

Cosmic fireworks:
The dawn of multimessenger astronomy
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Opening Remarks
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GW170817 is the nail-biting climax of a fascinating saga whose first chapter was the discovery of the binary pulsar in 1974 by Hulse and Taylor and whose prolog was the discovery of pulsars by Jocelyn Bell in 1967. It was a spectacular success taking a century to realize and made possible by the coming together of an unforgiving experiment and an exquisite theory complemented by the best in data analyses and state of the art computing.

A new astronomy was ushered in with the discovery of GW170817 on Aug 17 2017. The gamechanger was a network of GW detectors consisting of two LIGO's and Virgo and their ability to localize a GW source to a small enough region to realistically facilitate EM followup and about which you will hear in more detail in the talks today. It is a tribute to the vision of the founders who were brave enough to call the GW detection facilities GW Observatories so early on. The O has been earned twice over in a couple of years.. At the discovery of GW150714 that received the Nobel and now GW170817. It is remarkable that even at this first discovery of GW from a binary neutron star system , new insights into Astrophysics, Cosmology and Fundamental physics assessed feasible earlier have already emerged.

Personally for me it was gratifying to see the 100 second chirp from the two neutron stars. The chirp so accurately described by the analytical formulas coming from research I had the privilege to be involved in for more than two decades based on a cocktail of approximation methods combining multipolar, non-linearity post-minkowskian expansions and post-newtonian methods. This approach had its modern genesis in the work of Thibault Damour when analysing the observations of the Hulse Taylor pulsar and its improved algorithmic implementation in the thesis work of Luc Blanchet in the eighties.

At the first ICGC meeting in Goa in 1987, Richard Isaacson, Thibault Damour and Bernard Schutz lectured. Bernard Schutz was one of the earliest to think deeply about GWDA issues and I think Sanjeev's early involvement in GWDA was influenced by it. The research group led by Sanjeev Dhurandhar at IUCAA with notable contributions by B.S. Sathyaprakash initiated foundational work on developing data-analysis techniques to detect weak gravitational-wave signals buried in noisy data. Sanjeev, collaborated with almost all GW groups including Bar groups and later many Indo-French projects with John Yves Vinet.

I was introduced to the power of the MPM-PN formalism in 1989 when I had a sabbatical with Thibault when we revisited Linearized Gravity using this formulation. When LIGO was funded in early nineties, Kip Thorne put together an intense activity to assess the theoretical preparedness for analysing GW from CCB. It led to a famous PRL entitled “The Last three minutes.. Issues in Gravitational Wave Measurements of Coalescing Compact Binaries” and a meeting at Caltech where Blanchet, Dhurandhar and myself among others were participants. By this meeting Kip informally drafted researchers outside LIGO who could contribute to this endeavour. This led to the Indo-French collaboration of BDI and an American one of Will and Wiseman to independently work on the 2PN generation of GW ie corrections to Einstein’s quadrupole formula to order $(v/c)^4$.. In GR the problem is complicated since for self gravitating systems going to higher PN orders requires going to higher orders of nonlinearity. Due to work related to the binary pulsar, the required 2PN EOM was already available to the two groups. The quick success at 2PN by 1995 led us to believe that the next order correction would be obtained on the same time-scale..

However, in this case one had to first obtain the EOM to 3PN order before computing the radiation to that order. It was not to be and it was only after a decade the 3PN sumit was scaled by our collaboration. Among others Guillaume Faye and Esposito Farese were involved. In these developments the Jena group of Schafer and Jaranowski made seminal contributions to 3PN EOM. Recently groups using effective field theory methods have also attacked the problem. The consistency of different approaches is an important check in this complex problem and in spite of a decade of very hard work the 4PN radiation is still work in progress. The results of this research outside the LVC is also the starting point for EOB and Phenom approaches to extend results for Inspiral to Merger and Ringdown. It was indeed appropriate that the Breakthrough Prize added to LVC some from this external community.

In the nineties, NR work related to binaries started as a Grand Challenge in groups at USA, Seidel’s group at Potsdam, Marck’s group at Meudon and Nakamura at Japan. Though there was a lot of technical progress the problem remained unsolved until Pretorius outside made a breakthrough in 2005. Immediately after the earlier groups caught up leading eventually to the NR revolution. But, thanks to available PN results, GWDA was not held up and could go forward during initial LIGO.

With Damour and Sathyaprakash, I worked on use of Pade methods to extend applicability of PN expansions, and development of tools to critically characterize template banks and quantify them. Students in my group at RRI (Qusailah, Arun, Sinha, Mishra) worked on TOG using LIGO and LISA, studies on effects of phasing and amplitude corrections for parameter estimation of ICB, astrophysical and cosmological implications of higher harmonics of GW for the science case of LISA and finally, the extent to which LISA observations of supermassive black hole binaries can test general relativity. It was wonderful to see it finding its use using

Bayesian methods from the first detection. Delighted to add that Ajith began with me as a visiting student and now heads a very active GW group here at ICTS.

Starting 2009 IndIGO matters and 2011 onwards LIGO-India related issues occupied me and I was hoping that by 2014 when I would formally retire from RRI, all this would come to closure. It was not to be.. Fortunately, at ICTS, Spenta and later Rajesh offered me a Visiting Position and Support to continue my GW related involvement. This made it possible for me to be associated with all the exciting discoveries that happened with Advanced LIGO. On this memorable day in my GW life, I would like to end with a big Thank you to ICTS for making it possible for me to bring to harbour my personal GW Odyssey of the last twenty five years.

And now .. Let the fireworks and symphony begin..

Srini reminded me that it is Chandra's Birthday today. Chandra contributed to PN work and GW and it is wonderful that today's meeting be dedicated to him.