Black holes in star clusters

HRMOS Science Workshop
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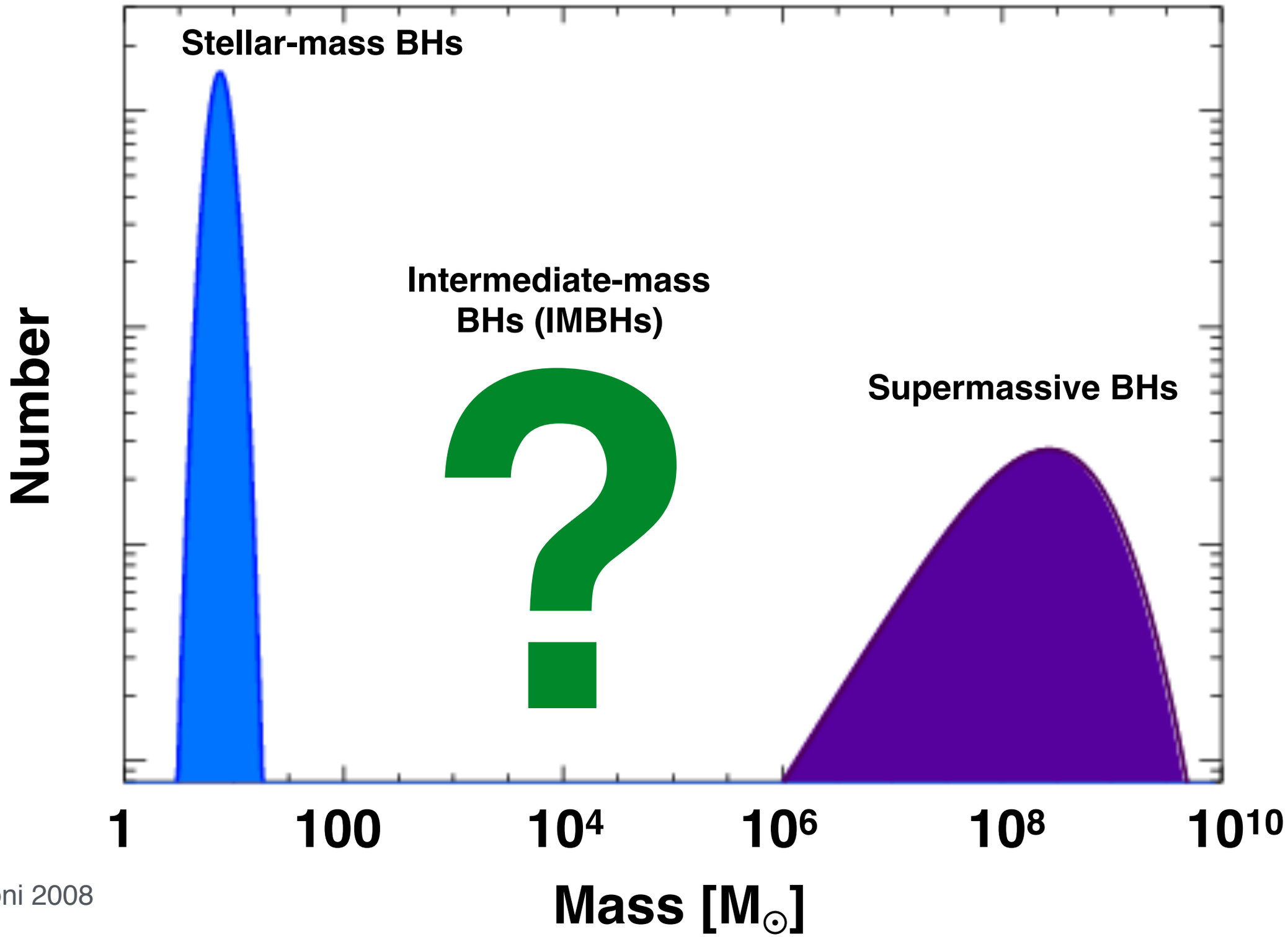
ICREA ICCUB Institut de Ciències del Cosmos UNIVERSITAT DE BARCELONA EXCELENCIA MARÍA DE MAEZTU 2020-2023 VIRGO GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Pal 5 Legacy Survey

Black holes in the Universe



Merloni 2008

IMBHs in globular clusters?

Yes! Newell+ 1976; Gerssen+ 2002

X-ray & cusp in velocity dispersion

No! Illingworth & King 1977; Baumgardt+ 2003

Neutron stars

Yes! Noyola+ 2008, 2010

Cusp in velocity dispersion

No! Anderson & van der Marel 2010; Zocchi+ 2017,2019; Baumgardt+ 2019

No cusp in HST proper motions; Degeneracy with stellar-mass BHs and radial velocity anisotropy

Yes! Lützgendorf+ 2011

$\sigma_0 \sim 25$ km/s

No! Lanzoni+ 2013

$\sigma_0 \sim 17$ km/s

Yes! Perera+ 2017

High pulsar acceleration

No! Gieles+ 2018; Baumgardt+ 2019

High density of white dwarfs

Yes! Kızıltan+ 2017

Velocity dispersion & radial distribution pulsars

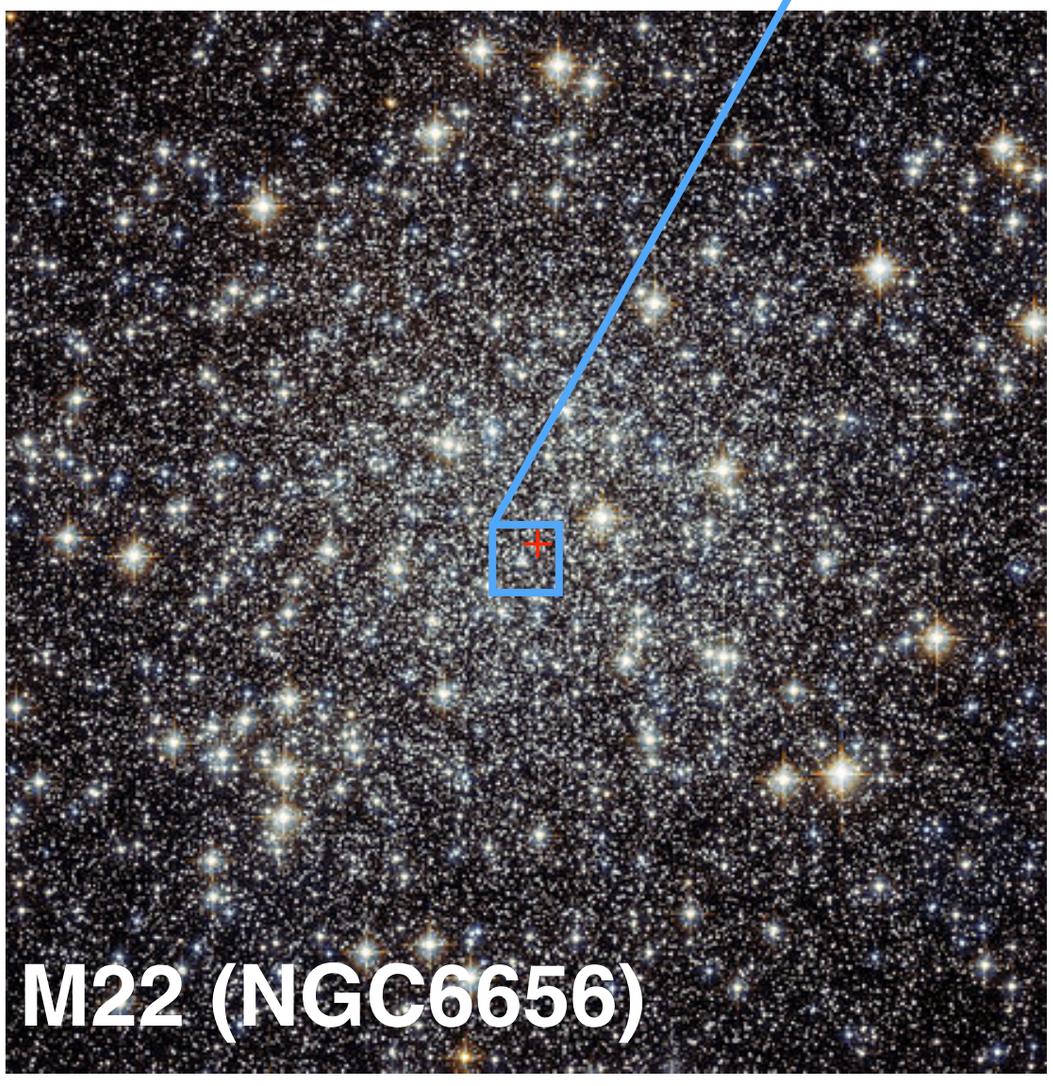
No! Hénault-Brunet+ 2020

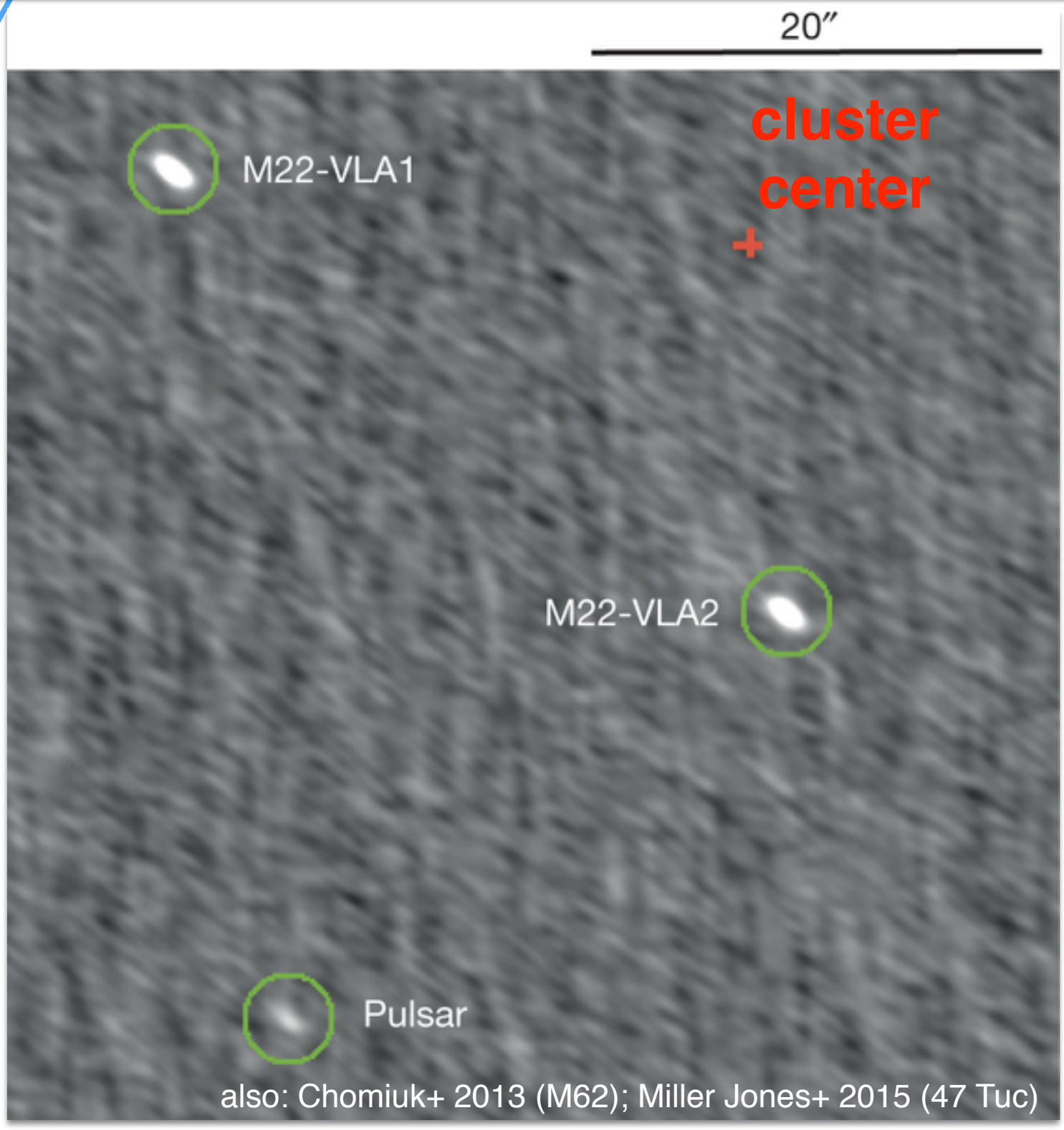
10% different cluster distance

Radio continuum constraints: $M_{IMBH} < 10^3\ M_\odot$ in 50 GCs

Strader+ 2012; Tremou+ 2018

but, stellar mass BHs!

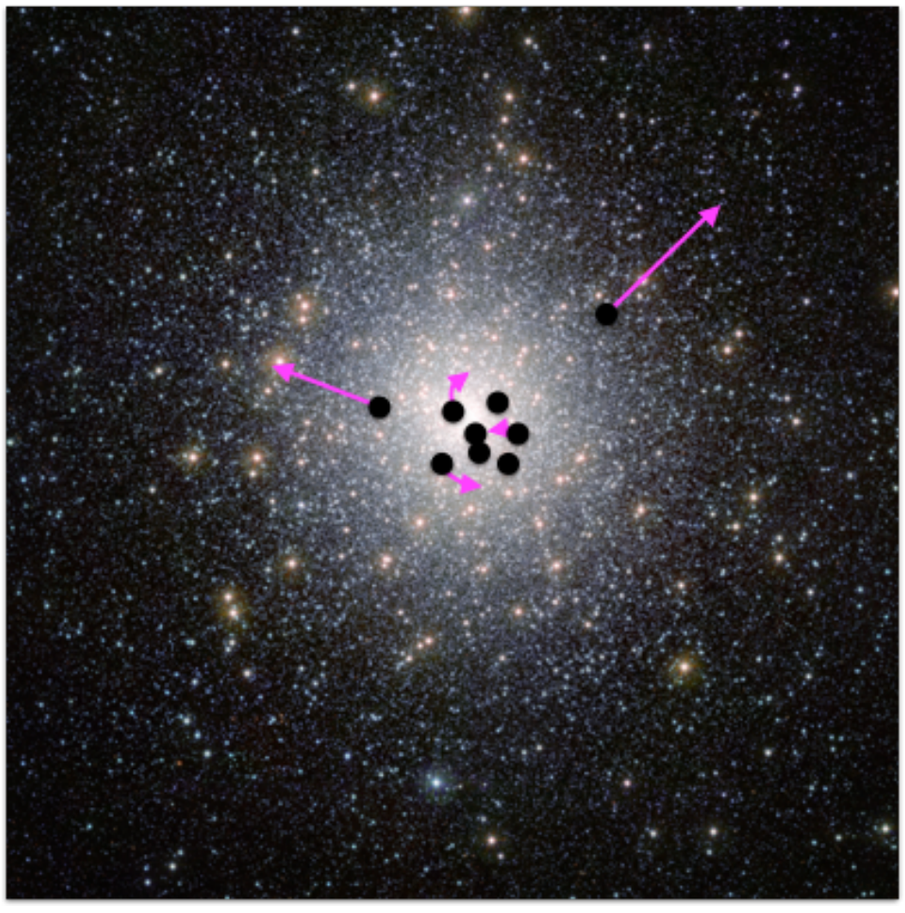




also: Chomiuk+ 2013 (M62); Miller Jones+ 2015 (47 Tuc)

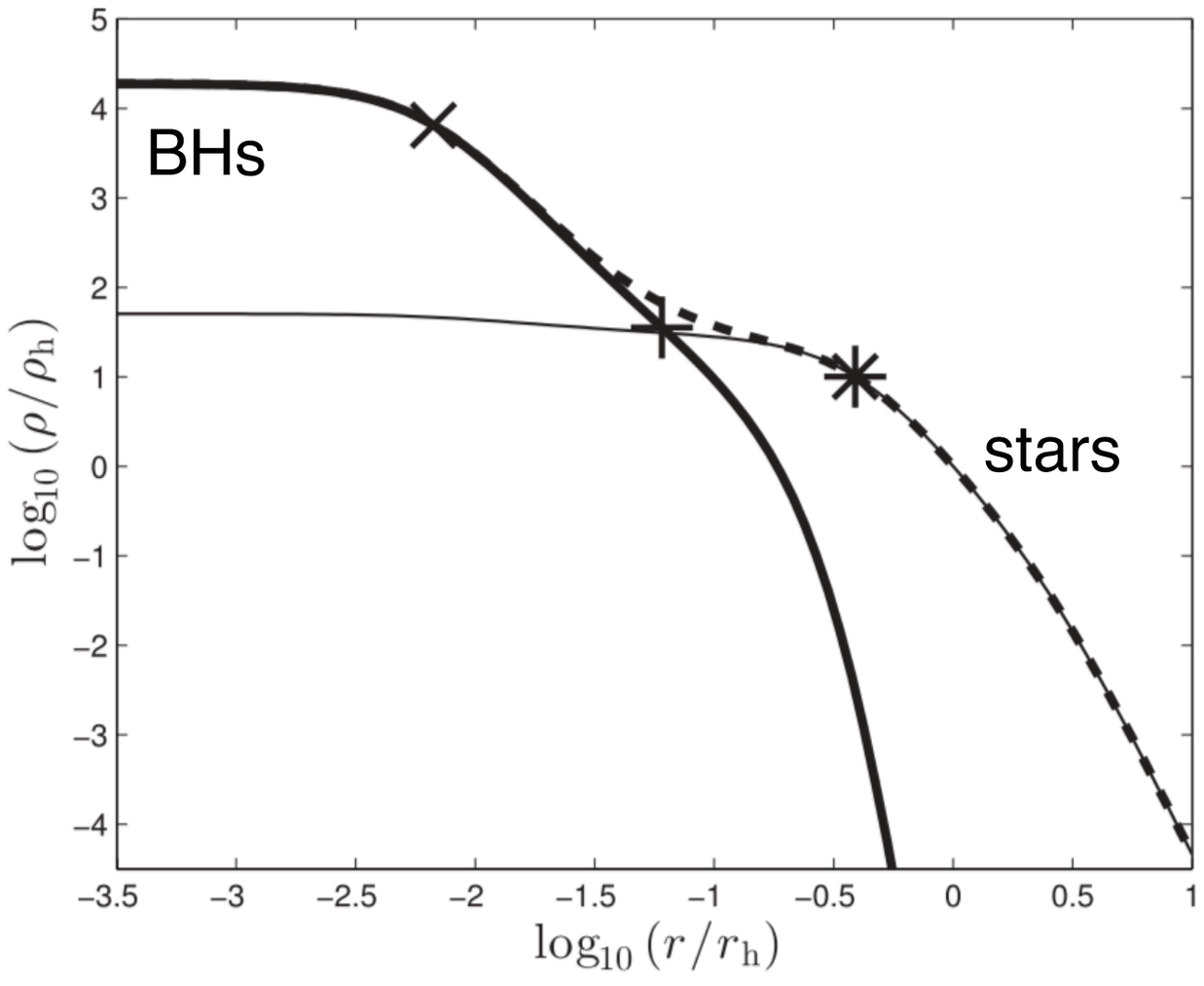
Stellar-mass BH populations are long lived!

We used to think:
Spitzer instability: rapid ejection of BHs



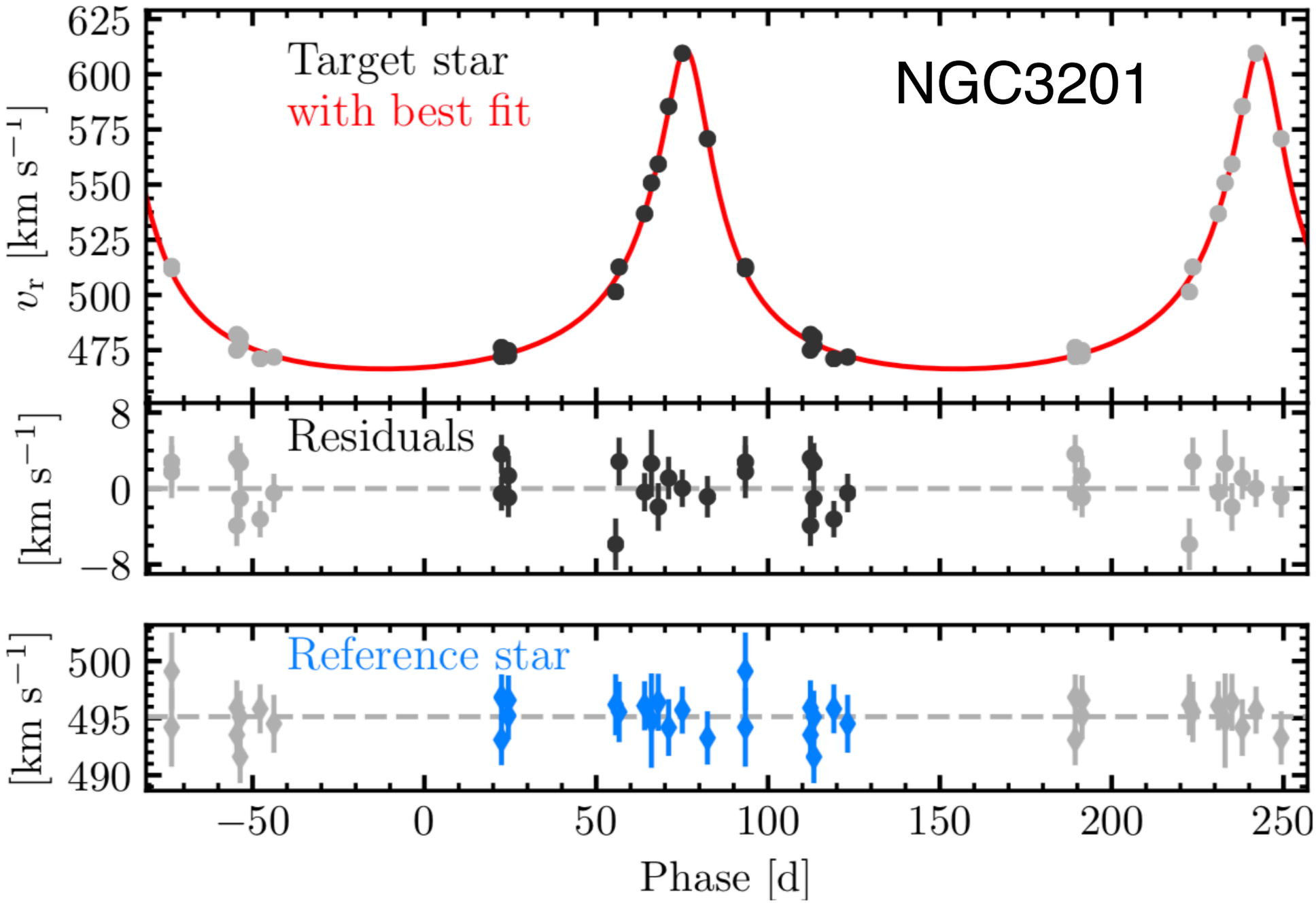
Spitzer 1969

Now we know:
BHs are energy source for GC dynamical evolution



Breen & Heggie 2013

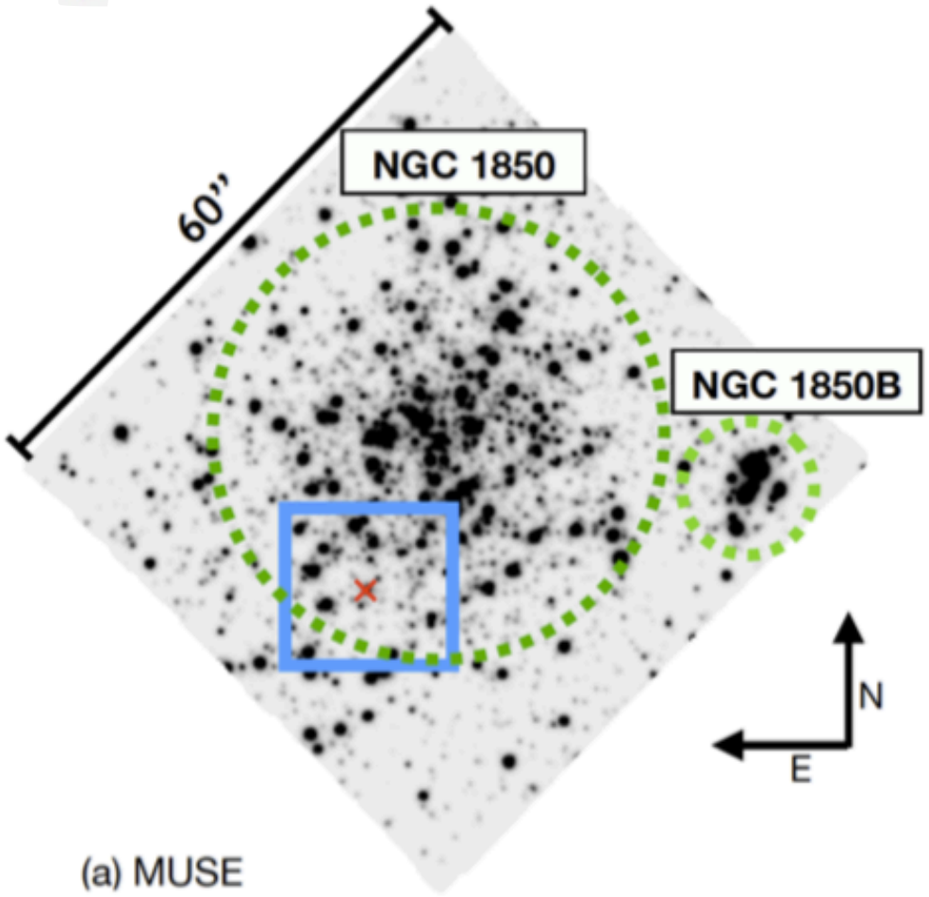
More BHs in GCs: 3 detached binaries with $M_\bullet > 4\ M_\odot$

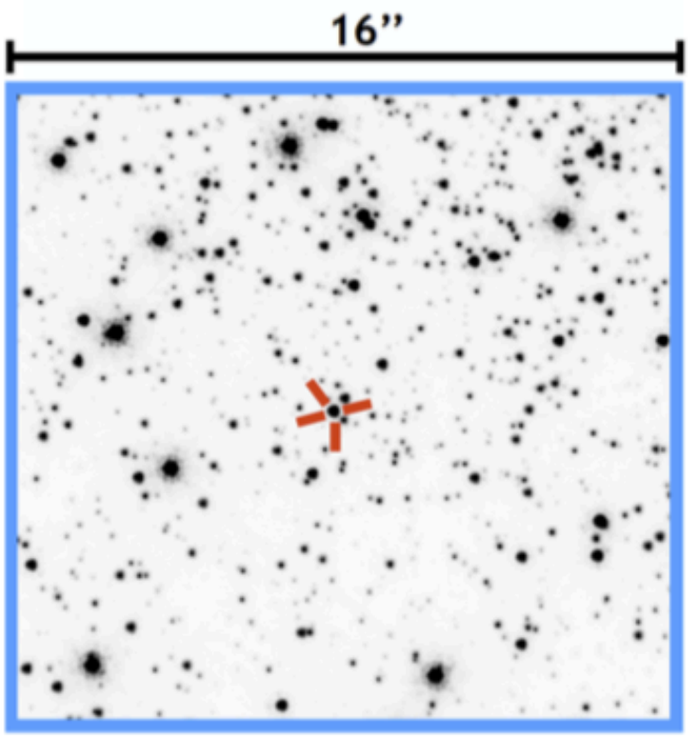


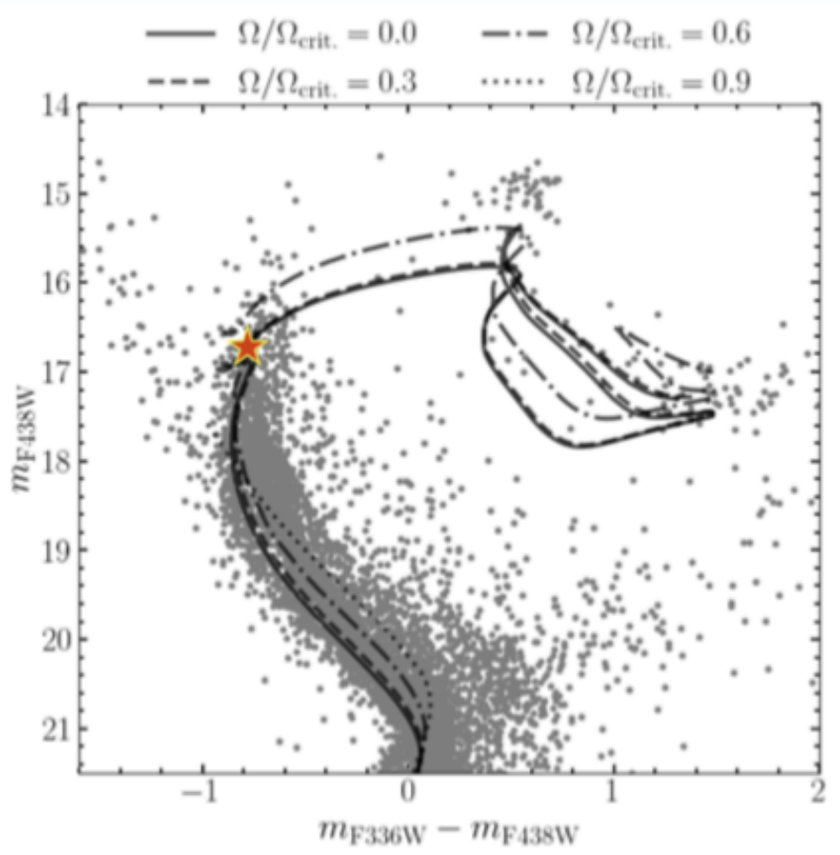
Giesers+ 2018, 2019

A semi-detached binary in 100 Myr cluster: $M_\bullet \simeq 11\ M_\odot$

NEW







Saracino+ submitted

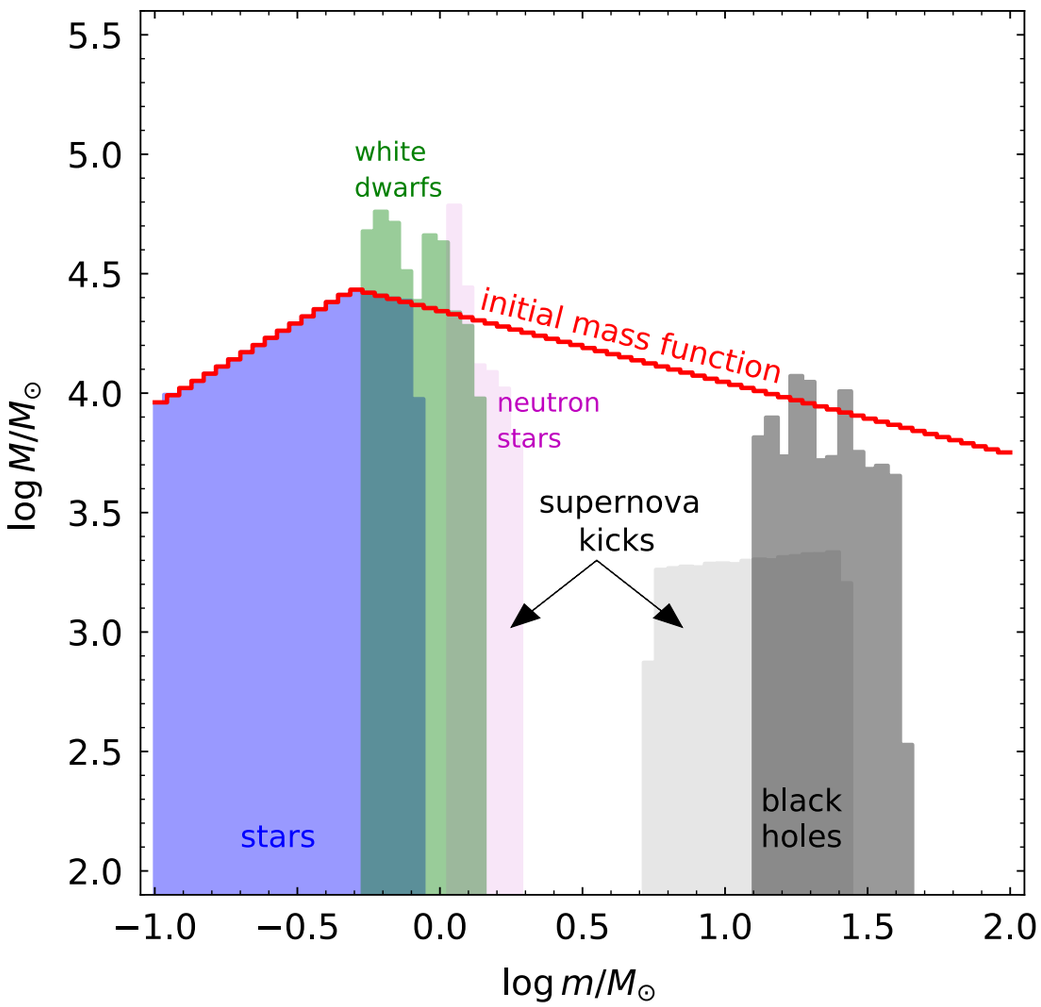
How many BHs can we expect?

IMF = Kroupa 2001

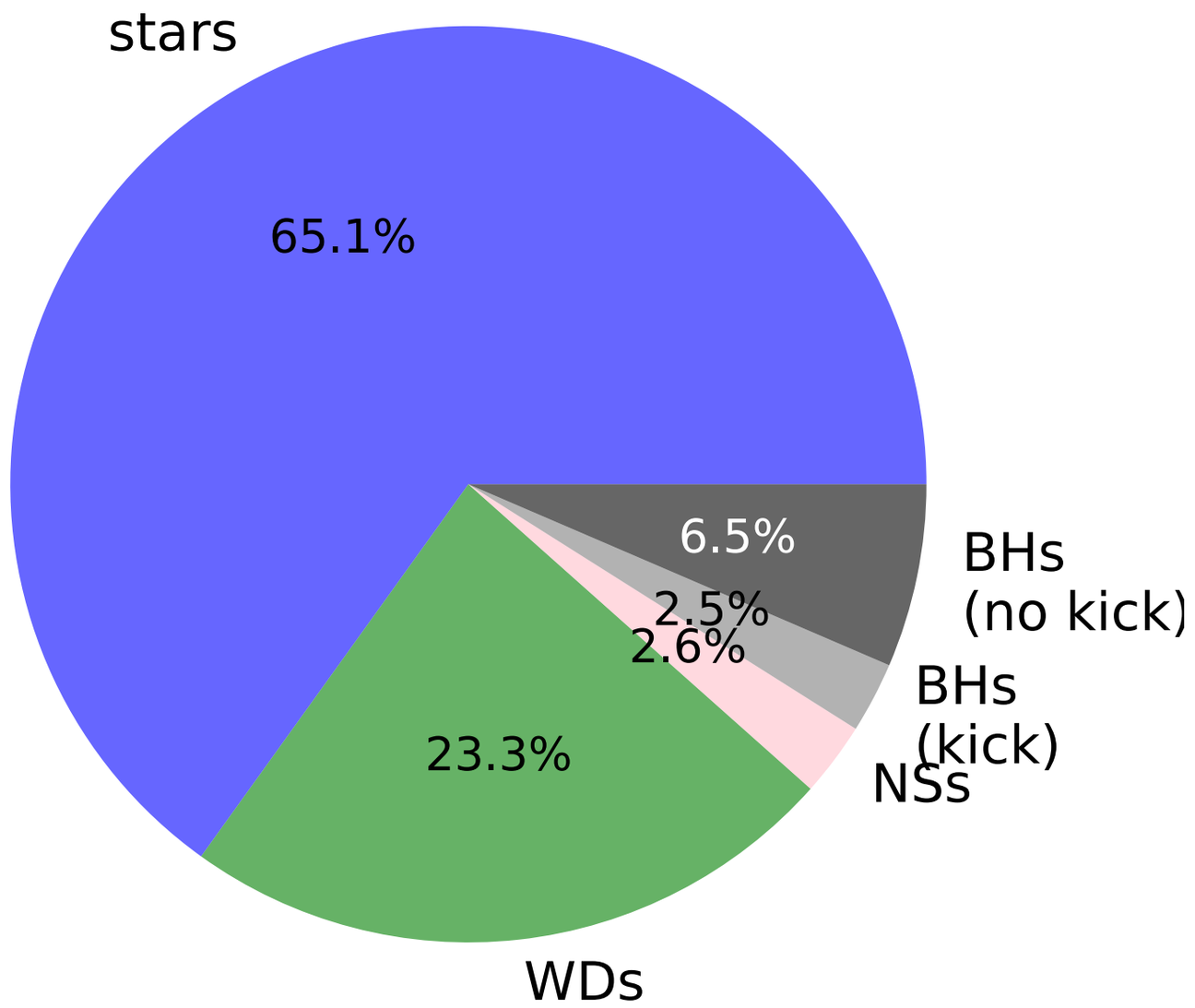
Mass = $10^6\ M_\odot$

[Fe/H] = -1.5

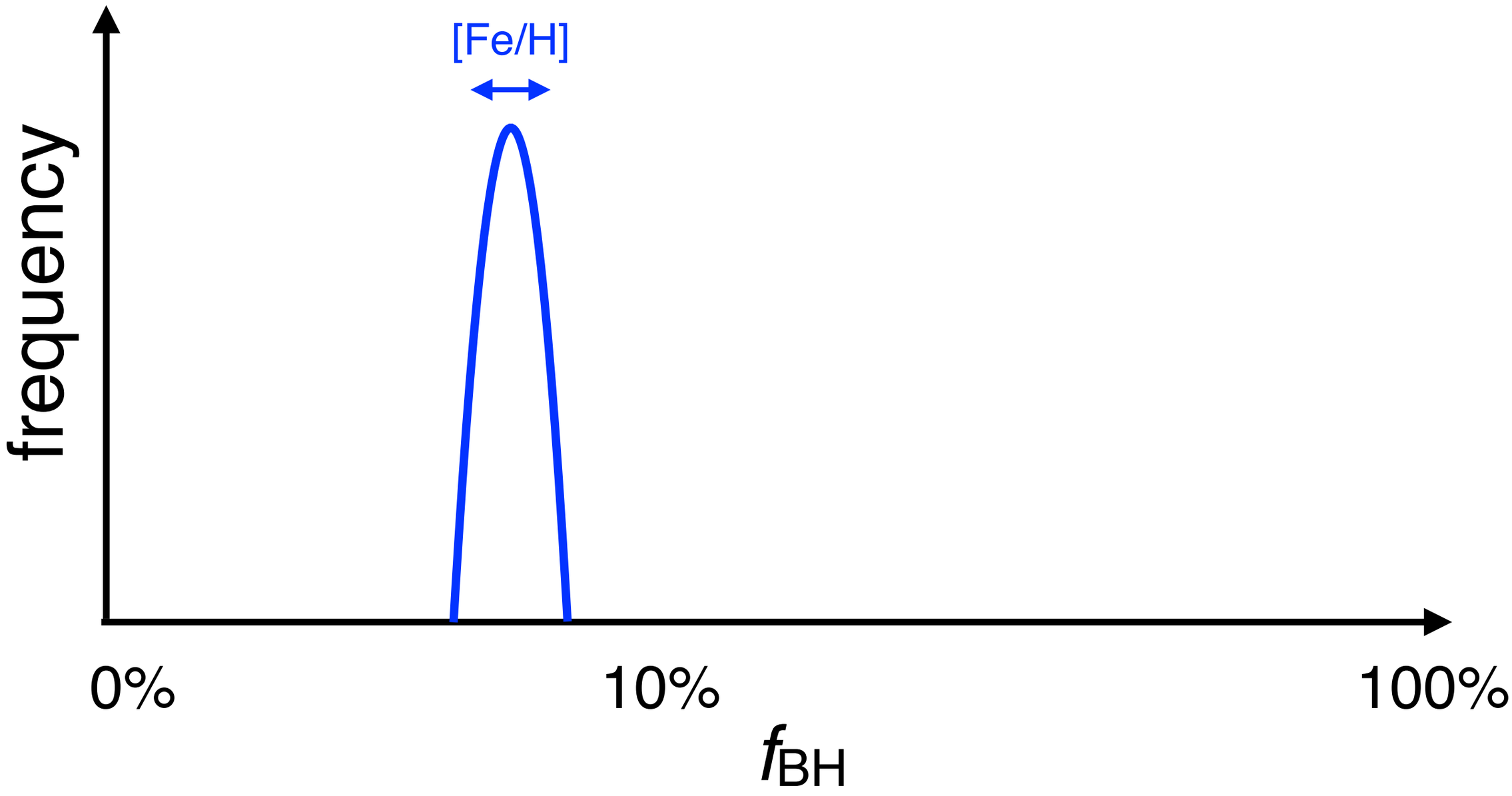
Evolve with SSE Hurley+ 2000; Banerjee 2020



mass fractions @12 Gyr



How many BHs can we expect in clusters?

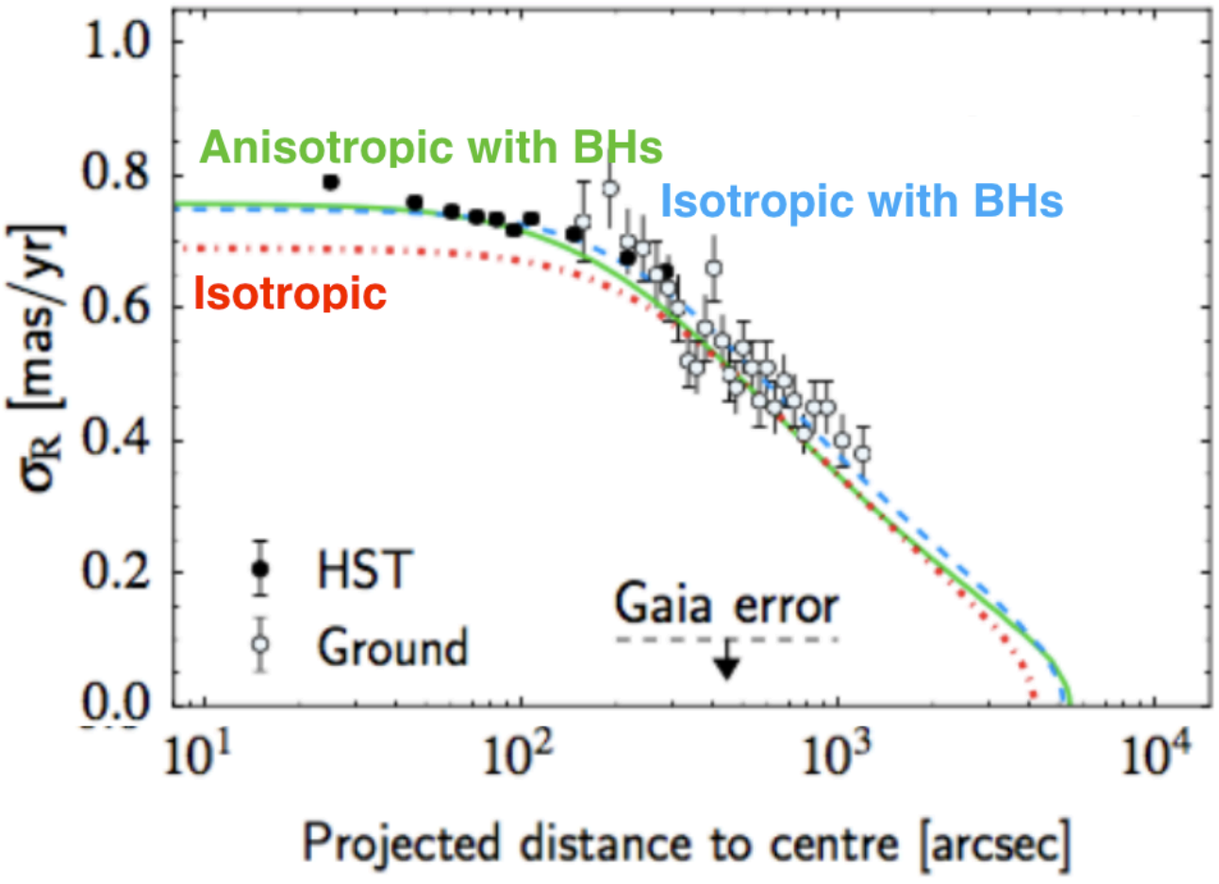


10^5 $M_\odot$ black hole population in Omega Centauri

5% of total mass!

velocity dispersion

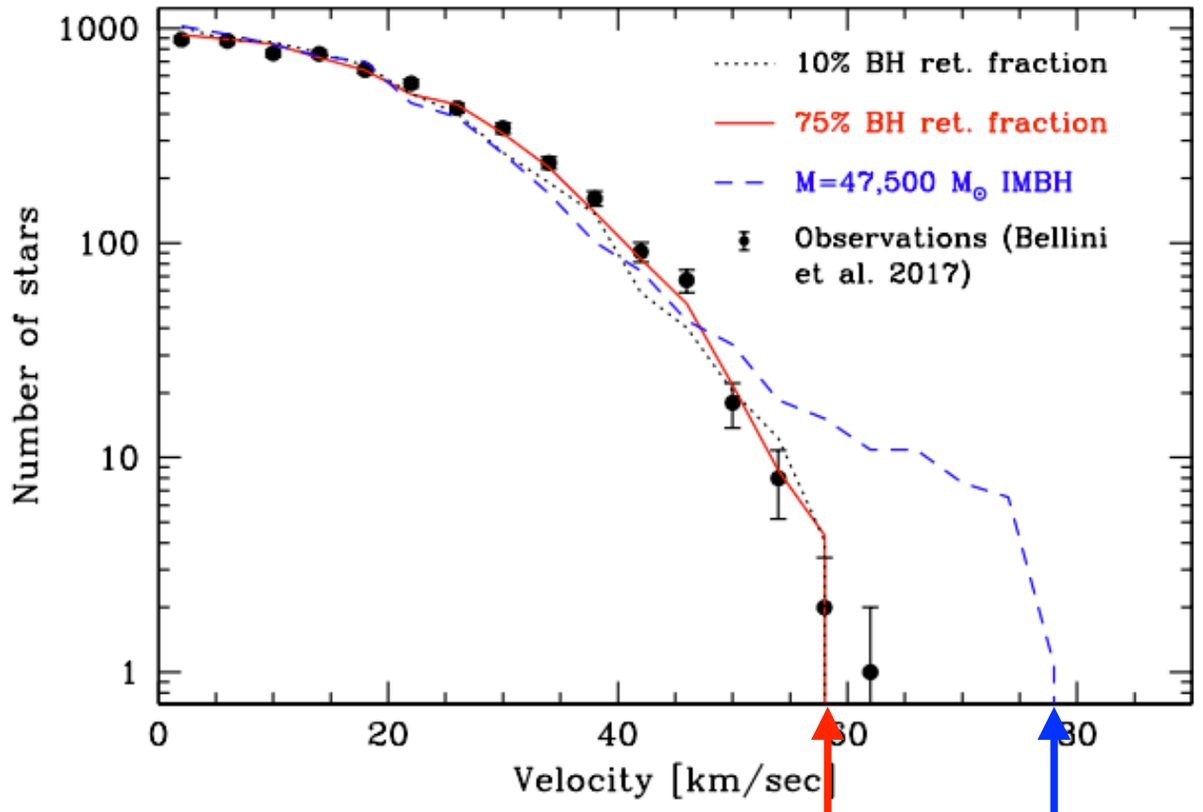
DF-based models (`limepy`)



Zocchi+ 2019

LOS velocity distribution

N-body models



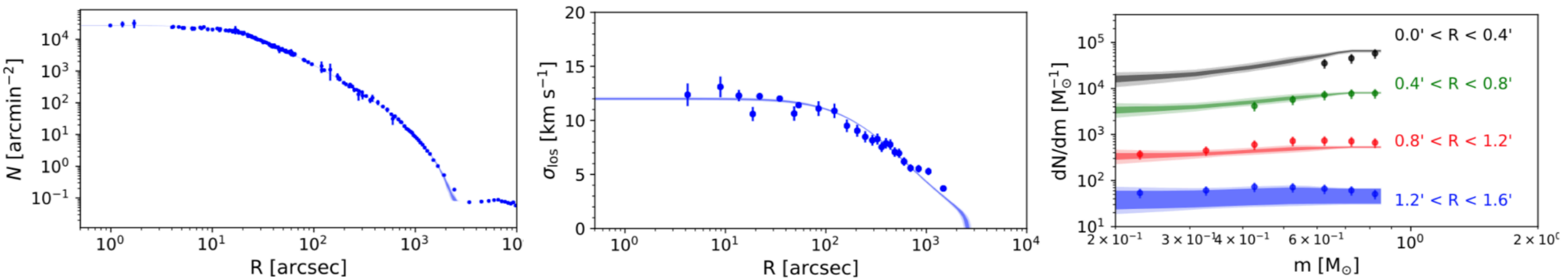
Baumgardt+ 2019

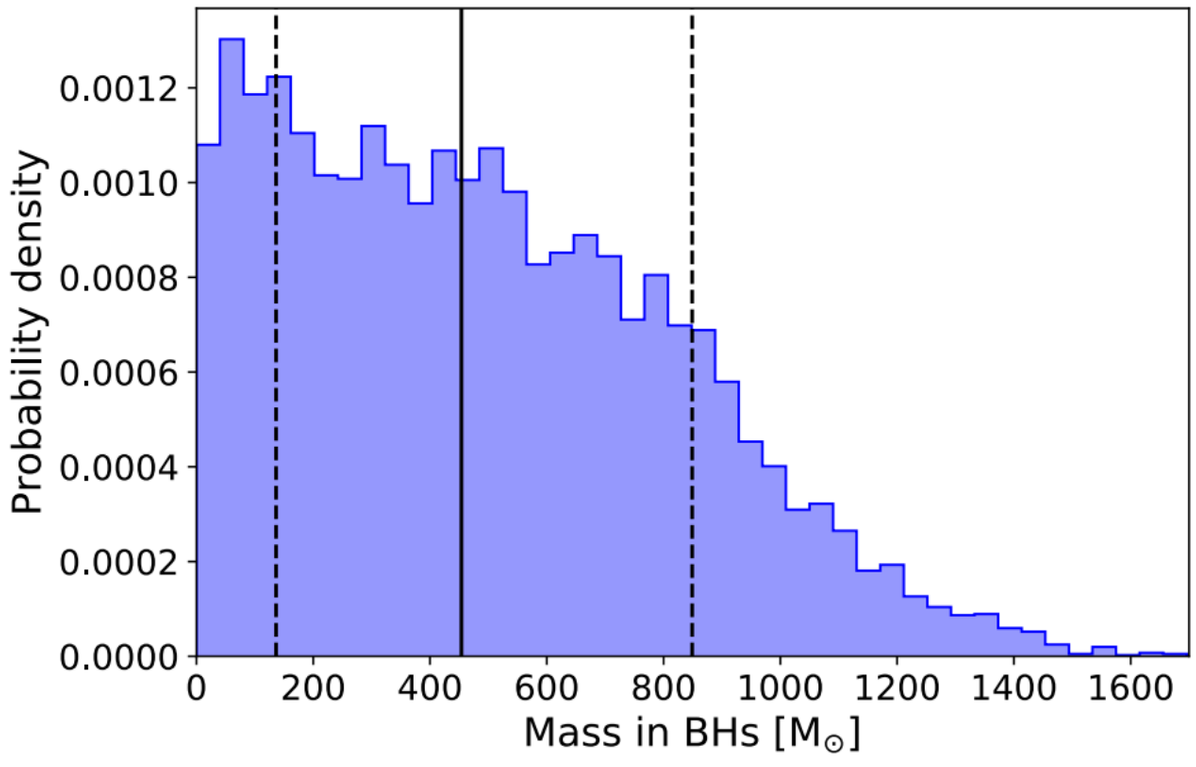
model with stellar-mass BH

model with IMBH

Some BHs in 47 Tuc

surface brightness + kinematics + stellar mass function





Similar results from dynamical Monte Carlo models:

~20 BHs

Giersz & Heggie ’11

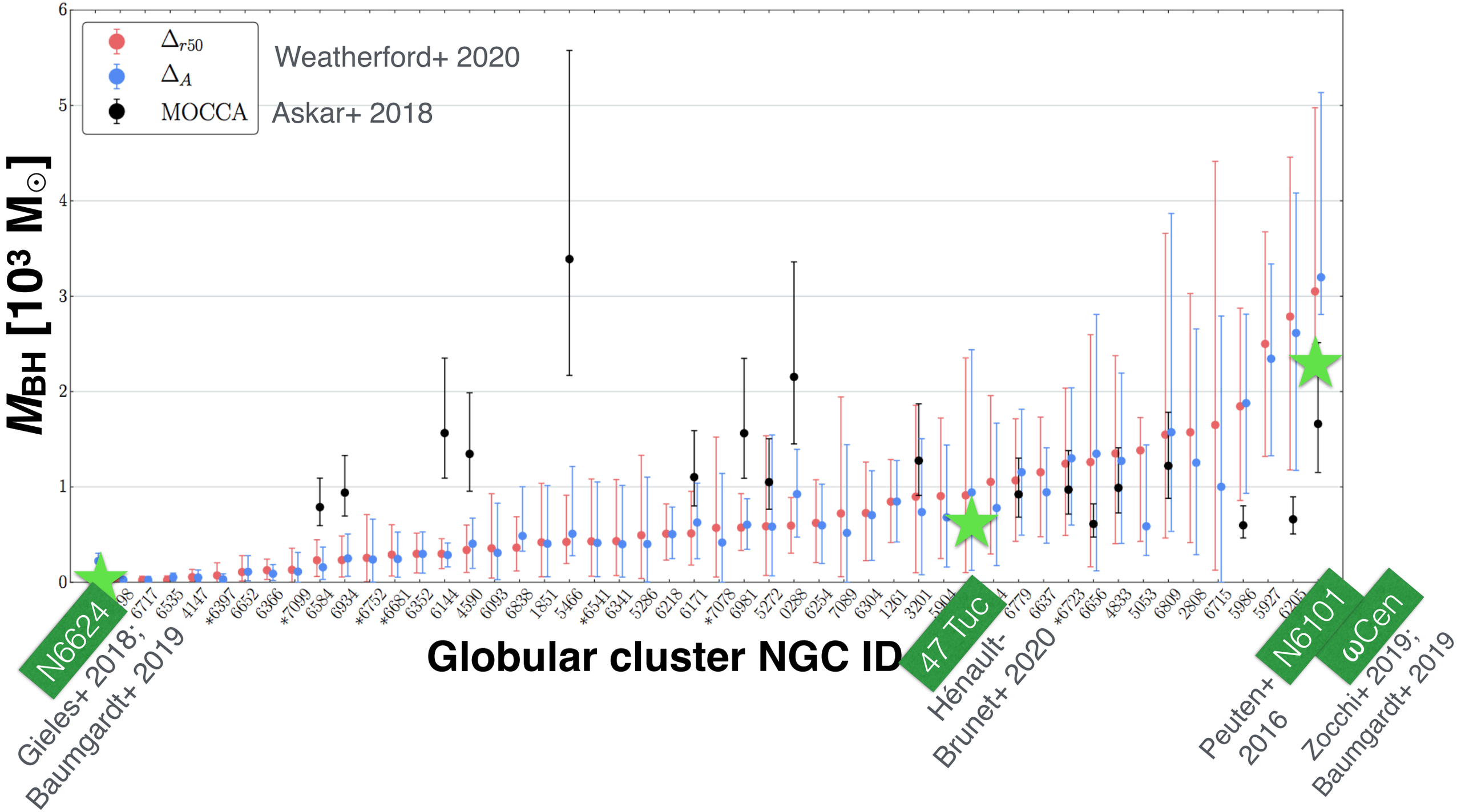
~300 BHs

Weatherford+ 2020

Hénault-Brunet+ 2020

BH populations in Milky Way GCs

GC structural properties & dynamical modelling



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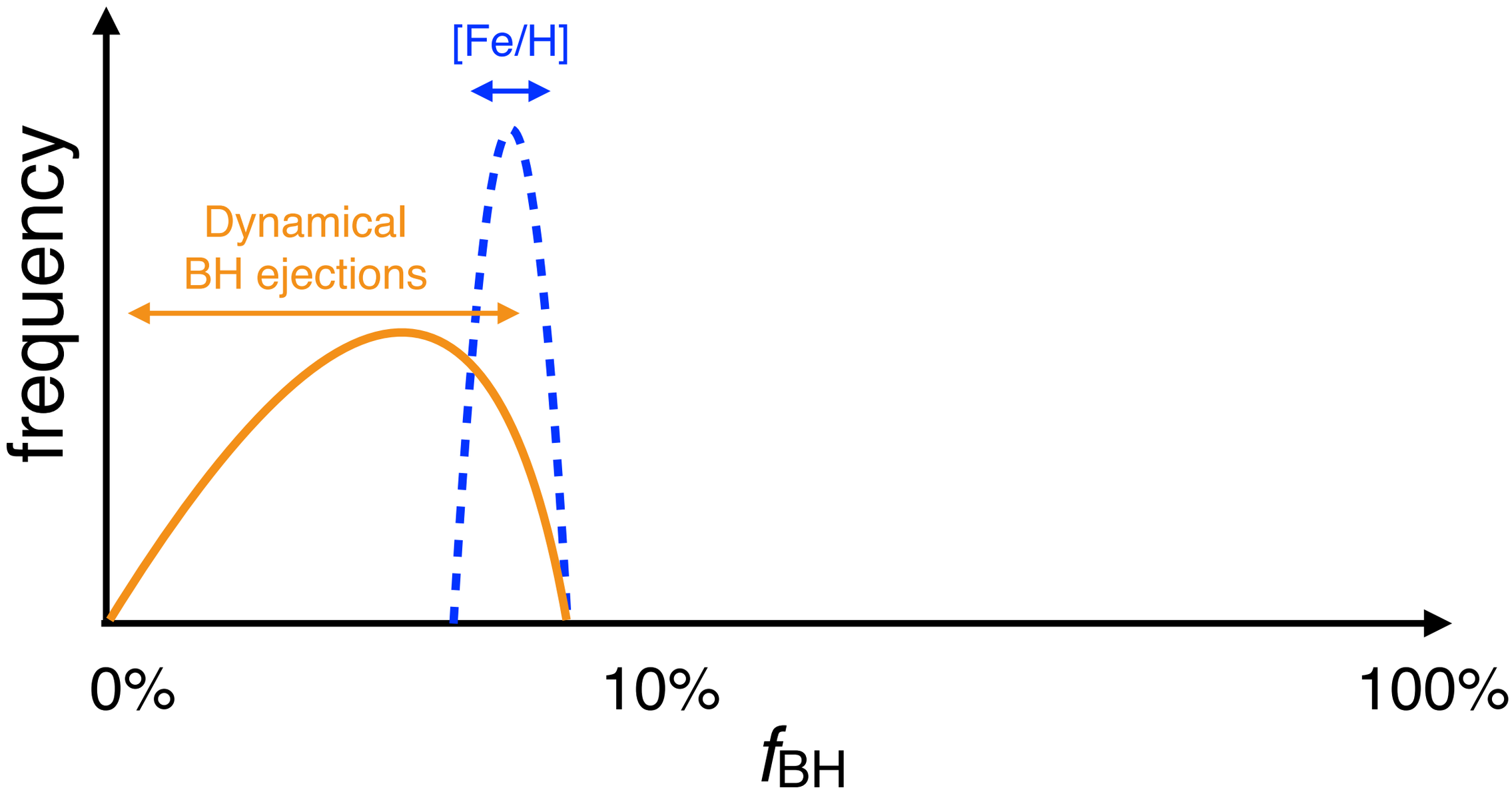
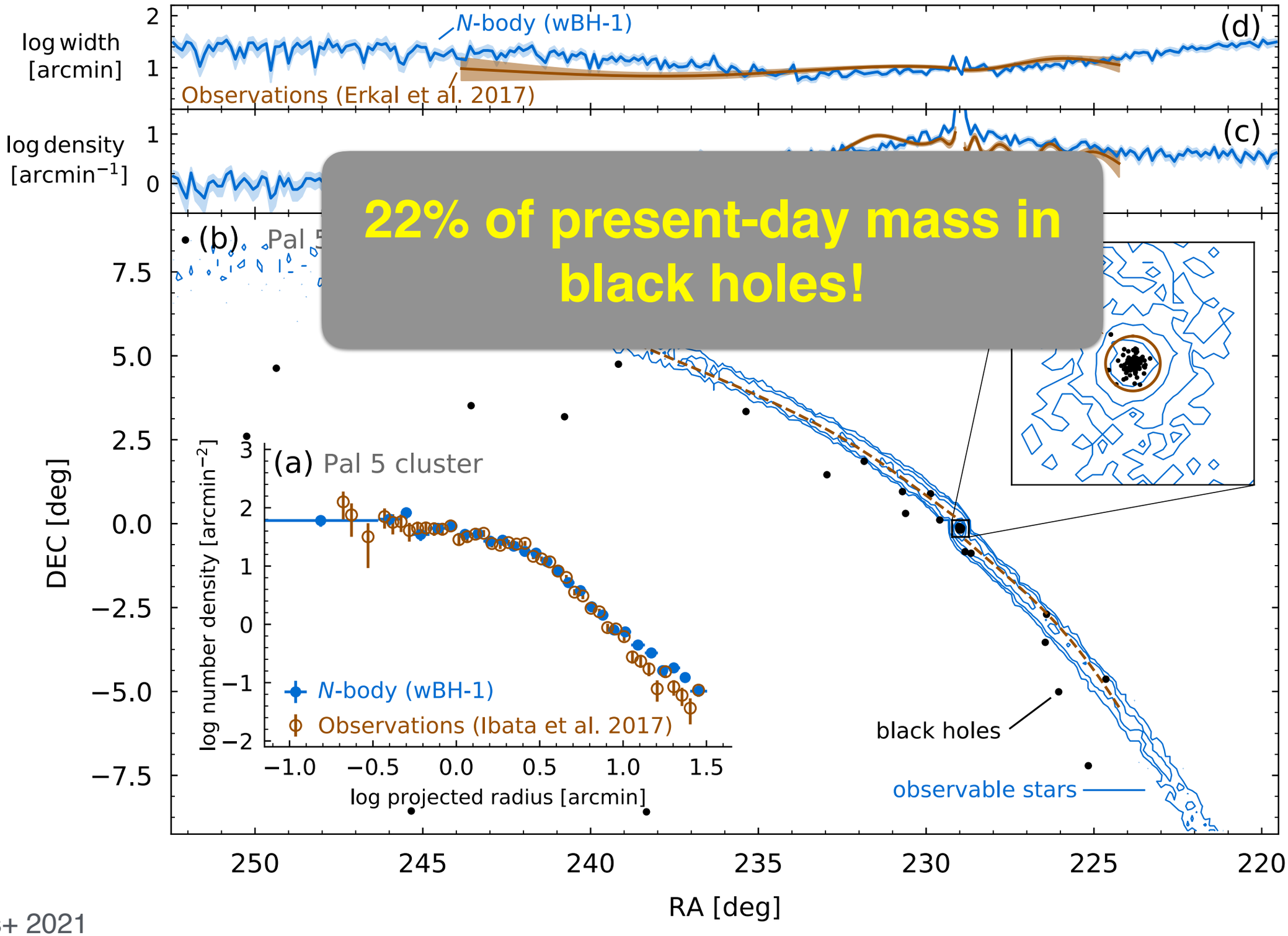
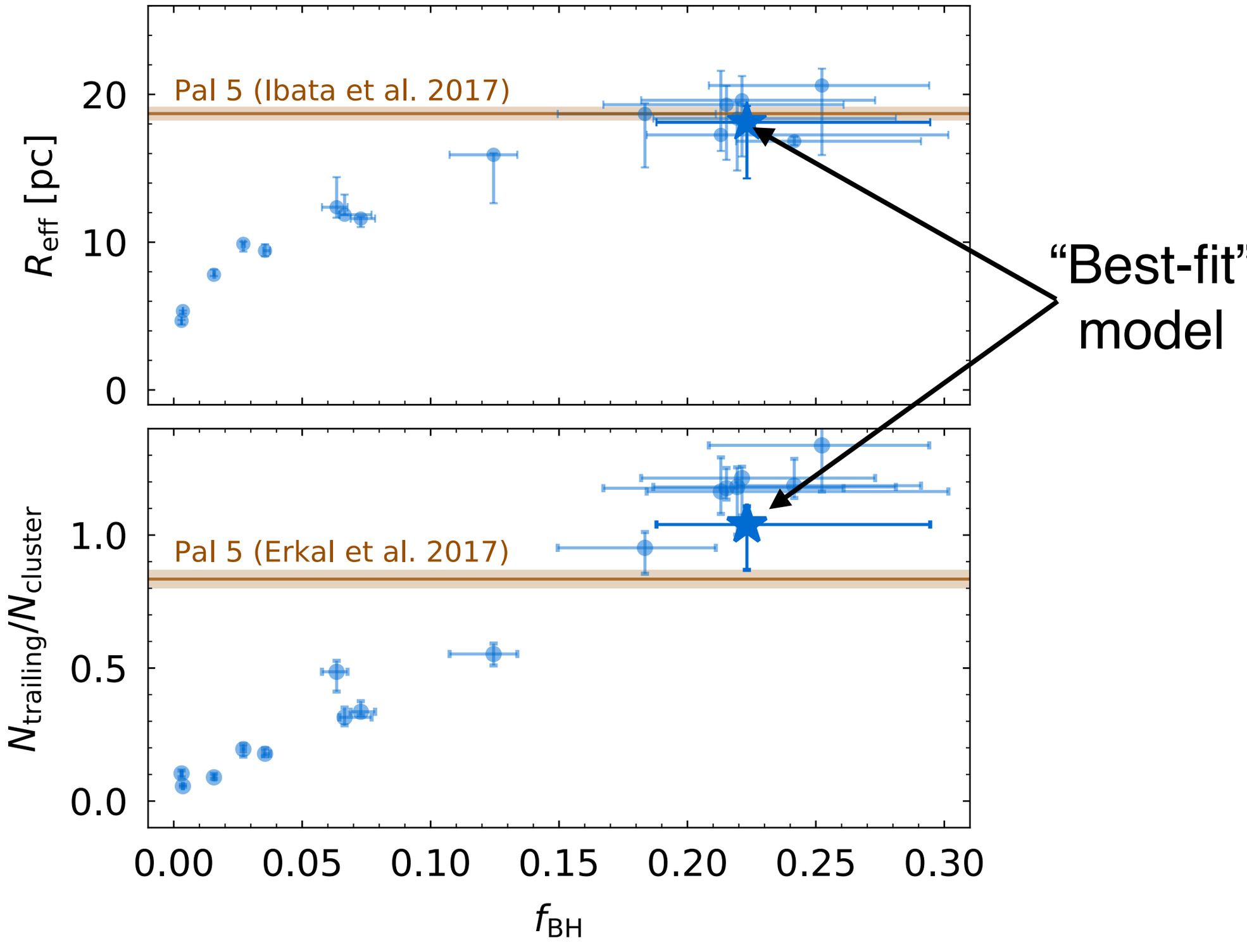


BHs needed to explain size and tidal tails of Pal 5



Gieles+ 2021

R_{eff} and tails as a proxy for BHs



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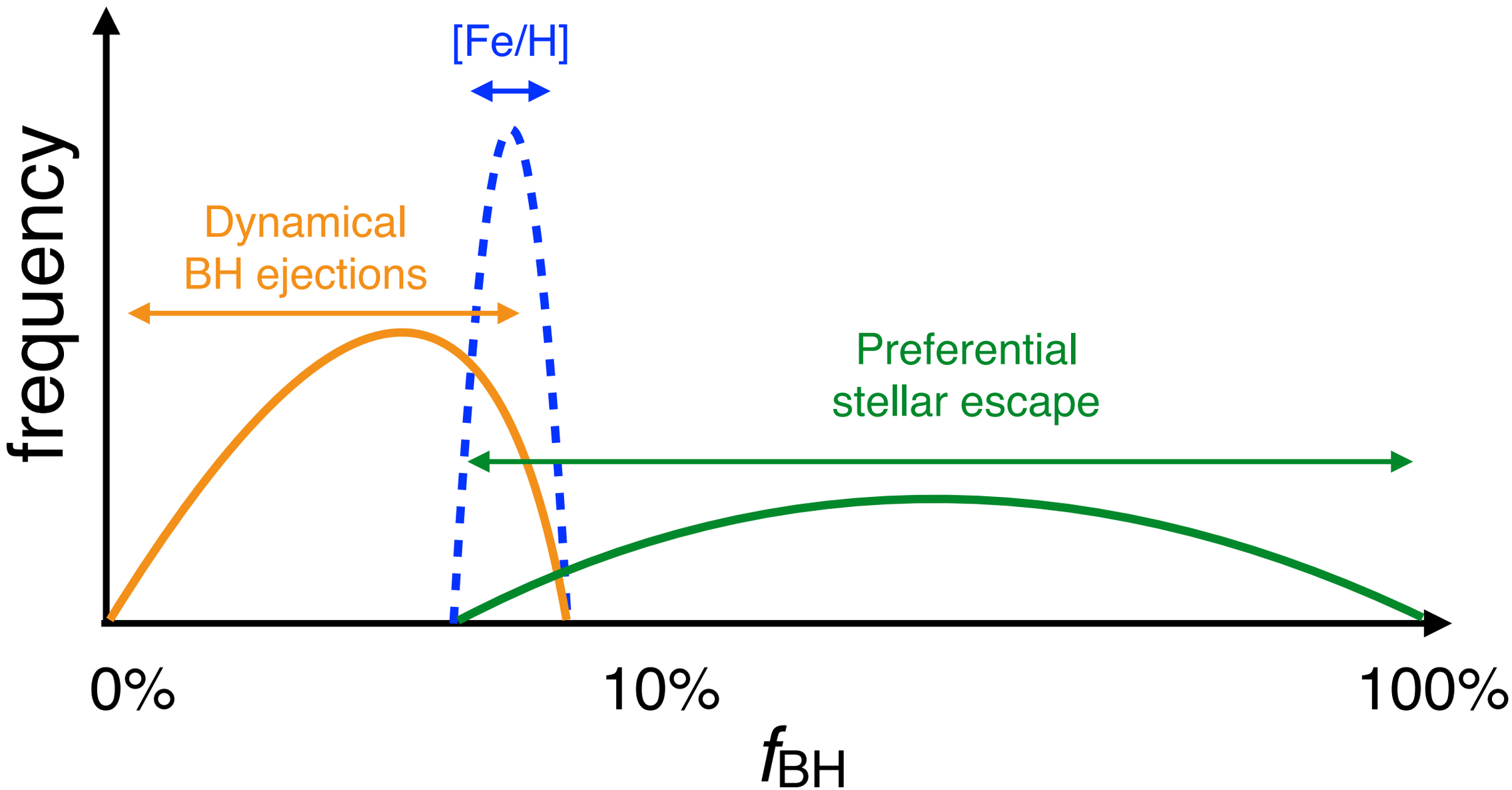
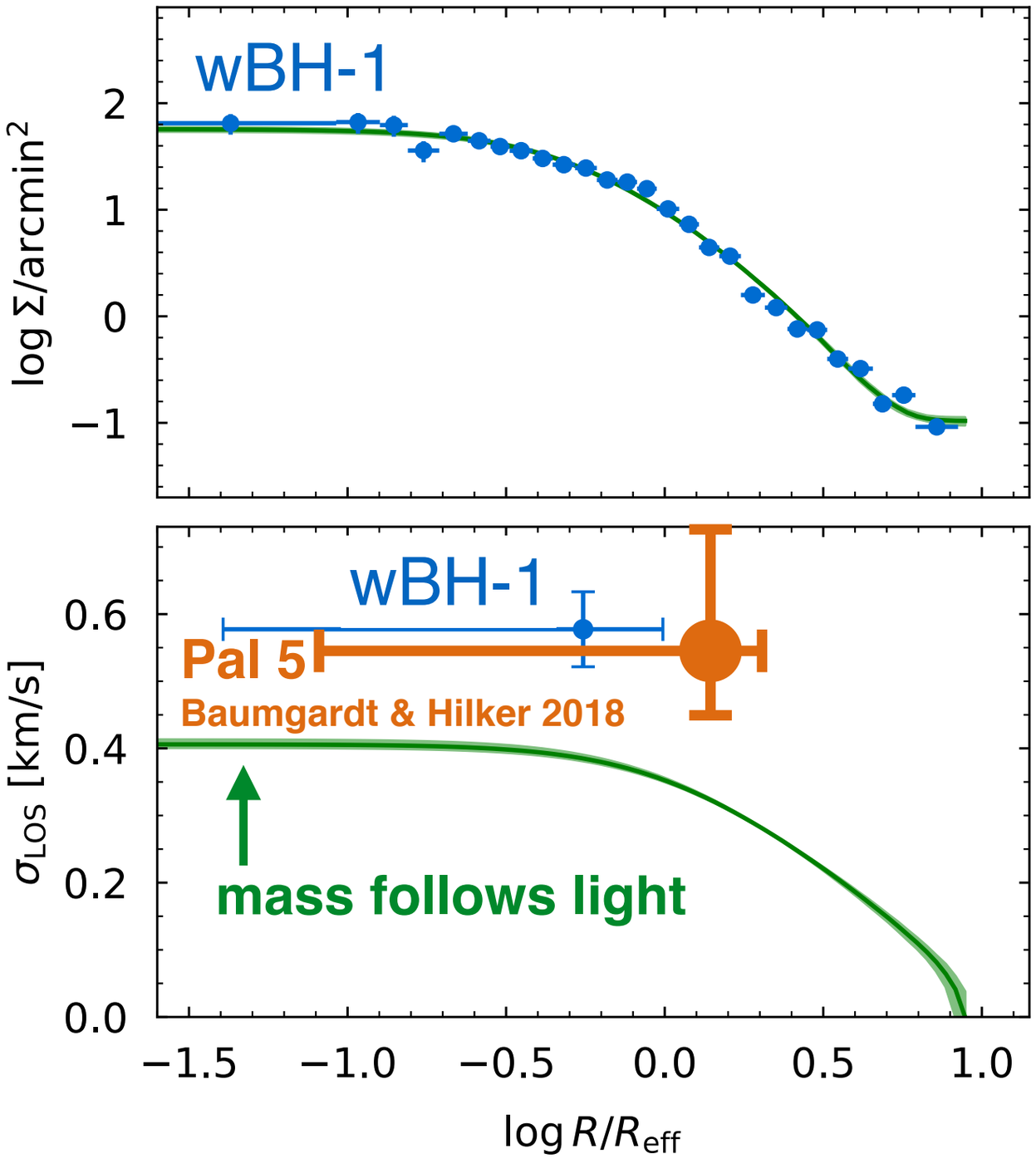
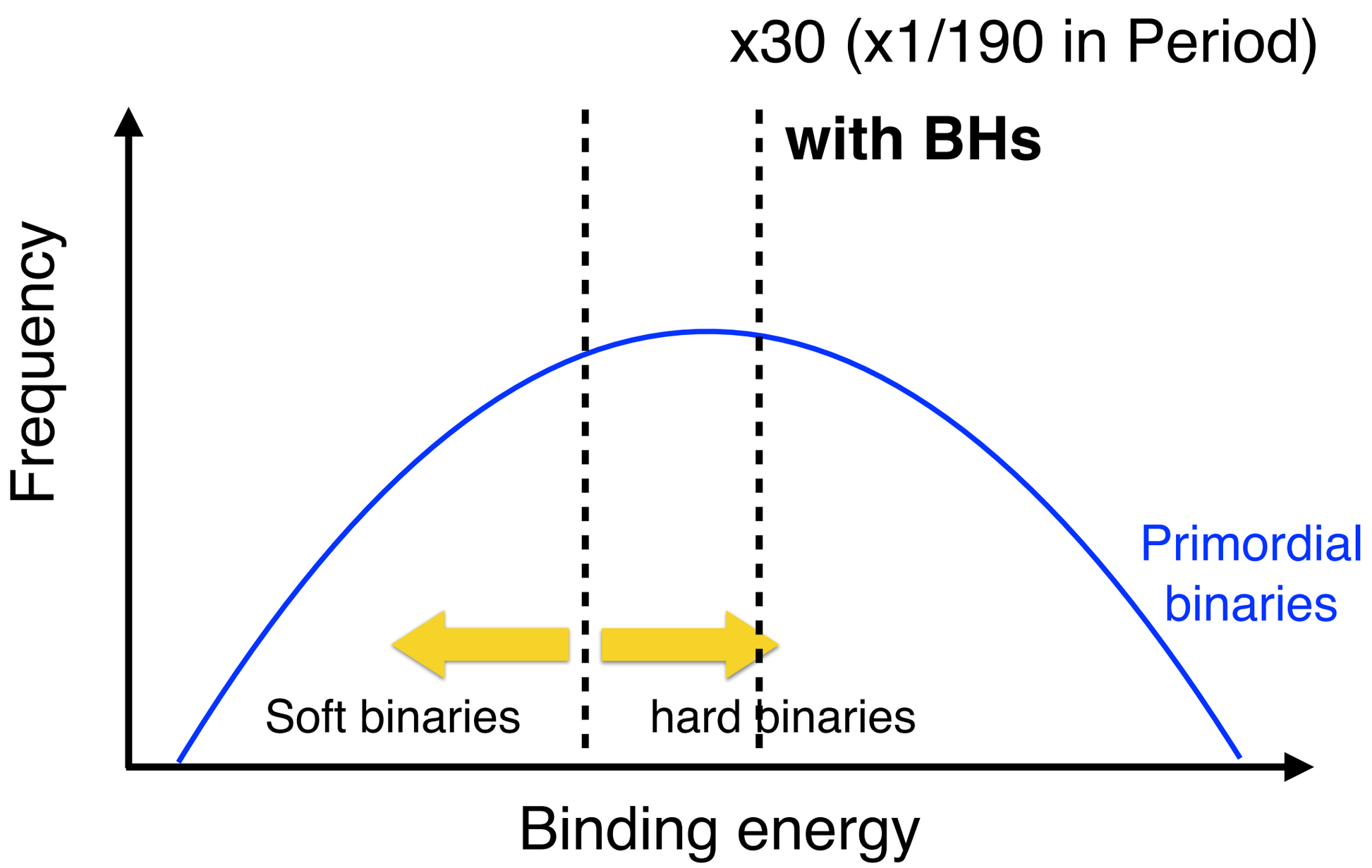


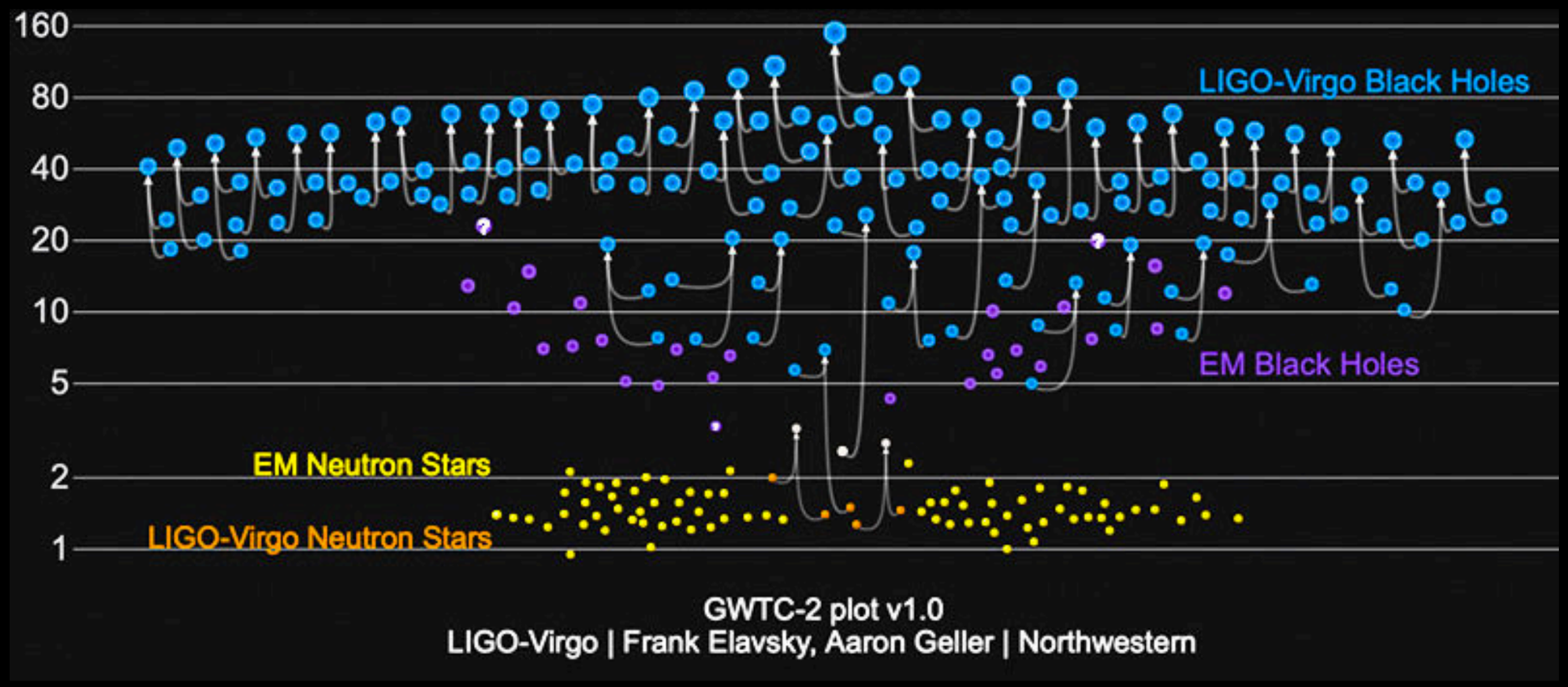
Prediction for Pal 5: velocity dispersion ~50% elevated



Imprints of BHs in binaries



Origin of gravitational wave sources?



or

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

Portegies & Zwart & McMillan 2000; Rodriguez+ 2015; Farr+ 2017; Silsbee & Tremaine 2017; Antonini+ 2018; Hong+ 2018; Rodriguez & Loeb 2018; Banerjee 2019, 2021; Antonini & Gieles 2020a,b

Charting the demographics of BHs in GCs *and open clusters*

Individual BHs

Radio

M22, M62, 47 Tuc Strader+ 2012, Chomiuk+ 2013; Miller Jones+ 2015

RV variations

NGC 3201 Giesers+ 2018, 2019 NGC 1850 Saracino+ submitted

HRMOS

BH populations

Structural properties of GC

Core radius/half-light radius Askar+ 2018; Kremer+ 2019

Degree of mass segregation Peuten+ 2016; Allesandrini+ 2016; Weatherford+ 2018, 2020

Dynamical modelling

Velocity dispersion, LOSVD + multimass DF/*N*-body modelling

Peuten+ 2016; Zocchi+ 2017, 2019; Baumgardt+ 2019; Hénault-Brunet+ 2020

Binaries

Binding energy/Period distribution