Optical Satellite Feeder Links
for Terabps Throughput

Institute of Communications and Navigation
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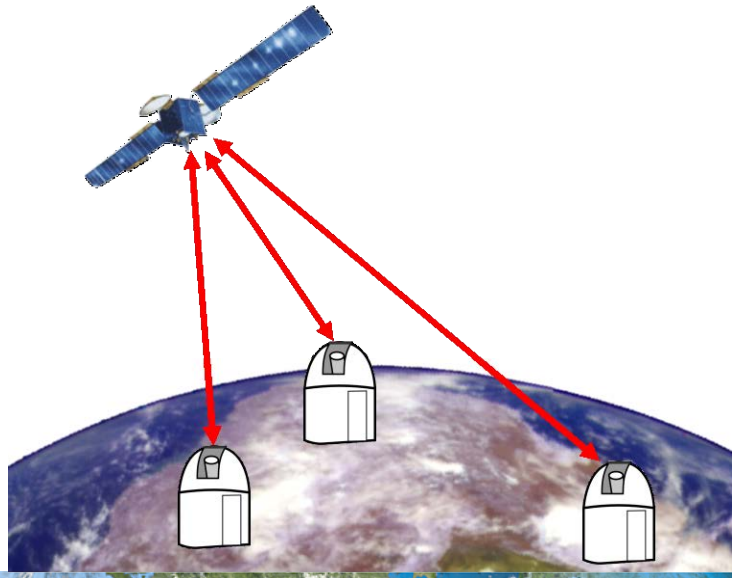
Motivation: Future Requirements in Geostationary Communication Satellite Systems

Example: Multimedia satellite for the ***European Digital Agenda***:

„All Europeans shall be connected by year 2020 with at least 30Mbps, half of Europeans with at least 100Mbps“

… Filling the voids of ground infrastructure with a GEO Satellite System:
200..300 user spot beams with 2.5Gbps each
→Up to 1Tbps in both directions

- …with Ka-Band feeder links: >40 GND-stations
- New unused spectrum is required:
  Q/V-band helps in near future
- **High-Speed Optical Feederlinks can solve this datalink bottleneck longterm**



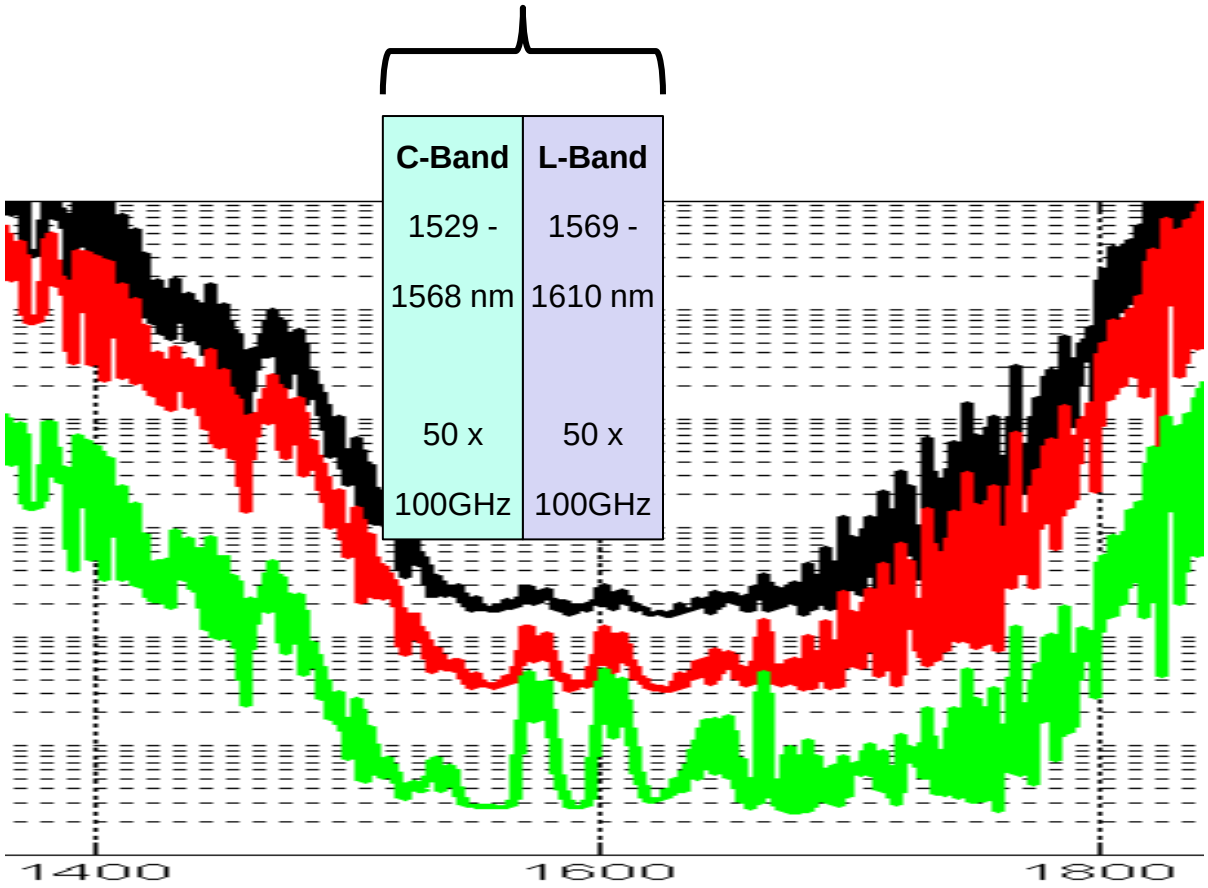
The Atmospheric Transmission Channel

Influence of the Atmosphere on Optical Waves

- **Attenuation Effects**
  - **Scattering:**
    - Rayleigh-Scattering
      Electron-Resonance
    - Mie-Scattering
      Aerosols
      and Droplets
  - **Absorption:**
    - Molecular Absorption
    - Absorption by Aerosols
      volcanic ash, sand
  - Free-Space Loss
- Index-of-Refraction Effects

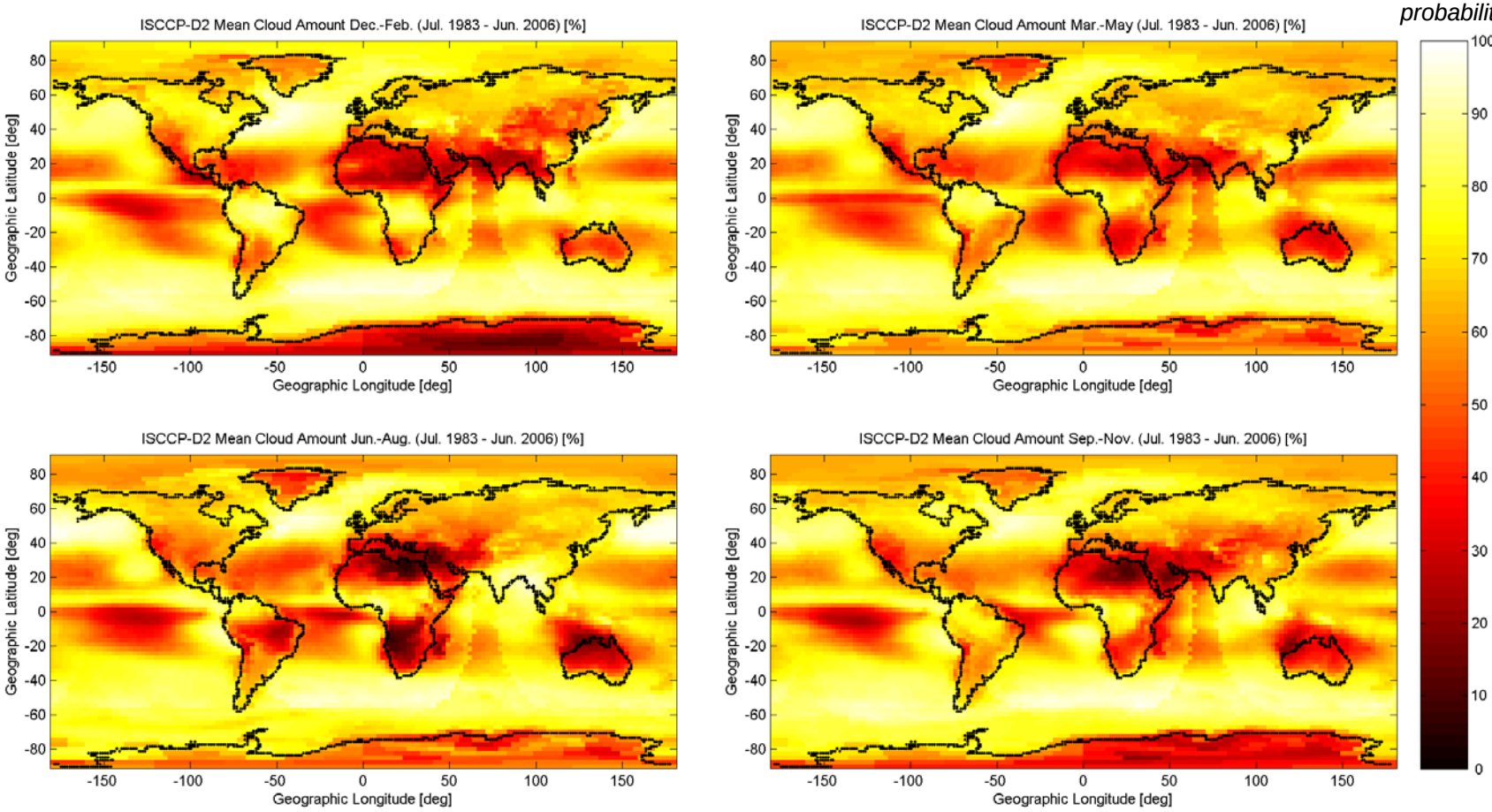
Available Optical Spectrum around 1550nm

10THz of transmission spectrum available

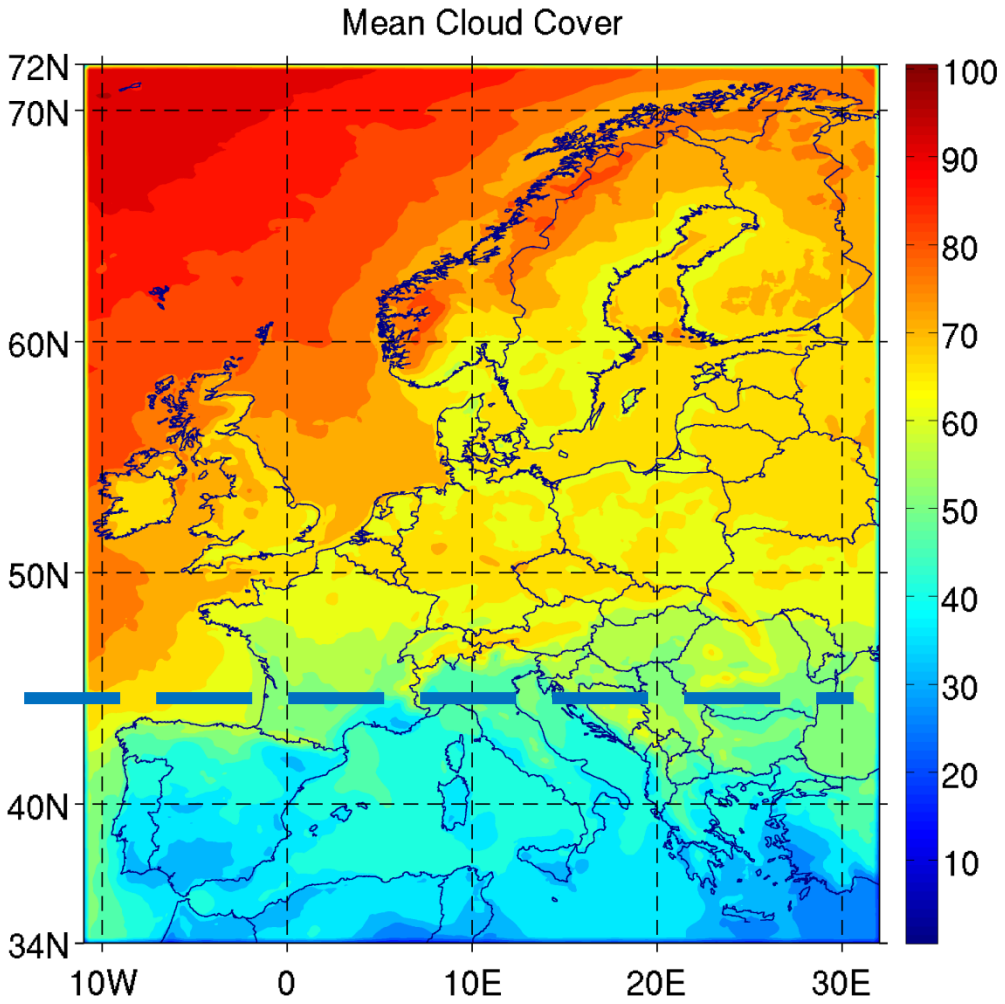


Global Seasonal Distributions of Cloud Blockage

brighter: higher cloud probability

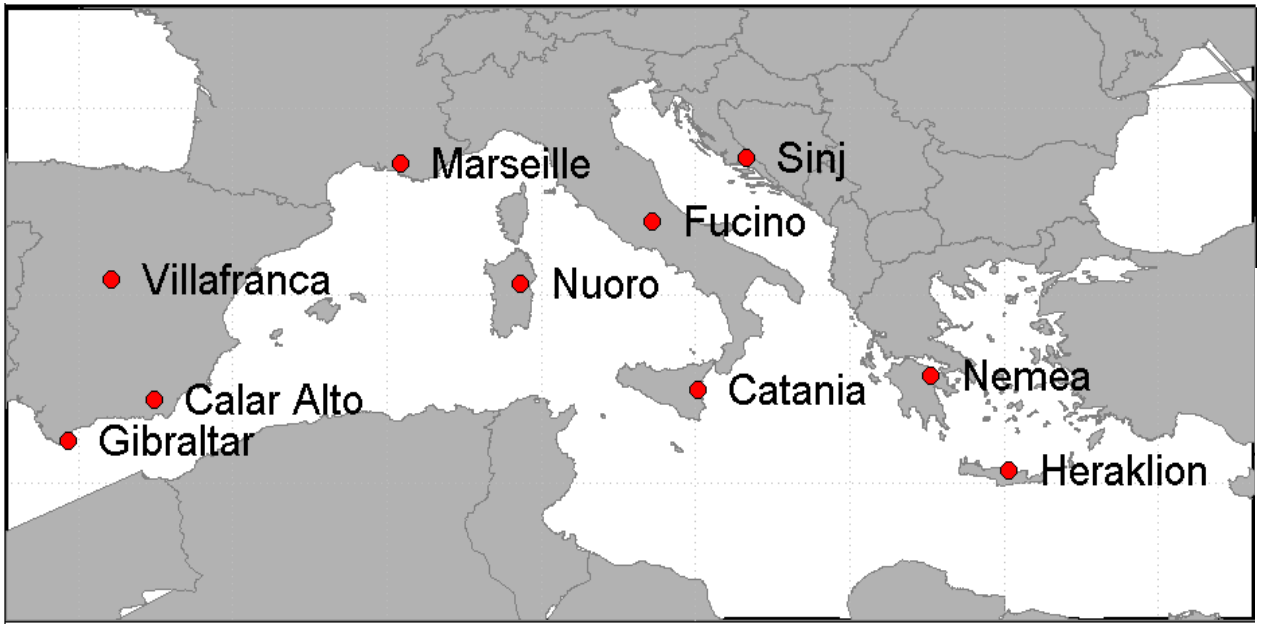


European Annual Cloud Probability

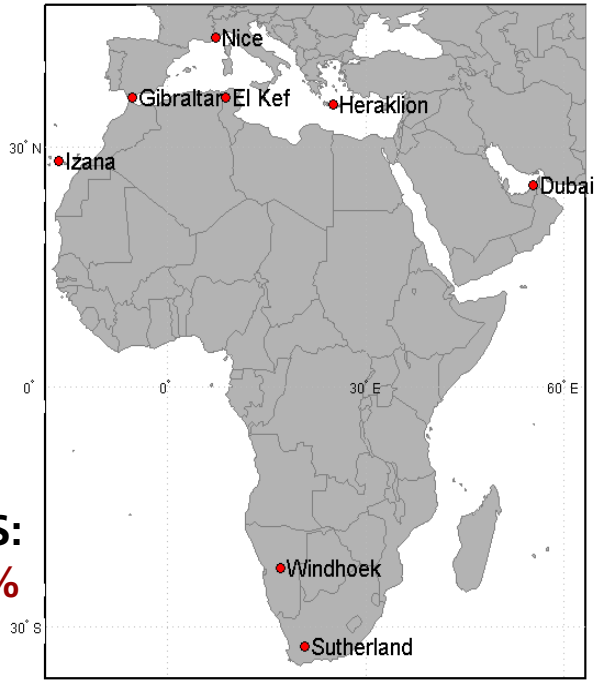


P < 40%

Cloud Blockage Mitigation: OGS-Network – Availability Statistics from Satellite Data



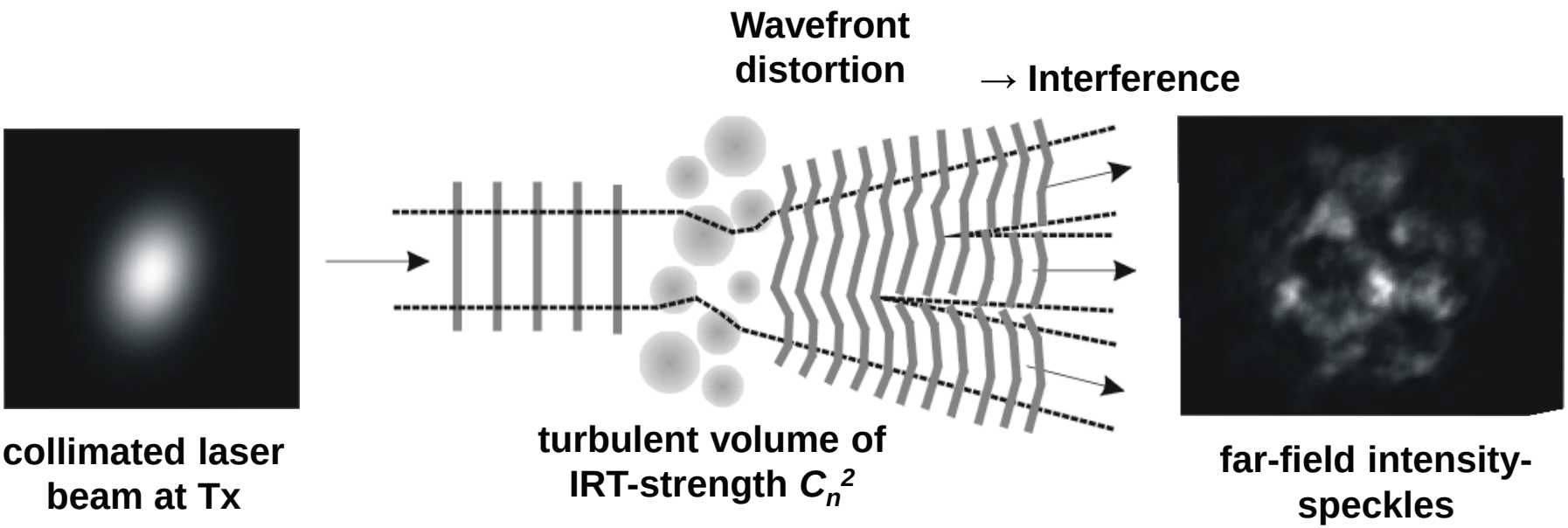
10 European Mediterranean OGS: Availability = 99.89% (winter-dominated LOP)



Change in feeder network on ground: All data is routed through *one* hub at a time

8 Inter-continental OGS: Availability = 99.97 %

Atmospheric Index-of-refraction turbulence (IRT)



Intensity-Speckles: glittering stars at night

Wavefront-Distortions: warped view over hot street

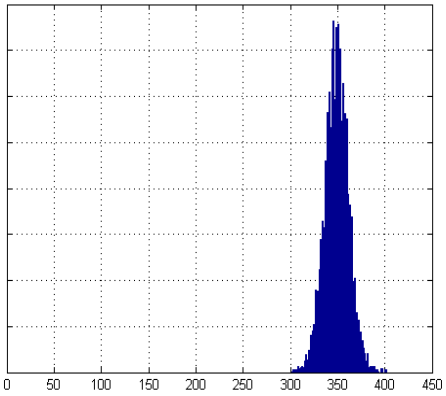
Signal Stability: ARTEMIS-OPALE Rx-power Measurements

(ESA-Project ArtemEx, Oct12/Apr13)

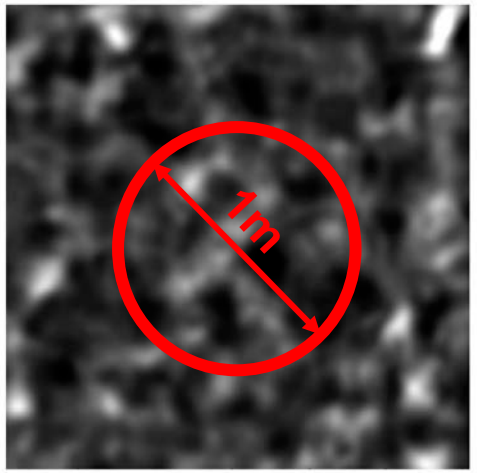
Downlink: signal at the optical ground station;

1m Rx-telescope is larger than scintillation-structures

→ ***aperture averaging***



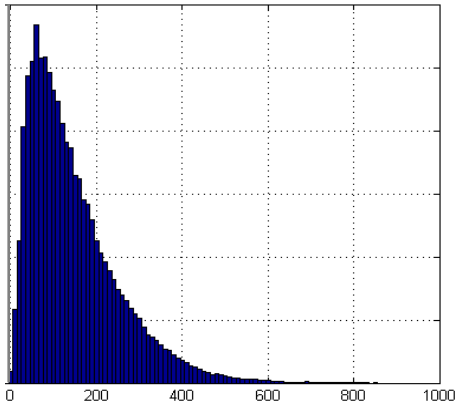
Histogram

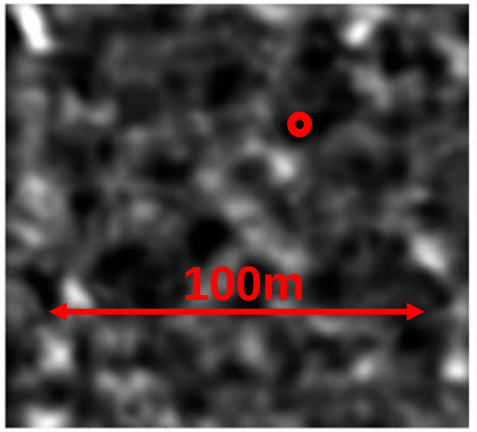


Intensity (simul.)

Uplink: signal at Artemis

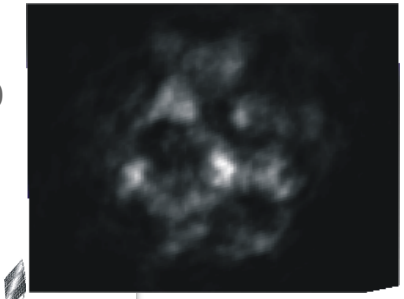
intensity structures are much larger than Rx-telescope → no aperture averaging

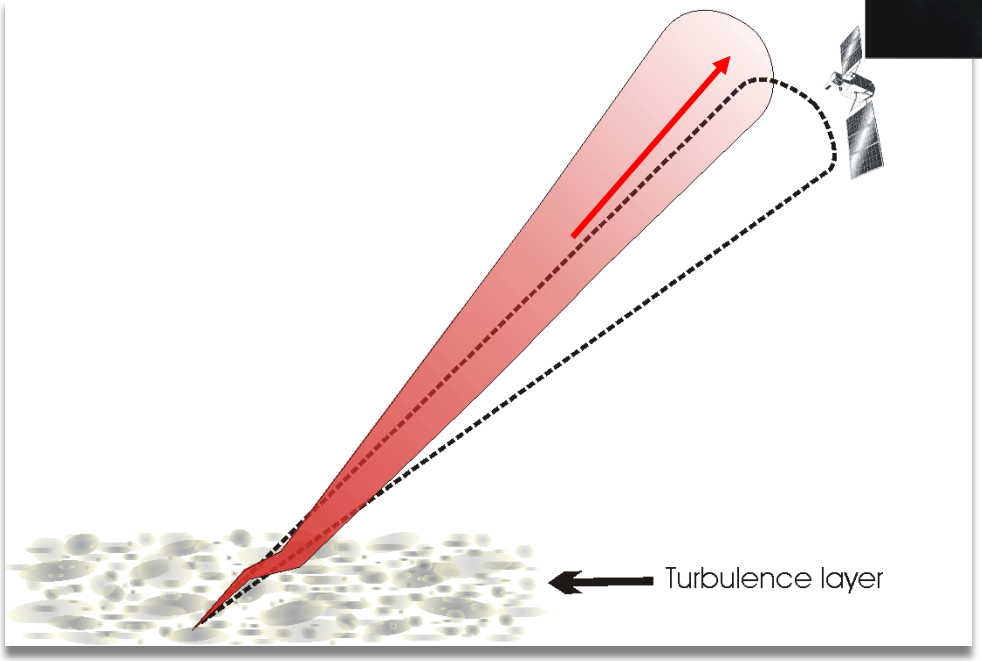




Fading Situation - Uplink

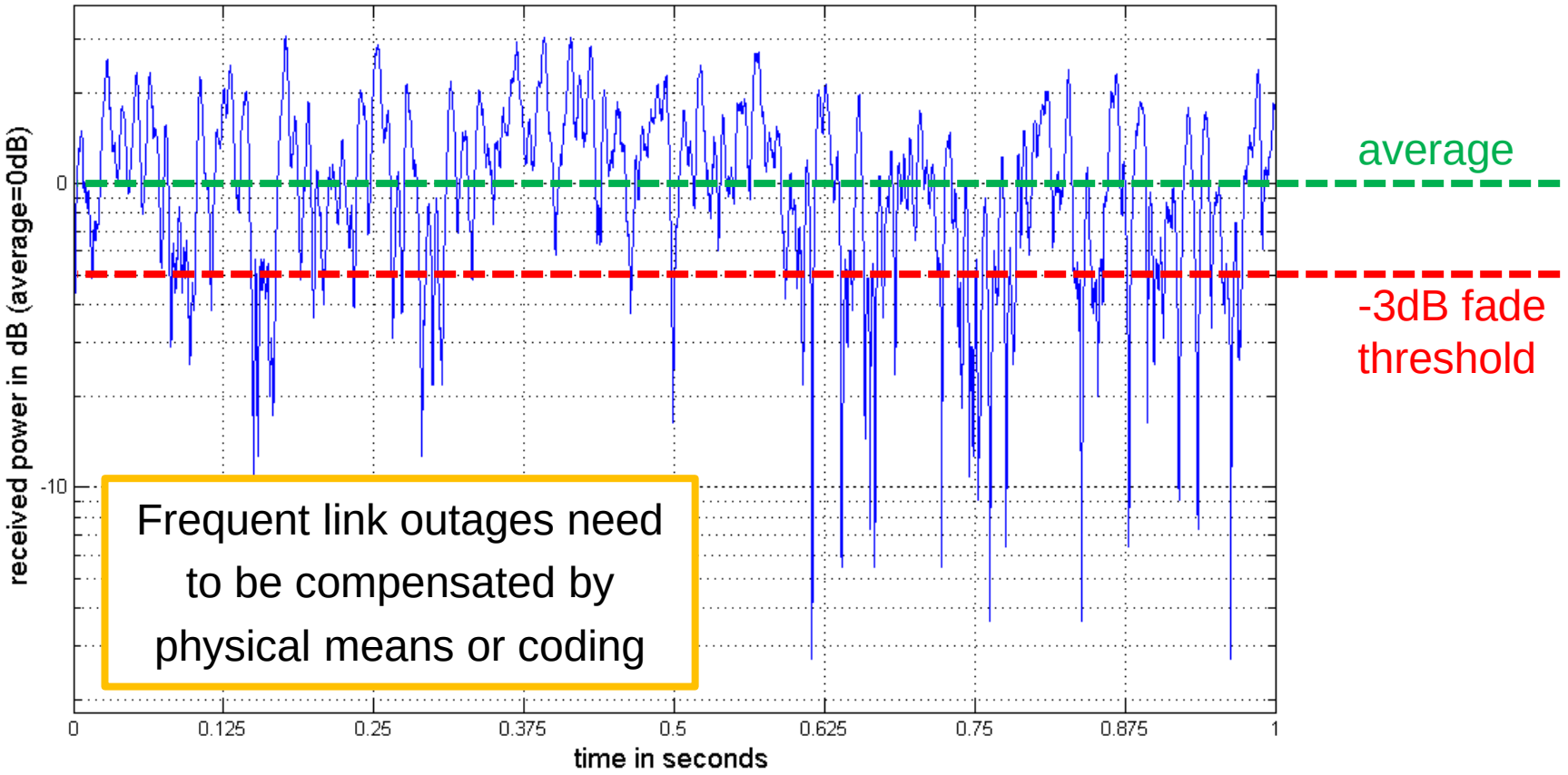
Beamwander adds to Farfield- Speckles





- Satellite terminal sees strong received power fluctuation;
- Effects are subject to beam divergence → trade-off with power efficiency
- Low link elevation strongly increases fading

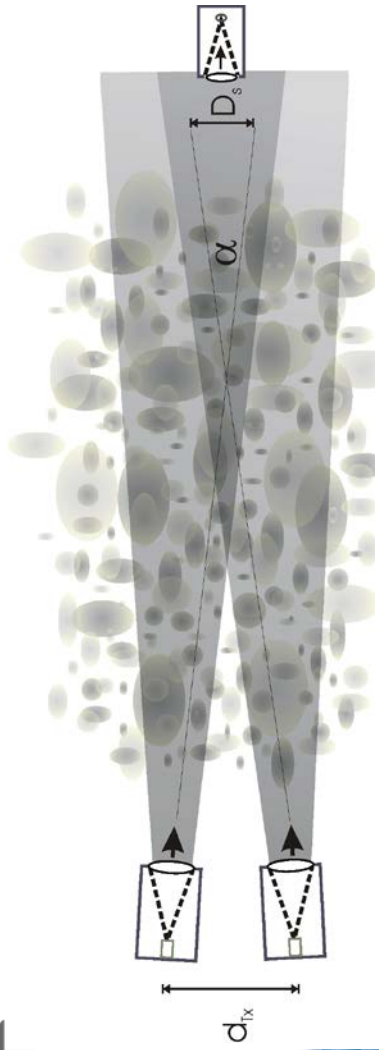
Measured Uplink Received Power

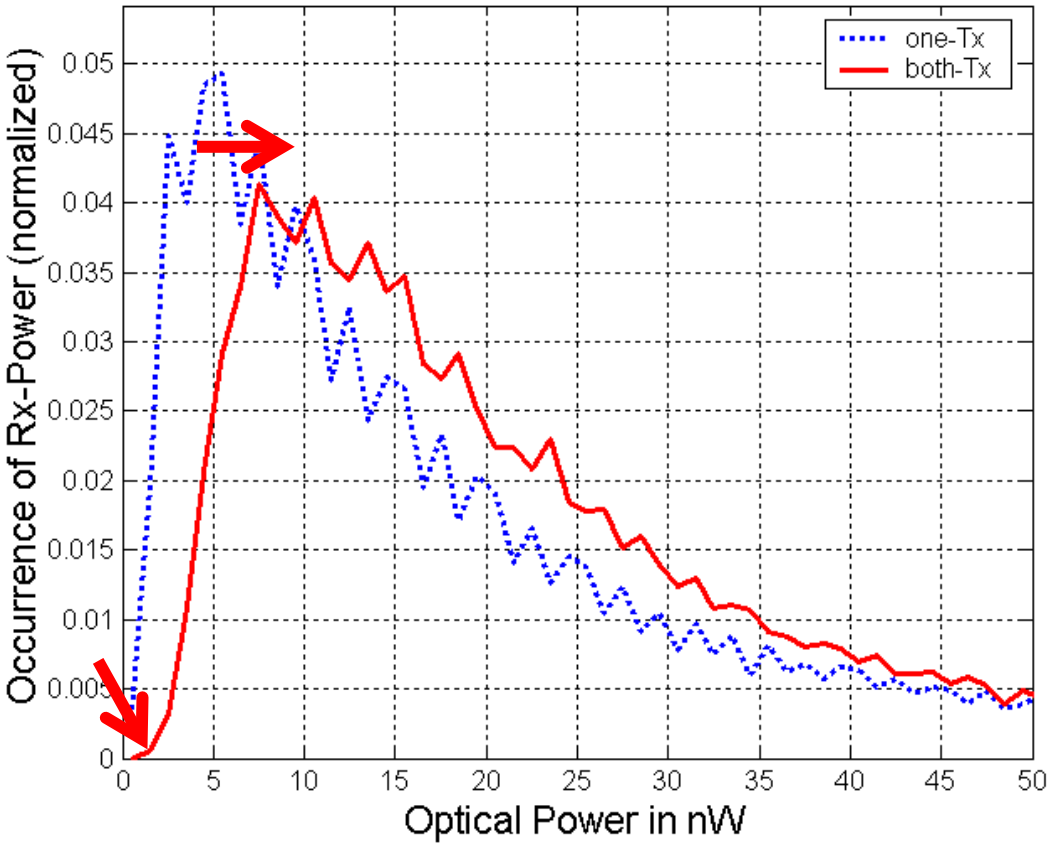


Source: „ArtemEx-Project“, 820nm Uplink to GEO Artemis, from ESA-OGS at Izania, Tenerife

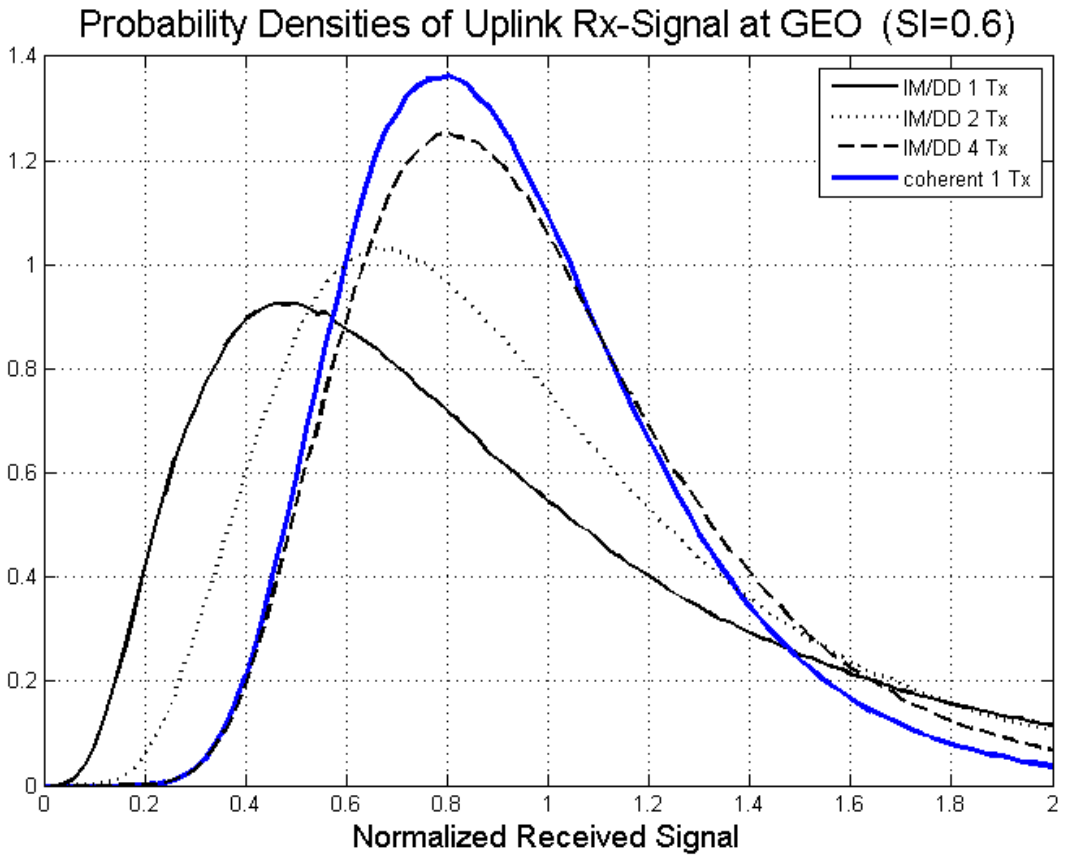
Tx-Diversity to Reduce Scintillation

(two laterally spaced transmitters will produce a superposition of independend speckle patterns)





Uplink Signal Stability with *1 / 2 / 4* Tx-Diversity vs. Coherent Reception



Simulations of ideal receiver performance, without pointing errors

Way Ahead for High-Capacity Optical GEO Feeder Links

- **European satellite industry shows strong interest in optical feeder links:**
  - Optical links can deliver the throughput required long-term
  - Transparent links are preferred for initial flexibility
  - Digitally-regenerative links (fading-FEC) will come as a second step
  - Several international studies and experiments ongoing

- **Ground infrastructure requires a change of concept:**
  - All traffic through one gateway at a time
  - Frequent switching between GND-hubs due to cloud cover dynamic

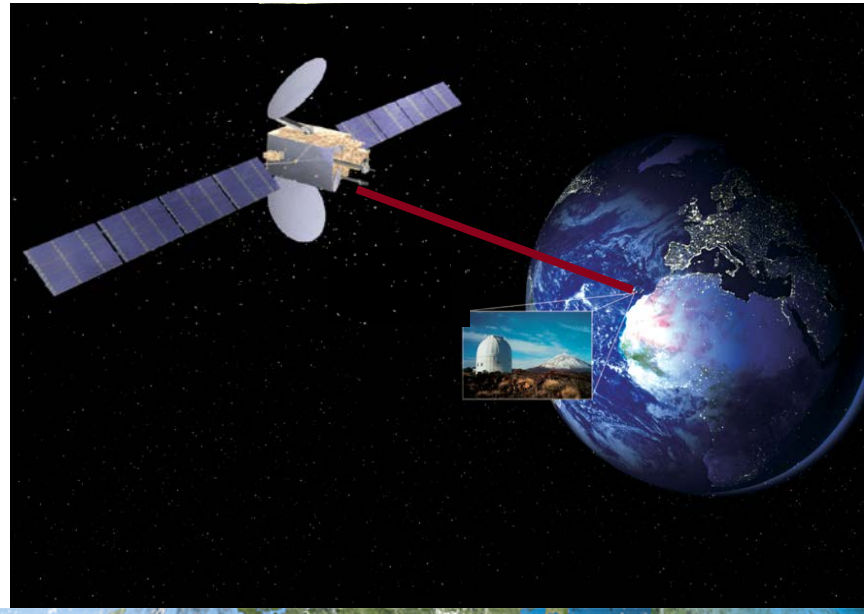
- **Link technology options are currently being verified**
  - Modulation format vs. transparent links and power efficiency
  - Diversity scheme for fading mitigation vs. bandwidth efficiency
  - IRT-quality depends heavily on OGS-site and link elevation

ArtemEx Measurement Campaign (ESA-project)

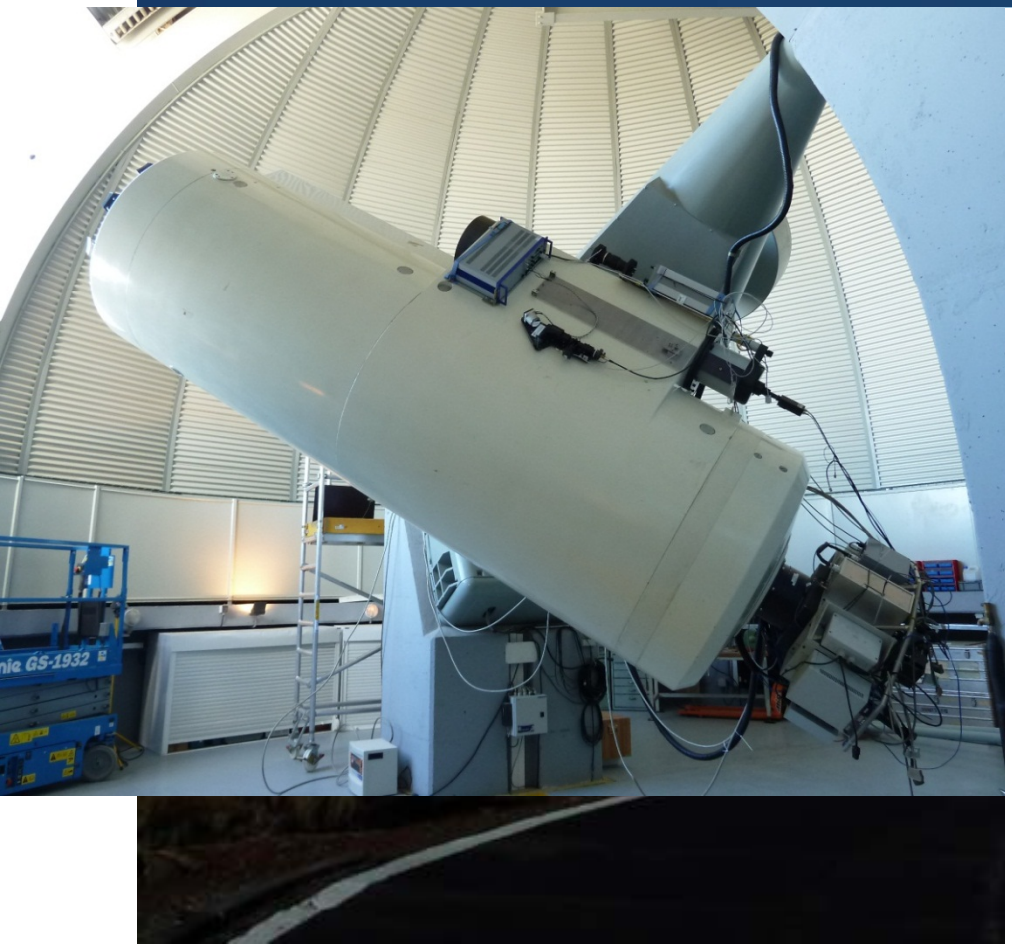
- Artemis‘ OPALE Terminal (820nm) to ESA-OGS (Tenerife-Mountain)

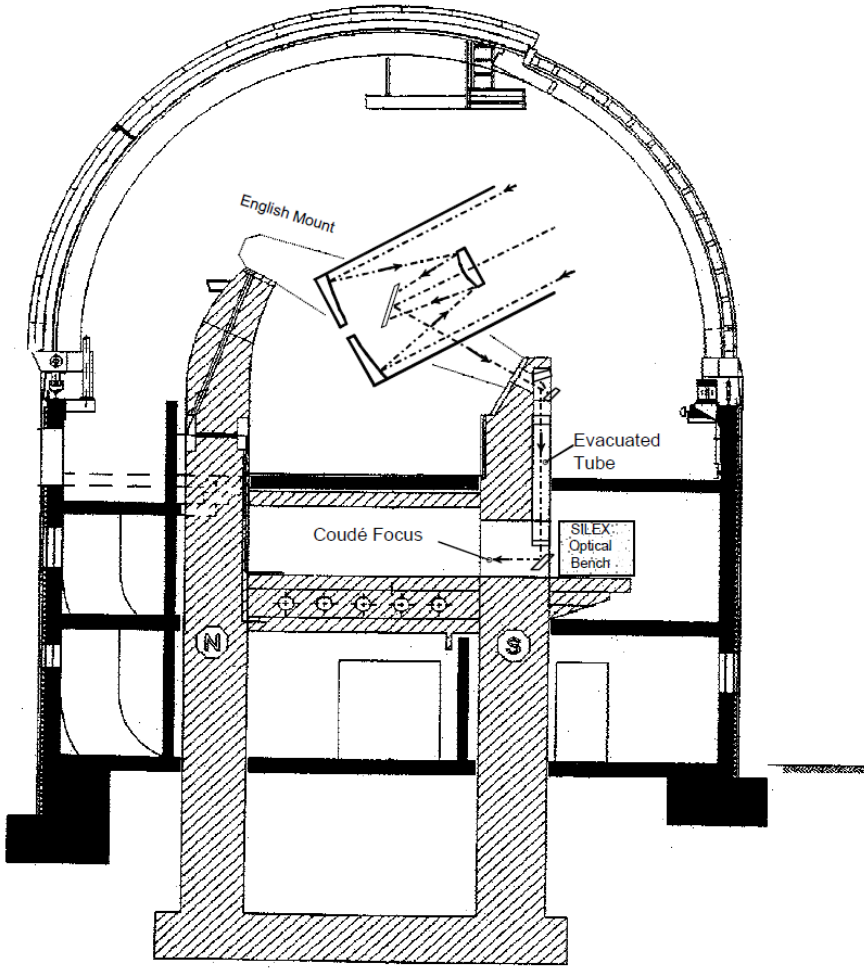
- Verification of the Performance of …
  - Transmitter diversity from OGS to GEO
  - Tx-Pointing by colocated Rx-tracking
  - Influence of point-ahead-angle

- Measurements with a variety of …
  - Aperture-diameters
  - Number of Tx-apertures
  - Colocated / independent apertures

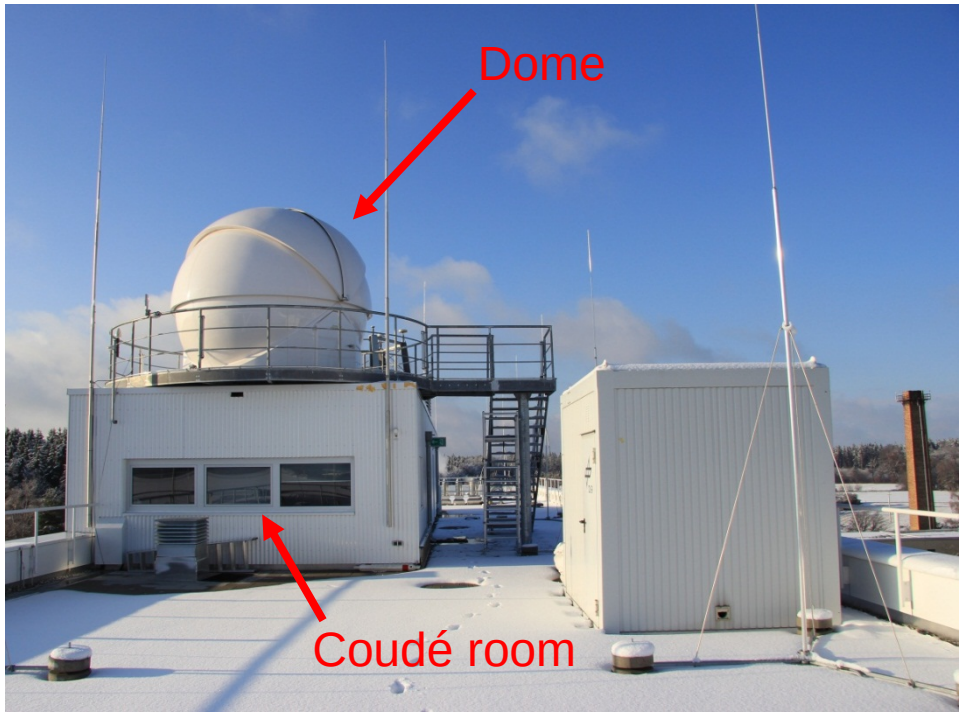


Experimental ESA-OGS on Tenerife (2400m a.s.l.)

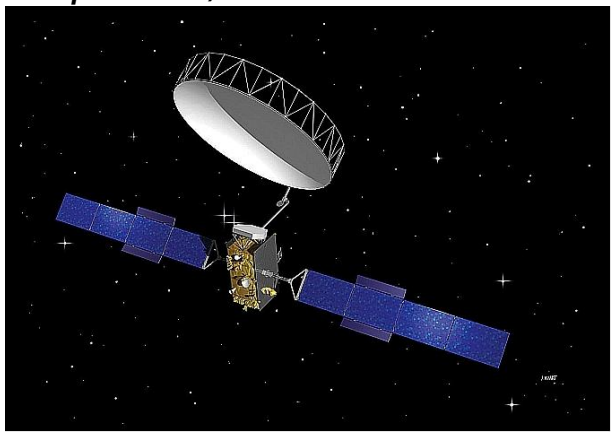




OGS-OP for future Feeder Link Experiments



AlphaSat, with coherent LCT



Source: Google-Earth

Thank you for your attention

With Contributions from
Ramon Mata-Calvo
and
Nicolas Perlot