

University of Southern California
Space Sciences Center
Department of Physics and Astronomy
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The following report covers activities from September 2002 through August 2003.

1. INTRODUCTION & PERSONNEL

Research in astronomy and the space sciences at USC is carried through in the Space Sciences Center and Department of Physics and Astronomy. Personnel include: 1. Space Sciences Center: Dr. Darrell L. Judge, Professor and Director of the Space Sciences Center, Dr. Geraldine J. Peters & Dr. C. Y. Robert Wu, Research Professors, Dr. Pradip Gangopadhyay, Dr. Andrew Jones, & Dr. Howard S. Ogawa, Research Scientists, Mr. Matthew Harmon, Industrial Design Engineer, Mr. Hosein Ghadimi, Engineering Technician, Cedrick Ngalande, Research Assistant, and Donald McMullin, Project Manager (through 2003 June), and 2. Department of Physics & Astronomy: Dr. Werner Däppen & Dr. Edward J. Rhodes, Jr., Professors, Dr. Vladimir Baturin, Postdoctoral Fellow, Dr. Zhigang Gong, Lecturer, Aihua Liang, Chia-Hsien Lin, Dan Mao, Katie Mussack, Jeffrey S. Nuttall, & Perry Rose, graduate students, and Dr. Melvin Daybell & Dr. Gibson Reaves, Professors Emeritus. Judge, Peters, and Wu are also affiliated with the Department of Physics & Astronomy.

2. RESEARCH

W. Däppen continued his research on using the Sun as a plasma physics laboratory. To pursue this goal, he participates in state-of-the-art solar modeling and the analysis of helioseismic data. Helioseismology is the first accurate “experiment” that puts strong constraints on the thermodynamic quantities of the plasma of stellar interiors. His own contribution to the field [the Mihalas-Hummer-Däppen (MHD) equation of state] is currently being used in collaboration with several international solar and stellar modeling groups. One of his current activities is devoted to the subtle thermodynamic effects of excited states in atoms and ions of the solar interior. Such effects have been detected by helioseismology. On the one hand, the effects have to be taken into account in the helioseismic determination of the helium abundance of the solar convection zone to enhance the reliability of the method. On the other hand, for the heavy elements, there are direct observations of the abundances, and here, a study of the excited-states effect gives information about the microphysics of the solar plasma. Very recently, W. Däppen, in collaboration with his current graduate students, has started to work with molecular-dynamics (MD) simulations of a plasma under solar-center conditions. Thermodynamic and nuclear-physics effects are targeted by this research. In August 2003, W. Däppen’s student Chia-Hsien Lin graduated with a PhD, and she has since moved to Armagh Observatory (Northern Ireland) to work as a postdoctoral fellow in solar physics.

P. Gangopadhyay, V. Izmodenov, M. Gruntman (Dept. of Aerospace Engineering), and D. L. Judge continue work on the interpretation of *Pioneer 10* and *Voyager Ly α* data. They have used the latest state of the art supersonic VLISM neutral hydrogen plasma and a Monte Carlo radiative transfer model, incorporating neutral hydrogen density, temperature, and velocity variations, actual solar line shape, a Mihalas Case II redistribution function, Doppler, and aberration effects. The Monte Carlo simulations for a number of neutral hydrogen models and the comparison with *Pioneer 10* and *Voyager 2* data have been discussed and presented.

D. L. Judge and A. R. Jones developed instrumentation for the Solar Dynamics Observatory (SDO) instruments continuing through Phase A with a successful presentation at GSFC of the Phase-A concept for the EUV Spectrophotometer (ESP) and Optics Free Spectrometer (OFS) concepts. The ESP is a direct descendent of the SOHO SEM instrument using the same EUV transmission grating technology developed at MIT. The ESP increases the number of spectral lines observed over SEM and will have a quadrant detector in the central-order to provide in-flight pointing information. The OFS is an extension of the Sounding Rocket instruments. A breadboard gas-system and analyzer has been constructed and tested to demonstrate viability of the OFS concept. As part of the SDO effort Judge and Jones have undertaken the development of a relatively simple radiation shield model to assess the required particle shielding needed to protect the relatively sensitive detectors we plan to fly on SDO. Experimental verification of the models is planned at the Idaho Accelerator Center in Early December 2003.

Jones and Judge continued work on the “Micro Light” double grating monochromator, an ultra light-weight double transmission grating instrument for solar or planetary atmospheric studies. A breadboard instrument has been built using commercial components and the very high ruling density transmission gratings developed by MIT. The gratings provide very strong ‘white’ light rejection. The plan is to develop a flight instrument that is not dependent on thin-film filters for ‘white light’ rejection, greatly increasing the stability and wavelength flexibility over current designs. Work on characterizing the gratings of different ruling densities was performed at NIST and USC, leading to an improved understanding of the grating behavior. The team is especially interested in ‘Blaze-like’ effects that improve the response for a specific wavelength by tilting the grating in the dispersion plane. This arises due to the finite thickness of the grating and guided-wave effects down the grating grooves. These effects are being investigated both experimentally and with a mathematical model. The SOHO SEM instrument continues to function nominally, despite a slight interruption of data due to spacecraft problems during the early Summer. A Sounding Rocket calibration under flight will be flown in

early December 2003 within an hour of an EIT calibration flight by the Naval Research Labs that will hopefully provide the best inter calibration of EIT and SEM so far achieved. The sounding rocket instrumentation and layout is identical to last years successful flight. Don McMullin left to work for Praxis/NRL though he is still helping to support both the sounding rocket and SDO programs.

G. J. Peters continued her long-standing study of Be Stars. She collaborated with D. R. Gies (Georgia State University) on an the analysis of very short-term *line profile variability* in π Aqr, a Be star that lost its circumstellar disk in the mid-1990s. Time series spectra taken with the Coudé Feed Telescope at KPNO in November 1999, October 2000, and January 2001 show prominent traveling ‘bumps’ in the profiles of all prominent absorption lines in the H α region (including He I 6678 Å, H α , and C II 6678,83 Å) with a period of ~ 1.88 hr. The observations are interpreted as nonradial pulsations with $\ell = -m = 5 \pm 1$. Peters organized and chaired the scientific session of the meeting of the Working Group on Active B Stars (WGABS) at the IAU General Assembly in Sydney. She also presented an invited talk on ‘‘Contemporary Directions in Be Star Research’’ at the Division V (Variable Stars) scientific session. Peters continues to serve as Editor-in-Chief of the *Be Star Newsletter*, a periodical published in both paper (D. R. Gies, GSU, technical editor) and electronic (<http://www.astro.virginia.edu/dam3ma/benews/>, D. McDavid, Univ. of Virginia, technical editor) editions for the WGABS of the IAU Divisions IV and V. Peters was elected by the AAS membership to a post on the US National Committee for the IAU for a term that runs from 2004 January 1 to 2006 December 31.

Peters continued a collaboration with R. S. Polidan (NASA’s GSFC) on the interpretation of *FUSE* data on the Algol binaries. Observations of V356 Sgr, TT Hya, and RY Per taken during totality reveal emission from O VI in all three systems. The high temperature plasma ($\sim 300,000$ K) that produces these lines appears to exist above/below the orbital plane and may be a bipolar flow that could be commonplace in Algol systems. *FUSE* observations of RY Per at phases 0.20, 0.57, 0.97, and 0.00 combined with archival *IUE* images of this system, suggest that the bipolar flow may be the result of a splash that occurs at the site of the gas stream impact. Since the CS material in the bipolar flow in RY Per flow appears to be quite depleted in carbon and but nitrogen rich, support is rendered to the above suggestion. Analysis of emission line data from O VI, C III, N II, N III, and Fe III is in progress. Peters presented a talk on the *FUSE* observation at JD09 (Astrotomography) at the IAU General Assembly in Sydney. Peters continues an extensive a study of the abundances of the heavy elements in early B stars that reside both in our galaxy and the Magellanic Clouds. In one project with S. J. Adelman (The Citadel) and C. R. Proffitt (CSC/STScI), she is determining the abundances of the Fe group and s-process species in 17 cluster and field O9-B6 main sequence band objects using coadded HIRES images from the *IUE* archives. The coadded data will be delivered to the MAST archive at STScI along with overplots of the best fitting synthetic spectra. The latter efforts will be enhanced with new *HST*/STIS SNAPSHOT echelle spectra of up to 33

B stars that will be acquired during HST/Cycle 12, in collaboration with S. J. Adelman, C. R. Proffitt, T. Lanz (University of Maryland), I. Hubeny (NASA’s GSFC), and J. Pickering (University College London). The abundances of the Fe group elements in sharp-lined B stars in the Magellanic Clouds are being determined (with S. J. Adelman) from new *FUSE* spectra of AV 304, NGC346-11, and NGC346-637 in the SMC, and NGC 1818-D1, NGC 2004-B15, and NGC 2004-B30 in the LMC. The abundance studies provide information on the chemical evolution of our galaxy and the Magellanic Clouds as well as important data for determining the opacities in stellar interiors used in stellar evolution calculations.

G. Reaves continues the activities reported in *BAAS*, 35, 415, 2003, but now at a slower pace. He donated his lecture notes from undergraduate courses given by S. Herrick at UCLA (1943 and 1946-47) and from graduate courses given by L. E. Cunningham and L. G. Henyey at UC Berkeley (1947-49) to the Niels Bohr Library, Center for History of Physics of the American Institute of Physics.

E. J. Rhodes continues to run the 60-Foot-Solar-Tower at the Mt. Wilson Observatory as P.I. for the high-resolution helioseismology project that has been in operation since 1985. The telescope is operated by A. Grubb and S. Irish on every clear day collecting a series of mega-pixel sodium filtergrams obtained with the Magneto-Optical-Filter taken at a cadence of two per minute. The team continues to process the filtergrams to dopplergrams and subsequently to a reduced data product on a daily basis, adding to the growing archive of over 9 Terrabytes. The group has started a collaborative effort with the Solar Oscillation Investigation group at Stanford University to archive dopplergrams collected at the 60-Foot-Solar-Tower. Data is stored at the MDI Science Center and made available on-line at <http://soi.stanford.edu/sssc/progs/mwo>. The data will be used to support the Michelson-Doppler-Imager experiment onboard the SOHO spacecraft, and to study Solar Cycle 22, prior to the start of MDI. Rhodes and J. Reiter, Technical University of Munich, Germany, are continuing their collaboration in developing techniques for fitting power spectra to obtain the high-degree p-mode frequencies that are trapped within the outer radius of the sun. Much work has already been done in correlating the frequency shifts of the p-modes with the changing levels of solar activity by utilizing dopplergrams collected by the 60-Foot-Solar-Tower and the Michelson-Doppler-Imager (MDI) on board the SOHO spacecraft. Recently, P. Rose has extended the data set by utilizing data collected by the Global Oscillation Network Group. The helioseismology group continues to collaborate with the Crimean Astrophysical Observatory and maintains another helioseismic instrument at the 60-Foot-Solar-Tower for the Birmingham Solar Oscillation Network (BiSON) in the UK.

C. Y. Robert Wu has continued his work with F. Z. Chen, T. Hung, D. L. Judge, T. Matsui, and K. Ito in the measurements of (1) temperature dependent photoabsorption cross sections of C₂H₄, cyclopropane, and methylethylene in the VUV region and (3) ultrahigh resolution (FWHM=0.0003 nm) absorption cross sections of O₂ in the 110 nm region under high temperature conditions (e.g. up to 550 K). The

above data will be made available to the planetary and aeronomy communities in application to various models of planetary atmospheres such as Earth, Saturn, Mars, Io, Titan, Jupiter, Saturn, and Neptune. Wu has recently implemented a joint research project with B-M. Cheng of the National Central University and the Synchrotron Radiation Research Center, Hsinchu, Taiwan, and T-S. Yih and W. H. Ip of the National Central University, Chungli, Taiwan, in the study of EUV-VUV photon-induced chemical reactions in pure, binary, and tertiary mixed ices at temperatures as low as 10 K. The recent studied samples include pure ices of CH₄ and CO and mixed ices of CO+H₂O and N₂+NH₃+H₂O. The results obtained in this project are important to our understanding of chemical syntheses in ice analogs, e.g., the cometary-type ices and icy satellites of the giant planets.

PUBLICATIONS

The publication list includes papers published or submitted between 2002 September 1 and 2003 August 31 by permanent staff. Selected published abstracts of presentations at scientific meetings are also included.

- Baturin, V.A. & Däppen, W.** 2003, "Equation of State for the Internal Structure of Solar-Type Stars" [translated from *Astronomicheskii Zhurnal*, **80**, No. 8, p. 744-752], *Astronomy Reports*, **47**, No. 8, 685.
- Chen, F.Z., & Wu, C.Y.R.** 2003, "Temperature Dependent Photoabsorption Cross Sections in the VUV-UV Region. I. Methane and Ethane," *J. Quant Spec. Radiat. Transf.*, in press.
- Chen, F.Z., Judge, D.L., & Wu, C.Y.R.** 2003, "VUV Photoabsorption Cross Sections of C₂H₄ (Ethylene), C₃H₆ (Cyclopropane), C₃H₆ (Methyl Ethylene)," *BAAS*, **35**, 940.
- Däppen, W.** 2002, "Helioseismic Studies of Dense Plasmas," in *Inertial Fusion Science Applications 2001*, eds. K.A. Tanaka, D.D. Meyerhofer & J. Meyer-ter-Vehn (Elsevier, 2002), 946.
- Däppen, W.** 2003, "Solar Constraints on the Equation of State," in *Astrophysical Fluid Dynamics*, eds. M.J. Thompson & J. Christensen-Dalsgaard (Cambridge University Press, 2003), 179.
- Gangopadhyay, P., Izmodenov, V., Quemerais, E., Gruntman, M., & Judge, D.L.**, 2003, "Interpretation of Pioneer 10 and Voyager 2 Ly α data: First results," submitted to *Adv. Space Res.*
- Izmodenov, V., **Gangopadhyay, P., Gruntman, M., & Judge, D.L.** 2003, "Interstellar Pioneer 10 EUV data: Possible Constraints on the Local Interstellar Parameters, Solar Wind X conference, 2002.
- Liang, A., & Däppen, W.** 2003, "Modifications of the Equation of State to Achieve Desired Changes in Thermodynamic Quantities," in *Proc. SOHO 12/GONG+ 2002 Workshop* (ESA SP-517, Noordwijk, The Netherlands), 333.
- Lin, C.-H., & Däppen, W.** 2003, "Helioseismic Constraints on the Chemical Composition and the Equation of State," in *Proc. SOHO 12/GONG+ 2002 Workshop* (ESA SP-517, Noordwijk, The Netherlands), 337.
- Lin, C.-H., & Däppen, W.** 2003, "Investigating Inversion Uncertainties Resulting from Mode Selections," in *Proc. SOHO 12/GONG+ 2002 Workshop* (ESA SP-517, Noordwijk, The Netherlands), 341.
- Lin, C.-H.** 2003, "Helioseismic Inversion Procedures to Probe the Chemical Composition and Thermodynamics of the Sun," PhD Thesis (USC 2003).
- Lin, C.-H., & Däppen, W.** 2003, "An Inversion Procedure to Investigate the Equations of State and Chemical Composition of the Sun," *ApJ*, submitted.
- Peters, G.J.** 2003, "The Nature of Short-Term, Long-Term, and Transient Wind Activity in Be Stars," in *Interplay Between Periodic, Cyclic, and Stochastic Variability in Selected Areas of the H-R Diagram* (ASP Conf. Ser. Vol. 292), ed. C. Sterken (San Francisco: ASP), 227.
- Peters, G.J., & Adelman, S.J.** 2003, "The Abundances of the Fe Group Elements in the SMC B0.5V Star AV 304 Determined from the Analysis of FUSE Data," *BAAS*, **34**, 1285.
- Peters, G.J., & Grigsby, J.A.** 2003, "The Abundances of the Iron Group Elements in AV 304, a Sharp-Lined B0.5 star in the Small Magellanic Cloud," *ApJ*, submitted.
- Peters, G.J., & Polidan, R.S.** 2004, "Eclipse Mapping of the Hot Circumstellar Plasma in Algol Binaries," *Astron. Nachr.*, **325**, in press.
- Reiter, J., A.G. Kosovichev, **E.J. Rhodes, Jr.**, and J. Schou 2003: "Accurate Measurements of SOI/MDI High-Degree Frequencies and Frequency Splittings," in *Local and Global Helioseismology: The Present and Future*, ed. A. Wilson, ESA SP-517, in press.
- Trampedach, R., **Däppen, W. & Baturin, V.A.** 2003, "A Synoptic Comparison of the MHD and the OPAL Equations of State," *ApJ*, in press.
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- Wu, C.Y.R., Chen, F.Z., & Judge, D.L.** 2003, "Temperature Dependent Photoabsorption Cross Sections in the VUV-UV Region. II. Ethylene," *Journal of Geophysical Research*, submitted.
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Geraldine J. Peters