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Workshop I – Black holes and compact objects: Classical aspects

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Abstract. This is a summary of the papers presented in session W1 on the papers submitted to the workshop I on the classical aspects of black holes and compact objects were classified into three categories: (i) theoretical aspects; (ii) astrophysical aspects; (iii) gravitational radiation. The three sessions were devoted each to one of the above categories. The chairmen of the workshop were J Bičák, Charles University, Prague (Czech Republic) and C V Vishveshwara, Indian Institute of Astrophysics, India.

List of contributions to Workshop I

1. *Theoretical aspects*

   (a) No scalar hair theorem for charged black holes in scalar tensor theories, by Somasri Sen

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   (b) Geometry of the Kerr black hole in the Einstein cosmological background by K Rajesh Nayak and C V Vishveshwara

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   (c) Black holes in non-flat backgrounds: The Schwarzschild black hole in the Einstein universe by K Rajesh Nayak, C V Vishveshwara and M A H Mac Callum*

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   (d) Black holes in Einstein cosmological background: Some physical effects by B S Ramachandra and C V Vishveshwara

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   (e) New classes of black hole space times in 2+1 gravity by Sukanta Bose[1], Naresh Dadich[1] and Sayan Kar[2]

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   [2]Department of Physics and Centre for Theoretical Studies, Indian Institute of Technology, Kharagpur 721 302, India

(f) Nature of singularity in transition from marginally bound to non-marginally bound in inhomogeneous dust collapse by S H Ghate and R V Saraykar
Department of Mathematics, Nagpur University Campus, Nagpur 440 010, India

(g) The structure of geodesics in the dust collapse by Shrirang Shashikant Deshingkar
A-251 TAP, Tata Institute of Fundamental Research, Colaba, Mumbai, India

2. *Astrophysical aspects*

(a) Model of a very compact star by R Sharma and S Mukherjee
Physics Department, P.O. North Bengal University, Siliguri District, Darjeeling 734 430, India

(b) GR effects on pulsar magnetic fields by Sushan Konar
Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India

(c) Temperature profiles of (thin) accretion disks around rapidly rotating neutron stars in general relativity and implications for Cygnus X-2 by Sudip Bhattacharyya
Indian Institute of Astrophysics, Bangalore, India

(d) Luminosities of disk accreting non-magnetic neutron stars by Arun Thampan
Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India

(e) A radiating and rotating metric by Pradeep Muktibodh and Sanjay Wagh
Central India Research Institute, Post Box 606, Laxminagar, Nagpur 440 022, India

3. *Gravitational radiation*

(a) Detection of gravitational wave signals from inspiraling compact coalescing compact binaries with a network laser interferometric broadband detectors by Sukanta Bose[1], Archana Pai[1,2] and Sanjeev V Dhurandhar[1,2].
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[2]Max Plank Institute fur Gravitations Physik, Albert Einstein Institut, Am Muhlenberg 1, Golm, D-14476, UK.

(b) Analysis of noise free response of interferometric antenna to gravitational radiation from pulsars I by D C Srivastava and S K Sahay
Department of Physics, D.D.U. Gorakhpur University, Gorakhpur 273 009, India

(c) Analysis of noise free response of interferometric antenna to gravitational radiation from pulsars II by D C Srivastava and S K Sahay
Department of Physics, D.D.U. Gorakhpur University, Gorakhpur 273 009, India

Theoretical aspects

Somasri Sen presented the results of certain investigations on the no scalar hair theorem for black holes. This theorem stresses the non-existence of scalar hair, for a wide class of scalar fields both minimally and non-minimally coupled to gravity. The investigations were carried out in static spherically symmetric as well as in stationary axisymmetric inhomogeneous charged spacetimes. In both spherical symmetry and axial symmetry the results were mostly in keeping with the no scalar hair theorem but in axial symmetry at least one solution has been found which appears to be a counter example of the theorem.

There followed two talks covering the work of (i) K Rajesh Nayak and C V Vishveshwara, (ii) K Rajesh Nayak, M A H Mac Callum and C V Vishveshwara, (iii) B S Ramachandra and C V Vishveshwara.

The theme of their work was the Kerr and Schwarzschild black holes in the background of the Einstein Universe. Firstly, the Kerr black hole in the background of the Einstein universe as given by Vaidya was discussed. Then as an example of a black hole in a non-flat background they presented a composite spacetime constructed by them which comprises a vacuum Schwarzschild spacetime for the interior of the black hole across which it is matched on to the spacetime of Vaidya. They have also studied the behaviour of scalar waves in this composite model.

Last was presented, some results of work on the physical effects in the spacetime of the Schwarzschild black hole in the background of the Einstein universe. Some results on the physical effects including geodesics, the classical tests – perihelion precession, bending of light and gravitational red shift, and the Hawking temperature were presented. Next, in connection with the structure of particle angular momentum in the spacetime of the Kerr black hole in the background of the Einstein universe, the Carter constant, the Killing tensor and the Killing–Yano tensor were discussed along with a relevant comment on the verification that this spacetime belongs to Petrov type D.

Sukanta Bose, Naresh Dadich and Sayan Kar presented work on 'New classes of black hole spacetimes in $2 + 1$ gravity'. New multi-parameter families of black holes in three-dimensional (3D) gravity have been obtained by them. They apply the electrogravity transformation (which implies an exchange of the Ricci and Einstein tensors) to the 3D field equations to obtain these solutions. Several properties of these geometries, including the nature of the matter that threads them, were discussed. Some of these properties are found to be strikingly different from known black holes in (2+1) dimensions.

S H Ghate and R V Saraykar's work dealt with the nature of singularity in transition from marginally bound to non-marginally bound in inhomogeneous dust collapse. The occurance of naked singularity in an inhomogeneous dust collapse depends on the choice of initial data that comprises of mass function in the marginally bound case, and mass function and energy function in the non marginally bound case. In their paper they have studied the change in the nature of the singularity under continuous transition of initial data from marginally bound to non-marginally bound case under suitable norm. They have also proved that with the choice of physically reasonable initial data there are conditions on mass and energy function under which the nature of the singularity changes from naked singularity to a black hole and vice versa. However there is always a subset of initial data for which the nature of the singularity is preserved under transition. They have studied transition separately in the cases where initial data comprises of C-1 functions and real analytic functions.

Shrirang Shashikant Deshingkar spoke on the structure of geodesics in the dust collapse. His work dealt with the behaviour of different radial geodesics with a view to understand the casual structure of the spacetime in the dust collapse. It was shown that when the singularity is naked and the parameter α is less than three, there is only one ingoing radial null geodesic and a family of radial null and timelike geodesics coming out of the singularity with the same tangent as that of the apparent horizon at the central $(r = 0)$ singularity. Also was shown the similarity of the limiting behaviour of the different types of geodesics in the limit of approach to the singularity.

Astrophysical aspects

R Sharma and S Mukherjee presented investigations concerning the model of a very compact star. Recent observations on Her-X-1, a compact X-ray pulsar, predict a large mass to radius ratio, which suggests that it cannot possibly be a neutron star or a strange star. To study such compact stars, they have made a departure from the standard method where one starts with a given equation of state and integrates the Tolman–Oppenheimer–Volkoff equations to get the mass-radius curve of the star. Here the authors prescribe a given geometry and use Einstein's equations along with the given values of mass and radius of the star to calculate the equation of state that supports it. It is believed that hadronic matter within such compact stars (with supernuclear density) undergoes a transition to a deconfined state of quarks and gluons. It has also been suggested that this deconfinement occurs through an intermediate stage, in which nucleons are dissociated but some quarks are correlated in spin-singlet pairs called diquarks, having a self-interaction described by an effective potential. The equation of state for such quark–diquark plasma is softer than that for a strange matter and agrees with the equation of state determined by their geometrical approach. They claim that their results agree qualitatively with those of Horvath *et al*, although the two approaches differ considerably. They also claim that the simplicity of the model permits them to determine a sequence of bound states of quark–diquark system.

Sushan Konar spoke on the GR effects on pulsar magnetic fields. The generation and evolution of magnetic fields in neutron stars (pulsars) continues to evoke much interest, particularly in view of the recent observations of objects like soft gamma ray repeaters, magnetars etc. The standard theory of the field evolution indicates accretion of mass, from a companion of the neutron star, to be the major cause of field evolution invoking ohmic dissipation of currents in the crust. Since the knowledge regarding the actual location of the currents supporting the field is not without ambiguity, such theories also need to take into account the superfluid nature of the interior, possible core-crust superfluid interaction and the like. So far these treatments have been purely classical. This work introduces the GR correlations to the standard theory of pulsar magnetic field evolution and compares the nature of departure from the classical results. It also mentions the relevance of such modifications in view of the sensitivity of the present observations.

Sudip Bhattacharya's paper was entitled 'Temperature profiles of (thin) accretion disks around rapidly rotating neutron stars in general relativity and implications for Cygnus X-2'. This work included calculations of the temperature profiles of (thin) accretion disks around rapidly rotating neutron stars (with low surface magnetic fields, taking into account the full effects of general relativity.) Then followed considerations on a model for the spectrum of the X-ray emission from the disk, parametrized by the mass accretion rate, the color temperature and the rotation rate of the neutron star. Constraints were derived on these parameters for the X-ray source using the estimates of the maximum temperature in the disk along with the disk and boundary layer luminosities, using the spectrum inferred from the EXOSAT data. The calculations in this work suggest that the neutron star in Cygnus X-2 rotates close to the centrifugal mass-shed limit. Possible constraints on the neutron equation of state were also discussed.

Arun Thampan spoke on 'Luminosities of disk accreting non-magnetic neutron stars'. Disk accretion onto a neutron star possessing a weak surface magnetic field ($B \leq 10^8$ G) provides interesting X-ray emission scenarios, and is relevant for understanding X-ray bursters and low mass X-ray binaries. The standard (Newtonian) theory of disk accretion predicts that the matter spiraling in from infinity loses one half of its total gravitational energy in the extended disk, and the remainder in a narrow boundary layer girdling the neutron star. In the case of neutron stars, general relativity plays an important role: not only in determining their structure but also in determining the spacetime geometry around them. The structure of these objects depend, in addition to general relativity, also on the property of ultra-high density matter constituting their interiors. Neutron stars that accrete matter from a companion over extended time-scales ($\sim 10^8$) can get spun up to very short periods ($\sim$ milliseconds). In this work it has been investigated how the incorporation of general relativity, rotation, and the relevant interior physics of neutron stars into the calculations reorder (as compared to Newtonian calculations) the contributions to the gravitational energy release from the boundary layer, and the extended disk.

Pradeep Muktibodh and Sanjay Wagh presented some results on 'A radiating and rotating metric'. A solution of the Einstein field equations representing the external gravitational field of a rotating and radiating star was reported. They claimed that their present solution was a generalization of the Vaidya metric to axisymmetric systems.

Gravitational radiation

Sukanta Bose, Archana Pai and Sanjeev V Dhurandhar's work was on 'Detection of gravitational wave signals from inspiraling compact coalescing compact binaries with a network laser interferometric broadband detectors'. They formulated the data analysis problem for gravitational wave (GW) signals from inspiraling compact coalescing binaries for a network of laser interferometric gravitational wave detectors with arbitrary orientations and locations around the globe. They used the maximum likelihood method for optimizing the problem. The noise in the detectors was assumed to be mainly gaussian, stationary and uncorrelated for every pair of detectors. They presented a geometric formulation which they claimed, was not only elegant but led to several physical insights. In the present work, the authors treated the case of the Newtonian inspiral. They then had to maximize the likelihood ratio over 8 parameters. They were able to analytically maximize over four of the parameters and use FFT for the time of arrival. This they claimed not only allowed them to scan the parameter space continuously over these parameters but also cut down substantially on the computational costs. For the remaining three parameters, namely, the direction to the source and the chirp time, they obtained the bank of templates. They estimated computational costs, errors in the parameters such as the direction to a given source.

Lastly, D C Srivastava and S K Sahay presented their work on 'Analysis of noise free response of interferometric antenna to gravitational radiation from pulsars' in two parts, carrying the same title. Pulsars are one of the most important sources of continuous gravitational radiation (GR). The signals from pulsars are very weak and masked by the broadband noise of the detector. In order to detect the signal, we have to enhance the signal-to-noise (S/N) ratio. The S/N is directly proportional to the square root of the observation time. Hence a strategy to achieve the objective could be to perform a coherent integration of the detector output stretching over months. But the long integration time introduces amplitude as well as frequency modulation in the detector output arising respectively due to the quadrupole nature of the GR and due to the translatory motion of the Earth around the Sun. Recently an analytical study of the Fourier transform of frequency modulated GR for one-day observation time was done by the authors. In paper I, they extend the analysis of the Fourier transform of monochromatic pulsar signal for one-year observation period by incorporating the effects of Earth's rotation about its axis and revolution around the Sun. This analysis is applicable for an arbitrary orientation and location of the detector and source position. They discuss the frequency resolution of the power-spectrum and find that it may be sufficient to study significant peaks statistically.

In paper II, the authors extend the analysis of frequency modulated GR for arbitrary time of observation. Further, they obtain FT of the complete response (the amplitude as well as frequency modulated) of interferometric gravitational wave detector for arbitrary period of observation time by taking into account the effect of the orbital and rotational motion of the Earth. They find that the bandwidth of the power spectrum of the response increases by about one Hz on both side of the source frequency of the frequency modulated signals.