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Title: Experimental study of an isochorically heated heterogeneous interface: a progress report

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Experimental study of an isochorically heated heterogeneous interface: a progress report

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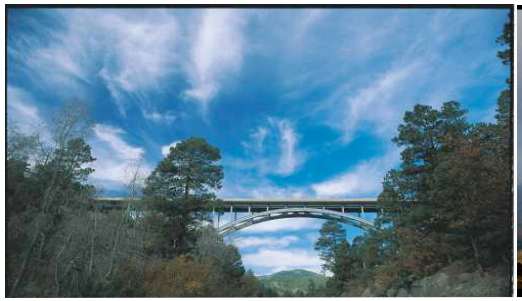

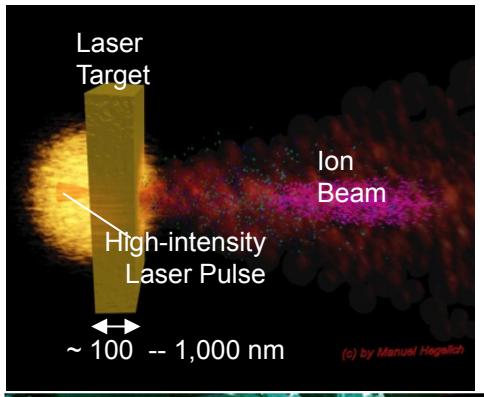

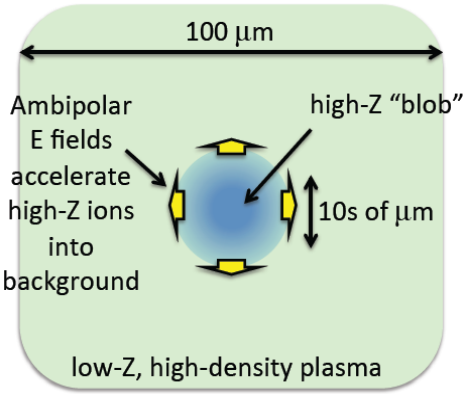

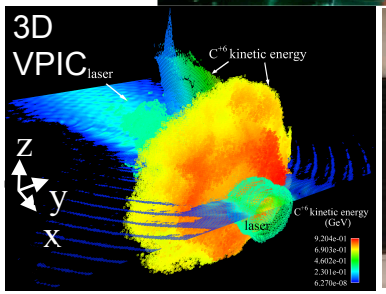

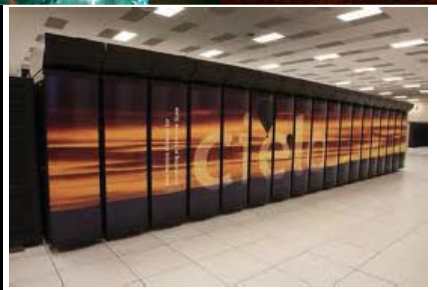

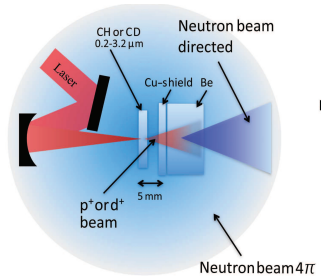

Acknowledgements

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  - Eric Vold, XCP-2
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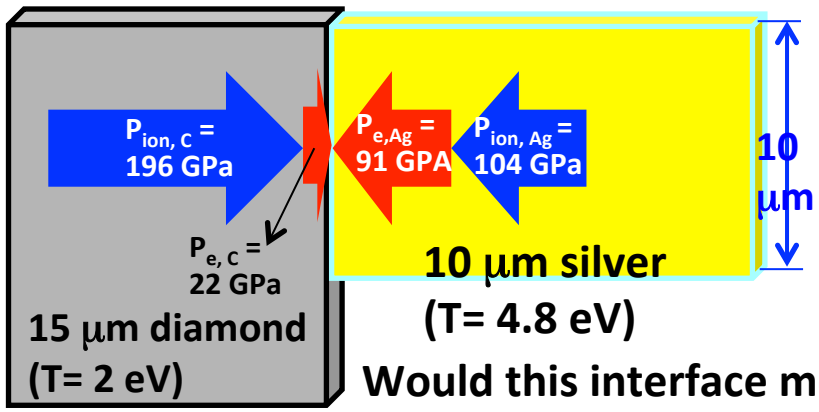
- Experiments
  - D. Cort Gautier, P-24
  - Woosuk Bang, P-24
  - Sasi Palaniyappan, P-24
  - Gillis Dyer, UT Austin
- Target fabrication
  - Miguel Santiago, MST-7
- Trident personnel, P-24

Outline

- Studying possible mix / interface motion between heterogeneous low/high Z interfaces driven by 2-fluid or kinetic plasma effects
  - Heated to few eV
  - Sharp (sub μm) interface
- Isochoric heating to initialize interface done with Al quasi-monoenergetic ion beams on Trident
- Have measured isochoric heating in individual materials intended for compound targets
- Fielded experiments on Trident to measure interface motion
  - Gold-diamond, tin-aluminium
- Measured heated-sample temperature with streaked optical pyrometry (SOP)
  - UT Austin led (research contract)
  - SOP tests ➔ heating uniformity Vs thickness on Al foils
- Results are being analyzed

Central question of the campaign is the behavior of a high-Z/low-Z interface

- Relevant test of NAMBE tools
- Ion source isochorically (flash) heats (~ 50 ps) a solid sample initially at rest, uniformly to a few eV
- Central question explored in heterogeneous heated samples with sharp interface initially at rest
  - Is the interface motion (sub-ns) dictated by the differential across the interface in *total pressure* (as predicted by rad-hydro codes) or *electron-pressure* (as predicted by kinetic or multi-fluid codes)?

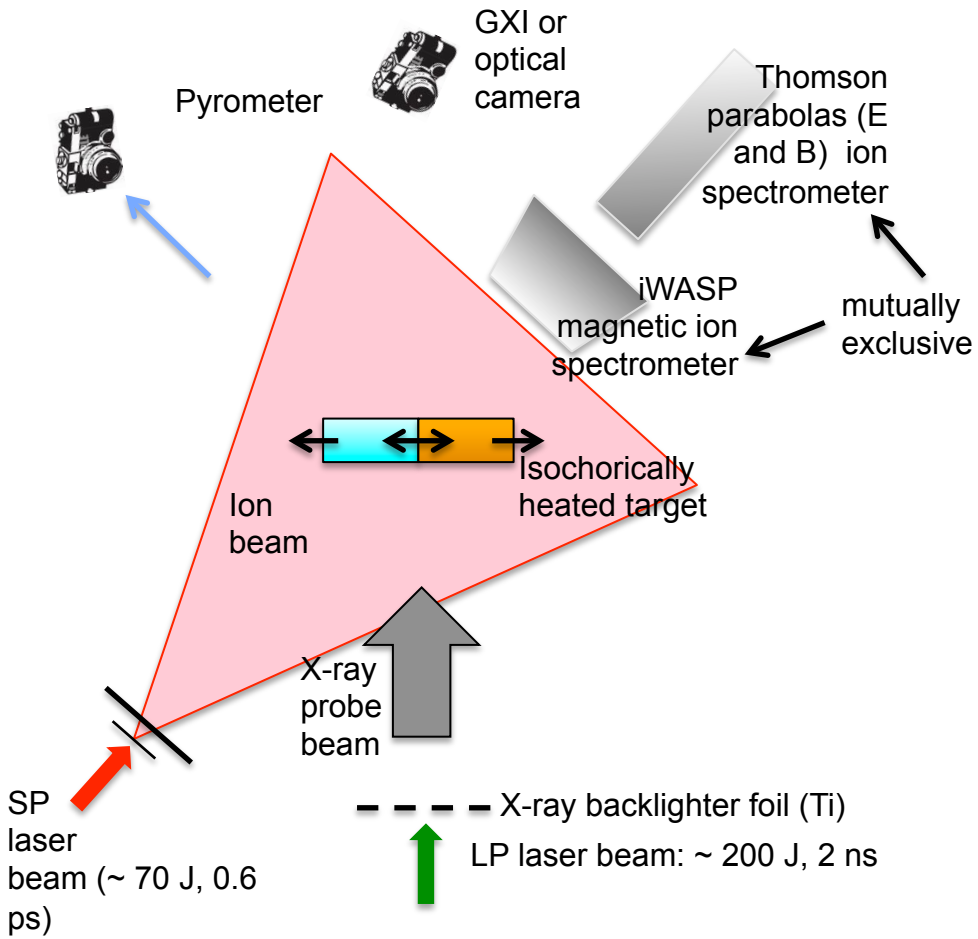


Would this interface move to the right (218 > 195 GPa) or to the left (22 < 91 GPa)?

  - Is there a transition, and when?

Experimental Configuration

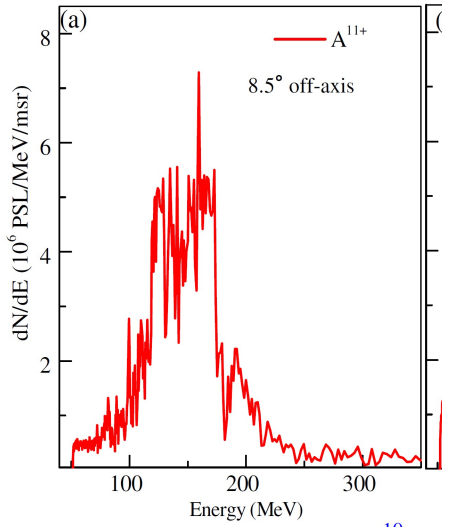
- Trident beam time, June 2015

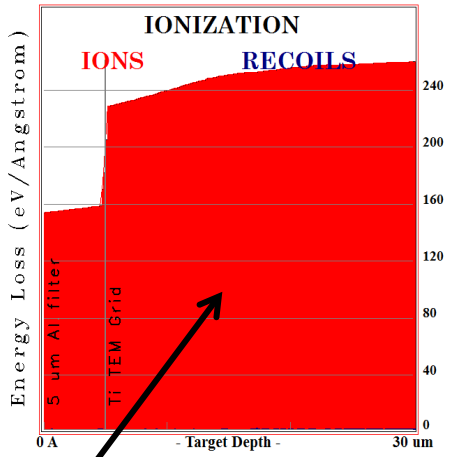


Al ion beams demonstrated on Trident are used for isochoric heating of targets to several eV

- Utilizing quasi-monenergetic Al^{11+} beams at the LANL Trident laser
- Made in novel laser-plasma regime of relativistic transparency
- Laser targets are 110 nm Al foils (need ~ 10^{12} laser pulse-pedestal contrast)
- Ion energy peaked at 165 MeV
- Laser conversion efficiency to 100-200 MeV is ~ 5% (3.5 J in ion beam)
- Ion beam charge changes to mostly Al^{13+} after passage through 5 μm Al light shield (protects package from direct laser illumination)
- Beam expands in a ~ 20 degree cone from ~ 1 μm to ~ 350 μm
- Ion heating is predicted to be even more uniform than with a perfectly monoenergetic beam

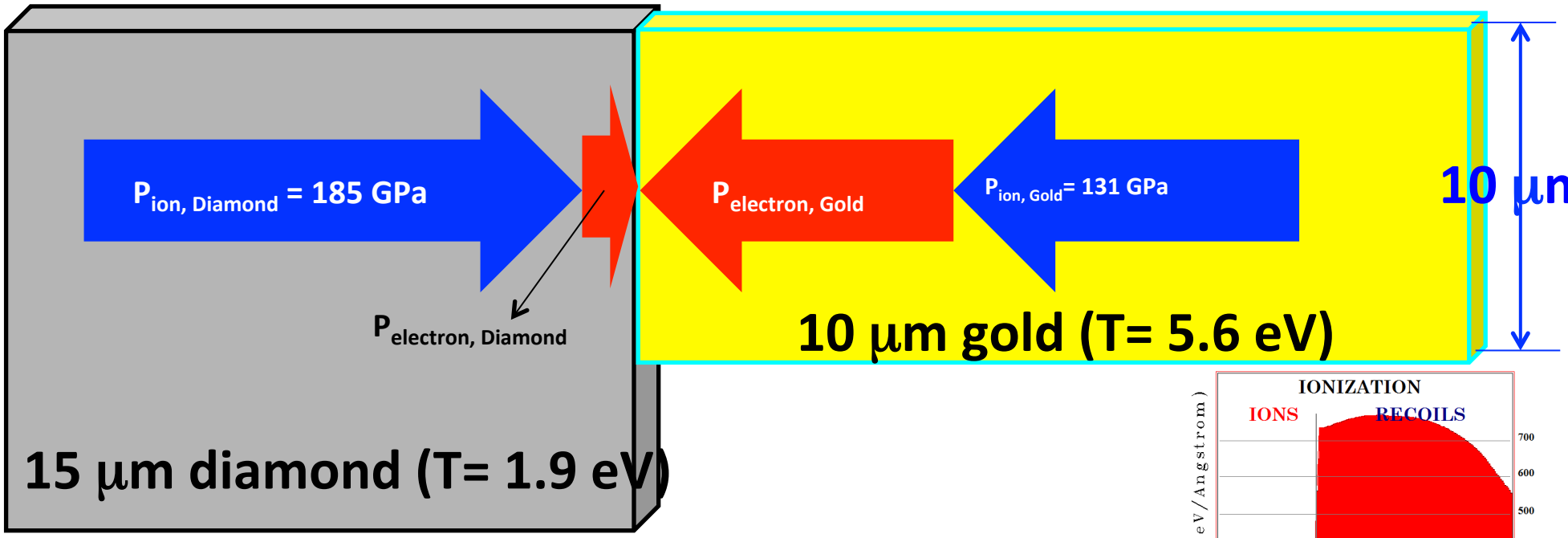
Palaniyappan et al., *Nature Comm.* (under review)

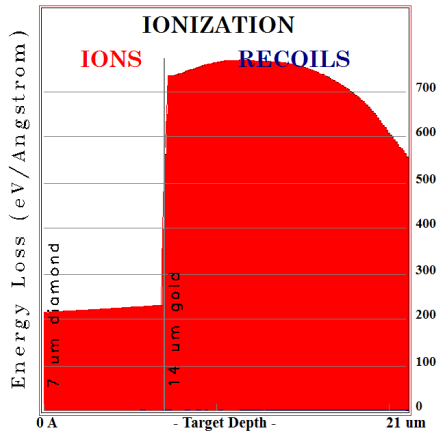




SRIM modeling shows high heating uniformity (Ti example)

A solid density gold-diamond compound target is baseline for the Trident 6/2015 campaign.





$$P_{electron, Diamond} (= 19 \text{ GPa}) \ll P_{electron, Gold} (= 116 \text{ GPa})$$

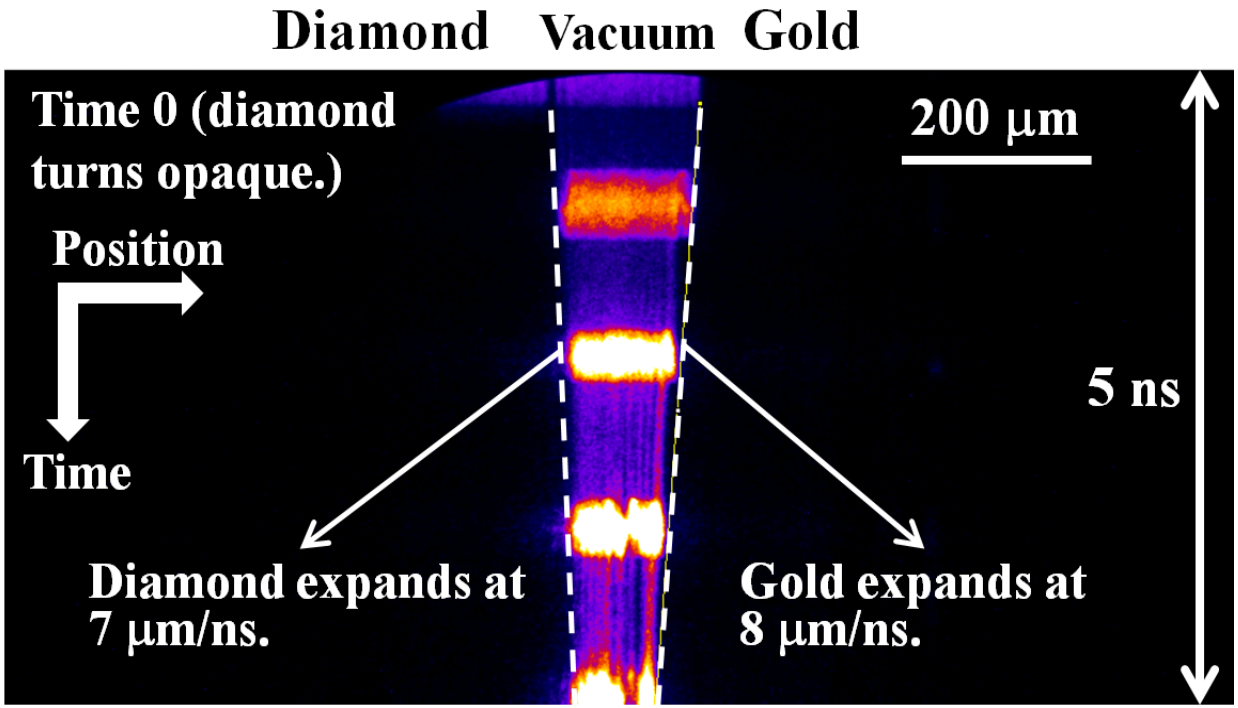
$$P_{electron, Diamond} + P_{ion, Diamond} \approx P_{electron, Gold} + P_{ion, Gold}$$

- Total pressure of gold is 25% larger than that of diamond.
- Electron pressure of gold is much bigger than that of diamond.
- Heating of individual materials separately diagnosed*
- Also have shot a few Al/Sn ion targets

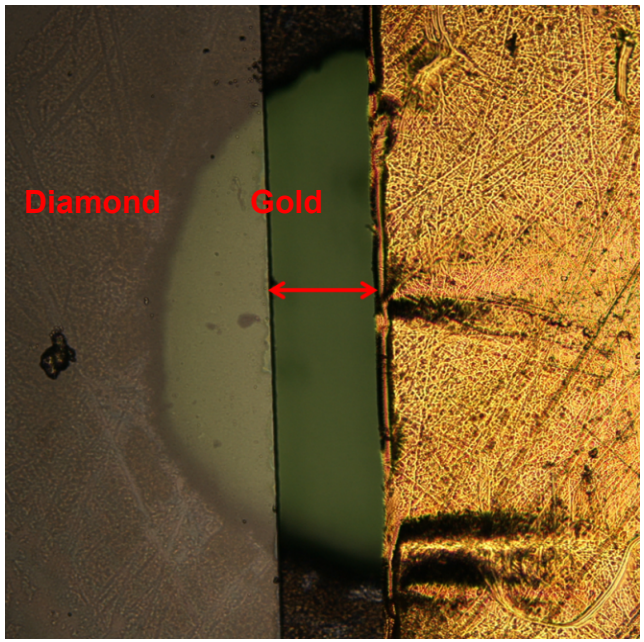
*W. Bang, et al., Scientific Reports, submitted (2015)

Imaged the expansion of Au & diamond with optical shadowgraphy recorded on a streak camera*

- Purpose: diagnose heating of individual species by observing expansion into vacuum and verifying consistency with SESAME tables



A streak camera image showing the expansion of gold and diamond

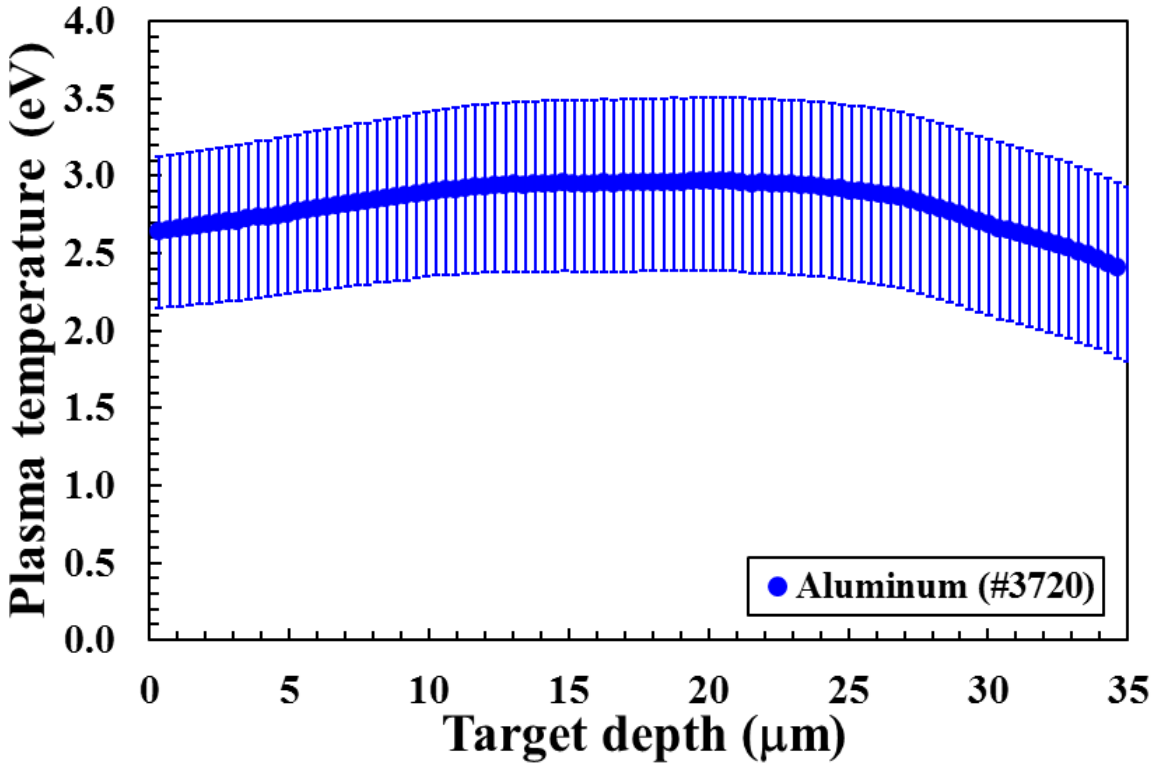


Picture of the target

- The measured expansion speeds agree with values from hydrodynamics simulations using 6 eV gold and 2 eV diamond.
- An optical fiducial confirmed the time-base of the streak camera.

*W. Bang, et al., *Visualization of expanding warm dense gold and diamond heated uniformly by laser-generated ion beams*, Scientific Reports, submitted (2015)

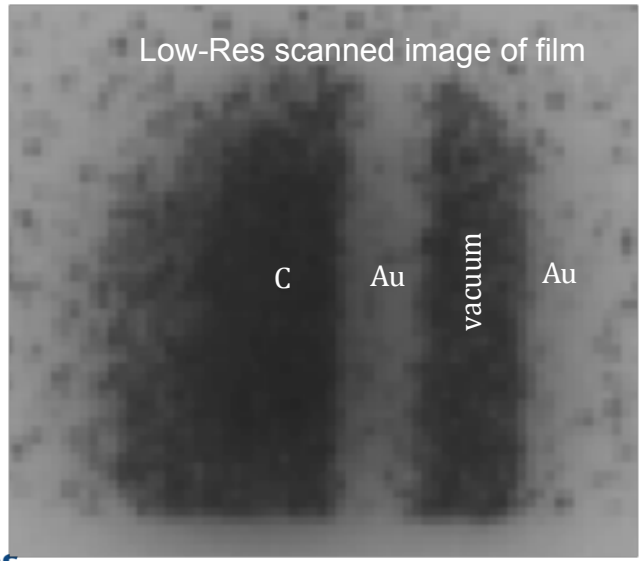
Heating uniformity has been tested with Al foils of varying thicknesses (UT Austin lead)

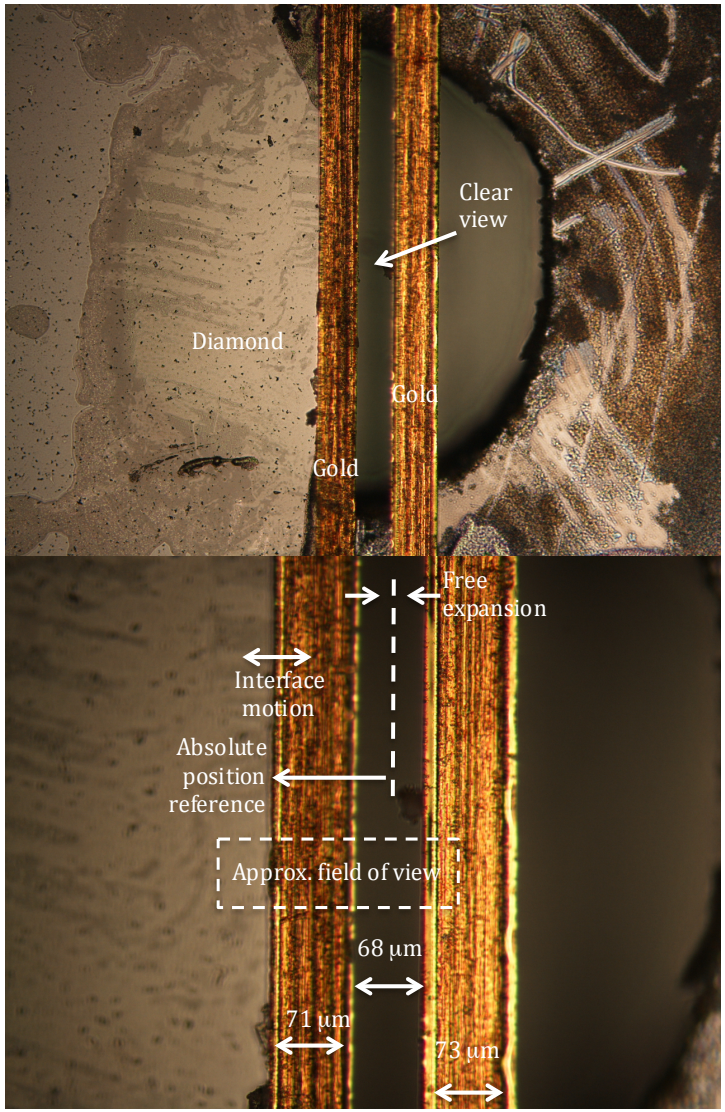


- Al foils 5, 8, 12, 25, 30 μm thick ion-targets prepared for Streaked Optical Pyrometry (SOP) diagnostics testing series.
- Analyzed data points successfully shot will be plotted in the above figure.

Improved, self-referencing target has been used in the 6/2015 campaign.

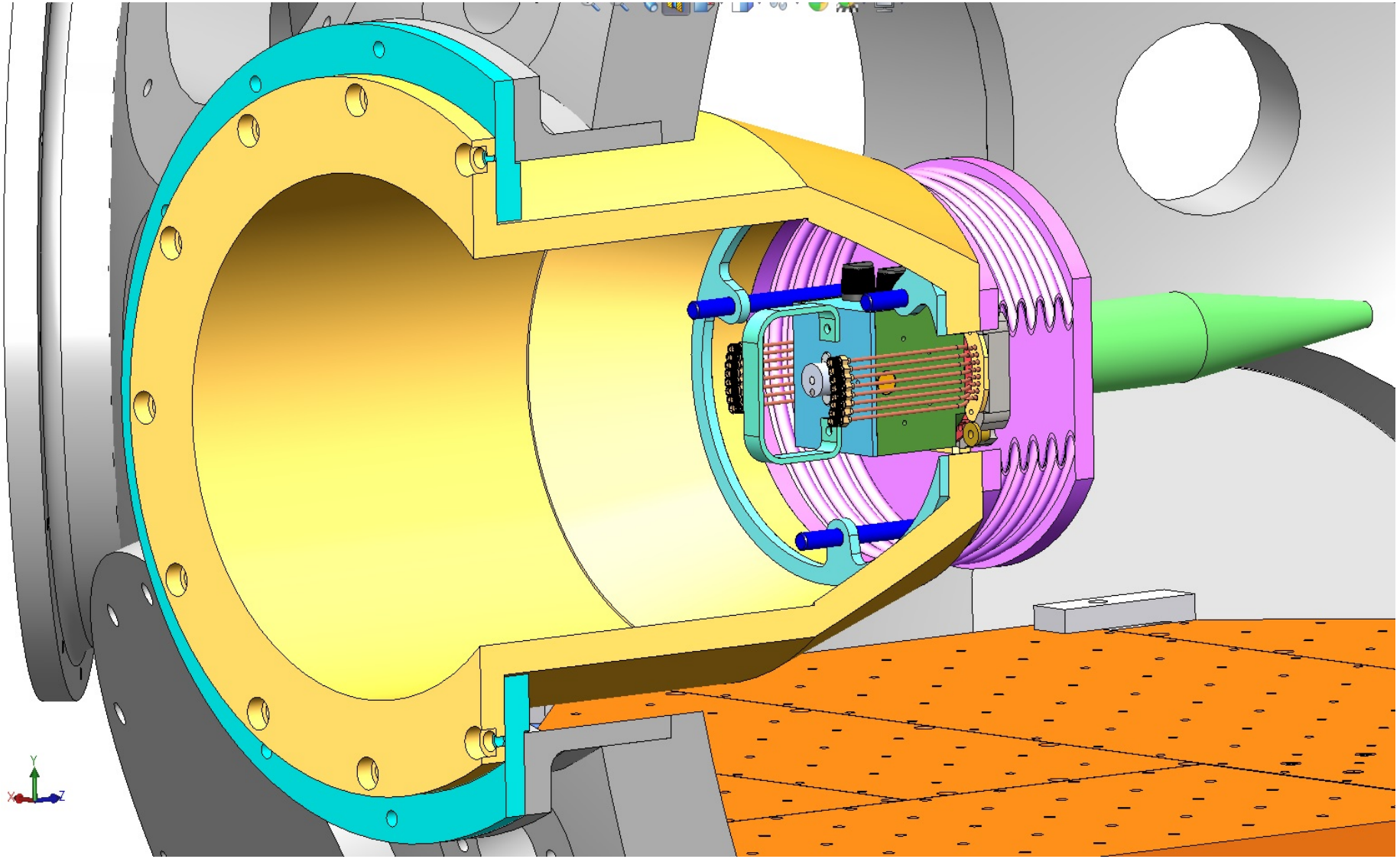
- (Used mirror image of the configuration shown to improve ion-heating uniformity)
- Relies on uniform areal heating
- Gap provides spatial fiducial – absolute registration not good enough (Mag, rotation)
- Au expansion into gap diagnoses heating
- Geometrical knowledge (fitting a line) increases spatial resolution (to ~ 2μm) over native GXI resolution (~ 10 μm, pinhole limited)





Face-on view of the compound ion-beam target to quantify the motion of the heterogeneous plasma interface. This is the view of the gated x-ray camera, which observes the target backlit with 4.7 keV photons from an area Ti-foil backlighter.

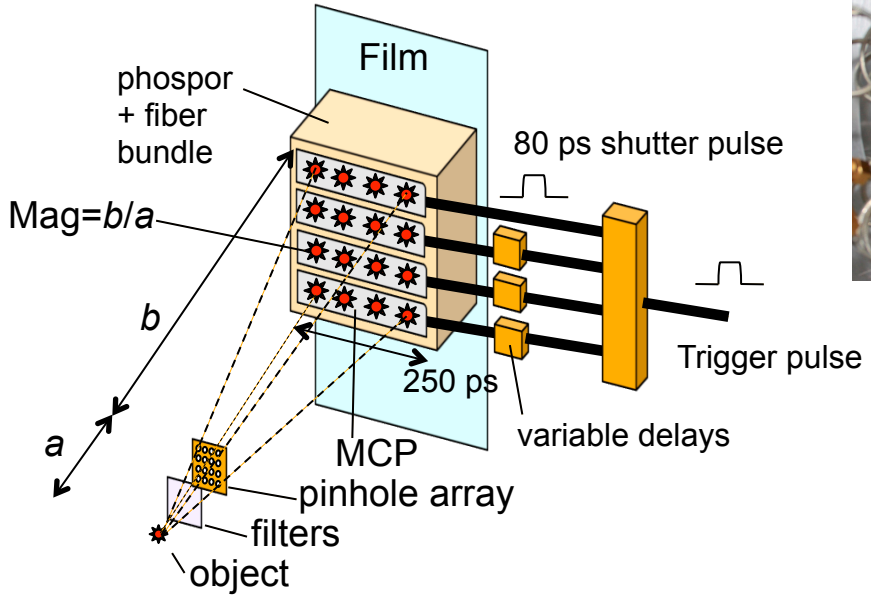
Used Gated X-ray Imager (GXI) to capture 16 images of the heated package.

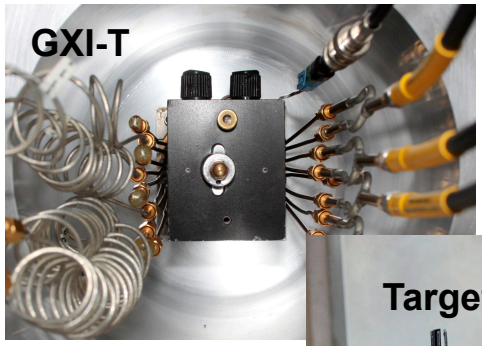


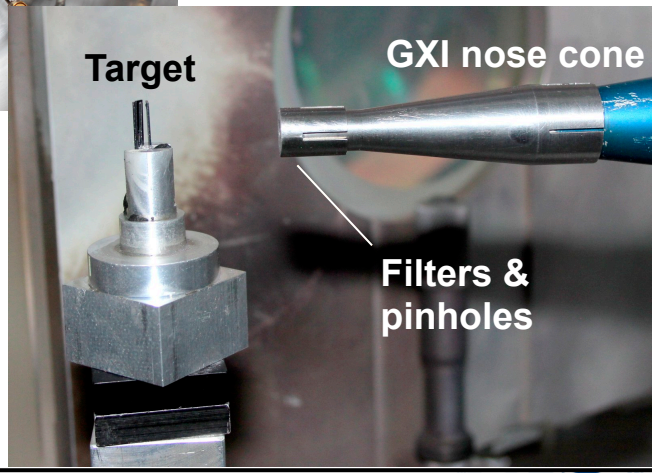
Gated x-ray imager is the primary diagnostic for interface motion

- Developed for ICF, Trident instrument (GXI-T) is an early prototype (not TIM based), refurbished for this campaign
- Built a dedicated backup MCP 2 wider strips (easier alignment)
- GXI is optimized for keV photon range – perfect for Ti 4.7 keV
- 5 – 10 μm spatial resolution (pinholes & detector matched)
- Nose cone shields MCP, holds pinhole array & filters, enforces alignment (*b*, colinearity & rotation). Use Mag=12x cone (sets *a*)

Gated x-ray imager (GXI) @ Trident



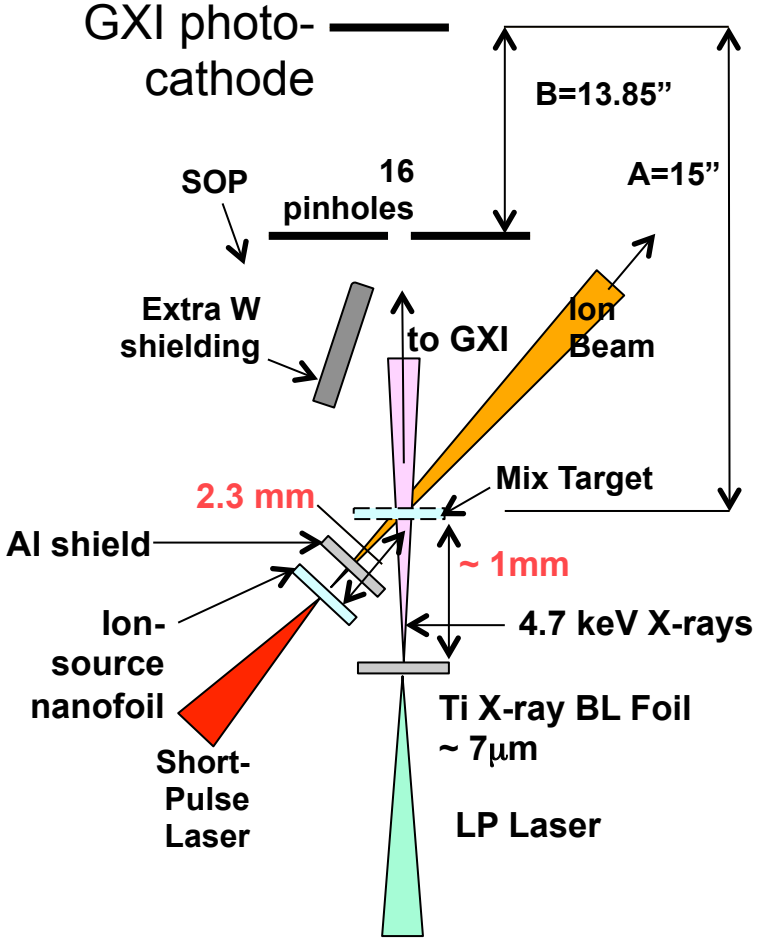




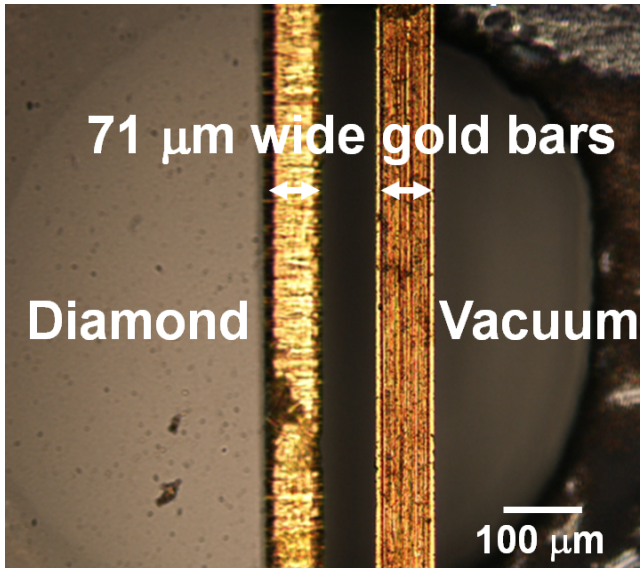
Experimental geometry requires precise multi-target registration & alignment

- Alignment on 3 axis
  - LP laser, mix target, GXI pinhole, GXI photocathode
  - SP laser, nanofoil, mix target, ion spectrometers
  - SOP, mix target
- Minimizing LP-beam laser spot size on X-ray BL ➔higher x-ray flux but smaller FOV
  - Smaller FOV ➔ sensitivity to pinhole parallax & possible X-ray preheat
- Registration, distances
  - Large BL-mix target distance: good for debris mitigation & minimizing preheat, bad for flux & smaller FOV
  - Small nanofoil-mix target distance: good to increase ion flux & ion beam temporal spread, bad for nanofoil integrity, heated area, geometric interference with BL
  - Mix-target to GXI distance: controls magnification (correct position on detector)

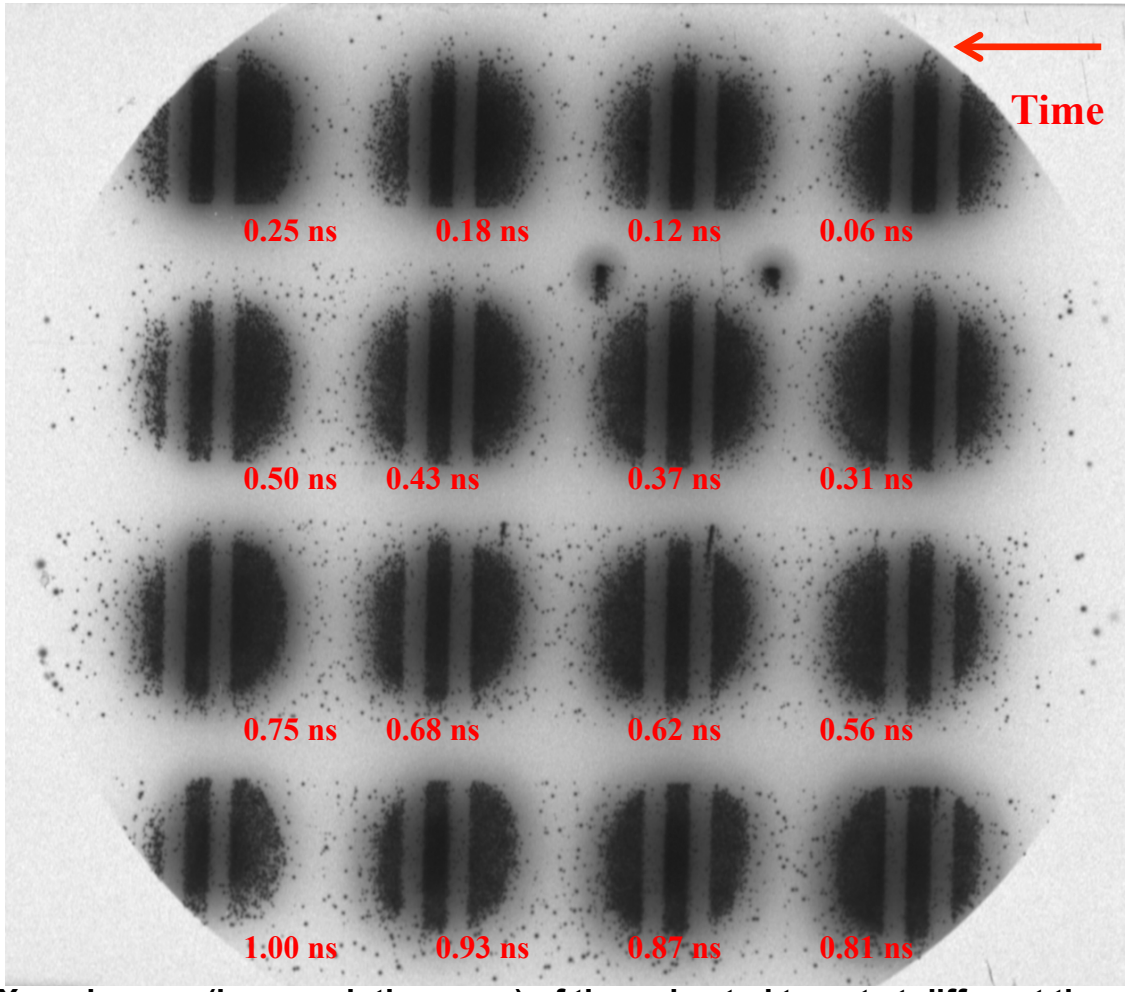
Experimental geometry



GXI on trident can image the gold/diamond ion-heated target

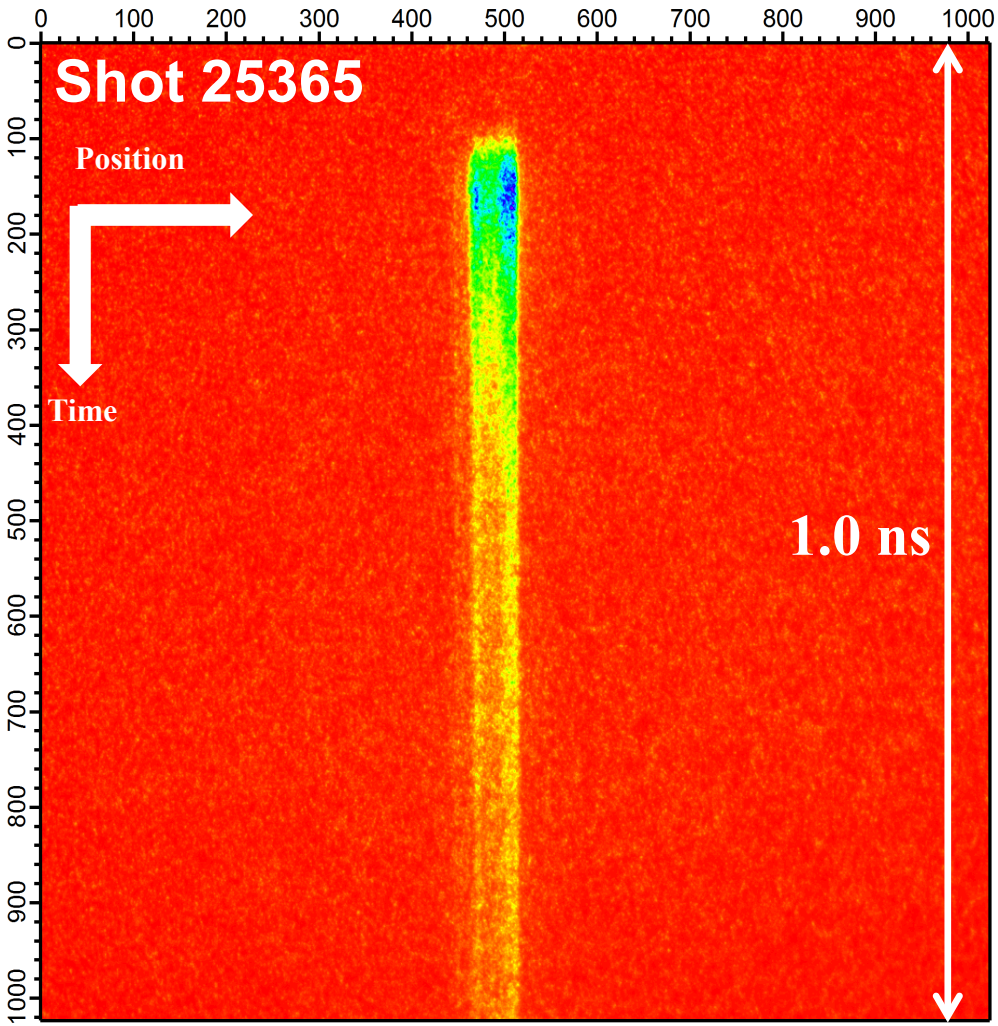


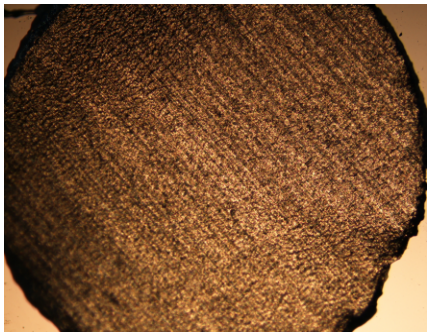
Proposed target geometry (actual microscope image)



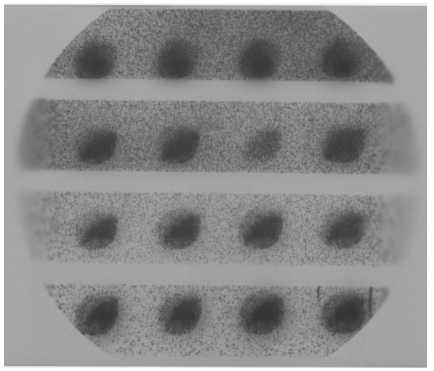
X-ray images (low resolution scan) of the unheated target at different times

The SOP measured plasma temperatures on some shots

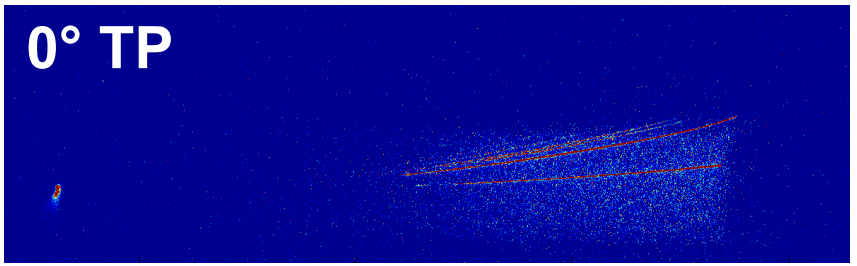




Al target for this shot (picture by Miguel Santiago, MST-7)



X-ray images on this shot (GXI)

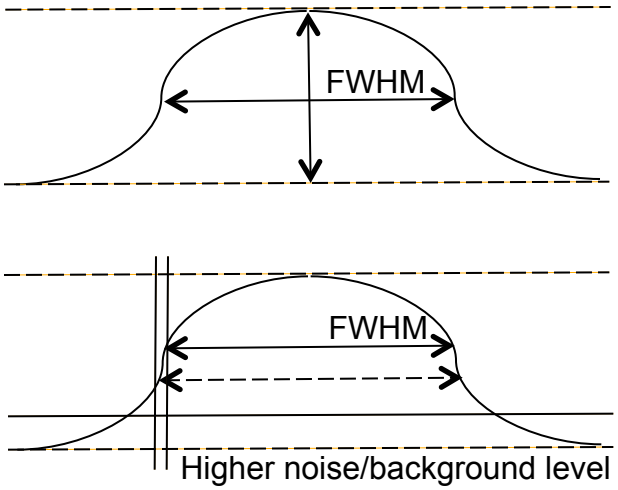


Good ion traces on the 0° TP

We had five shots with the SOP measuring the plasma temperatures of the targets.(6.3 μm thick Al foil on this shot)

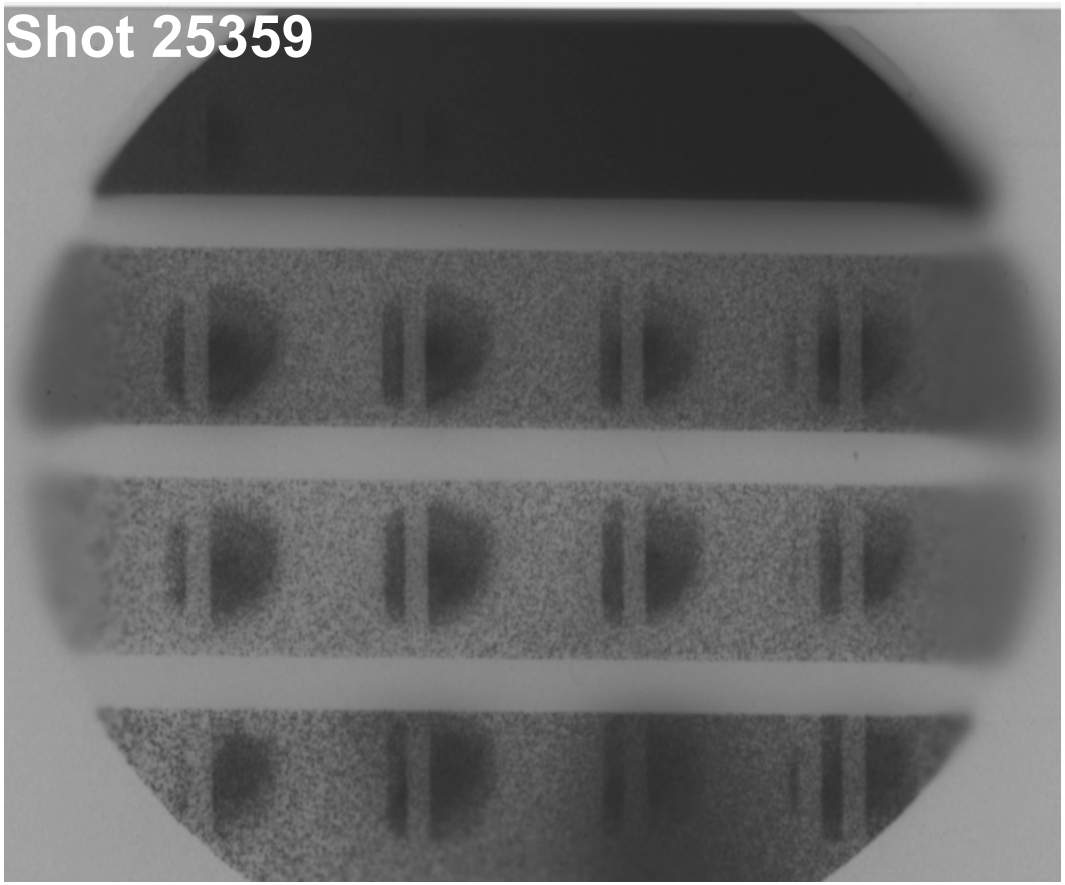
Data are being analyzed

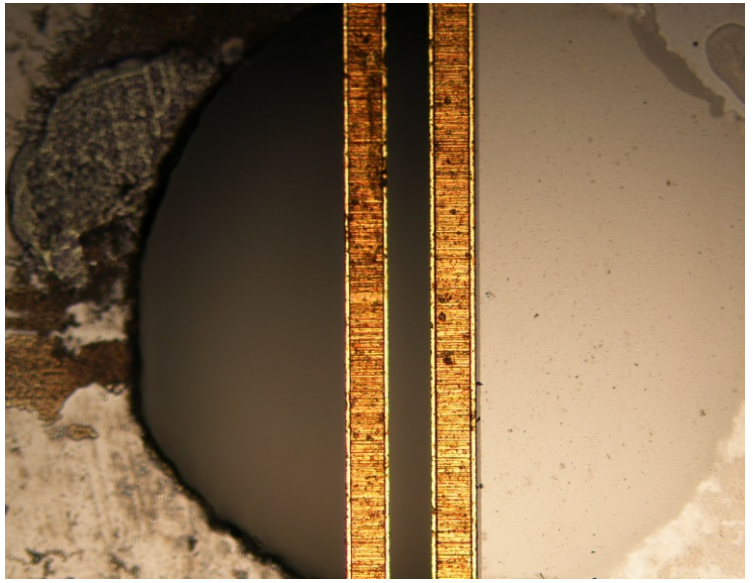
- Data analysis considerations:
  - Expect only ~ 10 μm of motion (speeds ~ 10 μm/ns)
  - Need formal computer-based data analysis to be sure
  - Background levels are important



- Real life experimental difficulties:
  - Rise time in SOP (sometimes slow) suggest "preheat"
    - Diagnostic failure?
    - X-ray preheat of package from x-ray backlighter? (Estimated to be about ~ 0.5 eV on Au)
    - SOP view (unintended) of the x-ray backlighter?
  - EMP / hot electrons wipe out ~ 0.25 -- 0.5 ns observation window on GXI

EMP and hard x-rays eliminate an observation window of ~ 0.25 ns





Target for this shot (picture by Miguel Santiago, MST-7)

- **Target = two gold bars + diamond foil**
- **Clear 12 images with both gold bars. (Strong C-beam noise)**

Summary

- Studying possible mix / interface motion between heterogeneous low/high Z interfaces driven by 2-fluid or kinetic plasma effects
  - Heated to few eV
  - Sharp (sub μm) interface
- Isochoric heating to initialize problem done with Al quasi-monoenergetic ion beams on Trident
- Have measured isochoric heating in individual materials intended for compound targets
- Fielded experiments on Trident to measure interface motion
  - Gold-diamond, tin-aluminium
- Measured heated-sample temperature with pyrometry
  - UT Austin led (research contract)
  - SOP tests ➔ heating uniformity Vs thickness on Al foils
- Results are being analyzed

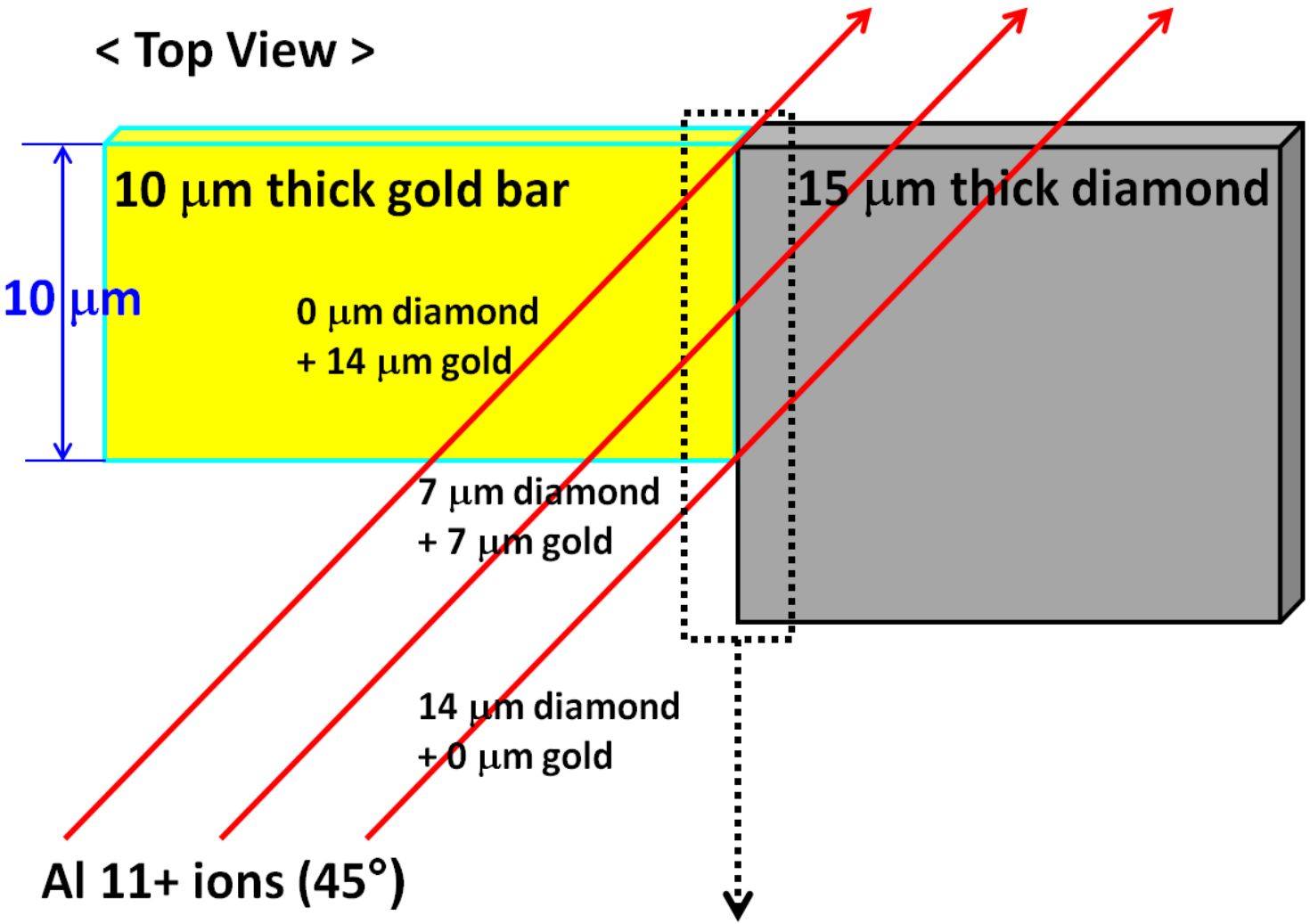
Goals and elements of the June, 2015 campaign

- Observe motion of heterogeneous dense-plasma interface isochorically heated to few eV temperatures (1st priority)
  - Gold-diamond (5 shots)
  - Tin-aluminium (5 shots)
- Measure heated-sample temperature with pyrometry (2nd priority)
  - UT Austin led (research contract)
  - Combine with vacuum-expansion observations to check Sesame EOS
  - SOP tests: heating uniformity Vs thickness on Al (5 shots) + 2 materials (5 shots)
- Test whether a secondary foil near the ion-source laser target can cool beam electrons and arrest beam expansion (3rd priority)
  - Pending targets from MST-7, ~ 3-5 shots
- Test whether Al coated with CD2 can deliver quasi-monoenergetic D beam (for neutron production, Favalli's beam time following, 4th priority), 3-5 shots
  - Based on results with Al-CH2 targets already tested.

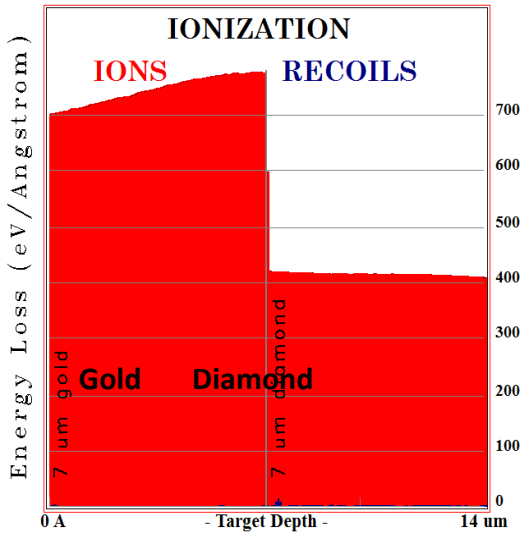
Status after May 2014 campaign:

- Ion source
  - ✓ Verify and optimize Al11+ source (under review in Nature)
  - ✓ Verify the laser does not propagate past the ion source and does not destroy ion-beam target
- Observe motion of edge of homogeneous ion target
  - ✓ Electron temperature (heating) diagnostic
  - ✓ Optical shadowgraphy (probe beam+ time streaked 1D image) and x-ray backlighting (A-beam, Ti or Cl backlighter, GXI)
- Validate estimates / ascertain isochoric heating estimates
  - ✓ Needed to establish the pressures in heated materials (potential for novel off-Hugoniot EOS measurements in WDM regime)
  - ✓ Extensive calculations with several models for diamond, Au, Ti, …
- Measure motion of heterogeneous (C-metal) interface in ~ ns scale
  - x-ray backlighting – only one measurement with large uncertainty in the ~1-week allocated for this portion of the beam time. Now Priority #1 for June 2015 run, as validated by DR review committee.

Gold should be on the left for more uniform heating



GXI will observe this interface after confirming a good contact between the two foils



Stopping power from SRIM