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Research: summary and future plans (October 2004)

Broadly, I am interested in astrophysics and in the physics of gravitational-wave interferometers (e.g., LIGO).

Main scientific achievements to date:

1. I have developed a method to compute thermal noise in LIGO (Levin 1998). This 'direct' method is now widely used by those working in the field of gravitational-wave interferometers. In the same paper, I have shown that coating thermal noise may be significant for LIGO. Subsequent experimental and theoretical efforts by groups at Caltech, Stanford, Moscow, Tokyo, and Glasgow have studied the coating thermal noise; it is now considered to be among the most serious sources of noise for LIGO.

2. Together with Jeff Kimble, Andrei Matsko, Kip Thorne, and Sergei Vyatchanin, I have designed a scheme to overcome the Standard Quantum Limit in the advanced LIGO interferometer (Kimble et. al. 2002).

3. I have proposed and analyzed a scenario in which both the spin and temperature of a strongly accreting rapidly rotating neutron star follow a limit cycle. The cycle is driven by the r-mode instability. My scenario is one possible explanation for the observed distribution of spins of both millisecond pulsars and neutron stars in Low-Mass X-ray Binaries (Levin 1999).

4. Together with Anatoly Spitkovsky and Greg Ushomirsky, I have developed a theory of conflagration in rapidly spinning, gravitationally stratified fluids. We have applied our theory to nuclear-powered type-I x-ray bursts (Spitkovsky et. al. 2002).

5. Together with Andrei Beloborodov, I have analyzed the 3-dimensional velocity data for He-I stars in the Galactic center, and have argued for the existence of a stellar disc near SgrA* (Levin and Beloborodov, 2003). We proposed that the puzzling young stars in the Galactic Center may have been born during fragmentation of a dense gaseous disc which existed a few million years ago. Concurrently, I have developed a theory of how massive stars may form at the outer edges of AGN discs (Levin 2003). I have argued that mergers of the compact remnants of these massive stars with the supermassive black hole may be detectable by LISA.

I have also worked on a number of projects which were more technical in nature, or less significant in their impact. Below, I give brief descriptions:

Other work.

1. Together with Andrei Beloborodov, I have developed the "orbital roulette" method for estimating the mass of a gravitating body or more generally, for constraining the parameters of a gravitating potential (Beloborodov and Levin, 2004). Our method is applicable when a number of the body's satellites is observed and a snapshot of their positions and velocities is available. "Orbital roulette" is relevant for some existing and future data sets and can be used for model-independent measurement of the Oort Limit, for inferring the SgrA* mass as seen on $\sim .5$pc scale, and for constraining the Galactic potential by using the kinematics of the Galactic Satellites measured by the upcoming Space Interferometry Mission.

2. Together with Chris Matzner, I have considered analytically gravitational instabilities in protostellar accretion discs (Matzner and Levin, 2004). We have shown that the irradiation of the disc by the rescattered accretion luminosity always quenches the

local Toomre instability; this finding may explain the observed dearth of brown dwarfs near main-sequence stars (the brown-dwarf desert).

3. Together with Caroline D'Angelo, I have developed the formalism to treat hydromagnetic and gravitomagnetic crust-core coupling in a precessing neutron star (Levin and D'Angelo, 2004). The immediate application of our formalism is the precessing pulsar PSR1828-11; we conclude that MHD stresses enforce rigid co-precession of its crust and core. We also predict that the precession should be damped by the mutual friction of the proton-electron plasma and the neutron superfluid in the core and argue that this damping may be observable over human lifetime.

4. Together with Greg Ushomirsky, I have computed the radial structure of the $l = m = 2$ r-mode in a rotating neutron star with an elastic crust (Levin and Ushomirsky, 2001b). We calculate the r-mode damping due to the crust-core boundary-layer friction and construct realistic r-mode instability curve. We thus show that the r-mode instability is a realistic mechanism for setting spins of millisecond pulsars and of neutron stars in Low-Mass X-ray binaries.

5. Together with Greg Ushomirsky, I have analyzed the nonlinear development of the r-mode instability for a simple model (Levin and Ushomirsky, 2001a). We have shown for the first time that the gravitational radiation reaction on the growing r-mode drives differential rotation in the oscillating star.

Current projects.

1. I have developed a Symplectic Integrator which allows efficient orbital integrations in the systems whose hierarchical structure is time-dependent. For example, if Jupiter's orbit were to shrink due to friction, its moons would get tidally stripped away and would end up on heliocentric orbits, thus changing the hierarchy of the system. Similarly, if an Intermediate-Mass Black Hole (IMBH) inspirals towards SgrA*, the stars originally bound to IMBH get stripped and end up on eccentric orbits around SgrA*. Currently I am applying my code to the latter example, which has been suggested by Hansen and Milosavljevic as a scenario for delivering young stars to the immediate vicinity of SgrA* black hole.

2. I am improving the theory of type-I x-ray bursts which we have developed previously with Spitkovsky and Ushomirsky. This is done through detailed analysis of Kelvin-Helmholtz and baroclinic instabilities which are responsible for mixing the hot ashes and the unburned fuel during the burst.

Future plans.

Generally, I work in a few different fields. Strategically speaking (e.g., in terms of projects for potential PhD students) I have an interest in

1. Understanding the interplay between gas and stellar dynamics in Galactic Nuclei, with potential applications to our Galactic Center and to the interpretation of megamasers in other galaxies.

2. Understanding the interplay between the magnetic field and superconducting/superfluid core of a spinning or precessing neutron star (pulsar). This field has a number of unresolved theoretical issues (e.g., the potential effect of flux-tube bunching on the evolution of pulsar magnetic field) and a number of old and new unsettled observational puzzles (small magnetic fields of recycled pulsars, slow precession of PSR1828-11, timing noise, etc.).

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Teaching experience and working with students.

I was a teaching assistant during both my undergraduate and graduate study. My tasks included leading a section in the first-year physics lab course at Caltech for two consequtive years, and grading a number of advanced graduate-level courses.

I have worked with 5 graduate and undergraduate students, who had varied levels of preparation. These collaborations have resulted in 4 published and 1 forthcoming papers. More specifically, I have supervised a project of a starting PhD student Deborah Santamore at Caltech (published in Phys. Rev. D), and have collaborated with Greg Ushomirsky and Anatoly Spitkovsky (published in MNRAS and ApJ) while they were finishing their PhDs at Berkeley. I have worked on summer projects with two undergraduate students at the University of Toronto, Caroline D'Angelo and Alice Wu. Our paper with Caroline is published in ApJ, and the paper with Alice is in preparation.

After working with five students, I think I can formulate my strategy for advising future graduate students under my supervision. The key for me is to establish friendly relations with the students, and to make sure that they feel comfortable asking questions. At the same time, I strongly believe that PhD is about independent research, and that each has to find her/his own way in science. Therefore, I will avoid handholding, but will instead try to identify and encourage the strengths of a particular individual.