Gravitational waves from neutron star and black hole binaries

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The search for Gravitational Waves (GW) has crossed a significant milestone with the commissioning of large baseline laser interferometric GW detectors like LIGO and Virgo . LIGO and Virgo have achieved design sensitivity in most of the sensitive bandwidths and completed scientific runs for close to two years. At this sensitivity LIGO and Virgo can hear binary neutron star inspirals at 35 Mpc with optimal orientation. Though there has been no direct detection of GW, LIGO and Virgo observations are able to constrain the GW emission for a variety of sources to values that in some cases are going beyond existing astrophysical limits. Upgrades are under way to go to Advanced LIGO and Advanced Virgo with ten times higher sensitivity. In these Advanced detectors double neutron star inspirals will be visible out to 300 Mpc and neutron star black hole inspiral to 650 Mpc.

Associated with this exciting path breaking experiment is a plethora of requirements related to the high accuracy modelling of sources of the GW. This stems from the fact that the GW from even highly relativistic systems like binary neutron stars or binary black holes represent the data analysis situation of a weak astrophysical signal buried in strong noise of the detectors. Consequently, an optimal data analysis strategy like matched filtering is mandated: first to extract the weak GW signal from the noise and next to estimate the parameters of the source from the GW signal.

The goal of the first CEFIPRA project (with Luc Blanchet) was to provide the GW of an inspiralling neutron star or black hole binary with 3.5PN phasing for construction of the best templates to be used to detect GW in detectors like LIGO and Virgo. The most serious stumbling block for almost a decade in using the available results was the incompleteness of the 3PN GW radiation field due to the appearance of unknown parameters arising from the incompleteness of the Hadamard regularisation used to manage the divergent self-field effects arising from the use of delta functions to model the point particles making up the binary. To address this issue we proceeded systematically by first locating the source of the problem and then identifying that the best and most efficient way to overcome it was by use of dimensional regularization. Using the multipolar post-Minkowskian and matching formalism we computed the GW phasing of inspiralling compact binaries moving in quasi-circular orbits at the 3.5PN approximation and GW amplitude at the 3PN order in a ready-to-use form for GW experiments. With this determination, the general relativistic prediction for compact binary inspiral up to 3.5PN order is complete and will form the basis for searching and deciphering the GW signals in the current network of gravitational wave detectors. They also lead to a more accurate parameter estimation accuracy which should be crucial in extracting cosmology from GW observations of LISA. More recently, Numerical relativity has been able to produce robust results for the GW from the merger of two black holes. Their validation and interpretation crucially depends on matching to the PN waveforms of inspiral that have been provided under this project. The results were generalised to the case of black hole binaries moving in quasi-eccentric orbits by a computation of the instantantaneous and hereditary terms in the energy and angular momentum fluxes to 3PN accuracy and subsequently the secular evolution of the orbital elements. The second and current project (with Luc Blanchet and Guillaume Faye) involves the computation of 3.5PN GW polarizations. It also involves the construction of a package PNComBin based on an efficient extension of Mathematica for tensor calculus, xTensor.

The efficient and timely progress in this project with global implications for GW Astronomy was facilitated in no small measure by the possibility of periodic mutual visits between the two principal collaborators at crucial stages in the collaboration. 4 Ph.D students from India, K.G. Arun, M.S.S. Qusailah, Sidhartha Sinha and Chandrakant Mishra and 1 from France, Sylvan Marsat, were involved in some of the projects. 9 papers in journals and about 12 presentations in conferences resulted from these projects. 3 papers are already among the well-cited ones in the field of GW.