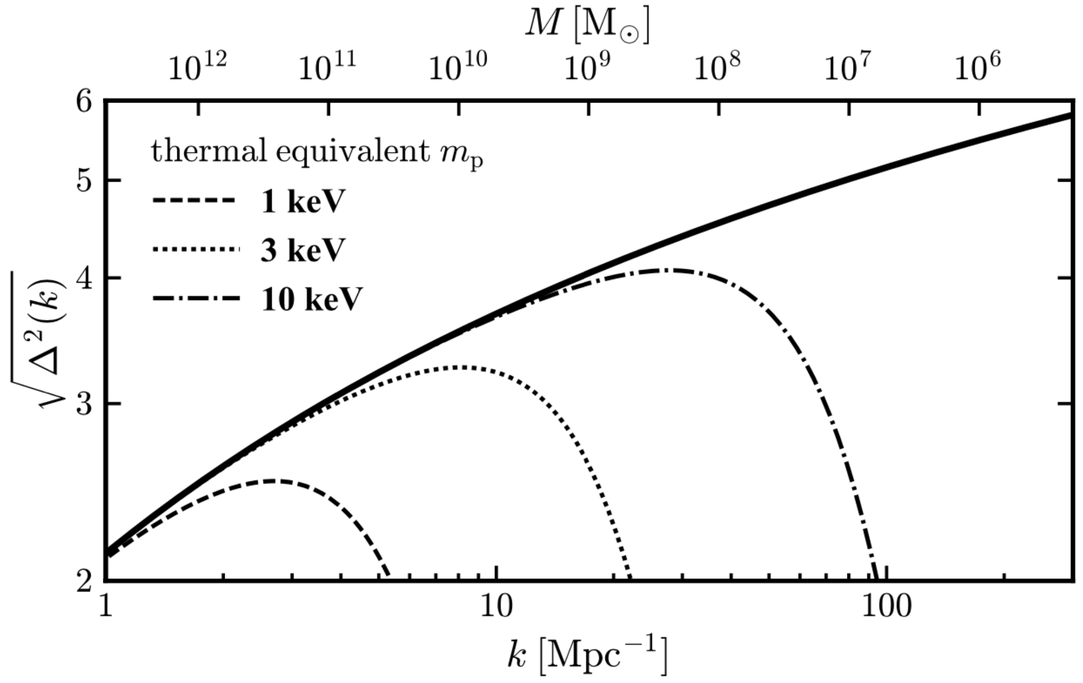
Looking for cold dark matter (CDM) subhalos with gravitational waves (GW)

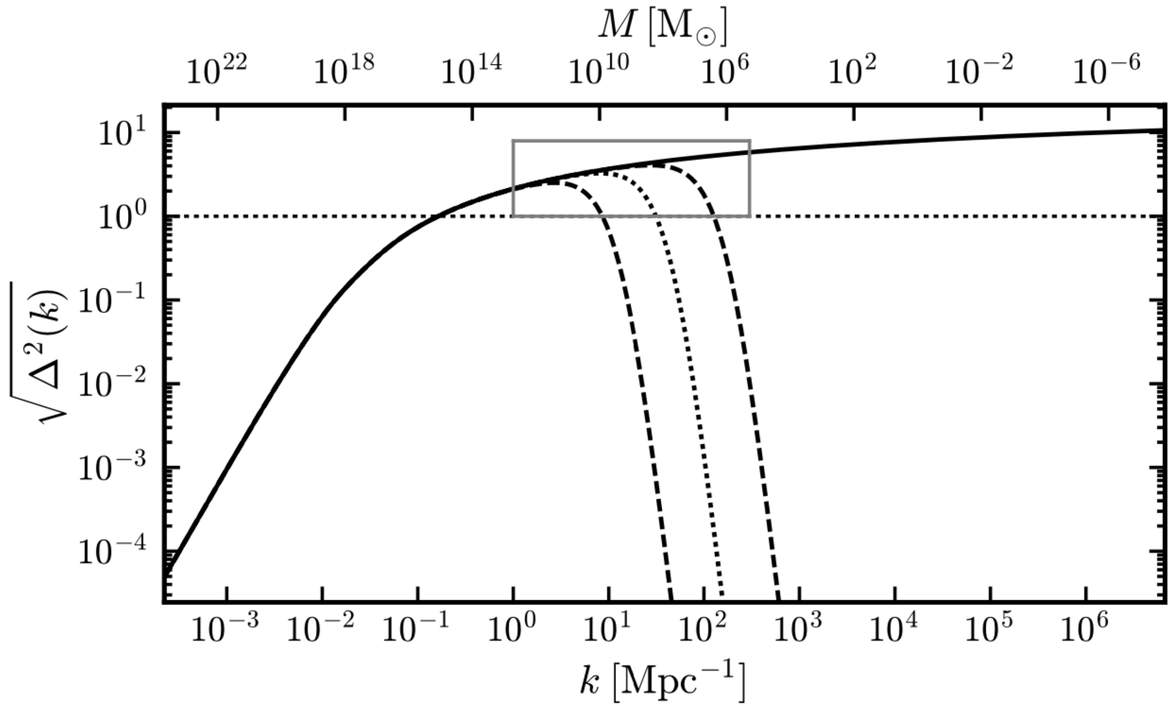
Juan Urrutia, PhD student, 2022, based on work done with Ville Vaskonen and Malcom Fairbairn

Why light DM halos are very relevant?

It is a unique prediction of CDM

Adiabatic fluctuations become linear and collapse in halos of the mass that is inside the collapsed volume.





https://arxiv.org/abs/1707.04256

Amplification function only wave effects

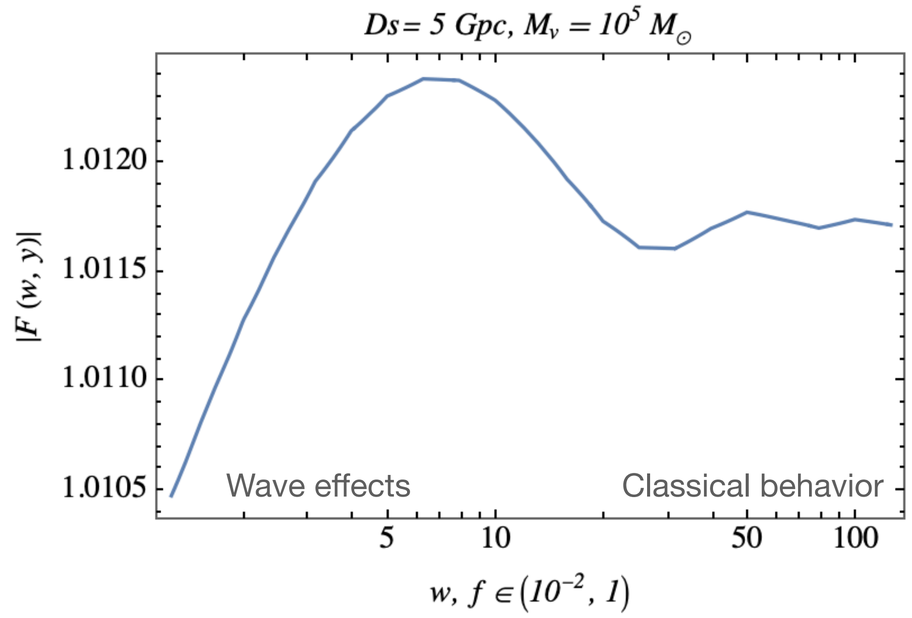
Light halos do not to produce more than one classical path

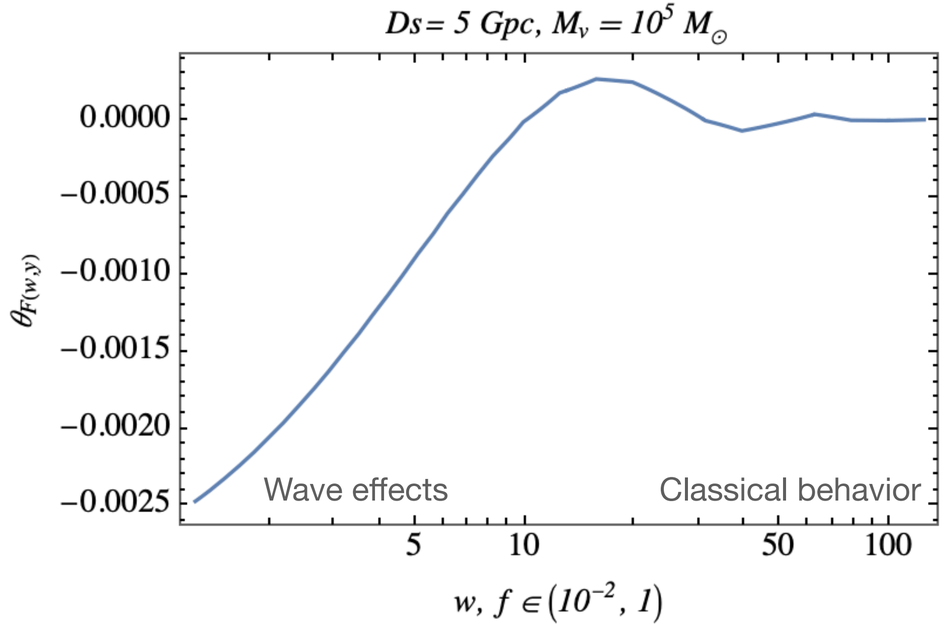
$$\phi_{\text{lensed}}(f) = F(f, y)\phi_{\text{unlensed}}(f)$$

Amplification function

Only wave effects

To maximize the tiny effect that the halo has on the GW we go to the atom interferometer band.





We can see how everything goes to constant values in the classical limit.

Detect the effect

We try to fit the unlensed waveform

$$\begin{aligned}\Delta\chi^2 &\equiv -2\left[\max_{\boldsymbol{\theta}} \ln \Lambda_T(\phi) - \ln \Lambda_{\rm opt}(\phi)\right] \\ &= \min_{\boldsymbol{\theta}} \left(\phi_{\rm opt} - \phi_T(\boldsymbol{\theta})|\phi_{\rm opt} - \phi_T(\boldsymbol{\theta})\right) \\ &= 4\min_{\boldsymbol{\theta}} \int \mathrm{d}f\, \frac{|\tilde{\phi}_{\rm opt}(f) - \tilde{\phi}_T(f;\boldsymbol{\theta})|^2}{S_{\rm n}(f)}\end{aligned}$$

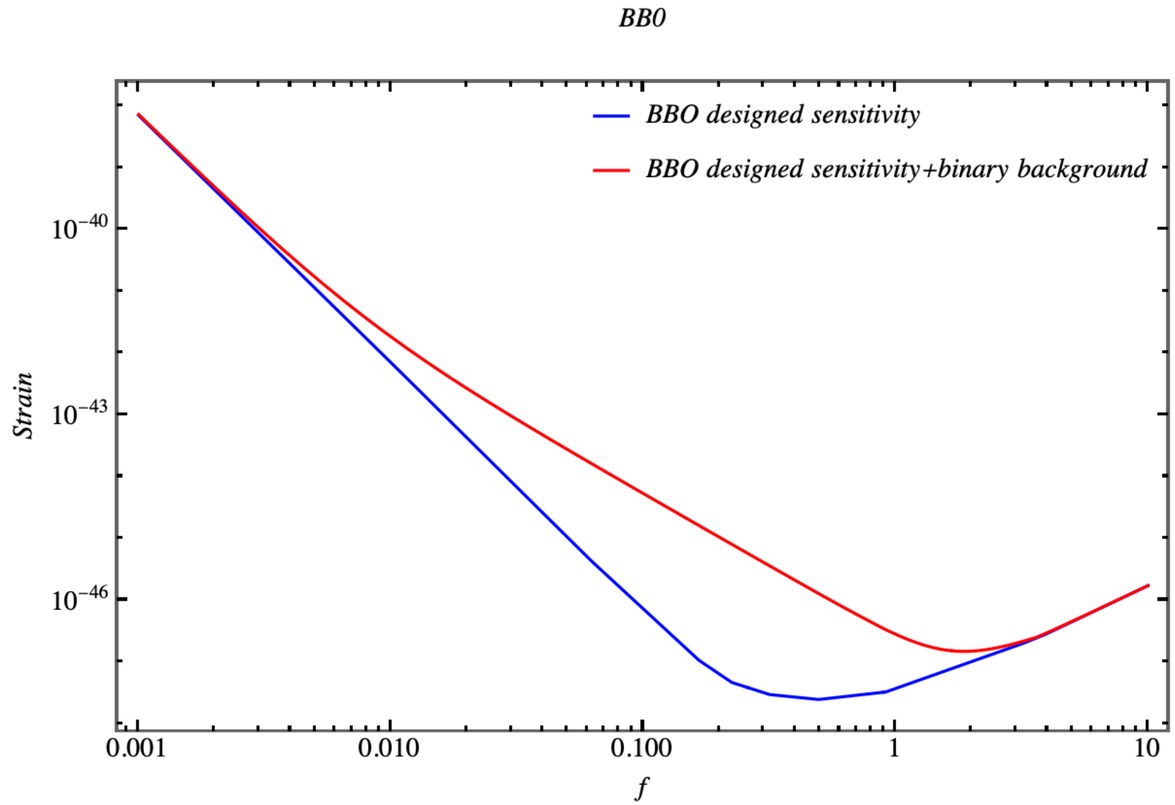
We minimize over the amplitude, the event looks closer, and with a constant shift.

$$\Delta\chi^2 = 4\min_{\lambda,\,\delta\phi_c} \int \mathrm{d}f\, \frac{A(f;\boldsymbol{\theta}_{\rm opt})^2 |F(f;\boldsymbol{\theta}_{l,\rm opt}) - \lambda e^{-i\delta\phi_c}|^2}{S_{\rm n}(f)}$$

Detect the effect

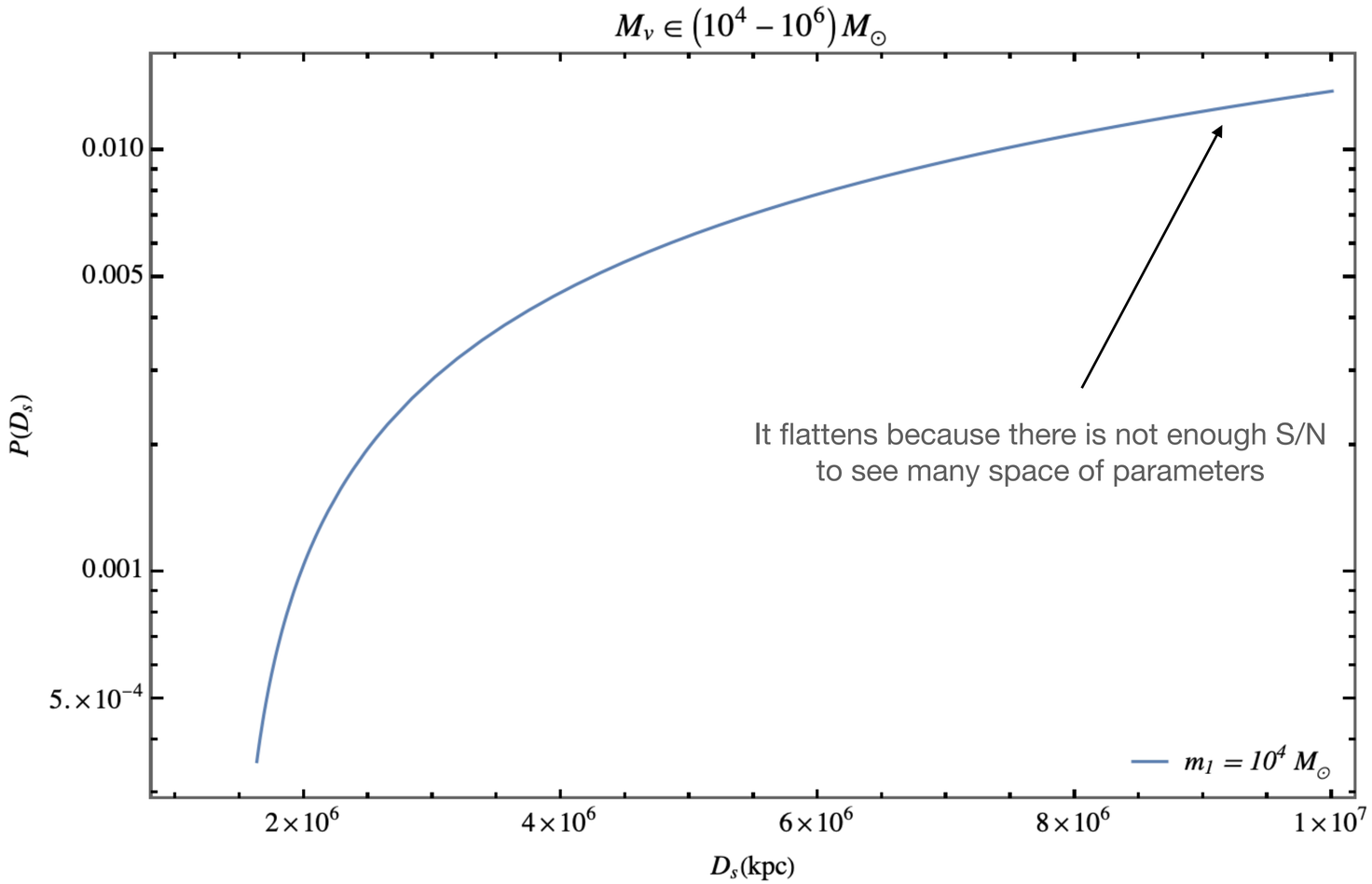
We have first considered Big Bang Observatory (BBO)

It has the best sensitivity of all the projected gravitational wave detectors, so it makes it very sensitive to unresolved background binaries



Probability of lensing

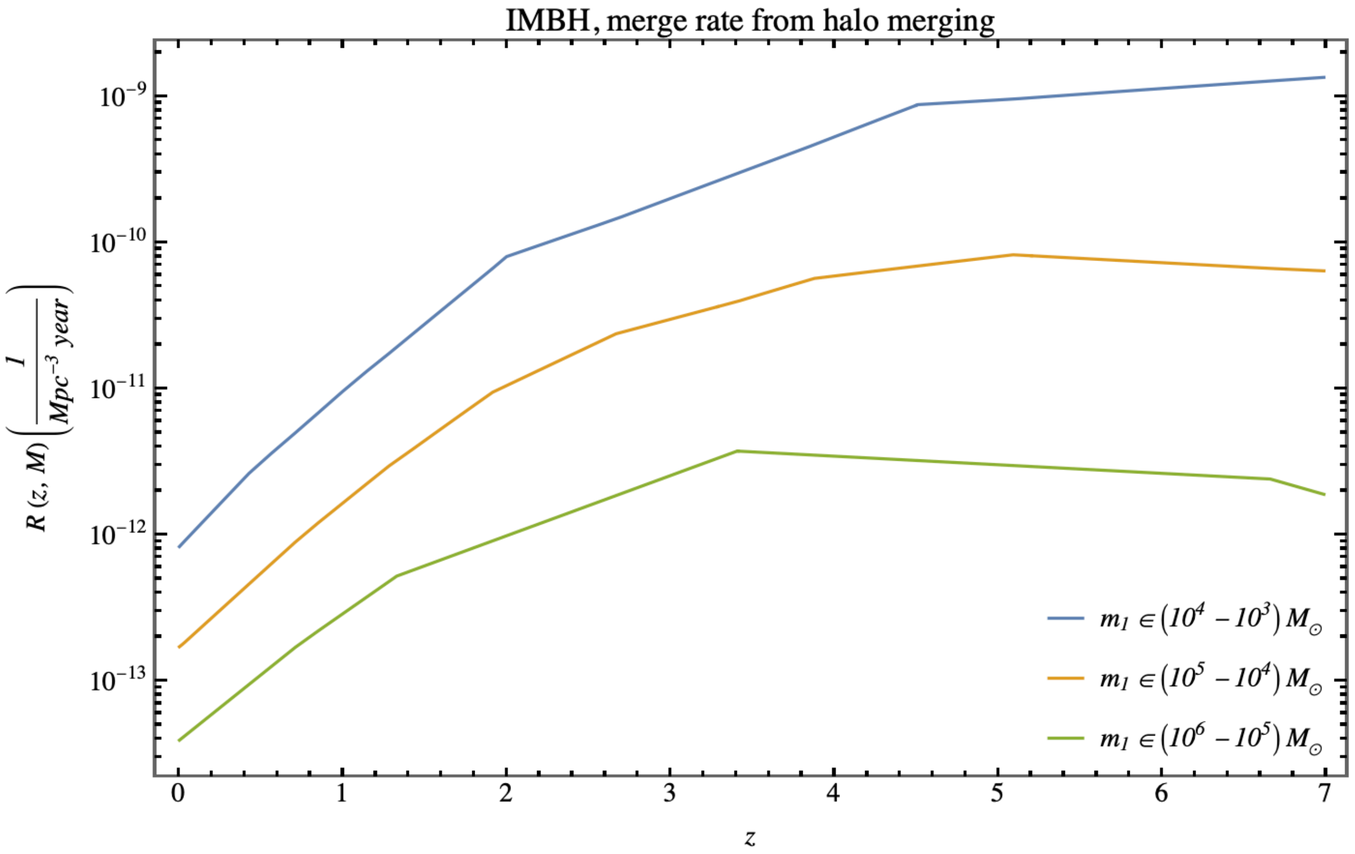
What is the probability to detect this events?



Probability of lensing

Merger rate for IMBH

https://arxiv.org/abs/astro-ph/0604281



Probability of lensing

Number of events that are going to be detected in a year

M_v \ m_1	10^3-10^4 $M_\odot$	10^4-10^5 $M_\odot$
10^3-10^4 $M_\odot$	2,39	0,00
10^4-10^5 $M_\odot$	584,89	168,92
10^5-10^6 $M_\odot$	1419,05	243,47

Things to do

And are not far from doing hopefully…

Study better the detectability of the merges: sky orientation…

Extended to other detectors: LISA, AEDGE…

Thanks for your time!