Have Primordial Black Holes been found by LIGO/Virgo?

Iberian GW Meeting, 20th Oct 2020

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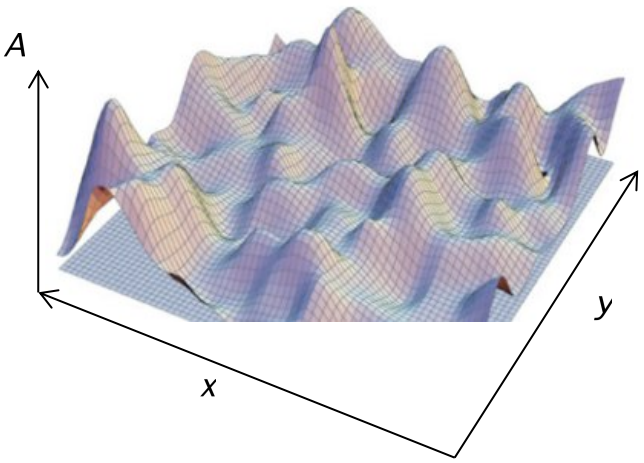
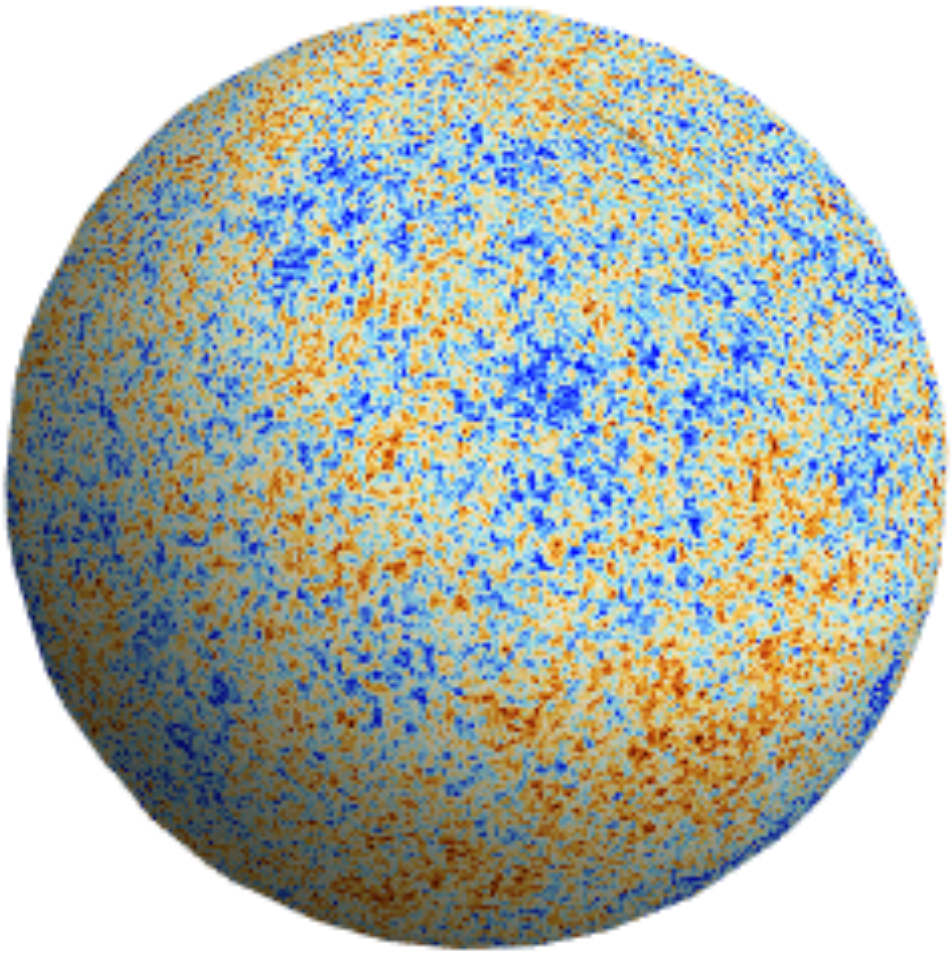
Inflation

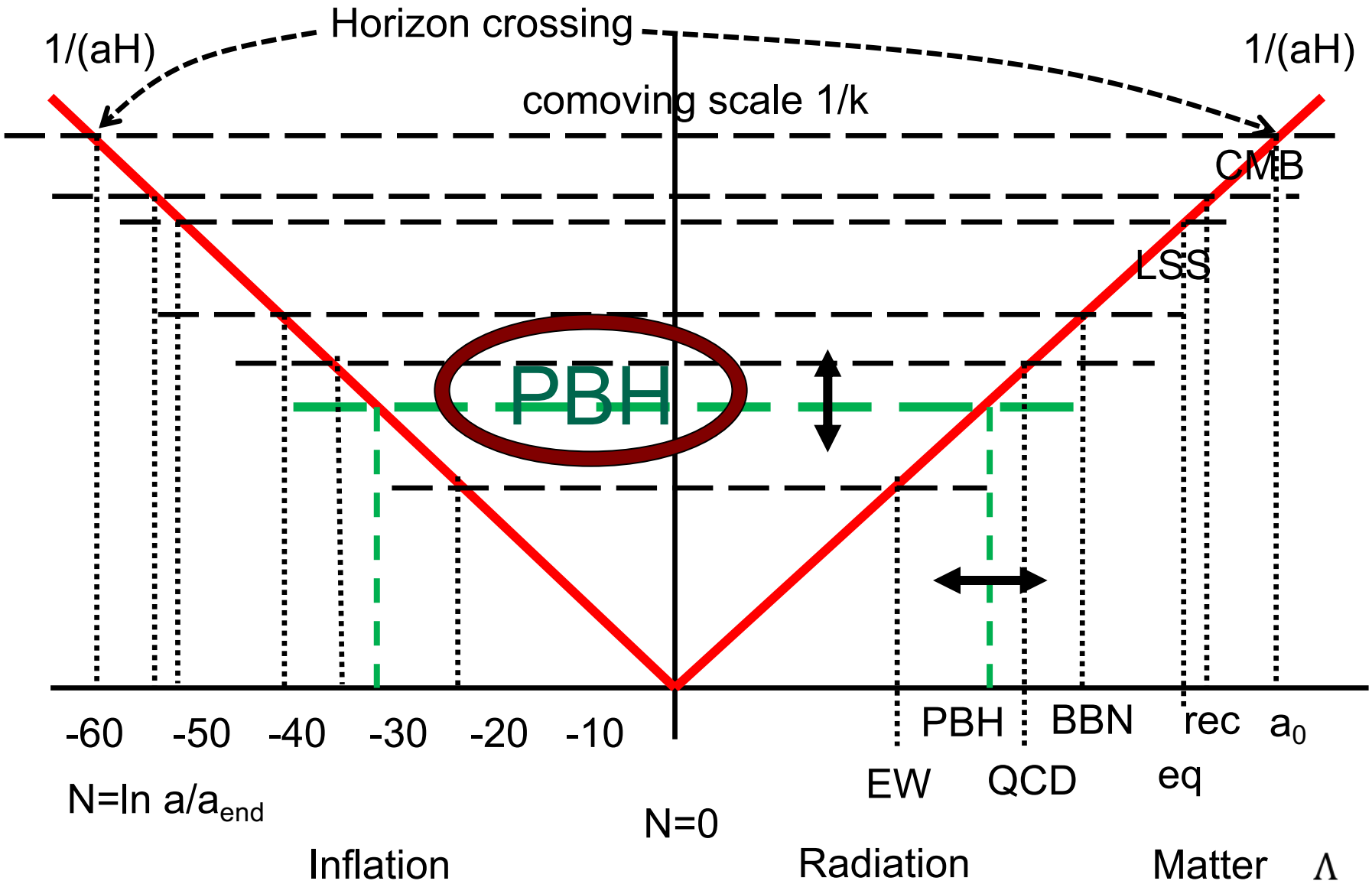


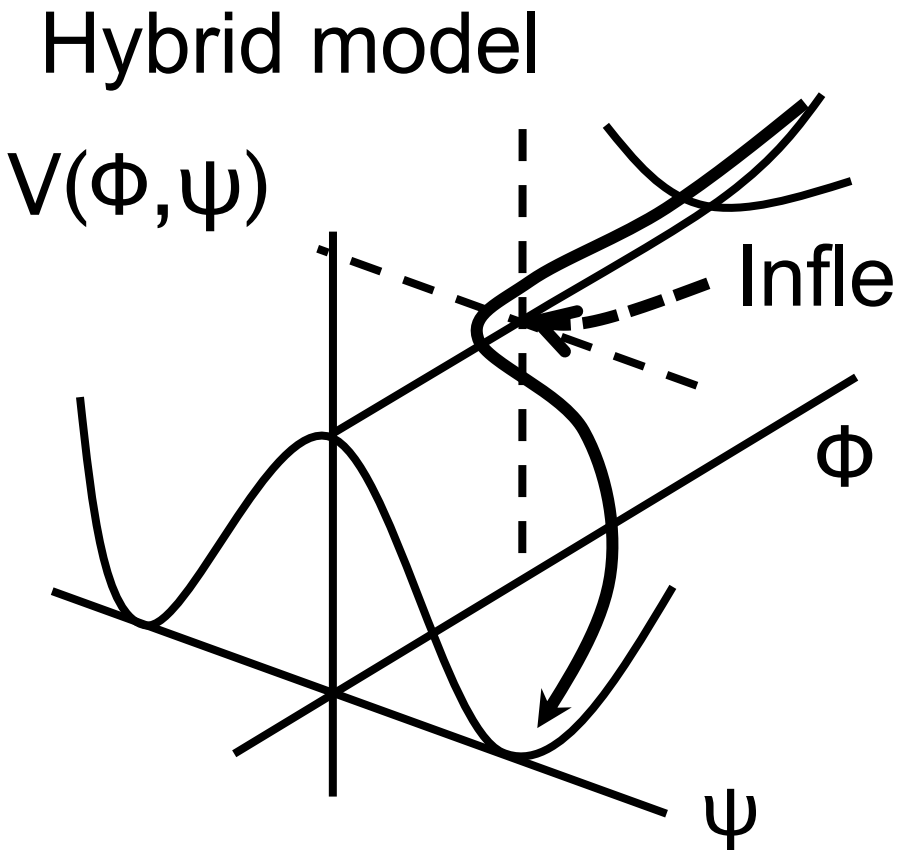
Quantum Fluctuations=
Ripples in Space-Time

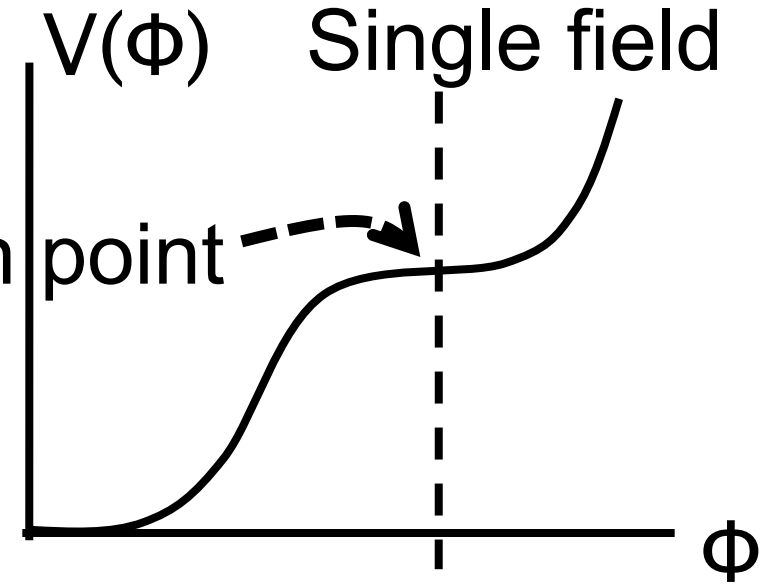


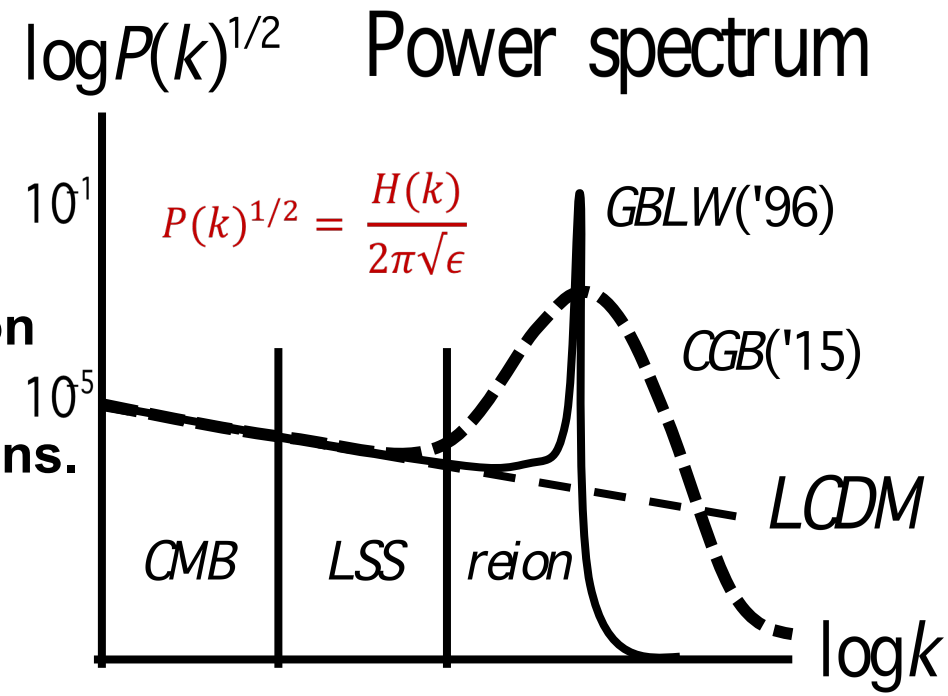
Stretched to cosmological distances

Inflation


Horizon crossing
1/(aH)
1/(aH)
comoving scale 1/k
CMB
LSS
PBH
-60
-50
-40
-30
-20
-10
PBH
BBN
rec
a_0
EW
QCD
eq
N=ln a/a_{end}
N=0
Inflation
Radiation
Matter
Λ



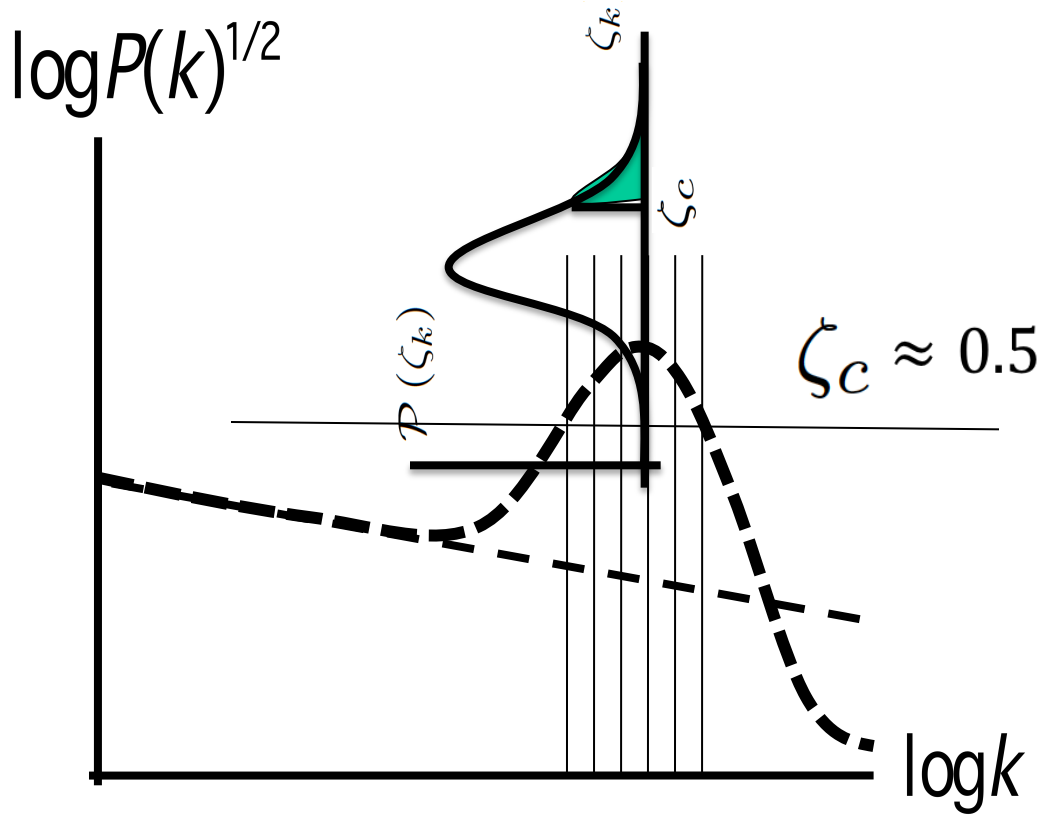




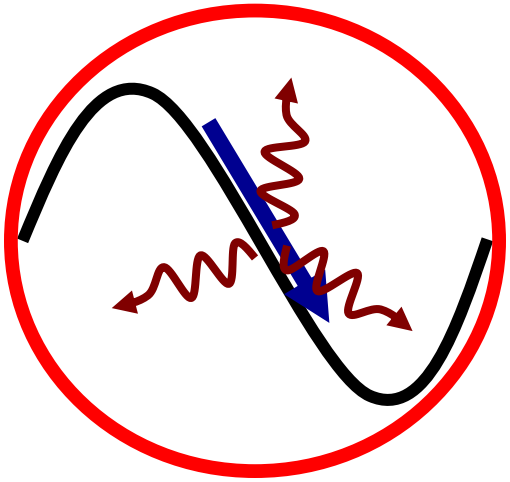
Quantum fluctuations during inflation may have enough amplitude to generate large curvature perturbations.

Quantum diffusion makes a narrow peak become a broad peak in k.

Gravitational Collapse of PBH



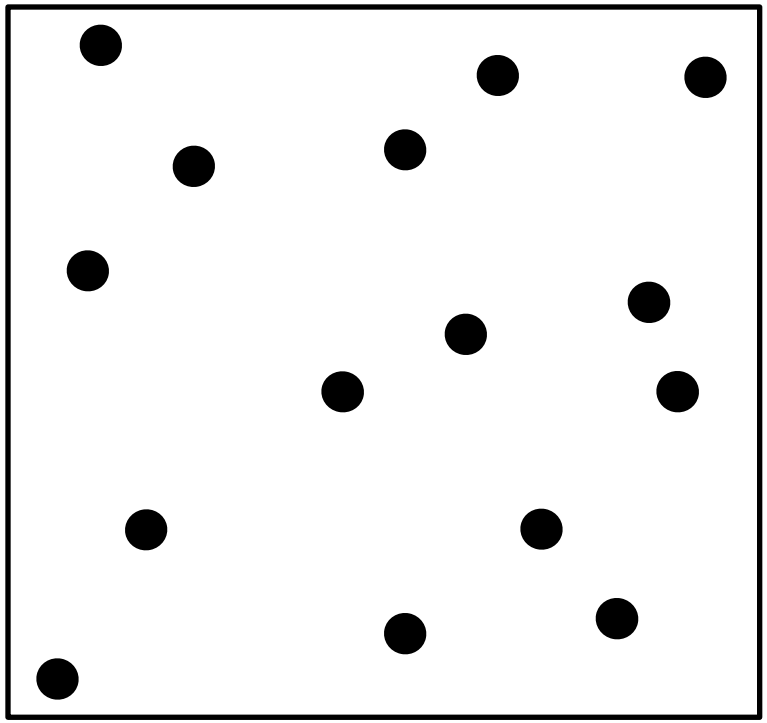
$$\beta^{\text{form}}(M_k) = \int_{\zeta_c}^{\infty} \mathcal{P}(\zeta_k)\, d\zeta_k$$



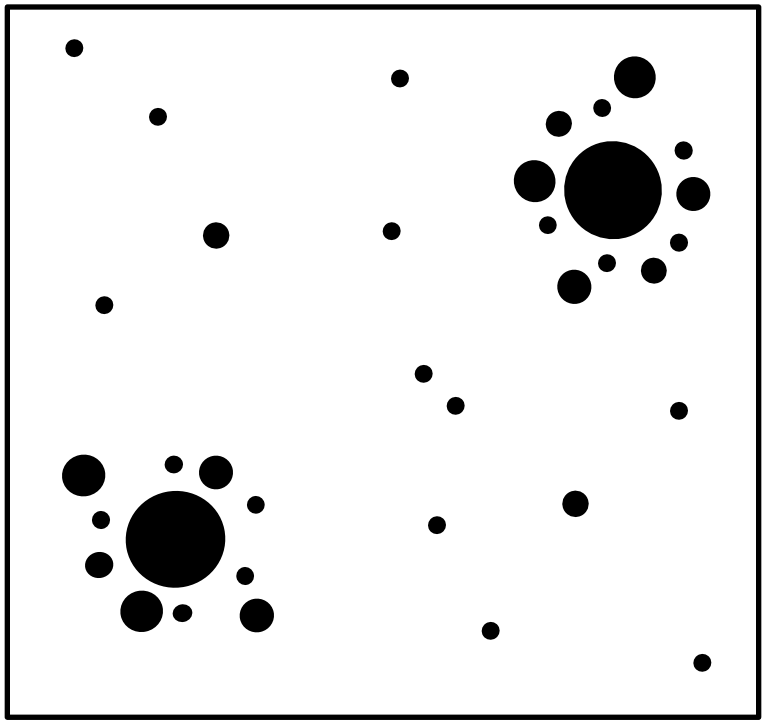
$$M_{PBH} \approx 30 M_{\odot}\, e^{2(N-36)}$$

$$\beta(N) = \begin{cases} \text{Erfc}\left(\frac{\zeta_c}{\sqrt{2P_\zeta(N)}}\right), & \text{Gaussian statistics}, \\ \text{Erfc}\left(\sqrt{\frac{1}{2} + \frac{\zeta_c}{\sqrt{2P_\zeta(N)}}}\right), & \chi^2 \text{ statistics} \end{cases}$$

Spatial Distribution PBH



- Monochromatic
- Uniformly distributed



- Broad range masses
- In clusters

Standard Model Lagrangian

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

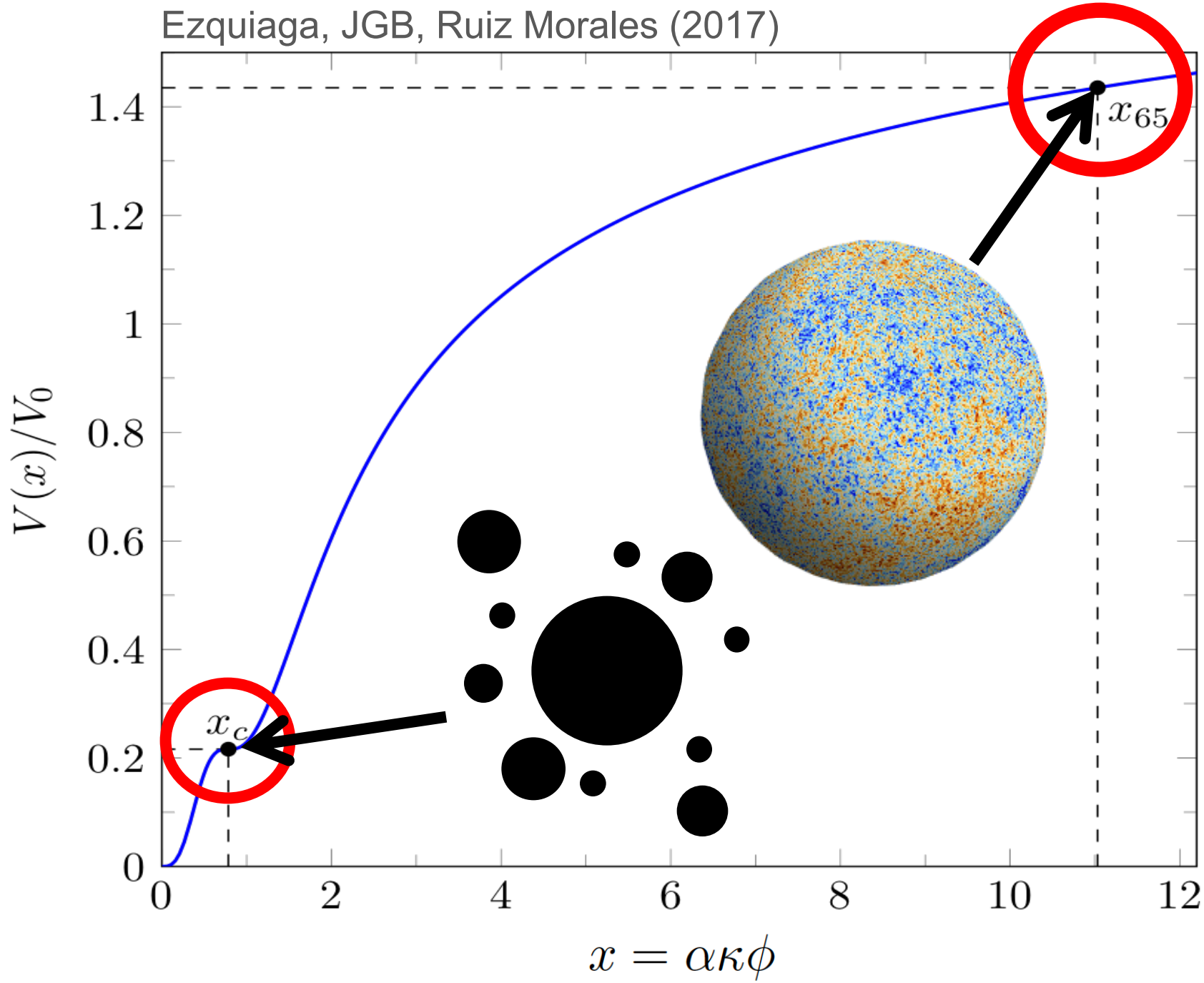
$$+ i \bar{\psi} \not{D} \psi + h.c.$$

$$+ \bar{\psi}_i y_{ij} \psi_j \phi + h.c.$$

$$+ |D_\mu \phi|^2 - V(\phi)$$

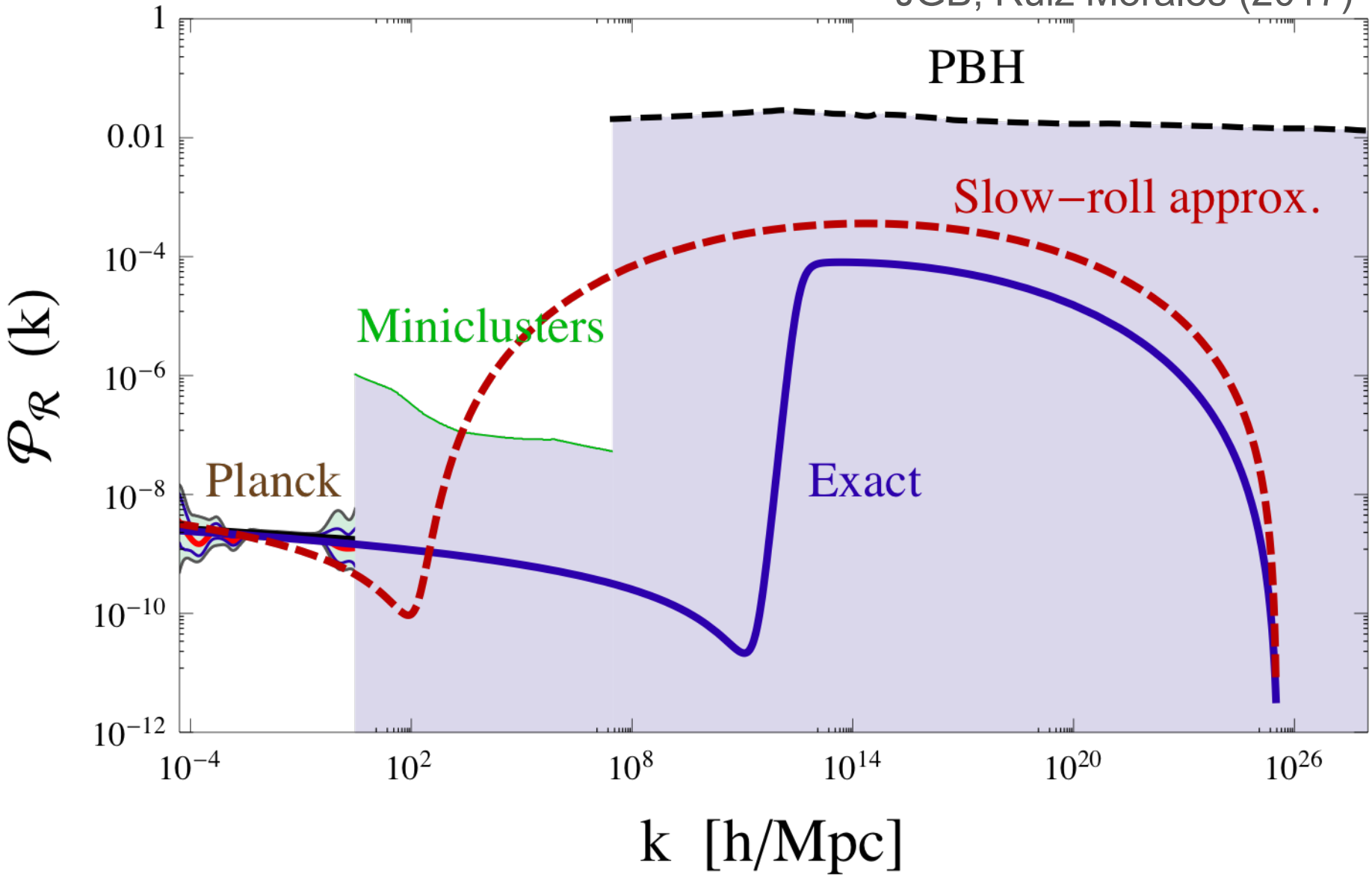
$$+ \xi |\phi|^2 R$$ gravity

Ezquiaga, JGB, Ruiz Morales (2017)



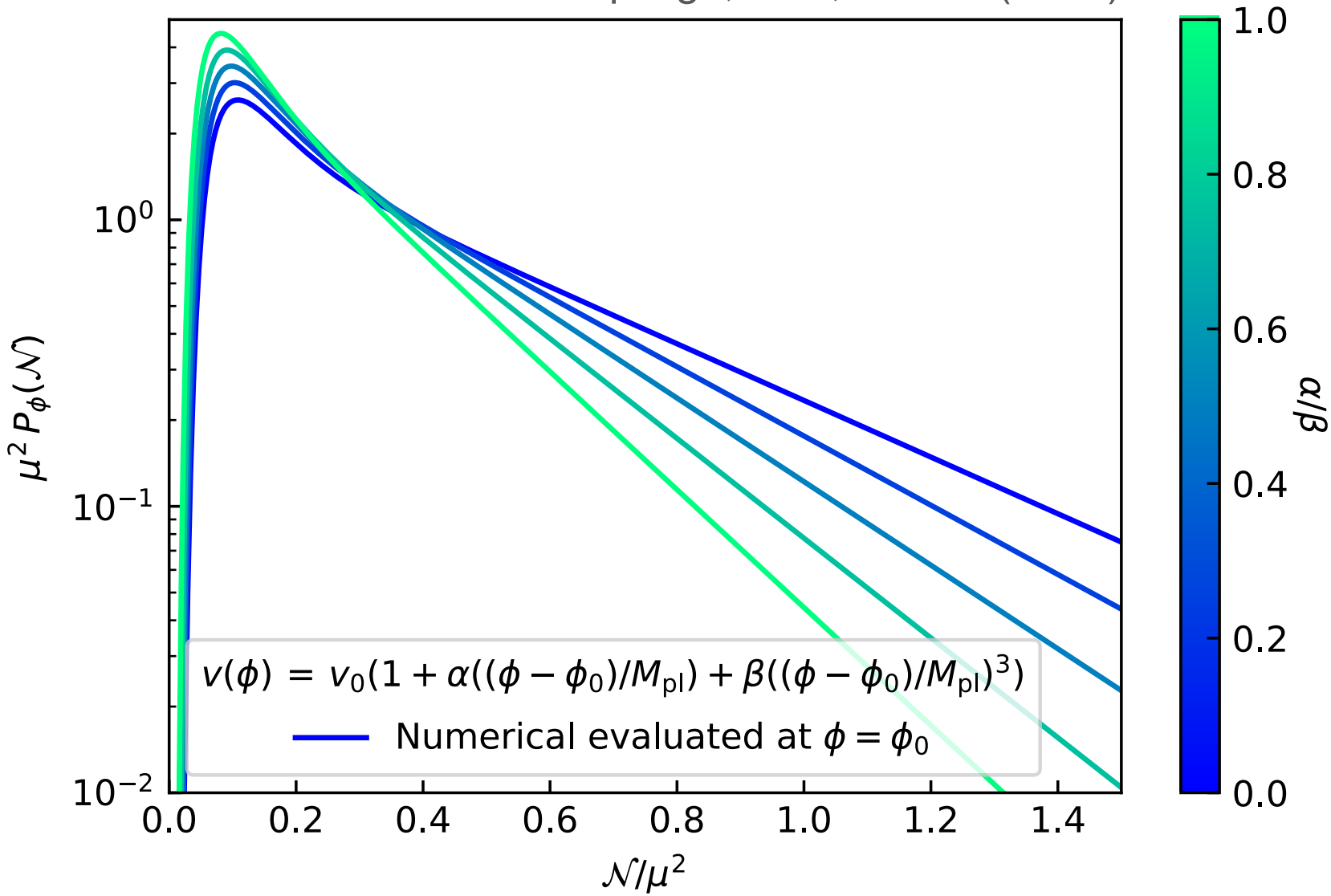
Primordial Spectrum PBH

JGB, Ruiz Morales (2017)

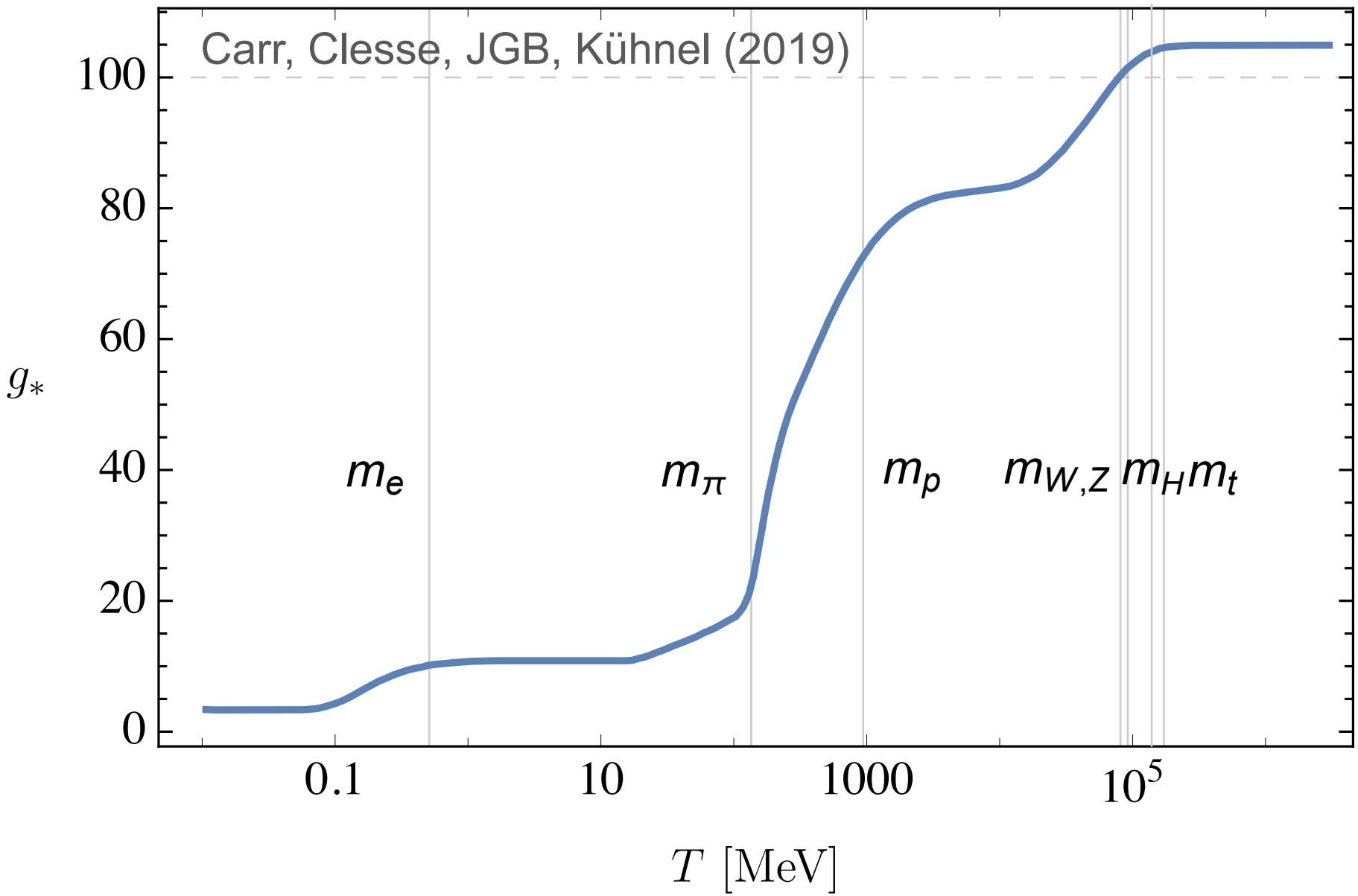


Non-Gaussian Exponential Tails

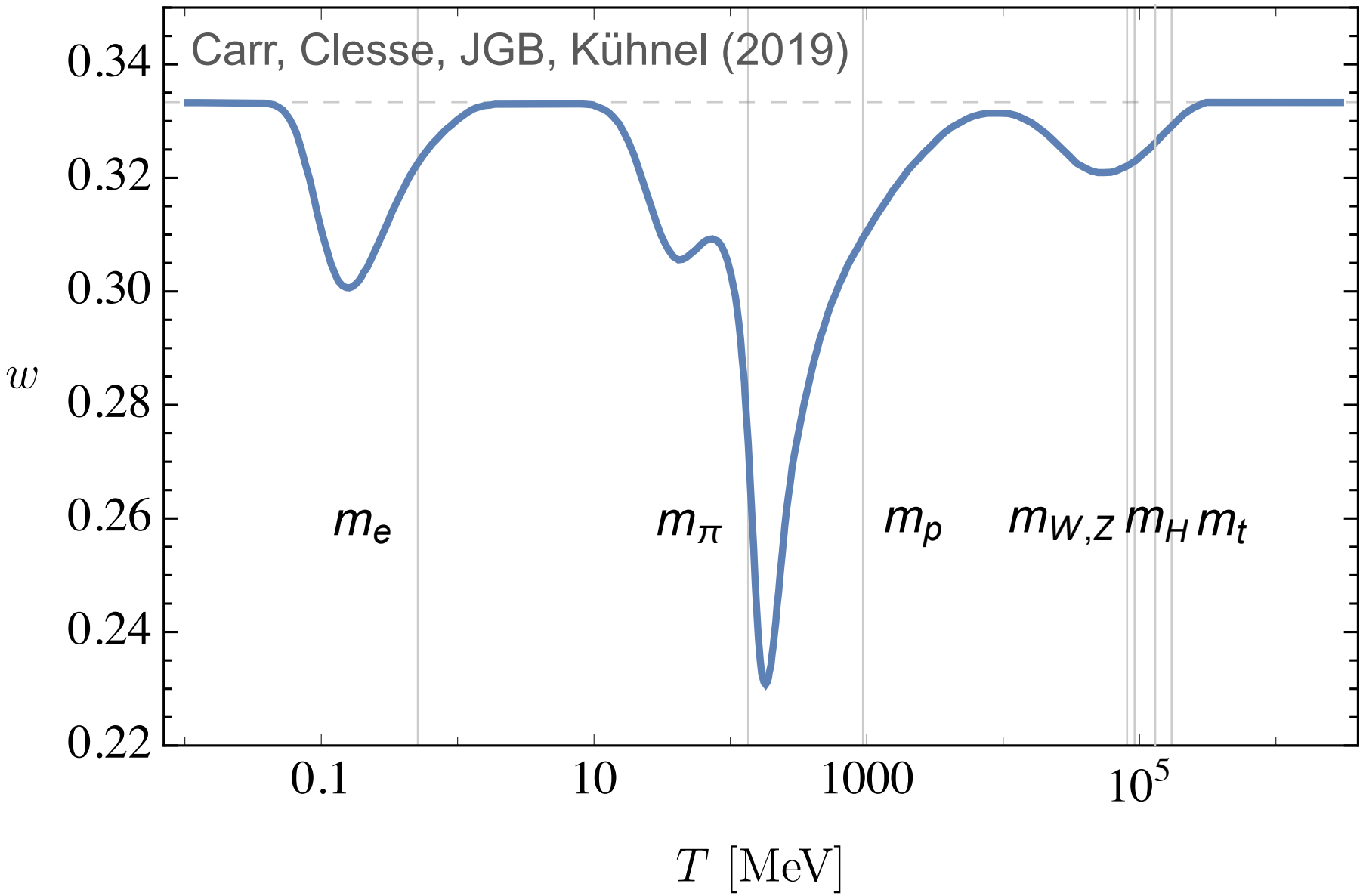
Ezquiaga, JGB, Vennin (2019)



Relativistic degrees of freedom

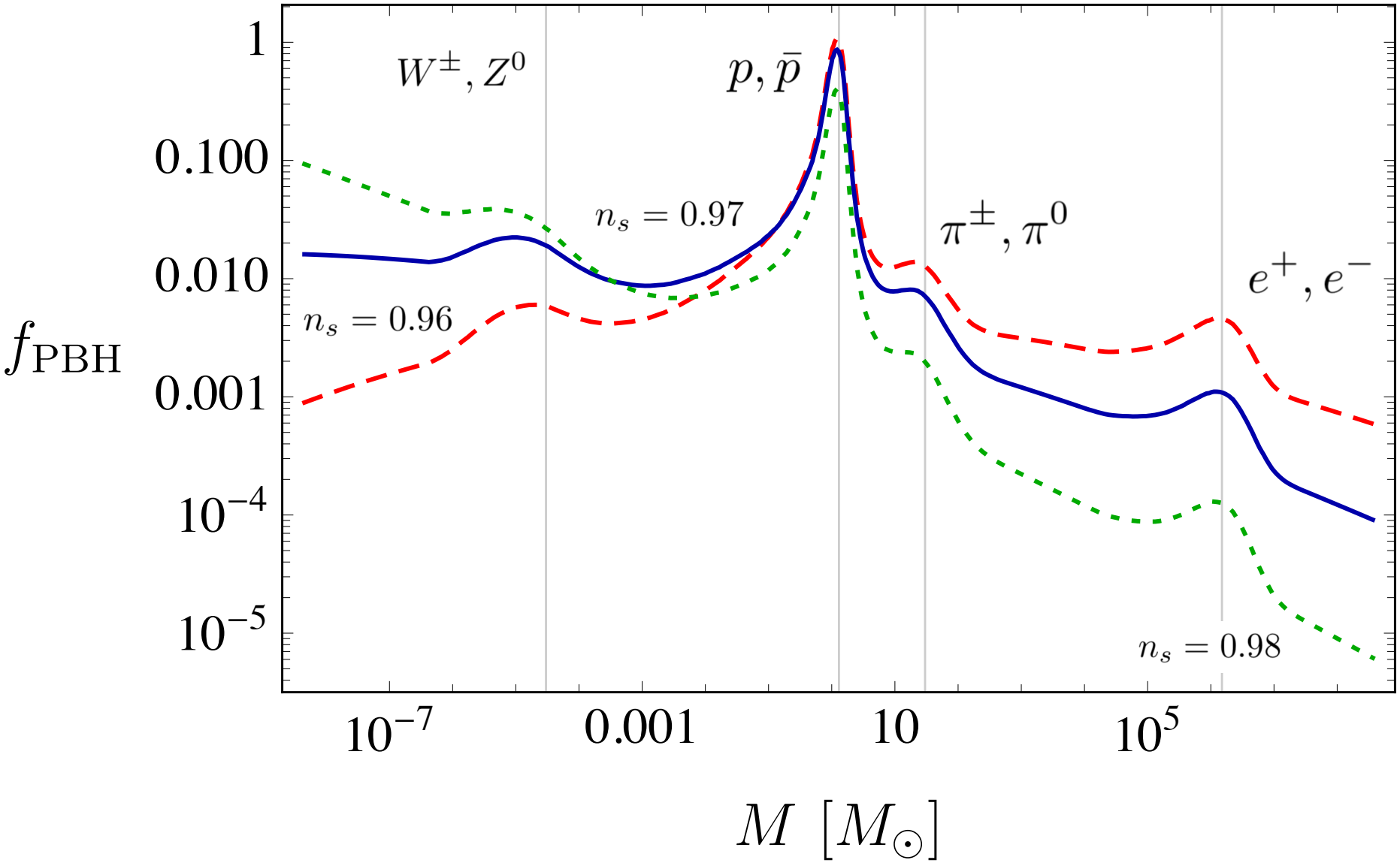


Equation of state parameter

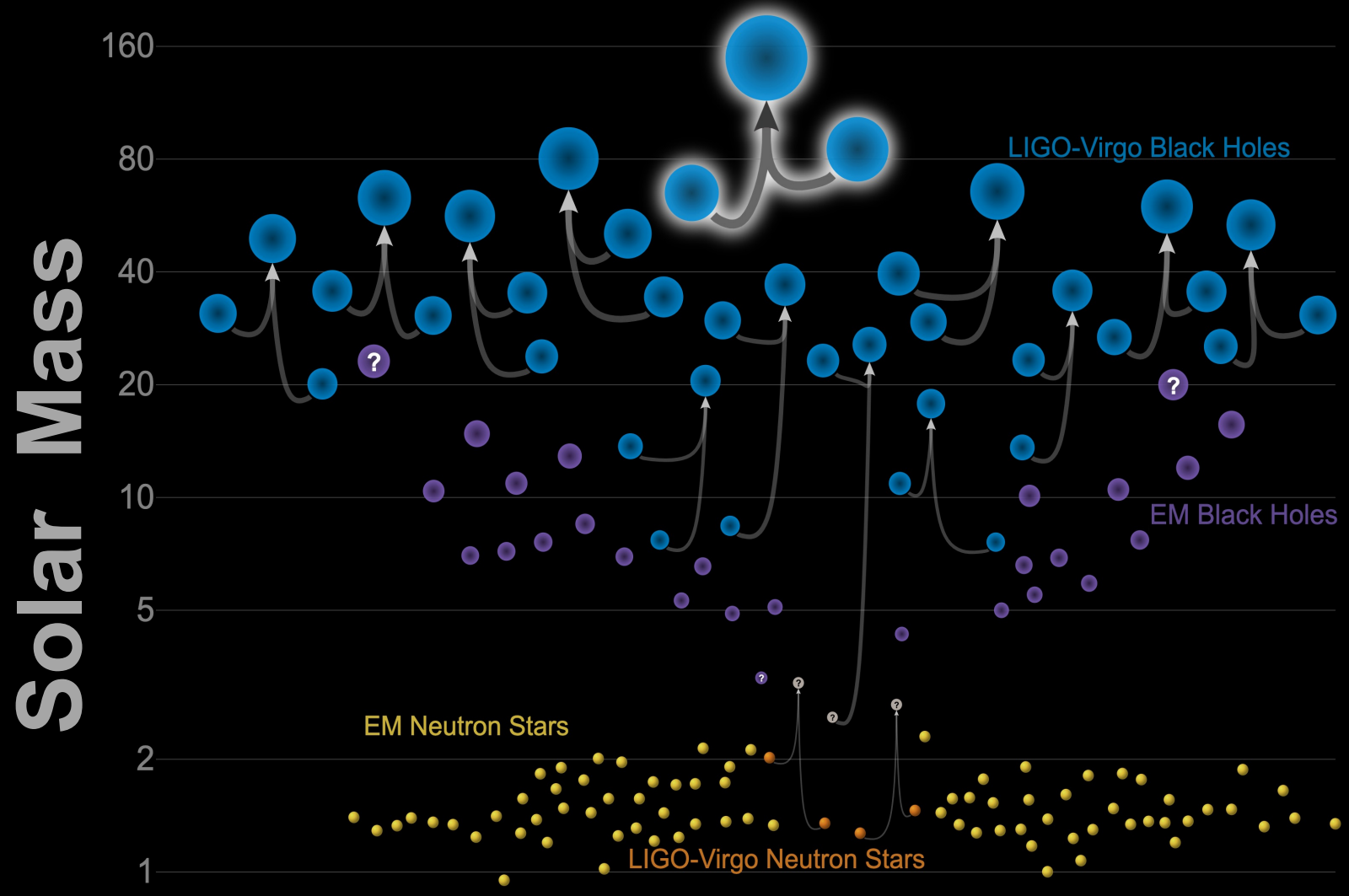


PBH mass spectrum

Carr, Clesse, JGB, Kühnel (2019)

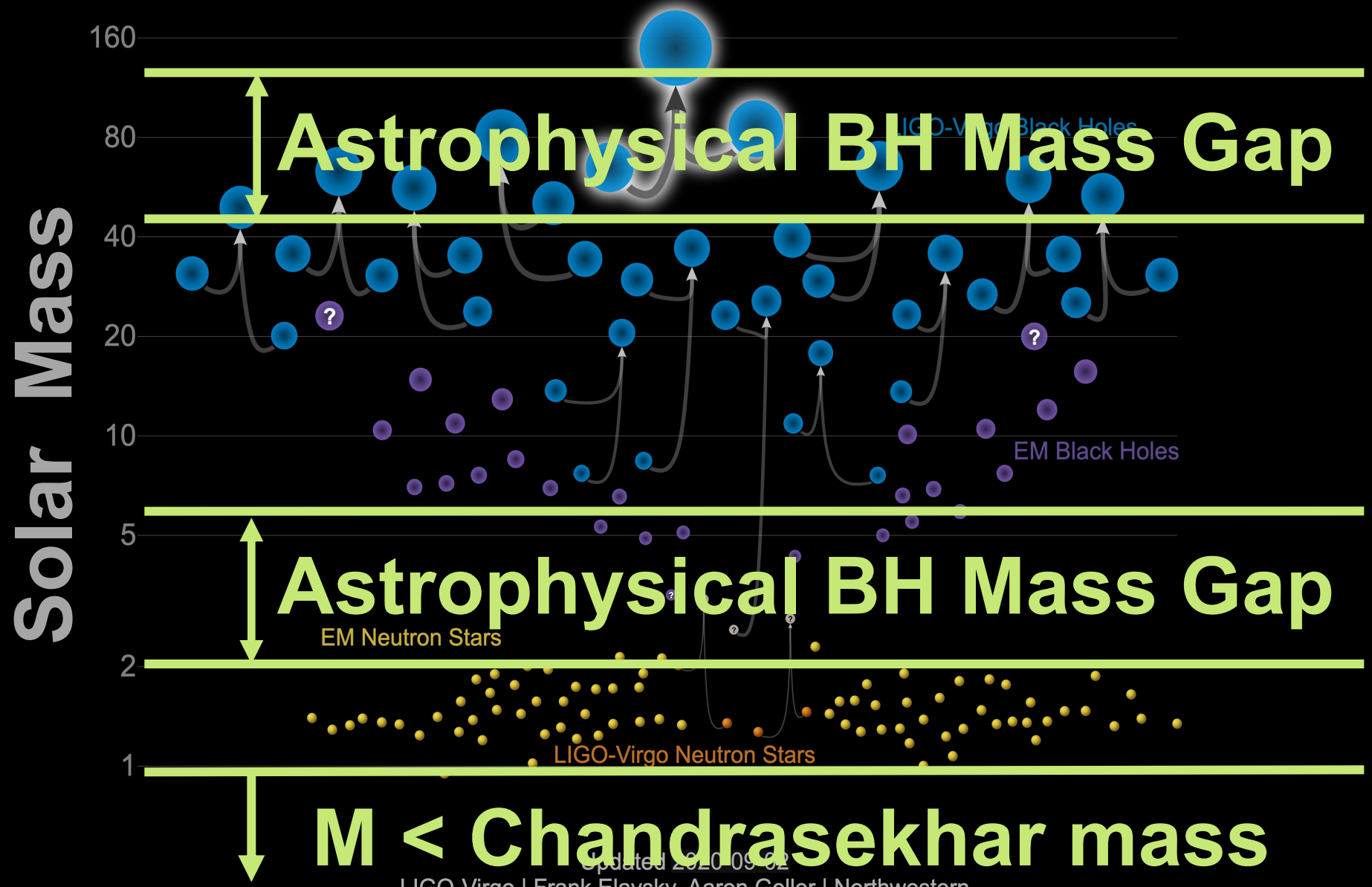


Black Holes and Neutron Stars

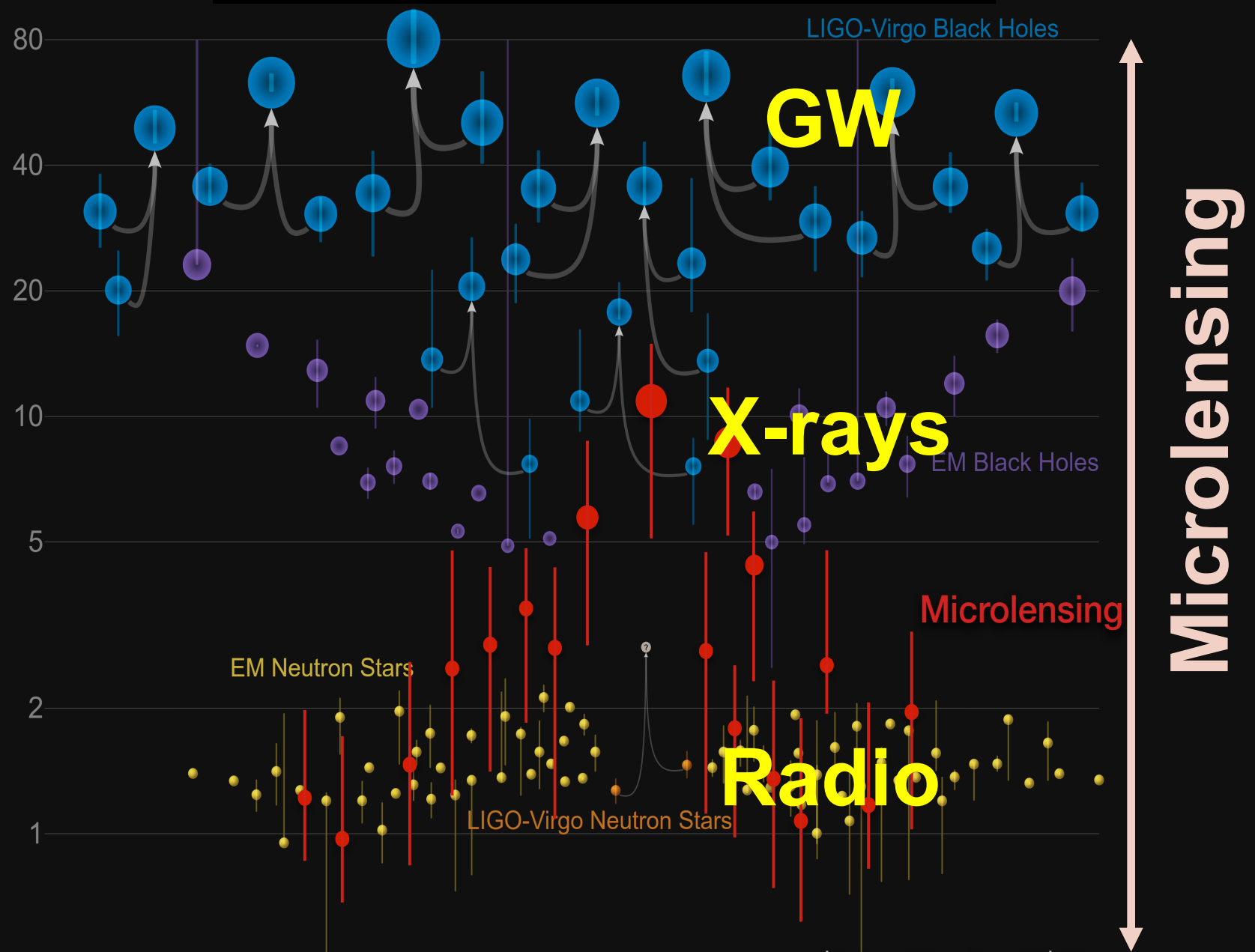


Updated 2020-09-02
LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern

Black Holes and Neutron Stars

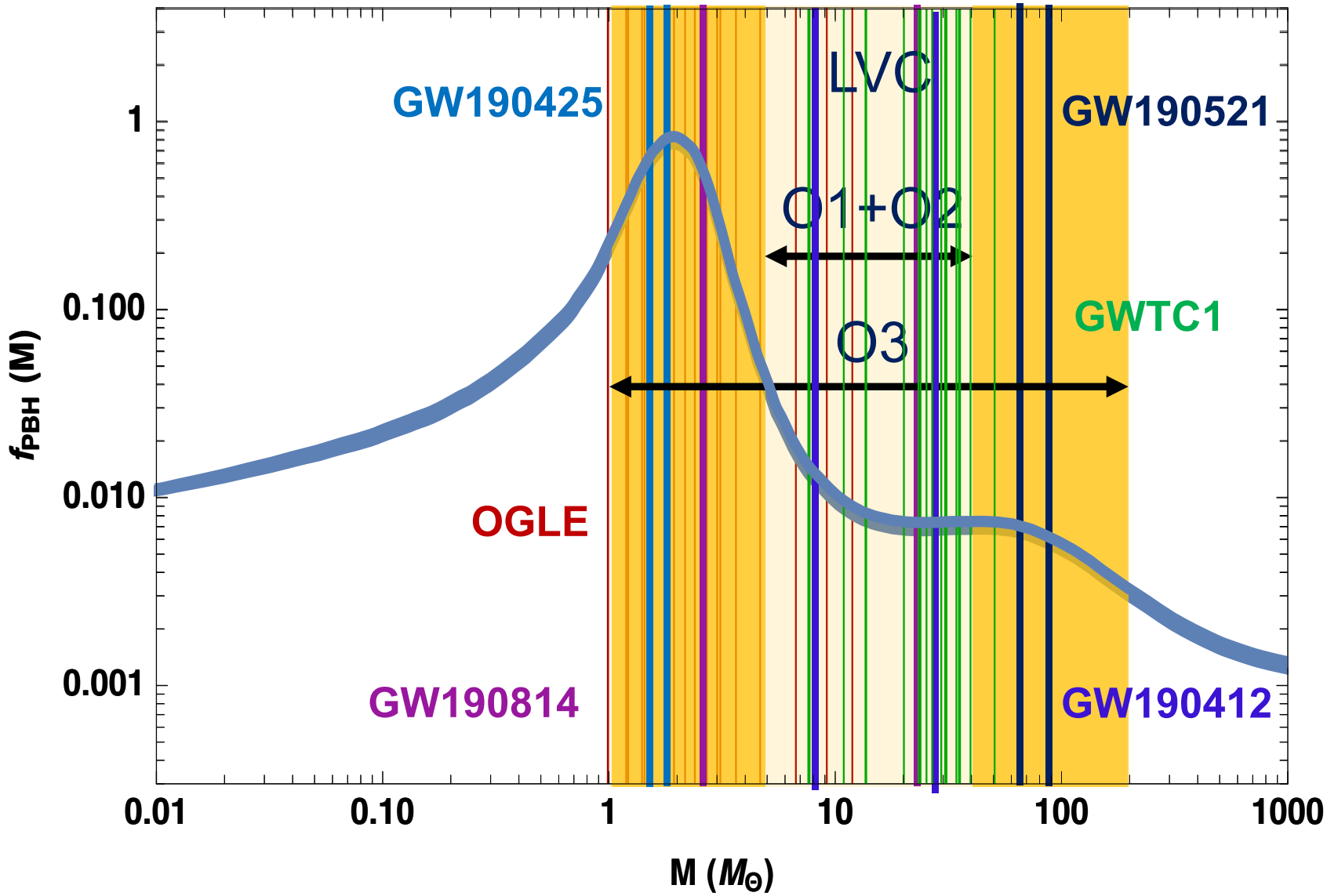


Black Holes and Neutron Stars

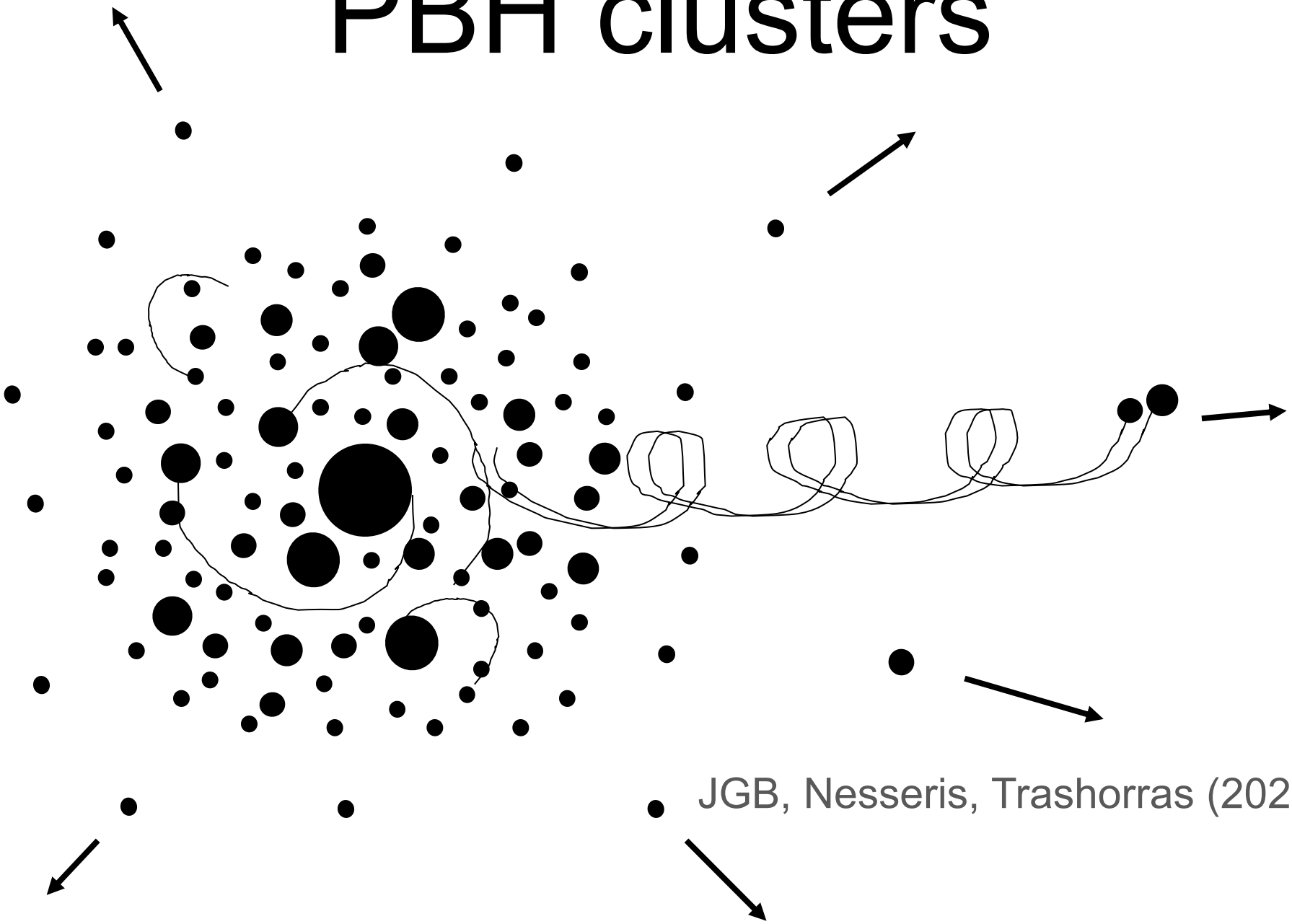


Model prediction: mass spectrum

JGB, Clesse (2020)

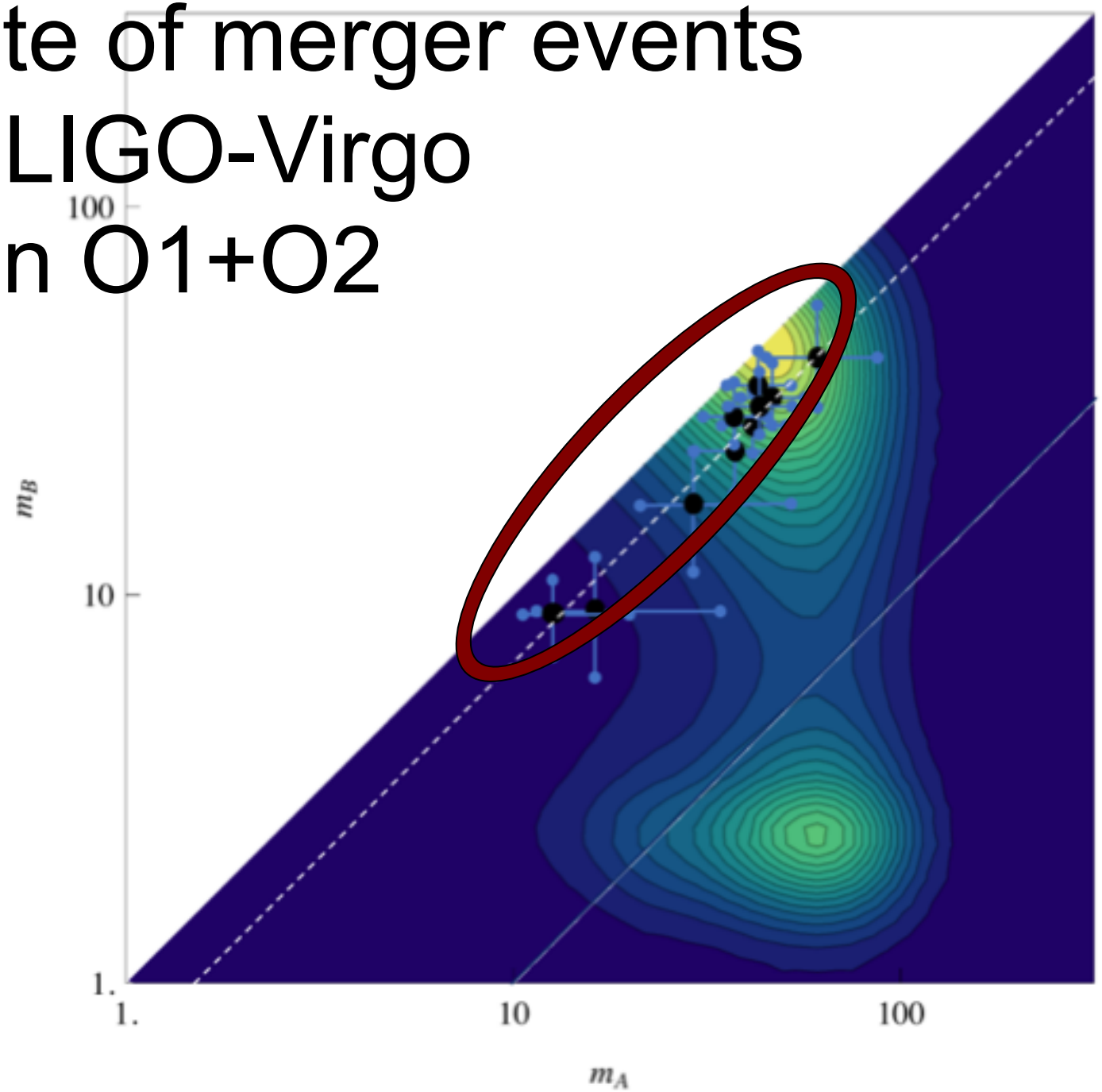


PBH clusters



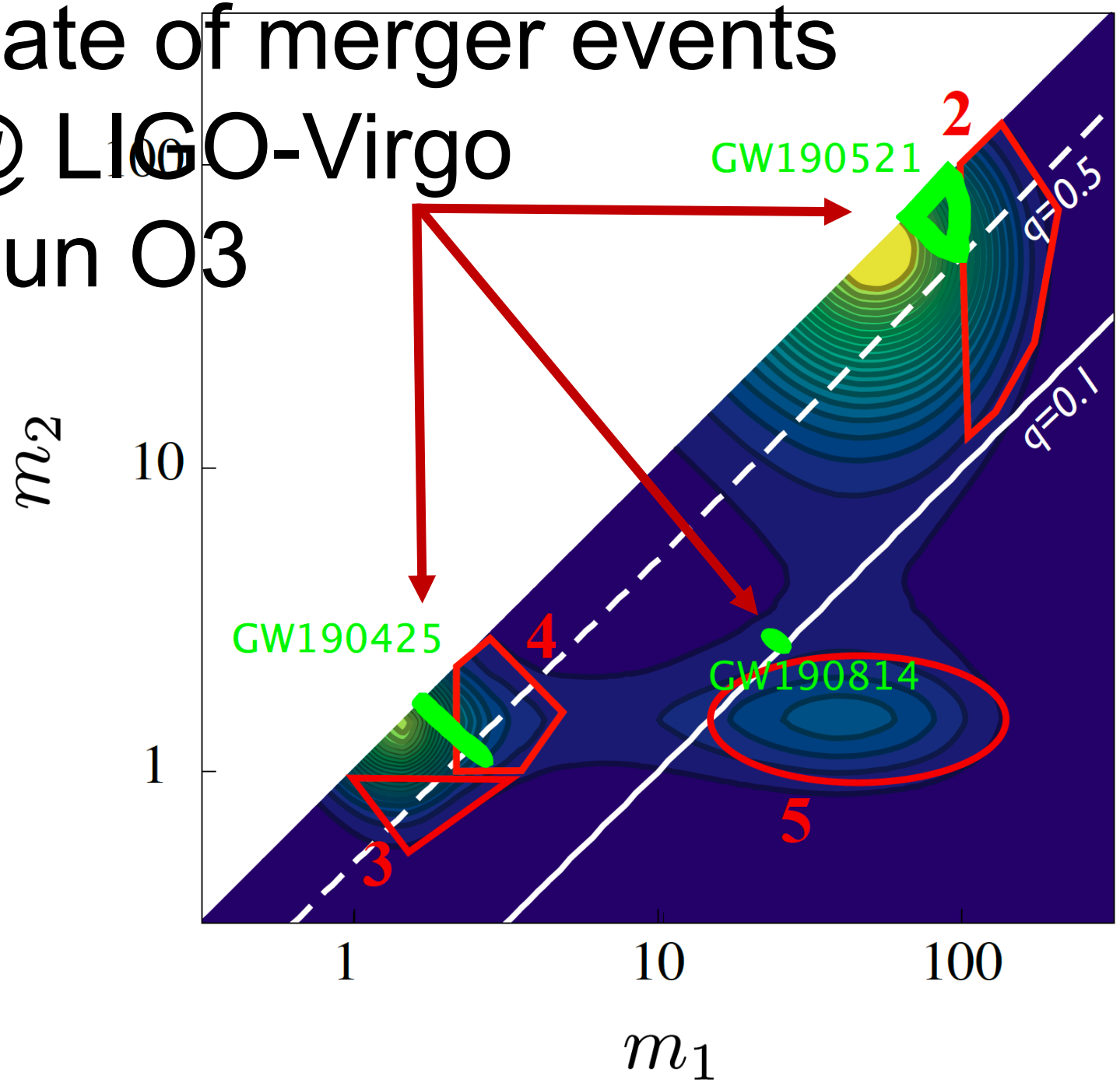
JGB, Nesseris, Trashorras (2020)

Rate of merger events @ LIGO-Virgo Run O1+O2



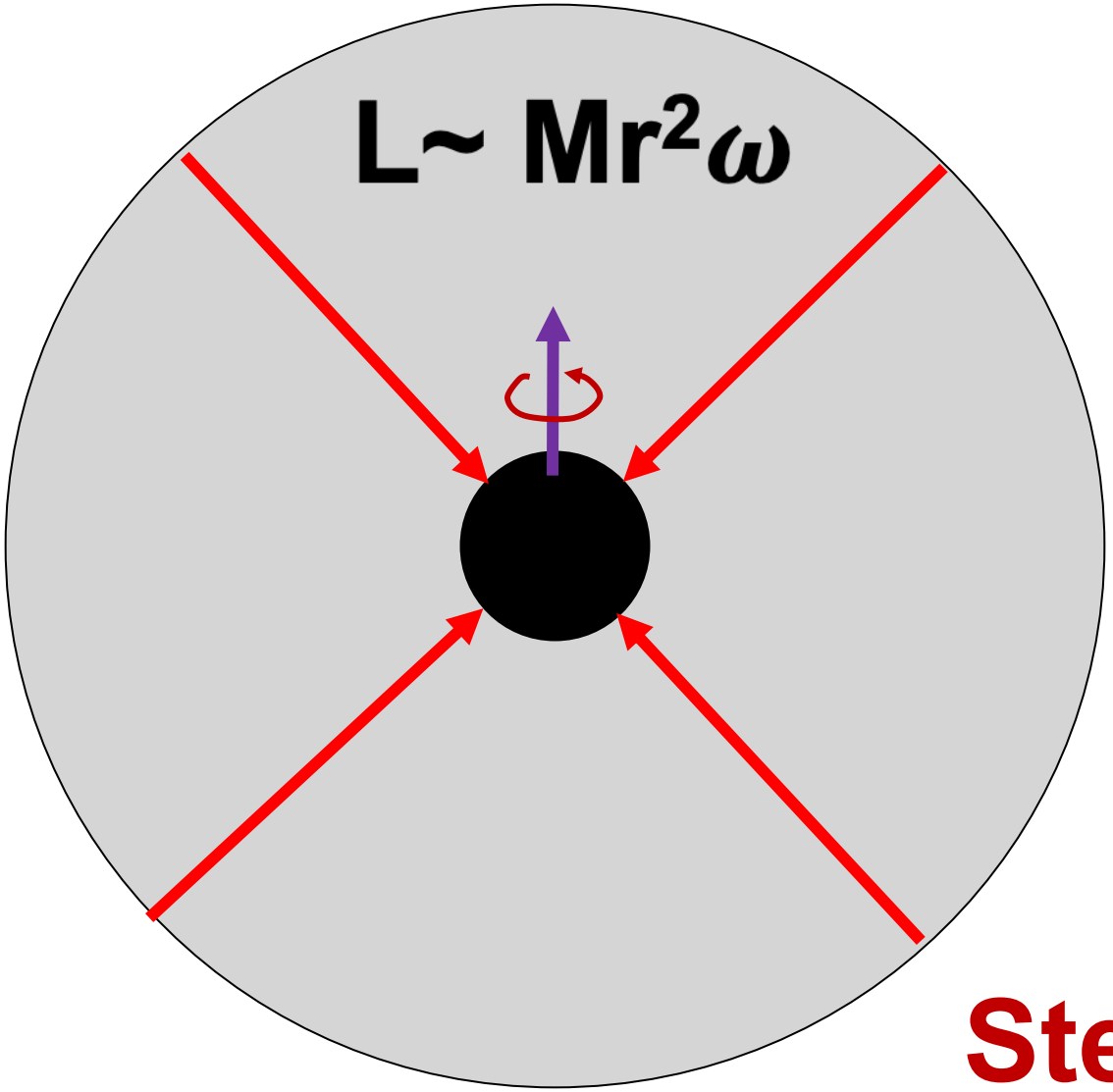
Carr, Clesse, JGB, Kühnel (2019)

Rate of merger events @ LIGO-Virgo Run O3

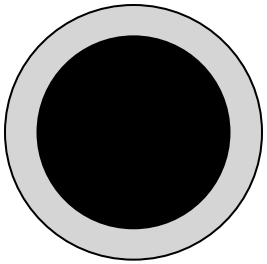


Carr, Clesse, JGB, Kühnel (2019)

PBH are ~ spinless



Primordial BH

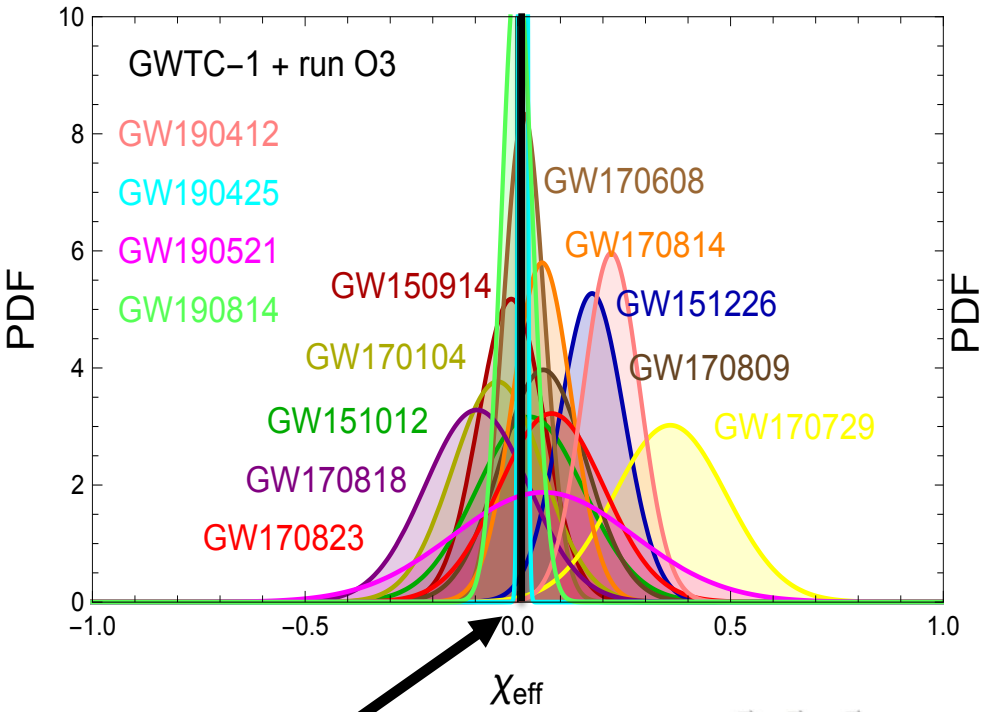


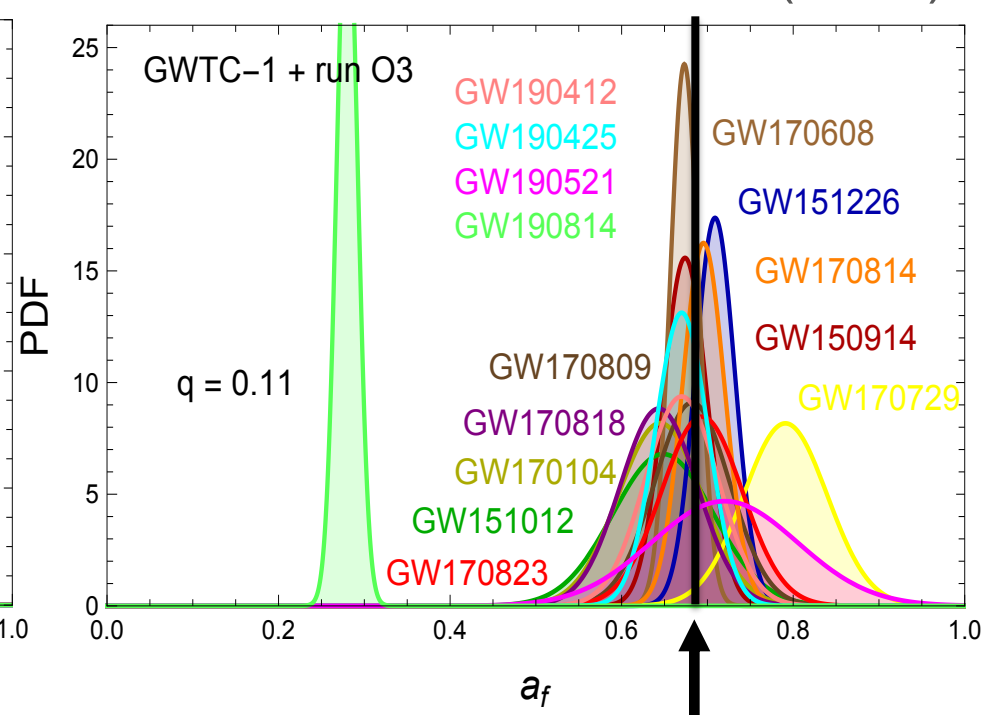
= Mass

Stellar BH

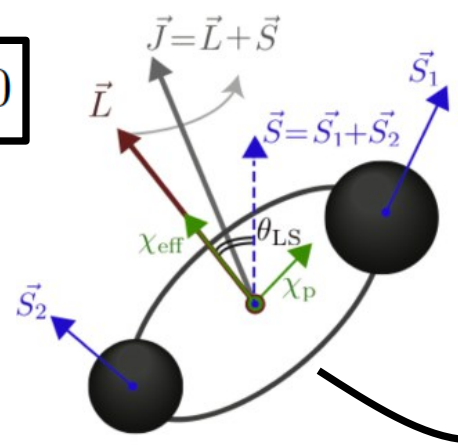
Effective & Final Spin

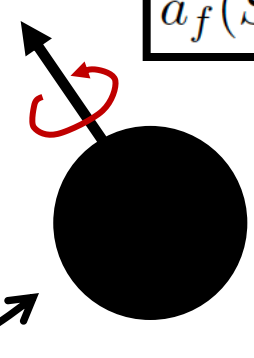
JGB (2020)





$$\chi_{\rm eff}(S_1 = S_2 = 0) = 0$$

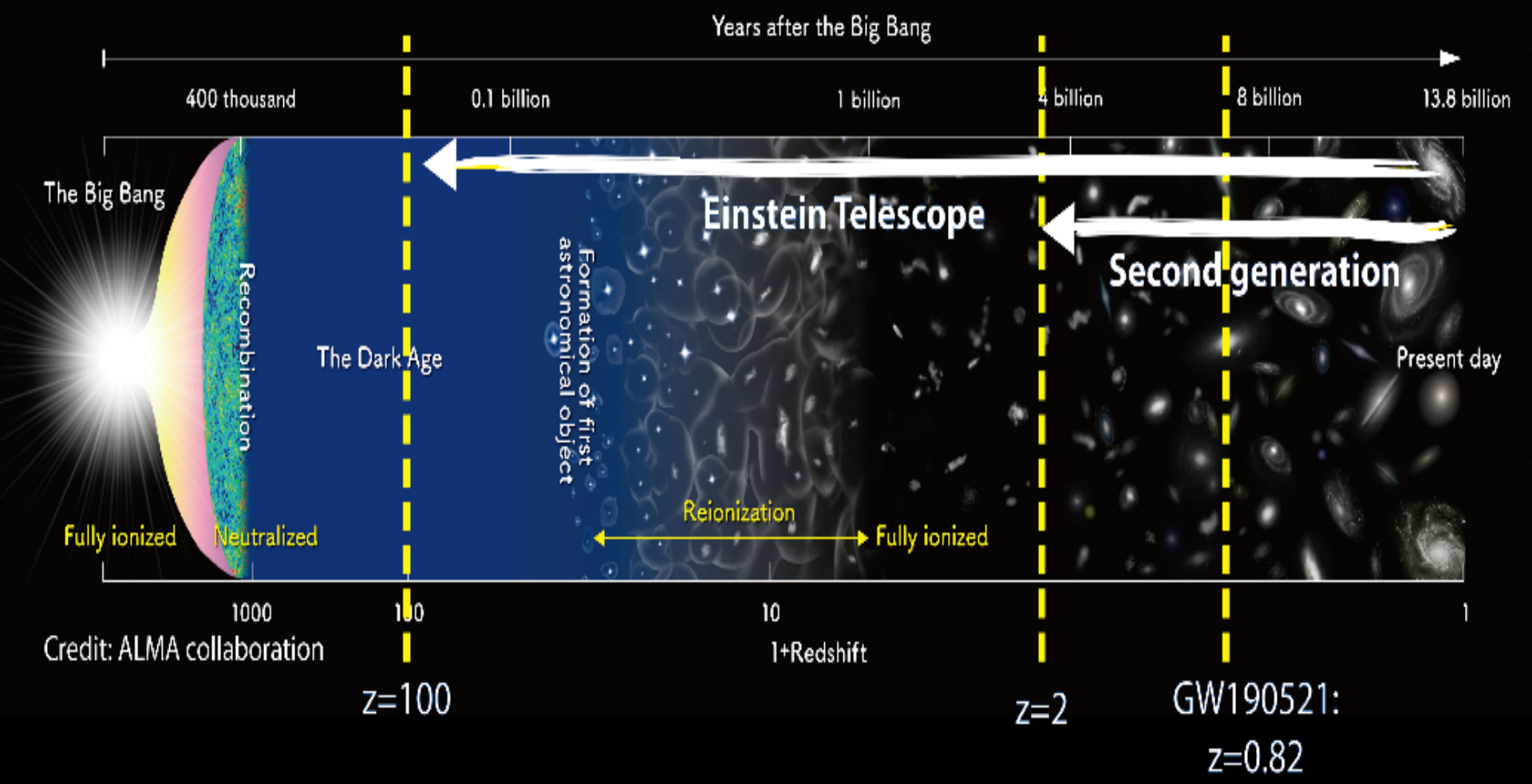




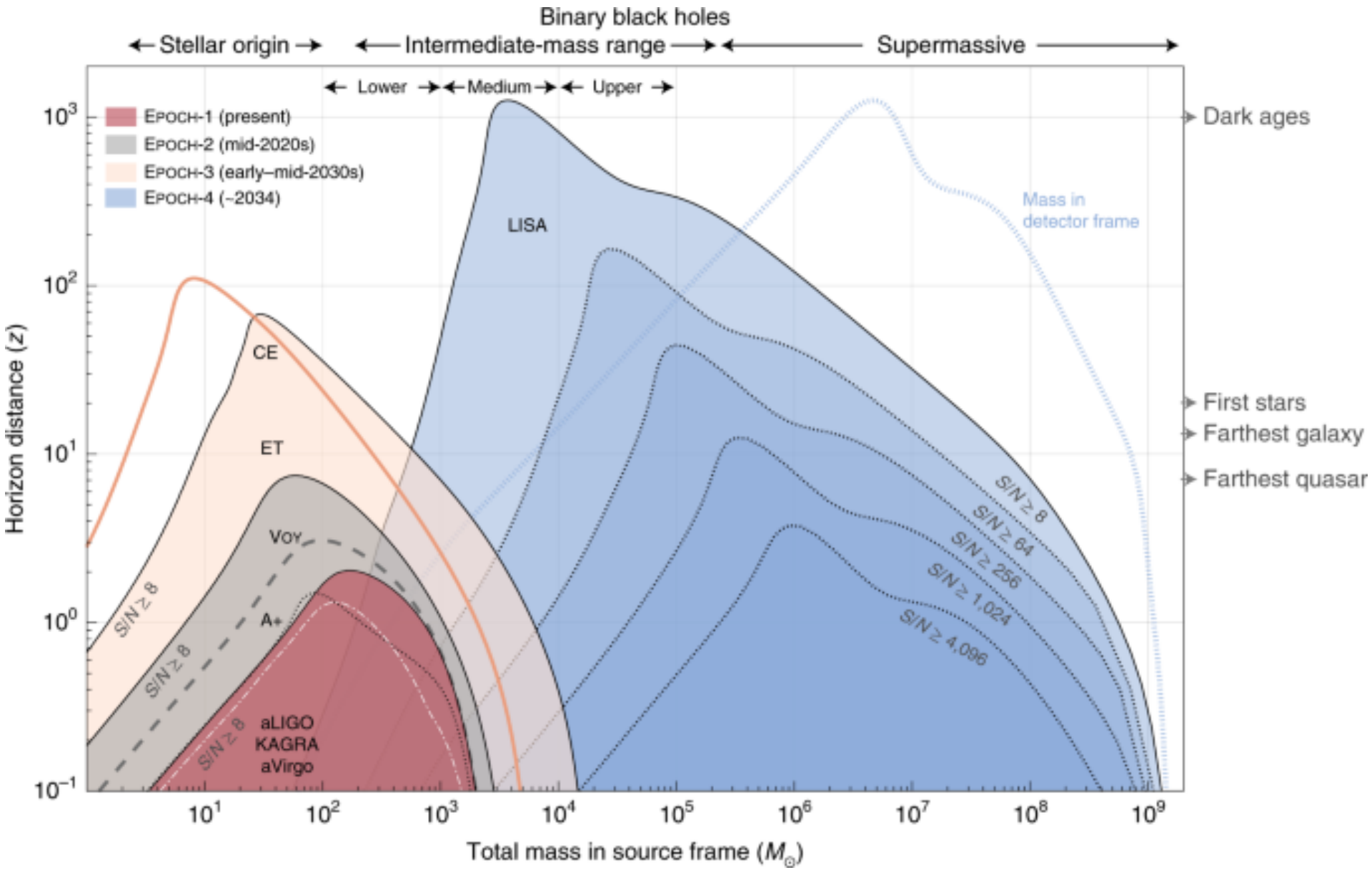
$$a_f(S_1 = S_2 = 0) = 0.686$$

The future of GW (G3)

Detection horizon for black-hole binaries



BBH sensitivity in future G3 GW



Conclusions

- Quantum diffusion during inflation generates PBH
- Thermal history predicts PBH have masses ~ Msun
- The predicted PBH spin and mass distribution has been measured by LIGO/Virgo + OGLE (features: peak+plateau)
- Other peaks could be explored with microlensing
- Very rich phenomenology: multiscale, multiepoch, multiprobe => Future G3 detectors (ET, LISA)
- Paradigm shift in Structure Formation of Universe