The Primordial Black Holes Quest

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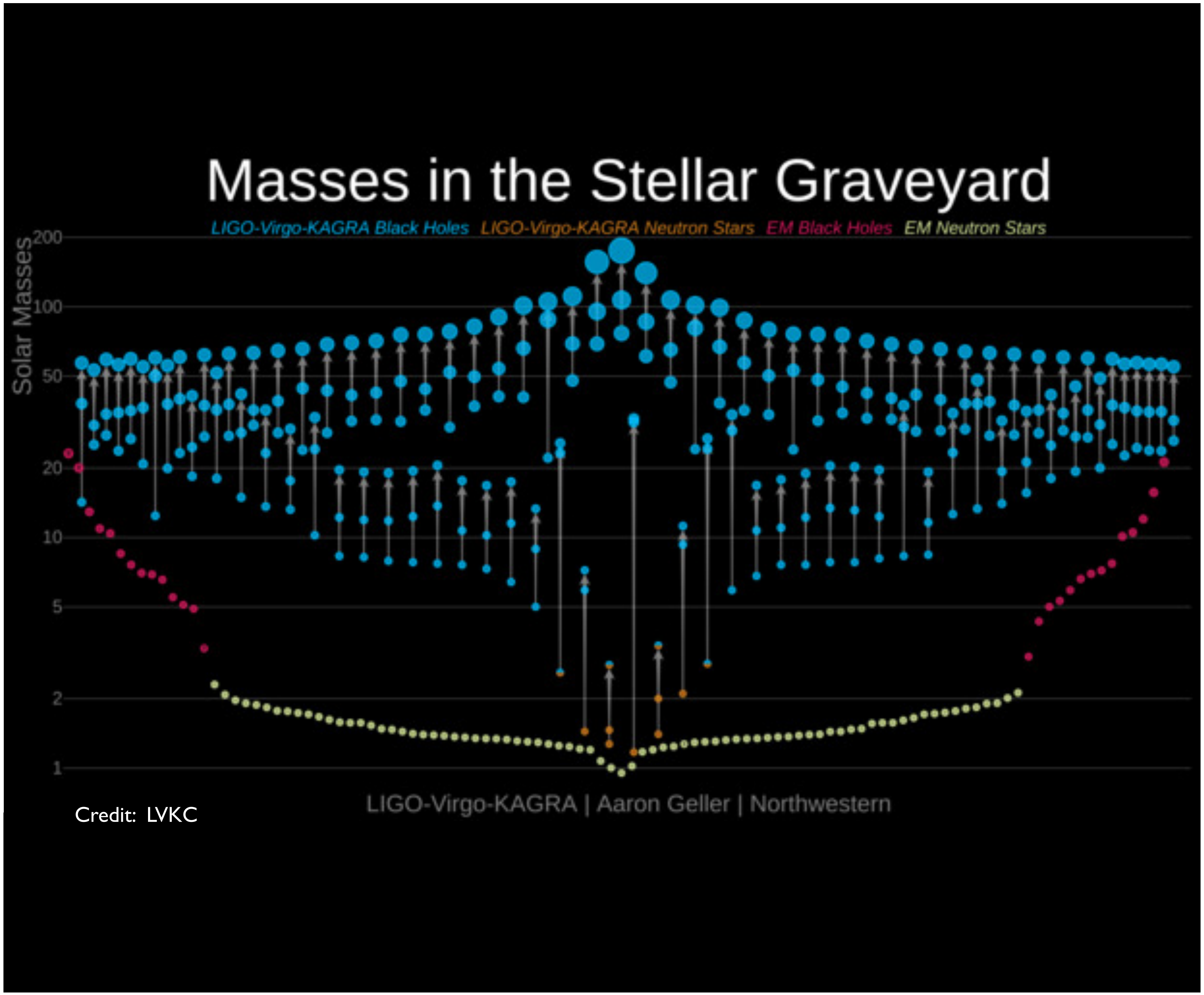
Motivation


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
Credit: LVKC

Motivation

Astrophysical BHs

They form from the gravitational collapse of a star, with mass bigger than the Chandrasekhar mass,

$$M > \mathcal{O}(1) M_\odot$$

Primordial BHs

They form in the early universe from the collapse of large inhomogeneities and are not evaporated until today,

$$M > 10^{-18} M_\odot$$

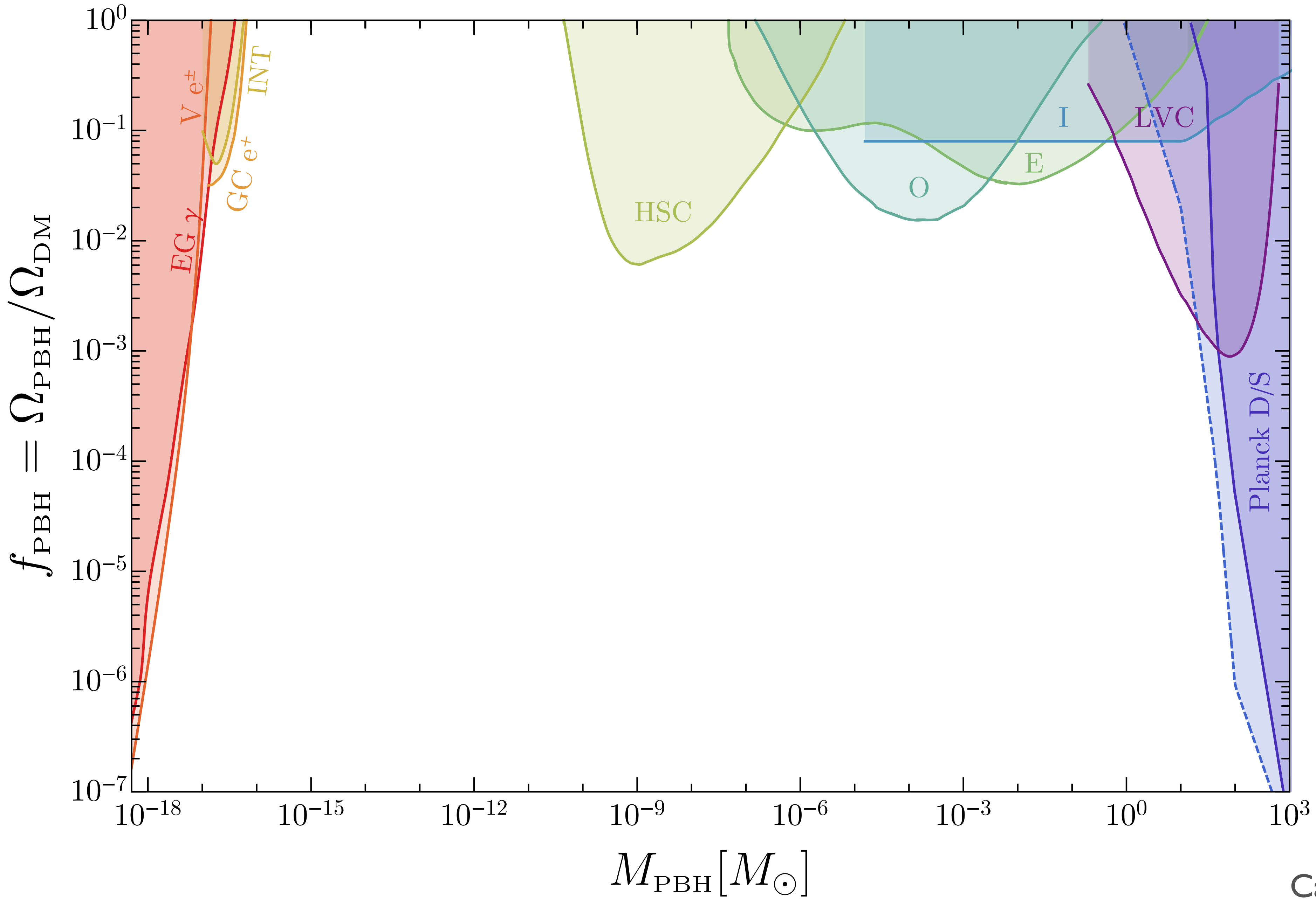
Mass

Spin

Merger rate

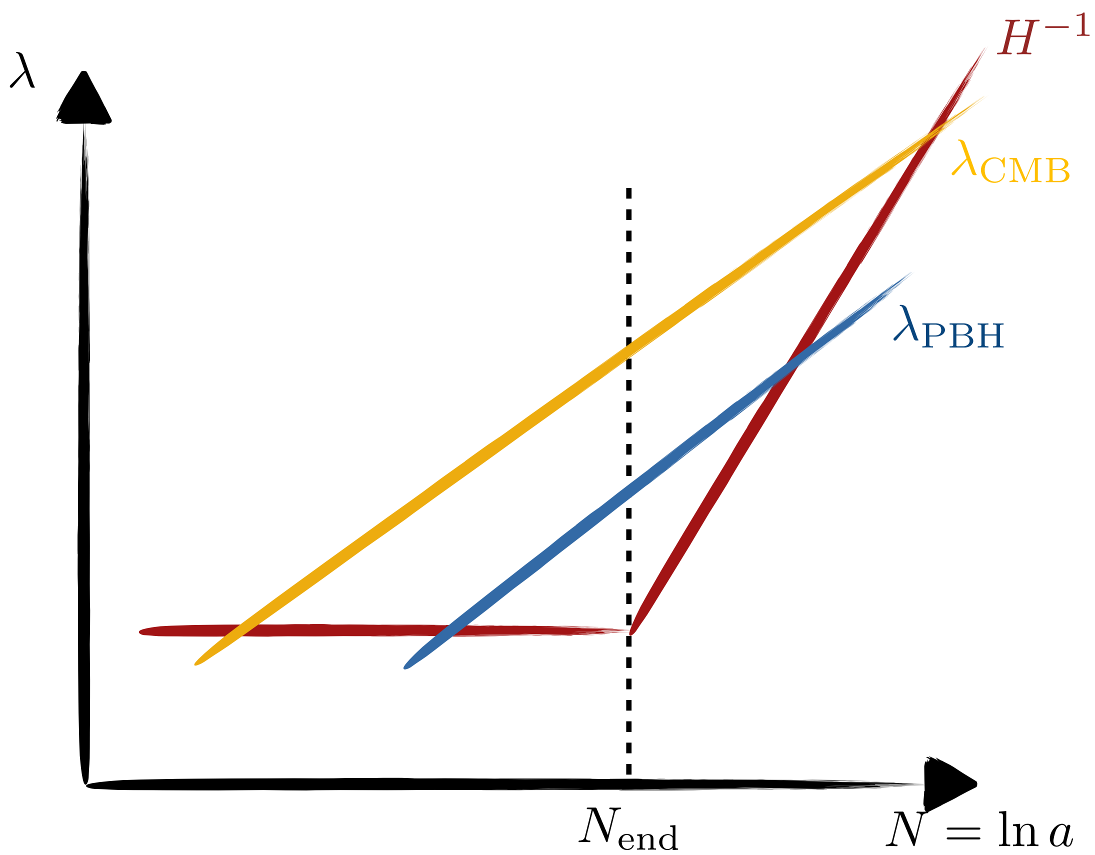
Motivation

PBHs on cosmological scales are a cold and collisionless fluid:
they may represent a fraction of the **Dark Matter** in the universe



Carr et al. (2020)

Formation

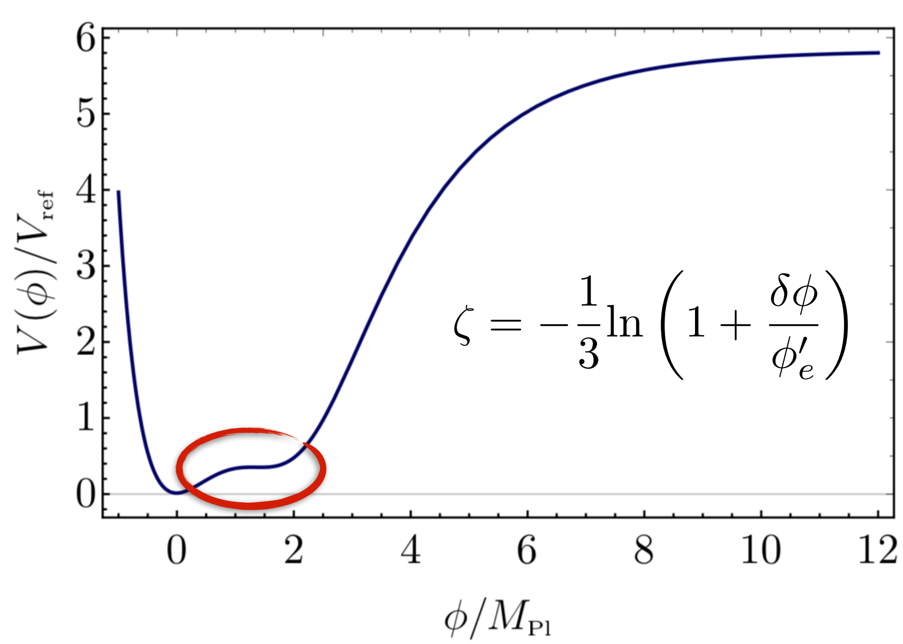


Enhancement of the curvature perturbation on small scales during inflation

↓

Perturbations transferred to radiation fluid during reheating. They may collapse into PBHs at horizon re-entry if large enough

To get an enhancement: Ultra Slow-roll (USR)

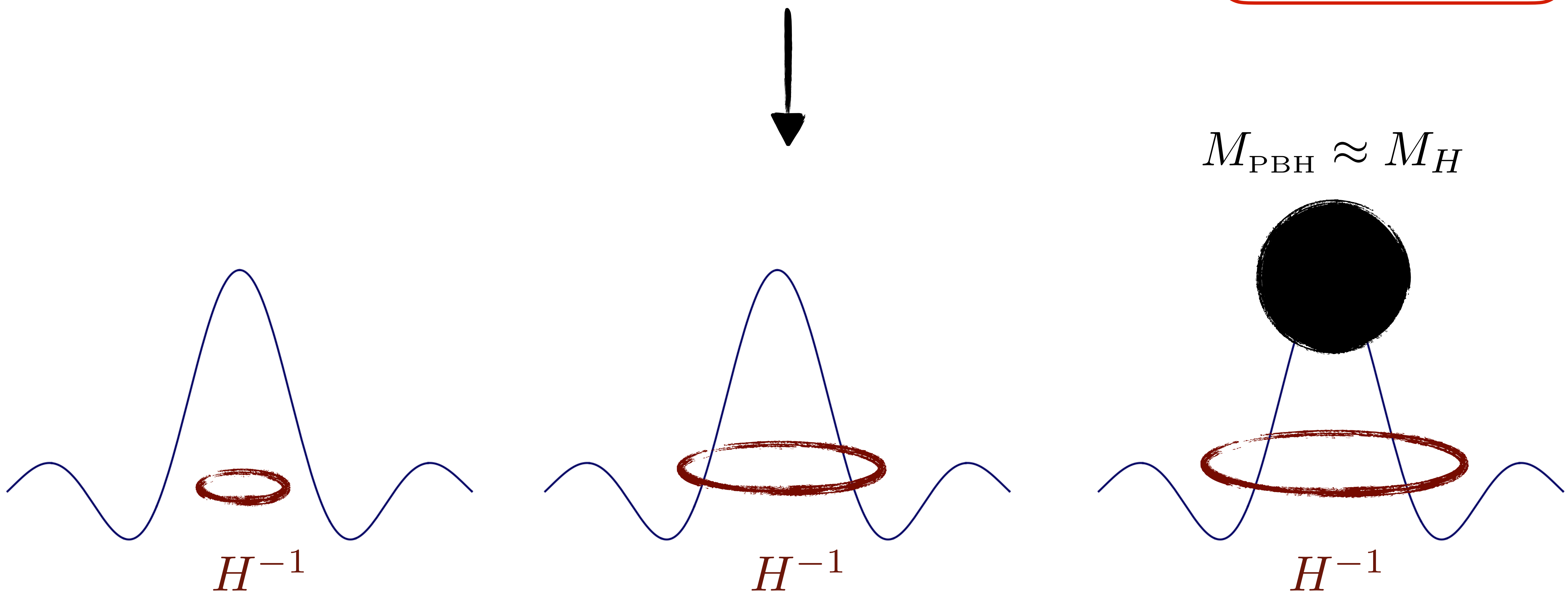


Biagetti, De Luca, Franciolini, Kehagias, Riotto PLB [2105.07810]

Formation

PBHs are originated from peaks of the density contrast:

$$\delta \equiv \frac{\delta\rho}{\rho} > \delta_c$$



Surrounding perturbations do not have time to spin up the collapsing peak due to small timescales of collapse → PBHs are born spinless

De Luca, Desjacques, Franciolini, Malhotra, Riotto JCAP [1903.01779]

Assemble in binaries

Initial spatial Poisson distribution

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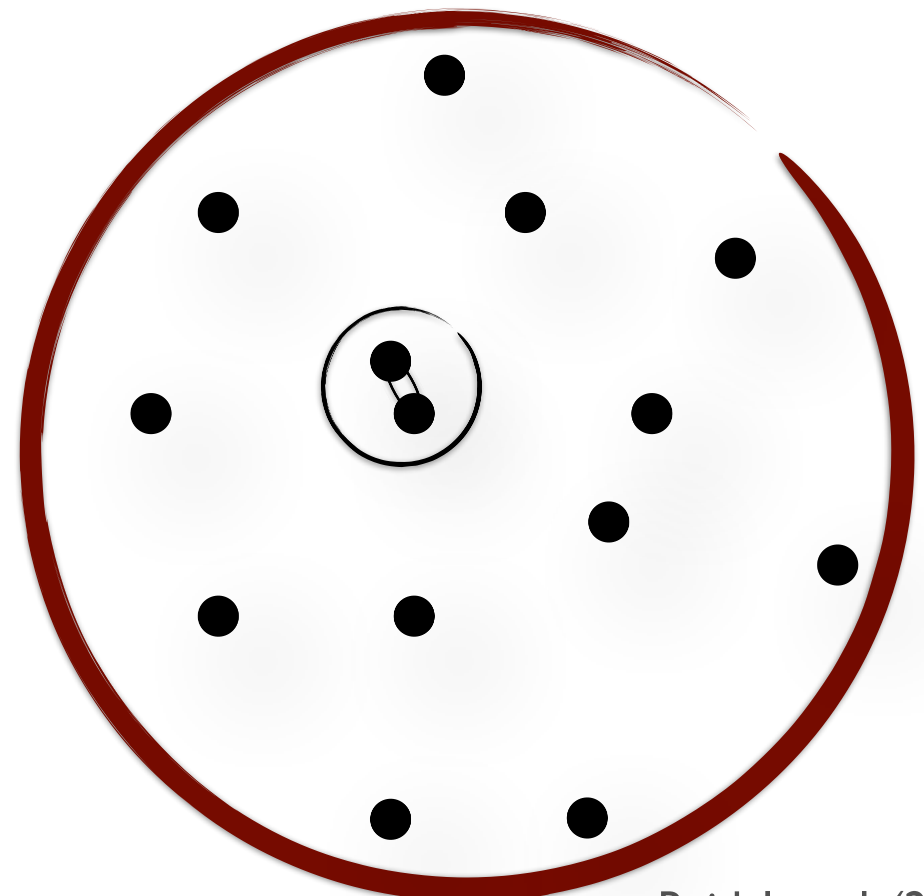
Probability of 2-body systems to decouple from the Hubble flow before matter-radiation equality, form a binary and merge



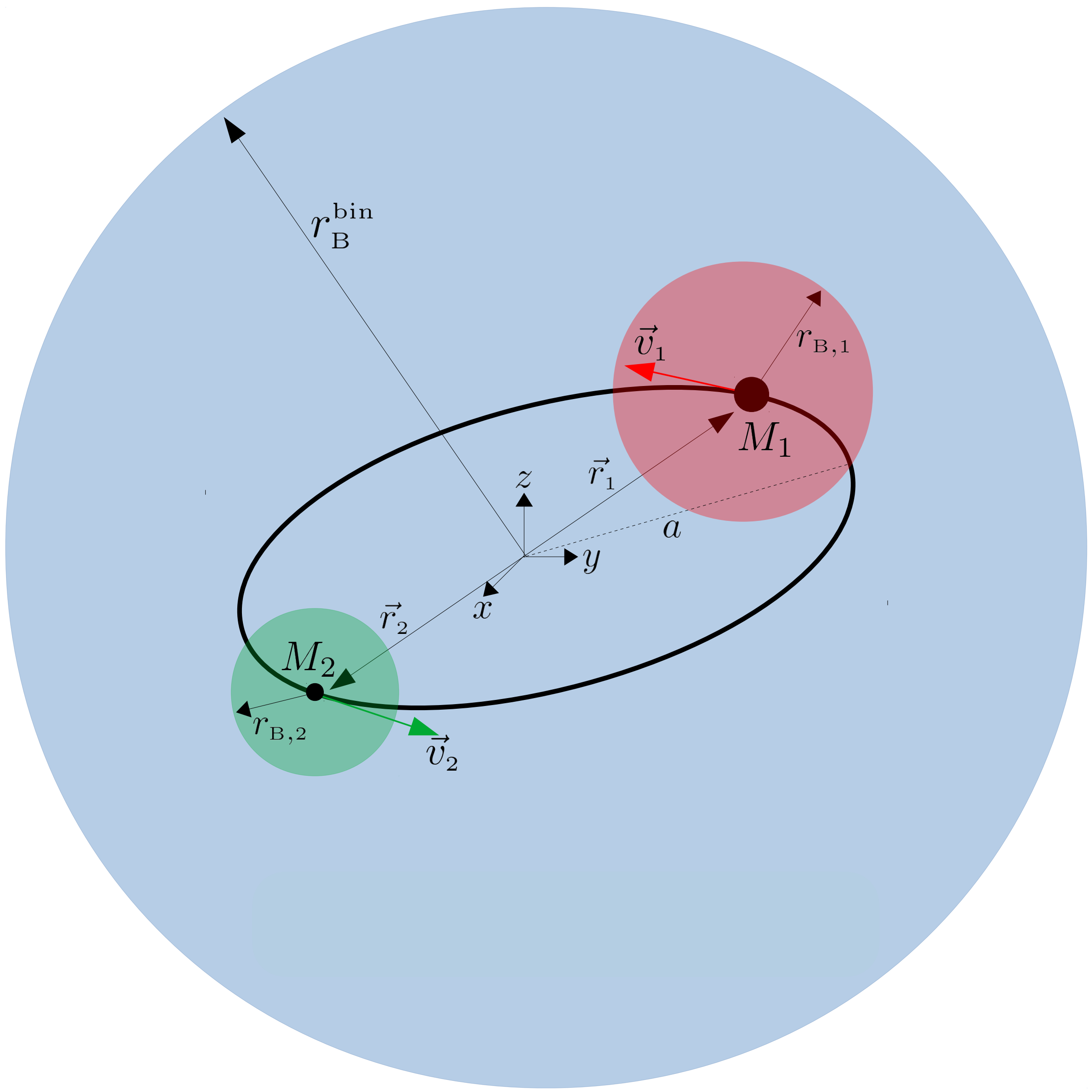
Raidal et al. (2019)

$$\mathrm{d}R = \frac{1.6\times 10^6}{\mathrm{Gpc}^3\,\mathrm{yr}} f_{\mathrm{PBH}}^{\frac{53}{37}}(z_{\mathrm{i}}) \left(\frac{t}{t_0}\right)^{-\frac{34}{37}} \eta_{\mathrm{i}}^{-\frac{34}{37}} \left(\frac{M_{\mathrm{tot}}^{\mathrm{i}}}{M_\odot}\right)^{-\frac{32}{37}} S\left(M_{\mathrm{tot}}^{\mathrm{i}}, f_{\mathrm{PBH}}(z_{\mathrm{i}})\right) \psi(M_1^{\mathrm{i}}, z_{\mathrm{i}})\psi(M_2^{\mathrm{i}}, z_{\mathrm{i}})\mathrm{d}M_1^{\mathrm{i}}\mathrm{d}M_2^{\mathrm{i}}$$

PBH abundance — Time evolution — Suppression factor — Mass function

Accretion

Baryonic material from the surrounding IGM is accreted by the PBH binary



Bondi-Hoyle mass accretion rate

$$\dot{M}_{\rm bin} = 4\pi\lambda m_H n_{\rm gas} v_{\rm eff}^{-3} M_{\rm tot}^2$$

↓

- Epochs of efficient accretion:
  $M \gtrsim \mathcal{O}(10) M_\odot$ at $z \lesssim 30$
- Presence of additional DM halo if PBHs are not the full DM
- Decrease of accretion efficiency around structure formation

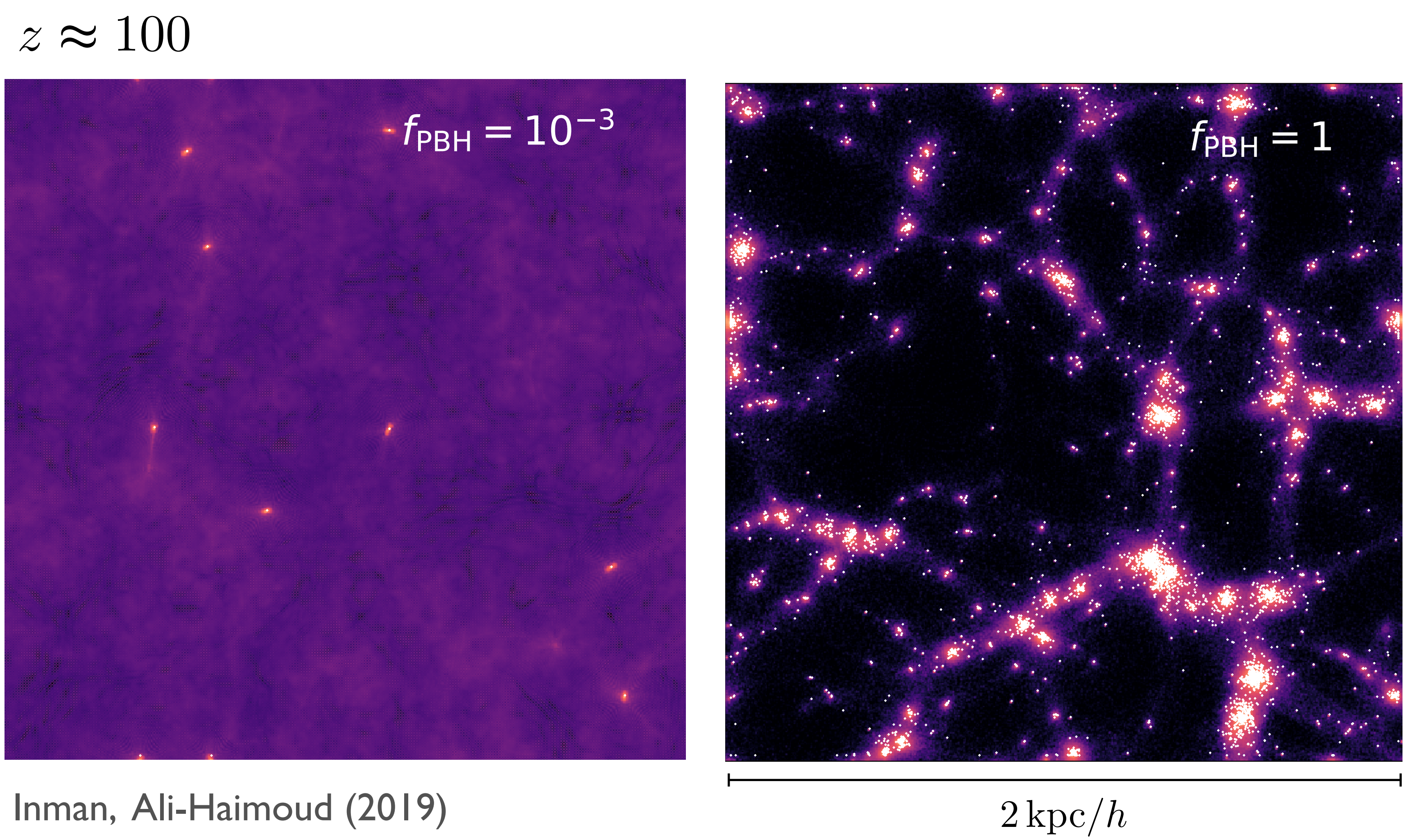
↓

Impact on PBH masses, spins and merger rate

De Luca, Franciolini, Pani, Riotto JCAP [2005.05641]

Clustering

After matter-radiation equality they may form clusters for large abundance



Inman, Ali-Haimoud (2019)

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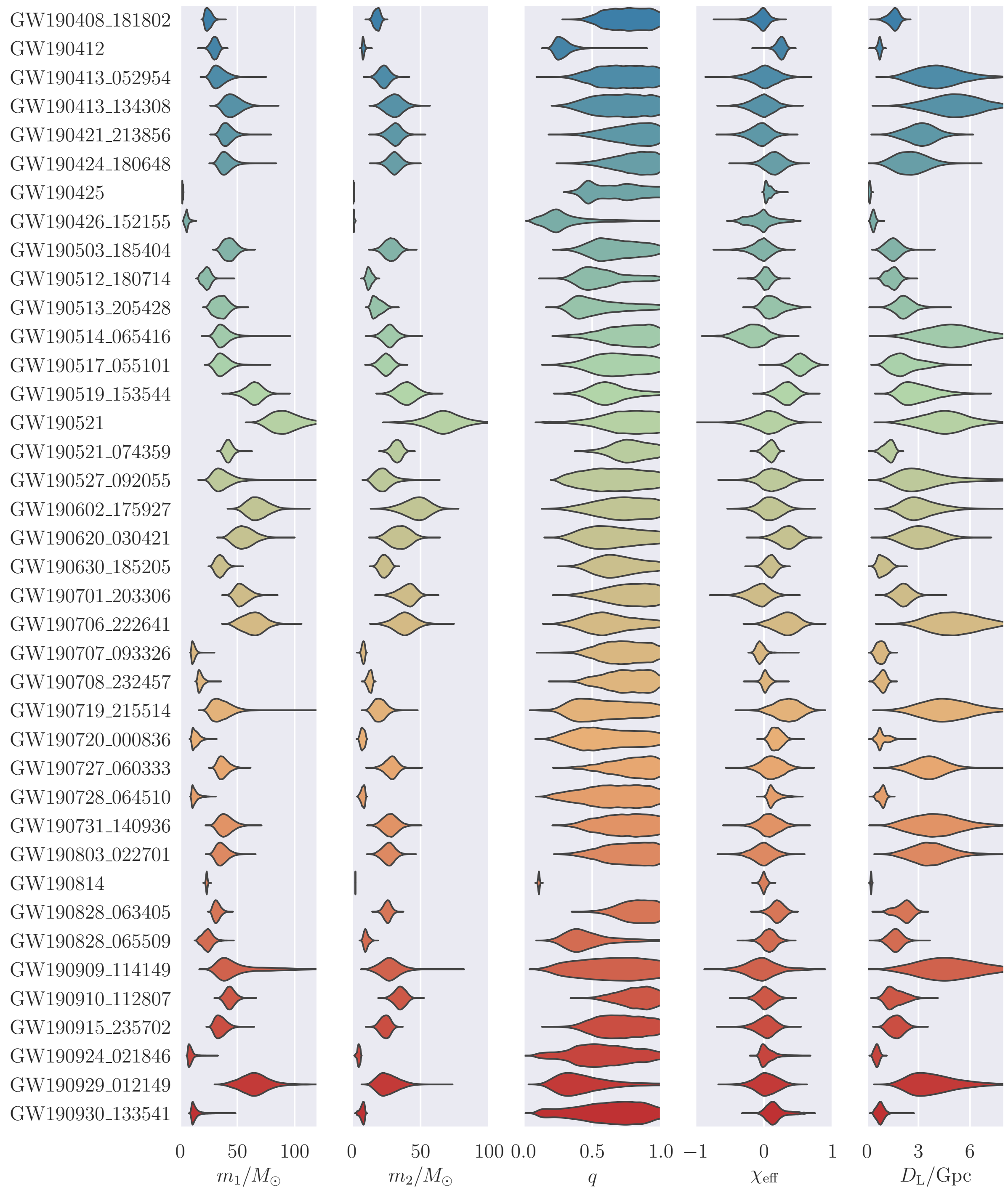
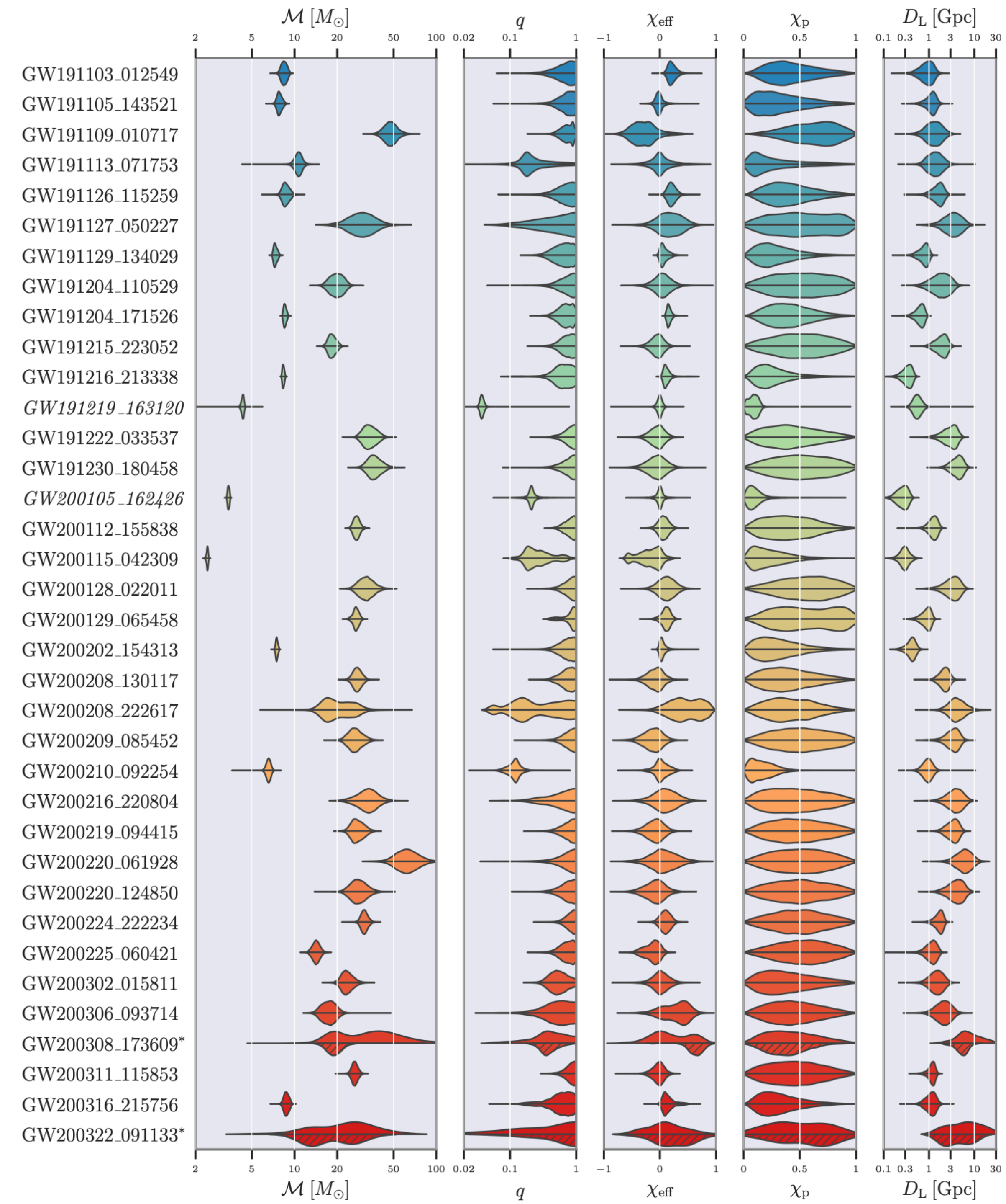
Early-time merger rate suppressed by binary interactions in clusters

De Luca, Desjacques, Franciolini, Riotto JCAP [2009.04731]

GWTC-2 & GWTC-3





Highlights:

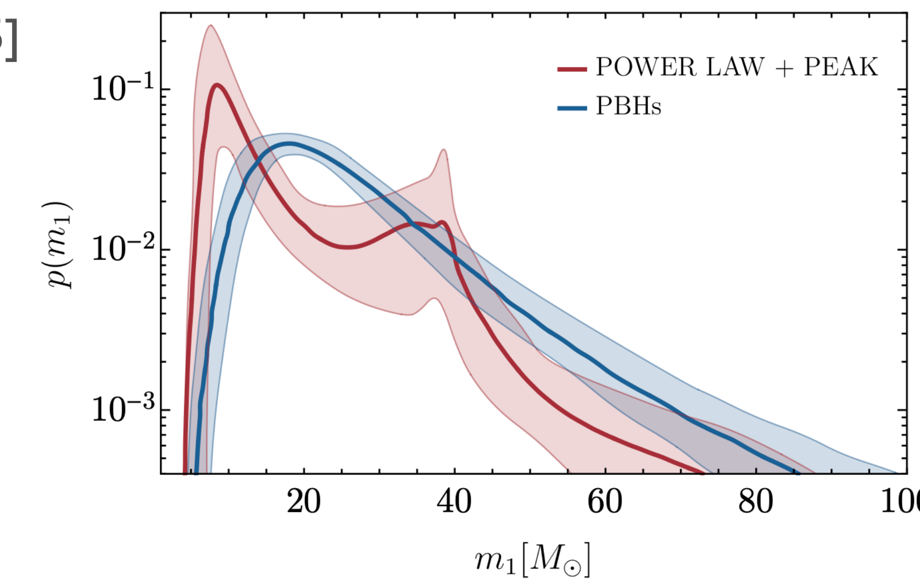
- Spinning events
- Events in the mass gap

→ Some features start to appear

Comparison with LVKC (GWTC-2)

Wong, Franciolini, De Luca, Baibhav, Berti, Pani, Riotto JCAP [2011.01865]

- PBHs "alone" are not able to reproduce all the features

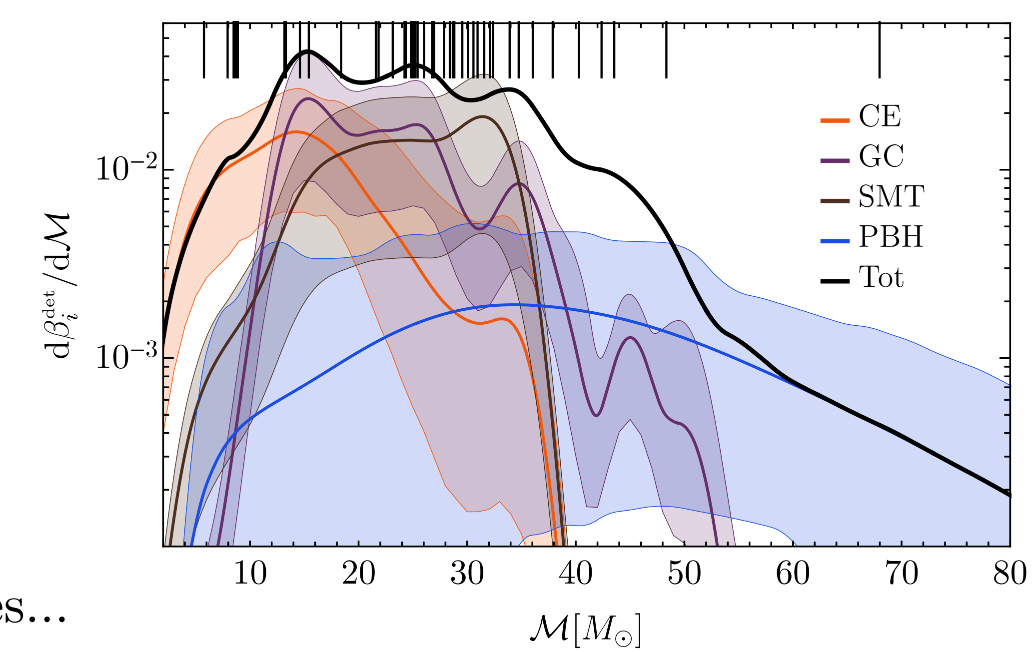


- Confront between PBH and ABH models (CE, SMT, GC, NSC, by Zevin et al.)

Role of PBHs depends on considered ABH models

Constraint on the PBH abundance: $f_{\rm PBH} \lesssim 10^{-3}$

PBHs may fill the astrophysical mass gap



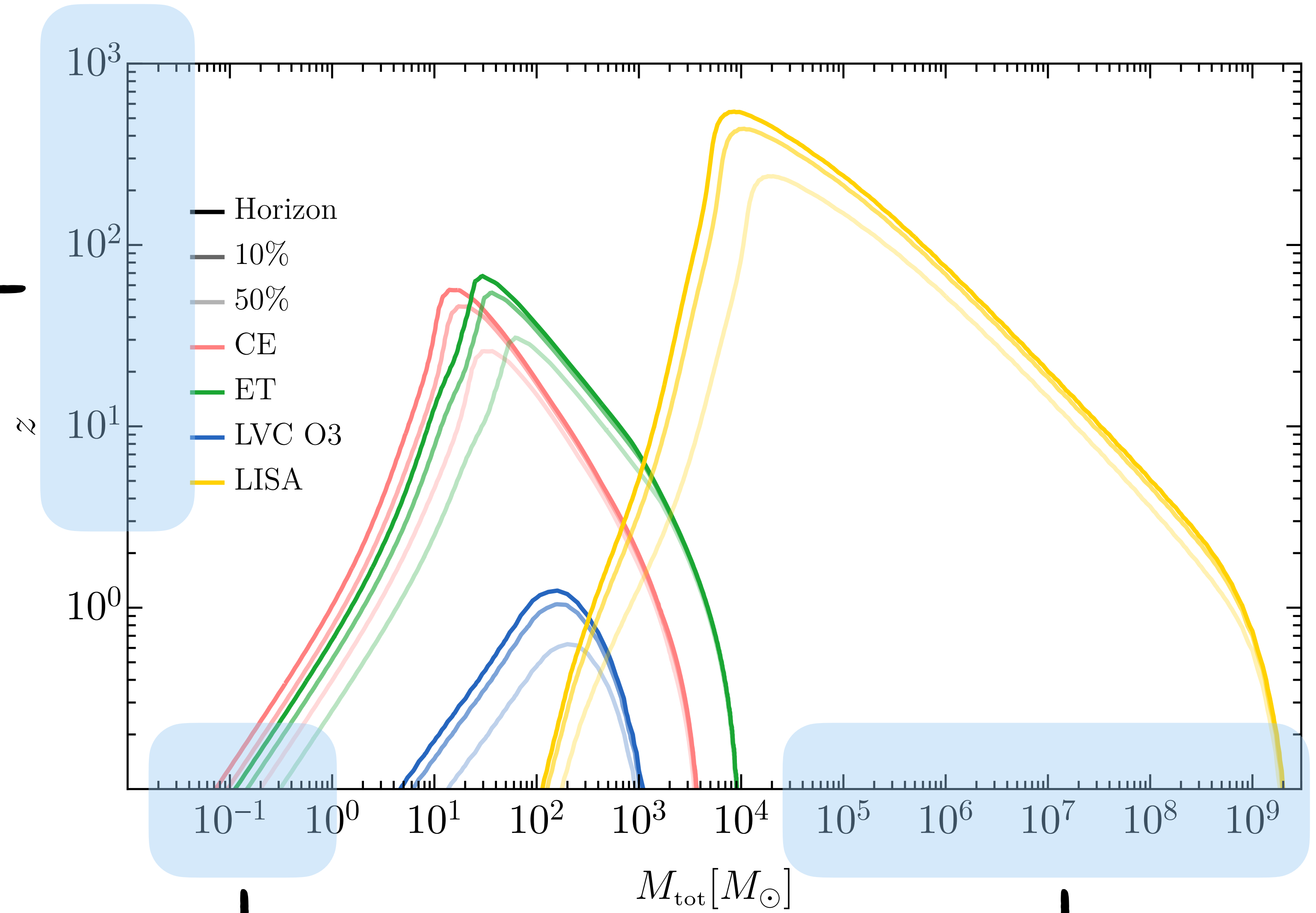
Extend the analysis with more ABH channels, uncertainties...

Franciolini, Baibhav, De Luca, Ng, Wong, Berti Pani, Riotto, Vitale PRD [2105.03349]

Future GW experiments

3G detectors (ET/CE) and LISA have larger horizon redshifts

Large redshift



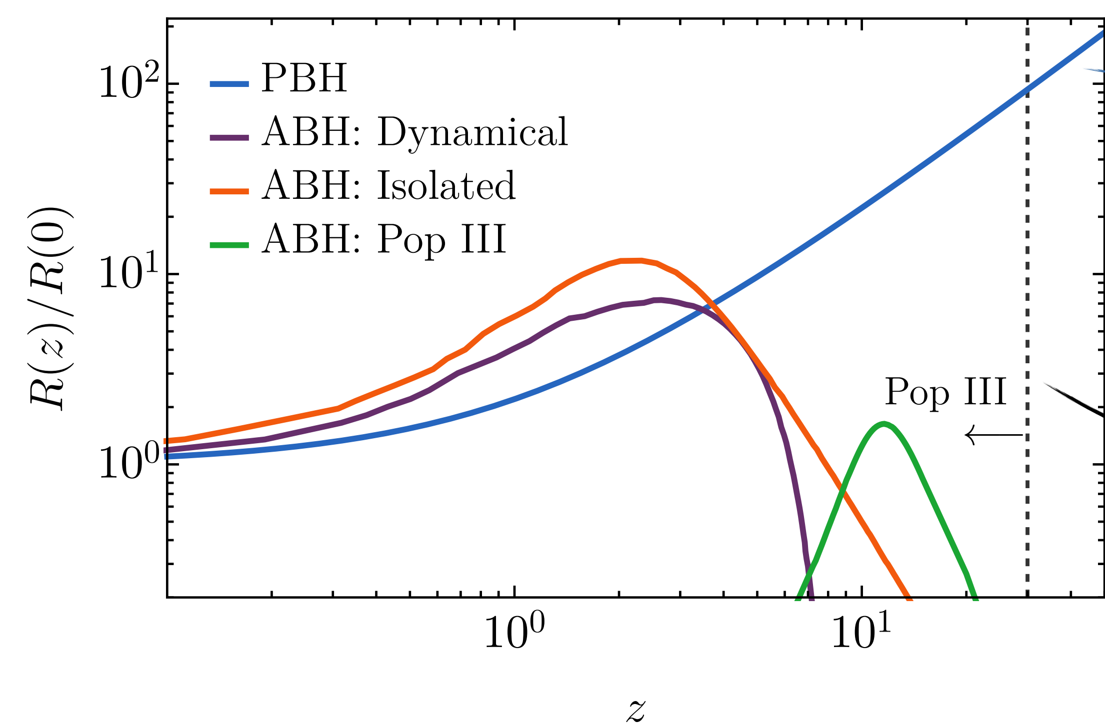
Subsolar objects

SMBHs

They may help in distinguishing PBHs from ABHs

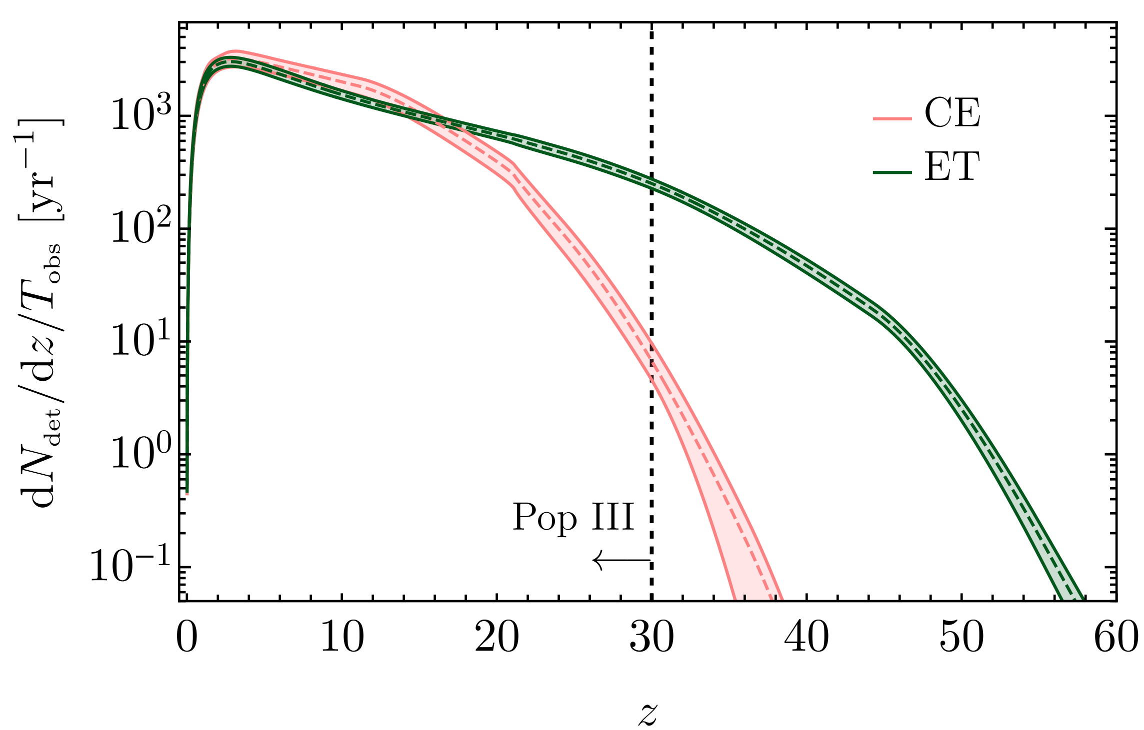
Merging at high redshift

GWs observation at high redshift with ET/CE may help in distinguish PBH from ABH



$R_{\rm PBH} \sim t(z)^{-34/37}$

No contamination from ABH (pop III)



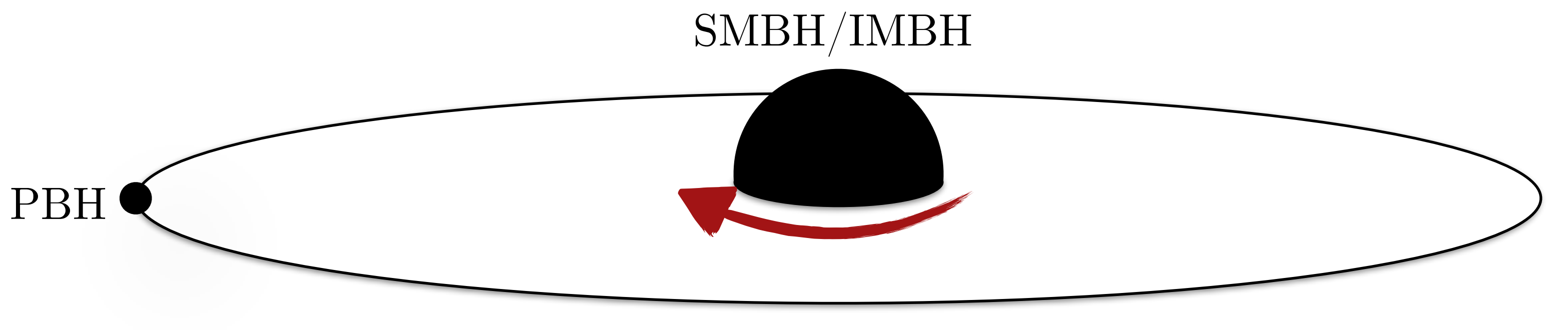
High redshift observations at ET in PBH/ABH mixed scenario:

$$N^{\rm det}_{\rm PBH}(z > 30) = 1315^{+305}_{-168}/\mathrm{yr}$$

De Luca, Franciolini, Pani, Riotto JCAP [2102.03809]

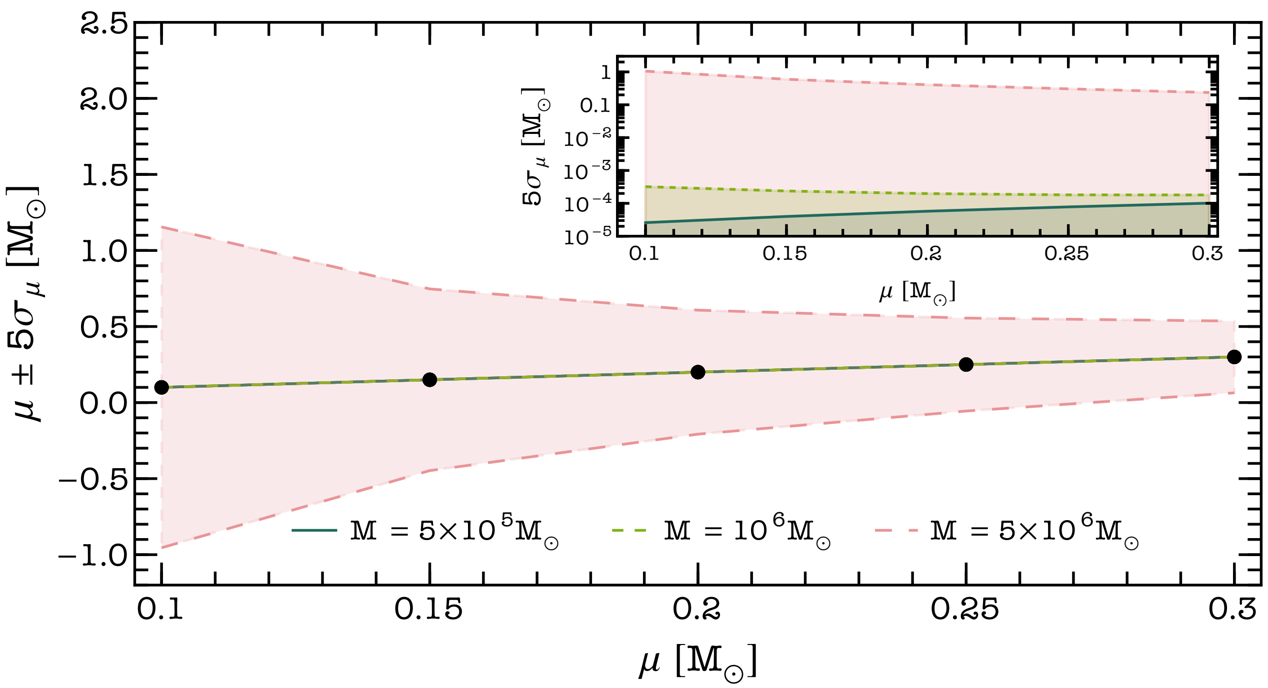
Extreme mass-ratio inspirals

Detection of subsolar compact objects may point to PBH discovery

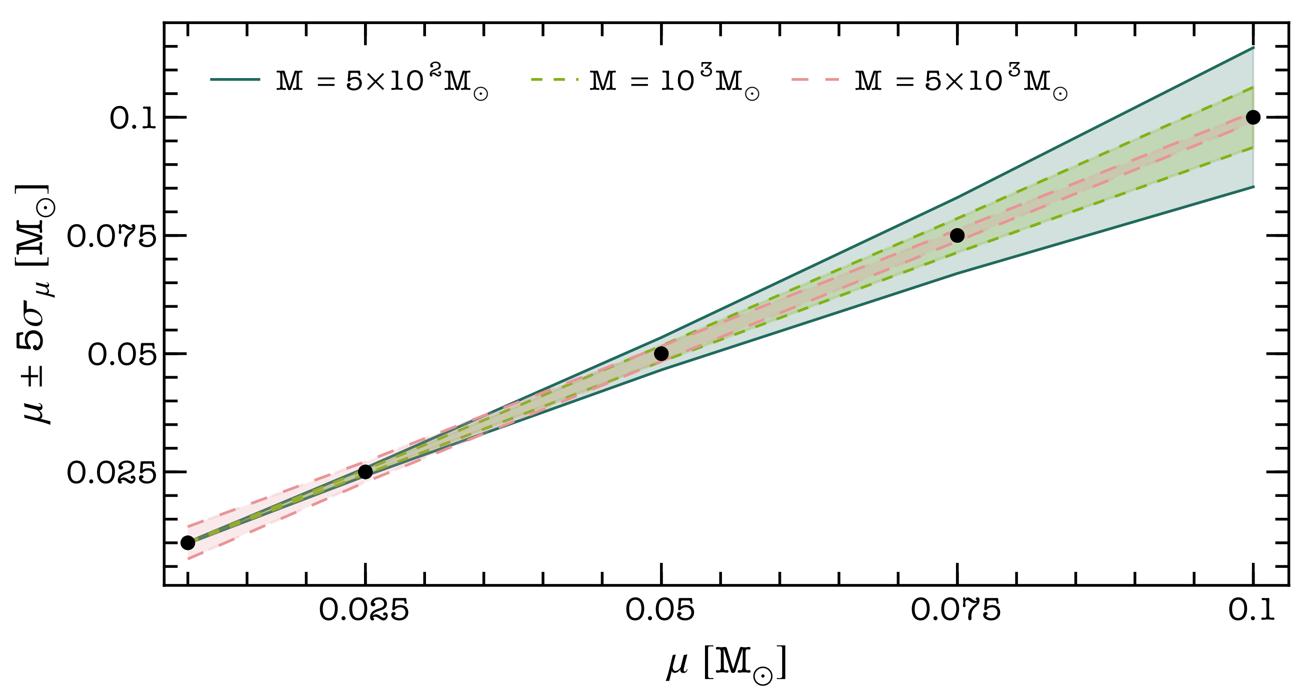


Barsanti, De Luca, Maselli, Pani PRL [2109.02170]

LISA



ET



- Detection of subsolar masses up to O(500 Mpc) at LISA and O(Gpc) at ET
- Exclude super-solar mass at more than 5-sigma confidence level

Conclusions

- PBHs are fascinating early-universe compact objects and provide a candidate for the dark matter

- They may be produced within different formation scenarios, and evolve during the cosmological history

- PBHs are competitive with ABH models and may contribute to the present GW data detected by the LVKC

- Future GW experiments like LISA or ET/CE may help in discovering PBHs and shed light on their properties

THANK YOU !