# Snowmass2021 - Letter of Interest

# *Gravitational waves from compact binary coalescence and effective field theory*

**Topical interest:**

☐ SCET
☐ SMEFT
☐ Naturaleness problem
☐ Swampland/WGC
☐ EFT for inflation
☐ EFT for dark matter
■ NRGR: Non relativistic General Relativity, EFT for 2-body problem in gravity
☐ Connections to CMT ☐ (Other)

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**Abstract:** Motivated by the observation of gravitational waves from coalescing binaries, the analytic computation of gravitational scattering processes have made tremendous progress recently. Increasing the accuracy of our understanding of the gravitational two-body dynamics is the basic ingredient for building better waveform templates to improve the physics output of gravitational wave detection from coalescing binaries. Effective field theory techniques have proven very powerful so far in this investigation and new tools like the double copy and multiloop techniques are expected to produce new results to take the theoretical investigation to unprecedented perturbative level.

**Motivation.** The detections of GWs [1–4] by the interferometric detector LIGO [5] and Virgo [6], beside initiating the new research field named Gravitational Wave Astronomy, spurred new interests into theoretical modelings of the two-body gravitational problem, which is at the base of any GW detection made by gravitational wave observatories so far: compact binary coalescences.

Inspired by a non-relativistic treatment of heavy quarks in particle physics, Non-Relativistic General Relativity (NRGR) [7] has provided new tools to investigate the post-Newtonian (PN) [8] approximation to General Relativity (GR). More recently in [9] the third order accurate post-Minkoswkian (PM) [10] analysis was produced, using the most advanced methods originally developed for scattering amplitude computations for particle physics like generalized unitarity and double copy techniques [11], which exploits an intimate connection between gauge and gravity theory.

**Observationally triggered theoretical research.** With the scheduled upgrade for the second generation ground-based interferometers, and even more with third generation one and with space-based interferometers planned for the next decade, high signal-to-noise ratios are expected (up to $O(10^3)$ [12, 13]), calling for more accurate source modeling to produce more accurate templates with the goal to maximize the physics output of future detections. On the other hand the gravitational scattering is a problem rich of intriguing theoretical aspects, representing an highly non-trivial test-bed for classical field theory beyond the phenomenological applications which give strong motivation to develop new powerful techniques.

Currently used waveforms, based on the effective-one-body [14–16] or phenomenological approach [17–21], describe the entire coalescence and are accurate enough for present sensitivities, however improvements in waveform modeling will be required in the future [22] and a deeper and more complete understanding of the underlying source dynamics is crucial for construction of faithful waveforms.

Out of the three theoretical methods pursued so far to analyze the relativistic two-body problem: exact numerical simulations [23, 24], self-force computations [25–28], perturbative PN and PM approximations, the last one can take full advantage of decades of development of quantum field theory techniques applied to particle physics which are expected to make further leaps forward due to the gravitational wave applications.

Owing to a correspondence between Effective Field Theory diagrams for massive-objects binary systems, within classical General Relativity, and Quantum Field Theory diagrams, within Particle Physics [29], future developments on Feynman integral calculus see e.g. [30], may constitute a topic of crossing-fertilization between theory and phenomenology of gravitational waves.

**Summary.** The field of Gravitational Wave Astronomy needs input from theoretical physics to develop more accurate waveform templates describing the coalescence of compact binary systems and it provides strong motivation for developing techniques for gravitational scattering computations at higher perturbative level. Effective field theory techniques have proven very powerful recently and it is expected that their full potential in mapping the gravitational scattering problem to the description of the two-body problem for bound orbits has not been fully exploited yet.

## References


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