TERRE - OCÉAN - ESPACE

Geoazur - Free Space Laser Communication Experiments & Prospective Applications for Satellite Laser Ranging

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Outline

1. Free Space LaserComm – Why?
2. LaserComm – How to work?
3. State of the art – LaserComm
4. Geoazur LaserComm Experiments
5. Prospective → Satellite Laser Ranging

1. Free Space LaserComm – Why?

Data rate **REQUIREMENT (Sat. to Ground)**

Year	Requirement
1990	20 Mbps
2000	200 Mbps
2010	**2 Gbps**
2020	**> 10 Gbps**

Gbps is inevitable!

Best current RF Ka - band system (26.5–40 GHz)
→ 500 Mbit/sec

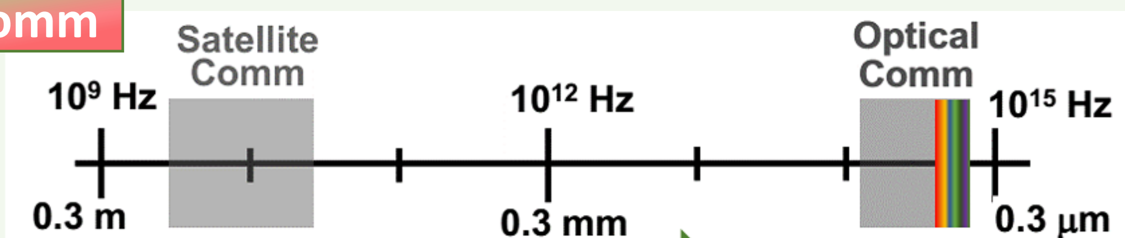
Cube Nano Micro Sat Data Debit.

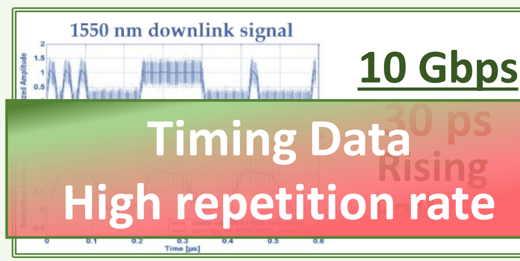
Type	Data rate
Nano	1 – 20 Kbps
Micro	0.02 – 1 Mbps
0.3 – 10 tone	0.01 - 1 Gbps

Cube Nano Micro Sat.
> 1 Gbps
1kbps - 1Mbps

RF techno. does not adapt the requirement!!!

LaserComm

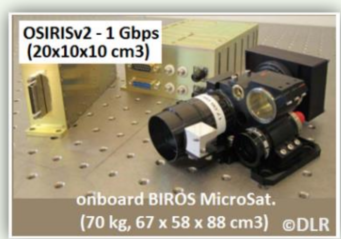




Timing Data
High repetition rate

RF - Ka (26.5–40 GHz) → **500 Mbit/s** × 1000 Laser (150 –800 THz) → **+100 Gbit/s**

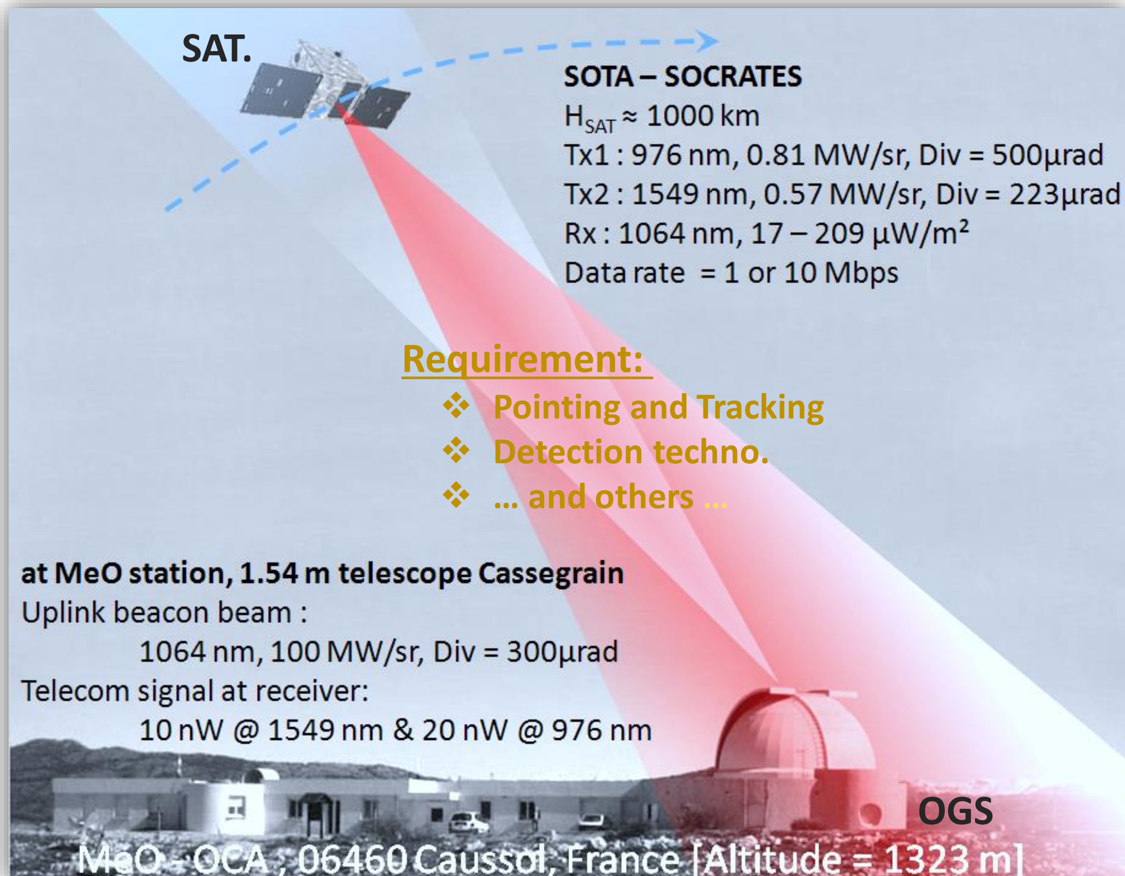
Satellite antenna



OGS receiver

2. LaserComm – How to work?

Link establishing procedure



LaserComm Advantages

- Multi – Gbps
- Multi colors.
- Greater Secu.
- More Compact
- Low Consum.

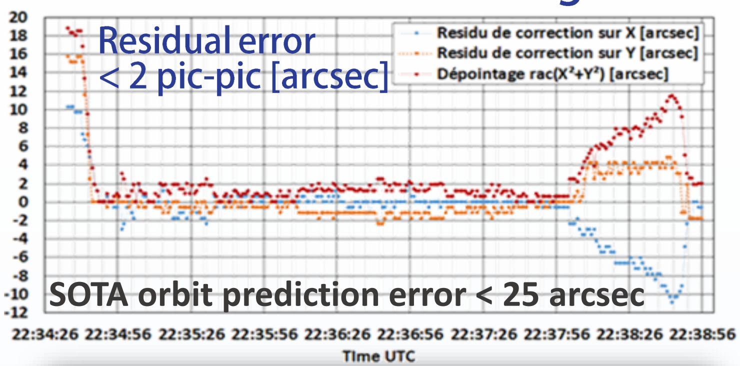
LaserComm Challenges

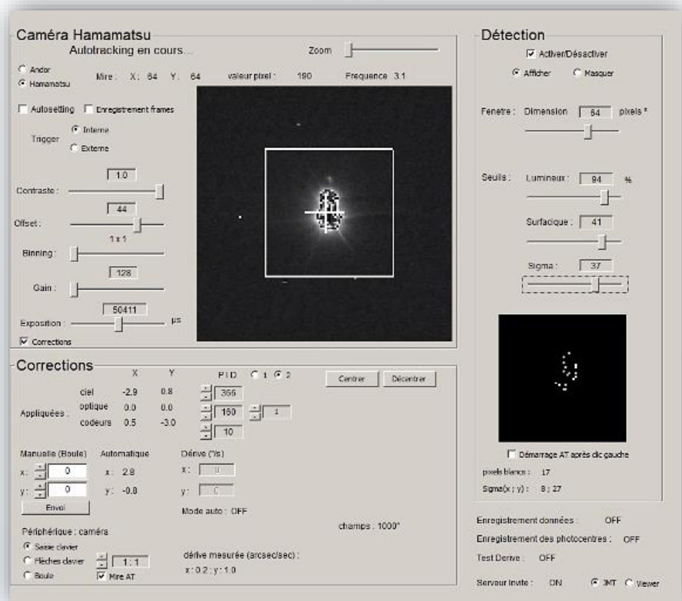
- **Tracking and Pointing**
  (coarse & fine pointing)
  (LEO sat. → 4.5 deg/sec OGS)
  → Pointing Losses
  + Free Space Losses
- **Atmospheric effects**
  - Atmospheric attenuation
    (by Scattering and Absorption)
  - Background noise
    (backscattered by Earth, direct Sun, Moon, Sky radiance)
  - Atmospheric turbulence
    (by wind and temperature gradients)
    → Scintillation + Wavefront distortion

→ **Low level signal with large fluctuation detected at OGS ! (nW at 10 Mbps!!!)**

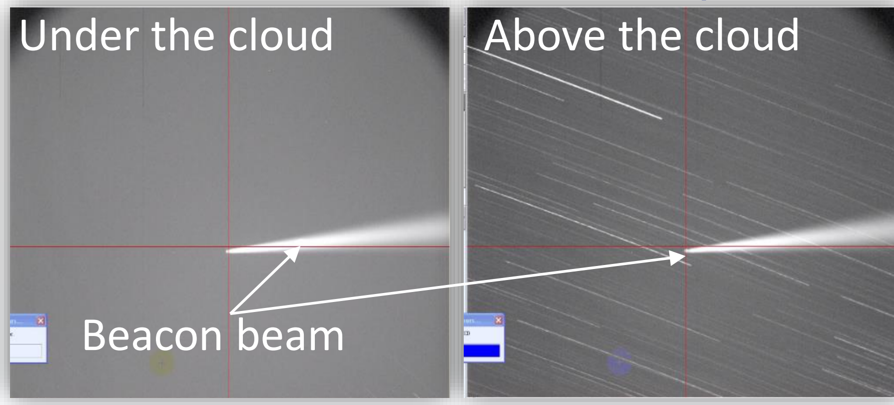
2. LaserComm – How to work?

SOTA Auto-Tracking

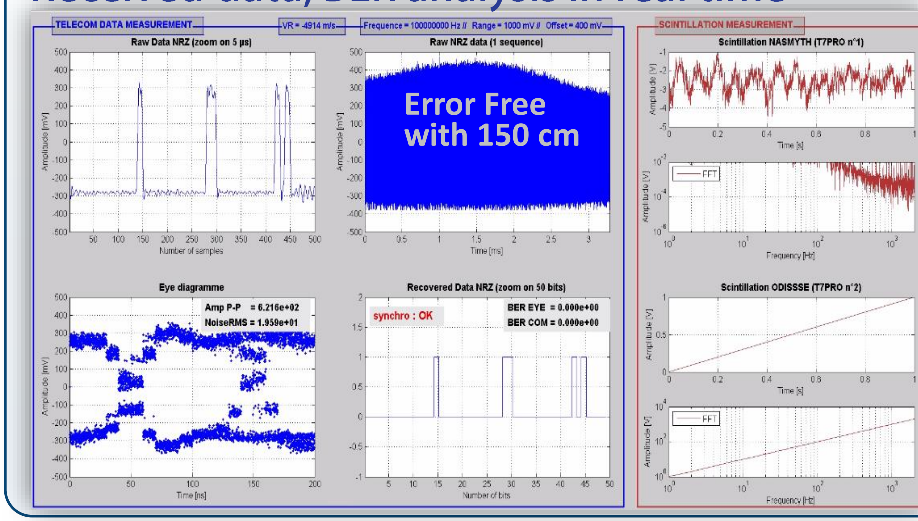




Wide Field of View camera (1×1 deg²)



Received data, BER analysis in real time

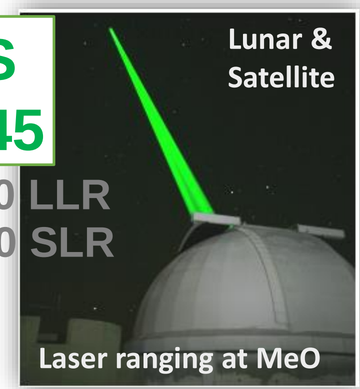


Geoazur LaserComm – Why?

- ❑ Lunar & Satellite Laser Ranging
  - – **Laser pulse (classic)**
    - AM BW : 20 GHz (50 ps) at repetition rate : 10 – 2000 Hz
    - Accuracy : centimetric
    - Precision : Single Shot - few mm
    - LIMITED by ATMOSPHERE & REPETITION RATE…

ILRS ID7845

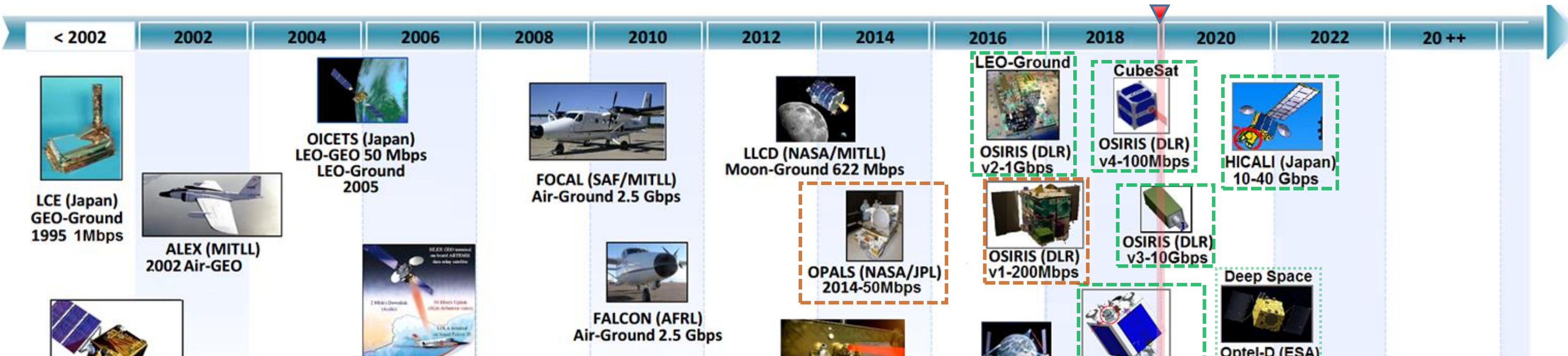
~ 900 LLR
>2500 SLR



LaserComm Projects → More Upgrade on MeO station for Laser Ranging

- ❑ **Auto-tracking LEO**, MEO, GEO satellite (Visible + IR), **more materials…**
  - – Manual mode → **Coarse & fine auto-tracking by Wide FoV camera + TipTilt Mirror**
  - – **More IR cameras** has been integrated for auto tracking
  - – **195 mm, f/9 telescope – carbon tube** for uplink beacon laser or Wide FoV observation
- ❑ Atmospheric turbulence understanding
  - – **Uplink and downlink budget** for free space laser link through atmosphere
  - – **Effect of Atmospheric Turbulence** (scintillation + wave-front) → **Adaptive Optics**
- ❑ High sensitivity + high BW IR detection → **Laser ranging by Telecom Link**
  - AM BW : Telecom Debit = 1 GHz – 20 GHz (50 ps) at repetition rate : GHz
  - Precision : 1 ps expected → sub-millimetric on distance measurement

3. LaserComm– State of the art



- ❑ Successful links LEO Sat. ↔ MeO: 20, 40, 150 cm subaperture - TESTED
- ❑ Data Transmission (Bit Error Rate) – TESTED **Error Free with 1.54 cm telescope**
  95% BER > 1% with 40 cm → LaserComm with 40 cm telescope OGS : POSSIBLE!
- ❑ Propagation channel measurements
  - Comparison with models – Link budget, scintillation …
  - Wave Front Sensor (Shack –Hartmann) → Turbulence profiles during satellite pass
- ❑ Adaptive Optics and SMF coupling – First demonstration

Geoazur, Where are we in this story? **middle 2014 →**

SOTA (Japan): Jun.-Oct.2015

OPALS (Nasa): Dec.2016

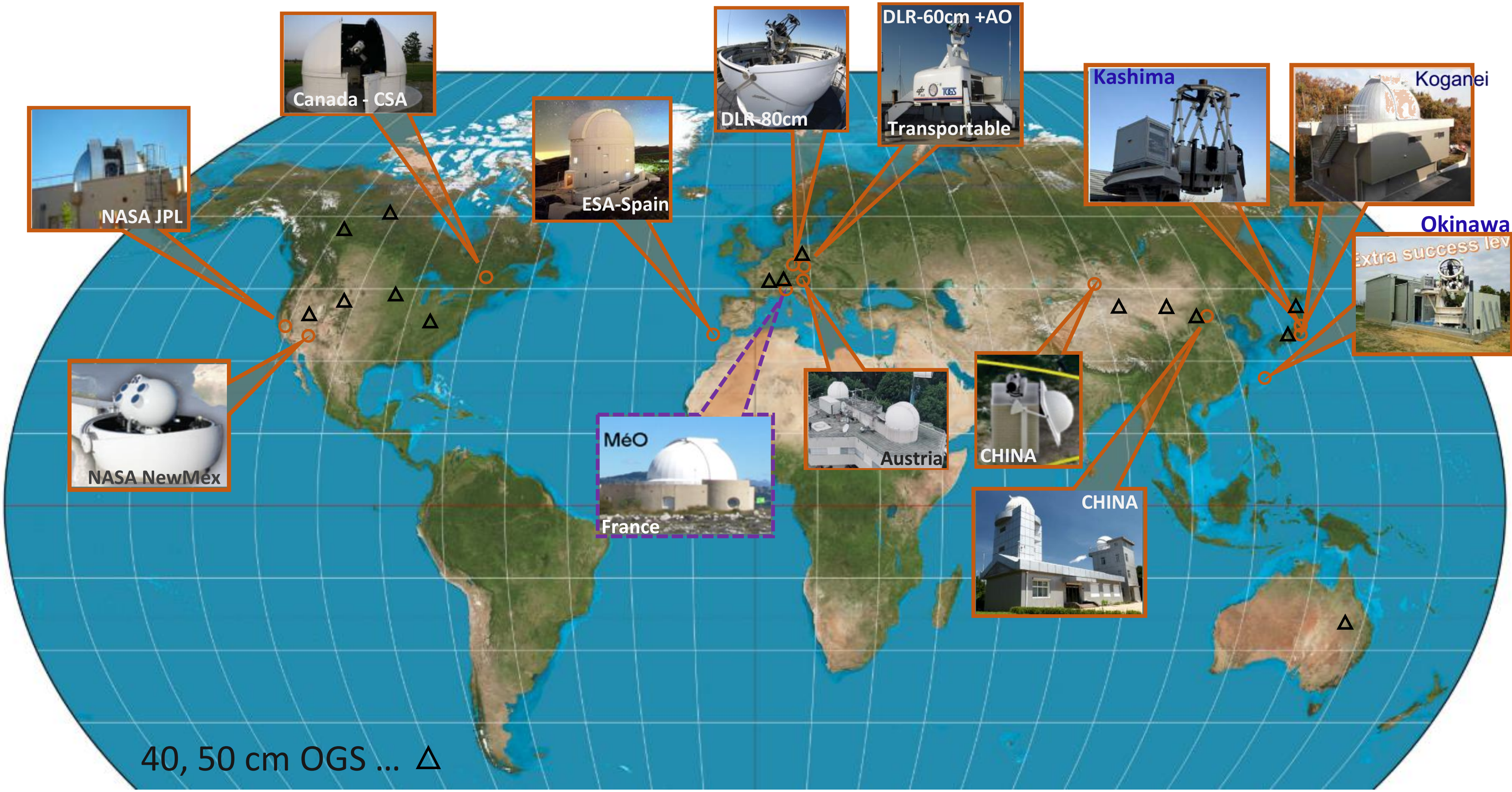
OSIRISv1-3 (DLR) : → 2020

GND-10Gbps: 2017 2018

OSIRISv1 (DLR): Dec.2019

HICALI (Japan): → 2022

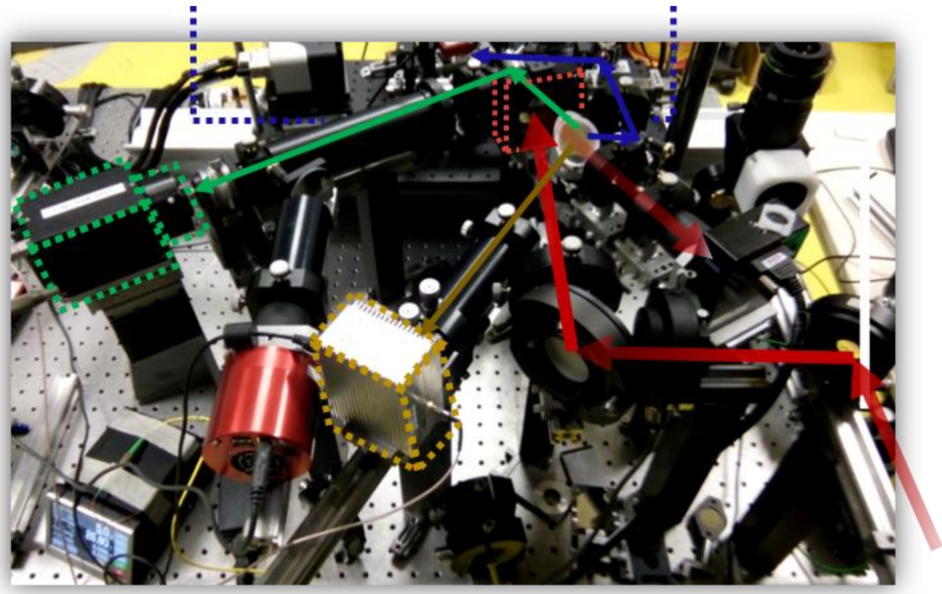
3. LaserComm– State of the art



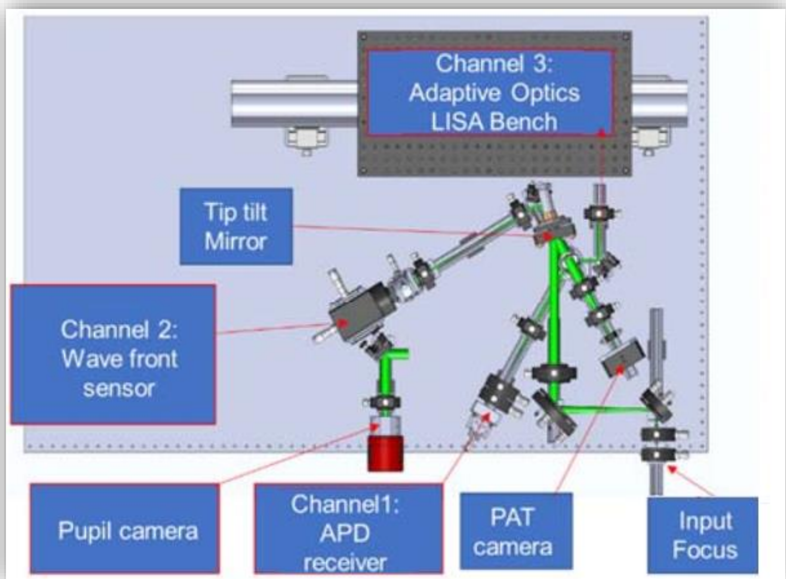
Since 2015, LaserComm Sat. → 40 cm OGS → OK

→ Development of 40 cm OGS Multi-functions (Telecom + SLR + Observation…)

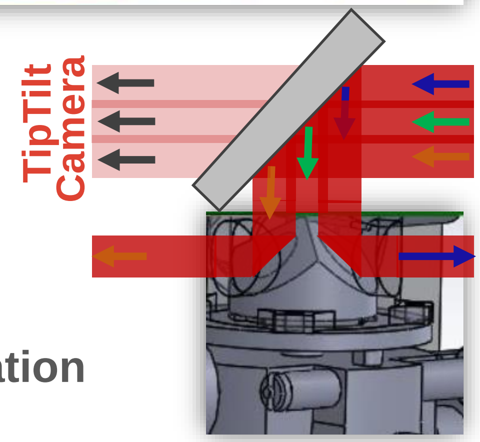
Test bench Nasmyth → Coudé



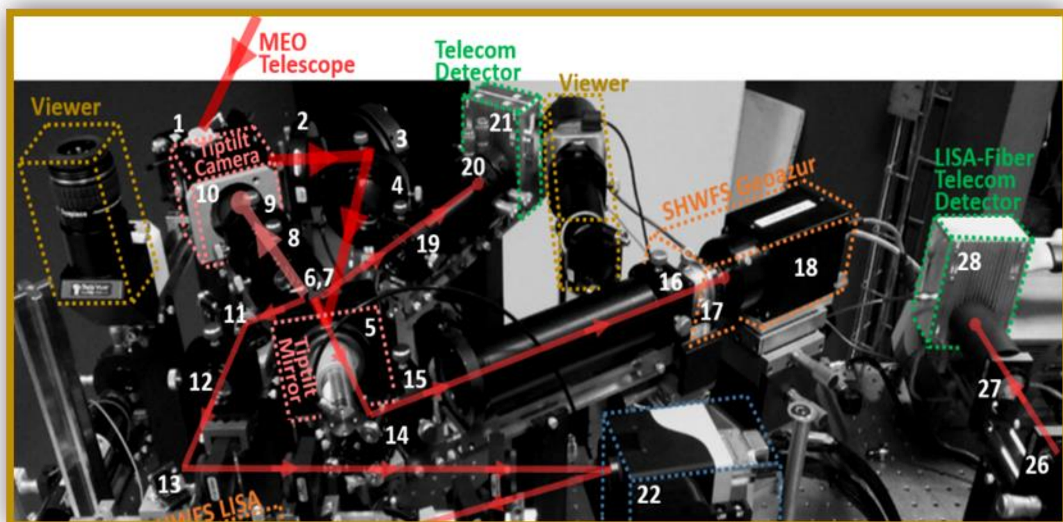
Designed by SigmaWorks



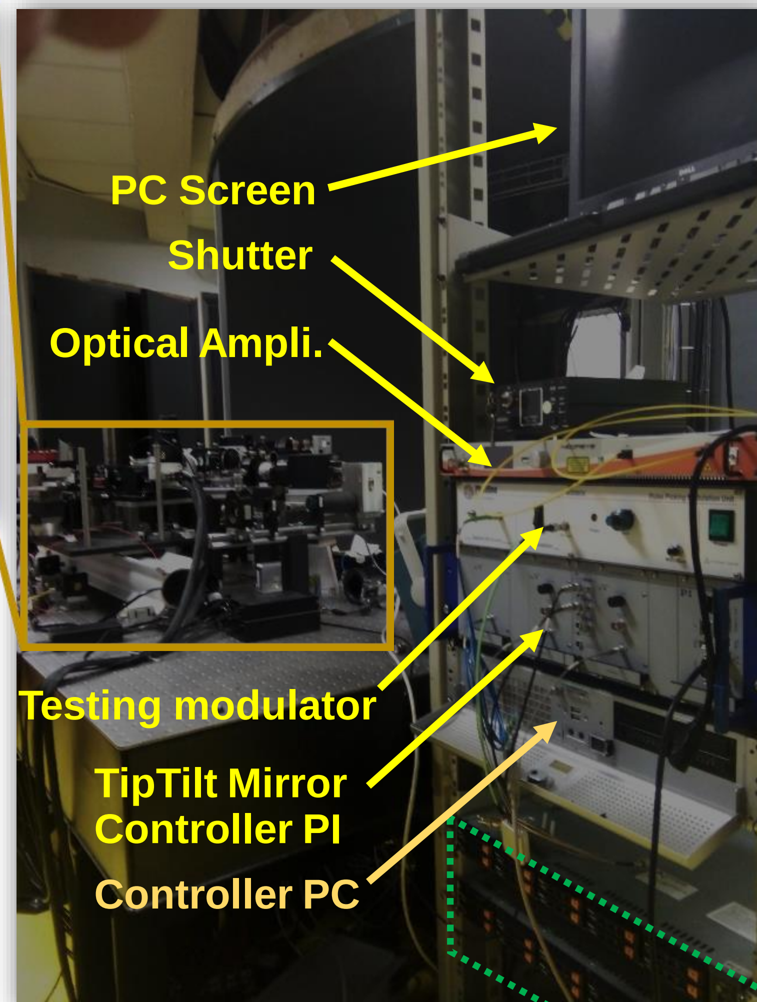
- 90% Triangle Beam splitter ➔ 3 sub-aperture channels (40cm)
  - 1. Telecom APD detector
  - 2. WaveFront sensor (high speed IR camera)
  - 3. LISA ONERA (Adaptive Optic → fiber coupling)
- 10% Fine tracking by TipTilt mirror + Camera → Pupil stabilization



4. Geoazur LaserComm – 2017, 2018 →



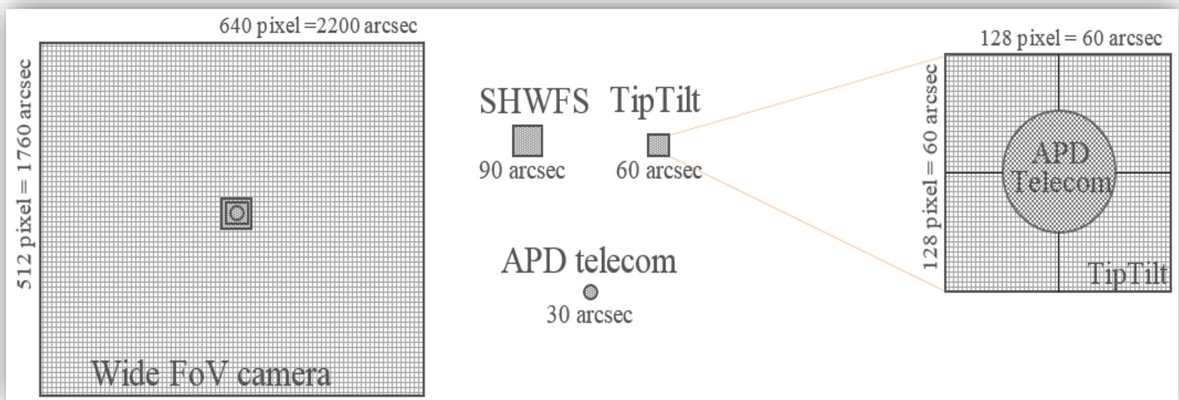
Wide FoV Camera (1700 arcsec) installed on 200 mm telescope mounted on MeO



Digitalization 3.2 GSps x2
Continuous – 6 GB/s on disk

4. Geoazur LaserComm – 2017, 2018 →

Combination of coarse and fine Auto-tracking



Objective: Maintaining spot laser on APD detector and LISA bench

- ❑ Coarse tracking : large + slow
  Wide FoV camera (1700 arcsec)
  → MeO control signal
- ❑ Fine tracking : small + fast
  TipTilt Mirror + camera (60 arcsec)
  → TipTilt Mirror orientation
- ❑ Saturation → discharged by Coarse.

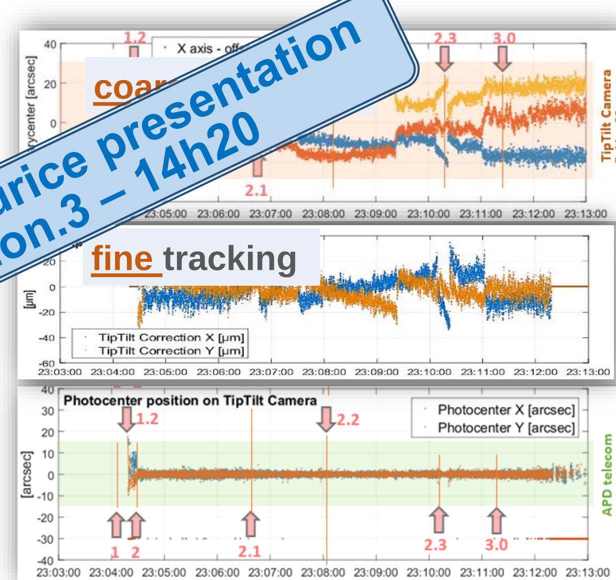
MeO auto-tracking performance

Spot laser position on TipTilt camera was stabilized with RMS < 1.1 arcsec at 50 Hz from low (10 deg) to high (48 deg) elevation LEO Sat.

- ➢ [Coarse + Fine] tracking : Confirmed
- ➢ TipTilt mirror PID : Confirmed
- ➢ Multi-axis Wide FoV : Covered

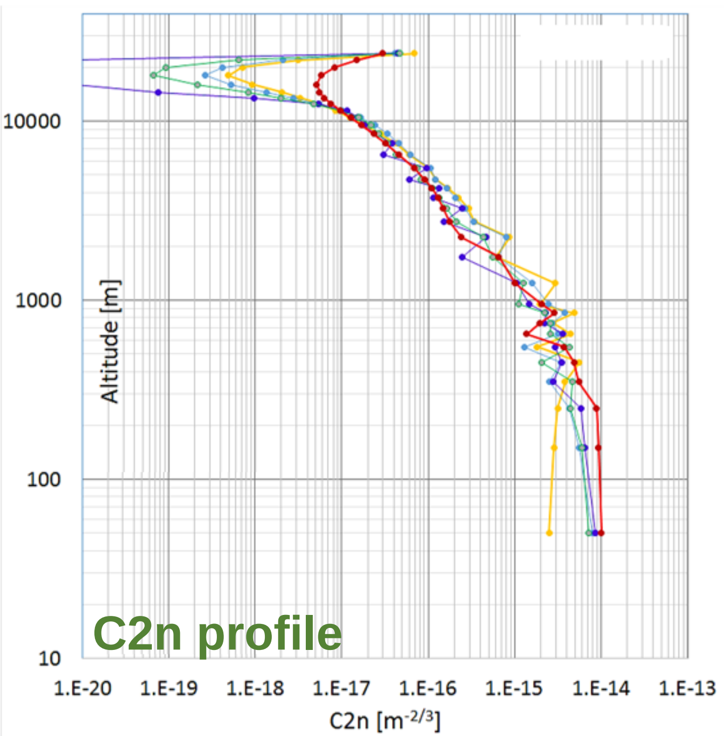
Time	0.03 s	0.10 s	1.00	10.0 s	100 s
Rms [“]	0.700	0.400	0.05	0.007	0.002
Gain	1.5	4	40	300	2000

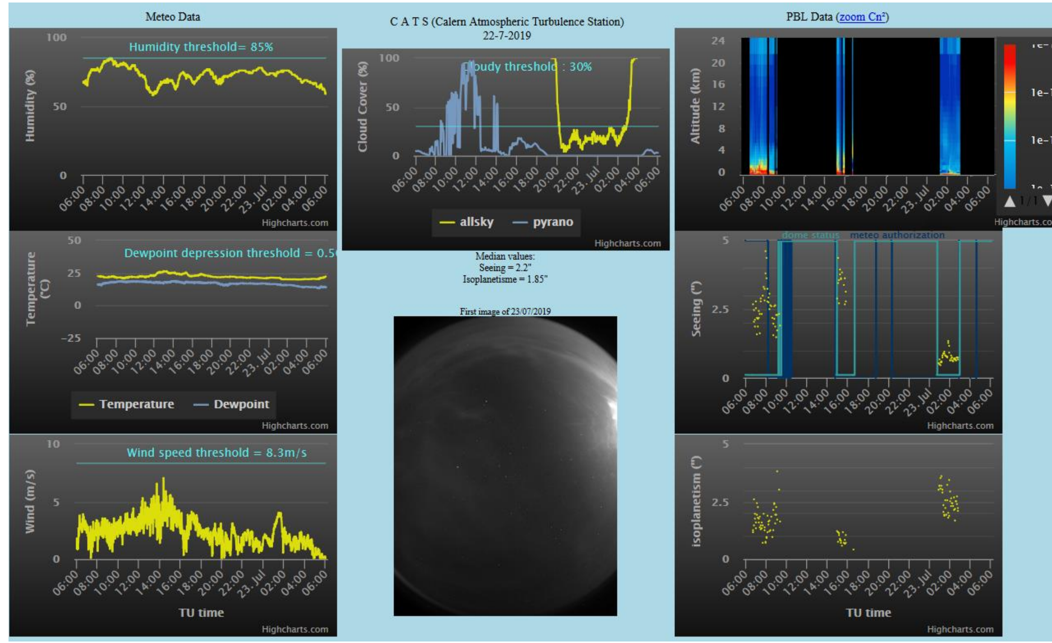
Nicolas Maurice presentation
Section.3 – 14h20



4. Geoazur LaserComm – 2017, 2018 →

PBL + GDIMM instruments → Scintillation σ_I^2 + Fried parameter r0 [cm]





- **Fried parameter r0 [cm]**

$$r_0^{-5/3} = 0.423k^2/cos\xi \int_0^H C_n^2(h)dh$$

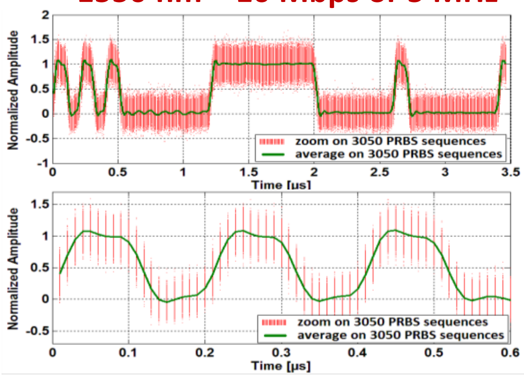
- **Scintillation index σ_I^2**

$$\sigma_I^2 = 17D^{-7/3}(cos\xi)^{-3} \int_0^H h^2 C_n^2(h)dh$$

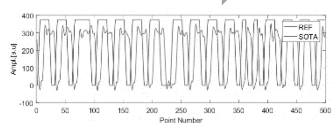
5. Prospective - Laser Ranging

➢ Telecom detection → Time Transfer by LaserComm link

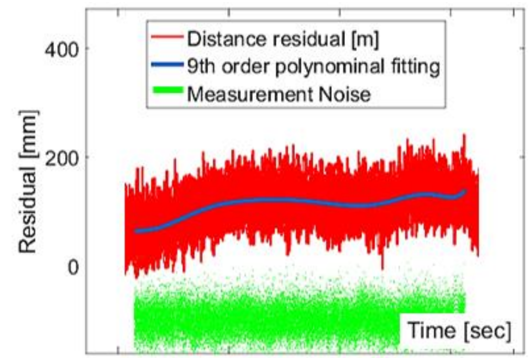
1550 nm – 10 Mbps or 5 MHz



Rising Falling Times Measurement



Distance Meas. From Telecom Signal

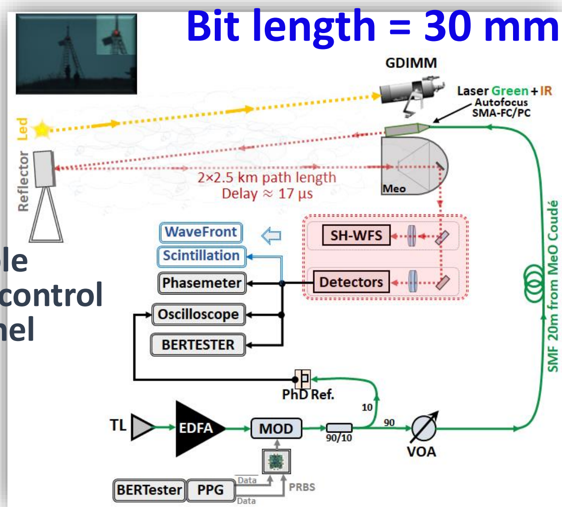


10 Gbps or 5 GHz modulation???

Bit length = 30 mm

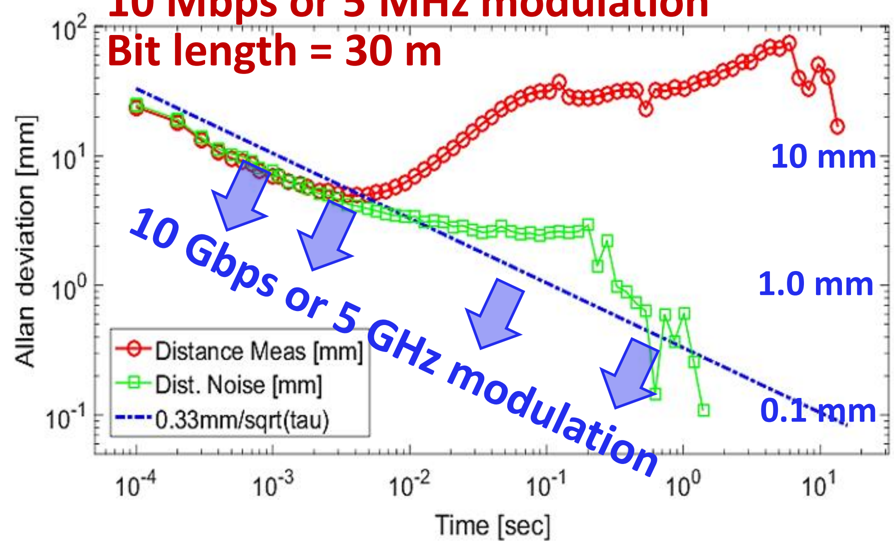
200 mm Mirror

Orientable Remote-control Solar Panel



10 Mbps or 5 MHz modulation

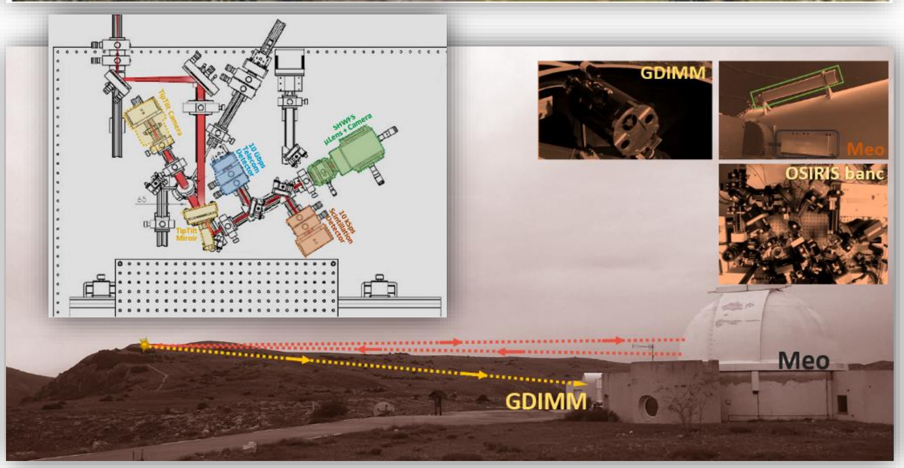
Bit length = 30 m



5. Prospective - Laser Ranging

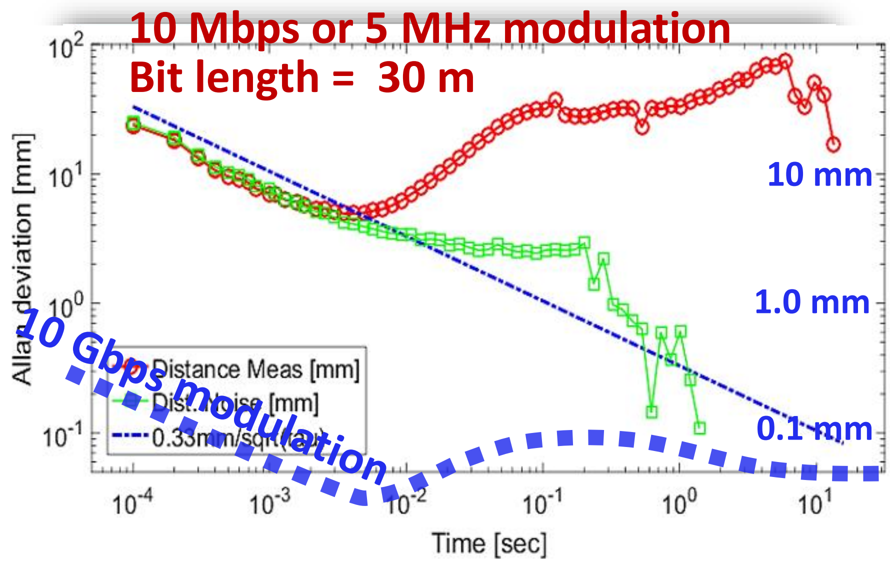
➢ Telecom detection → Time Transfer by LaserComm link

Ground : High data rate 10 Gbps on slant free space laser link + AO (TipTilt)



High sensitivity 10 Gbps Telecom detector: - 30 dBm

Telecom signal Generator + BER detection = FPGA cards
(Commercial Components in 1550 nm Telecom domain)



Expectation: 50 µm RMS at 1.0 ms
on 2.5 km distance (slant path)
& observe Tur.Atm effect

- ❑ Characterization Atmospheric turbulence effect: on High speed Telecom detection,
  - → Signal to Noise Ratio
  - → BER measurement
  - → 10 Gbps Rising + Falling Edge
- ❑ → Distance measurement from 10 Gbps telecom signal…

Conclusions & Perspectives

Laser Communication

- ❑ **Validation of Pointing, Acquisition, Tracking**
  - ✓ Acquisition instantaneous with precise orbit prediction
  - ✓ Robust & fine tracking using tracking camera + TipTilt Mirror
- ❑ **Data Transmission (Bit Error Rate) + SNR → Link Budget Validation**
  - ✓ Computation of BER on the non coded signal for various elevations and telescope diameters.
  - ✓ **Demonstration of Telecom Laser Sat → 40 cm OGS POSSIBLE!!!**
- ❑ **Propagation channel measurements → Understanding Atm.Turbulence**
  - ✓ Wave front sensor (Shack –Hartmann) measurements → Turbulence profiles
  - ✓ and integrated parameters (seeing, scintillation, …). → Comparison with models
- ❑ **Adaptive Optics and SMF coupling**

Prospective Applications for Satellite Laser Ranging

- ❑ **Timing measurement from High speed Telecom signal 10 Gbps**
  - ✓ **Sub – millimetric precision** with **high repetition rate**
- ❑ **Adaptive Optics for SLR (1st step: using TipTilt Mirror)**
  - ✓ **Less dispersion** on Single Photon Detection, Smaller detector → High repetition rate
  - ✓ Eliminate error prediction + pointing error, **Correction of 1st order - Atm.Turbulence**

Laser Ranging by LaserComm Link…

Thank for your attention!

Pôle R&D et Observatoire – Geoazur – Plateau de Calern, Grasse – France