Broadband microwave emissions from LWIR picosecond laser ablation with pre-ionization

Proposal #312114

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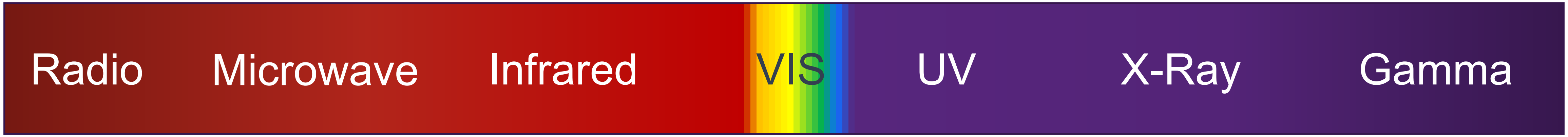
Funding: ONR (JHU/APL, received)
AFRL Program Funds (AFRL, received)

Broadband emissions from pulsed laser ablation

Extreme nonlinear optics of ultra-short pulse lasers enables research and applications across the entire electromagnetic spectrum…



RF EMP

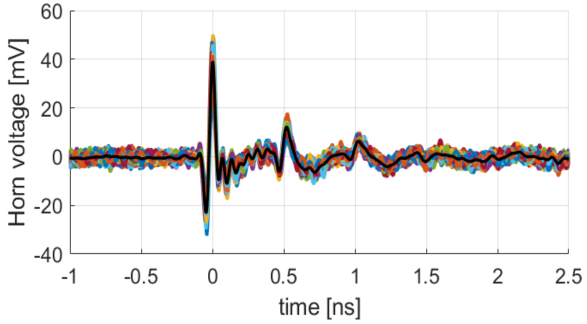
Terahertz Sources

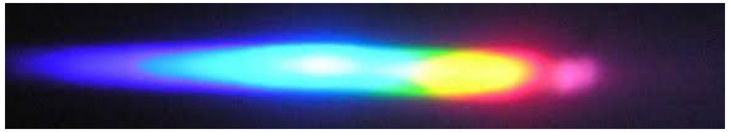
Parametric Conversion

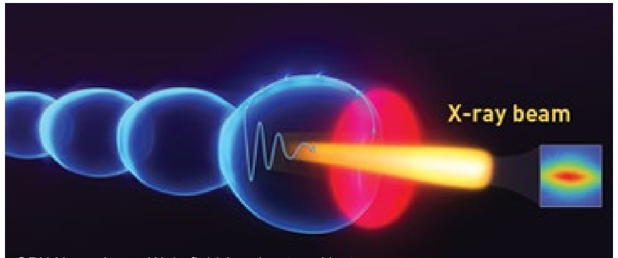
Optical Supercontinuum

High Harmonic Generation

Accelerator-based light sources



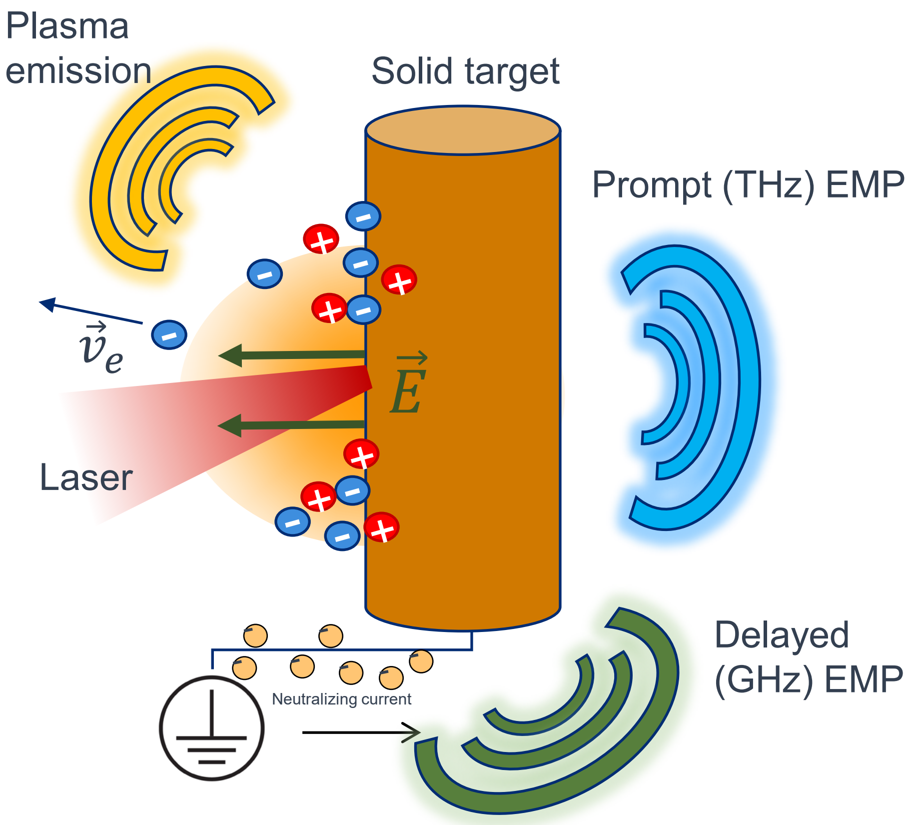




OPN News, Laser Wakefield Accelerators: Next-Generation Light Sources," Albert 2018.

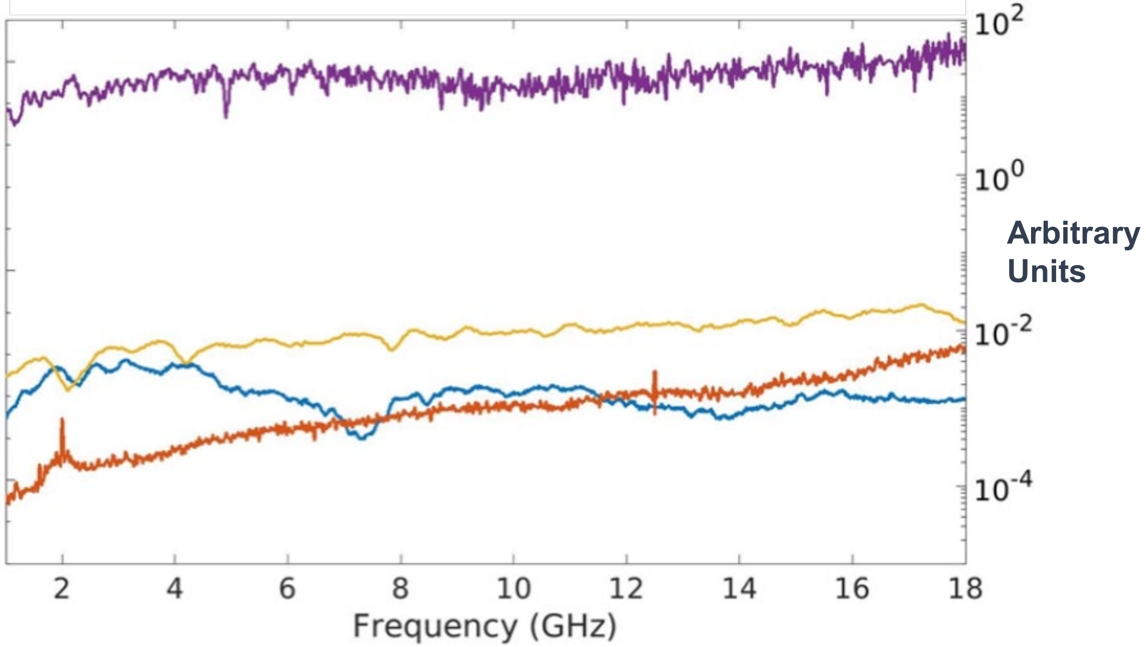
RF Emissions From Short Pulse Laser Ablation

- Low-frequency (RF) emissions measured from ablation as early as 1970's
- Typically found in large laser facilities with lasers reaching relativistic intensities
- Recent work has investigated "atmospheric" and relatively low intensity sources of EMP from laser-plasma interactions
- Three main sources of low frequency emission
  - "Rectification" physics
  - Long scale-length plasma currents
  - Target charging and neutralization



Wavelength Scaling into the LWIR

Measured RF Power Spectral Density



λ (microns)	Energy (joules)	Duration (fs)
0.8	.04	50
1.0	.03	1300
9.2	3	2000
10.6	.01	3000

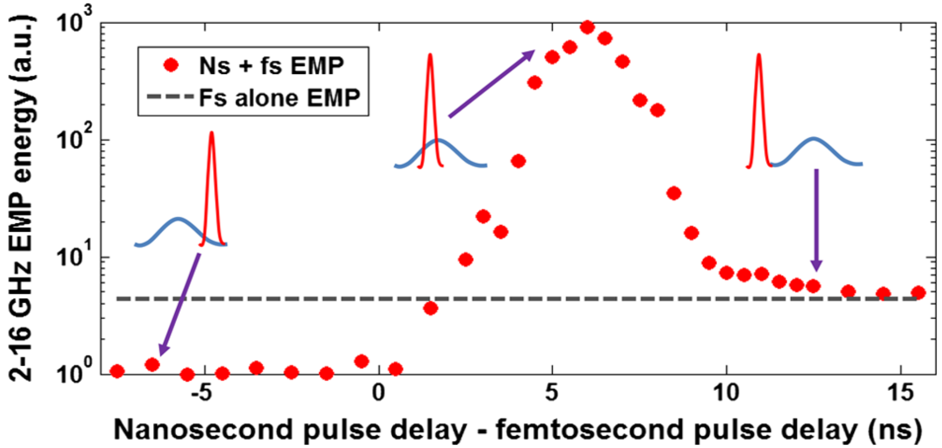
Laser Parameters: λ (μm), Irradiance ($\times 10^{11}$ W/cm^2)

- 0.8, 236.1
- 1.0, 21.1
- 9.2, 48.5
- 10.6, 3.1

- FY22 results exceeded expectations!
- Orders of magnitude improvement across all frequencies achieved with BNL laser

Target pre-ionization

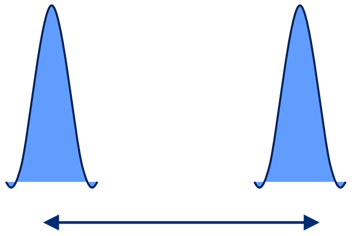
- Previous work at JHU/APL showed orders of magnitude increase in RF emissions from pre-ionized dielectric targets with NIR drive lasers
- Hypothesize improved laser absorption at the critical density layer in the expanding plasma causes a higher electron temperature



S. Varma, J. Spicer, B. Brawley, and J. Miragliotta, “Plasma enhancement of femtosecond laser-induced electromagnetic pulses at metal and dielectric surfaces,” *Opt. Eng.*, vol. 53, no. 5, p. 051515, 2014.

Option 1:

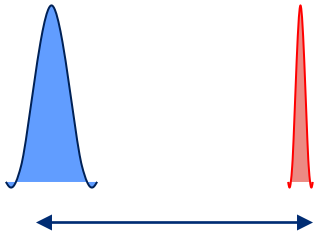
Pulse stacker before main amp



ps – ns delays ± 100 fs

Option 2:

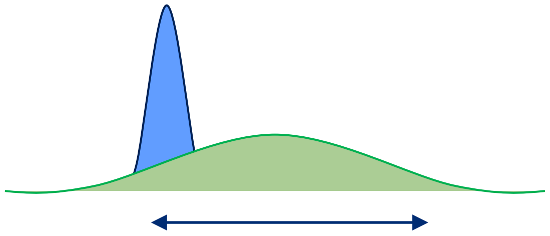
Ti:Sapphire fs pre-ionization



ps – 10s ns delays ± ps

Option 3:

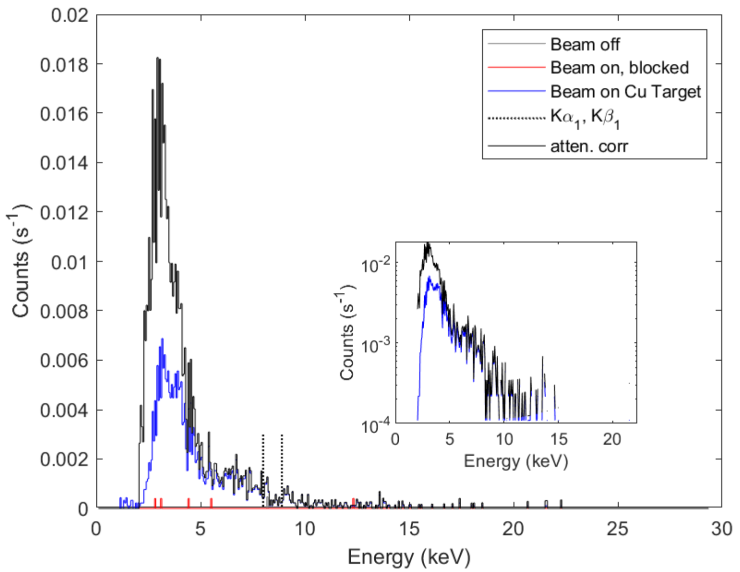
Nd:YAG ns pre-ionization



10s ns delays ± 0.25 ns

Key experimental questions

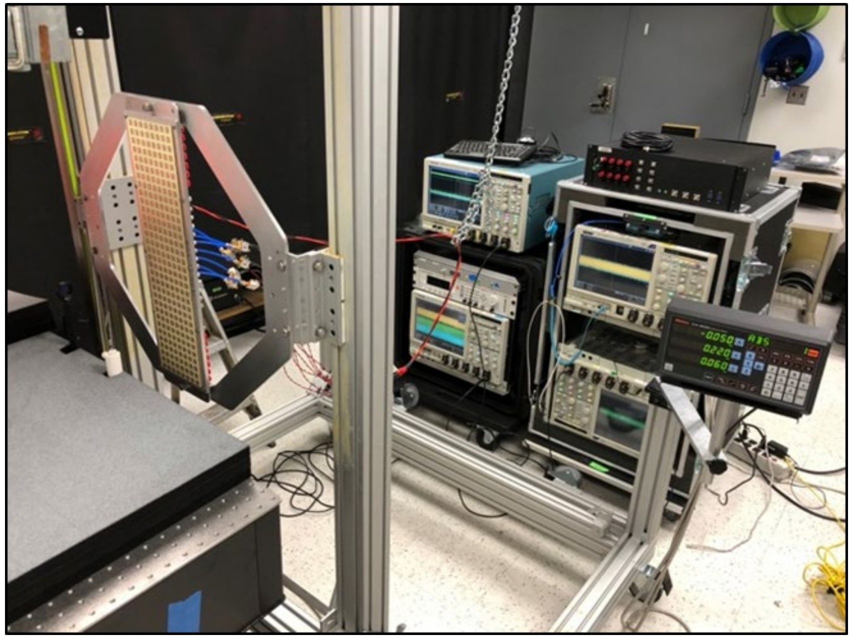
- How does RF emission change with laser incidence angle and intensity? Can we match theoretical models?
  - How does emissions strength compare between dielectric and metal targets?
- Does pre-ionization increase the RF emission from solid targets similar to what we see in the NIR?
  - What pulse separation time scale improves RF emission?
  - Does pre-ionization improve LWIR absorption by the plasma?
- Can we detect a temperature electron population through keV bremsstrahlung? Does the electron temperature correlate with RF emission?
- What effects does the emitted ultrawideband RF field have on electronic devices?

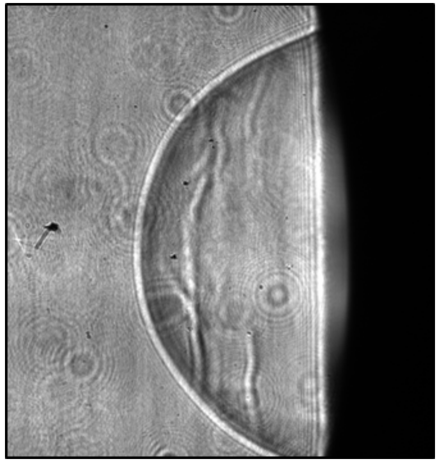


X-ray emission spectrum measured from USPL ablation of copper wire in air

Diagnostics

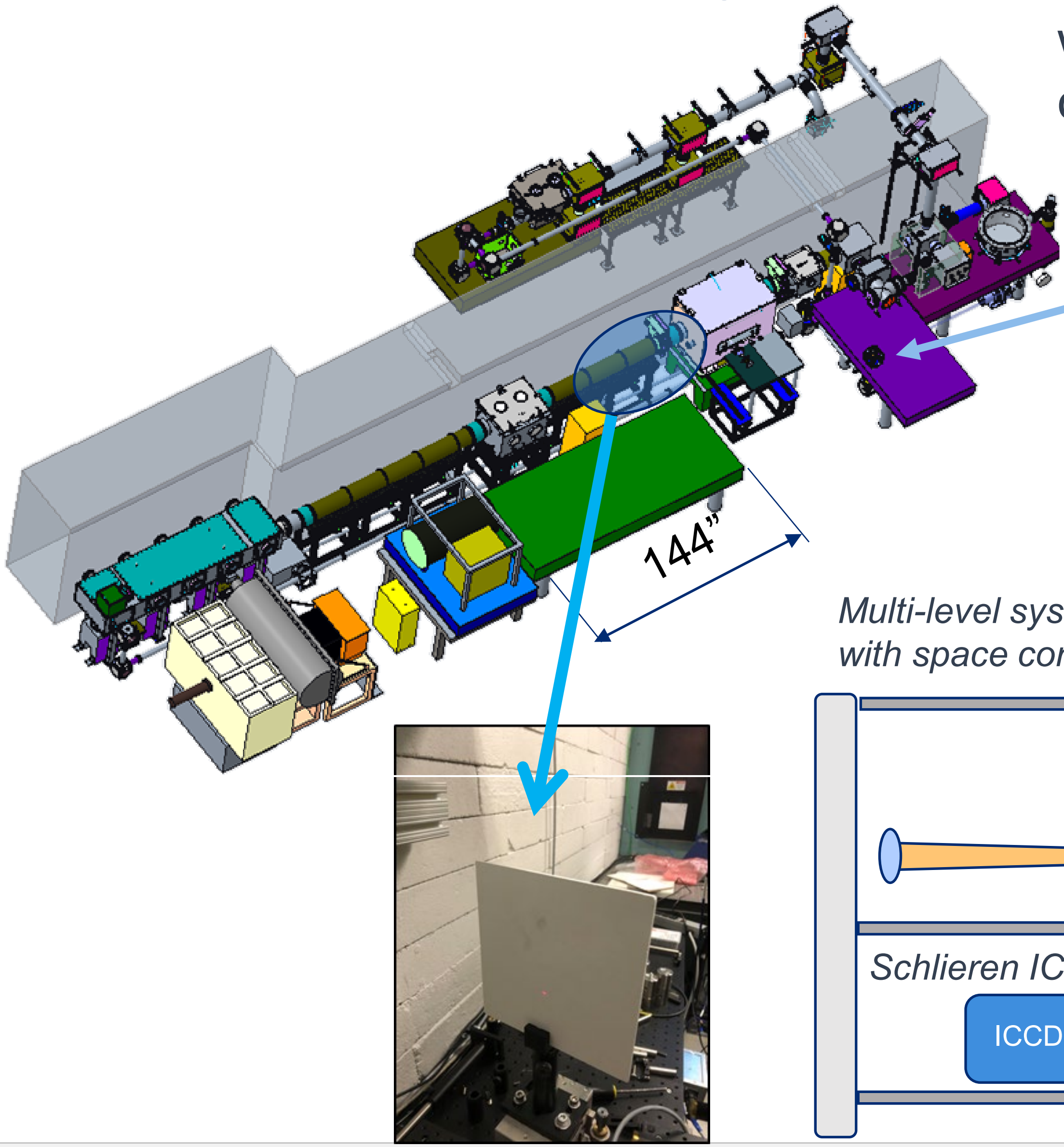
- RF collection equipment
  - High speed oscilloscope(s) and broadband horn antenna(s)
- Shadowgraph imaging of shock dynamics
  - mW-class laser diode and gated ICCD
  - Shock evolution allows estimate of laser absorption
- Pump reflectometer
  - Power meter based reflectance measurement
- X-ray spectrometer (preferably filter based)
  - Detects bremsstrahlung emission from hypothesized high temperature electrons
- “DUT” electronics
  - Field effects on transistors, etc.





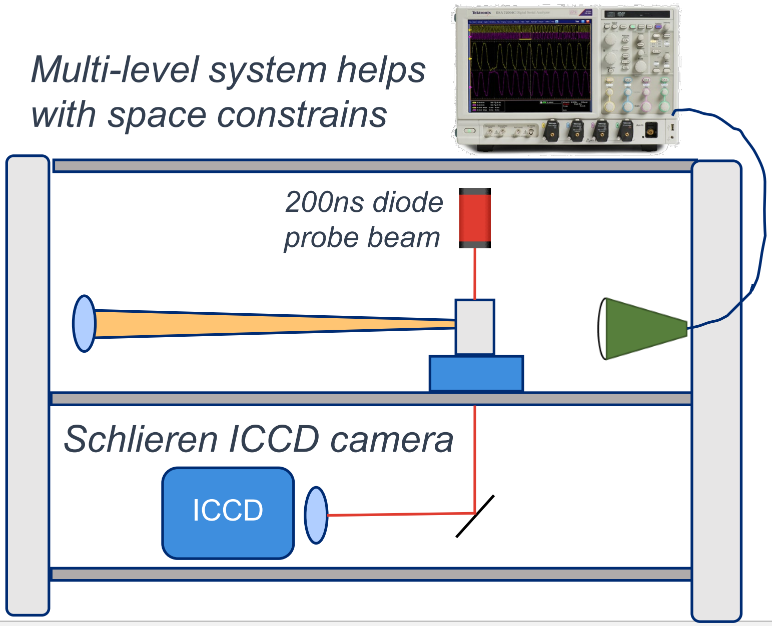
Experimental Layout

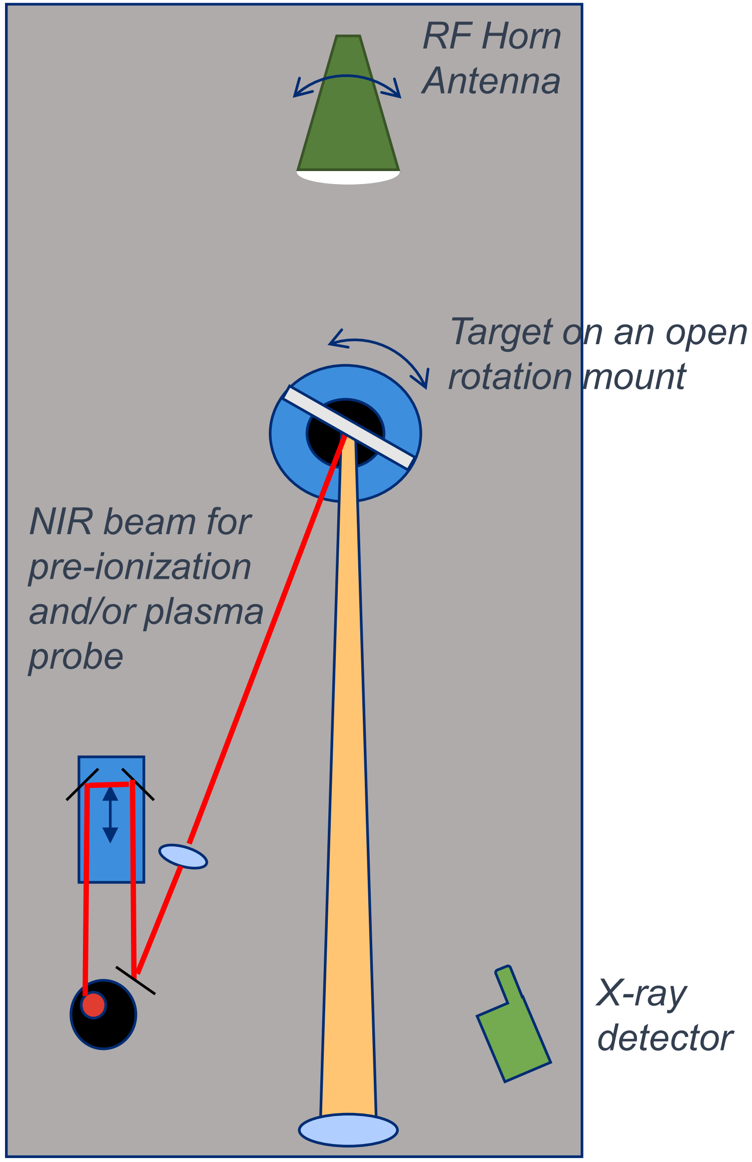
Plan to set up on 18" wide breadboard ahead of polarization rotator



Point of NIR lasers extraction; runs along the floor?

Multi-level system helps with space constrains





$f \approx 1\,m$

Funding / Timeline

- AFRL and JHU/APL programs are funded through FY23
- Lead times for experimental components push likely timeline to summer 2023
- Proposed 1 year effort – 2 to 3 weeks of beam time
  - Week 1 – Set up dual pulse pre-ionization formats. Check initial RF signal levels and begin setup of diagnostics.
  - Week 2 – Scan pulse delay with spectrometer and probe pulse diagnostics to verify optimal beam timing and overlap. Study RF emission as a function of incident laser properties.
  - Week 3 – Test electronic device response to high field RF.
- Potential FY24 proposal for more advanced plasma diagnostics (e.g. spectral interferometry on reflected and/or transmitted femtosecond probe beam)

Positive results likely to drive continued interest in ultrafast CO2 laser development from DoD sponsors

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APPLIED PHYSICS LABORATORY

Electron Beam Requirements

No electron beam time requested

CO_2 Laser Requirements

Configuration	Parameter	Units	Typical Values	Comments	Requested Values
CO_2 Regenerative Amplifier Beam	Wavelength	μm	9.2	*Wavelength determined by mixed isotope gain media*	
	Peak Power	GW	~3		
	Pulse Mode	---	Single	• Regen beam needed for beam path alignment. • Request access to regen output to install Mach-Zehnder style pulse splitter (2 pulses, provided by JHU/APL)	
	Pulse Length	ps	2		
	Pulse Energy	mJ	6		
	M^2	---	~1.5		
	Repetition Rate	Hz	1.5	*3 Hz also available if needed*	
	Polarization	---	Linear	*Circular polarization available at slightly reduced power*	
CO_2 CPA Beam	Wavelength	μm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2*
Note that delivery of full power pulses to the Experimental Hall is presently limited to Beamline #1 only.	Peak Power	TW	5	*~5 TW operation will become available shortly into this year's experimental run period. A 3-year development effort to achieve >10 TW and deliver to users is in progress.*	*0.5 – 2*
	Pulse Mode	---	Single	*JHU/APL to install a pulse splitter for some experiments*	*Single / Double*
	Pulse Length	ps	2		*2ps*
	Pulse Energy	J	~5	*Maximum pulse energies of >10 J will become available within the next year*	*1 – 4*

Other Experimental Laser Requirements

Ti:Sapphire Laser System	Units	Stage I Values	Stage II Values	Comments	Requested Values
Central Wavelength	nm	800	800	*Stage I parameters are presently available and setup to deliver Stage II parameters should be complete during FY22*	*800nm*
FWHM Bandwidth	nm	20	13		*13*
Compressed FWHM Pulse Width	fs	<50	<75	*Transport of compressed pulses will initially include a very limited number of experimental interaction points. Please consult with the ATF Team if you need this capability.*	*75*
Chirped FWHM Pulse Width	ps	≥50	≥50		
Chirped Energy	mJ	10	200		
Compressed Energy	mJ	7	~20	*20 mJ is presently operational with work underway this year to achieve our 100 mJ goal.*	*20+*
Energy to Experiments	mJ	>4.9	>80		*10+*
Power to Experiments	GW	>98	>1067		

Nd:YAG Laser System	Units	Typical Values	Comments	Requested Values
Wavelength	nm	1064	*Single pulse*	
Energy	mJ	5		
Pulse Width	ps	14		
Wavelength	nm	532	*Frequency doubled*	
Energy	mJ	0.5		
Pulse Width	ps	10		

Special Equipment Requirements and Hazards

- Electron Beam
  - N/A
- CO_2 Laser
  - ‘Single beam’ pre-ionization scheme will require installation of a pulse stacker between the CO2 regenerative amplifier and the main power amp.
  - Experiments performed in air will require disassembly of part of the beam routing vacuum tube. We anticipate using the existing 80/20 stands to help support our experimental diagnostics and alleviate space constraints. Setup will require at least 4’ x 1.5’ space, preferably a little more.
- Ti:Sapphire and Nd:YAG Lasers
  - Requesting use of the Ti:Sapphire beam for probe and/or target pre-ionization. Beam will need to be routed to our experimental area. Experiments at JHU/APL ongoing to determine if compressed vs uncompressed beam is needed.
- Hazards & Special Installation Requirements
  - Large installation (chamber, insertion device, etc.): Disassembly of vacuum beam line to accommodate experiment in ambient environment
  - Cryogens: N/A
  - Introducing new magnetic elements: N/A
  - Introducing new materials into the beam path: CO2 pulse stacker between regen and main amp (ZnSe optics)
  - Any other foreseeable beam line modifications: No

Experimental Time Request

CY2023 Time Request

Capability	Setup Hours	Running Hours
Electron Beam Only		
Laser* Only (in Laser Areas)	0.5 – 1 week	2 weeks
Laser* + Electron Beam		

Total Time Request for the 3-year Experiment (including CY2023-25)

Capability	Setup Hours	Running Hours
Electron Beam Only		
Laser* Only (in Laser Areas)	0.5 – 1 week	2 weeks
Laser* + Electron Beam		

* Results may warrant follow-on FY24/25 proposals if funding is secured

* Laser = Near-IR or LWIR (CO_2) Laser

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