POLITECNICO DI MILANO

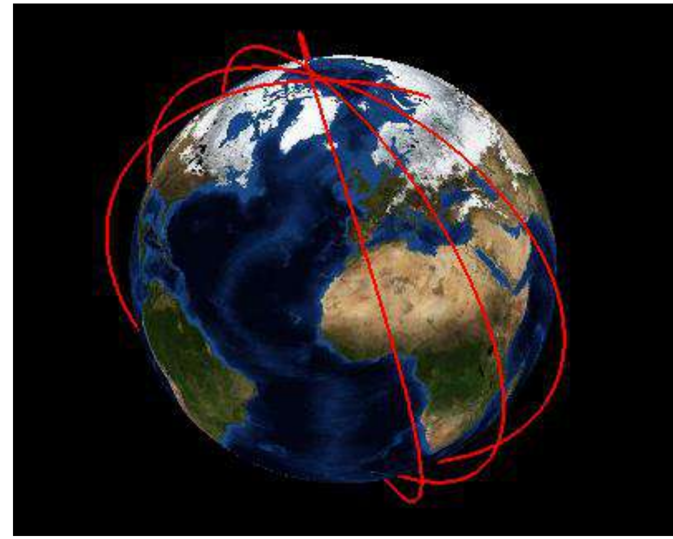
E.M. wave propagation at Politecnico di Milano: research activities and theses

Lorenzo Luini and Carlo Riva

Current and future E.M. wave propagation challenges

Growing interest of GEO satellite operators (e.g. EUTELSAT and SES) in very high frequency bands for feeder link networks (40-50 GHz) →

Increase in the operational frequency also for LEO/ MEO/HEO satellites and deep space probes (8 to 27 GHz)



Extreme increase in the data traffic generated by mobile devices foreseen for the next future
Use of millimeter waves to strongly enhance capacity in 5G/6G systems

Current and future E.M. wave propagation challenges

Growing interest of GEO satellite operators (e.g. EUTELSAT and SES) in very high frequency bands for feeder link networks (40-50 GHz) →

Increase in the operational frequency also for LEO/ MEO/HEO

For all systems → increase in carrier frequency → stronger detrimental effects due to the atmosphere

generated

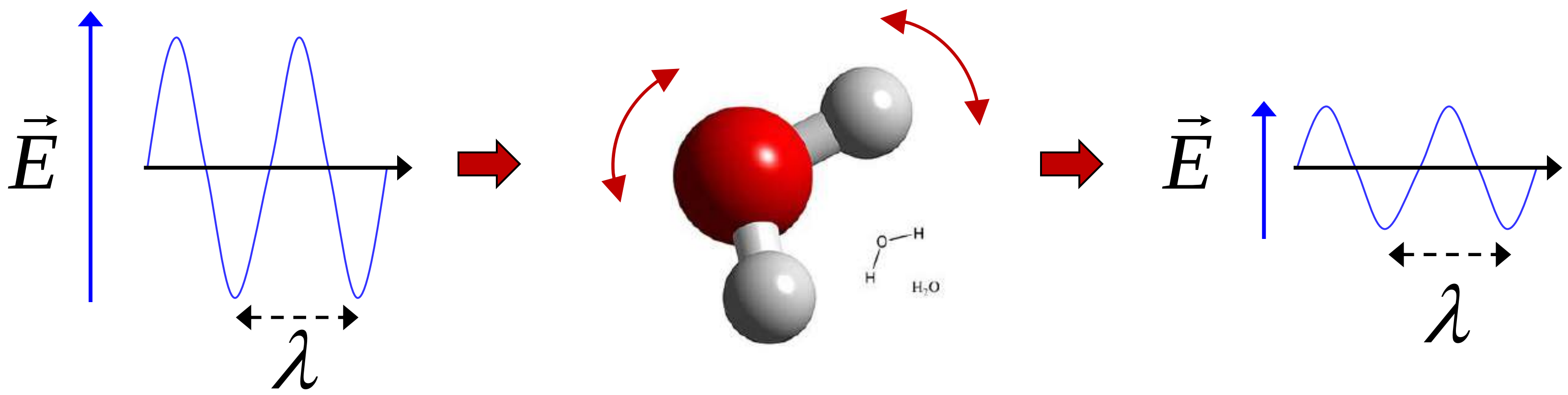
by mobile devices foreseen for the next future

Use of millimeter waves to strongly enhance capacity in 5G/6G systems

Atmospheric effects on E.M. waves: gaseous absorption

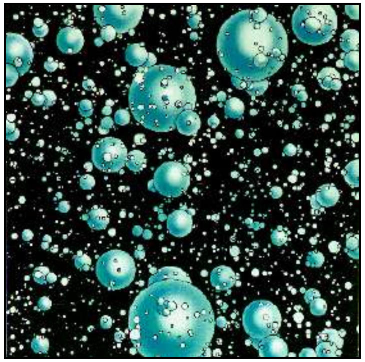
Signal fades caused by atmospheric gases (1–1000 GHz)

- Gaseous components affecting E.M. propagation in this frequency range → oxygen and water vapor
- Absorption → due to the rotation of oxygen (magnetic dipole) and water vapor (electric dipole) molecules induced by E.M. waves

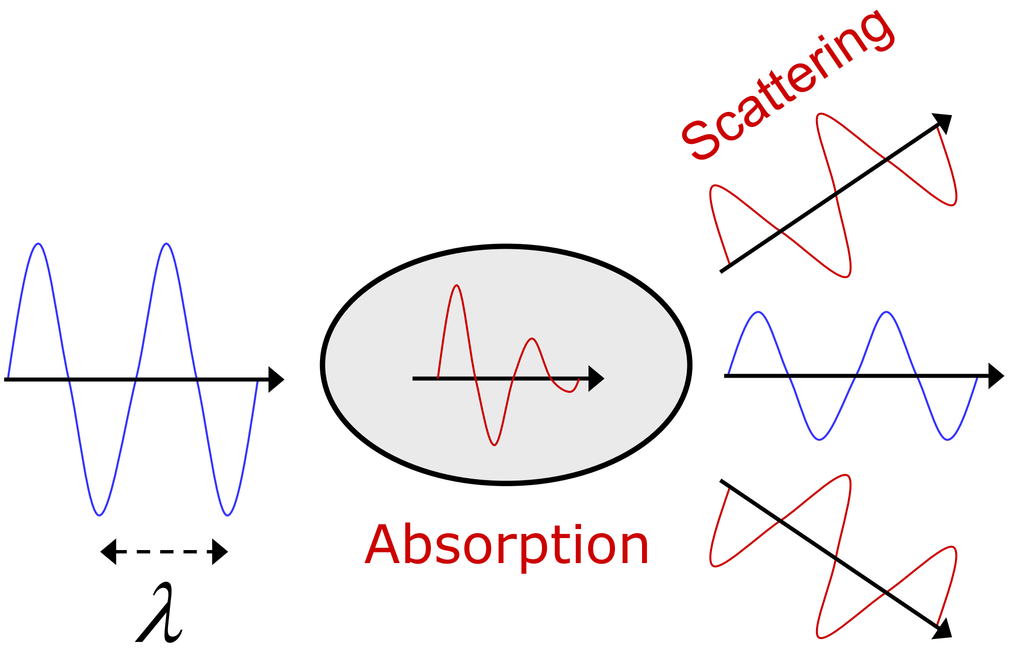


- Significant absorption levels only around specific frequencies → resonance
- Oxygen and water vapor absorption depends on temperature, pressure and relative humidity
- Both always present in the atmosphere, but low variability in space and time

Effects due to ice and water particles (rain, fog, clouds, hail, …)



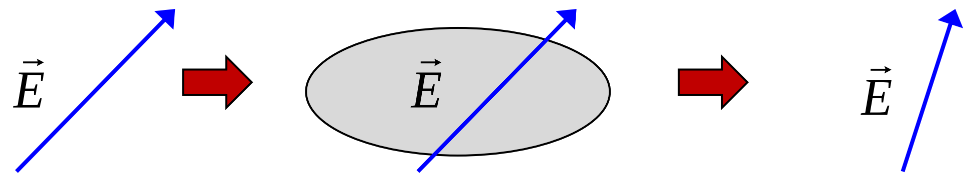
- Signal attenuation consisting of both scattering and absorption due to the ice and water particles
- Appreciable effects for frequencies above approximately 10 GHz → dimensions of particles (e.g. few mm for rain) comparable with the wavelength
- Different physical mechanism → unlike for gases, induced fade continuously increasing with frequency (10-100 GHz range) and concentration of the particles (e.g. rain rate)
- Different phenomena (e.g. rain and clouds) due to different size, concentration and physical state of the particles



Atmospheric effects on E.M. waves: secondary effects

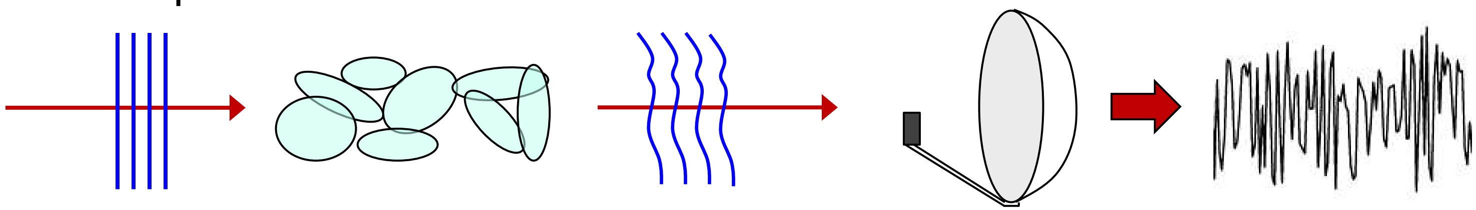
Depolarization

- Change of the wave polarization due to the non spherical shapes of ice/water particles



Scintillations

- Very fast oscillations of the received signal due to turbulence in the atmosphere (humidity variations, clouds, winds, rain drops …) → distortion of the wave front and generation of multipath

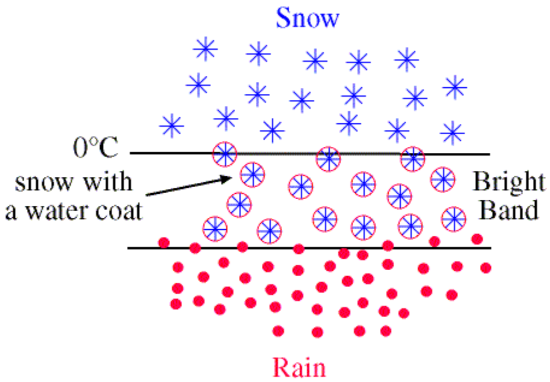


Snow/ice particles

- Negligible attenuation in the Ka/Q/V bands
- Depolarization issues (e.g. cirrus clouds)

Melting layer

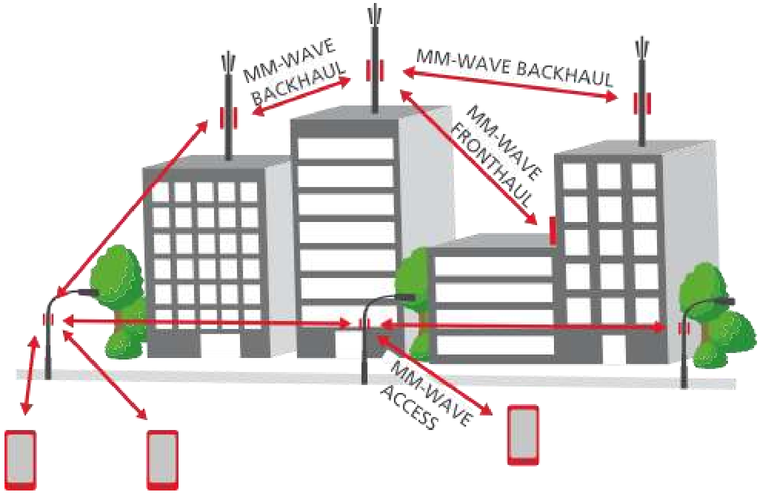
- Layer below the 0°C isotherm height where snow/ice particles gradually melt → higher attenuation, but limited thickness of the layer and not always present



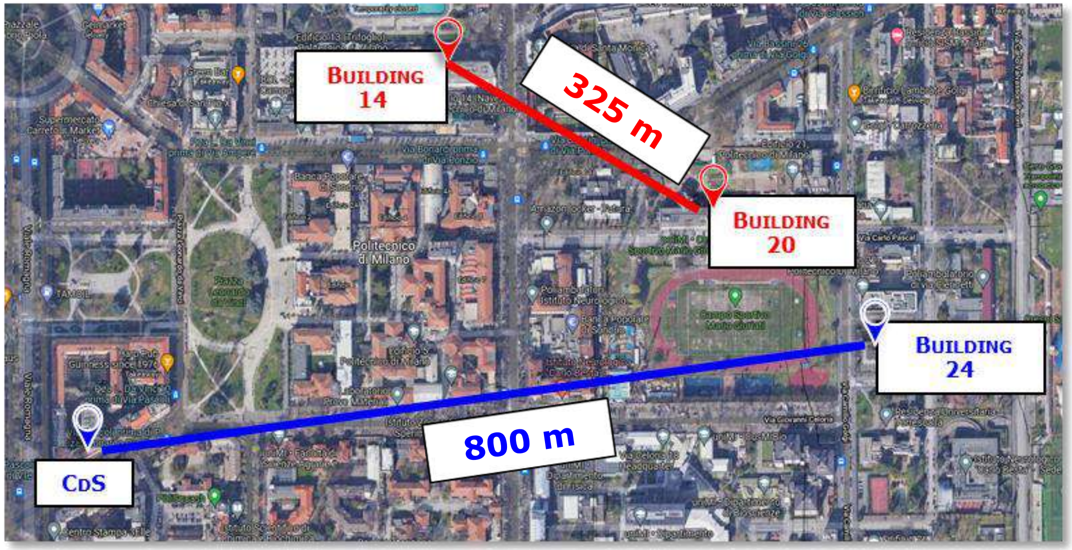
Terrestrial systems

Terrestrial communications (collaboration Huawei)

- Increasing interest in mm-waves and optical waves for next generation cellular systems (5G and 6G)
- Use of unlicensed (e.g. 60 GHz) or licensed frequency bands (e.g. 28 GHz) as a solution to strongly increase capacity
- Conceived for access links (overlay of mm-wave small cells) and backhaul links (connecting base stations to the core network)
- Atmospheric issues of relevance (precipitation, gaseous absorption, …)
- Environmental issues (e.g. NLOS, multiple rays, shadowing, …) to be addressed: need of wireless channel characterization in outdoor scenarios (path loss, impulse response, Doppler effects, …)
- Both experimental (measurements) and theoretical approaches (e.g. ray tracing)

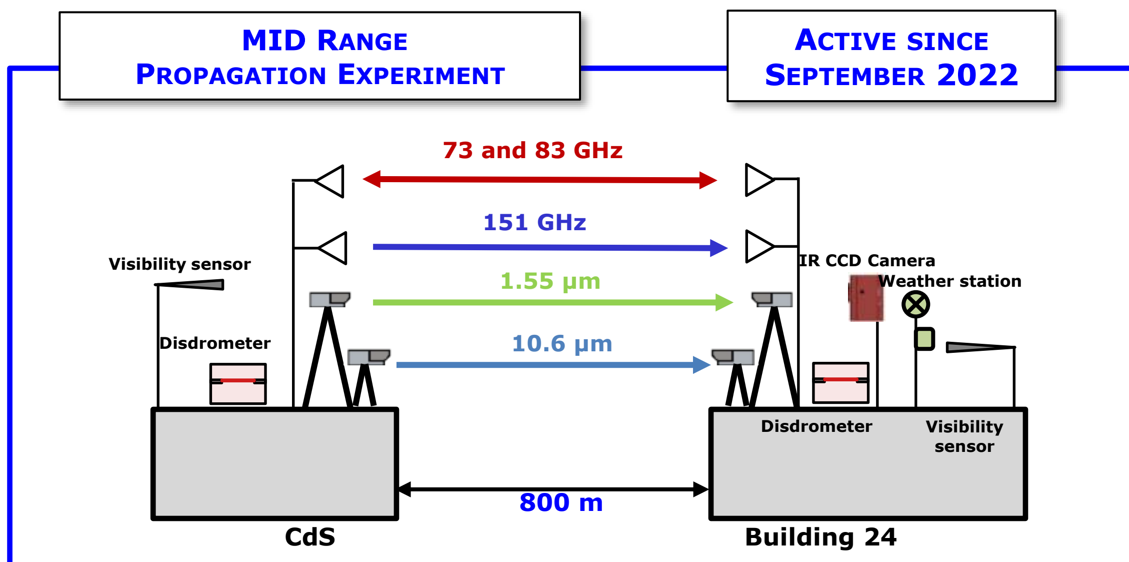


Hybrid RF/FSO propagation experiment



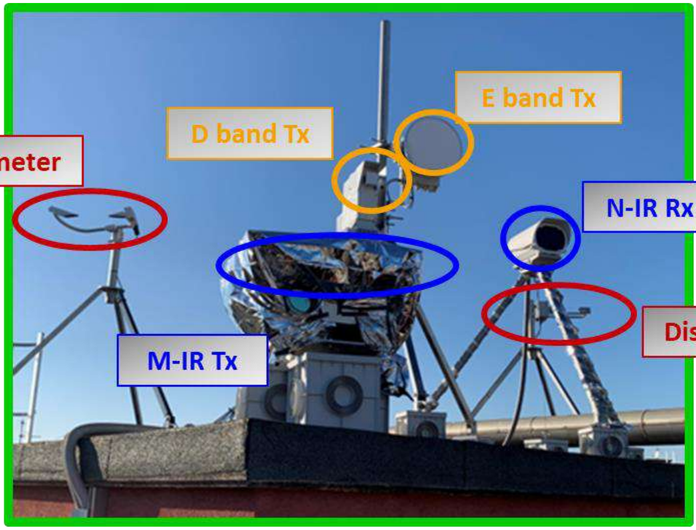
Multi-band propagation experiment along a mid-range link

- **E and D band →** 73, 83 and 151 GHz links
- **Near-Infrared →** 1.55 µm FSO link
- **Mid-Infrared →** 10.6 µm FSO link
- **Ancillary** instruments



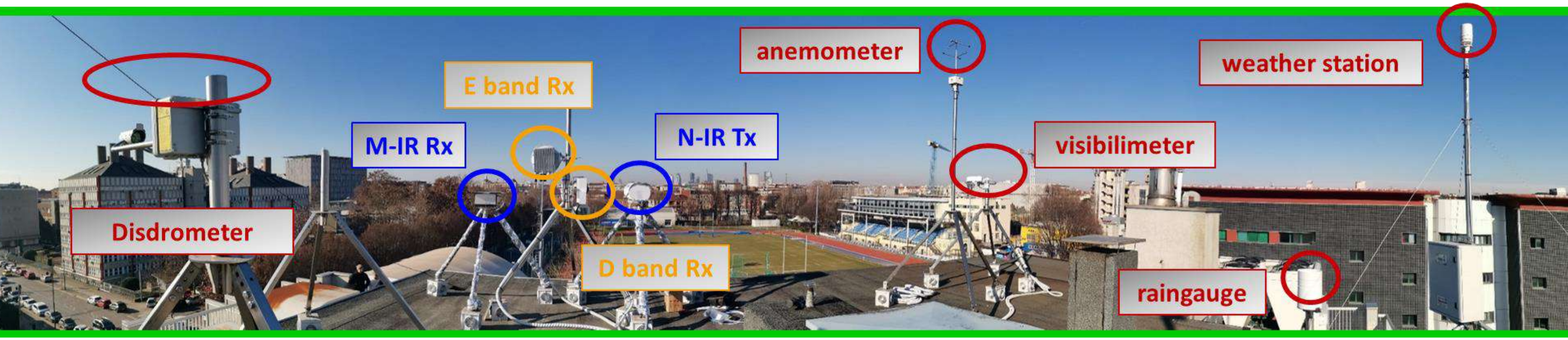
Hybrid RF/FSO propagation experiment

CdS SIDE



New setup installed in 2022

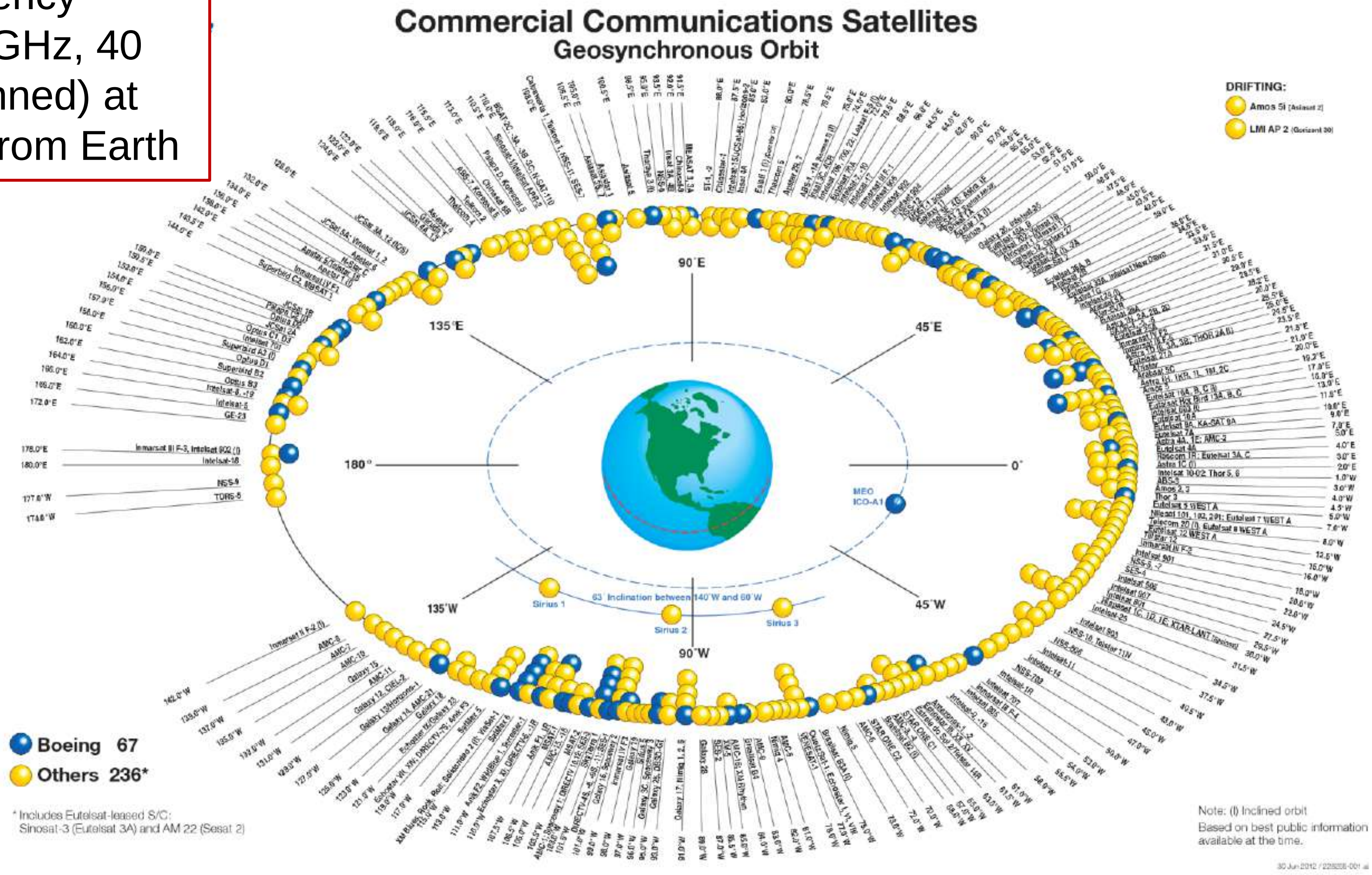
B.24 SIDE



Space systems

Modern satellite communication systems

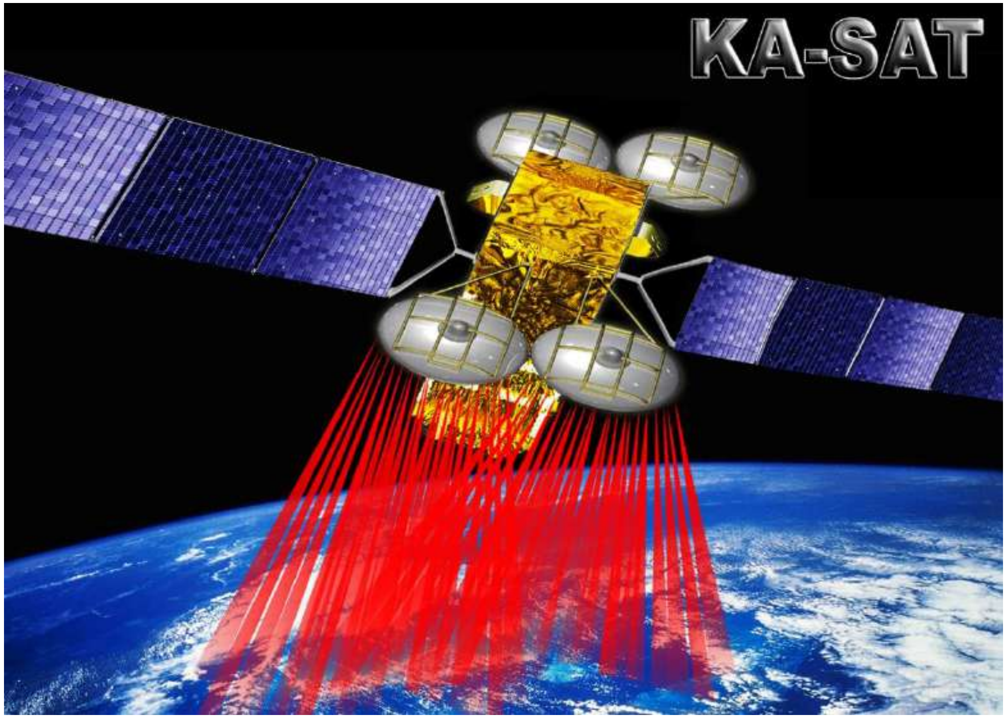
Many GEO satellites (max frequency around 30 GHz, 40 and 50 planned) at 36000 km from Earth

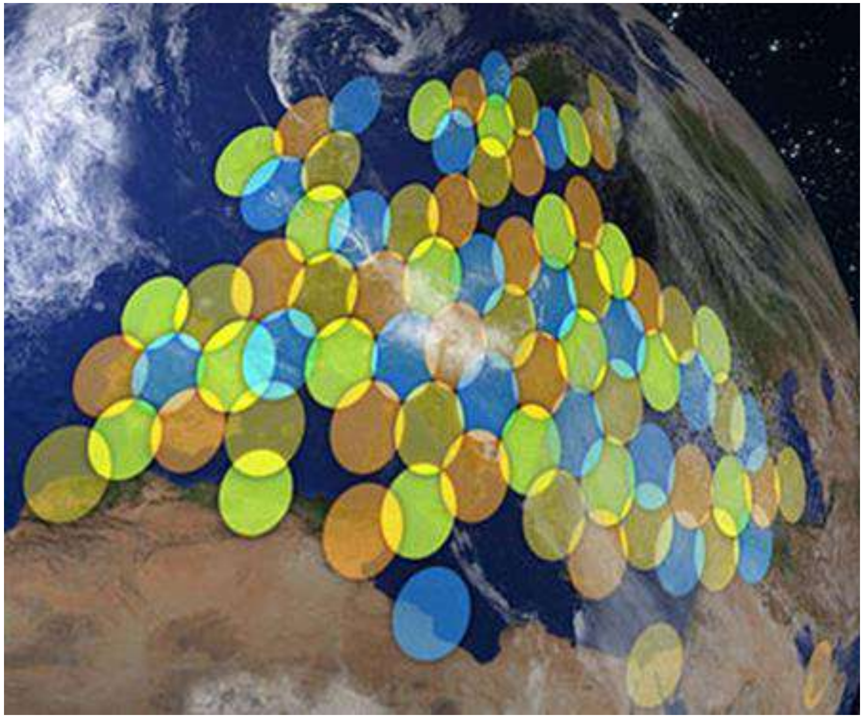


Modern satellite communication systems: GEO

From broadcast to interactive

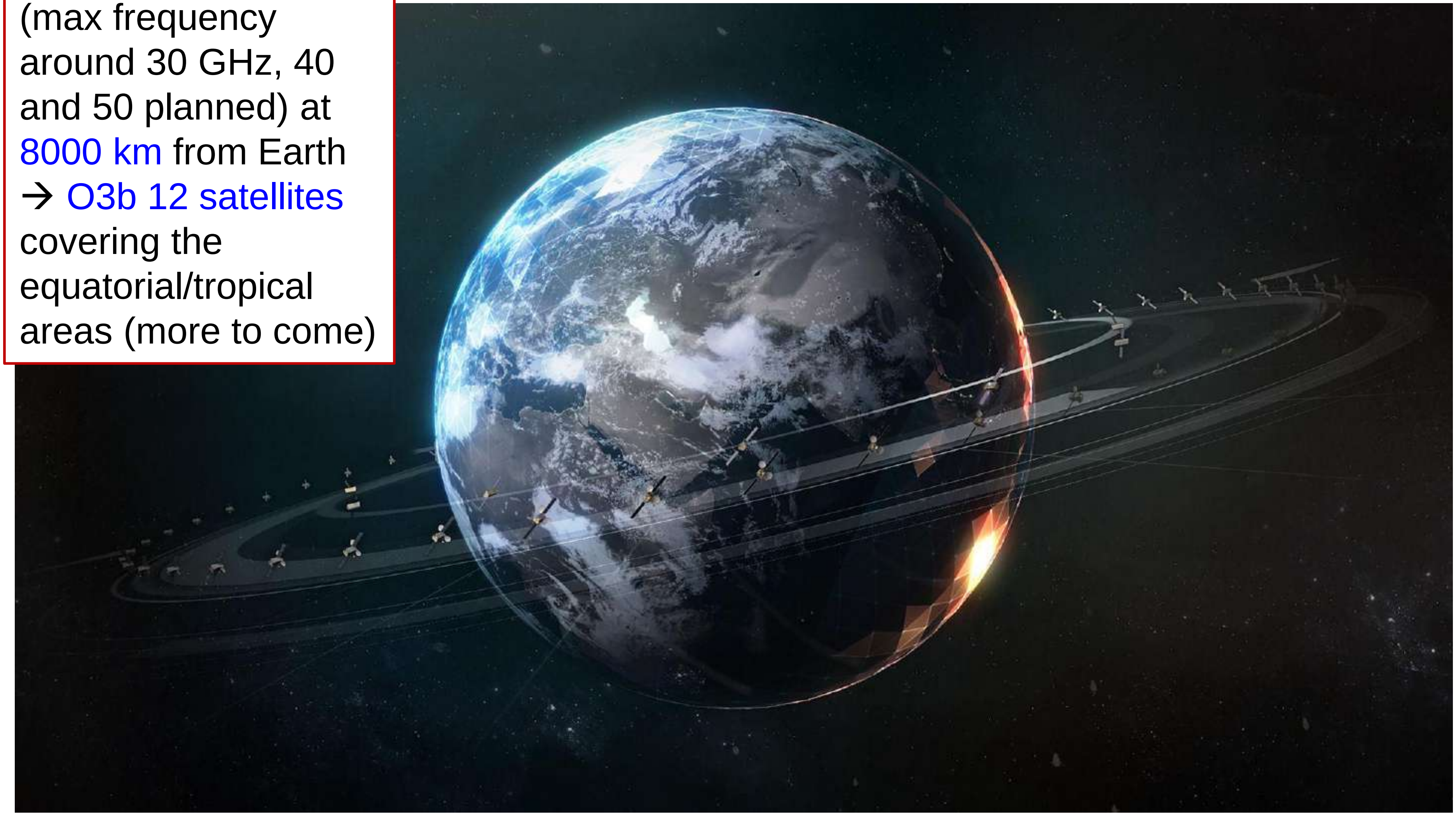
- It makes use of 82 beams covering the whole Europe
- Spots are arranged so as to reuse frequency channels (3 color scheme → increase capacity)
- Dual polarization system
- Total capacity → 70 Gbps (up to 475 Mbps per beam in 250 MHz BW)



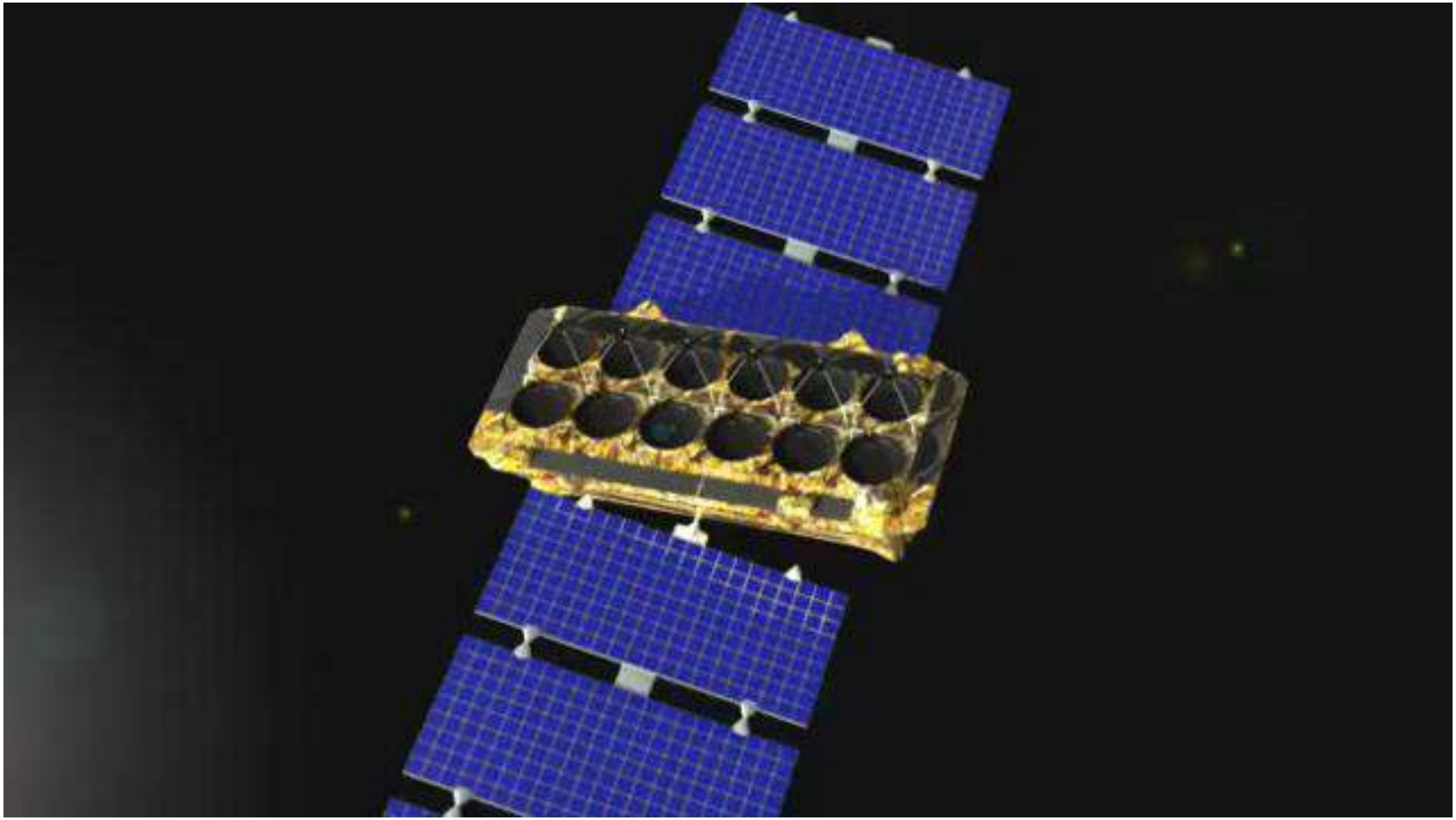


Modern satellite communication systems: MEO

Some MEO satellites (max frequency around 30 GHz, 40 and 50 planned) at 8000 km from Earth → O3b 12 satellites covering the equatorial/tropical areas (more to come)

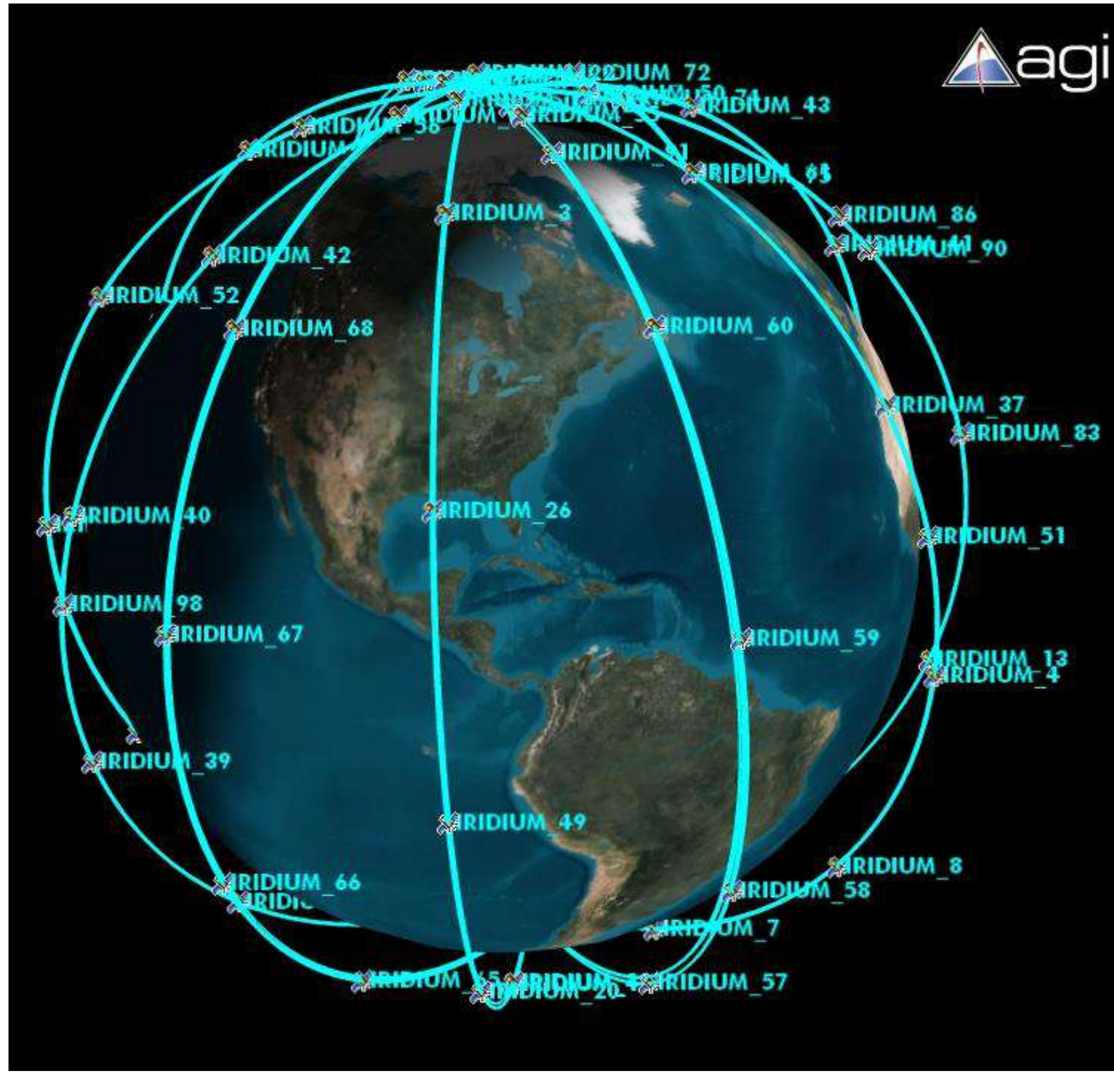


Modern satellite communication systems: MEO



Modern satellite communication systems: LEO

- SpaceX and OneWeb investigating projects to provide global broadband internet connectivity using other LEO constellations (or High Altitude Platforms)



Example: Starlink by SpaceX

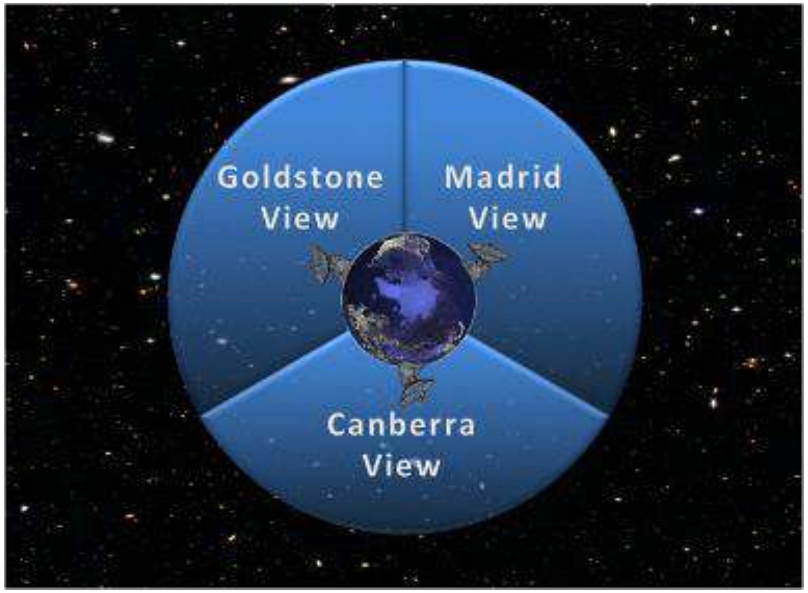
Cook Islands

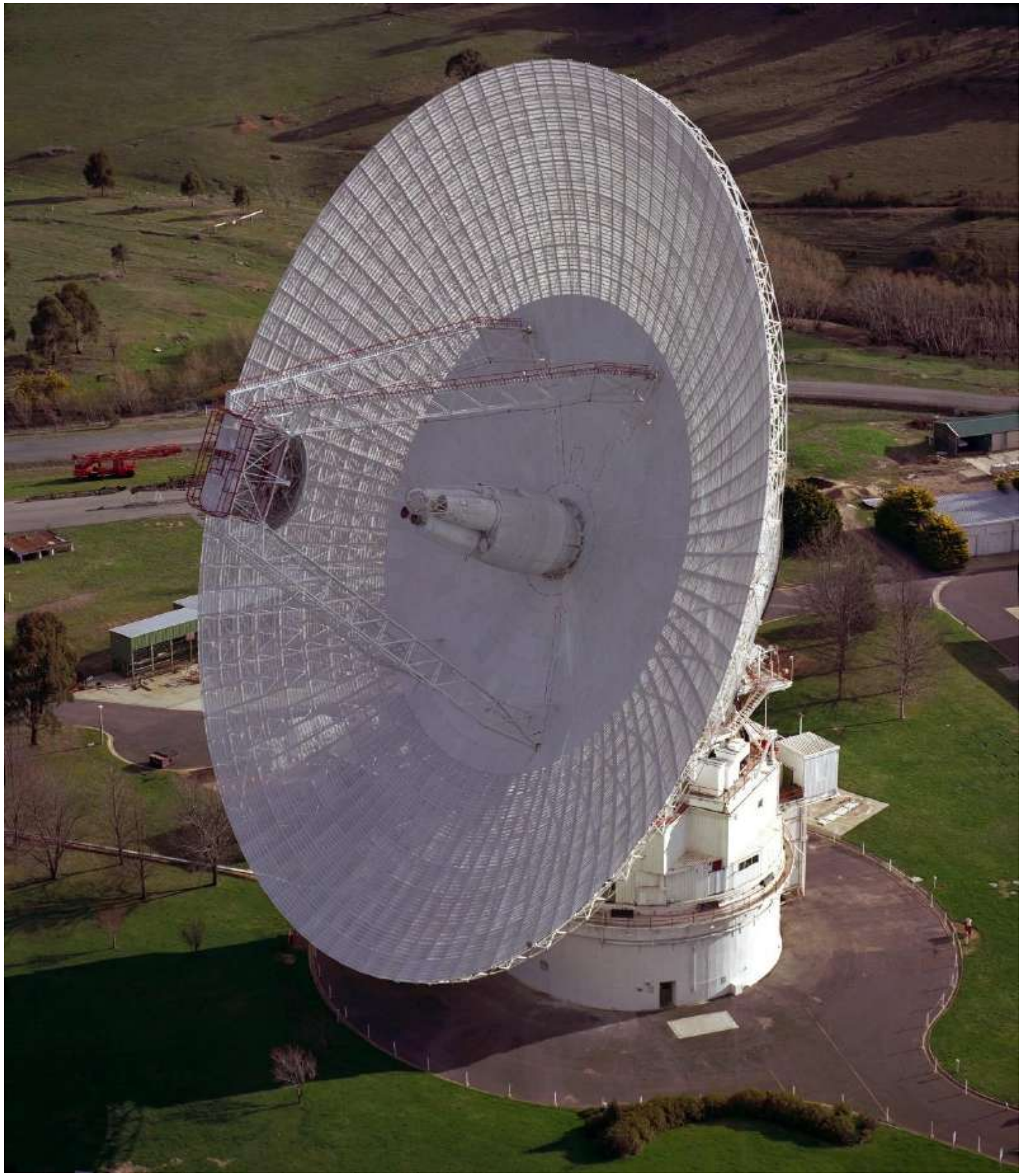
Why SatCom systems?

- Satellite communications to be integrated in the 6th generation of mobile systems (6G)
- To serve remote areas with broadband connectivity

Modern satellite communication systems: deep space

Track of deep space probes
(e.g. Mars Express)

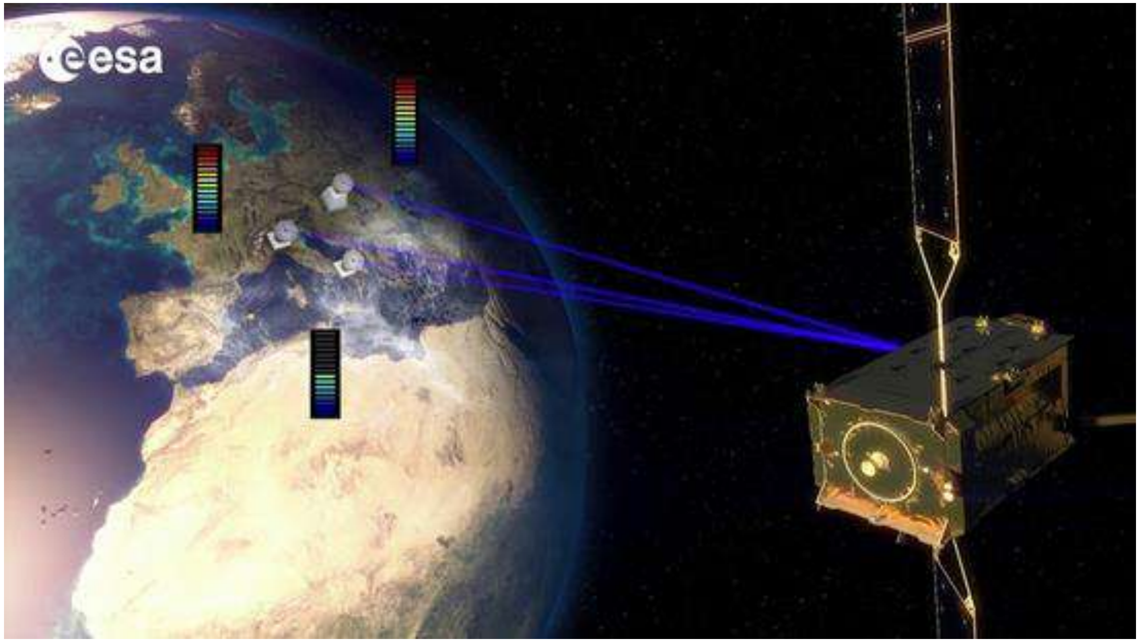




Alphasat experimental activity (ESA + ASI)

- Large platform by the European Space Agency (Alphabus)
- Satellite property → INMARSAT (UK satellite operator), for GEO broadcast service
- Call by ESA to embark also Technology Development Payloads (TDP)
- TDP5 → payload to study propagation and communication at Ka, Q and V bands developed by the Italian Space Agency

- PoliMi → principal investigator of the propagation experiment: 2 continuous-wave beacons at 19.7 (Ka) and 39.4 (Q) GHz
- Duration: 2013 → 2025
- Beacons illuminating the whole of Europe
- First satellite with communication in the 40-50 GHz band

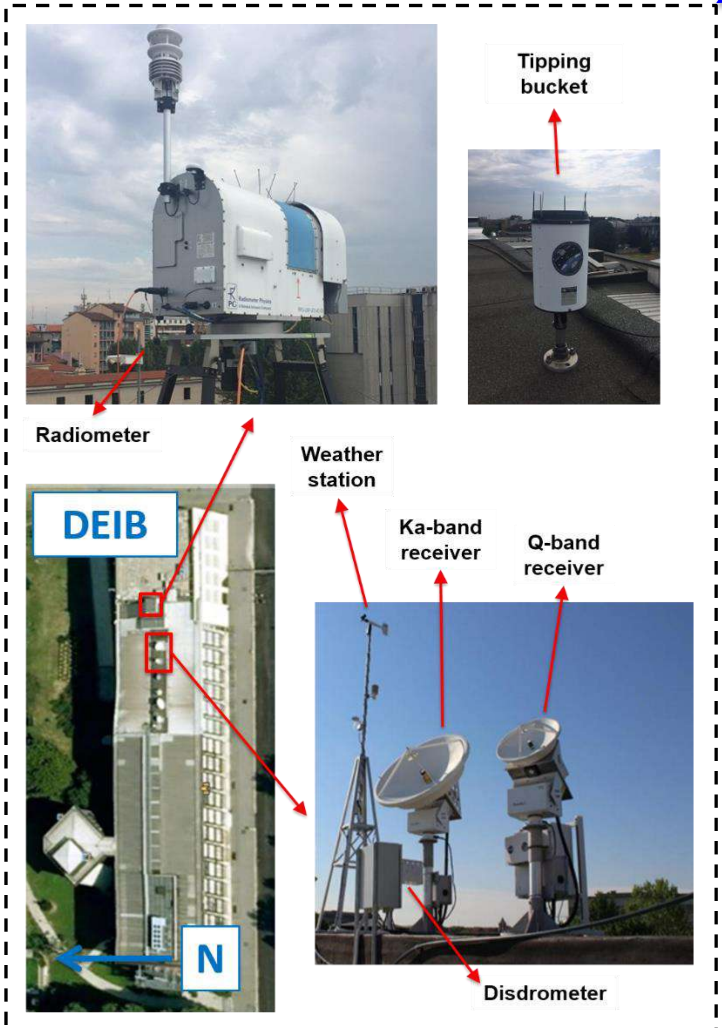


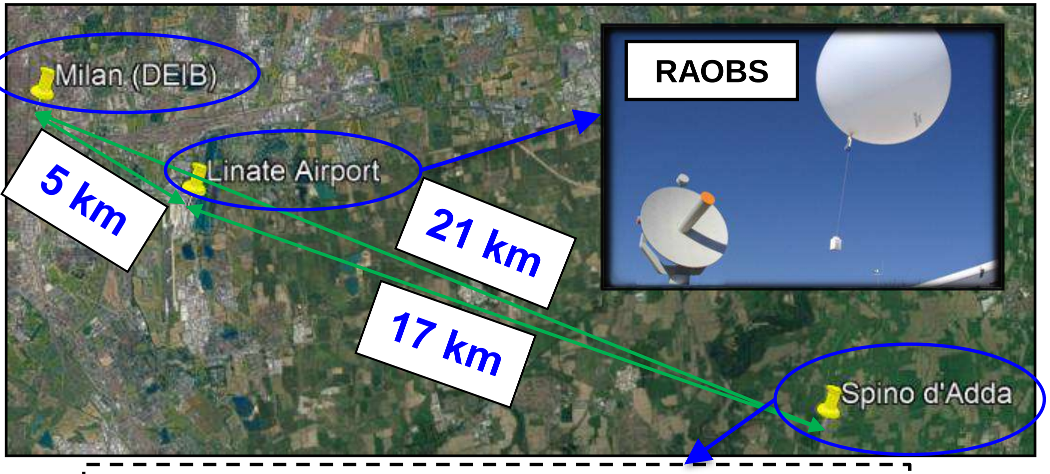
Research topics

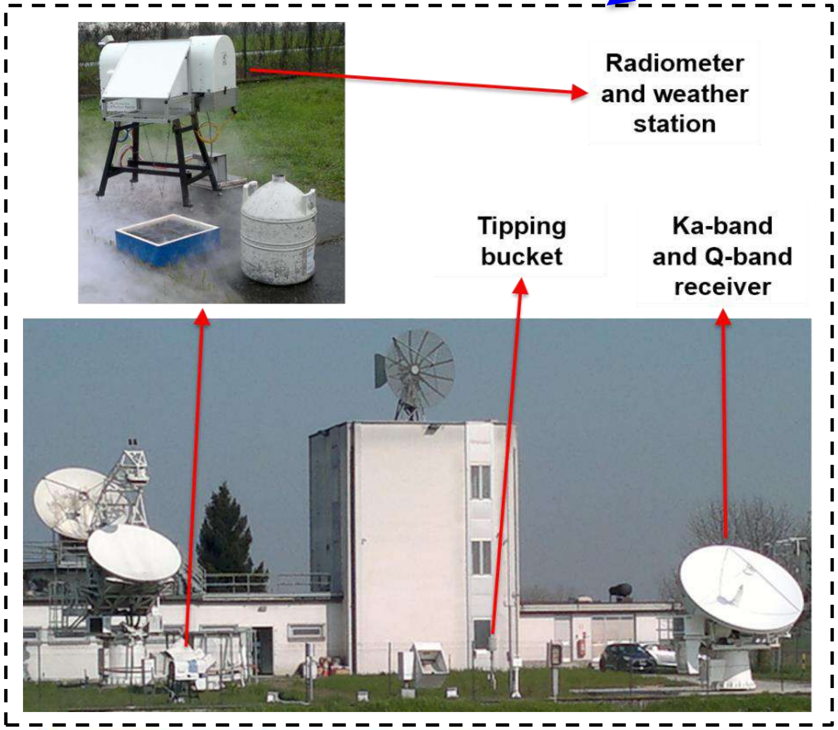
Tito Scalo

Spino d'Adda

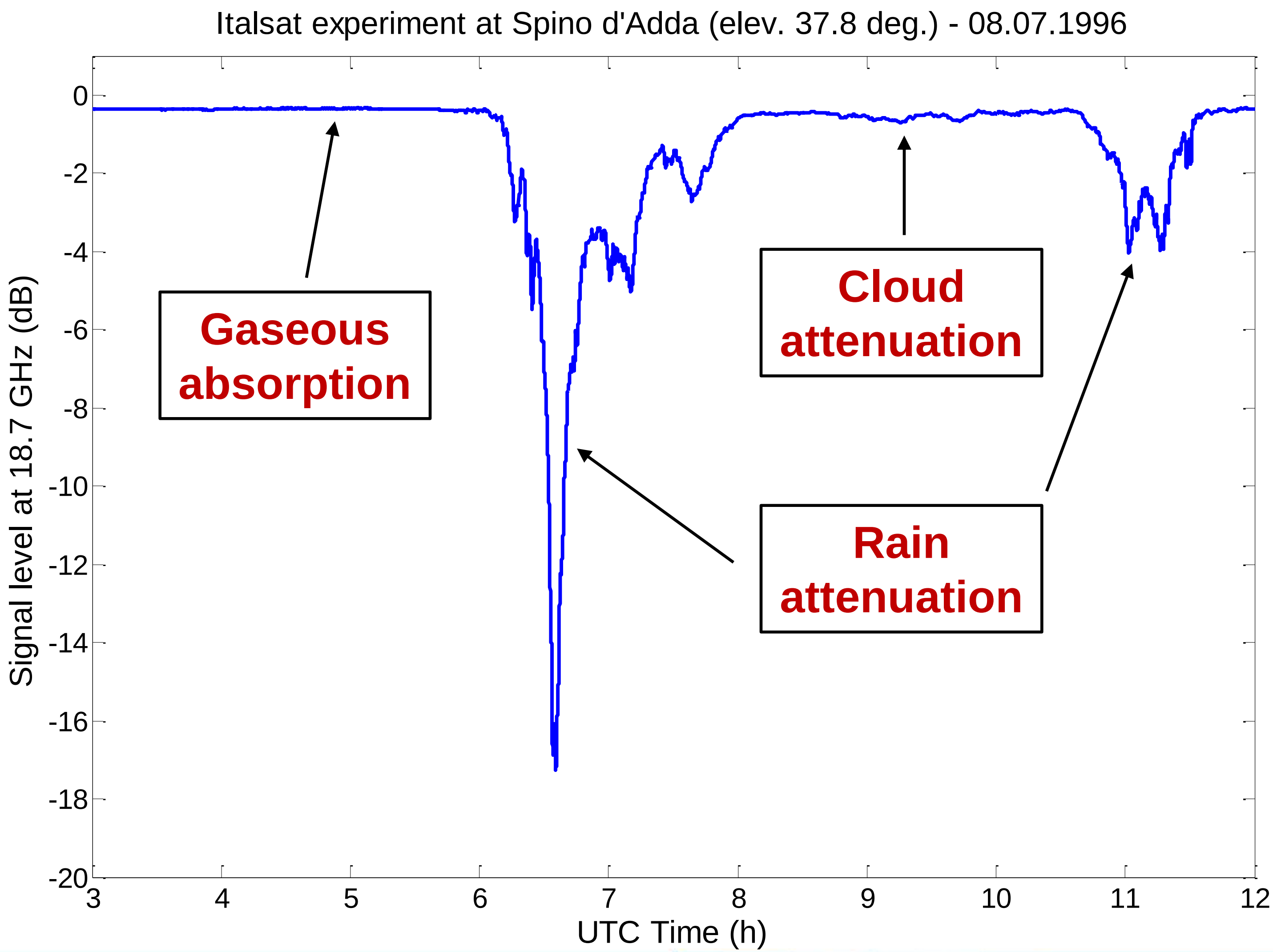
Experimental equipment



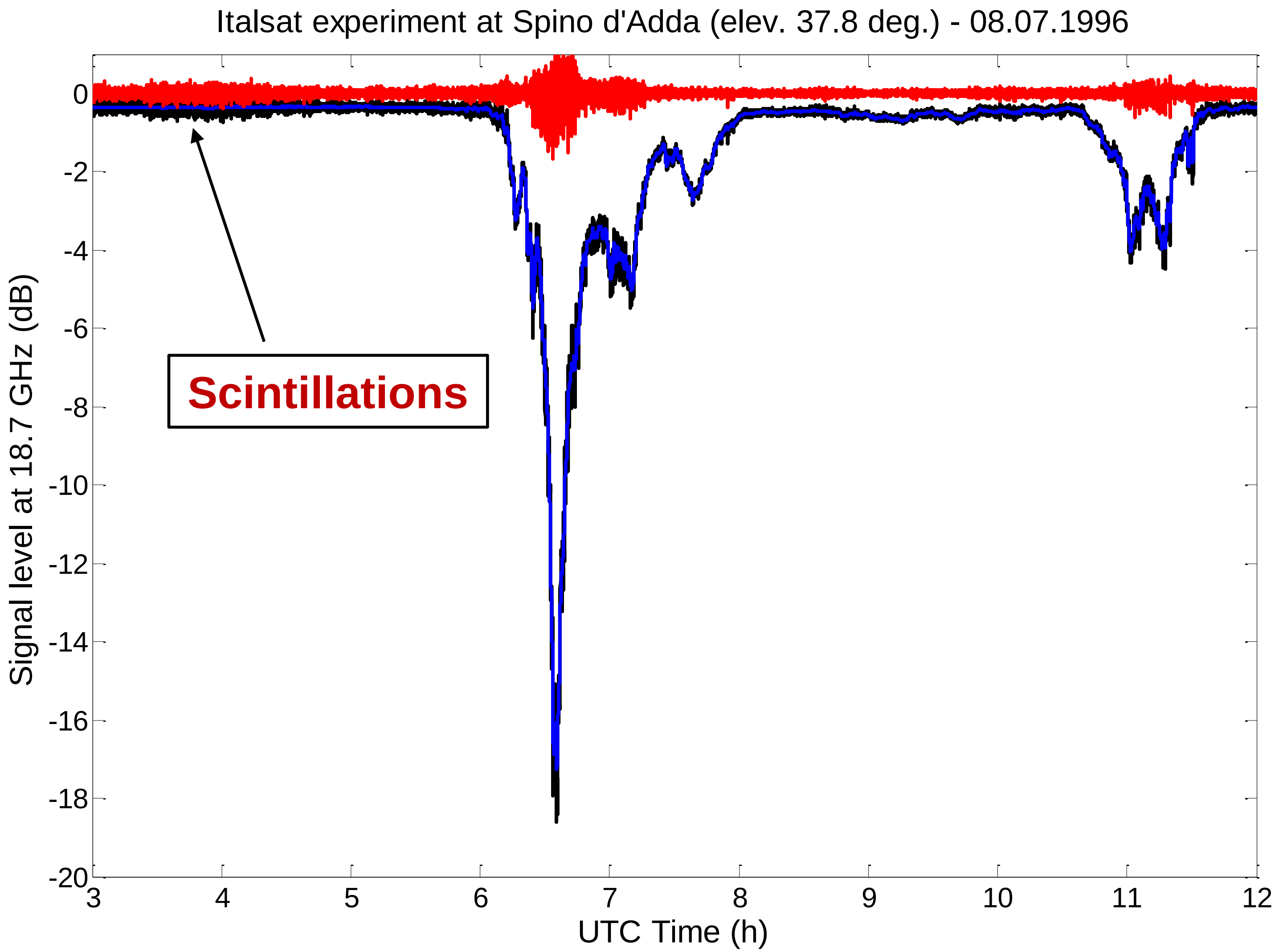




Beacon signal measurement in Spino d'Adda

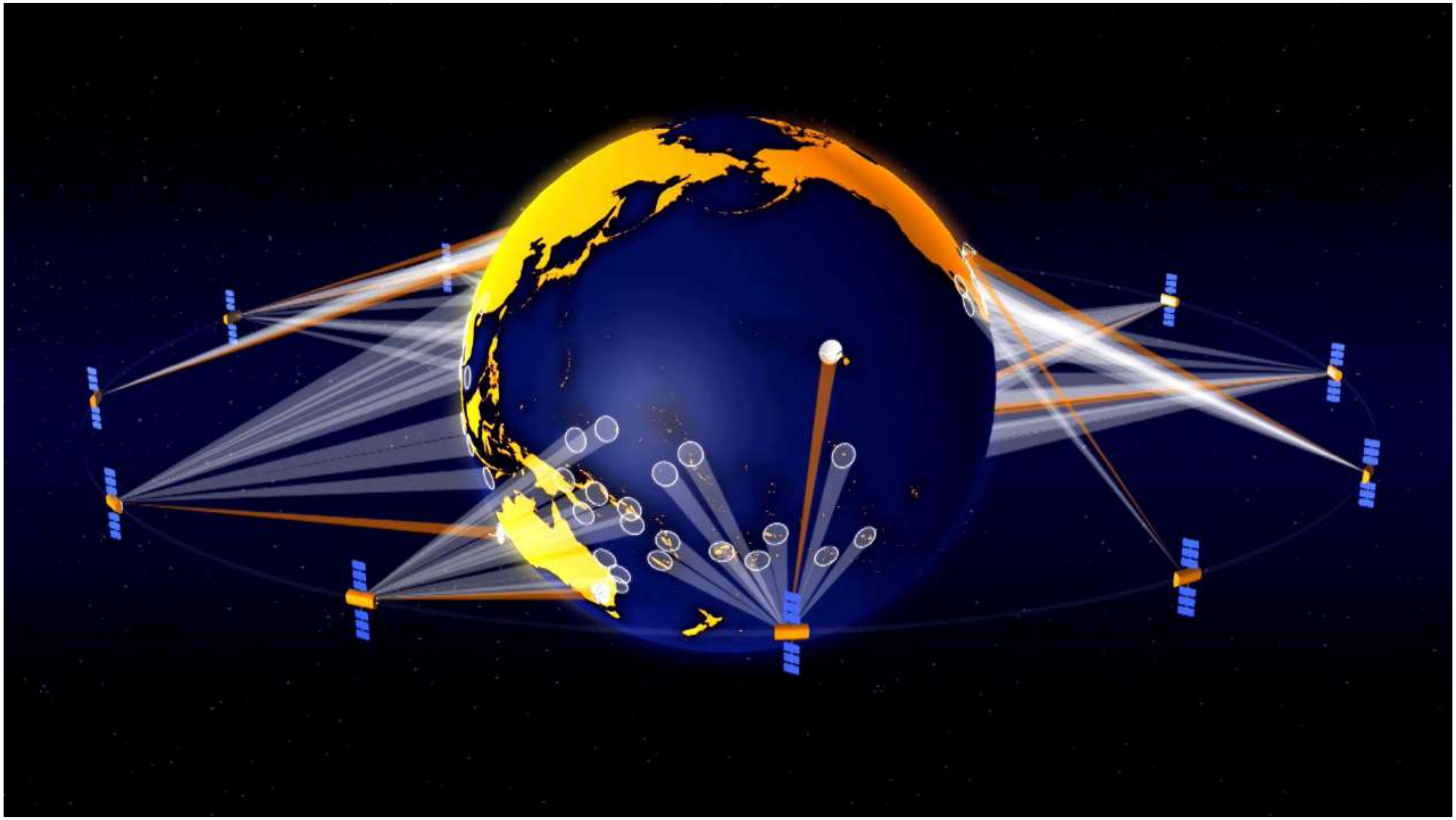


Atmospheric effects on E.M. waves: measured signal



MEKaP experimental activity (ESA)

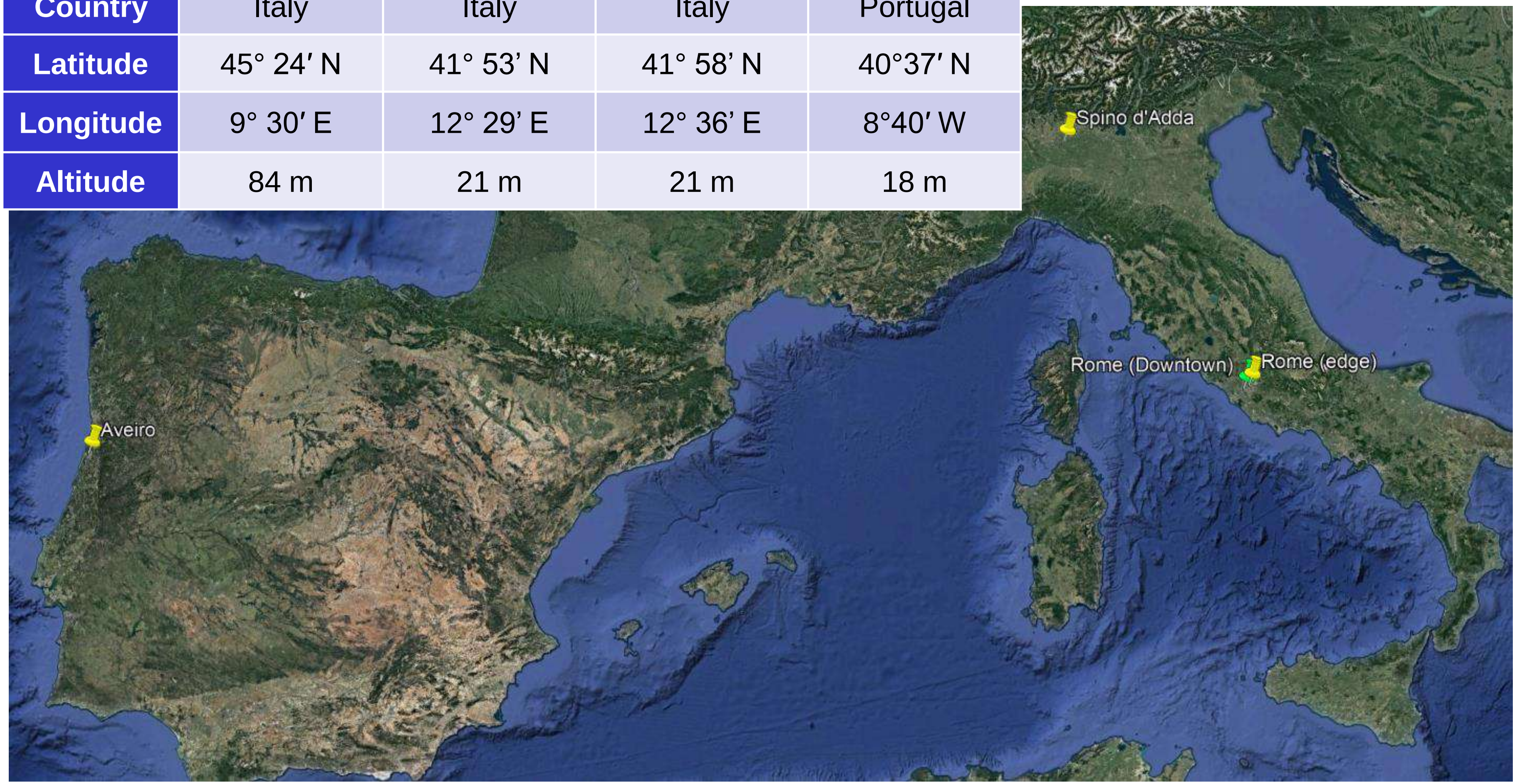
Space-segment → O3b MEO constellation (telemetry signal)



O3b Constellation	
Orbital Reference Systems	Geocentric/Medium Orbit (MEO)
Satellite Height	8064 km
Target Constellation	28
Lunched Satellites	21 operative
Frequency Band	Ka-band
Number of antennas	12 (2 GTW + 10 User)
Measurement signal	Telemetry signal (phase modulated, f = 19.3 GHz)

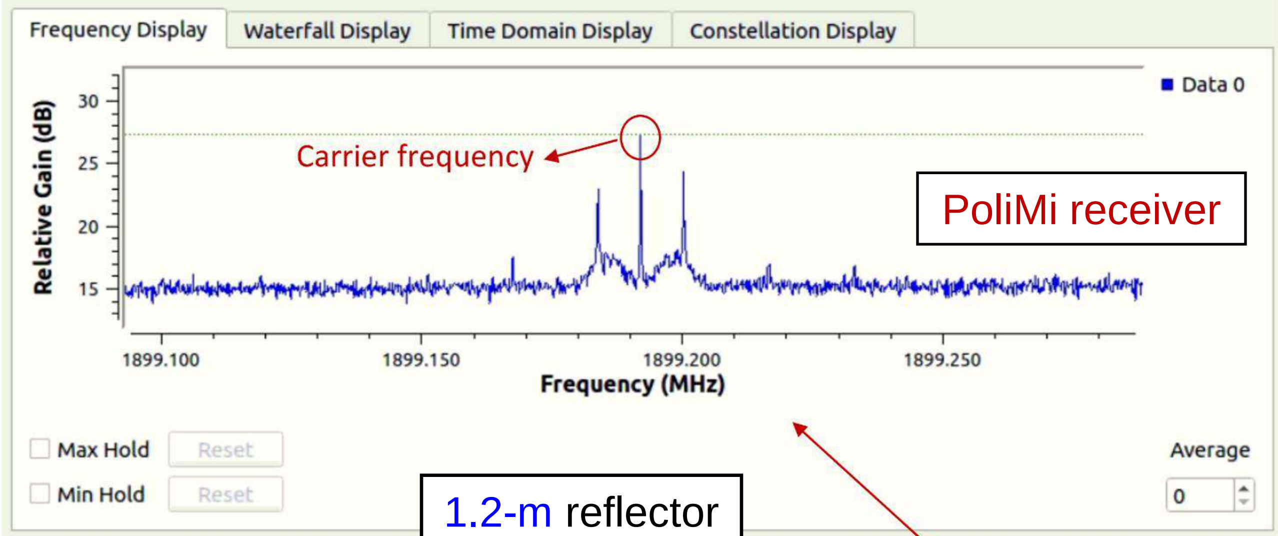
Ground segment: 4 experimental sites

Site	Spino D'Adda	Rome (downtown)	Rome (edge)	Aveiro
Country	Italy	Italy	Italy	Portugal
Latitude	45° 24′ N	41° 53’ N	41° 58’ N	40°37′ N
Longitude	9° 30′ E	12° 29’ E	12° 36’ E	8°40′ W
Altitude	84 m	21 m	21 m	18 m



The MEKaP experiment: architecture

Phase modulated telemetry signals (RHCP): 15 200-kHz channels at ≈ 19.3 GHz



Dynamic range: 15-18 dB (limited TX power of 0.5 W)

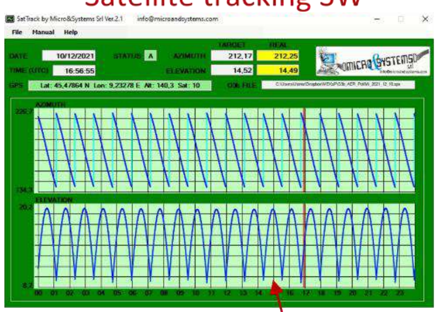
Measure carrier and noise power (1 Hz)

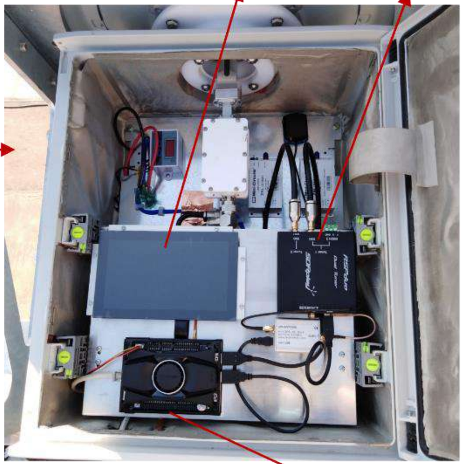
1.2-m reflector antenna

Satellites handover at 10° elevation angle

Max elevation angle: from 20.2° to 26.1°

Satellite tracking SW





Satellite ephemeris → daily NORAD TLE files + SGP4 propagator

Real-time FFT for carrier identification

SDR card sampling for digital processing

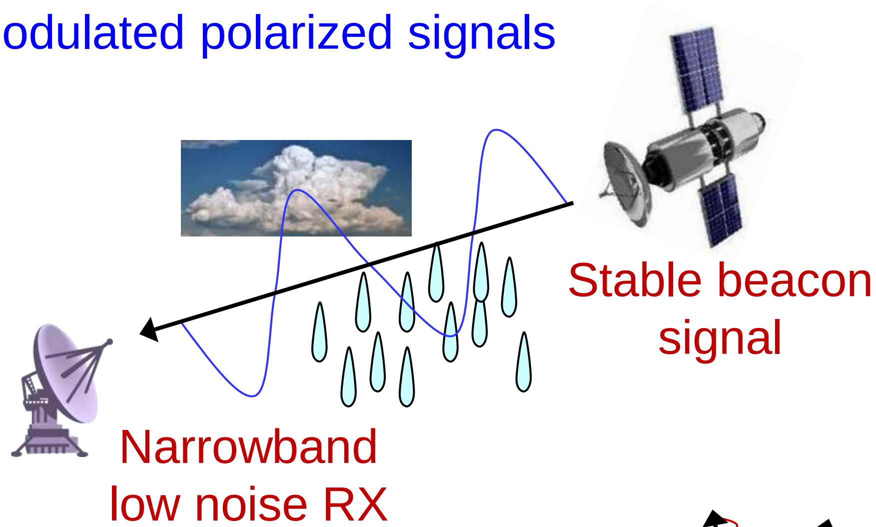
Down conversion at IF ≈ 1.9 GHz

W-band radiometric measurement campaign (Wrad): experimental activity (ESA)

Measuring the effects of the atmospherere

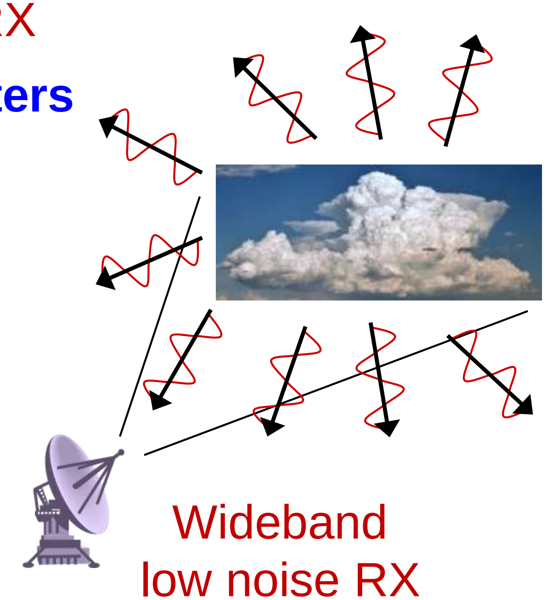
Experimental measurement of the attenuation → beacon signals

- Experiments employing narrowband unmodulated polarized signals (e.g. Sirio, Italsat, Alphasat experiments)
- Advantages: ad hoc stable signals; accurate measurements; measurable effects of gases, clouds and precipitation
- Disadvantages: extremely expensive experiments (both satellite and RXs)



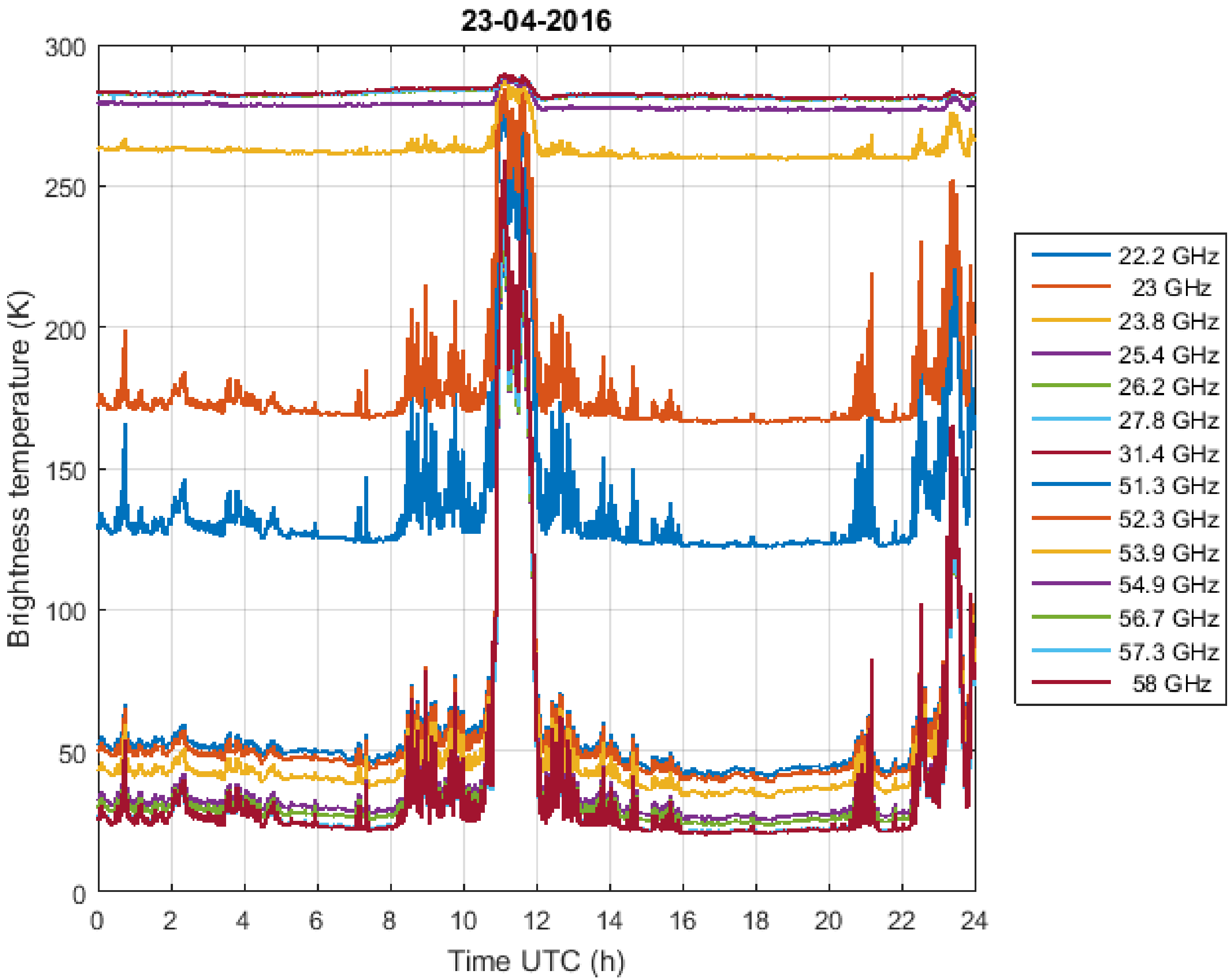
Experimental measurement of the attenuation → radiometers

- Passive remote sensing of the natural E.M. emission by atmospheric constituents using wideband low noise RX
- Advantages: less expensive equipment
- Disadvantages: precise and continuous calibration needed; critical to measure rain attenuation, especially for Ka band and beyond (no scattering hypothesis)



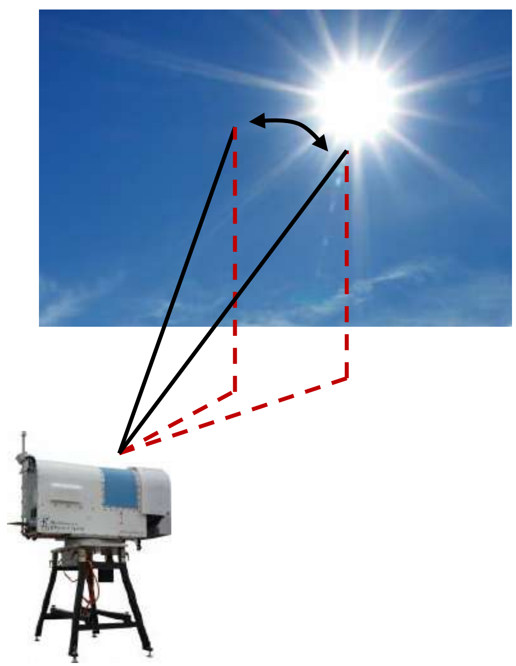
Radiometer with 14 channels from approximately 20 GHz to 60 GHz

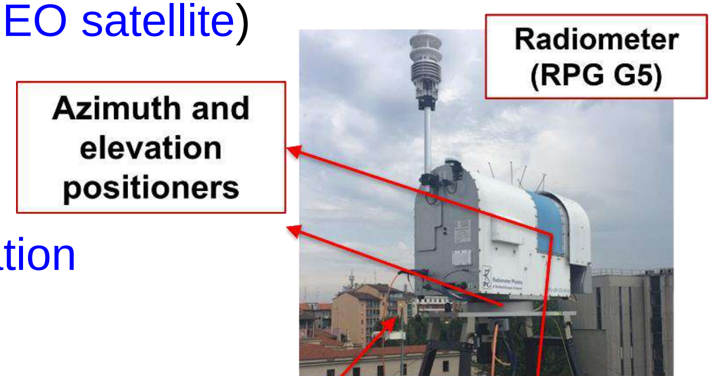
Radiometers



WRad project – Sun-Tracking measurements

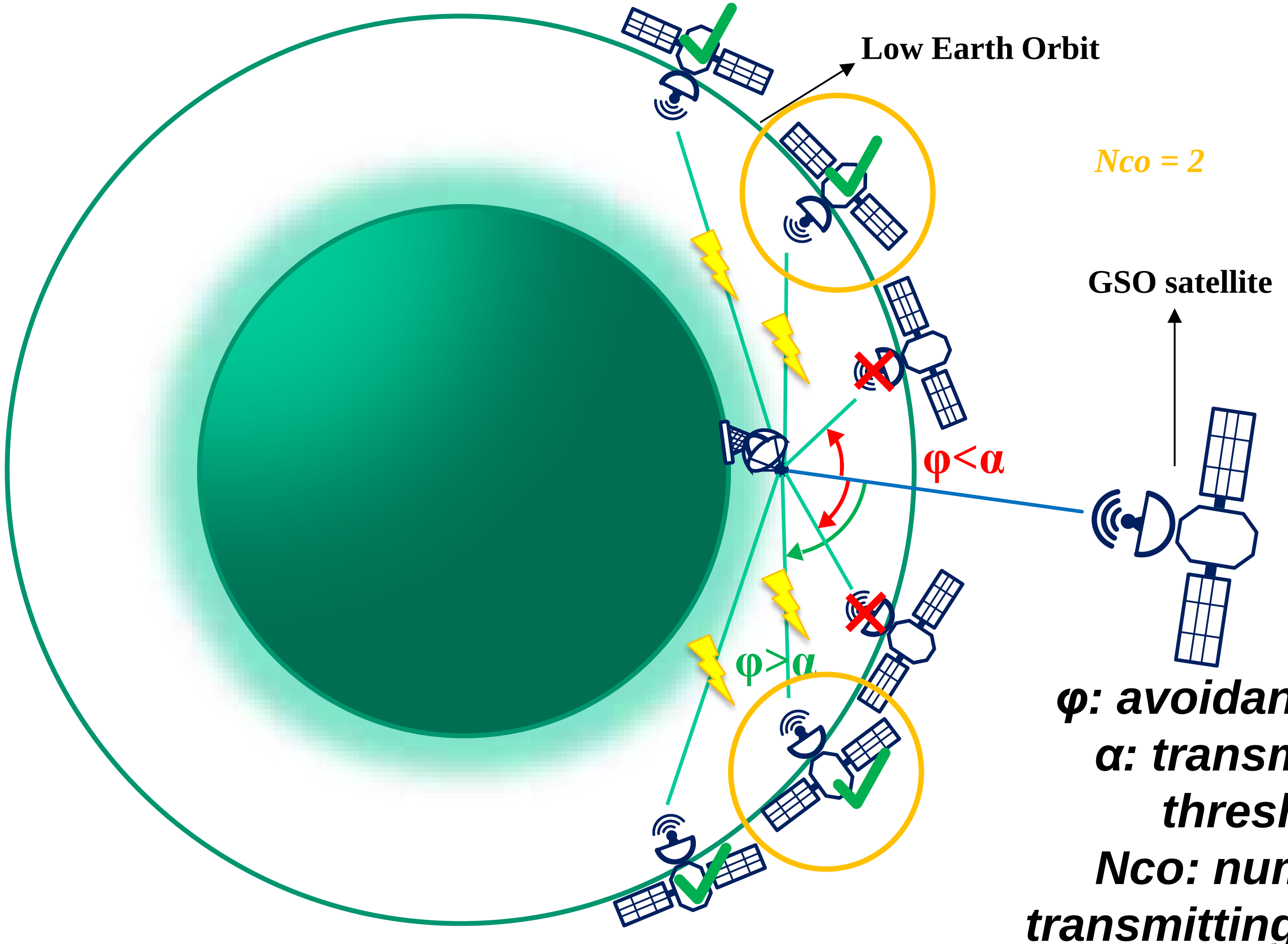
- No W-band space-borne beacon signals available (GEO satellite)
- Ka-band and W-band propagation experiment by means of a ground-based MWR installed at Politecnico di Milano
- Key objective → collect W-band tropospheric attenuation data using the Sun-Tracking (ST) technique
- Use the Sun as an equivalent beacon emitter
- Point at the Sun with elevation θ_0 and azimuth φ_0 → $T_{A\text{-}twS}$
- Point off the Sun with same elevation θ_0 and different azimuth φ_1 → $T_{A\text{-}ooS}$
- Continuous switch





Frequency (GHz)	Beamwidth (°)
23.8 GHz	3.5
31.4 GHz	2.7
72.5 GHz	1.2
82.5 GHz	1

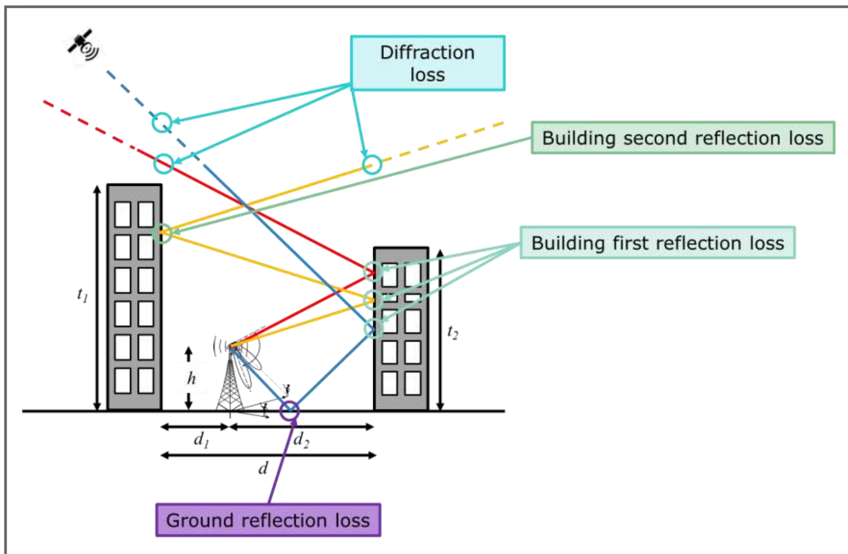
System co-existence: GSO vs NGSO

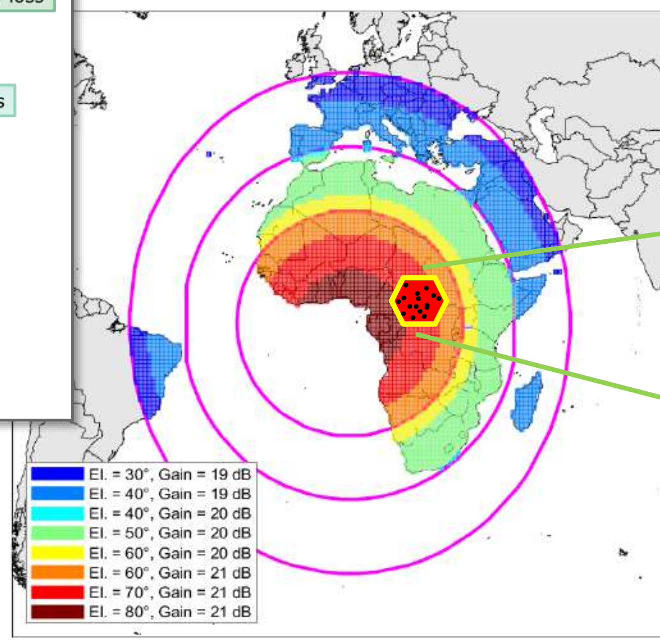


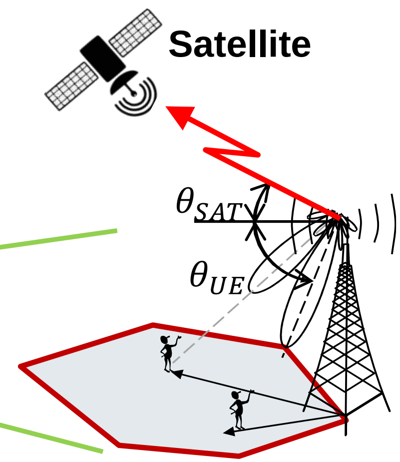
φ: avoidance angle
α: transmission threshold
Nco: number of transmitting satellites

System co-existence: IMT and GEO

+160 GEO satellites launched since 2000 with C-Band transponders (fixed voice, data telecommunications and Internet access, broadcasting satellite services) with continental coverage area

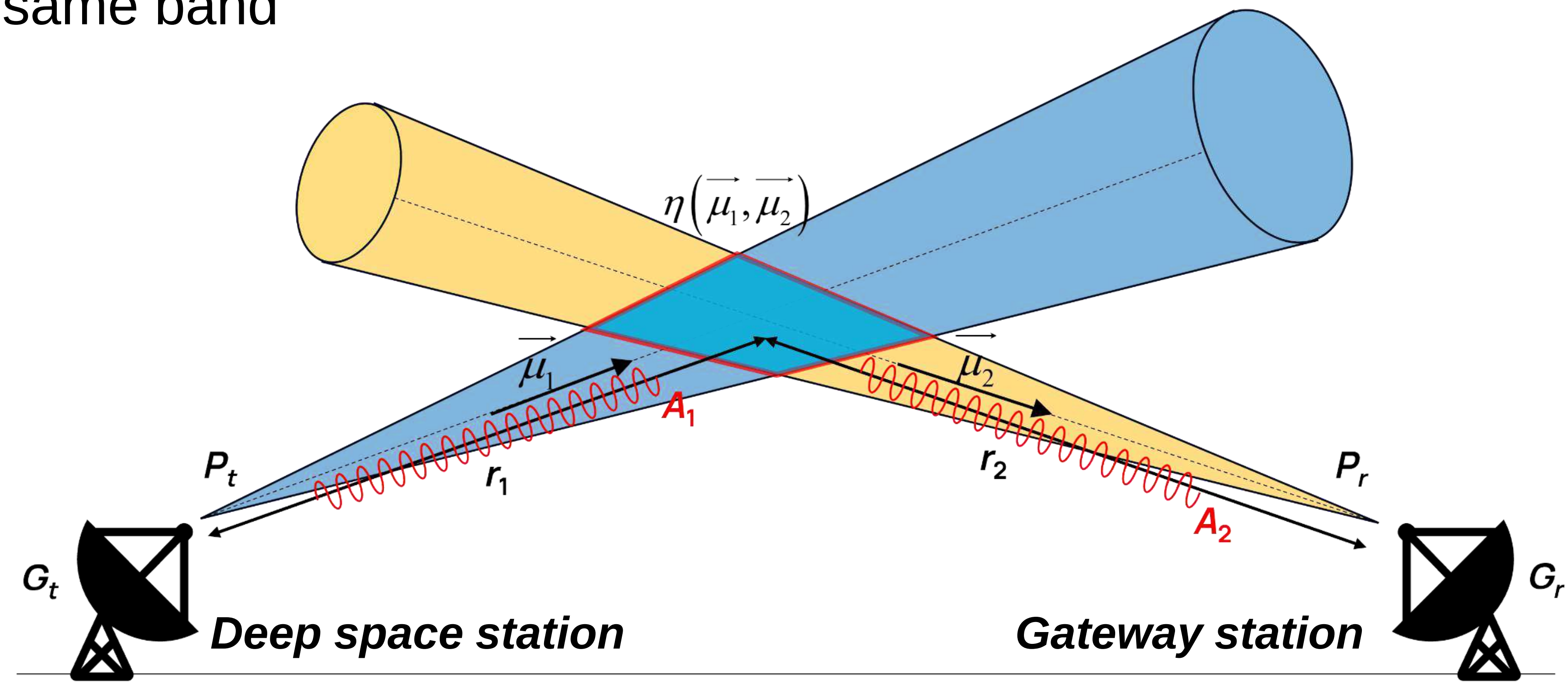






System co-existence: hydrometeor scattering

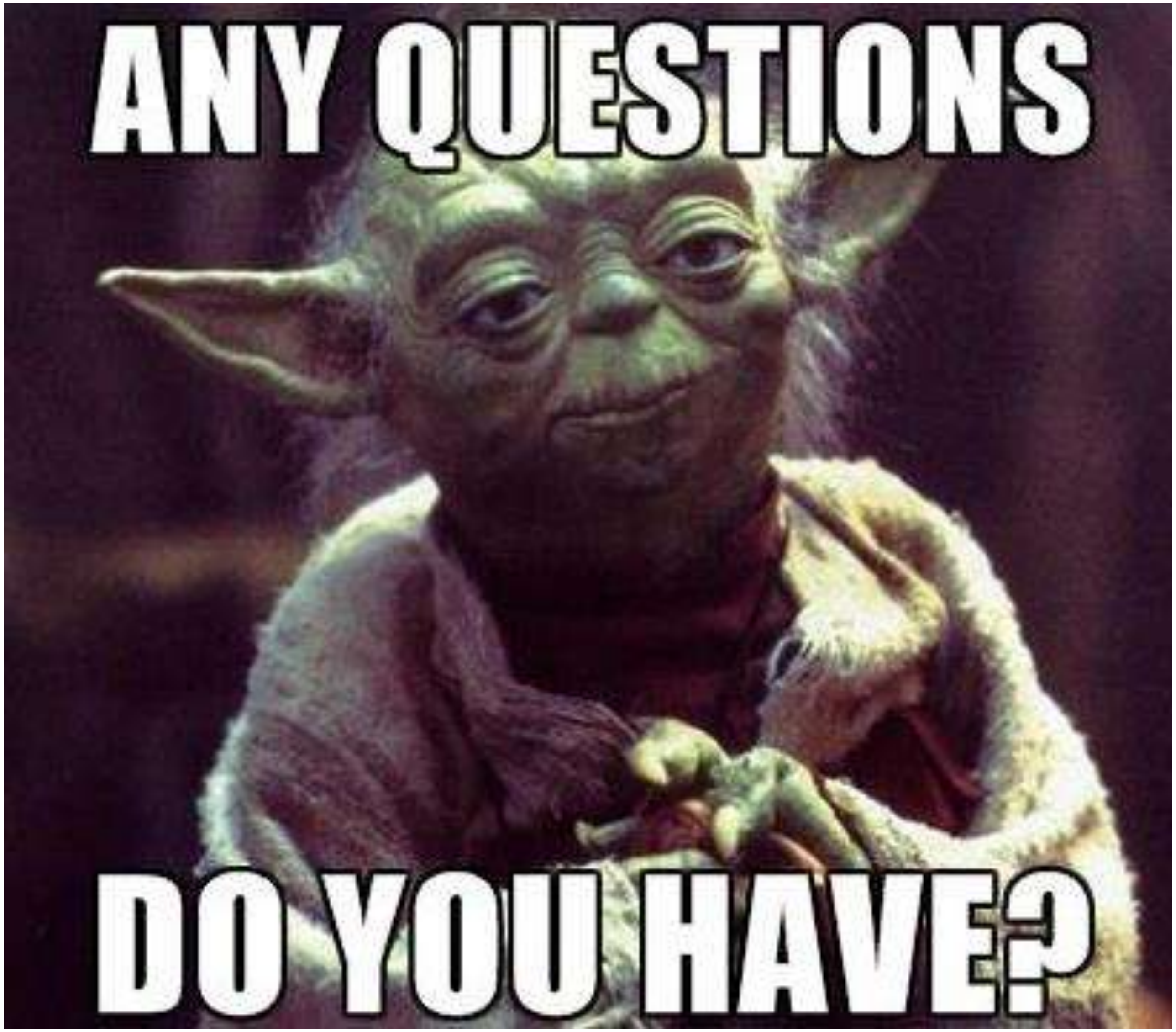
Hydrometeors cause E.M. wave scattering in all direction, which, in turn, induces interference between systems working in the same band



Thesis at companies

- Most of the theses at PoliMi in the framework of research projects
- Sometimes theses available also at companies:
  - Thales Alenia Space Italy (Gorgonzola, Milan): navigation systems (propagation, signal processing, antennas, …)
  - Thales Alenia Space Italy (Rome): space communication systems (various projects)
  - Argotec (Turin): space communication systems (various projects)

- Thesis duration:
  - 8-10 months for “full thesis”
  - 5-6 months for “tesina”


ANY QUESTIONS
DO YOU HAVE?

The only way
to do
great work
is to love
what you do.

Steve Jobs