47 Tuc X9
An ultra-compact X-ray binary with a black hole accretor

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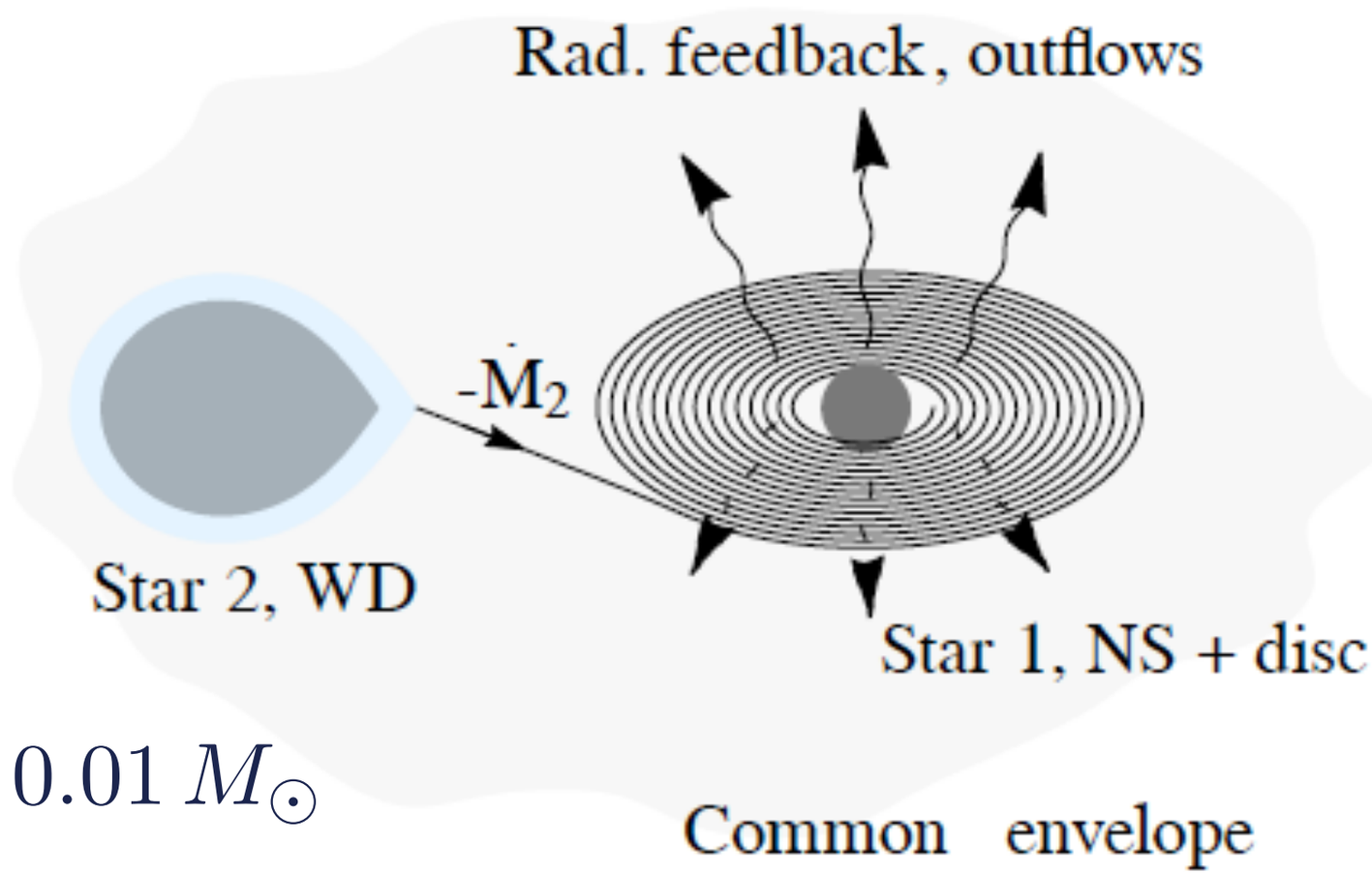
Ultra-compact X-ray binaries (UCXBs)



$M_{\rm WD} \approx 0.01\, M_\odot$

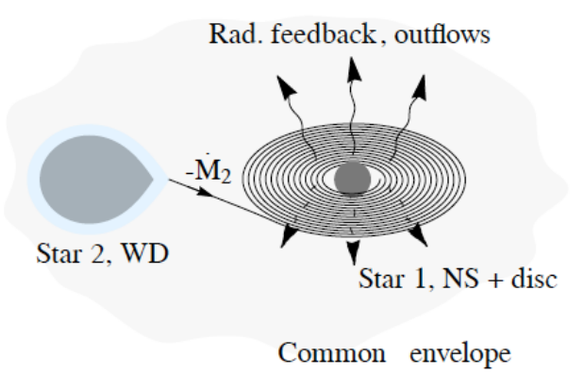
Observed as bright X-ray sources; e.g. 4U 1820-30

Talk summary

47 Tuc X9 is a black hole + CO white dwarf UCXB

Neutron star + CO white dwarf UCXBs undergo unstable mass transfer and merge

BH - CO white dwarf UCXBs like 47 Tuc X9 do not form in the field, but can form dynamically in dense clusters



Bahramian et al. (2017) *MNRAS* **467** 2199
Bobrick, Davies & RC (2017) *MNRAS* **467** 3556
Church et al. (2017) *ApJL* **851** 4

Observational summary

(Recap from Arash's talk yesterday)

X-ray / radio ratio implies a BH accretor

27-day orbital period

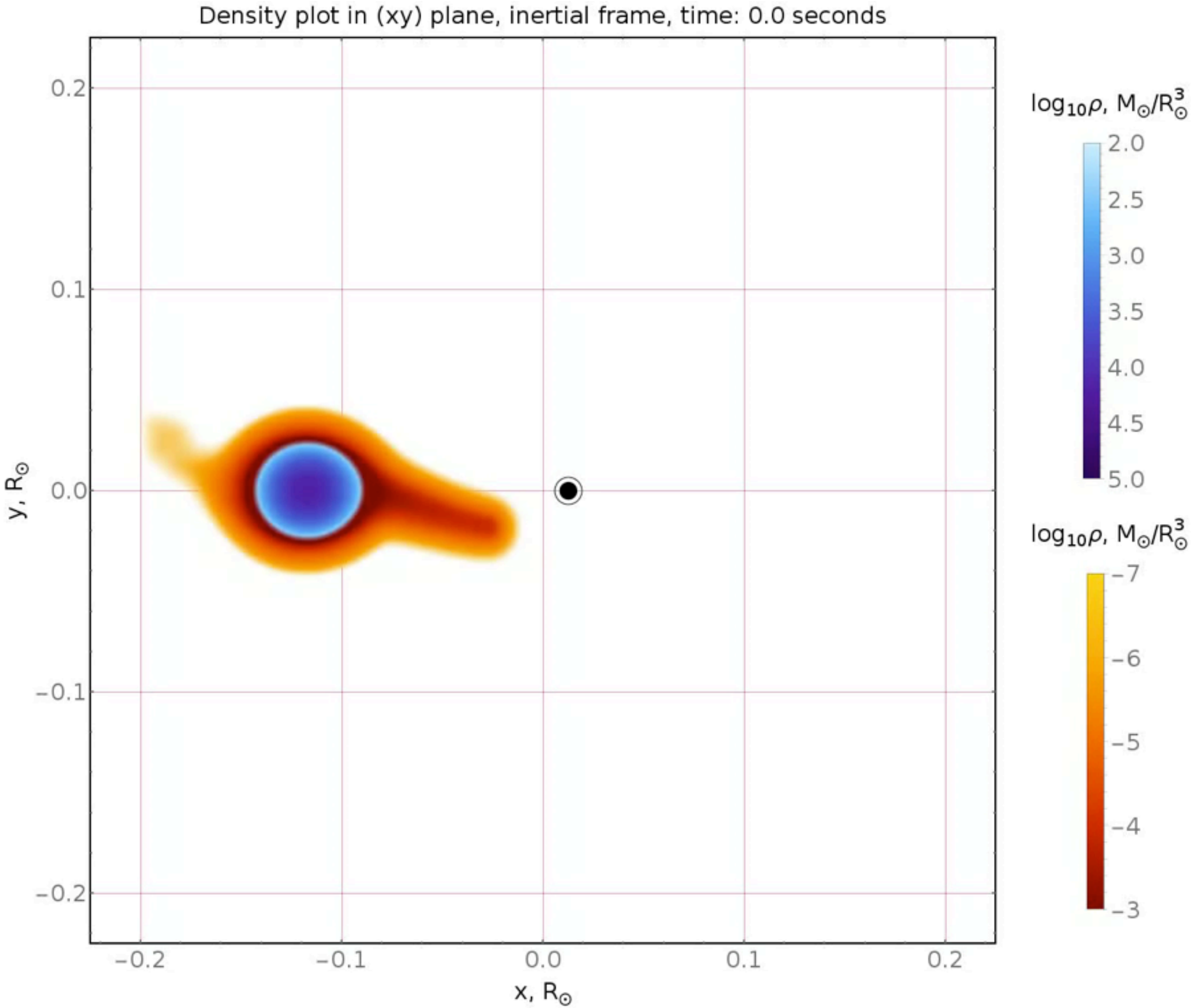
Strong O VIII and C IV emission lines in X-ray spectrum; lack of He lines

The first BH-COWD ultra-compact X-ray binary?

Miller-Jones et al. (2015) *MNRAS* **453** 3918
Bahramian et al. (2017) *MNRAS* **467** 2199
Tudor et al. (2018) *MNRAS* **476** 1889

Could the accretor be a neutron star?

Check stability of mass transfer in neutron star - white dwarf binaries


Density plot in (xy) plane, inertial frame, time: 0.0 seconds
0.2
0.1
0.0
−0.1
−0.2
y, R⊙
−0.2
−0.1
0.0
0.1
0.2
x, R⊙
log10ρ, M⊙/R⊙³
2.0
2.5
3.0
3.5
4.0
4.5
5.0
log10ρ, M⊙/R⊙³
−7
−6
−5
−4
−3

SPH bottom line

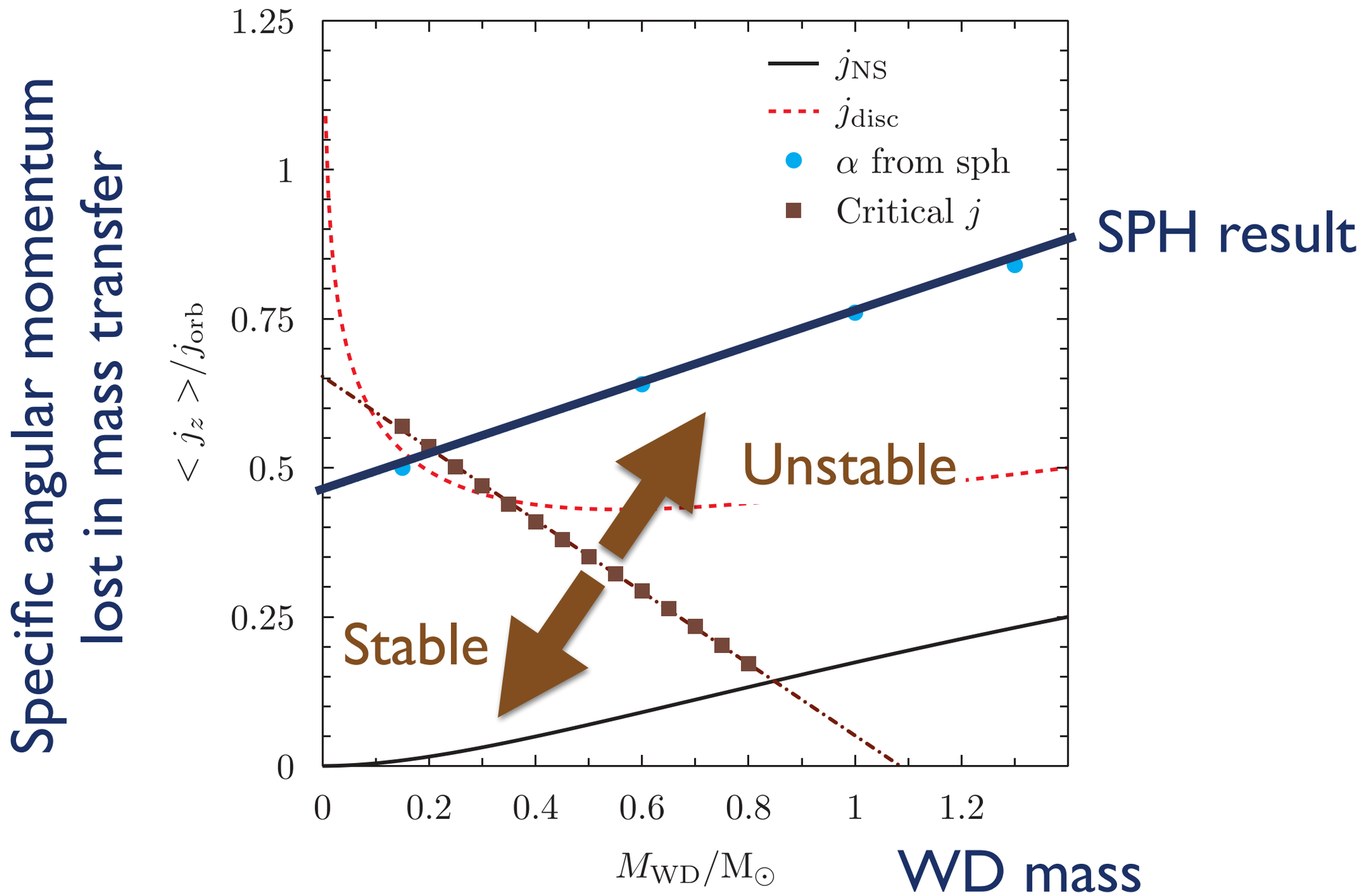
Only effect of eccentricity is to change $\dot{M}$

Super-Eddington mass transfer highly non-conservative

Mass lost carries away 0.5 - 0.75 of j_{orb}

For details see Bobrick, Davies & RC (2017) *MNRAS* **467** 3556

Stability analysis



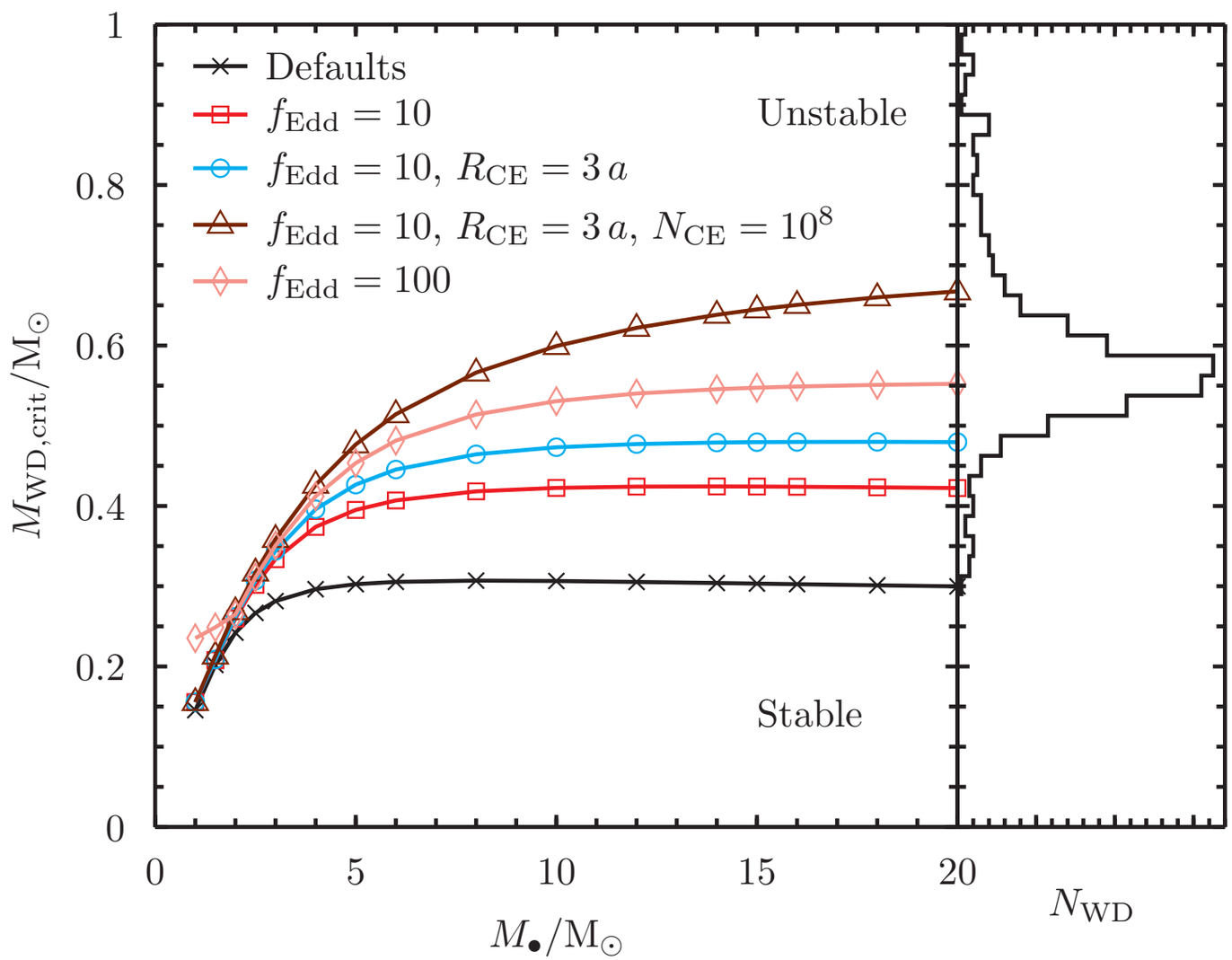
All massive WD-NS binaries are unstable!

Could the accretor be a neutron star?

No

Check stability of black hole - white dwarf
ultra-compact X-ray binaries

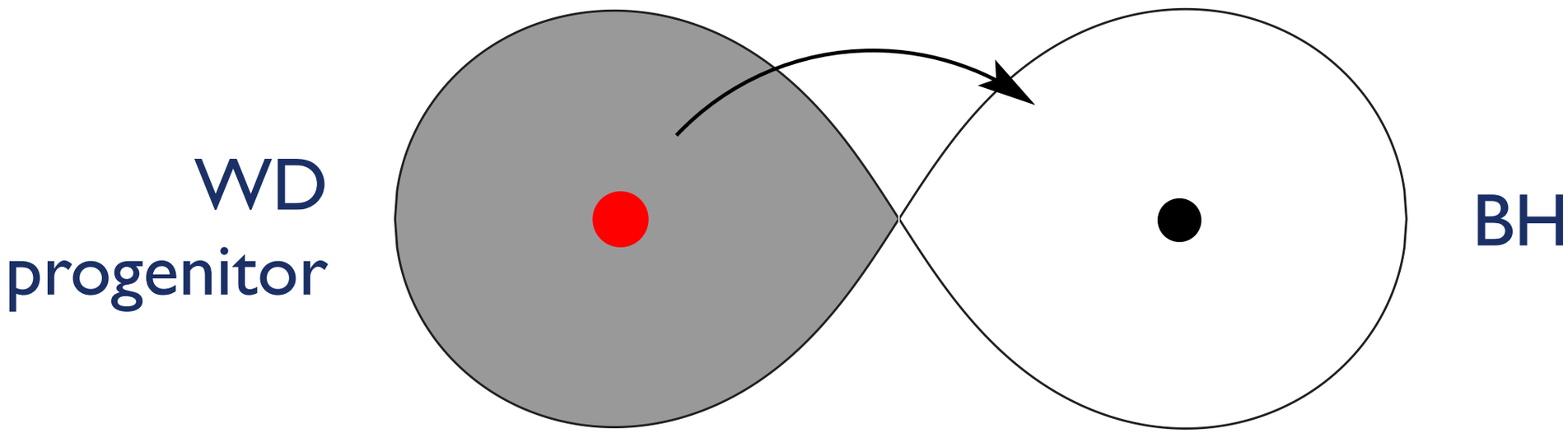
WD-BH mass transfer stability



Moderately efficient accretion permits WD-BH UCXBs

RC et al. (2017) *ApJL* **851** 4

BH-WD UCXBs don't form in the field

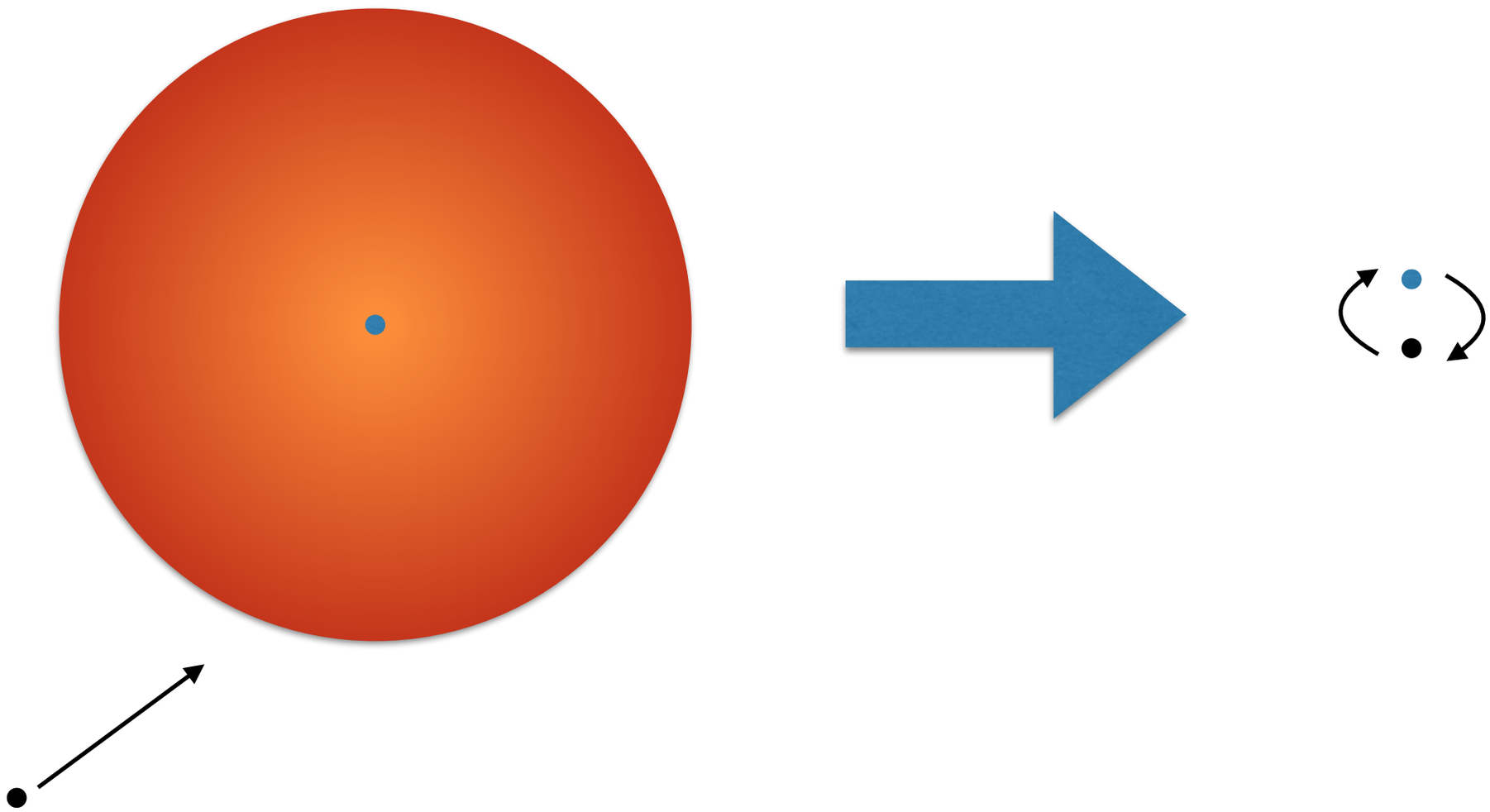


This mass transfer stage is stable:

The orbit widens

Form a non-interacting BH-WD binary

Making WD-BH binaries in clusters



Collision-induced common-envelope evolution

Rate and properties calculation

Fraction of BHs undergoing collision with an evolved star

$$\Gamma = 2\pi G f_{\rm p} f_{\rm seg} v_\infty^{-1} \sum_i n_i \int_t [M_i(t) + M_\bullet]\, R_{\star,i}(t) {\rm d}t$$

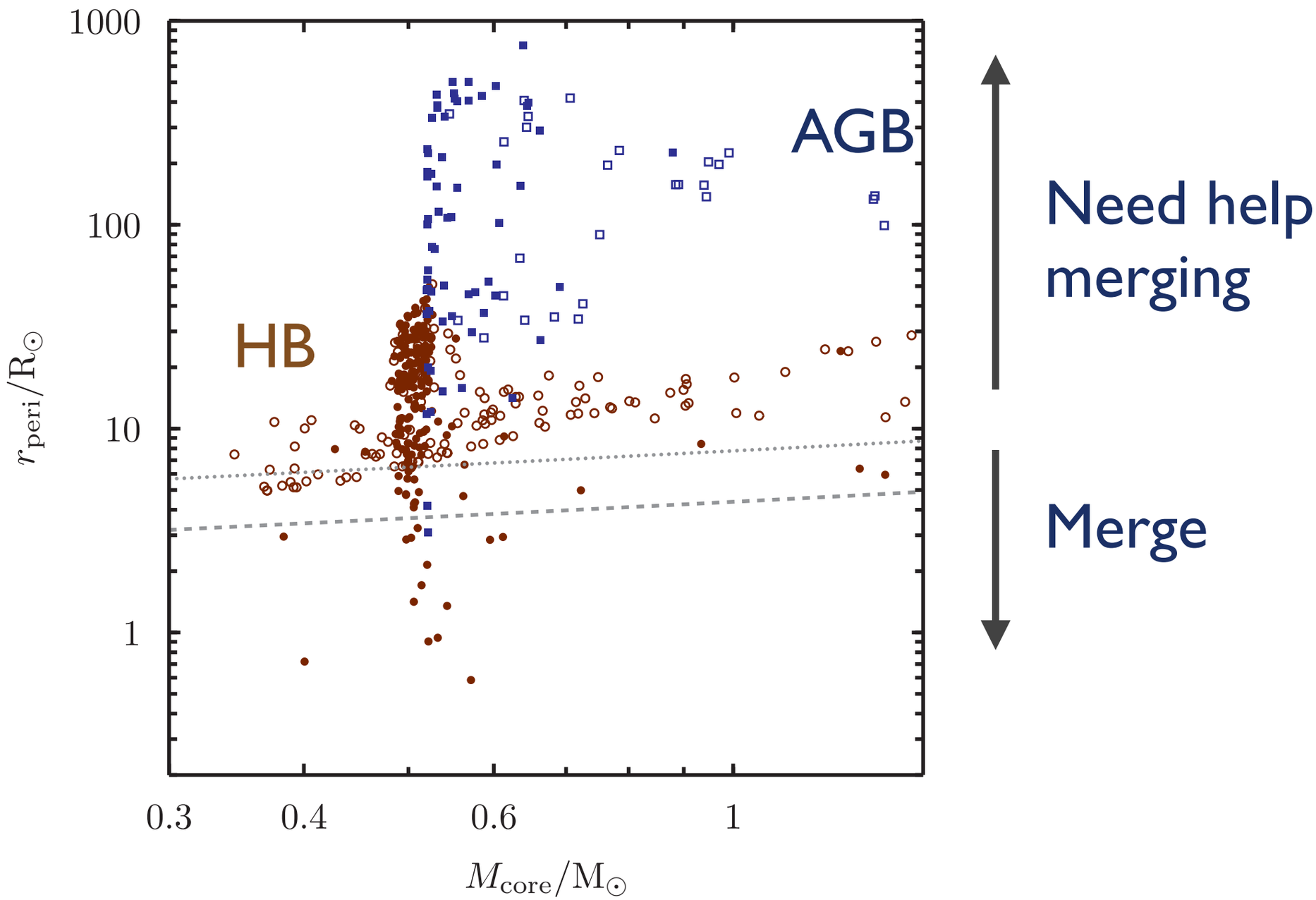
Tidal capture out to $f_{\rm p} \approx 3$ giant radii
Mass segregation increases rate by $f_{\rm seg} \approx 2$

$$a_{\rm f} = R_\star \frac{\alpha_{\rm CE}\lambda}{2} \frac{M_\bullet}{M_\star} \frac{M_{\star,\rm core}}{M_{\star,\rm env}}$$

Assume a common-envelope-like process after collision

Ivanova et al. (2010) *ApJ* **717** 948
RC et al. (2017) *ApJL* **851** 4

Collisionally-formed COWD-BH binaries



Bottom line: rate consistent with seeing one in the Galaxy

RC et al. (2017) *ApJL* **851** 4

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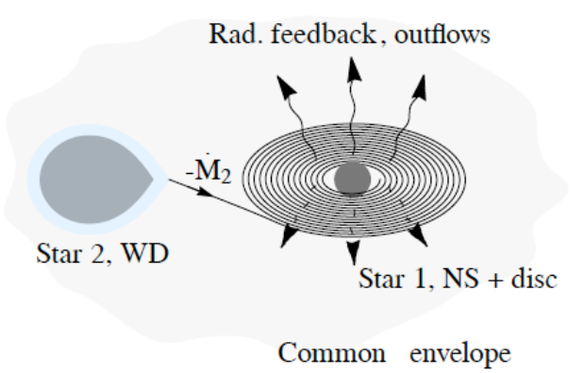

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