AUTOREFERAT

1. Basic data

a) Personal data

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b) Education and degrees

Ph.D. in Physics	2009, Maria Curie Sklodowska University
	Numerical simulations of magnetohydrodynamics waves in solar corona
	Supervisor: prof. Krzysztof Murawski
Ms.C. in Physics	2005, Maria Curie Sklodowska University
	Numerical simulations of MHD waves
	Supervisor: prof. Krzysztof Murawski

c) Employment

2013 - #	professor assistance, Department of Radiology Informatics and Statistics
	Faculty of Health Sciences
	Medical University of Gdansk, Gdansk, Poland

2009 – 2011	Post-Doctoral Fellow, Center for Fusion, Space and Astrophysics University of Warwick, Coventry, UK
2005 – 2009	Ph.D. student, Department of Theoretical Physics Maria Curie Sklodowska University, Lublin, Poland

2. Scientific achievements

My scientific achievements are series of monothematic publications entitled: ***Magnetohydrodynamics waves diagnostics of space plasmas.***

List of monothematic publications:

1. **M. Gruszecki**, V.M. Nakariakov, T. Van Doorsselaere, *Intensity variations associated with fast sausage modes*, 2012, **Astron. Astrophys.**, 543, A12

My contribution to this work concerned taking part to the idea of the study and interpretation of the results. I set up the numerical code, run the numerical simulations and analyzed all obtained data. I wrote the manuscript. According to the declarations of coauthors (V.M.N. – 25%, T.V.D – 15%) I estimate my contribution to be 60 %.

2. **M. Gruszecki**, V.M. Nakariakov, *Slow magnetacoustic waves in magnetic arcades,* 2011c, **Astron. Astrophys.**, 536, A68

My contribution to this work concerned taking part to the idea of the study and interpretation of the results. I set up the numerical code, run the numerical simulations and analyzed all obtained data. I wrote the manuscript and I took part in answer referee's reports. According to the declaration of coauthor (V.M.N. – 30%) I estimate my contribution to be 70 %.

3. **M. Gruszecki**, S. Vasheghani Farahani, V.M. Nakariakov, T.D. Arber, *Magnetoacoustic shock formation near a magnetic null point*, 2011a, **Astron. Astrophys.**, 531, A63

My contribution to this work concerned taking part to the idea of the study and interpretation of the results. I set up the numerical code, run the numerical simulations and analyzed all obtained data. I wrote the numerical part of the manuscript and I took part in answer referee's report. According to the declarations of coauthors (V.M.N. – 20%, S.V.F – 20% and T.D.A. – 5%) I estimate my contribution to be 55 %.

4. **M. Gruszecki**, V.M. Nakariakov, T. Van Doorsselaere, T.D. Arber, *The phenomenon of Alfvénic vortex shedding*, 2010, **Physic. Rev. Let.**, 105, 055004

My contribution to this work concerned taking part to the idea of the study and interpretation of the results. I set up the numerical code, run the numerical simulations and analyzed all obtained data. I wrote the manuscript and I took part in answer referees' reports. According to the declarations of coauthors (V.M.N. – 25%, T.V.D – 10% and T.D.A. – 5%) I estimate my contribution to be 60 %.

Introduction

The Sun is the star at the centre of the Solar System. It is almost spherical and consists of layers. The inner layers are the Core, Radiative Zone and Convection Zone. The outer layers are the Photosphere, the Chromosphere and the Corona (Priest 1984).

In my research I was interested in the outermost layer and the hottest part of the Sun's atmosphere – the corona. It is visible during total eclipses of the Sun as a pearly white crown. The corona displays a variety of features including streamers or loops. The corona also releases into space a stream of accelerated charged particles, the solar wind. The mechanisms behind these phenomena have interested physicists (Parker 1965, Leer et al. 1980, Verdini et al. 2009). They are important not only for our understanding of fundamental aspects of plasma astrophysics but also for the new branch of applied space physics known as space weather (Schwenn 2006). Plasmas are ubiquitous in the Universe and play significant role in the generation of the magnetic fields within star's interior and the production of activity in its atmosphere (Priest 1984). A full understanding of the physical processes in the Sun's corona should involve new theory and observations in near future.

Past and present studies have indicated that magnetic field is the key to understand the corona (Priest 1984, Roberts et al. 2003, Nakariakov et al. 2005). The corona is dominated by a magnetic field which controls much of what we see. It plays a significant role in dramatic and violent solar flares with material ejected rapidly into space or the quieter long-lived events that generate the numerous wispy structures e.g. coronal loops. Magnetic fields in solar corona are elastic medium which can oscillate creating magnetic waves (Nakariakov et al. 1999). We can describe those waves using magnetohydrodynamic (MHD) equations. The set of equations which describe MHD are a combination of fluid mechanics and electromagnetism. This theoretical approach gives rise to three kinds of waves: Alfven wave, fast and slow magnetoacoustic waves (Priest 1984).

In 1999 group of prof. Aschwanden (Aschwanden et al. 1999) and prof. Nakariakov (Nakariakov et al. 1999) analyzed TRACE observations that show transverse displacements of coronal loops after the occurrence of flare in its vicinity. Now other solar satellites have provided many observations which show oscillations of coronal loops.

Waves carry information about the medium through which they pass. This means possibility of obtaining information about the coronal plasma (Roberts et al. 2003, Nakariakov et al. 2005). This is quite new approach which can be compared to seismology where elastic waves are used to study Earth's interior or helioseismology where sound waves are used to learn about solar interior. Observing coronal oscillations, coupled with magnetic wave theory, heliophysicists have developed a new method for studying the Sun – coronal seismology (Uchida 1970, Roberts et al. 1984, Nakariakov et al. 2001). Because magnetic fields control the structure of the corona it is possible that the technique is able to investigate localized phenomena. In 1999 Nakariakov (Nakariakov et al. 1999) estimated strength of magnetic field to 13 Gauss in a coronal loop by fitting the observed oscillations with MHD wave theory. At this moment it is only way to estimate value of magnetic field in this part of the Sun. Coronal seismology using MHD waves could be also a useful tool in studying the outer solar structures.

MHD equations

Magnetohydrodynamics equations unite two disciplines: *electromagnetism and fluid dynamics.* MHD is a relatively new area, approximately 70 years old, but has been developing quickly since the 1950s when it was realized that MHD gave a good description of plasmas in the Sun as well as other stars and interstellar medium. To describe all phenomena in solar corona we used ideal and compressible MHD equations:

$$\frac{\partial \varrho}{\partial t} + \nabla \cdot (\varrho \vec{V}) = 0,$$

$$\varrho \frac{\partial \vec{V}}{\partial t} + \varrho (\vec{V} \cdot \nabla) \vec{V} = -\nabla p + \frac{1}{\mu} (\nabla \times \vec{B}) \times \vec{B},$$

$$\varrho \frac{\partial \varepsilon}{\partial t} + \varrho \vec{V} \nabla \varepsilon = -p \nabla \cdot \vec{V},$$

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{V} \times \vec{B}) = 0,$$

$$\nabla \cdot \vec{B} = 0,$$

where $\boldsymbol{\varrho}$ is the mass density, p is the gas pressure, $\vec{B}$ is the magnetic field, $\vec{V}$ is the flow velocity, $\boldsymbol{\mu}$ is the magnetic permeability, $\boldsymbol{\varepsilon}$ is the specific internal energy density, $p = \varrho \varepsilon (\gamma - 1)$ and $\gamma = 5/3$ is the ratio of specific heats. Here a number of implicit approximations have been made:

- ✓ the plasma has neutral charge,
- ✓ the plasma has a very large magnetic Reynolds number,
- ✓ characteristic velocities are much less than the speed of light.

We performed numerical simulations with the use of Lagrangian-remap code LARE2D. LARE2D operates by taking a Lagrangian predictor-corrector time step and after each Lagrangian step all variables are conservatively re-mapped back onto the original Eulerian grid using Van Leer gradient limiters. The code was designed for the simulation of nonlinear dynamics of low $\boldsymbol{\beta}$ plasmas. All details about numerical code can be found in Arber et al. (2001).

<u>Phenomenon of Vortex Shedding</u>

It is well known that the interaction of a flow with a non-moving bluff body results in a so called von Karman vortex street, where vortices with opposite vorticity are periodically generated alternating from either side of the blunt body in the downstream region (Tritton 1977, Williamson 1996). The effect of vortex shedding in a magnetised medium is less well understood. It is known to play a role in a number of applications and physical situations. In 2009 Nakariakov et al. suggested that periodic shedding of MHD vortices could excite kink oscillations of plasma loops in the solar corona.

The quantitative characteristics of the vortex shedding phenomenon is the Strouhal number that is a dimensionless parameter constructed from the period of the vortex shedding, the size of the blunt body and the flow velocity. In hydrodynamics, the typical value of the Strouhal number that describes the interaction of a steady flow with a cylindrical obstacle of a circular cross-section is in the range 0.15 to 0.2 (Williamson, 1996). In magnetized fluids and plasmas, there has not been a systematic and detailed studies of this parameter. It is value and dependence upon the physical parameters (such as plasma-beta, flow speed, size of the blunt body) is important for the development of diagnostic techniques and interpretation of observed phenomena. The aim of my study is to present the parametric numerical study of the interaction of a steady plasma flow with a cylindrical obstacle in the MHD regime, and to determine the dependence of the Strouhal number upon the plasma properties.

Interaction of steady uniform flow of magnetized compressible plasma with an obstacle body of a cylindrical shape leads to the periodic generation of Alfvenic vortices, which form a characteristic von Karman street (Gruszecki et al. 2010). The Strouhal number is about 0.2 for a broad range of the speeds and the ratios of the gas and magnetic pressures in the plasma (Gruszecki et al. 2010). Thus, as in hydrodynamics, the Strouhal number is a robust feature of the considered phenomenon in the case of rarified (e.g. space, laboratory) plasmas and can be used for plasma diagnostic. My studies justify the possibility of the excitation of transverse oscillations of plasma loops in the solar corona by external upflows (Nakariakov, 2009). Also, the independence of the vortex shedding period upon the macroscopic plasma parameters (the magnetic field, density, temperature, and the plasma beta), opens up interesting opportunities for the observational determination of the flow speed, e.g. in planetary magnetospheres and in the corona (Gruszecki et al. 2010).

The generated vortices are essentially compressible, with the mass density perturbation up to 50% - 70% of the ambient value (Gruszecki et al. 2010). The mass density perturbation in the vortices is accompanied by the perturbation of a similar strength of the absolute value of the magnetic field (Gruszecki et al. 2010). Both mass density and magnetic field perturbations have a shape of filamentary spiral arms (Gruszecki et al. 2010). The induced electric current has a similar structure (Gruszecki et al. 2010). The steep gradients of the current density in the generated vortices are the preferential sites for the magnetic reconnection and charged particle acceleration, and hence have implications for plasma heating and EM wave emission. Investigation of these phenomena requires modification of the model and could be a subject to a follow up study.

<u>Magnetoacoustic shock formation near a magnetic null point</u>

The mechanism responsible for the initiation of solar flares attracts attention in the context of the flare forecasting (Schrijver 2009) as well as of the understanding of quasi-periodic pulsations in flares (Nakariakov & Melnikov 2009) and the phenomenon of the sympathetic flares (Moon et al. 2002; Akimov et al. 2008). In particular, there is some observational evidence that the triggering of a flare can be associated with magnetohydrodynamic (MHD) waves and oscillations. Foullon et al. (2005) demonstrated that long-period pulsations of flaring emission can be associated with MHD oscillations of a large, trans-equatorial coronal loop. Sych et al. (2009) found that propagating slow magnetoacoustic waves could trigger flaring energy releases.

The specific mechanism for the triggering of magnetic reconnection by MHD waves has not been established yet. Chen & Priest (2006) proposed that slow magnetoacoustic waves can induce magnetic reconnection by modulating the density of the plasma in the vicinity of the reconnection site. Nakariakov et al. (2006) developed a model of the triggering of magnetic reconnection by fast magnetoacoustic waves. In this model, fast waves generate steep spikes of the electric current density in the vicinity of a magnetic null point which drive plasma micro-instabilities and, hence, the anomalous resistivity.

The aim of my study is to develop the work of McLaughlin et al. (2009), performing the parametric study of the nonlinear steepening of a fast magnetoacoustic wave near a null point. Using ideal MHD equations we developed a 1D analytical model of an initially axisymmetric m = 0 fast pulse in the weakly nonlinear regime (Gruszecki et al. 2011a). We derived the evolutionary equations for the radial velocity of the pulse, and showed that the evolution of the pulse leads to a departure from the azimuthally symmetric m = 0 mode, but is rather of the symmetry of the m = 2 mode or higher (Gruszecki et al. 2011a). Consideration of the excitation conditions and of the phase relations in the numerical experiments of McLaughlin et al. (2009) supported that observation. Numerical simulations of the nonlinear development of an initially Gaussian pulse of finite amplitude, confirmed the azimuthal dependency of the fast magnetoacoustic pulse (Gruszecki et al. 2011a). I also showed in my simulation that small amplitudes pulses coincide with the linear analytical solution of Craig & McClymont (1991).

I showed that the pulses of the plasma compression of higher initial amplitudes propagate faster (Gruszecki et al. 2011a). In contrast with that, pulses of rarefaction experience deceleration with the increase in the amplitude (Gruszecki et al. 2011a). Moreover, my numerical studies showed that similarly to the case of a uniform medium, the position and time of the pulse overturning is also determined by its initial steepness (Gruszecki et al. 2011a). Thus, initially lower amplitude and broader fast-wave pulses form fast shocks - “overturn”- closer to the null-point (Gruszecki et al. 2011a). Because the shock formation is accompanied by the generation of electric current density spikes, in the vicinity of the shock formation region we can expect the onset of plasma micro-turbulence, and hence the appearance of anomalous electrical resistivity and in consequence initiating magnetic reconnection.

My finding has interesting implications on the problem of sympathetic flares. The possibility of the triggering of a solar flare by another flare is still not understood. However, one can imagine that a fast wave generated by a flare can reach the site of another energy release and induce it, e.g. by seeding the anomalous resistivity. I showed that as the amplitude of the initial pulse increases, the overturning takes place farther away from the null-point, and as the width of the pulse increases, the overturning takes place at a closer distance to the null-point which has a greater effect (Gruszecki et al. 2011a). In other words, only wider and small amplitude pulses can reach a magnetic null-point before overturning and initiate magnetic reconnection. Narrower and high amplitude pulses overturn quicker and do not reach the null-point (Gruszecki et al. 2011a).

<u>Slow magentoacoustic waves in magnetic arcades</u>

Slow magnetoacoustic waves are one of the most studied magnetohydrodynamic (MHD) wave modes in the solar corona (De Moortel 2006, Roberts 2006, De Moortel 2009). Slow waves are detected in open and closed magnetic structures in the form of propagating (Verwichte et al. 2010) and standing (Wang 2011) waves. Because slow waves are essentially compressible, they are usually detected with imaging instruments as variations of the emission intensity, propagating along the presumed direction of the magnetic field (De Moortel et al. 2002). In some cases slow waves are also detected with spectral instruments that investigate the Doppler shift of coronal emission lines (Wang et al. 2003, Erdélyi & Taroyan 2008, Wang et al. 2009, Mariska & Muglach 2010, Van Doorsselaere et al. 2011). Typical periods of observed coronal slow waves are several minutes, and, in agreement with the MHD wave theory, the measured projected phase speed is typically subsonic.

The interest in coronal slow waves is primarily linked with their seismological potential. In particular, propagating slow waves were used for probing fine, sub-resolution structuring of active regions (King et al. 2003). Coordinated imaging and spectral observations of standing slow waves led to the estimation of the magnetic field strength in the waveguiding loops (Wang et al. 2009). The spectroscopically measured phase lag between the temperature and density perturbations in propagating slow waves was used to estimate of the effective adiabatic index γ (Van Doorsselaere et al. 2011). In addition, established phenomenological relationship between sunspot oscillations and quasi-periodic energy releases in solar flares (Sych et al. 2009), including slow waves as the signal carrier, opens up interesting perspectives for the seismological study of flaring sites and flare-triggering mechanisms. Nakariakov & Zimovets (2011) demonstrated that slow magnetoacoustic waves could be responsible for the observed progression of flaring energy releases along a magnetic neutral line (across the equilibrium magnetic field) in two-ribbon flares. It was shown that in coronal arcades slow magnetoacoustic waves propagate across a magnetic field at a group speed significantly lower than both the sound and Alfvén speeds, and that this behaviour was well-consistent with the observed evolution of two-ribbon flares. In my studies I aim to contribute to the understanding of this effect. In my numerical simulation I did not consider the whole "chain" of the physical processes leading to the progression of the flare along the arcade, including the "ignition" of magnetic reconnection by a slow pulse (Gruszecki et al. 2011c). Instead, I considered an individual act of the process, one of the two key building blocks of it: the "delivery" of the information about an energy release burst to another possible point of the release, at some distance along the axis of the arcade.

I performed a parametric study of running and standing slow magnetoacoustic pulses in a magnetic arcade in frames of ideal MHD (Gruszecki et al. 2011c). The arcade was modelled as a box filled in with uniform low-β plasma, penetrated by a constant and straight magnetic field (Gruszecki et al. 2011c). A slow magnetoacoustic pulse, excited by a localised increase in the plasma temperature, propagates in both directions along the magnetic field, and gradually develops in the direction across the field (Gruszecki et al. 2011c). The shape of the pulse becomes "fork-like", with obliquely extended prongs (Gruszecki et al. 2011c). The pulse shape is not destroyed by the reflection from the arcade footpoints (Gruszecki et al. 2011c). The speed of the propagation across the field is sub-sonic and sub-Alfvénic, growing with the increase in plasma-β (Gruszecki et al. 2011c). The speed of the progression across the field was found to be qualitatively consistent with the value obtained with analytical dispersion relations (Gruszecki et al. 2011c). The comparison was complicated due to the definition of the pulse travel distance.

A slow magnetoacoustic pulse contains perturbations of the magnetic field and the current density. The "magnetic component" of the pulse grows with the increasing **β** (Gruszecki et al. 2011c). This component has usually been ignored in the theoretical studies of slow magnetoacoustic waves in the corona, when the waves were considered in their degenerated, purely acoustic form (Nakariakov et al. 2000, 2004, Ofman & Wang 2002, De Moortel & Hood 2004, De Moortel & Bradshaw 2008, Tsiklauri et al. 2004, Taroyan et al. 2005, Taroyan & Bradshaw 2008). My results demonstrate that the magnetic component is an important part of a slow magnetoacoustic perturbation and hence it should be taken into account in more rigorous studies (Gruszecki et al. 2011c).

Pulses of higher amplitude propagate faster in the parallel and perpendicular direction and are subject to nonlinear steepening and associated increase in the current density (Gruszecki et al. 2011c). A spatially localised perturbation of plasma temperature excites slow and fast magnetoacoustic waves. Amplitude and energy of the excited fast wave are several times weaker than those of the slow waves (Gruszecki et al. 2011c).

Slow magnetoacoustic standing waves are also found to be subject to the progression across the field and development of the "magnetic component" – the perturbations of the magnetic field and the current density, more pronounced for higher **β** (Gruszecki et al. 2011c). Moreover, the progression across the field is accompanied by the generation of a phase-mixing pattern. Possible implications of this effect on the dissipation of the waves have been discussed in De Moortel et al. (2004) and Voitenko et al. (2005). However, in contrast with those works, in my study phase-mixing appears in a medium, uniform in the direction across the field (Gruszecki et al. 2011c).

The evolution of a slow magnetoacoustic pulse was found to be well consistent with the model of the two ribbon flare evolution (Nakariakov & Zimovets 2011). Moreover, my study demonstrates that the pulse could trigger another act of magnetic reconnection (Chen & Priest 2006). However, the second "building block" of the model, triggering of the other act of magnetic reconnection by the slow wave, was not addressed in my research. I showed that a slow magnetoacoustic pulse can perform the transfer of energy and information required for triggering the next energy release, across the magnetic field at the group speed consistent with the observed value (Gruszecki et al. 2011c).

Intensity variations associated with fast sausage modes

The properties of MHD modes are determined, in particular, by the azymuthal wave number 'm'. The axisymmetric fast mode perturbations with m = 0 are known as the sausage mode. Studies of this mode have attracted attention for many years (Rosenberg 1970, Zaitsev & Stepanov 1975, Roberts et al. 1984, Cally 1986). This mode is a symmetric perturbation of the cross-section of a plasma non-uniformity, that does not perturb the axis of the loop. The sausage mode is essentially compressive, and the density perturbations are in phase with the perturbations of the magnetic field and in anti-phase with the perturbations of the loop minor radius. In the low-β plasma typical of solar coronal active regions, the plasma motions induced by the sausage mode are almost perpendicular to the axis of the cylinder. There is also a slow magnetoacoustic mode of the same symmetry, m = 0, referred to as a slow sausage mode.

Observationally, the sausage mode has been identified in the microwave and hard X-ray emission produced by flaring coronal loops (Nakariakov et al. 2003, Melnikov et al. 2005, Inglis et al. 2008), in addition to Hα emission (Srivastava et al. 2008). Owing to the very short periods (1−10 s) of the observations high time-resolution instruments are required. The first spatially resolved detection of a sausage mode was made by Nakariakov et al. (2003) with the Nobeyama Radioheliograph. The oscillatory signal was strongest at the loop top and had minima near the footpoints. The more detailed studies of Melnikov et al. (2005) confirmed this conclusion. The interest in the coronal fast sausage modes is related to the possibility of a seismological estimate of the external magnetic field in the oscillating plasma non-uniformity, and also the possible role played by this mode in the acceleration of non-thermal particles and their dynamics (Brown & Hoyng 1975, Zaitsev & Stepanov 1982). Van Doorsselaere et al. (2011) used the detection of the fast and the slow sausage mode to measure the local plasma-β.

Theoretical studies of the sausage mode of a plasma cylinder were performed in terms of the dispersion relation formalism (Zaitsev & Stepanov 1975, Edwin & Roberts 1982, Roberts et al. 1984, Cally 1986, Kopylova et al. 2007). It was pointed out that, depending upon the ratio of the wavelength to the radius of the cylinder, there are two possible regimes, trapped and leaky. Trapped modes are confined to the cylinder, while leaky modes radiate the energy into the external medium. For the typical coronal conditions (**β** << 1), trapped sausage modes exist when the external Alfvén speed C_{Ae} exceeds the value of the internal Alfvén speed C_{ai}. Slow sausage modes are usually referred to as "longitudinal", as in the coronal conditions they practically do not perturb the radius of the cylinder.

The aim of my work is to study the observational properties of trapped and leaky sausage modes of a thick and dense flaring loop. I have performed (Gruszecki et al. 2012) a numerical simulation of fast magnetoacoustic oscillations of a thick and dense coronal loop, modelled by a plasma cylinder embedded in plasma with different properties and penetrated by a straight magnetic field. I considered (Gruszecki et al. 2012) only the oscillations of the sausage symmetry (with the azimuthal wave number m = 0). The plasma both inside and outside the cylinder was taken of low-β. The transverse profile of the plasma density was smooth, without any steep gradients or discontinuities. Only oscillations with low amplitudes were considered to avoid nonlinear effects.

The behaviour of short-wavelength sausage oscillations of a plasma cylinder is well closely with the analytical results obtained for a cylinder with a step-function profile (Zaitsev & Stepanov 1975, Edwin & Roberts 1983, Roberts et al. 1984, Cooper et al. 2003b). The oscillations are trapped in the cylinder, their phase speed has a value between the Alfvén speed inside and outside the cylinder, and their period is determined by the ratio of the wavelength to the phase speed (Gruszecki et al. 2012). Sausage waves are essentially compressible, perturbing the density of the plasma and the absolute value of the magnetic field, moving the plasma in the direction across the field (Gruszecki et al. 2012).

Sausage oscillations of wavelengths longer than the cut-off value are leaky (Gruszecki et al. 2012). The attenuation of the oscillations depends on the density contrast between the cylinder and the ambient medium, which is qualitatively consistent with the analytical prediction made by Cally (1986, 2003). For the plasma parameters typical of coronal plasma structures, e.g. dense plasma loops, the damping time can be of several oscillations periods (Gruszecki et al. 2012). Thus, long-wavelength sausage modes can last for a sufficiently long time before being detected in observations. Incidentally, we have numerically shown that the mechanism of resonant absorption does not operate for the axisymmetric sausage modes (Goossens et al. 1992). Although the simulation included a smooth transition layer, where in principle a resonance could occur between the global mode and Alfvén modes, no resonant behaviour has been found in the numerical results (Gruszecki et al. 2012). The sausage modes are damped only by MHD radiation (in the leaky regime), and not by resonant absorption (Gruszecki et al. 2012).

We conclude that the sausage mode is a good tool for the seismological probing of the plasma in oscillating coronal plasma non-uniformities, giving us information about the Alfvén speed inside, outside the non-uniformity and consequently to value of magnetic field (Gruszecki et al. 2012).

Summary

The project aims was to develop the novel technique for the diagnostics of fundamental physical mechanisms operating in solar corona using magnetohydrodynamic waves. The project advanced our understanding of basic processes responsible for the plasma dynamics in the atmosphere of the Sun. In my research I used numerical and analytical techniques. I also compared my results with data obtained with recent space missions.

The results obtained in the project opening up several research avenues. For the first time I estimated the Strouhal number for a broad range of the flow speeds and the plasma beta **β** in rarefied plasma in solar corona (Gruszecki et al. 2010). My results support idea proposed by Nakariakov et al. (2009) for the excitation of transverse oscillations of coronal loops. I concluded that planning new research it should be investigated the implications of compressible vortices to the kinematics of coronal mass ejections what have influence on space weather. Main result of my research on shock formation near a magnetic null point is which pulses (due to width and amplitude) can ignite magnetic reconnection (Gruszecki et al. 2011a). This finding has influence on the ongoing research on external triggering of solar flares and to the long-standing problem of sympathetic flares. For the first time I showed numerically that a slow magnetoacoustic waves can propagate across a magnetic field

(Gruszecki i inni 2011c). I analyzed this process for different values of plasma beta **β** (Gruszecki i inni 2011c). So far a slow magnetoacoustic wave was considered as acoustic perturbation and magnetic field was neglected. Additionally, I showed the transfer of energy by slow magnetoacoustic wave across the magnetic field during two-ribbon flare. Because I analyzed only first step of above process it justifies the further study of this mechanism both numerically and theoretically. During studies of sausage mode I considered trapped and leaky modes (Gruszecki iet al. 2012). Obtained results fully confirmed previous theoretical estimations. Additionally, I showed that a comparison between numerical and observational data is difficult due to poor spatial resolution of the present instruments. Thus sausage modes require the thorough re-consideration of previous interpretation of oscillatory processes in the UV and microwave band.

In conclusion, I can say that my research is valuable and useful studies. An original considerations and results suggested that the main objective of the research was achieved. All results were published in high impact papers. I was the first author of all publications and according to the statements of all coauthors my contribution was the highest. All results were presented during seminars at many universities and international conferences.

3. Other scientific achievements

3.1 Present scientific research

Fundamental research a mechanism of the toxicity of the antifungal antibiotic amphotericin B (AmB)

Systemic fungal infections are an increasing threat, especially in immunocompromised patients. One of the problems is a lack of good antifungal agents. Amphotericin B (AmB), the oldest antifungal antibiotic, has been widely used in the clinical treatment for over 50 years, due to its many superior properties. Nevertheless, it is not a good therapeutic agent because of its high toxicity. The rational design of the AmB derivatives with the better safety profile is hindered since, despite extensive experimental work, the mechanism of action of AmB at the molecular level is not clear. The molecular simulation approach allows a precise insight into the molecular nature of many phenomena and help to understand the membrane activity of AmB and its derivatives. Due to approximate nature of numerical methods obtained results we must treat as complement of traditional experimental approach. Therefore, numerical results will be confronted with the literature and experimental data prepared by the experimental group from Maria Curie Sklodowska University. Obtained results together with experimental data will be used to formulate a coherent hypothesis of biological activity of tested drug.

Research of cerebral hemodynamic during apnea

Research is focused on new aspects of cerebral hemodynamic. In particular we use new method called near infrared transillumination back scattering sounding (NIR-T/BSS) that allows measuring non-invasively changes in the pial artery pulsation (cc-TQ) and width of subarachnoid space (sas-TQ) in human. Currently we analyse the effects of prolonged apnea and involuntary breath movements on relationship between BP and pial artery oscillations at human cardiac frequency in apnea divers. Analysis is performed both in frequency and time domain. Breath hold divers are faced with two main physiological challenges: pressure induced compression and extended time without breathing, exposing them to extremes of hypoxia. The major physiological components of the diving response that occurs during very long breath holding are peripheral vasoconstriction, bradycardia, decreased cardiac output, increased cerebral and myocardial blood flow, increased blood pressure, splenic contraction and preserved O_2 delivery to the brain and the heart. Sympathetic nervous activity is exceptionally engaged at the end of voluntary breath holds. It is hypothesized that these adaptations to extended cessation of breathing ending with extreme hypoxia can be used as a model of brain survival response during conditions involving profound brain deoxygenation and in some instances reduced brain perfusion. The experiments are performed in co-operation with prof. Dujic team from Department of Physiology, Faculty of Medicine, University of Split in Split, Croatia.

3.2 Research projects

- ✓ Contractor of research project founded by Polish State Committee for Scientific Research - „Fale i oscylacje w pętlach magnetycznych korony słonecznej" (2007 - 2010).
- ✓ Grant Holder of Newton International Fellowship founded by Royal Society of London – „Magnetohydrodynamic Wave Diagnostics of Space Plasmas" (2009 - 2011)

Presently, together with Professor Gruszecki I apply for 'OPUS' research project founded by Polish National Science Centre - „Mechanizm molekularny toksyczności antybiotyku przeciwgrzybiczego amfoterycyny B".

3.3 Research visits

05/2008	one month research visit at Stanford University, **Palo Alto**, USA
04/2008	two weeks research visit at CEA Saclay, **Paris**, France
03/2007	two weeks research visit at University of Warwick, **Coventry**, UK
03/2007	two weeks research visit at University of St. Andrews**, St. Andrews**, UK
11/2006	two weeks research visit at Maxa-Plancka Institute, **Katlenburg-Lindau**, Germany

3.4 Invited talks, seminars and posters

11/2014	talk at the Center of Space Research in **Warsaw**, Poland
01/2014	talk at Technical University of **Gdansk**, Poland
11/2013	talk at University of **Gdansk**, Poland
04/2012	talk at Maria Curie Sklodowska University, **Lublin**, Poland
09/2011	talk at 13th European Solar Physics Meetings, **Rhodes**, Greece
05/2011	talk at University of Warwick, **Coventry**, UK
04/2011	talk at National Astronomy Meeting, **Llandudno**, UK
11/2010	talk at Maria Curie Sklodowska University, **Lublin**, Poland
11/2010	talk at workshop „The link of MHD waves and magnetic reconnection", University of Warwick, **Coventry**, UK
07/2010	talk at international MHD meeting BUKS 2010, **St. Andrews**, UK

04/2010	talk at University of Warwick, **Coventry**, UK
02/2010	poster at Royal Astronomical Society meeting, **London**, UK
02/2010	poster at Royal Society meeting, **London**, UK
06/2009	talk at international MHD meeting BUKS 2009, **Leuven**, Belgium
05/2008	talk at Stanford University, **Palo Alto**, USA
12/2007	talk at the Center of Space Research in **Warsaw**, Poland
06/2007	talk at Astrophysics and Space Research Workshop, **Serock**, Poland
03/2007	talk at University of Warwick, **Coventry**, UK
03/2007	talk at University of St. Andrews, **St. Andrews**, UK
11/2006	talk at Max-Planck Institute, **Katlenburg-Lindau**, Germany

3.5 Organizations of conferences

11/2010	Co-organization of workshop 'The link of MHD waves and magnetic reconnection' University of Warwick, **Coventry**, UK

3.6 Didactics

Presently, I am a secondary supervisor of PhD thesis of Joanna Zielinska entitled: „Mechanizm aktywności przeciwgrzybiczej amfoterycyny B oraz jej pochodnych – badania z zastosowaniem metod chemii obliczeniowej". PhD studies are carried out at Department of Pharmacy at Medical University of Gdansk. Professor Tomasz Baczek is a supervisor.

09/2014 – 01/2015	Information Technology, Students of Emergency Medical Services, GUMed, Gdansk
09/2014 – 01/2015	Information Technology, Students of Physiotherapy, GUMed, Gdansk
09/2014 – 01/2015	Biostatistics, Students of Environmental Medicine, GUMed, Gdansk
02/2014 – 06/2014	Dynamics of Pollutions, Students of Environmental Medicine, GUMed, Gdansk
02/2014 – 06/2014	Information Technology, Students of Public Medicine, GUMed, Gdansk
02/2014 – 06/2014	Information Technology, Students of Nursing, GUMed, Gdansk
09/2013 – 01/2014	Information Technology, Students of Emergency Medical Services, GUMed, Gdansk
10/2008 – 01/2009	Introduction to physics, Students of Chemistry, UMCS, Lublin
02/2008 – 06/2008	Numerical methods for hyperbolic equation, Students of Physics, UMCS, Lublin
02/2007 – 06/2007	Introduction to programming, Students of Physics, UMCS, Lublin
10/2005 – 01/2006	Introduction to physics, Students of Chemistry, UMCS, Lublin

3.7 Popularization of science

Lectures for high school students aimed at promoting astrophysics.

05/2009	Lectures for students from School Complex number 1 in Lublin
04/2008	Lectures for students from A. Mickiewicz high school in Biala Podlaska
04/2008	Lectures for students from J.I. Kraszewski high school in Biala Podlaska
04/2008	Lectures for students from E. Plater high school in Biala Podlaska
05/2007	Lectures for students from Unii Lubelskiej high school in Lublin

During lectures posters, postcards, pens and other materials from NASA were distributed.

3.8 Scientific collaboration

During research I collaborated with several scientists. During MHD research I colaborated with:

- ✓ prof. K. Murawski – Maria Curie Sklodowska University
- ✓ prof. V. Nakariakov – University of Warwick
- ✓ prof. L. Ofman – Catholic University of America
- ✓ prof. Tony Arber - University of Warwick
- ✓ prof. Sami Solanki – Max Plank Institute
- ✓ prof. A. Kosovichew – Stanford University
- ✓ dr M. Selwa – Maria Curie Sklodowska University
- ✓ dr T. Van Doorsselaere – Catholic University in Leuven
- ✓ dr J. McLaughlin – University of St. Andrews
- ✓ dr K. Parchevsky – Stanford University

Presently, I collaborate closely with:

- ✓ group of prof. W. Gruszecki - Maria Curie Skłodowska University
- ✓ group of prof. A. Frydrychowski - Medical University of Gdansk
- ✓ dr J. Czub - Technical University of Gdansk
- ✓ prof. T. Bączek - Medical University of Gdansk
- ✓ prof. T. Liberek i dr hab. A. Liberek - Medical University of Gdansk
- ✓ dr R. Korzon - Medical University of Gdansk

3.9 Summary of the publications

Total summary ***impact factor*** of published research papers estimated according to year of pubication is equal: **54.15**. Total ***impact factor*** of 4 monothematic research papers being my scientific achievements is equal: **21.88**.

Sum of the times cited – 88

Sum of the times cited without self-citations - 84

Hirsh-Index – 6

The data comes from Web of Science.

3.10 Awards

2007 special scholarship for best performance in science at Maria Curie Sklodowska University
2009-2011 Newton International Fellowship founded by Royal Society of London

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