1. Importance and Relevance of the Technical and/or Scientific Content

(max 20 pages)

1.1. Concept and objectives:

Explain the concept of the project. Describe the project objectives and the technical and/or scientific barriers that will be lifted by carrying out the project. Emphasise the original, novelty and innovative nature of the project. Present expected results and describe the project end products.

Fundamental researches in Theoretical Physics, Gravitation, Cosmology and Astrophysics provide a series of new computational methods (numerical, symbolic and graphical simulations) which can be applied in wide areas of space technologies, mainly designing new experiments and measurements in space. On the other hand, recent Astrophysical achievements (discovery of cosmic acceleration, Gamma-ray bursts, galactic black-holes nuclei, gravitational lensing, etc.) impose validation of different theories and models through future experiments and space missions. Thus, this project proposes a joint research program having the following three main directions described below.

The first direction (mainly contained in the WorkPackage no. 1) is dedicated to our computational investigations with space science applications. Its title is :

- ***Providing an entire computer library devoted to numerical, symbolic computation and algebraic programming methods in space science areas as numerical relativity, nonlinear flow equations and other applications.***

We will investigate the possibility of application and use of the new computational methods provided by different areas of fundamental research in gravitation, numerical relativity and cosmology for space sciences investigations. In numerical relativity (or recently called "numerical astrophysics") were developed high level methods for numerically and graphically solving of Einstein and hydrodynamic equations for various systems (black-holes colliding and merging, supernovae explosions, emission of gravitational waves, etc.). These new methods (BSSN, WISKEY, HYDRO, etc) are imposed by the strong nonlinearity of the equations (at least second order partial differential equations). On the other hand theoretical cosmology is in a frentic search for new models capable to describe the recent discovered cosmic acceleration of the universe. Different approaches and type of models are proposed and investigated based on einsteinian gravity or alternative gravity theories (higher order lagrangians for example) coupled (minimally or not) with one or more scalar fields. For these purposes a series of new computer algebra and graphical methods were developped. In the research proposed by the COMISIS project we will developp some of these methods in view of their application to investigations in space sciences. We will developp and run new routines and programs for numerical computation, algebraic programming and graphical processing in view of the next objectives and tasks described below. The main goal is to identify those terms and factors introduced by these new throries and models which can be measured in new type of space science experiments or even contained in data from existing experiments and missions. Thus in this research direction the COMISIS project will concentrate on the next main objectives and tasks:

Task 1.1: Study of alternative gravity theories for non-standard cosmologies. We will build the new Friedmann equations in the context of one massless scalar field coupled with gravity described by new field equations and investigate them processing with computer algebra and numerical routines (in Cactus code platform and/or using Maple + GrTensorII integrated platform)

Task 1.2: Investigations on the flow equations (geometric and hydrodynamic type) in view of their use for applications in plasma and turbulent media studies. Also here new routines from numerical, algebraic computing and graphical processing will be composed and tested.

Task 1.3: Identifying possible effects of different cosmological models on the astrophysical measurements in space missions (satellites and planetary movement in the solar system, supernovae, etc.). This task is related to the tasks of the thirs topic the COMISIS propose, to find those effects and variables which can influence measurements done using movement of objects and satellites in solar system (and not only) for providing new data on the theories and ideas related to the dynamic of the universe.

Task 1.4: Building all the routines and programs obtained in one or more special library for their use. Also User Guide texts will be provided.

All the routines and packages will be tested on different type of computers and on the UVT supercomputer (of course after adapting them for parallel computing) in certain specific cases for a professional debugging and optimization.

The second direction (mainly contained in the WorkPackage no. 2) is dedicated to our investigations in solar and space plasmas having as title:

- ***Analytical and numerical models for remote solar and space plasma diagnostics.***

The specific objectives within this research topic of the project are:

- assign to each magnetic structure a corresponding effective filter, i.e. a map of the specific physical parameters to a behavior in the frequency domain.This can later be encapsulated by a specific component of a dedicated software library
- combine observational and theoretical efforts in investigating the multi-scale properties of the solar corona and diagnostics using waves and oscillations in solar plasmas
- refine deterministic reconnection models by considering stochastic behavior of magnetic fields
- study the effect of stochastic magnetic field on the radiation emitted by a plasma

The research component implies the development of new analytical and numerical models for remote solar and space plasma diagnostics. These models will be complemented and validated by novel observations and corresponding data assimilation procedures.

To deal with proper seismological diagnostics of solar and space plasmas it is necessary to have available a comprehensive model that incorporates not only the dynamic process but its source, as well. In general the triggering mechanism of majority of waves and wave-like disturbances are solar flares and CMEs that are the subject of a recently emerged and rapidly developing discipline – Solar Weather.

Many physical processes in solar and space plasmas show a non-stationary behavior, i.e. various physical parameters describing the equilibrium are not only space dependent but they also show a variation with time. We aim to develop a *new model of plasma dynamics* and the associated diagnostics procedure in non-stationary plasmas.

In reality, high resolution EUV and X-ray observations show that plasma parameters do not vary smoothly and random or stochastic descriptions of, e.g. density and magnetic field are necessary. In a stochastic or random process there is some indeterminacy in its future evolution, described by probability distribution functions, with some evolutionary paths more probable and others less so.

All theoretical models and subsequent numerical implementations based on the classical Sweet-Parker model for magnetic reconnection fail to reproduce the rapid reconnection observed in various astrophysical conjectures and geometries. However, if one includes the stochastic properties of small-scale magnetic fields it can be shown that the reconnection rate increases, reaching the needed order of magnitude. We aim to refine reconnection models based on stochastic behavior of magnetic fields and to apply such models to explain the intraday variability observed in the spectra of accretion disks of AGNs (Active Galactic Nuclei). The different magnetic structures observed in the Sun are clearly behaving in a unitary manner; i.e. from the point of view of the input/output signals these structures represent a black box that changes the incoming/applied information in a certain way. Our purpose is to assign to each magnetic structure a corresponding effective filter, i.e. to map the specific physical parameters to behavior in the frequency domain. In Digital Signal Processing (DSP) theory this is done through computing of the transfer function of the filter. As already shown based on observational data, the solar magnetic field has a small-scale stochastic component that can be included in the transfer function formalism as noise and its effects on information transmission through solar magnetic structures will be investigated.

In concluson we can identify the main tasks of this part of the research assigned to the above specific objectives, as described in WP2, namely:

Task 2.1: Defining the magnetic structures as computer/programming entities
- provide a comprehensive theoretical review of magnetic structures
- assign to each magnetic structure an expected behaviour (based on theory and observations)
- develop a toy-code to encapsulate the behaviour as a function of input variables (i.e. local plasma and environment characteristics, perturbation characteristics).

Task 2.2: Impulsively driven waves and diagnostics of the driver and eigenoscillations
- determine nature of the wake left in the plasma by a moving magnetic flux tube and establish the conditions for which the drag force is attractive/repulsive (IB)
- determine the nature and amplitude of oscillations in the system of fine and mutually interacting structures

Task 2.3: Defining the multiscale behaviour of the solar magnetic field
- use current observational data to establish the multiscale behaviour of the solar magnetic field
- use current theoretical work to map each multiscale component to a proposed triggering mechanism
- analyse observational data to establish if and to what degree the radiation emitted by each component bears the signature of a stochastic behaviour

Task 2.4: Study the effect of a stochastic magnetic field on plasma radiation
- use the knowledge in Task 1 to decide upon the best analytical stochastic improvement of existing models
- solve the associated stochastic equations and compare the results with observations

A third research direction on which the project will focus (in the WorkPackage no. 3) consists in developing

- **Semi-analytical methods in studying the stability of constrained space flight dynamics.**

This direction takes into consideration the following specific objectives:
- Extension of the Draper Semianalytical Satellite Theory (DSST) in studing the stability of spacecraft orbits.
- Proposal of new types of measurements in space experiments based on the study of planet and satellite motions in post-newtonian approximation.
- Development of specific application of the stability theory in the study of phenomena in turbulent atmosphere.

A first idea of the research in this direction is related to the investigation of spacecraft orbits outside atmosphere through specific methods of the constrained dynamics. We shall use an already existent low-level space dynamics library known as OREKIT. This open-source software was developed by the company *CS Systemes d'Information* and offers accurate and efficient methods for computing satellite orbits based on elements as orbits, dates, frames, bodies, forces, altitude, etc. The novelty to be brought by the project will consist in extending the software for studying the stability of satellite flights within various perturbation forces. This task will be assumed by the partner no.1 (University of Craiova) in cooperation with CS Romania as subcontractor. We have to mention that this company has already a contract with ESA for extending the implementation of DSST.
The second idea which will be followed in the research related to semianalytical methods for the stability theory consists in studying the dynamics in turbulent media. The equation describing such evolutionary systems are strongly nonlinear differential equation and it is difficult to be solved.The method of symmetry and the similarity reduction procedure will be used as alternative tools for finding different class of solutions, and for make the difference between chaotic and regular trajectories. They will be applied on various models as Ricci flow, Rosbby waves, etc.
The project will also focus on the idea of using the results obtained in the first topic (routines, programes for alternative theories in gravitation and cosmology), mainly in Task no. 1.3, to investigate the movement of objets (planets and satellites) in solar system and in other stellar systems. Do to the fact that the Sun provides a small gravitational source, it is possible to do that by using their orbital and even geodesic movement around the source of gravitation. Post-newtonian approximation (PNA) method which considers strong source and slow motion will be applied. Those effects provided by alternative theories of gravity in

modern cosmology, as for example higher order lagrangians and/or scalar field interaction, will be pointed out. Kerr and Reissner-Nordstrom like exact solutions of field equations will be studied for the motion of satellites and/or gyroscopes and clocks on orbiting trajectories around the planets. We will propose new interpretation of the data from the existing space missions, as well as new possible types of measurements to be done in space. The tasks assumed on this research direction are:

Task 3.1: Development of an algorithm suitable for studying the satellite stability in the presence of small perturbative forces (Partner 1 in cooperation with CS Romania).

Task 3.2: Semi-analytical methods in studying chaotic and regular orbits in turbulent atmosphere. Transfer of methods for the chaos control in plasma physics to turbulent media (Partner 1 and Partner 2)

Task 3.3: Studies on the motion of objets (including geodesics) orbiting around massive masses (Earth, Sun, other massive stellar objects) and identification of possible effects of alternative gravity theories using PNA and computational new methods (CO).

*Task 3.4***:** Symmetry method and similarity solutions for noolinear evolutionary equation appearing in space dynamics (CO and Partner 1).