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Massive Runaway Stars in 30 Dor:

probes for binary and explosion physics?

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PhD @ API

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Outline

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Definition of Runaway

Ejection Mechanisms

- SN Explosion in a Binary
- Dynamical Ejection from Cluster

Observed Sample

Runaways From Binary Population Synthesis

- Preliminary Results

Conclusions

Definition of Runaway stars

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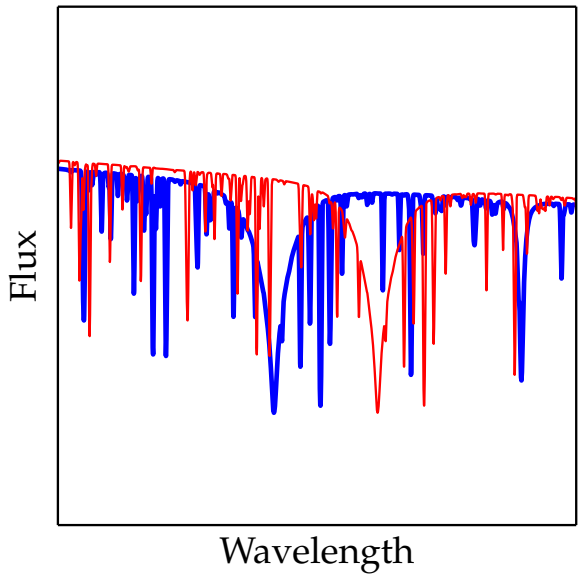
- Blaauw (1961): Runaway star $\overset{\text{def}}{\Leftrightarrow} v_r \gtrsim 30\ [\text{km s}^{-1}]$
- Later: added O type stars out of galactic plane, change $\min(v_r)$, $v_r \gtrsim v_{\text{esc}}$, etc.

No clear definition in the literature, but:

$\Leftarrow$ Bow shock of ζOph

Doppler shift of lines $\Rightarrow$



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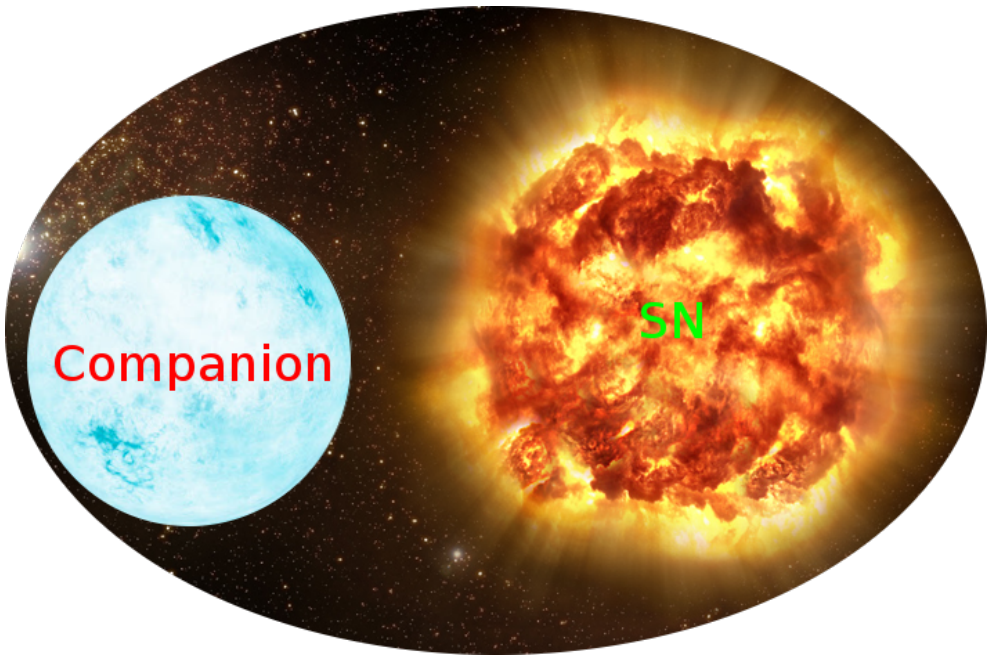
SN in a Binary

Blaauw, 1961



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

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SN in a Binary

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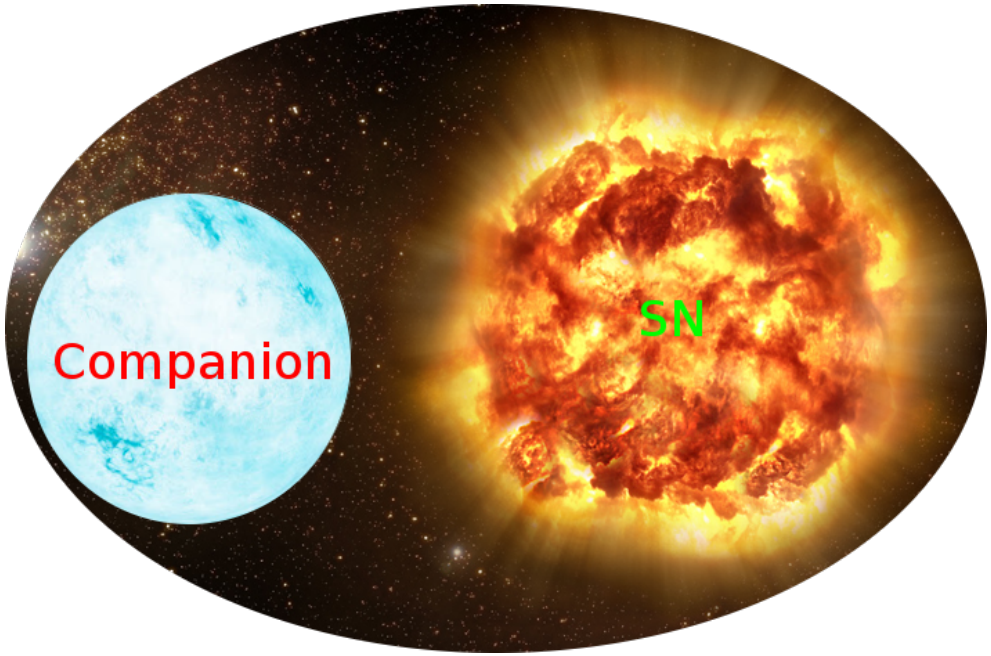

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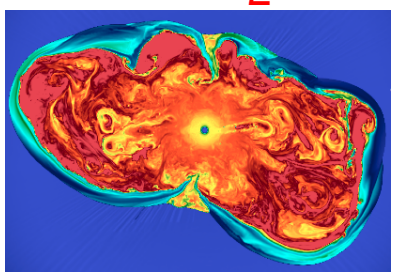
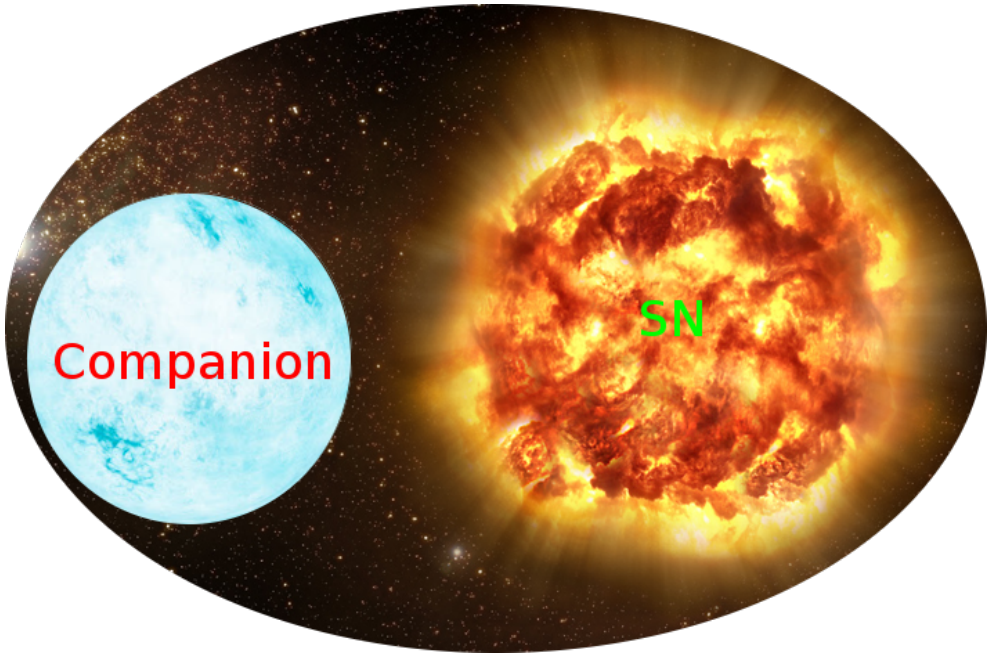


Explosion asymmetries $\Rightarrow$ extra kick (?)

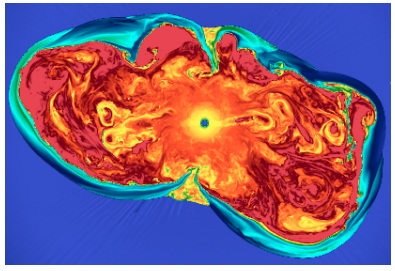
Two ejection mechanisms

SN in a Binary

Blaauw, 1961



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



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

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O type runaways in 30 Doradus

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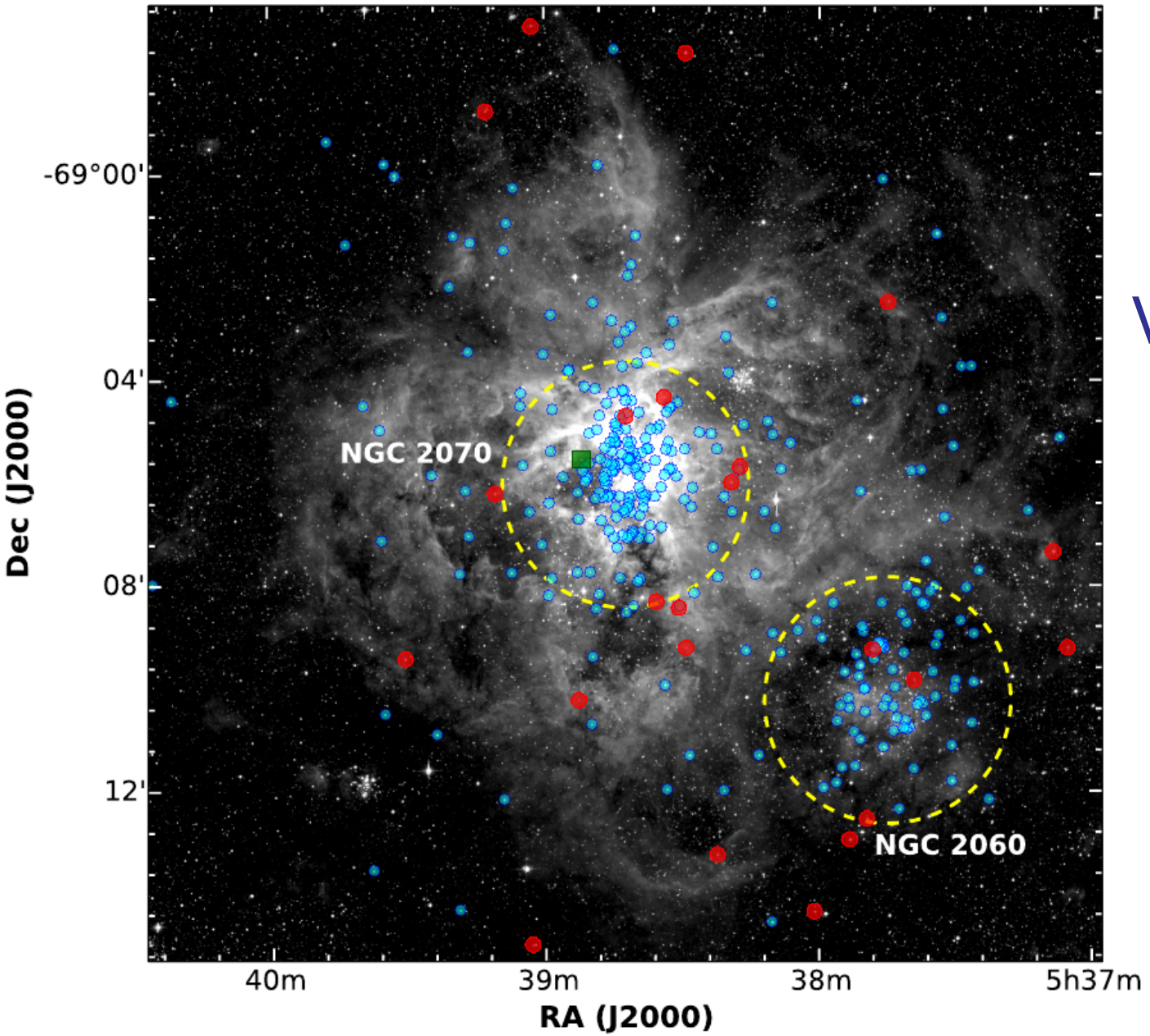

VFTS Flames:

- non-RW O stars;
- Single RWs;
- Binary RW;
- OB associations.

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

Properties of the RWs in 30 Dor 1/2

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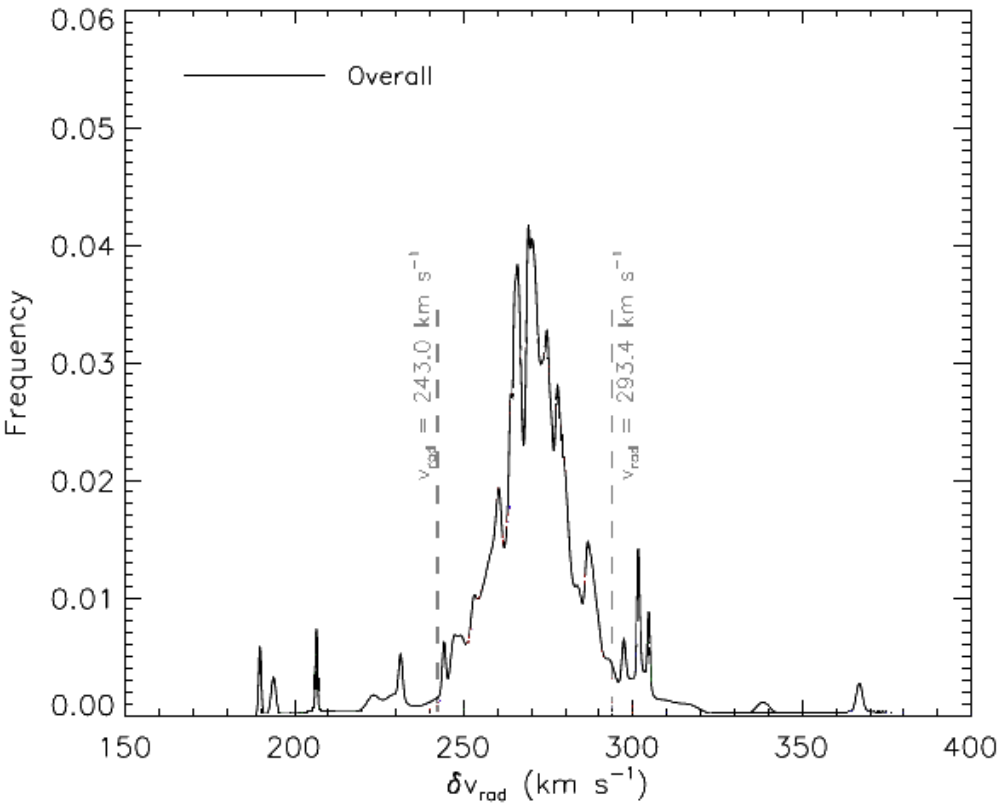
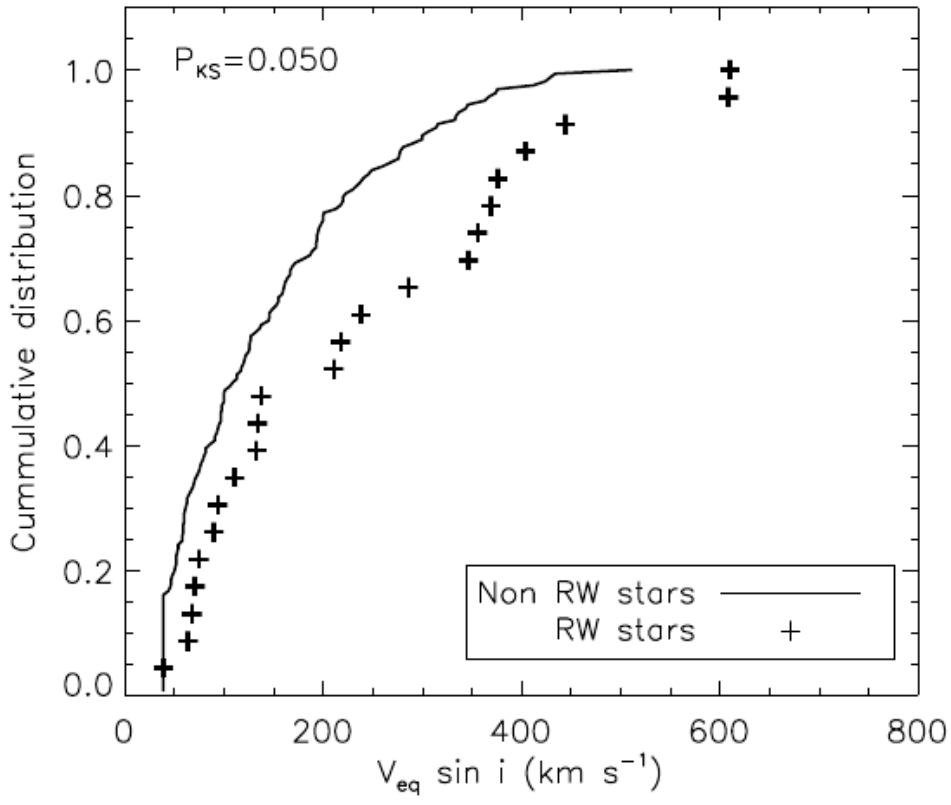
Line of Sight Velocities



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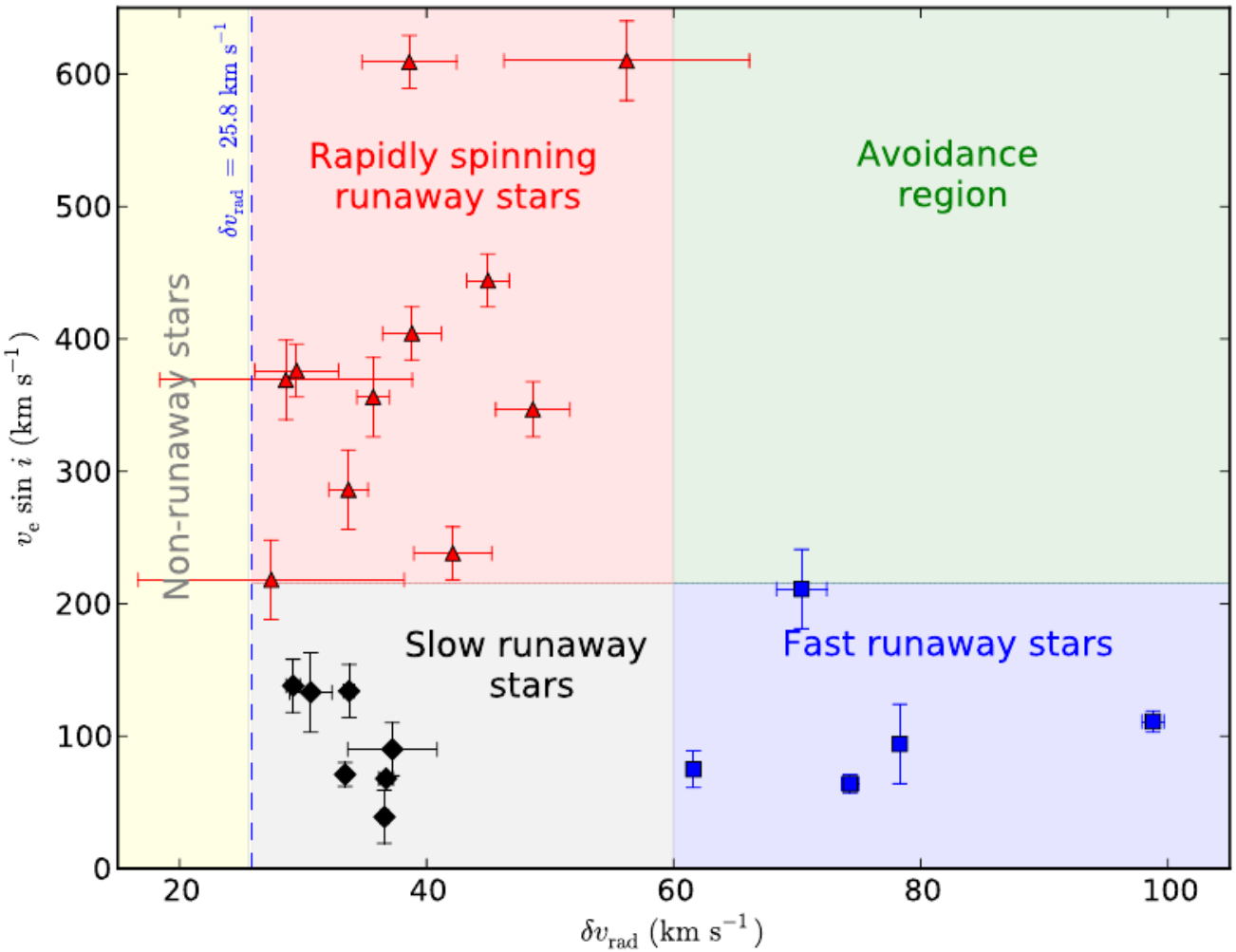
Observed Runaways form 3 groups on the $(v_r, v_{\rm eq} \sin i)$ plane



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

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

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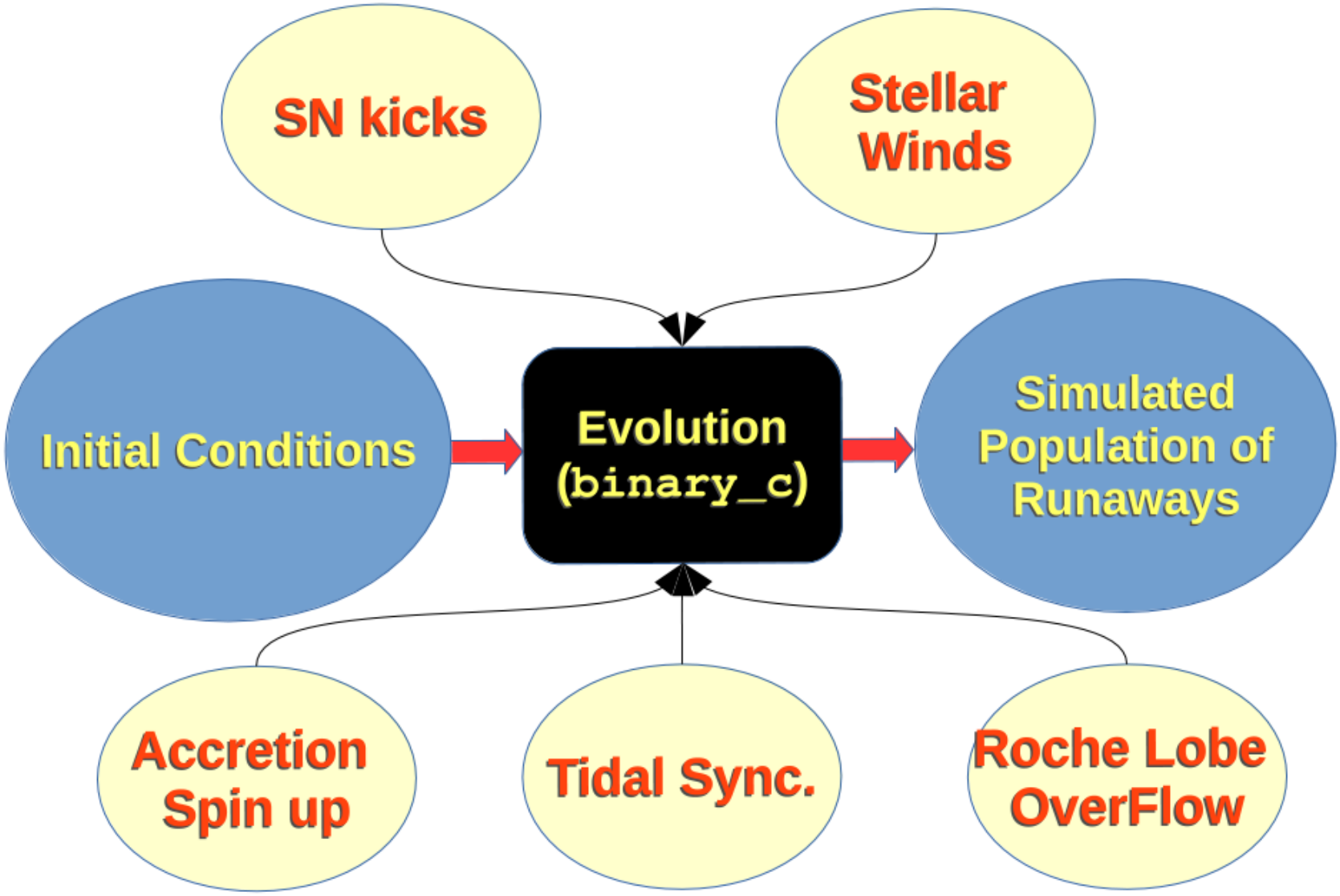
Population synthesys

Fast ⇒ allows to test input physics assumptions.



`binary_c`: R. Izzard *et al.* 2004, 2006, 2009

Initial distributions

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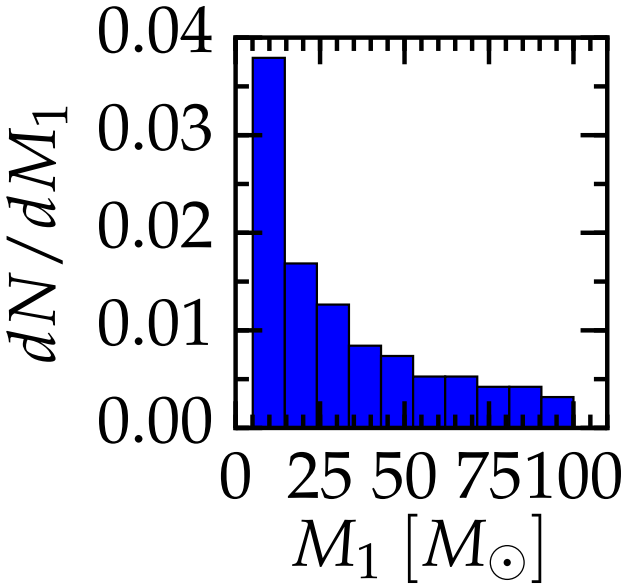
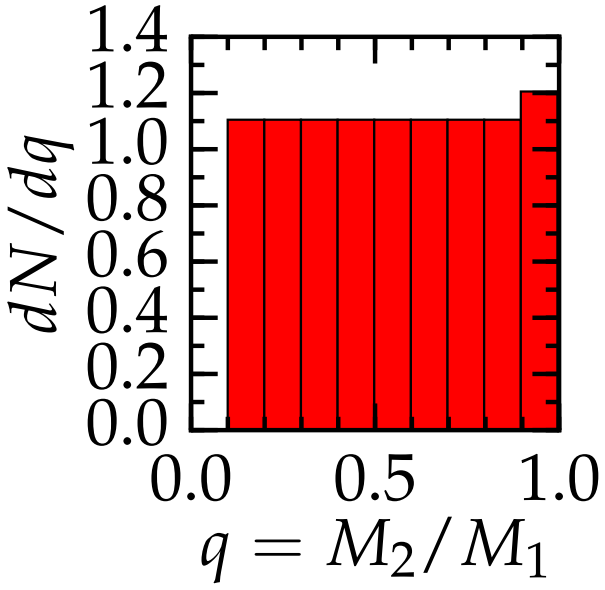
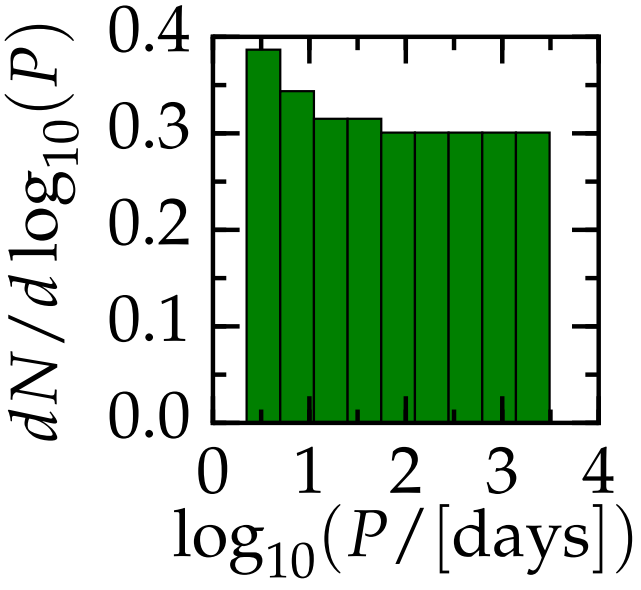


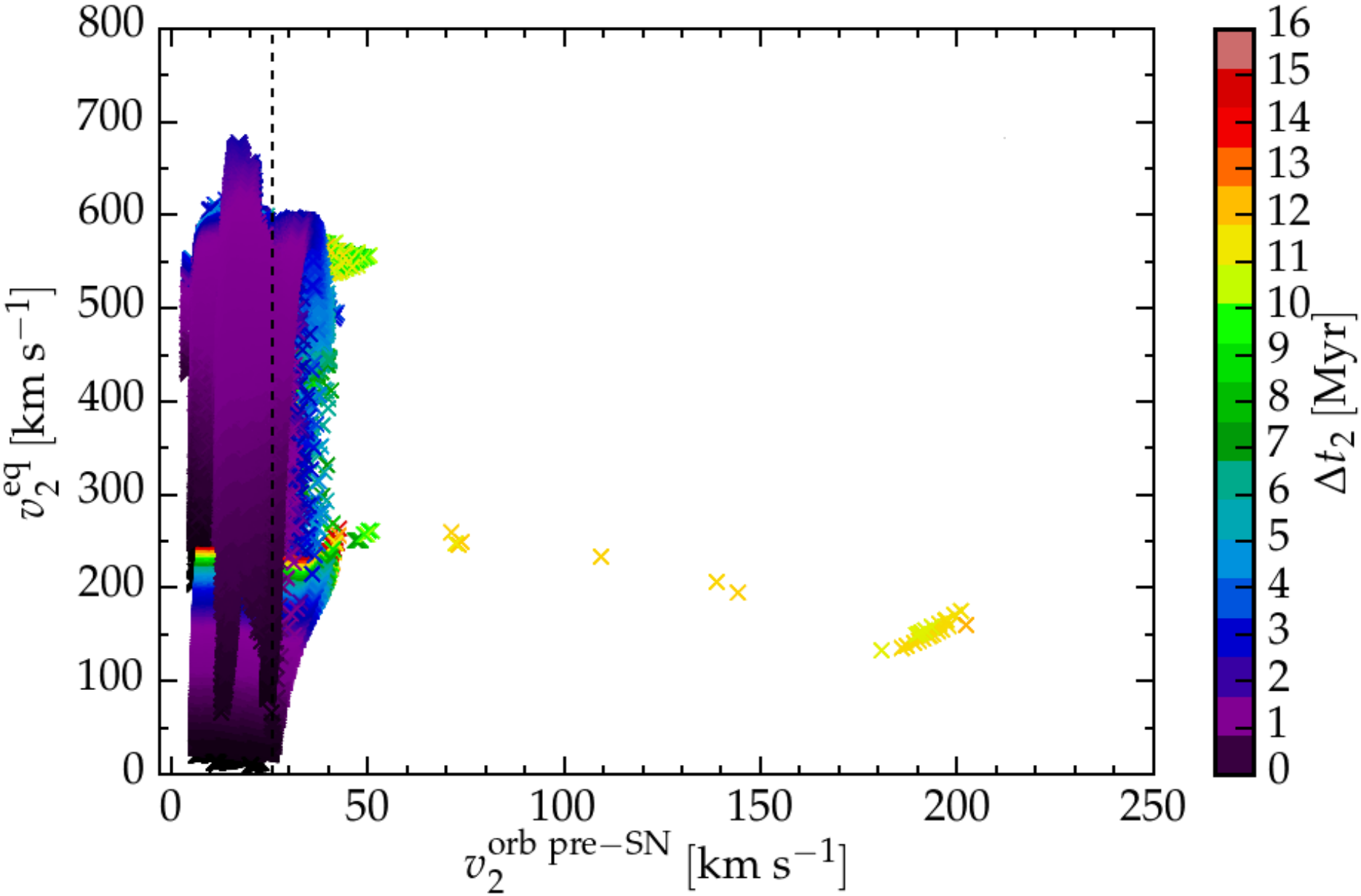




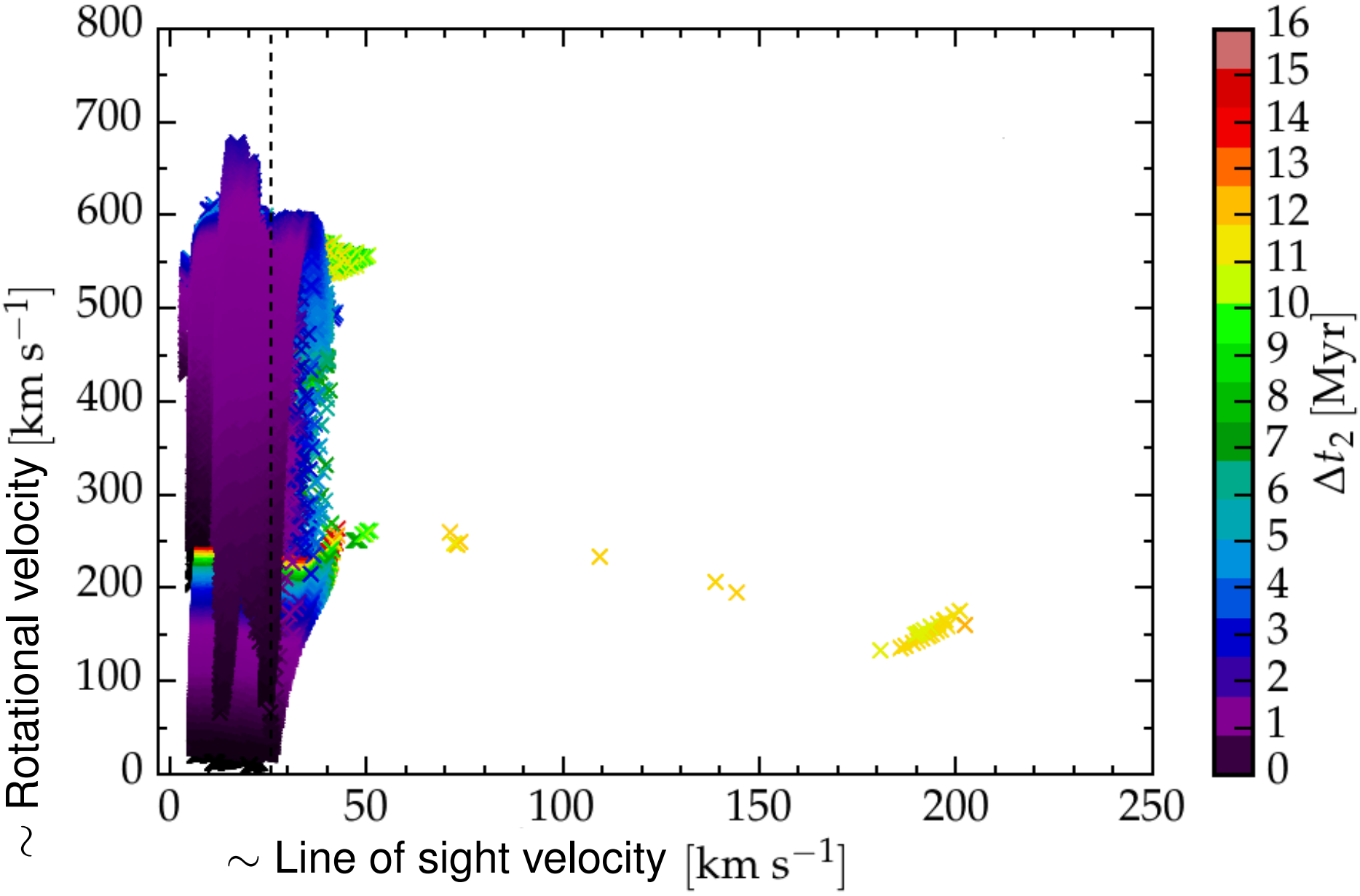
100 Primaries $\times$ 100 Secondaries $\times$ 200 Periods $\times$
10 birth kicks per SN (Maxwellian $\sigma_{v_{\text{kick}}} = 265[\text{km s}^{-1}]$)

Need to distinguish NS/BH kicks

Preliminary Results



Preliminary Results



Preliminary Results

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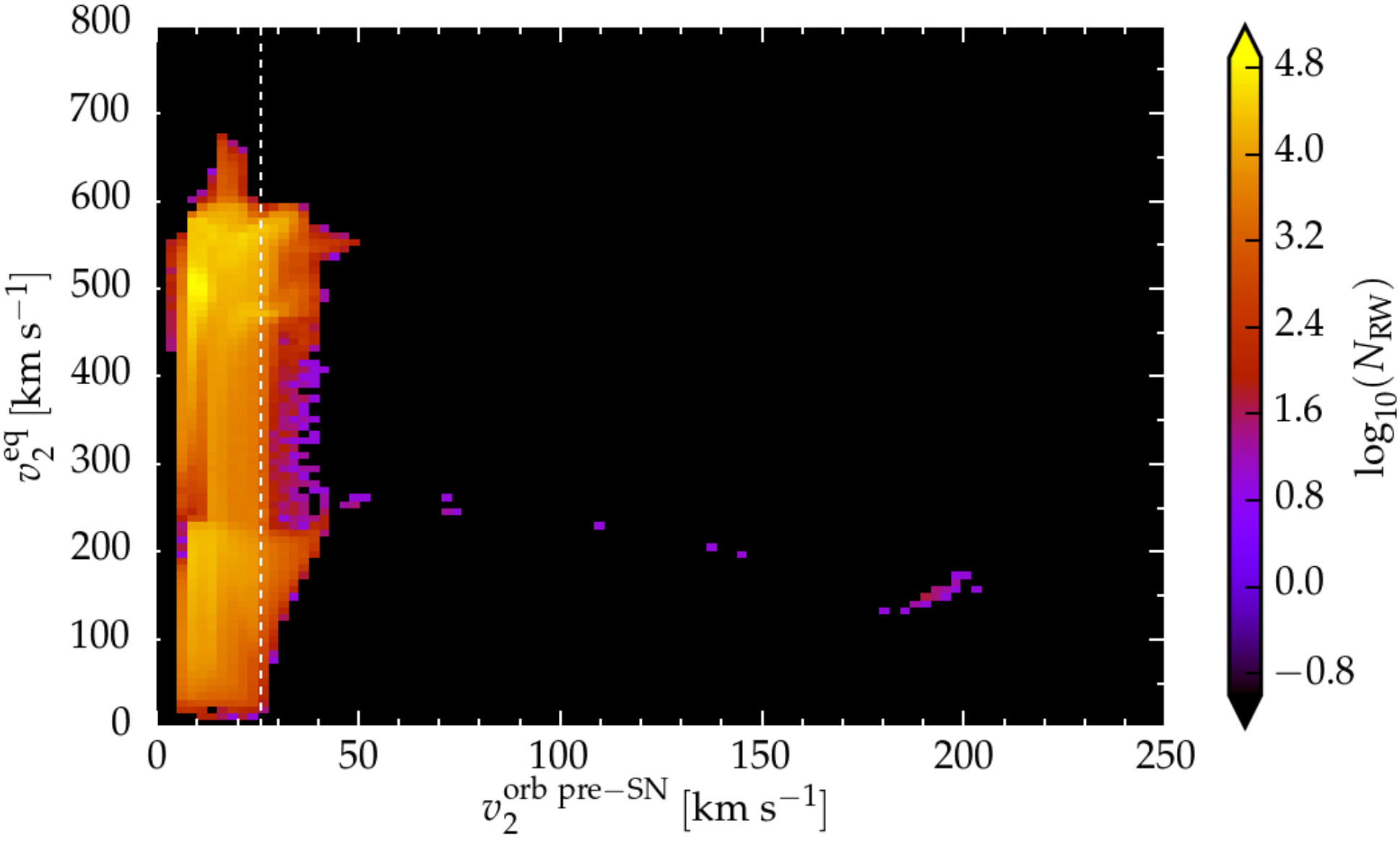
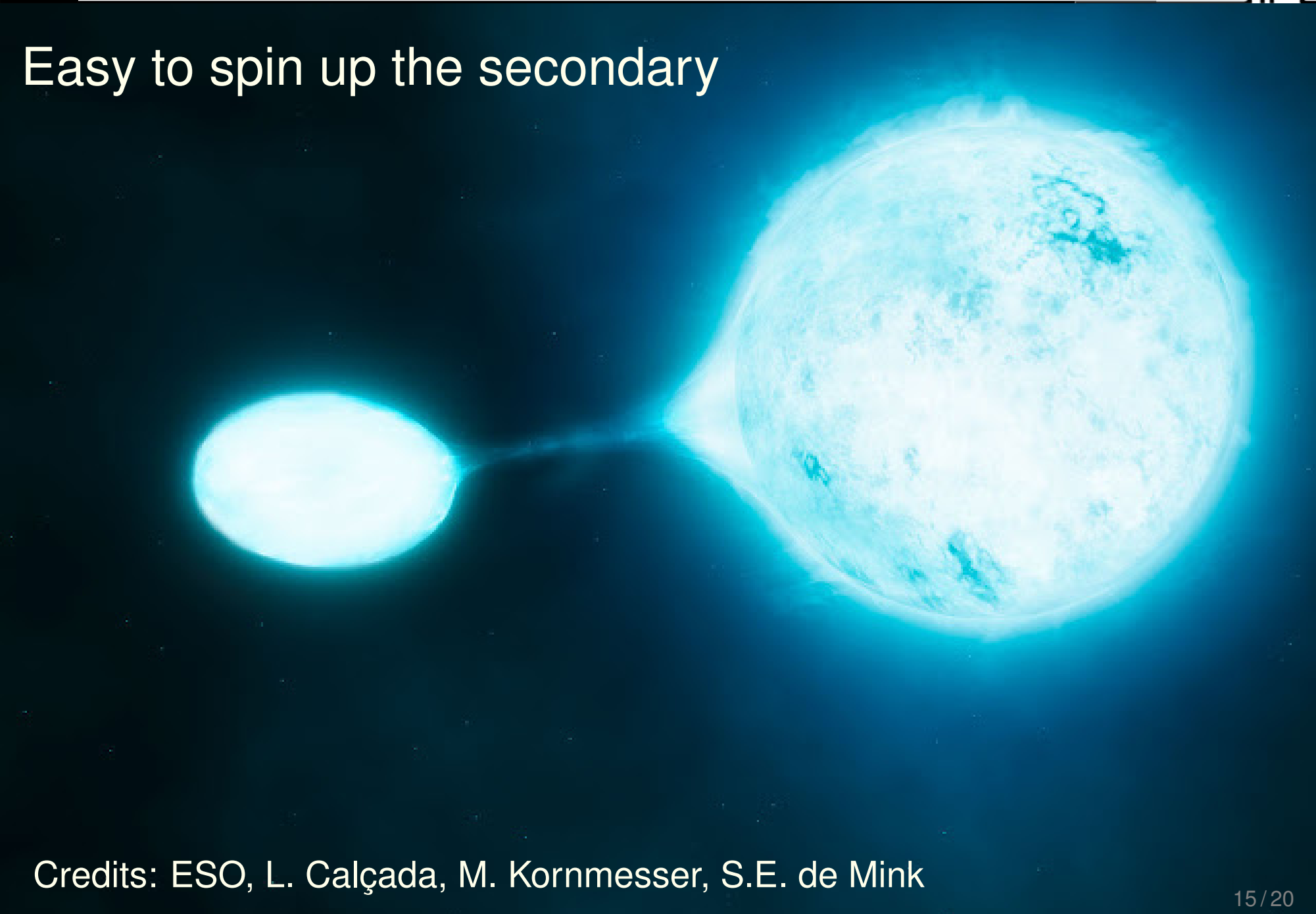


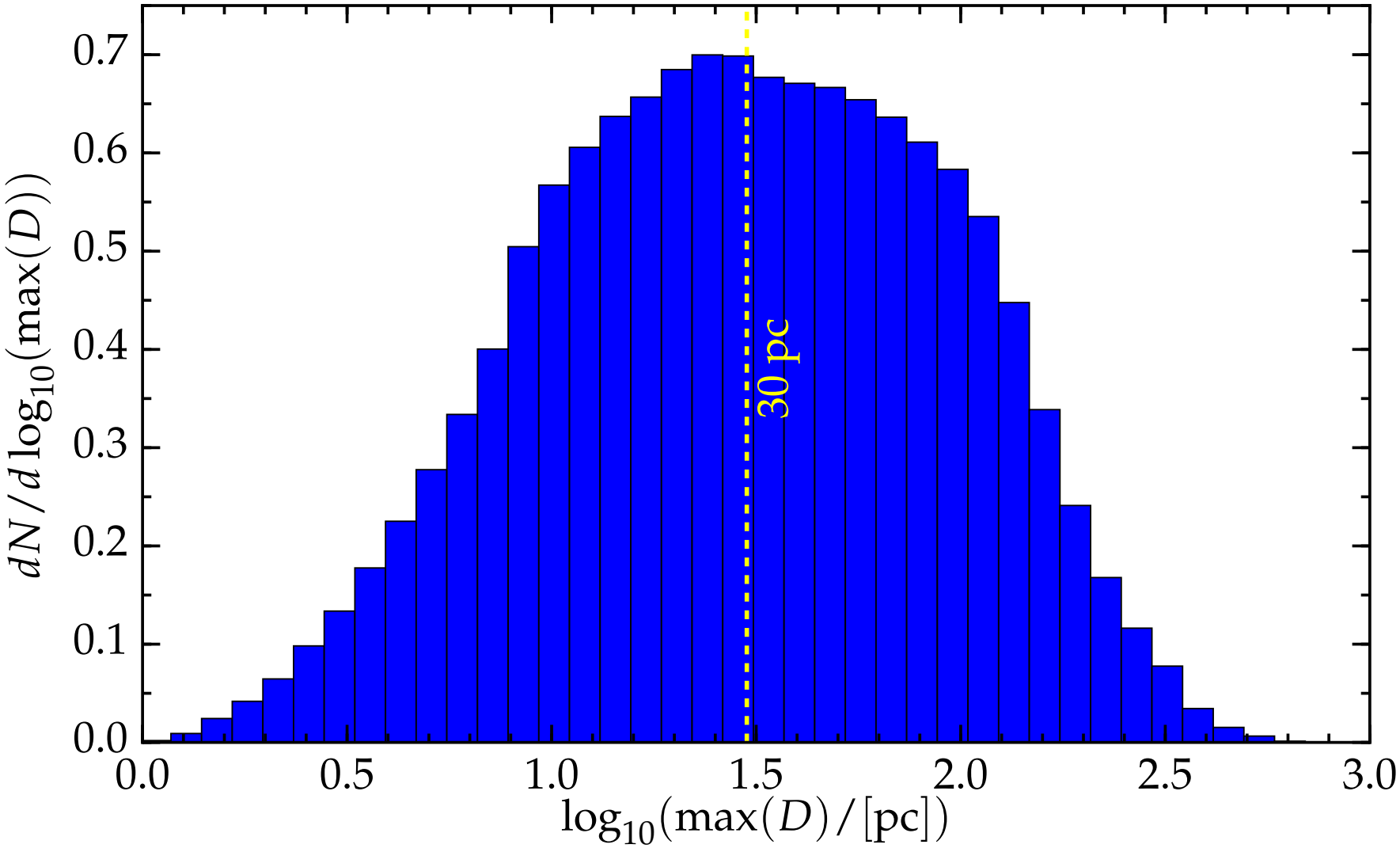
Why Fast Rotators? Accretion Spin-up

Easy to spin up the secondary



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

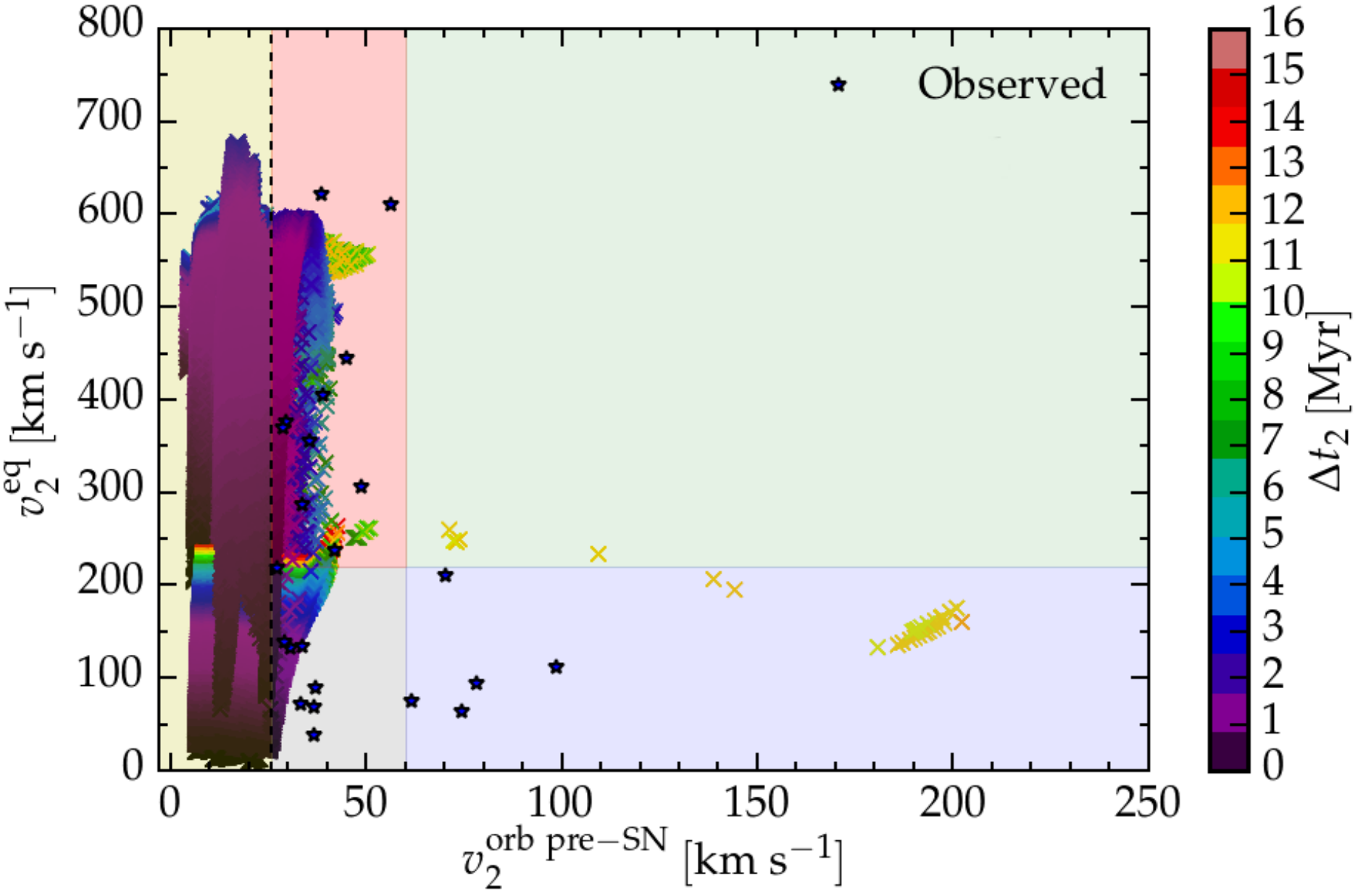
Preliminary Results: Traveled Distance



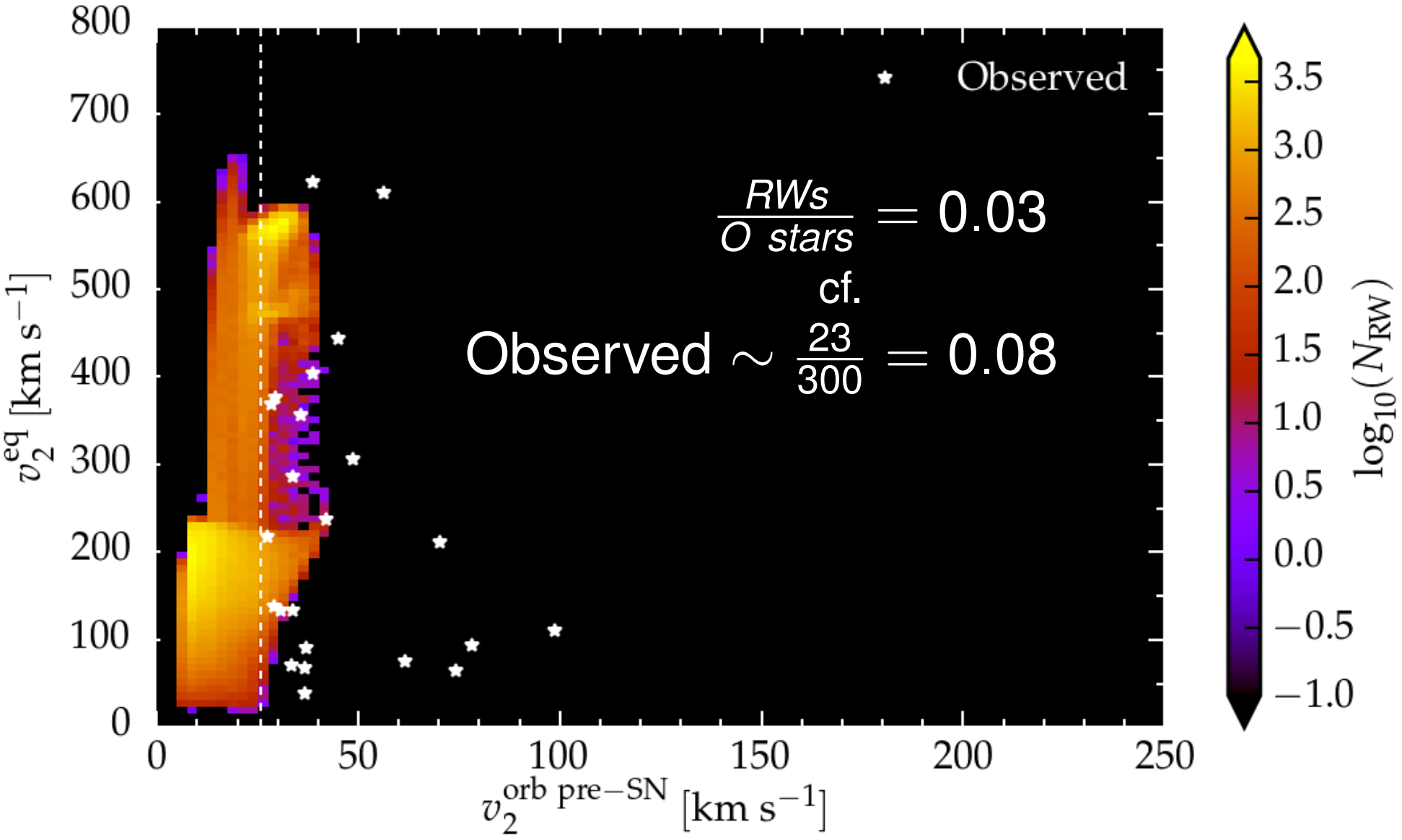
$\max(D) \stackrel{\mathrm{def}}{=} v_2^{orb} \times \Delta t_2 \Rightarrow$ No potential well

$1\mathrm{km\ s^{-1}} \simeq 1\mathrm{pc\ Myr^{-1}}$

Preliminary Results



Preliminary: Selecting the right RWs



- Constant SFR for 5 Myr
- still visible in VFTS FOV?
- still a RW?

Outline

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Conclusions & Outlook

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- Characterization of RWs might help disentangle ejection mechanism;
- Population of RWs might be helpful to constrain binary physics and explosion physics;
- Binaries produces both fast spinning slow RWs ($v_{\rm eq} \gtrsim 220\ [\mathrm{km\ s^{-1}}] \Rightarrow$ accretion spin up?) and slow rotators fast RWs ($v_r \gtrsim 100\ [\mathrm{km\ s^{-1}}] \Rightarrow$ tidal spin down?), but the latter are **rare**.

Next steps:

- Improve treatment of SN kick (and possibly v_r);
- Fold-in realistic SFR to compare with observations;
- Explore dependence on free parameters in binary evolution (e.g. $\alpha_{\rm CE}$, J-losses).

Thank you for your attention!

Backup slides

What could Runaways teach us?

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SN in a Binary (BSS)

Binary & Single star evolution:

- SN kick (and BH kicks!)
- Core-Envelope coupling
- SN timing

Dynamical Ejection (DES)

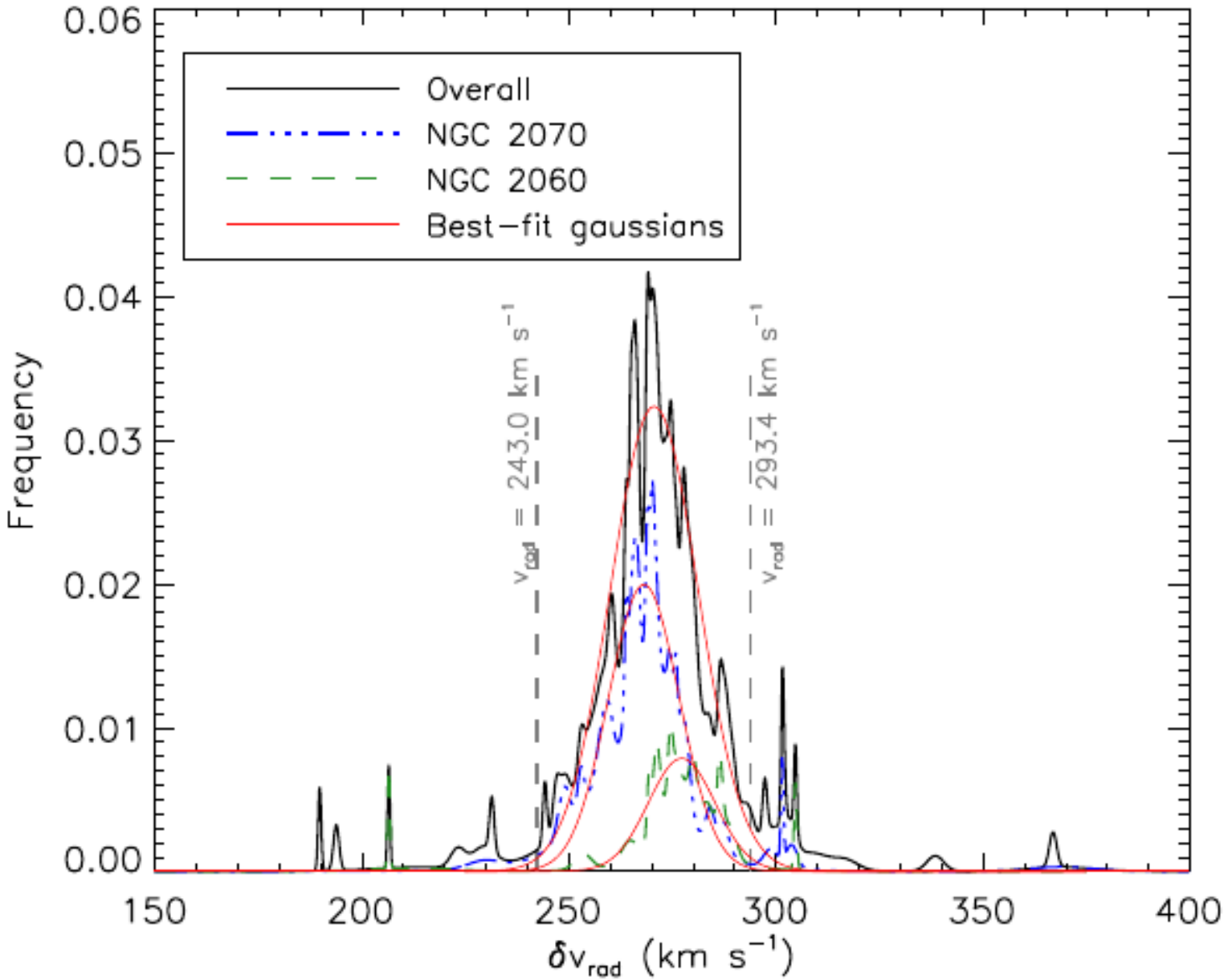
Cluster properties:

- binary fraction;
- stellar density;
- dark matter distribution;

(see e.g Ho & Kroupa 2016)

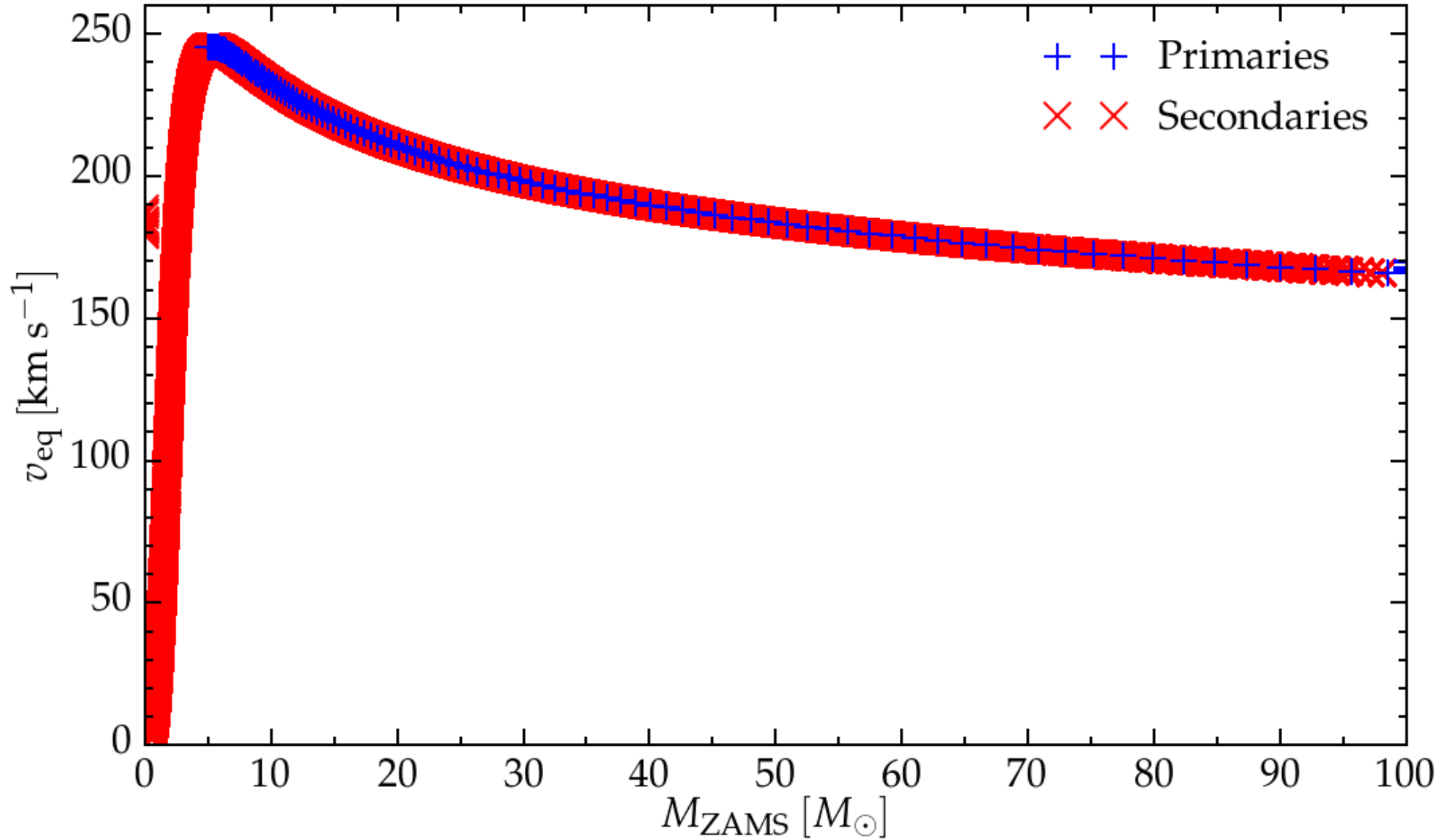
- Radiative, mechanical, and chemical feedback of Massive Stars *up to* Kpc away from their birth location.

Distribution of Line of Sight Velocities



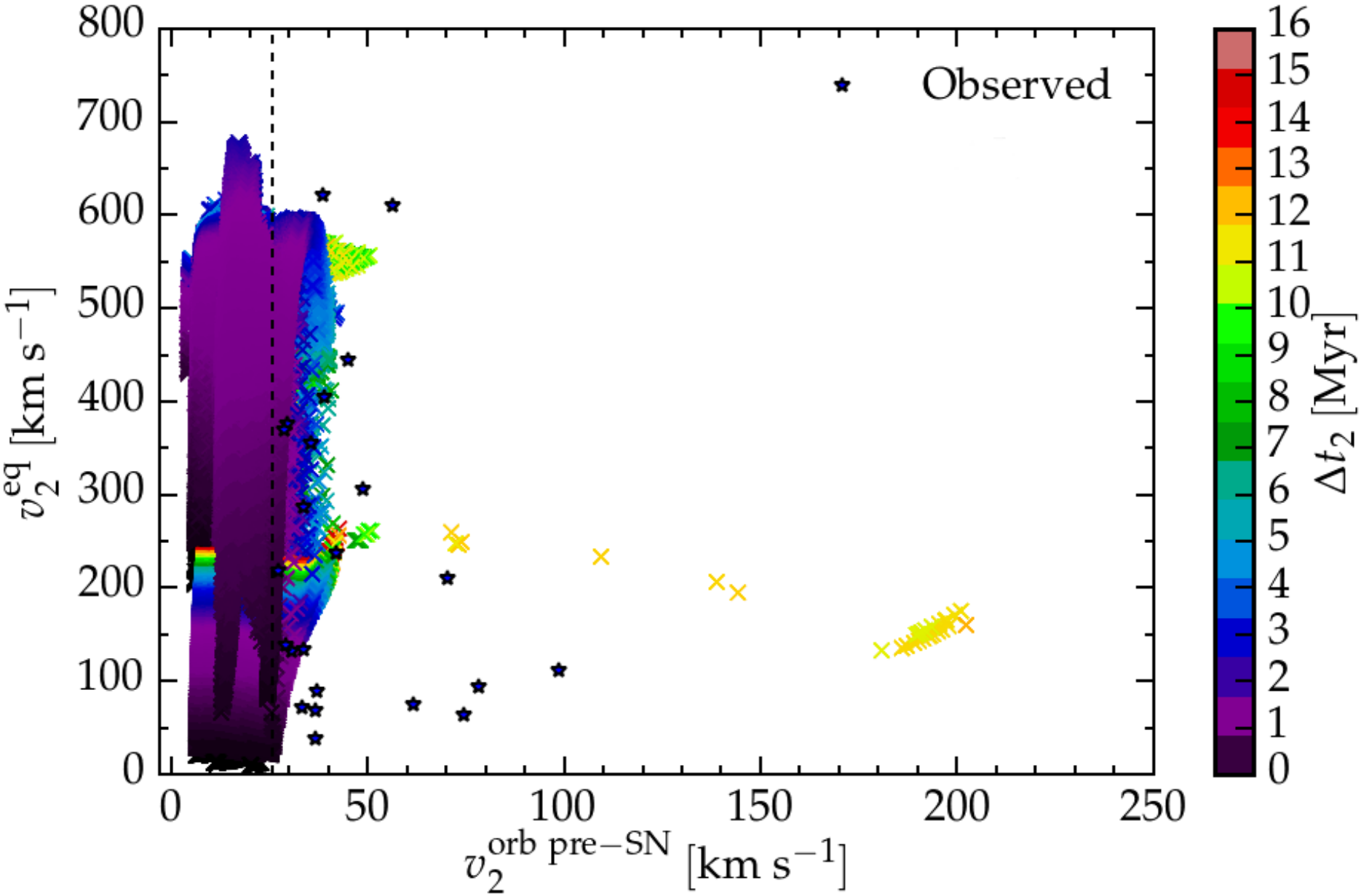
Credits: H. Sana *et al.* (in prep.)

Initial rotational velocity



cf. Hurley *et al.*, 2002

Preliminary Results



Preliminary Results: Relative Populations

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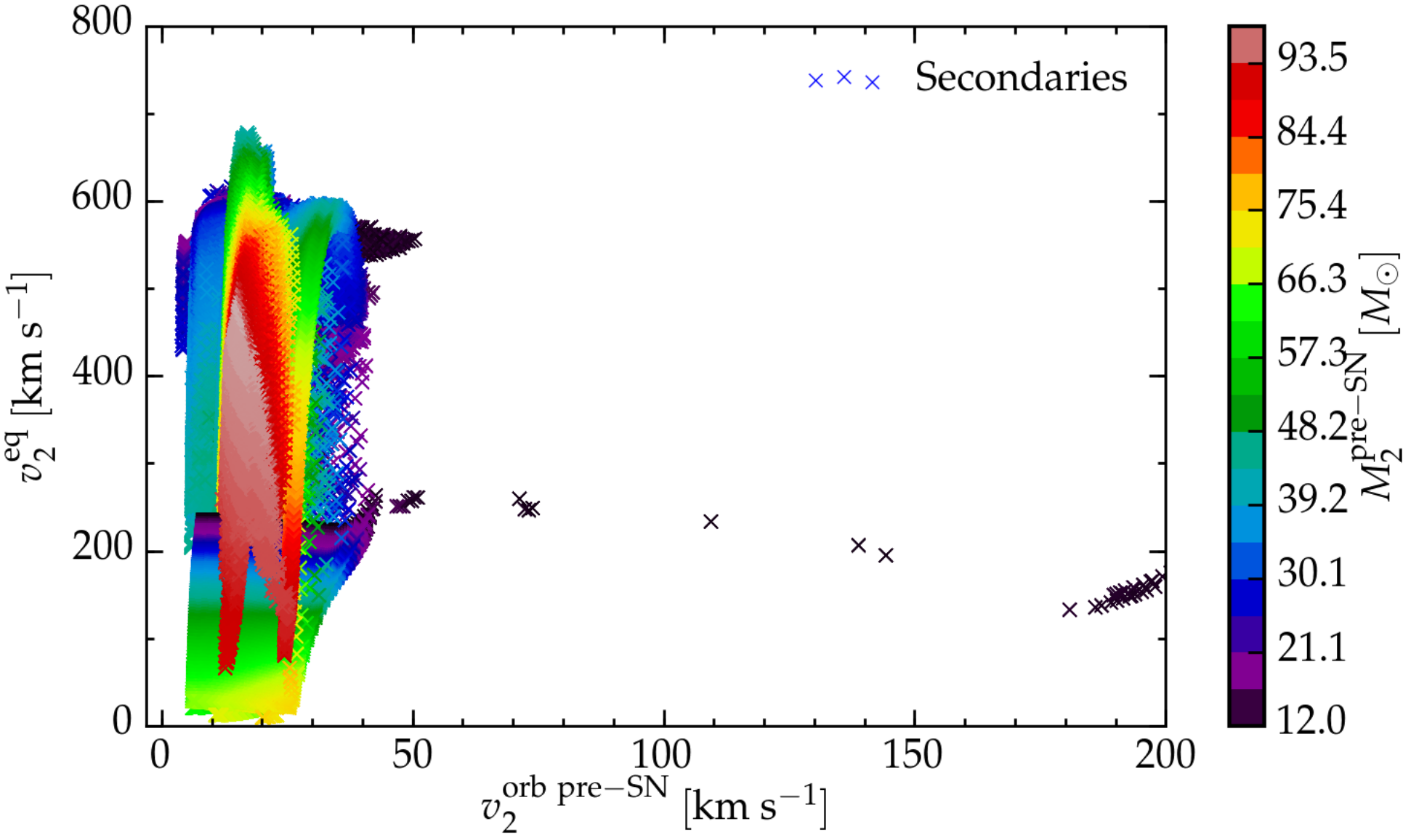
(with Probability weighting)

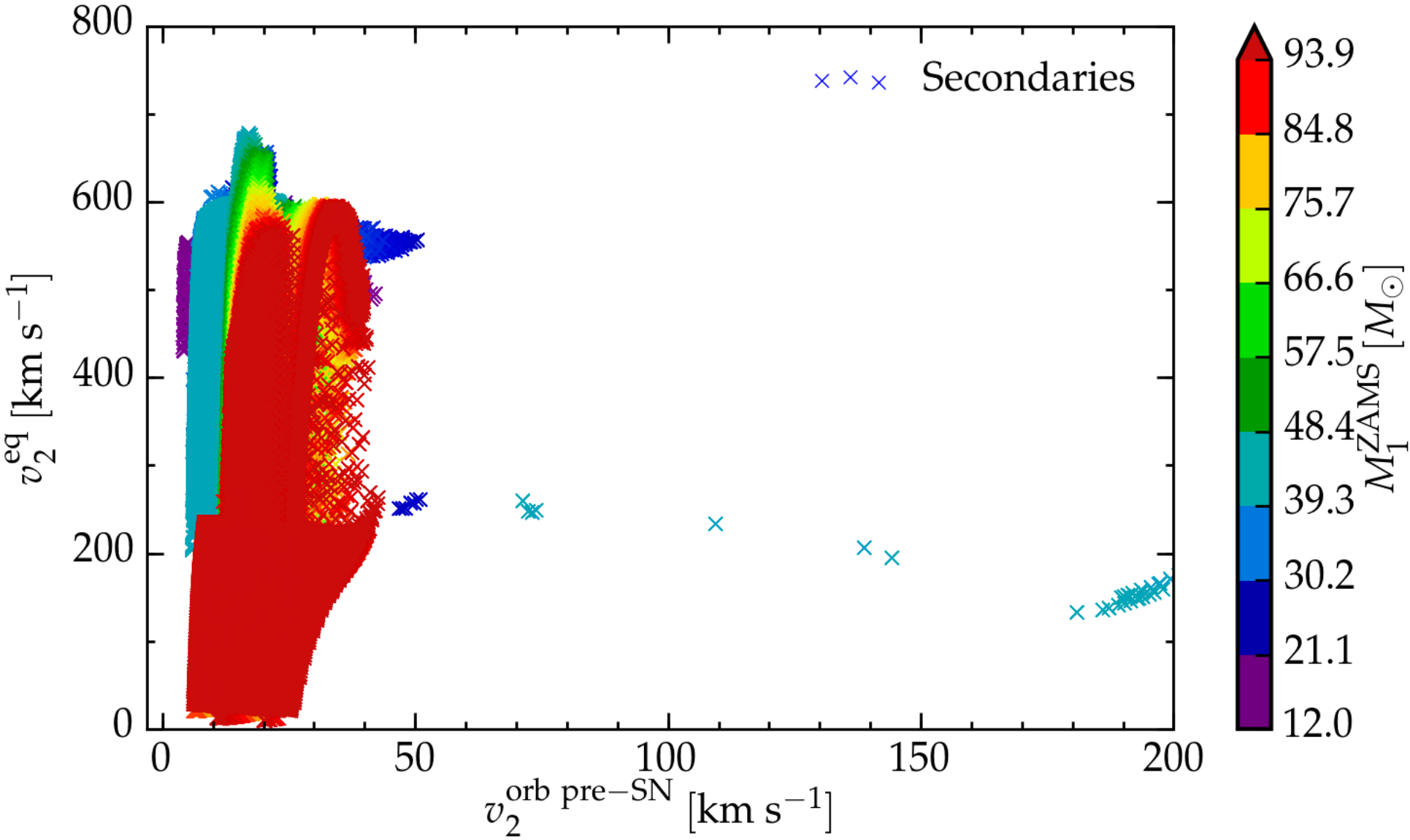
- $\frac{\textit{Rapidly Spinning slow RW}}{\textit{Slowly Spinning fast RWs}} = 1716 \quad (2390);$
- $\frac{\textit{Rapidly Spinning slow RW}}{\textit{Avoidance Region}} = 9266 \quad (13054);$
- $\frac{\textit{Rapidly Spinning slow RW}}{\textit{Slowly Spinning slow RWs}} = 5 \quad (13);$
- $\frac{\textit{Rapidly Spinning slow RW}}{\textit{"Walkaway" stars}} = 0.07 \quad (0.06);$

Preliminary Results



All binaries disrupted – non-accreted material takes away J_1

Preliminary Results



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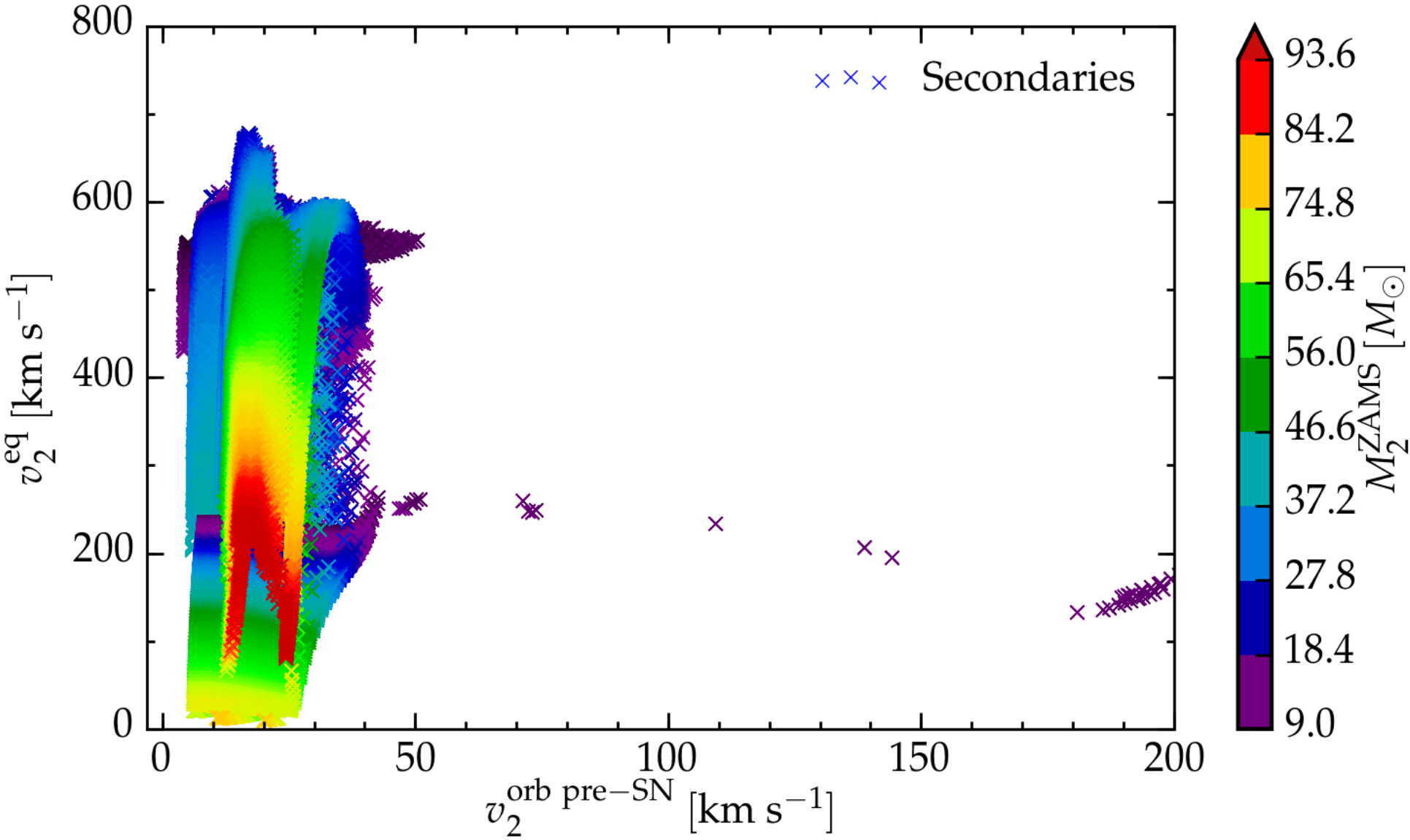

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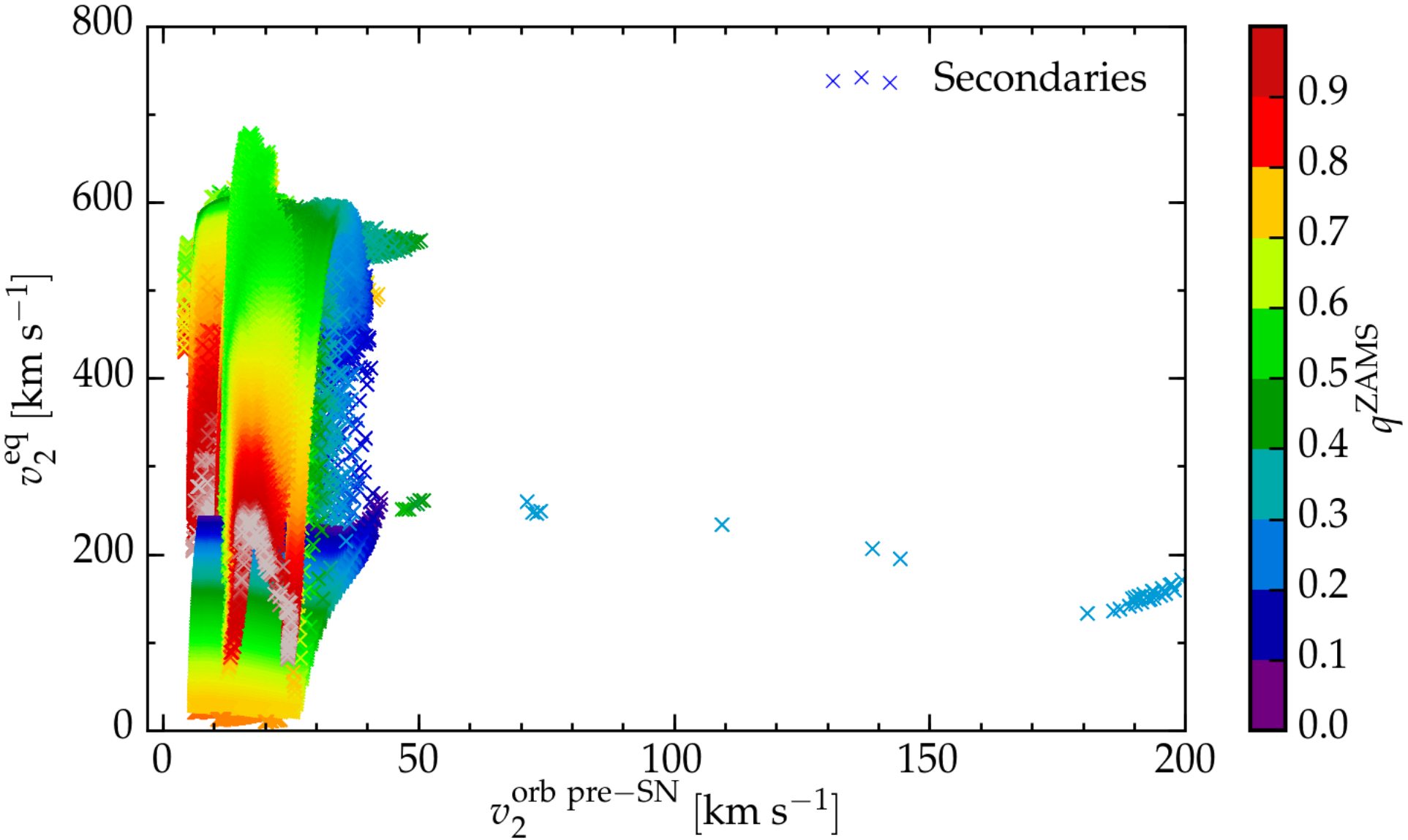

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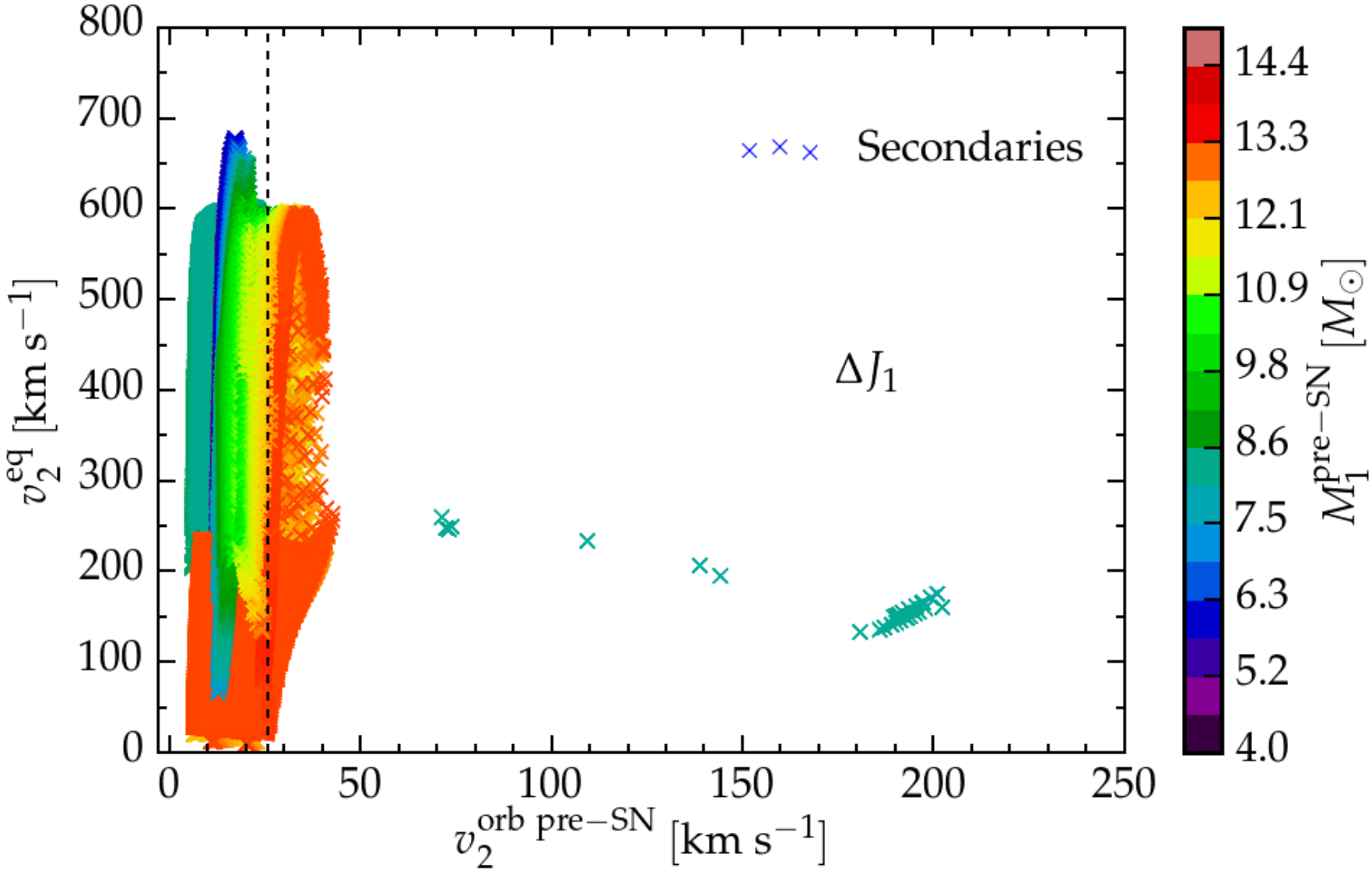
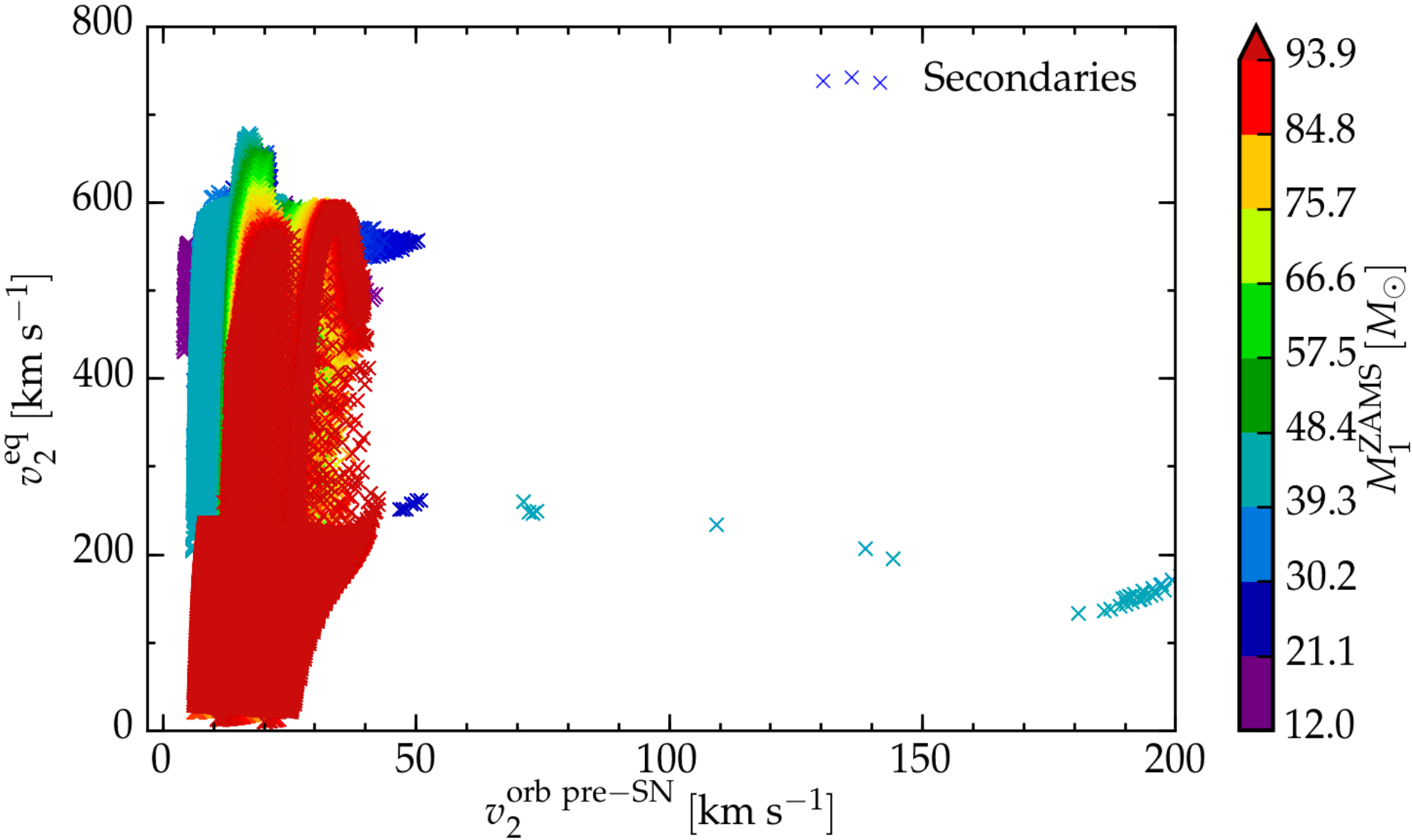


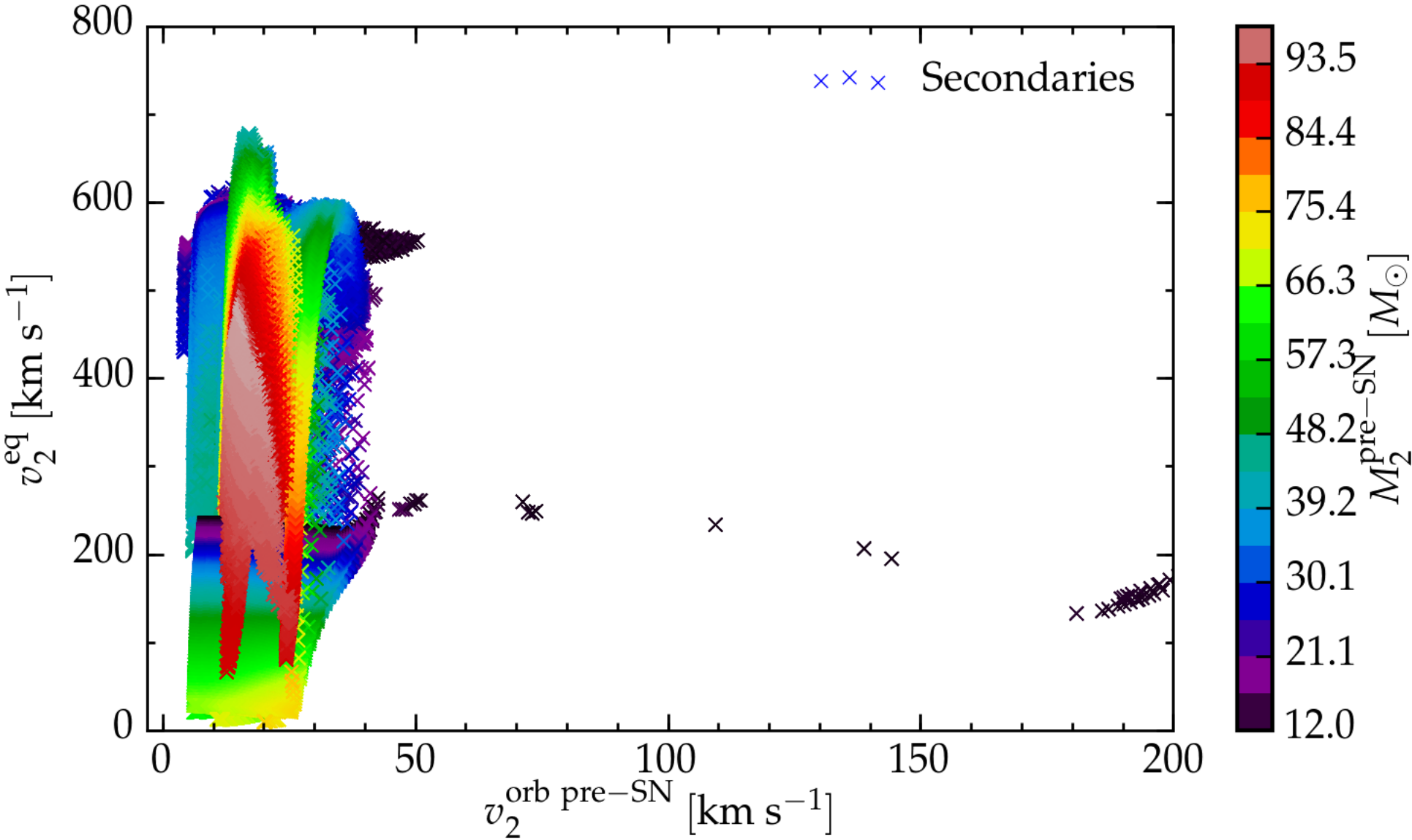
Only $t_{\rm SN} \leq 6$ Myrs – non-accreted material takes away J_1

Preliminary Results



All binaries disrupted – non-accreted material takes away J_2

Preliminary Results



All binaries disrupted – non-accreted material takes away J_2

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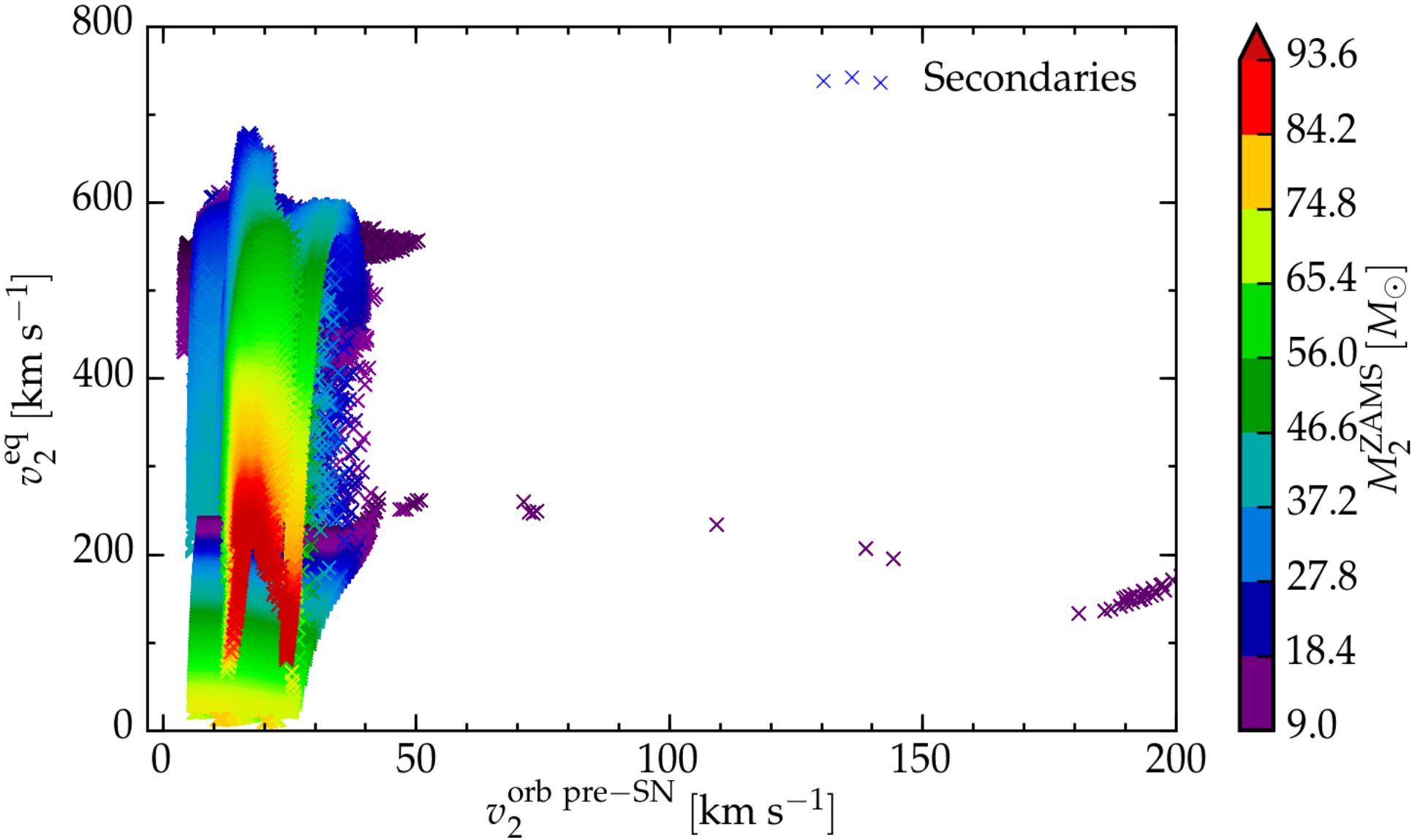

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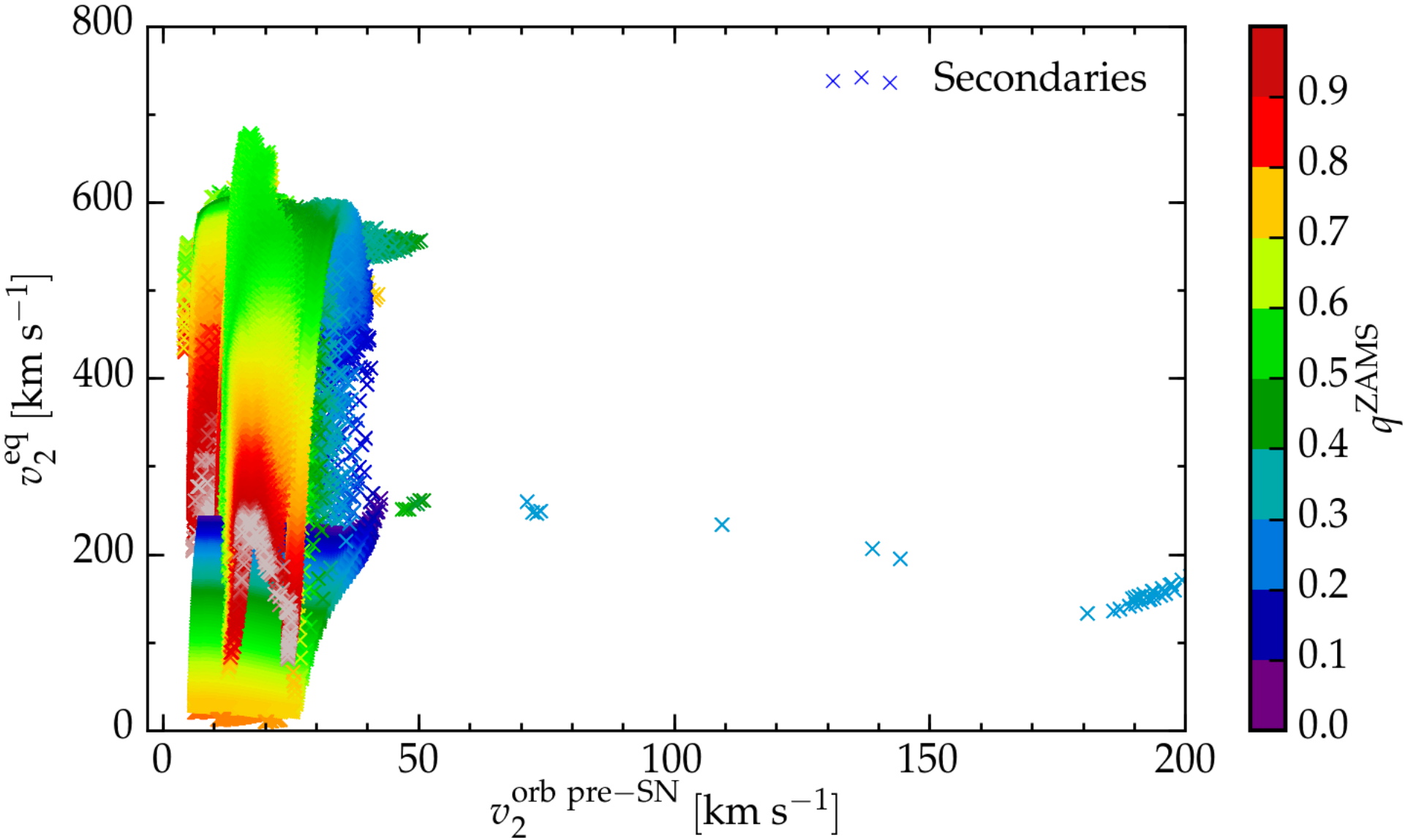

All binaries disrupted – non-accreted material takes away J_2