Tracer Spectroscopy Diagnostics of Doped Ablators in Inertial Confinement Fusion Experiments on OMEGA

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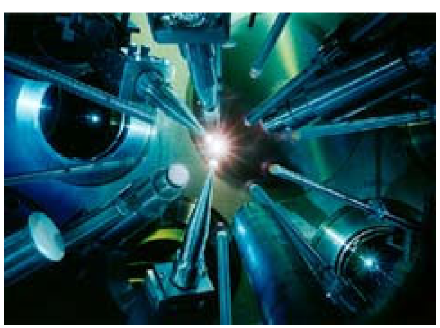

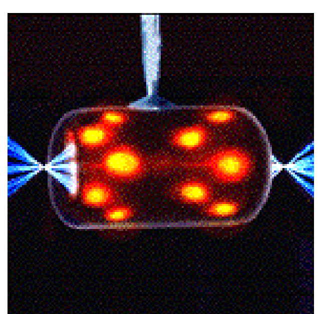

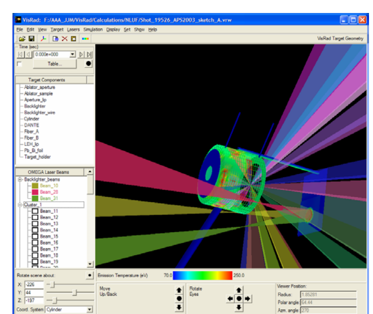

OUTLINE

1. Scientific Context
    - ablator dopants
    - tracer spectral diagnostics
2. Experiment Design
3. Targets
4. Data and Overview of Results
5. Modeling
6. Conclusions

Context

Ablator dopants are used to control fuel pre-heat, but they also affect the radiation hydrodynamics of the interaction between the hohlraum radiation field and the capsule.

Effects of variable x-ray preheat shielding in indirectly driven implosions*

O. L. Landen,† C. J. Keane, B. A. Hammel, W. K. Levedahl, P. A. Amendt, J. D. Colvin, M. D. Cable, R. Cook, T. R. Dittrich, S. W. Haan, S. P. Hatchett, R. G. Hay, R. A. Lerche, R. McEachern, T. J. Murphy, M. B. Nelson, L. Suter, and R. J. Wallace
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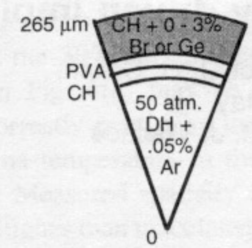
The performance of indirectly driven fusion capsules has been improved by mid Z doping of the plastic capsule ablator. The doping increases x-ray preheat shielding leading to a more isentropic compression, higher convergence, and higher neutron yield. A 4× increase in neutron yield is both calculated and observed as the Ge doping level is increased from 0% to 3% by atomic fraction. A predicted 40% decrease in x-ray image core size with increasing Ge content is confirmed. © *1996 American Institute of Physics.* [S1070-664X(96)93105-5]



[F]IG. 1. Cross section of typical deuterated fuel capsule design.

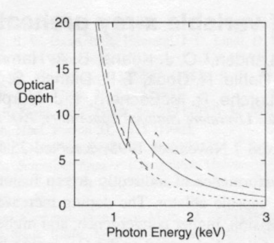


FIG. 3. Initial capsule ablator opacity vs photon energy for 58 μm thick undoped plastic ablators (short dashed curve), for 45 μm thick 1.3% Ge-doped plastic ablators (solid curve), and for 45 μm thick 1.9% Br-doped plastic ablator (long dashed curve).

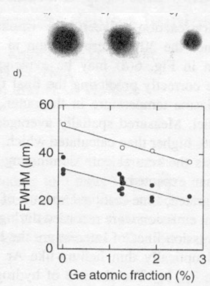
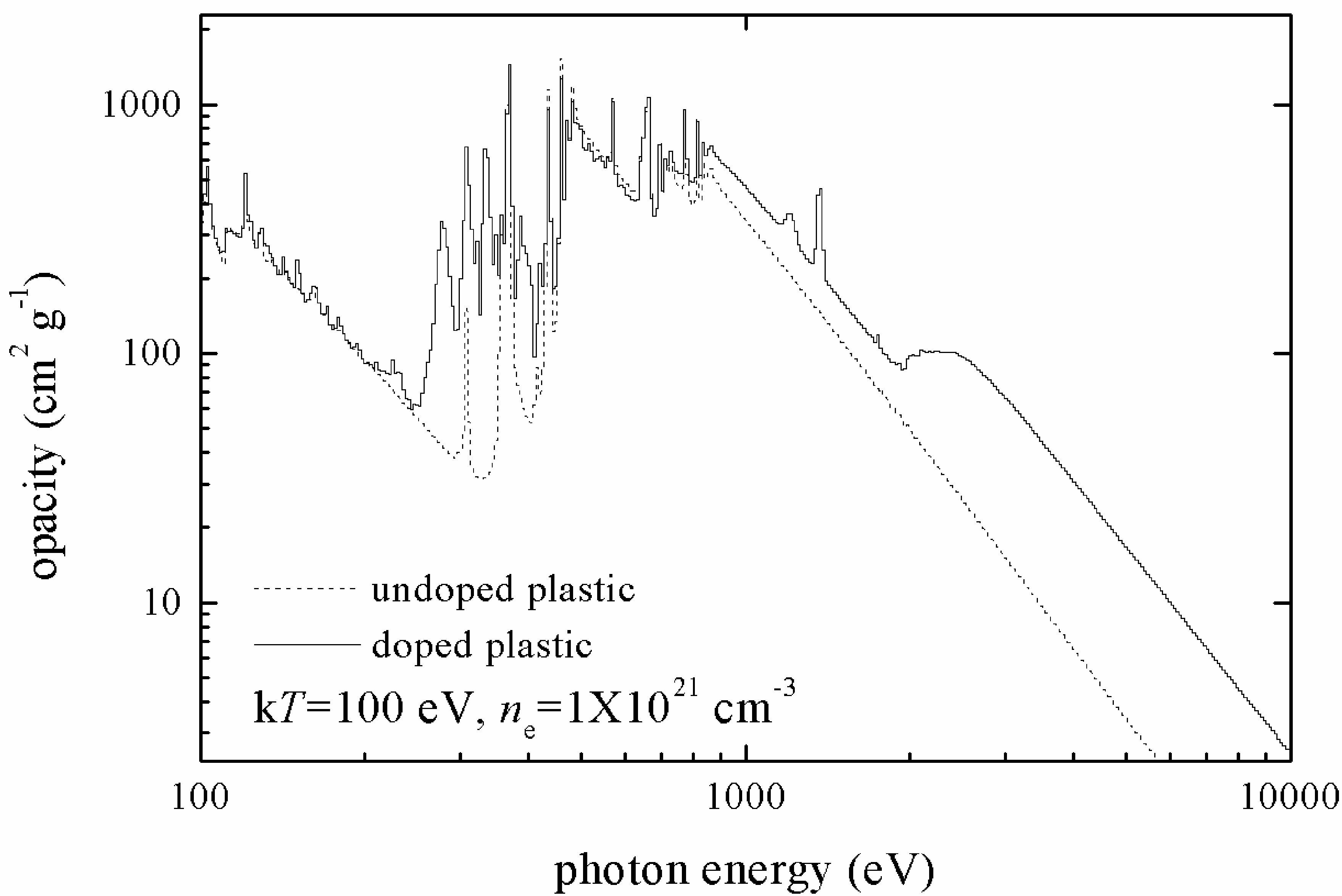


FIG. 7. X-ray images (4 keV) of imploded cores from smooth capsules at peak emission time for various Ge-dopant levels: (a) no Ge, (b) 1.3% Ge, (c) 2.7% Ge. (d) Measured (solid circles) and calculated (open circles) azimuthally averaged diameters of 50% contours vs dopant level. Solid lines are linear fits to data and simulations.

A small amount of dopant - here 1.8% by atom of germanium - can significantly increase the opacity of a low-Z ablator



Ablator dopants affect the opacity and density, changing the manner in which energy is absorbed by the ablator.

Controlling the process requires a means of **diagnosing** the properties of doped and undoped ablators in the hohlraum environment.

Burnthrough and shock breakout experiments (ex. shown at right) measure the properties of ablators and their response to hohlraum radiation fields *integrated* over the duration of the experiment.

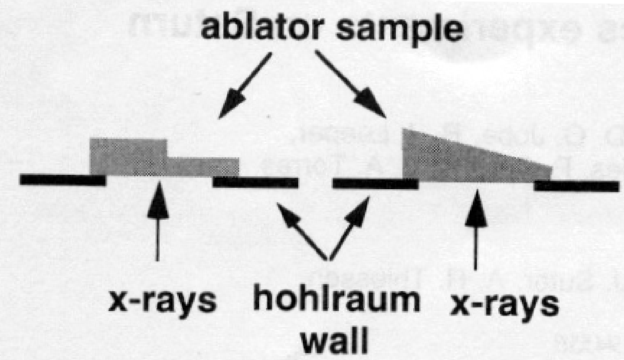


FIG. 1. Illustration of the experimental arrangement. Ablator samples were machined into steps (a) and wedges (b).

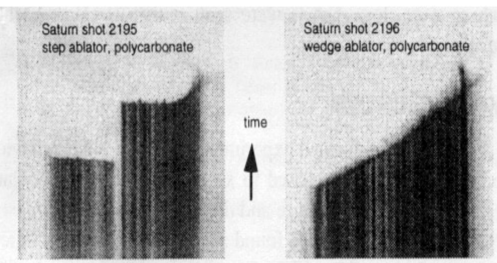
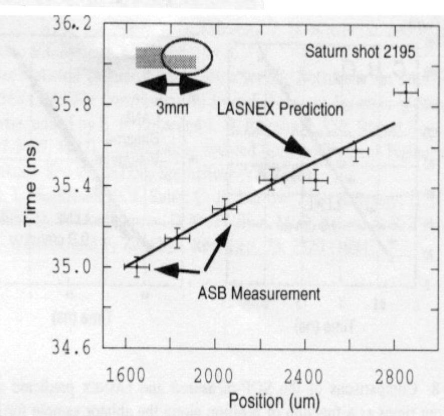


FIG. 6. Examples of the streak camera film record for Saturn experiments using step- and wedge-shaped ablator samples.



Also, ablators have been evaluated *spectroscopically* via emission in gas-filled capsule implosions.

Olson et al.

In a different context, Perry *et al.* showed that absorption spectroscopy in multi-layered targets could diagnose radiation transport.

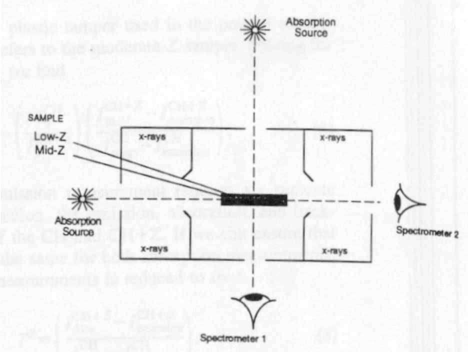


FIG. 1. (a) Schematic of an experiment designed to allow quantitative analysis of the absorption spectrum. The key elements are the backlight, the sandwich target, and a recording medium that allows the various sources to be measured at one time. (b) Schematic showing two spectrometers as used in the PPS technique.

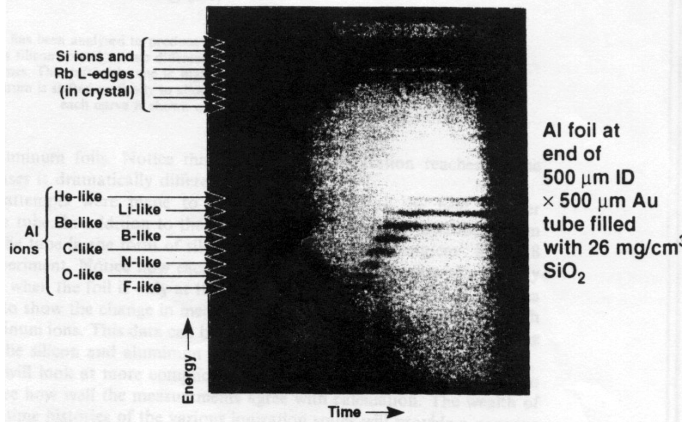


Fig. 8. The x-ray crystal streak camera record for a filled tube is shown. Filling the tube with 26 mg/cm^3 of silicon aerogel only slightly slows the transfer of heat but provides more information about the transfer of heat throughout the entire length of the tube. The Rb L-edges that overlay some of the silicon lines can be eliminated on future experiments by using a KAP crystal.

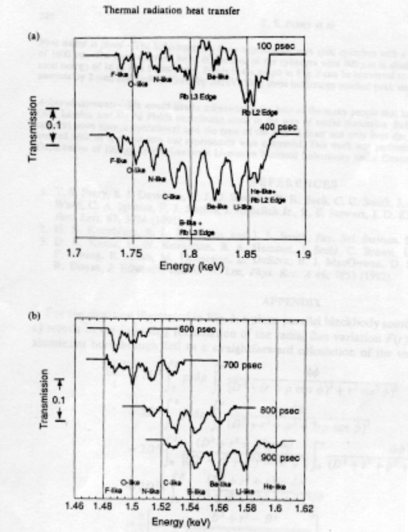


Fig. 9. The data in Fig. 8 has been analysed to produce spectra in transmission as a function of time. (a) The upper graph shows silicon spectra at two different times. (b) The lower graph shows aluminum spectra at four different times. The shift with time to higher ionization states as time changes is clearly seen. [Note that each spectrum is shifted vertically to allow easy comparison. The transmission scale for

And Chenais-Popovics *et al.* showed that Cl K_α absorption spectroscopy could diagnose material properties. Laser-produced Bi plasma provided the backlighter continuum source.

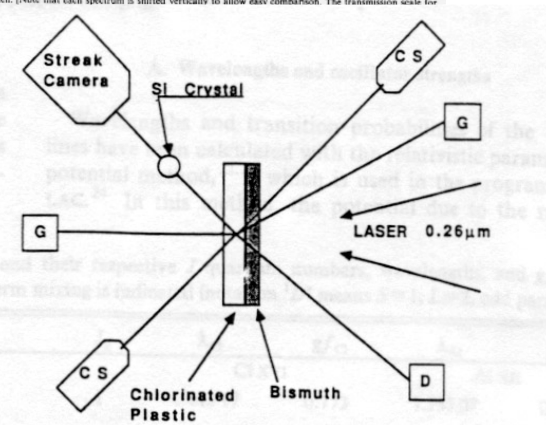


FIG. 2. Set up of the experiment. CS; crystal spectrographs with PET or ADP crystal; *G*; transmission grating spectrograph; *D*; filtered diodes array.

From Chenais-Popovics *et al.* 1989

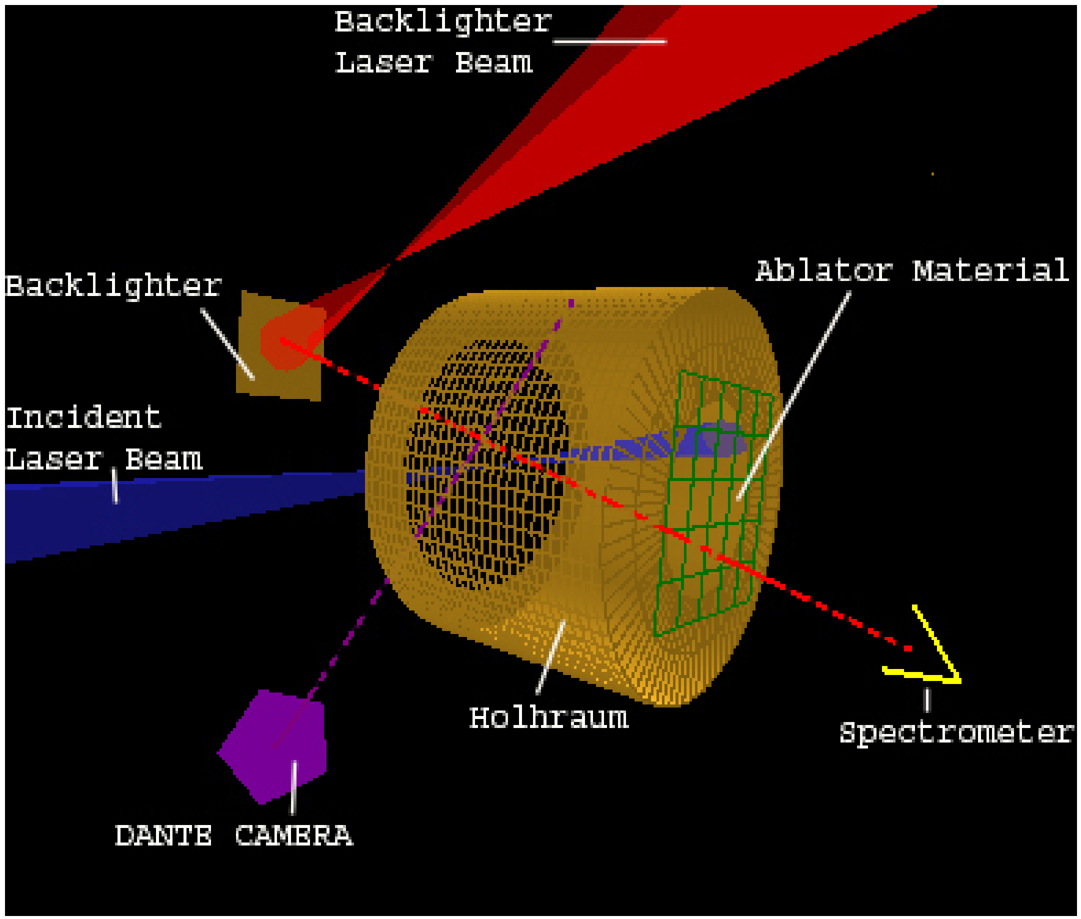
We have combined these ideas, and building on a previous effort to measure tracer emission spectra from aluminum witness plates with Tina Back, proposed an experimental campaign to use backlit Cl K_α absorption spectroscopy to diagnose radiation physics in the *interior* of ablator samples.

We proposed to do this by placing thin tracer layers at specified depths in the interiors of ablator samples mounted on hohlraums. The spectroscopy monitors the ionization conditions in that layer, effectively diagnosing the time-dependent plasma properties at a specific location inside the sample.

A time-delay in the turn-on time of the tracer signal between doped and undoped samples should allow us to determine the effects of dopants on the Marshak wave propagation.

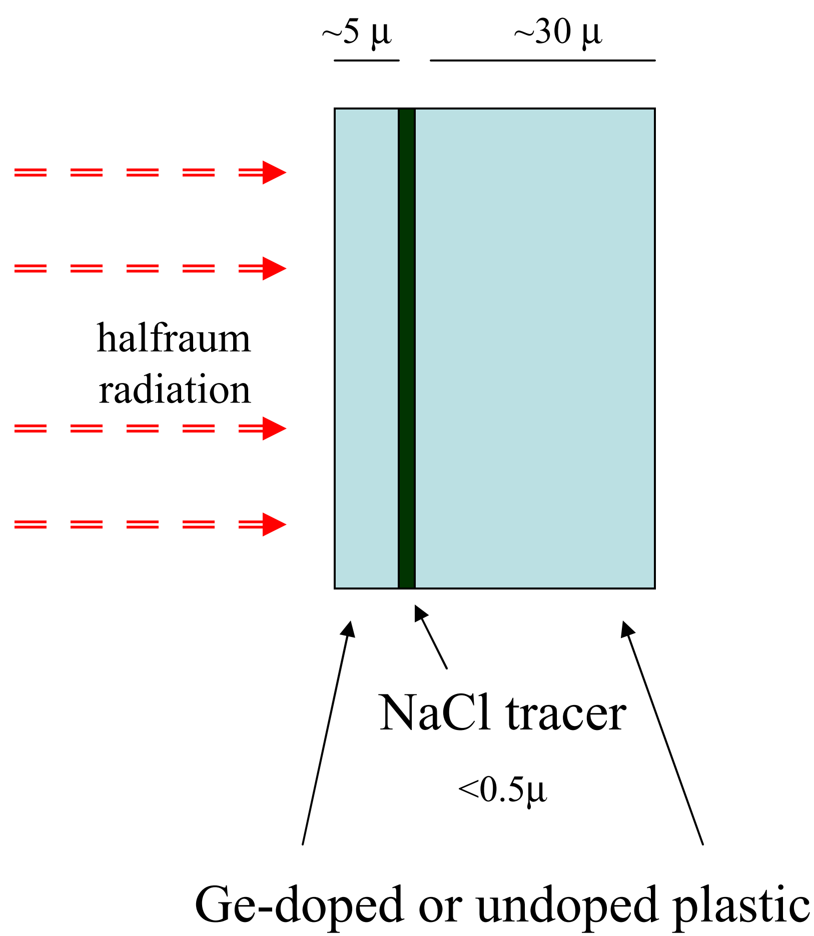
Experimental Set-up

Including schematics of diagnostic lines-of-sight



Note: only one (blue) beam into the halfraum is shown here,for simplicity.
All shots were carried out with 15 beams.

Thin tracers embedded at known depths in planar ablator samples provide a spectroscopic signal when the Marshak wave reaches a specific location in the ablator.



We will be comparing data from two shots in our OMEGA campaign:

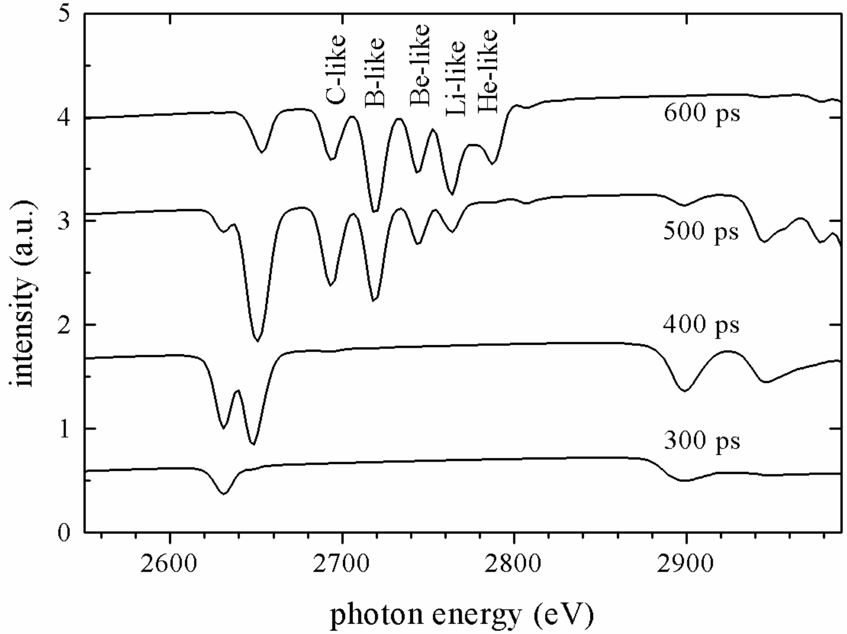
19526: undoped, tracer depth 6.3 μ

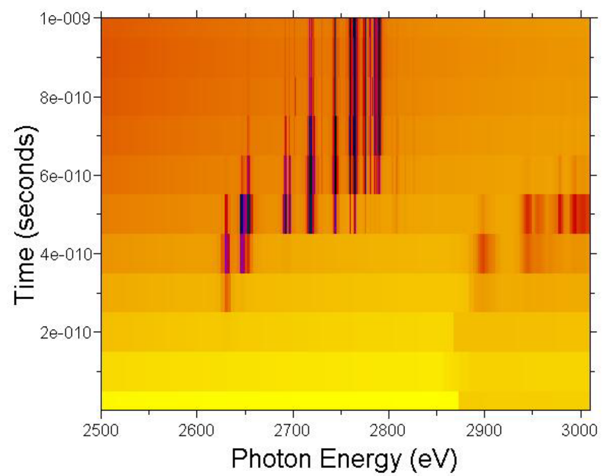
19528: doped, tracer depth 4.1μ

The time-dependent drive spectrum is *modeled* and constrained by DANTE

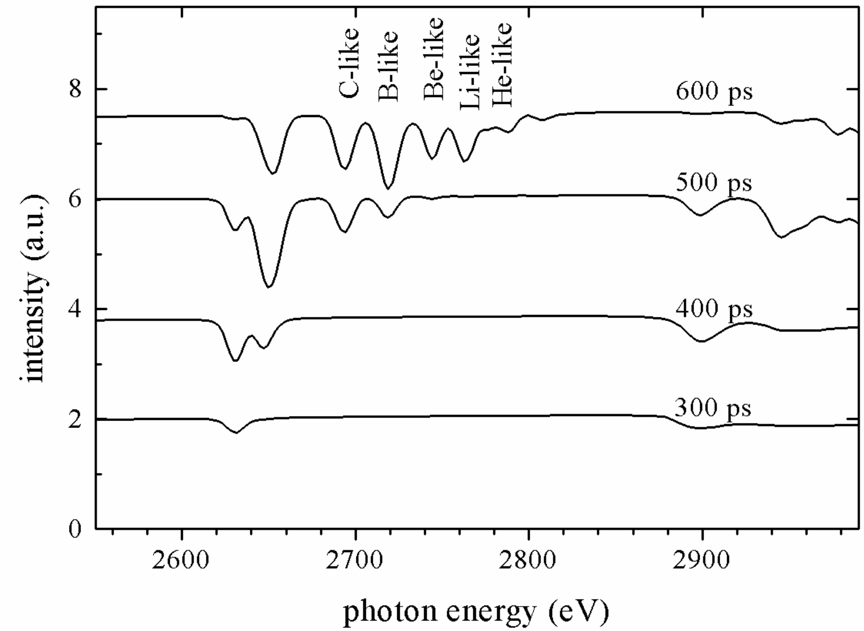
What do we expect to see?

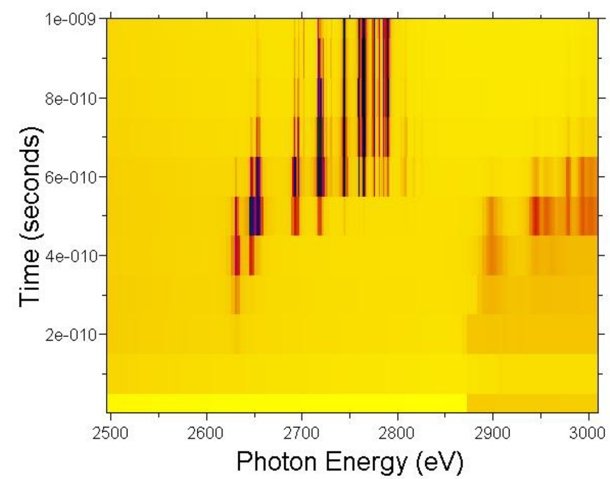
undoped





doped





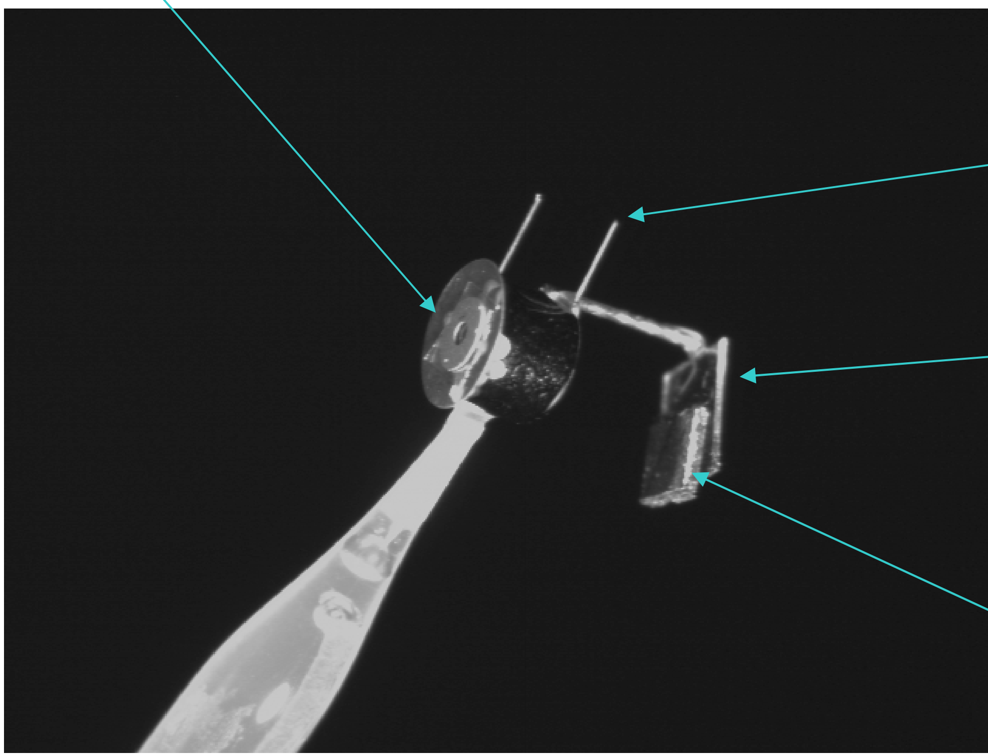
Tracer signals turn on earlier in the undoped sample

Targets: Fabrication and Assembly

Experimental Configuration

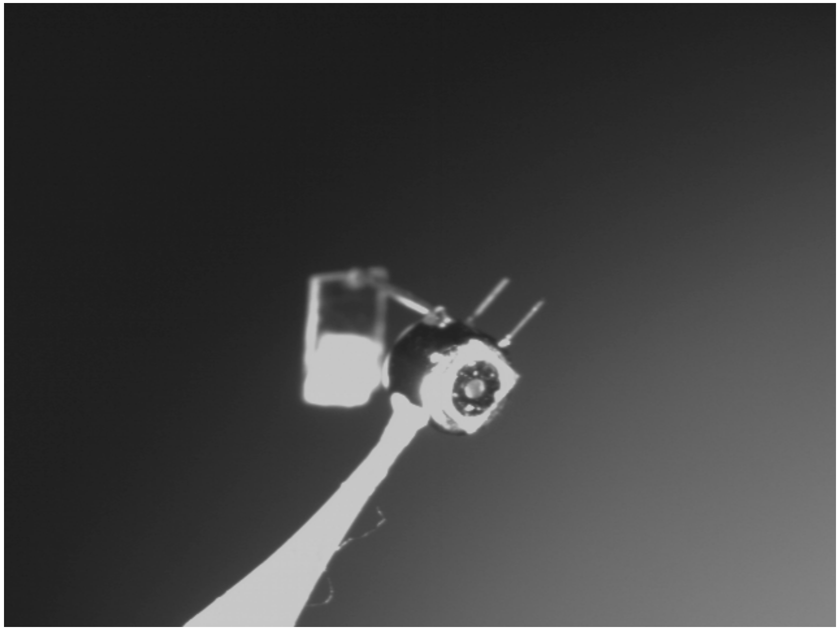
LEH facing P-7 (LXS in P-6)

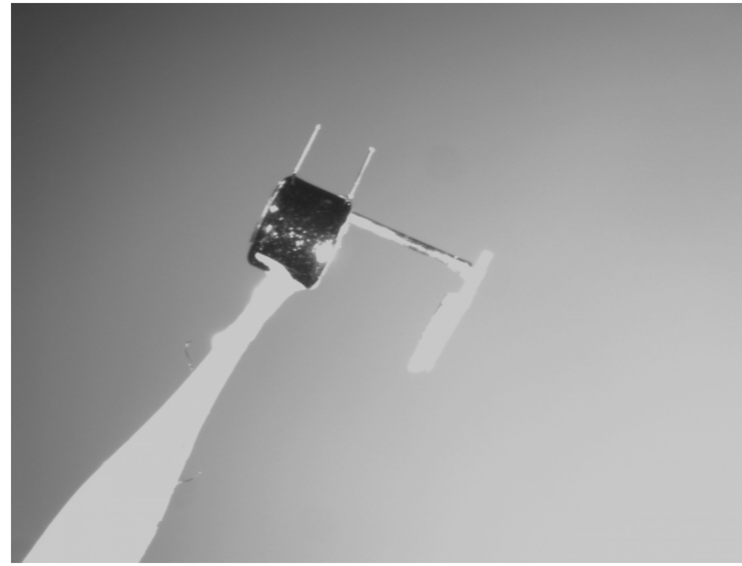
Gold Halfraums: L=1200μ, R=800μ



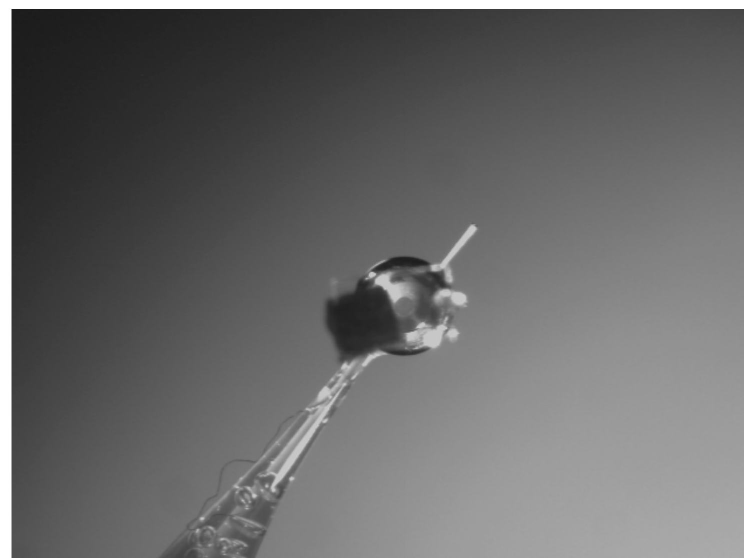
TVS-X view

Ablator samples were mounted on the ends of halfraums; backlighter foils hung ~1.5mm from LEH



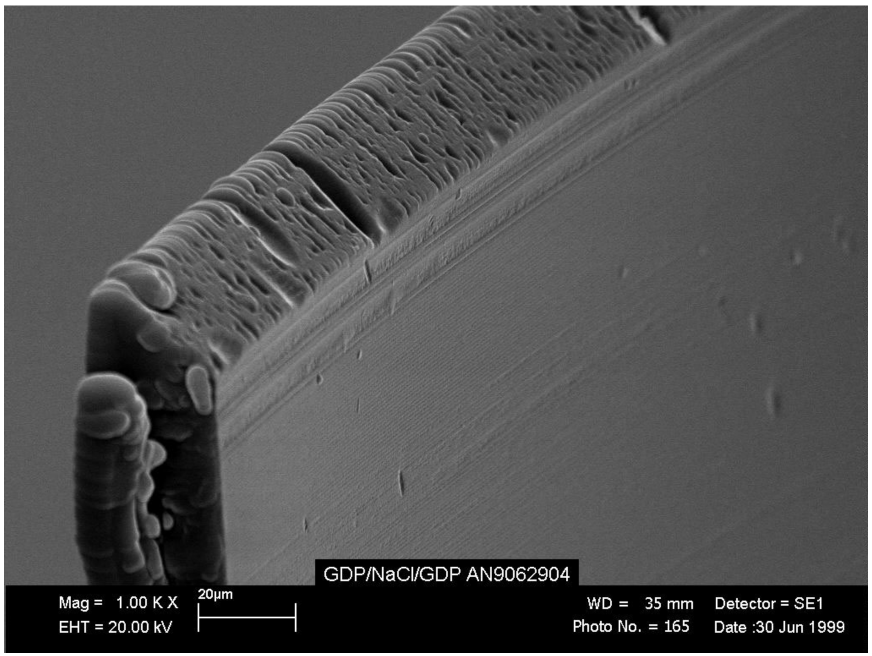


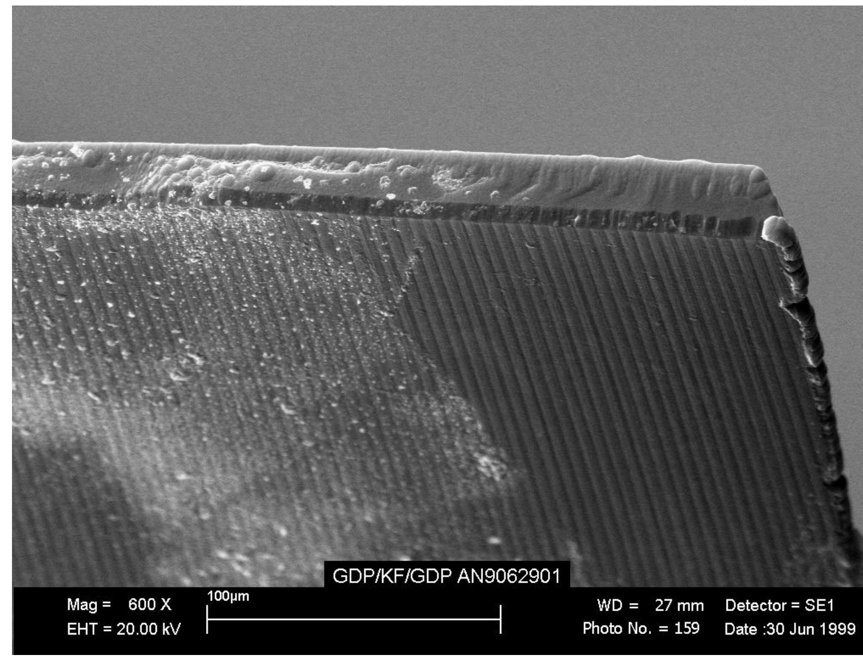
Several views of a target: taken at the LLE metrology lab



SEM images of finished ablator samples

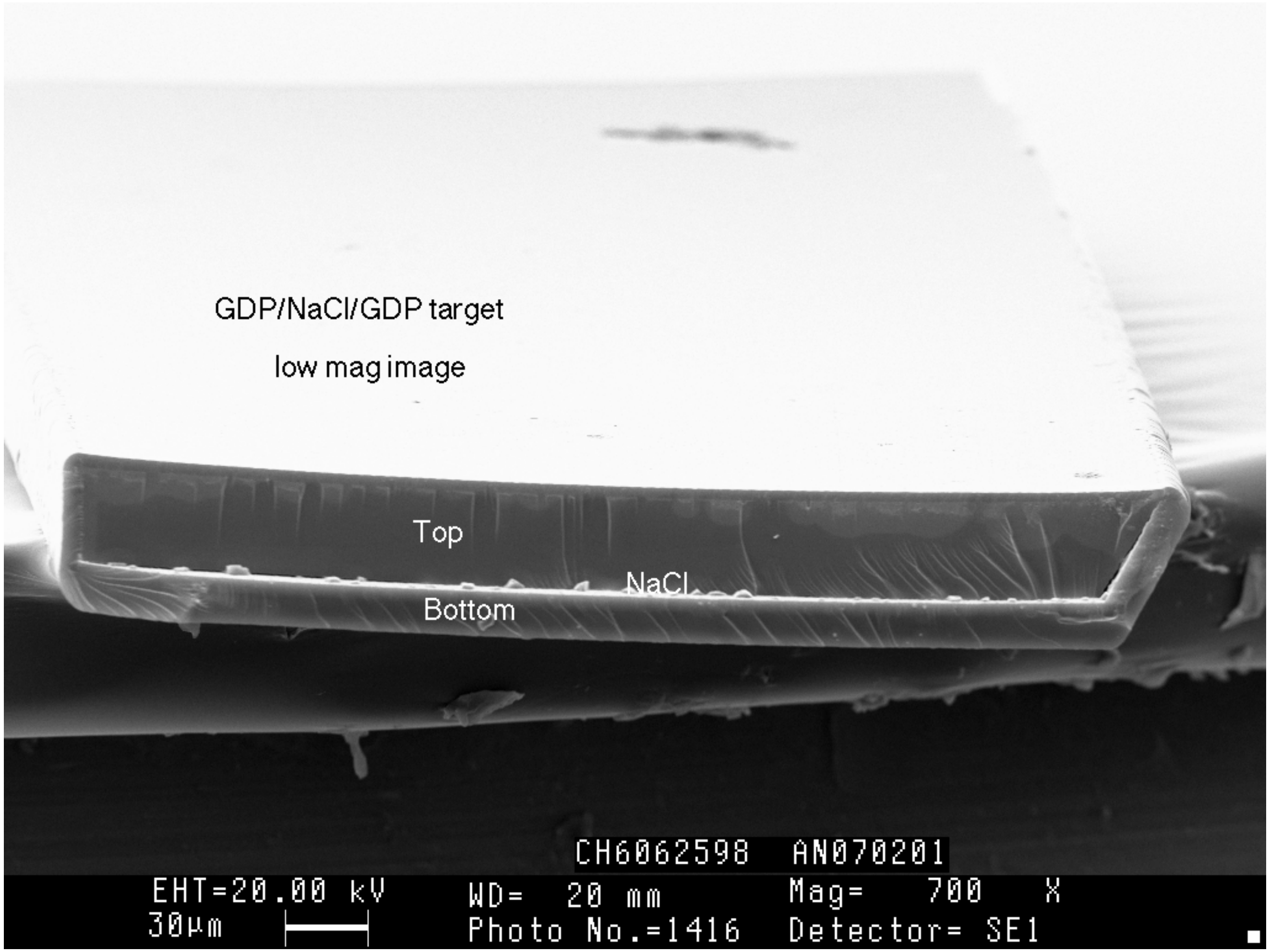
Leakage of KF tracer onto front of plate (right), but no similar problem in samples with NaCl tracer (left); we used the ablator samples with NaCl tracers.





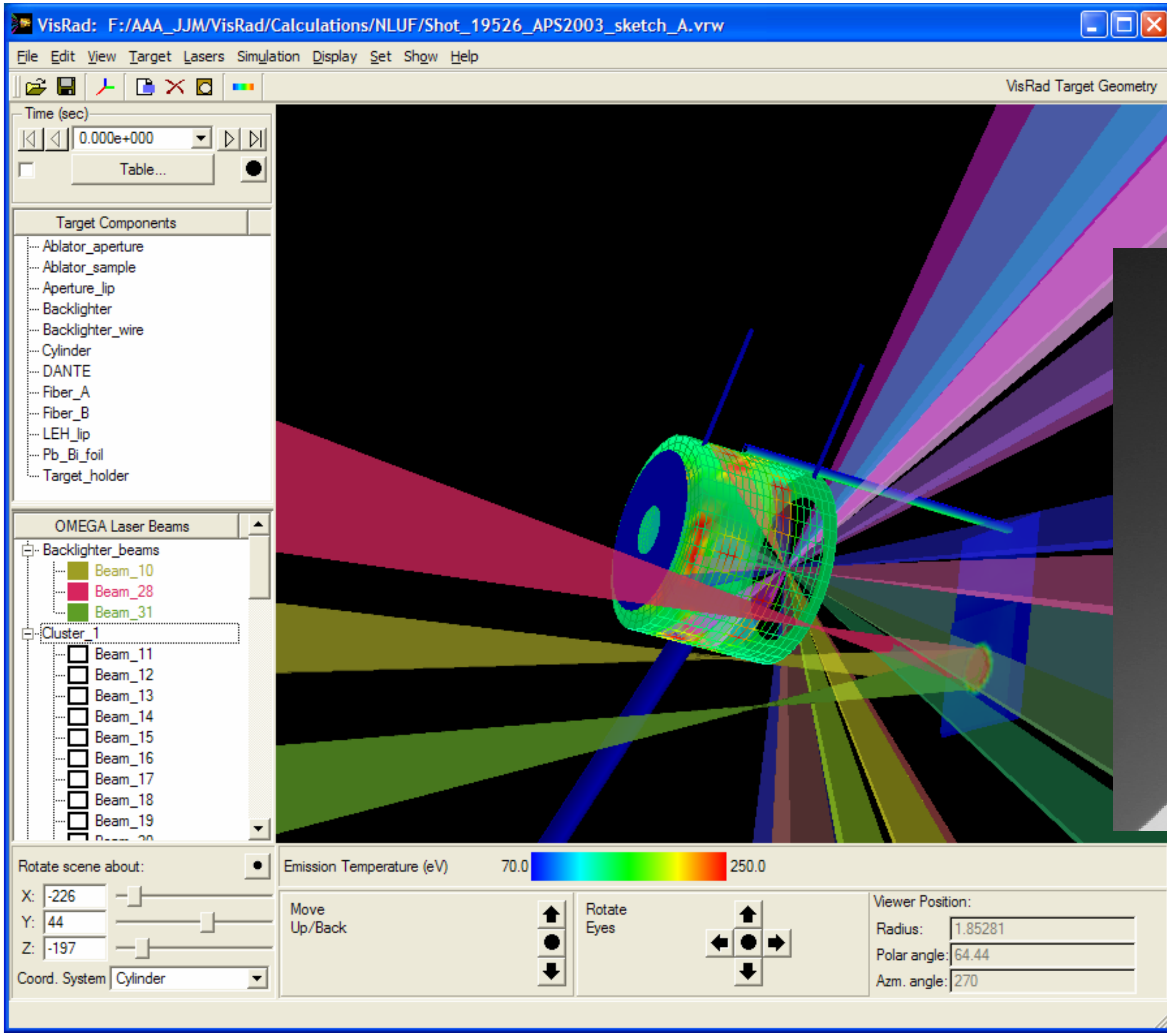
General Atomics produced these witness plates by first making the thicker plastic layer via glow-discharge polymerization (GDP); The salt layer was deposited on this plastic, and then the whole assembly was put back in the GDP chamber and an additional ~5µ of plastic was deposited on top.

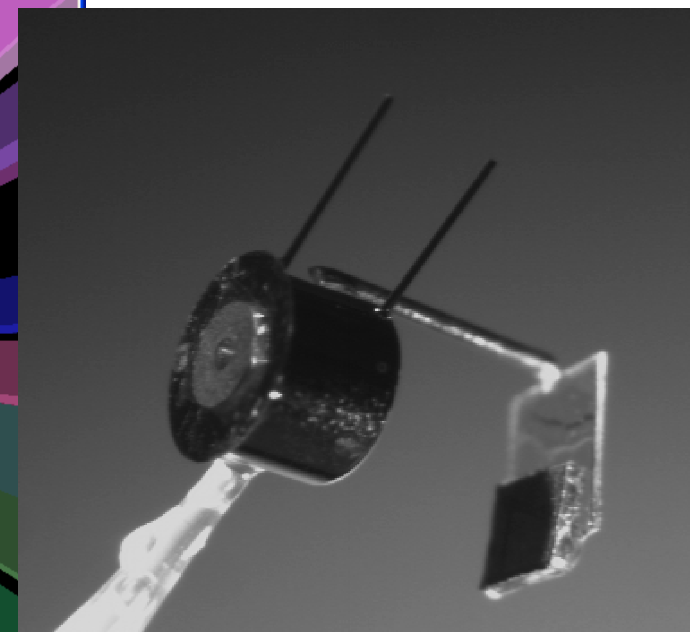
SEM image of cross-section of target



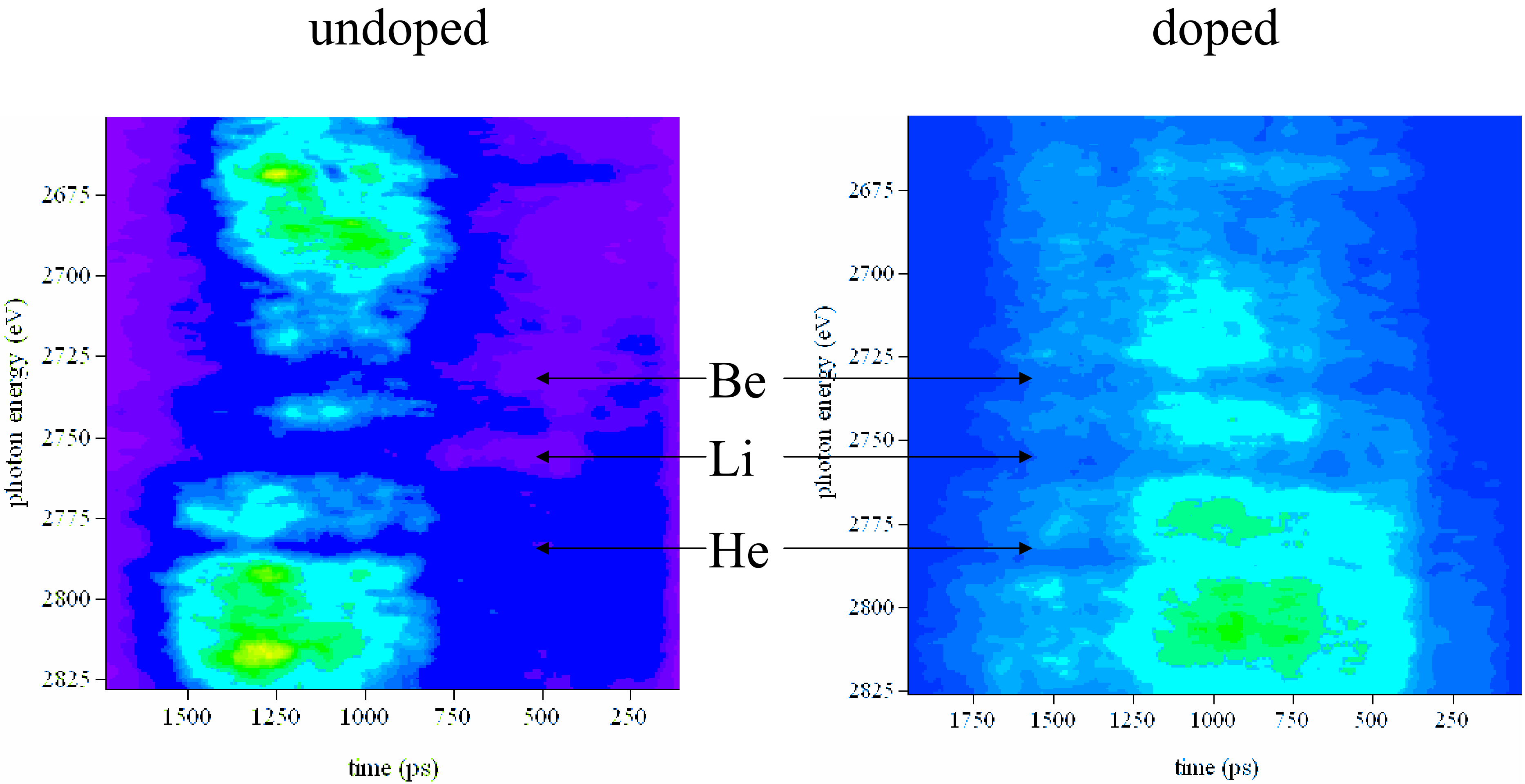
Note the salt crystals…perhaps an artifact of SEM sample preparation, but would weaken the spectral signal if representative of tracer properties in the samples we shot.

So, we've got our assembled targets, and now we're going to shoot the halfraums





The Spectroscopic Data



Digitized section of film from LXS/streak-camera:

Features from three ion stages of chlorine are indicated;

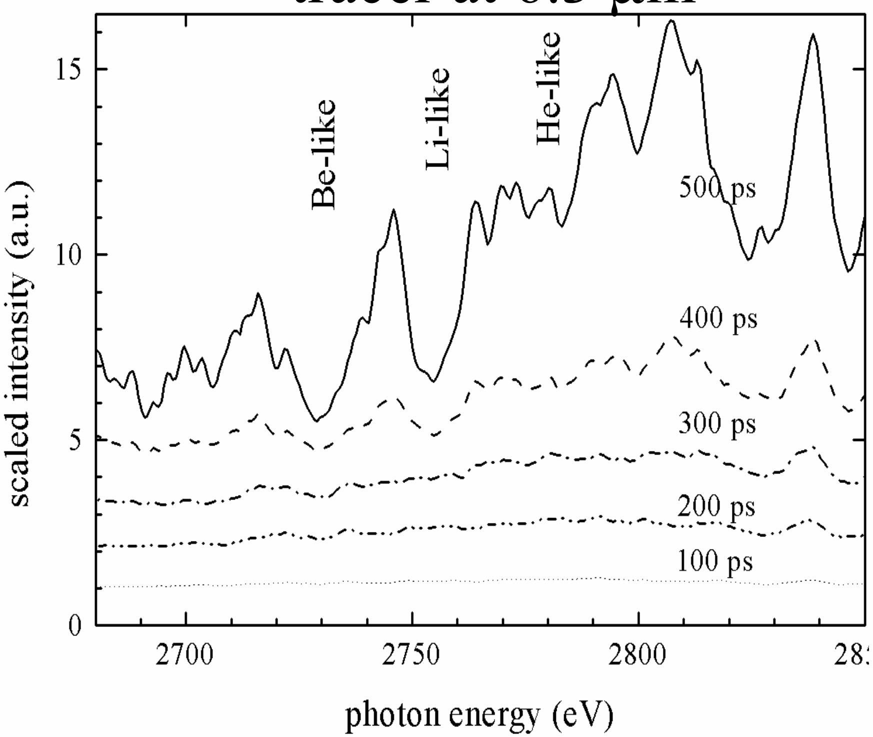
Note the temporal and spectral structure in the backlighter emission; this makes it difficult to bring out the tracer features effectively at all times in this color-scale representation. Note also that the backlighter signal is weak at early times (we staggered the backlighter beams in time).

Data: time-resolved tracer spectra:

lineouts from film shown on previous slide

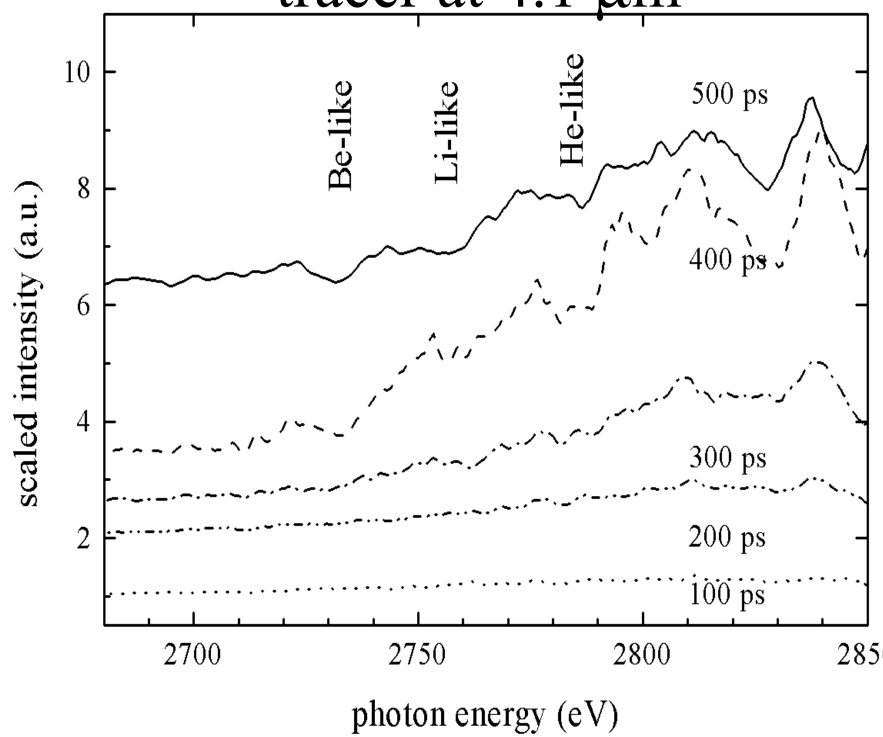
shot 19526: **undoped**

tracer at 6.3 μm



shot 19528: **doped**

tracer at 4.1 μm



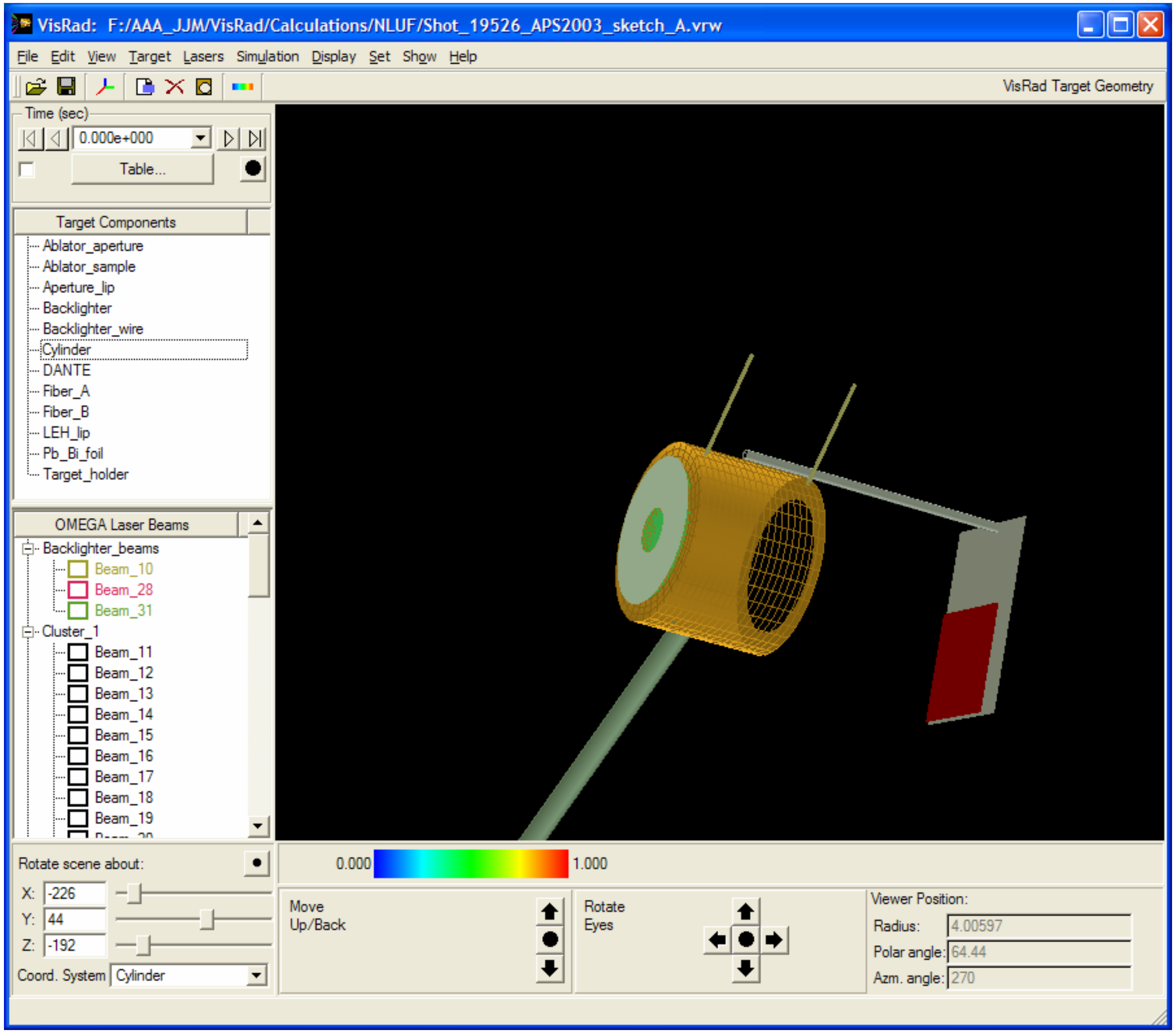
Undoped: Be-like @ 300 ps, Li-like @ 400 ps;

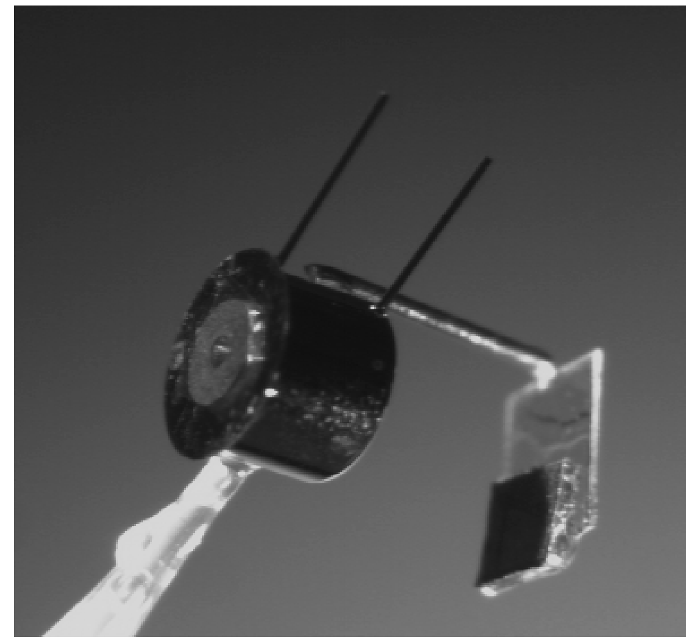
Doped: up to He-like @ 400 ps

Taken at face value, the data seem to indicate the slower Marshak wave propagation in the doped sample, but before we can draw any conclusions…

Modeling

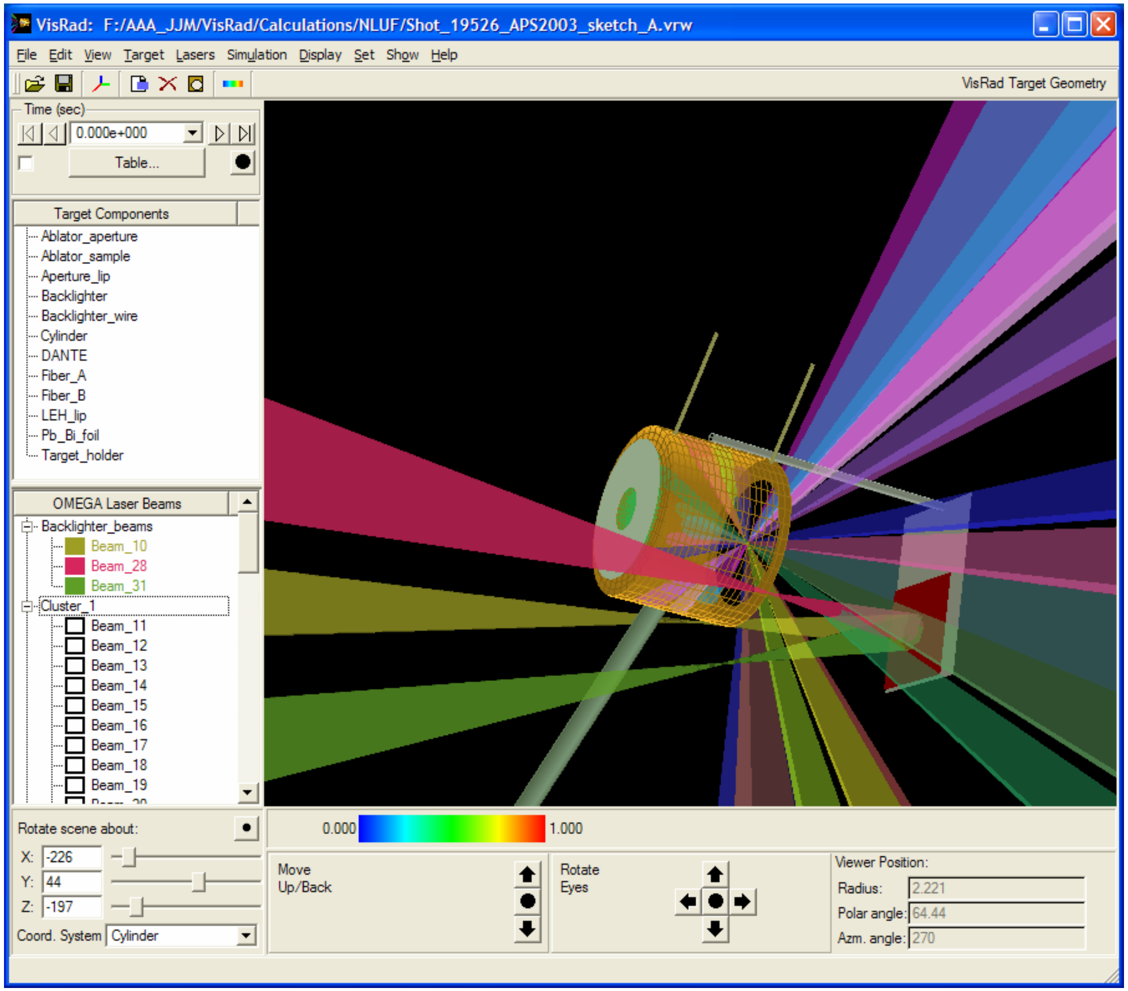
Set up a halfraum target model in the *VisRad* view factor code

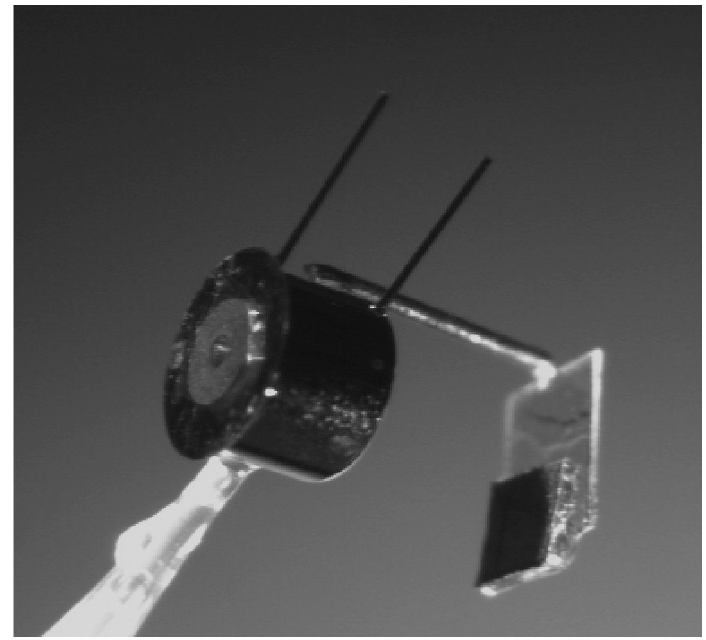




Specify material properties (albedos, laser reflectivities)

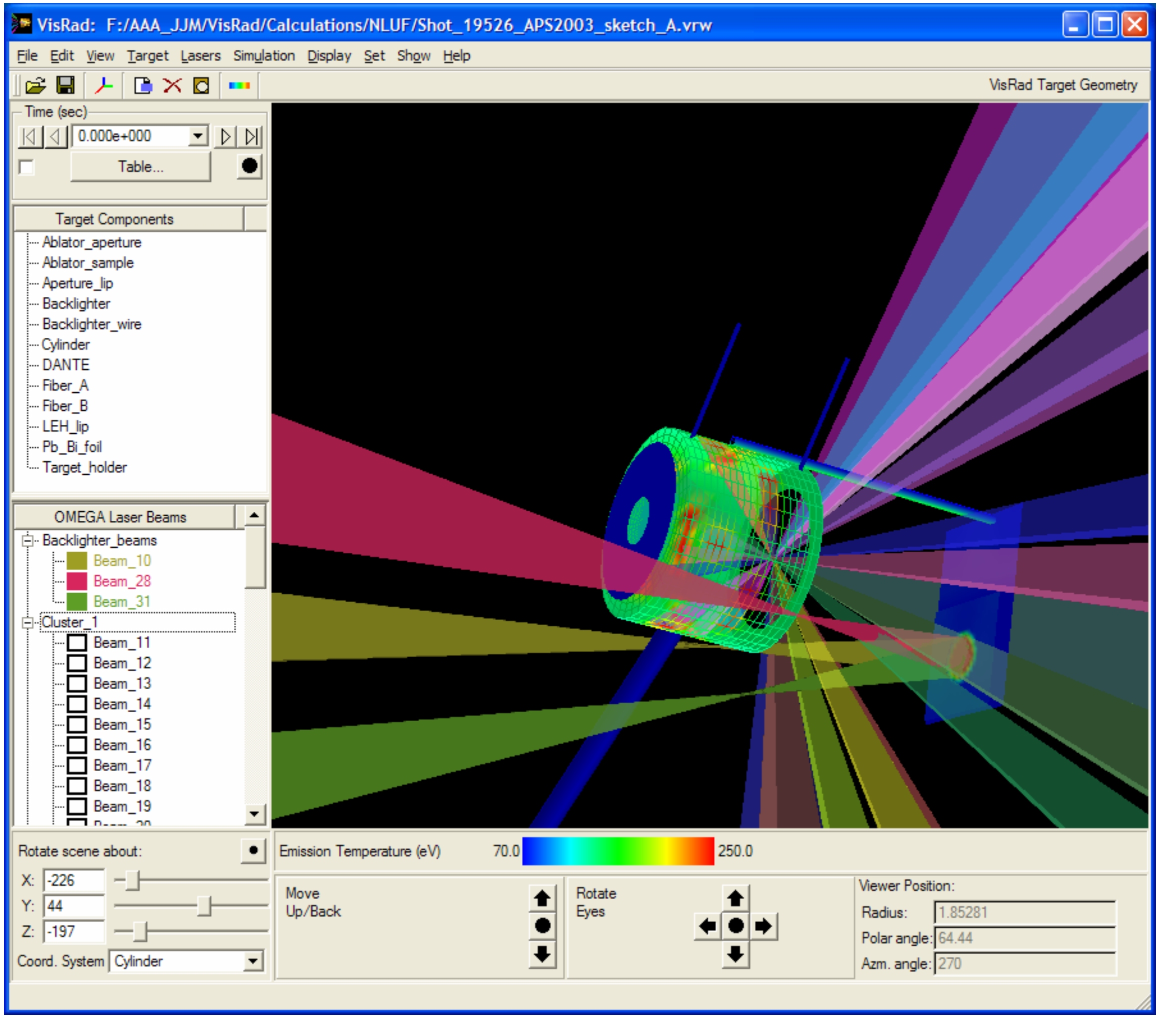
Put actual beam powers onto target (backlighter too)

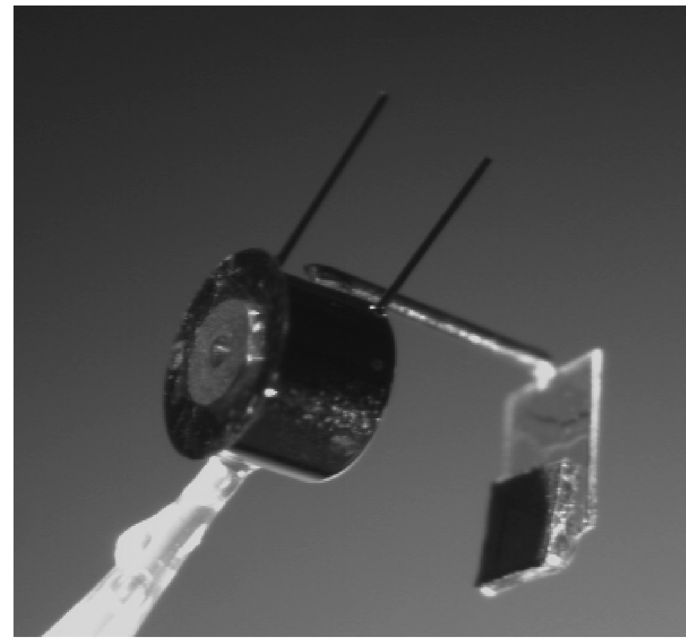




A series of time-independent calculations, with beam powers, albedos, XCEs varying at each time step

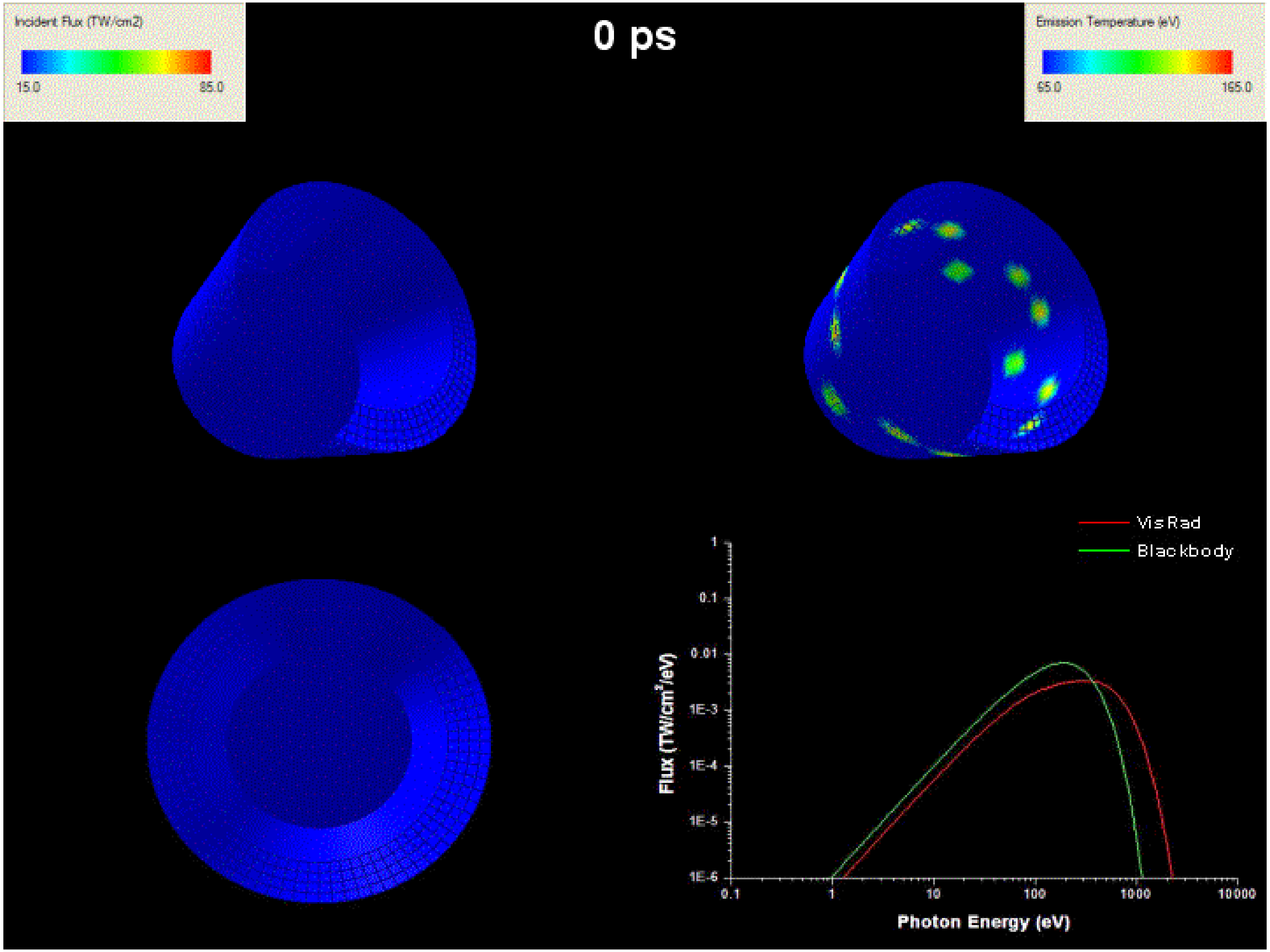
Calculate radiation field and material properties at every surface





Emission temperature shown here (note laser hot spots), but also calculate incident flux on ablator sample

VisRad simulations

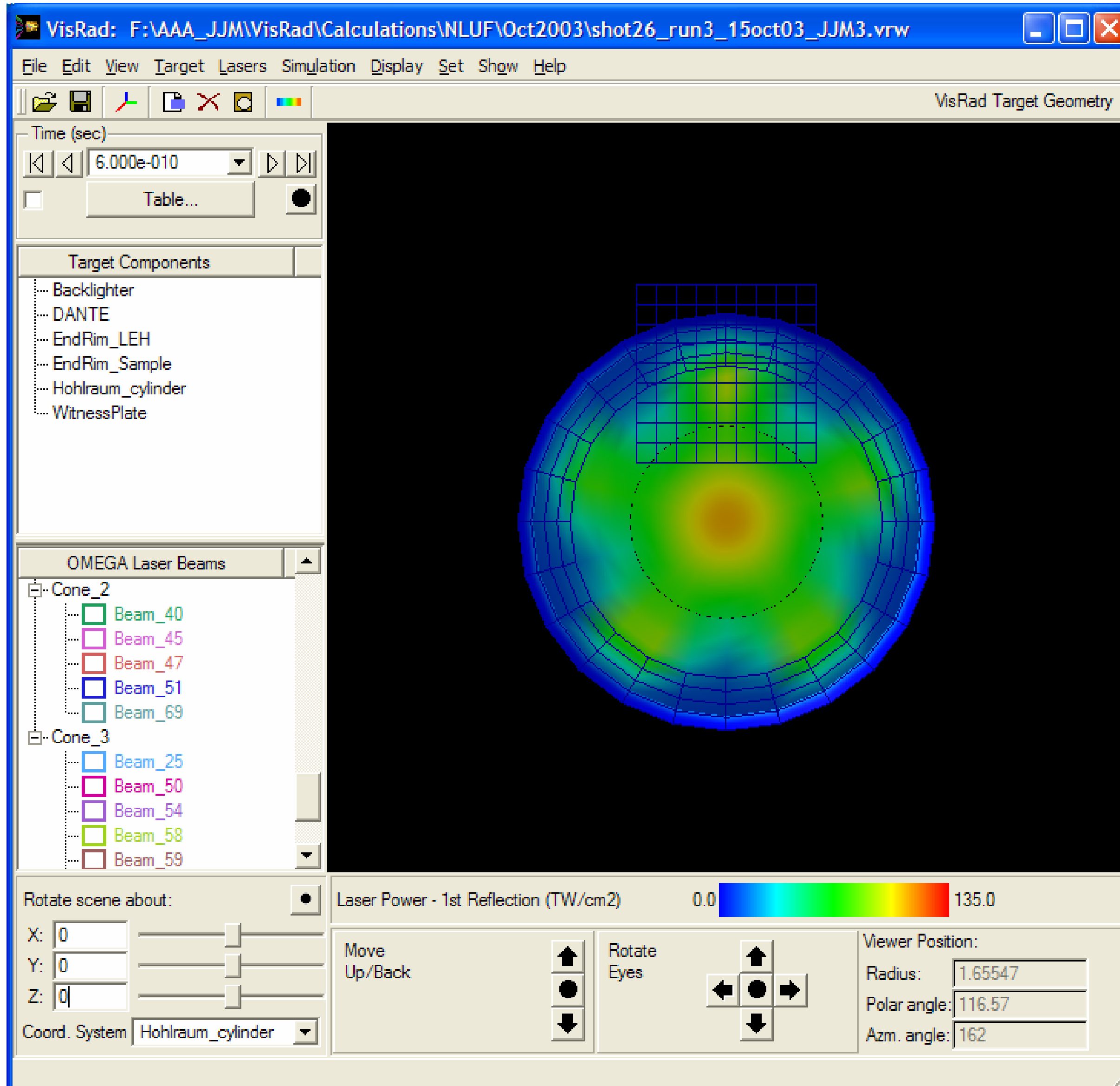


DANTE view on top, incident flux on left; spectrum incident on ablator sample in lower right

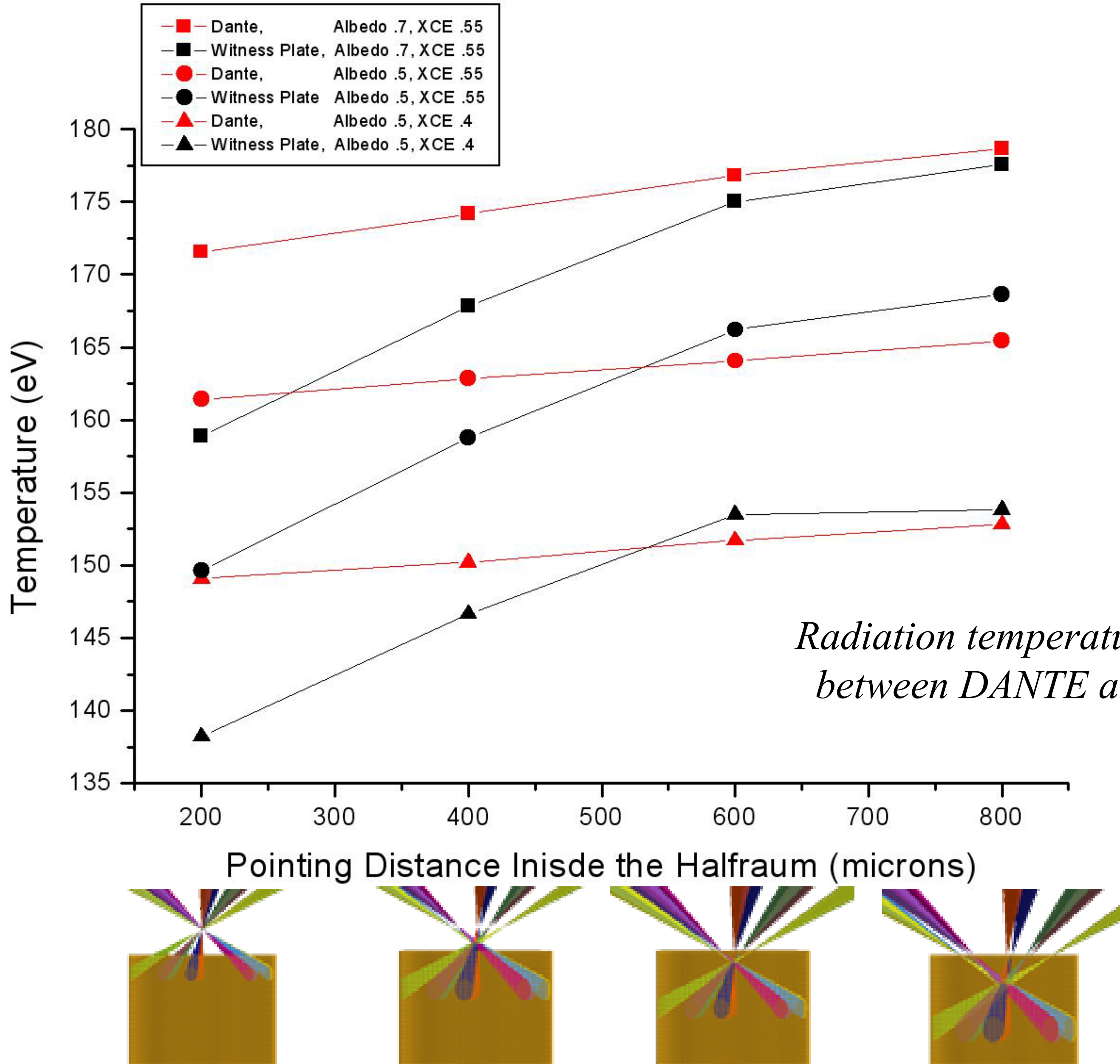
View-factor modeling is useful for addressing various issues related to hohlraum radiation conditions

Glint

Up to 135 TW/cm^2 of reflected laser light on to ablator sample.

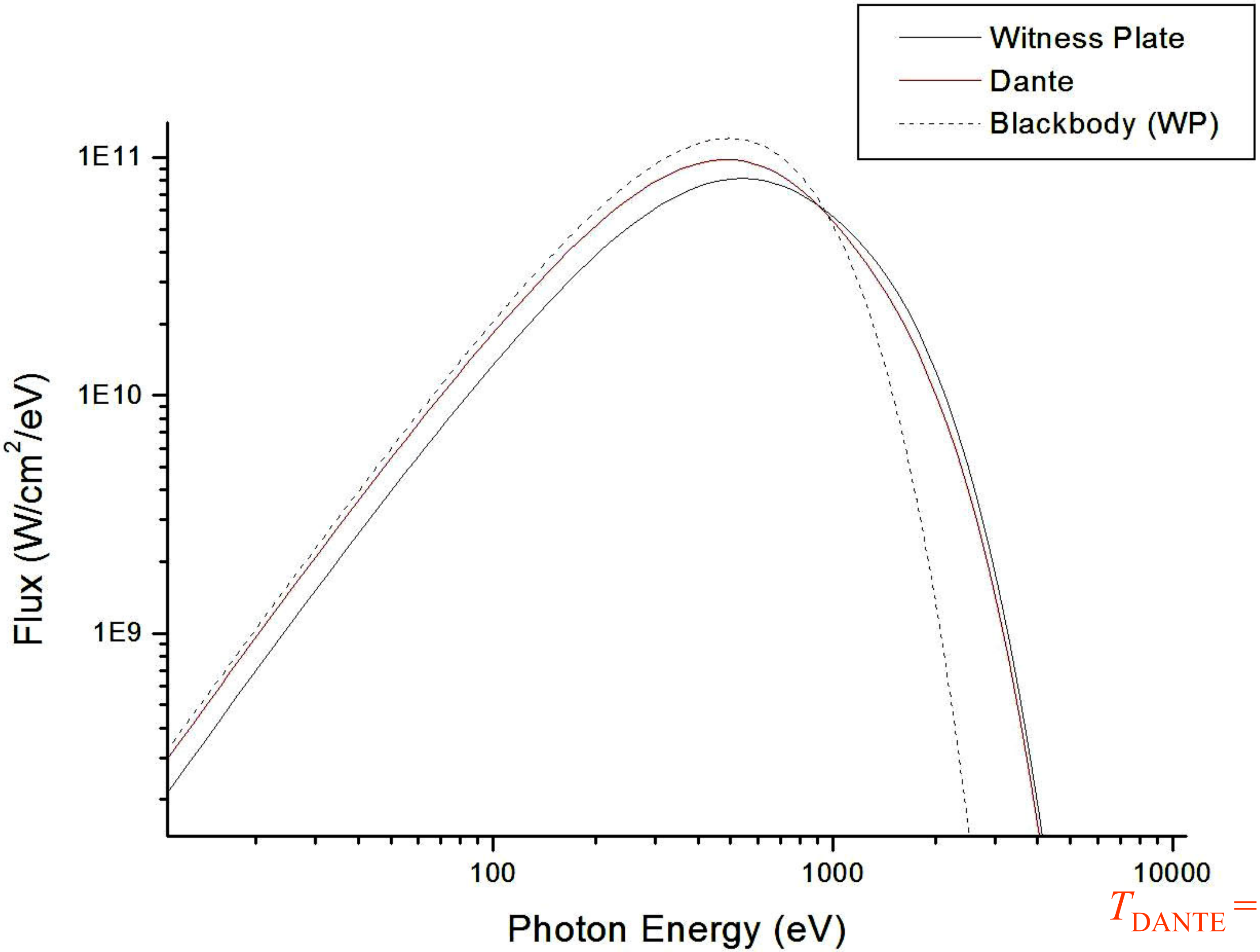


Radiation temperature as a function of beam pointing for three different albedo/XCE combinations, comparing DANTE (red) and WP (black) values.



Radiation temperature differences between DANTE and sample can be significant.

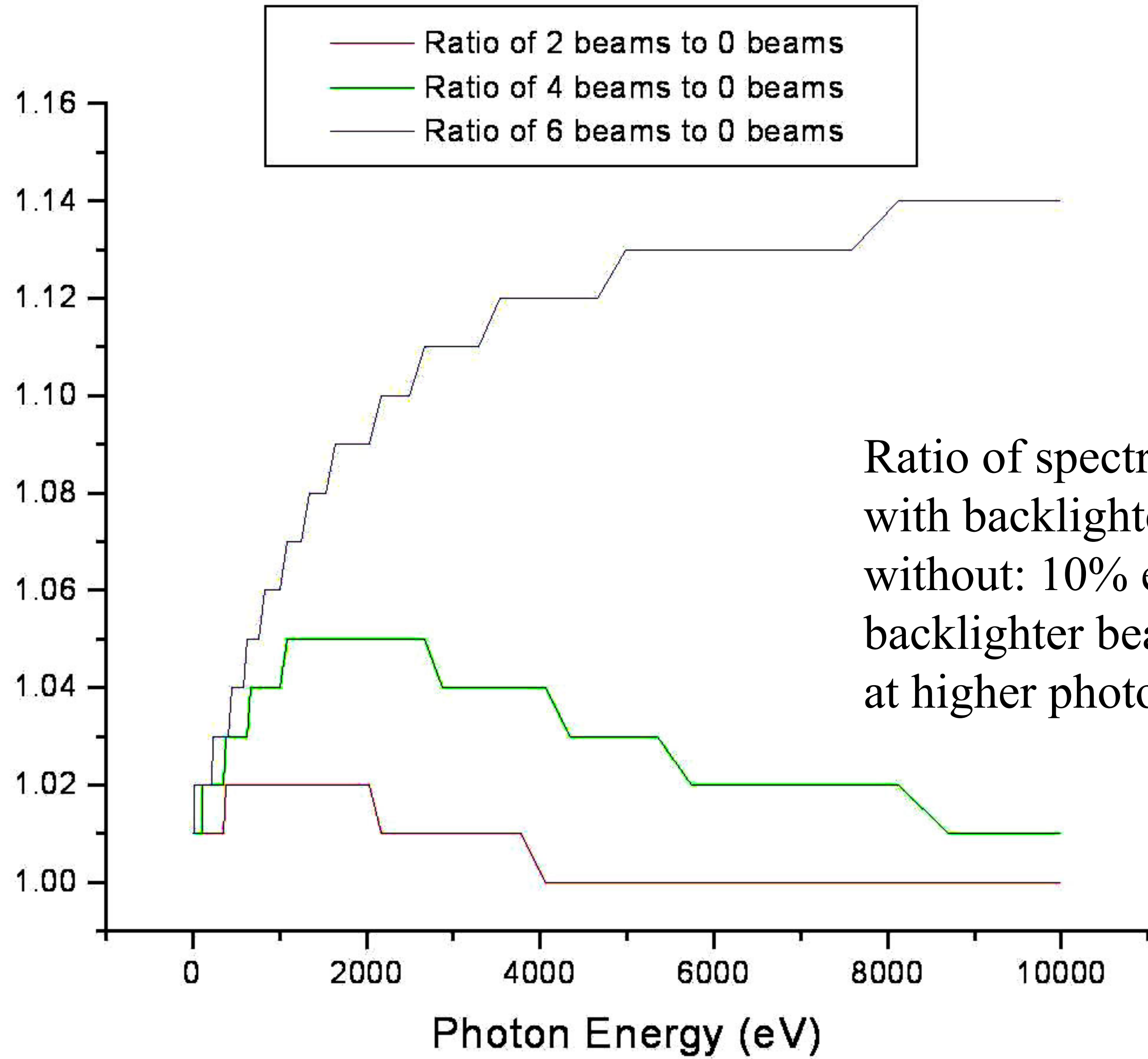
Modeled spectra onto the sample and DANTE-view: even when the radiation temperatures are very similar, the spectral energy distributions are different (from each other and compared to a blackbody).



$T_{DANTE} = 176.7$ eV

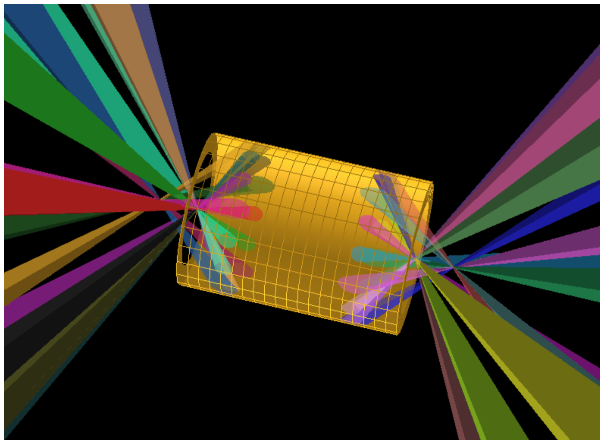
$T_{WP} = 175.0$ eV

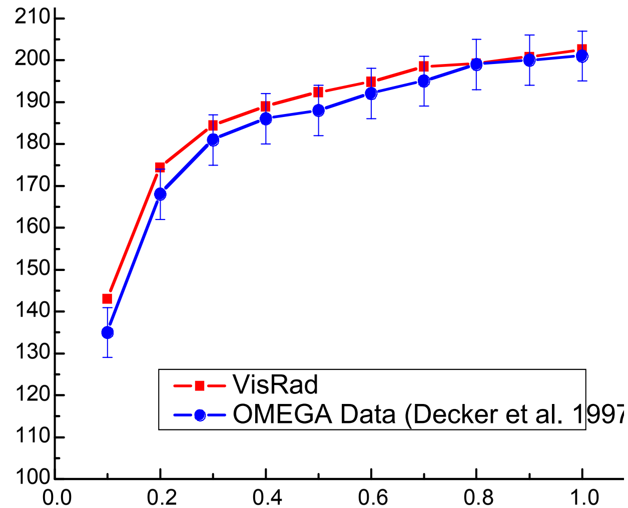
Effect of backlighter on radiation incident on ablator sample

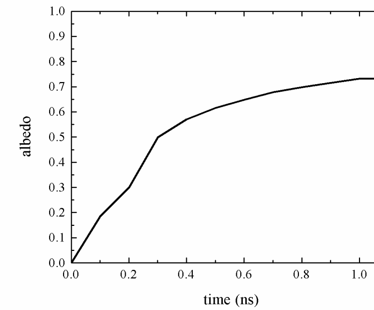


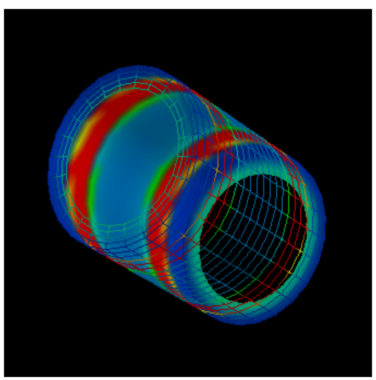
Ratio of spectrum onto ablator with backlighter included to that without: 10% effect with six backlighter beams; bigger effect at higher photon energies.

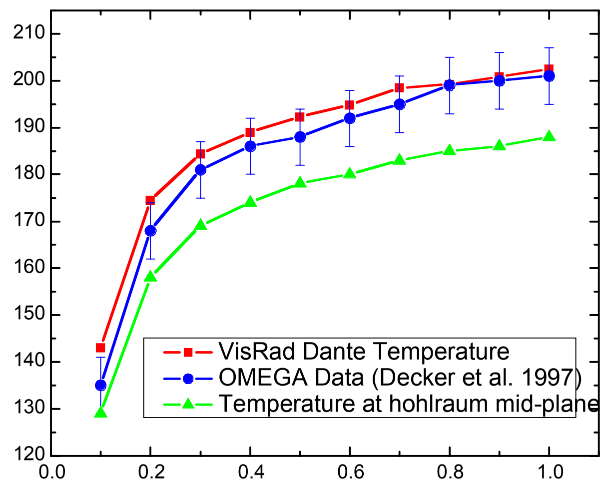
VisRad successfully modeled OMEGA hohlraum shots: DANTE data (Decker et al., PRL, 1997)

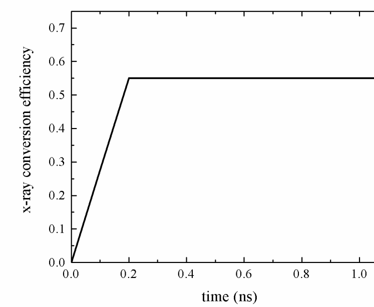






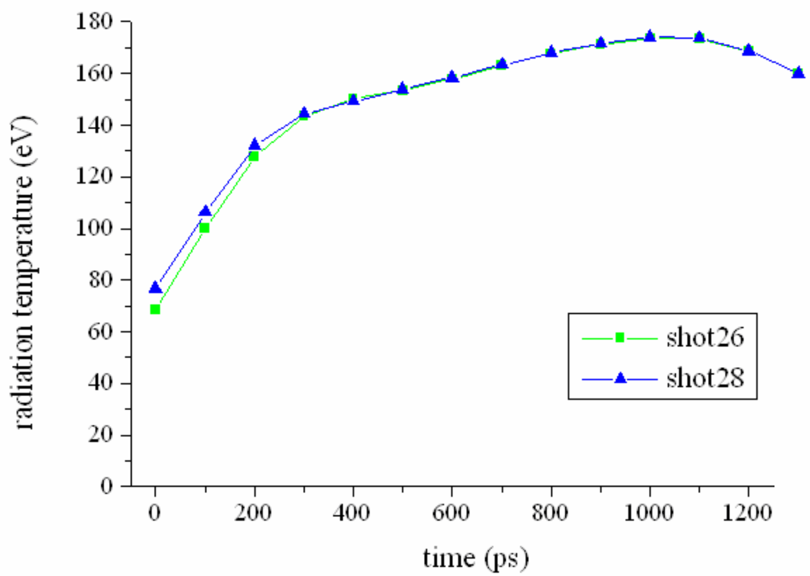






Assumed albedo (top) and XCE (bottom) vs. time

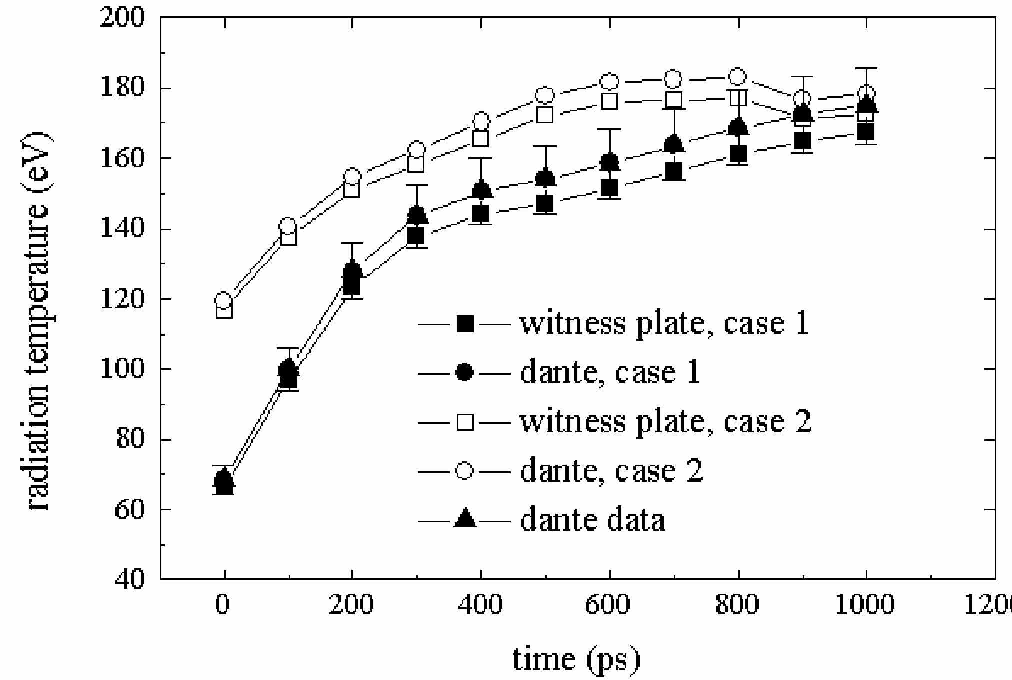
T_R at the midplane (green triangles) is different than wall re-emission seen by DANTE



DANTE data was almost identical for our two shots (left)

But it is low (filled triangles, right) compared to our modeling (open symbols, right)

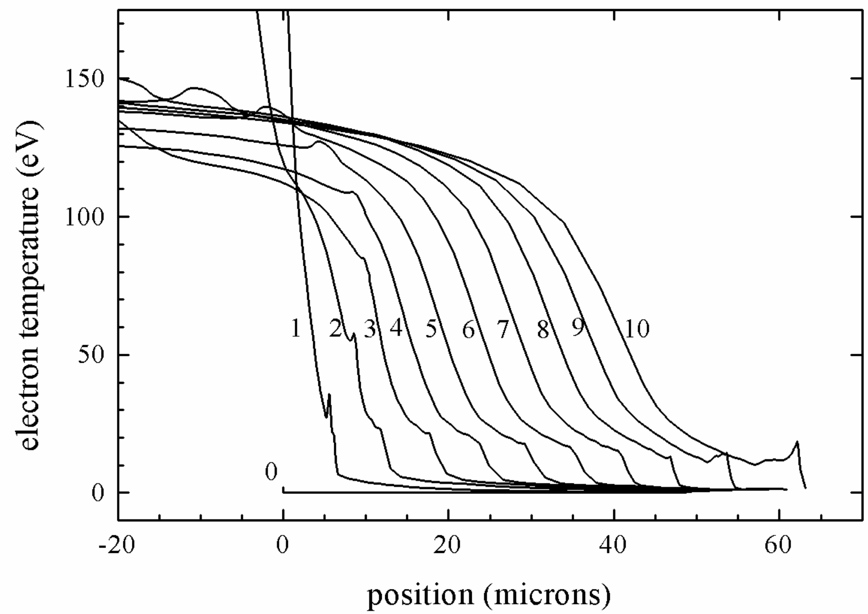
Note also: different T_R on ablator sample (squares) and seen by DANTE (circles)



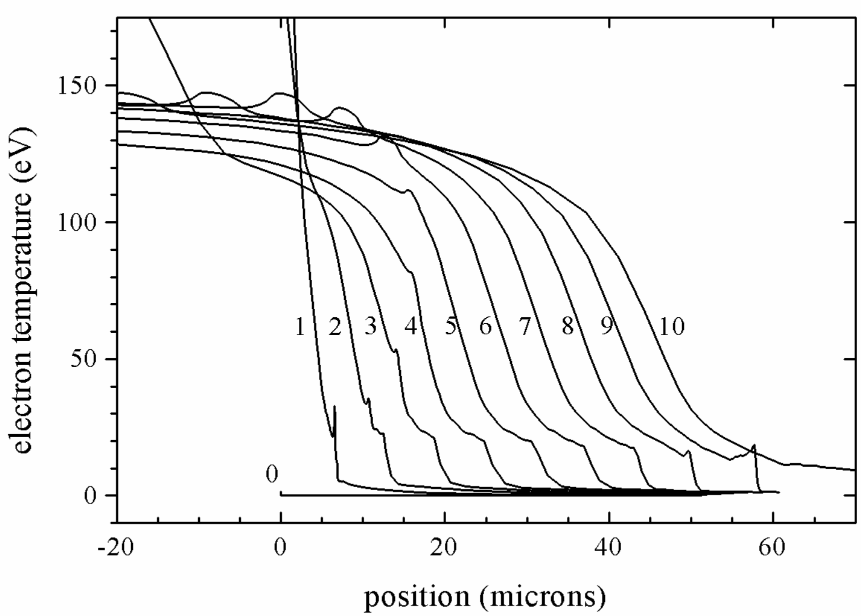
We are in the process of correcting for the reduced DANTE sensitivity at the time of our shots

HELIOS hydro modeling, using incident flux from view-factor modeling

Times indicated in units of 100 ps



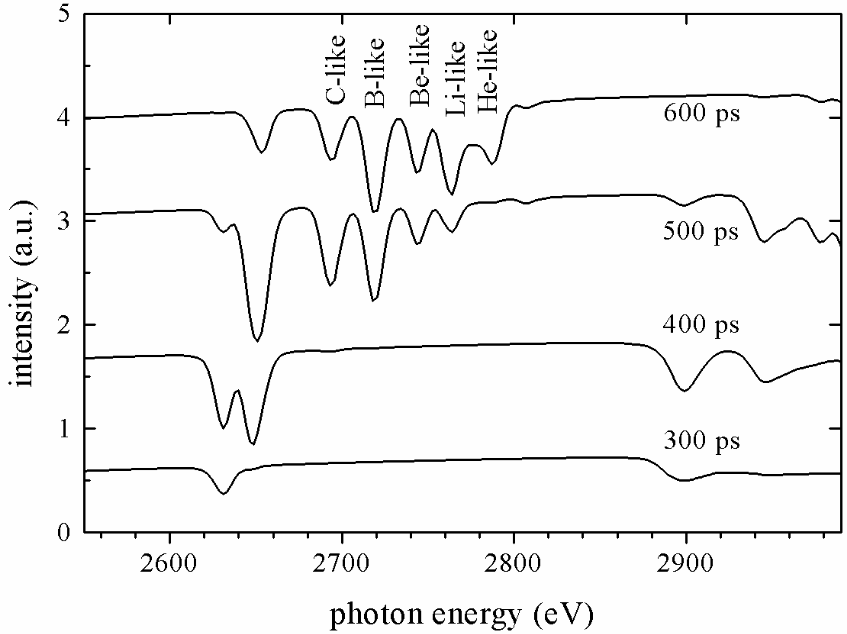
Undoped: faster hydro evolution

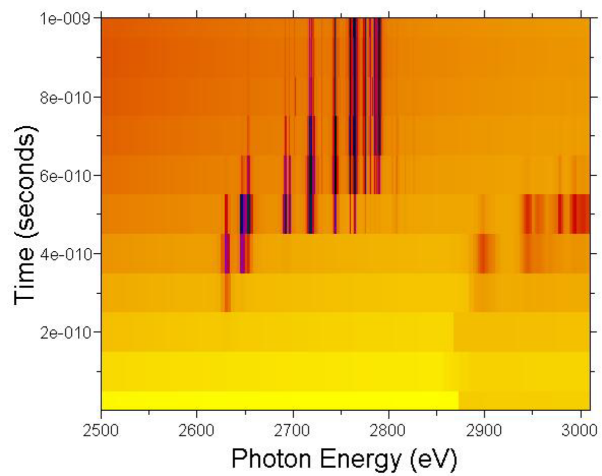


Doped: slower hydro evolution

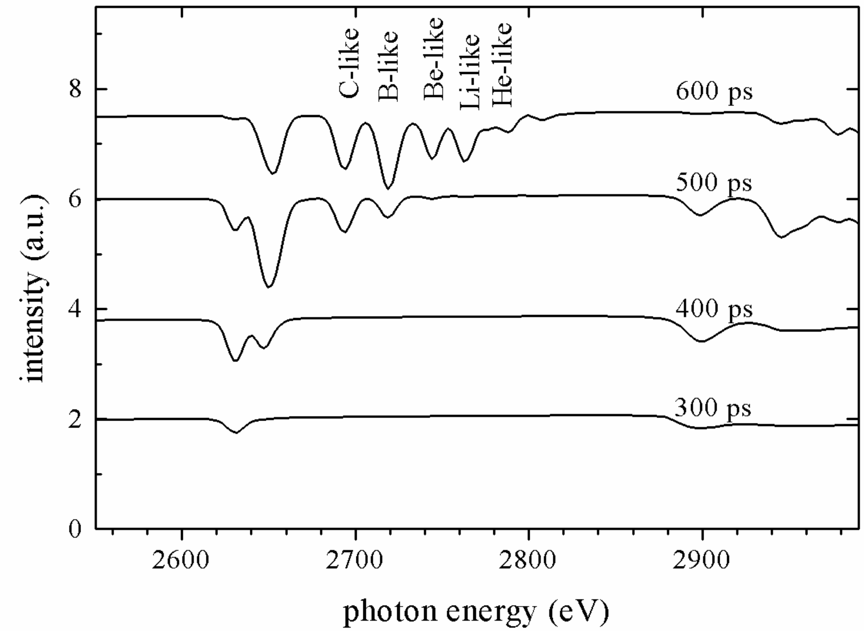
The hydro output is then post-processed with *Spect3d*: statistical equilibrium and spectral synthesis

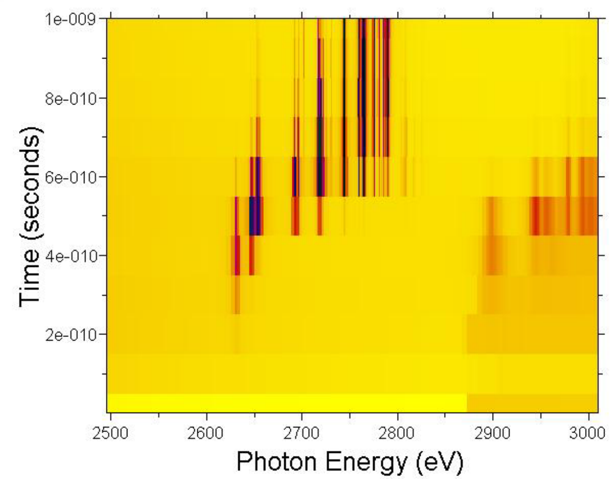
undoped





doped

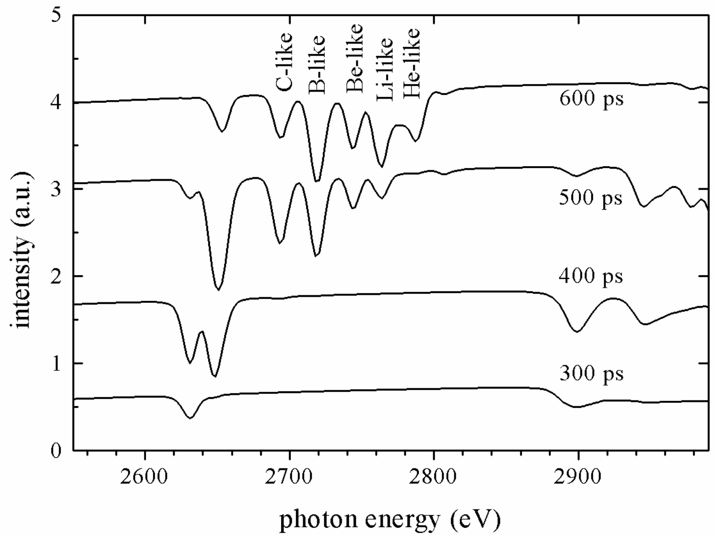




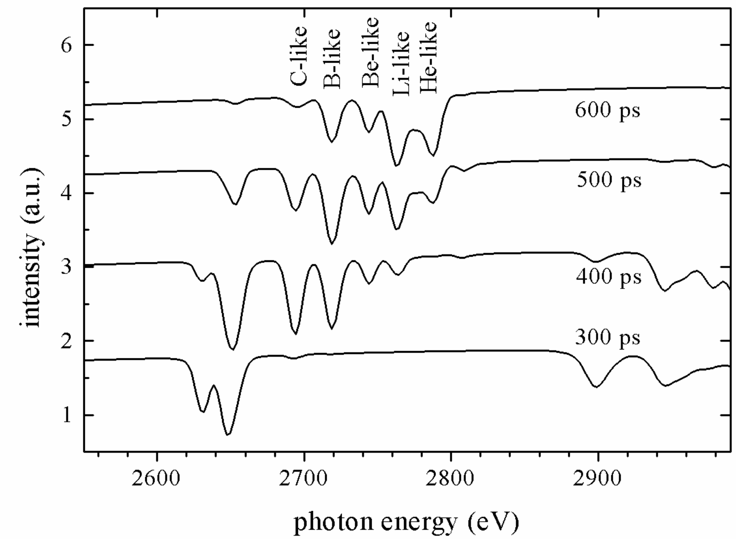
Tracer signals turn on earlier in the undoped sample

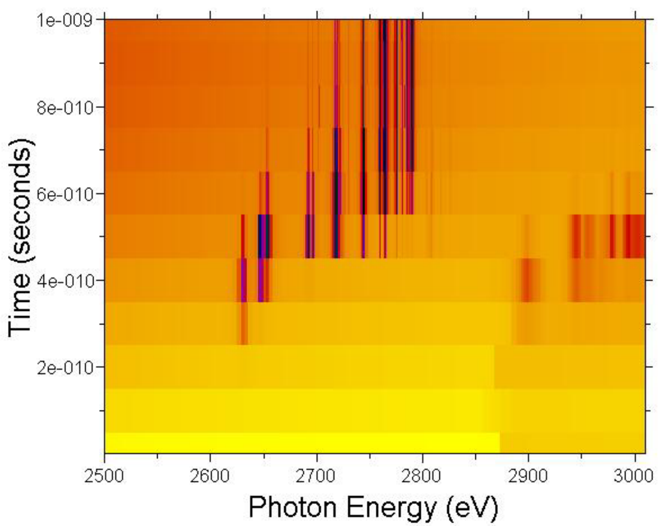
(as we saw before; when tracers in two samples are at the same depth)

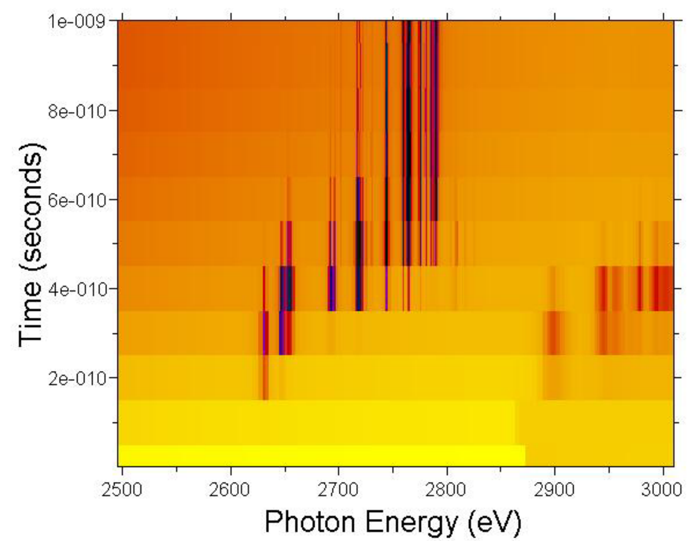
Undoped: tracer at 6.3 μm



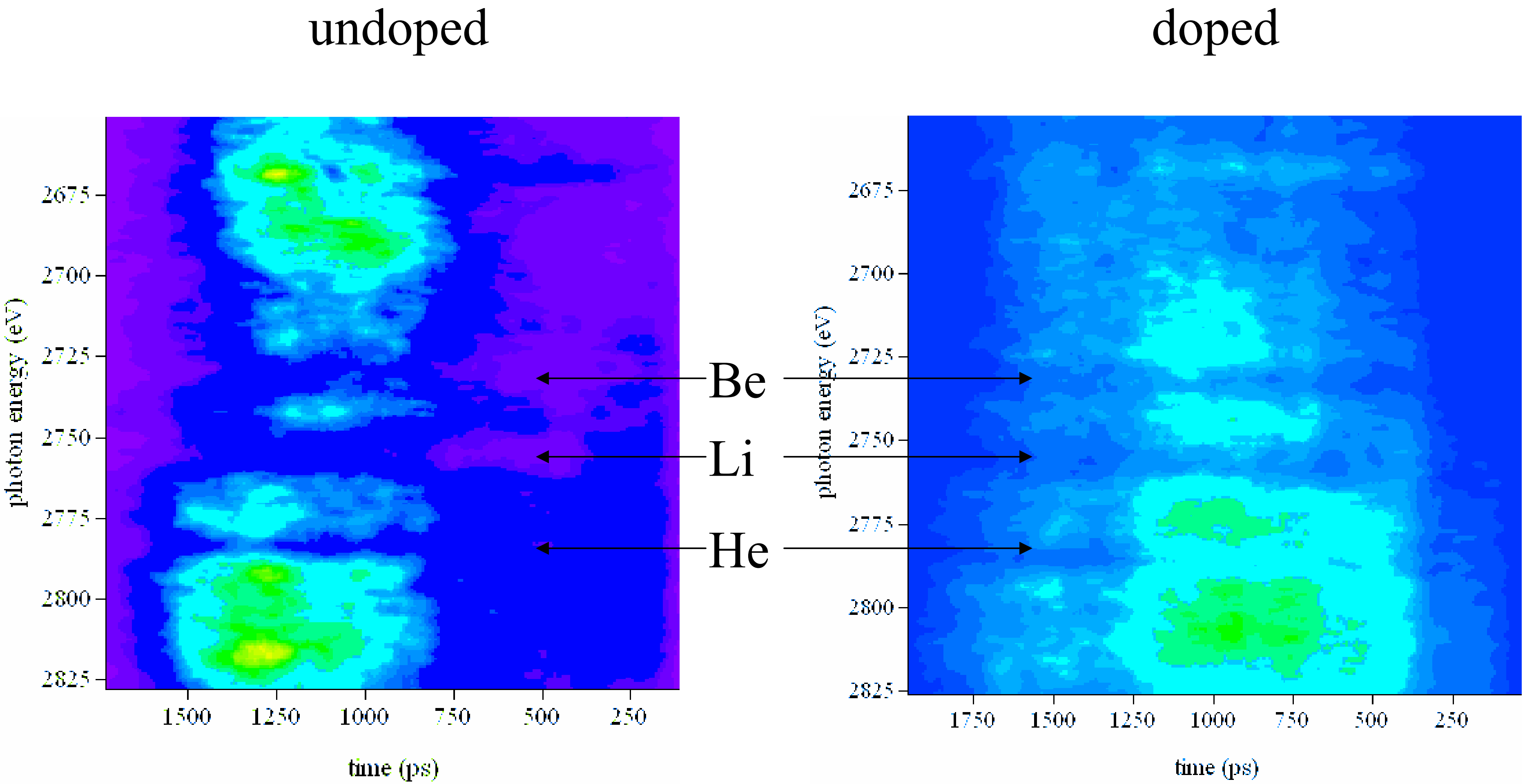
Doped: tracer at 4.1 μm







Shallower tracer in doped samples actually causes *earlier* turn on in this specific doped target

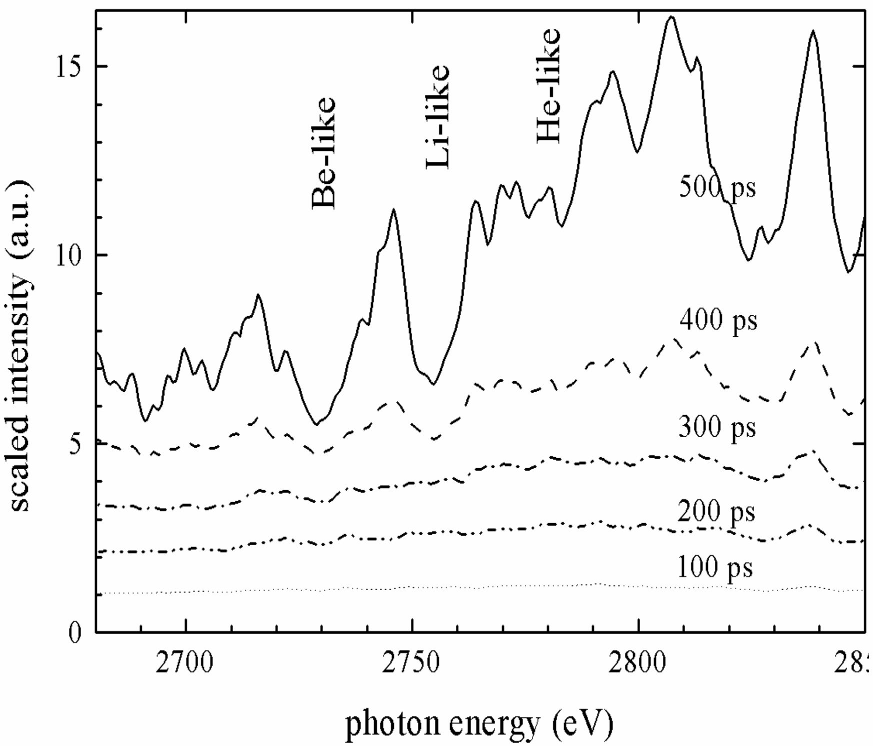


Back to the Data…

Data: time-resolved tracer spectra

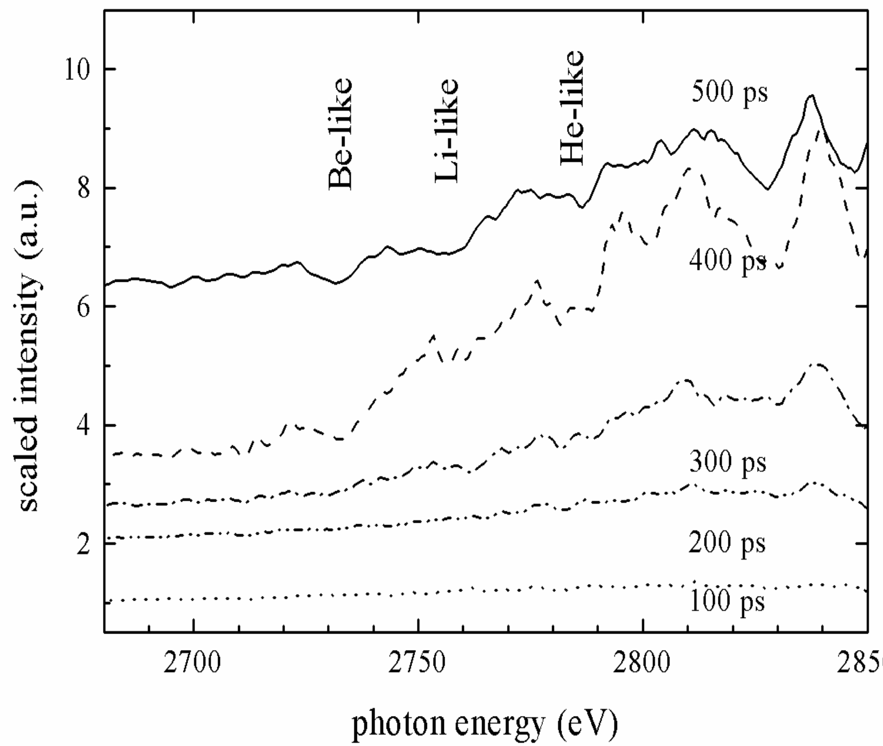
shot 19526: **undoped**

tracer at 6.3 μm

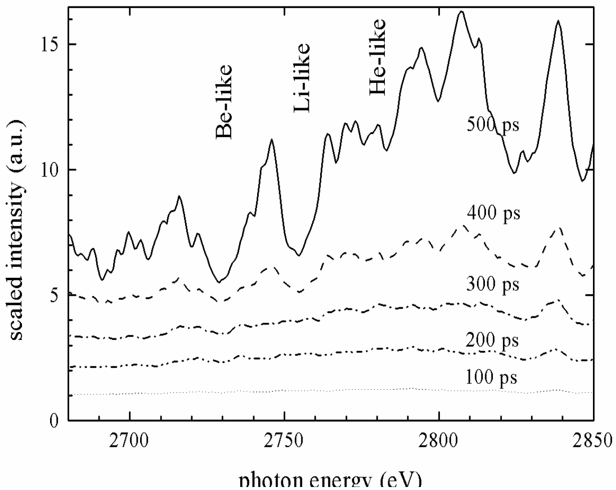


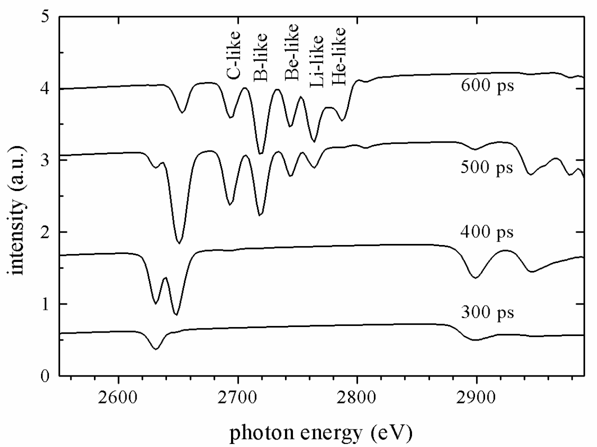
shot 19528: **doped**

tracer at 4.1 μm



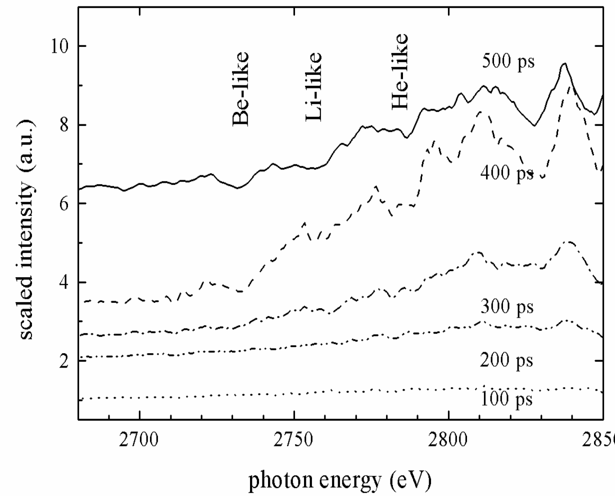
undoped

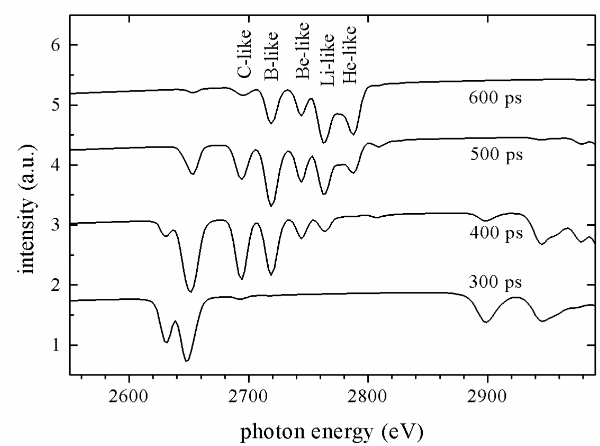




Turn-on of Be-like: earlier in data than model (300 vs 500 ps)

doped





Turn-on time in better agreement: 400 ps

Taking the turn-on times from the data, and the tracer depths:

The Marshak wave propagation:

2.5 mg cm^{-2} ns^{-1} for the undoped ablator

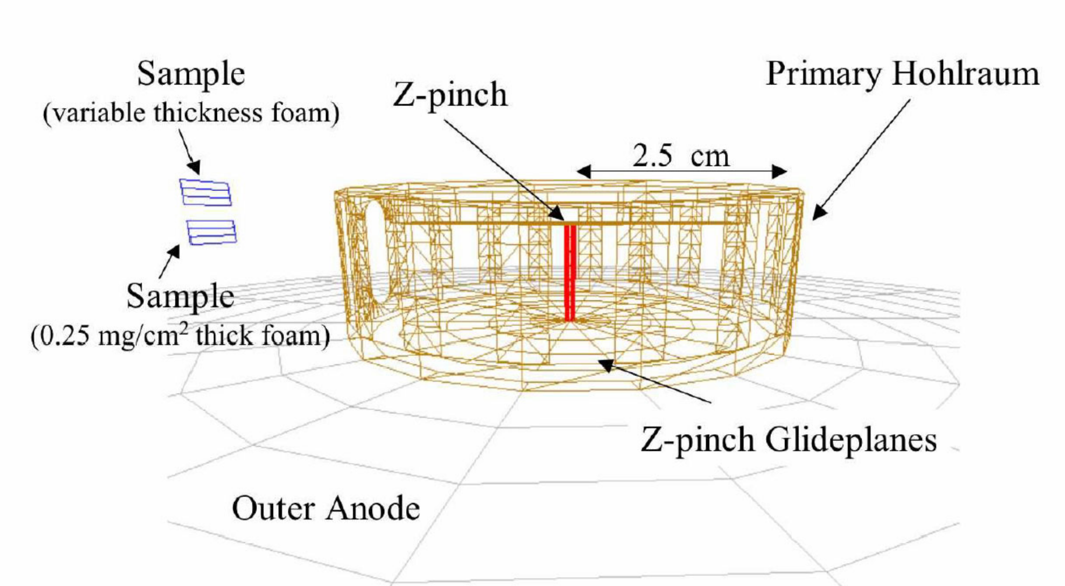
1.3 mg cm^{-2} ns^{-1} for the doped ablator

The dopant has a significant effect on the rad hydro

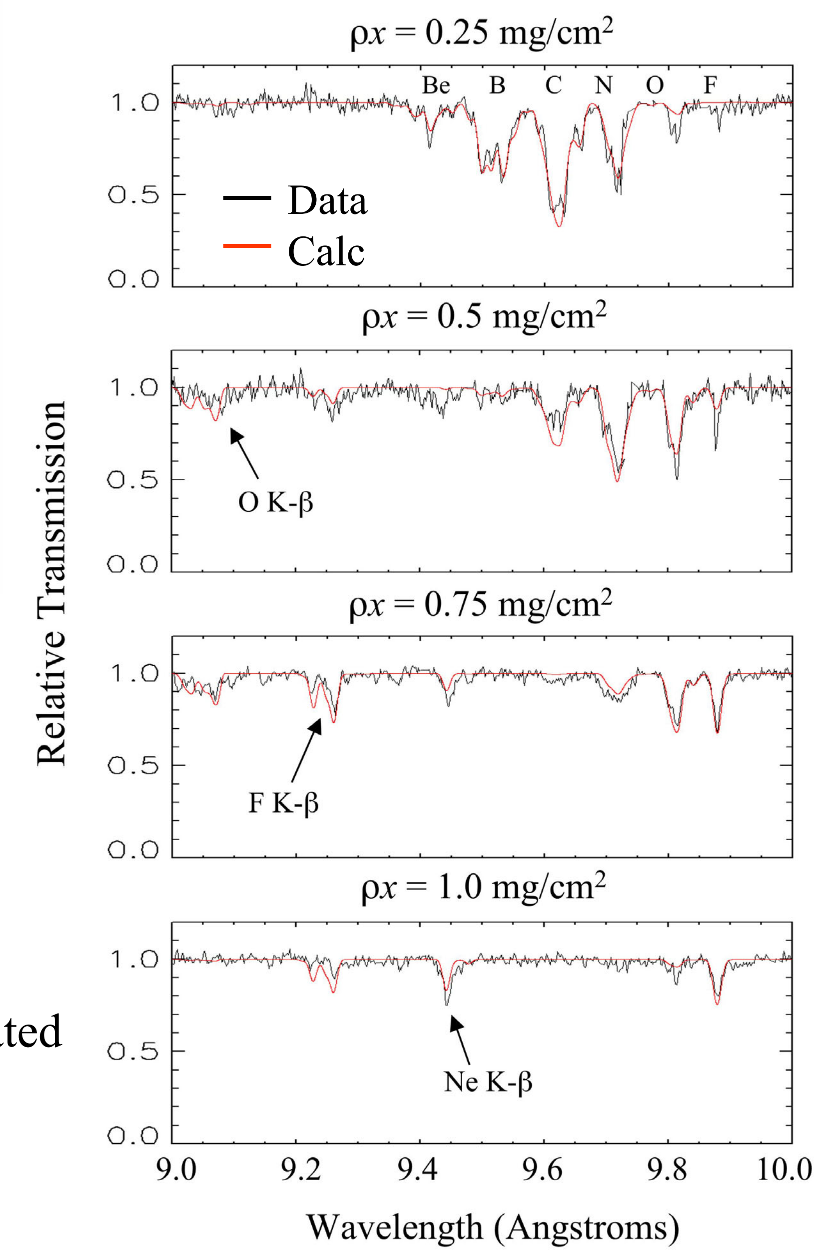
But, early turn-on time in undoped sample, relatively weak signal, inability to measure ion stages in the Cl tracer lower than Be-like…

Similar tracer spectral diagnostics have been shown to be quite useful on Z-machine experiments involving foams

And the *Spect3d* spectral modeling has shown very good agreement with those data



Mg absorption spectra



- 5 mg/cc CH_2 foam samples
- Z-pinch heats and backlights samples
- 3 samples on 3 lines-of-sight
- MgF_2 tracers placed at 4 different depths
- Mg absorption spectrum recorded on time-integrated convex crystal spectrometer (R ~ 800)

Sandia National Laboratories

Courtesy Greg Rochau

CONCLUSIONS

- Backlit tracer absorption spectroscopy is hard to accomplish cleanly in a hohlraum environment

- But, the tracer spectral data seem to indicate qualitatively the expected effect of the ablator dopant

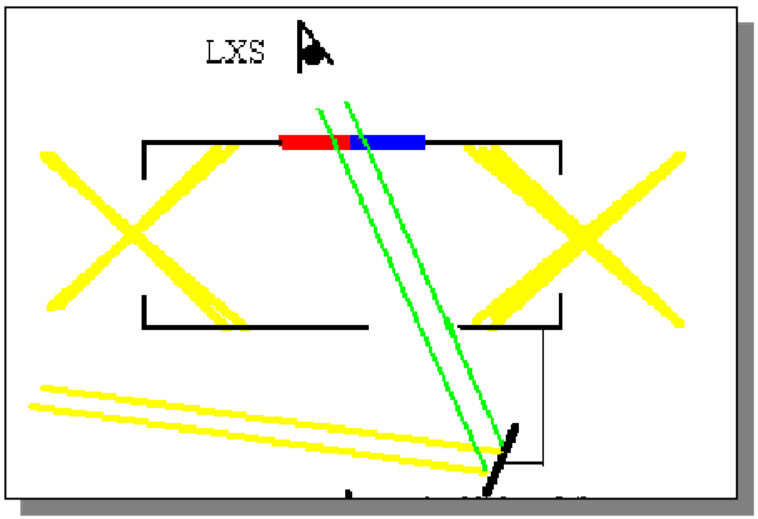
- Modeling the hohlraum environment is important

- Future experiments might emply chlorinated plastic rather than salt as a tracer and a more evenly powered backlighter

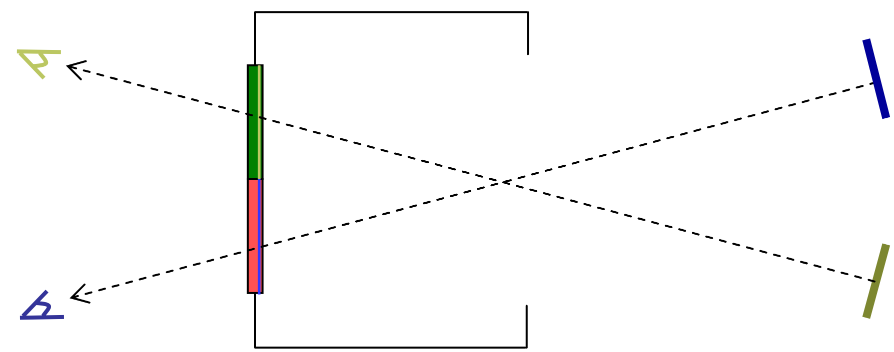
Supplemental Slides

Our original plan was to make side-by-side measurements on doped and undoped ablators mounted on the same hohlraum

Due to the complexity of these targets, we were not able to get good data



We mounted them first on the outside of hohlraums, near the midplane; one spectrometer with two separate crystals was used (K tracer in one side, Cl in the other)

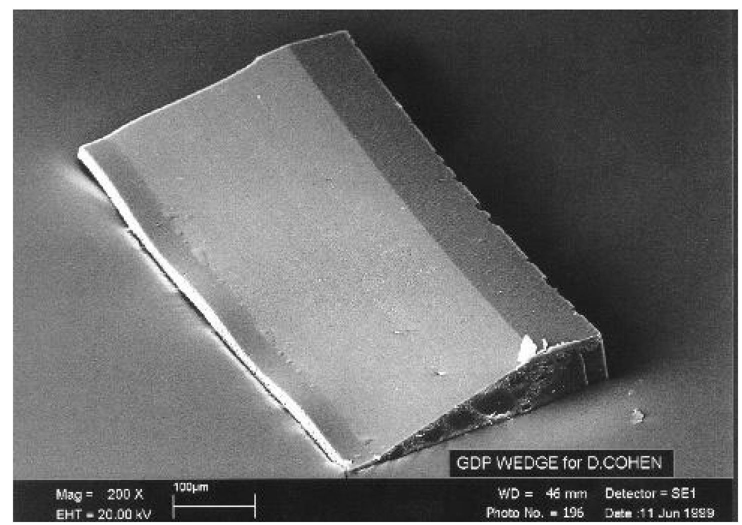


A halfraum with two samples (two tracers, two backlighters) and two spectrometers

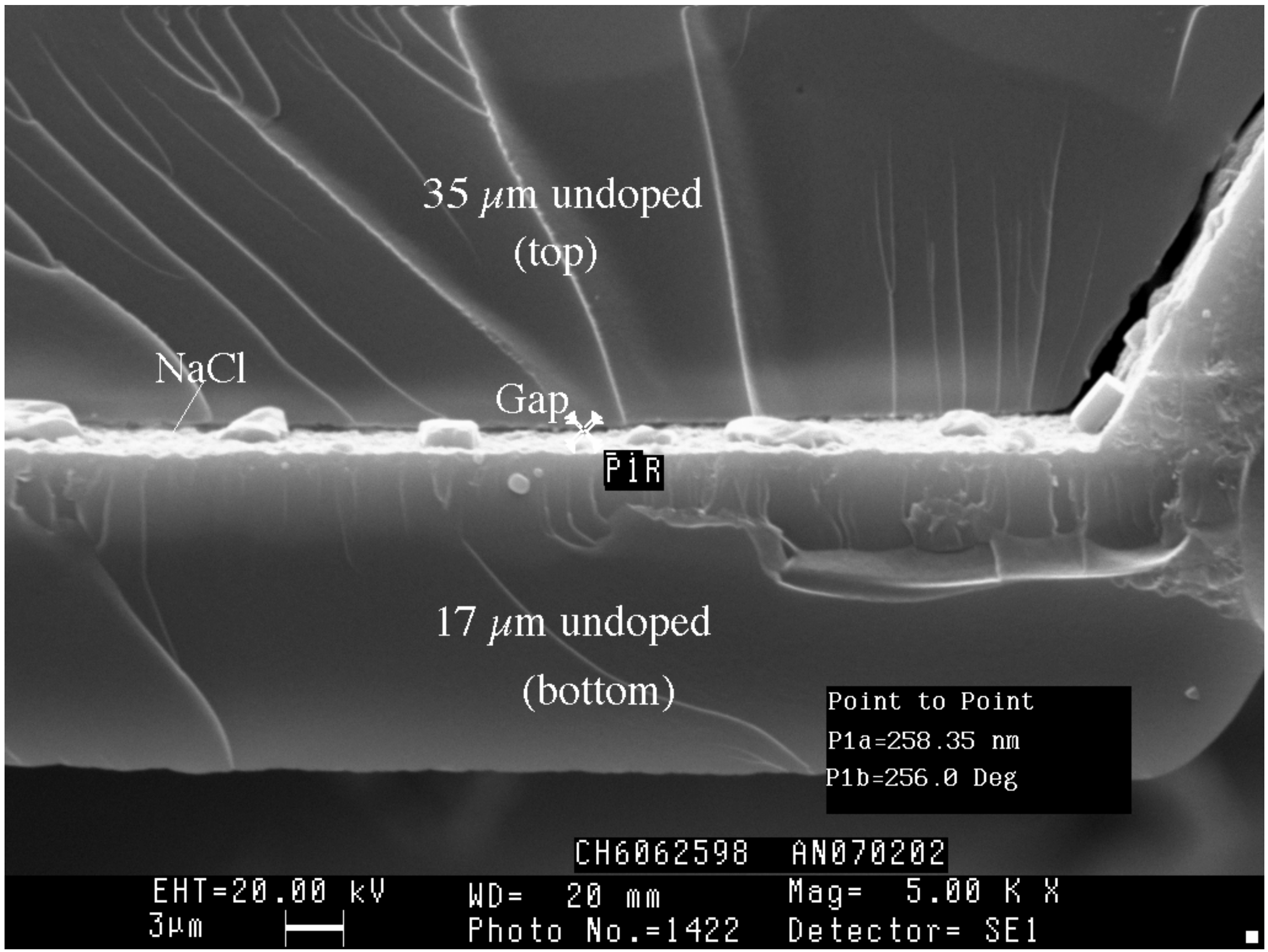
We never were able to successfully measure a tracer spectral signal on these experiments:

- Lower-than expected drive temperatures (tracers deeper than they ought to have been)
- “Cross-talk” between samples; emission seen by spectrometers not coming from line-of-sight through samples?
- Problems with one spectrometer

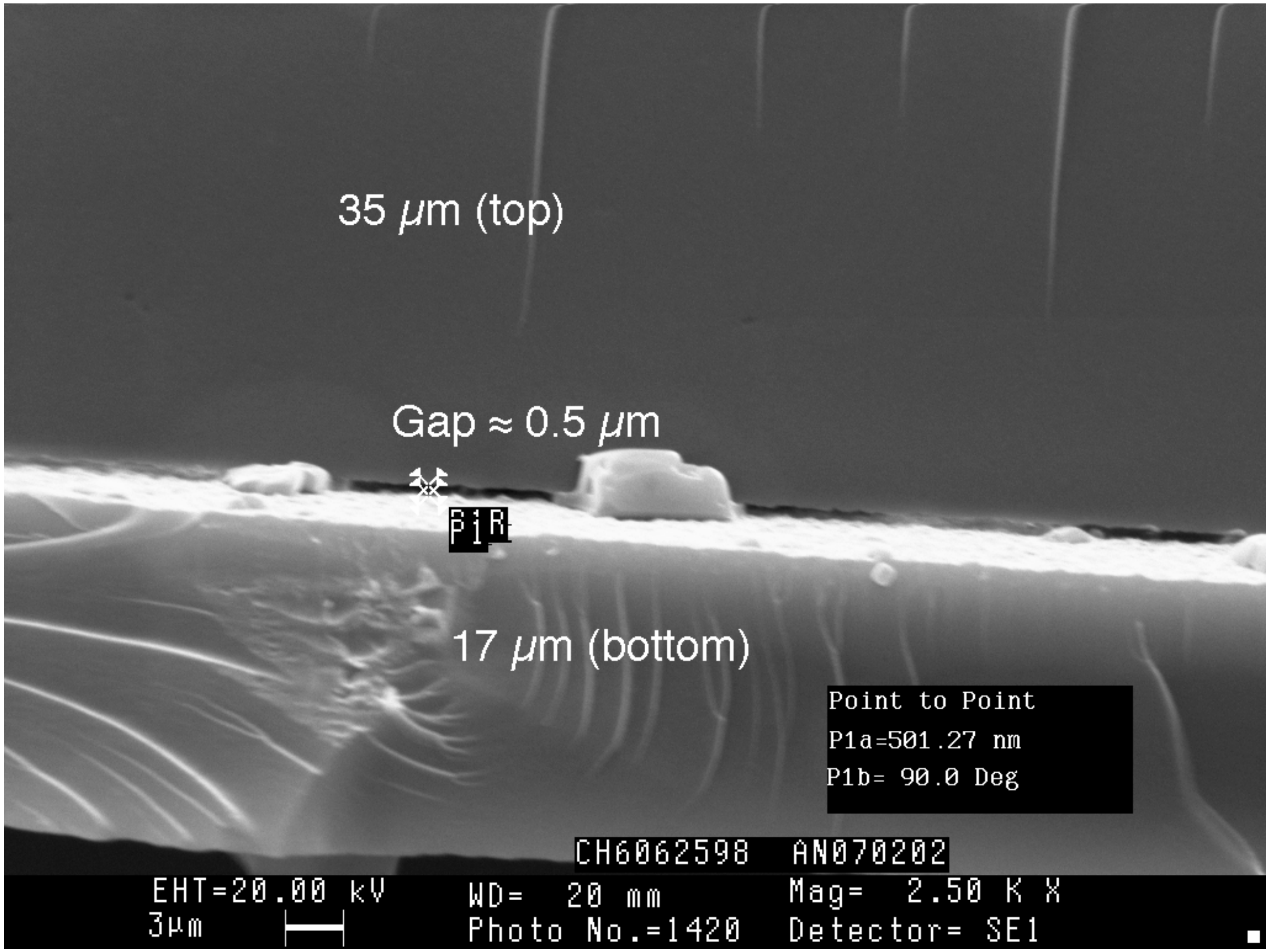
Other ambitious plans included use of wedge witness plates to make passive shock breakout measurements (VISAR with J. Oertel) simultaneously with tracer spectroscopy



higher magnification SEM image of ablator sample



And higher still…



If there are large gaps in the tracer layer, no amount of average areal mass will provide a strong signal.