Gravitational Waves and Scattering Amplitudes

Mikhail P. Solon

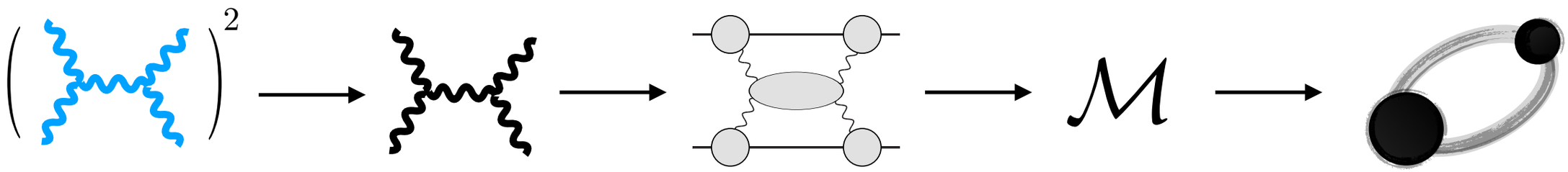
Bhaumik Institute for Theoretical Physics, UCLA

Snowmass White Paper by Radu Roiban et al.

Frontiers of Experiment

2015	**2020**	**2025**	**2030+**
LIGO	LIGO/Virgo	+ KAGRA, INDIGO, …	LISA, Einstein Telescope, Cosmic Explorer, …

Quantum Field Theory



Theoretical Structures

(virtuous cycle)

Quantum field theory tools for gravitational wave science

Produce state-of-the-art waveforms for compact binary coalescence.

Develop tools from theoretical high energy physics for application to gravitational waves.

Explore theoretical structures that emerge in the classical regime of scattering amplitudes.

Welcomed by the general relativity community.

High-energy gravitational scattering and the general relativistic two-body problem

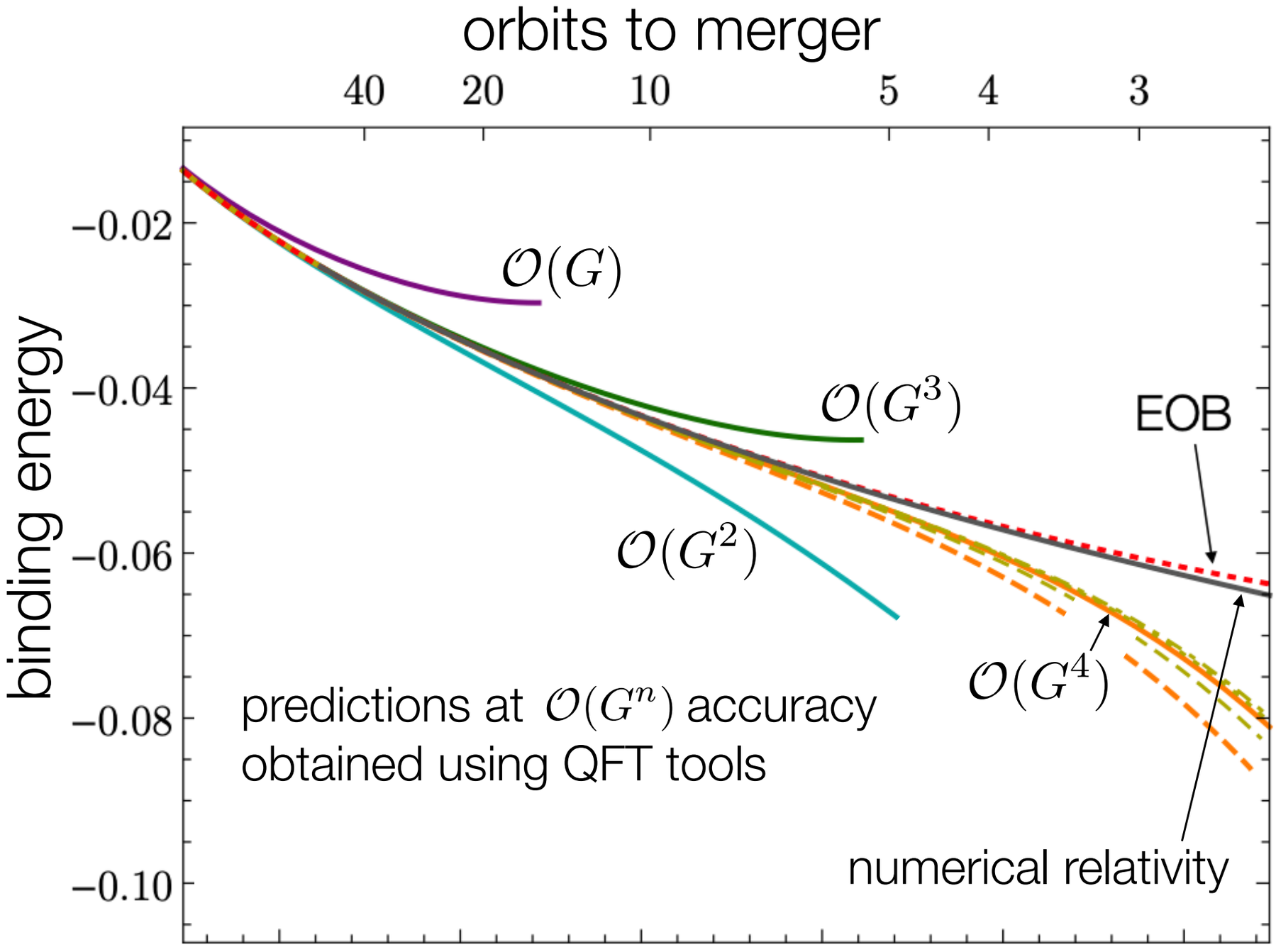
Thibault Damour*
Institut des Hautes Etudes Scientifiques, 35 route de Chartres, 91440 Bures-sur-Yvette, France
(Dated: October 31, 2017)

A technique for translating the classical scattering function of two gravitationally interacting bodies into a corresponding (effective one-body) Hamiltonian description has been recently introduced [Phys. Rev. D **94**, 104015 (2016)]. Using this technique, we derive, for the first time, to second-order in Newton's constant (i.e. one classical loop) the Hamiltonian of two point masses having an arbitrary (possibly relativistic) relative velocity. The resulting (second post-Minkowskian) Hamiltonian is found to have a tame high-energy structure which we relate both to gravitational self-force studies of large mass-ratio binary systems, and to the ultra high-energy quantum scattering results of Amati, Ciafaloni and Veneziano. We derive several consequences of our second post-Minkowskian Hamiltonian: (i) the need to use special phase-space gauges to get a tame high-energy limit; and (ii) predictions about a (rest-mass independent) linear Regge trajectory behavior of high-angular-momenta, high-energy circular orbits. Ways of testing these predictions by dedicated numerical simulations are indicated. We finally indicate a way to connect our classical results to the quantum gravitational scattering amplitude of two particles, and we urge amplitude experts to use their novel techniques to compute the 2-loop scattering amplitude of scalar masses, from which one could deduce the third post-Minkowskian effective one-body Hamiltonian

"… we urge amplitude experts to use their novel techniques to compute the 2-loop scattering amplitude of scalar masses …"

Theorists at LIGO are interested.

Antonelli, Buonanno, Steinhoff, van de Meent, Vines 2019; +Khalil in prep



Cheung, Rothstein, MS 2018

Bern, Cheung, Roiban, Shen, MS, Zeng 2019

Bern, Parra-Martinez, Roiban, Ruf, Shen, MS, Zeng 2021

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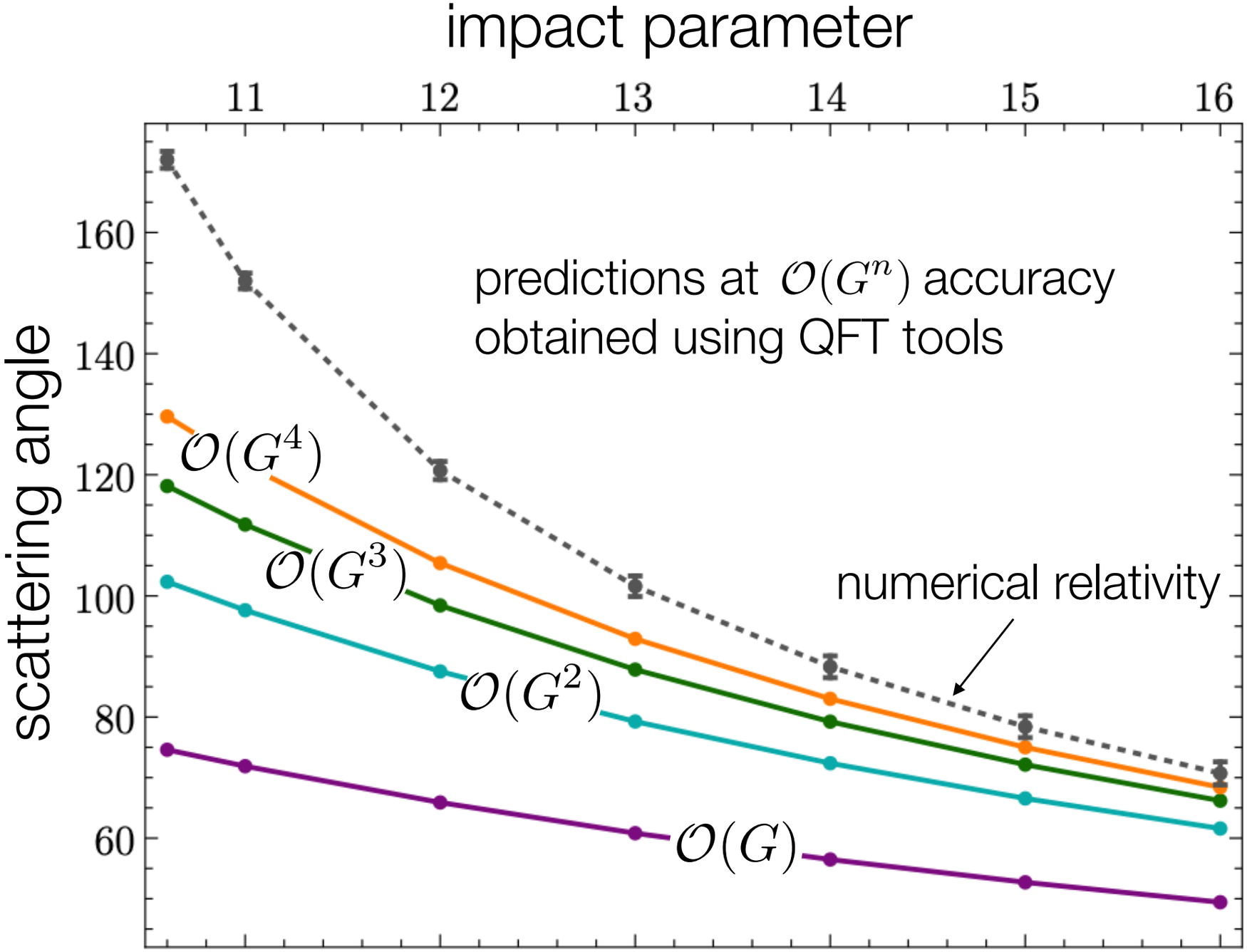

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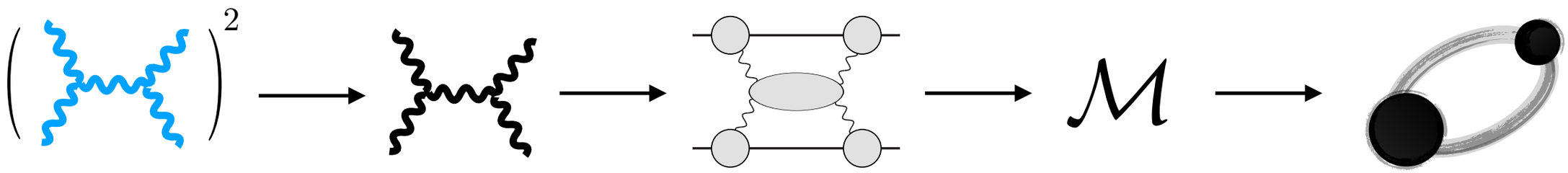


double copy

Kawai, Lewellen, Tye, Bern, Carrasco, Johansson, Ochirov, Chiodaroli, Jin, Roiban, Chen, Boucher-Veronneau, Dennen, Davies, Damgaard, Bjerrum-Bohr, Huang, Anastasiou, Borsten, Nagy, …

on-shell methods

Bern, Dixon, Dunbar, Kosower, Morgan, Britto, Cachazo, Feng, Witten, Ellis, Melnikov, Forde, Bader, Carrasco, Johansson, Arkani-Hamed, Y-T Huang, Trnka, Bourjaily …

advanced multiloop integration

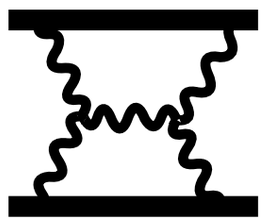
Chetyrkin, Tkachov, Laporta, V. Smirnov, A. Smirnov, Kotikov, Bern, Dixon, Kosower, Remiddi, Gehrmann, Chuharev, Tarasov, Lee, Henn, Beneke, Czakon, Ita, Zeng, …

effective field theory

Caswell, Lepage, Braaten, Isgur, Wise, Manohar, Stewart, Donoghue, Beneke, Goldberger, Rothstein, Neill, Vaidya …

New results in general relativity.

$$G(1 + v^2 + v^4$$



Bini, Damour, Geralico 19, 20
Damour 19, 20
Blumlein, Maier, Marquard, Shafer 20
Di Vecchia, Heissenberg, Russo, Veneziano 20

$$G^2(1 + v^2 + v^4$$

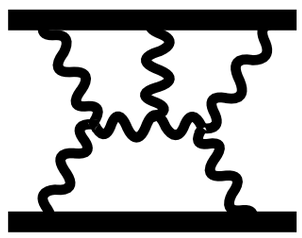
$$G^3(1 + v^2 + v^4 + v^6 + v^8 + v^{10} + v^{12} + \cdots)$$

$$G^4(1 + v^2 + v^4 + v^6 + v^8 + v^{10} + v^{12} + \cdots)$$

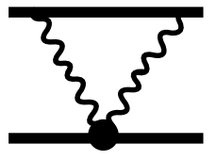
$$G^5(1 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad \cdots)$$

$$G^6 \quad \cdots)$$

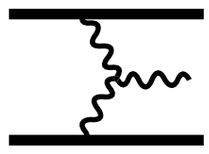
$$G^7(1 + v + v + v + v + v + v + v + \cdots)$$



Bini, Damour, Geralico 21
Blumlein, Maier, Marquard, Schafer 21
Bern, Parra-Martinez, Roiban, Ruf, Shen, MS, Zeng 21
Dlapa, Kalin, Liu, Porto 21

spin and tidal effects 

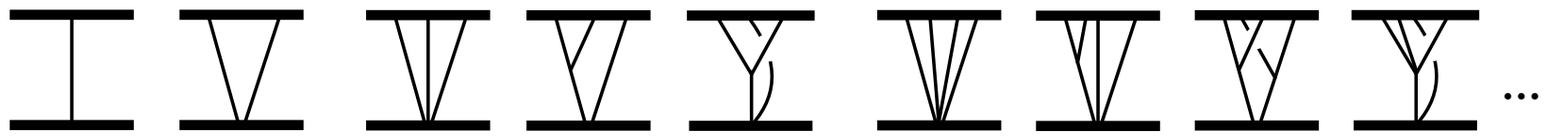
Guevara, Ochirov, Vines, Huang, Levi, Bern, Luna, Roiban, Shen, Zeng, Kosmopoulos, Jakobsen, Mogull, Cheung, Shah, Haddad, Helset, Chia, Charalambous, Dubovsky, Ivanov, Hui, Joyce, Penco, Santoni, Solomon, De Luca, Pani …

radiation 

Damour, Veneziano, Di Vecchia, Heissenberg, Russo, Herrmann, Parra-Martinez, Ruf, Zeng, Riva, Vernizzi, Cristofoli, Kosower, O'Connel, Jakobsen, Mogull, Plefka, Steinhoff, Bjerrum-Bohr, Damgaard, Plante, Vanhove, Shen, Manohar, Ridgway …

classical double copy

Luna, Monteiro, O'Connell, White, Nicholson, Ridgway, Wise, Carrillo-Gonzalez, Penco, Trodden, Kol, Adamo, Casali, Mason, Nekovar, Ochirov, Goldberger, Ochirov, Plefka, Shi, Shen, Arkani-Hamed, Huang, Bjerrum-Bohr, Donoghue, Vanhove, Gonzo …

theoretical structures 

Cachazo, Guevarra, Ita, Ruf, Herrmann, Luna, Zeng, Jakobsen, Mogull, Plefka, Steinhoff, Bjerrum-Bohr, Damgaard, Vanhove, Kol, Telem, O'Connell, Cristofoli, Gonzo, Kosower, Britto, Brandhuber, Johannson, Travaglini, Carrillo-Gonzalez, de Rham, Tolley, Jones, Gralla …

new methods

Kosower, Maybee, O'Connell, Bini, Damour, Geralico, Bjerrum-Bohr, Damgaard, Festuccia, Plante, Vanhove, Kalin, Porto, Parra-Martinez, Ruf, Zeng, Brandhuber, Chen, Johannson, Travaglini, Wen, Edison, Levi, Di Vecchia, Russo, Heissenberg, Veneziano, Chiodaroli, Johansson …

An open field with lots to explore.

LIGO

LIGO/Virgo

+ KAGRA, INDIGO, …

LISA, Einstein Telescope, Cosmic Explorer, …