

Lasers for Multiwavelength Satellite Laser Ranging

Karel Hamal, Josef Blazej, Ivan Prochazka
Czech Technical University, Brehova7,11519 Prague1, Czech Republic,
Voice: +420 221912246; Fax: +420 221912252; prochazk@mbox.cesnet.cz.

Yang Fumin, Hu Jingfu,
Shanghai Observatory, Chinese Academy of Science, 80 Nandan Road, Shanghai 200030, China

Jean Gaignebet
OCA/CERGA, Avenue Copernic, 06130 Grasse, France

Assuming the atmospheric dispersion, to find the right laser for multiple wavelength millimeter SLR, one can consider the Nd:YAG / SHG / THG, Nd:YAG / SHG / Raman in Hydrogene/1S/1aS [1], Raman in Methane /1S and the Titanium Sapphire fundamental / SHG, all of them at different repetition rates. The available detectors have to be considered. For the visible range we did examine Silicon [2], GaAs, GaAsP and GaP based SPADs, for the eyesafe SLR Germanium [3], GeSi and InGaAs based SPADs. Using the Quantel Laser 30 mJ / 1,06 μ m, 35 psec, different Raman tubes filled by Hydrogen at different pressure, different focusing lens, we were getting 8 mJ / 0.68 μ m, 1 mJ / 0.45 μ m [4]. Considering the eyesafe SLR using Methane we were getting 3 mJ / 1.54 μ m [5].

Our optimization of the four wavelengths Raman laser at 1.064, 0.53, 0.68 and 0.45 μ m gives 60, 20, 7, 2 mJ at 20 Hz for 35 psec pulses. The laser is dedicated for the new Shanghai SLR station.

Using Raman, one has to be cautious at higher pumping levels. Either to monitor the far field beam structure (CCD) or pulse structure (streak) might be a proper diagnostics.

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References:

1. J.Gaignebet, J.L.Hatat, K.Hamal, I.Procházka, H.Jelínková, *Two wavelength ranging on ground target using Nd YAG 2HG+Raman 0.68um pulses*, The Sixth International Workshop on Laser Ranging Instrumentation, Juan les Pins, Sept.1986
2. G.Kirchner, F.Koidl, J.Bla_ej, K.Hamal, I.Procházka, *Time Walk Compensated SPAD: Multiple Photon Versus Single Photon Operation*, Proceedings of the European Symposium on Aerospace Remote Sensing, published in **SPIE 3218-07**, (1997)
3. I.Procházka, K.Hamal, H.Kunimori, B.Greene, *Large aperture Germanium detector for picosecond photon counting in the 0.5 to 1.6 um range*, **Optics Letters**, Vol.21 (17), September 1, (1996), page 1375-1377
4. Karel Hamal, Josef Blazej, Ivan Procházka, Fu Min Yang, Jingfu Hu, *Raman laser for multiple wavelength satellite laser ranging*, presented at the conference Photonics, Prague, June 2002
5. B.Greene, H.Kunimori, K.Hamal, I.Procházka, *Atmospheric dispersion monitoring using 0.53 um and 1.54 um satellite laser ranging*, Technical Digest Cleo/Europe '96, Optical Soc.of America, IEEE Catalog Number 96TH8161, page 221, (1996)



13th Satellite Laser Ranging

Karel Hamal¹, Josef Blazej¹, Ivan Prochazka¹,
Yang FuMin², Jingfu Hu², Jean Gaignebet³

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¹ Czech Technical University in Prague, Czech Republic

² Shanghai Astronomical Observatory, Chinese Academy of
Sciences, People Republic of China

³ Observatoire de la Cote d'Azur, Grasse, France



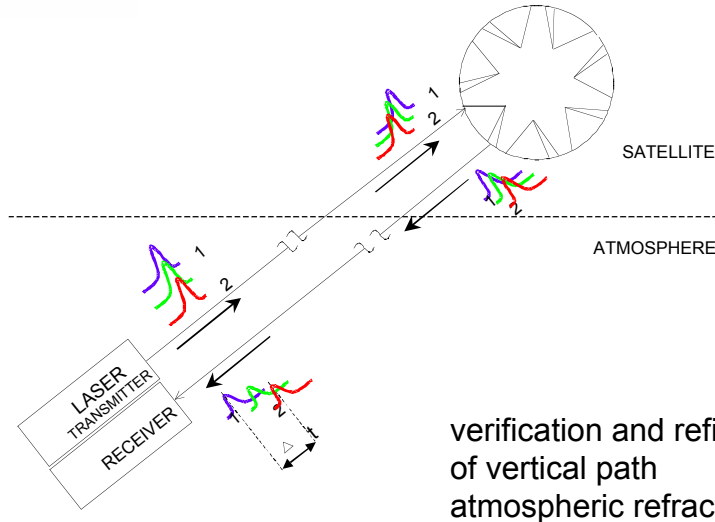
Requirements for Multiwavelength Satellite Laser Ranging

Goals

- MILLIMETER PRECISION ranging
atmospheric studies
- WORLD NETWORK
Prague, Graz, Shanghai, Tokyo, FP6
- LASER REQUIREMENTS
pulse length < 50 psec
energy > 1 mJ , CLEAN TEM 00
multi wavelength, ~ 1 psec time synchro.
- LASER CANDIDATES
Ti-Sapphire + SHG
Nd YAG + SHG + Raman in gas

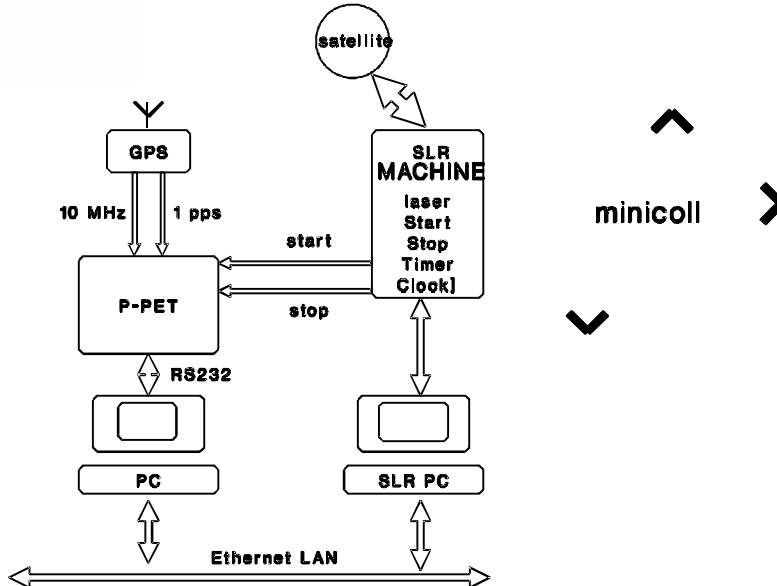
Satellite Laser Ranging

Why multiple wavelengths?



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Portable Calibration Standard Block Scheme



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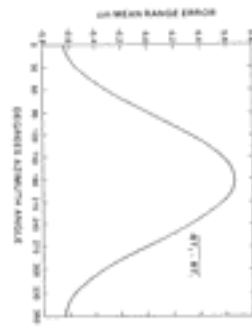


Fig. 1. Estimated atmosphere modeling error in 70° elevation angle. $R1-R2$ is the range correction calculated assuming a spherically symmetric atmosphere profile, and $R1$ is the range error correction calculated by a 2-D atmosphere profile.

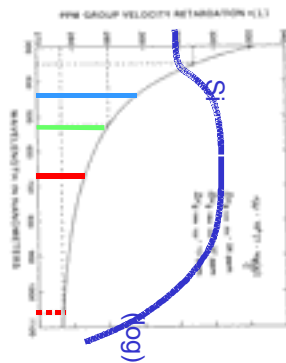


Fig. 2. Normalized group velocity retardation of light in standard air as a function of wavelength. Labeled lines represent the three wavelengths from a frequency triplet Nd:YAG laser.

In from 13 to 27 ppm depending upon which wavelength pair is chosen. Two system architectures to correct for atmospheric delay were first proposed by Bender and Thomas. Two color laser ranging systems using cw lasers have been in existence for over 10 years. These systems determine the differential propagation delay between the two optical colors by indirect means. Such systems have typical range limits of 10-20 km, which are determined by the atmospheric laser power and moderator efficiency. The systems also require 1-10 sec of pulse ranging to obtain time delays. The use of such systems for operating over fields of slowly changing

paths. Both these factors eliminate the use of such systems for satellite laser ranging, where the distance range from 100 to 6000 km, and the target is in sight most of the time. Pulsed multiwavelength ranging systems do not have these constraints. Short pulsed lasers are commercially available with sufficient output power to compensate for atmospheric delay. However, the receiver system must time the differential pulse arrivals with picosecond accuracy to make the atmospheric correction to the centimeter level. The next section reviews progress in developing such a pulsed system.

IV. System Design

Figure 3 shows the one-way propagation time delay for atmospheric transmission of a pulse pair in an attempt to select an atmospheric path. For example, at 70° zenith angle, the one-way propagation time difference would range from 1.2 to 2.3 nsec depending upon the particular wavelength pair chosen.

Since the uncorrected path delay for 632 nm radiation at 70° zenith angle is 7.8 ns, and the ranging goal is 1 cm, the multicolor receiver must measure the atmospheric delay to better than 1 part in 780. The expected separation times are from 1.2 to 2.3 nsec depending upon which wavelength pair is chosen. Therefore, the multicolor system must time the difference to 1 part in 780 or to between 3 and 9 psec. The initial system design goal is to build a system to meet these requirements either by a single measurement or by using data averaging.

Several receiver technologies are being investigated to achieve the required timing accuracy. Conventional

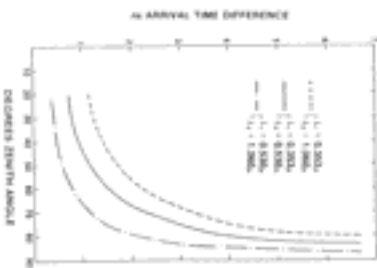


Fig. 3. Estimated atmospheric delay time for a one-way slant range in zenith angle for the three possible pulse pairs.

ers for Multiwavelength Satellite Laser Ranging

Group Atmospheric Refractivity vs. λ

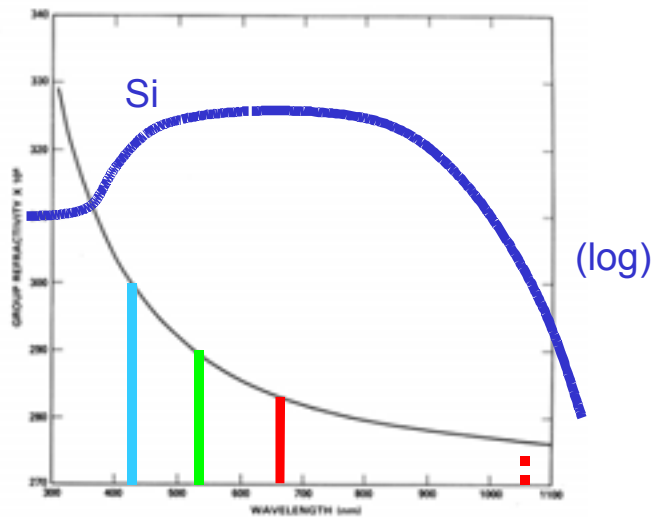
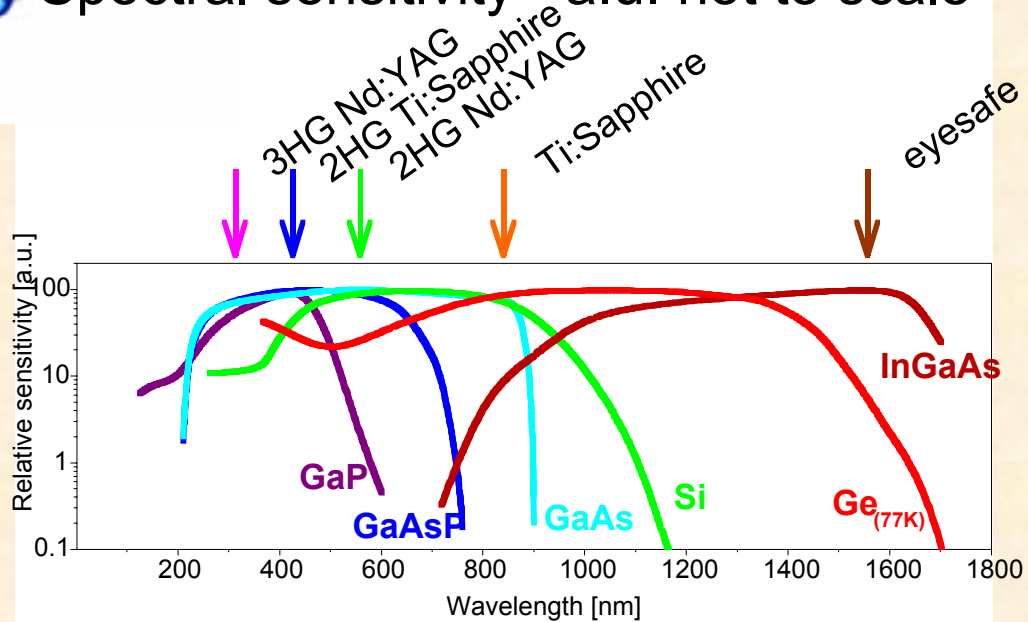


Fig. 2. Group refractivity of air at $P = 1013.25$ mbar, $T = 15^\circ\text{C}$, and $\text{RH} = 50$ percent.



Spectral sensitivity - a.u. not to scale



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Raman laser history

- J.Gaignebet, K.Hamal, I.Prochazka, J.L.Hatat
ground target ranging, Prague
green, red
Workshop Antibes, 1986
- K.Hamal, I.Prochazka, G.Kirchner, F.Koidl
satellite, ground ranging, Graz
green, red, blue
IQEC, Vienna, 1992
- H.Kunimori, B.Greene, J.Guilfoyle, K.Hamal, I.Prochazka
satellite, ground ranging, Tokyo
infrared eye safe, green
CLEO Europe, Hamburg, 1996

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Multiple wavelengths pair candidates

- Titanium Sapphire – fund. / SHG, 846 nm / 423 nm
(Germany, Swiss)
 - + high atmosphere transmission and dispersion
 - laser complexity (oscillator)
- Nd:YAG + Raman in CH₄ / SHG, 1543 nm / 532 nm
(Japan)
 - + eye-safe 1543 nm
 - Germanium, InGaAs detectors
 - to be optimized (Prague, Tokyo)
- Nd:YAG SHG + Raman in H₂, 532 nm / 680 nm / 436 nm
 - + Si detector optimum
 - to be optimized (Prague, Graz, Shanghai)

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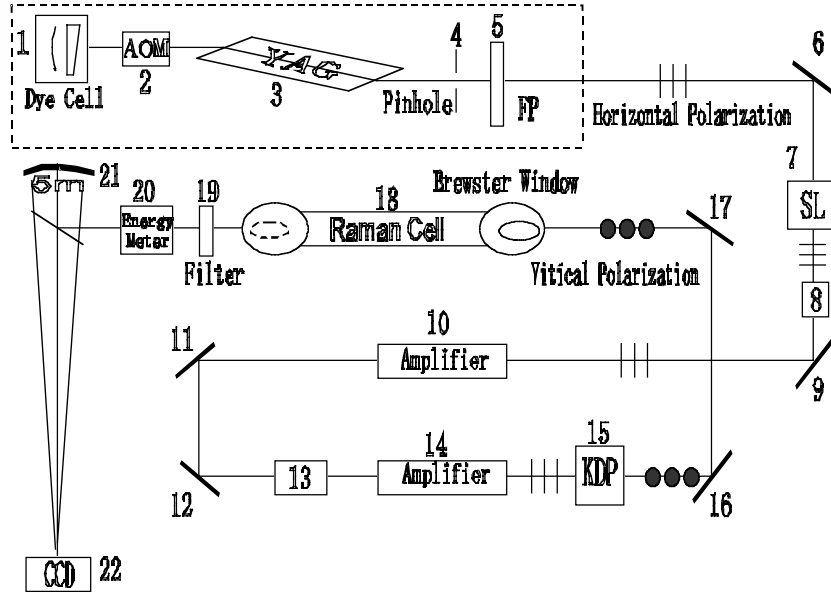
Budget Link

$$\varepsilon = \eta^2 f Q \left(\frac{nd^2}{R^2 \Phi^2} \right) \left(\frac{D^2}{R^2 \phi^2} \right)$$

- ε - link efficiency
- Φ - atmospheric divergence
- ϕ - corner cube divergence
- D - diameter of the collecting telescope
- d - diameter of the n corner cubes in array
- R - distance to the satellite
- η - telescope/atmospheric transmission efficiency
- f - receiver throughput
- Q - detector efficiency

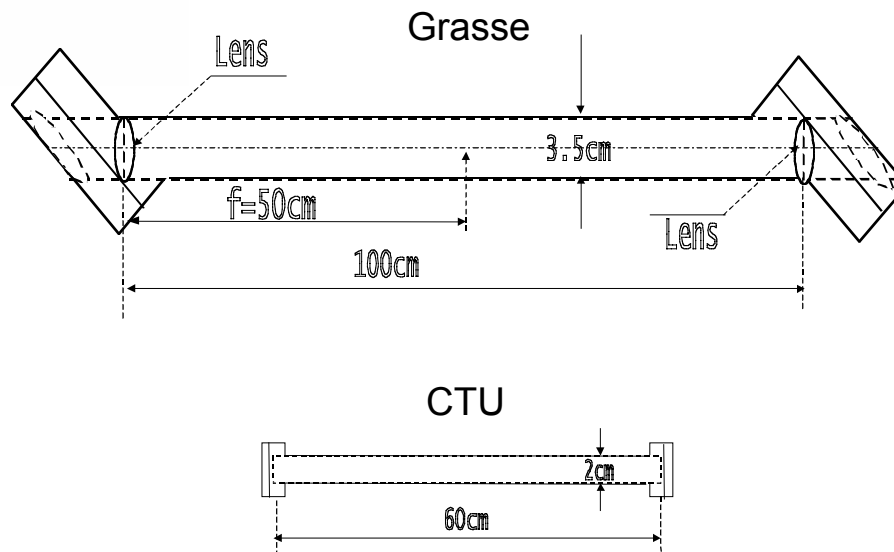
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Block Scheme



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Raman Tubes

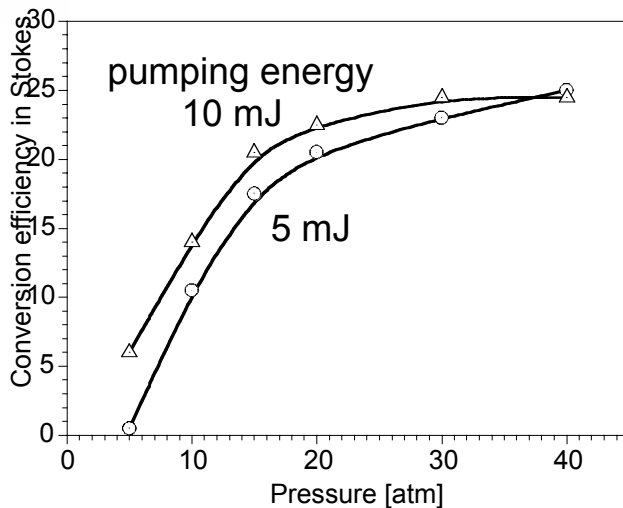


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Conversion Efficiency vs. Pressure

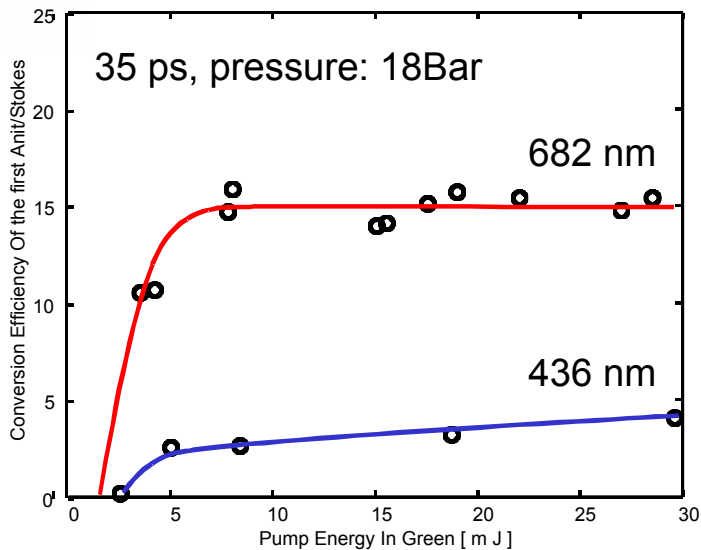
680 nm



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Conversion Efficiency vs. Pump



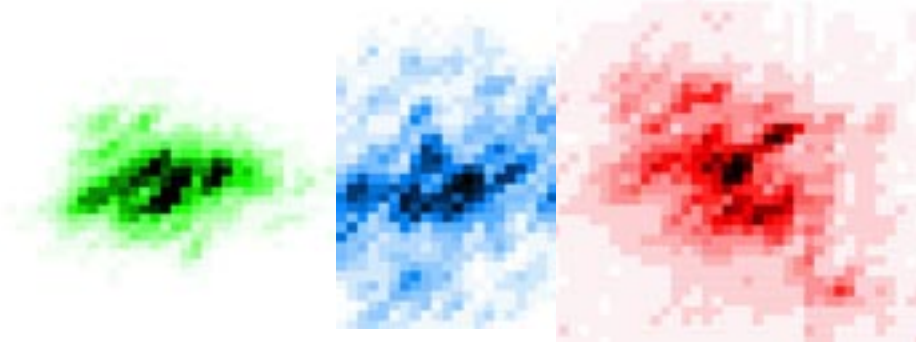
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Raman Stokes far field beam structure

532 nm

35 ps, 30 Bar
436 nm

680 nm

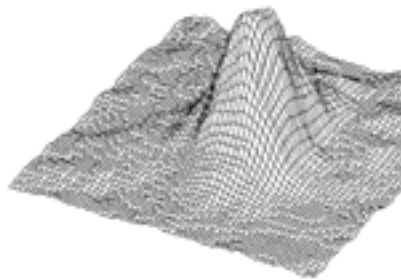


10 mJ

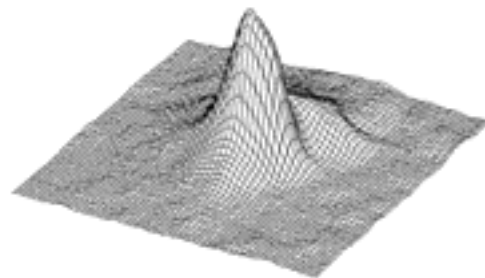
2.5 mJ

0.4 mJ

Raman Stokes far field beam structure



1064 nm



1540 nm

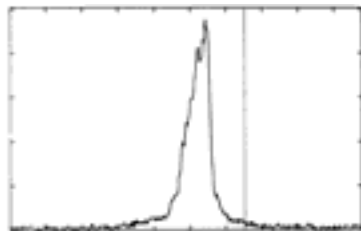


Raman Stokes temporal profiles

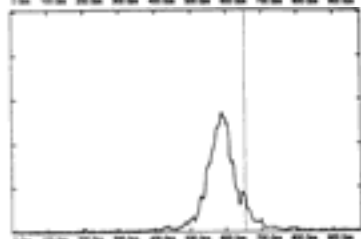
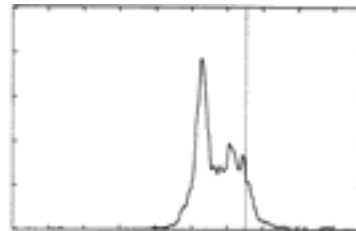
1064 nm shifted in methane, 1ns/screen

near above threshold

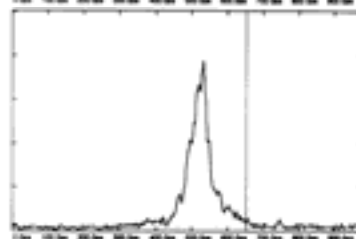
high above threshold



1064 nm
depleted



1540 nm



Kunimori et al, Tokio, 1996

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Conclusion

- Raman Stokes and AntiStokes generation in methane and hydrogen has been investigated
- for SLR application the Raman generator must be operated just above the threshold to preserve the spatial and temporal structure required
- the SLR applicable conversion efficiency is 5÷10%
- Raman conversion optimized in a range 35÷200 psec pump laser pulse length

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