Towards Comparison of RAMAN and HSRL LIDAR technique for CTA type Atmospheric Monitoring

P. Fetfatzis[a], E. Fokitis*[a], V. Gika[a], S. Maltezos[a], N. Maragos[a],
A. Aravantinos[b], and M. Kompitsas[c]

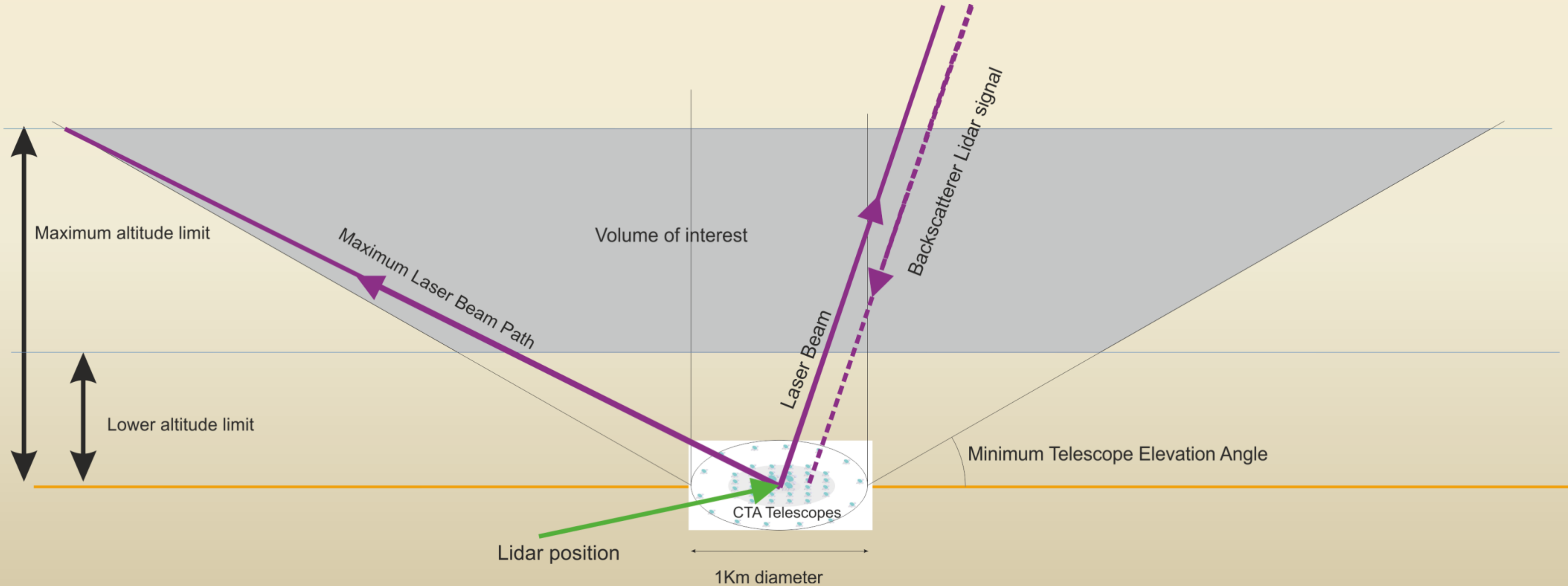
[a]Physics Department, NTUA, Athens, Greece,
[b]Physics Department, TEI, Athens, Greece,
[c]Theoretical and Physical Chemistry Institute, NHRF, Athens GREECE

OUTLINE OF THE TALK

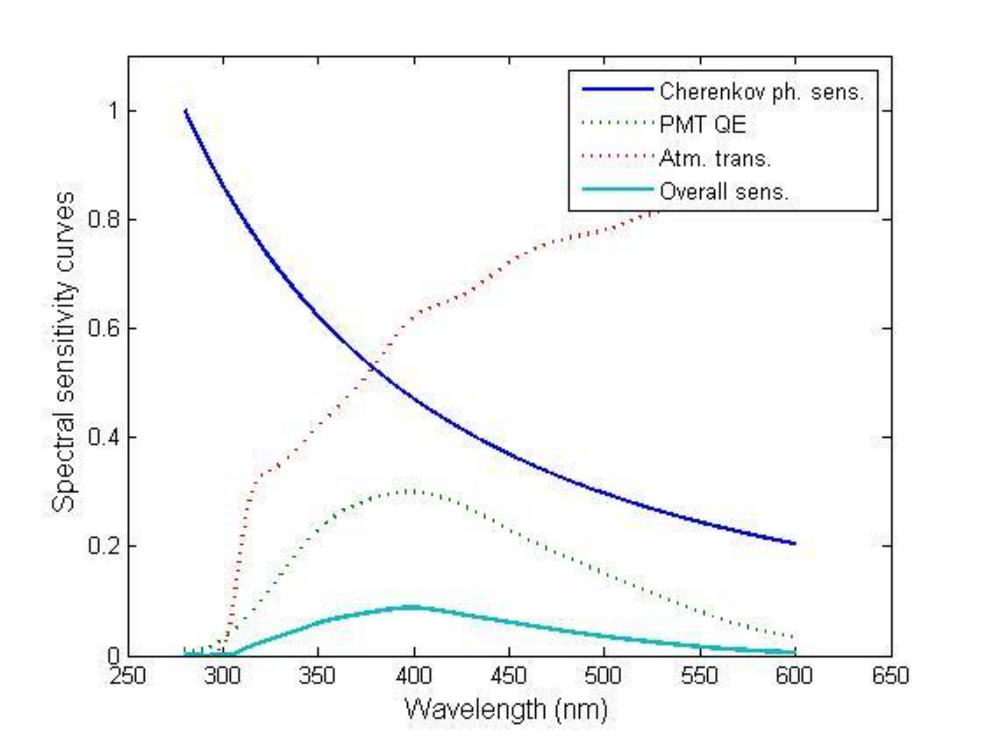
- Raman LIDAR at a Glance – Full Scale LIDAR concept
- HSRL at a Glance – Capabilities and Cost
- Estimated errors of RAMAN/HSRL
- Concurrent data acquisition for RAMAN/HSRL at NTUA
- Progress report on a prototype HSRL at NTUA
- Design of Laser Transmitters for HSRL
- Fabry-Perot etalon design and characterization
- Conclusions and Prospects

GENERALITIES

- In this work emphasis will be given in conceptual HRSL/Raman Comparison for CTA
-
- Understanding the Task of Atmospheric Monitoring in CTA



DETECTOR SENSITIVITY



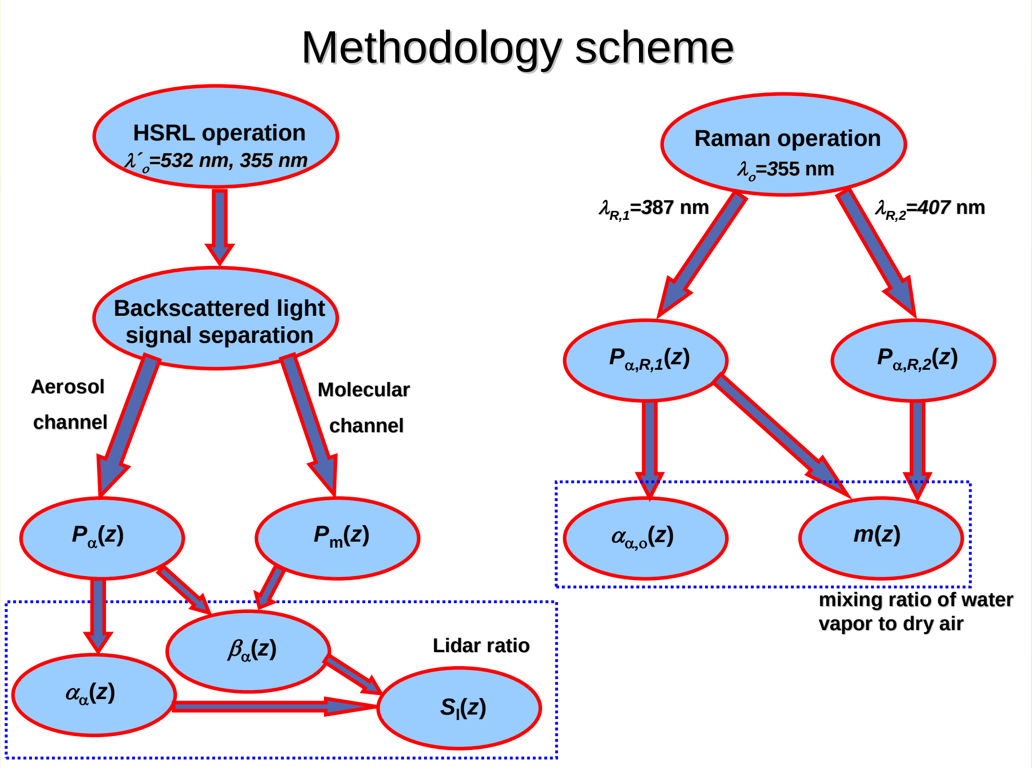
The wavelength of interest for atmospheric monitoring lies between 350 to 500 nm.

Diagram of overall spectral sensitivity assuming use of bialkali photomultiplier

DETECTOR SENSITIVITY

The above calculation of the spectral composition of air Cherenkov signal shows that we need to do atmospheric monitoring around a spectral range of 350-475 nm. We must take into account in our convolutions the spectral transmission of typical borosilicate glass (of the PMT). This plot is expected to change appreciably for UV glass window pmt's

COMPARISON OF RAMAN AND HSRL METHODOLOGIES



The methodology scheme illustrating the how to determine the optical parameters of the atmospheric constituents (enclosed in the boxes shown by dotted line) using both HSRL and Raman methods.

A. ANSMANN, et al, Appl. Phys. B 55, 18-28 (1992)
M. IMAKI, Y. TAKEGOSHI and T. KOBAYASHI, Japanese Journal of Applied Physics Vol. 44, No. 5A, 2005, pp. 3063–3067

RAMAN

$$\alpha_{a,0}(z)=\frac{\frac{d}{d_z}\left\{\ln\left[\frac{N_{\mathrm{Re}\,f}(z)}{P_{\lambda_{\mathrm{Re}\,f}}(z)\cdot z^2}\right]\right\}-\alpha_{m,0}(z)-\alpha_{a,0}(z)}{1+\left(\frac{\lambda_0}{\lambda_{\mathrm{Re}\,f}}\right)^k}$$

N_{Ref} : the molecular number density of the reference gas (nitrogen)
$a_{a,0}$: extinction coefficient for aerosols at λ_0
$a_{m,0}$: extinction coefficient for molecules at λ_0
$P_{\lambda_{\mathrm{Re}\,f}}$: reference Raman signal

HSRL

$$\alpha_a(z)=-\frac{1}{2}\frac{d\ln(P_m(z)\cdot z^2)}{dz}+\frac{1}{2\beta_m(z)}\cdot\frac{d\beta_m(z)}{dz}-\alpha_m(z)$$

$$\beta_a(z)=\beta_m(z)\frac{P_\alpha(z)}{P_m(z)}$$

$$S_1(z)=\frac{\alpha_a(z)}{\beta_a(z)}$$

$\beta_m(z)$: the molecular volume-backscatter coefficient
$\alpha_m(z)$: the molecular extinction coefficient
$\beta_m(z)$: the volume backscatter coefficient of aerosol and cloud
$P_m(z)$: the Rayleigh backscatter power
$P_\alpha(z)$: the Mie backscatter power

SOURCES OF TECHNOLOGICAL AND METHODOLOGY IMPROVEMENTS IN HSRL

1. Search for Gravitational Waves experiments.

They require ultrastable frequency lasers and Fabry-Perot Interferometers

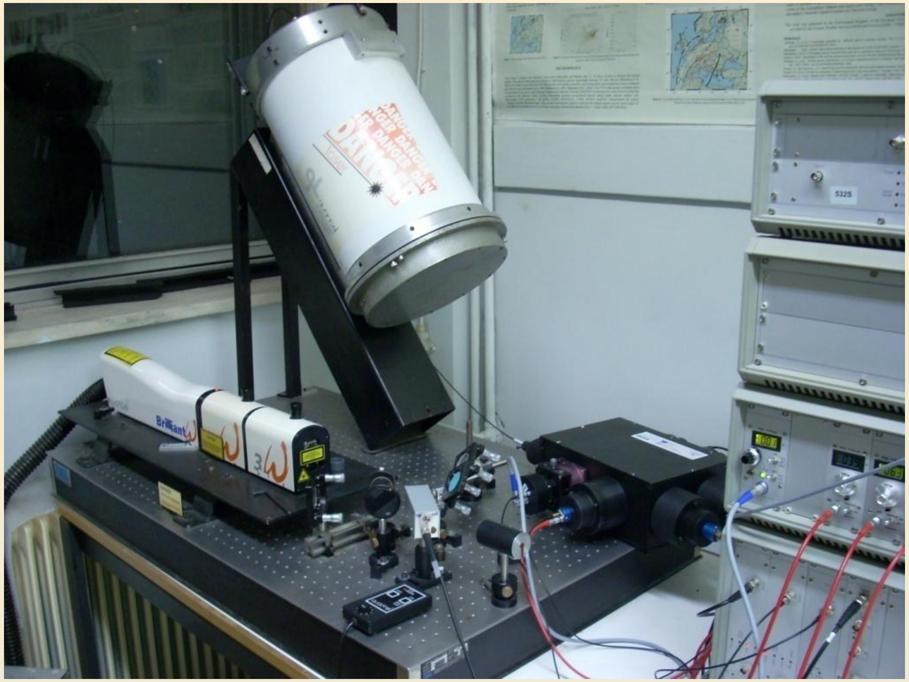
2. Space and Airborne LIDAR systems, especially related to ESA (ALADIN , EarthCare Missions, etc)

Several National Environmental and Climatology Agencies are promoting HSRL LIDARS

Therefore, significant amounts for R&D funds have been invested and Cosmic Ray Collaborations may profit and search ready low cost solutions in hardware and methodology.

One should note, that the class 1. lasers are of CW type and therefore their usefulness is limited mostly to class 2.

RAMAN LIDAR SETUP OF NTUA



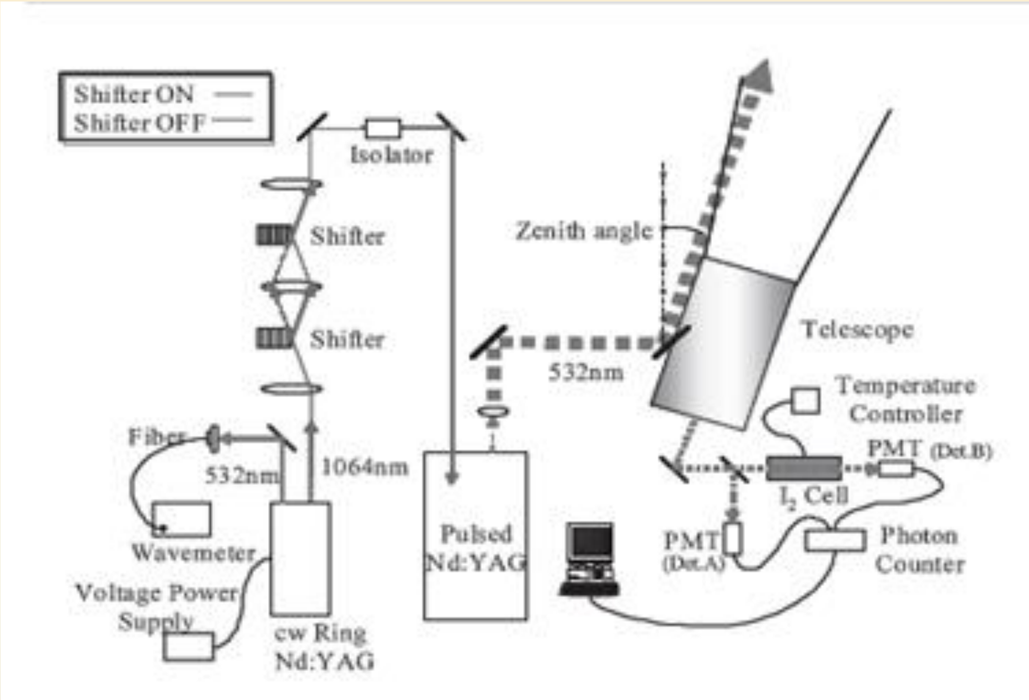
Raman LIDAR setup of NTUA Atmospheric Environment group

RAMAN LIDAR

Recently acquired 1.2 Joule per pulse Quanta Ray laser compatible with option of injection seeding for frequency stabilization. It can operate at 1064, 532 and 355 nm and is equipped with narrow optical filters (Barr Associates at 1064, 532 and 355 nm) for daytime and nighttime operation. The group has cooperated in European EARLINET project. The NTUA Raman lidar is equipped with a 300 mm receiving telescope and with a multi-wavelength detection box at the following wavelengths: 355-387-407-532-607-1064 nm.

If the seeder is funded, then there is serious possibility for operation in HSRL mode using the following infrastructure.

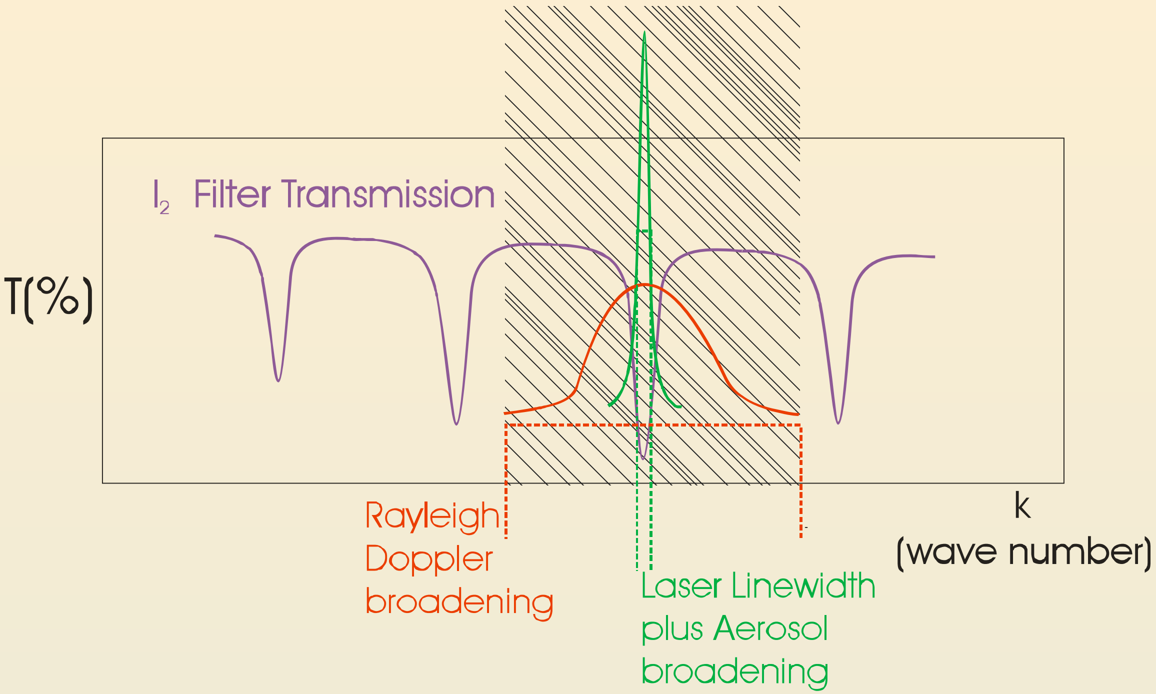
DOPPLER LIDAR OUTLINE



Outline of incoherent Doppler lidar system using iodine absorption filter.

In a Raman scattering lidar, the extinction coefficient of aerosol and cloud is measured by detecting the Raman backscatter signal from air molecules, assuming the height profiles of atmospheric density.
A density model can be assessed using standard atmospheric models with the measured ground temperature and pressure. However, a high-power laser is required for the accurate measurement of the optical parameters of aerosol and cloud. Typical HSRL Instrument in the Visible range

MOLECULAR IODINE FILTER



We see that the shaded area gives the wings of the molecular spectrum passing through the molecular filter while the aerosol signal is effectively absorbed

Alternative drawing

OPTICS LETTERS / Vol. 19, No. 3 / February 1, 1994 P. Piironen and E. W. Eloranta

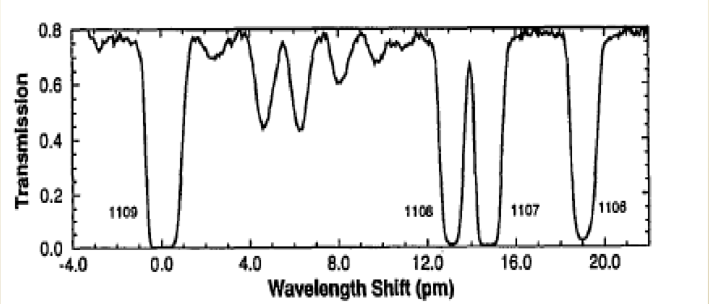
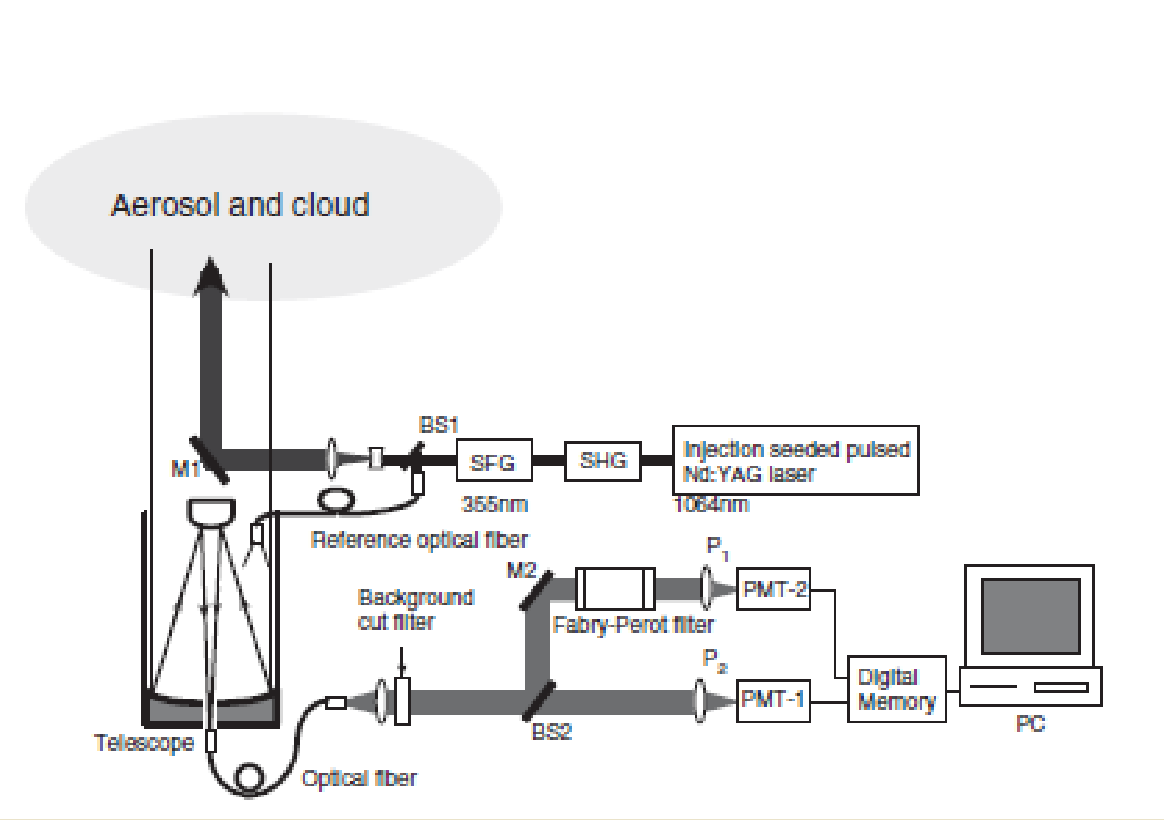


Fig. 2. Transmission of the 43-cm iodine cell as a function of wavelength shift. The identification line numbers are from Ref. 6.

SOME HISTORY OF HSRL

On the other hand, Piironen and Eloranta reported a high spectral-resolution lidar (HSRL) with a molecular absorption filter. The Rayleigh backscatter signal separated from the Mie backscatter signal is used to determine the extinction coefficient of aerosol and cloud. This system does not require an assumption about the relationship between the extinction and backscatter coefficients of aerosol and cloud. In this system, a high-accuracy measurement of the extinction coefficient of aerosol and cloud can be achieved by detecting the Rayleigh backscatter signal, which is three orders of magnitude larger than the Raman backscatter signal. An iodine absorption filter strongly rejects the Mie backscatter signal, making the separation between the Rayleigh and Mie backscatter signals easier at room temperature. For tuning the laser frequency to the iodine absorption line, a frequency-tunable Nd:YAG laser with 532-nm-wavelength second harmonics is necessary.
Using a Fabry–Perot interference filter (FPI filter), Shipley et al. and Trauger et al. have separated the signal received into the Rayleigh backscatter and Mie backscatter components However, the measurement accuracy of the extinction coefficient of aerosol and cloud is relatively low due to the low rejection rate of the Mie backscatter signal.

RECENT SUCCESSFUL OPERATION OF HSRL AT 355 nm



Ultraviolet High-Spectral-Resolution Lidar with Fabry–Perot Filter for Accurate Measurement of Extinction and Lidar Ratio

Schematics of Imaki et al system. We would like to develop a similar system. The most challenging item for us is the Injection seeded pulsed Nd:YAG laser Description of HSRL system parameters.

Masaharu IMAKI et al, Japanese Journal of Applied Physics, Vol. 44, No. 5A, 2005, pp. 3063–3067

RECENT SUCCESSFUL OPERATION OF HSRL AT 355 nm

Table I. System parameteres for transmitters and receivers.

Laser: Nd:YAG third harmonics	
Wavelength	355 nm
Energy per pulse	150 mJ
Pulse repetition frequency	20 Hz
Pulse width	10 ns
Spectral width	150 MHz
Optics:	
Telescope diameter	250 mm
Field of view	0.1 mrad
Fiber core dimeter	100 μm
Band width of background cut filter	1 nm
Transmittanc of background cut filter	0.60
Transmittanc of BS-1	0.98
Reflectance of BS-1	0.02
Transmittanc of BS-2	0.10
Reflectance of BS-2	0.90
Filter: Fabry–Perot interference filer	
Spectral width	300 MHz (0.13 pm)
Peak transmittance	0.4
Detector: Photomultiplier tubes	
Quantum efficienty (at 355 nm)	23%

Etalon corresponds to spacer distance around 8 cm

By operating only at nighttime we might need less powerful and smaller cost laser.

DISCUSSING THE ERRORS

Imaki 2005 **Discusses the errors in HSRL Resutls**

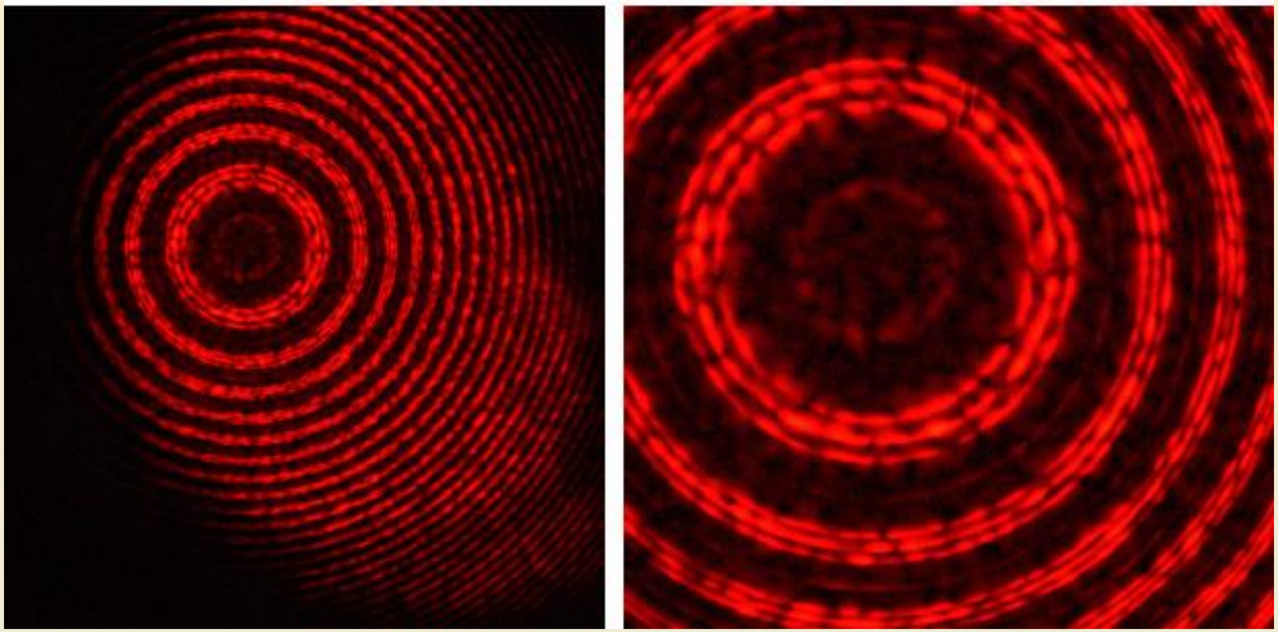
He finds accuracy in the extinction coefficient to be 1.3 x10^{-2} Km^{-1} at 3 Km height.
A large Value of LIAR ratio of 65 sr was observed below 3 km. Accuracy of this ratio at 3 km was 3 sr.
From this result, this system is useful for directly measuring absolute values of aerosol Optical properties without assuming specific scattering and extinction models, such as Klett or Fernand algorithms.
What is the error in RAMAN Method?

RECEIVER TELESCOPE IMPLEMENTATION AT NTUA

Mirror Characteristics

Type	Parabolic
Diameter	370 mm
Focal Length	1600 mm
Width	57 mm
Weight	~14 kg
General	Material BK7 Quality lambda/8 RMS Coating Al protected SiO2.

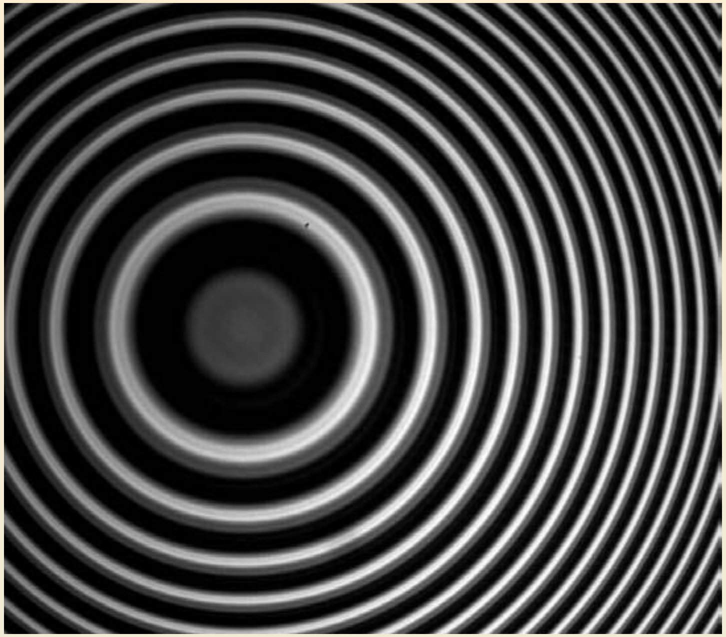
F-P CHARACTERIZATION (IN VISIBLE)

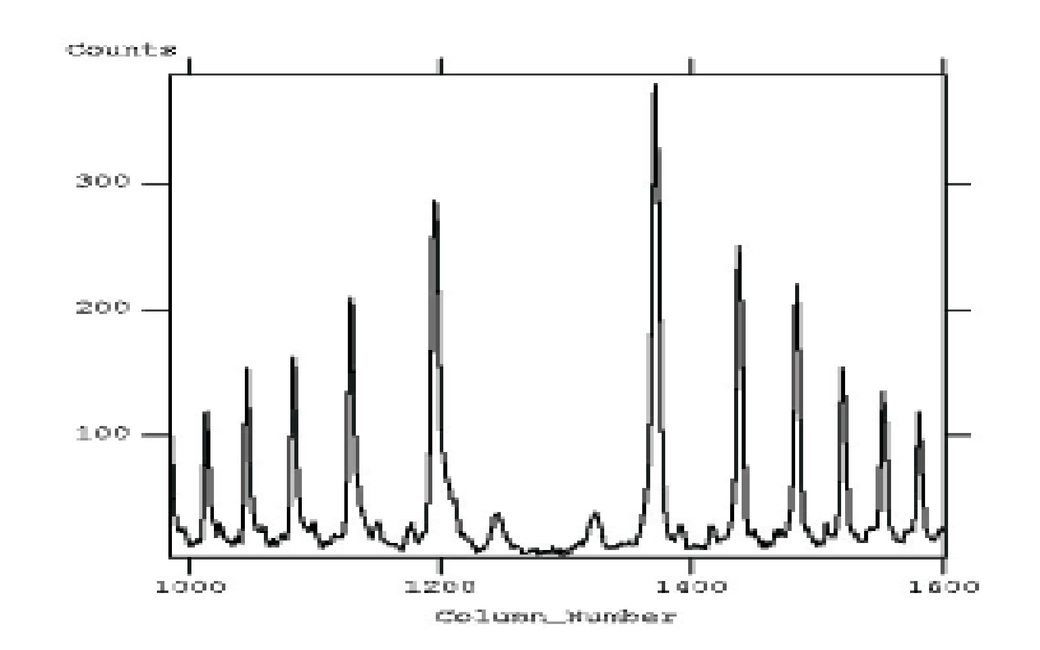


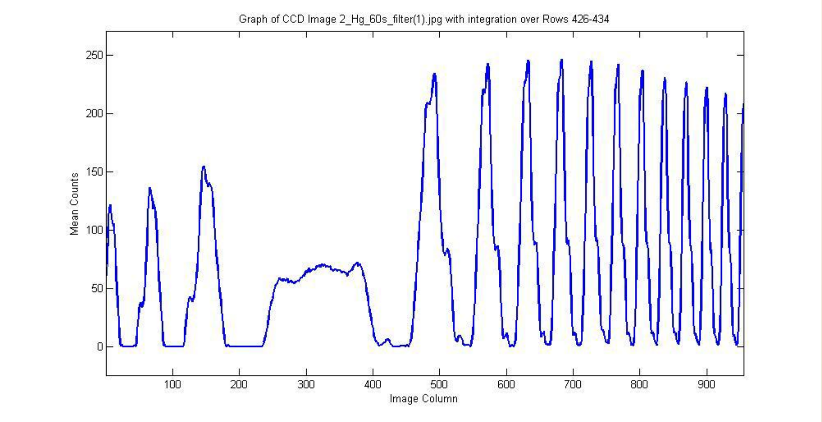
Preliminary lab results with He-Ne laser with several longitudinal modes analyzed by a 50 mm spacer etalon.

F-P CHARACTERIZATION (IN NEAR UV)

Characterization of 20 mm etalon





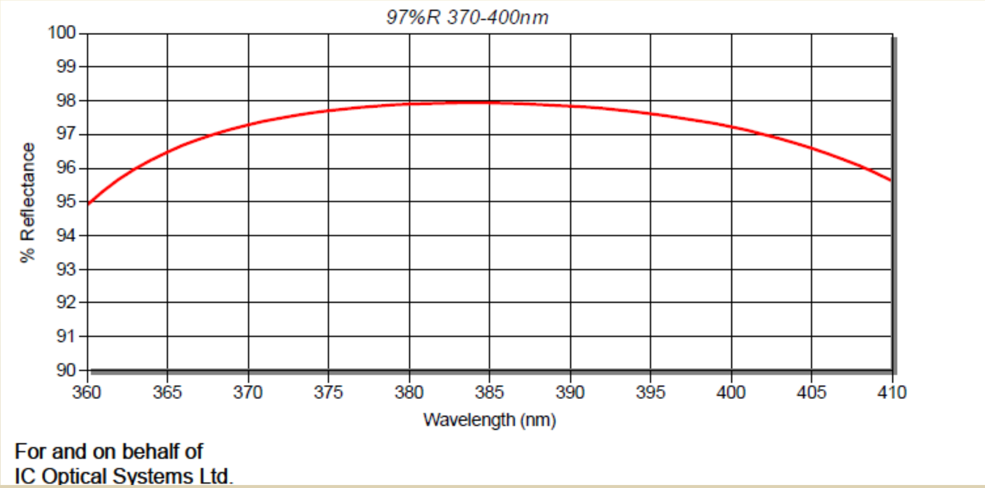


The interferogram obtained with SLM laser and 5 cm spacer thickness etalon used for determining the etalon finesse.

MIE CHANNEL F-P PROTOTYPE

- **The mount technique considered for the molecular UV channel is of the type of Hansen mount applied to the Dynamics Explorer etalon with 2 mm spacer thickness, while for the aerosol type we have followed the 10 cm hollow Zerodure cylinder spacer.**

- **The coating technique for the aerosol channel etalon plate pair has been selected to correspond to soft coating with proposed reflectance curve peaking at 380 nm (R= 98%), while at 355 nm R=92%.**

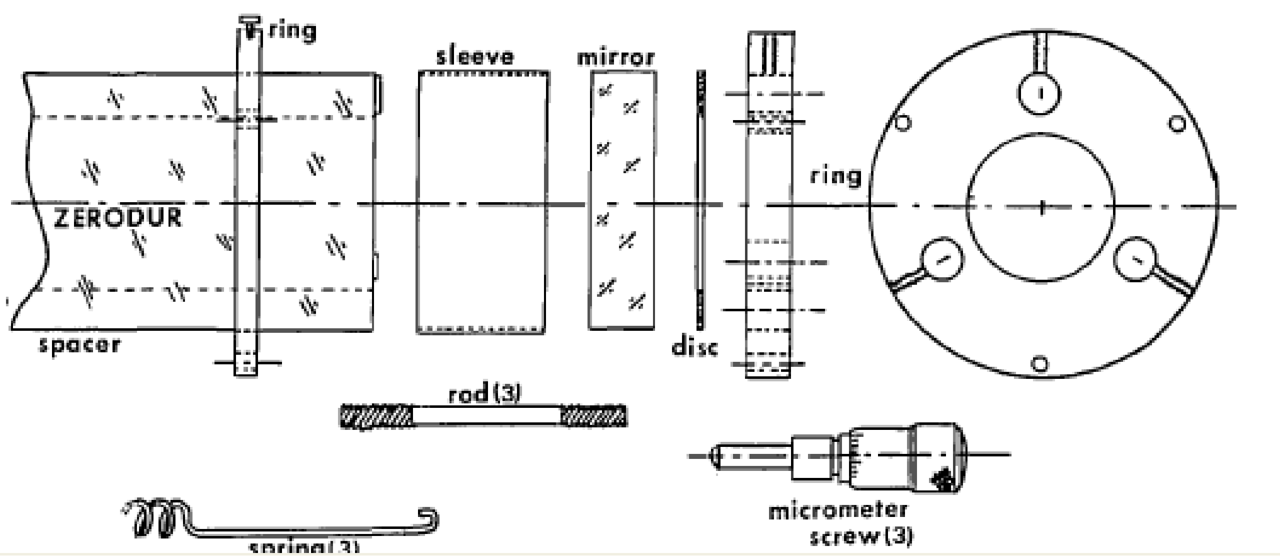


Our Mie channel etalon prototype without mounting

Method of aerosol channel etalon mounting

Fig. 1. Unmounted etalon plates and spacer.

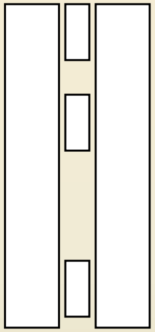
Fig. 3. Schem



M.Andersson eta lNovember 1987 / Vol. 26, No. 22 / APPLIED OPTICS

MOLECULAR CHANNEL DESIGN

For the molecular channel , we use an etalon with spacer length 2mm and diameter 70 cm. Etalon mirrors are available. Mounting type proposed is Hansen mount applied at Dynamic Explorer Fabry-Perot.



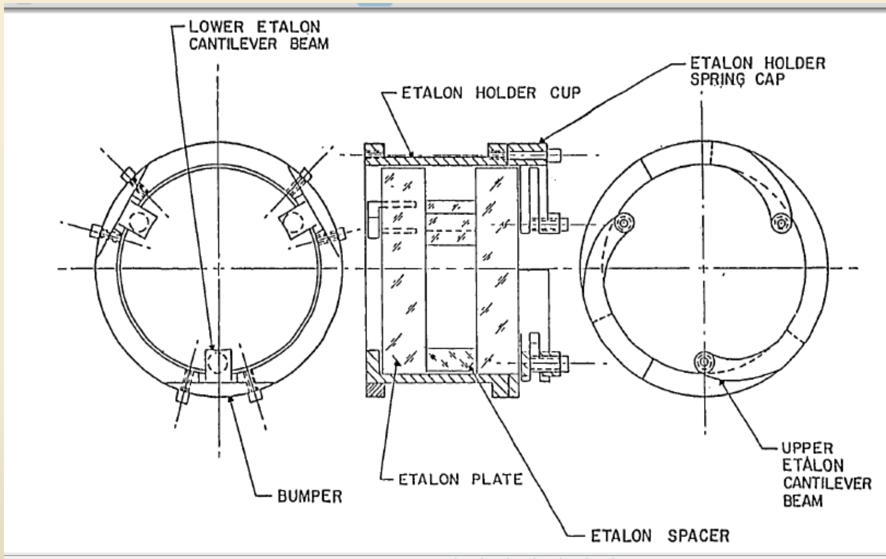


Fig. 6. Schematic of kinematic etalon mount.

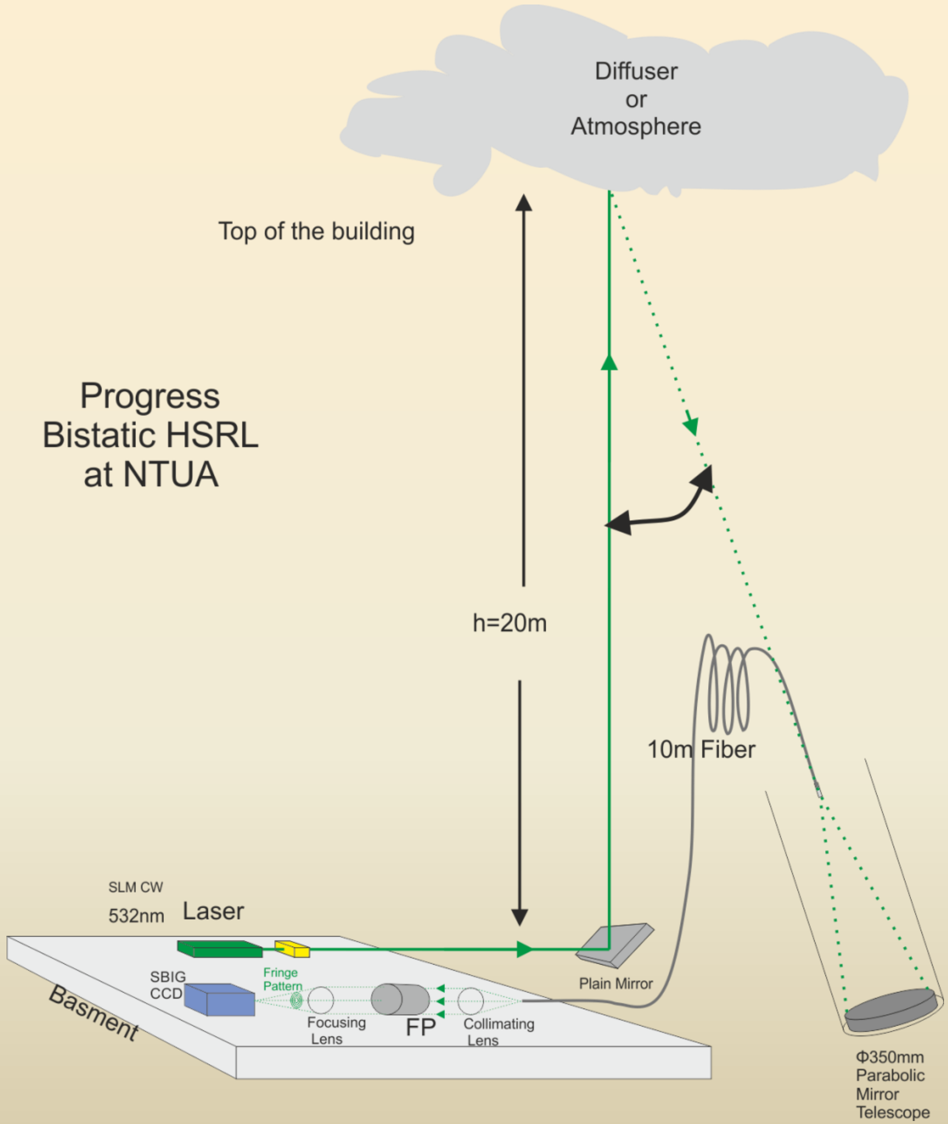
T. Killean et al, Appl. Opt. 21, 3903-3912 (1982)

NOVEL ETALON SPACER NON INVASIVE CHARACTERIZATION METHOD

A novel non-invasive complete method to determine the spacer thickness of an etalon was applied. A result for thickness was *d= 12.05361(4) mm*

Presented , 2010 at Siena Topical Conf. , IPRD2010, Maltezos et al

PLANNING OF TESTING HSRL AT 532 nm AT NTUA



PROPOSED PLAN FOR UV LASER-HSRL EMITTER

Planning to have a Laser source at 355 nm

Study of Raman LIDAR with a $Nd:YVO_4$ solid state laser as alternative to Nd:YAG pulsed laser. We have purchased a CW $Nd:YVO_4$ at 400 mW at 1064 nm, and by non-linear optics plus laser amplifier there will be a prototype pulsed laser source at 355 nm. We are studying the possibility, by using Raman cells, to achieve radiations at higher wavelengths. The laser of 1064 nm (around 400 m coherence length) has already arrived. It may be used in a MOPA system .

CONCLUSIONS AND PROSPECTS

- A HSRL prototype receiver is under development in NTUA.
- Performance tests of Fabry-Perot etalon receivers have been done in Visible and near UV showing their resolving capability.
- A complete non-invasive method to measure the F-P etalon spacers with the highest possible precision was established.
- A Raman lidar of Laser Group at NTUA can be used for evaluation tests.
- The development and assembly of a pulsed coherent SLM laser system at 355 nm with discrete tunability in UV region is on the way.
- We are searching for commercial vendors of laser amplifiers for visible and UV region for SLM Operation. Cooperation with research University groups is very welcome.

Capability of HSRL in measuring vertical temperature profile

Iodine-filter-based high spectral resolution lidar for atmospheric temperature measurements

Zhi-Shen Liu,[1] De-Cang Bi,[1,*] Xiao-quan Song,[1] Jin-Bao Xia,[1] Rong-zhong Li,[1] Zhang-jun Wang,[1] and Chiao-Yao She[2]

[1]*Key Laboratory of Ocean Remote Sensing, Ministry of Education of China, Ocean University of China, 5 Yushan Road, Qingdao 266003, China*

[2]*Department of Physics, Colorado State University, Fort Collins, Colorado 80523-1785, USA*

**Corresponding author: bidecang@gmail.com*

Received May 14, 2009; revised July 23, 2009; accepted July 27, 2009; posted August 10, 2009 (Doc. ID 111315); published September 4, 2009

This paper presents a method for measuring atmosphere temperature profile using a single iodine filter as frequency discriminator. This high spectral resolution lidar (HSRL) is a system reconfigured with the transmitter of a mobile Doppler wind lidar and with a receiving subsystem redesigned to pass the backscattering optical signal through the iodine cell twice to filter out the aerosol scattering signal and to allow analysis of the molecular scattering spectrum, thus measuring temperatures. We report what are believed to be the first results of vertical temperature profiling from the ground to 16 km altitude by this lidar system (power–

Internet

Overview of possible schemes in our range of interest

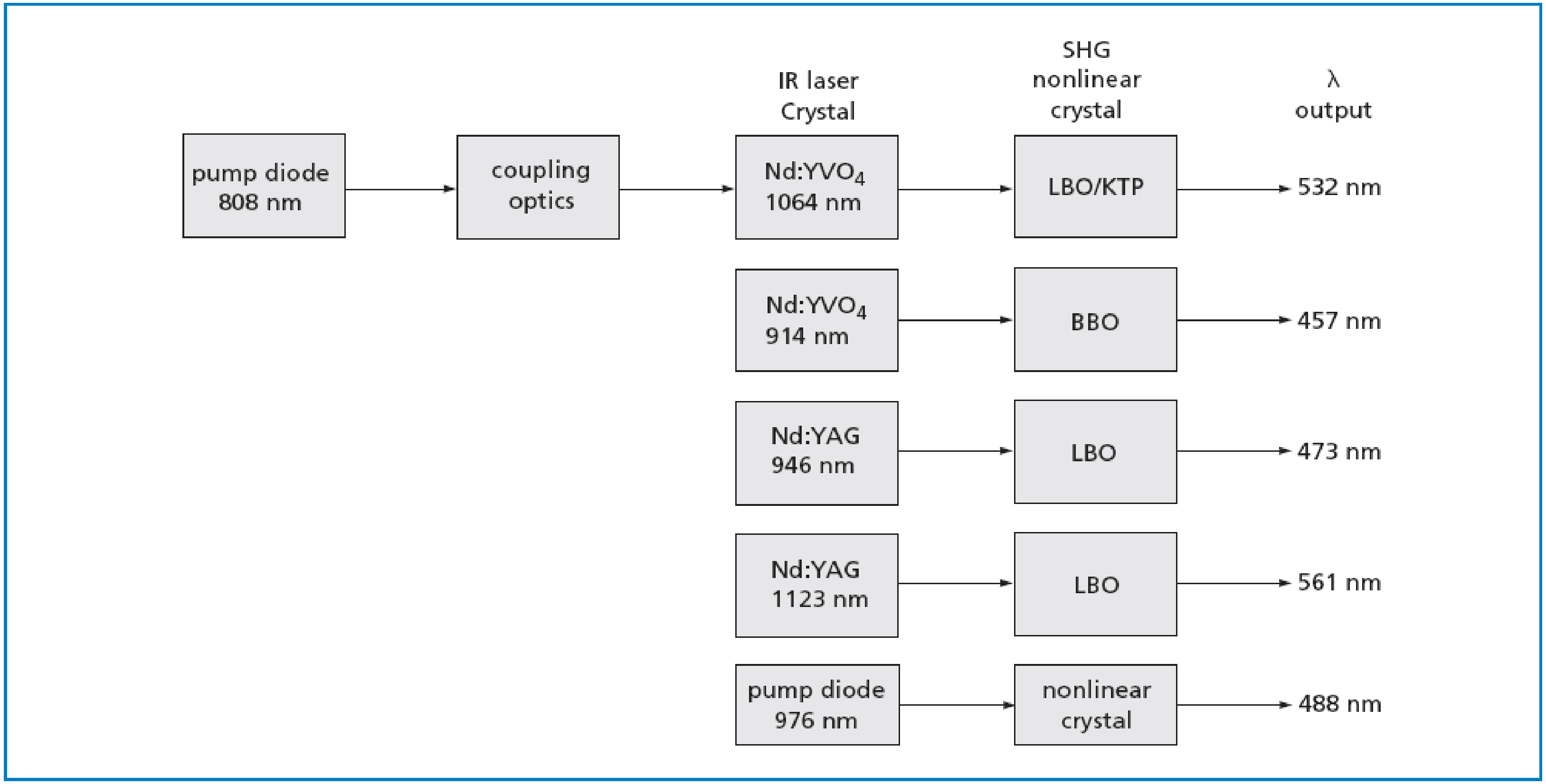


Figure 10.29 CVI Melles Griot solid-state laser optical trains for producing five different visible output wavelengths

This scheme indicates wavelength 457 nm could be an acceptable candidate according to comments on page 4 in our presentation