Characteristics of main research directions investigated at the institute and the achievements 2010−2014

Institute	Astronomical Institute of the CAS, v. v. i.

Research in Astronomy and Astrophysics has a long and internationally recognized tradition in the Czech Republic, formerly Czechoslovakia. The Astronomical Institute of the Academy of Sciences of the Czech Republic (the "Institute", hereafter) is the largest scientific institution in the field, involved also in educational activities and students supervision in the country. The Institute is traditionally active in solar physics, stellar and galactic astrophysics, and studies of interplanetary matter. Four Science Departments represent active research directions. These are led by Senior Research Scientists.

The Astronomical Institute of the Academy of Science of the Czech Republic is the foremost Public Research Organisation (v.v.i.) in the field. Its major part is located in the village of Ondřejov southeast of Prague, where it operates the largest Czech optical telescope and a variety of other instruments. Part of the Institute is placed in a detached section Prague. While the Organizational Structure of Institute has been stabilized since the major reorganization in early 1990s and an update in 2005, there exists a procedure involving the Director and the Institute Council which allows for modifications to be considered in case it might turn out to be desirable and substantiated in the future.

The Institute is one of the oldest scientific institutions in Czech lands, and it is a modern scientific institution. As a direct successor of Prague Clementinum, the Ondřejov observatory was established by Doctor J. J. Frič near the village of Ondřejov back in 1898. Since then it has been gradually developed to its current role as a significant player in the Czech scientific environment.

The Institute profile, its research activities and basic results and financial operation are described in Annual Reports, which have a structure defined by legal requirements, and in Activity Reports published bi-annually (English Edition). Further information can be found Annual Reports of the Academy of Sciences (available in both Czech and English Editions). Finally, the Institute has recently formed a renewed website (http://www.asu.cas.cz), which is also dedicated to the general public and youth.

In four Science Departments (Teams) the research staff of the Astronomical is primarily engaged in solar physics, stellar physics, meteors and asteroids, and galaxies and extragalactic objects. As a main academic institute in the field of Astronomy and Astrophysics in the Czech Republic, we examine the objects and the effects from the immediate vicinity of the Earth to the remote Universe. Variety of instruments is in daily use at the Observatory for different kinds of investigations and observational programs, suitably selected for the local conditions. The Institute operates the largest telescope in the Czech Republic – the Perek telescope for spectroscopy of stars. The other devices are mainly devoted to photometry of asteroids (near-Earth objects in particular), multichannel spectroscopy for monitoring solar flares, solar patrol service program and solar radio monitoring, a photographic zenith telescope, a robotic telescope for recording the optical counterparts of gamma-ray bursts within the network, and automated cameras to track bolides.

The scientific life of the Institute is organized within four Departments. These are equivalent to Teams for purposes of the present Evaluation:

Department of Solar Physics (Team #1, head RNDr. Michal Sobotka, DSc.) focuses on processes both in active and quiet solar atmosphere. Active processes affect the entire outer space including the Earth and its immediate environment (i.e. the space weather). At the Ondřejov Observatory, a long-term systematic study is carried out of the Sun in optical and radio wavelengths of electromagnetic radiation, and these observations are supplemented with the data gained thanks to the international cooperation from satellites providing information on solar radiation in the ultraviolet, X-ray and gamma-ray bands of the spectrum. Solar flares and prominences, structure and dynamics of the solar atmosphere and heliosphere, and space weather are examined. Processes in solar flares and prominences are numerically modelled with the particular emphasis on magnetic reconnection and the particle acceleration mechanisms. Regions of the Sun at different altitudes are studied in order to understand the interaction between the motion of plasma and the magnetic field. The dynamic phenomena of the solar wind are monitored, especially the formation and propagation of coronal mass ejections and their associated magnetic clouds, as well as the interaction of the solar wind with the solar system objects.

Department of Stellar Physics (Team #2, head RNDr. Miroslav Šlechta, Ph.D.) studies the stars, especially the stellar winds and outflows, double and multiple stars, with the emphasis to their evolution, interaction and mass exchange in close systems. The research mainly concerns the class of hot stars (especially the spectral class B). These are highly luminous bodies, often showing the presence of a circumstellar disc of accreted material. The formation and physical characteristics of accretion discs are not yet satisfactorily explained. Their research is divided into a practical study of stellar spectra and a theoretical investigation of the atmospheres and stellar winds using the sophisticated numerical simulations. The studied spectra are acquired by the two-meter telescope in Ondřejov and at other observatories thanks to the international cooperation (mainly in the framework of our membership in the European Southern Observatory – ESO, and elsewhere within the collaboration). The Department also deals with the study of the white dwarfs, their classification and determination of basic physical parameters of the acquired spectra. The Department is involved in the European Space Agency (ESA) Gaia satellite to systematically measure precise positions, brightness and radial velocity of billions of celestial objects. There also is an ongoing research of galactic and extragalactic cosmic sources of high-energy radiation in visible light and in the field of high-energy radiation, namely, flashes of gamma radiation and their optical afterglows.

Department of the Interplanetary Matter (Team #3, head RNDr. Pavel Spurný, CSc.) conducts research of the small objects of the solar system, namely, meteoroids and asteroids. The department studies the interaction of the interplanetary objects of various sizes with the Earth's atmosphere, observes meteors and works on theoretical interpretation of observations. The team contributes and employs the European Fireball Network, which was founded by the Astronomical Institute and it continues to be organized by the team. It also participates in similar projects of the Bolides Network in Australia. Both of these networks generate highly visible results – the so-called Meteorites with genealogy. The observed data are used for the study of the physical processes during meteoroid penetration into the Earth's atmosphere, which includes radiation, ionization, and fragmentation. The physical characteristics and chemical composition of various types of meteoroids are determined, as well as their origin and distribution in the solar system, their relationship to comets, asteroids and meteorites. Furthermore, we study non-gravitational processes in small asteroids, binary systems and paired asteroids, and asteroids in excited (non-principal) rotation states. We also observe so-called Near-Earth Asteroids and their source regions.

Department of Galaxies and Planetary Systems (Team #4, head Prof. Jan Palouš, DrSc.) studies the evolution of the isolated galaxies, galaxies in groups and clusters, the formation of stars and stellar systems. The team explores the dynamics of the Milky Way galactic system – Magellanic Cloud, also free gas blown from galaxies due to their movement in the environment and spatially resolved spectroscopy of galactic nuclei. Observations in radio, infrared, ultraviolet, and X-ray bands are compared with the results of analytical models and computer simulations of gravitational and magnetohydrodynamic processes. The team scientists are devoted to physics of compact objects (neutron stars and black holes) and study processes taking place in their vicinity. On the theory side, within the framework of the General Theory of Relativity the characteristics of the compact objects are analyzed and modelled, in particular, the nuclei of the active galaxies, neutron stars and microquasars. Modelling of multiwavelength characteristics of the produced electromagnetic signal is performed for spectra, polarization and temporal variability.

Furthermore, as another research line, part of the team studies the rotation of the Earth, orientation of its axis in space and the gravitational field.

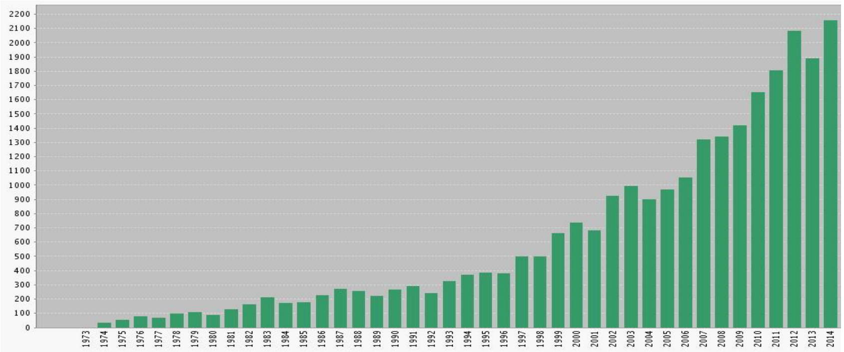


Figure 1. Numbers of yearly citations (since 1973) to papers published by the authors with the Institute affiliation. These demonstrate a gradually growing impact of the astronomers working at the Institute (source: Web of Science).

Steadily growing impact of scientific publications of the Institute's researchers is seen in Figure 1. Let us note that for Phase I of this Evaluation (bibliometry) we selected only a fraction of relevant publications where the role of our scientists is clearly demonstrated by their leading position on the author list. However, our scientists frequently join large consortia, where the Institute contributes in cooperation with many other international institutions. This is particularly important in preparations for space missions (e.g. White Papers on proposed satellites, often with hundreds of co-authors). In these cases the authorship is less visible, nevertheless, such activities are also highly important for future development of Astronomy and its technological basis.

The above-mentioned Science Departments – Teams are further sub-divided in total of ten Working Groups, where the actual research activities are carried out: see the Organizational Structure of the Institute. The Director establishes working Groups following a discussion in the Institute Council. Each of the Working Group is lead by a distinguished senior researcher with a supervision and management record. A more thorough exposition of scientific activities and results are thus given in the description of the individual Teams elsewhere.

A strong aspect of the Institute performance is its extensive international collaboration. Regardless of the difficulties in establishing international contacts before 1989, the Institute is now internationally recognized as a leading research organization in the field of Astronomy and Astrophysics. Since the General Assembly of the ***International Astronomical Union*** (IAU) in Prague in 2006, the Institute organizes numerous international meetings and symposia. While Prof. Jan Palouš continues to serve as IAU Vice-President, preparations have just started for the forthcoming European Week of Astronomy and Space Science as a major event to be held in Prague 2017.

In 2008 the Czech Republic became a regular member of the ***European Space Agency***, ESA. This membership was a successful ending of long-lasting negotiations with ESA representatives and preparation on the Czech side. During that preparatory period scientists of the Institute have been helping with organizational matters related to space research. Since then the Institute plays a visible role in the space research in the Czech Republic which helps us to build long term strategic partnerships between Industry and academia. The Institute continues to have representatives in the national Board for Space Activities, in the Board of Directors and Supervisory Board of the Czech Space Office, in the Czech PRODEX Board, in the Board of Space Activities of the Czech Academy of Sciences and in the Coordination Board of the Minister of Transportation. The ESA membership has opened new broad possibilities especially in the field of space-related sciences.

Observations from above the Earth atmosphere have had a crucial importance for astronomy and astrophysics since the very beginning of the Space Age. Therefore the Astronomical Institute of the Czech Republic has been involved in many space projects. For example, a new type of micro-accelerometer was developed and placed aboard the US Space Shuttle Atlantis, and a hard X-ray spectrometer was launched on the US Air Force satellite MTI where it successfully observed during three years. Micro-accelerometer know-how was transferred and that enabled companies to receive contracts with ESA-ASTRIUM, and to manufacture micro-accelerometers for three ESA satellites SWARM launched in 2013.

Tab. 1: Astronomical Institute in the context of Czech membership to International Astronomical Union (total 109 members as of 2012)

Astronomical Institute, Academy of Sciences	**54**
Charles University in Prague	18
Masaryk University in Brno	7
Silesian University in Opava	5
Technical Universities and other institutions of higher education (ČVUT, VUT, UJEP, HK)	5
Institute of Physics, Academy of Sciences	3
Public observatories	3
On leave of absence abroad	3
Other	11

Note: the ratio of population numbers with respect to the number of professional astronomers in several countries: F 65288/775=84, CZ 10505/109=96, GB 63495/657=97, USA 312781/2571=122, D 80328/632=127, PL 38538/159=242, RO 20096/31=648.

In 2011 ESA approved the Solar Orbiter (M2-class mission by ESA) and the work on phases C/D of the satellite construction started. We have participated in three international consortia to build the scientific payload instruments METI S (UV coronagraph), STIX (hard X-ray telescope) and RPW (in situ radio plasma-wave detector). The launch is expected in 2018. Also the formation flight project Proba-3, with a large externally occulting coronograph, is on track entering the production phase. The Institute scientists continue with their involvement in Gaia, GOCE, XMM and other ongoing projects of ESA. Recently the CLASP polarimetry mission of JAXA and NASA space agencies was approved, with the Institute's participation.

Within the ***European Southern Observatory*** (ESO), new opportunities for observations with the largest telescopes emerge and ongoing individual programs are submitted and carried out at VLT. Also, the Institute has signed an agreement between with ESO and Copenhagen University on the usage of the Danish (1.5 m) telescope at La Silla for successful asteroid research and stellar photometry.

The Institute takes an active role also in promoting all aspects of ESO membership in the Czech Republic, scientific as well as industrial. To this end a dedicated http://www.eso-cz.cz website is supported. In 2014, ESO hosted an industry event for Czech businesses at its Headquarters in Garching, where the meeting representatives of interested Czech companies and institutions were offered information about ESO, given an introduction to the E-ELT and presented potential opportunities that are available to take part in its industrial activities.

ESO has established one of European ALMA (Atacama Large Submillimeter/millimiter Array) nodes in Ondřejov, which provides expertise mainly for the solar physics community. The Institute proposed a new ALMA-CZ Research Infrastructure at 2014, and it is currently at a promising stage of negotiations for funding. ***The European ARC (ALMA Regional Centre)*** has been formed as a coordinated distributed network of seven nodes centered around ESO. One of the nodes is hosted at the Astronomical Institute of Academy of Sciences in Ondrejov. The Czech node provides services namely in ALMA-related research in solar physics and laboratory millimeter spectroscopy. In these areas it serves the ALMA user community in the Czech Republic and entire region of Central and Eastern Europe. In the solar research with ALMA this expertise is unique even at the European scale. Partly it serves also international community from Brazil and Chile (ALMA location). The services provided to the users range from help with proposal preparation (Phase I), negotiation of technical details of the project with the observatory (Phase II), data reduction and imaging (QA2) up to help with data analysis and interpretation. At the same moment the Czech node helps with further development of ALMA in commissioning of the new solar observing mode. In fulfilling its tasks the Czech node is closely collaborating with ESO, partner nodes in Europe, ARCs at NRAO and NAOJ, Joint ALMA Observatory (JAO) and also with academic institutions in the Czech Republic.

The ***European Fireball Network*** (EN) was established in former Czechoslovakia in 1963 and its current updated version represents the longest continuously operational fireball network in the World. The center of EN is located in Ondřejov and the Institute coordinates all its activity. At present it consists of eleven stations in Czech Republic, fourteen stations in Germany and two in Slovakia and Austria. Within the scope of this experiment we closely cooperate with our colleagues in Comenius University in Bratislava, who operate four video all-sky systems in Slovakia, and with several amateur groups active in the Netherlands, Poland, Slovenia, Croatia, Austria and Hungary. Recently, all ***Czech stations*** have been equipped with the very sophisticated instrument for optical observation of fireballs, the Autonomous Fireball Observatory (AFO). In the last three years the new instrument for fireball photography, the Digital Autonomous Fireball Observatory (DAFO) has been developed and gradually installed at all Czech stations. These modern and fully automated instruments significantly increase the efficiency of our observations and precision of the acquired data. Fireball spectra are simultaneously photographed at the Ondřejov Observatory. We also participate in the project of the Desert Fireball Network (DFN) in Australia equipped with AFO, and we analyze data from this remote experiment. We have continued to use the double station (Ondřejov–Kunžak base) video observations of faint meteors. Our goal in this research has been not only to monitor the activity of known meteor showers but also to look for unexpected events. In case of predicted outbursts or enhanced activity we promptly adjust our observational program. For this purpose we use an automatic double station MAIA cameras as well as original manual video cameras.

Examples of approved ESO observing programs for 2012 in which scientists of our Institute took part.

Project name	Telescope/Instrument	Scientist
Triggered Star Formation in the Carina Flare supershell	APEX/SHFI	J. Palouš, P. Jáchym, V. Sidorin, R. Wünsch
Star formation in the assembling cluster complex RXJ1347-11 at z=0.45	UT1/FORS2	I. Orlitová-Stoklasová
Abundances analysis of new DAZ white dwarfs	UT2/X-Shooter	A. Kawka, S. Vennes
Hot subdwarf binaries in the GALEX survey	NTT/EFOSC2	S. Vennes, A. Kawka
The magnetic field structure of white dwarfs	UT1/FORS2	A. Kawka, S. Vennes
Properties of rare double degenerates: A new class of nitrogen-polluted DQ white dwarfs?	UT2/X-Shooter	S. Vennes, A. Kawka
Photospheric signature of accreted material onto cool, old white dwarfs	UT2/X-Shooter	A. Kawka, S. Vennes
Resolving the inner dusty disk structure in the core of the evolved object Hen 2-90	VLT/MIDI	M. Kraus
Probing the mass-loss history and the evolutionary phase of massive evolved stars	UT4/SINFONI	M. Kraus
CO observation of ram pressure stripped galaxies ESO137-001 and ESO137-002 in A3627	APEX/SHFI	P. Jáchym
The study of the characteristics of the dusty disk around CPD-52 9243	VLT/MIDI	M. Kraus
Study of non-gravitational asteroid evolution processes via photometric observations	DK154	P. Pravec, P. Scheirich, A. Galád
Systematic observations of fields near the South Ecliptic Pole for calibrations of Gaia satellite measurements	DK154	P. Koubský, V. Votruba, P. Škoda

Tab. 2: Examples of successful observational programs carried by the Institute astronomers with ESO instruments.

Furthermore, we study rotational properties of asteroid pairs. Recently, we measured 35 pairs with our technique of time-resolved photometry. Most data were taken with the 1-m telescope at Wise Observatory, Israel, and the 1.54m Danish telescope at La Silla, Chile. We derived their primary spin and mass, and we found a strong correlation between the square of primary spin frequency and the mass ratio. Also, the 0.65m ***Ondřejov photometric telescope*** has been refurbished and it is remotely controlled and works in a semi-automatic mode. It is used for photometry of asteroids in the vicinity of the Earth and in their source regions in the asteroid main belt. It serves as a supplementary instrument for the 1.54m Danish telescope at ESO's La Silla station, within our project on non-gravitational processes in asteroids.

The Solar Activity Monitoring and Forecasting (http://www.asu.cas.cz/~sunwatch/) unit provides regular solar observations in the white light and the Hα line. It uses three small full-disc telescopes for drawings, white light, and Hα and two 20cm telescopes for imaging of active regions in the photosphere and Hα chromosphere. The results are shared within the International Space Environment Service (ISES) as a part of the Regional warning Centre Prague (station No. 31516), and the Solar influences Data Centre (SIDC) in Brussels. In addition to solar observations, the unit collects all the accessible data on the actual state of solar activity. Daily and weekly forecasts are compiled. Apart from the scientific usage, these are presented in the Czech Television as a part of daily weather forecasts. The solar-activity forecast, made in Ondřejov since 1978, is a national service and represents an integral part of the international space weather program.

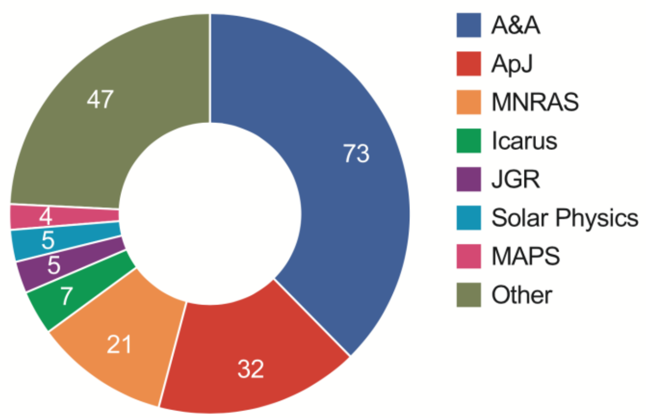


Figure 2. Number of scientific papers published in various professional journals by the Institute scientists, over a two-year period.

Teams of the Institute at the Ondřejov site as well as abroad pursue other important programs. These include an active involvement in the recently established EAST (European Association for Solar Observations) Organization as well as an active participation in large solar projects ***GREGOR***, the largest European solar telescope, where the Institute takes part under a bilateral agreement with the Leibniz Institute for Astrophysics. This has opened an opportunity for the Czech solar community to obtained the leading-edge data. The 1.5-m solar reflector, located at Observatorio del Teide, Tenerife, was developed and built under the leadership of the Kiepenheuer Institute for Solar Physics in Freiburg with the Leibniz Institute for Astrophysics Potsdam, the Institute for Astrophysics Göttingen, and the Max Planck Institute for Solar System Research in Göttingen as German partners and with the Instituto de Astrofísica de Canarias and the Astronomical Institute of the Czech Academy of Sciences as international partners. The telescope is designed for observations of the solar photosphere and chromosphere in the visible and near infrared and equipped with a high-order adaptive optics. It was inaugurated in 2012 and has started in early 2014 its “Early Science” phase with access restricted to the GREGOR partners. At this moment, there are three post-focus instruments: the broad-band imager, the GREGOR Fabry-Perot interferometer (GFPI), and the grating infrared spectrograph (GRIS). Members of the Solar Department took part in the installation and alignment of GFPI since 2011 and in three campaigns of Early Science observations.

Following a significant upgrade of the ***Zeiss Photographic Zenith Tube*** (PZT), the system is controlled remotely and works in a fully automatic mode. PZT is used for monitoring non-polar and non-tidal deflections of the local vertical caused by changes of mass distribution in near and distant surroundings. To obtain the full vector of gravity, we complete our observations of direction of local vertical with the observations of gravity acceleration performed at nearby located absolute and superconducting gravimeters of the Geodetic Observatory Pecný. Thanks to the achieved accuracy of PZT observations, our instrument can also serve as a reference station for the new mobile zenith cameras developed recently over the world.

International collaboration of the Institute is very broad, and this is reflected by the position of Director’s Deputy for International Relations in the Institute Management scheme. Natural focus of the cooperation goes toward European countries and institutions, which however reach far beyond the traditional definition of Europe (for example the European Southern Observatory is located in Chile and includes several Southern American countries). Over the evaluation period the Institute has been active in the ***ASTRONET*** network to shape the influential Roadmap for the future directions of Astronomy research in Europe, its planned infrastructures and personnel aspects. Furthermore, special projects cover joint research work of the Institute astronomers with the U.S. scientists (e.g. the scientific participation in Space Research performed within NASA programs or a continued research done jointly with collaborators at Massachusetts Institute of Technology or the Smithsonian Center for Astrophysics). More recently a promising opportunity has emerged within the Czech Academy and Chinese Academy of Sciences mutual cooperation scheme, and we actively pursue this path.

In addition to existing inter-academy agreements, the Institute has established a number of ***international cooperations*** and declared Memoranda of Understanding with relevant institutions and societies active in Astronomy and Astrophysics worldwide. These include:

- *Astronomical Institute of the Slovak Academy of Sciences*
- *Max-Planck-Institut für Astronomie in Heidelberg*
- *European Southern Observatory (ESO)*
- *Hvar Observatory of the University of Zagreb*
- *Faculty of Mathematics of the University of Belgrade*
- *Fachhochschule Nordwestschweiz in Windisch*
- *Institut für Physik in Graz*
- *Shanghai Astronomical Observatory*
- *Niels Bohr Institute in Copenhagen*
- *National Astronomical Observatory of Japan*
- *Leibnitz-Institut für Astrophysik in Potsdam*
- *Physikalische Institute der Universität zu Köln (Cologne)*
- *Center for Theoretical Physics of the Polish Academy of Sciences in Warsaw*

Among numerous ***domestic cooperations*** we can select the following formal agreements:

- *Agreement on scientific collaboration and joint accreditation of doctoral program in Theoretical Physics, Astronomy and Astrophysics with Charles University in Prague (Faculty of Mathematics and Physics)*
- *Agreement on scientific collaboration and joint accreditation of doctoral program in Theoretical Physics and Astrophysics with Masaryk University in Brno (Faculty of Science)*
- *Agreement with Research Institute of Geodesy, Topography and Cartography (Public Research Institution) in Zdiby about mutual cooperation in Geodesy, Astronomy and Astrophysics*
- *Agreement with the Czech Technical University in Prague about cooperation in experimental cosmic research*
- *Agreement with Institute of Atmosphere Physics (Public Research Institution) in Prague on shared use of supercomputing resources*
- *Partnership with ESERO Consortium – ESA Education Office in the Czech Republic*

In addition to formal agreements, as an example of (one of many) successful scientific results obtained in an informal cooperation of our researchers, we mention the Press Release from the Gemini observational program carried out by one of our Teams, which has been included among Science Highlights and elected by the Institute Council as among five important published results (see below).

The above-mentioned agreements and ongoing supervision of students prove that the Institute has established ***strong links with universities***, namely those in Prague, Brno, Opava, Ústí nad Labem, Plzeň, and Liberec. The Ph.D. program is based on accreditations approved by the Ministry of Education, Youth and Sports (MŠMT) and mutual agreements about collaboration with Charles University in Prague, Masaryk University in Brno, and other. Scientists are involved in teaching on the level of Master ("magister") and Ph.D. ("doctoral") programs. The Institute has four Full Professors, as well as Associate Professors (Docent) and Doctors of Science (DrSc., DSc) who serve in Doctoral Boards, State Examination Committees, Science Councils, and other relevant bodies.

As probably the first among Academy institutes, the Astronomical Institute has recently started meetings with representatives of several universities active in the field of astronomy and astrophysics. We will host such meeting regularly also in future in order to address current problems of higher education, postdoctoral employment, and related aspects.

In the frame of the state accreditation system the Institute's scientists supervise PhD students who take part in the ongoing research projects. After defending their Theses many of these students find post-doctoral positions at top research institutions abroad, thanks to extensive international contacts of the Institute's leading scientists. The Institute runs a ***post-doctoral program*** which is open to all qualified international applicants (currently, several Czech and foreign researchers work at the institute and some of them became staff members). The Institute has been successful in attracting doctoral grants and Centres of Excellence funded by the Grant Agency of the Czech Republic (previously Center for Theoretical Astrophysics, currently Albert Einstein Center for Gravitation and Astrophysics). This has enabled additional funding to our PhD program. The Institute provides the summer practice for undergraduate students from schools in Prague, Brno, as well as from abroad.

In addition to scientific and educational programs, the Institute forms ***partnerships with regional institutions*** in the Czech Republic, in particular, the Central Bohemian Region and the Region of Prague, where the Institute operates its premises, and also other regions where instruments are located and Areas of Dark Sky are introduced.

Figure 3. ALMA, an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA construction and operations are led on behalf of Europe by ESO. ESO has established one of European ALMA Regional Centres in Ondřejov. Following the recent proposal by the Institute, the Czech node of the European ARC has been included in the updated Roadmap of Research Infrastructures in the Czech Republic.


Awareness conference on European Astronomy in the Optical and IR domain:
An ESO / Opticon / IAU summer school on modern instruments, their science case, and practical Data Reduction
Brno, Czech Republic
01-11 September 2015
The summer school aims at training advanced MSc's, PhD students and postdocs on how to make use of the cutting edge facilities offered by institutions like ESO or other observatories available through the OPTICON access program (CAHA, La Palma, OHP, TBL, and so on)
The main part of the school will be a scientific project with real data. It will be accompanied by lectures given by experienced astronomers from different areas of astrophysical research.
Local costs will be covered by the school. A contribution to travel expenses can be envisaged on a duly justified case by case basis.
Registration is open until 8 May 2015 (13:00 CET)
Summer school webpage with registration form can be found under:
http://awareness2015.physics.muni.cz
http://www.iap.fr/opticon/conferences/AW_Brno2015.html
awareness2015@physics.muni.cz
Organizing partners:
Academy of Sciences of Czech Republic
European Southern Observatory
IAU
Masaryk University, Brno
OPTICON
The Czech Academy of Sciences
ES O
IAU
UNIVERSITAS MASARYKIANA BRUNENSIS
OPTICON

Research Report of the team in the period 2010–2014

Institute	**Astronomical Institute of the CAS, v. v. i.**

Scientific team	**Department of Solar Physics**

The research of the Department of Solar Physics (Team 1) is focused to our nearest star, the Sun, particularly the active phenomena in the solar atmosphere. This includes solar flares as well as accompanying heliospheric effects, structure and evolution of solar active regions, prominences, sunspots, and the physics of solar corona and transition region. The research of the Solar Department can be characterized as a combination of solar observations in optical, radio, UV, and X-ray wavebands, analysis and interpretations of data, and theoretical research with extensive numerical modeling of the processes under study. The Team has three working groups.

National and international impact. During the past five years, we have initiated and continued fruitful collaborations with a number of foreign partners at universities and science institutes: AIP Potsdam, MPS Gottingen, KIS Freiburg, MPA Garching, and Potsdam University in Germany, Observatoire de Paris, Inst. d'Astrophysique Spatiale Paris, IRAP Toulouse, and Obs. Midi Pyrenees in France, Harvard-Smithsonian Center for Astrophysics, SSL Berkeley, and Lone Star College Houston in USA, Universities of Cambridge, Dundee, and St Andrews in UK, Tor Vergata University Rome and Florence University in Italy, IAA Granada and IAC Tenerife in Spain, Sternberg Astronomical Inst. Moscow and ISTP Irkutsk in Russia, Wroclaw University and Space Research Centre in Poland, ISSI Bern and University of Applied Sciences and Arts Windisch in Switzerland, Astron. Inst. of the Slovak Academy of Sciences, IGAM Graz in Austria, Royal Observatory of Belgium, National Inst. for space Research in Brazil, NAOJ Tokyo in Japan, and Oslo University in Norway. We organized six successful international conferences: the Czech-Polish-Slovak Consultation on Solar Physics (19.-21. 5. 2011, Ondřejov, 39 participants), the ALMA Winter School (28.-29. 2. 2012, Prague, 30 participants), the CESRA 2013 conference "New Eyes Looking at Solar Activity" connected with the 2nd Solar ALMA Workshop (23.-29. 6. 2013, Prague, 125 participants), the COST meeting "Theory and Modeling of Polarization in Astrophysics (5.-8. 5. 2014, Prague, 39 participants), and finally the conference "Solar and Stellar Flares – Observations, Simulations and Synergies" (23.-27. 6. 2014, Prague), where 95 participants discussed flare processes and responses of the lower atmosphere to them, flare-related CMEs, stellar flares, and instrumentation for flare research. Also, we organize weekly the Team seminars to share results and reinforce the collaboration. We develop our science projects beyond the scope of pure research, especially thanks to teaching activities and supervising PhD students at the Charles University in Prague, the Czech Technical University in Prague, Comenius University in Bratislava, and the Wroclaw University. We take part in ESA space activities under the Czech PRODEX program and host the ALMA Czech ARC node in collaboration with ESO.

Funding. Combining the limited institutional support with project funding is necessary to maintain resources for excellence. We participated in 7 projects funded by the European Commission FP7 program and in 10 space science and development projects funded by ESA (PRODEX and PECS programs). We obtained numerous fundings from the Czech Science Foundation and from the Grant Agency of the Czech Academy of Sciences (23 grants in total). Moreover, 5 projects of international collaboration were supported by the Ministry of Education, Youth and Sports.

Physics of Solar Flares and Prominences working group

The main results of this group concern the radiative transfer diagnostics of the solar atmosphere, flares and prominences, studies of magnetic reconnection and particle acceleration in solar flares, and the physics of solar corona and transition region. The members of the group are also engaged in space research activities and the ALMA Czech ARC node. The group is located in Ondřejov.

Personnel: The working group was headed by M. Karlický until November 2014 and now it is led by E. Dzifčáková from December 2014. Research fellows: M. Bárta, A. Berlicki, B. Dabrowski, J. Dudík,

E. Dzifčáková, F. Fárník, S. Gunár, P. Heinzel, M. Karlický, J. Kašparová, P. Kotrč, A. Kulinová, H. Meszárosová, D. Nickeler, P. Schwartz, J. Štěpán, W. Liu, and there have been several PhD students.

Research results:

Solar flares represent the most violent processes on the Sun, with great impact on the heliosphere and our planet. Total power of individual flares can be determined by detecting their continuum radiation and this was recently highlighted by the discovery of superflares on Sun-like stars. Heinzel & Avrett (2012, Solar phys. 277, 31) made a review of the current knowledge about the most relevant optical continua and a prediction of the continuum emission of flares in mm/sub-mm radio domain, now covered by the ALMA interferometer.

Alfvén velocity and plasma beta are important parameters for modeling eruptive events, but they are difficult to obtain. Kotrč et al. (2013, Solar Phys. 284, 447) have shown a possible method to estimate these parameters through a comparison of observed and synthetic profiles of hydrogen lines. Along with other observables, the results indicate that the observed case of limb eruptive event is actually the initiation phase of a prominence eruption (Fig. 1).

Kulinová et al. (2011, A&A 533, A81) diagnosed independently non-thermal energetic distribution of electrons in solar flares using X-ray lines (RESIK satellite) and continua (RHESSI satellite). Results obtained from the two sources are consistent within the respective uncertainties. In addition, similar non-thermal distributions occurred during radio bursts observed in the 1-15 GHz range. The results represent a novel and consistent interpretation of flare spectra from combined observations.

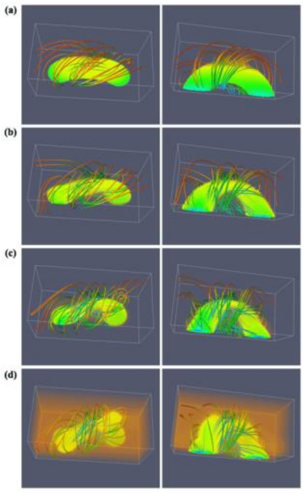


Fig. 1 - MHD model of the initial phase of a flux rope eruption. Colored lines represent magnetic field lines; the colors correspond to the local value of |B| (lower to higher values being coded from red to blue). The background color scale represents plasma density. Frames (a) – (d) were taken at different times. Top and side views are shown for each time.

The level of continuum emission from solar flares is directly related to the power of flares. Brightest emission is expected from the Balmer continuum, which is the hydrogen recombination continuum. In the study by Heinzel & Kleint (2014, ApJ 794, L23), the Balmer continuum was clearly detected for the first time from space, using the ultraviolet telescope and spectrograph IRIS (NASA). The result represents an important breakthrough in the flare physics with potential implications for space-weather studies.

These results come from an international collaboration with research institutes in Germany, Poland, Russia, Switzerland, and USA. The first authors and most of co-authors of published papers belong to the Team. They delivered new ideas, ground-based data and numerical simulations.

Processes of **magnetic reconnection and particle acceleration** in flares were studied extensively, using numerical simulations as well as observations. Karlický & Kliem (2010, Solar Phys. 266, 71) used unique radio observations taken at Nobeyama Observatory to study a solar flare that occurred just behind the solar limb. This partially occulted solar flare on 18 April 2001 had a form of the inverse gamma shape of the source with crossing legs. These legs interacted at the crossing point as was expressed by the location of radio brightness peak. It was shown that this flare can be described by the helical kink instability of a twisted magnetic flux rope.

Solar flares are always accompanied by particle acceleration in the form of electron beams. These beams are either in the form of high-energy tail, or a quasi-monoenergetic bulk. Dzifčáková et al. (2011, A&A 531, A11) addressed the effects of both the high-energy tail and the bulk of the distribution on the ionization equilibrium. They found that the high-energy tail has only a little effect on the relative ion abundances of Si XII-XIV, thereby enabling the diagnostics of the bulk of the distribution.

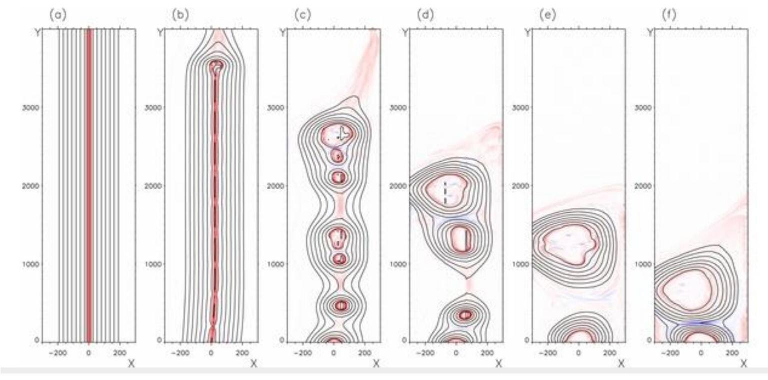


Fig.2 – Fragmentation of the current sheet into plasmoids. View of magnetic field lines and the corresponding current densities in the x–y computational plane at six

different times. The reddish and blue areas represent current densities with the initial and opposite orientations of the electric current, respectively.

Karlický & Bárta (2011, ApJ 733, 107) introduced a new concept of the magnetic reconnection (the primary process in solar flares) based on a fragmentation of the flare current sheet. Using a 2.5D electromagnetic particle-in-cell model, they have shown how the current sheet is fragmented into plasmoids (Fig. 2) and how these plasmoids interact. During these processes, the electrons are very efficiently accelerated and heated. These results were used for an explanation of the so-called above-the-loop-top hard X-ray sources.

MHD simulations by Bárta et al. (2011, ApJ 737, 24 and ApJ 730, 47) demonstrated multiple levels of the energy cascade in magnetic reconnection: Subsequent tearings in small-scale current sheets formed between separating plasmoids. It revealed also a further type of fragmentation – it was shown that current layer formed between two merging plasmoids is subjected to plasmoid instability. Hence, also the plasmoid coalescence contributes to energy cascade towards small scales. The result is essential in application of the theory of magnetic reconnection to solar flares but it exceeds the frame of solar physics and represents a contribution to the general theory of magnetic reconnection and MHD turbulence. The aforementioned theory was applied to solar flares. It was shown that the mechanism of cascading reconnection can account for observed characteristics of solar flares – organized large-scale dynamics and signatures of fragmented energy release.

Strong and localized electric currents and vortex flows, so called current-vortex sheets, are necessary to excite solar eruptions (flares and coronal mass ejections). A spontaneous current fragmentation caused by shear/vortex plasma flows was studied by Nickeler et al. (2013, A&A 556, A61). It was found that strong current sheets imply strong vortex sheets and vice versa. The investigation of such current-vortex sheets is important to understand how solar eruptions are triggered by such fragmented sheets and how the solar atmosphere is heated. Nickeler et al. (2014, A&A 569, A44) also studied the influence of a magnetic shear applied perpendicular to solar magnetic arcade structures, resulting in a formation of strongly filamented current sheets. The generated electric field parallel to the magnetic field is suitable to accelerate particles along the field lines and to heat the solar coronal plasma. The gained energies of the particles are comparable to observed values, emphasizing the importance of shear flows for particle acceleration in the solar corona. This work is an important new approach concerning the self-consistent connection between particle acceleration and MHD flows.

Intense beams of high energy particles generated in the corona are according to the standard flare model believed to transport the energy in flares downwards to the chromosphere. Varady et al. (2014, A&A 563, A61) suggested alternative scenarios, where the non-thermal particles are re-accelerated during their transport. It was shown that the re-acceleration allows to reduce the demands on the efficiency of the primary coronal accelerator and on the electron fluxes transported from the corona downwards.

These results come mostly from the Team, with an international contribution of researchers from Germany and Slovakia. The first authors and most of co-authors of published papers belong to the Team. New ideas, some ground-based data and numerical simulations were delivered by the Team members.

Solar prominences/filaments represent an important aspect of solar activity and their understanding is crucial for solar physics itself and for Sun-Earth connection studies. Quiescent prominences consist of a large number of moving small-scale plasma structures, regularly observed in UV by space-based spectrographs. Gunár et al. (2010, A&A 514, A43) for the first time compared Lyman spectra observed by SOHO/SUMER with synthetic spectra obtained by newly developed 2D multi-thread prominence fine-structure models. Using 2D modelling techniques, Berlicki et al. (2011, A&A 530, A143) demonstrated that integrated intensities analyzed alone are not sufficient to derive the realistic physical parameters of the prominence – the full profiles of Lyman hydrogen lines and the H-alpha line should be also taken into account to obtain 2D radiation-magnetohydrostatic models.

The prominences may become unstable and produce Coronal Mass Ejections that may directly affect the Earth. Plasma properties critical for prominence stability may be derived from observations using differential emission measure (DEM). For the first time, Gunár et al. (2011, A&A 535, A122) compared DEMs obtained by two different techniques, one based on the inversion of the observed UV and EUV lines and the other employing the 2D prominence multi-thread structure modeling of the Lyman spectra.

Density and volume of solar filaments are essential parameters for models of coronal mass ejections (CMEs) triggered by filament eruptions. Schwartz et al. (2012, Solar Phys. 281, 707) estimated these parameters by a non-LTE modeling of observations in the complete hydrogen Lyman spectrum that is rarely observed in filaments and prominences. These observations were complemented by observations in several EUV lines from space and in Hα by ground-based instruments. The results indicate that the observed filament consists of a fine multi-thread structure.

These results come from an international collaboration with research institutes in Belgium, France and Germany. The first authors and most of co-authors of published papers belong to the Team. The Team members have an extensive expertise in the non-LTE modeling of radiative transfer and of the prominence fine structures. Some data were acquired with the Ondřejov optical spectrograph HSFA2.

Radiative transfer methods are generally used to obtain physical parameters of solar atmosphere from spectral observations. The interpretation of linear and circular polarization of spectral lines is the only way to decipher the magnetization of the Sun and stars. Many spectral lines are formed under a very complicated physical conditions that require self-consistent calculation of the radiative transfer problem. A massively parallel 3D code PORTA was developed by Štěpán et al. (2013, A&A 557, A143), making it possible to perform such calculations in full 3D space, with multilevel atoms, and taking into account the relevant physical ingredients of the polarized line formation.

Ellerman bombs are small-scale bright structures observed in the lower atmosphere. They play an important role in the chromospheric heating. Non-LTE radiative transfer models of Ellerman bombs were constructed by Berlicki & Heinzel (2014, A&A 5567, A110) using simultaneously two spectral lines – Hα and Ca II H. They could be described by a “hot-spot” model, located close to the temperature minimum, with the temperature and/or density increase through a few hundred kilometers within the solar atmosphere.

The solar corona and transition region are outer parts of the solar atmosphere, where magnetic fields dominate the structure and motions of plasma, which is far from thermal equilibrium. The temperature rises by 2–4 orders of magnitude and mechanisms of this heating are not yet completely known. In order to understand the coronal heating it is crucial to understand the magnetic fields of its lower boundary, the transition region. To this end, measurement and modeling of the linear polarization of strong UV lines is needed. Using realistic 3D MHD simulations, Štěpán et al. (2012, ApJ 758, L43) calculated a synthetic polarized spectrum of the hydrogen Lyα line in the 2D geometry. Results of this work were obtained in collaboration with the scientists from Spain and Norway and will be used for interpretation of the observations of the upcoming international space mission CLASP, prepared by JAXA and NASA.

The magnetically dominated plasma of the solar corona is an elastic and compressible medium, which can support propagation of various types of waves that are investigated in the context of coronal heating. Meszárosová et al. (2013, Solar Phys. 283, 473) have shown that fast magnetoacoustic waves can propagate also in a fan structure of magnetic field lines above the coronal magnetic null point. They estimated plasma parameters in observed radio sources and found them to be consistent with a presented scenario involving a magnetic null point. Further, 2D magnetohydrodynamic simulations were made (Meszárosová et al. 2014, ApJ 788, 44), showing how propagating magnetoacoustic waves reflect basic physical parameters of their waveguides. Possibilities of detection of these waves in observations were studied.

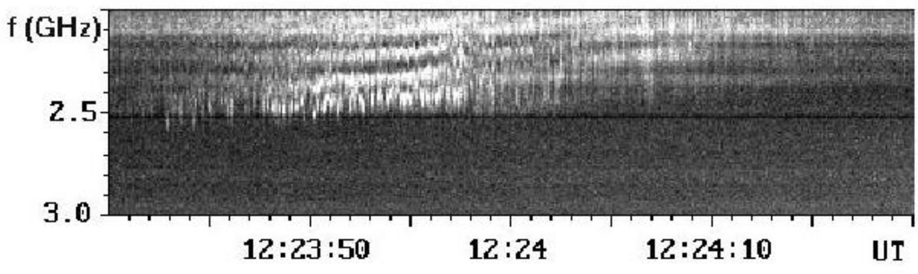


Fig. 3 - Zebra pattern observed during the 18 March 2003 event by the Ondřejov radio spectrograph.

A unique explanation of intriguing zebra patterns (Fig. 3) observed in radio emission of quite distinct astronomical objects, Sun and pulsars, was presented by Karlický (2013, A&A 552, A90). It was shown that the waves with density variations modulate the radio continua generated by the plasma emission mechanism. Considering single magnetoacoustic waves in both the radio sources, solar zebra patterns as well as the zebras observed in the radio spectra of the Crab Nebula pulsar were successively modelled.

In the corona, the energy distribution of particles is far from the thermal (Maxwellian) one. Possibilities to diagnose non-Maxwellian κ-distributions using EUV iron lines were explored for the first time by Dzifčáková & Kulinová (2010, Solar Phys. 263, 25). Separate techniques for diagnosing electron density as well as simultaneous diagnostics of temperature and κ values were developed. Sensitive line ratios were identified, showing that existing EUV spectra of the solar corona can be used for diagnostics of κ. The non-Maxwellian κ-distributions were observed in solar flares and solar wind. Dzifčáková & Kulinová (2011, A&A 531, A122) detected these distributions in the transition region, hinting at the possible non-Maxwellian nature of the outer solar atmosphere. The degree of departure from the thermal plasma was found to increase with magnetic activity, being higher in the active regions than in a quiet Sun region or a coronal hole.

The solar corona is heated by an unknown mechanism that may also accelerate particles. Dudík et al. (2012, A&A 539, A107) derived emissivity formulae for optically thin free-free and free-bound continuum arising in non-Maxwellian plasmas with accelerated particles. The continuum was found to be sensitive to the distribution of the accelerated particles mainly in the X-ray part of the spectrum. This offers new possibilities to diagnose presence of accelerated particles in solar and stellar coronae.

These results were obtained by the Team members with a minor contribution by scientists from Slovakia and Brazil, using data from HINODE and SOHO, and the Ondřejov radiospectrograph.

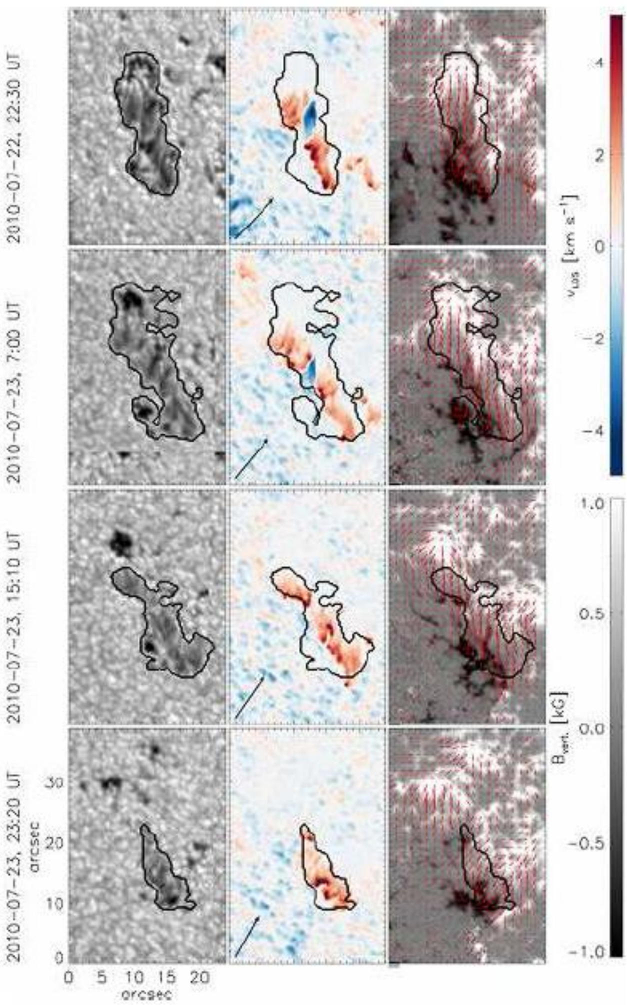
Structure and Dynamics of the Solar Atmosphere working group

The main results of this group concern the physics of sunspots, particularly the penumbra, solar pores, and the sub-photospheric convection. The members of the group are also engaged in ground-based instrumentation. The group is located in Ondřejov.

Personnel: The working group is headed by M. Sobotka. Research fellows: P. Ambrož, J. Jurčák, M. Klvaňa, and M. Švanda.

Research results:

Despite the detailed knowledge of both global and fine properties of **sunspots**, it was unknown what defines the stable position of penumbral boundaries. This question was answered by Jurčák (2011, A&A 531, A118) who found that the umbra/penumbra boundary is characterized by a unique value of the vertical component of the magnetic field strength. This supports the magnetoconvective origin of penumbral filaments, because the convective motions are sensitive to the vertical component of the magnetic field.



Orphan penumbrae (Fig. 4) are structures visually resembling sunspot penumbrae, but are not connected to any umbra. The nature of strong gas flows that are observed in both types of penumbrae was studied by Jurčák et al. (2014, A&A 564, A91). A simple magnetic field configuration of orphan penumbra allows to speculate that the fast flows are caused by the siphon flow mechanism. Based on the similarities between orphan and regular penumbrae, it was proposed that the Evershed flow is also a manifestation of the siphon flow.

Solar pores are intermediate-size magnetic flux features (small spots) that emerge at the surface of the Sun. Sobotka et al. (2012, A&A 537, A85) studied important relations between the magnetic field, line-of-sight velocities, and horizontal motions. They found at which values of magnetic field components horizontal motions in granulation start to be damped, convective upflows in granules are reduced and the granular convection is completely suppressed. These results put observational constraints to theoretical models and simulations. Despite the pores are lacking a penumbra, Sobotka et al. (2013, A&A 560, A84) have proven that in the chromosphere, pores can be surrounded by a superpenumbra like developed sunspots. In addition to that, they addressed the important problem of chromospheric heating. They found that acoustic waves leaking up from the photosphere along the inclined magnetic field in a light bridge transfer enough energy flux to balance the radiative losses, so that the light-bridge chromosphere is heated by acoustic waves.

These results come mostly from the Team, with an international contribution of researchers from Spain and Italy. The first authors and most of co-authors belong to the Team.

Fig. 4 - Temporal evolution of the orphan penumbra observed by HINODE/SOT in NOAA 11089. From left to right: continuum intensity, LOS velocity, and the vertical component of magnetic field with arrows indicating the strength and orientation of the horizontal component.

Supergranules are a convection-like velocity phenomenon with a yet unknown depth structure. In response to a model of sub-surface large-amplitude vertical flows in supergranules, suggested by Duvall & Hanasoge (2012), Švanda (2012, ApJ 759, L29) applied an alternative approach including proper helioseismic inversions for near-surface flows. Strong divergence signals found by means of statistical averaging can be explained by vertical flows, which is consistent with the proposed model.

A near-surface plasma flow in the vicinity of isolated symmetrical sunspots (the moat flow) was studied by Švanda et al. (2014, ApJ 790, 135), using the local helioseismology technique. They found that it resembles the radial streaming in convective supergranules. In the vicinity of sunspots, the flow is deformed due to the spot's proper motion, it is deflected backwards and to a downflow. This result contributes to our knowledge about the dynamics of sunspots – the most prominent phenomenon of solar activity. These results were obtained by the Team members with a contribution of a university student.

Heliosphere and Space Weather working group

The main results of this group concern the physics of the solar wind, including extended numerical simulations. The members of the group are also engaged in space research activities. The group is located in Prague.

Personnel: The working group is headed by M. Vandas. Research fellows: P. Hellinger, S. Šimberová, Š. Štverák, P. Trávníček, M. Vandas, and there are several PhD students.

Research results:

Proton thermal energetics represents one of the challenging problems of the **solar wind** physics. The proton energetics of the fast solar wind were analyzed by Hellinger et al. (JGR 116, A09105), using in situ data from Helios 1 and 2 spacecrafts. The proton heating rates were determined, which turned out to be strongly anisotropic with respect to the ambient magnetic field. The mechanisms (turbulence, kinetic instabilities) that may be responsible for the observed proton energetics in the inner heliosphere, were discussed. In continuation, the proton parallel and perpendicular heating rates in the slow solar wind were determined and compared with those in the fast solar wind using Helios in situ observations (Hellinger et al. 2013, JGR 119, 1351). The heating rates constrain possible heating processes. The necessary heating rates are comparable to estimated turbulent cascade rate, but it was shown that these estimates are based on questionable assumptions.

The proton temperature anisotropy in the solar wind exhibits apparent bounds compatible with theoretical instability constraints. Recent statistical analyses indicate that near these constraints, protons have enhanced temperatures and reduced collisionality. Hellinger & Trávníček (2014, ApJ 784, L15) analyzed the WIND spacecraft data and showed that these results are a consequence of superposition of multiple correlations in the solar wind such as the yet unexplained correlation between the proton temperature and their bulk velocity.

These results were mostly carried out by the Team within a long-term collaboration with University of Florence and JPL. The obtained results are important for preparation of the upcoming ESA's Solar Orbiter and NASA's Solar Probe Plus space missions.

Efficiency of electron acceleration by shock waves in space is an open problem. The acceleration in a wavy shock front was investigated analytically by Vandas & Karlický (2011, A&A 531, A55). They found that the acceleration efficiency is not very different from a plane shock wave, but unexpectedly, angular distribution of accelerated electrons is very anisotropic, with many spikes. Such a distribution is prone to invoke various plasma instabilities, which may intensify electron acceleration and associated radio emission.

Euler potentials have advantage that enable to study charged-particle motions with high accuracy. There are not many known analytic solutions for Euler potentials in magnetic systems. Vandas & Romashets (2014, JGR 119, 2579) constructed analytically Euler potentials of two current sheets of nonzero thickness parallel or antiparallel to each other and aligned with uniform ambient magnetic field and used them to investigate conditions for particle motion and trapping. The results can be applied to Birkeland currents in the Earth's auroral zone.

Ground-based infrastructures

The Team operates several instruments at the Ondřejov observatory – the solar patrol, the horizontal solar telescope with spectrograph HSFA2, three solar radio telescopes, and the robotic solar telescope SORT, which is under development. The Team is involved as a participant in two large international ground-based infrastructures – ALMA and GREGOR. In the years 2008–2011 the Team members participated in the Conceptual Design Study phase of the 4-m European Solar Telescope (EST) project. They took part in the formulation of scientific requirements for the telescope and prepared a preliminary design of the Auxiliary Full Disc Telescope that will be used as a finder telescope of EST and for synoptic observations.

Solar patrol. The Solar Activity Monitoring and Forecasting unit provides regular solar observations in the white light and the Hα line. It uses three small full-disc refractors for drawings, white light, and Hα and two 20-cm refractors for imaging of active regions in the photosphere and Hα chromosphere. The results, besides the use in the Team, are provided to the world net International Space Environment Service (ISES) as a part of the Regional warning Centre Prague (station No. 31516), and to the Solar influences Data Centre (SIDC) in Brussels. In addition to solar observations, the unit collects all the accessible data on the actual state of solar activity and regularly compiles and publishes daily and weekly solar-activity forecasts. The weekly activity forecasts are published every Thursday for approximately 50 Czech and international users (radio communications, radio amateurs, ISES, SIDC, and others). The daily solar activity forecasts are presented in the Czech Television as a part of the weather forecast. The solar-activity forecast, made in Ondřejov since 1978, is a national service and represents an integral part of the international space weather program. The observations can be found at the web site http://www.asu.cas.cz/~sunwatch/.

HSFA2: The 0.5-m horizontal solar telescope equipped with a large multichannel slit spectrograph is used mostly for observations of flares and prominences in five spectral regions simultaneously: Ca II H, Hβ, Na I D and He I D3, Hα, and Ca II 854.2 nm. At present, HSFA2 is fully computer-controlled and provides data on fast processes in solar flares and prominences. It is often utilized in coordinated campaigns with other European space and ground-based instruments (http://www.asu.cas.cz/~sos/).

Radio telescopes: The radio flux of the Sun is observed daily with a single-frequency 3 GHz receiver (RT3, 3-m dish), a 2.0–4.5 GHz radio spectrograph (RT4, 3-m dish), and a 0.8–2.0 GHz radio spectrograph (RT5, 10-m dish). Chosen time intervals with radio events are processed and archived (http://www.asu.cas.cz/~radio/).

SORT: The 0.28-m solar robotic telescope will be finished in 2015. It will provide a high-cadence detailed imaging of the solar chromosphere, particularly flares, in the Ca II H and Hα bands.

ALMA: The Atacama Large Millimeter/submillimeter Array is a revolutionary observing facility of current research in astronomy and astrophysics. Although officially inaugurated in 2013, it still operates in a regime of *Early Science*. Its further capabilities are being introduced. The special solar observing mode represents, in line with the ALMA development and implementation plan, one of such new capabilities. The solar observations require specific regime because of many peculiarities of the objects at the Sun, as the sources of radiation at mm/sub-mm wavelengths are – unlike their more usual counterparts in the remote Universe – very intense, variable on short timescales, with strong proper motion and frequently quite extended. In order to cope with those issues and to allow for regular (science) solar observations starting already in Cycle 4 (call expected in spring 2016), a mixed team of experts has been established from all the three ALMA Regional Centers (European ARC, North American ARC, and East Asia ARC) to be working on this task. Because of its unique expertise in solar radio astronomy within the EU ARC, it was the Czech node in Ondřejov that has been mandated (by ESO/EU ARC) to work on implementation and commissioning of the solar observing mode in frame of the project *Solar Research with ALMA*. This project that represents contractual research/development carried out for ESO is supported by 70 kEUR for 32 months and started in November 2014. Testing of suggested approaches to the above mentioned issues represents an important part of work on the project. Therefore, two astronomers from the Czech EU ARC node, M. Bárta and R. Brajša, took part in the Solar ALMA Observing Campaign in December 2014 directly at ALMA OSF in Chile. The acquired data is now being analyzed in collaboration with the groups from NA and EA ARCs. After the full commissioning of the solar observing mode, the Czech node will become unique-expertise place in Europe for supporting all solar-research oriented ALMA projects.

GREGOR: The Team participates in the project of the largest European solar telescope GREGOR under a bilateral agreement with the Leibniz Institute for Astrophysics, signed in 2002. This opens the possibility for the Czech solar community to get the leading-edge data. The 1.5-m solar reflector, located at Observatorio del Teide, Tenerife, was developed and built under the leadership of the Kiepenheuer Institute for Solar Physics in Freiburg with the Leibniz Institute for Astrophysics Potsdam, the Institute for Astrophysics Göttingen, and the Max Planck Institute for Solar System Research in Göttingen as German partners and with the Instituto de Astrofísica de Canarias and the Astronomical Institute of the Czech Academy of Sciences as international partners. The telescope is designed for observations of the solar photosphere and chromosphere in the visible and near infrared and equipped with a high-order adaptive optics. It was inaugurated on 2012 May 21 and has started in early 2014 its “early science” phase with access restricted to the GREGOR partners. At the moment, there are three post-focus instruments: the broad-band imager, the GREGOR Fabry-Perot interferometer (GFPI), and the grating infrared spectrograph (GRIS). Members of the Solar Department took part in the installation and alignment of GFPI since 2011 and in three campaigns of “early science” observations with GFPI and GRIS in 2014 so that, in addition to the obtained experience, the Team has an access to the very first GREGOR observations.

Space research activities

The Team currently participates in three space projects of European Space Agency (ESA): Solar Orbiter, PROBA-3 and JUICE. The Team scientists, as members of several consortia (which were created to realize onboard scientific instruments), participate in the science goals definition and they are responsible namely for the development and manufacture of:

STIX: Low and high voltage power supply (PSU) for the STIX X-ray spectrometer-imager onboard the Solar Orbiter mission and its controlling flight software. The STIX consortium was established in 2006 with the Czech and Swiss active participation. Later on the consortium was completed with participants from France, Germany, USA and Poland. Originally, it was supposed that the hardware would be developed and manufactured by a private company CSRC in Brno, flight software would be written by a private company ESC in Prague and a group of scientists from the Team would participate in defining and improving science goals of the project. At the same time a Czech-side manager from the Team serves as the contact point between ESA, ESA-PRODEX and all Czech partners. At the end of 2013 the CSRC disintegrated as a result of an internal conflict and to save the project, the PRODEX Office suggested to the Director of the Astronomical Institute (ASU) to employ a group of originally CSRC technicians and to overtake the PSU development. That proposal was accepted and the PSU development continues well under the ASU management.

RPW: Low voltage power supply and power distribution unit for the RPW experiment on the Solar Orbiter mission. The RPW consortium was formed as a response to the ESA announcement of opportunity for its M-class mission within the Cosmic Vision science program. Currently the consortium is led by CNES (France) and, besides ASU, it involves participants from Sweden, Austria, and USA. The RPW instrument’s science goal is to provide in situ measurements in solar wind of both the electrostatic and electromagnetic fields and waves in a broad frequency range. Like in the previous (STIX) case, the hardware is developed by the group of ASU technicians.

METIS: The Czech participation in the METIS instrument onboard the Solar Orbiter mission has been proposed by the consortium (Italy, Czech Republic, France, Germany, USA) in response to the ESA’s announcement of opportunity. The METIS design was aimed at performing off-limb and near-Sun coronagraphy, the task motivated by scientific questions of the origin and heating/acceleration of the solar wind streams, the origin, acceleration and transport of the solar energetic particles, and the transient ejection of coronal mass and its evolution in the inner heliosphere (coronal mass ejections, CME’s). According to the task allocation, the Team is responsible for manufacturing and delivering optical components, i.e., the primary telescope mirror M1, the secondary telescope mirror M2, and the heat-rejection mirror M0. All these optical elements are now developed and will be manufactured in Turnov (Czech Republic) in the Institute of Plasma Physics ASCR, v.v.i., Research Centre for Special Optics and Optoelectronic Systems - TOPTEC. The process of designing and manufacturing is managed by the Team. In 2011 the necessary funding was granted by the Czech PRODEX program for the period 2011-2017. These funds cover the ASU management as well as the industrial contract with TOPTEC. The Team will get scientific profit from a direct access to expected unique data received during observations with the instrument.

JUICE: Low voltage power supply and power distribution unit for the RPWI experiment on the JUICE mission to Jupiter. The RPWI consortium was formed as a response to the ESA announcement of opportunity for its L-class mission within the Cosmic Vision science program. Currently the consortium is led by CNES (France) and, besides ASU, it involves participants from Sweden, Austria, and USA. The RPW instrument's science goal is to provide plasma and electromagnetic wave measurements in situ in the Jupiter's magnetosphere including close environment of several Jupiter's moons.

PROBA-3: The aim is the development, manufacturing, testing and delivery of the hardware components for the space coronagraph ASPIICS. The main goal of the mission is an in-orbit demonstration of formation-flying techniques and technologies and this will be implemented with a pair of small spacecrafts. The ASPIICS solar coronagraph will fully benefit from exploiting the formation-flight technique to gain a unique access to the inner solar corona down to 1.04 solar radii over long periods of time under near-total solar eclipse conditions. The Team's responsibility is to coordinate the development of the Front Door Assembly and the Primary Objective together with the Relay Optics done by national industrial partners – SERENUM, a.s. and TOPTEC center of the Institute of Plasma Physics ASCR. The original design of the Front Door Assembly (which constitutes the closing mechanism of the aperture of the optical telescope) was transferred from the Max-Planck Institute for Solar System Research in Göttingen, Germany to the national industrial partner SERENUM, a.s. This allows SERENUM to develop an extensive knowhow for production of space-qualified mechanisms. Newly founded technological center TOPTEC of the Institute of Plasma Physics ASCR will develop and manufacture space-qualified optics.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Scientific team	Department of Stellar Physics

Overview of the department

Department of Stellar Physics is one of four departments of the Astronomical Institute. It is situated in Ondrejov. The department is divided in to three working groups: group of astrophysics of hot stars, group of operation and development of Perek 2m telescope and group of high energy astrophysics. The first two groups are closely involved with the Ondrejov 2m telescope. The high energy astrophysics group requires other instrumentation described below.

Perek 2m telescope is a national facility for Czech astronomers. It is named after the astronomer Lubos Perek (*1919) who supervised the construction of the telescope and was leading the stellar department in the first years. The diameter of the primary mirror is 2m and it was the ninth largest telescope in the world in 1967 when the telescope was inaugurated. The telescope is used for stellar spectroscopy and operates in the coude focus where the effective focal length is 64m (effective focal ratio is thus 1:32).

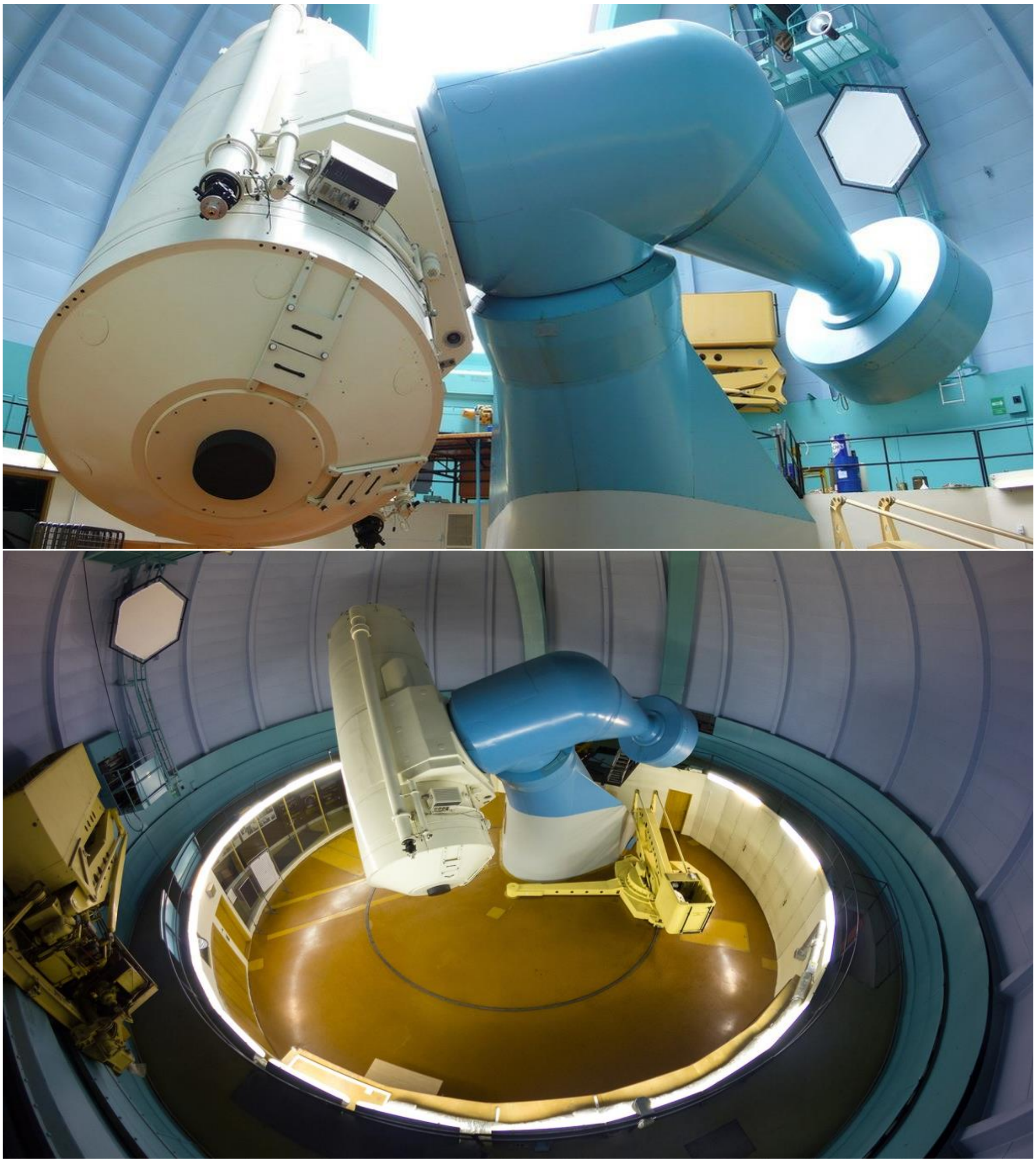


Figure 1: The Perek 2m telescope is the primary instrument in Ondřejov observatory; http://stelweb.asu.cas.cz/web/index.php?pg=2m_telescope .

For spectroscopy we use a single order spectrograph operating in the first and second spectral order. The first order covers a range of 48nm with a resolution of about 1.6nm per mm and the second order covers a range of 24nm with a resolution of 0.8nm per mm.

The 2m telescope, as it was just described, is not the only facility of our department. The group of the High Energy Astrophysics (HEA) operates two smaller telescopes (BART and D50). One of the main aims of this group is the research of energetic processes, for example gamma-ray bursts (GRB hereafter). This research requires the use of space-borne observatories, however the group also is interested in studying GRB optical counterparts (so called afterglows). The two mentioned small telescopes are used for the photometric monitoring of such effects. So one can say that these telescopes are a useful complement to the international satellite observations.

Generally, large telescopes, most of them located in the southern hemisphere, are heavily oversubscribed and cannot contribute to systematic monitoring programmes. Therefore, these instruments cannot explore the time-domain as efficiently as mid-sized telescopes spread all over the world, and especially in the northern hemisphere. We believe that the current, main programme for our telescope is sustainable in the long term. One can identify many relatively unknown stars in the northern hemisphere that are accessible to our telescope. Currently, the Ondrejov 2m telescope is used for a systematic monitoring of more than 880 objects. One major area of this programme consists of a study of hot stars with emission lines (Be-type) or forbidden lines (B[e]-type). Of course, studies of other classes of objects suitable for this telescope are conducted. For example, the bright, mysterious epsilon Aurigae (spectral type A8I) has been systematically monitored using the 2m telescope since 2006. We have collected a valuable data set of more than 470 spectra in various spectral ranges. This work contributed significantly to our knowledge of this enigmatic object. Many projects are conducted in collaboration with colleagues at Charles University in Prague and Masaryk University in Brno. But observation time is also made available to astronomers and students from foreign institutions, for example T. Shenar from Potsdam, Germany. Every year, a group of students from the University of Beograd, Serbia, visits Ondrejov for studies with local astronomers. We believe that the 2m telescope at Ondrejov observatory will continue to play a significant role in the development of astronomy in the Czech Republic.

Group of Hot stars

The group's main area of research is studies of hot stars, although other research topics are pursued. The group consists of observers and theoreticians who collaborate on projects.

In observational astronomy we concentrate on monitoring of relatively bright stars (typically up to 11th magnitude) which is an appropriate program for mid-sized telescopes. We have more than 880 stars (885 in March 9th) in our database that we systematically monitor.

One may think that the monitoring of bright stars has little value since most of these objects are well known and nothing new can be learned from additional observations. However, the reverse is true: The nature of some physical phenomena remains poorly understood and therefore these targets are appropriate for astrophysical research. Besides, the largest telescopes are generally used to observe faint targets while bright stars remain domain of mid-sized telescopes.

One of the main areas of research in the Ondrejov group is study of the so-called Be stars, i.e. hot stars with emission lines in their spectra. The main aim of this research is to explain the emission phenomenon. It is assumed that Be stars are in fact binary systems with a gaseous envelope around one component. The observed emission lines are thought to form in the hot, gaseous envelope. To confirm this hypothesis, one should systematically observe spectral lines and attempt to detect a period that corresponds to the orbital period of the system. Radiative-magneto-hydrodynamic models of the envelope can be used help explain the variability of the emission line. This research topic is led by Pavel Koubsky.

In our research we do not restrict ourselves to using only the 2m telescope. We also obtain complementary datasets with large telescopes. Using the 2m telescope we obtain spectra of carefully selected objects, and if some of these objects require complementary data from large telescope, the time is requested on telescopes such as the Very Large Telescope at Paranal, Chile. On the other hand, if some interesting phenomena was detected in a star with a large telescope that will require systematic monitoring, the 2m telescope is well suited for these observations. Michaela Kraus is leads projects that make good use of both the 2m telescope and large telescopes. Her are of research includes hot supergiants in our Galaxy and nearby galaxies such as M31 (Andromeda galaxy).

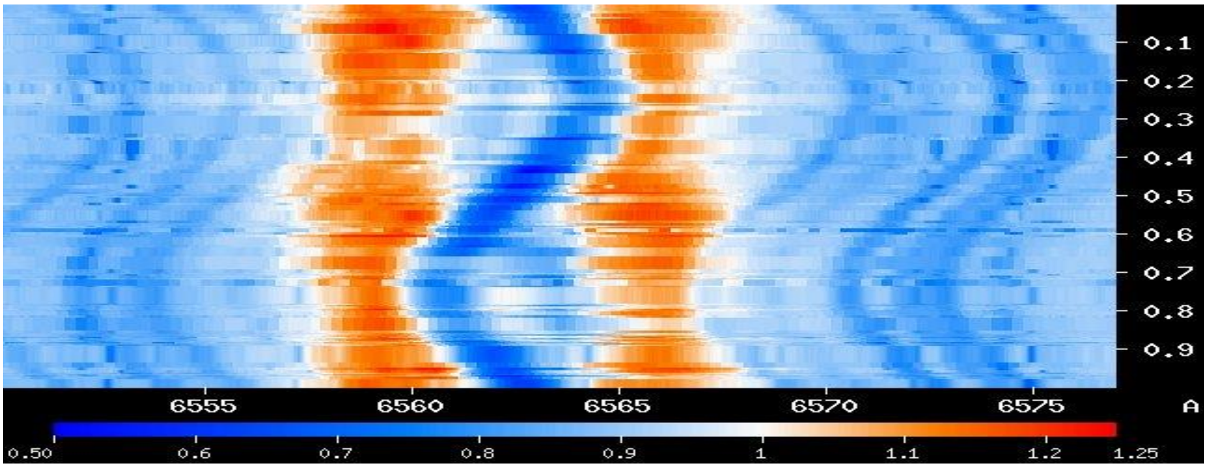


Figure 2. Dynamical spectrum of the binary star BR CMi. Horizontal axis – wavelength (Angstroms), vertical axis – phase, colour scale – intensity. Software for the depiction and analysis was developed in our stellar department (Lenka Kotkova).

Large telescopes, such as those at the European Southern Observatory and Kitt Peak National Observatory are used by Stephane Vennes and Adela Kawka. Their field of research focuses on evolved compact objects such as white dwarfs and hot subdwarf stars. Spectra of the observed stars are analysed using our own state-of-the-art model atmospheres, in order to determine the stellar parameters such as the composition, effective temperature and surface gravity.

Theoretical astrophysical studies nicely complement the observations conducted in our department. The aim is focused on the radiative magnetohydrodynamic modelling of stellar atmospheres and stellar wind. We also aspire to the better explain the phenomenon of accretion discs. This is interest of our colleague Jiri Kubat who closely cooperate with Jiri Krticka (Masaryk University, Brno, Czech republic) on this field.

Another example of our work is the study of epsilon Aurigae. It is a widely studied yet poorly understood bright star (which is visible by the eye). It is an eclipsing binary system (Algol-type), which has the longest known period (27.2 years) for this type of binary. The eclipsing body is a mysterious object, however we know that it is extremely large (eclipse duration is more than 2 years) and dark. The eclipsing body is yet to be detected by photometry or spectroscopy. We observed this interesting object for a long period of time before the eclipse (which occured in 2009-2011) and, of course, during the eclipse. Our study significantly improved our knowledge of the physical properties of the eclipsing disc. Data secured by our Ondrejov 2m telescope were used in the preparation of two PhD theses (P. Chadima, supervisor P. Harmanec, Charles University, Prague, and R. Stencel, supervisor B. Kloppenborg, University of Denver, USA).

Hereafter we introduce our research fields in detail.

<u>Research on hot supergiants</u> – prepared by M. Kraus

One major research topic in the stellar department is dedicated to massive stars. In particular, we aim to improve our understanding of the origin, structure, and dynamics of the circumstellar material around evolved massive stars in short-lived transition phases such as the B[e] supergiants and the luminous blue variables (LBVs). In addition, we seek to unravel the triggering mechanism for the phases of enhanced mass-loss and mass eruptions in these stars. Moreover, we study their less violent counterparts, the classical B-type supergiants. These objects display pronounced line-profile variability and excess broadening of their photospheric lines, which could originate from stellar pulsations. Therefore, we initiated an observing campaign to monitor a sample of Galactic B-type supergiants in different timescales. To achieve our goals, we perform both theoretical and observational investigations, combining optical observing facilities such as the Perek 2m-telescope at Ondřejov Observatory and the 2.15m-telescope at CASLEO, Argentina, with infrared facilities provided by the ESO VLT and by GEMINI (North and South), to which we have access via our intenational collaborations.

We studied the structure and kinematics of the circumstellar material around evolved massive stars based on different tracers: The size and inclination of dusty disk regions were studied using interferometry. We analysed the shape of the [CaII] and CaII infrared triplet line profiles, which we discovered as valuable diagnostics, to trace the atomic gas parts of the circumstellar disks or rings. In addition, we modeled the shape and strength of the CO band emission to constrain the structure (density and temperature) and dynamics of the molecular disk parts. Our investigations revealed that emission of the [CaII] lines is only detectable from stars with dusty rings or disks, i.e., stars with very dense circumstellar material, such as the B[e] supergiants, post-AGB stars, yellow hypergiants, and, occasionally, LBVs, while stars with less dense environments and pure gaseous disks (such as classical Be stars) do not display [CaII] lines, but can still show emission from the CaII infrared triplet. Combining the results from all disk tracers, we also found that the material around B[e] supergiants cannot be located in a continuous outflowing disk. Instead, it is detached from the star and arranged in multiple, high-density rings or spiral arm like structures in Keplerian (or quasi-Keplerian) rotation. This, in turn, means that the material release, resulting in the formation of these structures, cannot be continuous but must happen in several short and probably violent mass ejection events, similar to what is observed in LBVs. For one B[e] supergiant star we discovered the sudden appearance of CO band emission, and we conclude that this emitting material must result from a recent mass ejection event. Furthermore, our analysis of the molecular material in some B[e] supergiants in binary systems revealed that the accumulation of the material in circumbinary rings or spiral arms results from binary interaction processes. Like for single star B[e] supergiants, the molecular circumbinary material was found to revolve the systems on stable Keplerian orbits.

We also performed an abundance study, based on which we found that the B[e] supergiant phase occurs in the evolution of massive stars right after the main sequence rather than after the star has passed through the red supergiant phase. This is a surprising result, because this means that, despite many similarities, B[e] supergiants and LBVs are most probably not evolutionary linked but evolve from stars with different initial conditions. We performed an infrared survey of a large number of evolved massive stars. Based on their infrared characteristics, we discovered criteria that allow us to unambiguously classify a star as either an LBV or a B[e] supergiant. Application of our infrared diagnostics to a sample of unclassified evolved massive stars resulted in the discovery of the first B[e] supergiants in the Andromeda galaxy.

From our monitoring campaign of B-type supergiants we discovered in the line profiles of HD 202850 a stable variation with a period of 1.6 h, which is much shorter than any theoretical predictions for stars in this evolutionary stage. We also analyzed a large set of optical spectroscopic data for 55 Cygni, which we classify as a new member of the alpha Cygni variables. The observations were obtained with the Perek 2m-telescope at Ondřejov Observatory over a time interval of more than four years. The atmospheric lines of this object display strong line-profile variability, which we could assign to stellar pulsations. From a period analysis, we identified 19 pulsation periods, ranging from 2.7 h to 22.5 days. These could be assigned mainly to p- and g-mode pulsations, while the longest period of 22.5 days is in agreement with a strange mode pulsation. In addition, from an analysis of the wind emission lines, in particular of Hα, we recognized time-variable mass-loss in this object, with a similar period of ~20 days, suggesting that the strange mode could trigger the time-variable mass-loss in this object.

Modelling of stellar atmospheres and winds – prepared by J. Kubát

The collaboration with the Faculty of Science of Masaryk University in Brno in the field of stellar winds has existed for about 15 years. This collaboration is led by (doc. RNDr.) Jiří Kubát (,CSc.) in Ondřejov and (Prof. Mgr.) Jiří Krtička (,PhD) in Brno. They were successful in obtaining grants from Czech Science Foundation and from other agencies. They also published a large number of common scientific papers (mostly in the journal Astronomy and Astrophysics) about theoretical modelling of stellar winds. In the past 7 years, due to the gradually increasing number of PhD and master students involved in the field of theory of stellar atmospheres and winds, an informal group of scientists was formed. This group involves people from both the stellar department of the Astronomical Institute and Faculty of Science, and solves together problems of hydrodynamics of stellar winds and circumstellar disks, radiative transfer in stellar atmospheres and stellar winds, inhomogeneous stellar winds, and interaction of radiation and matter. This group meets regularly and their members discuss current specific problems stellar atmosphere and wind theories. Meetings, which started in 2011, have been taking place at one of the institutes, either at Masaryk University in Brno or the Astronomical Institute in Ondřejov. Since 2013 these meetings are organized as a regular seminar "Open problems of physics of stellar atmospheres and winds" which is scheduled in the Faculty of Science, so that other bachelor, master, and doctoral students may join. This enables a wider impact of the meetings. The meetings are very often visited by collaborating scientists from abroad (e.g. Argentina, Estonia, France, Serbia). Students from Masaryk University in Brno often visit the stellar department and the Perek 2m telescope to gain practical experience with observational astronomy using highly sophisticated instruments. Members of the stellar department often serve as committee members in various exams and defenses of theses at the Faculty of Science.

Research of white dwarfs and stellar evolution remnants – prepared by A. Kawka and S. Vennes

Using the revised New Luyten Two-Tenths (NLTT) catalogue, we continued our spectroscopic investigation of high-proper motion white dwarfs. Our work included the spectropolarimetric survey of cool white dwarfs using the FORS spectrograph attached to the VLT at the European Southern Observatory (ESO). This led to the discovery of a number of new magnetic white dwarfs, including the first close double degenerate system comprised of a magnetic white dwarf and a non-magnetic white dwarf companion offering clues for the origin of magnetic fields in compact objects.

Our spectroscopic survey also revealed several new polluted hydrogen-rich (DAZ) white dwarfs, which were targets for follow-up observations with the X-shooter spectrograph attach to the VLT at the ESO. These high signal-to-noise and high-resolution spectra enabled us to study the white dwarf atmospheric parameters including detailed abundance patterns. These stars participated in the demise of planetary systems, and studies of their abundance patterns enable us to determine the source of the accretion source (planet, comet, asteroid). Our studies of these cool DAZ white dwarfs have shown that a higher incidence of magnetism is present in this class of objects when compared to the general population of white dwarfs. This higher incidence suggests that planets/asteroids orbiting the progenitor star of the white dwarf plays a role in the formation of magnetic fields in white dwarf stars.

Our X-shooter observations also uncovered a double degenerate system that includes the first carbon-polluted (DQ) white dwarf showing traces of nitrogen. The nitrogen along with the carbon would have been dredged up from the core. The discovery of such a system is important to our understanding of the phases of evolution, during the red giant stage and beyond.

We have also conducted a survey of ultra-violet bright objects selected from the Galaxy Evolution Explorer (GALEX) all-sky survey. This resulted in the discovery of several bright hot subdwarfs suitable for detailed follow-up studies and of a rare oxygen-polluted white dwarf. The hot subdwarfs (sdB, sdO) were analysed for their atmospheric parameters (effective temperature, surface gravity, helium abundance). Since binarity is instrumental in the formation of hot subdwarf stars many of our stars were targeted for radial velocity measurements. Our radial velocity survey resulted in a binary fraction of about 40%. This survey also enabled us to discover the shortest period sdB plus white dwarf binary which a prime candidate progenitor for a Type Ia supernova.

All detailed analyses were performed using our own state-of-the-art model atmosphere codes. These codes were continuously optimised and upgraded to include the latest developments in model atmosphere physics including new molecular opacities.

<u>Other activities of Group of Hot stars</u>

The stellar department also takes part in observations with 1.54m telescope on La Silla, Chile. The telescope is a Danish facility which shares the observational time with Czech astronomers. There are three groups from Czech Republic: group of Petr Pravec (Department of the Interplanetary Matter, Ondrejov), Pavel Koubsky and Viktor Votruba (Department of Stellar Physics, Ondrejov), Filip Hroch (Departmen of Theoretical Physics and Astrophysics, Masaryk University, Brno). The team from our Stellar department together with our Brno colleagues are focused on long-term systematic monitoring of selected fields in the Magellanic Clouds. The teams are interested in short-period and double-period variable hot stars. The Magellanic Clouds are very good targets for astronomical research. The photometric images obtained with this telescope are archived, and therefore allowing the data to be used for other projects.

Group of operation and development of Perek 2m telescope

The operation and development of the 2m telescope group is a technical group rather than a scientific group. The team is responsible for the reliable operation of the 2m telescope.

The group consista of 7 members: Slechta Miroslav (head of the group, data reduction), Sloup Jan (mechanic), Honsa Jaroslav (engineer – electro-technician), Tlamicha Miloslav (electrician), Rezba Ludek (electro-technician - heavy current), Fuchs Jan (electro-technician - light current and IT expert), Kotkova Lenka (data reduction, databases, meteorologist). All members of the group also work as night assistants. Their rich experience with observations and, of course, their specialization, is optimally composed so it enables the complete care of the telescope and also the development the user-friendly observational interface optimized for the comfortable observations.

Two persons observe each clear night – the astronomer and night assistant. While the astronomer operates the spectrograph, the night assistant controls the telescope. To help the observing run to run reliably and comfortably, additional support is provided: meteorological station - humidity and temperature (both of them measured from outside of the dome, inside of the dome, on the telescope tube and at the primary mirror), air pressure, triple point, wind (speed and direction), rainfall, etc. Also the cloud cover can be monitored using the full-sky fish eye camera. An automatic warning is sent when the humidity exceeds the value of 90% requiring the dome and mirror covers to be closed so as to protect our mirrors. All data (from the meteorological station and from the fish-eye camera) are archived. Both night assistant and astronomer can watch the slit of the spectrograph (via the slit camera) to ensure the target remains on the slit. The astronomer can plan their observing strategy using an extensive database of observed stars. The astronomer can select a star (by name or catalogue number) and the database automatically displays the position of the star in the sky, the current altitude (indicating whether the target currently accessible by the telescope) and also its altitude for the following 24 hours (to help plan the observing strategy for the remainder of the night), list of reduced spectra of that target and a lot of other useful information about selected target.

Remote observing is available to astronomers. During the observing run, the night assistant is required to be in the dome while the astronomer can be anywhere with an internet connection. For security reasons, our IT expert (Jan Fuchs) has to give the astronomer's computer (i.e., individual IP address) permission to access the telescope/instrument computers. During the night only one IP address (i.e. only one "outside" computer) can access the observational interface. This permission is automatically cancelled the next day at noon UT. Of course, the remote astronomer also has all of the support data (meteorological station, slit camera and full-sky camera) at their disposal. Remote observing is now widely used. Only experienced users can observe remotely. Each astronomer is required to know the telescope and has to spend some nights in Ondrejov personally. Once he/she has adequate experience with the operation of the telescope and the spectrograph, we give him/her permission to observe remotely.

The observational user-interface (prepared by Jan Fuchs) is independent of the operating system; it works both on Linux and on Windows. It enables complete control of the spectrograph and it also enables the astronomer to drive the telescope (independently of the night assistant). However, we do not recommend this when the astronomer is observing remotely. Spectra are archived independently archived in two locations: on the dome data servers and on an independent data disc field that located in the department building (where offices are situated). Moreover, the dome is totally independent of the department building - it has an independent local network and its own independent electricity source (a diesel back up engine which allows one to complete the observation and close the dome shutter in case of a black out).

All the presented supporting tools are optimized so as to satisfy the requests of the astronomers. These tools are entirely prepared by the local working-group. Lenka Kotkova prepared the database of monitored objects and their visibility, list of raw and reduced spectra, etc. Jan Fuchs prepared the observational user-interface for local and remote control of the telescope. The electric/electronic tools are prepared by Jan Fuchs or Ludek Rezba.

Of course, the team is also responsible for the operation of the spectrograph. We use a single order slit spectrograph working in the first and second spectral orders. The first order covers approximately 48nm in the "red" region of the spectrum with wavelengths ranging from about 510 up to 900 nm. The second order covers approximately 370 up to 510 nm in the "blue" region of the spectrum. The resolution is about 1.6nm per milimeter in the first order and, of course, 0.8nm per milimeter in the second order.

The working group performs the standard service and maintenance of the spectrograph. However, more demanding upgrades must be performed by external experts since the spectrograph is very particular instrument. Therefore, in 2010 we realized a very careful upgrade of the spectrograph's driving electronics. Up to 2010, the spectrograph was controlled by unique electronic tools that were dependent on one-man contractor's company. One can therefore understand this was risky and unacceptable. A new company, ProjectSoft HK (Hradec Kralove, Czech Republic), which has a large company with international connections, was contracted. The new spectrograph driving electronics is based on standard Siemens prefabricated elements composed like a modular kit. Moreover, the Siemens guarantee 10 years of service and also guarantee that the new electronic elements will be compatible with older ones. Thus the new driving system of the spectrograph is much more acceptable and reliable than the previous one. We can also point out that the same electronic equipment (made by ProjectSoft and Siemens) is also used for operating the telescope itself (since 2007).

The operation and development of the telescope group is able to service and maintain the telescope using its own equipment. This is due to optimal structure of the member's specialization. For example, a few years ago the group performed service works on the dome shutter. It is, in fact, the most important part of the dome, it must perfectly work: the dome shutter must close when the rain or storm is approaching. No failure is allowed in such a situation. Thus we performed a very careful service of the shutter mechanism - it consists of two electric engines and a total of twelve (!) transmissions. Apart from the mobile crane that was used for manipulating heavy components, we performed the service autonomously. Nowadays we are performing a step by step, service and reconstruction of the trucks of the dome. The dome moves on 48 wheels joined by 24 trucks. Four trucks are driven by electric engines. We will remove the trucks, dismantle and service them. If we remove one truck, we can move the dome without limitation as since 23 trucks are sufficient for the operation of the dome. This work is planned completely autonomously without any "external" support. For comparison, equivalent service on the Tautenburg (Germany) 2m telescope was performed with the help of Karl Zeiss machinists (Jena is about 20 kilometers from Tautenburg).

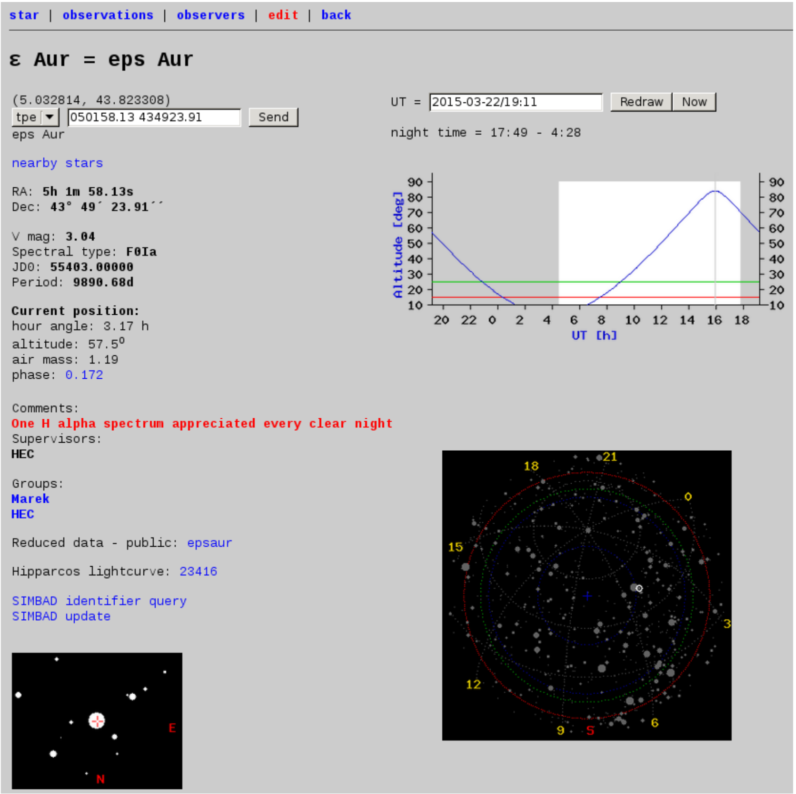


Figure 3: Example of the web–application (by Lenka Kotkova) for the support of astronomer. Upper left: characteristics of the star. Upper right: altitude of the star (grey are – astronomical night, white area – astronomical day). Lower left: field of view of the finding telescope (16 arc min in diameter). Lower right: position of the star on the sky.

To summarize, the technical team realized and organized several significant service work or upgrade in the last years. These include:

- new driving electronics of the 2m Perek telescope (2007),
- new driving electronics of the spectrograph (2010),
- new CCD chip EEV 42-10 BX – Pylon Excelon 2048x512 and the new driving user interface developed by Jan Fuchs (2013),
- service works on the dome shutter (2012),
- service works on the 24 trucks of the dome (2014–).

Group of High Energy Astrophysics

High-energy astrophysics (HEA) is a perspective science branch and represents a modern and rapidly developing area of recent astrophysics which requires specific approaches. The HEA group in the Institute participates in space projects based on extended international collaborations. The related publication activity is on a high level and includes publications in journals with an impact factor. The scientific activity and output of the HEA group is internationally recognized with numerous collaborations and presentations in international conferences.

This astrophysical field requires widespread international collaboration between teams in pure research and technical (design special devices, satellites, X-ray telescopes). The HEA group was established in the year 1990 and continues the work of the former Department of Space Research closed in 1990. The group is recently small but has numerous external collaborators and students.

The main research fields of the Ondrejov group are: the study of GRB, search for GRB optical counterparts, investigations of celestial X-ray and gamma-ray sources, multispectral analyses, design and development of space and ground based instruments (robotic telescopes). This group investigates afterglows of gamma-ray bursts (GRBs). The study concentrates on the analysis of the comprehensive properties of these events, the observed relation of the afterglow and the underlying supernova, and the implications for the environment in their host galaxies. The team made population studies of optical afterglows and obtained thus direct information about the environment of these GRBs. These studies also enabled to separate the contribution of synchrotron emission of a relativistic jet and thermal emission of the underlying supernova using commonly available observing methods

In our research, we have very rich experience in international cooperation, and collaborate e.g. with teams at the Dr Remeis Bamberg Observatory of Erlangen University, Wurzburg University, Pennsylvania State University, IAA Granada, University College Dublin, MPE Garching, NASA GSFC, NASA MSFC, ESA, INAF Roma, INAF Bologna, University of Boulder, Colorado, USNO Flagstaff AZ, University of Utah Logan, Sonneberg Observatory, Hamburg Observatory, and many others. Also collaboration with Czech Institutions is extensive (Czech Technical University in Prague, Institute of Chemical technology, etc.) We use data e.g. from satellites INTEGRAL, Swift, Fermi, RHESSI, RXTE, and simultaneously acquire data from optical telescopes, and so we can study the high-energy objects in a wide range of wavelengths. We also participate in the design and development of new innovative space experiments with an emphasis on X-ray optics, telescopes, and monitors, and participate in proposals for new space missions in the X- and gamma-ray astrophysics such as ATHENA, LOFT, THESEUS, LOBSTER etc. The group regularly organizes international conferences and workshops (AXRO and IBWS), and participates in the organization of large international conferences such as SPIE Europe, Frascati workshop on Multispectral behaviour of cosmic high-energy sources, and international conferences on Frontier objects in astrophysics.

The HEA group also studies the long-term activity of the astrophysical high-energy sources located in our Galaxy. It concentrates on the systems that contain a mass-accreting compact object such as low-mass X-ray binaries, cataclysmic variables and supersoft X-ray sources. The research of the HEA group concentrates on the analyses of the long-term activity in the X-ray and optical regions (e.g. transitions between the high and low states, outbursts). The team also investigates the dependence of the observed characteristics of these objects (and their activity) and their physical parameters. For investigating the activity in the X-ray band, this HEA group mainly uses data provided by the monitors on board satellites (in particular NASA RXTE and Swift). The group conducts time series analyses of the long-term variations and investigates the X-ray hardness ratios in various X-ray bands. It provides interpretations of the activity and the responsible physical mechanisms. It analyses the X-ray observations of the long-term activity of the X-ray transients and persistent X-ray sources, for example KS

1731-260 which underwent peculiar repetitive changes of its accretion disk during transition from its very long main outburst. This study enabled to place this activity in the context of the systems with the mass accreting compact object. These analyses also show the importance of monitoring of the sky in the X-ray region.

Figure 1. Conference poster from one of the meetings, held annually (since 2009) in Karlovy Vary (Czech Republic). Originally, the IBWS (INTEGRAL/BART) workshops focused on the work of High-Energy Astrophysics Group in Astronomical Institute, Academy of Sciences of the Czech Republic, and international collaborators in the field, with strong student participation. Recently, the IBWS workshops promote regional collaboration in high-energy astrophysics with the emphasis on interface between satellite projects and ground-based experiments (robotic telescopes). Conference website: http://www.ibws.cz .

Our specialty recognized worldwide is the study of archival photographic images, both direct and spectral, and we participate actively in the rescue of valuable old observations stored in the archives of various observatories on glass photographic plates and negatives. We use these archival data to monitor the long-term behaviour of high-energy radiation sources and can thus follow and interpret their physical nature. This enables us to study the activity of such sources on very long time scales (at least several decades back to the past). Its analyses also confirm the scientific importance of astronomical plate archives for astrophysics. They enable us to study the evolution of astrophysical objects during very extended time segments, in some cases even of the order of 100 years. Since many such optical counterparts display very strong activity which even undergoes large changes of its properties with time, such archival plates prove to yield very important information about the past activity which cannot be obtained by any other means. This research field is perspective because monitoring of a large sample of high-energy systems is needed to shed more light on the parameters of the state transitions (including the relation of these events to the state of the long-term activity) both of a given object and a group.

We operate our own two robotic telescopes (D50 and BART) that are used for photometry of high-energy radiation sources, with emphasis on rapid follow up of celestial gamma ray bursts. The HEA group built and operates a robotic D 0.5m telescope (D50) and a 0.25 m BART telescopes, both with CCD detectors. We use these instruments for obtaining observations of early phases of optical afterglows of GRBs in collaboration with the NASA satellite Swift. In this framework, it obtained CCD observations of the afterglow of GRB 090726 and provided a physical interpretation. This analysis also proved the efficiency of this ground-based segment of satellite observing. The HEA group participated in a large international collaboration that provided observations of the afterglow of the unique gamma-ray source SWIFT J1955+2614 by a large network of ground-based monitoring telescopes and a very deep image of the quiescent source after the outburst using a D 10 m Spanish telescope. The group also participates in interpreting the data. This included a discussion of the emission mechanisms and similarities between synchrotron emission of J1955, proved to be located in our Galaxy, and the optical afterglows of the extragalactic gamma-ray bursts. The HEA group also analysed the data from the instrument UVOT onboard the NASA satellite Swift for investigating the optical afterglow of GRB 060218. This team investigated the time evolution of this afterglow, and searched for the common properties of this unique event and other long GRBs. Nowadays; both robotic telescopes are included in the first worldwide network of robotic telescopes with free access, developed with our participation (EU project GLORIA).

Figure 2. D50 Ondřejov robotic telescope has been included within the GLORIA network, http://gloria-project.eu/tag/d50-en/ .

Besides observing optical afterglows of GRBs, the D50 instrument observes optical emission of selected high-energy sources. It is able to obtain series of images, which can be repeated for many nights and investigate the phenomena of the long-term activity of such sources. The group analyses these data and provides their physical interpretation. For example, it studied the activity of the cataclysmic variable V795 Her and showed how the tidal force is important in affecting the thermal-viscous instability of the accretion disk. This study has a general importance because it shows that the tidal heating like the one operating in V795 Her can also largely influence the state of the accretion disks in other systems (the so-called permanent superhumpers).

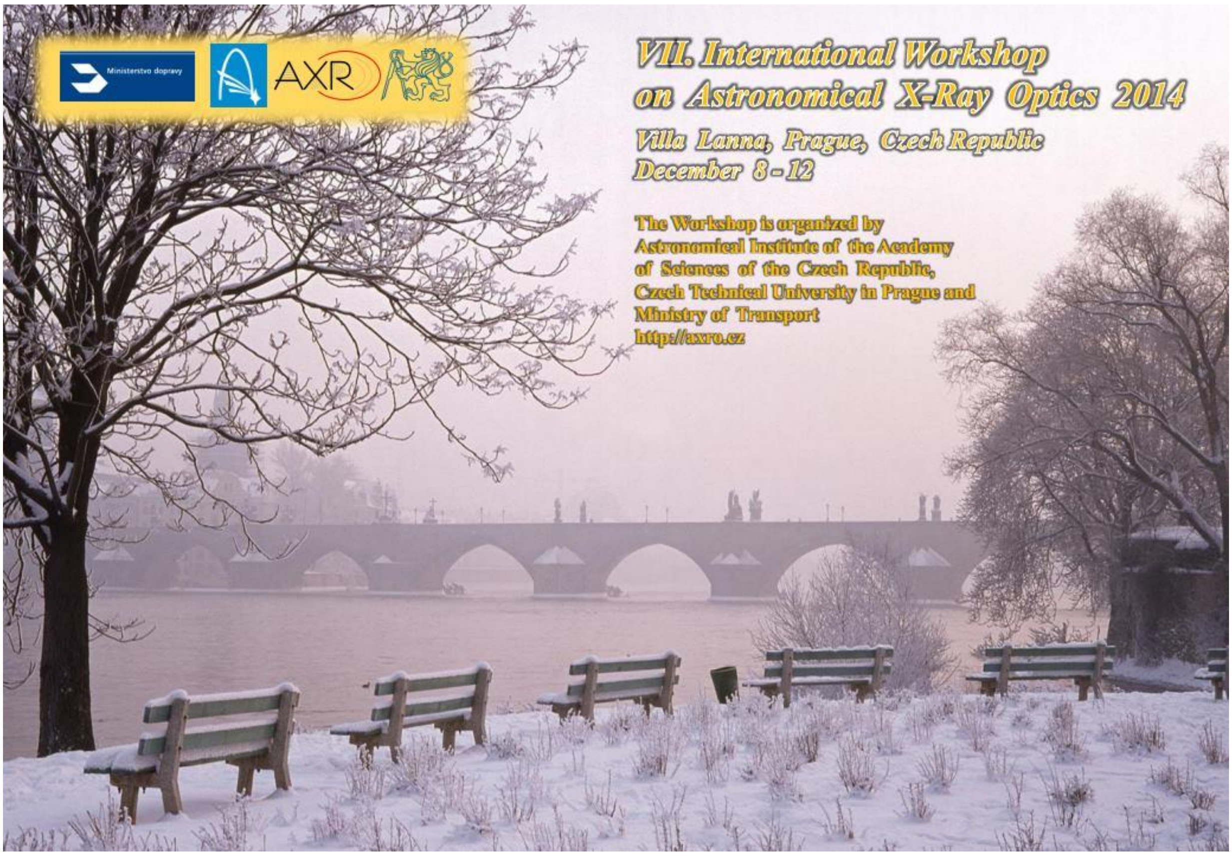


Figure 3. Group of High-Energy Astrophysics organizes workshops on Astronomical X-Ray Optics (AXRO) which are held annually with international participation in Prague Villa Lanna.

Research Report of the team in the period 2010–2014

Institute	Astronomical Institute of the CAS, v. v. i.

Scientific team	Department of Interplanetary Matter

The Department of Interplanetary Matter studies minor bodies of the Solar System, in particular meteoroids and asteroids. Attention is devoted to the study of the interactions of interplanetary bodies of different sizes with the Earth's atmosphere. Photometric studies of Near-Earth Asteroids are also performed. The Department consists of two working groups.

The Group of Meteor Physics observes meteors in the optical region, analyses observed data by own methods and procedures (continuously improved) and performs theoretical interpretations of the observations. The basic observational system is the European Fireball Network (EN) which was established in former Czechoslovakia in 1963 and it is the longest continuously operational fireball network on the world. The center of the EN is located in Ondřejov and all its activity is coordinated by our group. At present it consists of 11 stations in Czech Republic, 14 stations in Germany and 2 in Slovakia and Austria. In scope of this experiment we closely cooperate with colleagues from Comenius University in Bratislava operating 4 video all-sky systems in Slovakia and with several amateur groups active in the Netherlands, Poland, Slovenia, Croatia, Austria and Hungary. All Czech stations have been equipped with sophisticated instruments for optical observation of fireballs, the Autonomous Fireball Observatory (AFO) and, in the last three years, also the Digital Autonomous Fireball Observatory (DAFO). We significantly participated on development of these modern and fully automated instruments. They significantly increased efficiency of our observations and complexness and precision of the acquired data. Fireball spectra are simultaneously photographed at the Ondřejov Observatory. We also participate in the project of the Desert Fireball Network (DFN) in Australia equipped with AFO. Sensitive television cameras are used in the double station video observation program for observation of faint meteors and their spectra during the activity of interesting meteor showers. Similarly as in the case of fireball cameras we started modernization of the video observations of meteors. We developed new automatic video cameras MAIA (Meteor Automatic Imager and Analyzer). The cameras are located on two sites separated by 90 km (Ondřejov and Kunžak) and regularly carry out automatic double station observations. The observational data are used to study physical processes during the penetration of meteoroids into planetary atmospheres, including ablation, deceleration, radiation, and meteoroid fragmentation. The physical properties and chemical composition of different types of meteoroids, their origin and distribution in the solar system and their relation to comets, asteroids and meteorites are being determined. Theoretical calculations of the processes affecting meteoroids in interplanetary space (thermal destruction, changes of rotation) are also being performed.

The Asteroid group focuses on physical studies of asteroids in the Solar system. We study non-gravitational processes in small asteroids, binary systems and paired asteroids, and asteroids in excited (non-principal) rotation states. We also observe so-called Near-Earth Asteroids (NEAs; also NEOs – Near Earth Objects) and their source regions. NEAs are a part of the asteroid population, which represents an impact hazard for the Earth. Precise astrometry allows a determination of the orbits of NEOs and therefore to calculate their potential risk for the Earth. There is a number of observatories across the world which collaborate with us on the project. Our two main observational instruments are the 1.54m Danish telescopes at the European Southern Observatory, La Silla, Chile (since 2012) and the 0.65m telescope at Ondřejov. The observations on the 1.5m telescope at La Silla are run within our collaboration project with the Danish colleagues at the Niels Bohr Institute, Copenhagen University. The collaboration with the other observatories across the world provides us with data from a number of their instruments that allow us to get a substantially more thorough understanding of the studied objects.

In the following, we list the selected most important results obtained in the period 2010-2014 sorted according to the each working group and solved topic.

Group of Meteor Physics

The analyses of important individual bolides leading to meteorite falls

The Group of Meteor Physics is a world-leading group in observations of bright bolides and interpretation of bolide data. In the recent years, we specialized on the instrumentally observed meteorite falls. The scientific value of the data increases when both bolide and the corresponding meteorites can be analyzed. The number of instrumentally observed meteorite falls rapidly increased in the recent years thanks also to our observations and/or computations. At the moment, there are 23 instrumentally observed falls worldwide. Our group participated in the analyses of more than half of these cases. In the recent years, we analyzed the meteorite falls Benešov, Jesenice, Križevci, and Žďár nad Sázavou captured by the EN cameras, Bunburra Rockhole and Mason Gully captured by the DFN cameras, and Košice, Chelyabinsk, and Maribo captured by casual video cameras, which had to be calibrated subsequently. Not all of this work has already appeared in refereed journals, nevertheless, we published some important papers:

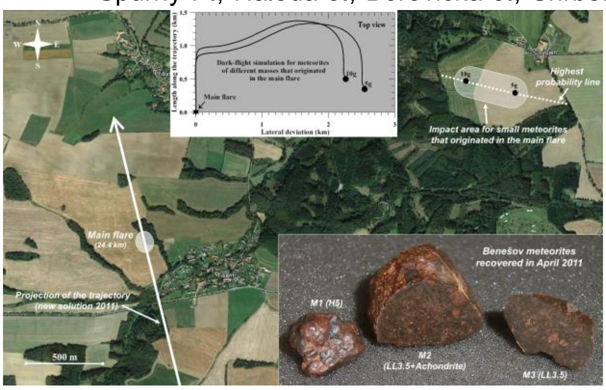
- Spurný P., Bland P. A., Shrbený L., Borovička J., Ceplecha Z., Singelton A., Bevan A.W.R., Vaughan D.,Towner M.C., McClafferty T.P., Toumi R., Deacon G., The Bunburra Rockhole meteorite fall in SW Australia: fireball trajectory, luminosity, dynamics, orbit, and impact position from photographic and photoelectric records. Meteoritics and Planetary Science 163-185, 2012

This work describes detailed analysis of the first instrumentally observed meteorite fall in Australia and on southern hemisphere. It was recorded by two cameras of the Desert Fireball Network on July 20, 2007. It is the fifth predicted meteorite fall in history and first such case from a relatively faint fireball with a terminal height of 30 km. Recovered meteorites are also very exceptional – they are classified as a new type of anomalous achondrite (Fig 3). BR is the first known meteorite from an unusual Aten type orbit. The most important part of this work was the determination of the atmospheric trajectory, dynamics, luminosity, orbit and impact location. It was done entirely by our team. We also measured all records and for all computations we used our own methods, procedures and software. We significantly participated also in data acquisition as all records were taken by the instruments which were designed and manufactured in Czech Republic. We participated also in searching activities in Australia.

- Spurný P., Borovička J., Kac J., Kalenda P., Atanackov J., Kladnik G., Heinlein D., Grau T.: Analysis of instrumental observations of the Jesenice meteorite fall on April 9, 2009. Meteoritics & Planetary Science 45, 1392-1407, 2010

In this paper we report an analysis of instrumental observations of a bright bolide connected with a meteorite fall near the town of Jesenice in Slovenia on April 9, 2009. From all available records we computed atmospheric trajectory, fragmentation history and heliocentric orbit. We proved that this fall is not connected with the Pribram-Neuschwanstein pair which occurred on similar date. This result is based on international cooperation but our team played a crucial role in this work. All photographic images and radiometric light curves are from our automated fireball observatories. We reduced photographic, video and radiometric records and performed all calculations concerning determination of atmospheric trajectory, fragmentation history and heliocentric orbit. PK analyzed seismic records, JK+JA+GK provided us with video data and DH+TG added data about meteorites.

- Spurný P., Haloda J., Borovička J., Shrbený L., Halodová P. Reanalysis of the Benešov bolide and recovery of polymict breccia meteorites - old mystery solved after 20 years. Astronomy & Astrophysics 570, A39, 2014



Using improved methods we performed a new analysis of the Benešov bolide of May 7, 1991. A revised atmospheric trajectory and a new impact location were obtained. This allowed us to recover four highly-weathered meteorites with a total mass of 12g exactly in the predicted area. For the first time a meteorite was found so long (20 years) after the bolide observation. Even more interestingly, the meteorites contain three different mineralogical types. The Benešov meteoroid and its parent asteroid were thus significantly heterogeneous.

The Ondřejov team did the most important part of this work. All records which we analyzed were taken by our cameras. We also did all measurements and computations which led to the revised atmospheric trajectory and determination of the new impact location.

Fig.1: Projection of the terminal part of the atmospheric trajectory of the Benešov bolide, dark flight and corresponding impact area for small meteorites originated in the main flare, and Benešov meteorites found in 2011.

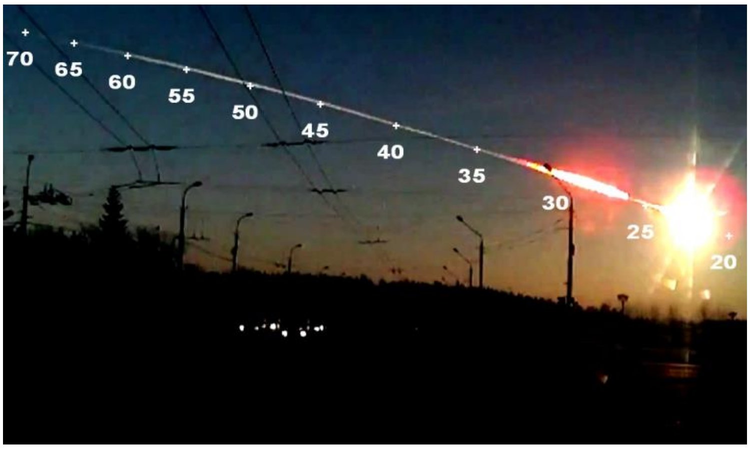
- Borovička J., Tóth J., Igaz A., Spurný P., Kalenda P., Haloda J., Svoreň J., Kornoš L., Silber E., Brown P., Husárik M. The Košice meteorite fall: Atmospheric trajectory, fragmentation, and orbit. Meteoritics and Planetary Science, 48, 1757-1779., 2013

The Košice meteorite fall occurred in Slovakia on February 28, 2010. Bad weather prevented direct imaging of the fireball by dedicated meteor cameras. Fortunately, three surveillance video cameras in Hungary recorded, at least partly, the event. These records allowed us to reconstruct the trajectory and velocity of the fireball and recover the meteorites. In addition, the fireball light curve was recorded by camera radiometers through the clouds. New method of modeling atmospheric fragmentation of bolides was also described and applied to the Košice fall. We took into account macroscopic fragments as well as dust formed during the fragmentation. The dust was allowed to be released either immediately or gradually. Most of the Košice meteoroid was found to be quite weak in comparison with other ordinary chondrites. The orbit was characterized by large aphelion distance, almost approaching the orbit of Jupiter.

We used the casual records and calibration images taken by the Hungarian colleagues according to our instructions to compute the trajectory and velocity. Based on our computations, Slovak colleagues found the first meteorites. Using the video data and light curves from our radiometers (working through clouds) we modeled the atmospheric fragmentation of the meteoroid using our new method. We also computed the heliocentric orbit and the expected strewn field.

- Borovička J., Spurný P., Brown P., Wiegert P., Kalenda P., Clark D., Shrbený L., The trajectory, structure and origin of the Chelyabinsk asteroidal impactor. Nature, 503, 235-237., 2013

The impact of an asteroid near Chelyabinsk, Russia, in February 2013 was the largest collision with cosmic body since 1908. It caused significant damage and worldwide attention. In this paper the atmospheric trajectory and velocity was determined from casual video records. Atmospheric fragmentation was described in detail with inferences about the internal structure of the body. Heliocentric orbit was determined and it was suggested that the impactor originated from larger asteroid 86039.



The most important part was the determination of trajectory and velocity from non-scientific records. That work was done entirely by our team. The method was invented here, the software was prepared and the measurements were done. Our team computed the fragmentation, the interpretation of the atmospheric behavior and the properties and landing points of individual fragments.

Fig. 2: Video frame of the Chelyabinsk bolide and its trail taken by A. Ivanov in Kamensk-Uralskyi with height marks added according to our trajectory computation (heights above sea level in km).

Results not published yet

- Borovička J., Spurný P., Šegon D., Andreić Ž., Kac J., Korlević K., Atanackov J., Kladnik G., Mucke H., Vida D., Novoselnik F.: The instrumentally recorded fall of the Križevci meteorite, Croatia, February 4, 2011. Submitted to Meteoritics & Planetary Science

We analyzed the **Križevci** meteorite fall which occurred over Croatia on February 5, 2011. The bolide was recorded by amateur meteor cameras in Croatia and Slovenia and our camera in Martinsberg, Austria. The meteorite was recovered by the Croatian group. We analyzed all available records including radiometric light curve from Martinsberg, computed the bolide trajectory, velocity, and orbit and modeled the meteoroid atmospheric fragmentation with our own model. Križevci can be ranked among the ten best documented meteorite falls. The paper was submitted in December 2014.

The papers of other three meteorite falls where we computed the trajectory are in preparation. They include **Mason Gully**, which was recorded by the Desert Fireball Network (DFN) on April 13, 2010, **Maribo**, which was captured by one casual video, one photograph, a radar and our radiometers on January 17, 2009, and **Žďár nad Sázavou** recorded by 7 digital (DAFO) and 3 film (AFO) all-sky cameras of the Czech part of the EN on December 9, 2014. The trajectory and preliminary analysis of Mason Gully was published as the LPI abstract. The Maribo results were presented on the conference Meteoroids 2013 in Poznan, Poland. Both were also included in our Asteroids IV chapter (see below). Žďár nad Sázavou is a very fresh and not yet completely finished case.

The analyses of other interesting bolides including artificial fireballs

- Spurný P., Shrbený L., Borovička J., Koten P., Vojáček V., Štork R. Bright Perseid fireball with exceptional beginning height of 170 km observed by different techniques. Astronomy & Astrophysics, A64, 6 pp., 2014

This work describes complex analysis of a very bright Perseid fireball recorded by different instruments operated by Ondřejov team. This is the highest meteor ever observed that does not belong to the Leonid shower. Its atmospheric trajectory and orbit belong to the most precise and reliable ever obtained for Perseid meteor. Its video spectrum is the highest spectrum of a meteor ever obtained. For the first time we proved that only atmospheric emissions of O, N and N2 were present above 130 km. This work was done entirely by our team.

- Borovička J., Abe S., Shrbený L., Spurný P., Bland P. A., Photographic and Radiometric Observations of the HAYABUSA Re-Entry. Publications of the Astronomical Society of Japan, 63, 1003-1009, 2011

The returning Japanese spacecraft Hayabusa caused an artificial fireball during its re-entry over Australia in June 2010. We analyzed photographs and radiometric data of the event. The trajectories, velocities and light curves of the spacecraft, its fragments, and the re-entry capsule were determined. The luminous efficiency was found to be 1.3%. This is one of most detailed works on artificial fireballs, enabling calibration and verification of the methods for natural fireball analyses.
The Desert Fireball Network in Australia, which provided part of the data, is partly operated by our team. Other data were provided by a dedicated Japanese expedition. All photographs were measured by our team and we also calculated the trajectory with our specific method for curved trajectories. The interpretation of the data was also done by us. The predicted Hayabusa trajectory, as prepared by the spacecraft operation team, was provided by our Japanese colleague.

Studies of meteor showers

We observed the predicted exceptional outbursts of meteor showers, namely Leonids in 2009 and Draconids 2011. For this purposed we organized special expeditions abroad, where video techniques were used. We regularly observe annual meteor showers with video techniques. The purpose is not only to infer the activity profile but also to study physical properties and spectra of meteoroid from various parent bodies or to search for possible new showers. The fireball networks provide data on large shower meteoroids (as for Quadrantids, Perseids and Geminids) and occasionally capture unexpected activity of some showers, as was the case of September Epsilon Perseids in 2013 and Kappa Cygnids in 2014. In some cases the video and photographic data can be combined leading to very complex analyses of individual fireballs (see the Perseid with exceptional beginning height above 170km). We organized two expeditions to observe the Draconid 2011 meteor outburst - the ground based expedition in Italy and the airborne expedition above the Northern Europe. In the latter case we were responsible for operations of one of two participating aircrafts.

- Koten P., Borovička J., Kokhirova G. I.: Activity of the Leonid meteor shower on 2009 November 17. Astronomy & Astrophysics, vol. 528, A94, 2011

The enhanced activity of the Leonid meteor shower connected with the material ejected from the parent comet in 1466 and 1533 was predicted for 2009. Using the video cameras we confirmed that the peak of activity occurred within the predicted time. The data shows that this old stream does not produce very bright meteors as the streams observed in 1998 to 2002 did. Duration of the peak was longer, what is consistent with a scattered, i.e. older filament encounter.
This event was invisible in Europe since it occurred at the time when the radiant of the shower was below the horizon. Longstanding cooperation with Tajikistan allowed us to record it. Tajik astronomers provided us with the local support and we carried out the double-station video observations. We were the only team in the world, who optically confirmed the predictions of the theoretical models.

- Koten P., Vaubaillon J., Čapek D., Vojáček V., Spurný P., Štork R., Colas F.: Search for faint meteors on the orbits of Příbram and Neuschwanstein meteorites. Icarus. vol. 239, pp. 244-252, 2014

Příbram and Neuschwanstein meteorites belong to the same meteorite stream. The trajectories and orbits of video meteors were analysed to determine whether such stream may contain also small particles. An orbital evolution model was applied on cloned particles to investigate possible connection. It was tested if such small sample of the orbits is similar by chance or if the stream is real. We found that is impossible to prove the existence of faint meteor shower connected with the stream. This work represents cooperation between Czech and French astronomers and connection of both experimental and theoretical approaches in study of the meteor showers. All the experimental data were obtained within the double-station observational program in the Czech Republic. The data were analyzed using the tools of the Czech part of the team. The French scientists contributed with the modeling of the orbital evolution of the meteoroids, since they are experts in this field of meteor astronomy.

- Kokhirova, G.I., Borovička J.: Observations of the 2009 Leonid activity by the Tajikistan fireball network. Astronomy & Astrophysics, vol. 533, A115, 2011

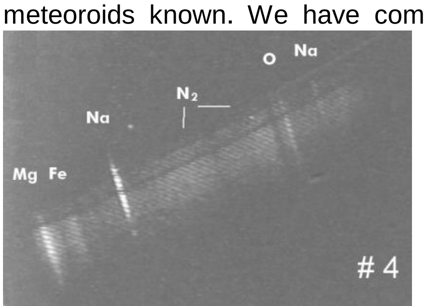
We analyzed fireball data from the 2009 Leonid outburst. According to the end heights, nearly half of Leonid fireballs belonged to the most fragile and weak fireball group IIIB and the rest to the slightly denser cometary group IIIA. The typical Leonid meteoroid mean bulk density was from about 0.6 to 0.2 g cm^{-3}. However, one detected Leonid with a size of about 5 mm belonged to the fireball group I and likely had a bulk density of few g cm^{-3}. This is the first detection of an anomalously strong Leonid individual. The chemical composition of the anomalous piece was not markedly different from other Leonids. However, that meteor did not show preferential ablation of sodium at high altitudes, which further confirms its stronger nature in comparison with other Leonids. The 2009 outburst was well observable only from central Asia and we organized expedition to Tajikistan with the help of G. Kokhirova. Fireball trajectories were observed by Tajik photographic cameras and computed by us. Spectra were taken by our video cameras. We performed the spectral analysis.

- Koten P., Vaubaillon J., Tóth J., Margonis A., Ďuriš F.: Three Peaks of 2011 Draconid Activity Including that Connected with Pre-1900 Material. Earth, Moon and Planets, vol. 112, p. 15-31, 2014

A Draconid meteor shower outburst was observed from on board two scientific aircraft deployed above Northern Europe on 8th October 2011. The activity profile was measured using a set of photographic and video cameras. The main peak of the activity occurred around 20:15 ± 0:0.5 UT which is consistent with the model prediction. The corrected hourly rates reached a value of almost 350. The brighter meteors peaked about 15–20 min earlier than the dimmer ones. This difference can be explained by different directions of the ejection of the meteoroids from the parent comet. One of the instruments was even able to detect meteors connected with the material ejected from the parent comet before 1900 and thus confirmed the prediction of the model, although it was based on uncertain pre-1900 cometary data. Another small peak of the activity, which was caused by material ejected during the 1926 perihelion passage of the parent comet, was detected around 21:10 UT. The mass distribution index determined using the narrow field-of-view video camera was 2.0 ± 0.1. This work shows that the observation of meteor outbursts can constrain the orbital elements, outgassing activity and existence of jets at the surface of a comet.

- Borovička J., Koten P., Shrbený L., Štork R., Hornoch K.: Spectral, Photometric, and Dynamic Analysis of Eight Draconid Meteors. Earth, Moon, and Planets, Volume 113, p. 15-31, 2014

The structure of small cometary meteoroids and the process of their ablation in the atmosphere are still not well understood. We analyzed complex data on 8 Draconid meteors, which represent the most fragile meteoroids known. We have combined spectroscopy, photometry, dynamics and morphology of the meteors to study the properties of 1 – 3 cm sized meteoroids.. Some meteors had smooth and flat light curves without any flares, high



decelerations, and the release of most sodium in the first half of their trajectories. All these features can be explained by the complete and quick disintegration of the meteoroids into small grains. Other meteors had low deceleration, exhibited flares at relatively low heights 84–83 km and sodium was present along the whole trajectories. Our analysis suggests that their bulk density was similar to the meteoroids of the previous group and their fragmentation started at similar heights. The main difference was that the grain release was much slower and not from the whole body. This work, which was done entirely by our team, demonstrated that various textures with various resistances to atmospheric fragmentation exist among Draconid meteoroids and even within single meteoroids.

Fig.3: The spectrum of one of the studied Draconid meteors (co-added video frames) showing clearly the shift of the Na emission to higher altitudes.

Results not published yet:

- Abedin, P. Spurný, P. Wiegert, P. Pokorný, J. Borovička and P. Brown: On the age and formation mechanism of the core of the Quadrantid meteoroid stream. Submitted to Icarus.

In this work, we present results on the most probable age and formation mechanism of the narrow portion of the Quadrantid meteoroid stream. For first time we use data on eight high precision photographic Quadrantids, equivalent to gram - kilogram size, to constrain the most likely age of the core of the stream. According to our results, from the backward integrations, the most likely age of the narrow structure of the Quadrantids is between 200 - 300 years. This work is based on the data from the Czech part of the EN.

Other unfinished work concerns the unique **Geminid** fireball which was recorded in the Czech part of the European Fireball Network (EN) on December 13, 2012. The uniqueness of this Geminid fireball consists in its record deep penetration in the atmosphere (32.6 km) and in the fact that in all likelihood a small part of its initial mass survived severe deceleration in the atmosphere and landed on the ground. This is for the first time when we have such clear evidence that it is possible to find real meteorite which undoubtedly belongs to any meteor shower and its parent body (Phaethon).

We also captured the unexpected outburst of **September epsilon Perseid** (SPE) meteors on September 9, 2013. Twelve bright meteors were recorded photographically from more than one station so that we could determine all important parameters describing their atmospheric trajectories, heliocentric orbits and basic physical properties. The orbit is of long period and the material has similar strength as (August) Perseids.

Theoretical work on meteoroids in interplanetary space

- Čapek D. and Vokrouhlický D. Thermal stresses in small meteoroids., A&A 519, A75, 2010
- Čapek D. and Vokrouhlický D. Thermal stresses in small meteoroids. II. Effects of an insulating surface layer. A&A 539, A25, 2012

Mechanical disintegration of rocks due to thermal stresses is well known phenomenon in Earth's arid areas. The question is if a similar process can destroy meteoroids in the interplanetary space. We focused on thermal shock which arises in a rotating spherical meteoroid, one hemisphere of which is heated by Sun, whereas the opposite one is cooled due to thermal radiation from the surface. The resulting temperature gradient causes thermal stress which can override the strength of the meteoroid. We solved this problem analytically and derived expressions for thermal stress tensor. It was proven, that the thermal stress is important phenomenon, which is able to destroy meteoroids. In the second paper we investigated the possibility that the fractured material remains at the surface, owing to either molecular sticking or an insufficiently interconnected system of fractures. Our results show that in one or a few revolutions about the Sun, a particulate surface layer develops and is able to thermally shield the core, preventing any further damage by thermal stresses.

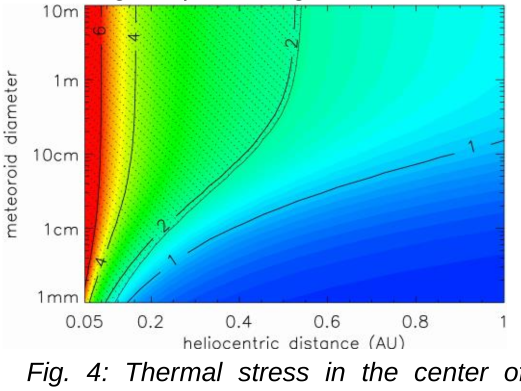


Fig. 4: Thermal stress in the center of fast rotating spherical meteoroid (C-chondrite). The stress overrides the tensile strength in dashed area (i.e. material failure occurs).

- Čapek, D., Rotation of cometary meteoroids. A&A 568, A39., 2014

The rotation of meteoroids after the ejection from comets has not been studied up to now. We developed a sophisticated numerical model that describes the rotation of irregularly shaped meteoroids due to action of a gas escaping from the nucleus of a parent comet. Meteoroid shapes were approximated by digitized shapes derived from distinct sets of different terrestrial rock samples.Simple relationship was derived for median of spin frequencies *f* (Hz) as a function of meteoroid size *D* (m) and ejection velocity v_{ej} (ms^{-1}) as $f = (2\text{-}5)\times10^{-3}\ v_{ej}\ D^{-0.88}$. The dependence of the median of spin frequencies on meteoroid density and on the physical properties of cometary nucleus is hidden in the value of v_{ej}. The distribution of spin frequencies is roughly normal on the log scale. It is relatively wide with more than 95% of values inside the interval (0.1, 10) times *f*. Most of meteoroids are non-principal axis rotators. The median of mean angle between angular momentum vector and spin axes is approximately 12°. Angular momentum vectors are not distributed randomly in space, but are concentrated it the perpendicular directions with respect to the gas flow.

Results not published yet:

- Pecina P. An analytical theory of a scattering of radio-waves on meteoric ionization. I. Basic equation. II. Solution of the integro-differential equation in case of backscatter. Two papers submitted to Monthly Notices of Royal Astronomical Society.

New analytical theory of radio-waves reflection on the ionization of the meteoric origin, based fully on the Maxwell equations was developed. The appropriate integro-differential equation, describing the behavior of the polarization vector inside the meteor trail, has been derived. The results show that the chosen approach is valid of yielding the time amplitude behavior that is much closer to that observed than the behavior obtained from the theory developed so far.

General work and reviews

In addition of the papers devoted to individual bolides, we also participated in work generalizing the results and finding the generals trends.

- Popova O., Borovička J., Hartmann W. K., Spurný P., Gnos E., Nemtchinov I., Trigo-Rodríguez J. M., Very low strengths of interplanetary meteoroids and small asteroids. Meteoritics and Planetary Science, 46, 1525-1550., 2011

Observations of asteroids provide almost no information on their internal structure, in particular mechanical strength. The strengths of meteorites are >30 MPa but meteorites represent only the strongest part of the original bodies. We compiled data on 13 instrumentally observed meteorite falls and concluded that the first breakup occurred at pressures of only 0.1 – 1 MPa. The meter-scaled asteroids are thus highly fractured. We did not find the theoretically expected dependence of strength on object size. This work was done in broad international cooperation under the leadership of O. Popova, who initialized this topic. Our contribution to data compilation and their interpretation was significant. Moreover, from the 13 studied meteorite falls, our team studied entirely or participated in the studies for 8 of them. For this work we also provided some additional unpublished data on smaller meteoroids.

- Borovička J., Spurný P. Brown P., Small near Earth asteroids as a source of meteorites. In Asteroids IV (P. Michel, F.E. DeMeo, W.F. Bottke, Jr., eds.) The University of Arizona press, accepted. arXiv: 1502.03307

J. Borovička was invited to be lead author of this chapter by the editors of the book Asteroids IV. He selected P. Spurný and P. Brown from Canada as co-authors. The chapter is a review of the current knowledge of properties of small (1 – 20 m) asteroids based on the observation of fireballs and, in particular, the instrumentally observed meteorite falls. The observation techniques and methods of data analysis are also reviewed. Most of the chapter was written by our team members. P. Brown contributed some special techniques (infrasound), described some individual events (carbonaceous meteorite falls, Carancas) and the influx section.

Group Asteroids

Formation of asteroid pairs

Asteroid pairs are couples of asteroids revolving the sun in separate, but highly similar orbits. Their existence was discovered by D. Vokrouhlický and D. Nesvorný in 2008, but their origin was not known.

- Pravec P., Vokrouhlický D., Polishook D., Scheeres DJ., Harris AW., Galád A., Vaduvescu O., Pozo F., Barr A., Longa P., Vachier F., Colas F., Pray DP., Pollock J., Reichart D., Ivarsen K., Haislip J., LaCluyze A., Kušnirák P., Henych T., Marchis F., Macomber B., Jacobson SA., Krugly YuN., Sergeev AV., Leroy A. Formation of asteroid pairs by rotational fission. Nature, 466, 1085-1088, 2010

We studied rotational properties of asteroid pairs. We measured 35 pairs with our technique of time-resolved photometry. Most data were taken with the 1-m telescope at Wise Observatory, Israel, and the 1.54-m Danish telescope at La Silla, Chile. We derived their primary spin rates and mass ratios. We found a strong correlation between the square of primary spin frequency and the mass ratio (*q*). We interpreted the data with a theory of rotation fission by D. Scheeres (2007). We have got a perfect match between the pairs' properties and the theory. Specifically, we found that the primaries of pairs with $q \ll 0.2$ rotate rapidly, near their critical frequency. As $q \rightarrow 0.2$, the primary period grows long. This occurs as the total energy of the system approaches zero, requiring the secondary to extract an increasing fraction of energy from the primary's spin in order to escape. We did not find asteroid pairs

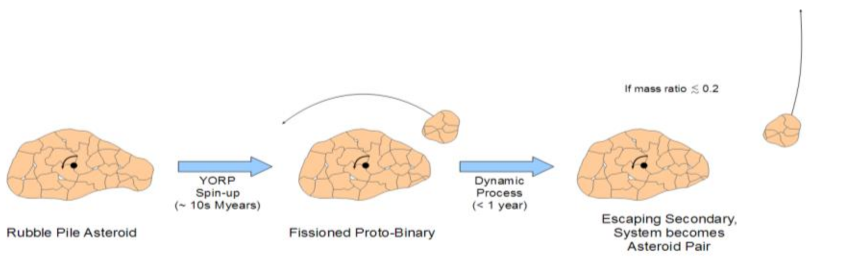


Fig. 5: Loosely bound asteroid is slowly spun-up to the critical frequency, then it fissions. The secondary gains a part of the primary's angular momentum and escapes at low relative velocity, forming an asteroid pair.

with $q > 0.2$. Rotationally fissioned systems beyond this limit have insufficient energy to disrupt. We concluded that asteroid pairs are formed by the rotational fission of a parent asteroid into a proto-binary system, which subsequently disrupts under its own internal dynamics soon after formation.
Our findings have contributed substantially to the growing knowledge on that asteroids are not inert giant rocks, but they are changing „little words" that give birth to smaller asteroids. The non-catastrophic evolution mechanism can re-shape the whole asteroid population.
Our contribution to the result: Our Ondřejov team obtained abundant photometric data for a few tens asteroid pairs, with the 1.54-m telescope on La Silla and the 0.65-m telescope in Ondřejov. Then we applied the theory of rotational fission in interpretation of the obtained data. The expertise of the team, both on photometric observations of asteroids and on the theoretical front, was crucial for the work. A thorough collaboration with a few other teams of experts in the world was also a key to this success.

Absolute magnitudes and albedos of asteroids

Two of the key physical quantities of asteroids are their absolute magnitudes and albedos. Their knowledge is needed in about any study of asteroids.

- Pravec P., Harris AW., Kušnirák P., Galád A., Hornoch K., Absolute magnitudes of asteroids and a revision of asteroid albedo estimates from WISE thermal observations. Icarus 221, 365-387, 2012

We analyzed our precise photometric observations that we obtained for 583 main-belt and near-Earth asteroids with the Ondřejov 0.65-m and the Table Mountain Observatory 0.6-m telescope since 1978 to 2011. With our precise data, we studied an accuracy of asteroidal absolute magnitudes published in the catalogs MPCORB, AstDyS and JPL Horizons. We found that the data in the catalogs are systematically biased for asteroids with absolute magnitudes $H > 10$ (corresponding to asteroid diameter D <~30 km), and especially above $H \sim 12$ (D <~10 km). As a result of the catalog data bias, asteroid albedos derived from thermal infrared observations made by the Wide-field Infrared Survey Explorer (WISE) spacecraft were severely biased; for small asteroids, the WISE albedos were overestimated by as much as 50% on average. We derived corrected albedos for the asteroids in our sample and we found that a trend of the mean WISE albedo estimates increasing with asteroid size decreasing from $D \sim 30$ down to ~5 km for S-type asteroids found by Mainzer et al. (2011) was largely due to the systematic bias in the MPCORB absolute magnitudes that they used. We showed that albedos of S-type asteroids actually do not change with asteroid size, and we derived the unbiased mean albedos for S/A/L and C/G/B/F/P/D asteroids. These results are important for many fields of studies of asteroids, and for our studies of asteroid evolutionary processes in particular, as our accurate, non-biased data are needed for correct physical interpretations.

Our contribution to the result: The whole paper is a result of the work of our Ondřejov asteroid photometry team, with a contribution of our American co-author Alan Harris with his supplementary data. We obtained the photometric observations with the 0.65-m telescope in Ondřejov and we analyzed and interpreted the data and revised the albedo measurements from the WISE satellite.

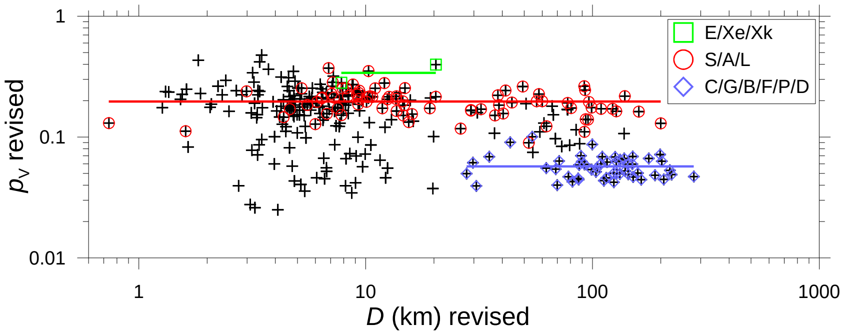


Fig. 6: Asteroids of different compositions have different albedos. The primitive types (C and similar) are dark, scattering only about 6% of incoming sunlight, but the diferentiated (rocky; S and similar types) asteroids are lighter with geometric albedos about 0.20.

Binary asteroids, their properties and constraints on evolutionary processes

Asteroids are weak structures, they split when spun up to the critical frequency and it can form binaries, i.e., systems of two bodies orbiting around their common center of mass.

- Pravec P., Scheirich P., Vokrouhlický D., Harris AW., Kušnirák P., Hornoch K., Pray DP., Higgins D., Galád A., Világi J., Gajdoš Š., Kornoš L., Oey J., Husárik M., Cooney WR., Gross J., Terrell D., Durkee R., Pollock J., Reichart DE., Ivarsen K., Haislip J., LaCluyze A., Krugly YuN., Gaftonyuk N., Stephens RD., Dyvig R., Reddy V., Chiorny V., Vaduvescu O., Longa-Pena P., Tudorica A., Warner BD., Masi G., Brinsfield J., Gonçalves R., Brown P., Krzeminski Z., Gerashchenko O., Shevchenko V., Molotov I., Marchis, F., Binary asteroid population. 2. Anisotropic distribution of orbit poles of small, inner main-belt binaries. Icarus, 218, 125-143, 2012

We studied 18 binary asteroids that we discovered during 2005-2011. We used the technique of time-resolved photometry. The data were taken with the Ondřejov 0.65-m telescope and from collaborating stations in Europe, North and South America and Australia. We derived parameters of the binary asteroids. We found that the binary orbits are not oriented randomly. We analyzed the data including simulations of observational selection effects and we found that the binary orbital poles concentrate within 30 deg from the poles of the ecliptic. We proposed two explanations for the concentration, both being due to an action of the thermal YORP effect on asteroids. The effect is a result of the torque of infrared photons emitted from asteroid's irregular surface. This effect, besides spinning up the asteroid up to the critical frequency, also moves its pole to the up- or downright position. The findings extend our knowledge on how the YORP effect acts on asteroids. This non-catastrophic evolutionary mechanism is a key process that re-shapes the asteroid population.

The Ondřejov team took a part of the photometric observations of the asteroid binaries and we collected observations taken from several collaborating stations in the world. We modeled the data and derived parameters of the binary systems. We run simulations of the photometric survey, described observational biases present in the data and derived the distribution of orbital poles of the asteroid systems.

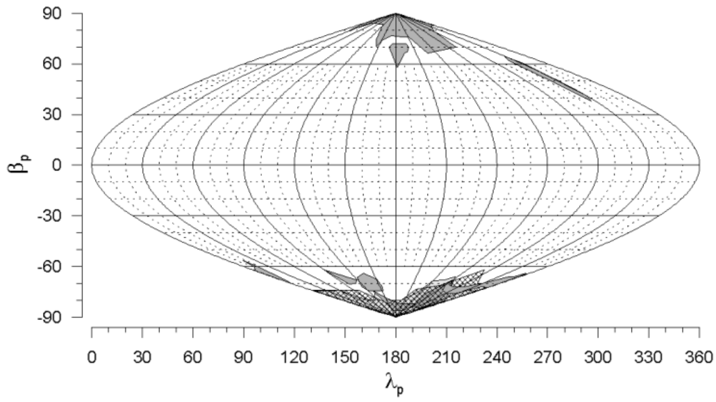


Fig. 7: Poles of binary asteroids concentrate around both the North and South Pole of the ecliptic. This anisotropy is explained as a result of the spin axis evolution under the influence of the non-gravitational thermal effect called YORP.

Excited asteroid rotations

Most asteroids are in basic states of rotation around the principal axis with the maximum moment of inertia, but some are in excited rotational states. Their properties and origin have been poorly understood so far, yet their knowledge is important for understanding evolutionary processes working in asteroids. We published three papers on excited asteroid rotations during the last five years.

- Scheirich P., Ďurech J., Pravec P., Kozubal M., Dantowitz R., Kaasalainen M., Betzler A.S., Beltrame P., Muler G., Birtwhistle P., Kugel F., The shape and rotation of asteroid 2008 TC3. Meteoritics & Planetary Science, 45, 1804-1811, 2010

We modeled the shape and rotation of the small (4-m mean diameter) asteroid 2008 TC3 that was discovered on 2008 October 6 and impacted Earth and exploded in the atmposhere over Sudan 20 hours later, leaving a multitude of meteorites (hundreds of them were recovered). We analysed photometric observations of the asteroid taken during the asteroid's final approach over an interval of five hours before the impact. We found that the asteroid was in a super-fast excited rotation with the rotational and precession periods of 99.2 and 97.0 seconds, respectively. We also estimated the asteroid's volume of 25 +/- 10 m^3 and the dimensions of its elongated figure.

This work was based on international collaboration of groups and individuals from Europe, USA and Brazil. The photometric data were acquired by foreign observatories and the method for their processing was developed by the Czech team with a co-operation with a colleague from Finland.

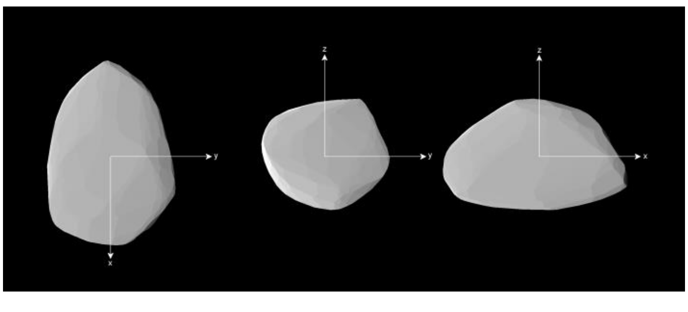
- Henych, T. & Pravec, P.; Asteroid rotation excitation by subcatastrophic impacts, MNRAS, 432, 1623-1631, 2013

We studied effects of subcatastrophic impacts of small asteroids. We simulated collisions between asteroids of various physical and material parameters. We found that tumbling is photometrically detectable for the rotational axis misalignment angle ß >~15 deg. We found that subcatastrophic collisions are a plausible cause of non-principal axis rotation for small slowly rotating asteroids. The determining parameter is the ratio of the projectile orbital angular momentum to the target rotational angular momentum, and we derived a relation between this ratio and the angle ß. We also compared the limiting energy for the onset of tumbling with the shattering energy. Slowly rotating asteroids of diameter >~100 m can be rotationally excited by collisions with energies below the shattering limit. This result was achieved during the doctoral studies of the lead author in close collaboration with his supervisor. The lead author was building his expertise in creating numerical model, running simulations and evaluating results. The great advantage for this research was the expertise of the second author in photometric data analysis and also his general knowledge in the investigated field.

- Pravec P., Scheirich P., Ďurech J., Pollock J., Kušnirák P., Hornoch K., Galád A., Vokrouhlický D., Harris AW., Jehin E., Manfroid J., Opitom C., Gillon M., Colas F., Oey J., Vraštil J., Reichart D., Ivarsen K., Haislip J., LaCluyze. The tumbling spin state of (99942) Apophis. Icarus, 233, 48-60, 2014

We analyzed a spin state of (99942) Apophis. This asteroid possesses a small risk of impacting Earth in 2068 and a knowledge of its spin state is important for improving modeling of its orbit and refining its impact probability estimate. We measured it extensively with the 1.54-m telescope on La Silla and a few collaborating stations. We analyzed the obtained data and we found that the asteroid is in a state of non-principal axis rotation (i.e., free precession, also called tumbling). Our results indicate a slightly increased probability of the asteroid's impact on 2068 April 12, but it is still very small; our follow-up paper with detailed modeling of the Apophis' orbit and analysis of the impact probability by Farnocchia et al. (2015) is in press. We also looked at Apophis in a context of the population of slowly tumbling asteroids, estimated their rotational damping times and discussed possible spin excitation mechanisms. We found that tumblers predominate among slowly rotating asteroids with damping times >~0.2 Gyr. Our results suggest that there are actually two or more asteroid spin evolution mechanisms in play, or that the factor of μQ (the rigidity times the quality factor) decreases with decreasing asteroid size. These findings have important implications for our understanding of properties and evolutionary processes working in near-Earth asteroids.

Our team obtained the most abundant data for Apophis, with the 1.54-m telescope on La Silla and the 0.65-m telescope in Ondřejov. Then we analyzed and modeled the data using methods we developed, with contribution by our colleague J. Ďurech. We applied the theories of asteroid de-excitation in interpretation of the results. The expertise of our team, both on the photometric observations and on the modeling and theoretical interpretation front,



was crucial for the work. A thorough collaboration with a few other teams of experts in the world was also a key to this success.

Fig. 8: Shape model of the potentially hazardous, asteroid (99942) Apophis.

Research Report of the team in the period 2010–2014

Institute	Astronomical Institute of the CAS, v. v. i.

Scientific team	Department of Galaxies and Planetary Systems

Research of the Team focuses in the areas of star formation and stellar clusters, evolution of galaxies in groups and clusters, super-massive black holes in center of the Milky Way and central parts of active galaxies. Another active theme is Earth's rotation and its gravity field, and precise astrometry. There are three working groups in the Department.

National and international impact. During the past five years, our Team has initiated and continued fruitful collaborations with a number of foreign partners at universities and science institutes. We have strong links with the MPIA in Heidelberg (Henning, Grödel), Excellence Cluster "Universe" in Muenich (Dale), University in Cologne (Walch), University of Cardiff (Whitworth), CAMK and CTP in Warsaw (Abramowicz, Czerny, Kluzniak, Rozanska), the Astronomical Observatory of Strasbourg (Goosmann, Porquet), and the Rome institutes (Bianchi, Matt, Muleri, Soffitta). We have an on-going, successful collaboration with the Physics Department of the University of Cologne (Eckart, Valencia-S.), the Massachusetts Institute of Technology (Remillard, Sadowski), Instituto Nacional de Astrofísica Optica y Electrónica in Mexico (Tenorio-Tagle, Silich), The Ohio State University (Schum), and Shangai Astronomical Observatory (Wenfei Yu).

Thanks to our involvement in large observational programs, a wide variety of observations are analyzed and interpreted: X-ray spectroscopy and timing (XMM-Newton, Suzaku), radio interferometry mapping (CARMA, ATCA), and NIR spectroscopy and polarimetry (VLT/NACO – ESO Messenger article in proofs). Future opportunities have been discussed and contributions prepared for white papers (Athena, LOFT, IXPE and XIPE). We are active in data processing, calibrating and orbit tuning of ESA scientific missions GRACE, GOCE, and Swarm.

We organized a successful international conference "Probing Strong Gravity Near Black Holes" (http://astro.cas.cz/bh2010/) in Prague 2010. Over 150 participants discussed new approaches to strong gravity effects near black holes of all masses, including the spectroscopy, timing, polarimetry and imaging. Theoretical and observational progress was thoroughly discussed (Fabian, McClintock, Schnittmann, Schoedel, Wilms) as well as prospects for future missions in a special session (Barret, Chakrabarty, Matt, Nandra). Also, on a regular basis we organize the team and institute seminars to share results and reinforce the collaboration.

The Annual Group workshop has been arranged for many years with foreign participation. We organized the closing workshop of Center of Earth Dynamic Research (CEDR) in 2011 with an attendance of 50 participants. We collaborate on FP6/FP7 project ASTRONET<http://www.astronet-eu.org/>, where we are as one of the contractors responsible for the work package 3 on integration of new Europe members states into the mainstream European astronomy.

We develop our science projects beyond the scope of pure research, especially thanks to teaching activities at the Charles University in Prague, the Silesian University in Opava, the students exchange with Cologne University executed on a regular basis. We continue to post news for public outreach (http://astro.cas.cz/) and produce educational articles (e.g. the Czech magazine Vesmír) and book translations (e.g. Stephen W. Hawking, Paul Murdin, and others). We are involved in the large international CALIFA galaxy survey and a fruitful collaboration on Lyman-alpha physics with the use of the NASA/ESA Hubble Space Telescope (HST).

Grant projects and funding. Combining the limited institutional support with project funding is necessary to maintain resources for excellence. Previously we obtained funding from the Center for Theoretical Astrophysics 2006–2011 (http://cta.cas.cz/), EU FP6 Marie Curie Research Training Network CONSTELLATION: The Origin of Stellar Masses (2006–2010), and CEDR (2000–2011). More recently, our group coordinates major EU FP7 StrongGravity (http://stonggravity.eu) (2013–2017) collaboration effort among partners in Cambridge (UK)–Cologne–Prague–Rome–Strasbourg–Warsaw.

We coordinate the project funded by the Ministry of Education Youth and Sports via action INGO: Tycho Brahe: supporting the ground based observations (2014 – 2016). We are involved in three COST Actions.

We keep strong bonds with the French CNRS, Polish Academy of Sciences, and we take part in the Czech Science Foundation Albert Einstein Center for Gravitation and Astrophysics (http://www.albert-einstein-center.cz/) in Prague.

Several team members are funded through individual research grants of Czech Science Foundation (in total 17 CSF grants in 2010–2014). We join applications for German SFB and DFG calls, as well as the new EU "Horizon 2020" scheme, such as the European Training Network for thirteen Early Stage Researchers in astrophysics including the partnership with Airbus Defence & Space.

Physics of Galaxies Working Group (led by Jan Palouš)

The mission of the group is to study star formation, to explore physical processes in young massive stellar clusters, and to discuss the evolution of galaxies in groups and clusters. Radio, infrared, optical, and X-ray observations are compared to analytical models and computer simulations of gravitational; and MHD processes

Personel. The working group is headed by Jan Palouš. As research fellows it includes Soňa Ehlerová, Pavel Jáchym, Bruno Jungwiert and Richard Wünsch, current and past post-docs are Michal Bílek, James Dale, Ivana Ebrová, Filiberto Hueyotl-Zahuantitla, Ivana Orlitová, Rhys Taylor, and there are several PhD students.

Past and current research:

Shells. We made a catalogue of HI shells in the Milky Way based on the Leiden/Argentina/Bonn (LAB) all-sky HI survey (Ehlerová & Palouš, 2013). We used an automated search routine, which was first used in the previous paper (2005). Now it was improved and applied to an all-sky survey. The advantage of using the automated search is the uniformity of results. We identified 333 shells in the Milky Way.

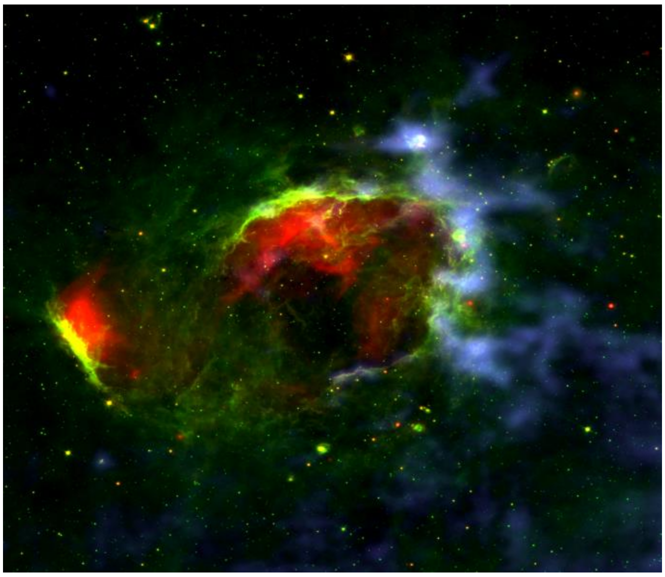


Fig. 1. N107: bubble in the Galactic plane (Sidorin et al. 2014).

We were also interested in the individual fate of smaller structures. Multi-wavelength studies of several IR bubbles (N094, N115, N131) were performed (Zychová & Ehlerová, 2014 - poster presentation). One IR bubble, N107, was intensively studied and numerically simulated (Fig. 1 – Sidorin et al, 2014). These objects are usually young and it is, at least theoretically, possible to find their progenitors, i.e.

young stars producing the energy. By comparing predictions and observations we can test our theories. A long studied topic in the group is the gravitational fragmentation of HI shells. We analysed the fragmented wall of the Carina Flare Supershell (Wünsch et al, 2012) and we performed new MHD numerical simulations. We obtained an Halpha spectrum of the wall of a big HI supershell GS242-03+37 in the Milky Way.

Young Massive Star Clusters. Young massive stellar clusters present large numbers of massive stars all of which lose substantial fractions of their mass in stellar winds and supernova explosions. Chevalier & Clegg (1985) -- CC85 -- proposed a model of SSC winds, where the mechanical energy of individual stellar winds and supernovae (SNe) is thermalized in random collisions causing the reinserted gas to heat up to large temperatures (~10^7 K). This produces a large overpressure able to drive a stationary cluster wind. The radiative and other energy losses are neglected in CC85's adiabatic model, given the low cooling rates expected from gas at such high temperatures. However, the adiabatic model becomes inadequate for massive and compact SSCs and NSCs (Silich et al. 2004): as soon as the cluster mass approaches a critical value, cooling becomes important and the CC85 model no longer applies. Tenorio-Tagle et al. (2007), Wünsch et al. (2007, 2008) and Palouš et al. (2010, 2011) proposed a new model in which clusters evolve in the bimodal hydrodynamical regime only a fraction of the inserted gas leaves the cluster as a wind.

In Palouš et al. (2013), we have generalized the model to use the radial distribution given by the Schuster profile and studied how the results depend on its steepness. There is solid observational and theoretical evidence that dust produced by supernovae can survive passage through the reverse shock and get into the hot medium where it may contribute to cooling. Since the cooling function is an essential input into the cluster wind model, we study the influence of the dust cooling in Tenorio-Tagle et al (2013). Another important process that has to be taken into account to predict the mass of the second stellar generation is the ionization of surfaces of dense clumps by the EUV radiation of massive stars of the first generation. We have developed an analytical model describing it and estimating time after which the clumps start to self-shield themselves and cool below 10^4 K (Palous et al., 2014). In Silich et al. (2010a), we predict that massive young galaxies with high star formation rates similar to those detected as SCUBA sources are likely to accumulate the mass in their interiors leading to a fast interstellar matter enrichment, as observed in high redshift quasars. Nuclear star clusters, that typically include supermassive black holes, have been studied in Silich et al. (2010b) and Hueyotl-Zahuantitla et al. (2010, 2013). We show, using radiation-hydrodynamic simulations including AGN X-ray heating, that a filamentary/clumpy structure is formed in the inner part of the cluster.

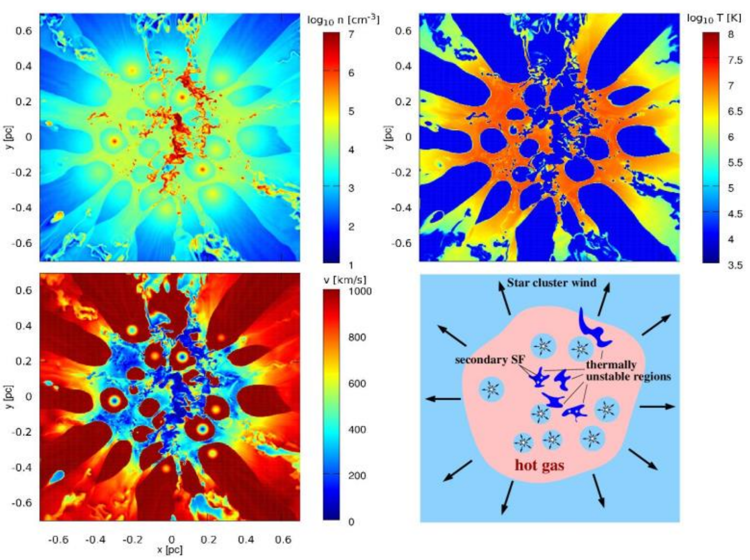


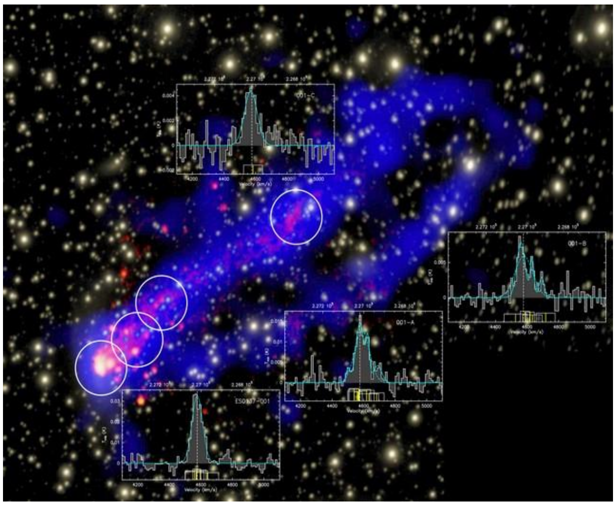
Fig. 2. Model of the cluster in the bimodal regime. The sketch on the bottom right panel shows how dense clumps are formed in the central cluster region by the thermal instability of the hot gas. At the same time, the cluster wind emerges close to the border of the cluster. The other panels show a snapshot from our 3D hydrodynamic simulation: logarithm of the particle density (top left); logarithm of temperature (top right); and the wind velocity (bottom left).

Gas stripping. Using millimeter telescopes ESO APEX and IRAM 30m we searched for cold, molecular gas in tails of ram pressure stripped (RPS) galaxies in galaxy clusters. The removal of star-forming interstellar matter (ISM) reservoir from orbiting galaxies by ram pressure of intra-cluster medium (ICM) is a powerful mechanism that can cause sudden quenching of star formation (SF) and make the cluster late-type galaxies migrate through the "green valley" of the color-magnitude diagram, towards passively evolving, gas-poor S0 and Sa types. The stripped ISM forms one-sided, "cometary" tails extending from the galaxies.

With the IRAM 30m telescope we further discovered abundant molecular gas along the 50 kpc long RPS tail of the Coma cluster galaxy D100. Our observations suggest that in massive clusters, compression of stripped gas by the surrounding ICM that determines the temperature and density distribution of gas in the tail, is efficient in producing observable levels of both hot and cold gas phases. In the less massive Virgo cluster, we searched for molecular gas in the prominent star-forming tail of the dwarf galaxy IC3418, but we reached only sensitive upper limits, and moreover our deep Chandra observations did not reveal any soft X-ray emission. Recently, our project was accepted for observations with the millimeter interferometer ALMA.

Galaxy mergers and gravitational field diagnostics. We focused on using stellar shells in so-called shell galaxies as tools to constrain their gravitational potential. Shells are faint arc-like features, mostly formed as tidal caustics through an accretion of a dwarf galaxy along an almost radial trajectory. They are kinematical density waves propagating from the center of the host galaxy. In the first phase, we developed, under the Lambda-CDM paradigm, a new method to constrain the dark matter distribution around elliptical galaxies. This is very important since shells occur predominantly in ellipticals where it is more complicated to infer the dark matter profile than in disk galaxies. The method (Jilková et al. 2010, ASPC 423, 243; Ebrová et al. 2012, A&A 545, 33; Ebrová, 2013, PhD thesis, arxiv:1312.1643) builds on our prediction of a quadruple-peak line-of-sight velocity profile; it relies on relating the four peaks to the gravitational potential. In the second phase, we embarked upon using shell galaxies to test the Modified Newtonian Dynamics (MOND), as alternative to the dark matter hypothesis solving the missing mass problem. In Bílek et al. (2013, A&A 559, 110), we used our newly developed shell identification method (1) to show that the shell distribution in the galaxy is well compatible with MOND, (2) to derive the age of the shell system and (3) to confirm the earlier expectations that the accreted galaxy has to make a few oscillations before it gets finally dissolved.

We developed a code for performing the shell identification method automatically. We used it in Bílek et al. (2014a, A&A 566, 151) to predict that if MOND works, then a new shell in NGC 3923 must exist at the distance of around 200 kpc from the center. This provides a strong test of MOND. CFHT 3.6m telescope accepted our proposal under the international Opticon Access Program and will try to find the shell observations in 2015. In Bílek et al. 2014b (accepted for A&A, arXiv:1412.6556) we showed what we would measure by the above method of Ebrová et al. if MOND is correct. Related developments on shell galaxies and MOND, namely a prediction of a counterpart of the Tully-Fisher relation, are given in Bílek et al. 2014c (accepted for Can. J. of Phys., arXiv:1407.3202). All the above research on shell galaxies was carried out fully at our institute with a strong participation of 6 PhD students; 3 PhD theses devoted to the topic (1 defended, 2 underway with defenses planned for 2015); 2



undergraduate students started their master theses on this topic in 2014.

Fig. 3. APEX CO(2-1) spectra in the ram pressure stripped Norma cluster galaxy ESO137-001.

Lyman-alpha Reference Sample survey (LARS). We have recently started using the Lyman-alpha line of hydrogen for studying nearby galaxies, in collaboration with Geneva Observatory, Stockholm University and other European and American institutions (see Hayes et al. 2013, ApJ 765, L27; Hayes et al. 2014, ApJ 782, 6; Pardy et al. 2014, ApJ 794, 101; Östlin et al. 2014, ApJ 797, 11). Lyman-alpha is the dominant tool for distant galaxy searches, thanks to its brightness. At the same time, Lyman-alpha resonantly scatters on the interstellar and intergalactic gas and dust, which makes the observational signatures complex. Therefore, we study in detail the mechanisms of Lyman-alpha transfer and escape from galaxies in the local Universe, using the most advanced astronomical facilities such as the Hubble Space Telescope, the Very Large Telescope (VLT), and the Very Large Array (VLA). In particular, we are in charge of the Lyman-alpha spectroscopic data interpretation with the use of numerical radiation transfer codes. HST spectroscopy demonstrates that in order to escape from the galaxy without being absorbed, Lyman-alpha must either scatter to large distances in dust-poor environment, or make use of gas outflows or low-density holes in a clumpy medium.

Calar Alto Legacy Integral Field spectroscopy Area survey (CALIFA – 3D spectrograph mounted at the Calar Alto 3.5m telescope). Our involvement in CALIFA builds on our previous experience with integral-field spectroscopy and spatially resolved studies of conditions in the central kiloparsec of both active and quiescent galaxies (Krips et al. 2011, ApJ 736, 37; Oh et al. 2013, ApJ 767, 117). Nearly 600 galaxies have been observed during 2010-2014, so far resulting in public releases of science quality datacubes for 200 galaxies in two spectral resolution setups. Our team members participate at both the general tasks – the survey design, sample selection/characterization, data release (see Sánchez et al. 2012, A&A 538, 8; Husemann 2013, A&A 549, 87; Walcher et al., 2014, A&A 569, 1) – as well as on specific galaxy evolution studies using CALIFA data with the emphasis on relation between stellar mass, stellar metallicity and gas metallicity. Three PhD students supervised at our institute have participated in CALIFA survey effort.

Relativistic Astrophysics Working Group (led by Vladimír Karas)

The mission of the group is to explore physical processes near accreting stellar-mass black holes in binary systems and super-massive black holes in active galactic nuclei, as well as the Milky Way's under-luminous core by theoretical approaches, numerical modeling, and data interpretation. In collaboration with our partners abroad, both archival and newly obtained data are employed (X-ray, near-infrared, optical, and sub-millimeter).

Personnel. Relativistic Astrophysics Working Group was established in Prague 2004 by Vladimír Karas who at that time was hired by the Institute as Leading Research Scientist (V6). During the evaluation period, Drs. Michal Bursa, Michal Dovčiak, Petr Hadrava, and Jiří Horák have worked as Research Scientists (V5), collaborating with post-doctorate fellows (V3): Jan Čechura, Ondřej Kopáček, Devaky Kunneriath, Frédéric Marin, Jiří Svoboda, and Audrey Trova. Several pre-doctoral and doctoral (Ph.D.) students proceeded to their degrees under supervision. The Group has continued collaboration with former members who had gained employment in science elsewhere (Tomáš Pecháček currently at University of Crete, and René Goosmann at Strasbourg University).

Past and current research. The research focus of the group during the evaluation period has concentrated on probing the vicinity of compact objects via a wide spectrum of observational techniques, numerical codes and analytical approaches: By studying stellar-mass black holes and compact stars we explore their interaction with the cosmic environment. ***We aim to understand matter under extreme conditions, including gravitationally collapsed bodies, and to explore the nature of space-time.*** By studying supermassive black holes, their role as active emitters allows detection in the distant Universe, thereby probing an epoch of several hundred million years after the Big Bang, as well as the more quiescent period of nearby galaxies and the Milky Way.

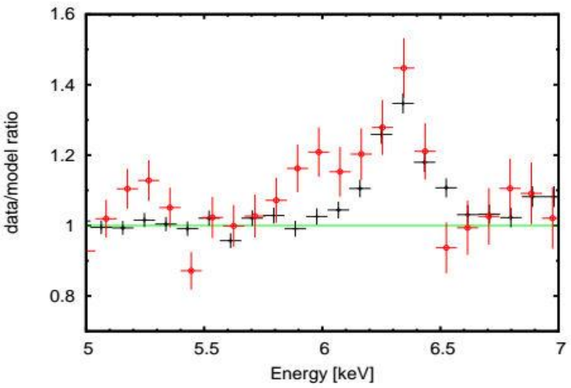


Fig. 4 Iron line in X-ray spectra of 4U 1344-60 observed by XMM-Newton (2001, red) and Suzaku (2011, black). Figure from Svoboda et al. (2012).

The innermost regions around black holes can be well studied by the X-ray spectroscopy. A relativistically broadened iron line has been reported in spectra of AGN and X-ray binaries. This feature has appeared to be transient in some sources (e.g., an active galaxy 4U 1344-60, see Svoboda et al. 2012, A&A, 545, A148). ***The exact shape of the line profile is scientifically valuable information because it allows us to measure the black hole spin and inspect the geometrical and physical properties of the accretion flow.*** The black hole spin and inclination define the extreme energy shifts of radiation (Karas & Sochora 2010, ApJ, 725, 1507; Sochora et al. 2011, MNRAS, 418, 276). The accretion-flow geometry influences the radial emissivity. Svoboda et al. 2012 (A&A, 545, A106) have been able to reproduce steep gradients of the emissivity profiles by a concentrated X-ray source close to the black hole, a radially-stratified ionisation of the disc, and the limb-brightening (see Fig. 4).

Dovčiak and Marin follow a Monte Carlo approach to produce near-infrared to X-ray spectro-polarimetry predictions to be compared with observations of accretion discs around supermassive black holes (collaboration with Univ. Strasbourg and Roma Tre; Marin & Dovčiak 2015, A&A, 573, A60). Taking into account heat advection and non-Keplerian rotation, Bursa has investigated slim disc models in with regard to spin estimates (collaboration with MIT/CfA Cambridge and CAMK Warsaw; Sadowski et al. 2011, A&A, 527, A17). The group has provided observational and theoretical studies of angular emissivity in strongly curved gravitational fields, and analyzed its effect on the resulting spectrum originating from discs. Such a complementarity is ensured by a close collaboration between the members of the group.

The X-ray spectral modeling suit of routines named KY has been continuously maintained and developed for the community. Since its early definition (Karas et al. 1992), particular features of the KY approach are the dual step of pre-computing the GR light rays that can be used *a posteriori* within the widely known (publicly available) spectral fitting package XSPEC as well as a stand-alone application for timing and polarization. New models fit the observed data with a particular physical model of the system, e.g. with a relativistically broadened iron line model (KYNRLPLI) and with a reprocessed disc emission (KYREFLIONX) in the lamp-post geometry (Dovčiak et al. 2014, arXiv:1412.8627).

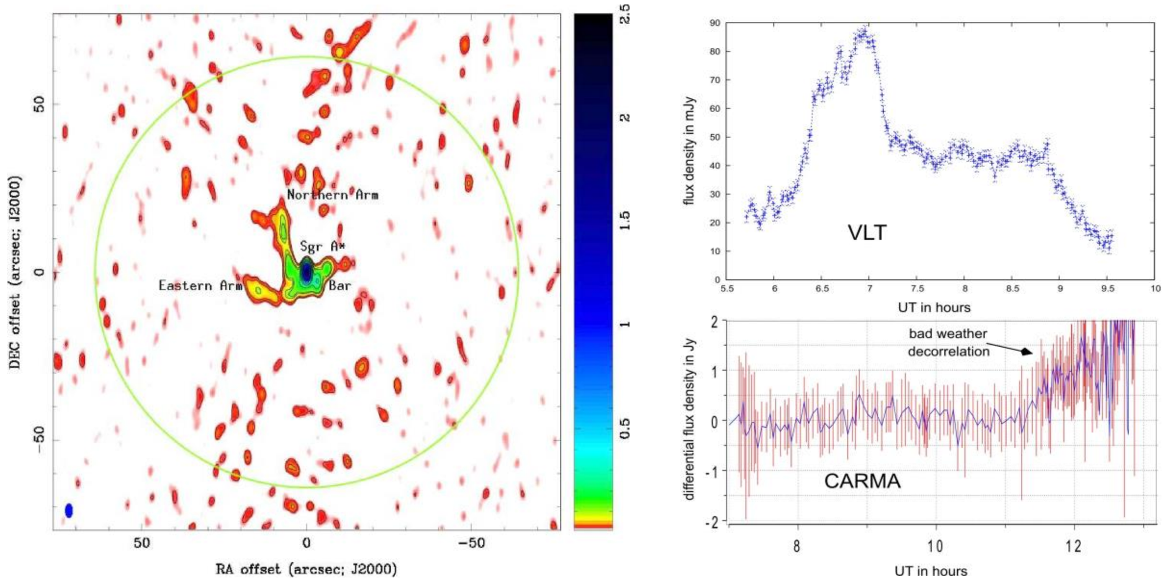


Fig. 5. Left panel: the Minispiral in the center of the Milky Way, as seen by CARMA at 3 mm. Right panel: Simultaneous coverage of 3.8 μm Galactic center NIR flare and the corresponding 3 mm CARMA light curve (Kunneriath et al. 2010, 2012).

Not every compact object is found in a state of high accretion rate. The nearest supermassive black hole to us, Sgr A*, is situated at the very center of our Milky Way galaxy where its faint luminosity is explained by low accretion and only episodic flares (see Figure 5). Its proximity and complex environment make Sgr A* an ideal astrophysical laboratory. Marin and Karas have modelled the reprocessed X-ray signal emerging from reflection nebulae in the Galactic center (Marin et al. 2014; MNRAS, 441, 3170). These provide strong observational constraints for future polarimetric missions, showing that the morphology of the scattering region can be explored, thus revealing the history of the source. Its recent activity is interpreted by multiple accretion events of gaseous clouds onto the central black hole (Czerny et al. 2013, A&A, 555, A97; Kunneriath et al. 2014, IAUS 303, 228).

Trova and Karas explore various aspects of ***self-gravity of fluid discs*** and its impact on hydrodynamical simulations (collaboration with Univ. Bordeaux in France; Trova et al. 2014, A&A, 563, A132). This work is done in collaboration with groups at Silesian University in Opava and Charles University in Prague. Deep in the potential well of ergosphere, new physical effects occur. Hamerský and Karas work on the formation of magnetized fluid tori (Hamerský & Karas 2013, A&A, 555, AA32), while Kopáček studies acceleration of electrically charged matter by reconnection near black holes (Kopáček & Karas 2014, ApJ, 787, 117). Such theoretical works include the effects of collimation and the transition from regular to chaotic motion (Kopáček 2011, Ph.D. Thesis). Horák and collaborators have developed a general-relativistic scheme for the corotation-instability mechanism that operates in accretion discs. They show that this is a generic feature of general relativity (Horák et al. 2012, PASJ, 64, 76; 2013, MNRAS 434, 276).

A code for three-dimensional ***time-dependent radiation hydrodynamic*** simulations of stellar winds in interacting binaries has been developed to improve models of high-mass X-ray binaries and to explore the properties of circumstellar matter (Čechura & Hadrava 2014, arXiv:1412.3924). Other codes by Hadrava continue to be updated by the author and widely used by the community: FOTEL for solving radial-velocity and light-curves, and KOREL for disentangling the spectra of multiple stars. These turned out very successful tools for the determination of pulsation velocities from observed spectra of Cepheids, and the Baade-Wesselink calibration of the primary distance markers.

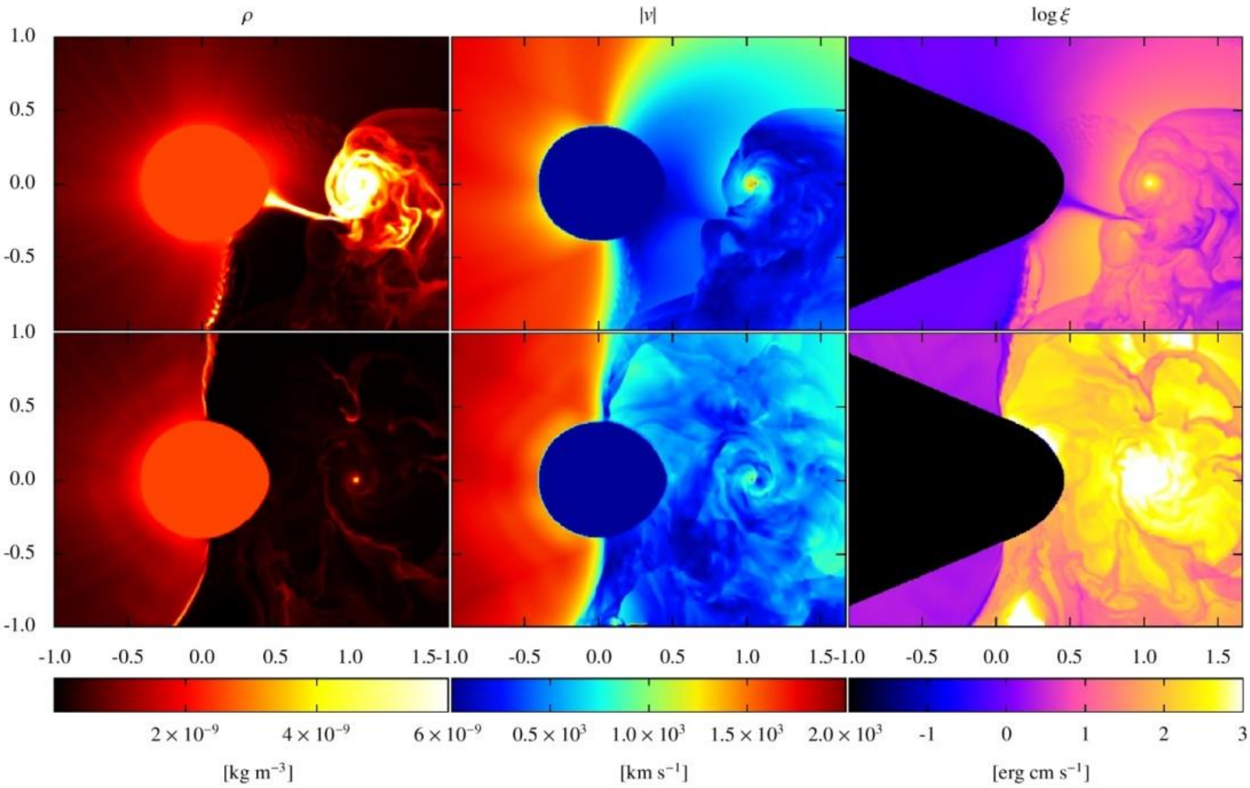


Fig 6. Radiation-hydrodynamical simulation of a stellar wind in the equatorial plane of Cygnus X-1, including effects of the X-ray ionization. From Čechura & Hadrava (2014).

Planetary Systems Working Group (led by Cyril Ron)

The missions of the group is the research in dynamics of Earth rotation, its gravity field, orbital analysis of space missions, and astrometry with Zeiss Photographic Zenith Tube in Ondřejov.

Personel: The group of Planetary Systems consists of two parts. In Prague there are Cyril Ron, Jan Vondrák, Vojtěch Štefka (post-doc up to 2011), who work mostly on global geodynamics, especially Earth rotation, and astrometry. At the Ondřejov section, Aleš Bezděk, Jaroslav Klokočník, Josef Sebera (post-doc), deal with the satellite geodesy, especially with studying the Earth's gravity field and non-gravitational perturbations acting on satellites in Earth's orbits.

Past and current research

In the frame of "Center for Earth Dynamics Research" (CEDR) several papers were published in the monitored period. Vondrák with co-authors (France, UK) derived new precession expressions for various precessional parameters that are valid for long time intervals (Vondrák et al. 2011, A&A, 534 A22) , see Fig. 7. We also derived the Earth's orientation parameters based on our own EOC-4 Astrometric Catalog (Vondrák et al. 2010, Acta Geodyn. Geomater (AGG), 7, 245). Klokočník et al. (2010, AGG, 7, 71) designed a method of detection of Earth impact craters based on the analysis of the gravitational model EGM2008. Careful orbit choice for specialized satellites was always important to fulfil particular goals of satellite missions. For GOCE (Gravity field and steady-state Ocean Circulation Explorer, ESA, in orbit 2009–2013), it was very important. This satellite was for the first time equipped by space gradiometer for direct measurements of the Marussi tensor of the anomalous gravitational potential, from which we can reconstruct harmonic geopotential coefficients characterizing the gravitational field. The satellite also had an ion motor which enabled orbit keeping in altitude with unprecedented precision ±5 meters. These two factors (the gradiometer and the ion motor) led to a fine orbit tuning with a goal to get the maximum sensitivity for the gravity field determination. For this purpose we selected high – order orbit resonances, see (Bezděk et al., 2010, ESA-SP 686).

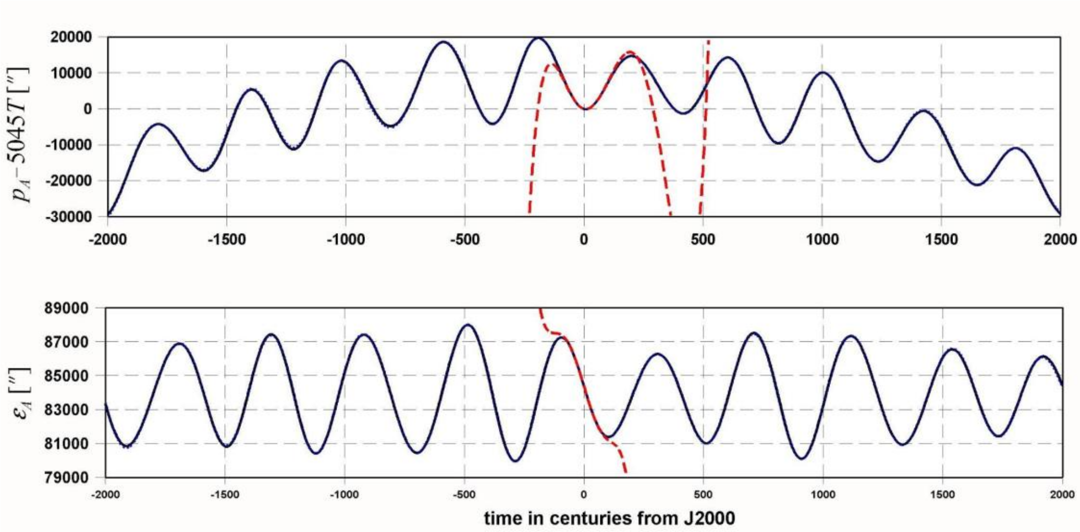


Fig. 7. Comparison of the new model (solid line) with the numerical integration (dotted line) and the model IAU2006 (dashed line), for general precession in longitude p_A and obliquity of the ecliptic ε_A. First two curves are graphically indistinguishable (Vondrák et al. 2011).

Orbital resonances played an important role in the past gravity field determination and evaluation (Klokočník et al., 2013, Surv. Geoph., 34, 43) and the GOCE's fine orbit tuning can be considered as a new application of resonant phenomena analyses to orbits of Earth's artificial satellites, see Fig 8. Gravity disturbance, the Marussi tensor, invariants of the gravity field, their certain ratio and other functions of the geopotential were computed based on the harmonic coefficients of the global gravitational field model EGM 2008 (newly also EIGEN 6C4). It is suggested that morphotectonic and landform patterns with very conspicuous combinations of significantly high positive or negative values of the radial derivatives in the Marussi tensor are under the strong influence of rapid and/or intensive geomorphic processes. These geophysical signatures reflect the regional dynamics of the Earth surface evolution. Based on the observed data, covering several years, we obtained an average annual continental hydrology signal, where the main geographical areas with important hydrological variations are evident. Currently the GNSS- based gravity field solutions are a topical theme in space geodesy. The results were published in (Bezděk et al., 2014, Adv. Space Res., 53, 412).

Space accelerometers are important devices for measuring the non-gravitational forces acting on Earth satellites, such as the atmospheric drag, radiation pressures, direct and Earth-reflected solar radiation and terrestrial infrared radiation, and the forces due to satellite thrusters. It is important to measure non-gravitational forces in order to improve the knowledge of their natural causes, this is especially true for atmospheric drag, and to reduce them as a perturbing signal in the precise orbit determination procedures, as is the case of recent gravity field dedicated missions (CHAMP, GRACE, GOCE). The problem with space accelerometers is that due to their ultra-high sensitivity they cannot be calibrated on the ground. Nowadays, their calibration is more a scientific problem rather than an engineering one. This is the reason why European Space Agency launched a call to scientific teams for a calibration of space accelerometers carried aboard each of three satellites in the mission Swarm. We developed an original method of calibration based on comparison of the measured accelerometer readouts with a calibration standard derived from precise GPS orbits (Bezděk, 2010, J. Geodyn. 50, 410). Our calibration proposal was accepted by ESA. The three Swarm satellites were successfully put in orbit in November 2013 and the accelerometer data have been available early in 2014. Together with other teams invited by ESA we try to solve problems so that the data could be finally released to scientific users. In 2014 we contributed at all three meetings of ESA Swarm calibration/validation teams. Our attention has also been drawn to particular algorithms for processing satellite and terrestrial gravity data. In (Sebera et al., 2012, J. Geod., 86, 713) the computation of the associated Legendre functions of the second kind was optimized up to degree of several thousand. The resulting procedures allow us to use spheroidal basis functions for flattened bodies that have many applications in planetary science.

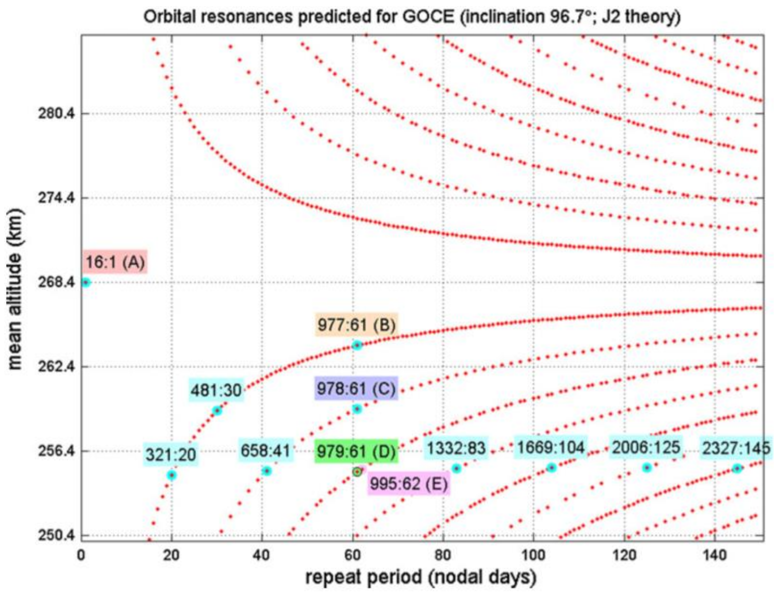


Fig. 8. Resonant evolution graph for GOCE and orbits suggested or selected for its gradiometry measurements. The x-axis shows the number of Earth's revolutions, the mean altitude of the satellite is on the y-axis. Choice of the repeat cycle was driven by the desire to optimise the spatial coverage for the GOCE gradiometer (Klokočník et al. 2013).

Sebera et al. (2013, J. Geod., 87, 223) have been investigating alternative relationships for the Cartesian derivatives of the spherical harmonic series. Although these formulas are known from the sixties, they are not widely used in gravity field modelling. We tested their capabilities in the spherical harmonic analysis of the scattered and heterogeneous input data (acceleration vector, gravitational gradients) and we found these are systematically faster when compared with our previous implementation. The routines are now being used in the acceleration approach mentioned above (Bezděk et al., 2014, Adv. Space Res., 53, 412).

Finally, an alternative way to work with gravitational data in a mass-free space was investigated in (Sebera et al., 2014, Surv. Geoph. 35, 941). The purpose was to downward continue satellite gravity data from the GOCE mission without using spherical harmonics. For this purpose, we suggested a two-step iterative procedure based on the Poisson integral equation, which allows to shift (or interpolate) gravity data in space to prevent dramatic noise amplification.

The nutation model IAU2000 is very close to the real motion of Earth's spin axis in space, so the celestial pole offsets measured by VLBI (deviations of the observed pole position from the model) are very small, typically smaller than 1 mas. However, some periodic terms can still be detected in the residuals, partly coming from the still possible deviations of the adopted model from reality, partly because of the presence of free variations that are unpredictable and thus not included in the model. They are due to the fact that the Earth's outer fluid core and inner solid core can rotate around the axes that are not coincident with the spin axis of the mantle. The possible additional excitation due to geophysical fluids (atmosphere, ocean and hydrology on continents) can be derived from their angular momentum functions that are publicly available with sub-diurnal resolution in 6-hour intervals. We studied the effects of the geophysical fluids on the spin axis using the integration of broad-band Liouville equations and have found the significant correlation between integrated and observed pole offsets in the interval 1989-present (Vondrák and Ron, 2010, AGG, 7, 19) and (Ron and Vondrák, 2011, AGG, 8, 243). The project "Growth rhythms as an indicator of Earth rotation and climate changes in the geological past" of Grant Agency of Academy of Sciences of CR has been finished in 2010. We co-operated with geologists and climatologists and our contribution consisted in the analysis of the long-term variations of the Earth's rotation. We started with decade variations (Chapanov et al., 2010, IAU Symp. 264, 407) and proceeded towards centennial (Ron et al., 2012, AGG, 9, 259) up to millennial ones (Chapanov et al., 2015, AGG submitted).

Probing Strong Gravity near Black Holes

15–18 II 2010
Prague

Conference Topics

Probing strong gravity in stellar mass black holes
continuum spectroscopy, line spectroscopy, timing, polarimetry, measuring black-hole spin

Probing strong gravity in super-massive black holes
spectroscopy, timing, polarimetry, measuring black-hole spin, compact black-hole binary systems

Probing strong gravity in the Galactic centre
flares from Sgr A* (IR/X-ray/sub-mm), synergy of different spectral domains, polarimetry

Observational perspectives and future techniques
prospects of X-ray spectroscopy, prospects of X-ray timing, prospects of X-ray polarimetry, BH imaging in different spectral domains, prospects of gravitational wave detection

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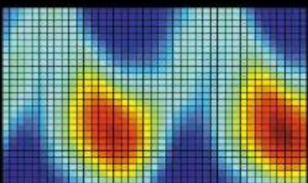

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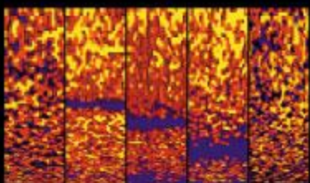
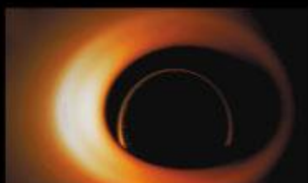


TIMING

POLARIMETRY



IMAGING