

Les communications en espace libre.

Le projet : DOMINO

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Grégoire Martinot-Lagarde : **UCA/OCA/Geoazur**

Géraldine Artaud : **CNES**

Nicolas Vedrenne, Cyril Petit : **ONERA**

JCOM 2016 - Nice



Observatoire
de la CÔTE d'AZUR



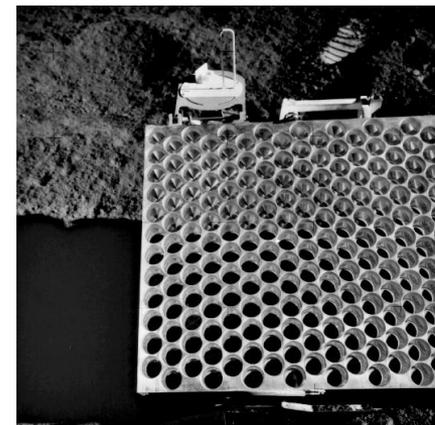
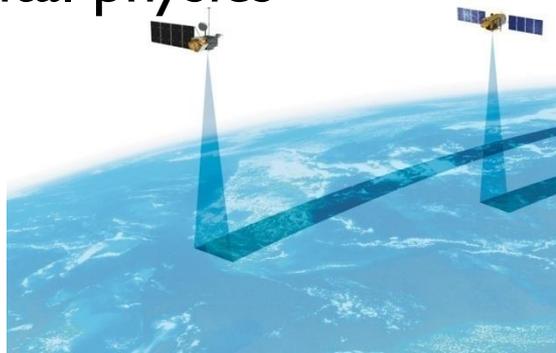
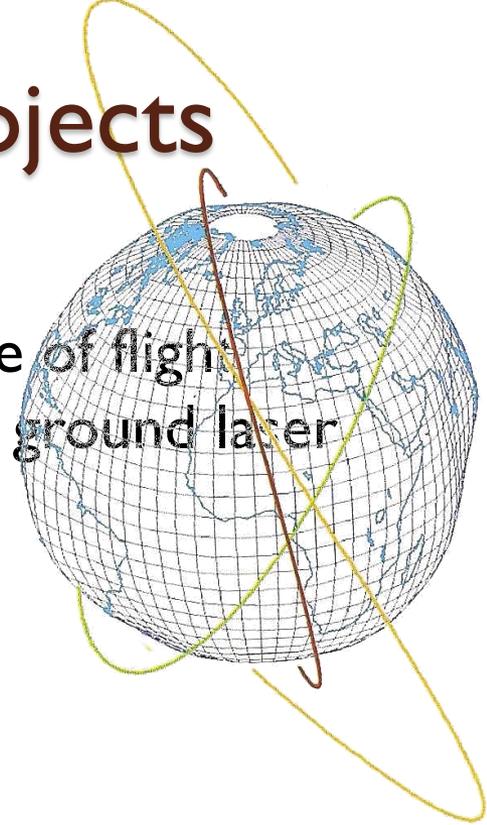
AstroGeo Optical link projects

Laser Ranging

- Satellite distance measurement from a Time of flight measurement of a short laser pulse from a ground laser station to a space target



- Earth gravity field
- Variation of the earth rotation
- Geodesy
- Altimetry calibration
- Fundamental physics



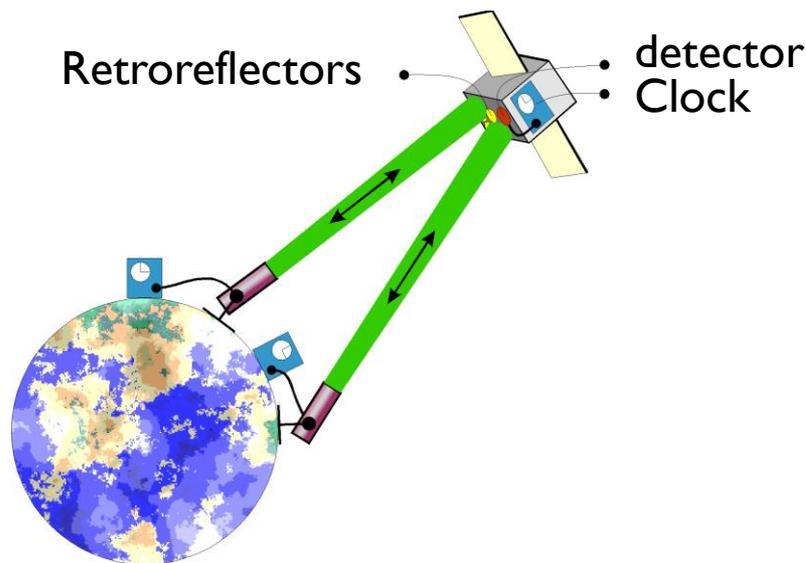
AstroGeo Optical link projects

Time Transfer by laser link T2L2

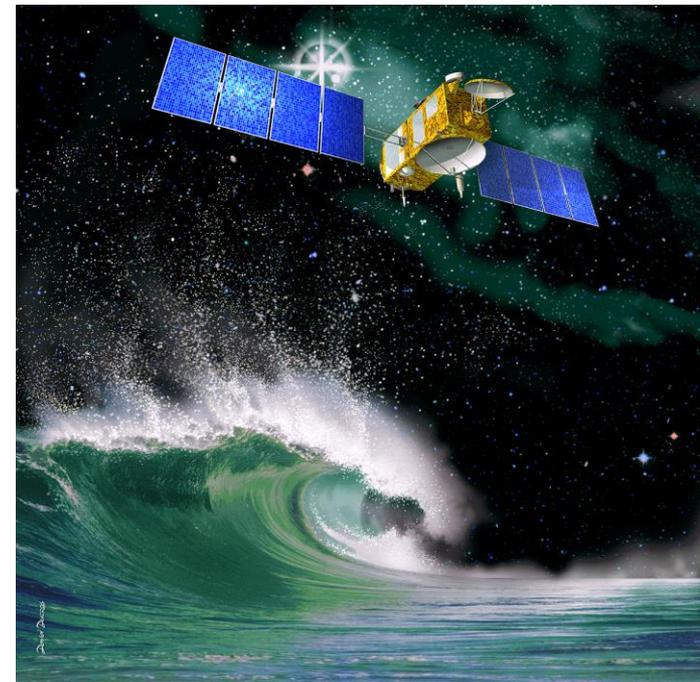
- Picosecond synchronization of remote clocks with laser ranging technology ; launch on Jason 2 in 2008



- Time and frequency metrology
- Fundamental physics



...Koganei Collaboration in 2012



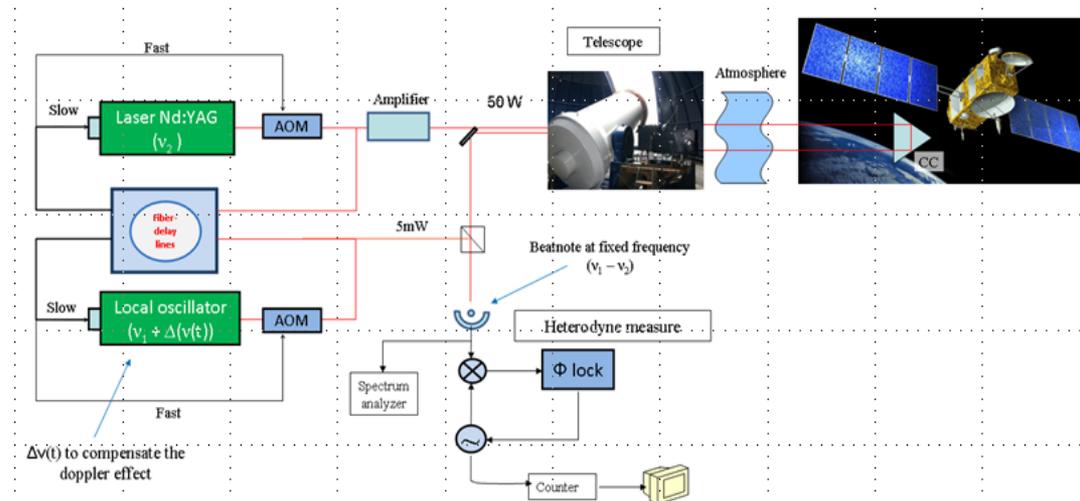
AstroGeo Optical link projects

Coherent laser link MiniDoll (Syrte)

- Doppler measurement from a ground station and a satellite with a Coherent interferometer



- Geodesy
- Frequency transfer
- Fundamental physics



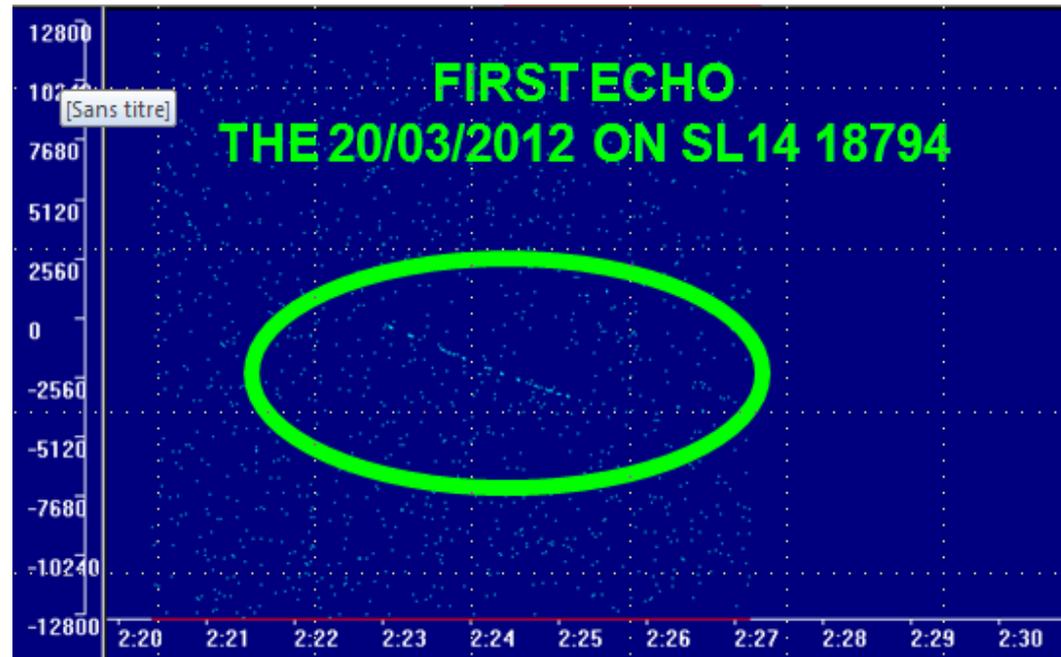
AstroGeo Optical link projects

Space Debris detection (Airbus DS)

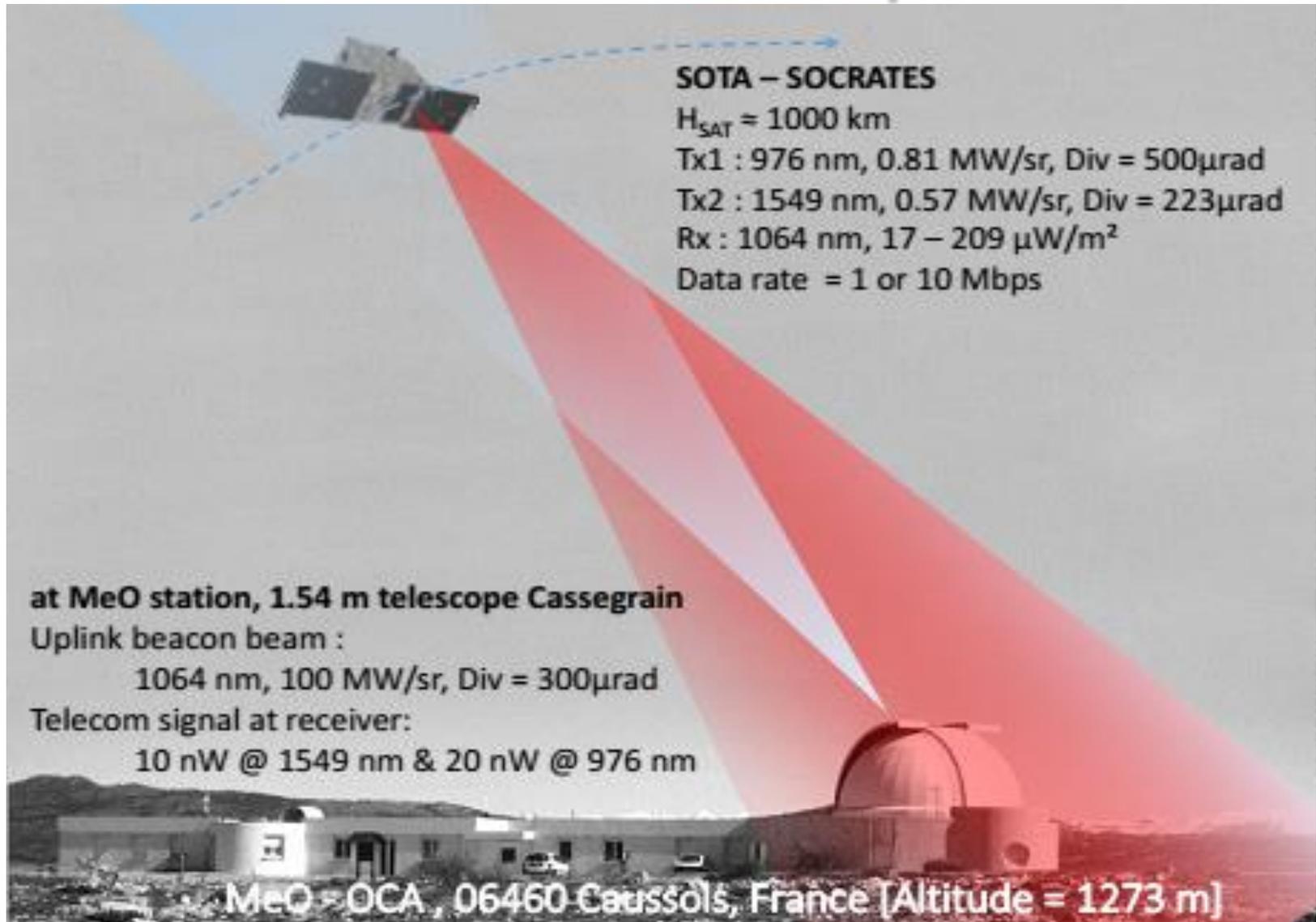
- Debris distance measurement done from Laser ranging on non cooperative targets



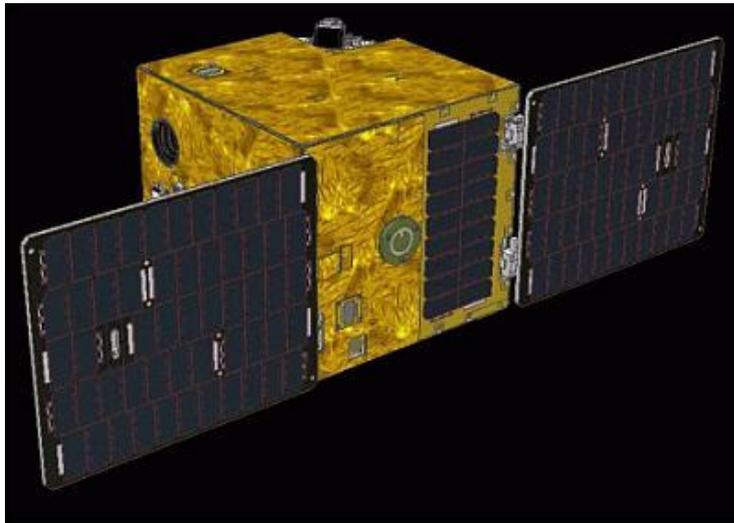
- Space security
- Optimization of satellite displacements



DOMINO – SOTA Experiment



Space segment Launched on May 24, 2014



Credit: NICT

SOCRATES Satellite

Mass : 48 kg

Size : 496 x 495 x 485 mm

Power : 100 W

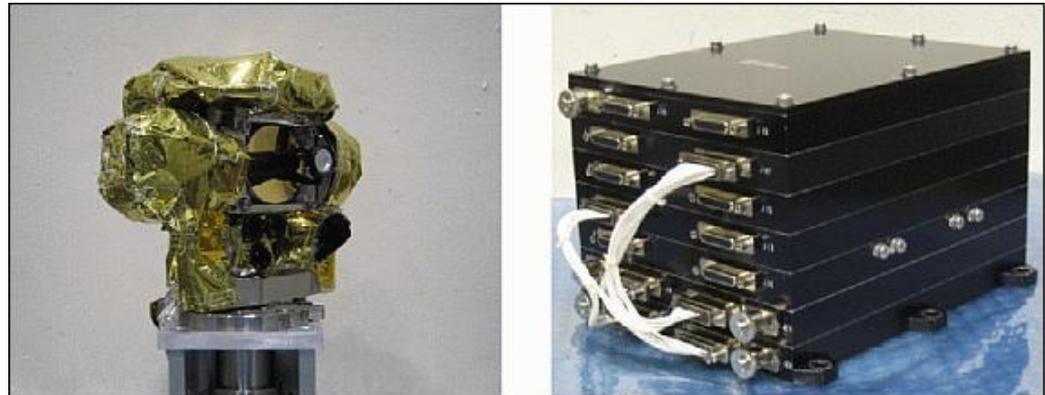
Three axis stabilized

SOTA PFM

Optical – Electronic

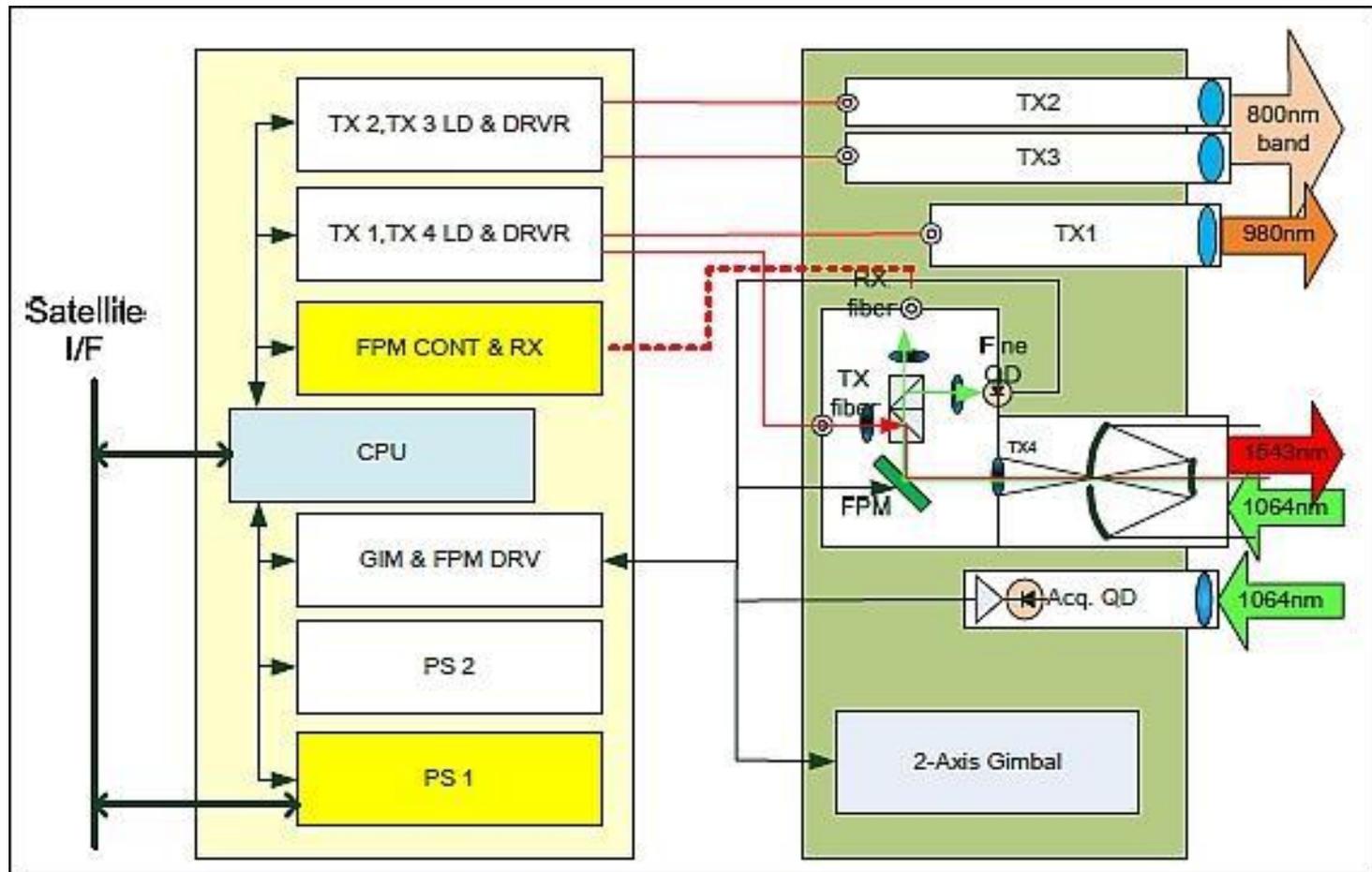
Mass : 6.2 kg

Size : 177 x 130 x 264 mm



Credit: NICT

Space Segment SOTA (Small Optical transponder)



Site Instrumenté Calern

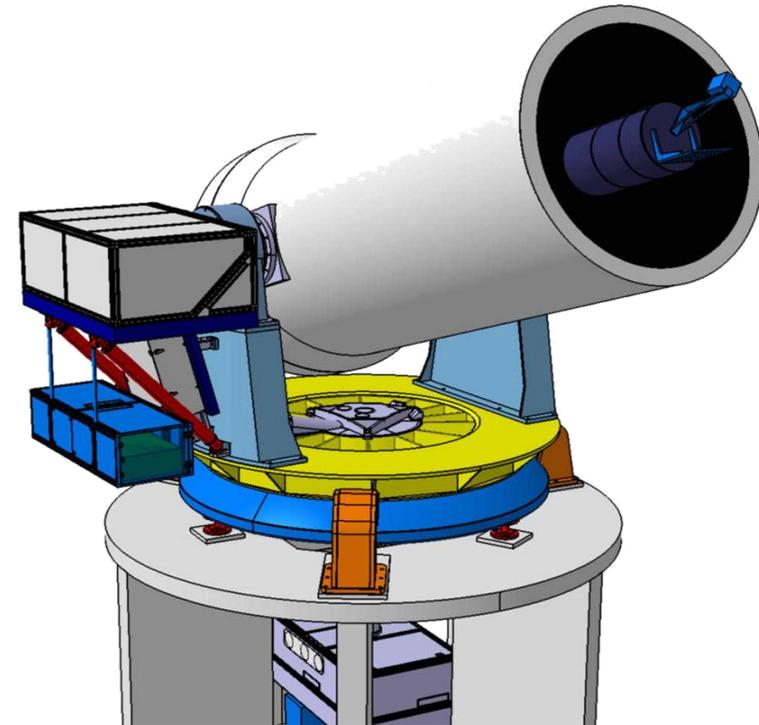
Lien Laser

- Meo Station
 - Ritchey Chretien Telescope: 1.54m - Direct drive motorization
 - 3 Focal laboratories
 - Laser ranging system (Moon, satellites)
 - Adaptive Optics ODISSEE Bench (ONERA-Geoazur)
- Time and frequency laboratory
 - H-masers, 2 Cs Atomic clocks
 - Two-Way and GPS time transfer equipment
- Atmospheric turbulence monitor (Lagrange)
 - Generalized Differential Image Motion Monitor GDIMM
 - Profiler Moon Limb

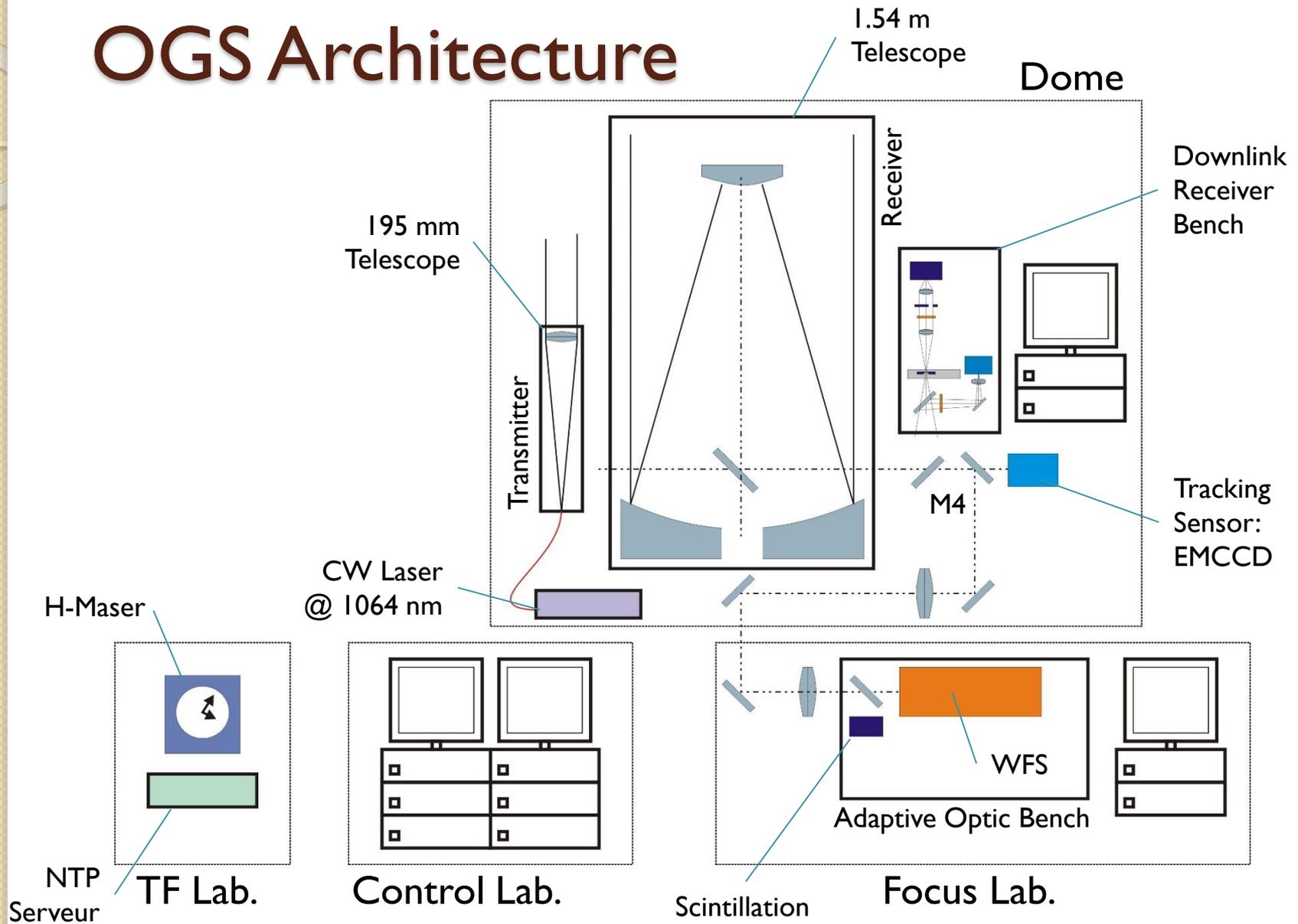


MeO (Métrologie Optique)

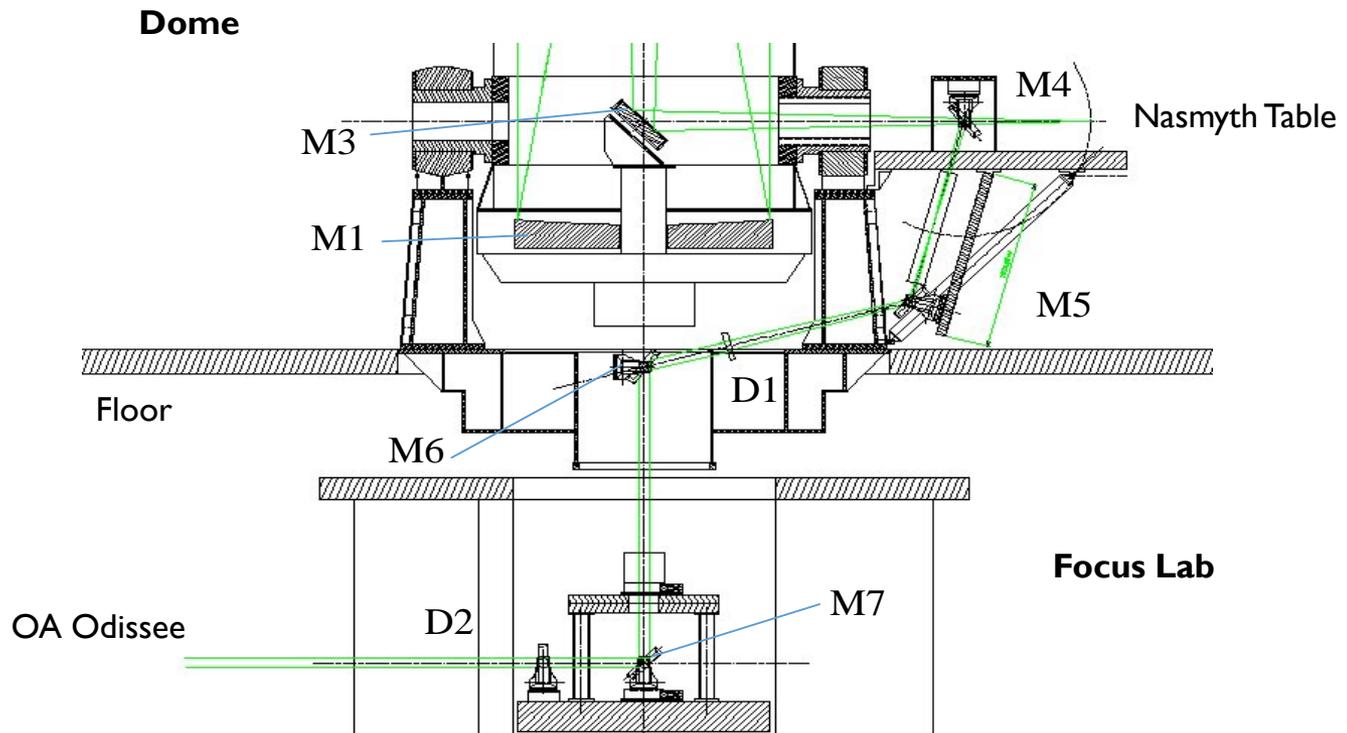
- Ritchey Chretien optical configuration
 - Primary Mirror: Parabolic 1540 mm
 - Nasmyth table (fold mirror)
- Encoders
 - Linearity: 1 arcsec
 - Repeatability error < 0.1 arcsec rms
 - Absolute accuracy < 2 arcsec rms
- Motorization
 - Direct drive Etel motors
 - Torque: 10000 Nm
 - Speed: 5°/s
 - Time constant: 0.1s



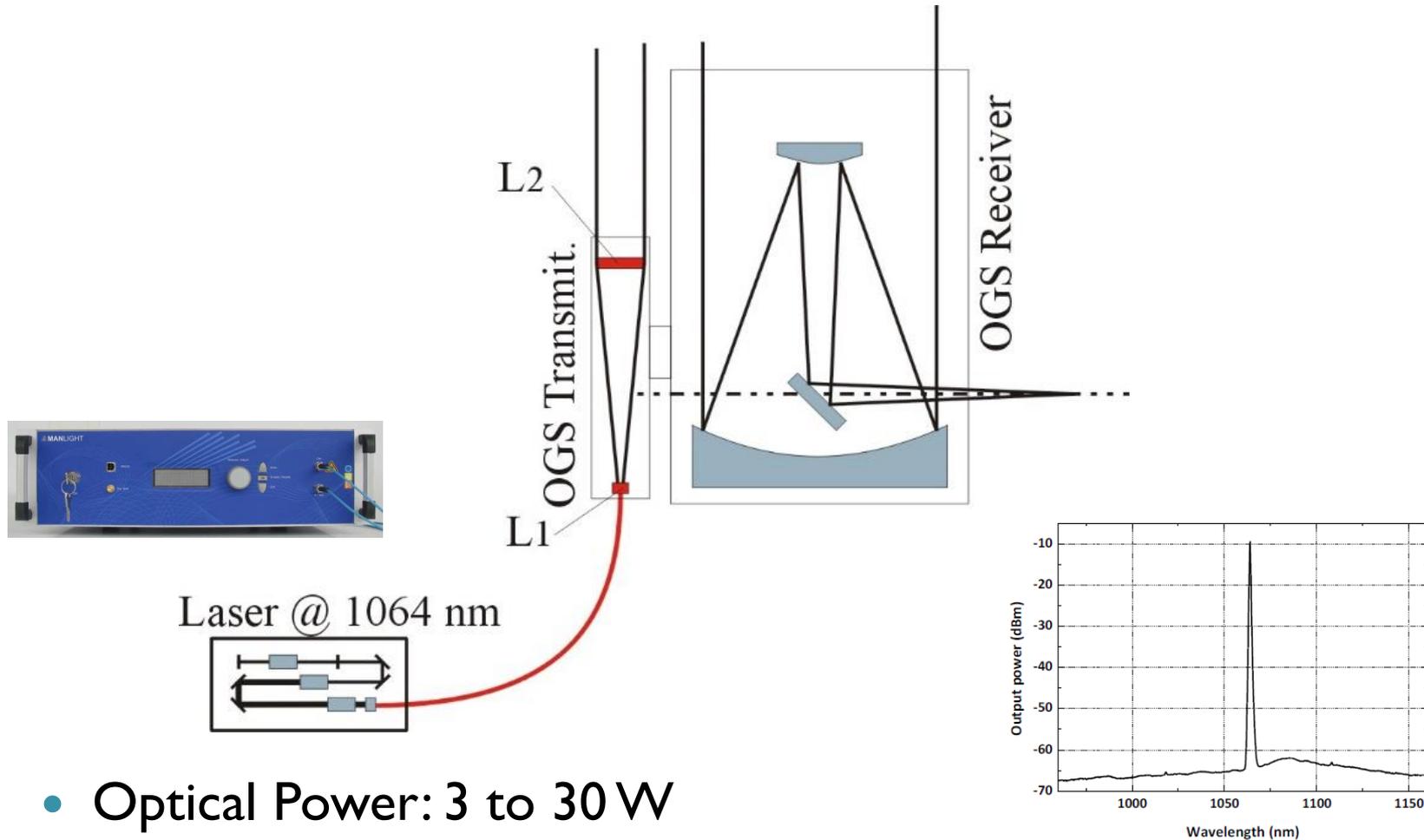
DOMINO OGS Architecture



MeO: Optics Cross Section View



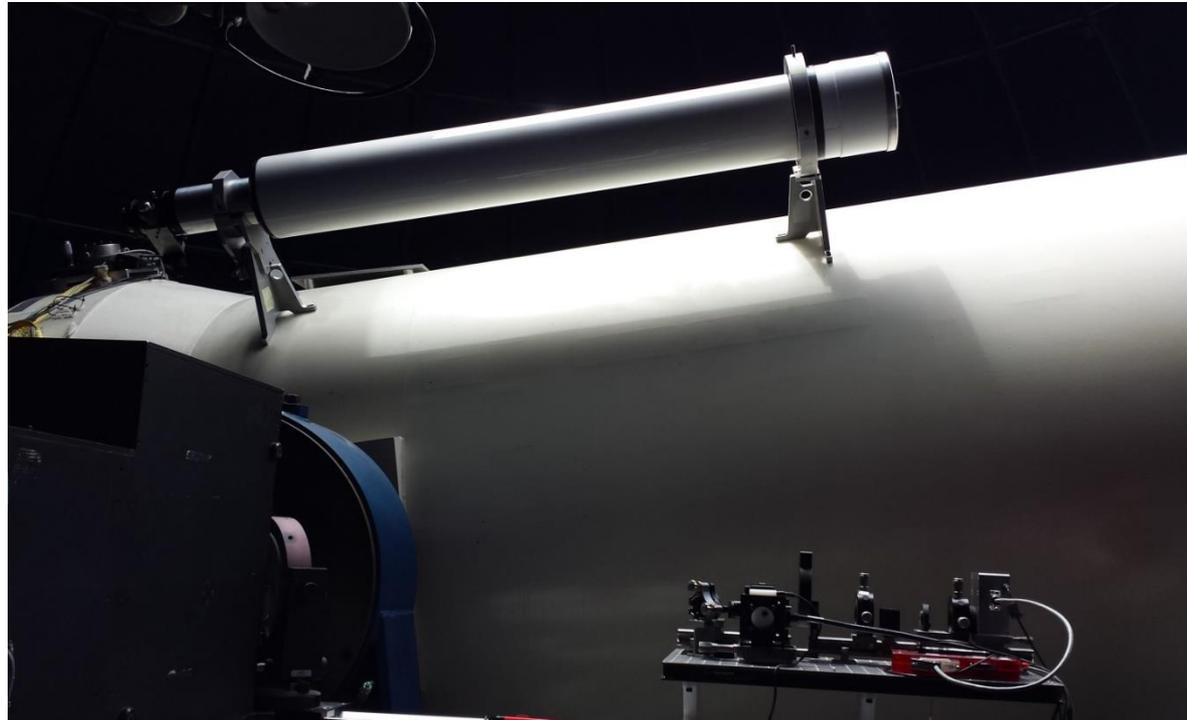
Transmitter



- Optical Power: 3 to 30 W
- Divergence: Spherical wave up to 500 μ rd full angle
- Orientation: manual

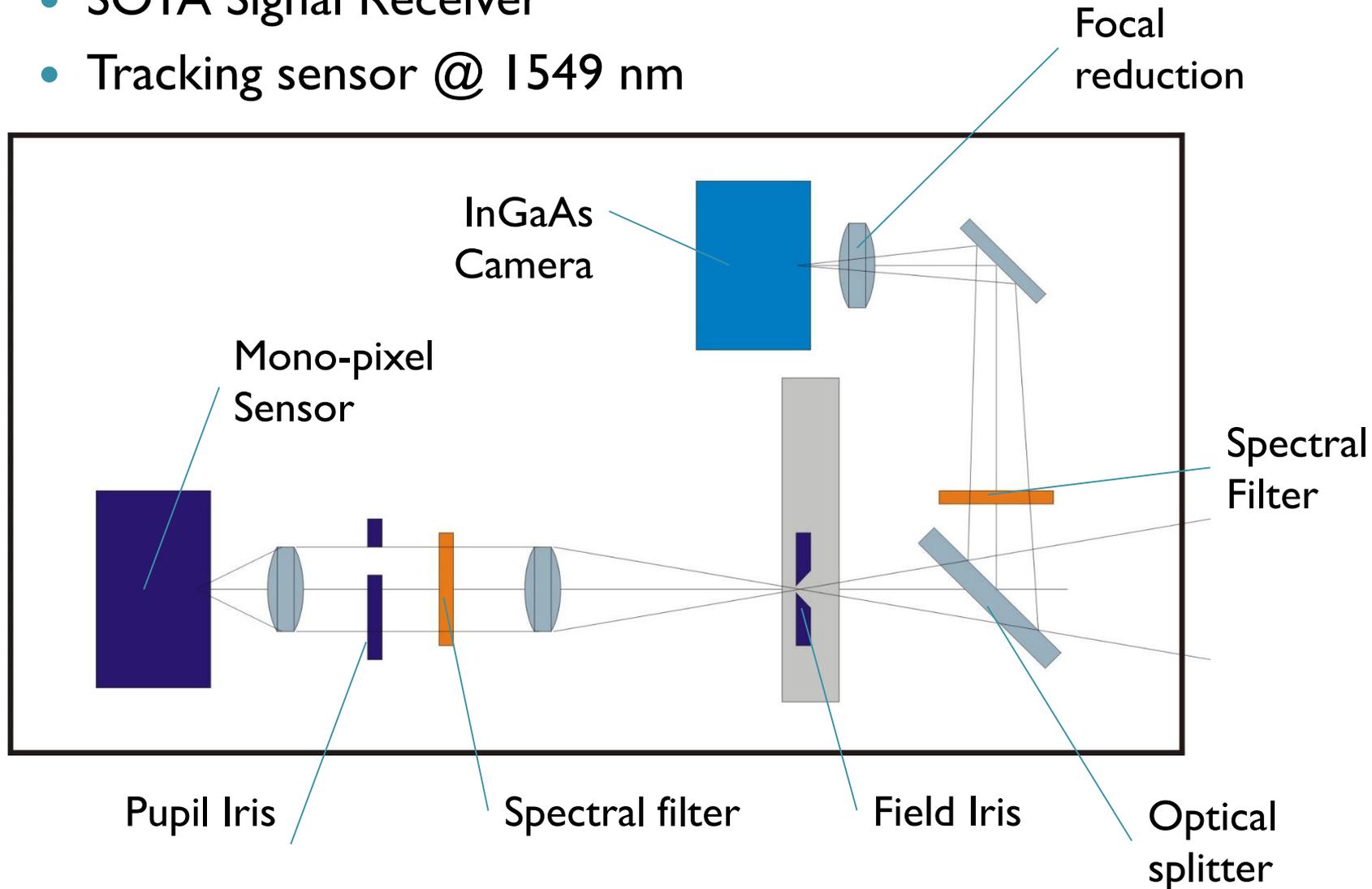
Transmitter 195 mm Telescope

- Aperture : 195 mm F/9
- Carbon
- Apochromatic
- Diffraction limited



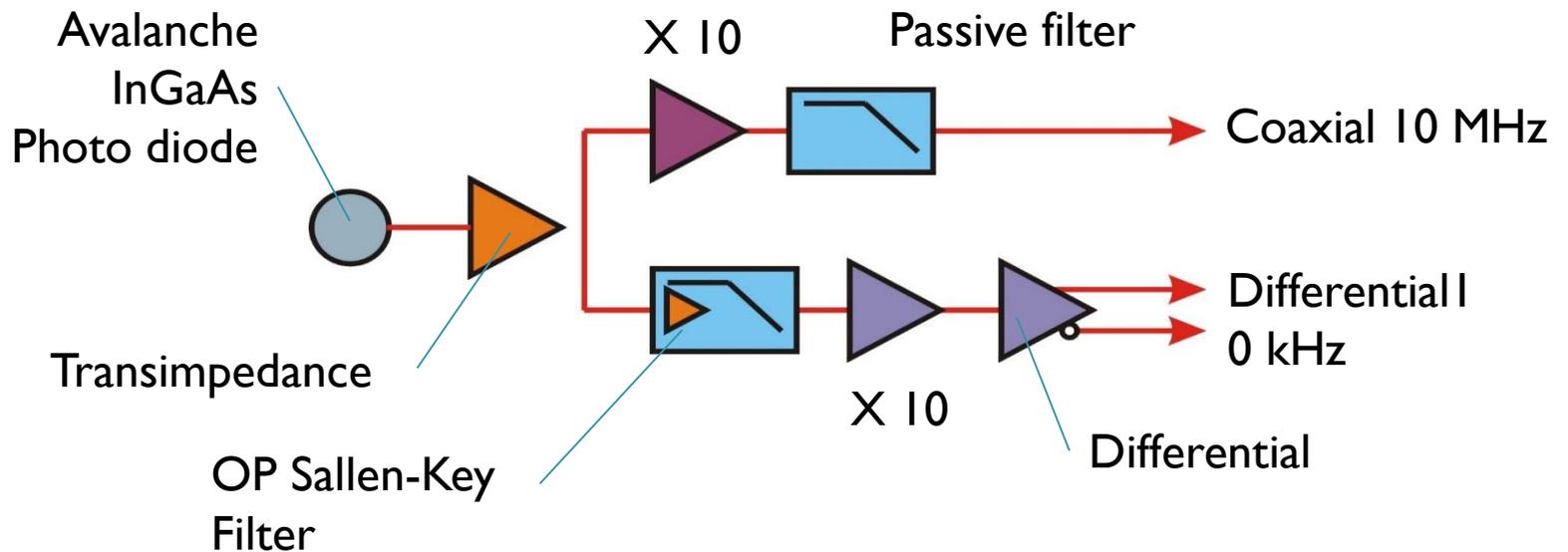
Downlink Receiver Bench @ Nasmyth

- SOTA Signal Receiver
- Tracking sensor @ 1549 nm



Mono-pixel Sensor

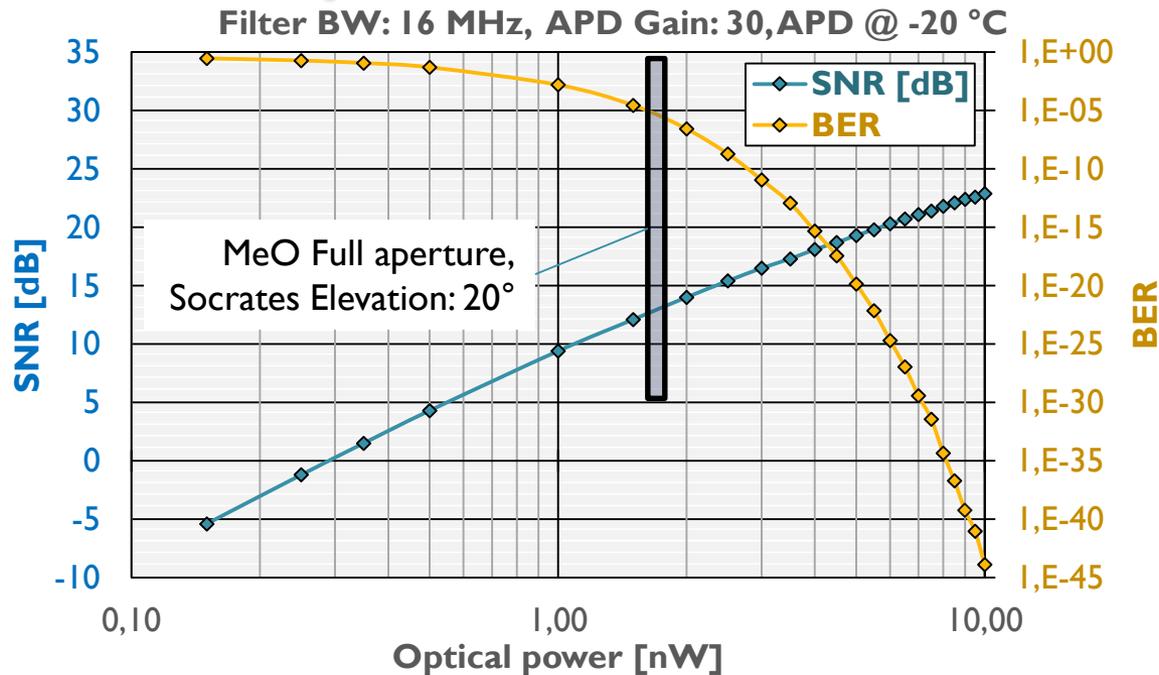
- Telecom detection @10 ou 1 Mbps
- Atmospheric scintillation measurement



Mono-pixel Sensor

- Sensor:
 - InGaAs avalanche photodiode thermo-regulated @ -20°C
 - Diameter: $350\ \mu\text{m}$, Band width: 600 MHz
 - Noise Equivalent Power: $0.12\ \text{pW}/\sqrt{\text{Hz}}$ @ $M=10$
- Amplifier
 - Transimpedance amplifier
 - High Gain Bandwidth product: 1600 MHz
 - Low Input Noise: $i = 1.3\text{fA}/\sqrt{\text{Hz}}$; $u = 4.8\ \text{nV}/\sqrt{\text{Hz}}$
- Filter (Telecom channel)
 - 5 order passive LC Tchebychev filter @ 2 or 16 MHz

Mono-pixel Sensor MeO Full aperture Performance



- Telecom Detection threshold
 - 300 pW @ 10 Mbps
 - 30 pW @ 1 Mbps
- Scintillation Detection threshold
 - 2 pW @ 10 kHz

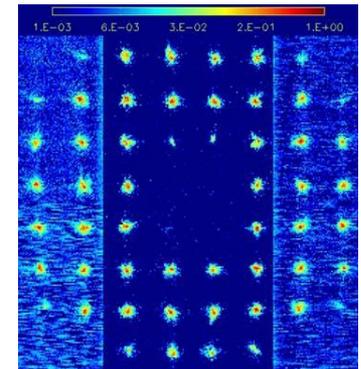
Optical Turbulence monitoring for DOMINO (ONERA-GeoAzur)

Spatial sampling of the receiver aperture

Wavefront slopes measurement $s(t)$

Scintillation spatial monitoring $I(t)$

=> Shack-Hartmann WFS



E2V EMCCD220, 1500 Hz
8x8 19 cm square subapertures

WFS on ODISSEE to analyze turbulence influence on stars around satellite trajectory and on the link (if possible)

Atmospheric turbulence Monitor (LAGRANGE - OCA)



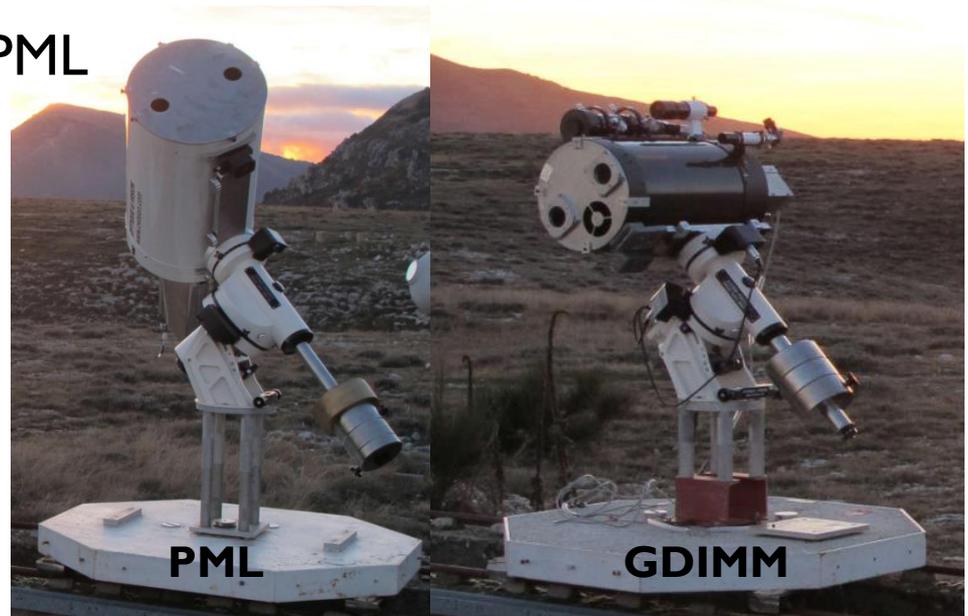
- Generalized Differential Image Motion Monitor GDIMM

$$r_0, L_0, \tau_0, \theta_0$$

- Profiler of Moon Limb PML

$$C_n^2$$

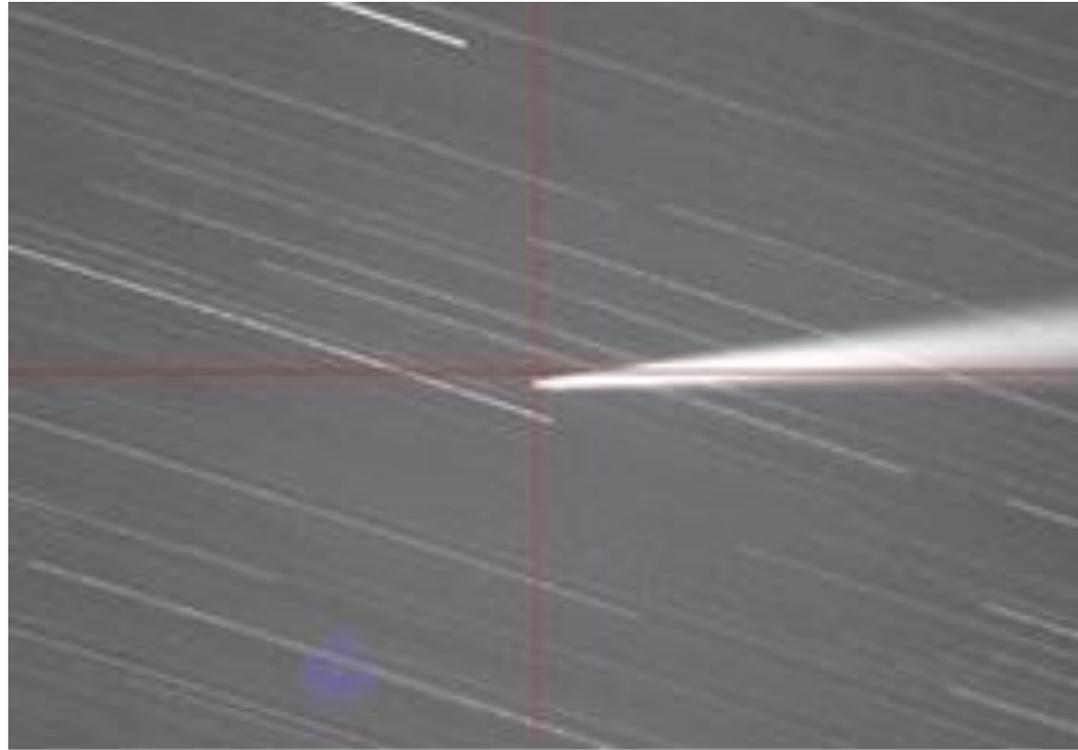
Profiler of Sun limb



Meteo

- Available meteo sensor at Calern
 - Pressure: 0.2 hPa
 - Temperature: 0.4 °K
 - Humidity : 2%
 - Wind Speed: 1 km/h
 - Wind Orientation: 22°
 - Sky background: 0.1 mag
 - Integrated Cloud cover
 - Cloud sensor (camera)
 - Rain
- Cooperation envisioned in cloud prediction propagation

Laser montant @ 1064 nm



Première acquisition SOTA

[Serveur Meo](#) lance

Client: [connecté](#)

Heure UTC (sod): 80927

Inductif site franchi !

Caméra Hamamatsu

Autotracking en cours...

Andor Mire X: 84 Y: 64 valeur pixel: 180 Fréquence 3.1
 Hamamatsu

AutoSetting Enregistrement frames

Trigger Interne
 Externe

Contraste:

Offset:

Binning:

Gain:

Exposition: μ s

Corrections

Détection

Activer/Désactiver

Afficher Masquer

Fenêtre: Dimension: pixels *

Seuls: Luminair: %

Surfaique:

Sigma:



Démarrage AT après clic gauche

pixels blancs: 17
 Signe(x; y): 8; 27

Enregistrement données: OFF
 Enregistrement des photocentres: OFF
 Test Derive: OFF

Serveur Inulte: ON IMT Viewer

Télescope

Poursuite en cours

	Statut	Puissance	Freins	Position	Vitesse
Axe Azimut	OK	ON	ouverts	489.0323	-0.2087
Axe Site	OK	ON	ouverts	24.5421	0.2305
Coupole	OK	ON		489.2	
Cimier	/				
Sala	OK	Statut Hydraul: ON	Pression Az: 49.84 Pression Site: 48.41	Pos Az Abs: 490.223	

Sécurités

Sala: ON 24 V: ON

Soleil: OFF

Pos Az Site Soleil: 345.005; -21.3814
 Distance axes-Soleil: 144.131; 45.0375

Options

Suivi coupole: ON Centrage auto: ON
 Charge Cimier: OFF

Mode de poursuite: Manuel Acquisitions

Interpolation fichier prev: aucune
 Dlais en temps appliqué: 0
 Aberration de vitesse: OFF

Corrections

	X	Y	P/D	C	I	G	2
ciel	-2.9	0.8	<input type="text" value="366"/>				
optique	0.0	0.0	<input type="text" value="150"/>	<input type="text" value="1"/>			
codeurs	0.5	-3.0	<input type="text" value="10"/>				

Manuelle (Boule) Automatique Dérive (%):

x: x: 2.9 x:

y: y: -0.8 y:

 Mode auto: OFF champs: 1000"

Périphérique: caméra

Saisie clavier dérive mesurée (arcsec/sec):
 Flèches clavier x: 0.2; y: 1.0
 Boule Mire AT

Commandes Meo (clear)

```

22h25 : #track Tle
22h25 : #stop AXES
22h14 : #track Tle
22h8 : #set telescope 50
167.709 167.709
22h5 : #stop AXES
21h52 : #track star1506222155
21h31 : #gel MOTEURS 200
21h17 : #track
grca1506222122
20h59 : #stop AXES
          
```

Sécurités et infos (clear)

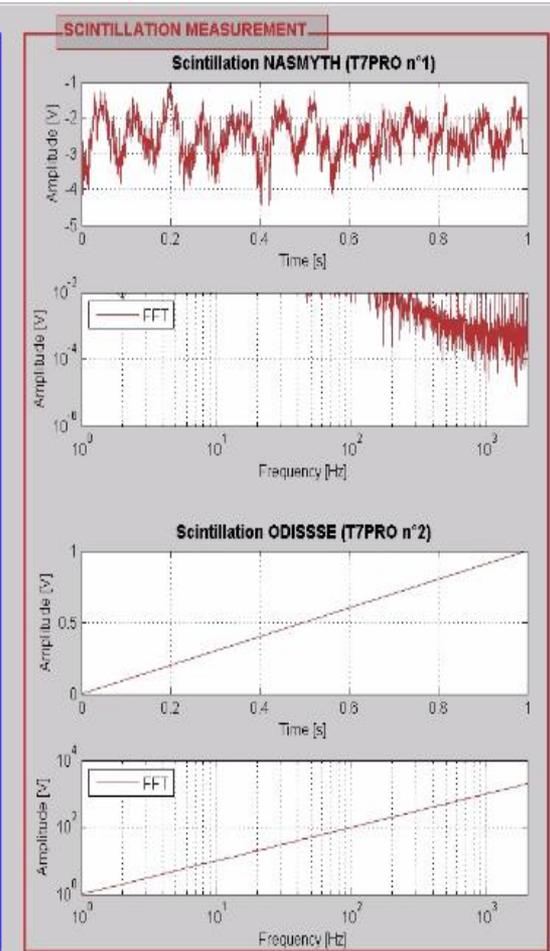
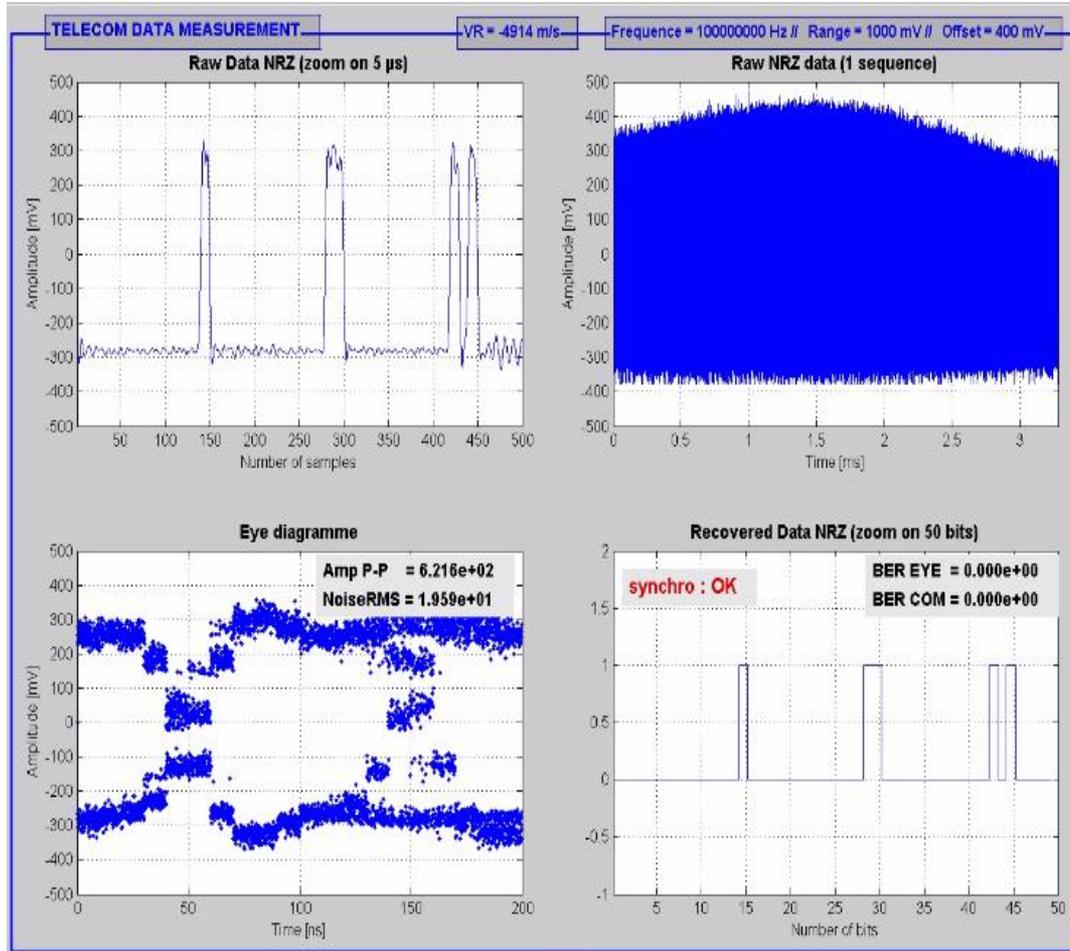
```

reset bulbes Site OK
lancement prev courante...
Pas de zone d'ombre
chargement poursuite OK:
Nombre de points: 5480
Heure Depart: 80750
Heure Fin: 81303
          
```

Retours Etel (clear)

Données reçues

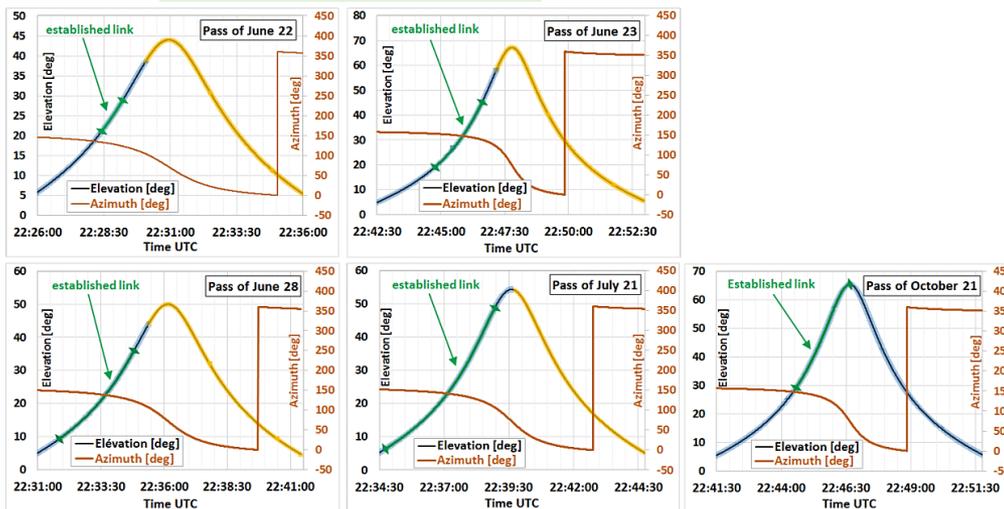
Analyse Temps Réel



Passages SOTA obtenus

Weathers					
	June 22	June 23	June 28	July 21	Oct. 21
Visibility	Cloudy → Clear	Cloudy → Clear	Clear + thin cloud	Clear	Clear
T [°C]	15.6	13.9	NA	21.2	5.8
H[%]	71	93	NA	63	95
P [hPa]	1010.9	1007.7	NA	1013.2	1013.1
Wind [m/s]	4.5	0.1	NA	0.0	0.5
Wind [deg]	252	176	NA	300	150

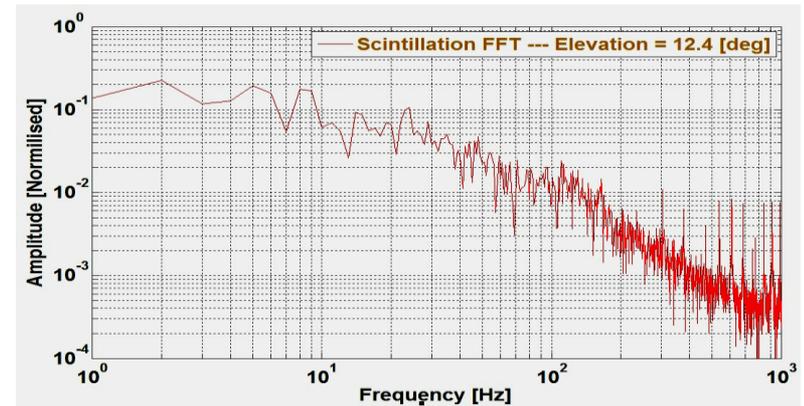
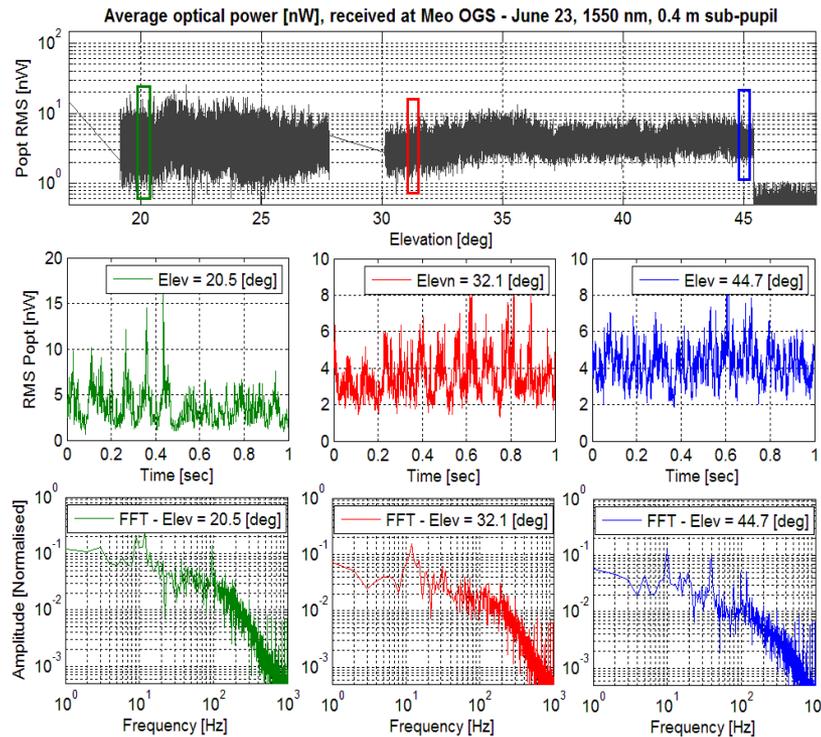
Orbits information



- ✓ Link established in about 730 s
 - ✓ ~ 68 Gbit recorded at OGS
 - ✓ Continuously recorded data
 - ✓ 1.5 m full + 0.4 & 0.2 m sub-pupil
- nm tested at 1549 & 976

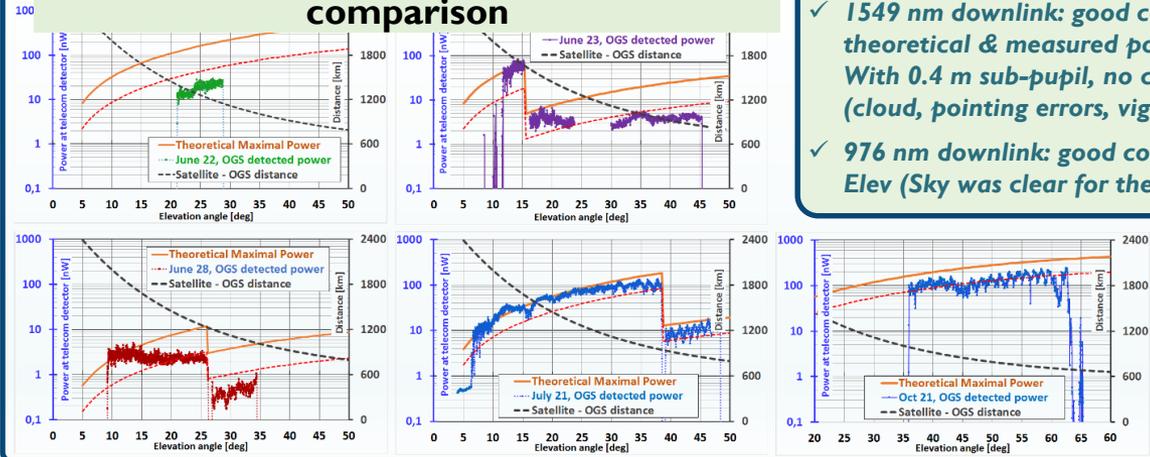
Analyse

Fluctuation de puissance @ 1549 nm



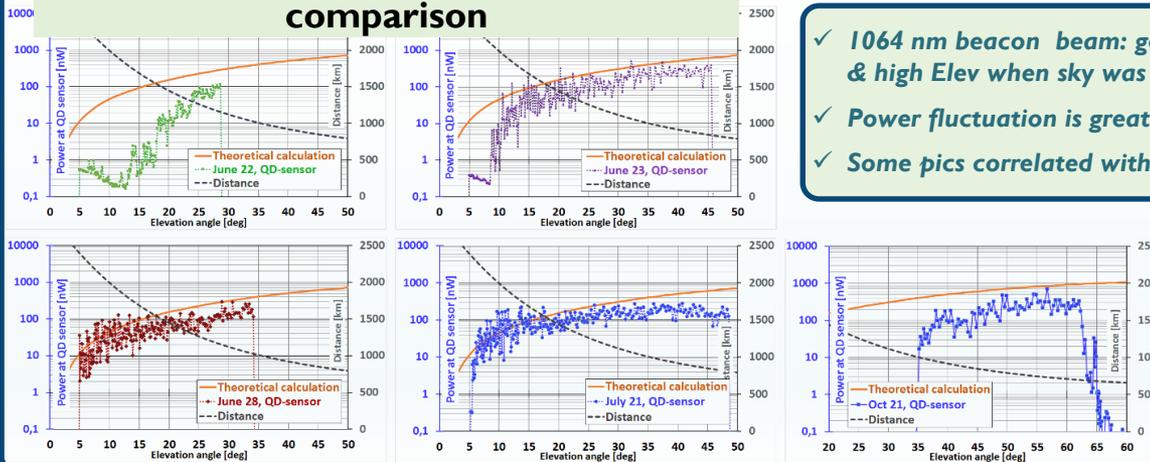
Analyse Bilan de liaison

Theoretical & measured downlinks comparison



- ✓ 1549 nm downlink: good correlation between theoretical & measured power at low Elev. With 0.4 m sub-pupil, no correlation at high Elev (cloud, pointing errors, vignetting...)
- ✓ 976 nm downlink: good correlation at low & high Elev (Sky was clear for these passes).

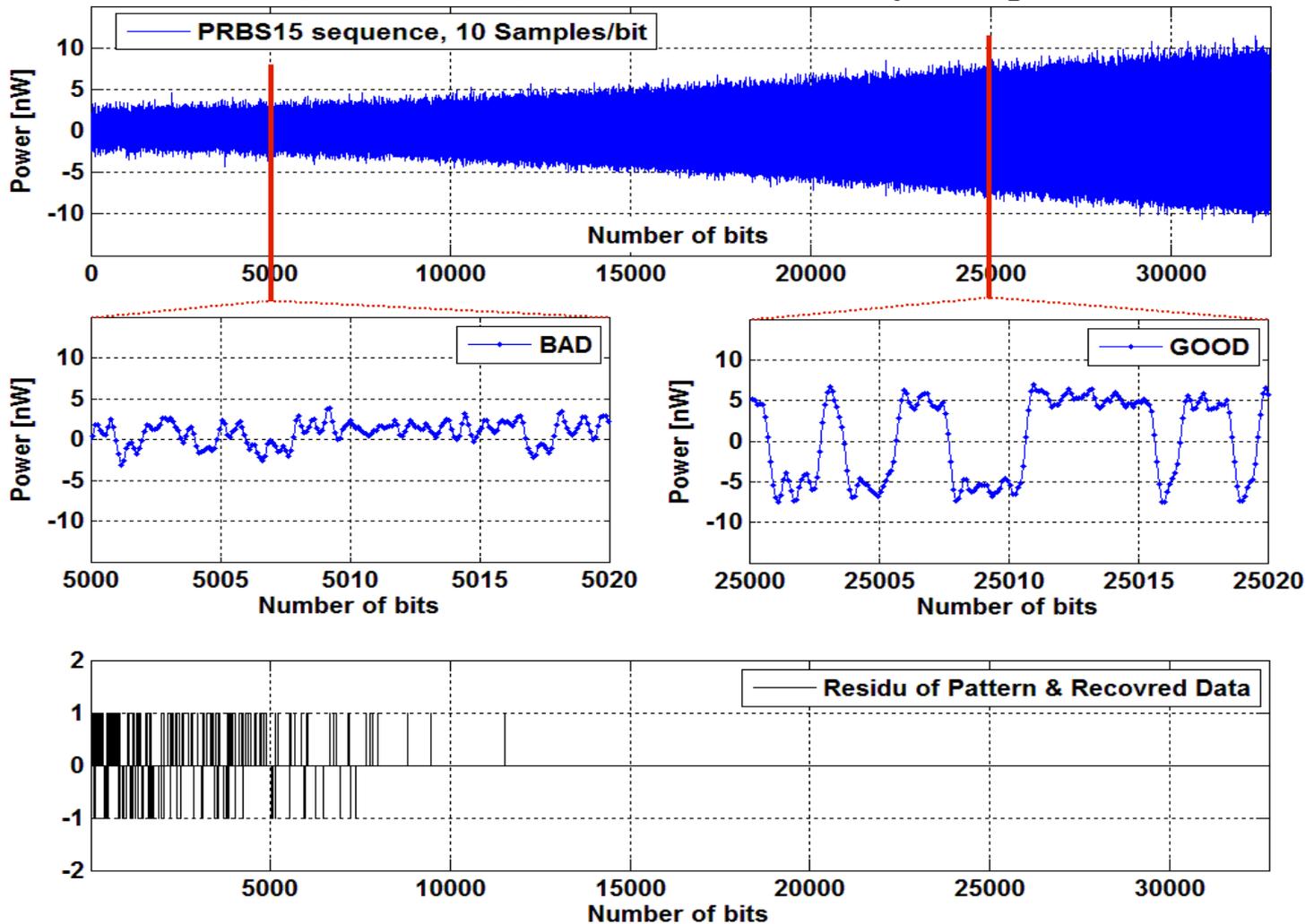
Theoretical & measured uplinks comparison



- ✓ 1064 nm beacon beam: good correlation at low & high Elev when sky was clear.
- ✓ Power fluctuation is greater at low Elev
- ✓ Some pics correlated with Meo pointing error.

Analyse Données Télécom

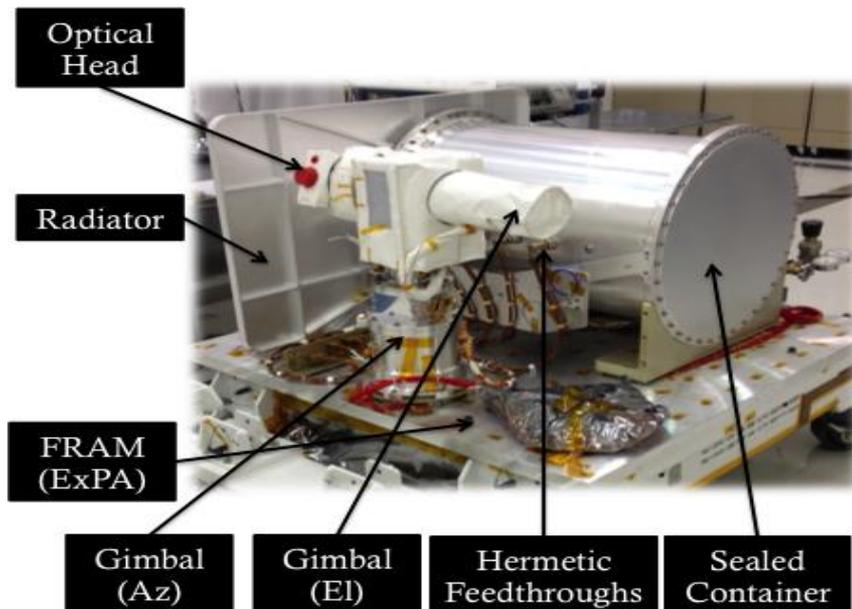
Telecom Data, BAD to GOOD, zoom on one PRBS15 sequence @ Power = 3.7 nW



OPALS

Optical PAYload for Lasercomm Science

- Caractéristiques
 - Débit 50 Mbits/s On Off Keying
 - Réception Lien montant $\lambda = 976 \text{ nm}$; 300 nW/m^2
 - Lien descendant $\lambda = 1550 \text{ nm}$; $P_t = 2.1 \text{ W}$; 1.1 mrd ; 22 mm

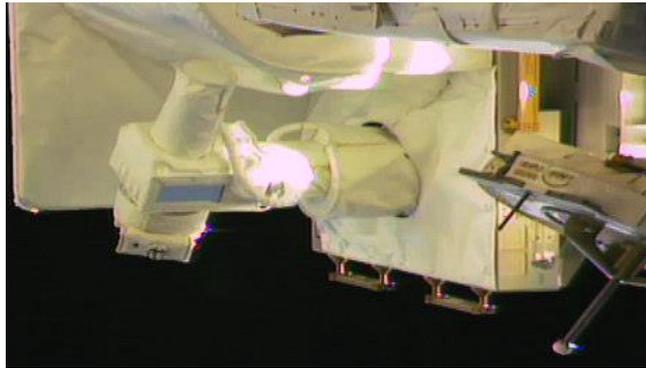


Crédit Photos : Phaeton JPL Nasa

OPALS

Optical PAYload for Lasercomm Science

- Installé sur International Space Station avril 2014

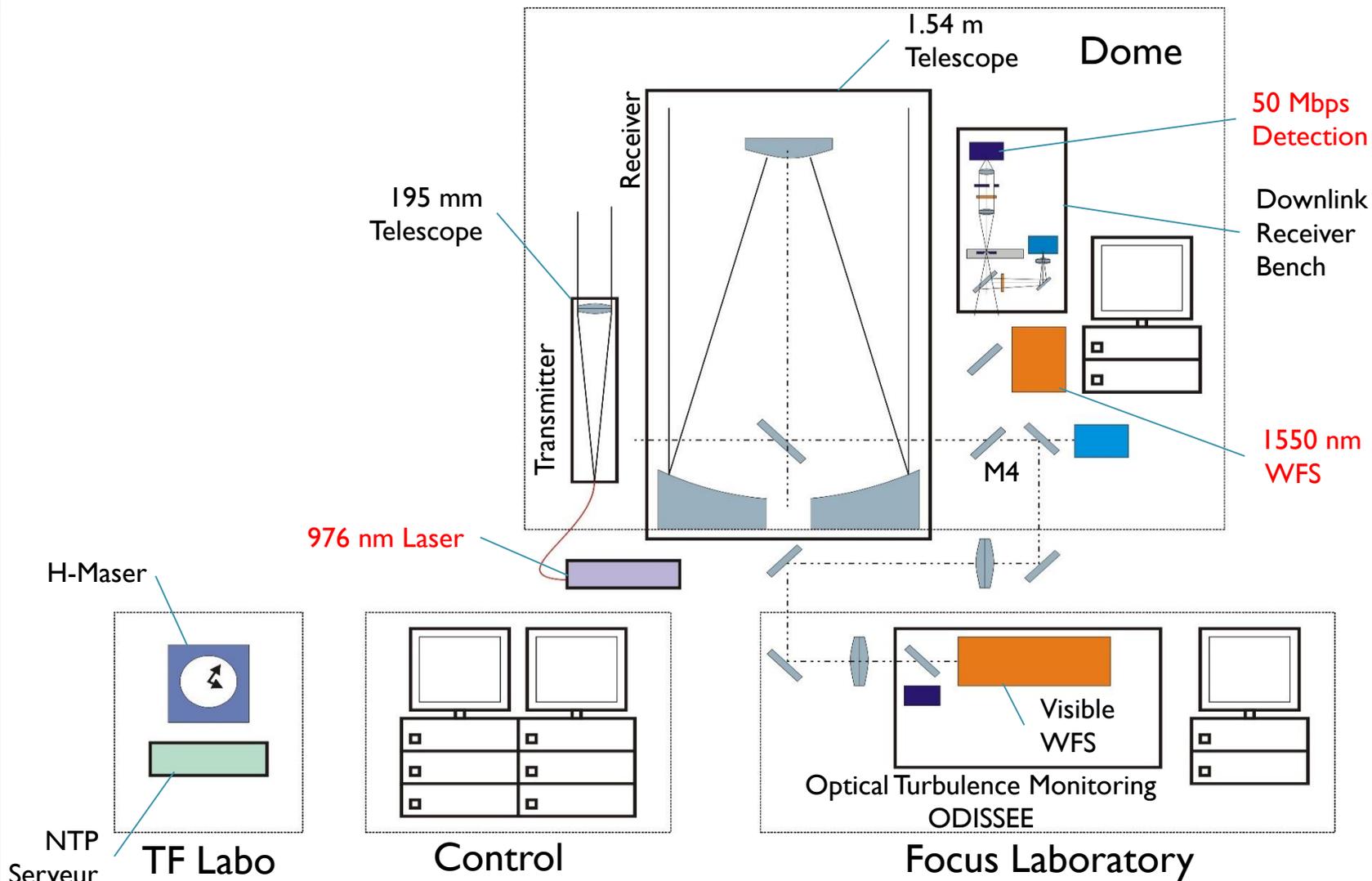


Crédit Photos : Phaeton JPL Nasa

- Lien établi en juin 2014 par la station OCTL (Optical Telescope Laboratory), Californie
- Campagne OCA/Géoazur
 - 5 passages du 13 au 25 juin



OPAL OGS Architecture

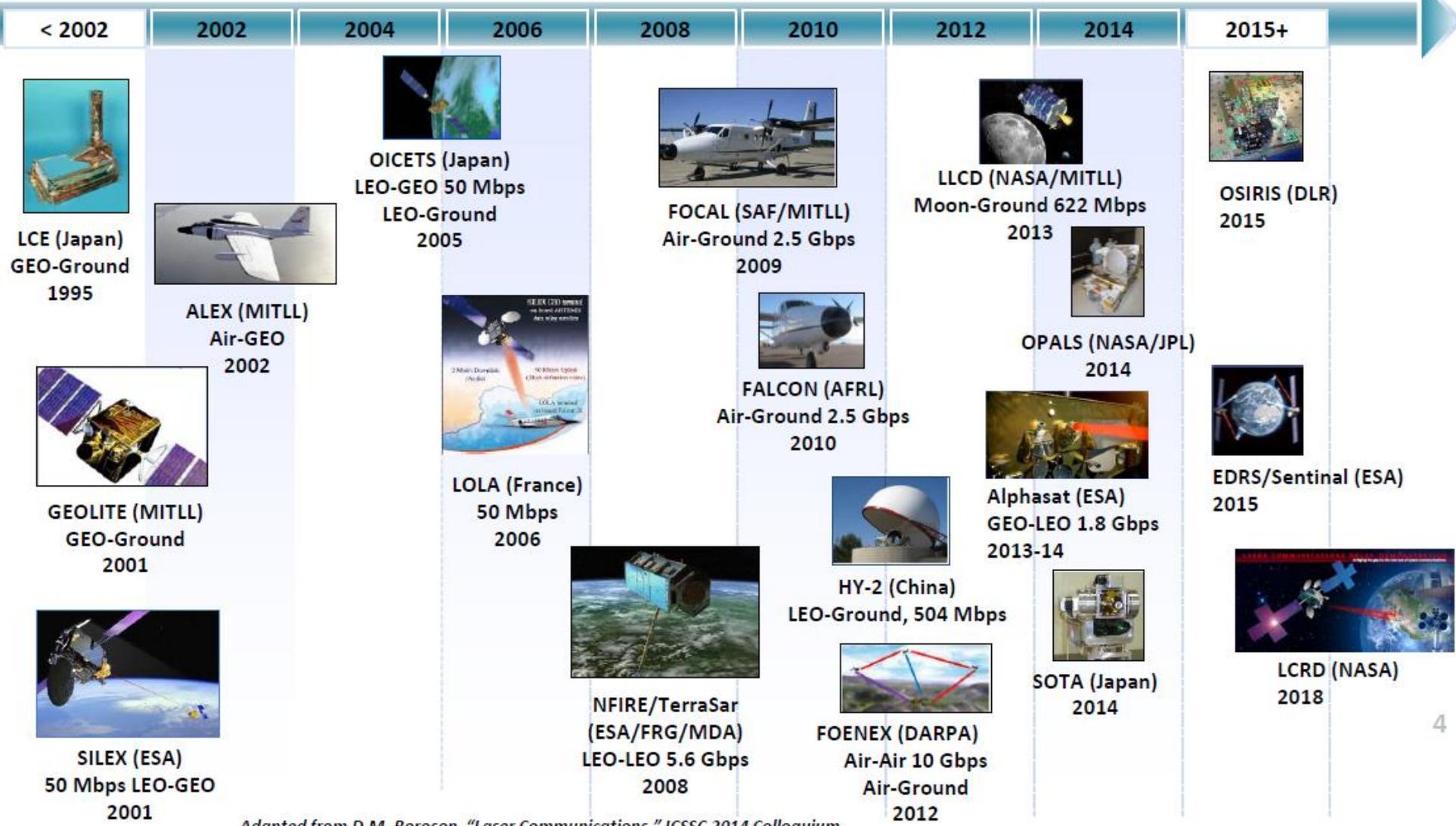


Perspectives

- Lien NICT : Campagne septembre 2016
 - Utilisation OA pour couplage fibre optique mono mode
 - Datation des fronts de monté du signal Télécom
- Collaboration NASA JPL : OPALS sur ISS
- Lien Télécom 10 Gbits (First TF)
 - Lien MeO – Calern : 5 km de propagation ; $d = 200$ mm
 - $\lambda = 1550$ nm ; modulation OOK ; BW = 20 GHz
 - BER Tester @ 12.5 Gbits
- Station Nouvelle Génération : Intégration des telecoms



Free Space Optical Communications Demonstrations



Past and Current Low-Earth Orbit Direct to Earth Flight Missions

Space Agency	Project	Bitrate
DLR-MDA	LCT - NFIRE	5.6 Gbs
DLR	OSIRISVI V2	620 MBs – 1 GBs
NICT	SOTA	10 MBs
CNSA	HY-2	500 MBs
NASA	OPALS - ISS	50 MBs
Aerospace Corporation	CubeSats OCSD	50/200 Mbs