Geoazur - Free Space Laser Communication Experiments & Prospectives for Satellite Laser Ranging and Time Transfer

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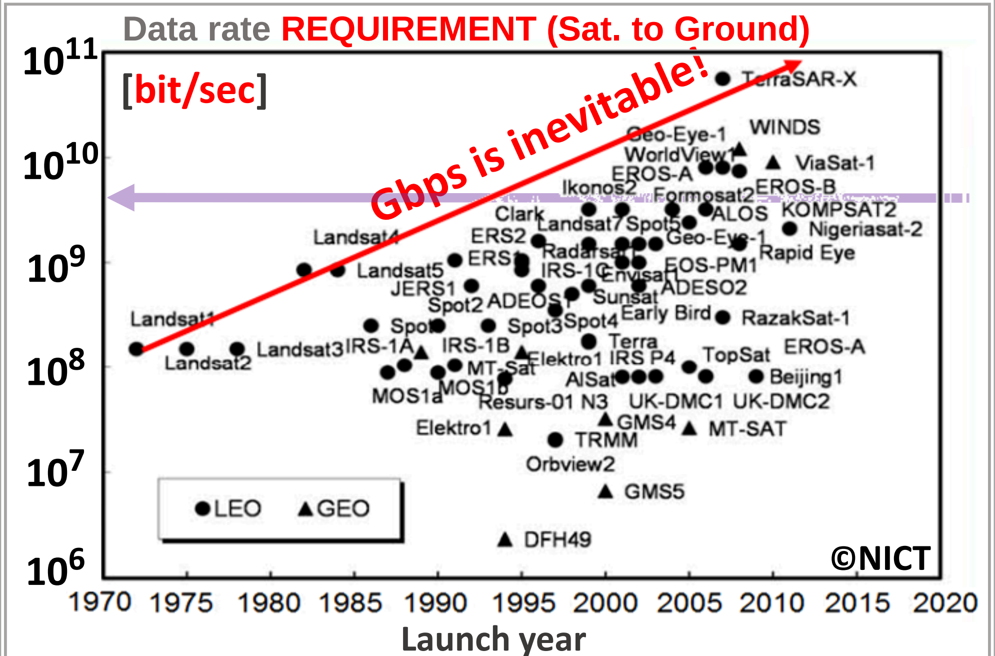
Outline

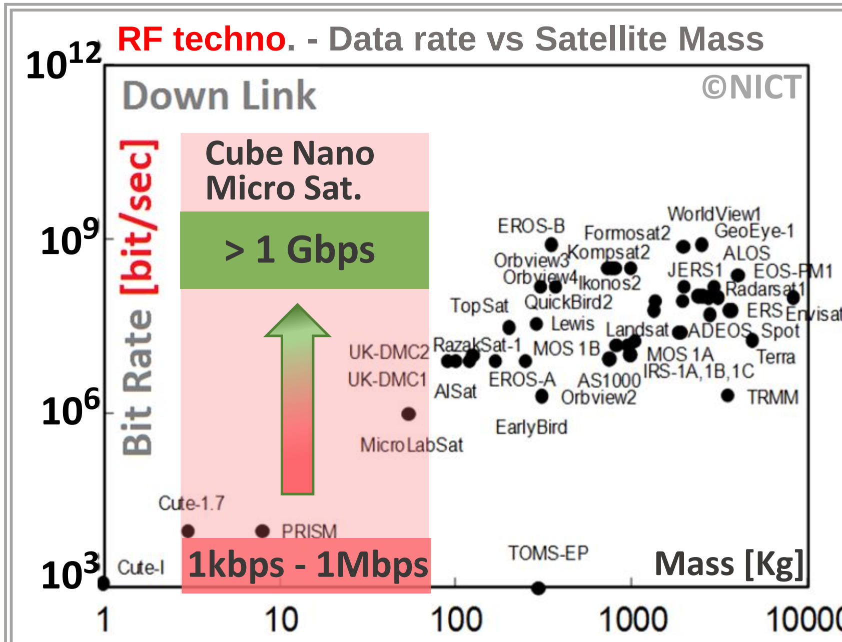
1. Free Space LaserComm – Why?
2. LaserComm – How to work?
3. State of the art – LaserComm
4. Geoazur LaserComm Experiments
5. Prospectives for Satellite Laser Ranging

1. Free Space LaserComm – Why?



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

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



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

RF techno. does not adapt the requirement!!!

Laser communication (26.5–40 GHz) → 1 - 500 Mbit/s × 1000 → (150 –800 THz) → 100 Gbit/s +

CubeSat Lasercomm could scale to Gbps, but **tech. development still required.**

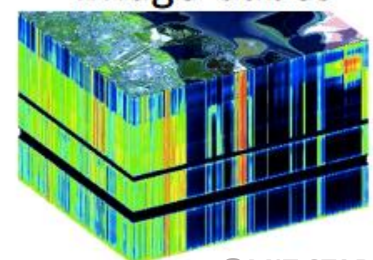
What if your **small satellite** could downlink **100 Gbit/day**?

100 Gb = 80,000 images

~ 1 every sec for a day

= 2 hours of GoPro video

= 120 Hyperspectral Image Cubes



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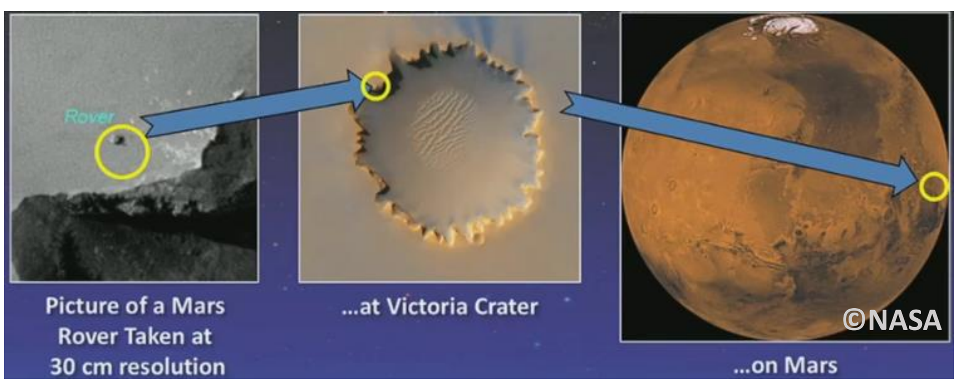


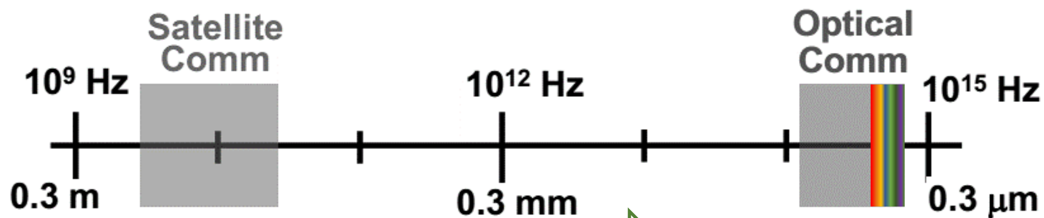
30 cm resolution "Google" map of the entire Martial surface

"Google" map <u>- entire Martial surface</u>

The best RF (Ka-band) system **would take 9 YEARS**

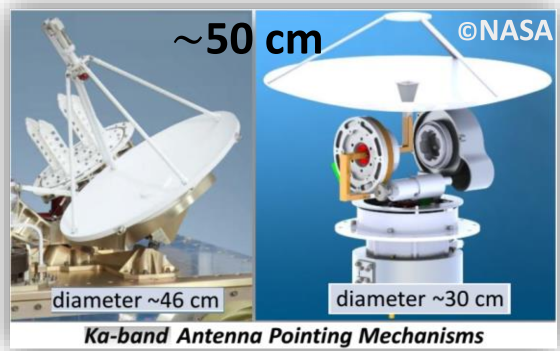
LaserComm can do it in 9 WEEKS

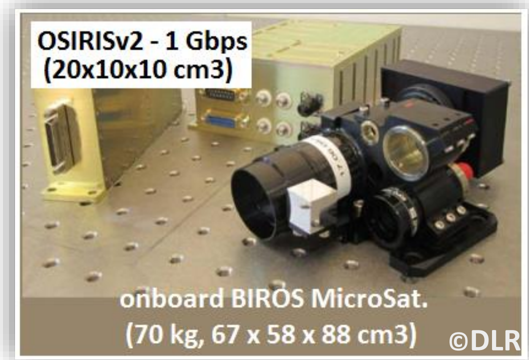
2. LaserComm – How to work?



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

Satellite antenna

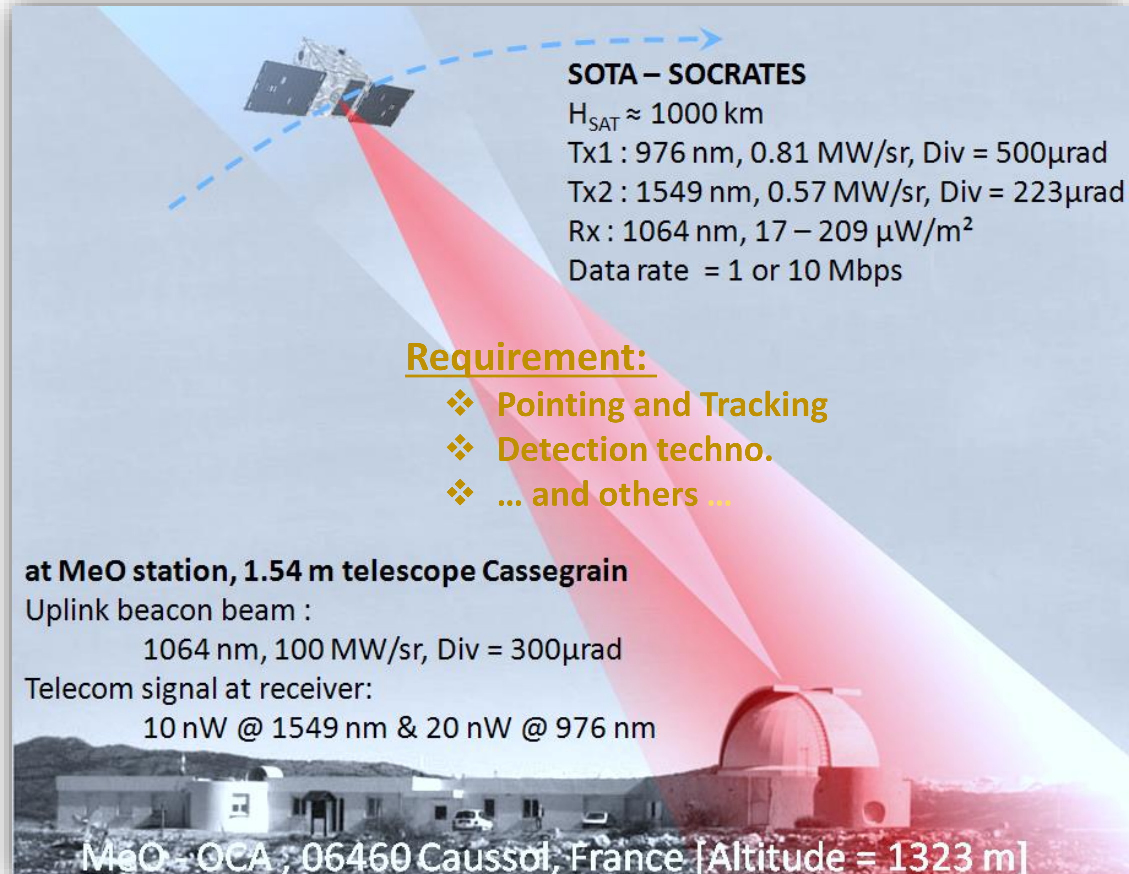


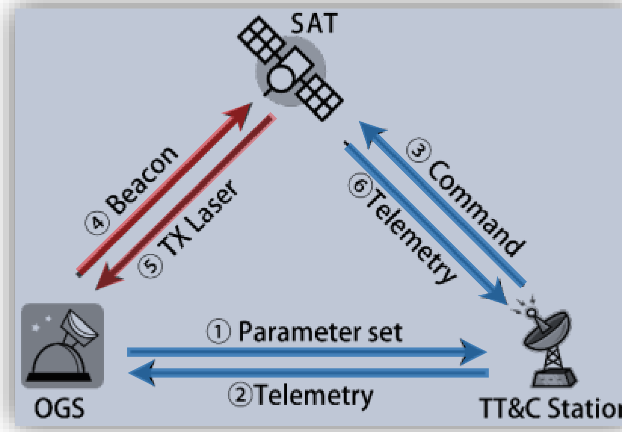


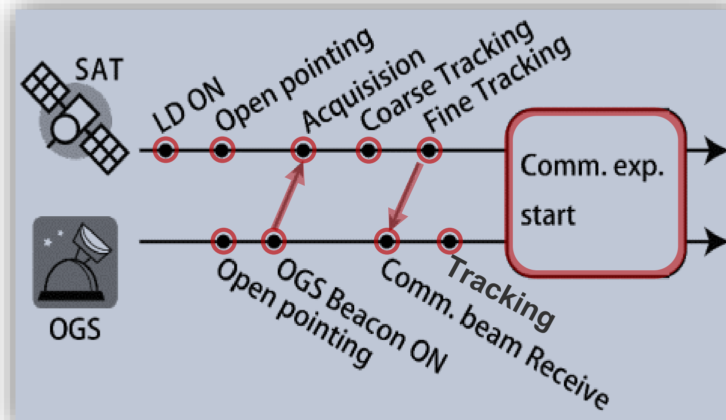
OGS receiver

2. LaserComm – How to work?

Link establishing procedure:



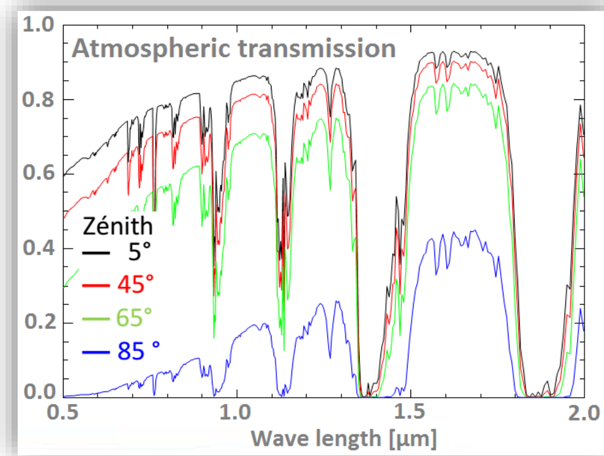




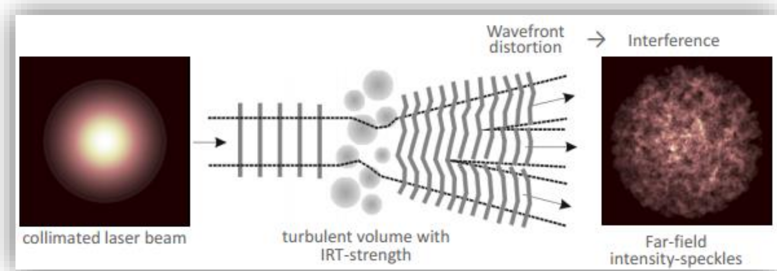
Challenges

- **Tracking and Pointing**
  - Satellite coarse & fine pointing (accuracy & speed)
    (pointing bias + jitter < 40 arcsec)
  - OGS coarse & fine tracking (accuracy & speed)
    (LEO sat. → 4.5 deg/sec demanded on OGS

  → Pointing Losses + Free Space Losses

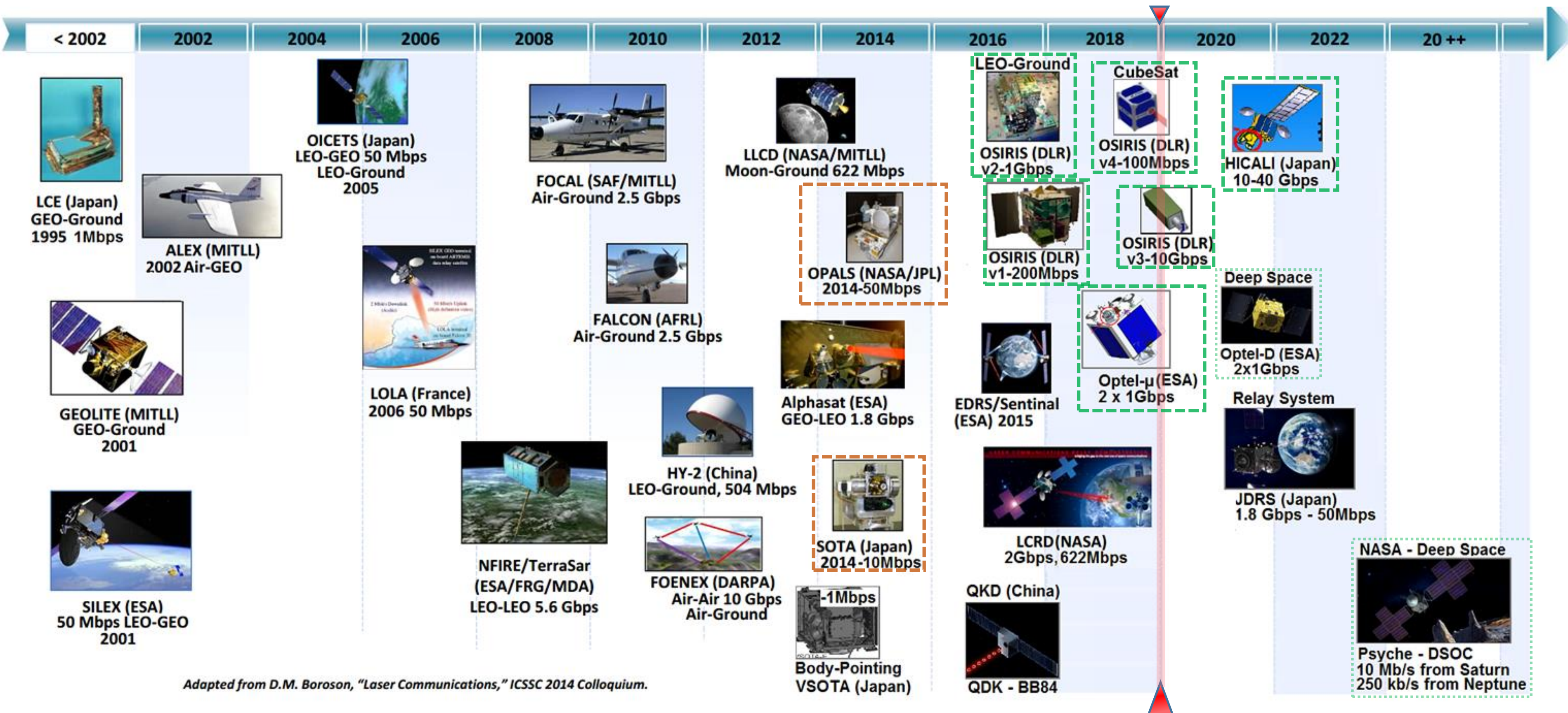


- **Atmospheric effects**
  - Atmospheric attenuation
    (visibility dominated by fog, clouds, rain…)
    (attenuated by Scattering and Absorption)
  - Background noise (backscattered by Earth, direct Sun, Moon light, Sky radiance)
  - Atmospheric turbulence
    (caused by wind and temperature gradients)
    → Scintillation + Wavefront distortion



→ **Small signal level with large fluctuation detected at OGS !**

3. LaserComm– State of the art



Adapted from D.M. Boroson, "Laser Communications," ICSSC 2014 Colloquium.

Geoazur, On est où dans cet histoire?

SOTA (Japan): Jun.-Oct.2015 GND-10Gbps: 2017

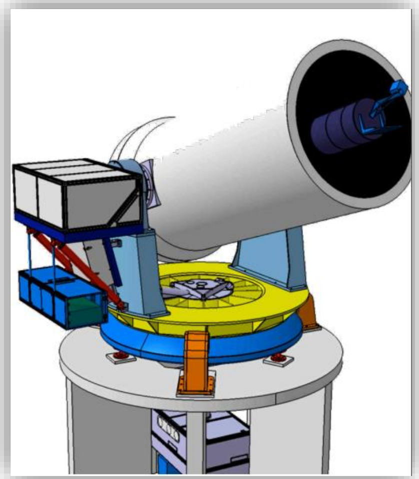
OPALS (Nasa): Dec.2016 OSIRISv1 (DLR): Dec.2019

OSIRISv1-3 (DLR) : → 2020 HICALI (Japan): → 2022

MeO telescope – Why?

- Tracking and Pointing performance
  - Speed max = 5 deg/sec → LEO Sat. possible
    Accuracy < 10 arcsec
- Telescope diameter : 1.54 m
  - low level signal from Sat. → solved
    Accuracy < 10 arcsec
    Repeatability < 0.1 arcsec RMS
- Experience on Sat. tracking, detection
  - Materials (Time & Frequency), orbit prediction…
- High altitude 1273 m
  - Visibility, transmission
    atm. Turbulence…
    → AO demonstration
- CATS instruments
  - GDIMM, PBL
    → AO calibration

Sub-system	Parameters
Telescope Diameter	1.54 m
Telescope speed	5 deg/sec
Pointing accuracy	< 10 arcsec
Pointing repeatability	0.1 arcsec RMS
Motor torque	10000 N m



Geoazur LaserComm – Why?

- ❑ Lunar & Satellite Laser Ranging
  - – **Laser pulse (classic)**
    AM BW : 20 GHz (50 ps) at repetition rate : 10 – 2000 Hz
    Accuracy : 100 ps (integrated over 100 meas.) - centimetric
    LIMITED by ATMOSPHERIC TURBULENCE & REPETITION RATE…

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 – GHz (50 ps) at repetition rate : GHz
  Accuracy : 1 ps expected → millimetric

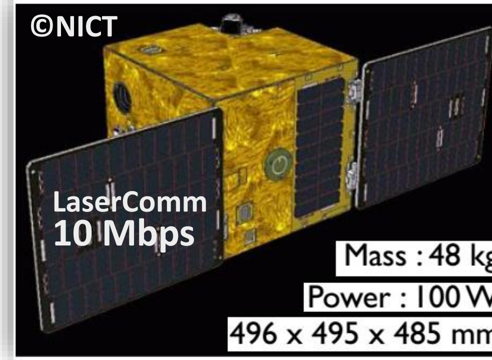
4. Geoazur LaserComm - Experiments

SOTA onboard SOCRATES


SOTA-CONT

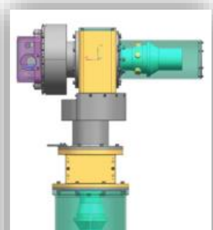

SOTA-OPT

Mass	5.9 kg (incl. both the optical & electric part)			
Power consumption	Sleep mode	Stand-by	Tx1	Tx2,3,4
	1.7W	2.0W	15.7W	12.6W
Gimbal range	Az: >±50deg, El: -22deg~+78deg			
Link range	1000 km			
Wavelength	Tx1: 976 nm			
	Tx2 and Tx3 : 0.8 µm			
	Tx4 : 1549 nm			
	Rx: 1064 nm, Acquisition/Tracking: 1064 nm			
Data Rate	1Mbps / 10Mbps (selectable)			

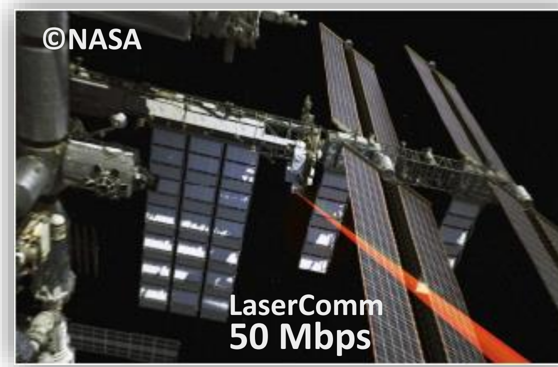


5/6 successful links 1550 nm & 976 nm (Jun., Jul., Oct 2015 and Mar., Apr. 2016)

OPALS on ISS

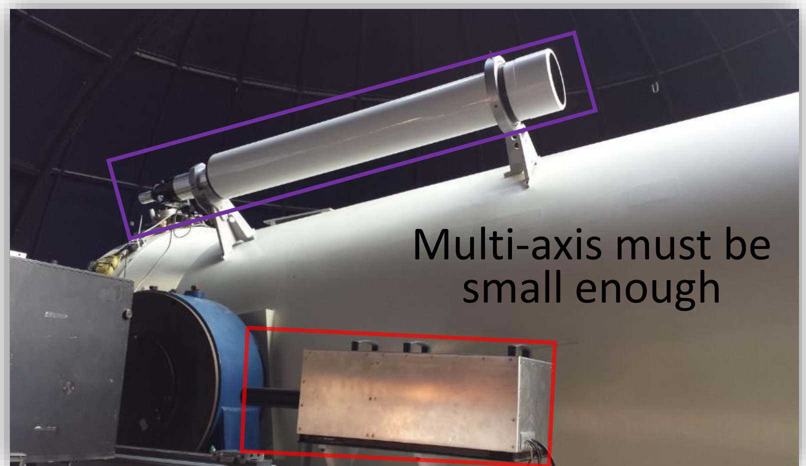

Gimbal ISS

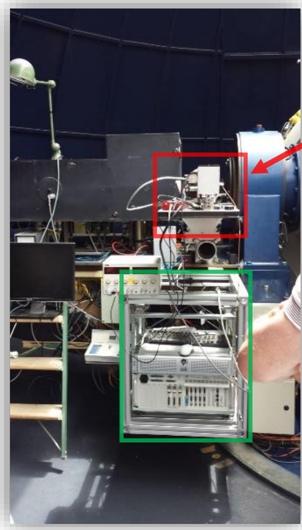
Modulation	OOK	-
Modulation Rate	30-50	Mb/s
TRANSMITTER		
Downlink wavelength	1550	nm
Beam Divergence (1/e^2)	1.1	mrad
Power transmitted from FS	>0.833	W
POINTING		
Pointing Bias	150.0	µrad
Pointing Jitter (RMS)	125.0	µrad

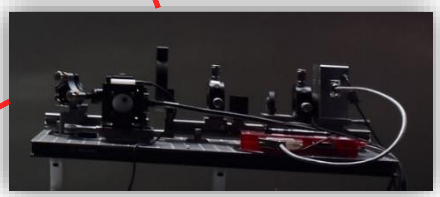


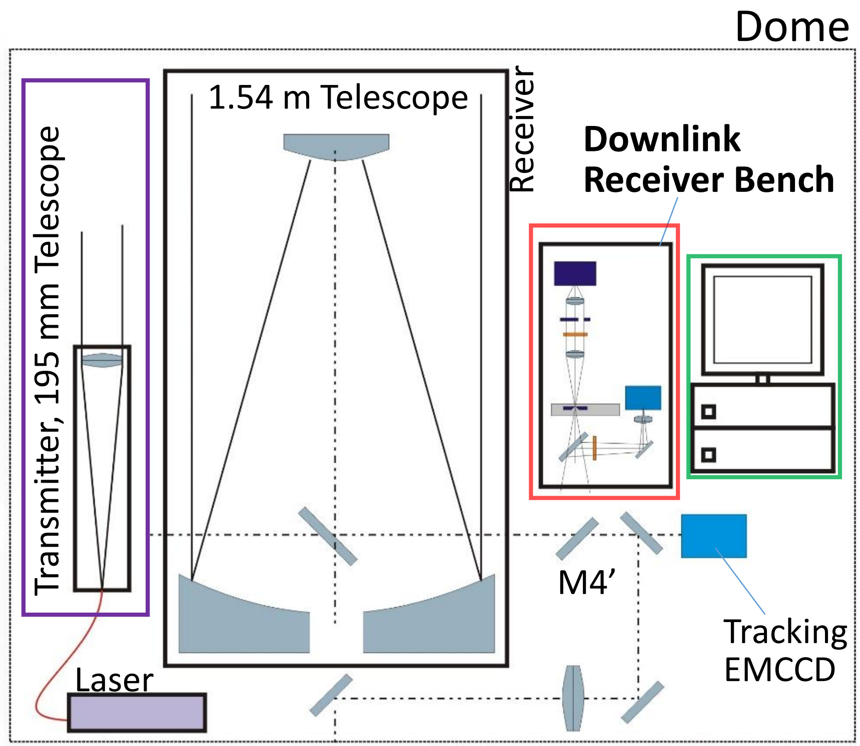
1/1 successful links 1550 nm (Dec 2016)

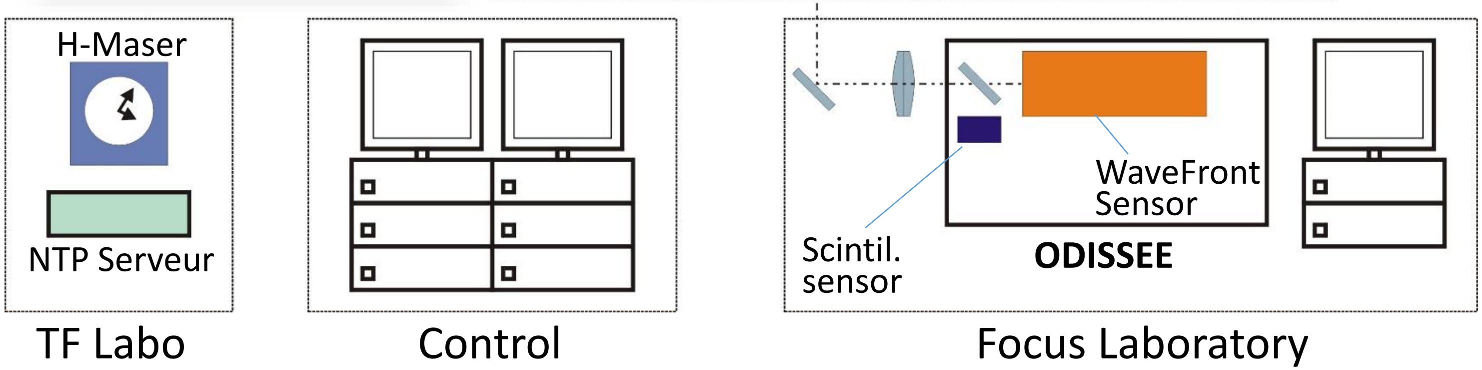
4. Geoazur LaserComm – SOTA 2015





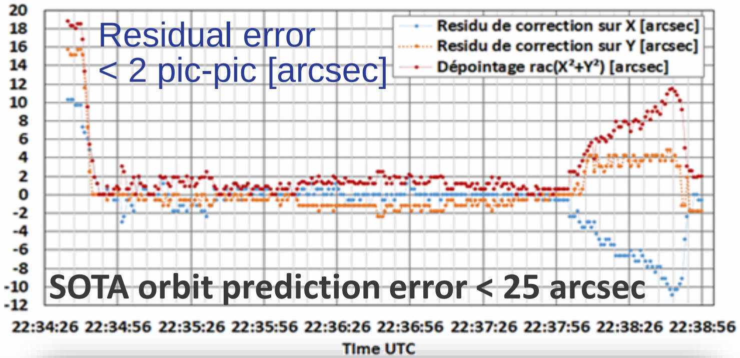


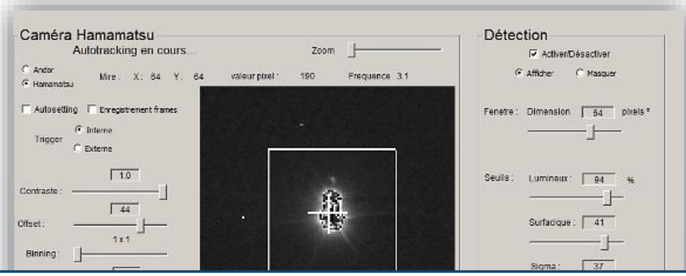




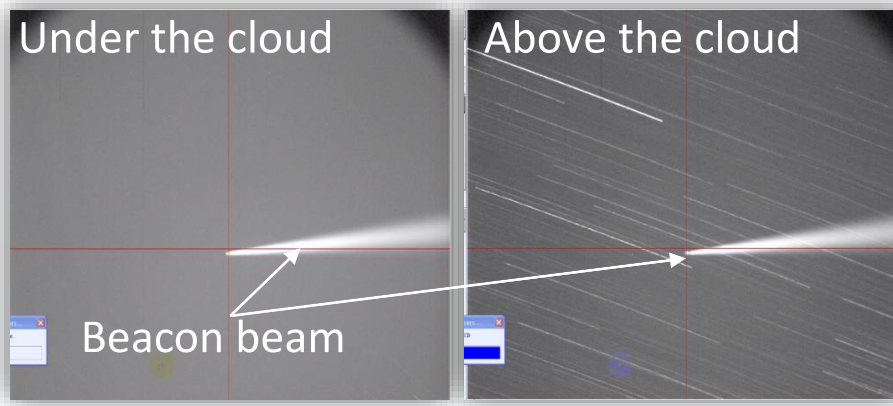
4. Geoazur LaserComm – 2015, 2016

SOTA Auto-Tracking

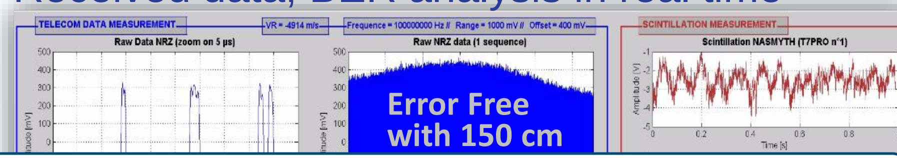




Wide Field of View camera



Received data, BER analysis in real time



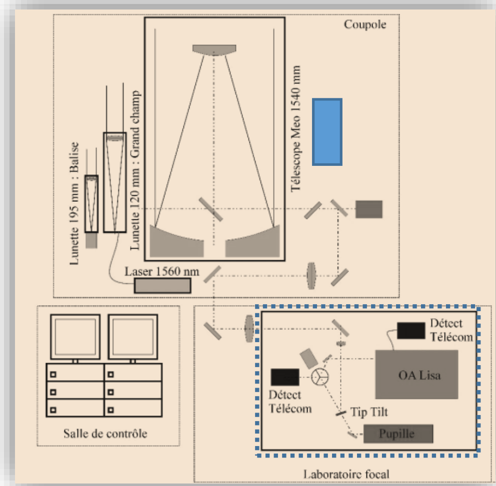
- ❑ **5/6 successful link LEO Sat. ↔ MeO: 20, 40, 150 cm subaperture - TESTED**
- ❑ **Data Transmission (Bit Error Rate) - TESTED**

  95% BER > 1% with 40 cm → LaserComm with 40 cm telescope: POSSIBLE!
- ❑ **Propagation channel measurements**
  - Wave Front Sensor (Shack –Hartmann) → Turbulence profiles during satellite pass
  - Comparison with models – Link budget, scintillation …
- ❑ **Adaptive Optics – First demonstration**

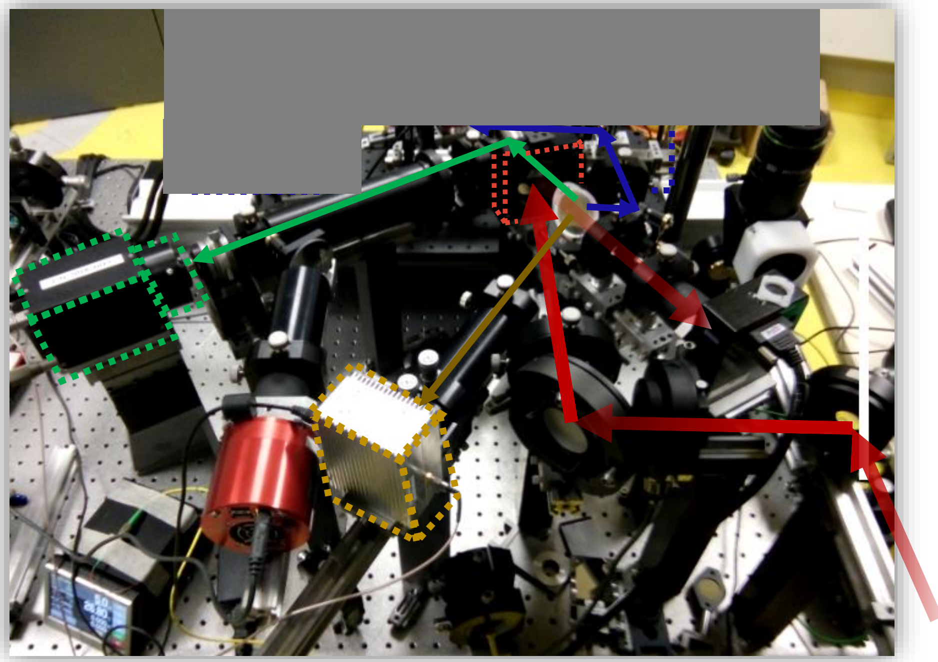
Experiment with OSIRISv1 – OSIRISv2 (10 Gbps)

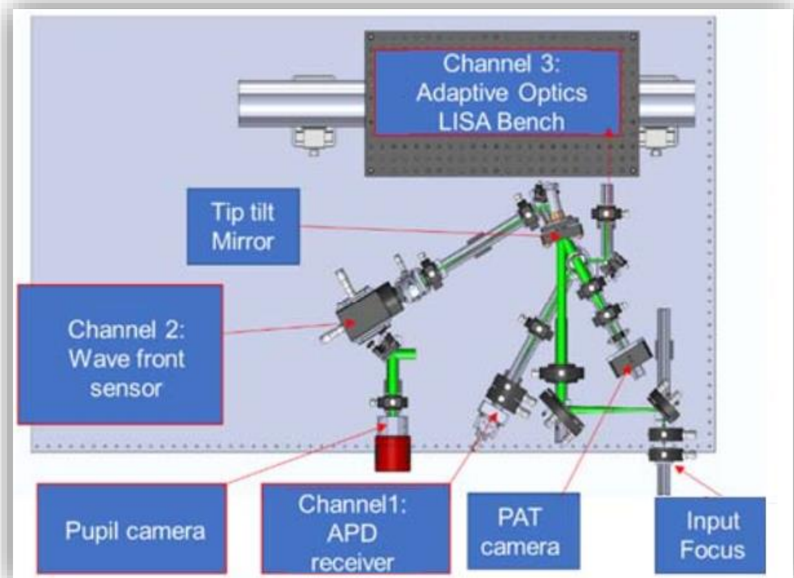
Challenges

- ❑ Test bench **Nasmyth → Coudé**
  - – **More detection channel (3 x 50 cm sub-aperture)**
- ❑ Tracking and Pointing Upgrade
  - – **tracking with coarse & fine corrections**
    (accuracy < 2 arcsec RMS)
    + IR fine tracking camera (FoV = 60 arcsec)
    + IR coarse tracking camera (Wide FoV)
- ❑ Telecom detection Upgrade **10Mbps → 1 Gbps**
  - – **High speed & high sensibility APD telecom 1 Gbps**
  - – Telecom signal **recording at <u>3200 MSps</u> – 16 bits**
- ❑ Atmospheric characterization

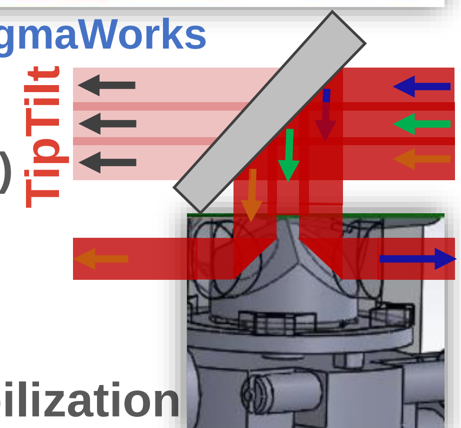


Test bench Nasmyth → Coudé



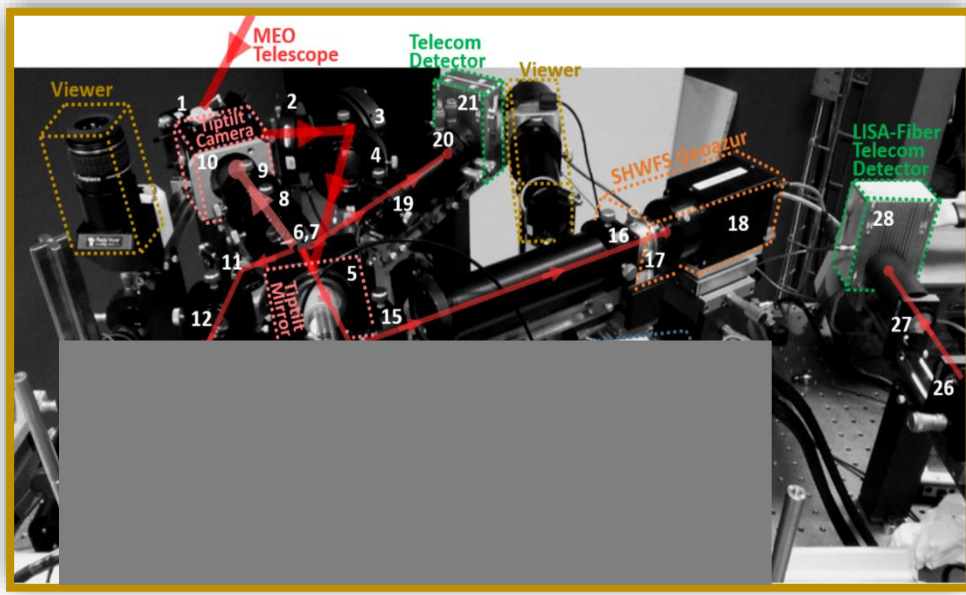


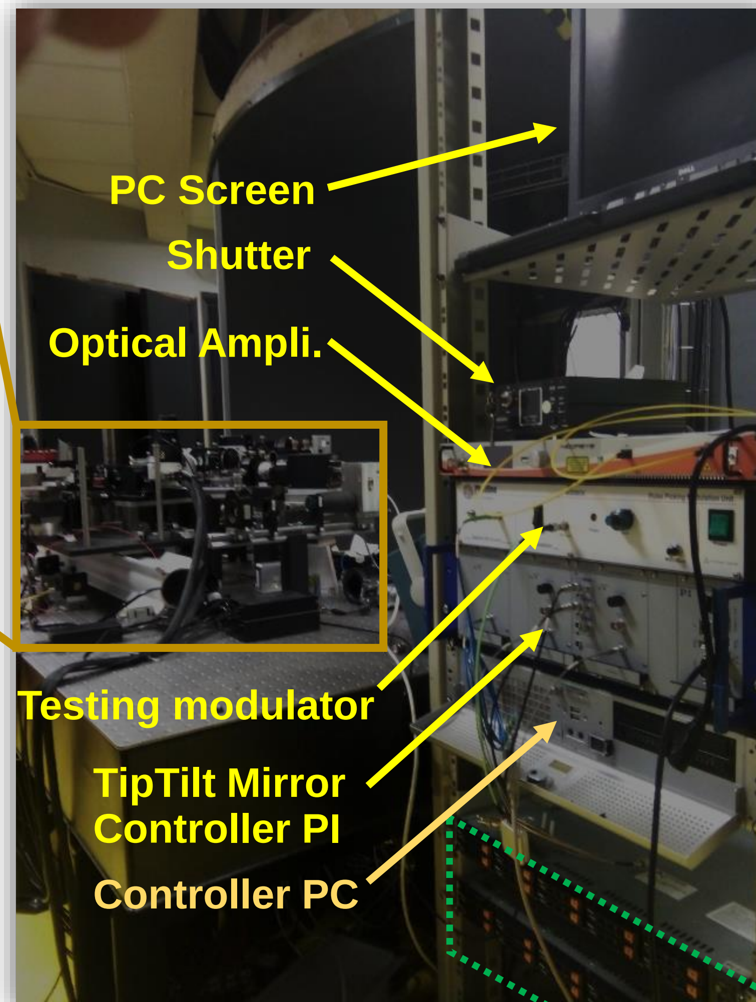
Designed by SigmaWorks



- ❑ 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 →



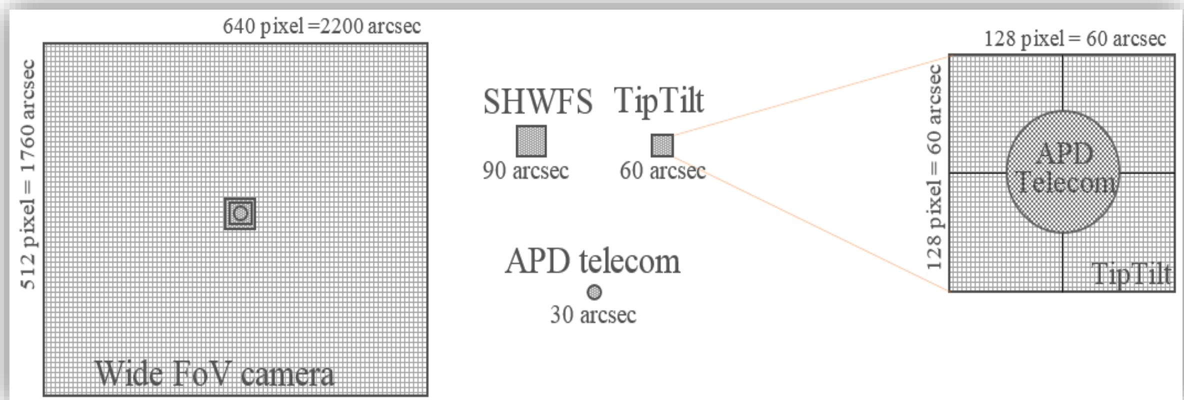


Wide FoV Camera (1700 arcsec) installed on 200 mm telescope mounted on MeO

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

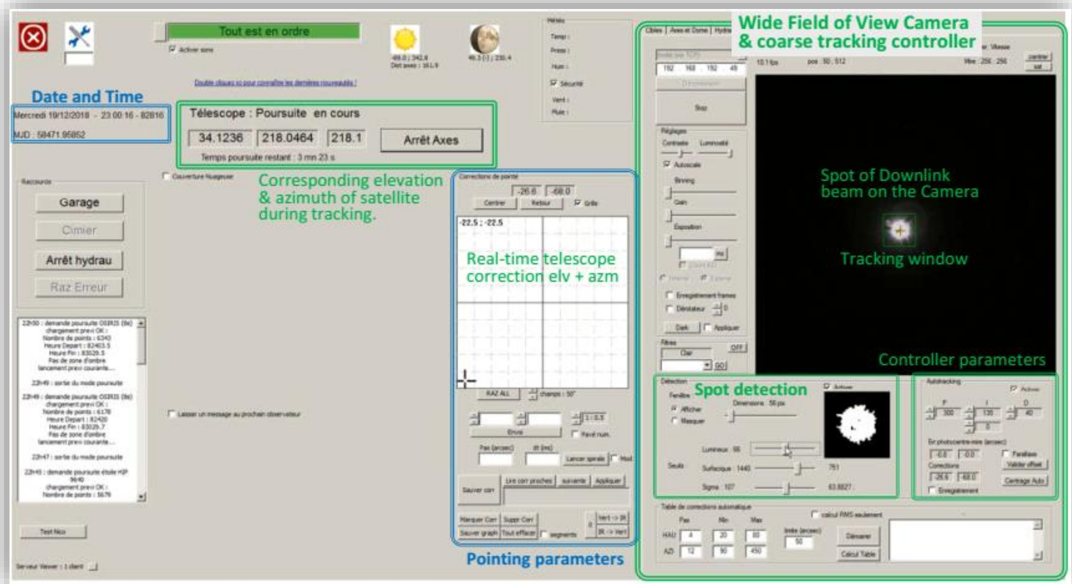
4. Geoazur LaserComm – 2017, 2018 →

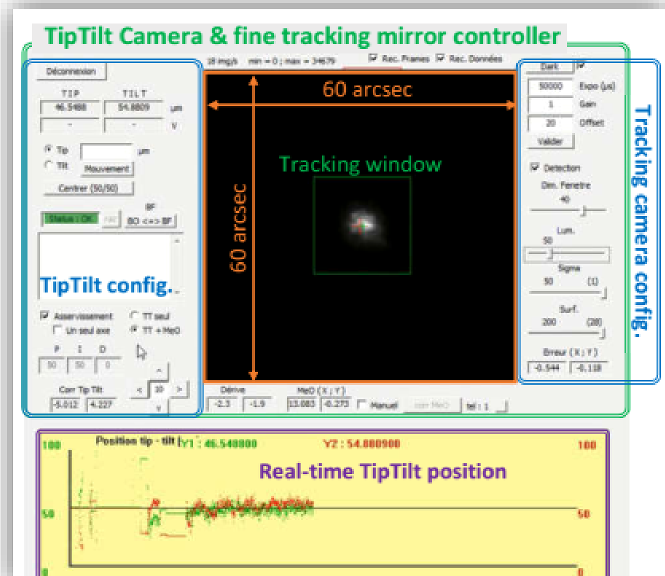
Combination of coarse and fine auto-tracking



Objective: Maintaining spot laser on APD detector and LISA bench

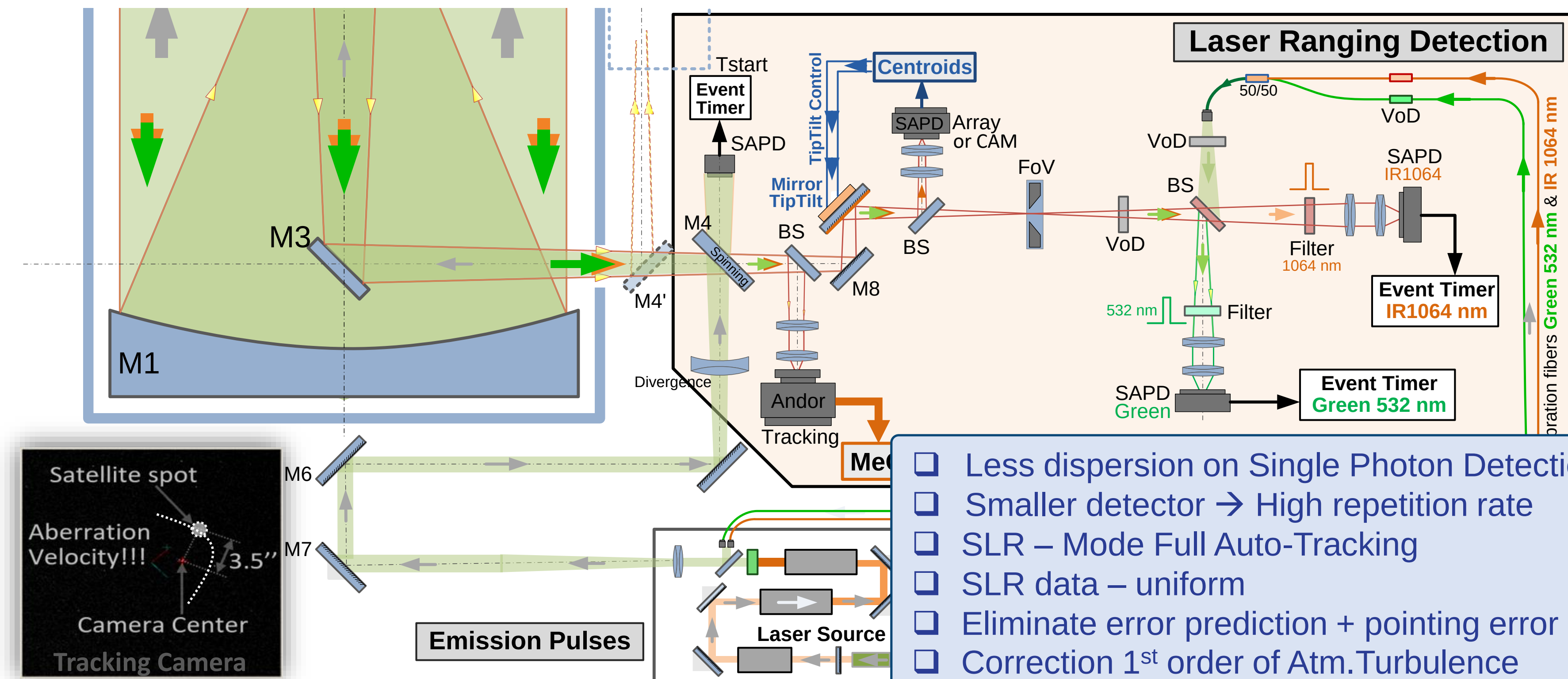
- ❑ Coarse tracking : large + slow
  Wide FoV camera (1700 arcsec)
  → MeO control signal
- ❑ Fine tracking : small + fast
  TipTilt Mirror + camera (60 arcsec)
  → TipTilt Mirror orientation
- ❑ Saturation → discharged by Coarse.





Geoazur LaserComm Experiences ➔

- ➢ **Adaptive Optic for SLR: Full-Autotracking, smaller Timing Jitter**
- ➢ **Telecom detection: Time Transfer by LaserComm link**

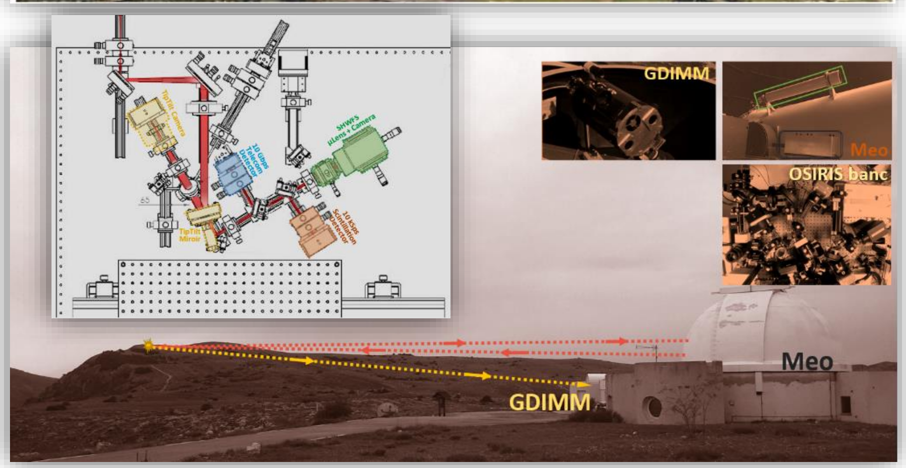


- ❑ Less dispersion on Single Photon Detection
- ❑ Smaller detector ➔ High repetition rate
- ❑ SLR – Mode Full Auto-Tracking
- ❑ SLR data – uniform
- ❑ Eliminate error prediction + pointing error
- ❑ Correction 1st order of Atm.Turbulence

Eliminate Sat. Aberration velocity issue
& Long Term Drift on MeO error pointing ➔ Smaller Timing Jitter on SPAD Event Timer

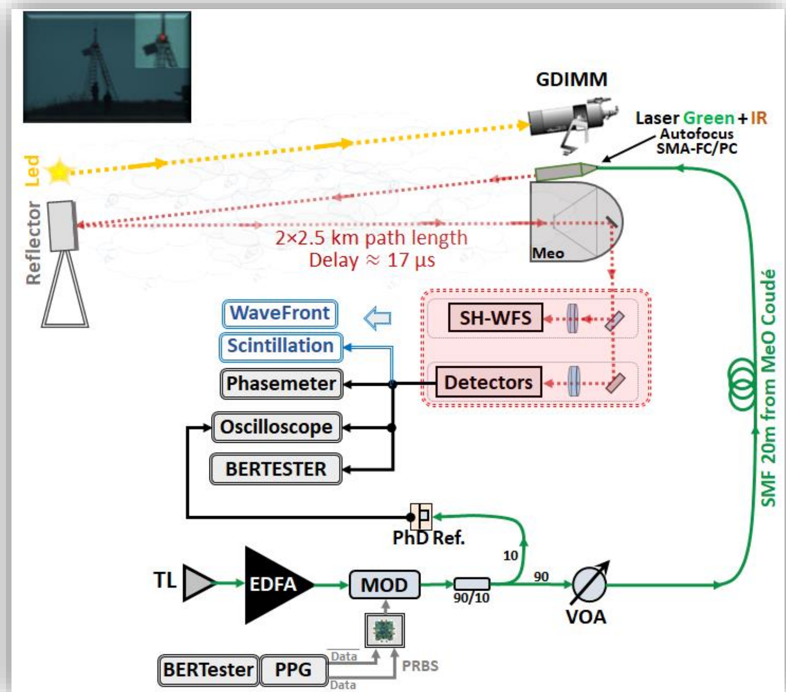
➢ Telecom detection → Time Transfer by LaserComm link

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
(Components on Telecom domain)



- ❑ Atmospheric turbulence effect:
  - + High speed Telecom detection,
    - → SNR, BER measurement
  - **+ Laser Ranging Measurement**
    - **High Speed > 10 kSps**
- ❑ Understanding SHWFS data
  - → model for Deformable Mirror

Transfert du Temps par un lien Télécom Laser
Pourquoi pas!

Merci de votre attention

Optique Adaptative pour la Télémétrie Laser
Lien descendant et Montant!!!

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