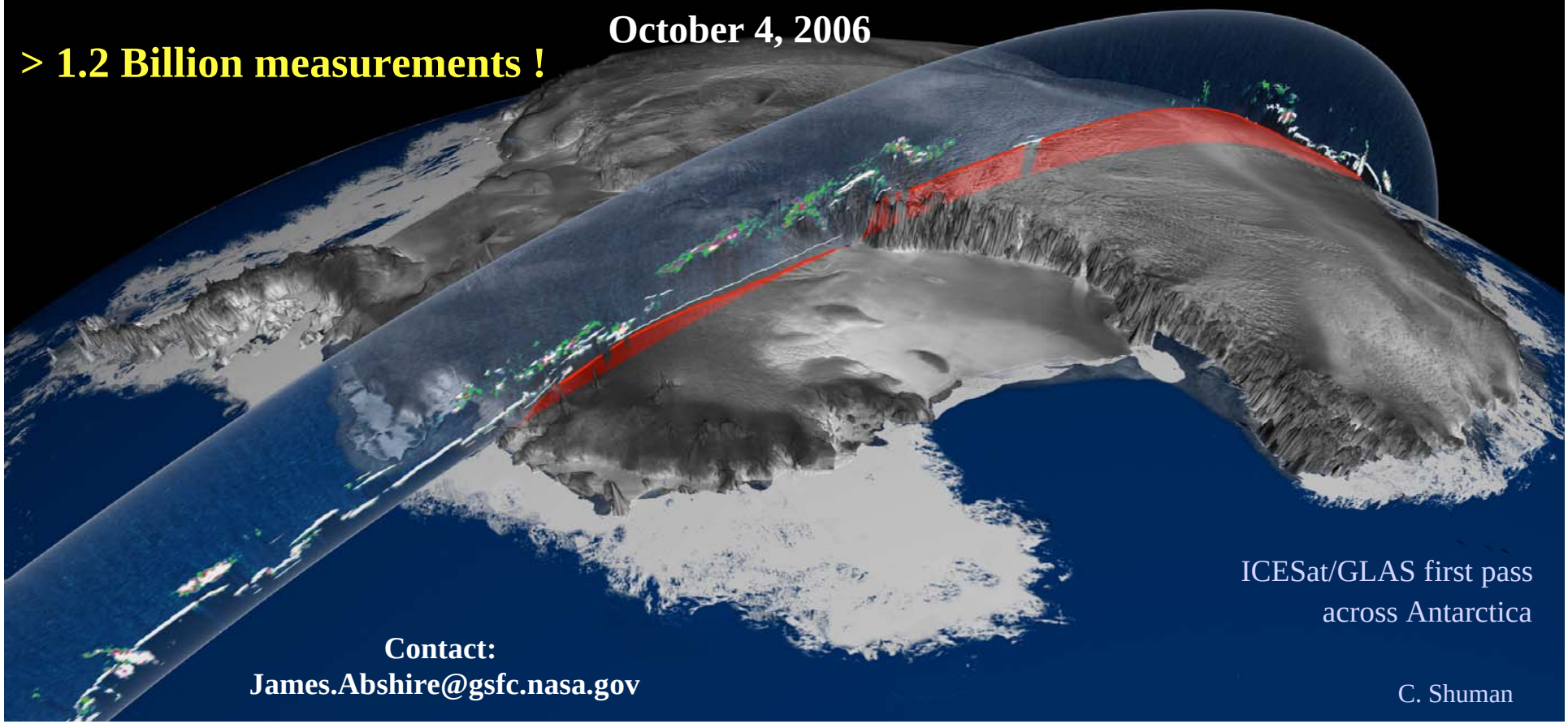
Geoscience Laser Altimeter System (GLAS) Update to Science Team

GARB Report

Jim Abshire, Haris Riris, Graham Allan, Tony Yu,
John Canham, Tom Field, Pete Liiva, Ed Dowdye

October 4, 2006

> 1.2 Billion measurements !



ICESat/GLAS first pass across Antarctica

C. Shuman

Contact:
James.Abshire@gsfc.nasa.gov

Laser Investigation (GARB) report

Outline:

- Ongoing work - better determine the causes of on-orbit laser changes
- Rationale:
  - Allow better predictions and operations of ICESat
  - Allow improved approaches for future space lidar
- Updates:
  - Energy History
  - Laser 3 “fire acquisition” signal drop out risk & potential impact
  - Laser 3 Energy history slope change
  - Energy step changes (bar drops)
  - Photodarkening hypothesis (L1 & L2)
  - Laser 3 Doubler (low 532nm energy) investigation
- Summary

Laser Measurements & Operations (10 campaigns so far)

Laser firings through 6/25/06

Total:

GLAS Laser Shot Counter

01,243,219,201

Total number of on-orbit shots emitted by Lasers 1, 2, and 3 since February 2003. ICESat is currently operating in science campaign 3F.

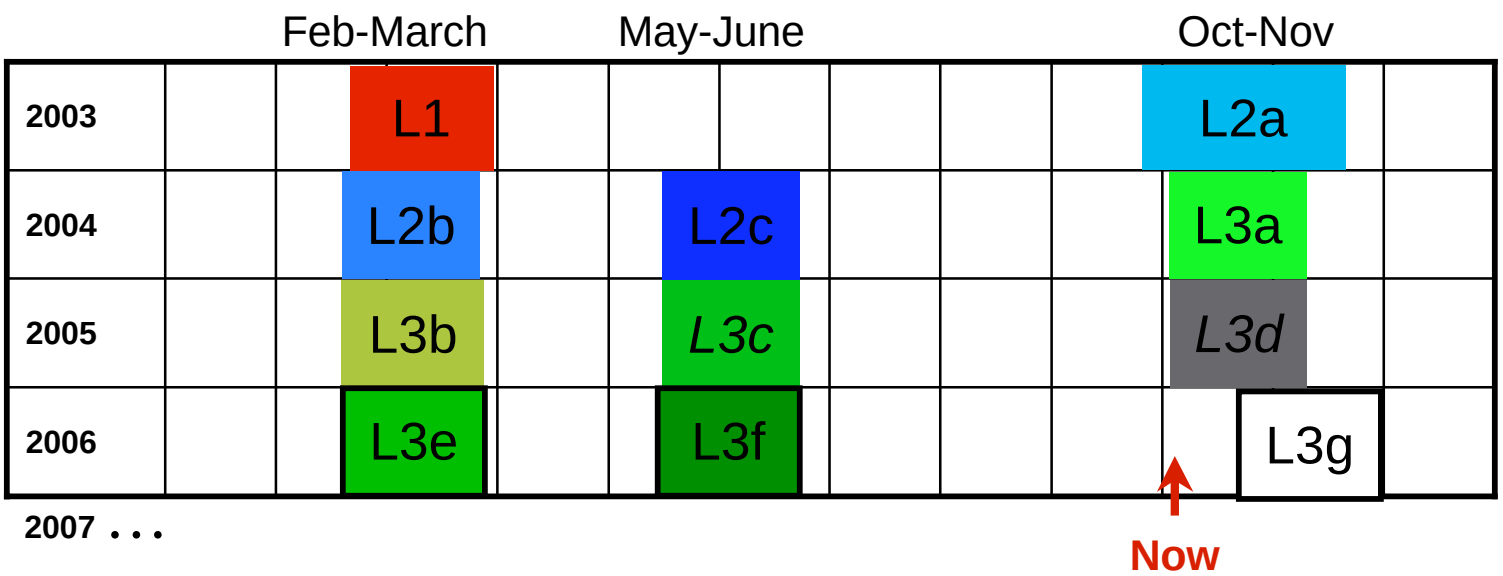
Laser 3:

GLAS Laser 3 Shot Counter

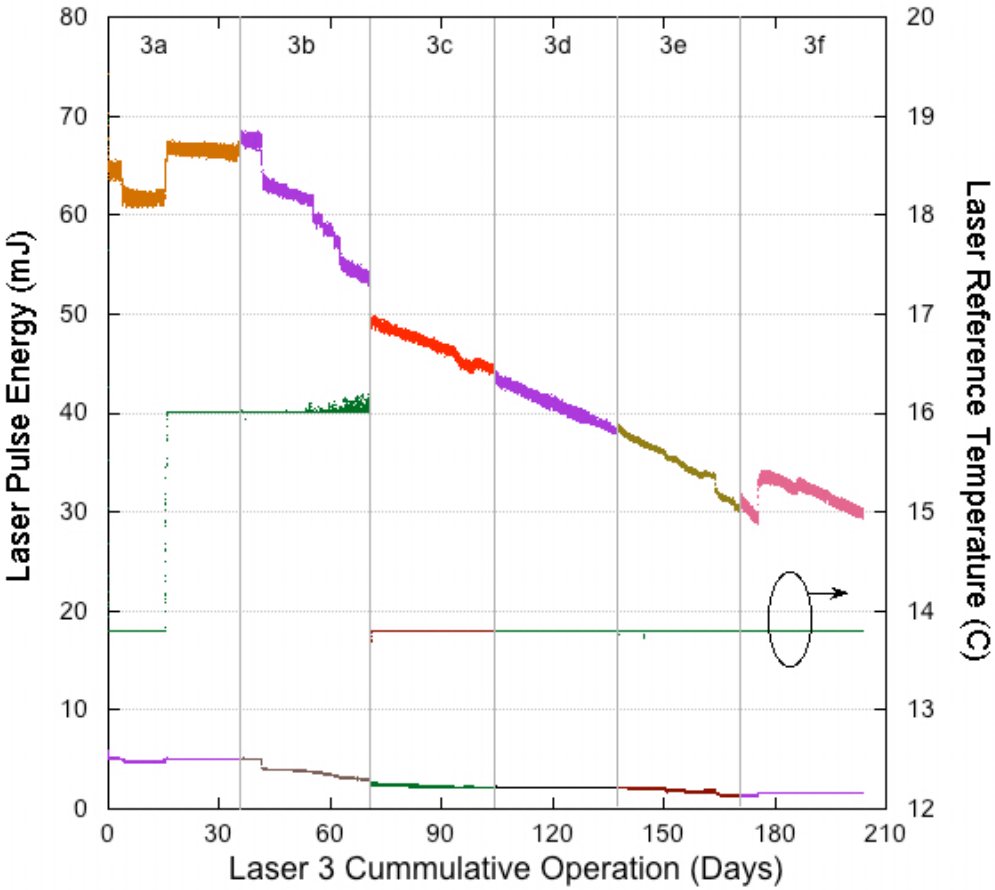
00,698,859,320

Individual laser pulses shot by GLAS Laser 3 starting on October 3, 2004 and continuing through six science campaigns. Currently, ICESat is operating in science campaign 3F.

ICESat Operating History - 10 campaigns to date



GLAS Laser 3 Energy History
Through end of 3f campaign



Simple linear extrapolation of Laser 3 1064 nm energy

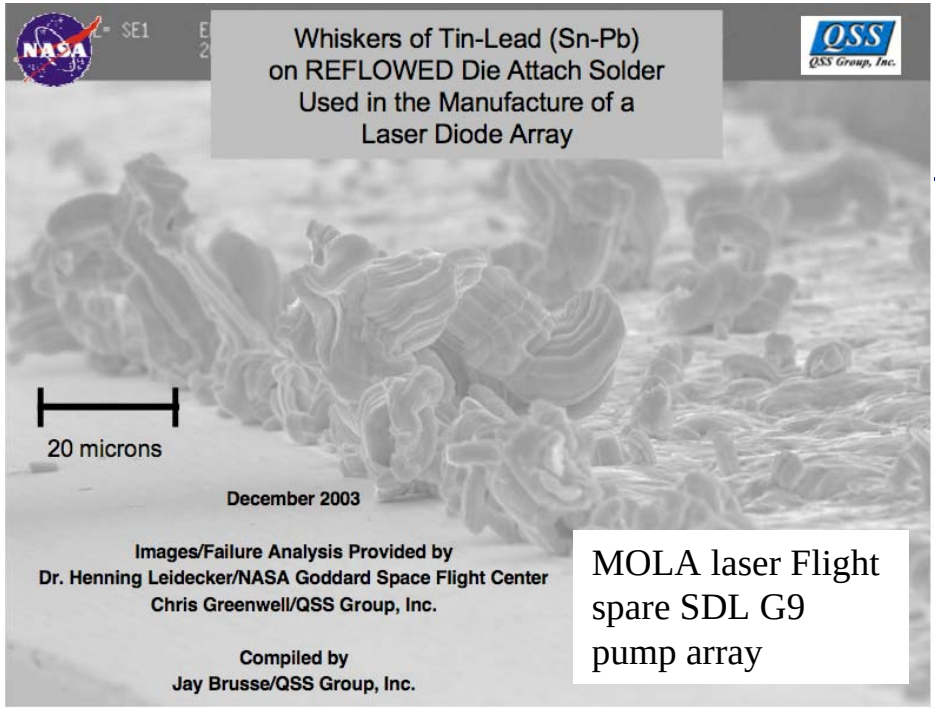
- 6 campaigns to date
- 1064 nm energy drop = 33 mJ
- Ave energy drop = 5.5mJ/ campaign
- Presently at 30 mJ

If trends continue:

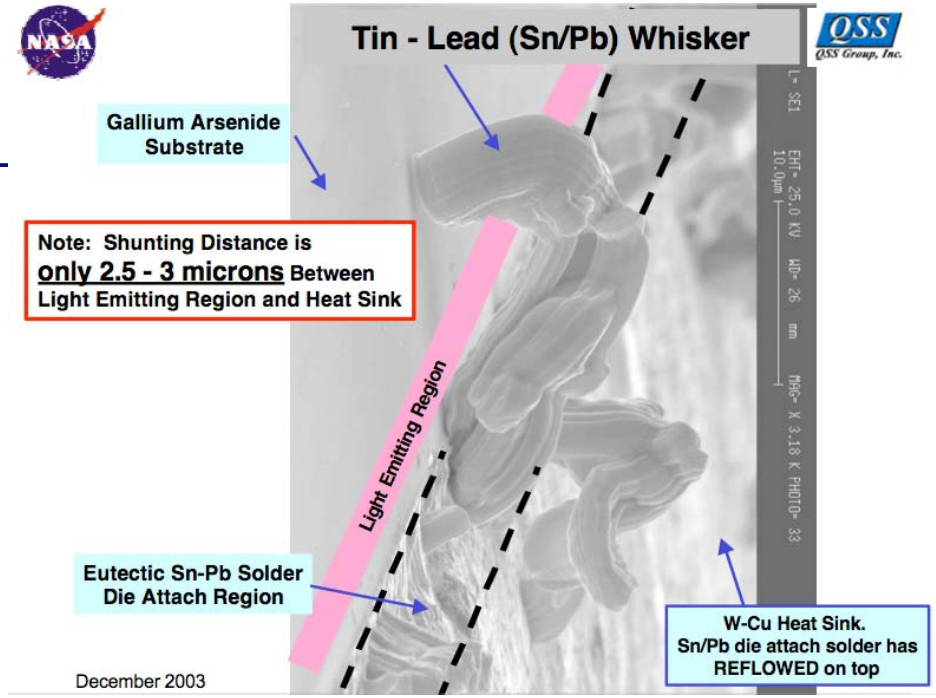
- Expect ~4 more campaigns to 10 mJ

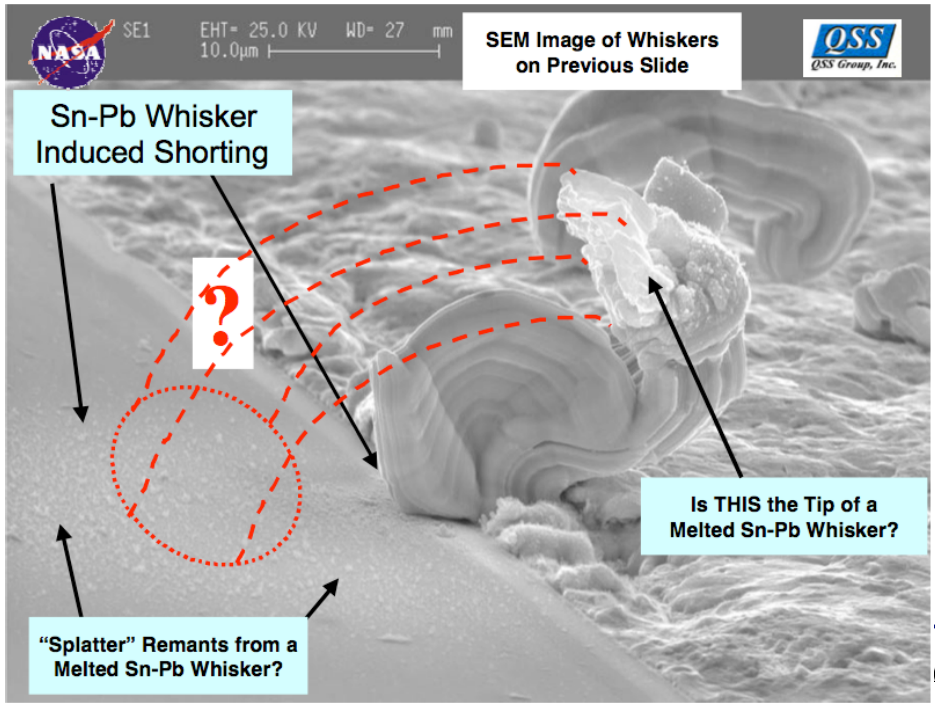
- Raise laser temperature
- Several (2 or more) campaigns with warmer laser
- Use Laser 3 at < 10 mJ
- Then use Laser 2

- Note - Still have some residual risk of a bar blowout



MOLA laser Flight spare SDL G9 pump array





Contact Information

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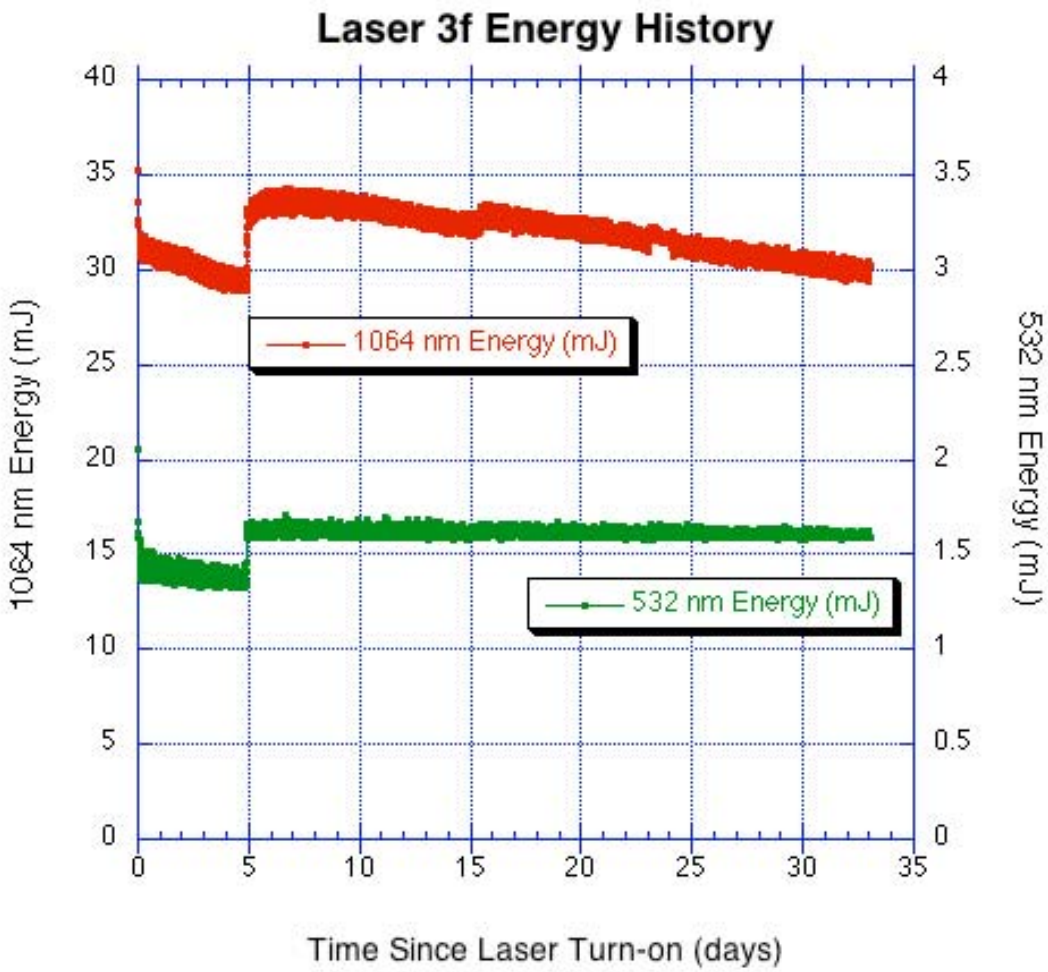
Working Hypothesis for L3 slope change: Vaporized Tin-Lead Whiskers from Diode Array

NASA Goddard Tin (and Other Metal) Whisker WWW Site

http://nepp.nasa.gov/whisker

Laser 3f Energy History



“Fire Acquisition” Risk for L3: 1 of 3

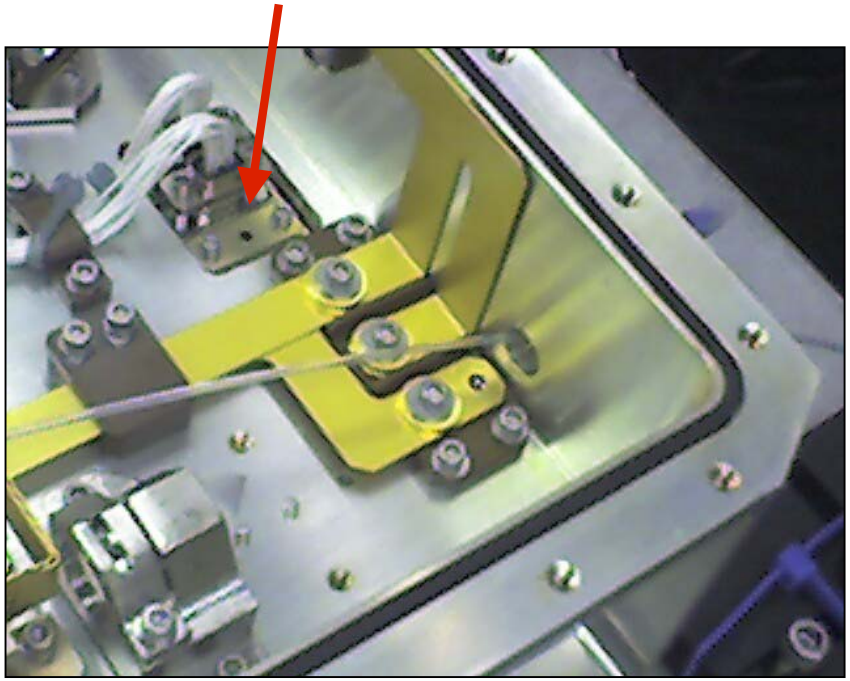
There is an internal optical detector inside the laser box used to determine when the oscillator has triggered (ie Q-switched) and to turn off the electrical drive pulse to the laser diodes when it occurs.

It is called the "fire acq" detector. It views scattered 1064 nm laser light inside the laser box.

Normally the diode pump electrical drive pulse width is about 200 usec. This pump pulse width is the laser fire delay - ie the time from when laser is commanded to fire to that when it actually emits the laser pulse.

When the 1064 nm energy inside the laser box decays far enough (< 10 mJ), the fire acq signal will not cross an internal threshold, and the electrical pump pulse will stay on.

We aren’t certain of the exact fire acq threshold - it is possible it is < 5 mJ



Laser 3 - “Fire Acquisition” Signal Risk: 2 of 3

Potential Impacts:

The laser drive pulse to the diodes will go to 244 usec. The laser will have emitted a pulse, but the pumps will stay on longer. This won't break the laser, but it may cause an error in selecting the start pulse for the altimetry. So the altimetry electronics may miss the time of the start pulse.

The current draw from the laser will increase about ~ 1A (30W) (ie from ~100 to 130 W).

Tom Feild looked into whether the spacecraft can supply these extra 30W to the laser box. Sometimes that that is marginal.

If it can't, then voltage to the laser will drop below its low threshold and laser power supply will reset. The laser will stop & go into a restart mode (several hundreds of seconds).

Plans (under development):

Operate Laser 3 as now, until 1064 nm energy reaches ~ 10- 16 mJ at end of a campaign (ie extrapolated energy at the end of the next campaign expected to be < 10 mJ)

Raise laser temperature for the next campaign by ~ 6C . This is expected to raise the output energy by ~ 6 mJ & likely keep the expected “end of campaign energy” > 10 mJ.

Likely recommend 2-3 steps. The # & maximum laser temperature are TBD.

We can’t be certain of the exact fire acq cutoff; it is possible it is < 5 mJ

GLAS Laser Oscillator Stage Current Analysis

Robert Afzal

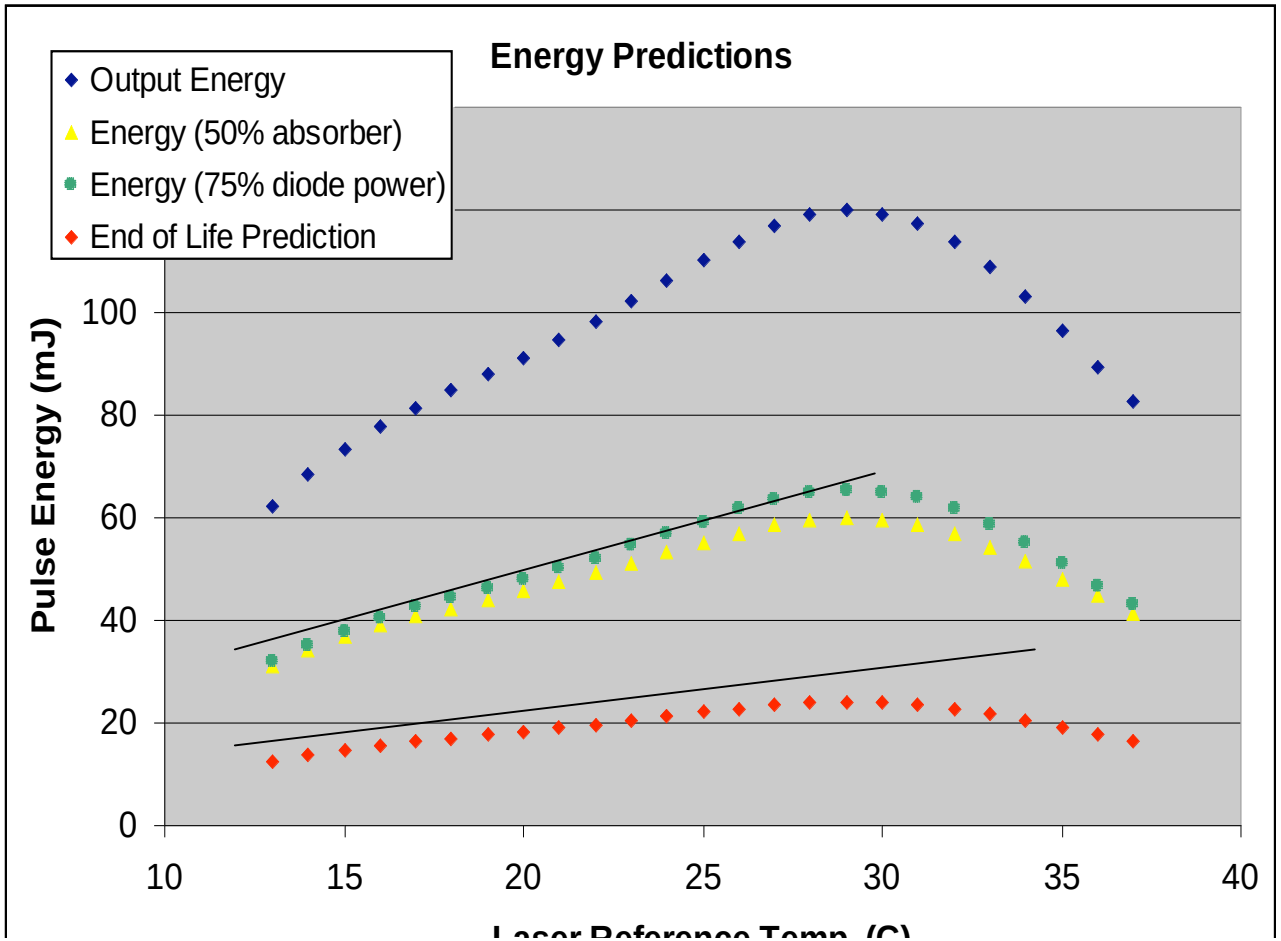
7/11/06

Summary:

- Oscillator current drive is monitored separately
- Performance history analyzed via its (slow) rate of current increase
- Done for all lasers through L3f
- **Results agree with pre-launch predictions for all lasers**
- Power Law Extrapolation is > 2 years/Laser
- Temperature dependence is consistent with pre-launch measurements for large DT (see appendix of report for details)

GLAS Laser Energetics - Model Predictions

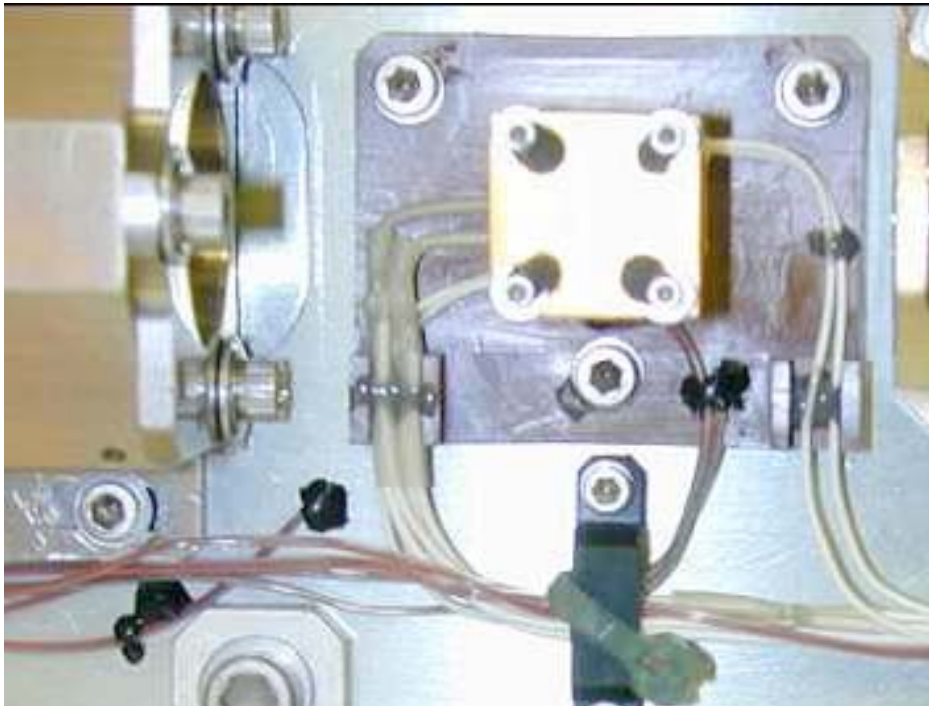
The GLAS Laser energy model was used to predict the laser energy at the beginning of life, with a hypothesized 50% absorber at the laser output, 75% available diode pump power, and estimated performance at EOL (10 mJ @ 13 C).



Present Slope = 2 mJ/C

Near "End of Life" Slope = 1 mJ/C

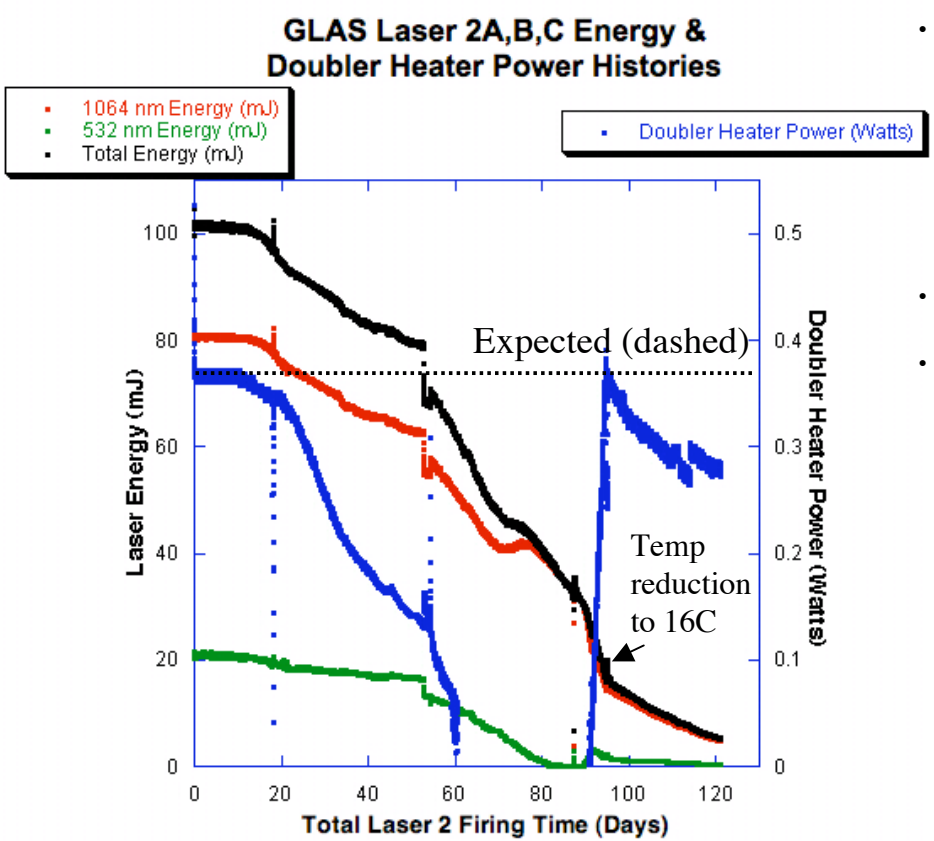
Doubler Photodarkening Investigation



Status Report Outline

- Modeling heating effects
- Wavelength investigation
- Extended vacuum test of ETU laser
- Ongoing work

Laser 2 Energy History



Note:
1 day = 3.46 M shots
Laser 2 still operational

Interim Results of GARB Analysis

- Decline in doubler heater power caused by:
  - A growing optically absorbing film on doubler
  - Film absorbs increasing amounts of laser power
  - Causes laser induced heating of doubler crystal
- Oscillator stage fine throughout
- Photo-darkening process (hypothesis):
  - A trace out-gassing contaminant from an adhesive used in laser cavity
  - 532 nm photons from frequency doubler break bonds
  - Dark film (from fragments) forms on doubler
  - Film absorbs laser light - heats film & doubler
  - Only occurs in vacuum
  - Very slow rate of growth (why effects were not seen in ground laser vacuum tests)
- Out-gassing rates are slower at colder temperatures

Photodarkening Hypothesis - Model of Impact

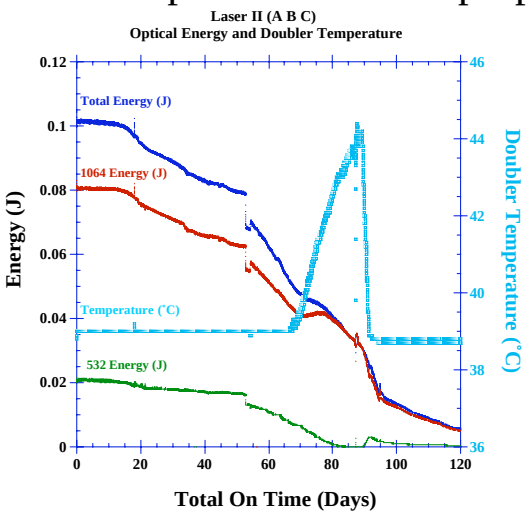
Graham R. Allan

Hypothesis:

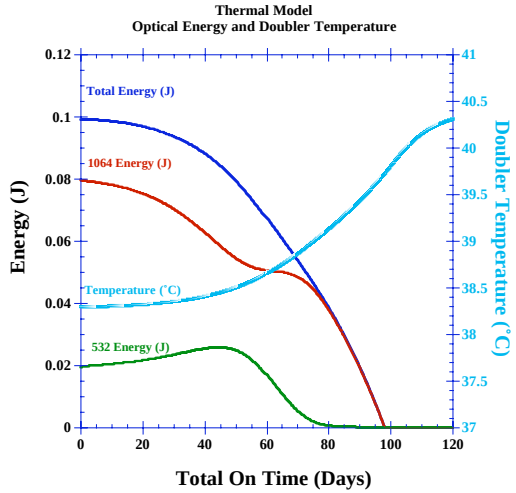
An outgassing product, when illuminated with 532 nm light , deposits absorbing film on exit face of the doubler.

Optical energy is absorbed from both the 1064 and 532 and converted to heat, this heat thermally detunes the doubler.

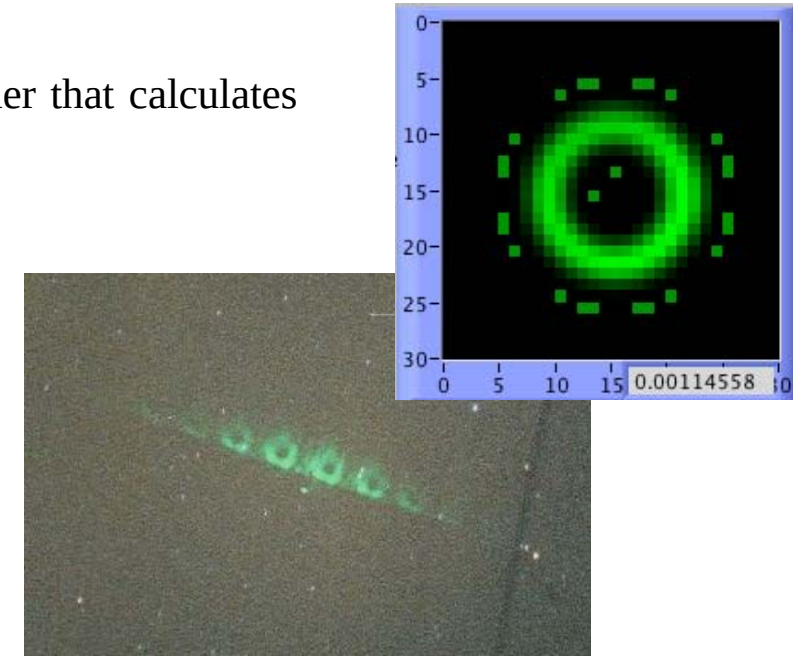
Have Developed a finite element model of GLAS doubler that calculates the optical & thermal properties of the doubler.



Laser-2 On-orbit telemetry



Numerical model



Long-exposure visible light photograph of a GLAS and prediction based on model (inset)

Numerical model qualitatively predicts the observed behavior of Laser-1 & Laser-2

Photodarkening Hypothesis - Cause

Are UV photons causing the reaction ?

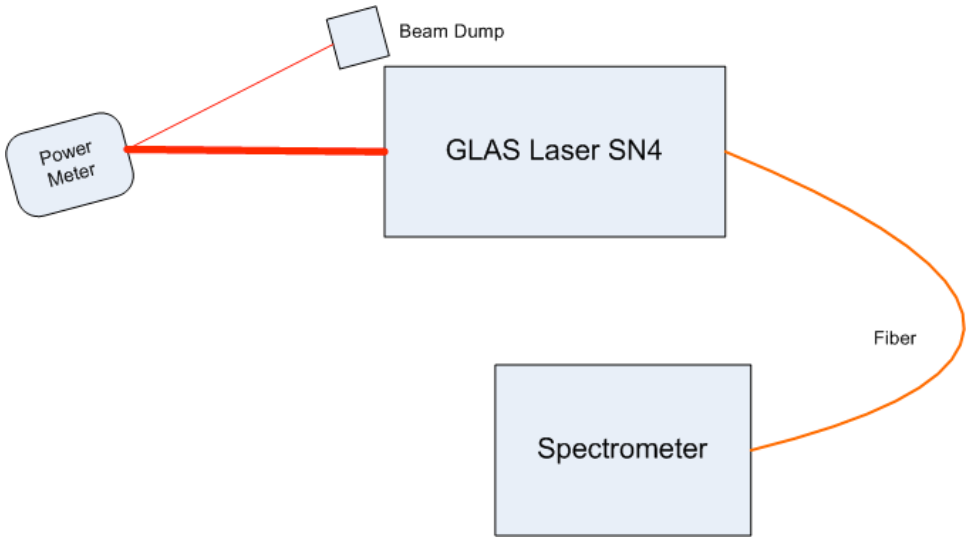
(UV investigation for GLAS Lasers)

Haris Riris

3/14/2006

- Does the doubling crystal generate any measurable UV energy ?
- If so, these high energy photons could be a contributor (or cause) of darkening of trace gases from laser adhesives
- An experiment was performed using the GLAS Laser SN4
- The fiber coupled spectrometer's detection limit was estimated
- **Results - No UV light was detectable from laser**

UV from Doubler ? - Experimental Setup



Power meter: Scientech Average Power Meter

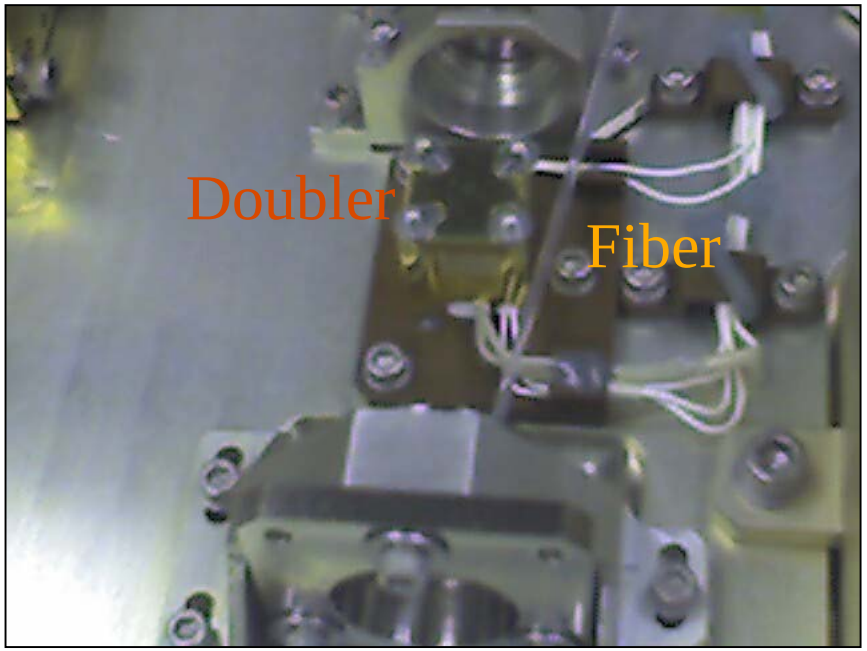
Spectrometer: Horiba Triax 320 with Symphony CCD detector (1024x256 Open-STE http://www.jobinyvon.com/usadivisions/osd/symphony.htm)

Fiber: 600 um core, NA=0.39 with a fiber collimator lens at spectrometer side – bare fiber (no lens) on laser side.
Fiber jacket was stripped from fiber inside laser cavity to minimize contamination

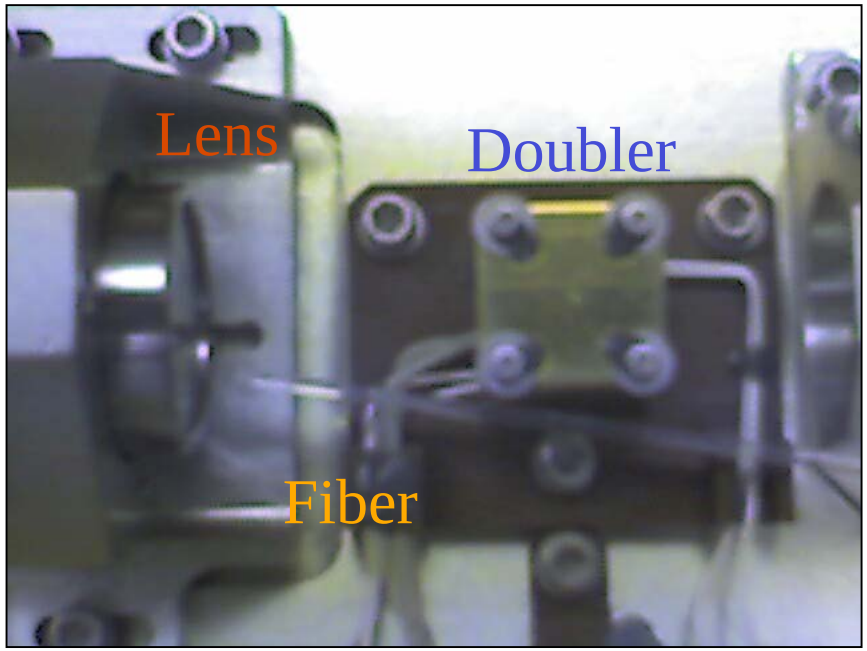
- Laser power: 4.6 W
- Fiber was placed close to first optic after the doubler (beam expander lens) to collect maximum amount of light possible.
- The fluence at lens is high and we have the best chance of collecting any UV light out of doubler.
- Minor adjustments to the alignment between the fiber and spectrometer between scans to optimize placement of various filters and maximize signal.
- Spectrometer shutter was manually triggered (not synchronous with the laser)

UV experiment - Fiber placement & Results

Fiber placement inside the laser cavity



Fiber placement inside the laser cavity (close up)



Results - No detectable UV from doubler

=> Most likely interaction process is a 2-photon effect with 532 nm or 532 & 1064 nm

Photodarkening Hypothesis
Adhesive Suspect: Staking compound

Total # of “dots” (not including inside of Pre-amp and amp module: 286

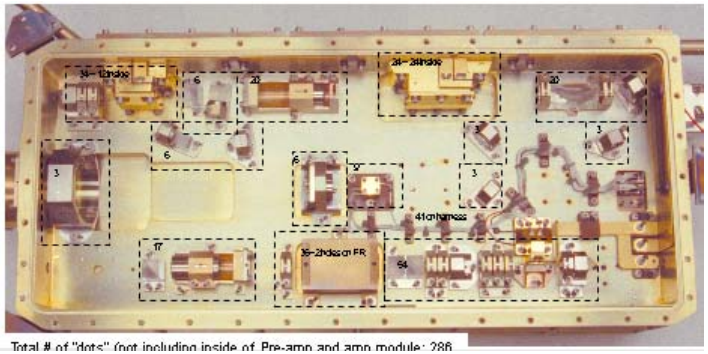
Estimated Volume per dot (assuming a 2mm dia hemisphere): 2.1 mm^3

Estimated Total Volume inside laser cavity: 600 mm^3

Estimated Surface Area per dot: 6.3 mm^2

Estimated Total Surface Area inside laser cavity: 1800 mm^2

Total Volume inside laser cavity 3.62 L



Primary chemical suspects:

Toluene
- or-
A loosely bound polymer in adhesive

Photodarkening Hypothesis - Ongoing Work

Plans:

Introduce known volume of adhesive into a clean vacuum chamber (< 10^{-5} mb) containing a test slide & then a LBO doubler operating at similar intensities as GLAS on orbit.

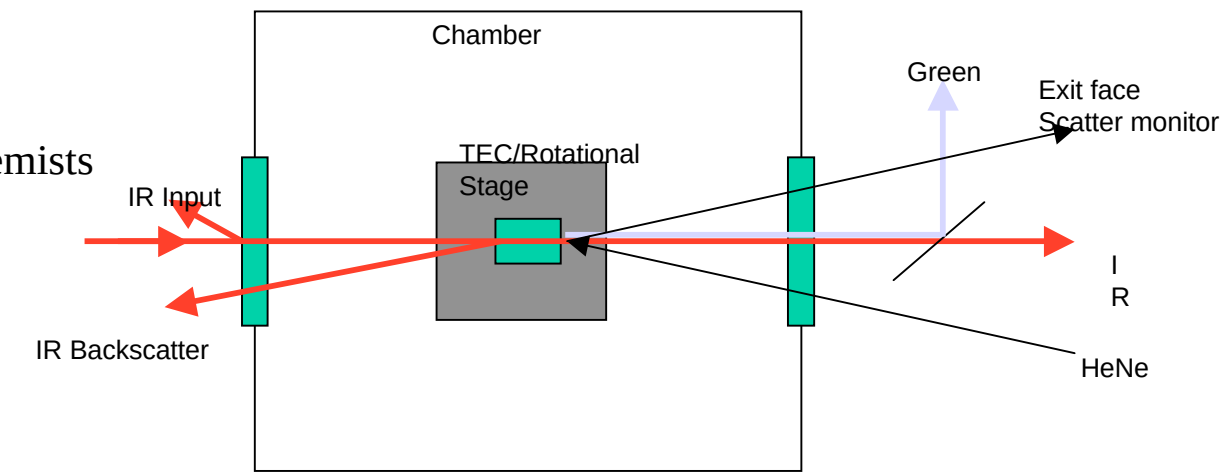
Monitor transmitted 1064 & 532nm energies & beam profiles, scatter from exit and entry face, temperature of the doubler and residual gas within chamber

Status:

Currently vacuum chamber is being tested. A mass spectrometer is being assembled.
The bread board GLAS laser has been re-assembled and is being tested for the source

Next Steps:

Enlist support of UMD photochemists to help guide both theoretical & experimental work



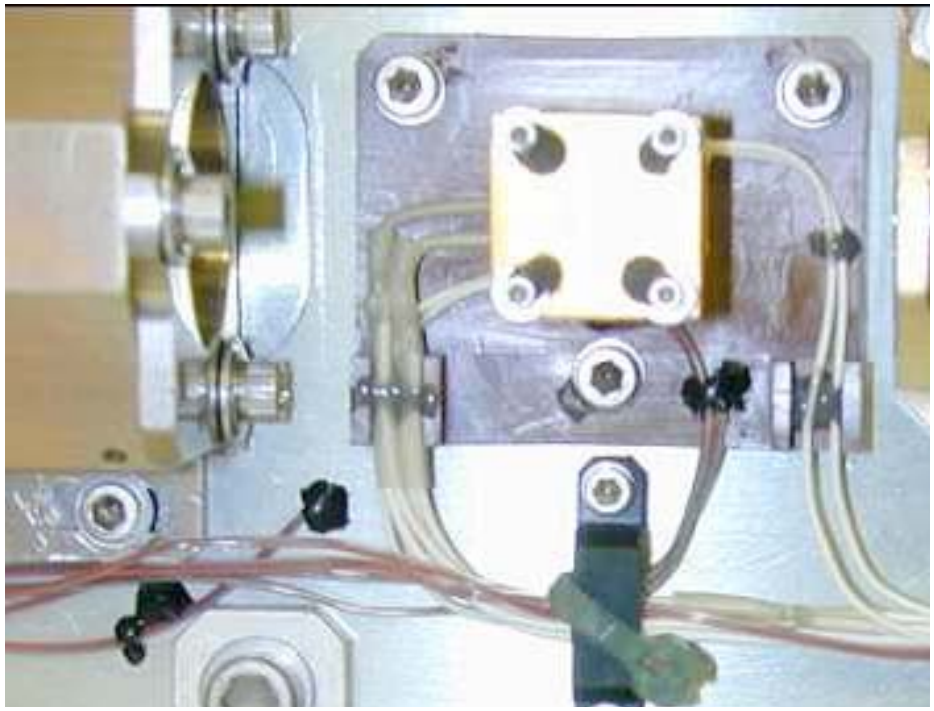
Stability Analysis of the GLAS Laser 3 Doubler

Why does L3 have low 532 nm energy ?

Armando Morell (544)
Craig Stevens (542)

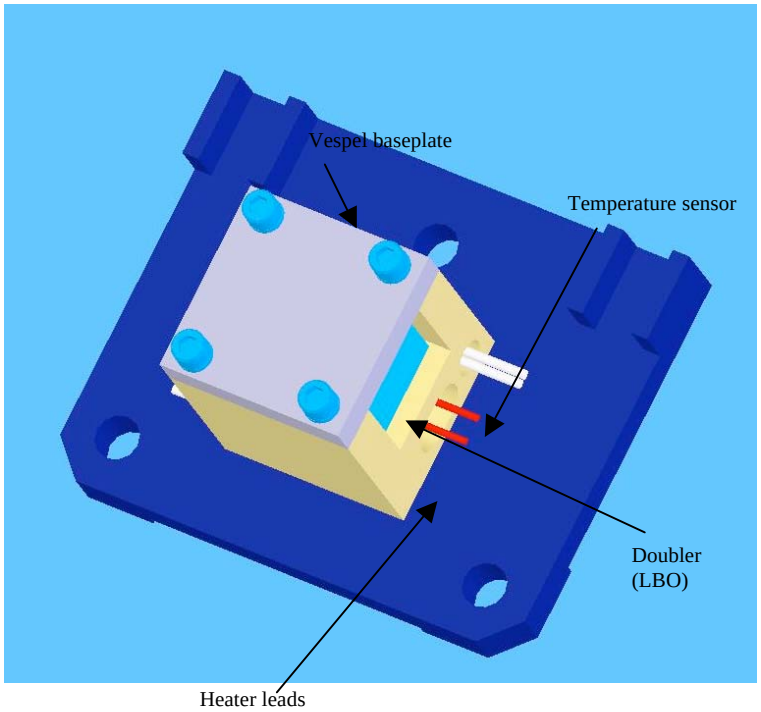
This report summarizes the analysis performed to date regarding the mechanical stability of the Laser #3 doubler.

We have inspected all optomechanically relevant aspects of the GLAS Laser "doubler assembly" in an attempt to explain or identify possible causes for the observable behaviors.

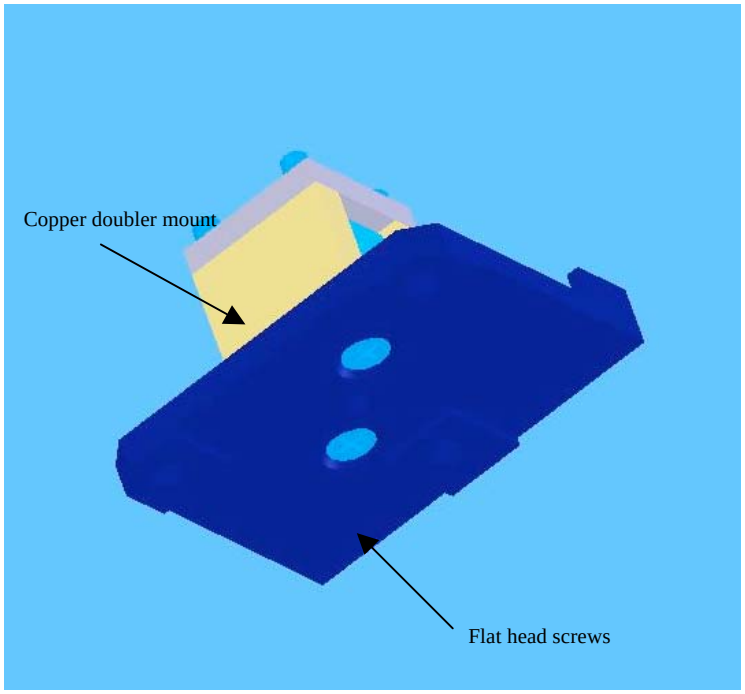


Doubler assembly - Mechanical/thermal model

Front View

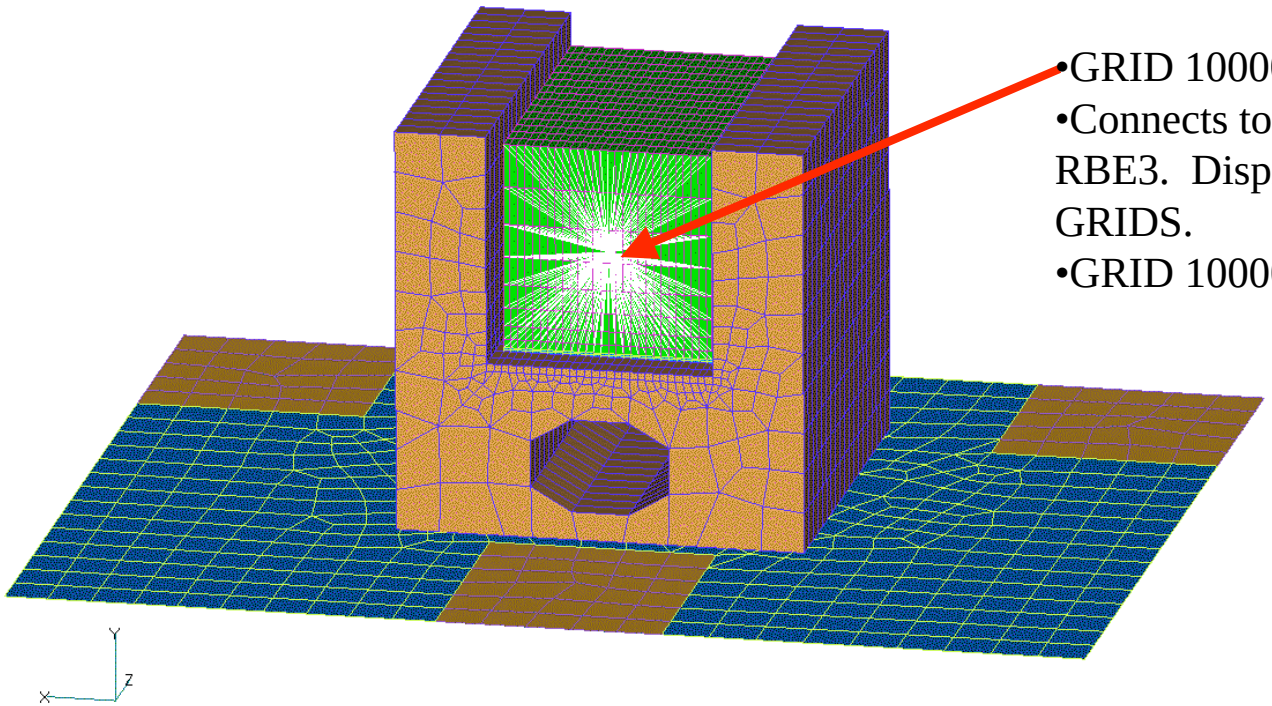


Backside



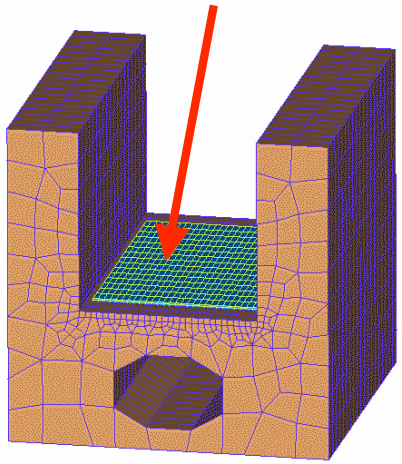
Vespel found (post laser development) to shink in vacuum
Flat head screws not a good approach
Assembly was not pinned & can shift

Doubler Adhesive - Model Details

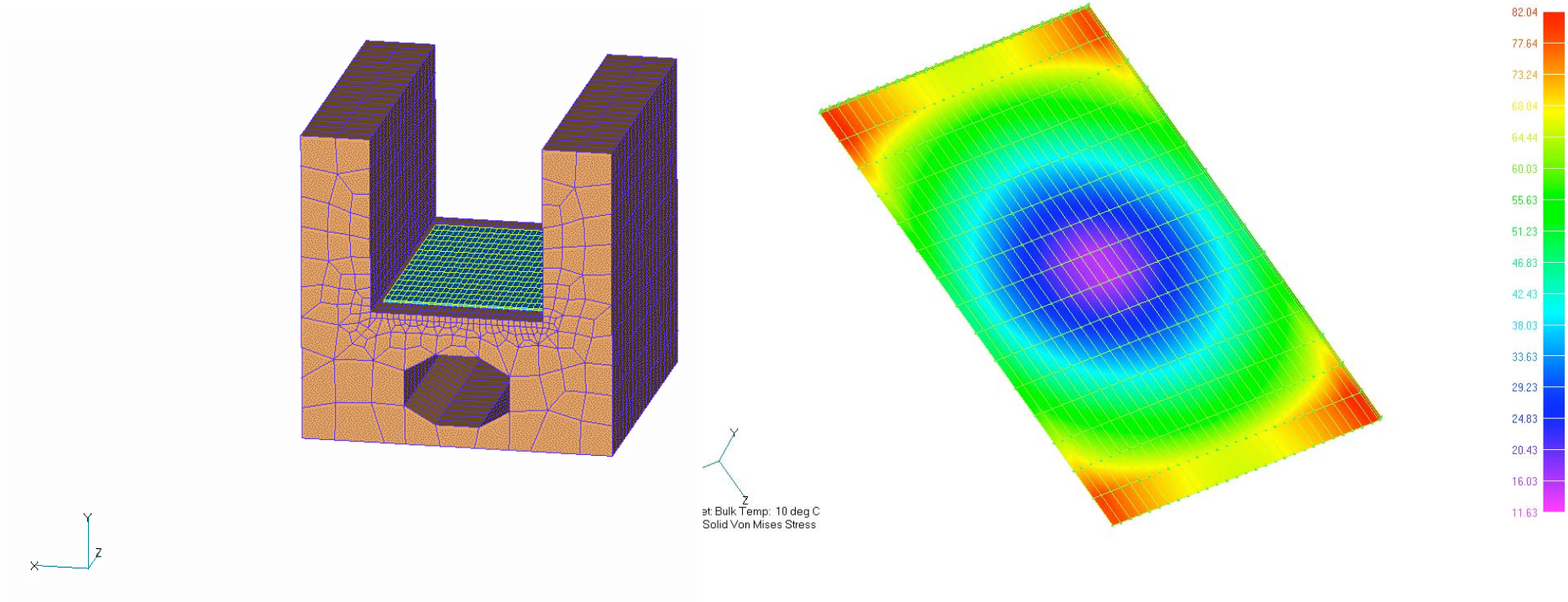


•GRID 100000
•Connects to all –z surface GRIDS using RBE3. Displacement is average of surface GRIDS.
•GRID 100001 is identical for +z surface.

•Adhesive
•Nusil (t = 0.005”)



Doubler Assembly & Nusil Stress



- Nusil allowable lap shear strength is only 125 Psi
- Is negative margin at the Nusil bonded joint for 10 C Bulk temperature change
- The LBO crystal may be partially debonded in Laser 3

Laser 3 Doubler change experiments

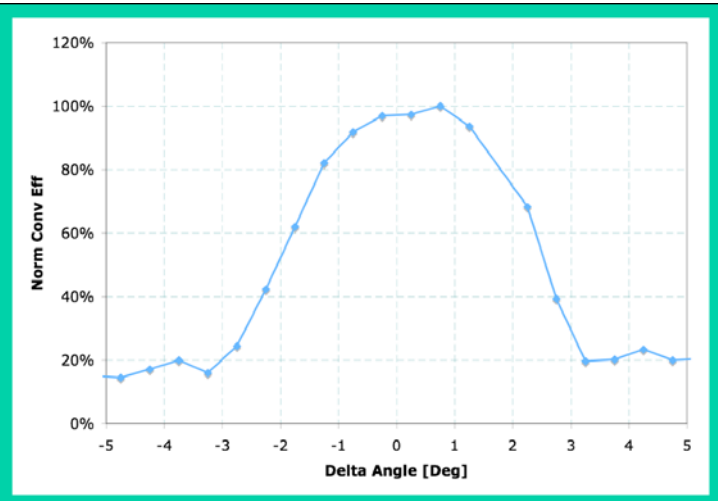
A.W. Yu, G. Allan and E. Dowdye

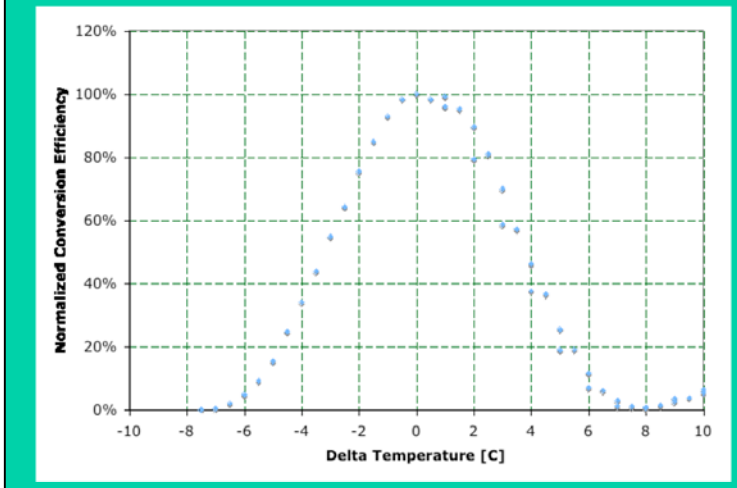
Laser 3 Doubler Change - Primary Suspects

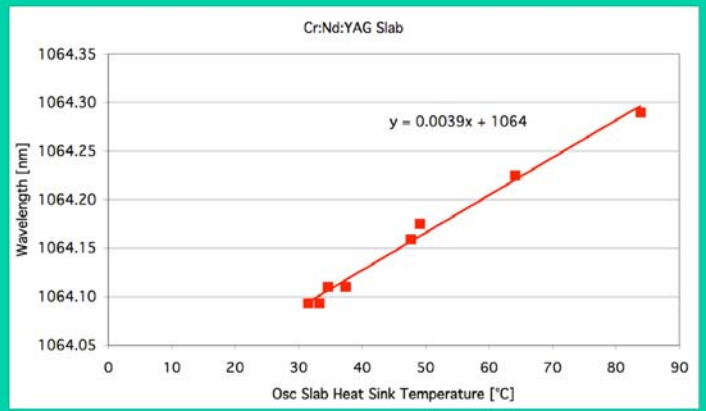
- *Mechanical Misalignment*
  - Analysis shows that doubler mount design not optimal - it may move.
  - Nusil stress shows negative margin. The effects of LBO de-bonding from copper heat sink needs to be investigated.
  - LBO stress is low but effect of stress on doubler performance needs to be investigated
- *Misalignment in Phase Matching Angle*
  - Mechanical misalignment will show as mismatch in phase matching angle which can lower SHG conversion efficiency.
  - Measurements on GLAS breadboard lasers showed a shift in angle of ±3°(~±50 mrad) cause a drop in 80% in conversion efficiency.
- *Temperature Differential*
  - SHG conversion efficiency optimized for LBO inside L3 similar to other lasers.
  - Change in 5°C in temperature will cause ~80% drop in SHG conversion efficiency.
  - If Nusil bond is compromised, then LBO crystal my have:
    - a temperature gradient
    - An average temperature which is low

Laser 3 Doubler Change - Experiments

Plots show Breadboard & Flight
Laser Measurements prior to delivery
Recent measurements on ETU
showed similar behavior







Present Hypothesis:

Most likely a combination of temperature and mechanical misalignment causing a drop in SHG conversion efficiency.

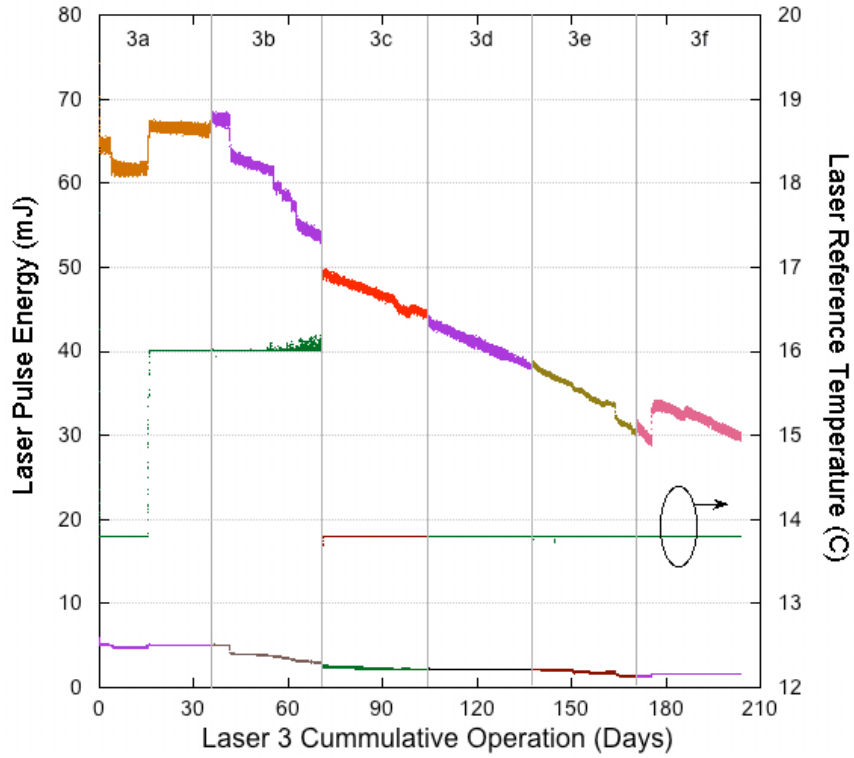
This may cause a temperature gradient along the optical axis of LBO.

The effect of the temperature change & gradient on SHG conversion efficiency are being investigated.

GARB Status Summary

GARB - better determine causes of on-orbit laser performance & help optimize mission

- Recent & ongoing work:
  - Laser 3 “fire acquisition” signal drop out risk & potential impact
  - Laser 3 Energy history slope change
  - Energy step changes (bar drops)
  - Photodarkening hypothesis (L1 & L2)
  - Laser 3 Doubler investigation



If Laser 3 energy trends continue:

- Expect ~4 more campaigns to 10 mJ
- Raise laser temperature
- Several (2 or 3) campaigns after that
- Use Laser 3 at < 10 mJ
- Then use Laser 2

Backup

GLAS Laser Oscillator Stage Current Analysis

Robert Afzal

Updated 7/11/06

Summary:

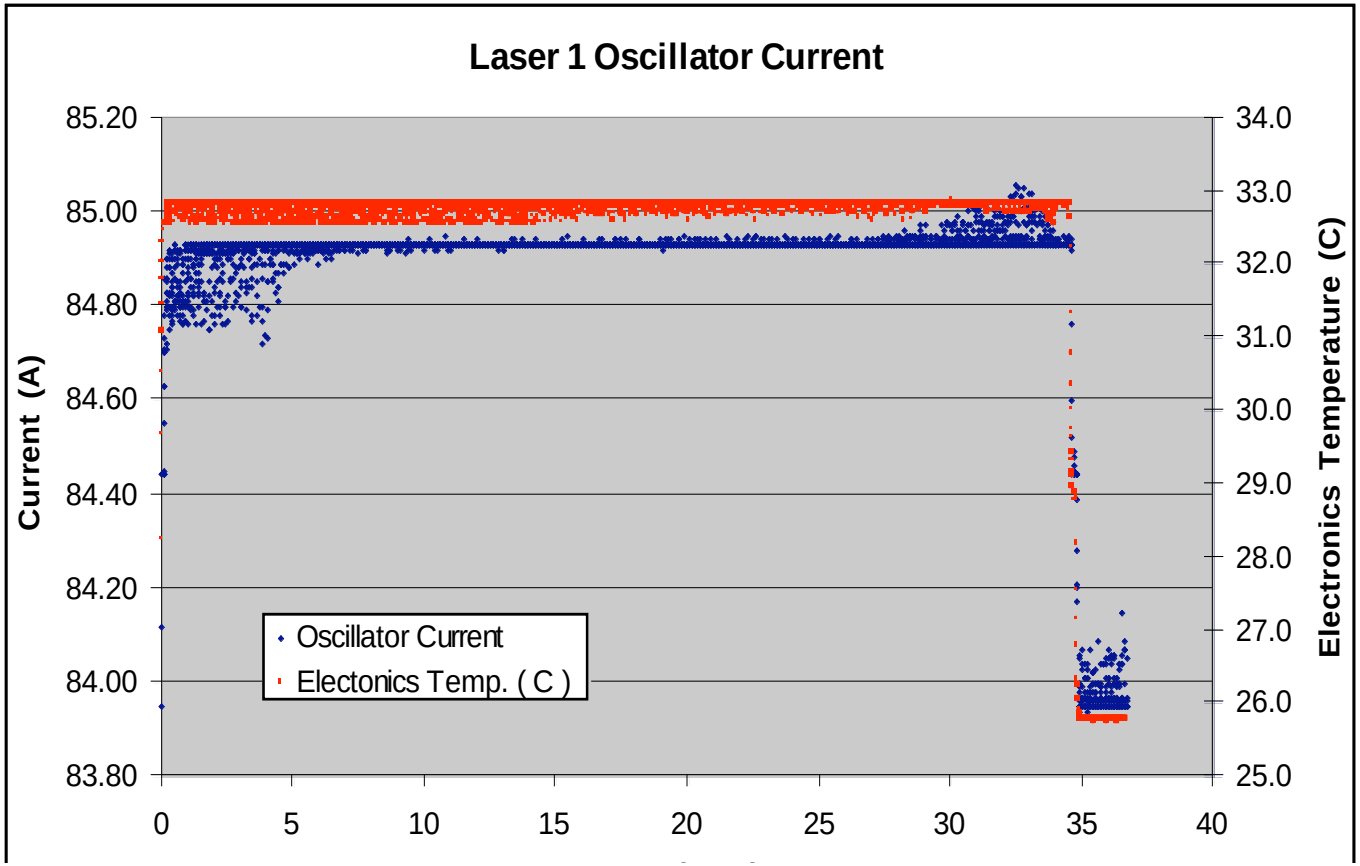
- Oscillator current drive is monitored separately
- Performance history analyzed via its (slow) rate of current increase
- Done for all lasers through L3f
- Results agree with pre-launch predictions
- Power Law Extrapolation is > 2 years for all Lasers
- Temperature dependence consistent with pre-launch measurements for large DT
- (see appendix of report for details)

Analysis Goals

- **Review Oscillator current values of Laser 3,2, &1.**
- **Determine if performance is consistent with prelaunch expectations.**
- **Review trends.**
- **Make assessment for the continued Laser 3 ops.**

- **Method:**
  - **For all campaigns of Laser 1, 2 and 3 plot Oscillator Current along with Laser Electronics temperature as best indicator of oscillator slab temperature changes.**
  - **Extrapolate linear trend to 100 A**

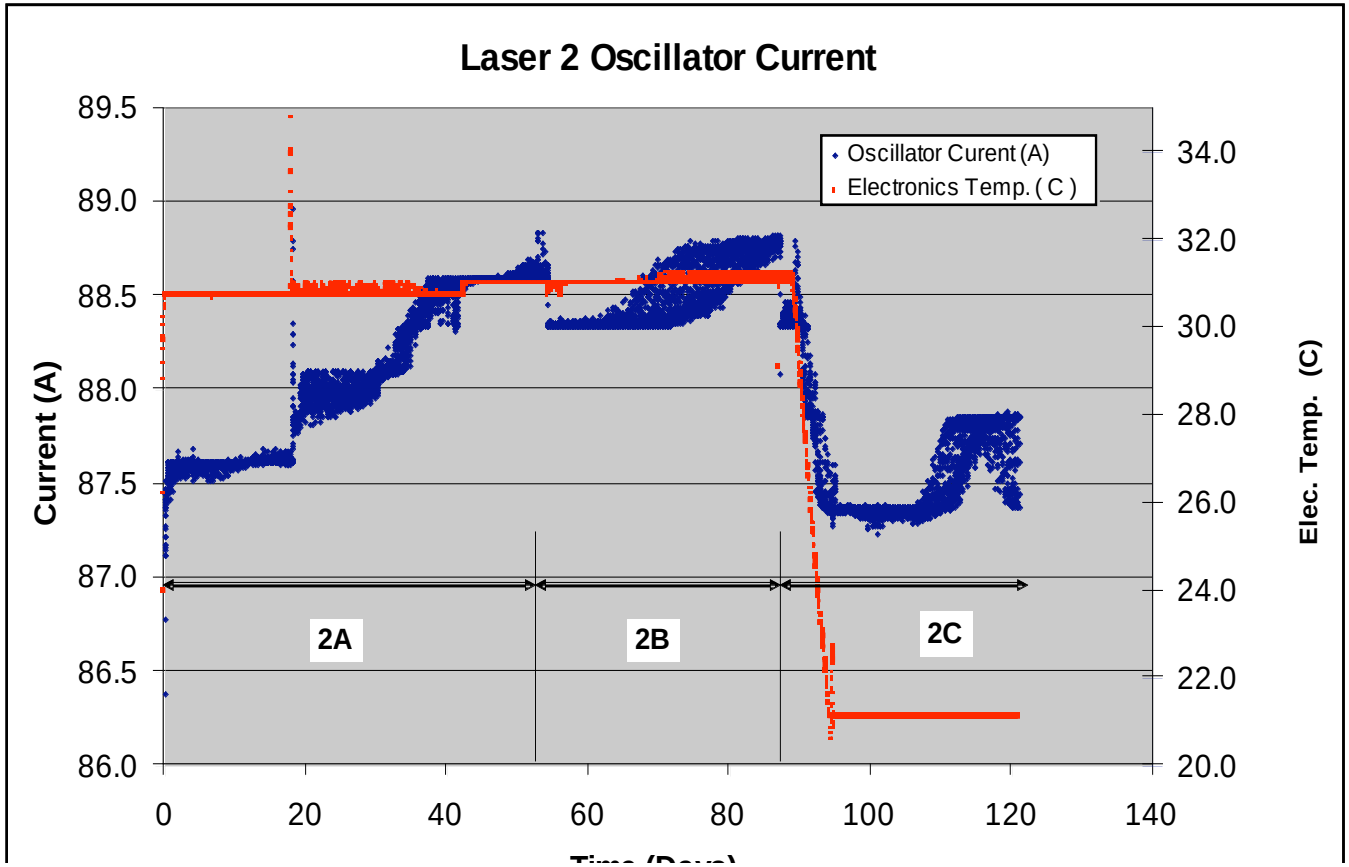
Laser 1



One Campaign =37 days
Decay trend (34 days) = 0.0014 A/day
Extrapolated Trend > 10,000 days

Temperature Change = 7 C
Temperature dependence = 0.14 A/C
Pre Launch SN2 = 0.14 A/C

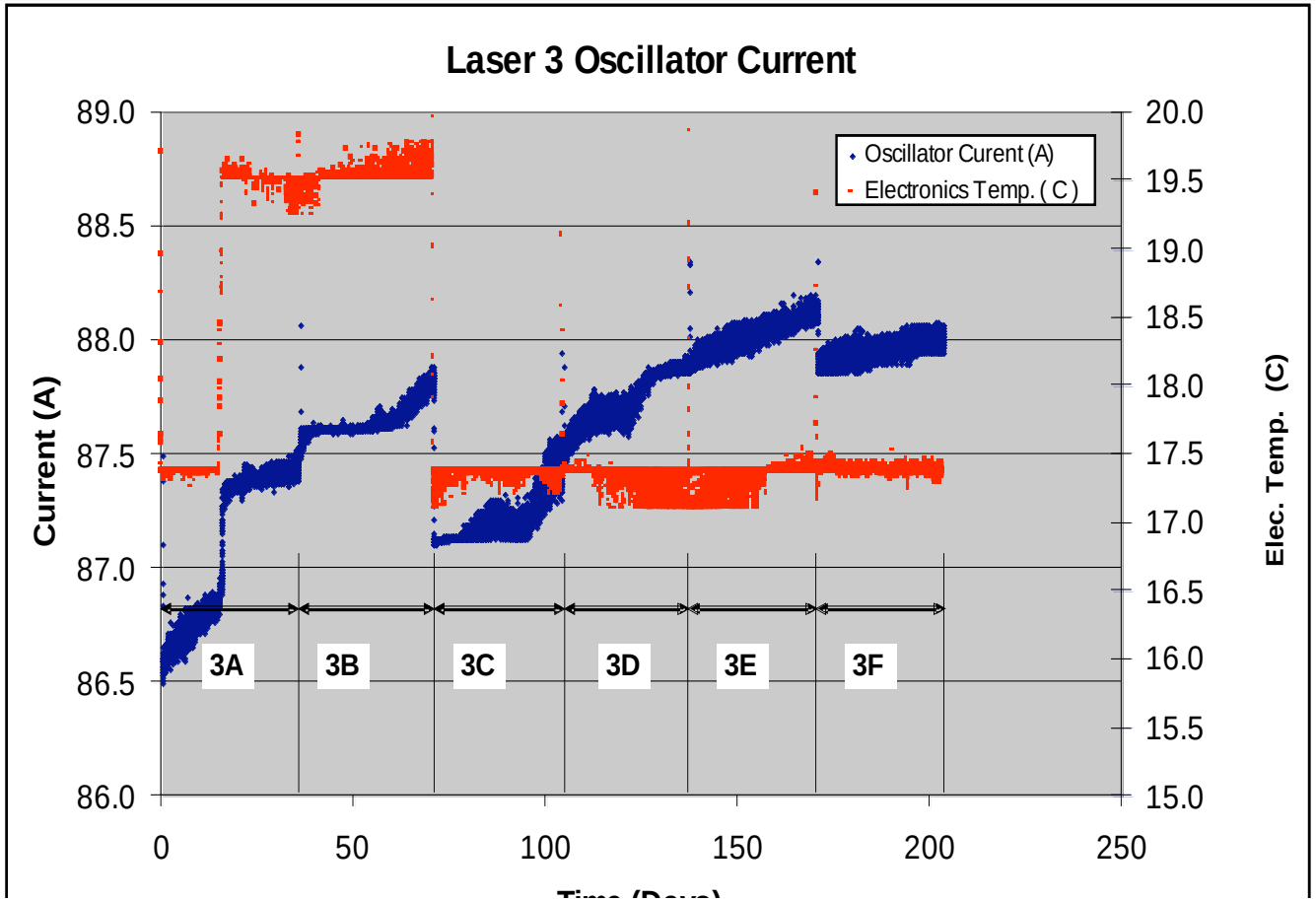
Laser 2



Three Campaigns = 121 days
Decay trend (2A, 2B) = 0.021, 0.013 A/day
Campaign 2C = ?
Extrapolated Trend = 700 days @ 0.017 A/day

Temperature Change = 10 C
Temperature dependence = 0.14 A/C
Pre Launch SN3 = 0.13 A/C

Laser 3

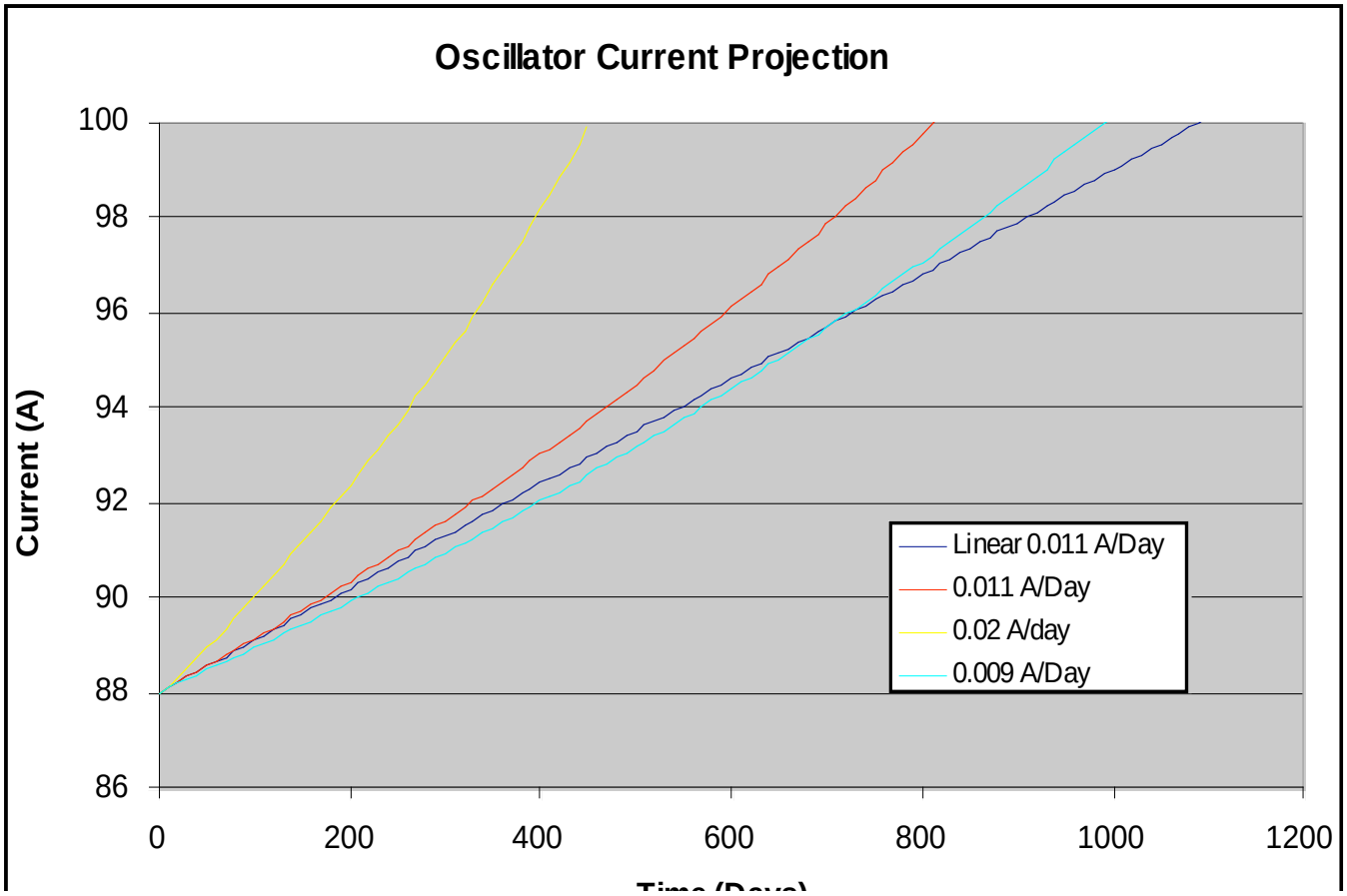


Six Campaigns = 204 days
Decay trend (3A → 3F) = 0.007 A/day
Extrapolated Trend > 1000 days @ 0.007 A/day

Temperature Change = 2.14 C
Temperature dependence = 0.21 & 0.31 A/C
Pre Launch SN1 = 0.15 A/C

Life Projection

- **Using Power derating relationship derived from life tests: $Life_1 = Life_2(P_1/P_2)^{3.5}$**
- **Plotted Current projections with differing initial decay rates**
- **2 years life projection**



Estimating Laser Degradation Rate from Osc Pump Diodes

- What can be inferred we about the amplifier diodes from this ?

- Oscillator Current degradation rate is about 0.011 A/Day
  - 0.012 W/Day at constant current
- Derating relationship from GSFC/SDL tests:
  - Amp bars 100 A and Osc bars at 88 A.
  - $Life_1 = Life_2(P_1/P_2)^{3.5}$
  - $X = 0.012\ (85\ W/67\ W)^{3.5} = 0.012*2.3$
- Implies Amp & preamp bars decaying at 0.028 W_{peak}/Day
- From Modeling:
  - Amp: 75 W lost from 44 bars = - 4 mJ
  - Preamp: 75 W lost from 8 bars = - 14 mJ
- Expected Energy Decline
  - Amp: 0.028*44/75 x 4 = 0.065 mJ/day
  - Preamp: 0.028*8/75 x 14 = 0.042 mJ/day
  - Total Energy Decline = 0.11 mJ/day

- 0.11 mJ/day is consistent with Prelaunch expectations.
- Observed Decline Rate = 0.2 mJ/day
- ½ observed decay from diodes & ½ from another source?

GLAS Laser Fire Acknowledge Analysis

Robert Afzal

GARB Presentation

11/15/05

Purpose

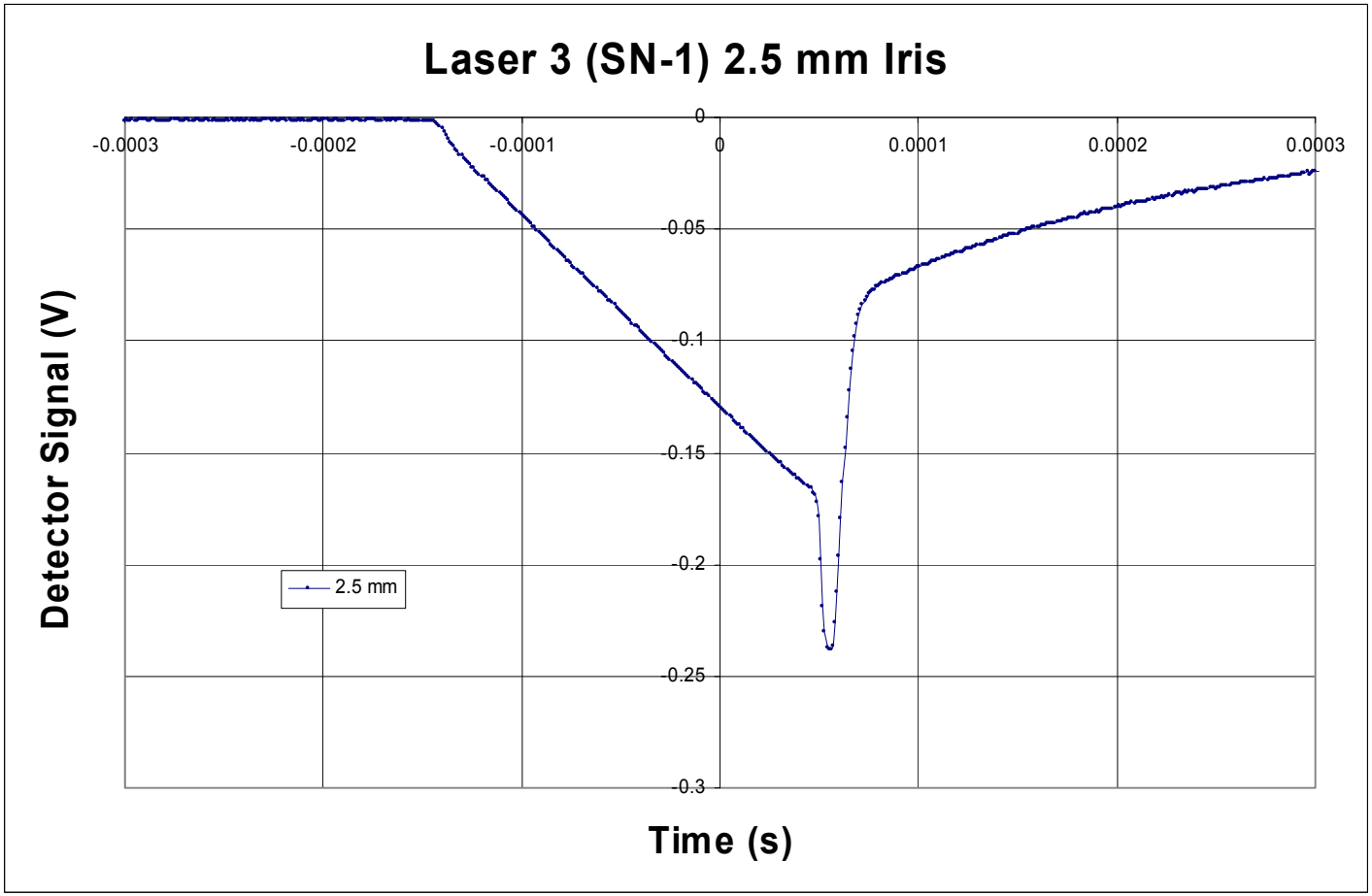
- Can analysis of the laser Fire Acknowledge (Ack.) signal tell us anything about the performance of the GLAS lasers?

- Background: Each laser has a built in Fire Ack. detector that determines when the laser pulse is emitted and switches off the current to the diodes. This timing signal is also used in the laser power supply feedback loop that regulates the current to the oscillator diodes keeping the pump time at 200 μsec.

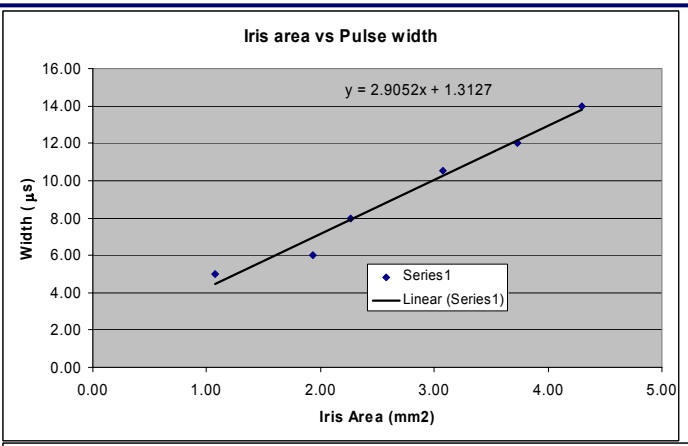
- Motivation: Laser 2 had decayed to 5 mJ/pulse. Could the fire ack. Detector still be getting enough signal at this level to maintain regulation? If not it's possible the laser was generating more than 5 mJ but not all the energy was being emitted by the transmitter.

Laser 3 (SN-1) Signal

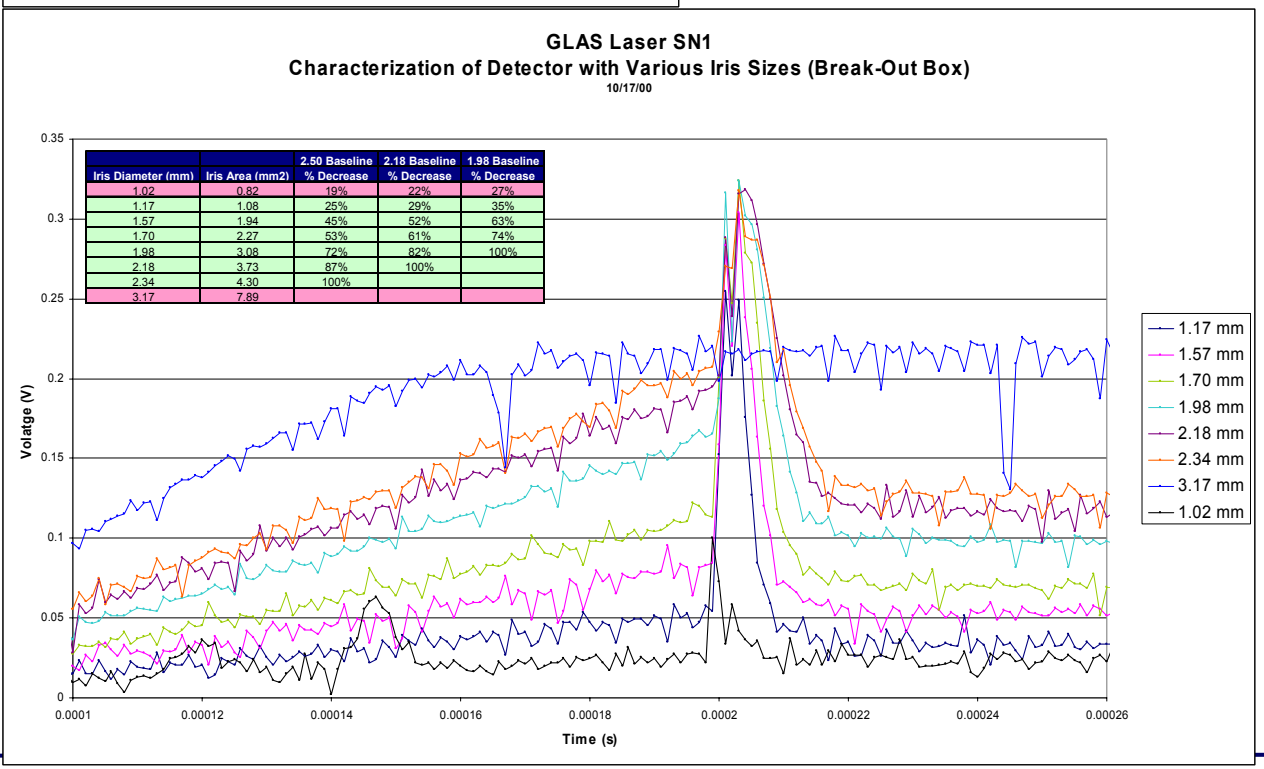
Example of a Fire Ack. signal during the build of SN-1. One can see the build up of signal from the florescence followed by the laser pulse. In this case, at full power, the response is about 10 µs. In other data following the impulse is closer to 1 µs.



Iris Area Dependence



The bottom plot is of detector signal vs iris area. The laser finally comes out of saturation at 1 mm. The laser multi-pulses as expected. Each individual pulse is probably around 25 mJ. The iris we typically flew were about 2.5 mm or about 4x the area. That means laser comes out of saturation around 8 mJ.

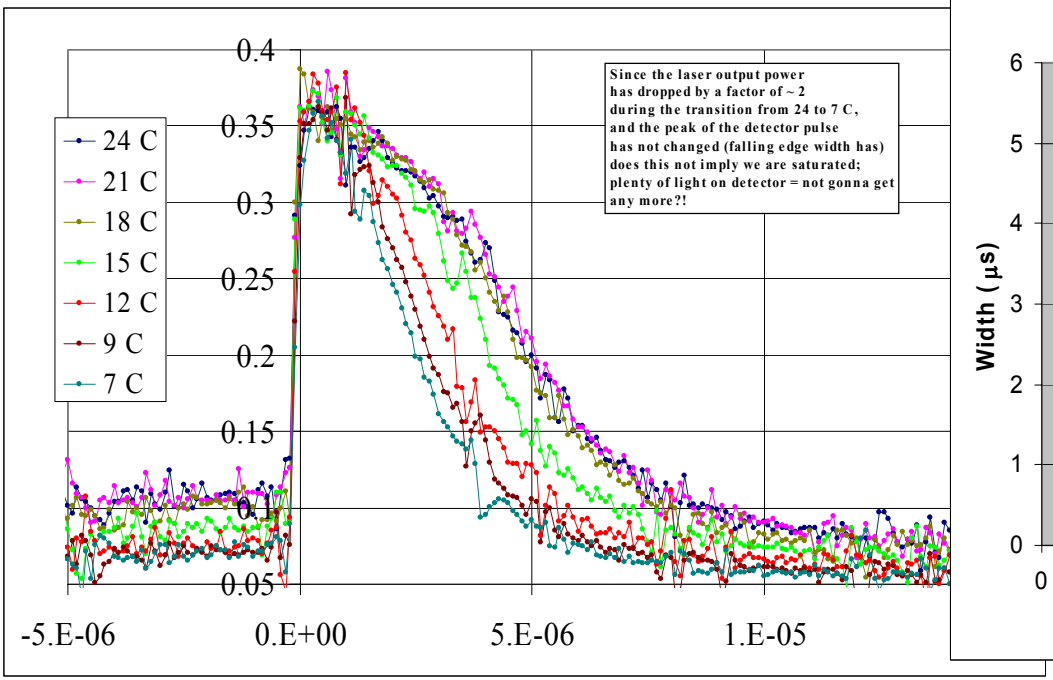


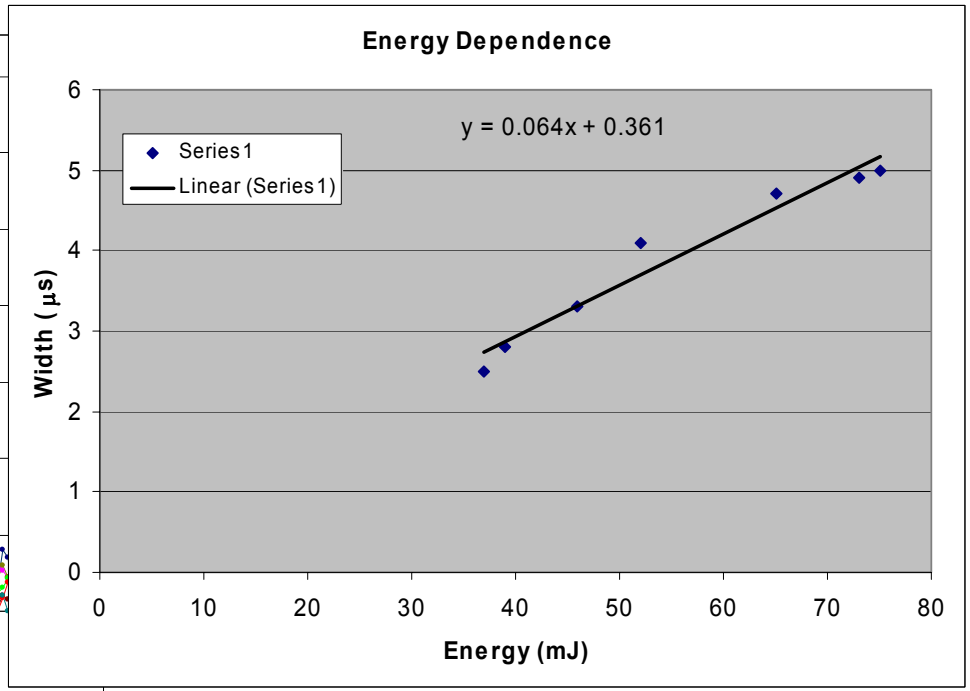
Iris Diameter (mm)	Iris Area (mm2)	2.50 Baseline % Decrease	2.18 Baseline % Decrease	1.98 Baseline % Decrease
1.02	0.82	19%	22%	27%
1.17	1.08	25%	29%	35%
1.57	1.94	45%	52%	63%
1.70	2.27	53%	61%	74%
1.98	3.08	72%	82%	100%
2.18	3.73	87%	100%	
2.34	4.30	100%		
3.17	7.89			

ETU Measurements

During ETU TVAC the Fire Ack. Signal was measured vs. temperature. The laser energy is about ½ energy at 7 C from the peak at 24 C. The detector is clearly in saturation but the pulse half width changes with energy. A plot of half-width vs energy taken from ETU TVAC show the width is roughly linear with energy.

Using a linear fit, the detector comes out of saturation at about 10 mJ. The fire ack signal stops functioning when the signal drops below 200 mV. Scaling from 10 mJ means 6 mJ would be the minimum pulse energy.





Conclusions

- It seems the laser should still be operating in regulations to energies less than 10 mJ.
- It is inconclusive regarding the operation of Laser 2 whether 5 mJ should have still been able to exceed the Fire Ack. threshold.

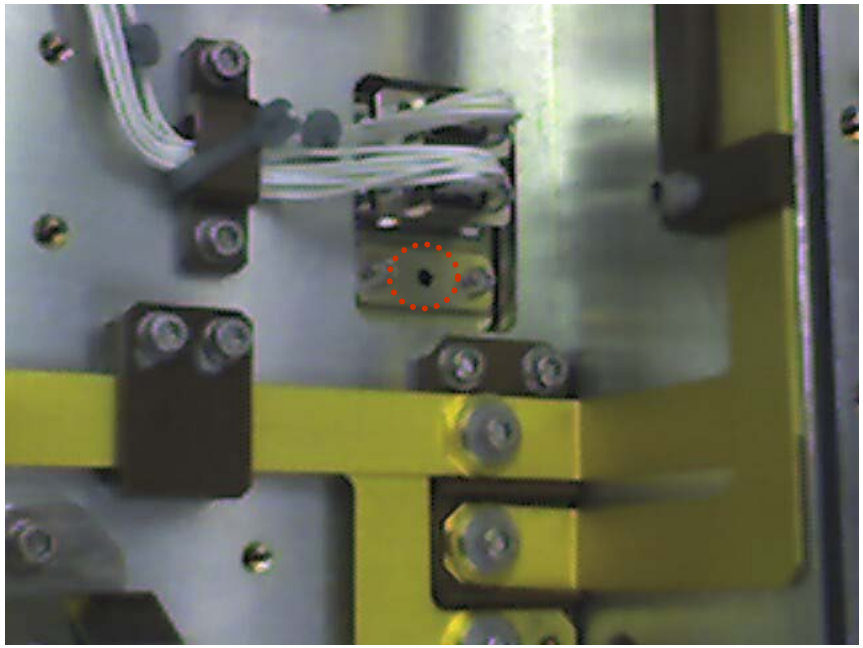
- Resolution of this issue could be obtained by continuing to operate Laser 2 until it losses regulation.
- Possibly more information could be gained by performing a power dependent signal level test on SN-4.

Fire Ack. Investigation for GLAS Lasers

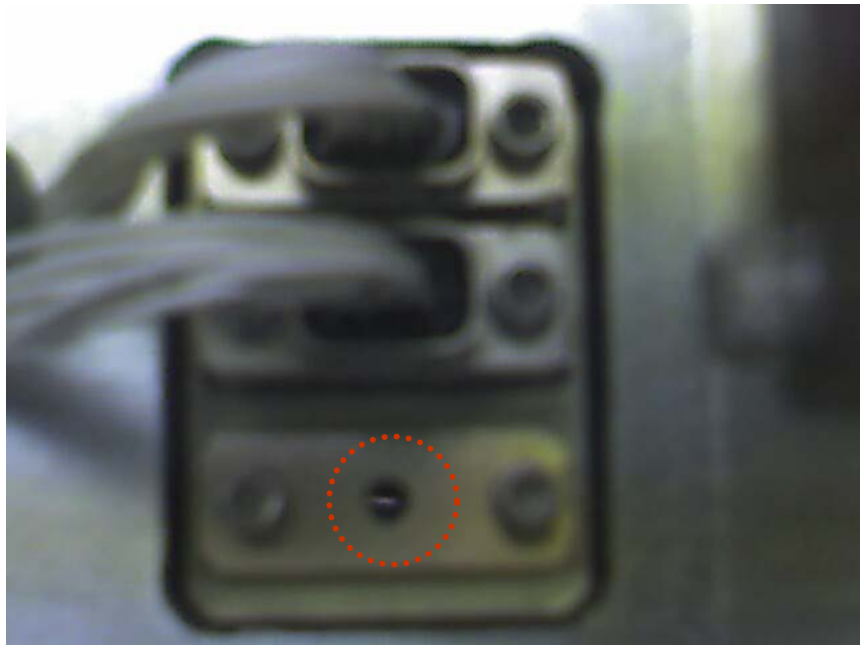
Haris Riris

4/24/2006

Fire Ack. Detector Location



Location of Fire Ack. Detector

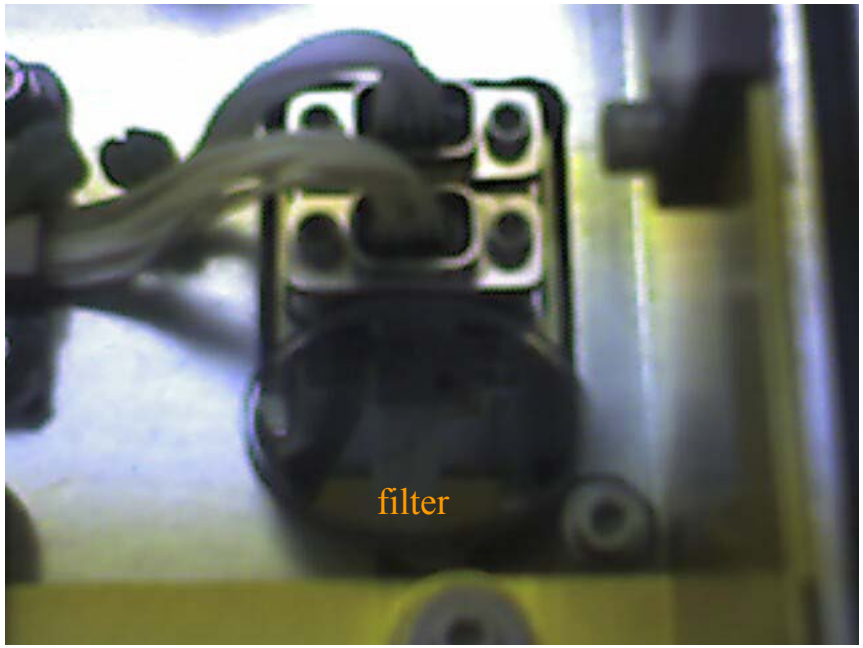


Location of Fire Ack. Detector (close up)

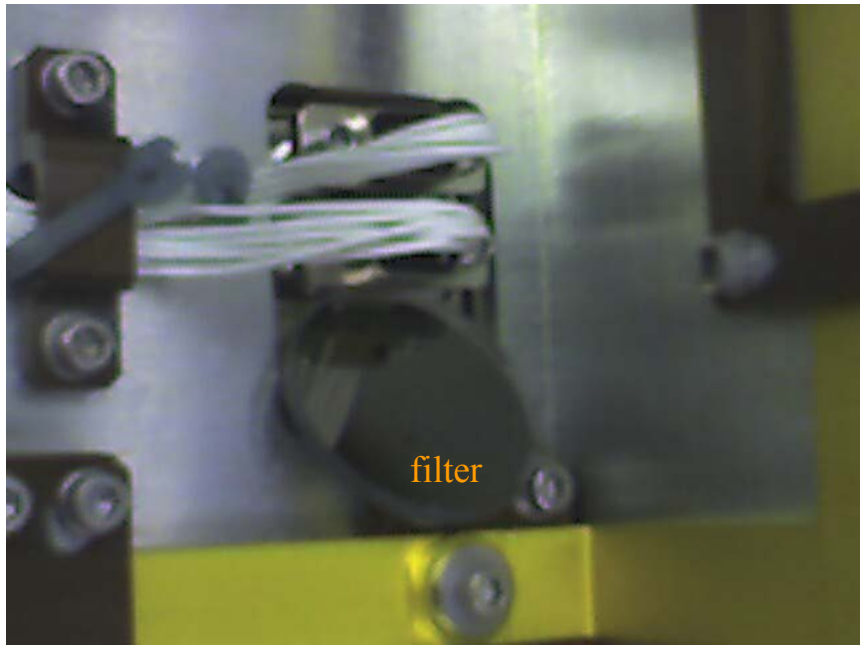
Experiment #1 (cont.)

- Different ND filters were placed on top of the detector. However, due to the size of the filters and the mechanical constraints of the laser box, the filters still left a small (2-4 mm) gap through which light could scatter into the detector.

Experiment #1



ND filter on top of the detector
(top view)



ND filter on top of the detector
(side view)

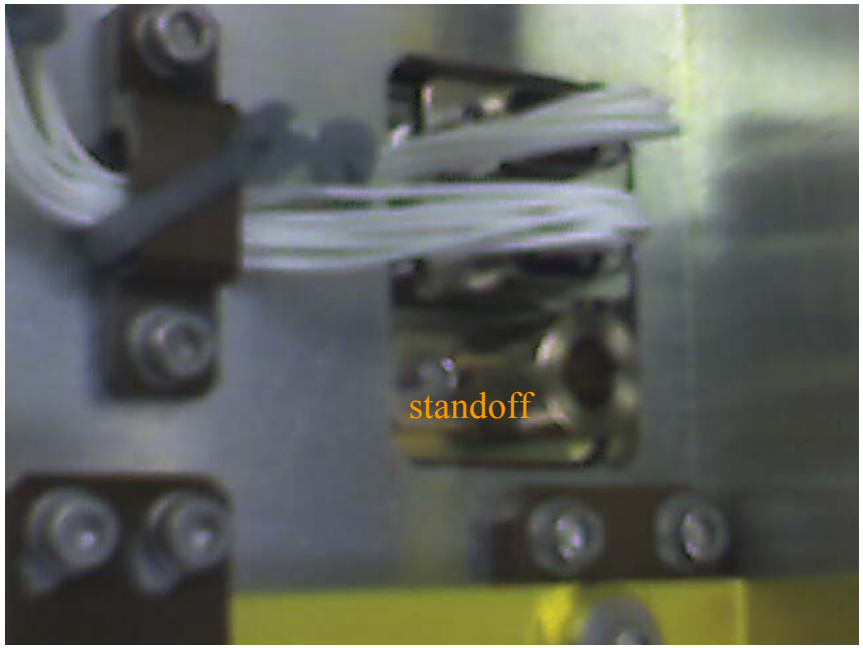
Experiment #1 (cont.)

- Filters with a combined ND 6.1 (4.1+1.99) attenuation were placed on top of the detector and the laser still operated normally.
  - Drive pulsewidth ~ 199-200 us
  - I_{osc}~ 80 A
  - I_{amp}~ 95-96 A
  - Power ~ 4.5-4.7 W

Experiment #2

- In order to block scattered light entering the detector below the filters we placed a small cylindrical stand-off on top of the detector (diameter$_{in}$=0.2 in, height=0.5 in) and then placed the ND filters on top of the standoff.
- Assume uniform scattering distribution .
- Assume that the viewing (solid) angle of the detector without the standoff is 2π.
- The viewing (solid) angle of the cone subtended by the detector *with* the standoff is $\pi\{1-\cos(0.1/0.5)\}$.
- The reduction in solid angle with the standoff is ~ 50.
- The laser operated normally with no filter placed on the standoff.

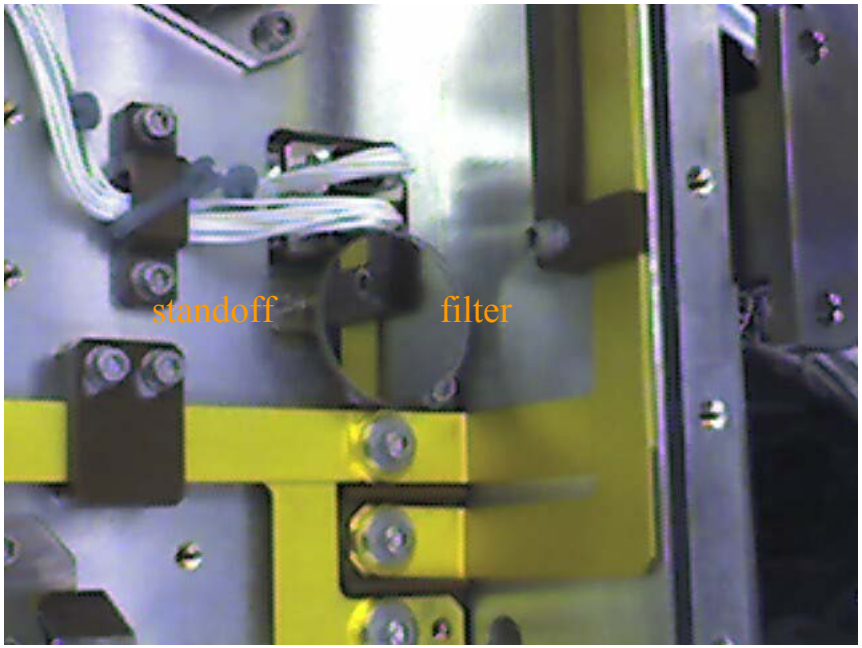
Experiment #2



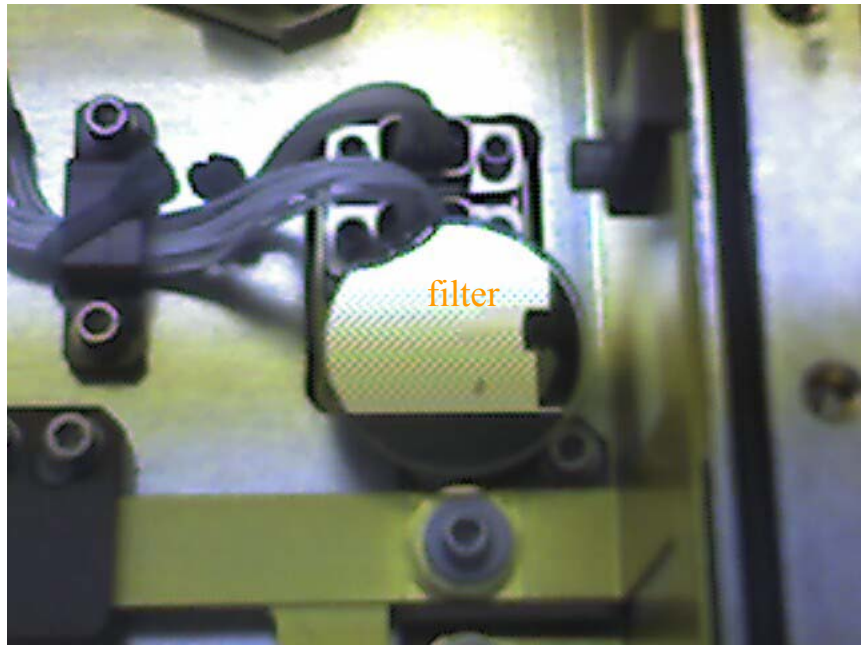
Standoff placement (side view)

Standoff placement (top view)

Experiment #2



Filter placement (side view)



Filter placement (top view)

Experiment #2

ND	Pulsewdith (us)	I osc (A)	I amp (A)	Power (W)
No filter	199	80	94	4.6
0.04	199	80	94	4.6
0.3	242	94	95	2.8
0.6	242	95	94	2.7
0.9	242	95	94	2.8
1.28	242	94	94	2.8

Summary

- Without the standoff, the Fire Ack. detector operated with a ND of 6.1.
- With the standoff, the Fire Ack. Detector operated with an ND0.04 but not an ND0.3. The total attenuation due to the standoff and the ND is:
  - 50 x (ND0.3) = 100
  - 50 x (ND0.04) = 45

  So the fire ack. Detector will stop working between:

  115mJ/100 = 1.15 mJ and 115mJ/45=2.5 mJ.

  This result assumes a uniform scattering distribution over 2π. The distribution is probably not uniform. The actual value is slightly higher, closer to 5mJ-10mJ depending on the distribution.

  This value is consistent with previous estimates by R. Afzal based on Fire Ack. signal strengths during the laser built.