para los países de América Latina, a condición que logremos un desarrollo tecnológico acorde a nuestras condiciones económicas y sociales, y se promueva la cooperación entre países latinoamericanos en varios proyectos.

La vocación de América Latina para colaborar en diferentes ramas espaciales en nuestro país, se muestra en la creación de la Sociedad de Expertos Latinoamericanos en Percepción Remota (SELPER), que se reúne cada año en diferentes países de América Latina.

Por otro lado contamos con el "Grupo de Río" (México, Brasil, Argentina, Perú, Venezuela, Colombia, Bolivia y Ecuador) cuyo proyecto principal es la cooperación en varias ramas, entre otros la creación de un mercado latinoamericano. Es interesante señalar que, gracias a los cambios que se están dando hoy en Chile, este país decidió reintegrarse al resto de América Latina. Dada esta situación, conviene realizar diferentes proyectos espaciales en cooperación. De lograrlo podríamos pensar en construir satélites con tecnologías adecuadas a nuestros países.

Por lo pronto, es conveniente colaborar con diferentes países involucrados en proyectos espaciales, como son, por ejemplo, la NASA de los Estados Unidos de América, ISRO de la India, NADSA de Japón, Kosmos de la URSS y la Agencia Espacial Europea, en la que participan todos los países de Europa Occidental. Ciertamente esta agencia sirvió a la regionalización europea.

Me gustaría terminar esta ponencia proponiendo a esta Conferencia, analizar la posibilidad futura de crear una Agencia Latino-americana, que serviría a todos los países de la región. El éxito de esta empresa conjunta dependerá crucialmente no sólo de la disposición de nuestros gobiernos, sino más importante todavía del desarrollo de nuestras infraestructuras y capacidades locales en las ciencias y tecnologías espaciales.

Como un ejemplo de interés académico la Prof. Amanda Gómez del Programa Universitario de Investigación y Desarrollo Espacial dará una breve exposición sobre la red de satélites que la UNAM ha puesto en servicio, apoyándose en los satélites Morelos.

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# SPACE PLASMA PHYSICS

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## INTRODUCTION

Nowadays applications of Space sciences and technologies must be developed within the frame of coordinated-oriented programs. Individual countries, or, regions must base their space activities on programmatic priorities according to their specific needs, rather than be indiscriminately involved in programs from more advanced partners whose priorities may be of a different nature. Also, fundamental research about our space environment should not be seen as the specific activity of highly developed countries in space research, but of general concern. Ultimately the better we understand our space neighborhood, the better the control we will obtain of it for our specific needs. Here we discuss one of the main fields of basic space research, namely Space Plasma Physics (or Solar System Plasma Physics).

The importance of Space Plasma Physics may be understood by the fact that more than 99 % of the matter in the universe is in a highly ionized state, known as plasma. Exceptions to this are the matter of planets and their interfaces. So, human enterprises in space take place in a plasma environment. Solar system plasmas are composed predominantly of protons, electrons, some species of heavy ions, electrostatic and hydromagnetic waves. Most of them are organized and controlled by strong magnetic fields. Space Plasma Physics may be defined as the study of plasma phenomena extending from the Sun interior to the exterior border of the heliosphere.

The heliosphere is the cavity distended within the interstellar medium by the solar wind. The solar wind is the magnetized plasma flux generated in the solar corona. The solar wind flows radially out of the solar system until it is stopped by its interaction with the interstellar medium. The solar wind also interacts with the different objects of the Solar System: planets, comets, asteroids and cosmic rays. When a planet has a strong enough intrinsic magnetic field, this interaction gives rise to a planetary envelope known as magnetosphere. The interaction of the solar wind and magnetospheres is reflected to some extent on the planetary atmospheres modulating certain phenomena therein.

The main goals of Space Plasma Physics are primarily the understanding of the physics of the Sun, the heliosphere, planetary magnetospheres and planetary atmospheres. Secondly, to study the interactive processes of phenomena generated in the Sun, their effects on the solar wind and in turn on the terrestrial environment, since such processes reveal basic physical mechanisms and have important effects on several areas of human activity.

The main reasons that motivate the intensive study of space plasma physics are: 1)Its intrinsic interest and intellectual significance of the deepest and basic human desire to know and understand our natural environment in space; 2)its value for other scientific disciplines, since space plasmas are not only part of the global astrophysical context, they also provide an extension of the available conditions on a laboratory scale, playing an important role in illuminating general plasma physics. Most of present and future world wide activities in space, from the most practical aspects to the most abstract and cosmogonical problems, are influenced at some stage by space plasma research, and 3) its present and future impact on man and its technology, in particular as a source of applications, e.g. the prediction of solar phenomena affecting the earth environment (magnetopheric substorms) and implications on terrestrial communications, metereology, spacecraft systems and even possible climatological variations.

## INTERDEPENDENCE BETWEEN SPACE PLASMA PHYSICS AND OTHER SCIENTIFIC DISCIPLINES

Space plasma physics may in some extent be considered as the interplay that joins the so called Solar System Space Physics with Laboratory plasma physics on the one hand and with Astrophysics on the other hand. In fact, Solar System Space physics is the synergetic fusion of several disciplines: Solar physics, Heliospheric physics, Magnetospheric physics, Aeronomy (Ionospheric, thermospheric and mesospheric physics), and Solar-Terrestrial physics. These disciplines are coupled interactively by several basic processes that characterize magnetized plasmas.

When the Van Allen radiation rings and the solar wind were discovered, in 1958 and 1960 respectively, it became clear that the exploration and future understanding of the solar system phenomena would develop in terms of Plasma Physics. The foundation of the modern plasma physics was built. Thereafter, it would evolve in two separate but parallel directions: Controlled thermonuclear fusion searching for an accessible and clean energy source able to last indefinitely, and the physics of space plasmas looking for the comprehension of the natural processes, on a global scale, in recognition of the deep and sensitive dependence of man on his space environment. Its is now clear that the barriers to achieving controlled thermonuclear fusion, at the beginning of the space age in 1957 as well as now, lie not on our limitations of nuclear physics but on our ignorance of plasma physics. At present, the same discipline, plasma physics, defines a basic language used in space research and thermonuclear fusion.

On the other hand, since the Solar System is presumably a microcosms of the interstellar, galactic and extragalactic spaces, the study of the extraordinarily varied conditions and diverse plasma phenomena, prevailing in the solar system, has become fundamental to deepen our knowledge in Astrophysics. Thirty three years of space plasma research has shown us that many of the physical processes observed in the Sun, the solar wind and planetary magnetospheres are important sources of analogy for astrophysics. For instance, the present conviction that pulsars, radio-galaxies and x-ray stellar sources all have magnetospheres, and that our research on stellar and galactic winds is a direct consequence of the progress achieved in the study of the solar wind.

The detailed analysis of Solar System processes, by means of *in situ* observations and remote sensing, has made it possible to infer information, as well as restrictions, for the study of more distant astrophysical phenomena. Plasmas of the solar wind and planetary magnetospheres have the important characteristic that they can be observed closely and in many cases to be probed locally with *in situ* detectors. In contrast, the information from the rest of the Universe is available to us via electromagnetic or corpuscular radiation. However, plasma processes in the Sun have been studied until now only by remote sensing techniques. This constitutes a transition stage between space plasmas and astrophysical plasmas.

The study of space plasmas affords opportunities to learn about certain plasma range of parameters that are inaccessible to normal laboratory experiments, and to investigate the behavior of plasmas that are unaffected by containment devices. In some areas Solar System plasma research has made the keystone contribution to basic plasma physics. In other processes, the dominant contribution has been made by laboratory plasma research. A mutual interdependence has been established between these two levels enriching the advancement of fundamental plasma science.

This complementarity is due to the fact that both disciplines explore different regions of plasma physical parameters. Plasma configurations in the laboratory are constructed intentionally, while space plasmas assume spontaneous forms. Laboratory plasmas are more dense than space plasmas. The later are free of boundary effects; laboratory plasmas are not, and very often suffer from strong surface contamination. Due to the differences in scale, sounding a laboratory plasma disturbs it; probing a space plasma does not affect it seriously, at least the perturbation can be induced intentionally as in the case of the so called active experiments. High temperature laboratory plasmas are concerned with static equilibria, whereas space plasma physics is concerned with large-scale time dependent flows. On the basis of such differences and similarities the turbulent loss of trapped particles from fusion reactors and from the Van Allen radiation belts has been studied in parallel. Also scattering of electromagnetic radiation from ionospheric plasmas and from turbulent laser fusion has been pursued in parallel. In tokomaks, reconnection processes similar to those of the space plasmas determine the global stability of the plasma and also affect microscopic transport. Large static plasma devices in the laboratory are studying beam-plasma interactions, whose results are yielding useful information about interpreting some space plasma phenomena, particularly in the physics of Aurorae. Collisionless shock waves were studied and parametrized originally in space plasmas. At present particular shock structures are also being investigated in the laboratory. Problems related to large-scale turbulent hydromagnetic flows, acceleration and transport of energetic particles are best studied in space, whereas parametric studies of the effects of geometry and plasma behavior on reconnection are best investigated in the laboratory.

Furthermore, modern astrophysics is founded on our basic knowledge of plasma physics. Our experience with laboratory and space plasmas, which can be sounded directly, provides enough insight into general problems of plasma physics, allowing astrophysical theories to be compared with observations. In other words, without the constraints imposed by the direct observation of plasmas, our theories of astrophysical phenomena would be made on a much more speculative basis. The range of parameters found in astrophysics is different from that of laboratory plasma processes and the interpretation of phenomena is not affected considerably by the closeness of confinement frontiers, as in laboratory conditions. However, the range of parameters and boundary conditions in Solar System plasmas are much more close to those in Astrophysics providing a relatively accessible laboratory where many of the phenomena observed in astrophysics can be seen closely.

The study of space plasmas has been focused on two interdependent points of view: the macroscopic processes (large-scale behavior) and microscopic processes (small-scale behavior). The former are studied by Magnetohydrodinamics which describes the plasma as a conducting fluid, a simplification that enables and efficient description of the large-scale structure and dynamics of hydromagnetic phenomena. The microscopic behavior of plasmas is studied by the Kinetic Theory of plasmas, which treats it as a collection of individual charged particles that collide among themselves infrequently and interact with self-consistent electric and magnetic fields auto-induced by the motion of particles. Heliospheric physics in particular, has motivated a considerable amount of MHD research, becoming a real laboratory where hydromagnetic fluxes and their interactions, as well as non-linear turbulence have been studied directly. Also the Kinetic Theory of plasmas has been applied, for instance in particle acceleration and transport processes, particle-wave interactions and so on. A third point of view is the hybrid one that communes both MHD and Kinetic theory to solve some specific problems.

## RESEARCH METHODOLOGY

The scientific method employed in space plasma physics is different from that used in the laboratory. In the laboratory, experiments are designed and controlled for comparison with theory. This is only occasionally feasible with space plasmas (active experiments within the geosphere). In space plasma physics, mathematical models of physical phenomena are developed to compare with observation data. In the case of *in situ* measurements the evolutive phases of research are:

- **Recognition phase:** The initial penetration and examination of a certain space volume by an instrumented spacecraft; discovery is its objective.

- **Exploration-phase:** Re-examination of a given space volume, whose aim is the complete identification of prevailing physical processes and accurate phenomenological description.

- **Intensive-Resolutive phase:** Quantitative evaluation of physical processes and their intercorrelation among them, within the frame of models addressed to draw predictive inferences of phenomena.

For research based on remote sensing techniques the methodology which applies is:

- **Preliminary monitory-phase:** With inherent limitations by spatial resolution and line-of-sight integration; with the aim of discovery.

- **Global monitory-phase**: With enough coverage and resolution to identify basic physical processes.

- **Intensive-Resolutive-phase**: For quantitative and predictive modeling. The ultimate objective of space research is to construct an accurate model for the observed phenomenon that is being studied. Suitable models must describe the main traits and peculiarities of the studied phenomena. If possible it also should be able to describe their secondary details.

When research approaches its intensive-resolutive phase, its progress can be evaluated by the quantitative understanding achieved of a given phenomenon, based on the degree of agreement of its predictions with observational events. However, until now the comprehension of a given phenomenon is normally "open ended" in nature, since usually new information from new missions narrow the range of answers to previous questionableness, while given rise to new ones.

Once comprehensive phenomenological understanding has been achieved, then and quantitative modeling is undertaken; this is usually done in three steps:

- **Preliminary models**: usually empirical in nature, when basic relationships are being established either on statical grounds, or by invoking quite simple physical concepts. These models may or not be correct, but their "mere" formulation implies moderate quantitative understanding and allows for the motivation of new observations of an oriented nature; research becomes problem-focused.

- **Accurate Functional models**: when based on new observational information an adequate description of every involved process is achieved, allowing for a systematic comparison of theory with observational data; (either by analytical or numerical methods) for each input situation they give a correct output situation. Accurate-Functional models may often be used successfully for forecast purposes.

- **Predictive models**: when the threshold of practical utility has been achieved. These must be able to give not only the global physical essence of the phenomenon but when applied to specific needs they must give the best possible quantitative description of each particular physical process, and be as suitable as possible for forecasting and predicting purposes, as well as for extrapolations to other scales.

The systems under consideration in space plasma physics are open, non-linear and multidimensional ones, and observations always suffer from the lack of information on the states and parameters of the system; e.g., lack of *in situ* high heliographic latitude measurements limits the understanding of many investigations of the solar wind. A lack of *in situ* measurements near the Sun limits interpretations of the available intensive remote-sensing studies, insufficient measurements in the deep geomagnetical tail has prevented full understanding of how the upper atmosphere, ionosphere and magnetosphere couple to the lower atmosphere. For this reason, the basis for model construction must be formed by A long term series of observation of a large number of physical observables.

Observations of single event of certain phenomenon, may paint a vivid picture, but only of one particular aspect. Based on such observation, models may fail in applications to the next event of same phenomenon. Therefore, models must be developed in the more global context, so that model physical systems are as similar as possible to the natural physical systems. Only in this way can it be expected that the lack of observational data may be supplanted by theory. Moreover, due to because the non-linear nature of the physical systems many problems can not be solved analytically by either the MHD or the Kinetic theory of plasmas, except in so idealized cases where comparison to observational data does not make any sense. This is why models based on numerical simulations of physical systems are the necessary tools in the intensive-resolutive phase of research. At this level, when a bottleneck is found in theoretical development, it makes sense to undertake active experiments in the near earth environment, to assist in the lack of observational data required for a full understanding of a given physical mechanism.

Agreement between theory and observational data forces intellectual rigor in research. Theorists are obliged to produce accurate and detailed models with specifications of concrete mechanisms, specific range of parameters, determined spatial and temporal location of individual events and concrete predictions, to assist experimentalists in designing missions. Experimentalists are forced to design missions of highest scientific return, to collect and reduce significant informations in such a way that understanding and interpretation of observational data may be done within the frame of an adequate theoretical context. Data must be adequately documented in terms of meaningful physical quantities, stored and disseminated in an accessible way to the community. The strategy followed for a more efficient compilation of significant data returns is the implementation of oriented-missions toward scientifically focused problems. When scientific objectives have been stated and documented clearly the problem lies in how to achieve them, and this is more feasible technologically and economically within the frame of international coordinated programs, as has been the case in the SMY (Solar Maximum Year program), the IGBP (International Geosphere-Biosphere Program), the STEP (Solar-Terrestrial Energy Program), etc.

## GENERAL FUNDAMENTAL PROBLEMS IN SPACE PLASMA PHYSICS

Most of space plasma phenomena involve non-linear effects that are still understood poorly. Non-linear effects mean the second order or smaller effects relative to those of the determinant physical processes. However, to some extent they have certain impact within the context of the global dynamics of the phenomenon. A great deal of analytical and theoretical modeling supported by modern computing techniques is required to approach non-linear dynamics. Among the general physical problems found in Solar-System plasmas, in the laboratory and in astrophysics, that still need further observational and theoretical efforts:

- **Magnetic field line reconnection:** one of the most fundamental energy dissipation and reconfiguration process in the universe. It takes place in a variety of forms impulsive, patchy, steady or time-dependent reconnection, in the solar atmosphere, solar- wind, magnetopause, magnetotail, fusion devices and several astrophysical sites.

- **Acceleration of charged particles:** in any place where hydromagnetic turbulence is formed, in shock waves, in magnetic reconfigurations, energetic particles are produced; as in solar flares, magnetic substorms, auroral archs, interplanetary shock waves, the heliopausic shock, and so on.

- **Confinement and transport of charged particles:** the Van Allen radiation belts and geomagnetic distribution, coronal storage and coronal azimuthal transport, interplanetary propagation and so on.

- **Collisionless shocks:** they originate in solar impulsive transient events, superposition of solar-wind fluxes of different velocity, interaction of different magnetized plasmas (bow shock, heliopausic shock, etc).

- **Boundary layers:** in contrast to gravitation where spheric structures are produced, electromagnetic interactions of large scale plasmas produce filamentary structures (or thin layers) given the astrophysics space cellular structure

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In tables 1 to 5 the progress of understanding some paradigmatic space plasma problems are illustrated.

# Table 1.
# Understanding Status in Solar Physics

A = Preliminary Models B = Accurate-Functional Models C = First Predictive Models

| PROBLEM | RECOGNITION PHASE<br>ELEMENTARY COMPREHENSION | EXPLORATION PHASE<br>PHENOMENOLOGICAL COMPREHENSION | QUANTITATIVE, INTENSIVE-RESOLUTIVE PHASE | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| DISAGREEMENT OF OBSERVATIONAL AND THEORETICAL NEUTRINO FLUX | X | O | | | |
| NEUTRINO FLUX VARIATIONS | X | | | | |
| SOLAR LUMINOSITY VARIATIONS | | X | | | |
| ORIGIN OF SOLAR MAGNETIC FIELDS | | | X | | |
| LARGE SCALE CIRCULATION | | | X | | |
| SOLAR CONVECTION | | | X | | |
| GLOBAL OSCILLATIONS (HELIOSISMOLOGY) | | | X | O | |
| CHAIN OF PROCESSES RELATING THE SOLAR INTERIOR TO LAYERS OF THE SOLAR ATMOSPHERE | X | O | | | |
| PHOTOSPHERIC SECTORIAL STRUCTURE AND MAGNETIC FIELD BOUNDARIES | | | X | O | |
| VARIABILITY OF MAGNETIC FIELD PROPERTIES RELATED TO DISTANCE OF BOUNDARY SECTORS | | X | | | |
| RELATIONSHIP OF BACKGROUND MAGNETIC FIELD TO CHROMOSPHERIC CORONAL AND INTERPLANETARY MAGNETIC STRUCTURES | | | X | | |
| CORONAL HOLES STRUCTURES ANCHORED FAR FROM BOUNDARY -LAYERS T HIGH LATITUDES | | X | | | |
| RELATIONSHIP BETWEEN LARGE-SCALE MAGNETIC FIELD AND CHROMOSPHERIC AND CORONAL STRUCTURES | | | X | | |
| PHOTOSPHERIC GRADIENT TEMPERATURE | X | | | | |
| DYNAMICS, STABILITY AND ENERGY BALANCE OF SUNSPOTS | | | X | O | |
| EVOLUTION OF ACTIVE REGIONS | | | X | O | |
| THE INHOMOGENEOUS STRUCTURE OF CHROMOSPHERE | | | X | O | |
| BASIC FLARE MECHA-ISM ENERGY BUILD UP, STORAGE AND DISSIPATION | | | X | | |
| THERMAL EVOLUTION OF FLARE PLASMA IN CHROMOSPHERIC AND CORONAL FIELDS | | | X | | |
| THE PRE-FLARE SITUATION AND TRIGGER MECHANISM | | X | | | |

X= main status 0= some present or near-future attempts

## (Table 1.)
## (cont. Understanding Status of Solar Physics)

A = Preliminary Models  **B** = Accurate-Functional Models  C = First Predictive Models

| PROBLEM | RECOGNITION PHASE<br>ELEMENTARY COMPREHENSION | EXPLORATION PHASE<br>PHENOMENOLOGICAL COMPREHENSION | QUANTITATIVE, INTENSIVE-RESOLUTIVE PHASE | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| DISSIPATION OF MAGNETIC ENERGY IN EFFICIENT PARTICLE ACCELERATION PROCESSES | | | X | O | |
| LOCATION OF FLARE ENERGY IN EFFICIENT PARTICLE ACCELERATION | | | | X | |
| RELATIONSHIP BETWEEN FLARE MAGNETIC FIELD EVOLUTION AND PHOTON AND PARTICLE PRODUCTION | | | X | O | |
| ORIGIN OF MAGNETIC FLUX TUBES (FLUXULES) | | | X | O | |
| THE VELOCITY FIELD IN THE TRANSITION ZONE AND CORONA | | | X | O | |
| DIFFERENTIAL LOCAL ELEMENTAL AND ISOTOPIC COMPOSITION OF SOLAR ATMOSPHERE | | | X | | |
| THE PROPERTIES OF PROMINENCES | | | X | O | |
| CORONAL HEAT MECHANISMS, TRANSPORT AND DISSIPATION | | | X | O | |
| CORONAL MAGNETIC FIELDS: LARGE-SCALE WEAK FIELD AND SMALL-SCALE STRUCTURES | | | X | O | |
| CORONAL ROTATION | | | X | | |
| INHOMOGENEOUS CORONAL STRUCTURES | | | X | O | |
| MASS EJECTIONS (CORONAL TRANSIENTS) | | | X | | |
| CORONAL EXPANSION | | | X | | |
| HEATING AND ACCELERATION OF SOLAR WIND | | | X | | |
| SOURCES OF HIGH SPEED STREAMS OF SOLAR WIND | | X | O | | |
| STRUCTURE AND DYNAMICS OF CORONAL CONDENSATIONS | | | X | O | |

X= main status  0= some present or near-future attempts

# Table 2.
# Understanding Status in Heliospheric Physics

**A** = Preliminary Models **B** = Accurate-Functional Models **C** = First Predictive Models

| PROBLEM | RECOGNITION PHASE<br>ELEMENTARY COMPREHENSION | EXPLORATION PHASE<br>PHENOMENOLOGICAL COMPREHENSION | QUANTITATIVE, INTENSIVE-RESOLUTIVE PHASE | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| GENERATION OF SOLAR-WIND | | | X | O | |
| SPATIAL AND TEMPORAL VARIATIONS OF SOLAR WIND TURBULENCE SPECTRUM | | | X | | |
| EVOLUTION OF SUBSONIC TO SUPERSONIC VELOCITY OF THE SOLAR-WIND | | | X | O | |
| ANGULAR MOMENTUM OF SOLAR-WIND AND LOSS OF ANGULAR MOMENT BY THE SUN | | X | O | | |
| RELATION OF SOLAR-WIND TO CORONAL HOLES AND ACTIVE REGIONS | | X | O | | |
| INTERACTION OF HIGH SPEED STREAMS WITH STATIONARY SOLAR-WIND | | | | X | O |
| HEAT CONDUCTION IN THE SOLAR-WIND | | | X | | |
| INTRINSIC TURBULENT NATURE OF THE SOLAR-WIND | | | X | O | |
| HIGH-HELIOSPHERIC LATITUDE SOLAR-WIND (OUT OF THE ECLIPTIC PLANE) | O | | | | |
| IN-ECLIPTIC SOLAR-WIND BEYOND 40 A.U. AND WITHIN 0.3 A.U. | O | | | | |
| HELIOPAUSE AND SOLAR-WIND INTERACTION WITH INTERESTELLAR MEDIUM | O | | | | |
| CHEMICAL COMPOSITION OF SOLAR-WIND AND ITS RELATION TO CORONA | | | X | | O |
| SHORT-TERM SOLAR WIND VARIATIONS AND RELATION TO TRANSIENT EVENTS | | | | X | |
| LONG-TERM SOLAR WIND VARIATIONS AND RELATION TO SOLAR ACTIVITY | | | X | O | |
| EVOLUTION OF SOLAR WIND-SECTOR STRUCTURES TANGENTIAL AND ROTATIONAL DISCONTINUITIES, NEUTRAL CURRENT SHEETS | | | X | | |
| INTERPLANETARY DIFFUSIVE ACCELERATION OF ENERGETIC PARTICLES | | | | X | |

X= main status 0= some present or near-future attempts

## (Table 2.)
## (cont. Understanding Status in Heliospheric Physics)

A = Preliminary Models B = Accurate-Functional Models C = First Predictive Models

| PROBLEM | RECOGNITION PHASE ELEMENTARY COMPREHENSION | EXPLORATION PHASE PHENOMENOLOGICAL COMPREHENSION | QUANTITATIVE, INTENSIVE-RESOLUTIVE PHASE | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| MODULATION OF HIGH ENERGY GALACTIC COSMIC RAYS | | | | X | O |
| ORIGIN OF THE ANOMALOUS COMPONENT PRESENCE OF INTERSTELLAR IONIZED AND NEUTRAL ATOMS | | X | | | |
| INTERACTION OF SOLAR-WIND WITH PLANETS | | | X | O | |
| INTERACTION OF SOLAR-WIND WITH COMETS | | | X | | |
| RELATION OF SMALL-SCALE TO LARGE SCALE PROCESSES IN THE SOLAR-WIND | | X | O | | |
| COSMIC RAY CONDITIONS AT MIDDLE AND HIGH HELIOCENTRIC LATITUDES AND OVER SOLAR POLES | O | | | | |
| MODULATION OF LOW ENERGY COSMIC RAYS | | X | O | | |
| SOLAR CONNECTION WITH TRANSIENT INTERPLANETARY PROCESSES | | | X | O | |

X= main status 0= some present or near-future attempts

# Table 3.
# Understanding Status in Magnetospheric Physics

A = Preliminary Models B= Accurate-Functional Models C = First Predictive Models

| PROBLEM | RECOGNITION PHASE<br>ELEMENTARY COMPREHENSION | EXPLORATION PHASE<br>PHENOMENOLOGICAL COMPREHENSION | QUANTITATIVE, INTENSIVE-RESOLUTIVE PHASE | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| GLOBAL TIME-DEPENDENT HYDROMAGNETIC INTERACTION OF SOLAR WIND WITH THE MAGNETOSPHERE | | | X | O | |
| SOLAR-WIND ENERGY COUPLING WITH MAGNETOSPHERE | | | | X | |
| SOLAR-WIND MASS COUPLING TO MAGNETOSPHERE AND FLOW DISTRIBUTION THEREIN | | | | X | |
| TIME-DEPENDENT BEHAVIOR OF PHYSICAL PARAMETERS IN THEMAGNETOSHEET | | | X | | |
| ENERGY TRANSPORT IN THE MAGNETOPAUSE AND BOUNDARY LAYERS | | | X | O | |
| GEOMAGNETIC TAIL DYNAMICS | | | X | O | |
| MAGNETIC SUBSTORMS: BUILD UP, ENERGY DISSIPATION, PARTICLE ACCELERATION | | | X | O | |
| LARGE-SCALE MAGNETIC RECONFIGURATION IN SUBSTORMS | | X | O | | |
| PLASMA SHEET DYNAMICS | | | X | | |
| TIME-DEPENDENT BEHAVIOR OF TRAPPED RADIATION IN VAN ALLEN BELTS | | | | X | |
| GLOBAL MAGNETOSPHERIC PLASMA SOURCES, SINKS ACCELERATION AND TRANSPORT | | | X | | |
| GLOBAL AURORAL PHYSICS | | | | X | |
| MAGNETOSPHERIC COUPLING TO IONOSPHERE, THERMOSPHERE AND MESOSPHERE | | | X | | |

X= main status 0= some present or near-future attempts

# Table 4.
# Understanding Status in Aeronomical Physics

A = Preliminary Models B = Accurate-Functional Models C = First Predictive Models

| PROBLEM | RECOGNITION PHASE<br>ELEMENTARY COMPREHENSION | EXPLORATION PHASE<br>PHENOMENOLOGICAL COMPREHENSION | QUANTITATIVE, INTENSIVE-RESOLUTIVE PHASE | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| EFFECTS OF VARIABILITY OF PHOTON AND PARTICLE FLUXES ON THE THERMOSPHERE, MESOSPHERE AND STRATOSPHERE | | | | X | O |
| GLOBAL INTERACTION OF POLAR THERMOSPHERE AND MESOSPHERE WITH THE MAGNETOSPHERE | | | | X | |
| CHEMICAL, DYNAMICAL AND RADIATIVE ENERGY BALANCE FROM MESOSPHERE TO STRATOSPHERE | | | | X | O |
| GENERATION OF POLAR AND THEMOSPHERIC WIND | | | X | O | |
| MESOSPHERIC COUPLING AND DYNAMOS | | | X | O | |
| GLOBAL DYNAMICS OF UPPER ATMOSPHERE | | | | X | O |
| ELECTRICAL COUPLING BETWEEN HIGH AND LOW LATITUDE IONOSPHERE | | | | X | |
| IONOSPHERE-THERMOSPHERE COUPLING AND RESPONSE TO ENERGY AND MOMENTUM INPUTS | | | | X | |
| STRATOSPHERE-MESOSPHERE RESPONSE TO FORCING FROM ABOVE AND BELOW | | | X | O | |
| ENERGY TRANSFER WAVE PROCESSES IN THE UPPER ATMOSPHERE | | | X | O | |
| EQUATORIAL ELECTROJET SYSTEMS | | | | X | O |
| POLAR MESOSPHERIC CLOUDS | | | X | O | |
| LOWER STRATOSPHERE STRUCTURE AND TROPOSPHERIC CLIMATE | | | X | O | |
| GLOBAL PLASMA CIRCULATION SOURCES AND SINKS | | | X | O | |

X= main status 0= some present or near-future attempts

## Table 5.
## Understanding Status of Solar-Terrestrial Physics

A = Preliminary Models B = Accurate-Functional Models C = First Predictive Models

| PROBLEM | RECOGNITION PHASE<br>ELEMENTARY COMPREHENSION | EXPLORATION PHASE<br>PHENOMENOLOGICAL COMPREHENSION | QUANTITATIVE, INTENSIVE-RESOLUTIVE PHASE | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| LONG-TERM CLIMATIC CHANGES DUE TO CHANGES IN SOLAR CONSTANT | | X | | | |
| RELATIONSHIP BETWEEN SOLAR ACTIVITY AND WEATHER AND CLIMATE | X | | | | |
| UPPER AND LOWER ATMOSPHERE COUPLING EFFECTS ON WEATHER AND CLIMATE | | | X | | |
| OZONE VARIATIONS WITH UV, COSMIC RAYS VARIATIONS AND GEOMAGNETIC ACTIVITY | | | | X | |
| EFFECT OF OZONE CONCENTRATION ON GLOBAL CIRCULATION PATTERN | | | | X | |
| INFLUENCE OF GLOBAL SOLAR, HELIOSPHERIC, MAGNETOSPHERIC AND UPPER ATMOSPHERIC VARIABILITY ON THE LOW-ATMOSPHERE, BIOSPHERE AND HUMAN TECHNOLOGY | | X | | | |
| EFFECTS OF SHORT-TERM SOLAR VARIABILITY IN THE TROPOSPHERE | | | | | |
| ANTROPHOGENIC EFFECT ON THE LOWER ATMOSPHERE | | | X | | |

X= main status 0= some present or near-future attempts

appearance. Such boundary layers separating plasma fluxes of different properties are so thin that they can only be discerned by *in situ* measurements. The coupling of small scale (local) systems with large-scale (global) systems determines the transfer and balance of mass, momentum and energy between both different fluxes, as in the case of energy dissipation by reconnection in neutral current sheets, and so on.

- **Turbulent magnetized plasmas**: the onset and development of turbulence is still not understood well in non-magnetized fluids. The interaction of plasma turbulence with magnetic field is even more complex: eddy diffusion, vorticity, plasmoid formation, compressible convection, are found in the magnetopause, neutral current sheets, boundary layers, etc.

- **Microstructures and macrostructures of plasmas and E.M. fields**: the macroscopic description of hydromagnetic systems is incomplete without dissipation and transport processes due to microscopic systems. The coupling of Kinetic theory with MHD allows the study of typical transport processes in the magnetopause, boundary layers and shock waves. Viscosity, electrical conductivity and heat coefficients inserted into hydromagnetic equations require microscopic individual particle parameters, diffusion and collision mean free paths, gyroradii and gyrofrequences. Paradigmatic phenomena are magnetic field reconnection and transport processes in boundary layers. Propagation of low energy cosmic rays and solar particles is probably dominated by solar wind microstructures.

- **Dynamics of magnetic flux tubes**: involving aligned current flux processes, which are essential ingredients for transfer phenomena in magnetospheric - atmospheric systems, magnetic archs of solar activity centers, auroral arches, etc.

- **Stochastic heating**: involving wave-particle interaction processes, associated with anomalous transport and dissipation of energy and momentum in plasmas, as well as the selective transport of individual constituents of solar and terrestrial atmospheres (with subsequent basic implications regarding chemical composition)

- **MHD waves**: an exhaustive study of these is of central import-ance in such diverse fundamental phenomena as the heating of the solar corona, generation of the solar-wind, structuration of magnetospheric oscillations, magnetospheric oscillations, magnetosphere-ionosphere coupling, particle acceleration of charged particles (Fermi-Kind acceleration), etc.

## INCIDENCE OF SPACE PLASMA PHYSICS ON EARTH AND HUMAN ENVIRONMENT

Solar-Terrestrial Physics (STP) is the study of energy generation, transfer, storage, dissipation and mass-transfer processes through the coupled solar-terrestrial system of regions extending from the solar core to the Earth's surface and biosphere. The objective of this discipline is to understand and modelate for predictive purposes the chain of causes and effects characteristic of solar-terrestrial relationships, where every component is part of highly interactive complex system, whose global behavior differs significantly from the mere linear superposition of its parts.

Our star and planet form a binary system of irreversible relations of the Sun to Earth, which can be investigated with a detail impossible to match with any other binary system in the universe. The total solar electromagnetic radiation received on earth is 1.73 x $10^{14}$ kW (Solar Constant), which is more than one thousand times the solar-wind power received at the level of the magnetopause ($\sim 10^{-10}$kW), and about one million times the solar-wind power received at earth level (<4.3 x $10^7$ kW). However, in terms of mass loss by the Sun, the corresponding amounts are 4.2 x $10^9$ kg/s and 1.35 x $10^9$ kg/s respectively. The total energy and mass released in sporadic events of solar activity - the solar transients - give a contribution per average event of 1.8 % and 3 % respectively, of the solar-wind release.

During the sporadic magnetic substorms ~$10^9$ kW per event is released within the geosphere, whereas antrophogenic power may reach 5 x $10^8$ kW. This sharp contrast between corpuscular and electromagnetic energy seems to indicate the nothing other than to solar light significantly affects the terrestrial system. However, it is well known that in spite of the quasi-constant nature of solar radiation input on Earth, our geospace is highly variable. We know at present, that such a variability is associated with the variability of the solar outputs, mainly solar-wind variations. Though the energy content of the solar-wind is minuscule relative to solar radiation, these variations produce of sporadic, or even intermittent signals that make the geospheric system react in a highly non-linear way. This indicates that our Earth environment is such a sensitive system that even second order effects may disturb it. In fact, the upper atmosphere is a dynamically active layer where variable fluxes of mass and energy are processed, and whose effects spread to lower altitudes, other latitudes and longitudes, providing the magnetosphere with substantial amounts of mass and energy. In this way such spectacular phenomena as magnetic substorms and aurorae are produced sporadically.

Regarding solar electromagnetic output, it is well known that small variations in radiation incidence, either in amount or in distribution, produce variations in the Earth orbital parameters. Such effects have been associated with main glacial ages. In addition, the lack of solar activity over several decades in the Middle Age, affected solar radiation input to produce the so-called small glacial ages. In fact, the solar luminosity is only of a quasi-constant nature; during the last solar cycle a global variation of ~0.25 was a measured. In periods of maximum solar activity the high energy end of the electromagnetic spectrum is enhanced greatly. However, this energetic range represents only 2 % of the spectrum and is absorbed preferentially by the Earth atmosphere. Nevertheless, these minuscule variations, increasing and decreasing with solar activity maximums and minimums, are enough to cause expansions and contractions of the Earth atmosphere. These in turn result in a wide variety of upsets, for instance, satellite orbits (e.g. Skylab, 1978).

Since the interplanetary magnetic field orientation relative to the geomagnetic axes regulates the solar-wind energy and moment transfer rate into the magnetosphere, it follows that solar-wind disturbances are reflected as magnetospheric disturbances, which in turn are transmitted to the different layers of the atmosphere, preferentially over the polar regions. The variability of the steady solar-wind is due to its interaction with the solar-wind high speed streams emanating from coronal holes (where they draw such a high amount of energy that the regions become cooler than surrounding areas) and with eject a phenomena by solar activity transient events: shock waves, plasmoids and high energy particles and protons.

Shock waves and plasmoids directly disturb the interplanetary magnetic field, while energetic particles and photons, arriving some minutes after the solar event cause severe disturbances on the ionization state of atmospheric layers, thus upsetting the electrification of the same. Well known phenomena like the Sudden Ionospheric Disturbances are produced by this energetic radiation. In particular, the interaction of shock waves and plasmoids with the Earth system is highly sensitive to the relative position between transient events on the Sun, the heliospheric neutral current sheet and the orientation of the interplanetary magnetic field at the Earth orbit level. This interaction often acts as a magnetic substorm detonator. Shock waves and plasmoids are also associated with Galactic Cosmic Ray decrease (Forbuch effect) with its subsequent implications on atmospheric dynamics.

Solar cycle modulations of solar wind disturbances can be seen from:

- the number of transient events and shock waves differ by a factor of ten between the maximum and the minimum;

- the intensity of solar energetic particles is directly proportional to solar activity behavior;

- the intensity of galactic cosmic rays in the Earth's environment is inversely proportional to solar activity behavior. In spite of these dramatic disturbances of the steady solar-wind, the measured deviations of average solar-wind properties are lower than 10 %, at least in the ecliptic plane. This implies that solar wind has no way to disturb the geosphere in linear form, but only as kind of sporadic "peck" effect.

Unfortunately, there is no a one - to - one correlation between these sporadic effects and the observable properties of solar activity, such as sunspots. Correlations exist only on a statistical basic. To what extent do these "peck" effects affect the environment of man and his technology? It is precisely STP where the benefits of understanding space plasma phenomena can be measured in terms of human, social, economical and technological implications. Some of the most typical implications of solar- terrestrial relationships that must be studied for predictive purposes are:

- Changes in solar-wind properties (density, composition and velocity) due to solar disturbances sensitively affect the global magnetospheric-atmospheric system, which can affect seriously terrestrial and space equipment. In fact, content power in steady solar wind is ~0.1 $mW/m^2$ and high speed solar wind streams may reach 3$mW/m^2$ at the magnetopause level, with a small factor transmission to the magnetosphere. In contrast, solar radiation power is 1.37 x $10^6$ $mW/m^2$, however, the "peck" effects of disturbed solar-wind may be felt due to two main factors: 1st, because energy is mainly concentrated in a very narrow latitudinal band, the polar areas, whose surfaces comprise about 1% of the total Earth's surface, and 2nd, energy is stored in the magnetotail for several hours before being suddenly liberated. Based on these factors the power transmitted to the atmosphere is amplified at least by an order of magnitude.

- When impulsive enhancements of high frequency solar radiation emissions take place, at least an enhancement of ~1 $mW/m^2$ is received on Earth, affecting long distance communication systems (HF). Though Earth-satellite communications (GHz) are not based on ionospheric reflection, they are affected by scintillations produced in equatorial ionospheric regions.

- When a solar particle event takes place, energetic particle flux intensity is at least three times higher than the G.C.R. background. Solar particles penetrate into the mesosphere and stratosphere, where through ionization they modify their chemical composition, which can last for weeks or even months. The drastic increase of electronic density in the low ionosphere produces absorption of radio-waves that are reflected normally at that level. Interruptions of radio-communications may occur on consecutive days if the solar particle source remains active. Penetration of these particles in polar regions produces the so called Polar Cap absorption events, approximately 3 hrs after the solar event, which is the average Sun-Earth fly time of ~10 MeV protons.

- The ionization rate at very low altitudes is determined by secondary radiation of Galactic Cosmic Rays. In periods of Forbush effects, the decrease of incident fluxes results in electric conductivity changes in those low layers.

Modifications of electrical conductivity changes the cloud formation rate and eventually the albedo may be altered, which presumably may have implications on the Earth's climate.

- The sudden and located energy deposition of the solar wind high speed streams produces polar auroras about three days after the disturbance event at the solar level. Due to the precipitation in these zones of charged particles, a ionospheric intense current system is created, at about an altitude of 100-150 km, which is known as an auroral electrojet, and whose intensity may reach millions of amperes. These currents produce magnetic disturbances which can be detected in high latitude of the Earth's surface. By induction in the Earth's resistive crust potential differences of about -5 v/km are created. These may have grave consequences on man-made long dimension conducting systems, such as pipe-lines, power-lines and telephone cables. Also geological surveys, searching for anomalies of the Earth's surface, that are indicative of petroleum and other natural resources, may be seriously upset by induced currents on Earth during magnetic substorms. In the case of highly expensive explorations it is advisable to base them on predictions of geomagnetic and solar activity.

- Energetic particle fluxes (~Kev) generated during magnetic substorms produce electric charge increases in spacecrafts. Differences of electric resistivity between different places of the spacecraft may lead to potential differences up to ~20 kV, and thus, may produce severe damage to electronic system.

- Geomagnetic storms only produce quasi-static currents (10 - 15 amperes) that are unable to produce corrosion of pipe-lines, but they may produce serious problems for their monitoring and control electronics. May large storms (May 1969, August, 1972, etc.) have been responsible for temporary black-outs and transformer station break downs. Because power transformers are at ground level, large unexpected DC currents (~100 amperes) may flow in the winding, thereby inducing a half-cycle saturation in cores which in turn, leads to very strong voltage drop-out. Overheating and subsequent destruction of the insulators may cause the removal of transformers from the supply network.

- During auroral substorms, when large ionospheric electric fields are produced at high altitudes (>100 km), a displacement of ions ("ion drag") take place, in such a way that their friction against the neutrals causes change in the neutral wind system (at an altitude of ~200 km). This seems to be the origin of drastic changes in the vorticity of the atmospheric circulation.

- In auroral zones, at altitudes of 90 km, the neutral atmosphere is directly heated by energetic electrons, and at altitudes of 100-150 km, by Joule heating associated with the ionospheric currents. In periods of intense geomagnetic activity such extra heating functions like a thermal shock wave. As a consequence, atmospheric waves propagates to other altitudes and latitudes, resulting in density and temperature increases (between 150-600 km of altitude). These increases shorten the life-span of low orbiting satellites passing through this region, this is the case of GEO-5, and the unexpected decay of Skylab due to an unexpected high number of sunspots in 1978. Another collateral effect of those generated waves is the alteration of the relative concentration of minor atmospheric constituents.

- Since electronic systems are sensitive to the accumulated radiation dose of energetic particles and since application satellites are being planned to last for long periods of time, it is clear that damage induced by solar flare particles, geomagnetic substorms and storm injected particles, and by exposition to the Van Allen radiation belts may be a considerable problem in the future. Also, astronauts and passengers of stratospheric flights through polar zones may have serious problems in future family planning. Repercussions may be much more dangerous for astronauts exposed for several days to this kind of energetic radiation: during the proton event of the solar flare of August 1972 the radiation dose of photons and particles in the magnetosphere reached levels much higher than for health standards permitted, and even higher than some accidents in nuclear reactors.

- The performances of solar arrays can be degraded by as much as 15% after five days of operation in a geosynchronous orbit through Van Allen belts. In addition large solar proton flares may be responsible for a ~5% loss in efficiency within a few days. Also, the projects of large solar arrays in space to send solar energy to the Earth must take into account such kind of degradation by energetic particles. In addition the absorbed power in the atmosphere from one of those microwave beams should be at least 1 $mW/m^2$. This is of same order of the most energetic fraction of solar radiation (producing ionization and heat above 100 km of altitude), which inexorably would produce non-desirable effects.

- Some studies of a total statical nature indicate that certain cyclonic activity is present in the stratosphere one day after a solar wind boundary sector crosses the Earth. Also, the preciseness of meteorological survey methods is upset after the passage of a boundary sector of the interplanetary magnetic field, apparently because they do not consider such vorticity effects. Also, a 20 % increase in the vertical electric field and the earth's air current system (3 km above sea level) can be argued on statistical grounds after the passage of the magnetic boundary sector.

- Several coupling of the Earth's climate and weather parameters exhibiting periodicity of 11 and 22 years with solar activity phenomena, are still of a speculative nature, since the basic physical mechanisms have not been elucidated.

In addition to disturbances on the geospace plasma system from the exterior there are the antrophogenic disturbances induced by the increasing industrialization, reaching a power ~108 - 109 kW, without considering the latent power of nuclear armament.

In order to obtain some control of our space environment, predictive techniques must be improved. To do so a great deal of theoretical work, modeling and numerical simulations, supported by *in situ* and remote sensing observations are required. A very helpful tool is the development of the so called controlled active experiments, to produce in space situations and processes of phenomena unable to be reproduced until now at the laboratory level, because of the sharp differences in scales and range of parameters. These controllable stimuli in specific regions of the magnetosphere and atmosphere are generally the injection of beams of protons and electrons, and more complex constituents, as well of waves of very diverse nature. However, these experiments can not be carried out indiscriminately without studying the possible non-desirable effects on our space environment, which is now being done in organized-coordinated programs.

Many of the phenomena described may have an appreciable influence on man's immediate environment technology and society. Their interpretation has not been quantitatively established in a reliable manner. We now realize , more than ever, that physical processes operating in our plasma environment are more frequently found in the universe than usually credited, and its understanding may be used to model the understanding of other astrophysical objects. It must be admitted that an almost unavoidable consequence of the evolution taking place in space sciences is the need for Latin American scientists to make a quantum jump from the background state in their participation in the joint world-wide space-ventures.