Mars Orbital Lidar
for Global Atmospheric Measurements

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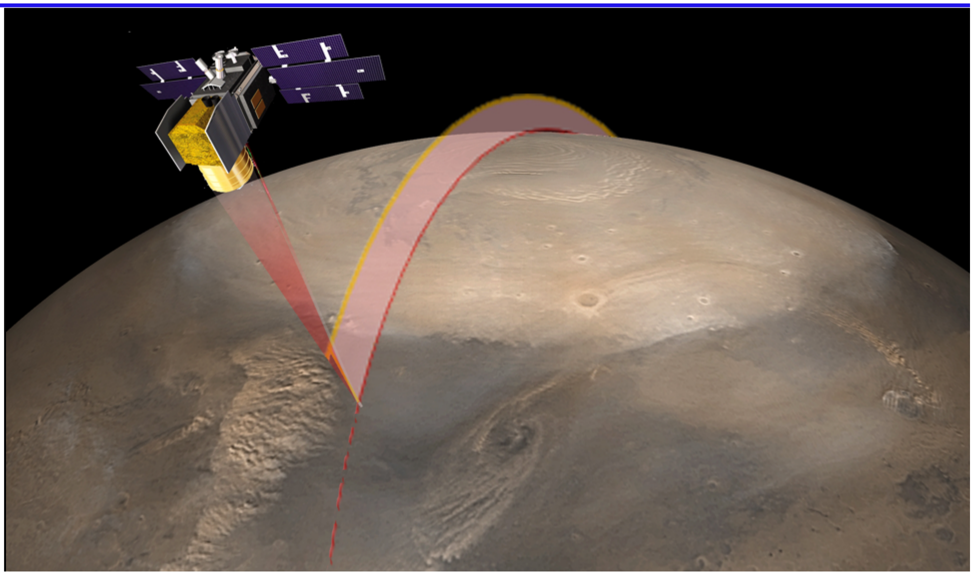
Mars Climate Lidar - Overview



Ongoing Work:

• Are studying a Mars orbital atmospheric lidar

Motivations:

• MEPAG reports

• Climate emphasis in Mars chapter of 2011 Planetary Decadal

• Science measurement needs to allow more accurate EDL (landings) for robots & people

Objectives:

• Target continuous global measurements of:

- **Wind profiles** (in lidar line-of-sight) - for improving landings & for climate science
- **Dust and ice backscatter profiles**
- **CO_2 gas column abundance (surf press.)**

Assumptions:

• Mission & spacecraft allow measurements from ~400 km near-polar orbit

Approach:

• Adapt direct detection lidar techniques & new high efficiency laser technologies

• Stay compatible with a medium size orbiter

• Target readiness for 2018/2020 launches.

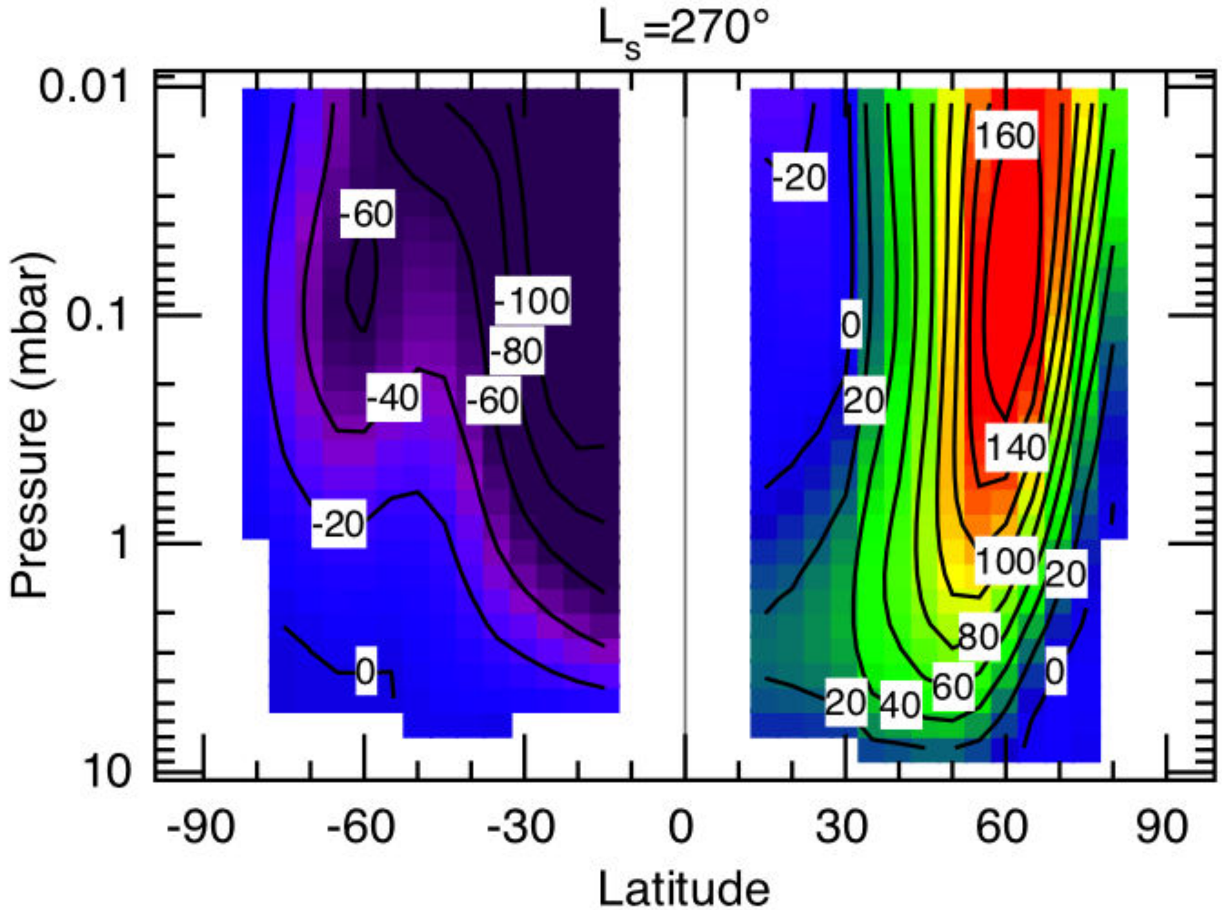
Why Global Wind Measurements ?

Wind profiles will provide crucial new information

- Winds regulate the transfer of gases and heat throughout the atmosphere, raise dust at the surface, and are a primary player in all surface-atmosphere interactions

- Measured wind profiles provide sensitive input and needed validation for improving current GCM models

- Winds are of critical importance for the safety and precision of spacecraft entry, descent and landing (EDL) on Mars

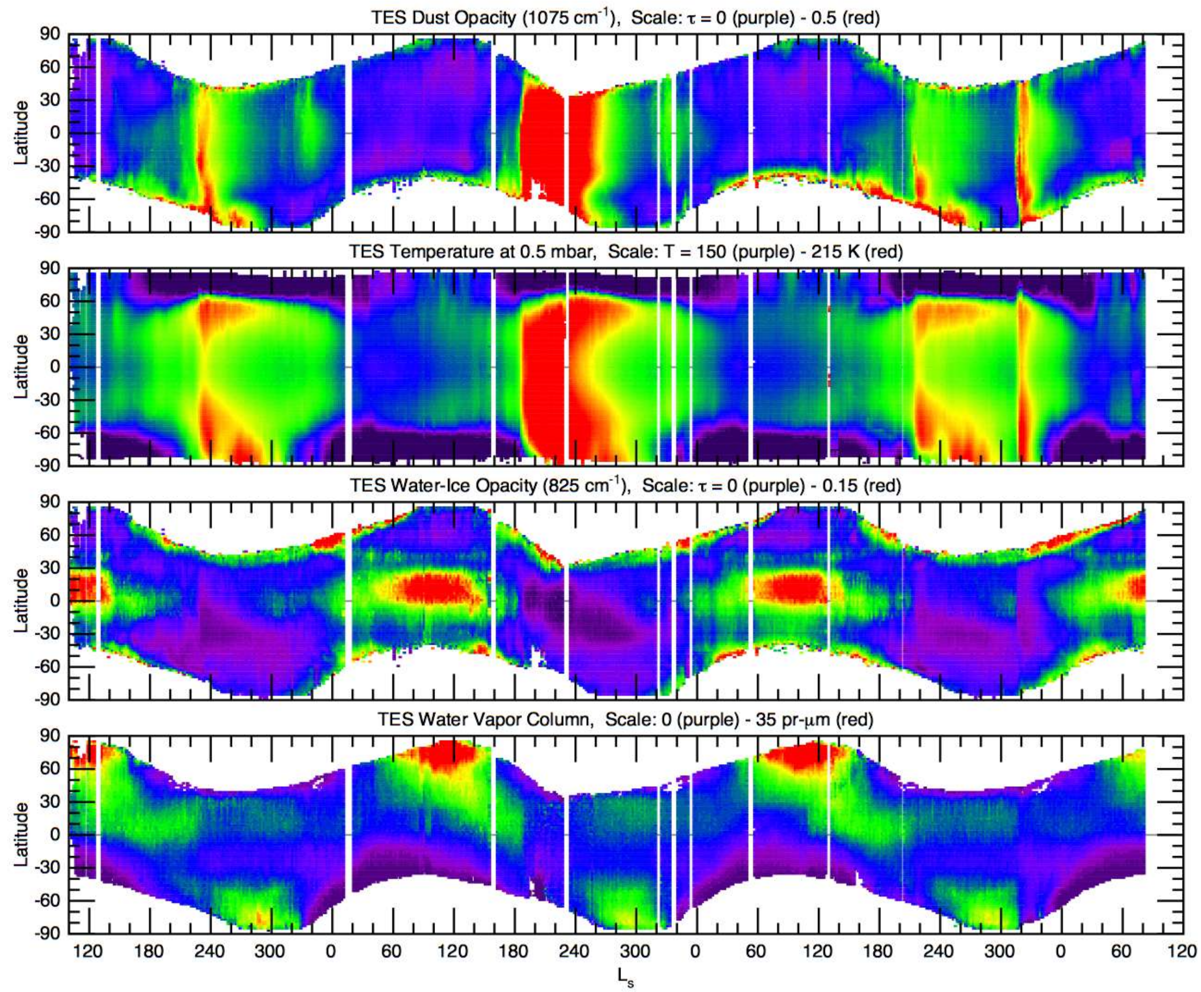


Calculated "gradient winds" (m/sec) for season Ls=270, inferred from latitude gradients of temperature. Presently, this is the best way to estimate global-scale winds from observations. They describe in a very broad sense the general modeled winds from GCMs. Shortcoming are these require lots of assumptions, don't work near the equator, only give zonal (east-west) winds, don't include weather or any local phenomena, and are not very precise.

Why these measurements together ?

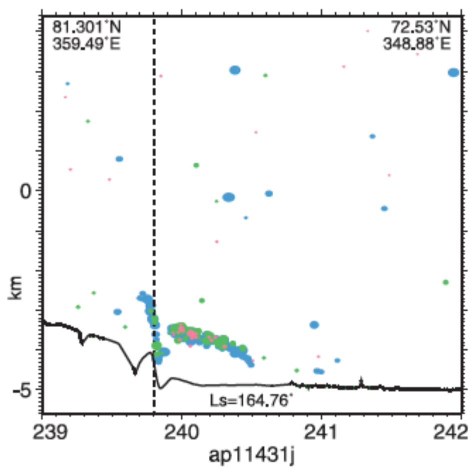
Simultaneous measurement of wind, gas abundance and aerosol profiles maximizes science return

- Dust aerosols interact strongly with IR radiation, driving atmospheric motions at all spatial scales.
- Water ice clouds play an important role in the water cycle altering the global transport and distribution of water vapor
- LIDAR observations over a range of local times will provide a <u>self-consistent data set</u> enabling new understanding of many important processes including circulation, waves, radiative balance, and the transport, sources and sinks of trace gases



Summary of of current climatology as retrieved from TES.
Dust (top), atmospheric temperatures (2nd panel), water ice clouds (3rd panel) and water vapor (bottom) are all interrelated. Dust warms the atmosphere. Dust and water ice clouds are anti-correlated. Water ice clouds and water vapor are related.

Mola/MGS Cloud Measurements
(Neumann et al., JGR, 2003)



Reflective Clouds:
Examples and distribution

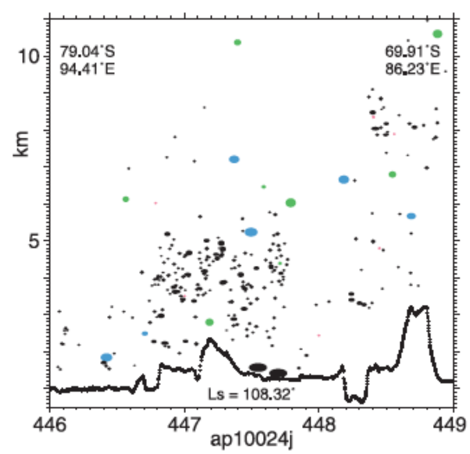


Figure 9. Circumpolar belt of channel 1 clouds observed on 11 March 1999. In this profile segment nearly 1/3 of MOLA shots trigger on clouds. Two unusually strong channel 1 returns occur at 160–200 m above ground.

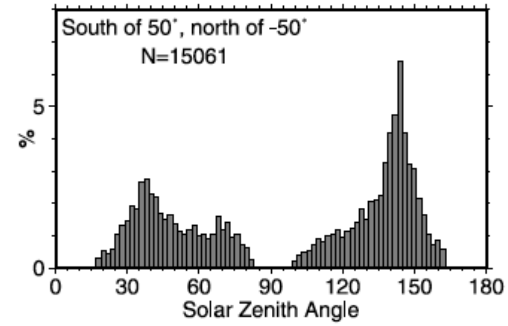


Figure 11. Histograms of reflective clouds versus solar zenith angle. Most clouds occur at night or twilight. Equatorial clouds are almost equally distributed day and night.

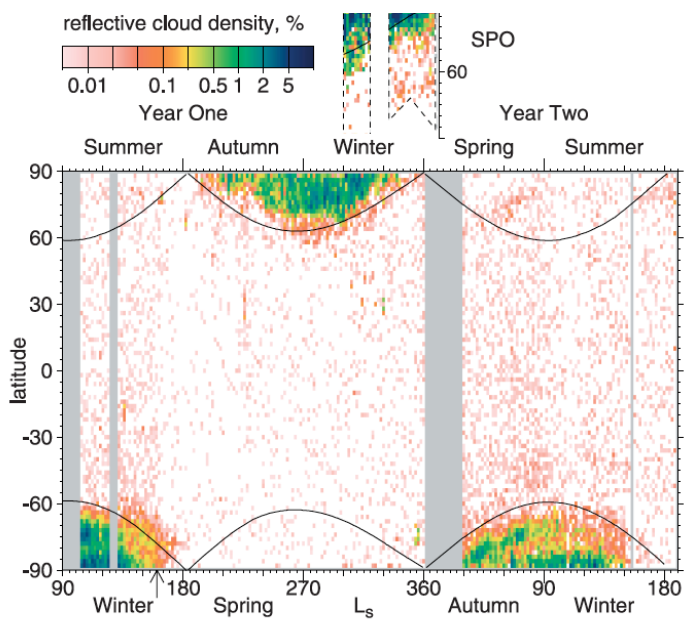
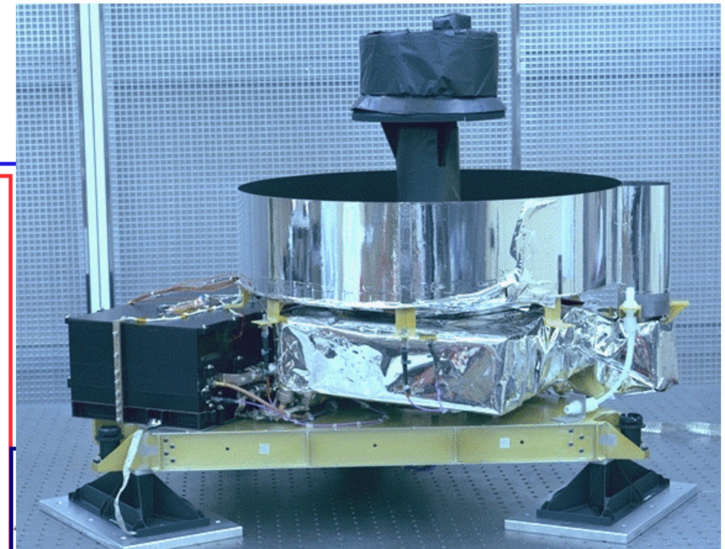


Figure 5. Percentage of reflective cloud counts in 2° × 2° bins, as a function of the solar longitude L_s and latitude. The cloud frequency as a fraction of nadir-looking shots is normalized by laser energy. The nearly constant rate of false returns thereby appears to increase as the laser energy declines during Year Two. The inset shows the limited extent of coverage during the Science Phasing Orbits (SPO). The curves show latitude of the terminator along the MOLA ground track, offset from the arctic circles due to the ~2 pm Sun-synchronous orbit. The arrow shows the time at which threshold of channel 1 was raised to mitigate saturation of ground returns; the background resulting from false triggers was thereby reduced.



MOLA (D. Smith/PI)
Direct Detection Lidar
Nd:YAG laser, Si APD detector

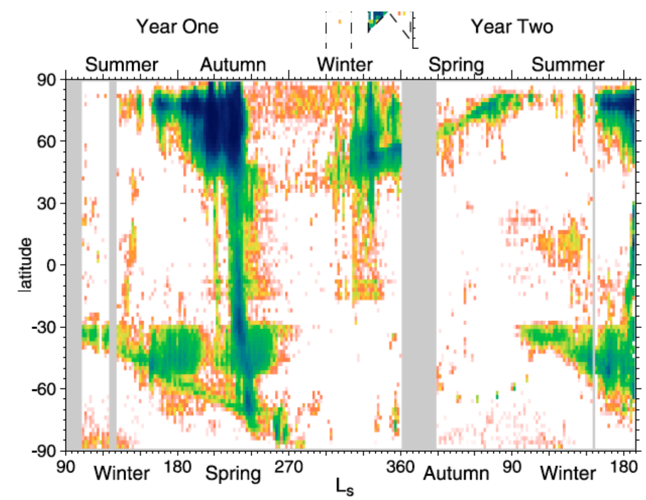


Figure 6. Frequency of absorptive clouds with latitude and season. Nadir frames with average reflectivity-transmission product <0.02, or more than two shots that return no ranges, indicate significant opacity. The percentage of frames in b … scale.

Absorptive Clouds:
Distribution

Lidar Measurements of the Mars Atmosphere from the Surface on the Phoenix Lander (J. A. Whiteway et al., 2008, 2010, 2011)

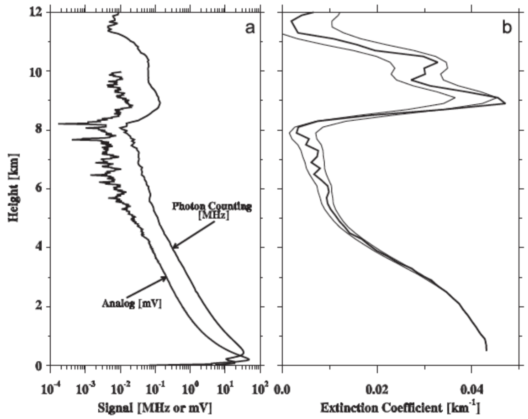
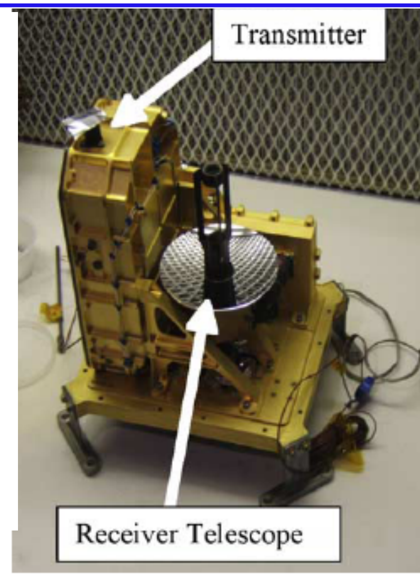


Fig. 1. (a) Lidar backscatter signal recorded with Analog (mV) and Photon Counting (MHz) on Sol 65, 07:11 Local True Solar Time (L_s = 106°). (b) Derived extinction coefficient profile for Sol 65 using a lidar ratio of 40. The Analog signal was employed from ground to 2.5 km, and Photon Counting signal from 2.5–20 km. Relative uncertainty is provided for the extinction coefficient.



Phoenix lidar (Nd:YAG laser & direct detection)

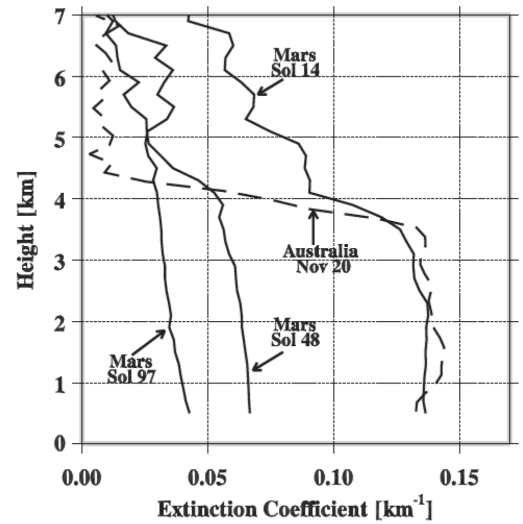
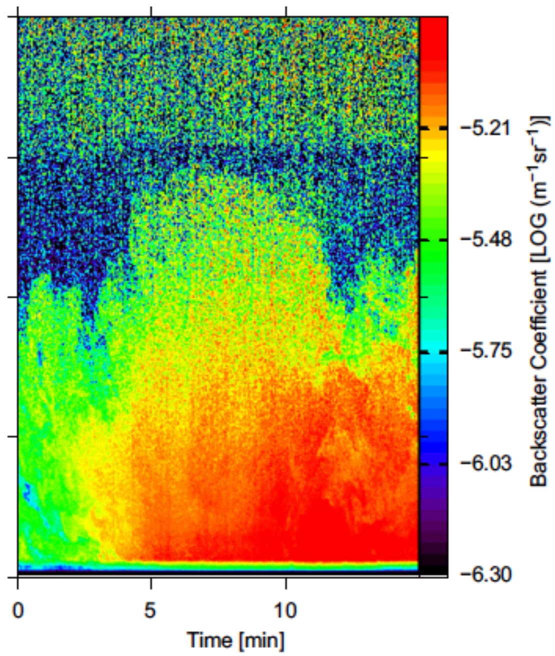


Fig. 2. Lidar extinction coefficient profiles for Mars Sols 14, 48, 97 (solid) and at Muloorina Australia on Nov 20th 05:00 GMT (dashed). The solar longitudes of Mars on these dates were L_s = 84°, 99°, and 122°.



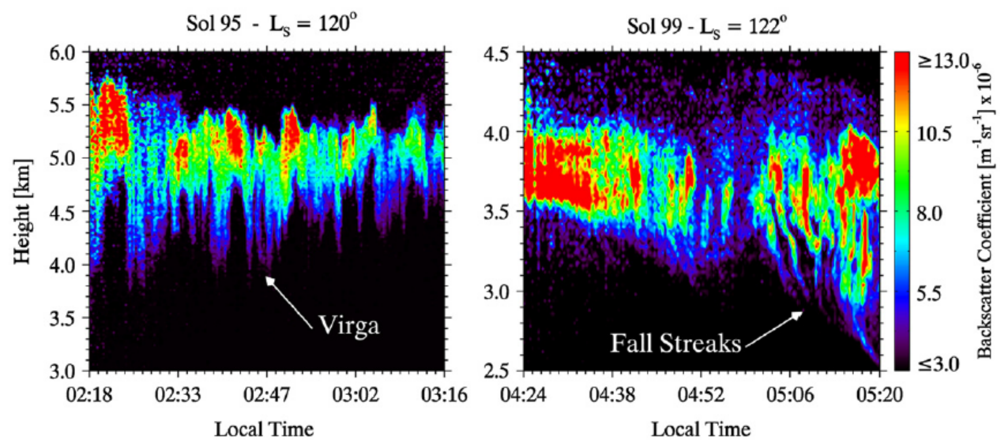
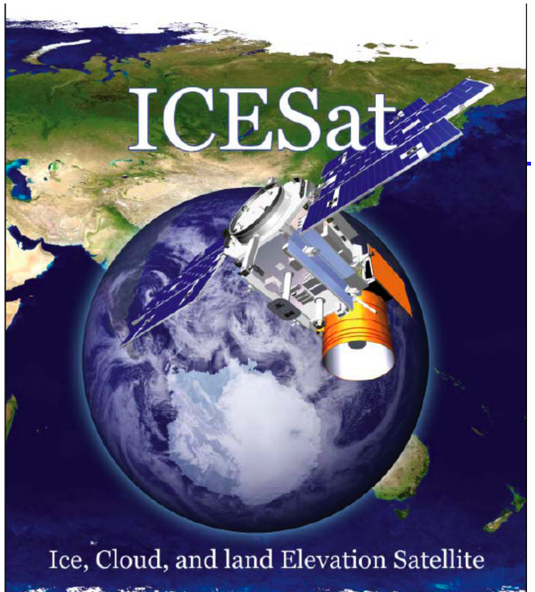


Fig. 8. Two case studies of lidar cloud measurements on Mars. Each shows the height distribution of backscatter coefficient over a 1 h interval. The colored area is the outline of a cloud that drifted above the landing site.



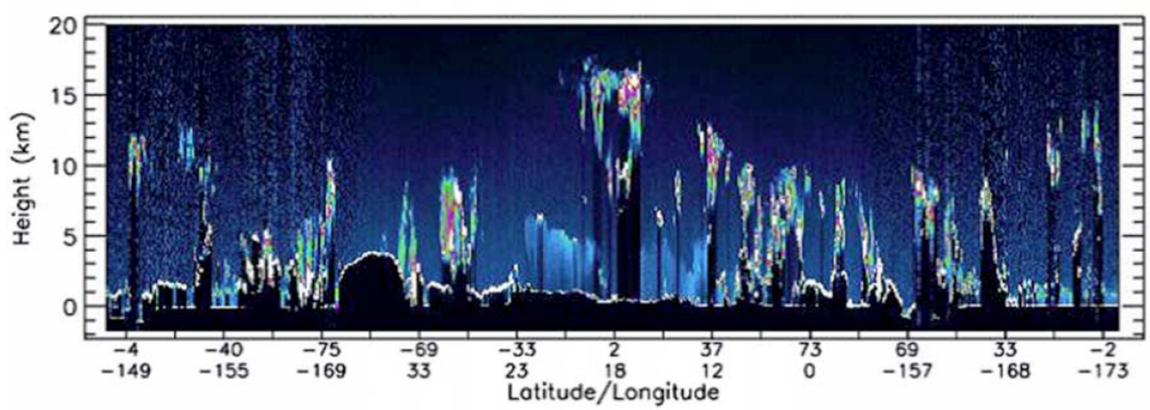
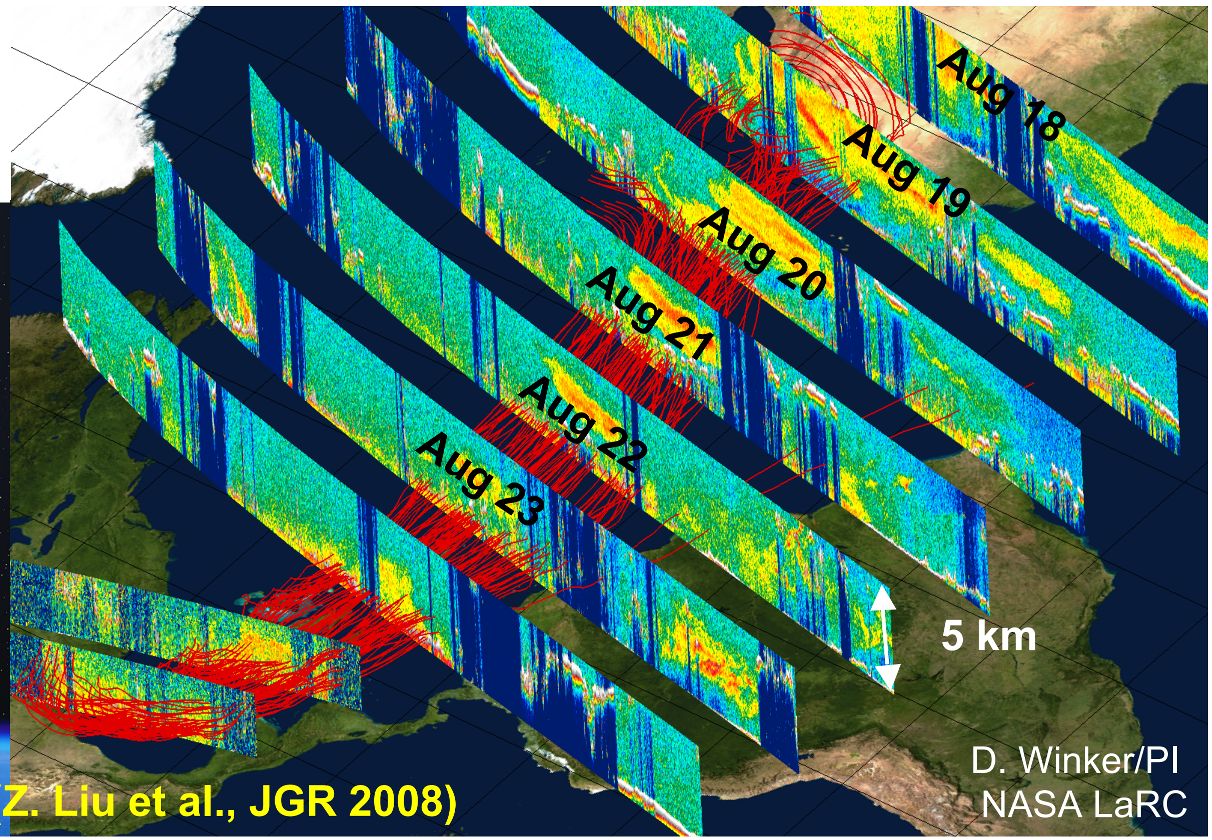


Figure 2. The 532 nm lidar signal of GLAS depicted for an entire global orbit from October 6, 2003. The signal scaling is the same as for Figure 1. The track starts in the central Pacific, crosses Antarctica, proceeds across Africa and Europe and then crosses northern Greenland and Alaska.

Aerosol Backscatter Profiling Lidar measurements from Earth Orbit

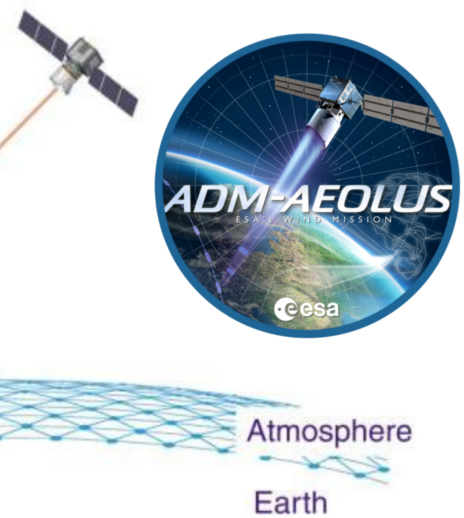


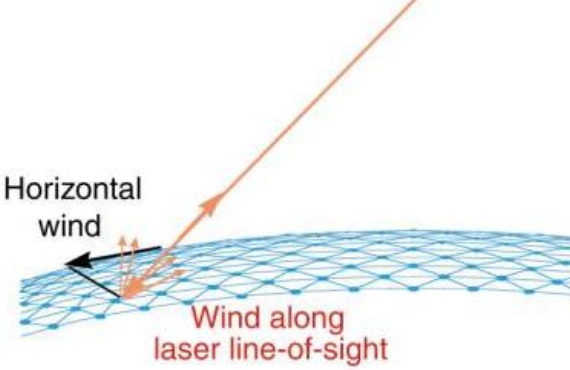
Wind Lidar for Earth to be Launched 2014

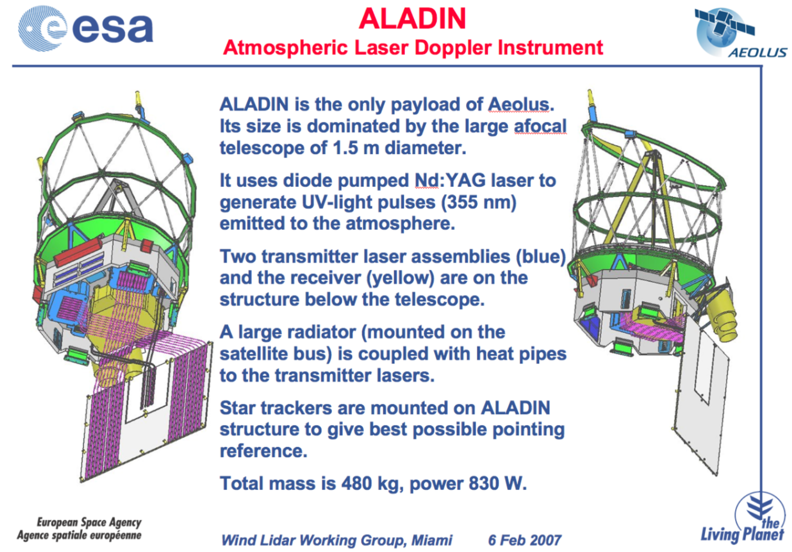
ESA's ADM-Aeolus Wind Lidar Mission

GSFC

Measures Line of sight winds via lidar in Earth Orbit







ALADIN Lidar for Earth:

- Need high resolution to improve Earth weather models
- Measures Doppler shift of broad Rayleigh scatter from clean air

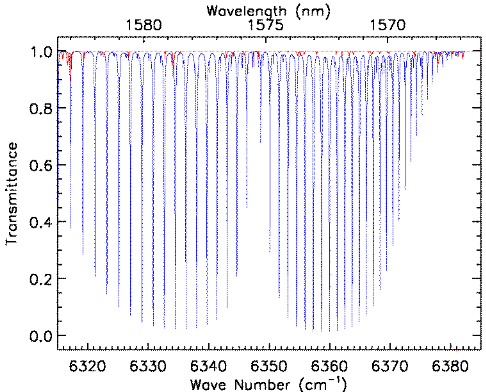
    => 355 nm laser
- Laser is power inefficient (~1%) & difficult (UV)
- Backscatter spectrum is varying mix of Mie & Rayleigh scattering
- All these result in a large complex lidar, needing ~800W power

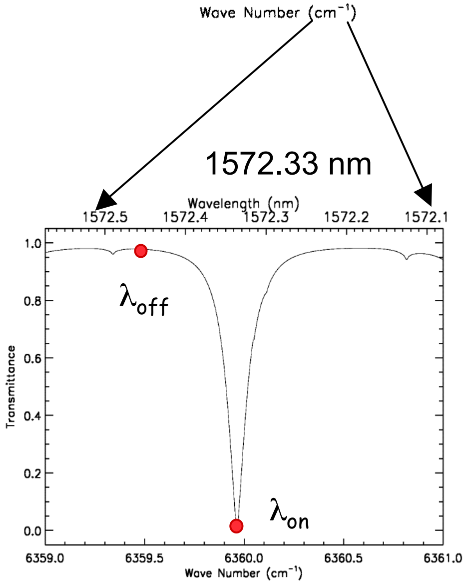
Wind lidar for Mars atmosphere

- Measurement requirements aren't nearly as demanding
- Mie scattering (fine suspended aerosol (dust)) dominates (by far)
- Very narrow backscatter spectrum simplifies receiver
- **Allows a smaller, simpler lidar working in VIS/NIR**

Examples of Airborne Lidar Measured CO2 Line shapes vs Altitude

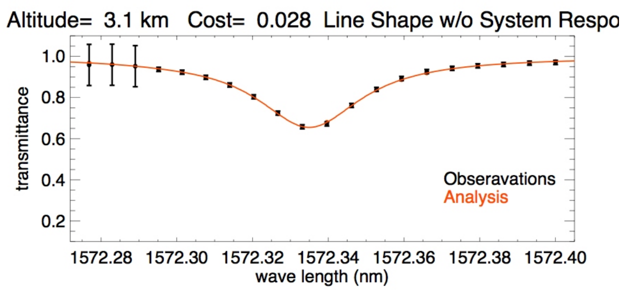
GSFC CO2 Sounder over SGP ARM Site - August 4, 2009

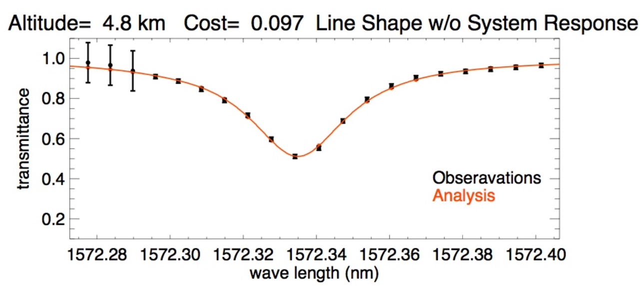


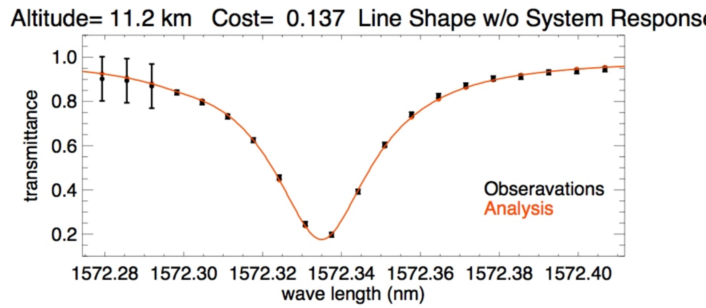


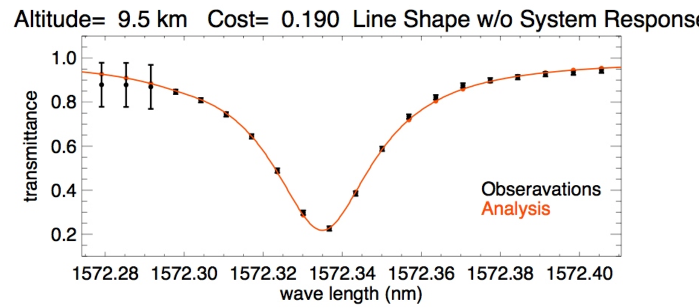
- Integrated Path differential absorption (IPDA) technique

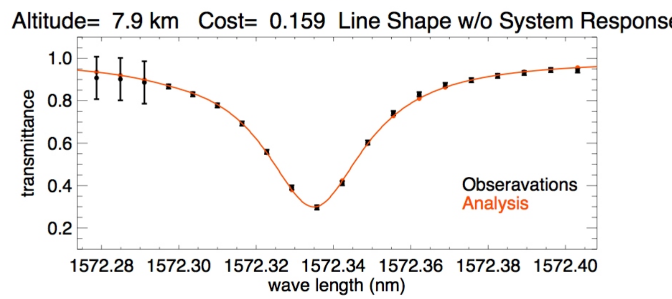
$$N_t = \int_R^{Sat.} N(r) \cdot dr = \frac{1}{2 \cdot \Delta\sigma} \cdot \ln\left[\frac{E_{off}(R)}{E_{on}(R)}\right]$$

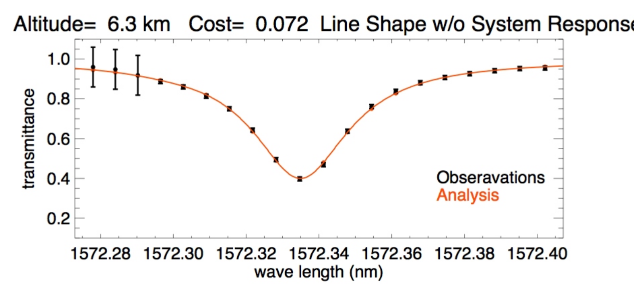








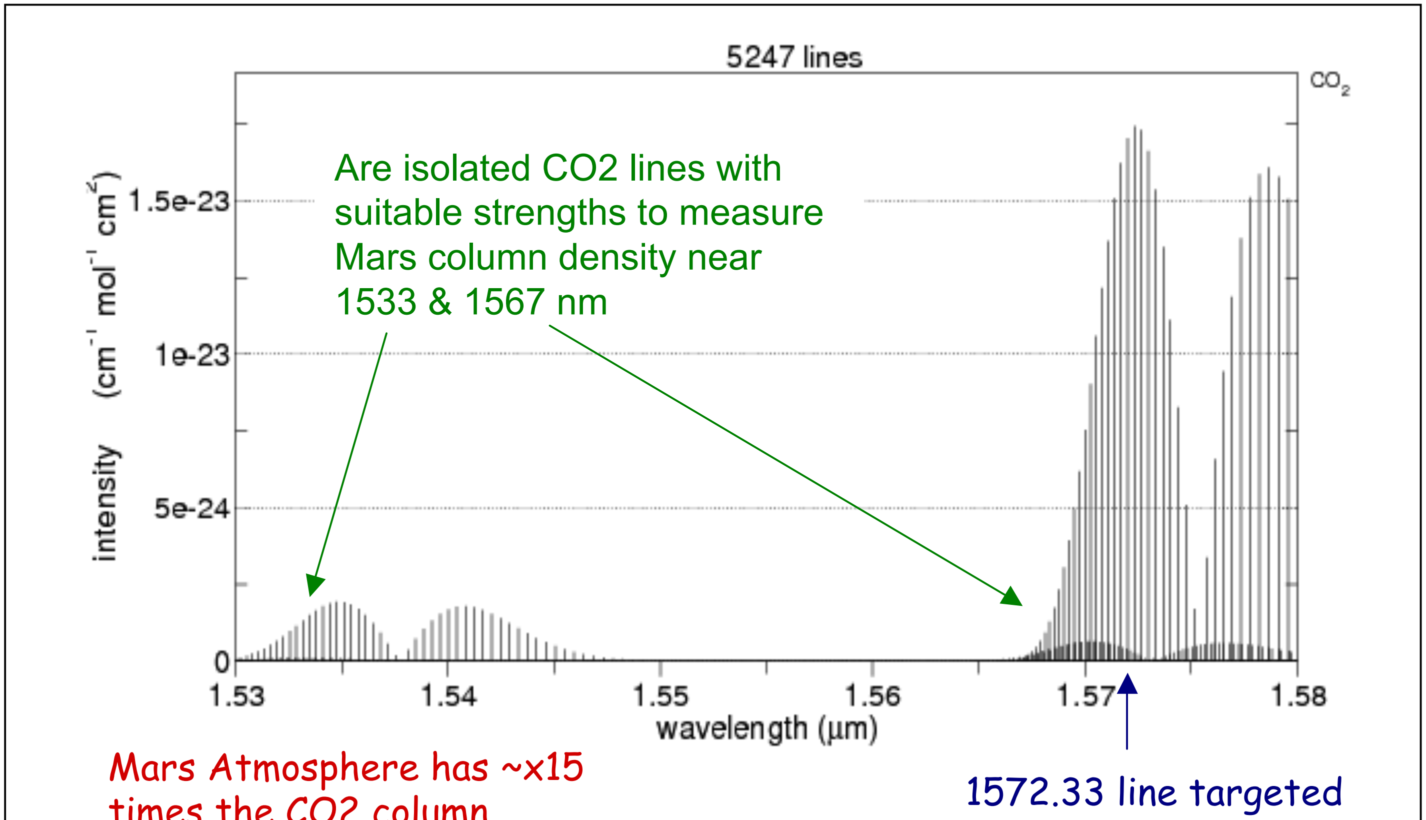




- Absorption increases with altitude
- Smooth line shapes at all altitudes !

Candidate CO2 absorption Regions
For CO2 column density (pressure) measurement

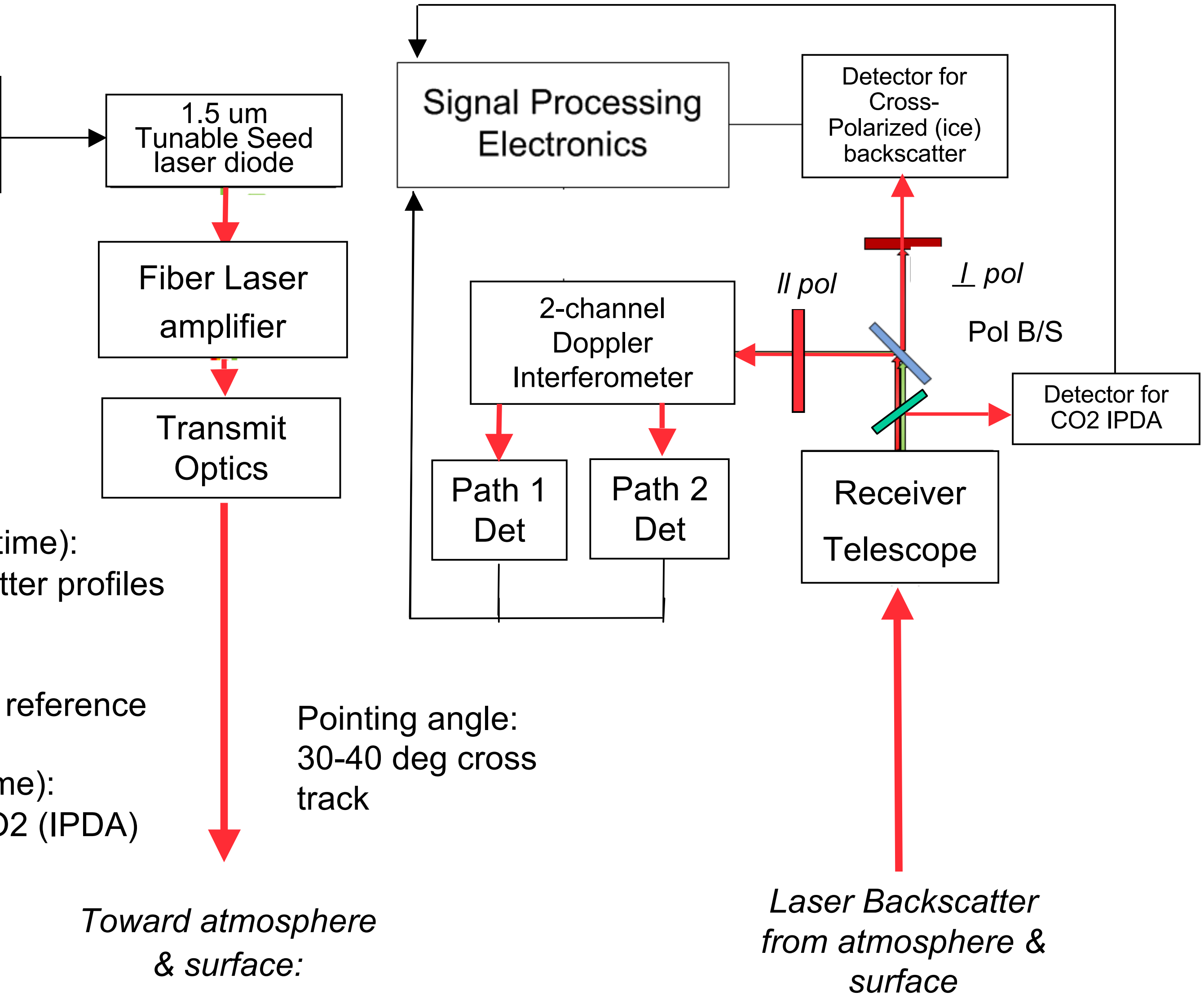
GSFC



Mars Atmosphere has ~x15 times the CO2 column abundance => target weaker CO2 lines

1572.33 line targeted for Earth for ASCENDS mission

Mars Climate Lidar - Instrument Diagram

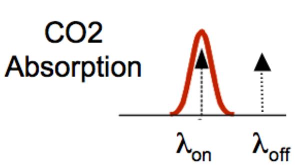


* $-\lambda_{off}$ (~90% of time):

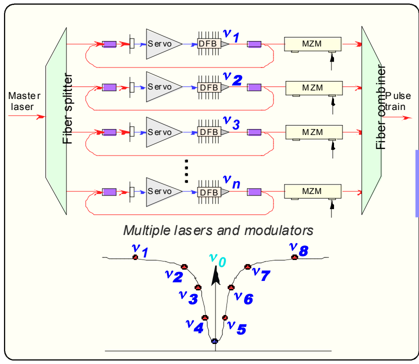
- Atmospheric backscatter profiles
- Dust/ice ratio profiles
- Doppler wind profiles
- IPDA Surface energy reference

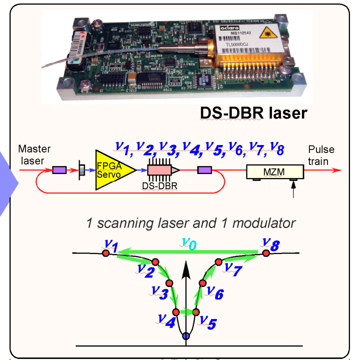
λ_{on} (~10% of time):

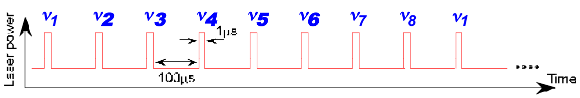
- Column density of CO_2 (IPDA)

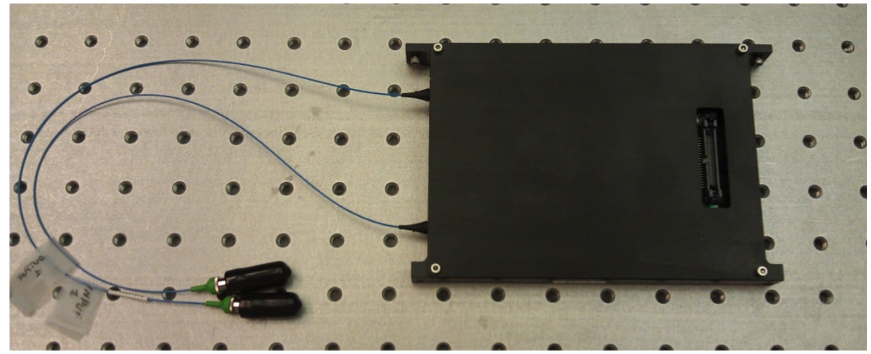


Some High Efficiency Lidar components being developed for Space (most with NASA ESTO support)





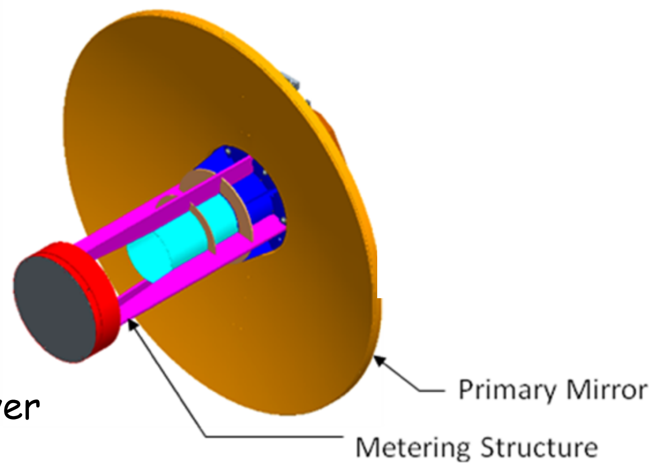




Laser transmitter

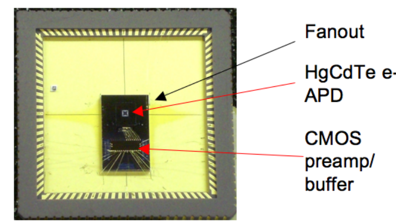
fiber laser amplifiers
(typically 7-8% efficient)

Precise frequency-stepped
laser seeder
(< 1 MHz stability)
J. Chen & K. Numata, GSFC

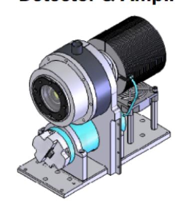


Low mass Be/SiC Receiver
Telescopes
50-80 cm diameter

High Sensitivity NIR Detector



Detector & Amplifier Chip

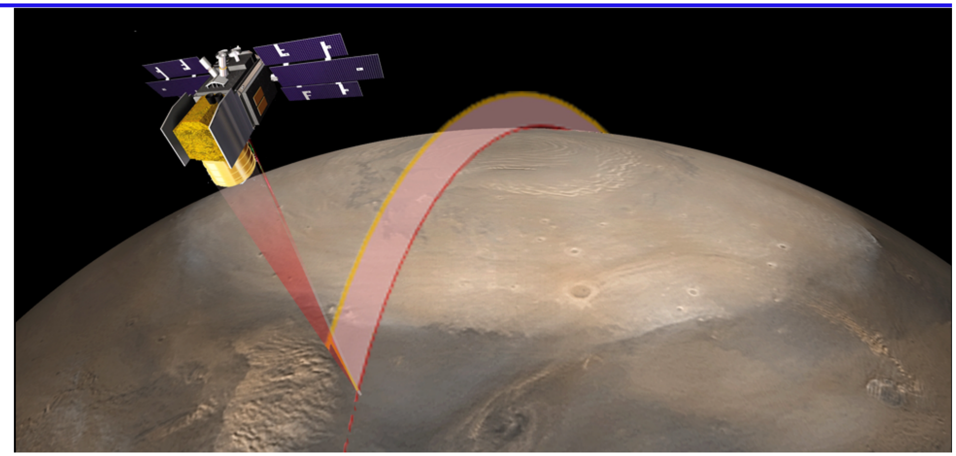


Detector/Preamp in Dewar cooled by Closed Cycle Cooler

Xiaoli Sun, GSFC

Mars Climate Lidar Study - Status

GSFC



Preferred Mars Mission:

- ~Circular polar orbit ~400 km altitude
- Non-synchronous (variable time of day) orbit

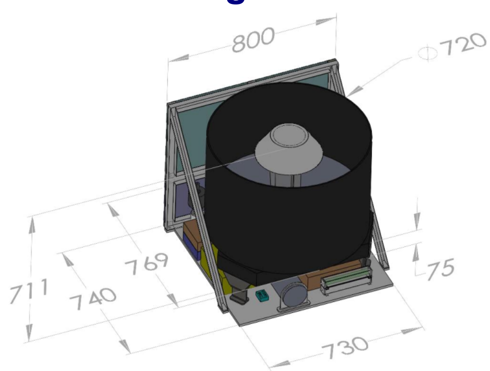
Heritage:

- Well-established direct detection lidar approach
- Similar measurements demonstrated from the ground (Earth & Mars), aircraft & from orbit

Technology Leverage:

- New laser & detector technologies from NASA ESTO & from industry; => (~x10-x15) lower power

One Configuration Concept (70 cm diam. tel):



Estimated Capabilities:

- Continuous global measurements of atmospheric:
  - **CO_2 column abundance (surf pressure):** < 2 %
  - **Backscatter profiles:** < 2%, 2 deg latt, 2 km vert
  - **Wind profiles**: ≤ 3 m/sec, 2 deg latt, 2 km vert
  - **Depolar. (ice-dust discr.) profiles** < 5%
- Readout resol: ~100 m vertically, 1 Hz rate

Why these measurements ?

- Directly address high priority needs for Mars:
  - 2011 Planetary Decadal Survey
  - Strategic knowledge gaps in Mars program

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Backup