Nuclear Science Opportunities at NIF

Report on National Ignition Facility Workshop

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Developments

Nuclear Astrophysics at the National Ignition Facility
August 27-30, 2007, Lawrence Livermore National Laboratory, USA

1st report to Ed Moses on Opportunities for Nuclear Astrophysics at NIF submitted April 2009
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Neutron-Capture Nucleosynthesis at the National Ignition Facility
March 23 - 25, 2010, Lawrence Berkeley National Laboratory, USA

JINA/NIF Workshop
Nuclear Physics in Hot Dense Dynamic Plasmas
London Centre of the University of Notre Dame
London, UK, March 13-14, 2011

55 participants from 28 institution and 8 countries, representing the nuclear physics and astrophysics community. Presentations have been made available at the web: http://www.jinaweb.org/events/NP2011/
Developments & Conferences

2011 NIF Workshop

Sponsored by: the National Nuclear Security Administration
Hyatt Crystal City, May 10 - 12, 2011

Chairs:
John Sarrao, Los Alamos National Laboratory
Kimberly Budil, Lawrence Livermore National Laboratory
Michael Wiescher, University of Notre Dame

Panel Chairs:
Laboratory Astrophysics
R. Paul Drake, University of Michigan

Nuclear Physics
William Goldstein, Lawrence Livermore National Laboratory
Richard Petrasz, Massachusetts Institute of Technology
Michael Wiescher, University of Notre Dame

Materials in Extremes and Planetary Physics
Russell Hemley, Carnegie Institution of Washington

Beam and Plasma Physics
Chan Joshi, University of California, Los Angeles
Warren Mori, University of California, Los Angeles
Margaret Murane, University of Colorado, Boulder
Alan Wooton, Vector Resources

Cross-Cut/Facility-User Issues
Roger Falcone, Lawrence Berkeley National Laboratory

3/7/2012 NSAC Meeting Bethesda MD
Recommendations

Plasma Nuclear Physics as an important component in nuclear astrophysics. The program will concentrate on the environmental effects of hot dense plasmas on nuclear reaction and decay processes in stellar interiors. This affects primarily nuclear processes in stellar plasma environments. Discussion focused primarily on possible nuclear astrophysics applications includes low energy plasma screening, electron capture processes at high densities, and thermal excitation effects in neutron capture reactions.

Nuclear physicists have made major advances in understanding the origin of the elements using a suite of accelerator facilities for cross-section measurements. Many gaps in that understanding will be addressed by future facilities, including the Facility for Rare Isotope Beams (FRIB) and Deep Underground Science and Engineering Laboratory (DUSEL), which are expected to be available in the ten-year time frame. But even with these new capabilities, a full, experimentally validated picture of nucleosynthesis will be missing, because critical elements of the phenomena—interaction between the nuclear processes and the plasma environment in which they take place—cannot be accessed.

Experiments at the NIF will certainly manifest these interactions. Work underway now—including diagnostic development, experimental design, and preliminary measurements—suggests that NIF experiments can be designed to observe and measure this interaction and its effects. Such a program of nuclear physics at NIF would be complementary, and possibly equally important, to programs planned at FRIB and DUSEL in solving the problem of nucleosynthesis. Without such plasma-based experiments, our increased understanding from these future facilities will remain incomplete.
Scientific Opportunities

- Plasma coupling to nuclear excitation and decay processes
- Plasma screening effects in low energy charged particle capture reactions
- Thermal excitation of low level states and impact on neutron capture reactions
- Density dependence on electron capture processes ($^7$Be, $^{44}$Ti)

Naturally addresses important questions in nuclear astrophysics and matches the overall goals/needs of the broadly interdisciplinary nuclear astrophysics community.
Nuclear Astrophysics

SN Ia
- screening
- C, O fusion
- He-induced reactions
- electron capture

Star formation

Short XRB
- hot CNO cycles
- ap-process
- rp-process
- EC rates
- pycnonuclear fusion

Neutron

SN II
- r process
- vp process
- p process
- EC rates
- radioactivity ($^{26}$Al, $^{44}$Ti, $^{56}$Ni, $^{60}$Fe)

Nova
- hot CNO cycles
- Ne-Ca burning

Star
- pp-chains
- CNO cycles

White Dwarf

Red Giant
- He-burning
- neutron sources
- s-process
- C, O fusion rates
Reliable diagnostics of temperature, density, neutron flux, gamma flux is performed with X-ray imaging, $\gamma$-radiation, MRS Neutron spectrometer, and neutron-ToF systems. While knowledge of shock environment and timescale is essential new diagnostic tools for science program are required.
Gamma & neutron flux environment

Gamma & Ray Energy (MeV)

DT
D
C
Au
Al
Si
Total

12C(n,γ)
D(n,γ)
12C(n,n'γ)
13.5-14.5 ≈13%
0-1 MeV ≈65%

D+T
≈45%
1-2 MeV ≈65%

D+D
T+T

0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0
Neutron Energy (MeV)

1.0E+12 1.0E+11 1.0E+10 1.0E+09 1.0E+08 1.0E+07
Neutrons/MeV

1.0E+07 1.0E+06 1.0E+05 1.0E+04 1.0E+03 1.0E+02

N11103 Post-shot Simulated Neutron Spectrum

Import
CD-foil

MRS

Fiber light insertions

Off-axis Parabolic Mirror

NIF Shield

Pressure Window

PM

W

Mach Zehnder

6 m from TCC

CO2 or SF6

10 cm (Ω)
26 cm (NIF)
210 cm (Ω)
570 cm (NIF)

3-18 MeV (d)

3/7/2012
NSAC Meeting Bethesda MD

courtesy: Wolfgang Stoeffl LLNL

courtesy: Lee Bernstein, LLNL
Nuclear Astrophysics with neutrons

$s$-process

$^{197}\text{Au}(n,\gamma)^{198}\text{Au}$ as benchmark for mapping the thermal neutron contribution, future reactions may serve as benchmarks for reactions on thermally excited states.

Activation measurement results indicate high thermal flux

n_tof experiment on $^{197}\text{Au}$ groundstate

$^{197}\text{Au}(n,2n)^{196}\text{Au}$

$^{197}\text{Au}(n,\gamma)^{198}\text{Au}$

*N111103 DT cryo with $Y_{14}=5\times10^{14}$

Courtesy: Lee Bernstein LLNL
Reaching stellar energies

$^3\text{H}(t,n)^5\text{He}(n)^4\text{He}$ from accelerator experiments

$^3\text{H}(t,n)^5\text{He}(n)^4\text{He}$ from NIF MRS experiments

Three body break-up with a strong final state interaction?
Model calculations performed.

C. Wong et al., Nuclear Physics 71, 106 (1965).
$^3\text{He}+^3\text{He}$ plasma screening

LUNA underground measurement with proton spectrum at $E_{\text{cm}}=30\text{keV}$

Omega laser plasma measurement with proton spectrum at $E_{\text{cm}}=90\text{keV}$

Low energy experiments at plasma conditions are feasible; this provides unique opportunity to probe reaction plasma interaction.
Connections to other Fields

Hydrodynamic studies of the evolution of convection and mixing or rapid Rayleigh Taylor instabilities from late stellar evolution to supernovae as shock driven plasma events.

Material evolution towards extreme densities as anticipated for neutron star crust and white dwarf core environments.

Planet formation, condensation at high density, shock impact, conditions and nature of exo-planets.

Astro-Biology, formation of organic molecules in dense ice materials under intense radiation exposure during a NIF shot.
Complementary Activities

ELI-Beamlines Facility, Czech Republic
intense beams

Orion, AWE, UK

ELI-Attosecond Facility, Hungary
fast timing

ELI-Nuclear Physics Facility, Romania
intense photon beams.

European efforts
US-European Workshop

sponsored by GSI ExtreMe Matter Institute EMMI and Joint Institute of Nuclear Astrophysics JINA

Coupling the US and European nuclear, plasma & high density physics communities to formulate a list of scientific goals in astrophysics

Notre Dame London Centre at Trafalgar Square:
October 14-15, 2012