Development of a Sodium LIDAR for Spaceborne Missions

Measurement Techniques in Solar and Space Physics (MTSSP)
April 20-24 2015
NCAR Center Green Campus, Boulder, CO

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April 21, 2015
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.

![Graph](image)

- 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.

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:YVO₄ – 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
HR – High Reflective Mirror
OC – Output Coupler
AOQS – Acousto-Optic Q-Switch
c-Nd:YVO4 – c-cut Neodymium doped yttrium orthovanadate crystal
KTP – Potassium Titanyl Phosphate
TEC – Thermoelectric Cooler

From LD

0.5 W at 589 nm
Laser for Sodium Spectroscopy
Tuning vanadate

Fig. 2 Schematic arrangement of the tuneable CW Nd-doped vanadate laser. 1: pump diode, 2: fibre pigtail, 3: focusing optics, 4: laser resonator, 5: crystal, 6: intracavity Fabry–Pérot etalon, 7: powermeter, 8: spectrometer, 9: beam splitter

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

Fig. 4 Small signal absorption spectrum of a 1 mm thick PbS-doped glass slide

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

Tunable external cavity seed laser

External Cavity Seed Laser Spectra
Sodium line (lamp) calibration source
• Performed real-time experimental spectroscopy of sodium vapor (in a closed cell heated to 110°C) using a frequency-doubled (1178 nm to 589 nm) Distributed FeedBack (DFB) tunable diode laser.
• The laser is tuned in real-time by modulating the electrical current input to the laser.
• The spectra is replicated because the current amplitude is increased and decreased by a sinusoidal input electrical waveform.
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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

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

Quad Detector

From LBSM

To Lidar Box

G10 Spacers for thermal isolation

Fiber Input Port
Sodium lidar instrument

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Sodium lidar leverage from ICESat/GLAS Mission

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)
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
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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.