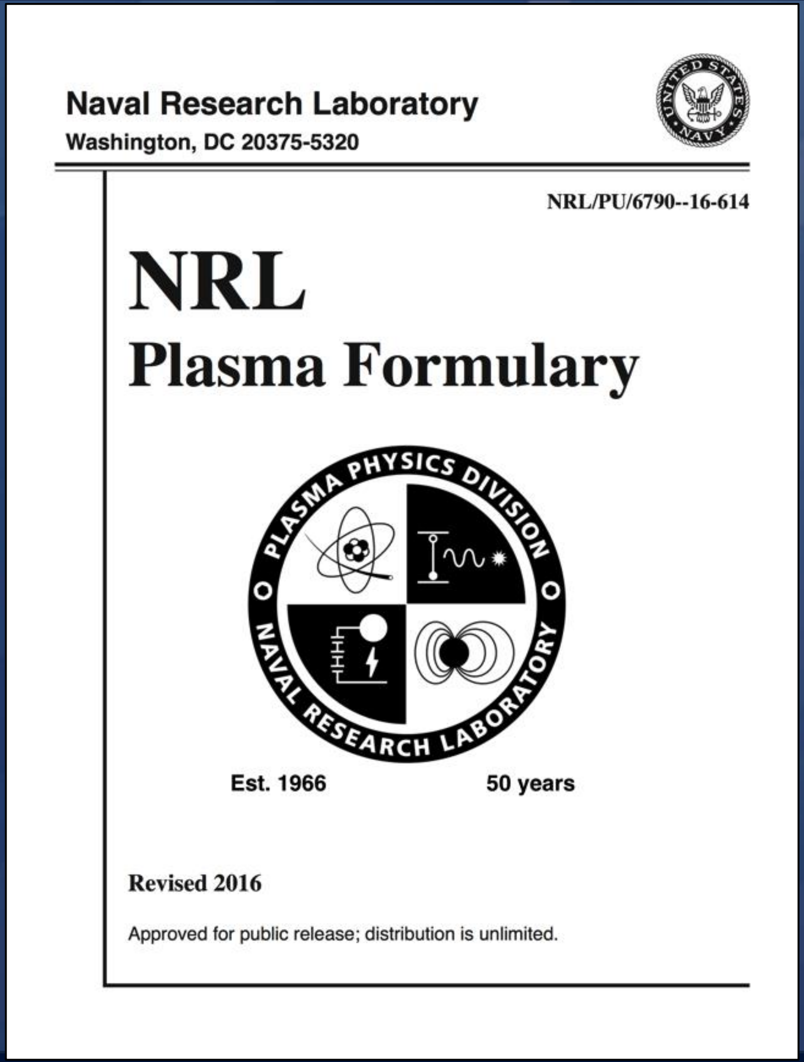
NRL/OPNP/6700-19-101

Plasma Physics in the Navy

NRL- ONR Perspective

NAS Plasma 2020 Decadal Study Panel


Naval Research Laboratory
Washington, DC 20375-5320

NRL/PU/6790--16-614

NRL
Plasma Formulary

Est. 1966 50 years

Revised 2016

Approved for public release; distribution is unlimited.

Dr. Tom Mehlhorn
Superintendent
Plasma Physics Division, Code 6700
Tom.mehlhorn@nrl.navy.mil

Washington DC
October 15, 2018

ESTABLISHED IN 1966 - NRL PLASMA PHYSICS DIVISION CONDUCTS BASIC & APPLIED RESEARCH FOR NAVY & MARINE CORPS NEEDS

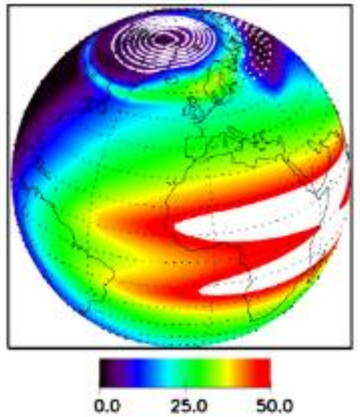
U.S. NAVAL RESEARCH LABORATORY

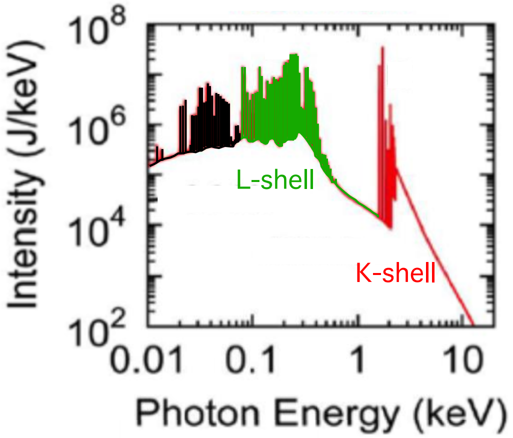
NRL PPD

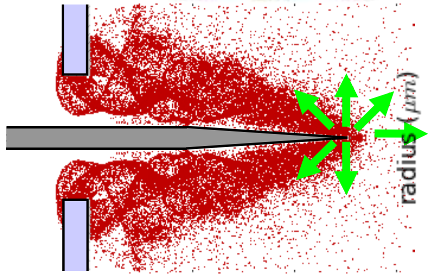
Expertise

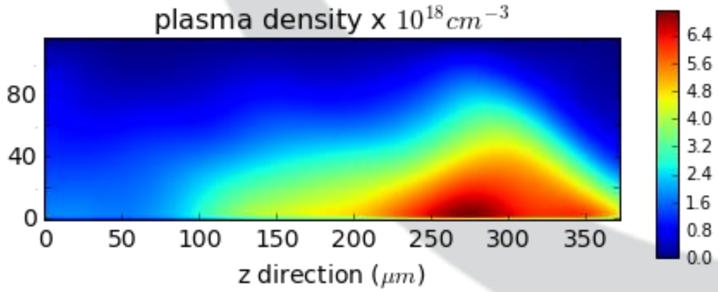
~90 Federal, 30 Contractor, 5 Postdocs

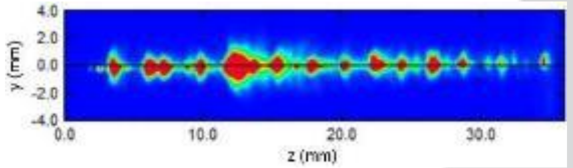
Theory & Codes



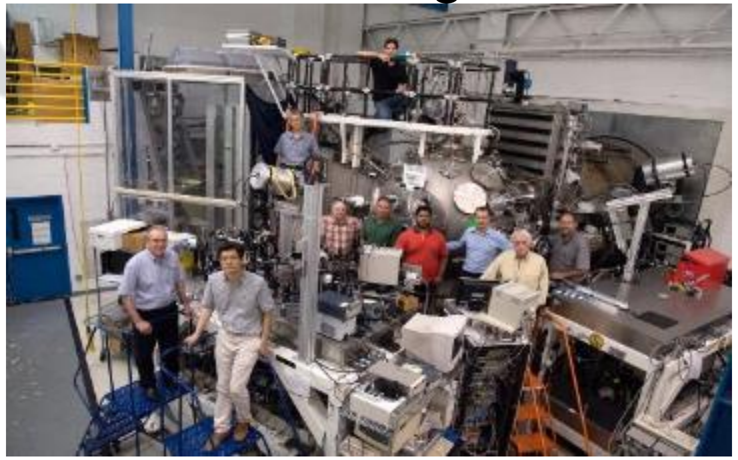


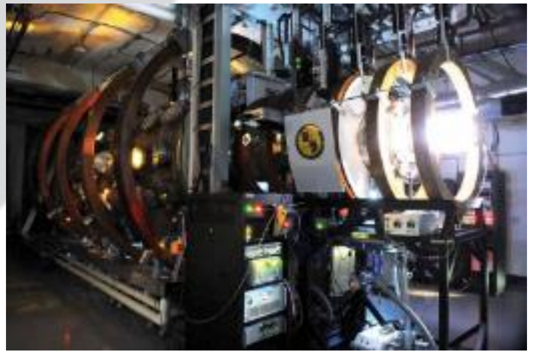


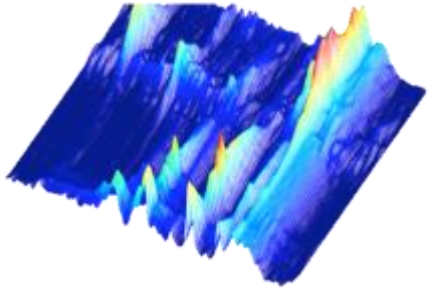




Facilities & Diagnostics

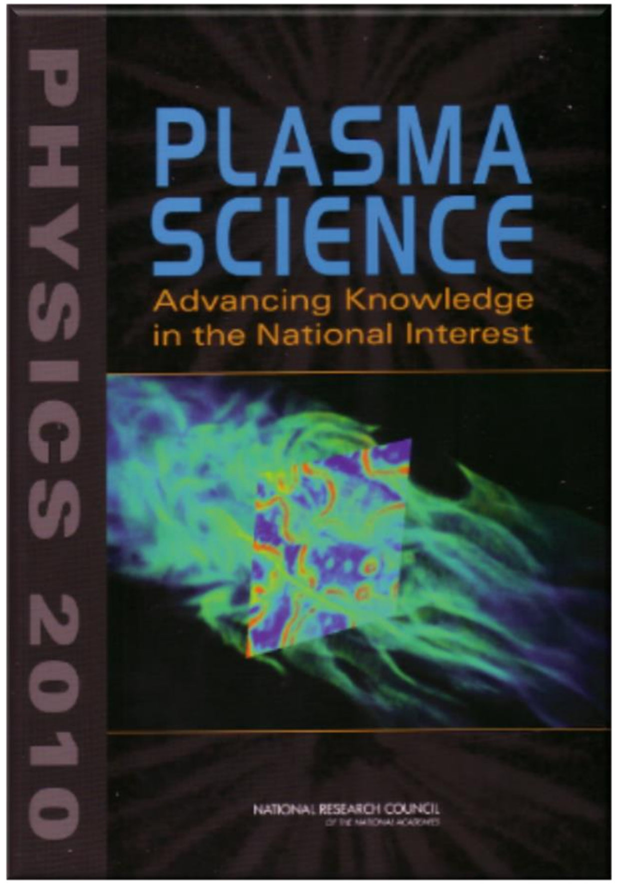






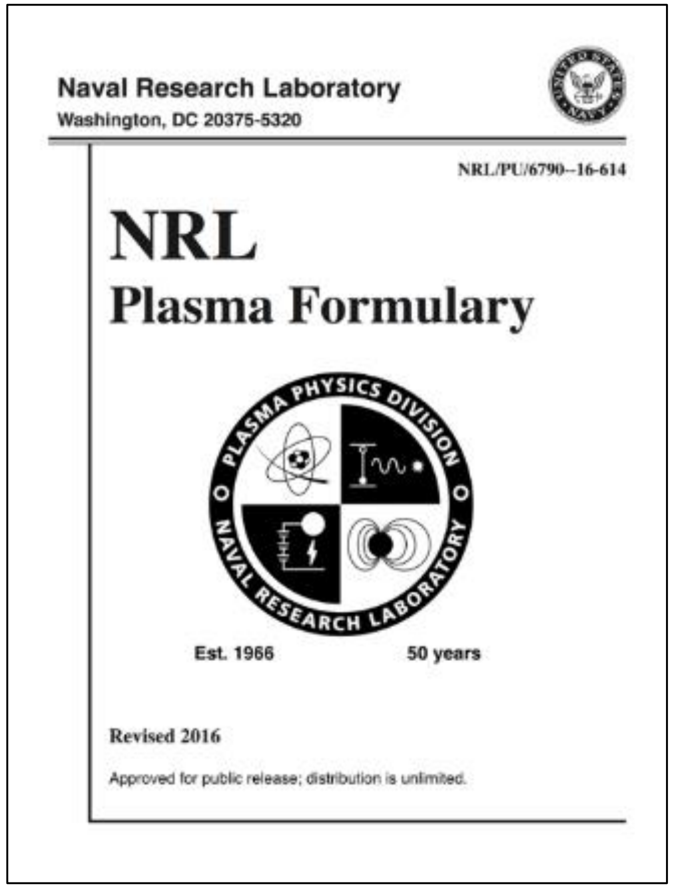
NRL BRIDGES THE INTERNATIONAL PLASMA PHYSICS COMMUNITY AND NAVY/MARINE CORPS STRATEGIC NEEDS

Scope of Plasma Science

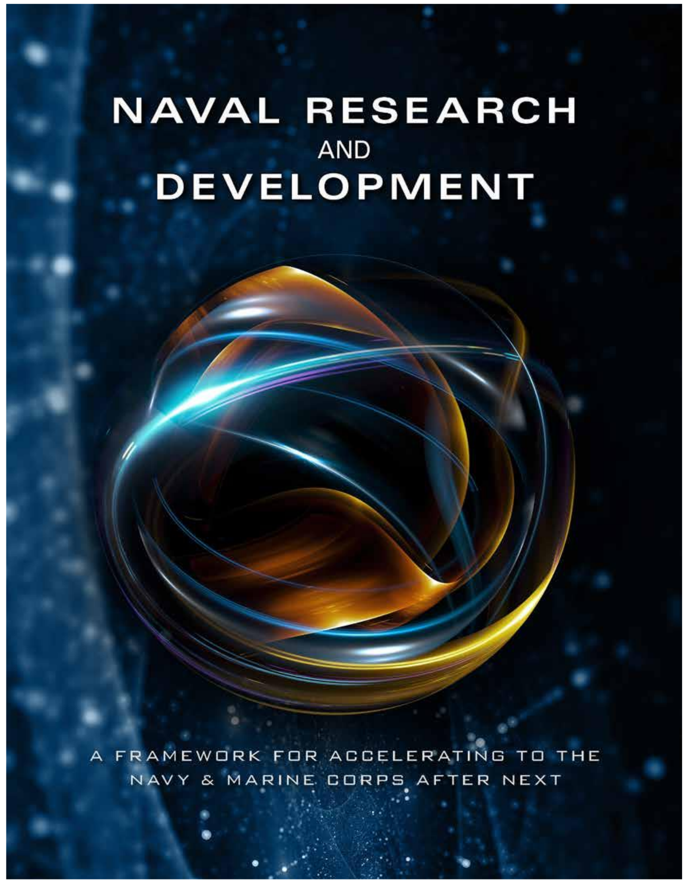


No MFE, 1/3 in space plasma physics

NRL PPD Capabilities & Base Program



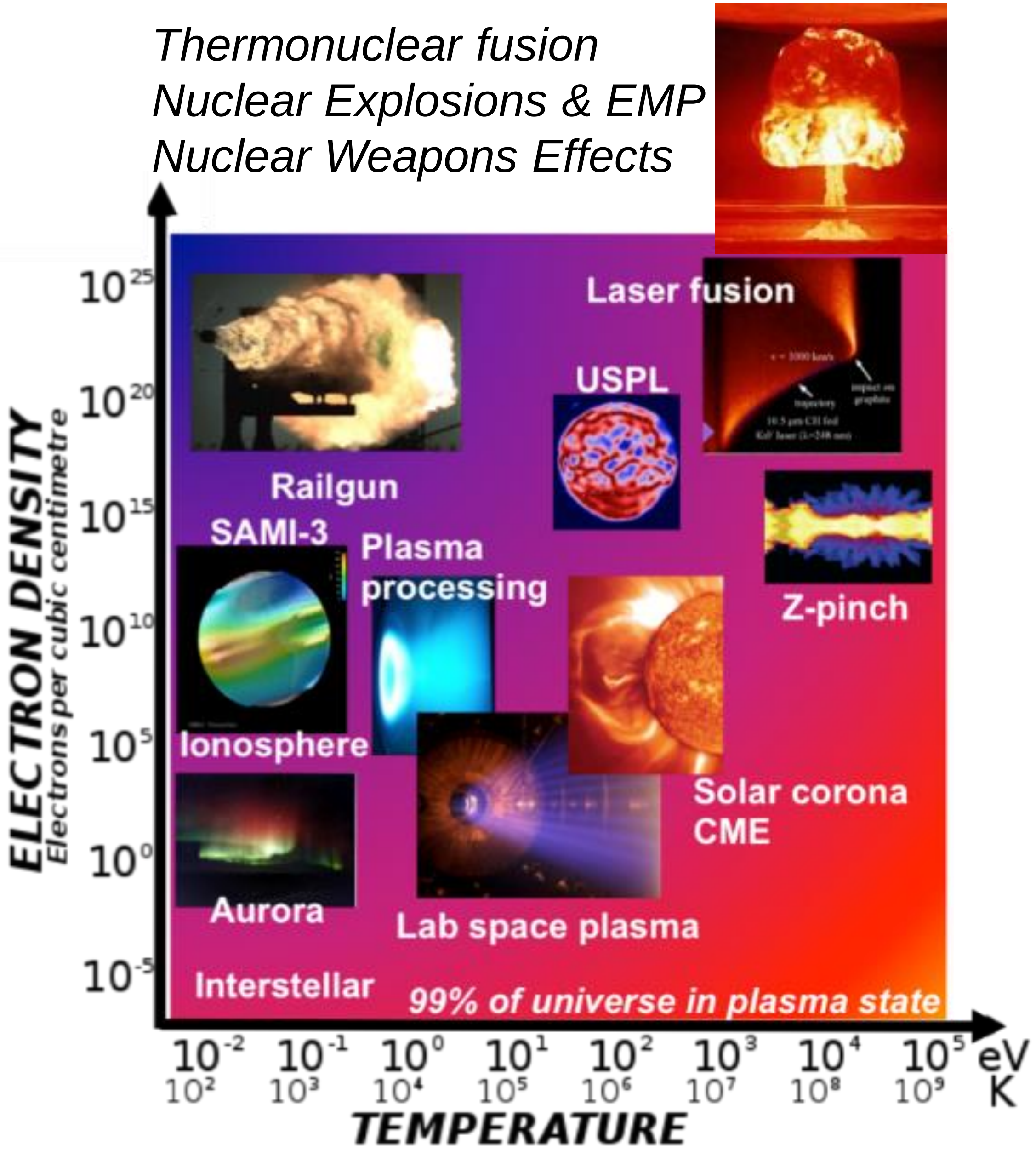
ONR Interests: Navy/Marine Corps Needs



ONR funds relevant PPD research from multiple codes (30, 31, 33, **35**)

NRL is a Navy Working Capital Fund activity: stabilized rates - total cost recovery

Navy Missions & Needs are Connected with NRL Plasma Physics Research Across the Entire Parameter Space



Missions & Applications

Inertial confinement fusion

Electromagnetic railguns

Directed energy & HPM

USPL physics & acceleration

Nuclear Weapons Effects & HANE

High power particle beams

Radiation-atomic physics

Space plasma physics

Plasma processing & LTPs

Hypersonics

Nonlinear dynamics & autonomy

NRL's 18 Research Divisions provide a „University with a Fence“ to the Navy and US Government

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Executive Leadership

Business Operations
- Contracting
- Financial Management
- Supply
- R&D Services

Systems
- Radar
- Information Technology
- Optical Sciences
- Tactical Electronic Warfare

Materials Science & Component Technology
- Computational Physics & Fluid Dynamics
- Chemistry
- Materials S&T
- Plasma Physics
- Electronics S&T
- Biomolecular Science & Engineering

Ocean & Atmosphere Science & Technology
- Acoustics
- Remote Sensing
- Oceanography
- Marine Geosciences
- Marine Meteorology
- Space Science

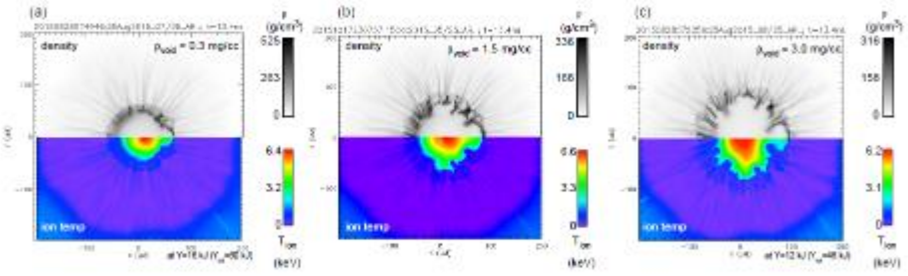
Naval Center for Space Technology
- Space Systems
- Spacecraft Engineering

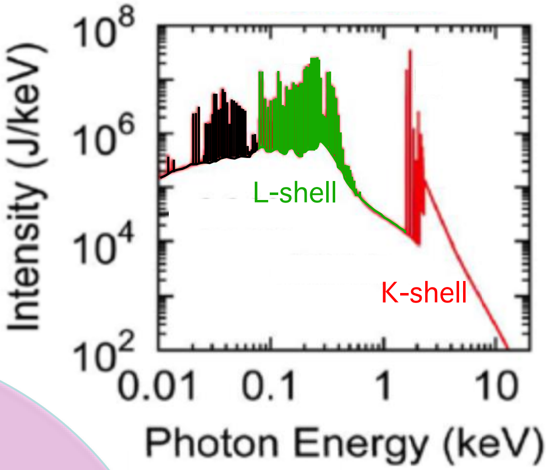
Pasteur's Quadrant research: Basic & applied research toward Navy/Marine Corps goals

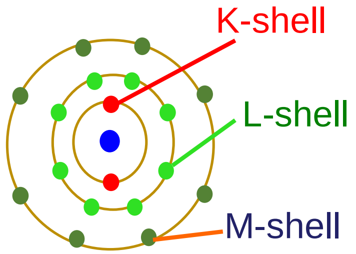
Three Plasma Physics Division capabilities synergistically bridge Navy needs with DTRA, NNSA, & AWE Missions

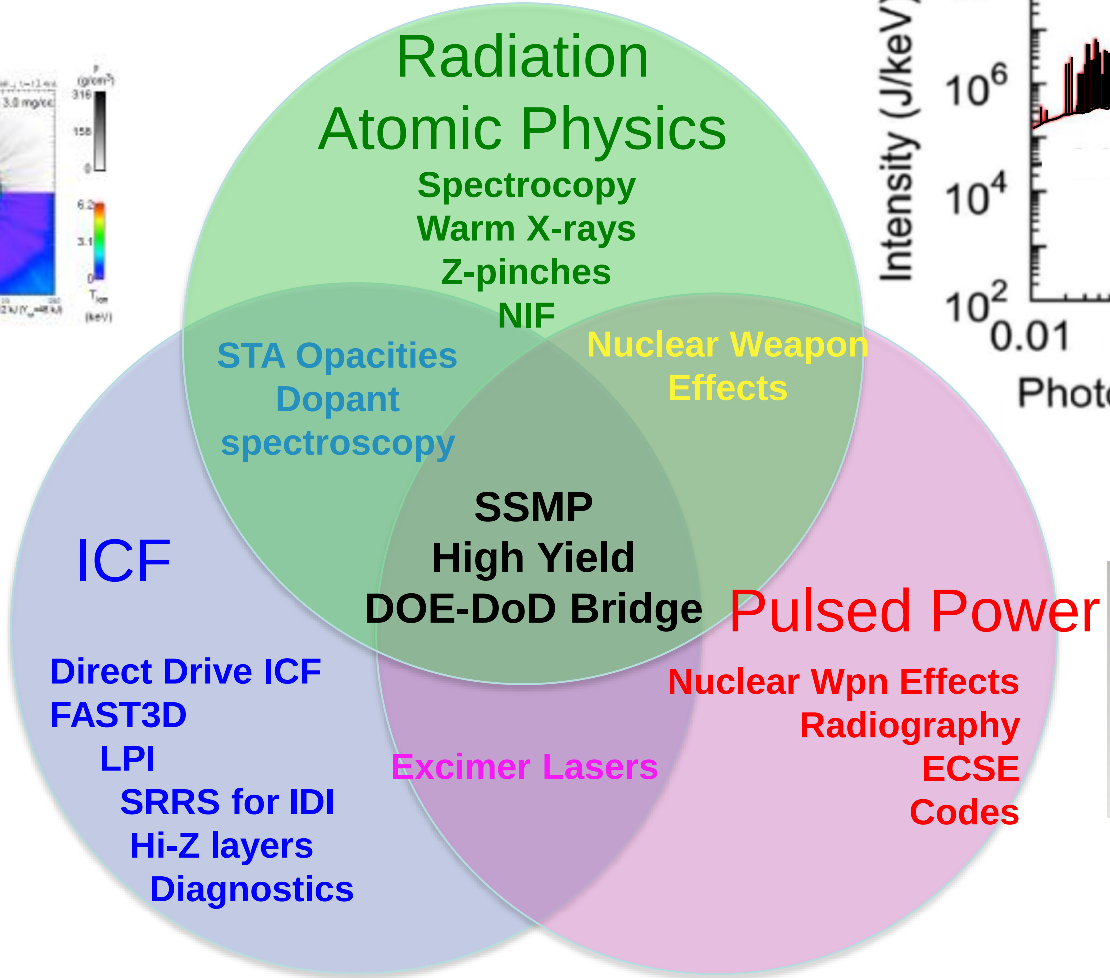
U.S. NAVAL RESEARCH LABORATORY

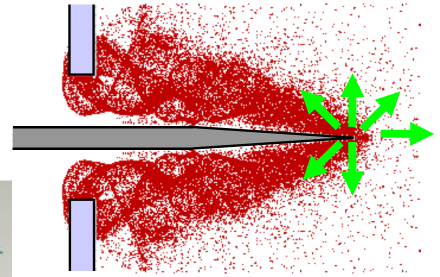
NRL PPD

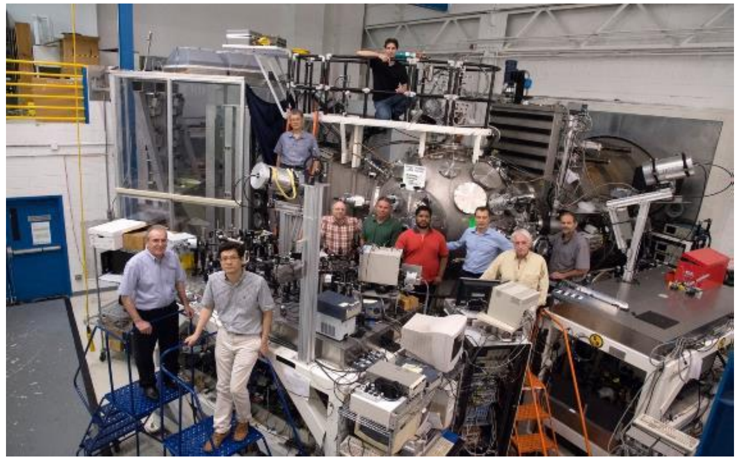


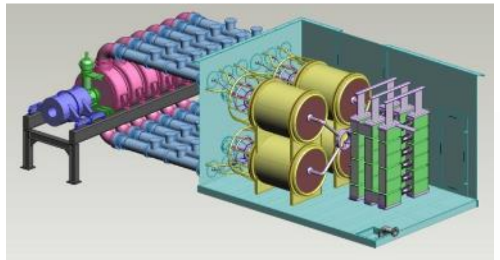


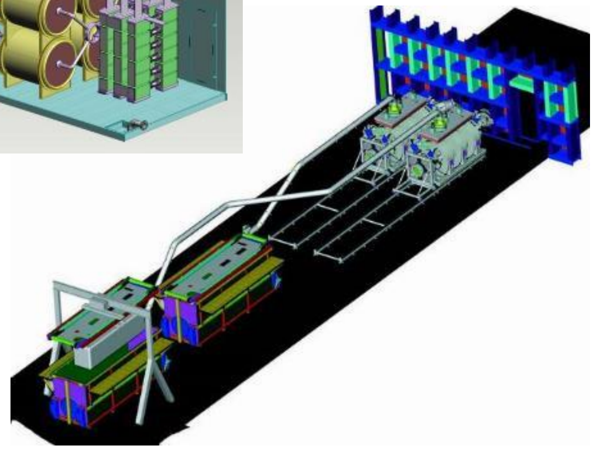












NRL PPD Bridges the DoD & DOE/NNSA

Leverages NRL 6.1, CPP, & other sponsor investments

ONR · NAVY Strategic Systems Programs · NNSA National Nuclear Security Administration · UR LLE · Los Alamos National Laboratory · Sandia National Laboratories · AWE

NRL LASER FUSION PROGRAM IS DEVELOPING S&T THAT COULD BE "GAME CHANGERS" FOR INERTIAL FUSION

U.S. NAVAL RESEARCH LABORATORY

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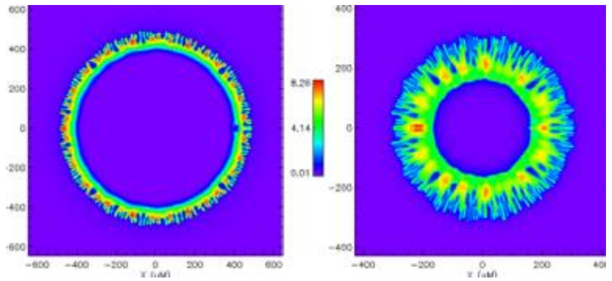
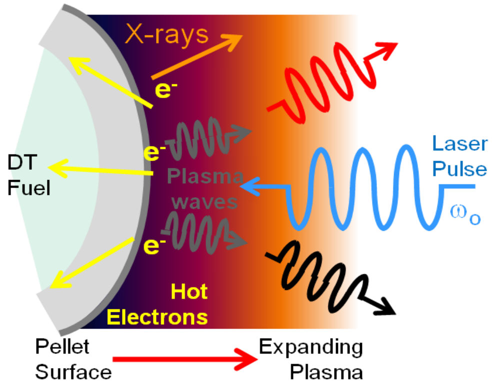
Major challenges to laser ICF

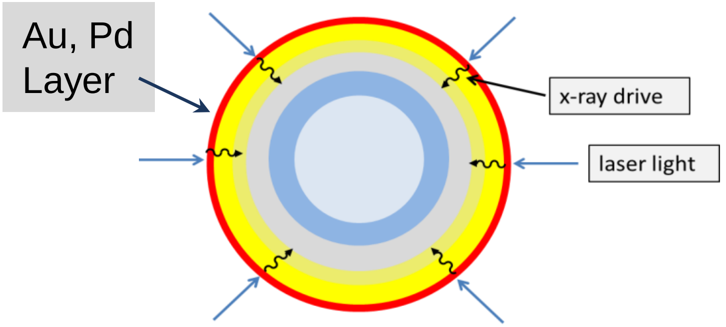


Early time laser imprinting seeds hydro instability



Laser plasma instabilities limit max laser drive irradiance

NRL advanced solutions



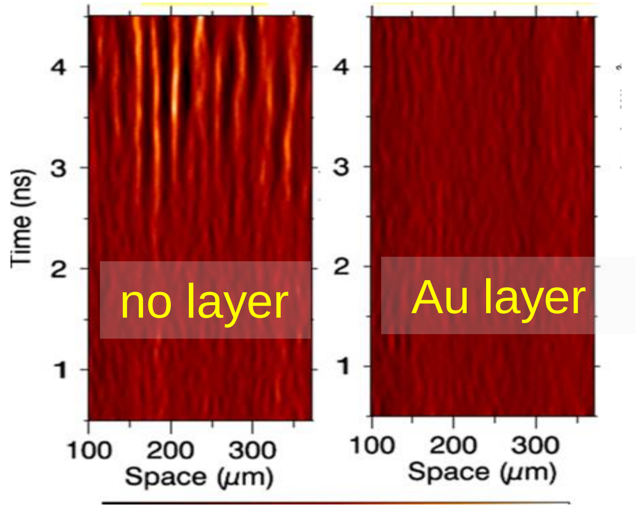
Early time x-ray drive from thin high-Z target overcoat separates laser light from target

Broad laser bandwidth (>>1 THz) imposed on current ICF lasers by SRRS in nitrogen or air to mitigate LPI

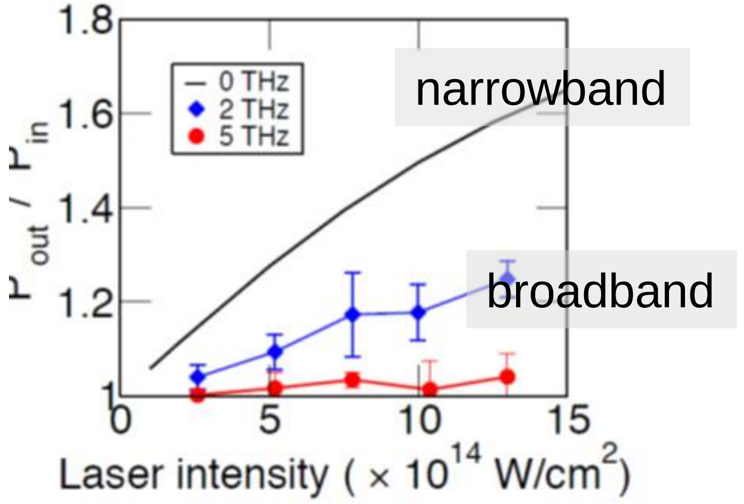
and the best long term solution

Deep UV broad native bandwidth excimer lasers KrF (248 nm) and ArF (193 nm) as ICF drivers

Hydro-instability seeded by laser imprint (Nike experiment)

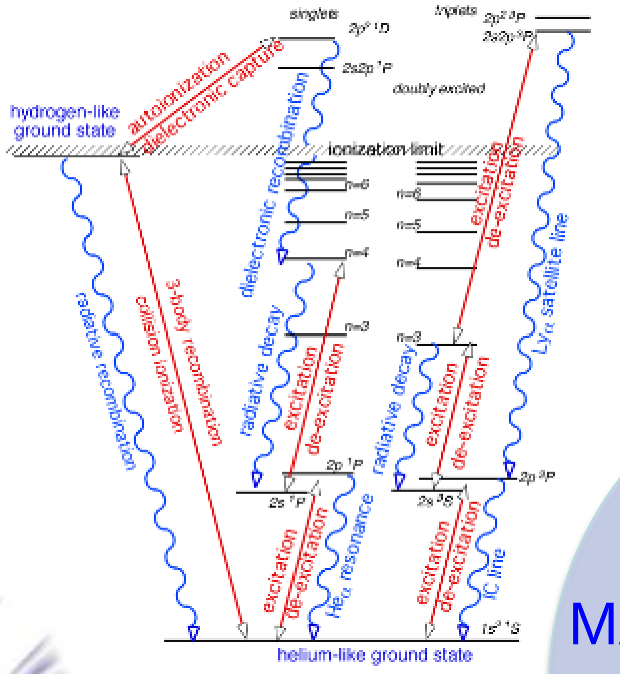


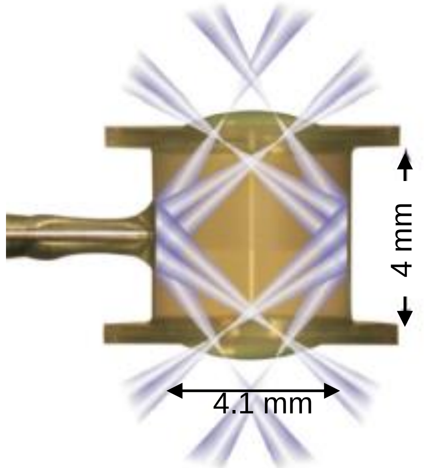
LPSE simulation of CBET suppression by broad laser bandwidth

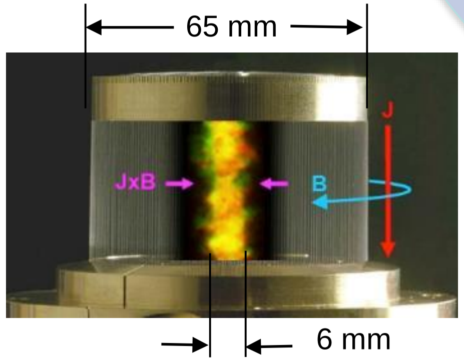


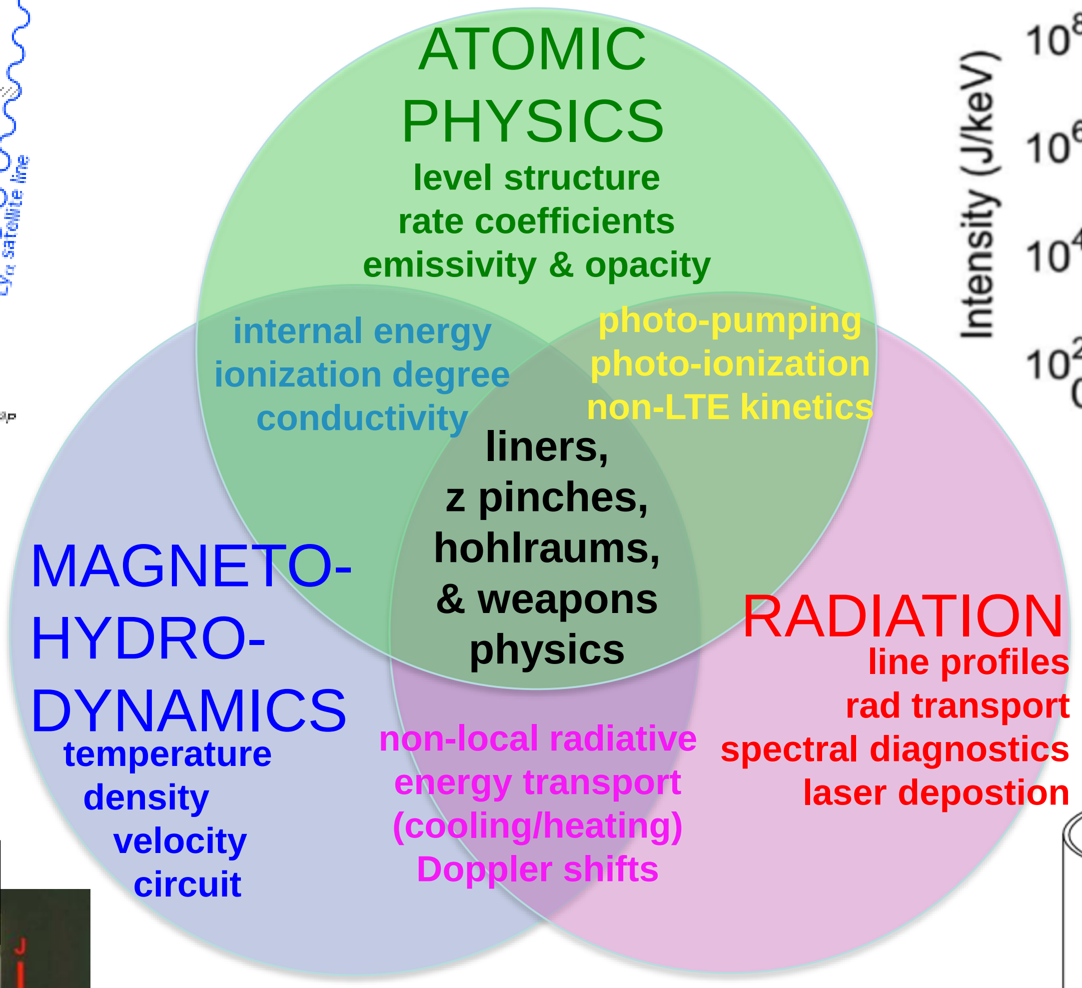
Steve Obenschain (Head), Laser Plasma Branch

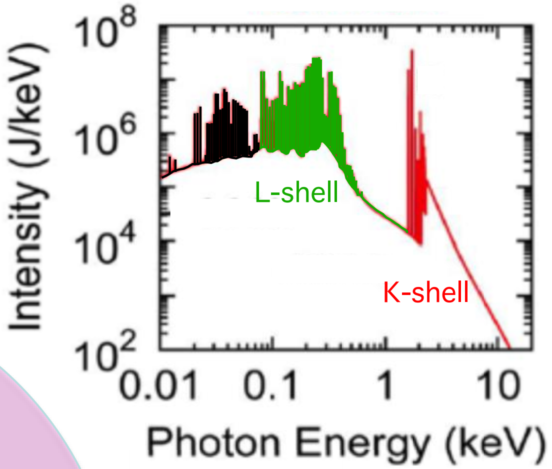
Radiation atomic physics & Spectroscopy of HED, non-LTE plasmas are important to DoD & NNSA missions

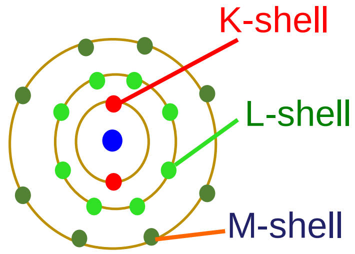


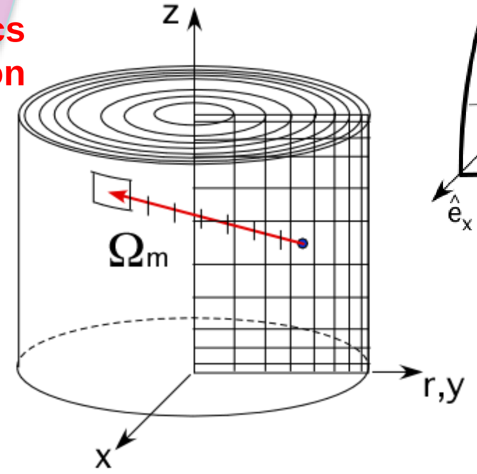


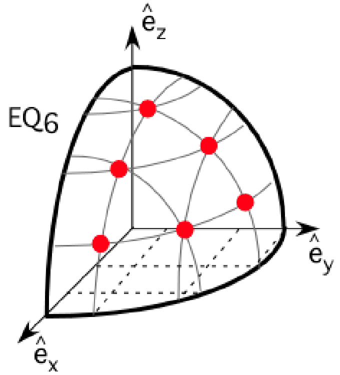










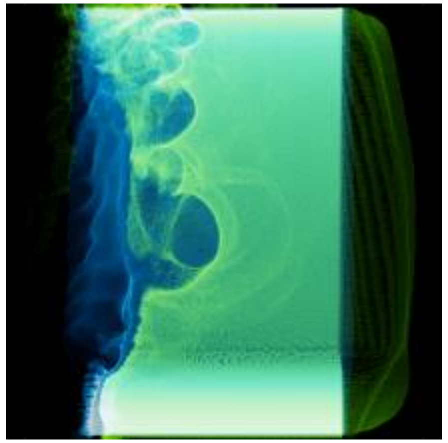


NRL has been modeling non-LTE plasmas for more than 30 yrs.

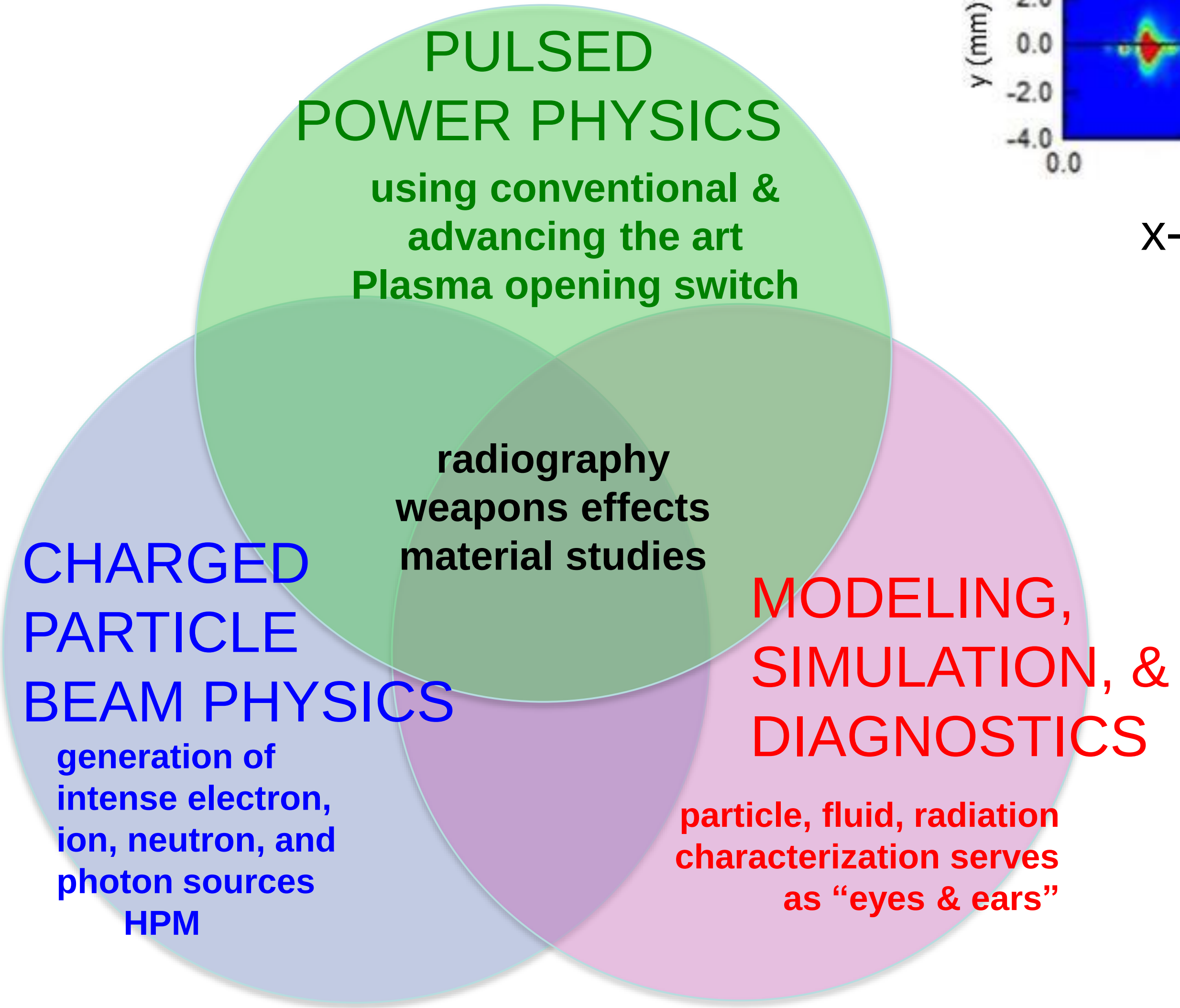
John Giuliani (Head), Radiation Hydrodynamics Branch

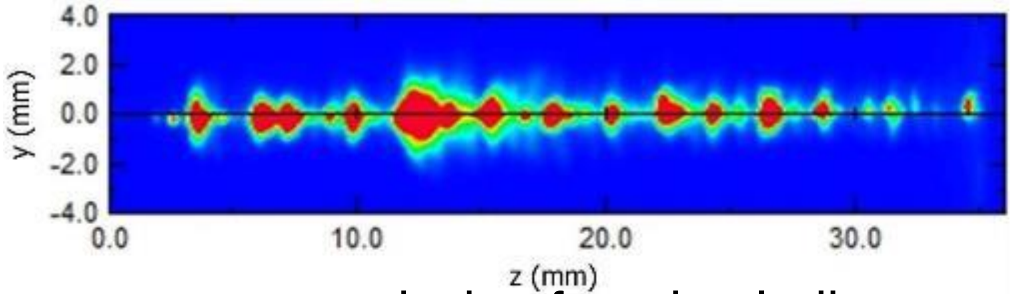
Pulsed Power Physics is an enabling technology - used to develop high-power particle beams & radiation sources

Mercury
+6 – 8 MV, 200 kA, 50 ns

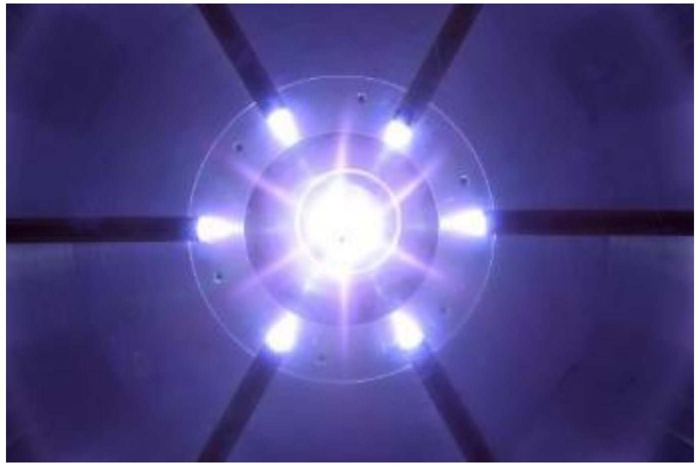


PIC simulation of species separation in plasma opening switch





x-ray emission from imploding tungsten wire

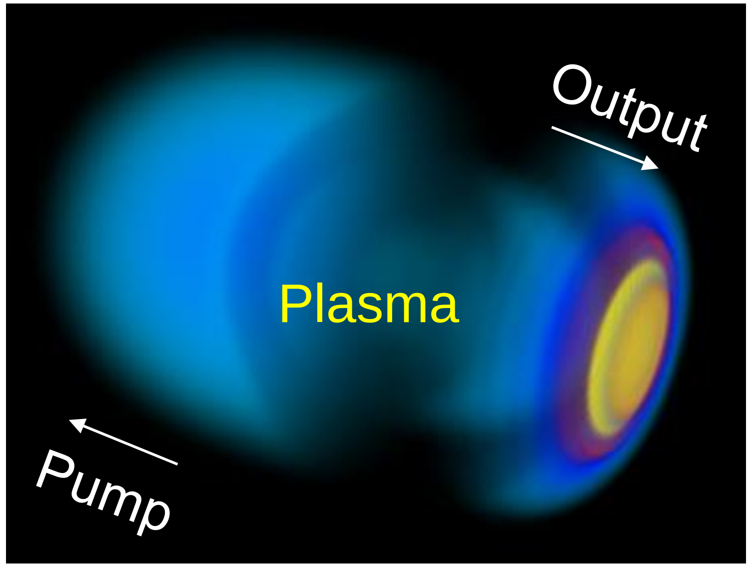


cable gun injection for plasma-filled rod-pinch diode

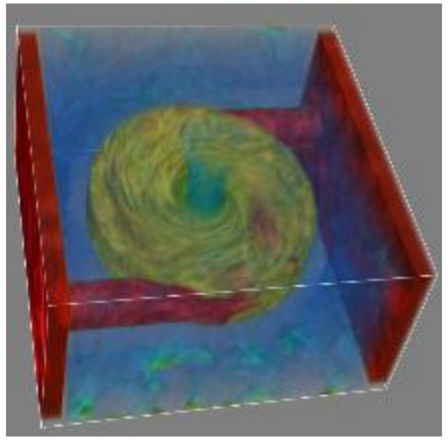
Joe Schumer (Head), Pulsed Power Physics Branch

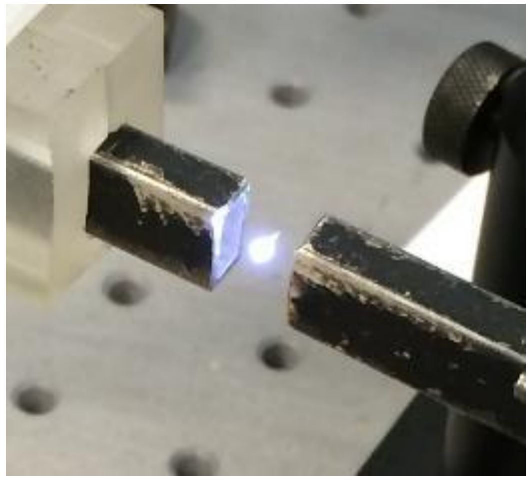
LASER-PLASMA SCIENCE: MILITARY & COMMERCIAL USES OF HIGH-INTENSITY LASER OPTICS, PARTICLE-RADIATION SOURCES, & DIRECTED ENERGY

Plasmas for High Intensity Lasers & Optics (ONR)



Generation of multi-terawatt pulses in the long wavelength infrared (~15 um) from plasmas

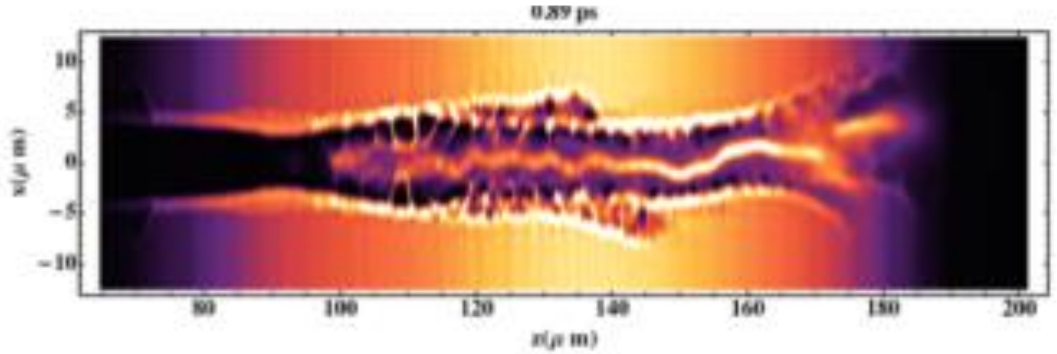




Plasma vortex lens for high-intensity laser optics

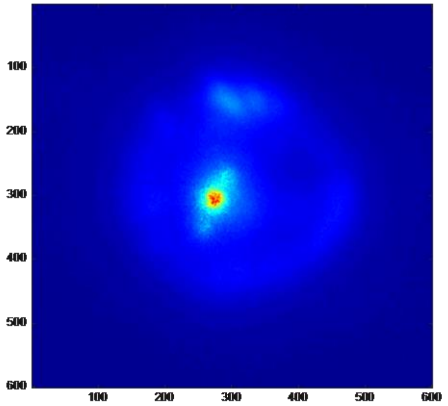
Laser-generated plasma for manipulation of high-power microwaves

Secondary Beams from Ultra-Intense Lasers-Plasma Interactions (DOE)

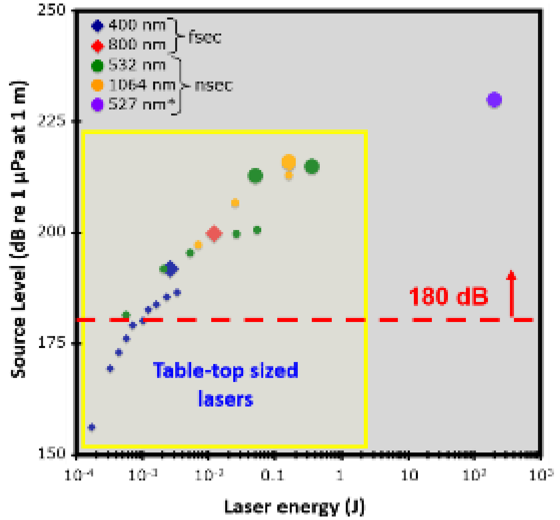


Proton acceleration in near-critical density plasma foils

Underwater laser-plasma interactions (ONR, NRL)



Laser-plasma filament propagation in water



Underwater plasma acoustic sources

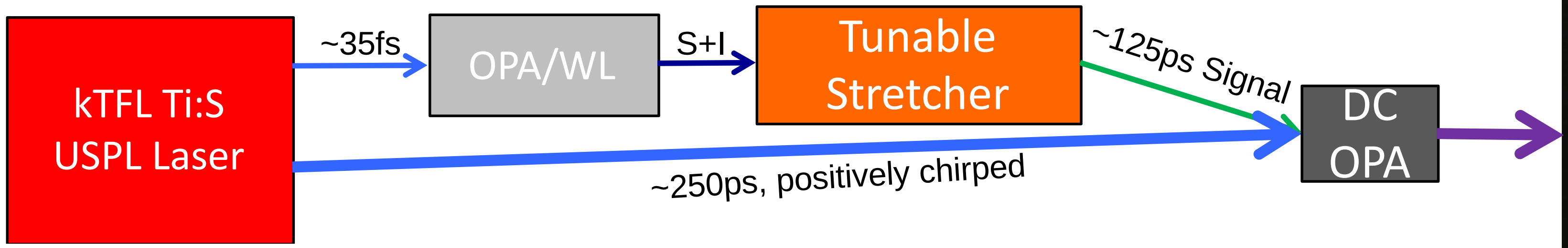
Joe Penano (Head), Beam Physics Branch

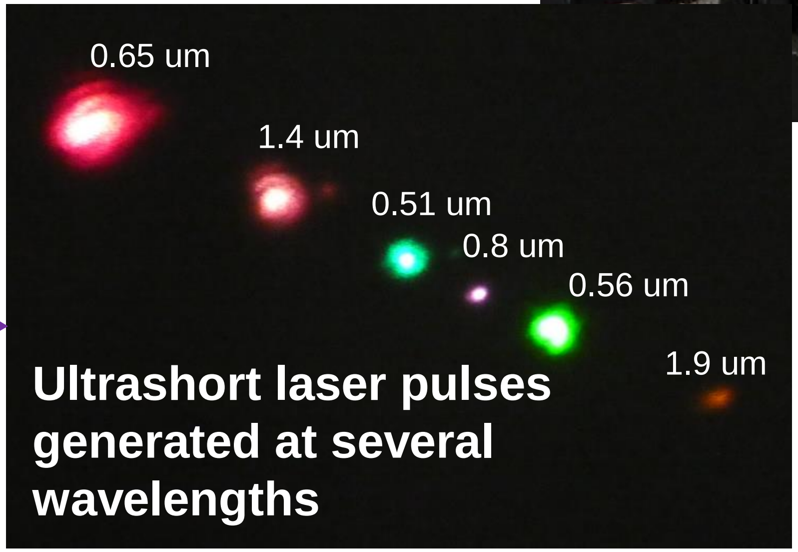
MATRICS LAB: HIGH-PRECISION, PUMP-PROBE EXPERIMENTS COMBINING PHOTONS (THz - X-RAYS) WITH HIGH ENERGY ELECTRONS & IONS

- 350 sq. ft. ISO 4 cleanroom
- 20TW 5Hz high energy laser upgrade (50 TW by Winter 2018)
- 0.5TW 1kHz repetition rate laser
- Tunable OPA
  - Currently: 1.1-2.6um
  - Upgrade: 200nm-15um (2018)
- Laser-driven electron and ion accelerators

- Ultrafast laser-matter interactions and propagation
- Novel radiation sources
- USPL technology development

Dual-Chirp OPA design*



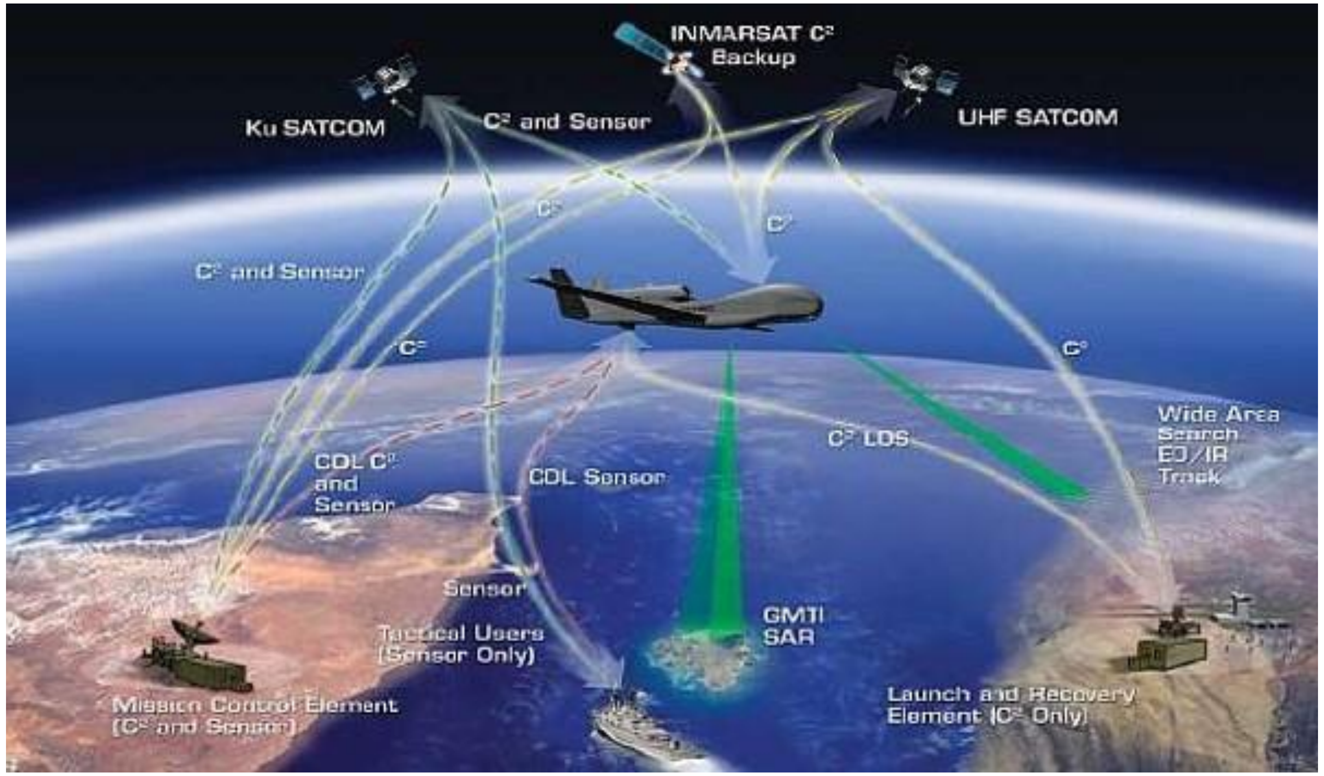


*Patent disclosure filed

Joe Penano (Head), Beam Physics Branch

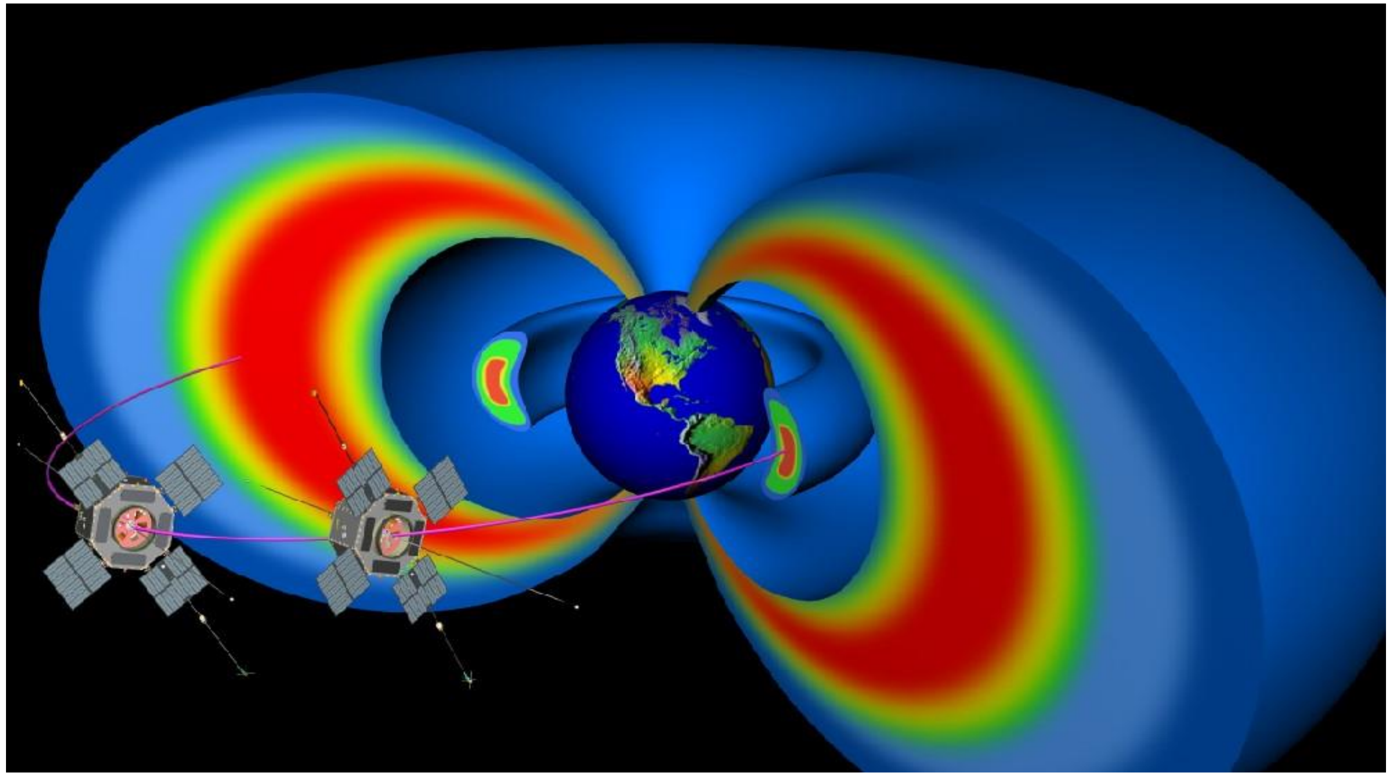
NRL's Comprehensive Approach To Space Plasma Offers Deeper Insight into the Strategically Important Near-earth Region

Near-Earth Plasma Environment:
21st Century Plasma Frontier



- Geospace dominance gives 21st century world leadership
- Economy, internet, medicine, etc. exploit near-earth space
- Human activity in space is rising
- Indispensable to national security: Space Force
- ~1/3 of Division research budget in Space Plasma Physics

Taming a Wild Plasma Domain:
Near-Earth Plasma System Challenges



- Many unknowns: Multi-scale processes in multi-species plasma
- Subject to multiple drivers: uncertain boundary/initial conditions
- Lack ability to model critical regions where wave-particle interactions are critical
- Space-time ambiguity & lack of repeatability in measurement

2020 NRL/ONR PRIORITY: ADVOCATE FOR THE DEVELOPMENT OF AN INTEGRATED APPROACH IN GEOPLASMA PHYSICS

U.S. NAVAL RESEARCH LABORATORY

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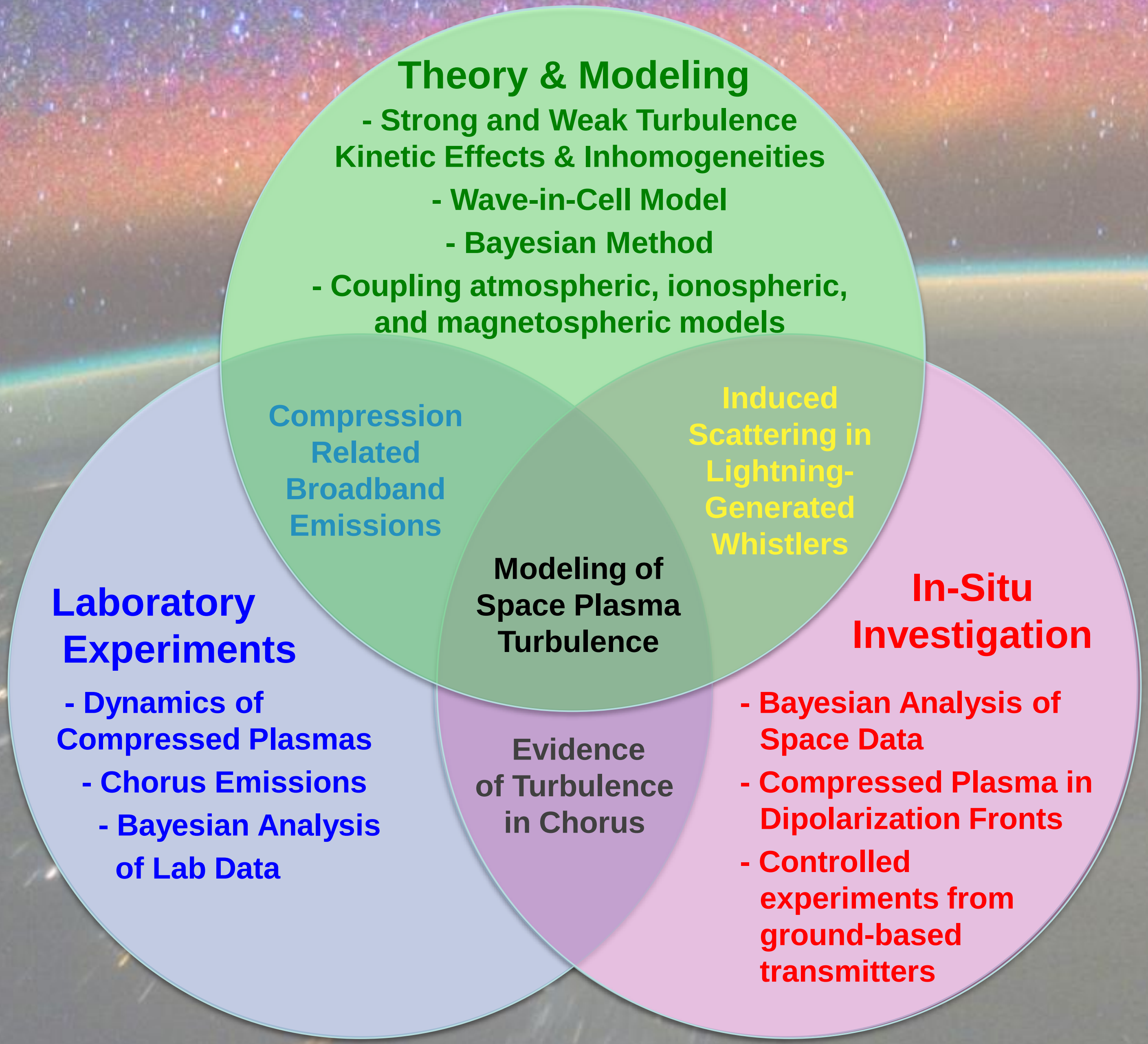

Strategic Vision Going Forward: Plasma 2020

Understand the nature of external forcings that drive the geoplasma system

Develop new modeling architectures to address large swaths of geospace where wave-particle interactions play crucial roles

Exploit plasma properties to mine free energy from space for applications: e.g., control satellite-damaging trapped energetic particle populations

Create realistic space conditions in ground facilities for detailed characterization of space plasma processes to aid space data analysis

Ground-Based Space Plasma Physics

Complementing Theory, Modeling, and In Situ Measurements with Laboratory Experiments

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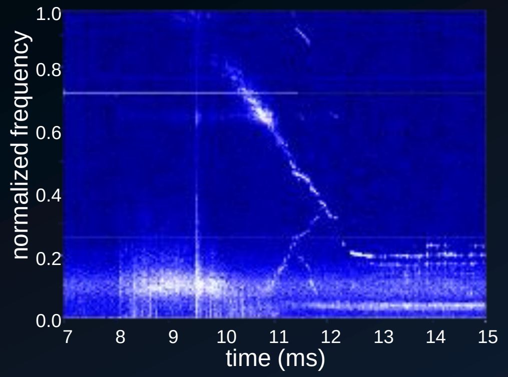
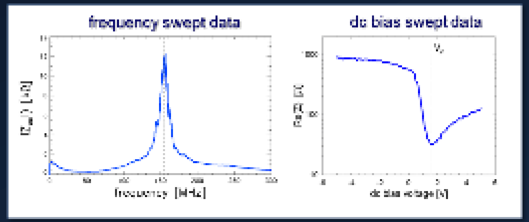
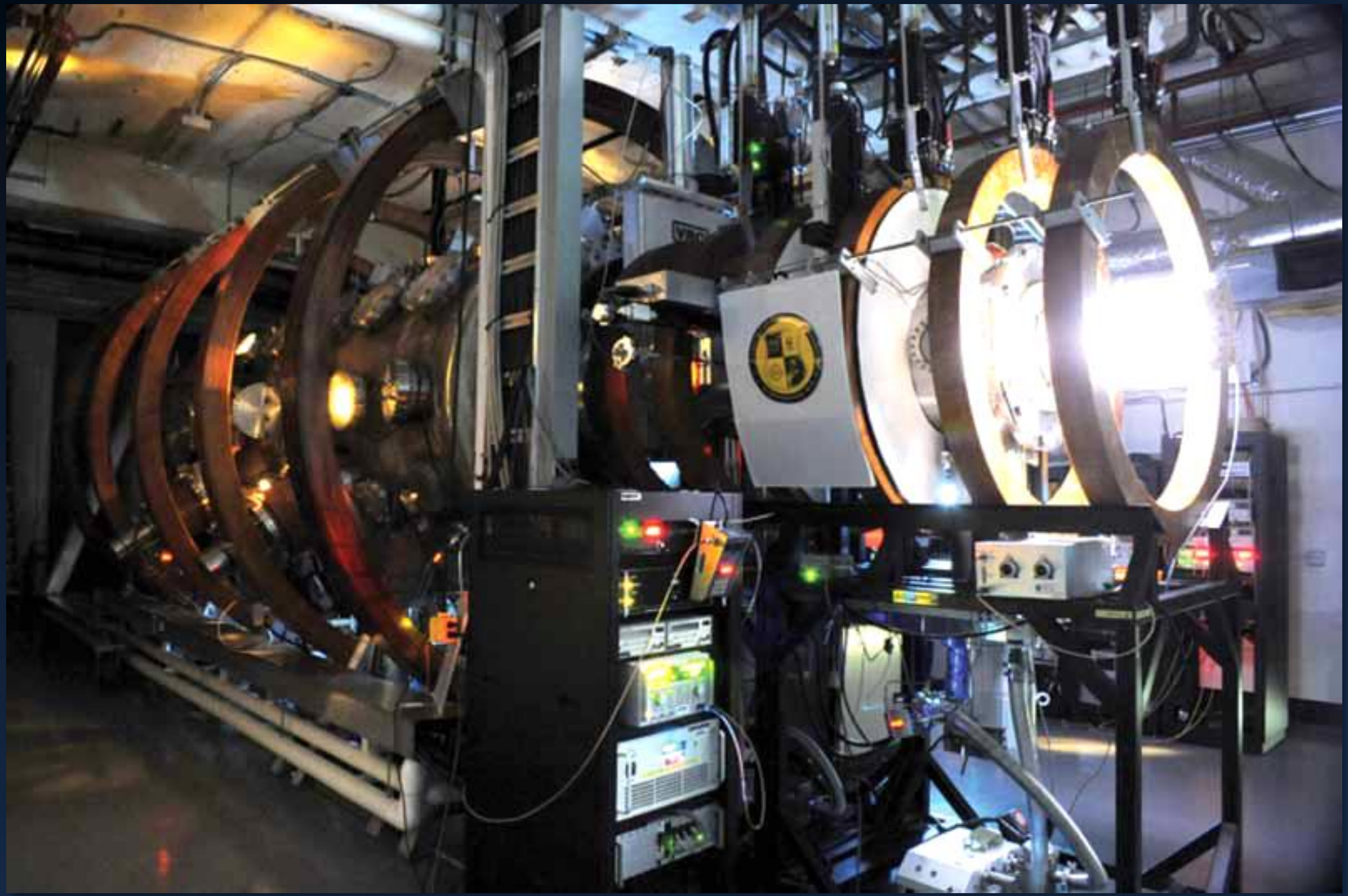
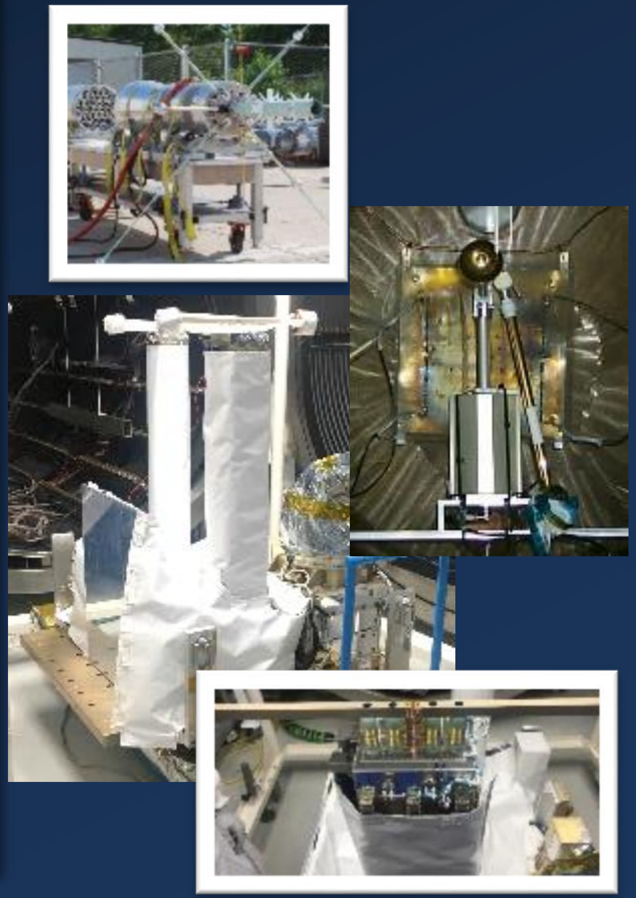
Investigations of Fundamental Topics in Space Plasma Physics







Space Hardware Development, Testing, and Deployment



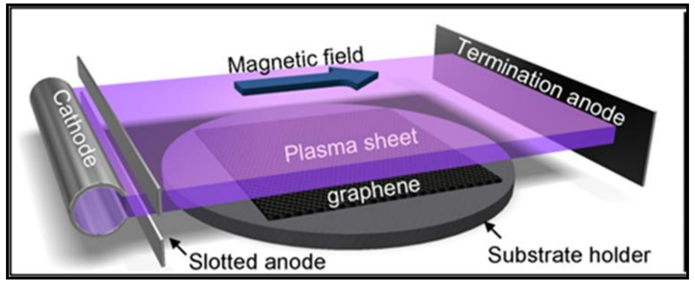
NRL Space Physics Simulation Chamber

Collaboratively investigate the underlying physics of space plasmas under controlled, reproducible, scaled laboratory conditions and provide a realistic testbed for the development and pre-flight testing of space diagnostics and hardware.

Navy has needs in Low Temperature Plasmas for Advanced Electronics, Sensors, Material Processing, & Biophysics

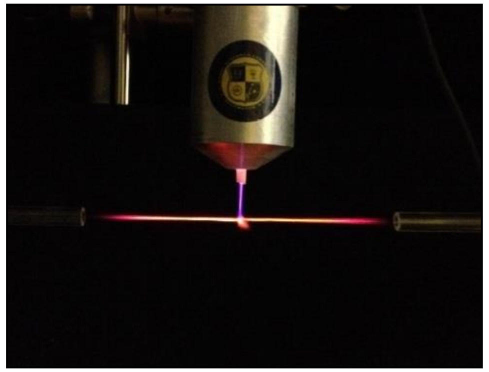
Ultra Low Temperature Plasma Processing (Low pressure)

- **Description**
  - Plasma production driven by electron beam instead of traditional RF power
  - Plasma electron temperature (<1 eV) and ion energy (<5 eV) is substantially lower than in conventional discharges
- **Desirable features**
  - Low ion energy minimizes damage to the workpiece
  - Ion species densities are proportional to neutral gas densities, simplifying process control
- **Target applications**
  - Atomic layer etch (enabling technology for future electronics)
  - Atomic layer deposition (ALD)
  - Atomic layer processing (e.g., graphene)
  - Functionalization of easily damaged materials
  - Enhanced UV reflectance in future space telescope mirrors



Atmospheric Pressure Plasma (APP) Sources

- **Goals of NRL program**
  - Reduce size, weight, power and cost of APP systems
  - Increase plasma volume, treatment area , and uniformity
- **Approaches**
  - Replace conventional HV power supplies with low voltage power supplies and novel power delivery approaches
  - Increase plasma volume with minimal increase in power using gas flow management
- **Target application**
  - Applications not compatible with vacuum environment (aerodynamics, combustion, water treatment, wound healing)
  - Applications requiring low cost and modest precision (Functionalization/treatment of polymers, fabric treatment)



Topics, areas, themes that NRL/ONR would like to see emphasized in Plasma 2020 study

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Inertial confinement fusion science

- Laser plasma instabilities
- Hydro instabilities (RM/RT)
- Role of kinetic effects

High yield fusion for NNSA applications & energy (overcome "fusion fatigue")

- IFE (opportunity for US leadership)
- Alternatives to IDI –
  - direct drive – suppression of LPI by large bandwidth (with UR/LLE)
    - SRRS, excimers
  - pulsed power MHD – Z-pinches (with Sandia)

Atomic physics and dense plasma spectroscopy & MHD

- time and space resolved spectroscopy with high spectral resolution (1-D to 2-D)
- hybrid code development combining MHD, PIC, detailed atomic state ionization kinetics among the particles, and energy transport
- plasma transport mechanisms, such as the Nernst effect
- x-ray Thomson scattering for locally probing high density plasmas.

Pulsed power, high power beams, HPM

- decreased size, increasing power density makes plasma formation/control more important
- Understanding, control, & hybrid modeling of pulsed power plasmas (power flow, diodes, z-pinches)
- Nonlinear physics – inductive acceleration of particles to high energies (warm x-ray sources)

Topics, areas, themes that NRL/ONR would like to see emphasized in Plasma 2020 study

U.S. NAVAL RESEARCH LABORATORY

NRL PPD

New USPL regimes

- plasma optics (lenses, fibers, etc)
- New challenges/opportunities with high average power USPLs
- Plasmas created in laser-water interactions
- High power microwave sources & interactions with plasmas (DE, Counter-DE)

"Geoplasma physics" – space plasmas

- Ionosphere, Radiation belts, space weather
- Space situation awareness (probes)
- Wave-particle interaction physics
- Impacts on communications, precision navigation & tracking, sensing

Low Temperature & Atmospheric plasmas

- Advanced electronics – ALE/ALD
- Advanced materials processing & functionalization: graphene, biosensors …
- Non-equilibrium plasma chemistry: fuel production, waste remediation, material processing
- Plasma biology / medicine – sterilization, decontamination

Plasma physics issues in emerging hypersonic R&D

For more information, please visit the Plasma Physics Division

Our individual and team researchers are our greatest asset (75% have PhDs)

ONR

Revolutionary Research . . . Relevant Results