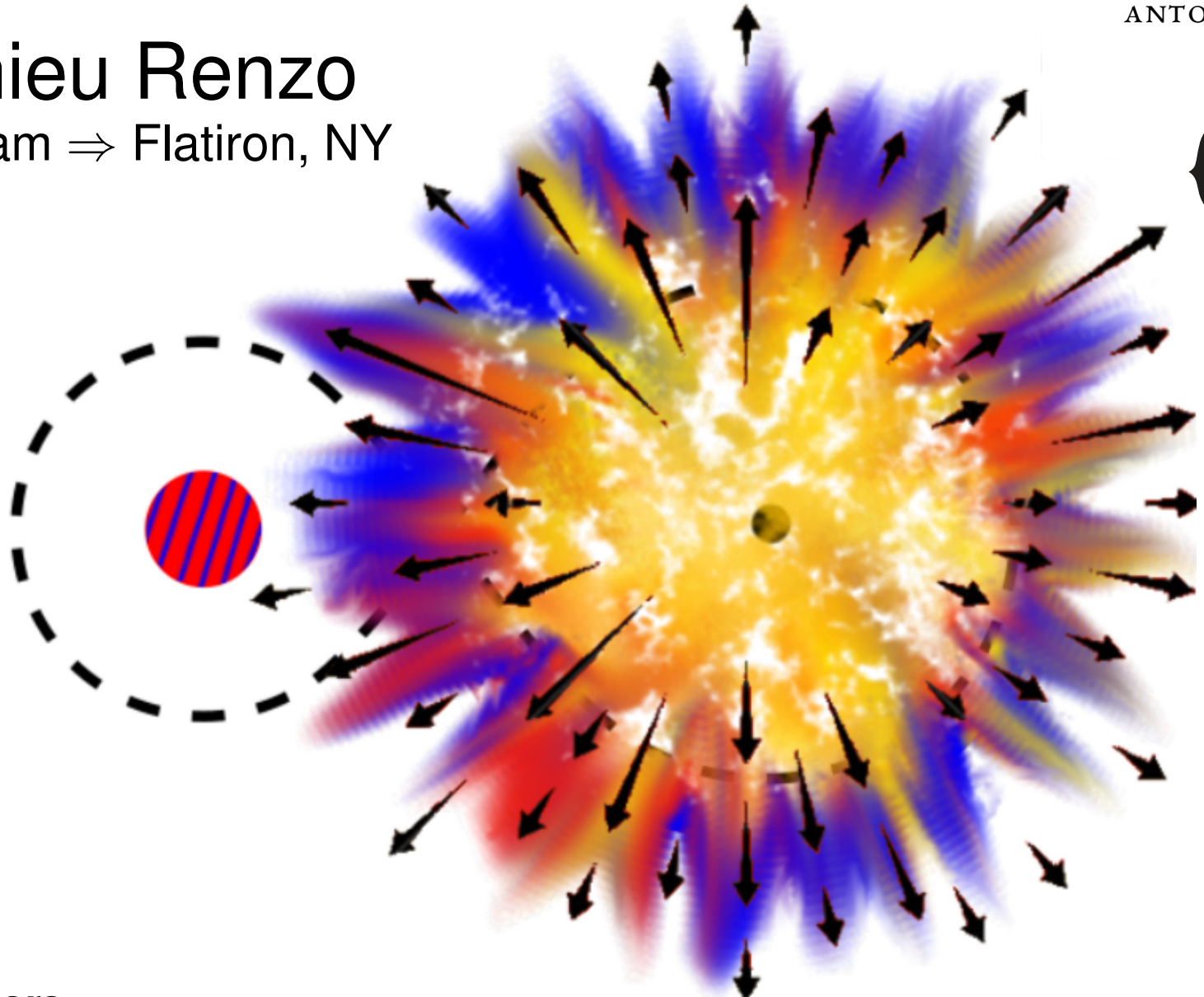
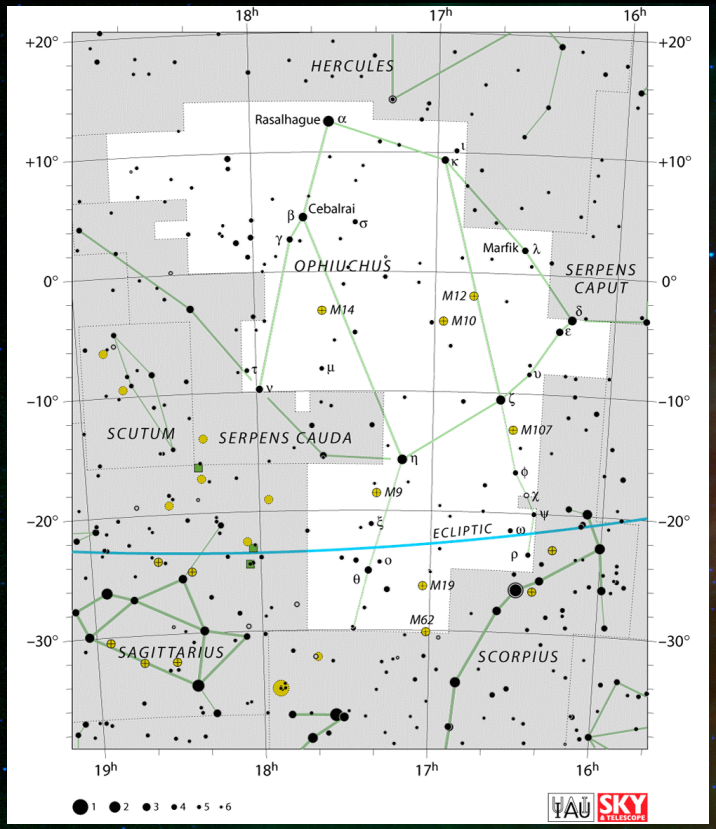
Mathieu Renzo
Amsterdam ⇒ Flatiron, NY



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

ζ Ophiuchi: nearest O type star to Earth

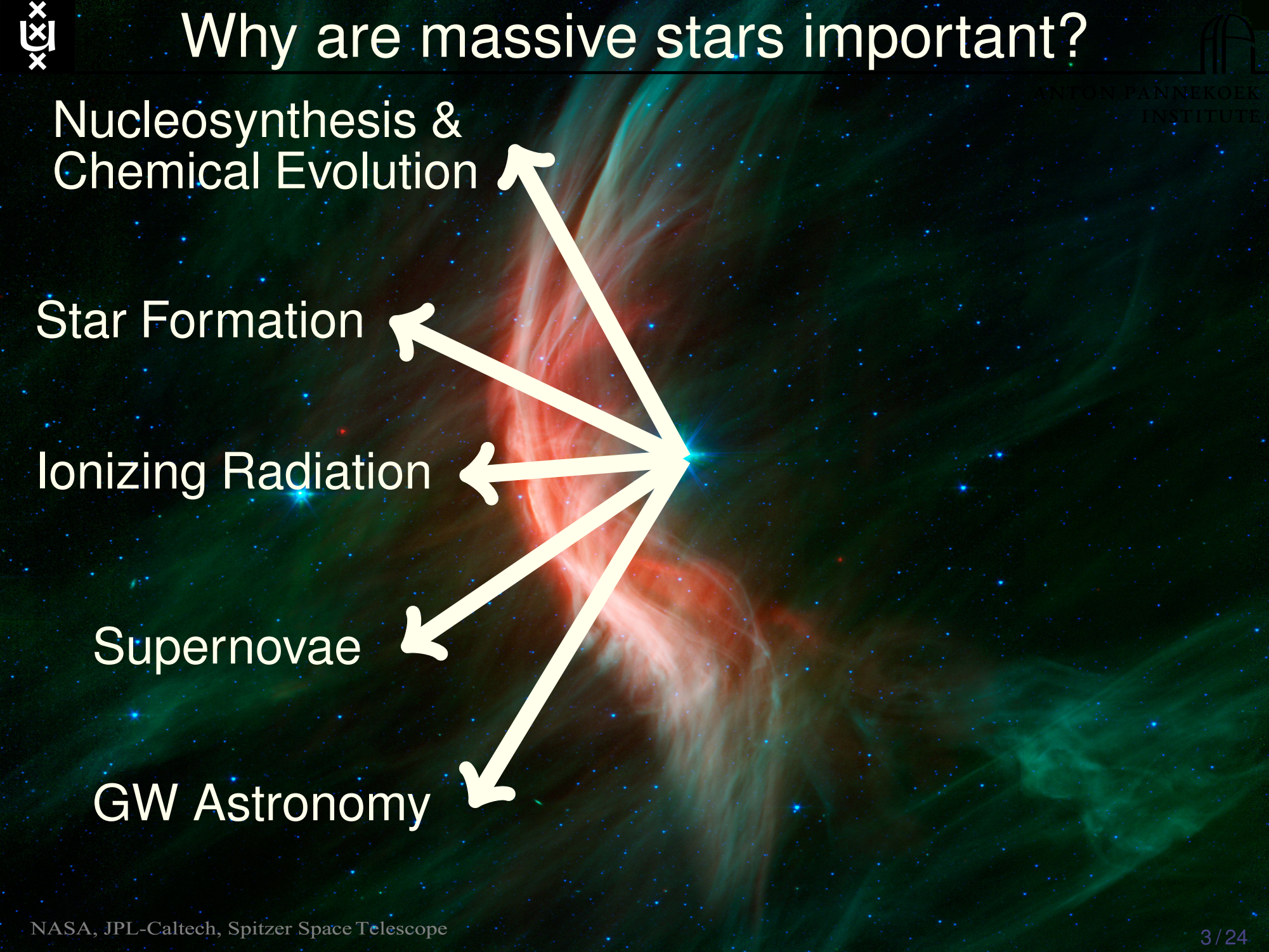


Successfully starting in Astronomical Spectroscopy

Author: F. Cochard

NASA, JPL-Caltech, Spitzer Space Telescope

Why are massive stars important?



NASA, JPL-Caltech, Spitzer Space Telescope

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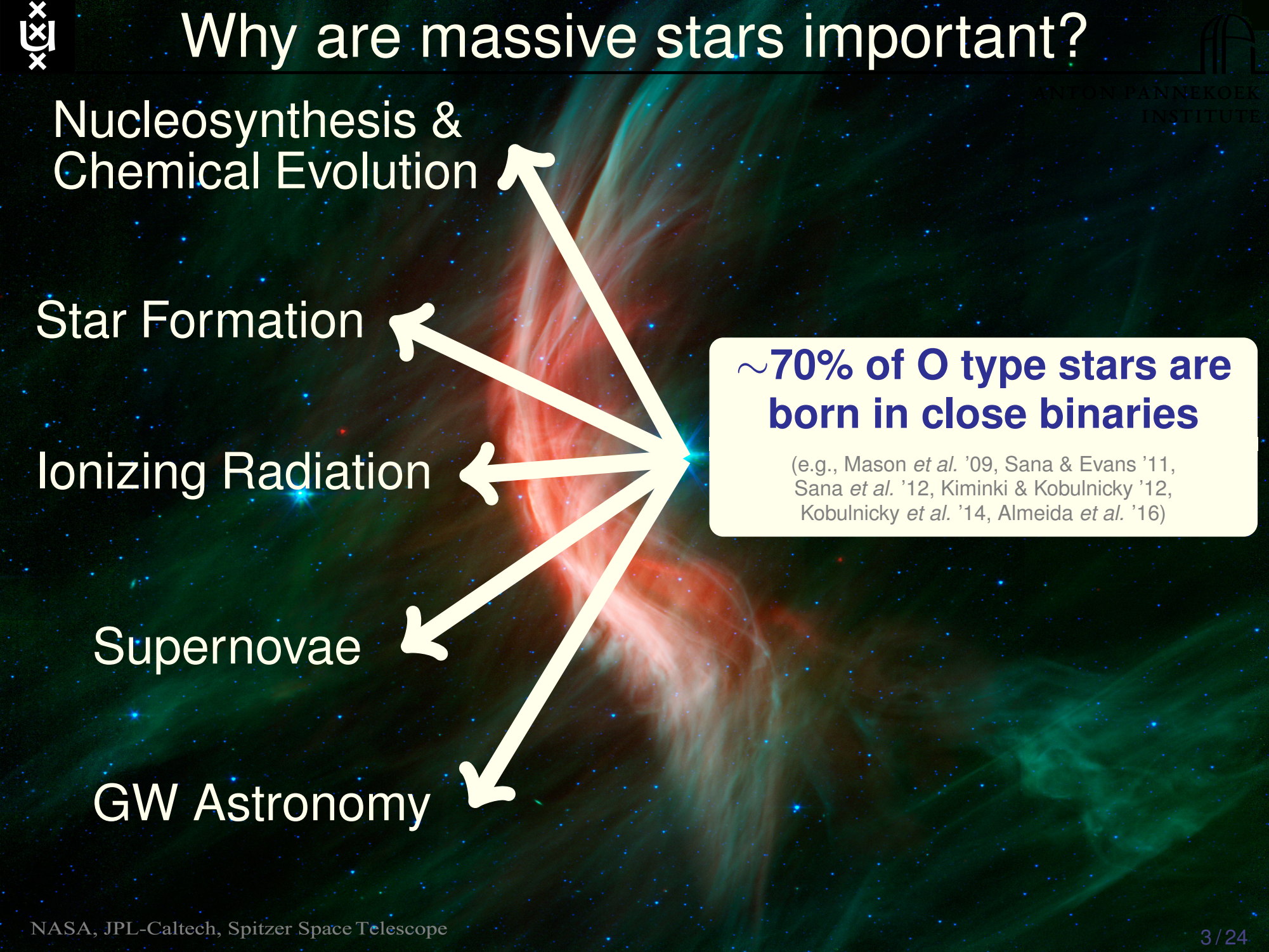

~70% of O type stars are born in close binaries

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

NASA, JPL-Caltech, Spitzer Space Telescope

Outline

How explosions can affect the binaries

The most common massive binary evolution path

"Widowed" stars as runaways and walkaways

How binaries can affect the explosions

SN rates & binarity

Binaries with a compact object

SNe typically break binaries

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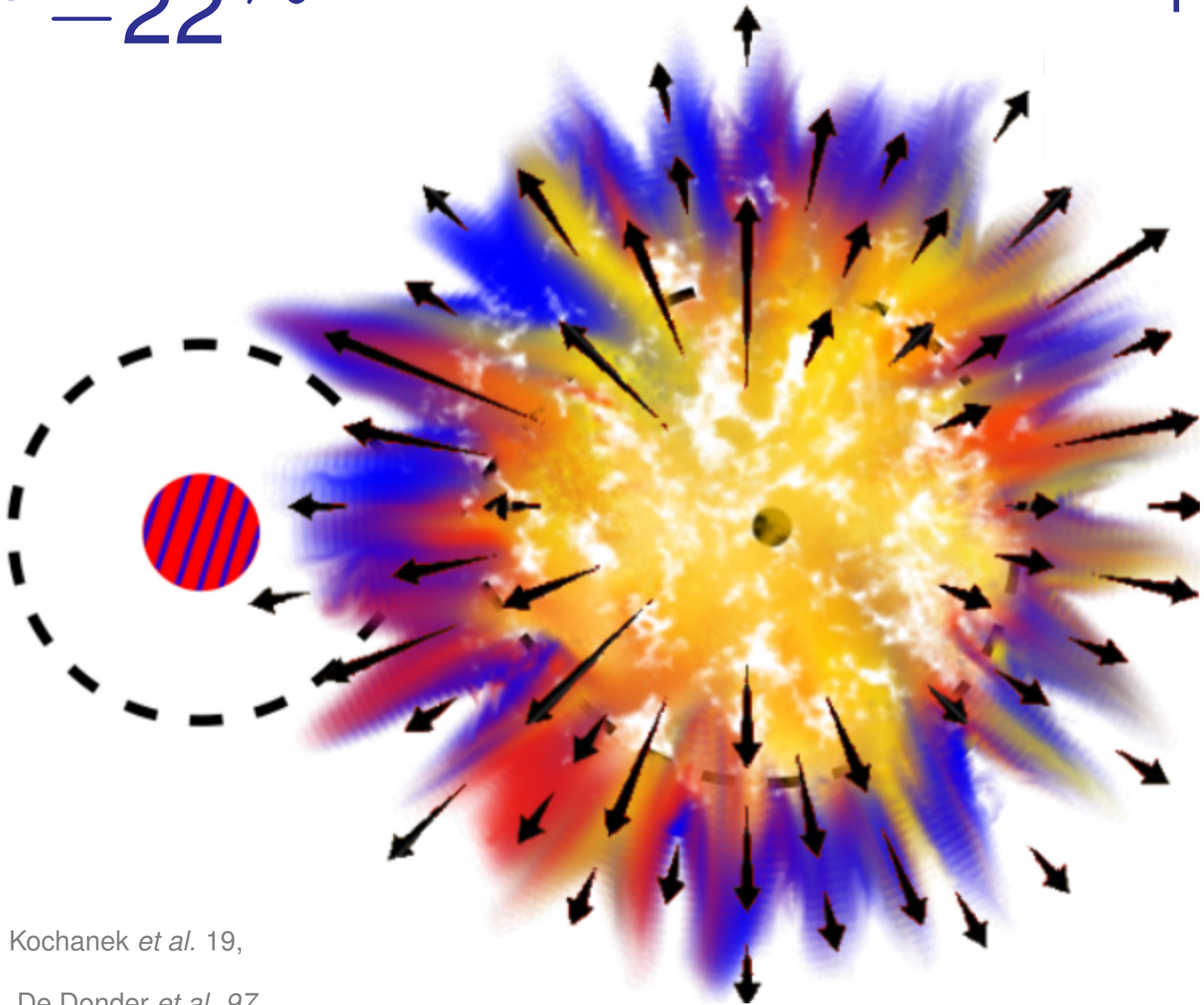
$86^{+11}_{-22}\%$ of massive binaries are disrupted



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

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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

What exactly disrupts the binary?

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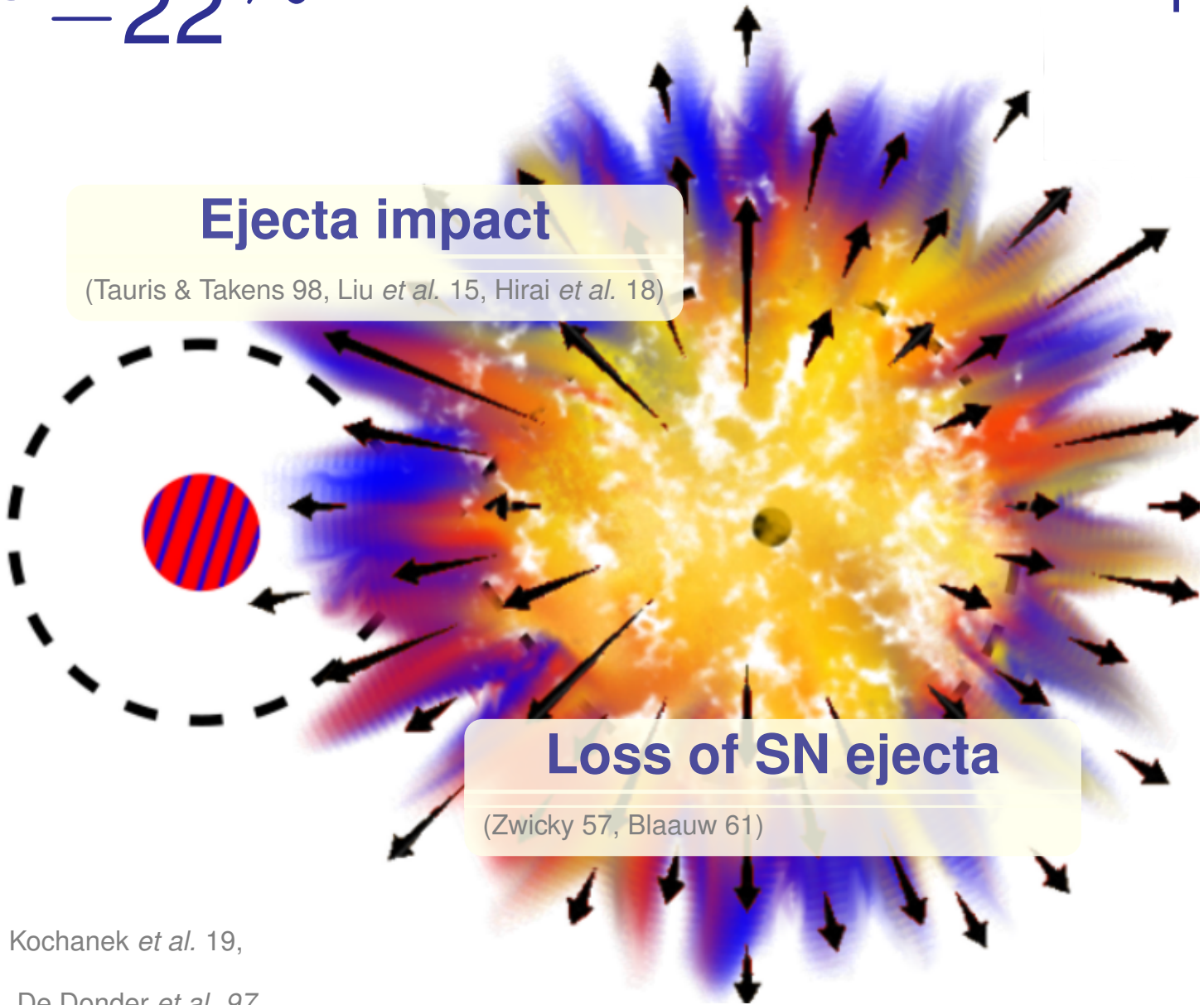

Ejecta impact

(Tauris & Takens 98, Liu *et al.* 15, Hirai *et al.* 18)

Loss of SN ejecta

(Zwicky 57, Blaauw 61)

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

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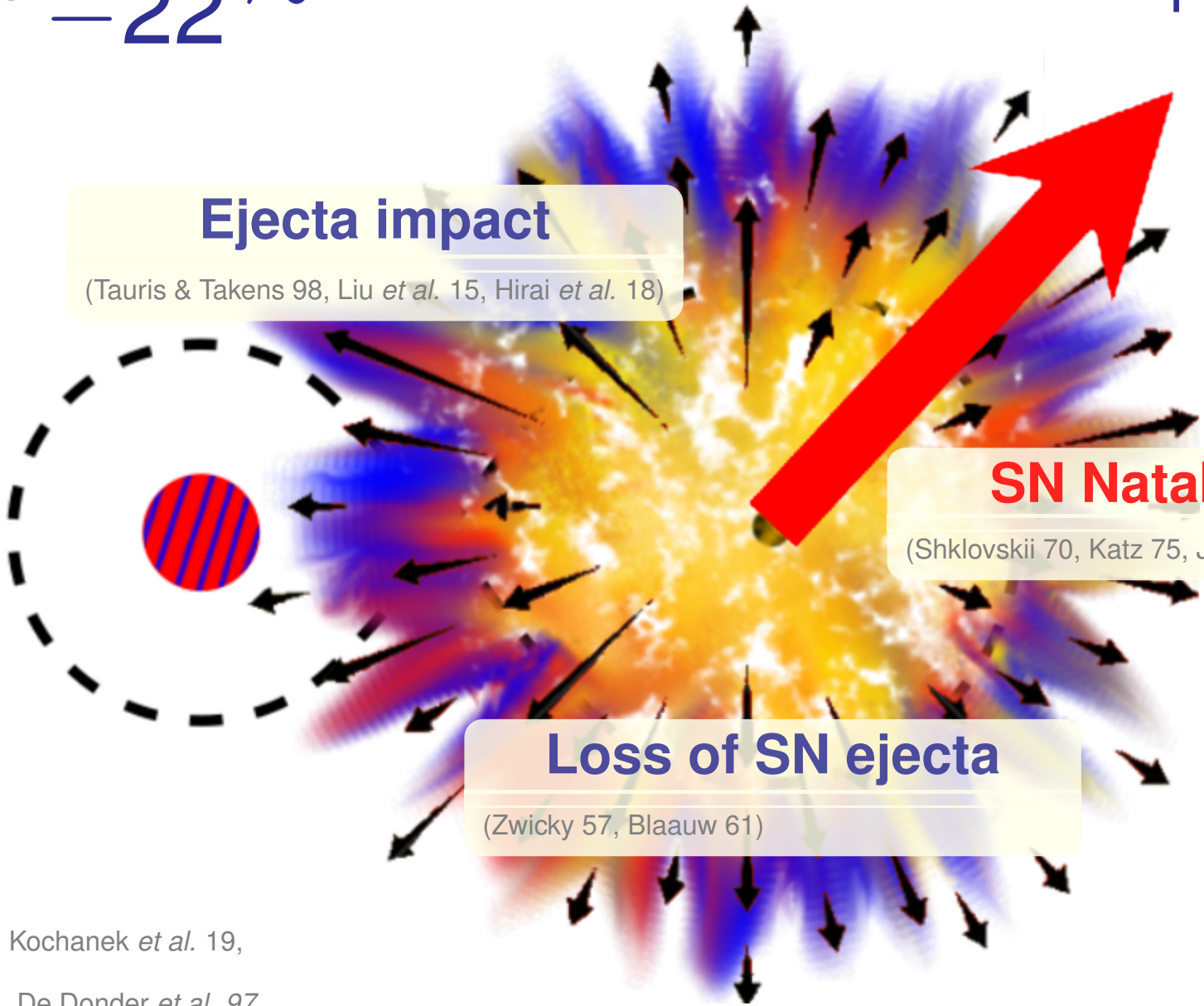

Ejecta impact

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SN Natal kick

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

Loss of SN ejecta

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

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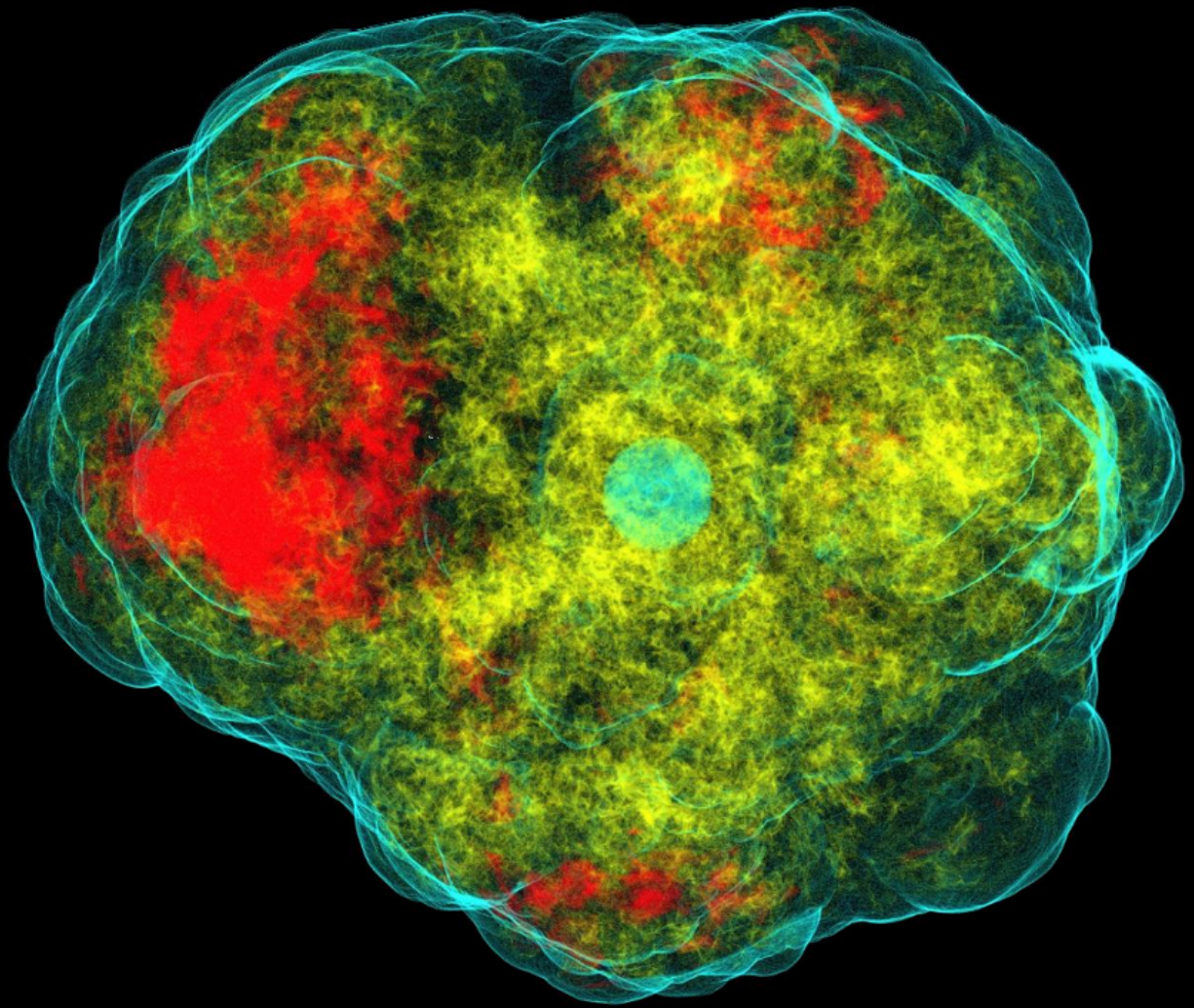
SN natal kick

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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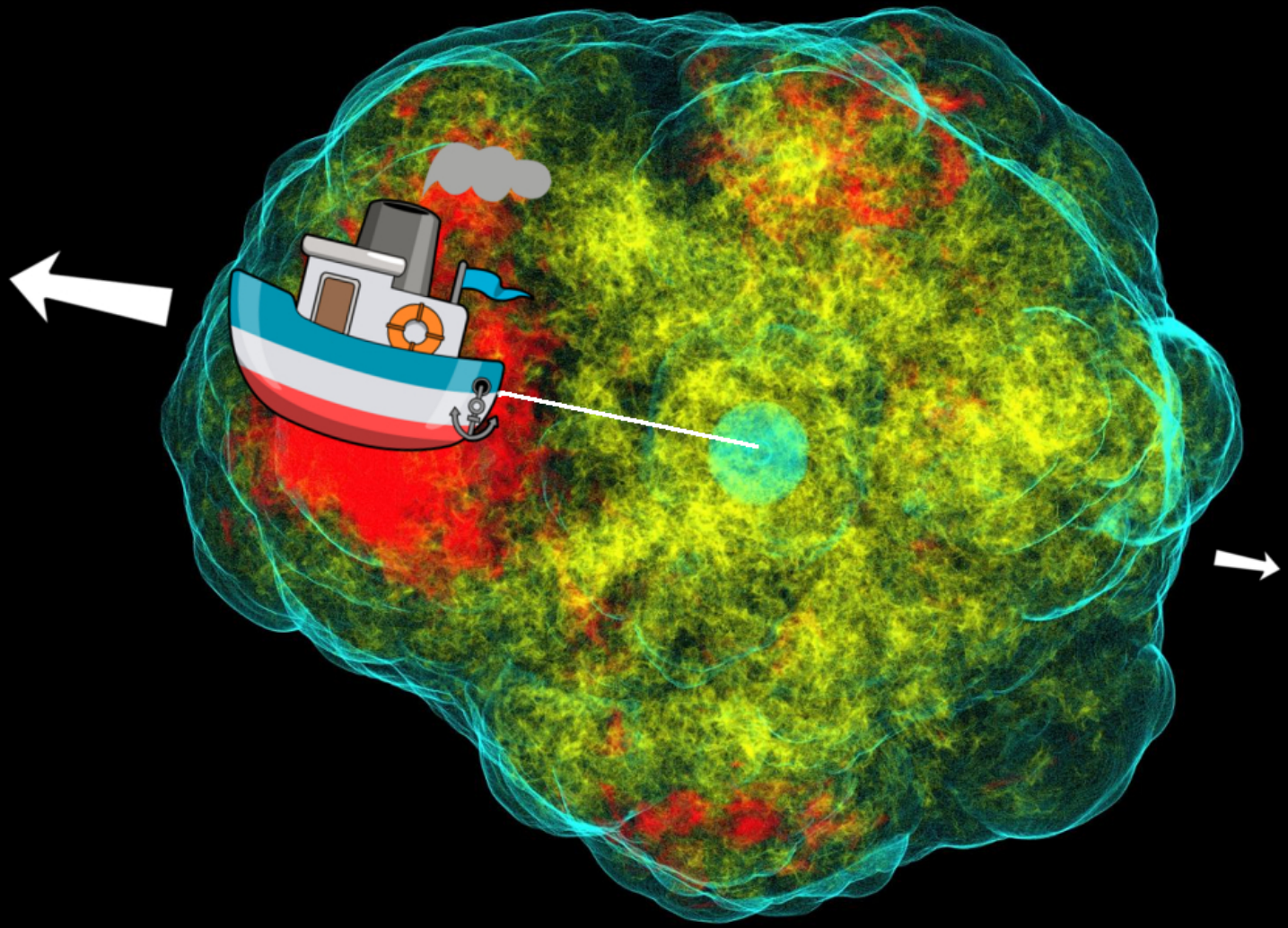

Credits: C. D. Ott, S. Drasco

Do BHs receive kicks?

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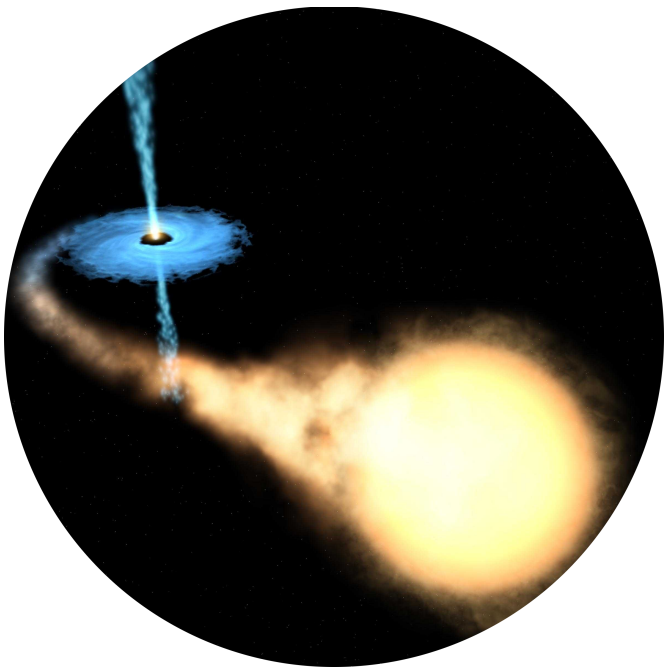
NO

$\Rightarrow$ most remain together with their widowed companion



YES

$\Rightarrow$ 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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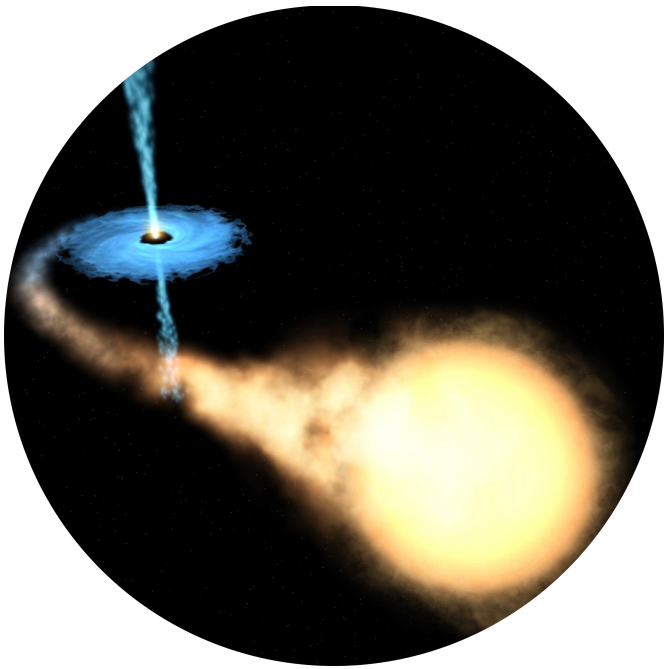

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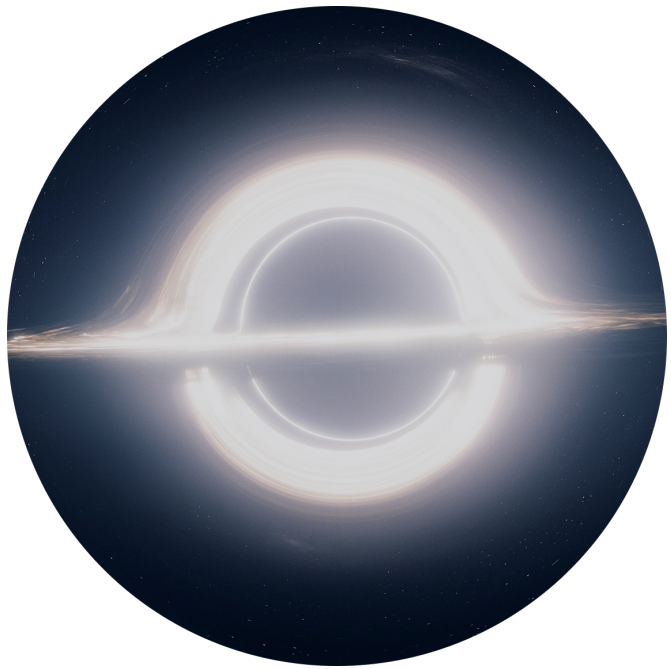

...but we can see the widowed companion

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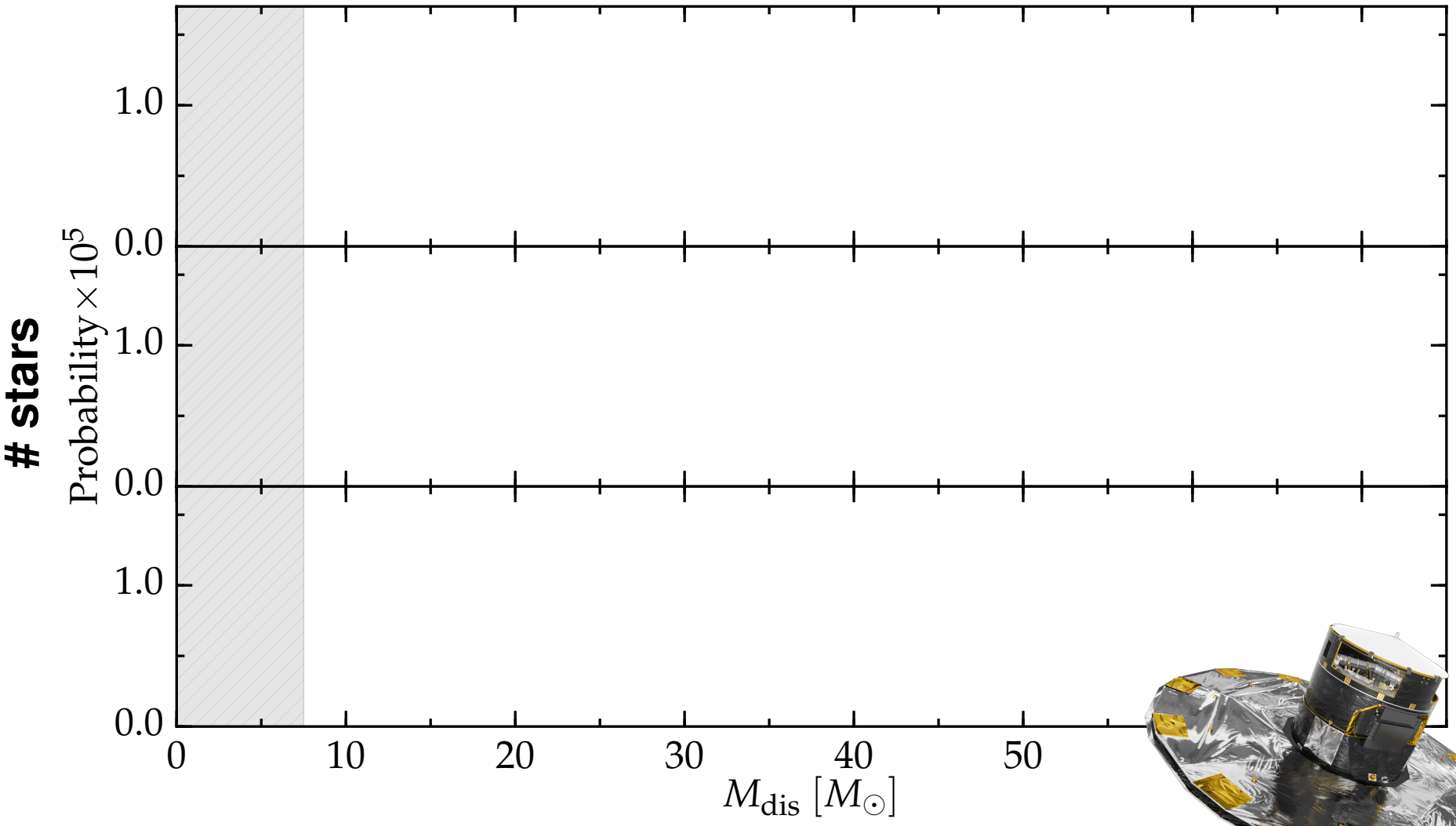
Massive runaways mass function ($v \geq 30\,\mathrm{km\ s^{-1}}$, $M \geq 7.5\,M_\odot$)



gaia

A way to constrain BH kicks with Gaia

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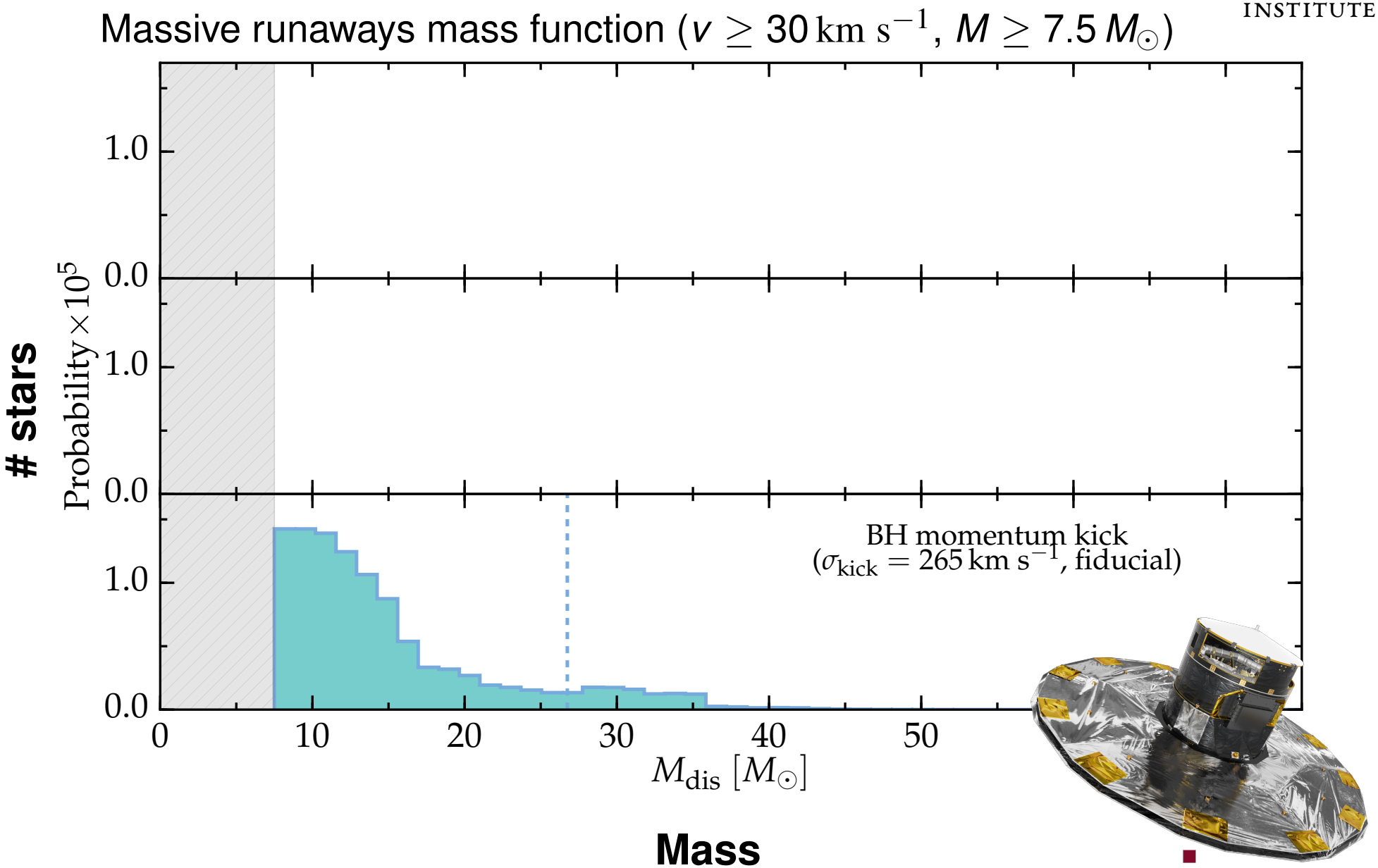

gaia

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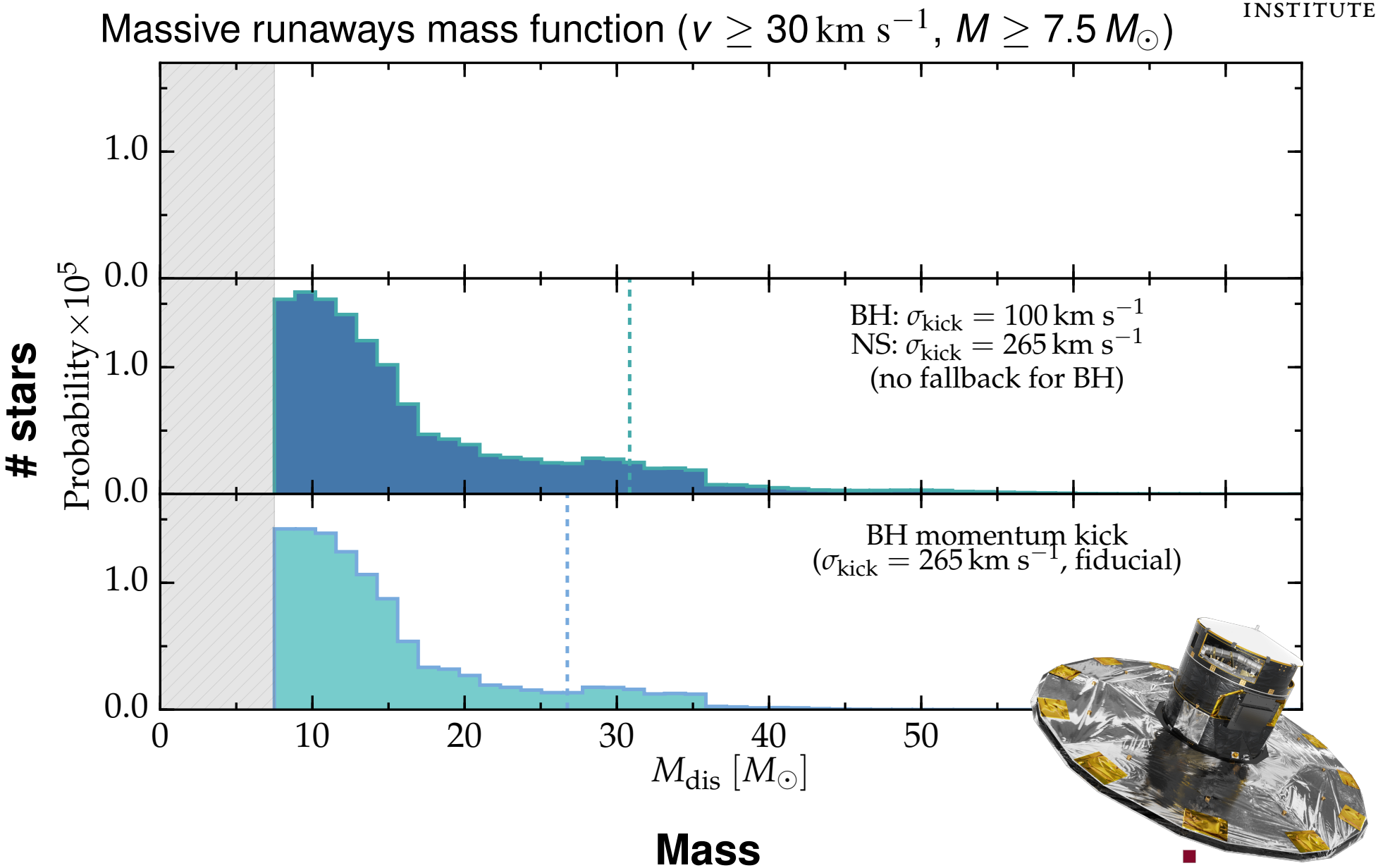

gaia

Renzo *et al.* 19b

A way to constrain BH kicks with Gaia

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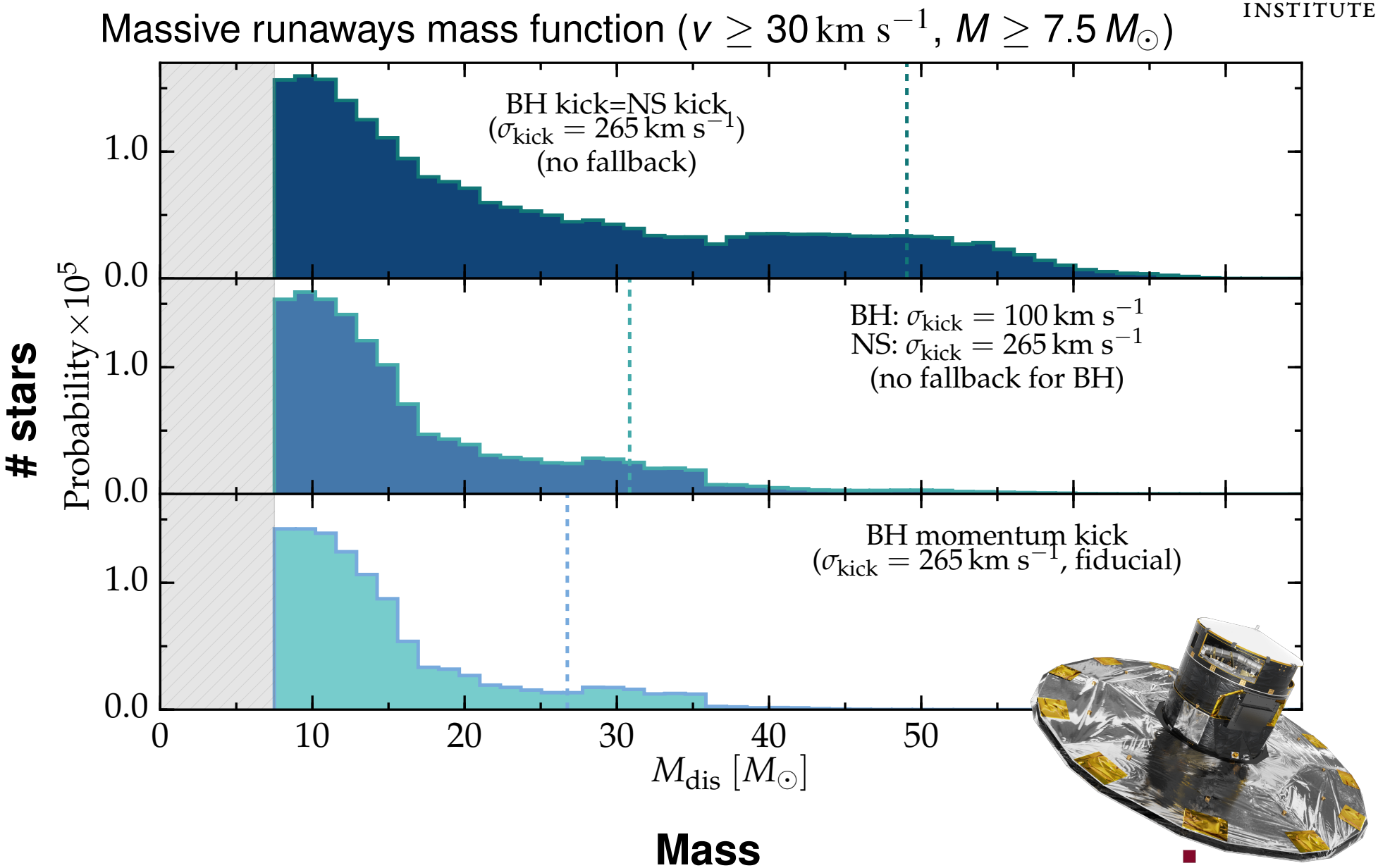

gaia

Renzo *et al.* 19b

How explosions can affect the binaries

The most common massive binary evolution path

"Widowed" stars as runaways and walkaways

How binaries can affect the explosions

SN rates & binarity

Binaries with a compact object

Kicks do not change companion velocity

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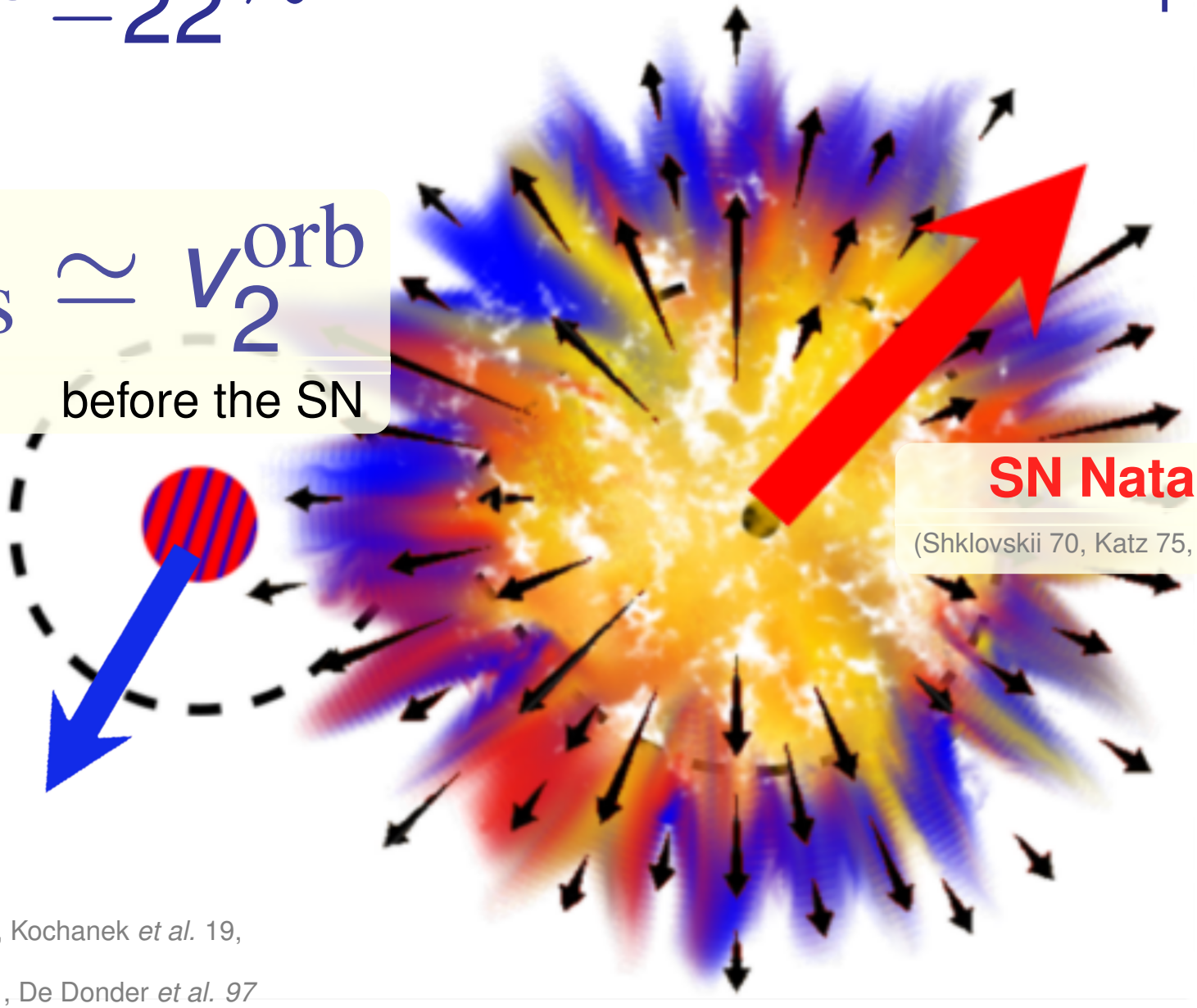
$86^{+11}_{-22}\%$ of massive binaries are disrupted

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

before the SN



SN Natal kick

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

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

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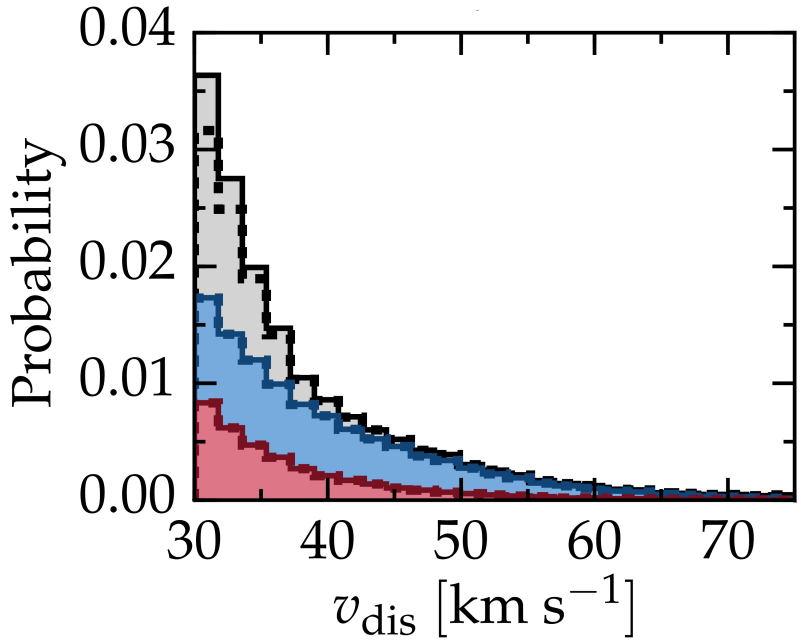
Velocity distribution: **Runaways**



Velocity distribution: **Walkaways**

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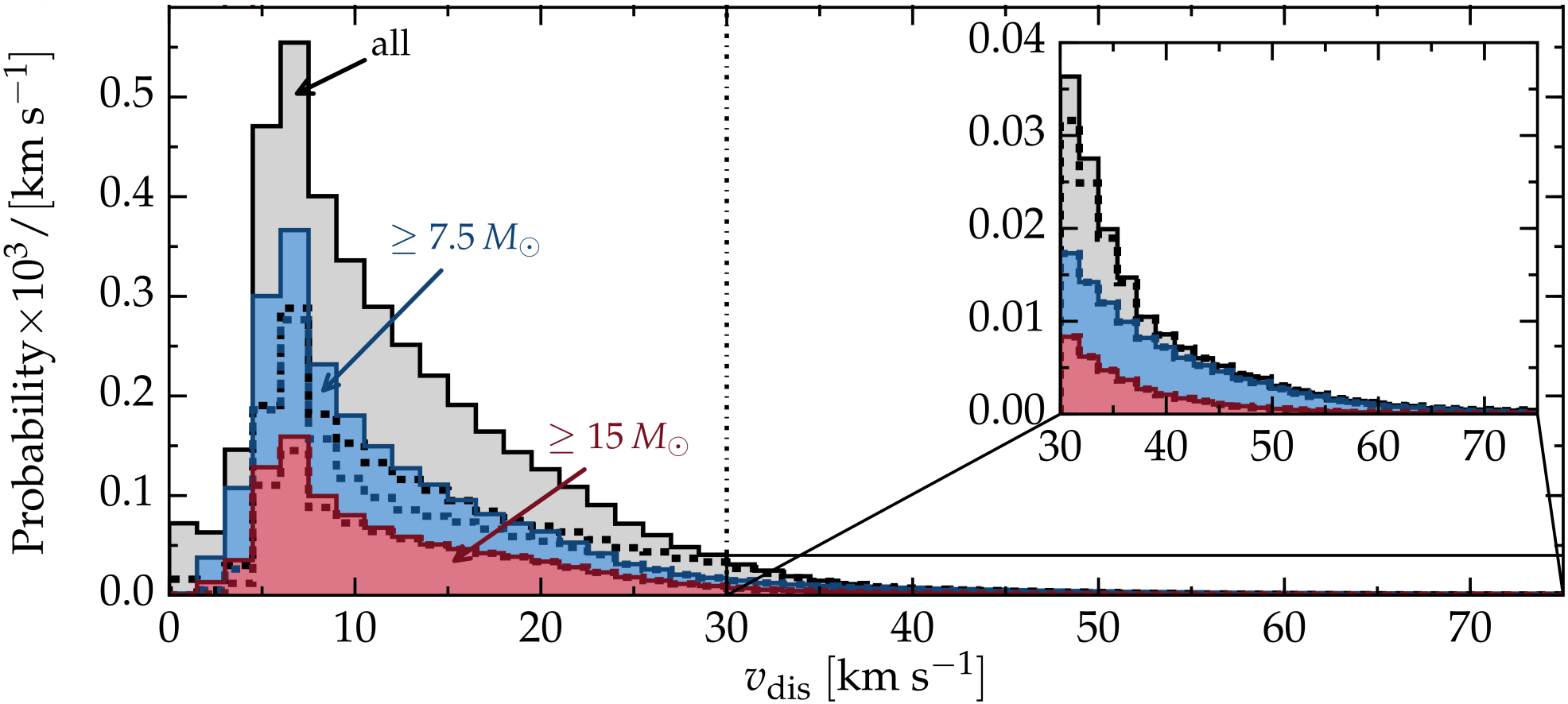

Velocity respect to the pre-explosion binary center of mass

Renzo *et al.* 19b

Velocity distribution: **Walkaways**

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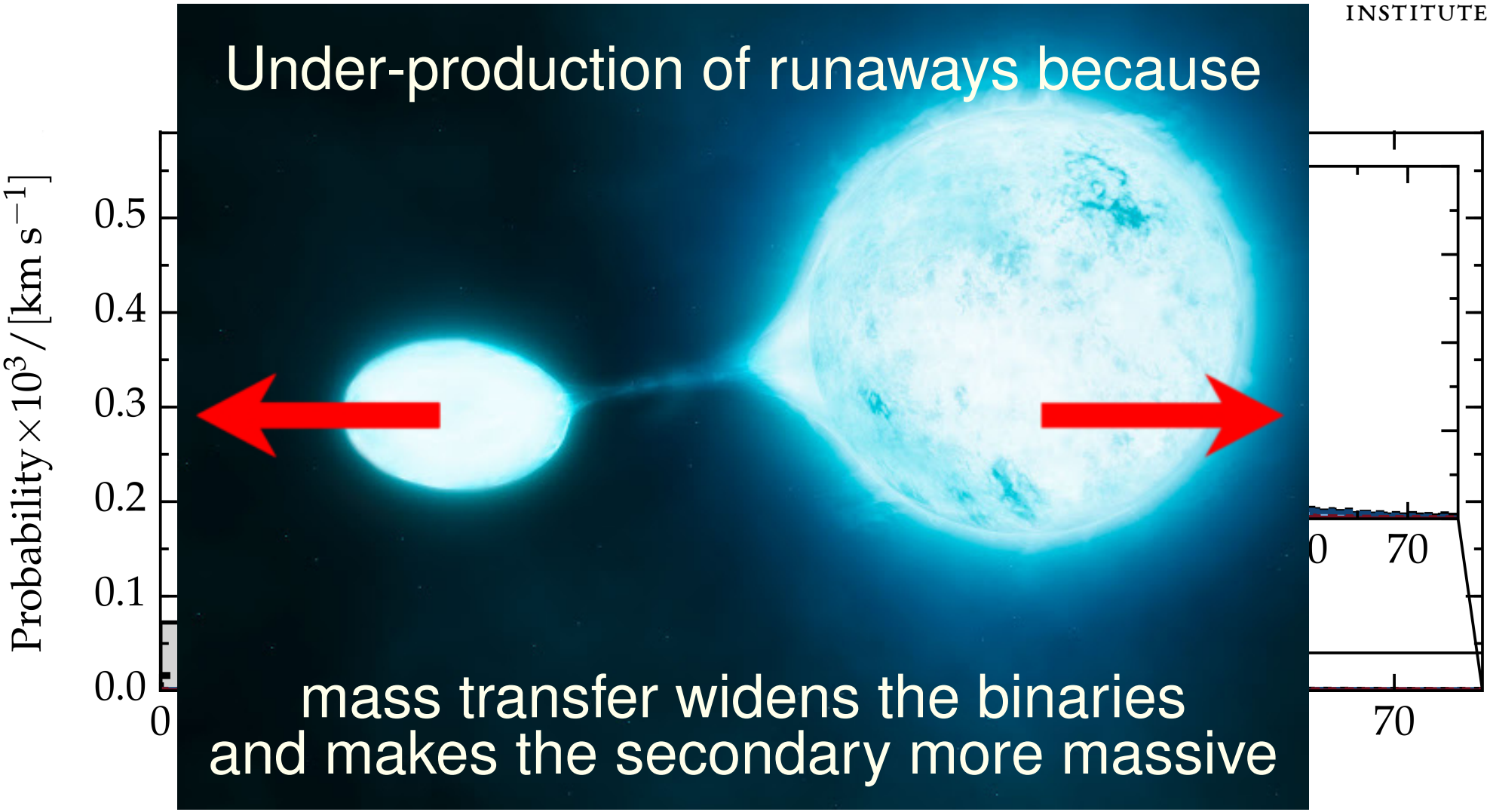

Velocity respect to the pre-explosion binary center of mass

Outline

Oversimplified: If not merging ⇒ two SNe

(because of mass loss & reverse interactions)

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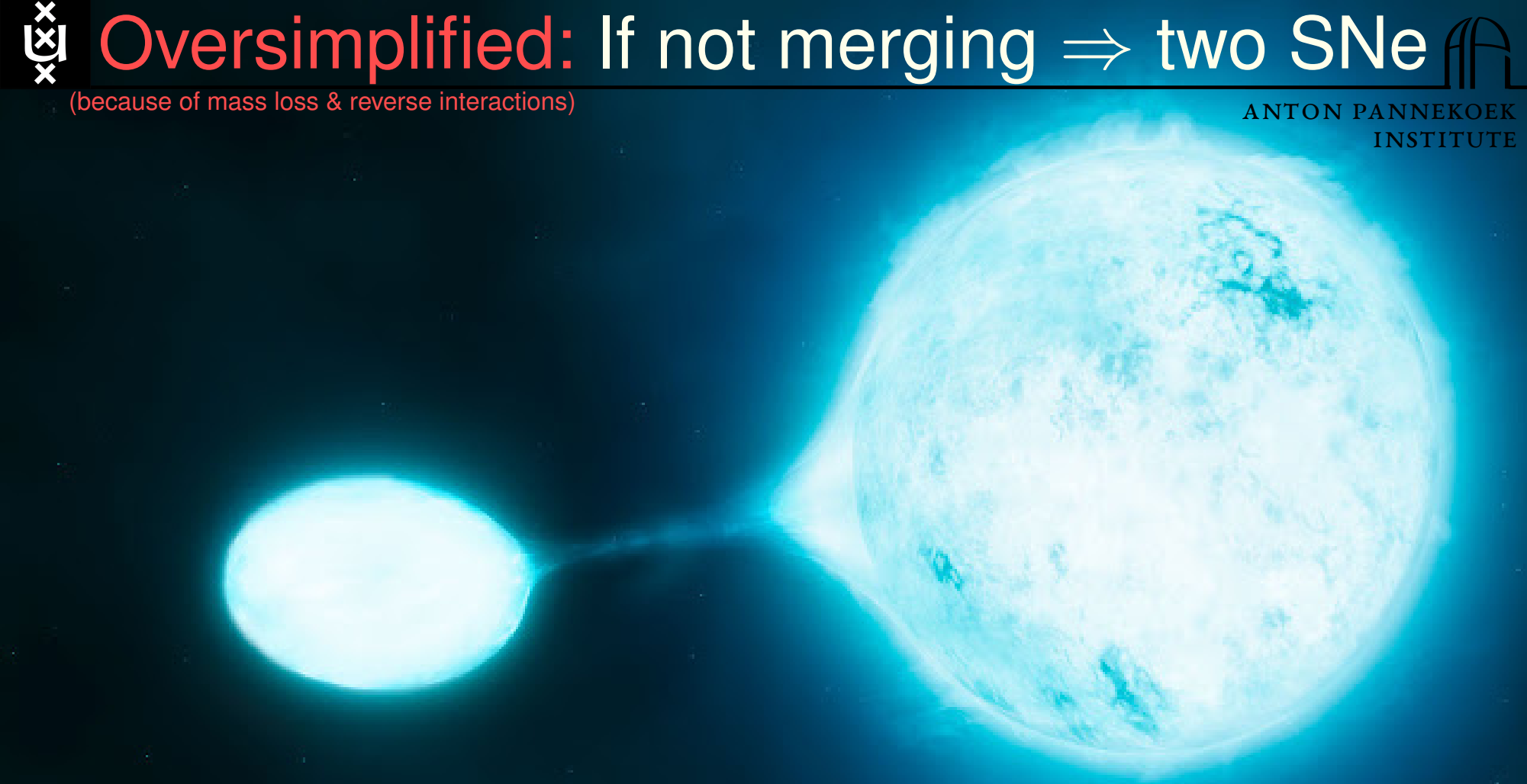

Explodes after accreting mass

SN type II

except if wind strong enough to remove H envelope, or if

reverse binary interactions if binary not disrupted

Explodes after losing envelope

SN type IIb/Ib/Ic

depending on winds (and thus Z)

e.g., Zapartas *et al.* (incl. MR) 17a, 17b, 19, Eldridge *et al.* 11, 18, 19

Companions to H-less SNe (type IIb/Ib/Ic)

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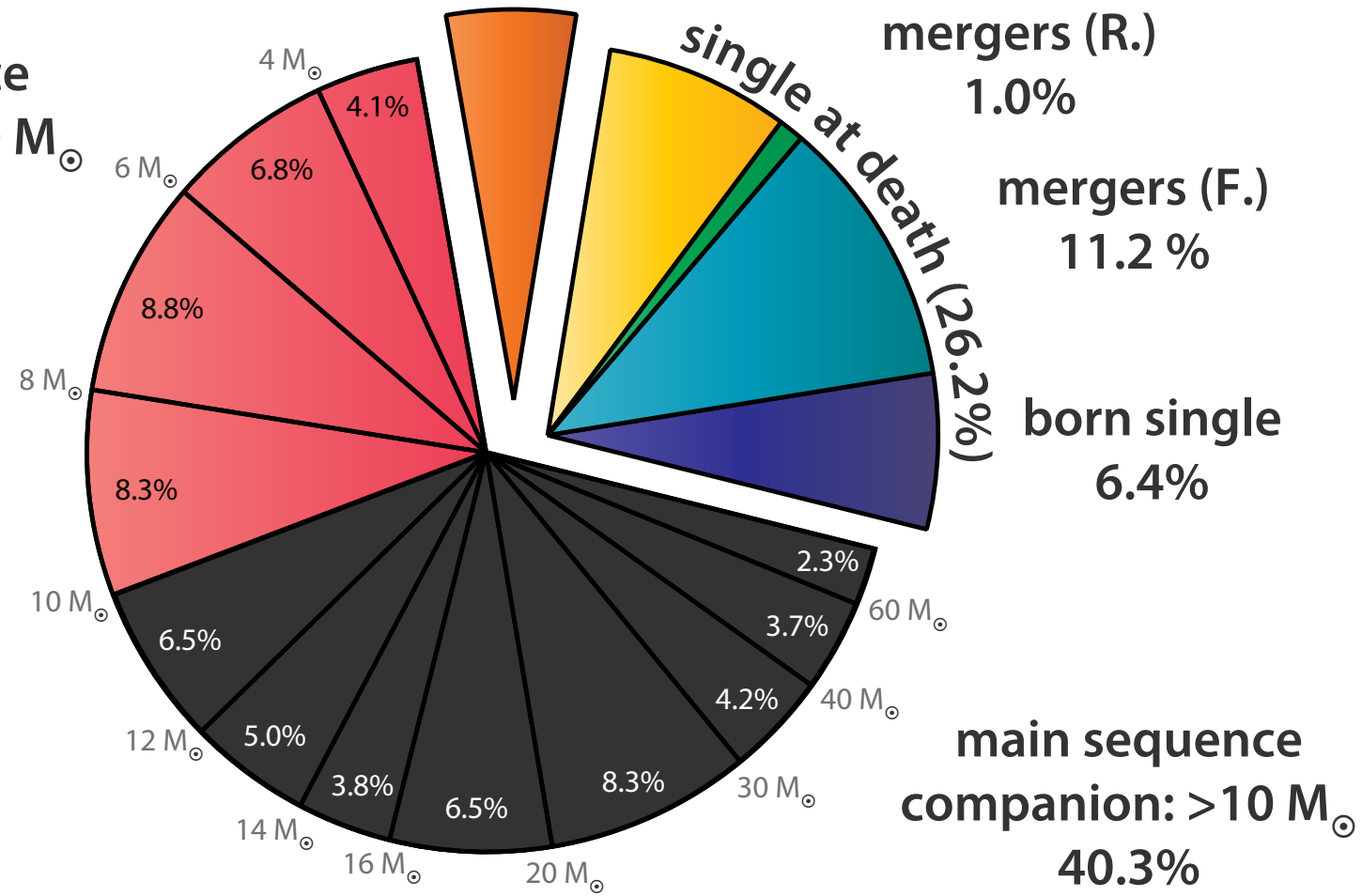

Stripped-envelope SNe (Z = 0.0055)

e.g., Zapartas *et al.* (incl. MR) 17b

Type II SNe also know about binarity

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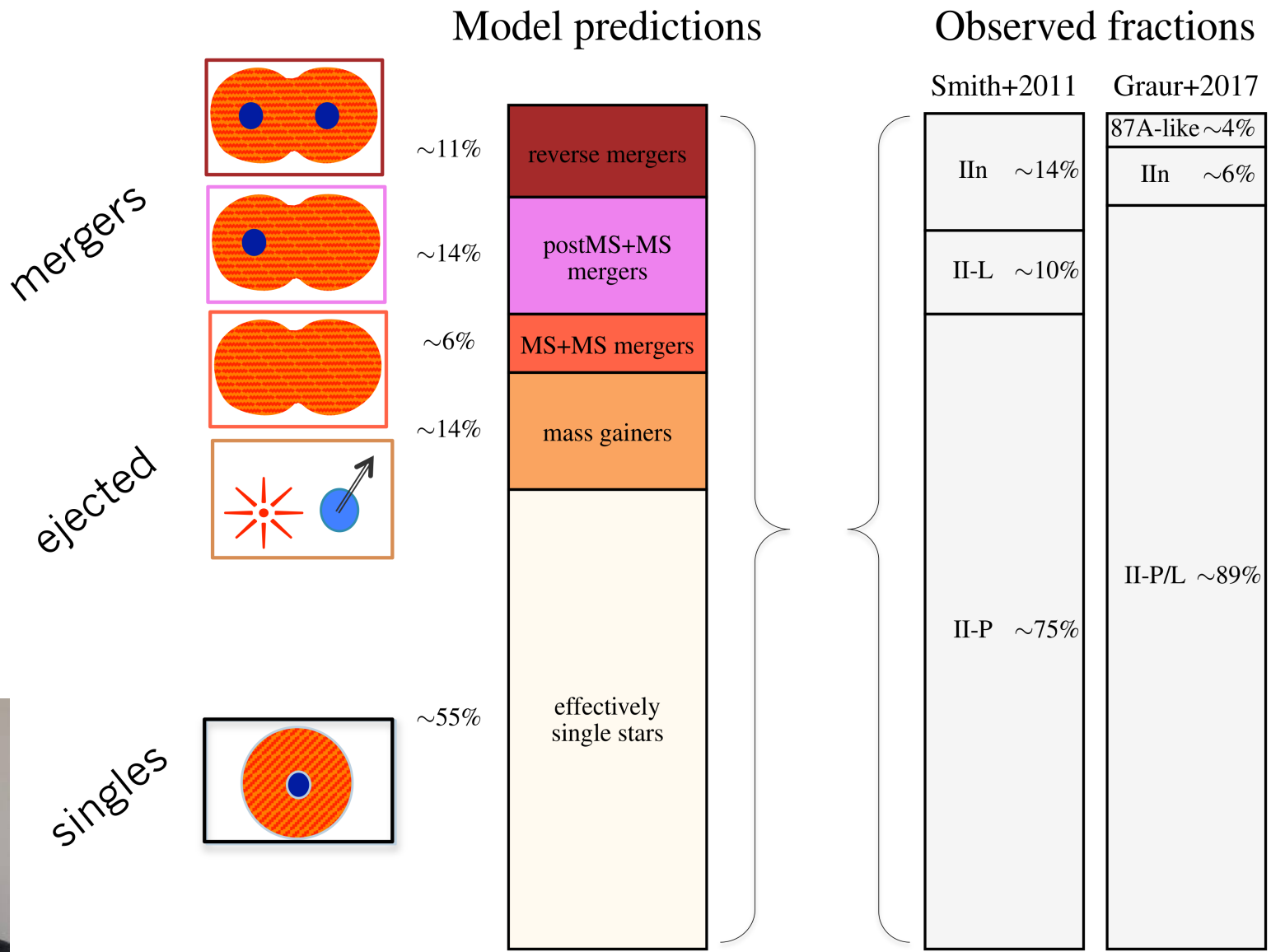
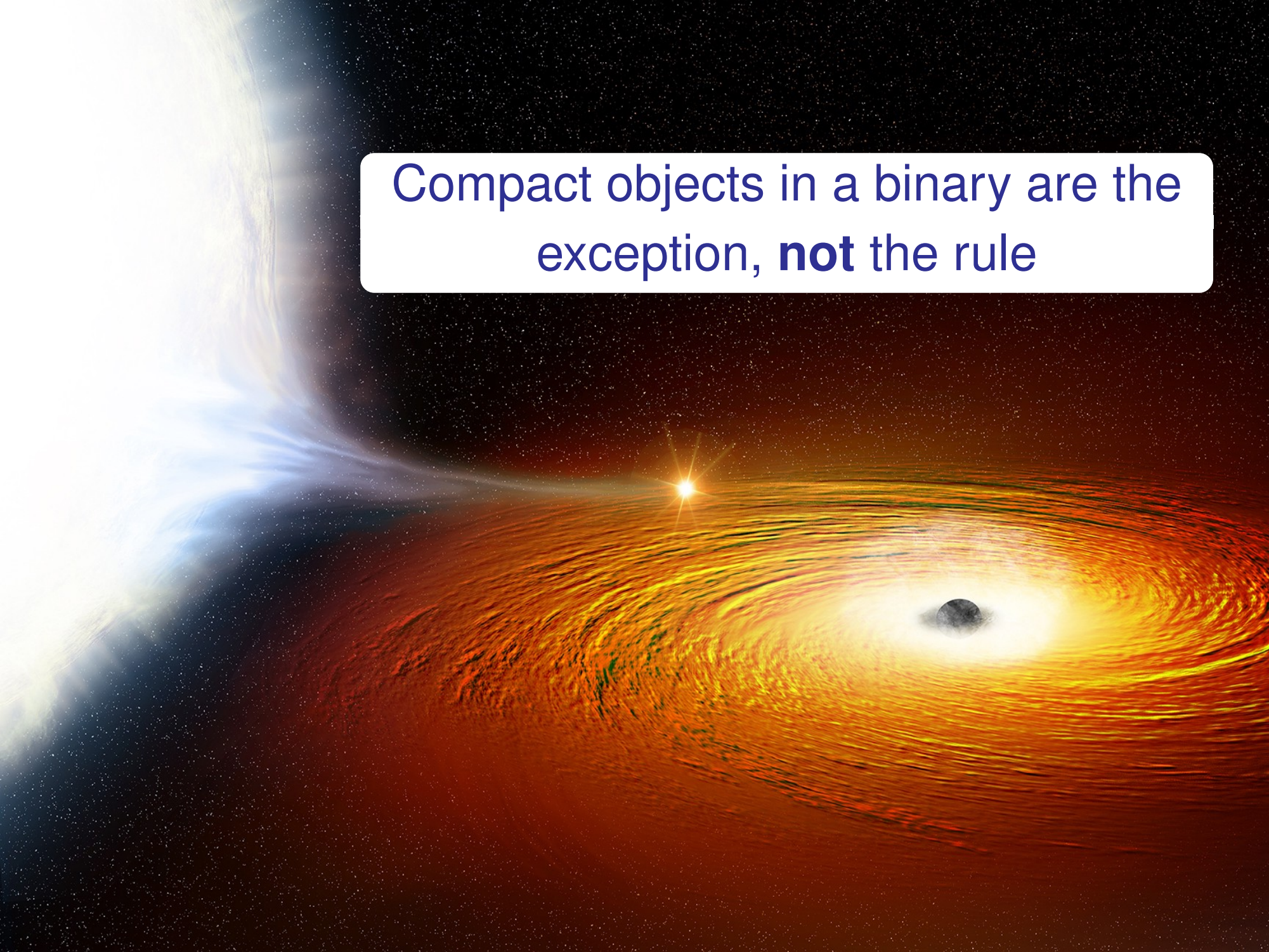


e.g., Zapartas *et al.* (incl. MR) 19, Eldridge *et al.* 18, 19, Smartt *et al.* 09, Arcavi *et al.* 10, Li *et al.* 11, Shivvers *et al.* 16


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

Post-SN velocity of surviving binaries

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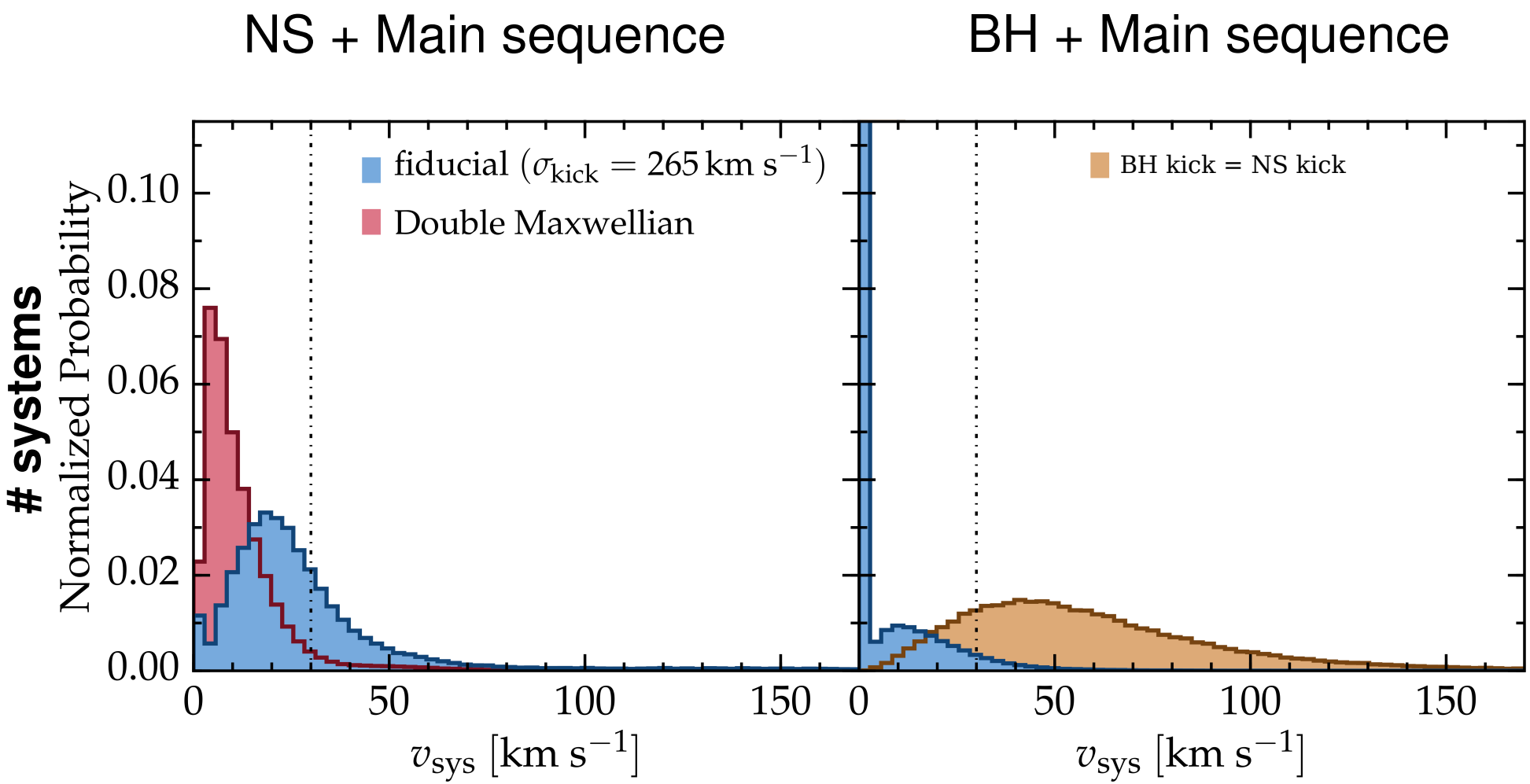
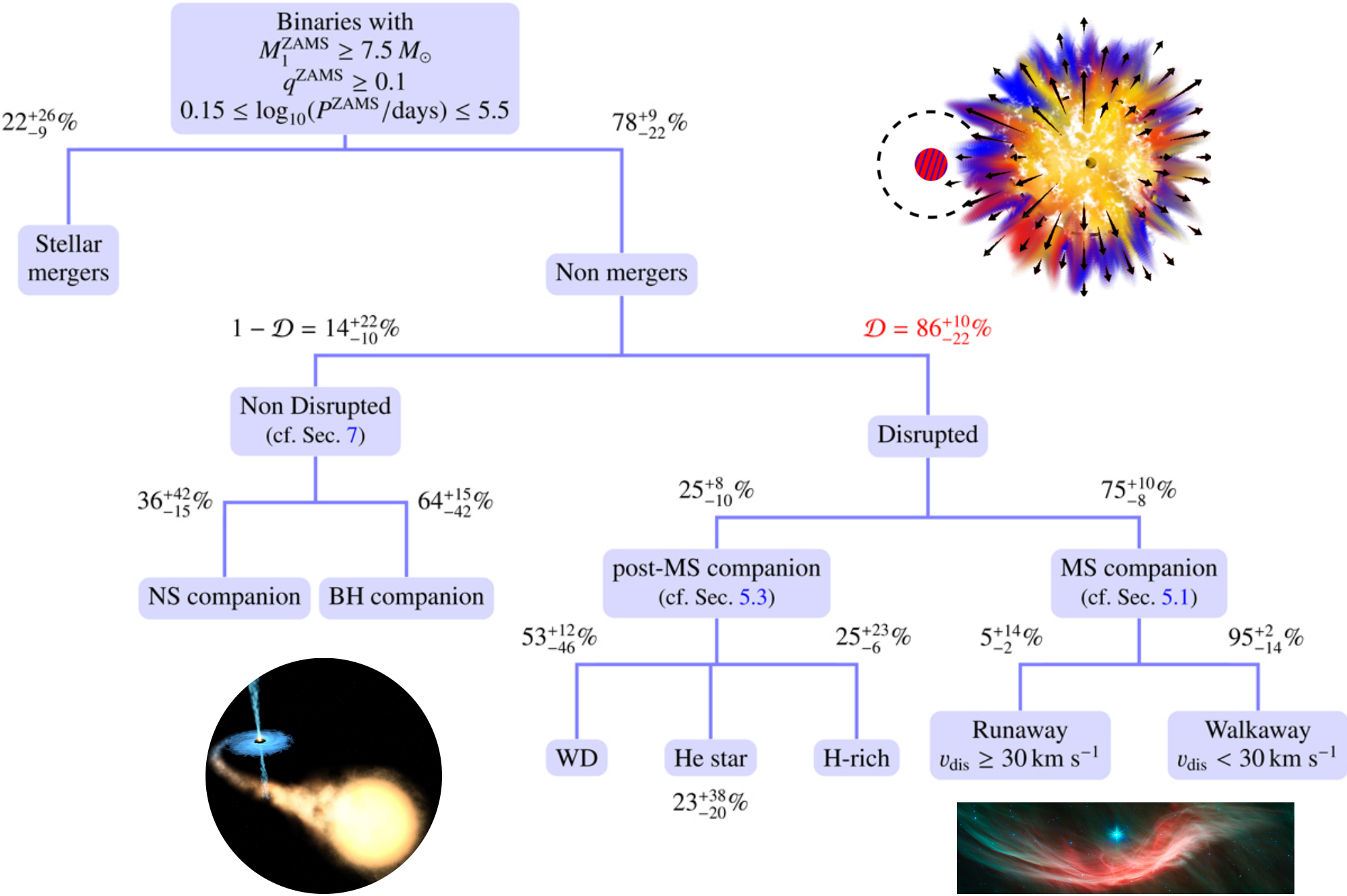


Velocity respect to the pre-explosion binary center of mass

Renzo *et al.* 19b

Conclusions

The variety of binary products



e.g., Renzo *et al.* 19b

Take home points

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

$\Rightarrow$ NSs and BHs with companion are the exception, **not** the rule

- Even single stars can be binary products

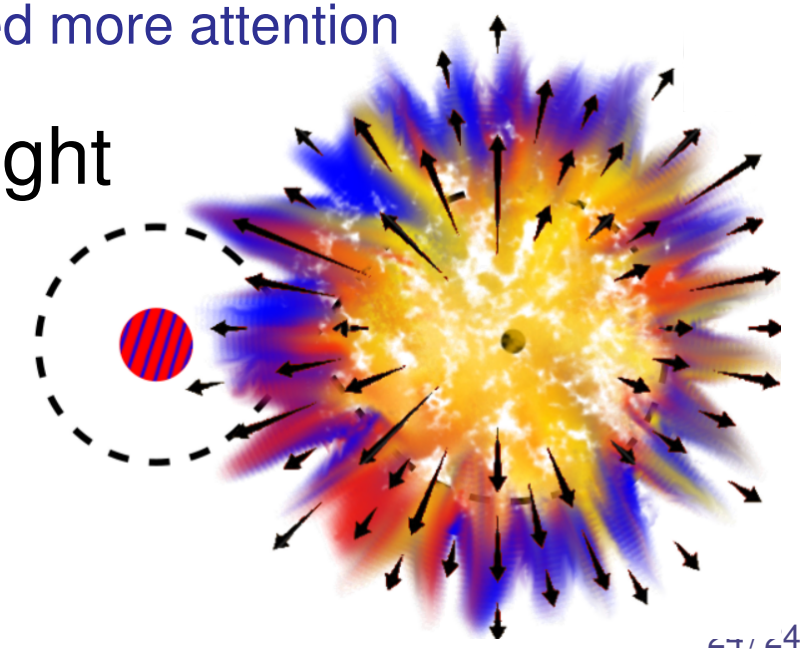
$\Rightarrow$ if found, "widowed" stars can constrain BH formation and orbital evolution

- Binarity changes the initial conditions for explosions

$\Rightarrow$ Initial conditions for core-collapse SNe need more attention

- Up to $\sim$50% of H-rich SNe might have binary progenitors

$\Rightarrow$ Diversity of transients is related to binarity



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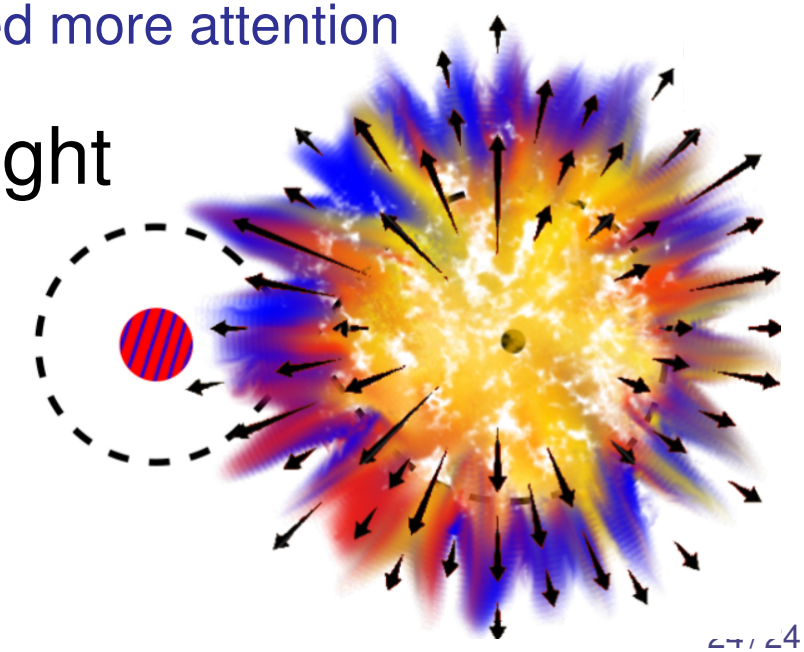

Thank you!

Backup slides

Contamination from dynamical ejections

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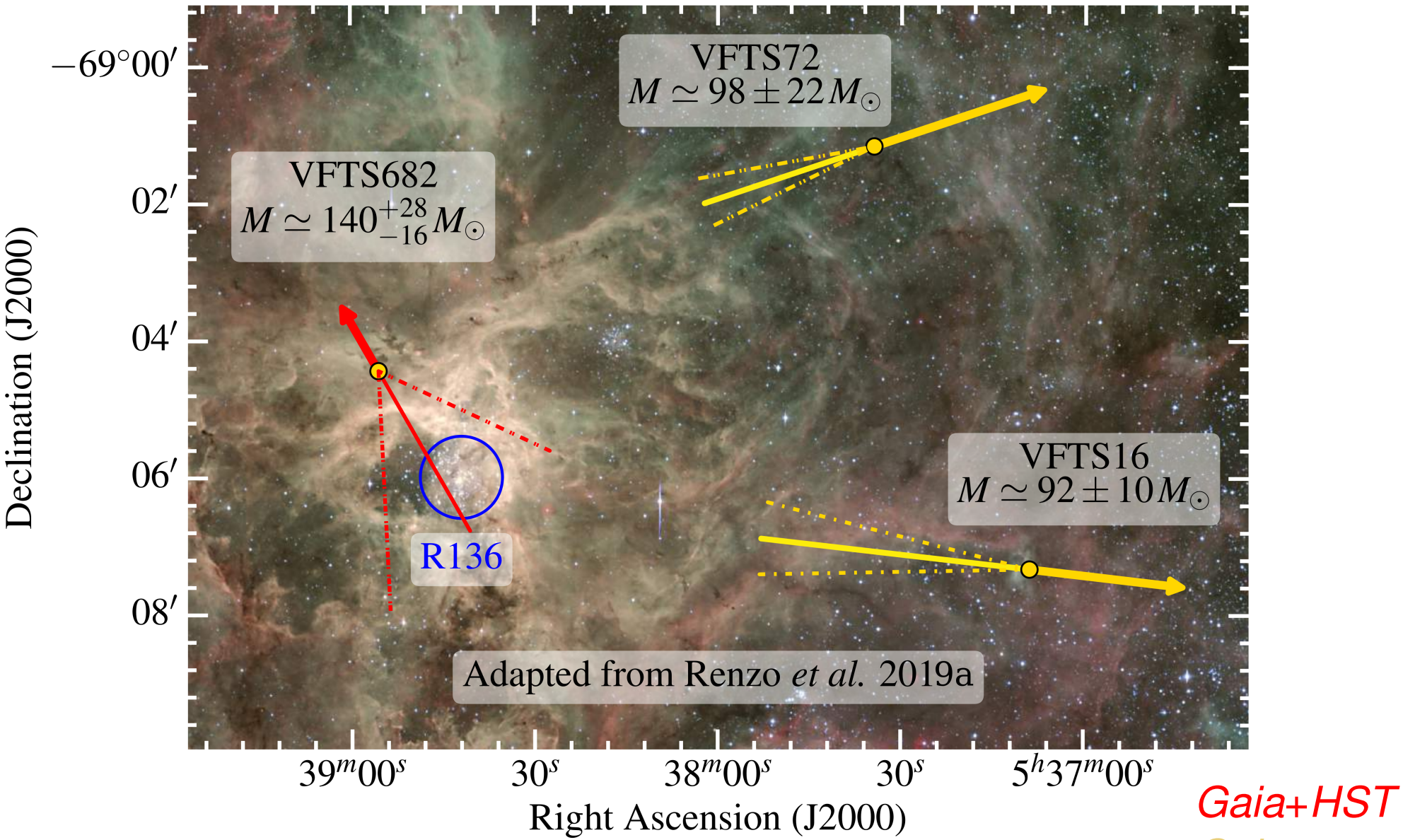
Proper motions relative to the cluster R136



Gaia+HST

Gaia

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

Mergers and reverse mass transfer can produce a variety of transients

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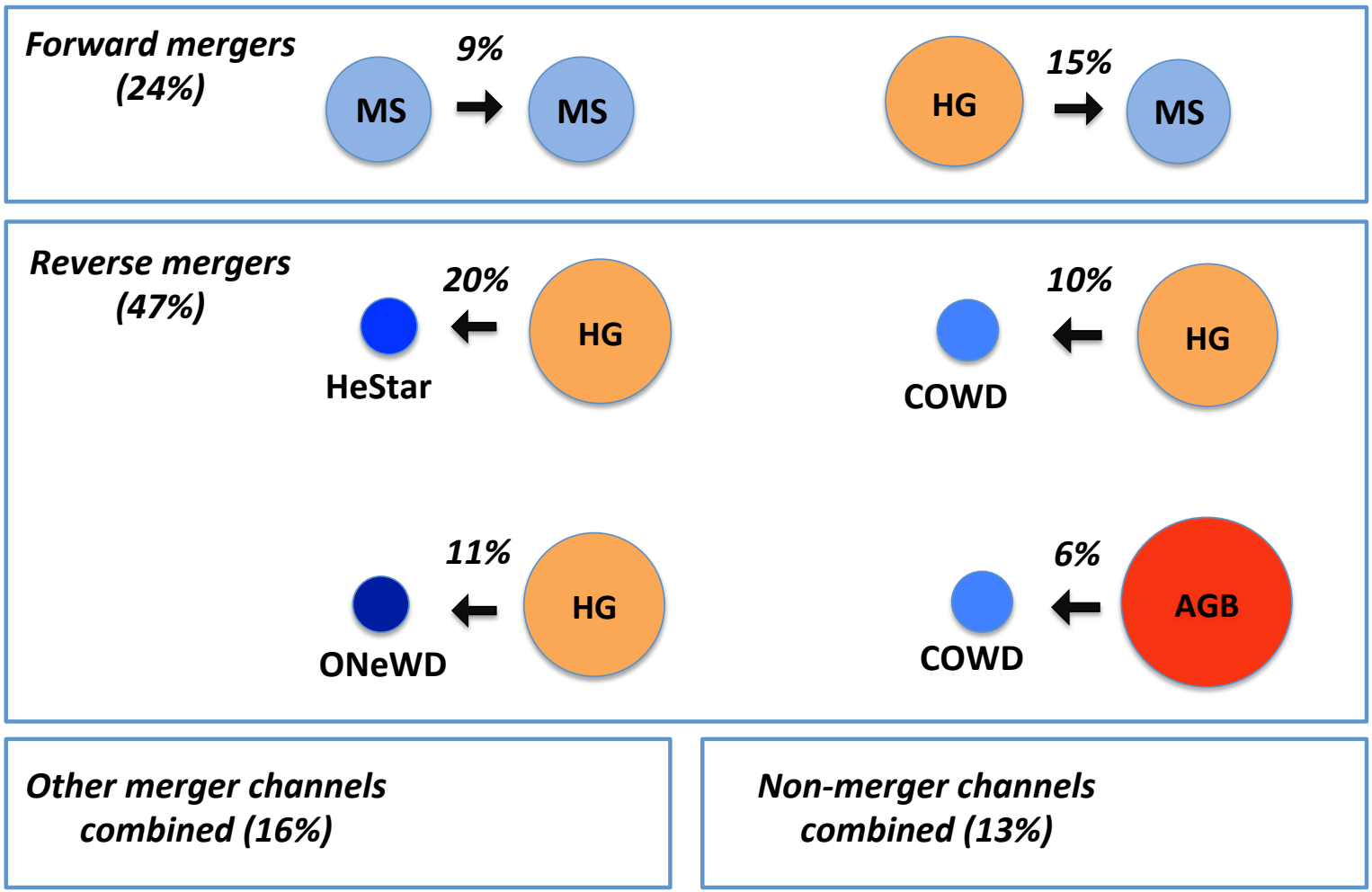
Evolutionary channels for "late" core-collapse Supernovae



e.g., Zapartas *et al.* (incl. MR) 17a

Delay time distribution of CCSNe events

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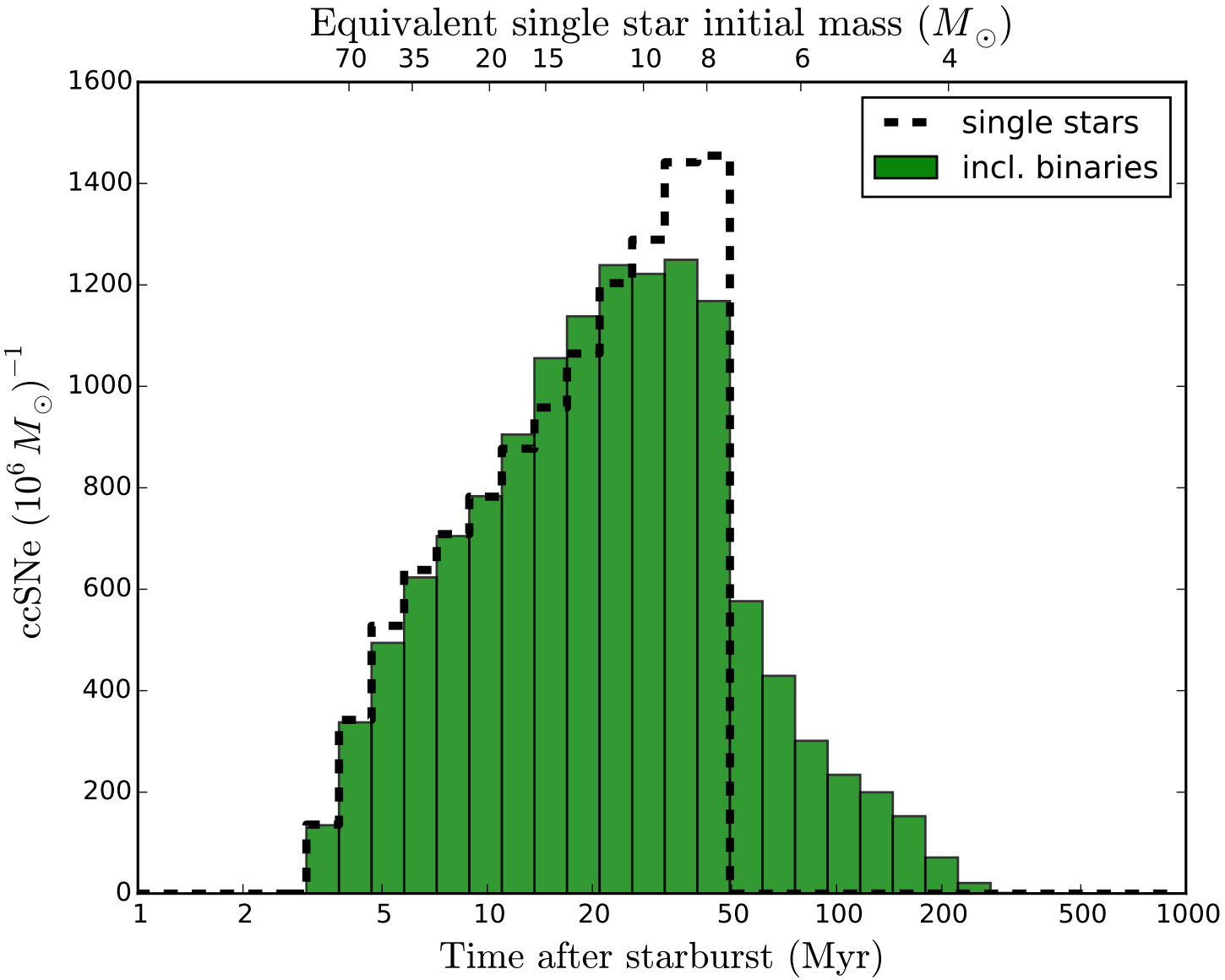

e.g., Zapartas *et al.* (incl. MR) 17a

Methods: Population Synthesis

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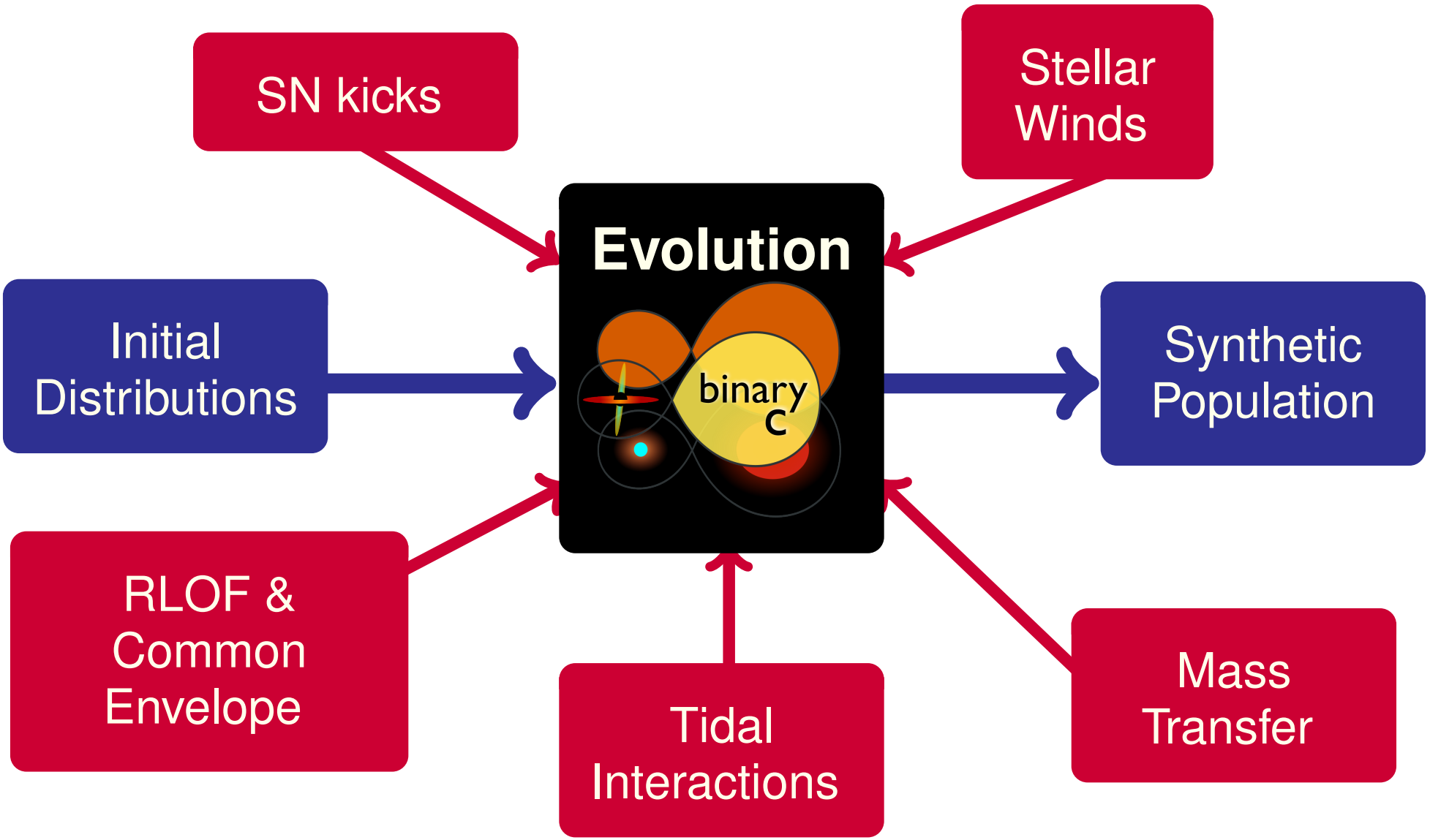
Fast $\Rightarrow$ Allows statistical tests of the inputs & assumptions



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