

Summary Talk

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Of the many important topics that were discussed at the workshop, I summarize and comment on 25 presentations, which I found to be particularly interesting. They fall into all of the areas covered in the conference: basic plasma phenomena, space and astrophysical plasmas, technological applications of plasma, and thermonuclear fusion.

1 Introduction

The Latin American Workshop on Plasma Physics (LAWPP) meets every two years, uniting plasma physicists from all over Latin America. These workshops also include the participation of physicists from all over the world.

There were 40 oral talks and 205 posters presented at the workshop, covering the areas of basic plasma physics phenomena, space and astrophysical plasmas, technological applications of plasma, and thermonuclear fusion.

From among the many excellent presentations, I have chosen to summarize and comment on the following 25, that seem to me to be the most interesting, in the limited time available for this summary talk.

A. Basic Plasma Phenomena

1. Supersonic plumes through magnetized plasmas;
2. Coupled map lattices;
3. The Kelvin-Helmholtz instability dependence on the structure of the transition layer;
4. Stabilization of ion-bead instabilities;
5. The nature of ball lightning: a force-free magnetic field;
6. The nature of ball lightning: coupled vortex-magnetic field;
7. Observing plasma temperatures;
8. Multi-harmonic Langmuir wave generation in beam-plasma interactions.

B. Space and Astrophysical Plasmas

1. The effective charge of a neutrino in a plasma;
2. The influence of solar plasma density perturbations on neutrino propagation;
3. Lightning bead instabilities;
4. Gyrophase electron organization in space plasmas.

C. Technological Applications of Plasma

1. Plasma processing of domestic and industrial waste;
2. Space plasma propulsion using the Hall effect.

D. Thermonuclear Fusion

1. Alfvén wave heating in tokamaks;
2. Instability suppression in a Z-pinch by an axial sheared flow;
3. Spark ignition in an inertially confined plasma;
4. Present status of ITER;
5. Present status of IGNITOR;
6. Reflectometry diagnostics for burning plasmas;
7. Pellet injection in toroidal plasmas;
8. Controlling turbulence;
9. Effects of electric fields on MHD activity;

10. Magnetic islands, radial electric fields, and plasma rotation in tokamaks;
11. Diffusion of heavy charged ions, radial electric fields, and plasma rotation in tokamaks.

This summary is organized around the main ideas in the talks and posters which are reviewed. The original titles of the presentations as well as all of the names of the authors can be found at the end of the summary.

2 Summary and comments

A. Basic Plasma Phenomena

1. Supersonic plumes moving through magnetized plasmas

Morales and Tsung discussed supersonic plumes moving through magnetized plasmas. Supersonic plumes created by laser ablation are generated in the Basic Plasma Facility at UCLA. Investigating the properties of these plumes with an electromagnetic particle-in-cell code, it was found that there is a ballistic expansion of energetic electrons along the field. The return currents excite various electromagnetic waves: shear Alfvén waves along the field and Whistler and compressional modes in the transverse direction.

Comment on the presentation

What is the energy loss rate of the expanding plume as a function of the density and magnetic field of the background plasma?

2. Coupled map lattices

Coupled map lattices (CMLs) are spatially extended systems with discrete time and space intervals and a continuous, connected dynamical variable. Vasconcelos and Viana computed a correlation integral and evaluated a spatial correlation dimension for the lattices.

Comment on the presentation

Is it possible to use CMLs to evaluate the correlation of galaxies in astrophysics?

3. The Kelvin-Helmholtz (KH) instability dependence on the structure of the transition layer

It was shown by Gratton et al. that, whereas a smooth transition between two uniform regions of different densities, velocities, and magnetic fields may be unstable, a discontinuous transition may, in fact, be stable. This is due to the stabilizing effect of magnetic shear. (A discontinuous transition has a very large shear.) A stability diagram of d/λ vs M_A , where d is the gradient length scale, λ is the wavelength of the instability and M_A is the Alfvénic Mach number, was presented. For a given d and M_A as well as a sufficiently large λ (i.e., small d/λ), the region is KH stable.

Comment on the presentation

Could this be relevant to astrophysical jets, which are subject to KH instabilities?

4. Stabilization of ion-beam instabilities

The ion-beam stream instability is well-known in plasma physics. It was shown by Gomberoff, Hoyos and Brinca that right-handed electromagnetic instabilities can be stabilized by nonlinear left-handed polarized waves. Stabilization occurs above a certain threshold, which increases with increasing beam velocity.

Comment on the presentation

Can ion-beam plasma instabilities be stabilized by detecting the instability that is developing and then applying a sufficiently intense electromagnetic wave of the opposite polarization?

5. The nature of ball lightning: a force-free magnetic field

The phenomenon of ball lightning, a bright glowing ball of hot plasma floating around in a room, has been reported by many independent observers. It was frequently observed in the battery area of American submarines during World War II. Afterwards, it was reproduced in the Los Alamos Laboratory. Tsui suggested that the ball is a force-free plasmoid, with the current parallel to the magnetic field in a minimum energy state, under the constraint of magnetic helicity conservation. The magnetic field decays adiabatically in a sequence of force-free configurations with lifetimes of many seconds.

Comment on the presentation

A high magnetic field is required to produce ball lightning. Can this field be detected experimentally?

6. The nature of ball lightning: coupled vortex-magnetic field

Taveira, Sakanaka and Scussiatto studied a coupled vortex-magnetic field solution for ball lightning, investigating the triple Beltrami equation. This equation is the sum of four terms with arbitrary constant coefficients: 1) the magnetic field \mathbf{B} ; 2) the curl of \mathbf{B} ; 3) the curl of the curl of \mathbf{B} ; and 4) the curl of the curl of the curl of \mathbf{B} . Their solutions to the triple Beltrami equation are able to explain ball lightning.

Comment on the presentation

It is assumed that the ball lightning is rotating. Can the rotation be observed experimentally?

7. Observing plasma temperatures

Doppler or Stark broadening of spectral lines are generally used to determine the temperature of plasmas. However, this method is difficult to apply to high temperature plasmas with highly ionized atoms, when the spectral lines are in the ultraviolet. Borges et al. studied the relative intensity of spectral lines as a function of temperature, using a multiple level approach. They calculated the transition probabilities in terms of the oscillator strength parameters.

Comment on the presentation

It is interesting to compare the methods of Borges et al. for determining the temperature of plasmas with the Doppler and Stark line broadening methods. Do both methods give the same temperatures for laboratory plasmas?

8. Multi-harmonic Langmuir wave generation in beam-plasma interactions

Gaelzer et al. discussed the multi-harmonic generation of Langmuir waves from electron beams in plasmas. These waves are observed in solar flares as well as in the earth's foreshock. A power law dependence of the intensity on frequency proportional to $\omega^{-\alpha}$, where α varies from 2 to 5, is observed. Five harmonics which appear early in the linear growth phase have been observed. A theory was presented to explain these observations.

Comment on the presentation

Can the theory be tested in the laboratory?

B. Space and Astrophysical Plasma

1. The effective charge of a neutrino in a plasma

It was argued by Serbeto et al. that collective plasma effects induce an effective charge on neutrinos in dense magnetic plasmas. The effectively charged neutrinos easily couple to plasma oscillations. This effect could reactivate the stalled shock in type II supernovae explosions. It can also generate electric currents and intense magnetic fields in supernovae cores as well as at the surfaces of neutron stars.

Comment on the presentation

Can this effect be observed in the interaction of solar neutrinos emitted from the center of the sun with the turbulent plasma near the sun's surface?

2. The influence of solar plasma density perturbations on neutrino propagation

There exists a resonance between the g-modes and Alfvén waves inside the sun. This resonance can create density fluctuations $\delta\rho/\rho$ on the order of 4-8%. It is known that different types of neutrinos (electron, muon, τ meson) mix with one another. The mixing is characterized by the mass difference and the mixing angle. Larger $\delta\rho/\rho$ indicates a

smaller mixing angle. It was shown by Reggiani, Guzzo, and Holanda that $\delta\rho/\rho \sim 4 - 8\%$ can cause observable changes in the mixing angle.

Comment on the presentation

Can the mixing angle of neutrinos from reactors (i.e., without $\delta\rho/\rho$) be measured sufficiently accurately so that the $\delta\rho/\rho$ in the sun can be determined?

3. Lightning bead instabilities

Ludwig studied the origin of the observed beaded structure of decaying lightning strokes. The self-induced magnetic field is unstable to the kink and sausage MHD instabilities. These instabilities lie in the correct range to explain the spatial structure of the beads.

Comment on the presentation

Can the characteristics of the beaded structure of lightning be reproduced in the laboratory in order to test the theory?

4. Gyrophase electron organization in space plasmas

The velocity distribution of electrons in the plane perpendicular to the ambient magnetic field is not angular independent. This electron nongyrotropy has been suggested as the source of ion acoustic waves in the solar wind. Moraes and Alves presented solutions of the nongyrophase dispersion equations.

Comment on the presentation

In addition to ion acoustic waves in the solar wind, what are the other possible effects of the electron nongyrotropy?

C. Technological Applications of Plasma

1. Plasma processing of domestic and industrial waste

Leal-Quiro discussed plasma torch processing of domestic and industrial solid waste. There exist seven plants in the world, two of which are already in operation, which process waste in this way. The organic waste is converted into Synthesis gas (Syn gas), which is essentially a mixture of H_2 and CO. The inorganic components are converted into construction bricks and architectural tiles. The plasma torch operates at a temperature of $\sim 5000^\circ C - 100,000^\circ C$, whereas the simple burning of garbage occurs at a temperature $\simeq 2000^\circ C$. At the plasma torch temperatures, the garbage is completely transformed into the tiles and Syn gas, while the simple burning of paper, for example, leaves a residue to 50% by weight in ash. It has been shown that the initial investment in the processing plant pays for itself within seven years.

Comment on the presentation

Why isn't this process used throughout the world?

Space plasma propulsion using the Hall effect

Ferreira et al. discussed the Hall Thruster for space propulsion. This propulsion method has the great advantage of low power consumption when using permanent magnets.

Comment on the presentation

Is the Hall Thruster likely to be used for future deep space, long duration satellite missions?

D. Thermonuclear Fusion

1. Alfvén wave heating in tokamaks

Elfimov discussed Alfvén wave heating in tokamaks. This process is based on the mode conversion of compressional waves, created by an external antenna, into shear Alfvén waves which heat the plasma. The conversion takes place at the Alfvén resonance layer, where the local Alfvén velocity matches the phase velocity of the compressional wave. Using an electric cyclotron emission radiometer, local Alfvén heating of the plasma in the Brazilian TCABR tokamak has been observed.

Comment on the presentation

Can Alfvén wave heating decrease instabilities in tokamaks?

2. Instability suppression in a Z-pinch by an axial sheared flow

Herreira and Yopez analyzed the studies made on instability suppression in a Z-pinch by shear flow. The stabilizing effect of shear flow in a Z-pinch has been experimentally observed.

Comment on the presentation

Is shear flow the principal stabilizing mechanism in extremely long collimated astrophysical jets, which have been observed?

3. Spark ignition in an inertially confined plasma

It was argued by Bilboa et al. that spark ignition seems to be more promising than volume ignition, based on their numerical simulations of spark and volume ignition in a D-T plasma, compressed by an imploding liner. The objective of their investigation was to amplify the fusion energy in a small conical channel to a level, at which, detonation can be triggered in a large plasma volume.

Comment on the presentation

This method is essentially the same as that of a hydrogen bomb. Can the energy be confined in the small spark region so that ignition occurs before it leaks into the entire volume?

4. Present status of ITER

Varandas and Novrati discussed the present status of the ITER program. ITER will study $Q \sim 1 - 10$ (JET has a $Q \sim 0.6$), where Q is the ratio of the power produced by fusion to the power needed to heat the plasma. For $Q \sim 10$, ITER will have a particle density $n \sim 2 \times 10^{20} \text{ m}^{-3}$, a temperature $T \sim 10 \text{ keV}$, a magnetic field $B \sim 5 \text{ T}$ and a confinement time $t \sim 1.5 \text{ seconds}$.

Comment on the presentation

Will ITER study all the physics necessary to make a fusion reactor?

5. Present status of IGNITOR

Bombarda discussed IGNITOR, which will be able to ignite a plasma. It will have a toroidal magnetic field of 13 T, a poloidal field of 3.5 T and a confinement time of 0.62 seconds. This is a relatively inexpensive machine, with which to study ignition physics.

Comment on the presentation

Although IGNITOR is relatively inexpensive, compared to ITER, as well as being an interesting experiment, it does not replace ITER. While ITER will be used to study fusion reactor physics, the purpose of IGNITOR is primarily to achieve ignition. Will it be possible to study the details of the ignition process with IGNITOR?

6. Reflectometry diagnostics for burning plasmas

The diagnostic experiments for ITER present a great challenge since the equipment will have to operate in a harsh environment for a long time. Manso reviewed the present status of reflectometry, which is a robust diagnostic, capable of making a wide range of plasma measurements. In particular, it can be used for density distribution studies as well as for the study of edge-localized modes (ELMs).

Comment on the presentation

Can the ELMs detected by reflectometry be controlled by auxiliary heating?

7. Pellet injection in toroidal plasmas

The complete interaction between a pellet and a plasma has not been thoroughly studied until now. Sato discussed our present knowledge about pellet injection. Fast density oscillations have been observed just after pellet injection. A long helical tail, which is independent of the magnetic field, has been observed.

Comment on the presentation

Can pellet injection suppress instabilities and/or create transport barriers?

8. Controlling turbulence

In general, plasma edge turbulence should be avoided since it is responsible for increasing particle transport, driving particles out of the plasma and decreasing confinement. Baptista et al. studied the effect of Alfvén waves on the structures present in the plasma edge turbulence. They showed that the injection of Alfvén waves in the Brazilian tokamak, TCABR, decreases the plasma edge turbulence, though not completely destroying it.

Comment on the presentation

Is it possible to create Alfvén waves that completely destroy the plasma edge turbulence?

9. Effects of electric fields on MHD activity

It is well known that electric fields in a tokamak can create H-modes, which are important in plasma confinement. The effects of electric fields on MHD activity, however, have not been appreciably studied. In the previous Brazilian tokamak, TBR-1, Nascimento et al. found that an applied radial electric field increased the periods of rotation of the $m=1, 2,$ and 3 magnetic islands by a factor of 2.

Comment on the presentation

Can we control the instabilities and transport in tokamaks by applying radial electric fields?

10. Magnetic islands, radial electric fields, and plasma rotation in tokamaks

In the nonlinear stage of the tearing mode instability, magnetic islands are created in toroidally confined plasmas. Magnetic islands in tokamaks are characterized by their width and rotation frequency. Plasma rotation is connected with the radial electric field in the plasma column. Sheared radial electric fields can create transport barriers. Severo et al. studied these effects in the Brazilian tokamak, TCABR. They found that the plasma rotates with the magnetic islands and that the rotation velocity agrees with neoclassical theoretical predictions, within the error limits.

Comment on the presentation

To what accuracy can the neoclassical theory predict the width of the magnetic islands and their rotation velocities?

11. Diffusion of heavy charged ions, radial electric fields, and plasma rotation in tokamaks

Using a Hasekawa-Wakatani (HW) potential for a turbulent plasma, Tendler predicted a strong diffusion of C^+ ions. The charge separation creates a radial electric field on the order of kV/m. Plasma rotation results due to the $E \times B$

drift.

Comment on the presentation

Can this theory be tested quantitatively?

III. AUTHORS AND TITLES OF PRESENTATIONS

M. S. Baptista, I. L. Caldas, M. V. A. P. Heller, and A. A. Ferreira
“Periodic Driving of Plasma Turbulence”.

L. Bilbao, G. Linhart, and L. Bernal
“Ignition in an Inertially Confined Z-Pinch”.

F. Bombarda
“The IGNITOR Project”.

F. O. Borges, G. H. Cavalcanti, N. L. P. Mansur, and A. G. Trigueiros
“Determination of Plasma Temperature by a Semi-Empirical Method”.

A. Elfimov
“Results of Alfvén Wave Heating in TCABR”.

J. L. Ferreira, D. A. Raslan, G. M. de. Carvalho, J. Cezario, M. Junior, R. B. Santiago, I. do Rego, and I. S. Ferreira
“Plasma Diagnostics and Performance of Permanent Magnet Hall Thruster”.

R. Gaelzer, P. H. Yoon, T. Umeda, and Y. Omura
“Harmonic Langmuir Wave Generation in Weak Beam-Plasma Interaction”.

L. Gomberoff, J. Hoyos, and A. Brinca
“The Effect of a Large Amplitude Circularly Polarized Wave on Linear Beam-plasma Electromagnetic Instabilities”.

F. T. Gratton, G. Gnani, L. Bender, and C. Farrugia
“On the MHD Boundary of the Kelvin-Helmholtz Stability Diagram at Large Wavelengths”.

J. J. E. Herrera and M. Y. Yépez
“Instability Suppression by Axial Sheared Flow in Dense Z-Pinch Devices”.

E. Leal-Quiros
“Plasma Processing of Municipal Solid Waste”.

G. O. Ludwig
“Macroscopic Instabilities in Lightning”.

M. E. C. Manso
“Reflectometry Diagnostics for Burning Plasma Experiments”.

G. J. Morales and F. S. Tsung

“Dynamics of Supersonic Plumes Moving Through Magnetized Plasmas”.

I. C. Nascimento, I. E. Chamaa Neto, Y. Kouznetsov, V. S. Tsypin, and J.H.F. Severo

“Influence of Electric Fields on Plasma MHD Activity in a Small Tokamak”.

G. Navrati

“Assessment made of the FiRE, IGNITOR, and ITER projects at the Snowmass Meeting”.

N. Reggiani, M. M. Guzzo, P. C. de Holanda

“Influence of the Solar Density Perturbations on the Neutrino Propagation”.

K. Sato

“Studies on Various Phenomena During the Ice Pellet Injection into Toroidal Plasmas”.

A. de P. B. Serbeto, L. A. Rios, P. K. Shukla, and J. T. Mendonça

“Neutrino Effective Charge in a Magnetized Plasma”.

J. H. F. Severo, J. C. Nascimento, V. S. Tsypin, R. M. O. Galvão, Y. K. Kouznetsov, E. A.

Saettone, A. Vannucci, A. B. Mikhailovskii, and M. Tendler

“Magnetic Islands and Plasma Rotation in TCABR Tokamak”.

A. M. A. Taveira, P. H. Sakanaka, and C. E. Scussiatto
“Coupled Vortex-Magnetic Field Solution for Ball Lightning”.

M. Tendler

“Physics of the Transport Barriers”.

K. H. Tsui

“Ball Lightning as a Magnetostatic Spherical Force-Free Field Plasmoid”.

C. Varandas

“Overview of the European Fusion Program with Emphasis on the ITER Activity, Leading to the Study of Burning Plasmas”.

D. B. Vasconcelos and R. L. Viana

“Recurrence Plots in the Investigation of Spatial Behaviour in Coupled Map Lattices”.

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