Space-based Lidar Systems and Instruments Developed at NASA Goddard Space Flight Center

Xiaoli Sun
Outline:

• Introduction
• Early planetary lidar systems:
  • APOLLO 15, 16, 17
  • MOLA-1, NLR, LITE, SLA, and MOLA-2
• Recent space lidar missions:
  • GLAS, CALIPSO
  • HAYABUSA lidar, PHOENIX Lidar
  • MLA, LALT, LAM, LLRI, LOLA
• Observing laser light from space lidars
• Future lidar missions
Lidar: Light Detection And Ranging
(Laser + Photonics + Light Scattering + Space Geodecy)

Range -> Elevation
Pulsewidth -> Surface roughness
Received/Transmitted Pulse Energy -> Surface reflectivity

Lidar can also be used to measure atmosphere backscattering and absorption.
Space Lidar Systems to Date
(not including Space Shuttle Missions)

- Apollo, moon NASA (1971-1972)
- Clementine, moon LLNL/NRL (1994)
- NEAR/NLR, Eros JHU/APL (1996)
- MGS/MOLA, Mars NASA GSFC (1996)
- MESSENGER/MLA, Mercury NASA GSFC (2004, still operating)
- CALIOP/CALIPSO, Earth NASA LaRC (2006, still operating)
- Phoenix Lidar, Mars CSA (2008)
- SELENE/LALT, moon Japan (2007)
- Chang’E, moon China (2007)
- Candrayaan/LLRI, moon India (2008)
- LRO/LOLA, moon NASA GSFC (2009, still operating)
## Comparison of Earth & Planetary Lidar Systems

<table>
<thead>
<tr>
<th>Missions</th>
<th>Instrument</th>
<th>Launch Date</th>
<th>Laser Energy</th>
<th>Pulse Rate</th>
<th>Precision</th>
<th>Mass/Power</th>
<th>Number of Altimetric Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clementine</td>
<td>LIDAR</td>
<td>25 Jan 1994</td>
<td>170 mJ</td>
<td>0.6, 8 Hz (burst)</td>
<td>40 m</td>
<td>2.4 kg, 6.8 W</td>
<td>72,000</td>
</tr>
<tr>
<td>NEAR</td>
<td>NLR</td>
<td>17 Feb 1996</td>
<td>15 mJ</td>
<td>1/8, 1, 2, 8 Hz</td>
<td>0.3 m</td>
<td>5 kg, 17 W</td>
<td>11 million</td>
</tr>
<tr>
<td>MGS</td>
<td>MOLA</td>
<td>7 Nov 1996</td>
<td>50 mJ</td>
<td>10 Hz</td>
<td>0.4 m</td>
<td>26 kg, 34 W</td>
<td>670 million</td>
</tr>
<tr>
<td>ICESat</td>
<td>GLAS</td>
<td>12 Jan 2003</td>
<td>75 mJ/35 mJ*</td>
<td>40 Hz</td>
<td>0.1 m</td>
<td>330 kg, 300 W</td>
<td>3 billion</td>
</tr>
<tr>
<td>HAYABUSA</td>
<td>LIDAR</td>
<td>9 May 2003</td>
<td>10 mJ</td>
<td>1 Hz</td>
<td>1-10 m</td>
<td>3.6 kg, 17 W</td>
<td>4.1 million</td>
</tr>
<tr>
<td>MESSENGER</td>
<td>MLA</td>
<td>3 Aug 2004</td>
<td>20 mJ</td>
<td>8 Hz</td>
<td>0.15 m</td>
<td>7.4 kg, 25 W</td>
<td>11 million and counting</td>
</tr>
<tr>
<td>CALIPSO</td>
<td>CALIPO</td>
<td>28 Apr 2006</td>
<td>110 mJ/110 mJ*</td>
<td>20 Hz</td>
<td>-</td>
<td>170 kg, 200 W</td>
<td>2 billion and counting</td>
</tr>
<tr>
<td>SELENE</td>
<td>LALT</td>
<td>14 Sep 2007</td>
<td>100 mJ</td>
<td>0.5, 1 Hz</td>
<td>5 m</td>
<td>19 kg, -</td>
<td>13 million</td>
</tr>
<tr>
<td>Chang‘E-1</td>
<td>LAM</td>
<td>24 Oct 2007</td>
<td>150 mJ</td>
<td>1 Hz</td>
<td>5 m</td>
<td>16 kg, 25 W</td>
<td>8 million</td>
</tr>
<tr>
<td>Phoenix</td>
<td>LIDAR</td>
<td>4 Aug. 2008</td>
<td>0.3 mJ/0.4 mJ</td>
<td>100 Hz</td>
<td>-</td>
<td>6 kg, 30 W</td>
<td>65 million</td>
</tr>
<tr>
<td>Chandrayaan</td>
<td>LLRI</td>
<td>22 Oct 2008</td>
<td>13 mJ</td>
<td>10 Hz</td>
<td>1 m</td>
<td>10 kg, 15 W</td>
<td>millions</td>
</tr>
<tr>
<td>LRO</td>
<td>LOLA</td>
<td>18 Jun 2009</td>
<td>3 mJ/5</td>
<td>28 Hz x 5</td>
<td>0.15 m</td>
<td>13 kg, 34 W</td>
<td>5 billion and counting</td>
</tr>
</tbody>
</table>
Early Planetary Lidar
1970 - 2000
First Lidar in Space (1971) Apollo Laser Altimeters (Lunar orbit)

RCA Aerospace built flash lamp pumped, mechanically Q-switched ruby lasers for Apollos 15, 16 & 17 0.05 Hz
Clementine (1994, LLNL/NRL)

- 72,534 shots - 22x22 km “average” pixel size
- Cross-track spacing limits resolution to 80 km (deg. 66)
- 100 m vertical accuracy in COM coordinate system
- Resolves S. Polar basin; 16 km dynamic range

Diode pumped Nd:YAG laser
1064 nm, 170 mJ/pulse,
0.6Hz and 8Hz
10 cm telescope diameter
Si APD photodetector
2.4 kg, 6.8W
Near Laser Rangefinder (1998, APL)

The Shape of 433 Eros from the NEAR-Shoemaker Laser Rangefinder

Maria T. Zuber, 1,2* David E. Smith,2 Andrew F. Cheng,3 James B. Garvin,2 Ödöd Aharonson,4 Timothy D. Cole,8 Peter J. Dunn,8 Yangping Guo, Frank G. Leboffe,9 Gregory A. Neumann,1,2 David P. Paige,3 Mark H. Tamppari,3

GSFC/Smithsonian Institution
June 20, 2012
SGP seminar, NASA GSFC

General
Mass: 5 kg
Power: 20.7 W peak, 16.5 W average
Volume: overall TX/RX assembly 37.5 cm (deep) × 21.6 cm (high) × 22.9 cm (wide) inclusive of overhangs; 10.9 × 15.2 × 3.8 cm laser power supply; 7.6 × 2.5 × 14 cm medium voltage power supply
Data rates: commandable, 51 bps or 6.4 bps

Specifications
Technical
Laser wavelength: 1.064 μm
Range accuracy requirement: 6 m
Range requirement: 50 km
Inflight range calibration capability
Pulse repetition rate: commandable among 1/8, 1, 2, and 8 Hz
Pulse energy: 15 mJ
Pulse divergence: 235 μrad
Pulse duration: 12 ns
Range gates: two, commandable
Detector threshold: commandable, eight values
Receiver aperture: 7.6 cm (effective)
Range quantization level: 31 cm
Predicted range at asteroid acquisition: 150 km

Fig. 3. Six perspective views of a three-dimensional shape model of 433 Eros from the NB plotted to spherical harmonic degree and order 24. The mesh represents the scaled shape, and the surface facets are color-coded according to the surface slope with respect to a constant-density gravity field derived from the shape model (32). The asteroid is viewed at the following (elevation, azimuth, range) pairs: (A) 30°N, 60°E; (B) 30°N, 120°E; (C) 30°N, 180°; (D) 30°N, 30°E; (E) 30°S, 135°E; (F) 30°S, 0°W.

Fig. 4. (A) Vectors showing directions of gravitational acceleration (g). Units are Gal, where 1 Gal = 1 cm s⁻². The asteroid is viewed from 30°N, 60°E. Colors represent the magnitude of g and arrows indicate the direction. (B) Histogram and cumulative frequency distribution of 3°-baseline surface slopes (32).

poorly constrained because the structure is situated within a regional low. Even given the depth uncertainty, Psyche is deeper relative to its size than simple (bow-shaped) craters on the terrestrial planets, consistent with its formation in a low-gravity and perhaps a low-velocity regime. A second, larger crater, provisionally named Himera, is centered at (30°N, 15°E). This structure spans a diameter on the surface of slightly greater than Eros’s mean radius and displays a saddle shape (Fig. 3), with the symmetry axis of its broad inflation in curvature (Web Fig. 2 (32) oriented approximately longitudinally). The structure also exhibits complex short-wavelength curvature variations to the north and west of the structure that trend approximately latitudinally. Himera lacks the steep, flat scar characteristics that are commonly associated with an impact origin such as a closed rim, terraces, and ejecta blanket (30, 32, 33). If Himera’s present morphology was preserved since its time of formation, then this feature likely formed as a consequence of collision, i.e., contact between two bodies of roughly similar size. However, at the current resolution of the topographic model we cannot rule out the possibility that this structure formed as a result of impact when Eros was part of a larger parent body, or during the process of the asteroid’s breakup into a separate entity. In either of these scenarios, the morphology of an originally impact-generated Himera would have been modified from its original configuration. We see no geophysical evidence that would suggest that Eros attained its present shape by accretion or macromixing of smaller asteroidal bodies. A mesh view of the shape of Eros (Fig. 4A) is the vicinity of Himera includes superposed vectors of gravitational acceleration (32) that indicate directions of downslope movement. The highest slopes on the asteroid cluster to the southwest and northeast of Himera, which are regions that have lower than average crater density (30), and collectively suggest that these are regions where regolith has been transported downward (with respect to the gravitational potential) by mass wasting.

The histogram in Fig. 4B shows that the average slope on a surface baseline of ~3° is about 10°, substantially higher than that on the comparable spatial scale on the terrestrial planc...
Mars Orbiter Laser Altimeter (1996, GSFC)
(initially on Mars Observer Mission, launched Sept., 1992)

MGS spacecraft (JPL)

MGS Launched Nov. 7, 1996
Operated around Mars until 2006.
Was in circular polar orbit around Mars
400km altitude, 110 minute orbit period.

- Laser Wavelength: 1064 ± 0.2 nm
- Laser Pulsewidth: 8 nsec
- Pulse energy (start of mapping): 48 mJ
- Pulse repetition frequency: 10 Hz
- Range resolution: 38 cm
- Return pulses detected: ~99%
- Maximum range (hardware limit): 786 km
- Surface spot size in mapping orbit: ~168 m
- Along-track shot spacing: ~330 m
- Vertical accuracy (radial orbit error): <1 m
- Number of laser firings: 671,121,600
- Operated in lidar & radiometer modes
MOLA System Block Diagram
Topography of Mars from MOLA

671 million altimeter measurements, <1 m topographic accuracy
MOLA ‘Noise Map’ of Mars
Earth Orbiting Lidars
• The LITE instrument was flown aboard Space Shuttle Discovery on mission STS-64 in September 1994.
• Three measurement wavelengths: 355, 532, and 1064 nm.
• During its 11-day operation LITE accumulated 53 h of 10-sec averaged backscatter profiles within a few degrees of nadir
• First lidar profiles of the Earth’s atmosphere from space!
Shuttle Laser Altimeter (SLA-1 & SLA-2)
GSFC Shuttle Hitchhiker Experiments

Jack Bufton, Jim Garvin, Bryan Blair, David Harding and others ...

Laser Altimeter Canister integration into HH canister prior to SLA-01 Mission

– SLA-01: Jan. 1996 flight, ± 28.5° orbit inclination, 80 hours operation
– SLA-02: August 1997 flight, ± 57° orbit inclination, 80 hours operation
ICESat/GLAS - Launch Feb 2003
Measurement Approach
GLAS being integrated onto the spacecraft at the Ball Aerospace in 2002.
GLAS Receivers and Key Components

1064nm detectors assembly (1 prime and 1 spare)

Laser beam steering mechanism

Bandpass filter assembly

SPCM (x8)

8-way beam splitter assembly

Telescope, 1 m dia.
Lidar used to monitor thinning of Greenland ice, and height (→ flow rates) of major ice streams

Zwally et al., Preliminary Results
ICESat Sea Ice Measurements

Feb 20-Mar 29, 2003

Freeboard

Thickness

Mean = 0.30 m

Mean = 1.96 m

June 20, 2012

SGP seminar, NASA GSFC
Active lakes under ice streams

Elevation range 2003-06 (m)

Conway Ridge
Mercer Ice Stream (A)
Subglacial Lake Mercer
Whillans Ice Stream (B)
Subglacial Lake Whillans
Engelhardt Ridge
Subglacial Lake Engelhardt

MOA (NSIDC)
Fricker et al. SCIENCE, Vol. 315, 2007
GLAS Measurement of Echo pulse from Trees

1064 nm, 7 nsec laser pulse

~ 80 m diameter laser footprint spaced 175 m apart along ground track

Transmit Pulse

Echo Pulse

Amplitude (volts)

Time (nsec)

Highest detected elevation

Outer Canopy Relief

Average detected elevation (alternate “land” elevation)

Ground Relief

Lowest detected elevation

Max Canopy Height

Crown Depth

Height Distribution of Reflected Laser power with 15 cm Vertical Sampling

Harding/NASA- GSFC
Global Forest Canopy Height Map from ICESat/GLAS (M. Lefsky, GRL, 2010)
CALIPSO Mission
Earth Orbit, Atmospheric Structure
NASA LaRC

Calipso First light: 7 June 2006

Dave Winker et. al.
NASA Langley, Hampton, VA

Sun-synchronous orbit
Three co-aligned instruments:
CALIOP: polarization lidar
- 70-meter footprint
- 1/3 km footprint spacing
IIR: Imaging IR radiometer
WFC: Wide-Field Camera
Three-channel profiles provide insight into aerosol type and mixing.
Recent Planetary Lidars (2000-present)
Hayabusa Lidar (2003-2005)
(JAXA/NEC/TOSHIBA, Asteroid Itokawa landing lidar)

- Diode pumped Nd:YAG laser
- Operated from 50 km to 30 m
- 4.1 million laser shot measurements
- Hayabusa also had a four-beam laser rangefinder to measure altitude and slope from 100 to 7m

<table>
<thead>
<tr>
<th>Items</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>50m~50km</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±1m(@50m)</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>1Hz</td>
</tr>
<tr>
<td>Laser</td>
<td>Q-SW, Nd:Cr:YAG</td>
</tr>
<tr>
<td>Wave length</td>
<td>1064 nm</td>
</tr>
<tr>
<td>Output Power</td>
<td>8 mJ</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>14 msec</td>
</tr>
<tr>
<td>TX Beam Width</td>
<td>φ 1.7 mrad (1/e²)</td>
</tr>
<tr>
<td>RX FOV</td>
<td>φ 1 mrad</td>
</tr>
<tr>
<td>RX Optics</td>
<td>Cassegrain φ 126 mm, SiC</td>
</tr>
<tr>
<td>Weight</td>
<td>3.7kg</td>
</tr>
<tr>
<td></td>
<td>Include: DC/DC, Radiator</td>
</tr>
<tr>
<td>Power</td>
<td>17.0W (+LD Heater max5W)</td>
</tr>
<tr>
<td>Size</td>
<td>240mm × 228mm × 250mm</td>
</tr>
<tr>
<td></td>
<td>Radiator: 240mm × 300mm</td>
</tr>
</tbody>
</table>

Examples of Hayabusa Lidar measurements
(Science, June 2006)
(Canadian Space Agency, Mar Atmosphere Backscattering Profile)

Operated at Mars
~1 hour/day for ~6 months

From Whiteway et. al., Science, July 2009
MESSENGER - MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MLA – Mercury Laser Altimeter

MESSENGER sunshade has to face the sun at all time and MLA has to range in non-nadir direction most of the time.

• Developed by JHU/APL under NASA’s Discovery Program
• Launched on 8/3/2004 from KSC, arriving Mercury orbit on March 18, 2011
### Mercury Laser Altimeter (MLA)

#### Electro-Optics & timing electronics assembly

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser pulse energy</td>
<td>20 mJ</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>8 Hz</td>
</tr>
<tr>
<td>Pulse width</td>
<td>6 ns FWHM</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1064.30 ±0.05 nm</td>
</tr>
<tr>
<td>Beam divergence</td>
<td>80 µrad (TEM00)</td>
</tr>
<tr>
<td>Receiver aperture</td>
<td>11.5 cm diameter, X4</td>
</tr>
<tr>
<td>Receiver field of view</td>
<td>400 µrad</td>
</tr>
<tr>
<td>Receiver optics transmission</td>
<td>77%</td>
</tr>
<tr>
<td>Receiver optical bandwidth</td>
<td>0.7 nm FWHM</td>
</tr>
<tr>
<td>Detector quantum efficiency</td>
<td>&gt;35%</td>
</tr>
<tr>
<td>Receiver dark noise equivalent power (NEP)</td>
<td>200 pW (over 33 MHz Noise BW)</td>
</tr>
<tr>
<td>Receiver timing electronics</td>
<td>6 channel event timers</td>
</tr>
<tr>
<td>Receiver timing accuracy</td>
<td>&lt;1 ns</td>
</tr>
<tr>
<td>Operation duty cycle and lifetime</td>
<td>30 min/12 hour orbit, for 365 earth days</td>
</tr>
<tr>
<td>Data rate while in operation</td>
<td>2.4 kbits/s</td>
</tr>
<tr>
<td>Weight</td>
<td>7.4 kg</td>
</tr>
<tr>
<td>Size</td>
<td>30x30x30 cm</td>
</tr>
<tr>
<td>Electrical power consumption while in operation</td>
<td>23 W</td>
</tr>
</tbody>
</table>
Venus Flybys

Passive Radiometry Scans

Venus shine seen by MLA during first flyby in Oct. 2006. The spacecraft pointing was shown to be accurate to ~30 urad.

Venus shine seen by MLA during second flyby.

Laser Ranging

- Laser pulses were transmitted to Venus atmosphere during the closest approach (~200km) during the 2nd Venus flyby, but no signal was detected, indicating the apparent cloud and haze cross section was below 0.001/m^2sr^-1.
Mercury Flyby on Jan. 14, 2008

MLA was pointed to Mercury for about 10 minutes about the closest approach.
MLA could still see earth shine from nearly 1 AU away with an estimated cw optical power of ~10 pW.
MLA Measurement Coverage on Mercury

MLA measurement coverage, >5 millions range measurements, as of 12/31/2011
MLA is the first space lidar that has to range to surface at oblique angle.

MLA ranged to >1500 km in nadir direction.

MLA range to 700 km at 70° slant angle.
MLA Measurement Results

Mercury Topography, north pole to 5 deg South from MLA Data Mar-Oct, 2011
(Zuber et. al., Science Apr, 2012)

Surface Reflectance
North pole to 75 deg N
(Neumann et. al., LPSC 2012)
Sample MLA Science Results - Gravity

Mercury gravity anomaly derived from MLA measurements

Mercury crustal thickness derived from MLA measurements

Smith et al., Science, 2012

Smith et al., Science, 2012
Going Back to the Moon
Kaguya-LALT (2007)

Structure of LALT(2)

Receiver telescope
Receiver detector (APD)
Transmitter detector (PIN-PD)
Laser oscillator
45 degrees mirror
Ranging counter
Q-SW driver
High voltage power supply
LD driver

LALT-TR

NEC

Topography (km)

A
NORTH>85°

B
SOUTH<-85°

Rozhdestvensky
Hermite
Peary

Far side
Near side

Topography (km)

June 20, 2012

SGP seminar, NASA GSFC
Chang’E-1 Laser Altimeter (2007)

Table 1 Chang’E-1 LAM Instrument Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective distance range</td>
<td>200km±25km</td>
</tr>
<tr>
<td>Footprint</td>
<td>120m@200km</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1064nm</td>
</tr>
<tr>
<td>Energy</td>
<td>150mJ</td>
</tr>
<tr>
<td>Width of Laser Pulse</td>
<td>&lt;7ns</td>
</tr>
<tr>
<td>Repeat rate</td>
<td>1Hz</td>
</tr>
<tr>
<td>Receiver telescope diameter</td>
<td>140mm</td>
</tr>
<tr>
<td>Telescope focal length</td>
<td>538mm</td>
</tr>
<tr>
<td>Distance resolution</td>
<td>0.96m</td>
</tr>
<tr>
<td>Distance error</td>
<td>&lt;±5m</td>
</tr>
<tr>
<td>Data rate</td>
<td>384bps</td>
</tr>
<tr>
<td>Weight</td>
<td>15.7Kg</td>
</tr>
<tr>
<td>Power</td>
<td>25W</td>
</tr>
<tr>
<td>Life</td>
<td>1 Year</td>
</tr>
</tbody>
</table>
Table 1. Specifications of the lunar laser ranging instrument.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser wavelength</td>
<td>1064 nm</td>
</tr>
<tr>
<td>Laser type</td>
<td>Nd:YAG diode-pumped Q-switched laser</td>
</tr>
<tr>
<td>Laser energy</td>
<td>20 mJ</td>
</tr>
<tr>
<td>Beam divergence</td>
<td>0.5 mrad (half)</td>
</tr>
<tr>
<td>Pulse width</td>
<td>10 ns</td>
</tr>
<tr>
<td>Pulse repetition rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Transmitter optics</td>
<td>38 mm Galilean telescope</td>
</tr>
<tr>
<td>Receiver optics</td>
<td>Reflective, 170 mm</td>
</tr>
<tr>
<td>Detector</td>
<td>Avalanche photo detector</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>5 m</td>
</tr>
<tr>
<td>Footprint on Moon</td>
<td>100 m</td>
</tr>
<tr>
<td>Power</td>
<td>Less than 15 watts</td>
</tr>
<tr>
<td>Weight</td>
<td>Less than 10 kg</td>
</tr>
</tbody>
</table>
Lunar Reconnaissance Orbiter (LRO, 2009)
the Lunar Orbiter Laser Altimeter (LOLA) GSFC/ Lunar Orbit

- Launched June 18, 2009, still in orbit and collecting data
- LOLA is one of the 7 payload instruments on LRO
- Objectives are to measure lunar surface topography and to establish a global lunar geodetic coordinate system.

Smith et al., *Space Science Reviews*, 2010
LOLA - 1st Multi-beam Space Lidar

- Use of a diffractive optical elements (DOE) to split the laser to illuminate five spots on ground
- Use of an optical fiber array to direct each spot into a separate receiver channel
- Make five measurements from a single laser shot to give range, slope and direction

DOE and the optical fiber array

Each fiber couples to a separate Si APD detector

Fiber Pattern at telescope focal plane
GSFC

⦁ 5.5 billion altimeter measurements; ~2 billion laser shots
⦁ 20-m along-track resolution; 0.7-km average orbit track spacing at equator
Shackleton Crater; Lunar South Pole

- Shackleton Crater
  - Is adjacent to lunar south pole
  - Lies mostly in permanent shadow
  - Has anomalously high 1064-nm reflectivity
  - Lacks a hydrogen signature from neutron flux

Mazarico et al. (2011)

Bidirectional 1064-nm reflectance

Zuber et al. (2012)
South polar regions of “eternal light”

- Several small areas close to south pole are in sunlight for most of month.
- Most illuminated area appears to be ~10 km wes of Shackleton rim.

June 20, 2012  SGP seminar, NASA GSFC
Observing Lidar Light from Space

- Lidar made by NASA were designed to be safe for people and amateur astronomers with commercial equipments.
- It is extremely difficult to observe lidar light from space without official help from NASA on the spacecraft ephemeris and other details.
Observing Lidar Light from Space - ICESat

- The 532 nm laser light from ICESat/GLAS was visible to unaided human eyes.
- The laser light from ICESat/GLAS was green, brighter than Venus, and hit only once on each passing.
11/6/2003
Santa Rosa, NM
~120’ from ICESat
ground track

ICESat laser appeared as a streak to human
eyes when viewed through thin clouds

ICESat laser, 2003
Viewed directly under the
laser beam from Boulder CO
11/2/2006
ICESat over NASA GSFC
Recorded with an old Sony video camera
11/2/2006
ICESat over NASA GSFC
Recoding laser pulse waveforms

The GLAS EM detector and aft optics piggy backed on a Meade 10" telescope. A diffuser was placed in front of the detector to attenuate the signal by ~1000 and widen the field of view to +/-3° FWHM.
Images of the sunlit MESSENGER spacecraft shortly after the Earth fly-by at 120,000 km distance. MESSENGER appeared as a 17th Visual Magnitude star. The raw images were taken with a 14” Meade LX200GPS telescope and a SBIG ST-9E CCD camera. The image shown above is the sum of 27 raw images, each with 3 seconds exposure time. The spacecraft position solved from these images using Astrometrica software was, Time: August 3, 2005 01:27:08 (UTC), RA: 15h 13m 11.18s, DEC: -29°29’02.8”, which agreed with the predicted ephemeris to within 8 arc-seconds.
MLA–Earth Two-way Laser Ranging during Earth Flyby in 2005

- 1st successful 2-way laser ranging: >24 million km at ~20cm precision
- Verified instrument performance
- Detected relativity effect (~500m longer light path due to solar gravity)
- Confirmed link equation for deep space laser ranging and communication

Check Optical Alignment from Earth Shine during Earth Flyby

- One of the MLA receiver channels was configured as a high performance radiometer, sensitive to cw Earth shine light;
- The Earth shine image taken by MLA gave a measure of MLA receiver FOV alignment wrt the spacecraft coordinate system;
- The timing of the Earth shine signal and the detection of the MLA laser on Earth gives a measure of MLA bore sight offset <110 urad (~1/4 FOV).
LOLA Diagnosis Tests
– Earth Scan (2009)

- Two-way laser ranging test between LOLA and SLR station on Earth in Aug. 25, and Sept. 13-14, 2000
  - Scanning the LOLA laser beam about the SLR station at NASA GSFC
  - SLR station tracking LOLA and transmitting and receiving laser pulses
  - Solving LOLA pointing and bore-sight from the time tags of the laser pulses
  - Recording LOLA laser pulse energy and pulse shape using an oscilloscope

The test results verified DOE far field pattern and revealed a bore sight shift at low temperature
Future Space Lidar Systems

- ADM-Aeolus Wind Lidar, ESA, launch 2013
- BepiColumbo Laser Altimeter, ESA, launch 2015
- ICESat-2/ATLAS, NASA, launch 2016
- OSIRIS-REx Laser Altimeter (OLA), NASA/CSA, launch 2016

- MERLIN (MEthane Remote sensing LIdar missioN), DLR/CNES
- ASCENDS (Active Sensing of Carbon-dioxide Emission over Nights, Days, and Seasons), NASA
- LIST (LIdar Surface Topography), NASA
Multi-beam Micropulse Laser Altimeter

- Single laser beam split into 6 beams
- 10 m ground footprints
- 10 kHz rep. rate laser (~1mJ)
- Multiple detector pixels per spot
- On-board boresight alignment system
- Laser Reference System gives absolute laser pointing knowledge
Simultaneous laser measurements:

1. CO2 lower tropospheric column  
   One line near 1572 nm  
2. O2 total column (surface pressure)  
   Measure 2 lines near 765 nm  
3. Altimetry & atmospheric backscatter profile from CO2 signal:

   Measures:
   - CO2 tropospheric column
   - O2 tropospheric column
   - Cloud backscattering profile

   Planned Launch Date: 2019

   Measurements use:
   - Single frequency tunable pulsed lasers
   - 8-10 KHZ pulse rates
   - Time gated Photon counting receiver
   - High SNRs (~ 1000 in 10 sec)
**Lidar Surface Topography Mission (LIST)**

“Swath Imaging” Lidar:
- 5 m pixels
- 1000 Parallel beams
- Echo pulse resolved
- 10 cm vertical resolution

Approach studied:
- Lidar Pushbroom
- Efficient short pulse laser
- Very sensitive detector array
- Low power digitizers
- Airborne demonstration (16 chan) (being developed)

D. Harding
NASA Goddard
Summary:

- Dramatic progress since early 1990s
- Many space lidar observations demonstrated:
  - Planetary topography
  - Land & sea ice, tree heights, water height
- Enabled new geophysical science & discoveries
- Space lidar is now a primary tool for science!