COST
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Gravity@Malta 2018

Final Programme

Funded by the Horizon 2020 Framework Programme of the European Union

Monday 22 January 2018	
Time	**Talk Title**
08:15 – 08:30	Registration
08:30 – 08.45	Opening by COST Chair
08:30 – 09:00	Introduction and WG1 status and challenges
Author	Samaya Nissanke, Radboud University, the Netherlands
09:00 – 09:30	The black holes of the gravitational universe: genesis and growth
Author Abstract	Monica Colpi, University of Milano Bicocca Following the direct detection of gravitational waves by the LIGO-Virgo Scientific Collaboration, and the success of the LISA Pathfinder mission, we can firmly claim that we are heading into a new era of discoveries that will shed light into the processes of black hole formation and growth, using gravitational waves as messengers. There is a fil rouge connecting stellar origin black holes and supermassive black holes. Supermassive black holes, already in place when the universe was less than one Gyr old, may rise from a unique building block, the black holes of stellar origin. But other avenues are possible that call for the existence of intermediate mass black holes as seeds, elusive to EM observations, and of yet unclear origin. The Laser Interferometer Space Antenna (LISA) shall have the capability of detecting the early-forming heavy seeds and track their growth across all cosmic ages, surveying the low-mass tail of the supermassive black hole population. Ground based interferometers in their advanced configurations will push observations of stellar black holes close to the epoch of cosmic reionization, unveiling light seeds and the high-mass end of stellar origin black holes. I will review processes of black hole formation in binary systems to highlight the richness in the astrophysical phenomena that accompany the hardening of binaries in galactic field and in galaxy collisions. The gravitational universe is just in its infancy, but within the next decades we will be able to discover black holes over a wider mass spectrum, and uncover whether they are the unique, universal outcome of the un-halted relativistic collapse that Nature as provided to us to observe the universe from a new perspective.
09:30 – 09:55	Dynamics of BBH
Author Abstract	Bence Kocsis, Eotvos University With the detections of gravitational waves emitted during black hole and neutron star mergers, LIGO has recently opened the field of gravitational wave astrophysics. In this talk I will review some of the astrophysical processes that may be responsible for the observed events. Although less than 0.5% of the stellar mass is in dense stellar systems, I will argue that a large fraction of the black hole mergers may originate in these environments. In particular, I will review black hole mergers in dense stellar systems, including sources which form and harden due to multibody

	interactions, gravitational wave capture events, mergers driven by the central massive black hole and by gaseous disks. The event rate distribution may be used to understand the astrophysical origin of the observed gravitational wave events. I will argue that the eccentricity, mass, and spin distributions may be key to discriminate different processes that lead to black hole mergers.
09:55 – 10:20	The Discovery of Radio Emission from GW170817
Author Co-Authors Abstract	Assaf Horesh, The Hebrew University of Jerusalem Kunal Mooley, Gregg Hallinan On August 17, 2017, the first discovery of a gravitational wave (GW) event from a binary neutron star merger has been made by Advanced LIGO and Advanced VIRGO (dubbed GW170817). About two seconds after the GW, a short gamma-ray burst has been detected by the Fermi satellite. A few hours later, a panchromatic follow-up observing campaign has been launched worldwide leading the to first electromagnetic counterpart discovery across the spectrum and to the precise localization of the event. Our team discovered the radio afterglow of GW170817 at 3 GHz and 6 GHz with the VLA, 16 days after the GW discovery. Using further radio follow up observations along with optical and X-ray data, we were able to initially constrain the possible afterglow emission mechanism to two models 1) the conventional off-axis relativistic jet and 2) a mildly relativistic wide-angle cocoon model. Further radio observations by our team have shown that the radio emission is continuing to rise (at the time of this abstract submission) thus ruling out the off-axis jet model and favoring the cocoon model. Our team continues to monitor GW170817 with various radio facilities around the globe including the VLBI telescope. These future observations are expected to provide more information and constraints on the model.
10:20 – 10:50	**Coffee Break**
10:50 – 11:15	Numerical simulations of compact object mergers
Author Abstract	Albino Perego TBA
11:15 – 11:40	Shedding light on dark matter with gravitational waves
Author Abstract	Gianfranco Bertone TBA
11:40 – 12:05	Cosmology and cosmography of gravitational waves
Author Abstract	Germano Nardini Gravitational wave measurements can be used to infer the history of the Universe. In the present talk we review some gravitational wave observables that permit to

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	constrain the Hubble parameter at unexplored redshifts, and some measurements that allow to probe the first second of the Universe. We also highlight several open questions that the GWverse action could clarify.
12:05 – 12:30	Multi wavelength observations of gamma-ray binaries
Author Abstract	Masha Chernyakova, DCU Gamma-ray-loud binary systems form a newly identified class of X-ray binaries in which either accretion onto a compact object, or the interaction of an outflow from a compact object with the wind and radiation, emitted by a massive companion star, produces very-high energy gamma-ray emission. The number of these sources is very limited, less than 10 binary systems has been detected at TeV energies. The nature of the compact source in most of these systems is not known.In my talk I will review latest multiwavelength campaigns and discuss the possibility that the classical gamma-ray binary LSI +61 303 harbours a black hole.
12:30 – 12:50	Discussion and wrap up
12:50 – 14:00	**Lunch**
14:00 – 14:15	Standard sirens cosmography with LISA
Author Co-Authors Abstract	Nicola Tamanini, AEI Potsdam Chiara Caprini I will summarise the potential of the LISA mission in constraining cosmological parameters using gravitational waves sources as standard sirens. There are three classes of standard sirens that can be used to probe cosmology with LISA stellar origin black hole binaries (SOBHBs), extreme mass ratio inspiral (EMRIs) and massive black hole binaries (MBHBs). These different gravitational wave sources will provide cosmological information at different redshift ranges and will allow measurements of the expansion rate of the universe from very small (z=0.01) to very large (z=10) redshifts, making LISA a unique cosmological probe able to test the universe during at different cosmic epochs.
14:15 – 14:30	Black holes from other black holes?
Author Co-Authors Abstract	Davide Gerosa, Caltech Emanuele Berti Advanced LIGO/Virgo detectors have now made 4 confirmed detections of black-hole binaries. The first event, GW150914, was from the merger of two black holes much heavier than those whose masses have been estimated so far, indicating a formation scenario that might differ from "ordinary" stellar evolution. One possibility is that these heavy black holes resulted from a previous merger. When the progenitors of a black hole binary merger result from previous mergers, they should (on average) merge later, be more massive, and have spin magnitudes

	clustered around a dimensionless spin ~0.7. Here we ask the following question can gravitational-wave observations determine whether merging black holes were born from the collapse of massive stars ("first generation"), rather than being the end product of earlier mergers ("second generation")? We construct simple, observationally motivated populations of black hole binaries, and we use Bayesian model selection to show that measurements of the masses, luminosity distance (or redshift), and "effective spin" of black hole binaries can indeed distinguish between these different formation scenarios. More on arXiv1703.06223.
14:30 – 14:45	Black Hole Mergers induced by tidal encounters with a Galactic Centre Black Hole
Author Co-Authors Abstract	Shiho Kobayashi, Liverpool John Moores University Joseph Fernandez The LIGO/Virgo observatories recently detected gravitational waves (GWs) from several black hole (BH) mergers. Although BH mergers seem to be frequent in the Universe, it is still in debate how to form binaries that can merge in less than the age of the Universe. We discuss a new formation mechanism of BH mergers. The tidal disruption of stellar binaries by a massive BH is well known to produce hypervelocity stars. However, such tidal encounter with a massive BH does not always lead to the break-up of binaries. Our numerical simulations show that 10 percent of binaries survive even for very close encounters. The survivors tend to be hard and eccentric. Since the GW merger time of binaries is sensitive to the semi-major axis length and eccentricity, we find that this could lead to a reduction of the merger time by several orders of magnitude. Therefore, tidal encounters of stellar mass BH binaries with a massive BH at the centre of galaxies or in dense star clusters can provide a new formation channel of BH mergers. We also have evaluated how the effective spin parameter of BH binaries changes at the tidal encounter, and we found that post-encounter binaries could rotate in opposite direction in some cases (i.e. negative effective spin parameters). The distribution of the effective spin parameter is evaluated by using Monte Carlo calculations, and the results are compared with the LIGO/Virgo observations and the distributions expected from other models.
14:45 – 15:00	Model-independent constraints on astrophysical parameters of gravitational-waves sources
Author Abstract	Bence Bécsy, Eotvos University, Budapest With the increasing sensitivity of the LIGO and Virgo detectors, the chance of observing gravitational waves from sources other than compact binaries, including those from as-yet-unknown sources, is increasing. In this talk, I present methods to give constraints on astrophysical parameters of the sources observed with gravitational waves without assuming any specific source model. From the model-independently reconstructed gravitational-wave waveform we can give upper limits on the characteristic size, total mass and distance of the source. By knowing the

	source distance e.g. from electromagnetic observations, we can also give lower limits on the characteristic size and total mass. For signals lacking detailed and solid models on their astrophysical origin, this approach provides the only possibility for quantitative characterization of the astrophysical source. For well-modeled signals, we can use them to provide independent cross-checks of template-based parameter estimations.
15:00 – 15:15	Binary Black Hole Mergers from Globular Clusters Masses, Merger Rates, and the Impact of Stellar Evolution
Author Co-Authors Abstract	Dorota Rosinska, University of Zielona Gora, Poland Abbas Askar, Tomasz Bulik, Mirek Giersz The direct detection of gravitational waves from binary black hole mergers by the advanced Laser Interferometer Gravitational-Wave Observatories has ushered astrophysics into a new era of observing cosmic events that were previously invisible. Using results for around two thousand star cluster models simulated using well-tested the MOCCA Monte Carlo code for star cluster evolution we determine the astrophysical properties and local merger rate densities for coalescing binary black holes (BBHs) originating from globular clusters. We extracted information for all coalescing BBHs that escape clusters and subsequently merge within Hubble time along with BBHs that are retained in our GC models and merge inside the cluster via gravitational wave (GW) emission. By obtaining results from a substantial number of realistic star cluster models that cover different initial parameters (masses,metalicities, densities etc), we have an extremely large statistical sample of BBHs that merge within Hubble time. In my talk I will discuss the importance of BBH mergers originating from GC for gravitational wave observations.
15:15 – 15:30	Relativistic mergers of black hole binaries have (1) large, similar masses, (2) low spins and (3) are circular
Author Abstract	Pau Amaro Seoane, Institute of Space Sciences (ICE, CSIC) & Institut d'Estudis Espacials de Catalunya (IEEC) Binaries of stellar-mass black holes are among the most interesting sources for ground-based detectors, and have constituted the first detections. In this talk I will show that there is a selection effect for ground-based detectors, which should predominantly observe binaries of black holes with (1) large, similar masses, (2) low spins and (3) low eccentricities. "Hyperstellar" black holes (HSBs) (i.e. black holes with masses larger than the nominal $10M_{\odot}$ are predicted to be principally observed with an associated low value for the spin, typically of a<0.5, regardless of the formation channel. Also, when two HSBs build a binary, each of the spin magnitudes is also low, and the detection is mostly of binary members with similar masses. To address the distribution of the eccentricities of HSB binaries in dense stellar systems,

	I have used a large suite of dedicated three-body scattering experiments that include binary-single interactions and long-lived hierarchical systems with a highly accurate integrator, including relativistic corrections up to O(1/c^5). The results show that most sources in the detector band mainly have nearly zero eccentricities.
15:30 – 15:45	Primordial black hole formation during the QCD phase transition
Author Abstract	Christian Byrnes, University of Sussex Following the unexpected detection by LIGO of intermediate mass black hole mergers, there has been a large interest about whether these black holes are primordial and if they could constitute all of dark matter. In order to form primordial black holes, the primordial power spectrum needs to be boosted on small scales. In this talk I will show that the reduction in pressure during the QCD phase transition leads to a significant enhancement of primordial black hole formation with approximately one solar mass, an order of magnitude lighter than those detected by LIGO.
15:45 – 16:00	X-ray properties of radio loud Sy1 AGN 3C111 detailed case-study
Author Co-Authors Abstract	Elena Fedorova, Taras Shevchenko National University of Kiev, Astronomical Observatory B.I. Hnatyk, V.I. Zhdanov 3C 111 is a broad line radio galaxy with signatures of FSRQ and Seyfert type disk corona in X-ray spectrum. We use all X-ray data publicly accessible in INTEGRAL, XMM-Newton, SWIFT and Suzaku database to recover the contribution of thermal disk corona emission and nonthermal SSC quasar jet emission to the total X-ray spectrum of 3C 111. We show that the both components are varying with time independently. This causes also the variability of equivalent widths (EWs) of Fe-K emission lines. From obtained observational data set on EWs of Fe-K lines and total spectral fluxes of continuum emission at E=6.4 keV for different observational periods, we recover parameters of disk corona and jet spectra.
16:00 – 16:30	**Coffee Break**
16:30 – 16:45	Searching for continuous gravitational-waves from spinning neutron stars
Author Abstract	Alicia M Sintes, Universitat Illes Balears Spinning neutron stars are expected to be sources of continuous gravitational waves. Only a small fraction of the neutron stars, which are believed to exist in our Galaxy, is observed through electromagnetic emission. Detecting continuous gravitational waves from neutron stars, especially in parallel with with electromagnetic observations would provide a unique view on these fascinating objects. In this talk, I will introduce some source models and then review some search results, depending on the degree of accuracy with which neutron star

	parameters - position, rotational frequency and its derivative(s) - are known, from the first observing run of advanced LIGO. Finally, I'll conclude with thoughts on future research in the field.
16:45 – 17:00	Supermassive black holes and their environment in active galactic nuclei
Author Abstract	Marko Stalevski, Astronomical Observatory Belgrade Active galactic nuclei (AGN) are powered by matter spiralling into a supermassive black hole (SMBH) in a form of an accretion disk. In a widely accepted picture, this matter comes from an obscuring “dusty torus” which absorbs radiation from the accretion disk and re-emits it in the infrared. However, recent high angular resolution observations resolved for the first time the mid-infrared (MIR) structure of nearby AGN and surprisingly revealed that a major fraction of their MIR emission comes from the polar regions. One such object is archetypal AGN in the Circinus galaxy. We obtained new high quality MIR images of this AGN with the upgraded VISIR instrument at the Very Large Telescope. The detailed modeling we undertook showed that its peculiar morphology can be explained by a dusty wind in a form of a hollow cone driven by the radiation pressure. This newly emerging paradigm for the dust structure in AGN fits into our understanding of how SMBHs are affecting their immediate environment.
17:00 – 17:15	Testing General Relativity with X-Ray Reflection Spectroscopy
Author Co-Authors Abstract	Sourabh Nampalliwar, University of Tuebingen, Germany Cosimo Bambi, Kostas Kokkotas Astrophysical black holes are the ideal laboratory for testing gravity in the strong field regime. X-ray binaries are astrophysical systems with a black hole (or a neutron star) as one component of the binary. These black holes are described by the Kerr metric within general relativity. Since the X-ray radiation comes from the strong field region around the black hole, it can used to test the applicability of general relativity in the strong field regime. I will give an overview of a model developed to test the validity of Kerr metric in this context. I will also describe the latest analyses of real sources done with this model.
17:15 – 17:30	A novel inertial sensor for future gravitational wave detectors
Author Co-Authors Abstract	Joris van Heijningen, Nikhef Alessandro Bertolini, Johannes van den Brand To detect gravitational waves, precise measurement is required. The effect of each and every noise source within the detector must be accounted for and minimized to ensure the instruments are capable of detecting the weak GW signals. Better vibration sensing would allow more aggressive controls to be applied to the optics suspensions therefore improving their accuracy without injecting noise in the detector sensitive band. This aspect will be even more relevant for the next generation detectors as Einstein Telescope and Cosmic Explorer for which a lower

	frequency cut-off (<2Hz) for seismic noise has been envisaged. An active isolation platform can be combined with cascaded pendulums. The performance of (the last stage) of such active platform is mostly dependent on the performance of the inertial sensor providing error signals for the feedback loops. We present a novel inertial sensor designed and developed at Nikhef that features an interferometric readout for a horizontal monolithic accelerometer. It will be able to measure 3×10^{-15} m/√Hz displacement levels from 20 Hz onwards. Current results show (self) noise levels of 8×10^{-15} m/√Hz from 30 Hz onwards, which is an order of magnitude better than the world's most sensitive commercial sensors. In spite of these unprecedented results, the result is worse than the sum of modeled noise contributions. Several possible unmodeled noise sources and possible solutions have been identified.
17:30 – 17:45	Recoiling black holes in analytical and numerical galaxy potential
Author Co-Authors Abstract	Majda Smole, Astronomical Observatory, Belgrade Miroslav Micic During a black hole merger asymmetric emission of gravitational wave radiation can lead to black hole kick. Gravitational wave recoil can completely eject black hole from it's host if the kick velocity is larger than the escape velocity from the galaxy. We calculate trajectories of recoiling black holes in different models of merger remnant galaxies in order to investigate how central black hole mass and mass ratio of progenitor galaxies influence escape velocities of the recoiling black holes. In numerical models, black holes are ejected before the remnant galaxy could reach the virialized state, so the special attention is given to the differences between escape velocities from analytical and numerical merger remnants.
17:45 – 19:00	**Poster Session and Reception**

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Time	**Talks**
09:00 – 09:30	Motivation and overview of WG2
Author	Leor Barack, University of Southampton
09:30 – 10:00	Perturbation methods
Author Abstract	Barry Wardell, University College Dublin Exact models for gravitational waves from binary black holes can only be obtained by exactly solving the full Einstein field equations. However, there is an important regime in which a perturbative treatment yields a highly accurate approximation. For binary black hole systems in which one of the black holes is much less massive than the other, one may treat the mass ratio as a small perturbation parameter.

	Then, the Einstein equations are amenable to a perturbative expansion in powers of this parameter. Such an expansion is particularly suitable for Extreme Mass Ratio Inspirals (EMRIs), binary black hole systems where the ratio of the black hole masses is very small. In this talk I will review recent progress and future challenges to the application of perturbation methods to study black holes as sources of gravitational waves.
10:00 – 10:30	Post-Newtonian and post-Minkowskian approximations
Author Abstract	Alexandre Le Tiec, Observatoire de Paris The post-Newtonian (PN) formalism is an approximation method in general relativity that is well suited to describe the orbital motion and the gravitational-wave (GW) emission from binary systems of compact objects, in a regime where the orbital velocity is small compared to the speed of light and the gravitational fields are weak. This approximation method has played a key role in the recent detections, by the LIGO and Virgo observatories, of GWs generated by inspiralling and merging black-hole and neutron-star binaries, by providing accurate template waveforms to search for those signals and to interpret them. We will give an overview of the application of the PN approximation to binary systems of compact objects, focusing on recent developments and future prospects.
10:30 – 11:00	**Coffee Break**
11:00 – 11:30	Numerical Relativity in astrophysics
Author Abstract	Patricia Schmidt, Radboud University The past two years have seen the first detections of gravitational waves from astrophysical black holes as well as from a binary neutron star by Advanced LIGO and Advanced Virgo. Numerical relativity simulations of merging black holes played a crucial role in their discoveries. In this talk, I will first review the current status of numerical simulations of binary black holes, their usage in the detection of gravitational waves and the determination of the characteristics of the binary source before highlighting some of the outstanding challenges.
11:30 – 12:00	Numerical Relativity in fundamental physics
Author Abstract	Ulrich Sperhake, CAMB Gravity plays a central role in the most important outstanding problems in contemporary physics, ranging from the enigmatic nature of dark matter and energy to the seeming irreconcilability of general relativity with quantum theory. In this talk we provide an overview of the applications of numerical relativity to numerous physical systems studied in the ongoing quest for answers to these profound questions. Specifically, we summarize how black holes and their emission of

	gravitational waves serve as particle laboratories in outer space, how compact objects composed of fundamental fields may act as sources of gravitational waves, how we can search for signatures of modified gravity in gravitational-wave astronomy and discuss observable consequences of spatial extra dimensions. We will focus therein on the role of using numerical methods on supercomputers and highlight open challenges facing the community.
12:00 – 12:30	Discussion
12:30 – 12:35	Conference Photo
12:35 – 14:00	**Lunch**
14:00 – 14:15	A new algorithm for characteristic extraction and matching in numerical relativity
Author Co-Authors Abstract	Nigel Bishop, Rhodes University, South Africa Denis Pollney, Chris Stevens An important aspect of a simulation in numerical relativity is the extraction of gravitational waves, which is non-trivial since the simulation is normally on a physical domain of finite extent but gravitational waves are unambiguously defined only at future null infinity (scri+). While there are a number of methods for waveform estimation, only in characteristic extraction is the waveform calculated at scri+. We present a new algorithm and code for characteristic extraction. The code has the option to include characteristic matching, in which the characteristic evolution provides outer boundary data for the "3+1" simulation. The key motivation for this is a speed-up in the time required for a numerical simulation. Provisional results on code performance are presented.
14:15 – 14:30	Gravitational waves from eccentric binary black-hole coalescence
Author Co-Authors Abstract	Maria Haney, University of Zurich Achamveedu Gopakumar, Sascha Husa We will present recent work on the development of eccentric waveform models in the time and frequency domain, discuss preliminary gravitational-wave data analysis implications and highlight significant challenges for a complete and accurate model of eccentric binary black-hole coalescence.
14:30 – 14:45	Fourier domain gravitational waveforms for precessing eccentric binaries
Author Co-Authors Abstract	Yannick Boetzel, University of Zurich Antoine Klein We build waveforms for precessing binaries on eccentric orbits in the Fourier domain. To achieve this, we use a small eccentricity expansion of the waveform amplitudes in order to separate the periastron precession timescale from the orbital one, and use a SUA transformation to compute the Fourier transform. We show that the resulting waveform can yield a median faithfulness above 0.998 when compared

	to an equivalent time domain waveform with an initial eccentricity of e 0 ≈ 0.3. We also show that when spins are large, using a circular waveform can potentially lead to significant biases in the recovery of the parameters, even when the system has fully circularized. This is an effect of the residual eccentricity present when the objects forming the binary have non-vanishing spin components in the orbital plane.
14:45 – 15:00	Radiation Reaction for Binary Systems of Compact Bodies Spin Effects
Author	Natalia Tenorio Maia, University of Pittsburgh
Co-Authors	Adam K. Leibovich, Rafael A. Porto
Abstract	Coalescing binary systems of compact bodies (black holes or neutron stars) are currently the most important sources of gravitational waves which can be detected by laser interferometric observatories such as LIGO and Virgo. During the inspiral stage, the dynamics of binary systems can be described analytically using the Post-Newtonian (PN) approximation, which takes the relative velocity of the bodies as the expansion parameter of the theory. Higher order terms in the PN expansion are required for accuracy, since at the late stages of the inspiral the velocity gets high. In this talk I will present our results for the leading spin contributions to the radiation-reaction and spin evolution for binary systems of compact bodies. The calculation is carried out, from first principles, using the effective field theory framework for spinning compact objects. A non-trivial consistency check is performed on our results by showing that the energy loss induced by the resulting radiation-reaction force is equivalent to the total emitted power in the far zone, up to so-called "Schott terms". To compute spin-orbit effects in radiation reaction, which enters at 4PN order, we use two different supplementary conditions - Newton-Wigner and covariant condition - to enforce the reliability of our results. For spin1-spin2 and spin-spin contribution to radiation reaction, which enter at 4.5PN order, no spin supplementary conditions are needed. We find that at 4PN order radiation reaction does no affect the spin evolution of the compact bodies in a binary system, while at 4.5PN order radiation reaction makes the spins precess.
15:00 – 15:15	Secular dynamics of precessing compact binaries
Author	Zoltán Keresztes, University of Szeged
Co-Authors	Márton Tápai, László Árpád Gergely
Abstract	Since all gravitational waves detected to date originated from coalescing compact binary systems, the accurate description of their evolutions is both timely and important. The inspiral regime of the evolution is characterized by three timescales. The radial timescale, where the object with reduced mass spends a full radial period about the central total mass, is the shortest. A second timescale occurs when the spins and the orbital angular momentum are not parallel with each other. Then the spin and orbital angular momentum vectors undergo a precession-like motion. This determines the precession timescale which is much longer than the orbital period.

	The third is the timescale where the backreaction of the gravitational radiation becomes significant. We investigate the dynamics on the precession timescale, where the averaging over one radial period of the evolution equations can be applied and simplifies significantly the description of the dynamics. The derived conservative secular evolution equations are of second post-Newtonian order accuracy, containing the leading-order spin-orbit, spin-spin and mass quadrupole-monopole interactions. The variables in the system of first order differential equations are the polar and azimuthal angles of the spin and orbital angular momentum vectors together with the periastron angle. In contrast with the instantaneous dynamics, the secular dynamics is autonomous. The system reliably describes the dynamics over timescales starting from a few times the radial period to several precessional periods, but less than the radiation reaction timescale. These analytic equations are applied to study the spin flip-flop effect, found by numerical relativity methods. The system turns extremely useful in the mapping the parameter space for the occurrence of the spin flip-flop effect.
15:15 – 15:30	Tidal deformations in coalescing compact binary systems
Author Co-Authors Abstract	Tiziano Abdelsalhin, Sapienza University of Rome Paolo Pani, Leonardo Gualtieri Tidal effects play a fundamental role in coalescing compact binary systems. They can affect significantly the emitted gravitational waveform during the last cycles of the inspiral phase. Tidal interactions can be effectively used in fundamental physics, testing the real nature of black holes against other exotic compact objects. Furthermore, they can shed new light on the neutron star internal composition, constraining the equation of state. I will discuss how current models describing tidal interactions in compact binary systems can be improved, including higher-order multipolar tidal deformations, both in the electric and magnetic sectors, and taking into account the coupling between the tidal field and the rotation of the compact object. This will lead to more accurate templates for the gravitational waveforms.
15:30 – 15:45	Zoom whirl orbits of spinning bodies in rotating spacetimes
Author Co-Authors Abstract	Balázs Mikóczi, HAS Wigner RCP, Hungary Zoltán Keresztes The Mathisson-Papapetrou-Dixon (MPD) equations governing the motion of spinning bodies will be reviewed. In order to close the system of MPD-equations it is necessary to choose a spin supplementary condition (SSC). The dynamics of spinning compact binaries with leading order spin-orbit coupling will be presented in different SSCs. Hereafter the most expedient Tulczyjew-Dixon SSC will be applied for numerical investigation of spinning bodies. The zoom-whirl orbits in rotating spacetimes such as in the Kerr and in different regular black hole (e.g. Bardeen and Hayward black holes) spacetimes will be analyzed. In addition these kind of orbits

	will also be presented in the case of a rotating spacetime emerged in a vector-tensor gravity model.
15:45 – 16:00	Gravitational Waves from Oscillaton Star Collisions
Author Co-Authors Abstract	Thomas Helfer, King's College London Eugene Lim, Mustafa Amin and Marcos Garcia I will talk about the GW signatures from the collisions of Oscillatons -- which are long-lived non-topological solutions of massive scalar fields. I will describe the technical challenges and present the GW wave forms of such collisions calculated using the numerical relativity code GRCHOMBO. I will show that for black hole end states, the total gravitational waves energy released in such collisions is more than that of BH-BH collisions of equal masses by a significant amount.
16:00 – 16:30	**Coffee Break**
16:30 – 16:45	Gravitational-wave spin memory effect for compact binaries
Author Abstract	David A. Nichols, Radboud University The gravitational-wave memory effect and the more recently discovered spin memory effect are predictions of general relativity that can be caused by nonlinearities in Einstein's equations in asymptotically flat spacetimes. The effects are characterized by constant changes in the strain and in the time integral of the strain's magnetic-parity part, respectively, before and after a burst of gravitational waves passes a detector. These constant changes are produced by astrophysical objects that radiate energy and angular momentum asymmetrically with high luminosities. Observing these effects would not only confirm this feature of general relativity, but it would give insight into the symmetry group of asymptotically flat spacetimes, which has recently been revisited. In this talk, I plan to introduce these effects, estimate their amplitude for binary-black hole mergers, and discuss strategies that ground-based gravitational-wave detectors can use to observe these memory effects.
16:45 – 17:00	Gravitational multipole moments from Noether charges
Author Co-Authors Abstract	Roberto Oliveri, Universite Libre de Bruxelles (ULB) Geoffrey Compère, Ali Seraj In this talk, we will define the multipole moments of the gravitational field (in an arbitrary theory of gravity) in terms of canonical Noether charges associated with specific residual transformations in canonical harmonic gauge, which we call multipole symmetries. This new definition exactly matches Thorne's mass and current multipole moments in Einstein gravity, which are defined in terms of metric components. For radiative configurations, the total multipole charges – including the contributions from the source and the radiation – are given by surface charges at

	spatial infinity, while the source multipole moments are naturally identified by surface integrals in the near-zone. The conservation of total multipole charges is used to derive the variation of source multipole moments in terms of the radiative multipole fluxes. The talk is mainly based on arXiv1711.08806 [hep-th], in collaboration with G. Compère and A. Seraj.
17:00 – 17:15	Analytic waveforms of EMRIs for nearly extremal supermassive black holes
Author Co-Authors Abstract	Geoffrey Compere, ULB Jiang Long, Thomas Hertog and Kwinten Fransen I will present analytic time domain gravitational waveforms produced from equatorial, corotating, non-spinning compact objects plunging into a nearly maximally spinning supermassive Kerr black hole. These analytic results are made possible thanks to enhanced conformal symmetry in the near-horizon region. The resulting waveforms display special features that I will detail a polynomial ringdown phase due to quasinormal mode stacking, followed by exponential quasinormal ringing. Also, a new type of critical behavior is found at a minimal orbital angular momentum, which leads to amplitude enhancement. I will finally show that such signals lie within the observability range of LISA.
17:15 – 17:30	Gravitational waves from domain walls moving in media
Author Co-Authors Abstract	Dmitry Gal'tsov Pavel Spirin, Elena Melkumova In anticipation of experimental study of the relic gravitational waves (GW) we revisit generation of gravitons by domain walls (DW) in the early universe. The standard mechanism appeals to graviton production from collapsing DWs due to their intrinsic instability within the models with biased potentials. The spectral properties of such GW are well understood now. We show that in any model of DWs there is an additional mechanism of gravitational radiation similar to bremsstrahlung, which might produce gravitons in the spectral segment damped in the spectra from collapsing walls. It consists in the following. DWs moving in media are subject to the friction force due to the scattered particles. However certain particles are not reflected by the walls, but perforate them. Due to this the walls get excited in the from of the branon waves, while the particles experiences an acceleration jump in the moment of perforation. This gives rise to gravitational radiation which we call ``piercing gravitational radiation'' (PGR). Though it is of higher order in the gravitational constant than the (mostly) quadrupole radiation from the collapsing DWs, its amplitude is enhanced in the case of the relativistic particles or photons due to absence of the velocity factor present in the quadrupole formula. We derive the spectral-angular distribution of PGR within the simplified model of the particle-wall collision treating their gravitational interaction perturbatively in the Minkowski space-time. In this problem the wave zone can not be defined in a usual way, so we

	present the derivation of the spectral-angular distribution formula without recurring to the wave zone. Using it, we discuss various properties of PGR caused by non-relativistic, relativistic or massless particls in arbitrary space-time dimensions, so our results are applicable both to cosmological DWs and to braneworld models. We present estmates of the relic GW produced in the early universe via this novel mechanism and discuss persectives of their experimental detection by LISA.
19:30 –	Optional Dinner: Haywharf Restaurant, Xatt it-Tiben, Floriana Price: EUR32 per person (to be paid at the registration desk)

Wednesday 24 January 2018	
Time	**Talks**
09:00 – 09:30	Motivation and overview of WG3
Author	Thomas Sotiriou, School of Mathematical Sciences & School of Physics and Astronomy University of Nottingham
09:30 – 10:00	Testing the Kerr hypothesis
Author Abstract	Carlos Herdeiro, University of Aveiro The Kerr hypothesis is that astrophysical black hole candidates are well described by the Kerr metric. Theoretically, this hypothesis is based on the uniqueness theorems for electro-vacuum. But in the presence of other types of matter or modified gravity are there any viable alternatives? In this talk I will illustrate obstructions to the existence of non-Kerr black holes, known as no-hair theorems, but also provide some examples of black holes with hair and horizonless compact objects, commenting on their phenomenological viability. I will also briefly mention non-Kerr parameterisations as a more agnostic path.
10:00 – 10:30	Black holes beyond General Relativity
Author Abstract	Enrico Barausse, IAP/CNRS I will review the reasons and motivations to study black-hole solutions in theories that extend General Relativity, and highlight present and future experimental tests constraining them. I will also explore some conceptual issues that one may encounter when deriving these solutions, and which typically have to do with their causal structure.
10:30 – 11:00	**Coffee Break**
11:00 – 11:30	Black hole perturbation theory and fundamental physics

Author	Paolo Pani, Sapienza University of Rome
Abstract	GW astronomy has opened a new era in physics, giving access to the hitherto unexplored strong-gravity regime. In parallel to their countless astrophysical applications, present and future GW observations also allows us for unprecedented tests of gravity, of the nature of compact objects, and of fundamental physics at large. I will present two aspects of this broad and interdisciplinary program: 1) Signatures of new physics in the binary coalescence, including late-inspiral post-Newtonian corrections and post-merger ringdown tests of black holes and exotic compact objects; and 2) onstraints on ultralight bosons from black-hole superradiant instabilities, and their relevance for dark-matter searches.
11:30 – 12:00	Binary compact objects in alternative theories of gravity
Author	Carlos Palenzuela, Universitat de les Illes Balears (UIB)
Abstract	The merger of binary black holes and/or neutron stars might serve to test the highly dynamical and strongly non-linear gravity regime, which can only be modeled by using numerical simulations. In this talk I will overview recent numerical studies of compact binary mergers by considering plausible alternative gravity theories. I will also discuss the techniques to generically construct a well-posed evolution system for these theories.
12:00 – 12:30	Discussion
12:30 – 14:00	**Lunch**
14:00 – 14:15	Gravitational wave signatures from string theory?
Author	Bert Vercnocke, KU Leuven
Co-Authors	Thomas Hertog, Frederik Goelen
Abstract	Advances in quantum theories of gravity in the last decade suggest that black holes could receive quantum corrections that can alter the near-horizon region, changing the predictions of General Relativity. In this talk, I will discuss possible signals from black hole alternatives known as "fuzzballs", that appear in the well-developed quantum gravity formalism of string theory, and how they might or might not lead to smoking-gun signals such as gravitational wave "echoes".
14:15 – 14:30	To be a black hole, or not to be a black hole
Author	Andrea Maselli, Instituto Superior Tecnico (IST)
Co-Authors Abstract	Exotic compact objects (ECO), with microscopic corrections at the horizon scale, may form in Nature as binary sources, and mimic the coalescence of ordinary black holes. In this talk we discuss the signatures which may be used, together with gravitational wave observations, to distinguish between such exotic states of matter. We investigate two possible smoking gun effects, namely the ECO's tidal deformation,

	and the absence of absorption at the horizon. We assess the ability of present and future interferometers to detect the ECO's Love numbers and tidal heating, and their constraints. For space observatories, like LISA, we demonstrate how these effects can be used to bound the compactness of the exotic object down to the Planck scale.
14:30 – 14:45	Charged Boson Stars and Black Holes in Horndeski Gravity
Author Abstract	Yosef Verbin, The Open University of Israel Y. Brihaye We find new spherically symmetric charged boson star solutions of a complex scalar field coupled non-minimally to gravity by a ''John-type'' term of Horndeski theory, that is a coupling between the kinetic scalar term and Einstein tensor. We study the parameter space of the solutions and find two distinct families according to their position in parameter space. More widespread is the family of solutions (which we call branch 1) existing for a finite interval of the central value of the scalar field starting from zero and ending at some finite maximal value. This branch contains as a special case the charged boson stars of the minimally coupled theory. In some regions of parameter space we find a new second branch (''branch 2'') of solutions which are more massive and more stable than those of branch 1. This second branch exists also in a finite interval of the central value of the scalar field, but its end points (either both or in some cases only one) are extremal Reissner-Nordstrom black hole solutions.
14:45 – 15:00	Exotic compact objects and how to quench their ergoregion instability
Author Co-Authors Abstract	Elisa Maggio, University of Sheffield Gravitational-wave astronomy can give us access to the structure of black holes, potentially probing microscopic or even Planckian corrections at the horizon scale, as those predicted by some quantum-gravity models of exotic compact objects. In this talk I will present a model consisting of a Kerr geometry with a reflective surface near the horizon under scalar field perturbations. Such compact objects are prone to the so-called ergoregion instability when they spin sufficiently fast. I will show that the instability depends on the spin, on the compactness, and on the reflectivity coefficient at the surface. An interesting property of exotic compact objects with a perfectly reflecting surface is that the instability time scale increases when the compactness of the object is extremely close to the black hole limit. However, this increase is not enough to prevent the instability from occurring on dynamical time scales. On the other hand, I will show that an absorption rate at the surface as small as 0.4% (reflectivity coefficient as large as R^2=0.996) is sufficient to quench the instability completely. This level of absorption might be provided by the viscosity of the body and can be naturally achieved in exotic compact objects. This finding has important consequences for the viability of exotic compact objects and it suggests

	that they are not necessarily ruled out by the ergoregion instability. Finally I will show how this model can serve as a foundation for the analysis of electromagnetic and gravitational perturbations. Reference for the talk Phys. Rev. D 96, 104047 (2017)
15:00 – 15:15	How well can ultracompact bodies imitate black hole ringdowns?
Author Abstract	Kostas Glampedakis, University of Murcia George Pappas In this talk we examine to what extent the early ringdown signal of Kerr black holes can be imitated by rotating ultracompact (and horizonless) objects. The frequency and damping rate of the early ringdown are closely related to the properties of the unstable geodesic photon ring. Adopting a slow-rotation approximation we derive general expressions for these two parameters as a function of the object's multipole moments. We apply our formalism to the case of a thin shell gravastar and for a wide range of compactnesses we find a few percent deviation from the ringdown of a Kerr black. We discuss the implications of our results for the forthcoming LIGO GW searches.
15:15 – 15:30	New Gauss-Bonnet black holes with curvature induced scalarization in the extended scalar-tensor theories
Author Co-Authors Abstract	Stoytcho Yazadjiev, Sofia University Daniela Doneva In this talk we consider a class of extended scalar-tensor-Gauss-Bonnet (ESTGB) theories for which the scalar degree of freedom is excited only in the extreme curvature regime. We show that in the mentioned class of ESTGB theories there exist new black hole solutions which are formed by spontaneous scalarization of the Schwarzaschild balck holes in the extreme curvature regime. In this regime, below certain mass, the Schwarzschild solution becomes unstable and new branch of solutions with nontrivial scalar field bifurcate from the Schwarzschild one. As a matter of fact, more than one branches with nontrivial scalar field can bifurcate at different masses but only the first one is supposed to be stable. This effect is quite similar to the spontaneous scalarization of neutron stars. In contrast with the standard spontaneous scalarization of neutron stars which is induced by the presence of matter, in our case the scalarization is induced by the curvature of the spacetime.
15:30 – 15:45	Spontaneous scalarization of black holes in Gauss-Bonnet gravity
Author Co-Authors Abstract	Leonardo Gualtieri I will discuss under which conditions Gauss-Bonnet gravity - a class of scalar-tensor theories which modify the strong-field regime of general relativity - can exhibit the phenomenon of spontaneous scalarization of black holes. I will also discuss the

	instability mechanism associated to the scalarization, and the prospects of detectability of this phenomenon by gravitational wave interferometers.
15:45 – 16:00	
Author Abstract	**Coffee Break**
16:00 – 16:30	Spontaneous scalarization with an extremely massive field and heavy neutron stars
	Teruaki Suyama, Research Center for the Early Universe, University of Tokyo Soichiro Morisaki We investigate the internal structure and the mass-radius relation of neutron stars in a scalar-tensor theory in which a massive scalar field undergoes spontaneous scalarization inside neutron stars. We focus on the case where the Compton wavelength is shorter than the size of the neutron stars, which has not been investigated in the literature. By solving the modified Einstein equations, either purely numerically or by partially using a semianalytic method, we find that not only the weakening of gravity by spontaneous scalarization but also the scalar force affect the internal structure significantly in the massive case. We also find that the maximum mass of neutron stars is larger for certain parameter sets than that in general relativity and reaches 2 solar mass even if the effect of strange hadrons is taken into account. There is even a range of parameters where the maximum mass of neutron stars largely exceeds the threshold that violates the causality bound in general relativity.
16:30 – 16:45	Compact stars in massive scalar-tensor theories - models and gravitational wave emission
Author Co-Authors Abstract	Daniela Doneva, University of Tuebingen Soytcho Yazadjiev, Kostas Kokkotas In this talk, we will present our latest results on compact star models in massive scalar-tensor theories. An important property of this class of alternative theories of gravity is that the inclusion of scalar field mass leads to big deviations from pure general relativity in comparison with the massless case. The models we consider cover the rapidly rotating regime as well where the differences with pure Einstein's theory are even larger. We will also present our results on neutron star oscillations of rapidly rotating compact stars in these theories and the related gravitational wave emission with a special emphasis on the rotational instabilities.
16:45 – 17:00	Scalar field coupling with matter inside scalarized neutron stars
Author Co-Authors Abstract	Nicola Franchini, University of Nottingham In scalar-tensor theories, spontaneous scalarization is a phase transition that can occur in ultradense environments such as neutron stars. The scalar field develops a non-trivial configuration once the star exceeds a compactness threshold. If the

	scalar exhibits some additional coupling to matter, it could give rise to significantly different microphysics in these environments. In this presentation, I will show a toy model in which the photon is given a large mass when spontaneous scalarization occurs. These results demonstrate clearly the effectiveness of spontaneous scalarization as a Higgs-like mechanism in neutron stars.
17:00 – 17:15	Spontaneous growth of tensor fields in strong gravity
Author Abstract	Fethi M Ramazanoğlu, Koç University Any alternative theory of gravitation has to closely imitate general relativity in the weak-filed regime to satisfy known experimental bounds. However, large deviations are desirable in strong fields since the limited precision of gravitational wave parameter estimation makes small deviations hard to uncover. Spontaneous scalarization phenomena in scalar-tensor theories satisfies both these criteria. The scalar field vacuum becomes unstable in the presence of neutron stars in this theory, and the instability grows to large values near the star, providing a relatively easy target for gravitational wave science. I will explain the mechanisms causing this behavior, and how it can be replicated for fields beyond scalars. I will also discuss black hole-neutron star merger scenarios that can be used to explore such theories.
17:15 – 17:30	Penrose-like process in shift-symmetric Horndeski theories
Author Abstract	Mehdi Saravani, University of Nottingham R. Benkel, N. Franchini, T. P. Sotiriou Non-canonical kinetic terms in the Horndeski action allow for perturbations of the scalar field to propagate superluminally. Consequently, scalar perturbations are not necessarily trapped by the metric horizon of a black hole. As demonstrated in the context of Lorentz violating theories of gravity, superluminally propagating species give rise to a structure of nested horizons and an ergoregion where the existence of particles carrying negative Killing energy is allowed. This bears similarity to the Penrose process where the existence of the ergoregion allows for extraction of energy. However, the origin of the ergoregion is different, and the process can be imagined to take place even in stationary, spherically symmetric spacetimes. I discuss the possibility of this process and its implications for black holes in shift-symmetric Horndeski theories.
17:30 – 17:45	Black Hole Stability in Horndeski Gravity
Author Co-Authors Abstract	Apratim Ganguly, Rhodes University Radouane Gannouji In this talk, I will report the stability under linear odd-parity perturbations of static spherically symmetric black holes in Horndeski gravity.

Thursday 25 January 2018

09:00 – 10:00	Core Group Meeting
10:00 – 12:00	MC Meeting

Updated on 15/01/2018

Funded by the Horizon 2020 Framework Programme
of the European Union