# Modern Challenges in Nonlinear Plasma Physics

## A Conference honouring the career of Dennis Papadopoulos

# Book of Abstracts

Sani Resort, Prefecture of Halkidiki,

Macedonia Region, Greece

June 15-19, 2009

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## A Conference Honoring the Career of Dennis Papadopoulos

Sani Resort, Prefecture of Halkidiki,
Macedonia region, Greece
June 15-19, 2009

*Editing and typesetting:*

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# Welcome! Καλωσορίσατε!

Dear participant,

We welcome you to the conference "Modern Challenges in Nonlinear Plasma Physics: a Conference Honoring the Career of Dennis Papadopoulos". Advances in the many and varied branches of plasma physics have been breathtaking in the last few decades and it is fitting to slow down once in a while, meet, and discuss a number of these advances from an interdisciplinary perspective. Thus we have chosen to limit the scope of the meeting to just three of the many subdisciplines: solar, geospace, and laboratory plasma science. Even so this choice is really stretching our timetables and we have had to leave out of the program a large number of truly fascinating developments.

The conference seeks to concentrate the diversity and exciting developments in plasma physics, but is also focused on one of the few people who contributed significantly over a long time to this progress. The original motivation of the meeting was for a group of former graduate students and postdocs of Prof. Konstantinos Papadopoulos to celebrate his long, productive, ongoing career. Dennis is widely known not only for his personal achievements and contributions to plasma and other fields of physics, but also for being an energetic and clear-thinking science leader. His enthusiasm and inventiveness have been a source of inspiration for many of us and we are glad to acknowledge it.

We are also pleased to welcome you to Halkidiki, the historical birthplace of Aristotle, a place known for sacred Mt. Athos as well as for its natural beauty. The three-pronged Halkidiki peninsula is at the center of Macedonia, a land firmly placed in world history by Alexander the Great (Aristotle's best student!), his father Philip, and their dynasty… Gazing across the Aegean from Sani Resort, you will quickly spot the snows of Mt. Olympus, the tallest mountain in the country and justifiably the abode of gods. During the mid-week excursion we will have an opportunity to visit the foothills of Olympus and enjoy the mountain and its historic and geographic richness from close by.

We wish you the best for an enjoyable and an intellectually stimulating meeting!

The Organizers

# Organizers

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The meeting is endorsed by the American Physical Society.

# Meeting Program

## Sunday, June 14, 2009

| | |
|---|---|
| ***6:00-7:30 pm:*** | Registration in *Aristotle 1* hall |
| ***7:30-9:00:*** | Welcome reception on Sani Hill. |

## Monday, June 15, 2009

| | |
|---|---|
| ***7:30 am-2:00 pm:*** | Registration |

### 1. Introduction[1] (Chairman: I.A. Daglis)

| | |
|---|---|
| ***8:20-8:25 am:*** | EC, Welcome remarks |
| ***8:25-8:30:*** | LOC, Welcome remarks |
| ***8:30-9:10:*** | E. Priest, Nonlinear plasma physics of the solar corona (review) |
| ***9:10-9:50:*** | D. Baker, Perspectives on geospace plasma coupling (review) |
| ***9:50-10:30:*** | R. Dendy, Some issues at the interface of strongly nonlinear space and fusion plasma physics (review) |
| ***10:30-11:00 am:*** | Coffee break – discussion |

### 2. The building blocks of nonlinear plasmas (Chairman: H. Isliker)

| | |
|---|---|
| ***11:00-11:15 am:*** | J. Albert, Analytical estimates of nonlinear wave-particle dynamics (in the radiation belts) |
| ***11:15-11:45:*** | A. Ram, Kinetic formulation of transport of charged particles interacting with electromagnetic waves in magnetized plasmas |
| ***11:45-12:15 pm:*** | M. Scholer, Progress in plasma physics by numerical simulation: Collisionless shocks |
| ***12:15-12:45:*** | G. Parks, Upstream density holes and the bow shock |
| ***12:45-1:00:*** | I. Kourakis, Electrostatic solitary waves in superthermal plasmas: nonlinearity off the Maxwellian frontier |
| ***1:00-3:00 pm:*** | Lunch break |

[1] All oral presentations take place in *Aristotle 2* hall.

### 3. The building blocks of nonlinear plasmas (Chairman: K. Hizanidis)

| | |
|---|---|
| ***3:00-3:30 pm:*** | J. Pickett, Electrostatic solitary waves observed in space and laboratory experiments |
| ***3:30-3:45:*** | J. Samson, High-beta disruptions in the Earth's magnetosphere |
| ***3:45-4:00:*** | A.T.Y. Lui, The cross-field current instability for substorm expansion onset |
| ***4:00-4:30:*** | Discussion |

***4:30-5:00 pm:*** Coffee break – discussion

### 4. Statistical approaches (Chairman: T. Pulkkinen)

| | |
|---|---|
| ***5:00-5:15 pm:*** | I. Roth, Statistical/evolutionary models of power-laws in plasmas |
| ***5:15-5:45:*** | S. Chapman, Fractal, multifractal, and generalized scaling in the turbulent solar wind |
| ***5:45-6:15:*** | S. Sharma, Multiscale phenomena of the magnetosphere |
| ***6:15-6:30:*** | I. A. Daglis, Investigating the dynamics of the magnetosphere using various complexity measures |

***6:30 pm:*** Adjourn

## Tuesday, June 16, 2009

### 5. Structures and stability: magnetic reconnection (Chairman: C. Goodrich)

| | |
|---|---|
| ***8:30-8:45 am:*** | H. Karimabadi, Magnetic reconnection: an ultimate problem in nonlinear plasma physics |
| ***8:45-9:00:*** | J. Huba, 2D and 3D Hall magnetic reconnection |
| ***9:00-9:30:*** | W. Gekelman, Experiments which observe magnetic-field reconnection within structures in a magnetoplasma |
| ***9:30-10:00:*** | J. Drake, Ion acceleration during magnetic reconnection |
| ***10:00-10:30:*** | V. Angelopoulos, Bursty flows and non-linear plasma structures in Earth's magnetotail as revealed from THEMIS |

***10:30-11:00 am***: Coffee break – discussion

## 6. The building blocks of nonlinear plasmas: waves (Chairman: L. Vlahos)

***11:00-11:30 am:*** M. Balikhin, Nonlinear dynamics of mirror waves: THEMIS observations vs. theories

***11:30-12:00 pm:*** Y. Omura, Theory and simulations of nonlinear whistler-mode chorus waves in the magnetosphere

***12:00-12:30:*** C. Cully, Nonlinear whistler waves in Earth's radiation belts: THEMIS observations

***12:30-1:00:*** P. Bernhardt, Electrostatic waves excited during active experiments in the ionosphere

***1:00-3:00 pm:*** Lunch break

## 7. Turbulence: development and effects (Chairman: S. Fung)

***3:00-3:30 pm:*** G. Ganguli, Evolution of whistler turbulence in the magnetosphere

***3:30-3:45:*** S. Ghosh, Co-existence of turbulence and discrete modes in the solar wind

***3:45-4:15:*** F. Sahraoui, Small-scale solar wind turbulence: recent observations and theoretical modeling

***4:15-4:45:*** T. Pulkkinen, Nonlinear solar wind-magnetosphere coupling using MHD models

***4:45-5:00 pm:*** Coffee break – discussion

## 8. Poster session A (Chairman: D. Vassiliadis)

All poster sessions take place in *Aristotle 1* hall

***5:00-6:30 pm:*** Poster presentations.

1. M. Dimitropoulou et al., On the correlation of fractal structures in the photospheric and the coronal magnetic field
2. P. Henri et al., Vlasov simulations of electrostatic decay and consequences for solar wind observations
3. I. Kourakis et al., Electromagnetic envelope pulses in relativistic magnetized plasma
4. G. Livadiotis, On the theoretical basis of kappa distributions and their application in the solar wind
5. Th. Pisokas et al., A self-organized criticality model for ion-temperature gradient (ITG) mode-driven turbulence
6. I. Sandberg, Solar particle event analysis using the Standard Radiation Environment Monitor of ESA
7. C. Tsironis et. al., Fokker-Planck modeling of EC wave scattering by edge turbulence in ITER-relevant plasma

8. X. Shao et al., Relativistic electron acceleration by compressional mode ultra-low-frequency waves
9. M. Taylor et al., A machine-learning approach to space weather modelling: initial results from SCIANNS
10. M. Tornquist et al., Energetic electron transport due to ultra-low-frequency waves in the radiation belts
11. K. Tziotziou, Solar origin of solar particle event detected by the Standard Radiation Environment Monitor of ESA
12. J. Valdivia, Self-organization and the storage-release of energy in a simple plasma model
13. I. Vogiatzis et. al., Cluster observations of energetic particle acceleration up to supra-thermal energies in the cusp region related to the presence of low-frequency waves.
14. Y. Voitenko and J. De Keyser, Cross-scale nonlinear coupling between MHD Alfven waves and small-scale dissipative waves and resulting plasma energization
15. J. Wanliss, More evidence of the critical nature of the magnetosphere during space storms
16. O. Yaakobi, Equal-energy phase space trajectories of coupled waves governed by a time dependent Hamiltonian

***6:30 pm:*** Adjourn

# Wednesday, June 17, 2009

Excursion day

# Thursday June 18, 2009

## 9. Phase-space structures and their stability (Chairman: M. Wiltberger)

***8:30-9:00 am:*** S. Vladimirov, The turbulent bremsstrahlung (nonlinear plasma-maser) effect

***9:00-9:30:*** M. Lampe, Whistler triggering associated with singular electron velocity distribution

***9:30-10:00:*** G. Milikh, HAARP-induced ionospheric ducts

***10:00-10:30:*** E. Mishin, Nonlinear plasma effects in natural and man-made aurora

***10:30-11:00 am:*** Coffee break – discussion

## 10. Structures and stability in space and solar plasmas (Chairman: S. Sharma)

| | |
|---|---|
| ***11:00-11:30 am:*** | A. Streltsov, Nonlinear coupling between density structures and feedback-unstable ULF waves in the ionosphere |
| ***11:30-12:00 pm:*** | J. Chen, CME dynamics and physical connection between CMEs and flares |
| ***12:00-12:30:*** | M. Velli, The solar wind throughout the solar activity cycle |
| ***12:30-1:00:*** | B. Tsurutani, MDs in interplanetary space and mirror-modes in planetary magnetosheaths and the heliosheath |
| ***1:00-3:00 pm:*** | Lunch break |

## 11. Revealing plasma structures via active experiments (Chairman: M. Lampe)

| | |
|---|---|
| ***3:00-3:30 pm:*** | A. Zigler, Control of high intensity laser propagation in the atmosphere |
| ***3:30-4:00:*** | C.-L. Chang, Tethered satellite system |
| ***4:00-4:15:*** | G. Gunell, Simulations of a plasmoid penetrating a magnetic barrier |
| ***4:15-4:30:*** | C. Gontikakis, Particle acceleration and radiation processes through solar reconnecting current sheets |
| ***4:30-4:45:*** | B. Eliasson, Injection of ELF magnetic fields and currents into the equatorial E-region ionosphere |
| ***4:45-5:00 pm:*** | Coffee break – discussion |

## 12. Poster session B (Chairman: X. Shao)

***5:00-6:30 pm:*** Poster presentations.

1. J. Cook et al., Particle-in-cell simulations of the emission mechanism for fusion product-driven ion cyclotron emission from tokamak plasmas
2. I.A. Daglis et al., Study of storm-time ring current buildup through ion acceleration simulations
3. K. Dialynas et al., Energetic neutral atom (ENA) production from ions trapped in Saturn's magnetosphere
4. M. Georgiou et al., Characteristics of ULF waves observed at low latitudes and their influence on storm-time radiation belt electron enhancements
5. A. Iliopoulos, Nonlinear analysis of in situ data obtained by the GEOTAIL satellite concerning the magnetospheric plasma sheet
6. I.A. Karakatsanis et al., Evidence for co-existence SOC and chaos processes in the solar flares dynamics
7. S. Mahmoud, Nonlinear effect of relativistic laser power on the second-harmonic generation in plasma

8. P. Marhavilas, Occurrence of high-beta superthermal plasma conditions in the interplanetary medium as observed by Ulysses during 1990-2008
9. K. Nielson, Linear calibration of collision operator coefficients in AstroGK
10. E. Siminos, State-space geometry of a continuous symmetry reduced Kuramoto-Sivashinsky flow
11. V. Tsoutsouras et al., Nonlinear spatiotemporal analysis of a five day ordit of the GEOTAIL satellite during the period of 26-30 July 2004 including a superstorm
12. D. Vassiliadis et al., Response of the trapped-electron phase-space density to wave activity during radiation belt storms
13. S. Vladimirov, Mobility-limited distributions for charge transfer collisions
14. S. Vladimirov, Instability of ionization-absorption balance in a complex plasma at ion time scales

| | |
|---|---|
| ***6:30 pm:*** | Adjourn |
| ***8:00-11:30 pm:*** | Conference reception |
| ***Keynote speaker:*** | C.S. Liu |

# Friday, June 19, 2009

## 13. Dynamic and interacting space plasmas (Chairman: S. Ghosh)

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|---|---|
| ***8:30-8:45 am:*** | A. Mikhailov, A non-linear reaction of the ionosphere and thermosphere to solar-cycle EUV variations |
| ***8:45-9:15:*** | W. Horton, Nonlinear ionospheric turbulence and magnetic substorms driven by the solar wind |
| ***9:15-9:45:*** | M. Abdalla, The study of non-linear acceleration of particles during substorms using multi-scale simulations |
| ***9:45-10:00:*** | M. Wiltberger, Modeling the magnetosphere with the multi-fluid Lyon-Fedder-Mobarry magnetosphere model |
| ***10:00-10:15:*** | D. Baker, MESSENGER at Mercury: old questions and new insights |
| ***10:15-10:30:*** | N. Sergis, Particle pressure radial profile in the dayside magnetosphere of Saturn during near-radial parts of Cassini's trajectory |
| ***10:30-11:00 am:*** | Coffee break – discussion |

## 14. Dynamic and interacting plasmas in space and lab (Chairman: X. Shao)

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|---|---|
| ***11:00-11:30 am:*** | S. Krimigis, Dynamic planetary magnetospheres: Gas-plasma interactions at their best |
| ***11:30-12:00 pm:*** | S. Bulanov, Fundamental physics and relativistic astrophysics with super powerful lasers |
| ***12:00-12:30:*** | C.S. Liu, Laser acceleration of monoenergetic protons via a double layer emerging from an ultra-thin film |
| ***12:30-1:00:*** | A. Ting, Second harmonic and off-axis electron generation in a high-intensity laser-produced plasma cavitation |
| ***1:00-3:00 pm:*** | Lunch break |

## 15. Dynamic and interacting lab plasmas (Chairman: A. Anastasiadis)

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|---|---|
| ***3:00-3:15 pm:*** | K. Akimoto, Validity of plasma resonance and pulse-particle interaction |
| ***3:15-3:30:*** | G. Livadiotis, On the theoretical basis of kappa distributions |
| ***3:30-3:45:*** | R. Chin, Self-organization in thermally unstable plasmas |
| ***3:45-4:00:*** | I. Sandberg, Universal extreme statistical properties (of plasma edge transport) |
| ***4:00-4:15:*** | H. Isliker, A self-organized criticality model for the magnetic field in toroidal confinement devices |
| ***4:15-5:00 pm:*** | Coffee break – discussion |

## 16. Closing remarks (Chairman: J. Huba)

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|---|---|
| ***5:00-5:20 pm:*** | Summary on magnetoshperic plasmas (S. Krimigis) |
| ***5:20-5:40:*** | Summary on solar and interplanetary plasmas (M. Velli) |
| ***5:40-6:00:*** | Summary on lab plasmas (A. Ram) |
| ***6:00-6:15:*** | D. Papadopoulos, The last word |
| | |
| ***6:15 pm:*** | Adjourn |

# Abstracts

# Session 1: Introduction

## Nonlinear plasma physics of the solar corona

E. Priest

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A review is given of the basic properties of the solar corona and of its basic plasma physics. Many fundamental topics in which Dennis Papadopoulos has made ground-breaking contributions are of key importance in the Sun's corona, including particle acceleration, shock waves, instabilities, waves and magnetic reconnection. Here, in particular, we summarise the current status of understanding and present new results on the nature of magnetic reconnection and on mechanisms for coronal heating.

## Perspectives on solar wind-magnetosphere coupling

D.N. Baker

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There is a wide range of fascinating aspects to understanding the coupling of mass and energy from the solar wind into the magnetosphere. Past research has suggested that magnetic reconnection on the dayside magnetopause plays a key role in controlling the energy coupling. However, both linear and nonlinear coupling aspects have been suggested by various types of innovative data analysis. In this talk we describe new examinations of solar wind-magnetosphere coupling scenarios. We particularly emphasize the study of solar wind driving of magnetospheric substorms, geomagnetic storms, and radiation belt particle enhancements.

## Issues at the interface of space and fusion physics

R. Dendy[1, 2]

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(Tel: +44- 1235-466377, Fax: +44-1235-466435, E-mail: richard.dendy@ukaea.org.uk),
[2]Warwick University, Dept. of Physics, Centre for Fusion, Space and Astrophysics, Coventry CV4 7AL, U.K.

The behaviour of space and fusion plasmas is typically governed by multiple distinct nonlinear processes, which operate on a wide range of lengthscales and timescales, and are coupled together in innumerable feedback loops. Quantifying this nonlinear behaviour is crucial at all levels of description, ranging from individual events to global phenomenology, and is essential for establishing the interpretive and predictive power of plasma physics models and simulations. In recent years, a range of new techniques, oriented towards capturing and quantifying nonlinear phenomenology, has been applied successfully to experimental and

observational plasma datasets. These new nonlinear techniques complement Fourier-derived methods such as the power spectrum and autocorrelation, whose perspective is essentially linear. The present paper reviews several of these techniques in the context of applications spanning fusion, space, solar, and astrophysical plasmas. Topics include: non-Gaussian probability density functions, notably extreme event distributions in fusion and astrophysics, and power law distributions in the solar context; differenced fluctuations, and the scaling properties of associated structure functions, which yield information on the dominant turbulent processes, and the spatiotemporal ranges over which they operate, in plasmas ranging from microquasar accretion discs to fusion plasmas such as the MAST tokamak and LHD stellarator; and quantitative measures of mutual information content and pattern repetition between causally linked but spatiotemporally separated nonlinear events in solar wind and magnetospheric plasmas. These developments in nonlinear plasma characterisation provide fresh insights into the underlying physics. They also provide new opportunities for comparing models with data, and with each other, and for the development of a more rigorous predictive capability.

Acknowledgment. This was work supported in part by the Engineering and Physical Sciences Research Council U.K.

# Session 2: The Building blocks of Nonlinear Plasmas

## Analytical estimates of nonlinear wave-particle dynamics

J. Albert

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The behavior of energetic particles in a magnetized plasma is dictated by their adiabatic invariants, which are primarily affected by resonant waves. An outstanding example is that of relativistic electrons in the Earth's radiation belts interacting with cyclotron-resonant whistler mode hiss, chorus, and electromagnetic ion cyclotron (EMIC) waves. Although these interactions have been modeled using quasilinear theory, it is becoming increasingly appreciated that these waves are often sufficiently strong, and sporadic enough, to require nonlinear treatment of the particle behavior. Analytical estimates of the adiabatic invariant breaking have long been available for several distinct types of motion (diffusion, phase bunching, phase trapping), and lead to convenient expressions for energy and pitch angle rates of change, in terms of parameters of the waves (which, as always, are the largest source of uncertainty). These regimes may apply to different parts of a typical particle population simultaneously. These expressions will be surveyed, and a Fokker-Planck framework will be demonstrated which incorporates both the quasilinear and nonlinear effects.

# Kinetic formulation of transport of charged particles interacting with electromagnetic waves in magnetized plasmas

A.K. Ram[1], Y. Kominis[2], and K. Hizanidis[2]

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[2]Association EURATOM, Hellenic Republic, National Technical University of Athens, Athens, Greece.

The twentieth century has witnessed maturity of the field of regular and chaotic dynamics. The first studies on the occurrence of chaotic phenomena in the dynamics of charged particles interacting with electromagnetic waves in a magnetized plasma started in the 1970s. Among the contributors to these studies in that decade was Professor Papadopoulos [1]. In these studies it was noted that the motion of particles could be regular or chaotic depending on various wave parameters, and energies of the interacting particles. The dynamical phase space turns out to be a mixture of regular and chaotic motion – and the chaotic motion is not necessarily Markovian, i.e., akin to the random walk dynamics.

The interaction of particles with electromagnetic waves is a ubiquitous phenomenon in laboratory, space, and astrophysical plasmas. A description of the evolution of the particle distribution function has to properly account for the particle dynamics. Previous formulations of the kinetic equation have assumed that the particle dynamics is completely Markovian. From the dynamics of particles interacting with waves, we know that this assumption is not valid.

We have recently formulated the kinetic equation for the evolution of a particle distribution function in which the particle motion can be perturbed by waves in a magnetized plasma [2]. The derivation makes use of the mathematical tools that have been developed for Hamiltonian systems. Even though our study is directed towards a magnetically confined fusion plasma in a laboratory, the basic principles apply to any magnetic configuration. This talk will elucidate the derivation of the kinetic equation using the Lie perturbation technique. The underlying particle dynamics is assumed to be non-Markovian. The diffusion operator describing the evolution of the distribution function is time dependent and valid for a dynamical phase space that is a mix of correlated regular orbits and decorrelated chaotic orbits. The diffusion operator includes resonant and non-resonant momentum space diffusion, and non-resonant spatial transport of particles.

Acknowledgment. Work supported by DoE grants DE-FG02-99ER-54521 and DE-FG02-91ER-54109, and by Association EURATOM, Hellenic Republic.

[1] K. Papadopoulos, J. D. Gaffey, Jr., and P. J. Palmadesso, Geophys. Res. Lett. 7, 1014, 1980.

[2] Y. Kominis, A. K. Ram, and K. Hizanidis, Phys. Plasmas 15, 122501, 2008.

## Microinstabilities in collisionless shocks

M. Scholer

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At a quasi-perpendicular shock a large percentage of the incident ions is specularly reflected by the combined action of the cross-field potential and the magnetic field increase in the shock ramp. The reflected ions gyrate in the upstream magnetic field, are accelerated by the motional electric field and move eventually downstream. The relative drift between incident ions, incident electrons, and reflected ions in the foot region is a source of free energy for a number of microinstabilities. For large relative drift speeds between incident electrons of low thermal speed and reflected ions the Buneman instability is excited. Furthermore, because of the magnetic field, the electron cyclotron drift instability is excited across the field. The ion acoustic instability can get excited when the electron to ion temperature ratio is large and the drift velocity exceeds the ion acoustic speed. In addition, the modified two-stream instability between ions and electrons can get excited even when the relative bulk velocity between ions and electrons is smaller than the electron thermal velocity. When the growth time of any instability is smaller than the gyration time of the ions in the foot the instability can have a profound effect on ion and/or electron heating. If a certain instability is strong enough other instabilities are subsequently excited either due to nonlinar processes or in a two-step process in which a second instability is excited after a change of the plasma parameters as a result of the first stage instability. We will review theory and simulations of microinstabilities in quasi-perpendicular collisionless shocks and will discuss their influence on particle acceleration and shock non-stationarity.

## The upstream density holes and the bow shock

G. Parks

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The Earths bow shock is the best-studied collisionless shock discontinuity in space. Although much is known about the bow shock, fundamental questions still remain unanswered. We still do not know what mechanisms can thermalize the super-Alfvenic flows on scales of ion Larmor radius. Clues to the bow shock problem have been recently obtained from observing the behavior of “density holes” upstream of Earths bow shock. Density holes are regions of substantial density depletions below the solar wind level with dimensions of about an ion gyroradius. They represent the smallest nonlinear ion structures produced by the solar wind. Density holes are accompanied by similarly shaped magnetic holes indicating fields and

particles are strongly coupled. The density and magnetic field are amplified at the edges typically by a factor of 2-5. As the density holes propagate earthward, the magnetic field steepens nonlinearly into a shock-like structure. The temporal changes of density holes indicate they could represent the different stages of nonlinear evolutionary processes that finally end up as shocks.

## Electrostatic solitary waves in superthermal plasmas: nonlinearity off the Maxwellian frontier

I. Kourakis

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The propagation of localized electrostatic (ES) pulses in plasmas is investigated, in the presence of an excess superthermal electron population in the background, modelled via a kappa-type nonthermal distribution. The occurrence of ES solitons is studied, relying on exact and perturbative nonlinear techniques. The deviation from the Maxwellian distribution is shown to influence soliton dynamics and stability. Our theoretical analysis is twofold. A multiple scales method is employed to model modulated ES wavepackets and test their modulational stability. Bright and dark type envelope solitons are shown to occur and their characteristics are discussed. Furthermore, a pseudopotential theory is employed to describe localized ion-acoustic excitations, and the associated conditions of existence are determined, in terms of the soliton propagation speed (Mach number), background non-thermality (via kappa) and, eventually, direction of propagation (obliquity, with respect to a magnetic field). The focus in made on ion-acoustic excitations, although existing results on electron-acoustic waves (in two electron-temperature plasmas) may also be briefly addressed.

Work carried out in collaboration with: N.S. Saini, S. Sultana, A. Sharma (Queen's University Belfast, UK), M. Hellberg and T. Baluku (UKZN, Durban, S. Africa).

# Session 3: The Building blocks of nonlinear plasmas

## Electrostatic solitary waves observed in space and in laboratory experiments

J.S. Pickett[1], L.-J. Chen[2], I.W. Christopher[1], B. Lefebvre[2], and D.A. Gurnett[1]

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With the advent of several high time resolution waveform receivers in the 1990s, observations of nonlinear Electrostatic Solitary Waves, or ESWs, on various spacecraft were reported. ESWs appear in the electric field waveform data as isolated pulses. We briefly review the history of the connection of ESWs to the earlier observations of Broadband Electrostatic Noise, or BEN. We follow this by presenting some of the characteristics of ESWs detected in Earth's magnetosphere. ESWs are generally observed in every boundary or current layer of the Earth and wherever turbulence is present, i.e., bow shock, magnetosheath, magnetopause, cusp, and polar cap and plasma sheet boundary layers, as well as the auroral acceleration region. They are also observed around other planets, in the solar wind, and at interplanetary shocks. Using Cluster data we show propagation of some ESWs from one spacecraft to another over distances of a few km, which speaks to the stability of such nonlinear structures. ESWs are also observed to be generated during the magnetic reconnection process and in response to substorm-triggered processes. In order to better understand the space observations, we compare examples of ESWs generated by means of a weak electron beam in recent laboratory experiments at the UCLA large plasma device (LAPD) to those observed in space. We find that the time scales of these ESWs, while vastly different in terms of their pulse time durations, are quite comparable relative to the time associated with one period of their local plasma frequency. Finally, we discuss the proposed generation mechanisms and how well they fit the observations. Electron and ion phase space holes and double layers generated out of a beam-type instability, and density enhancements and decreases generated out of an acoustic instability are discussed as candidate physical entities represented by the ESWs.

## High-beta plasma disruptions in the Earth's magnetosphere

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Explosive, nonlinear, magnetohydrodynamic (MHD) instabilities in laboratory plasmas, the solar corona and the Earths magnetosphere play a major role in disrupting configurations associated with magnetic confinement and plasma energy storage. The presence of resonances in Hamiltonian systems can have a destabilizing effect on the system as a whole. In Tokamaks,

toroidally localized, high-n (toroidal) ballooning modes are driven to instability due to toroidally localized changes in the pressure gradient caused by low frequency, low-n modes. I shall examine the nonlinear stability of the magnetic field topology and possible nonlinear plasma instabilities that might occur in the near Earth magnetotail (8-10 RE) during the substorm growth phase. These nonlinear instabilities lead to the initiation of the substorm intensification at the Earthward edge of the plasma sheet. I consider models with ultralow frequency (1-4 mHz), shear Alfven normal modes (field line resonances). The analysis is based, in part, on a Lagrangian-Hamiltonian approach, with possible further refinements of measures of nonlinear instability in MHD systems. If time permits, I shall show that observations of aurora can be used to determine the configuration of the near Earth magnetotail during the interval of the substorm process, and the possible evolution toward a topology that is nonlinearly unstable.

### The cross-field current instability for substorm expansion onset

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The cross-field current instability was proposed in 1990 as a physical process responsible for the expansion onset of substorms. In this presentation, we highlight the progress in the investigation of this instability since the first analysis in 1990. The investigation involves linear and quasilinear analyses of the instability, the observational support from past and present space missions, and particle-in-cell simulations of the instability. The nonlinear development of the instability will be emphasized.

## Session 4: Statistical approaches

### Statistical analysis of the power-law particle distributions

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Distribution functions of ions and electrons with (broken) power laws appear frequently in plasma space observations. The classical statistical theory predicts that an ergodic, weakly interacting system satisfies the Boltzmann-Gibbs statistics. The process, which results in a particular distribution function of charged particles, depends on the details of the statistical encounters between them and the electromagnetic field. Therefore, distribution of particles which interacts stochastically with electromagnetic fields and performs Brownian motion, characterized by short range interaction and short term microscopic memory will approach asymptotically a Gaussian, while interaction probability function with a diverging variance will tend to a (skew) stable Levy distribution. Statistical interactions with parameterized encounters allow to discern the processes which result in the observed non-Gaussian distributions, as well as time scales of their evolution. Several techniques for an analysis of distributions with broken heavy tails will be discussed.

## Fractal, multifractal, and generalized scaling in the turbulent solar wind – observations and implications

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The solar wind exhibits fluctuations over a broad range of timescales characteristic of magnetohydrodynamic (MHD) turbulence evolving in the presence of structures of coronal origin. In- situ spacecraft observations of plasma parameters are at minute (or below) resolution for intervals spanning the solar cycle and provide a large number of samples for statistical studies. The magnetic field power spectrum typically has two characteristic components, an inertial range of turbulence over several orders of magnitude with approximately Kolmogorov power law and at lower frequencies, an approximately $1/f^{\Box}$ energy containing range believed to be of direct coronal origin. With a magnetic Reynolds number estimated to be of order $10^5$ the solar wind provides a unique "laboratory" for the study of MHD turbulence, and dissipation processes. Recent results however also suggest that in the ecliptic, signatures of scaling which are of direct coronal origin are embedded in the inertial range of turbulence of the solar wind, and as a consequence these show solar cycle and latitudinal dependence. At high latitudes, in uninterrupted streams of fast solar wind flow, there is the opportunity to study evolving finite range turbulence which can also inform our understanding of turbulence in boundary layers.

## Multiscale phenomena of the magnetosphere

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The plasma processes in Earth's magnetosphere exhibit scales characteristic of electrons to global or MHD dynamics. The cross-scale coupling among these processes is largely responsible for the multiscale phenomena underlying the magnetospheric complexity. This requires the use of many approaches for the understanding of the magnetosphere and its dynamics. At the shortest scale, the electron-MHD model yields the structure of the thin current sheets during reconnection in the magnetotail, as observed by Cluster. The quadrupole magnetic field, which is a hallmark of reconnection, shows a nested structure at electron scales and, along with the structure at ion scale, is a multiscale phenomenon. Considering the magnetosphere as a global dynamical system the distribution of scales has been studied using the extensive ground-based data. This approach enables the study of the inherent features of the global phenomena such as storms and substorms in particular, and extreme events in general. For these studies the mutual information function is found to yield the statistical properties better than the widely used auto-correlation functions. In the case of substorms the features of the long range correlations are found to be similar to the case of multifractal cascade processes, and this is used to characterize the extreme events. The statistical studies require large data sets covering many scales and the ground-based data, which are essentially remote sensing data, have been used so far. The data from multispacecraft missions can provide the in-situ data over many scales that can enable the understanding of the multiscale phenomena using approaches based on first principles as well as nonlinear science.

## Investigating dynamical complexity in the magnetosphere using various entropy measures

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The complex system of the Earth\'s magnetosphere corresponds to an open spatially extended non-equilibrium (input-output) dynamical system. The non-extensive Tsallis entropy has been recently introduced [Balasis et al., 2008] as an appropriate information measure to investigate dynamical complexity in the magnetosphere. The method has been employed for analyzing $D_{st}$ time series and gave promising results, detecting the complexity dissimilarity among different physiological and pathological magnetospheric states (i.e., pre-storm activity and intense magnetic storms, respectively). This paper explores the applicability and effectiveness of a variety of computable entropy measures (e.g. Block entropy, Kolmogorov entropy, T-complexity and Approximate entropy) to the investigation of dynamical complexity in the magnetosphere. We show that as the magnetic storm approaches there is clear evidence of significant lower complexity in the magnetosphere. Overall, Approximate entropy and Tsallis entropy yield superior results for detecting dynamical complexity in the magnetosphere in comparison to the other entropy measures presented herein. Ultimately, the analysis tools developed in the course of this study for the treatment of $D_{st}$ index can provide convenience for space weather applications.

# Session 5: Structures and stability: magnetic reconnection

## Magnetic reconnection: An ultimate problem in nonlinear plasma physics

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Reconnection physics has been the subject of active research since the 1950s but many basic questions are still subject of contentious debate. Is reconnection time-dependent or quasi-stationary or both, what is the onset mechanism(s), what is the physics that gives rise to fast rates? One of the aspects of reconnection is its multi-scale nature where electron kinetic physics affects the large-scale dynamics. Use of reduced models, which ignore details of electron kinetic physics, have led to conclusions that are in direct conflict with those based on first principle approach where electron kinetic effects are retained. Given that the proper closure remains an open question, full particle simulations remain the ideal tool for study of reconnection. However, the multi-scale nature of the problem has posed a great computational challenge. We have made significant progress in overcoming this challenge through several innovations in full particle simulations. Using these simulations, and guided by linear Vlasov and analytical theory, we are well positioned to answer many of the remaining outstanding issues. In this talk, we discuss the latest advances in our understanding of magnetic reconnection and contrast the results with the traditional pictures. We find, in particular, that reconnection physics is much more complex and exhibits much richer diversity than those expressed in the classical works of Sweet-Parker and Petschek.

## 2-D and 3-D Hall magnetic reconnection

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In recent years it has been realized that fast magnetic reconnection can be achieved by including the Hall term in the MHD equations. In this presentation both 2D and 3D Hall MHD simulation results will be presented. We will consider both “unforced” and “forced” magnetic reconnection, and its impact on the reconnection rate. Additionally, we will show the impact of a guide field on magnetic reconnection.

## Magnetic field line reconnection in the plasma current systems of flux ropes and Alfvén waves

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Magnetic Field Line reconnection is still considered, by some, to be one of the most important topics in plasma physics. It has been in this category for close to thirty years and the "problem of reconnection" has still not been solved. Magnetic field topologies are part and parcel of the current systems within a plasma whatever their source. Plasma currents may initially be induced or injected but they soon become entangled or part of the currents of plasma waves, flows and structures. We first present experimental results of un-driven reconnection which occurs when two magnetic flux ropes are generated from initially adjacent pulsed current channels in a background magnetoplasma. The currents exert mutual **J**x**B** forces causing them to twist about each other and merge. In addition the currents are observed to filament after merging. Volumetric space-time data show multiple reconnection sites with time-dependent locations. The quasi-separatrix layer (QSL) is a two-dimensional surface within the plasma. Two closely spaced field lines which enter the QSL wind up at very different spatial separations at finite distances along the current channel. Outside the QSL neighboring field lines remain close by. In the flux rope experiment the self-fields are of order 2% of the background field which is enough for them to interact over their length. The second example which will be presented is the 3D currents associated with colliding laser produced plasmas. The currents in this situation are those of shear Alfvén waves. The wave fields are a small fraction of the background field; nevertheless, reconnection regions, multiple magnetic "X" points (which are three dimensional) and induced electric fields are observed. When the background field is added the field lines and reconnection regions become highly elongated. These measurements lead one to suspect that reconnection is not an independent topic, which can be studied in isolation, but part of the phenomena associated with broader subject of 3D current systems in plasmas.

## Particle acceleration during magnetic reconnection

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A significant fraction of the magnetic energy released during magnetic reconnection in solar flares appears as energetic electrons and protons. How this conversion of magnetic energy takes place so efficiently has been a scientific topic of great interest for many years. Recent developments in our understanding of reconnection have important implications for understanding energetic particle production. In the corona the classical picture of the formation of a single large x-line does not seem to be viable: the narrow current layers that

develop near the reconnection sites break up into secondary magnetic islands whose dynamics and size spectrum are likely to control particle acceleration. Energetic electrons can be produced by reconnection induced parallel electric fields or through Fermi-like reflection in contracting magnetic islands. Acceleration through Fermi reflection links electron energy gain to released magnetic energy, a key observation in flares. Efficient ion acceleration takes place as ions move from upstream into the Alfvenic reconnection exhausts – the ions act like pickup particles and gain a thermal velocity equal to the exhaust velocity. During reconnection with a guide field high mass-to-charge ions are more efficiently heated than protons, which may explain the abundance enhancements in impulsive flares. Particle acceleration in a multi-island environment remains a modeling challenge because of its inherently 3-D kinetic nature.

## Bursty flows and non-linear plasma structures in Earth's magnetotail as revealed by THEMIS multi-point observations

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Recent results from THEMIS revealing the location of substorm onset and the critical role of magnetic reconnection in destabilizing the tail current focuses renewed attention on the particle distributions that lead to explosive reconnection and the effect of waves in acceleration and heating of ions and electrons. Self-consistent modeling of non-Harris current sheet profiles reveals important asymmetries of the observed distributions. Topological reconfigurations of the magnetotail after reconnection can explain partially the observed prompt acceleration of ions. Non-linear waves in the whistler regime are inherent in the observed propagating flow and field structures after reconnection onset and may be responsible for the electron acceleration. The flow shear of the localized bursty bulk flows results in low Reynolds number turbulence, sufficient to produce strong local dissipation and possibly explaining why many of the observed events are short lived and do not propagate far enough close to Earth. The ionospheric coupling is an important factor to the evolution of plasma sheet flows. Low conductivity impedes closure currents and flows and results in localized activations. As the conductivity builds up due to Joule heating and precipitation the ionospheric response increases resulting in a step-like evolution of plasma sheet reconnection and substorms.

# Session 6: The building blocks of nonlinear plasmas: waves

## Nonlinear dynamics of mirror waves: THEMIS observations vs. theories

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Mirror waves are common feature for many key regions of space plasmas such as solar wind, planetary magnetosheaths, cometary plasma, Io wake and terrestrial ring current. Kinetic mirror instability has been theoretically identified by Vedenov & Sagdeev [1958] at the very beginning of plasma physics development. However, in spite of the apparent simplicity, observations of mirror waves pose a number of puzzles. In contrast to other wave modes, the mirror waves are only occasionally observed as periodic structures. More often they observed either as sporadic decreases of magnetic fields referred to as magnetic holes or as mirror picks. Various theoretical models have been proposed to explain observed mirror structures. Comprehensive THEMIS data allow us to validate proposed models. Previous nonlinear magnetic mirror models were based on either phenomenological modelling of nonlinear effects such as the particle trapping, the reductive perturbation method in which kinetic effects arise at the linear level or the hybrid model where the perturbation approach has been supplemented by phenomenological description of the particle trapping effects. However among existing models only kinetic description accounting for trapped particles at all stages of mirror waves nonlinear evolutions is in accordance with THEMIS observations. A comprehensive review of all these models and their relevance to recent satellite data is presented.

## Theory and simulations of nonlinear whistler-mode chorus emissions in the magnetosphere

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We develop a nonlinear wave growth theory of magnetospheric chorus emissions, taking into account the spatial inhomogeneity of the static magnetic field and the plasma density variation along the magnetic field line. Based on a detailed analysis of self-consistent simulations that reproduce chorus emissions, we derive theoretical expressions for the nonlinear growth rate and the amplitude threshold for the generation of self-sustaining chorus emissions. We assume that nonlinear growth of a whistler-mode wave is initiated at a specific localized region where

the linear growth rate maximizes. Self-sustaining emissions become possible when the wave propagates away from the equator during which process the increasing gradients of the static magnetic field and electron density provide the conditions for nonlinear growth. The amplitude threshold is tested against both observational data and self-consistent particle simulations of the chorus emissions. The self-sustaining mechanism can result in a rising tone emission covering the frequency range of 0.1 - 0.7 of the equatorial electron gyrofrequency. Higher frequencies are subject to stronger dispersion effects during propagation, and the dispersion effects can destroy the self-sustaining mechanism. We obtain a pair of coupled differential equations for the wave amplitude and frequency. Solving the equations numerically, we reproduce a rising tone of VLF whistler-mode emissions that is continuous in frequency. Chorus emissions, however, characteristically occur in two distinct frequency ranges, a lower band and an upper band, separated at half the electron cyclotron frequency. We explain the gap by means of the nonlinear damping of the longitudinal component of a slightly oblique whistler-mode wave packet propagating along the inhomogeneous static magnetic field.

## THEMIS Observations of large-amplitude whistler waves in the Earth's magnetosphere

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The THEMIS mission includes five satellites in near-equatorial orbits, and offers an excellent opportunity to observe the whistler-mode waves that can exist in the Earths radiation belts and elsewhere in the magnetosphere. Although the observed amplitudes are small compared with the background magnetic field, they are sufficiently large that nonlinear effects such as phase trapping must be considered. Packets of bursty, large-amplitude waves are observed in spatially extended and surprisingly persistent regions of the radiation belts, supporting the importance of emerging nonlinear theories of whistler growth and electron acceleration [e.g. Omura and Summers, 2008]. This trapping can reach more extreme levels in the weaker magnetic fields farther out in the magnetosphere, leading to whistler-mode electron phase space holes analogous to the whistler mirrors that have been produced in the laboratory [Stenzel et al, 2008].

# Excitation of low-frequency electrostatic waves with active experiments in the ionosphere

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For the past 30 years, we have been conducting experiments in the F-region ionosphere using both Space Shuttle Exhaust and High Power Radio Waves to generate low-frequency electrostatic waves. When the Space Shuttle OMS engines are operated on orbit near 300 km altitude, the large quantities of exhaust vapors charge exchange with the ambient oxygen ions. The resulting pickup ions have energies between 2 and 12 eV depending on the orientation OMS nozzle relative to the orbit vector. Using ground radar scatter from Millstone Hill, MA and Arecibo, PR, the non-linear excitation of ion-acoustic waves has been detected as enhanced and highly distorted ion line spectra. Other experiments with high power radio waves at the HAARP facility in Alaska have used Stimulated Electromagnetic Emissions (SEE) to detect both ion acoustic waves and ion Bernstein waves produced by interactions of high power electromagnetic waves. The theory for the first measurements of stimulated Brillouin scatter in magnetized plasmas has been derived with matching conditions for the decay of a high power electromagnetic wave into a low-frequency electrostatic wave and a scattered electromagnetic wave. The theoretical derivation shows that either an ion acoustic wave with frequency less than the ion cyclotron frequency or an electrostatic ion cyclotron wave could be produced by this generalized stimulated Brillouin scatter (GSBS) process. To estimate the growth rates, the coupled equations describing GSBS instability are solved for a non-uniform plasma driven by large amplitude electromagnetic (EM) wave. Exciting laboratory-in-space research for remote sensing is provided by the low-frequency electrostatic waves produced by both exhaust from orbiting vehicles and by high power EM waves from the ground.

# Session 7: Turbulence: Developments and effects

## Evolution of whistler turbulence in the magnetosphere

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A recent article of Saito et al. [1] points to the importance of whistler turbulence in the determination of magnetospheric plasma state and hence the near-earth space weather. The Saito et al. investigation was conducted in a two dimensional (2D) simulation in which the magnetic field was in the simulation plane. They reported that the whistler turbulence cascades towards short wavelength (larger frequency), as in the classic Kolmogorov picture. In this 2D configuration the most important nonlinearity which is essentially 3D in nature [2, 3] is missed. Hence, we generalize the Saito et al. work by tilting the magnetic field with respect to the simulation plane. The tilt introduces the important nonlinear physics (wave-wave and wave-particle scattering due to slow plasma density perturbation) which was lost in [1]. We find that evolution of whistler turbulence is dominated by scattering in which energy flows from short to long wavelengths (towards smaller frequency) instead of the Kolmogorov-type cascade. This is a markedly different physical process than that described in Saito et al. The ramification of this conclusion on the evolution of whistler turbulence and its effects on the magnetospheric plasma state will be discussed.

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## Co-existence of Turbulence and Discrete Modes in the Solar Wind

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Motivated by apparently contradictory reports of turbulence and discrete frequency wave-like signals in the interplanetary medium, we employ numerical simulations to investigate the persistence of wave-like spatial structures in the presence of strong low-frequency turbulence. We seek to identify the time scales and other conditions that permit them to remain as identifiable structures in the turbulent medium. The wave-like structures are initialized as discrete modes in wavenumber in a series of spectral method magnetohydrodynamic turbulence computations. We find that discrete modes can survive from one to many nonlinear times, and that the main factor that determines their survivability is the separation from turbulence in parallel wavenumber. This corresponds to a separation in their corresponding Alfven mode frequency.

## Dispersive cascade and dissipation of solar wind turbulence at electron scales: recent observations and theoretical modelling

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Over the past few decades, large-scales solar wind (SW) turbulence has been studied extensively, both theoretically and observationally. Observed power spectra of the low frequency turbulence, which can be described in the magneto-hydrodynamic (MHD) limit, are shown to obey the Kolmogorov scaling, $k^{-5/3}$, down the local proton gyrofrequency ($f_{ci}$~0.1Hz). Turbulence at frequencies above $f_{ci}$ has not been thoroughly investigated and remains far less well understood. Above $f_{ci}$ the spectrum steepens to $\sim f^{-2.5}$ and a debate exists as to whether the turbulence has become dominated by dispersive kinetic Alfvén waves and is dissipative, or has evolved into a new dispersive turbulent cascade dominated by whistler waves. Here we report the first direct determination of the dissipation range of solar wind turbulence near the electron gyroscale (Sahraoui et al., *Physical Review Letters, submitted*). Combining the high

resolution magnetic and electric field data measured by the Cluster spacecraft, we compute the spectrum of turbulence over more than five decades, ranging from $10^{-3}$ Hz to $10^{2}$ Hz (in the spacecraft reference frame). A new inertial range is thus evidenced characterizing the energy cascade above $f_{\square i}$, and up to $f_{\square e}$, with a scaling $f^{-2.3}$. Above $f_{\square e}$ the spectrum is shown to have a steeper power law $f^{-4.1}$ down to the noise level of the instrument. We interpret this as the dissipation range. Using the (gyro)kinetic Vlasov theory, we show that these observations are remarkably consistent with theoretical predictions of a quasi-two-dimensional cascade into kinetic Alfvén waves (KAW), and a dissipation via electron Landau damping. Implications of the results on the heating problem of the solar wind will be discussed.

## Nonlinear solar wind - magnetosphere coupling using MHD models

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The magnetosphere is a system of thin plasmas with multiple populations, where the fluid MHD description is often used, but seldom valid. However, because of the driven nature of the dynamics, the large-scale properties of the solar wind - magnetosphere coupling can be examined using global MHD simulations. Magnetic reconnection at the dayside magnetopause controls the rate of energy input, and tail reconnection governs the energy dissipation processes in the plasma sheet and in the ionosphere. Thus, the energy through the magnetopause is mostly in the form of the Poynting flux, and the magnetopause reconnection efficiency can be evaluated from its divergence. We have developed quantitative methods to examine the energy input and conversion properties in the GUMICS-4 global MHD simulation. This presentation reviews our results both from observations and MHD simulations on the routes of energy transfer, the prameters driving the energy input, and the magnetospheric dynamics following the solar wind driving. Furthermore, we discuss the large-scale features of magnetic reconnection as they appear in the global simulations.

# Session 9: Phase space structures and their stability

## The turbulent bremsstrahlung (plasma-maser) effect

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Because of nonlinear interaction between particles and waves, energy conversion between waves of large frequency difference can occur without particle population inversion or resonant wave-wave interaction. The effect involves the nonresonant interaction of the plasma particles with a pair of plasma modes of large frequency difference, and wave energy is converted into particle energy. This effect can appear in laboratory as well as astrophysical plasmas and is important in determining the transport properties of weakly turbulent plasmas. Here, the theory of the plasma-maser effect is discussed.

## Whistler triggering associated with a discontinuity in the electron velocity distribution

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We report on a simulation study of the instability of a coherent whistler parallel-propagating in a simplified model radiation belt, with a background of cold electrons as well as a distribution of energetic electrons which either is a delta-function or has a step-discontinuity. A nonlinear instability is initiated at the location $z+$ where the electrons are cyclotron resonant with the wave, on the side of the equator ($z=0$) where the wave is propagating away from the equator. The instability propagates backwards toward the equator, growing both spatially and temporally. As the instability develops, frequency falls in such a way as to keep the electrons nearly resonant with the waves over the entire region $0<z<z+$. The instability causes a sharp drop in the pitch angle of the resonant electrons, and eventually saturates with peak amplitude near the equator.

## HAARP-induced artificial ionospheric ducts

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It is well known that strong electron heating by a powerful HF-facility can lead to electron and ion density perturbations stretching along the geomagnetic field. These density perturbations can serve as ducts for ELF waves, both of natural and artificial origin. This paper presents the experimental evidence of plasma modifications associated with ion outflows due to HF heating. The experiments were conducted using the HAARP heater and two diagnostics satellites, DEMETER and DMSP-16, flying at altitudes 700-800 km close to the magnetic zenith of HAARP. Onboard detectors provided in situ measurements of the ion temperature and composition. The experimental verification of strong ion outflows and formation of the ionospheric ducts by F-region ionospheric heating is presented. Generation of the ionospheric ducts requires strong F-region heating, which is optimum in quiet ionosphere with a distinct smooth F2 region and minimal D/E region absorption. The ion outflows and density structures are best detected by satellites passing within less than a hundred kilometers to the HAARP magnetic field line. The experimental results are in qualitative agreement with the existing numerical model of inter-hemispheric artificial ducts.

## Nonlinear plasma effects in natural and man-made aurora/airglow

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The common features of natural aurora/airglow and produced by electron beams and high-power HF radio waves in the Earth's ionosphere are discussed. First, we present the results of observations of natural auroras and active rocket experiments with electron beam injections. These show the fundamental role of strong Langmuir turbulence (SLT) in the formation of auroral rays' structure. The SLT development in weakly-ionized plasmas significantly differs from that in collisionless plasmas due to electron-neutral collisions. Their effect is negligible at high altitudes, but dominates at low altitudes, thereby an intermediate regime of SLT is formed in-between. Here bulk electron heating and suprathermal acceleration proceed at much higher rates than in adjacent regions. Next we present novel results from multi-

instrument observations of HF ionospheric modification during O-mode pumping near the second electron gyroharmonic from the HAARP heating facility. These observations in the F region indicate that both the thermal and parametric instabilities can coexist above the second gyroharmonic and that up to four mechanisms of electron acceleration can be acting, depending on the pump frequency relative to the second gyroharmonic. Clear evidence is found for the presence of lower hybrid (LH) waves. We show that damping of the LH wave energy in collapsing cavities by suprathermal tails in the field-aligned electron distribution is effective in the energy range below 10 eV, and can thus contribute to the red (630.0 nm ) and green-line (557.7 nm) emissions. In a precipitation-produced E layer high-power HF waves from HAARP produce highly localized 557.7 nm optical emissions. The specific transmitter pulsing period does not appear to be a critical factor, ruling out ULF resonances as a possible mechanism. The observed locations of the enhanced emissions are consistent with a small number of long-lived inhomogeneities traveling steadily across the field of view over several minutes. These persistent regions are preferentially excited even at a small fraction of peak power well away from the beam center, and can reappear along the same trajectory after gaps of more than 1 minute. The absence of any detectable enhancements in directly coincident 630.0 nm data or side-looking 557.7 and 630.0 nm images focused on the F-region portion of the field line conclusively locates these artificial emissions in the ionospheric E region. The results are consistent with the acceleration of ambient secondary electrons by SLT driven by the HF pump wave.

# Session 10: Structures and stability in space and solar plasmas

## Nonlinear coupling between density structures and feedback-unstable ULF waves in the ionosphere

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Results from a numerical study of the nonlinear interaction between ultra-low-frequency (ULF) shear Alfven waves, slow MHD waves, and the ionospheric plasma are presented. The main hypothesis investigated in this study is that observed in the topside auroral and subauroral ionosphere density inhomogeneities including plasma cavities and ducts (magnetic field-aligned density striations), can be produced by intense ULF electromagnetic waves standing and/or propagating along geomagnetic field lines in these regions. The study is based on a two-fluid MHD model describing ULF MHD waves in the cold, low-altitude magnetospheric plasma. The model includes nonlinear coupling between shear and slow MHD modes (parallel ion dynamics) as well as effects of E-region ionospheric activity leading to

feedback instability. Numerical simulations of the model equations have been performed in dipole magnetic field geometry with realistic parameters of the ambient plasma. The simulations show that the ionospheric feedback is one of the major mechanisms responsible for formation of intense electromagnetic waves and plasma structures inside the ionospheric E and F layers.

## Physics of CMEs: dynamics and energetics in the corona and interplanetary space

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The new SECCHI/STEREO observations allow one to directly observe from two vantage points the dynamics of coronal mass ejections (CMEs) at high time cadences in the corona and in interplanetary space. The recent theoretical and observational work has established that CMEs can be well described as erupting flux ropes, expanding under the action of the Lorentz hoop force and interacting with the ambient plasma via the drag force. In particular, the semi-analytic erupting flux rope model has been extensively tested against SOHO and SECCHI data, out to HI1 and HI2 fields of view. The model is formulated using an integrated MHD approach to take into account the fully 3D flux rope geometry. The initial-value solutions of the model for flux-rope motion show excellent agreement with the trajectories of observed CMEs from the inner corona to nearly 1 AU. In addition, the resulting model structure at 1 AU closely resembles that of magnetic clouds associated with CMEs: the magnetic field, size, speed, and density are in agreement with ACE data for a number of CME-magnetic cloud events. Another issue studied with the model is the physical connection between CMEs and associated flares. It has been shown that the calculated temporal profiles of the electromotive force generated during CME eruptions are closely correlated with those of the observed GOES soft X-ray emissions. It is shown that if there is any nonzero dissipation, the magnetic energy associated with CMEs asymptotes to a finite number in any heliospheric sphere of finite radius, exhibiting no "flux catastrophe". I will discuss the basic physics represented by the model and show that the model provides a quantitative and unified theoretical framework of understanding the CME-flare phenomena and numerical simulation models.

## The solar wind throughout the solar activity cycle

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The Ulysses spacecraft, presently terminating its mission, has conclusively demonstrated that the solar wind, at solar minimum, has a well defined bi-modal structure, with the prevailing source of the high speed streams located within coronal holes, and the slow solar wind apparently confined to the magnetic activity belt, possibly escaping from previously closed coronal magnetic regions. Alternatively, the source of the slow wind could be the rapidly expanding magnetic field regions at the coronal hole boundary. In this talk I will rapidly review our present knowledge of the source regions of the solar wind throughout the activity cycle, then discuss what coronal heating and acceleration mechanisms might be prevalent in each, to conclude with which observations from current and future experiments might be crucial in disproving or discriminating among the panoply of models – from Alfven waves, high frequency cyclotron modes and MHD turbulence to shocks and magnetic reconnection between closed and open fields - developed since Parker's original prediction of the solar wind outflow 50 years ago.

## Magnetic decrease (MD) formation in interplanetary space (from <1 AU to 5 AU) and mirror-mode formation in planetary magnetosheaths and the heliosheath

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Magnetic Decreases (MDs) have been identified and studied throughout a Ulysses fast latitude scan at a distance ~ 5 AU from the sun. MDs were found to occur in high occurrence frequency "clusters" with the top ten peak events varying in magnitude from 116 MD/day to 36 MD/day. For comparative purposes, quiet, nonpeak intervals had an occurrence rate of 4.3 MDs/day. MD clusters were often found to occur within corotating interaction regions (CIRs), mainly localized in the trailing portions of CIRs between the interface (IF) and the reverse shock (RS). The MD clusters were divided into smaller subclusters. Within the limits of this study, MD subclusters were always found to occur in high □ 1< □ 102) regions (HBRs). Only 13.5% of MDs were "linear" with angular changes < 10 across the structures. Because MDs are found in abundance in the region spanning the CIR RS to close to the IF, it is argued that

MDs must be formed continuously from close to the sun (r < 1.0 AU) to ~ 5 AU. A scenario is presented to explain the HBRs downstream of CIR RSs. The location of MD clusters in the trailing parts of CIRs and the paucity of linear MDs indicate that MD generation by mirror mode (MM) instability is unlikely. More promising candidates are shock compression of phase-steepened Alfvén waves, shock-directional discontinuity (DD) interactions, and downstream turbulence. We emphasize the phase-steepened Alfvén wave mechanism. It is argued that MM structures have been detected in the heliosheath by the Voyager 1 magnetometer. The typical scale size is ~57 $r_p$ (proton gyroradii) with little or no angular changes (~3º long. and ~3º lat.) across the structures. The size and nature of the magnetic oscillations are comparable to those in the magnetosheaths of Earth (20 $r_p$), Jupiter (25 $r_p$) and Saturn (40 $r_p$). It is argued that upstream PUI anisotropies, perpendicular shock compression of the upstream PUIs and additional injection of PUIs thoughout the heliosheath drive the MM instability. MM structures in the magnetosheath at Saturn are revisited (Pioneer 11). It is shown that shock compression alone is insufficient for MM instability at Saturn. The magnetic field line draping mechanism is needed to inject additional free energy into the system.

# Session 11: Revealing plasma structures via active experiments

## Propagation of ultra high laser intensities in air

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In the last several years, there has been significant interest in the propagation of high power subpicosecond pulses in air and its applications. The phenomena associated with propagation of these high-power beams are complicated and involve pulses that undergo strong spatial and temporal reshaping. While propagating in free air a pulse with initial power over a critical value will collapse into intense localized light channels. In the localized light regime the temporal as well as spatial dynamics are equally important and cannot be separated from each other. One of the remarkable properties of these filaments is that they can travel tens or even hundreds of meters producing fine and as often assumed relatively uniform ionized channels on their wake. The ability to generate in this way very long thin plasmas is clearly of significant interest for the use of ultrashort pulses to guide and trigger electric discharges in large systems.

In this presentation we will discuss our recently developed a simple method, that allows obtaining a single and highly stable filament, out of a high power pulse which would otherwise generate a random multiple filamentation patterns. This setup allows us to change continuously the effective focus, thus controlling the collapse. Therefore, we been able to reduce the number of filaments dictate their position and arrange the spatial pattern, making the task of measuring a single filament plausible. The ability to obtain select and stabilize a single filament allowed us to study the longitudinal structure of plasma channel left in its wake. We will present the first mapping of the fine plasma structure generated by a single high-intensity filament. Our measurements reveal that along a distance of several meters, the electron density in the channel varies by more than three orders of magnitude. These variations emphasize the existence of a post-ionization regime maintaining the beam in self-guided shape coupled with a low plasma level. In addition, we present the first detailed measurements and numerical 3-D simulations of the longitudinal plasma density variation in a laser-plasma filament.

The possible applications of these plasma channels will be discussed.

## Tethered Satellite System

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The concept of an electrodynamic Tethered Satellite System is to deploy a tethered satellite from the space shuttle (the Orbiter) and, by its motion through the earth's magnetic field and an emf developed across the long conducting tether, to collect electric current from the ambient ionosphere. There were two such TSS missions conducted from space shuttle under a joint venture between NASA and ASI (Agenzia Spaziale Italiana). The first mission TSS-1 took place in August, 1992 on the shuttle flight STS-46. The second mission TSS-1R took place in February, 1996 on the shuttle flight STS-75. Dr. Dennis Papadopoulos was the leading theoretician on both missions from the SAIC team known as the Theoretical and Modeling Support for Tether (TMST) investigation. The overall scientific objective of the TMST team was to understand the physics underlying the current-voltage characteristics of the TSS system, specifically, on critical questions such as:

- How is current collected by charged satellite moving with orbital velocity?
- What are the effects of electron beam injection and neutral gas release on current collection?

Answers to these questions would require understanding the behavior of the sheaths at the Orbiter and at the tethered satellite, the electrodynamics of the sheath region in motion, the physics on ionization of neutrals and discharges, and the nature of the current closure path in the ionosphere.

The TSS missions produced many surprising results. The first surprise from the mission was that the current collection at the satellite consistently exceeded expected values predicted by the static models known as the Parker-Murphy model and the Beard-Johnson model. On many occasions, the tethered satellite collected maximum amount of current (~ 0.5 Amps) allowed by the rate of electron release on the Orbiter side, at satellite potentials as low as 400 Volts. The second surprise was the observation of electrons with energies as large as 20 times the sheath potential, thus implying an efficient acceleration mechanism in the sheath region. The dynamic motion of the satellite (~ 8km/s) contributed to both the current collection and the acceleration processes. The third surprise was the saturation of current collection (~0.5 Amps) at very low satellite potential (~100 V) when gas was released into the sheath. The fact that high current levels were achieved at low satellite potential suggested that active gas discharge occurred in the satellite sheath. The final and the most striking result came after tether break in the second mission (TSS-1R). After tether was severed, possibly by arcing with the body of the Orbiter, a high current level of ~ 1.1 Amps was reached in tether. This high current state lasted ~ 75 s after the break when the tip of the broken tether was the electron emitter. A process similar to vacuum arc was proposed to explain this observation, with "vacuum" implying that the arc starts in vacuum, but is burning in the cathode vapor.

## Simulations of plasmoids penetrating a magnetic barrier

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Perturbed currents perpendicular to the magnetic field are generated by plasma motions in which the equilibrium magnetic field (and the corresponding equilibrium currents) are compressed, stretched, and deformed. One example of this is the Earth's magnetopause with its ever-present equilibrium transverse currents and its strong perturbations. These perturbations may allow plasma and energy transfer past the magnetic barrier of the magnetopause. Laboratory experiments have recently been performed using a plasma cannon to shoot a plasma at a magnetic barrier (Brenning et al., PoP, 2005) in order to study the physics of such plasma and energy transfer. Simulations of the above scenario for different values of the plasma density have reproduced experimentally observed lower hybrid frequency oscillations (Gunell et al., Plasma Phys. Control. Fusion, 2008). We present a set of simulations of plasmoids with different dimensions. For plasmoids that are longer than those previously published we find waves propagating upstream from the barrier,and that the penetration process causes the part of the plasmoid that is upstream of the barrier to rotate. We study the role of plasmoid width and cross sectional shape in penetration and find that, for plasmoids that are less than half an ion gyro radius wide, the plasmoid is compressed to obtain a vertically oriented elliptical cross section, regardless of the initial shape. Finally, we present one case where the initial plasmoid width exceeds the ion gyro radius.

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## Particle acceleration and radiation processes through reconnecting current sheets

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The acceleration process of charged particles (electrons and protons) inside solar reconnecting current sheets is investigated using numerical and analytical methods. The kinetic energy gain of particles traveling through a single Harris-type reconnecting current sheet follows a simple analytical law. Particles interacting consecutively with a number of reconnecting current sheets have a limited kinetic energy gain as it is found through numerical experiments and explained with analytical theory. Finally, the computation of X-ray spectra by a "thick target" model is given for the produced kinetic energy distributions.

## Injection of ELF magnetic fields and currents into the equatorial E-region ionosphere

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We present a numerical study of the injection of magnetic fields and current structures into the equatorial E-region ionosphere. In the E-region plasma 90-120 km the Hall conductivity dominates over the Pedersen conductivity. Here currents are closed by helicon wave dynamics in the frequency range much lower than the ion cyclotron frequency. The induced vertical and horizontal currents may be utilized as antennas for the injection of electromagnetic waves into the earth-ionosphere waveguide. Above 120 km the Pedersen conductivity dominates, and we have diffusive coupling to the upper ionosphere.

# Session 13: Dynamic and interacting space plasmas

## A non-linear reaction of the ionosphere and thermosphere to solar cycle EUV variations

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Total EUV solar flux responsible for ionization of the ionospheric F2-layer varies by 1.9-2.9 times (according to different models) from solar minimum to solar maximum while daytime electron concentration in the F2-layer maximum, NmF2 varies by 5-6 times in winter and by 2-2.5 times in summer. Unlike winter season with a linear NmF2 increase versus solar activity, in summer NmF2 demonstrate a saturation effect at high solar activity despite increasing EUV. This indicates a complicated non-linear reaction of the thermosphere to solar activity variations. Along with the EUV increase we have general increase of geomagnetic activity when we pass from solar minimum to solar maximum and this two-channel impact produces complex seasonal/solar cycle variations in the thermosphere-ionosphere system. Millstone Hill ISR observations under solar maximum, moderate and minimum conditions were used to estimate a quantitative contribution of various processes and aeronomic parameters to the observed solar cycle and seasonal NmF2 variations. An original method was applied to extract a self-consistent set of the main aeronomic parameters from routine ISR observations. The list of the obtained parameters includes: thermospheric neutral temperature $T_n$=f(Tex, T120, S) and composition [O],[$O_2$],[$N_2$], vertical plasma drift W which can be converted to the meridional thermospheric wind, and the total solar EUV flux. The extracted set of aeronomic parameters along with initially observed plasma characteristics provide a complete picture of the neutral and ionized upper atmosphere components distribution in the vicinity of the ISR installation for the geophysical conditions in question. Physical mechanisms resulting in the observed seasonal and solar cycle NmF2 variations are discussed. The obtained aeronomic estimates of the total EUV flux and thermospheric parameters are compared with modern empirical models used in ionosphere physics.

## Nonlinear ionospheric turbulence driven by the solar wind

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Following the pioneering work of Papadopolous on ionospheric turbulence, we present models of the E-layer and lower F-layer turbulence with coherent structures using theory and simulations that are driven by solar wind data from the ACE spacecraft [1]. The ACE data gives about a one hour lead time before the enhanced ionospheric currents develop. The currents in the ionosphere are computed with the REAL-TIME WINDMI model running on the Community Coordinate Modeling Center website. From the model's prediction of the R1 and R2 network of currents in the auroral oval we use theory to compute the growth rates for low frequency drift wave instabilities, the high frequency lower hybrid drift, the ion acoustic turbulence, and the Farley-Buneman instabilities. Pseudo-spectral codes [2] are used to compute the nature of the turbulence structures. From the turbulent fields we then estimate the standard measures for scintillation in the ionosphere. In particular, the normalized variance of the transmitted radio power called S4 and the variance of the radio wave phase shifts for signals propagated from radio beacons to the receivers. We record the time series of the electron density and potential fluctuations following the path of a virtual spacecraft like the DMSP satellites through the turbulent fields for comparison with data. The problem of modeling the ionospheric turbulence from rising and falling coherent structures of fundamental scientific importance. The large scale ionospheric structures have secondary instabilities associated with sharp gradients on the leading edges of the coherent structures that effect the accuracy of the global positioning system GPS data and the degree of scintillation of radio waves propagating through the ionosphere.

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## The study of non-linear acceleration of particles during substorms using multi-scale observations

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By combining observations and theory we are able to investigate magnetospheric processes on scales not achievable by spacecraft observations alone. Recent observations from the THEMIS spacecraft indicate that during magnetospheric substorms particles in the near-Earth magnetotail gain large amounts of energy (>100 keV) in a short amount of time (~ minutes). In this talk we use theory and simulations to understand the observations and to investigate the acceleration and losses of the energetic particles. To understand the effects of non-adiabaticity in the time dependent magnetospheric electric and magnetic fields we use global magnetohydrodynamic (MHD) simulations with large scale kinetic (LSK) calculations. Initial calculations indicate that non-adiabatic motion can lead to the observed acceleration in some cases. Wave-particle interactions may also play an important role in particle energization and to examine this phenomenon we will use particle in cell (PIC) simulations. This multi-scale simulation approach will allow us to determine the underlying physical processes, as well as to understand the local observations in a more global context.

## Modeling the magnetosphere with the multi-fluid Lyon-Fedder-Mobarry magnetosphere model

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During geomagnetic storms and substorms observations in the magnetosphere indicate the presence to Oxygen that has been accelerated out of the ionosphere. Multi-fluid reconnection studies have shown that the presence of Oxygen can dramatically effect the rate at which reconnection occurs. In this presentation we use the recently developed multi-fluid version of the Lyon-Fedder-Mobarry global magnetospheric simulation to model the impacts of outflowing ionospheric oxygen on the magnetosphere. In order to quantify the effects of this outflow we model it as a patch in the ionosphere of a specific size, location, and magnitude. By varying each of these parameters independently we will examine how it impacts the strength and location of reconnection within the magnetosphere. We will pay particular attention to the effects this outflow has on the occurrence of substorms within the idealized simulations. We will conclude with a few remarks on the next steps required to include a more accurate model for ionospheric outflow.

## MESSENGER at Mercury: Old questions and new insights

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The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft mission to Mercury has offered the first opportunity to explore the planet since the brief flybys by Mariner 10 in 1974 and 1975. MESSENGER flybys of the planet in January and in October of 2008 have returned a wealth of new data about the interior, surface, atmosphere (exosphere), and extended magnetosphere of the Sun's nearest neighbor. Because of Mercury's proximity to the sun (0.3 – 0.5 AU) the planet and its magnetosphere experience the most extreme solar wind driving forces in the solar system. Magnetic reconnection at the dayside magnetopause can erode the outer magnetosphere, allowing solar wind ions to impact directly onto the surface. The lack of a dense Mercury ionosphere is probably the underlying reason for the brevity of the very intense, but short-lived (~ 1-2 min) energy bursts (substorms) observed by Mariner 10 during its first traversal of Mercury's magnetic tail in 1973. All of these factors can produce complicated interactions involving the exchange and recycling of particles among the solar wind, magnetosphere, and surface regolith. MESSENGER's broad range of instrumentation and tailored trajectories are giving key insights into all aspects of the planet and its solar wind interactions. We compare and contrast in this talk the magnetospheric properties observed on the first two flyby passes.

## The Saturnian plasma sheet, as revealed from combined plasma, energetic-particle, and magnetic-field data from CASSINI

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Combined plasma, energetic particle and magnetic field measurements, obtained by the Magnetospheric Imaging Instrument (MIMI), the Cassini Plasma Spectrometer (CAPS) sensors and the magnetometer (MAG) respectively, are used to study the Saturnian plasma sheet as revealed through a number of passes of Cassini between July 2004 and early 2009. The in-situ Cassini measurements offer complete energy coverage (eV to MeV) of the cold plasma and the energetic particle population, making possible the computation of the particle temperature and total plasma pressure. The extent and temporal variation of the plasma sheet is examined, with emphasis to physical processes active in the magnetosphere of Saturn, and in

particular the direct comparison between pressure radial gradient and inertial (centrifugal) forces and their relative contribution to the planetary ring current. Initial results indicate that (1) the dayside plasma sheet is wide in latitude (45 deg) and extends up to the magnetopause, while the night side plasma sheet is much thinner, with a larger scale height for energetic ions ($\sim 2R_S$) compared to the cold-warm plasma ($\sim 1R_S$); (2) The suprathermal (E>3keV) pressure component maximizes in the ring current region, representing more than half of the total particle pressure; (3) The in-situ measured radial pressure gradient appears higher than the corresponding inertial force, within their variation range ($3\ 10^{-19}$ vs. $2\ 10^{-19}$ N/m), in agreement with the results from the statistical approach of the radial force balance in the equatorial plane.

# Session 14: Dynamic and interacting plasmas in space and laboratory plasmas

## Dynamic planetary magnetospheres

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Planetary magnetospheres are prime examples of interacting plasma regimes at different scales. There is the principal interaction with the solar wind that seems to be the main driver of the dynamics at Mercury and Earth. But these inner planet magnetospheres are relatively simple when compared to those of the outer planets which are primarily driven by planetary rotation and include internal plasma sources from various moons and rings, in addition to those from the planetary ionospheres and the solar wind. Io's volcanic source at Jupiter is a prime example, but now Enceladus at Saturn has joined the fray, while Titan is a surprisingly minor player despite its thick nitrogen atmosphere and its continued bombardment by energetic particles. Mass loading of plasma leads to interchange instability in the inner magnetospheres at both Jupiter and Saturn, while ionospheric slippage, among other processes, seems to contribute to a variable rotation period in the spin-aligned dipole field of Saturn, manifested in auroral kilometric radiation (SKR), components of the magnetic field itself, and the plasma periodicities measured at several energies. Through use of the ENA (energetic neutral atom) technique, it is now possible to observe bulk motions of the plasma and their connection to planetary auroral processes. Such imaging at Saturn by Cassini has revealed the location of a region of post-midnight acceleration events that seem to corotate with the planet and coincide with auroral brightening and SKR. These and other observed dynamic phenomena will be described and discussed in the context of current models.

## Fundamental physics and relativistic astrophysics with super powerful lasers

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The talk is devoted to the prospects of using the laser radiation interaction with plasmas in the laboratory relativistic astrophysics context. The dimensionless parameters characterizing the processes in the laser and astrophysical plasmas are discussed and a similarity between the laser and astrophysical plasmas in the ultrarelativistic energy limit is emphasized. The collisionless shock waves, magnetic reconnection, vortex dynamics in relativistic plasmas relevant to the problem of ultrarelativistic particle acceleration are addressed. A nonlinear interaction of electromagnetic waves mediated by plasma waves resulting in the light intensification towards the Schwinger limit when nonlinear vacuum probing becomes possible is discussed.

## Laser acceleration of monoenergetic protons via a double layer emerging from an ultra-thin foil

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We present theoretical and numerical studies of the acceleration of monoenergetic protons in a double layer formed by the laser irradiation of an ultra-thin film. The ponderomotive force of the laser light pushes the electrons forward, and the induced space charge electric field pulls the ions and makes the thin foil accelerate as a whole. The ions trapped by the combined electric field and inertial force in the accelerated frame, together with the electrons trapped in the well of the ponderomotive and ion electric field, form a stable double layer. The trapped ions are accelerated to monoenergetic energies up to 100 MeV and beyond, making them suitable for cancer treatment. We present an analytic theory for the laser-accelerated ion energy as a function of the laser intensity, foil thickness and the plasma number density. We also discuss the underlying physics of the trapped and untrapped ions in a double layer. The analytical results are compared with those obtained from direct Vlasov simulations of the fully nonlinear electron and ion dynamics that is controlled by the laser light.

# Second Harmonic and Off-Axis Electron Generation in a High Intensity Laser Produced Plasma Cavitation

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In the blowout (cavitation) regime of a Laser Wakefield Accelerator, the intense laser field expels the plasma electrons through its intense ponderomotive force and creates a “bubble” inside the laser pulse. Very high energy electrons (>1 GeV) have been reported experimentally and their origin has been attributed to the dynamics of the background electrons in this bubble. There has yet to be a verification of the existence of such a bubble since its dimension is too small to be observed. However, the interaction of this highly nonlinear plasma structure with the intense laser field can lead to novel radiation and particle acceleration phenomena that can reveal the presence of such bubbles. In our experimental and numerical studies of the Laser Wakefield Acceleration, novel harmonic generation was indeed observed. It is interpreted as the nonlinear interaction of the intense laser field with the high density shell of electrons surrounding the plasma bubble. The nonlinear density perturbation in this density shell can have dimensions less than the wavelength of the harmonic being generated, leading to an electro-optic shock effect where the radiation is emitted in a cone diverging at the Cherenkov angle [1]. The equivalent particle speed for this Cherenkov angle is the phase velocity of the nonlinear density perturbation in the shell. It is also observed that the interaction of the laser field and the plasma creates high energy electrons emitting at large off-axis angles [2] for a set of appropriate laser and plasma parameters. These electrons are of particular interest since they are well suited for external injection into a laser wakefield acceleration structure. Recent experimental results at the U.S. Naval Research Laboratory, using a 10 TW, 50 fs, Ti-Sapphire laser, have shown the existence of such second harmonic ring and off-axis high energy electrons. Characterization of this optical radiation and the off-axis electrons will be presented.

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1. D. Gordon, B. Hafizi, D. Kaganovic, A. Ting, Phys. Rev. Lett. 101, 45004, 2008.

2. D. Kaganovich, A. Ting, D. Gordon, Phys. Rev. Lett. 100, 215002, 2008.

# Session 15: Dynamics and interactions of lab plasmas

## Validity of plasma resonance and pulse-particle interaction

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Particle accelerations by an electrostatic as well as electromagnetic pulse with various amplitude and length (width) are investigated analytically and numerically. For example, power of particles interacting with a square-pulse is evaluated. Consequently, it is found that as a function of pulse length, there may exist two types of distinct phases in the interaction. When an electrostatic pulse is sufficiently long compared with the wavelength of the wave the properties of interaction such as particle's velocity shift and power may be consistent with Landau's theory. However, when not, the value of particle velocity shifts differ considerably from Landau's theory. Particles may be accelerated by as much as tens of times as predicted by Landau damping, while at times they may be even decelerated on average, depending upon the pulse length. It turns out these transient effects correspond to transit-time acceleration of charged particles due to a relatively short pulse. Therefore, the transit-time acceleration may be regarded as the elementary process of the Landau damping. Meanwhile, for relatively short electromagnetic pulses, transit-time cyclotron acceleration becomes dominant. This process is, thus, the elementary process for cyclotron resonance that becomes dominant for long enough pulses. Moreover, as the amplitude of a sufficiently long pulse increases, a weakly nonlinear regime characterized by multiple resonances emerges. This is caused by trapping of particles penetrating the pulse. Above this regime, the interaction transforms into a strongly nonlinear one, which is characterized by unique velocity-dependent regions, i.e., multiple resonances at relatively small velocities, chaotic interactions with fractal structures of numerous peaks, and reflections at larger velocities. This study systematically reveals also that particle reflections are a sign of largest-amplitude pulses, and essential to their dissipation. Applications of this study include plasma turbulence and/or heating/acceleration by electromagnetic solitons that are generated by intense laser-plasma interactions.

## Beyond kappa distributions: exploiting Tsallis statistical mechanics in space plasmas

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Tsallis Statistical Mechanics offers a solid background for describing stationary states out of equilibrium. Based on a generalization of Boltzmannian entropy and a consistent adaptation of expectation values, the Tsallis-like Maxwellian distribution of velocities is deduced by extremizing the entropy under the constraints of the Canonical Ensemble. Most importantly, the Tsallis formalism leads naturally to the definition of temperature for stationary states out of equilibrium. This is the "physical temperature", being consistent with the zero-th law of thermodynamics and the kinetic definition of temperature - that is the second statistical moment of the distribution of velocities. Having interpreted the identity of each stationary state by its specific value of the entropic index $q$, a novel isothermal procedure is introduced. This is the system's transition into different stationary states by varying the $q$-index. Now the variation of temperature is realized under a procedure, in which the system is relaxing into a fixed stationary state, namely, a state of fixed $q$-index. Finally, the zero-th law can be postulated in terms of any stationary state out of equilibrium: "Two bodies that are in the same stationary state with a third are identically in the same stationary state with each other."

## Self-organisation of magnetoacoustic waves in a thermal unstable environment

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The properties of nonlinear magnetoacoustic waves in thermally active plasmas, which includes linear and nonlinear profiles of optically thin radiation, are studied. A nonlinear evolutionary wave equation is derived and its properties investigated through linear stability analysis around stationary states. Analytical results are verified by solving the full evolutionary equation numerically. We demonstrate the presence of autowave dynamics in the linear thermally active regime, i.e. an initially sinusoidal wave steepens to form a sawtooth like profile of constant amplitude that is independent from the initial amplitude. In the nonlinear thermally active regime, we show that limit cycle and auto-solitary solutions exist. For both these wave solutions, a novel perturbation method is developed that matches closely the full numerical results. The application of the developed theory to the dynamics in solar prominences and tokamak plasma edges will be discussed.

## On the scaling of kurtosis with squared skewness in plasma turbulence

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A useful approach to describe turbulent fluctuations is the determination of high order statistical moments. The non-Gaussianity is usually quantified in terms of the skewness S (the third order moment) and the kurtosis K (the forth order moment) of the probability density function (PDF).

A striking similarity in the scaling relation between the square of the skewness, $S^2$ and the kurtosis K of density fluctuations has been observed in several plasma devices (e.g. TORPEX, TCV tokamak). Remarkably, a similar scaling has been also shown to hold in a global database of sea-surface temperature fluctuations. There are several PDF distributions that can support, in principle, the observed scaling in various limits (e.g. gamma, beta distributions). However, the key question is: which is the physical mechanism responsible for the observed scaling?

In this presentation, it is shown that the observed "universal" K-S scaling can be attributed to the quadratic non-linearities involving perturbed Gaussian distributions. The K-S scaling relation is explicitly derived, and the results are compared with experimental and numerical data of plasma turbulence. As a paradigm, we use numerical simulations of the Hasegawa-Wakatani drift wave turbulence in order to gain deeper understanding on the properties of high-order moments in plasma turbulence.

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## A self-organized criticality model for the magnetic field in toroidal confinement devices

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We present a Self-Organized Criticality (SOC) model for the magnetic field in the reversed field pinch, which is a particular toroidal confinement device. The model is in the form of a Cellular Automaton (CA), where the temporal evolution is determined by local rules. A main aim in the construction of the model is that the usual physical variables are used, and that they are physically interpretable in a consistent way. The core of the model is formed by a two-dimensional cellular automaton (CA) for the evolution of the magnetic vector-potential in the poloidal plane, with a driving mechanism and an instability criterion that allow the CA to reach the SOC state. The CA is embedded in a set-up that allows to have access to the magnetic field and the current in a way fully compatible with MHD and Maxwell's equations, e.g. the divergence-freeness of the magnetic field is guaranteed. This is achieved by interpolating the vector-potential in 2-dimensional space, which makes it possible to calculate its derivatives at any point inside the simulation box of the else discrete CA model. The magnetic field and the current are thus continuously defined spatial vector-fields and are calculated in the usual MHD way. In the application to toroidally confined plasma, we first implement an analytical equilibrium magnetic topology as initial condition (a relaxed Taylor state). The system is driven by the toroidal and the poloidal currents, which occasionally trigger local resistive instabilities that are relaxed in local diffusion events. The system self-organizes and reaches the SOC state, with a characteristic magnetic SOC topology, around which the magnetic field fluctuates, staying though very close to it and exhibiting thus a high degree of stiffness. The magnetic SOC topology is qualitatively in agreement with the topologies realized in the reversed field pinch.

# Poster Session A

# 1. On the correlation of fractal structures in the photospheric and the coronal magnetic field

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The context of this work is to examine the relation between the fractal properties of the photospheric magnetic patterns and those of the coronal magnetic fields in solar active regions. This work aims to investigate whether there is any correlation between the fractal dimensions of the photospheric structures and the magnetic discontinuities formed in the corona. In order to investigate the connection between the photospheric and coronal complexity, we use a non-linear force free extrapolation method that reconstructs the three-dimensional magnetic fields using two-dimensional observed vector magnetograms as boundary conditions. We then locate the magnetic discontinuities, which are considered as spatial proxies of reconnection-related instabilities. These discontinuities form well defined volumes, called here Unstable Volumes. We calculate the fractal dimensions of these Unstable Volumes and compare them to the fractal dimensions of the boundary vector magnetograms. Results: Our results show no correlation between the fractal dimensions of the observed two-dimensional photospheric structures and the extrapolated Unstable Volumes in the corona. This result is independent of efforts to (1) bring the photospheric magnetic fields closer to a non-linear force-free equilibrium and (2) omit the lower part of the modeled magnetic field volume that is almost completely filled by Unstable Volumes. We conclude that the complicated transition between photospheric non-force-free fields and coronal force-free ones hampers any direct correlation between the fractal dimensions of the two-dimensional photospheric patterns and their three-dimensional counterparts in the corona.

## 2. Vlasov simulations of electrostatic decay and consequences for solar wind observations

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The electrostatic decay enables energy transfer from a finite amplitude Langmuir pump-wave (L) to a backscattered Langmuir wave (L') and ion acoustic density fluctuations (S): L→L'+S. This mechanism is frequently observed in laser plasma experiments. It is also thought to be a step for the generation of type-III solar radio emissions at twice the plasma frequency. We recently reported [1] observations of electrostatic decay of beam-driven Langmuir waves during a type-III solar event. The electrostatic decay dynamics is here investigated through Vlasov-Poisson simulations for both a monochromatic pump-wave and a pump-wave packet. Instability thresholds, growth rates and saturation are studied in both cases. Particular attention is given to the dynamics and the saturation level of ion acoustic-like density fluctuations generated by the electrostatic decay when electron and proton temperatures are identical, as it is the case in the solar wind plasma. The results are discussed in the context of solar wind observations from the STEREO mission.

1. Henri, P., C. Briand, A. Mangeney, S. D. Bale, F. Califano, K. Goetz, and M. Kaiser, Evidence for wave coupling in type III emissions, J. Geophys. Res., 114, A03103, doi:10.1029/2008JA013738, 2009.

## 3. Electromagnetic envelope pulses in relativistic magnetized plasma

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The system of fluid plasma-Maxwell equations describing a weakly nonlinear circularly polarized electromagnetic pulse in magnetized plasma is solved via a multiple scales technique. A-one dimensional geometry is adopted. A nonlinear Schrodinger-type equation is shown to govern the amplitude of the vector potential. The conditions for modulational instability occurrence, on one hand, and for the existence of localized envelope modes (bright-type and dark-type envelope solitons), on the other, are investigated in terms of relevant parameters, and in particular of the magnetic field strength. Right-hand circularly polarized (RCP) waves are shown to be modulationally unstable regardless of the value of the ambient magnetic field and propagate as bright-type solitons (electric field envelope pulses). The same is true for left-hand circularly polarized (LCP) waves in a weakly to moderately magnetized plasma. In other parameter regions, LCP waves are stable in strongly magnetized plasmas and may propagate as

dark-type solitons (electric field holes). The evolution of envelope solitons is analyzed numerically, and it is shown that solitons propagate in magnetized plasma without any essential change in amplitude and shape. A Gaussian pulse, not corresponding to a soliton solution of NLS equation, can propagate without changes in the anomalous dispersion region of plasma, though it undergoes broadening in the normal region, while it preserves its symmetry.

Work carried out in collaboration with: J. Borhanian and S. Sobhanian (Tabriz, Iran).

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## 4. On the theoretical basis of kappa distributions and their application in the solar wind

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Empirically derived kappa distributions are becoming increasingly widespread in Space Physics as the power law nature of various suprathermal tails is melded with more classical quasi-Maxwellian cores. Two different mathematical definitions of kappa distributions are commonly used and various authors characterize the power law nature of suprathermal tails in different ways. In this study we examine how kappa distributions arise naturally from Tsallis Statistical Mechanics, which provides a solid theoretical basis for describing and analyzing complex systems out of equilibrium. This analysis exposes the possible values of kappa, which are strictly limited to certain ranges. We also develop the concept of temperature out of equilibrium, which differs significantly from the classical, equilibrium temperature. This analysis clarifies which of the kappa distributions has primacy and, using this distribution, the kinetic and physical temperatures become one, both in and out of equilibrium. Finally, we extract the general relation between both types of kappa distributions and the spectral indices commonly used to parameterize space plasmas. With this relation, it is straightforward to compare both spectral indices from various space physics observations, and models and theoretical studies that use kappa distributions on a consistent footing that minimizes the chances for misinterpretation and error. Now that the connection is complete between empirically derived kappa distributions and Tsallis Statistical Mechanics, the full strength and capability of Tsallis Statistical tools are available to the Space Physics community for analyzing and understanding the kappa-like properties of the various particle and energy distributions observed in space.

## 5. A self-organized criticality model for ion temperature gradient (ITG) mode driven turbulence

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We present a Self-Organized Criticality (SOC) model for Ion Temperature Gradient (ITG) mode driven turbulence. The model is in the form of a Cellular Automaton (CA), with the temporal evolution determined by local rules. Our purpose is to model the evolution of the ion temperature on global spatial scales, i.e. the evolution of the temperature profile along the entire minor radius, with the ion temperature itself as the physical variable, and where the local (micro-)physical processes are consistent with the physics of ITG mode driven turbulence. We use a one-dimensional grid along the minor radius, with grid variable the ion temperature. The system is heated by systematically increasing the temperature locally, following a specified spatial heating pattern (e.g., central heating, off-axis heating, etc.). Instabilities are defined to occur if the inverse ion-temperature gradient-length locally exceeds a threshold, exactly as in ITG driven turbulence, whereby the temperature profile is interpolated in order to calculate its gradient. Local instabilities are relaxed in local diffusion events, which basically cause a local smoothing of the temperature profile. The system reaches the SOC state, with ion temperature profiles that are qualitatively in agreement with those seen in tokamaks, e.g. in JET (in the L-mode). The temperature profiles exhibit very high stiffness, their shape is largely independent of the applied loading pattern. Thus, despite the normal character of the diffusive processes that act at local scales, the model exhibits anomalous diffusive behaviour on global scales, in particular we find that heat is systematically transported “up-hill” (against the driving gradient).

## 6. Solar particle event analysis using the standard radiation environment monitor of ESA

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The ESA Standard Radiation Environment Monitor (SREM) is the second generation of instruments in a program established by ESA's European Research and Technology Centre (ESTEC) to provide minimum intrusive particle radiation detectors for space science and applications. SREM is a solid state particle detector consisting of three silicon diode detectors in a two-detectors-head configuration. All the pre-amplified detector pulses are scrutinized by a set of fifteen fast comparators. Using a regularization method based on the Singular Value Decomposition of the response matrix of SREM we have derived the flux spectra of various Solar Particle Events of the 23rd Solar Cycle. Furthermore, correlations of these SREM detected events have been established with their generating sources by using solar observations from several space- and ground-based instruments.

## 7. Quasilinear vs. Nonlinear modeling of EC wave scattering by edge turbulence in ITER-relevant plasma

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The localized deposition of EC current drive is very crucial for the control of the NTM instability in fusion devices, and therefore is of great importance for ITER. In ITER experiments, the EC wave will propagate over a large distance before it reaches its resonance layer. However, during the propagation, the wave will cross the edge of the plasma where turbulence can be rather strong, such that the associated density gradient may scatter the wave leading to diffractive beam broadening. One could expect this scattering to be inconsiderable, however, since the wave has to propagate for several meters until the resonance position, even a small scattering angle may lead to a deviation of the current deposition by several centimeters. Hence, this effect can be important and might straiten the usage of EC waves for the stabilization of NTMs in ITER. Here we present a quasilinear model for the wave scattering process in terms of the Fokker-Planck equation, where the diffusion coefficient is computed using a ray-tracing code, in contrast with nonlinear calculations based on the statistics of ensembles of wave trajectories in an edge-turbulent ITER plasma environment.

## 8. Relativistic electron acceleration by compressional-mode Ultra-Low Frequency waves

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There have been increasing evidence for magnetospheric Ultra-Low Frequency (ULF) waves in the Pc-5 frequency range in enhancing the magnetospheric relativistic electron (MRE) flux in the outer radiation belt region. Past theories and simulations suggest that compressional mode ULF wave can be more effectively in accelerating relativistic electron than shear Alfven waves. However, the observational evidence of drift-resonant interaction of magnetospheric electrons with compressional mode ULF waves is limited due to lack of multi-spacecraft observations covering a large L range in the outer belt. This paper presents evidence of relativistic electron acceleration by the compressional mode ULF waves during a sudden storm commencement (SSC) event on 2001 September 25. Analyses of Cluster and LANL satellite data during this event show the presence of global, compressional mode ULF waves and modulation of low-energy electrons and acceleration of high-energy electrons. Further, LANL observations show an energy threshold that discriminates between modulation and acceleration of electrons, which can be explained by the drift-resonance interaction. Our test particle simulations further shows that broadband (2-8 mHz) compressional mode ULF waves with a strong day-night asymmetry of wave distributions can be responsible for the observed relativistic electron acceleration.

## 9. A machine-learning approach to space weather modelling: initial results from SCIANNS

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State of the art databases containing measurements and indices of the near-Earth space environment currently involve a plethora of some 47 variables relating to space weather events, and in many cases having 1 minute resolution over a time span of many years. Armed with this staggering array of data, modelers are turning to systems theory and various statistical approaches to understand how subsets of these parameters may regulate geospace plasma dynamics. While the systems approach has been capable of loosely identifying macroscopic

relationships, an outstanding problem is how exactly we can identify the minimal sets of parameters that are necessary to accurately describe and ultimately forecast individual processes and events.

We present a machine learning methodology based primarily on neural networks and nonlinear time series analysis tools to help address this issue and introduce SCIANNS, a Matlab GUI that we have created to generate univariate and multivariate prediction models and to perform nonlinear dimensionality reduction, and time-domain, frequency-domain and time-frequency domain analysis of space weather time series.

Using a dataset involving 11 daily-averaged parameter time series measured between 1993 and 2001, we have investigated the finite impulse-response (FIR) between pairs of parameters and also the autoregressive-moving average (ARMA) lag times needed for accurate forecasts of solar energetic particle (SEP) events. We also combined a nonlinear principal components analysis (NLPCA) network with a multivariate matrix input network to perform dimensionality reduction and to test the forecast ability of the Lund space weather model Dst = f(Bz,N,Vsw), finding that it should be augmented by additional parameters. Finally, we are developing suites of nonlinear time series analysis tools in the time, frequency and time-frequency domains. Initial results in the time domain using detrended fluctuation analysis (DFA), multifractal wavelet analysis (MWA) in conjunction with phase space and recurrence plots suggest that it is possible to pin down the correlation properties of the time series as well as to begin to understand their nonlinear dynamics.

## 10. Energetic electron transport due to Ultra-Low-Frequency waves in the radiation belts

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We model radiation-belt electron acceleration and transport due to wave-particle interactions with toroidal ultra-low-frequency (ULF) waves in the Pc3-Pc5 range on the equatorial plane. The specific waves of interest here are those generated by the Kelvin-Helmholtz instability at the dawn and dusk regions. A relativistic guiding-center code uses realistic magnetic field (T-96) and convection electric field models which can be driven with time-dependent interplanetary inputs. We measure the location and extent of the separatrix region between stable and unstable electron orbit. We also measure the energization in the separatrix region as a function of the wave spectrum and the ambient fields. We will report on the observed radial and energy diffusion coefficients and compare with observational values.

## 11. Solar origin of solar particle events detected by the Standard Radiation Environment Monitor of ESA

K. Tziotziou[1], I. Sandberg[1], A. Anastasiadis[1], I.A. Daglis[1], I. Panagopoulos[1], H. Mavromichalaki[2], A. Papaioannou[2], M. Gerontidou[2], P. Nieminen[3], and A. Glover[3]

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Solar Particle Events (SPEs) of the 23rd Solar Cycle detected by the ESA Standard Radiation Environment Monitor (SREM) onboard the INTEGRAL satellite have been studied in order to find their connection to solar sources. X-ray, optical and radio data of solar flares that occurred during the aforementioned solar cycle and were observed by several space- and ground-based instruments have been selected, reduced and analyzed in order to establish the corresponding solar origin of the selected SPEs. The extensive scientific analysis has produced clear correlations with X class solar flares for the events of the October-November 2003, January 2005 and December 2006 periods while for the events that occurred during September 2005, correlations with X class flares are possible but not straightforward due to the complexity of the registered solar particle fluxes.

## 12. Self-organization and the storage-release of energy in a simple plasma model

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The study of self-organization (SO) and its relation with turbulence is a subject at the forefront of astrophysics and space research, and in particular, it may have relevance in the behavior of the magnetospheric environment. In the case of the magnetotail, this self-organized state [Chang 1998] is necessary to bridge the two seemingly contradicting observations. While the magnetotail plasma sheet appears to be a dynamic and turbulent region [Borovsky et al., 1997], the magnetotail activity seems to be predictable [Vassiliadis et al., 1995], repeatable and globally coherent [Baker et al., 1998] as characterized by its different phases. We will study some issues related to the complex behavior of the magnetosphere, that are consistent with the multifractal intermittent energy dissipation in simple plasma models of a current sheet. Particular attention will be given to the intermittent loading and unloading of the energy, with the hysteresis in the model as the storage-release mechanism for energy dissipation and self0organization under different driving conditions. The multi-scale behavior present in this model seems to occur naturally in complex systems, and is of particular relevance for the existence of an out-of-equilibrium globally stable state with underlying turbulent behavior. The complex behavior of this system will also be studied using the techniques that are being developed for spatio-temporal chaotic dynamics.

## 13. Cluster observations of energetic particle acceleration up to supra-thermal energies in the cusp region related to the presence of low-frequency waves.

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We have investigated the way particles are accelerated up to supra-thermal energies in the cusp diamagnetic cavities. To carry out such a study we have examined several Cluster cusp crossings for the years 2001 and 2002 using data from various experiments. In the present work we show two representative cusp crossings, which demonstrate in a clear way, the general characteristics of the events in our survey. Both events exhibit very sharp spatial boundaries seen both in CNO (primarily single-charged oxygen of ionospheric origin based on CIS observations) and $H^+$ flux increases. While one of the two events demonstrates a moderate electron flux increase the other does not show any energetic electron activity at all. The fact that the duskward electric field $E_y$ has relatively low values <5mV/m while the local wave activity is very intense provides a strong indication that particle energization is caused primarily by wave-particle interactions. The wave power spectra and propagation parameters during these cusp events are examined in detail. It is concluded that the high ion fluxes and at the same time the presence or absence of any sign of activity in the energetic electrons clearly shows that the particle acceleration depends on the wave power density near the local particle gyrofrequency. Furthermore, the continuous existence of energetic $O^+$ every time Cluster passes through the cusp suggests that energetic $O^+$ ions is a permanent feature of the polar cusp region indicating the spatial nature of the energetic $O^+$ population.

## 14. Cross-scale nonlinear coupling between MHD Alfven waves and small-scale dissipative waves and resulting plasma energization

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High-amplitude large-scale MHD Alfven waves (MHD AWs), observed in active regions of solar-terrestrial connection, are nearly always accompanied by a strong anisotropic plasma heating and particle acceleration,. Also, an enhanced level of electric and magnetic fluctuations at small kinetic length scales is noticed there. Usually MHD AWs carry most of the energy but cannot produce observed particle energization directly, which implies a preliminary spectral redistribution of their energy towards small dissipative length scales. A popular approach assumes local nonlinear interactions and turbulent cascades towards small perpendicular wavelengths, where the dissipation range is formed. We consider alternative

processes of a cross-scale (nonlocal) coupling and direct energy deposition in the dissipation range by large-scale MHD AWs via nonlinear excitation of small-scale waves. One possibility, the nonlinear excitation of kinetic AWs (KAWs) by MHD AWs has been studied [1]. However this process can only occur in the regions where the plasma beta drops below the electron/ion mass ratio, whereas in most solar-terrestrial plasmas (solar corona, solar wind, terrestrial magnetosphere) this condition does not hold. Here we study new feasible mechanisms for the cross-scale coupling due to nonlinear interaction between MHD AWs and highly oblique (kinetic) sound waves (KSWs) and KAWs. This interaction is not restricted to low-beta plasmas and is faster than the well-known interactions involving MHD Alfven and sound waves. The nonlinearly driven KSWs and KAWs are very efficient in wave-particle interactions and can produce anisotropic plasma heating and particle acceleration observed in the acceleration region of the solar wind and in the auroral zones. We will formulate observational constraints that could help discriminating these processes by in-situ observations (in the near-Earth plasmas) and remote sensing (in the solar corona).

1. Voitenko and Goossens [Phys. Rev. Lett., 94, id 135003 (2005)]

## 15. More Evidence of the Critical Nature of the Magnetosphere during Space Storms

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We provide new evidence that the terrestrial magnetosphere exhibits statistical signatures of complex scaling behavior involving scale-independent burst of activity predicted by the contemporary theory of nonequilibrium phase transitions. We examine statistical properties of bursty multiscale energy dissipation in the inner magnetosphere of Earth based on the dynamics of the SYM-H index, a global marker of low-latitude geomagnetic fluctuations. We show that on average, and for time scales shorter than 2 hours, temporal development of SYM-H bursts follows an algebraic form which is consistent with the predictions from the theory of nonequilibrium phase transitions in disordered media. Probability distributions of sizes and lifetimes of the activity bursts reveal no characteristic scales other than the scales imposed by technical limitations of the analysis. This behavior is observed for the a wide range of SYM-H burst durations starting from about 5 minutes up to 10-15 days. The power-law exponents describing the probability distributions suggest that the main energy dissipation in the inner magnetosphere takes place due to large activity bursts such as major space storms as opposed to smaller activations whose contribution is less significant despite their much higher relative occurrence. The results obtained provide statistical new evidence for dynamical and statistical self-similarity in the inner magnetosphere.

## 16. Equal energy phase space trajectories of coupled waves governed by a time dependent Hamiltonian

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Adiabatic evolution of a nonlinear resonantly driven wave system and two/three coupled waves system generic to a variety of plasma physics problems is studied. The corresponding Hamiltonian, depending on the coupling, detuning and nonlinear frequency shift parameters has a variable number of fixed points. The system can be bistable due to repeated separatrix crossing in the phase space. It is analytically shown that the oscillation periods along trajectories corresponding to the same value of the Hamiltonian are equal, and the difference of the corresponding areas under them is obtained as a function of the system parameters. A scheme of simultaneous adiabatic change of system parameters is constructed, in such a way that any pair of trajectories that have equal energy at some time will continue to have the same energy anytime.

# Poster Session B

## 1. Particle-in-cell simulations of the emission mechanism for fusion product-driven ion cyclotron emission from tokamak plasmas

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Suprathermal ion cyclotron emission (ICE) was the first collective radiative instability, driven by fusion products observed on JET and TFTR [Dendy et al., Nucl. Fusion 35, 1733, 1995]. Strong emission is found at sequential cyclotron harmonic peaks of the energetic ion population, as evaluated at the outer mid-plane edge. The measured intensity of ICE spectral peaks scales linearly with measured fusion reactivity, including its time evolution in the course of a discharge. It appears that the underlying emission mechanism is the magnetoacoustic cyclotron instability (MCI), identified theoretically by Belikov and Kolesnichenko [Sov. Phys. Tech. Phys. 20, 1146, 1976] and subsequently extended to JET and TFTR regimes [Dendy et al., Phys. Plasmas 1, 1918, 1994; Cauffman et al., Nucl. Fusion 35, 1597, 1995]. The MCI involves resonance between: the fast Alfvén wave; cyclotron harmonic waves supported by the energetic particle population and by the background thermal plasma; and a subset of the centrally born fusion products, lying just inside the trapped-passing boundary in velocity space. The properties of the linear growth rate of the MCI have been intensively studied analytically, and yield good agreement with the key observational features of ICE. This agreement extends into areas where a nonlinear treatment might be thought necessary, notably the scaling of intensity with fusion reactivity and the structure of spectral peaks. To explain this and observed emission at background cyclotron harmonics that are not degenerate with energetic particle harmonics, we have developed a fully nonlinear first principles treatment of the MCI scenario for ICE. This is based on a particle-in-cell (PIC) code. The growth rate of the MCI, as it evolves from the linear into the nonlinear regime for JET-relevant parameter sets, has been studied, and these results form the focus of this paper.

## 2. Study of storm-time ring current buildup through ion acceleration simulations

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We address the acceleration and transport of ions to the inner magnetosphere during geospace magnetic storms through a test particle simulation approach. Protons and oxygen ions with energies of the order of few keV, as typically observed in the plasma sheet, are launched from the near-Earth magnetotail under the influence of the large-scale convection electric field. The resulting ring current build-up is compared to the case of additional acceleration through impulsive induced electric fields, which are typically observed at substorm expansion onset. Ion trajectories are nonlinear with strong dependences on initial and boundary conditions, such that they become stochastic and irreversible in the presence of the slightest field fluctuations. The results of our simulations partially confirm observational features of magnetic storms. The energization of oxygen ions is more pronounced than the energization of protons, as observed by many spacecraft. However, the dominance of oxygen ions is very limited in time, while spacecraft observations suggest that oxygen dominance is pronounced throughout storm maximum. The observed fast loss of energetic oxygen ions after storm maximum is reproduced by the simulations, but appears quicker than expected. We discuss the benefits and the shortcomings of our approach and suggest improvements to be implemented in the future.

## 3. Energetic neutral atom (ENA) production from ions trapped in Saturn's magnetosphere

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Energetic Neutral Atoms (ENAs) result from charge exchange collisions between fast ions trapped in planetary magnetic fields and residual neutral gases resident in the magnetosphere. ENAs thus escape and can be detected and imaged by the INCA (Ion and Neutral CAmera) camera on board Cassini to produce a picture of the population in the entire magnetosphere. Using all available INCA images in the time period 183/2004 to 200/2008 and selecting those times during which the INCA imager was looking at Saturn's magnetosphere from

approximately the same vantage position, we were able to produce average images of the neutral gas cloud that correspond to 4.6 Saturn rotations. In the present study, we demonstrate a technique to retrieve the global neutral gas distribution in Saturn's magnetosphere using these average ENA images. The neutral gas distribution at Saturn is retrieved by simulating INCA images using ion distributions of combined CHEMS, LEMMS and INCA in-situ ion measurements that cover several passes from SOI (183/2004) to day 100/2007, at various local times over the dipole L range 5<L.

## 4. Characteristics of ULF waves observed at low latitudes and their influence on storm-time radiation belt electron enhancements

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The magnetospheric environment supports a variety of waves induced by plasma instabilities, which are in turn the ultimate result of the outer and inner magnetosphere's interaction with the solar wind. By using ground measurements from the 210MM and SAMBA magnetometer arrays, along with measurements from the magnetometers on-board GOES satellites, we have studied the development of ultra-low frequency (ULF) waves that have been associated with changes in the flux level of radiation belt electrons. The amplitude of Pc5 waves with frequencies in the range of a few mHz, which are controlled by varying solar wind conditions, decays rapidly with decreasing L shell. During intense geomagnetic storms, however, there is evidence for enhanced geomagnetic field fluctuations in the Pc 5 frequency band at even lower L shells. We discuss the results in the framework of the influence of magnetospheric configuration changes on radiation belt enhancements through ULF wave growth.

## 5. Nonlinear analysis of in situ data obtained by the GEOTAIL satellite concerning the magnetospheric plasma sheet

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During the last two decades the concept of low dimensional chaos was supported by theoretical and experimental studies as explicative paradigm of the magnetospheric dynamics including substorm processes, (Pavlos et al., 1988; Baker et al., 1990; Klimas et al., 1991, 1996; Pavlos et al., 1994; Horton, 1999). However, the concept of magnetospheric chaos was criticized by other scientists such as Price and Richard (1993), Price et al. (1994), Prichard (1995). In a new series of papers the group of Thrace reestablished the concept of magnetospheric chaos (Pavlos et al., 1994, 1999, 2001, 2003). Parallel, the concept of self organized criticality and space-time intermittency were introduced as new and opposite to low dimensional chaos concepts (Consolini et al., 1996; Angelopoulos, 1999; Klimas, 2000). The theoretical compromising between SOC and Chaos was obtained by the application of the renormalization-group theory for the far from equilibrium magnetospheric plasma system (Chang, 1992, 1998, 1999; Chang et al., 2002, 2003). In this study we apply modern nonlinear analysis of time series concerning the Earth's Magnetosphere plasma sheet obtained by the spacecraft GEOTAIL, corresponding to a Superstorm which took place at 27 July of 2004. In particular, we estimate geometrical and dynamical characteristics in the reconstructed state space of the Magnetic field (Bz – component), Electric field (Ex – Component), Ion moments (Velocity – Vy) and Energetic Particles (Electrons) time series.

## 6. Evidence for co-existence SOC and chaos processes in the solar flares dynamics

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In this study the modern algorithm of Nonlinear Analysis in Solar Flares data was applied, in order to test the hypothesis of low dimensional chaotic dynamics. In particular, two time series, the Solar Flares Index and its filtered time series (exclusion of periodicity), were used. We estimated the autocorrelation coefficient, the power spectrum, the correlation dimension, and the maximum Lyapunof exponent.

Finally, we used the method of surrogate data in order to exclude the case of an infinite dimensional stochastic process that can mimic the profile of low dimensional process (null hypothesis).

## 7. Nonlinear effect of relativistic laser power on the second-harmonic generation in plasma

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The effect of relativistic and ponderomotive nonlinearities on the filamentation of high power laser pulse is investigated in three dimensions within the paraxial ray approximations. Generations of second harmonic and electron plasma wave at pump wave frequency in these filamentary structures are reported. The generation of plasma wave is on account of intensity gradient (in the transverse direction of the laser beam in filamentary structure) and density gradient (due to ponderomotive force effect). It is found that the maximum intensity of electron plasma wave (EPW) comes out to be 2.0 $10^{13}$ W/cm$^2$ when both nonlinearities (relativistic and ponderomotive) are operative. Interaction of the plasma wave with the incident laser beam leads to second harmonic generation and the yield comes out to be ~0.26 when both nonlinearities are operative.

## 8. Occurrence of high-beta superthermal plasma conditions in the interplanetary medium as observed by Ulysses during 1990-2008

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The value of the ratio of the thermal pressure of the interplanetary plasma to the magnetic pressure -plasma parameter beta (β)- is critical in determining the dynamics of the interaction of the solar wind with the terrestrial magnetosphere. In the interplanetary space the value of beta is usually in the range of 0.1-1.0 and the contribution of the superthermal particles to the plasma pressure is generally assumed negligible. However the analysis of energetic particles and magnetic field measurements by the Ulysses Spacecraft shows that in a series of events the energy density contained in the superthermal tail of the particle distribution is comparable to or even exceeding that of the magnetic field, creating conditions of high-beta plasma. In this paper, we extensively survey and analyze measurements of the energy density ratio (parameter βep) of the energetic particles (20 keV to ~5 MeV) to the magnetic fields by the Ulysses spacecraft for its entire trajectory (corresponding to the period of years 1990-2008), both in and out of the Ecliptic. As expected, periods of dominant magnetic energy were observed most of the time, for the above particle energy range. Nevertheless a number of 668 distinct periods were identified when the energy density carried by the energetic ions overwhelmingly dominated that of the magnetic field. These interplanetary events with very high parameter βep (up to ~3142) was associated with energetic particle intensity enhancements due to: a) re-acceleration at interplanetary corotating (CIR), solar flare (blast), and/or CME shock waves, b) Jupiters bow shock acceleration, c) Jupiters magnetosphere contribution, d) unusually large magnetic field depressions ("magnetic holes"). The occurrence of high-beta plasma conditions in the interplanetary space has important implications for the propagation of energetic particles, the structure of interplanetary shocks and the interaction of the solar wind with planetary magnetospheres.

## 12. Linear calibration of collision operator coefficients in AstroGK

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The introduction of an improved energy-, momentum-, and number-conserving particle collision operator to a kinetic plasma code has opened the possibility of performing dynamical (vs. statistical) simulations of turbulent plasma interactions. This collision operator is included in the Astrophysical Gyrokinetics code AstroGK, a five-dimensional gyrokinetic code based on the GS2 code. We aim to simulate the non-linear interaction of two colliding Alfvén modes using AstroGK and quantitatively compare our results to experimental data from the Large Aperature Plasma Device (LAPD) at UCLA. It has been found in experiments at LAPD that simple analytical treatment of collisions is insufficient to predict plasma behavior in many regimes. We present results of our efforts to calibrate AstroGKs collision operator parameters against data from linear LAPD experiments.

## 10. State-space geometry of a continuous symmetry reduced Kuramoto-Sivashinsky flow

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A dynamical description of spatially extended systems can be achieved by the study of the geometry of state-space in terms of compact, flow invariant objects. In systems with continuous symmetries such a description is obscured by the traveling nature of the solutions. We propose a scheme to implement symmetry reduction in high-dimensional truncations of partial differential equations and demonstrate its effectiveness in the context of Kuramoto-Sivashinsky equation, one of the simplest spatially extended systems with non-trivial dynamics. The procedure simplifies phase space visualization and provides new insight into the role that the unstable manifolds of equilibria and traveling waves play in organizing the flow. This in turn elucidates the mechanism that creates unstable modulated traveling waves (periodic orbits in reduced space) that provide a skeleton of the dynamics. Finally, the compact description of dynamics thus achieved sets the stage for reduction of the dynamics to mappings between a set of Poincare sections.

## 11. Nonlinear spatiotemporal analysis of a five day ordit of the geotail satellite during the period of 26-30 july 2004 including a superstorm

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The physical systems underlying the solar, or magnetospheric time series belong to the general kind of distributed, dissipative and externally driven dynamical systems which live at far from equilibrium states.

As the magnetospheric- plasma sheet system goes through varius critical points, it may reveals different macroscopic behaviour with different spatiotemporal patterns. Symmetry breaking and emergence of new patterns (spatial or temporal)can be explained or can be predicted in this way, as the relevant eigenvalues or eigenvectors of the linearized renormaliazation group operator applied to the magnetized plasma of the magnetosphere are changed, passing from the original to the final fixed point (Chang 1992, 1999). According to this point of view the high dimensional SOC process and the low dimensional chaos can be manifestations of different kind of fixed points and critical states of the same underlying stochastic plasma system and the same far from equilibrium dynamical process. As the magnetospheric system evolves from one critical state to another it can reveal changes in its observable characteristics, such as correlation dimension and other geometrical and dynamical characteristics.

J.L. Chang (1992), IEEE Transactions on Plasma Science 20, 691-694

J.L. Chang (1999), Physics of Plasmas 6, 4137-4145

## 12. Response of the trapped electron phase space density to wave activity during radiation belt storms

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Recent spacecraft missions have demonstrated the complexity of the dynamics of the inner magnetosphere and its electron radiation belts. The phase-space density (PSD) of the energetic tail of the electron distribution has been locally reconstructed and is the basis of a time-dependent model in invariant-space coordinates ($\mu$,K,L*). We present the statistical response of the electron PSD to interplanetary plasma and field variables and compare with the response of the ultra-low-frequency (ULF) wave power measured at geosynchronous orbit and remotely-sensed from ground magnetometer arrays. At L=4-8, the energetic electron PSD has significant similarity to the ULF wave activity and the electron transport is diffusive with $\tau=3$ days while above the plasmapause, L=3-4, and in the inner belt (L<2.5) it is impulsive with timescales of ~2 hours.

## 13. Mobility-limited distributions for charge transfer collisions

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Mobility-limited velocity distributions of ions are investigated in a weakly ionized plasma in the case where the charge transfer collisions dominate. The distributions are found numerically by solving the kinetic equation with the modified BGK-type collision integral under a realistic assumption of a velocity-independent cross-section. The results are compared with those derived analytically from the widely used BGK collision integral with velocity-independent collision frequency. The comparison of the distributions is made for the same values of the ratio of the flow velocity to the thermal velocity of neutrals and shows certain differences even in the limit of small (subthermal) flow velocities: the two models yield somewhat different shapes of the first- and second-order field-induced corrections to the Maxwellian velocity distribution. This implies that the BGK collision integral with constant collision frequency should be used with caution even in the case of subthermal flow velocities. This has certain implications on the recent theoretical investigations of the role of the ion-neutral collisions in complex (dusty) plasmas.

## 14. Instability of the ionization-absorption balance in a complex plasma at ion time scales

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The stability of ion plasma perturbations is investigated in a homogeneous isotropic complex plasma where a balance between plasma creation due to ionization and plasma loss due to absorption on dust particles has been reached. The analysis is performed on the basis of a self-consistent fluid description including dust charge variations and ion-neutral friction. It is shown that the stability depends primarily on the nature of the ionization source. For an ionization source proportional to the electron density, an instability takes place at wavenumbers below a certain threshold, and the instability mechanism is explained in detail. No instability is found for a constant ionization source.

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# Konstantinos Papadopoulos

Konstantinos (Dennis) Papadopoulos received the B.Sc. in Physics from the University of Athens in 1960, the M.Sc. in Nuclear Engineering from Massachusetts Institute of Technology in 1965 and the Ph.D. in Physics from the University of Maryland in 1968. He held positions in the Naval Research Laboratory and the Department of Energy and since 1979 he has been a professor at the Department of Physics and Astronomy in the University of Maryland. In addition he has held various consulting positions with private, government, and academic organizations.

Professor Papadopoulos has received a number of awards including the Navy Meritorious Civilian Service Award, the E.O. Hulbert award for science, the Washington Academy of Science award for scientific achievement, and the NASA Certificate of Commendation for distinguished service to space sciences. He is a Fellow of the American Physical Society and of the Washington Academy of Sciences, and listed in Who's Who in the US and Greece. He is a member of numerous scientific and professional societies, organizations, and committees including APS, AIP, IAEA, and NASA. He has organized several international meetings and conferences, has more than 200 invited presentations, has authored or co-authored more than 240 publications, and has been the editor of two books and several journals. In his academic capacity Professor Papadopoulos has overseen 17 Ph.D. dissertations.