Relativistic modelling of EMRIs environments

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A long road ahead

The next-generation GW detectors have ambitious goals

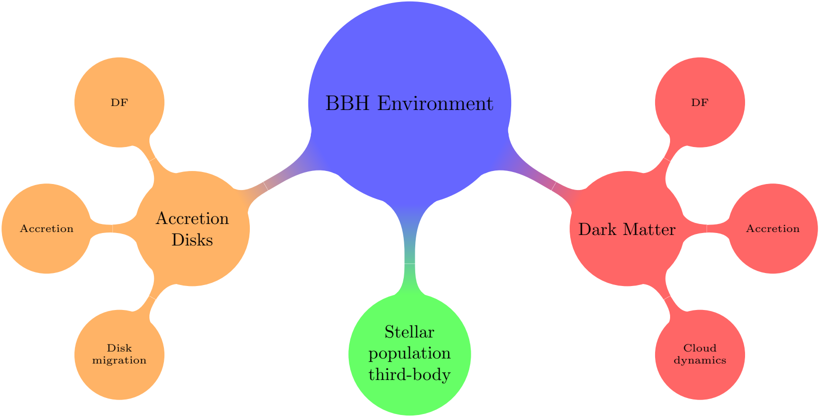
- High-precision tests of GR, of the Kerr hypothesis,
- Search for new physics.

To be fulfilled, they need better modelling

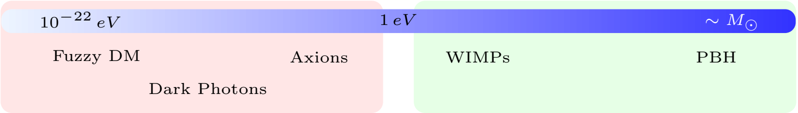
- Efficient and accurate waveform generation (Self-force, EOB, PN),
- Precise understanding of degeneracies and systematics,
- Relativistic description of astrophysical environment and its impact on the waveform.

Environments of BBH dynamics

Astrophysical sources for LISA are expected to be affected by some environmental effect (at least 10% [Barausse et al. 2014])



Dark Matter environment



Light DM :

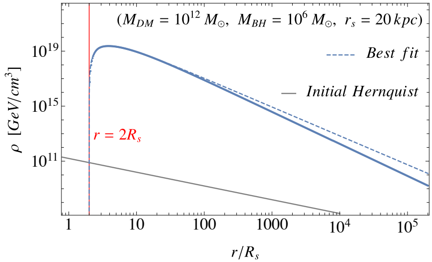
- Superradiant clouds [Brito et al. 2020], emit monochromatic GW [Arvanitaki et al. 2011];
- Secondary BH$\rightarrow$ DM excited to higher energy states, orbital resonances [Ferreira et al. 2017] and DF.

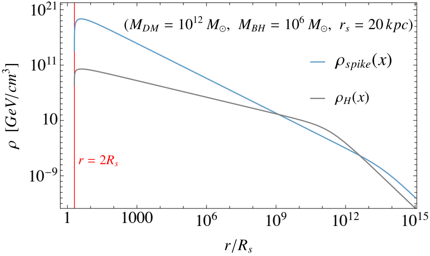
Heavy DM:

- Creates density spikes around BHs [Gondolo et al. 1999]. Binary inspiral driven by DF and accretion [Yue et al. 2018].

Relativistic CDM spikes

Collisionless DM can create a steep overdensity around a slowly growing BH [Sadeghian et al. 2013; Speeney et al. 2022].





$$\rho(x) = A\left(1 - \frac{2}{x}\right)^{w} x^{-q}\left(1 + \frac{x}{x_0}\right)^{-4+q},$$

$A\ [GeV/cm^3]$	$1.72 \cdot 10^{21}$
w	1.99
q	2.09
x_0	$4 \cdot 10^{13}$

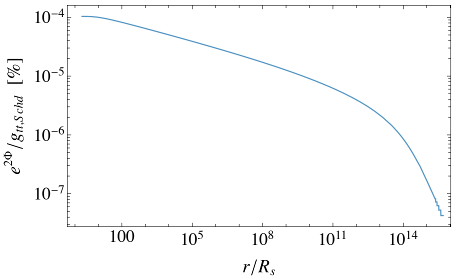
Encode the matter information into an effective metric.

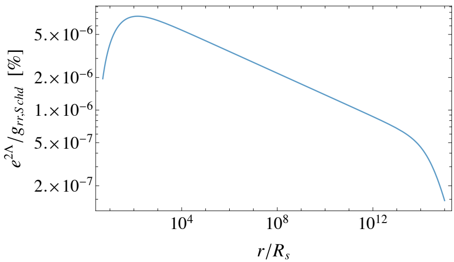
- Stress-energy tensor source:

$$T_t^t = -\rho(r), \qquad T_\theta^\theta = T_\phi^\phi = P(r)$$

- Spherically symmetric metric

$$ds^2 = -e^{2\Phi}\mathrm{d}t^2 + e^{2\Lambda}\mathrm{d}r^2 + r^2\mathrm{d}\Omega^2.$$





Perturbation scheme

$$\mathrm{d}s^2 = g^{(0)}_{ab}\mathrm{d}x^a\mathrm{d}x^b = -e^{2\Phi}\mathrm{d}t^2 + e^{2\Lambda}\mathrm{d}r^2 + r^2\mathrm{d}\Omega \quad \rightarrow \quad g_{ab} = g^{(0)}_{ab} + h_{ab}.$$

The perturbation splits between polar and axial sectors

- Polar sector

$$D_{even}[\partial_t^2, \partial_t^2\partial_r, \partial_r^2, \partial_r, g^{(0)}_{ab}]Z^{(+)} = S_{even},$$

- Axial sector

$$D_{odd}[\partial_t^2, \partial_r^2, \partial_r, g^{(0)}_{ab}]Z^{(-)} = S_{odd}.$$

Extract the fluxes of energy and angular momentum

$$\left\langle \frac{\mathrm{d}E}{\mathrm{d}t} \right\rangle^{\mathcal{I}} \sim \left\langle |\dot{\mathcal{Z}}^{(+)}|^2 + |\dot{\mathcal{Z}}^{(-)}|^2 \right\rangle, \quad \left\langle \frac{\mathrm{d}J}{\mathrm{d}t} \right\rangle^{\mathcal{I}} \sim \left\langle \bar{\mathcal{Z}}^{(+)}\dot{\mathcal{Z}}^{(+)} + \bar{\mathcal{Z}}^{(-)}\dot{\mathcal{Z}}^{(-)} \right\rangle$$

Future work is aimed at

- Evaluating the fluxes on a grid of spacetime points,
- Efficiently evolving a quasi-circular inspiral,
- Inferring the dephasing and comparing it to different treatments of the problem,
- Integration with dynamical spike models [Kavanagh et al. 2020],
- Applying the methods to different environments.

Stay tuned!

References I

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