MODELLING CHALLENGES IN GRAVITATIONAL WAVE ASTROPHYSICS

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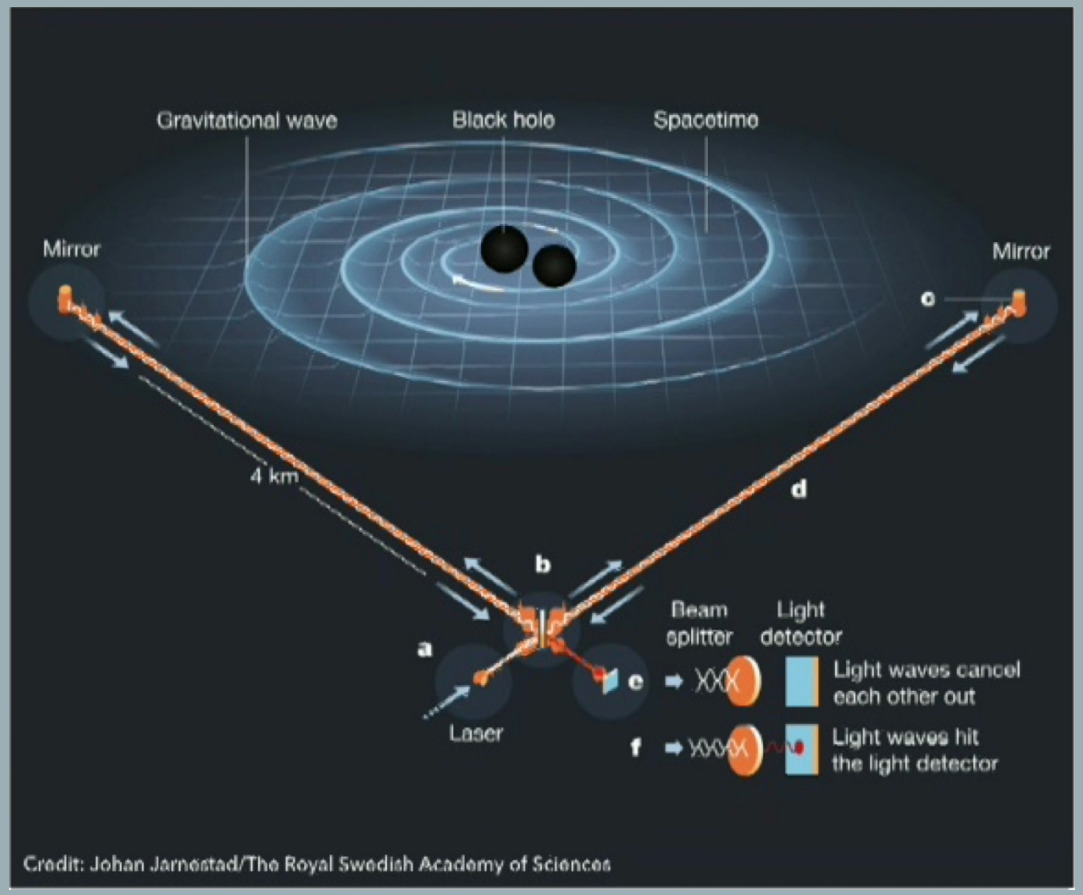
PHYSICS DEPARTMENT CONVOCATION DAY

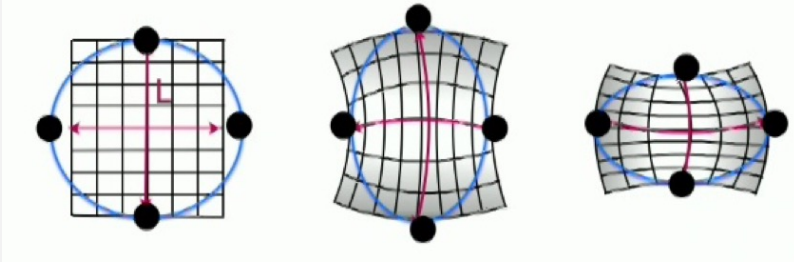
GRAVITATIONAL WAVES



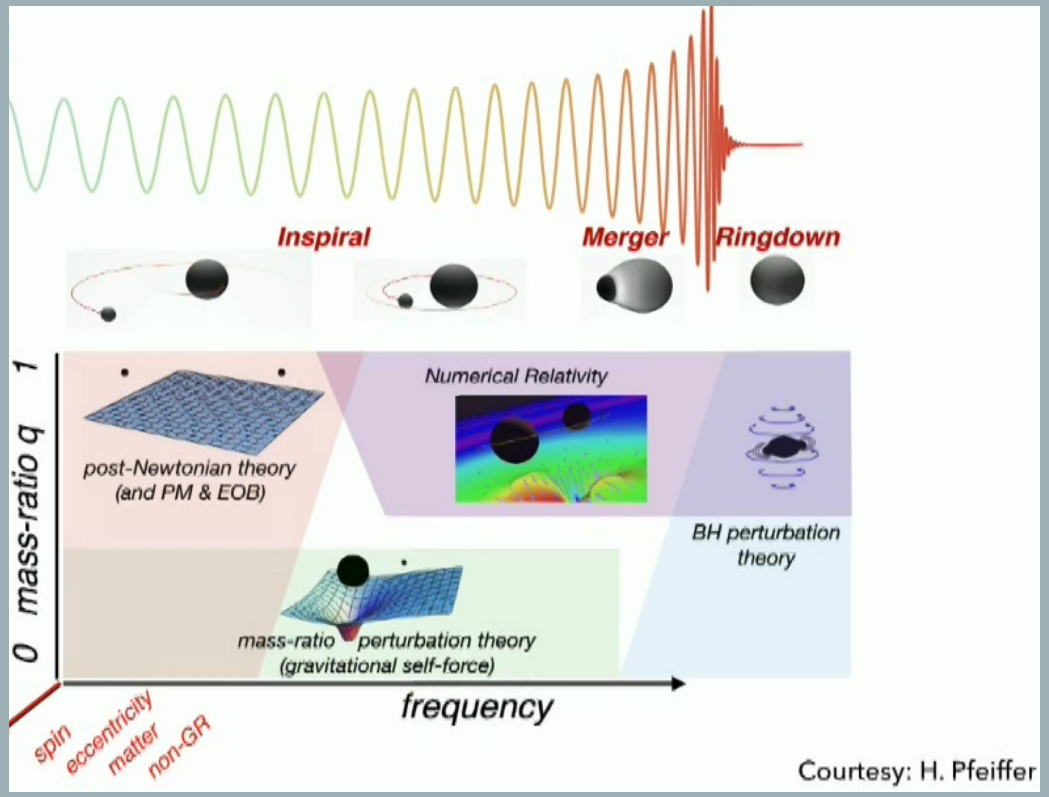
- Einstein proved that mass creates geometry, namely coordinates (space)
- Accelerated masses induce space perturbations described by a time-varying mass quadrupole (monopole = mass , dipole = spherical distribution, quadrupole = axial distribution)

$$h \sim \frac{\ddot{Q}}{D} \propto \frac{\Delta L}{L}$$

- Gravitational waves are transverse, travel at the speed of light and have two independent polarizations: (+, x)

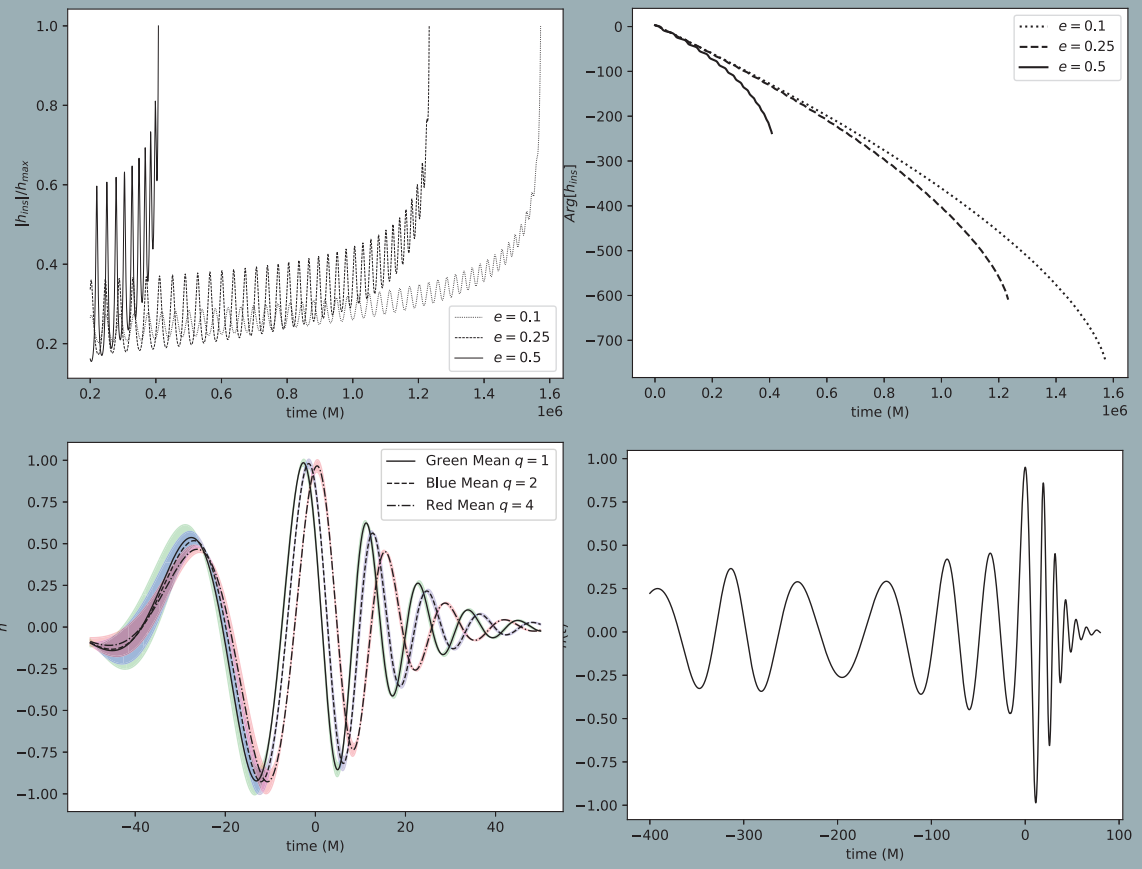


MODELLING CHALLENGES



- Analytical Challenges
  - Spacetime: Einstein Field Equations
  - Radiation: Maxwell Equations
  - Matter: Boltzmann, Navier-Stokes
- Numerical Challenges
  - Multi-spatial scales
  - Very expensive simulations
  - Singularities, shocks, instabilities
- Dynamics Challenges:
  - Unequal Masses
  - Unequal Spins, Precession
  - Eccentricity

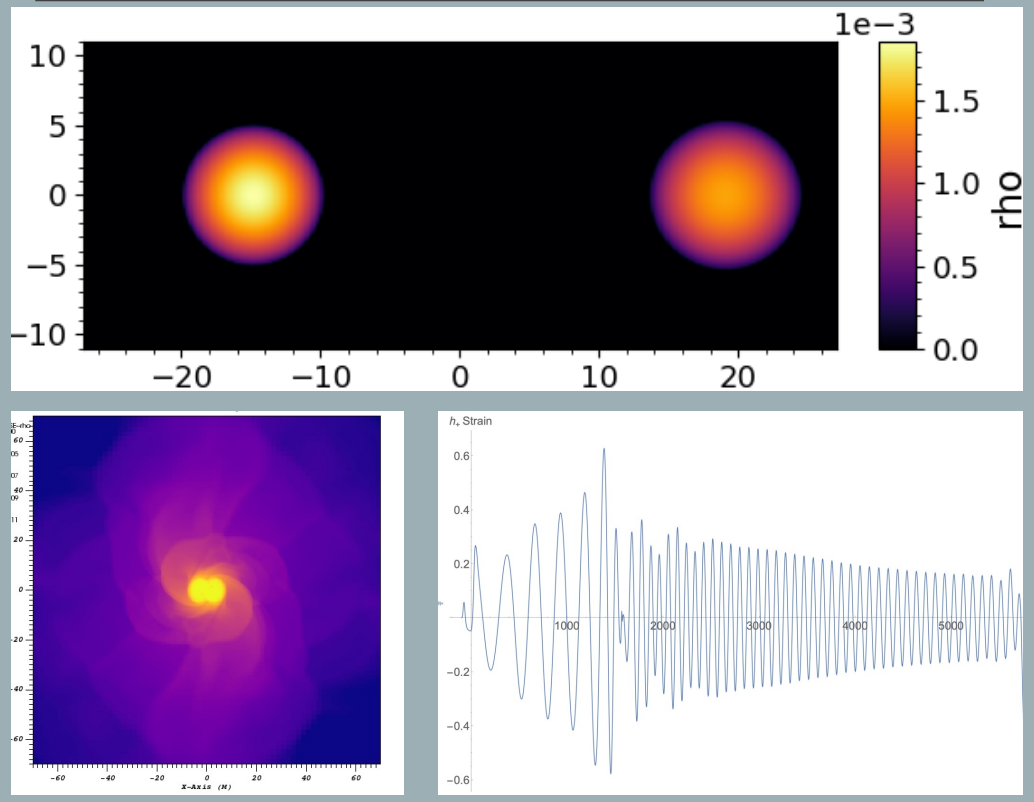
ECCENTRICITY



Dillon Buskirk, Maria C. Babiuc Hamilton (2022)
http://arxiv.org/abs/2203.08998

- Gravitational waves from eccentric binaries have intricate signals
- Dynamics encodes the location, creation and evolution of the sources.
- Eccentricity shortens the merger time.
- Eccentric GW signals statistically predominant when detectors will reach the required sensitivity.
- We accurately implemented fully analytical GW templates from eccentric binary black hole mergers.
- We compared two models for the merger, and reached overlap when building the hybrid GW waveform.

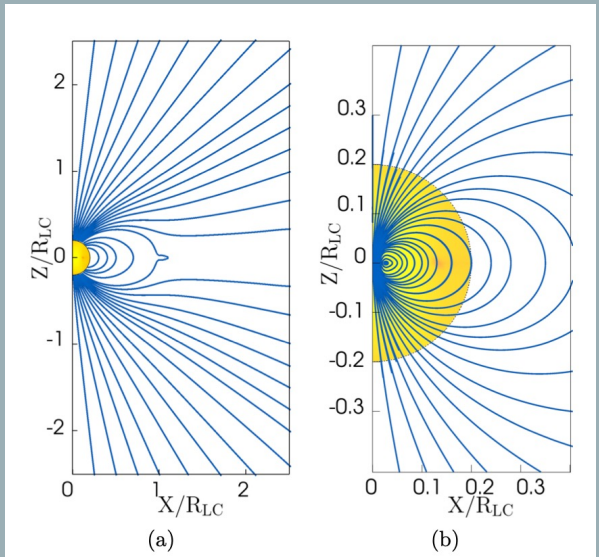
MATTER EFFECTS



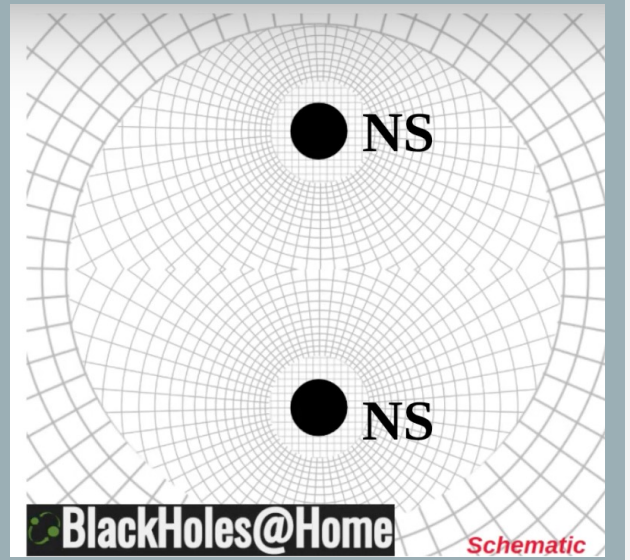
Numerical Simulations of Realistic Binary Neutron Star Collision (in-work)

- Neutron Stars are perfect natural laboratories of extreme multi-physics
  - Nuclear physics: equation of state (EOS) for matter beyond nuclear densities.
  - Gravitational Wave astronomy: source properties, binary population
  - High-energy-astrophysics: short Gamma ray bursts, heavy elements formation
  - Fundamental Physics: tests of General Relativity and unification theories
- EOS constraints – tension?
  - soft – GW170817
  - mild – GW190425
  - stiff – NICER

MAGNETIC FIELDS



Z.B. Etienne, M.-B. Wan, M.C. Hamilton, S.T. McWilliams, A. Choudhary (2018) https://arxiv.org/abs/1704.00599



Code to model the magnetosphere of NS binaries in Curvilinear Coordinates (in-work)

- NSs classification after their B-field:
  - Magnetars (10^{13}-10^{15}) G
  - Radio pulsars (10^{11}-10^{13}) G
  - Recycled radio pulsars (10^{8}-10^{11}) G
- Origin, evolution and structure of NS magnetic field yet unclear, NICER revealed complicated shape.
- The B-field of the NSs in the binary break, reconnect and release energy.
  - Closer to merger the interaction can generate fast radio bursts (FRB).
  - During the merger the B-field is amplified, through magneto-collisional instabilities and may launch gamma ray bursts (GRB).