Laboratory Astrophysics

Report

NASA Laboratory Astrophysics Workshop
University of Nevada, Las Vegas
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NAS Plasma Science Committee
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Laboratory Astrophysics

...is the “Rosetta Stone” that enables astronomers and astrophysicists to unlock the mysteries of the cosmos.

Laboratory Astrophysics

A working definition

- The studies are aimed at improving our ability to analyze, interpret, model, and predict the properties of objects throughout the cosmos.
- The work is driven by missions, observatories, and the parameter space of expected physical conditions.
- It consists of theoretical and experimental work on atoms, molecules, solids, (particles/neutrinos), (nuclear material), and (plasmas).

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More specifically

- Laboratory astrophysics is observation driven.
- Many of these observations are spectral in nature.
- Spectra are produced by atomic, molecular, and optical (AMO) processes.
- AMO physics is the key to unlocking deeper messages in the spectrum.

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Recent exciting results:

- Halo star abundance determinations using new laboratory oscillator strengths suggest that two different rapid neutron-capture processes may exist.
- Theory and experiment have shown that cometary X-ray emission is due to charge exchange between solar wind ions and neutrals in the cometary coma.
- The detection and identification of molecules in space is mainly the result of previous high-resolution laboratory spectroscopy.

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Some exciting new developments:

- Atmospheric studies of extra-solar planets and their atmospheres use synthetic stellar atmosphere models. These require detailed theoretical and experimental atomic, molecular, and optical data.
- Interstellar Medium studies probe the evolutionary pathway towards life. These require spectroscopic data for organic molecules and understanding the chemical networks by which they are formed.
- Models of protogalaxy and first star formation are approaching the point where a fully ro-vibrational early universe chemistry is needed.

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Atomic data

- Wavelengths.
- Oscillator strengths and transition probailities.
- Photo-excitation and ionization cross sections.
- Collisional excitation and ionization cross sections.
- Ion recombination cross sections.

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Molecular data

- High resolution spectroscopy.
- Line assignments.
- Collisional excitation.
- Chemical reactions and products.
- Formation and destruction mechanisms.
- Reaction pathways.
- Three body reactions.
- Pressure and temperature dependent reactions.

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Solid material data

- Properties of dust grains.
- Dielectric constants.
- Emission features.
- Optical properties.
- Surface reactions.
- Covering gas-phase molecules to nanoparticles to bulk material.
- X-ray spectroscopy and absorption edges.

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Past NASA Laboratory Astrophysics Workshop

- 1998 Harvard-Smithsonian Center for Astrophysics.
- 2002 NASA Ames Research Laboratory.
- 2006 University of Nevada, Las Vegas

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2006 NASA Laboratory Astrophysics Workshop

- Two days of invited lectures (by users), short contributed talks (users and providers), and a poster session.
- Third day devoted to breakout sessions (atoms, molecules, and solid material).
- 86 participants.
- www.physics.unlv.edu/labastro
- Led to White Paper.

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Scientific Organizing Committee:

- Nancy Brickhouse – Harvard-Smithsonian CfA
- Steve Federman - University of Toledo (Chair)
- Victor H. S. Kwong - University of Nevada
- Farid Salama - NASA Ames Research Lab
- Daniel Savin - Columbia University
- Phillip Stancil - University of Georgia
- Joe Weingartner - George Mason University
- Lucy M. Ziurys - University of Arizona

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General Findings Include:

- A study of the importance of laboratory astrophysics for all of astronomy under the auspices of the National Research Council and involving NASA, NSF, DOE, and DoC/NIST is long overdue.
- The data requirements for advances in astrophysics from NASA missions are more often than not the same requirements for DOE-sponsored research on plasmas and NSF-sponsored astronomical research. The need for critical evaluations of available data highlights the close connection to DoC/NIST and DOE.

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General Findings (cont.):

- There is an urgent need to maintain the infrastructure, in terms of both personnel and facilities.
- Databases are needed of atomic, molecular, and solid state parameters that are complete (e.g., wavelength lists for all stages of ionization) and also critically evaluated.
- As we probe earlier into the Universe, phenomena associated with high energies (short wavelengths) are redshifted and observed with instrumentation designed for low energies (long wavelengths).

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Data Needs (spanning wavelengths and fields):

far infrared/sub-millimeter – spectroscopy of simple hydrides and larger organic molecules; collision cross sections; chemical reaction rates; photoabsorption cross sections; optical constants of solids.

x-ray and infrared – dielectronic recombination, charge exchange, and electron impact ionization data; photoionization cross sections; surface reactions; particle/photon bombardment of solids and ices; optical constants of solids.

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Data Needs (cont.):

ultraviolet/visible – atomic and molecular spectroscopy; oscillator strengths; photoabsorption cross sections; chemical reaction rates; collision cross sections; optical constants of solids.

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Databases:

- Critically evaluated data are needed by those analyzing astronomical measurements and modeling the associated environments.
- True astrophysical understanding requires collections of the highest quality data.
- The relevant agencies and departments need to coordinate their efforts. Database compilation and the associated, vital critical evaluation, is a skill that is developed over decades in many cases. Long term commitment of funds is essential.

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Recommendations:

- Conduct a study of the importance and need of laboratory astrophysics for all of astronomy under the auspices of the National Research Council (NRC) and involving the principal funding sources for astronomical research, NASA and NSF, as well as DOE and DoC/NIST, whose activities encompass similar areas of study.
- Increased support for laboratory astrophysics.
- Mission support of laboratory astrophysics is important.

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Recommendations (cont.):

- There is a need to provide adequate support for databases.
- Higher visibility among the astronomical community is required. A Working Group of the AAS has been proposed with close ties to IAU Commission 14.
- Another laboratory astrophysics workshop should take place in four years. With NASA as the lead agency, other agencies and departments (NSF, DOE, DoC/NIST) should be active partners in this workshop.

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The NRC Report should include:

– how to support the development and maintenance of laboratories and their unique instrumentation for ground-breaking research.

– how to encourage and retain faculty in this area, in terms of ensuring the future supply of laboratory astrophysicists and in maintaining and revitalizing infrastructure in the field.

– how to foster graduate student participation and PhD theses in these areas to strengthen an exciting and enabling area of research.

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The NRC Report should also include:

– how to coordinate the activities of the agencies and departments that benefit from a robust effort in laboratory astrophysics.

– how to combine interdisciplinary teams and/or centers while continuing to support ground-breaking ideas of individual researchers that could potentially revolutionize aspects of astrophysics.

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Bottom Line...

Laboratory astrophysics, like detector and instrument development, is a necessary ingredient for making full use of astronomical facilities.

Laboratory astrophysics research should be initiated early in a program and should continue during the life of the program, as new questions arise.

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Postscript – suggestions from the Astronomy and Astrophysics Advisory Committee (AAAC) of the National Science Foundation:

Become members of mission science teams during the proposal process.

Actively participate in the next Astronomy and Astrophysics Decadal Survey from the National Research Council.

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Postscript – one conclusion from the NRC Decadal Survey "AMO 2010: An Assessment of and Outlook for Atomic, Molecular, and Optical Science":

> AMO science is an enabling component of astrophysics and plasma physics but is not adequately supported by the funding agencies charged with responsibility for those areas.

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Postscript – response of the National Academy of Science Board on Physics and Astronomy:

A study of laboratory astrophysics, broadly defined, would be appropriate and the staff would consult with the relevant agencies and departments to determine how to proceed.

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Postscript – response of the American Astronomical Society (AAS) Executive Council:

at the 209th AAS Meeting, January 2007 in Seattle, set up a steering committee to formulate By-laws for a Laboratory Astrophysics Working Group.