Title: Black Holes and Neutron Stars Abound! The Diverse Zoo of Gravitational-Wave Sources

Speakers: Zoheyr Doctor

Series: Strong Gravity

Date: March 07, 2024 - 1:00 PM

URL: https://pirsa.org/24030102

Abstract: Gravitational waves detected by advanced ground-based interferometers have given us an unprecedented look at the universe. Yet, a central mystery remains: How are sources of gravitational waves -- in particular, black-hole and neutron-star mergers -- formed in nature? The measured masses, spins, and redshifts of these compact objects offer some clues to solving this mystery. In this talk, I will describe state-of-the art techniques for characterizing and simulating pairs of black holes and neutron stars. To conclude, I will argue that a multi-pronged approach combining both model-agnostic data analysis and detailed simulations will help unlock the histories of these exotic objects.

Zoom link

Black Holes and Neutron Stars Abound!

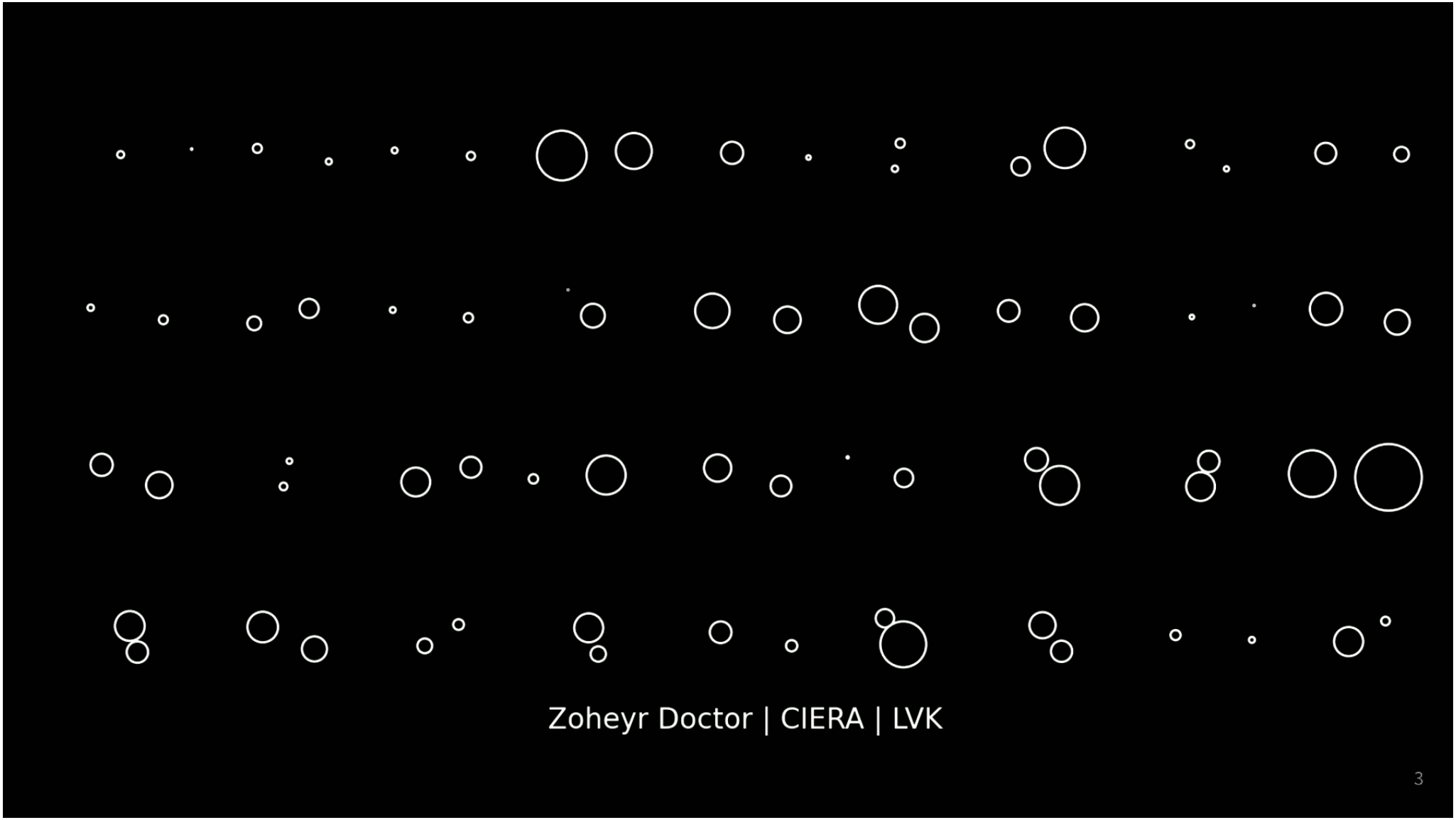
The Diverse Zoo of Gravitational-Wave Sources

Zoheyr Doctor
CIERA Board of Visitors Research Assistant Professor
PI Strong Gravity Seminar
March 7, 2024

Northwestern
CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

@actualdrdoctor

LIGO VIRGO KAGRA


Zoheyr Doctor | CIERA | LVK
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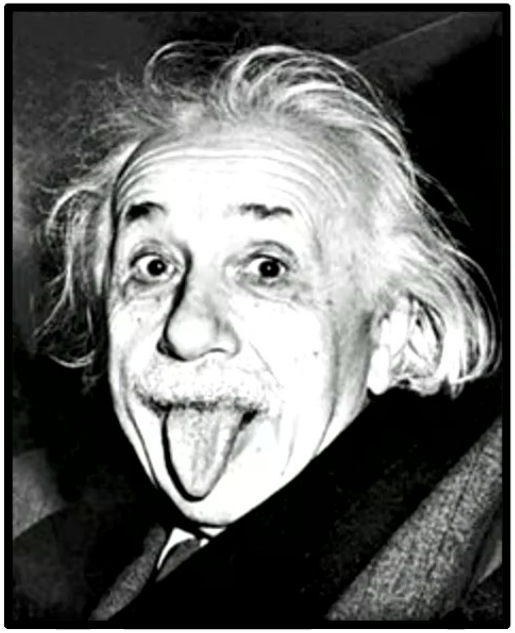

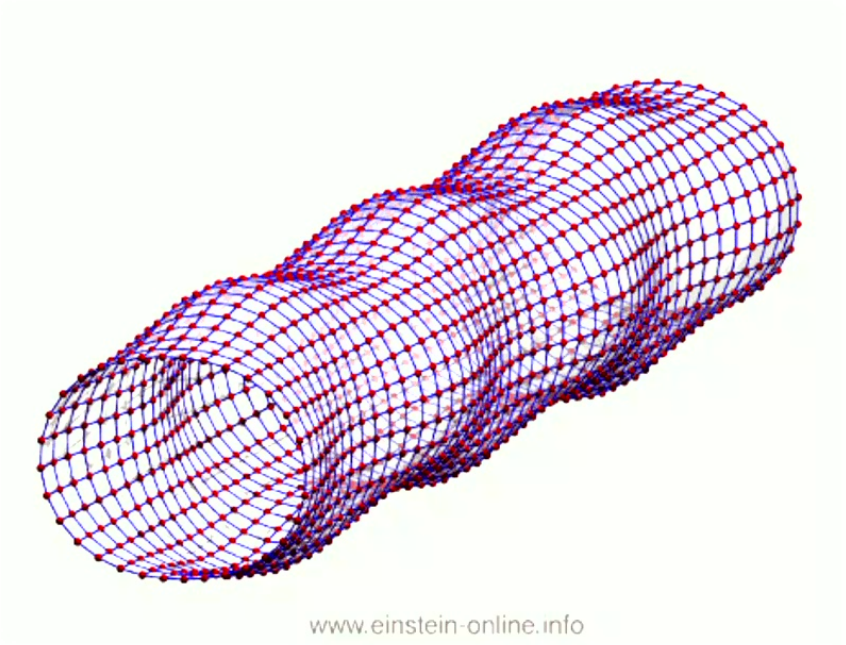
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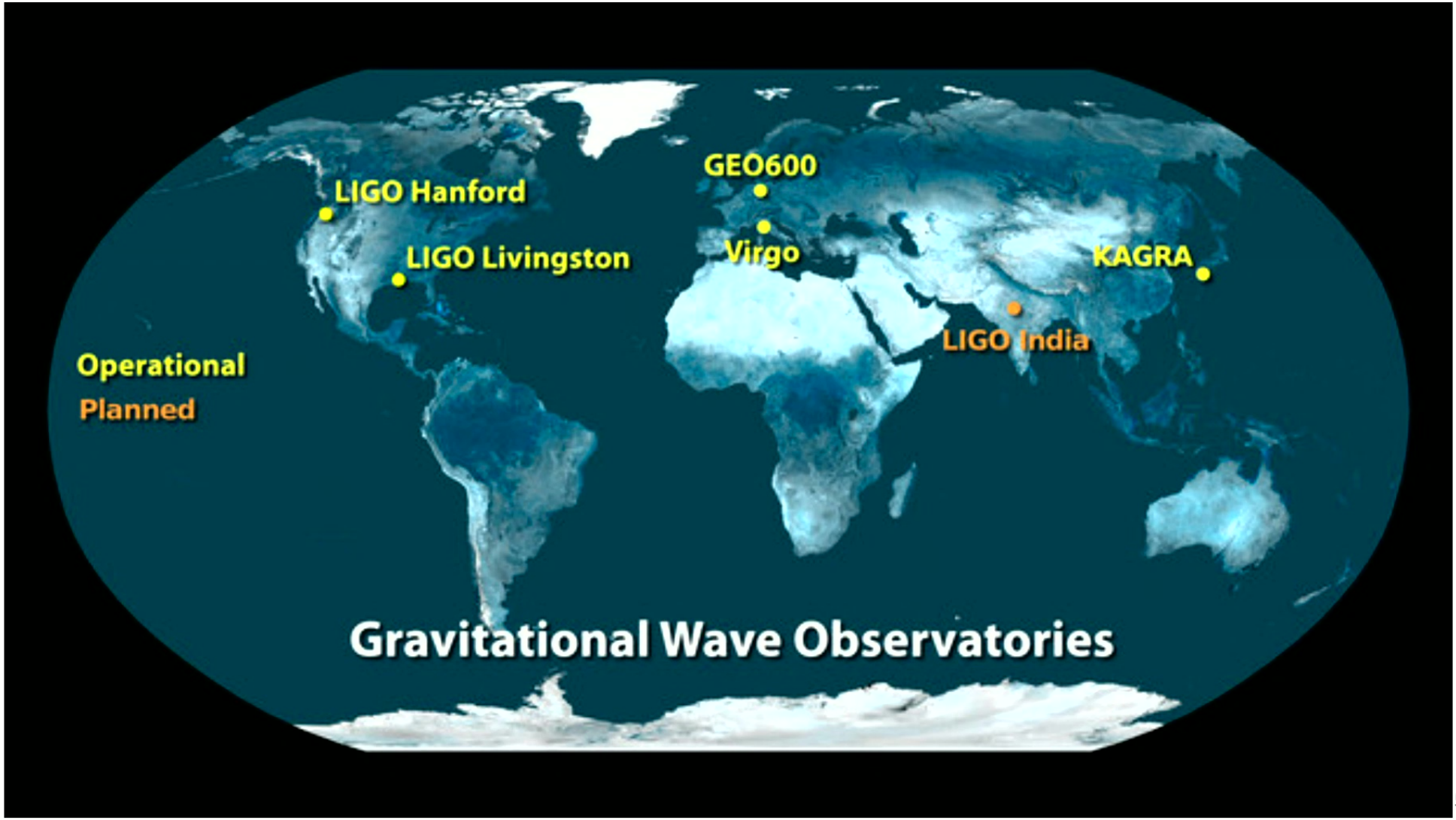
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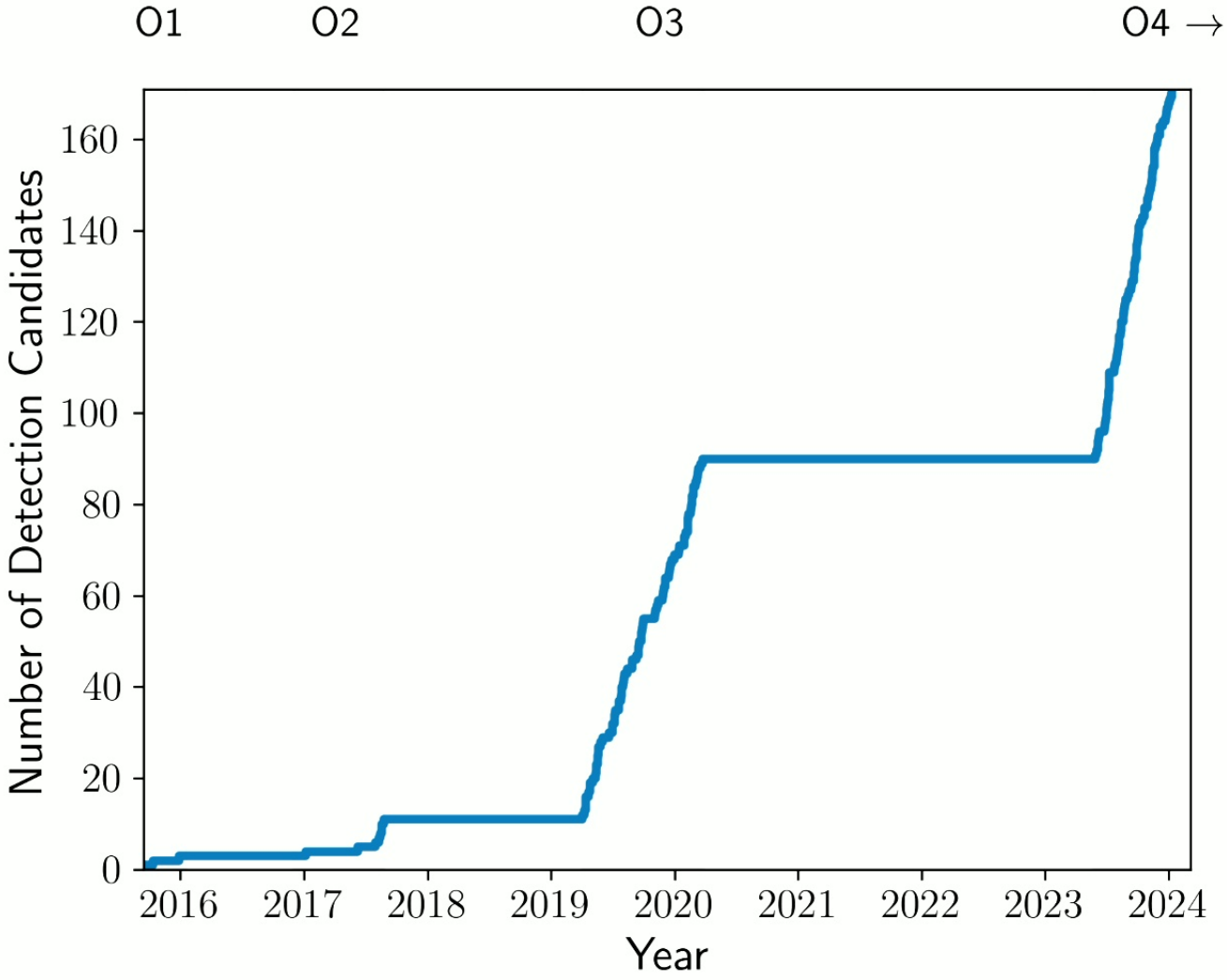
Operational
Planned
Gravitational Wave Observatories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Number of Detection Candidates
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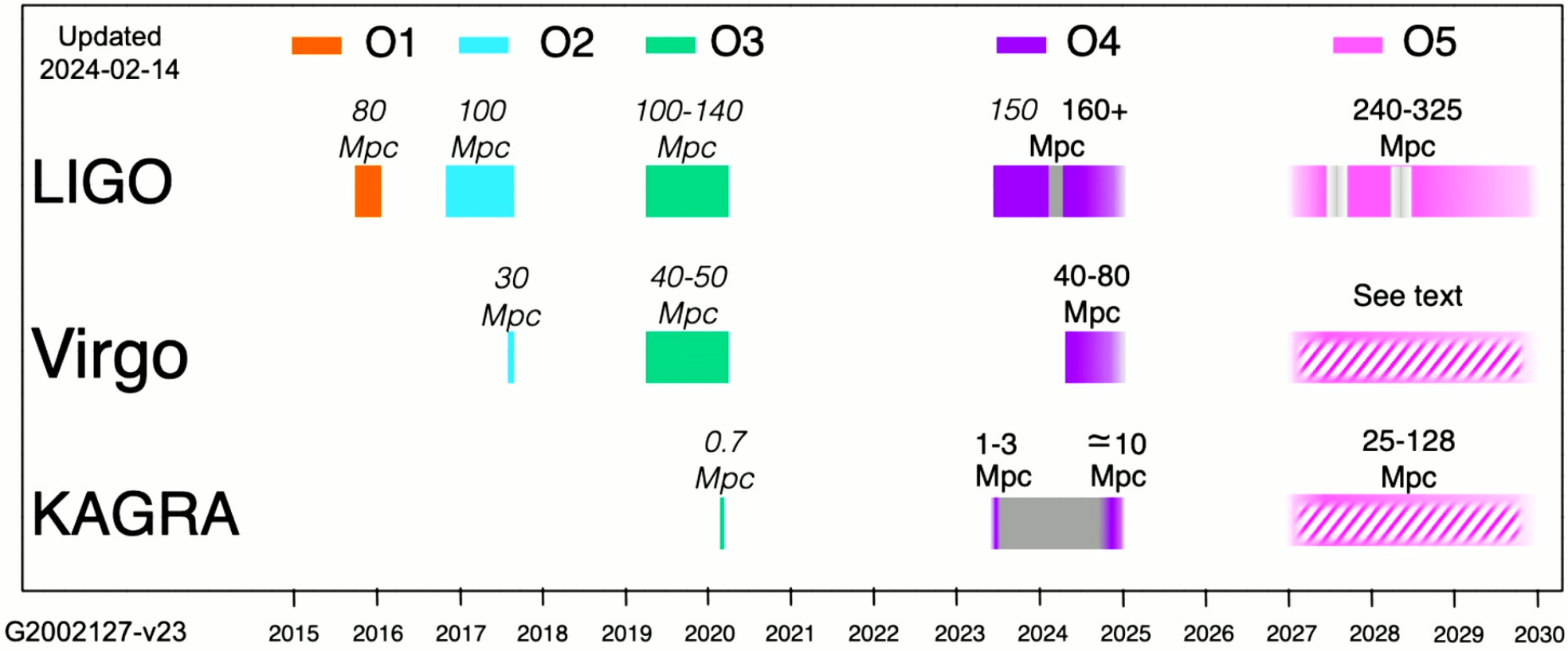
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80 Mpc
100 Mpc
100-140 Mpc
150 160+ Mpc
240-325 Mpc
Virgo
30 Mpc
40-50 Mpc
40-80 Mpc
See text
KAGRA
0.7 Mpc
1-3 Mpc
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25-128 Mpc
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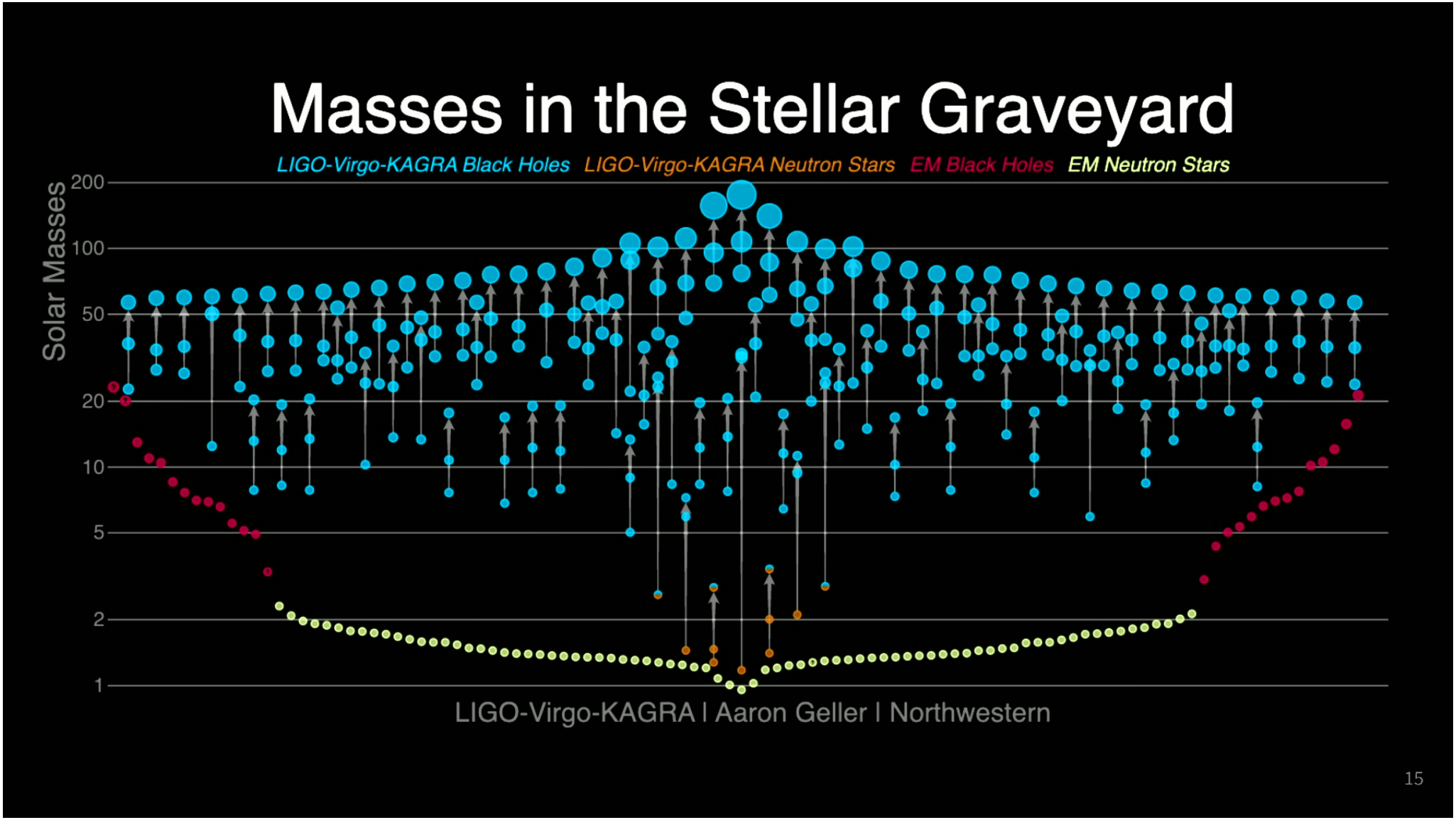

Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
EM Black Holes
EM Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern
15

October 12, 2020

AARON JONES

Post a Comment

January 19, 2021

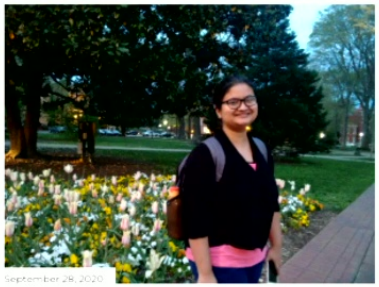
FRANCISCO LLAMAS

Post a Comment

May 27, 2020

ASHINI MODI

Post a Comment



September 28, 2020

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JOCELYN READ

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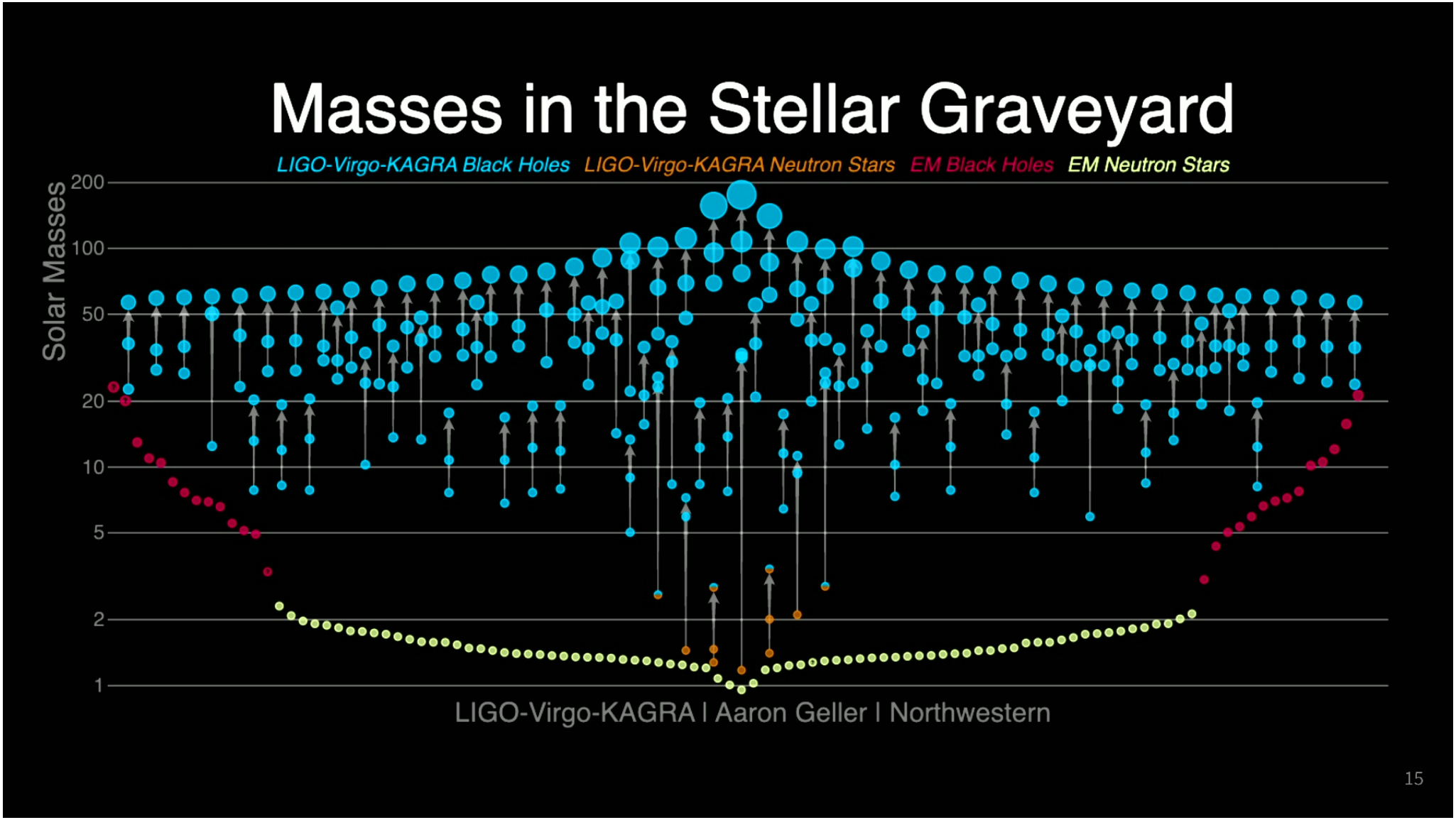
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LIGO-Virgo-KAGRA | Aaron Geller | Northwestern
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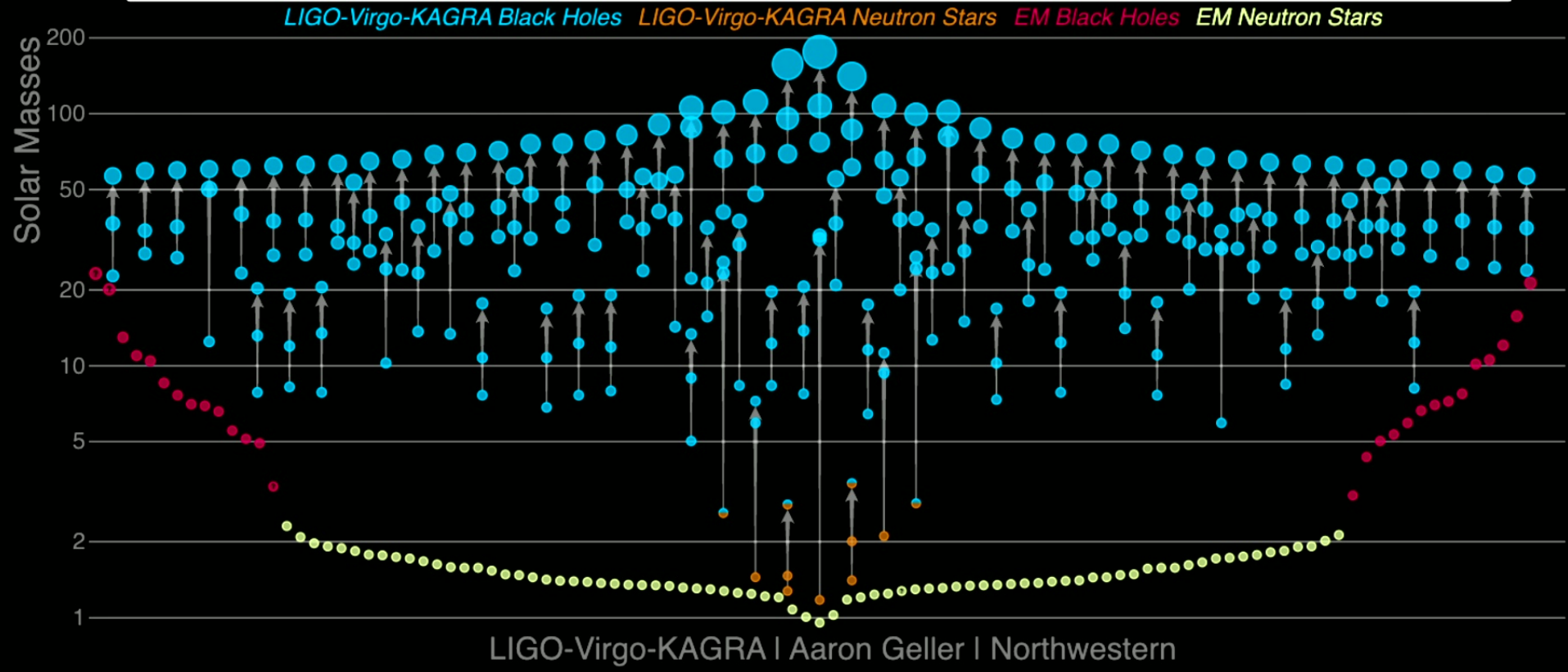
Why this observed distribution of compact objects?



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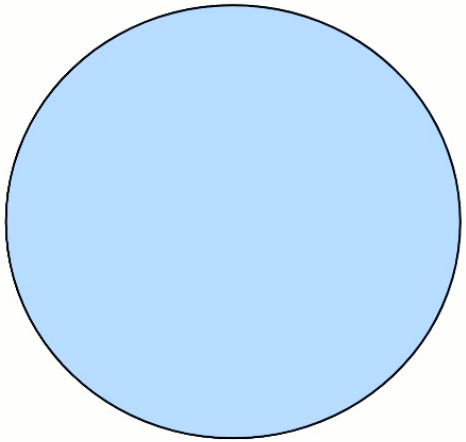
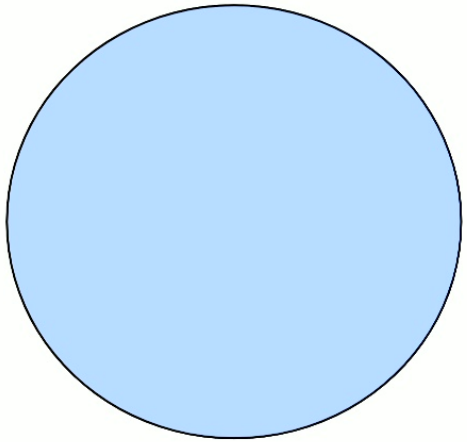
How are compact-object mergers produced?

What DOESN’T Work…





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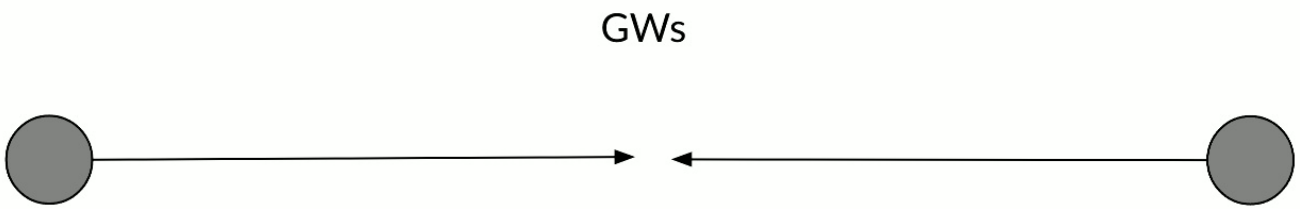

The Big Mystery…

Peters (1964):

$$a = \left(\frac{64 G^3}{5 c^5} M^3 t_{\mathrm{merge}} \right)^{\frac{1}{4}}$$

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$$a = \left(\frac{64G^3}{5c^5} M^3 t_{\rm merge}\right)^{\frac{1}{4}} \sim 50\,{\rm R}_\odot \left(\frac{M}{60\,{\rm M}_\odot}\right)^{\frac{3}{4}} \left(\frac{t_{\rm merge}}{14\,{\rm Gyr}}\right)^{\frac{1}{4}}$$

The Big Mystery…

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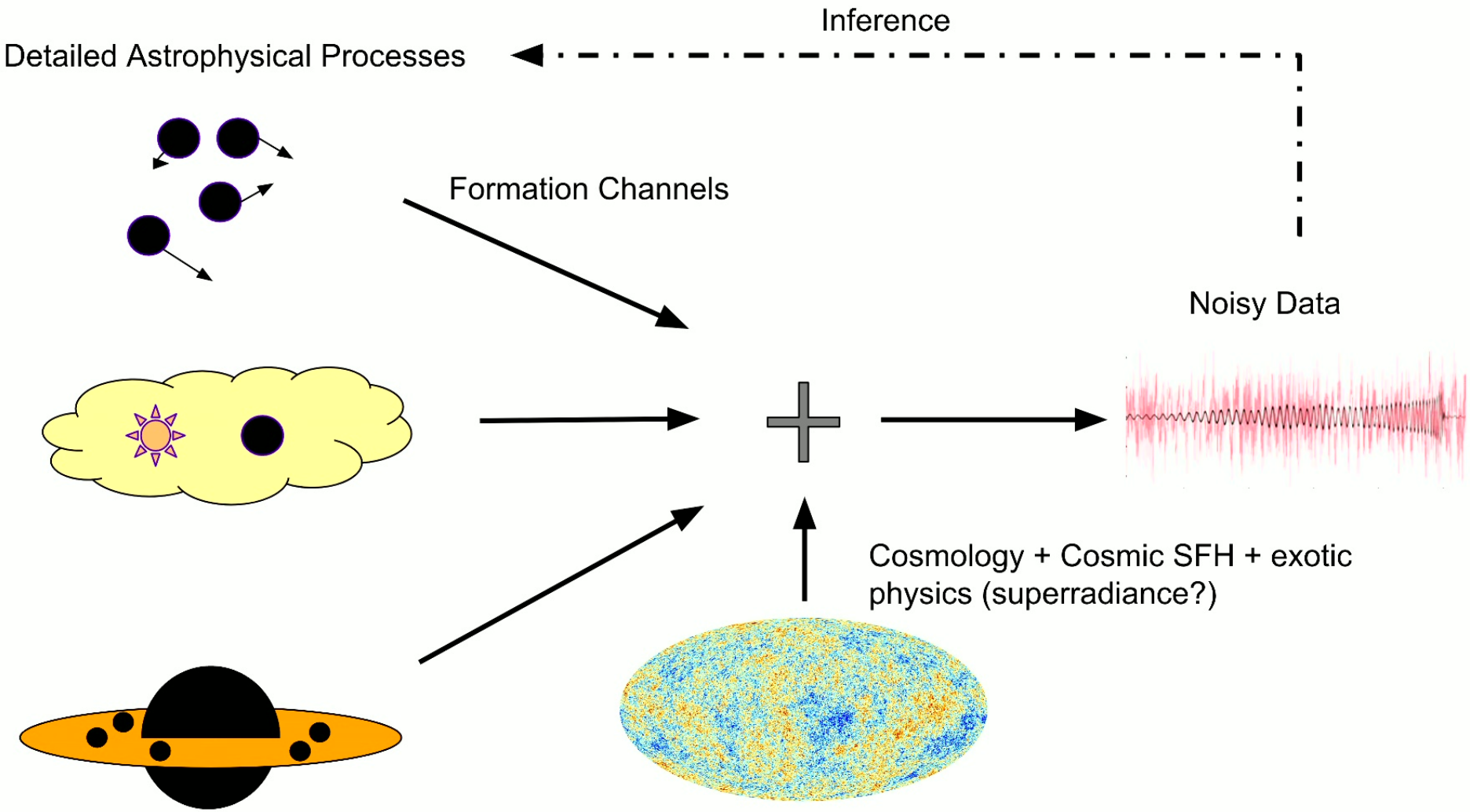
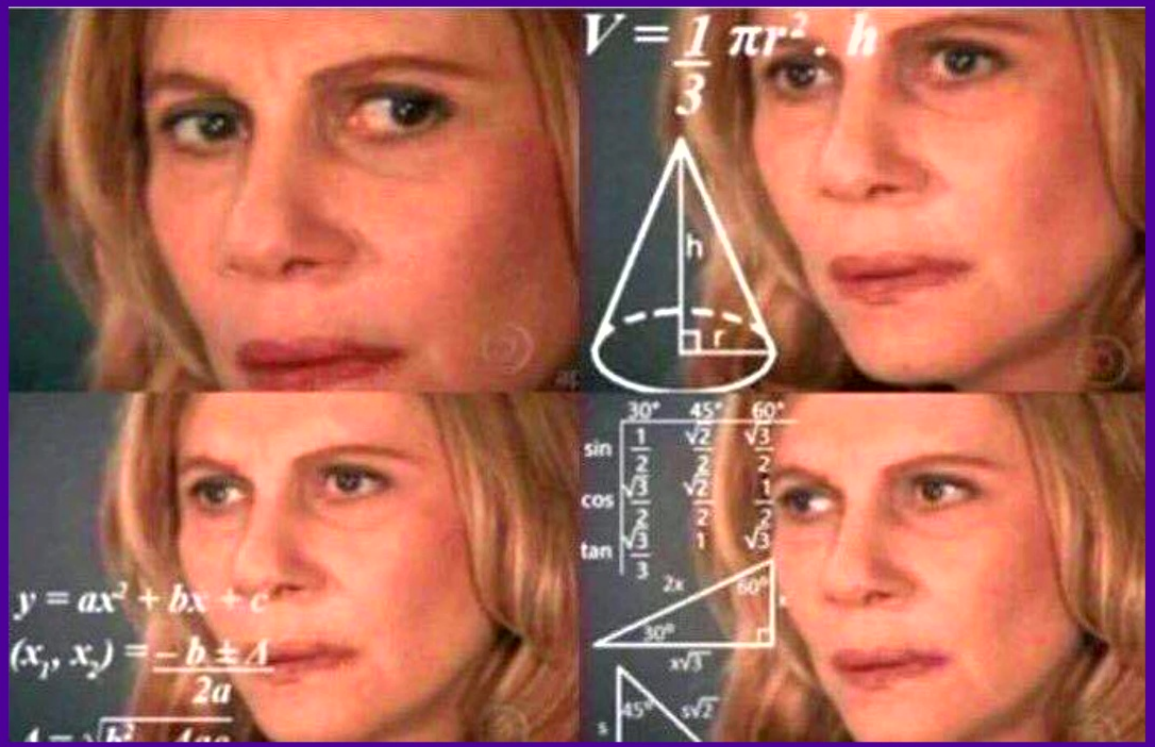
To merge stellar-mass COs in a Hubble time, they must be closer than the radii of their progenitor stars!

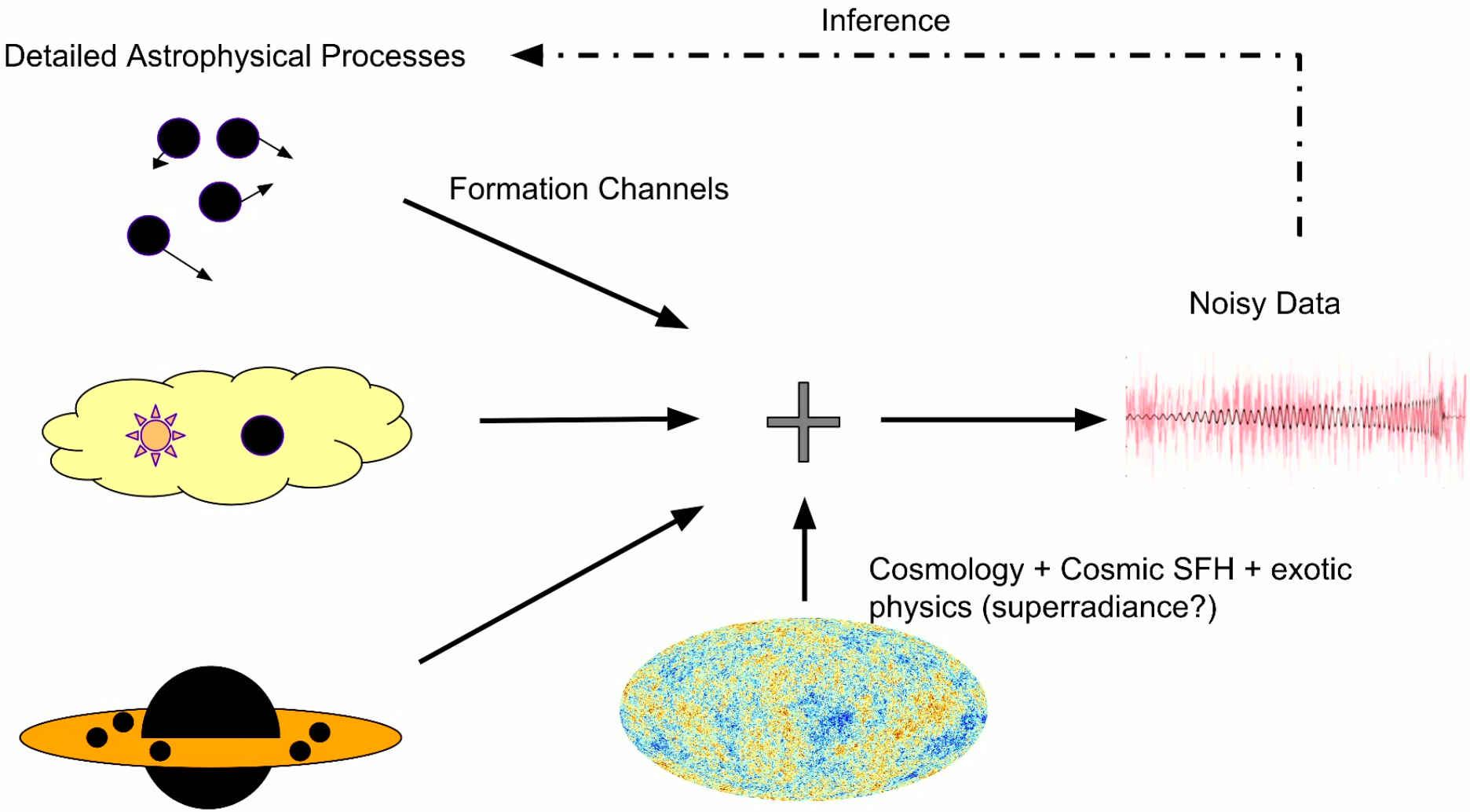

Inference
Detailed Astrophysical Processes
Formation Channels
Noisy Data
Cosmology + Cosmic SFH + exotic physics (superradiance?)

High-Dimensional Source Parameter Space!

Noisy Data!

Systematic Uncertainties!




Inference
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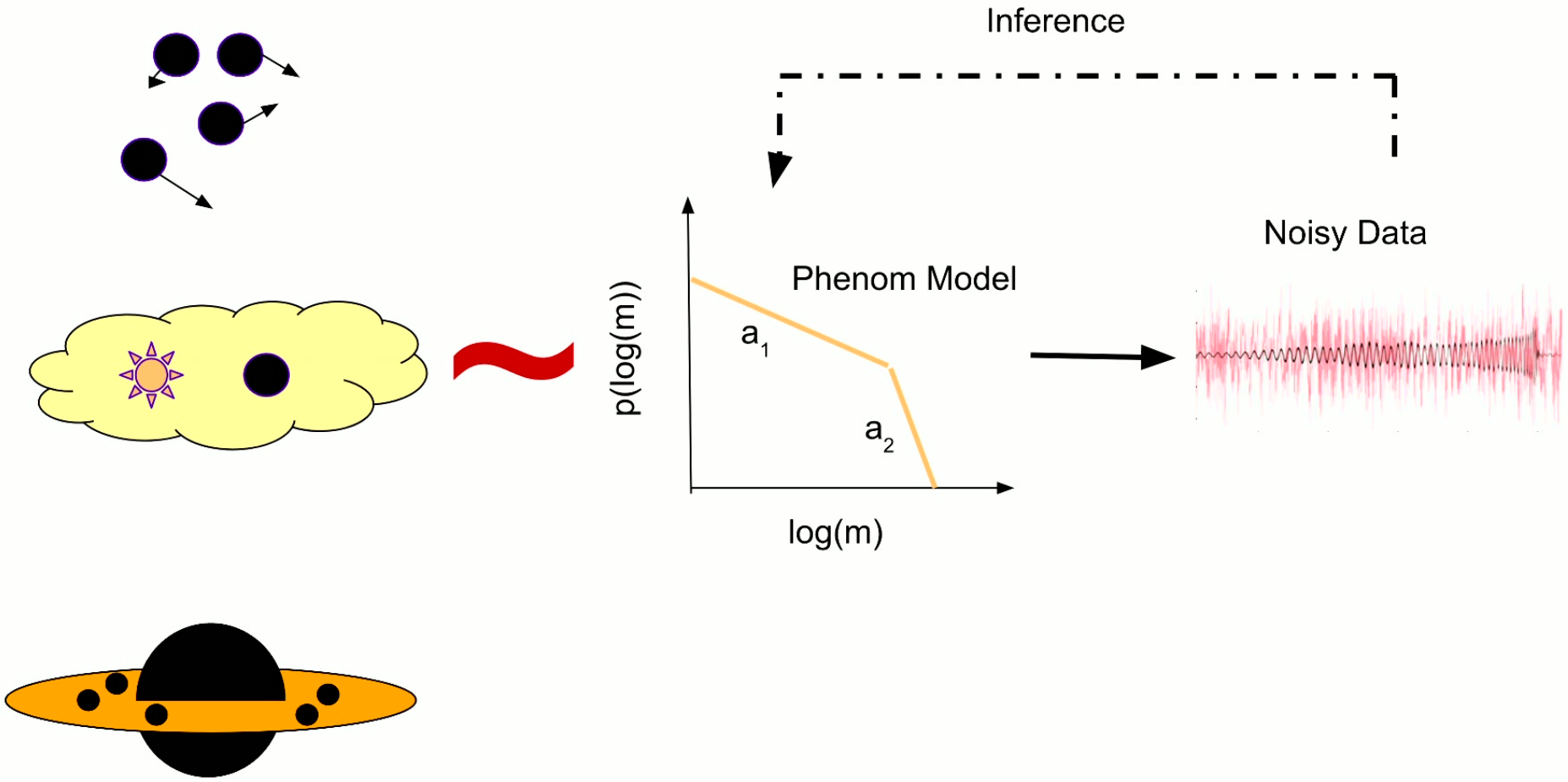
Cosmology + Cosmic SFH + exotic physics (superradiance?)

Detailed Astrophysical Processes



Simple Models

- Targeted questions (e.g. mass gaps)
- Easy to write down (e.g. power laws)
- Somewhat agnostic to astrophysical details
- Could miss important features

Detailed Astrophysical Models

- Can include our best understanding of BHs + interactions
- Can be tuned via other data sets
- Hard to write down
- Many parameters
- Possible systematic errors

Data-Driven Models

- Find unexpected features in the population
- Corroborate results of simple models
- Compare with features in detailed models
- Black-box predictions

Simple Models

Fishbach & Holz (2017)
Talbot & Thrane (2018)
Wysocki, Lange, and O'Shaughnessy (2019)
Doctor et al (2020)
Kimball et al (2021)
Landry & Read (2021)
Farah, Fishbach, Essick et al (2021)
…

Let’s use these different modeling approaches to study gravitational-wave populations!

Simple Models

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- Easy to write down (e.g. power laws)
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Detailed Astrophysical Models

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SYNERGY!

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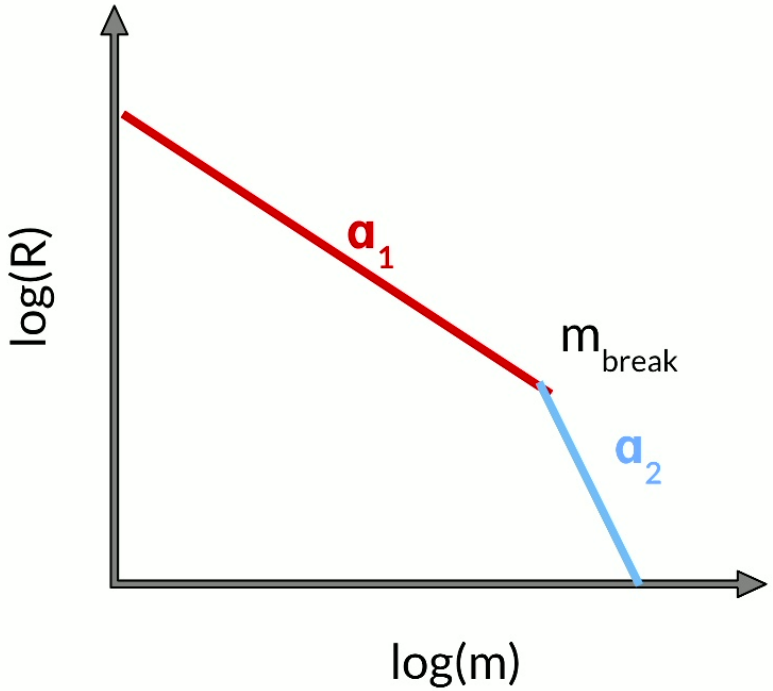
Does the mass distribution of black holes change with redshift?



Fishbach, **ZD**, et al. ApJ 912 98 (2021)

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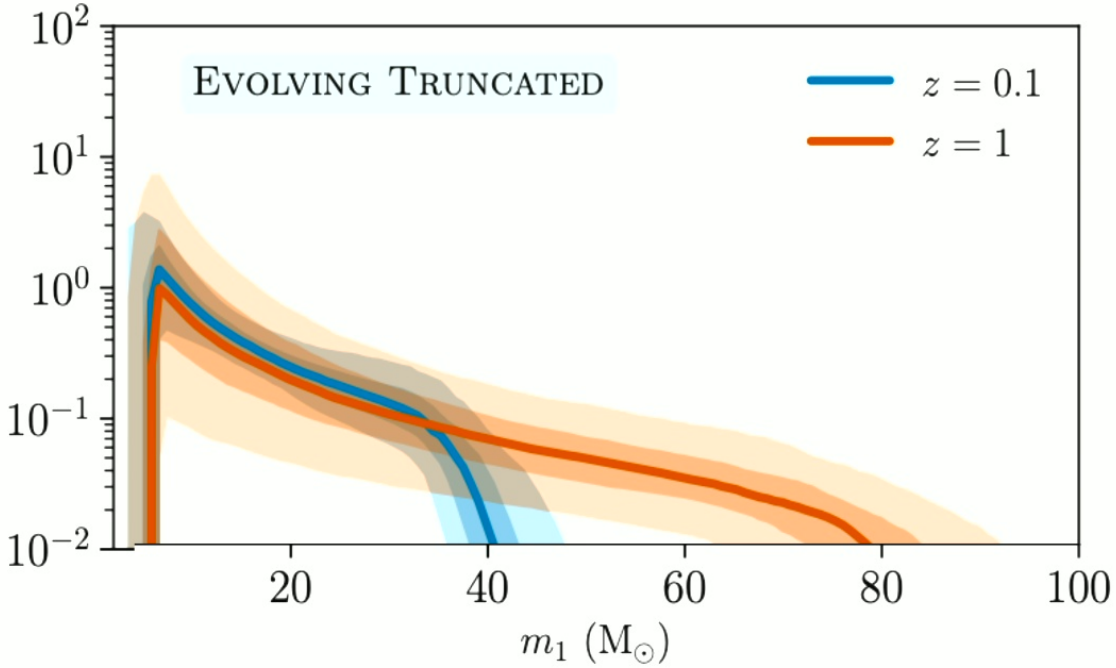

Fishbach, **ZD**, et al. ApJ 912 98 (2021)

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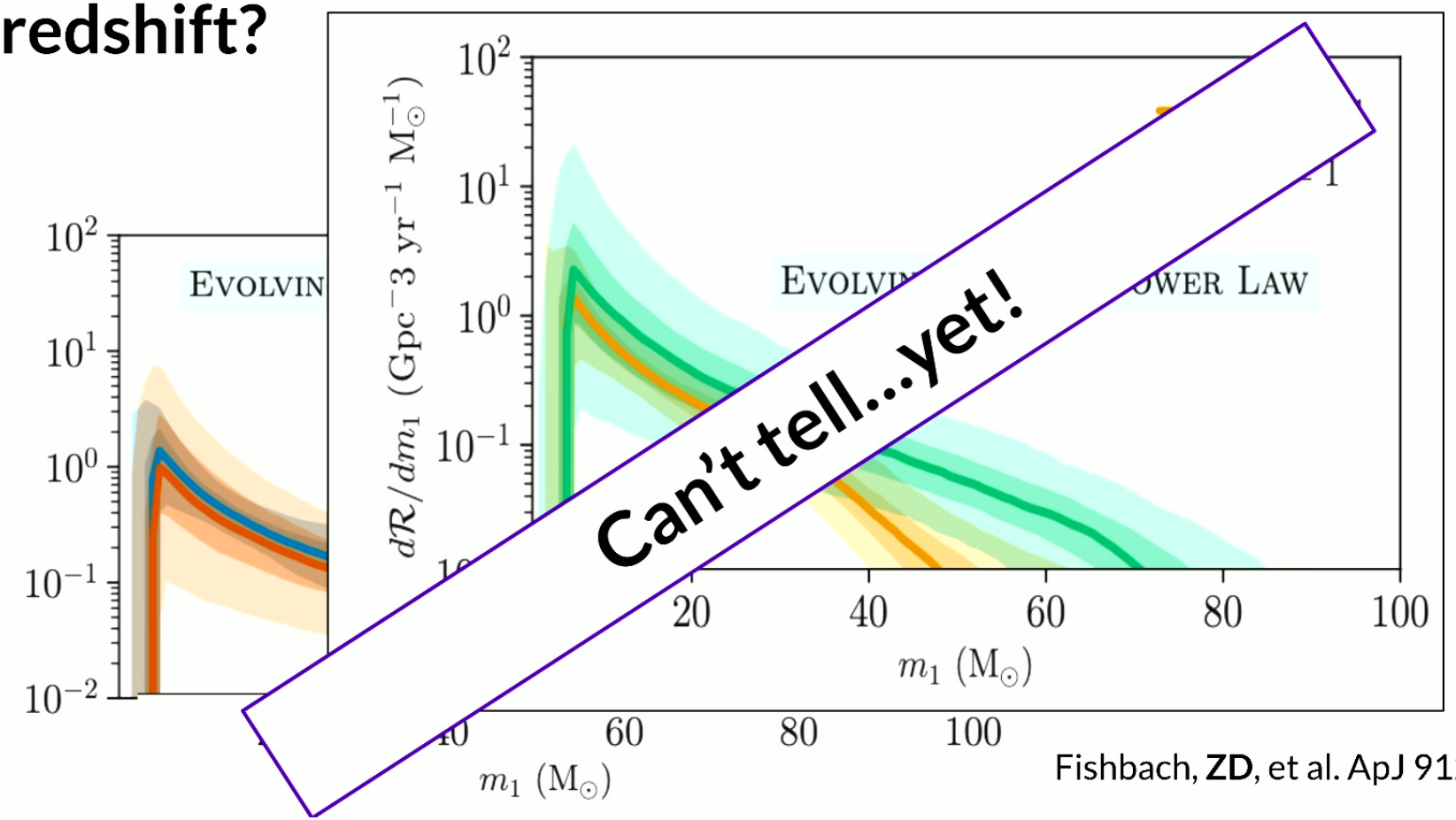
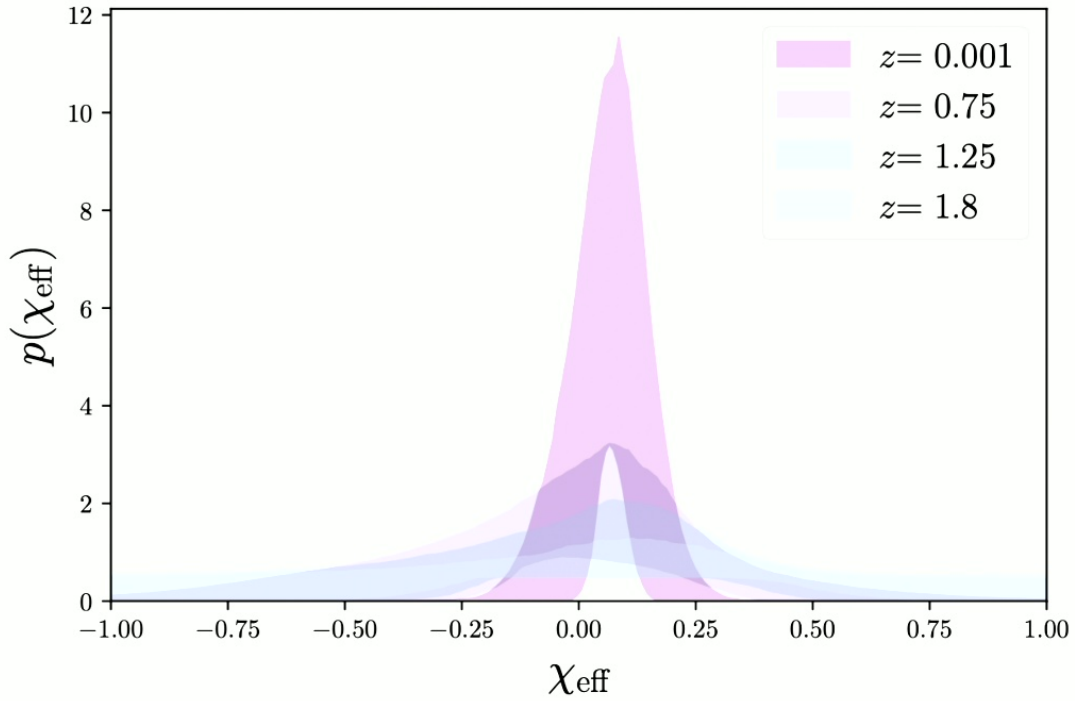


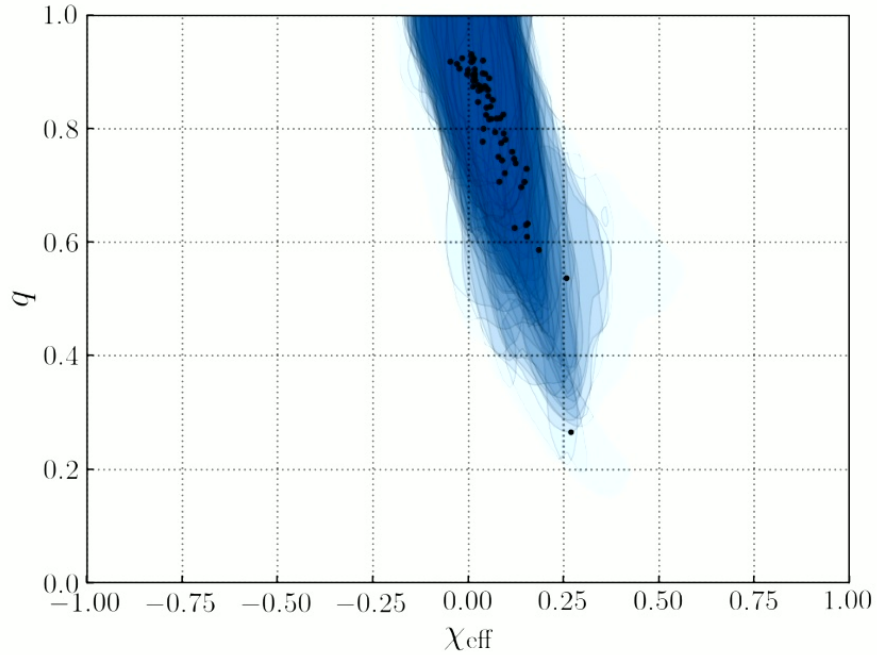
Fishbach, **ZD**, et al. ApJ 912 98 (2021)

But the spin distribution does vary with redshift…



Biscoveanu, Callister, Haster, et al ApJL 932 (2022) 2, L19

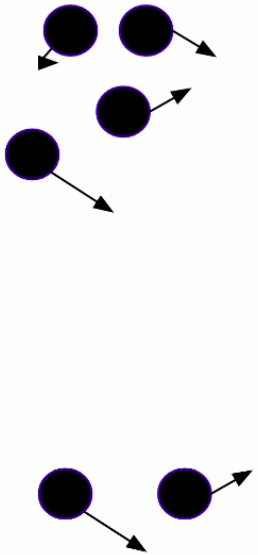
…and there is a correlation between spins and mass ratio!



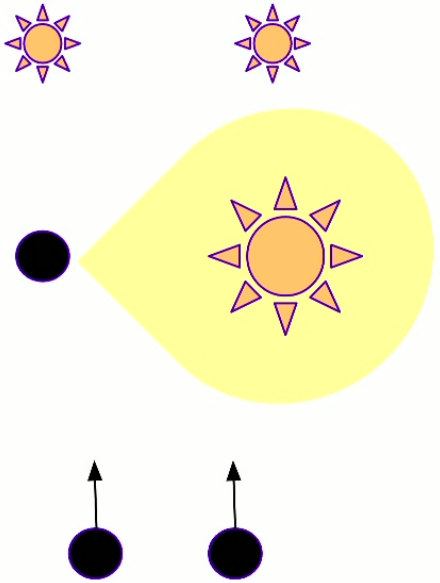
Callister, Haster, et al. ApJL 922 L5 (2021)
LVK PRX 13, 011048 (2023)

Do BH sub-populations of spin have different masses?

Dynamical Channel



Isolated Binary Channel



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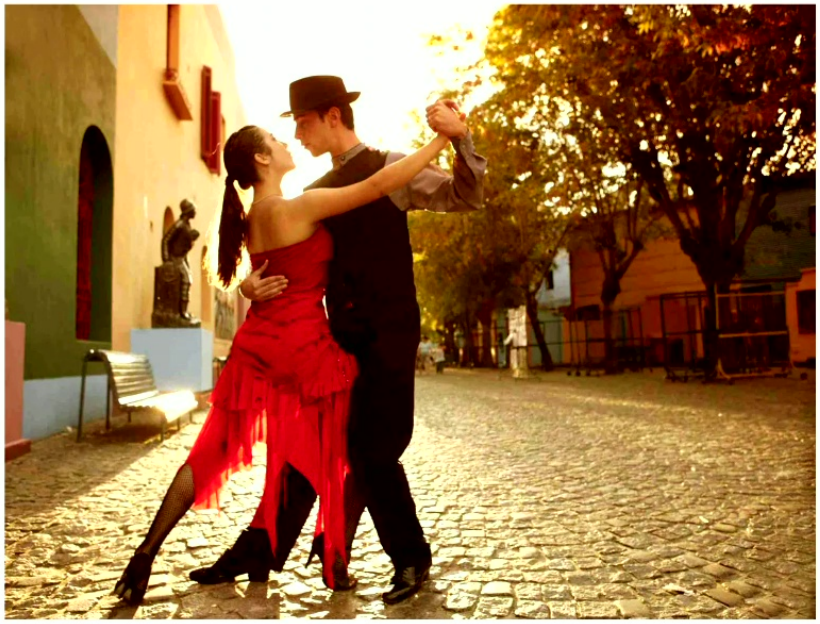

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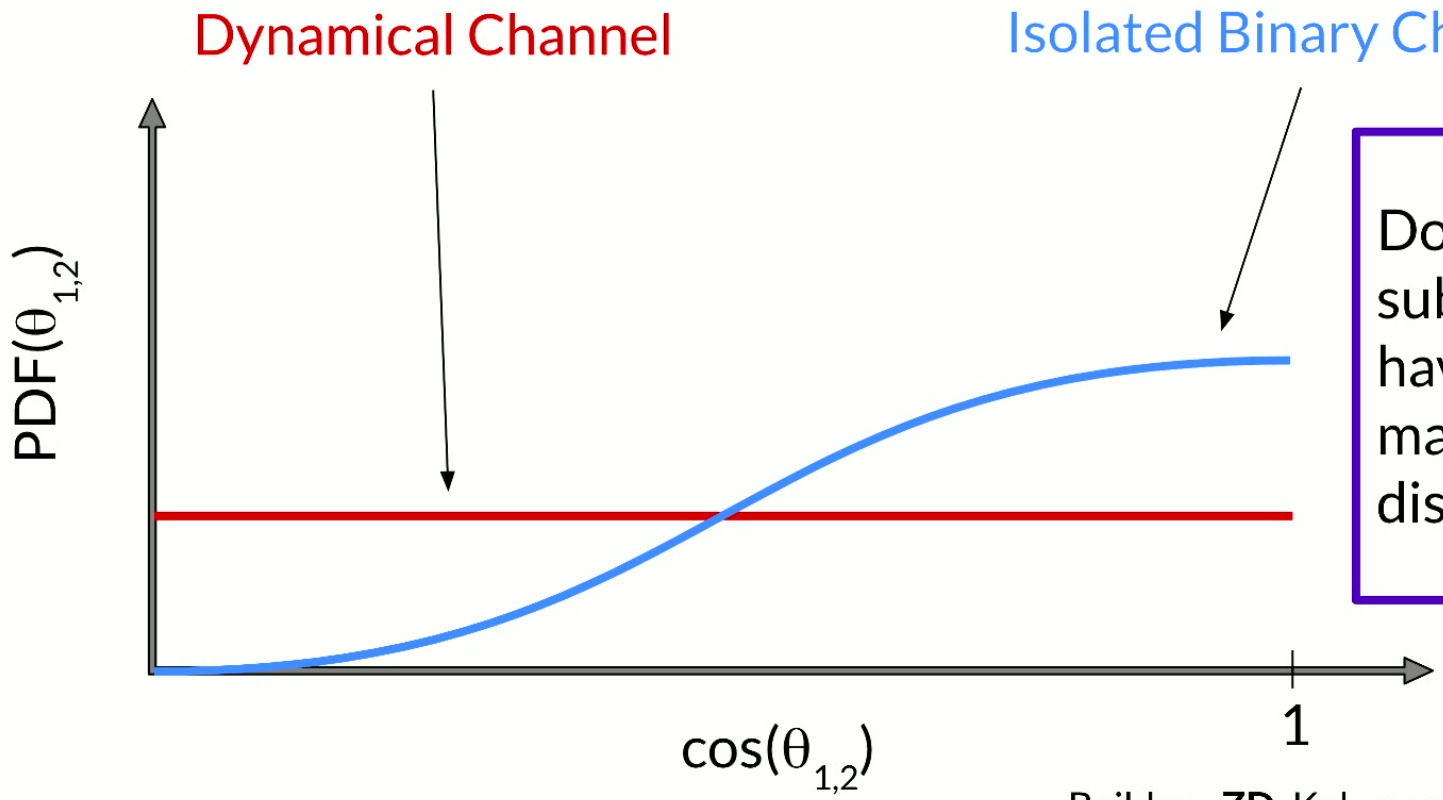
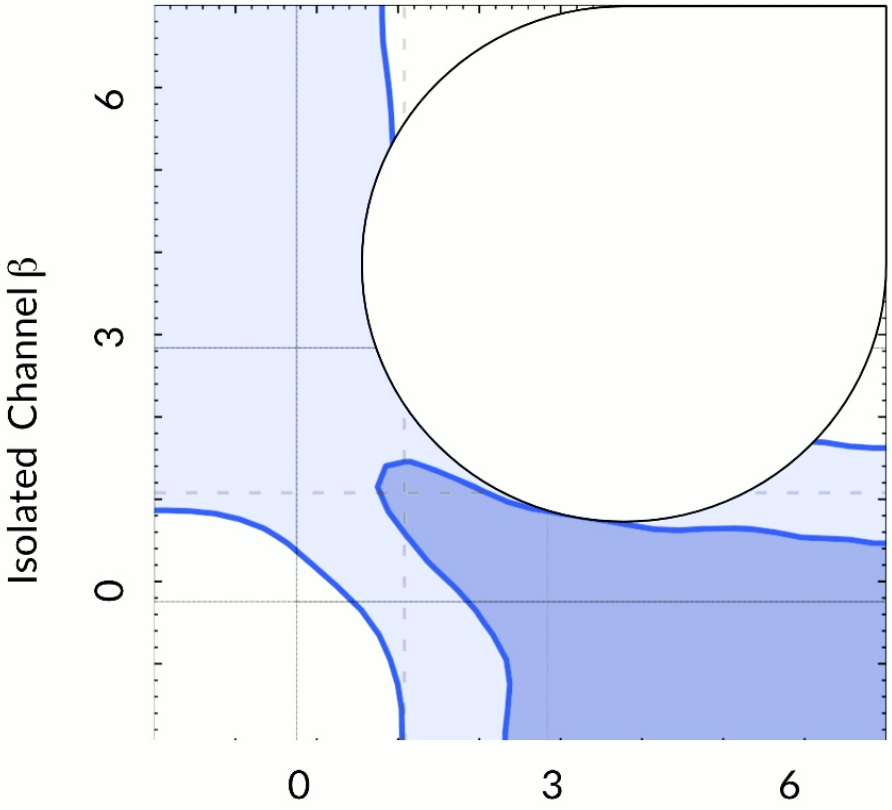


Do these putative sub-populations have different mass-ratio distributions?

Baibhav, **ZD**, Kalogera. ApJ 946 50 (2023)

Do BH sub-populations of spin have different masses?



$$p(q) \sim q^{\beta}$$

CIERA Fellow
Vishal Baibhav

Baibhav, **ZD**, Kalogera. ApJ 946 50 (2023)

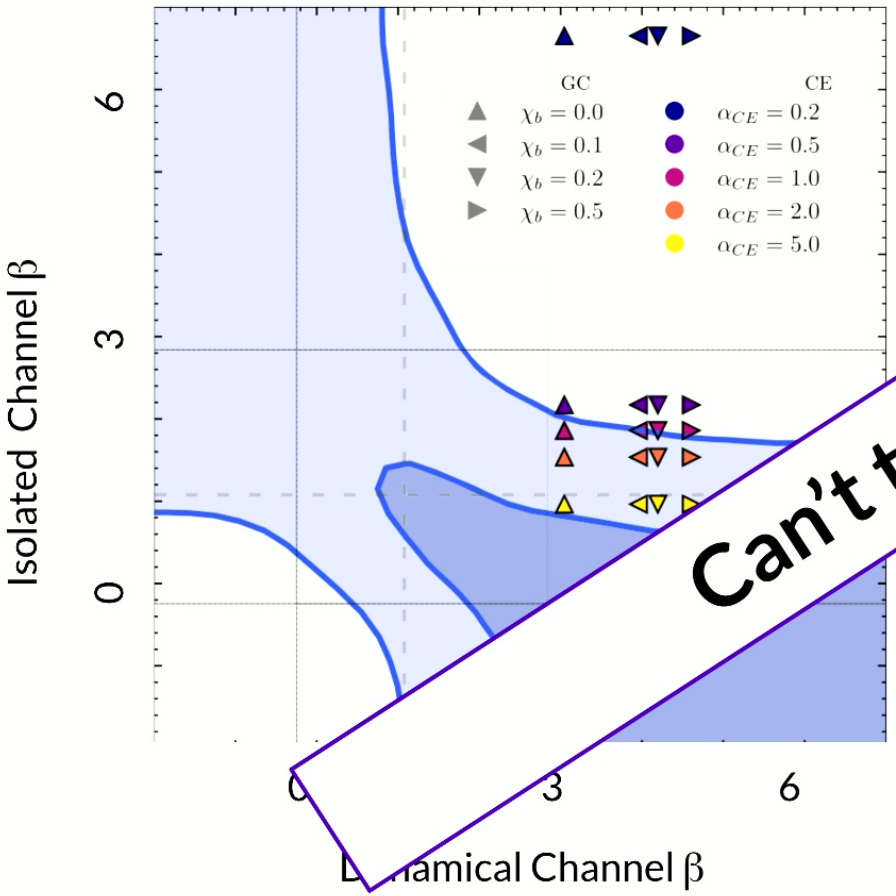
The Stochastic GW Background from NS Mergers

Darsan S. Bellie
NSF Graduate Fellow

Dr. Sharan Banagiri
CIERA Fellow

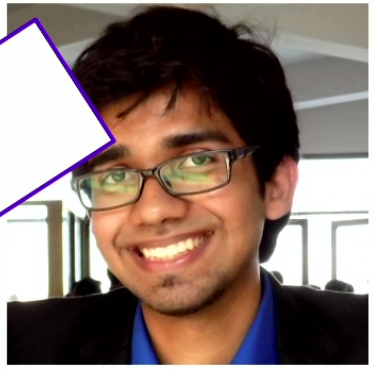
Bellie, Banagiri, **ZD**, Kalogera. arXiv: 2310.02517 (2023)

Do BH sub-populations of spin have different masses?



Can't tell...yet!

$p(q) \sim q^{\beta}$



CIERA Fellow
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Baibhav, **ZD**, Kalogera. ApJ 946 50 (2023)

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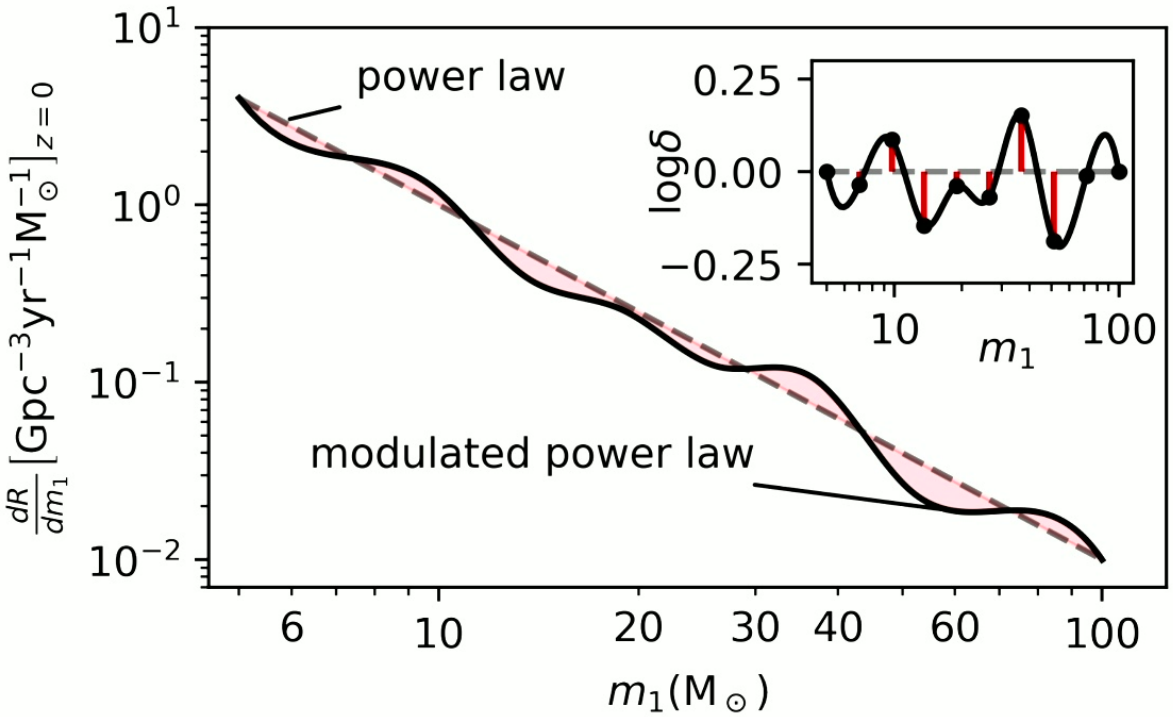
Bellie, Banagiri, **ZD**, Kalogera. arXiv: 2310.02517 (2023)

Data-Driven Models

Mandel et al (2016)
Farr et al (2018)
Powell et al (2019)
Tiwari (2021)
Rinaldi et al (2021)
Sadiq et al (2021)
Godfrey et al (2023)
…

Is there structure in the BBH mass distribution?



Edelman, **ZD**, Godfrey, Farr. ApJ 946 16 (2022)

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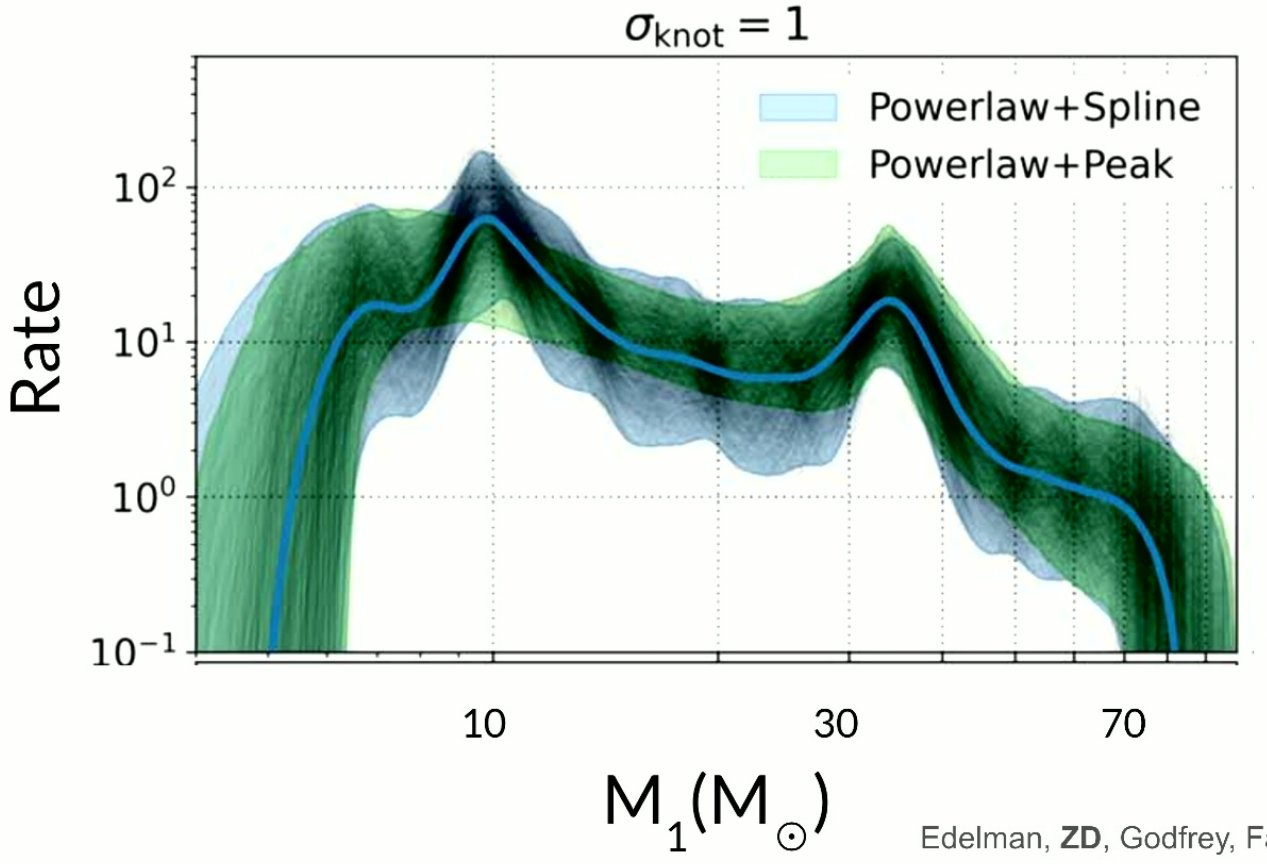
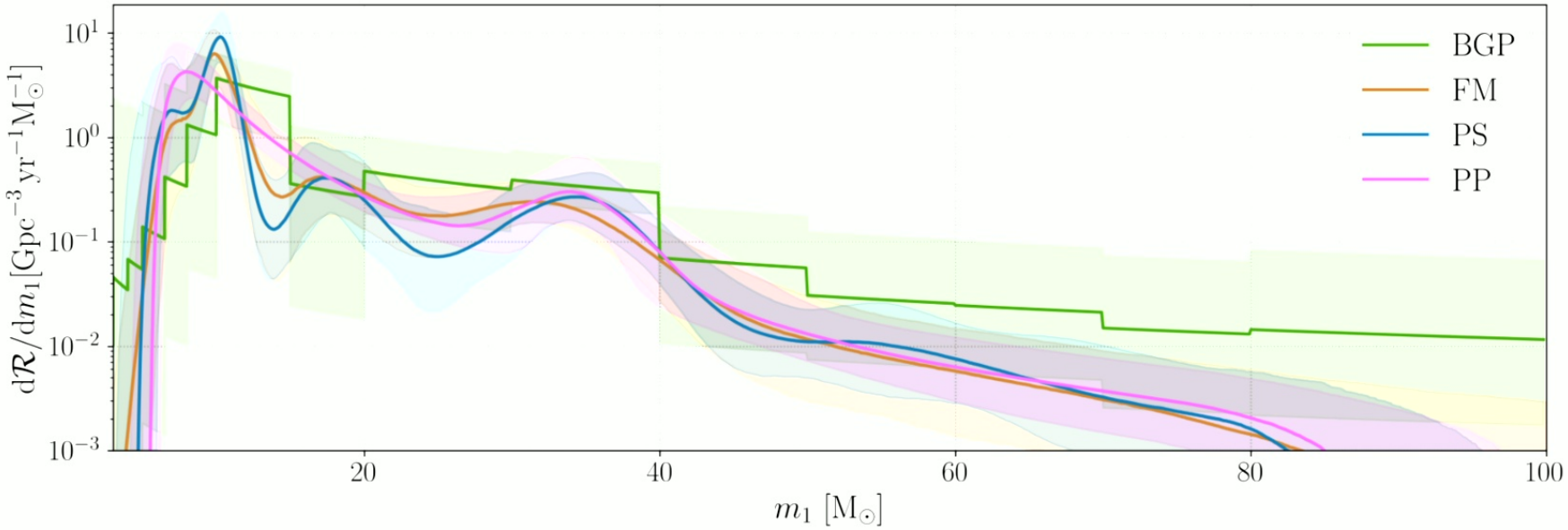


Bruce Edelman
Research Software Engineer
(UOregon)

Edelman, **ZD**, Godfrey, Farr. ApJ 946 16 (2022)

Is there structure in the BBH mass distribution?

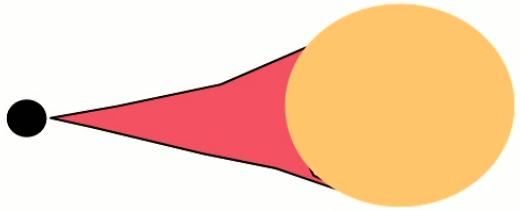
Other approaches find the same result



LVK PRX 13, 011048 (2023)

The Isolated Binary Channel

The Isolated Binary Channel



Modeling the Isolated Binary Channel

Ingredients:

- Binary stellar evolution + mass transfer
- Supernovae / Stellar collapse
- Initial conditions
- Selection effects

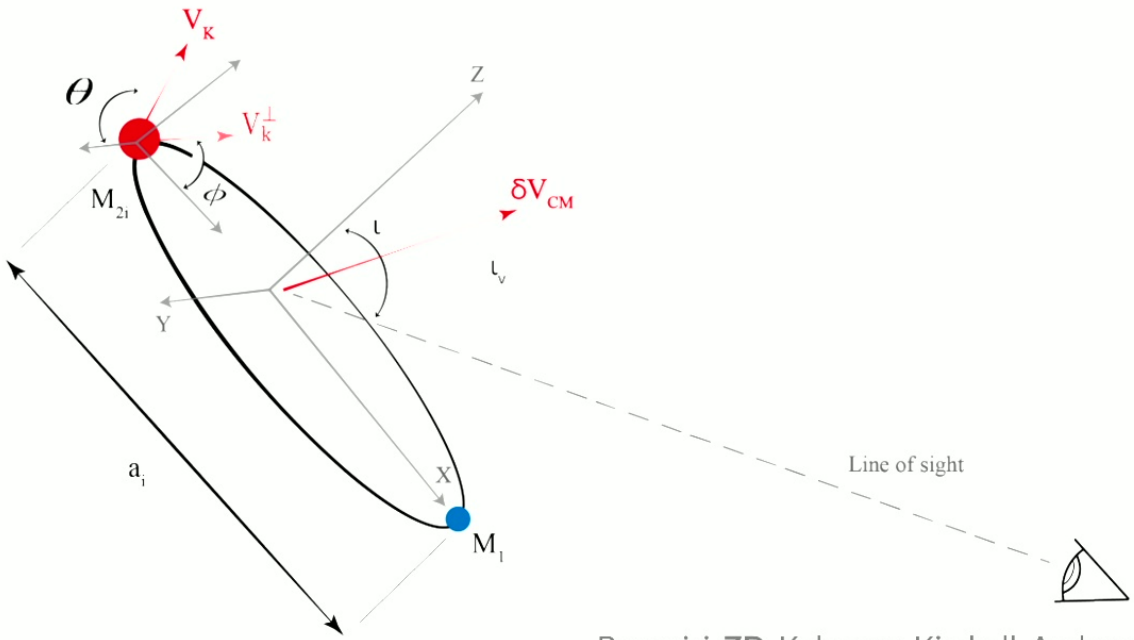
Observables:

- GWs
- X-ray binaries
- Wide binaries with a luminous companion
- Supernovae

Images generated with Midjourney

Supernova Kicks to Black Holes

- Do black holes experience asymmetric kicks from the collapse of their progenitor stars?



Banagiri, **ZD**, Kalogera, Kimball, Andrews. ApJ 959 106 (2023)

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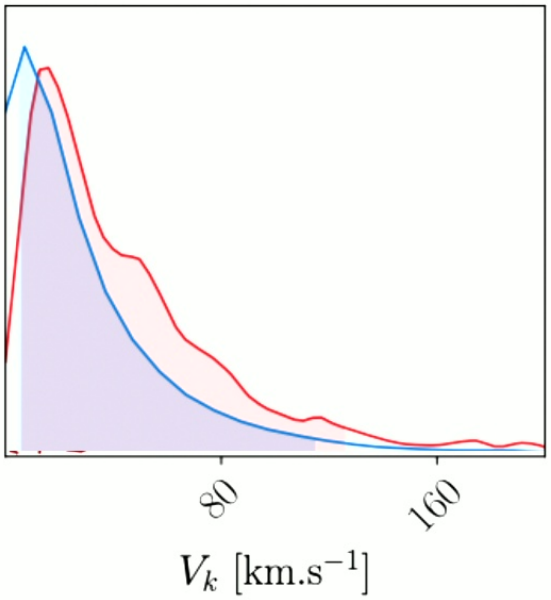
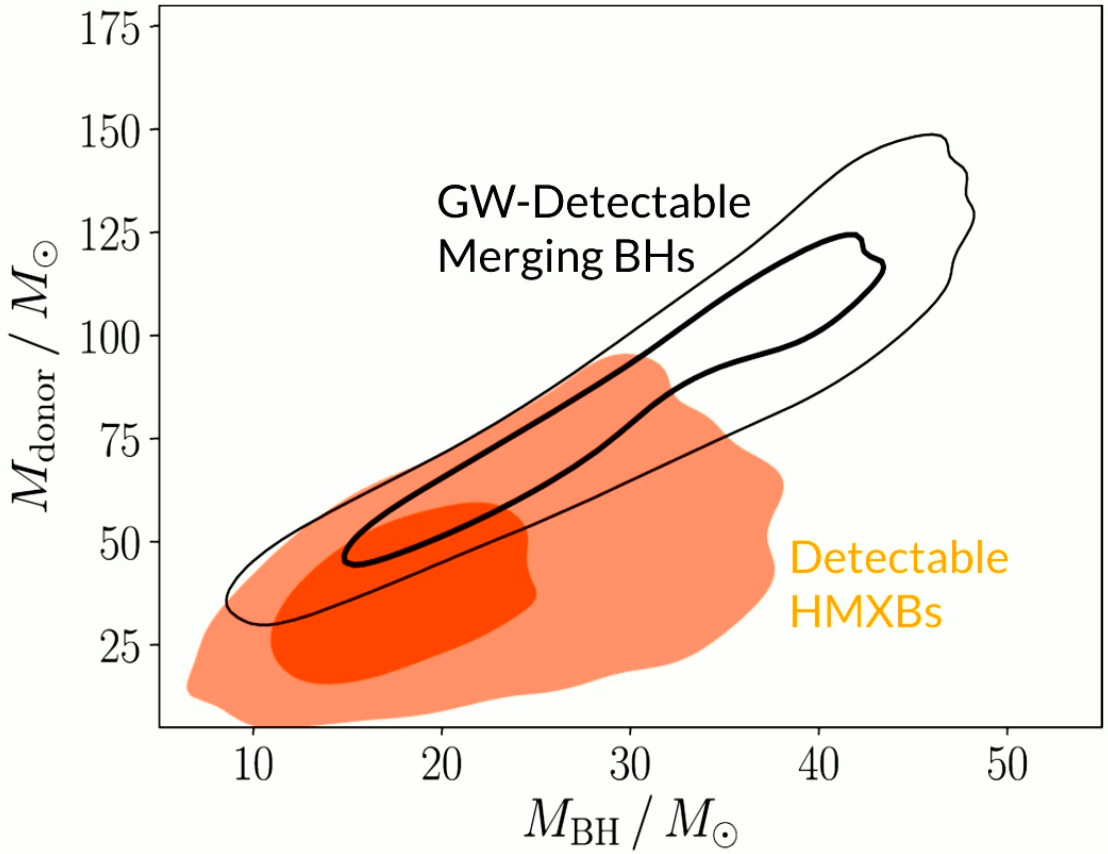


Small or zero BH kick inferred for wide binary VFTS 243 in LMC

Dr. Sharan Banagiri
CIERA Fellow

Banagiri, **ZD**, Kalogera, Kimball, Andrews. ApJ 959 106 (2023)

How do merging BH masses compare to those in HMXBs?



Camille Liotine (CIERA grad)

Liotine, Zevin, Berry, **ZD**, Kalogera (2023)

Remarks

- Multiple population modeling approaches enable us to understand CO mergers from different angles
- Detailed models: Incorporate our full astrophysical picture, but expensive and many systematics
- Simple parametric models: Empirically test specific questions
- Data-driven models: Look for the unexpected
- Team effort! A rich set of problems for everyone to get involved in
    - Stars, dynamics, statistics, machine learning, detectors and instrumentation…