Long gamma-ray bursts from interacting binaries

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Long gamma-ray bursts - model

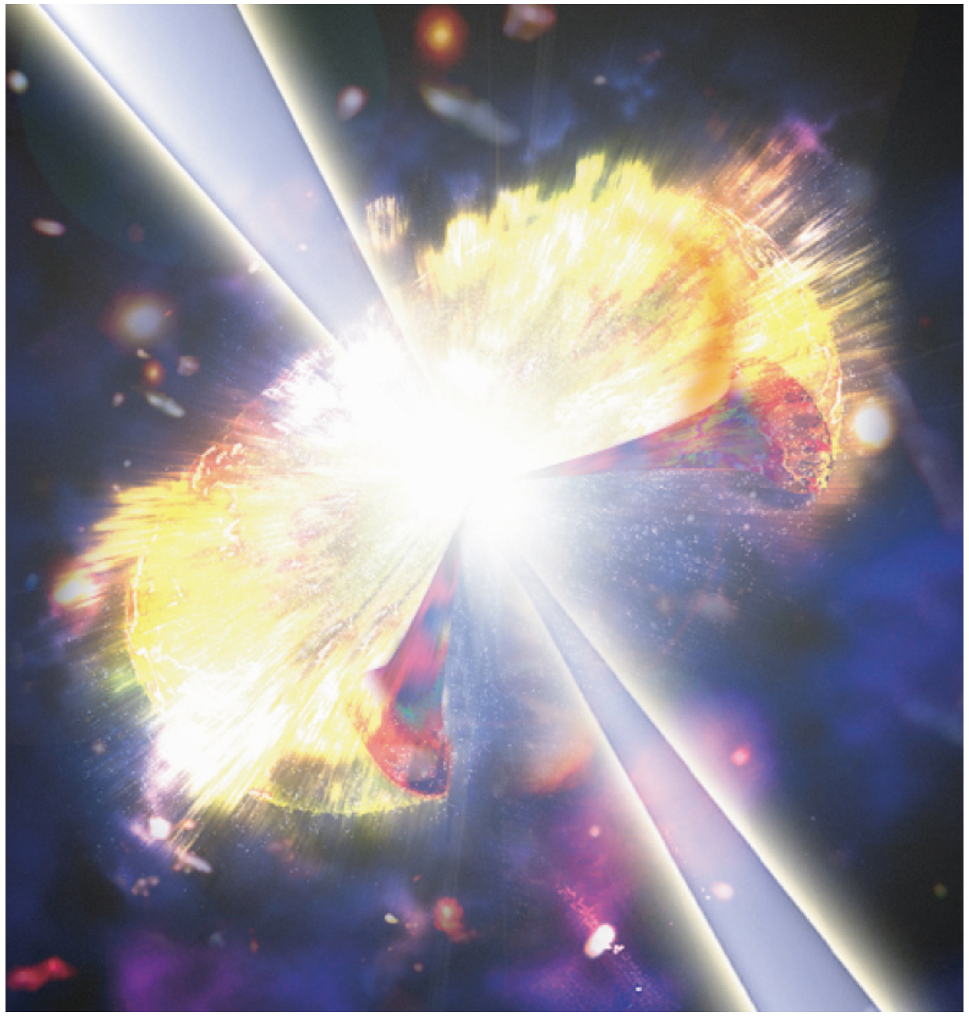
Core collapse of rapidly-rotating massive star

High specific angular momentum: some material falls back into a disc

Accretion of the disc produces relativistic jets at the poles

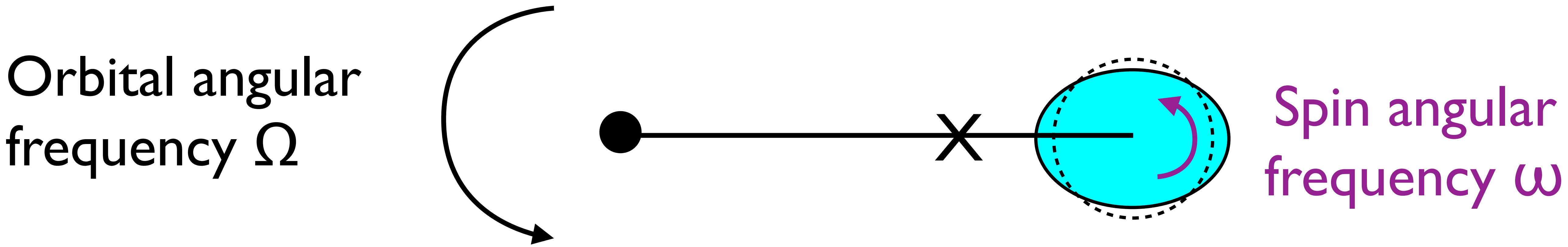
Problem: strong stellar winds should spin the star down

Woosley (1993) *ApJ* **405** 273



Close binaries

In a close binary, one star will raise tidal motions on the surface of the other.



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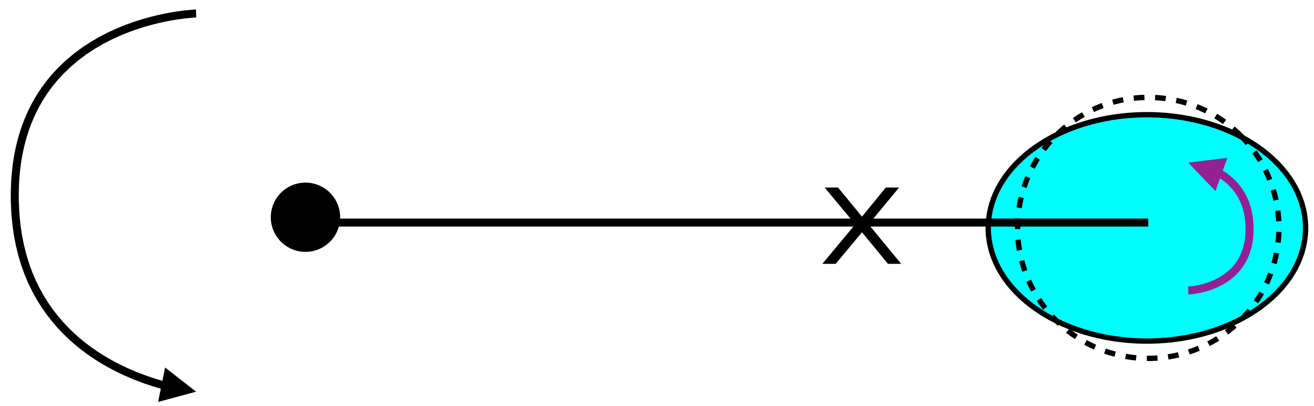
Orbital angular frequency Ω



Spin angular frequency ω

If $\omega < \Omega$

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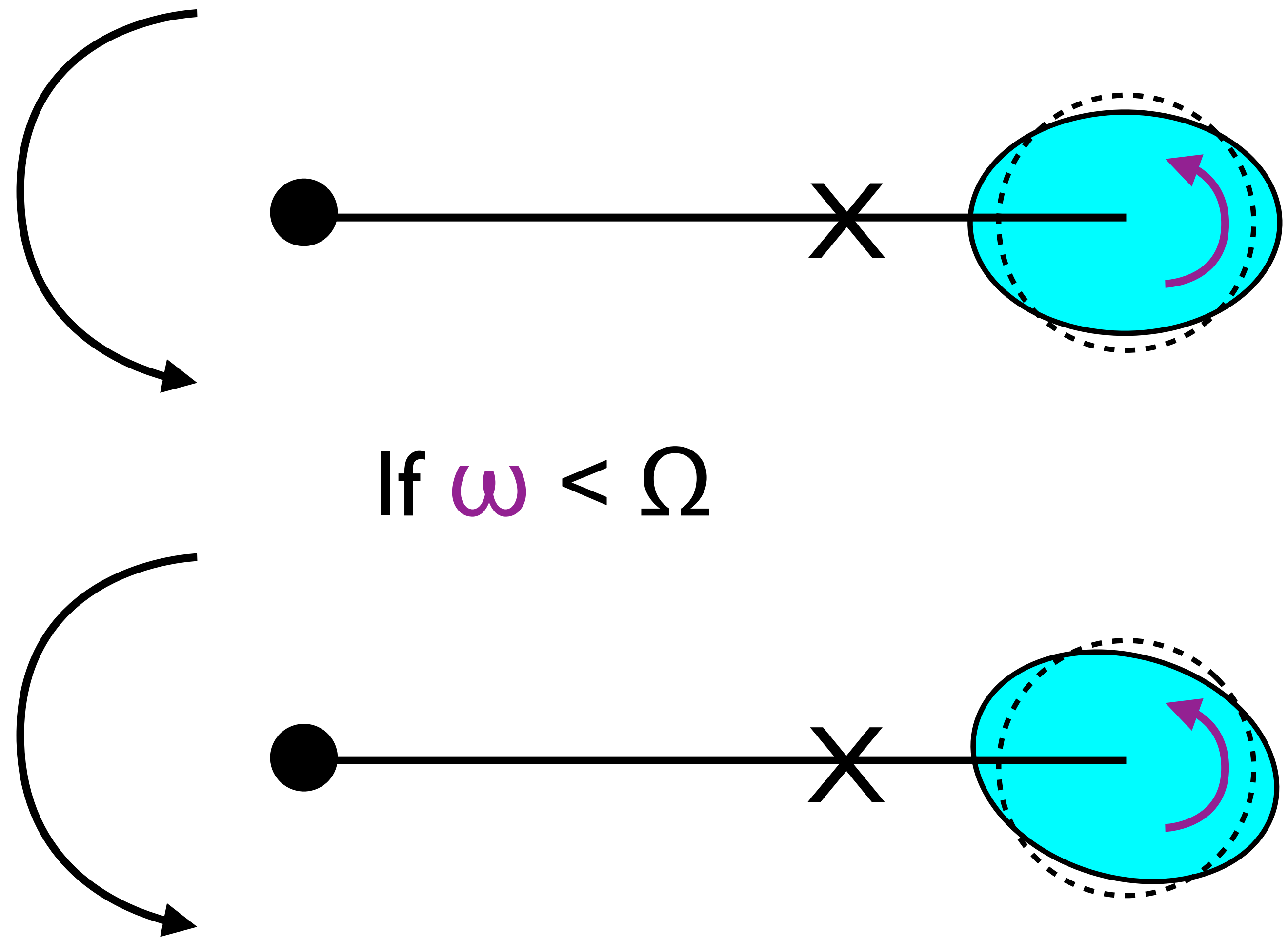
Orbital angular frequency Ω

Spin angular frequency ω



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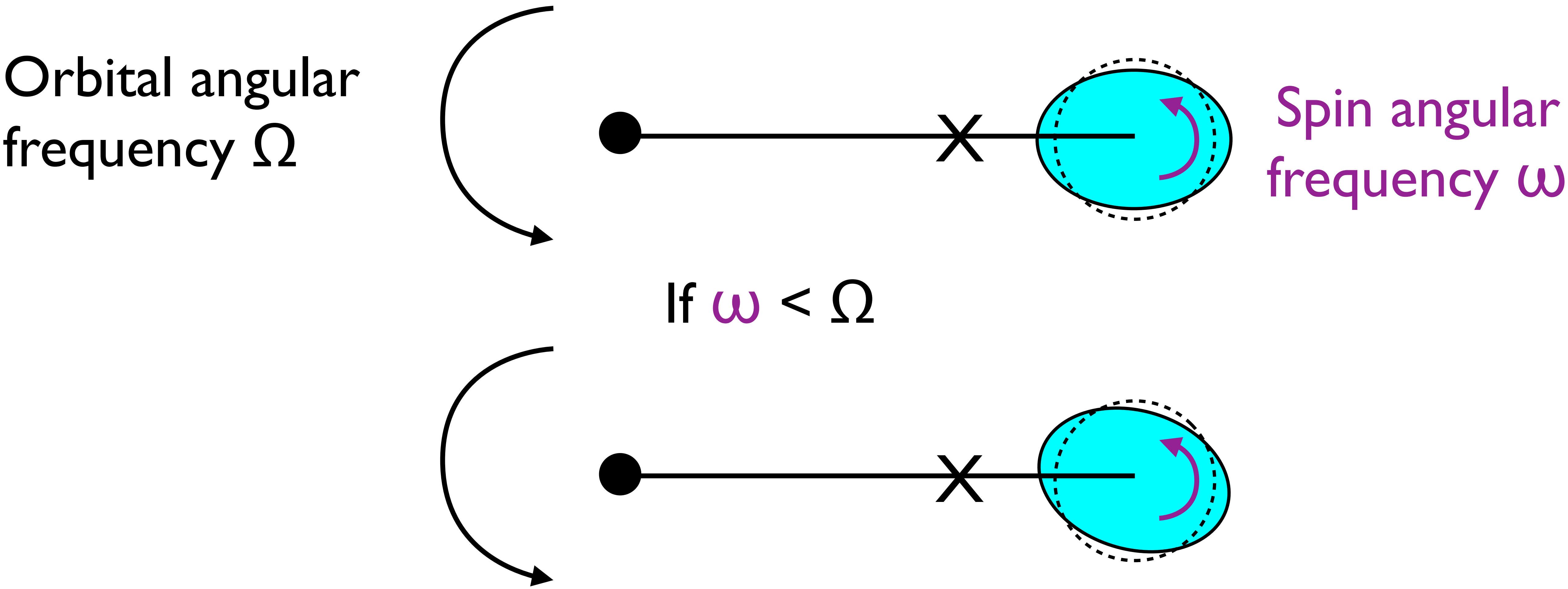
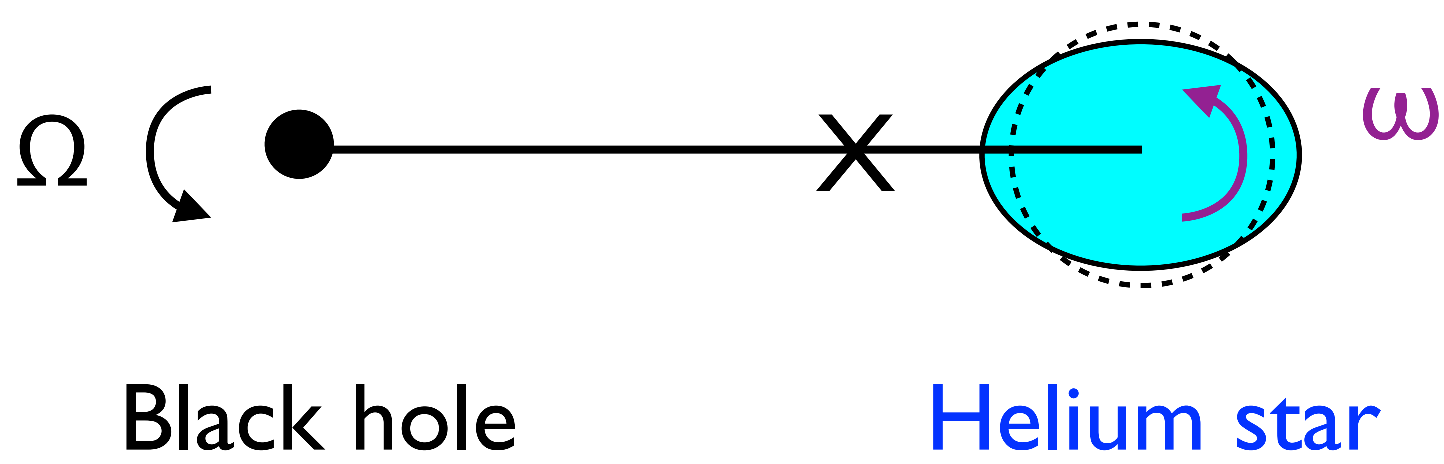


Tidal torque transfers angular momentum and can spin the star up

Tidal spin-up

Spin star up near end of evolution



(Podsiadlowski et al. 2004, Izzard et al. 2004, Levan et al. 2006)

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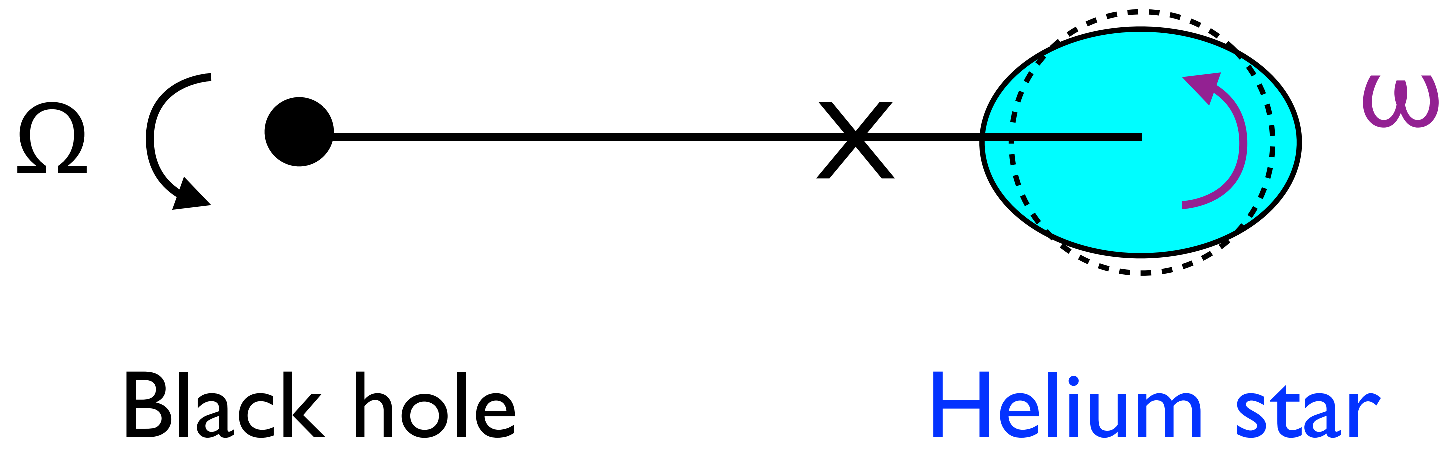

Stars are both small

(Podsiadlowski et al. 2004, Izzard et al. 2004, Levan et al. 2006)

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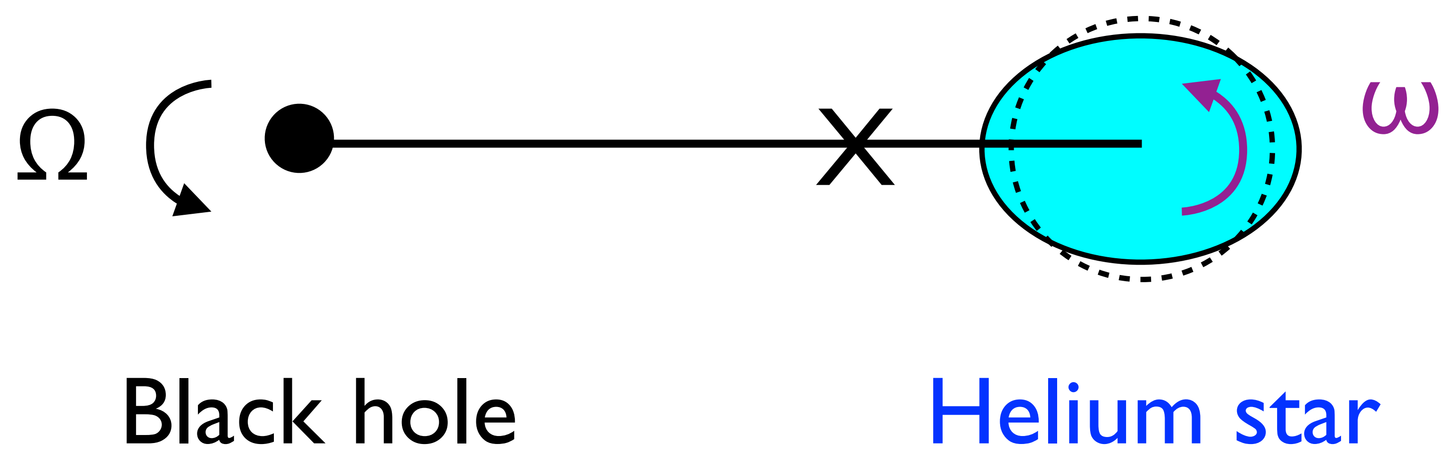

Stars are both small

Allows a close binary

(Podsiadlowski et al. 2004, Izzard et al. 2004, Levan et al. 2006)

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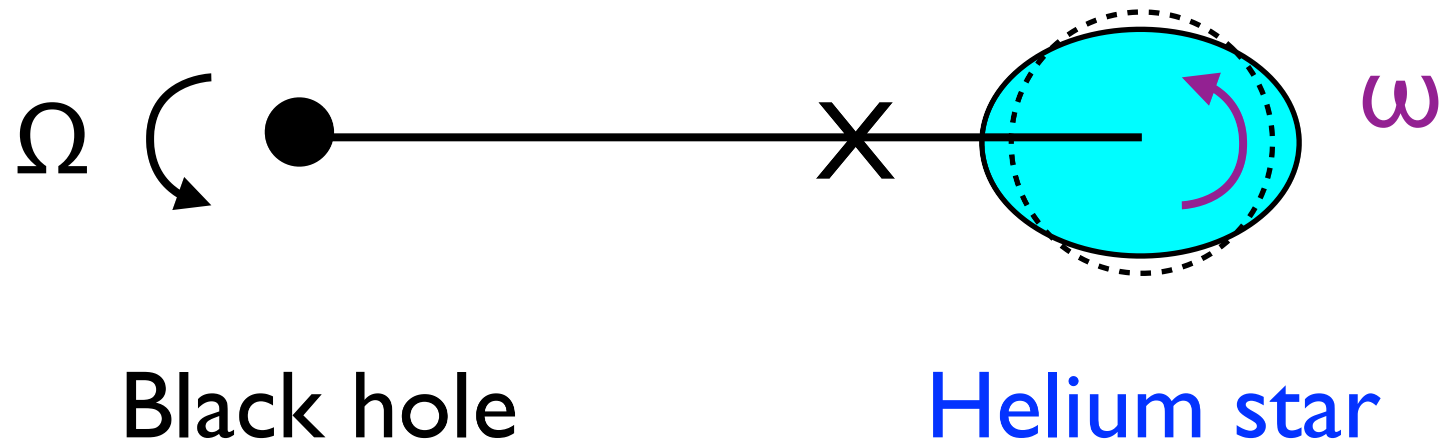


Stars are both small

- Allows a close binary
- Maximises possible spin

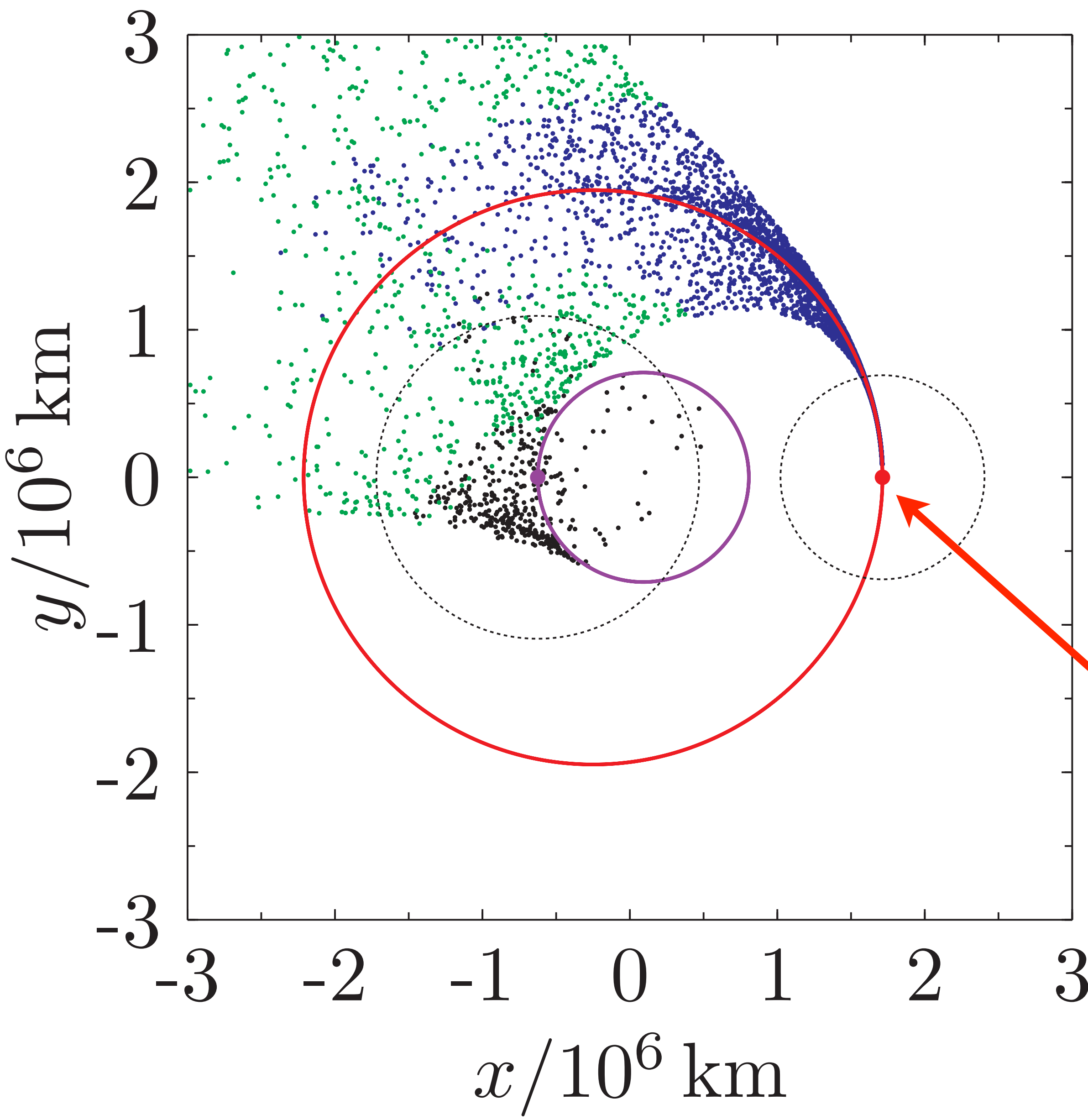
(Podsiadlowski et al. 2004, Izzard et al. 2004, Levan et al. 2006)

Consequences

The companion black hole is still there

Does it have any effect on the gamma-ray burst?

The view from above



Newly-formed black hole

arXiv: 1205.0552

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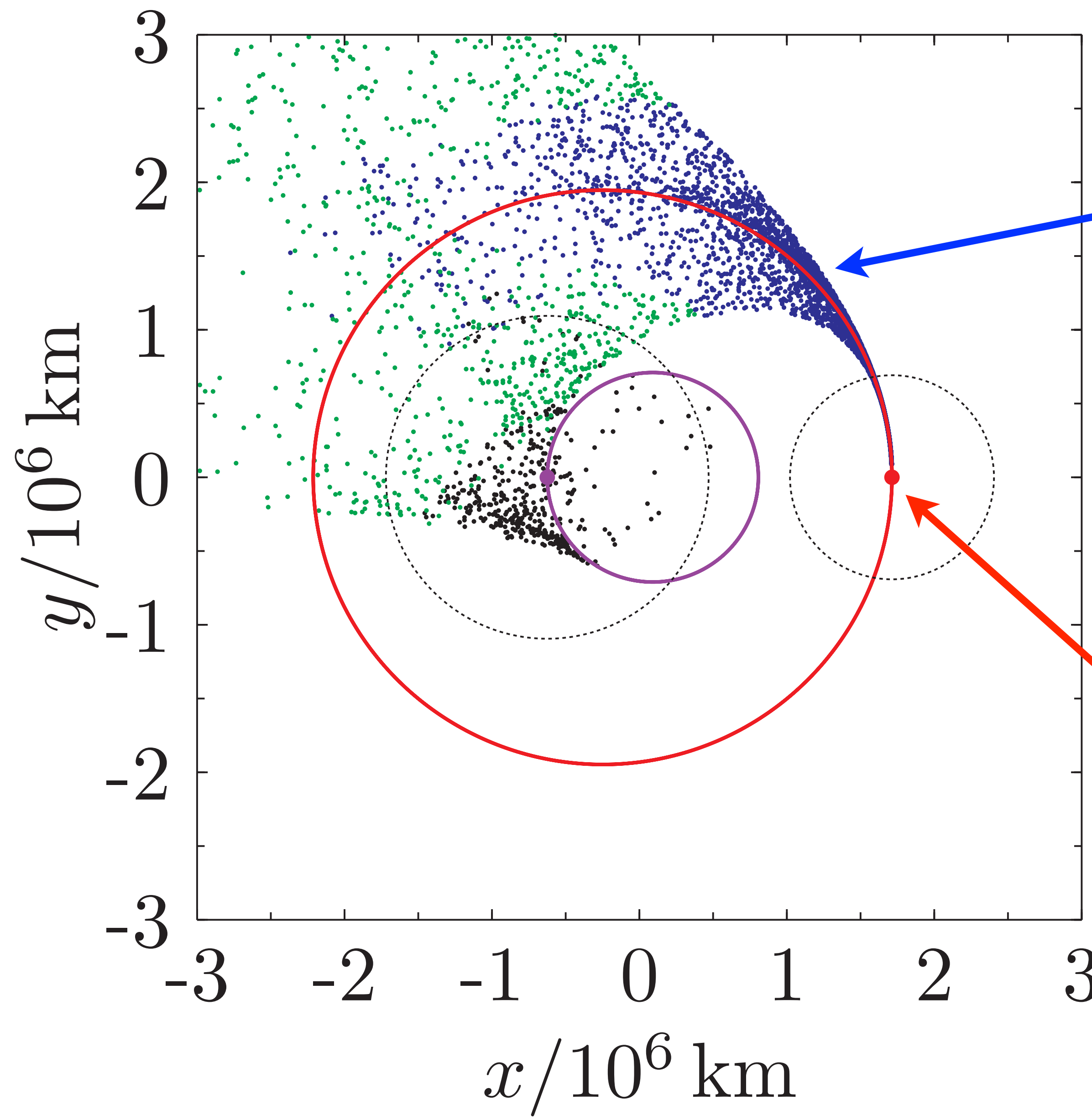

Material falling back into disc around new black hole (as in single star case)

Newly-formed black hole

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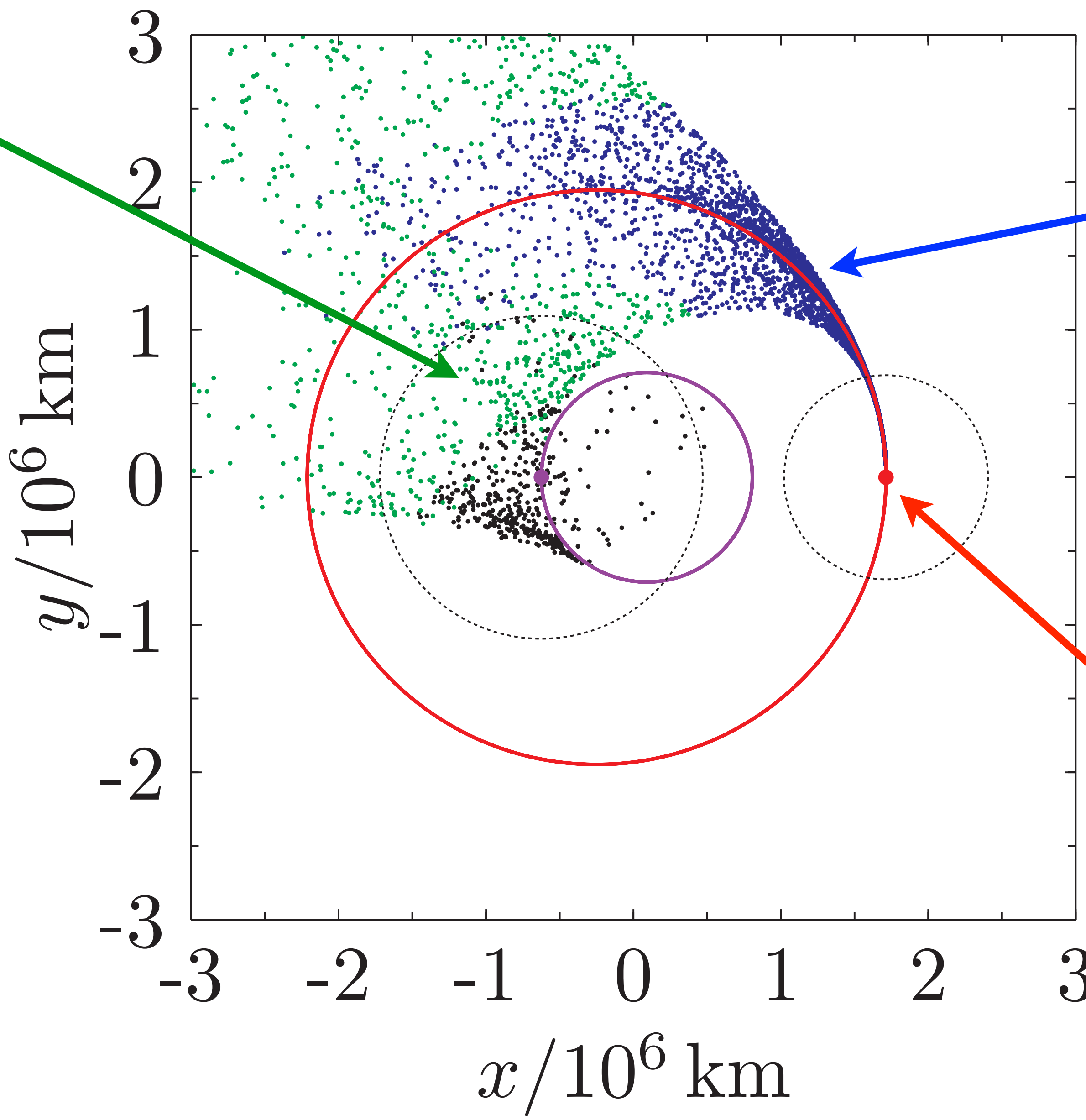
The view from above

Long fall-back time material lands outside either star's Roche Lobe



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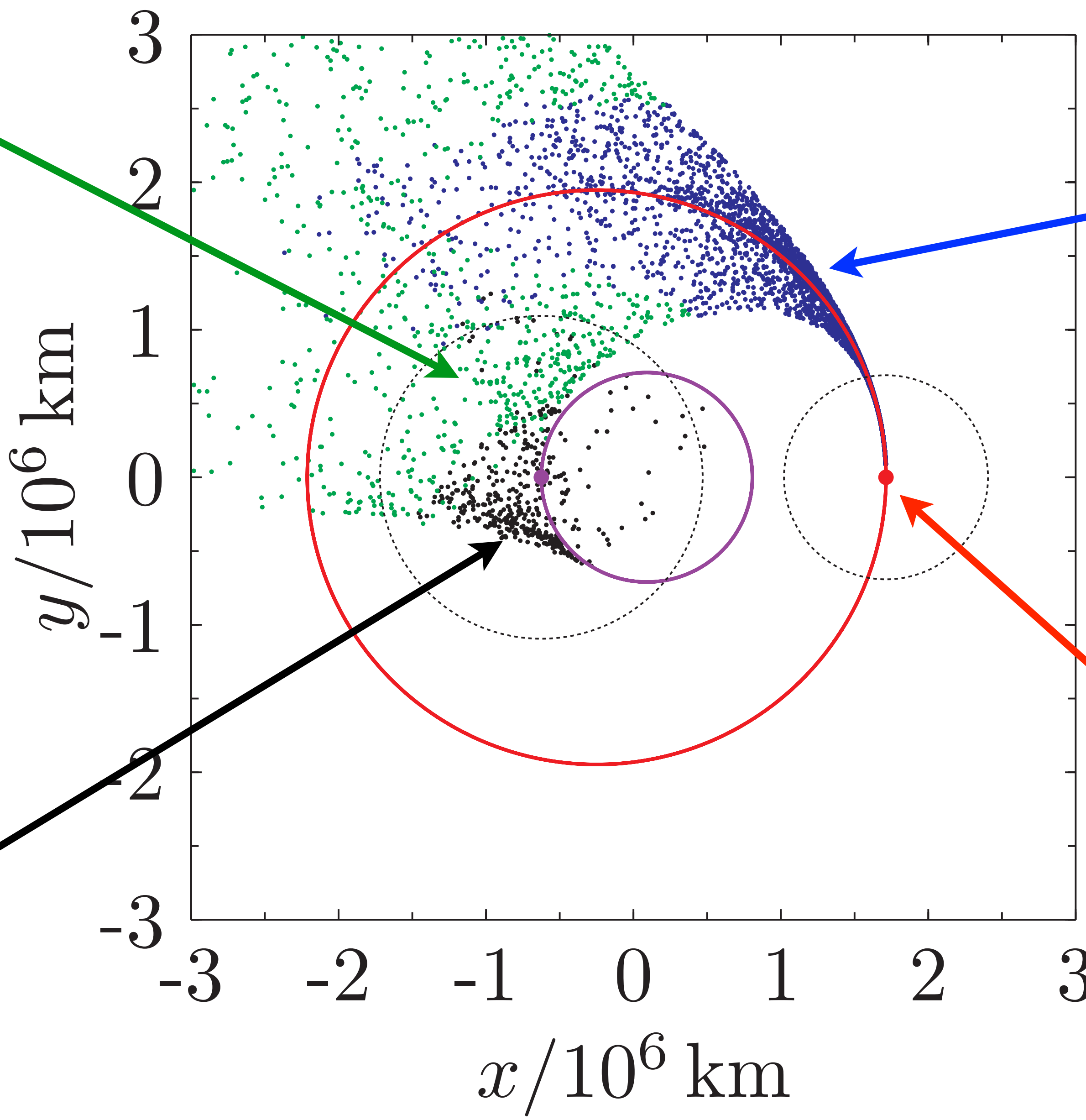

Material falling back into disc around new black hole (as in single star case)

Some gas sufficiently deflected to form a disc around the companion black hole

Newly-formed black hole

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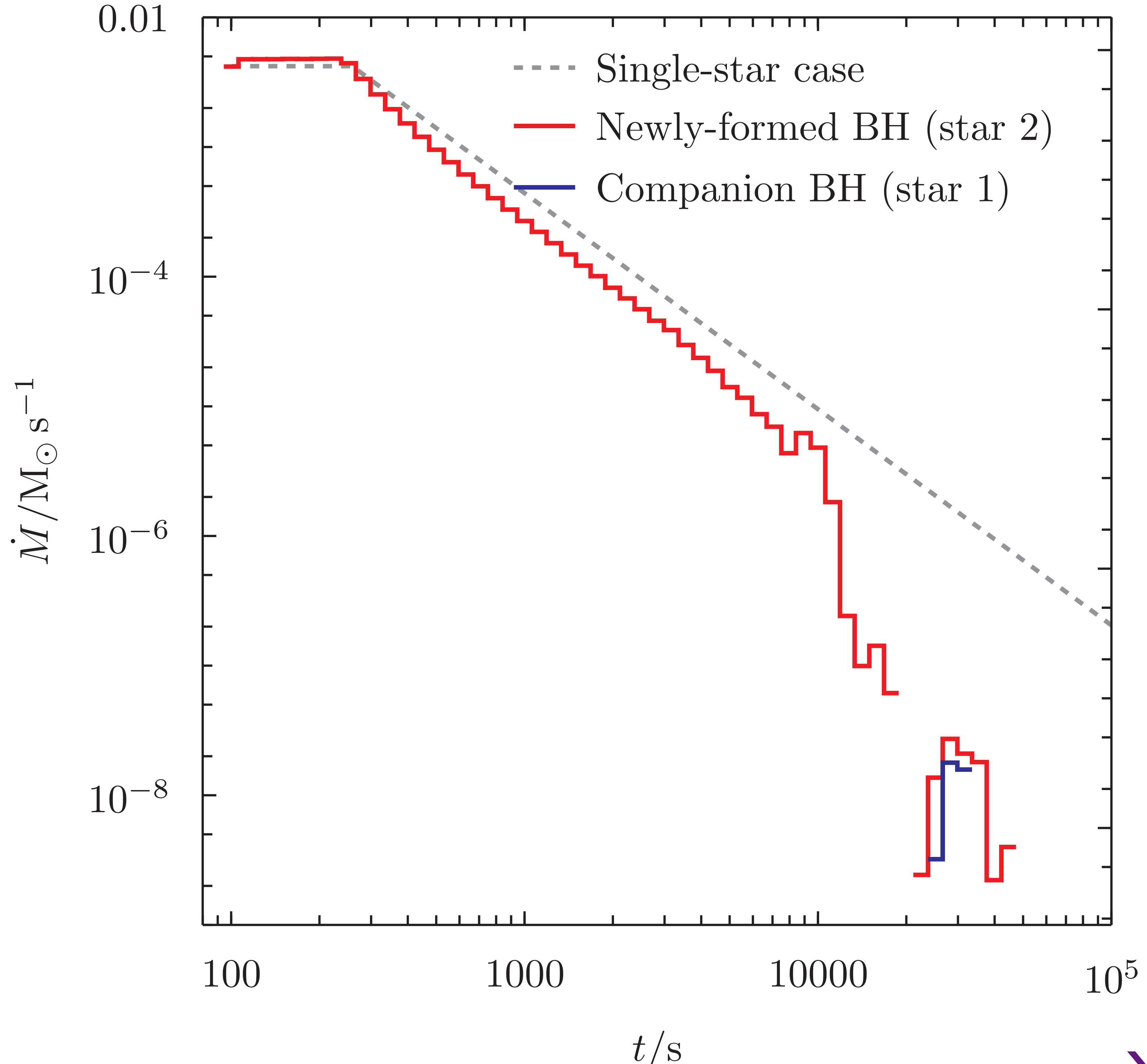
Typical accretion curve



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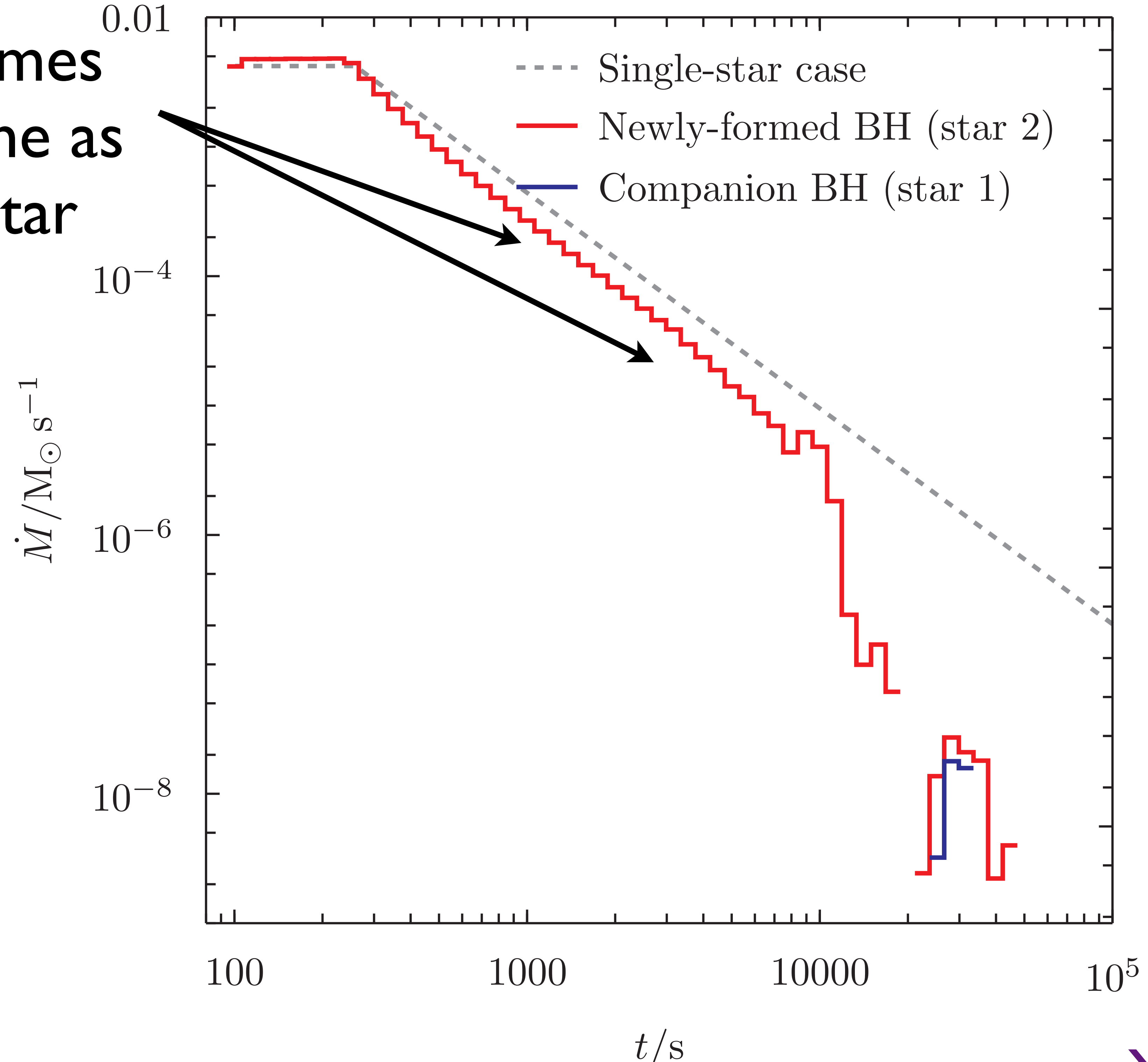
Typical accretion curve

Early times the same as single star case



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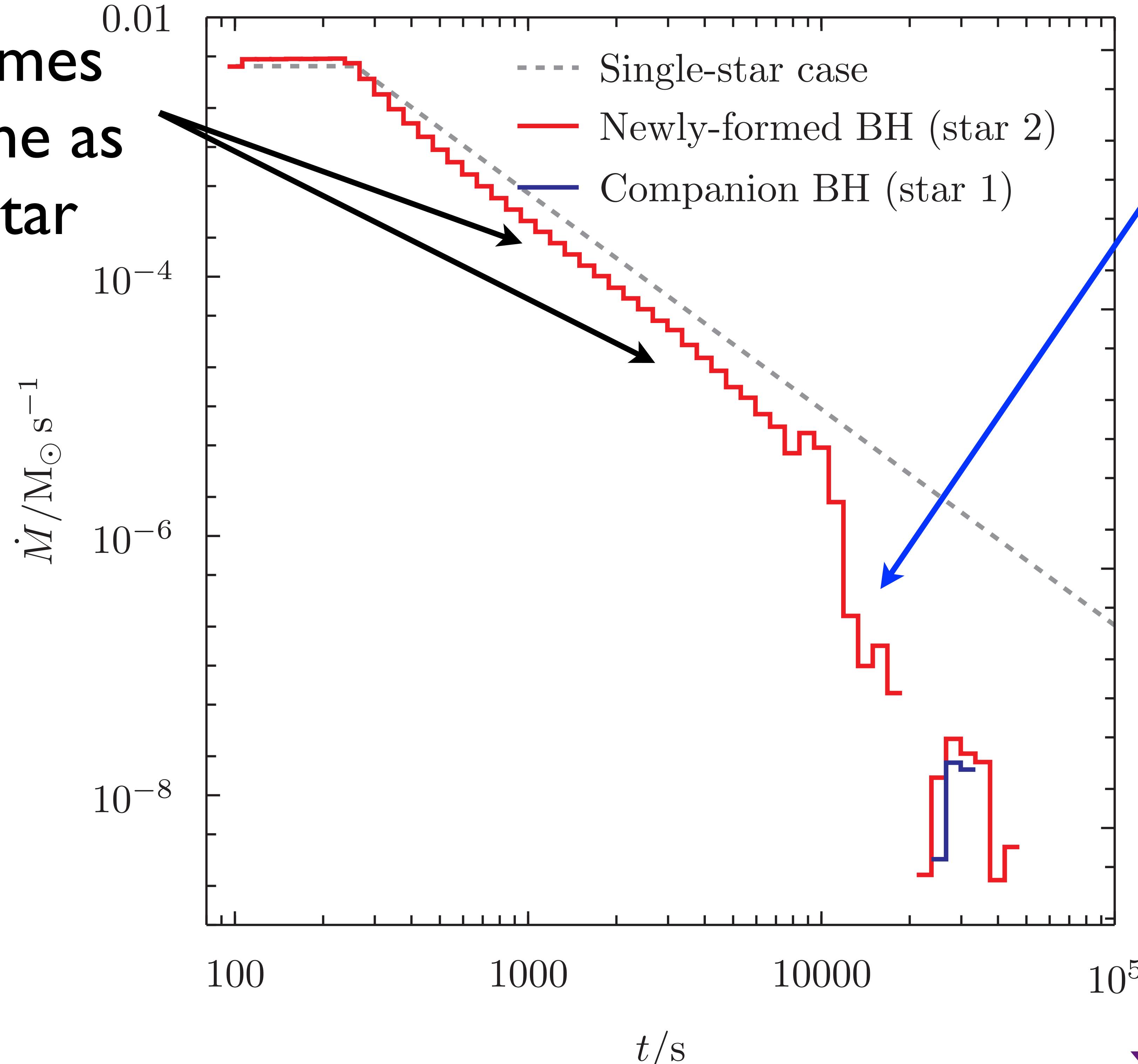

Sharp break from Roche Lobe truncation

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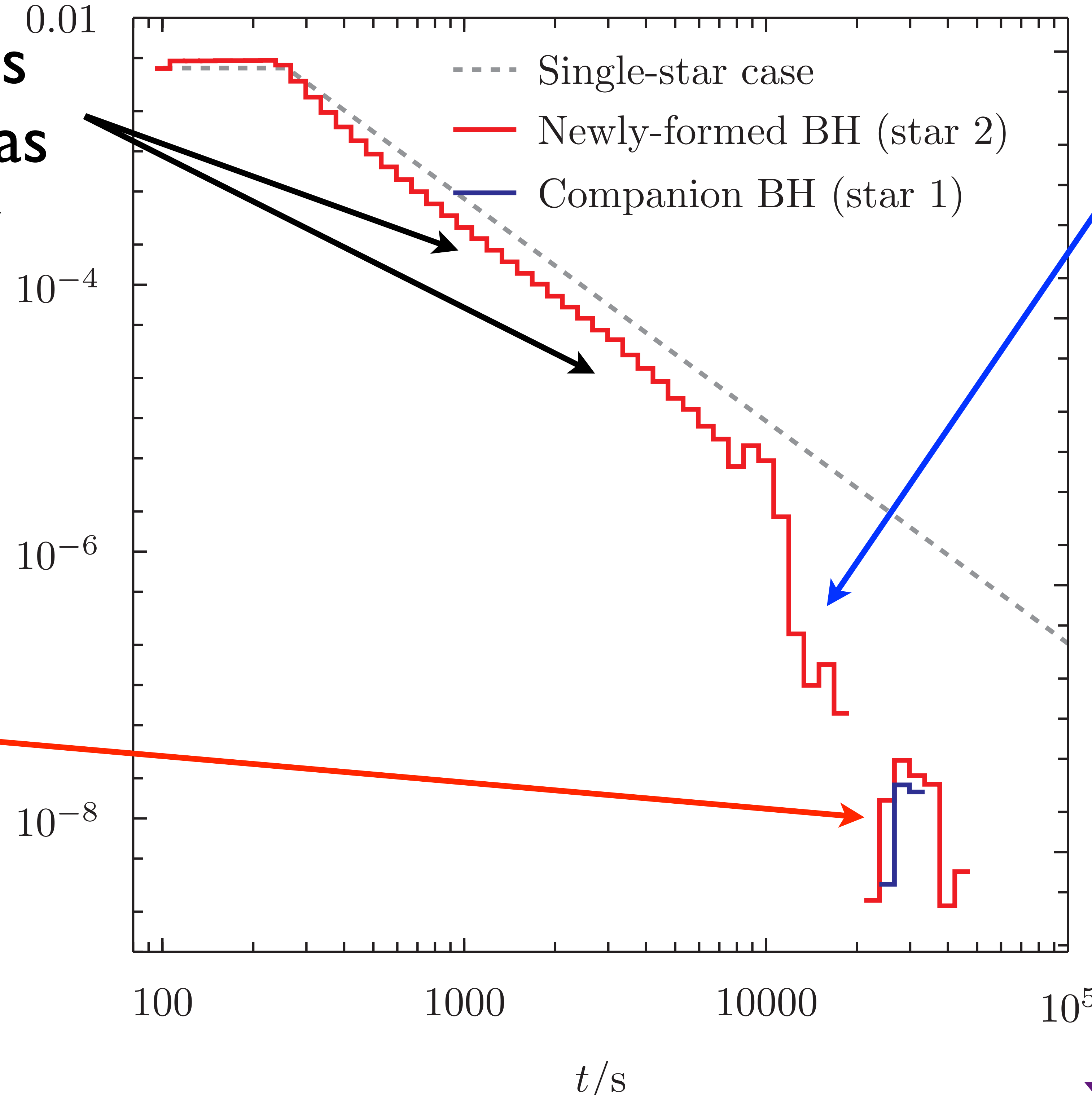
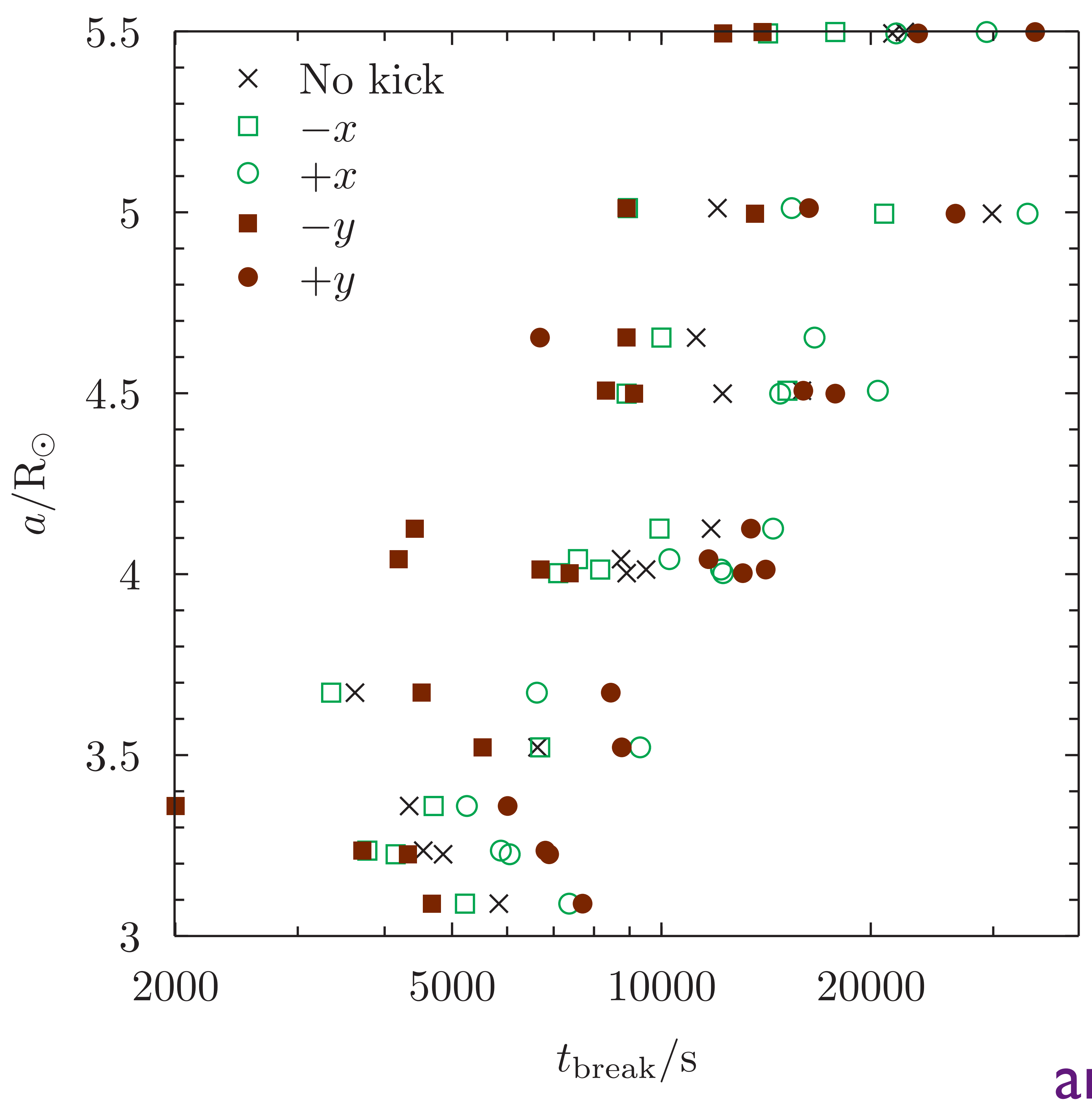


Sharp break from Roche Lobe truncation

Late-time flaring activity

arXiv: 1205.0552

Break times



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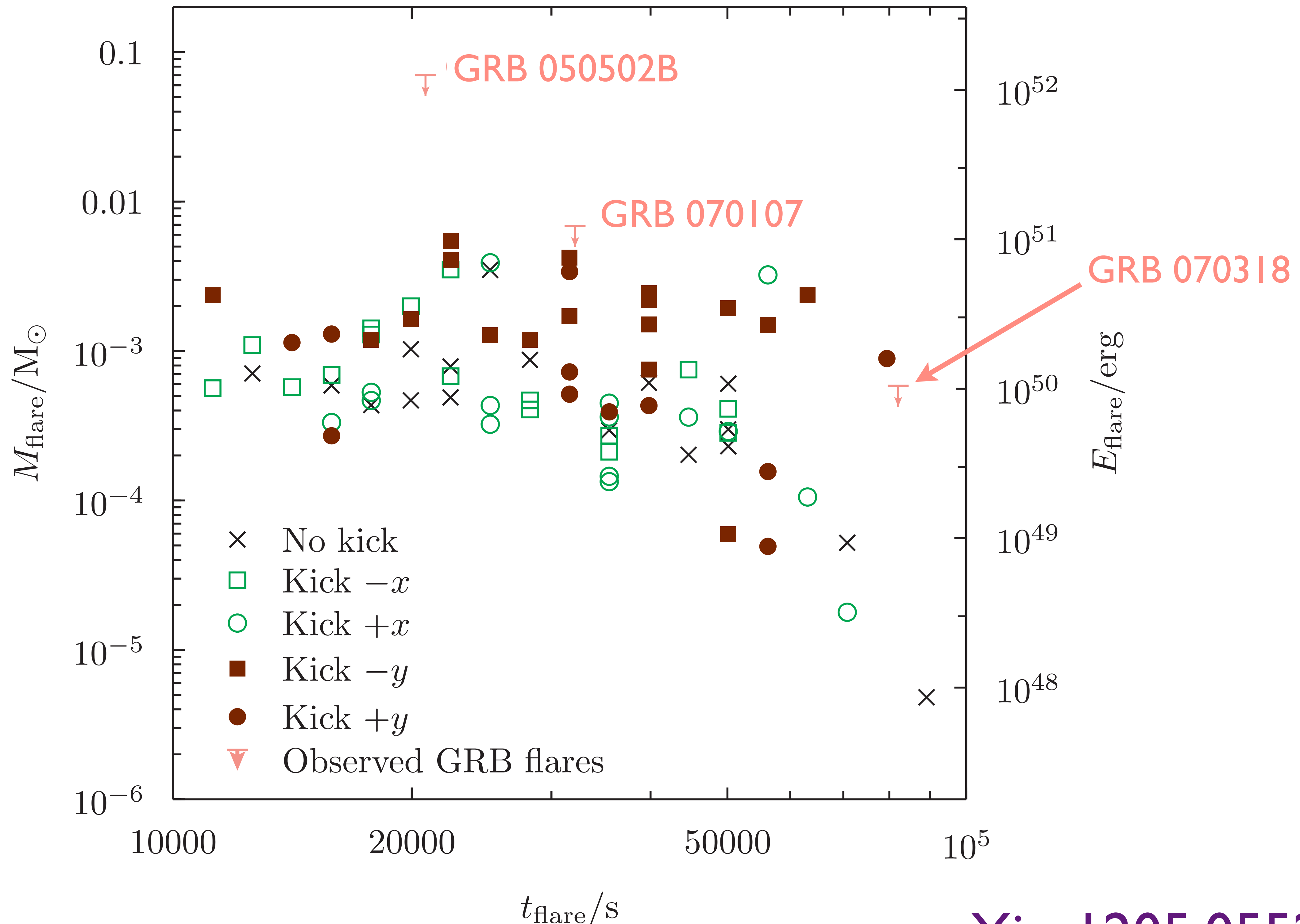
Flare properties



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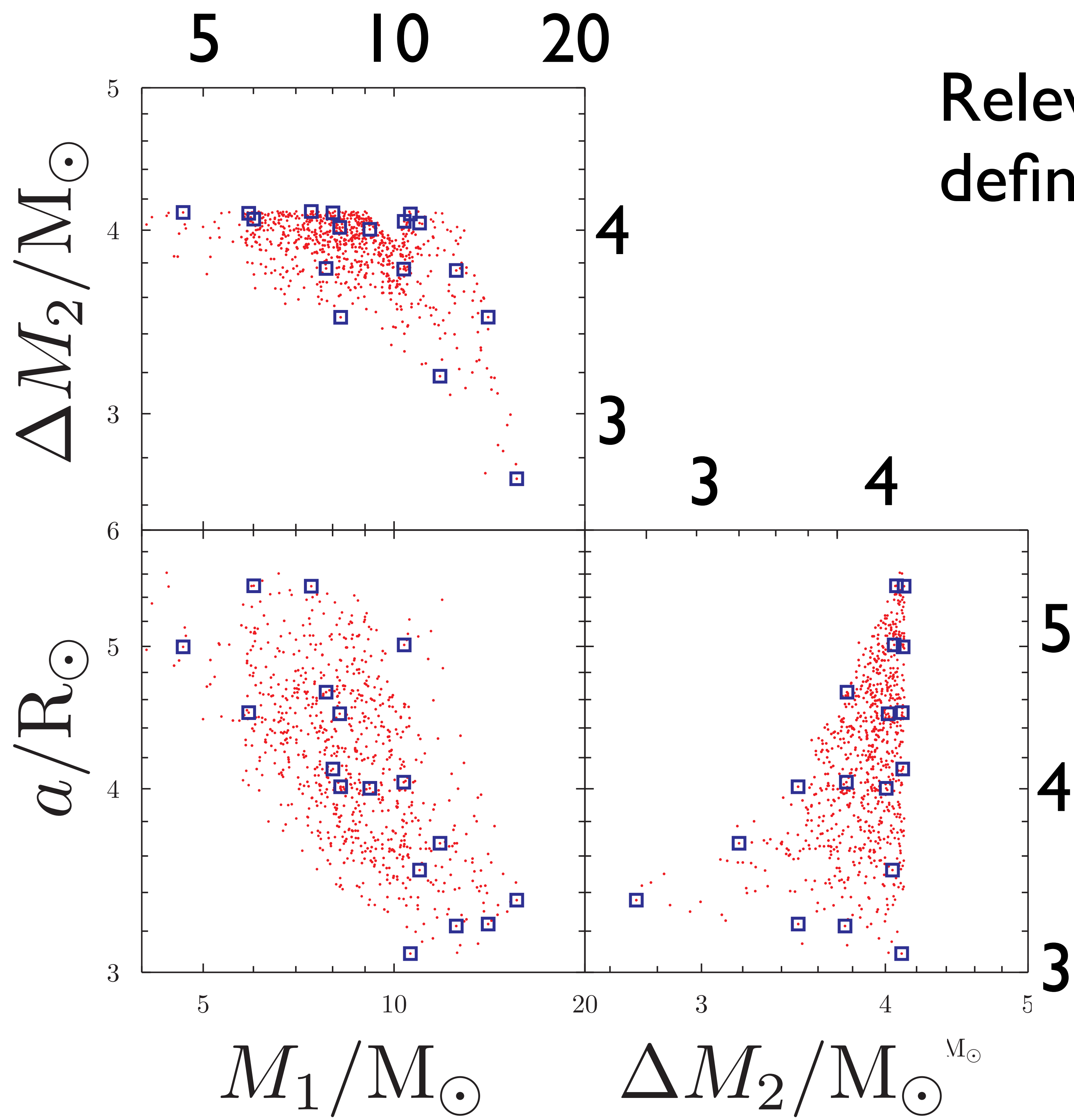
Such a companion will affect the material that falls back on to the black hole.

This interference produces sharp light curve breaks and late-time flares.

Population at time of supernova

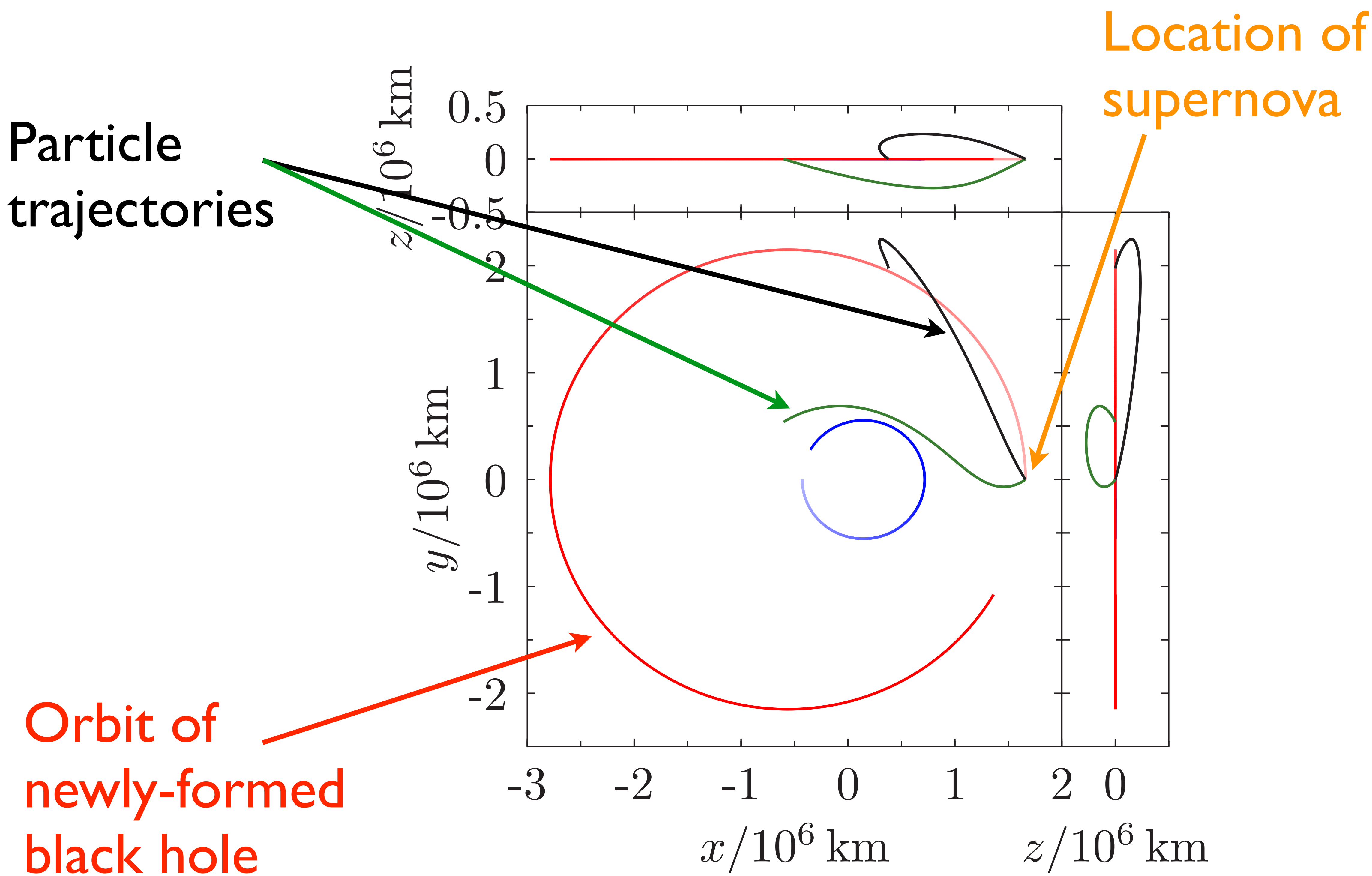


Relevant binaries occupy a well-defined phase space:

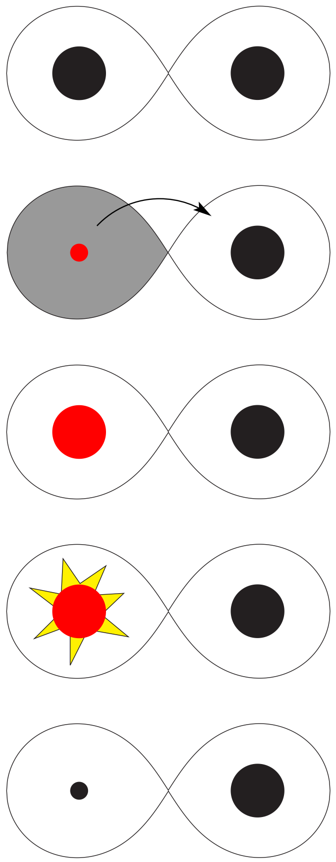
$$a \simeq 3 - 5\,R_\odot$$
$$M_{2,\mathrm{pre}} \simeq 7 - 8\,M_\odot$$
$$M_{\mathrm{BH}} \simeq 5 - 15\,M_\odot$$

Distribution reflects realistic initial conditions

Example trajectories



Evolutionary pathway (not to scale)



Initial main sequence–main sequence binary

Stable mass transfer from primary

Helium star–main sequence star binary

First supernova

Black hole–main sequence star binary

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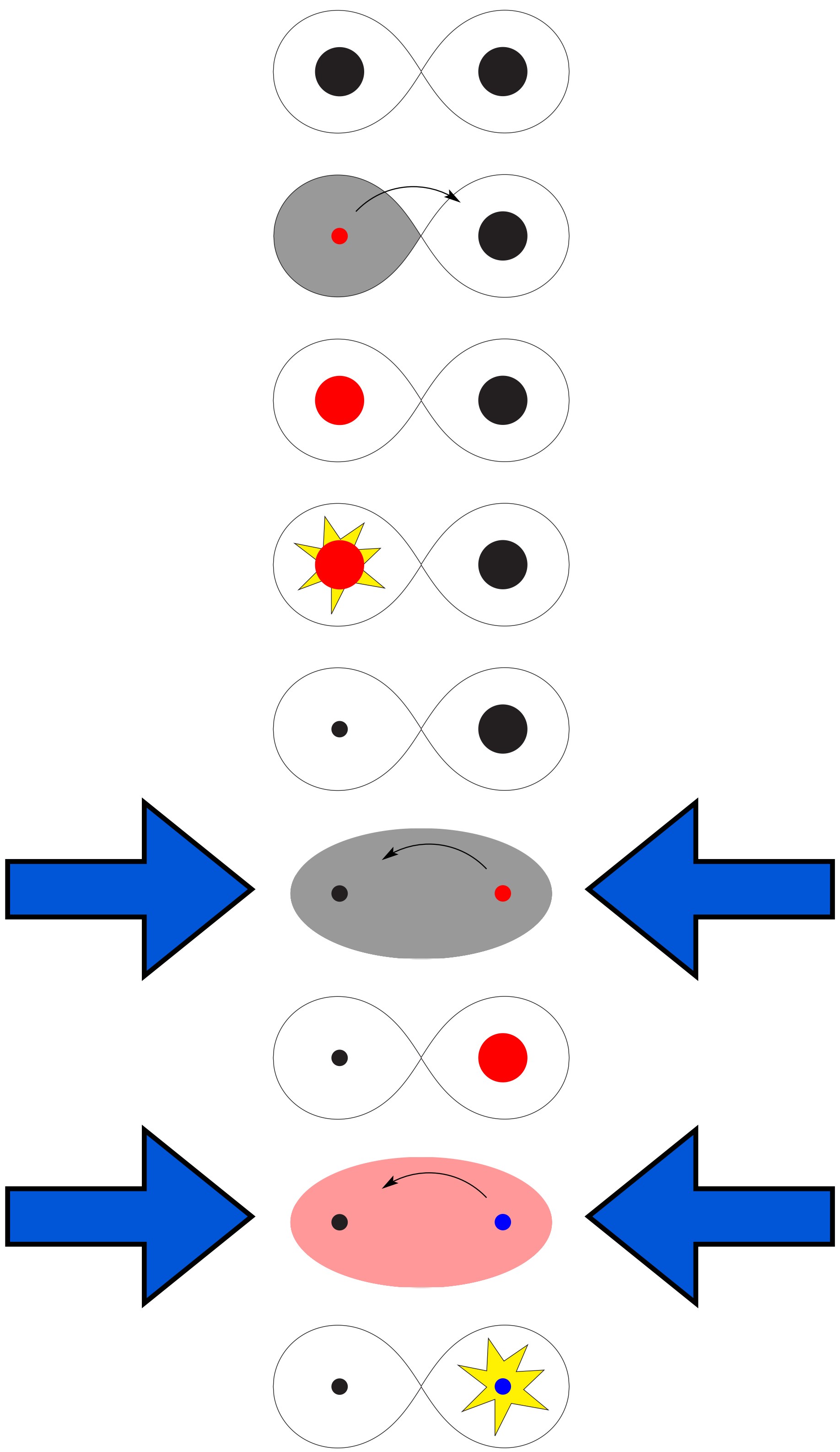

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Stable mass transfer from primary

Helium star–main sequence star binary

First supernova

Black hole–main sequence star binary

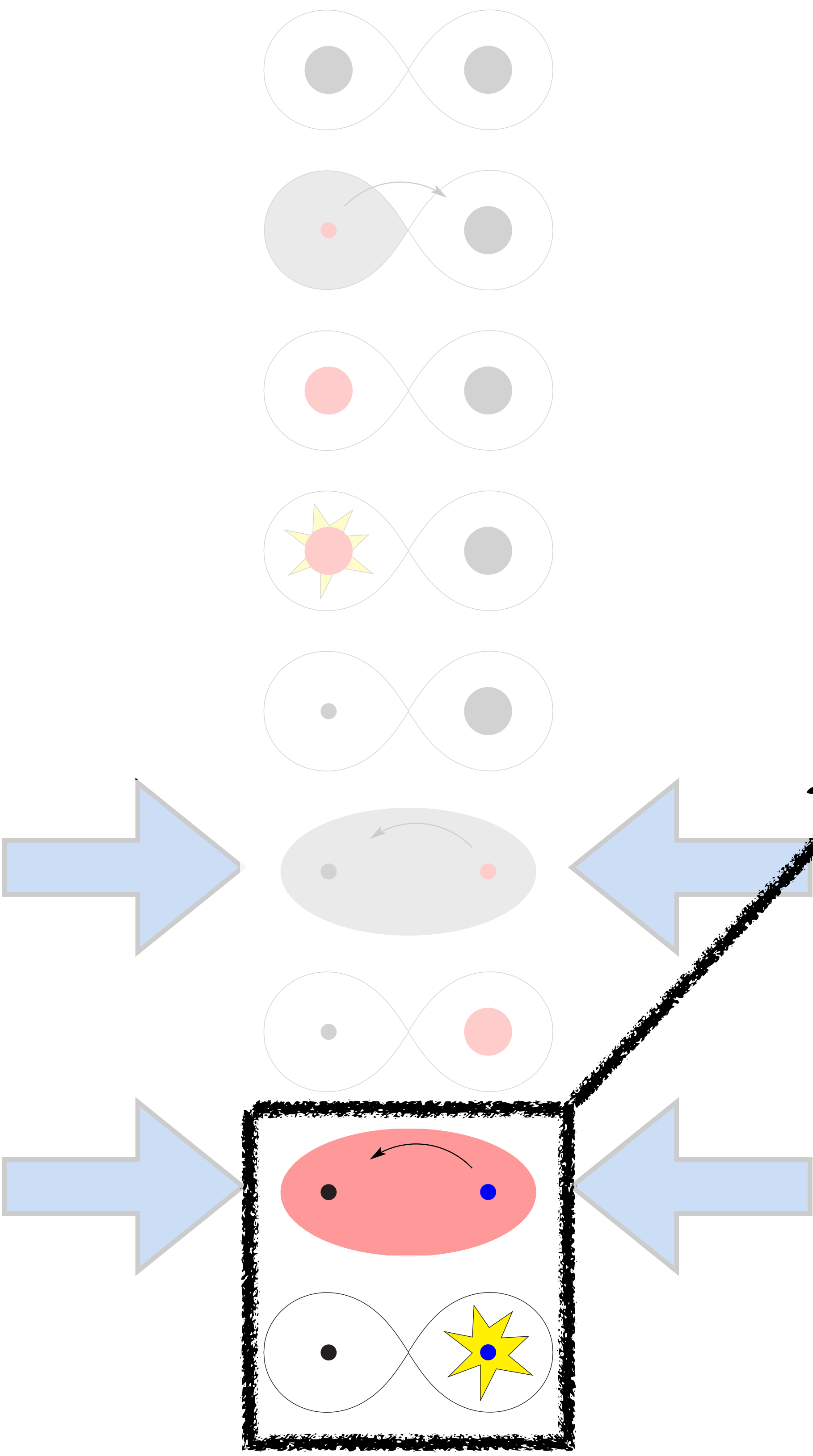
Common envelope evolution

Close black hole–helium star binary

Common envelope evolution (round 2)

Final supernova

Evolutionary pathway (not to scale)



Binary is closest at the end
⇒ Tides can spin the star up before the final supernova

Common envelope evolution (round 2)

Final supernova