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Plasma and Electro-energetic Physics

Date: 05 March 2013

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Program Officer
AFOSR/RTB**

Air Force Research Laboratory

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Plasma and Electro-Energetic Physics

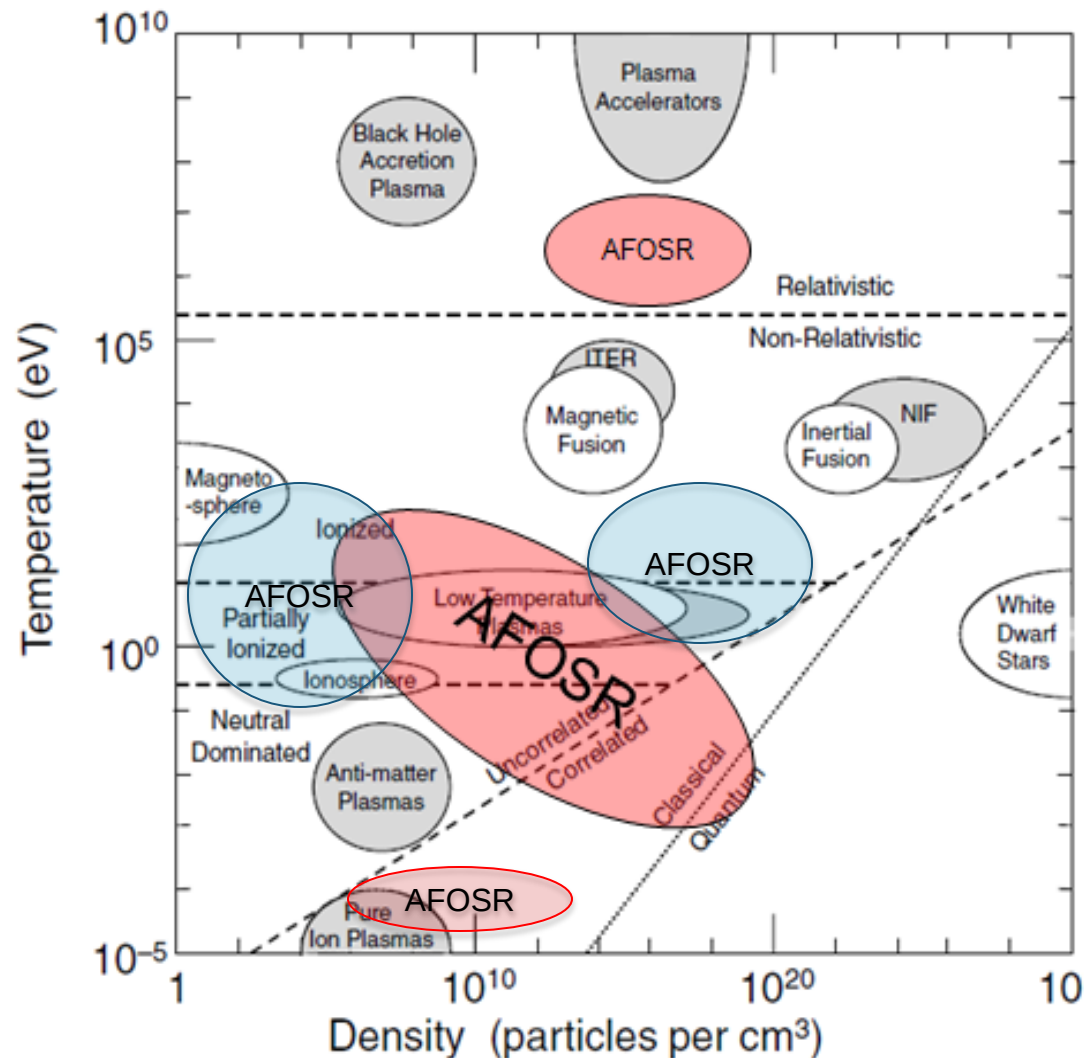


NAME: John Luginsland ,
**Plasma and Electro-energetic
Physics**

BRIEF DESCRIPTION OF PORTFOLIO:

Explore scientific opportunities in plasmas and electro-energetic physics where energy-dense objects powered by electromagnetic energy can provide new vistas in high-power electronics, plasma-enabled chemistry, and fluid/turbulence dynamics arenas

Sub-area: High Power Microwave (HPM) sources, non-equilibrium plasmas, and pulsed power





“What’s past is prologue...”



2008 Spring Review

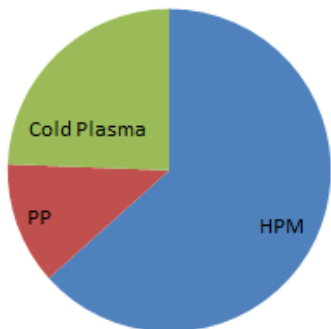
BRIEF DESCRIPTION OF PORTFOLIO:

To advance the state-of-the-art in high power electronics for USAF applications in DEW, radar, EW, and communications.

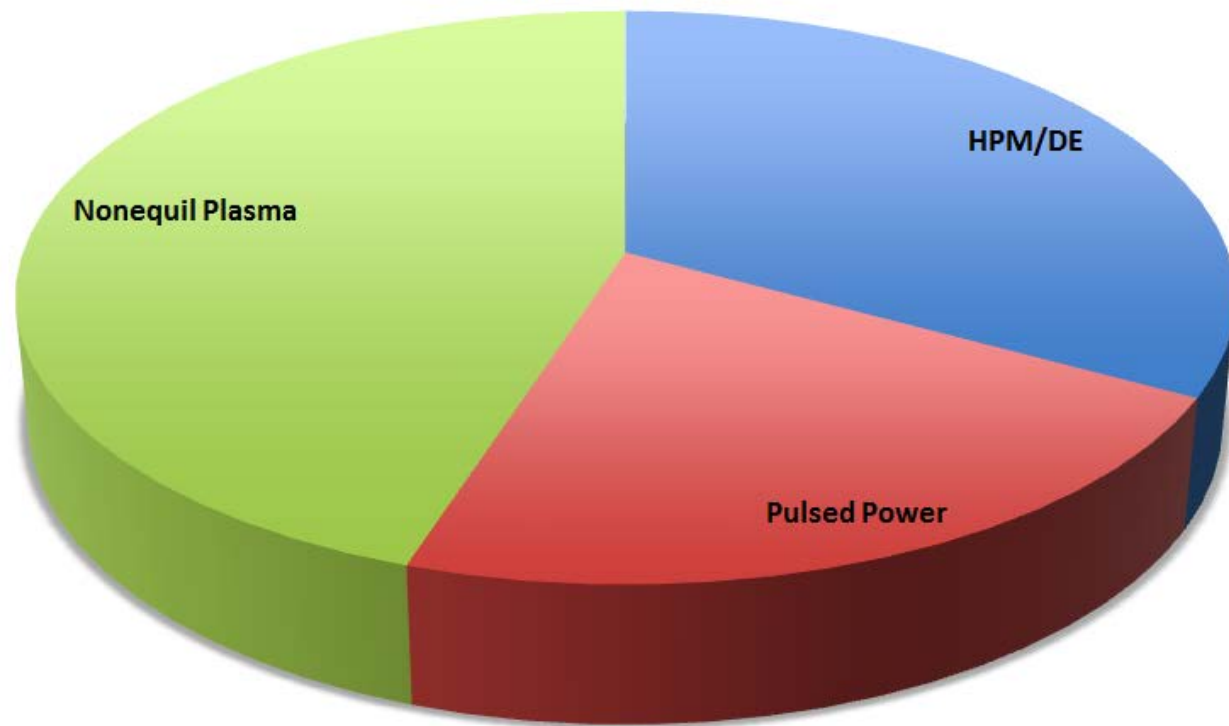
Sub-area:

- HPM sources
- Pulsed power
- Cold plasma

2008 Portfolio

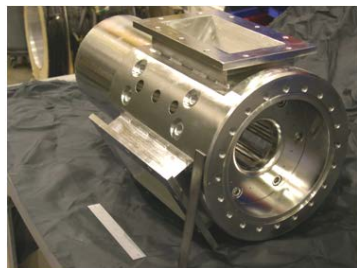


2013 Portfolio

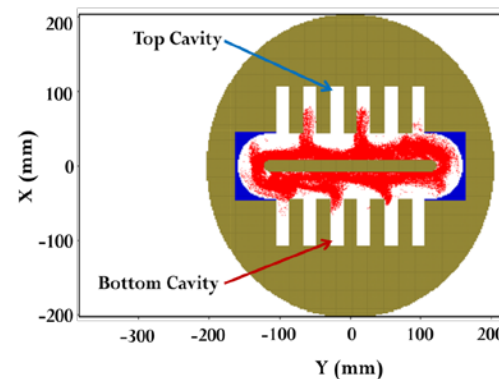




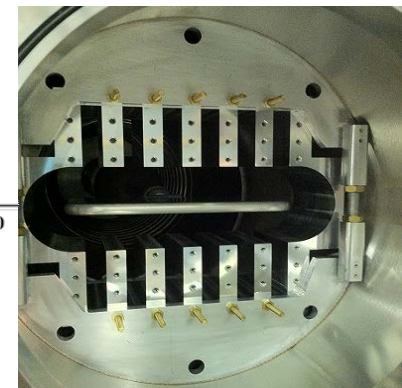
Plasma and Electro-energetic Physics



~GW for short periods

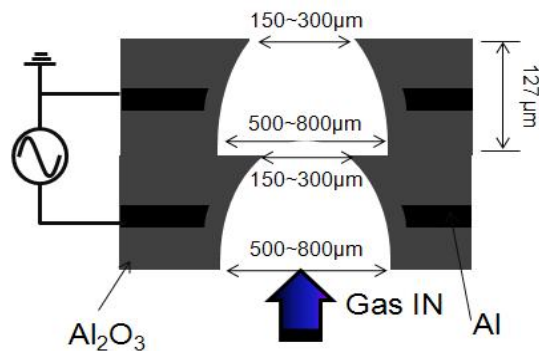
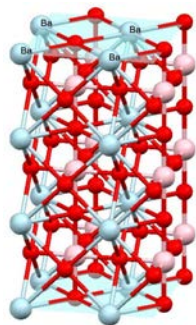
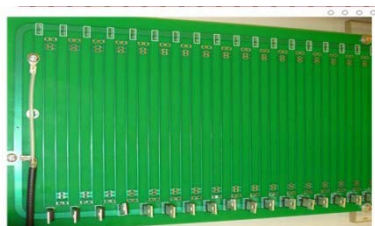


HPM/DE

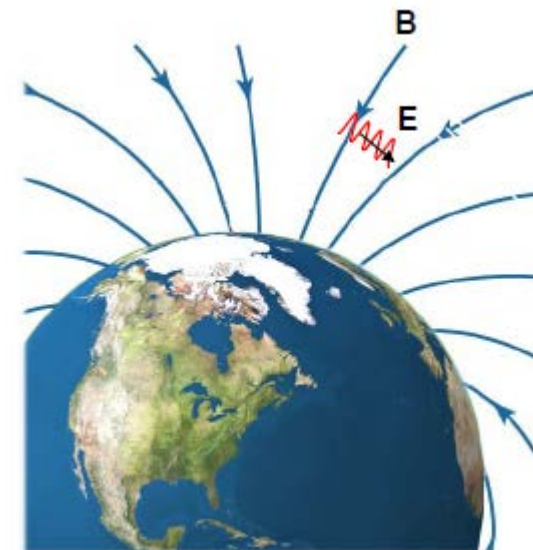
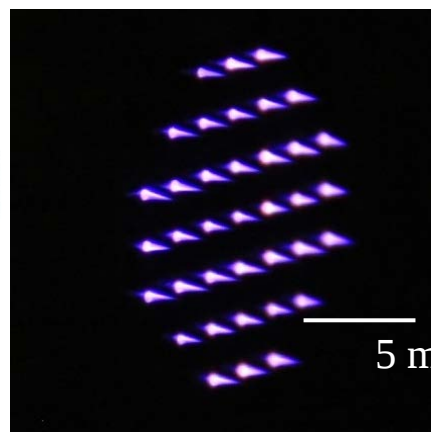


Often far from equilibrium

PP



NEP

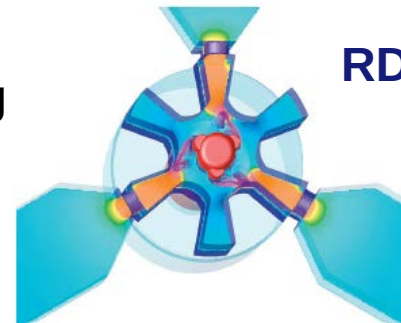




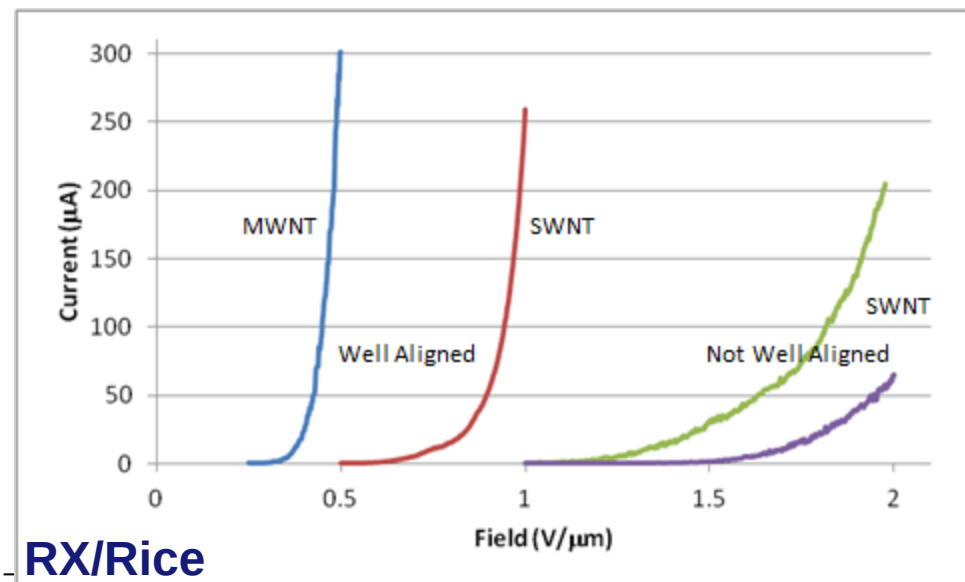
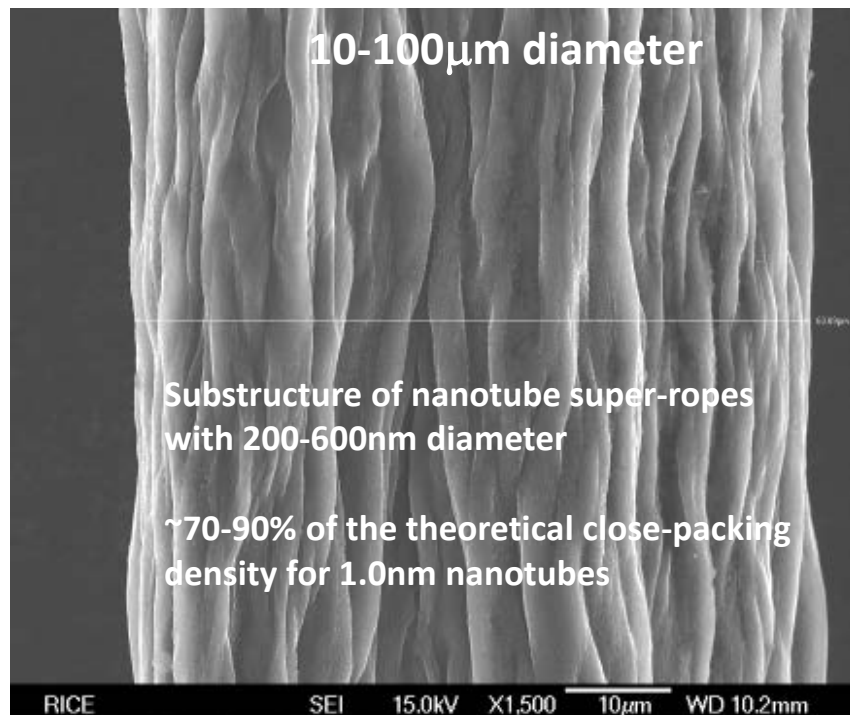
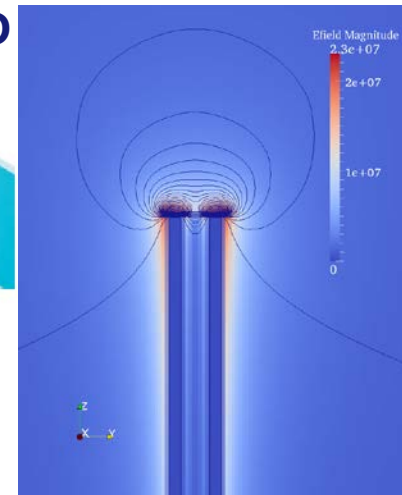
High Power Microwaves



- HPM and vacuum electronics has demonstrated Pf^2 (energy density) doubling every 26 month since 1930
 - MW-GW, ~30-40% efficient, 0.1-1 μs
- Emission physics fundamental physics for input power (Joint RD/RX/EOARD/AFOSR)

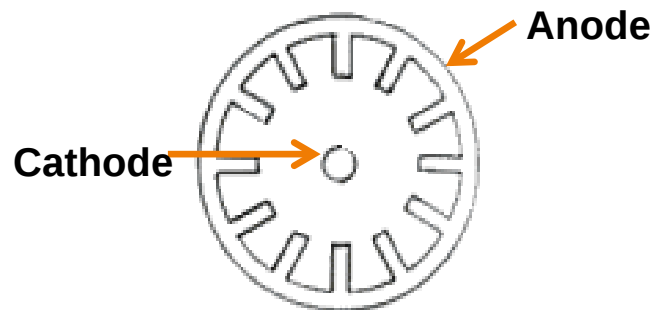


RD

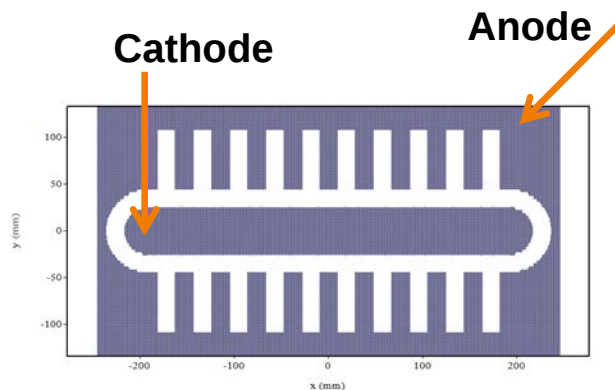




Recirculating Magnetron (U-Michigan and AFRL/RD)

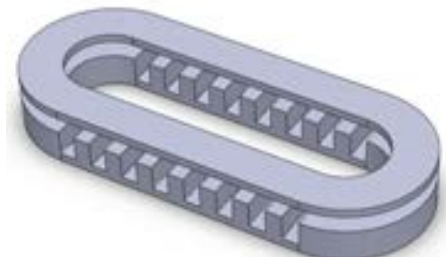
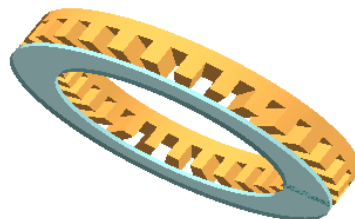


Conventional 12 vane magnetron



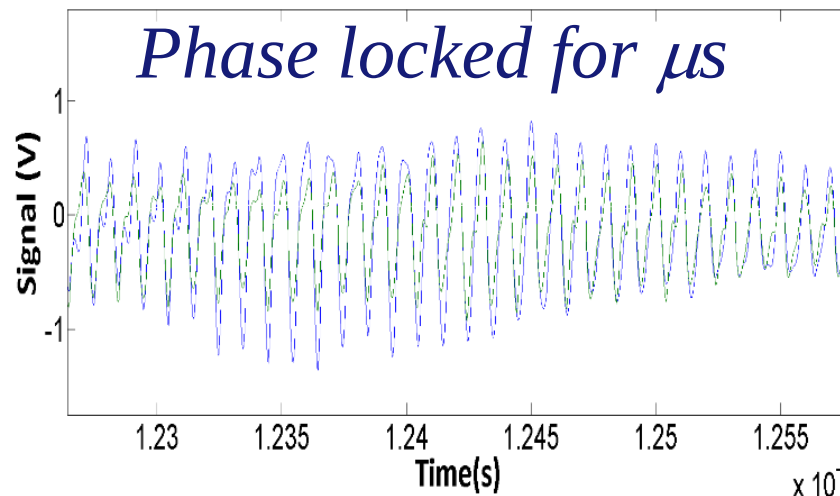
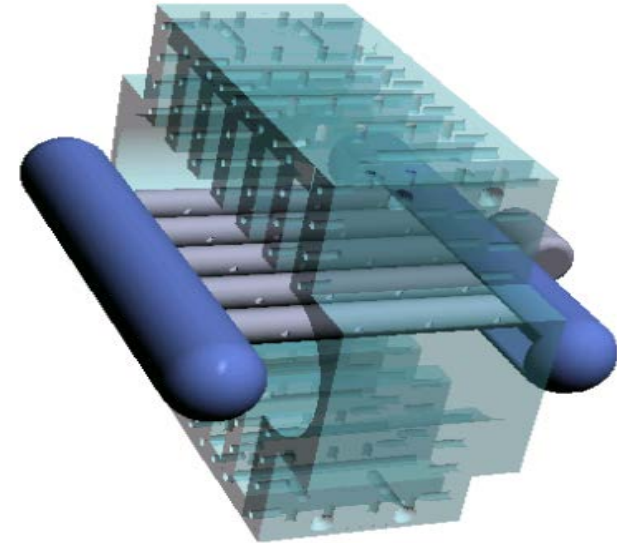
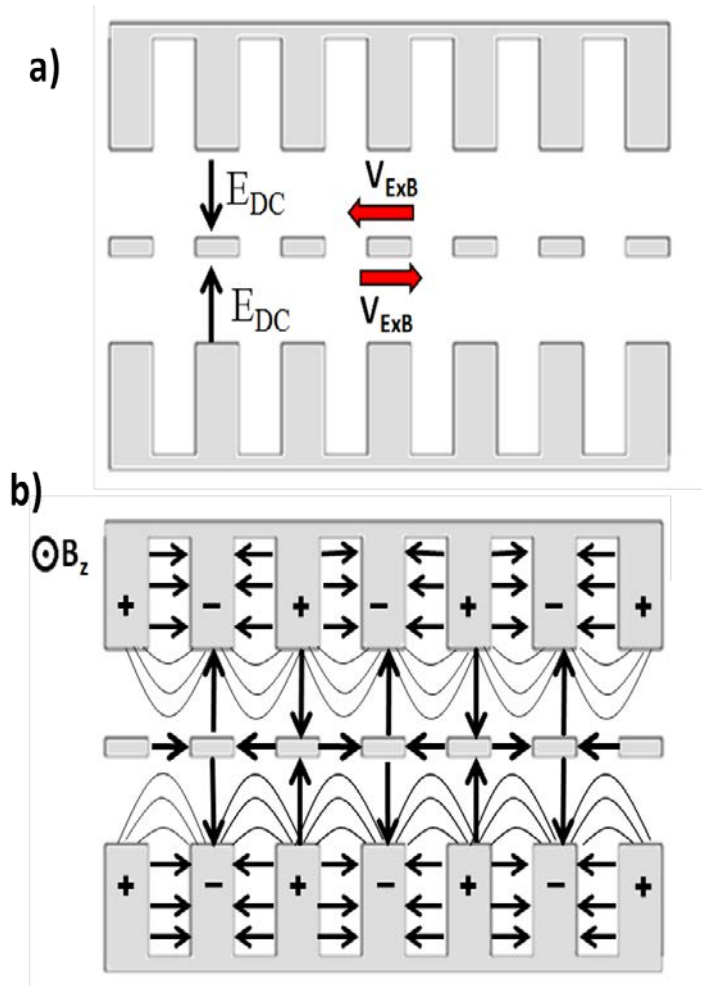
Conventional-polarity 20-vane RPM

- Larger cathode surface area provides higher current
- Larger anode area allows for faster heat dissipation
- RPM allows for nearly full electron beam recirculation
- Planar cavities are decoupled from the anode-cathode and spacing
- Magnetic field volume (V) scales linearly with # cavities (N) instead of (N^2) as with cylindrical magnetron





Phase Control





Amplifiers vs Oscillators

A Grand Challenge

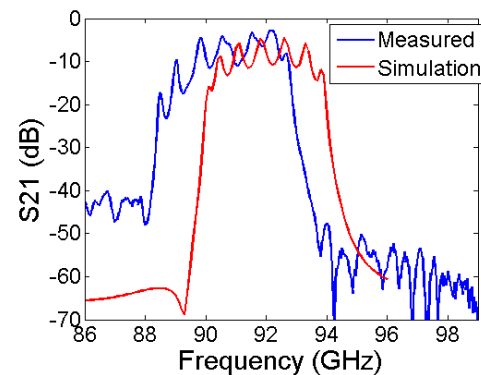
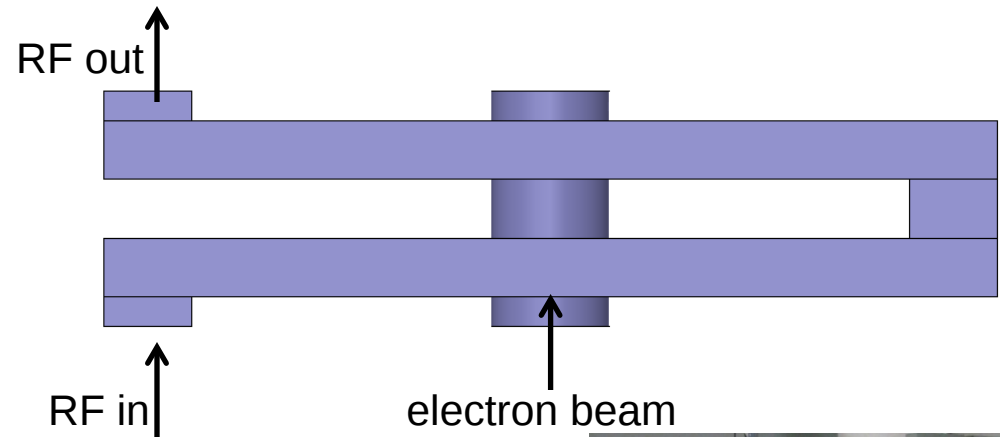


Haystack/Warloc



80kW (10kW ave)

Fundamental challenge in mating high power (nonlinearity) and amplification (linearity)



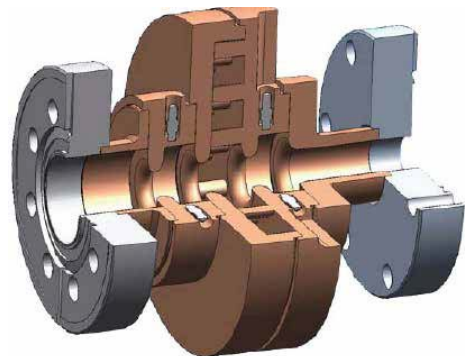
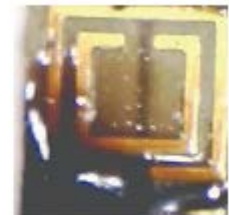
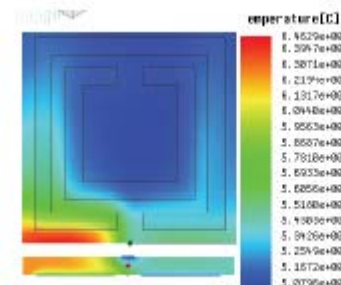
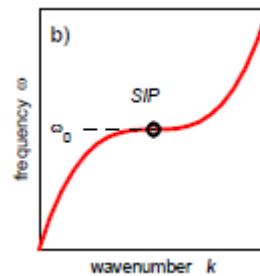
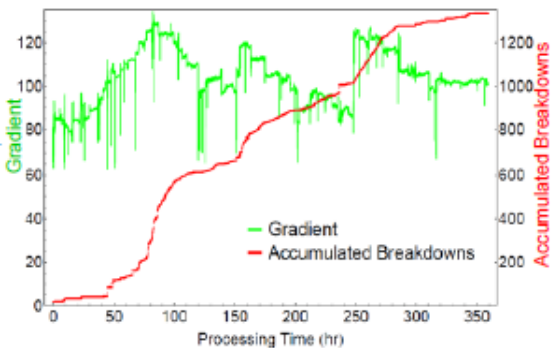
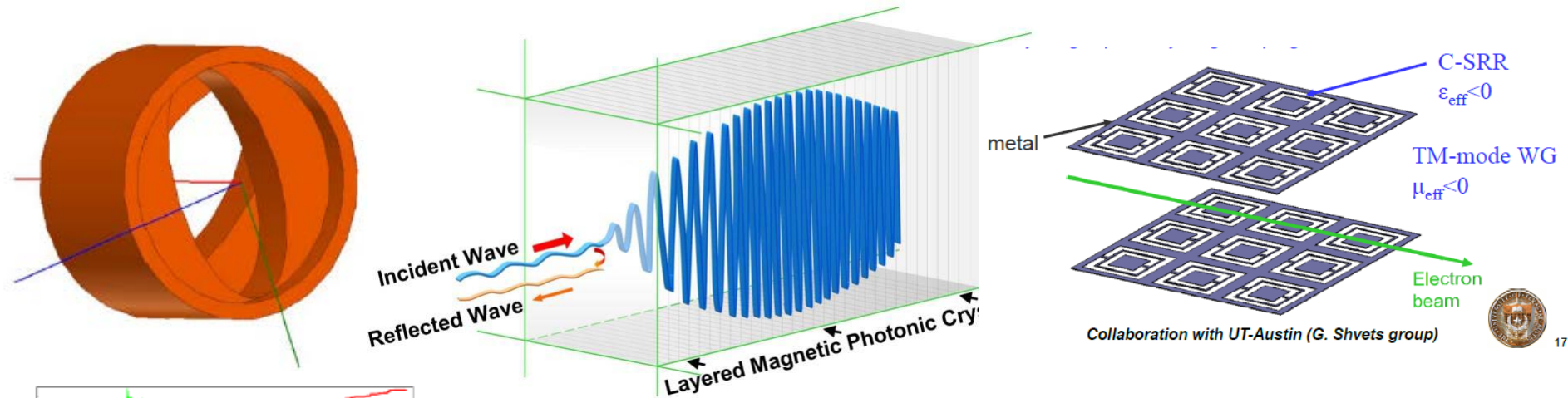
30dB gain at 300W (200MHz BW)

MIT





High Power MM for Transformation Optics



FY'12 MURI

Transformational Electromagnetics



MTMs design



MTMs design and
characterization,
antennas



Electrical &
Computer Engineering

High Power VEDs, MTMs,
plasma diagnostics

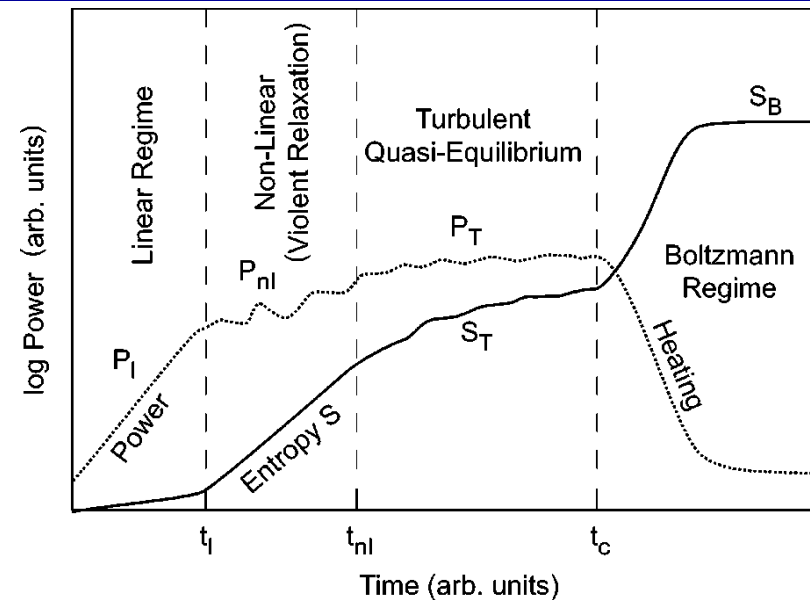


VEDs, MTMs

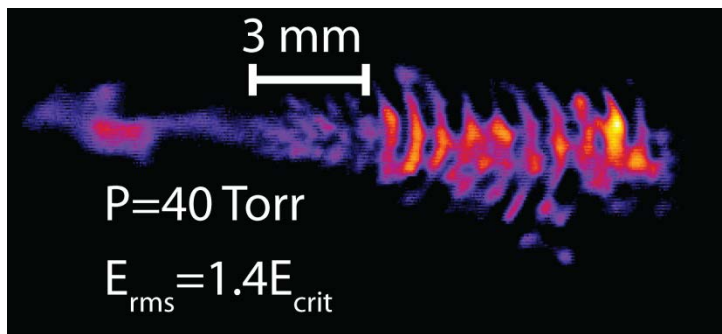
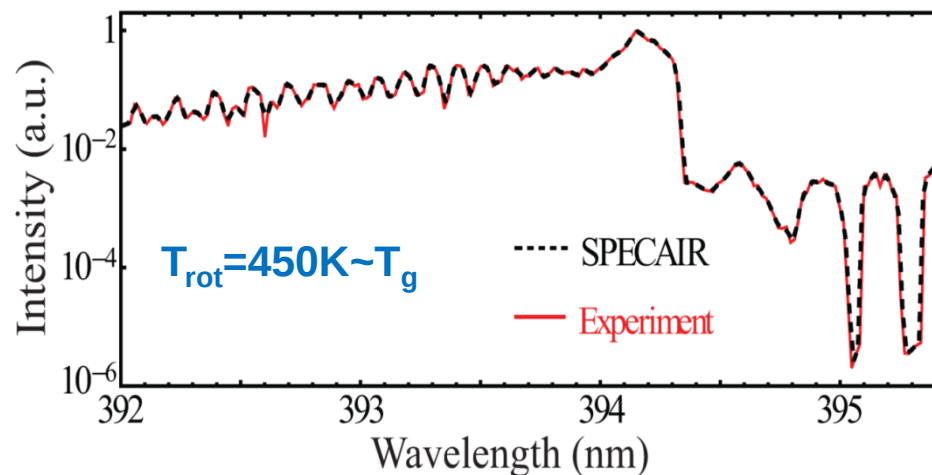
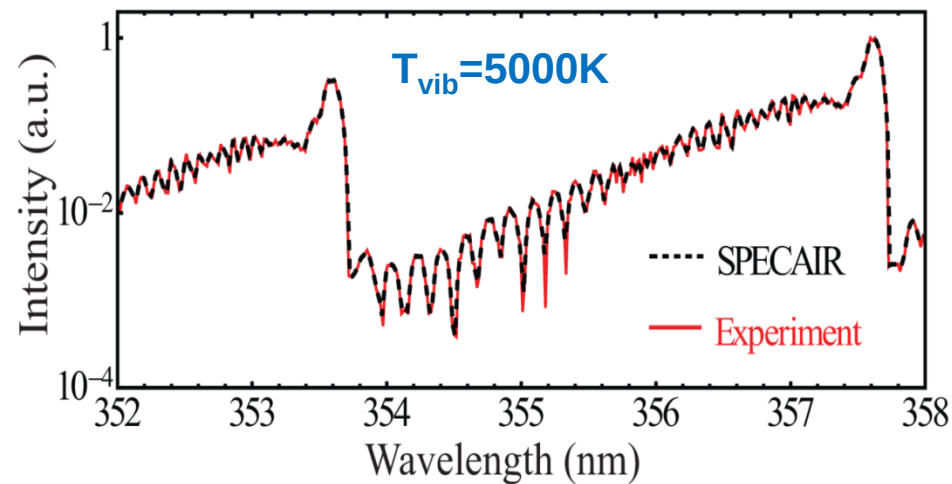




Non-Equilibrium Air Plasma



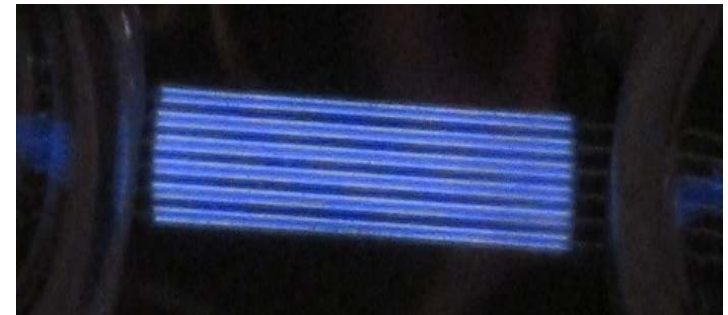
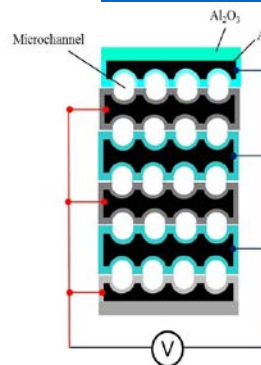
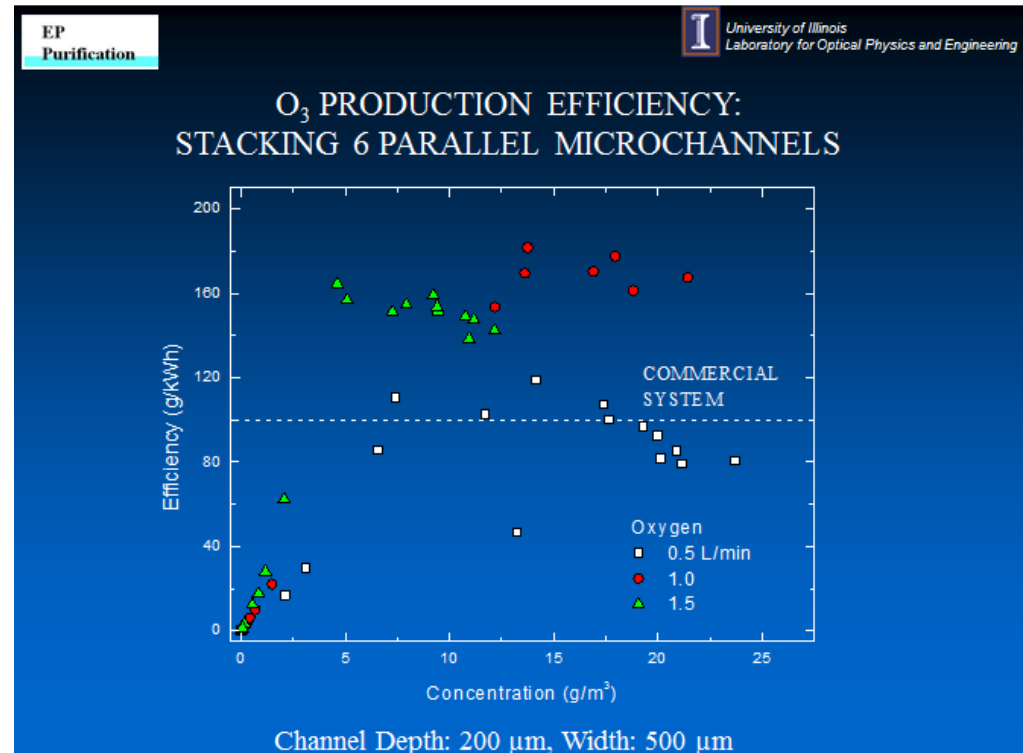
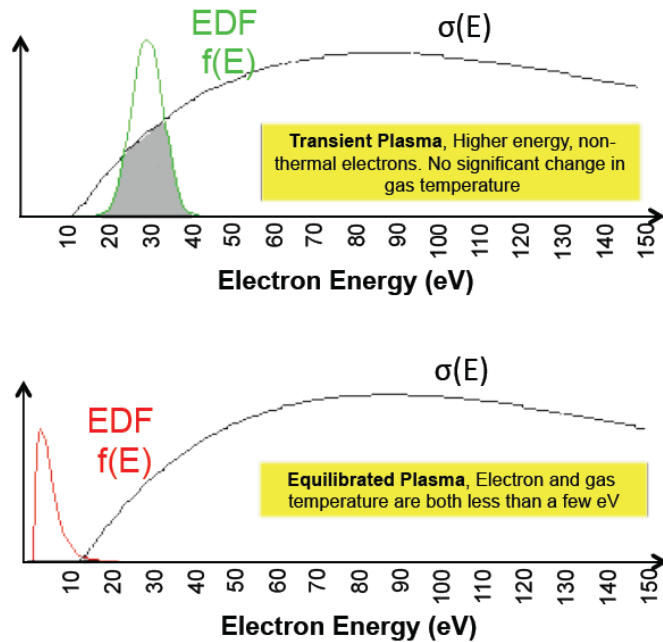
Entropy (arb. units)



Light from 3 μs discharge



Novel Plasma Chemistry

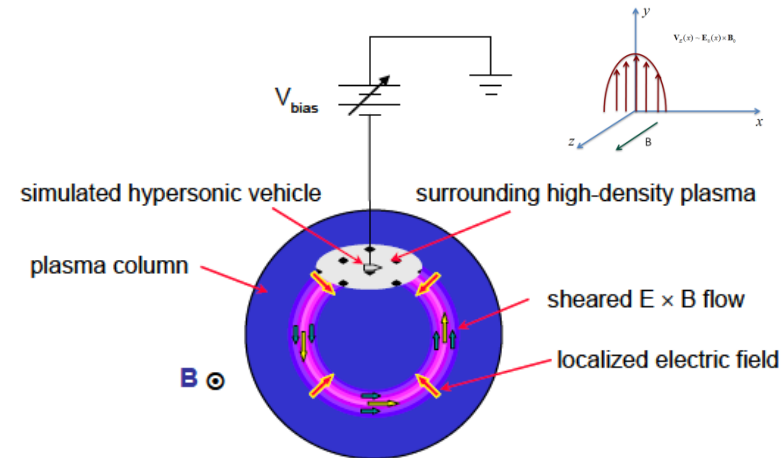
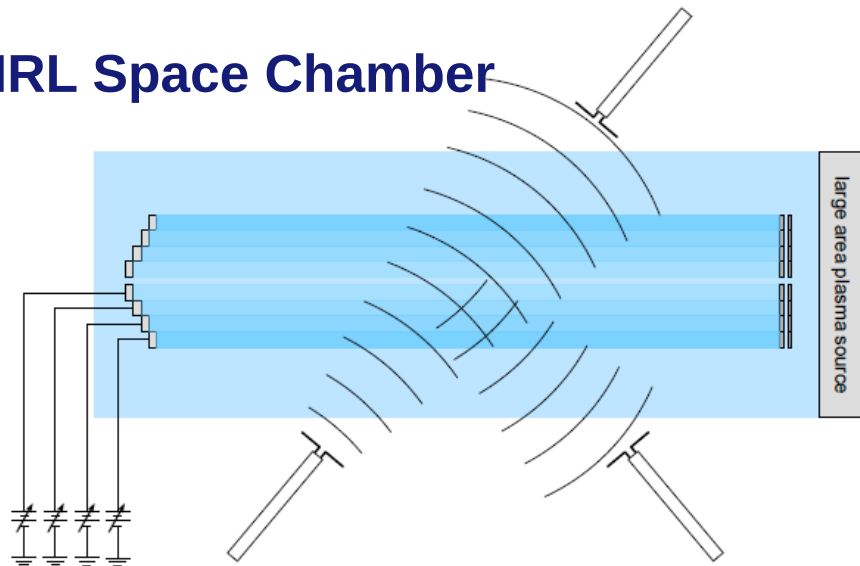




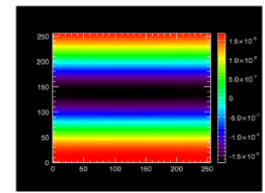
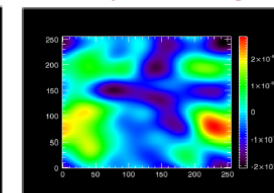
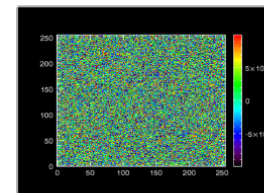
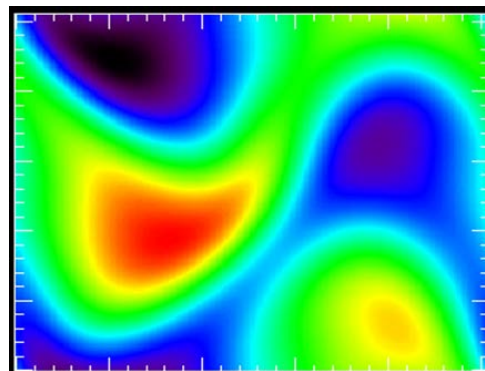
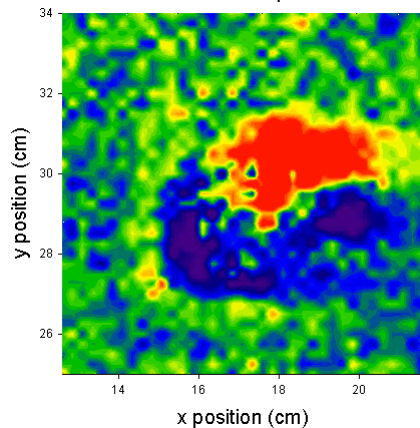
Non-Equilibrium Plasma in Space



NRL Space Chamber



AFRL/RV Theory on LH and IAW

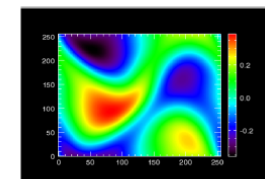
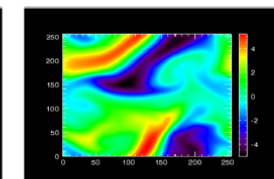
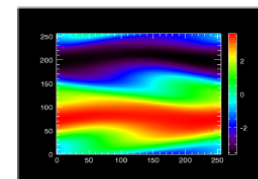


$\Omega_e t = 0$

$\Omega_e t = 10$

$\Omega_e t = 300$

Density in nonlinear stage and formation of zonal flows and nonlinear vortex structures



$\Omega_e t = 2700$

$\Omega_e t = 2800$

$\Omega_e t = 2980$

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Distribution A: Authorized for public release

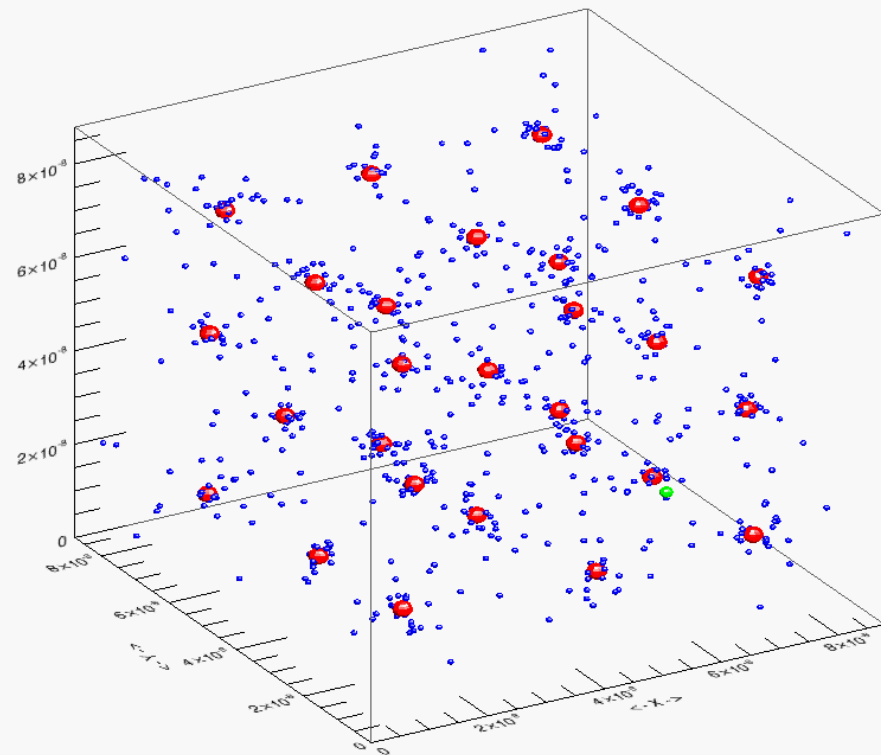
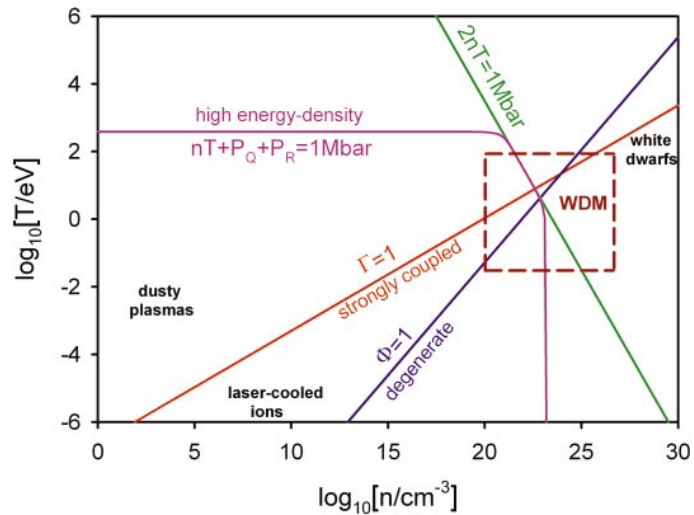


Strongly Coupled Plasma

($\Gamma = 99 = PE/KE$)



Voss Sci/OSU



$t = 1.411\text{E-}006 \text{ ns}$

Ultracold, neutral plasma



Strongly Coupled Plasma



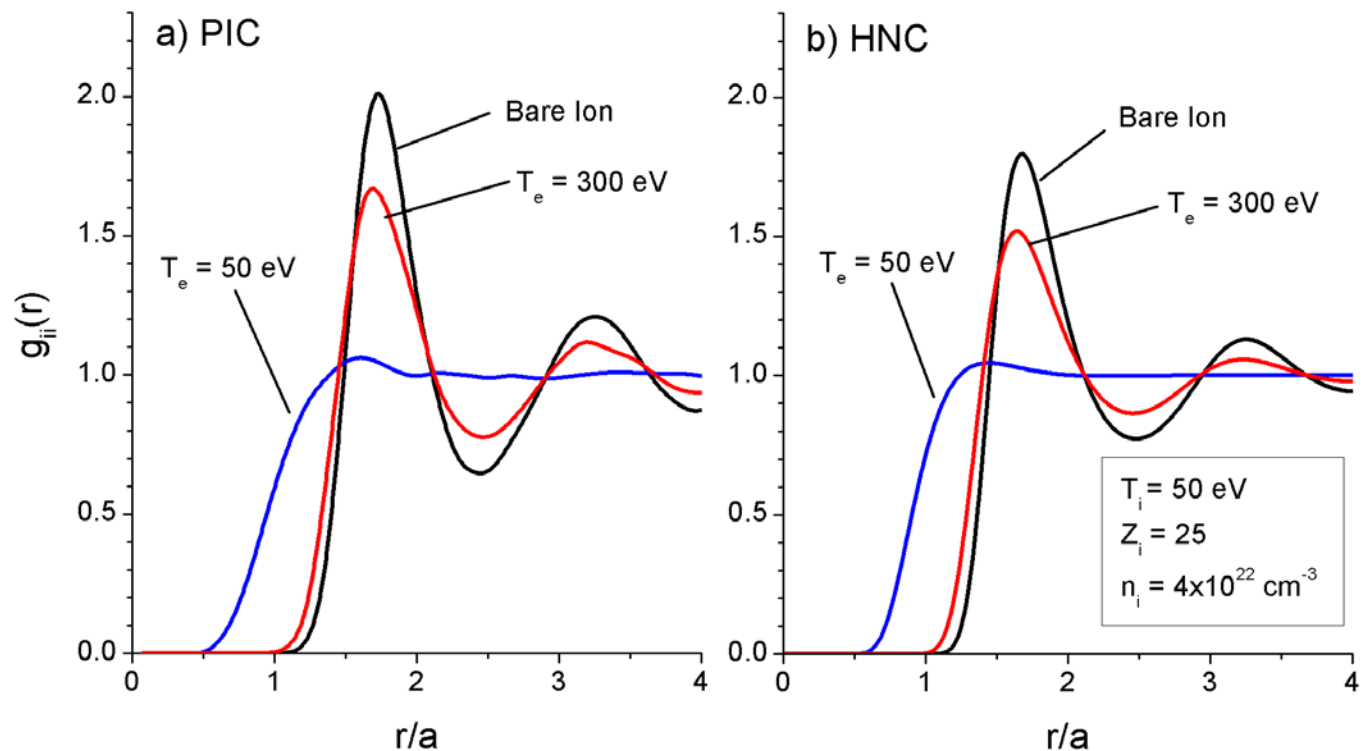
$$\begin{aligned}Z_i &= 25 \\m_i &= 56m_p \\n_e &= 10^{24} \text{ cm}^{-3} \\T &= T_i = T_e\end{aligned}$$

Wigner-Seitz radius:
 $a = (3/4\pi n_i)^{1/3}$

Coupling Parameter:
 $\Gamma = Z^2 e^2 / akT$

Plasma typically defined by kinetic energy > ionization energy
Strongly coupled plasma occurs when PE > KE

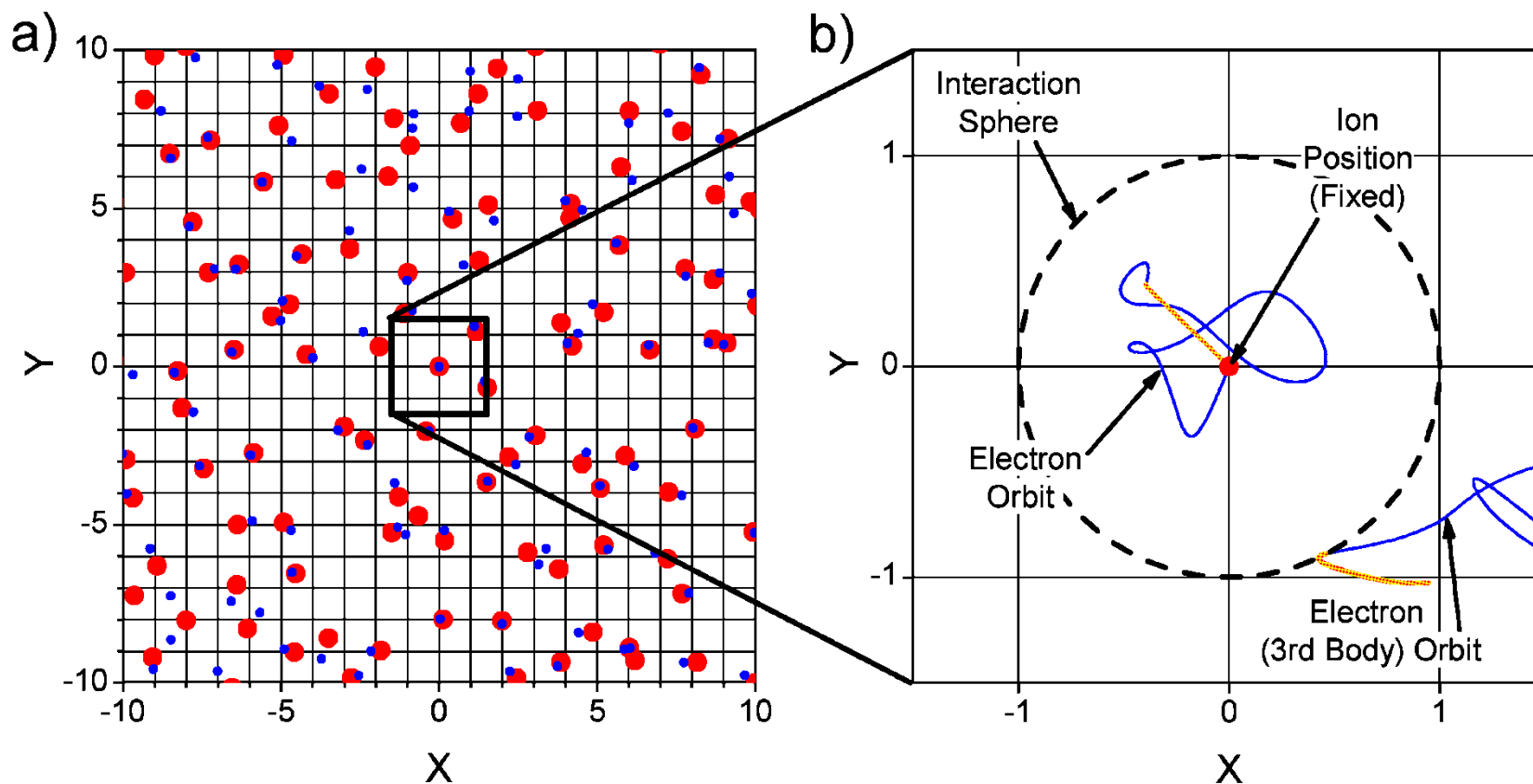
Voss Sci/OSU



BRI with T. Curcic + STTR Transition

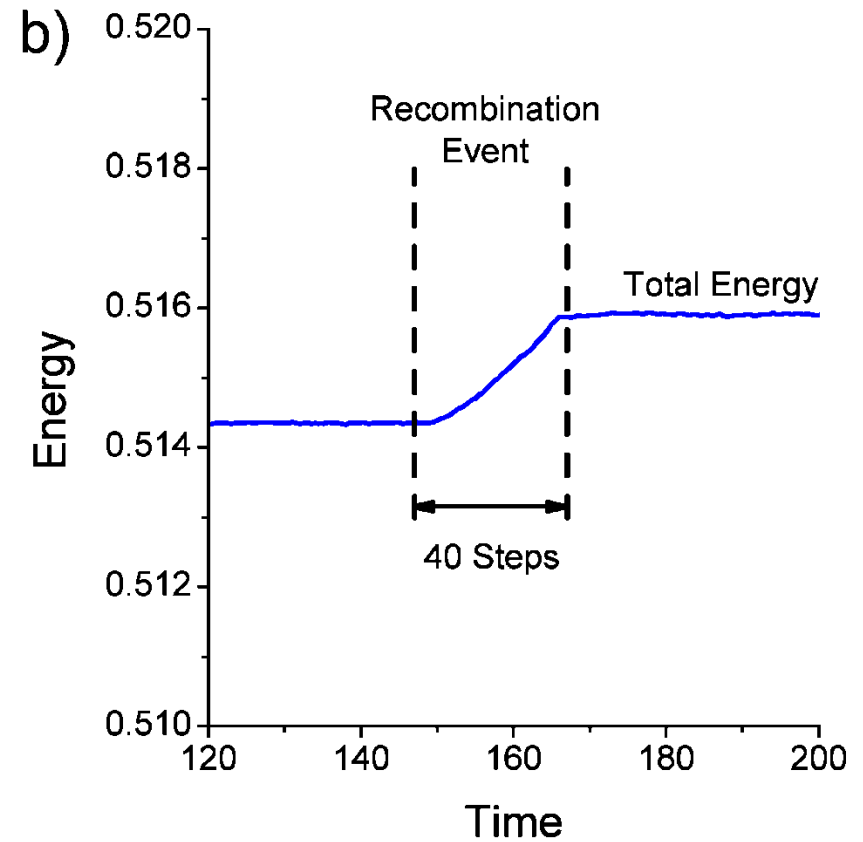
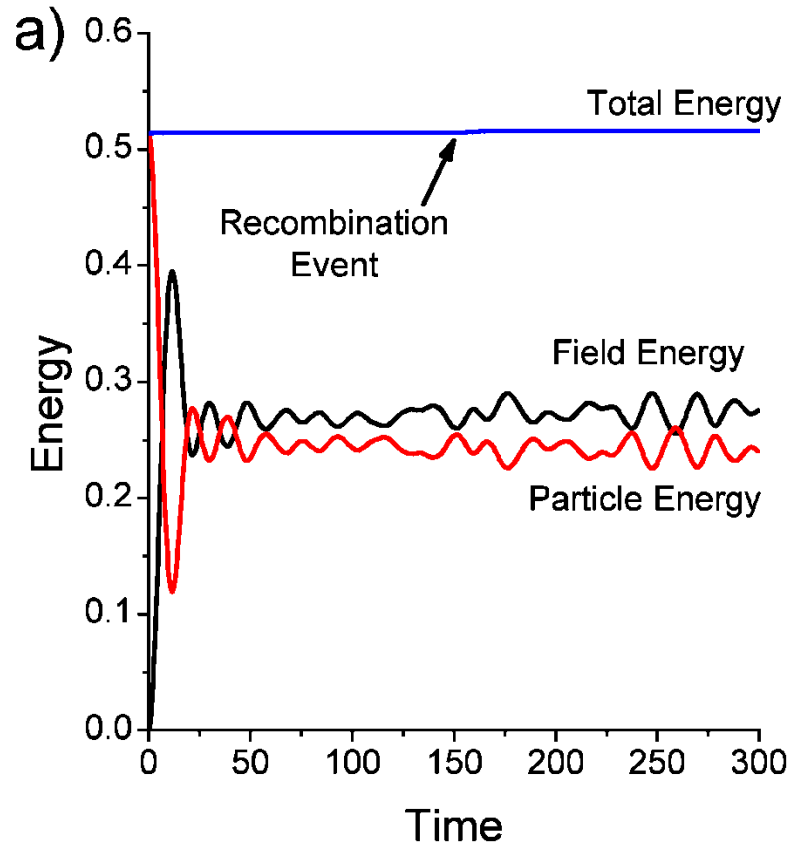


Sample PIC simulation using the density decomposition scheme including a non-local three-body recombination event.





Energy Evolution (40 time step duration)

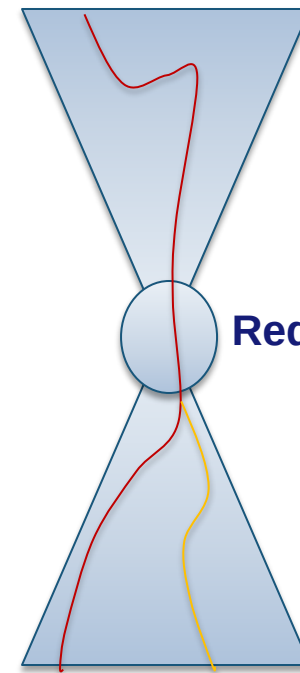
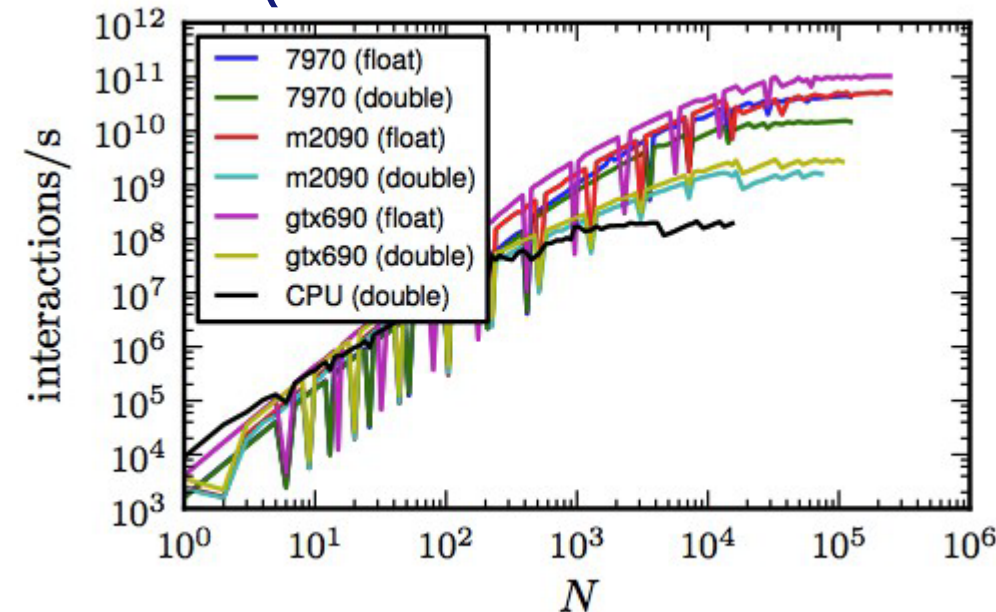




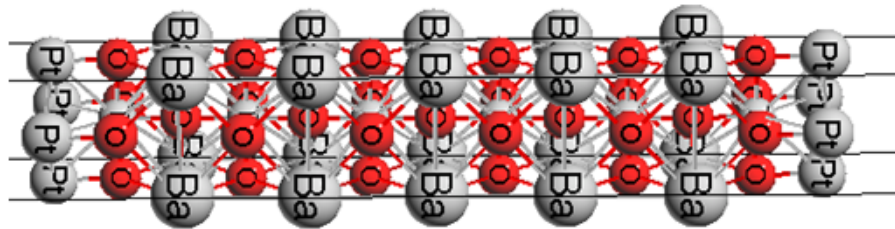
An Aside: Transformative Computation



Tech-X (treecode for SCP on GPU)



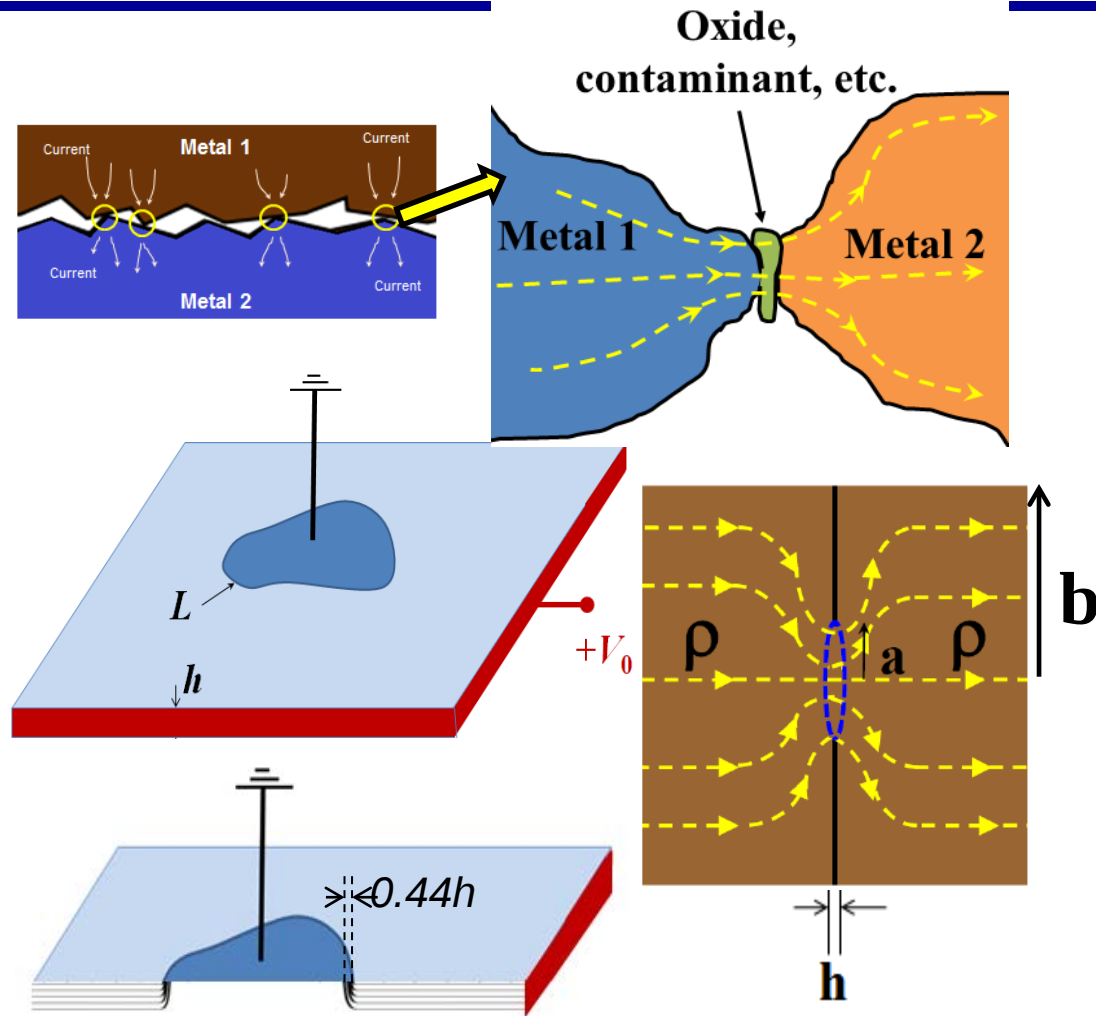
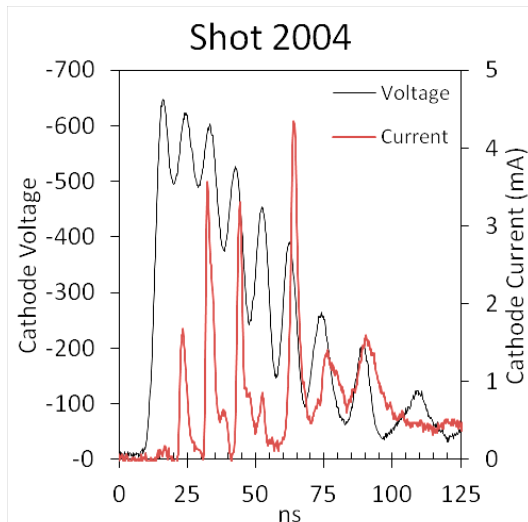
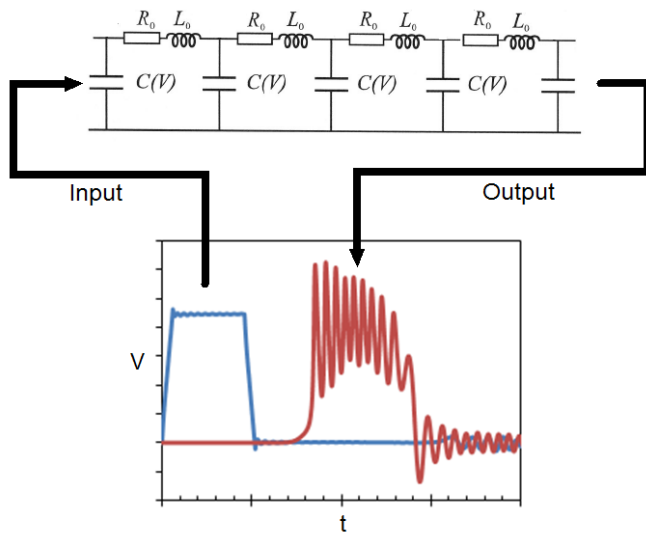
- 3 Recent Basic Research Initiatives (Curcic, Fahroo, JWL, Smith, Stargel)
 - Ultra-Scale and Fault-Resilient Algorithms: Mathematical Algorithms for Ultra-Parallel Computing
 - **Transformational Computing via Co-Design of High-Performance Algorithms and Hardware**
 - Transformational Computing in Aerospace Science and Engineering (Q. Algorithms for Physics)



- **Fundamental focus on transport of charge and energy through solid-state high-energy materials**
- **MURI on Magnetic-Energy Conversion with Sayir**
- **BRI on Metal-Dielectric Interfaces with Sayir**
- **Engineer materials to provide competing characteristics of**
 - **Energy density (ϵ)**
 - **Rapid discharge capability**
 - **Breakdown Dielectric strength (E)**



Pulsed Power Successes



S. Heidger, STAR team

Zhang, UM

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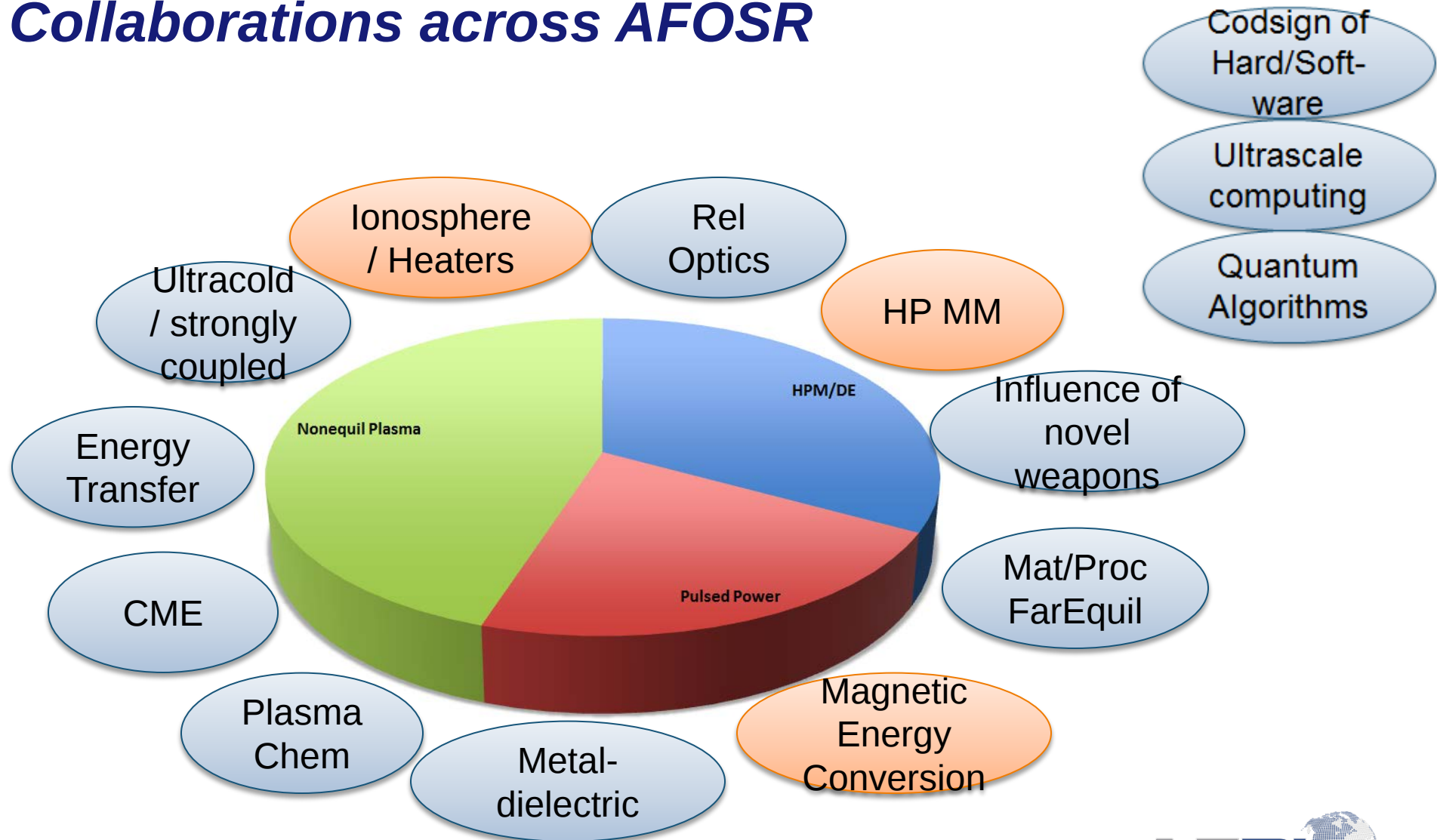




New Initiatives and Resources

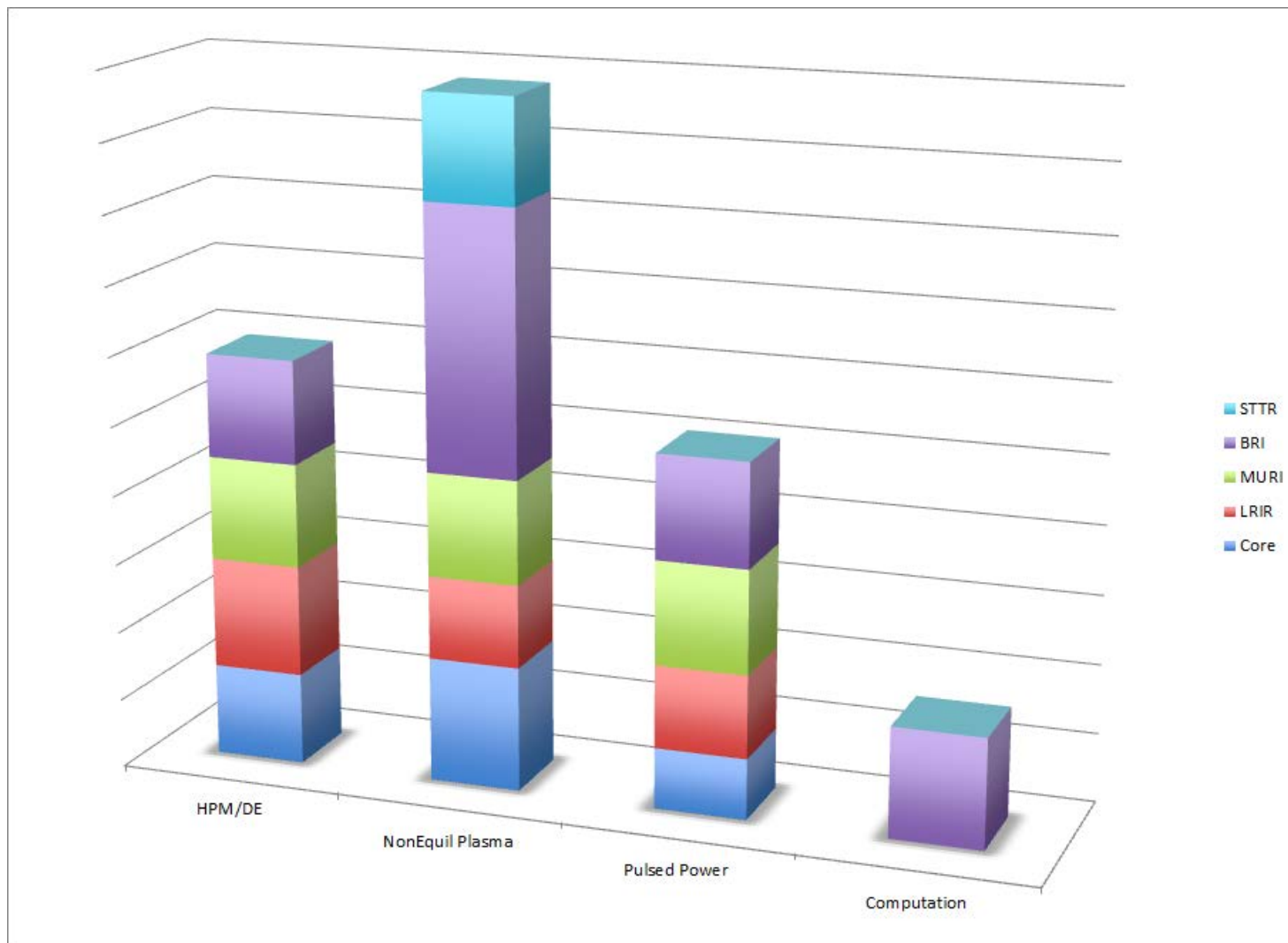


Collaborations across AFOSR



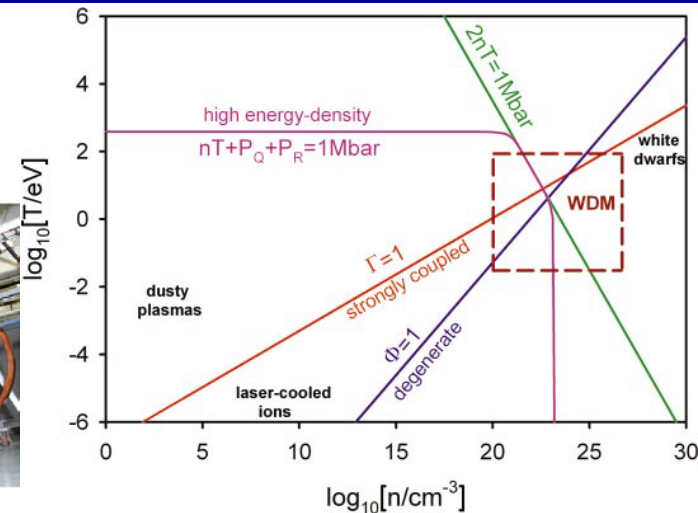
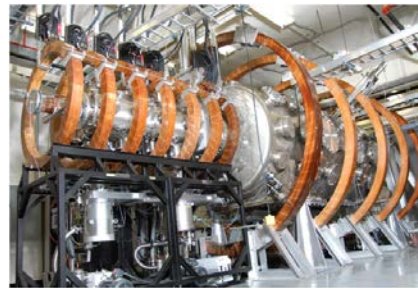
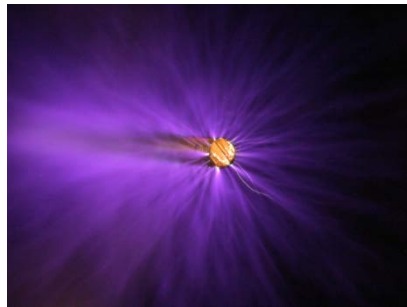
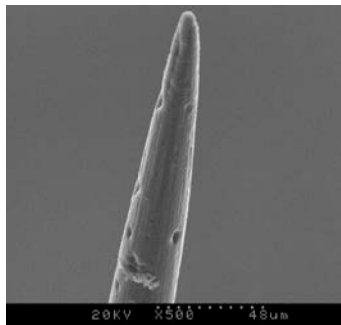


Resources





AFOSR is the leading DOD 6.1 organization for non-equilibrium plasma physics, especially for HPM/vacuum electronics EM sources



fs to hrs; nm to 100s km; solid-state energy/charge transport to plasma to WDM

Collaborators/Teammates

- Active collaborations with AFRL, ONR, ARL, DTRA, DARPA, NSF, DOE, and Air U
- Joint project with DARPA in micro-plasmas
- Close interactions with 9 LRIR, 3 MURI, and 11 BRI (fundamental sciences finds a wide range of collaborations)



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