APVV project proposal – general call 2011

Solar corona: investigation of physical processes

Subject-matter of the project

Principal investigator:

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VV 2011

VV-E SUBJECT-MATTER OF THE PROJECT

OBLIGATORY SCHEME

(BASIC RESEARCH)

Project number: **APVV–0816–11**	Principal investigator: **RNDr. Ján Rybák, CSc.**
Project title: **Solar corona: investigation of physical processes**	
Applicant organisation: **Astronomical institute, Slovak Academy of Sciences, Tatranská Lomnica 18, 05960 Vysoké Tatry**	
Statutory representative(s): **RNDr. Aleš Kučera, CSc., director of the Institute**	
I, the undersigned statutory representative of the applicant organisation, hereby declare on my honour that the subject-matter of the project submitted in a printed form is identical to that submitted electronically through the APVV system. .... signature of statutory representative 1	.... signature of statutory representative 2

1. Timeliness and the scientific nature of aims and objectives, the scientific level and the quality of the project

- Specify the timeliness of the problem solved in the respective field of science and technology from the worldwide point of view including the relevant references to the specialised publications;
- Specify the scientific level of the project and the scientific nature of the methodologies used during the project implementation;
- Specify the project aims and objectives and the feasibility of your aims and objectives;
- Describe the suggested methodology for the project implementation, justify its selection and effectiveness of its use with a view to meeting the declared aims and objectives.

1.1 Timeliness of the problem solved in the respective field of science

Activity of our nearest star – the Sun has a fundamental influence on physical processes taking place in vicinity of the Earth and in heliosphere which essentially affect technological, navigation, energetic equipment and telcommunications of our state-of-art civilization. Solar corona is a source of solar wind, place of generation of solar flares and coronal mass ejections which drag the magnetic fields into the interpanetary space. Therefore, investigation of the solar corona and its active phenomena are very up to date and vital in the world-wide scale.

Despite of the fact that this is an intesively developing branch of the astrophysical research (see e.g. the latest textbook on physics of the solar corona and its active phenomena - Aschwanden, 2006), there are still missing answers to the basic open questions in research of the solar corona. One of the critical factors, which slow down progress in this research branch is ***an absence of measurements of velocity and magnetic fields***, located in the outermost solar atmosphere – chromosphere and corona, performed with sufficient spatial, temporal and spectral resolution. The main reason is that these regions of the solar atmosphere are of a very low density what causes very low flux of the emitted photons leading to low-level acquired signal. Therefore we are still facing the observational confimation of rejection of validity of the teoretically proposed physical mechanisms:

- for heating of the solar corona and its separate structures
- for acceleration of solar wind
- for inicialization and propagation of flares and coronal mass ejections,

- for large-scale disturbances in chromosphere and in corona,
- for relation of colder prominences and the surrounding hot corona.

A comprehensive list of the teoretically proposed physical mechanisms is published in papers of Narain and Ulmschneider (1990, 1996).

The above mentioned observations allowing determination of the velocity and magnetic fields are inevitable and essential for unambiguous results of an astrophysical analysis. This fact is documented both by theoretical arguments (e.g. Judge and McIntosh, 1999, Walsh and Ireland, 2003, Klimchuk, 2006), and also by the first very unique observations obtained although with lower resolution but providing limited information on the velocity and magnetic fields in the corona (Tomczyk at al., 2007). ***The proposed project is actual at most as with a new instrument called „Coronal multi-channel polarimenter“,*** *obtained for the Lomnicky Peak Observatory using the Structural funds of EU for science,* ***we will perform unique measurements of the velocity and magnetic fields in the solar corona and its active structures. These observations will allow a theoretical interpretation inevitable for answering above mentioned open questions.*** Coronal multi-channel polarimeter for Slovakia“ (CoMP-S) is an unigue instrument, one of two existing in the world and the only one of such kind in Europe.

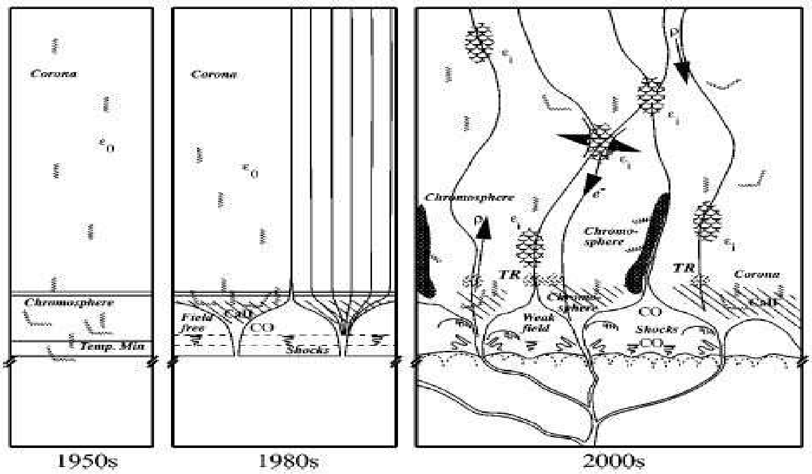

Fig. 1. A sketch illustration on temporal development of imagination on magnetic and dynamic structures in the outer solar atmosphere. From static and homogenous chromosphere and corona we have stepped forward towards a structural and dynamic corona with quantity of dynamic eruptive processes and oscillations (Schrijver, C.J., 2001).

It could seem that the above mentioned measurements can be replaced by measurements of an intergal intesity (intensitygram) of individual emission lines of corona and prominences. Nowadays, such measurements are freely accessible in a large extend and of very high quality. Results of previous studies, based on analysis of intensitygrams of the emission corona, has shown that waves (oscillations of different kind) and eruptive processes (flres of low energies mainly) can play a key role in the mentioned dynamic processes in sthe solar corona and prominences (fig.1). This fact has been confirmed also by results of technically limited spectroscopic measurements of emissionl ine profiles of the corona and prominences (see e.g. review of Wilhelm at al., 2011). Situation is more complicated by a fact, that calculation of a physical model (inversion) from such observables is not unambiguous (Judge and McIntosh, 1999). Therefore for an unambiguous analysis it is inevitable also an inverse process, e.i. determination of observable quantitites from numerical modelling when a consistent model of the solar corona taking into account radiation transfer effects is needed. For such task it is inevitable to have at the diposal direct measurements of the velocity and magntic fields in the outer atmoshere of the Sun. Therefore without spectropolarimetric measurements and their interpretation a definitive solution of the coronal heating problem and accelleration of the solar wind is impossible.

1.2 The scientific level of the project and of the methodologies used during the project

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High scientific level of he project is based on combination of the state-of-art observations of the highest world level from different instruments and their high grade theoretical interpretation.

a) Observational data for solution of tasks will be:

- obtained by a own unigue Coronal multi-channel polarimeter (CoMP-S), (fig.2), installed at the Lomnický Peak Observatory (time series of 2D spektro-polarimetric observations)
- completed in frame of cooperation with complementary data from older instriment CoMP, placed at the Observatory Maona Loa/HAO (Hawaii, USA),
- completed also by additional filtegrams and spectra of the solar corona from observations of the Sun acuired in the UV spectral range by instruments placed at space-born satellites,
- obtained also in frame of own coordinated observing campaigns managed by the team members of the project with the CoMP-S instrument and with instruments placed on the space-born satellites according special demand.

b) In order to keep a high scientific level of the project models of the radiation transfer and configurations of the mangetic fields will be used for interpretation and publications. In cooperation with colleagues abroad, inversion methods and observable quantities as results of numerical simulations of plasma will be available.

Fig.2. The CoMP-S instrument attached to the 20/300 ZEISS coronagraph at the Lomnicky Peak Observatory during the comissioning phase. The camera and filter modules are clearly seen in the right part of the picture.

Nowadays, there exist only 5 ground-based high-altitude observatories devoted to research fo the solar corona (Lomnický Štít/ Observatory/AsÚ SAV, Observatory Maona Loa/HAO, (USA), Sacramento Peak/NSO (USA), Kislovodsk/GAO (Rusko), MICA/OAFA (Argentina)). However only two ground-based observatories are equipped at the moment by instruments for 2D spectropolarimetry of the solar corona (Lomnický štít and Mauna Loa). These instruments will face no analogy in the next 10 years in existing or planned projects of the space agencies for observations of the Sun. Space agencies are preparing at the moment only 2 projects of 2D spectrometers, which should provide (but only in a limited range and specified time interval) measurements of the velocity fields or some components of the full Stokes vector in the solar corona - ASPIICS@PROBA-3 (ESA, 2 years since 2015) and ADITYA-1 (ISRO, India, yet nspecifed lift-off and duration). There is one more instrument for 2D measurements of the Stokes vector of the emission lines of prominences (ProMag, SacPeak/NSO). To summarize the project is based on usage of unique data. Acquisition of them is limited in the nearest period mainly to two ground-based observatories.

Methods used for implementation of the project are the following:

- spectro-polarimetry of structures in the solar corona for determination of the full vector of the magnetic field and determination of the velocity field,
- simultaneous spectroscopy and measurements of the integral intensity of emissions from X-ray to radio spectral ranges by instruments onboard satellites and on the ground-based telescopes
- determination of models of physical parameters with a help of inversion codes and semiempiric 1D-3D NLTE modelling of the radiation transfer.

1.3 The project aims and their feasibility

The main aim of the project is to achieve **new** knowledge **on physics and temporal behaviour of processes** in quiet and active structures in the outer solar atmosphere including their **magnetism and dynamics**. In particular:

a) to determine temporal behaviour of the full vector of magnetic induction (modulus and direction in space) in quiet and active prominences, coronal condensations, spicules, in coronal mass ejections,
b) to analyze the velocity and different large/scale oscillations including Alfvén waves in the corona, promieneces, spicules, coronal mass ejections, possibly flares,
c) to determine physical parameters of oscillations and low-energy flares including consequences of these events for still un/resolved problem of the solar corona heating,
d) to derive influence of temporal variability of the magnetic and velocity fields in the corona for propagation of solar activity phenomena to heliosphere.

The feasibility of aims and objectives is supported by the following facts:

a) we own and operate all year round a unique intrument CoMP-S for 2D spectropolarimetry of the solar corona and active phenomena in it,
b) we have established extended international cooperation with leaders of the research branch (see project and coperation),
c) we are quite optimum team with several senior researchers and also young generation of scientists including PhD student,
d) there is technical background of two electronics engineers which guarantie operation and improvements of the required instruments and computers,
e) development of own programs for data reduction and model and inversion for adequate interpretation of observational data.

1.4 Methodology for the project implementation, justification of its selection and effectiveness of its use

Experimantal methodology:

a) the basic method in the experimental parts of the project is **spectropolarimetry,** i.e. measurement of the full Stokev vector S=(I,Q,U,V) of emission lines originating in the corona and in prominences (fig.3.) with help of which we are able to determine magnetic and velocity fields in the solor corona and its individual structures. These methods are new but technically demanding which are inevitable for fulfilment of the project goals.

$$I = \left\langle |E_x|^2 + |E_y|^2 \right\rangle$$
$$Q = \left\langle |E_x|^2 - |E_y|^2 \right\rangle$$
$$U = 2\left\langle |E_x||E_y| \cos \phi \right\rangle$$
$$V = 2\left\langle |E_x||E_y| \sin \phi \right\rangle$$

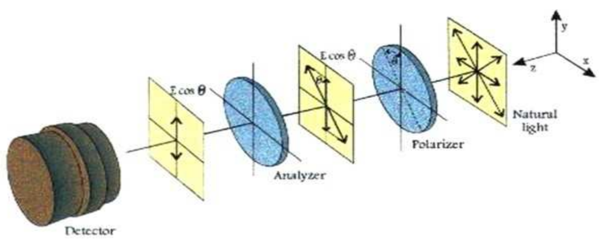

Fig. 3. Definitions of the Stokes vector S and a sketch of spectropolarimetric measurements in solar astrophysics.

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Using our own new instrument CoMP/S, istalled at the Lomnicky Peak Observatory, we can measure the velocity and magnetic fields (full Stokes vector) with a unique precision and resolution world-wide. Uniqueness rely on the facts that we reach an extreme spatial resolution (~1“) and also temporal resolution of the consequitive 2D images (~1s), what will allow to broaden considerably our knowledge about plasma and its temporal evolution in the solar corona, prominences and coronal mass ejections. An illustration of the first observational data obtained by the CoMp-S instrument is shown in fig.4.

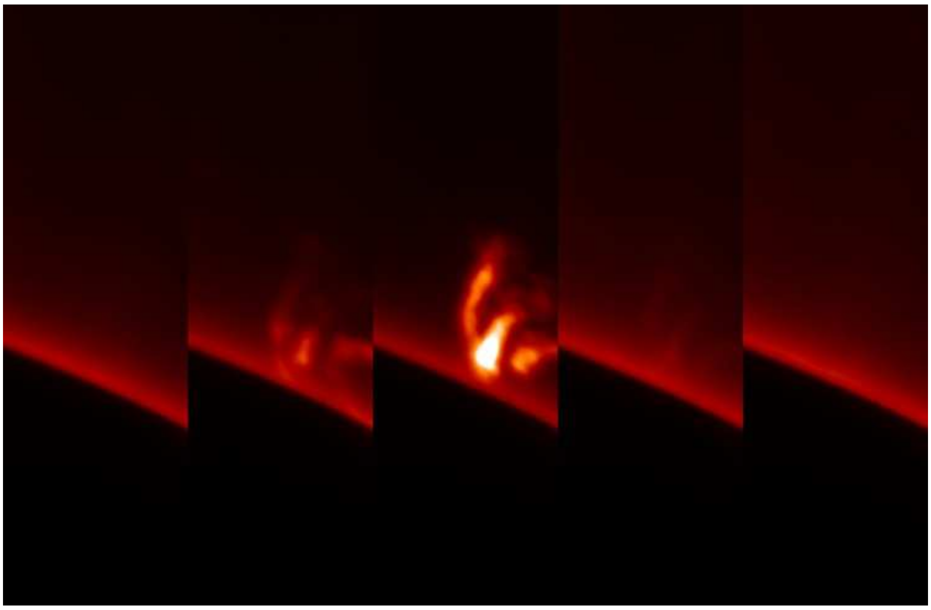

Fig.4. An illustration of the first acuired data of the CoMP-S observations – selection of the FoV with a priminence image measured in the emission line H alpha (656,3 nm). The FoV is repeated in the image for 5 positions of the Lyot filter passband (from left to right) for shifts -0.2, -0.1, 0.0, +0.1, +0.2 nm from the line center. Exposure time was 1s. Images are „raw data“, i.e. data before detail photometric reduction.

b) the project will use also **method of simultaneous coordinated observing campaigns of solar corona and prominences** for extension and complemetarity of the data. Campaigns will cover the CoMP-S instrument with the space-born instruments on satellites (e.g. SDO, Hinode, SoHO, STEREO) as well as with large ground-based telescopes (e.g. SST, VTT, GREGOR, THEMIS), which provide **spectroskopic data and filtergrams**. Access to these instruments we have got guarantied by international collaboration and by project I3 FP7 - INFRA-2012-1.1.26. „Research Infrastructures for High-Resolution Solar Physics“ which is under preparation.

Interpretation methods:

a) the besic interpretation method will be ***1D-3D NLTE modelling*** of the physical properties of promimences and active events in the corona,

b) the next method will be an inversion of the aquired spectropolarimetric data for calculation of the distribution of the magnetic field induction vektor in the coronal structures.,

c) we will develop a new software for an ***analysis of appearence and propagation of waves and oscillations in plasma*** of the solar corona and prominences,

d) statistical methods will be also applied when a sufficient amount of the observational data will be gathered for determination of the basic properties of events and processes in the solar corona,

e) results of our experimental data will be also compared with observational signatures derived from the ***3D magnetohydrodynamic numerical simulations*** perfomed by the theoretical groups abroad.

2. Original character of the project and conceptions of the project implementation

- Specify the originality of the project;
- Describe the suggested conceptions of the project implementation and formulate the scientific hypothesis;
- *Specify the importance of preliminary results, relation of the suggested solution and own published results.*

2.1 Originality of the project

Project is of **high level of originality** as it will bring completely new data of such type and parameters which can be acquired by no other ground-based or space-born instruments nowadays and in the near future.. These new data and their interpretation are fundamental for future progress in research of the solar corona from both experimental as well as theoretical point of view.

Originality of the project is based on usage of the unique instrument located at our all-year-round operated observatory while the project will have the whole observing time at its disposal. The instrument provides measurements of he velocity fields – Doppler shifts, measurements ofthe turbulent motions – not/thermal broadening of the line, and measurements of the magnetic fields – full vector of the magnetic induction, with spatial resolution of ~1“ and cadence of data acquisition ~0.1 s a ~1 s for lines of prominences and corona respectively. Measurements of the emission lines of the corona and prominences will be made by the same instrument.

We expect a significant step forward towards a new knowlegde on behaviour of dynamic phenomena in the solar corona and prominences. (For comparison: spatial resolution of the CoMP/S instrument is 4 times better and temporal resolution 5 times better than the parameters of the only one comparable instrument of such type in operation (CoMP, Maona Loa/HAO, USA).

2.2 Suggested conceptions of the project implementation

The basic conception of the project implementation is an acqusition of the high quality observational data, its reduction and the following theoretical interpretation of the results. (Conception of implementation for particular scientific tasks is given below). Observational program and selection of the targets in the upper solar atmoshere for observations by instrumentation at the Lomnicky Peak Observatory, with supplement from the freely accessible data archives of the space-born instruments (e.g. SDO, Hinode, SoHO, STEREO), will be performed in relation to the planning of the space/born instruments.

For maximum exploitation and a synergetic effect of the accessible observing posibilities we plan to organize and perform simultaneous coordinated observational campaigns of the solar corona and prominences using the CoMP-S instrument, instruments onbaord satellites as well as the ground-based telescopes. Project team members will be leaders of the observing programs and also selection of the targets will be done by the project team members. Project team has got a sufficient experience from several campaigns organized in the past.

The main scientific topics, we would like to deal with in frame of the project, is possible to separate into the following tasks according their focus:

A) Dynamic processes and heating of the solar corona

For explanation of the heating of the solar corona there exist nowadays the following most preferred mechanisms:

- concept of Parker (Parker 1983, 1988, 1994) on nanoflares created in the bended coronal magnetic fieldlines, developed further by Priest et al. (2002) to a more realistic “tektonic” mechanism of heating. Wave mechanism concept is favoured in case of the solar coronal „open“ structures like e.g., coronal funnels and coronal holes (Ofman 2005). Observational signatures of thi mechnism was supported also in our work Gömöry et a. (2006).
- next hypotesis on role of the high frequency MHD waves potential of significant heating of the coronal plasma (napr. Porter a kol. 1994, Aschwanden 2006) could not be confirmed unambiguosly as the particular results are still contradictive (e.g. Pasachoff and Landman 1984, Williams et al. 2001, 2002, Rudawy et al., 2004),
- Alfvén waves, which were detected recently by Tomczyk et al (2007) are the next

candidate for heating of the corona. New confirmations in this way were published just few months ago by McIntosh et al. (2011) claiming that there is sufficient power input for heating of the corona by these Alfvén waves. There was suggested also an alternative interpretation of these observations by van Doorsselaer et al. (2008).

- De Pontieu et al. (2011) summarized arguments in favour of the type II spicules (and their dynamic consequences in the corona) as another possible source/energizer of energy for heating of the corona.

Our aim is an attempts to indetify unambiguosly process(es) causing heating of plasma in the solar corona an in its particular coronal structures on base of the spectropolarimetric observation oby the CoMP-S instrument in cooperation with instruments on satellites and ground/based telescopes including the rediotelescopes providing the complementary measurements, or using the new planned instrument at the second koronagraph of the Lomnicky Peak Observatory (see below).

We wull further continue to compare predictions of the postflare phenomena by the calculated numerical simulations of the dynamic phenomena with real observations as it was done in case of postflare phenomena calculated by Nakariakov et al. (2004) and radio measurements of the type IV burts (Meszarosová et a., 2009).

We will contine with the method developed for analysis of oscillations (described in work of Gömöry et al., 2006) using a extended observational material acquired by the instrument CDS/SoHO.

We will develop an own software analyzing appearence and properties of waves in the time series of 2D measurements of the emission profiles of the spectral lines and/or 2D measurements of the integral line intensity from X-ray to the radio spectral ranges extending properties of the alternative tools (napr. McIntosh, 2008, Tomczyk and McIntosh, 2009, Sych et al., 2010).

B) Nature of the large/scale waves and relation to flares and CMEs

Large-scale disturbances, propagating with the typical velocities ~300 km/s, were discovered using EIT instrument onboard SOHO satellite (Thompson et al., 1998). The first models of the EIT waves described this phenomena as a coronal counterpart of the well know chromospheric Moreton waves. Later on, significant statistical differences were found between Moreton and EIT waves what led to the developing of new models for EIT waves. These can be simply split into wave and non-wave group, where each of these big groups have some observational evidences supporting their validity.

To specify the correct one from the proposed models the plasma diagnostics of the EIT waves (i.e. density, temperature, plasma flows) is very important. Definitely spectroscopic observations of such waves are needed (e.g. Harra and Sterling, 2003). Unfortunately, a complete plasma tool is still missing.

Therefore aim of this task is to realize several runs of the coordinated observing campaign HOP180 of the intruments EIS/Hinode, SWAP, and AIA/SDO, simultaneously with observations of the CoMP-S. This campaign has been already performed once[1]. In this campaign where we combine high cadence spectroscopic observations provided by Hinode/EIS with imaging of the solar corona taken by SDO/AIA. The first HOP 180 observing run was realized during 2011 February 11-17 and the EIT wave was caught on February 16. Analysis of this event is currently in progress but the very first reuslts were already published in paper of Harra et al. (2011).

This task has in mind to analyze also observations of the coronal mass ejections which will not cause detectable large/scale waves. We expect observations of such phenomena during next runs of the campaign.

In order to understand nature of this global dynamic phenomenon in the solar corona there is

1 HOP 180: http://www.isas.jaxa.jp/home/solar/hinode_op/hop.php?hop=018

needed a significantly extended amount of the observational data.

C) 1D-3D NLTE modelling and dynamics of solar prominences

Up to now there si still not well undestood not only process of creation and conditions of prominence stability but also there is unclear what is relation between the coronal cavities surrounding prominences and the broad EUV channels of filaments. Current observations and their interpretation still confirm differences between the mentioned structures in different space and physical parameters (e.g. Gunar et al., 2010 or Schwartz et al., 2006).

The observational aim of this task is therefore to perform observing campaigns of prominences and filaments by the CoMP-S instruments with instruments onbaord satellites and the groud/based telescopes for acqusition of the high quality multi-spectral data for detail spektroscopic analysis of prominences and cavities, which surround them, and/or filaments and their significantly broader EUV channels. A base will consists of satellite observations of the Sun in EUV and X-ray spectral ranges from Hinode and SDO, together with observations od the ground/based instruments – mainly with the CoMP-S at the Lomnicky Peak Observatory and with multi/camera spectrographs MFS and HSFA2 of the AI AV ČR.

Besides new data we plan to improve also numerical modelling of prominences in the way to take into accout also effects of the prominence fine structure and inclination of the line/of/sight to the magnetic field, distribution of mass derived from MHD and to use also variable radiation boundary conditions.

The main interpretation goal is to answer the open question whether the cavity around prominence and EUV broadening of the filament is the same object.

D) Coronal consequences of the chromospheric spicules

De Pontieu et al. (2011) have invoked type II spicules and their assumed disk counterparts called rapid blueshifted events (RBE) as another possible energizers of the solar corona. Soon after, the hypothesis was challenged in Madjarska et al. (2011). We think that much of this controversy is due to different geometries, instruments, diagnostics, and spectral lines employed in De Pontieu et al. (2011) and Madjarska et al. (2011).

We propose to perform coordinated observations at the solar limb by the CoMP-S instrument, for which 2D imaging with a 2D FoV observed simultaneously is an inherent property, with instruments on the space-born satellites (e.g. AIA/SDO).

Besides of this we plan for settling the controversy to carry out also observations similar to that ones which were proposed by Martínez-Sykora et al. (2011). This approach involves the same instruments, diagnostics, and the spectral lines as used in De Pontieu et al. (2011) but supplemented with Hinode/EIS simultaneous observations of the spectral line Fe XII 195. Observations will be done at the solar disk.

Such observations will allow more detail and more definitive answers to question whether on-disk RBEs, observed on the solar disc, and type II spicules, seen on the limb, are identical and do manifest some coronal response or not.

E) Develpment of a new instrument and realization of improvements of instrumentation

Goal of this project is also a taking part on development and realization of a new intrumentation at the Lomnicky Peak Observatory. Project plans to exploit both coronagraphs ZEISS 200/3000 with ***a sufficient coalignment*** of them and with sufficiently precise ***photoelectric pointing*** (precision of pointing better than 2“ in an hour). The coalignment and the pointing ststem will be ready until the end of the year 2012. At one of the coronagraphs the complete CoMP/S instrument will be mounted including the IR cameras, arranged in the year 2012.

For extension of the observing capabilities at the Lomnicky Peak Observatory the team will work on replacement of the current difraction grating spectrograph, used on the second coronagraph for spectrometry of the coronal emission lines. ***New instrument*** with the provisional name ***„Solar Coronal Dopplermeter“ (SCD),*** based on principle of the MSDP spectrometer (Mein, 1991), is in process of development at the moment. The instrument should allow very fast simultaneous 2D imaging of the green coronal emission Fe XIV 530.3 nm line profile. This instrument is planned to be developed within a broader international cooperation with institutes in Great Britain (MSSL/UCL, London, ARC/Queen's University, Belfast), Poland (AI Uni Wroclaw/Wroclaw) and France (Observatoire de Paris/Meudon). The instrument should be developed and produced during the year 2012 and the following installation at the Lomnicky Peak Observatory should be in spring 2013. Budget for production of the instruments is coming outside from the proposed project but the instrument implementation at the Lomnicky Peak Observatory will need finacial support of the project (see below).

The planned couple of the post/focus instruments CoMP-S a SCD would be unique in the world ans it should allow simultaneous spectroscopic observations of the emission corona and prominences sith different cadence needed for diagnostics of different dynamic phenomena, which can not be performed nowadays.

Realization of the scientific tasks

All five above mentioned scientific tasks of the project will be realized in frame of cooperation with institutions abroad, in particular: HAO/NCAR (Boulder, USA), IGAM/Uni (Graz, Austria), MSSL/UCL (London, Great Britain), AsÚ AV ČR (Ondřejov, CR), Hvar Observatory/Uni Zagreb (Zagreb, Croatia), AI/Uni (Wroclaw, Poland).

Cooperation with institutions and teams working on numerical simulations of dynamic phenomena in the solar corona is in progress. Team of the project has made an agreement on cooperation with the leading institution in this branch of research – National center for atmospheric research in Boulder, USA (dr. S. Tomczyk) as well as nonformal cooperation with a group at the Oslo university, Norway (prof. M. Carlsson and prof. V. Hansteen).

2.3 Importance of preliminary results, relation of the suggested solution and own published results

Proposed project is a logical continuation and development of the previous research activities of the project members adapted and extended according evolution of the research in the world. Nevertheless it is on significantly higher qualitative level thanks to possibility to use new, unique instrument CoMP-S at the Lomnicky Peak Observatory and due to progress in handling new interpretation techniques.

Relation of the proposed implementation on own published results

All above mentioned proposed scientific tasks A) - E) logically relate to own published results of the project tem in the past.

Team members have already worked on development and improvements of the instruments (Ambroz et a., 2009) as well as on computational methods for data reduction and their analysis (e.g. Wohl et al., 2002, Meszarosova et al., 2011). The team has been involved in tests and calibrations of the CoMP-S instrument during its preparation as well as after its installation at the Lomnicky Peak Observatory (Kučera et al., 2010).

Member of the team organized a led several observing campaigns using groun-based telescopes DOT, VTT, SST aswell as instruments onboard satellites SoHO, TRACE, Hinode, SDO. For repeated runs there are alredy prepared and testes several campigns like JOP171, JOOP180, HOP088 či HOP180. These activities were popularized also by repeated news published at the web page of the Slovak Academy of Aciences - item „Aktuality“.

Members of the project team in international collaboration have published ***during the last 5 years*** in the research branch related to the proposed project in total ***20 refereed publications in the best journal in the world*** from which we introduce here the most important ones: we have interpreted obtained results of observations of waves at the supergranulation boundary (fig.5., Gömöry et al., 2006), on modelling of prominences using radiation transport and models of its magnetiuc configuration (fig.6, Schwartz et al. 2006, Gunar et al., 2010), on dynamics of spicules (fig.7, Koza et al., 2009), on dynamics of the photospheric G-band bright points (Utz at al., 2010, Bodnárová et al., 2010), on evolution of the coronal flare activity in an active regionv (Wu et al., 2009), on presence and propagation of waves in the post-flare structures on the base of the analysis of the radio emisson of the corona (Meszarosova et al., 2009, 2011).

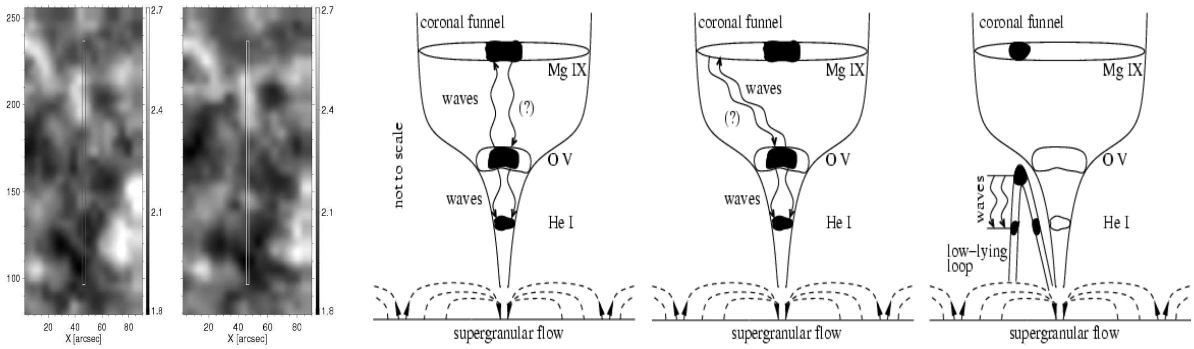

Fig.5. An examle of the observed location on the supergranular boudary (left) and a sketch of the wave propagation (right) between individual layers of the outer solar atmoshere (from paper of Gömöry et al., 2006).

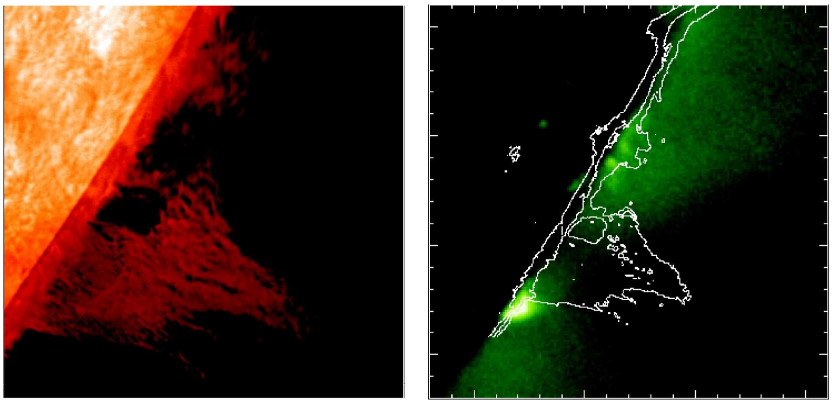

Fig.6. An example of the simultaneous observations of a prominence in the prominence emission line (left) and its coronal cavity in the X-ray emission (right) (from paper of Heinzel et al., 2008).

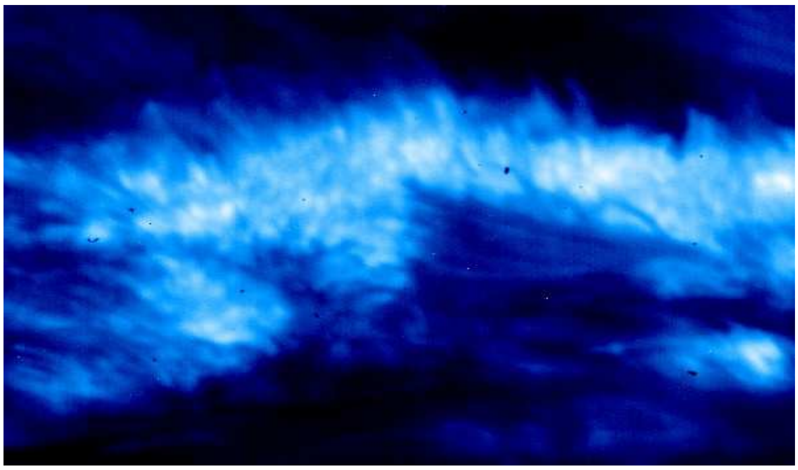

Fig.7. An detail example of the Lyman alpha fibrils at the boundary of the supergranule, taken by the VAULT instrument and analyzed in paper of Koza et a. (2009).

3. The structure of the project, the quality of preparation, the logical interconnection of the project procedures

- Specify the timetable for the project implementation taking into account the logical interconnection of the procedures and meeting the declared aims and objectives;
- Explain the adequacy of the used methodology;

<u>3.1 Timetable for the project implementation and the logical interconnection</u>

Within the project we plan an implementation of different activities. Some of them are logically coupled in time, but other ones are overlapping in time during the project period.

An example of the first type of actions is work on preparation, testing and operation of new instruments at the Lomnicky Peak Observatory (CoMP-S, SCD, coalignment of coronagraphs, pointing system) after which step by step the data acqusition will start. The main instrument of the project CoMP-S will be in the regular operation at the start of the proposed project as its commisioning phase will be finished not later than in spring 2012.

An example of the second type of actions is the data acqusition on satellites idependently without support of the coordinated campaigns, data reduction of such or older observations, or analysis of the previously acquired measurements respectively.

An important factor is the time phasing of the proposed project with the maximum of the solar activity cycle. Maximum of the current solar cycle is expected for years 2013-2014 and offers a higher number of dynamic phenomena, which are the main target of this project.

3.2 Adequacy of the used methodology

Project is based on modern scientific methods of the astrophysical research. Some parts of the methods are completely new and developed in the recent time as e.g., strategy for an acqusition of the spectropolarimetric measurements using the CoMp-S instrument. It is based on simultaneous acquisition of a linear combination of all four Stokes parameters of the emission lines (Tomczyk a kol., 2010). Method of the spectropolarimetry with high spatial and temporal resolution is new and determining progress in solar physics research.

In the first phase of the project implementation we will develop our own new sofware for analysis of the 2D time series of the emission profiles or 2D measurements of the intergal intesities from X-ray to radio spectral ranges for determination of the oscillations properties. New alternative approches will be used (see e.g., McIntosh, 2008, Tomczyk and McIntosh, 2009, Sych et al., 2010). The new sofware will be able to analyse any time series of the 2D data taken by different instruments (e.g.. CoMP-S, AIA/SDO, XRT/Hinode, SOT/Hinode, ALMA, VTT, SST, DOT) and of different kind (e.g. intensitograms, dopplergrams, magnetograms, difference images).

3.3 Schedule of project implementation

A table given below gives a schematic time schedule of the implementation of the work specified in the scientific tasks of the project.

Period	Type of actions
07/2012-12/2013	Improvements, development and extenstions of the observing capabilities at the Lomnicky Peak Observatory
07/2012-07/2013	Developlment of a new software package for data reduction and analysis of data, work related to acreation of a database and data archive
07/2012-06/2014	Preparation of the coordinated observing campaigns of instruments at the Lomnicky Peak Observatory with other ground-based telescopes and space-born instruments
01/2013-12/2015	Data acqusition accordinzískavanie pozorovaní podľa vedeckých zameraní A) - D) at the Lomnicky Peak Observatory and using coordinated observing campaigns
03/2013-12/2015	Handling of data from observing campaigns: redukction of data and their coalignment
06/2013-12/2015	Analysis and interpretation of the acquired data using observational signatures from the numerical simulations and modelling of the radiation transport and configurations of the magnetic structures, preparation of publications
06/2015-12/2015	Work on preparation of the followup projects and cooperations

4. Professional qualifications of the principal investigator

- Specify no more than 5 the most important scientific outputs of the principal investigator during the last 5 years, indicate their importance at both the national and international levels;
- Specify 3 the most important projects implemented by the principal investigator over the last 5 years as follows: the project title, the grants scheme, the implementation period, the project budget, the position of the principal investigator in the project (the main researcher/researcher), explain the importance of the project outputs in both national and international context
- Specify the personality of the principal investigator in the respective field of the basic research (in the context of scientific, as well as scientific and pedagogical outputs) at the worldwide level and/or in the European Research Area, as the case may be.

4.1. 5 the most important scientific outputs of the principal investigator during the last 5 years

1) **„Acceleration in Fast Halo CMEs and Synchronized Flare HXR Bursts“:**
We studied two well-observed, fast halo CMEs, covering the full CME kinematics including the initiation and impulsive acceleration phase, and their associated flares. We find a close synchronization between the CME acceleration profile and the flare energy release as indicated by the RHESSI hard X-ray flux onsets, as well as peaks occur simultaneously within 5 minutes. These findings indicate a close physical connection between both phenomena and are interpreted in terms of a feedback relationship between the CME dynamics and the reconnection process in the current sheet beneath the CME. (Temmer, M., Veronig, A., Vršnak, B., Rybák, J., Gömöry, P., Stoiser, S., Maričić, D., 2008, 'Acceleration in fast halo CMEs and synchronized flare HXR bursts', Astrophysical Journal 673, L95, web výsledkov AsÚ SAV: *http://www.astro.sk/l4.php?rok=2008&id=3*).

2) "Multi-wavelength fine structure and mass flows in solar microflares“:
We studied the multi-wavelength characteristics at high spatial resolution, as well as chromospheric evaporation signatures of solar microflares. To this end, we analyze the fine structure and mass flow dynamics in the chromosphere, transition region and corona of three homologous microflares (GOES class 3 keV) was carried out. EUV line spectra provided by the CDS/SOHO spectrometer are searched for Doppler shifts in order to study associated plasma flows at chromospheric (He I, T~39000 K), transition region (O V, T~260000 K), and coronal temperatures (Si XII, T~2MK). RHESSI X-ray spectra provide information about non-thermal electrons. The multi-wavelength appearance of the microflares is in basic agreement with the characteristics of large flares. We find the flow dynamics associated with the events to be very complex. For all three microflares, multi-component fitting is needed for several profiles of He I, O V, and Ne VI lines observed at the flare peaks, which indicate spatially unresolved, oppositely directed flows of 180 km/s. We interpret these flows as twisting motions of the flare loops. RHESSI X-ray spectra show evidence of non-thermal bremsstrahlung for two of the three microflares. The electron beam flux density deposited in the chromosphere for these events is estimated to straddle the threshold heating flux between gentle and explosive evaporation. (Berkebile-Stoiser, S., Gömöry, P., Veronig, A., Rybák, J., Sütterlin, P., 2009, 'Multi-wavelength fine structure and mass flows in solar microflares', Astronomy and Astrophysics 505, 811, web výsledkov AsÚ SAV: *http://www.astro.sk/l4.php?rok=2009&id=10*).

3) „Tadpoles in Wavelet Spectra of a Solar Decimetric Radio Burst“:
In the solar decimetric type IV radio event observed on 2001 June 13, we have found wavelet tadpole patterns for the first time. They were detected simultaneously at all radio frequencies in the 1.1-4.5 GHz frequency range. The characteristic period of the wavelet tadpole patterns was found to be 70.9 s. The parameters of the tadpoles on different frequencies are very similar and the correlations between individual radio fluxes are high. These tadpoles are interpreted as a signature of the magnetoacoustic wave train moving along the flare loop through the radio source and modulating its gyrosynchrotron emission. (Meszarosova, H., Karlicky, M., Rybák, J., Jiricka, K., 2009, 'Tadpoles in Wavelet Spectra of a Solar Decimetric Radio Burst', Astrophysical Journal 697, L108, web výsledkov AsÚ SAV: http://www.astro.sk/l4.php?rok=2009&id=12)

4) „Multiwavelength imaging and spectroscopy of chromospheric evaporation in an M-

class solar flare“:
We studied spectroscopic observations of chromospheric evaporation mass flows in comparison with the energy input by electron beams derived from hard X-ray (HXR) data for the white-light M2.5 flare of 2006 July 6. The event was captured in high-cadence spectroscopic observing mode by SOHO/CDS combined with high-cadence imaging at various wavelengths in the visible, extreme ultraviolet, and X-ray domain during the joint observing campaign JOP171. During the flare peak, we observe downflows in the He I and O V lines formed in the chromosphere and transition region, respectively, and simultaneous upflows in the hot coronal Si XII line. The energy deposition rate by electron beams derived from RHESSI HXR observations is suggestive of explosive chromospheric evaporation, consistent with the observed plasma motions. However, for a later distinct X-ray burst, where the site of the strongest energy deposition is exactly located on the Coronal Diagnostics Spectrometer (CDS) slit, the situation is intriguing. The O V transition region line spectra show the evolution of double components, indicative of the superposition of a stationary plasma volume and upflowing plasma elements with high velocities (up to 280 km s-1) in single CDS pixels on the flare ribbon. However, the energy input by electrons during this period is too small to drive explosive chromospheric evaporation. These unexpected findings indicate that the flaring transition region is much more dynamic, complex, and fine structured than is captured in single-loop hydrodynamic simulations. (Veronig, A., Rybák, J., Gömöry, P., Berkebile-Stoiser, S., Temmer, M., Otruba, W., Vršnak, B., Pötzi, W., Baumgartner, D., 2010, 'Multiwavelength imaging and spectroscopy of chromospheric evaporation in an M-class solar flare', Astrophysical Journal 719, 655, web výsledkov AsÚ SAV: *http://www.astro.sk/l4.php?rok=2010&id=8*).

5) „Magnetic loop emergence within a granule“:
We investigated the temporal evolution of a small-scale magnetic loop emerging within a granule in the quiet-Sun internetwork. Although direct measurements of the 3D topology and the temporal evolution of such magnetic loops have already been reported in the past, to our knowledge this is the first time that they have been carried out successfully from a ground-based facility (VTT). The ~12 min episode of loop occurrence is illustrated in the Figure. In the early phases, a horizontal magnetic field with a distinct linear polarization signal dominated the emerging flux. Later on, two patches of opposite circular polarization signal appeared symmetrically on either side of the linear polarization patch, indicating a small loop-like structure. The middle part of the appearing feature was blueshifted during its occurrence, which also supports the scenario of an emerging loop. The mean magnetic flux density of this loop was roughly 450 G, with a total magnetic flux of around 3x10^(17) Mx. For unambiguous interpretation of observations we also created a simplified model of a rising loop in 3D. A comparison of the observed Stokes profiles with those arising from a model shows general qualitative (and in some particular cases even quantitative) agreement, proving that the observed event can be explained as a case of flux emergence in the shape of a small-scale loop. (Gömöry, P., Beck, C., Balthasar, H., Rybák, J. Kučera, A., Koza, J., Wöhl, H., 2010, 'Magnetic loop emergence within a granule', Astronomy and Astrophysics 511, article no. 14, web výsledkov AsÚ SAV: *http://www.astro.sk/l4.php?rok=2010&id=4*).

4.2 3 the most important projects implemented by the principal investigator over the last 5 years

1) Project APVV "Heating of the solar corona: observational verification of the physical mechamisms" / "Ohrev slnečnej koróny: observačná verifikácia fyzikálnych mechanizmov", projekt APVV VV-0066-06, 2/2007-12/2009, budget: 2.669.000 Sk, J. Rybák – **principal investigator**, final mark of the project: **excellent.** Web page: *http://www.astro.sk/~choc/open/apvv_0066-06/*

2) Project 7.RP EÚ "EST - the European Solar Telescope" / "EST - Európsky slnečný ďalekohľad", výzva FP7-INFRASTRUCTURES-2007-1 Capacities, Collaborative project, 212482, 02/2008-01/2011, budget: 6 365 718 EUR, leadet at AISAS A. Kučera, J. Rybák – **member of the research team**, web page: *http://www.iac.es/proyecto/EST/*.

3) "Physical mechanisms driving solar microflares and network dynamics fibrils - relevance for coronal heating and mass supply - Dutch Open Telescope", OPTICON Trans-national Access Programme (EU 6FP), 7E1404/2008/055, 10/2008, rozpočet projektu – 1.091.000 Sk, J. Rybák – **principal investigatorľ**, web page: *http://www.astro.sk/~choc/open/08_dot/08_dot.html*.

4.3 Personality of the principal investigator in the respective field of the basic research

Ján Rybák is senior researcher of the Department of Solar Physics of AISAS in Tatranska Lomnica since 1985[2.] He works in 3 areas of solar astrophysics:

- research of solar corona and dynamic phenomena in the corona,
- dynamics of solar photosphere,
- solar activity cycle.

Summary of publication activity and citations of the principal investigator is given in the following table:

Database	Number of papers	Number of citations	h-index	Period
WOS	78	309	10	1985-2011
SCOPUS	82	228	8	1996-2011
NASA/ADS	168	351	-	1985-2011

Ján Rybák has got a lot of experience coordinating extensive international and domestic projects and coordinated observing campaigns. Up to now he organizes several coordinated observing campaigns which led to relevant contrinutions in research of flares, microflares, results were obtained typically in frame of intrnational cooperations - KIS (Freiburg, Germany), IGAM (Graz, Austria), Hvar Observatory (Zagreb, Croatia), MPI (Lindau, Germany), UCL (Londýn, GB), AI Uni Wroclaw (Wroclaw, Poland).

Projects:
Ján Rybák has been **the principal coordinato**r of an international project NSF (USA), the **principal coordinator** of the project APVV 2006 and **principal coordinator** of 3 projects of bilateral cooperation. J. Rybák has been also **the principal coordinato**r of the above mentioned international coordinated observing campaigns supported by projects OPTICON in 6RP and 7RP of EU.

He was **member** of 7 projects of grant agency, **member of the European projekt** EU-7RP 212482 „European Solar Telescope- EST“, and **memberiof the project** EU-5RP HPRN-CT-2002-00313 Europen Solar Magnetism Network“.

Teaching activities:
Ján Rybák performed **11 lecture courses** since 1999 at PrF UPJŠ, Košice and doktorandské FMFI UK, Bratislava, he led **6 diploma works** (PrF UPJŠ, Košice, FMFI UK, Bratislava, UKF, Nitra) a **3 PhD studies** (Gömöry, Tomasz, Bodnárová).

J. Rybák is a vicepresident of JOSO - Joint Organization for Solar Observations, member of IAU – International Astronomical Union, head of NK SCOSTEP and member of NK COSPAR. He is member of board no.2of the grant agency VEGA.

2 Web stránka zodpovedného riešiteľa: *http://www.astro.sk/~choc/index.html*

5. Professional qualifications of the research team

- Describe the competence of the participating research organisations with regard to the submitted project;
- Describe the competence of individual researchers for the solution of the submitted project and fundamental tasks during the project implementation; (this does not concern the project manager);
- Describe the manner of co-operation of researchers and their mutual complementarity and substitutability during the project implementation;
- Describe instruments, equipment and personnel infrastructure of the workplaces participating in the project implementation
- Describe the level of engagement of young researchers up to 35 years including postgraduate students from the respective field of research and development in the project implementation.

5.1 Competence of the participating research organisations

AISAS in Tatranská Lomnica is leading institution of the astronomical and astrophysical research in Slovakia. AISAS is the principal investigatorv of two Centra of excellence: „Centra kozmických výskumov: vplyvy kozmického počasia" a „Centra kozmických výskumov: vplyvy kozmického počasia - druhá etapa".

Department of solar physics of AISAS has got broad international cooperation based on projects, cooperations and personal contacts.

AISAS has the inevitable infrastrukture (instruments, computers, networks) for performance of high level scientific research.

5.2 Competence of individual researchers

Team of the project consists of two senior researchers, one of them has got extensive experience in the research field a with leading the scientific projects. Other three younger researchers are after PhD degendence and they already finished long-term post-doc stays abroad, several short-term stays abroad, and several schools for young astronomers. Next two members are electronics engineers and one of them has just started his PhD study related to the instrument CoMP-S. One member is and researcher but at the same time the system administrator of the AISAS and he will take care for needed software, database and system support of the project. The last member of the team is an assistand and at the same time PhD student.

Scientific researchers in the project has got long-term experience with a scientific research including the development of the instruments, performing of observations, reduction of data and development of the software, modelling of the physical parameters in the plasma , publication in the world-class astrophysics journals.

Majority of the team mebers have alredy participated in another scientific project of the Grant agency APVV.

Competence of individual researchers and the basic duties:

RNDr. Aleš Kučera, CSc. principal investigator of 7 VEGA projects, principal investigator of four projects of 5., 6. a 7. RP EU, member of several international scientific organizations, member of 2 scientific boards of journals, member of SOC and LOC of 12 international conferences. He has got long-term post-doc stay at the Kiepenheuer-Institute for Solar Physics, Freiburg (Germany). He was supervisor of 2 PhD students and 4 diploma students and2ddoktorandovhe has given in years 2001-2011 13 lecture courses ob „Physics of the Sun" PrF UPJŠ in Košice. Published papers: 120, CC papers: 23. Citacions: more than 160. Web page: http://www.astro.sk/~akucera/.

Basic duties: vide principal investigator, scientific research: observations, data reduction, presentation of results.

Mgr. Július Koza. PhD. scientific researcher, projects: Marie-Curie EU stipendium FP6-2002-Mobility-5 N° 011379-MULTIDOT (2 years, University Utrecht, The Netherlands), beneficier of the reintegration project FP6-2007-MERG-CT-2007-046475, short stays (IAC, LA Laguna/Spain, ITA, Oslo/Norway KIS, Freiburg/Germany), scientific orientation: detail structure of chromosphere and transition region, scientific papers: 18, CC papers: 6, leading practica for students of PrF UPJŠ, lectures for public, popular science papers to journals, web page „Astronomické novinky" of AISAS, principal coordinator of the projekt 6.RP EU VENUS TRANSIT 2004 in Slovakia, čmewmber of LOC and SOC of scientific conferencesí, price of SAS for popularization. web page: *http://www.astro.sk/~koza/*.

Basic duties: scientific research: – mostly scientific task D): observations, data reduction, interpretation and presentation of results.

Mgr. Pavol Schwarz, PhD. senior scientific researcher, after the several year post-doc stay at AsÚ AV ČR in Ondřejov, short stays abroad (Observatoire de Paris/Meudon), scientific orientation: modelling of radiation transfer and magnetic configurations in prominences and developments of the semiempiric modelling codes for plasma diagnostics, scientific papers: 18, CC papers: 8,8.

Basic duties: scientific research: – mostly scientific task C): observations, data reduction, interpretation and presentation of results, development of the semiempiric modelling codes for plasma diagnostics.

RNDR. Richard Komžík, CSc. scientific researcher of Stellar department of AISAS and at the same time the system administrator of AISAS, leader of the SANET local gate, scientific orientation: operating systems and computer, database and archive applications for astrpohysics.

Basic duties: operating systems and computers, database and archive applications for observations and data reduction.

Ing. Jaroslav Ambroz. assistant – electronics engineer, the system administrator of AISAS, scientific orientation: hardware a software of computers for operation and control of the astrophysical observations.

Basic duties: operating systems and computers, creation of computer applications for control of the astrophysical observations.

5.3 Manner of co-operation of researchers

Team of the project works together in fact already in roughly the same shape for several years.. Work on preparation of observations, their support and performance is a highly team work which requires a close cooperation. The team shares together informations, software and experience of each member of the team. Besides public colloquia of AISAS the team holds regular meetings and exchange of informations on internal meetings of the working group of the Lomnicky Peak Observatory. In frame of project we plan to perform quaterly meetings of the project team.

5.4 Instruments, equipment and personnel infrastructure of the workplaces

Instrumentation infrastructus of institute

Institutes runs since 1962 the high-altitude observatory Lomnicky Peak which is at present one of 5 ground-based observatories devoted to observations of the solar corona in the world. Instrumentation is at the moments at the world-class level (CoMp-S instrument, servers, data storages, pointing system in preparation, coalignment in preparation). The above mentioned improvements are maily from the Structural funds of EU for science.

Long-term sttistics of astroclimate shown that there is sufficient number of observing days for observations of prominences (~1/3) and the solar emission corona (~1/5) (Rybák et al., 2010).

In headquarters of AISAS there is available suffcient computer capabilities for reduction and analysis of observational data including the software licences (multilicense of IDL, SolarSoft). AISAS owns a mechanical and elektrotechnical workshops with the basic equipment for preparation of new and profylactics of existing instrumentation. The institute has a large library with acess to all important scientific journals and books.

Personal infrastructure

AISAS has 27 researchers (1 professor, 5 DrSc., 22 CSc/PhD.) There are for support work 3 electronics engineers, 3 system administrators, and 5 assistant observers. Description of personal structure of the project is given in sections 5.2 a 5.5.

5.5 Describe the level of engagement of young researchers up to 35 years

The team of the project has 3 members under the age limit of 35 years (from 9 members in total):

Mgr. Peter Gömöry, PhD., scientific researcher of AISAS (1979). He passed 2 shools for young solar physicists, several short-term stays abroad (AIP/Potrdam (Germany), Astronomical Institute, Uni Utrecht, (The Netherlands), IAS/CNRS, Orsay (France)), two-year post-doc stay (IGAM/Uni Graz, Graz, Austria). He has taken part at several observational campaigns organized by AISAS and by IGAM/Uni Graz, Graz (Rakúsko). He is the first author of 2 scientific papers and co-author of another 5 papers in the wold-class journals. He has lecture course at the PrF UPJŠ in Košice „Upper solar atmosphere and solar-terrestrial relations“. Peter Gömöry is also populariz astronomy mostly by lectures for public auditories (member of two popularizing grants of APVV). Web page: http://www.astro.sk/~gomory/.

Ing. Matúš Kozák is an assitant – electronics engineer of AISAS 91985). Since 2011 he is a PhD student as well - Fakulta elektrotechniky a informatiky, Technická univerzita Košice, topic: "Handling of signals obtained by observations of the solar corona", supervisor: prof. Ing. Dušan Kocur, CSc.. This work is completely related to his work within the project on development, realization and tests of the observing instrumentation at the Lomnicky Peak Observatory as well as its electrotechnical and computer support.

Mgr. Marcela Bodnárová works as an assistant of AISAS and at the same time she is the PhD student of FMFI UK in Bratislava but supervised at the AISAS (1985). Topic of her PhD study is "Atmosphere of the quiet Sun and heating of the solar corona", supervisor: J. Rybák, start of her studies: 1/9/2008. She is the first author of one refereed publication so far.

Members of the project team regularly issue topics of the PhD studies closely related to the scientific tasks of the project. For the school year 2011/2012 there were 4 topics available (http://www.astro.sk/l3_sk.php?p3=phd). In this activity the project members will continue innovating the topics yearly.

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