Self-Raman Nd:YVO4 laser and electro-optic technology for space-based sodium lidar instrument

SPIE Solid State Lasers XXIII: Technology and Devices
Paper 8959-19

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Sodium lidar instrument
AGENDA

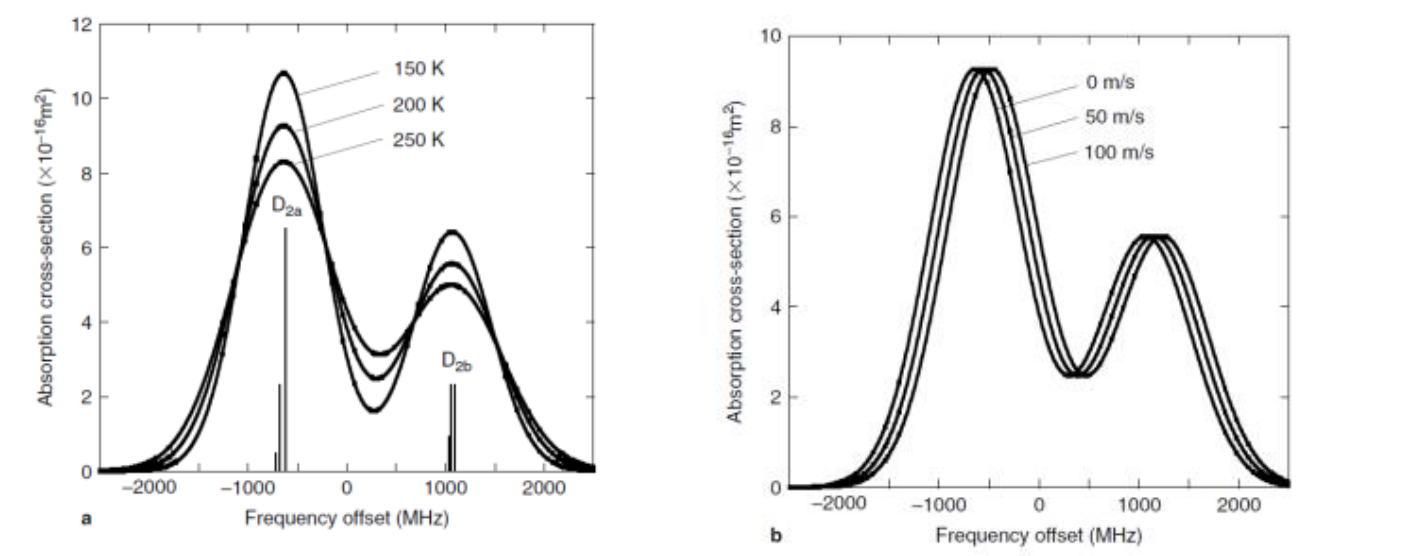
- Heliophysics in the Earth mesosphere with spectroscopy of sodium
- Key candidate technology for space-based sodium lidar:
  - Laser transmitter: Self-Raman Nd:YVO4
  - Laser spectroscopic technique: leverage from ASCENDS
  - Laser receiver: filter
  - Laser receiver: single photon detectors

Heliophysics with sodium lidar

- **Ablation from meteors** is believed to be the chief source of **metals** such as Na, Mg, K, Fe, and Ca in the **middle atmosphere.**
- Metal (e.g. sodium) fluorescence lidar can provide temperature measurements in the Earth's atmosphere mesopause region (75 - 115 km).
- This will enable scientists to delineate and understand the middle and upper atmosphere chemistry, structure and dynamics, especially the impact of gravity waves – the parameterization of which is a fundamental issue in current atmospheric modeling for climate and meteorology.
- **In summary, this helps to delineate and separate solar vs. Earth induced heat causing change in the Earth atmospheric temperature.**

Atmospheric Sodium spectra
Temperature and wind effects

- The D2 resonance line of atomic sodium is **589.159 nm**
- The D2 resonance line of Na is a Doppler broadened doublet composed of six hyperfine lines as shown below.



- The Doppler **broadening of the lines** is a **function of temperature** and the ratio of the D2a peak to the value at the minimum between the peaks is a very sensitive function of temperature.
- The **wind speed** may be inferred from the **Doppler shift** induced to the structure of the line as shown above.

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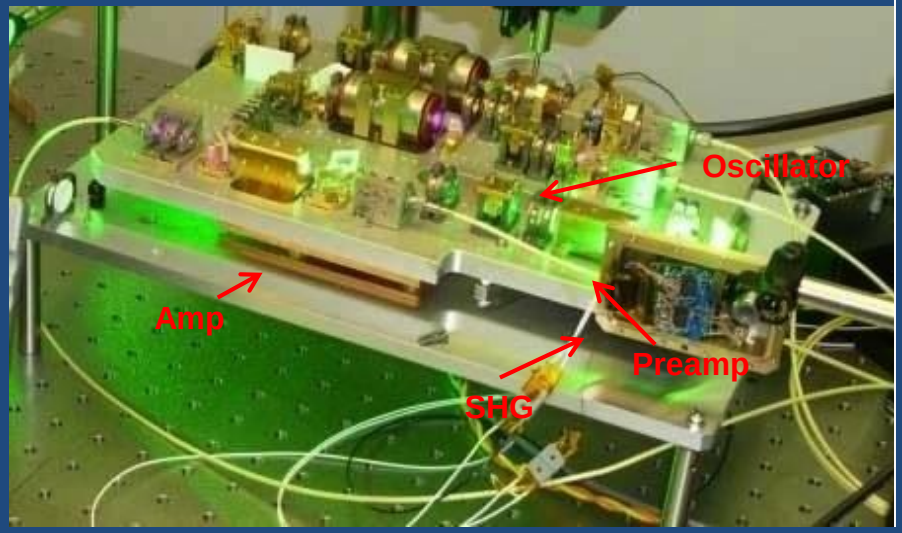
Sodium space-based lidar - leverage

ICESat2/ATLAS laser

ICESat = Ice Cloud & land Elevation Satellite
ATLAS = Advanced Topographic Laser Altimeter System **2017 launch**

9W @ 532 nm Nd:YVO4 laser built by Fibertek Inc.



CALIPSO/CALIOP laser

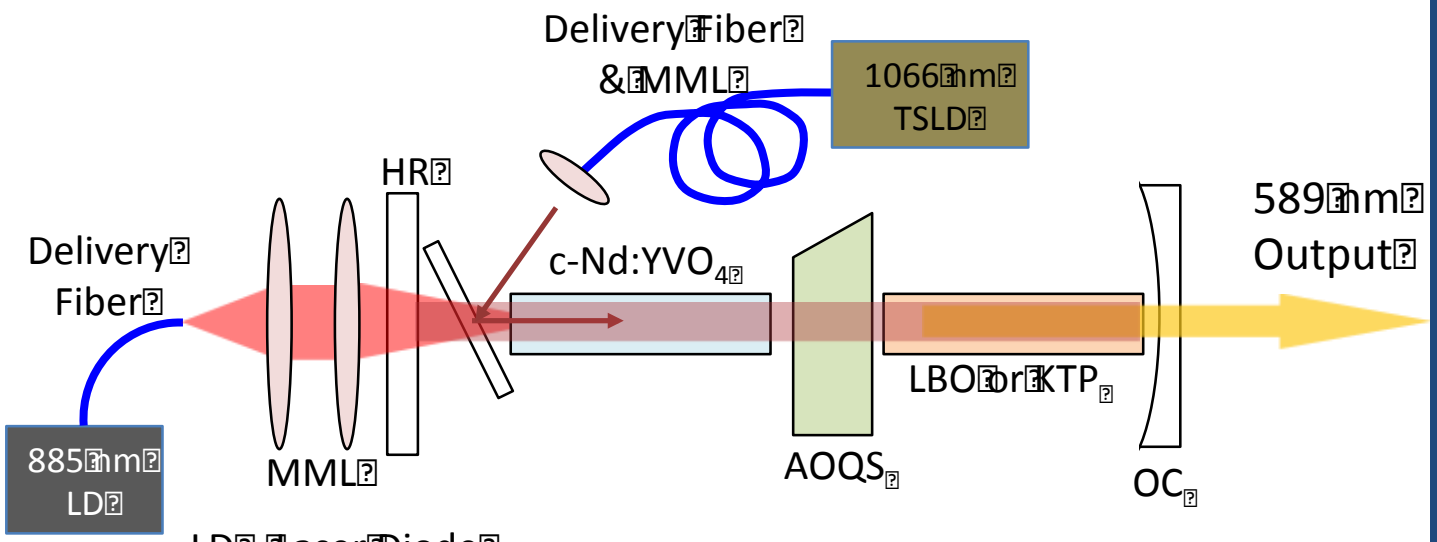
CALIPSO = Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations
CALIOP = Cloud-Aerosol LIdar with Orthogonal Polarization **2006 launch**

2.2 W @ 532 nm, 2.2W @1064 nm Nd:YAG laser built by Fibertek Inc

REFERENCE:

"High efficiency laser designs for airborne and space-based lidar remote sensing systems"
F. Hovis, R. Burnham, M. Storm, R. Edwards, P. Burns, E. Sullivan, J. Edelman, K. Andes, B. Walters, K. Le, C. Culpepper, J. Rudd, T. Chuang, X. Dang, J. Hwang, and T. Wysocki Proc. SPIE 8159, 815903 (2011)

Self-Raman Nd:YVO4 Laser for Sodium Spectroscopy



LD – Laser Diode
TSLD – Tunable Seed Laser Diode
MML – Mode Matching Lens
HR – High Reflective Mirror
OC – Output Coupler
AOQS – Acousto-Optic Q-Switch
c-Nd:YVO_4 – c-cut Neodymium doped yttrium orthovanadate crystal
LBO – Lithium Triborate
KTP – Potassium Titanyl Phosphate

Nd:YVO4 Self-Raman laser
NASA-GSFC breadboard

LD – Laser Diode
MML – Mode Matching Lens
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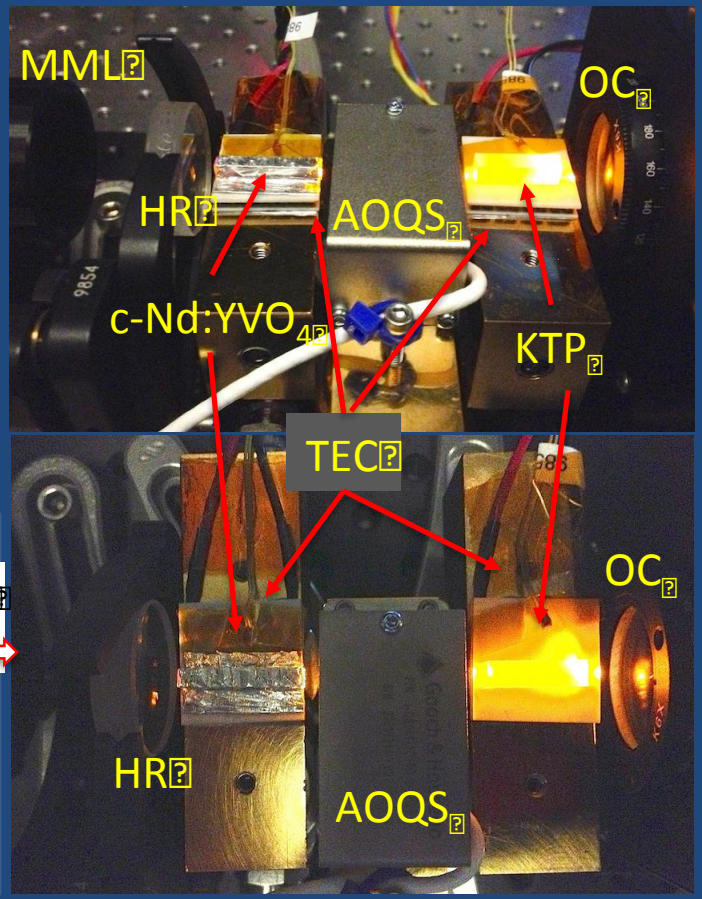
AOQS – Acousto-Optic Q-Switch
c-Nd:YVO_4 – c-cut Neodymium doped yttrium orthovanadate crystal
KTP – Potassium Titanyl Phosphate
TEC – Thermoelectric Cooler



0.5 W at 589 nm

Laser for Sodium Spectroscopy

Tuning vanadate

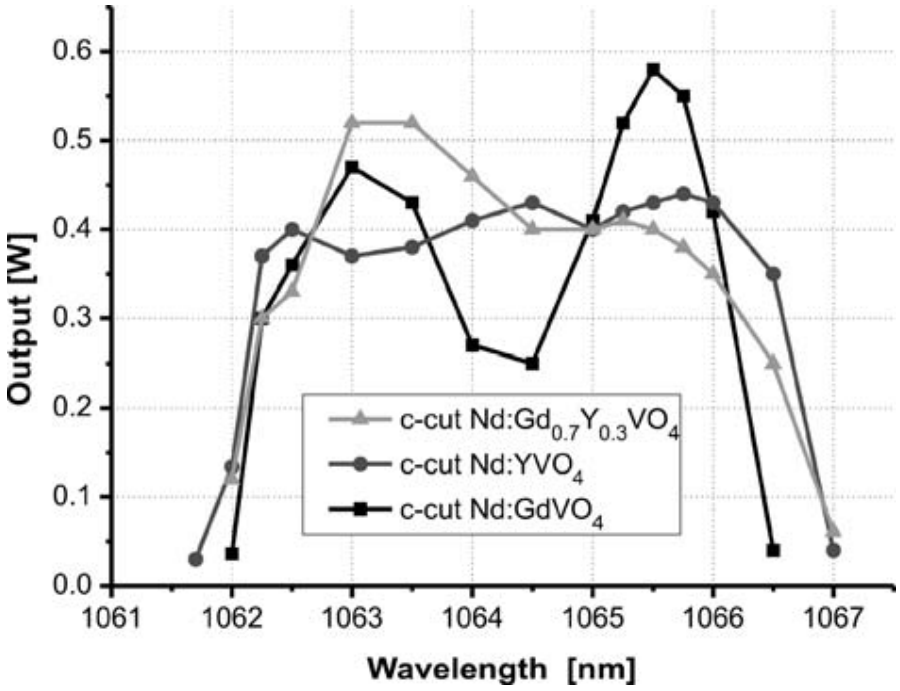
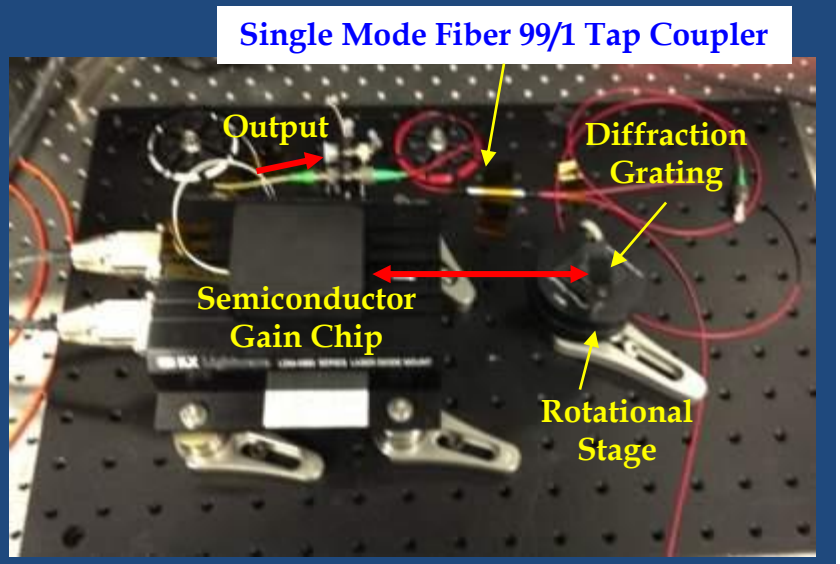


Fig. 3 The tuning curves of c-cut Nd:$Gd_{0.7}Y_{0.3}VO_4$, Nd:YVO_4 and Nd:$GdVO_4$ lasers

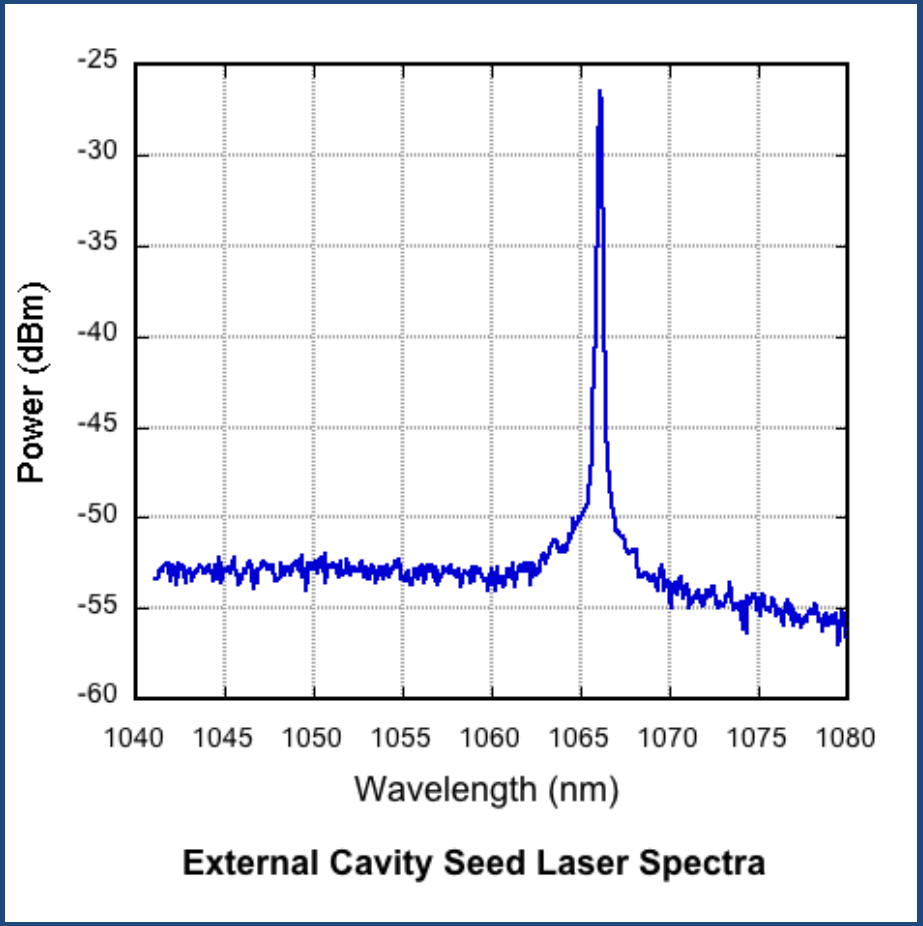
From: " Mode-locked diode-pumped vanadate lasers operated with PbS quantum dots"

A.A. Sirotkin et al. Appl Phys B (2009) 94: 375–379

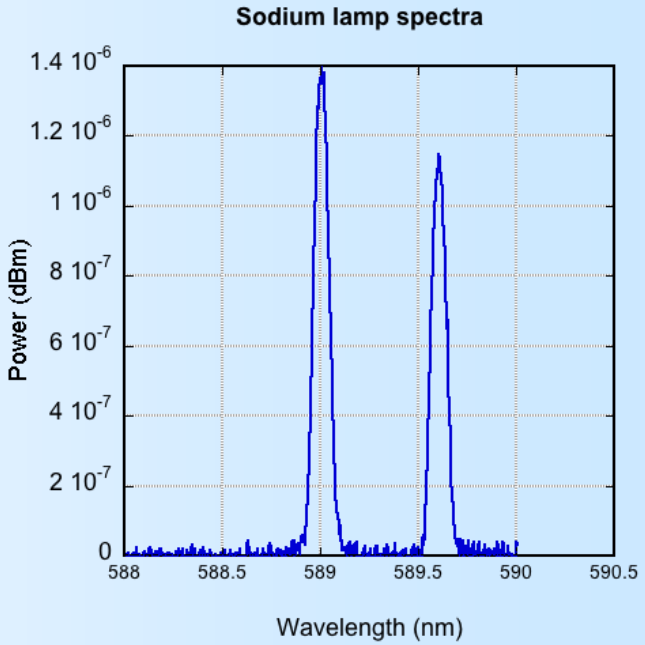
1066 nm External cavity laser (ECL) – Tunable injection seeder



Tunable external cavity seed laser



Sodium line (lamp) calibration source



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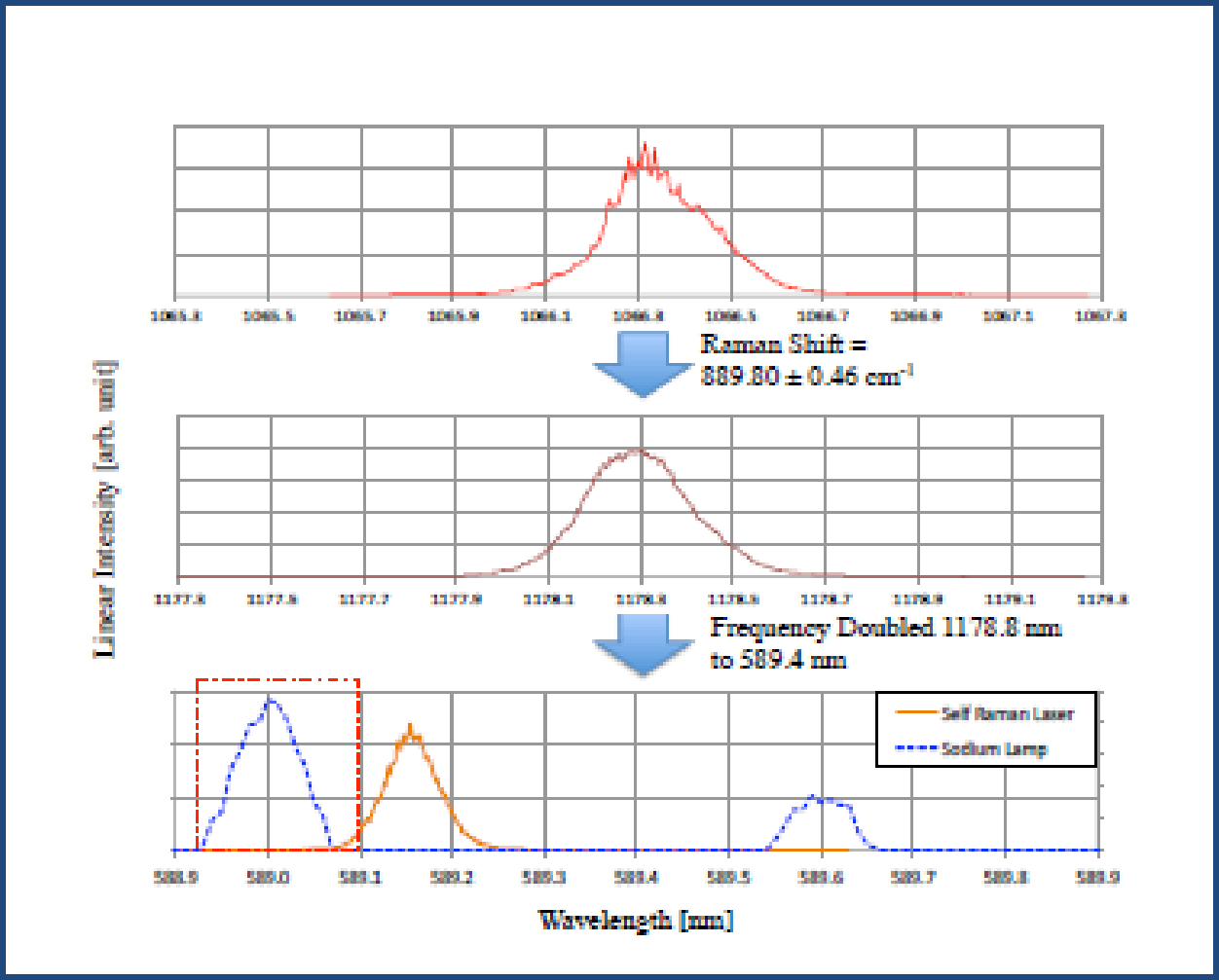
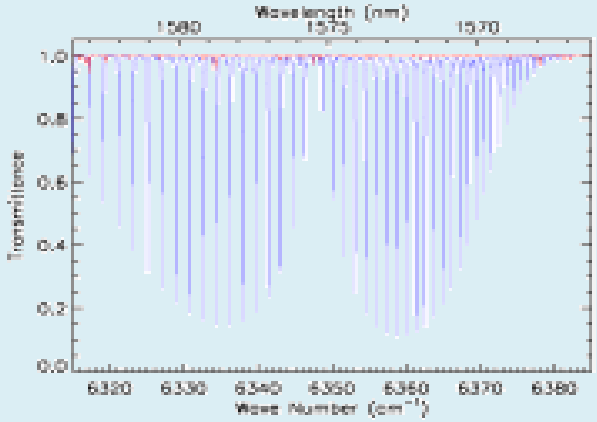
Self-Raman Nd:YVO4 laser spectra (unseeded)
NASA-GSFC breadboard



Sodium lidar instrument - leverage
Laser Spectrometer for ASCENDS Mission

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



~ 400 km Sun sync orbit
- CO2 at 1570 nm
- O2/pressure at 765 nm
- Altimetry & atm scattering profile from CO2 signal

Clouds and aerosol: λ=1064nm

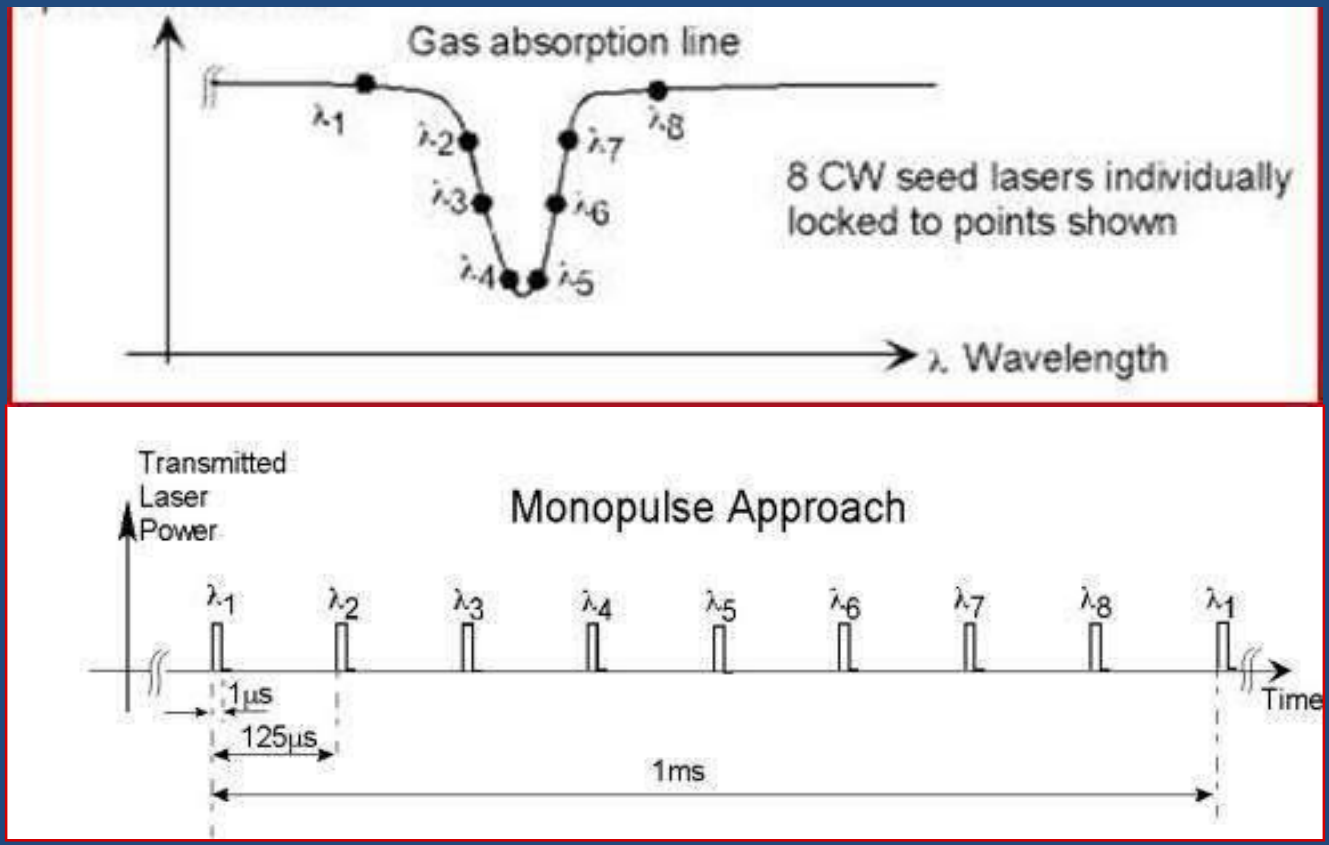
clouds

ASCENDS = Active Sensing of Carbon Emissions over Nights, Days and Seasons **2022 launch**

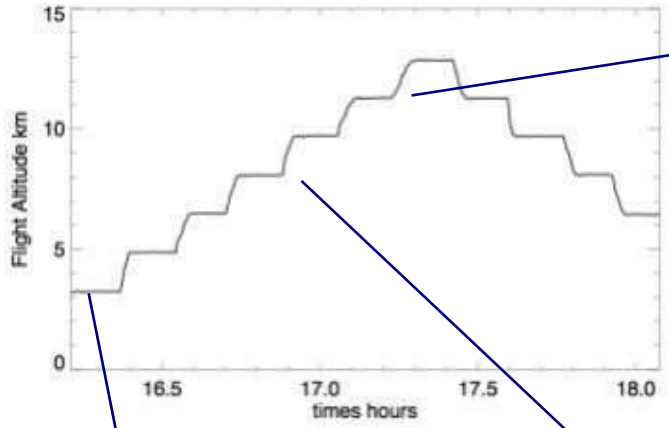
Sodium lidar leverage from ASCENDS Mission

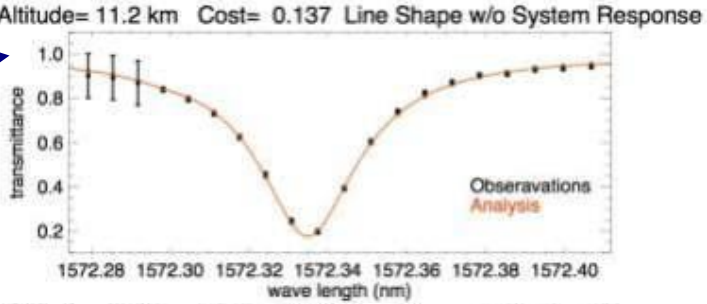
Time/wavelength multiplexing

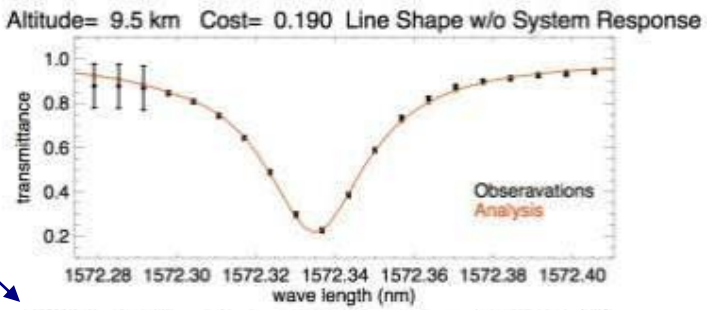
using electrically tunable DFB laser and modulator

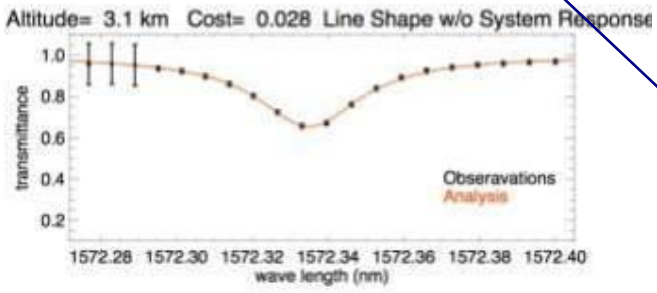


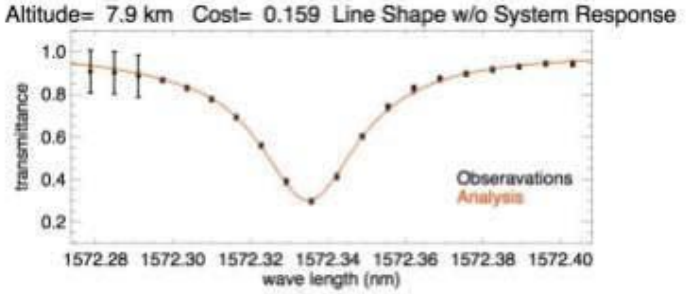
Airborne instrument retrievals of CO2 absorption line - August 4, 2009

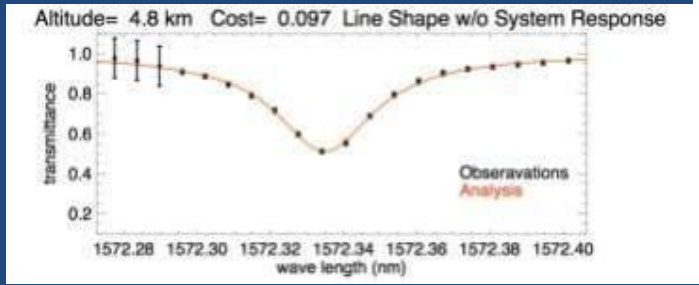


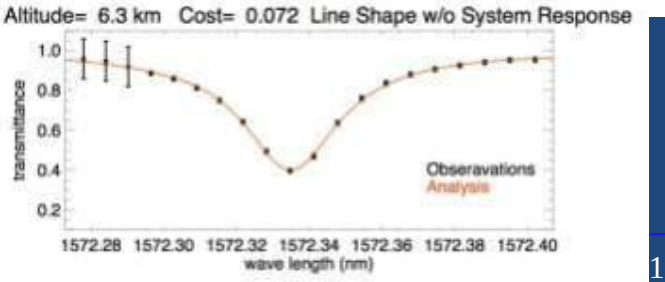












- Black dots - sampled line shape from lidar
- Typ. 60 sec ave time

- Red curves - best fit line shapes (based on HITRAN) from retrieval process

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

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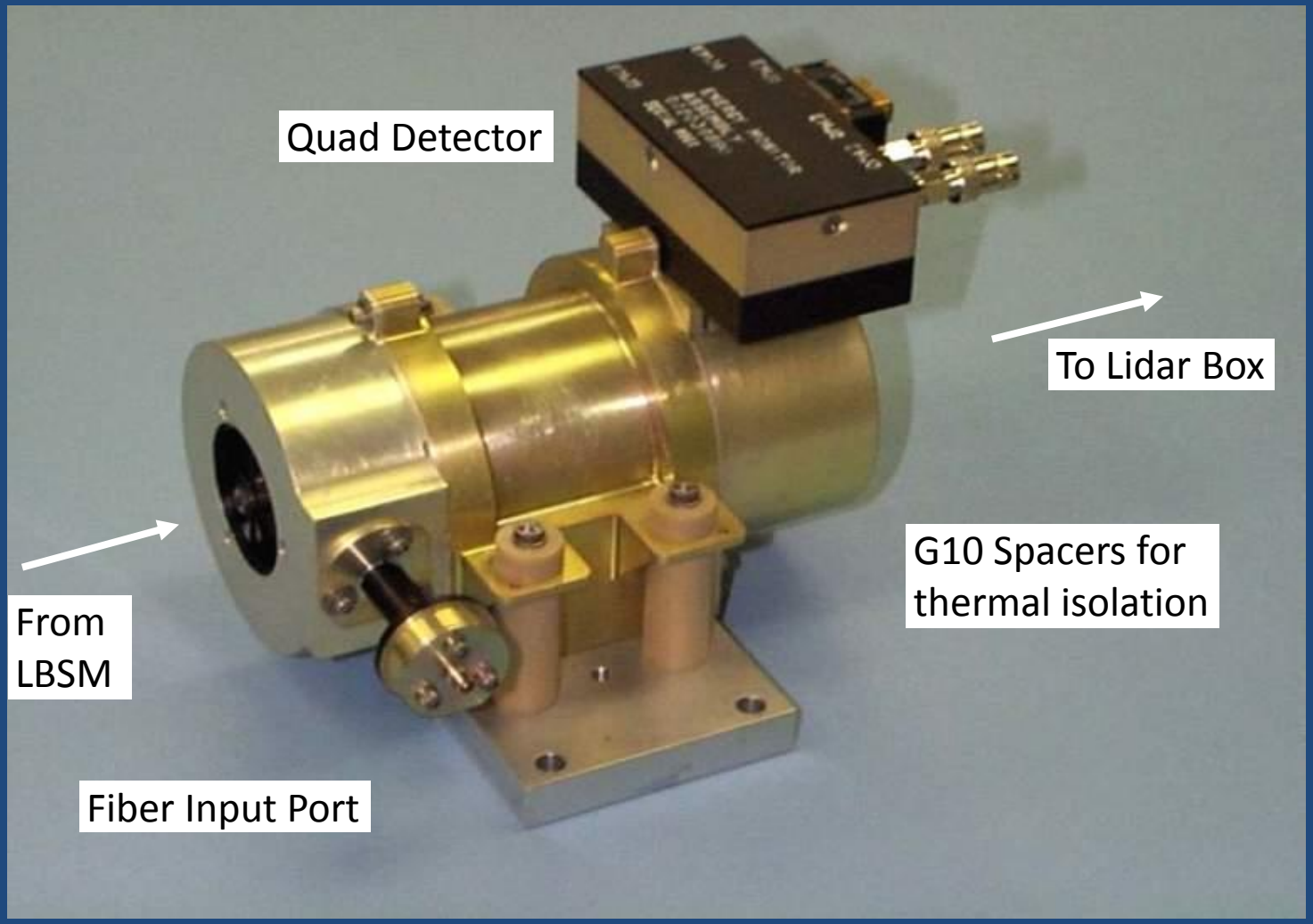
Sodium lidar leverage from ICESat/GLAS Mission

ICESat/GLAS Etalon Assembly

Also considering sodium vapor Faraday filter



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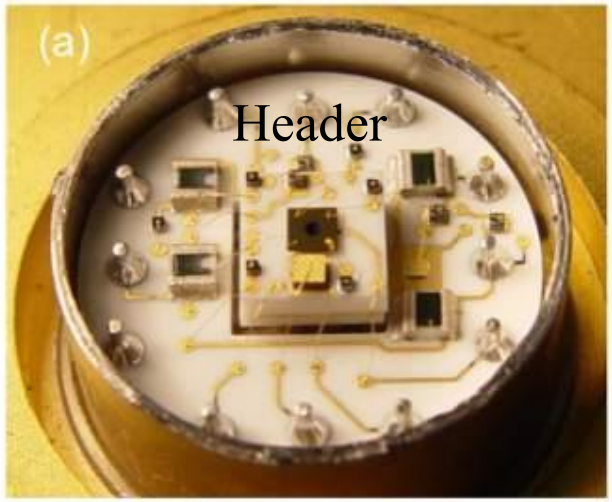
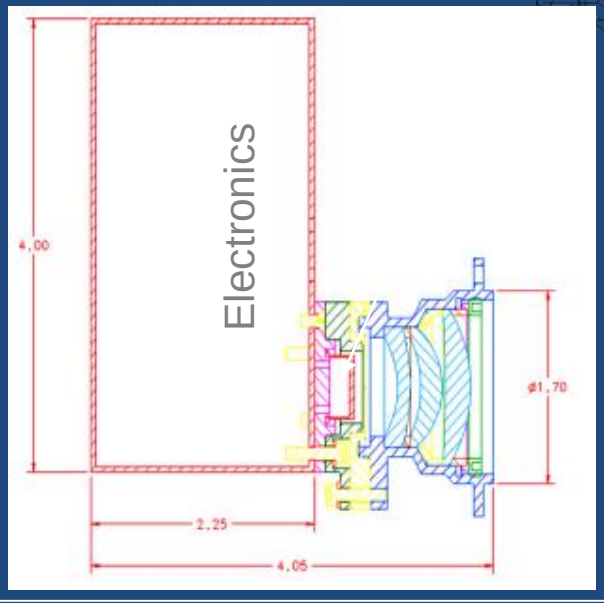
ICESat/GLAS Single Photon Counting Module (SPCM)





- 0.17 mm diameter active area
- >65% QE at 532 nm
- >13e6/s max. count rate
- < 1.5% afterpulsing (500ns)
- <500/s dark counts
- 280g (electronics with header)
- 2.1 W (module only)
- 4.8 W (with power supply)

Sodium lidar instrument
SUMMARY

- NASA-GSFC is exploring concepts for a heliophysics mission using spectroscopy of sodium in the Earth mesosphere

- We have identified key candidate technology for space-based sodium lidar:
  - Laser transmitter: Self-Raman Nd:YVO4
  - Laser spectroscopic technique: leverage from ASCENDS
  - Laser receiver: filter
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- We have proposed (to NASA Heliophysics) development of a ground-based lidar using space-flight pre-cursor components to evolve to a space-based mission.