Ideas of new technological developments for future French SLR stations

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OCA – GéoAzur
Astrogéo – France

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Context in 2014

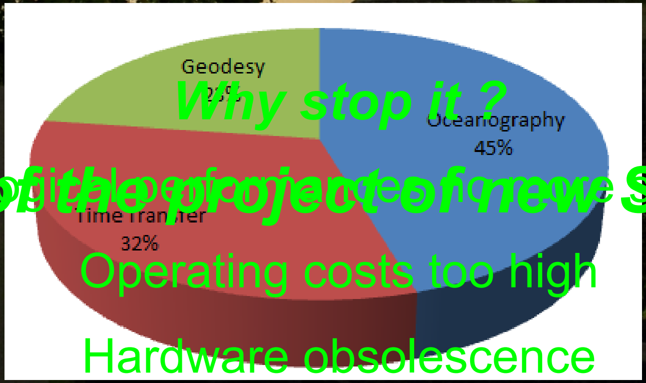
Shutdown of the French Transportable Laser Ranging Station

Funded by the CNES-IGN-CNRS for the calibration of TOPEX-Poséidon

In operation between 1997 – 2013

10 campaigns all over the world

More than 1000 passes / campaign



Why stop it ?

Metrological performances no more sufficient

Operating costs too high

Hardware obsolescence

Startup of the project of new SLR station

A new station: What should be improved ?

Oceanography **Geodesy** **Time Transfer**

1. Improve the satellite tracking at high elevation

   Solution to the key-hole of Alt-Az mount

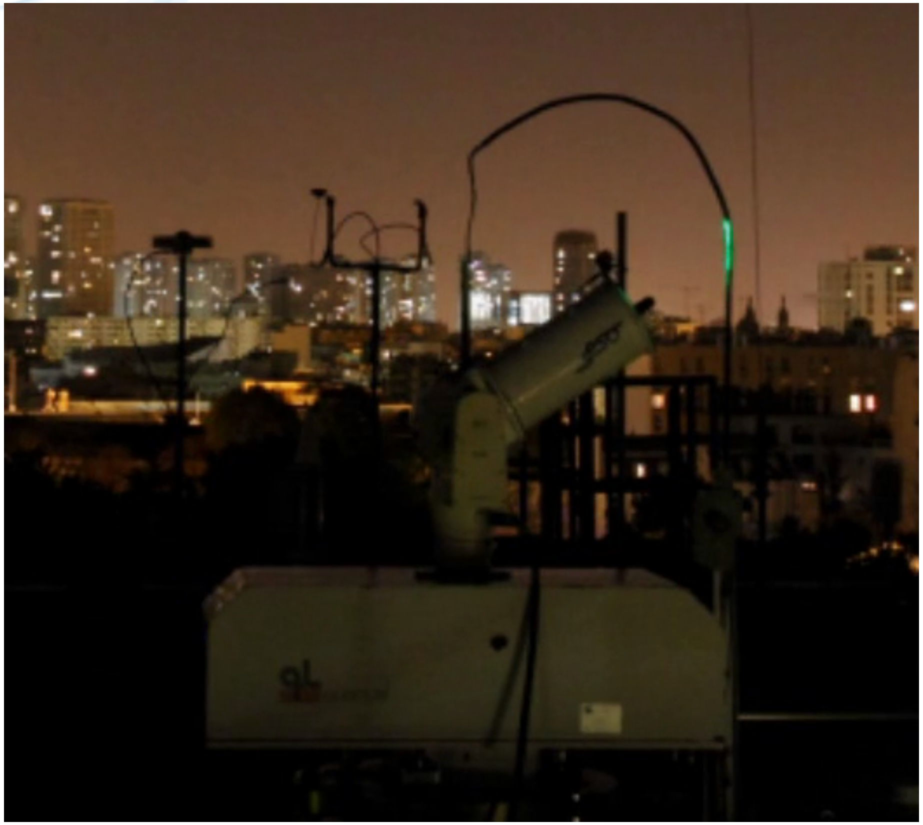
2. Automate and ensure the sky safety

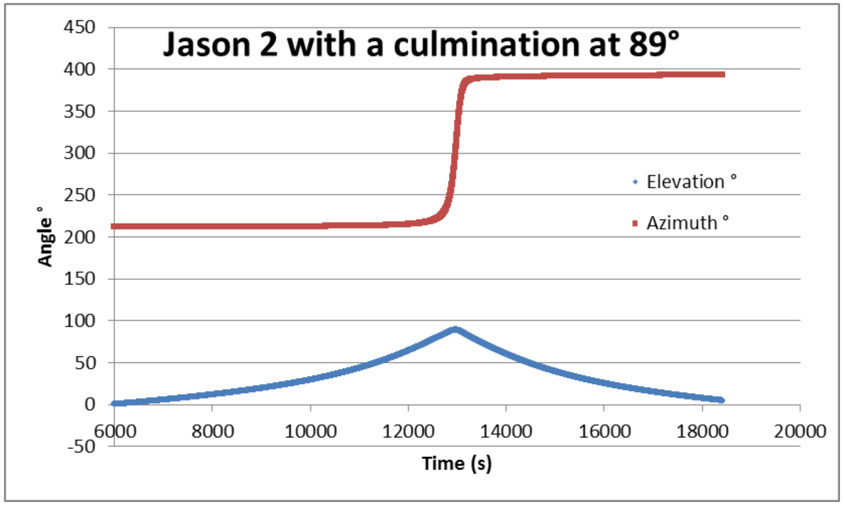
   Solution to replace the human monitoring by an image processing software

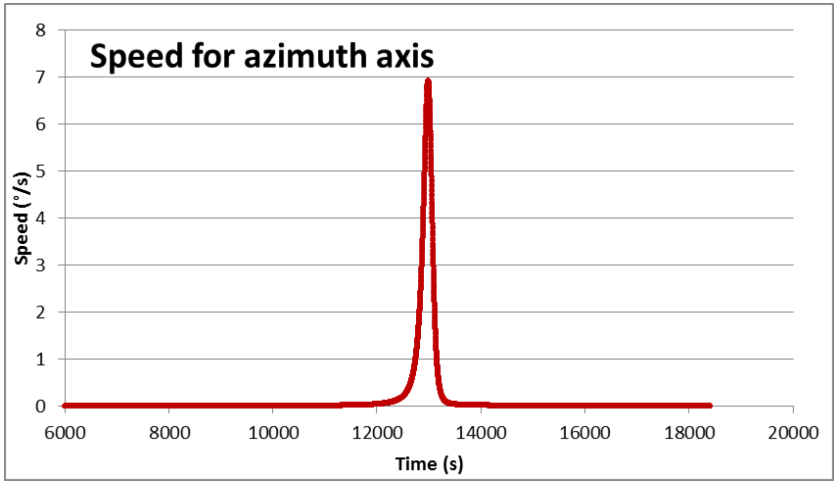
3. Improve the metrological performances

   Try to obtain the millimetric accuracy

Improve the satellite tracking at high elevation







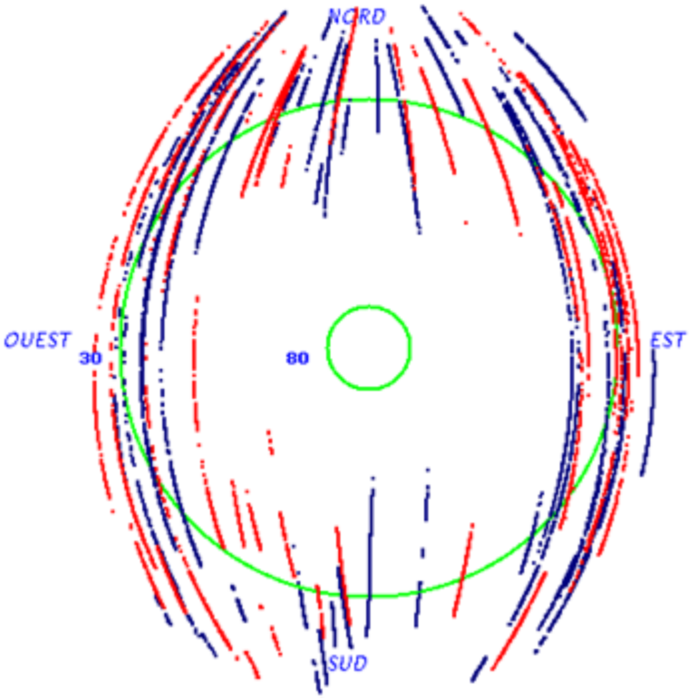
⇨ Key-hole of Alt-Az mount

Improve the satellite tracking at high elevation

- Key-hole of Alt-Az mount

- Lack of data above 80° of elevation angle ….

  Despite observations at high elevation is a highlight of SLR technique



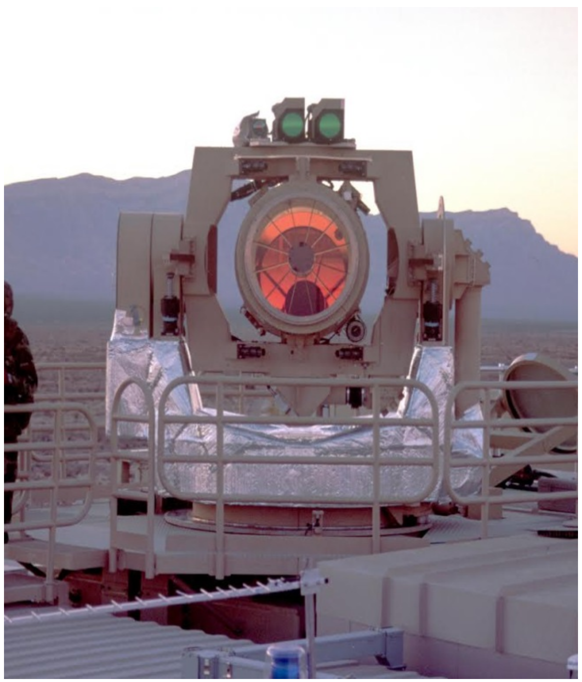
Observations of GRACE A & B with MéO

Satellite	Altitude (km)	Max elevation angle for max tracking speed of 5°/s (°)
Jason 2	1336	85.8
Saral	814	83.7
TandemX	514	80.6

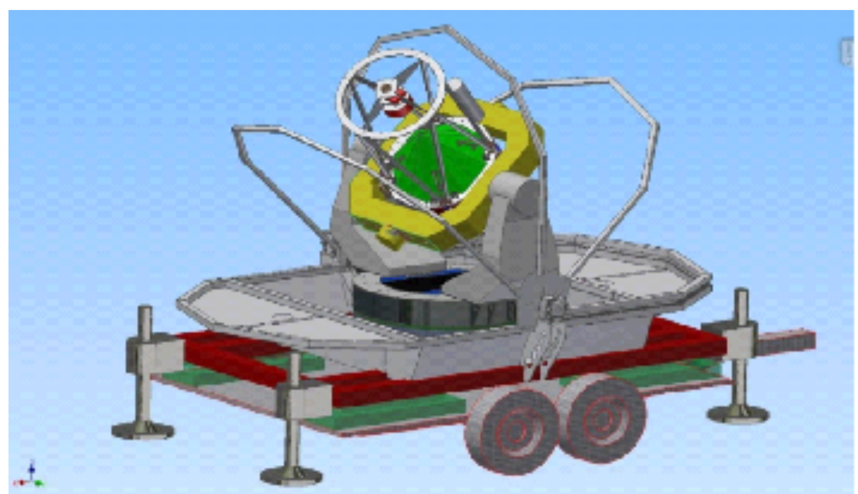
Improve the satellite tracking at high elevation

To track all satellites whatever their culmination:
3 axis mount Alt-Alt-Az

- Alt-Az for low culmination
- -Alt-Alt for high culmination



Example of industrial solutions

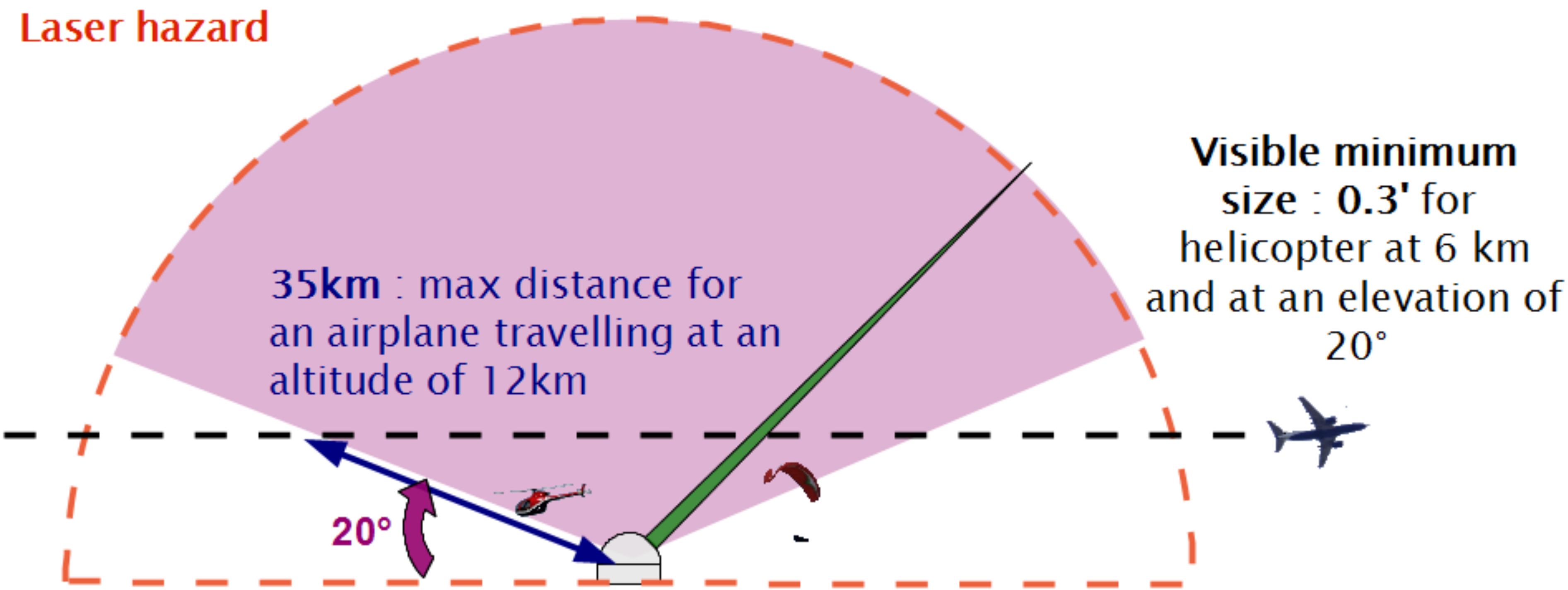


Automate and ensure the sky safety

Current techniques:

- Radar ADS-B for aircraft equipped with transponder
- Human monitoring for other objects (helicopter, small airplane, glider)

⇨ We have to develop a software able to replace the human monitoring



Automate and ensure the sky safety

First tests with a camera on the telescope:

- Field of view = 7°
- Resolution = 1920 X 1080
- 10 pixels for 1.8'
- Max speed of the object detected 1.75°/s

The software (Works of J. Combier):

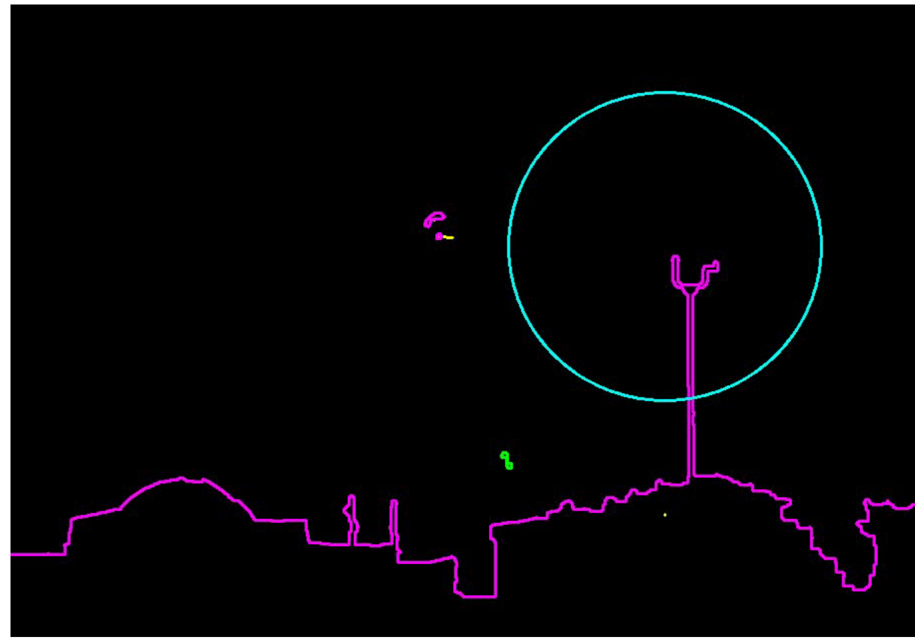
- C++
- Combine shape and color detection

Different skies possible during a day:

Automate and ensure the sky safety

First test on a blue sky

Works well !



Second test with clouds

Helicopter detected !!

But pieces of cloud are also detected and generates some false alarms and slow the processing.

Improve the metrological performances

- Currently:
  - One-color measurement + ground measurement of meteorological parameters:
    - Error in the measurements of the meteorological parameters (± 0,1 mb, ± 0,5°C, ±5-10% d'HR)
    - Difference between real and modeled vertical profiles
    - Transverse gradients not taking into account
    - Local and seasonal effects

⇨ **<u>Accuracy > cm</u>**

Improve the metrological performances

- Two-colors measurement + water vapor radiometer

$$2D = R1 + v(R1 - R2) + (vP_{21} - \kappa_{1}) + H_{21}\,SIWV$$

*P*21 represents the propagation corrections from the ray path *p*2 to *p*1
κ1 is the arc-to-chord correction for the ray path *p*1 which accounts for the curvature effect
v the power of dispersion
*H*21 the water vapor factor
SIWV the slant integrated water vapor

Millimeter accuracy possible with a significant precision improvement

Precision to reach at each wavelength

λ_1/λ_2 (μm)	$\sigma_{\mathcal{R}_1}$ (μm)	$\sigma_{\mathcal{R}_2}$ (μm)	σ_v (−)	σ_{κ_1} (mm)	$\sigma_{P_{21}}$ (μm)	$\sigma_{H_{21}}$ ($m^3 kg^{-1}$)	σ_{SIWV} ($kg\ m^{-2}$)
0.532/1.0684	47.16	45.03	6.61×10^{-4}	1	45.03	2.89×10^{-6}	7.4017
0.4235/0.847	76.60	71.15	3.80×10^{-4}	1	71.15	3.05×10^{-6}	7.5444

From D. D. Wijaya et al., Springer Verlag, 2011

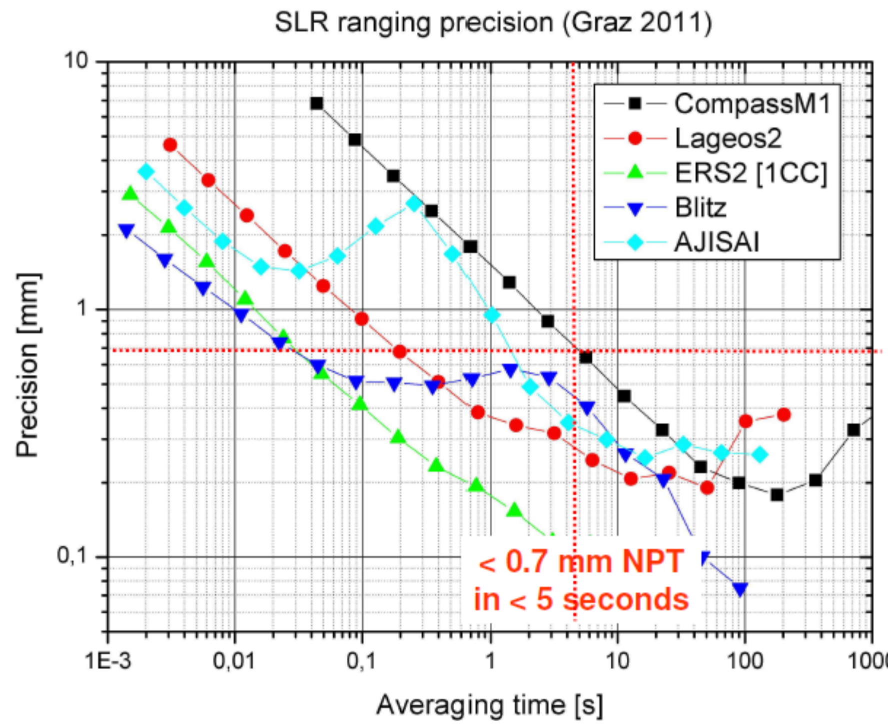
Improve the metrological performances

- Precision of the Graz laser station (kHz repetition rate)

[I. Prochazka, 17th ILRS Workshop, 2011]

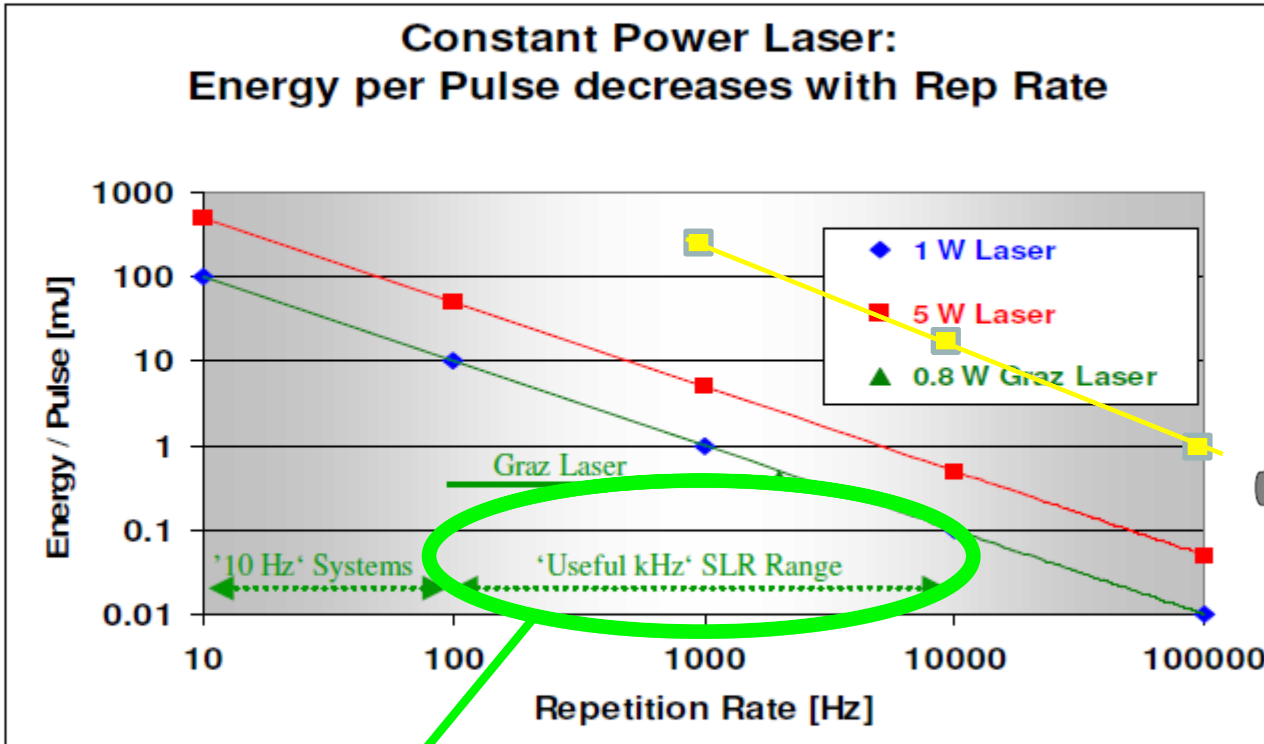
< 0.7 mm precision ~<5 secondes for all satellites

⇨ To obtain mm accuracy, we have to:
- improve the precision by a 10 factor which requires to increase the measurement rate by 100
- be able to realize the measurements at two wavelengths

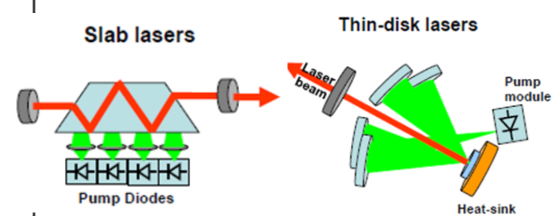


Improve the metrological performances

[G. Kirchner, 17th ILRS Workshop, 2011]



[T. Metzeger et al., Optics letters, Vol. 34, No. 14, 2009]
[C. Yuriko Teisset et al., Advanced Solid-State Lasers Congress, OSA 2013]
[M. Schulz et al., optics Letters, Vol. 36, No 13, 2011]



1 mJ/pulse laser @ 100 kHz repetition rate is now possible

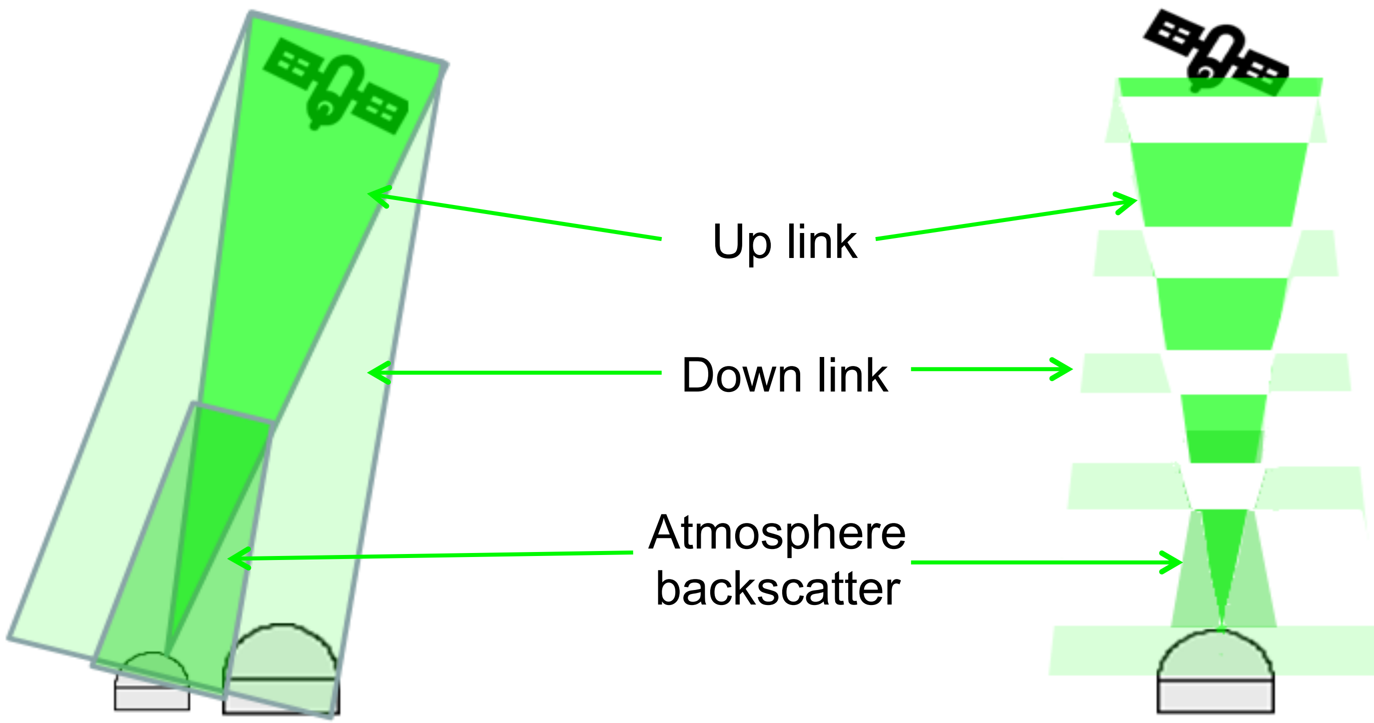
Above 10 kHz, overlap between receive/transmit pulses due to atmosphere backscatter

Improve the metrological performances

Solutions to use laser with repetition rate of 100 kHz

use 2 telescopes separated by ~tens of meter: one for transmit, one for receive

Work in burst mode:
modulate the output to generate pulse trains @ repetition rate of 2 kHz



Status & Future

1. Improve the satellite tracking at high elevation

   No key-hole problem with three axis mount.

   Future: Quantify the contribution of more data acquired at high elevation on the network

2. Automate and ensure the sky safety

   First tests on shape detection are encouraging for gliders or small ariplane.

   Future: optimization of the software and combine with ADS-B radar

3. Improve the metrological performances

   New high speed lasers give possibility to work at higher repetition rate

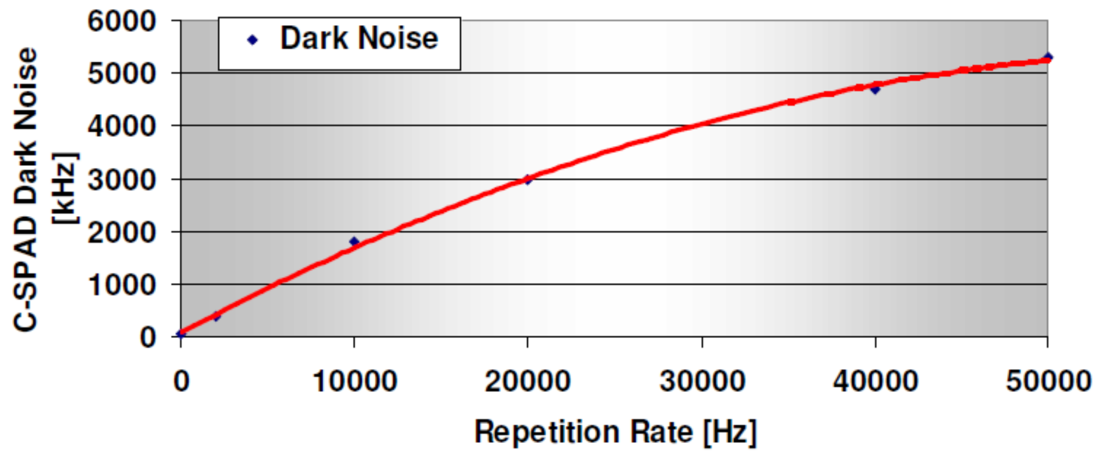
   Future: works on high speed single-photon detection.for green and IR

Improve the metrological performances

- Detection at high repetition rate for green
  - Gated Hamamatsu MCP-PMT R5916U-50
    - Repetition rate of 100 kHz with gate width max of 100 ns
    - Quantum efficiency < 10% @532 nm
    - Timing jitter ~ 100 ps FWHM
  - SPAD

Noise of C-SPAD may be reduce with shorter gate width and electronics able to stop as soon as possible the avalanche to keep off the SPAD and to release carriers trapped in deep levels of the semi-conductor

C-SPAD dark noise: Increases with Rep Rate: From < 60 kHz to > 5 MHz (10 Hz to 50 kHz)



[G. Kirchner, 17th ILRS Workshop, 2011]