Highlights from Fundamental Interactions Laboratory, Gravitation Group, DHEP, TIFR during 2005-2008

1) Magnetic mirrors for ultra-cold atoms and the measurement of van der Waals force:

   Laser cooled alkali atoms at have very low velocity dispersion, and they can be fully reflected from a magnetic thin film if dropped from a small height over the film. The strip-like magnetic domains on such thin films (of Cobalt, for example) produce an exponentially varying magnetic field and gradient with a decay length that scales the thickness of the film. We devised a novel way to measure the short range quantum mechanical van der Waals and Casimir-Polder force on atoms. Since the distance from which the atoms reflect depends on the exponential decay length of the magnetic gradient which in turn depends on the thickness of the film, the thinner the film the closer the atom approaches the film before complete reflection. Therefore, reflection from thinner films will be affected by the attractive van der Waals force that competes with the repulsive magnetic gradient. We measured the reflectivity of atoms, cooled in a magneto-optical trap to below 10 microKelvin, from Cobalt thin films at various thickness ranging from 300 nm (almost 100% reflection) to 50 nm (30% reflection) and detected and characterized the van der Waals interaction. (*Ashok Mohapatra and C. S. Unnikishnan, Europhys. Lett. 73, 839 (2006).* (Journal highlight paper, 2006)

   We also extended this work obtaining new results on domain relaxation and magnetic phase transition in Lanthanum Calcium Manganite, complementing condensed matter techniques (*A. K. Mohapatra, S. Chaudhuri, S. Roy and C. S. Unnikrishnan, Eur. Phys. Jl D* ***42****, 287 (2007).*

2) Bose-Einstein Condensation in Optical trap and in Optical Lattice

   Bose-Einstein Condensates in dilute alkali vapours were first produced in 1995, in magnetic traps. This technique produces spin-polarized condensates. Six years later, BEC was produced in a purely optical trap that relies on dipole forces that are nearly independent of the spin state, in focused laser fields. However, it is a difficult route to BEC. Hence, there are only a few all-optical BECs produced from 2001 till now (10% of all BECs) in spite of the uniqueness of all-spin-state condensates and their usefulness in studying a host of new phenomena specific to spinor condensates.

   We conceived a strategy for sure-shot optical trap BECs in 2002-03 (when no optical trap BEC experiment except the first one was successful) in which the starting point was the implementation of a fast loading beam source of ultra-cold atoms, based on a 2-dimensional magneto-optical trap (S. Chaudhuri. S. Roy and C. S. Unnikrishnan, Phys. Rev. A **74**, 023406 (2006). This allowed us to load nearly 10^{10} atoms in less than a second to the main magneto-optical trap, and we trapped an order magnitude more atoms ($2x10^7$) than any other experiment in our optical trap of two crossing focused CO_2 laser beams, with all optics arranged outside the UHV chamber. Rest was straightforward, exactly as we planned, and we produced a Rubidium BEC in January 2007 (*Saptarishi Chaudhuri, Sanjukta Roy, C. S. Unnikrishnan , Jl. Phys.: Conf. Series* ***80*** *012036 (2007)*. The one second evaporative cooling time required to cool to below 200 nK is still the fastest. This is the first, and at present the only BEC in India, where the idea of boson statistics originated in the work of S. N. Bose, which was generalized by Einstein to predict the condensation.

   Recently, we retroreflected one of the CO_2 laser beams and produced a standing wave 1D optical lattice to which we loaded the atoms. Evaporative cooling for 1 second produces BECs reliably, with the largest ever number of atoms in optical lattices (over 80,000 in 4-10 lattice sites, separated by 5.3 micrometer), with the largest single site occupation, exceeding $2x10^4$ atoms (*Sanjukta Roy, Saptarishi Chaudhuri and C. S. Unnikrishnan,* paper submitted). We have studied simple expansion dynamics, and hope to carry this expertise now to build our new experiment that can cool both bosons and fermions to quantum degeneracy, to explore few-atom quantum mechanics, atom interferometry and its application, as well as dynamics in optical lattices.

3) <u>Cosmic Relativity and Physics in the Once-Given Universe: theory and experiments</u>

All our fundamental theories including Special Relativity and General Relativity fail to incorporate the fact that there is permanent and unavoidable gravitational background of all the matter in the universe, possibly affecting all physical phenomena. Building from this, we conceived the theory of Cosmic Relativity (CR) in which all relativistic effects, including the familiar time dilation, are due to the gravitational effects arising from motion through the matter-filled universe. This manages to unify kinematics and dynamics, and enables first principle derivations of Newton's laws, equivalence principle, Thomas precession, spin-statistics connection etc. Two of its major predictions are that (a) Clocks transported at equal relative speeds in a frame that itself is moving relative to cosmic matter will show unequal time dilations reflecting the unequal absolute velocities with respect to cosmic matter, (b) the speed of light relative to inertially moving reference frame is not an invariant constant, but shows first order anisotropy. In effect, CR replaces the Lorentz-Poincare aether with the matter-filled Universe. The first prediction is verified to be true from a careful analysis of clock comparison experiments using atomic clocks. The second and most important prediction needed a method of measuring the genuine one-way speed of light relative to an inertial reference, without using two spatially separated clocks. It is important to realize there has been no such measurement ever, and also that there is not a single experiment till date that could rule out an absolute frame theory with real Lorentz contraction, contrary to general beliefs. We found such a method of remarkable simplicity and logical rigour, and managed to compare the one-way speeds of light in opposite directions in a one-dimensional folded path, relative to an inertial platform. The startling result is that the speed of light is indeed anisotropic, contradicting directly the fundamental assumption of special relativity. This is supported by a reanalysis of one-way clock comparisons over stable optical fiber links. Given the importance of the findings, it is clear that an extended debate and scrutiny will be required, but the empirical evidence to replace special relativity with cosmic relativity is strong (*C. S. Unnikrishnan, Proc. SPIE Conf. 6664, Paper 6664R (invited); Proc. 11th Marcel Grossmann Meeting, Berlin, to appear*).

4) <u>Quantum Correlations and Fundamental Conservation Laws</u>

Our result that quantum correlations follow uniquely from demanding the validity of classical conservations laws on the average over ensembles, and that local hidden variable theories do not respect the fundamental conservation laws, making Bell's inequalities redundant, is perhaps an important result. It has not enjoyed the discussion it deserves but with further clarifications, this result is expected to be understood better in the future (*Europhys. Lett.* ***69****, 489-495 (2005).*