Nuclear Science Opportunities at NIF

Report on National Ignition Facility Workshop

Michael Wiescher
University of Notre Dame

Developments

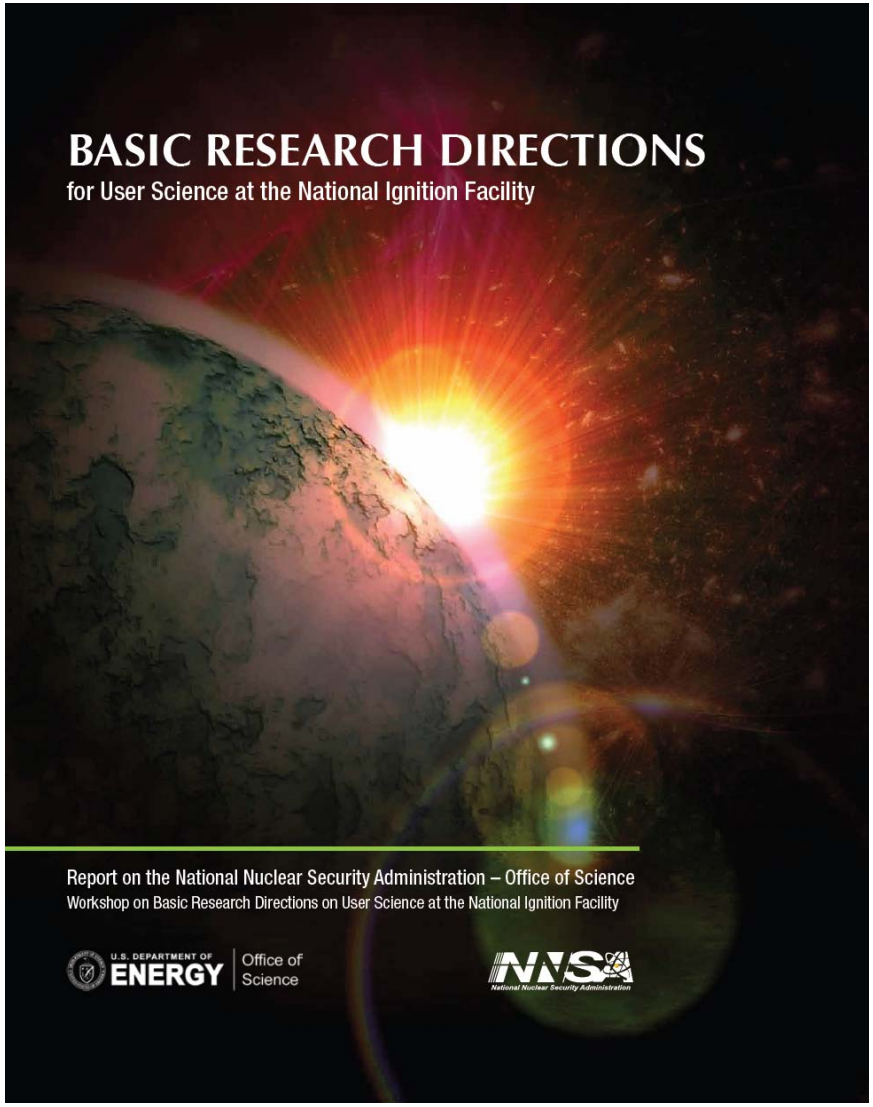
Nuclear Astrophysics at the National Ignition Facility
August 27-30, 2007, Lawrence Livermore National Laboratory, USA

1st report to Ed Moses on Opportunities for Nuclear Astrophysics at NIF submitted April 2009
K. Langanke & M. Wiescher

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

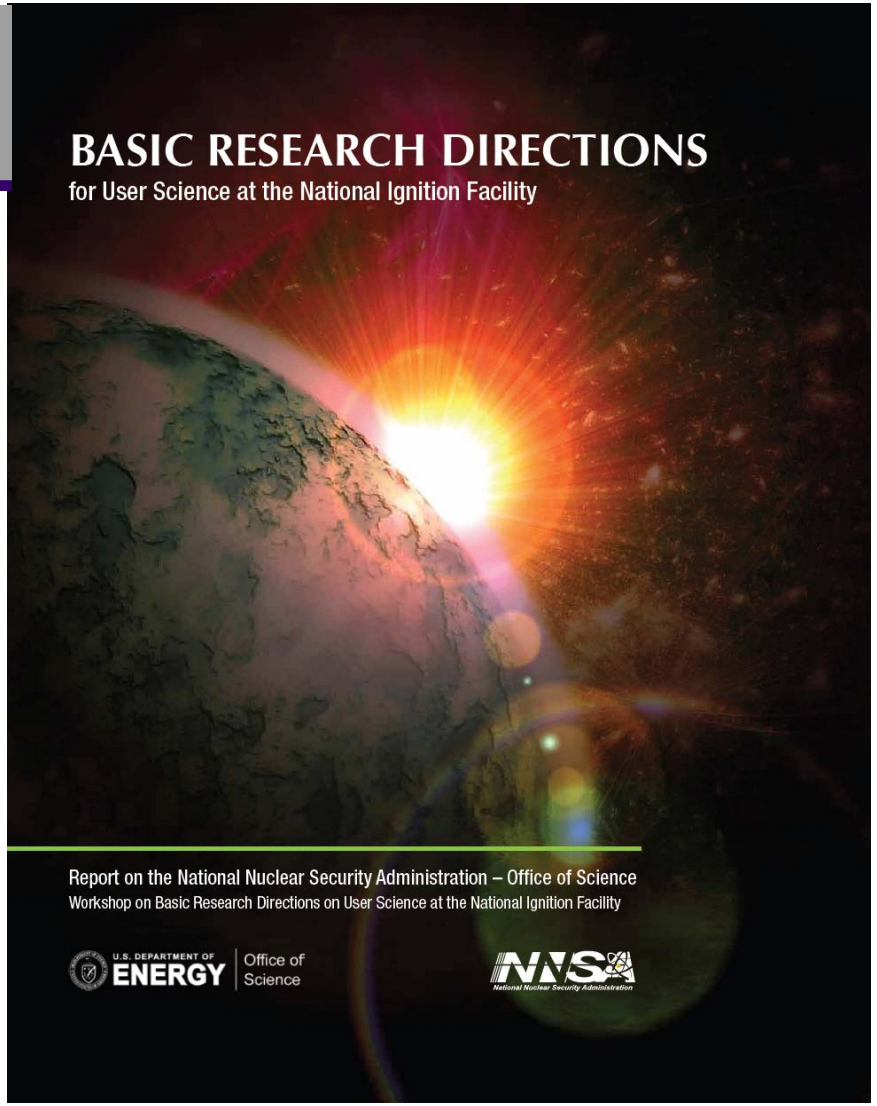
2011 NIF Workshop

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

National Nuclear Security Administration

U.S. DEPARTMENT OF ENERGY | Office of Science

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 Petrasso, 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 Murnane, University of Colorado, Boulder Alan Wootton, Vector Resources
	Cross-Cut/Facility-User Issues Roger Falcone, Lawrence Berkeley National Laboratory



Recommendations

Nuclear Physics Panel Members

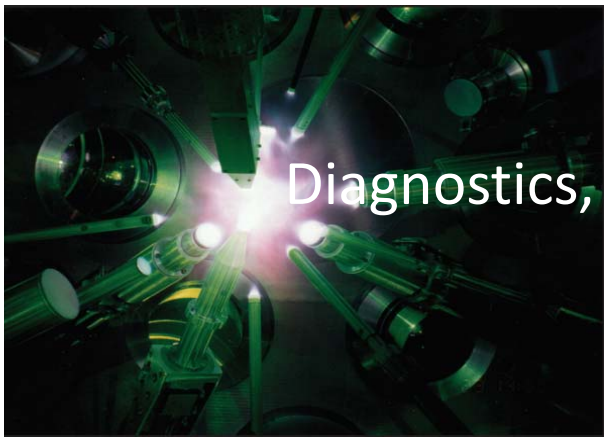
Ani Aprahamian (ND)
Radha Bajukutumbi (LLE)
Jolie Cizewski (Rutgers)
Aaron Couture (LANL)
Kurt Fletcher (SUNY Geneseo)
Stefan Frauendorf (ND)
Johan Frenje (MIT)
Bill Goldstein (LLNL)
Anna Hayes LANL)
Hans Hermann (LANL)
Ken Ledingham (Strathclyde)
Dennis McNabb (LLNL)
Joe Natowitz (Texas A&M)
Richard Petrasso (MIT)
Tomasz Plewa (FSU)
Udo Schröder (Rochester)
James Symons (LBNL)
Michael Wiescher (ND)

Plasma Nuclear Physics as 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.

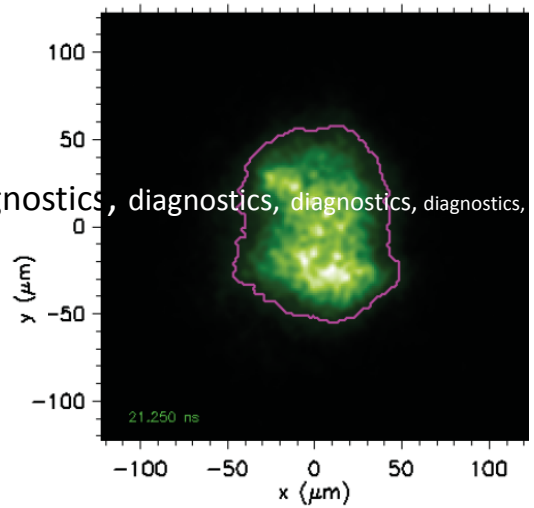
Experiments at the NIF will certainly manifest these interactions. Work underway now—including diagnostic development, experimental design, and preliminary measurements—suggests that NIF experiments can be designed to observe and measure this interaction and its effects. Such a program of nuclear physics 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



Diagnostics, diagnostics, diagnostics, diagnostics, diagnostics, diagnostics, diagnostics, diagnostics,

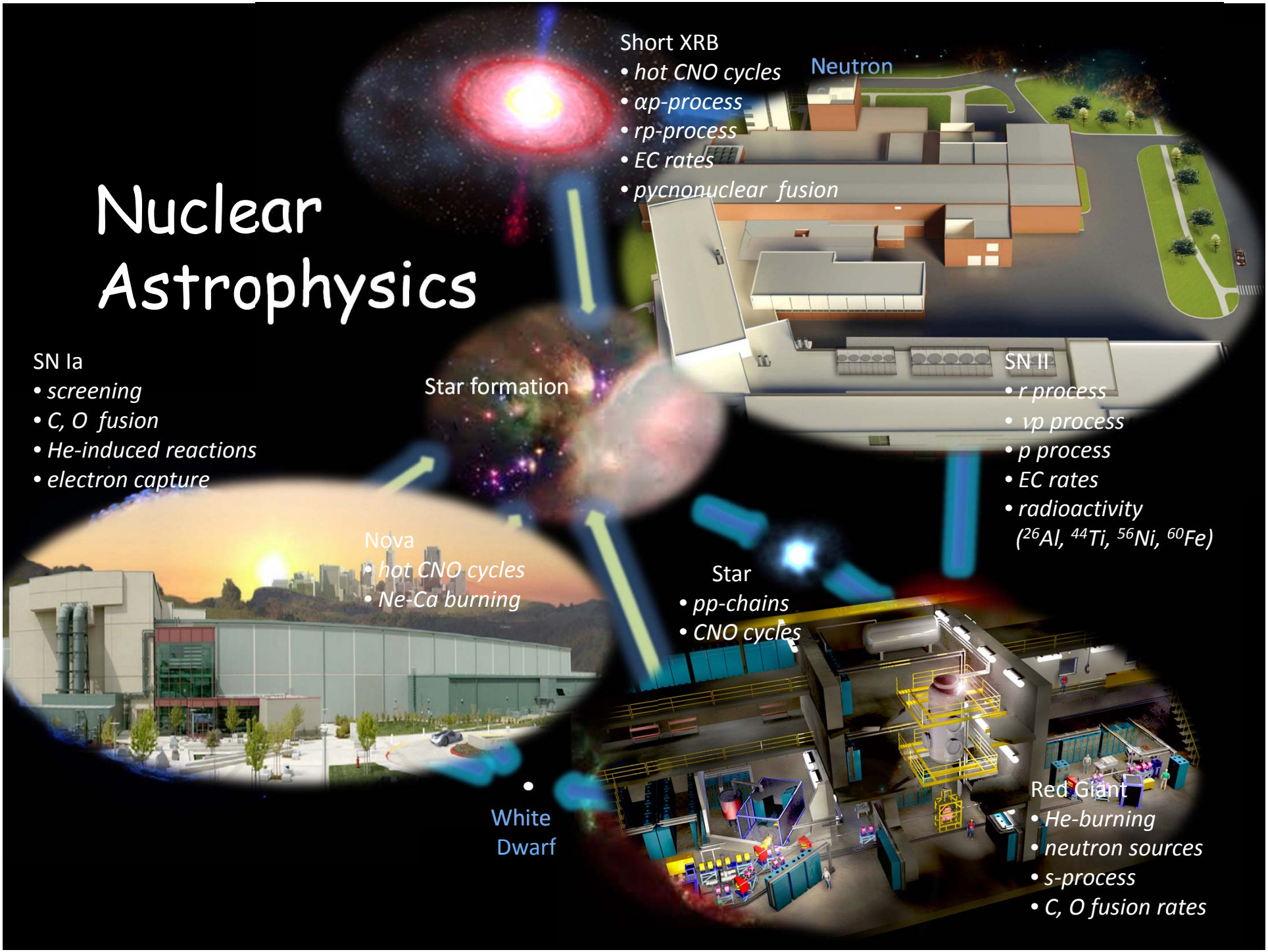
Development of new tools and techniques for the identification and diagnostic of nuclear events.



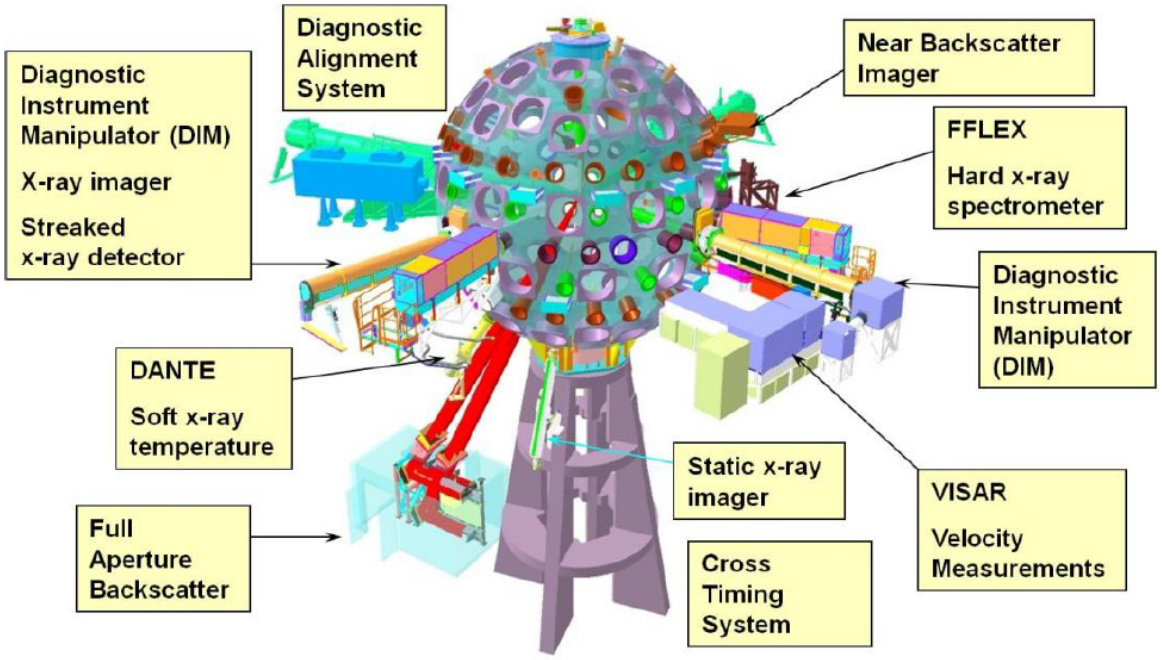
- Plasma coupling to nuclear excitation and decay processes
- Plasma screening effects in low energy charged particle capture reactions
- Thermal excitation of low level states and impact on neutron capture reactions
- Density dependence on electron capture processes (^{7}Be, ^{44}Ti)

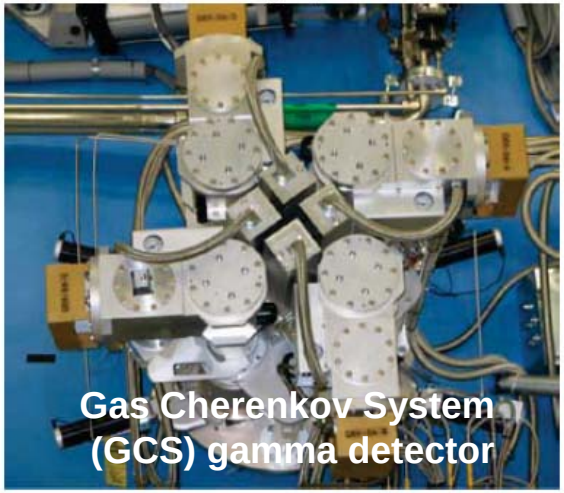
Naturally addresses important questions in nuclear astrophysics and matches the overall goals/needs of the broadly interdisciplinary nuclear astrophysics community

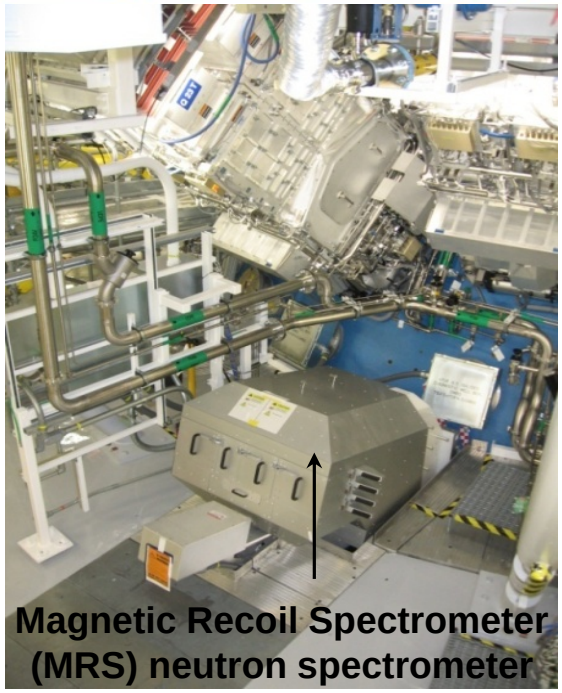
Nuclear Astrophysics



Nuclear Plasma Diagnostics

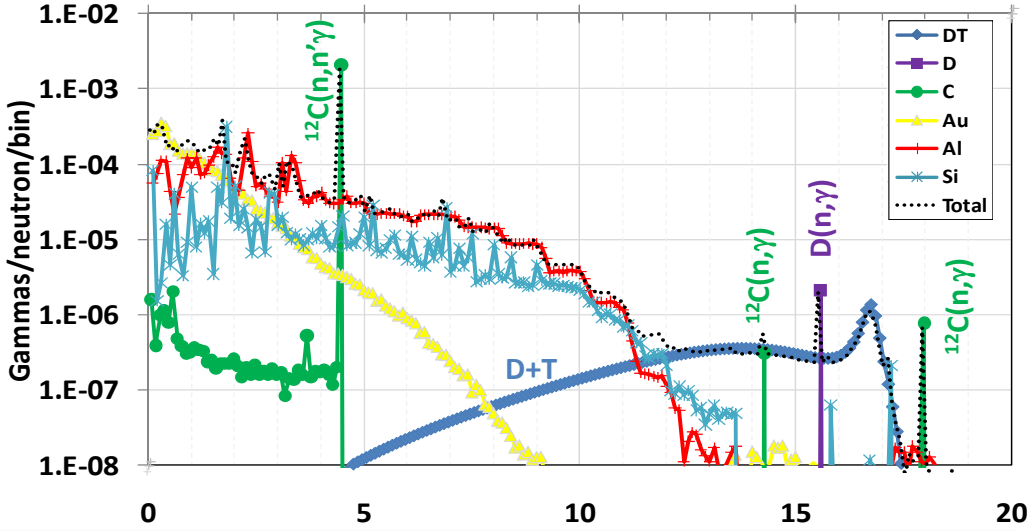


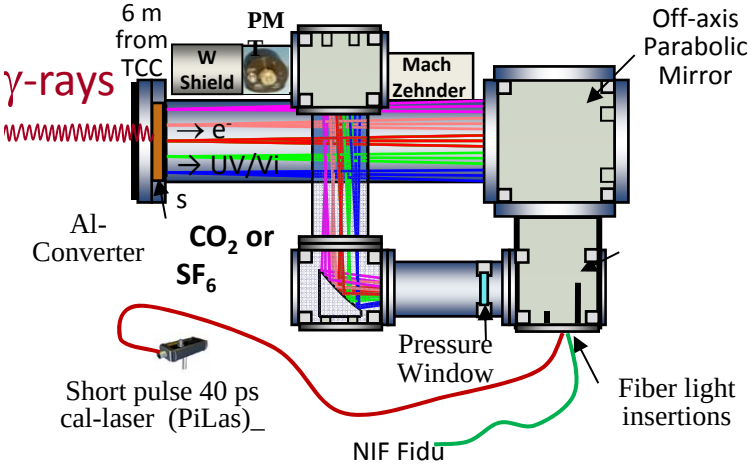




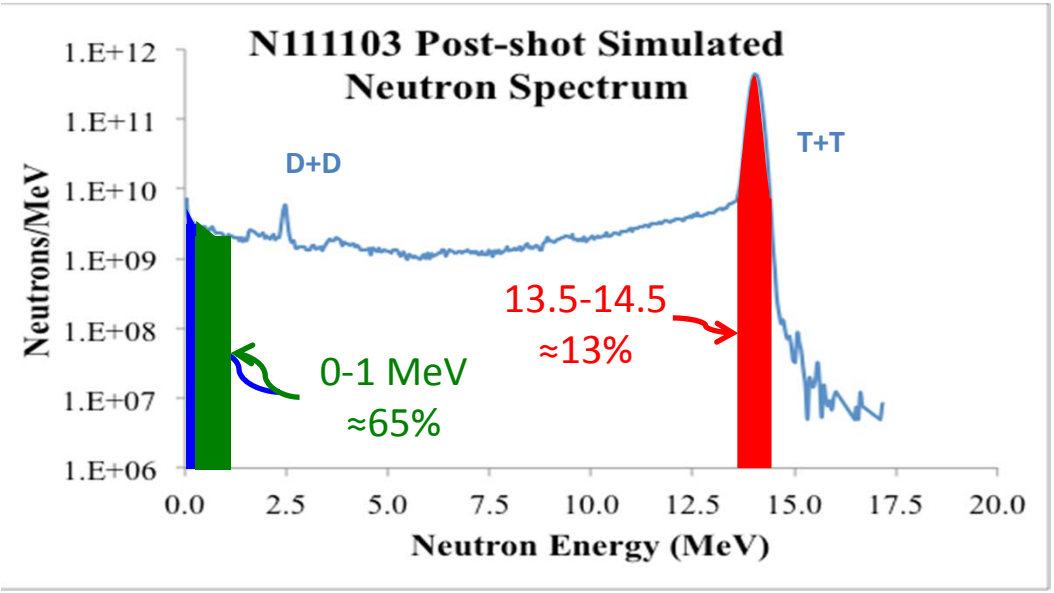
Reliable diagnostics of temperature, density, neutron flux, gamma flux is performed with X-ray imaging, γ-radiation, MRS Neutron spectrometer, and neutron-ToF systems. While knowledge of shock environment and timescale is essential new diagnostic tools for science program are required.

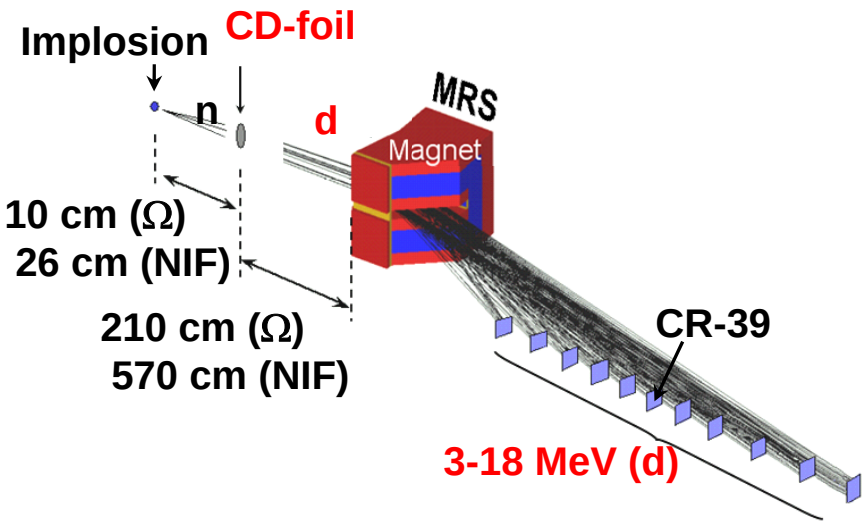
Gamma & neutron flux environment





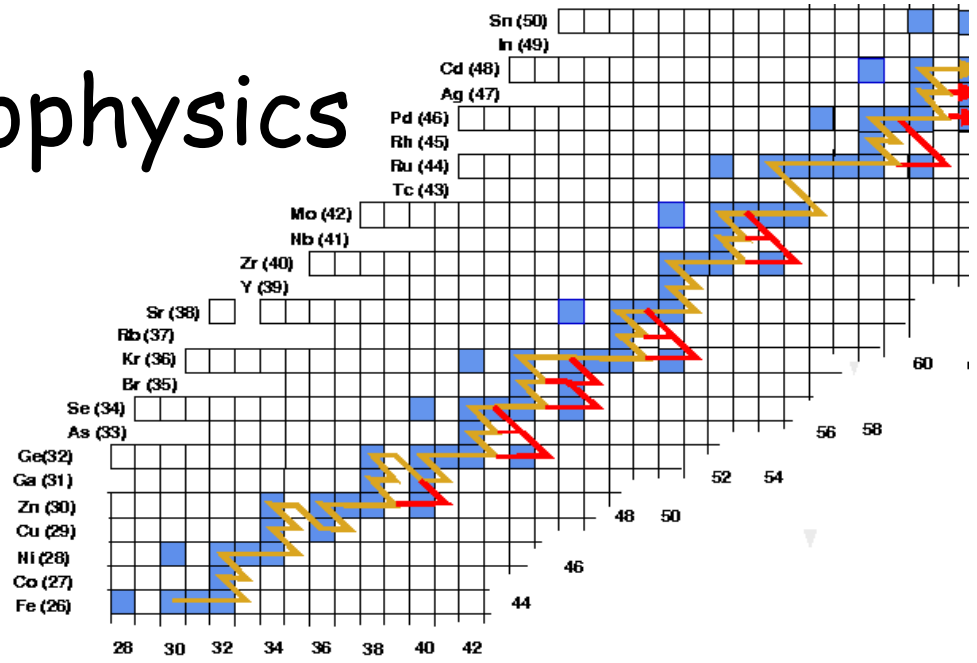
Courtesy: Wolfgang Stoeffl LLNL





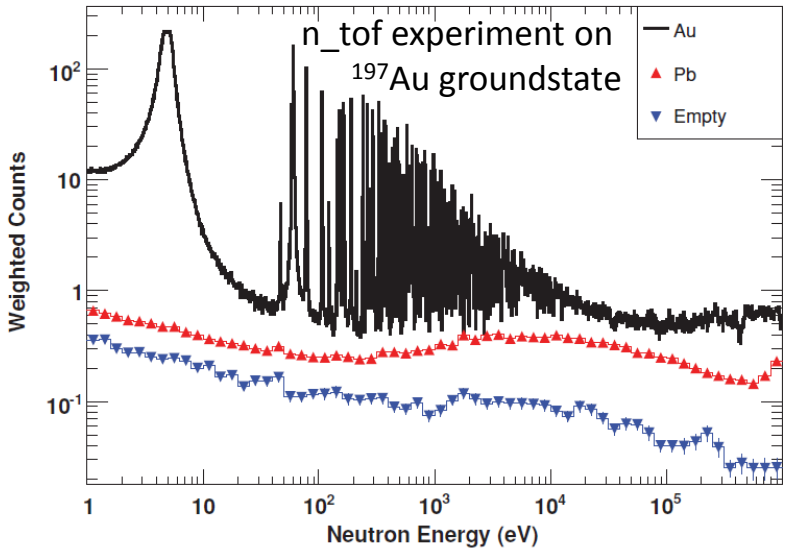
Courtesy: Lee Bernstein, LLNL

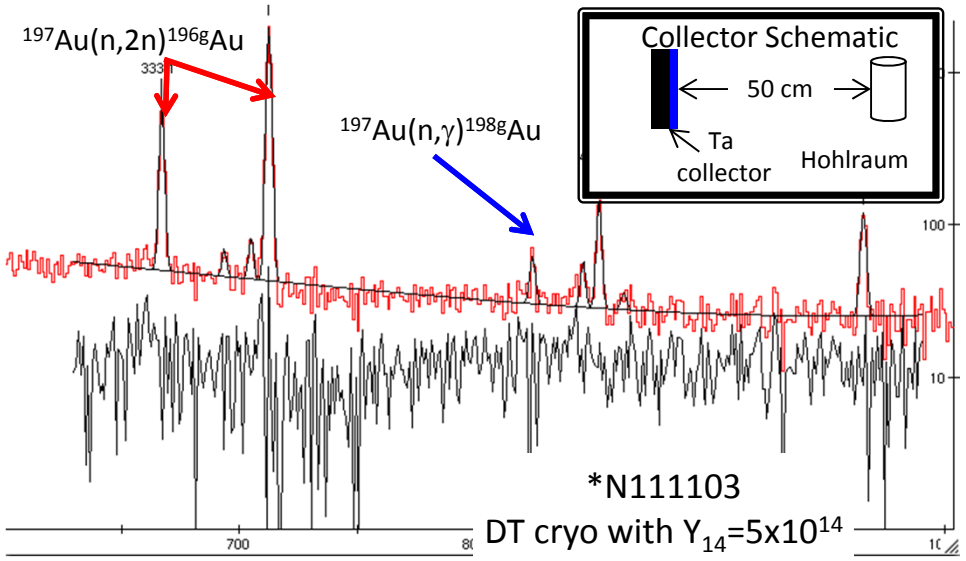
Nuclear Astrophysics with neutrons s-process



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

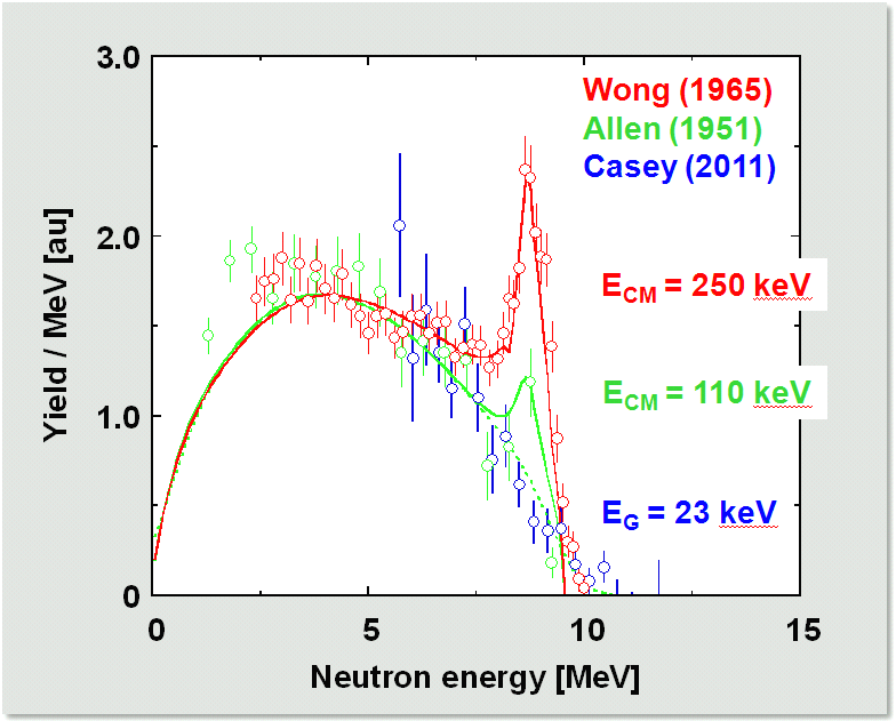




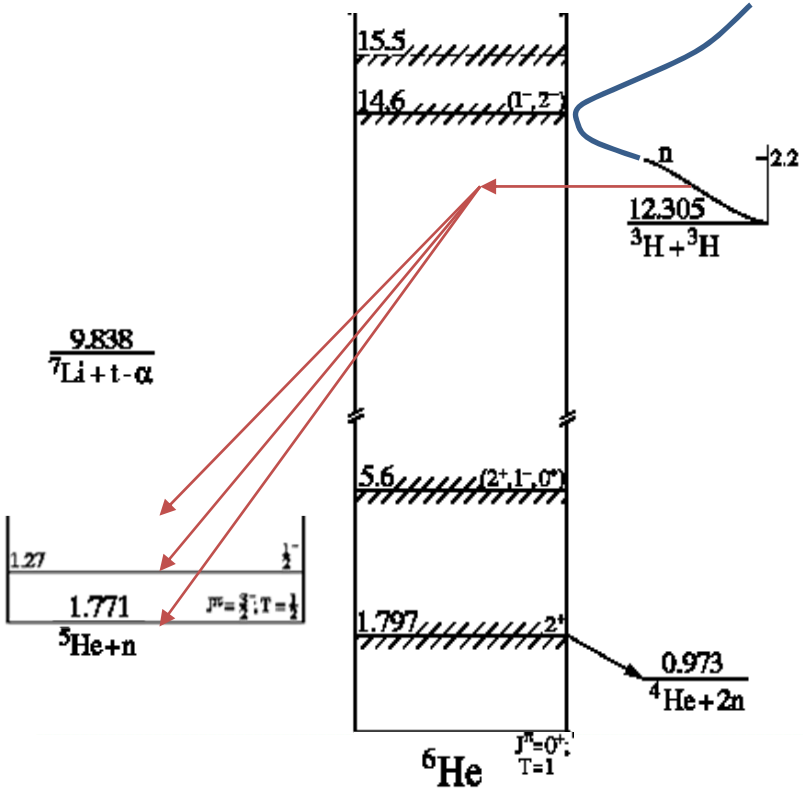
Courtesy: Lee Bernstein LLNL

Reaching stellar energies

$^3H(t,n)^5He(n)^4He$ from accelerator experiments



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



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

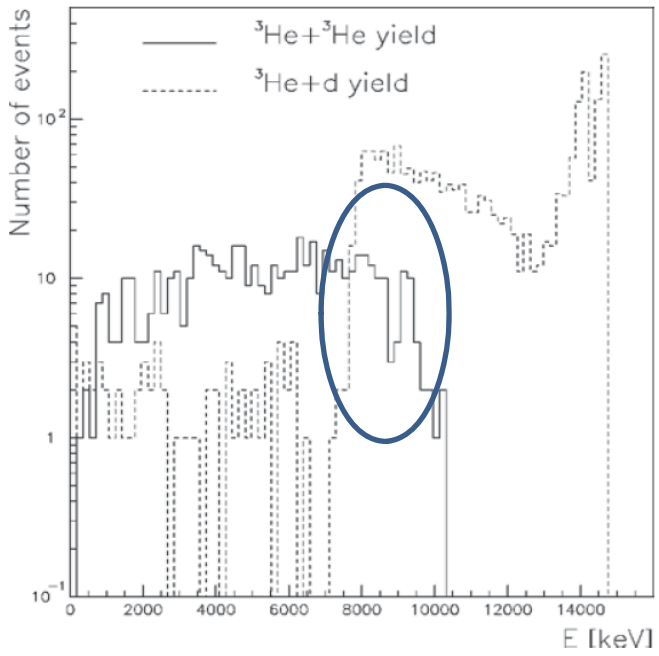
D.T. Casey et al., to be submitted to Phys. Rev. Letters (2012).
K. W. Allen et al., Phys Rev 82, 262 (1951).
C. Wong et al., Nuclear Physics 71, 106 (1965).

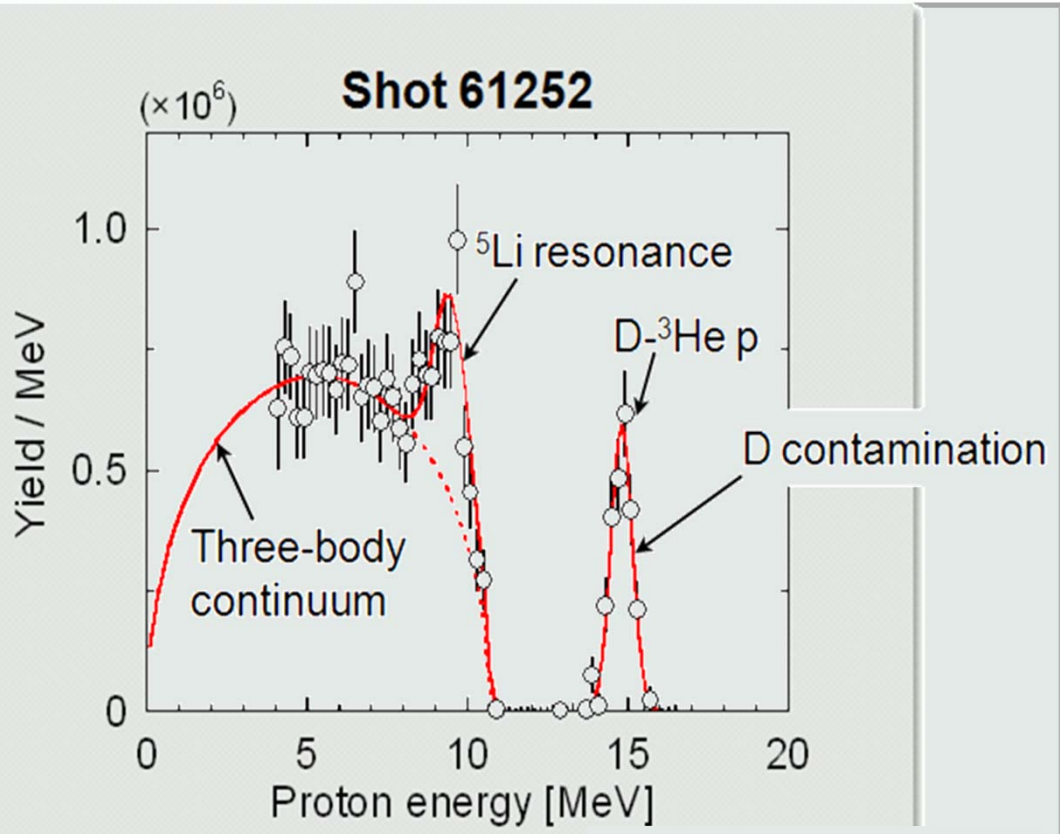
Courtesy: Johan Frenje MIT

^{3}He+^{3}He plasma screening

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

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

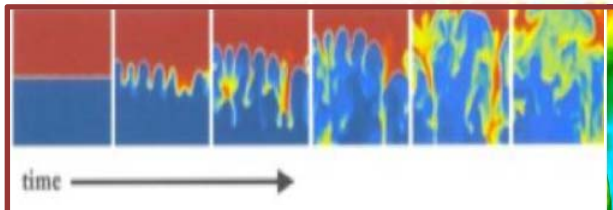




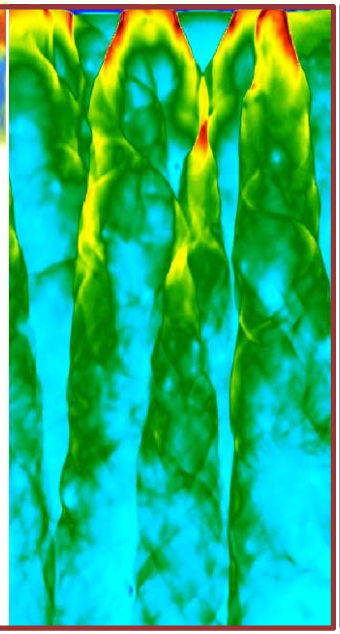
Low energy experiments at plasma conditions are feasible; this provides unique opportunity to probe reaction plasma interaction

Courtesy: Johan Frenje MIT

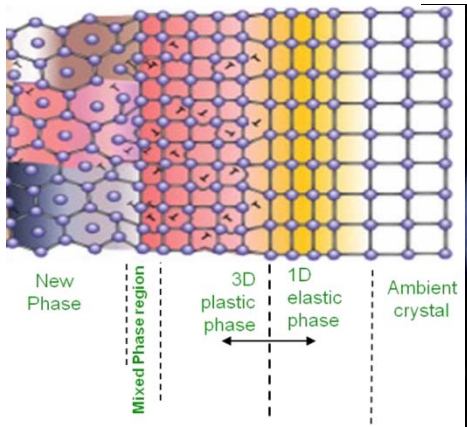
Connections to other Fields

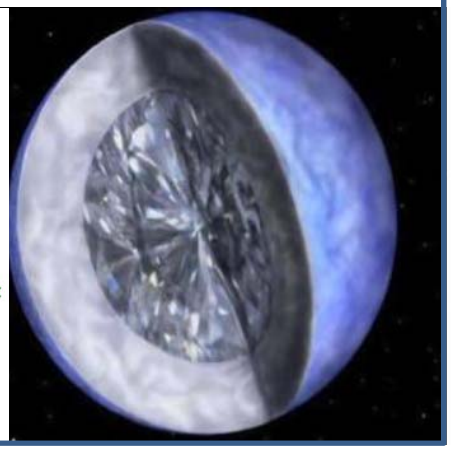


Hydrodynamic studies of the evolution of convection and mixing or rapid Rayleigh Taylor instabilities from late stellar evolution to supernovae as shock driven plasma events.

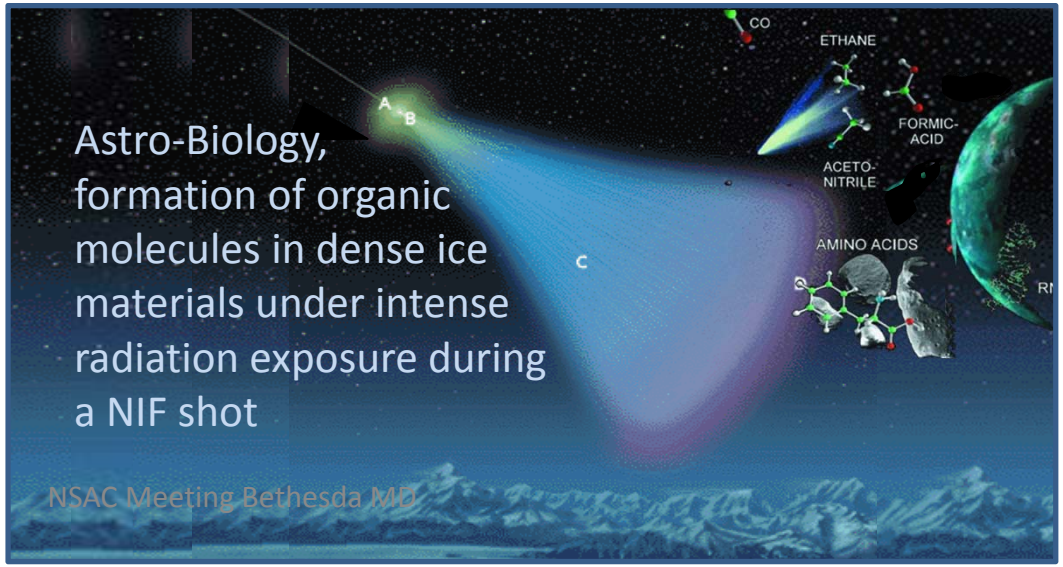


Material evolution towards extreme densities as anticipated for neutron star crust and white dwarf core environments.



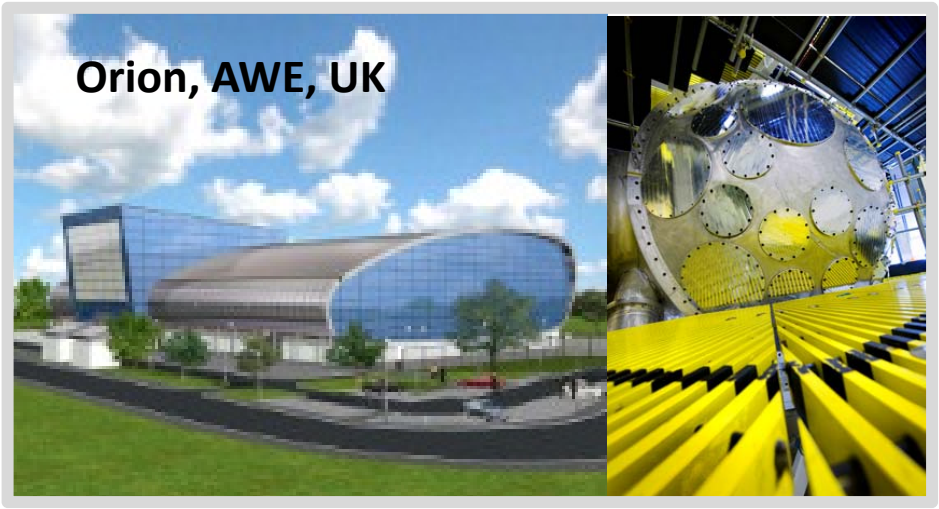


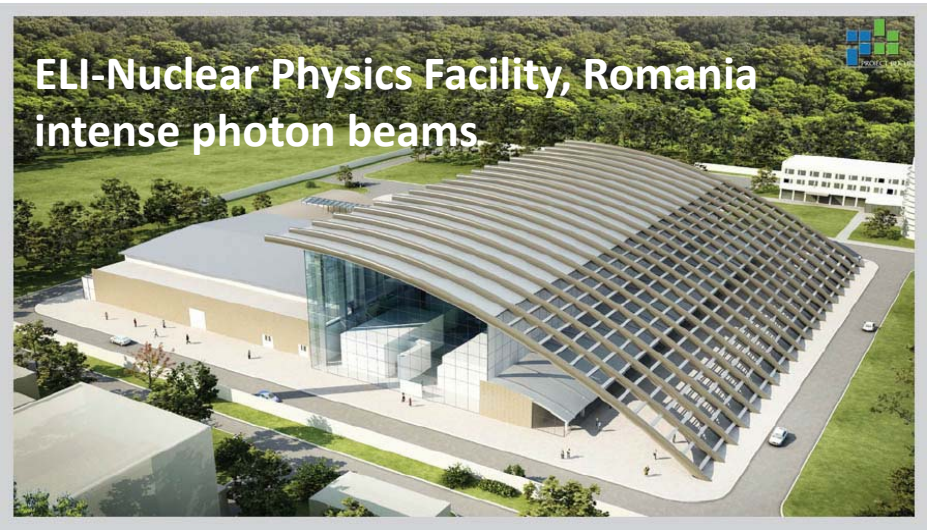
Planet formation, condensation at high density, shock impact, conditions and nature of exo-planets.



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

Complementary Activities





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