Detecting dark matter with Einstein Telescope

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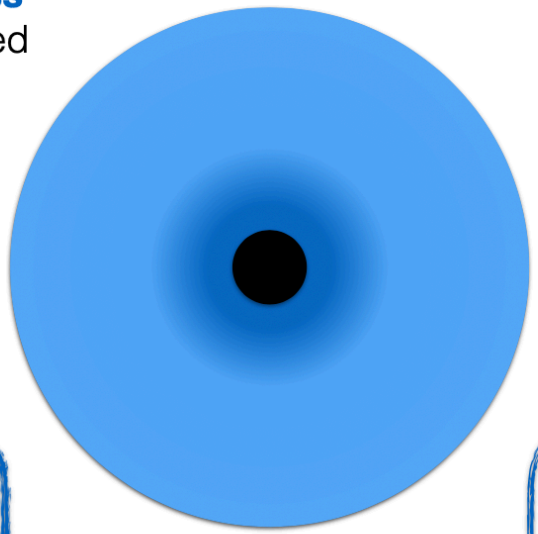
Dark Matter Spikes

Consider now a cold **DM** '**spike**' or '**dress**' around the central BH (not to be confused with ultralight boson clouds).



Study the following benchmarks:

$$m_1 = 10^3\, M_\odot$$
$$m_2 = 1\, M_\odot$$
$$\rho_{\rm DM} = \rho_6 \left(\frac{10^{-6}\,{\rm pc}}{r}\right)^{\gamma_{\rm sp}}$$

Astrophysical scenario

$$\gamma_{\rm sp} = 7/3 \approx 2.3333\ldots$$
$$\rho_6 \approx 5.45 \times 10^{15}\, M_\odot\, {\rm pc}^{-3}$$

…depending on a number of environmental factors…

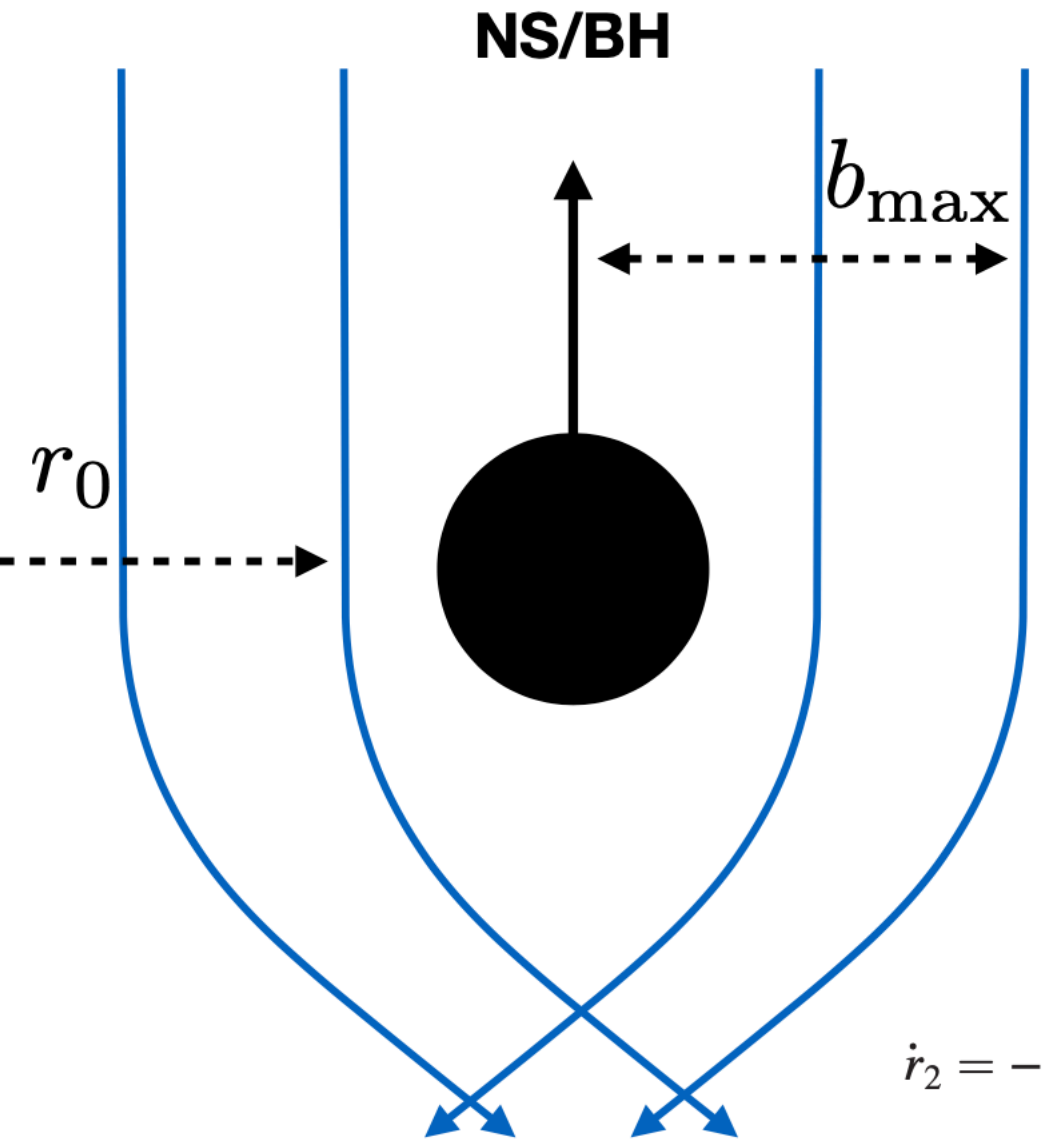
[astro-ph/9906391, astro-ph/0509565, 1305.2619, …]

PBH scenario

$$\gamma_{\rm sp} = 9/4 \approx 2.25$$
$$\rho_6 \approx 5.35 \times 10^{15}\, M_\odot\, {\rm pc}^{-3}$$

[Bertschinger (1985), astro-ph/0608642, 1901.08528, …]

Dynamical Friction



$$\frac{\mathrm{d}E_{\rm orb}}{\mathrm{d}t} = -\frac{\mathrm{d}E_{\rm GW}}{\mathrm{d}t} - \frac{\mathrm{d}E_{\rm DF}}{\mathrm{d}t}.$$

$$\frac{\mathrm{d}E_{\rm GW}}{\mathrm{d}t} = \frac{32G^4M(m_1m_2)^2}{5(cr_2)^5}.$$

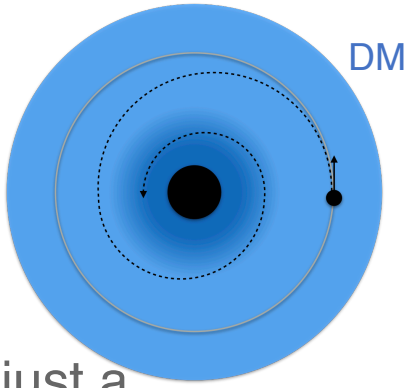
$$\frac{\mathrm{d}E_{\rm DF}}{\mathrm{d}t} = 4\pi(Gm_2)^2\rho_{\rm DM}(r_2)\xi(v)v^{-1}\log\Lambda.$$

$$\Lambda = \sqrt{\frac{b_{\max}^2 + b_{90}^2}{b_{\min}^2 + b_{90}^2}},$$

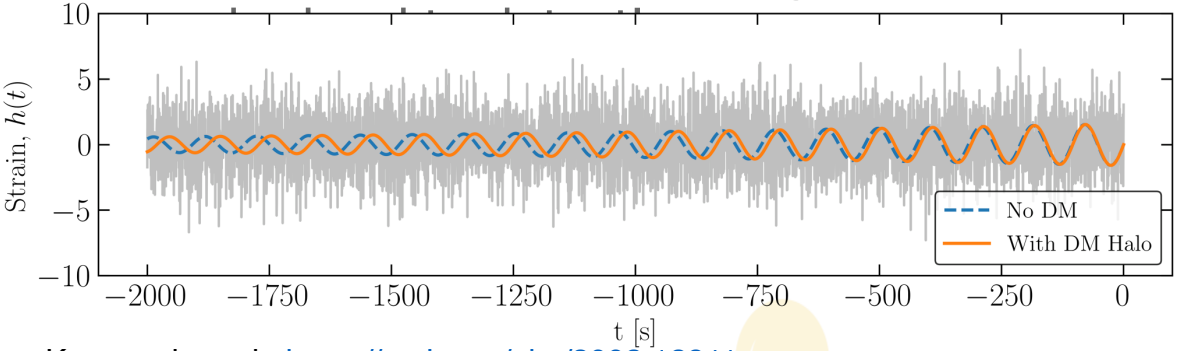
$$\dot{r}_2 = -\frac{64G^3Mm_1m_2}{5c^5(r_2)^3} - \frac{8\pi G^{1/2}m_2\rho_{\rm sp}\xi\log\Lambda r_{\rm sp}^{\gamma_{\rm sp}}}{\sqrt{M}m_1r_2^{\gamma_{\rm sp}-5/2}}$$

Detecting DM with Einstein Telescope

- Presence of DM ‘spikes’ around BHs can alter inspiral dynamics



- GW waveform gradually goes out of phase with the corresponding vacuum-only waveform
- Possibility to detect and constrain dense DM ‘spikes’ with just a few cycles of GW ‘dephasing’ → but these subtle differences



Ideal case for
Machine learning!

Kavanagh et al., https://arxiv.org/abs/2002.12811
Coogan et al., https://arxiv.org/abs/2002.12811

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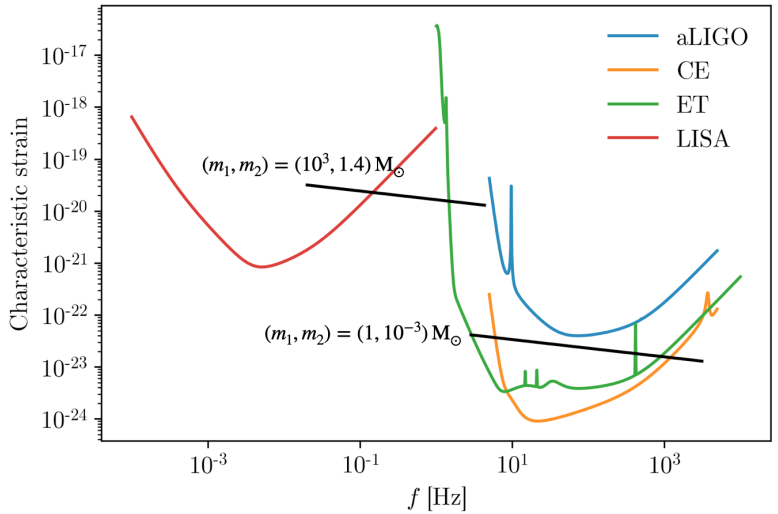
Observational Questions

- Detectability: which dark dresses could Einstein Telescope see?
- Discoverability: can we distinguish from GR-in vacuum?
- Measurability: how well can parameters be measured?

Detecting DM with Einstein Telescope

- Frequency band of ET means that most promising target would be solar and sub-solar mass binaries

- **Primordial black holes** (PBHs) could form such binaries, and must be surrounded by dense spike of particle DM



- Currently developing an ET pipeline to search for ‘de-phased’ GW waveforms due to DM around PBHs, using machine learning

- Waveform generation & search pipeline will all be public → implementation in virtual research environment will allow easy **access** and **re-use**

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Thank you for your attention