Observing mass-transfer in double white dwarfs with LISA *and* Gaia

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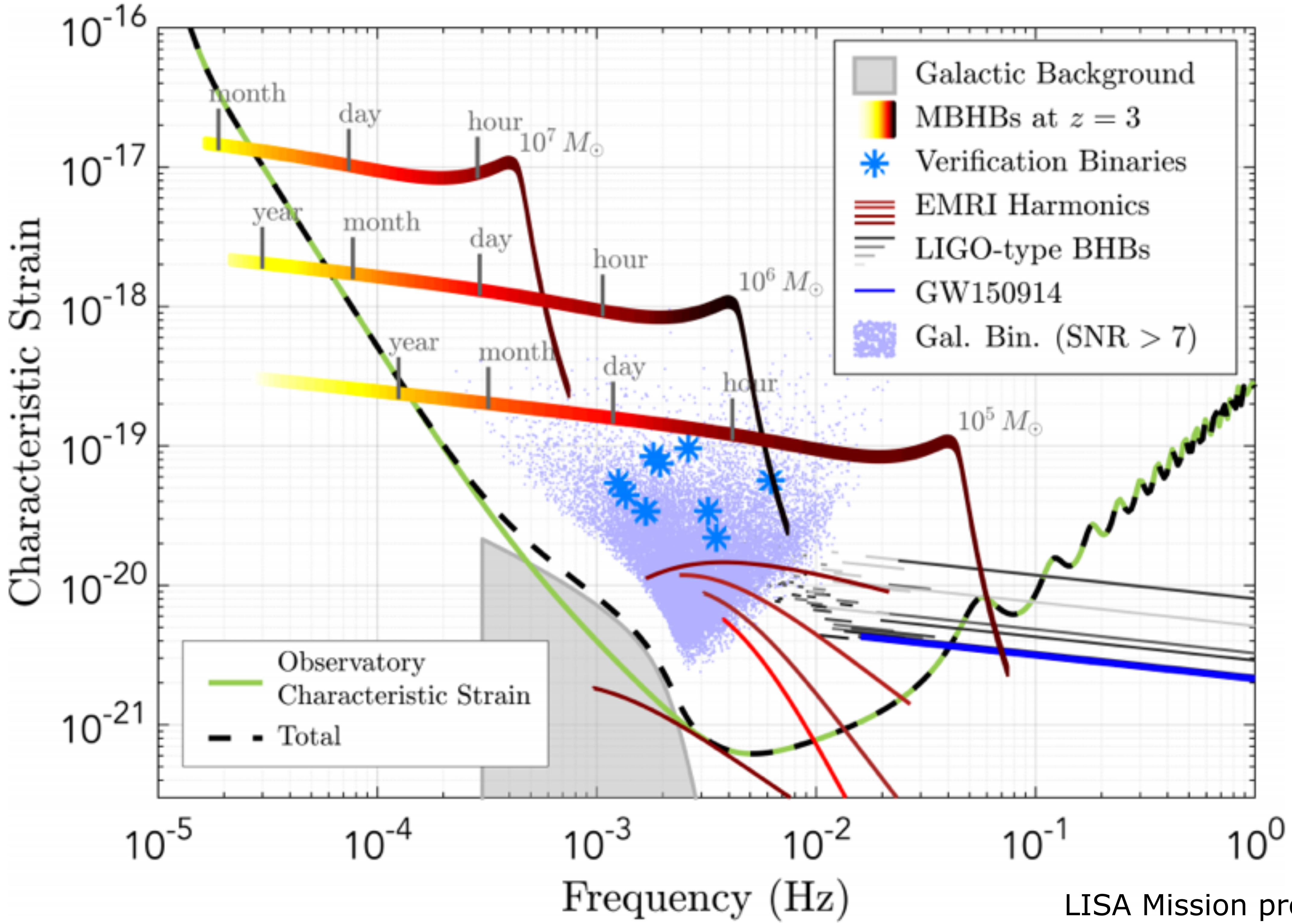
Amaldi Conference
July 11, 2017

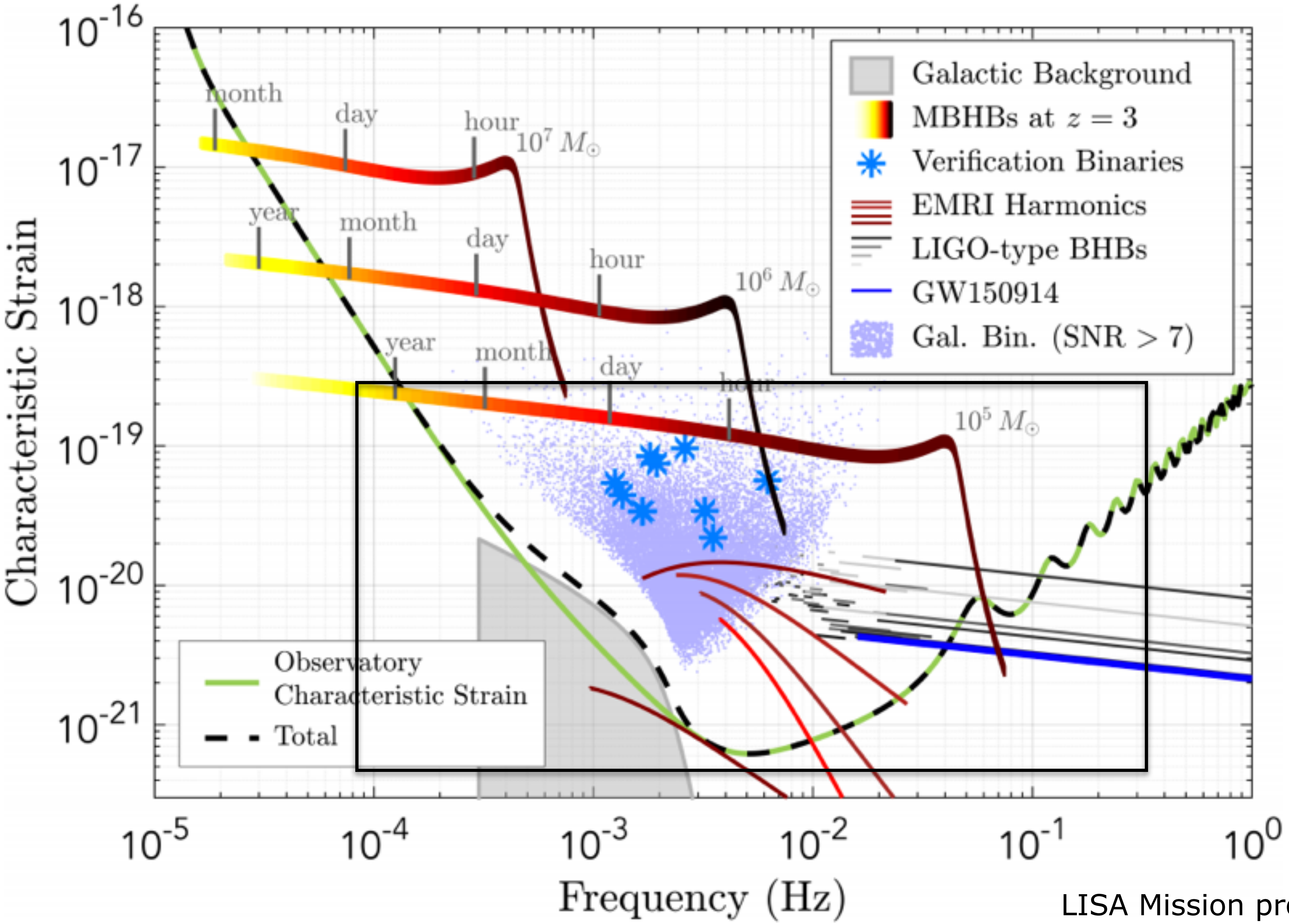
Simulating a Milky Way population

Observing mass-transferring double white dwarfs with LISA

Observing mass-transferring double white dwarfs with LISA *and* Gaia



LISA Mission proposal
arxiv: 1702.00786



LISA Mission proposal
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Milky Way compact binaries & LISA

2.1 SO1: Study the formation and evolution of compact binary stars in the Milky Way Galaxy.

SI1.1: Elucidate the formation and evolution of GBs by measuring their period, spatial and mass distributions.

SI1.2: Enable joint gravitational and electromagnetic observations of GBs to study the interplay between gravitational radiation and tidal dissipation in interacting stellar systems.

- How many compact binaries are observable by LISA?
- What are their parameters (m_1, m_2, P_{orb}, ecc)?

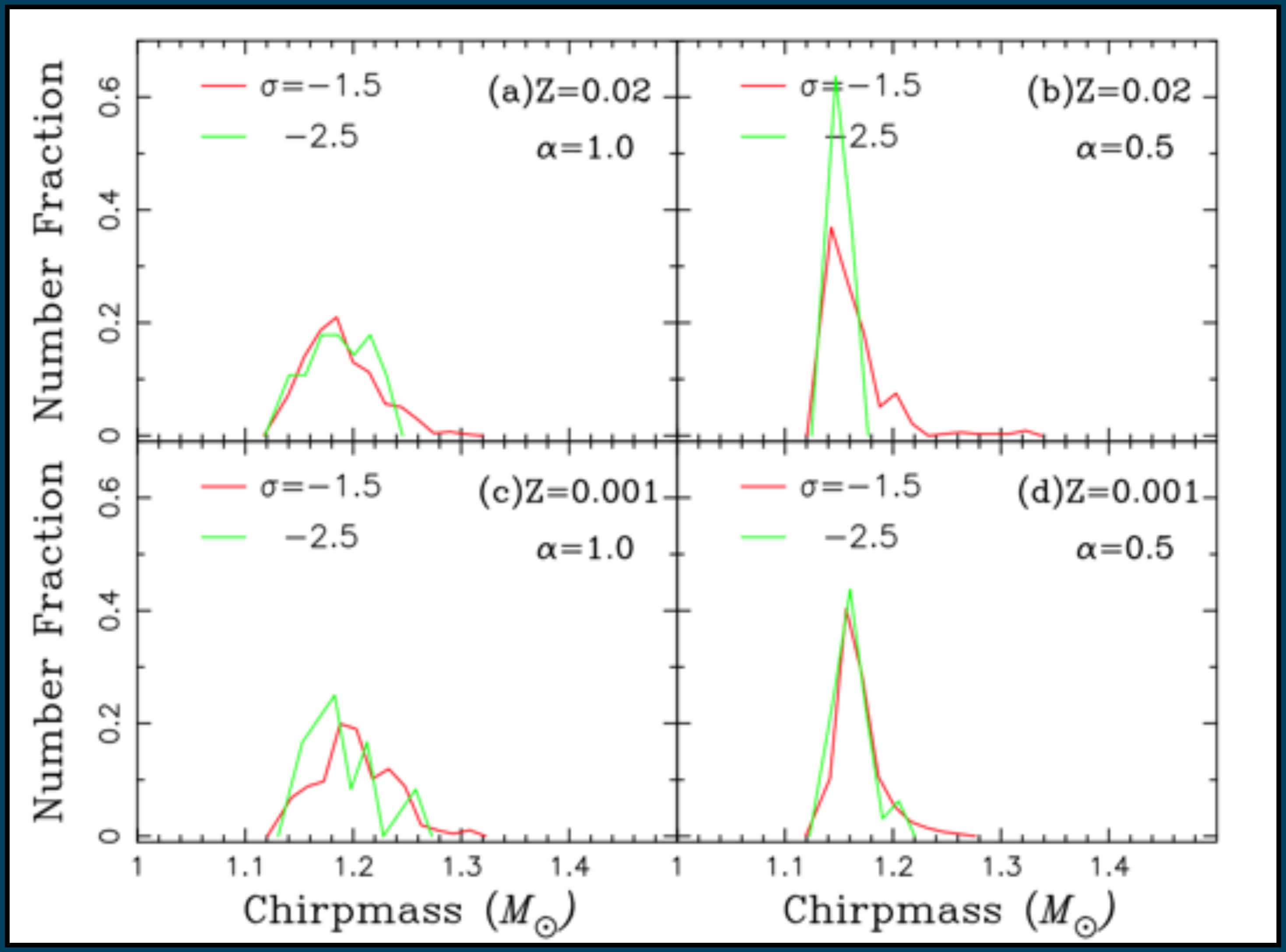
Milky Way compact binaries & LISA

Nelemans et al (2001a,b,c, 2004), Belczynski et al (2010), Benacquista et al (2004), Liu and Zhang(2010,2014), van Haaften et al (2013), Yu and Jeffery (2010,2013,2015)

Process:

(1) Simulate 10^7 binary systems for several models

(2) Find LISA-detectable sources



Yu and Jeffery (2015)

⇒ 10^7 systems in confusion background
10^4 systems resolved

Limitations on the status quo: COSMIC variance

$$SNR \sim \frac{h_0\sqrt{T_{obs}}}{\sqrt{S(f)}} \propto \frac{\mathcal{M}_c^{5/3} f_{orb}^{2/3}}{D}$$

intrinsic parameters: $\mathcal{M}_c^{5/3} f_{orb}^{2/3}$

extrinsic parameters: D

Previous work on cosmic variance:
Shuffle sources spatially and vary inclination
Littenberg, Larson et al. (2012)

COSMIC: Compact Object Synthesis and Monte-Carlo Investigation Code

Features:

- Agnostic to binary evolution code
- Quantifies convergence of binary parameter distributions
- Quickly generates Milky Way realizations using Monte-Carlo sampling
- Open source python code - stay tuned :-)

COSMIC : Compact Object Synthesis and Monte-Carlo Investigation Code

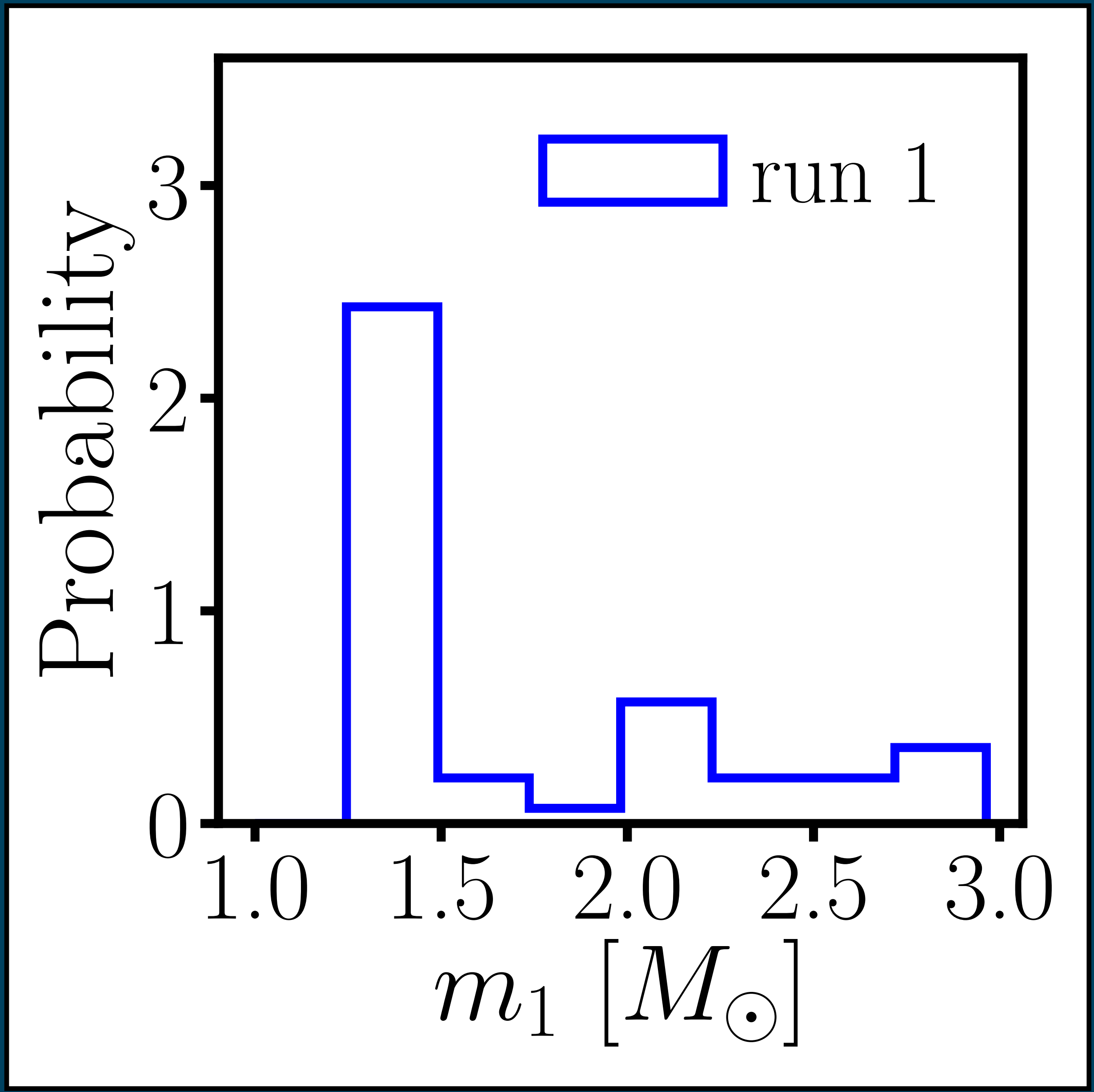
Step one

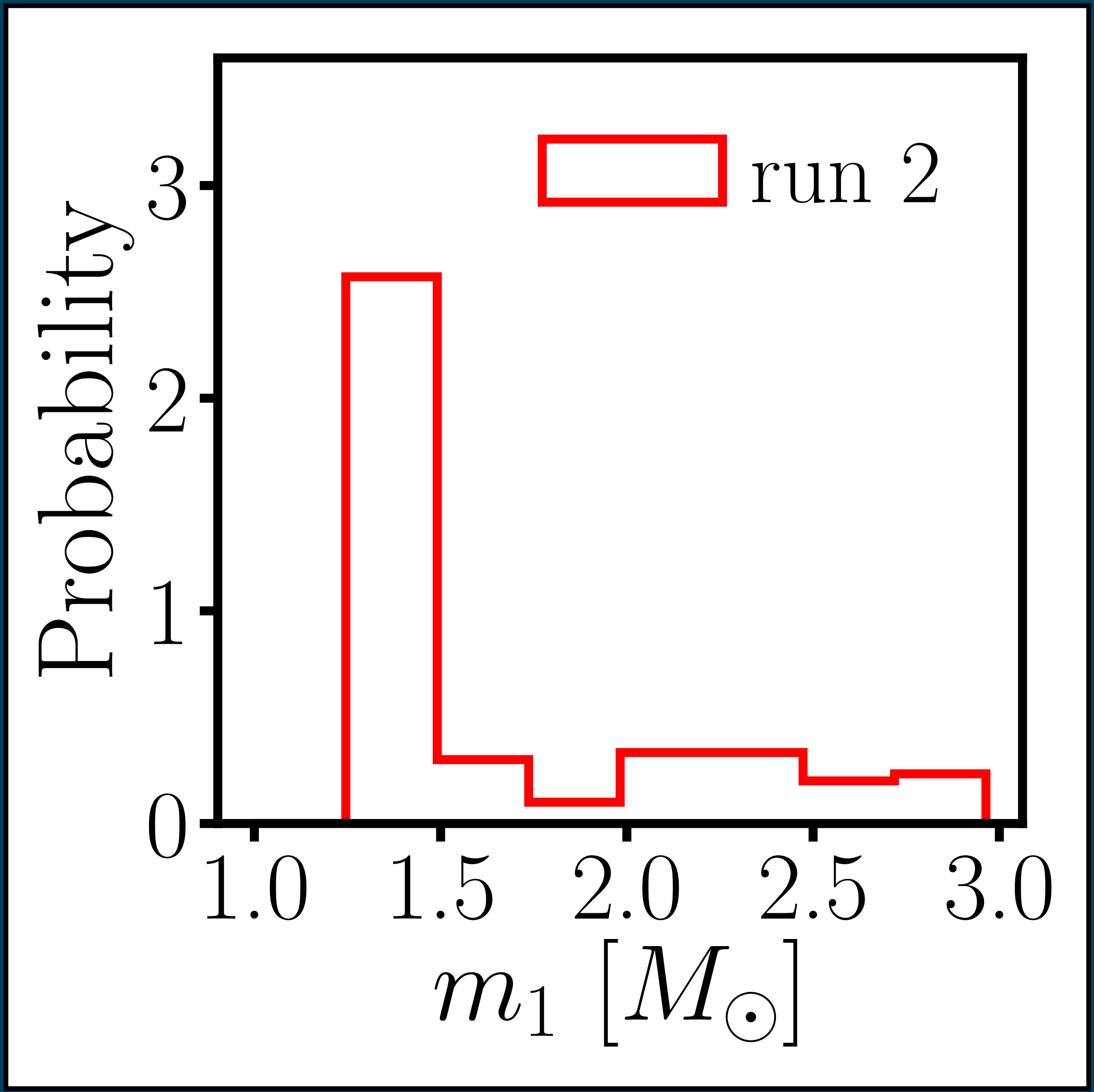
Evolve a population using your favorite binary evolution physics and Milky Way star formation history

Step two

Monte-Carlo sample as many Milky Way populations as you'd like

COSMIC : Compact Object Synthesis and Monte-Carlo Investigation Code





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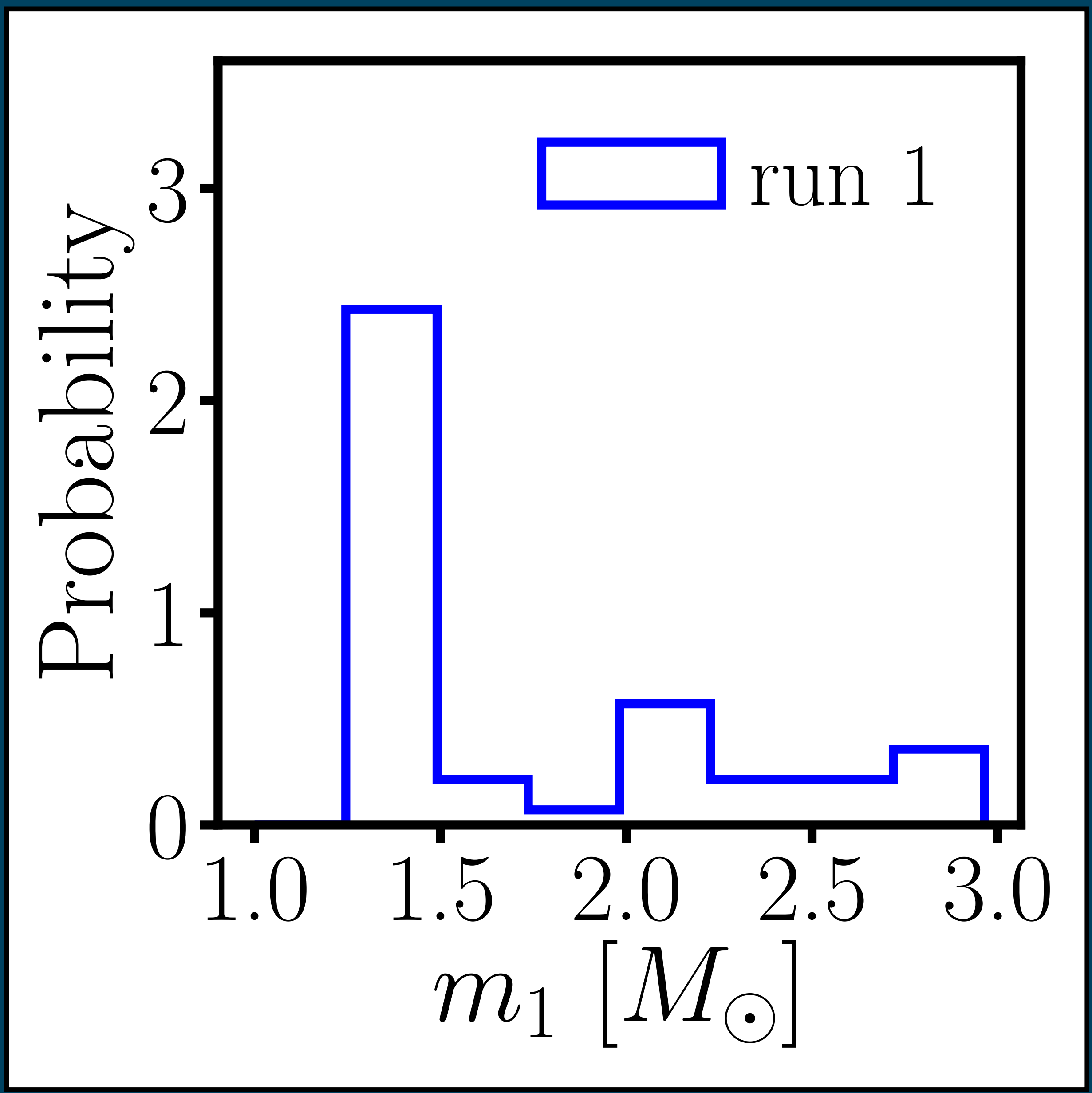
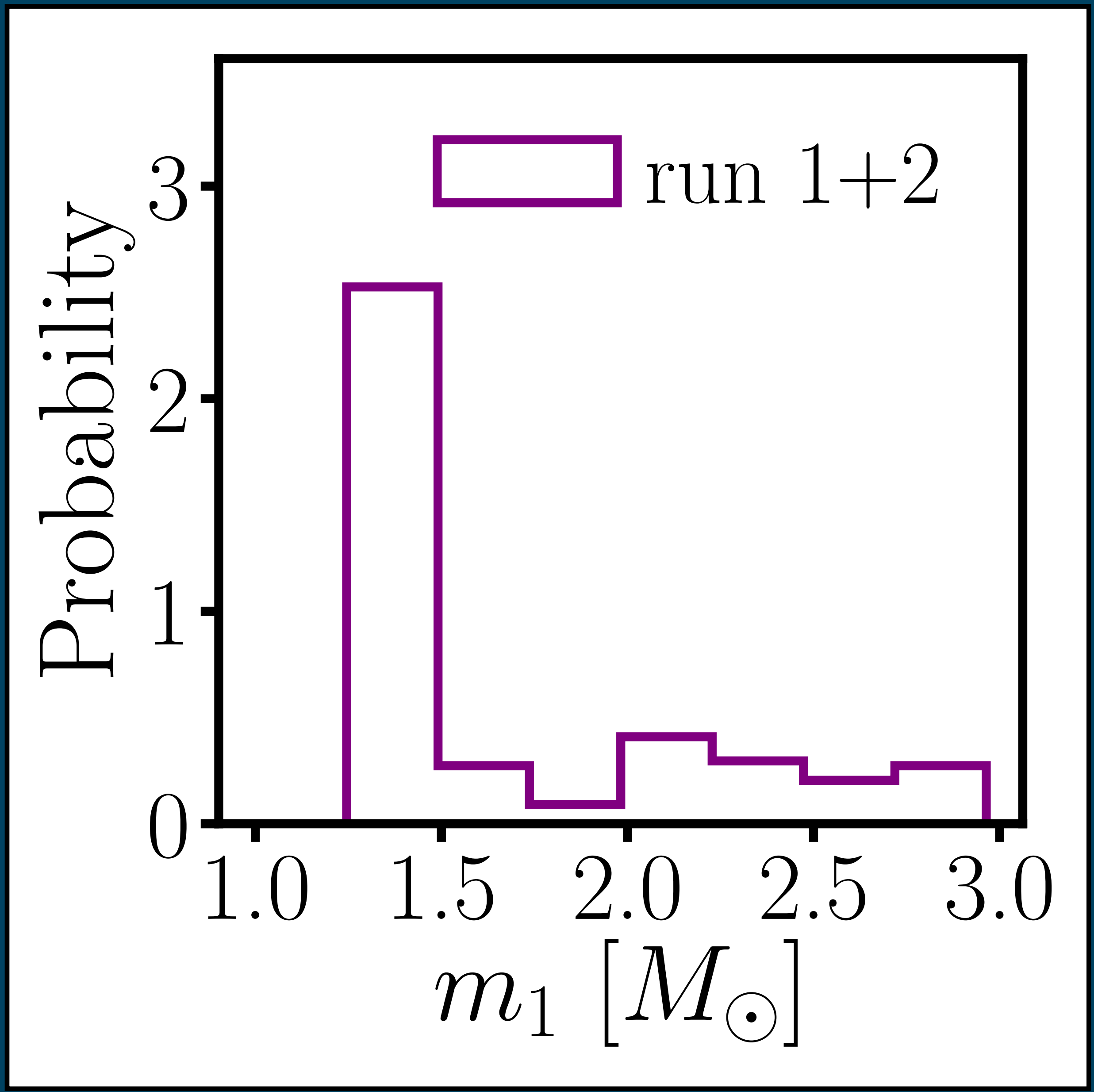
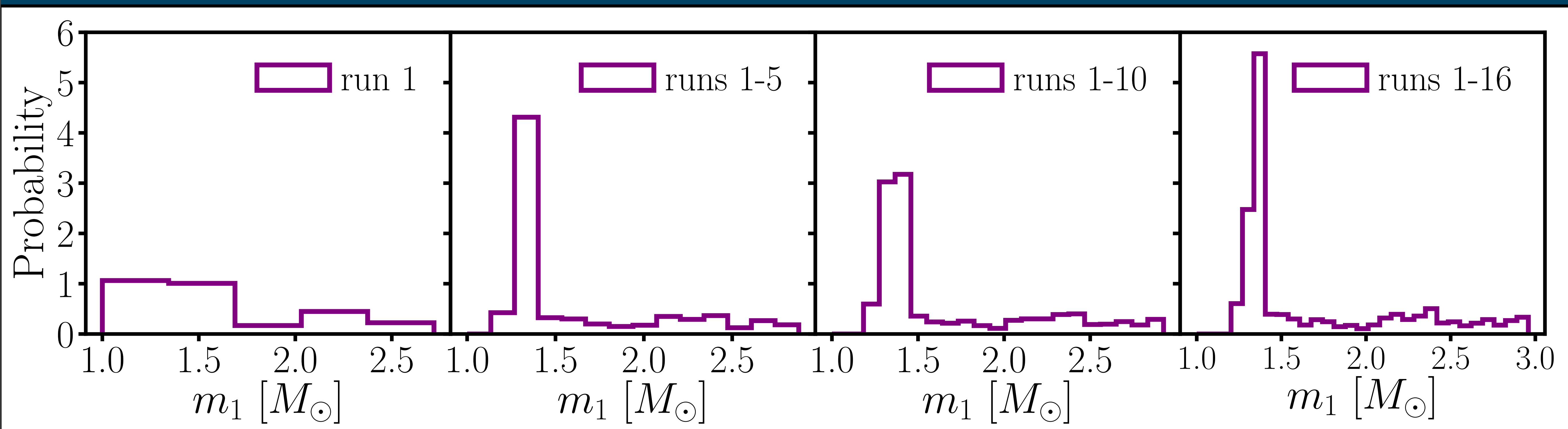




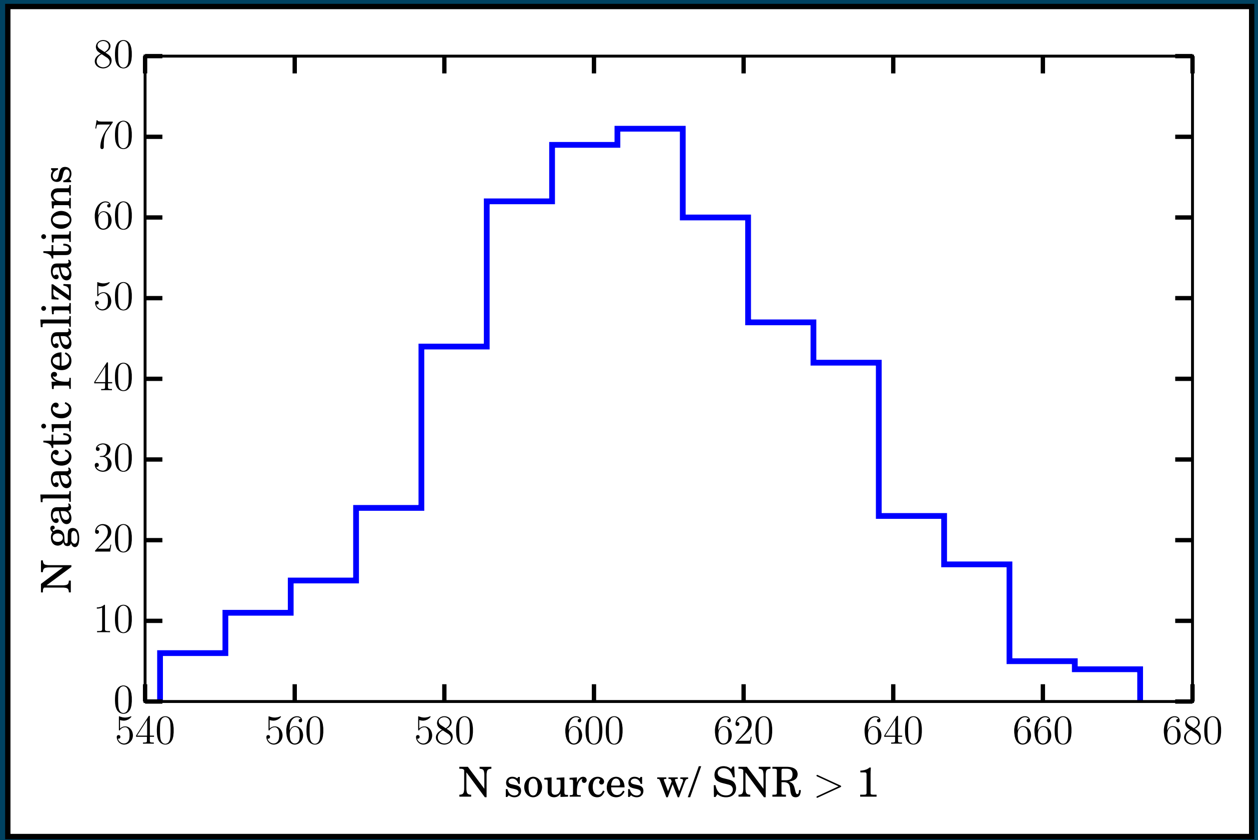
COSMIC: Compact Object Synthesis and Monte-Carlo Investigation Code

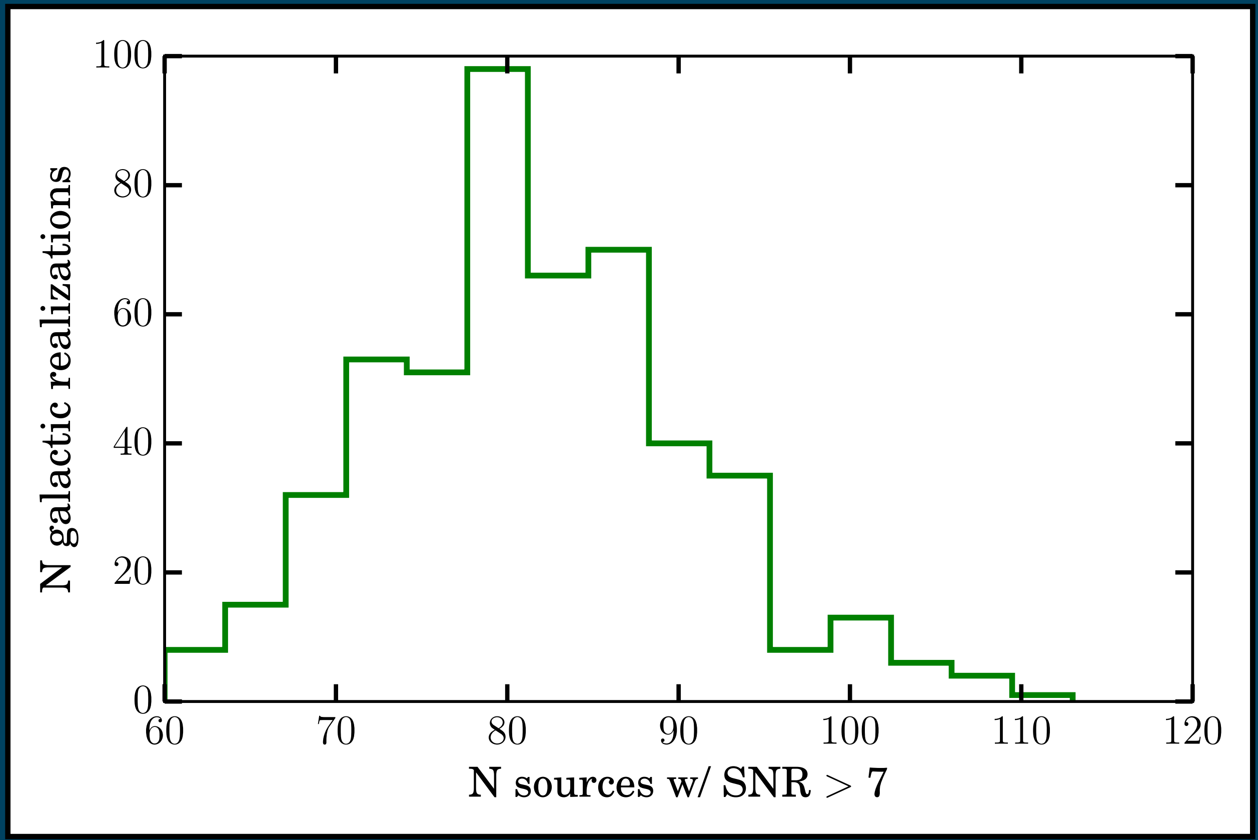
$$match = \frac{\sum_{k=1}^{N} P_1 P_2}{\sqrt{\sum_{k=1}^{N}(P_1 P_1) \sum_{k=1}^{N}(P_2 P_2)}}$$



COSMIC : Compact Object Synthesis and Monte-Carlo Investigation Code

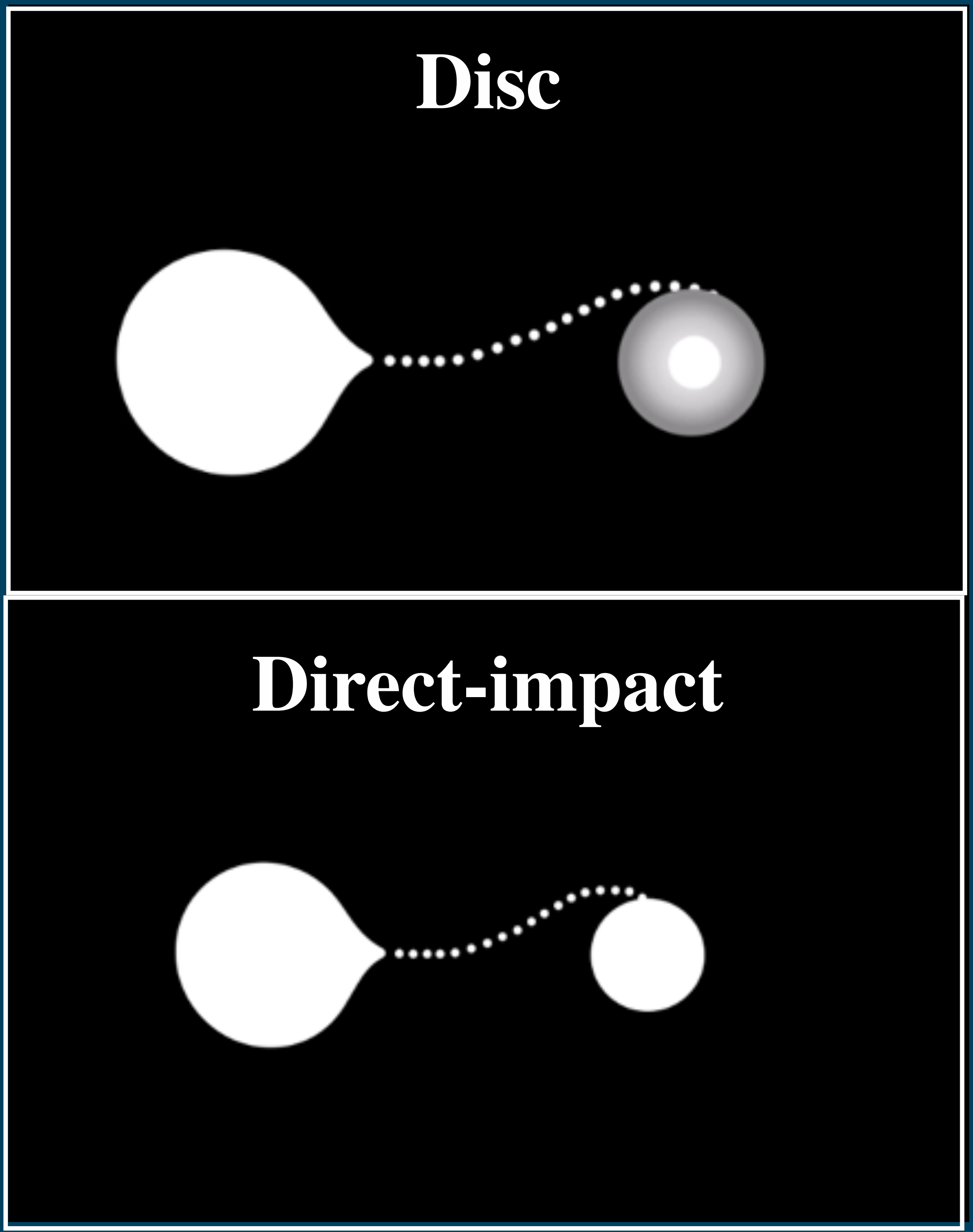
The “real” Milky Way is contained in the realizations





Maybe we are lucky, maybe not!

Direct-impact accretion in double white dwarfs (DWDs)



credit: Kyle Kremer

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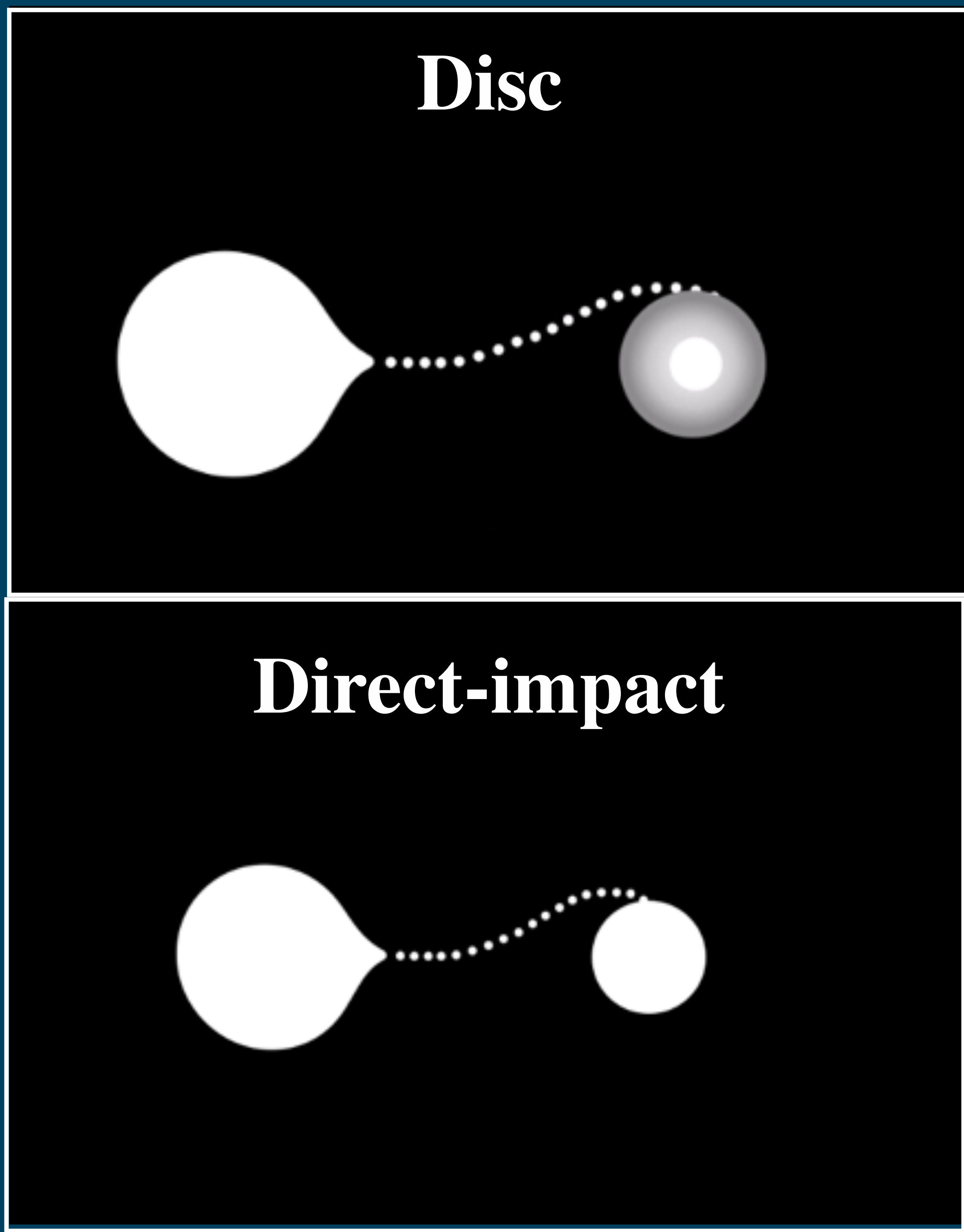

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Tidal torques from disk maintain synchronization and allows stable mass transfer

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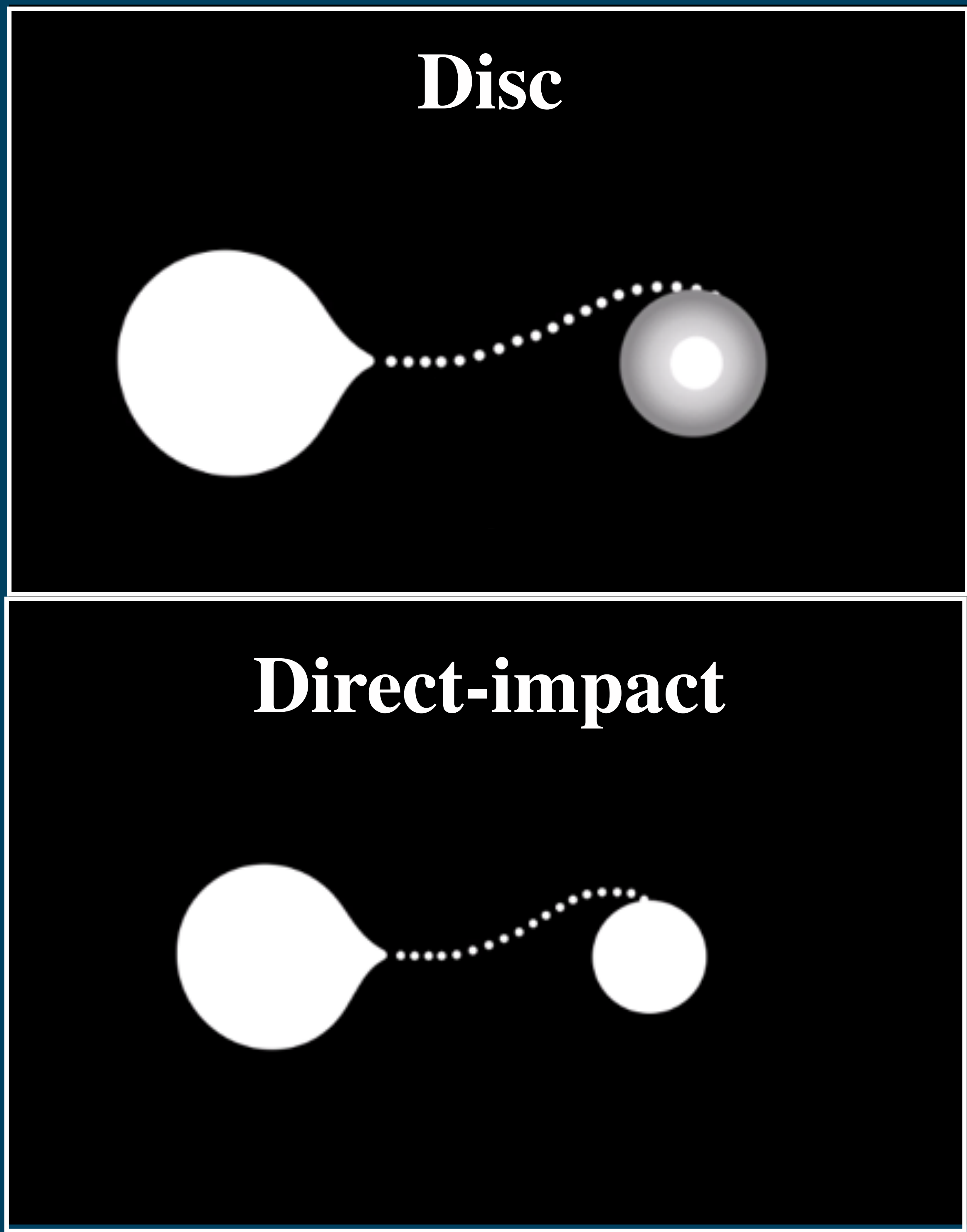


credit: Kyle Kremer

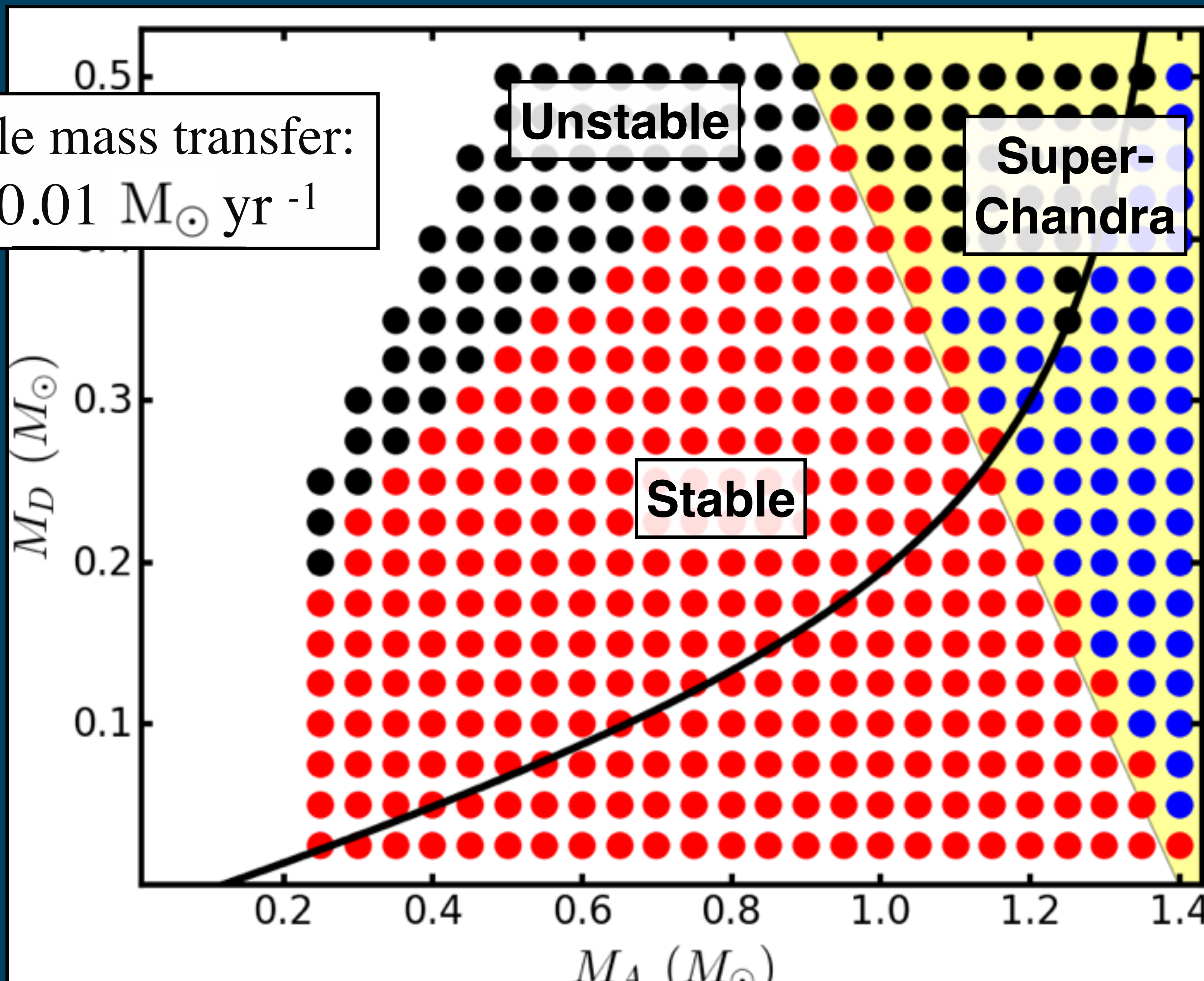
Tidal torques from disk maintain synchronization and allows stable mass transfer

No disk torques!

Mass transfer can be stable or unstable based on mass ratio

Direct-impact accretion in double white dwarfs

Unstable mass transfer:
$\dot{M} > 0.01\ M_\odot\ yr^{-1}$

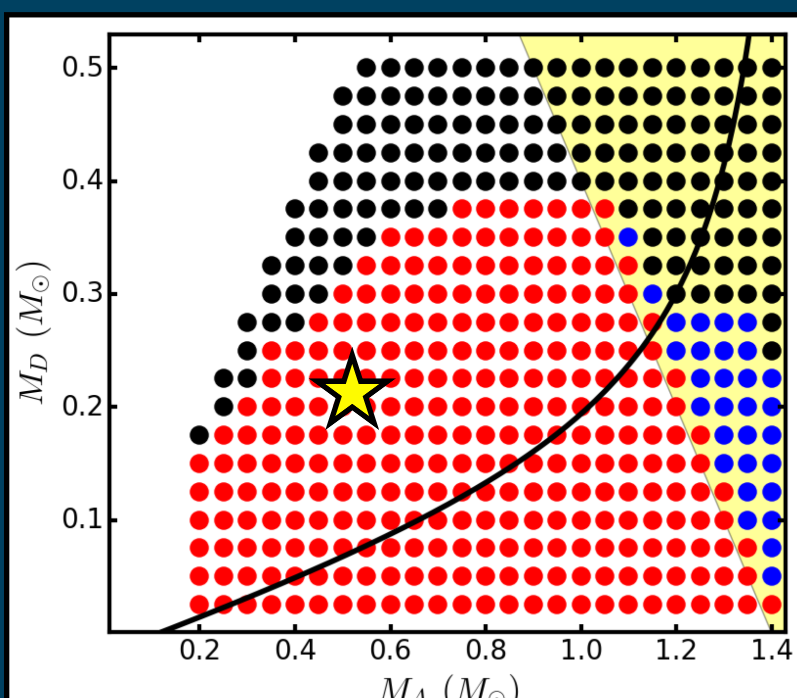


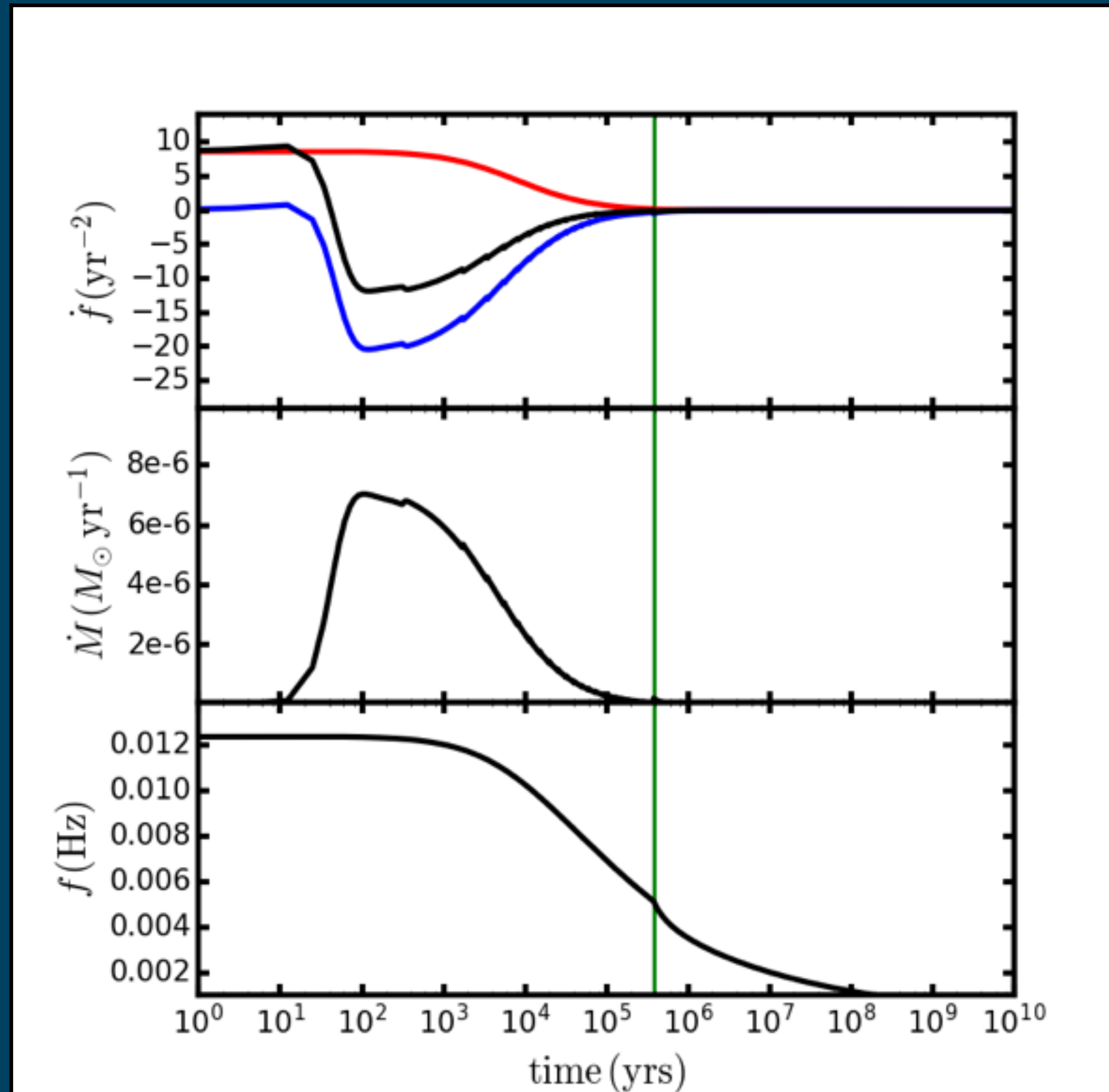
Kremer et al. (2016)

Direct-impact phase → HUGE negative chirps

LISA fiducial
minimum chirp

$$\dot{f} < -0.1\ bin/yr$$





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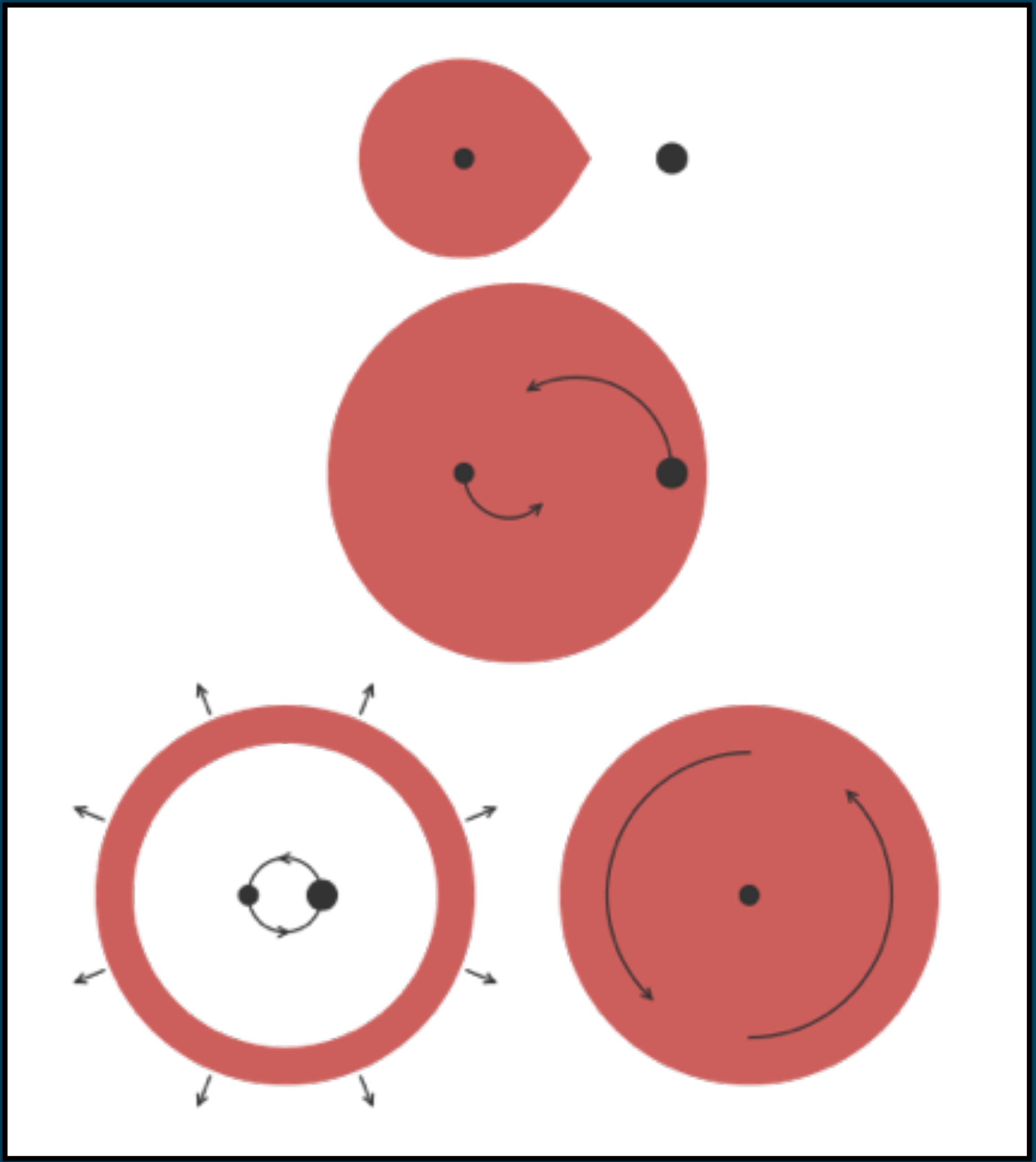
Kremer et al. (2016)

Generating a population of mass-transferring DWDs

Close DWDs are a result of common envelope evolution

Final separation depends on envelope binding energy: λ

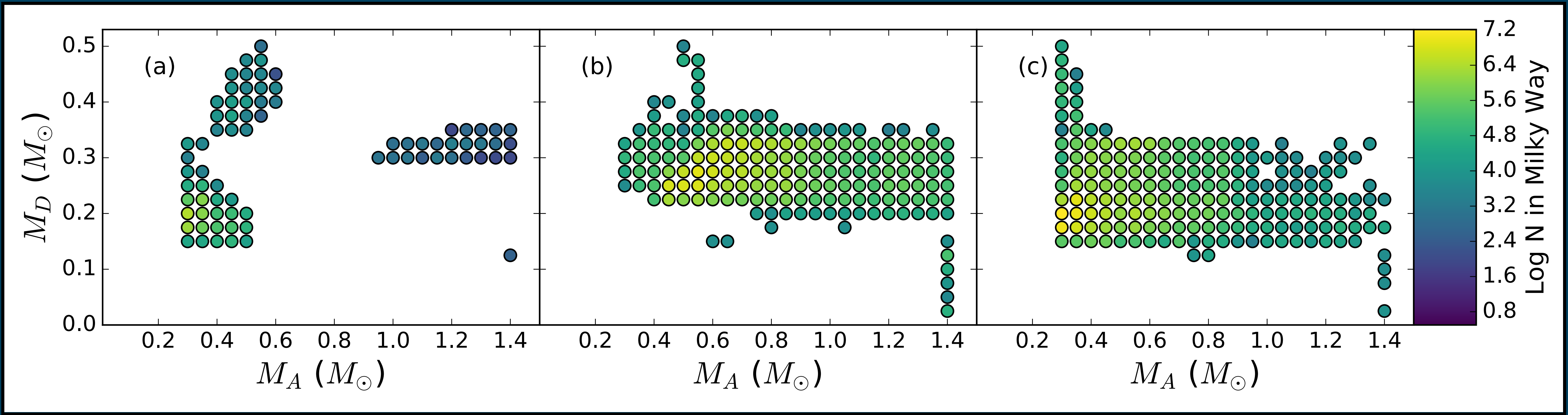
e.g. Dewi & Tauris (2000)



He-donor DWD systems that transfer mass

high envelope binding energy → low binding energy

λ = 0.1 λ = 1.0 λ = 10.0



Kremer, KB, Larson, Kalogera: arXiv: 1707.01104

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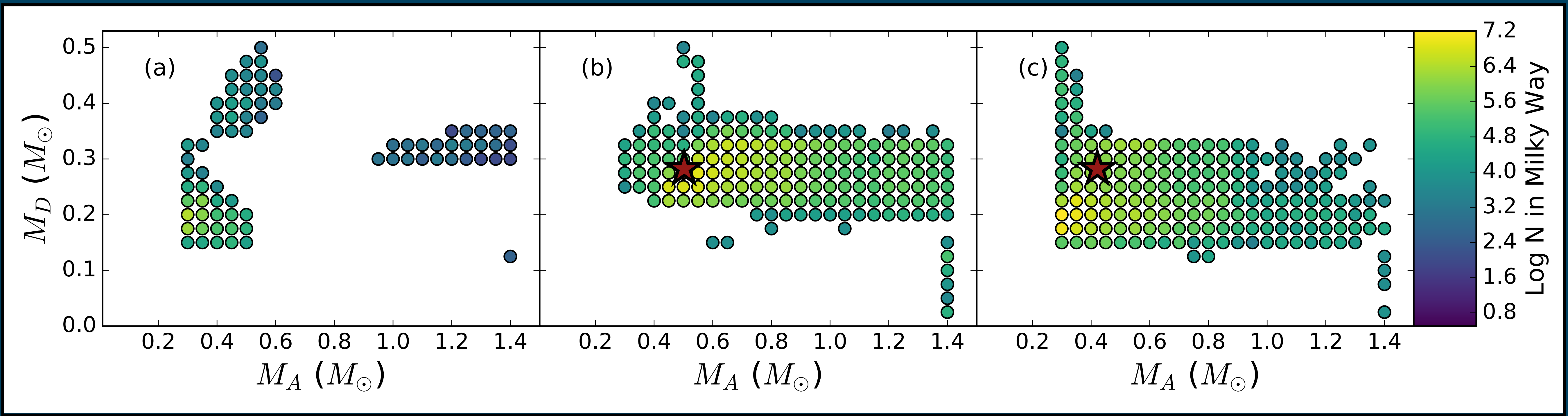

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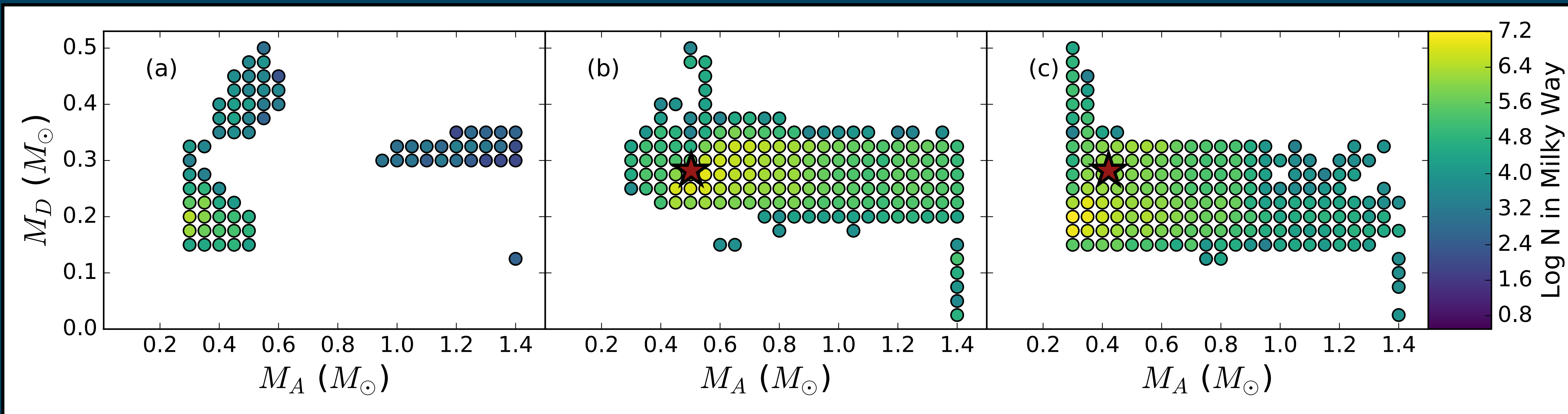

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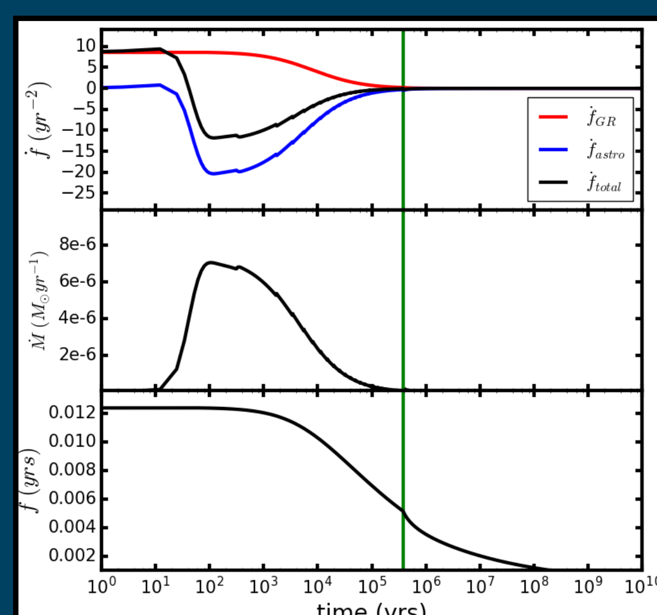
M_A
M_D
T_{MT}

+



=

$M_{A,f}$
$M_{D,f}$
f_{orb}
All chirps

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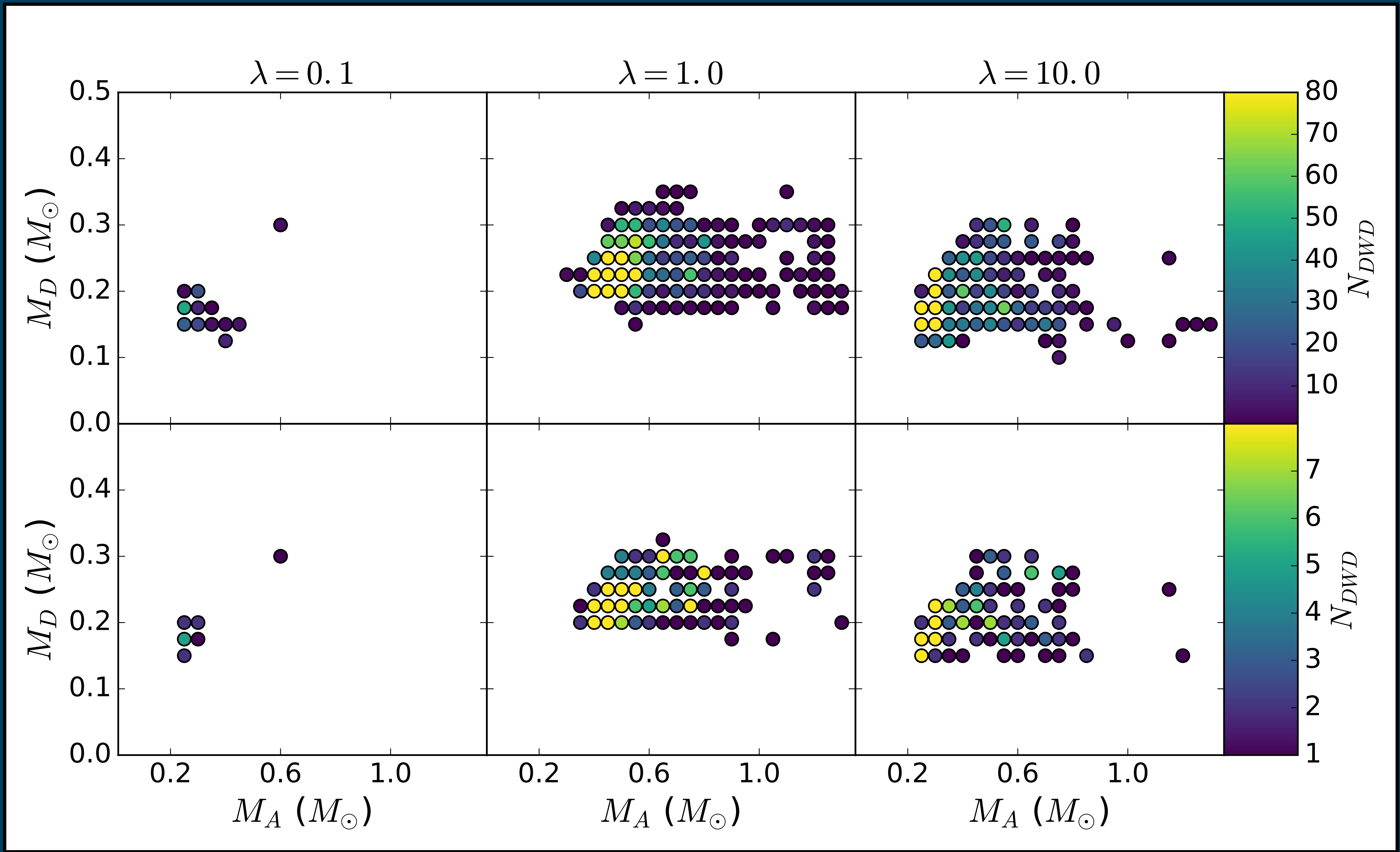
Single Milky Way realization

Few thousand DWDs: chirps < -0.1 bin/yr (top row)
Few hundred DWDs: chirps < -1.0 bin/yr (bottom row)



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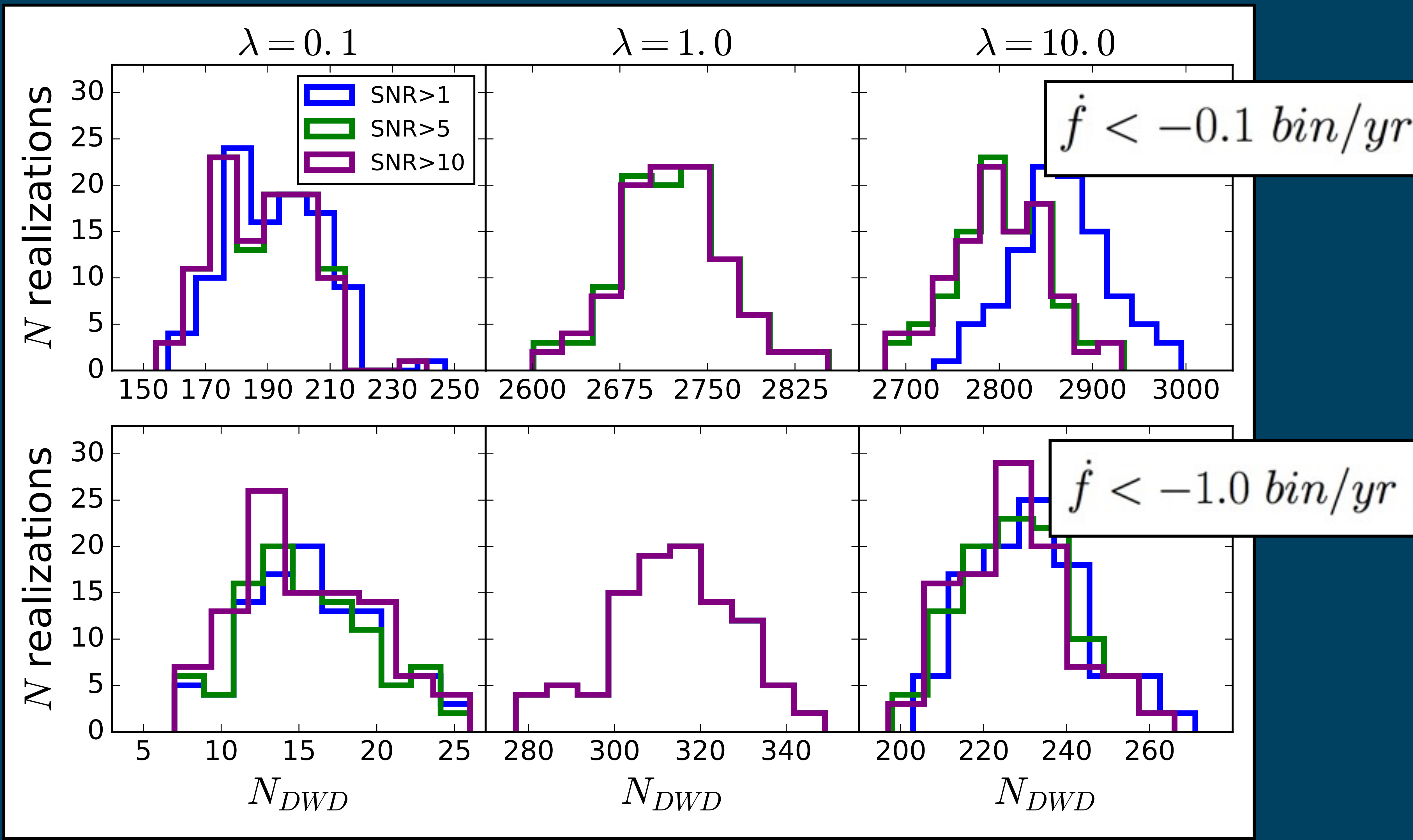
100 Milky Way Realizations



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How does Gaia come in?

LISA observes: h_o f_{orb} $\dot{f}$

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$$\dot{f} \neq \dot{f}_{GR}$$

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$$\dot{f} = \dot{f}_{GR} + \dot{f}_{astro}$$

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GAIA observes: D

$$D \propto \frac{h_o \dot{f}_{GR}}{f_{orb}^3}$$

How does Gaia come in?

LISA observes: h_o f_{orb} $\dot{f}$

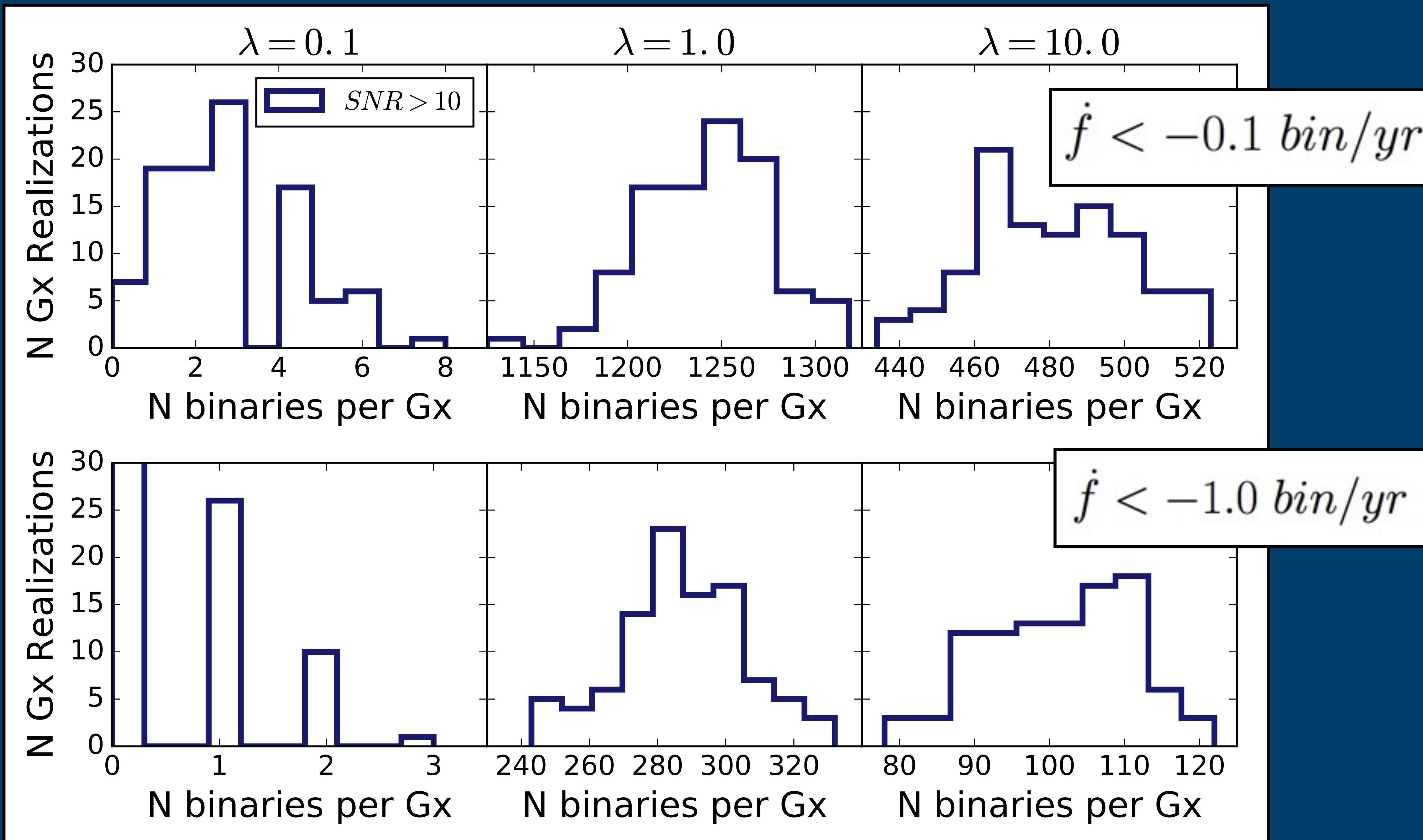
$$\dot{f} = \dot{f}_{GR} + \dot{f}_{astro}$$

GAIA observes: D

$$D \propto \frac{h_o \dot{f}_{GR}}{f_{orb}^3}$$

How many DWDs will Gaia *and* LISA see?

Disk accreting DWDs with $m_V < 20$: donor, accretor, disk



KB, Kremer, Bueno, Larson, Kalogera (in prep)

Milky Way population synthesis needs to handle the effects of COSMIC variance

LISA will potentially observe thousands of mass-transferring DWDs with measurable negative chirps

LISA and Gaia together will potentially observe several hundred mass-transferring DWDs allowing direct measurements of astrophysically driven chirps

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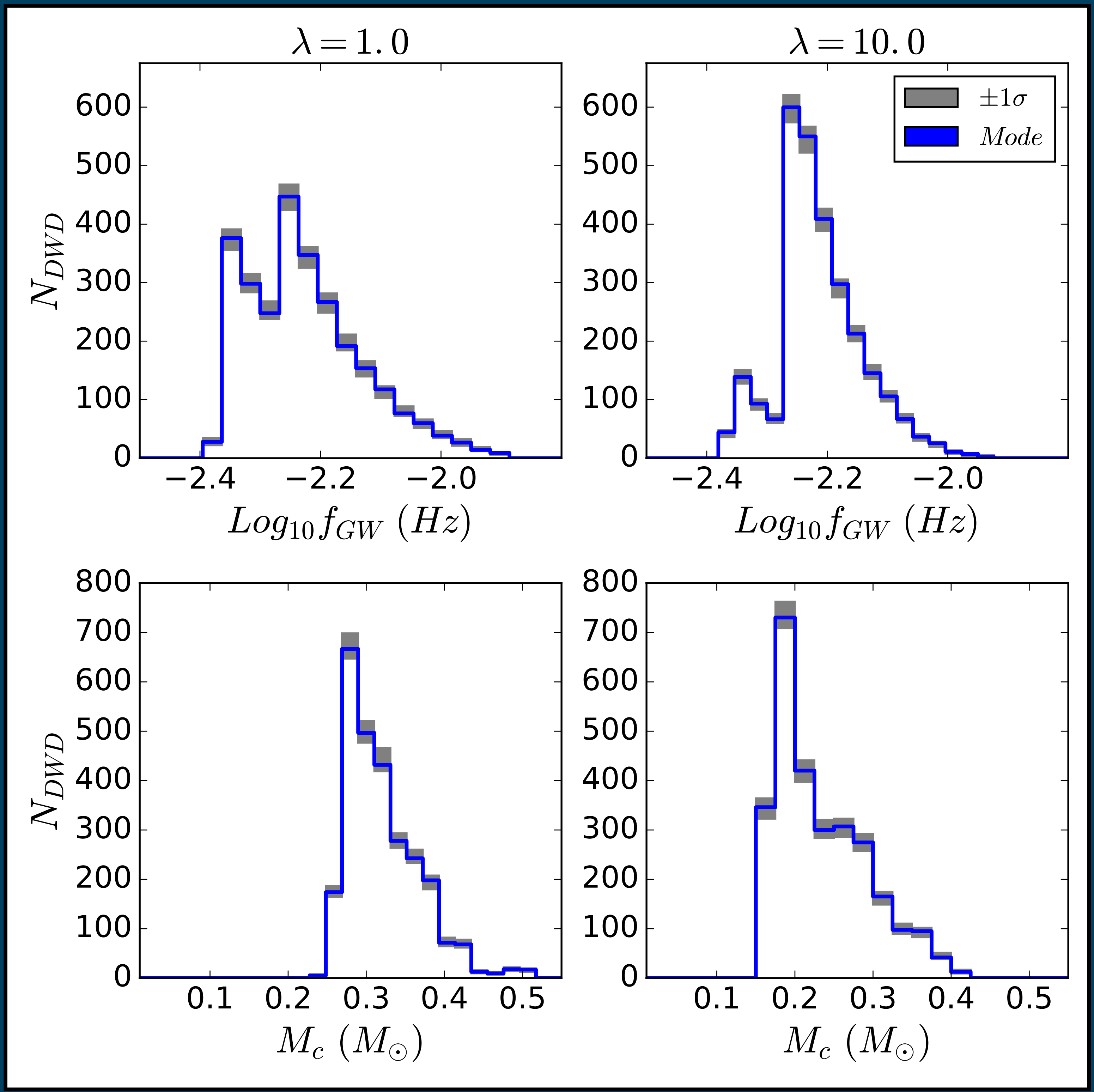
FLY LISA!

Informing binary evolution models



$SNR > 5$

$\dot{f} < -0.1\ bin/yr$

cosmic variance can change bin heights but does not wash out overall distribution shape!

Kremer, KB, Larson, Kalogera: arXiv: 1707.01104