Dark matter, GWs and numerical relativity

Science Fair 2025

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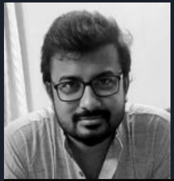
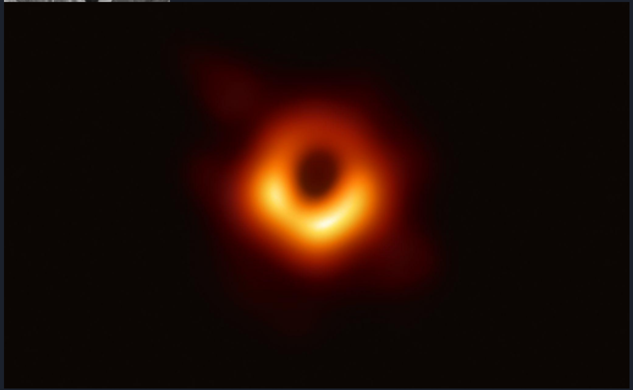
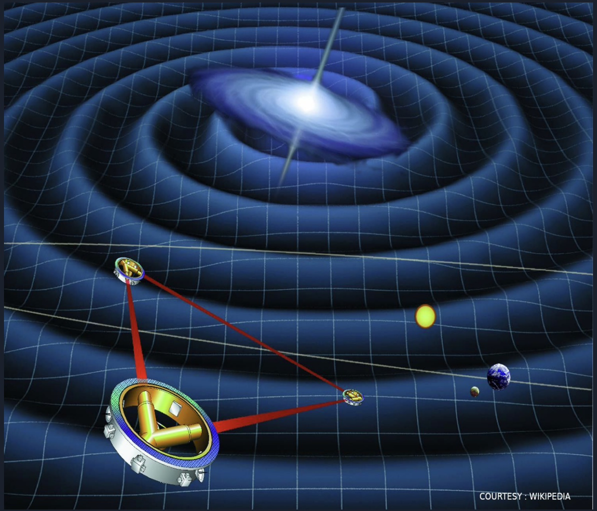
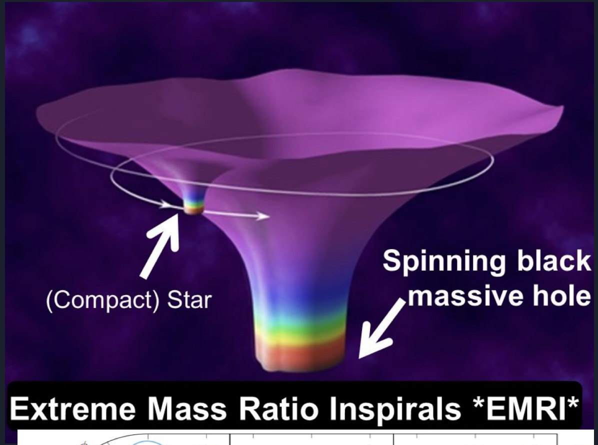
Extreme Mass-Ratio Inspirals (EMRI)

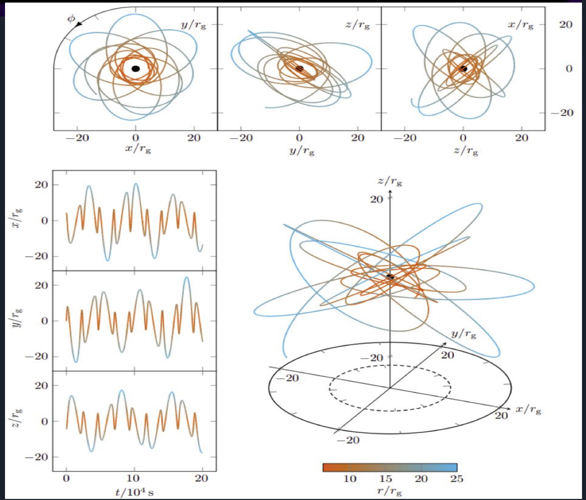
- ❑ Supermassive BH+stellar object
- ❑ BHs are not alone
- ❑ Dark Matter Halo, accretion etc
- ❑ Environment affects EMRI?





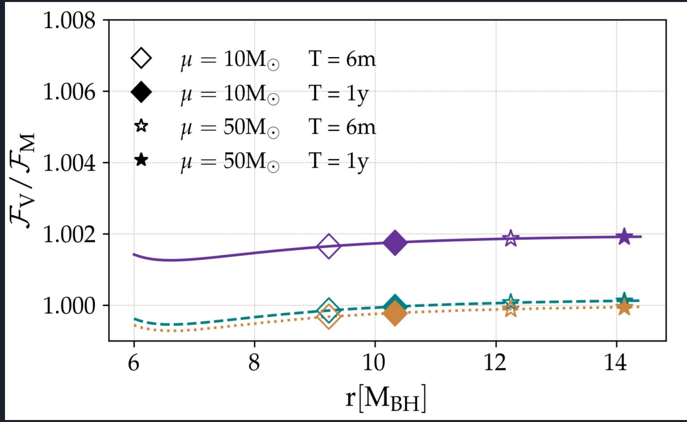






Formalism for environment in EMRIs

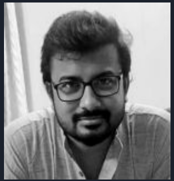
- ❑ Identify it's strength
- ❑ Add it perturbatively on BH
- ❑ Compute EMRI
- ❑ Non-rotating DONE!!!
- ❑ Is it spinning?



Formalism for environment in EMRIs

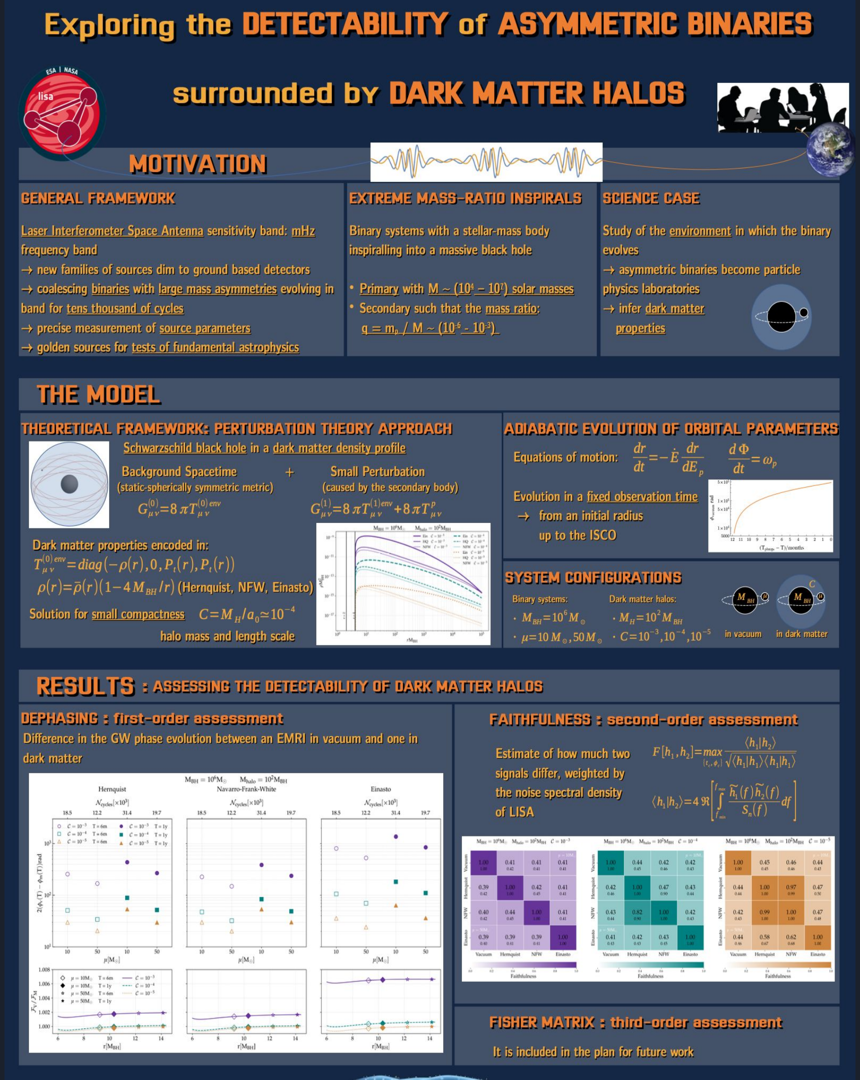
- Is that all?

Formalism for environment in EMRIs



- ❑ Halo rotation
- ❑ Halo structure
- ❑ Dark matter Accretion
- ❑ Baryonic matter accretion
- ❑ Hot environment
- ❑ Viscosity
- ❑ Dynamical friction
- ❑ Migration
- ❑ Compact object properties
- ❑ Anisotropy?
- ❑ All important?
- ❑ Who knows!

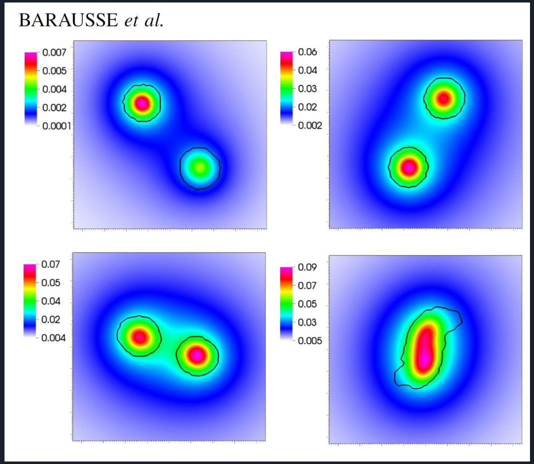
❑ Is that all?

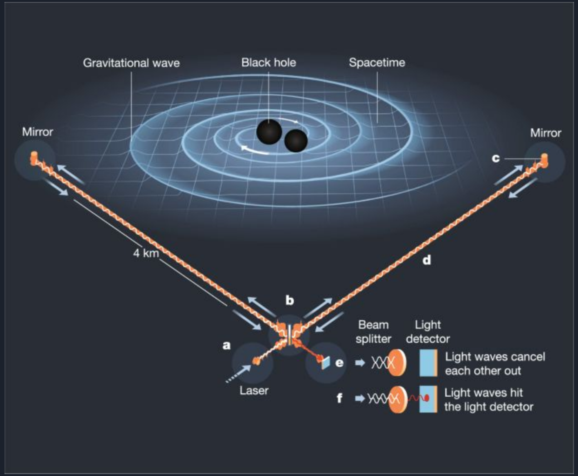


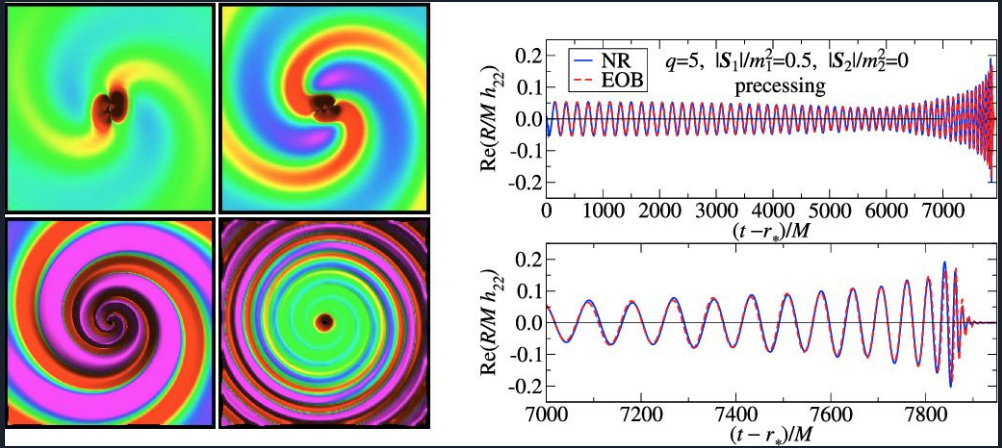
See Sara’s poster!

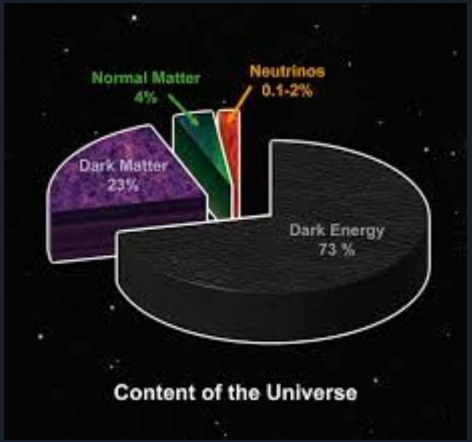
Numerical Relativity

- scenarios that cannot be accurately modelled by perturbative or analytical calculations
- little or no symmetry at all!
- GR and beyond...



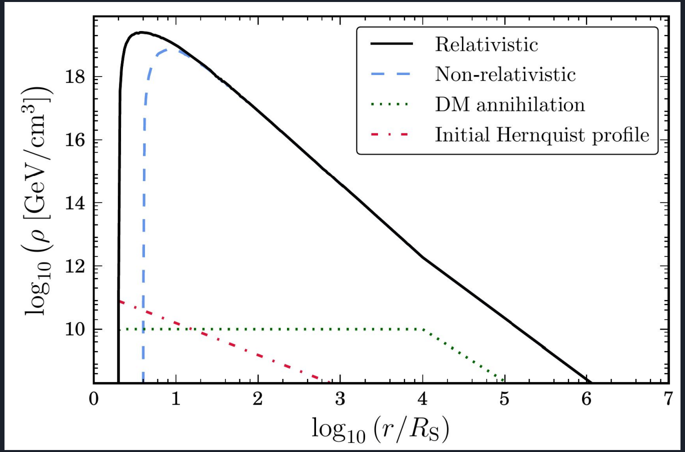


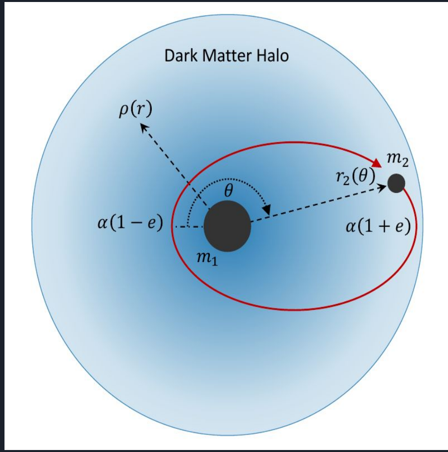




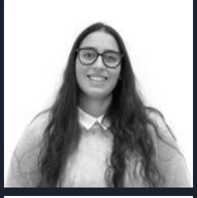
Dark matter spikes

- ❑ Prediction of DM spikes
- ❑ Use NR to evolve initial DM configurations leading to the development of DM “spikes”
- ❑ Compare with analytical predictions

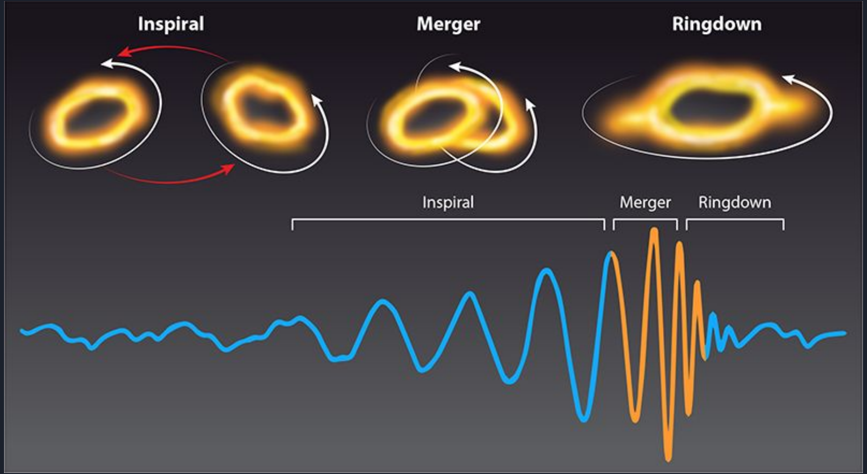




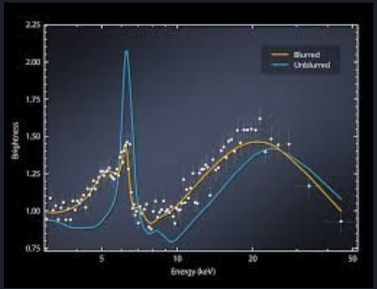
Asymmetric mass binaries and BH spectroscopy

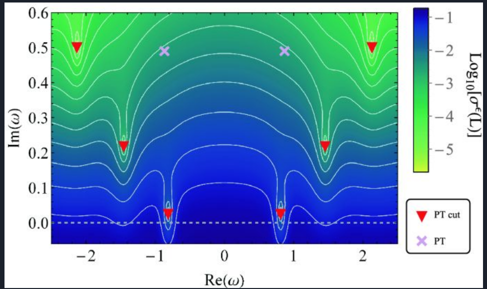


- ❑ ringdown phase for BH systems with significant mass asymmetry
- ❑ characterize the associated GW signals from orbital configurations (inclination, eccentricity).



- ❑ Use BH spectroscopy to find BH QNMs, embedded in matter halos.





See also Laura’s poster!

Ringing Black Holes: the soundtrack of spacetime

GRAN SASSO SCIENCE INSTITUTE

Modeling the ringdown to probe new physics

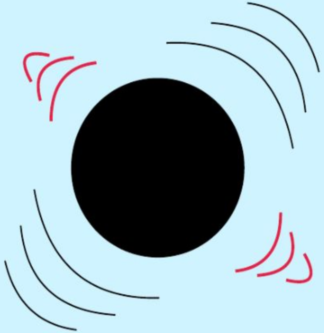
Laura Pezzella

Supervisor: Prof. Andrea Maselli

INFN

Ringdown

- For coalescing events, the signal should comprise three pieces: an **inspiral**, a **merger** and a **ringdown** waveform.
- The **ringdown** waveform originates from the **distorted final product** of the merger.
- The **amplitudes** depend on the **specific process** that formed the final BH.



Quasi-normal modes

- The **gravitational signal** emitted during the ringdown is well modeled by a **superposition** of quasi-normal modes (**QNMs**)
- The quasi-normal modes are **complex eigenvalues** $\omega^{(n)} = \omega_R^{(n)} + i\omega_I^{(n)}$
- QNMs **frequencies** depend only on the **final BH’s parameters** (mass M and spin J in GR)