Development of a Sodium LIDAR for Spaceborne Missions

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Anthony W. Yu, Michael A. Krainak, Diego Janches, Sarah L. Jones, Branimir Blagojevic, Jeffrey Chen

NASA Goddard Space Flight Center
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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:YVO$_4$
  - 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.
Sodium lidar instrument

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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.

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**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

885 nm LD
1066 nm TSLD
589 nm Output

MML
HR
c-Nd:YVO₄
AOQS
LBO or KTP
Delivery Fiber & MML

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 on Water Chilled Heat Sink

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

0.5 W at 589 nm

From LD

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MTSSP 2015, Boulder CO
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

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

Tunable external cavity seed laser

External Cavity Seed Laser Spectra
Sodium line (lamp) calibration source
Laser spectroscopy of sodium vapor

- 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

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

Clouds and aerosol: $\lambda \sim 1064$ nm

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

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

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

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

Fiber Input Port

G10 Spacers for thermal isolation

To Lidar Box
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)
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:YVO$_4$
  – Laser spectroscopic technique: leverage from ASCENDS
  – Laser receiver: filter
  – Laser receiver: single photon detectors

• 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.