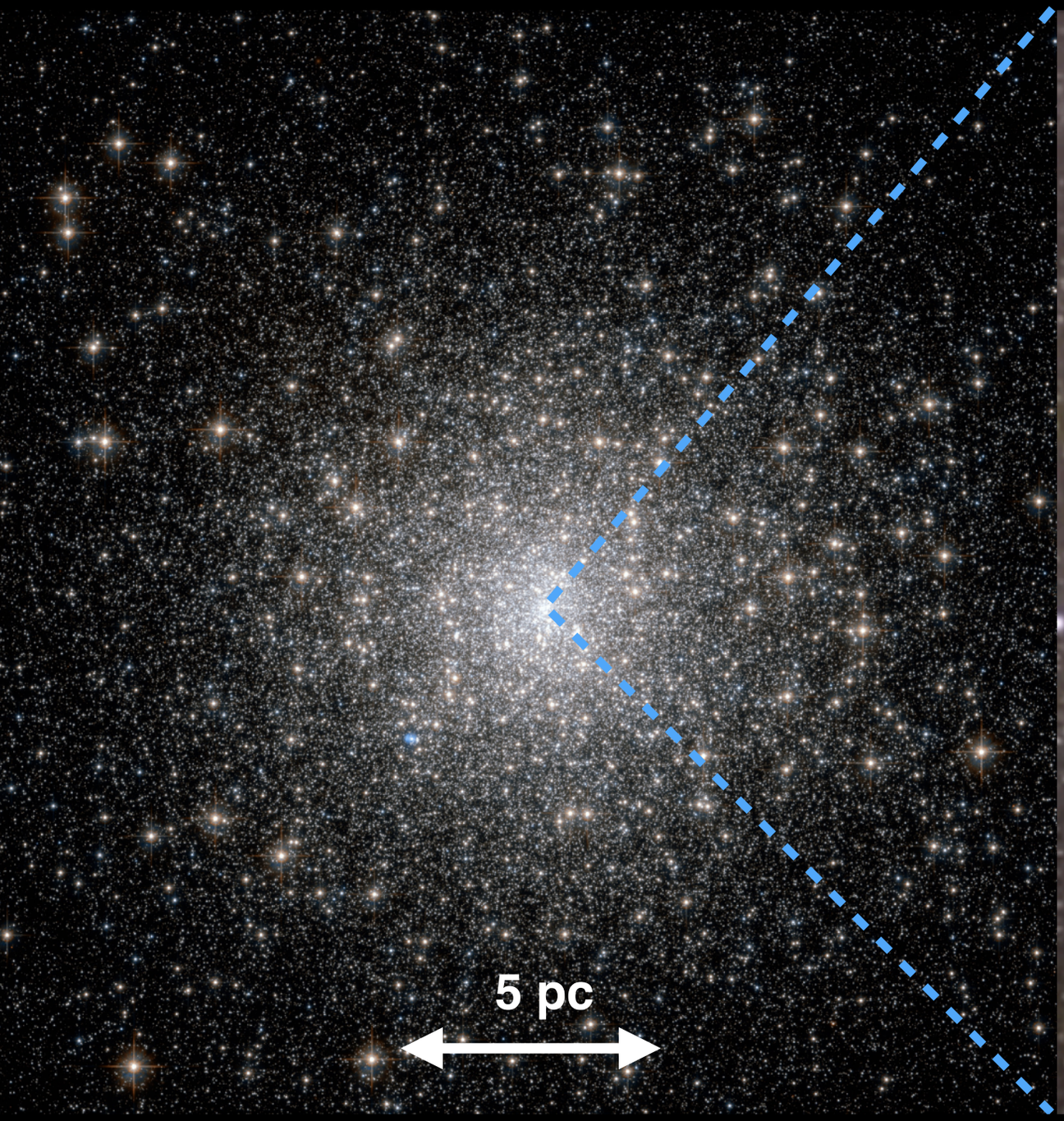
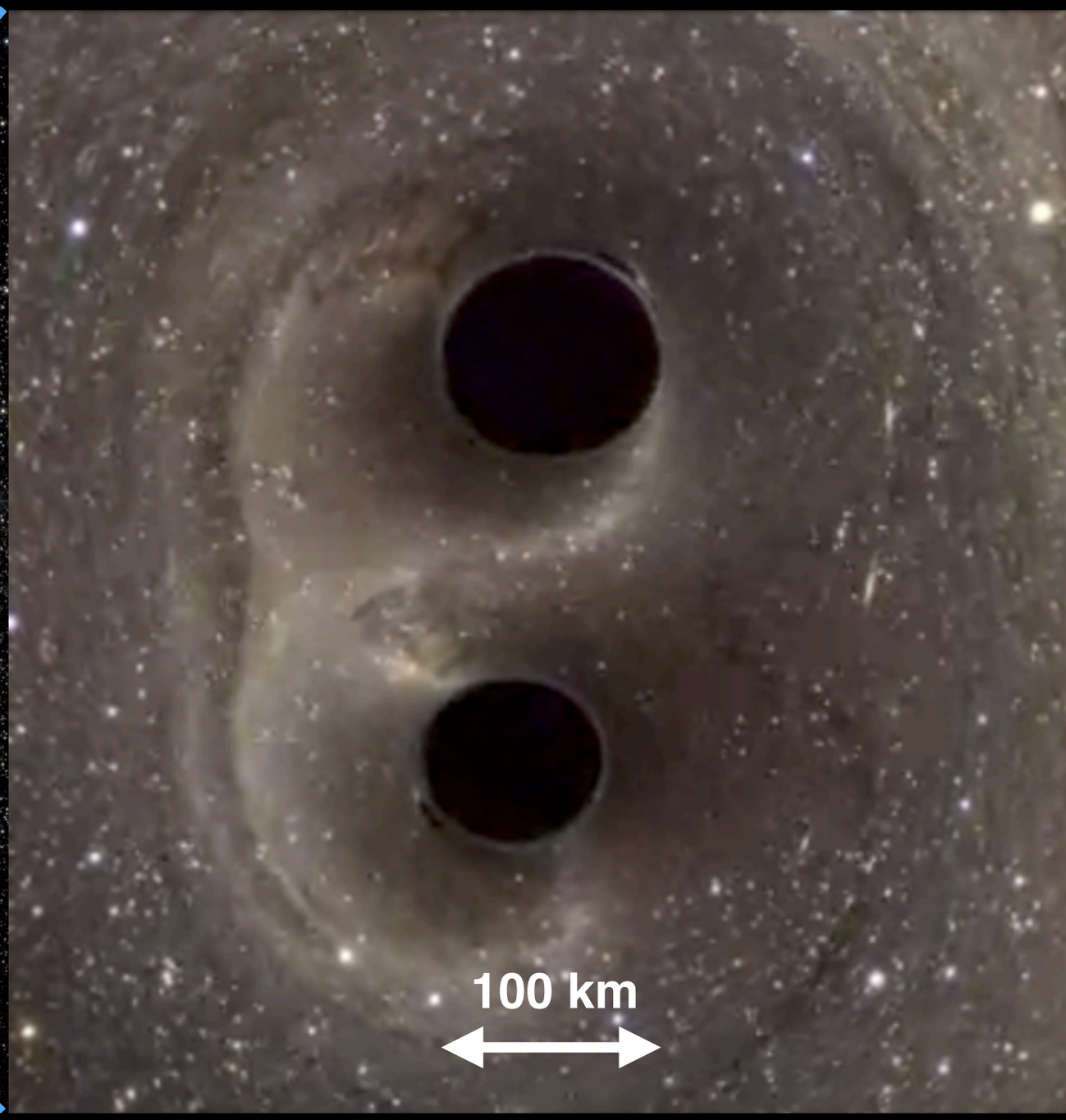
Binary black holes: from formation to coalesence

Mark Gieles

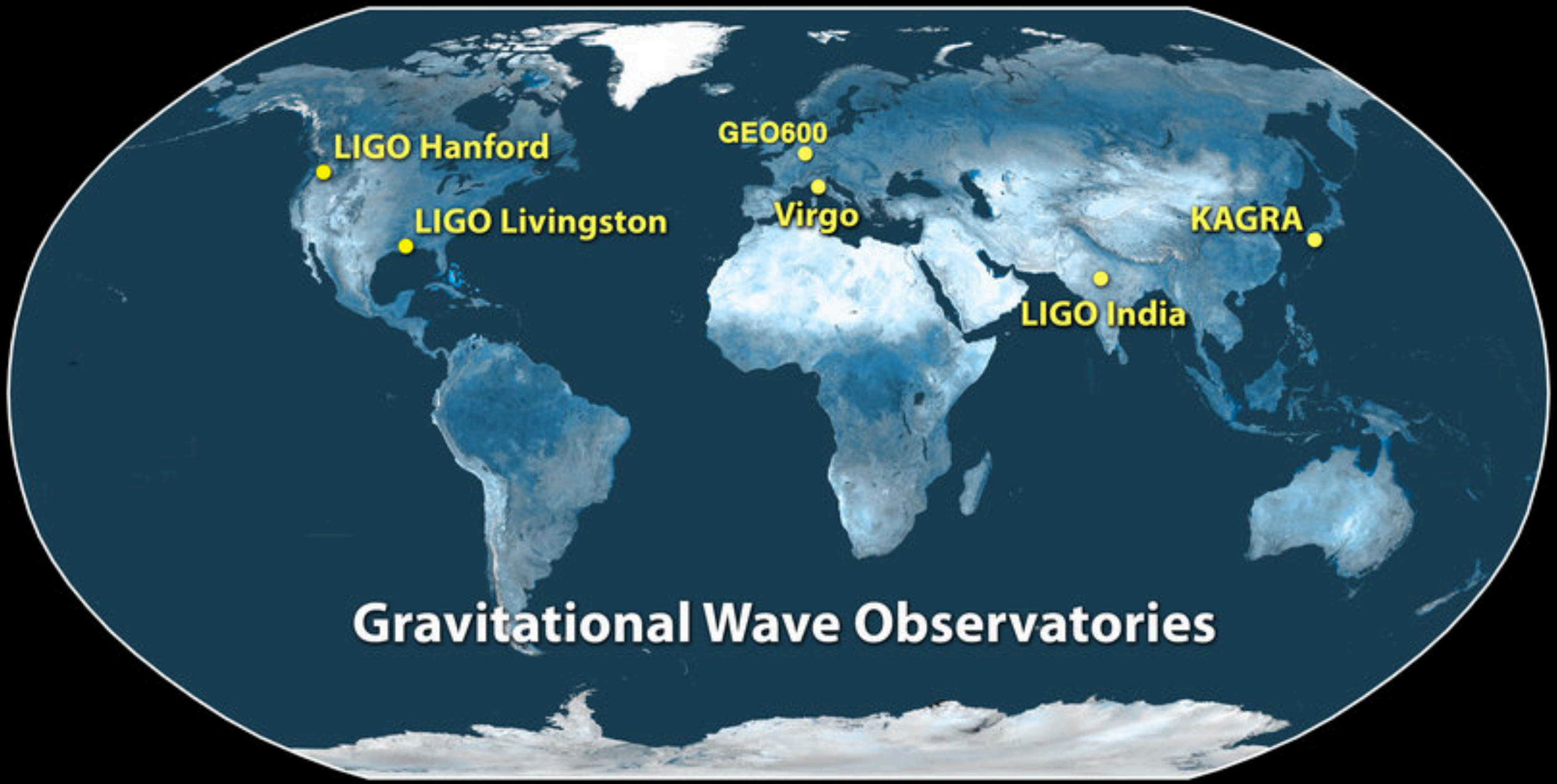
ICCUB Winter Meeting 2023

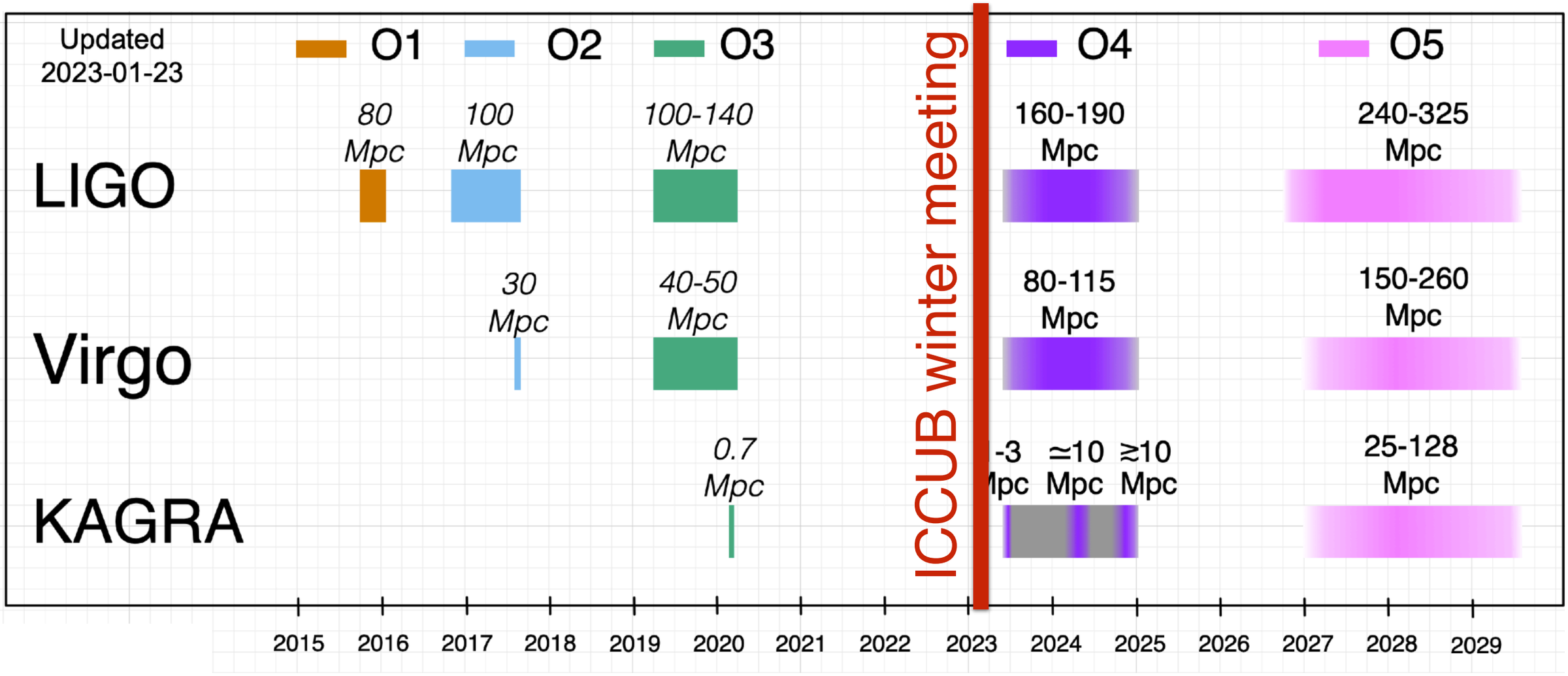


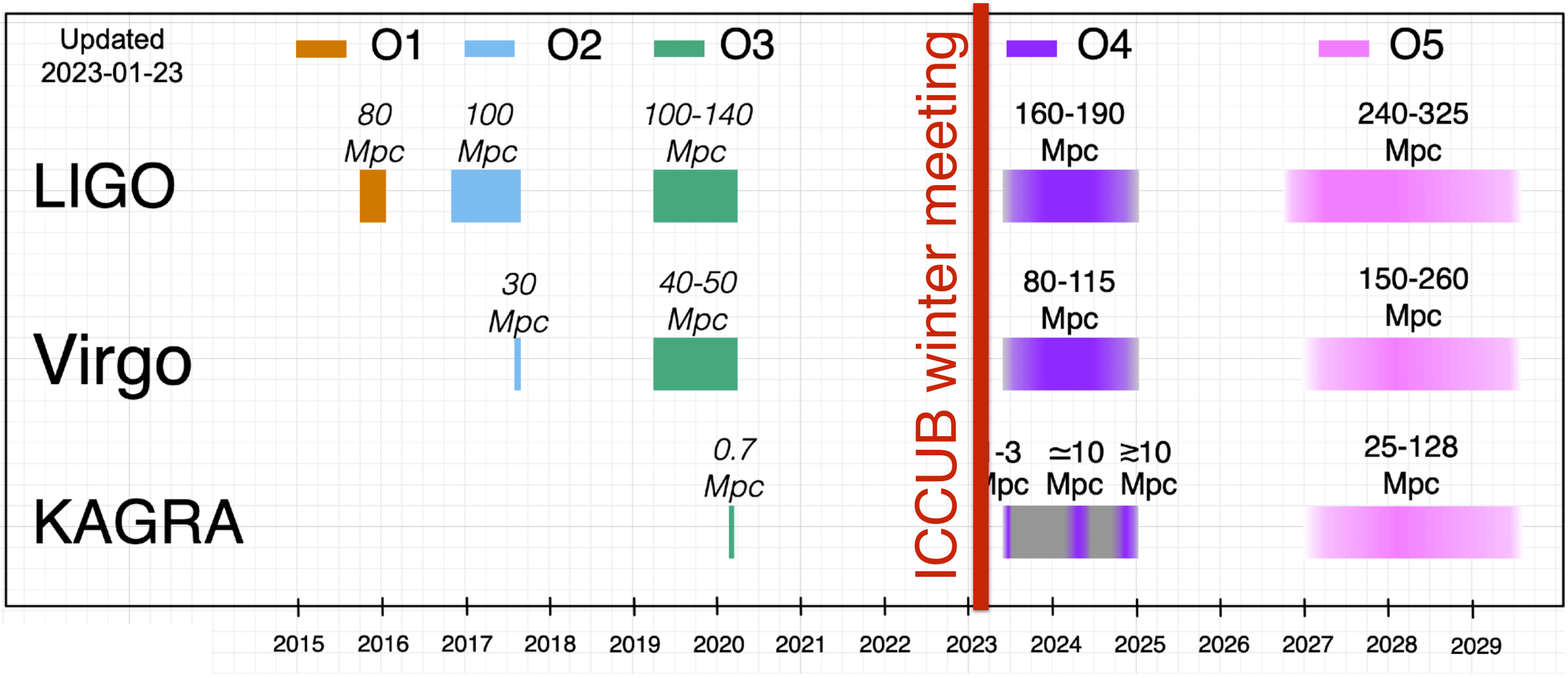


ICCUB Virgo group (Barcelona) **Fabio Antonini** (LIGO, Cardiff) **Daniel Marín** (Barcelona) **Denis Erkal** (Surrey) **Vincent Hénault-Brunet** (Halifax) **Stefano Torniamenti** (Padova) **Oleg Gnedin** (Michigan)

ICREA ICCUB Institut de Ciències del Cosmos UNIVERSITAT DE BARCELONA EXCELENCIA MARÍA DE MAEZTU 2020-2023 VIRGO GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES SGR-Cat 2021 AGAUR Agència de Gestió d'Ajuts Universitaris i de Recerca


LIGO Hanford
LIGO Livingston
GEO600
Virgo
KAGRA
LIGO India
Gravitational Wave Observatories


Updated
2023-01-23
O1
O2
O3
O4
O5
LIGO
Virgo
KAGRA
80 Mpc
100 Mpc
100-140 Mpc
160-190 Mpc
240-325 Mpc
30 Mpc
40-50 Mpc
80-115 Mpc
150-260 Mpc
0.7 Mpc
-3 Mpc
≃10 Mpc
≳10 Mpc
25-128 Mpc
ICCUB winter meeting
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029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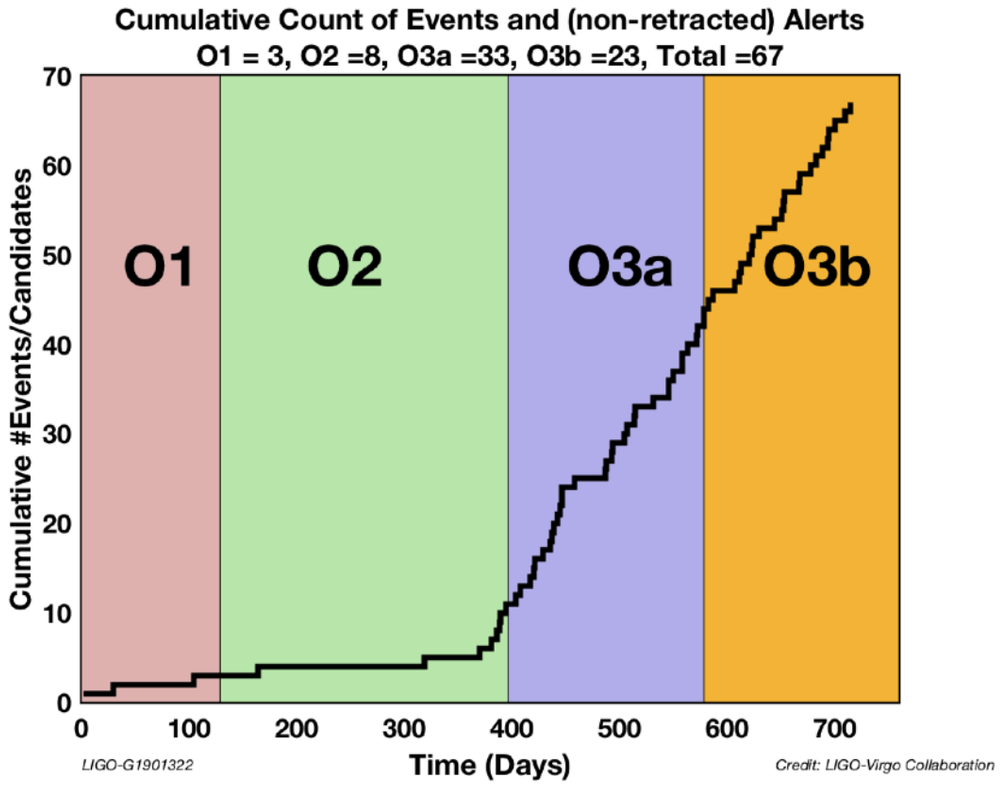
Cumulative Count of Events and (non-retracted) Alerts
O1 = 3, O2 =8, O3a =33, O3b =23, Total =67
Cumulative #Events/Candidates
Time (Days)
O1
O2
O3a
O3b
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
LIGO-G1901322
Credit: LIGO-Virgo Collaboration

ICCUB Virgo group

Science

- BBH dynamics
- Waveforms NR
- Data analysis
- NS EoS BNS
- GW lensing & polarization

Technological Unit














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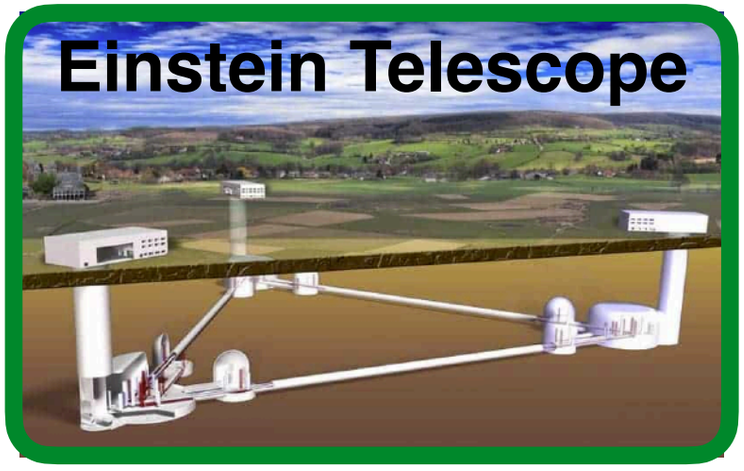

Proyectos de Generación de Conocimiento 2021

"Gravitational-wave astrophysics from upcoming Advanced Virgo observing runs" (GWAnext)

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

In coordination with University of Valencia

Toni Font

Isabel Cordero

G1. Modelling of Astrophysical Sources of GW:

- G1.1. Eccentricity distribution of dynamically formed BBH mergers
- G1.2. GW templates for eccentric and hyperbolic BBH encounters
- G1.3. BNS mergers and post-merger HMNS remnants
- G1.4. PNS oscillations and asteroseismology
- G1.5. Multimessenger aspects of NS crustal fracture and magnetars
- G1.6. ECO and BH miscellanea
- G1.7. NR - Formulation and methods

G2. GW data analysis:

- G2.1. Gravitational lensing of GW
- G2.2. GW denoising and waveform reconstruction
- G2.3. GW polarization studies
- G2.4. ML for GW data analysis
- G2.5. EM follow-up of GW sources

ICCUB

G3. Contributions to Advanced Virgo:

- G3.1. Computing and software engineering
- G3.2. Commissioning of Advanced Virgo + in preparation for O4
- G3.3. Development of new pipelines in preparation for O4
- G3.4. Development of new waveform models
- G3.5. Participation in GW searches during O4
- G3.6. Participations in Advanced Virgo committees and service tasks

SGR-Cat 2021 Grup de recerca emergents (GRE)

"Gravitational Wave Astrophysics" (GWA)

SGR-Cat 2021

Agència de Gestió d'Ajuts Universitaris i de Recerca

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+

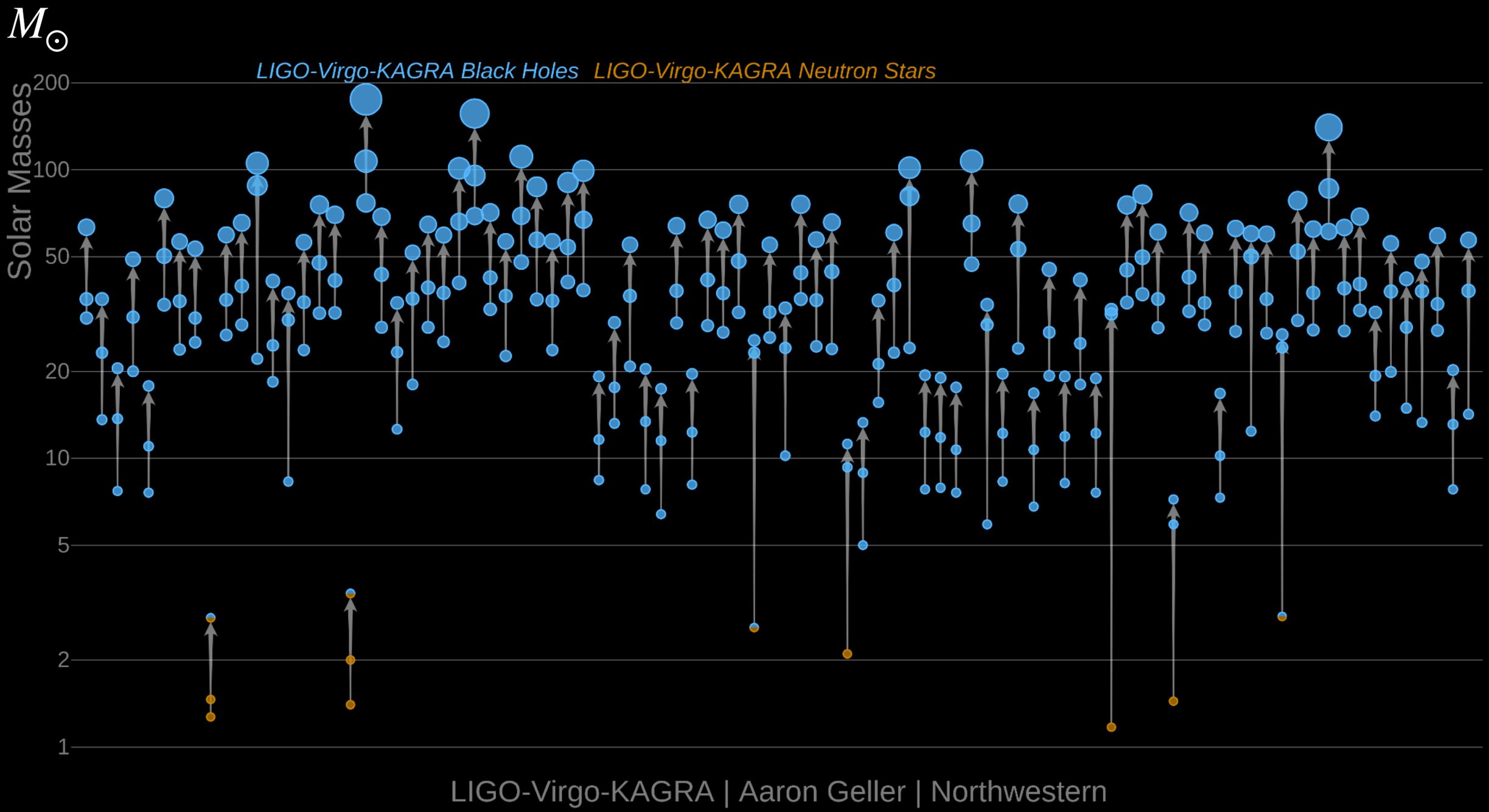
EM follow-up

BlackGEM

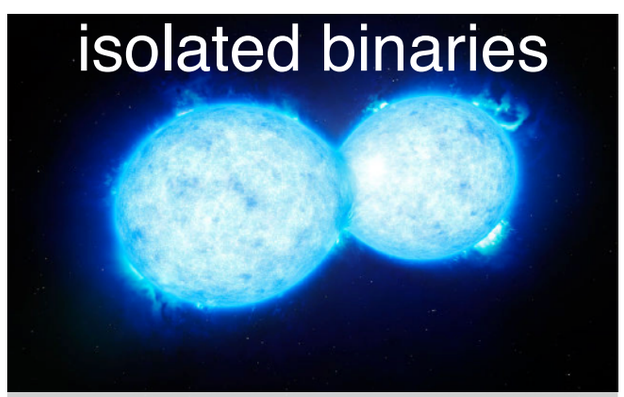
Nadia Blagorodnova

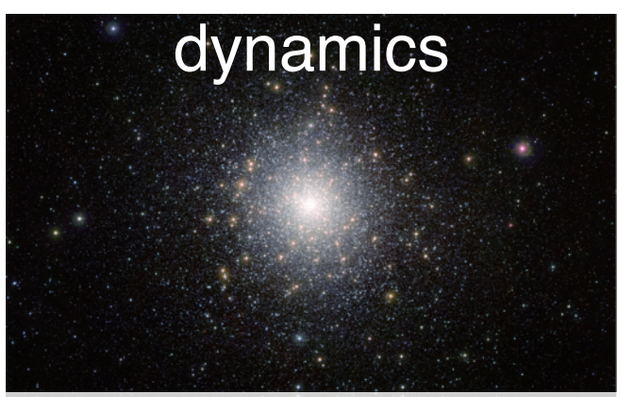
Gravitational waves: an exploding field!

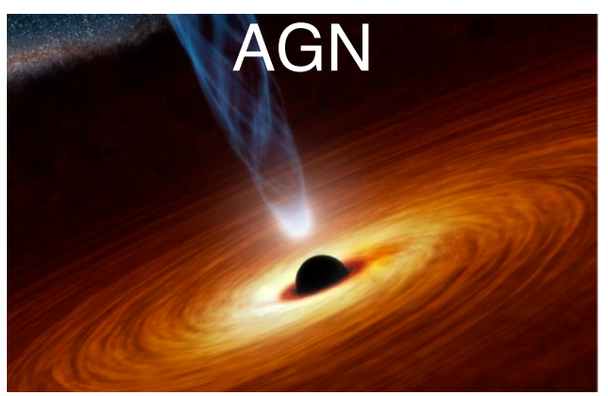
2015-2020 LVK O1-3: 90 detections!
2023 May 18 LVK O4: several 100 detections expected
~2028 LVK O5 $\gtrsim$1000 detections expected
~2035 Einstein Telescope: all BBH mergers up to $z \sim 20$



How do binary black holes (BBHs) form?







Belczynski+ 2002; de Mink & Mandel 2016; Mandel & de Mink 2016; Marchant+ 2016; Farr+ 2017; Mapelli+ 2017; Schneider+ 2017; Gerosa+ 2018; Broekgaarden+ 2022; Mandel & Broekgaarden 2022

Portegies & Zwart & McMillan 2000; Samsing+2014; Rodriguez+ 2015; Antonini+ 2018; Hong+ 2018; Rodriguez & Loeb 2018; Antonini & Gieles 2020a,b

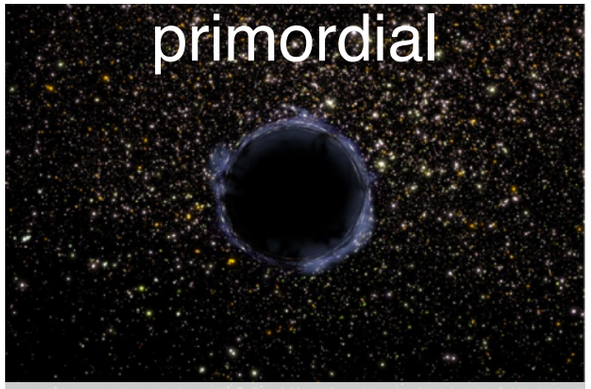
McKernan+ 2012, 2018; Bartos+ 2017; Stone+ 2017; Samsing+ 2022

Carr & Hawking 1974; Carr+ 2010; Bird+ 2016; Clesse & García-Bellido 2017

How do binary black holes (BBHs) form?

2017; Schneider+ 2017; Gerosa+ 2018; Broekgaarden+ 2022; Mandel & Broekgaarden 2022

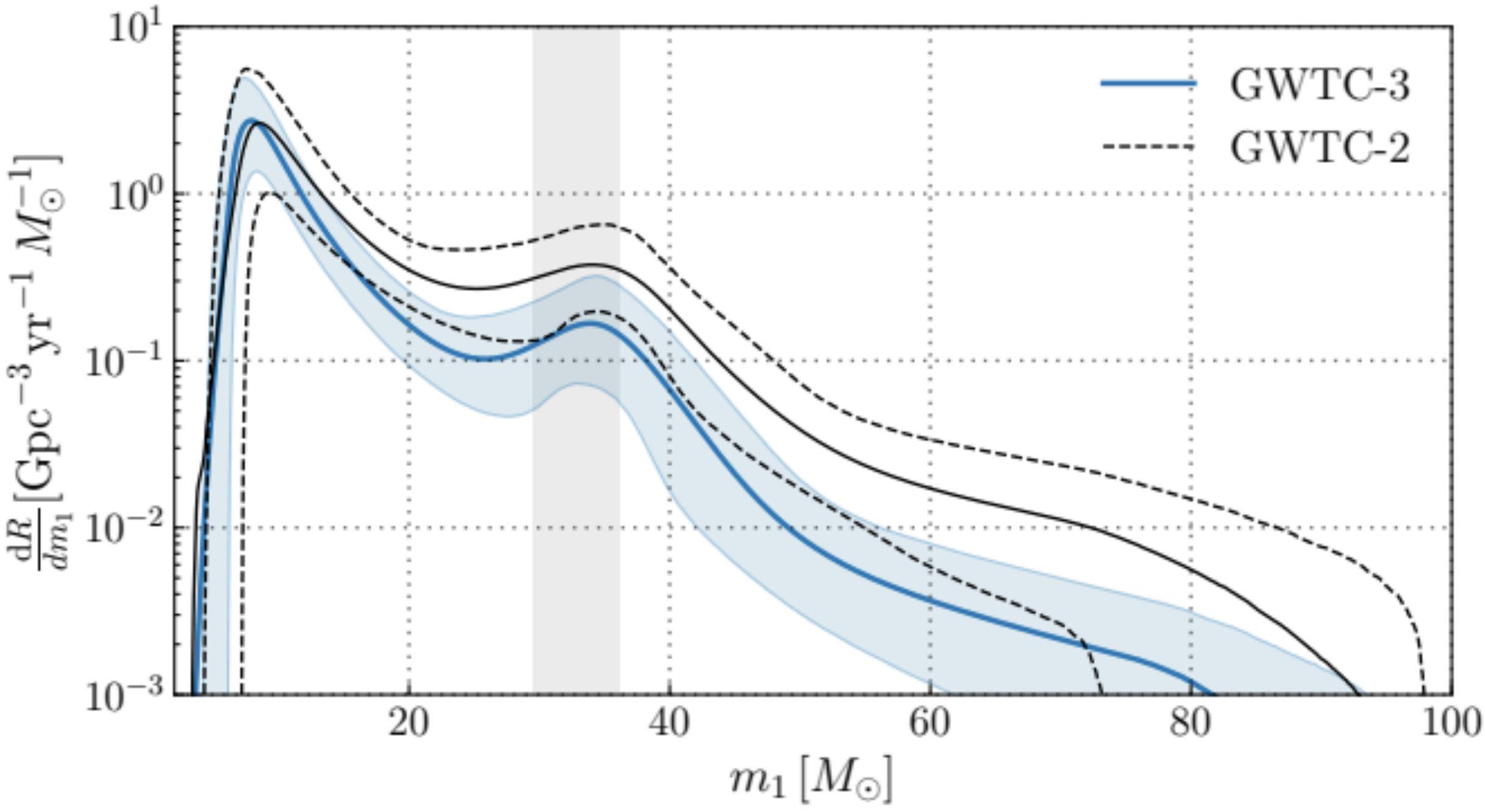
Hong+ 2018; Rodriguez & Loeb 2018; Antonini & Gieles 2020a,b



McKernan+ 2012, 2018; Bartos+ 2017; Stone+ 2017; Samsing+ 2022

Carr & Hawking 1974; Carr+ 2010; Bird+ 2016; Clesse & García-Bellido 2017

Mass-dependent BBH merger rates



The LVK Collaboration 2021, arXiv:2111.03634

The isolated binary channel

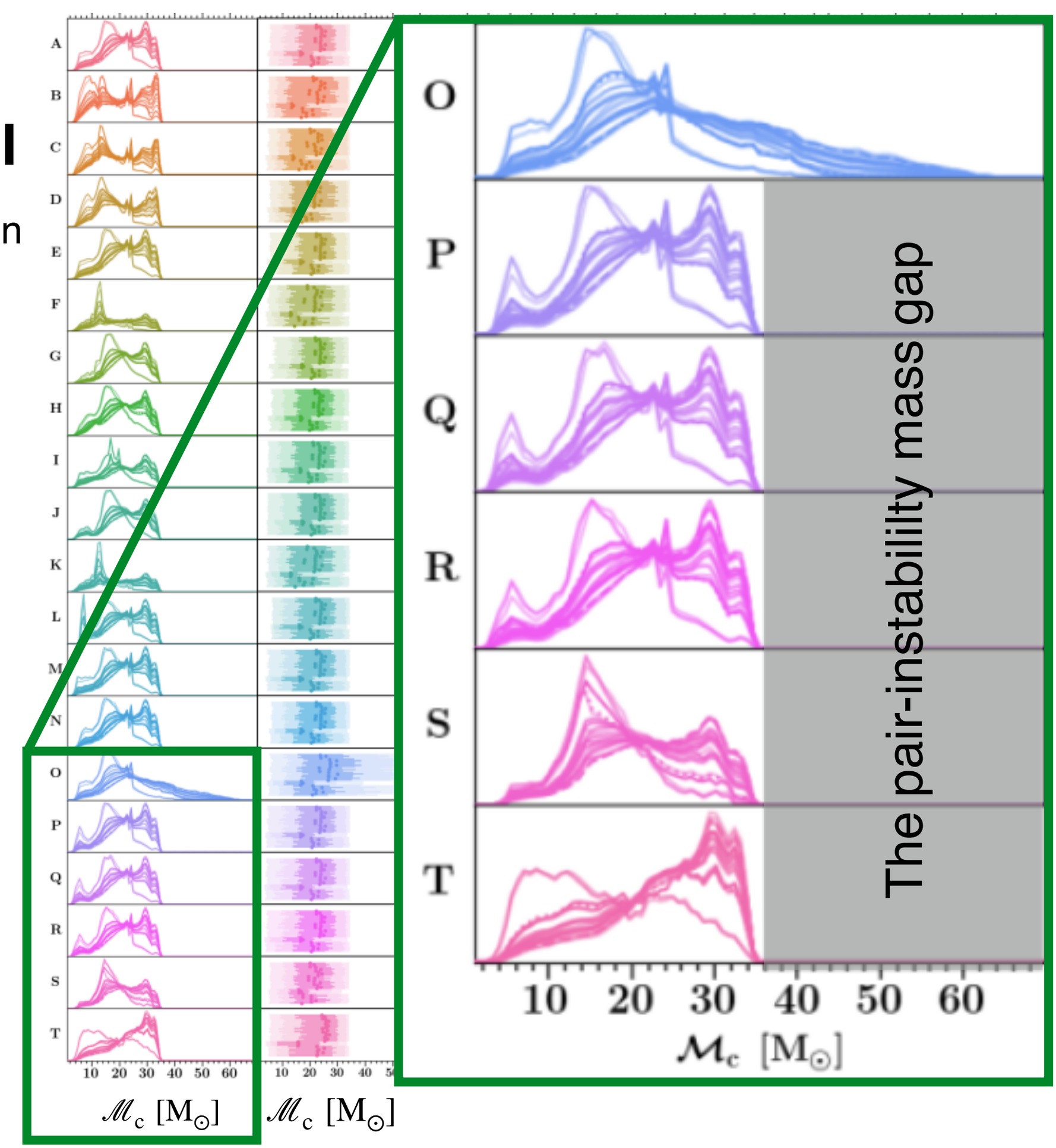
Results from population synthesis models

Broekgaarden+ 2022

Chirp mass:

$$\mathscr{M}_c = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

$$\dot{f} \propto \mathscr{M}_c^{5/3} f^{11/3}$$



Fast model for cluster evolution

... to follow how all those stars in a globular cluster move is quite beyond our ability. It is complicated in its actions, but the basic pattern or the system beneath the whole thing is simple." Richard Feynman, 1964

Fast model for cluster evolution

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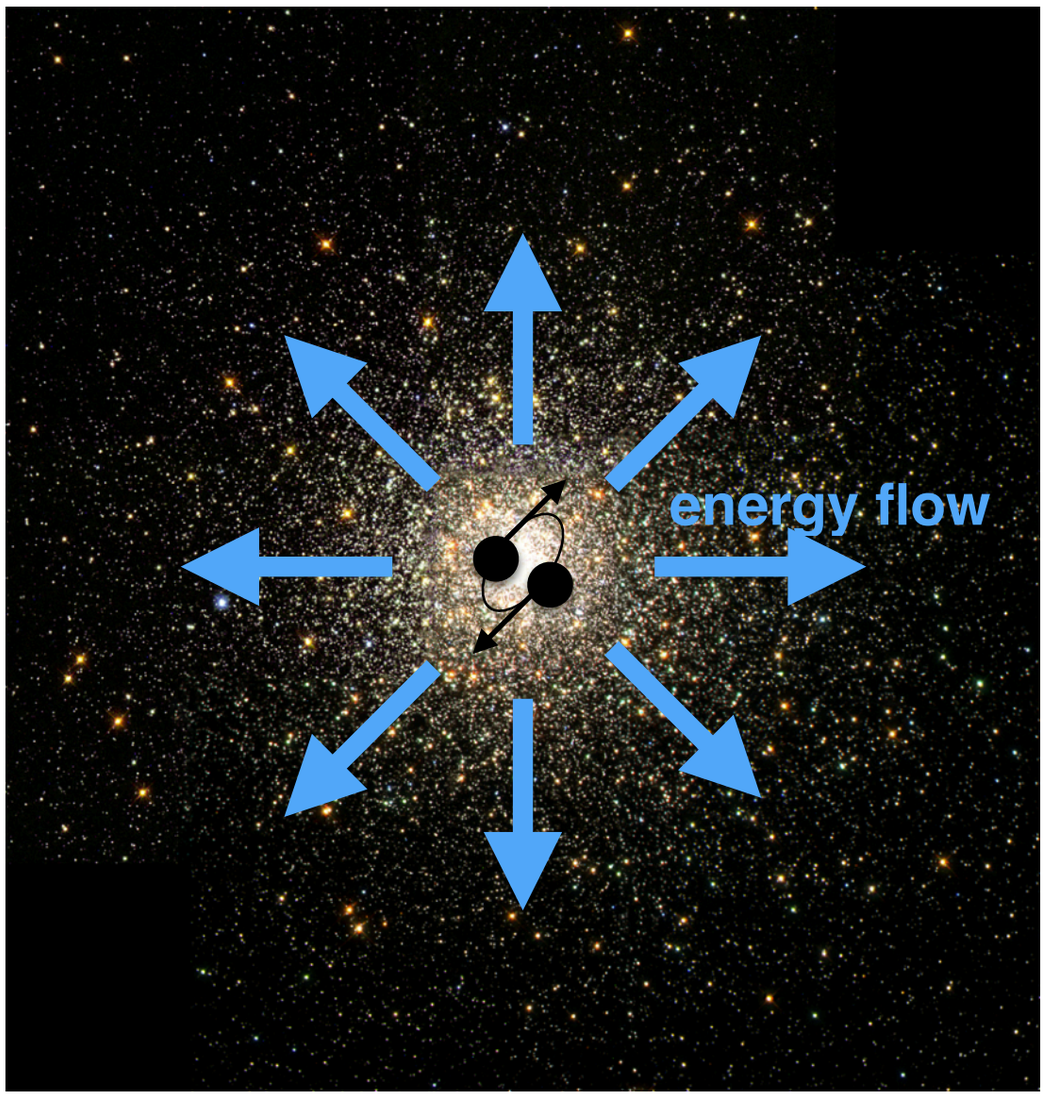
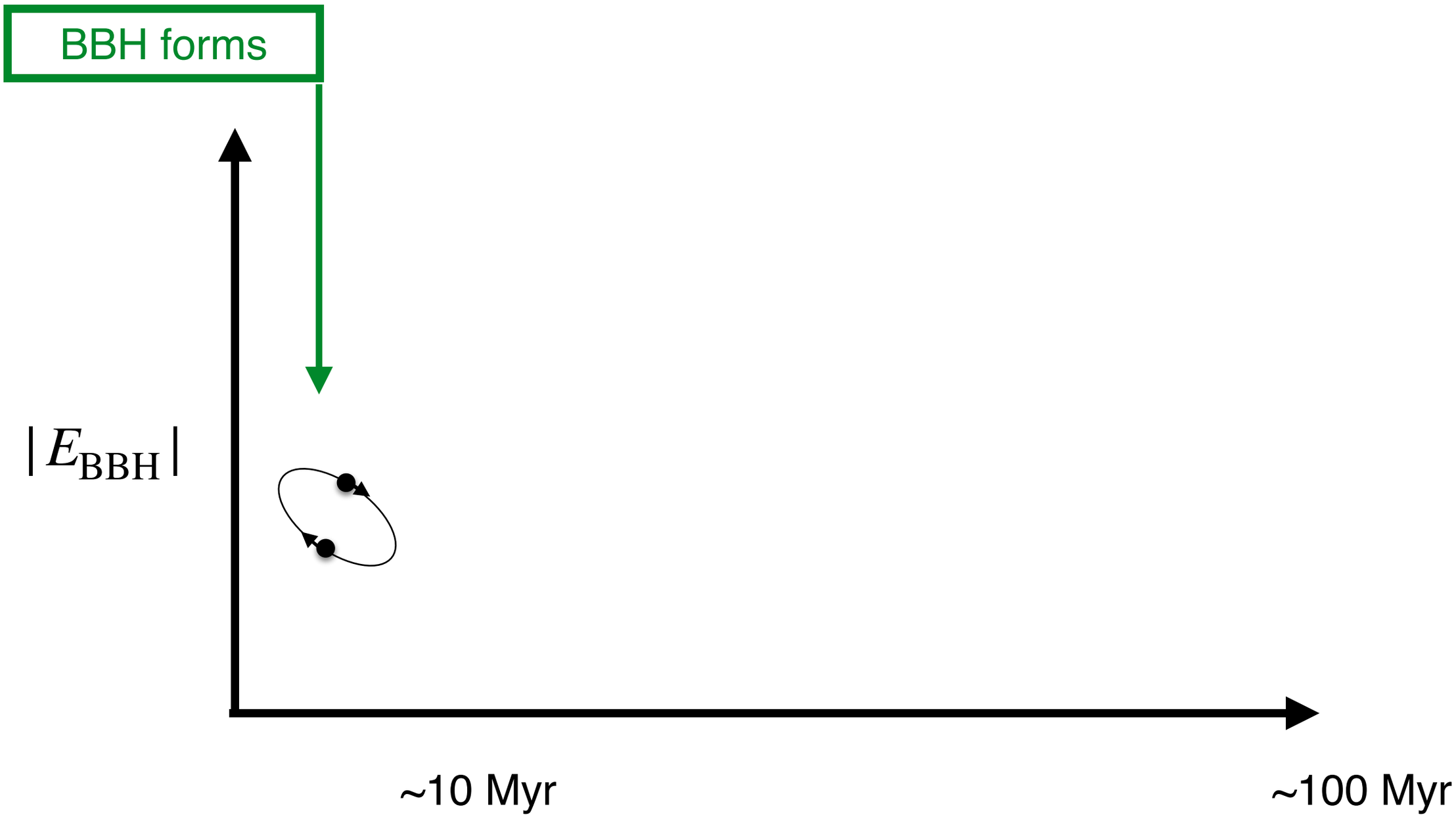
$$\dot{E}_{\rm BBH} = -\dot{E}_{\rm cluster}$$

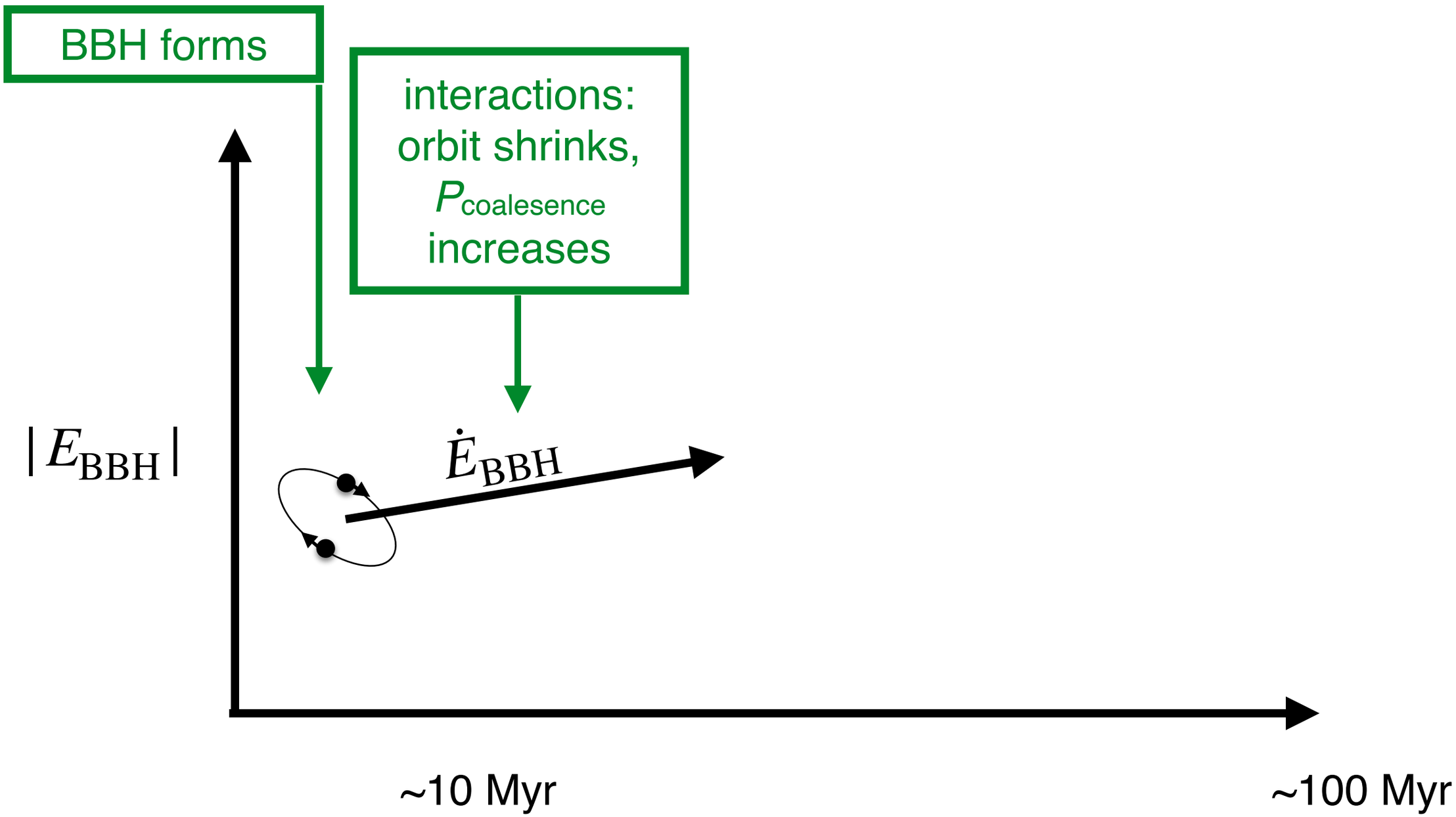
Hénon 1961, 1965, 1975



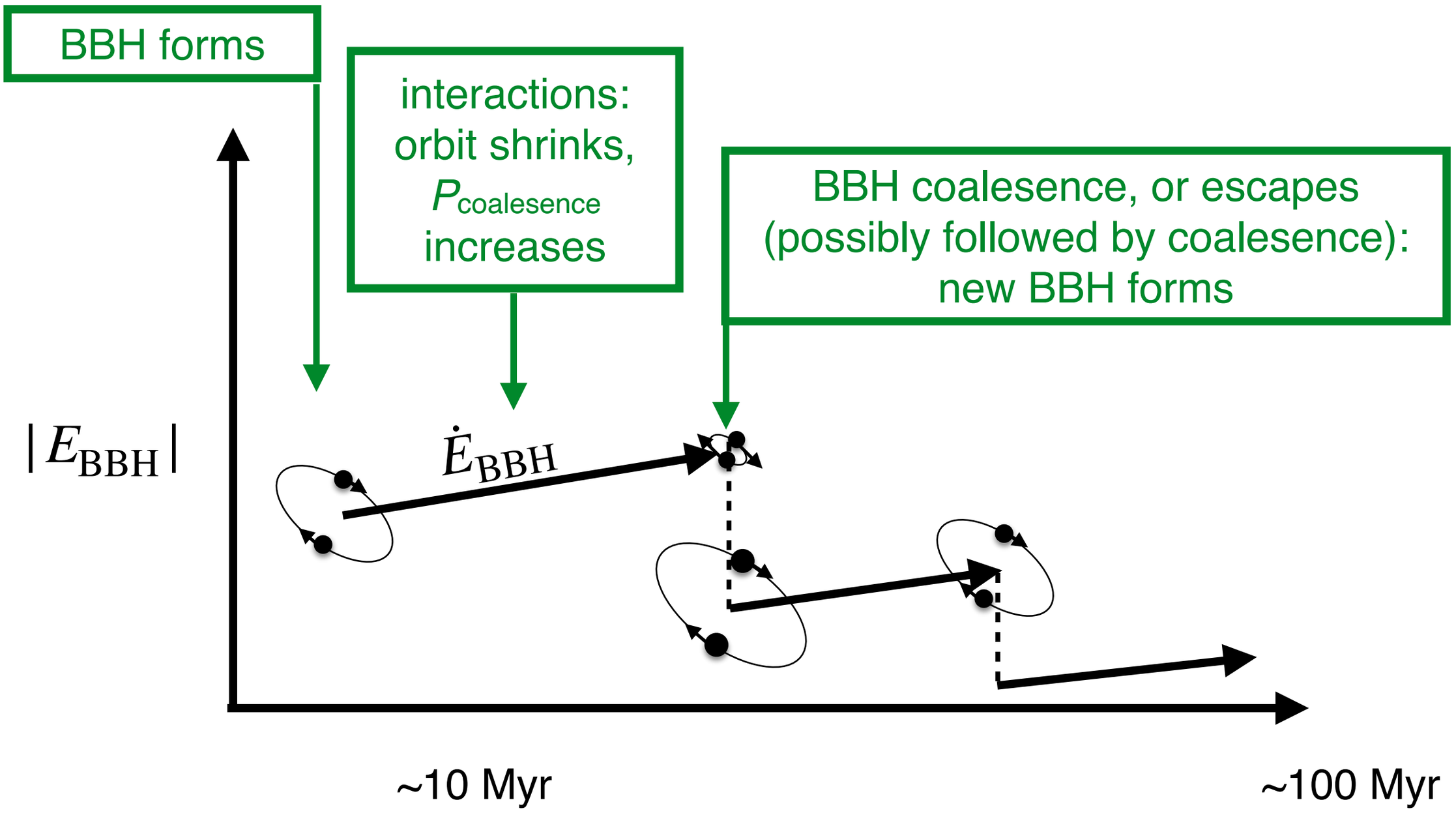
Dynamical BBH coalesence, the idea



Dynamical BBH coalesence, the idea

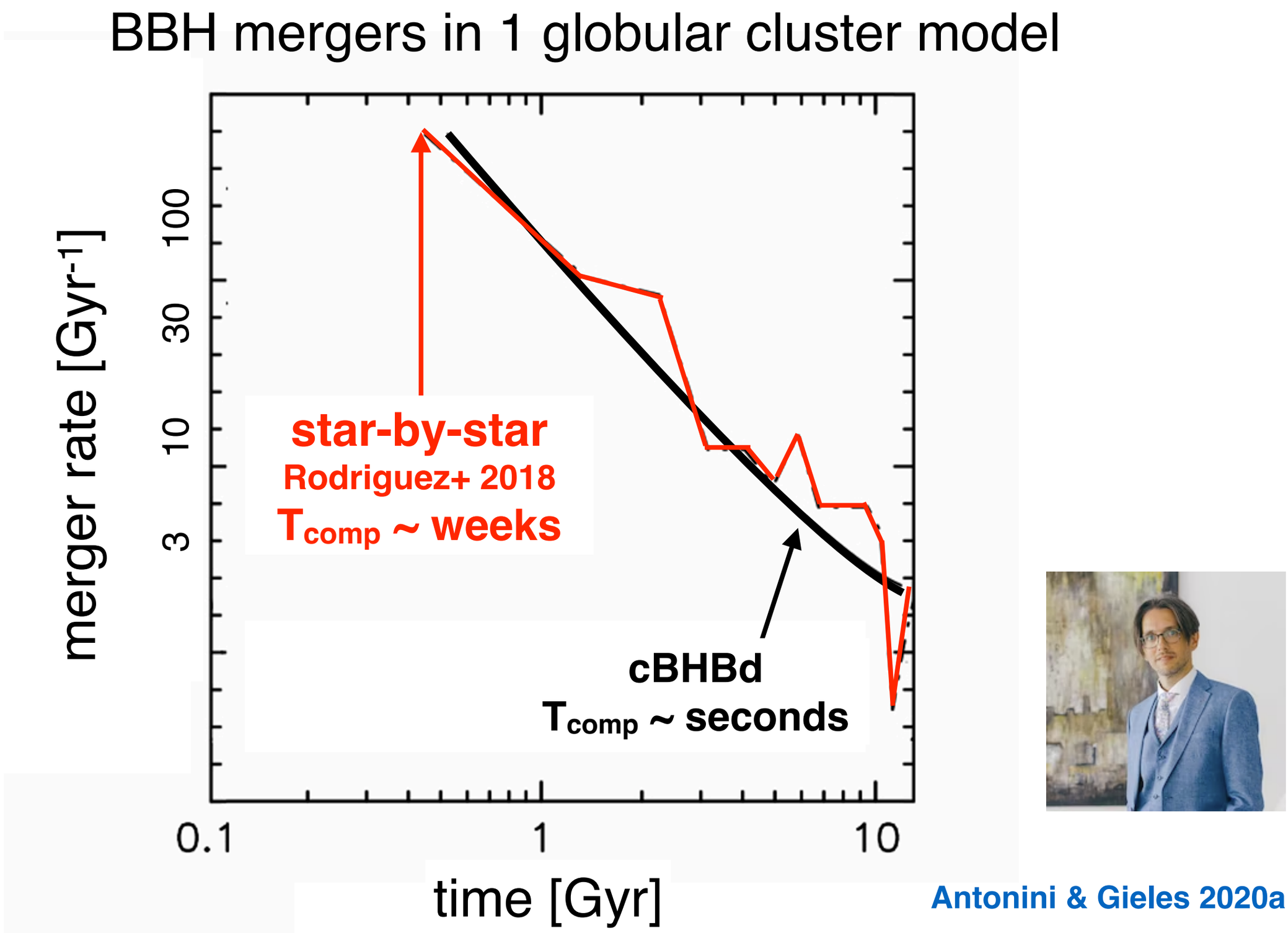


Dynamical BBH coalesence, the idea



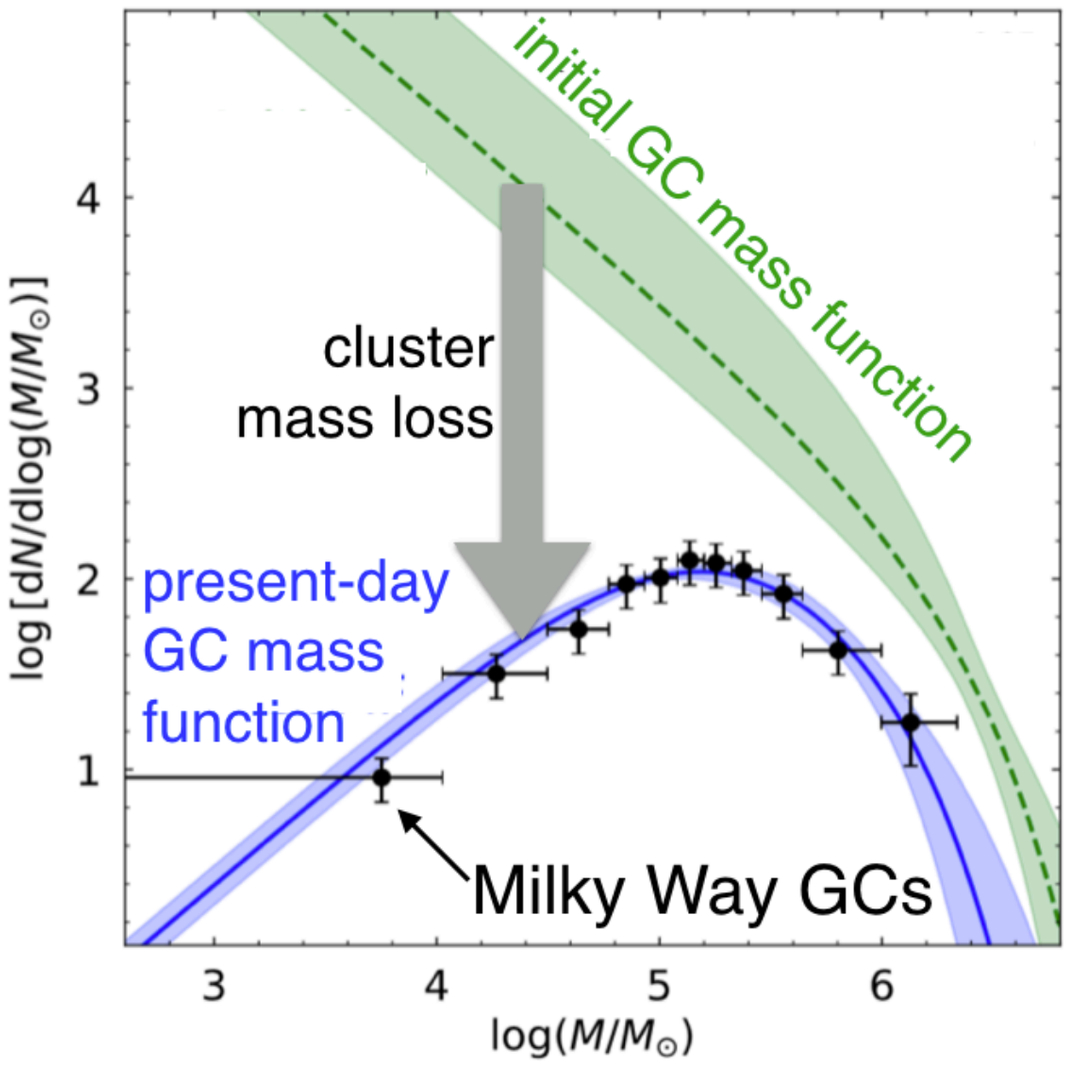
A fast forward model for dynamical BBH mergers

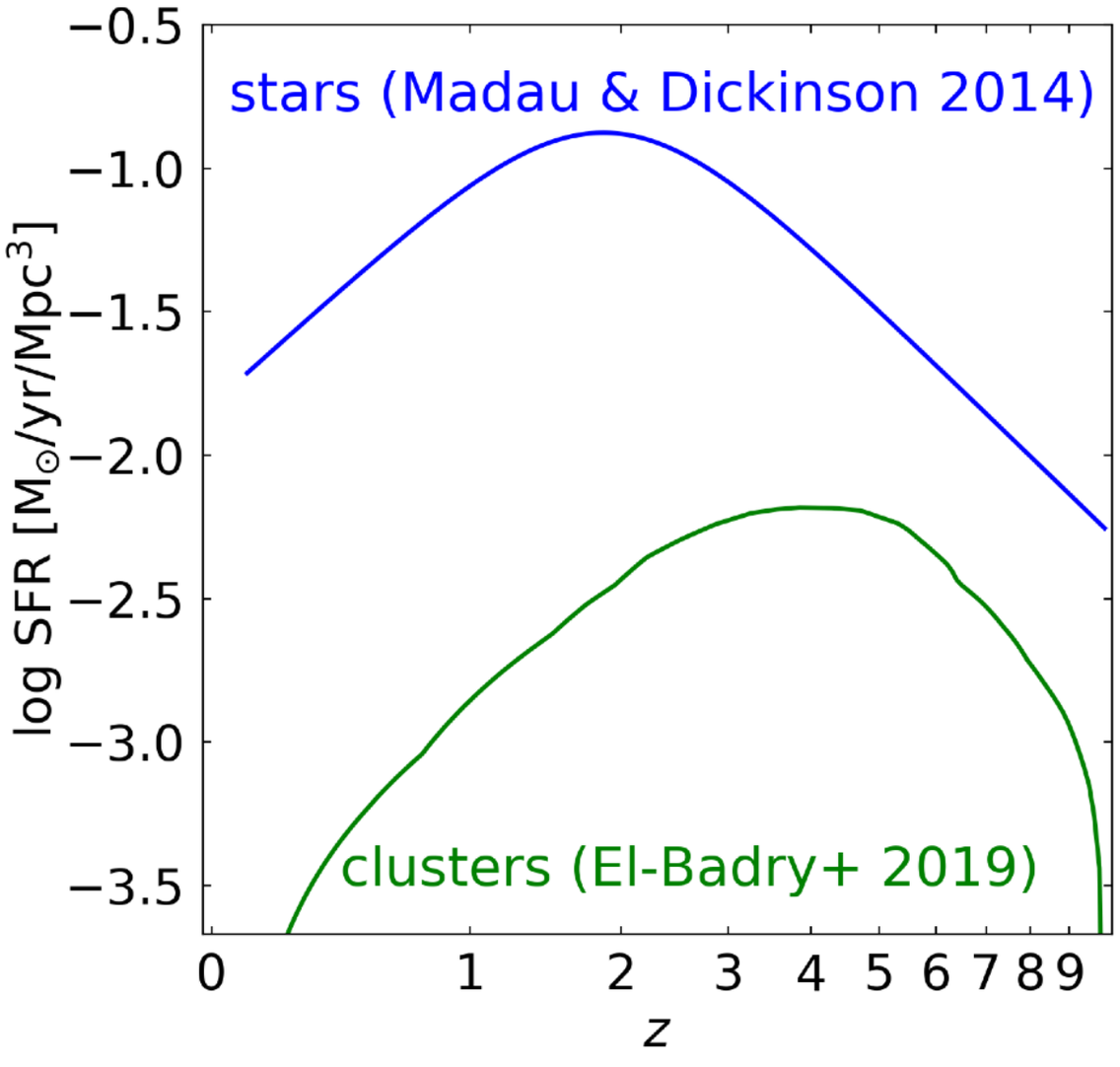
clusterBHBdynamics (cBHBd)



Antonini & Gieles 2020a

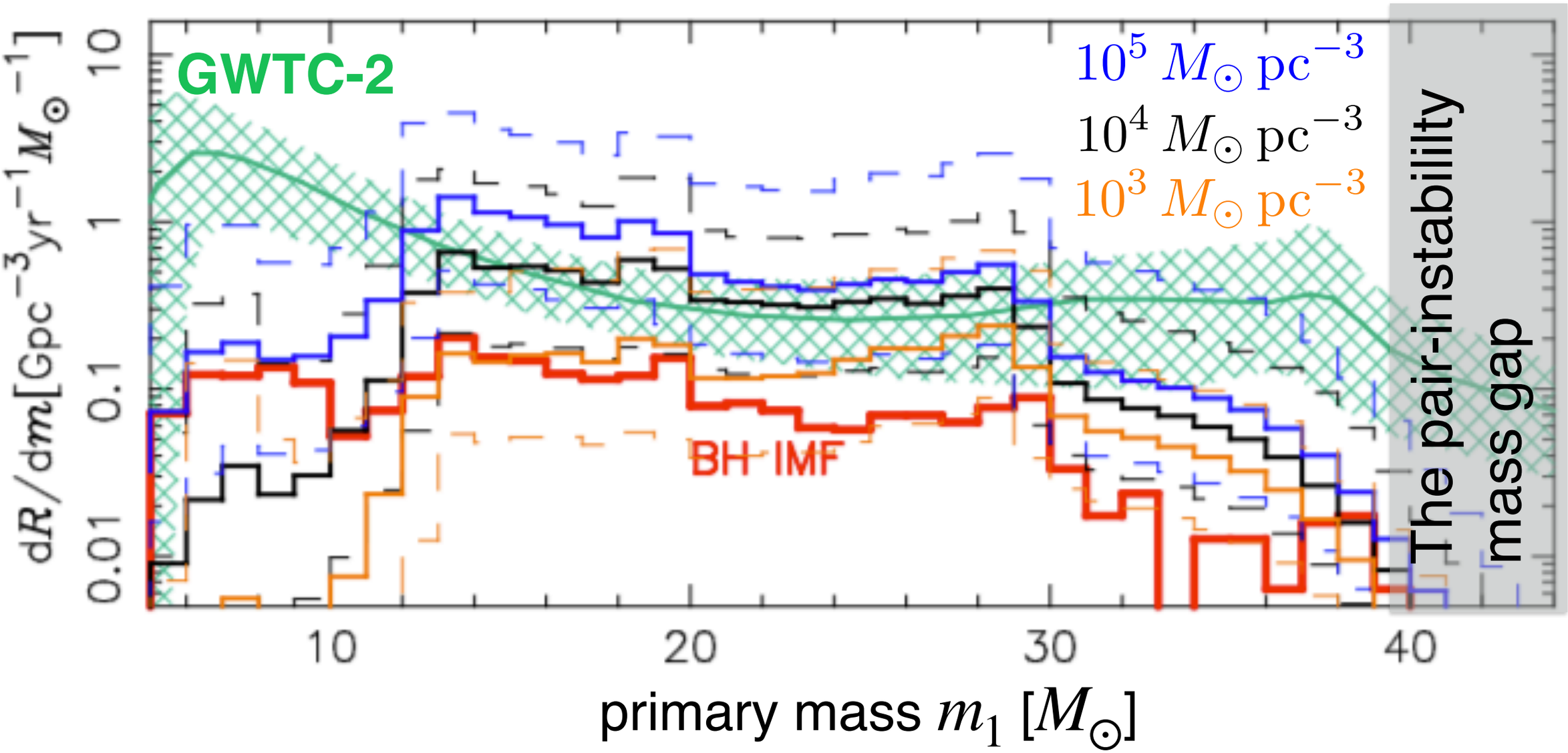
Population synthesis of the dynamical channel





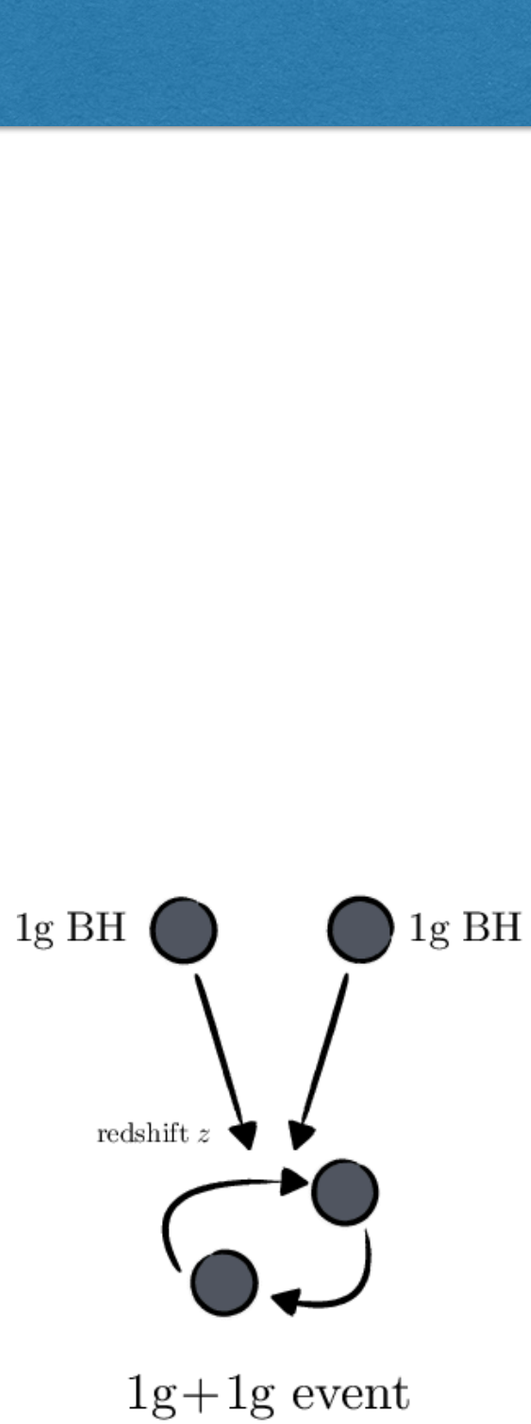
Antonini & Gieles 2020b, PRD

Mass-dependent merger rate

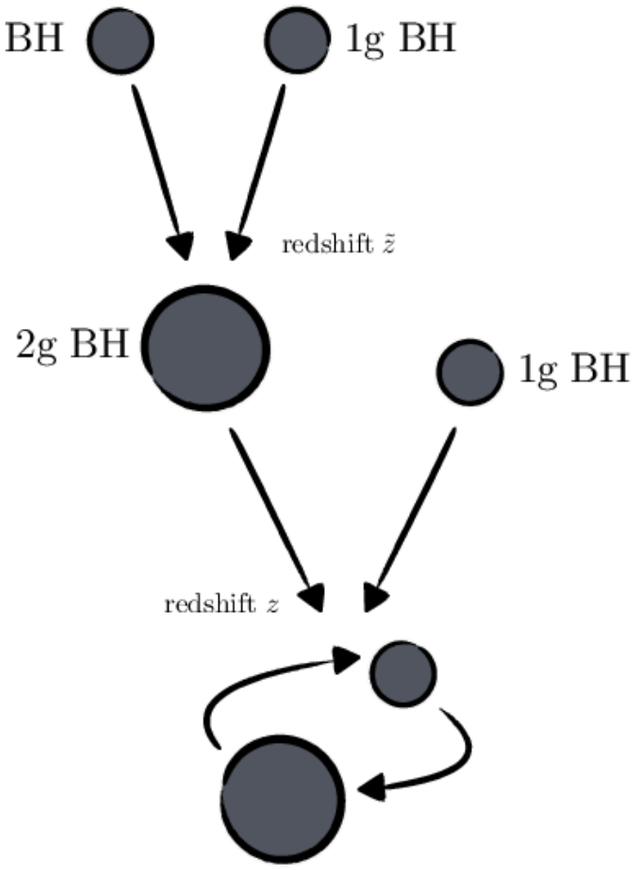


Antonini & Gieles 2020b, PRD

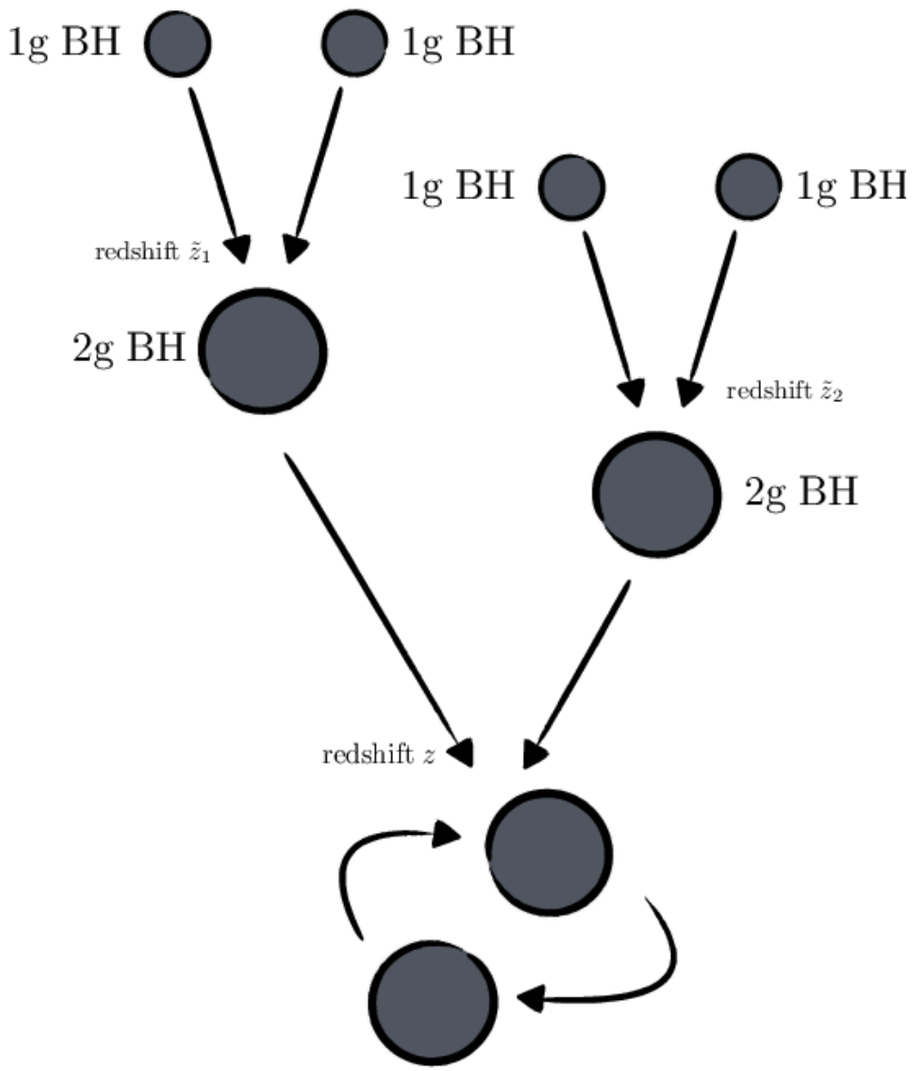
Hierarchical mergers



1g+1g event



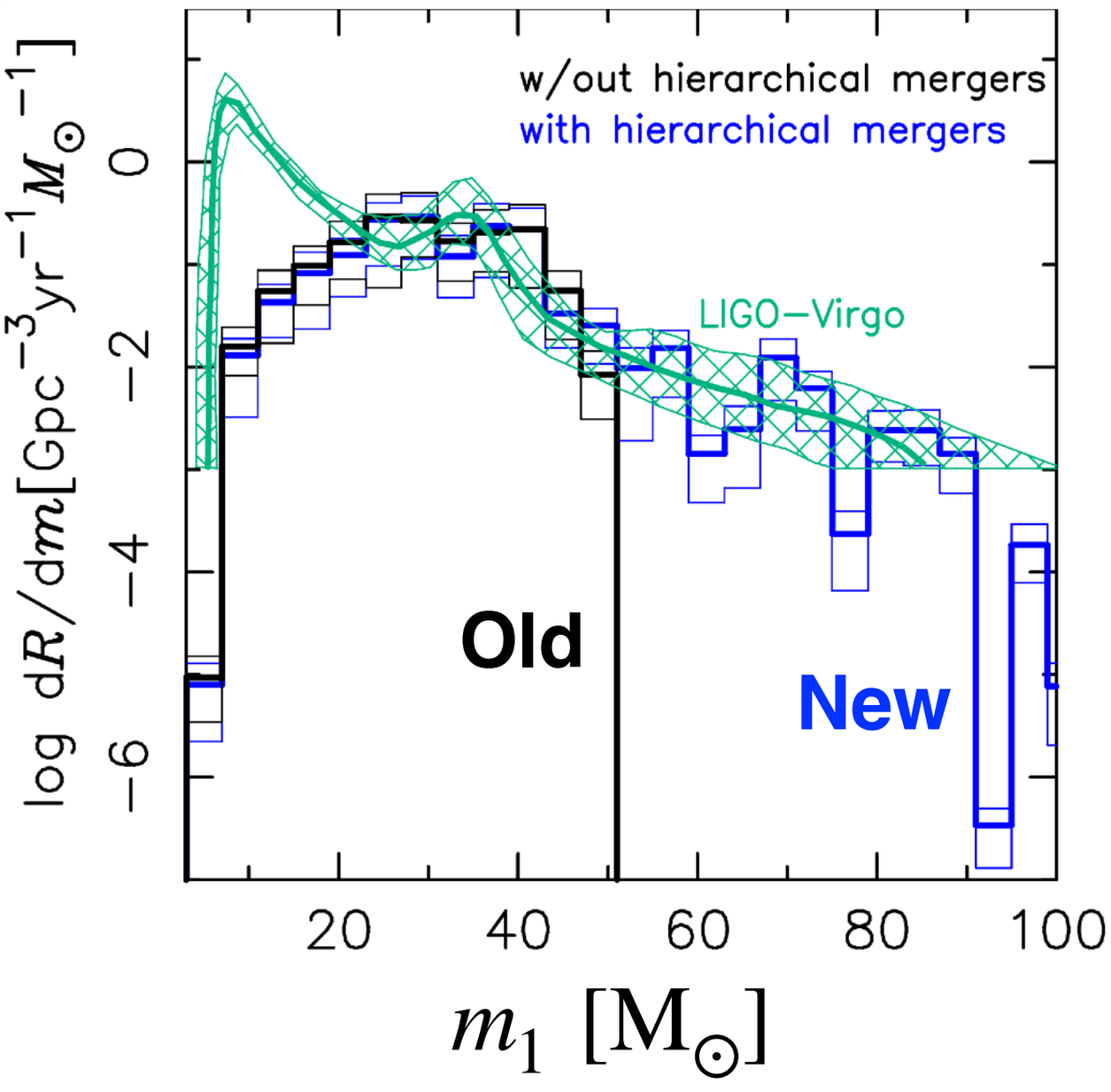
1g+2g event

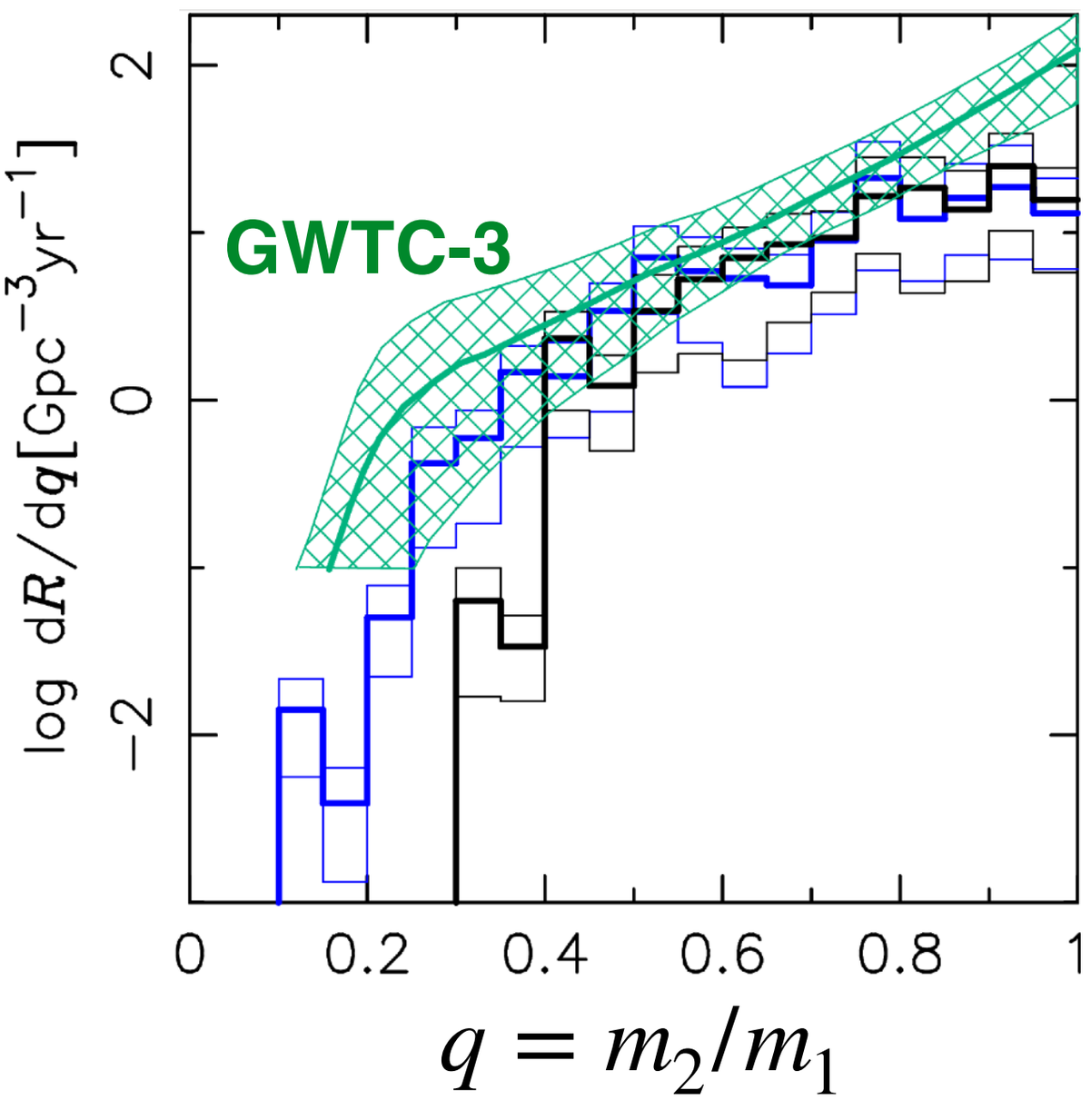


2g+2g event

Gerosa & Berti 2017

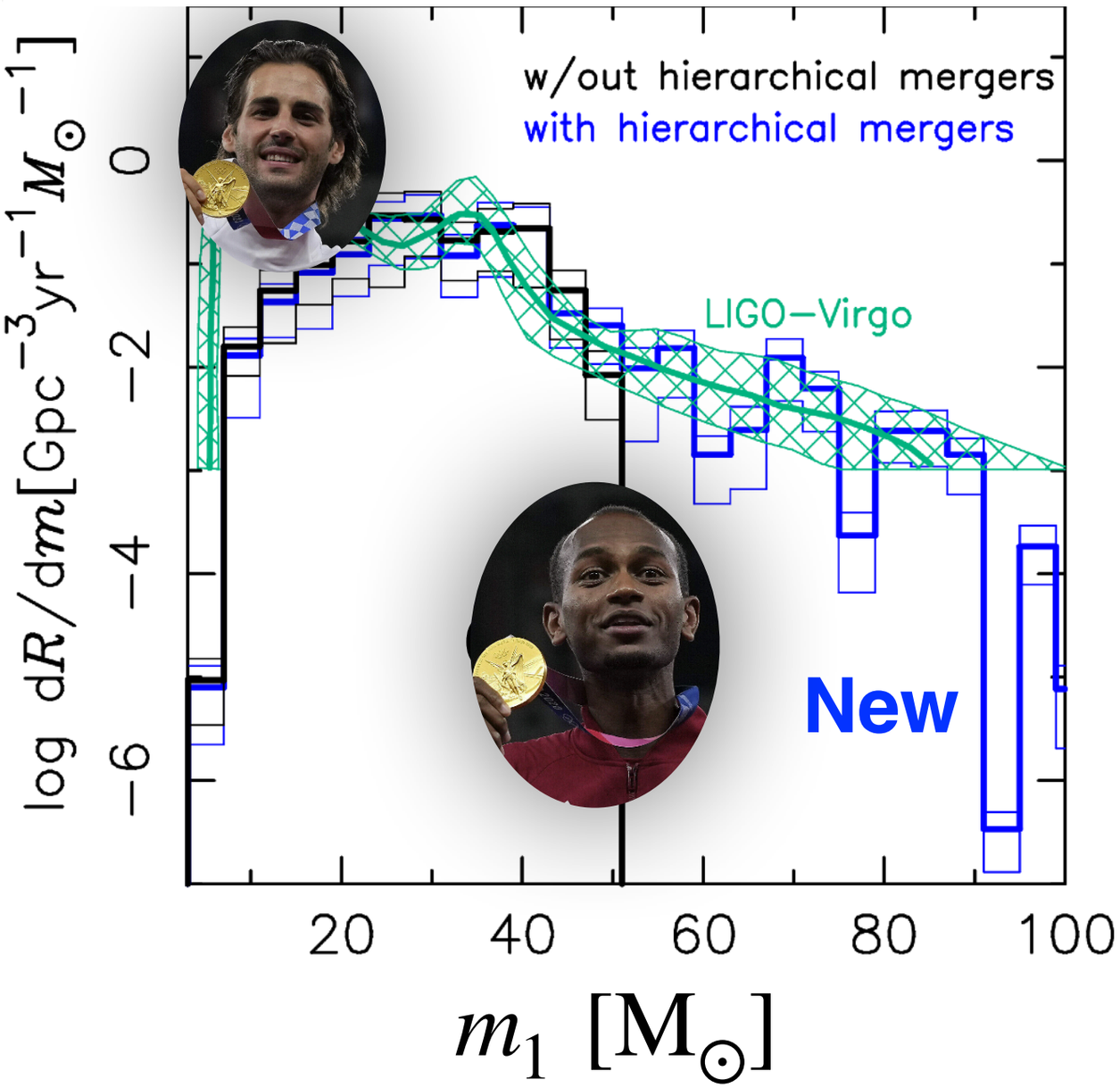
Population model with hierarchical mergers

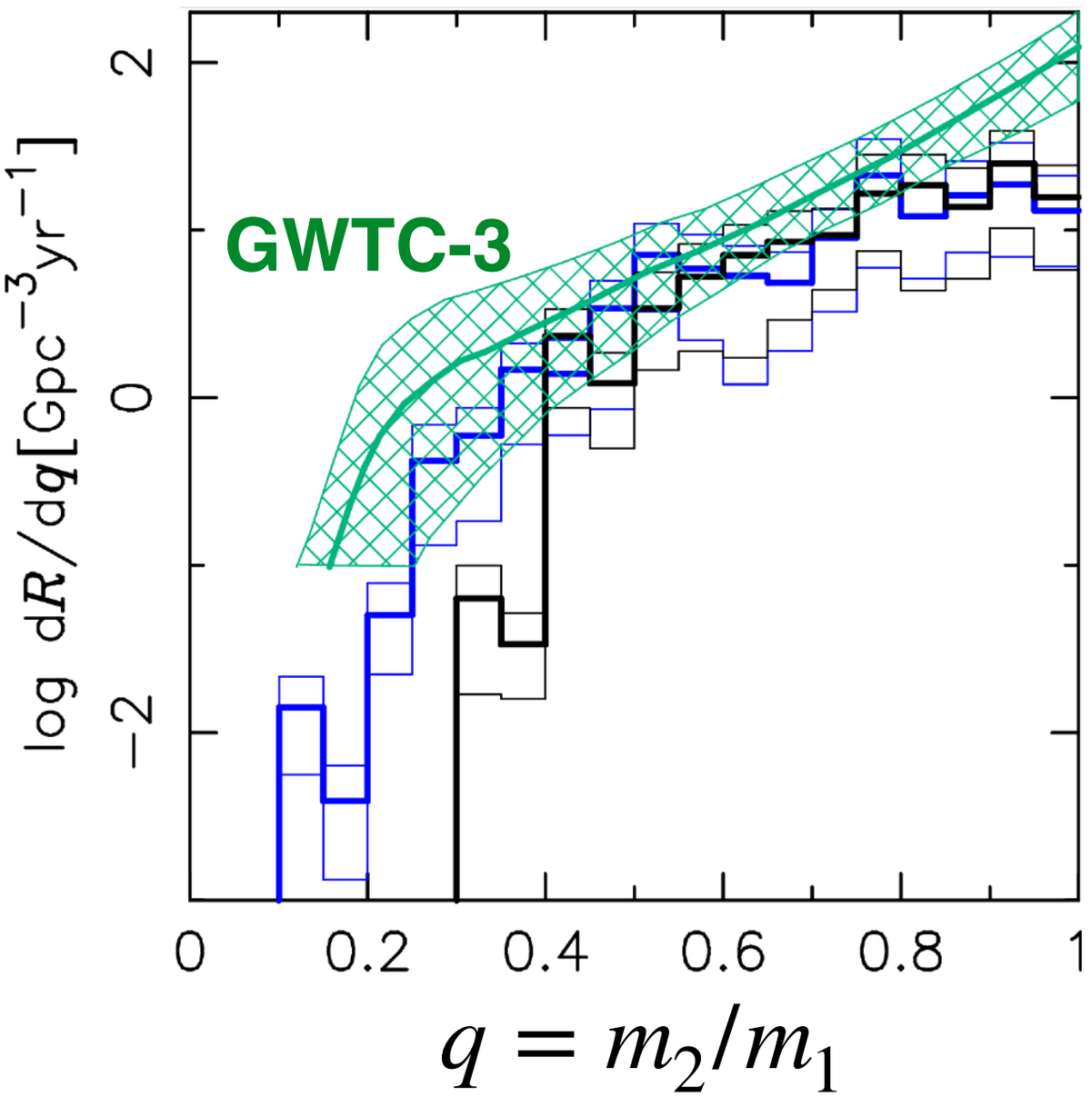




Antonini, Gieles+ 2023, arXiv:2208.01081

Population model with hierarchical mergers

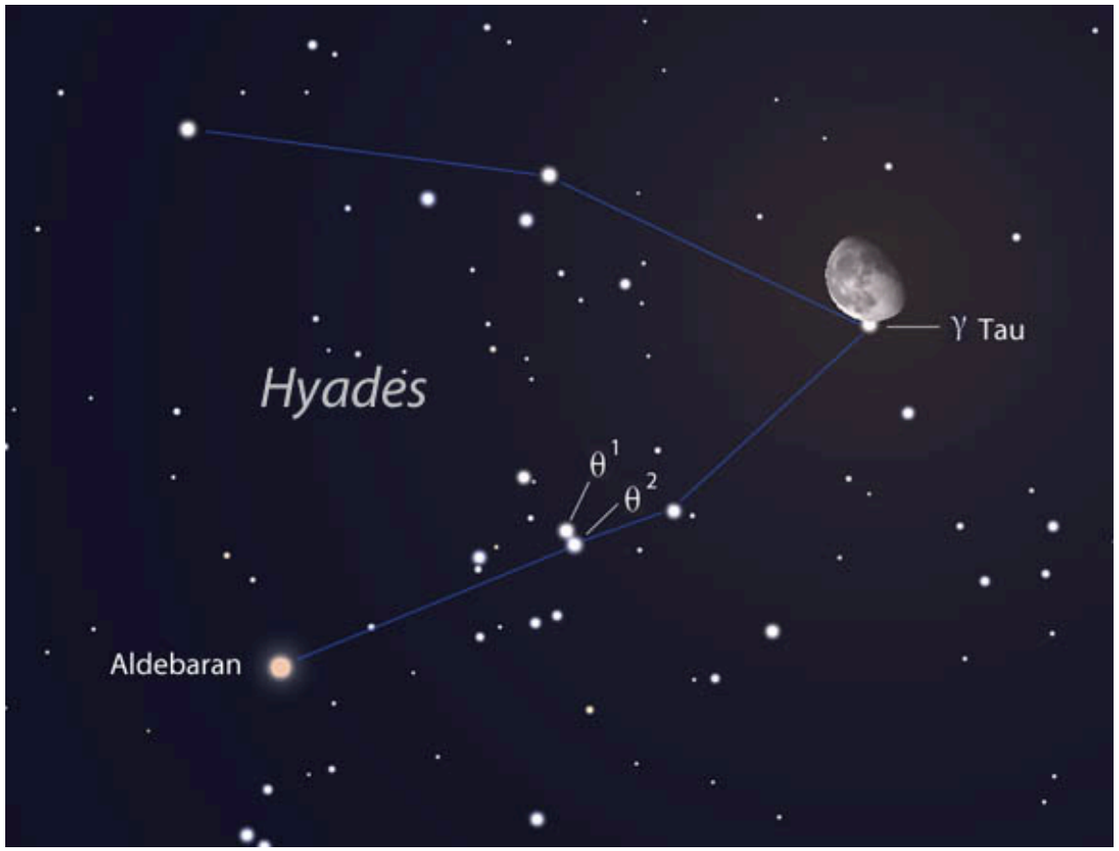


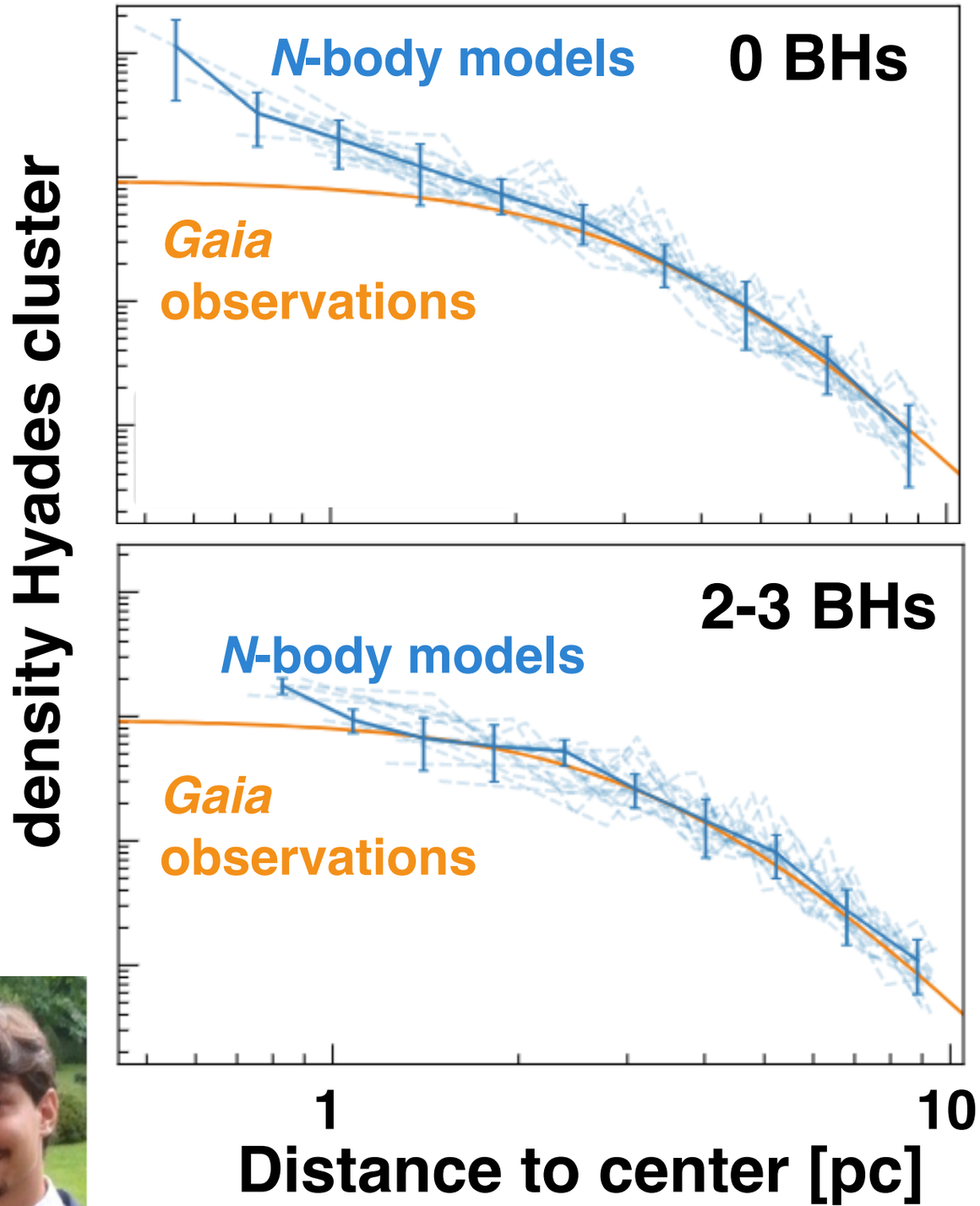


Antonini, Gieles+ 2023, arXiv:2208.01081

Additional constraints: BHs in open clusters

The closest black hole(s) to the Sun!?





Torniamenti+ 2023, to be submitted

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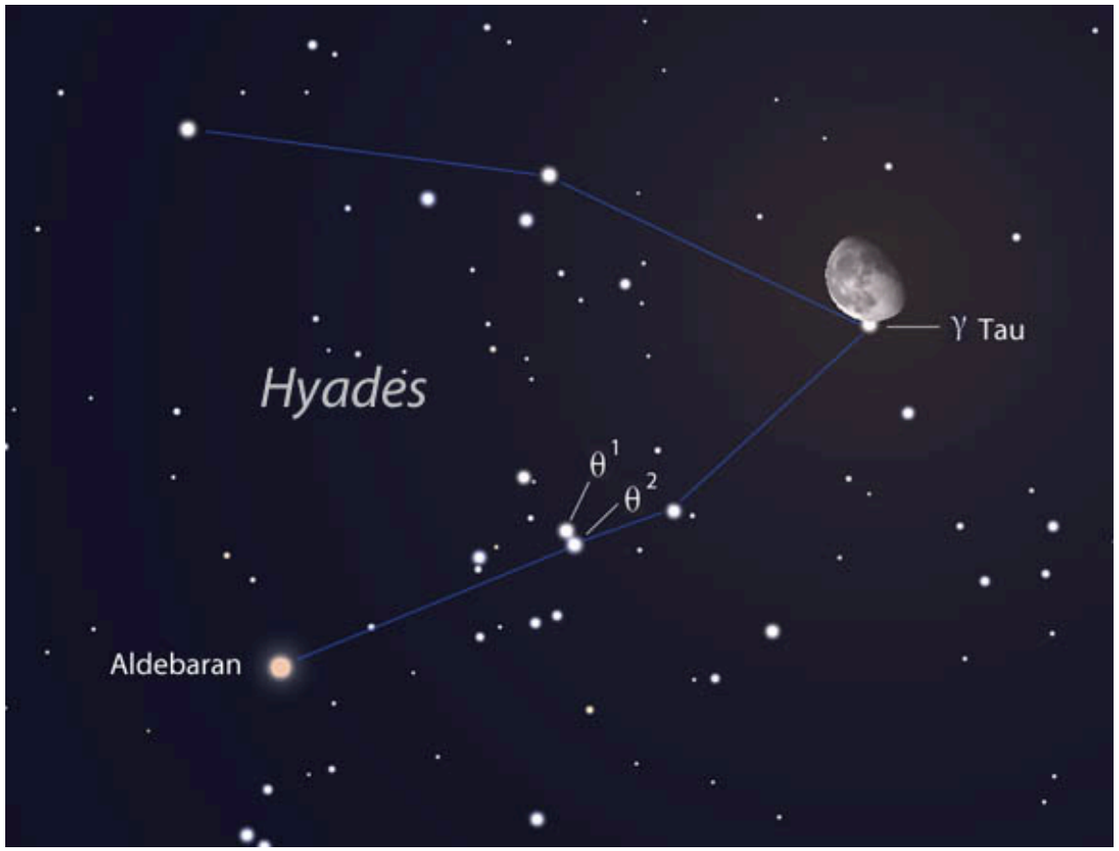
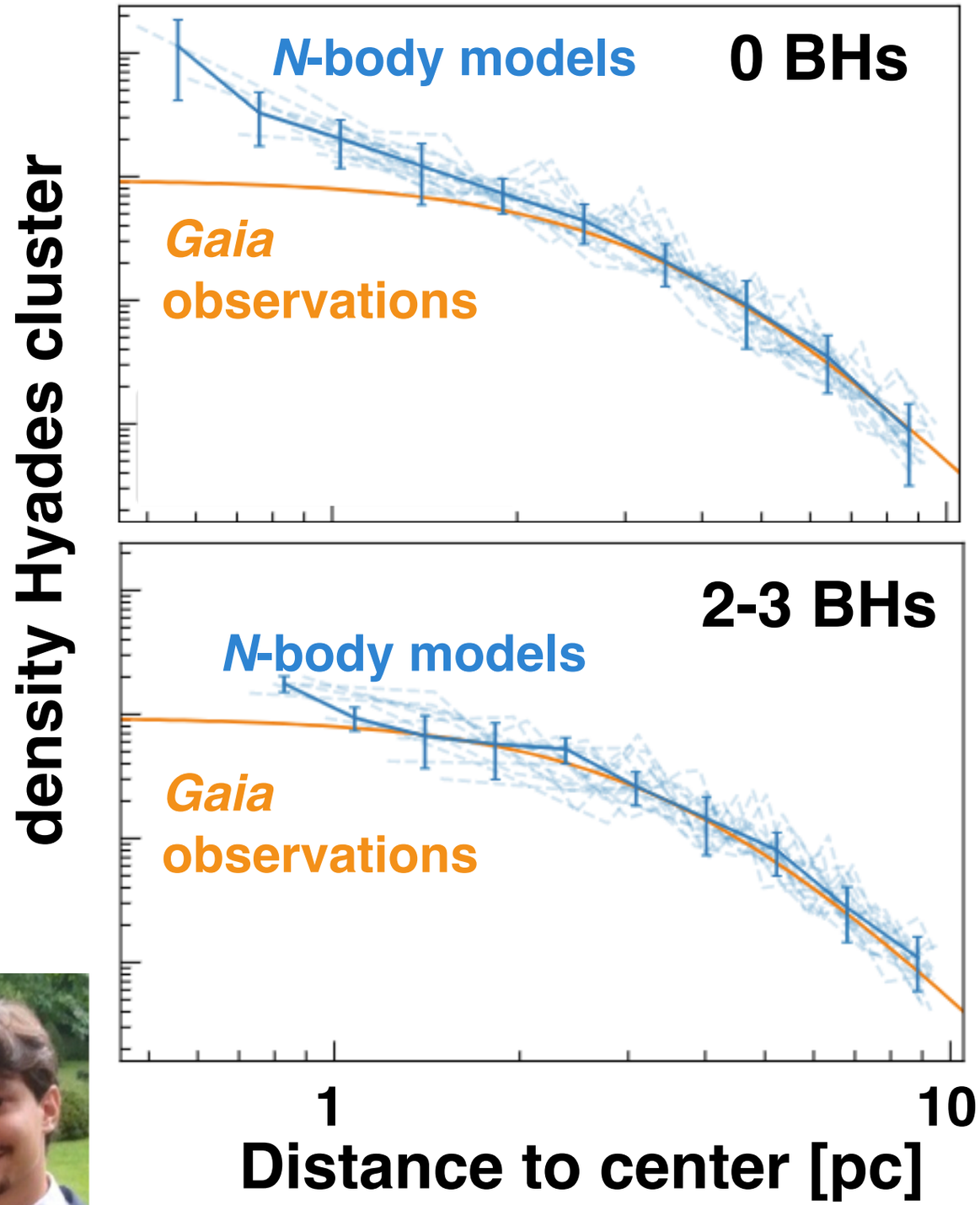


Low-mass clusters form BH binaries, triples, quadruples, etc. → GW capture

Marín & Gieles 2023, to be submitted



Torniamenti+ 2023, to be submitted

~50% of BBH mergers ($m_1 \gtrsim 20\,\mathrm{M}_\odot$) originate from globular clusters

Ongoing:
charting BH demographics in globular and open clusters

(Near) future:
O4 (18 May 2023), O5 (~2028), Einstein Telecope (~2035)