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Massive runaways: constraints on binary interactions explosion physics and field contamination

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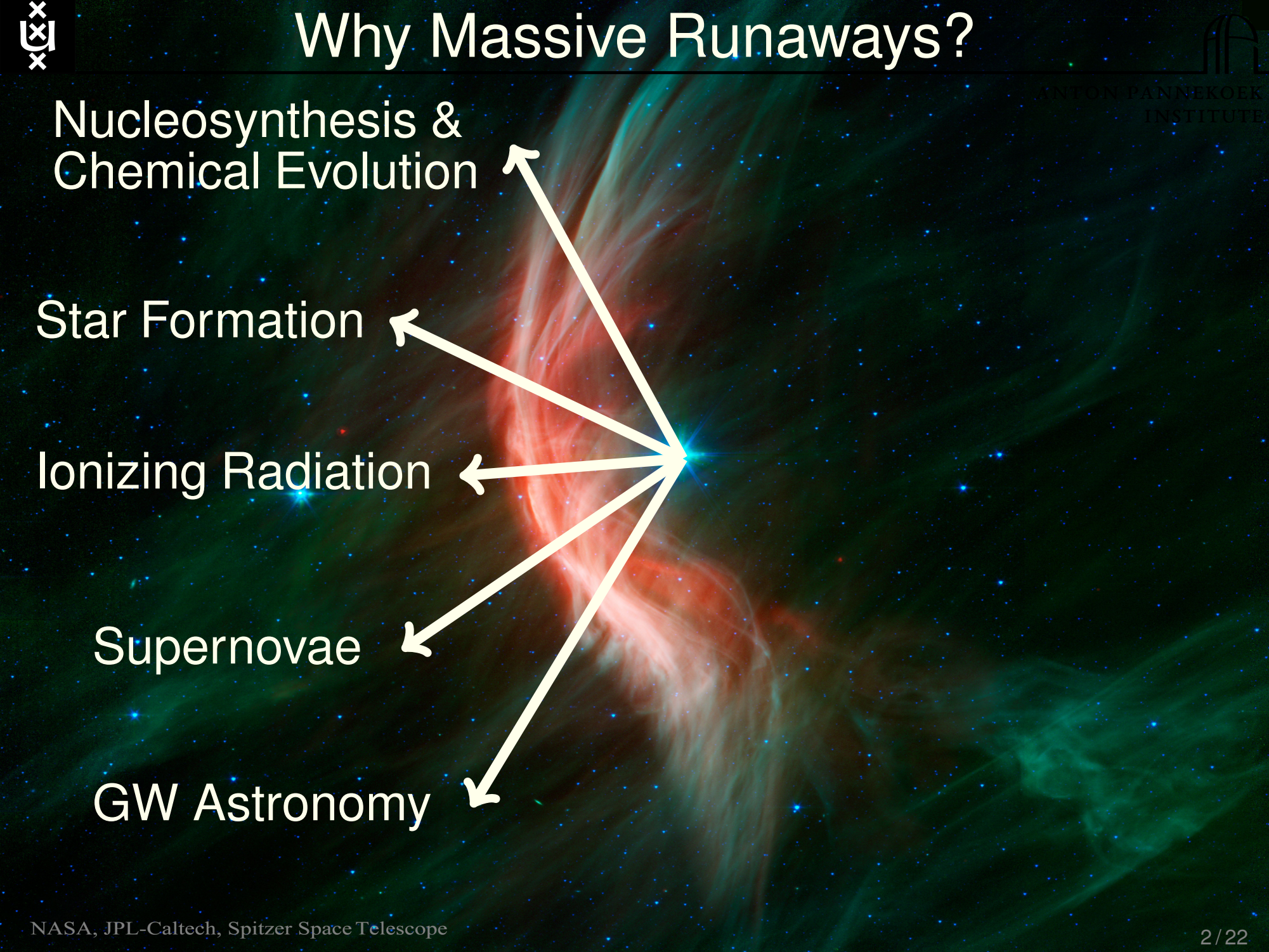
PhD in Amsterdam

Collaborators: S. E. de Mink, E. Zapartas, Y. Götberg, F. R. N. Schneider, R. G. Izzard, H. Sana

Why Massive Runaways?



NASA, JPL-Caltech, Spitzer Space Telescope

Why Massive Runaways?

Nucleosynthesis & Chemical Evolution

Star Formation

Ionizing Radiation

Supernovae

GW Astronomy

$\sim$ 70% of O type stars are in close binaries

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

$\sim$ 10% of O type stars are runaways!

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

NASA, JPL-Caltech, Spitzer Space Telescope

How do we know?

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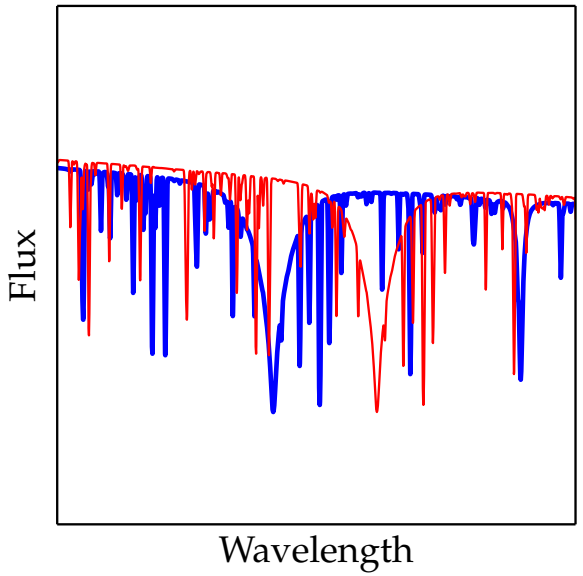
⇐ Bow shocks

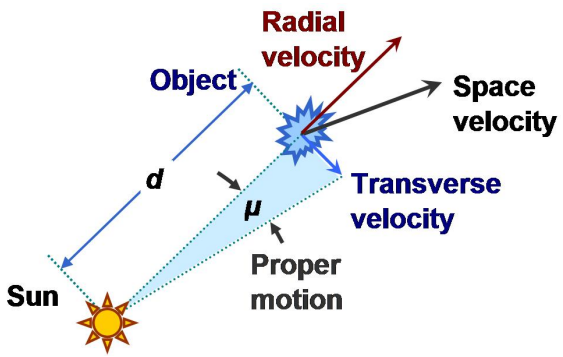
Doppler shifts ⇒



Proper motions

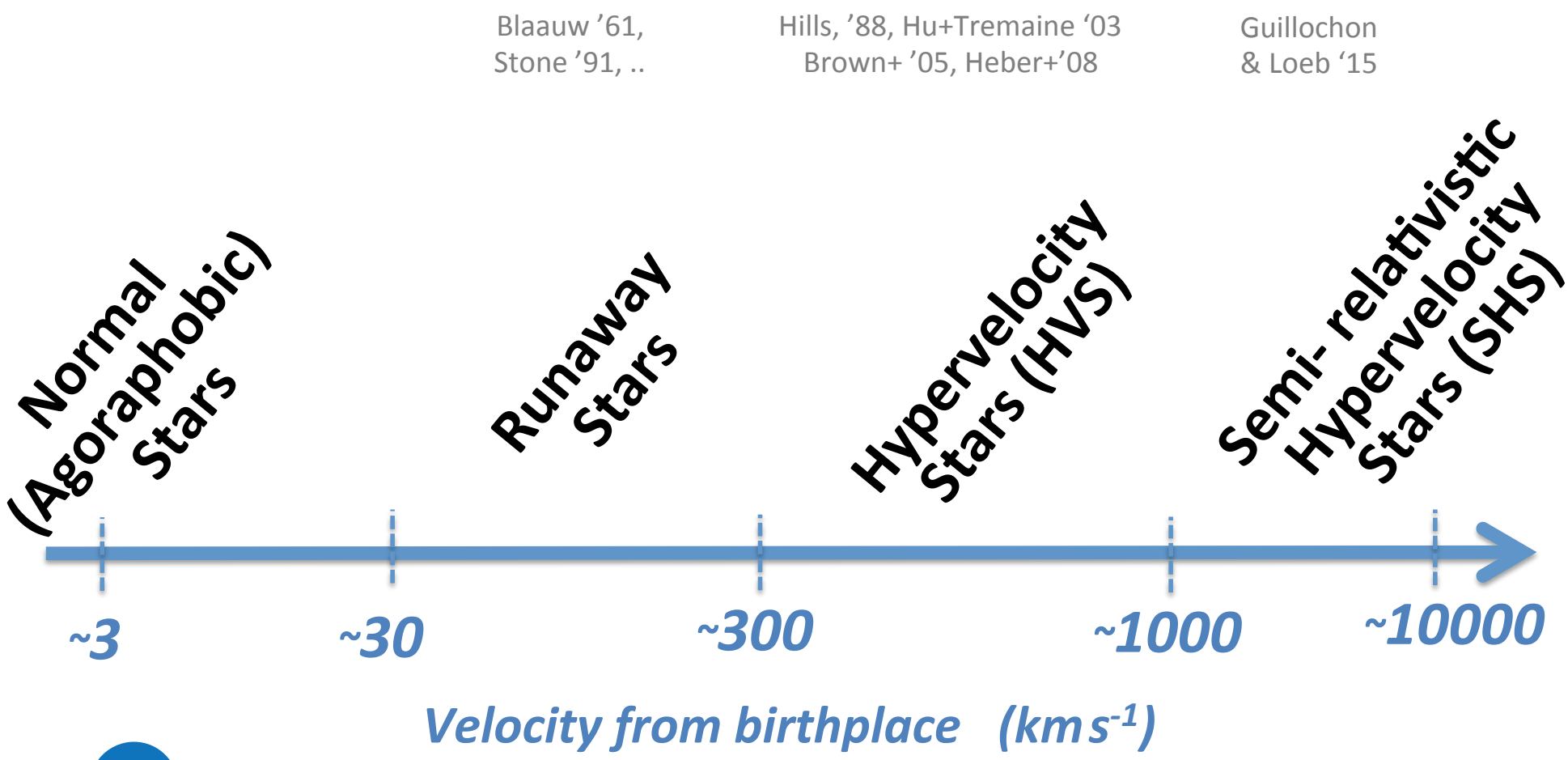
(if distance known)

⇓



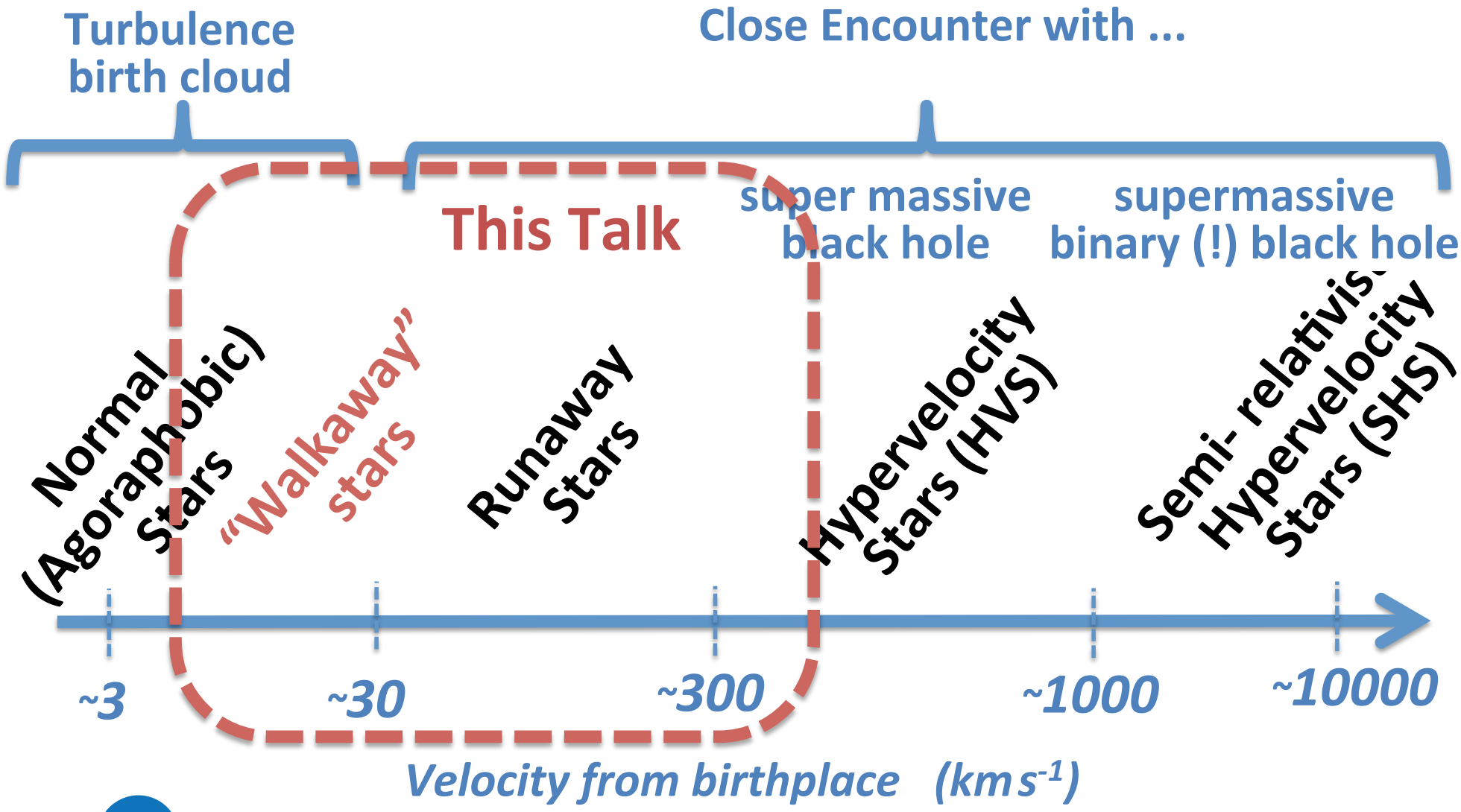
How fast?

(courtesy of S. E. de Mink)



Why so fast?

(courtesy of S. E. de Mink)



Outline

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Introduction

Binary SN Scenario

What can we learn?

- SN kicks
- Binary physics
- Field contamination

Methods

- Binary Population Synthesis

Overview Preliminary Results

- Do they come from a binary?
- How fast can they be?
- Fraction of field stars from a binary?

Conclusions

From Binary to Runaway

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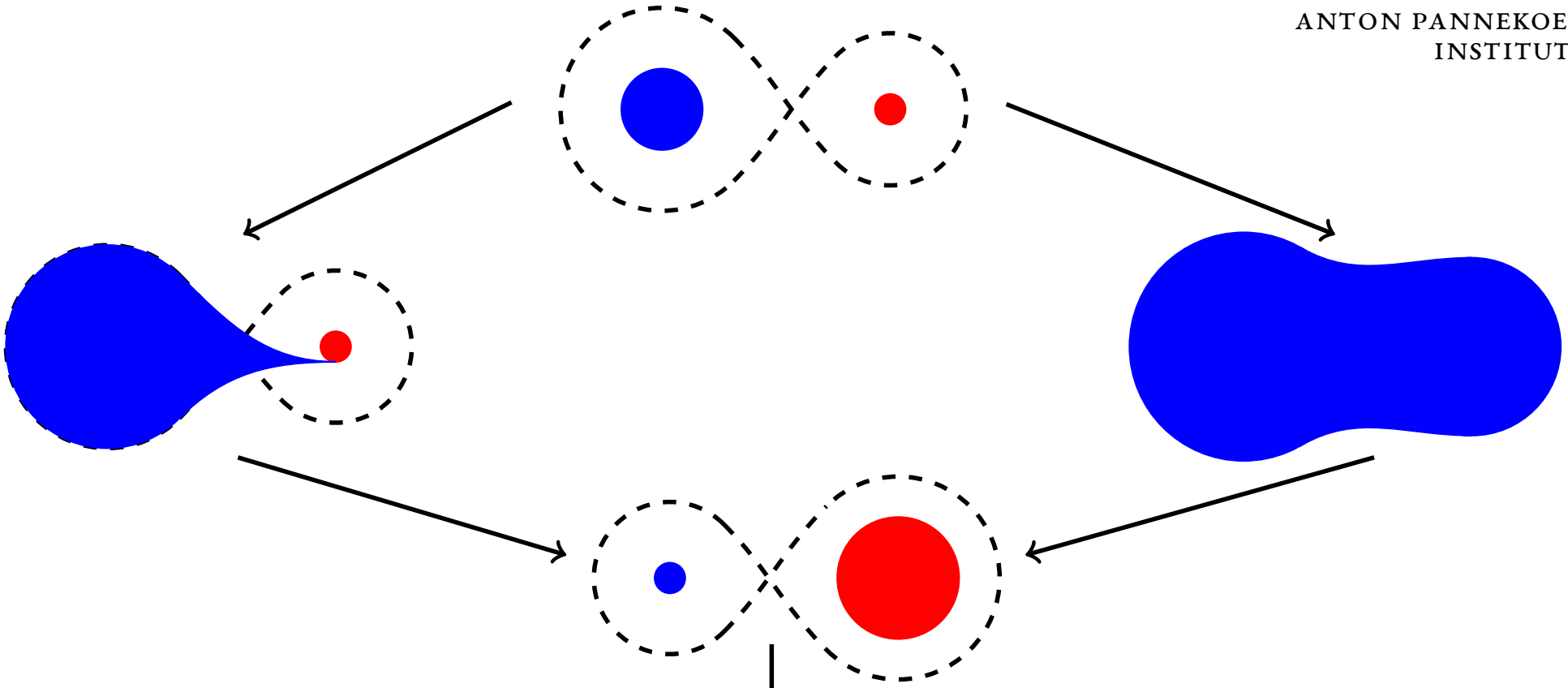


- Unbinding Matter

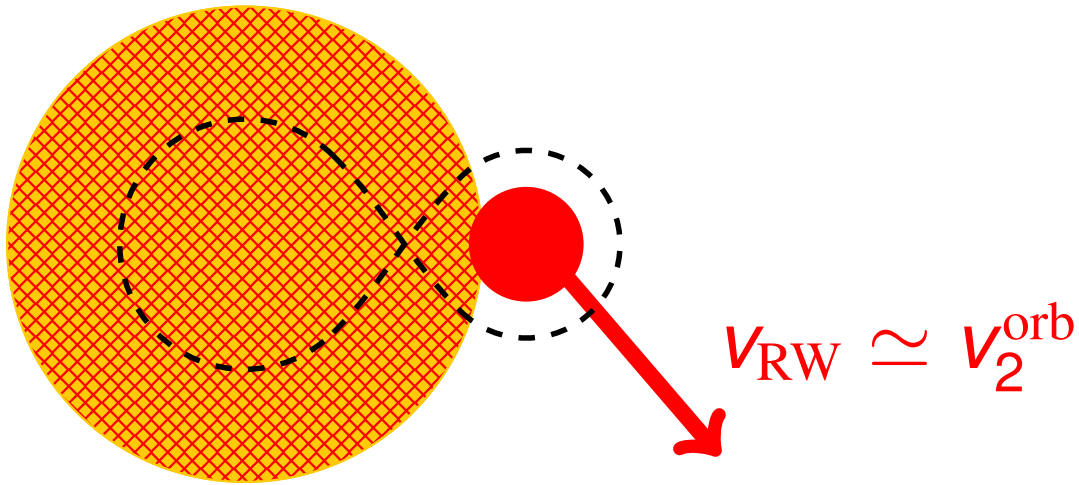
  (e.g. Blaauw '61)

- Ejecta Impact

  (e.g. Tauris & Taken '98)

- SN Natal Kick

  (e.g. Cordes *et al.* '93)



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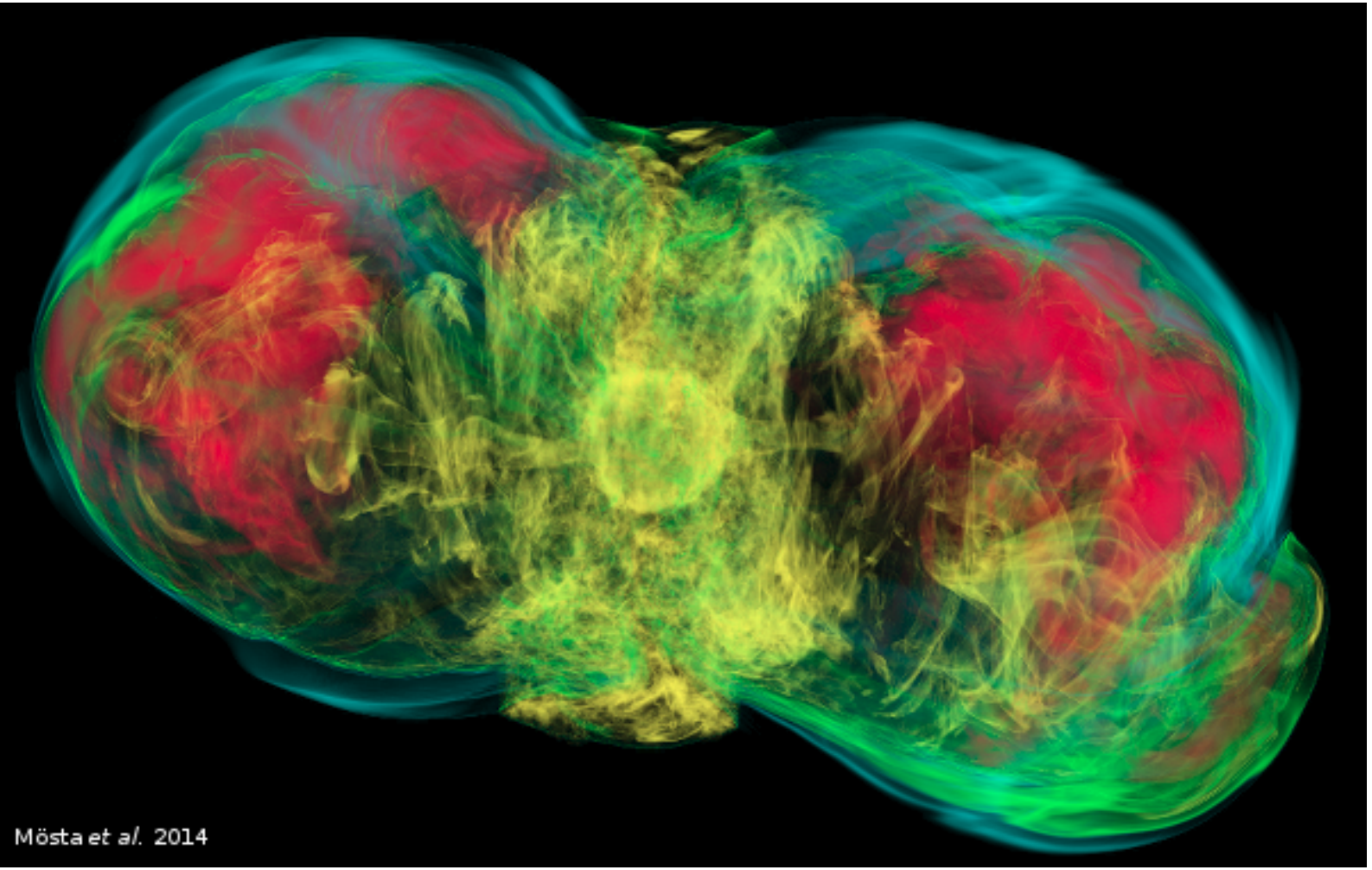
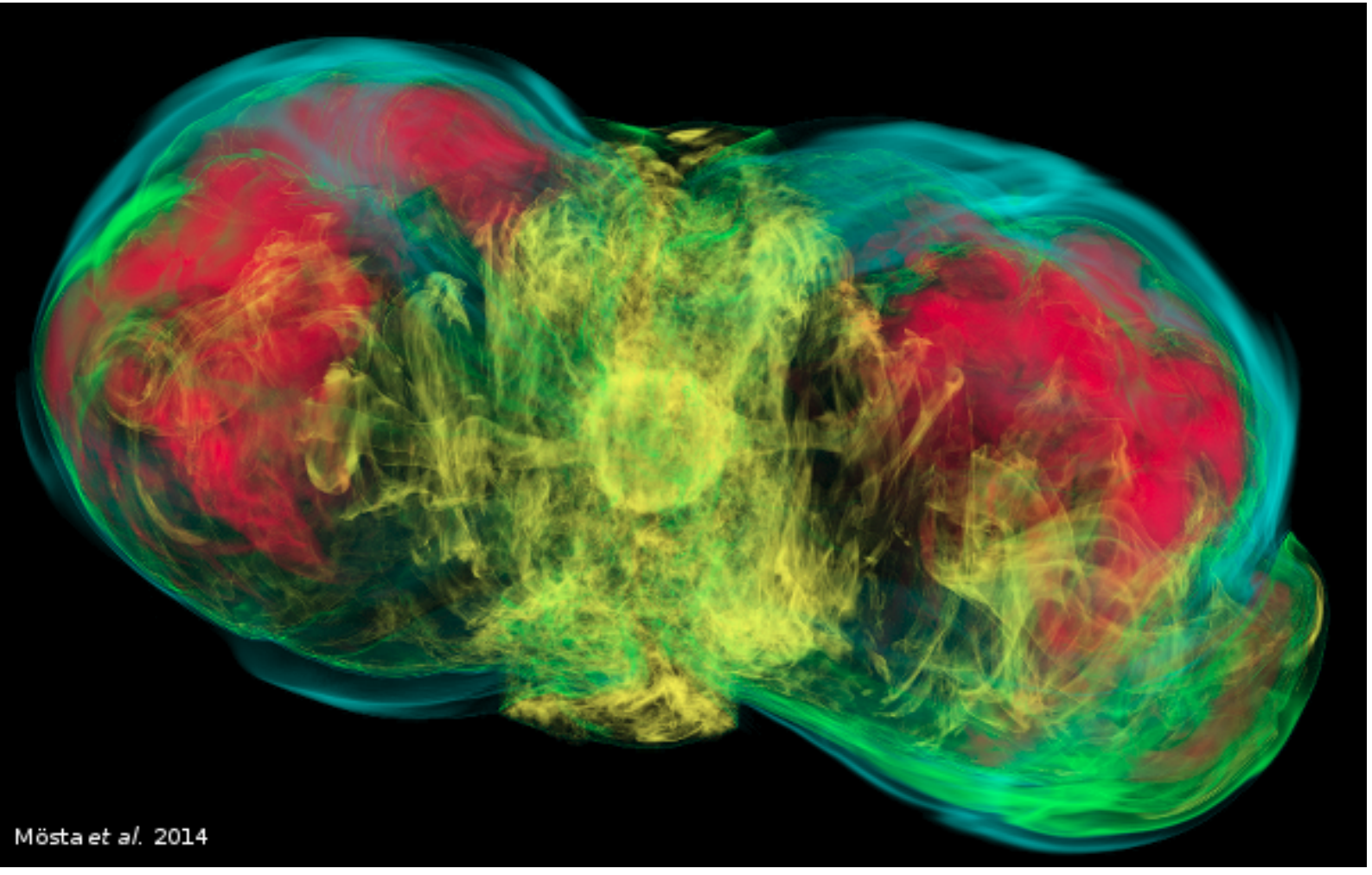
SN natal kick



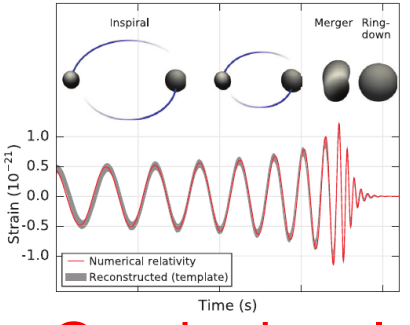
ν emission and/or ejecta anisotropies

SN natal kick

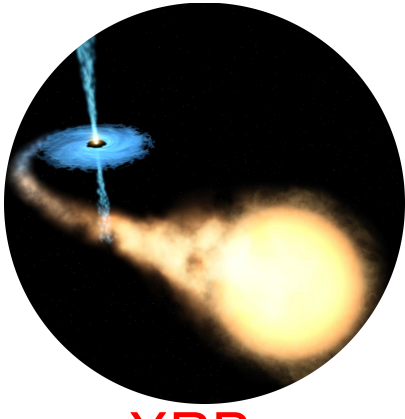
Question: do BH receive a kick?



Runaways



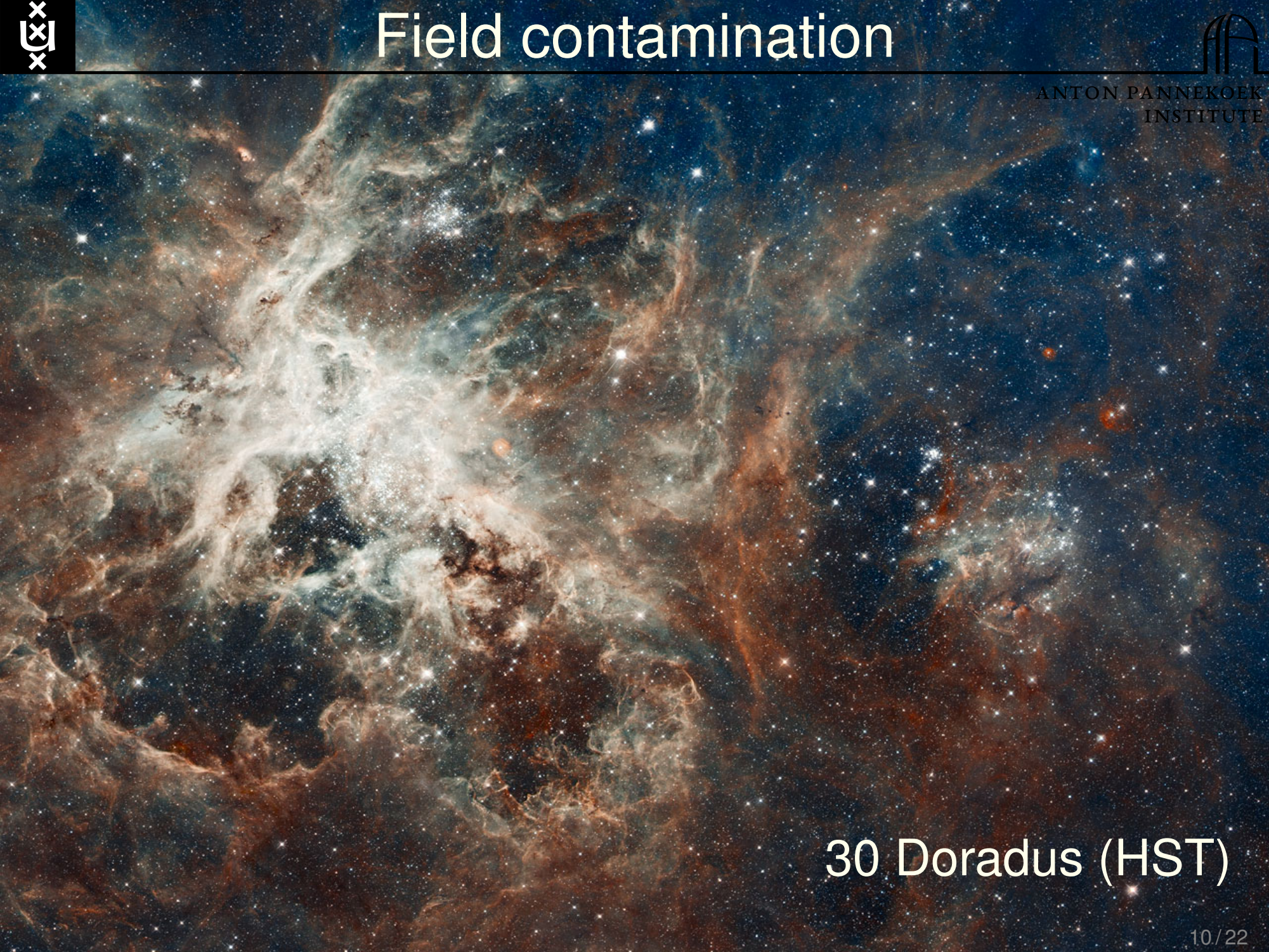
Gravitational Waves



XRBs

ν emission and/or ejecta anisotropies

Field contamination



30 Doradus (HST)

Field contamination

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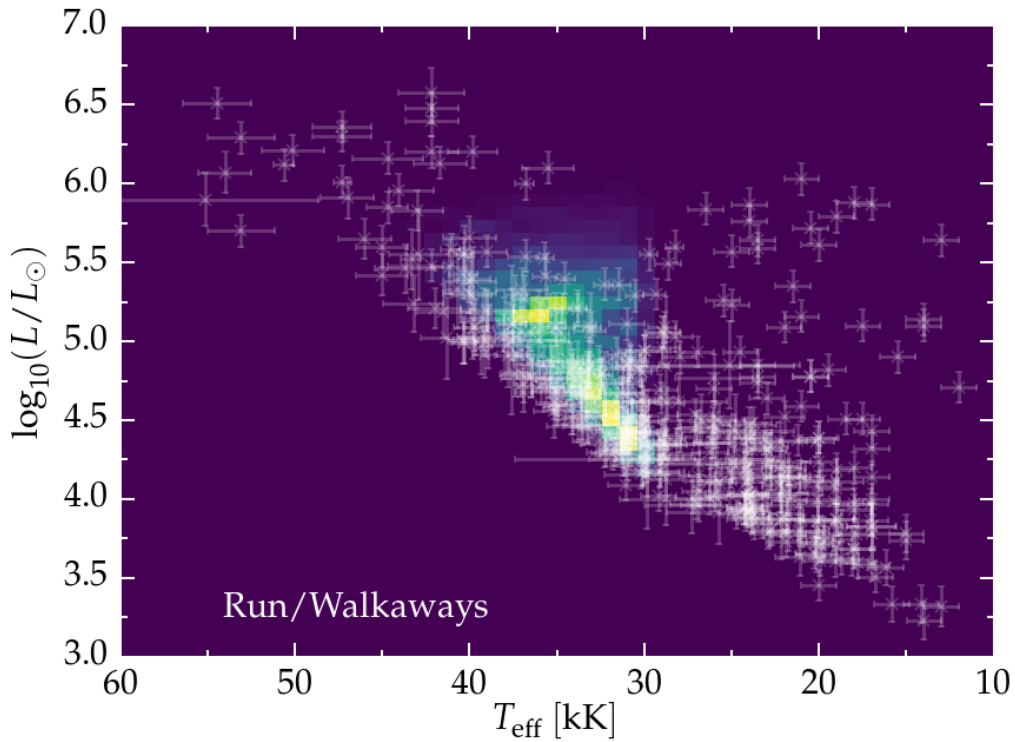
Preliminary



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Population Synthesis

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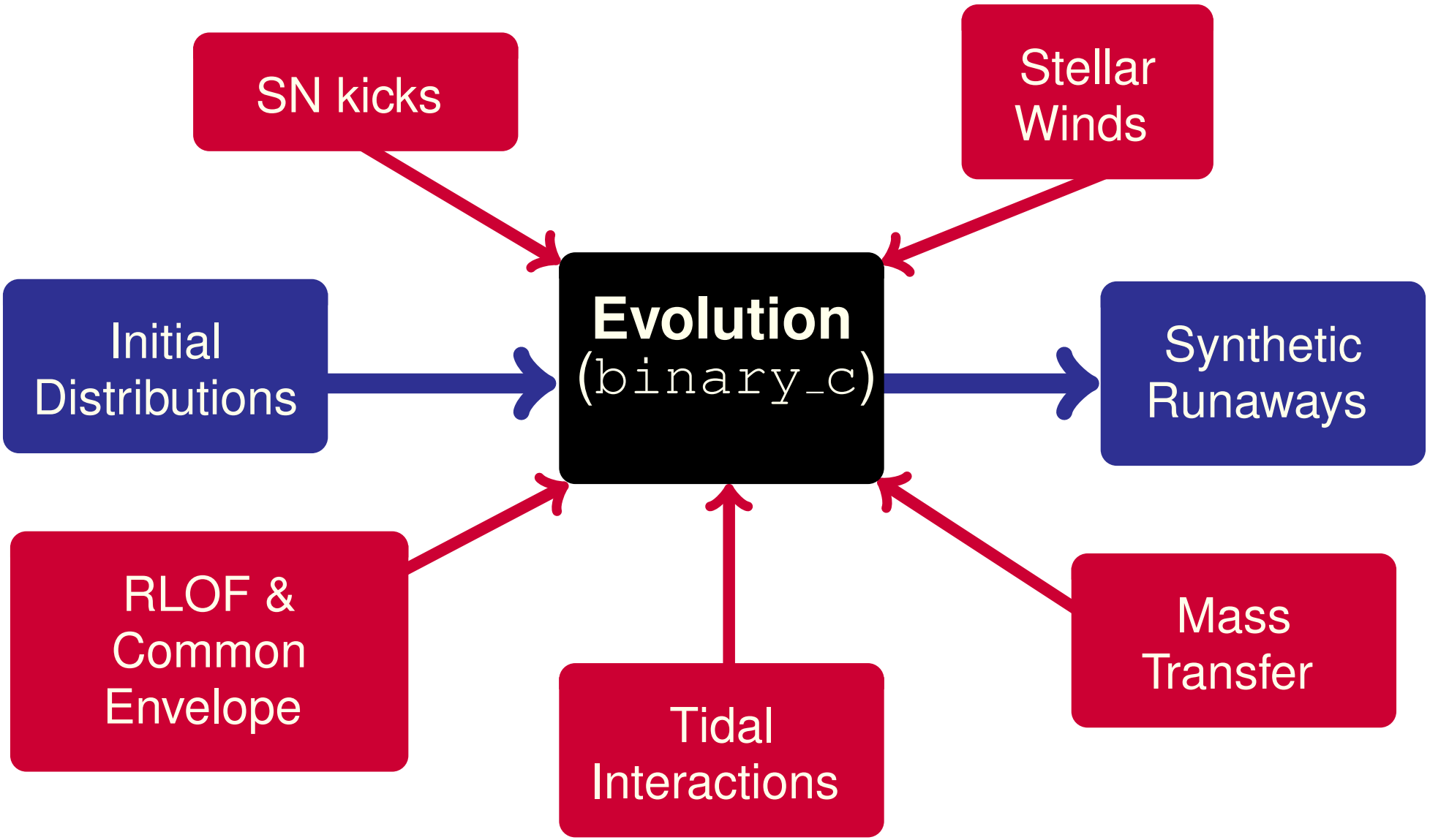
Fast $\Rightarrow$ Allows statistical tests of the inputs & assumptions



binary_c: R. G. Izzard *et al.* '04, '06, '09; S. E. de Mink *et al.* '13

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Preliminary: Rotational velocity

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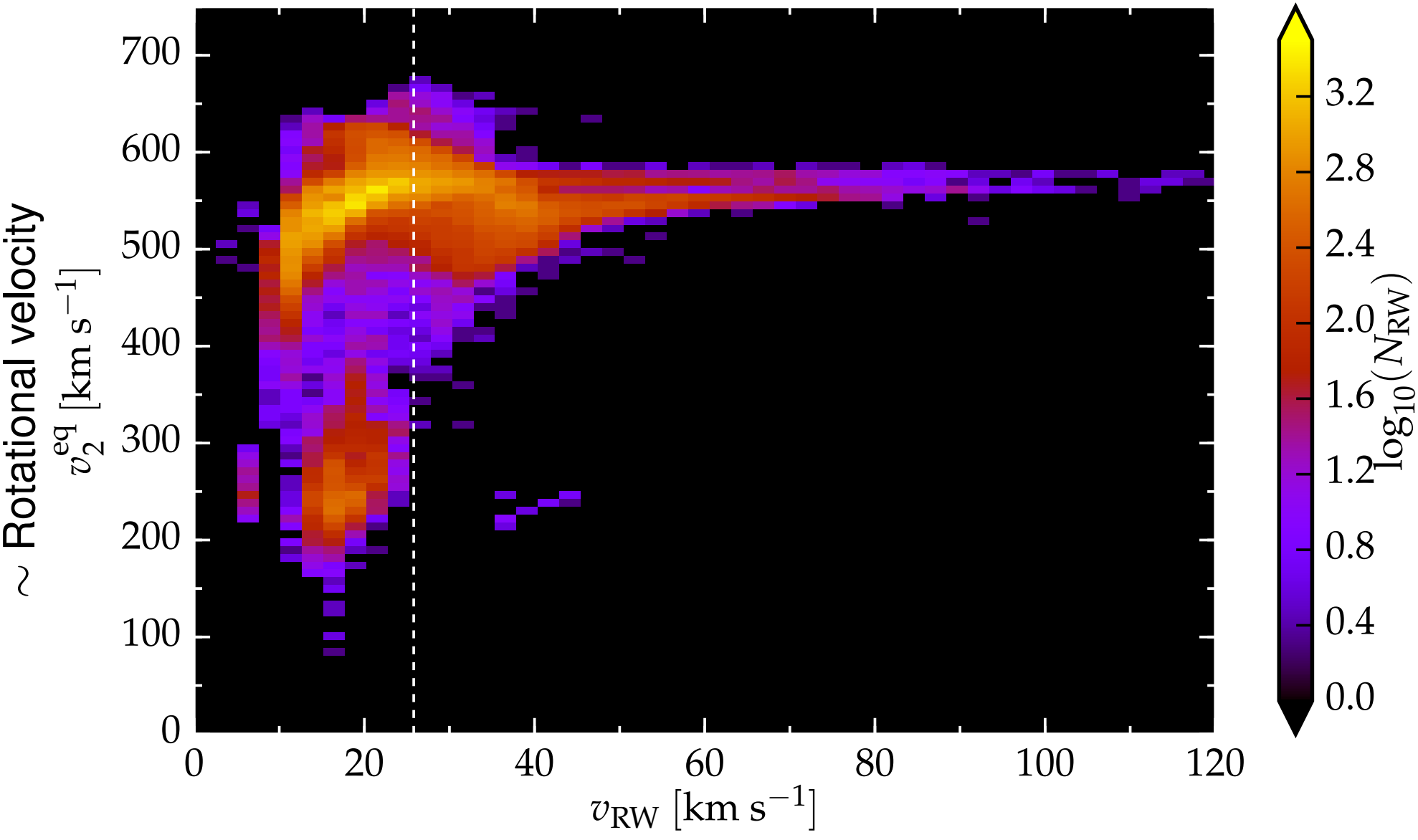

Spin up

Runaways from binary disruption are accretors

Preliminary: Runaways in 30 Doradus

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$\sim$ Rotational velocity

$\sim$ Line of sight velocity

Preliminary: Velocity Distribution

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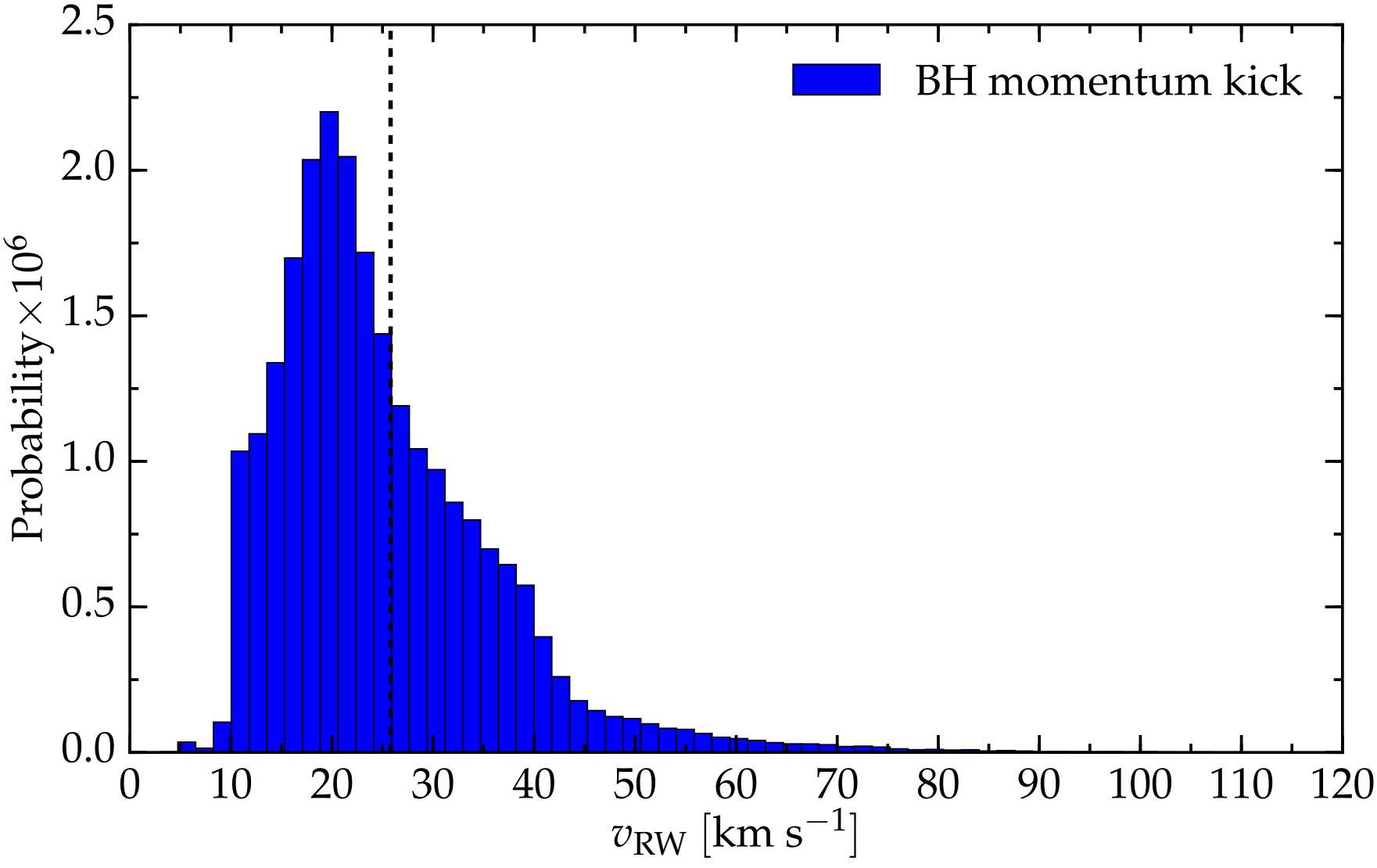
O-type from disrupted binaries only



Preliminary: Velocity Distribution

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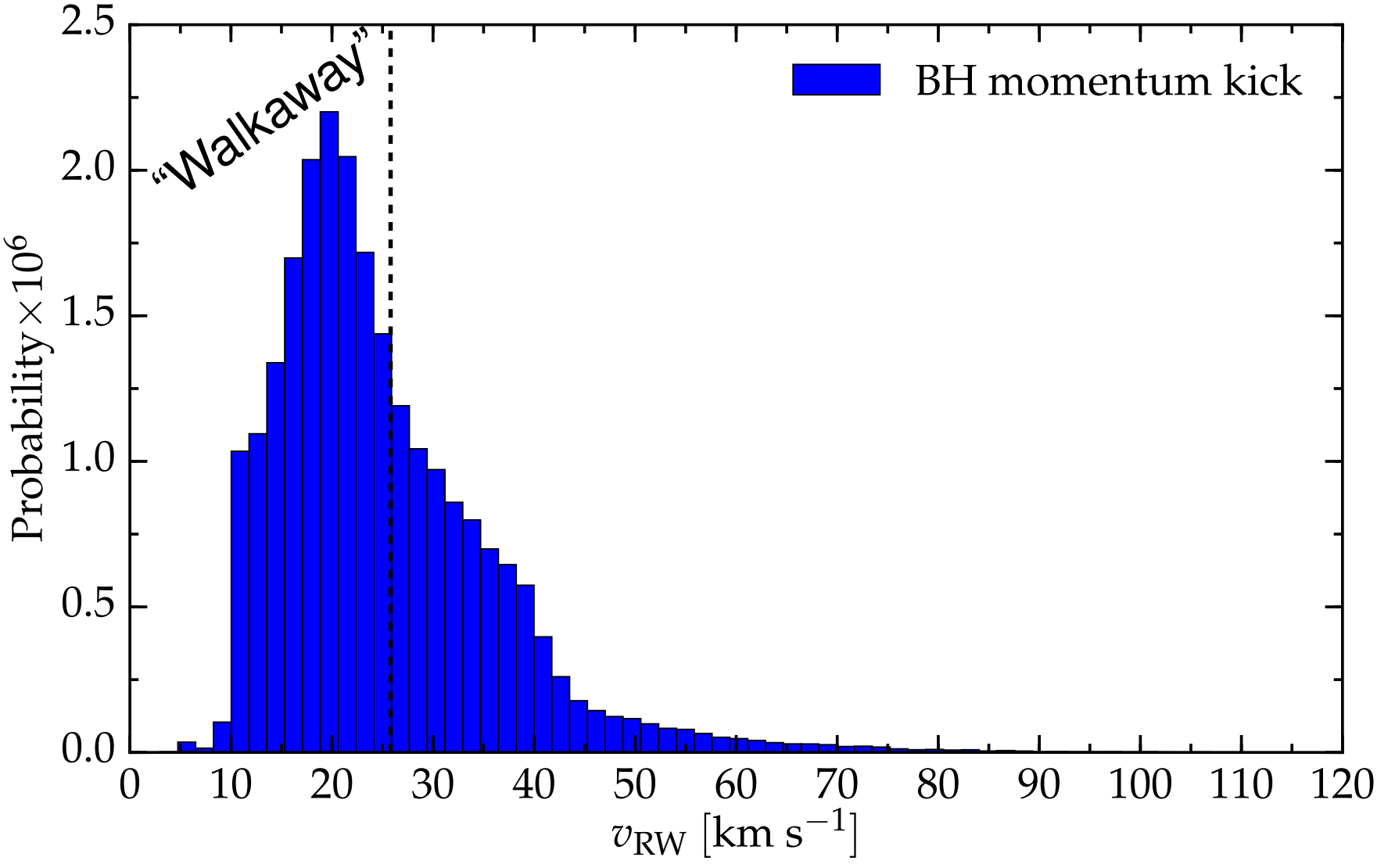
O-type from disrupted binaries only



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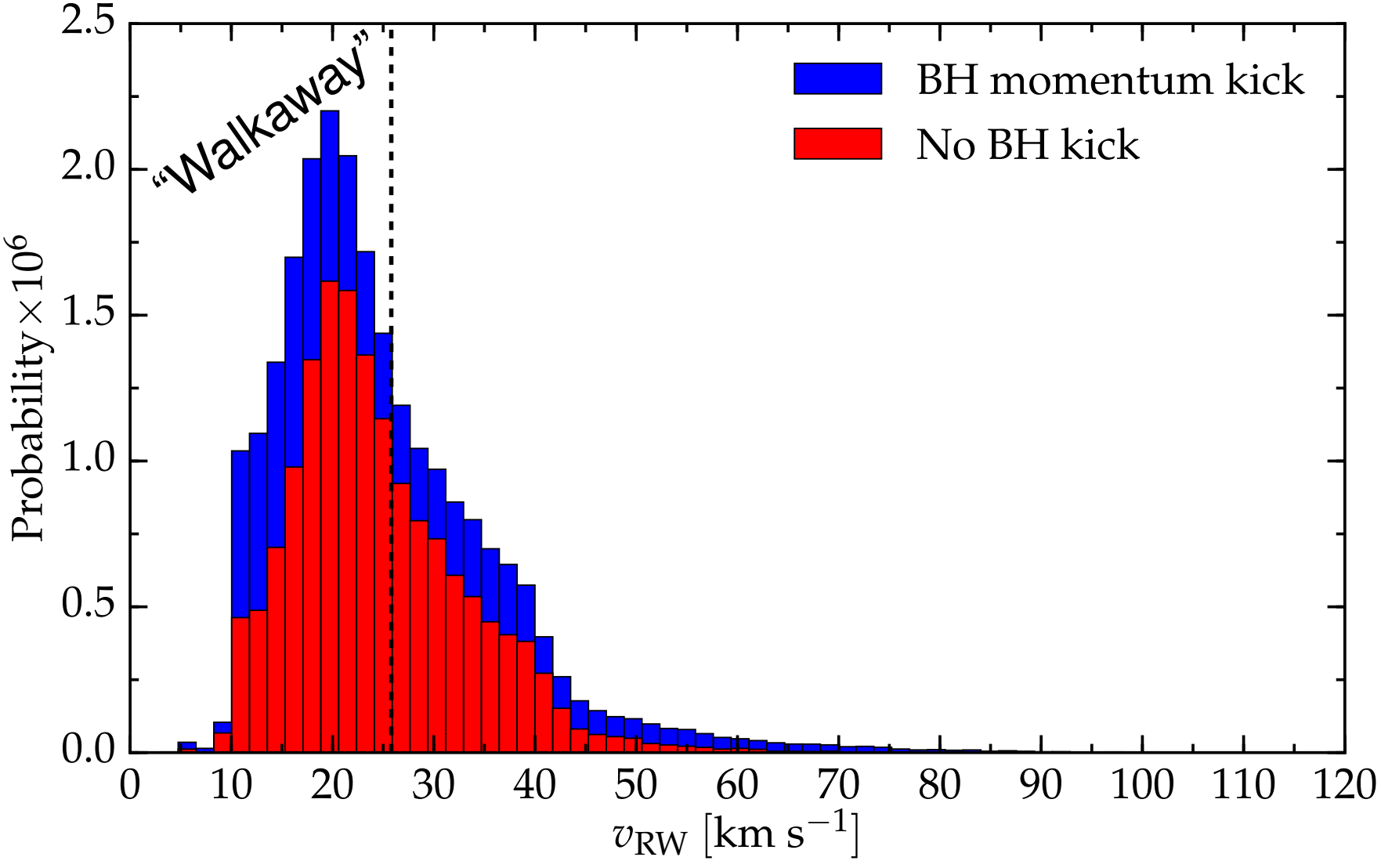
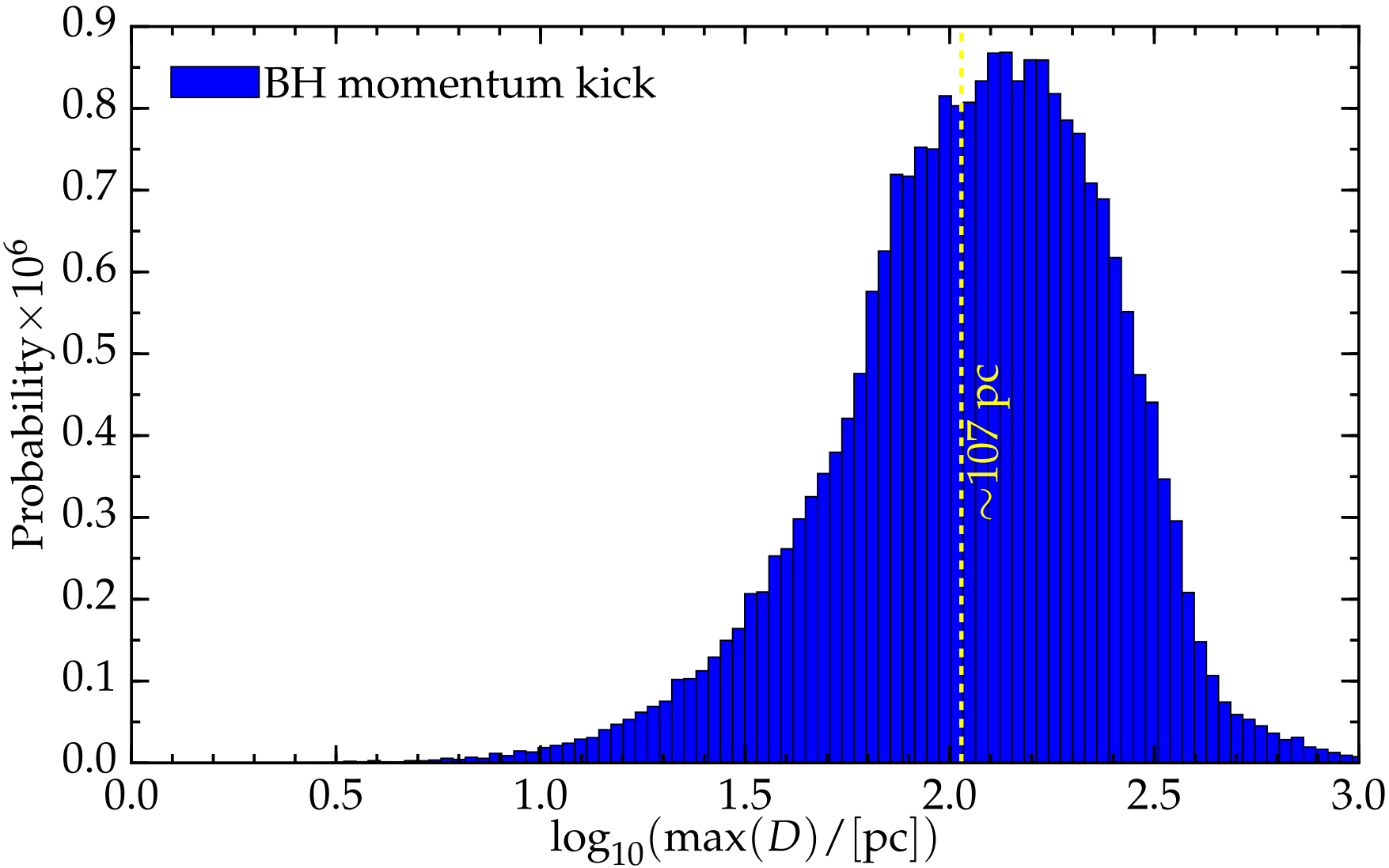


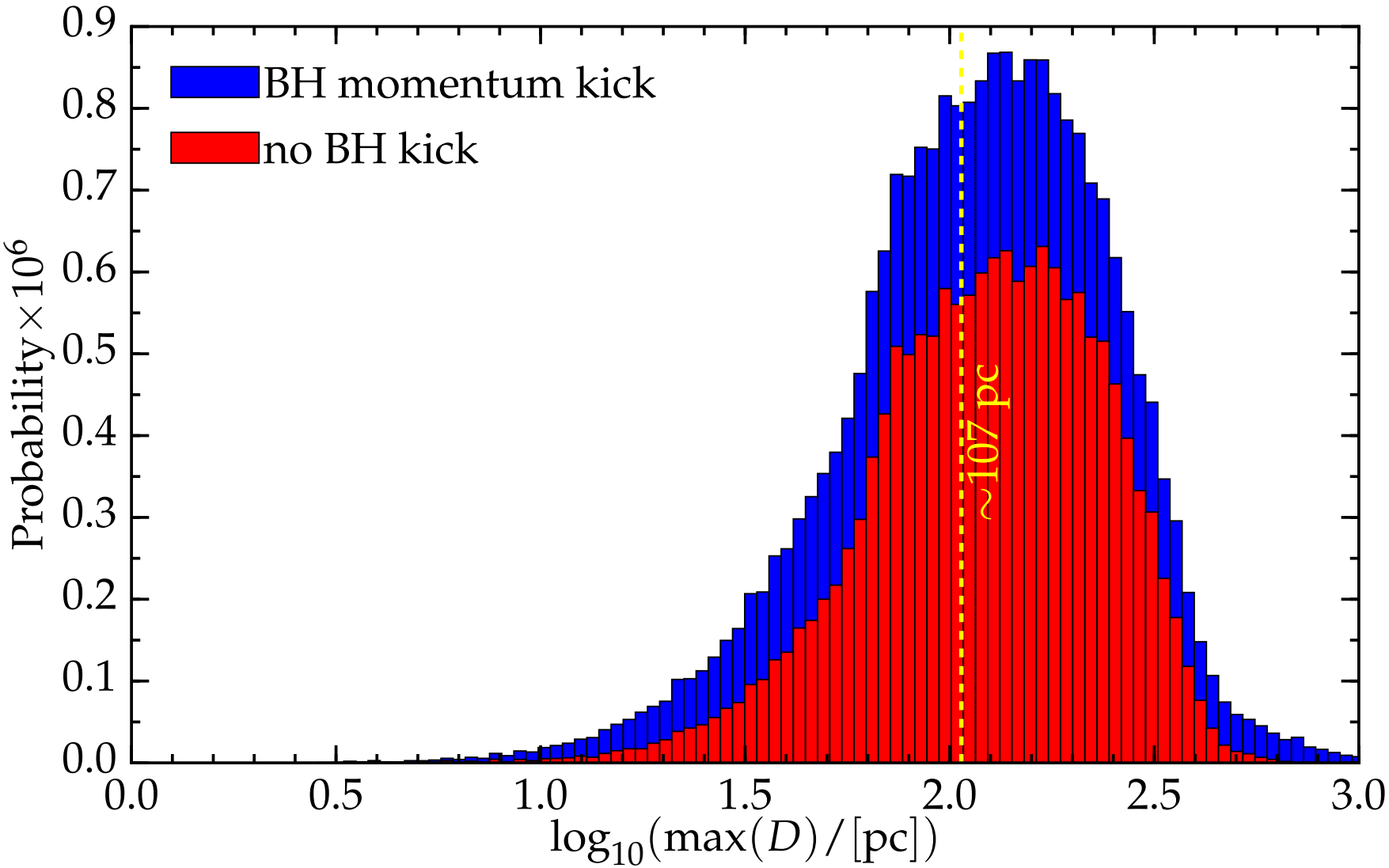
Preliminary: How far can they go?



Upper limit on distance traveled

$\max(D) \stackrel{\text{def}}{=} v_{\text{RW}} \times \Delta t_{\text{RW}} \Rightarrow$ No potential well $\quad 1\,\text{km s}^{-1} \simeq 1\,\text{pc Myr}^{-1}$

Preliminary: How far can they go?



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Preliminary: Binary Contamination

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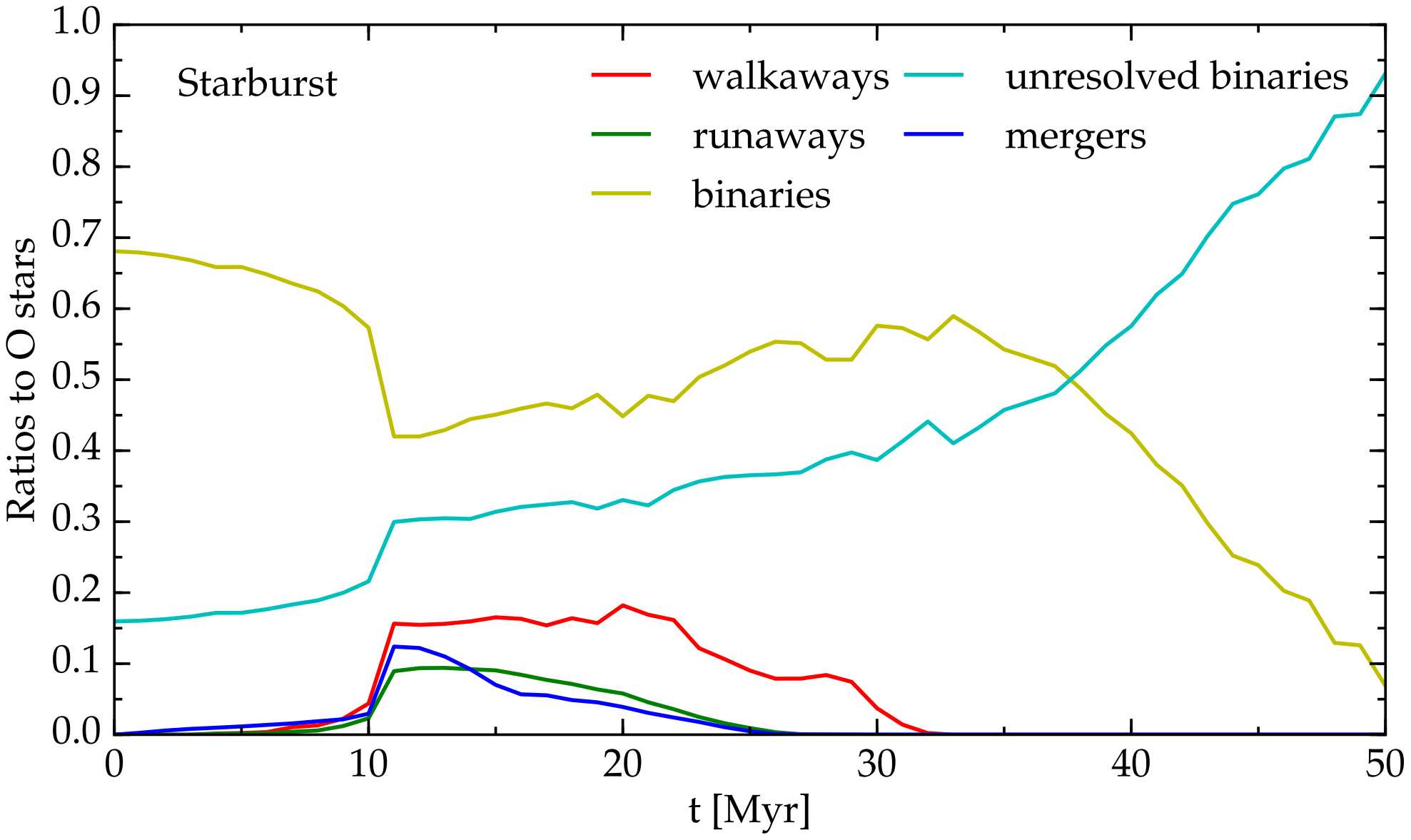

Preliminary: Ratio of Runaways

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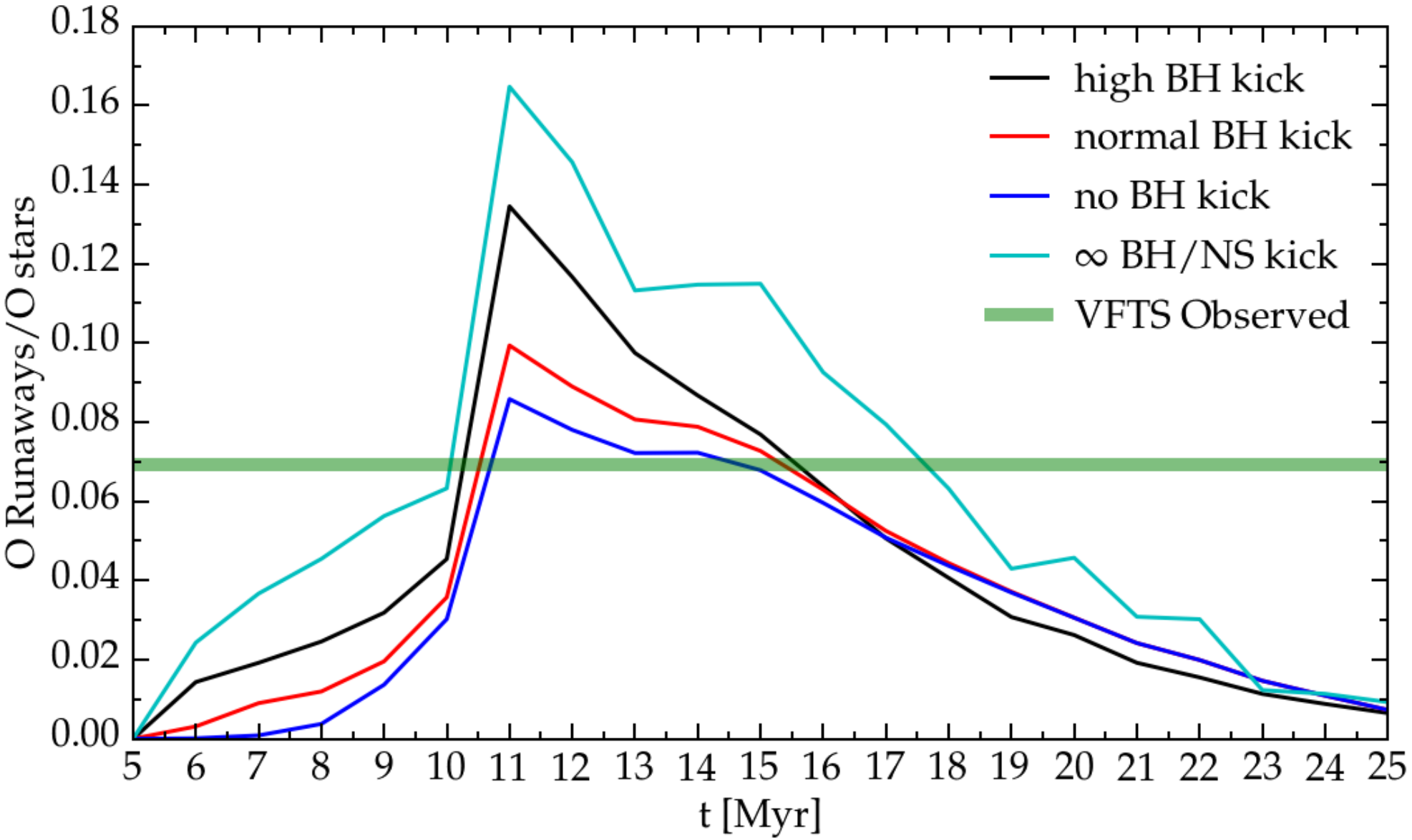

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Future Plans & Conclusions

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Robustness checks:

- Binary physics assumptions;
- Initial distributions;
- Star Formation History;
- Different BH-kick models.

Take home points

Massive walk/runaways stars...

- **...carry info on previous binary evolution;**
- **...can be used to learn about companion explosion;**
- **...enhances role of massive stars in galaxies.**

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Thank you!

Backup slides

Preliminary: Mass vs. $v_{\rm RW}$ velocity

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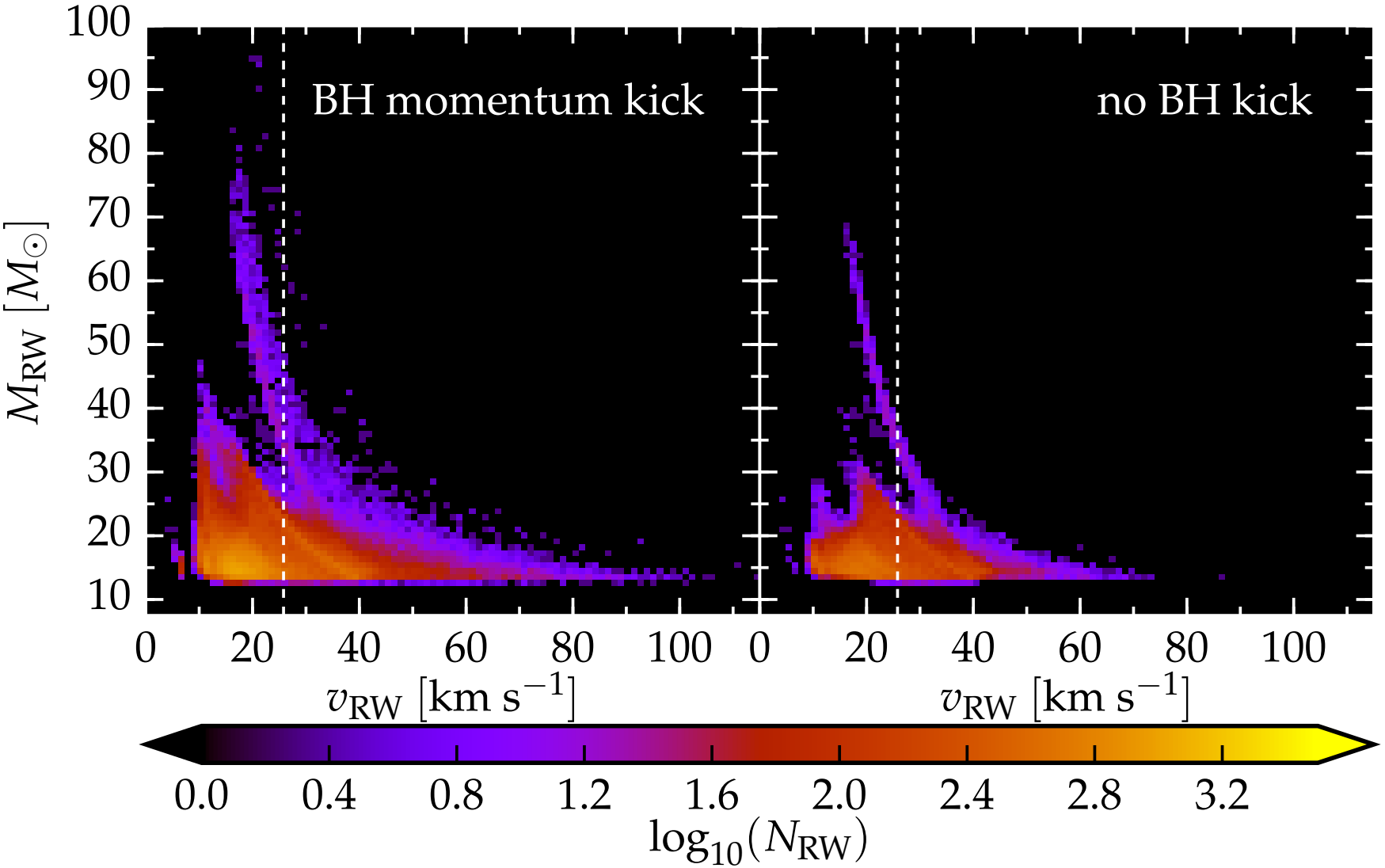
O-type from disrupted binaries only



Preliminary: Rotational velocity

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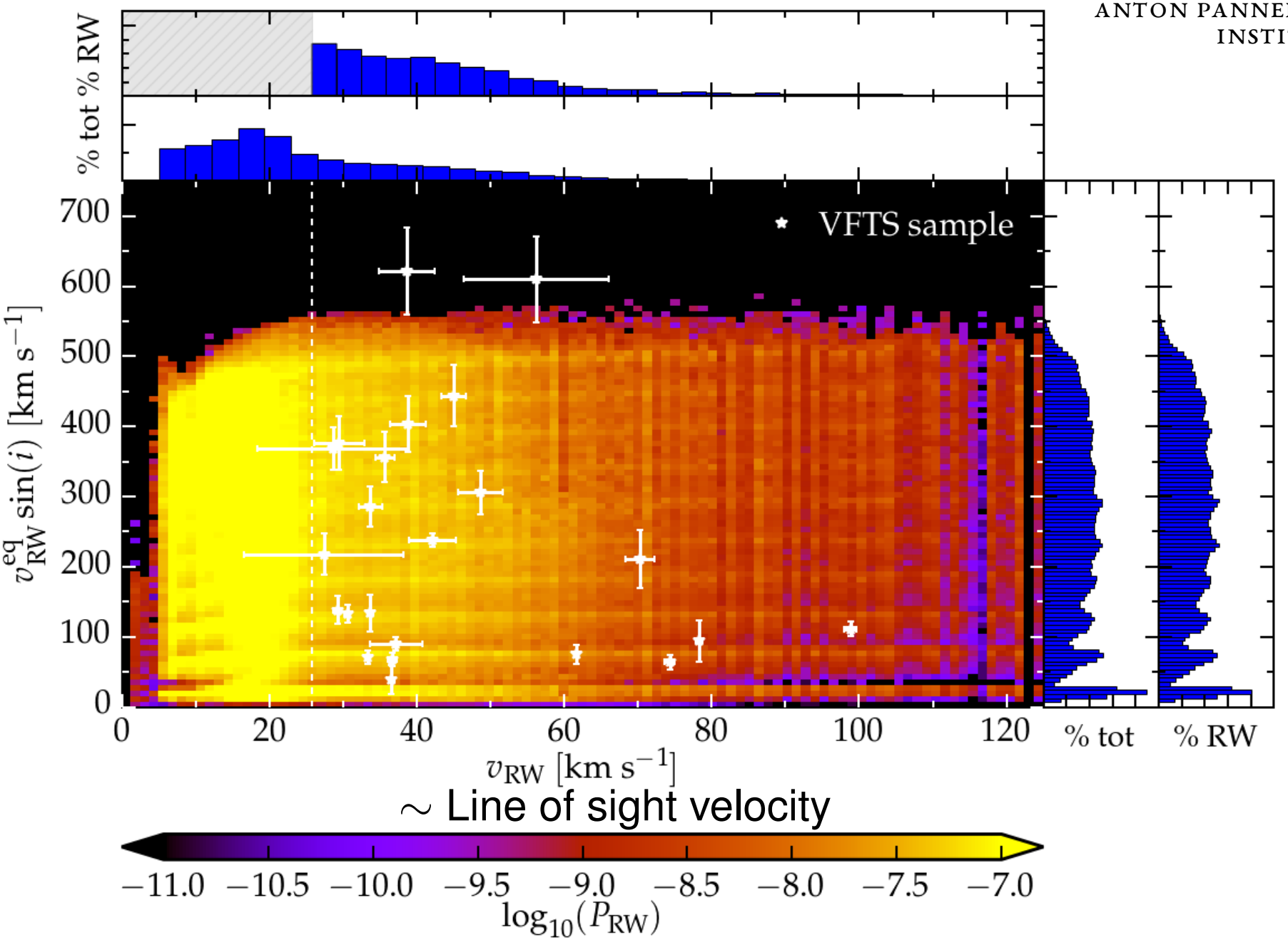
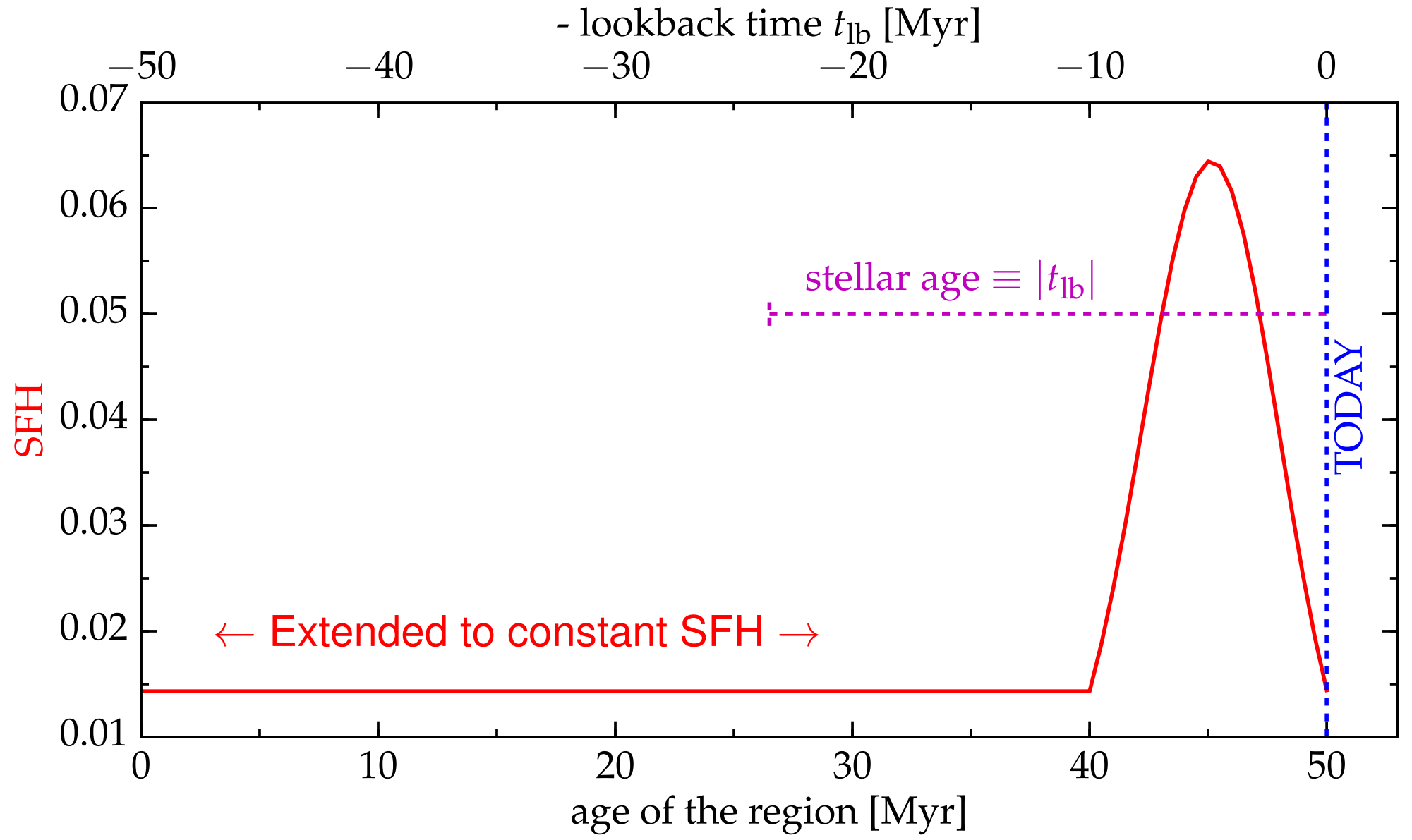


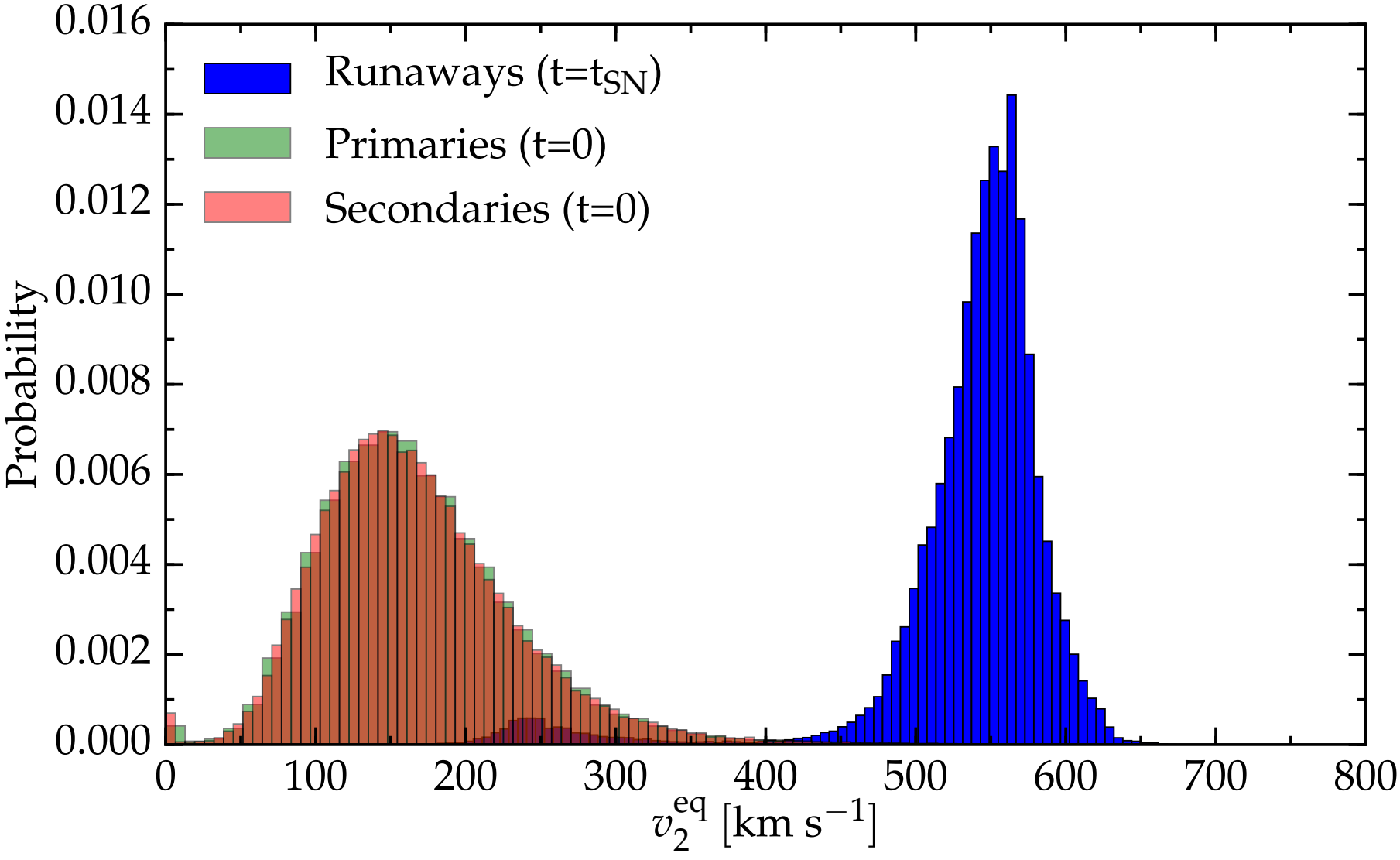
~ Rotational velocity

~ Line of sight velocity

30 Doradus Star Formation History

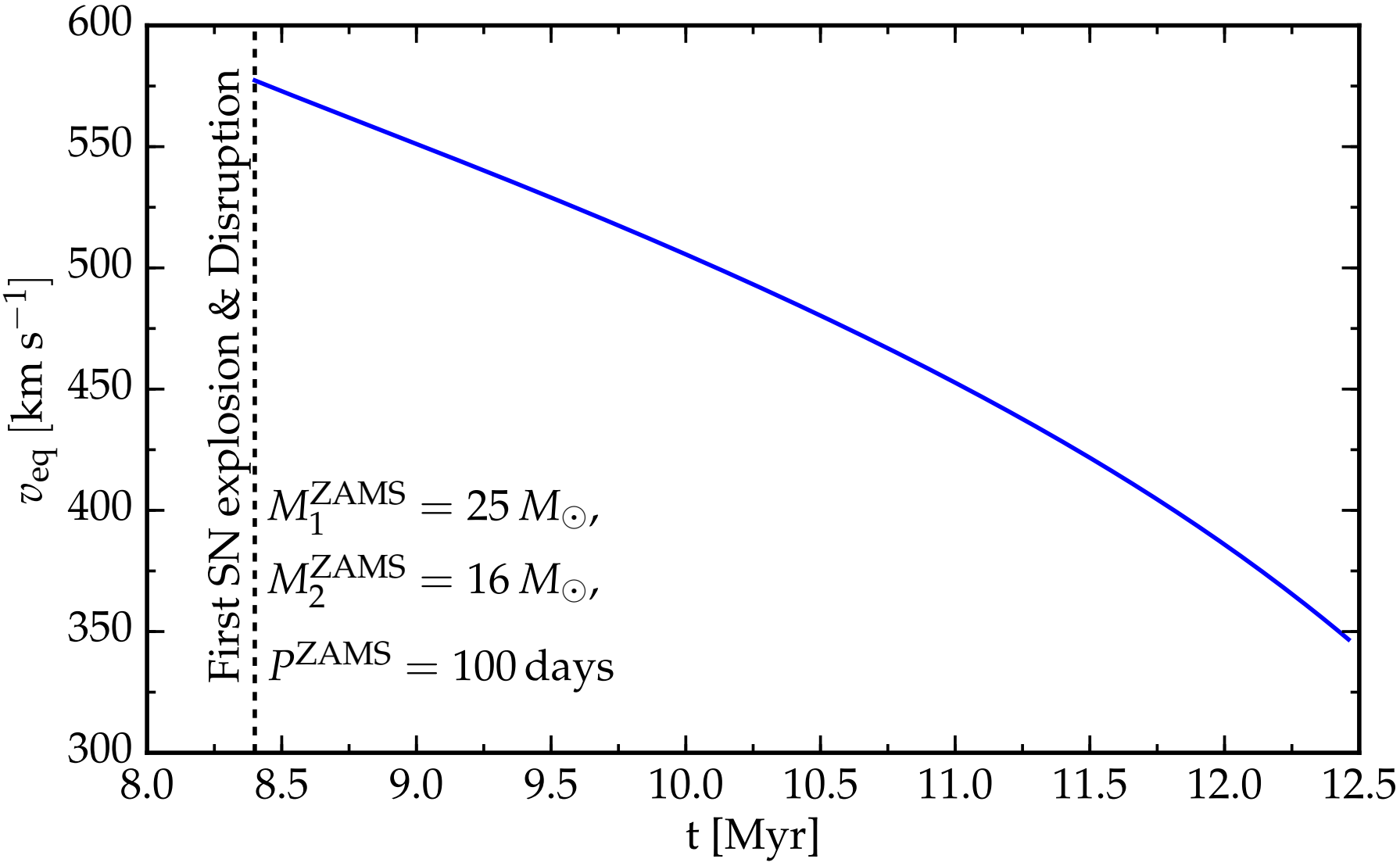


Initial Rotational Velocities

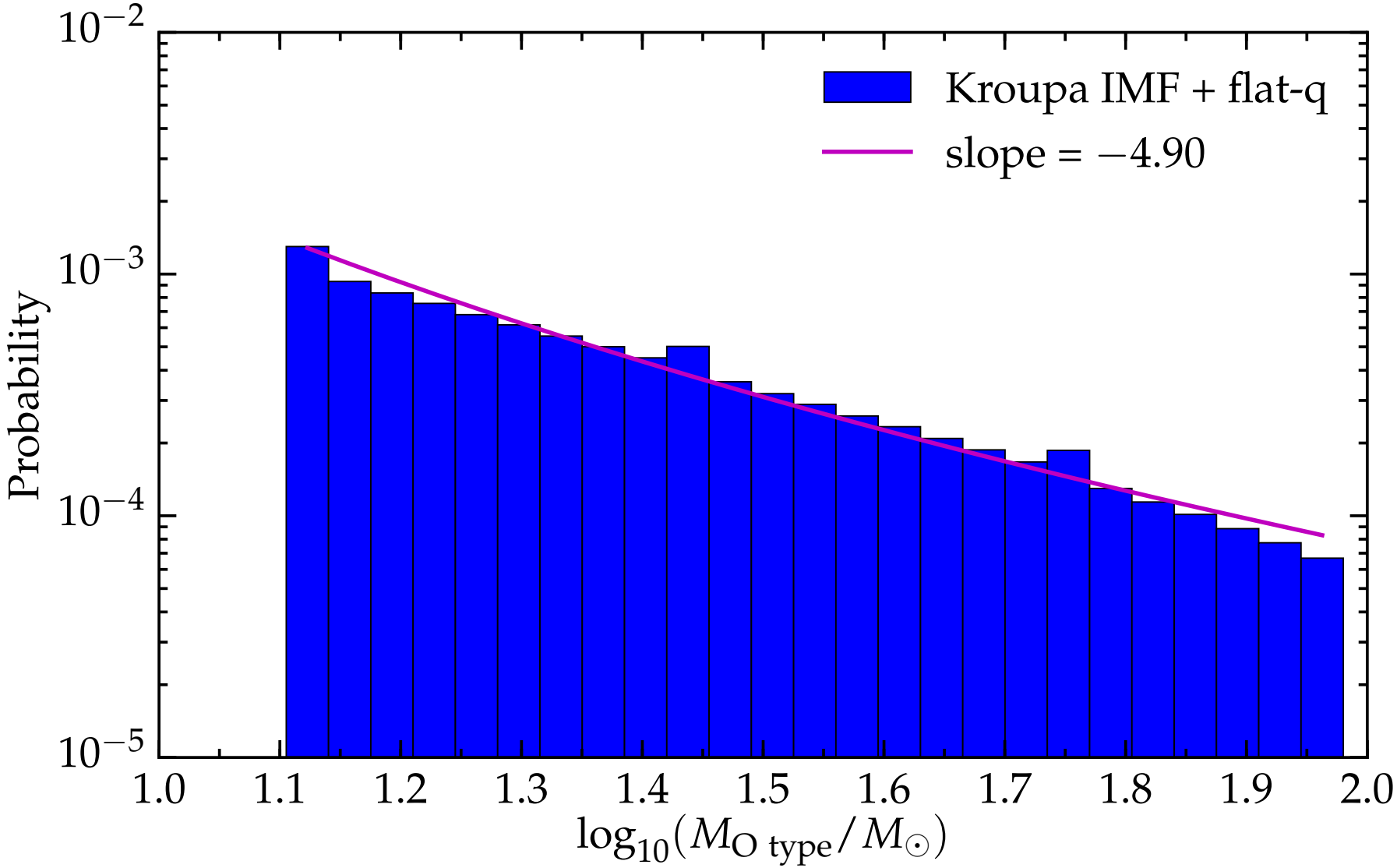


Rotation @ t=0 from O. Ramirez-Agudelo *et al.* '15

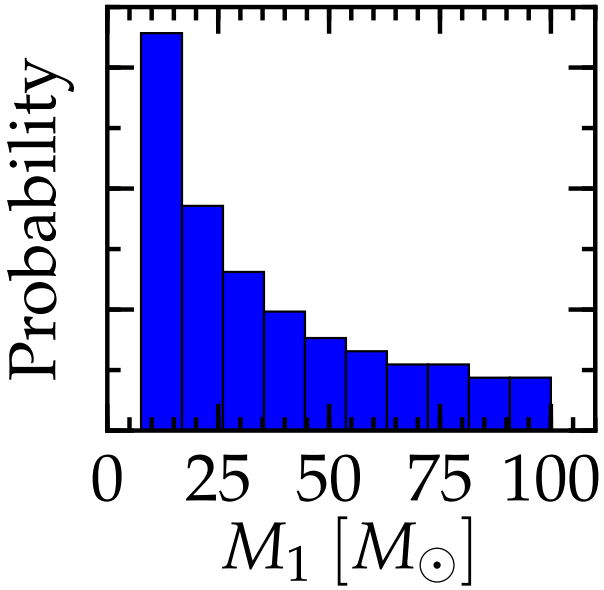
Spin Down: Winds



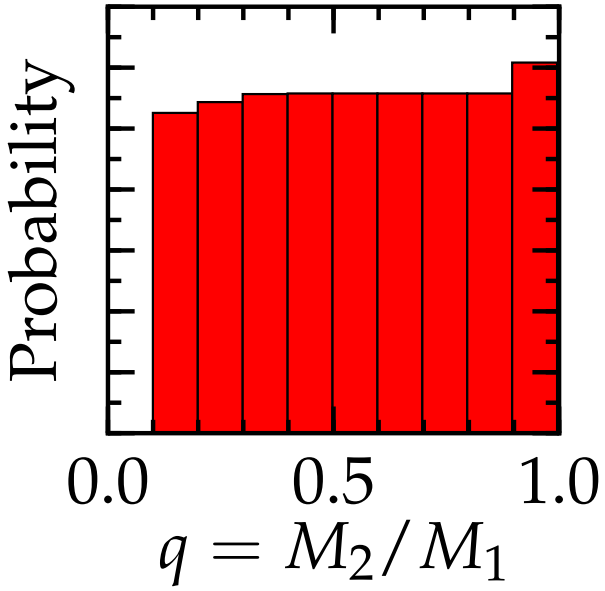
IMF O Stars (Including Secondaries)

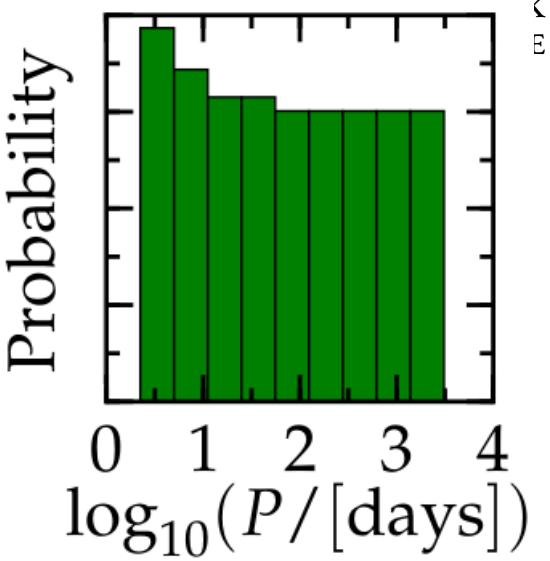


Initial Distributions



Kroupa '01

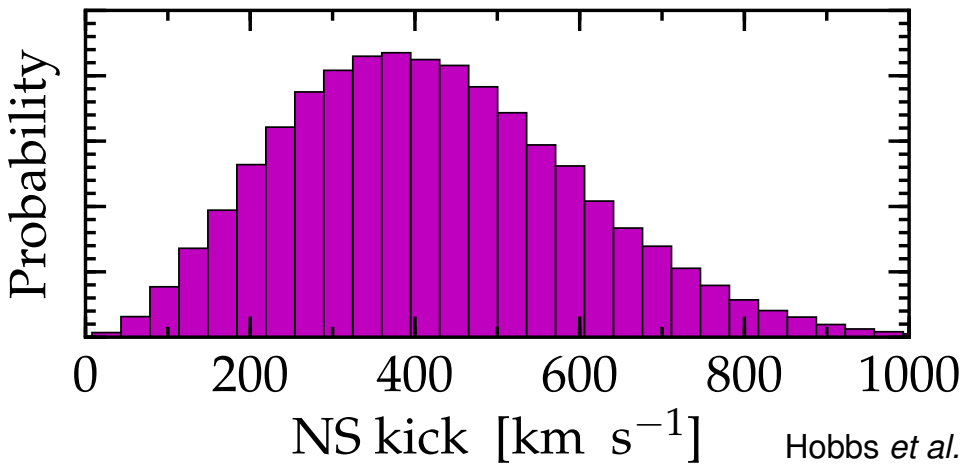




Sana *et al.* '12

Total Population: 2×10^6 stars

Maxwellian $\sigma_{v_{\text{kick}}} = 265[\text{km s}^{-1}]$



Hobbs *et al.* '05

Properties of the RWs in 30 Dor 1/2

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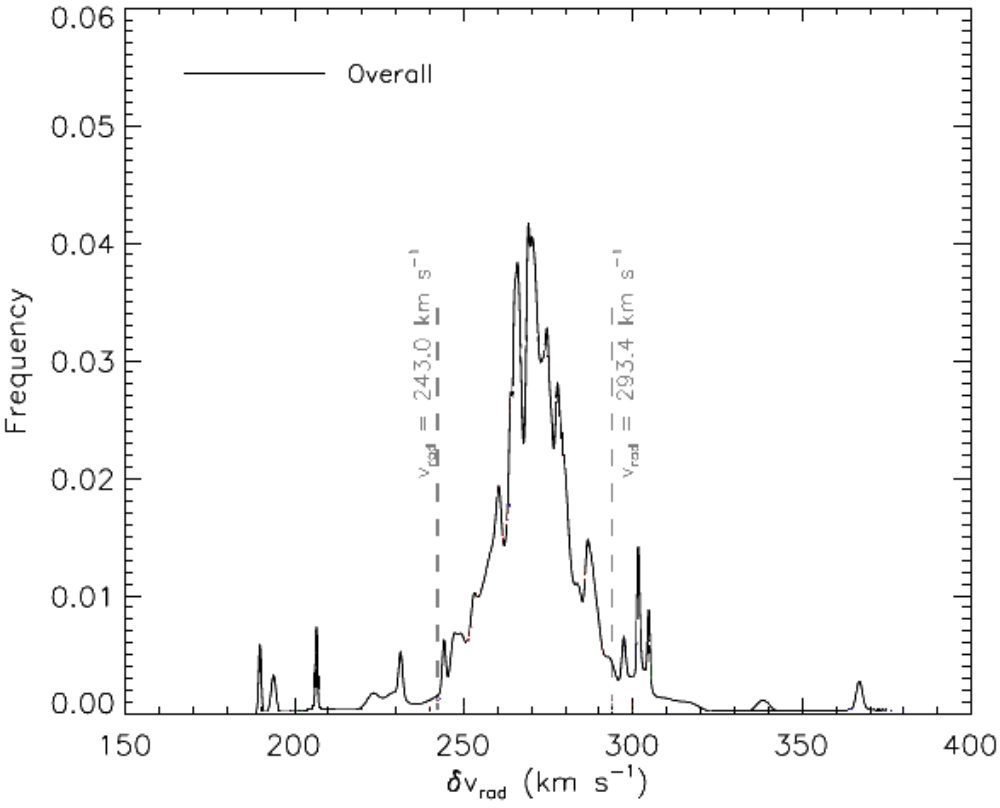
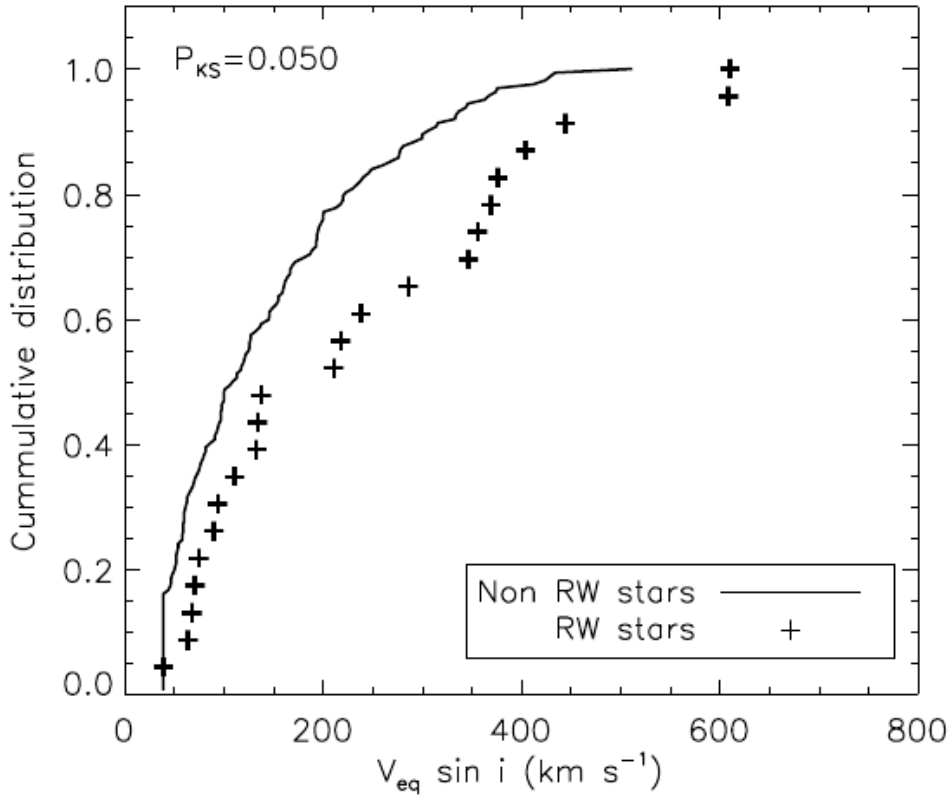
Line of Sight Velocities



Rotational Velocities



Credits: H. Sana *et al.* (in prep.)

Soon HST will provide proper motion of these stars!

Properties of the RWs in 30 Dor 2/2

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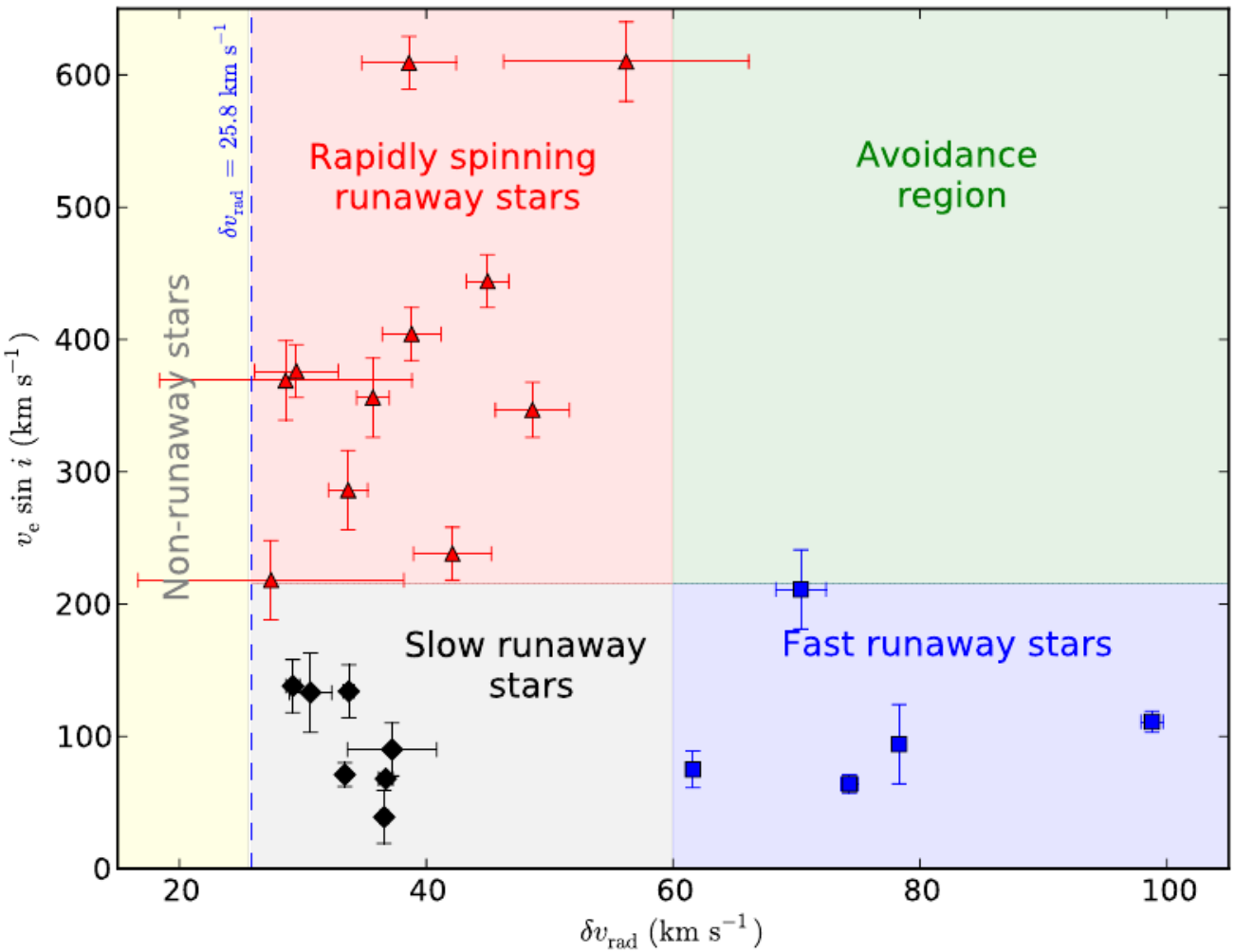
Observed Runaways form 3 groups on the $(v_r, v_{\rm eq} \sin i)$ plane



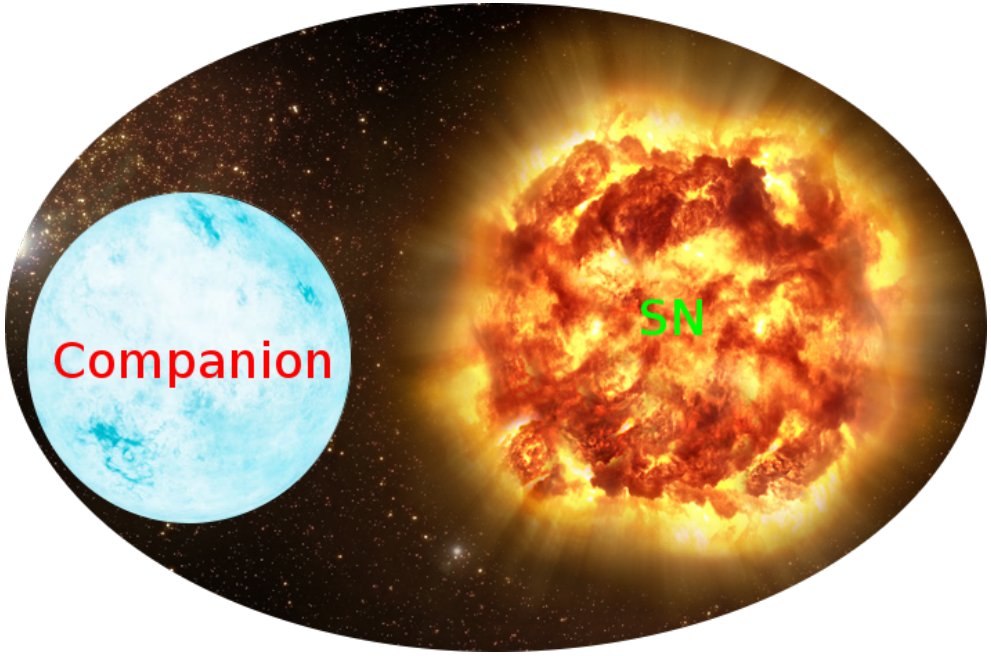
- 23 (mostly) single O-type RWs
- Fast rotators are slow
- Fast RWs are slow rotators

Credits: H. Sana *et al.* (in prep.)

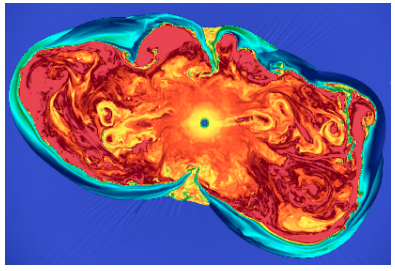
Two ejection mechanisms

SN in a Binary

Blaauw, 1961



$v_r \simeq v_2^{\mathrm{orb}}$



Explosion asymmetries $\Rightarrow$ extra kick (?)

Dynamical Ejection

Poveda *et al.*, 1967

...but binaries are still important!

- (Binding) Energy reservoir
- Cross section $\propto a^2 \gg R_*^2$
- $\sim$ 100% O stars are in binaries