Description of my Research and other activities

I use the tools of Plasma Physics, Magnetohydrodynamics, electromagnetics and Signal Processing in my explorations of the solar system. Using these tools, I have obtained insights in research areas as diverse as subsurface oceans in the icy Galilean satellites, magnetic fields of satellites and magnetospheres, plasma convection in magnetospheres and asymmetries of planetary bow shocks. In the following section, I provide some highlights of my research career.

Past and Current Research

Research on the Jovian satellites

Discovering Liquid Oceans on Europa, Ganymede Callisto and Io

Perhaps the most thrilling scientific work in which I played a central role was the discovery of liquid water oceans in the icy Galilean satellites. In the late nineties, several lines of geological evidence pointed towards the existence of a subsurface liquid water ocean in Europa but could not rule out other interpretations such as warm soft ice with only localized melting. In 1998, based on Galileo magnetic field observations, I along with other colleagues in UCLA and Caltech published a paper (# 46) in the journal Nature which showed unequivocally that subsurface oceans in Europa and Callisto generate strong electromagnetic induction signatures in response to the rotating field of Jupiter. Several subsequent papers published by our group and others have reconfirmed our original findings and placed stronger limits on the strength of the induction signals. In another publication (#78), I showed how future induction measurements at multiple frequencies could be used to further define the physical properties of Europa's ocean. Recently I wrote a book chapter which reviews our current understanding of the electromagnetic induction from Europa and its implications for the properties of Europa's ocean (#133).

In another major discovery in this area, in a research investigation led by Prof. Kivelson (#79), we showed that Ganymede also harbors a subsurface water ocean under an ice layer of ~ 150 km thickness. Recent MHD simulations of Ganymede's magnetosphere by our group have confirmed these findings and provide better constraints on the properties of the subsurface ocean (#123).

Finally, in an important late-breaking development I have shown the presence of a strong magnetic induction signature arising from Io (Khurana et al., 2009, Fall AGU presentation) from a reanalysis of magnetic data from Galileo. This work performed with the support of a large group of colleagues at UCLA and University of Michigan suggests that the induction signature arises from high conductivity in the interior of Io from very large melt fractions (> 25%) of rocks in its interior and the possibility of a subsurface global magma ocean cannot be ruled out. I am currently writing up this work for publication in the journal Nature.

Internal fields in Jovian satellites

Another discovery of a life time in which I had the good fortune of playing a central role was in discovering an internal magnetic field in Ganymede (#31) and providing evidence for the existence of a magnetosphere around it. In a series of publications led by Prof. Kivelson (#31, #35, #52), we characterized the strong internal magnetic field of Ganymede and the properties of its magnetosphere. My role was to invert the magnetic field data using generalized inversion techniques to place strong constraints on the strength of the dipolar field of Ganymede.

In a series of publications we placed upper limits on the internal fields of the other three Galilean satellites based on Galileo magnetometer observations (#37, #39, #73 and #87). In a related work, I explore the consequence of the internal magnetic field of Ganymede on the surface of Ganymede [#116]. I showed that the boundaries of Ganymede's polar caps (polar regions on the surface of Ganymede marked by bright frost deposits) lie very close to the open-closed boundary of the magnetic field topology. This finding is consistent with the idea that Jupiter's plasma has access to the surface of Ganymede in the polar regions and creates fine frosty material through plasma sputtering. The lower latitude regions are inaccessible to plasma bombardment.

Discovery of a dynamic atmosphere at Enceladus

Another highlight of my career has been the discovery by our magnetometer team of a dynamic atmosphere at Enceladus maintained by a water plume erupting from its south pole (#107). Observations from the first two flybys of Enceladus by Cassini showed that large magnetic field perturbations were being generated around Enceladus which we (correctly) interpreted as resulting from mass-loading near Enceladus from a dynamic atmosphere. This finding was confirmed later by the imaging instruments which imaged the plume and the tiger stripes in the polar region where the plume is generated. I have modeled the observed magnetic field from the first three flybys of Enceladus (# 115) and show that the amount of plasma pick-up is quite small (1-3 kg/s). The rest of the neutral material (100-300 kg/s) escapes the exosphere of Enceladus to populate the neutral torus of Saturn. These findings have now been confirmed by detailed MHD simulations performed by Dr. Ying Dong Jia of our group (#134, #135, #136).

Research on the Jovian Magnetosphere

Structure and dynamics of Jovian magnetosphere

Over the last decade, I have studied observations from various Jupiter-bound spacecraft to understand asymmetries and convection in its magnetosphere. From a study of asymmetries in the electric current systems in Jupiter's magnetosphere, I have shown that on the dawnside of Jupiter, the convection driven by the solar wind reaches the middle magnetosphere (#70). I have also shown that the azimuthal currents are much stronger on the nightside (~ 144 MA between the radial distances of 10 and 50 R_J) than they are on the dayside (~ 88 MA in the same distance range). Continuing on the theme of asymmetries, we have now shown that the current sheet lags from the prime meridian as a strong function of local time and radial distance (paper #102) presumably because of asymmetries in plasma outflow and Alfvén velocity in the magnetosphere.

Global models of Jupiter's magnetospheric field

I have been funded by NASA to utilize the vast magnetic field dataset from Galileo, Ulysses, Voyager and Pioneer spacecraft to construct new empirical models of Jupiter's magnetospheric field. These models are required by space scientists to characterize the field and plasma environment of the magnetosphere. The models also find use in studies of particle dynamics (bounce and drift of plasma, plasma diffusion into and out of the radiation belts, changes in pitch angle distributions of plasma from convection etc. For this purpose, I construct magnetic field modules that yield the field of planetary interior, planetary current sheet, planetary magnetotail and planetary magnetopause. I have used a technique called generalized deformation method to construct the models. I am collaborating with Dr. Nikolai Tsyganenko, a well-known expert on magnetic field modeling for this project.

Research on the Saturnian Magnetosphere

I am a member of the Magnetometer team of Cassini Spacecraft Mission to Saturn. To support the team work, I am constructing a global model of Saturn's magnetospheric field on the lines of my work for Jupiter. I have already constructed an initial version of the model which I have presented at the AGU and EGU meetings and the team is now evaluating it. Further work is continuing to incorporate more data from the magnetotail. I am working on a first draft of the paper to be submitted to JGR on this topic.

One of the puzzling but exciting findings from Saturn's magnetosphere is the presence of spin period modulations in field and plasma parameters even though Saturn's magnetic field is highly axisymmetric. In paper # 128, I showed the presence of longitudinal asymmetries in field and plasma parameters in the ring current region. I further showed that the solar wind can produce an asymmetric lift in the magnetosphere in the presence of these longitudinal asymmetries of its ring current. The asymmetric lift of the magnetosphere causes a tilt to develop in the current sheet presence of a large solar elevation angle. I have recently developed a heuristic model that explains how the particle and current density longitudinal asymmetries are maintained in the magnetosphere by a synchronous reconnection process in the magnetotail. I am now writing up this work for publication in the Journal of Geophysical Research.

Research on the Saturnian Icy Satellites

In addition to the exciting results from Enceladus, I am also focused on understanding the interactions of other icy moons of Saturn with its magnetosphere. Based on magnetic field observations from Cassini, I have shown that Tethys and Rhea are inert objects devoid of any internal magnetic fields or ionospheres (#118). In this work, I also show that the sub-magnetosonic nature of the plasma interaction has interesting consequences for the absorption of plasma. Because, particles move appreciably along the field line direction over the time the upstream magnetic flux tube moves over these satellites, the ions and electrons form overlapping shadows called particle shadow wings depending on their field-aligned velocities. A major consequence of this interaction is that the plasma absorption wake is elongated appreciably in the direction of the magnetic field.

Research on the Earth's magnetosphere and the Moon

I am a co-investigator on the Cluster and THEMIS spacecraft mission that are investigating magnetic substorm processes in the Earth's magnetosphere. For Cluster II, I developed magnetometer intercalibration techniques (#24, #27, #45) which were used to determine the electric current density in the Earth's magnetosphere by performing first differences on the magnetic field measurements made by Cluster. We are using a variants of these techniques for THEMIS spacecraft to intercalibrate the THEMIS magnetometers.

Another area where I have made major contributions is in the area of magnetotail flux ropes. In a first of its kind, in paper #19, we had reported electric currents derived directly from plasma moments obtained from a plasma detector and showed that the derived values were consistent with those obtained from modeling of magnetic field data. In another major work in this area, Prof. Kivelson and I developed force-free and stress-balance models of flux ropes embedded in the current sheet of the Earth's magnetotail (#21, #25). These models can be used to evaluate the scale sizes and current strengths of flux ropes in the magnetotails of planetary magnetospheres.

Finally, I had developed a model of the bow shock of Venus based on the variable speed of the fast mode in a magnetized plasma (#15). The model was later generalized by our group to obtain a variable cross-section model of the Earth's bow shock (#41) which predicted its shape and size on the flanks of the magnetosphere extremely accurately.

Collaboration with scientist from IGPP and external institutions

I actively seek out and am invited by prominent planetary scientists for collaborations in different areas of planetary and space research. This is reflected in the diversity of my publications.

Community service

I routinely referee papers for the Journal of Geophysical Research and Geophysical Research Letters, Planetary and Space Science Letters, Annales Geophysicae and Science. Areas in which I have reviewed papers are: ULF waves in other magnetospheres, structure and dynamics of planetary magnetosphere, convection in the planetary magnetospheres, interaction of Jovian satellites with the Jovian magnetosphere, the structure and motion of planetary bow shocks, the motion of dusty plasmas and electromagnetic induction in planetary bodies.

I also routinely review funding proposals for NASA, NSF, PPARC (U.K) and Israel Science Foundation. I also participate in NASA panels to select proposals for NRA funding.

Organizational Activities

Co-organized the Division IV symposia on outer planets with Prof. Toshi Mukai and Prof. Andy Nagy for IAGA/IUGG held in Hanoi, Vietnam in August, 2001.

Organized the Division III session entitled "GAIII.14: How do the Magnetospheres of Other Planets and their Satellites Compare with the Earth's Magnetosphere?" in the IUGG meeting held in Sapporo, Japan.

Co-organized with Dr. John Cooper of GSFC a special session on JIMO magnetospheric science at the Fall AGU 2003 meeting on the topic of "Radiation-induced atmospheres, ionospheres, and surface chemistry at the Galilean moons."..

Organized Slichter Lectures delivered by Prof. Don Gurnett, April 4-8, 2005.

Organized special sessions at the spring and fall AGU meetings on icy satellites over the last five years.

Committee duties

IGPP colloquium and Conference committee 1994-1998.

IGPP Merit review committee 1997-1999.

Served on a NASA panel to define the objectives of a Europa lander to study the prebiotic chemistry. (1998-2000, Chaired by Prof. Chris Chyba).

Advised the Space Studies Board (Committee on Lunar and Planetary Exploration) on defining the specifications for the Europa Orbiter, Feb-March 1998.

Member IGPP colloquium and Conference committee 2004 – 2005.

Member National Research Council (NRC) Decadal Survey of Solar System Exploration, 2001-2002.

Member Europa Focus Group 2002-2003.

Member NRC committee COMPLEX (Committee on Planetary and Lunar Exploration) 2002-2005.

Member Space Science Board appointed committee on Nuclear Power Enabled Missions, 2004.

Member Science Definition Team (SDT) for Jupiter Icy Moon Orbiter (JIMO) 2003-2004.

Member NASA's Planetary Data System Working Group (PDSWG) 2004-2006.

Member NASA SDT for Europa Orbiter. 2005-2007.

Member NRC committee on Solar and Space Physics (CSSP). 2007-2010.

Editorial Services

Editor for Special Volume of ICARUS on JIMO magnetospheric environment papers. 2004.

Edited the special volume of Advances in Space Research, JASR-D04, 2006 on Cassini related science papers.

Edited a book on "Europa" in University of Arizona Press Space Science Series with co-editors, Robert Pappalardo of JPL and Prof. William McKinnon of Washington State University, 2009.

Honors, Awards

NASA Group achievement awards, for Galileo (1991, 1993, 1995 and 1998), for Jupiter Icy Moon Orbiter Science Definition team (2005), for THEMIS (2008) and for Cassini (2009).

Reporter Reviewer for division III of IAGA on the topic of “Magnetospheres of the outer planets” 2001-2004.

IGPP Distinguished Researcher Award, 2004.

Memberships of professional bodies

Member: American Geophysical Union

Associate Member: American Physical Society

Associate Member: Division of Planetary Sciences, American Astronomical Society.