Summary of the workshop: classical general relativity and gravitational waves

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Abstract. In the workshop, classical general relativity and gravitational waves at ICGC-2007, eleven lectures were presented on classical general relativity and nine on gravitational waves. Lectures covered diverse topics in these areas during the three days of parallel sessions. We classify and summarize here the research work and results of the oral presentations made.

1. Classical General Relativity
The classic paper by Oppenheimer and Snyder (1939) analyzes the gravitational collapse of a spherically symmetric massive object to conclude that the collapse of a homogeneous dust cloud would result into a black hole in the spacetime. Such a black hole is characterized by the presence of an event horizon, and the spacetime singularity at the center, which is covered by the horizon. This scenario provides the basic motivation for the black hole physics, and the cosmic censorship conjecture, which states that even when the assumptions contained in the above case are relaxed, in the form of either perturbations in the symmetry or form of matter etc., the outcome would still be a black hole in generic situations. As no proof, or a rigorous mathematical formulation of the censorship hypothesis has been available so far, the course of action that has emerged in past decade or so has been to carry out a detailed investigation of different gravitational collapse scenarios in general relativity to understand the final fate of collapse.

S. Deshingkar presented his work on singularities which arise in gravitational collapse of general matter fields. Assuming weak energy condition he showed that no energy can reach an outside observer from a null naked singularity proposing an astrophysical cosmic censorship.

U. Debnath presented his work on gravitational collapse of null fluid with various equation of states. An interesting result showing that the the final state of collapse is independent of the choice of equation of states namely, barotropic, generalized Chaplygin, modified Chaplygin, polytropic, in higher dimensional spacetime, was claimed.

A proposal for a time dependent geometry inside a black hole with a stress tensor on the r.h.s. of Einsteins equations corresponding to an anisotropic fluid was made by H. Culetu. This model leads to a time dependent cosmological constant.
The work on equations of motion with no singularities was presented by S. Otarod. He showed that the equation of motion introduced by Narlikar for classical Cosmology have non singular solutions. Based on his nonsingular solutions he derived the physical parameters and discussed the results.

Isolated horizons were introduced for understanding problems related to black holes. Isolated horizons have advantage over even horizon as they can be characterized locally. The Isolated horizon boundary conditions have been relaxed supposedly to their weakest form. The horizons satisfying these weak conditions are called as the Weak Isolated Horizons. A. Chatterjee demonstrated that both zeroth and the first law of black hole mechanics (both for rotating and non-rotating) can still emerge, thus making the formulation more amenable for applications in both analytic and numerical Relativity. As an additional gain they were shown to explicitly bring the non-extremal and extremal black holes at the same footing.

The work on the correspondence between the diffeomorphism and gauge invariance in different, generally covariant, models was discussed by Anirbaran Saha, which include relativistic membrane, generic p-brane and second order metric gravity using a general Hamiltonian methodology. Further, he showed that exact mappings between the re-parametrization parameters and the gauge parameters can been worked out which make the underlying unity of the gauge and diffeomorphism invariances of the theories explicit.

The Bianchi Type V Magnetized String Dust Bulk Viscous Fluid Cosmological Model with Variable Magnetic Permeability was the subject of the talk by Raj Bali. He discussed the behavior of the model in presence and absence of magnetic field and bulk viscosity. The other physical aspects of the models and singularities in these models are also discussed.

Aseem Paranjape spoke on covariant approach to spatial averaging in cosmology. They have applied the formalism of Zalaletdinovs Macroscopic Gravity (MG), which is a fully covariant and nonperturbative averaging scheme, in an attempt to construct gauge independent corrections to the standard Friedmann-Lemaître- Robertson-Walker (FLRW) equations. He pointed out that whereas one cannot escape the problem of dependence on one choice of time slicing which is inherent in the assumption of large scale homogeneity and isotropy it is however possible to construct spacetime scalar corrections to the standard FLRW equations. This partially removes the criticism concerning the corrections being gauge artifacts.

Ishwaree P. Neupane reported his work on physical constraints on Gauss-Bonnet gravity. In his talk, he offered an interesting discussion on how to test any such models against cosmological and astrophysical observations, including the classical tests of General Relativity.

Amrey Gareth presented his work on global isometric and analytic embeddings of pseudo-Riemannian spacetimes into higher dimensional pseudo-Riemannian spaces. He motivated his wok using recent developments in higher dimensional theories in high-energy physics and cosmology. He showed that recent claims for existence proofs pertinent to this problem are deficient.

Sunil Maharaj presented his work on new classes of exact solutions to the Einstein-Maxwell system of equations for a charged sphere with a particular choice of the electric field intensity and one of the gravitational potentials. The condition of pressure isotropy in these models was reduced to a linear, second order differential equation which could be solved in general. Consequently, exact solutions to the Einstein-Maxwell field equations corresponding to a static spherically symmetric gravitational potential could be written in terms of hypergeometric functions.

2. Gravitational Waves
Bala Iyer gave a brief review on doing precision cosmology using Laser Interferometer Space Antenna (LISA). LISA is a proposed space-based gravitational wave (GW) interferometer dedicated to low frequency GWs in the frequency range $10^5$–1 Hz. Due to its orbital motion
around solar system barycentre, the signals that LISA observes gets modulated and these modulations encode the information about the source position and orientation. For binary black hole (BBH) inspirals, which are among the most promising sources for LISA, template based search strategies will be employed using post-Newtonian waveforms. They made a comparison of the angular resolution of LISA if one employs the usual restricted waveforms as templates, with that of the amplitude corrected PN waveforms which have additional harmonics other than the dominant one at twice the orbital frequency. What is found is that angular resolution of LISA, especially or BBHs of $10^7$ solar mass will be significantly improved by employing the amplitude corrected PN waveforms. He further showed that in a subset of the source parameter space the angular resolution increases by more than a factor of 10, thereby making it possible for LISA to identify the host galaxy/galaxy cluster. This increase has interesting implications for doing high precision cosmology with LISA. In particular we examine the possibility of measuring the dark energy equation of state of the universe by the LISA measurements of BBH inspirals. The bounds on the equation of state are comparable with those of other, dedicated dark energy missions. We emphasize the importance of improved low-frequency sensitivity of LISA in doing cosmology.

Sucheta Koshti presented her work on the analysis of stable flight formation of LISA, which is arguably the most ambitious space mission till date. The three spacecraft of LISA are on heliocentric and weakly eccentric orbits forming a nearly stable triangular configuration. Laser light running between these spacecrafts over 5 million km. armlengths would act as a large scale interferometer. One the most important technical challenges for LISA are to maintain a stable configuration and then invoke time delay interferometry to cancel laser noise. We explicitly solve for the spacecraft orbits, and demonstrate that the arms keep constant distances to the first order in eccentricities when the plane of the orbit is maintained at a tilt of 60 deg. to the ecliptic plane. However, exact orbitography exhibits the so-called breathing modes resulting in slow variations of the arm-lengths of 110,000 km. during each 1-year orbit. Analysing the breathing modes (flexing of the arms) with the help of the geodesic deviation equation up to the octupole order, which is shown to be equivalent to higher order Clohessy- Wiltshire equations, she showed that the flexing of the arms can be reduced to a peak-to-peak variation of about 50 000 km, and the corresponding peak-to-peak variation in the Doppler laser frequency shift to about 8 m/s. The minimization is achieved by slightly tuning the tilt by 0.6 degree more than the 60 degrees configuration obtained at the first order. The significance of these results for LISA were discussed.

Rajesh Nayak presented his work on the tomographic approach to resolve the distribution of LISA Galactic binaries. The space based gravitational wave detector LISA is expected to observe a large population of Galactic white dwarf binaries whose collective signal is likely to dominate instrumental noise at observational frequencies in the range $10^{-4}$ to $10^{-3}$ Hz. The motion of LISA modulates the signal of each binary in both frequency and amplitude, the exact modulation depending on the source direction and frequency. Starting with the observed response of one LISA interferometer and assuming only doppler modulation due to the orbital motion of LISA, he showed how the distribution of the entire binary population in frequency and sky position can be reconstructed using a tomographic approach. The method is linear and the reconstruction of a delta function distribution, corresponding to an isolated binary, yields a point spread function. An arbitrary distribution and its reconstruction are related via smoothing with this point spread function.

In the area of ground based experiments related to search of gravitational waves K. G. Arun reported on the search for gravitational wave (GW) bursts using the data from the seventh commissioning run (C7) of Virgo. The search focussed on unmodelled GW bursts in the frequency range 150 Hz–2 kHz. Though no gravitational wave signal was detected, the sensitivity of the analysis in terms of root sum square amplitude can be translated into a frequentist upper
limit on the event rate of detectable GW events of 1.1 events per day at 90% confidence level. Using numerical relativity waveforms as models of binary black hole mergers, they showed that such a search was capable of detecting a merger of a binary black hole in the mass range 60-100 $M_\odot$ within a distance of 2-2.9 Mpc at 50% efficiency.

Anand Sengupta reported on the search for gravitational waves from coalescing compact binary systems generated during the inspiral phase of their evolution, in the third (S3) and fourth (S4) LIGO science runs. The following types of binary systems were considered ordered by component mass: primordial black hole binaries (between 0.35 and 1 $M_\odot$), binary neutron stars (between 1 and 3 $M_\odot$) and binary blackholes (between 3 and 40(S3), 80(S4) $M_\odot$). He also gave an overview of the current compact binary searches in progress on the first calendar year of the fifth (S5) LIGO science run. Improvements made in the pipeline and data quality since the previous runs were highlighted, and a brief report on the status of the searches was also given.

Himan Mukhopadhyay presented a comparison between two strategies of multi-detector detection of compact binary inspiral signals, namely, the coincidence and the coherent plotting the Receiver Operating Characteristics (ROC) for the two strategies. The three cases considered were: a) two detectors having same orientation and location with uncorrelated noise, b) two detectors having same orientation and location with correlated noise and c) two arbitrarily oriented geographically separated detectors with uncorrelated noise. The bottom line is that the coherent strategy although more computationally expensive in general than the coincidence strategy, is superior to the coincidence strategy - considerably less false dismissal probability for the same false alarm probability in the viable false alarm regime.

The universe is expected to have a stochastic gravitational wave background (SGWB) generated by unmodeled / unresolved astrophysical and cosmological sources. SGWB is dominated by the nearby universe, hence it is anisotropic. A gravitational wave (GW) radiometer algorithm is well suited for probing SGWB. Sanjit Mitra presented a general Maximum Likelihood (ML) based analysis to probe SGWB anisotropy in any given basis using a network of detectors. The special cases of pixel basis and spherical harmonic basis are currently being implemented to analyze data from the LIGO-Virgo detectors. Map-making strategies in the pixel basis and primary developments in the spherical harmonic basis were summarized in the presentation.

A scheme for extracting the gravitational radiation from a null code using the Bondi News function was presented by Shrirang Deshingkar. In this scheme, based on direct transformation to Bondi coordinates, the news is extracted in Bondi coordinates. The test cases for which scheme was implemented, the new news module was shown to give very accurate results.