BLACK HOLE MERGERS IN NUCLEAR CLUSTERS

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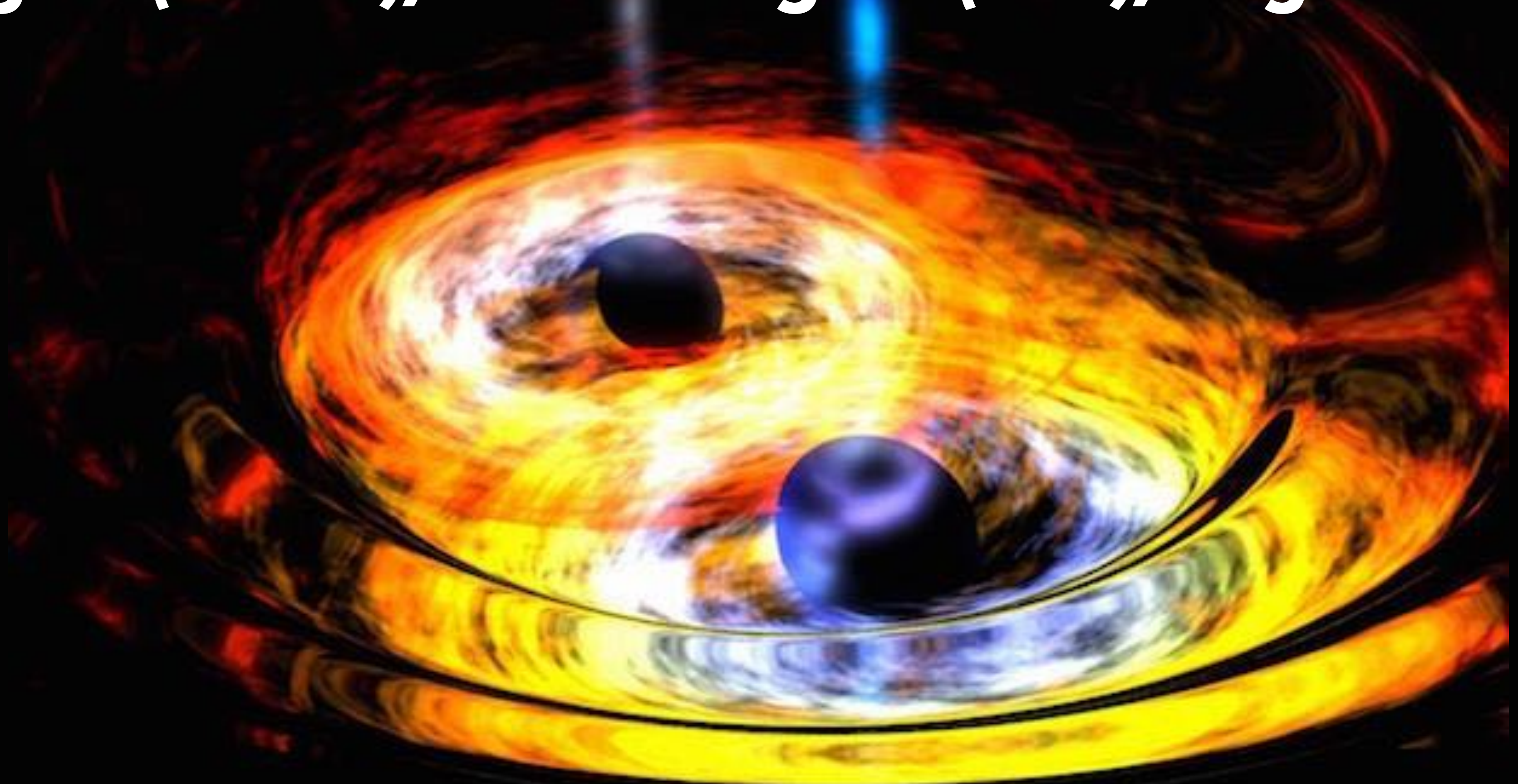
Carl Haster (CITA); Fani Dosopulou, Sourav Chatterjee, Fred Rasio, Vicky Kalogera (CIERA); Carl Rodriguez (MIT); Hagai Perets (Technion).



HOW DO BH-BINARIES FORM?

1) *ISOLATED BINARY EVOLUTION*

(e.g., Belczynski+ '02, Dominik '12, Spera+ '15, Belczynski+ '16)

2) *DYNAMICAL FORMATION IN GLOBULAR CLUSTERS*

(e.g., Portegies Zwart & McMillan 2000, Banerjee+ '10, Rodriguez+ '16)

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2) DYNAMICAL FORMATION IN GLOBULAR CLUSTERS

(e.g., Banerjee+ '10, Rodriguez+ '16, Haster+ '16, Antonini+ '16)

3) BH-BH CAPTURES IN GALACTIC NUCLEI

(O'Leary et al. 2009, Hong and Lee 2015)

4) FORMATION IN TRIPLES

(Thompson '11, Antonini+ '14,'16, Silsbee and Tremaine '16)

5) PRIMORDIAL BLACK HOLES

(e.g., Birds '16)

6) DYNAMICAL FORMATION IN NUCLEAR CLUSTERS

*(Miller and Lauburg '09, Antonini and Perets '12,
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NUCLEAR CLUSTERS

(Antonini and Rasio '16)

- *Continuous star formation*
- *Some host central SMBHs*
- *High escape velocities ($\sim$100 Km s^{-1})*

GLOBULAR CLUSTERS

(Rodriguez+ '16)

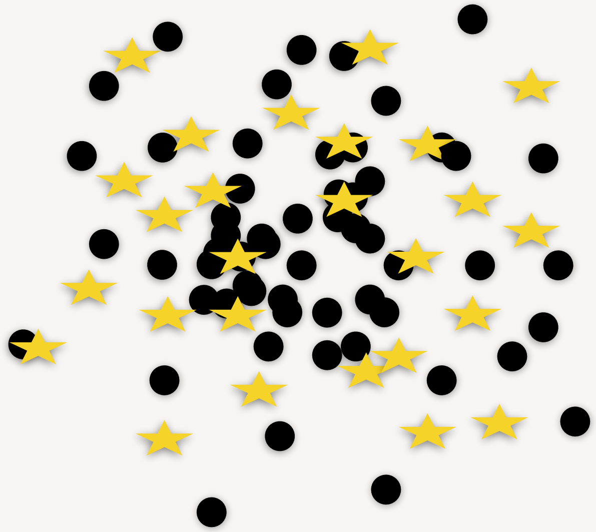
- *GCs are old*
- *No central SMBH*
- *Low escape velocities ($\sim$20 Km s^{-1})*

BH mergers from nuclear clusters have distinct properties from those formed in globulars


NUCLEAR CLUSTERS
WITHOUT MASSIVE BLACK
HOLE

DYNAMICAL FORMATION

BH cluster formation



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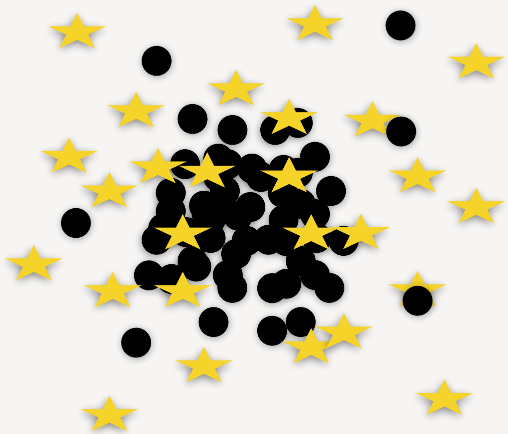

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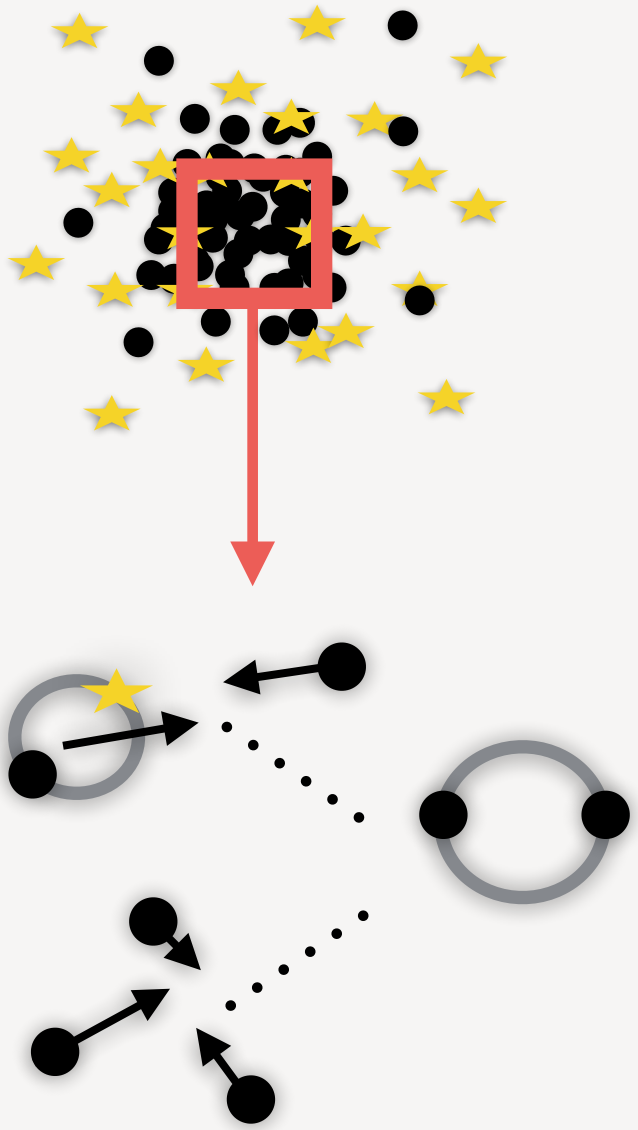
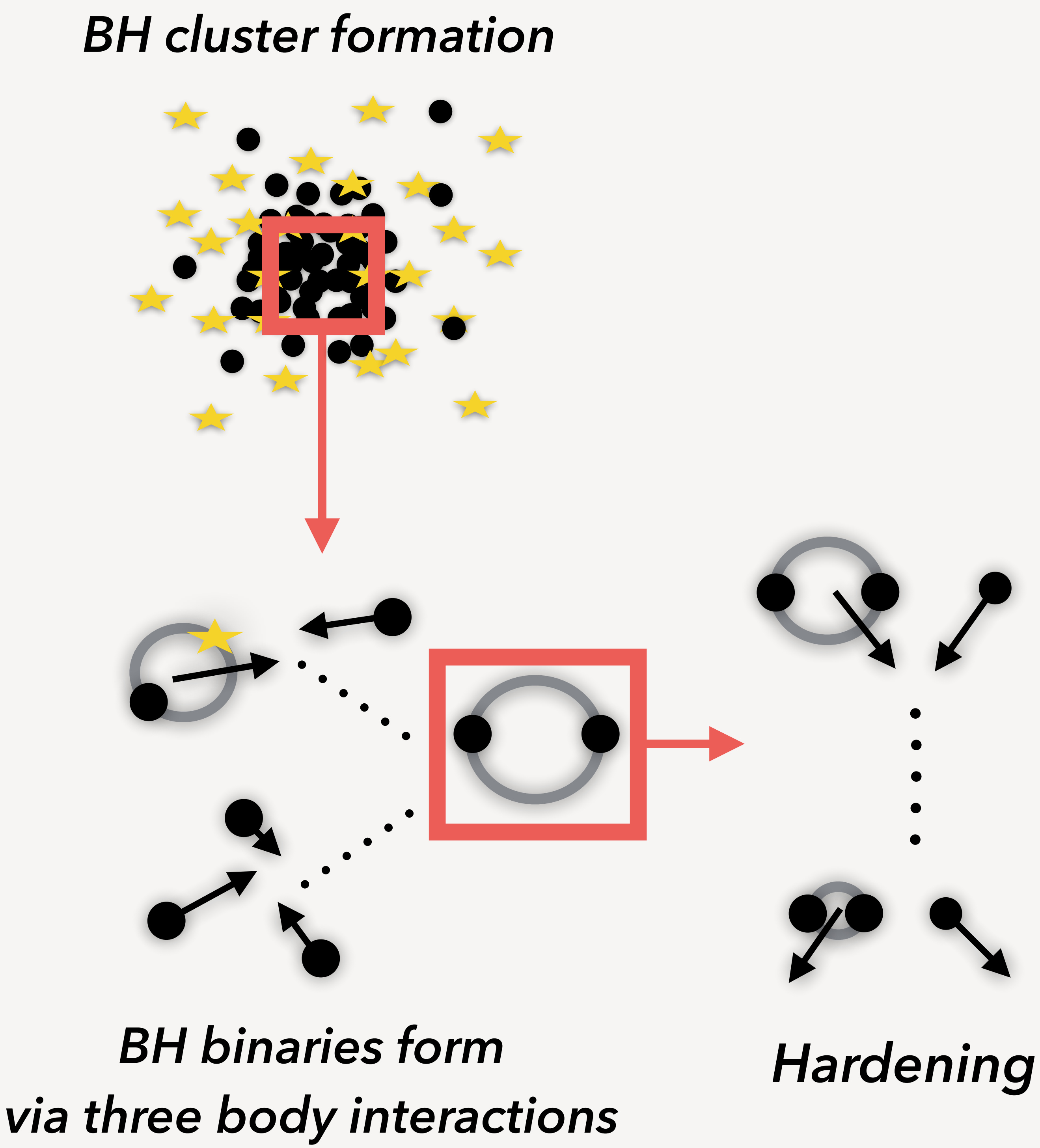


BH binaries form
via three body interactions

DYNAMICAL FORMATION



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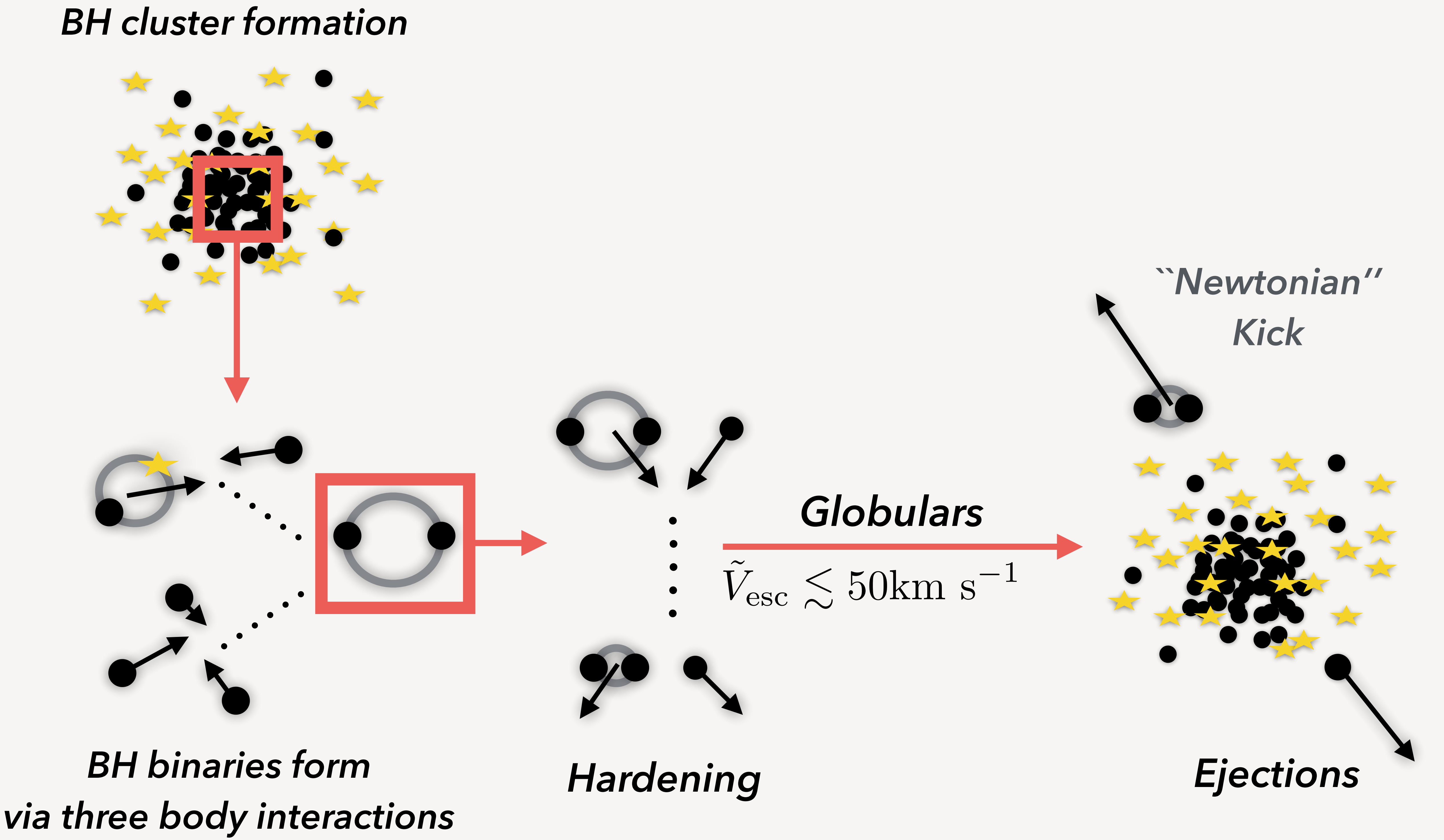

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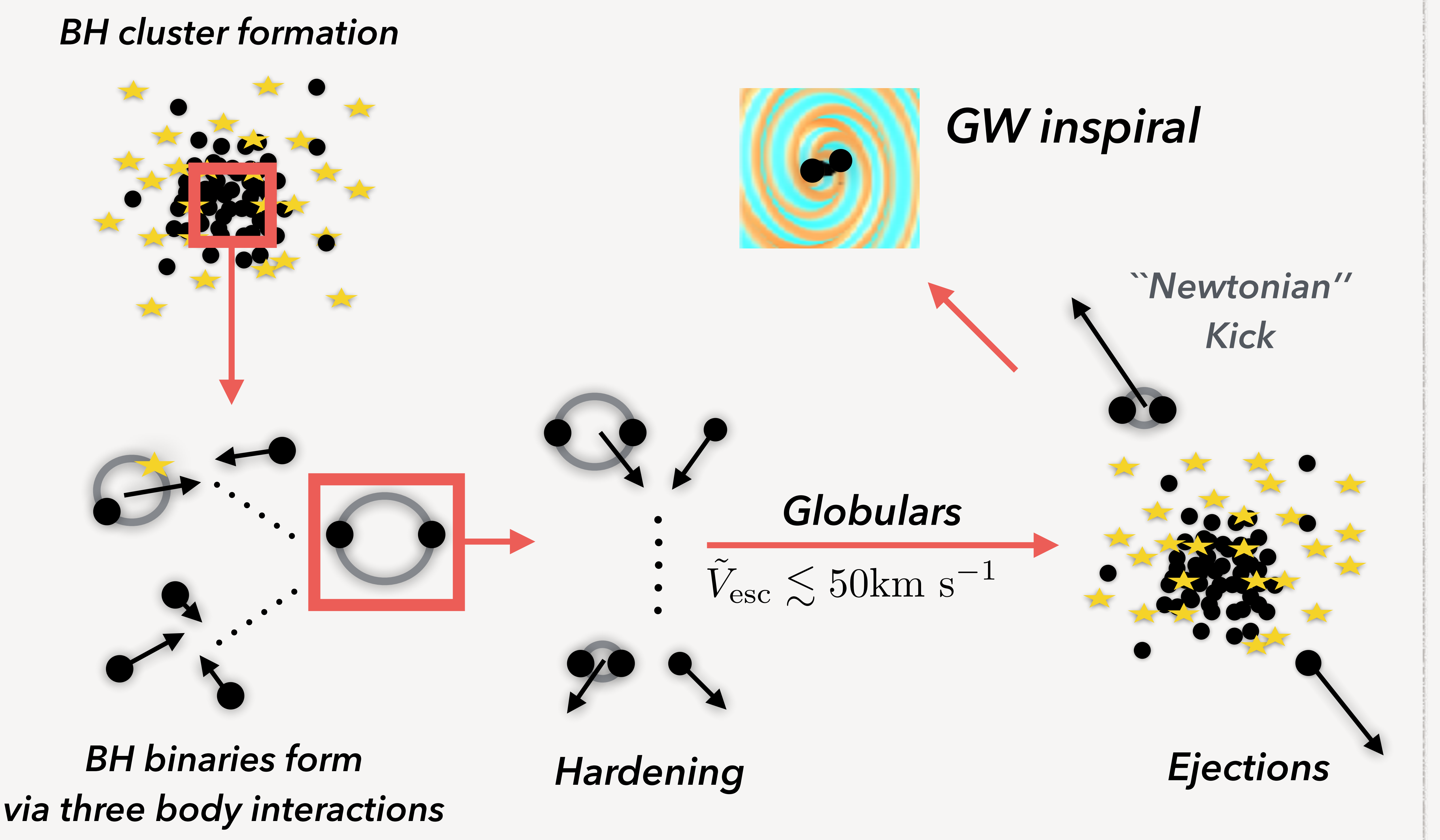

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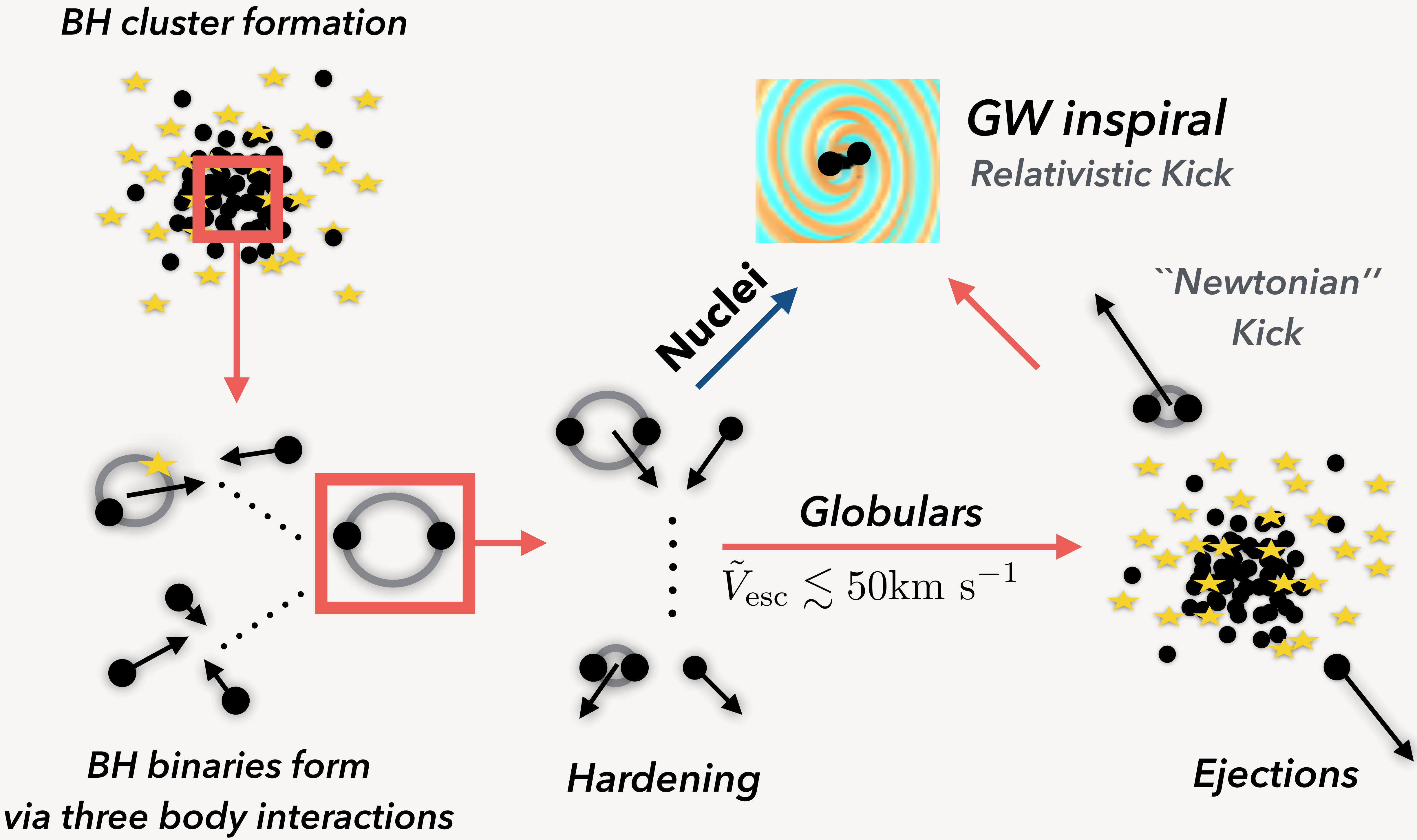

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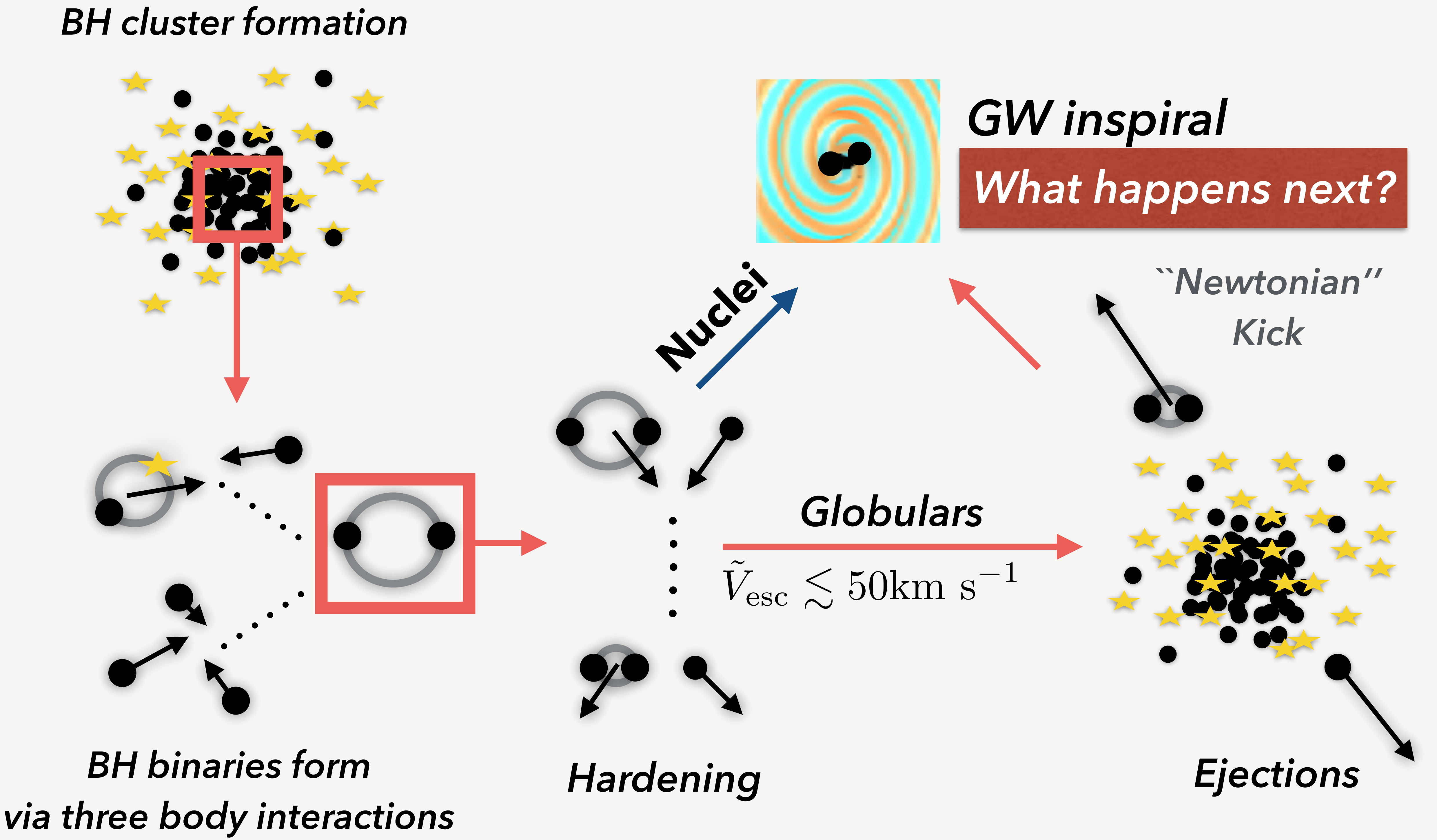
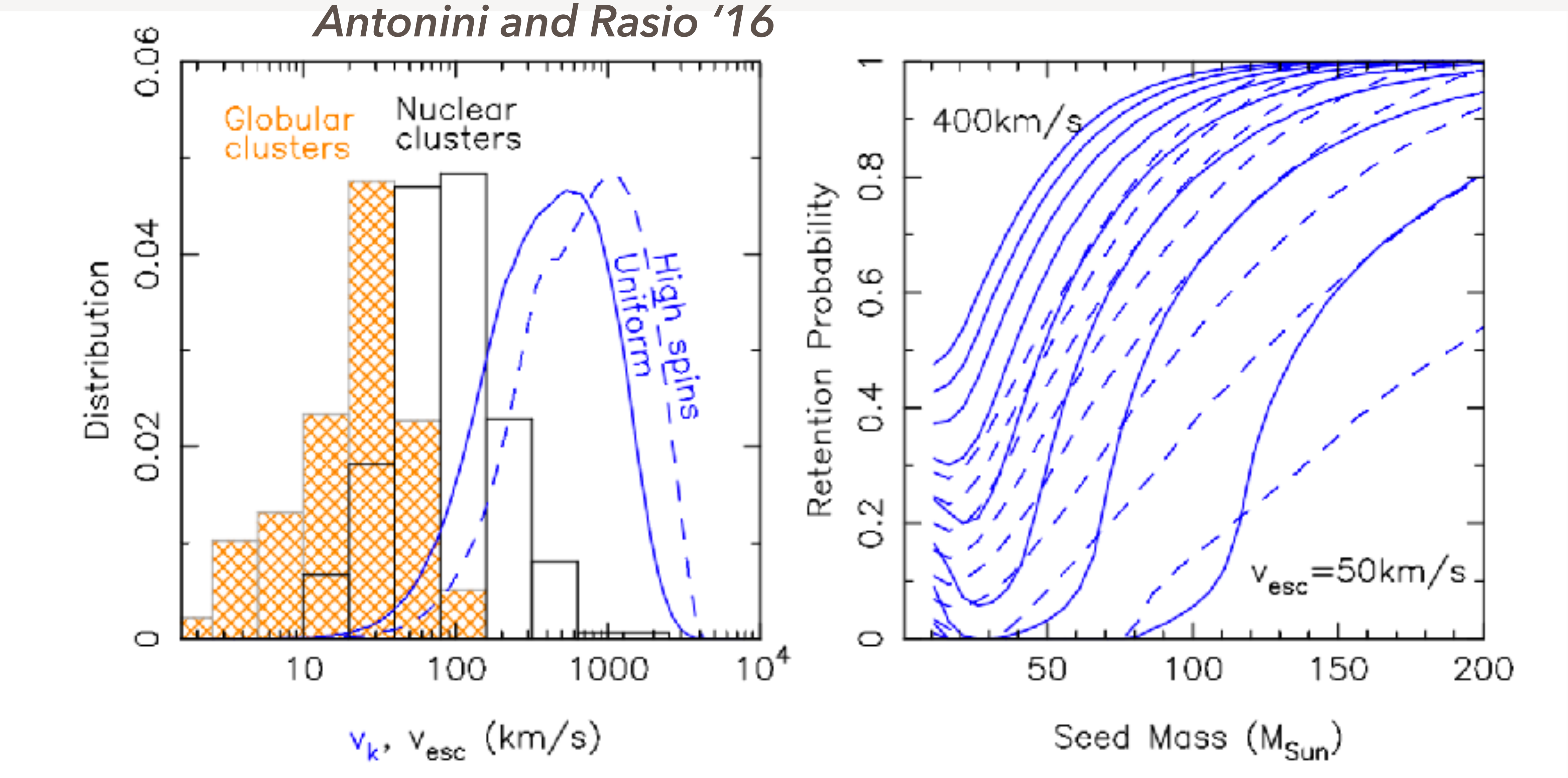


RETENTION OF MERGER REMNANTS

Antonini and Rasio '16



A large fraction of BH merger remnants is retained in NCs; Significant growth can occur.

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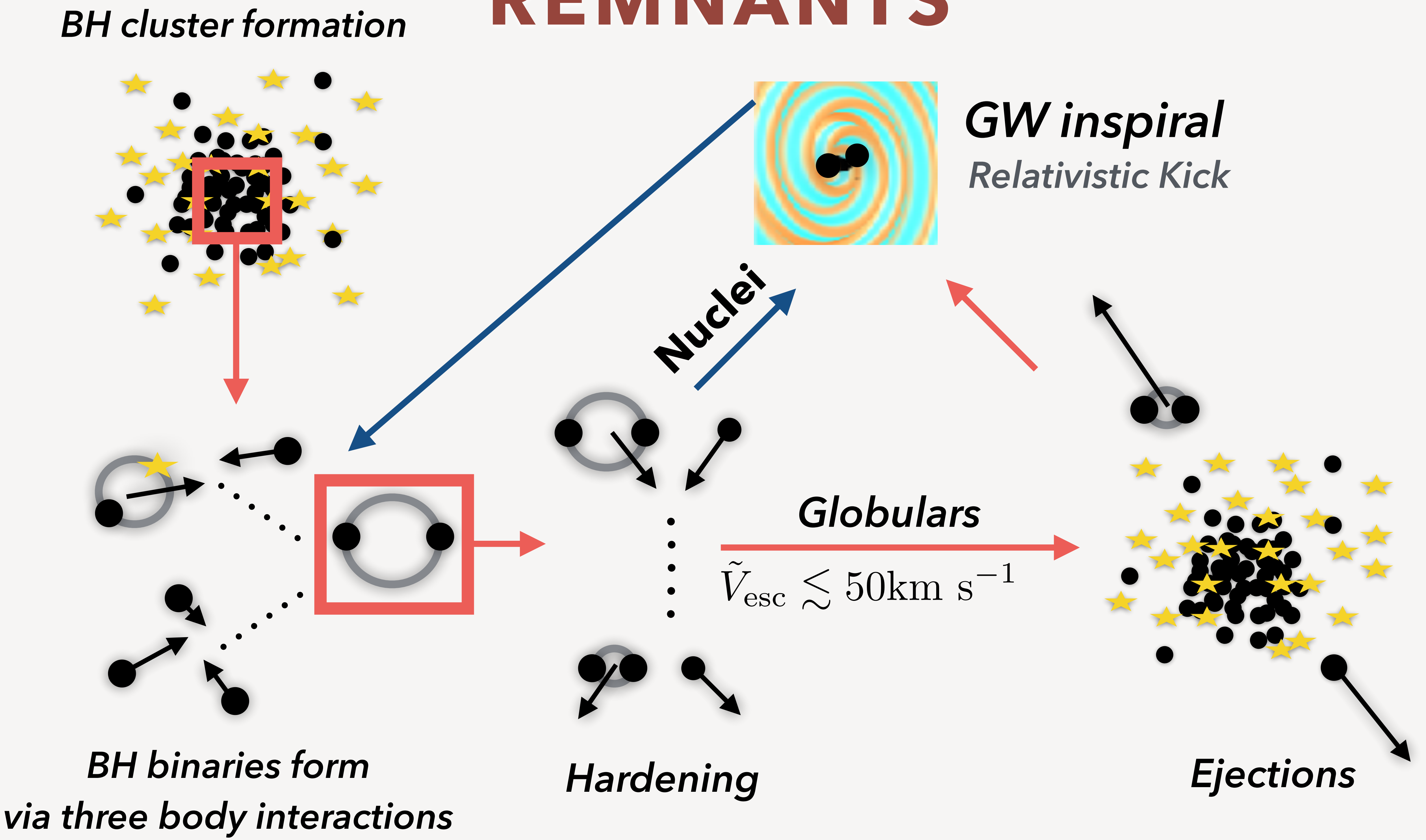

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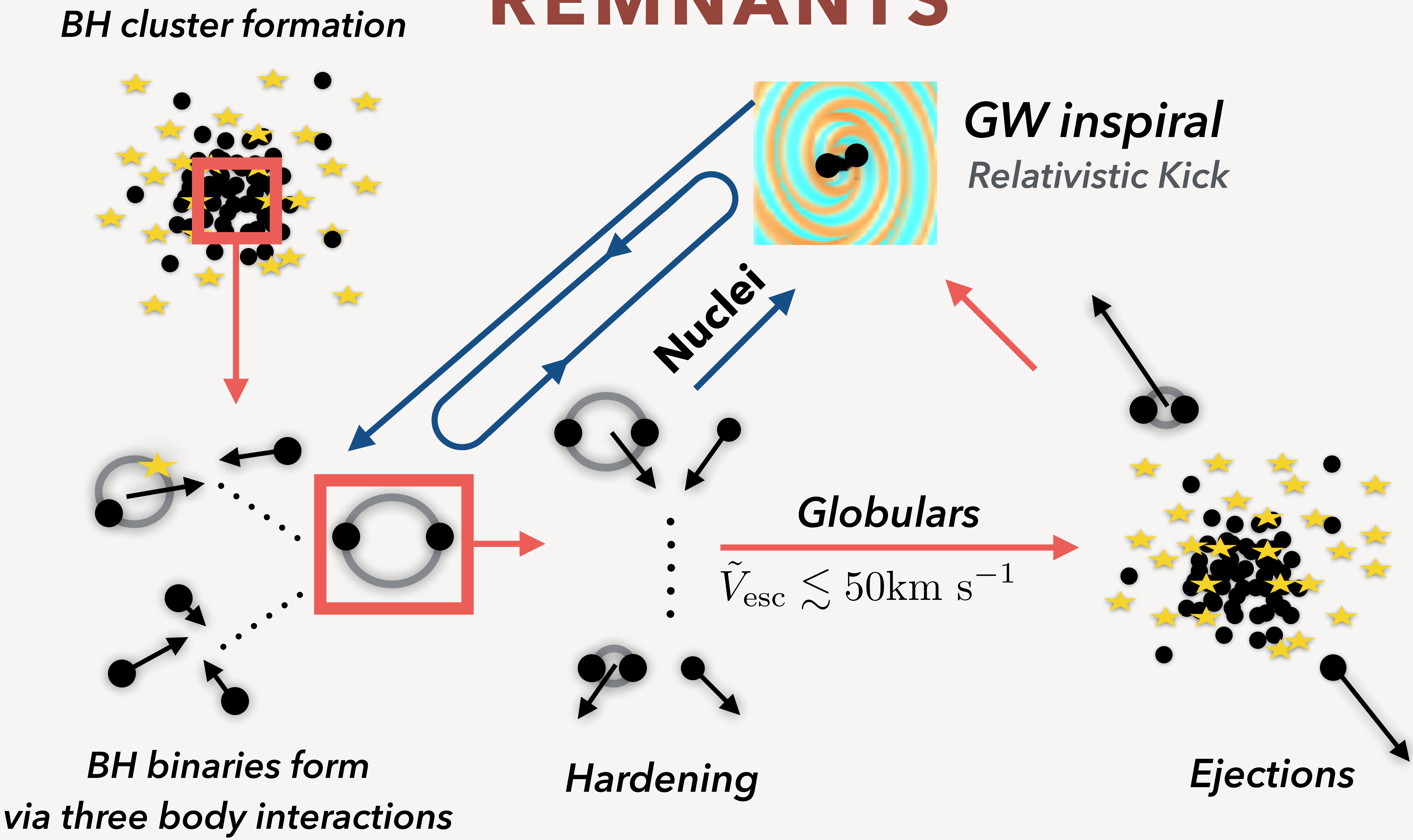

MODEL PREDICTIONS

Antonini and Rasio ‘16

Nuclear clusters are efficient factories of BH-BH mergers

$$\Gamma_{\rm NC} \approx 2{\rm Gpc}^{-3}{\rm yr}^{-1}$$

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Nuclear clusters are efficient factories of GW150914-like mergers

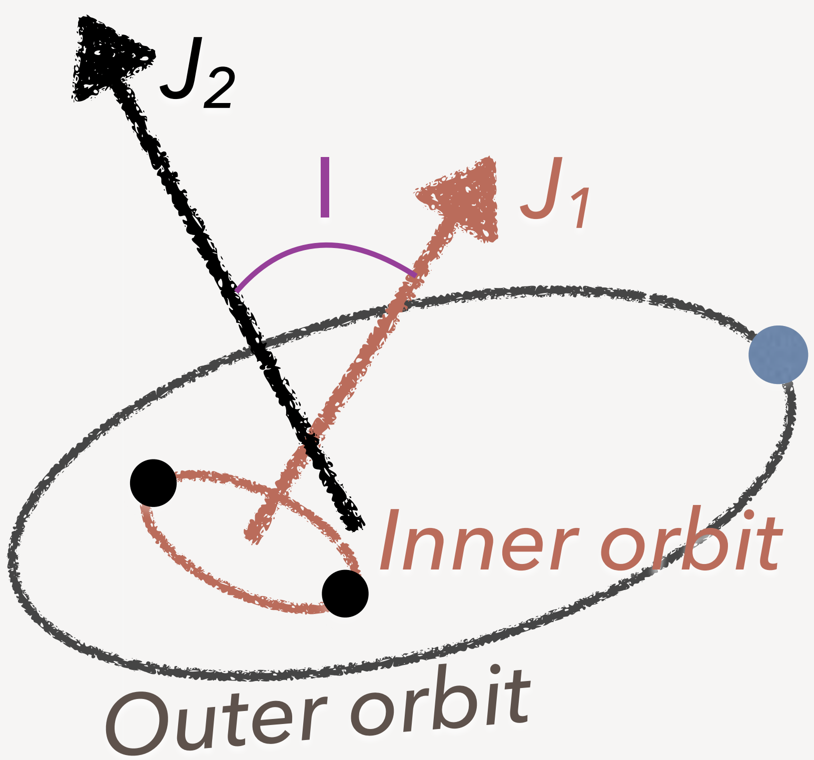
$$\Gamma_{\rm NC}(z < 0.3; M > 50M_{\odot}) \approx 0.4 - 1.5{\rm Gpc}^{-3}{\rm yr}^{-1}$$

$$\Gamma_{\rm GC}(z < 0.3; M > 50M_{\odot}) \approx 0.05 - 1{\rm Gpc}^{-3}{\rm yr}^{-1}$$

NUCLEAR CLUSTERS WITH MASSIVE BLACK HOLE

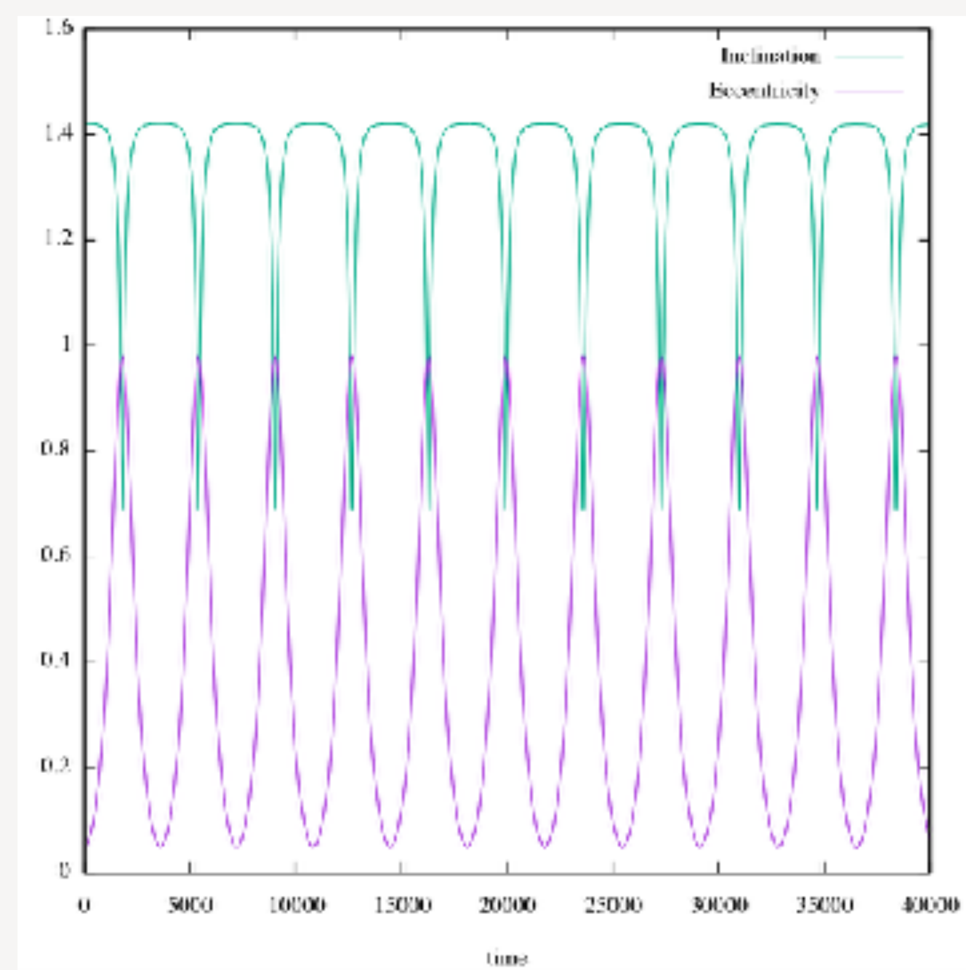
THE LIDOV-KOZAI MECHANISM

Triple system is stable and can be thought as two interacting wires rather than point masses on orbits (orbit-average approximation):



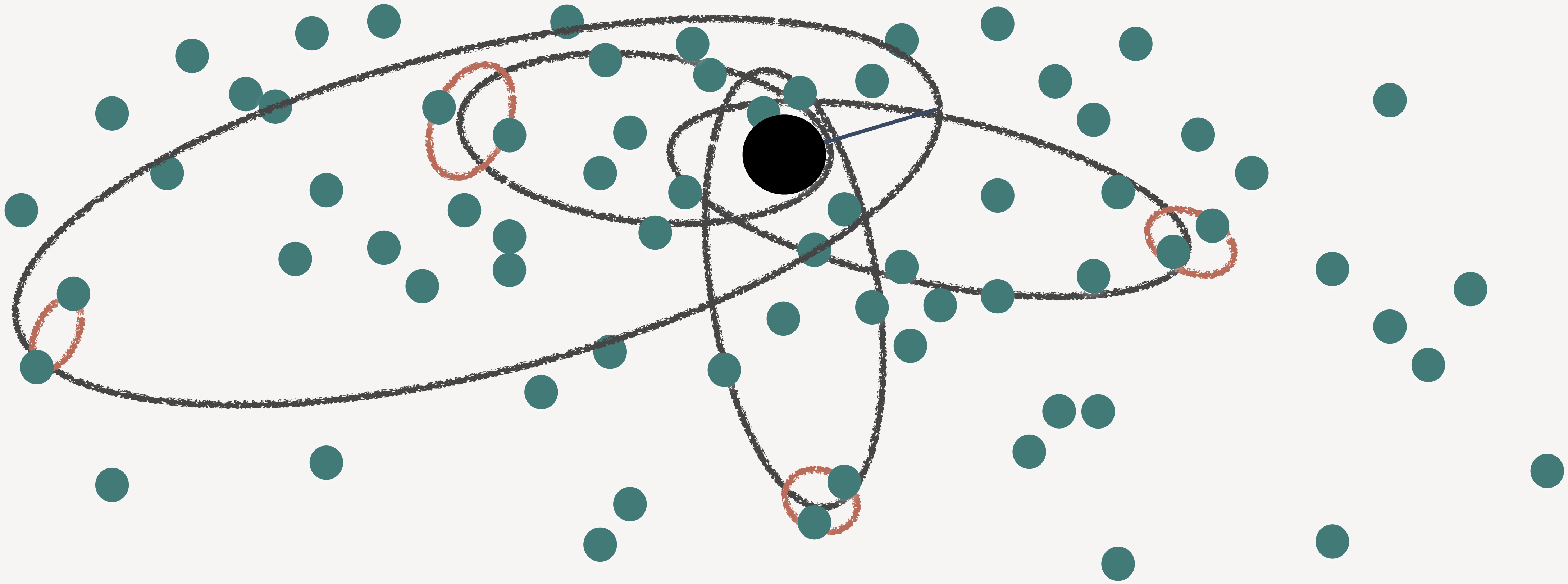
Reaches $e_{\max} = \sqrt{1 - 5/3\cos^2 I}$

after a time $T_{\rm LK} \simeq P_1 \left(\frac{M_b}{m_2}\right)\left(\frac{a_2}{a_1}\right)^3 (1-e_2^2)^{3/2}$



Example of LK mechanism

THE LIDOV-KOZAI MECHANISM NEAR A MBH



Antonini and Perets '12

Prodan, Antonini and Perets '15

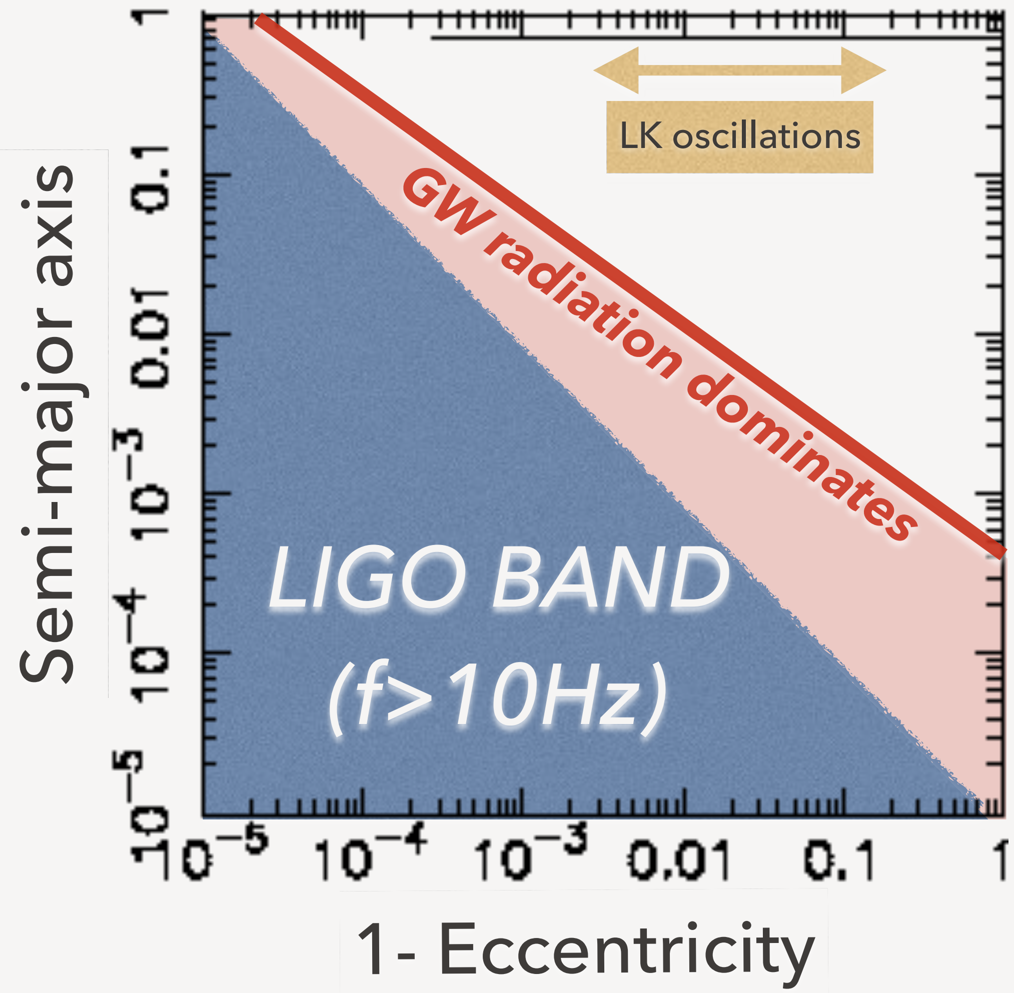
Antonini, Dosopoulou in prep.

MERGERS OF BLACK HOLE BINARIES

$T_{GW} \sim (1-e^2)^{7/2}$

Kozai cycles can reduce the merger timescale by many orders of magnitude

(e.g., Blaes 2002; Antonini+16; Haster, Antonini, Kalogera, Mandel '16)

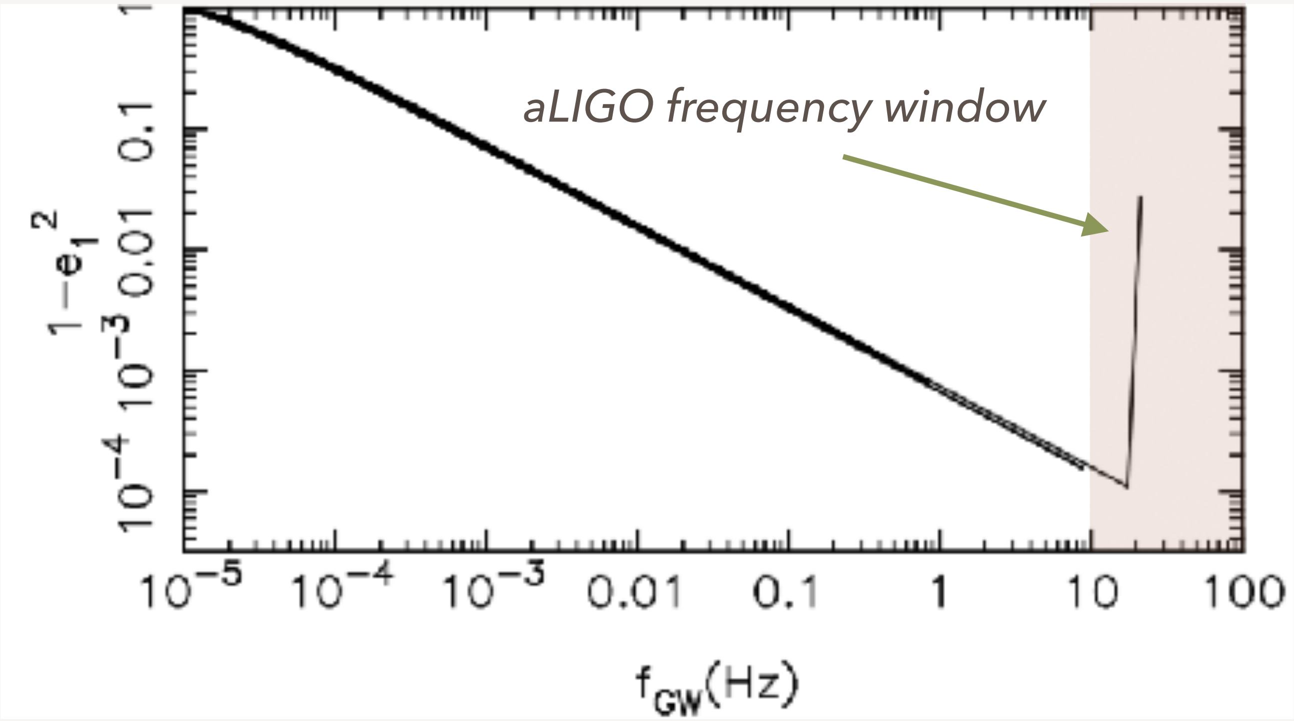


Example of BH merger near a MBH

Rate: ~100 $Gpc^{-3}yr^{-1}$ (VanLandingham, Miller et al. 2016)

Rate (observed): 9-240 $Gpc^{-3}yr^{-1}$ (Abbott et al. 2016)

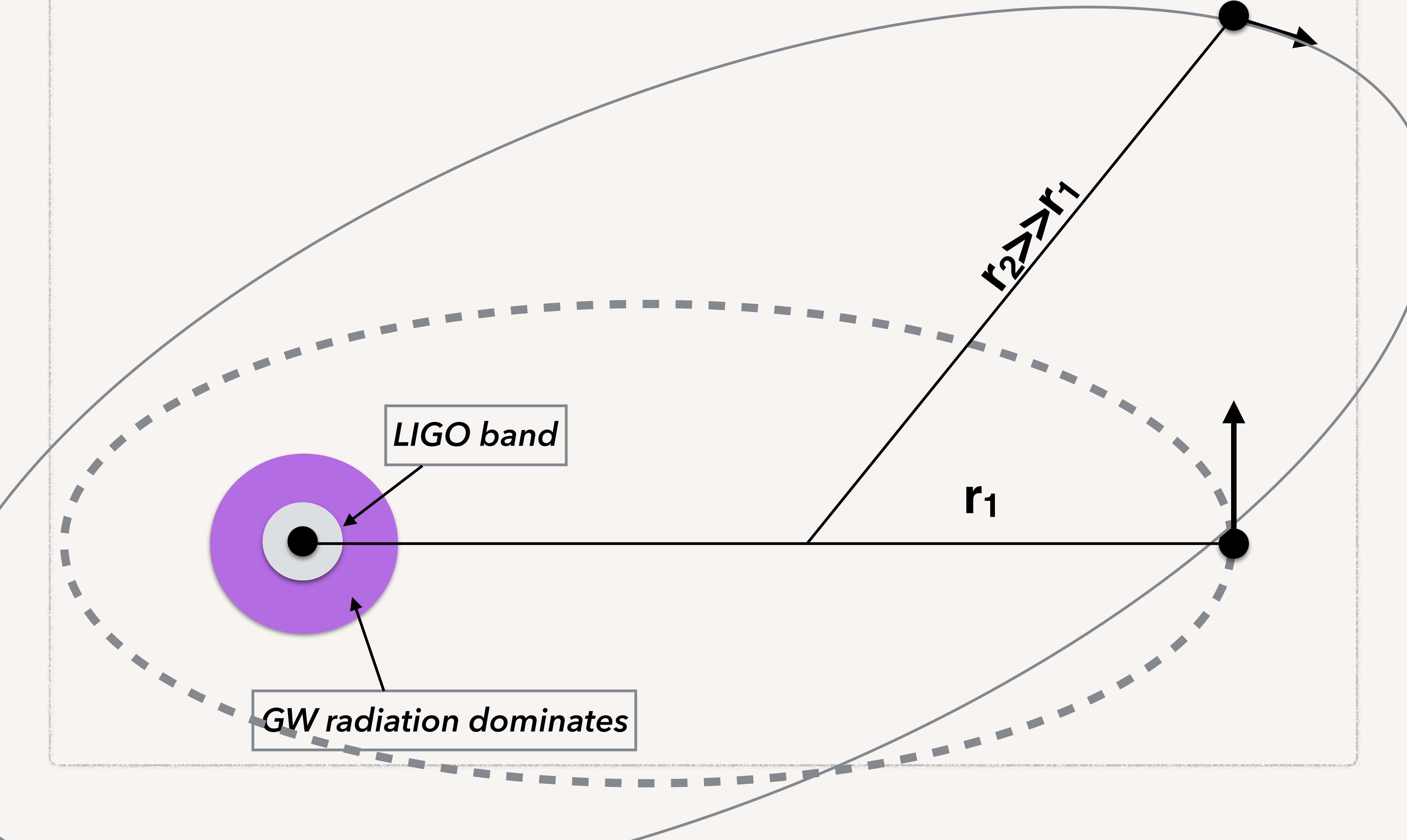
BREAKDOWN OF THE ORBIT AVERAGED APPROXIMATION



Kozai timescale shorter than the binary orbital period: secular approx. fails; Eccentric sources for aLIGO are produced (Antonini and Perets '12, Antonini+ '14, '16)

ORBIT AVERAGED APPROXIMATION

Ford (2000), Blaes et al (2002), Naoz (2013) etc.



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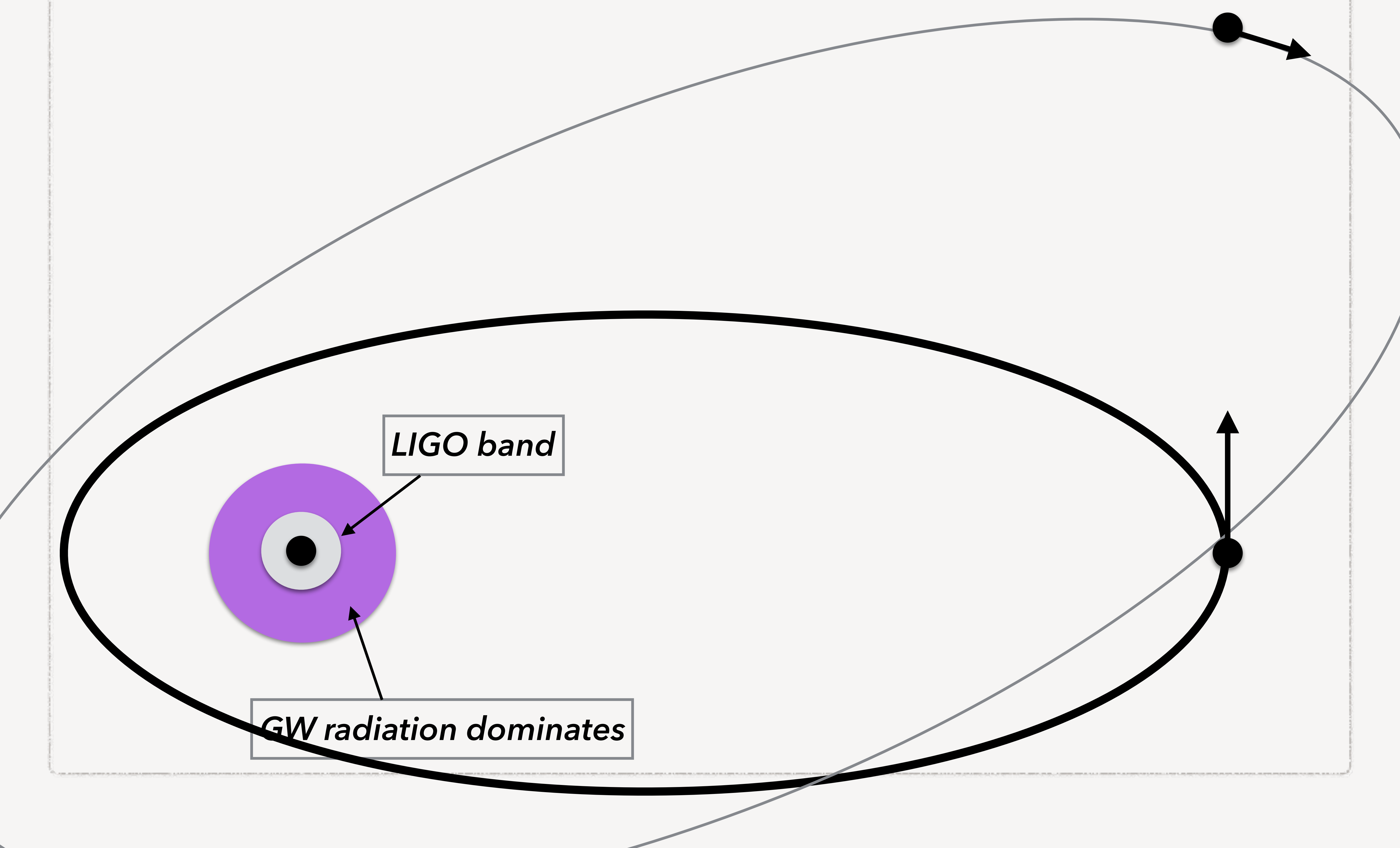

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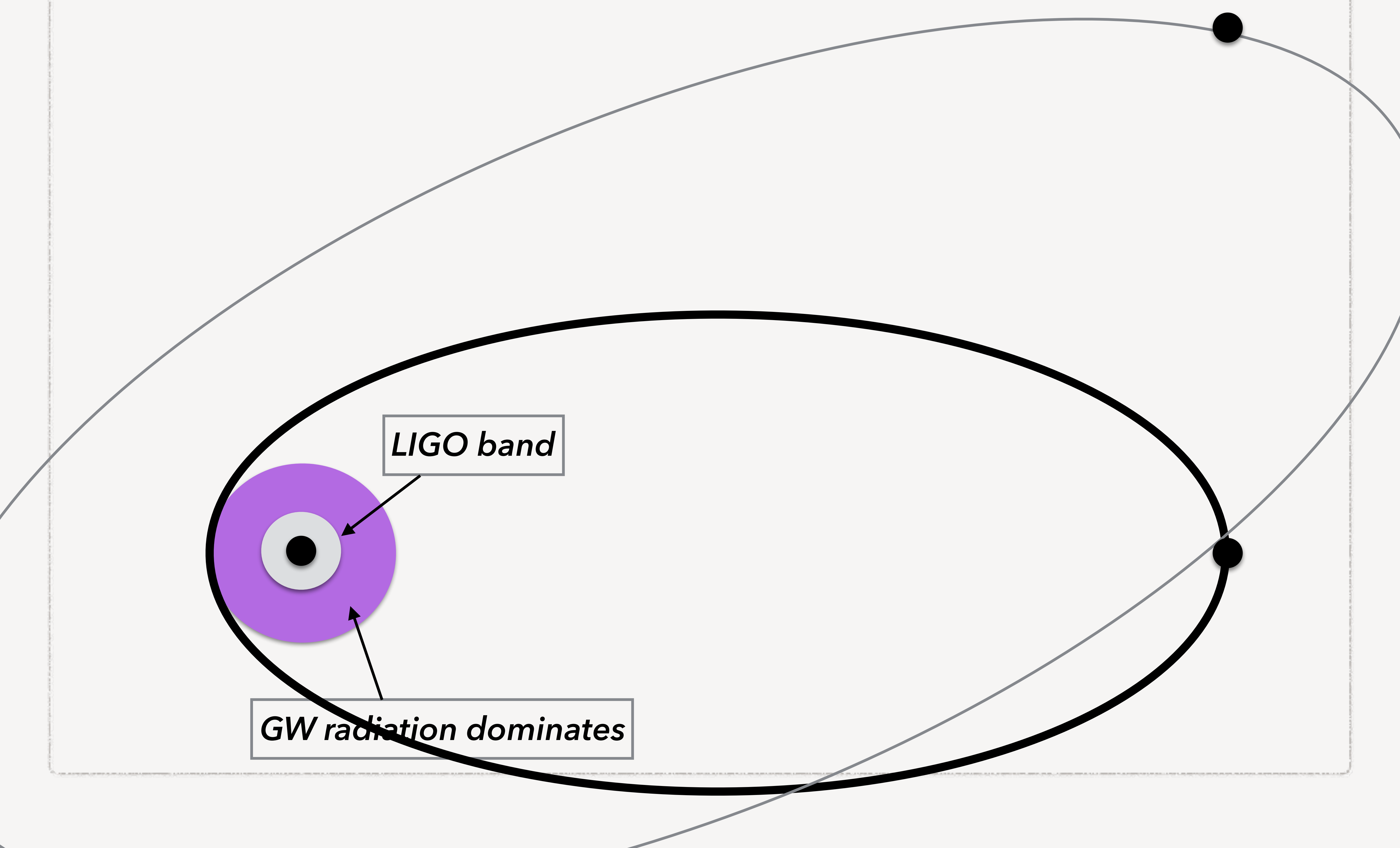

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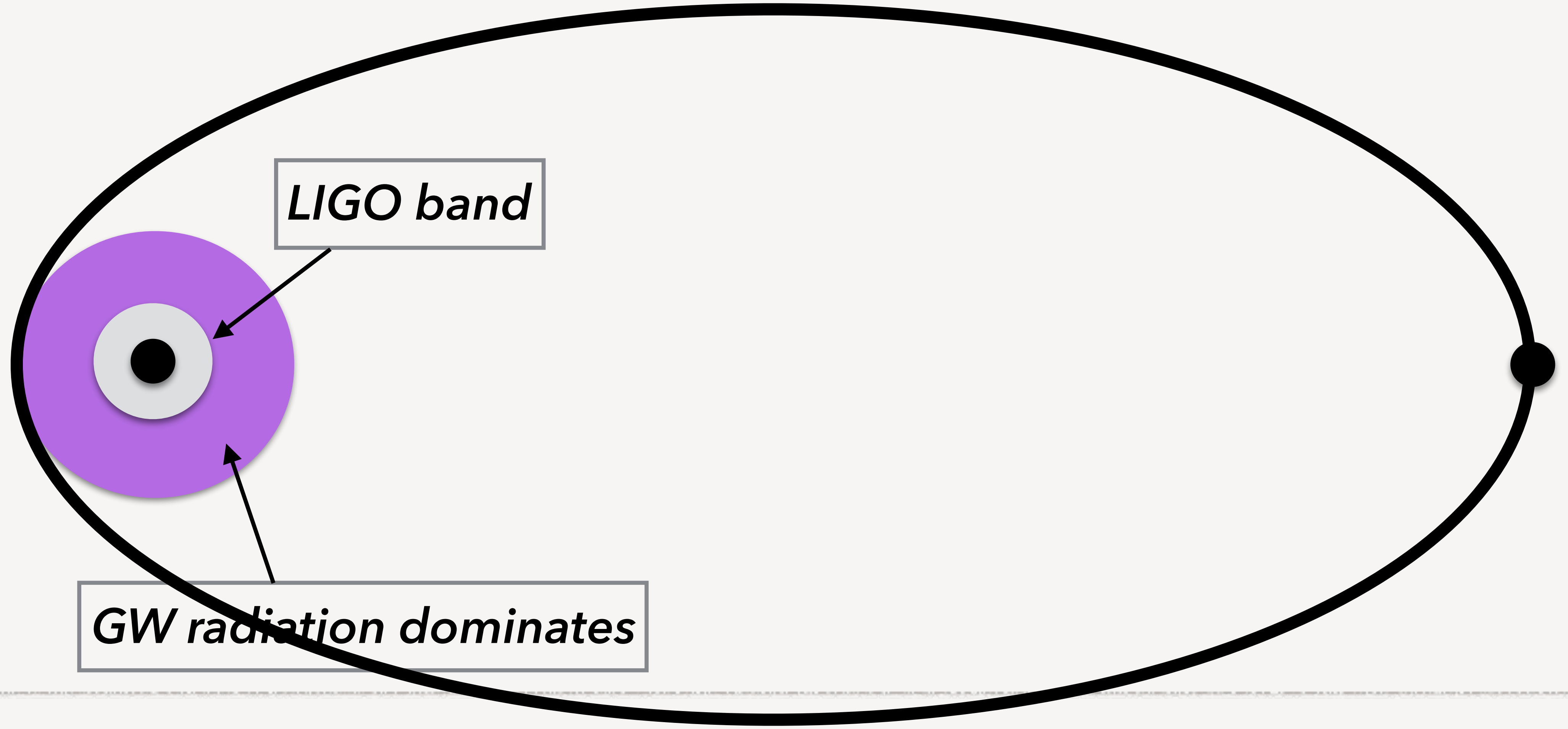

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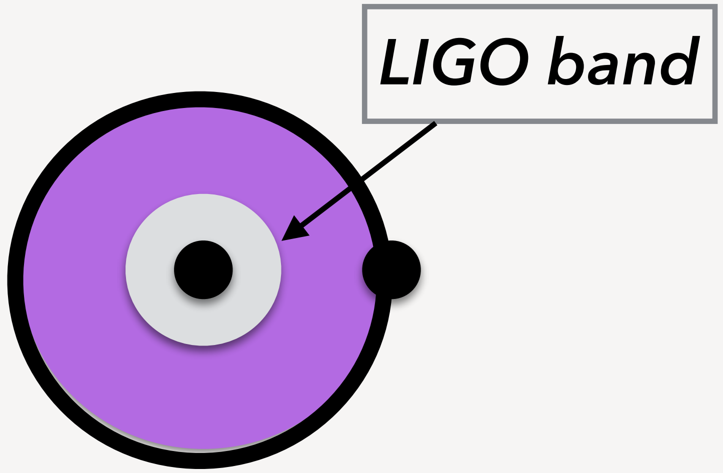

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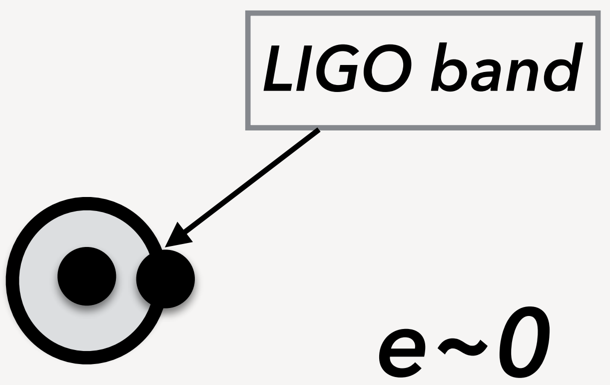

BREAKDOWN OF THE ORBIT AVERAGED APPROXIMATION

Antonini and Perets '12, Katz and Dong '12, Antonini '14, '16

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Timescale, T_k, to reach e~1: $T_K \approx P \frac{M_b}{m_3} \left[\frac{a_2(1-e_2)}{a_1} \right]^3 \sqrt{1-e_1}$

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Set T_k<Orbital period:

$$r_{\rm cr} \equiv \frac{a_2(1-e_2)}{a_1} \lesssim 10$$ *For three BHs*

$$r_{\rm cr} \equiv \frac{a_2(1-e_2)}{a_{td}} \lesssim 20$$ *For a binary around a massive BH*

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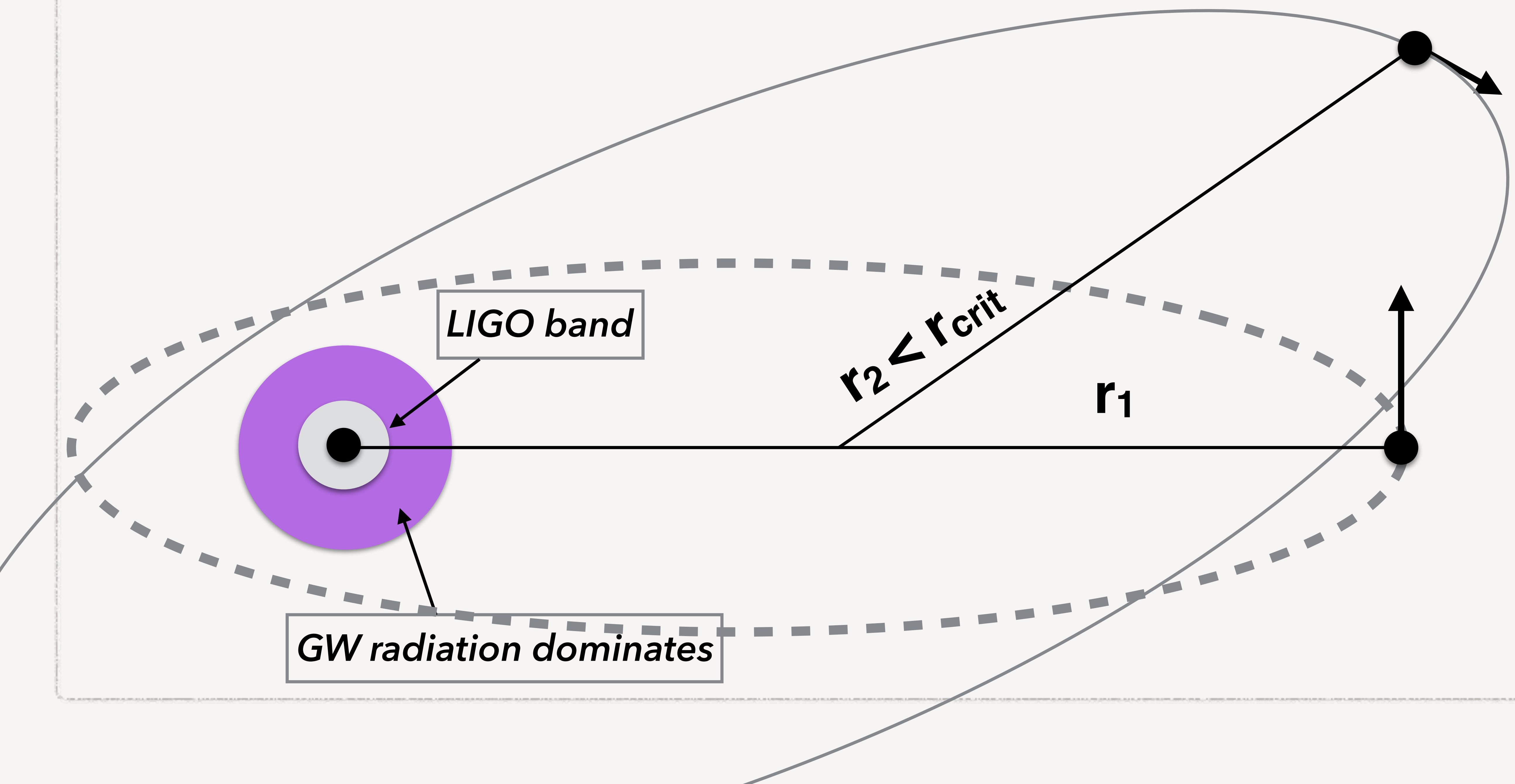

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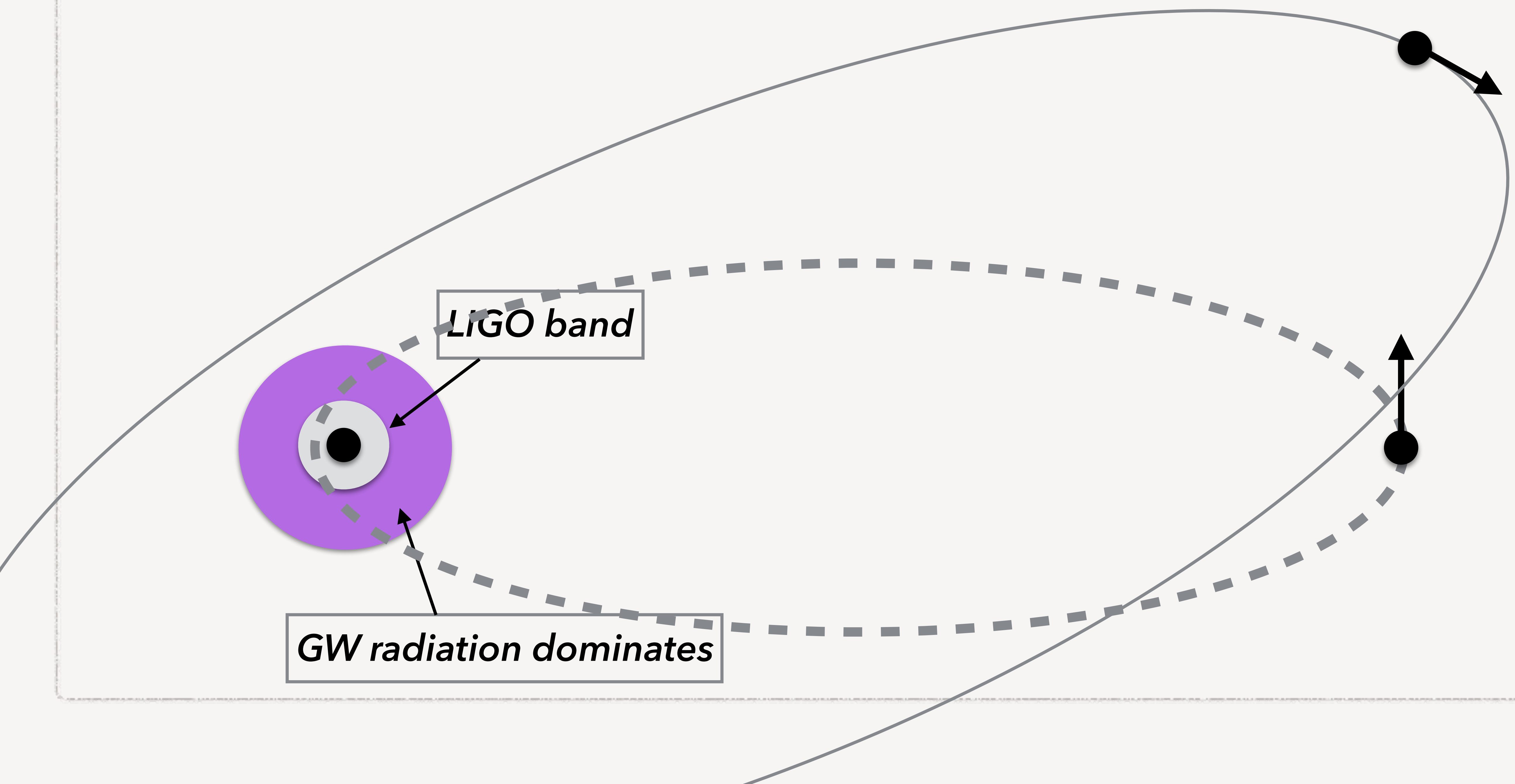

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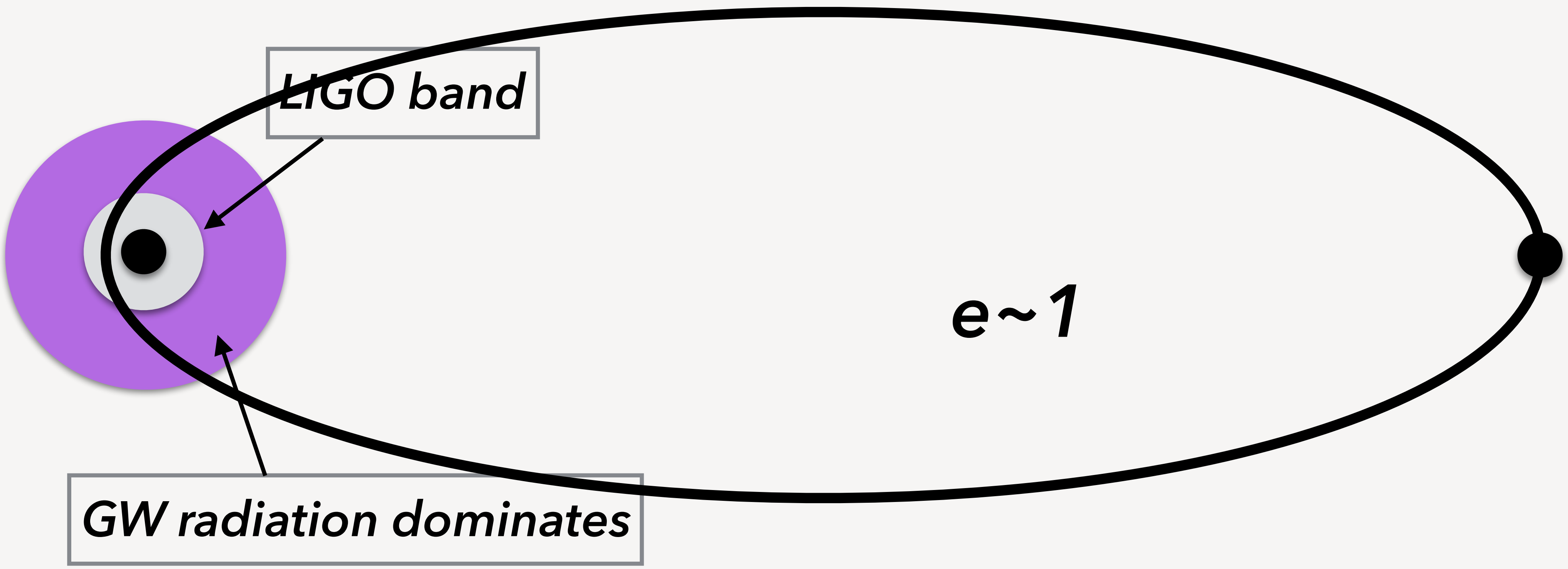

BREAKDOWN OF THE ORBIT AVERAGED APPROXIMATION

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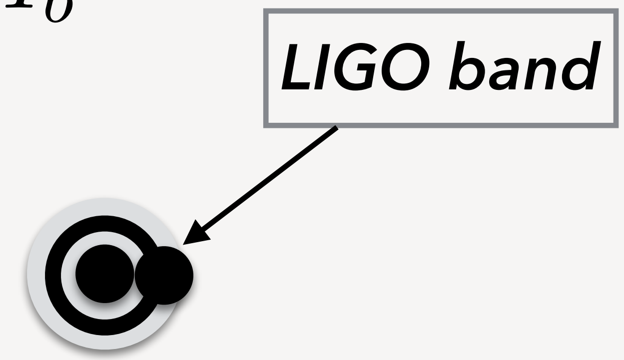
Unique GW signal.

Bursts with duration:

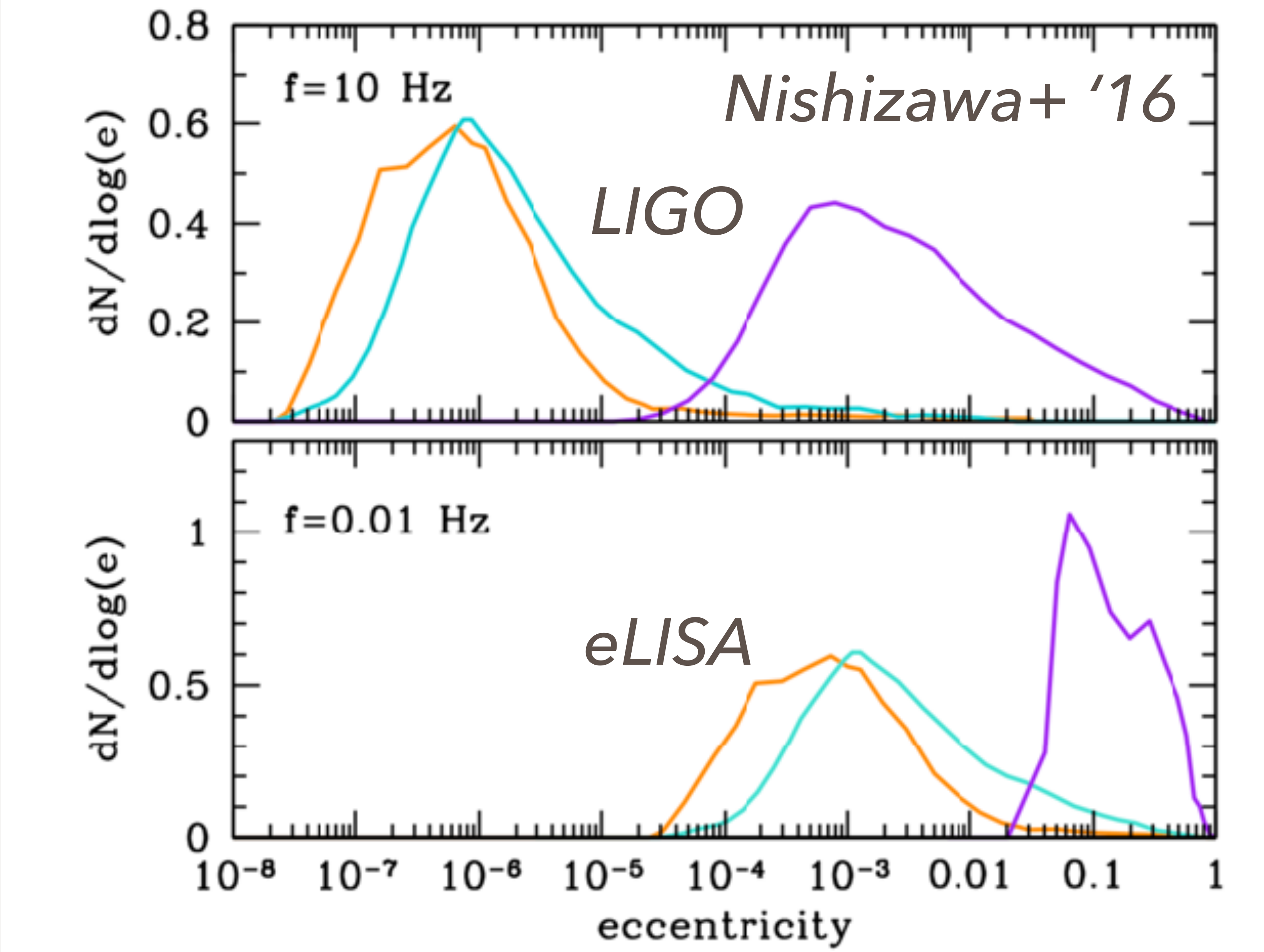
$$\Delta T_p \sim \sqrt{\left[a_1(1-e_1)\right]^3/GM_b}$$

every

$$\Delta T \sim \sqrt{a_1^3/GM_b}$$



ECCENTRICITY DISTRIBUTION



From the field (Kowalska+ 11)

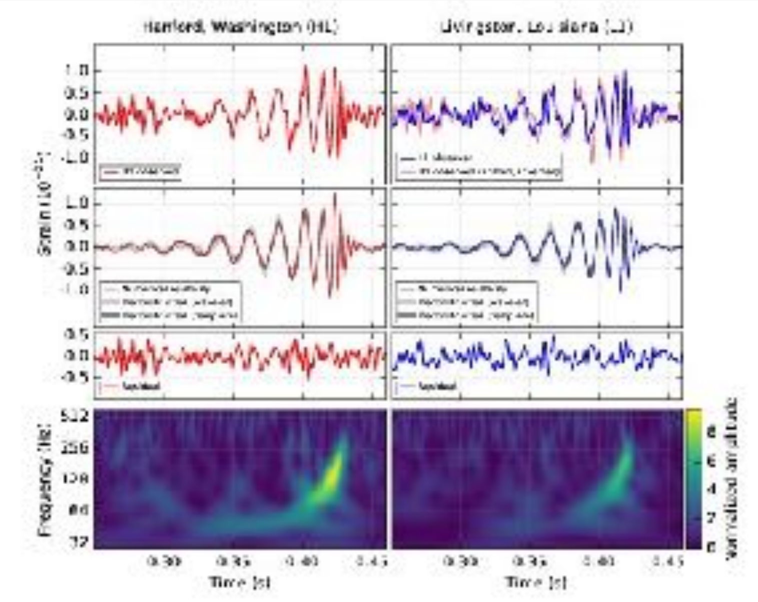
From globular clusters (Rodriguez+ 16)

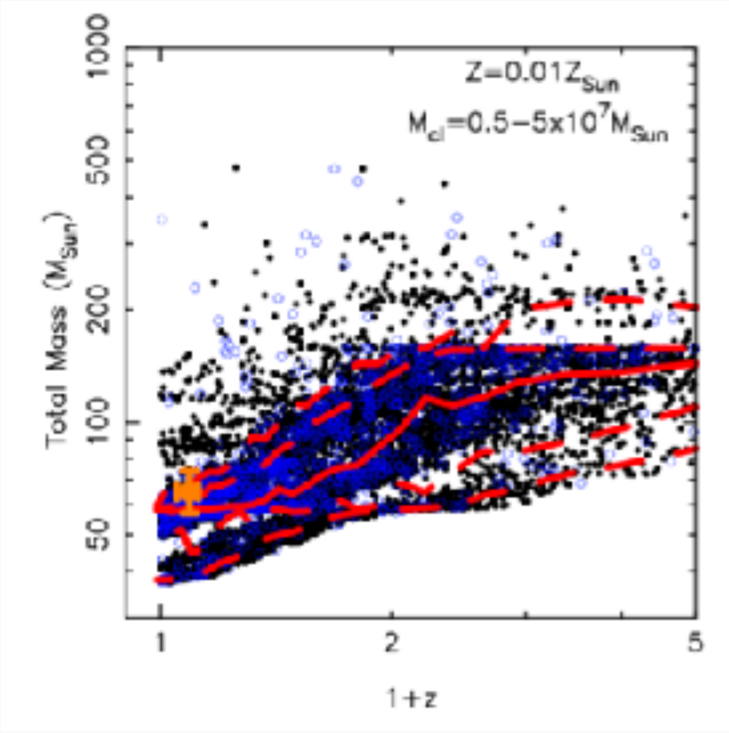
From nuclear clusters (Antonini, Perets '12)

A handful of detections would suffice to tell whether most black hole mergers form in the gravitational field of a massive black hole

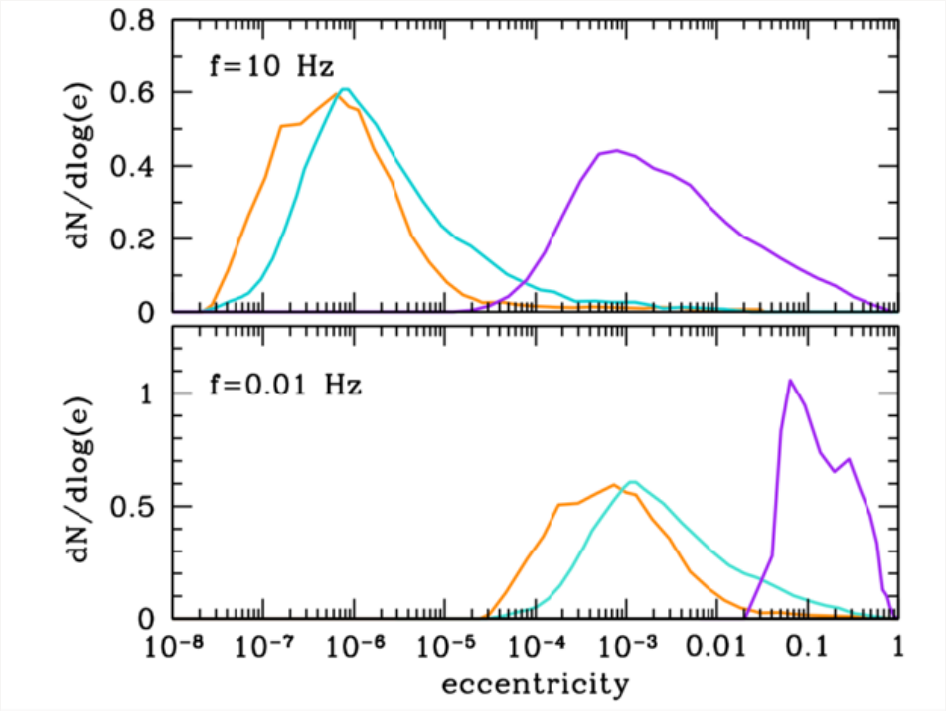
CONCLUSIONS

Stellar dynamics in nuclear clusters produce black hole binaries that merge at a high rate in the local Universe





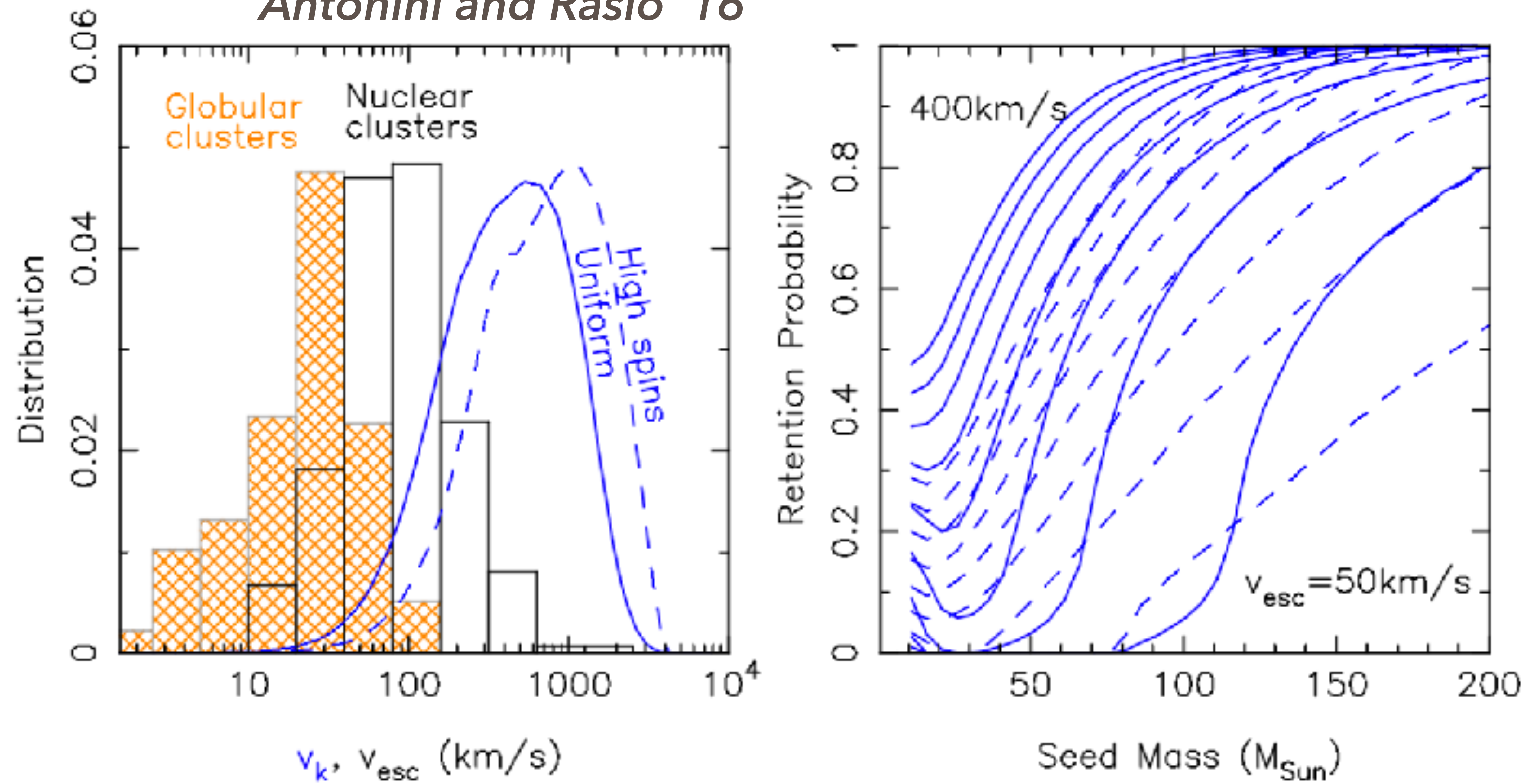
More massive mergers can be naturally formed in NCs



Unique statistical distribution of their properties

RETENTION OF MERGER REMNANTS

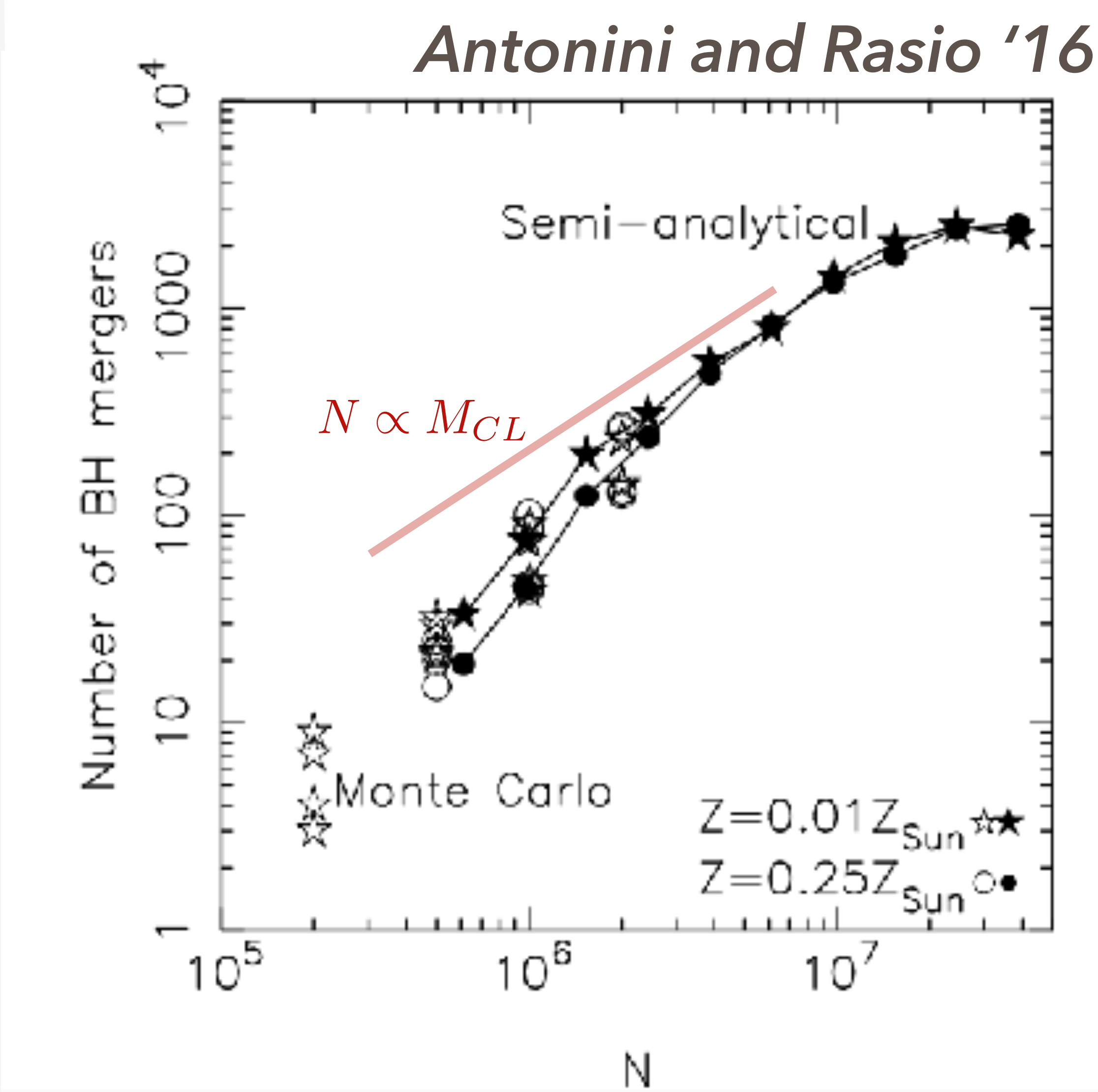
Antonini and Rasio '16

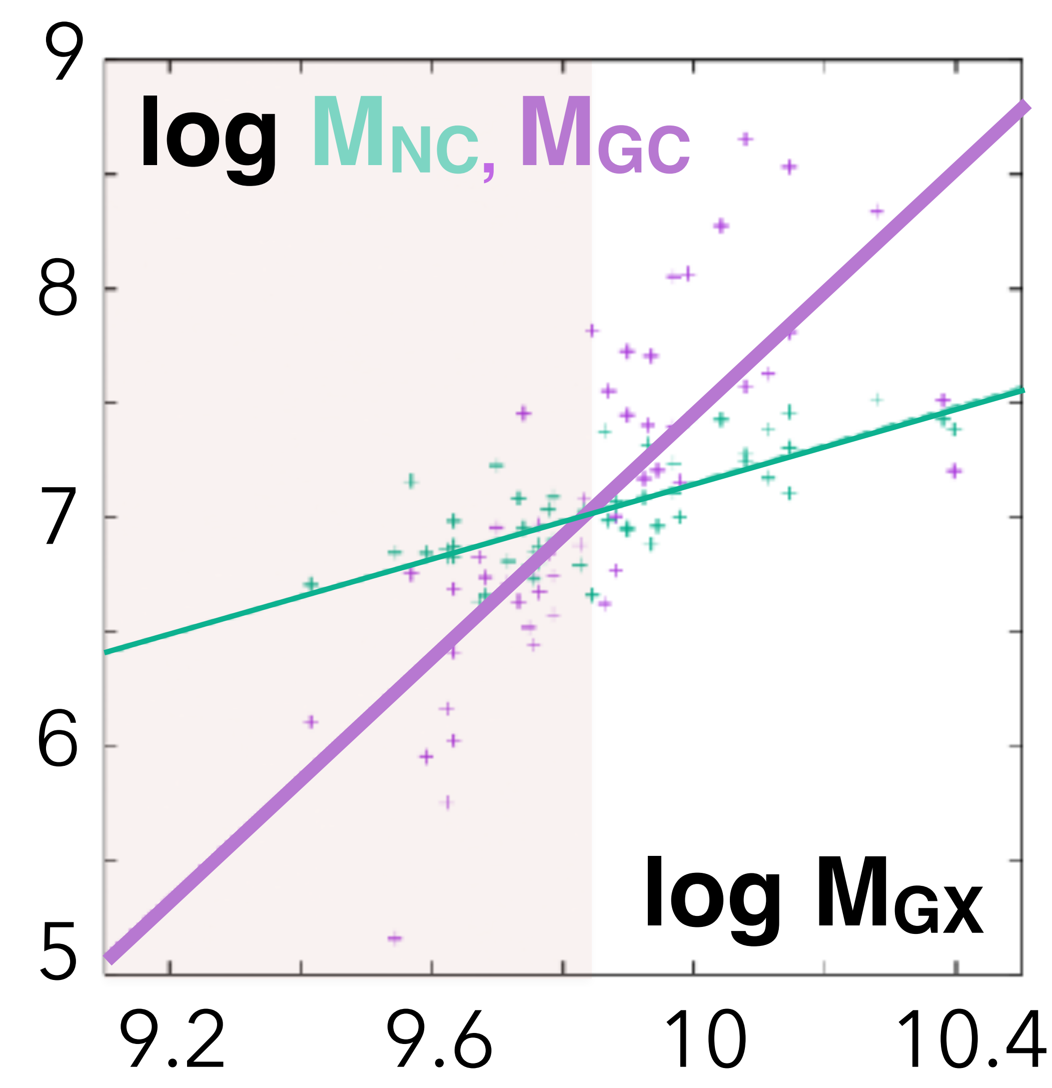


A large fraction of BH merger remnants is retained in NCs;

Significant growth can occur.

NUCLEAR CLUSTERS ARE EFFICIENT FACTORIES OF BH-BH MERGERS



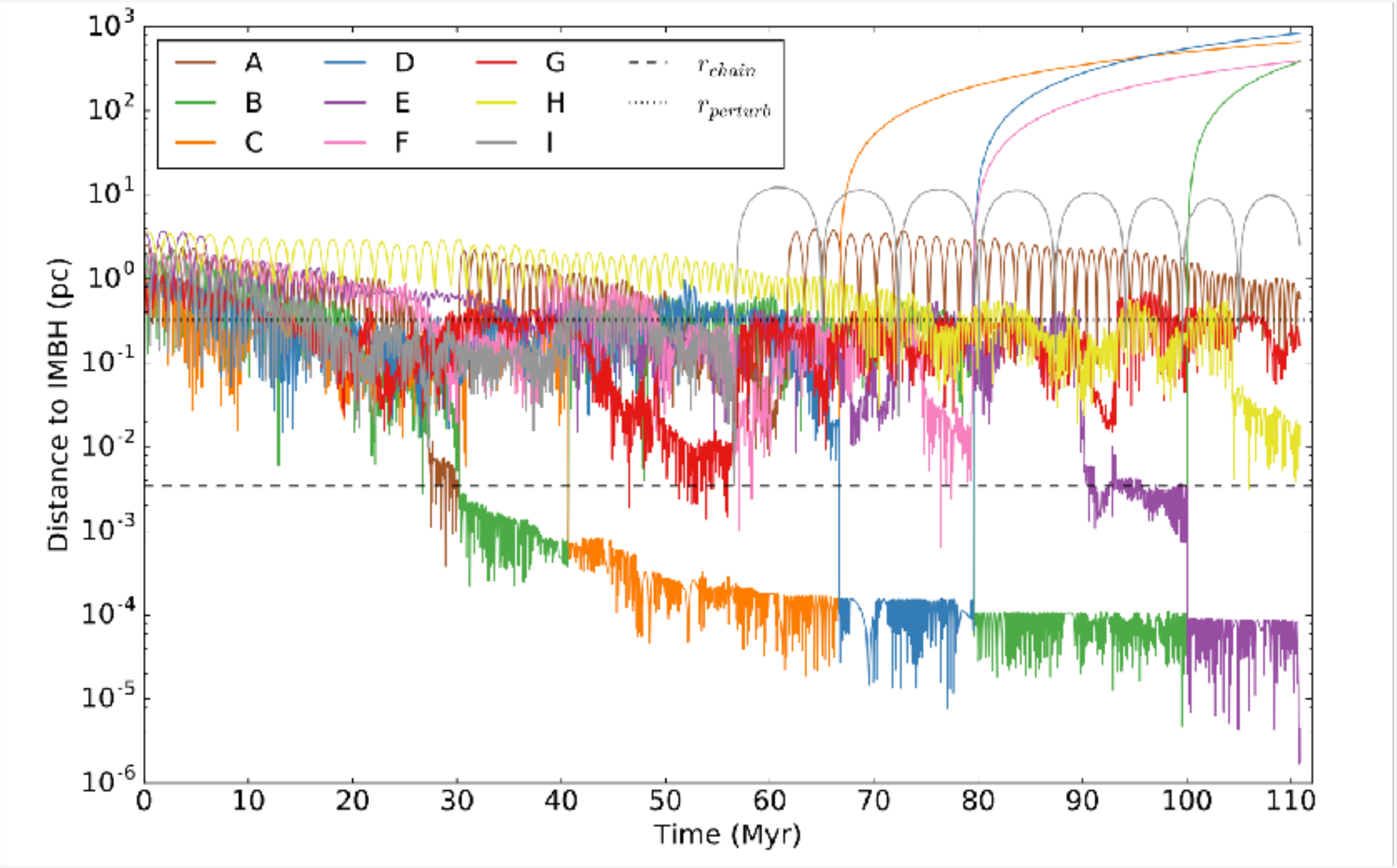


$$\Gamma_{NC} \approx 2\text{Gpc}^{-3}\text{year}^{-1}$$

Tens of detections of BH-BH mergers formed in NCs are expected

EXAMPLE CASE

Haster, Antonini, Kalogera, Mandel (2016)



Regularized+PN terms

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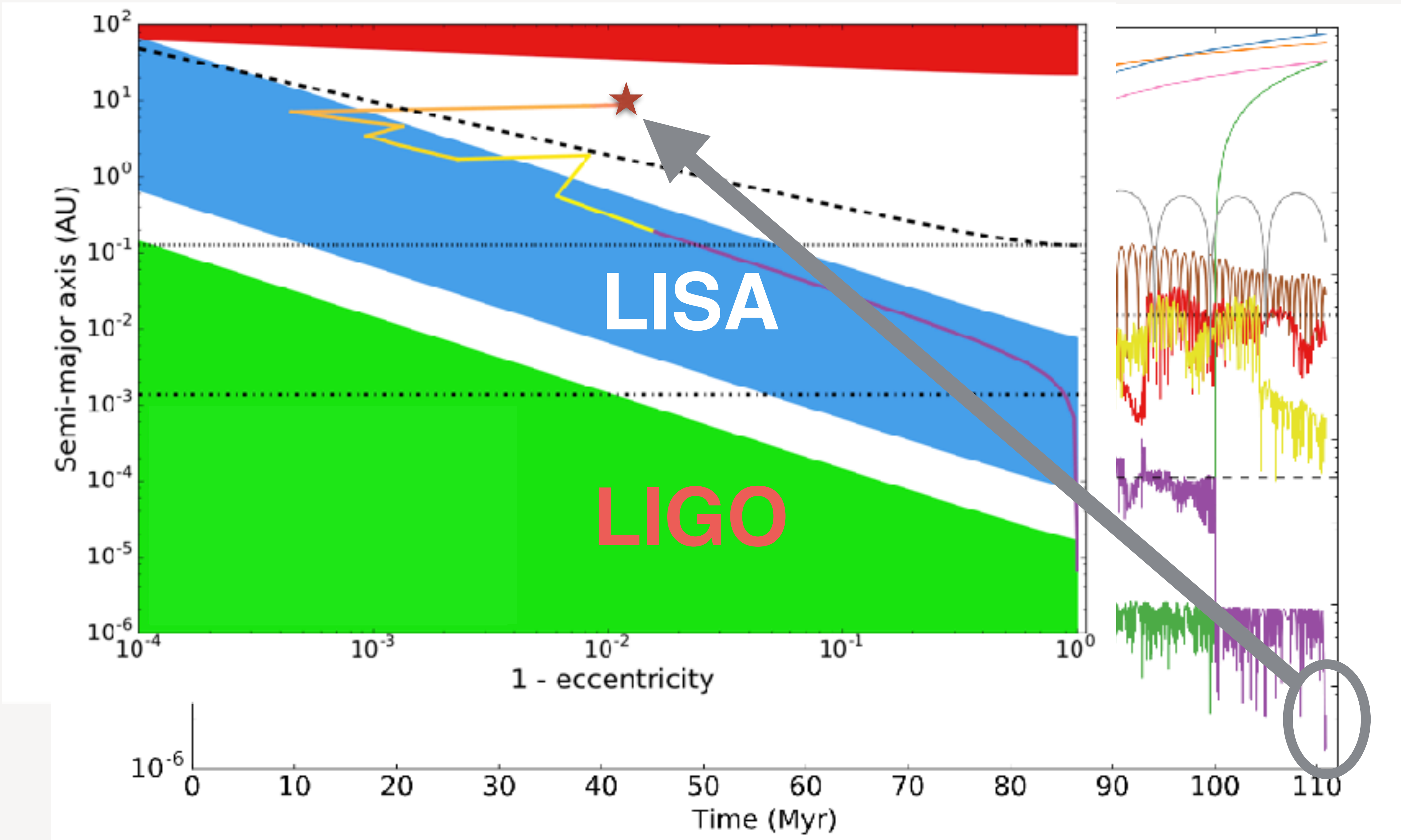
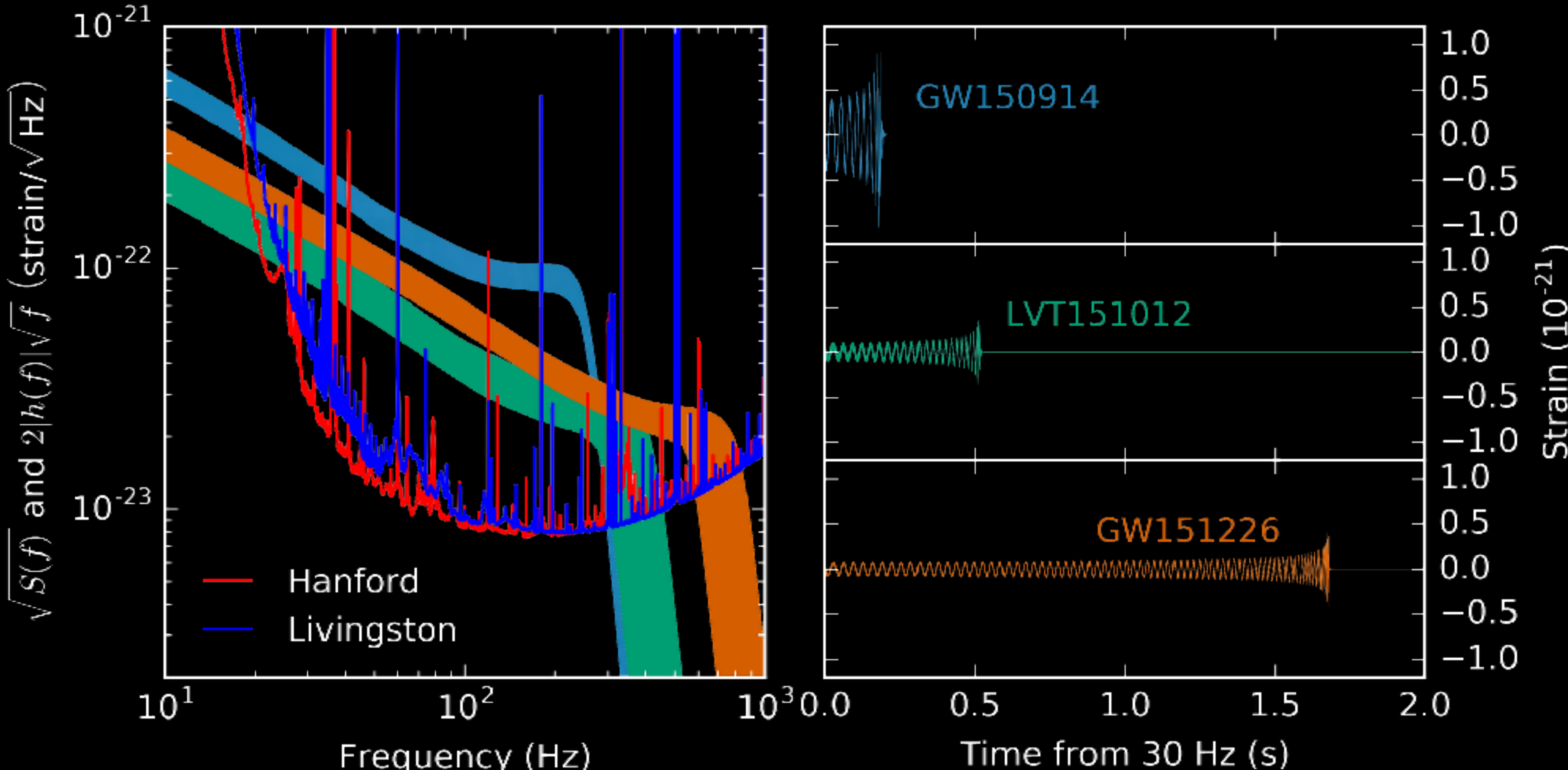


Regularized+PN terms

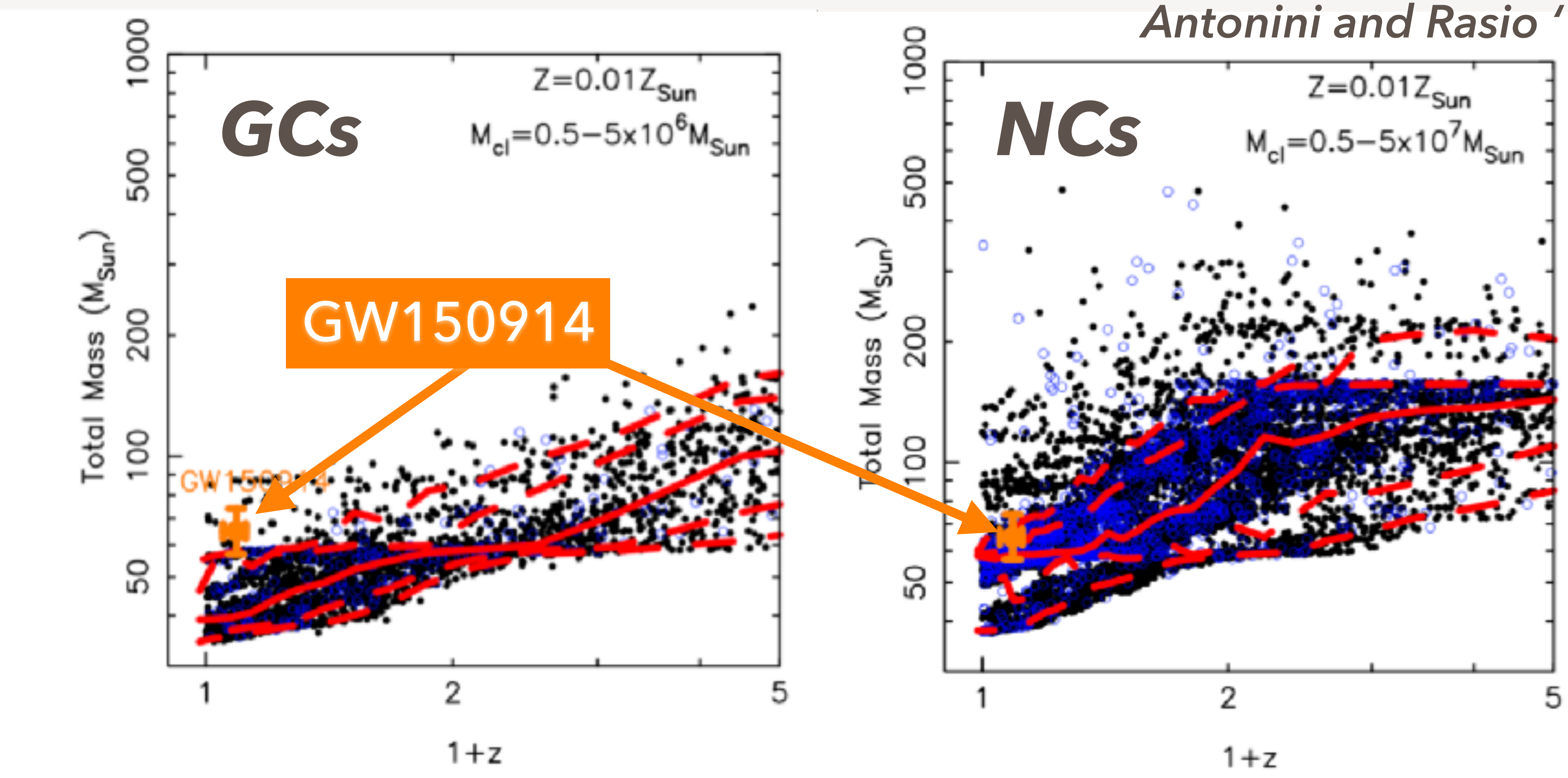
FIRST DETECTIONS

Abbott+ '16



NUCLEAR CLUSTERS ARE EFFICIENT FACTORIES OF GW150914-LIKE MERGERS

Antonini and Rasio '16



$$\Gamma^{\rm NSC}_{\rm aLIGO}(z < 0.3; M > 50 M_\odot) \approx 0.4 - 1\ {\rm Gpc}^{-3}\ {\rm yr}^{-1}$$

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