Progress of plasma table-top X-ray lasers at LLNL

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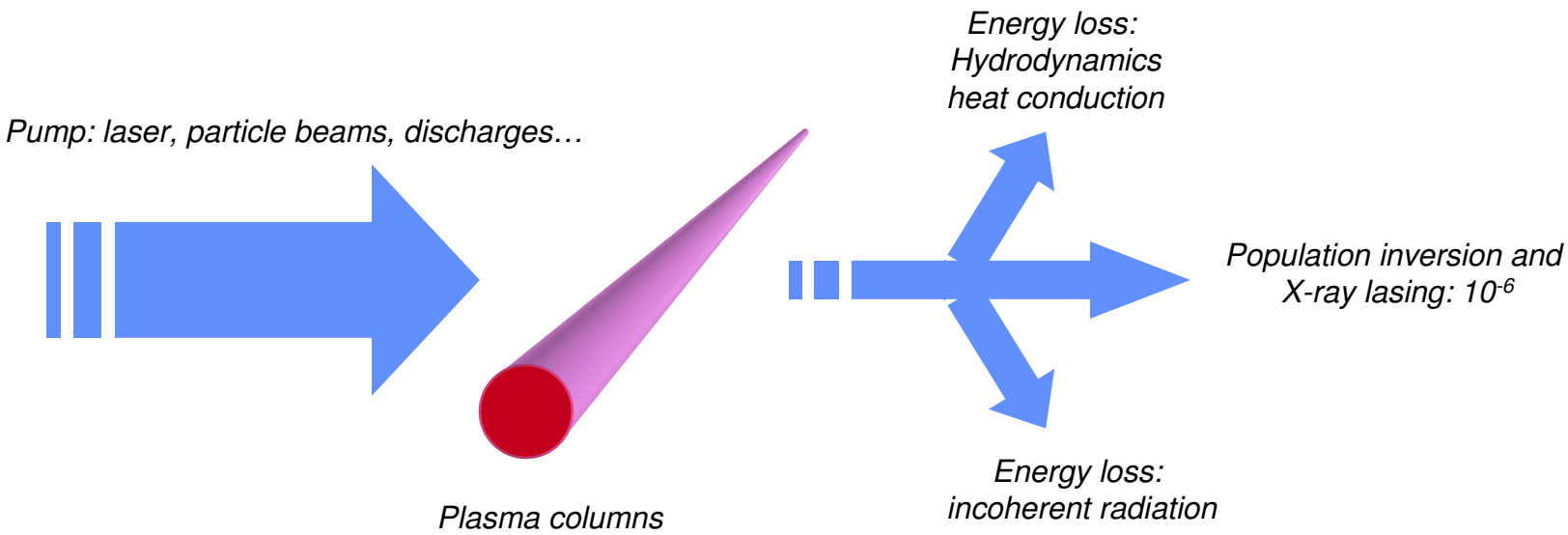
What is a plasma X-ray laser

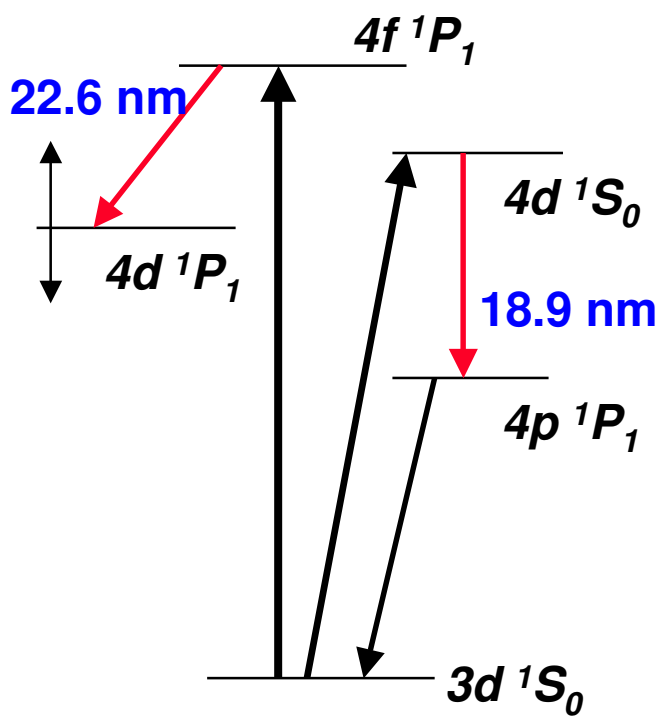
Plasma lasers are traditional lasers that lase via population inversion on atomic and ionic energy levels



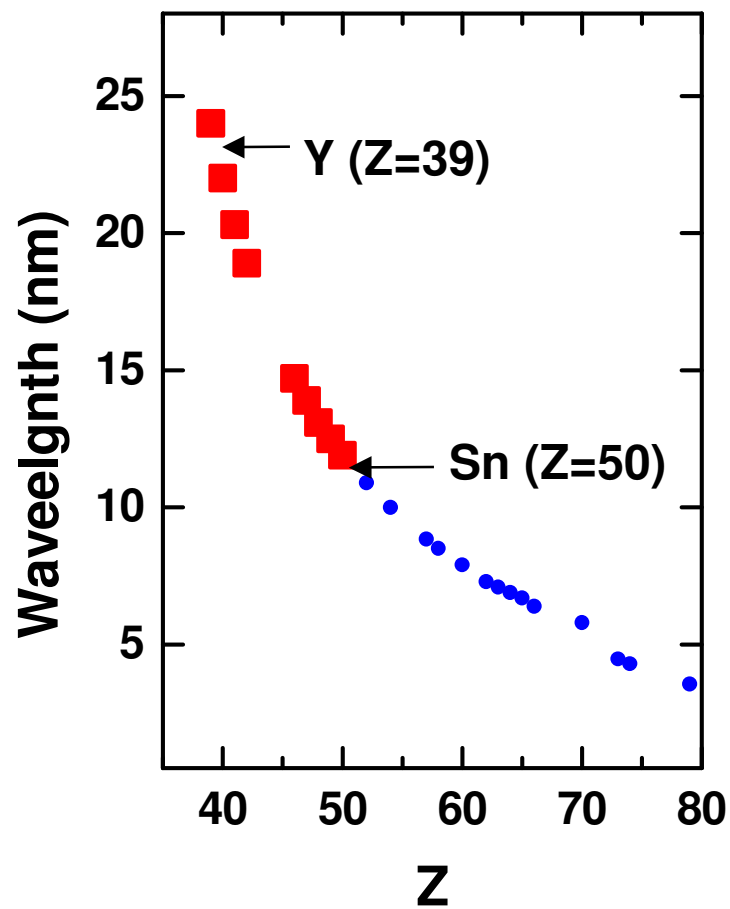
Population inversion: Ni-like X-ray lasers

Ni-like Mo (Z=42) (Mo^{14+})

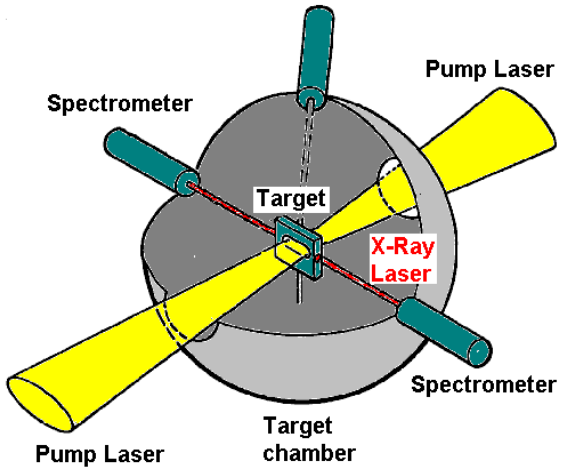
Ground state: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^{10}$



Wavelengths of Ni-like lasers

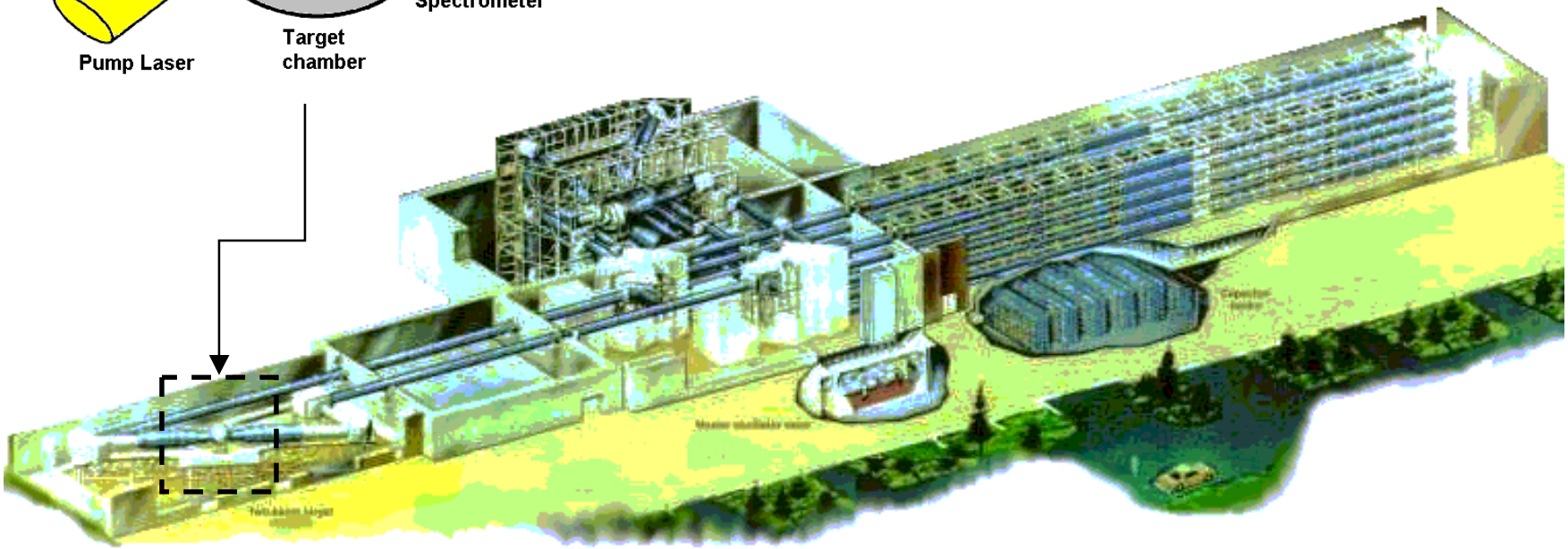


X-ray laser at LLNL: NOVA experiments (1980s-early 1990s)

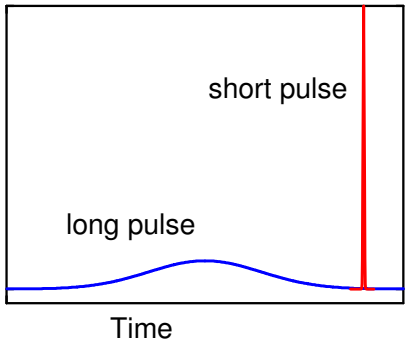


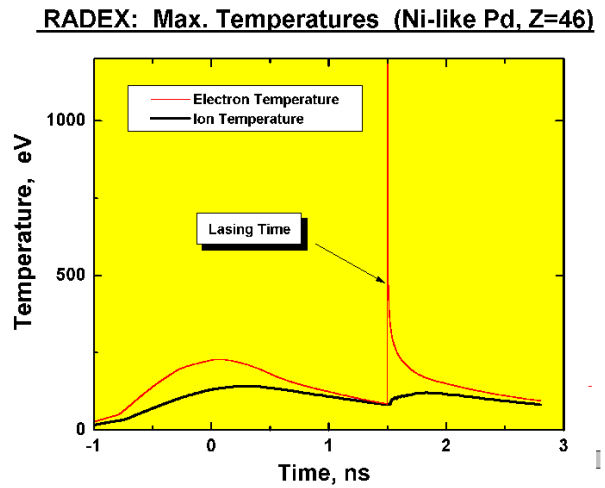
- *Lasing from 3.5 to 33 nm*
- *X-ray laser interferometer/More deflectometory*
- *X-ray laser microscopy/holography*

Pump energies: ~kJ
Rep Rate: ~hours



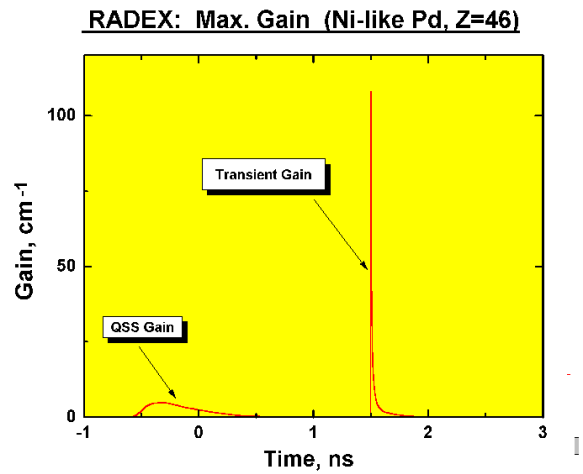
The transient collisional excitation scheme





The long pulse prepares a large plasma
The short pulse generates the high gain

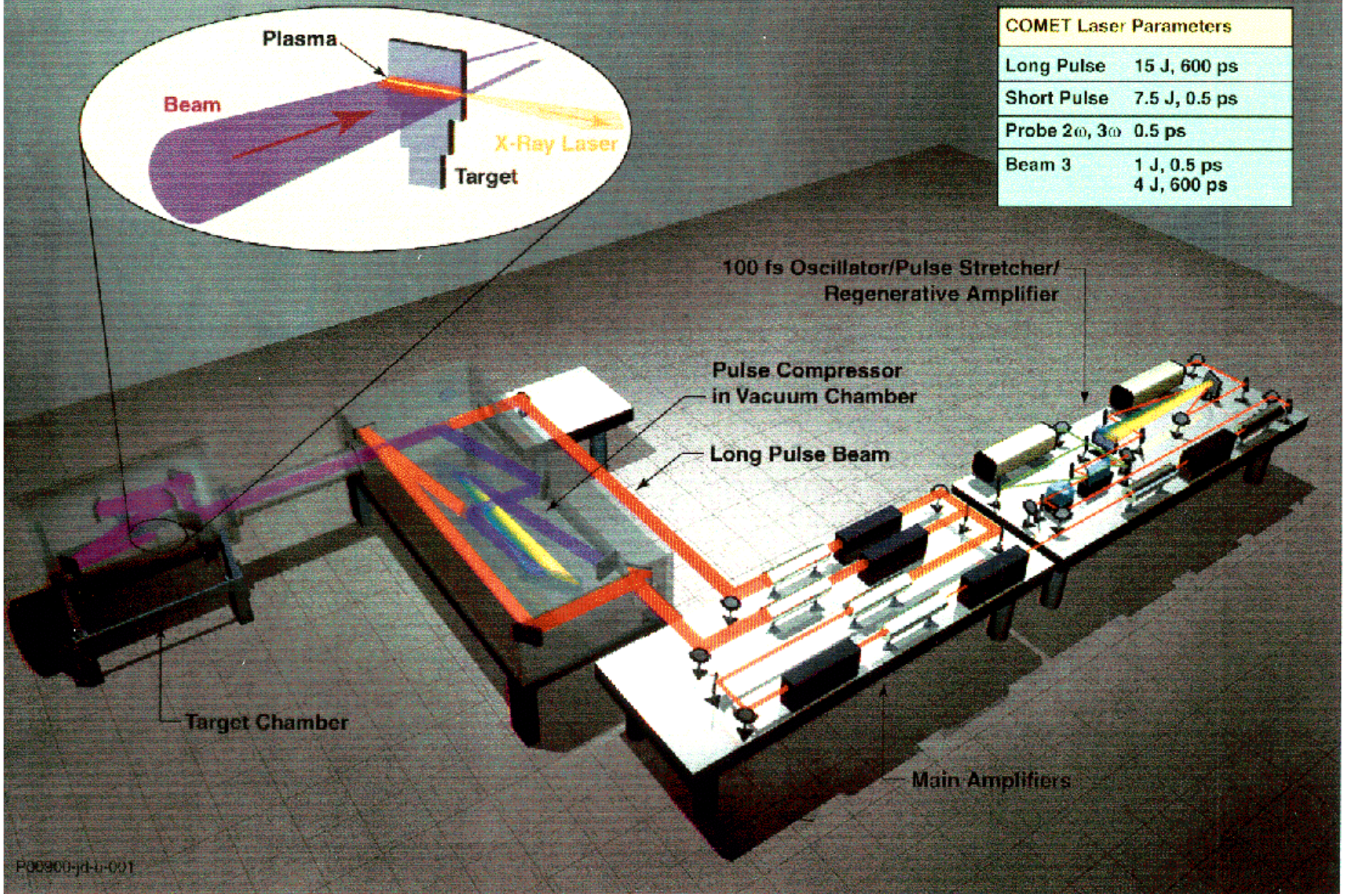
- **The high gain allows efficient amplification (saturation) with a short target length**
- **Using the compact CPA lasers**



Notes:
Plasma X-ray laser gain = (FEL gain length)$^{-1}$
Plasma X-ray laser gain length = ln(FEL gain)

Nickles *et al*, *Phys Rev Lett* 78, 2748 (1997); Dunn *et al*, *Phys Rev Lett* 80, 2825 (1998)

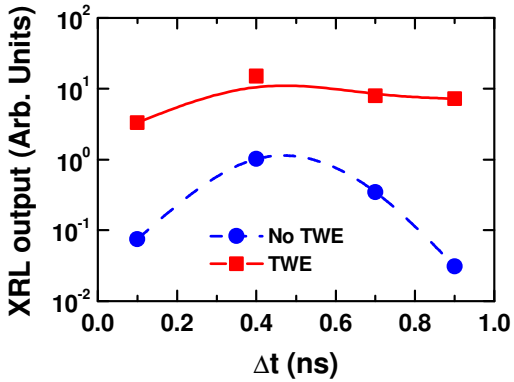
LLNL Table-Top X-ray Laser Facility — COMET

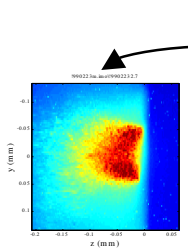


COMET Laser Parameters	
Long Pulse	15 J, 600 ps
Short Pulse	7.5 J, 0.5 ps
Probe 2ω, 3ω	0.5 ps
Beam 3	1 J, 0.5 ps 4 J, 600 ps

P00900-jd-u-001

Detailed setup: traveling wave (TWE) and diagnostics





CCD

Parabola

multilayer mirror

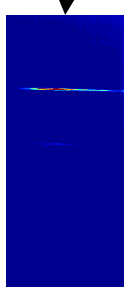
multilayer mirror

Laser beam

Cylindrical lens

Spectrometer+CCD camera

multilayer mirror



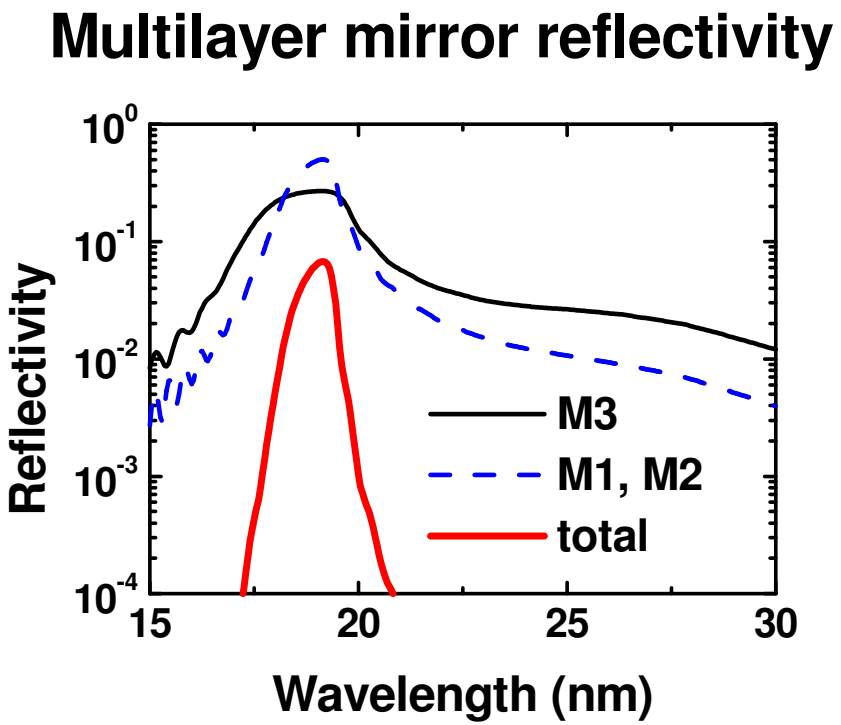
TWE

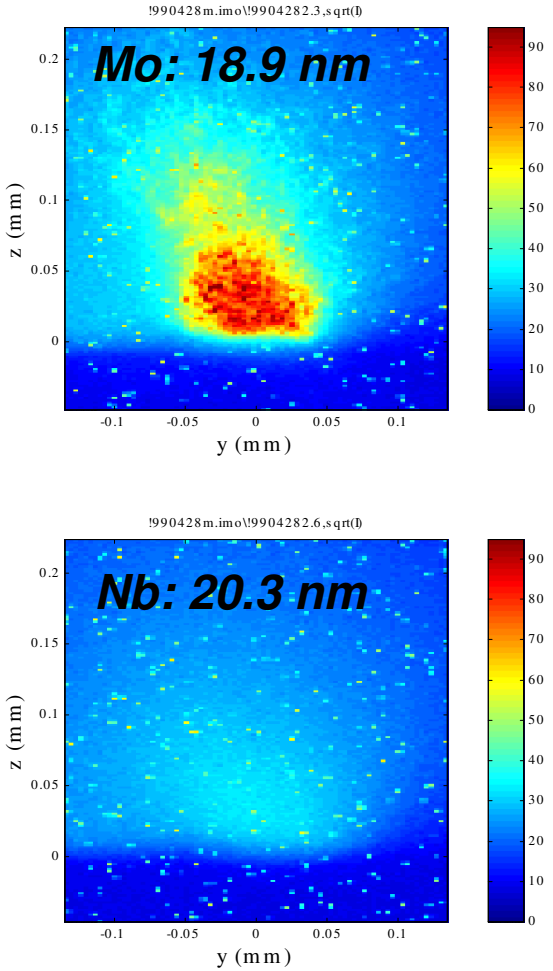
Flat mirror

Echelon

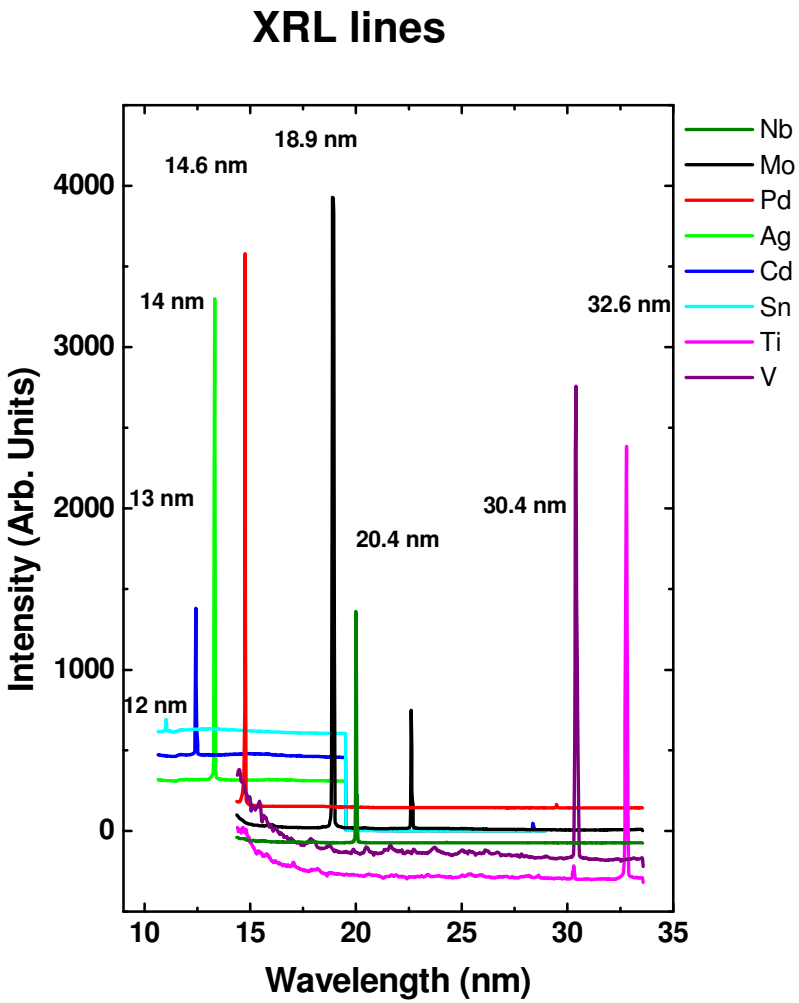
target

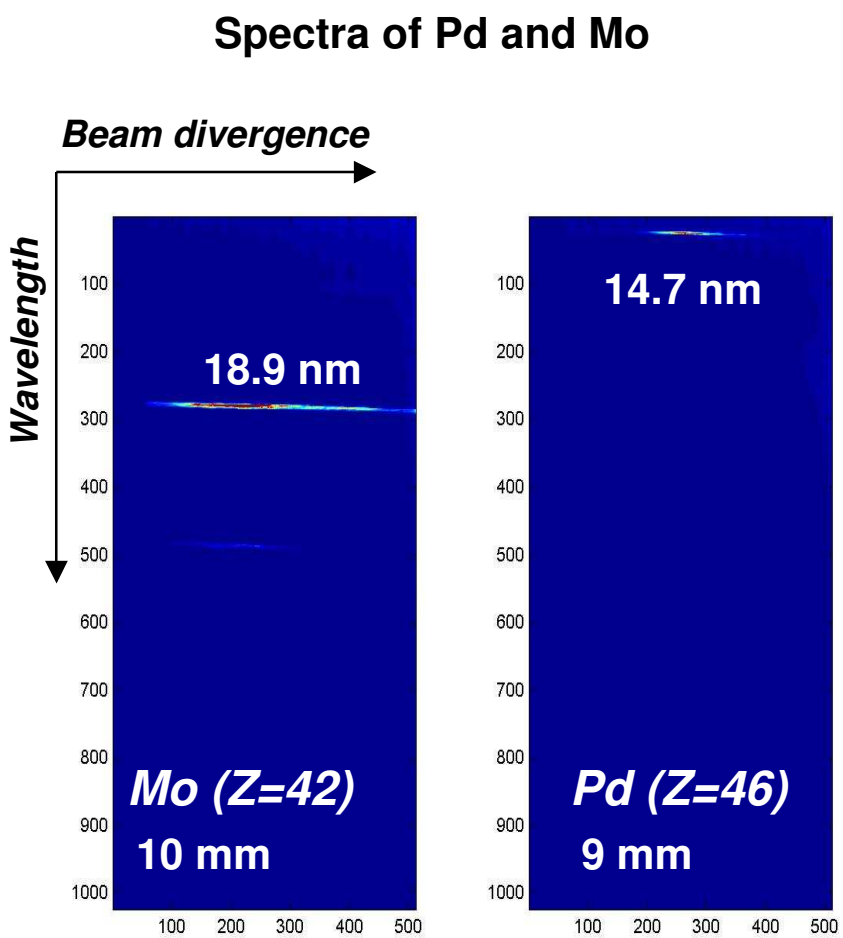
X-ray laser diagnostics: multilayer imaging system





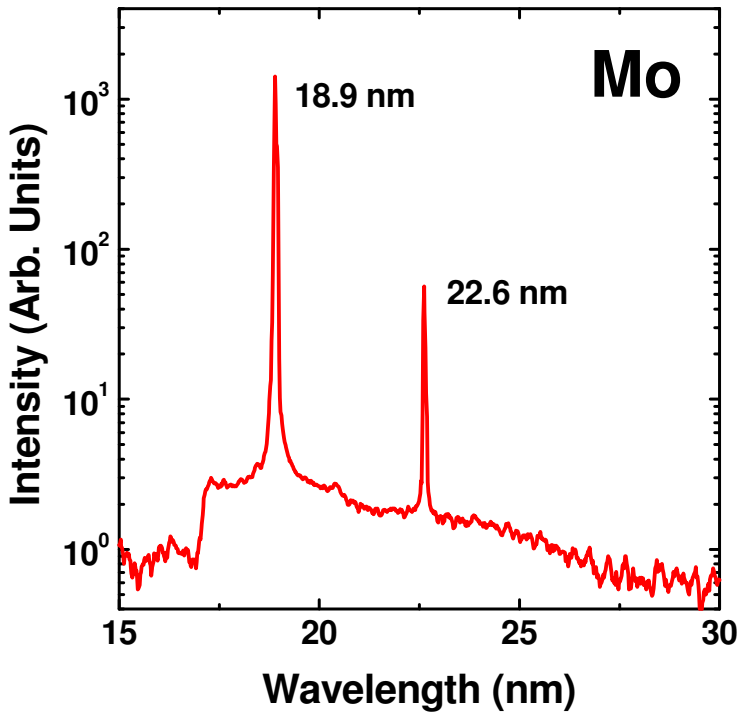
On-axis X-ray laser (XRL) spectra



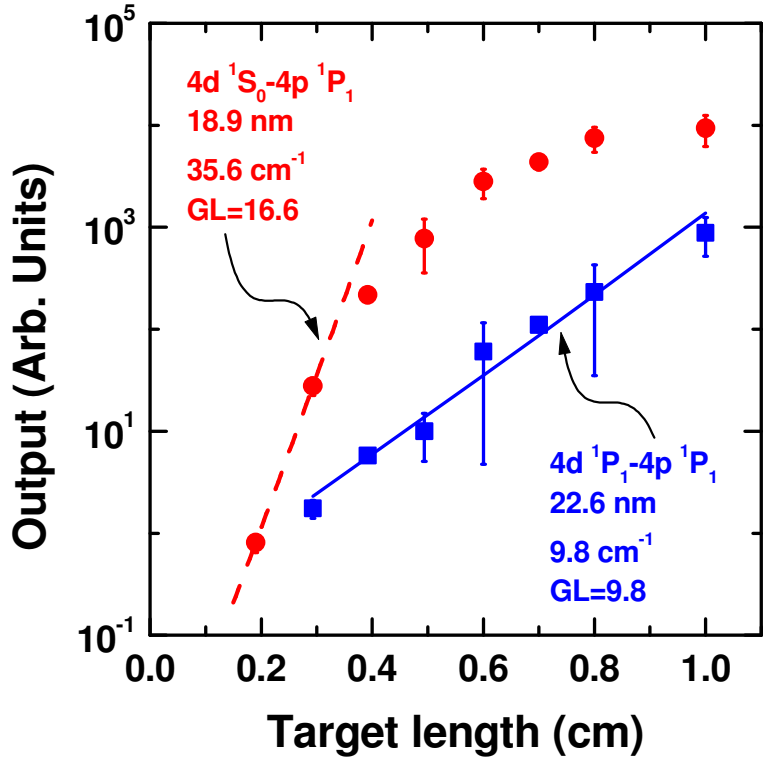


Saturation of the 18.9 nm Ni-like Mo X-ray laser

Spectrum of a 1 cm target



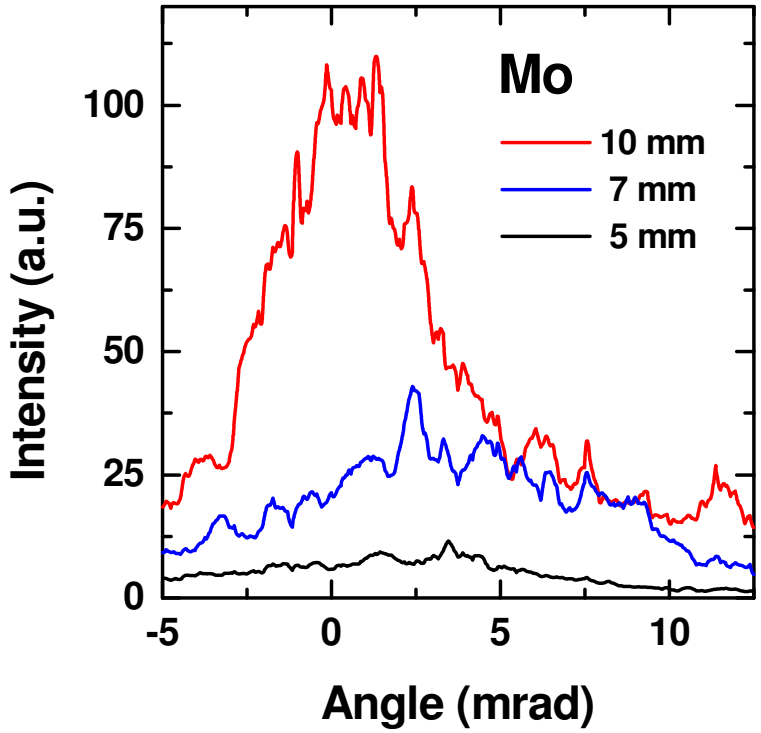
A gain length of 16.6 is obtained

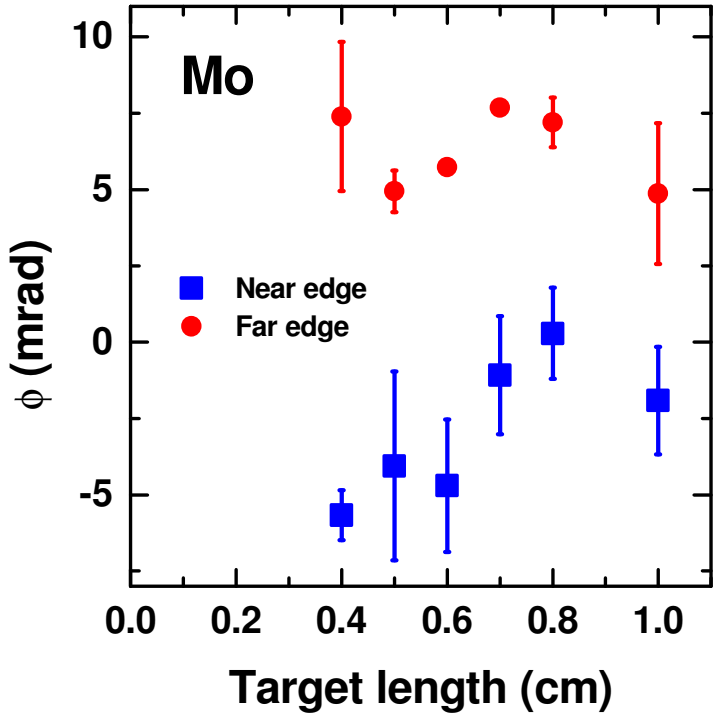


Li et al, submitted to *Science*

XRL divergence

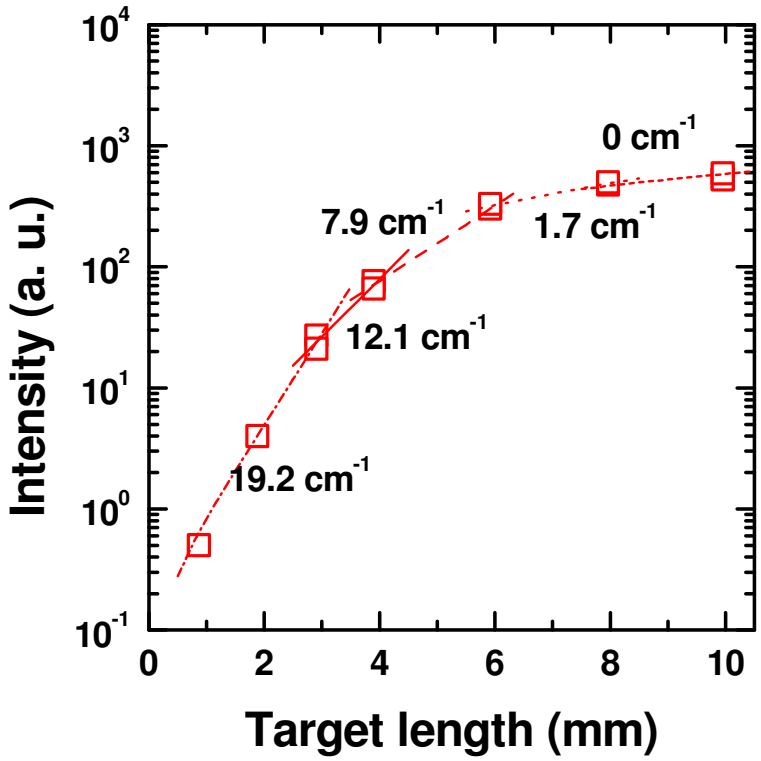
Measurement of the Ni-like Mo 18.9 nm XRL beam divergence

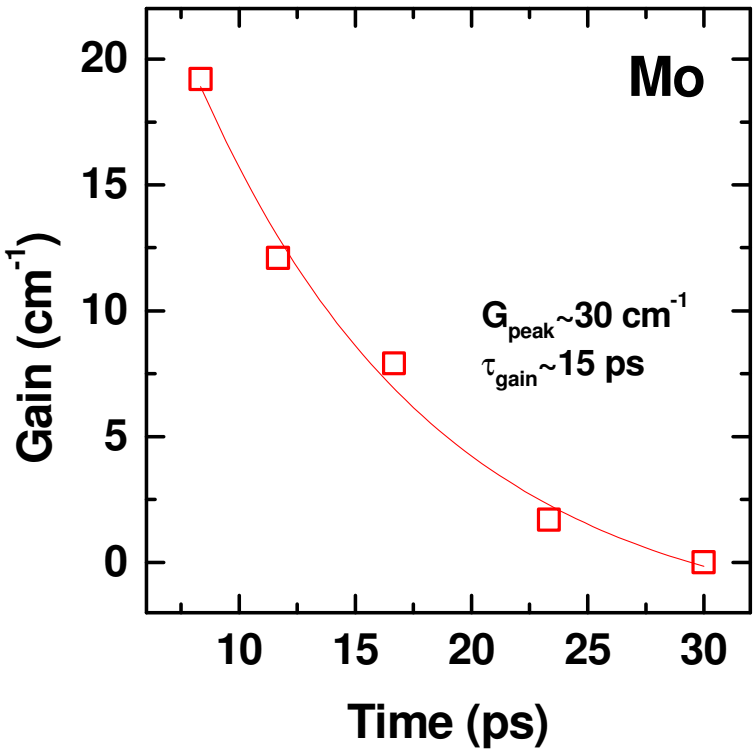




Temporal characterization of Ni-like Mo XRL at 18.9 nm

When no traveling wave is applied, the X-ray experiences the gain as a function the propagation distance, i.e., the traveling time

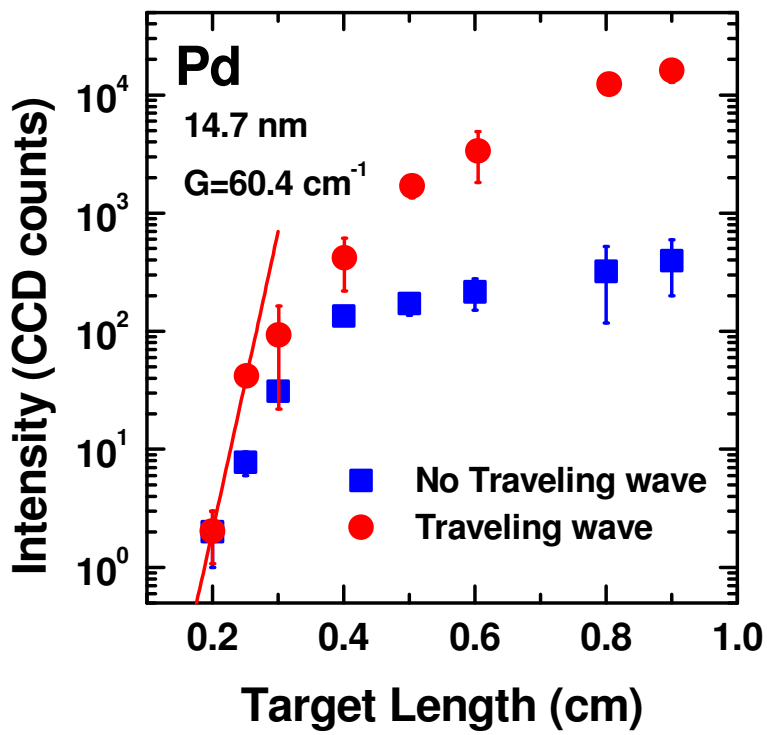




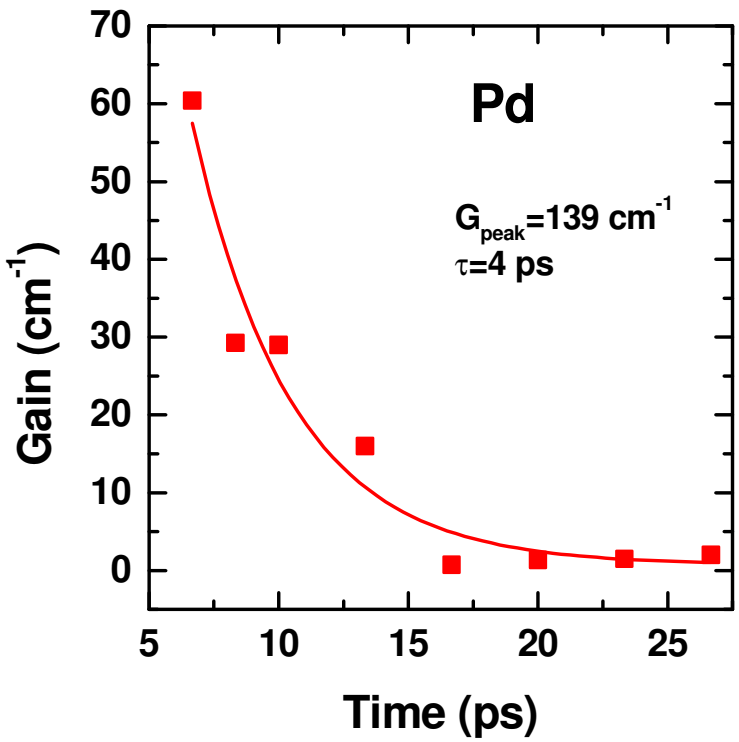
Dunn et al, *Opt Lett* 24, 101 (1999)

Saturation and temporal characterization of the 14.7 nm Ni-like Pd X-ray laser

A gain length of 21.6 is obtained

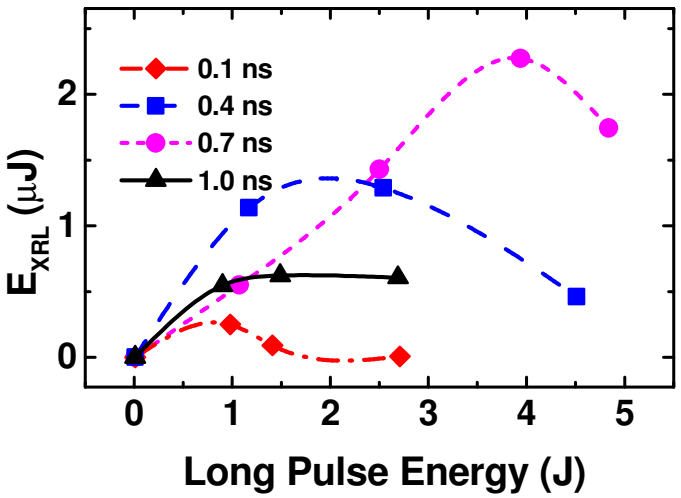


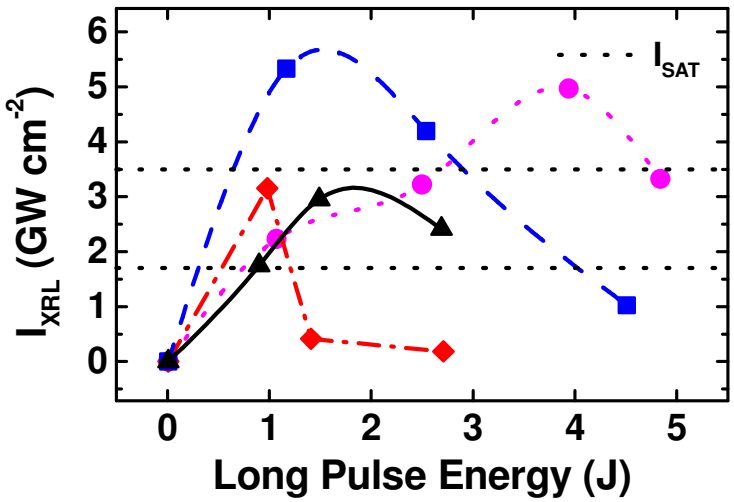
A gain life time of ~4 ps is deduced from the non-traveling wave measurement



Dunn et al, submitted to *Phys Rev Lett*

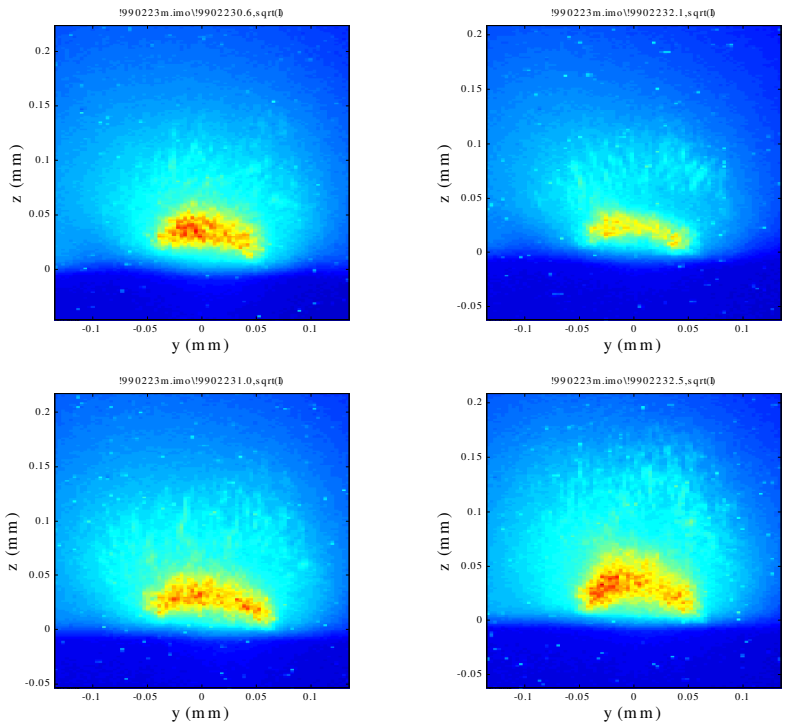
Mo 18.9 nm XRL output energy and intensity



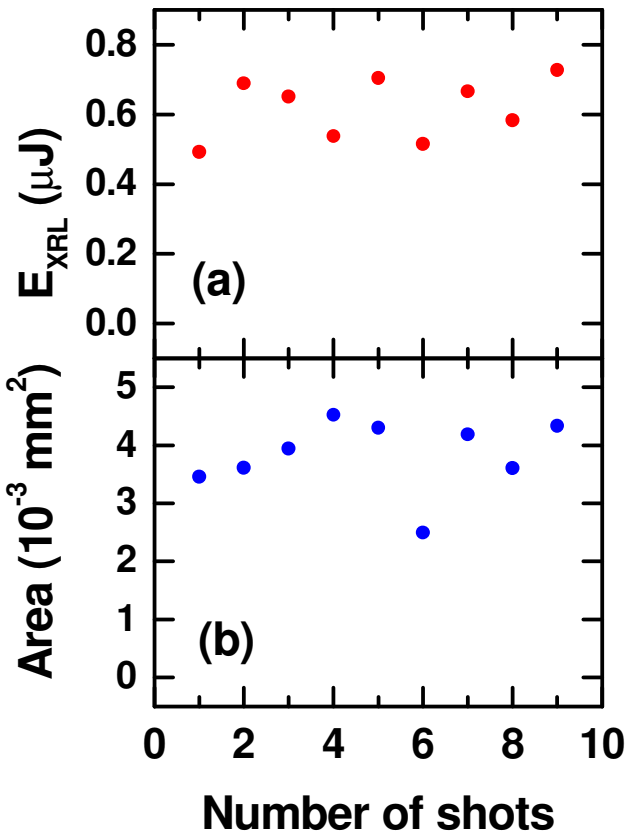


Stability of the Plasma XRL

Comparison of near-field images

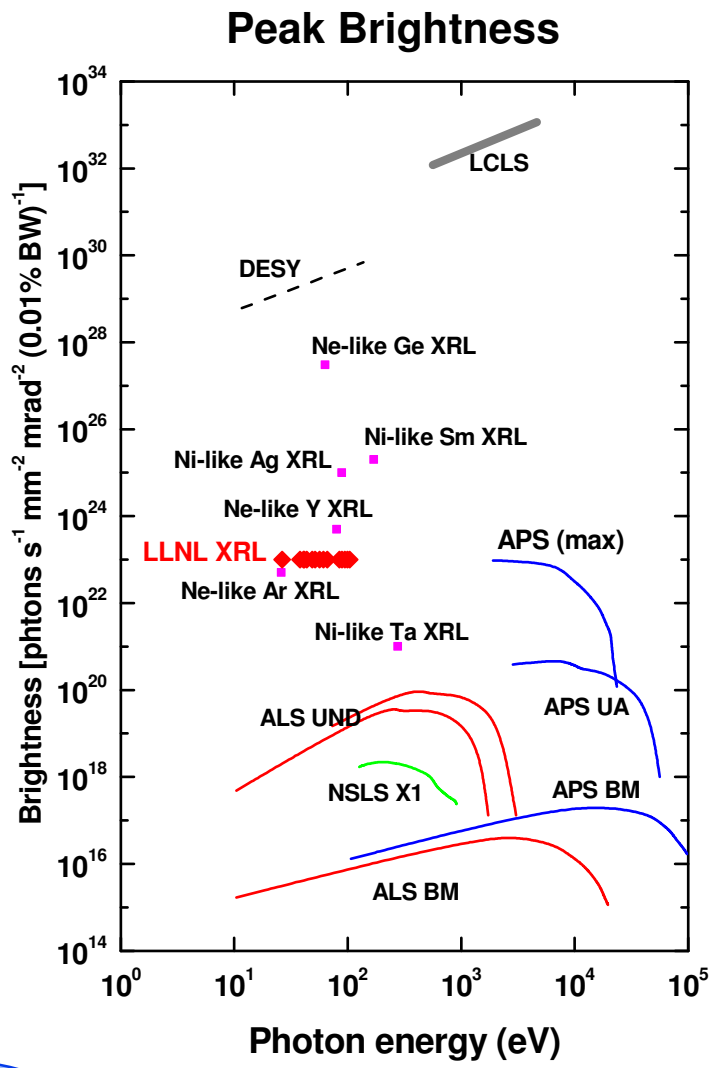


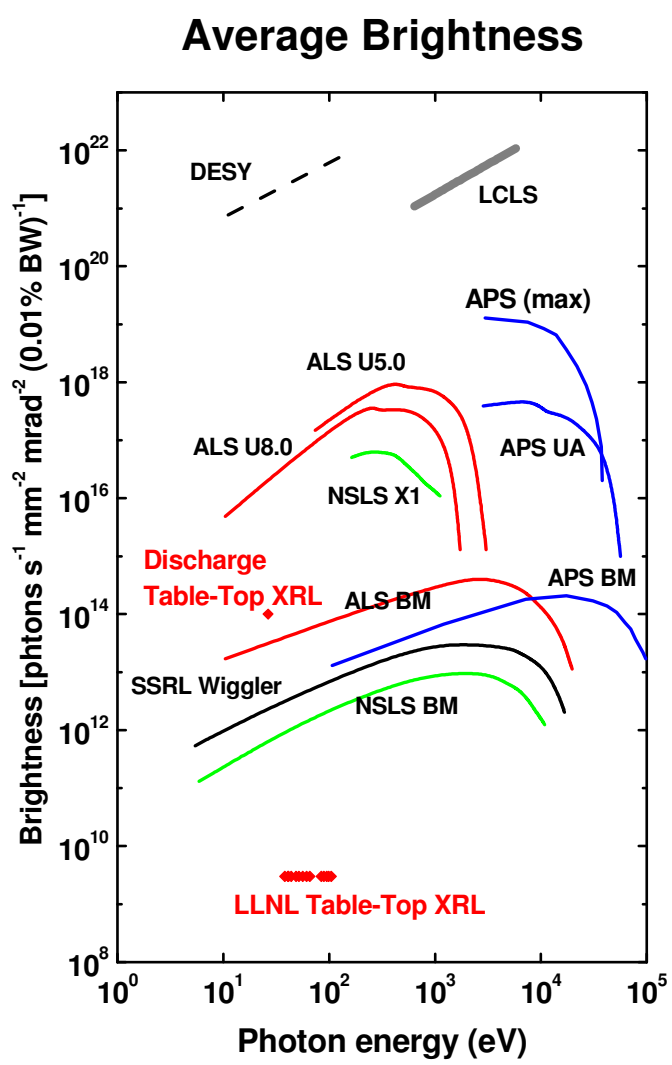
XRL output of a set of non-consecutive shots



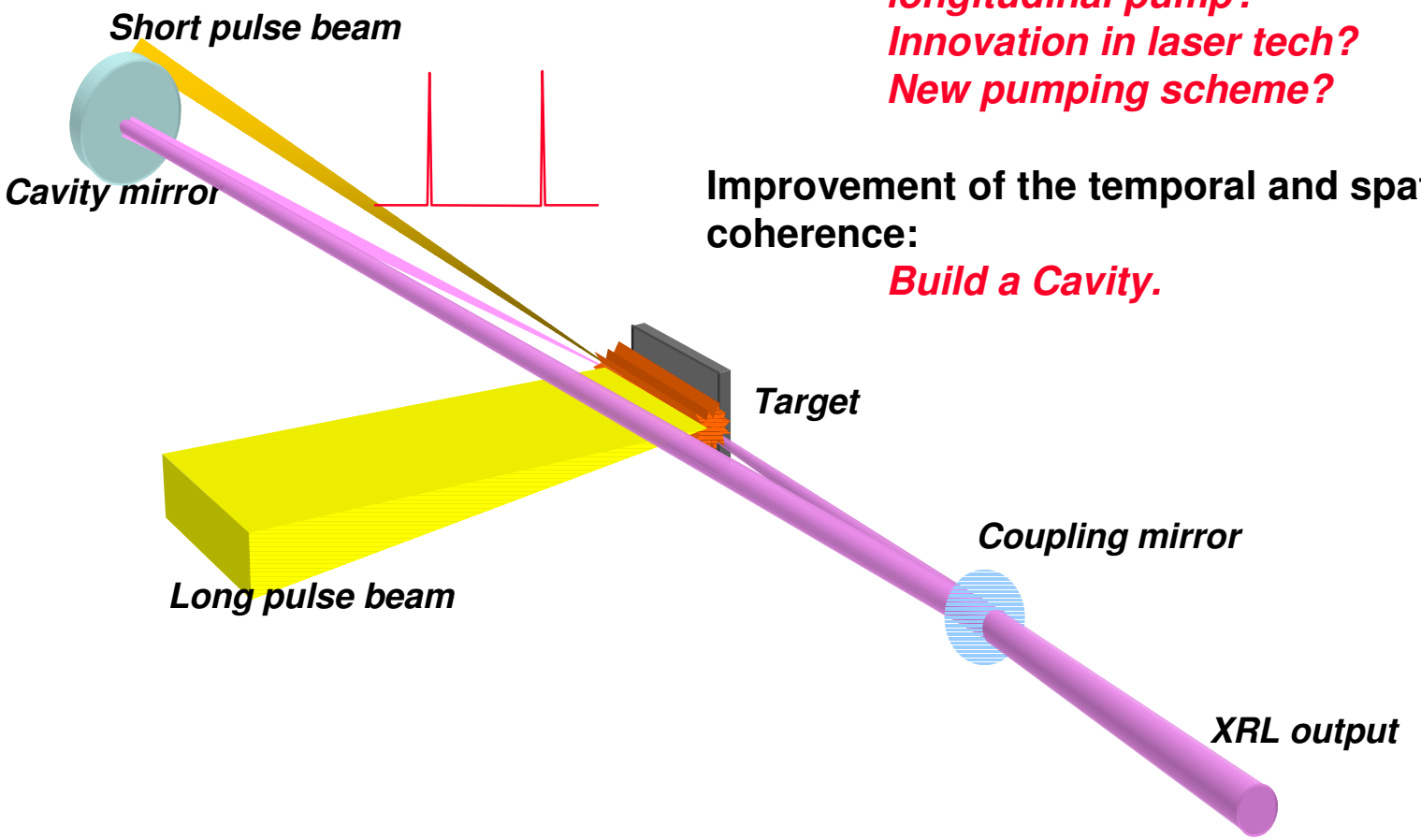
E_L=1-1.5 J, E_S=5 J, Δt=0.7 ns, targets are 1 cm long.

Brightness of the Plasama XRL





Future work



Further reduction of the pump power for high rep rates:

longitudinal pump?
Innovation in laser tech?
New pumping scheme?

Improvement of the temporal and spatial coherence:

Build a Cavity.

Summary

Demonstration of X-ray lasers at wavelengths from 12 to 33 nm, the first saturated table top XRL system at wavelengths below 20 nm, characterization of the XRL output and demonstration of control of the XRL output

This research has laid the foundation of further development of a user facility for application in plasma diagnostics, surface physics, and imaging experiments, as well as a seeding source for X-ray FEL

Plasma XRL will complement the third and the fourth generation light sources with comparable brightness but better compactness.