Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter
PRISMA

Mainz Institute for Theoretical Physics

The Sound of Spacetime: The Dawn of Gravitational Wave Science

Organized by Luis Lehner (Perimeter Institute), Rafael Porto (ICTP SAIFR)], Riccardo Sturani (IIP Natal) and Salvatore Vitale (MIT).

4 - 15 June 2018

The recent historical detection of gravitational waves (GWs) by the LIGO scientific and Virgo collaborations heralded an unprecedented new era for fundamental physics investigations. After the remarkable landmark of detection, GW science will soon turn into the study of the properties of the sources and address fundamental questions in astrophysics, fundamental gravity and cosmology. In particular, binary coalescences – of comparable masses or extreme-mass ratios – are posed to become the leading probe to test gravitational dynamics and the physics of compact objects under unique conditions. The number of events detected up to now has demonstrated the feasibility of direct detection of GWs emitted by coalescing compact objects and that black holes in binary systems are relatively common in nature. We expect many events per year once LIGO is running at designed sensitivity. The correct interpretation of results and their physical consequences will thus become the ultimate goal of the field. Typical searches for GWs thus require very precise signal templates, which in turn demands state-of-the-art numerical and analytical models to make the most accurate parameter estimation possible. Moreover, extracting the most information from the waveforms requires very efficient search algorithms for data analysis.

The new era of GW science will become a truly interdisciplinary subject. The nascent field of gravitational wave astronomy encompasses source modeling, data analysis, fundamental gravity, cosmology and astrophysics to realize the full potential of this new era.

The scientific program brought together researchers focusing in different areas of this emerging field that is under the umbrella of GW physics and ranging from field-theoretical methods, numerical gravity, astrophysics to signal analysis. Our main motivation is to create an environment that fosters exchange between scientists with different backgrounds. The format of the meeting consisted of 2-3 long talks (1h each) in the mornings and 1 in the afternoons, followed by open discussions.

Maria Haney presented the most recent LIGO/Virgo gravitational wave (GW) detection results with emphasis on the fundamental physics tests made possible by these observations. Badri Krishna talked about testing general relativity consistency in the signals from compact binary coalescence by comparing the inspiral phase in which the two initial compact objects are approaching each other to the ring-down phase in which the two initial objects have merged into a final black hole. The discussion session was about the question how much more accurate theoretical modelling one needs to interpret observational results.

Talks by John Carrasco, Stefano Foffa, Natalia Maia and Rafael Porto all focused on the use of effective field theory to model the two-body dynamics in gravity theory. Carrasco introduced new ideas for amplitude computations, Foffa gave an introductory talk about reducing the gravitational dynamics to computable scattering amplitudes. Maia showed her latest results on next-to-next-leading order in radiation reaction force of compact object with spin. Porto concluded with an overview of the effective field theory approach to general relativistic 2-body dynamics. The discussion was about the impact of theoretical computation on wave form modelling.

Matalia Korsakova gave an overview on the sources and data analysis issues foreseen for LISA. The space GW detector is due to start its mission in the mid 30ies. Salvatore Vitale presented a comprehensive study of the astrophysical implications obtained so far. He also considered possible implications in the near future of GW detections on stellar mass black astrophysical parameter distributions. Following on this line, Matias Zaldarriaga presented the binary formation mechanism favored by present data and asked what can be expected from further LIGO/Virgo detections. The discussion was centered on how GW detections can constrain the binary formation channels, with the conclusion that at present the common envelope model (object already in pairs before they become compact) is favored.

The next topic was the use of the luminosity distance measured by GWs to test gravity in the weak curvature, long distance regime. Stefano Foffa showed how the current standard cosmological model can be challenged by other models with the same number of parameters and comparable evidence. He also showed how future GW observations by third generation detectors can enable choosing between one model and the other. Jose Exquiaga reiterated the topic by demonstrating how dark energy - or whatever is at the basis of the present cosmological acceleration - can be probed by future GW detections in a model-independent way. The discussion was about all possible ways - beyond standard sirens – how cosmological information can be inferred from GW data.

The talks by David Nichols, Horn Sheng Chia, Badri Krishnan and Xavier Calmet were dedicated to exotic aspects of gravitational waves. Nichols talked about memory effects, which are effects in standard general relativity. Chia explained the concept of super-radiance (amplification of GWs by a spinning black hole) and how it can be detected if it is further enhanced. Krishnan gave a data analysis perspective of the non-standard source of GWs and the way to detect them. Calmet presented the results of his approach which consists of adding higher curvature corrections inspired from quantum gravity to Einstein equations. He also looked for detectable effects in both the conservative and dissipative sector of gravity. The discussion after the talks focused on possible exotic effects in GWs. Krishnan presented ongoing efforts to connect the GWs measured at infinity to assess the behavior of horizons. This mapping would provide crucial insights on the nature of strong field gravity and trapped surfaces. Frans Pretorius discussed opportunities and challenges in the context of eccentric mergers, reviewing the rich phenomenology such systems could display and the physics one can conclude from this. Georgios Gerakopoulos, in turn, surveyed what is known on the possible existence of chaos in binary system of large mass ratio and its consequences, stressing, however, that further research is needed on this topic. These talks were followed by a discussion on gravitational wave building blocks, specifically considering the extent to which departures from general relativity are taken into account currently. Moreover, possible limitations in light of the limited theoretical knowledge were also discussed.

Luis Lehner summarized possible surprises with respect to current templates that compact binaries in General Relativity might display. He also offered an overview of what is known regarding extensions of GR and alternative compact objects. Hinderer surveyed the know-how on semi-analytical ways to encode the full waveform for both vacuum and non-vacuum binaries. Aaron Zimmerman presented a detailed description of the analysis and physics drawn from GW170817 (binary neutron star coalescence). He also gave an overview of results and opportunities to extract information of gravitational physics from pulsars. The discussion focused on the question if and how currently used waveform models can catch appropriately non-dominant feature in the data.

Donal O'Connel showed how to recover gravitational dynamical quantities like scattering amplitudes in gravity by appropriately squaring analogue computations in vector-gauge mediated processes. Nicola Franchini showed the result of his investigations on how strong field gravity like in neutron star interior can hide new physics to be probed by GWs. The discussion focused on the possibility that modern field theory techniques like double copy can open for classical gravity phenomenological computations.

There was also an intense journal club discussion led by Jose Exquiaga about papers that recently appeared on the archive, namely arXiv:1801.00386 on dark matter (small) effects on GW2 propagation and on arXiv:1806.04920 which showed how to derive the classical, non-relativistic limit of general relativity from relativistic scattering amplitude of massive particle with graviton-mediated interactions.

Aaron Zimmerman focused on The Bayesian inference and model comparison, displaying the caveats that one has to keep in mind when looking for deviations from general relativity in GW data - deviations which cannot only be model dependent, but are also dependent on the astrophysical system, loosening the strength of the tests published by several groups, including the LIGO/Virgo collaboration.

Salvatore Vitale concluded the program with an overlook of future generation GW detectors and their foresee-able impact in astrophysical parameter estimations to constrain stellar mass black hole population and galactic evolution history. Throughout the scientific program, a flexible schedule allowed and encouraged ample discussions which provided a forum where ideas and expertise were exchanged in a lively and constructive environment.