Mobile Optical Communication projects at DLR and prospects on future developments

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presented at "**BroadSky Workshop",** in conjunction with the **13th Ka and Broadband Communications Conference**, 24.09.2007, Turin, Italy

Content

- Introduction of DLR's OCG, their fields of work and methodology
- Projects
  - HAP-Downlinks: CAPANINA
  - LEO-Downlinks: KIODO
- Technological options for future optical space communications with emphasis on EO-downlink

Optical Communications Group (OCG) at IKN - Fields of Works:

- Atmospheric Optical Freespace Communications with OOK- and Phase-Modulation, at 850nm / 1064nm / 1550nm
- Mobile Links between Ground / HAP / UAV / Balloon / Aircraft / Satellite / GroundVehicle
- Optical Space Communications with LEOs and Studies on GEO- and Deep-Space-Links
- Simulation and Analysis of the Propagation through the turbulent Atmosphere -> Index-of-Refraction Turbulence, Pressure Turbulence around AC
- Methods for Fading-Mitigation:
  - Diversity (Space, Wavelengths, Time)
  - asynchronous Transmission with FEC and Interleaving
- Pointing, Acquisition and Tracking (PAT): Optical / GPS / INS / Orbit
- System Demonstrations, Field Trials, and System Tests

The Three Principals to Investigate IRT Propagation

Analytical theory

theory inherent restrictions apply

(The Rytov theory is valid only under weak fluctuations (the multiple scattering effect is ignored)

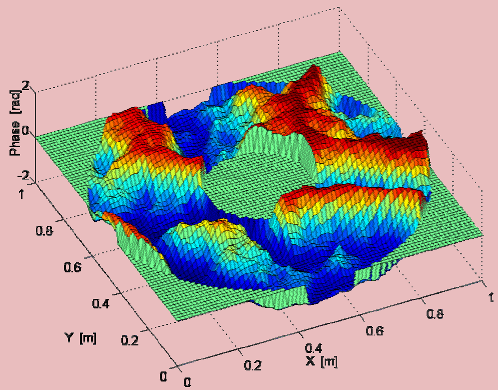
$$\nabla^2 U(P) + k^2 n^2(P)\cdot U(P) = 0$$

$$\sigma_R^2 = 1.23\, C_n^2 k^{7/6} L^{11/6}$$

Numerical simulation

PILab

split-step Fresnel propagation

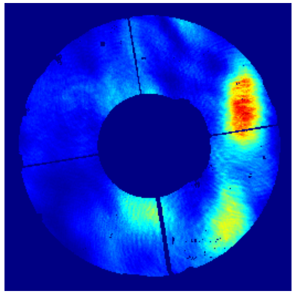


Field trials and measurement campaigns

results only valid for one specific scenario

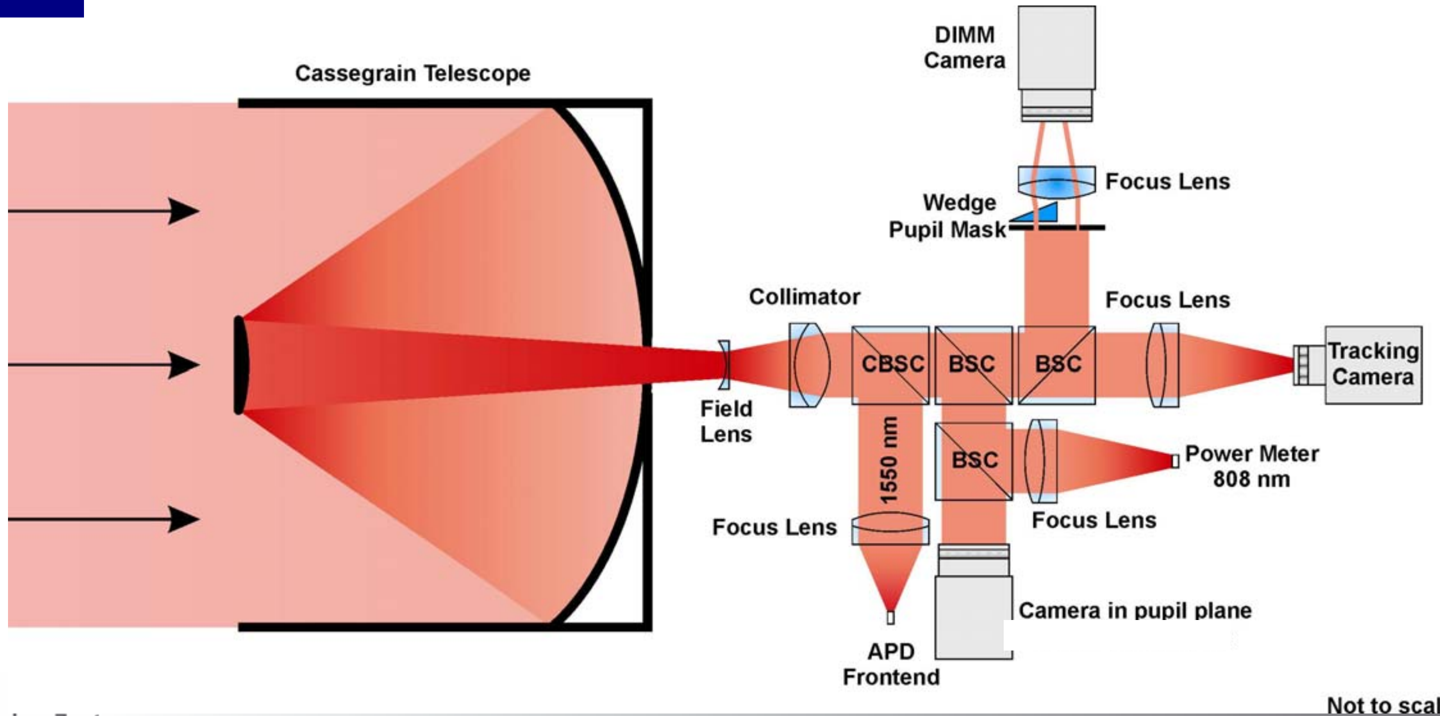
-> Verification by measurements is indispensable

Measurements of IRT:
The *Atmospheric Transmission Monitor (ATM)*



Pupil Camera
- Estimates C_n^2-profiles
- Calculates scintillation indices
- Calculates intensity correlation

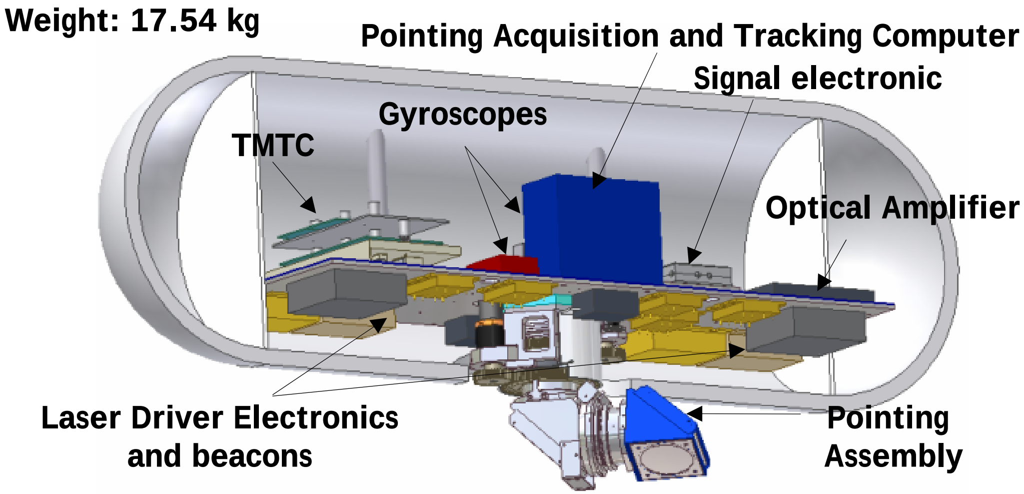
DIMM
(Differential Image Motion Monitor)
- measures parameters of the wave-front distortion
- 2b replaced by Shack-Hartm.

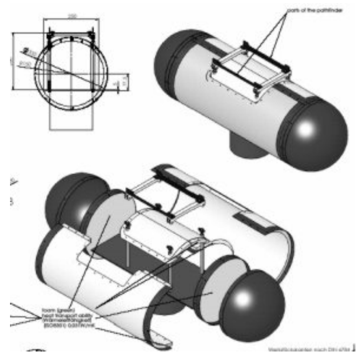


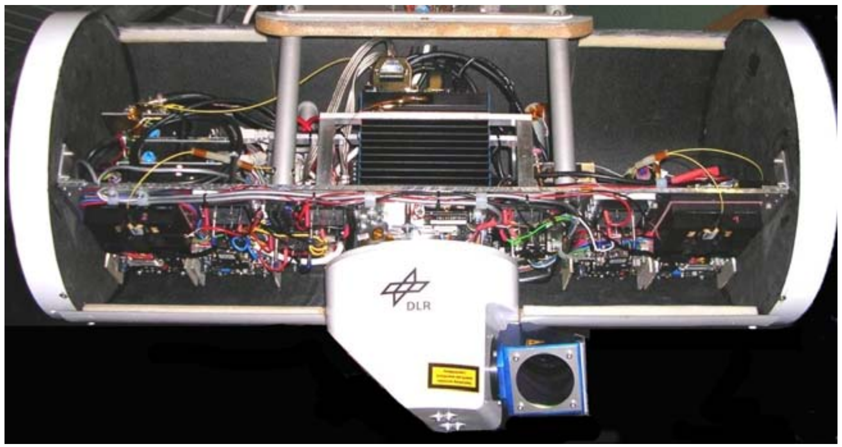
Projects:

- CAPANINA: Stratospheric Optical Downlink
- KIODO: LEO Downlink from Japanese *OICETS*

CAPANINA - Trial: Stratospheric tests "STROPEX", Optical Downlink at 1.25Gbps (IM/DD)

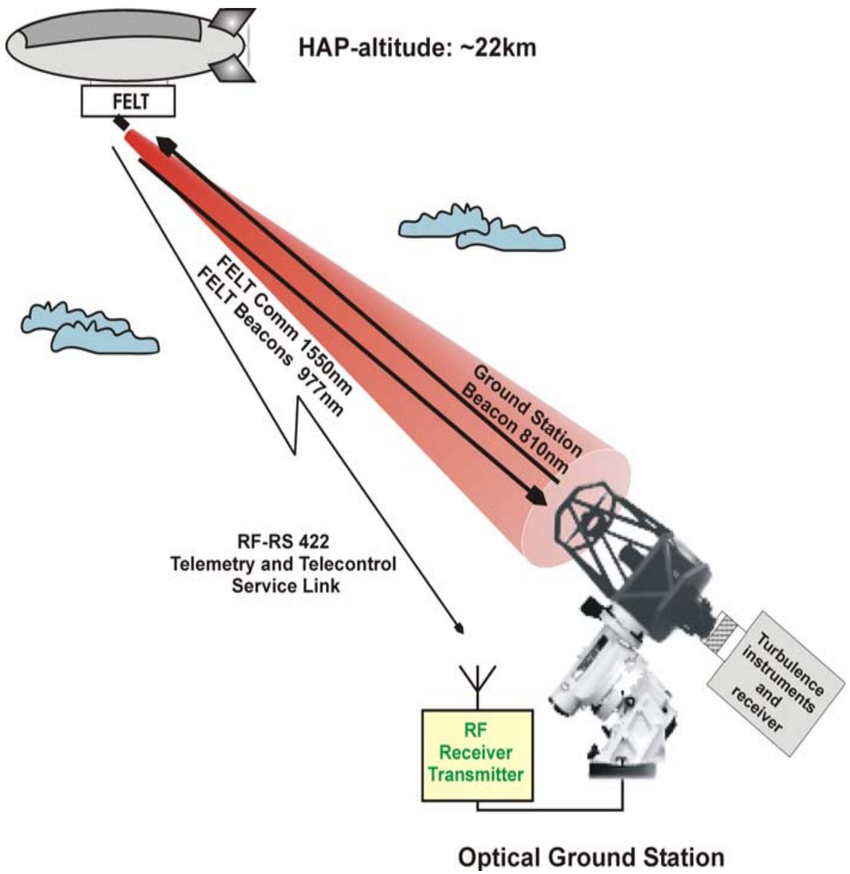






Measurement campaign at Site “ESRANGE” (Sweden)

- Downlink from a stratospheric test-bed
- Nacelle with Backup systems for Acquisition
- Turning mechanism for secure landing
- Transportable ground station



Acquisition of ground station from balloon terminal

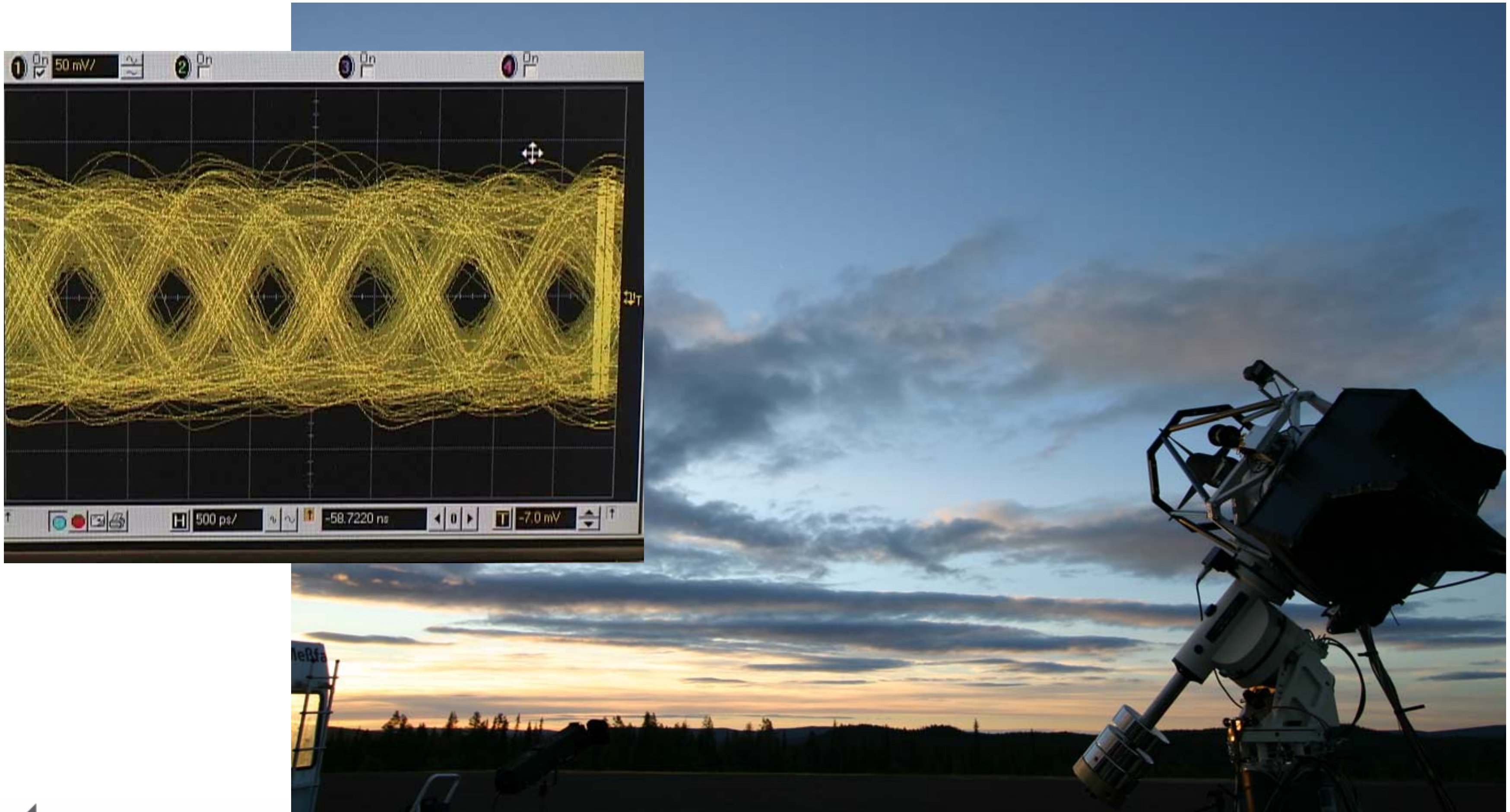
- Typical acquisition time 30 s (with no heading information available!)
- Tracking accuracy of HAP-terminal was better than 142 µrad (0.0081deg)

STROPEX Control room

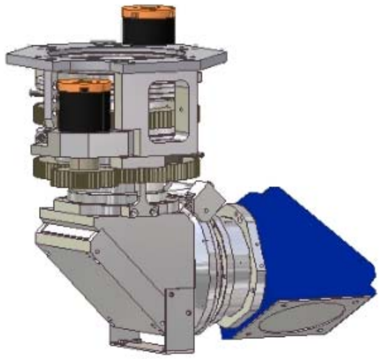
Video: Acquisition sequence

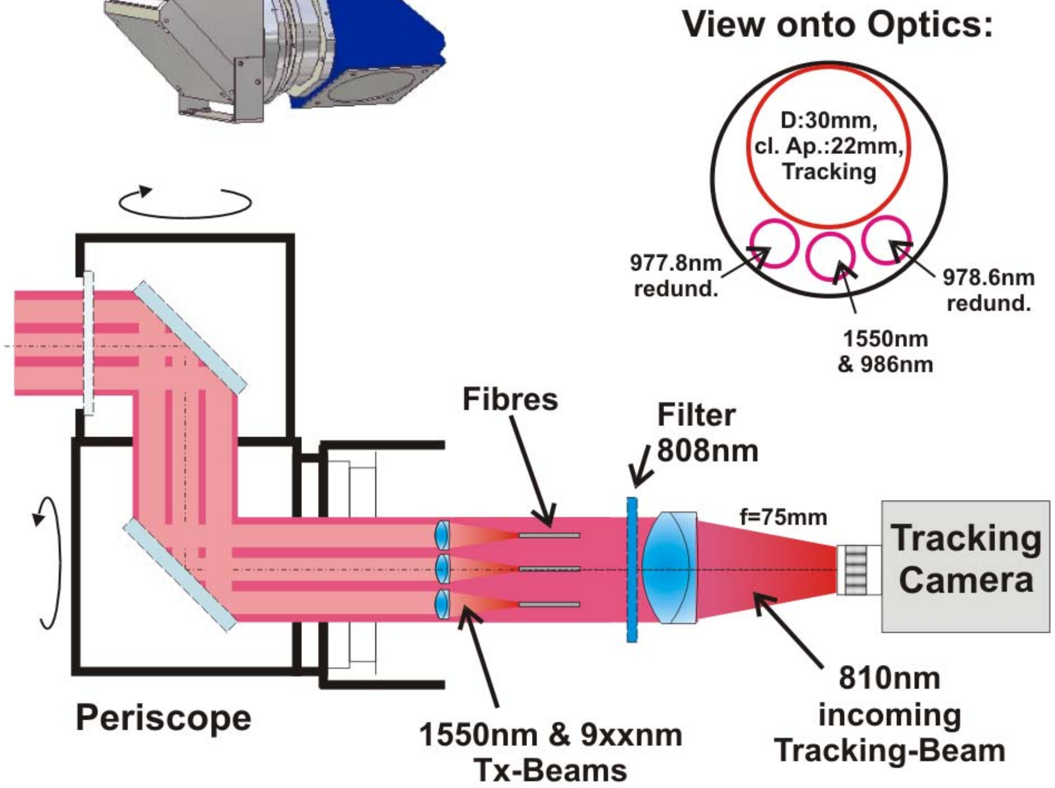
1.25 Gbps Signal received at Optical Ground Station

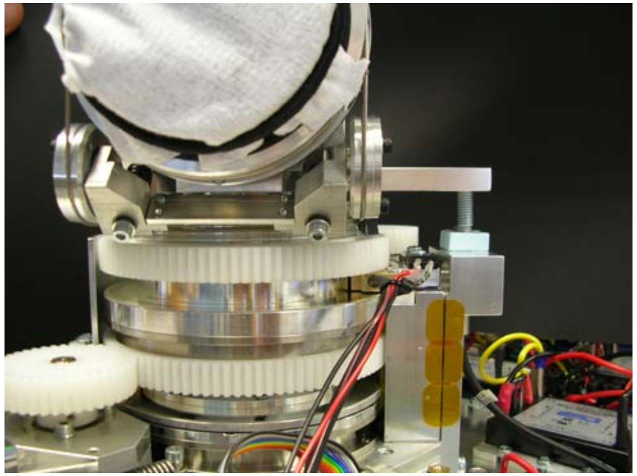
distance 64km, from 22km altitude, 100mW Tx-power



Details of the Stratospheric Downlink Terminal





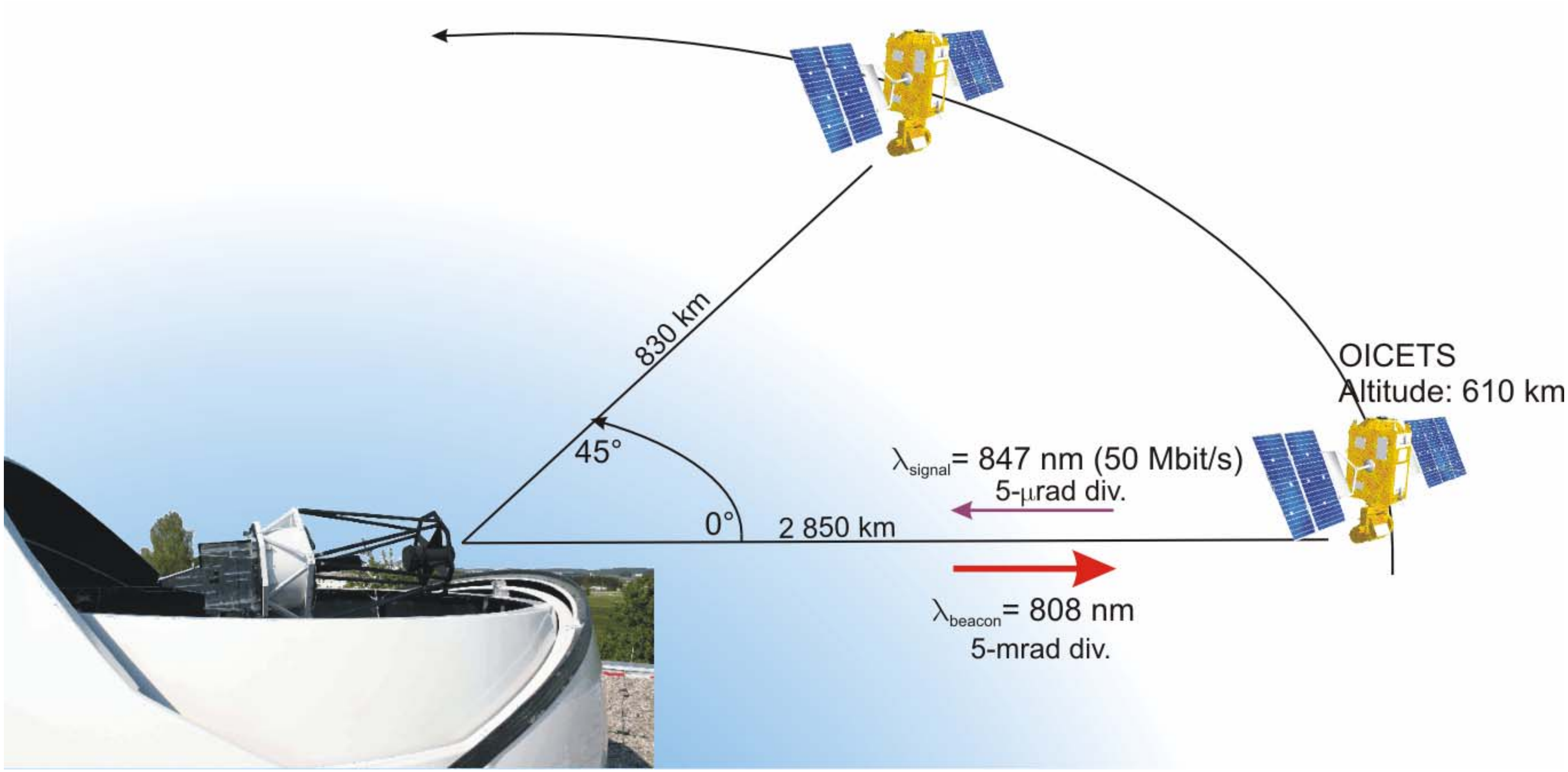


KIODO - LEO-Downlink
(Kirari Optical Downlink to Oberpfaffenhofen)
- Joint Experiment with *JAXA,* in June 2006

JAXA's *Kirari* Satellite (=OICETS)

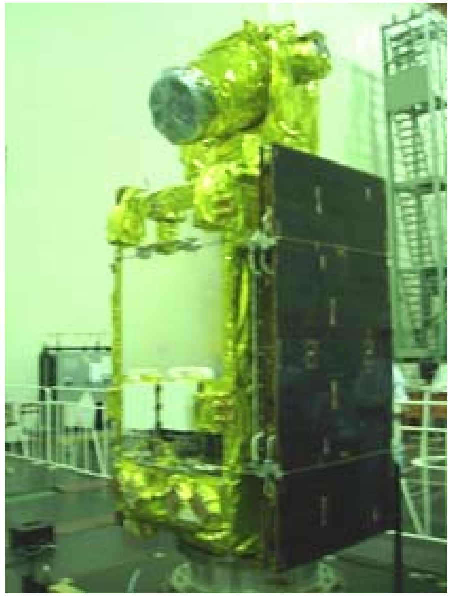
OGS-OP: Optical Ground Station Facilities at DLR-Site Oberpfaffenhofen (near Munich)

KIODO - Parameters

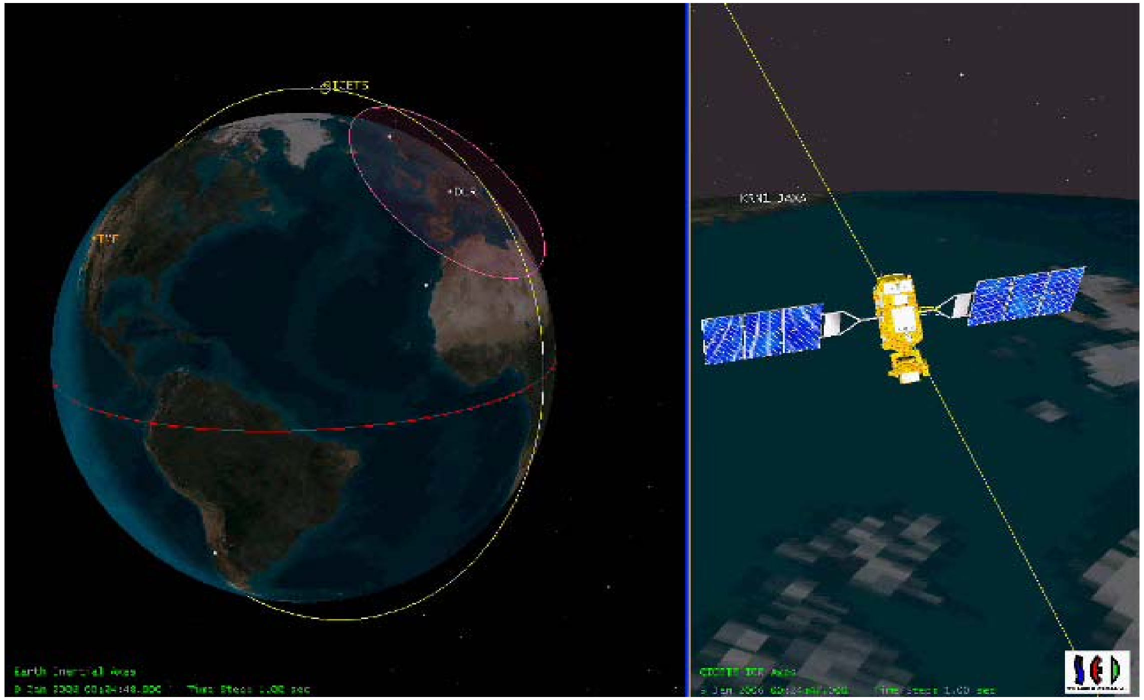


Measurements in the IM/DD satellite downlink channel

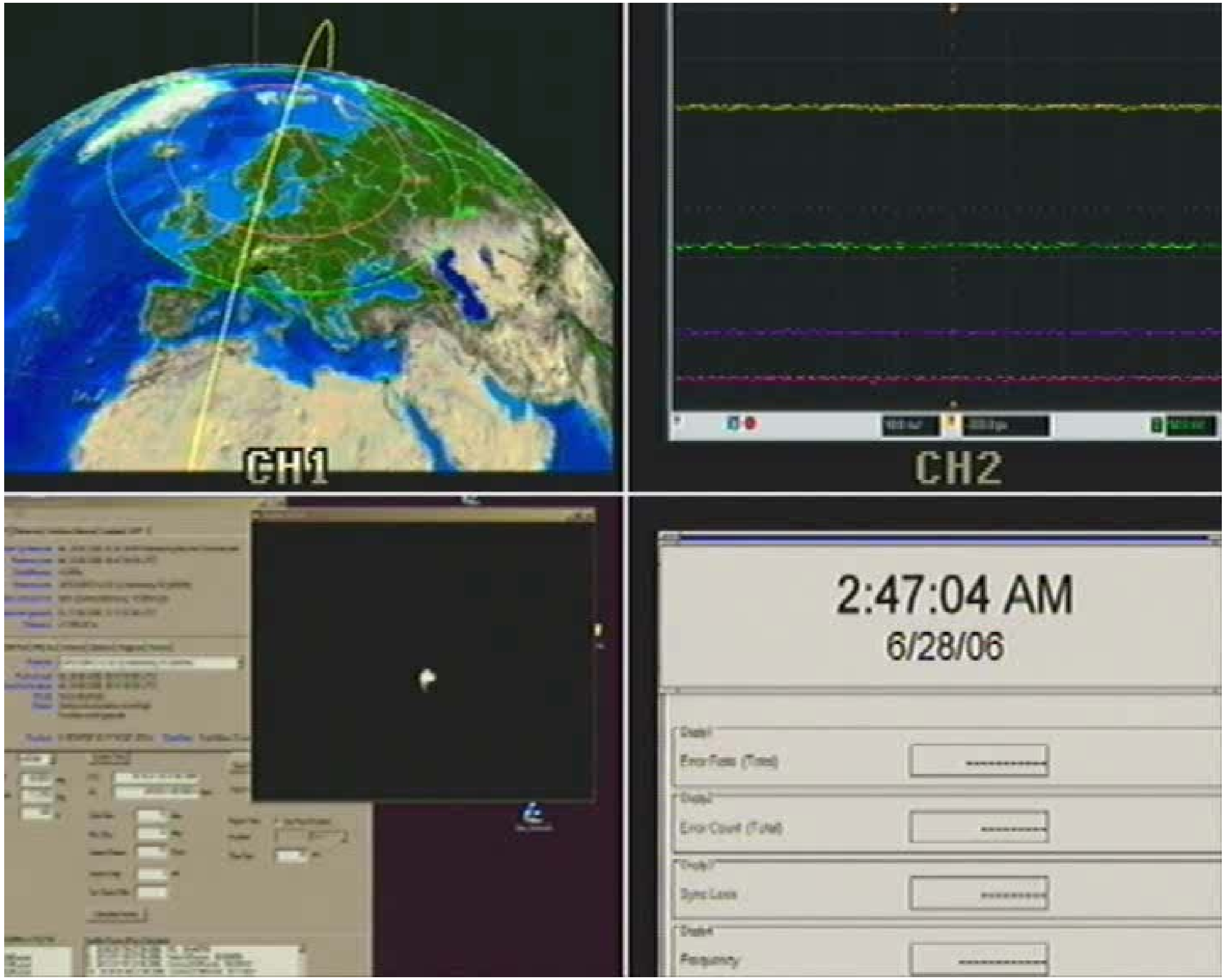
- 8 Downlinks from JAXA's Kirari to OGS-OP in June06
- Successful data-reception (50Mbps, 847nm)
- Channel-measurements



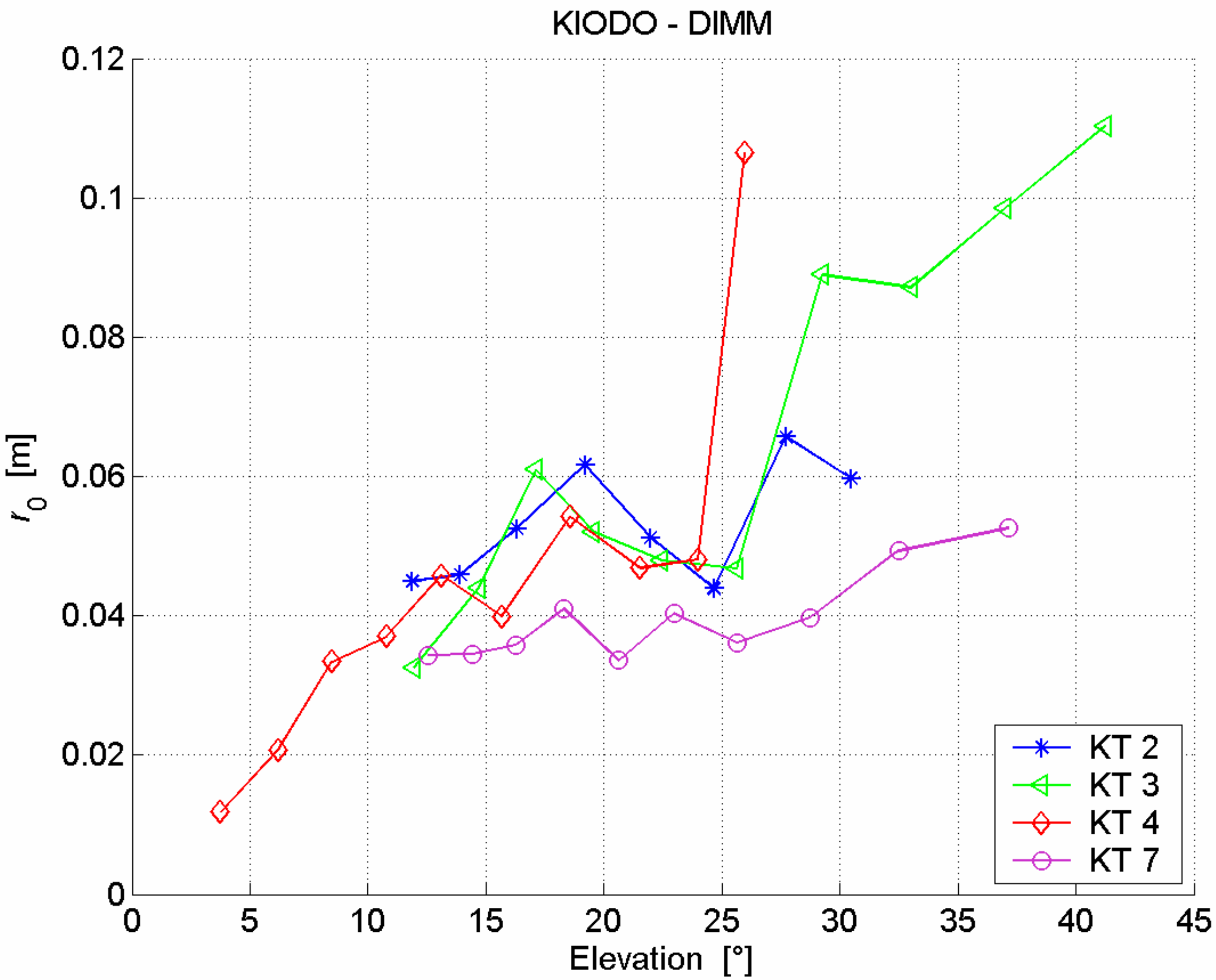
JAXA's *Kirari* Satellite with *LUCE* on top



Measurement-Monitoring during KIODO-Trial 7

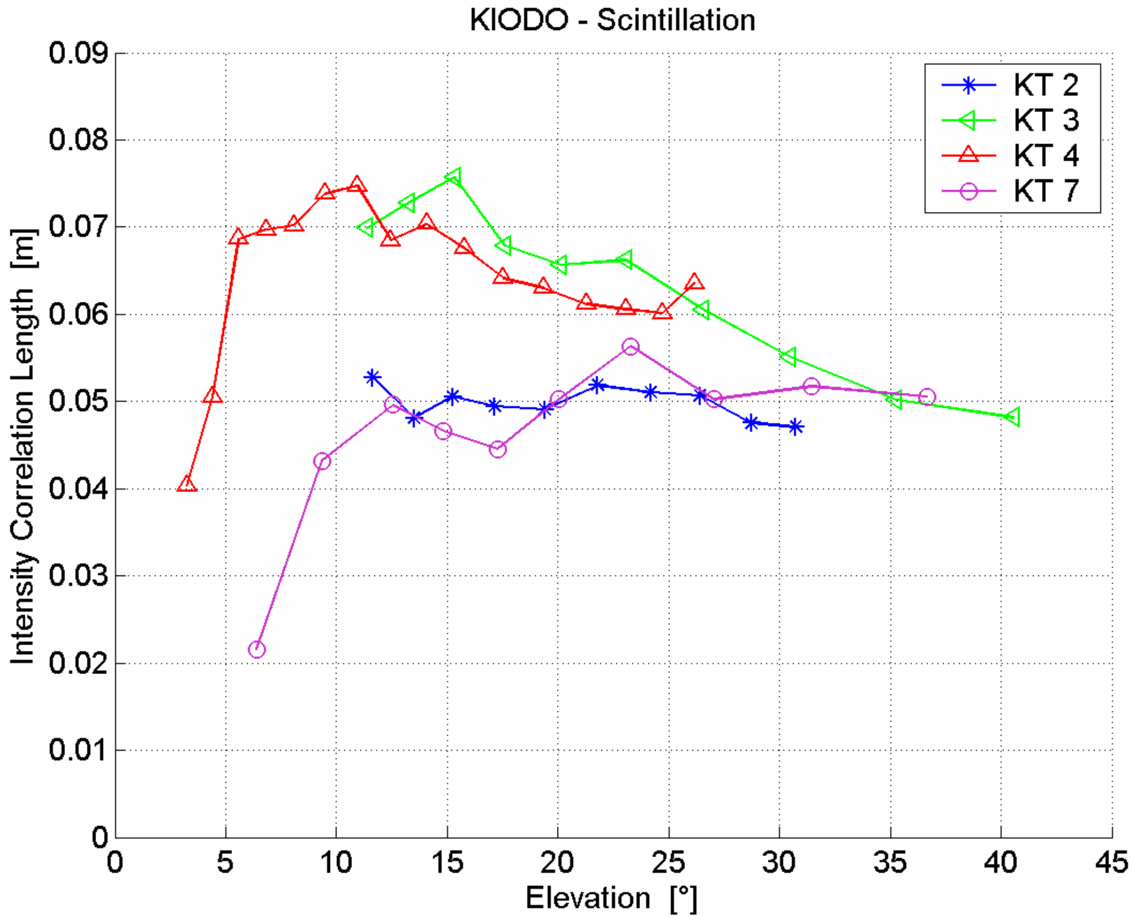


Downlink: r_0-Estimations from DIMM-data

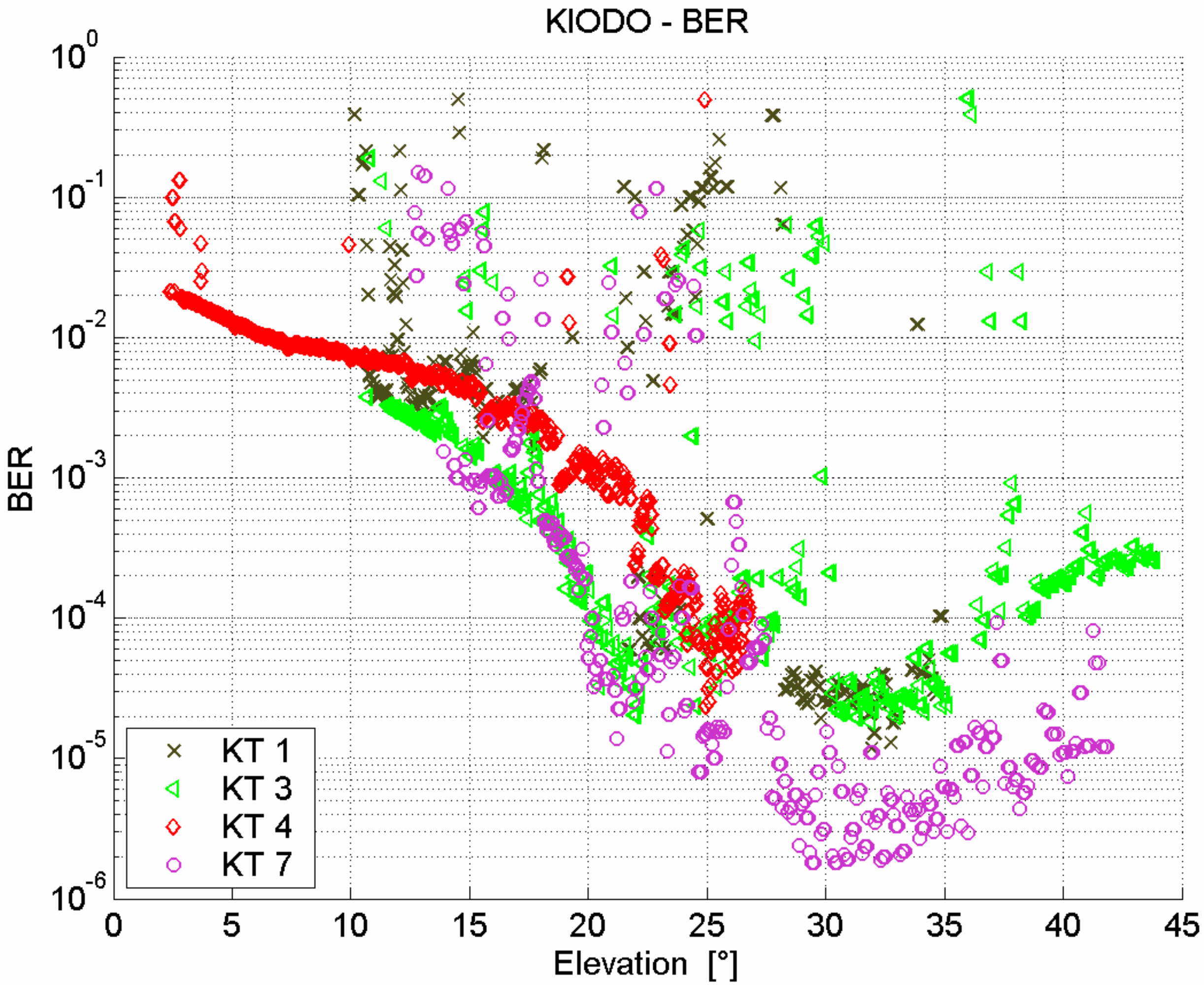


Exposure time = 80 µs

Downlink (847nm): Intensity Correlation Length (from PROF-Data)



Downlink: Measured BER



- mean Rx-power was more than enough for error free reception
- BER was limited by Rx-electronic's spectral behaviour; electronics and algorithms were optimized between trials
- ongoing research in lab testbed at DLR to optimize Rx-electronics

KIODO-Results:

- Successful optical downlink from LEO to "lowland" OGS-site
- Optical Downlink from LEOs proved feasible with low effort on ground
- Measurements of the Atmospheric Optical Index-of-Refraction-Turbulence Fading Channel during LEO-Overflight

- Remark: Japan's *NICT* conducted similar trials in 2006 to their OGS near Tokyo

Current and future projects at DLR-OCG:

- Downlink experiments with the coherent DLR-LCT onboard TerraSAR-X, to OGS-OP (at DLR-Oberpfaffenhofen) and to Calar Alto (Spain), ongoing
- Aeronautical optical links investigations with in-flight tests (MINERVAA-project)
- Adaptive Optics and other concepts for link quality enhancement
- Stratospheric Optical Inter-Platform Links
- Optical downlinks from UAVs

Future Scenarios (1-3)
EO-Sat Downlinks over optical GEO-Relays

- pros:
  - real-time data connection to the EO-Sat during half of its orbit
  - increased data throughput
  - simple operations planning when using µwave downlink from GEO to GND: no dealing with hard-to-predict cloud blockage
- cons:
  - strained link-budget over long distance (40,000km)
  - several link-components need to be in place in time

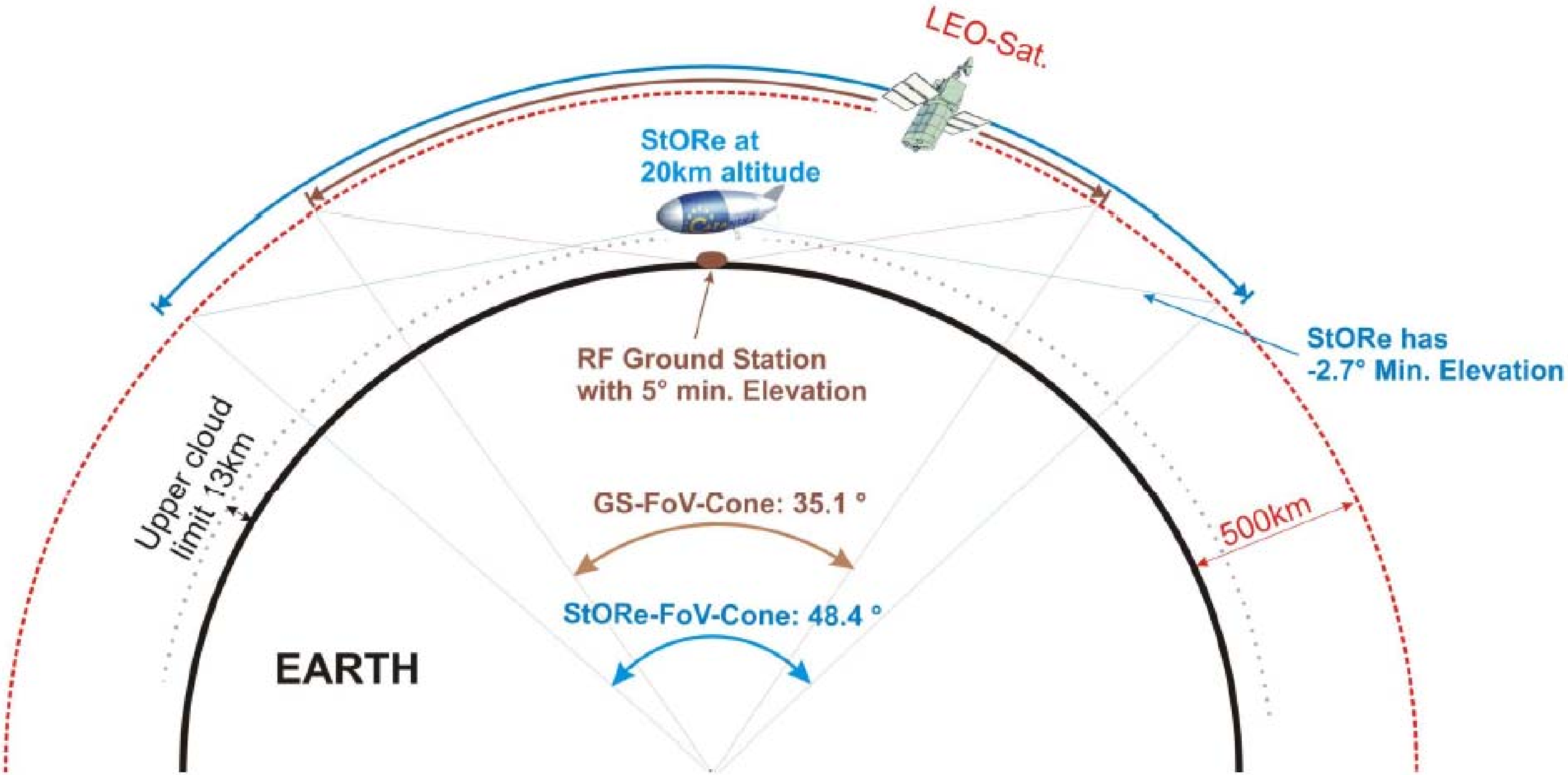
Future Scenarios (2-3)
Optical EO-LEO Downlinks directly to Ground

- pros:
  - short distance allows low power consumption with small Tx-terminals
  - easy to be installed also on *very small* LEOs
  - agile LEOs can do the pointing to the OGS – no CPA needed (this feature is mission dependent)
  - low costs for Sat-Tx-Terminal and for OGS
- cons:
  - cloud blockages require several ground stations ("OGS-Diversity") for secured downlink-throughput
  - large data storage capacity required if only few/one OGS is used, to overcome blockage periods
  - atmospheric IRT reduces performance at low elevation
    -> specialized FEC required
- further issues:
  - special protocols to be developed for ensured data throughput (FEC, efficient retransmission, buffering) -> is a current research objective at DLR

Future Scenarios (3-3)
Optical Sat-Downlinks to Stratospheric Relays (HAP)

- pros:
  - cloud-blockage is no problem as HAPs are located far above cloud-ceiling
  - IRT only a minor problem and only at very low/negative elevations
  - enhanced contact time for downlinks by factor two (5700km footprint-diameter, as LEO-visibility starts at -2° elevation)
  - also beneficial for bidirectional (communications-) links from satellites
  - very low costs for simple Sat-Tx-Terminal; HAP also used for other tasks
- cons:
  - HAP-technology not mature ye, many problems still to be solved
- further issues:
  - link from HAP to ground can be done by "short-range" (~30km) µwave-links or also optical (combined with buffering onboard the HAP when clouds block the direct downlink to ground) or with re-routing to other HAPs w/o cloud blockage underneath
  - one can also use unsteered stratospheric balloons which can be kept in a loose station keeping box for several weeks by altitude-control

Geometrical Relations with OGS and Stratospheric Optical Relays



Technological Considerations

- highest sensitivity is required for LEO-GEO OISLs which can be delivered by coherent BPSK better than by OOK/DD
- for shorter distances like in LEO-downlinks, larger ground-based Rx-telescopes (in the order of few dm) together with the reduced freespace-loss relax the link budget
- an open technology is desirable, which allows simple transmission schemes (e.g. OOK, DPSK) where applicable but can be upgraded to sophisticated schemes (e.g. BPSK) where necessary
- when considering transmission through (thin) clouds, inter-symbol-interference (ISI) has to be evaluated to chose the most robust modulation format

Summary – Technological Options for EO-Downlinks

- Optical downlink-terminals can provide an immense increase in operational usability of EO-sensors, but are restricted by cloud cover over the OGS
- Direct optical downlinks can provide simple online region-of-interest access for optical sensors (e.g. forest fire detection, boarder control, …)
  – "when optical sensors can see the ground also the optical downlink works"
- An internationally organized OGS-Network for civil EOSat-Missions would be very beneficial for all members; could also be used for deep-space missions
- Even geographical areas with high average cloud coverage can benefit from optical downlinks when using OGS-diversity on national territory with optimally chosen OGS-sites
  (e.g. optical downlinks to Germany with four OGS: 96% combined availabilty in summer-term and 75% in winter-term)
- International cooperation is required for coordination of wavelengths and modulation formats