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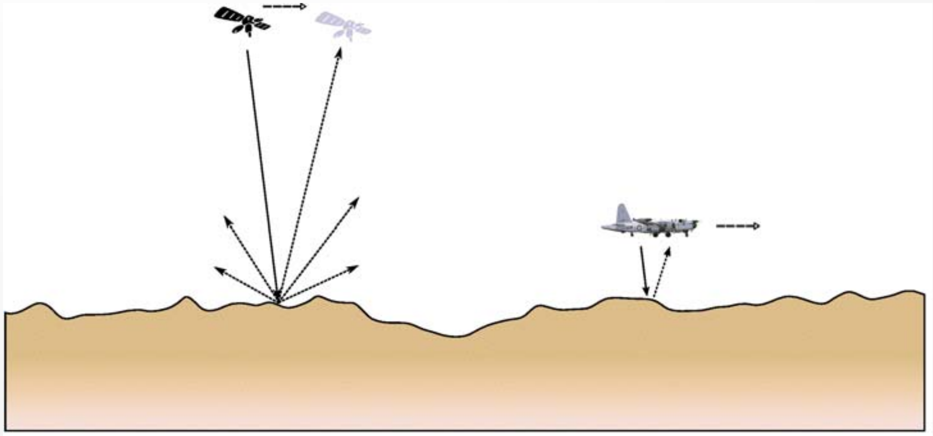
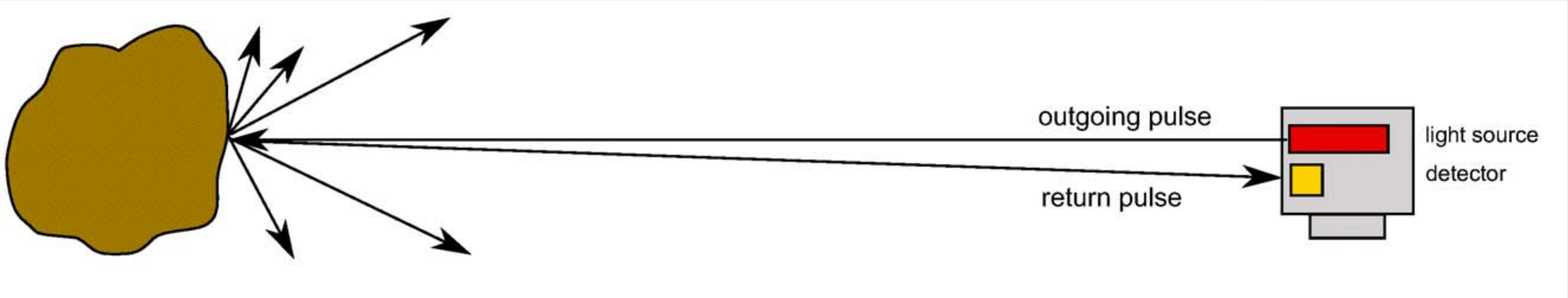
Laser Altimetry

Max-Planck-Institute for Solar System Research

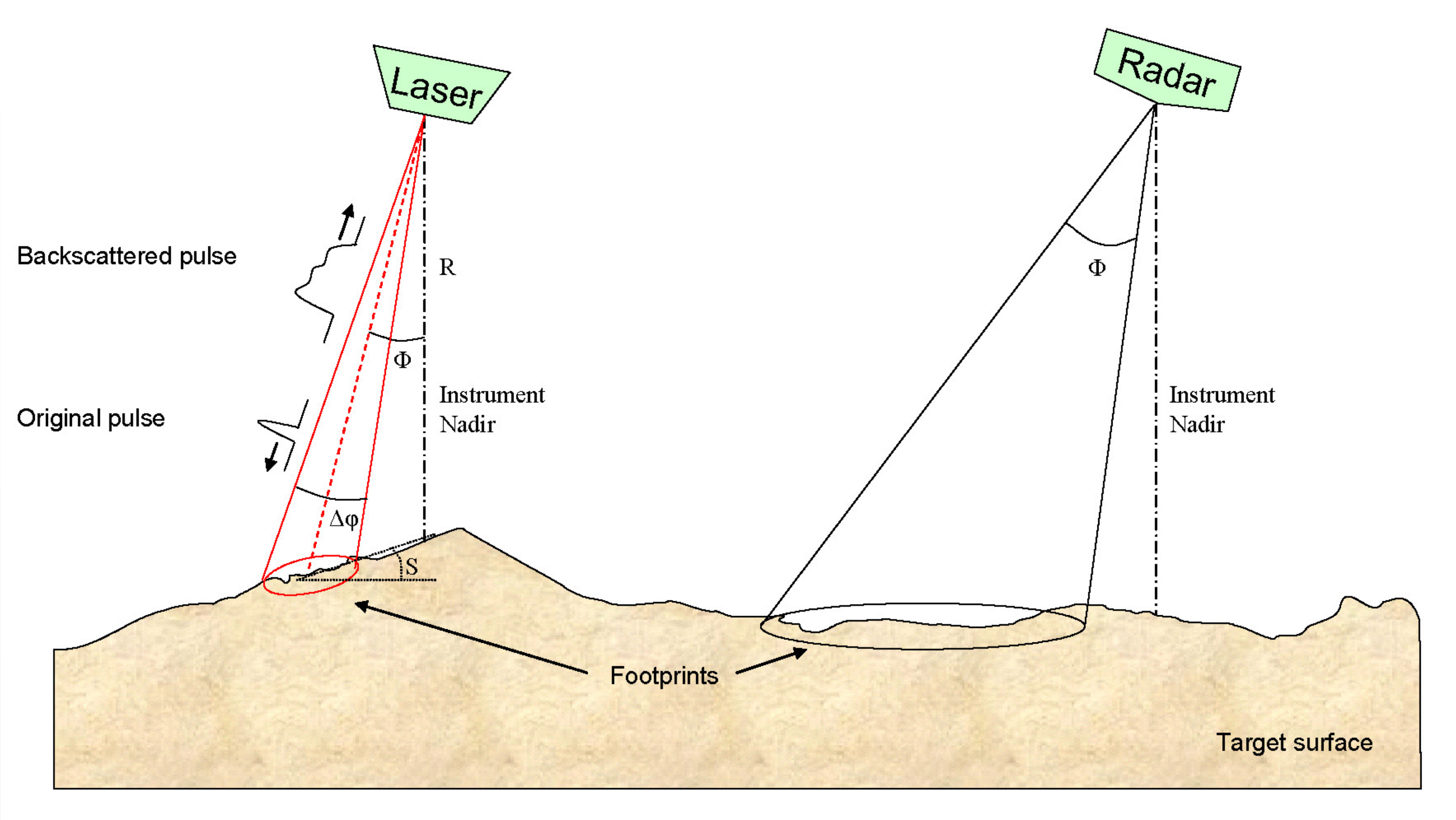
Reinald Kallenbach



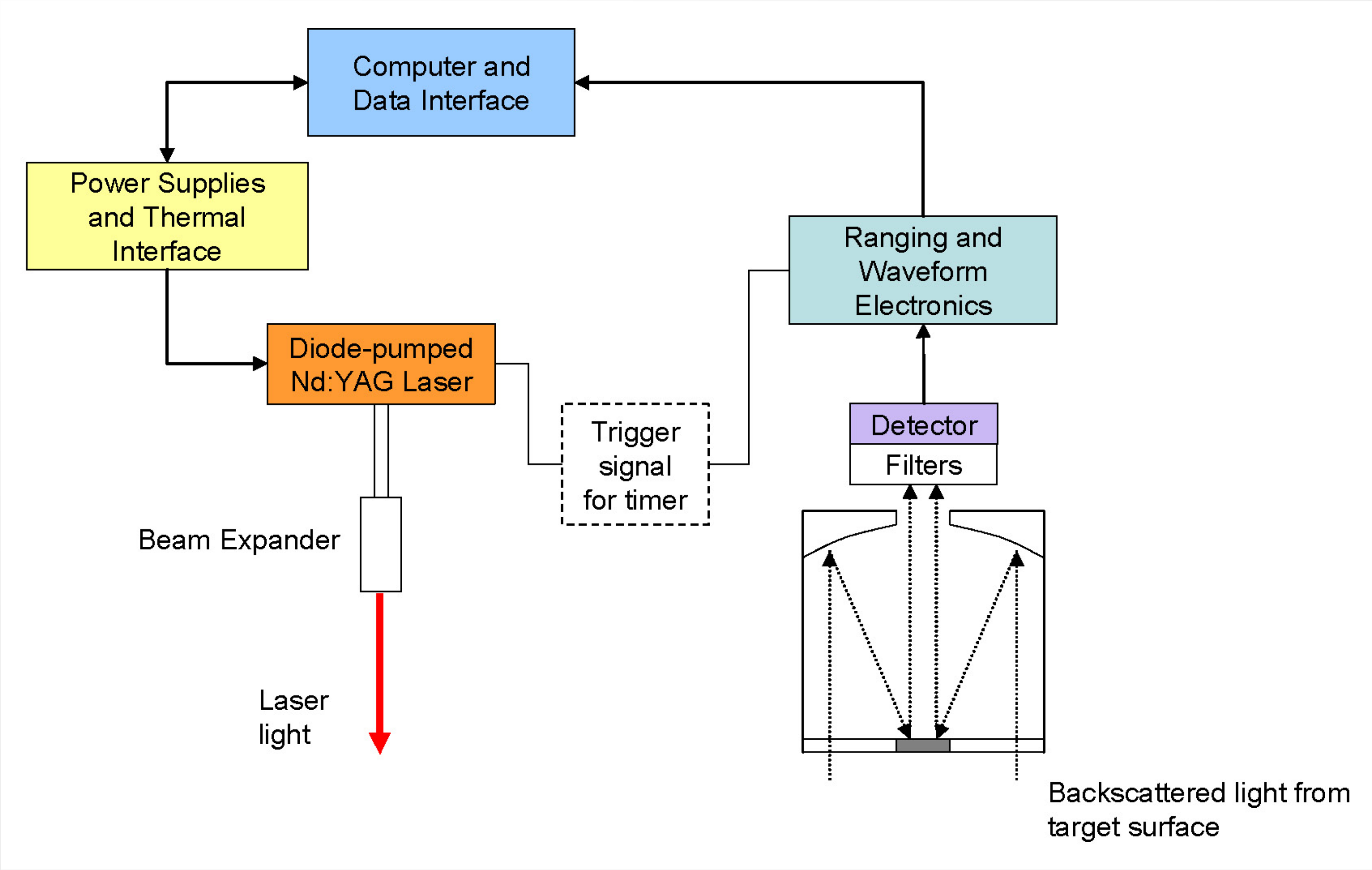
- Measurement Technique
- Instruments
- Planetary Science
- BepiColombo Laser Altimeter Project at MPS



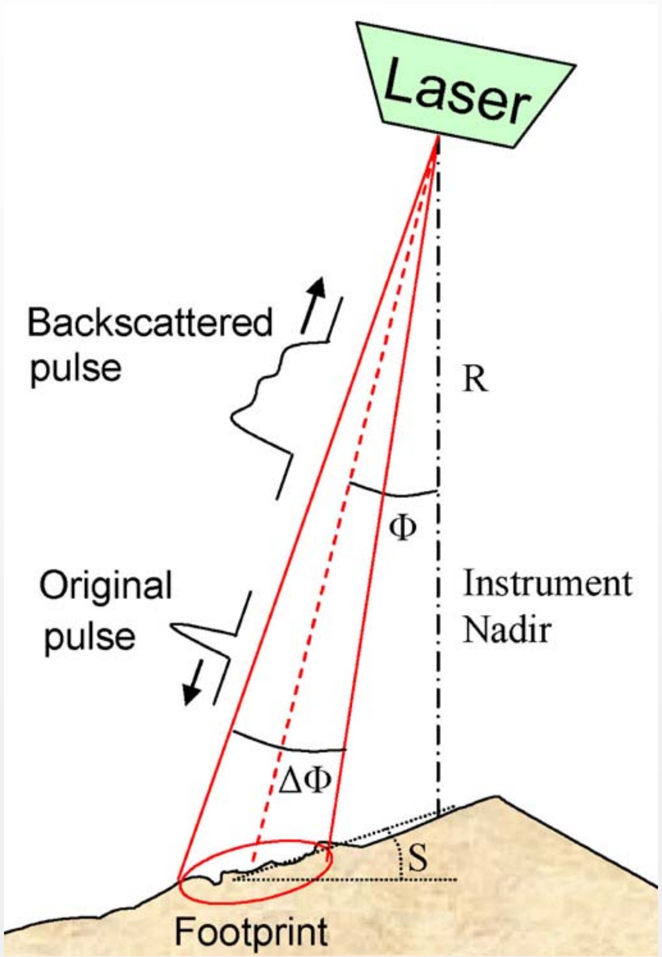
Measurement Technique

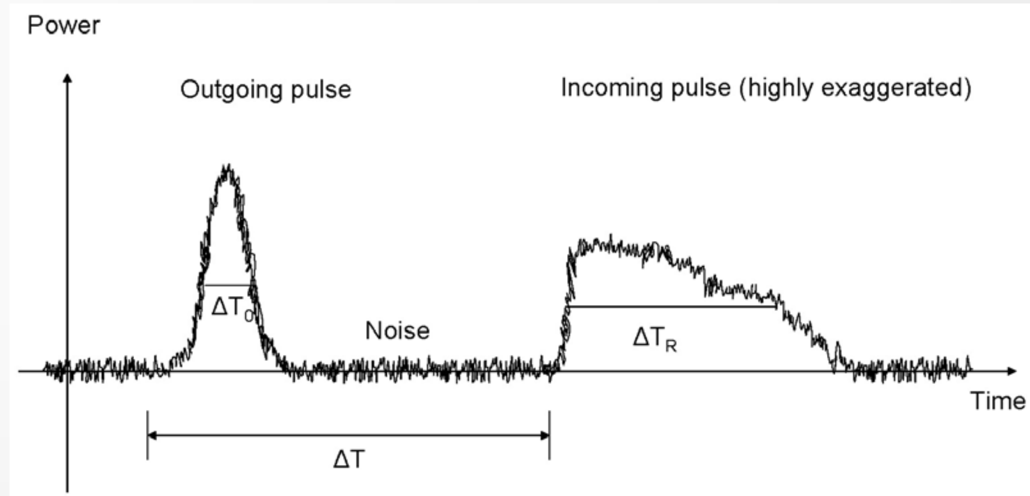


Measurement Technique



Measurement Technique



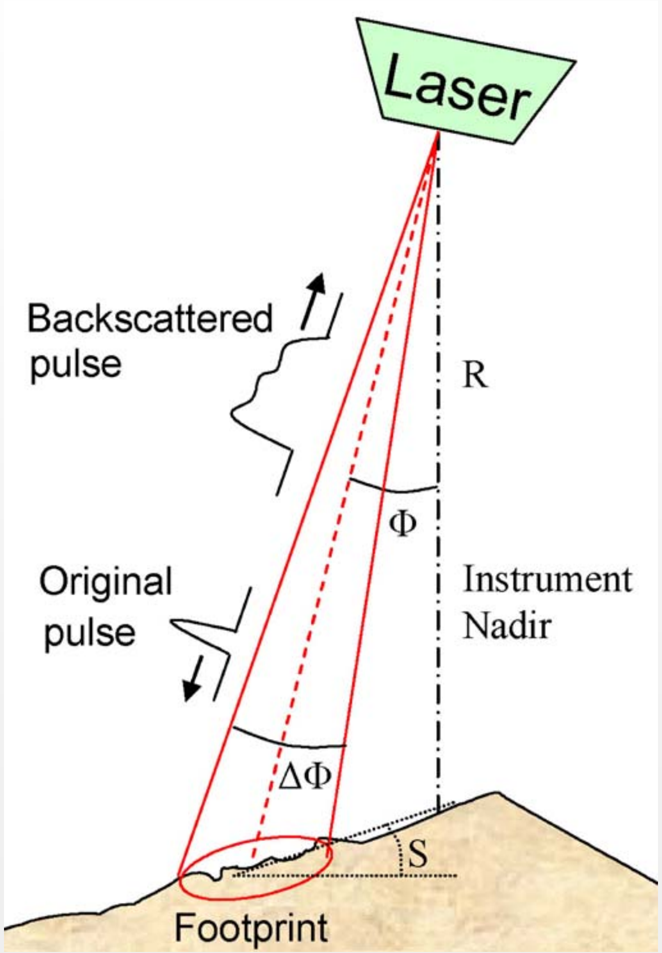


extra pulse spread:

$$\Delta T_S = \frac{2}{c} \cdot \tan(\Phi + S) \cdot Z \cdot \Delta\Phi$$

- c: speed of light
- Φ: off-nadir pointing angle
- S: surface slope
- Z: slant range to the surface
- ΔΦ: laser divergence angle or uncertainty in pointing angle

Measurement Technique



Link budget (Example BELA)

Number of photoelectrons on detector:

$$N_r = \left(\frac{E_t \cdot \eta}{h\nu}\right) \cdot \left(\frac{A_r}{Z^2}\right) \cdot t_{sys} \cdot t_{atm}^2 \cdot \left(\frac{r_{tar}}{\Omega_{tar}}\right)$$

Parameter	Symbol	Value
Transmit laser energy	E_t	50 mJ
APD quantum efficiency	η	0.36
Photon energy	$h\nu$	$1.875 \cdot 10^{-19}$ J
Receiver telescope area	A_r	$0.049\ m^2$
Range to Mercury	Z	400 km
System transmission	t_{sys}	0.77
Atmospheric transmission	t_{atm}	0.9
Target scattering angle	Ω_{tar}	π
Target diffuse reflectivity	r_{tar}	0.25

$N_r = 1460$ at $Z = 400$ km to Mercury

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Instruments

Mercury Laser Altimeter (MLA)

Cavanaugh et al. (2007)

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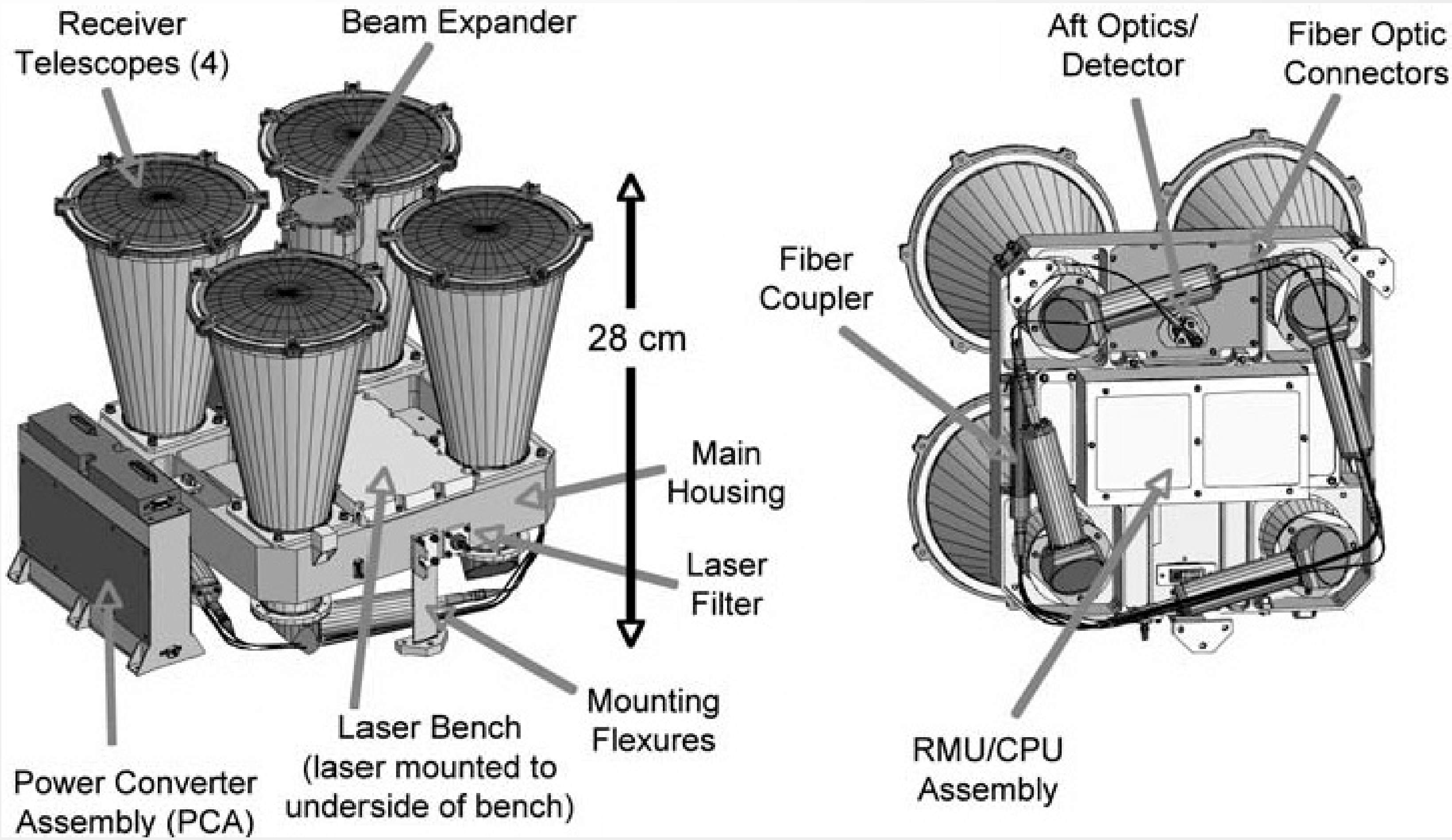
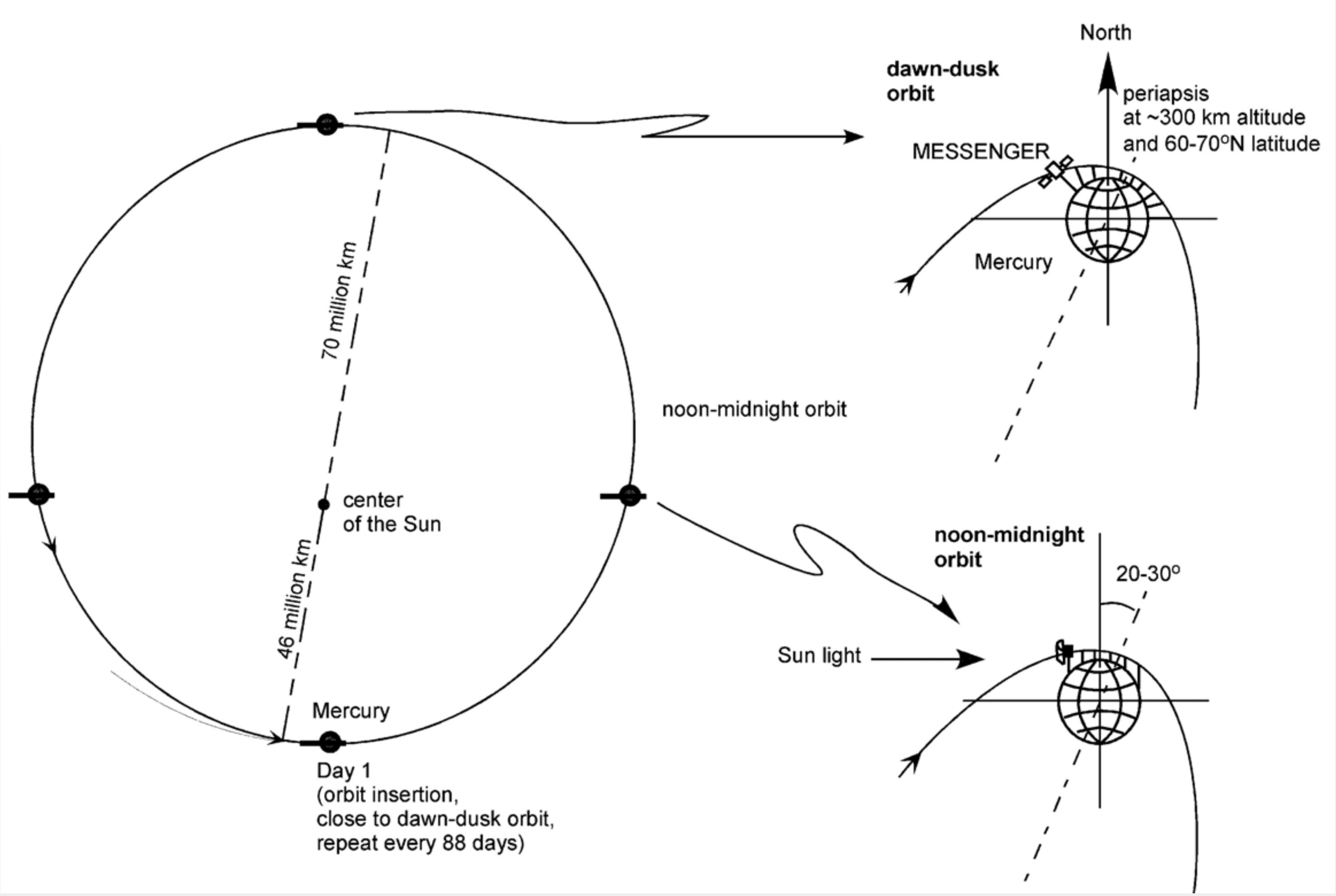


Instruments

MLA orbit (Cavanaugh et al., 2007)

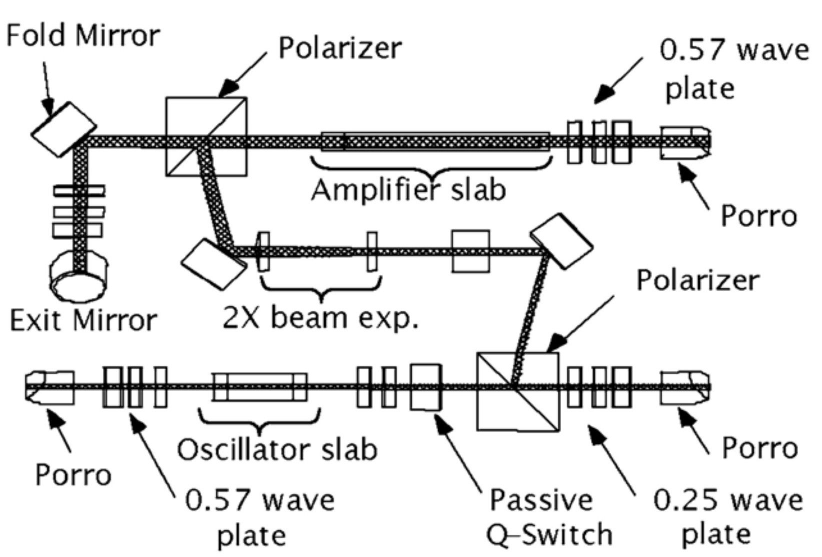


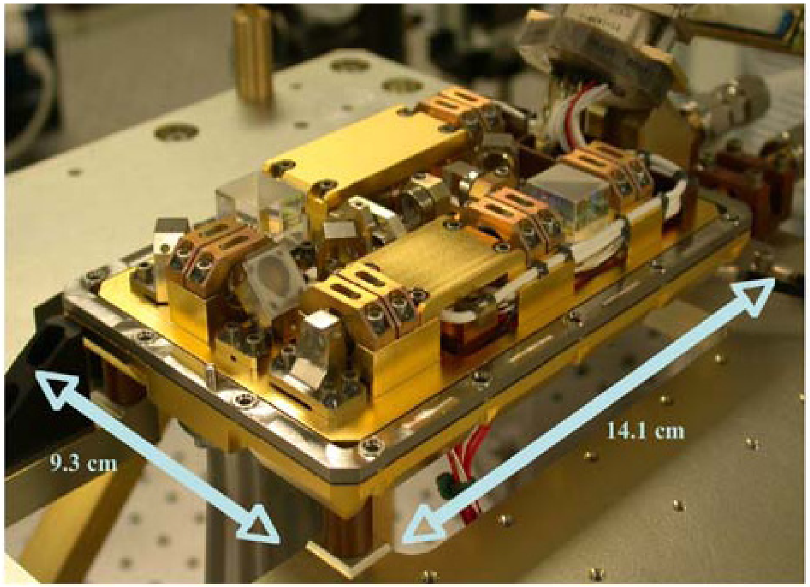
Instruments

MLA Transmitter (Cavanaugh et al., 2007)

Parameter	Requirement
Wavelength	1,064.5 nm ± 0.2 nm
Pulse energy	20 mJ ± 2 mJ
Pulse width	6 ns ± 2 ns
Pulse repetition rate	8 Hz
Beam divergence ($1/e^2$)	less than 80 μrad

Error source	Contribution
Leading edge timing	0.06 m
Clock frequency error (0.1 parts per million)	0.20 m
Measurement quantization (2.5 ns)	0.11 m
Pointing angle uncertainty (0.13 mrad)	0.68 m
Spacecraft orbit knowledge error	0.75 m
Total (root sum squared)	1 m





Instruments

Detector: Avalanche Photodiode (APD)

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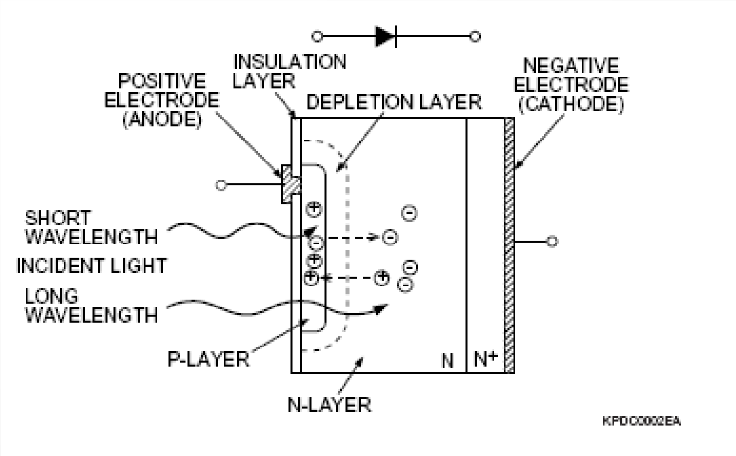
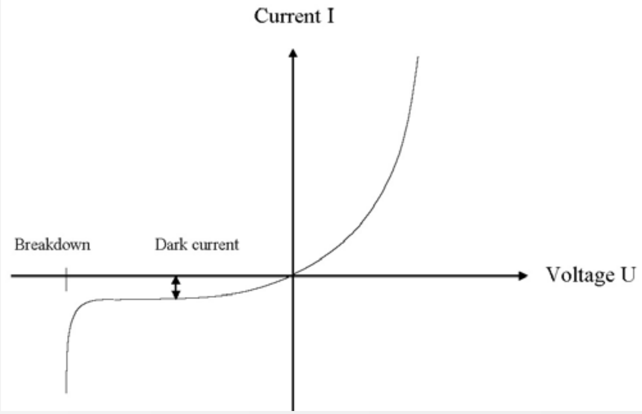
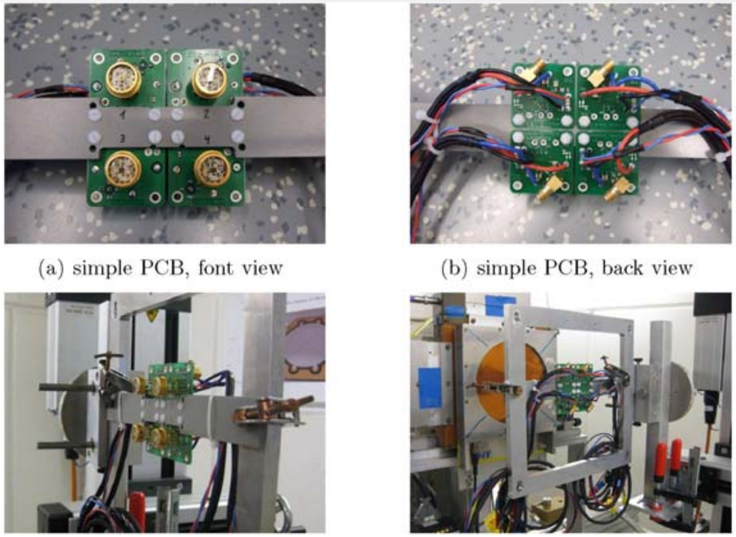




$$\frac{S}{N} = \frac{I_L^2 \cdot M^2}{2q \cdot (I_L + I_{DG}) \cdot B \cdot M^2 \cdot F(M) + 2q \cdot I_{DS} \cdot B + \dfrac{4 \cdot k_B \cdot T \cdot B}{R_L}}$$

where

- q: Charge of the electron
- I_L: Photocurrent at M=1
- I_{DG}: Dark current component to be multiplied
- I_{DS}: Dark current component not to be multiplied
- B: Bandwidth
- M: Multiplication ratio (gain)
- F: Excess noise factor
- T: Temperature
- k_B: Boltzman constant
- R_L: Load resistance



(a) simple PCB, font view

(b) simple PCB, back view

(c) PCB mounted on test frame, front view

(d) PCB mounted on test frame, back view.

Instruments

MOLA: Mars Orbiter Laser Altimeter
NASA – Mars Global Surveyor MGS

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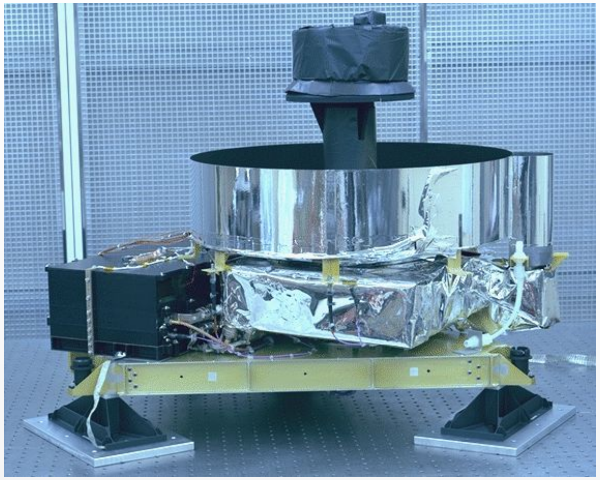
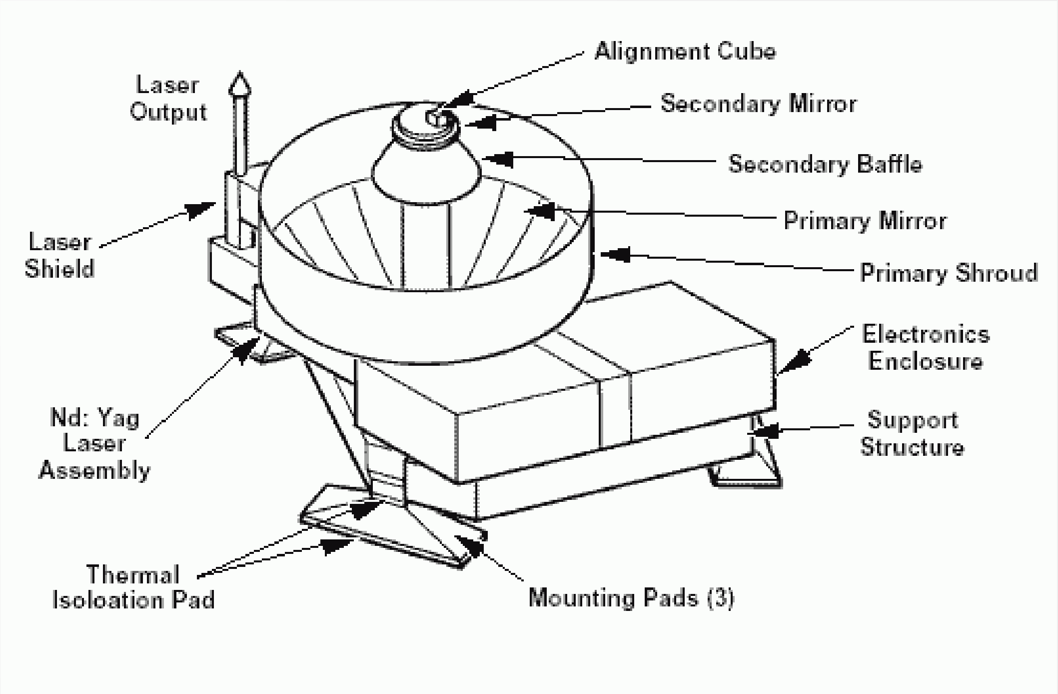
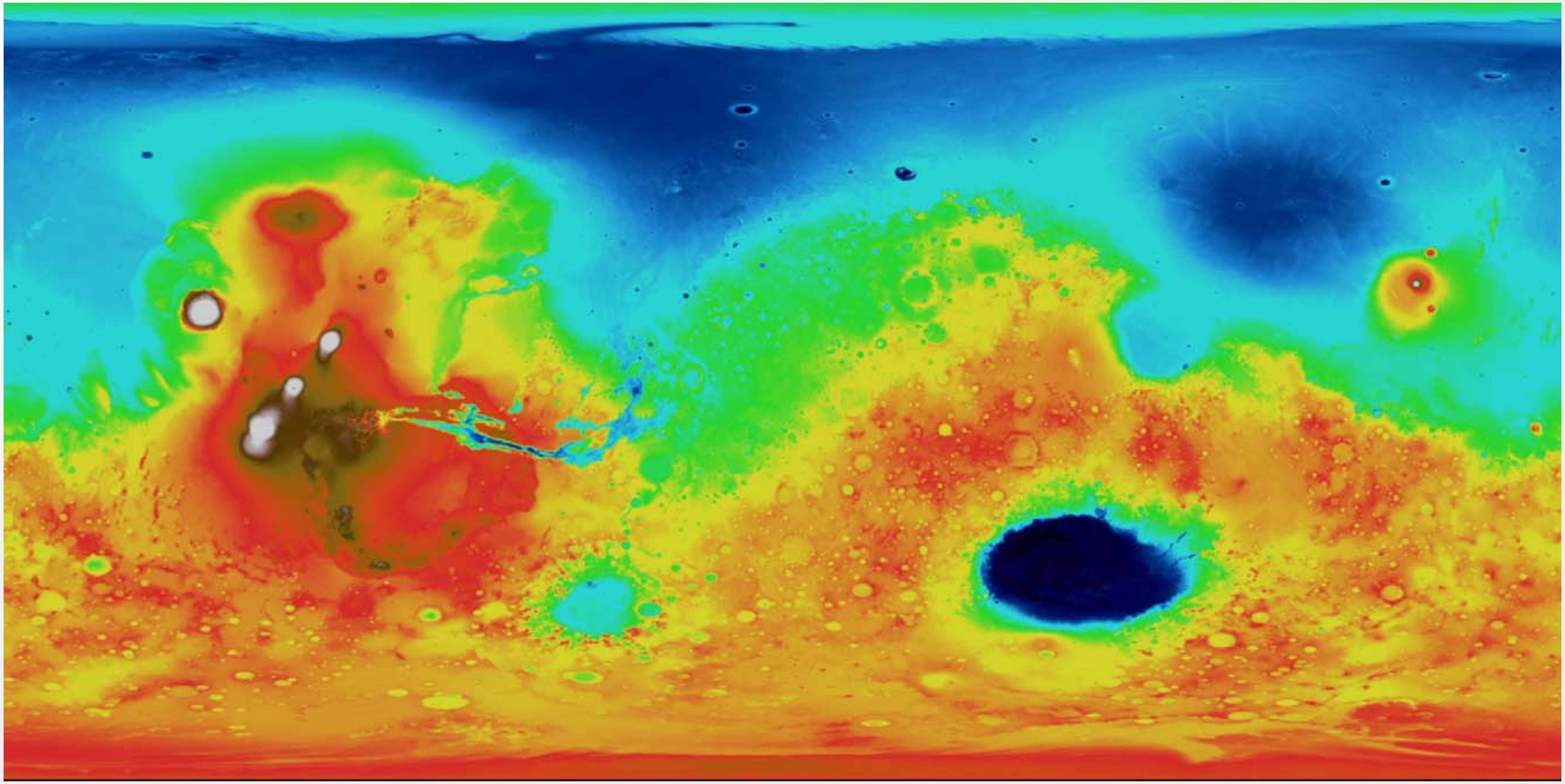


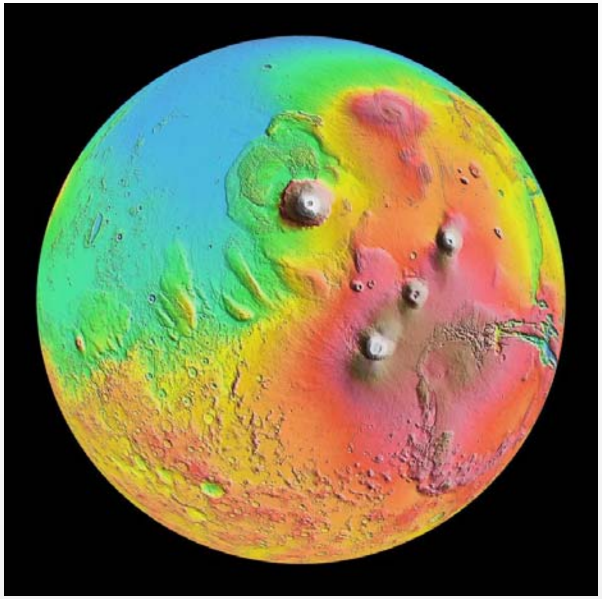


Planetary Science

MOLA: Mars Orbiter Laser Altimeter
NASA – Mars Global Surveyor MGS

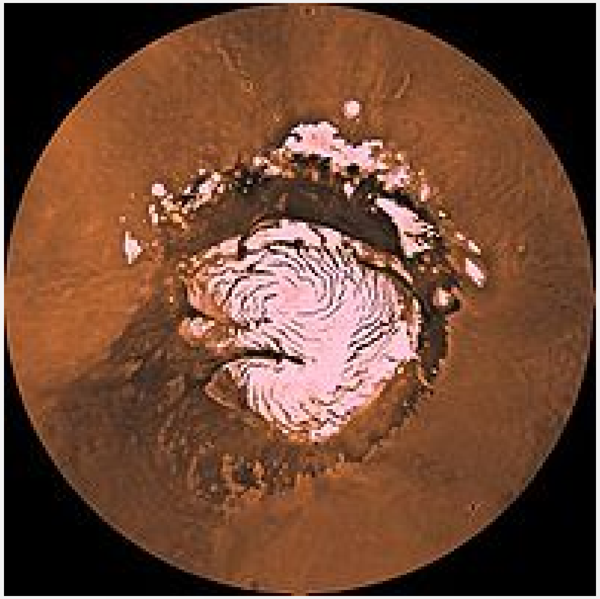


Planetary Science
Seasonal variations of Mars polar ice caps



MGS/MOLA

Hubble



Viking I

Laplace resonance Io, Europa, and Ganymed in Jupiter system: <u>Europa diurnal tides</u>

- Love number h_2: vertical displacement of surface relative to height of tidally perturbed potential surface
  depends on presence of subsurface ocean

Theoretical values

	no ocean	ocean
Europa:	0.1	30 m
Ganymede:	0.5	7 m
Callisto:	0.3	5m

Moore & Schubert (2000, 2003); Tobie 2003

- Love number k_2: additional gravitational potential due to displaced mass, relative to tide generating potential
  depends on (Wu et al., 2001) thickness of ice shell, rigidity of mantle, density of ocean (not depth), presence outer/liquid core

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Laser altimetry & Radio Doppler tracking

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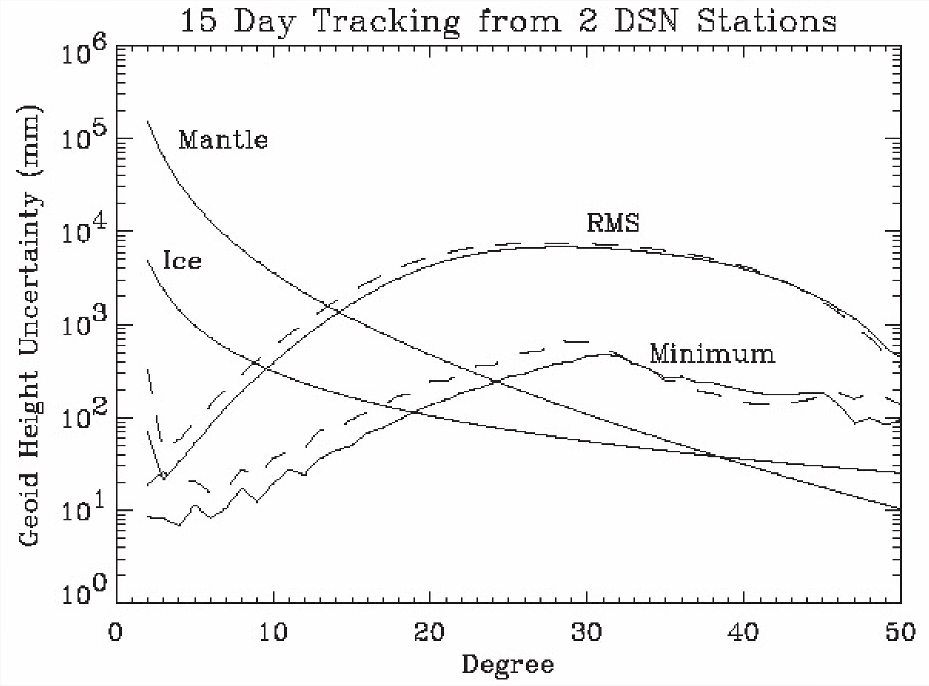
- X-band Doppler tracking
  0.09 mm/s range rate error
  Goldstone & Madrid stations
  (degree > 20)
  - static and tidal gravity
  - Jupiter attraction
  - Europa Albedo
  - IR thermal radiation
  - 3.55 day forced libration



Wu et al. (2001): Error of 0.002 in h_2/k_2 corresponds to 1 km thickness of ice shell

- Simulations laser altimetry:
  Koch et al. (2009)

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Planetary Science

Time-dependent variation of Mercury's topography due to solar gravitation

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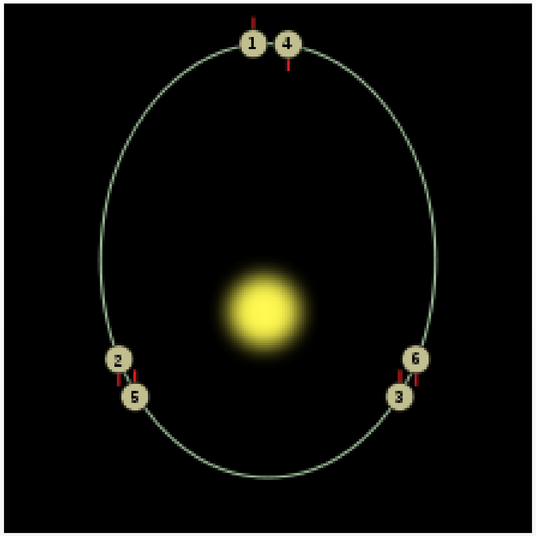
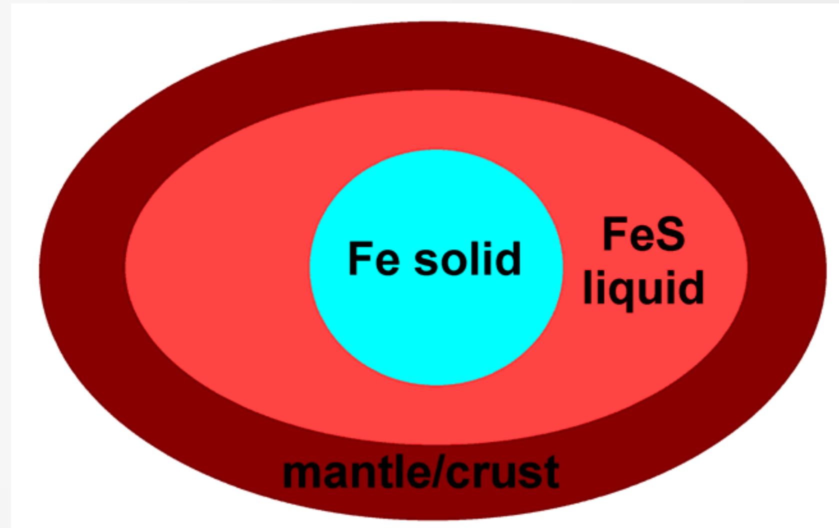
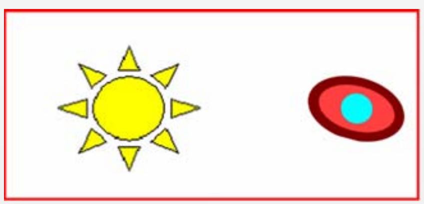


3:2 Spin-Orbit Resonance of Mercury



Solar tides

$$\delta r_{tide} = h_2 F_{tid}(\psi, R) = h_2 \frac{M_{sun}}{M_{merc}} \frac{a^4}{R^3} \left(\frac{3}{2} \cos^2[\psi - \delta] - \frac{1}{2} \right)$$



Forced libration

$$\frac{C_m}{C} = \frac{C_m}{B-A} \times \frac{B-A}{Ma^2} \times \frac{Ma^2}{C}$$

Planetary Science

Forced libration of Mercury

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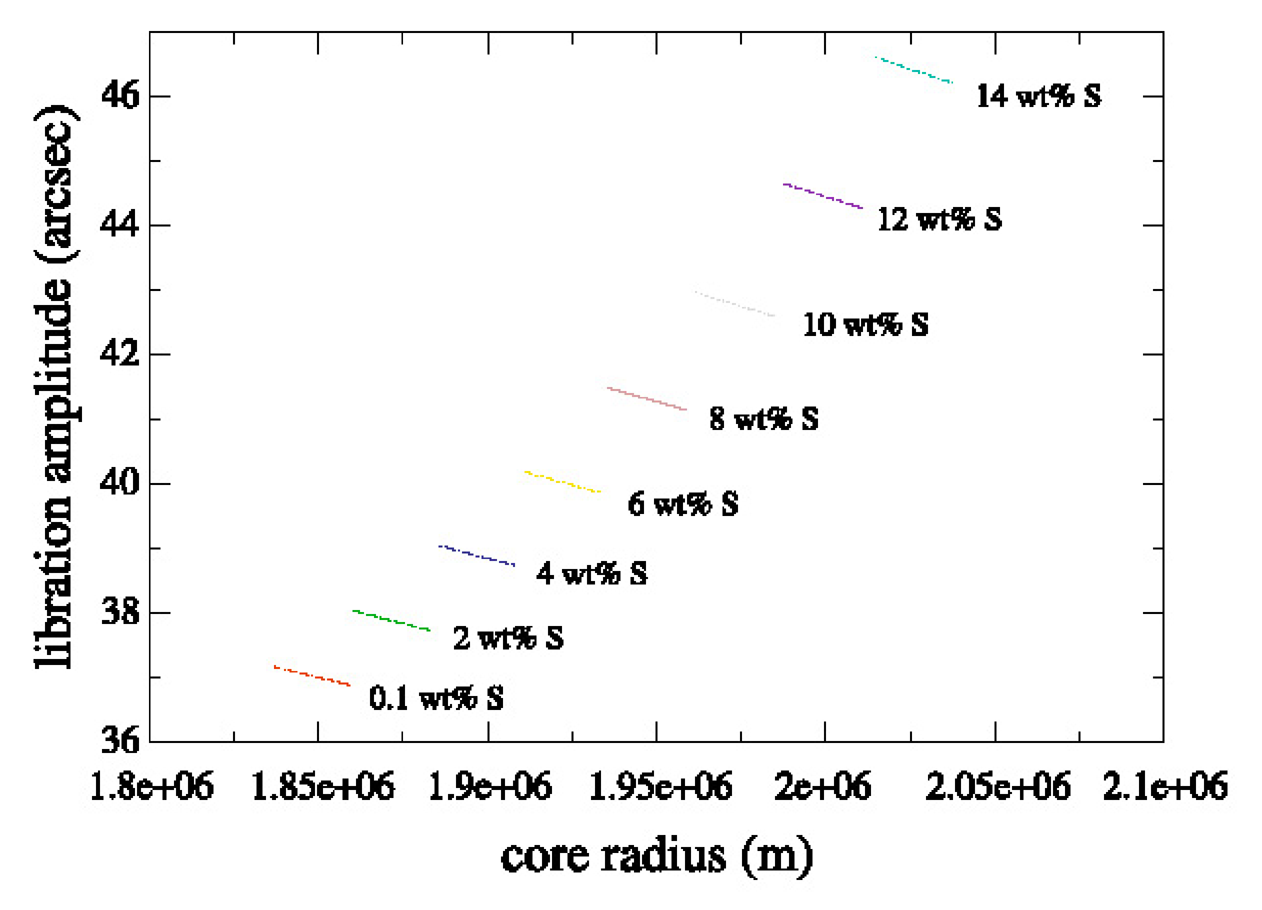

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Forced libration of Mercury

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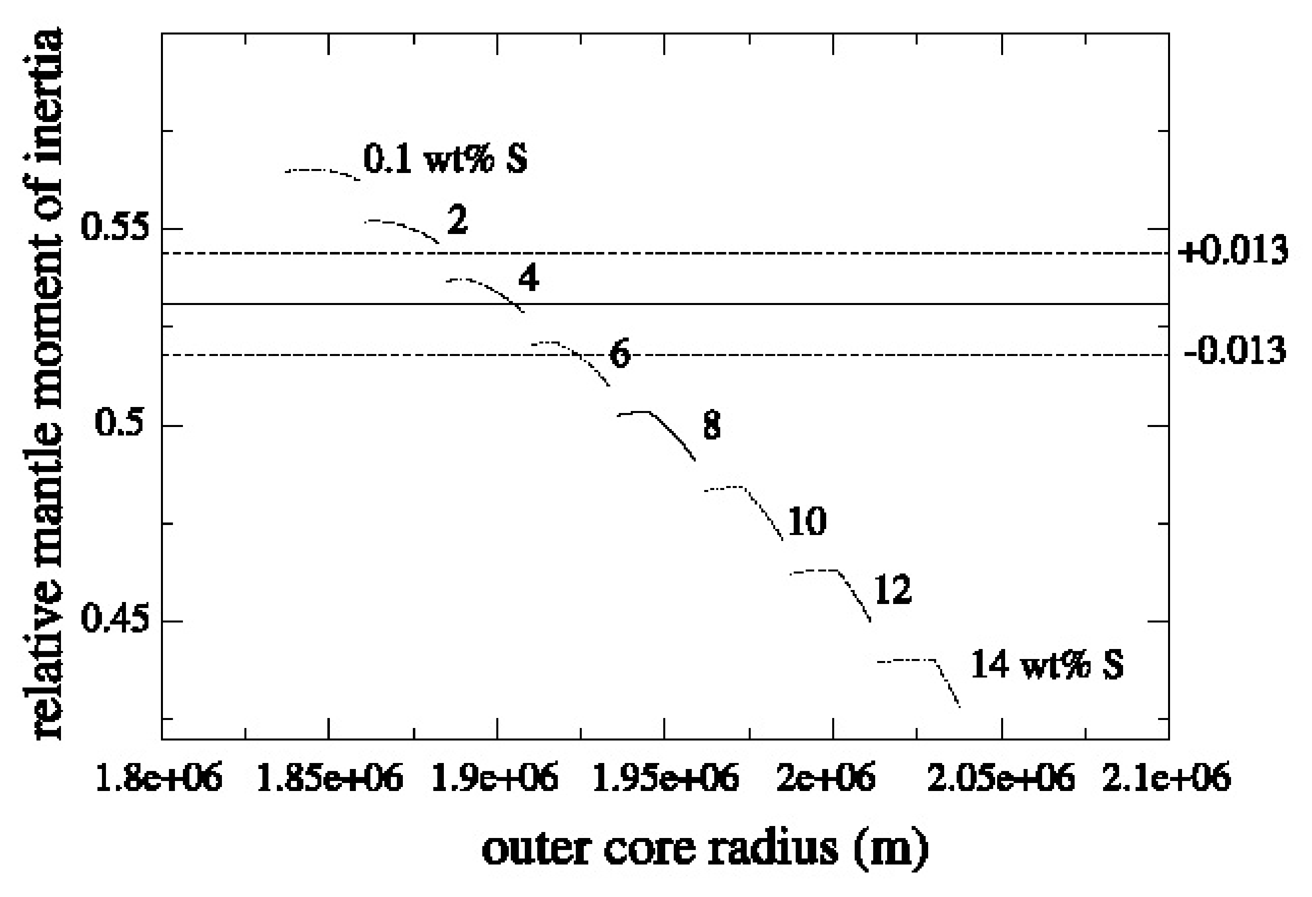

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Tidal amplitude

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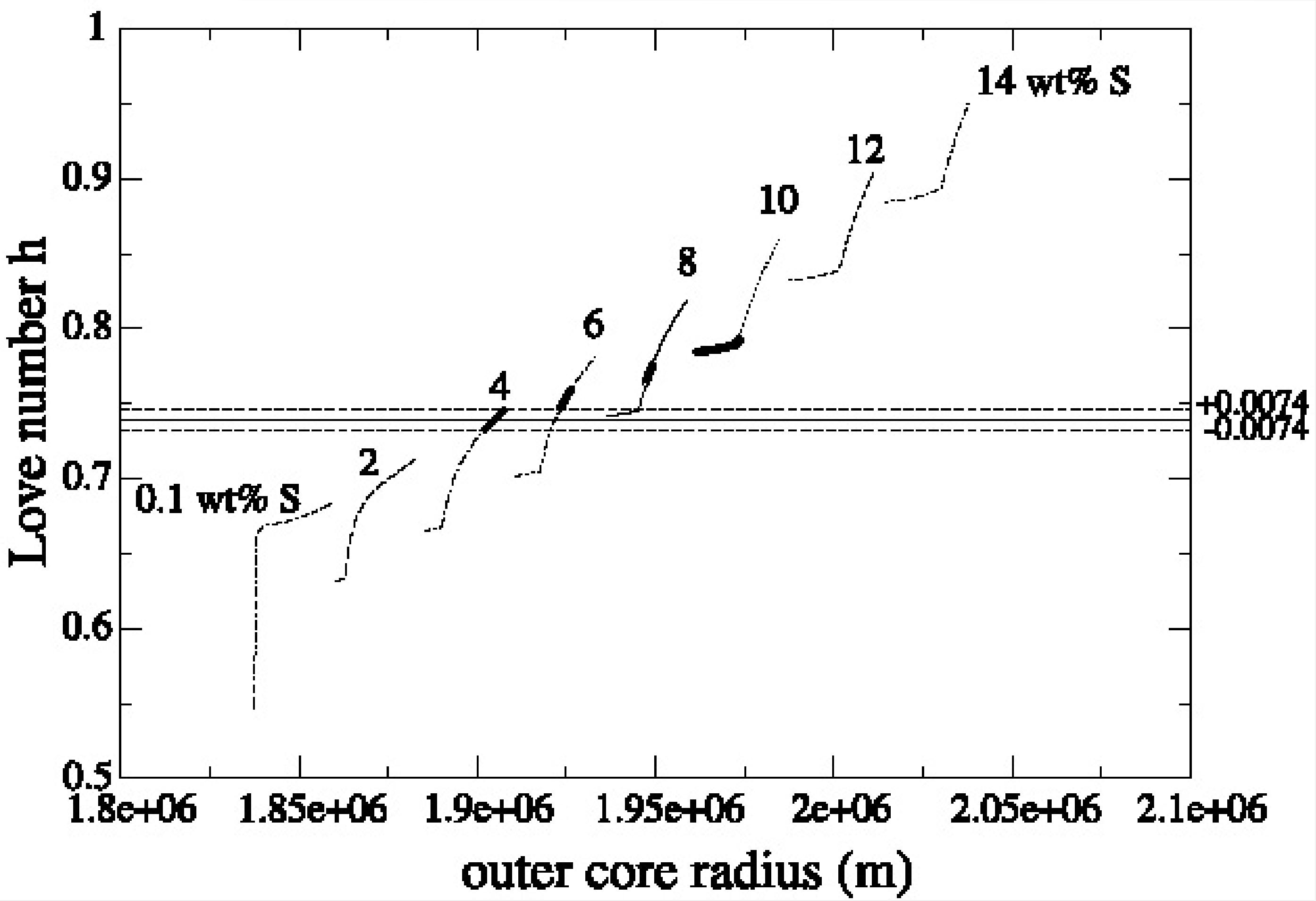
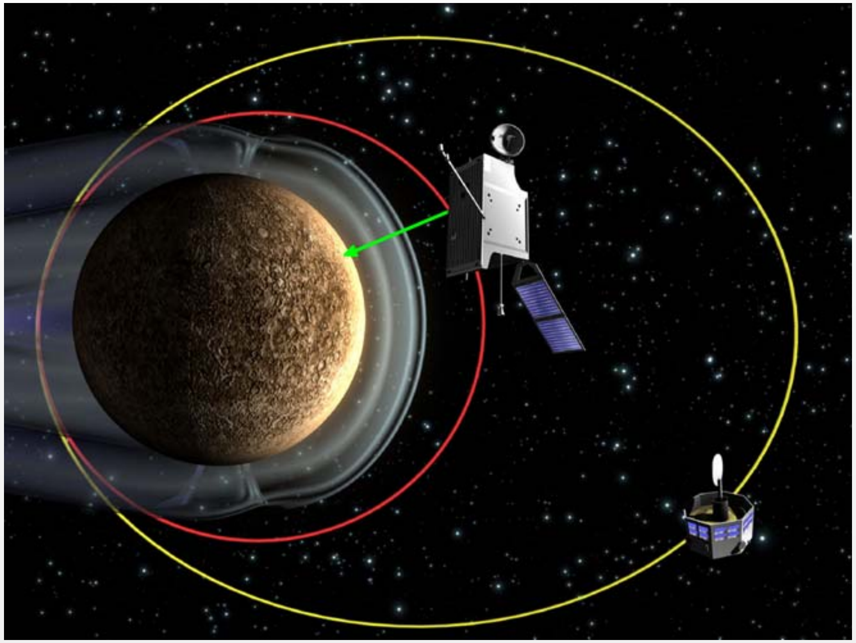
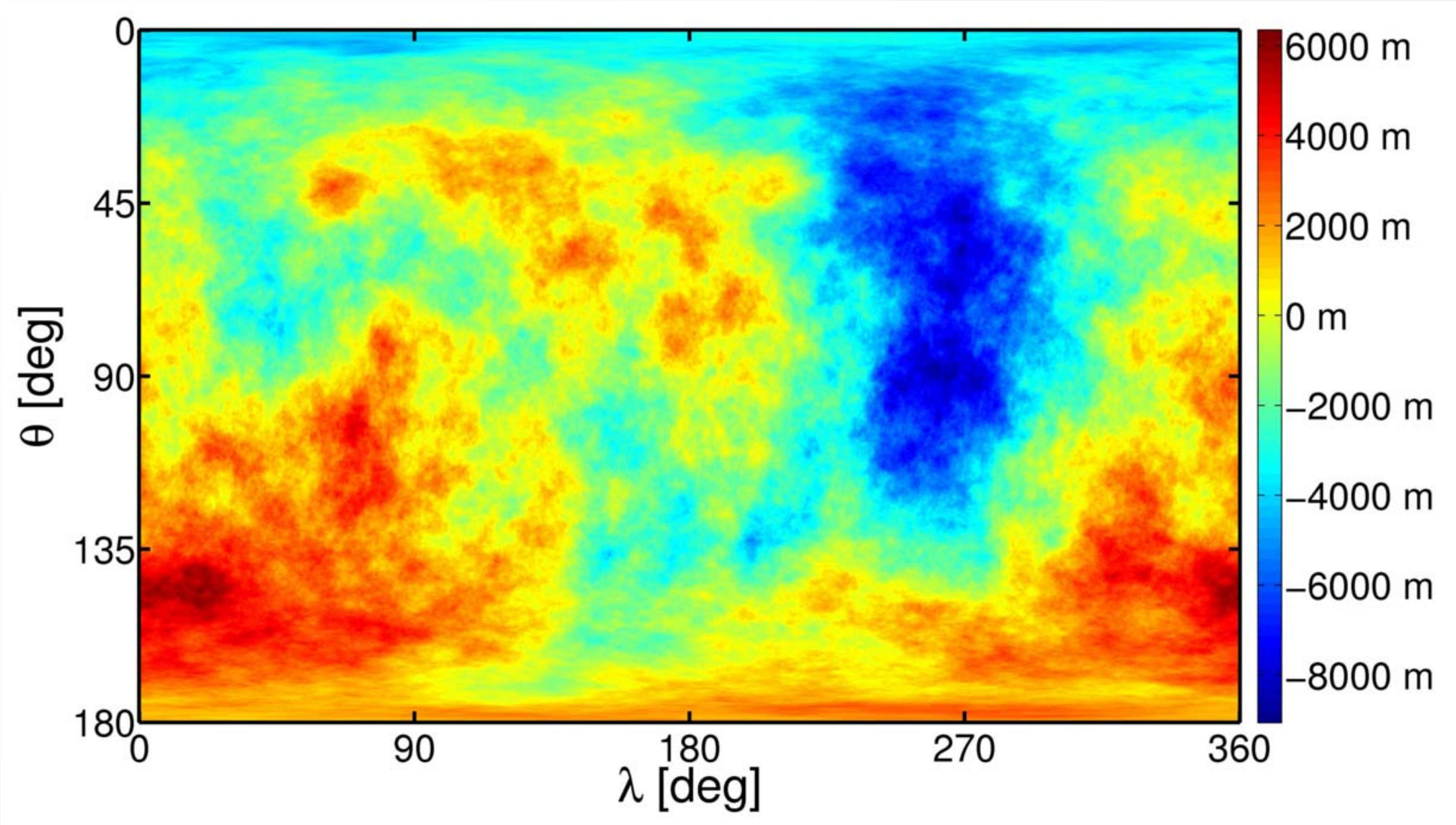


Planetary Science
BepiColombo Laser Altimeter BELA



BELA at MPS

Thesis by C. Koch – Simulations on Instrument performance



BELA at MPS

Thesis by C. Koch – Simulations on Instrument performance

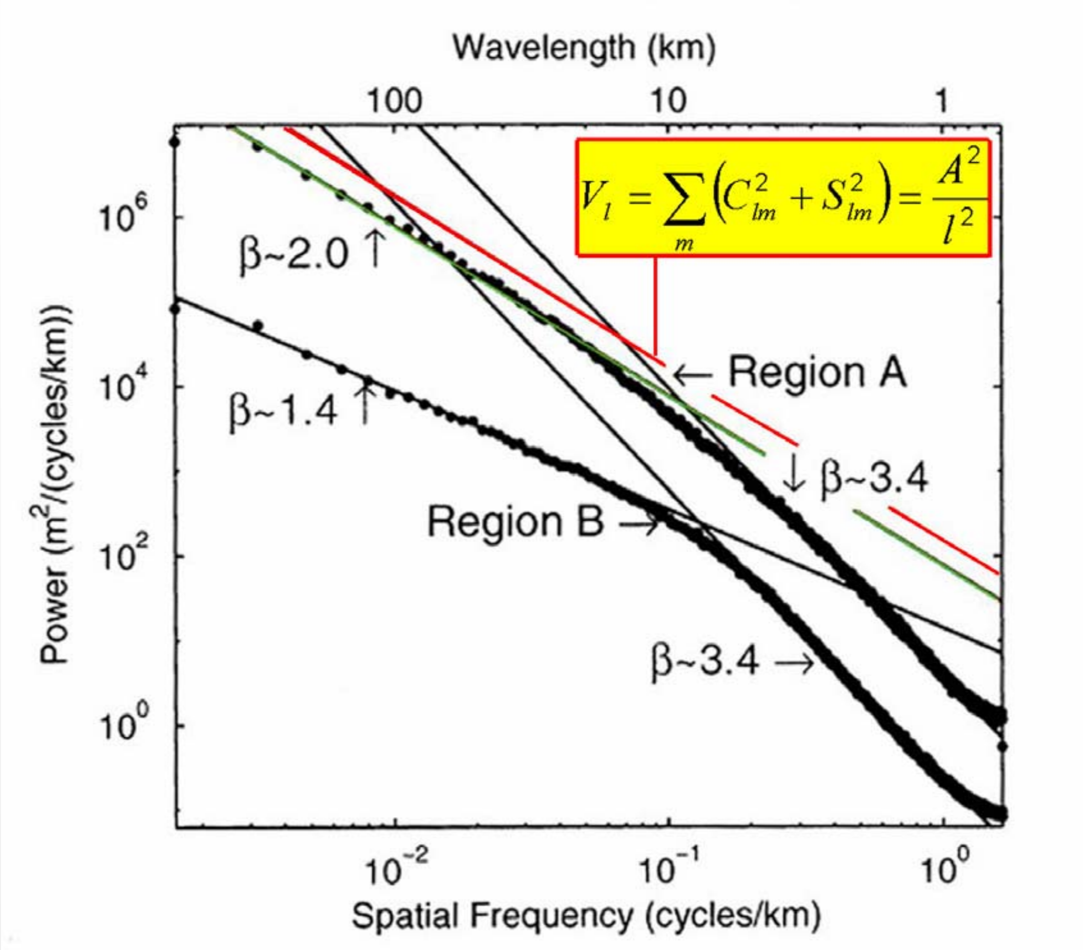
- Simulate observations for different, nominal elliptical orbit of MPO (continuous and/or with
  data gaps):
  resonant: 910.000 MPO orbits within 1 Mercury year
  non-resonant: 909.234 MPO orbits within 1 Mercury year

- Add tidal elevation.

- Add noise (including small-scale topography, orbital and measurement errors).

- Add offset in longitude due to libration.

BELA at MPS
Assumptions on Mercury Topography



Martian (Aharonson et al., 2001) & lunar topographic spectral density as reference

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Extraction of tidal Love number & libration amplitude

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Take „topographic measurements“ T_k at a constant frequency:

$$T_k = T(\theta_k, \lambda_k + \Delta\lambda_{libr}) + \delta r_{tide}(\psi_k) + N_k$$

Deterministic topog. — Tidal elevation — Noise

$$\Delta\lambda_{libr} = \phi_o (\sin M + a_2 \sin 2M + \ldots) = \phi_o f(M)$$

$$\sum_k w_k \left[T_k - h_2 F_{tid}(\psi_k) - \sum_{\ell=0}^{\ell_{max}^{irw}} \sum_{m=0}^{\ell} p_\ell^m(\cos\theta_k) \{ C_\ell^m \cos(m\lambda_k') + S_\ell^m \sin(m\lambda_k') \} \right]^2 \to Min$$

$$\sum_k w_k \left[T_k - h_2 F_{tide}(\Psi_k) - \sum_{l,m=0}^{l_{irw},l} P_l^m(\cos\theta_k) \{ C_{lm} \cos m\lambda + S_{lm} \sin m\lambda \} \right]^2$$

$$w_k \left[\Delta\Phi_{lib} f_{lib}(M) \sum_{l,m=0}^{l_{irw},l} P_l^m(\cos\theta_k) \{ \hat{C}_{lm} \cos m\lambda + \hat{S}_{lm} \sin m\lambda \} \right]^2 \to Min$$

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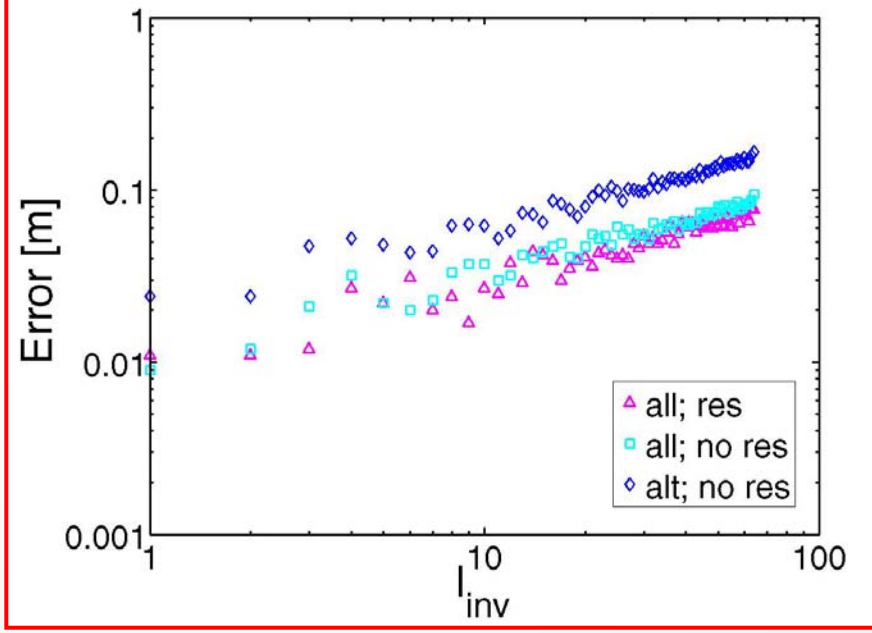

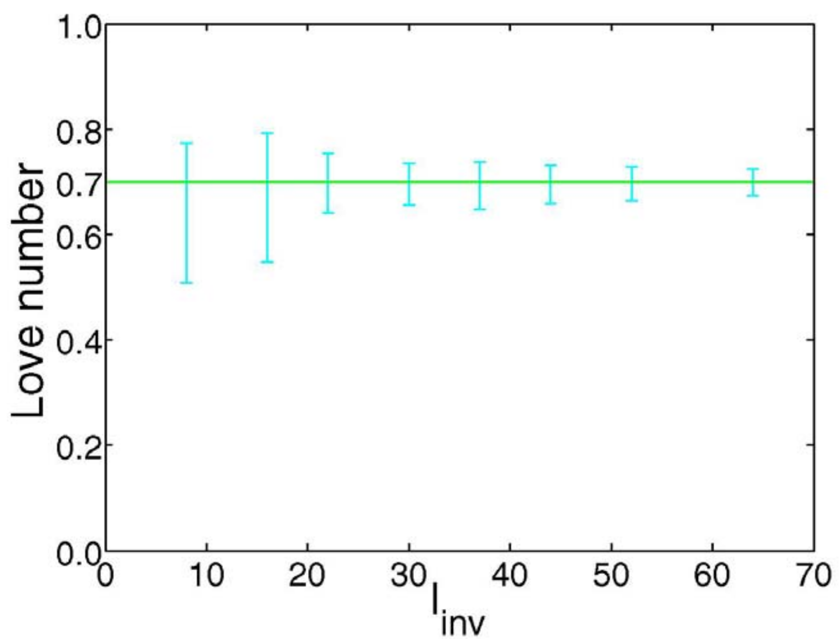

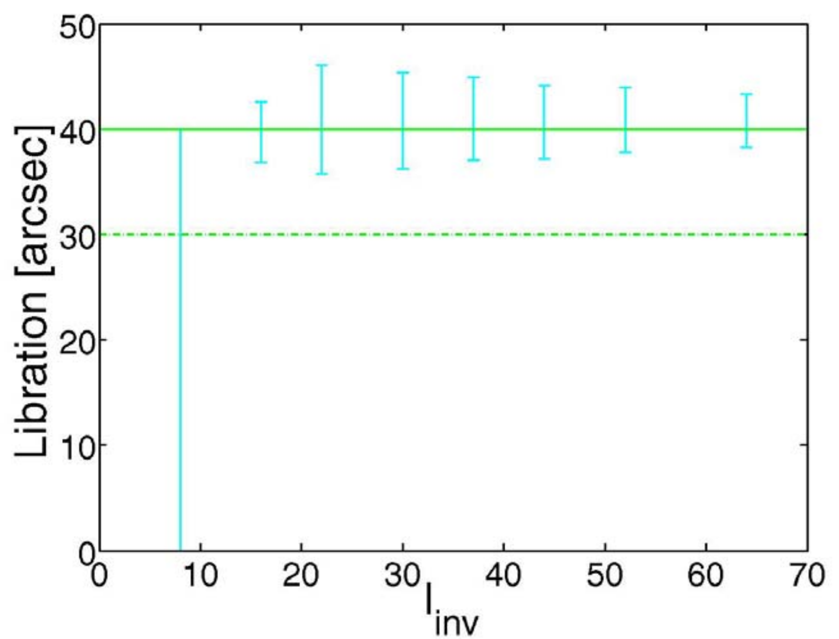

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BELA at MPS

Simulation results C. Koch

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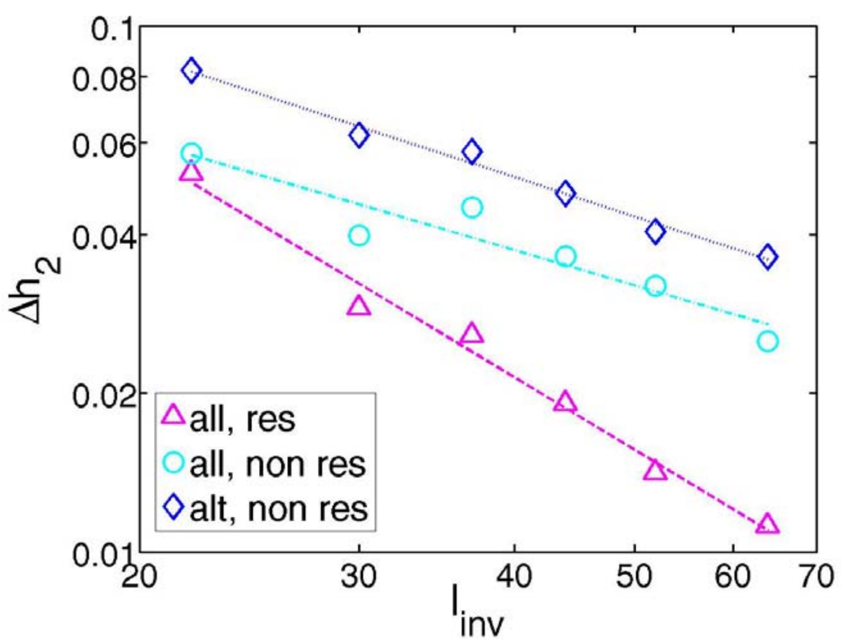
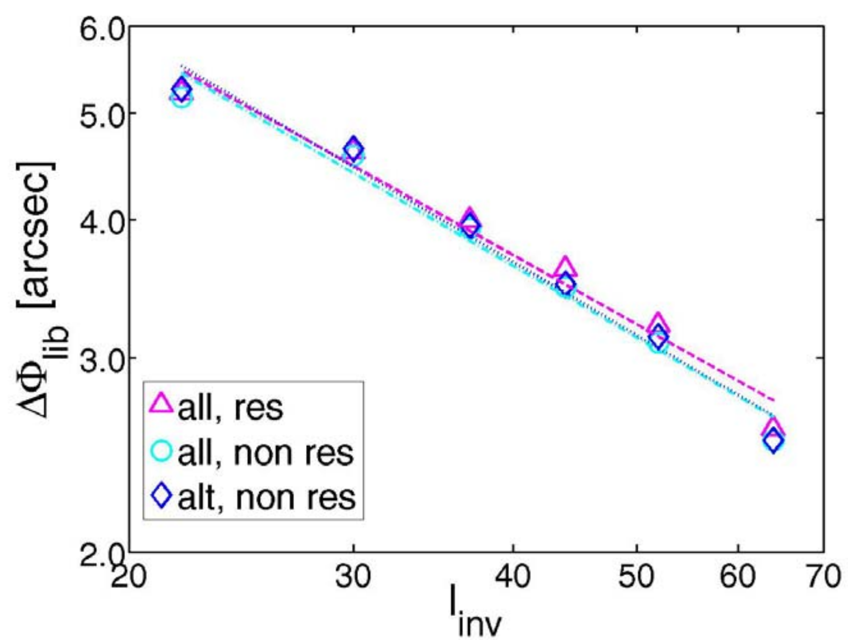
$$\Delta h_2 \propto l_{inv}^{-2/3}$$

$$\Delta\Phi_{lib} \propto l_{inv}^{-2/3}$$





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Crossing point analysis

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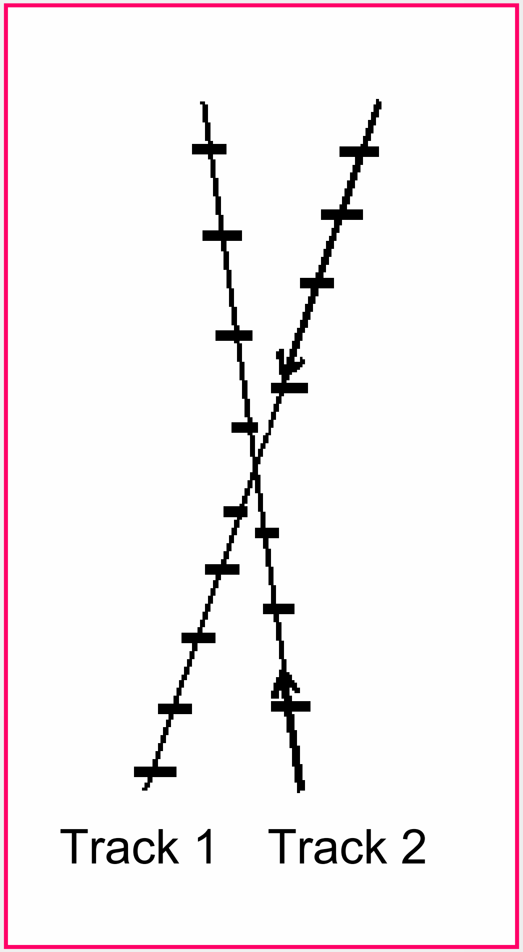
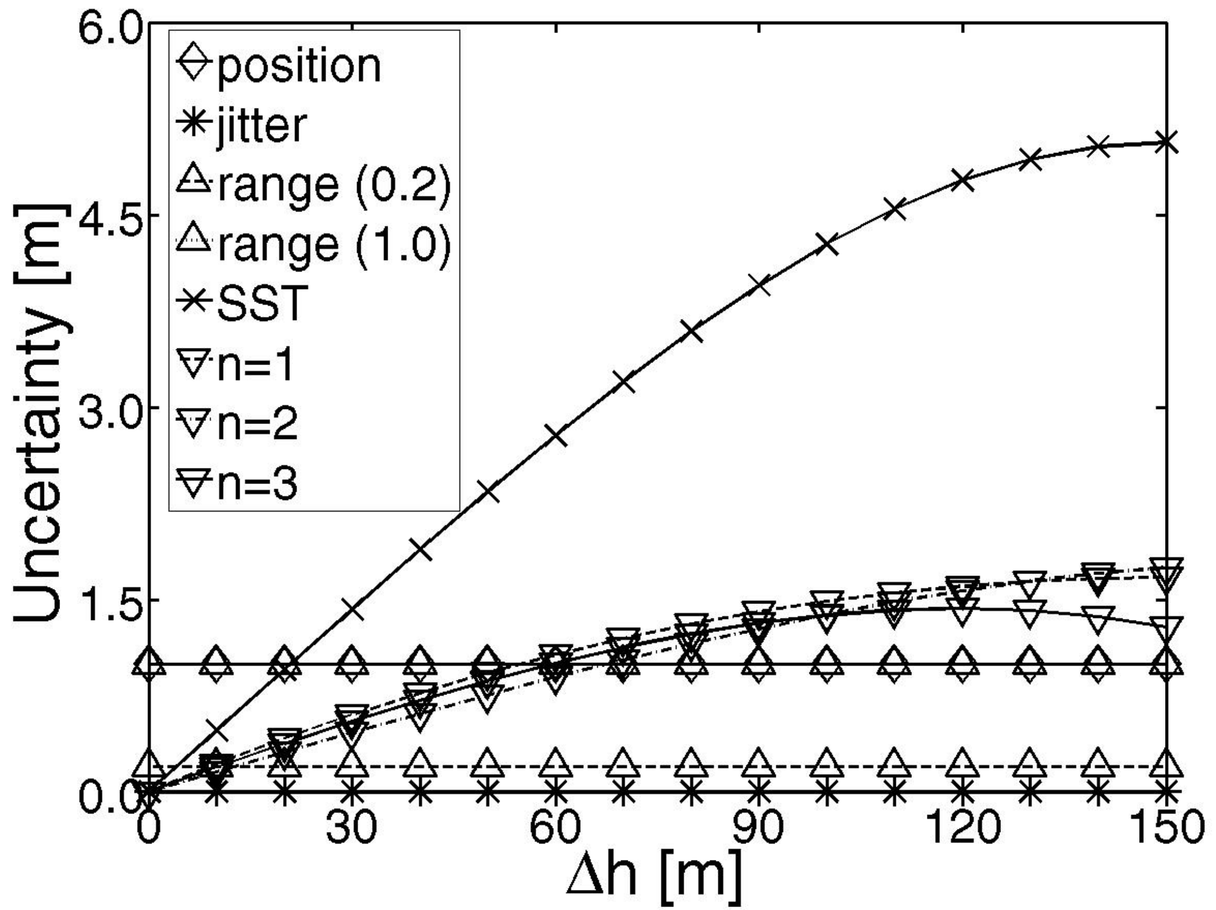
- Large number of crossing points close to the Poles due to MPO's orbit.
- Amplitude of the tidal Love number approximately 30 cm at the Poles.
- 455/910 tracks are crossing each other within 2/4 Mercury years.



BELA at MPS
Crossing point analysis



BELA at MPS

GALA – Ganymede Laser Altimeter

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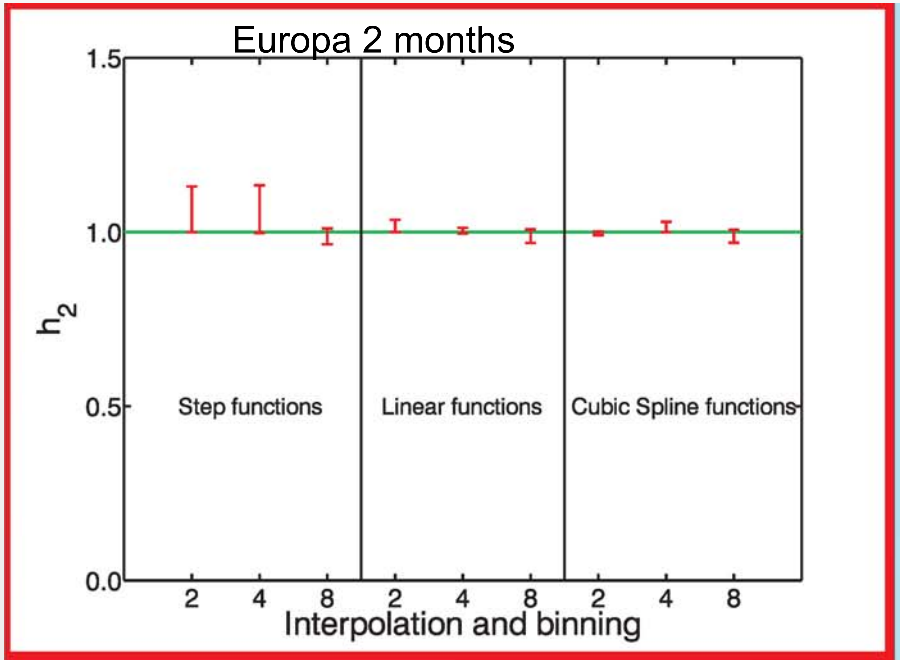
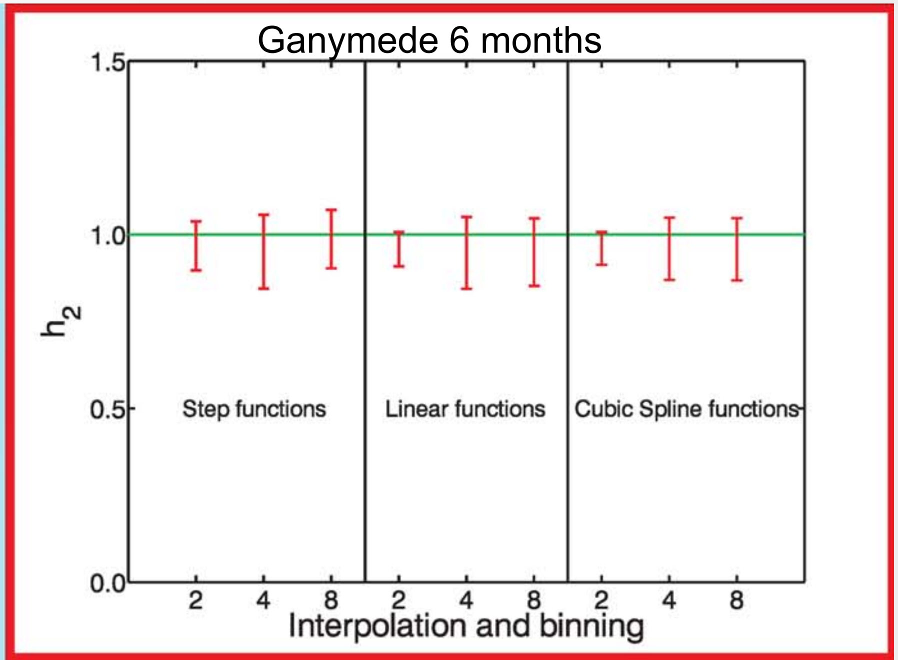
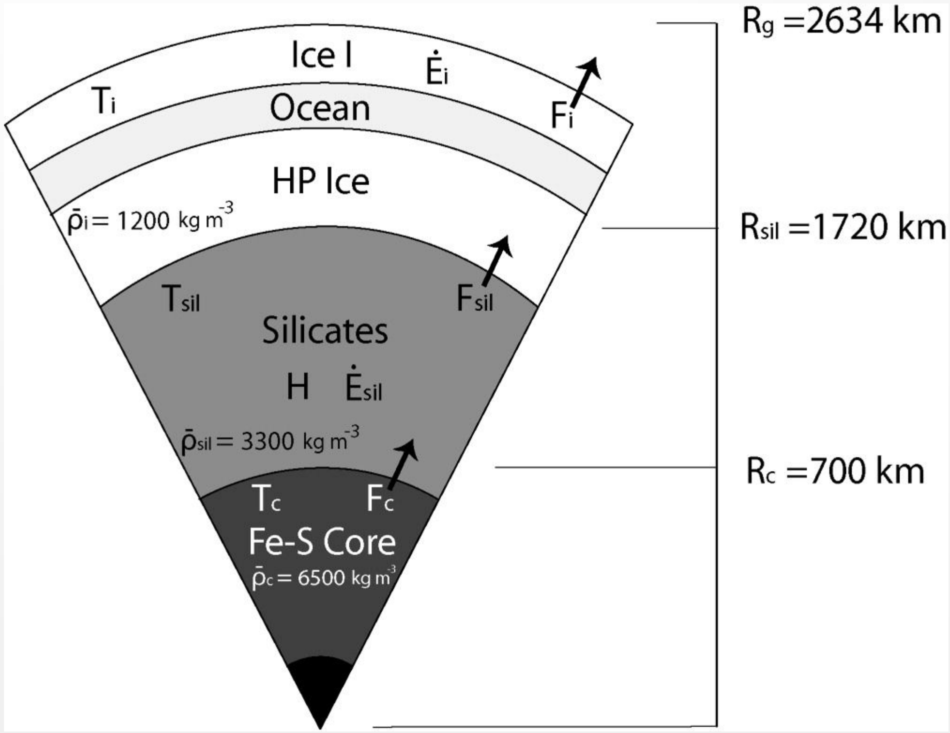
Parameter	Symbol	Value JEO	Value JGO
Semi major axis	a	1769 km	2834 km
Eccentricity	e	0.00001	
Relative orbital period	$T_{JEO/JGO}$	3819.216 s	7744.294 s
Inclination	i	89.9 deg	

Near-polar orbit of JEO/JGO, 10 Hz repetition rate, 8 km ground track spacing in longitude
1536 x 3072 grid, decomposition spatial and time-dependent topography





Ganymede: dynamo?



- Magnetoconvection
- Remanent magnetization due to Jupiter's magnetic field
- Internal active dynamo
- Remanent magnetization due to an internal dynamo which is no longer active

M.T. Bland, A.P. Showman, and G. Tobie (Icarus, 2008)

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„Micro“ Laser I

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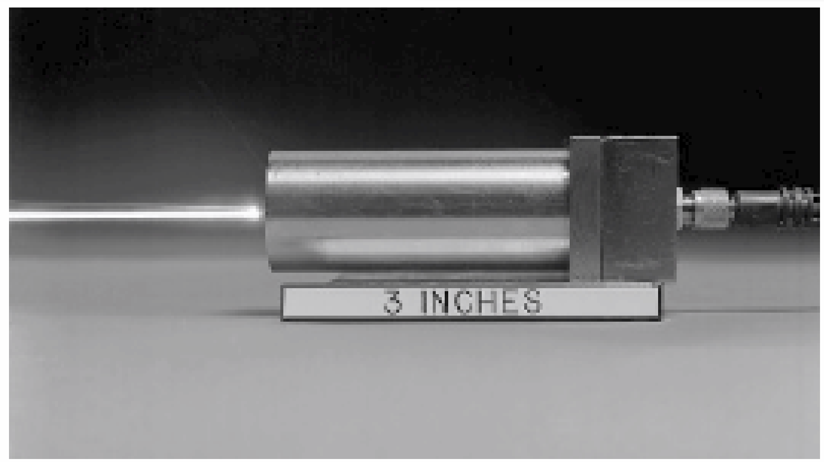
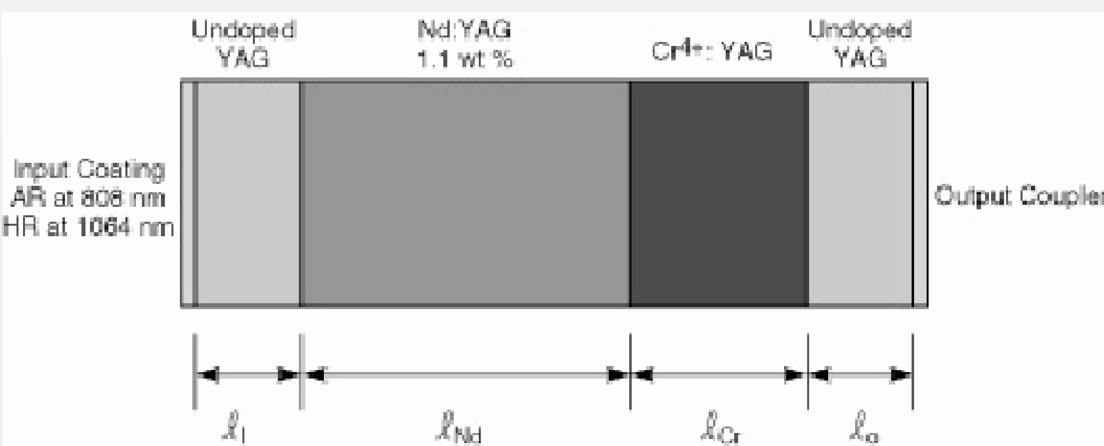
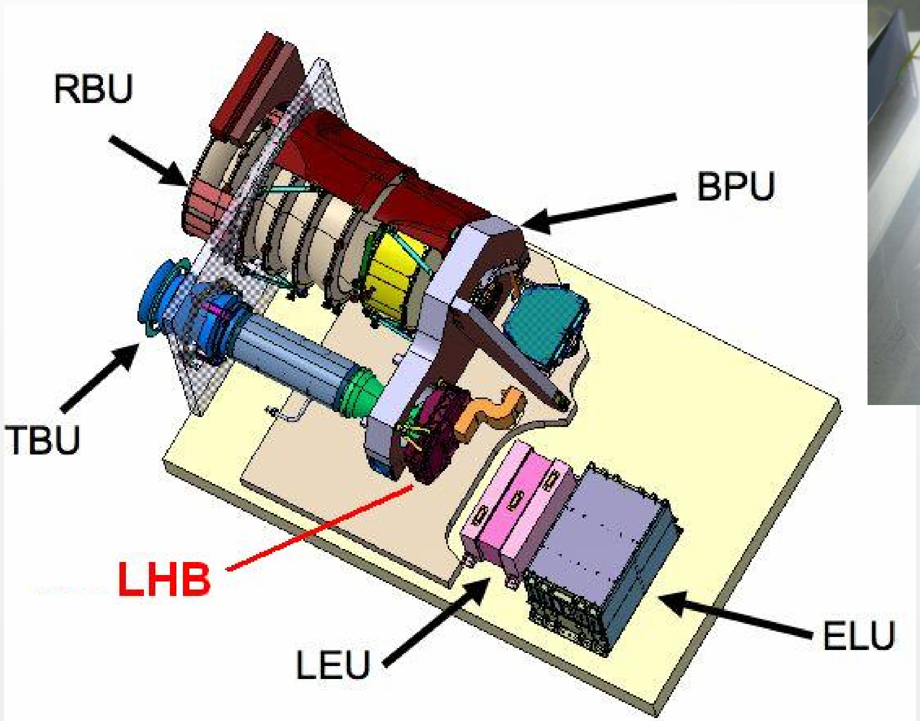


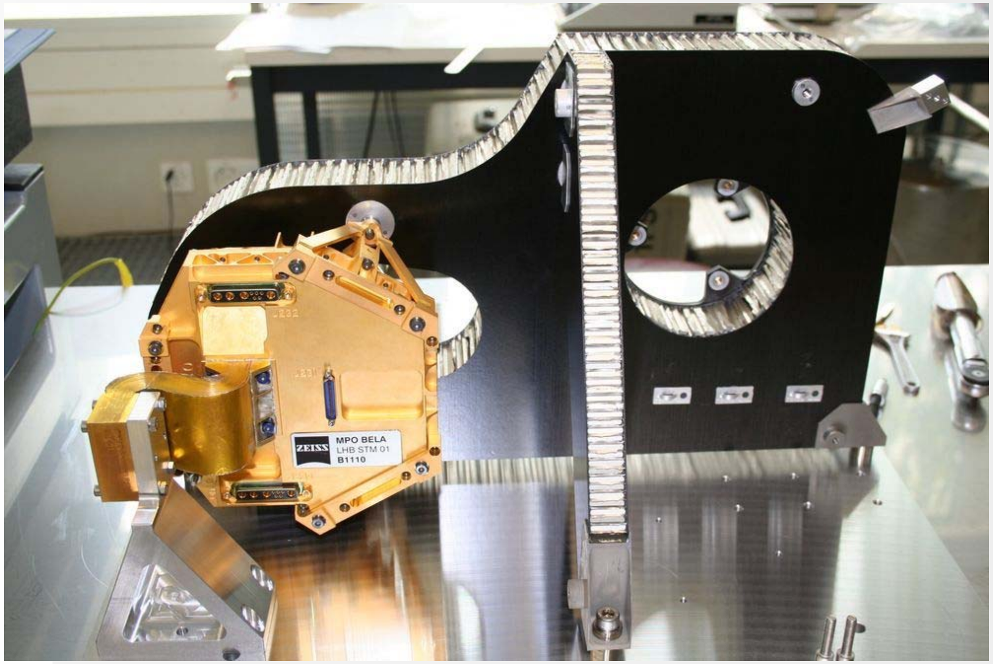
- **Several devices jointly developed by NASA/GSFC and MIT/Lincoln Lab (SLR2000)**
- **Power:**
  - **>1 Watt @1064 nm**
  - **Repetition Rate: up to 16 kHz**
- **Energy: up to 250 μJ/pulse**
- **Pulsewidths: 300 to 2200 psec**
- **Pumped by single GaAs diode laser array at 808 nm (< 20W)**
- **Passively Q-switched**
- **Monolithic Structure**
  - **Thermally bonded Nd^{3+}:YAG, Cr^{4+}:YAG and undoped YAG**
  - **Coatings applied to crystals**
  - **laser resonator < 11 mm in length**
  - **Can't misalign**



„Micro“ Laser II

BELA heritage





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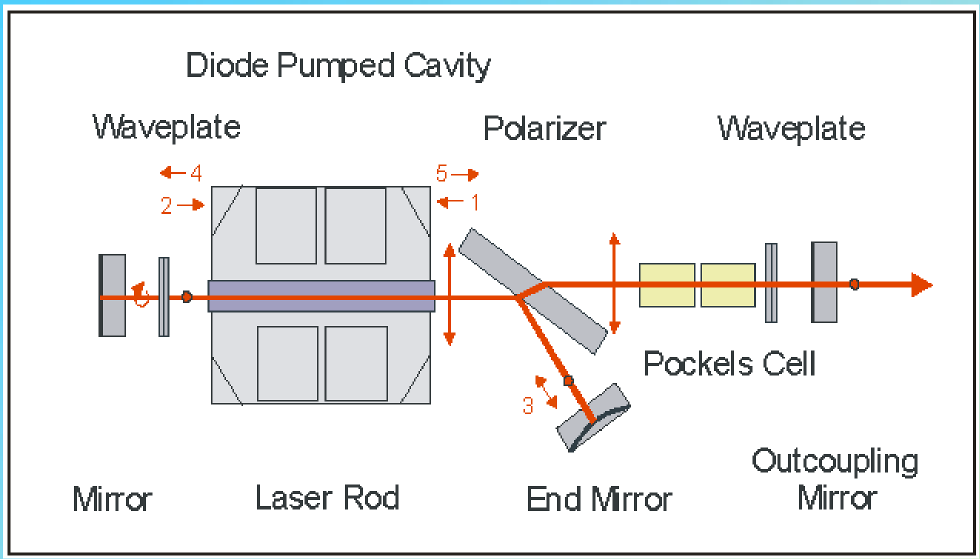
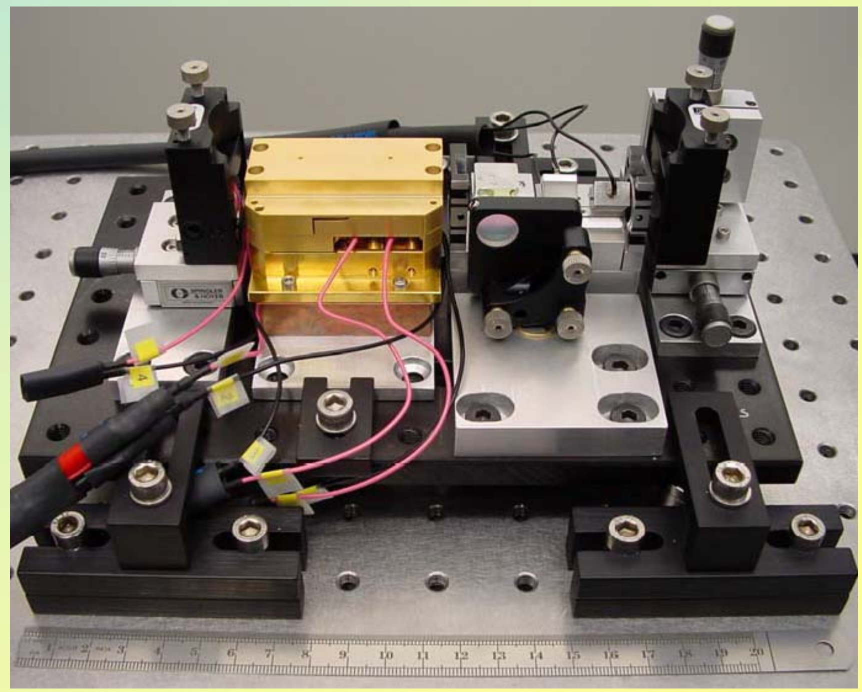
BELA MPS Zeiss Laser





BELA MPS Laser
ZeO Subcons

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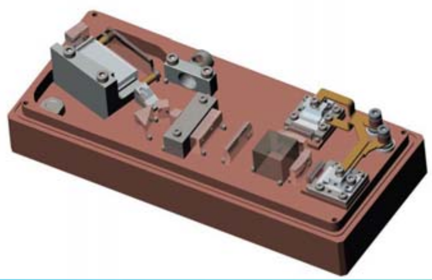
ZEISS

ILT

Fraunhofer Institut Lasertechnik



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Raumfahrttechnik

Für Kunden aus der Raumfahrttechnik führt die KOLT Engineering GmbH CAE-Simulationen mit den Schwerpunkten auf

- strukturdynamische Berechnungen wie Frequency, Random & Shock Response Analysen
- sowie Thermalanalysen

mit entsprechenden **raumfahrtspezifischen Nachweisen und Dokumentationen** durch.

Signatrans Gesellschaft für Ultraschall-Elektronik mbH

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System-Entwicklung und Beratung
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Active Space Technologies GmbH i.G.

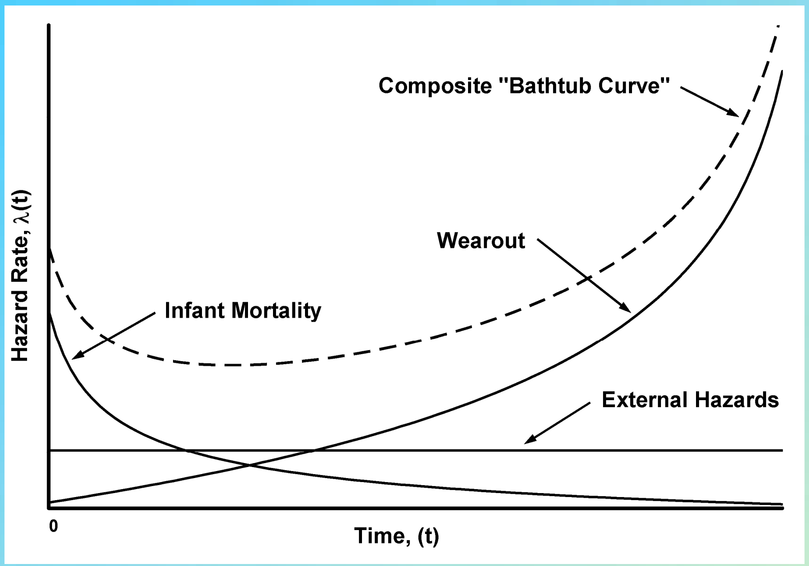
Rudower Chaussee 29, 12489 Berlin
Ansprechpartner: Herr R. Nadalini

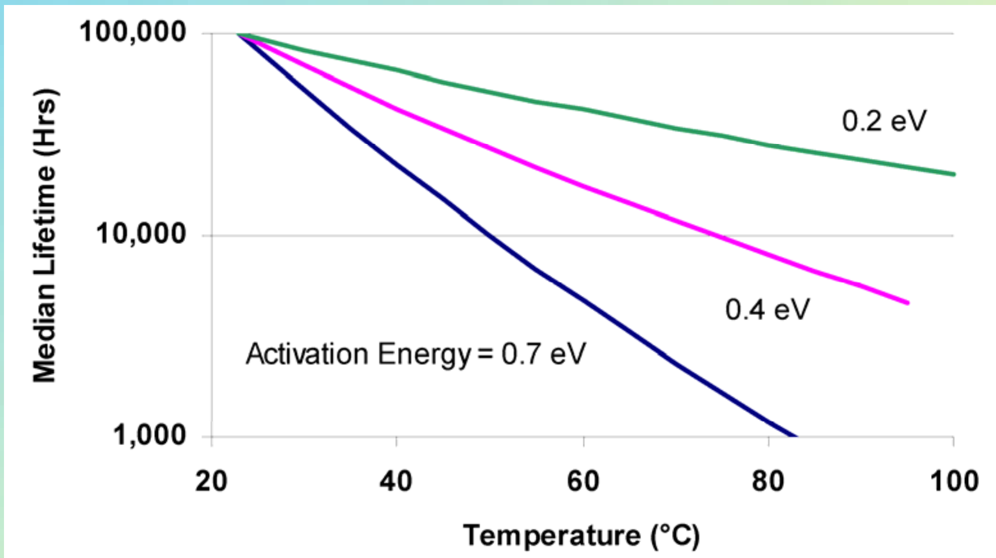
Schwerpunkte:

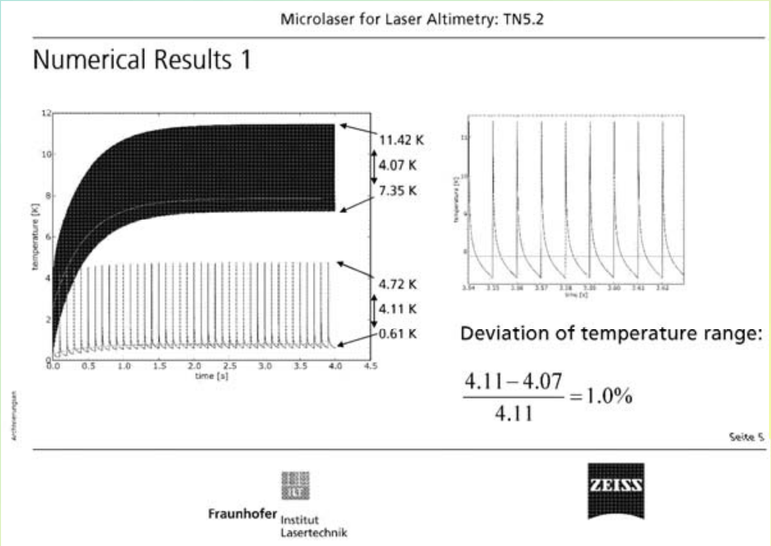
Beratunmg und EDV-gestützte Dienstleistungen im Bereich des thermischen und strukturmechzanischen Engineering für die Luft- und Raumfahrt und für andere hochtechnologische Sektoren.

Max-Planck-Institut für
Sonnensystemforschung

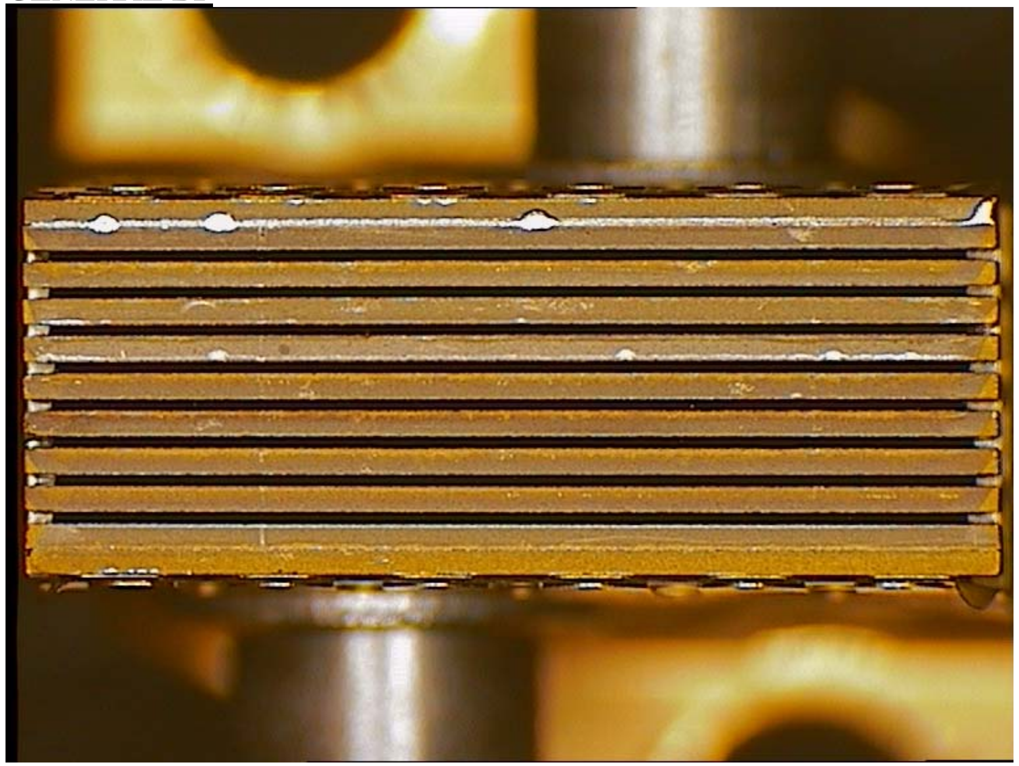
BELA MPS Laser
SCD test activities



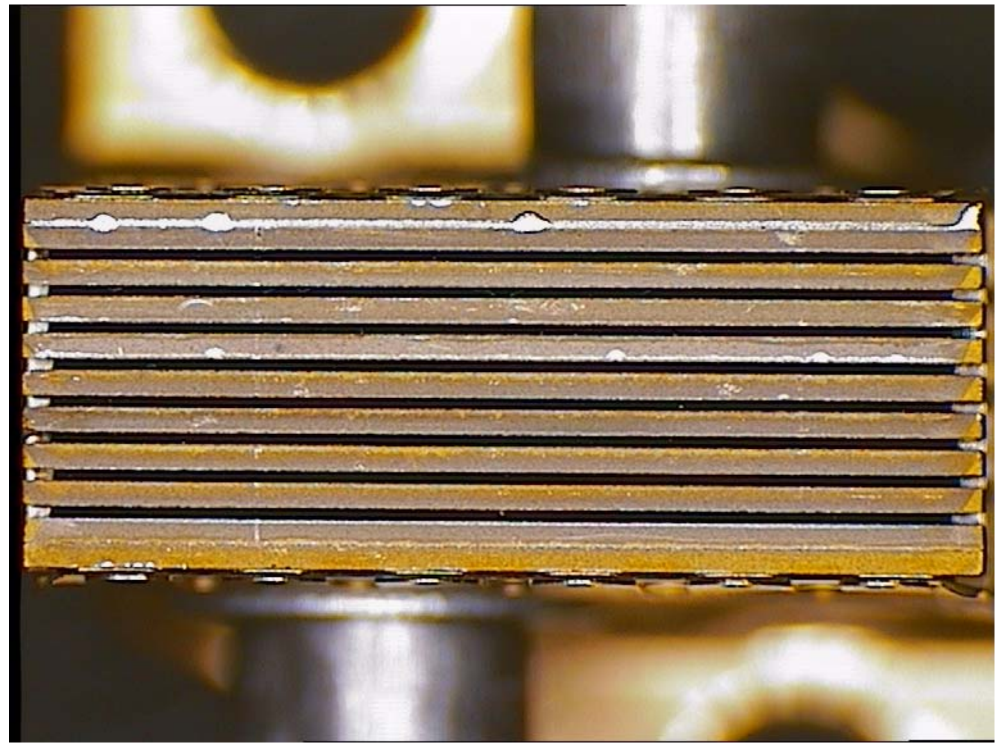




GENERAL BF



BEFORE CYCLING



AFTER CYCLING