Current performances and developments of the MéO laser station

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Overview

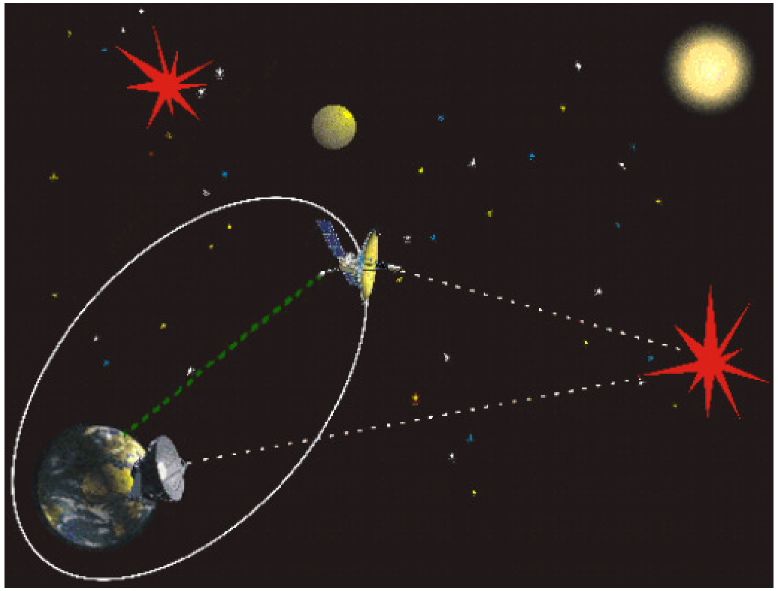
- Laser ranging on RadioAstron
  - RadioAstron Description
    - Project description
    - On-board laser ranging equipment
    - RadioAstron Navigation
    - Some scientific tasks which could be solved by SLR
  - Laser ranging on RadioAstron with MéO
    - MéO description
    - Results obtained with MéO
- MéO new developments
  - Coherent laser ranging: the Mini-DOLL project
    - Aim of the project
    - Ground-ground experiment
    - Noise estimation of a ground-satellite link with ground-ground results
  - Adaptive Optic
    - Aim of the collaboration with ONERA
    - Adaptive Optical bench
    - ONERA campaigns

Description of the RadioAstron Project

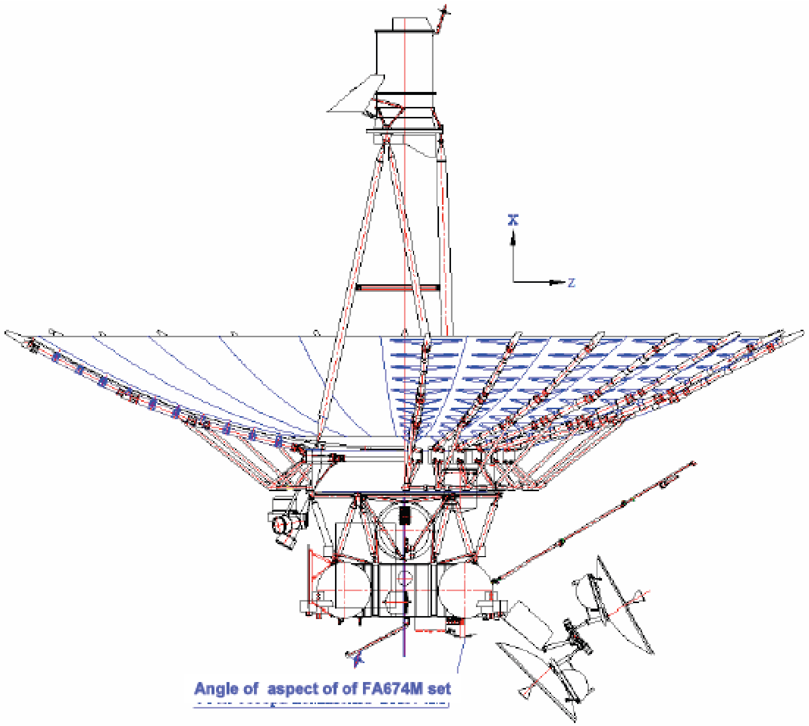
- 10 meters Space Radio Telescope
  - designed by the Astro Space Center (Russia)
  - launched in 2011
  - 5 years of life time
  - Operated in P, L, C, K-band
- International Collaborative Mission dedicated to investigate radio-source objects of the universe
- Very Long Baseline Interferometry technique (VLBI): best fringe size possible 7 μas
- Website: www.asc.rssi.ru/radioastron

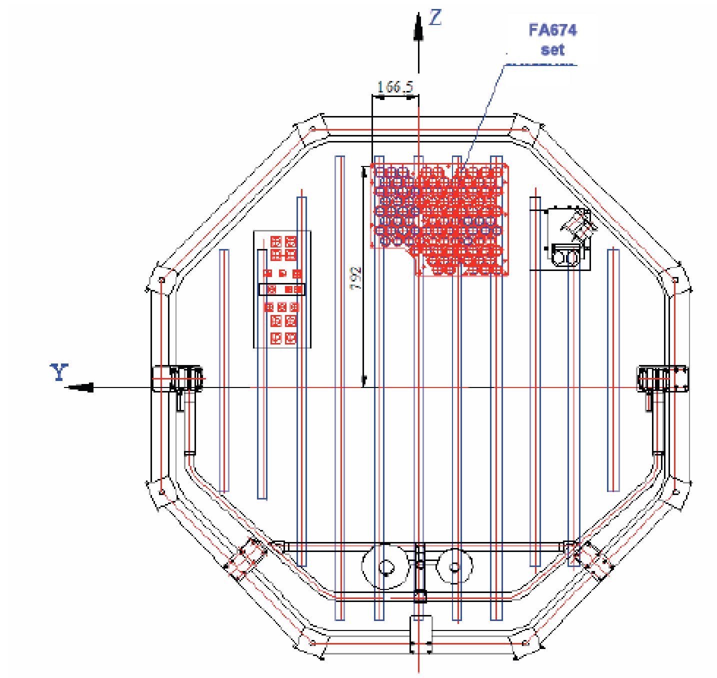
- Initial Orbit parameters:
  - Apogee height: 330 000 km
  - Perigee height: 400 km
  - Period: ~8-9 days
  - Inclination: ~51.4°

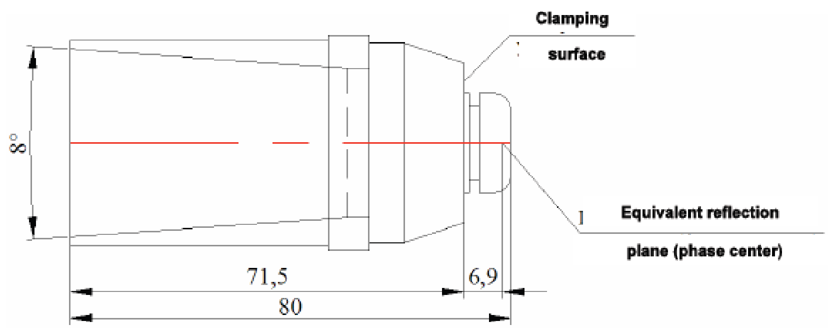
=> Elliptical orbit around the earth



On-board laser ranging equipment







100 corner cubes not spoiled
Area ~0.18 m^2

RadioAstron Navigation

Navigation techniques used:

- Radio-tracking
- Doppler tracking
- Astrometrical observations
- Precise open loop Doppler from on-board hydrogen maser
- Laser ranging

Current accuracy :

Position +/- 600 m

$\Rightarrow$ not sufficient for solving astrometrical problems

Navigation difficulties are due to

- Great distance from the earth
- Uncertainty of the gravitational field at large distances from earth
- Uncertainty of the Sun radiation model
- Uncertainty of earth magnetic field
- Non gravitation perturbation due to absence of the orientation moments scheme in wheels desaturation procedure
- Location of the laser retro reflector array limiting time of using SLR only to some special technological hours

Some scientific tasks which could be solved by SLR

- Highly accurate definition of gravitational fields
  - of the earth and the moon
  - influenced mainly by lower (J2, J3) harmonics of the earth gravitational field
- Sharp resonance motion
- Test of the gravitational redshift
  - test with an accuracy one or two orders of magnitude higher than the last measurement

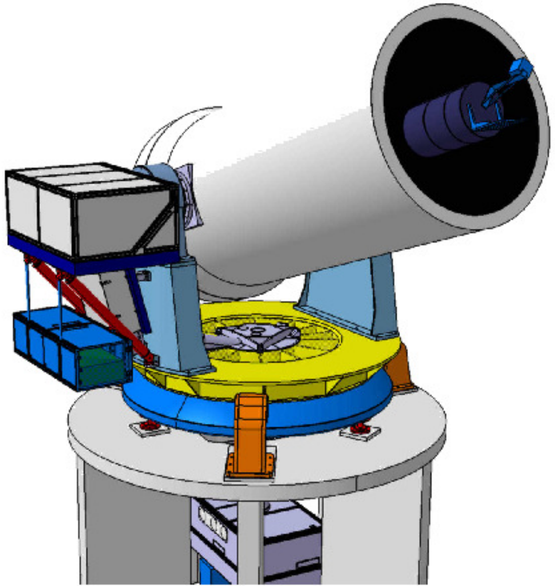
MeO description

Laser station dedicated for Satellite and Lunar Laser Ranging

Fork mount with direct drive motors:
- Az axis speed : 5° /s
- Az axis acceleration: 1° /s^2
- Pointing accuracy: +/- 5 arcsec

Laser:
- Repetition rate: 10 Hz
- Energy max per pulse: 200 mJ at 532 nm
- Pulse width: 70 ps

Telescope:
- 1.54 m diameter
- Photodetection FoV : 10 arcsec
- Camera FoV: 3 arcmin



Since October 2012:
Grasse team is become an institutional member of the RadioAstron International Science Council

Results obtained with MéO

First echoes:

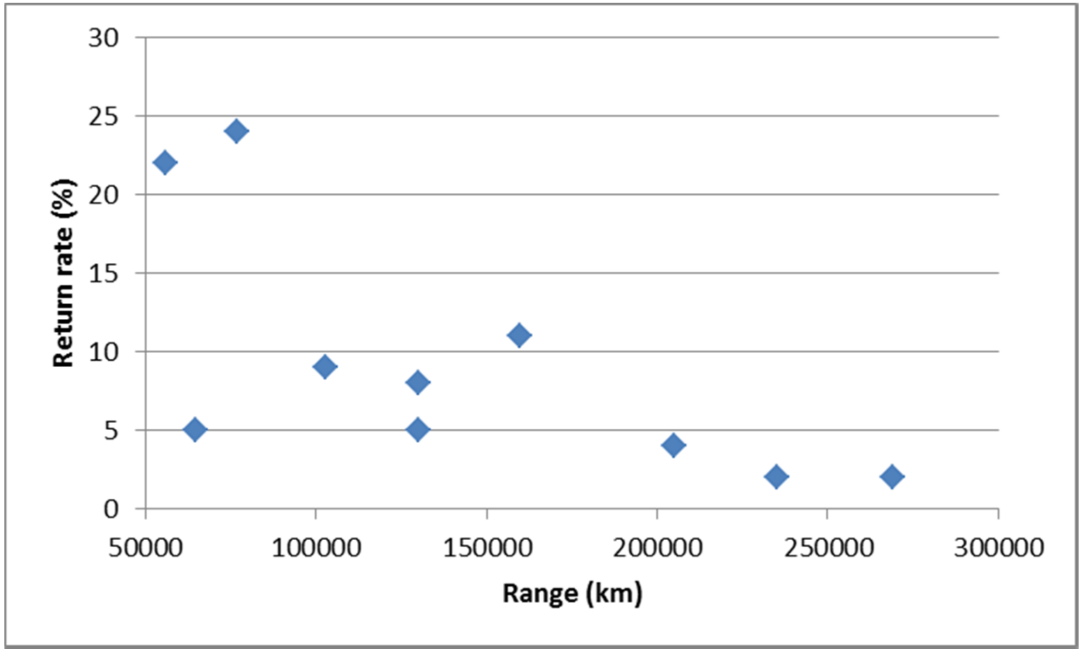
11/15/2011 with MeO   Elevation : 31°   Normal points: 31

Since:

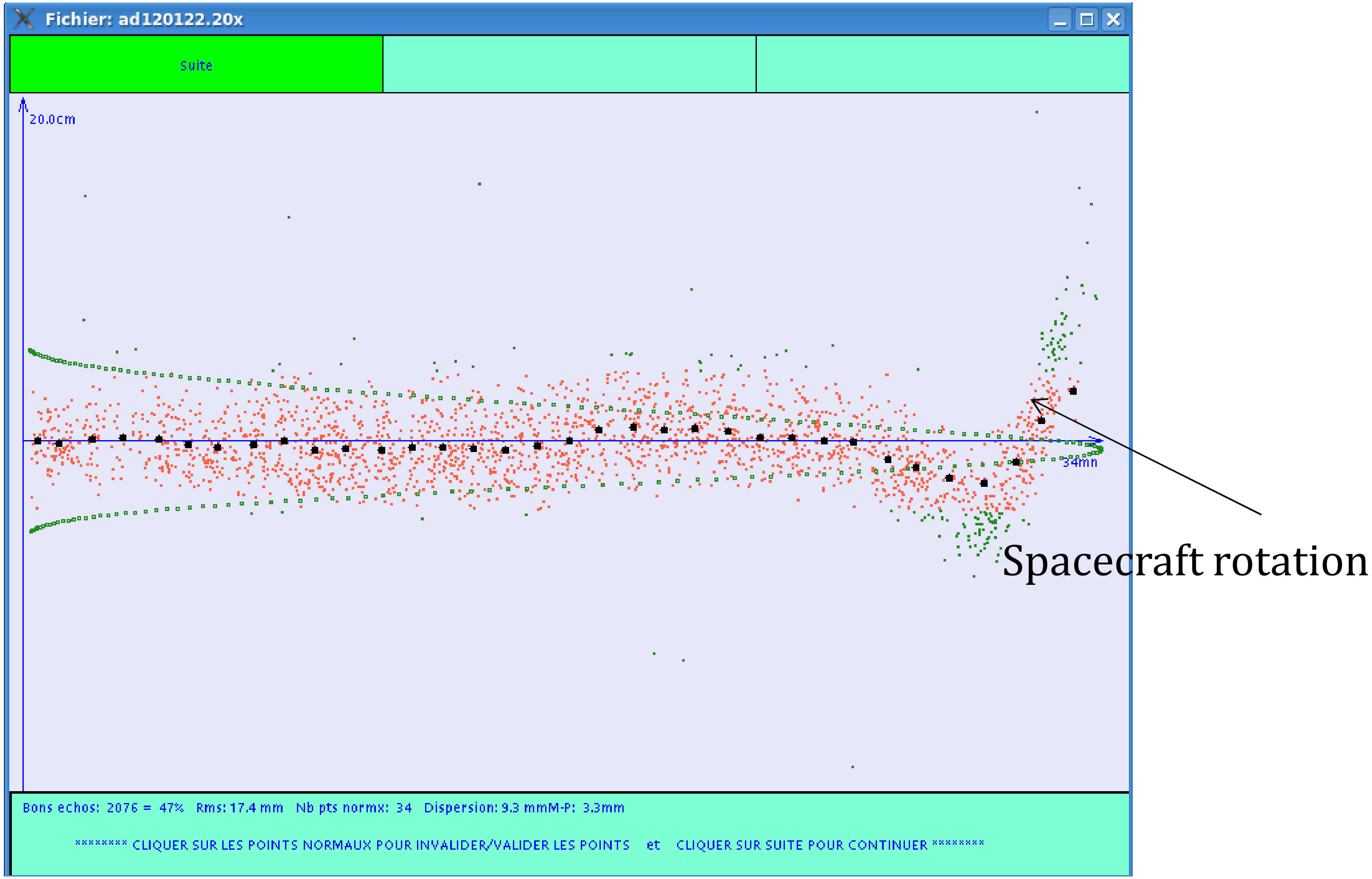
Only 10 trackings with 374 normal points

Only 2 stations have performed:

- Russian experimental station on the Northern Caucasus
- Grasse



Results obtained with MéO



Conclusion and Suggestions for RadioAstron tracking

- Conclusion

  Poor link budget

- Suggestions
  - Only station designed for lunar laser ranging can performed
  - Used camera
  - Used Real Time Exchange Protocol to share the bias in time and the station status.

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Mini-DOLL project

- Objectives: Deep Space coherent laser link
- Project lead by « l'Observatoire de Paris-Syrte »
- Benefits compared to pulsed link:

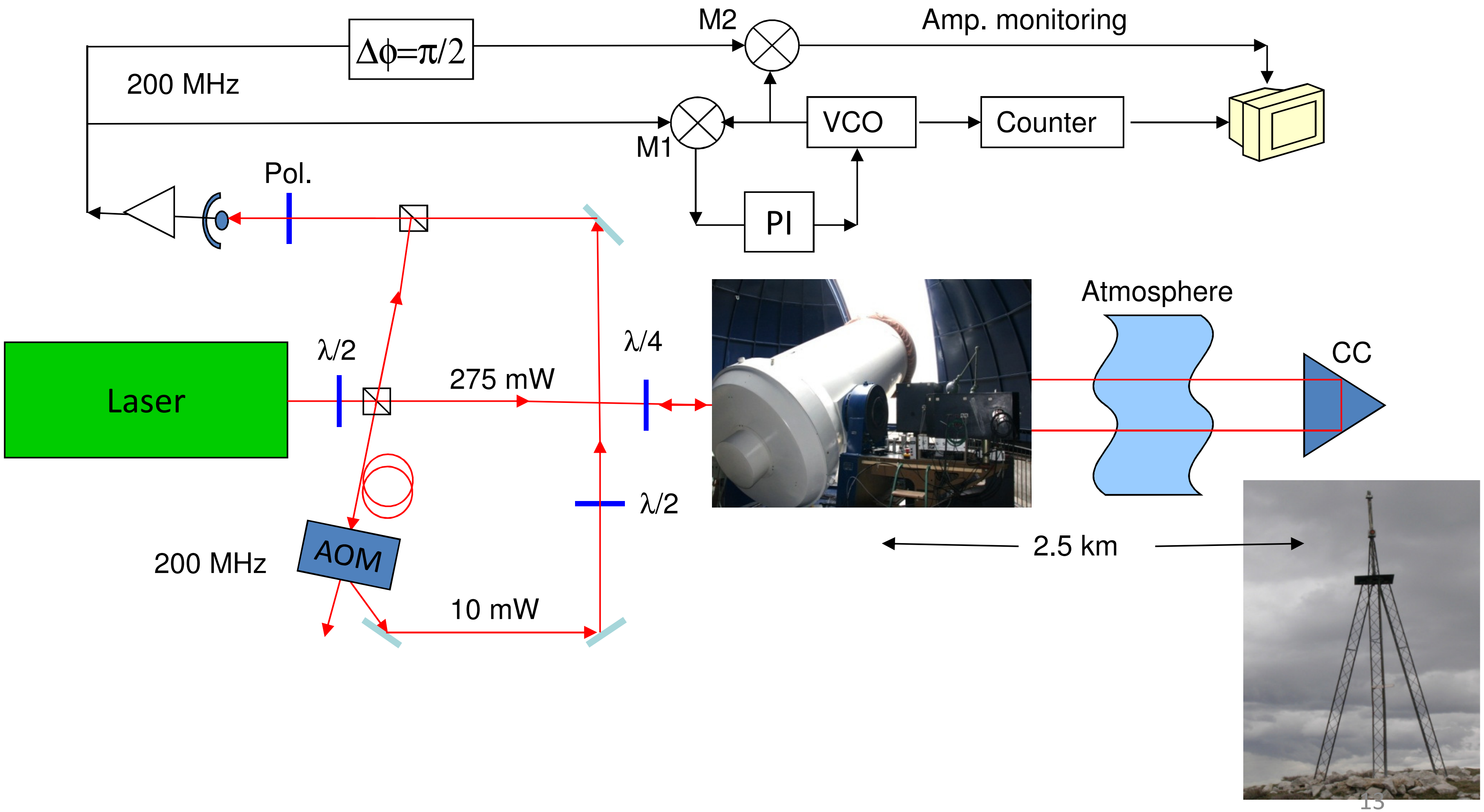
  Performances could be improved by a **factor 4** (pulse width*optical frequency) ; solution implemented in fibered links

  Advantages: high precision, low sensitivity to intensity fluctuations, unsensitive to parasitic light

  Drawbacks: sensitive to atmospheric turbulence; need power

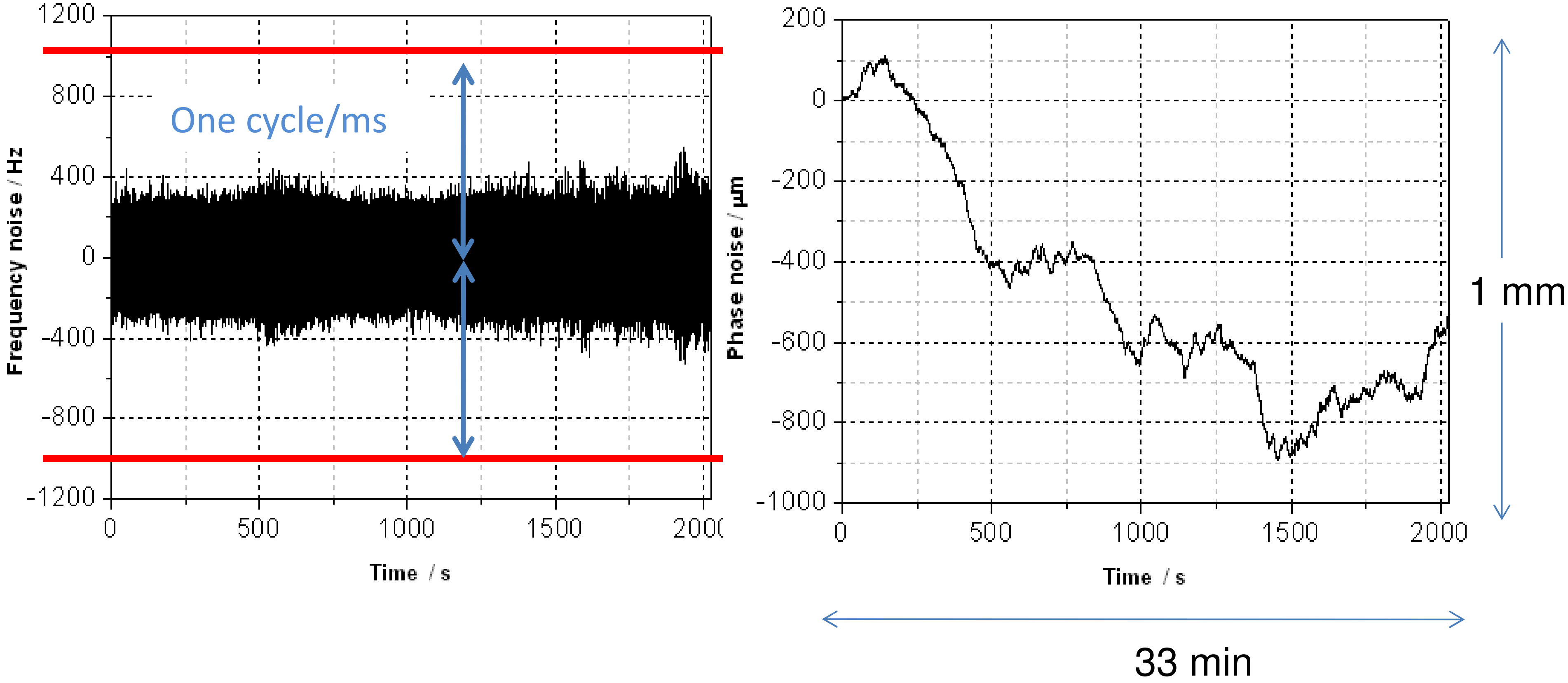
- 2 steps:
  - Ground-ground measurement
  - Ground-satellite measurement

Ground-ground experiment



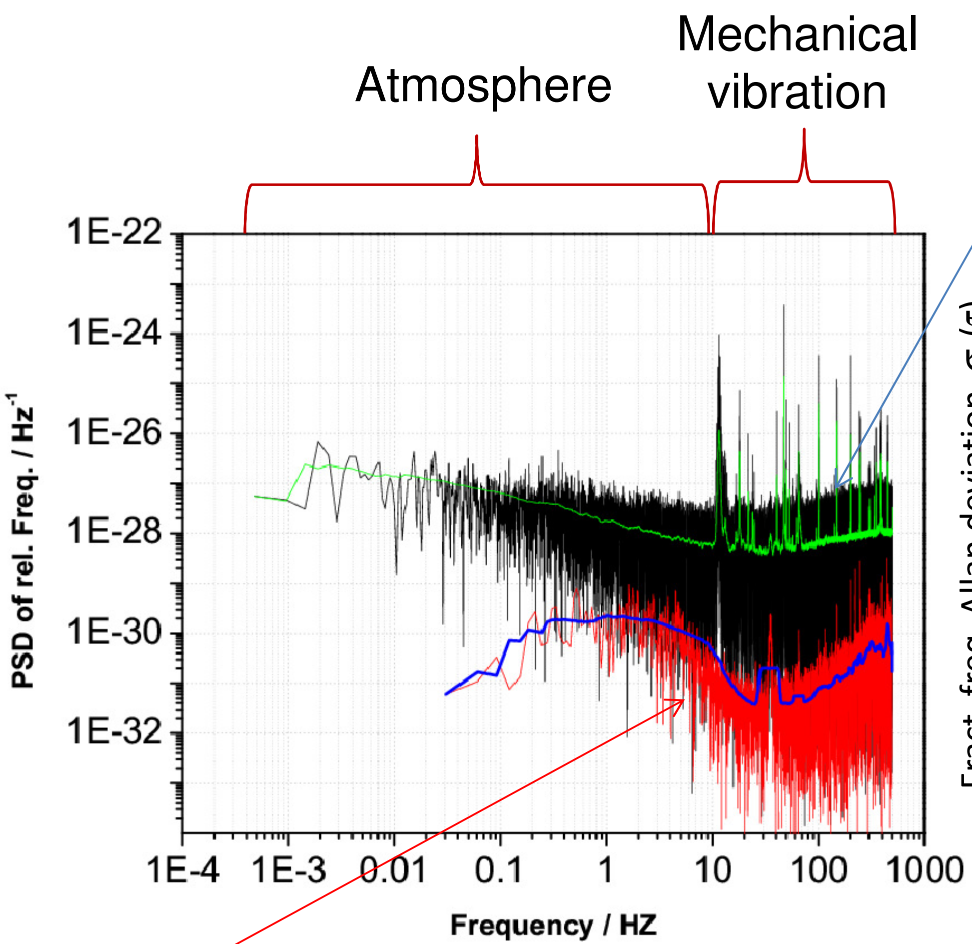
Ground-ground results

CCR on the Calern hill(@2.5 km)

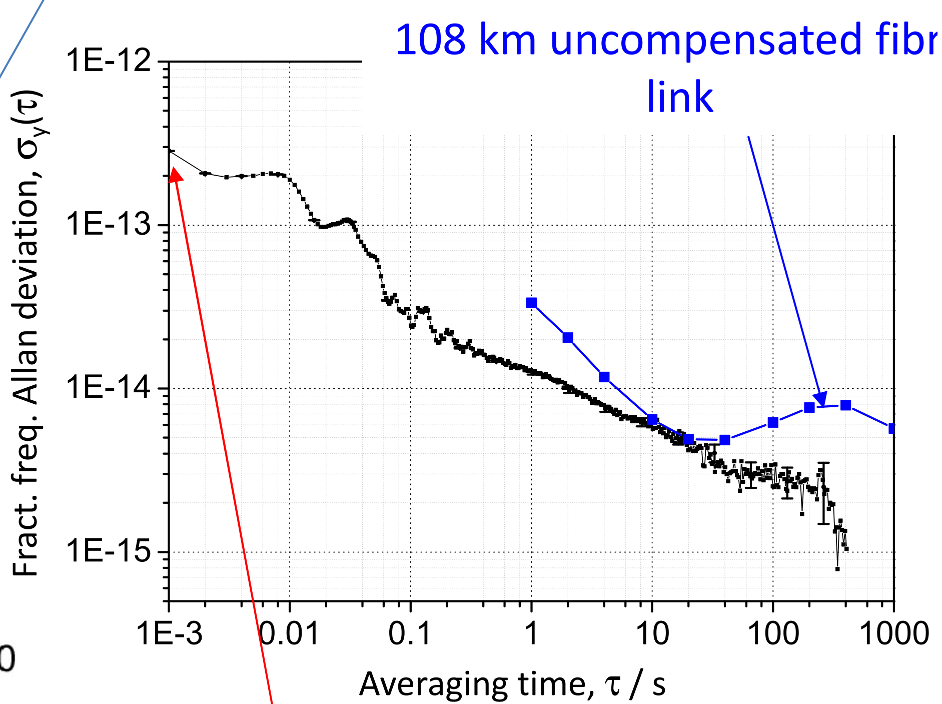


Data rate : 1 kHz
Total recorded points ≈ $2.027\ 10^{6}$
Fraction of deleted points ≈ $4\ 10^{-5}$

Ground-ground results



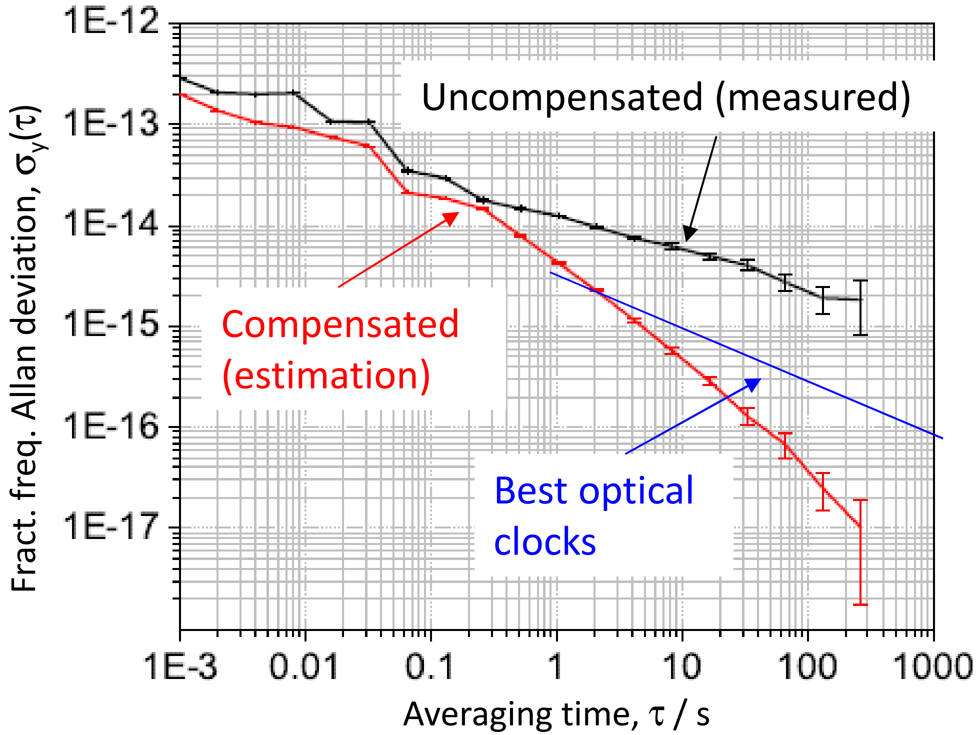
Amplitude to phase noise conversion



Noise floor

$\sigma_x(1\ \text{ms}) = 2 \times 10^{-16}$ s
$= 45$ nm

Noise estimation of a ground-satellite link with ground-ground results



Djerroud et al., Optics Letters **35**, 1479, 2010

Solution: 2 lasers

- One laser with high power and fixed frequency
- One laser with low power and tunable frequency

Challenges:

Cycles jumps (scintillation) have to be detected and compensated

Difficulties:

- Low power received => 20-100 W amplificator
- Long time of flight (~15 ms)=> need of a laser stabilized PSD S(f)=10-27
- Satellite motion => Doppler effect (+/- 12 GHz, 120 MHz/s) => need of tunable laser
- Scintillation => need of adaptive optic

Conclusions for the mini-DOLL project

- Coherent horizontal laser link trough atmosphere have been realized
  - > Phase noise dominated by atmospheric turbulence but encouraging for T/F applications

- Lasers are ready (OP-Syrte)
- Campaign is scheduled in november 2012

Adaptive Optic in collaboration with ONERA

- Objective:
  - Improve the link budget
    - Without Adaptive Optic (AO), the laser beacon on the lunar surface is between 2 to 10 km, depending on the atmospheric condition
    - Diffraction limited, we could have a spot in the range of 200m
  - Implement an adaptive optical bench on MeO
    - On the down link:

      We could reduce the detection field of view by a factor 10

      $\Rightarrow$ S/N improved by 10

      The analysis of the wave front has to be done on the details of the lunar surface (lighted by the sun)

    - On the up link:

      We could improve the link budget by a factor 100

      Difficulties:

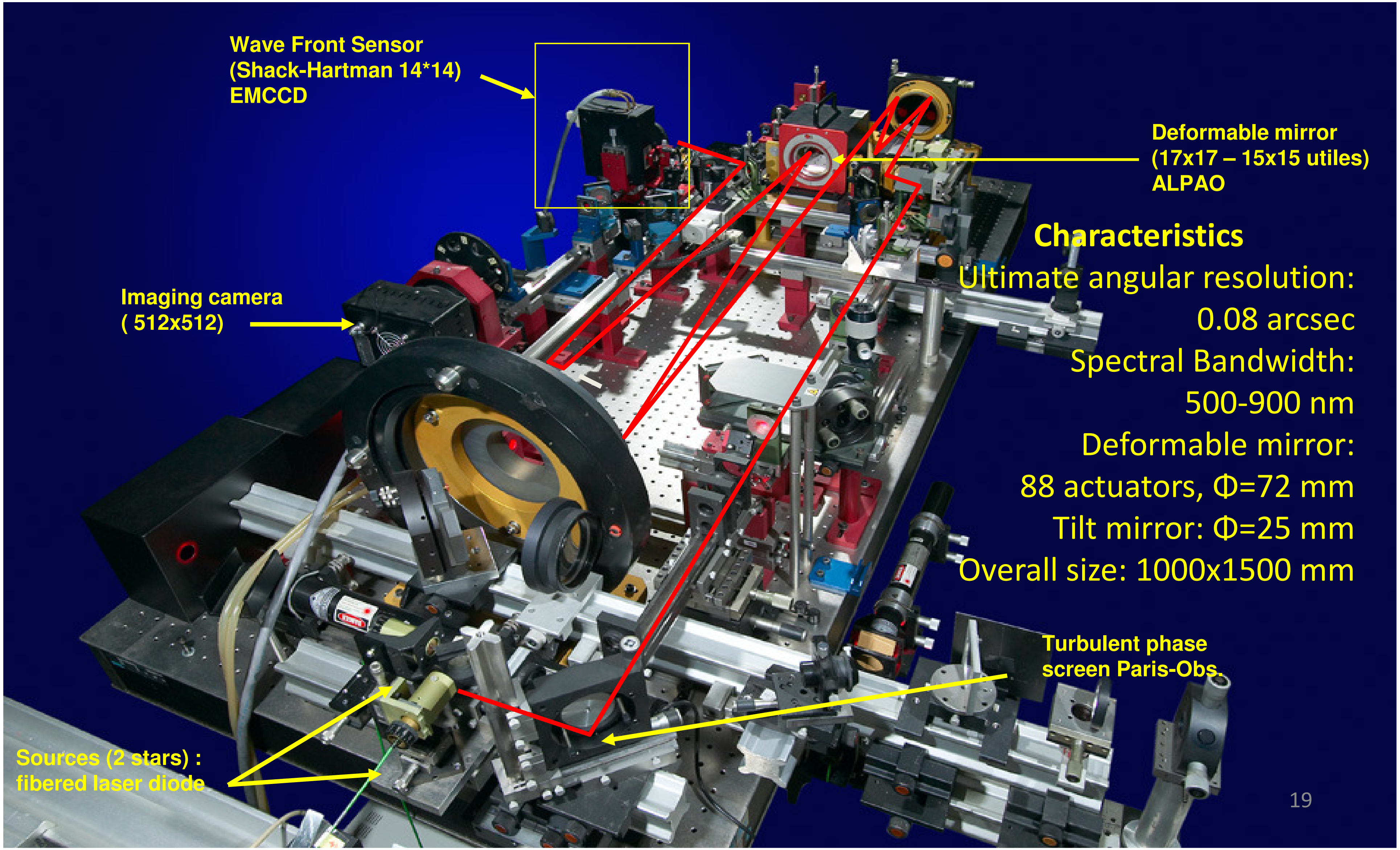
      - needs high energy deformable mirror

      - velocity aberration introduces an angular shift between the uplink and the downlink.

      If this angle > isoplanetisme area => two different corrections between up and down link

      - the analysis of the wave front sens has to be done on an artificial star

ONERA adaptive optical bench



Characteristics

Ultimate angular resolution: 0.08 arcsec

Spectral Bandwidth: 500-900 nm

Deformable mirror: 88 actuators, Φ=72 mm

Tilt mirror: Φ=25 mm

Overall size: 1000x1500 mm

ONERA Campaigns

- June & October 2012: Implementation of a test bench
  - Results very insteresting but not-disclosable

- 2013: Implementation of the final adaptive optical bench


Thanks for your attention