Research interest (László Árpád GERGELY)

<u>Fundamental problems in physics involving gravitational phenomena</u>

On the Earth scale Newtonian gravity works perfectly, with the important exception of the Global Positioning System (GPS), where general relativistic corrections are implemented. On the larger scale of the Solar System **general relativity** proved itself as an accurate gravitational theory. On the galactic scale however there is need to either introduce **dark matter** or modify the gravitational theory, in order to be in agreement with observations. On the even larger, cosmological scale **dark energy** turns out to be dominant, unless gravity is again modified. Either dark matter / dark energy need phenomenological explanations or beyond galactic and cosmological distances, respectively, gravity has to be described by alternative theories.

Deriving therefore accurate theoretical predictions of general relativity and existing alternative gravity theories or dark matter / dark energy models, also confronting them with observations is of uttermost importance. Galactic structure (including **rotation curves**) and dynamics, gravitational **lensing**, **accretion** phenomena and the related **jet** physics, the study of the **Cosmic Microwave Background**, **pulsar** timing, stellar and pulsar kinematics in the center of the Galaxy, **gravitational waves** emitted by compact binaries and their redshift dependence as a test of dark energy models fall into this class of possible tests.

I have done research in **general relativity**, string-theory inspired **brane-worlds**, the Lorentz-invariance breaking **Hořava-Lifshitz** theory and fourth order **fI** theories. As for dark matter and dark energy models, I investigated **Bose-Einstein Condensate** dark matter and various scalar field **dark energy models**.

My cosmology-related work is in collaboration with colleagues from the ***<u>Cosmology of Fundamental Interactions</u>*** network. The *string-theory motivated* **tachyonic cosmological model**, compatible with type Ia *supernova data*, has a scalar field interpreted as a two-component fluid. This behaves as ordinary dust in the distant past, modeling *dark matter and dark energy* in the same time. Space-time evolves into a *future sudden singularity* dubbed *Big Brake* and has the remarkable feature that geodesics can be continued through it, leading to a *recollapse* into a Big Crunch. Similar features emerge for an **anti-Chaplygin gas** model. These evolutions are very different then those predicted by the standard LCDM cosmological model, still they turn out to be compatible with observations.

General relativity differs from Newtonian gravity mostly in the strong gravity regime. Such strong fields emerge in compact stellar interiors or in the vicinity of **black holes**. Due to my interest in this field I became Management Committee member of the EU COST Collaboration ***<u>Black Holes in a Violent Universe</u>***. I actively participate in two of the workgroups of the collaboration, WG4: **Supermassive Black Holes**, and WG1: **Quantum Black Holes**. With the venue of the Square Kilometre Array (SKA) I also made contacts with the Pulsar Group of the Institute of Radioastronomy in Bonn, planning to start **pulsar-black hole binary related research**.

With my other collaborators we have investigating **accretion processes** and the maximal **energy emission efficiency** in a *symbiotic system of black hole, accretion disk, energetic jet and magnetic* *field*, including elements from general relativity, electrodynamics, hydrodynamics, plasma physics and particle physics. We also studied accretion into *magnetically and tidally perturbed black holes*, then **weak** and **strong gravitational lensing** by black holes and galaxy clusters, comparing the predictions of various alternative gravitational theories and general relativity. We are interested in *image formation, magnifications*, and related observable predictions, the most important of which is a modified power-law dependence of the observables.

The first direct detection of **gravitational waves** is foreseen in 2016-17 with the Advanced LIGO Detector network. As a member of the ***LIGO Scientific Collaboration*** I work on developing specific waveforms for unequal mass spinning compact binaries, and investigate the relation of the **astrophysical characteristics** of the binary with the **gravitational waveform**. I have derived the *full conservative inspiral dynamics* of spinning black hole binaries, given *as a closed system of first order coupled differential equations* in terms of a physically motivated set of *independent variables*. I plan to develop a *hierarchic sequence of effective dissipative dynamics,* valid on the *orbital* time-scale, the *spin precession* time-scale and the *inspiral* time-scale, respectively, each one being orders of magnitude longer than the previous one. I foresee interesting applications of this research.

A recent statistical survey led to an accurate *mass distribution of supermassive black holes*. Starting from this we derived a **typical mass ratio** of mergers, with implications to gravitational radiation emission, **spin-flip** process and cosmological evolution of the black hole spin distribution.

I plan to work out predictions on gravitational waves emitted by compact binaries lying either at cosmological distances or derived in the framework of alternative gravity theories. I wish to address the determination of dark energy parameters and the parameters characterizing various alternative gravity theories through measurements on gravitational waves; either arriving from isolated sources or building up a background. In particular I plan to **i)** study gravitational wave imprints of wormhole / naked singularity / alternative gravity black hole binaries; **ii)** employ the typical mass ratio of mergers in the gravitational radiation emission to re-derive the cosmic gravitational wave background due to this process; and **iii)** constrain various dark energy parameterizations by taking into account the (non-identical) cosmological modifications of both the gravitational wave amplitude and phase.

The realignment of the dominant spin (spin-flip) implies the realignment of the magnetic field structure with subsequent formation of new **high energy particle jets**. By this mechanism we explained the formation of a large subset of **X-shaped radio galaxies**. Next we will model how a spinning binary at the jet base acts on the **jet morphology**, and confront this with available VLBI data.

Black hole geometries are important test beds for attempts of **quantizing gravity**. Indeed, the high symmetry degree of such black holes makes them ideal candidates for quantization in a restricted superspace. Earlier I have completed this program for a two-component radiation atmosphere of a star and I wish to continue this type of research for **rotating black hole geometries**.

Space-time deformations in the vicinity of electrons accelerated by strong electromagnetic fields could lead to the creation of **microscopic black holes** by the **next generation of lasers**, allowing for an experimental study of black hole (Hawking) evaporation. This is one of my research topics in progress.

In the long run I also plan to study the **interaction of gravitational waves with plasma** in cosmic environment.

SUMMARY OF RESEARCH RESULTS

Cosmology and dark energy models: tachyonic scalar field, generalized Chaplygin and anti-Chaplygin gases; supernova tests; soft cosmological singularities (Big Brake) and singularity crossing.

Galaxy structure and dark matter models: Bose-Einstein Condensate cored halo model and Weyl fluid model tested by galactic rotation curve data of High Surgface Brightness, Low Surface Brightness and dwarf galaxies; Weyl fluid model tested by weak gravitational lensing.

Gravitational lensing: weak and strong; for black holes with tidal charge, in fourth order fAZ gravity theories and Hořava-Lifsic theory; power-law dependence of magnification ratios as function of image separations derived (observational signature); critical behaviour □nt he deflection angle found.

Black holes, accretion, jets: accretion into magnetically and tidally perturbed Schwarzschild black holes; spin limit and radiation efficiency in a symbiotic system of supermassive black hole (SMBH), accretion disk, magnetic fields and jets; active galactic nuclei (AGN) as sources of ultra high energy cosmic particles.

Gravitational waves from compact binaries: orbital evolution, gravitational wave (GW) amplitude and phase, radiation losses (spin and mass quadrupole contributions); GW generated recoil; spin-dominated waveforms derived; waveform generation for the LIGO Scientific Collaboration.

Supermassive black hole binaries: gravitational waves and jets: spin-flips and their relation to X-shaped radio galaxies; typical mass ratios and typical final spin in precessing or aligned SMBH mergers (0.2 and 0.45 respectively); signatures of SMBH binaries in VLBI jet base analysis.

Brane-worlds and black strings: covariant, canonical and 3+1+1 brane dynamics; variable brane tension; asymmetric brane embedding; radiative brane-bulk interaction; induced gravity models; black strings; gravitational collapse on the brane; Friedmann branes; geometro-thermodynamics of tidal charged black hole.

General relativity: exact solutions and special perturbations; new cosmological, naked singularity and wormhole solutions for crossflowing radiation shells; perfect fluid source of NUT metric; junction of space-times; symmetry reductions and dilatonic models.

Constrained dynamical systems: Dirac quantization of the Schrödinger field; Barbour-Bertotti theory with application to 3-bodies; geometrodynamics with internal time for crossflowing radiation shells.