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Creation of ultra-high energy density matter using nano structured targets

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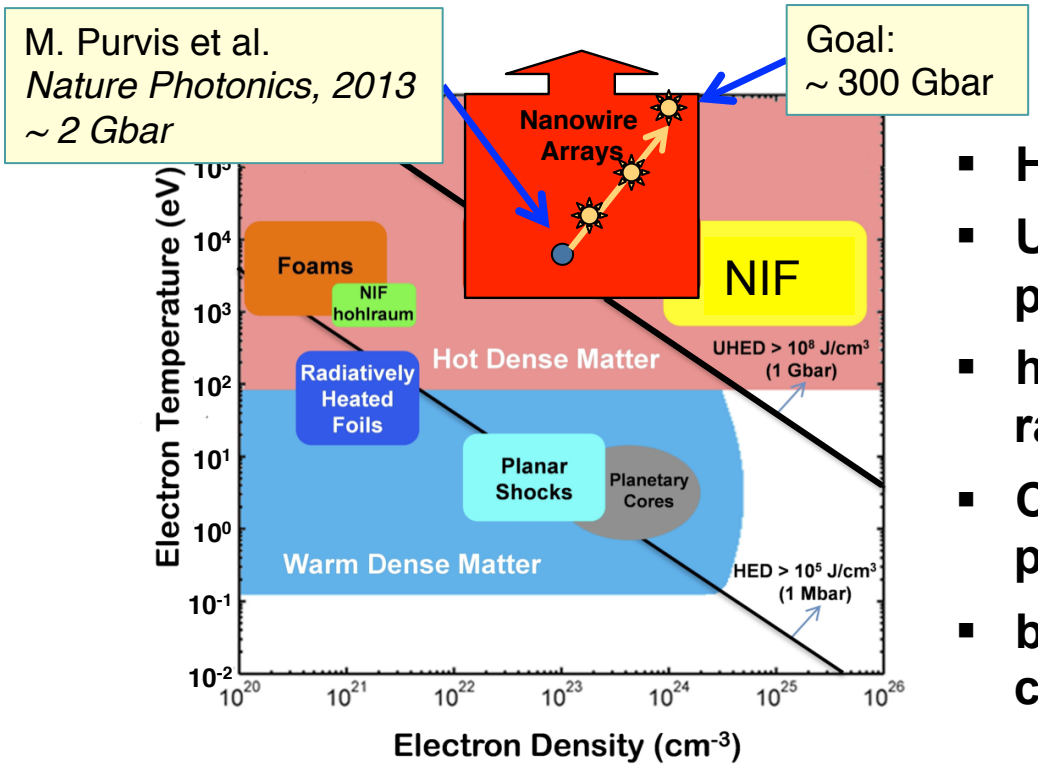
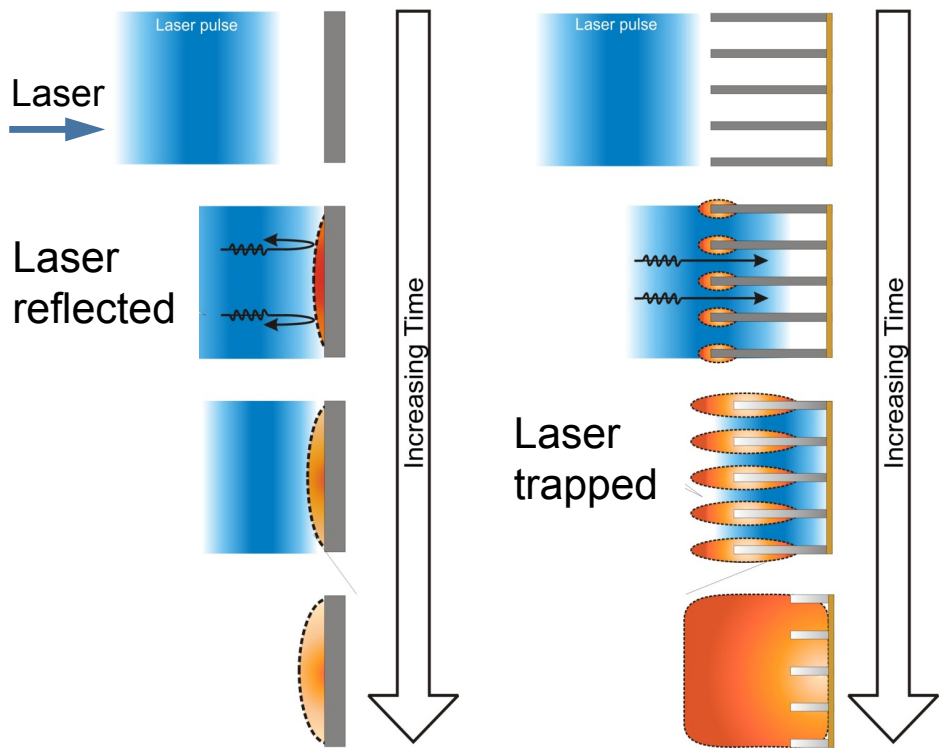
Nanostructured targets can achieve higher energy density than NIF can achieve via Spherical compression of fuel



- **Highly ionized**
- **Ultra high energy density (UHED) plasmas**
- **high-flux high-energy x-ray radiation source**
- **Complement to traditional long pulse methods, i.e. NIF**
- **benchmarking of PIC/HYDRO codes at extreme regimes**

Prepared by LLNL under Contract DE-AC52-07NA27344.

Nano wire arrays trap laser light and induce volumetric heating of near solid density matter

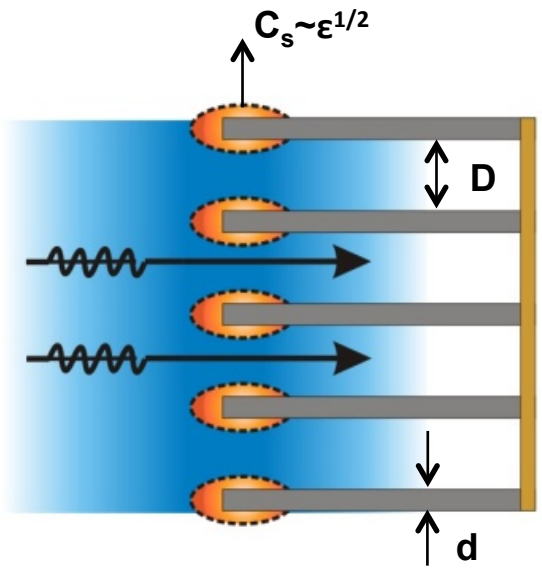


Requirements

- **High contrast**
- **Laser pulse length < Plasma expansion time**

High density increases ionization rates and radiation efficiency.

Laser pulse length and fluence determine the wire-wire gap (D) and wire diameter (d)

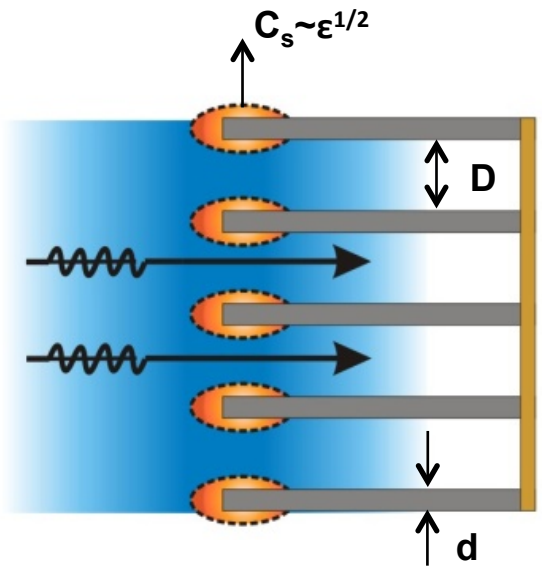


	Quantity	CSU	multiplier	TITAN	units
Energy	E	0.5	100	50	J
Spot size	s	15	1	15	um
Laser pulse length	t_l	60	8	500	fs
Laser Fluence	F	2.2E+05	100	2.2E+07	J/cm^2
Wire-Wire gap	$D \sim F^{1/3} t_l^{2/3}$	141	19	2700	nm
Wire Diameter	d ~ D	55	19	1050	nm

Condition:

$$D/2 \geq C_s\, t_l$$

Simple scaling suggests ~1 µm wires could achieve Energy densities up to ~ 10GJ/cm^3 using Titan laser



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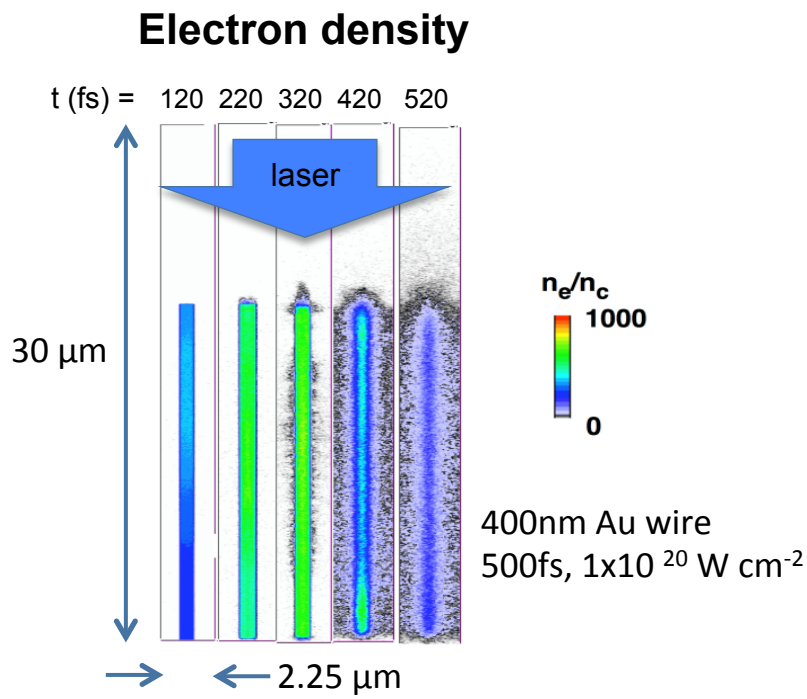
Wire Diameter	d ~ D	55	19	1050	nm
Energy Density	$\varepsilon \sim F/D \sim F/d$	2	5	10	GJ/cm^3

3-D PIC shows that the ponderomotive potential confines the wire longer than the $C_s t_l$ scaling



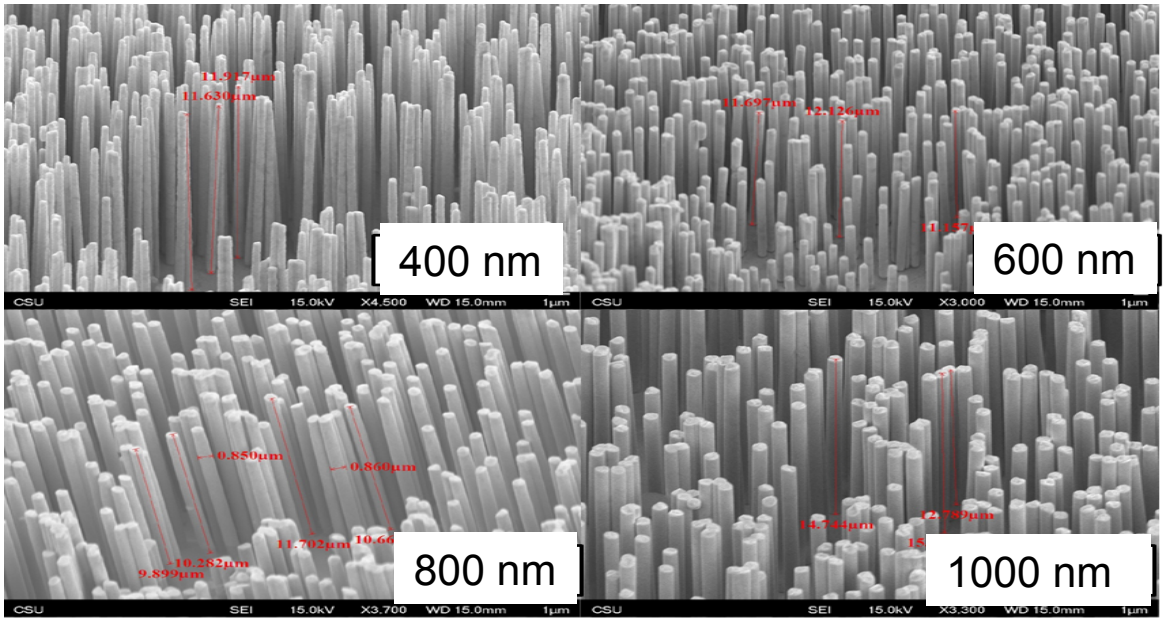
Wires with 400 ~ 800 nm diameters could be used on Titan laser

Even higher energy density, ~ 100 GJ/cm^3, could be reached

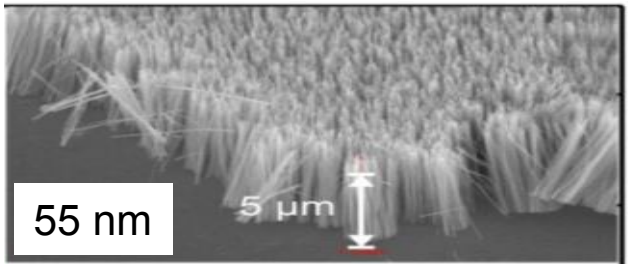
~ 0.1 laser energy conversion efficiency into x-rays is expected

Colorado State Univ. fabricated larger diameter nanostructured targets for the TITAN experiment

Targets for Titan experiment

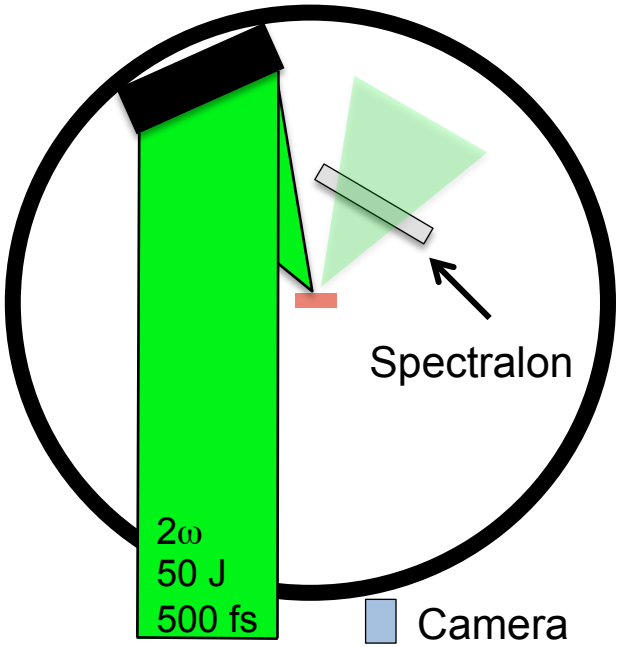


Targets for CSU

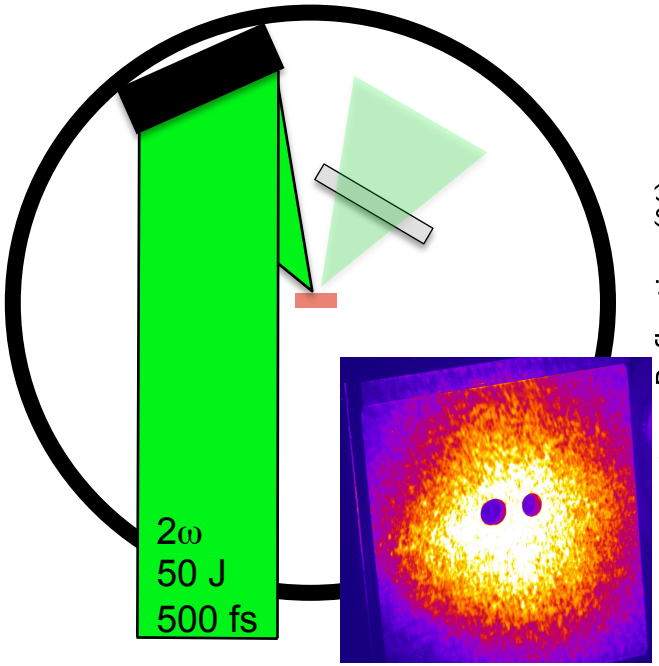


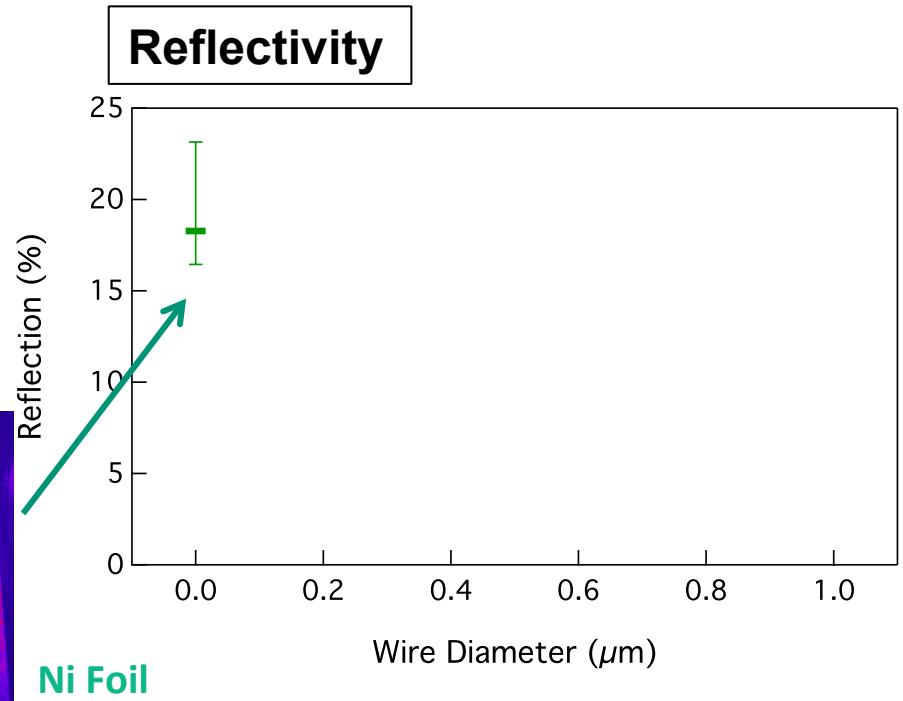
High contrast 2ω Titan laser was used to compare the performance of nanowire targets against flat targets

Setup to measure reflectivity



The 5x decrease in reflectivity indicates much higher laser energy coupling into nanowire targets





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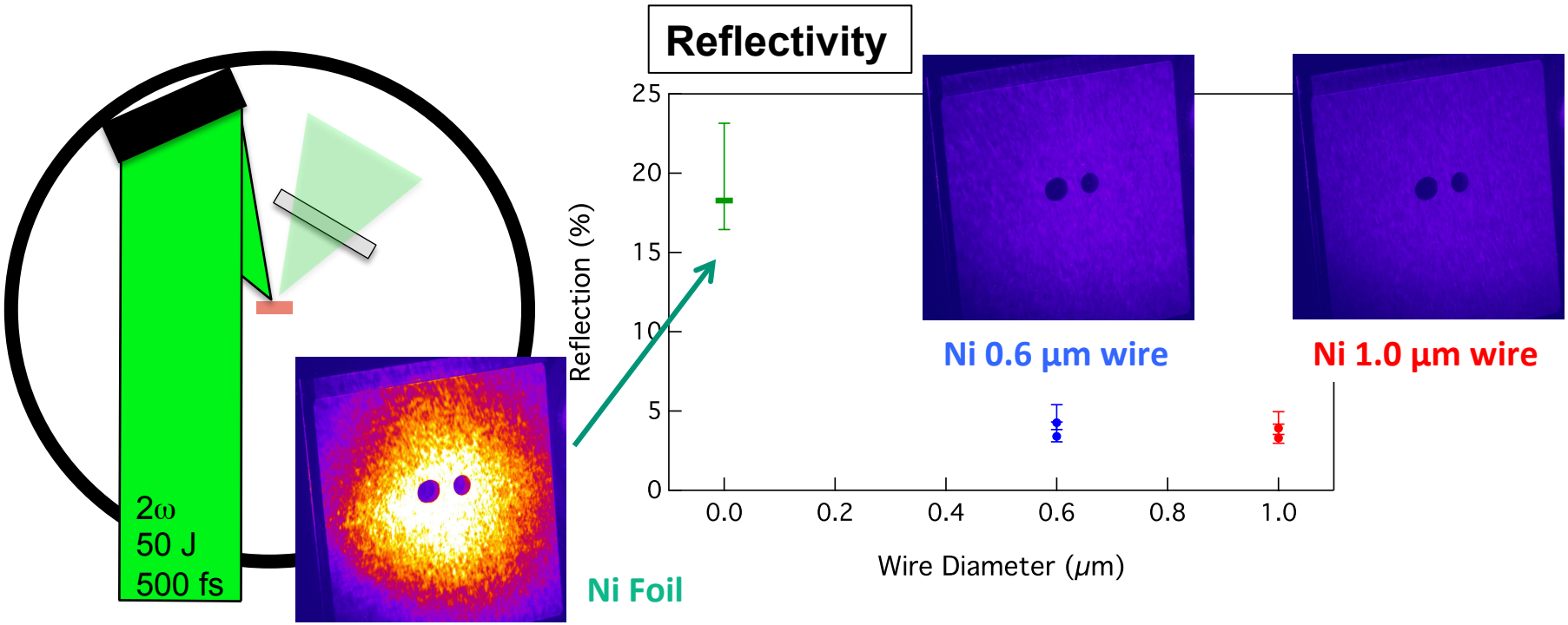
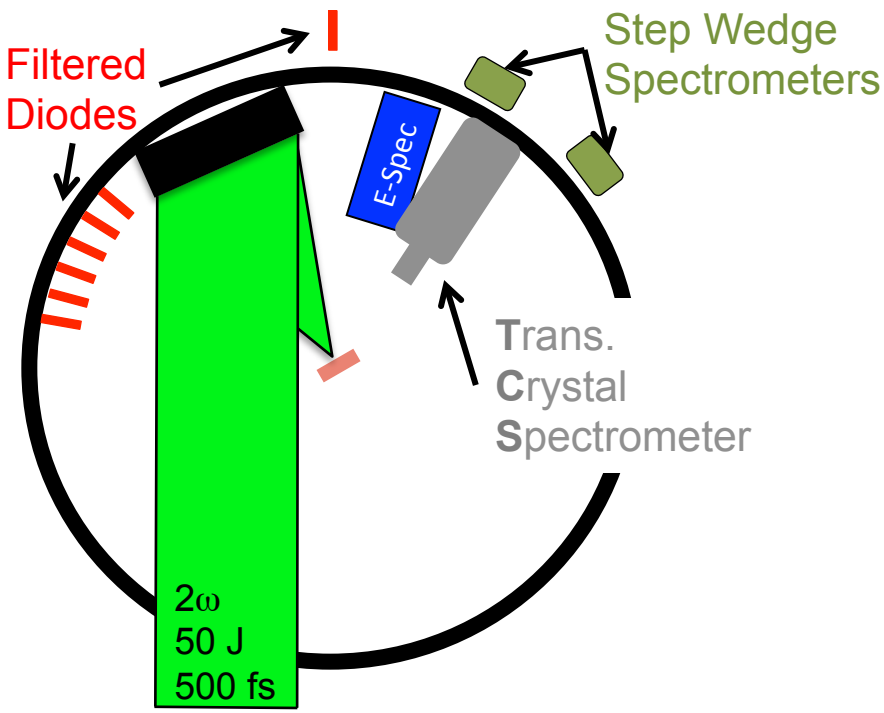


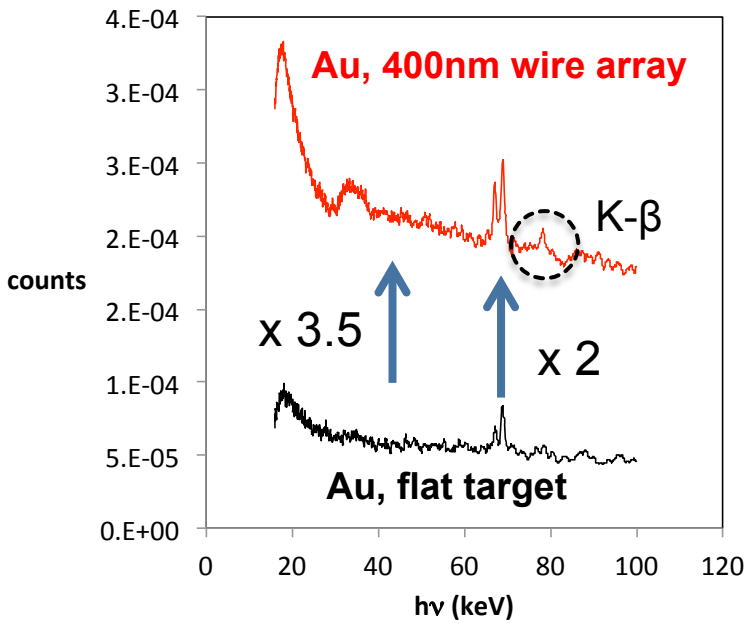
Various diagnostics were fielded to measure x-ray emission and electron spectrum from nanowire and flat targets

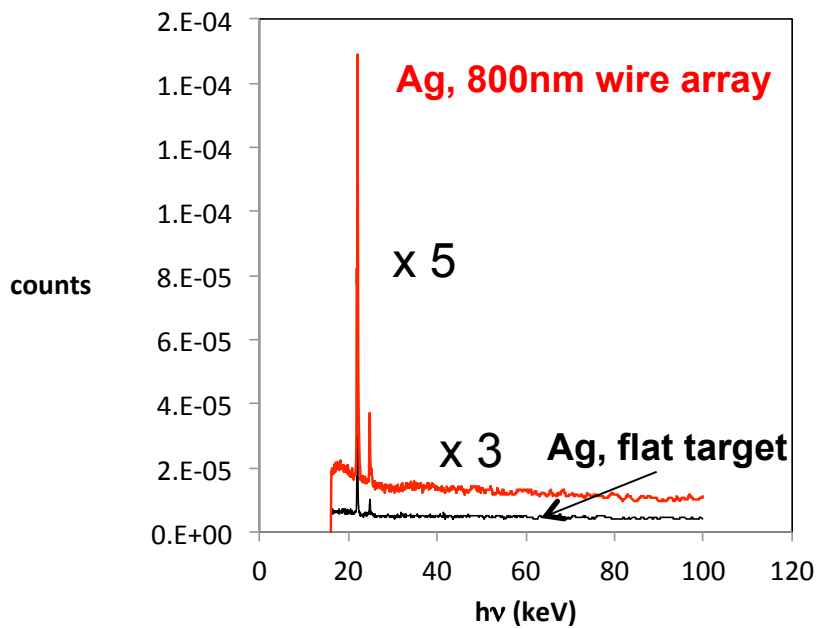


- **TCS:**
  16 - 100keV, x-ray Spectra
- **Step Wedge Spectrometers :**
  40-800 keV, electron temperature, conversion efficiency
- **Filtered Diodes:**
  > 14 keV, Angular x-ray emission, conversion efficiency
- **E-Spec: up to 110 MeV electrons**

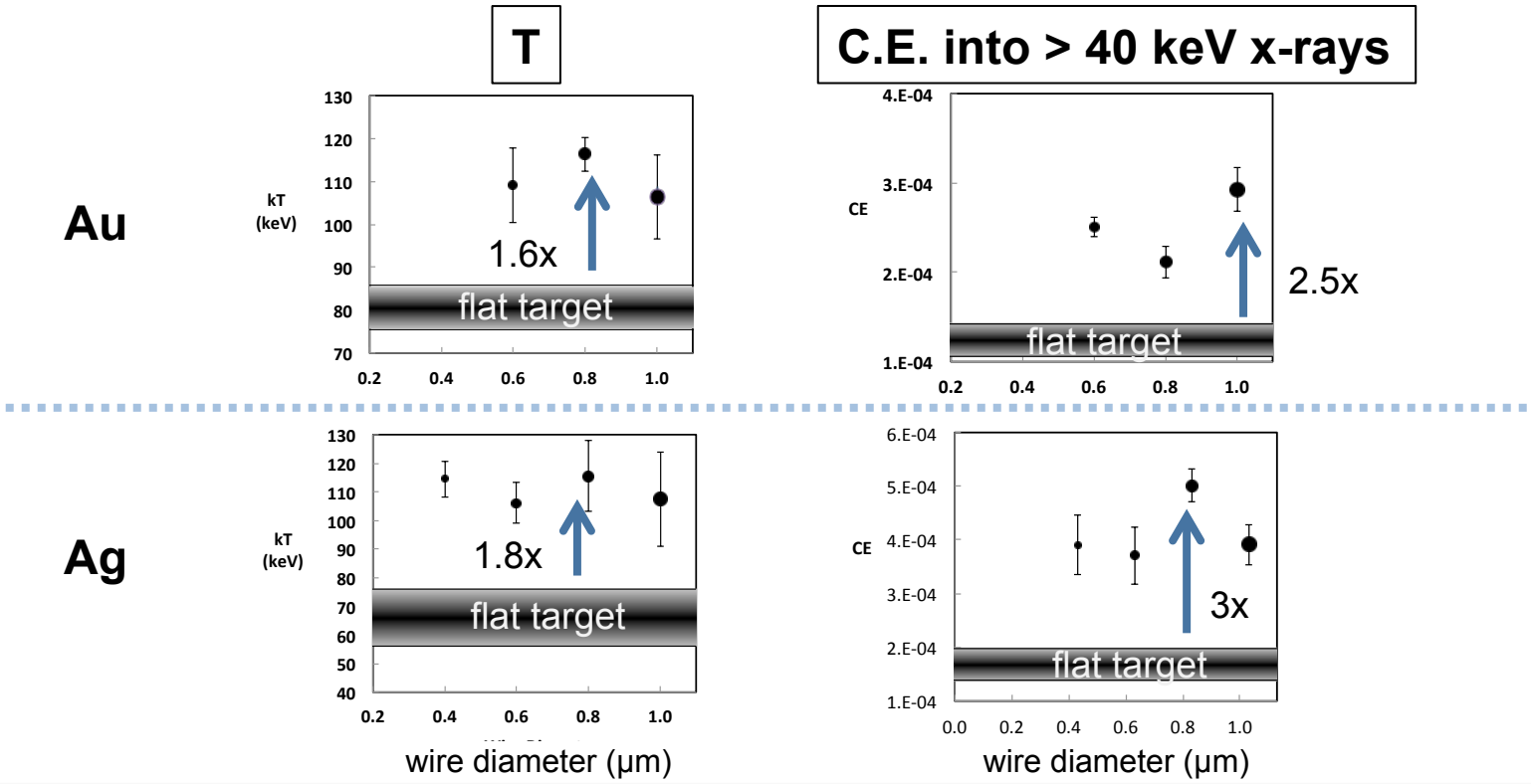
Great increase in continuum and K-α emission were recorded using nanowire targets (Au and Ag)

X-ray spectrum (continuum and K-α)

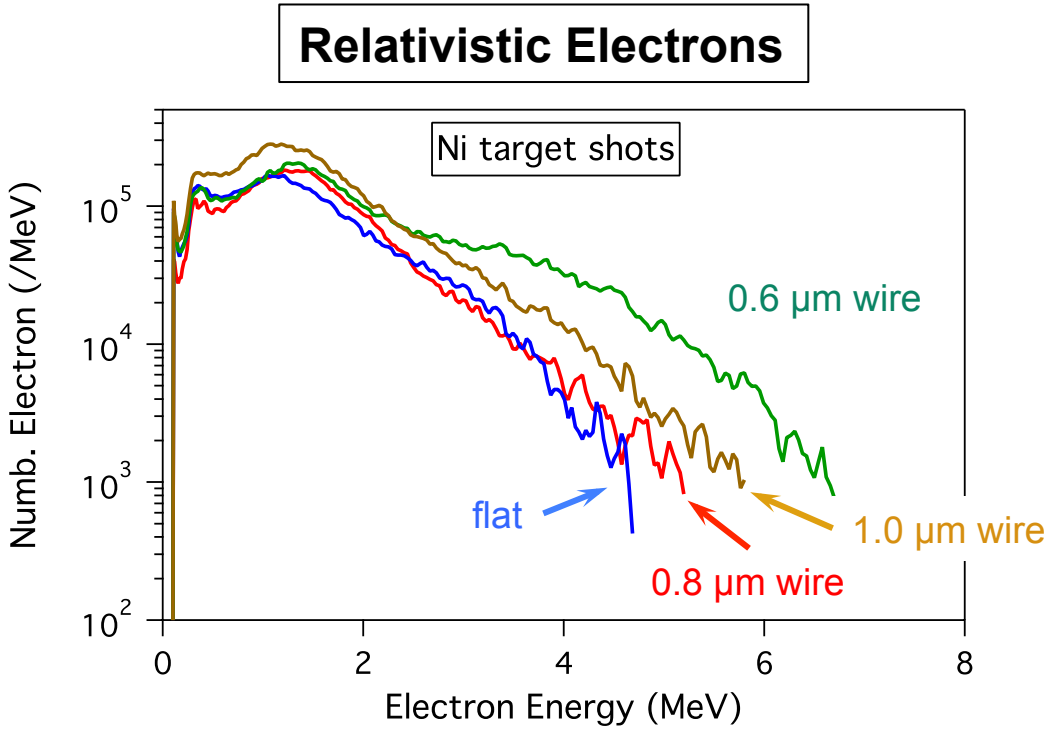




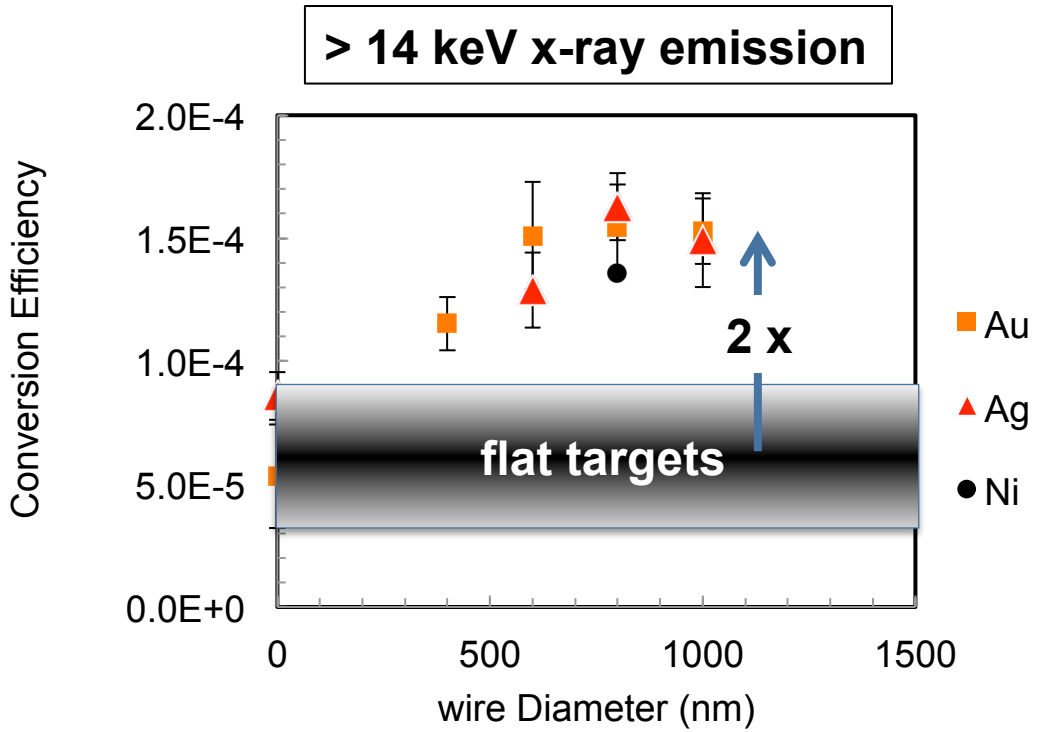
Continuum emission showed large increase in temperature and conversion efficiency into x-ray with nanowire targets



An order of increase in ~ 5 MeV electron emission was recorded with nanowire targets



Lower energy continuum x-ray showed increased conversion efficiency with nanowire targets



The increase in CE from > 14 keV x-ray emission shows the dependence on the wire diameter.

Nanowire targets show great promise to achieve UHED plasmas and high-flux high-energy x-ray sources

- **Reduced the reflectivity by ~ 5x :**
  laser light trapping and significant increase in laser energy coupling
- **Increased signature K_α emission by 3~5x and continuum x-ray by 3x**
- **Enhanced hot electron temperatures by > 1.6x**
- **Enhanced Conversion Efficiency ~ 3x**

Future work

- **Optimization of target parameters**
- **Simulations**

Thank you

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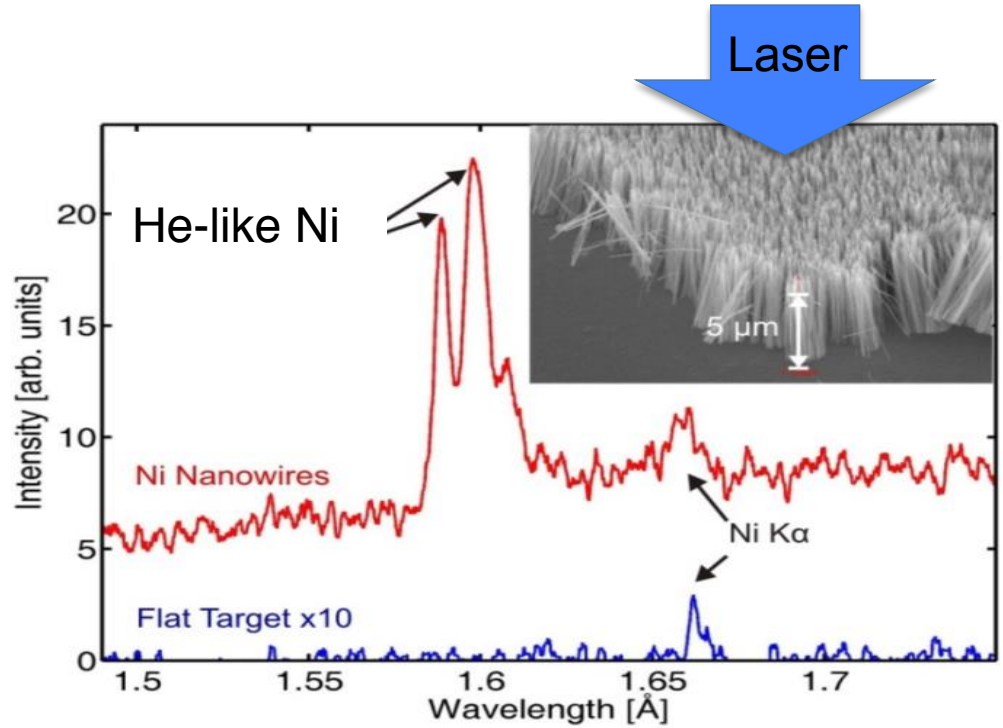
High temperature plasmas were observed using nanostructured targets using 0.5 J / 60 fs table top laser

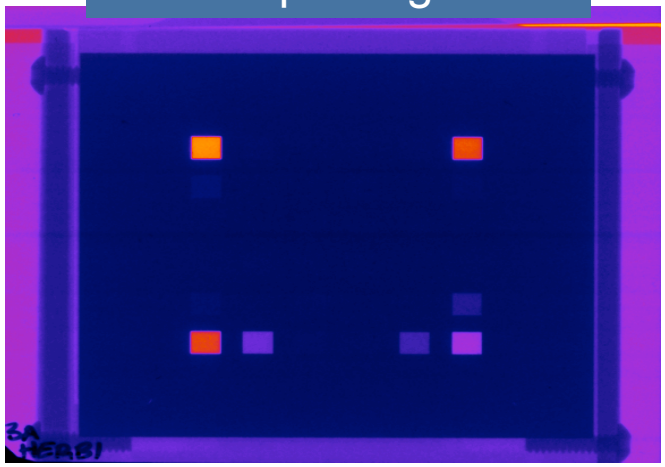
4 keV average thermal electron temperature was estimated from simulations.

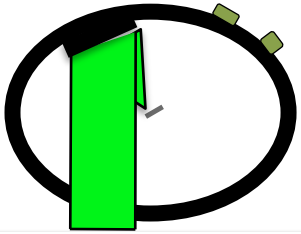


M. Purvis et al. *Nature Photonics, Oct. 2013*
Colorado State University (**CSU**)

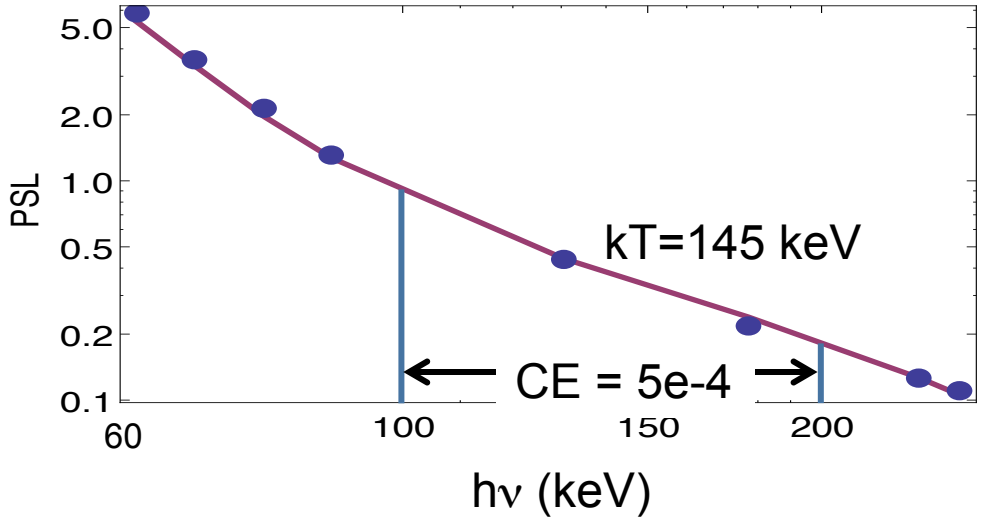
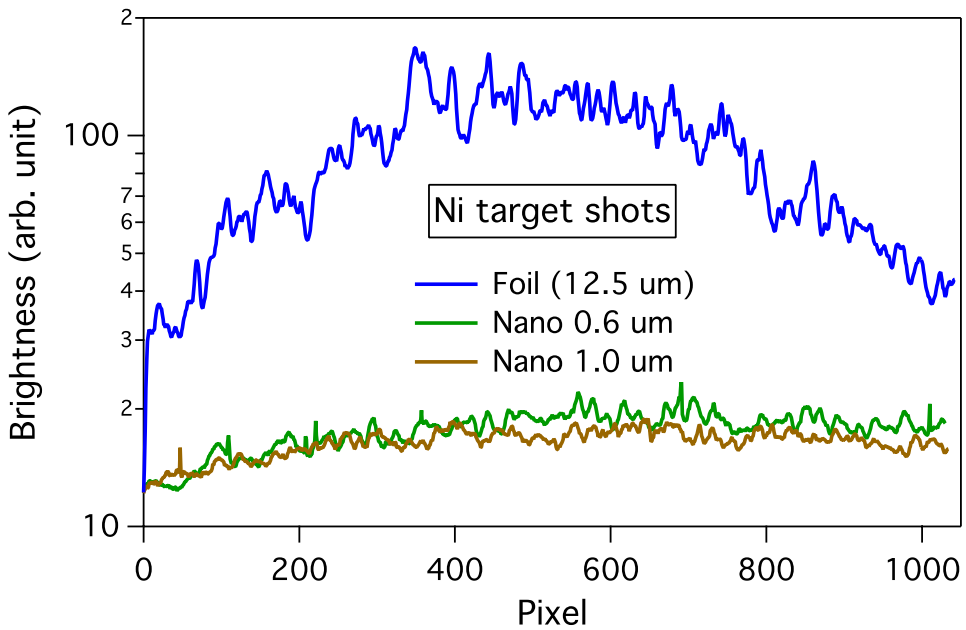
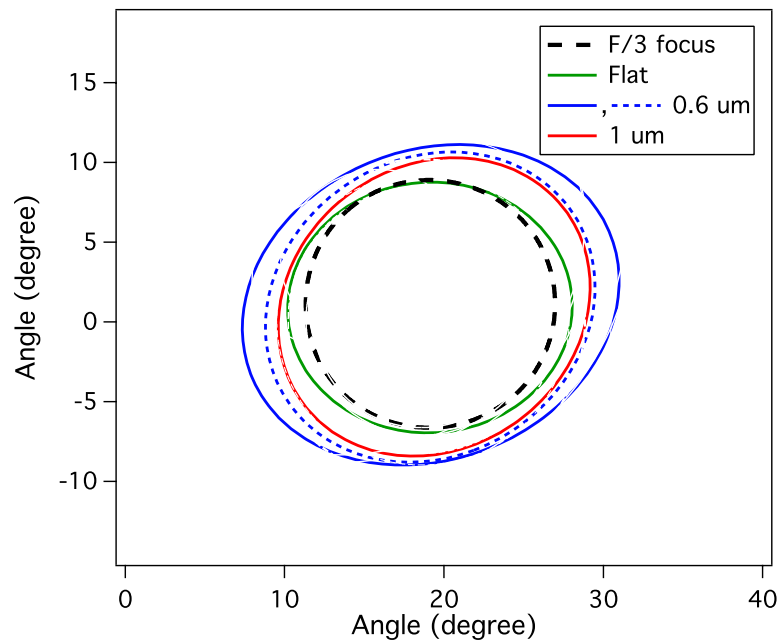
Bremsstrahlung spectra are measured using Ta step wedge with thicknesses ranging from 50µm to 8mm

Raw step wedge data





Reconstructed spectrum



2-D profiles of reflected laser light