Black Hole Seeds

Discover black hole binary coalescences at the "extremes"
with a network of 3G detectors

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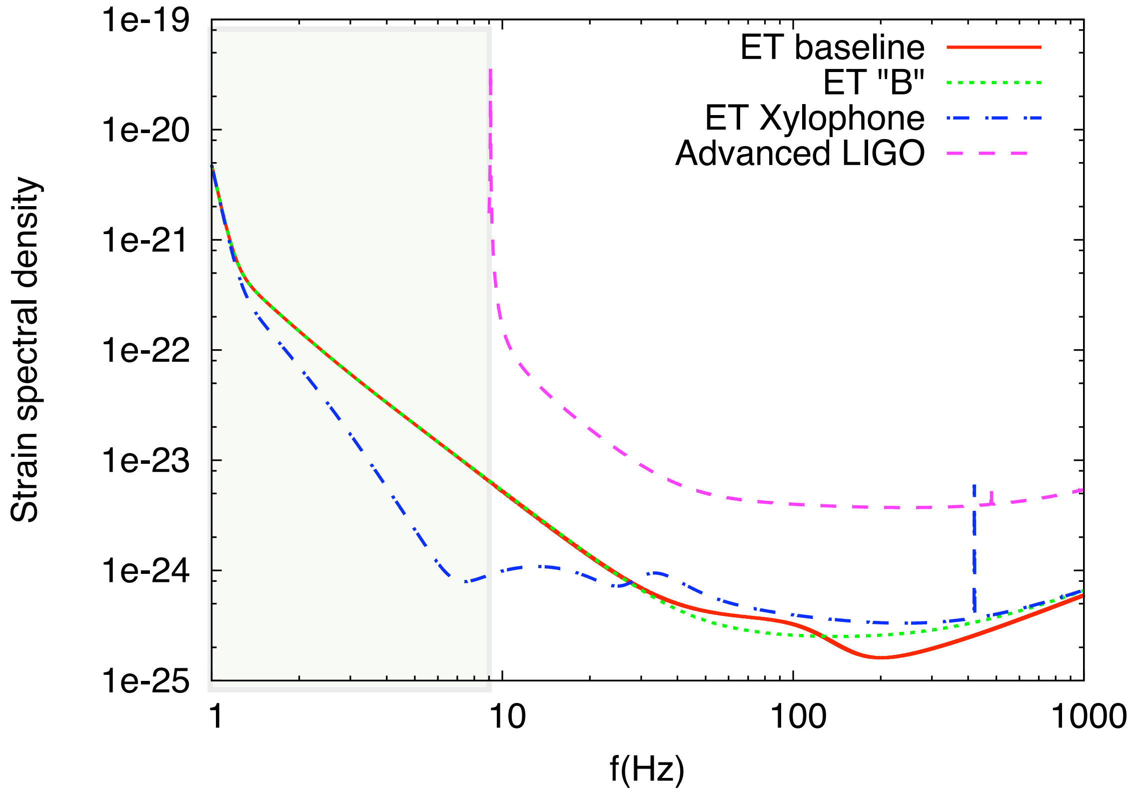
on behalf of the
"Black Hole Seed WG"

Panel Discussion: Cole, Mapelli, Valiante

3FSCT meeting
October 1st, 2018
Potsdam

Black Holes @ Extremes

Extending the sensitivity down to ~ Hz in frequency will let us detect extreme systems with a network of 3G detectors



<u>unique probe for transformational science</u>

<u>discovery of heaviest black holes</u>

(language of stars)

highest redshifts

shortest duration signals

weakest signals

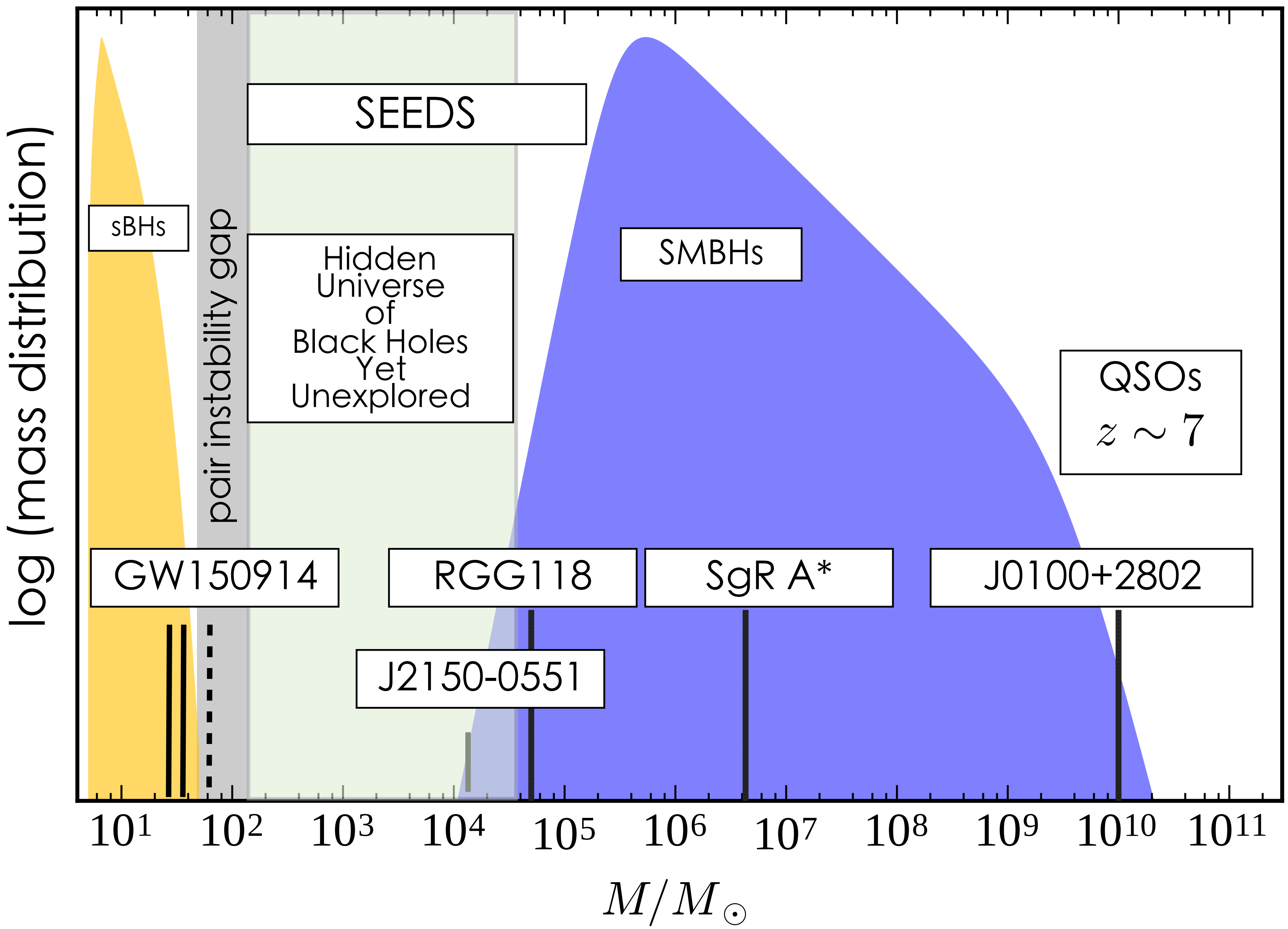
highest mass ratios (1:10)

extreme waveforms (IMRIs)

$(100, 1000)\ \mathrm{M}_\odot$

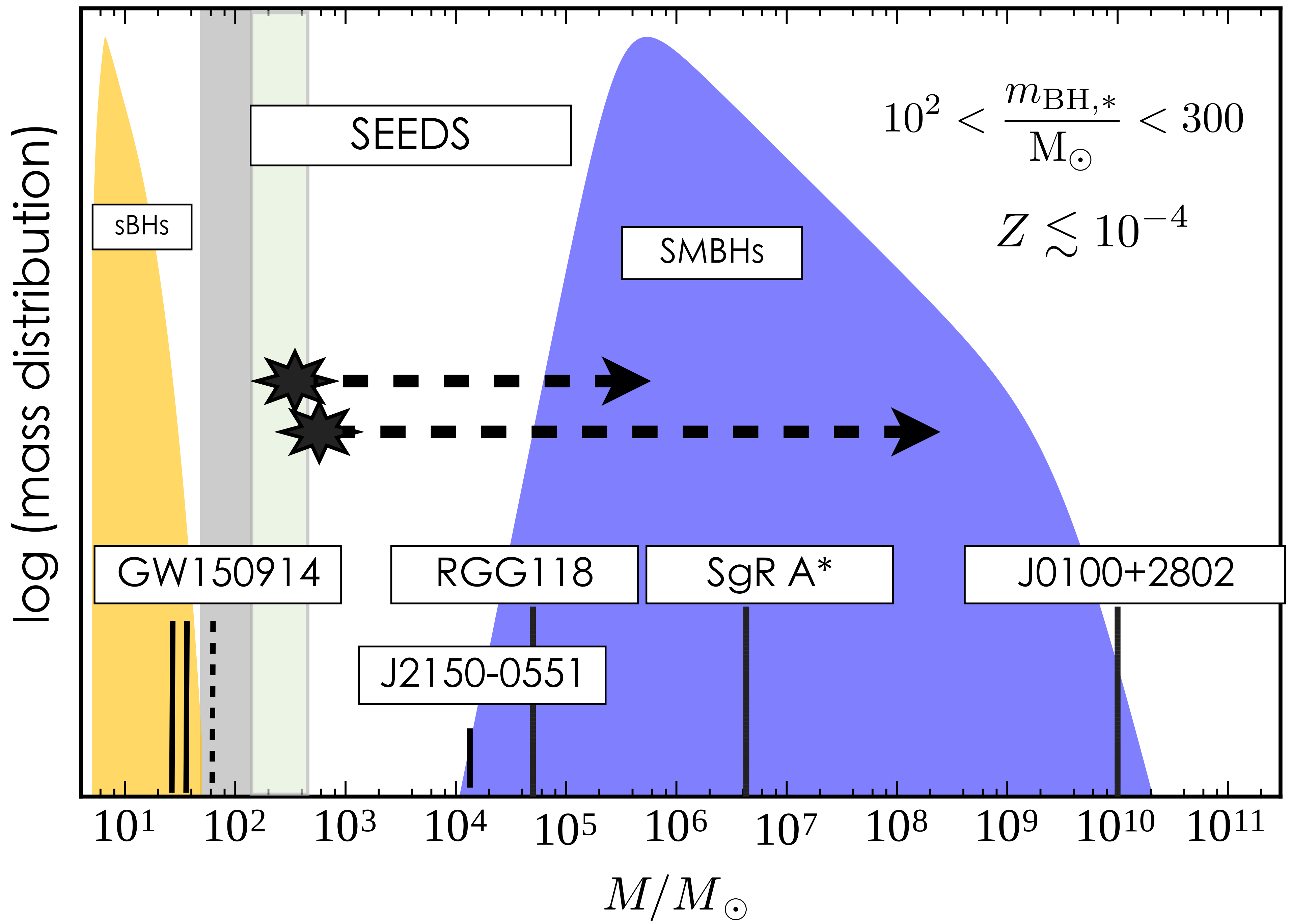
$(44, 4.4)\mathrm{Hz}$

Black Holes - Universe



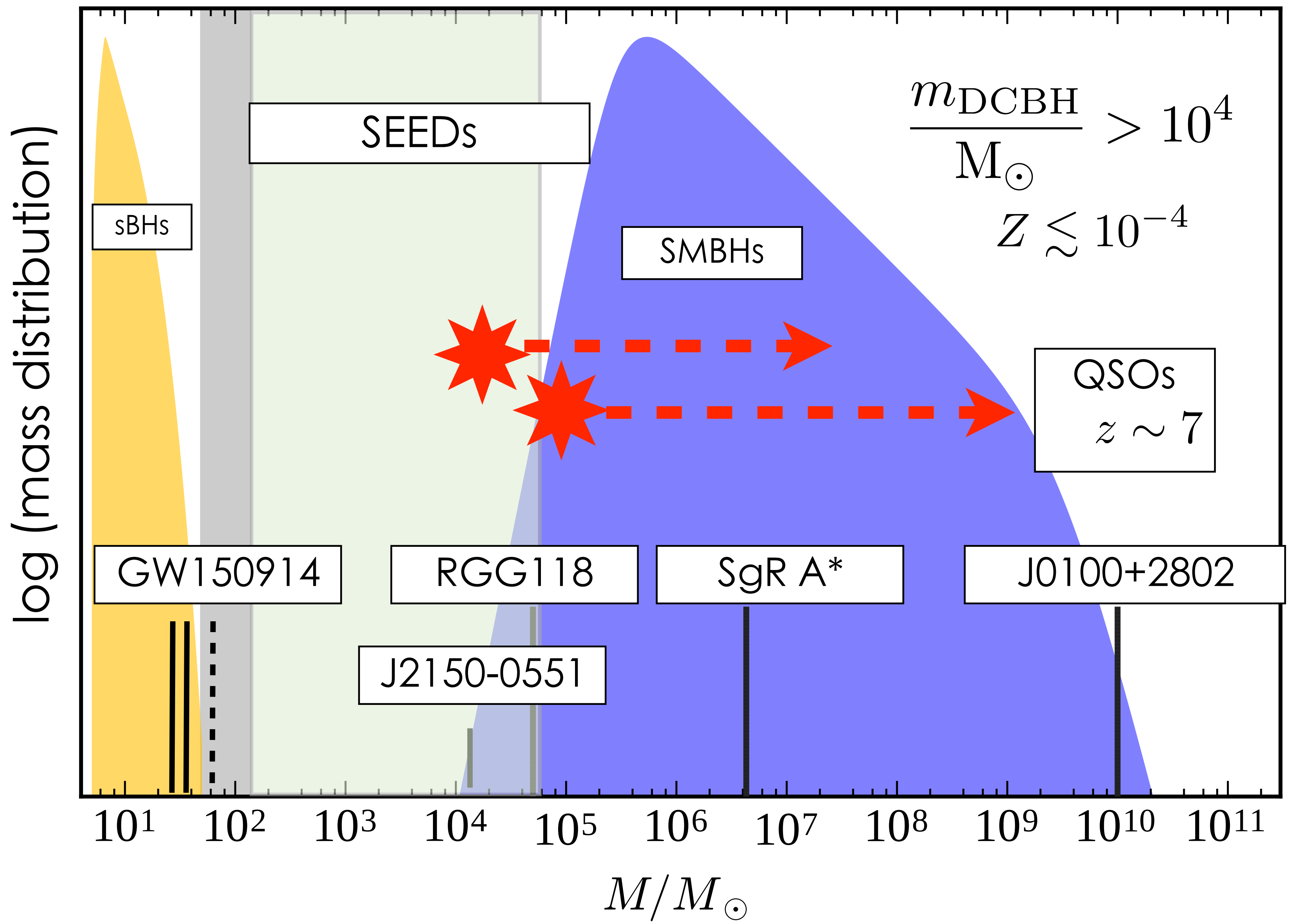
a fil rouge (only stars make black holes) ?
genetic divide?

Black Holes in the High Redshift Universe - POP III relics - “LIGHT SEEDS”



star formation in pristine dark matter halos

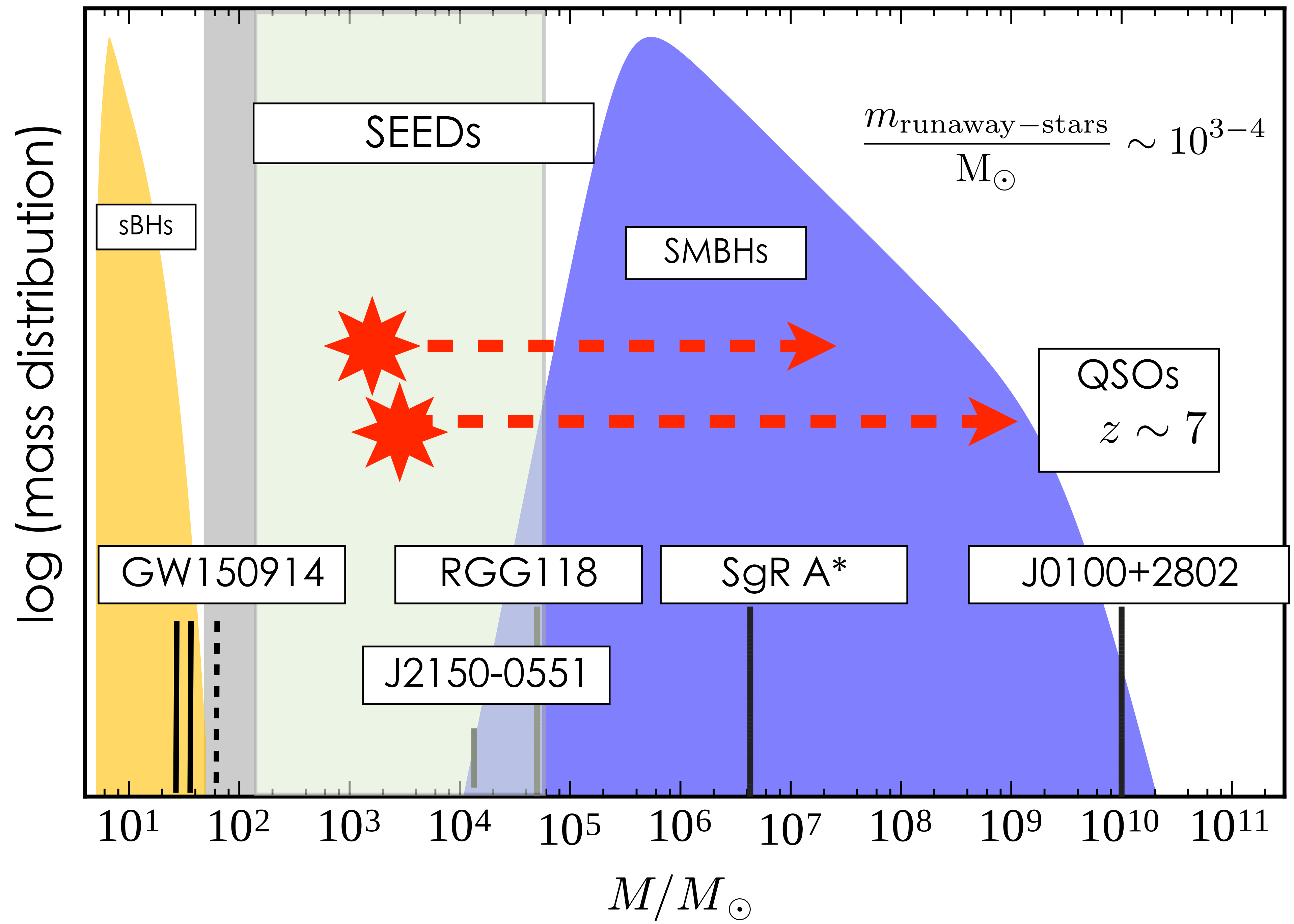
Black Holes - new, yet unseen objects - "HEAVY SEEDS"



Agarwal 2018
Haemmerlé+2018
Schleicher+2013
Hosokawa+2913
Pezzulli_2016
Omukai 2001

Direct monolithic collapse of Pop III supermassive stars in atomic cooling halos illuminated by UV radiation

Black Holes: collisional runaway of stars, Pop II clusters @z~10



Katz 2018
Devecchi + 2012
Schleicher+2018

Formation of runaway stars in the stellar clusters

Fundamental, unanswered questions

How did supermassive black holes form and evolve?

Did they form from light or heavy seeds, or both?

Do light seeds exist?

Objectives

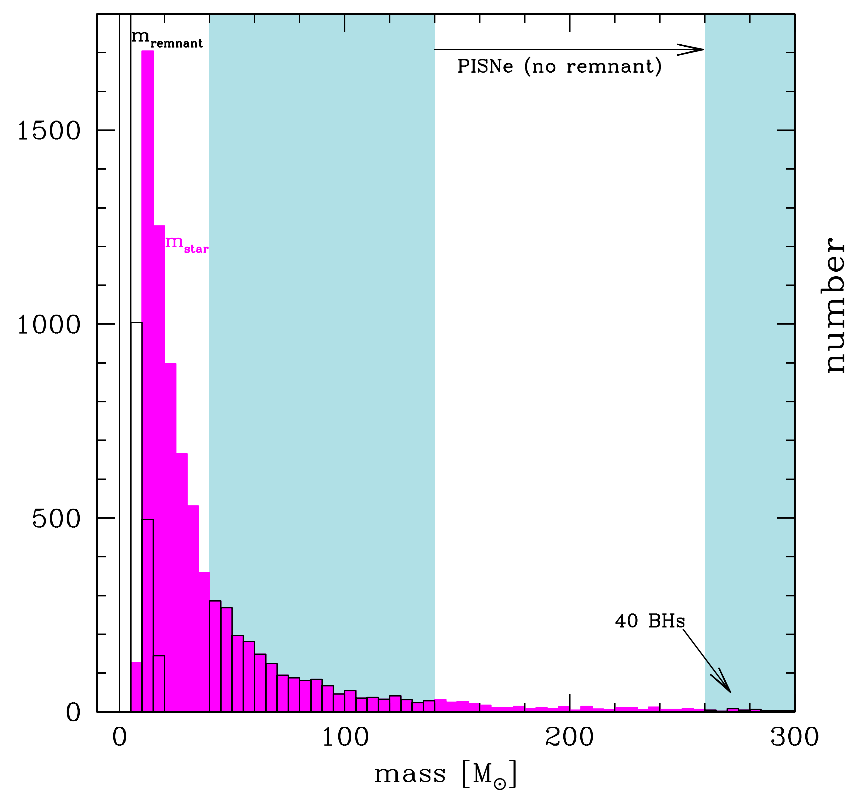
Discover "earliest most massive black hole binaries" a few hundred suns on their way to grow massive at the largest z as possible

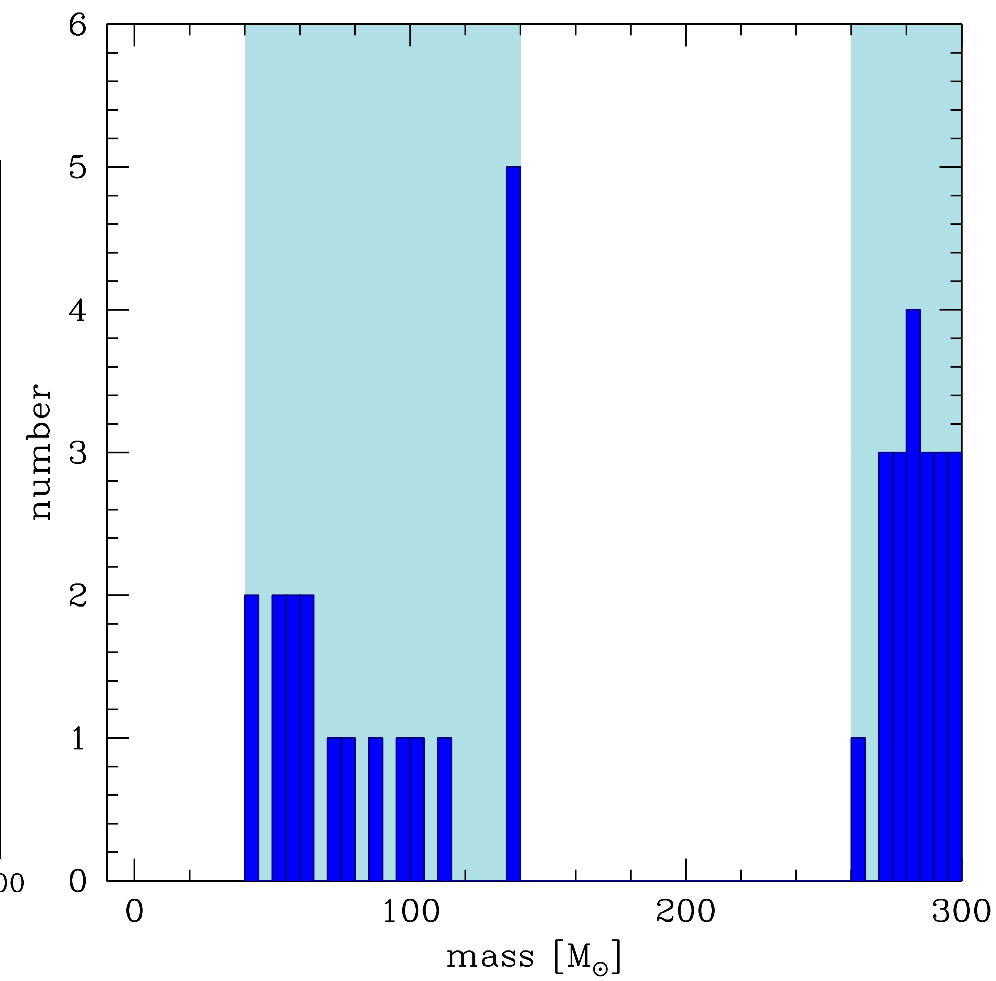
Observe intermediate mass black holes of thousand suns @ low z
Observe intermediate mass ratio inspirals @ low z

-OBSERVE THE FIRST MOMENT OF MASSIVE BLACK HOLE GROWTH -

$10^{13}\,M_\odot$

$10^{7-8}\,M_\odot$



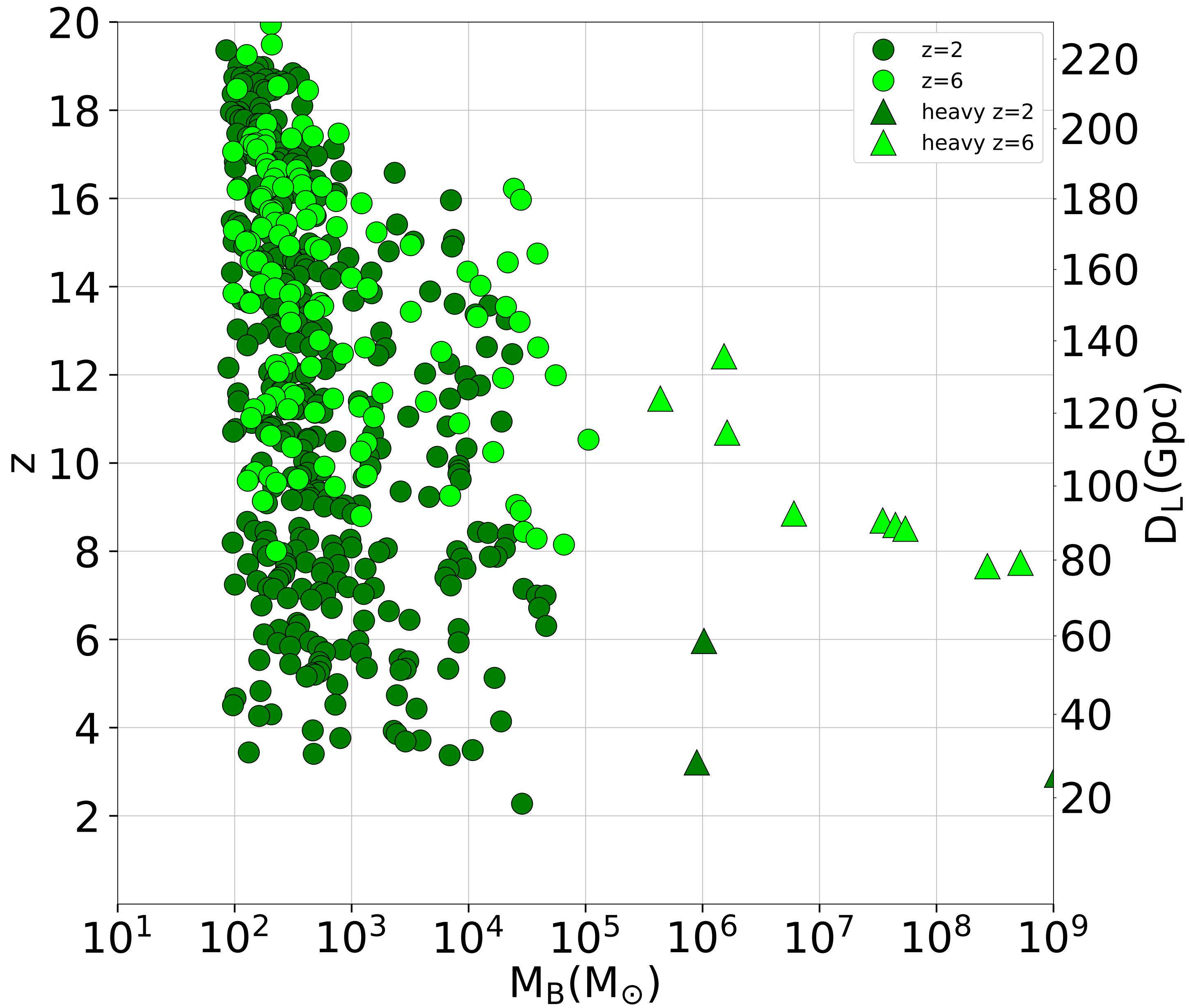


of the most massive black holes

- z~15-20
- 20 Myrs star burst
- For every 1000 stars - 1 massive black hole
- Fated to become a "Light seed"
- Formation of a QSO @z=6 (z=2)
- How do they pair

Valiante+ 2018

Black Holes in the Cosmological Framework

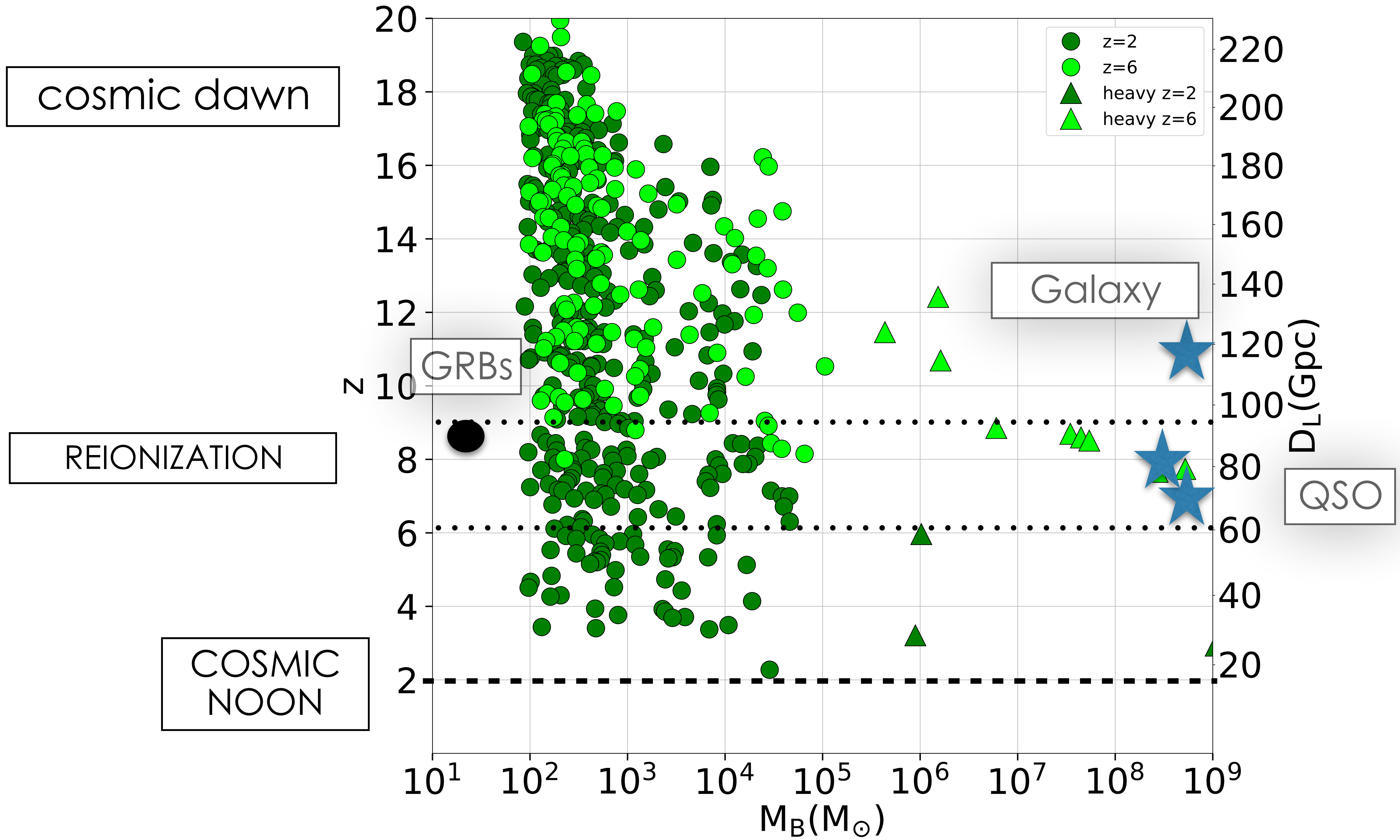


$M_{\rm halo} = 10^{13} M_\odot$

Black holes forming in pristine halos and pairing during halo-halo mergers
"cosmologically-driven mergers"
…. remember that also in situ mergers can occur !

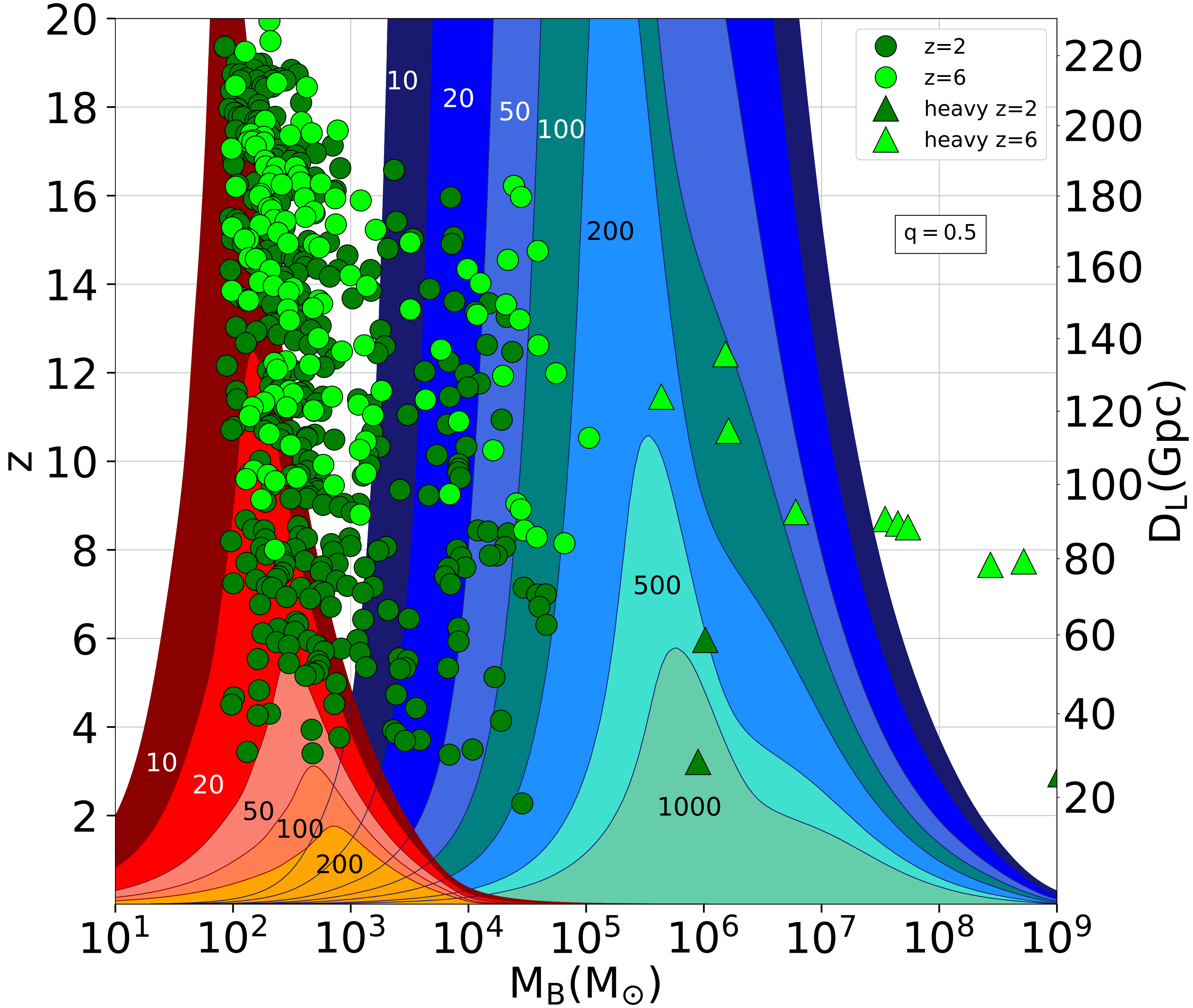
Valiante + 2018

Black Holes in the Cosmological Framework



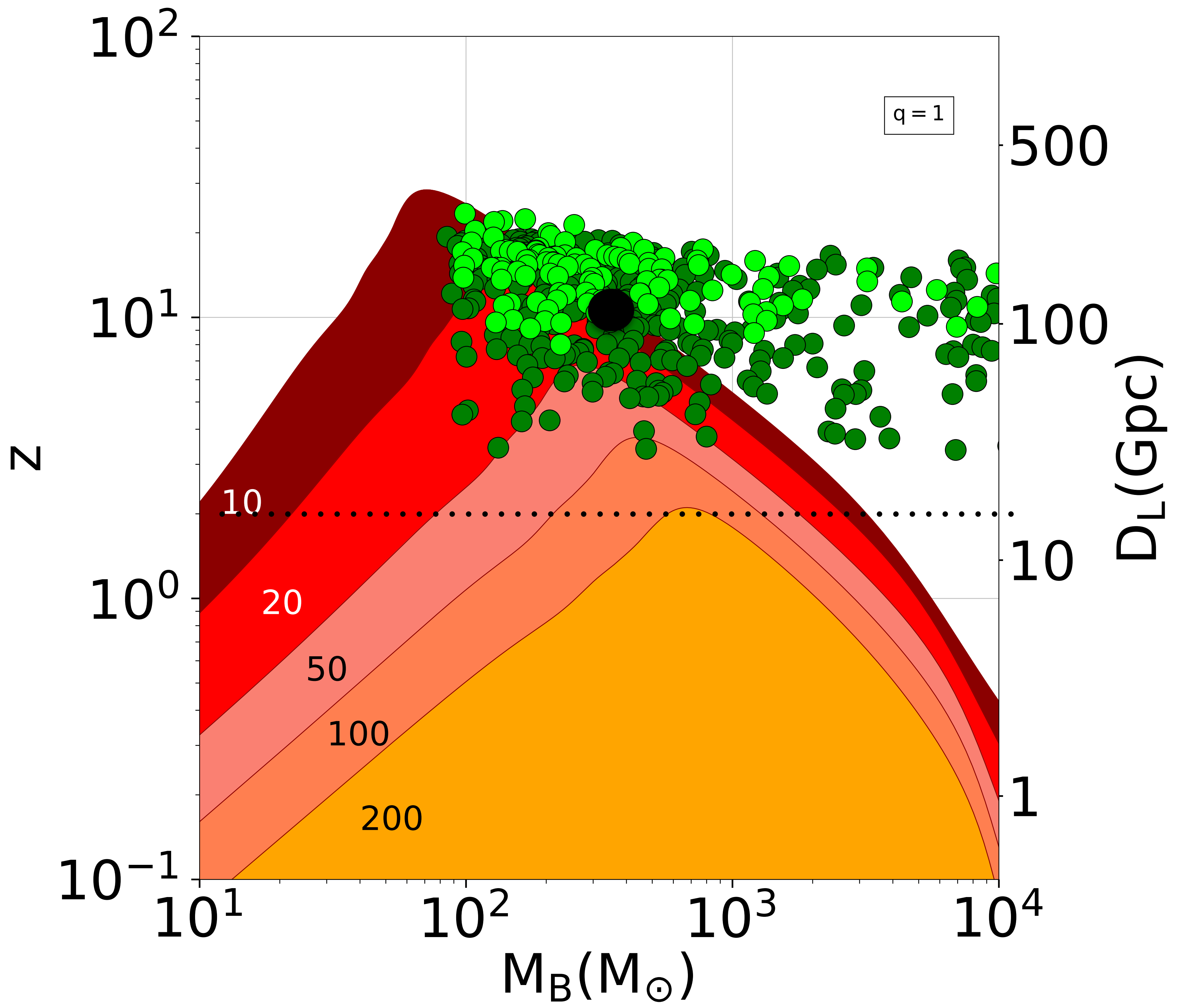
Valiante + 2018

Black Holes in the Gravitational Universe

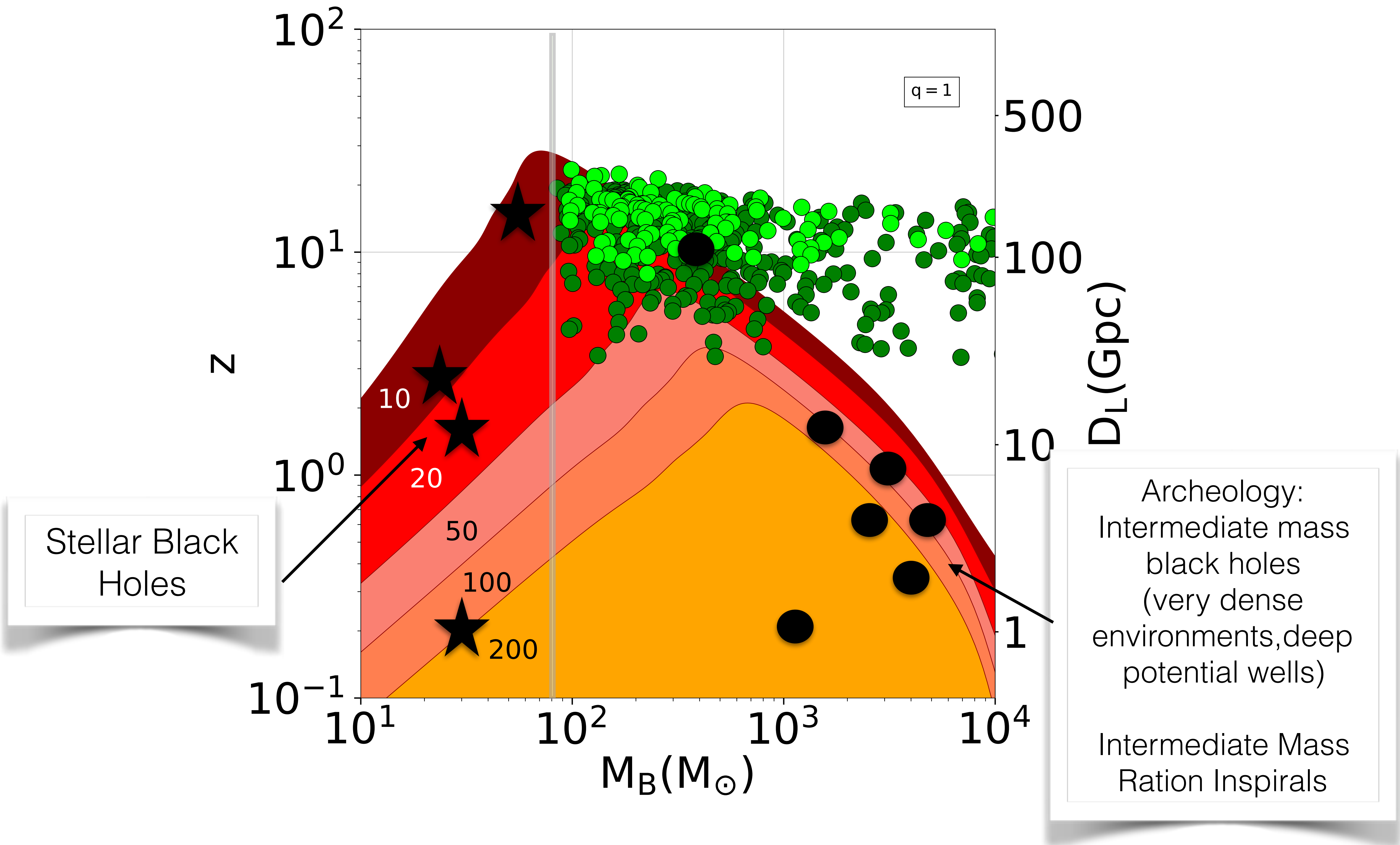


Valiante + 2018

Waterfall plot for non spinning black holes: PhenomC
ET_D sensitivity curve + LISA



Delays enable to detect coalescences at lower z but rates get lower



q = 1
10
20
50
100
200
z
$M_B(M_\odot)$
D_L(Gpc)
500
100
10
1
Stellar Black Holes
Archeology: Intermediate mass black holes (very dense environments,deep potential wells)
Intermediate Mass Ration Inspirals

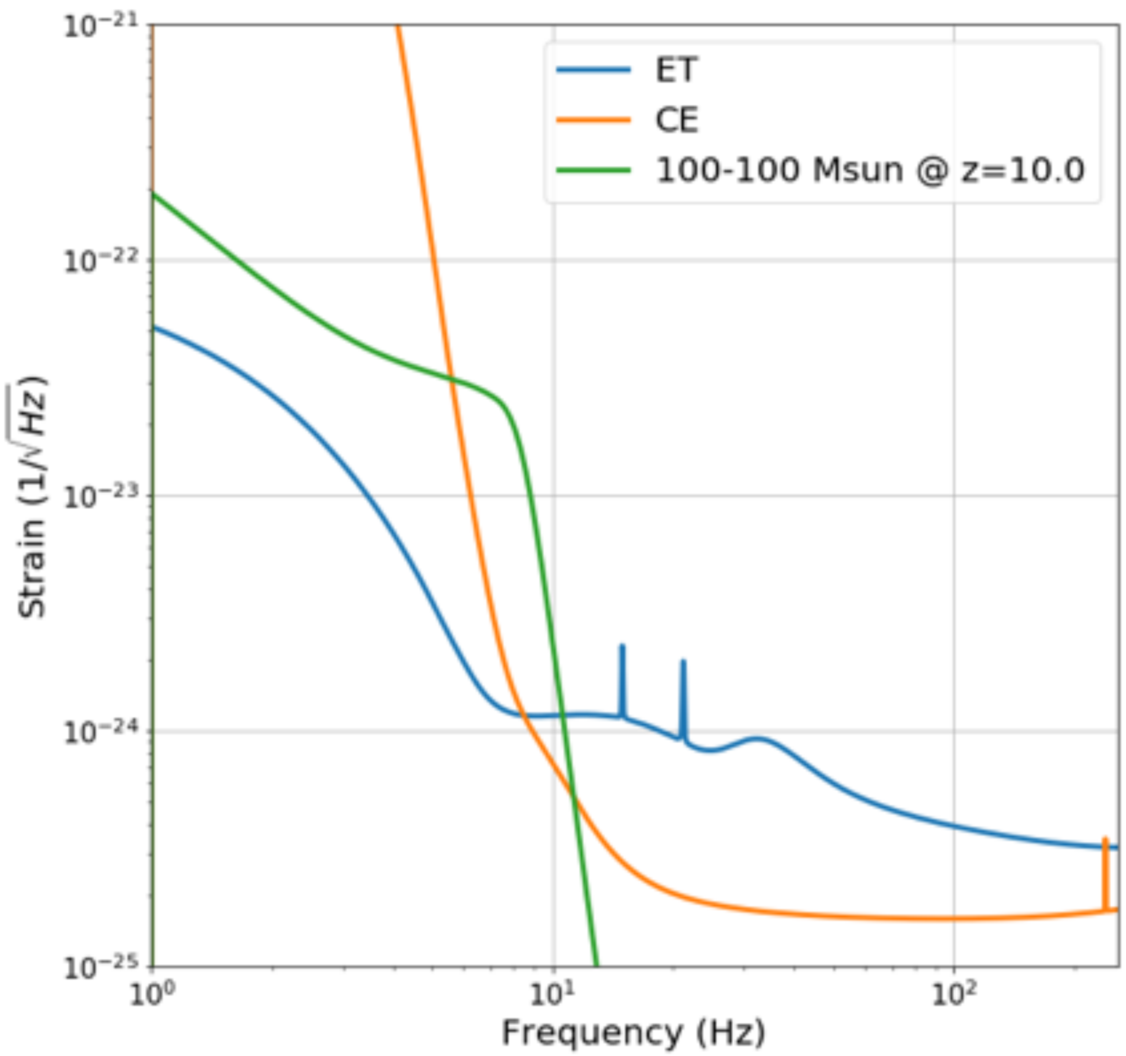
Gair+2001

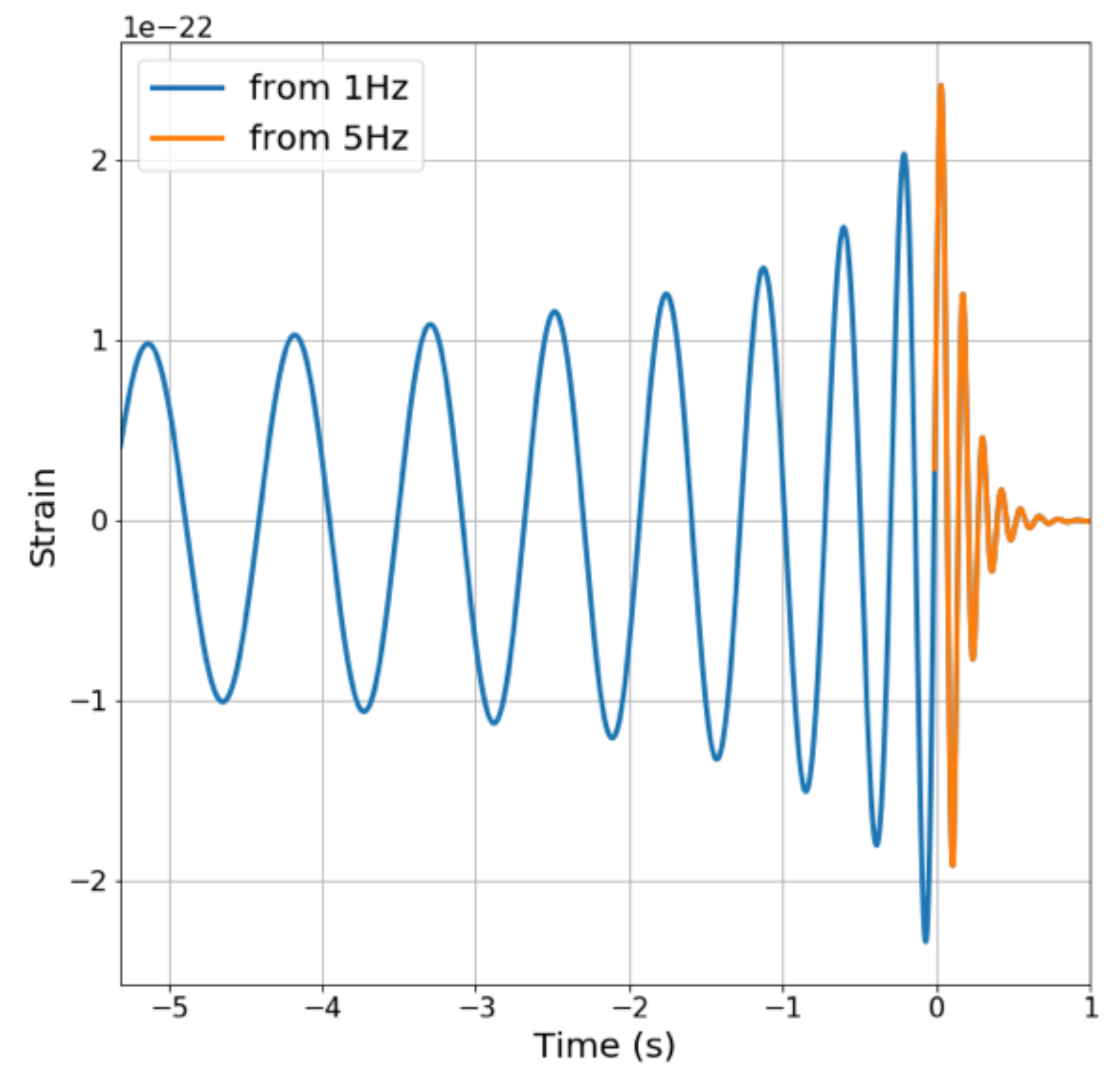
PARAMETER ESTIMATION

$$m_{\rm obs} = (1+z)m_{\rm source}$$

- GW signals are week
- How well can we infer the intrinsic masses of coalescing black holes at the edges of the sensitivity curve?
- Can we distinguish, from the weak GW signals, if the binary hosts a pair of intermediate mass black holes at a given redshift z from a pair of stellar black holes at a much higher redshift?
- Can we separate the two populations?

EXAMPLE SIGNAL: $100\ M_\odot$ - $100\ M_\odot$ at z=10





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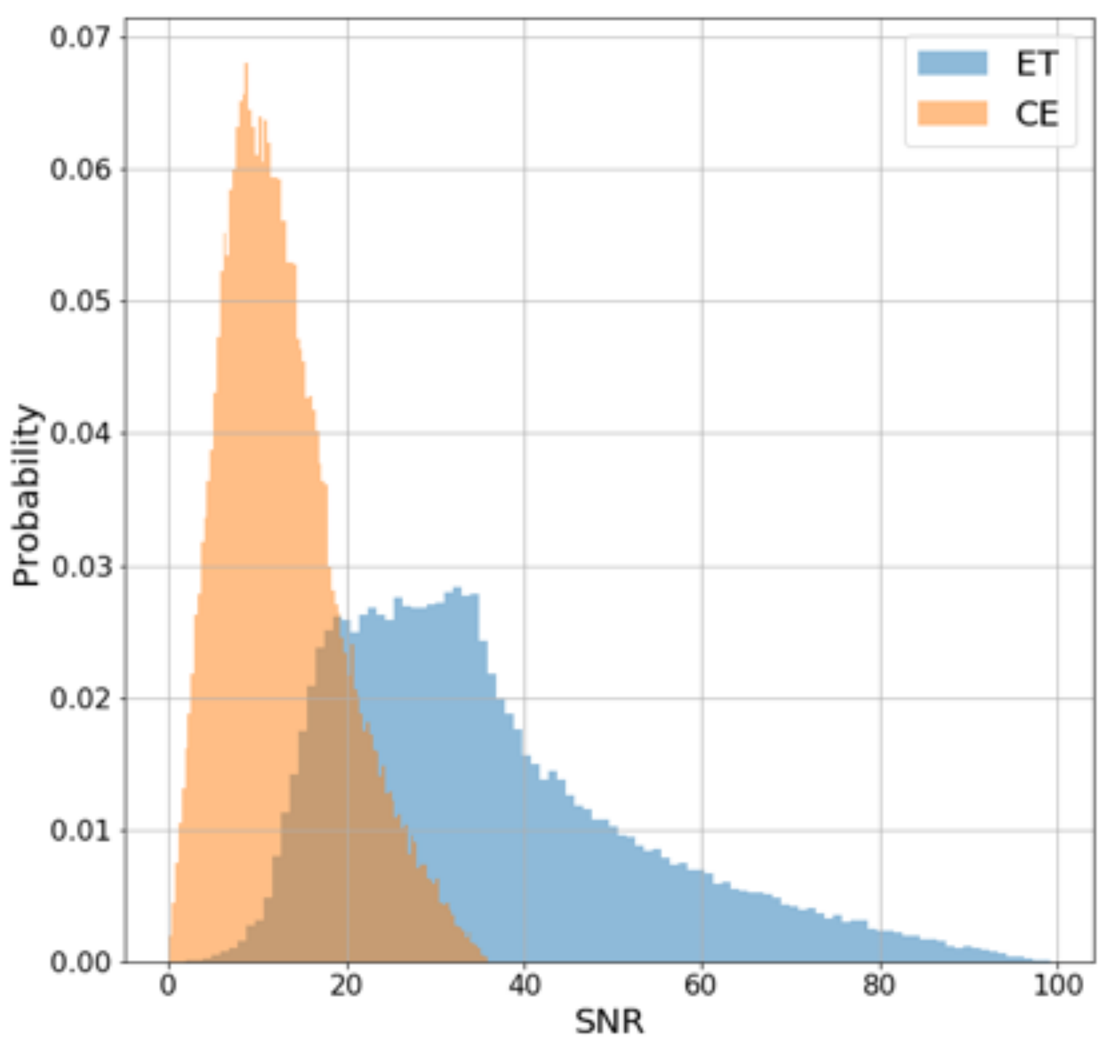
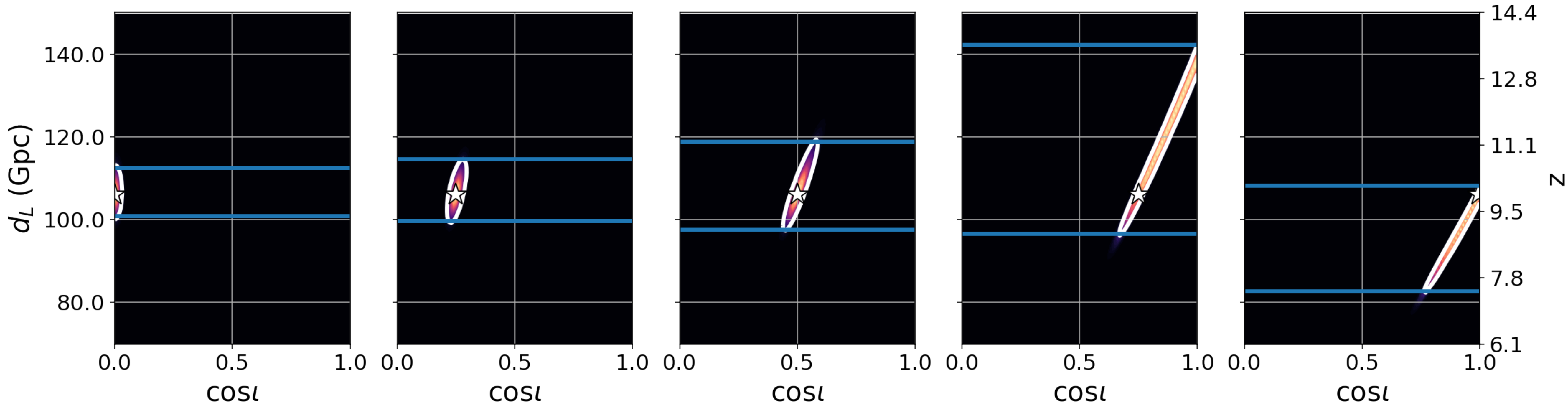


SNR distribution for sources, varying sky location and orientation

- Observe essentially all signals
  - Low frequency sensitivity critical
- Expect intrinsic mass accuracy of 10s of percent
- Poor timing accuracy leads to poor localization and distance measurement

EXAMPLE SIGNAL: $100\ M_\odot$ - $100\ M_\odot$ at z=10

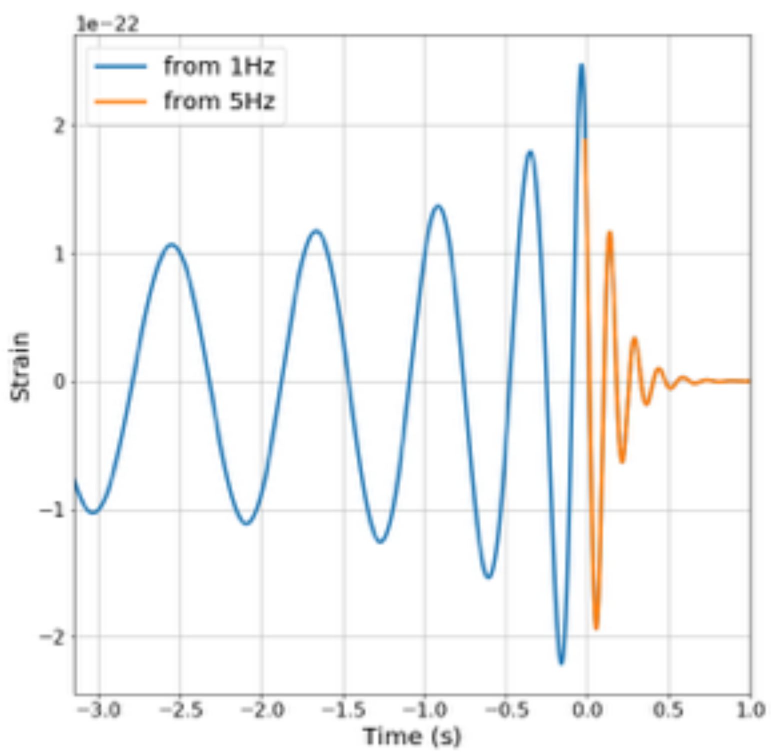


- Even with accurate sky location, degeneracy between distance and inclination leads to uncertainty in distance -> redshift -> mass

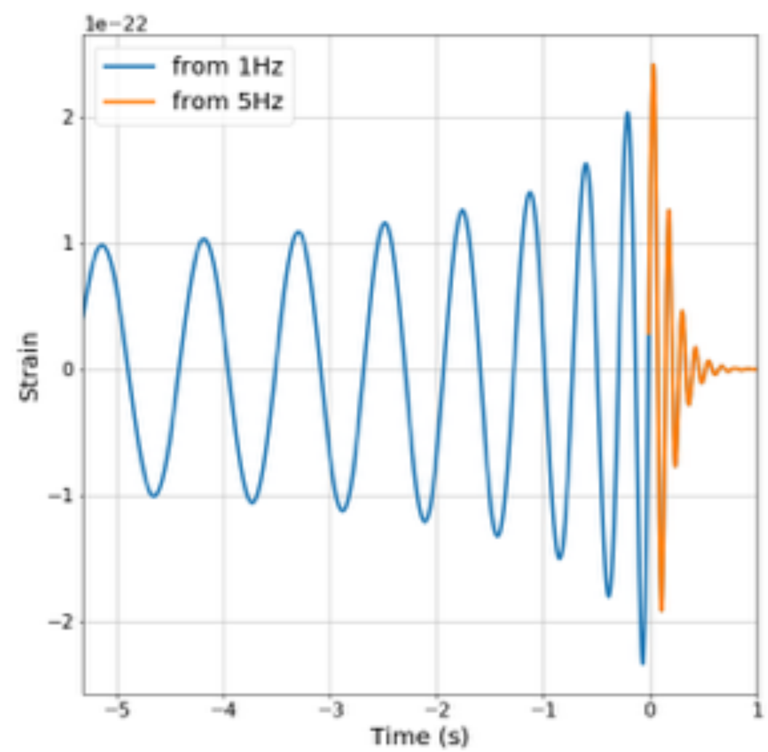
- Need to understand if higher harmonics and/or precession will help significantly

EXAMPLE SIGNAL: $100\,M_\odot$ - $100\,M_\odot$ at z=10

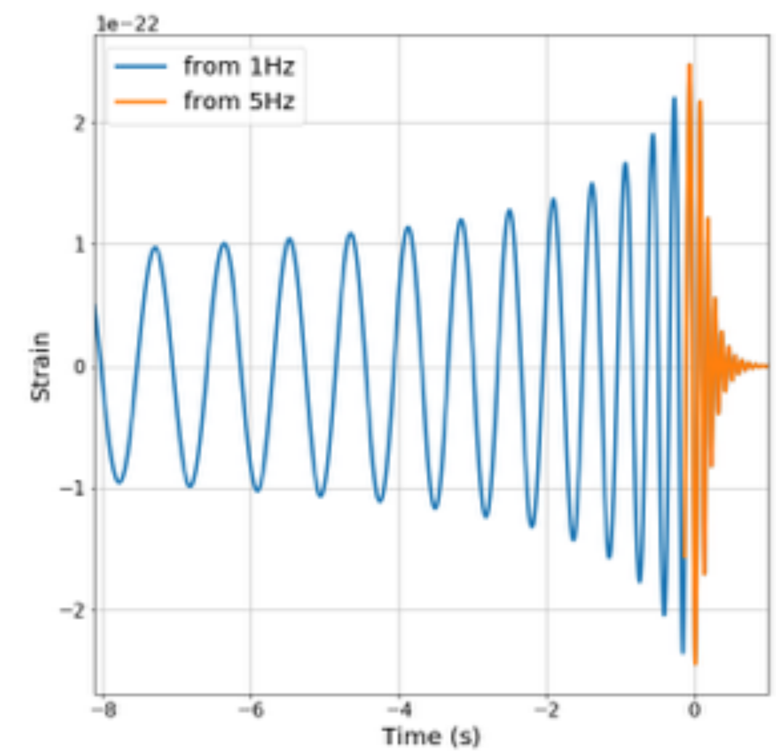
- Waveform length and SNR highly dependent on spin
- Will measure spins - infer formation scenarios



spin = -0.8



spin = 0

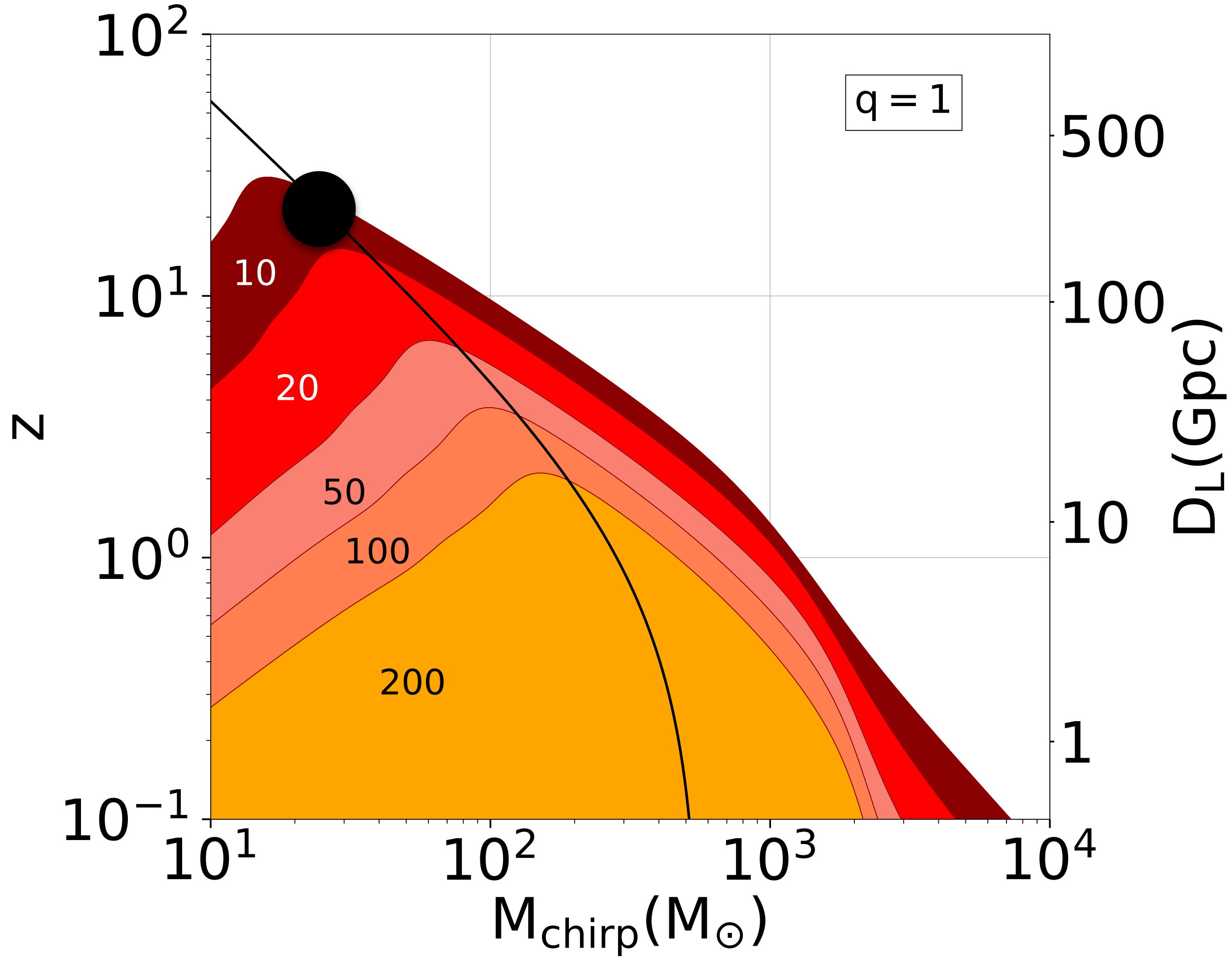


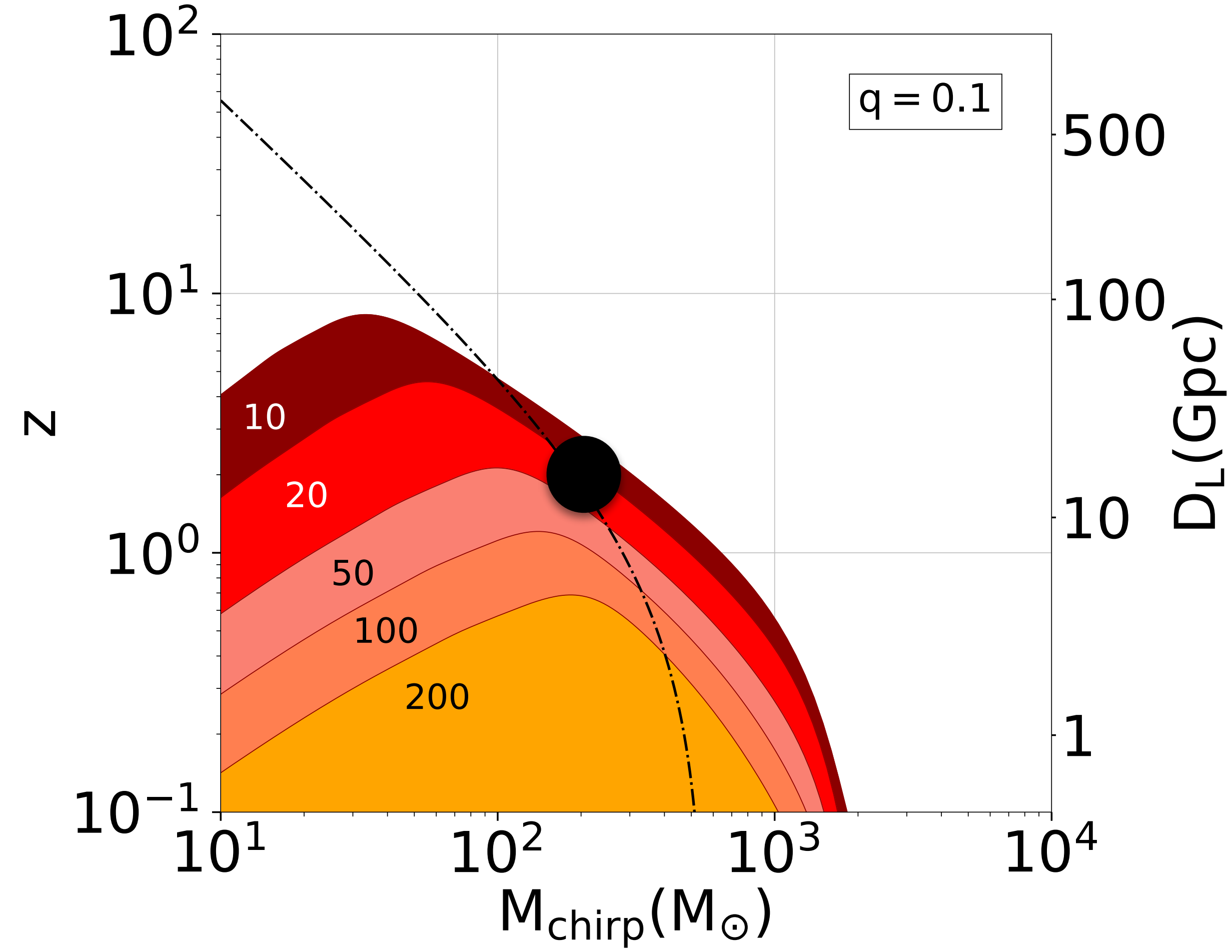
spin = 0.8

Distinguishing mass ratios

$(50M_\odot, 50M_\odot)$ @ $z = 12$ $\quad$ $(1000M_\odot, 100M_\odot)$ @ $z = 1.3$

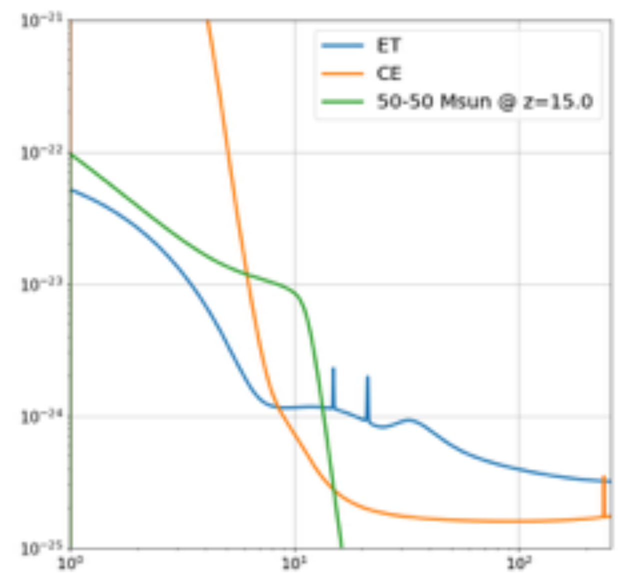
Both systems have the same (observed) chirp mass



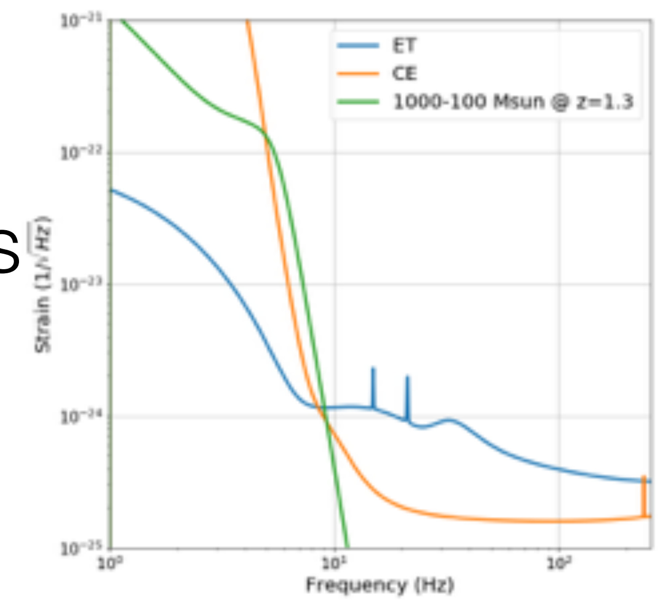


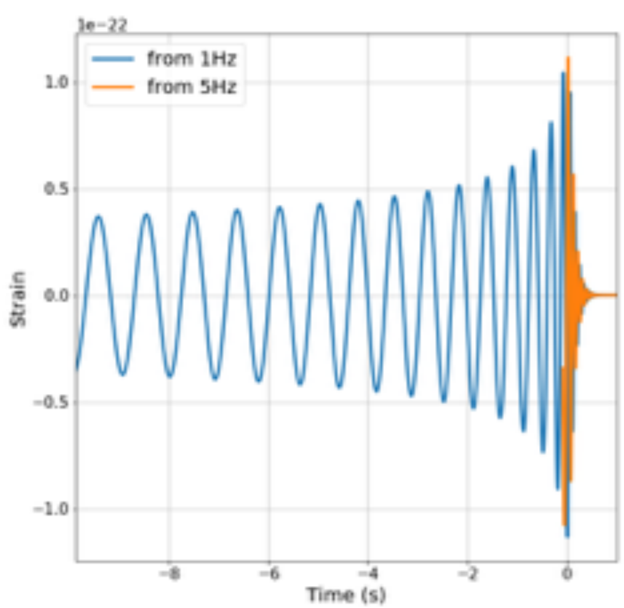
Distinguishing mass ratios

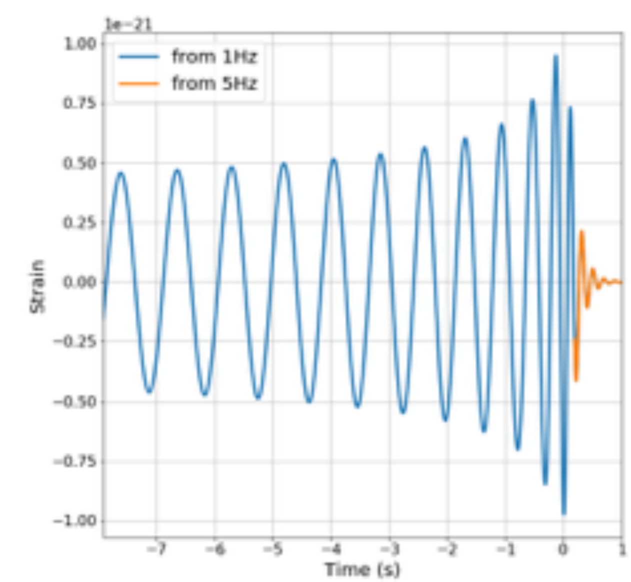
$(50M_\odot, 50M_\odot)\,@\,z = 12$ $\qquad$ $(1000M_\odot, 100M_\odot)\,@\,z = 1.3$



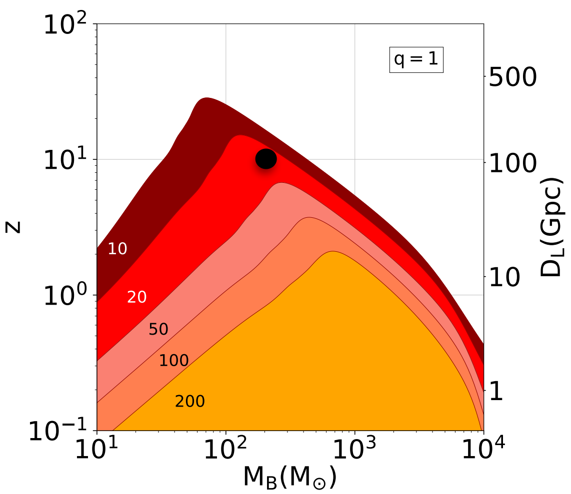
Don't expect precision measurement of mass ratio, but will distinguish equal mass from intermediate mass ratios







into the realm of the “extremes”

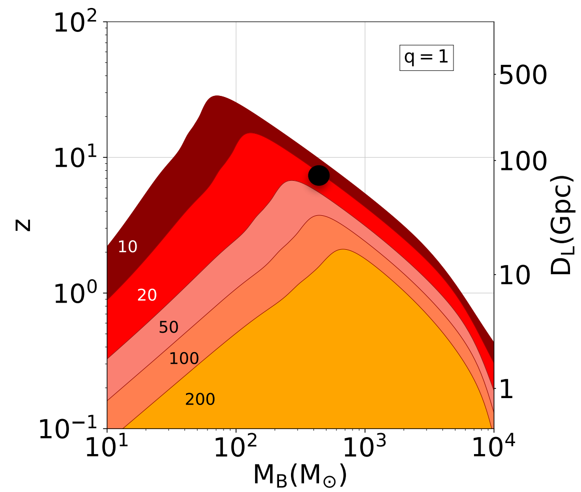


$$(100M_\odot, 100M_\odot) \ @ \ z = 10$$

	fraction detected	median dz/z	10% dz/z	1% dz/z
1CE+1ET+1V	0.91	0.309 $z = 10^{+3}_{-3}$	0.114	0.0715
1ET+2CE	0.986	0.195	0.0935	0.0616
3ET	1	0.102	0.0554	0.0379
3CE	0.898	0.58	0.24	0.153

$$(200M_\odot, 200M_\odot)\ @\ z = 7$$

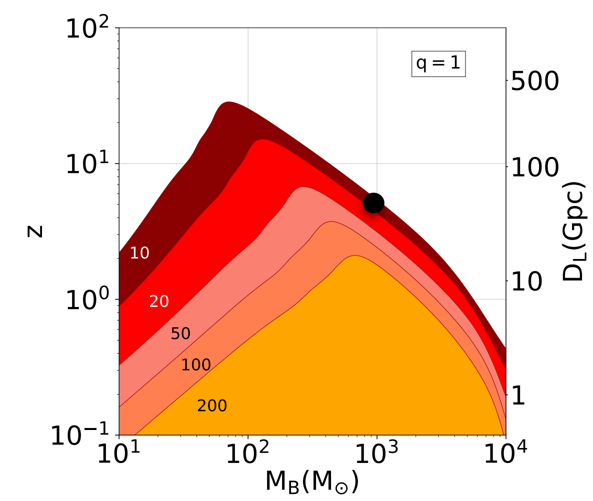
measured redshift: $z = 7^{+7}_{-7}$



	fraction detected	median dz/z	10% dz/z	1% dz/z
1CE+1ET+1V	0.112	1.58	0.269	0.16
1ET+2CE	0.177	1.05	0.275	0.157
3ET	1	0.101	0.0538	0.0377
3CE				

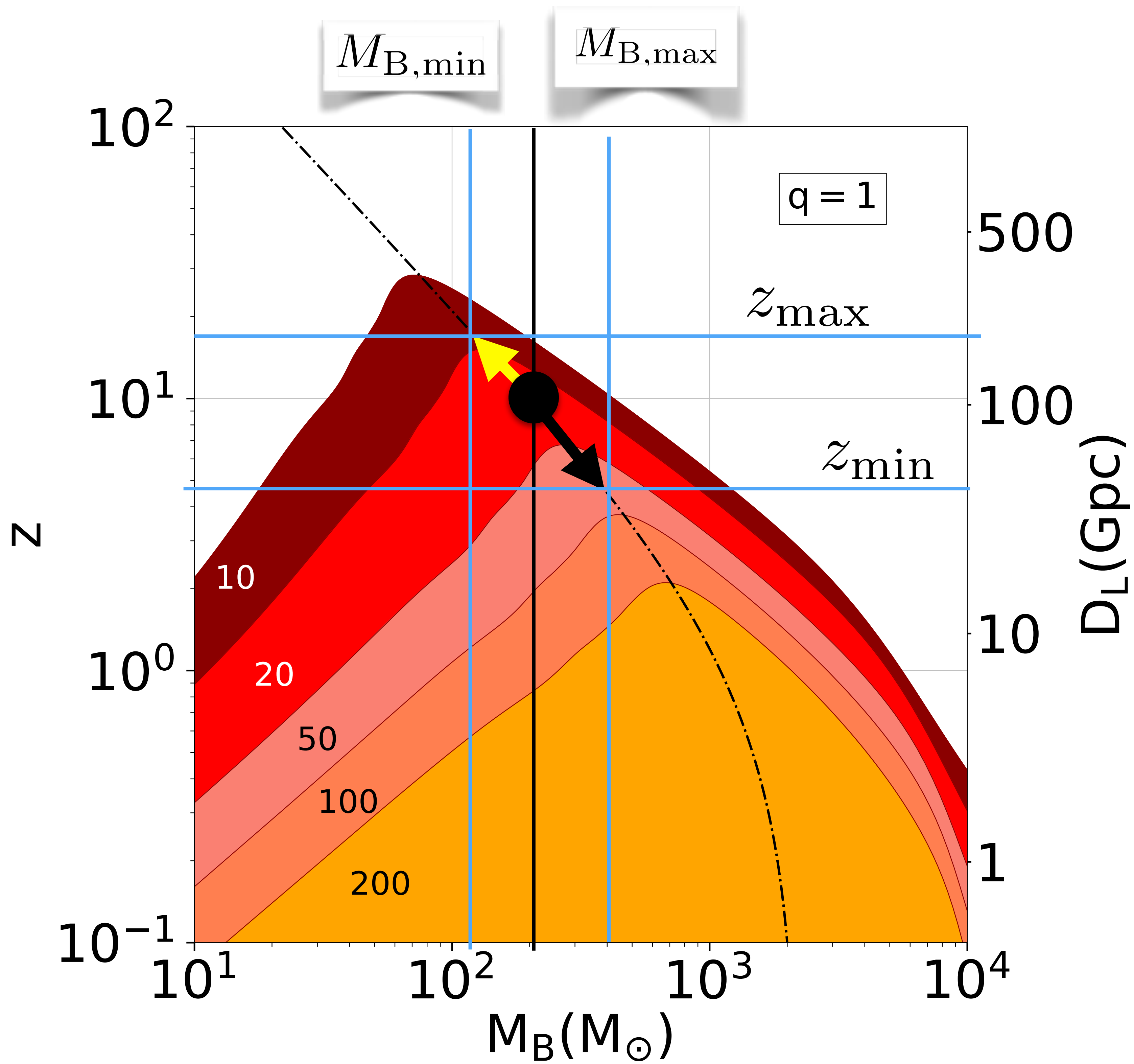
$(500 M_\odot, 500 M_\odot)$ @ $z = 4$

measured redshift: $z = 4 \pm 0.52$



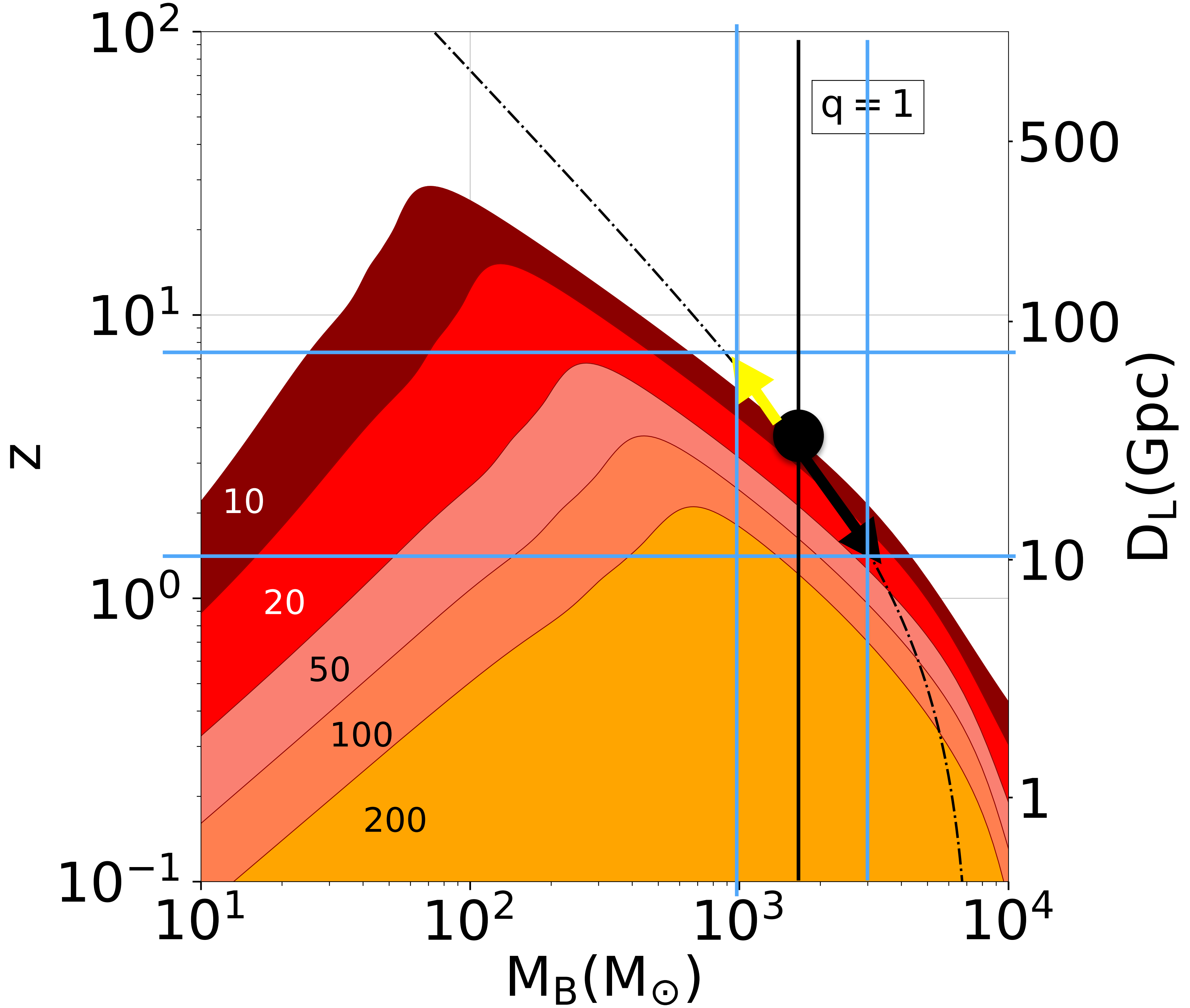
	fraction detected	median dz/z	10% dz/z	1% dz/z
1CE+1ET+1V	0			
1ET+2CE	0			
3ET	1	0.13	0.07	0.0477
3CE	0			

$(100M_\odot, 100M_\odot)@z = 10$

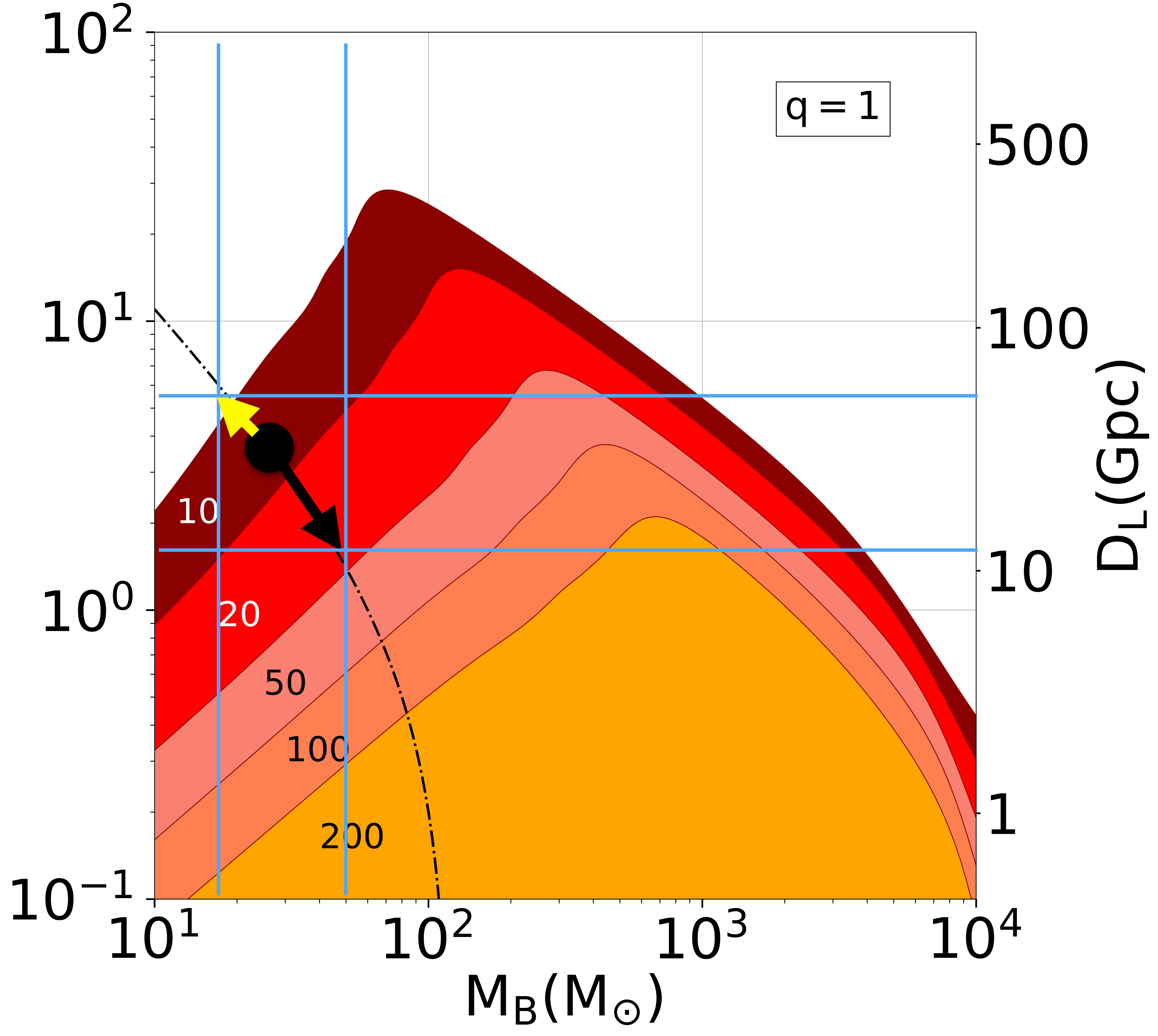


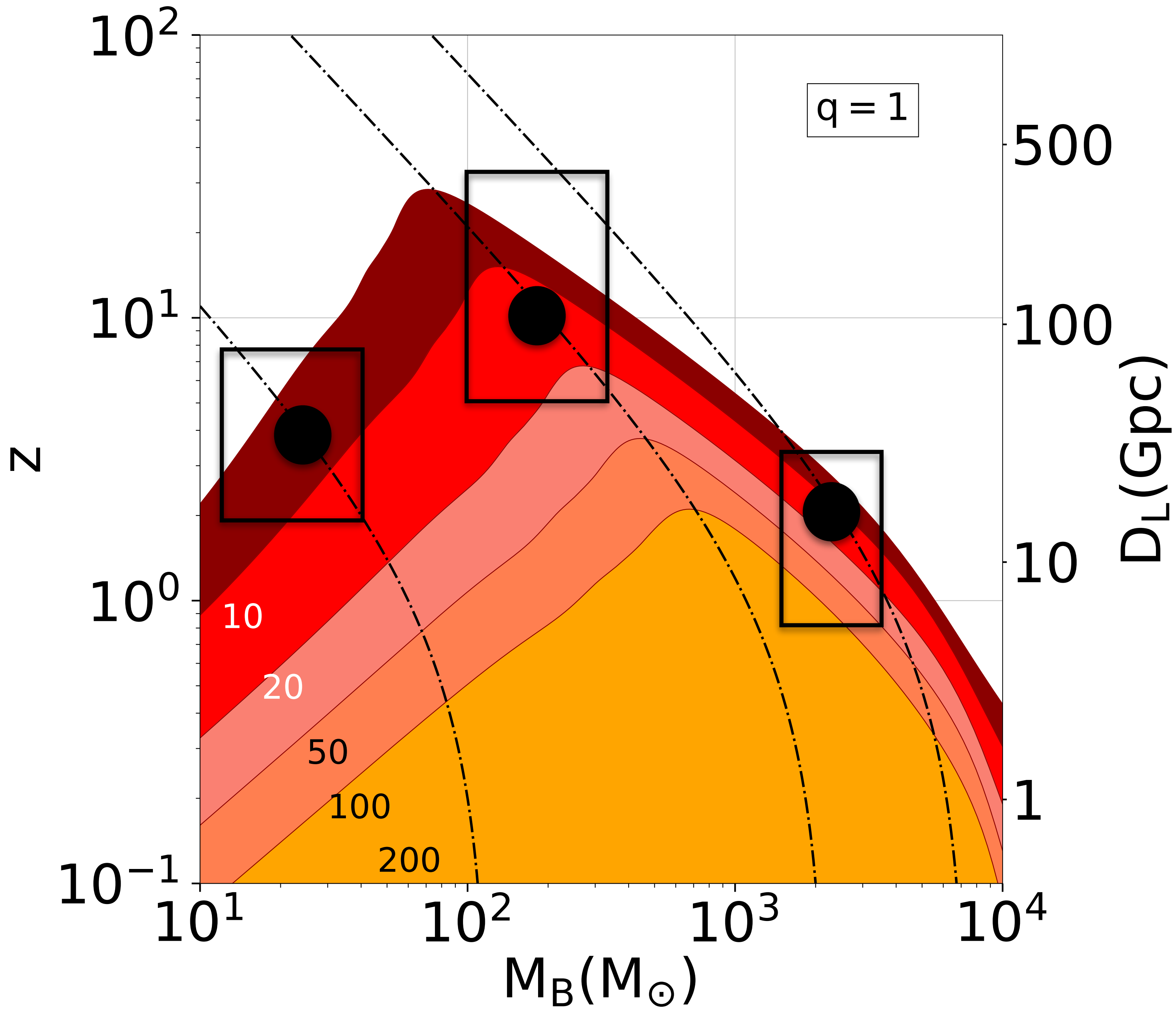
dash dotted line is a line of constant redshifted total mass

$$(1000M_{\odot}, 1000M_{\odot})@z = 2.7$$



$(15M_\odot, 15M_\odot)@z = 3$



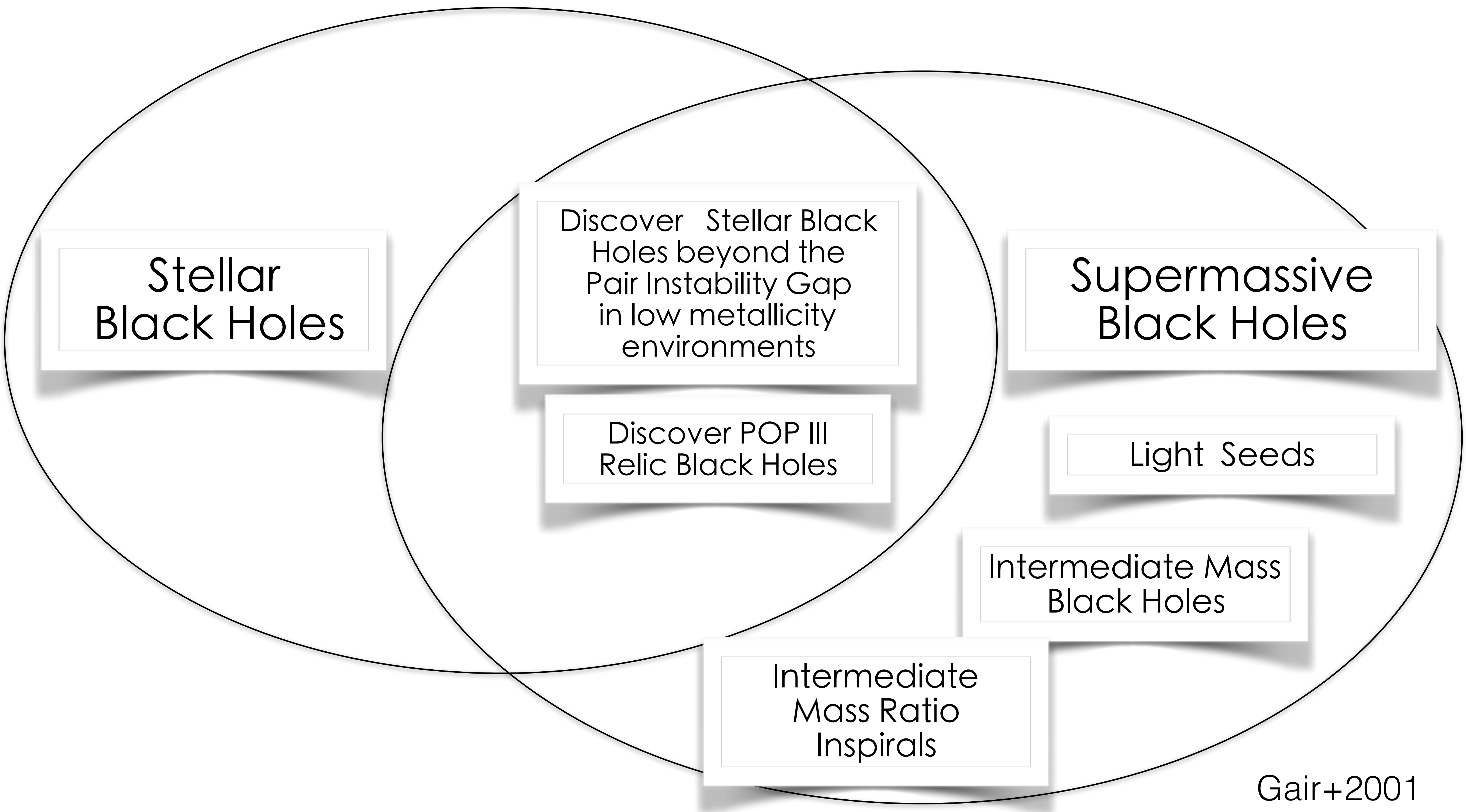


Despite uncertainties we can distinguish between stellar black holes and “heavy black holes (light seeds)”

Summary

- Light seed black holes are uniquely observable by 3rd Generation GW detectors
    - Synergy with LISA that will see the heavy seeds and supermassive black holes
- Give an (indirect) view of the formation and evolution of the first (pop III) stars
- Observations critically dependent upon low-frequency sensitivity
- Despite significant degeneracy between mass and redshift measurement, expect to be able to distinguish seed BH from stellar BH

OVERLAP CBCs - SEED GROUPS
high-z Universe



Gair+2001