

# High Energy Physics and Gravity Theory

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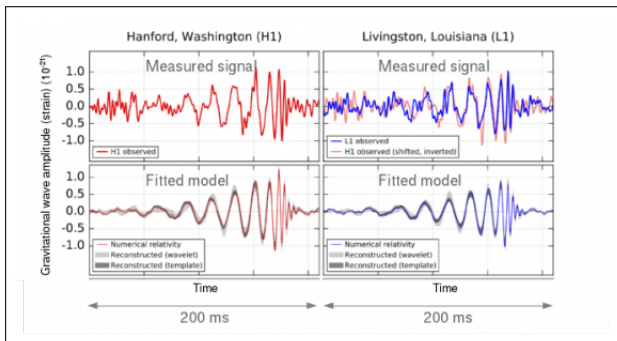
NBIA MSc Day  
Niels Bohr Institute  
October 24, 2019



The Niels Bohr  
International Academy



## GW detections: Complete O1-O2 catalog



1 GW150914 (above)

2 GW151012

3 GW151226

4 GW170104

5 GW170608

6 GW170729

7 GW170809

8 GW170814

9 GW170817

10 GW170818

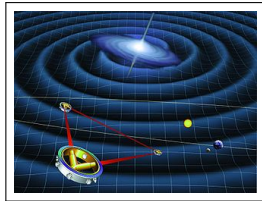
11 GW170823

# GWs through Time & Space

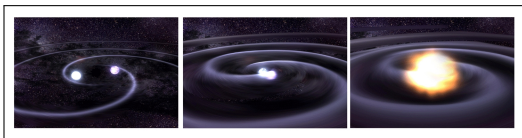
Theoretical prediction	1916 Einstein
1st evidence	1974 Hulse & Taylor
1st detection	2015 LIGO!

GW detectors worldwide:

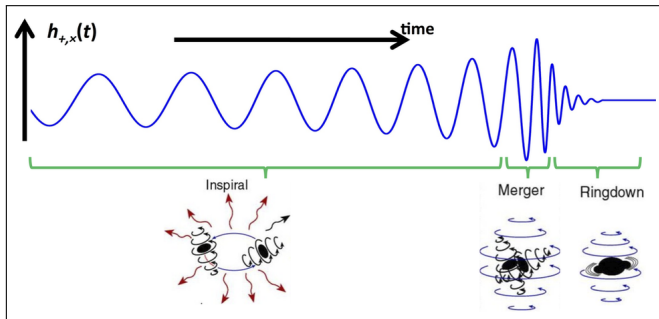
- Ground-based
  - TAMA 1999-2004
  - LIGO x 2 2002-10
  - GEO 600 2002-
  - Virgo 2007-11
- 2nd generation ground-based
  - Advanced LIGO x 2 2015-
  - Advanced Virgo 2017-
  - KAGRA 2019?
  - IndiGO 2024?
- 3rd generation & space-based
  - LISA 2034?
  - Einstein Telescope ?
  - Cosmic Explorer ?



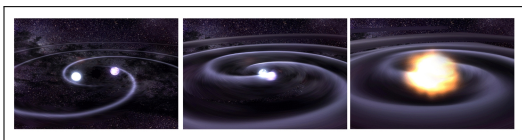
# GW signal from compact binaries



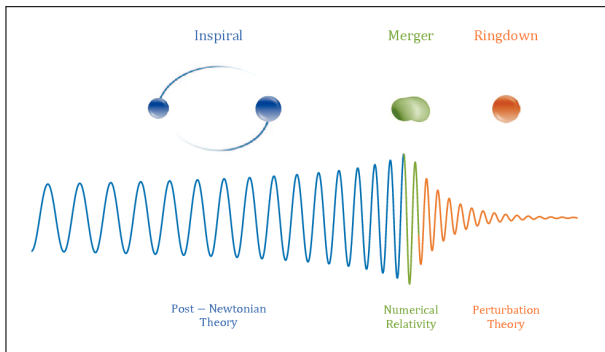
## 3 phases in the life of a compact binary



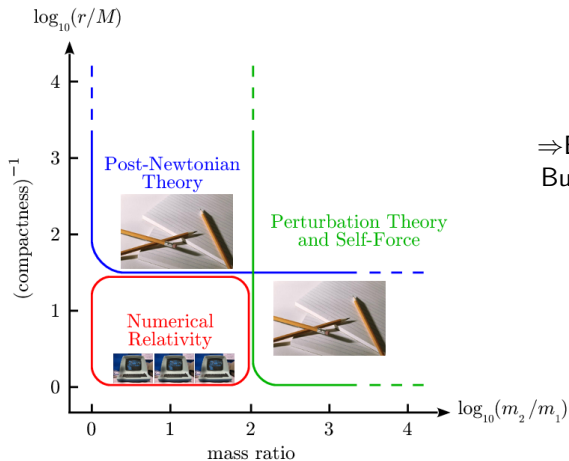
# GW signal from compact binaries



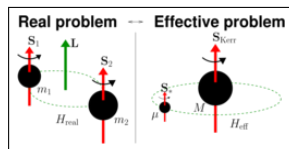
## 3 phases in the life of a compact binary



## Physics of GW templates



⇒ Effective One-Body (EOB),  
Buonanno and Damour 1999



Detection by **matched filtering**

⇒ High demand on **accurate theoretical** waveform templates

# Effective Field Theories (EFTs) are universal



$r_s$   
Internal  
Structure



$r$   
Orbital  
Separation



$\lambda$   
Radiation  
Wavelength

## There is a hierarchy of scales

[Goldberger et al. 2007]

- 1  $r_s$ , scale of **internal structure**,  $r_s \sim m$
- 2  $r$ , **orbital separation** scale,  $\frac{r_s}{r} \sim v^2$
- 3  $\lambda$ , **radiation wavelength** scale,  $\frac{r}{\lambda} \sim \omega r \sim v$

It's a multiscale, let's use EFT!



$v \ll 1$ ,  $nPN \equiv v^{2n}$  correction in General Relativity to Newtonian gravity

For EFTs of PN gravity proceed in stages corresponding to each scale

# Setup of EFTs is universal

## Bottom-Up or Top-Down?



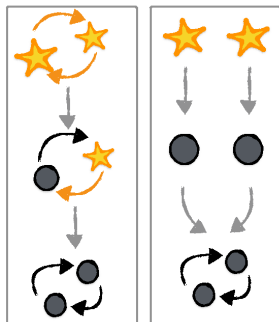
Two generic procedures to construct effective field theories (EFTs):

- 1 **Bottom-Up**, no theory for the system in close-up, so we look from the far, and gradually zoom in. Identifying the **Degrees Of Freedom** and **Symmetries** enables that.
- 2 **Top-Down**, theory in high resolution/close-up is known, so we reduce resolution by systematically removing extra pixels out of the picture. **Feynman formalism/technology** enables that.



# Stage 1: Remove internal structure of isolated object

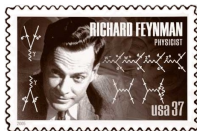
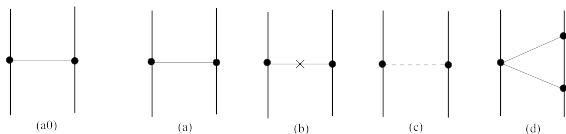
Identify the **DOFs** and **Symmetries** of the system at the scale of the desirable effective theory.



It is crucial to take into account **rotating DOFs**.  
 Mass + **Spin** = The 2 unique parameters of  
 black holes in nature.

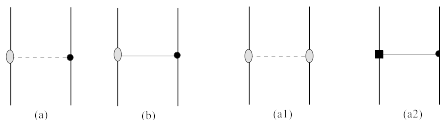
# Stage 2: Remove orbital separation between 2 objects

## Feynman graphs of interactions without spin



Newton

## Feynman graphs with spin



Spin-Orbit

Spin-Spin

# Highlights and Prospects

ML, Rept. Prog. Phys. 2019

From our Effective Field Theory approach:

- Effective theory for a spinning gravitating object
- High precision results for gravitational interactions with spins
- Public code of the whole framework: Feynman + Gravity

Still lots of work to be done!

- Extend the effective theories to new sectors, theories of gravity. . .
- How can we use knowledge from scattering amplitudes and more generally high energy physics to further simplify computations, or even extend analytical prediction power to the strong gravity regime of the GW signal?
- Continuous (public!) development of computational tools...