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MLM monochromatic imaging of Ar gas puff implosions on Saturn

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Saturn shot 3699, 12/17/2007, DTRA;
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National Nuclear Security Administration

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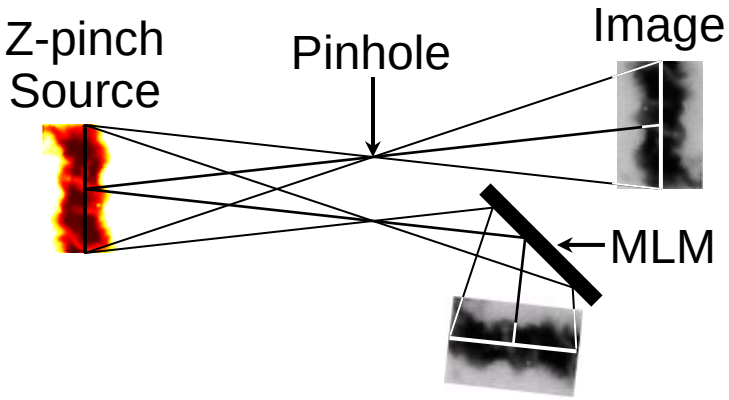
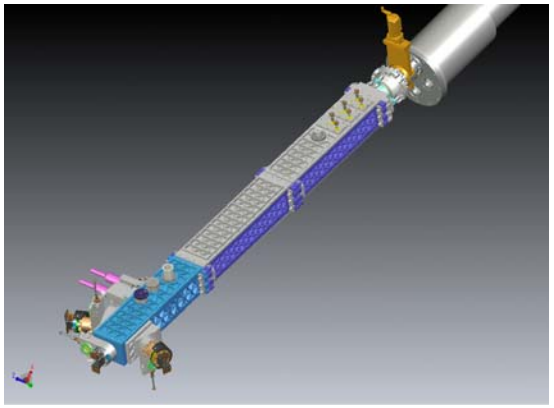
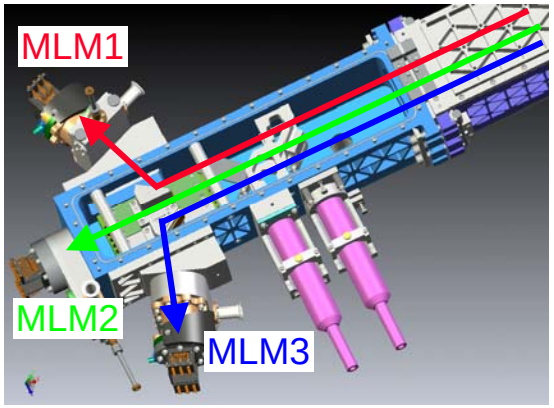
MLM pinhole camera produces monochromatic images

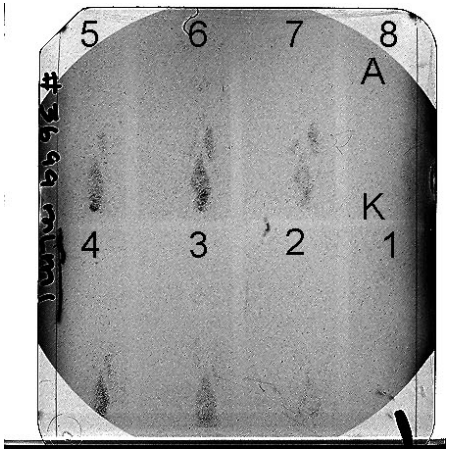




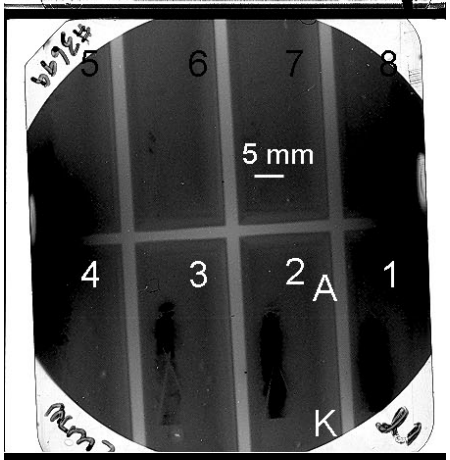


- Pinhole images are reflected from planar multilayer mirror (MLM); thin filter blocks UV/visible light, suppresses second order MLM reflection; time-resolved microchannel plate detector images multiple frames.
- Instrument on Saturn combines two MLM-reflected cameras and standard pinhole camera filtered for Ar K-shell (50 um kapton + 2500 A Al). All have source-to-pinhole distance 4.455 m, and 1/2 magnification.
- MLM1, MLM3 were both configured to image 528 eV photons, corresponding to a prominent Ar L-shell line. This nominal configuration is described in [B. Jones *et al.*, Rev. Sci. Instrum. **77**, 10E316 (2006)]:
  - 33.97° grazing angle, peak reflectivity at 527.6 eV, 3.9 eV FWHM, 5.1% peak reflectivity, W/Si multilayer, 21.18 A bi-layer period, N=175, Gamma=2.86, Sigma=2.86 A, 350 um spatial resolution with optimal pinhole diameter 82 um (assuming 3.56 m distance from source to pinholes as on Z; this will be different slightly for Saturn).
- Record of what was installed at Saturn for 12/07 DTRA shots:
  - Left camera (MLM1): W/Si MLM XRO#21302-7, OV#040A10, label SNL-005 (528.0 eV at 33.97° grazing angle); 1 um Cr filter; 129 um pinholes, 435 um spatial resolution
  - Middle camera (MLM2): No mirror, 50 um kapton + 2500 A Al filter; 52-56 um pinholes, 180 um spatial resolution (for 3.1 keV photons)
  - Right camera (MLM3): W/Si MLM XRO#12027-3, OV#040AML MTD-02, label SNL-06 (527.0 eV at 33.97° grazing angle); 1 um Cr filter; 100-101 um pinholes, 395 um spatial resolution

Last DTRA shot demonstrated that MLM imager can work



MLM1: 528 eV photons
MLM-reflected images

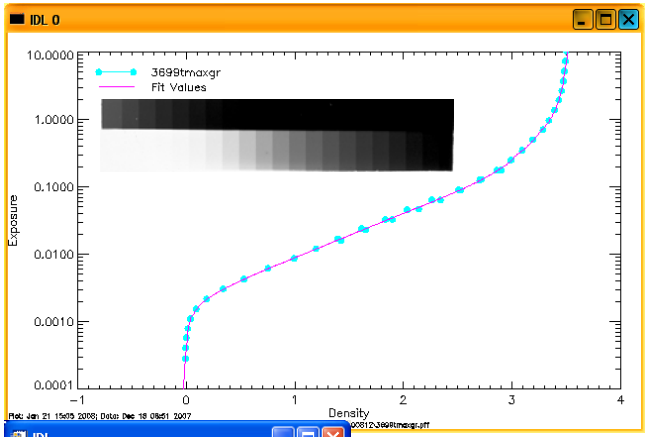


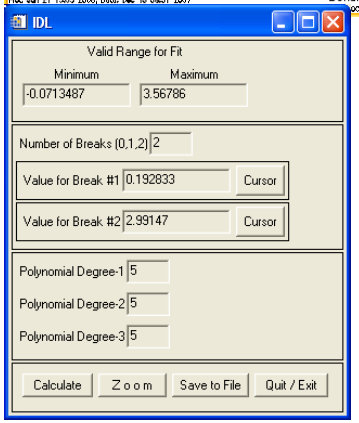
MLM2: ~3.1 keV photons
Ar K-shell (no mirror)
50 μm Kapton + 2500 Å Al
Background exposure probably due to MCP/phosphor arc

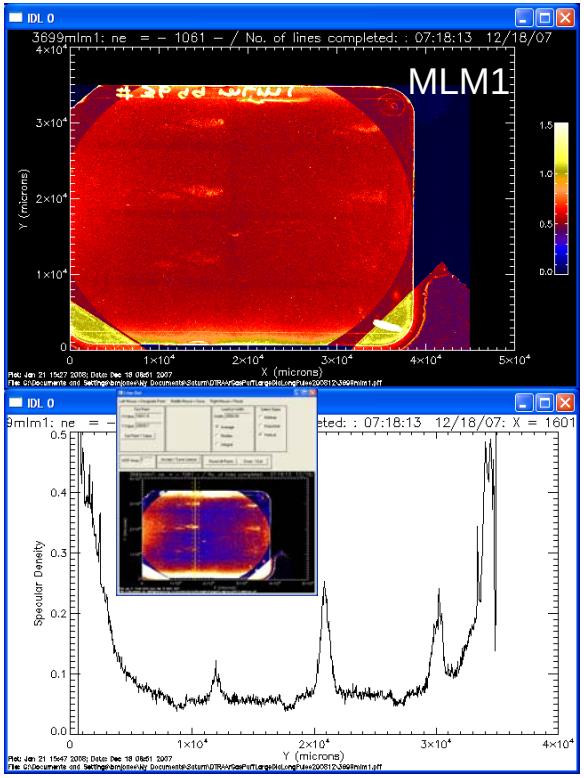
MLM3: 528 eV photons
MLM-reflected images
No data

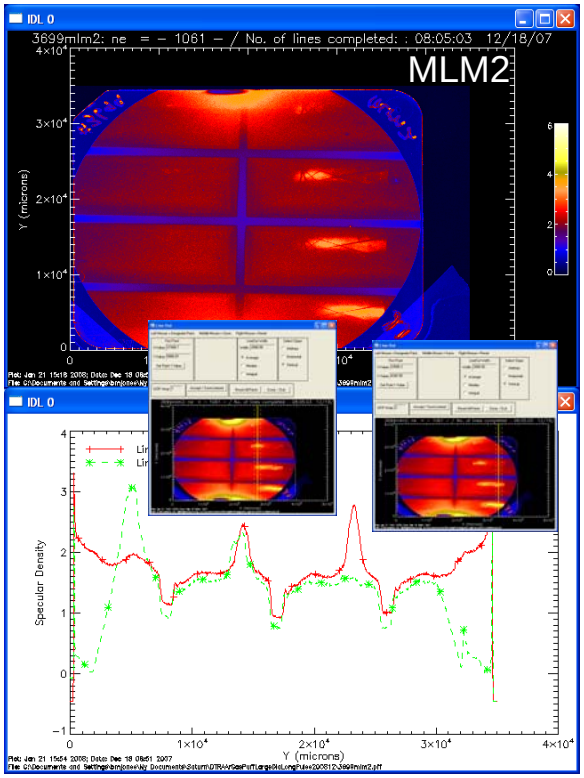
- Example data from Saturn shot 3699 shown. This was the last shot and (sadly) the best data from the DTRA 12/07 series. I will spend some time analyzing it.
- All cameras used Kodak TMAX 400 film
- 1 ns pulse, 1 ns interframe times used
- MCP DC biases
  - MLM1 = -350 V (528 eV)
  - MLM2 = -300 V (Ar K-shell)
  - MLM3 = -250 V (528 eV)
- This shot did demonstrate that the 528 eV configuration can work (MLM1), but the gain is too low and the signal-to-noise is not good. Try higher gain next time. May need to broaden pulse to collect more photons. Note that the anode wires obscure much of the pinch—the opaque diameter is larger at 528 eV than 3.1 keV (MLM2).
- Despite bad background on MLM2, it is clear that there is a significant zipper in the Ar K-shell images, and the pinch diameter is of order 3 mm. I will be able to be a bit more precise about this after detailed analysis of the images. Note that the background is worse on the sides of the camera (i.e. frame 1 is worst) so this will affect the apparent exposures—in general we do not quantitatively compare exposures between frames as gain can vary and the MCP is not absolutely calibrated.

Film exposure analyzed to few % accuracy using step wedge



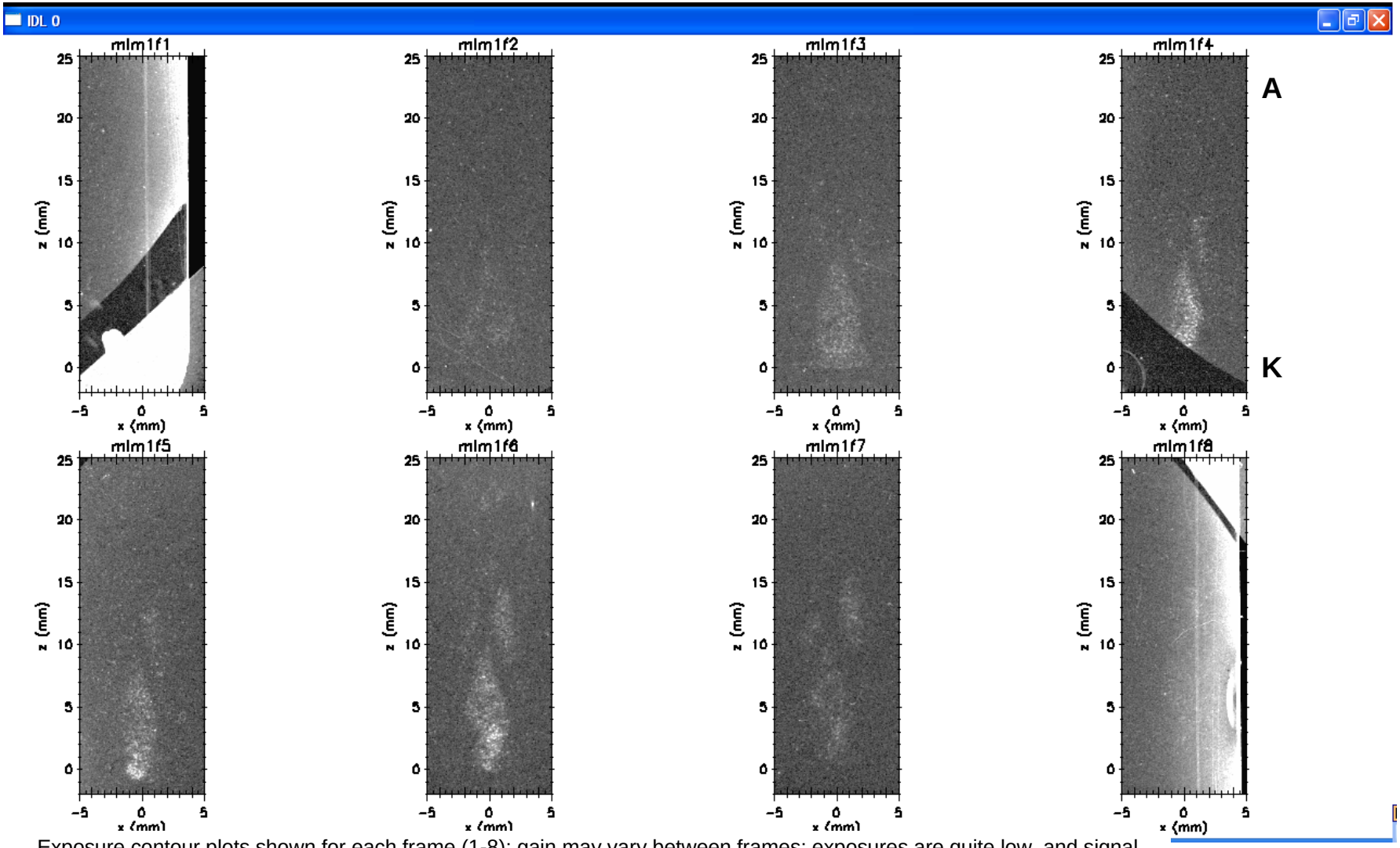






- Step wedge data used to convert from OD to exposure (linearly proportional to x-ray intensity)
- TMAX green step wedge 3699tmaxgr.pff
- IDL routines by Greg Dunham and Paul Mix
  - alt_wedgeBJ20051220.pro, alt_wedge; 0.477 background from first (maybe part of second) step; 2500 height of regions for step averaging; Output saved as 3699tmaxgr.fit, 3699tmaxgr.vida
  - Regrid: pixels=1, film fog background=0.480 (MLM1), 0.470 (MLM2, taken near peak x-ray frame)
- A few percent accuracy expected in film calibration
  - G. Dunham *et al.*, Rev. Sci. Instrum. **75**, 928 (2004).
- Note from upper left plot: data is only reasonable in the range OD~0.1-3.3; outside of that range the calibration is varying too quickly and data is suspect
- MLM1 had weak images; the weakest two probably cannot be used to determine pinch diameter reliably, but the four strongest probably are just barely usable. In the future, the pulse width should be increased to enhance the gain on these images (DC bias is already at -350 V, and MCP was flashing at -400 V)
- MLM2 had strong images, but also high background; the OD is not too high (>3.3) so these images are not saturated. The high background will have to be subtracted and is somewhat troubling; it is likely due to phosphor/MCP arc flash, and could affect the lineout shapes of the pinch images somewhat. In the future, gain could be reduced somewhat on this camera, but no more than 50 V adjustment to start.

Saturn 3699 MLM1 image processing



- Exposure contour plots shown for each frame (1-8); gain may vary between frames; exposures are quite low, and signal to noise is poor
- Corrected for instrument MAG to show pinch dimensions, but not corrected for 35° viewing angle (i.e. these are dimensions in a plane centered on the pinch and perpendicular to the viewing direction)
- Note that large anode mesh wire size is due to the lower photon energy—these wires obscure a significant portion of the image and make only the image near the cathode usable. Could the anode wire pattern be changed in the future to accommodate a better view?
- It looks like with higher gain we might be able to image the implosion with this camera—frame 3 shows a wider column than frame 4, but it is very dim.

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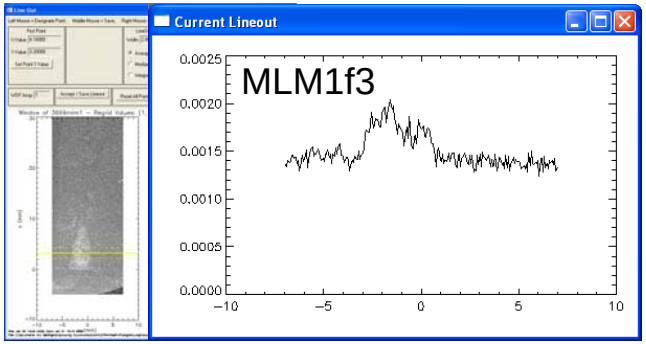
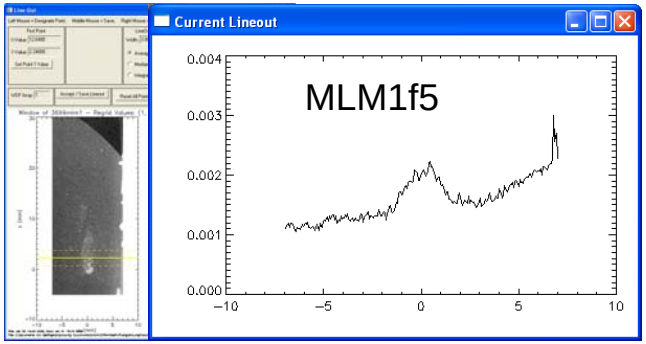
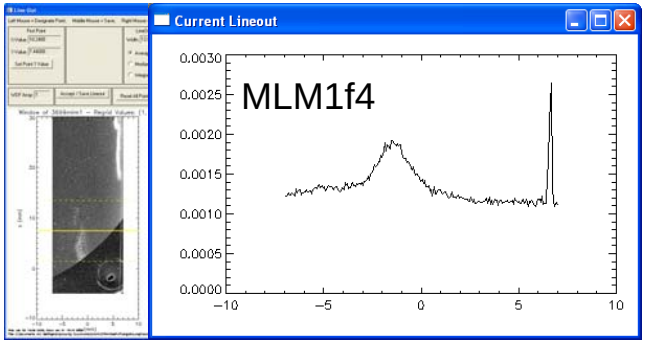
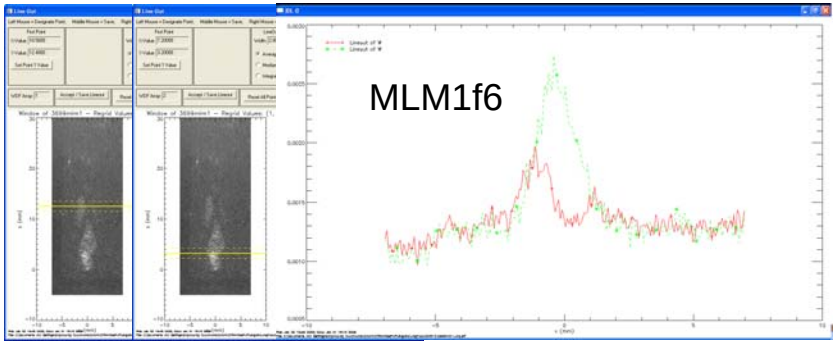
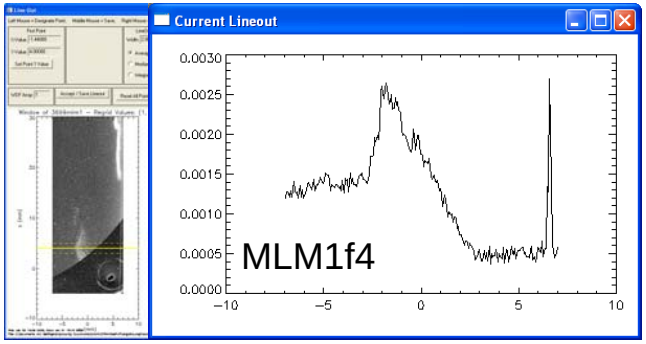
Saturn 3699 MLM1 lineouts

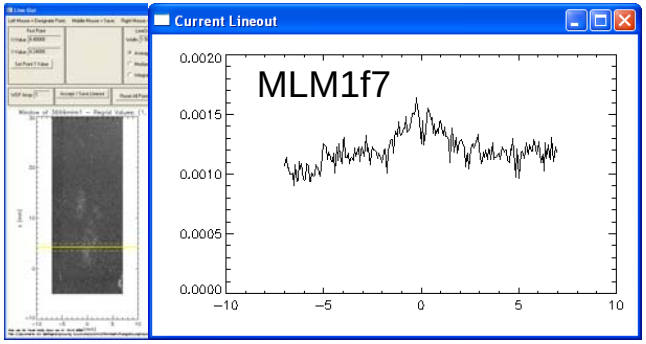












- Pinch diameter is 3-4 mm base-to-base, 2-3 mm FWHM; hard to be accurate given anode wires that obscure images and low signal-to-noise

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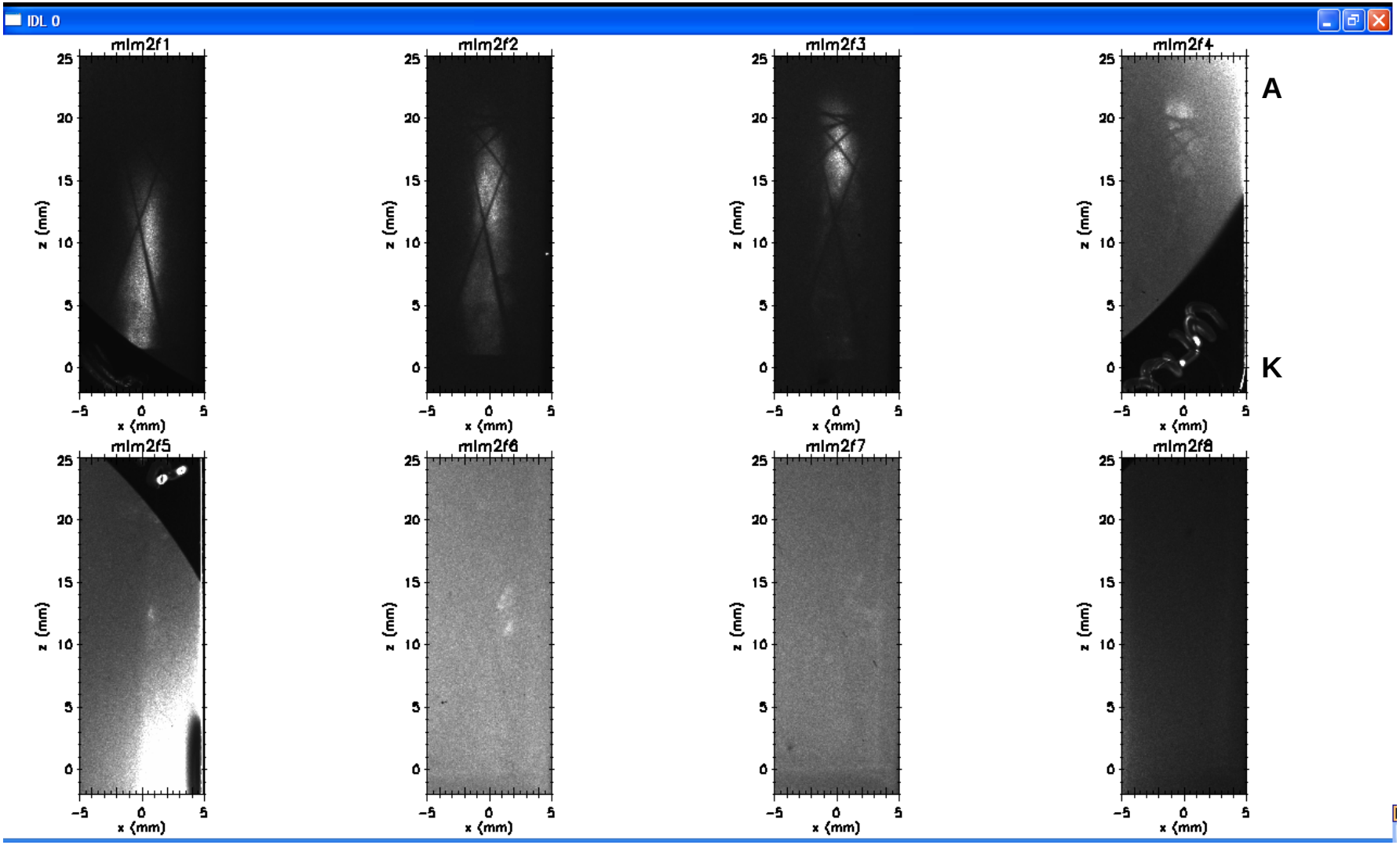
Saturn 3699 MLM2 image processing



- Exposure contour plots shown for each frame (1-8); each frame is renormalized for best contrast, so don't pay attention to relative brightness of the frames; gain may vary between frames anyway
- Corrected for instrument MAG to show pinch dimensions, but not corrected for 35° viewing angle (i.e. these are dimensions in a plane centered on the pinch and perpendicular to the viewing direction)

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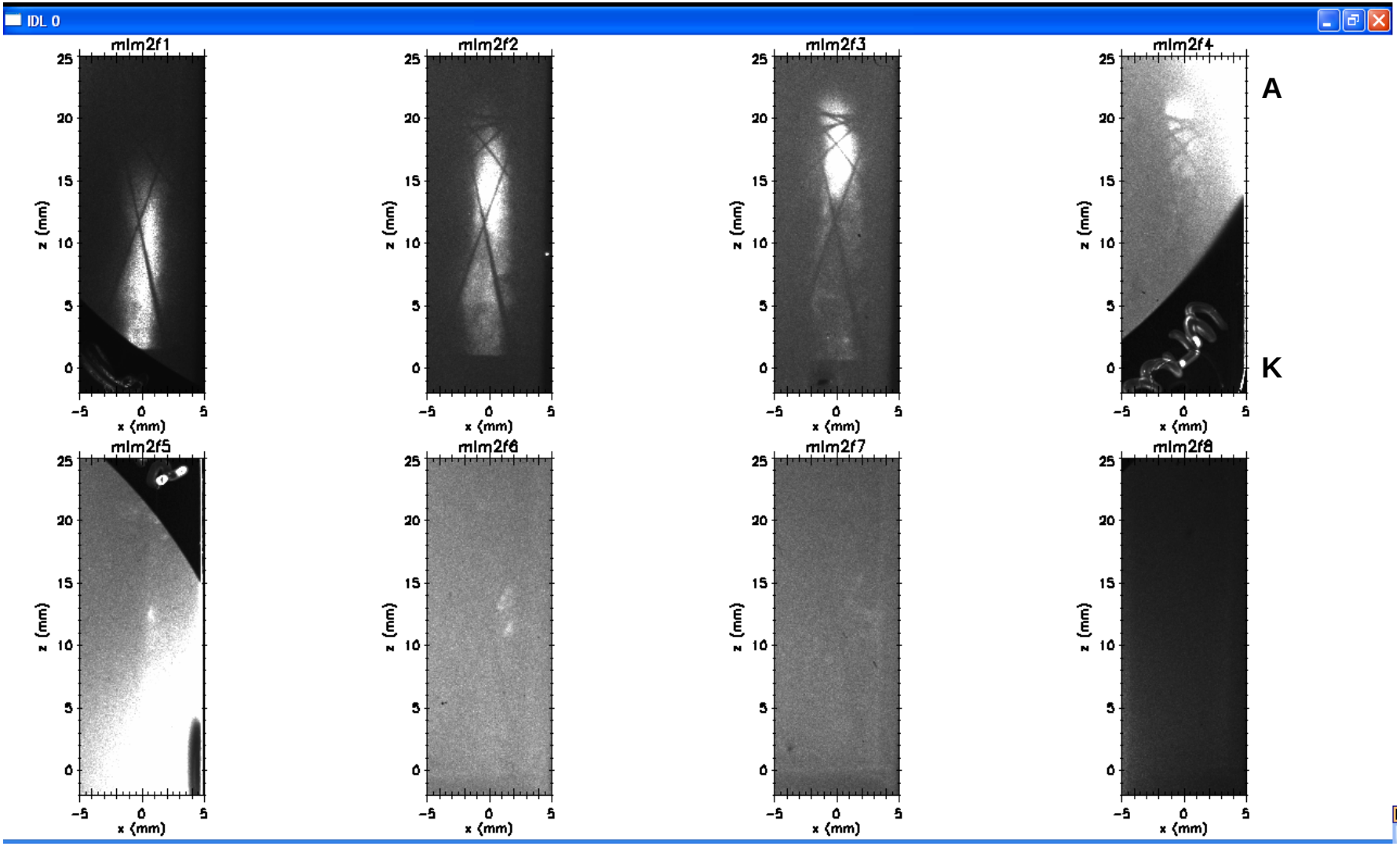
Saturn 3699 MLM2 image processing (higher brightness)



- Same as last page, but color scale changed to see dimmer regions
- Note that after minimum radius and maximum brightness at a given axial position, the plasma reexpands and exhibits limb brightening (hollow radial emission profile). This could be a bounce coupled with radiative cooling in the core.

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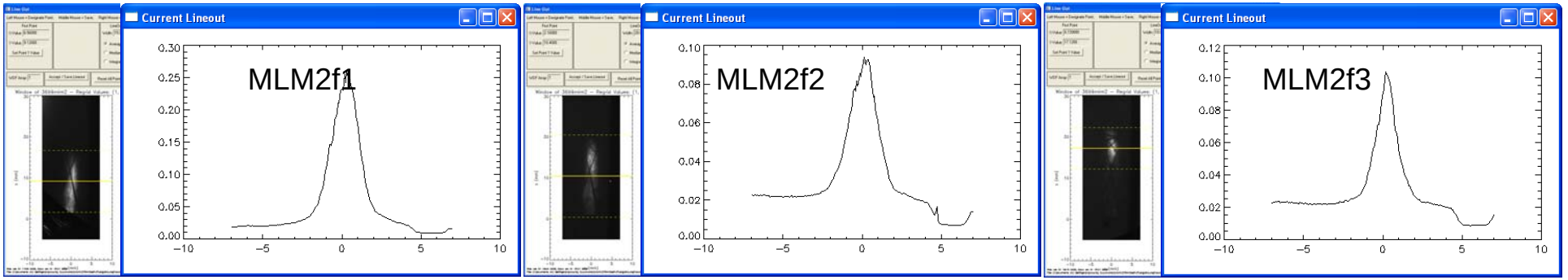
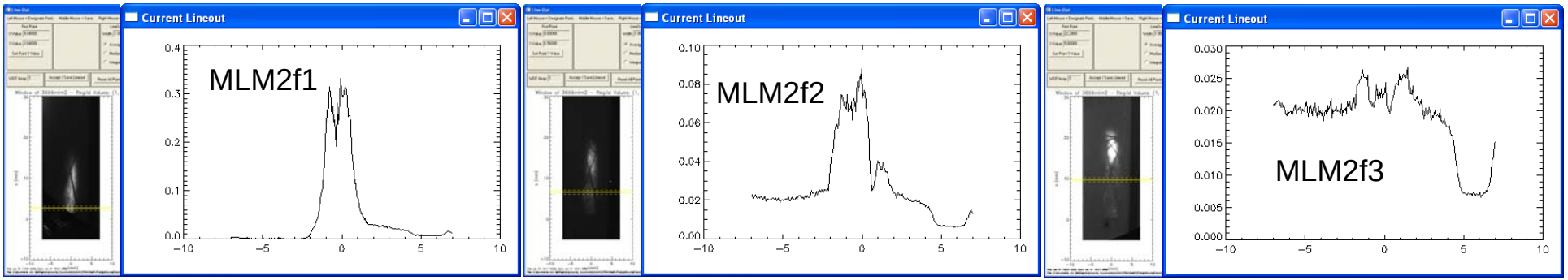
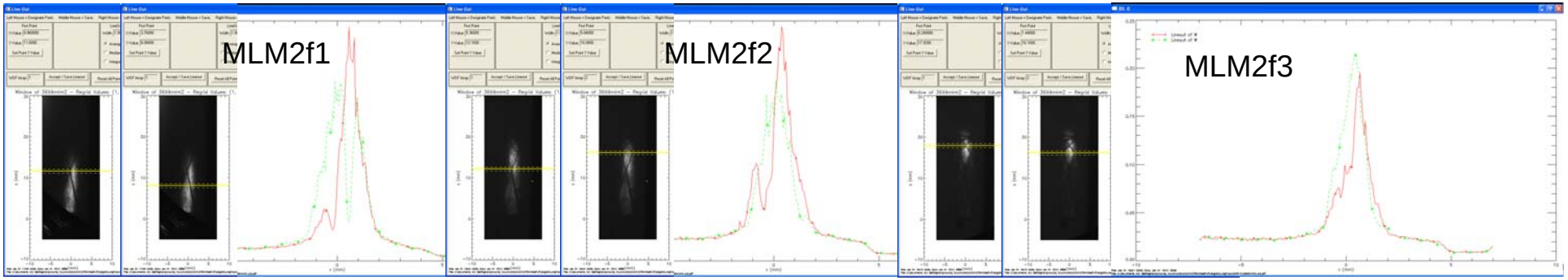
Saturn 3699 MLM2 lineouts







- Pinch diameter is 3-4 mm base-to-base, 2-3 mm FWHM; hard to be accurate given anode wires that obscure images
- Note expanding limb-brightened plasma nearer to cathode after zipper has passed (middle plots)

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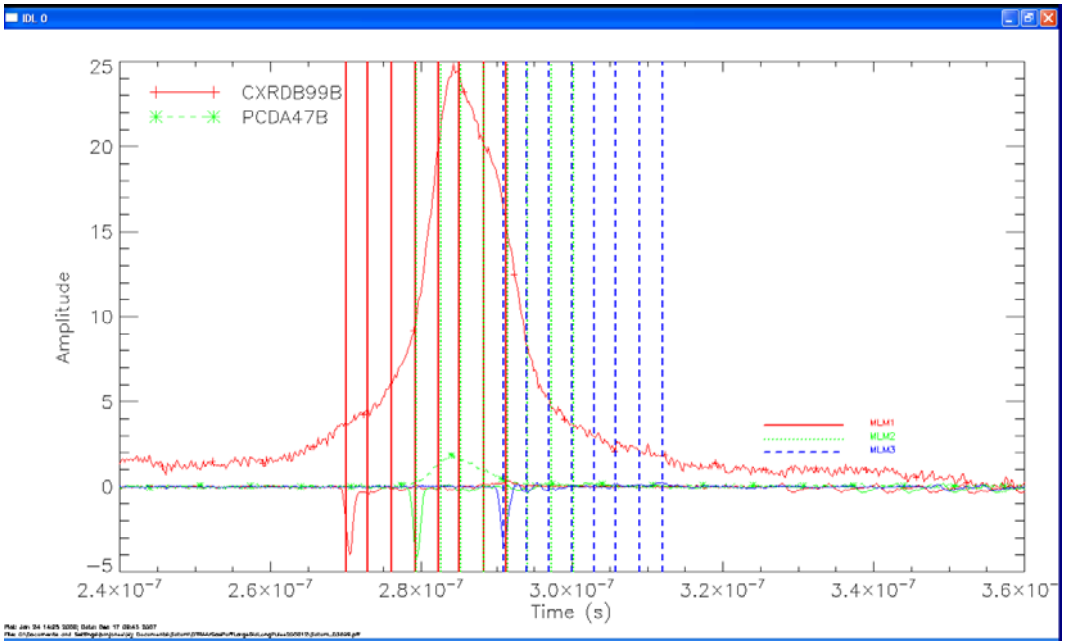
Saturn 3699 camera timing

	Start of x-ray foot (ns)	Start of main x-ray rise (ns)	Peak x-rays (ns)
CXRDB99B	210	277	284.3
PCDA47B	273	279	284.2

- Camera frame 1 time given by:
  - MLM1 (528 eV images) = 270.6 ns
  - MLM2 (Ar K-shell images) = 278.9 ns
  - MLM3 (528 eV images) = 290.8 ns
- 3 ns interframe time, 1 ns pulse widths used on all cameras



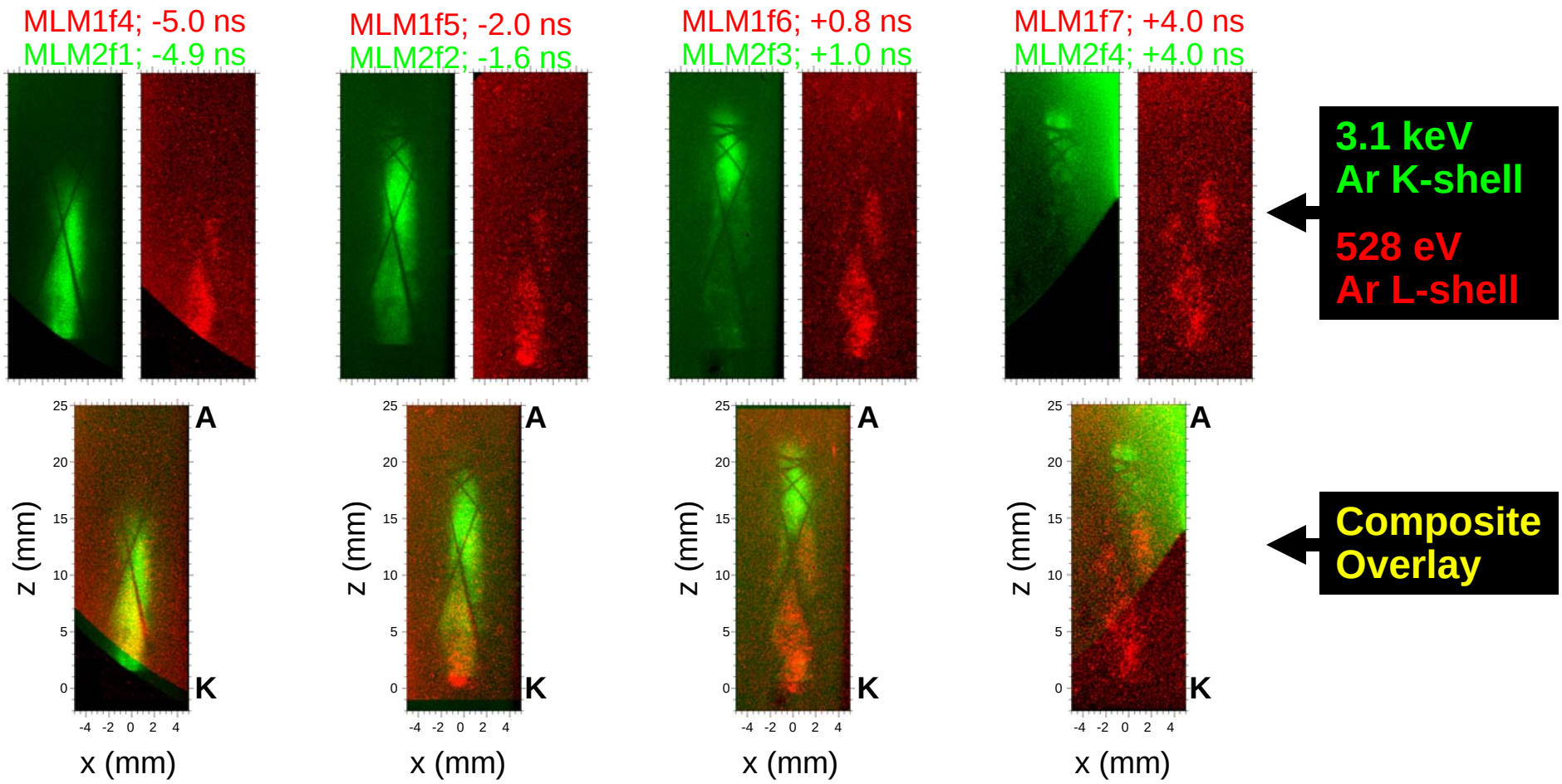
- Frame timing (machine time, ns) including chassis/camera corrections (accurate to 1 ns):

Frame	1	2	3	4	5	6	7	8
MLM1	270.1	272.9	276.1	279.3	282.3	285.1	288.3	291.3
MLM2	279.4	282.7	285.3	288.3	291.5	294.1	297.3	300.3
MLM3	291.0	294.0	297.0	300.0	303.0	305.8	309.0	312.0

- If you agree with the x-ray timing above, then the camera timing relative to peak XRD is:

Frame	1	2	3	4	5	6	7	8
MLM1	-14.2	-11.4	-8.2	-5.0	-2.0	+0.8	+4.0	+7.0
MLM2	-4.9	-1.6	+1.0	+4.0	+7.2	+9.8	+13.0	+16.0
MLM3	+6.7	+9.7	+12.7	+15.7	+18.7	+21.5	+24.7	+27.7

Saturn 3699 MLM1-2 image overlay (timing relative to XRD)



- Overlaying images with different spectral cuts provides additional insight into dynamics. Contrast and color scales assigned separately for each frame to make images look nice, and do not give an accurate quantitative indication of emission intensities.
- Comparing various features in the images provides confidence that relative camera timing is correct, and allows images to be shifted for proper alignment.
- Zipper clearly seen, with plasma expanding below the zipper and producing a limb-brightened K-shell emission profile (with structure). L-shell is preferentially emitted below the zipper, implying that zipper is hotter (shock heating, generating K-shell) while expanding plasma below is cooler (generating L-shell, radiatively or adiabatically cooled).
- Note that I have double checked timing with Matt Torres, and I currently believe this timing to be correct. This would mean that peak power corresponds to about half way through the zipper/cooling process. If the 528 eV images reflect where the total x-ray power is being emitted, this means that the softer photons are preferentially coming from where the zipper has already passed and the plasma is no longer emitting K-shell. This implies that Ar K-shell production is not limited by radiative cooling in the L-shell, which the 2006 scaling model of Thornhill et al. would probably corroborate given the low Z and the low masses on Saturn.
- It will be interesting to compare the zipper seen by this diagnostic to data from Phil Coleman's zipper array to determine if they agree on timing of the zipper dynamics, and on the timing relative to peak XRD/PCD powers.