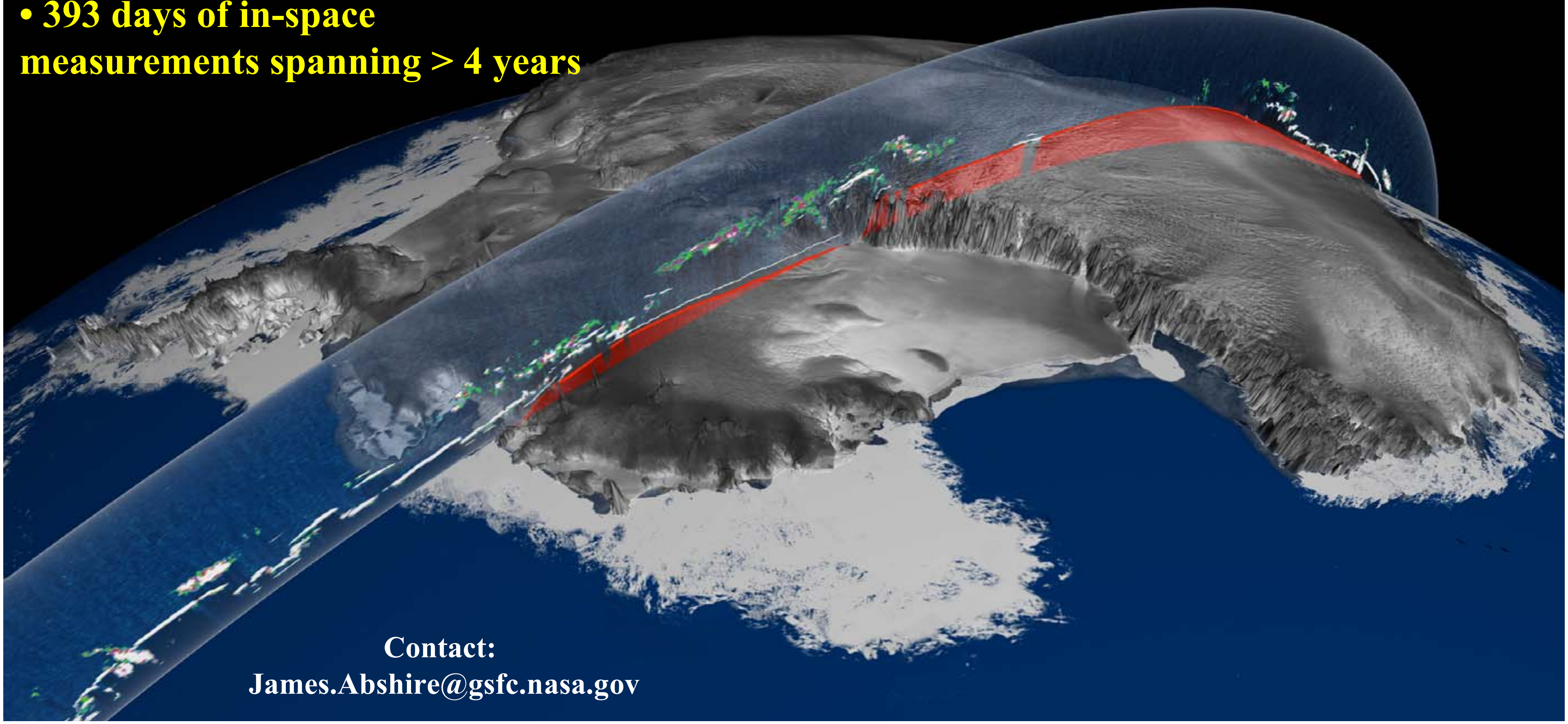
Geoscience Laser Altimeter System (GLAS)
Update to Science Team

GLAS Instrument Team and GARB

October 1, 2007

- **1.4 Billion measurements**
- **393 days of in-space measurements spanning > 4 years**



Contact:
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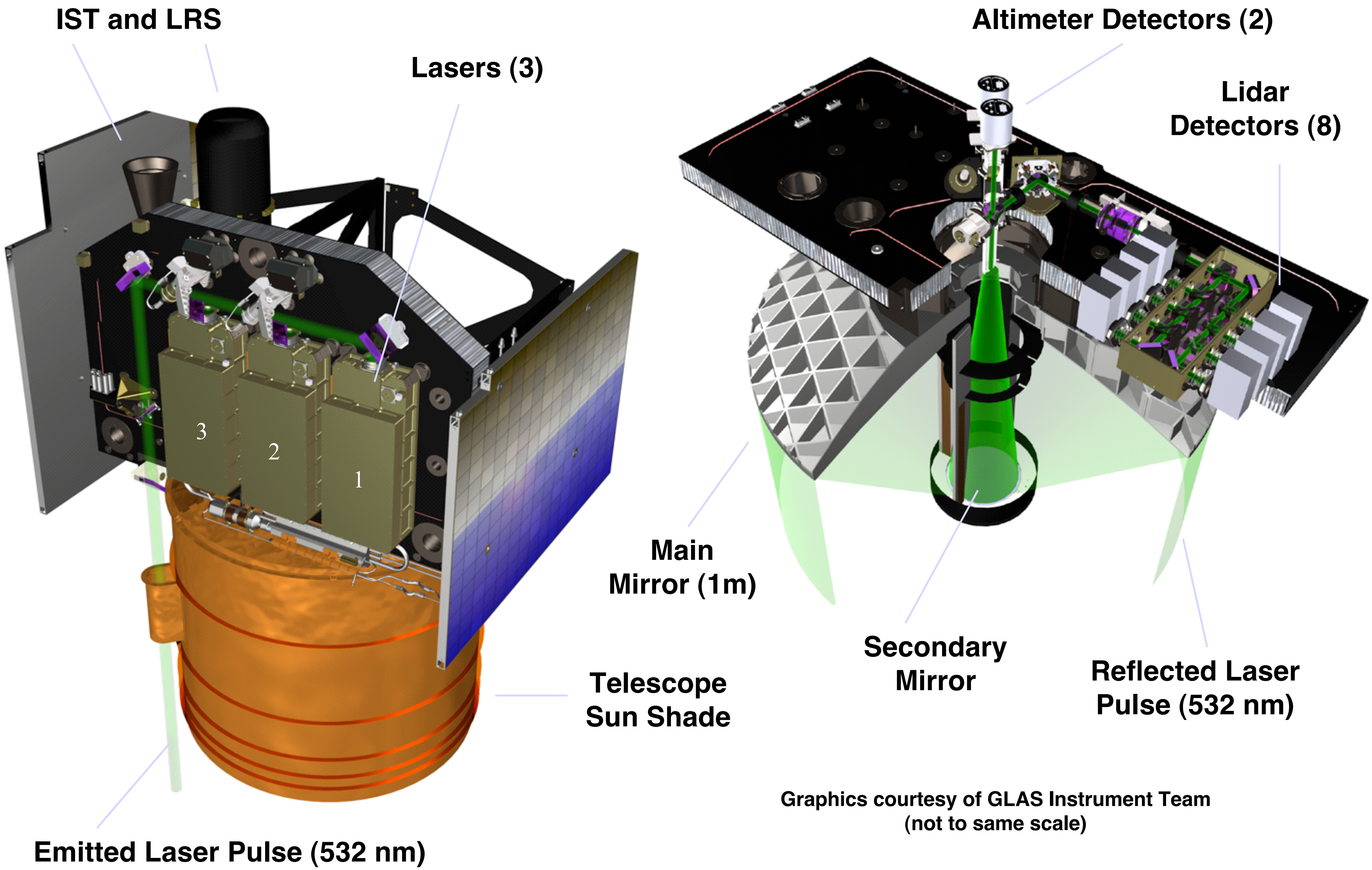
Outline

- GLAS overview
- Energy History
- Extrapolated Laser 3 lifetime
- Recommendation for Laser 3i operations & beyond & rationale
- GARB recommendations for future space lidar missions
    - (Section 6 & 7 from larger briefing)
- Appendices:
    - Temperature effects on laser energy (Rob Afzal)
    - Impacts of pump bar “drop outs” vs # of bars (Tony Yu)

1. GLAS Instrument



Graphics courtesy of GLAS Instrument Team
(not to same scale)

3. GLAS Laser Measurement Campaigns (12 so far)

Laser firings through 9/14/07

Total:

GLAS Laser Shot Counter

01,477,412,119

Total number of on-orbit shots emitted by Lasers 1, 2, and 3 since February 2003. ICESat has completed 12 science campaigns and is currently in science hiatus between campaigns.

Laser 3:

GLAS Laser 3 Shot Counter

00,933,051,520

Individual laser pulses shot by GLAS Laser 3 starting on October 3, 2004 and continuing through eight science campaigns. Currently, ICESat is science hiatus between campaigns.

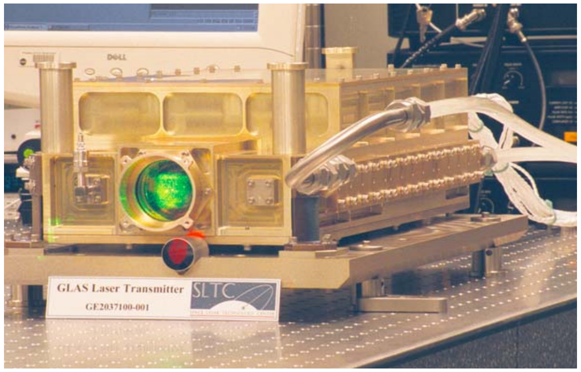
ICESat/GLAS Operating History

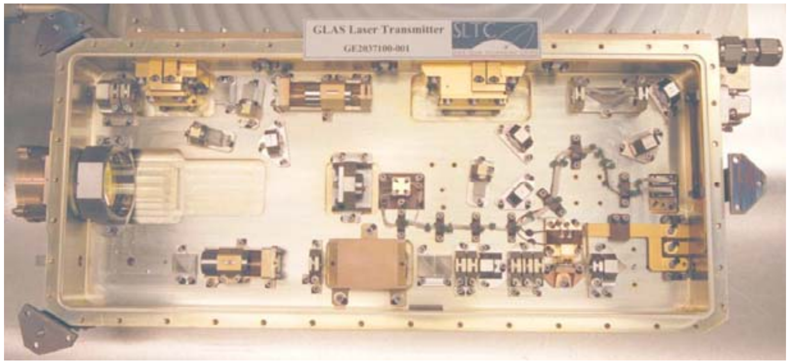
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003			L1							L2a		
2004			L2b			L2c				L3a		
2005			L3b			L3c					L3d	
2006			L3e			L3f					L3g	
2007			L3h						Now ↑	L3i		
2008			…									

5-6 more campaigns planned

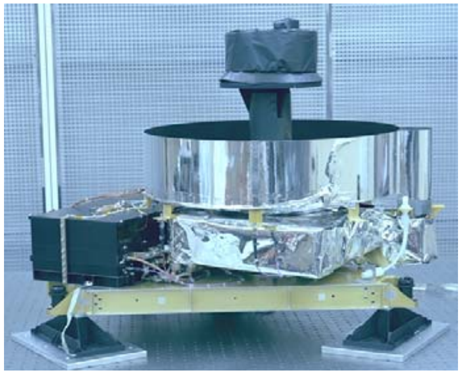
GLAS Flight Laser Firings (Millions)
through 9/14/07

	Laser 1	Laser 2	Laser 3	TOTAL*	% of Mission Goal (3,784M)	Comparison to MOLA
Ground Testing*	158.8	140	128.8	427.6	11%	63% on orbit measurements
On-Orbit*	126.8	417.5	933	1477	39%	219% of MOLA
TOTAL*	285.6	557.5	1063	1905		
Status	Failed	Off	Between campaigns			



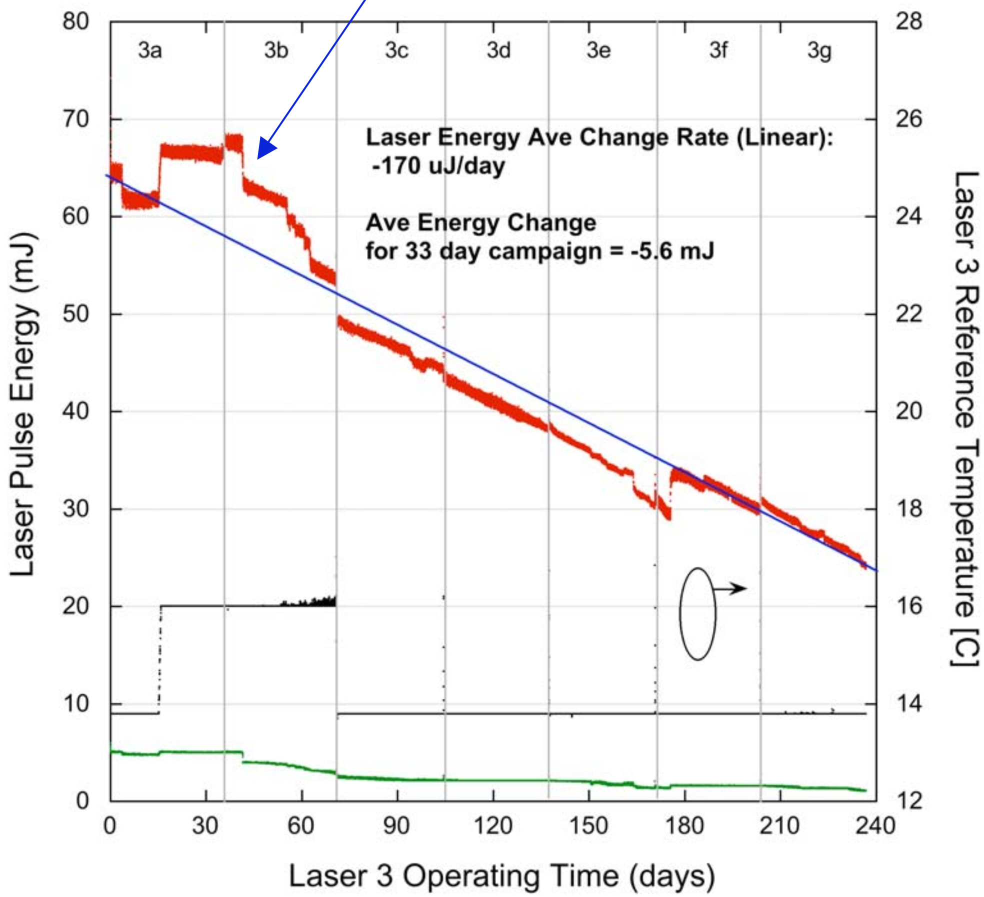


MOLA



4. GLAS Laser 3 - Average Energy Trend through end of L3g campaign

Slope change after "bar drop" at ~Day 40



Note:
1 day = 3.46 M shots
Laser 3 presently in use

- 8 campaigns completed to date
- At 21 mJ at end of L3h

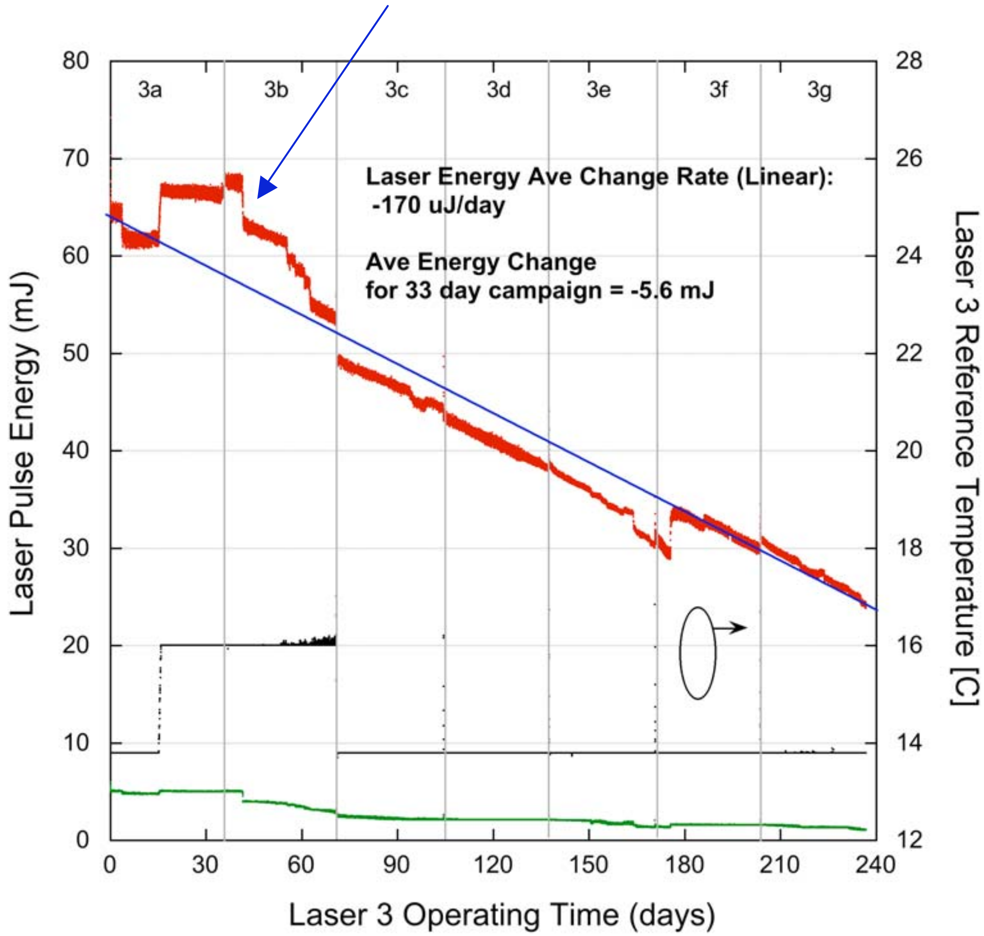
- No evidence of external heating ("photodarkening") seen from Laser 3 Doubler heater cycling

Notes:

- Laser 3 was in space the longest before use of all GLAS lasers
- Operated the coldest (GARB recommendation)
- Laser 3 emits the least 532 nm

4. GLAS Laser 3 - Average Energy Trend through end of L3g campaign

Slope change after "bar drop" at ~Day 40



Note:
1 day = 3.46 M shots

The 2nd bar drop in L3, at around day 40, changed the L3 power decline slope.

Since then energy change with time has been roughly constant at -5.6 mJ/campaign.

Is unlikely that slope change was caused by either optical damage to the laser surfaces, or from photodarkening. L3 shows little excess doubler heating.

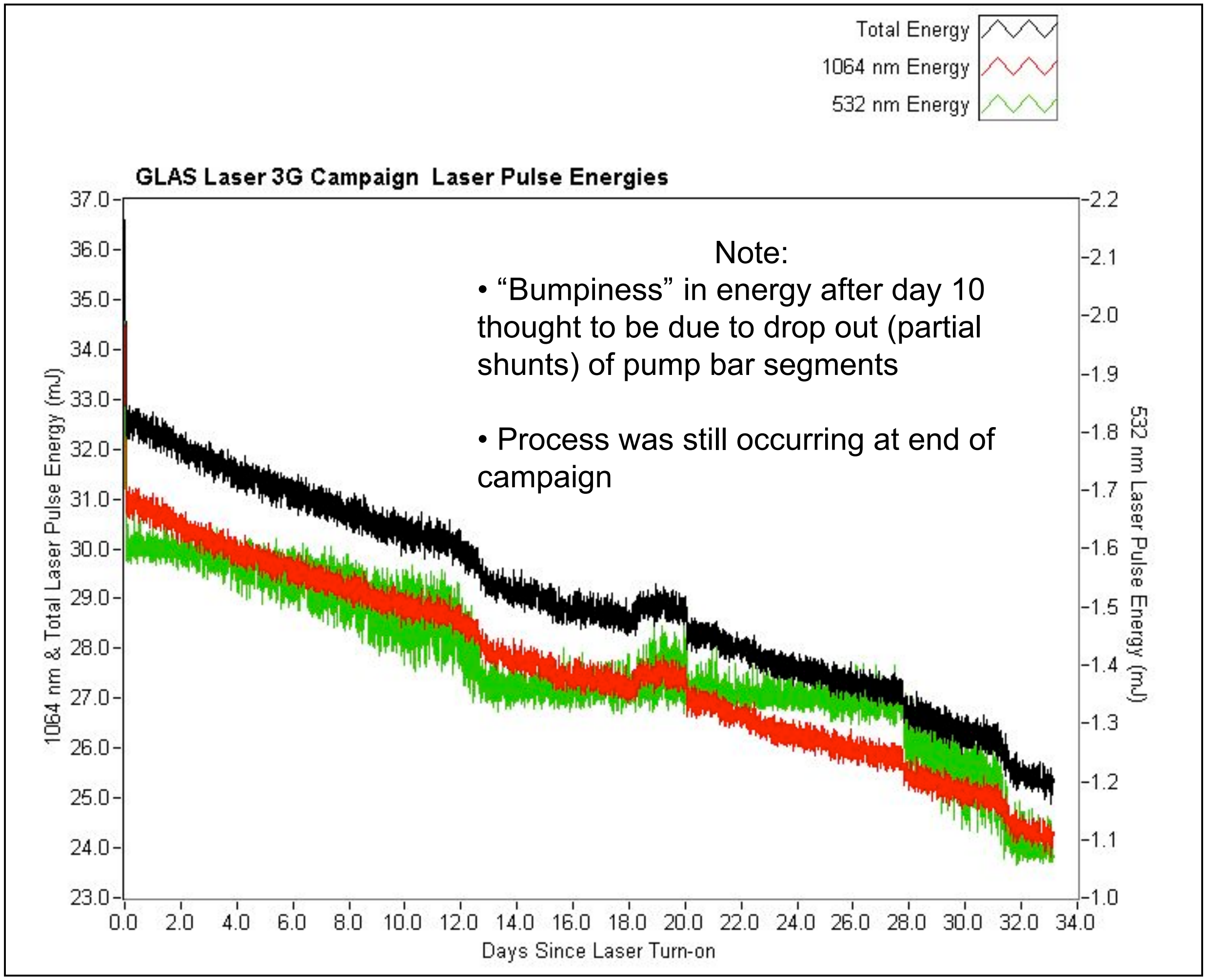
Leading hypothesis is degradation of pump diode facets from vaporized solder whiskers, which are thought to be the cause of the bar drop events.

Ground testing showed that solder whiskers occur on the SDL pump diode parts, and that whiskers can get vaporized by current passing though the arrays.

Pump diode facets are under considerable optical stress, particularly near their small emission areas. It is plausible that any extra coating on their surface, such a a thin layer of vaporized metal, would cause an increased rate of degradation to the diode facet and hence to diode pump's optical power.

This hypothesis hasn't been proven. However it seems a good fit to the evidence, and appears the most likely cause.

Laser 3G Campaign Energy History



GLAS Lasers - L3H Energy History

1064 nm Laser Energy change:

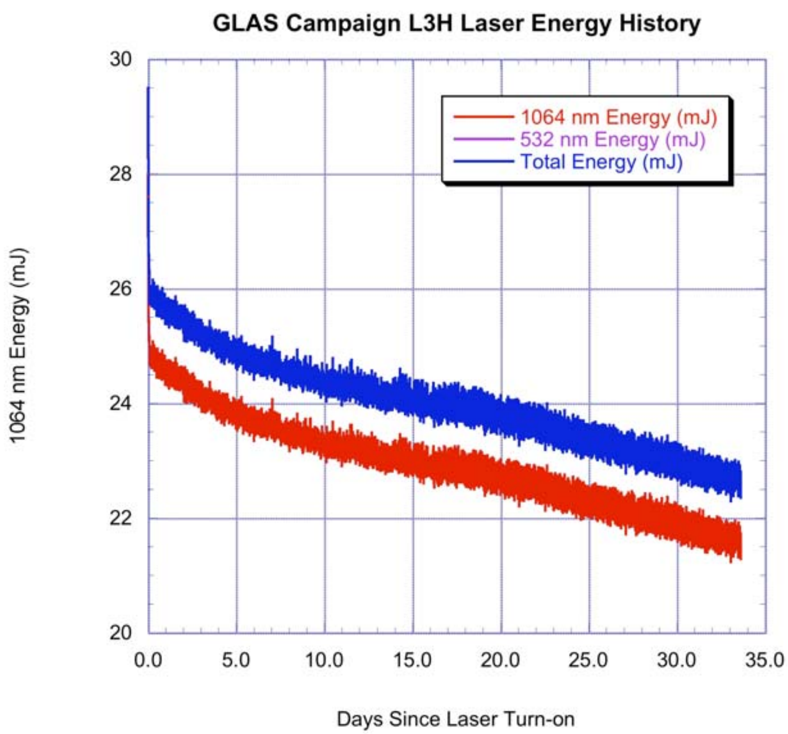
Prior ave.per campaign (L3C & later):~ - 5.6 mJ; rate: ~ -150 uJ/day

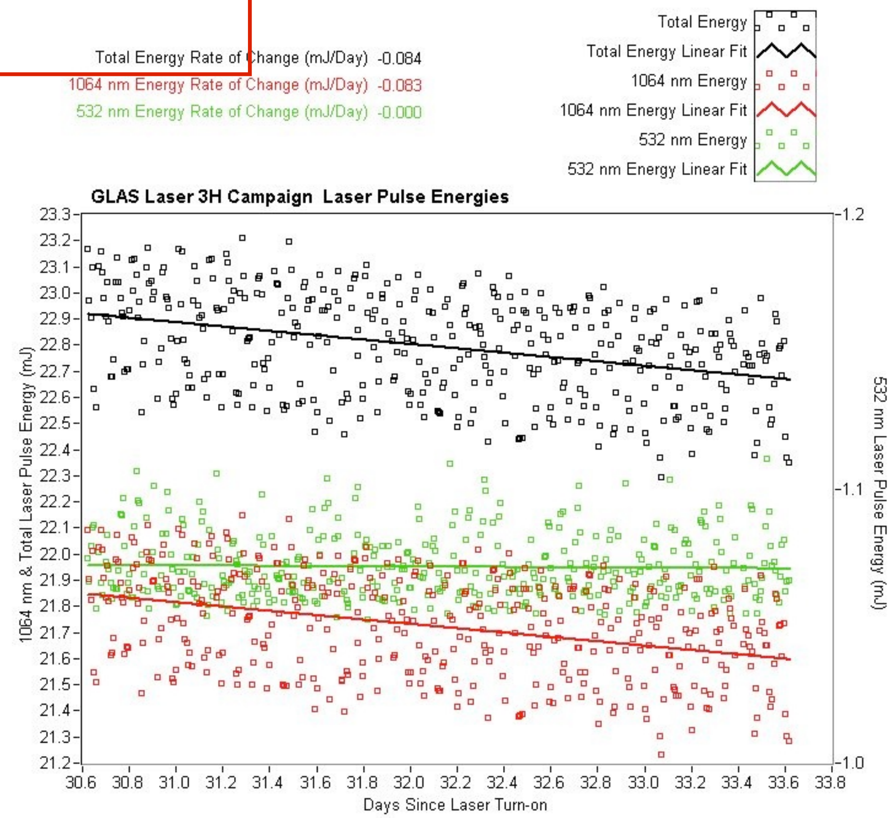
Average change over L3H campaign: -3 mJ rate: - 90 uJ/day

Average change over last 15 days: -1.1 mJ rate: - 84 uJ/day

Slowing of energy change rate during L3H was favorable

Don't know if trend will continue





GLAS Laser 3
Operating Plan for L3i and afterward

GARB

Basis of Approach:

- Plan was developed to:
  - reduce some risk factors to laser lifetime:
  - minimize of number & magnitude of laser temperature changes.
  - minimizes # of laser temperature changes during campaigns

- However:
  - It results in operating laser at lower pulse energy for a longer period of time.
  - It also adversely impacts the quality (ie # and SNR) of science measurements, because
  - The lower laser energy:
    - Reduces # of successful measurements made in poorer conditions (ie through clouds).
    - Reduces measurement SNR of “good” measurements.

Plan for L3i - (1 of 3)

GARB Recommended Laser Operations contingencies and responses for L3 updated 9/21/07
The guidance below applies to the total energy.

Expected behavior during Campaign L3i:

Based on the data from the last several campaigns the GARB expects the Laser 3 total transmitted energy to decline about 5 mJ over the course of Campaign 3i and that the fire acknowledge signal (fire ack) will be maintained throughout the campaign. At the end of Campaign 3h the total energy was about 21.5 mJ; if the laser behaves as expected at the end of Campaign 3i the energy will be about 16 mJ. Loss of fire acknowledge is not expected until the energy falls below 10 mJ.

Contingency Plans:

1. *If* - Extrapolated laser 3 energy trends show that transmitted energy may fall below 10 mJ during campaign 3i:

Then - raise the laser temperature about 5C at the rate of ~3C/day. (note: 3C/day is the GARB recommended rate used in operations.)

Expected outcome - a 5 degree LLHP set-point increase is expected to raise the reference temperature about 5 degrees but it will not be exact. The GARB expects for each 1 degree temperature raise the total energy will go up about 1 mJ.

Process - It is expected that the GARB/science teams will meet to discuss/approve before actually raising the temperature.

Plan for L3i - (2 of 3)

2. *If* - L3 energy unexpectedly falls below 10 mJ during campaign 3i , but there is no loss of the fire ack:

Then - Raise laser temperature about 5C at the rate of ~3C/day. The operations team will notify science and GARB teams and automatically prepare commands and load to spacecraft within 12 hours of determining the sudden energy loss. (note: 3C/day is the GARB recommended rate used in operations.)

Expected outcome - a 5 degree LLHP set-point increase is expected to raise the reference temperature about 5 degrees but it will not be exact. The GARB expects for each 1 degree temperature raise the total energy will go up about 1 mJ.

Process - GARB then to examine data and recommend the next steps.

3. *If* - L3 energy unexpectedly falls below 10 mJ, and laser fire ack is lost, with L3 still firing in "max pulse width" mode.

Then - Command Laser 3 to stop firing. The operations team will notify the science and GARB teams and automatically prepare and execute commands to stop laser firing within 8 hours of determining the sudden energy loss.

Expected outcome - Campaign will be interrupted but there is additional risk to operating the laser with the loss of the fire ack signal.

Process - GARB then to examine data and recommend the next steps. A possibility is to raise laser temperature and restart campaign.

Plan for L3i - (3 of 3)

4. *If* - L3 stops firing for other (unanticipated) reasons

Then - Send a "stop fire" command (remove the fire signal). The operations team will notify the science and GARB teams and automatically prepare and execute commands to stop laser firing within 8 hours of determining the sudden energy loss. There is some additional risk operating with loss of fire ack.
Expected outcome - Most likely this will end the campaign.

Process - The GARB will examine the data. There is some possibility the GARB will recommend attempting to restart the laser, but this would likely be in an "engineering test mode" and not a science mode.

At end of campaign L3i:

1.- *If* - Extrapolations show L3 energy is predicted to be < 10mJ at end of next campaign (L3j)

Then - Raise laser temperature about 5C near the end of or after this (L3i) campaign.
Expected outcome - a 5 degree LLHP set-point increase is expected to raise the reference temperature about 5 degrees but it will not be exact. The GARB expects for each 1 degree temperature raise the total energy will go up about 1 mJ.

Process - The GARB/science teams will meet to discuss/approve before actually raising the temperature. A decision from GARB/science teams must be given to operations team at least 7 days prior to scheduled campaign end date (tentatively November 3).

Laser 3 - A Lifetime Extrapolation

Based on round #’s, assuming that trends continue & temp predictions for L3 energy are accurate.

Using round #'s:

Laser 3 energy is now 20 mJ.
Laser 3 has been dropping ~5 mJ/33 day campaign.
Laser temp is now at 14C
Laser energy expected to increase with temp at ~1 mJ/C up to 29 C.
Expect to avoid fire acq issues down to 10 mJ,
(L3 may be OK at < 10mJ, but likelihood of losing fire acq. is higher at lower energies.)

If trends continue, expect L3 to have 5 more campaigns left to 10 mJ.

A suggested scenario:

With Laser 3 at 14C, operate 2 more campaigns. At end, laser energy is ~ 10 mJ.
Raise temp to19C -> laser energy to 15 mJ,
Run another campaign, laser energy back to 10 mJ.
Can repeat 2 more times, with L3 at 24 and 29C

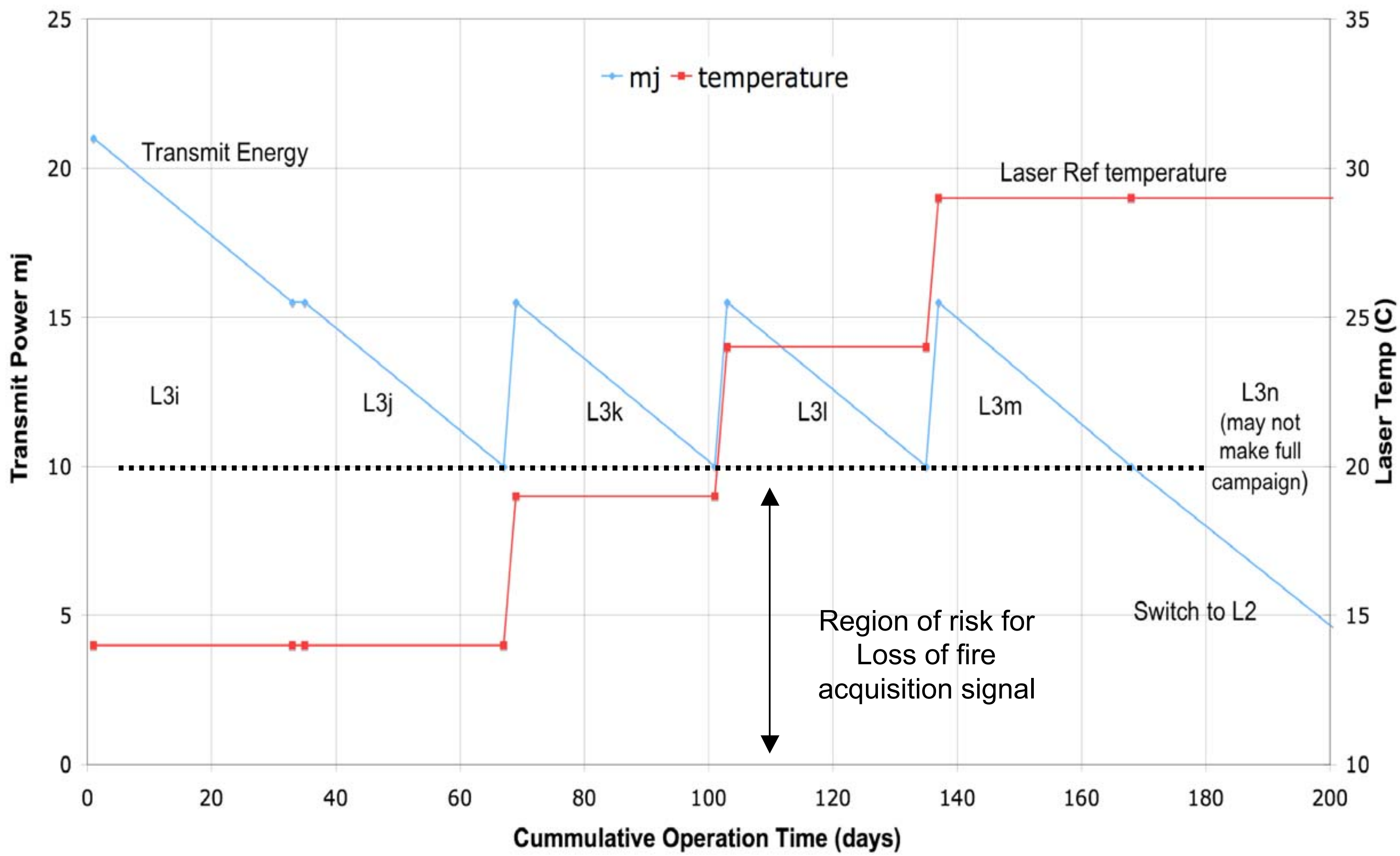
Total is 2+3 = 5 more 33 day campaigns.

Is some possibility of getting in some of a 6th campaign (ie running laser below 10mJ).
This depending on when fire acq problems start. The first part of campaign will probably be OK.

Corollary - if plan to use L3 for a 91 day campaign (ie 3 campaigns put together), then, need to plan it no later than 2 campaigns from now (ie starting with L3k).

Extrapolated Laser 3 Energy Trend
And an operating plan

(based on extrapolating past trends)

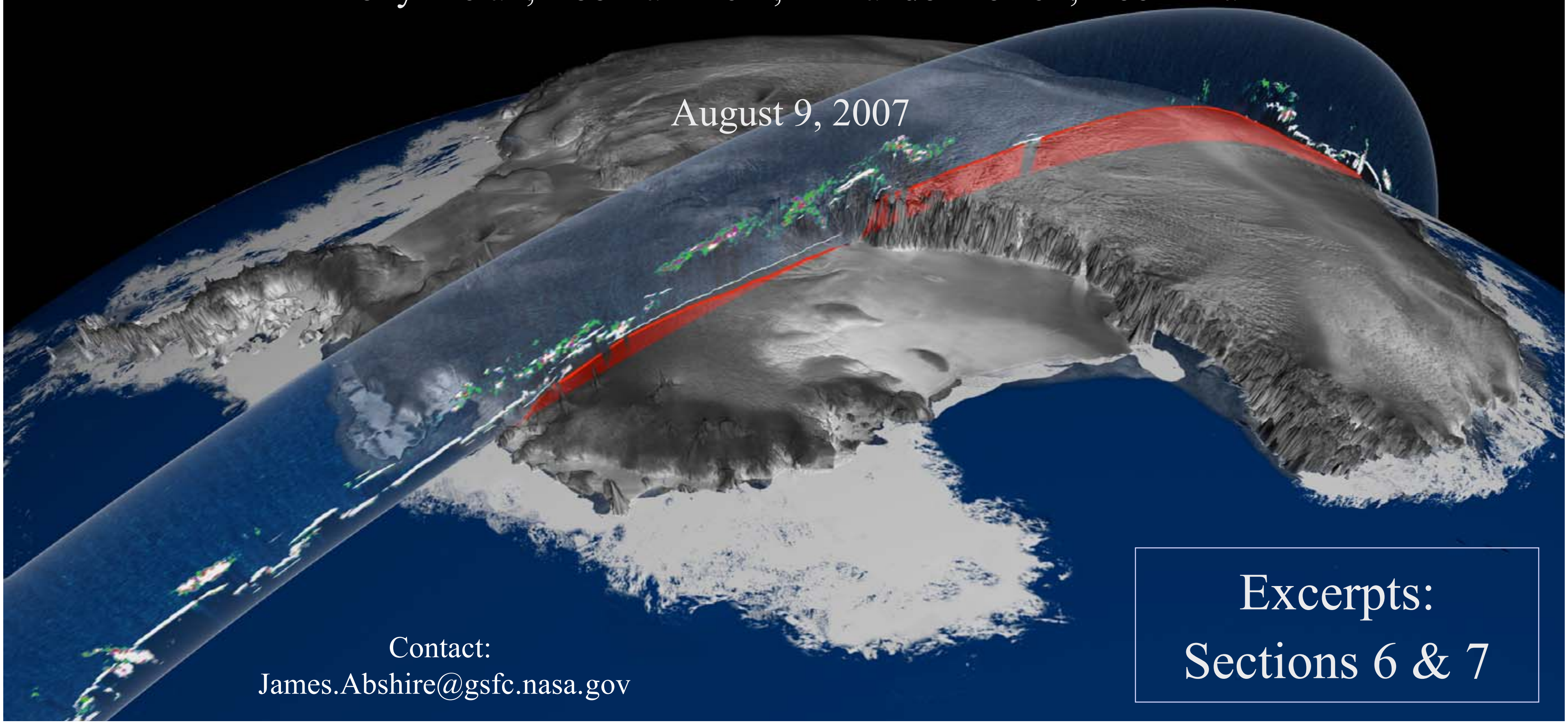


GLAS Instrument and Lasers
Recommendations for future Laser Missions

GLAS GARB and Instrument Science Teams

Jim Abshire, Haris Riris, Pete Liiva, John Canham,Tony Yu,

Tony Melak, Rob Taminelli, Armando Morrell, Rob Afzal



August 9, 2007

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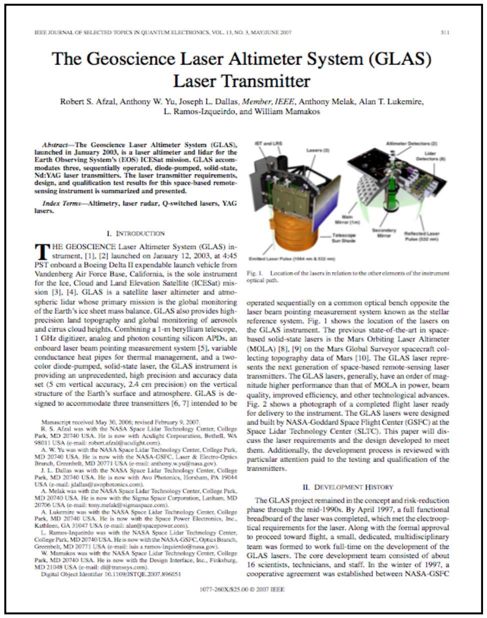
Excerpts:
Sections 6 & 7

For more information

GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L21S02, doi:10.1029/2005GL024028, 2005

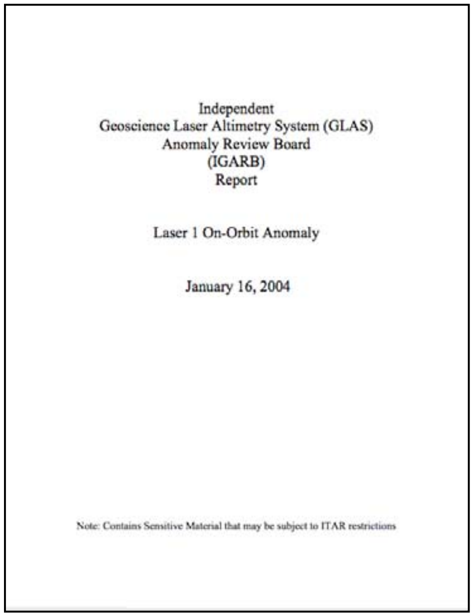
Geoscience Laser Altimeter System (GLAS) on the ICESat Mission: On-orbit measurement performance

James B. Abshire, Xiaoli Sun, Haris Riris, J. Marcos Sirota, Jan F. McGarry, Steve Palm, Donghui Yi, and Peter Liiva



The Geoscience Laser Altimeter System (GLAS) Laser Transmitter

Robert S. Afzal, Anthony W. Yu, Joseph L. Dallas, *Member, IEEE*, Anthony Melak, Alan T. Lukemire, L. Ramos-Izquierdo, and William Mamakos

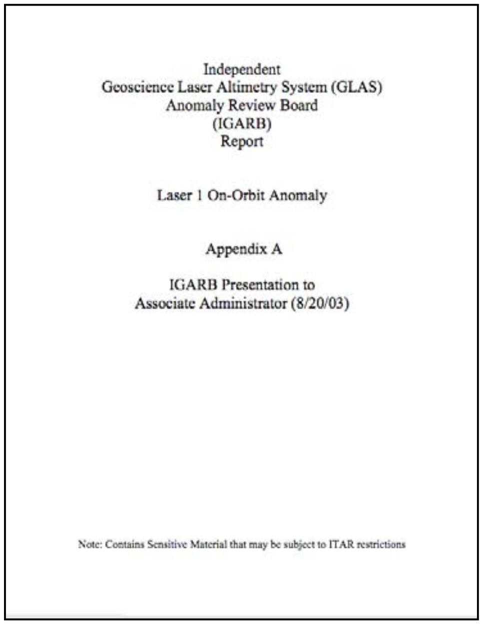


Independent
Geoscience Laser Altimetry System (GLAS)
Anomaly Review Board
(IGARB)
Report

Laser 1 On-Orbit Anomaly

January 16, 2004

Note: Contains Sensitive Material that may be subject to ITAR restrictions



Independent
Geoscience Laser Altimetry System (GLAS)
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(IGARB)
Report

Laser 1 On-Orbit Anomaly

Appendix A

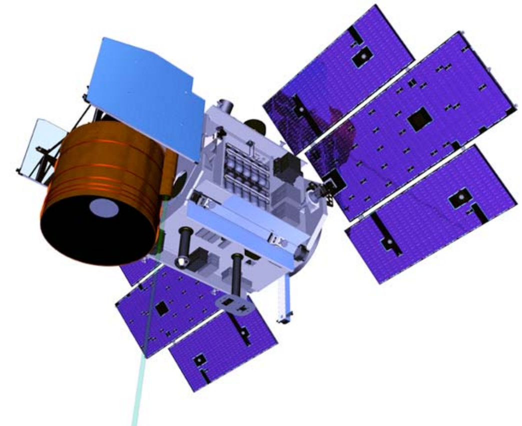
IGARB Presentation to
Associate Administrator (8/20/03)

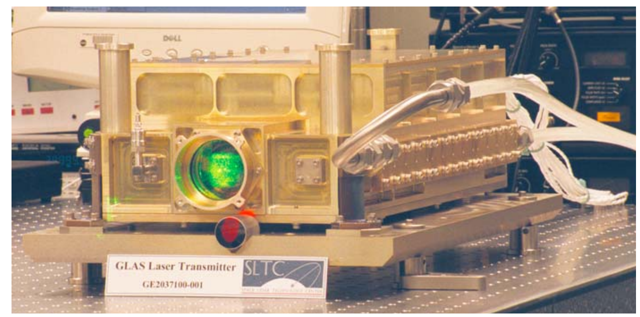
Note: Contains Sensitive Material that may be subject to ITAR restrictions

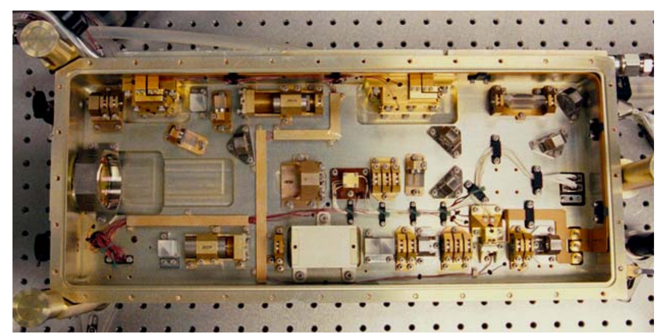
4 pages	26 pages	71 pages	399 pages

Outline

1. GLAS development context & overview
2. GLAS instrument & Lasers
3. GLAS Space operating history to date
4. GLAS laser operating histories
5. ETU laser - extended vacuum experiment
6. GARB recommendations for the future
   - General recommendations
   - Pump diode context & GLAS experience
   - Pump diode recommendations
7. Lessons not to forget - Factors which led to GLAS laser delivery & launch







6. Recommendations for future Laser Missions
Risk posture, management, science planning

1. *Risk management* - Adapt a mission class, level of redundancy, subsystem and parts quality and testing standards which are consistent with the risk posture, project and community expectations.
   - Will the mission viewed as a pathfinder, or as a mature & operational mission ?
   - Ensure risk posture & instrument requirements are consistent with "post launch" expectations of project & science community.
2. *Risk posture* - Consider options for probability of success, and their trades on needed lifetime & mission cost.

   What are the impacts, which aspects must be low risk, and which ones can have more risk ?
3. *Risk management* - Improve management strategies to deal with issues during instrument development:

   Is it more important to stay within planned mission cost & schedule (ie and allow risk to increase) ?

   or adjusting the scope of effort (ie cost &/or schedule increases) to maintain the targeted risk level ?
4. *Risk management for laser* - Plan to demonstrate the critical laser specs (including lifetime in the relevant environment) in ground testing before flight lasers are built. Allocate resources for in project planning.
5. *Robustness* - Explore and understand impacts of instrument changes, including the unexpected ones, on other subsystems. Minimize cross dependencies, to the extent possible, to maximize the robustness of the instrument.
6. *Science data analysis* - Better understand impact of post launch laser changes on final science measurements. Flow them back to help determine laser specs. What level of changes can't be dealt with in post processing ?

6. Recommendations for Laser Missions
Laser requirements & models

7. *Laser requirements* - Revisit and revise the laser & measurement requirements based on analysis of GLAS measurement environment (SNR, cloud thickness, cloud scattering errors, surface slopes). Also the needed science measurement density across spectrum of environments, including most challenging areas.

- Where can laser specs be traded against other instrument changes (eg larger telescope&/or less receiver noise from tighter receiver FOV's) ?
- Where would tighter laser specs (e.g. shorter pulses) improve the science ?

8. *Impact of on-orbit changes* - The impact of laser changes on science measurements need to be quantified & specs established. For example, GLAS Laser 1 showed changing FF pattern with pump diode changes.

- How much can parameters change on orbit and what rate is acceptable ?

9. Laser reliability & lifetime model - develop one which captures all the important physical effects in the lasers. Include pump diode changes, photodarkening, etc. Use reliability model to:

- Select specs or criteria for laser parts, subsystems or processes. For example, if effect x is held to < y%/year (along with other expected changes) then model shows laser will meet its lifetime.
- Once model predicts needed performance, then use it determine parts reliability requirements, and/or predict impact of parts changes.

6. Recommendations for Laser Missions
Laser lifetimes, architectures, leverage

10. *Laser part quality* - Establish quality standards and specs, and acceptance criteria for all critical parts (including DPA) in all critical parts, including diode arrays. Fully understand the failure modes of critical parts.

11. Laser changes with time. - Significantly extend the "qualification" test time for early laser models to try to expose more ways the flight lasers may change with time. Ideally test several pre-flight units in the flight environment beyond their needed on orbit operation time.

12. Laser physics after long exposure - After long qualification tests, take the laser apart and examine all important surfaces to learn of changes & physical processes which occurred inside the laser with time.

13. Laser lifetime predictions - The community is still learning about physical processes, which occur inside lasers, over time. Given the present uncertainties, GSFC should reduce degree of extrapolation it uses when predicting laser lifetimes. It needs to perform much longer "lifetime experiments" on pre-flight lasers. The purpose is to look for and to understand unanticipated physical effects, more than to "prove" a design.

14. Laser cavity environment - There are fewer unknown factors for lasers operated with air in cavity, vs vacuum. If the mass and alignment budgets will accommodate it, consider cavity operation in air to minimize lifetime risk from unknown factors. Alignment mechanisms can be used to compensate for pointing shifts which will occur with pressure leaks. The heritage & relaxed requirements can save cost, development time, and reduce risks.

15. Leverage technology - Developing reliable space lasers is expensive - leverage industrial & military investments

6. Recommendations for Laser Missions
Laser physics & design

16. *Laser Architecture* - for more reliable space laser instruments in presence of uncertainties:

– Pursue approaches using more smaller lasers vs fewer larger lasers

– Pursue space laser architectures which are more robust against the failure of single parts,

– Based on stronger established reliability parts (e.g. 9xx pump diodes)

17. Laser team & project organization - Extend the scope of laser development team's duration to cradle to grave, to continue to improve & test models, continue life-testing, and to assess on-orbit performance

18. Laser physics after long operations - Develop and maintain a laser physics/R&D/lifetime activity running in parallel with the flight laser development. Ideally these results can be used to improve the understanding of the various processes which impact laser performance vs time, as the flight lasers are built and tested. It can form a much stronger knowledge base and used to improve the various models for the lasers operation.

19. Laser operational model. Need one to compare against on orbit performance.. That is a numerical model which can be tuned during the laser qualification process which captures predictable aspects of laser performance on orbit. The more the model can capture processes and predict observable effects, the better.

20. Output beam patterns - Understand the potential impact of any irregularities in the near field of the laser output.

6. Recommendations for Laser Missions

Laser engineering

21. Laser adhesives - Epoxies slowly leak organic compounds - be quite cautious about using them inside lasers

22. Photodarkening hypothesis. Complete the investigation of photodarkening seen in Lasers 1 & 2

Need to complete studies (UMD & GSFC) to determine chemical & photochemical process.

Until then extend bake-out times for adhesives to at least those experienced by the ETU laser.

23. Laser Temperature control - Include limits or interlocks to prevent operating lasers outside its temperature limits

Operating outside specs (particularly thermal shocks) will degrade (Laser 2) & break (ETU) a laser

24. Laser internal monitors - Use more measurements inside laser to allow better understanding of behavior during testing and on-orbit.

25. (GLAS specific) Improve Long. mode control - The oscillator can run in 1-3 longitudenal modes. Some minor temp adjustment on slab, using feedback from a detector & high pass filter, can be used to adjust & increase single mode operation to over 95%. This can reduce peak power in pulse by ~ x2 & increase margin for damage.

26. (GLAS specific) Laser engineering - reposition “fire acq” optical pickoff to maximize lifetime when energy drops.

27. (GLAS specific) Laser engineering - Redesign mounting of doubler crystal to pin its alignment & fix shear strength issue on Nusil.

6.1 Diode Array Parts - GLAS Context

- Laser diode arrays used all GLAS lasers were COTS from SDL & were "best avail" at the time
- Same vendor, construction approach & similar parts were used successfully on MOLA-2 laser
- The manufacturing process used was proprietary
- Parts were expensive (several K$ or more/unit)
- Under the Class-C guidelines, Grade-3 parts and the vendor's construction techniques & controls on their manufacture were considered acceptable
- Part was being phased out (less importance to vendor) at the time of flight unit purchase
- GLAS several aging rate tests vs current and temperature to set current de-rating levels
  - Performed at GSFC and at the part vendor

6.1 Laser Diode Arrays for GLAS Degradation & Failure Modes

Expected before Launch:

1. Normal aging of semiconductor bar, resulting in gradual "normal" decline in power vs time.
2. Defect within semiconductor, which grows with time, ie "dark line defect". Causes bar to stop lasing

Surprises to GLAS:

3. *Lead-tin solder whiskers* erupting from solder under the bars, and contacting diode bar above active region (seen in GLAS flight spare SDL arrays)
   Likely cause of "bar dropouts" seen in MOLA and GLAS
   Causes metal vapor to be emitted from pump assembly when operated in vacuum.
4. *Indium whiskers* from indium solder at die attachment (also seen in Coherent arrays)
5. A *"pin-hole" type defect* opens in semiconductor barrier metallization on anode side of bar, which permits solder to diffuse into bar, re-doping diode's active region and killing its ability to lase
6. *Crack develops in a diode bar* (over time) permitting the die attach solder to somehow move into crack, which shorts the bar. Creates very low resistance short. (seen in MOLA era-spare array).
7. *Bond wire failures*, induced by either partial current shunting of the bar, or by indium solder attack.
8. *Mechanical failures of various solders* holding package together, caused by temperature cycles.

6.2 Recommendations for Laser Missions
Diode Pump Array Parts

28. Number of Pump diode suppliers - Are quite vulnerable if have only a single vendor for a mission critical part.

- Develop a laser design which is compatible with two or more pump diode suppliers

29. Pump array contamination - QCW pump diode assemblies are seen to be an internal source of cavity contamination. These emissions present a risk of triggering other laser degradation modes, including other pump array changes, and possible optical damage inside the laser cavity.

- Pursue approaches to better isolate the molecular and particulate emission from the pump diodes from the laser's optical path to reduce the impact from diode contamination and improve laser lifetime.

30. Pump array coupling - Fiber coupled 808 nm pump modules are becoming available. They appear to offer advantages for space to isolate contamination, improve reliability, increase flexibility, & improve redundancy.

- Investigate possibility of using fiber coupled pump diodes

31. Pump array electrical configuration - Minimize length of series connections of pump diodes - There is risk of failure since an open circuit in one diode element or its connection will disrupt string and cause laser to fail.

- Consider possible electrical configurations where at least some of the diode stacks are run in parallel.

6.2 Recommendations for Laser Missions
Diode Pump Array Parts

32. Pump array max. current - Derate max current of the pump diodes to degree at least as much as GLAS oscillator, and consistent with other electrical parts used under similar stress levels. (ie derated perhaps 30% or more).

33. Adjust Pump diode current - The capability to adjusting pump array drive current on orbit is beneficial to:

- Reduce laser's output energy, when measurement environment is good & less pulse energy is sufficient.
- As the laser ages, small upward adjustments in current can be used to keep more constant output energy
- Reduce power & diode aging while operating over less important parts of mission (e.g. oceans)
- Allow on-orbit adjustment to allow flexibility & robustness in the event of the unexpected

34. Pump diode quality & consistency - Ideally find & use parts from established "high rel" or mil-spec parts line, with tightly controlled production processes. These have not been available for qcw pump arrays. If not avail., try purchase the highest quality parts with most tightly controlled processes available. Purchase parts in "lots" where parts are as identical as possible, so that results from qualification tests with some parts of the lot will be reasonably close to those of other parts on the lots. This approach can help minimize the impact of lot-to-lot variability. Try to estimate the statistics of the lot via sampling.

7. GLAS Accomplishments

- GLAS was completed, launched and has made >1.4B science measurements so far
  - Team overcame countless hurdles (in many dimensions) during its development
  - Although it has shown some surprises, > 95% of GLAS has worked well
- Most aspects worked really well, because:
  - Great teamwork, leadership and commitment
  - Support by GSFC management
  - Planning assessed major risk areas correctly (originally planned 4 lasers more R&D, more $s)
  - Successful at handling the anticipated risks - the “known unknowns”
  - Strong team and subsystem teams - many R&D oriented people
  - Overcame many hurdles and unexpected problems
- Designed & space qualified 4 lasers => laser design is essentially sound
  - Successes in laser development:
    - Passive q-switch, 3 stage MOPA vs power oscillator, 2-colors, alignment stability
    - GLAS laser derivatives used (to date) on MLA and LOLA instruments
- Developed & demonstrated new levels of capability for space lidar

7. GLAS Laser Development Accomplishments & Enabling Factors

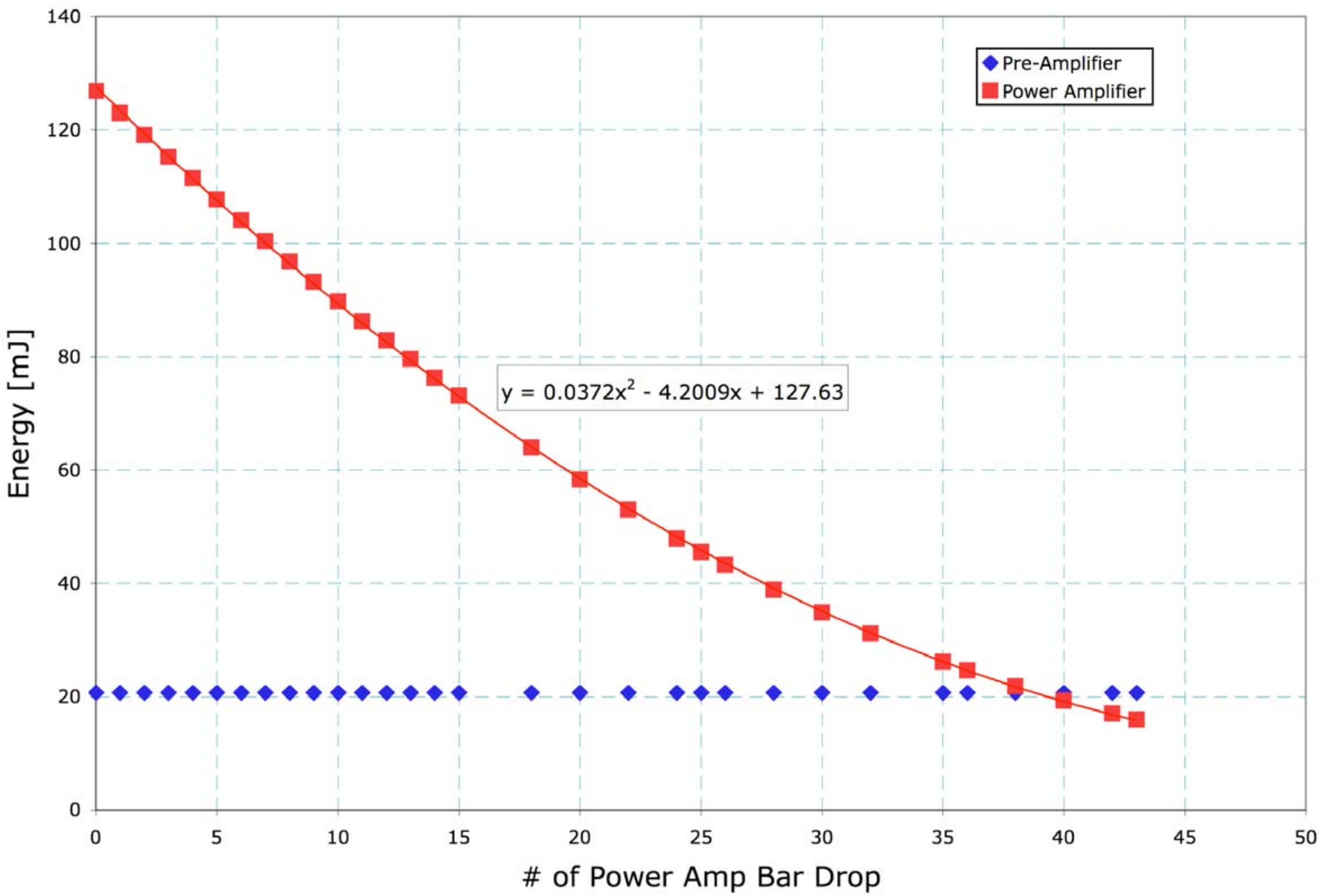
- Accomplishments - Developed:
  - First GSFC lasers flown in space (3 flown, ETU, a flight spare (SN4))
  - A new space laser development facility (SLTC)
  - Procedures for building and testing flight laser hardware
  - Capability for evaluating flight laser performance
  - Largely stayed within budget & schedule (were not the driving subsystem in budget or schedule)
- Enabling Factors:
  - Good tradeoff analysis & logical performance demonstration sequence (breadboard, EM, ETU, …)
  - Dedicated laser team in a skunk-works environment - promoted ownership and responsibility
    - Majority of core group (15 people) were on team from Phase A through delivery.
    - Team members took on different roles (as needed) as the project progressed
    - Supporting skills and people were brought in and released as needed
    - Capability allowed solutions to be quickly developed in parallel to baseline
  - Consolidated self-contained facilities
    - Most laser design, development, build & testing could be carried out in a single facility
    - Continuous informal communication allowed for quick course corrections
    - Dedicated labs & procedures were established for duration - allowed repeatability & instant access
  - Stable project over years with adequate resources
    - Minimized disruptions (“resource stalls”) during development
    - Allowed a stable team and logical progression from concept to flight hardware

GLAS Lasers - Energy Loss with Pump Bar Losses

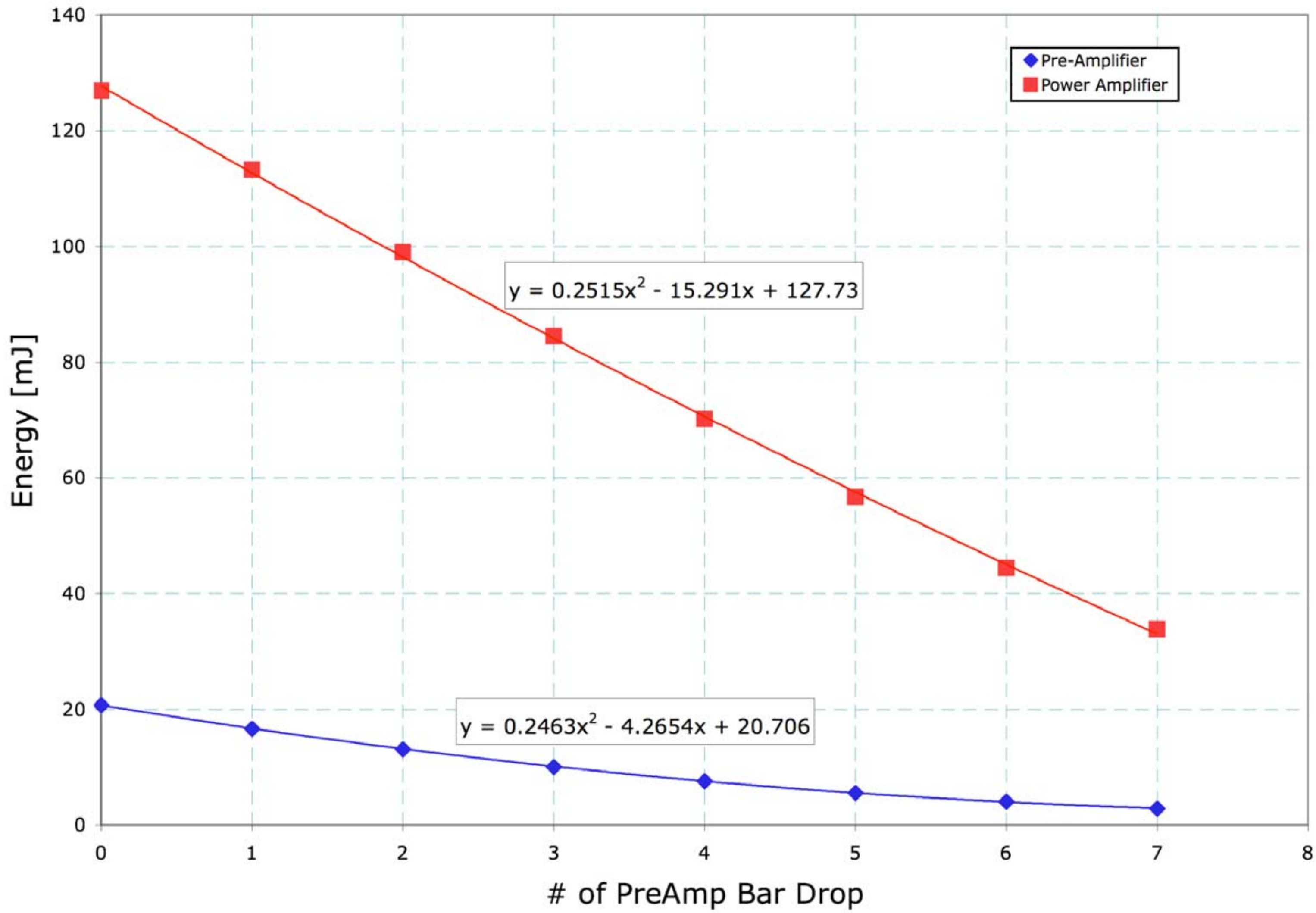
Anthony Yu
GARB
2/7/07

Laser Energies calculated assuming 32.3C for Oscillator, 14C for preamplifier heatsink and 18C for power amplifier heatsink.

Output Energy as Function of Power Amp Bar Drop



Output Energy as Function of Pre-Amp Bar Drop



GLAS Laser Life Extension via Temperature Change

Robert S. Afzal

GARB

6/1/06

Motivation & Method

- **Motivation: Predict the increased energy available from Laser 3 (&2) by raising the temperature thereby extending mission life.**

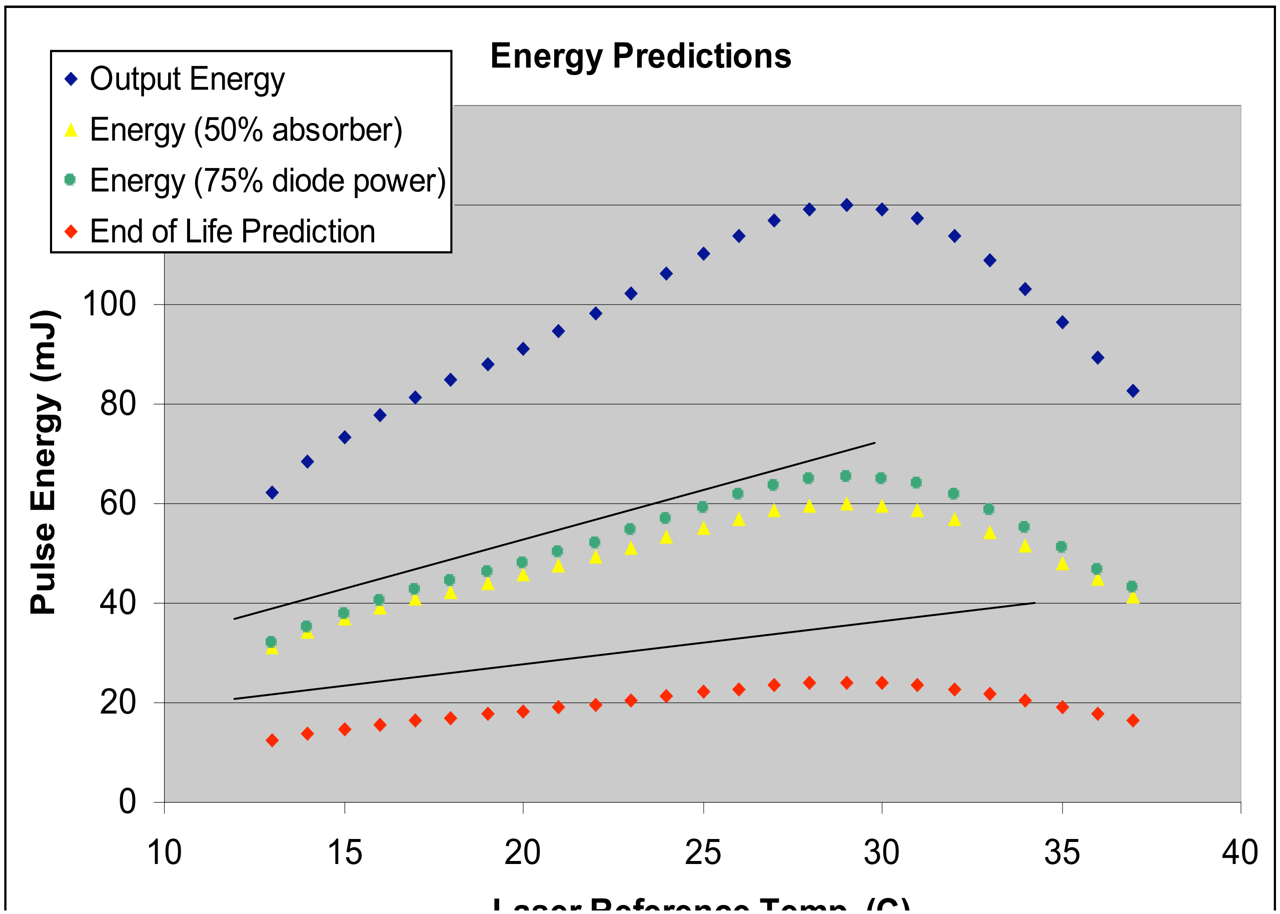
- **Using GLAS Laser Energetics model, predict current and future laser performance over temperature.**

- **Based on corroborated model results, predict the increased laser energy with increasing laser reference temperature.**

- **During campaign start-up there is a temperature transient that can shed light on laser energy over temperature.**

Model Predictions

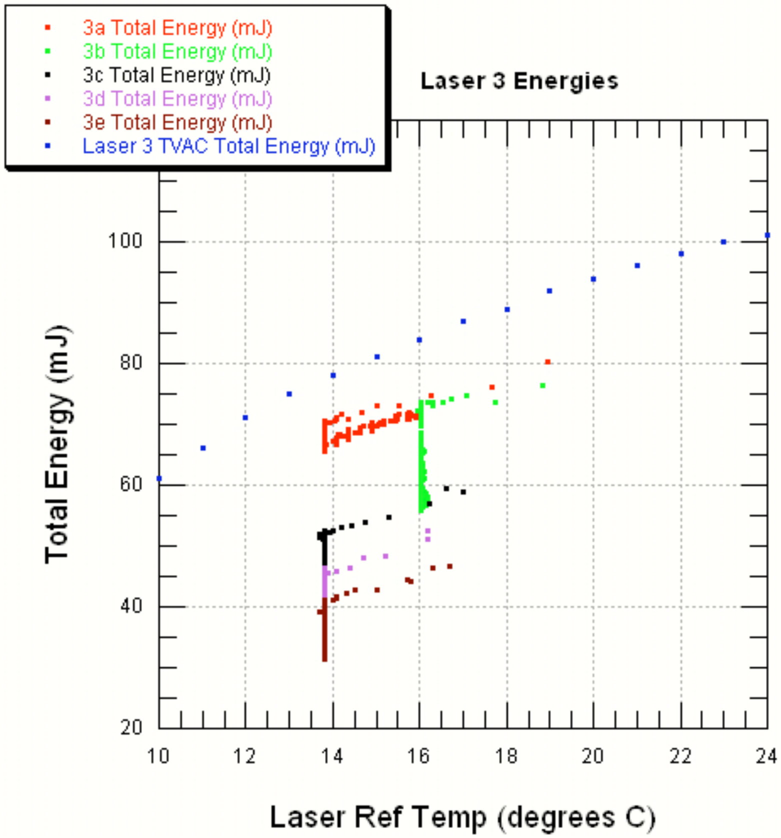
The GLAS Laser energy model was used to predict the laser out ut energy at the beginning of life, with a hypothesized 50% absorber at the laser output, 75% available diode pump power, and estimated performance at EOL (10 mJ @ 13 C).

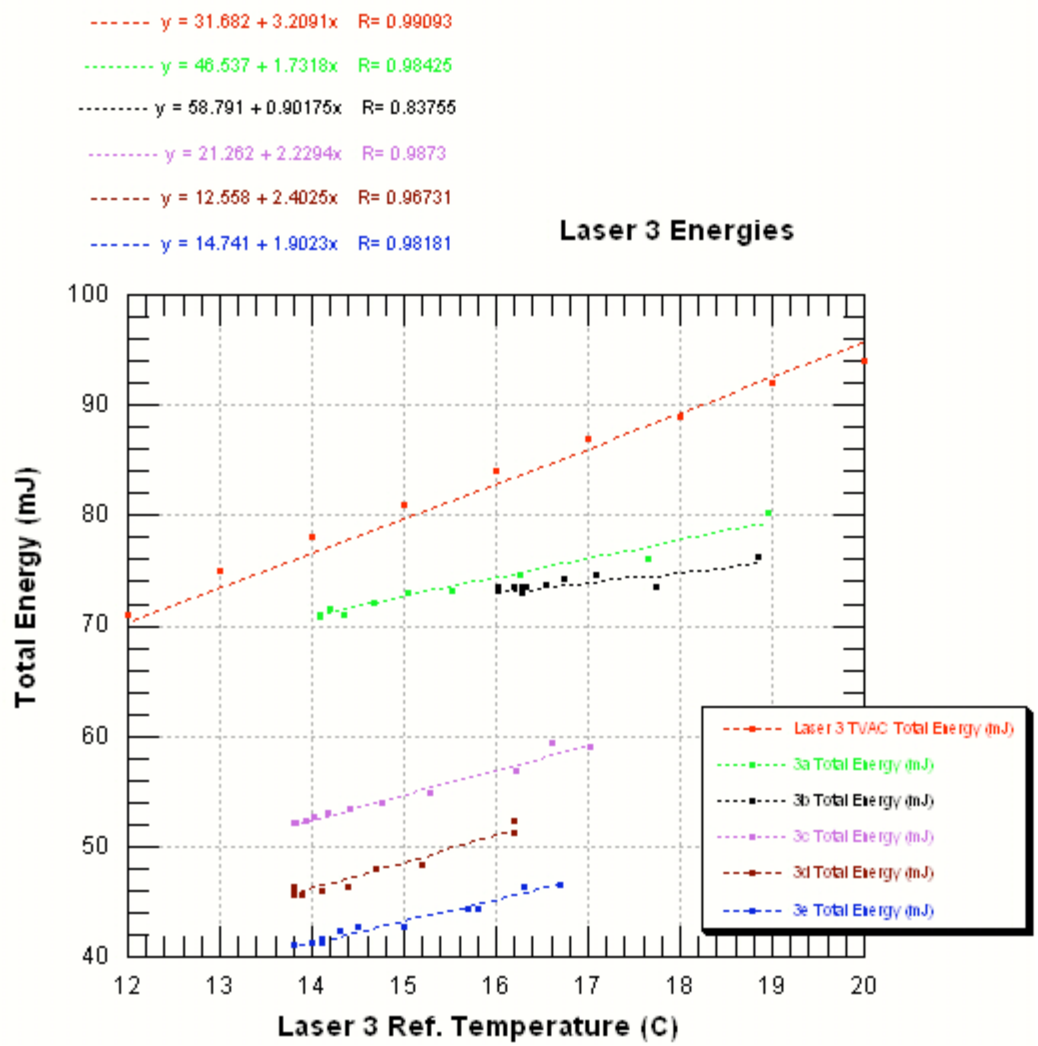


Current Slope = 2 mJ/C

EOL Slope = 1 mJ/C

Laser 3 Energy vs. Temperature





Plotting and fitting all Laser 3 energies shows a match
Between model and observed behavior

Current Slope ≈ 2 mJ/C

Predicted Slope ≈ 2 mJ/C   Projected Slope ≈ 1 mJ/C

Conclusions

- **At Laser EOL, defined as 10 mJ @ 14 C, the laser energy can be increased by increasing the laser temperature.**
- **Initial projected energy increase is ≈ 1 mJ/C.**
- **Maximum Energy available by increasing temperature to 30 C ≈ 24 mJ total.**
  (Δ = 14 mJ)
- **NOTE: No prediction on degradation rate changes with temperature.**

GLAS Lasers
A quick overview of some
Known Factors influencing Planning

Diode pump array parts - metallic changes

Fire acquisition sensor detection threshold

GLAS Lasers - pump diode parts issue

GLAS Laser Heritage and Testing

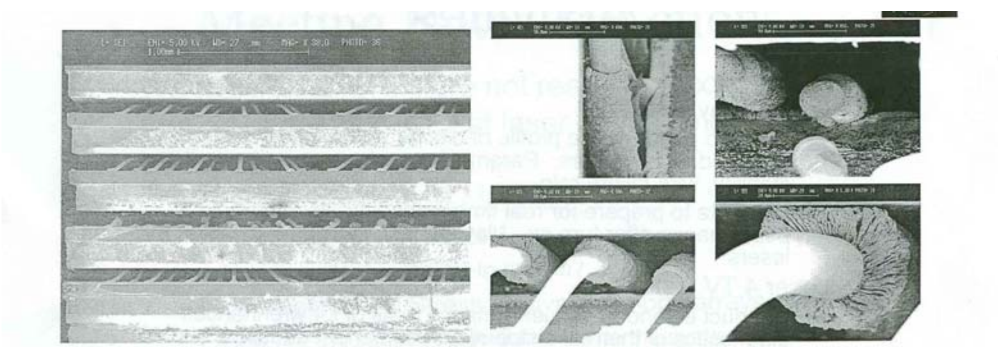
- GLAS pump diodes & osc stage tested for 3-6 billion pulses
- Pump arrays were selected versions of commercial parts
- Used de-rated (less drive current than commercial spec)
- Gold-indide defect was latent & did not surface in life- or pre-launch tests

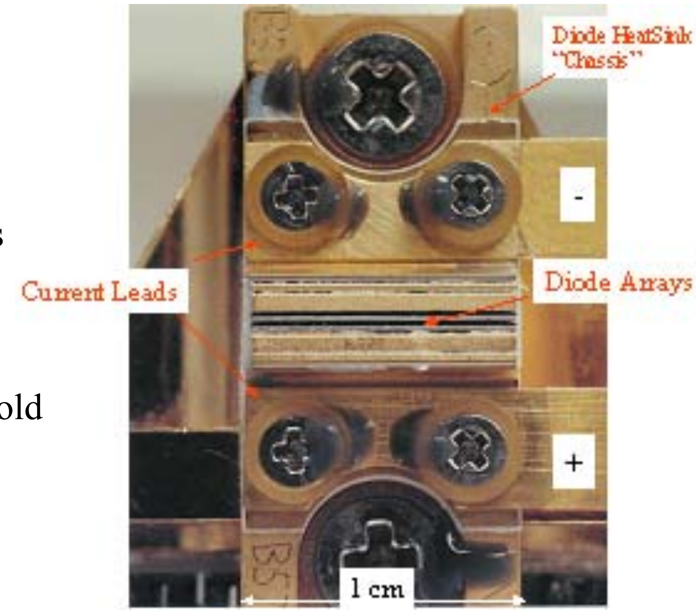
GLAS Anomaly Review:

- Laser 1 failure was from a parts problem
  - vendor's use of indium in diode pump array assembly, leading to gold erosion & bond wire failure
- Laser 2 energy decay likely from slow contamination

Programmatic:

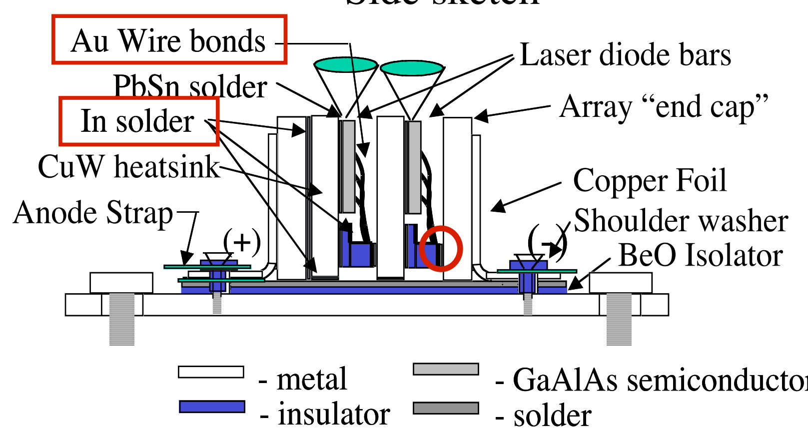
- GLAS was Class C instrument with Grade 3 parts program
- One vendor for an expensive & surprisingly complex part





SDL 100W diode array (G2)

Side sketch



Reminder - “Fire Acquisition” Loss Risk for Laser 3

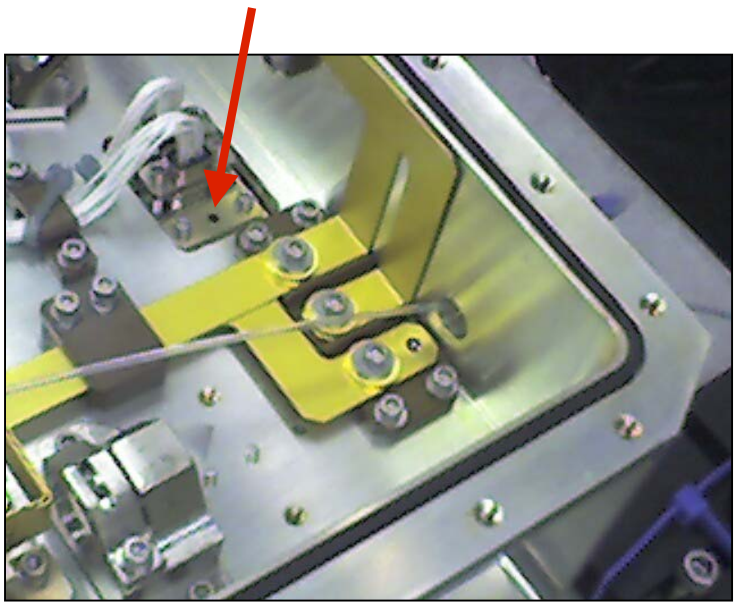
There is an internal optical detector inside the laser box used to determine when the oscillator has triggered (ie Q-switched) and to turn off the electrical drive pulse to the laser diodes when it occurs.

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 diode 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.

The GARB isn’t certain of the exact fire acq threshold - it is possible it is < 5 mJ



Laser 3 - Risk from loss of “Fire Acquisition” Signal

- At some point, for output energies <10 mJ, Laser 3 is expected to lose its “fire acquisition” signal - an internal trigger signal inside the laser.
- The expected consequence of this are:
- The laser drive pulse to the diodes will go from 200 to 244 usec. The laser will emit a pulses, but the pumps diodes will stay on longer. This won't break the laser, but it may cause an error in selecting the start pulse for the altimetry. 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). The extra 30W needed by the laser will stress the spacecraft’s power system, particularly if it occurs during eclipse,when the spacecraft is drawing power only from its batteries.
- As expected, with the worst-case predicted end-of-eclipse battery voltage at the laser could be from 22.7 to 23V. The lasers low voltage cut-off is 23.1V => a problem. If the voltage falls to this point, the laser will stop and go into “restart mode”, which takes severla hundred seconds. This power cycling will be extra stress on the laser, particularly on its pump diodes.
- If, for worst case conditions, the GLAS power can be reduced by 45W, there should be ~0.15V or more of margin. There are several other options that may give us extra voltage.
- Other possibilities might be to not operate during the worst case conditions for spacecraft power, (ie early in the spring campaign), or shift it to a later time.

Backup

Previous L3 Energy Change Calculations and Extrapolations for L3i

1. Average Laser Energy change/campaign:

Prior campaigns (L3c-L3g) = -5.6 mJ
Energy change during L3h = - 3.0 mJ
Ave. for campaigns (L3c-L3h) = - 5.2 mJ

2. Energy changes with Temperature and Bar Losses:

Laser energy change with temperature = ~ 1 mJ/C (from R. Afzal model)
Laser energy change with loss of laser pump bars: (from T. Yu model)

Preamp bar: - 15 mJ
Amplifier bar: - 4.2 mJ

3. Estimate of # of pump bars operating in L3:

Assumes that all L3 energy losses are from bar losses
1064 nm Laser Energy change (drop) through end of L3h: 63-21.7 = 41.3 mJ
If all losses were bar drops and assuming one preamp bar loss:

Lost 1 preamp bar (of 8) -> 7 preamp bars remaining
Lost 6.3 power amplifier bars (of 44) -> 37.7 amplifier bars remaining

4. *Energy Extrapolations for campaign L3i:*

Assume L3i shows average energy loss rate (no add'l bar losses):

Extrapolated energy at end of L3i = 21.7- 5.2 mJ = 16.5 mJ
With additional bar drop = 16.5 - 4.2 = 12.3 mJ
Both are above 10 mJ safe point for fire acquisition signal.

5. Recommendation for L3i:

Laser temperature for L3i same as L3g & L3h (ie no temperature change)