# MBRYONICS

Bringing Satellite Optical Communication Down To Earth

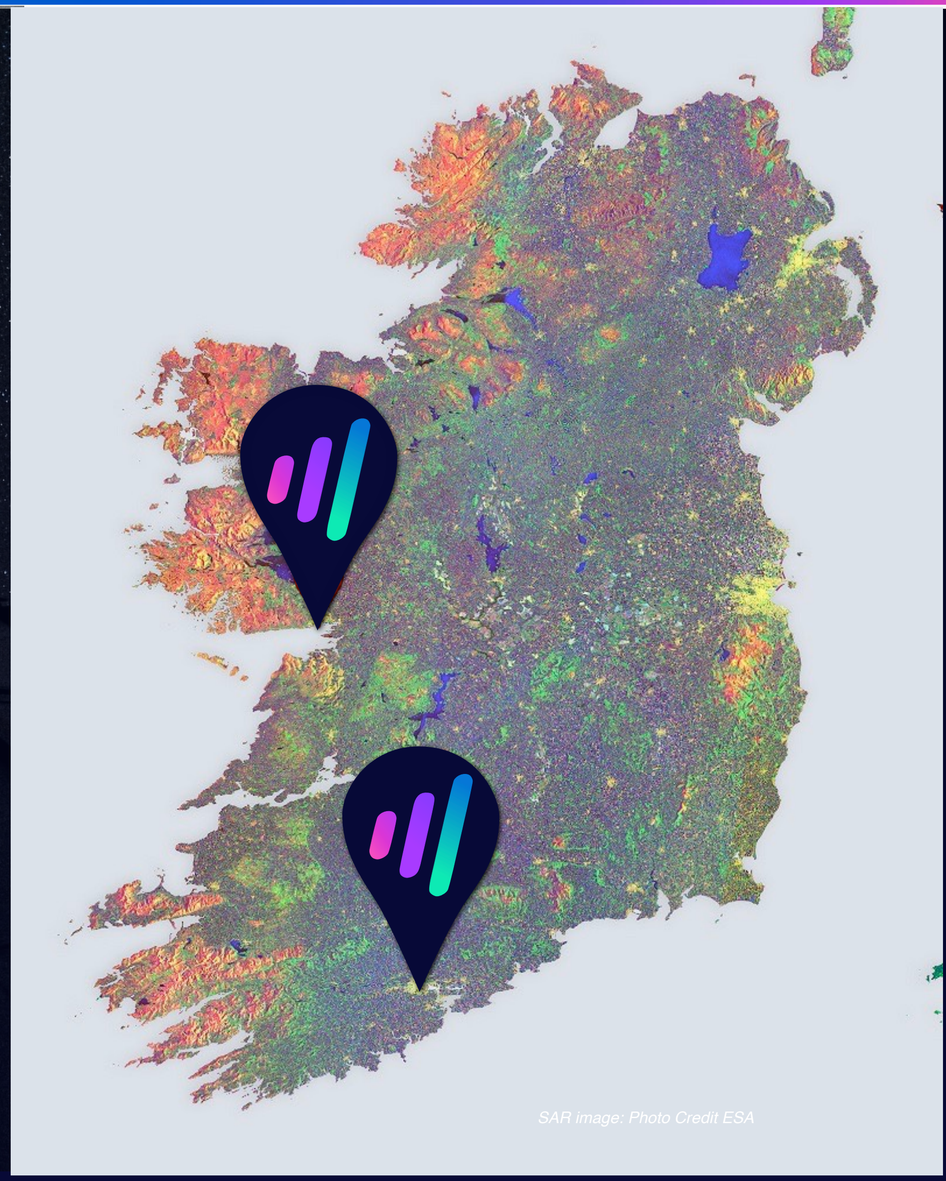
# Presentation Overview & Background

- **Mbyonics Introduction:** Optical Communications and Photonics
- **Space Applications:** Satellite Applications & Communications Overview
- **Free Space Applications:** Satellite and terrestrial laser links with adaptive atmospheric correction
- **Space Photonics:** Photonics applications in Space (time permitting)

# mbryonics Introduction

# Mbryonics Company Overview

- A private Irish SME, family-guided space company - with offices in Galway city, & the National Tyndall Institute, Cork, Ireland.
- Formed as a spin out of NUIG, Applied Optics Group in 2014 to commercialise free space optical communication solutions for Space, pseudo satellites and terrestrial markets.
- Vendor of Satellite Optical Communications Infrastructure, equipment and components.
- Currently 15 employees and growing!



*SAR image: Photo Credit ESA*

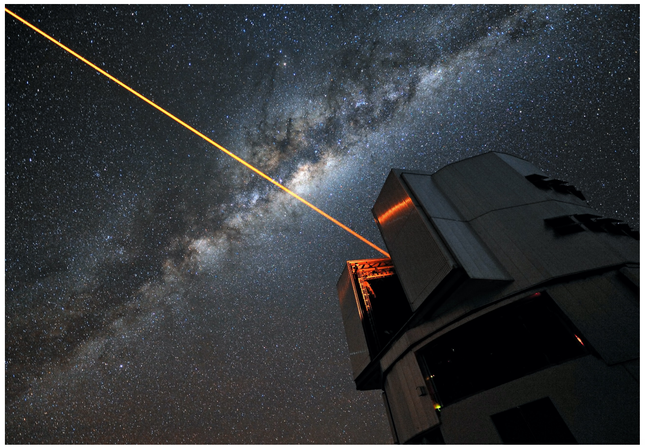
# Non-Destructive Physical Analysis Facility for TRL 5 Components


# Mbryonics Company Background

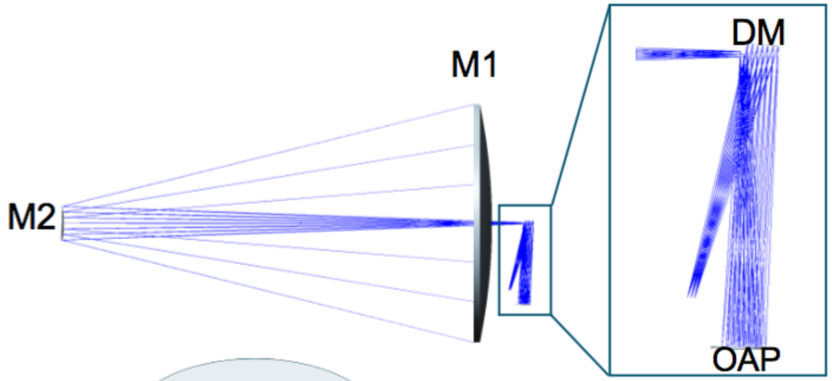
NUI Galway
OÉ Gaillimh

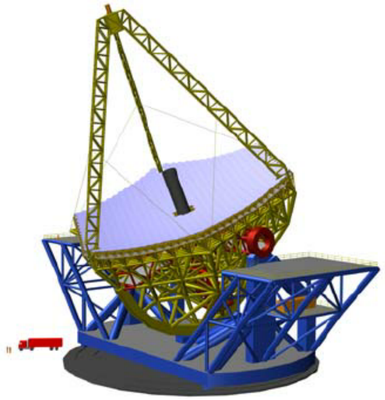
An Grúpa Optaice Feidhmí
applied Optics
PHYSICS nuigalway

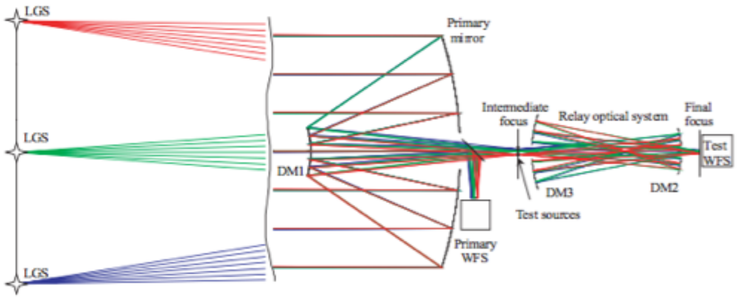
sfi
science foundation ireland

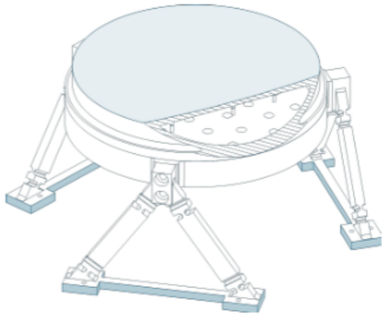


- Areas of Expertise:
  - Optical Design - Astronomical Telescopes, imaging systems
  - Adaptive Optics, Wavefront Sensing, Optical Metrology
  - Photonics, Camera Sensors, Image Processing, Computational Imaging





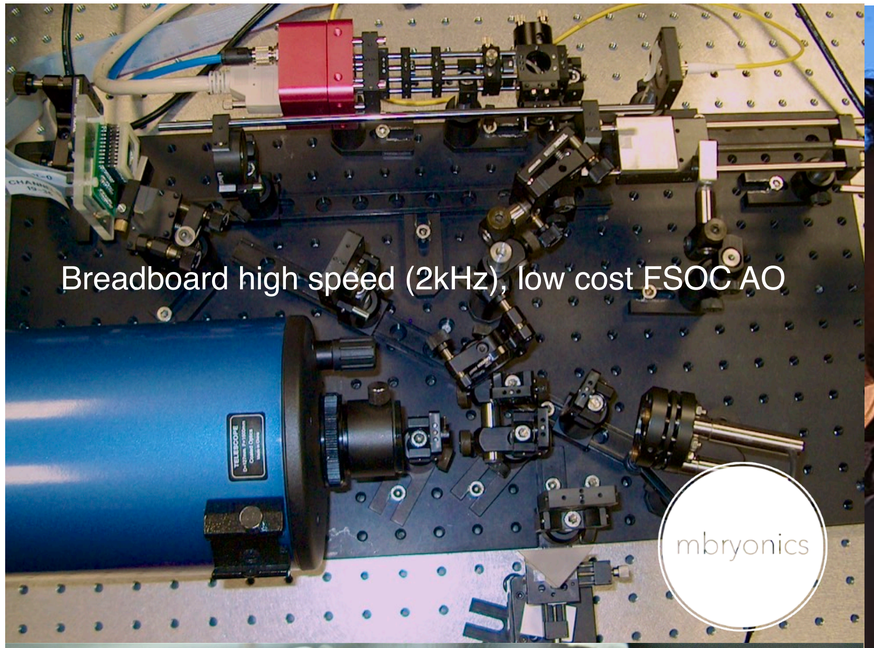



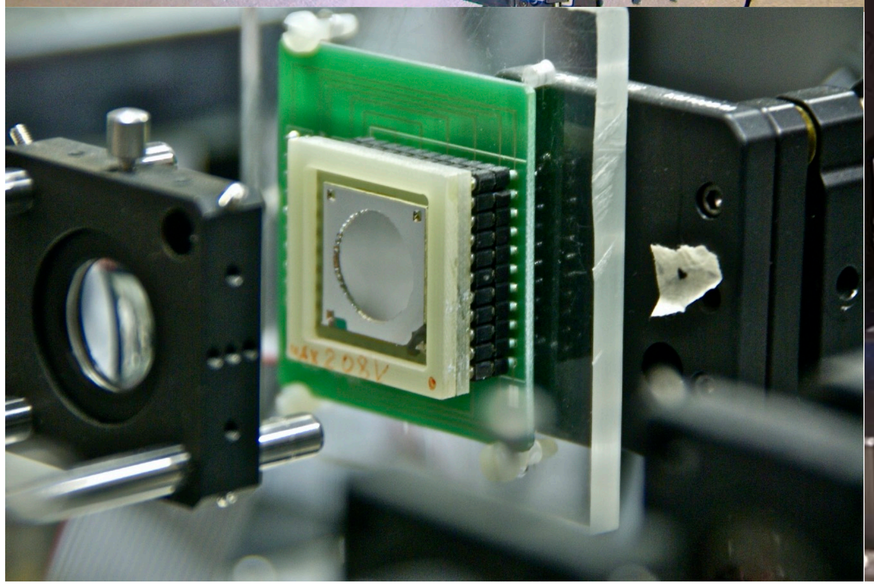
OÉ Gaillimh
NUI Galway

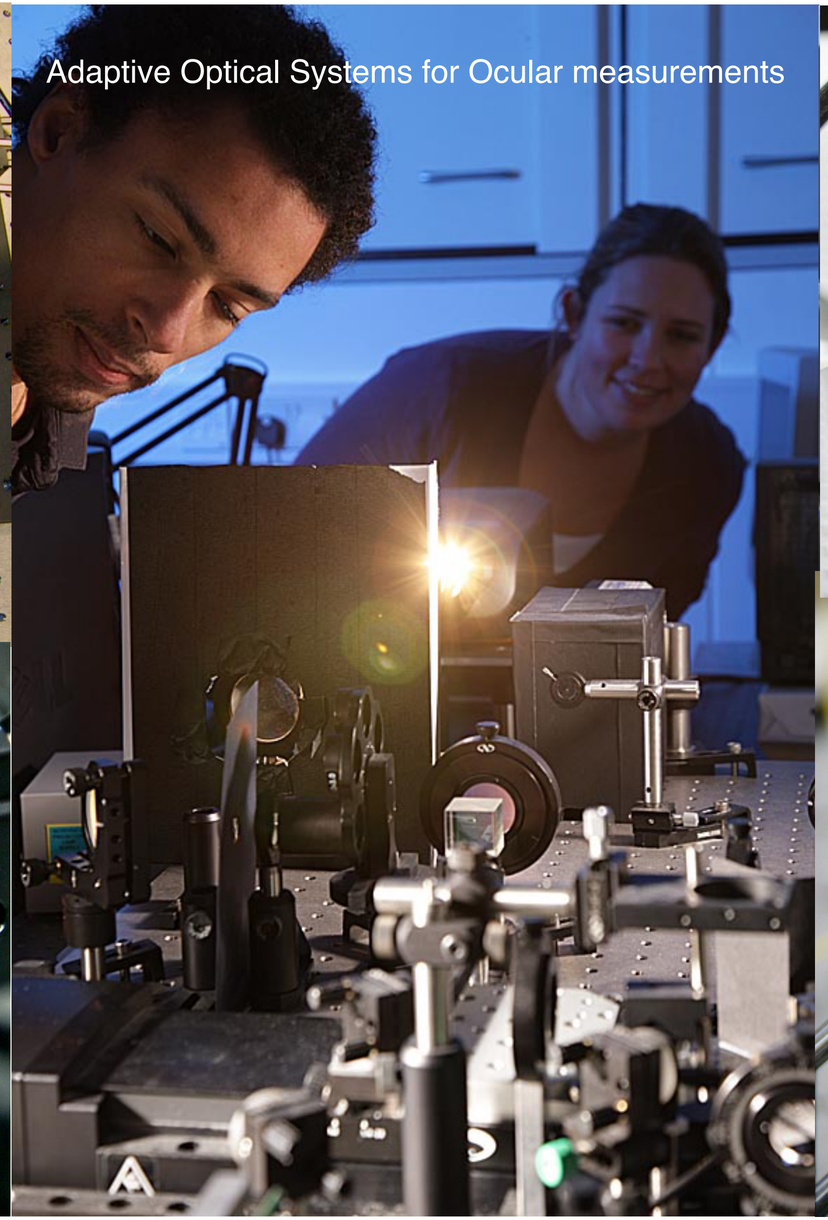
esa

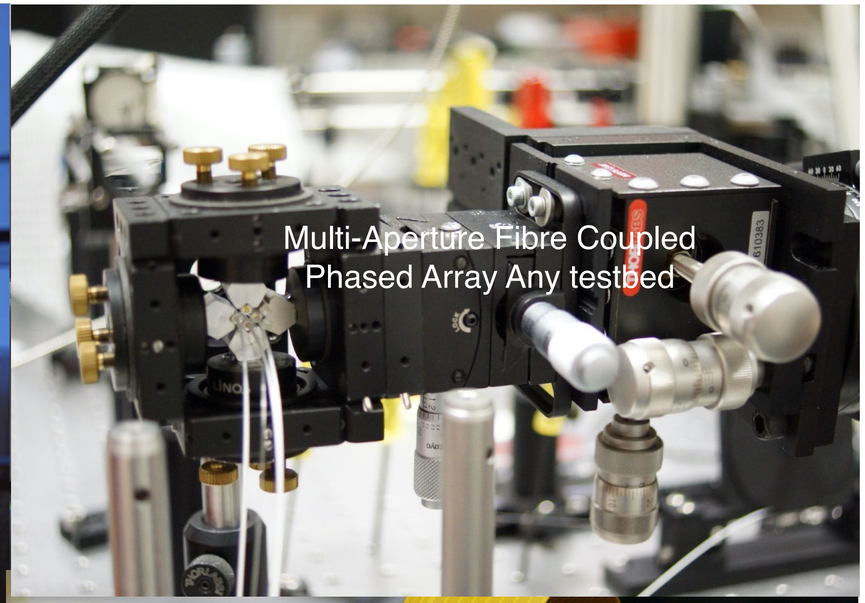
Fraunhofer
IOF

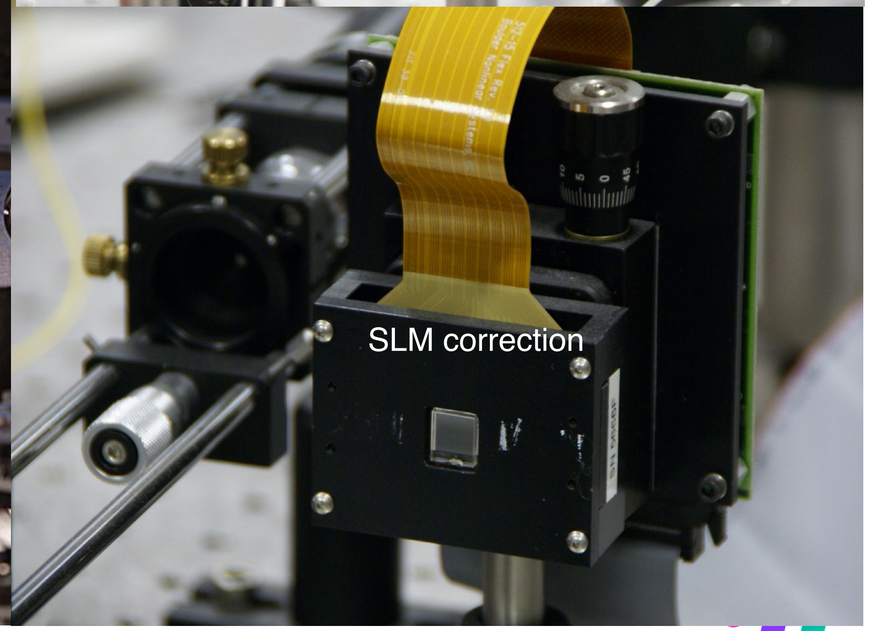
# Mbryonics Company Background



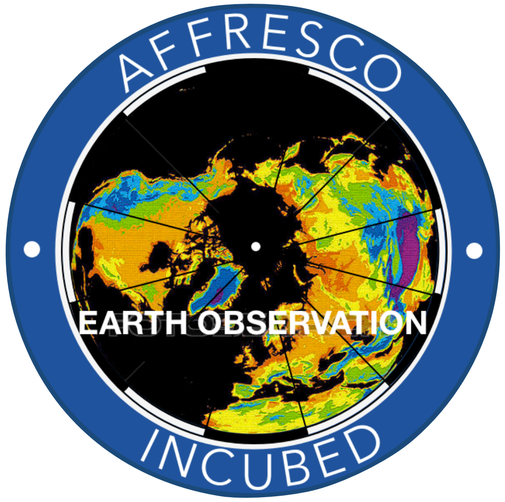





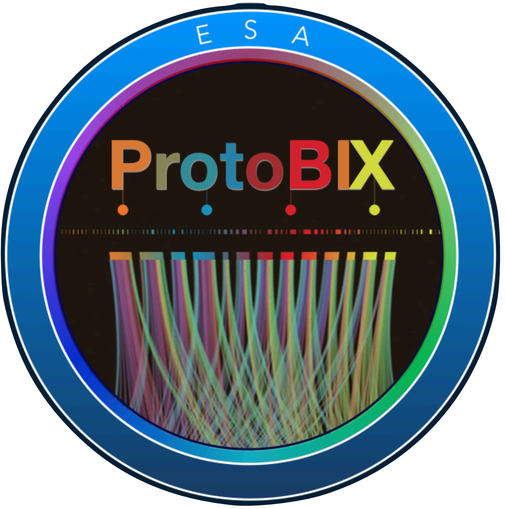



# ESA, EU, & Defense Projects














Rialtas na hÉireann
Government of Ireland

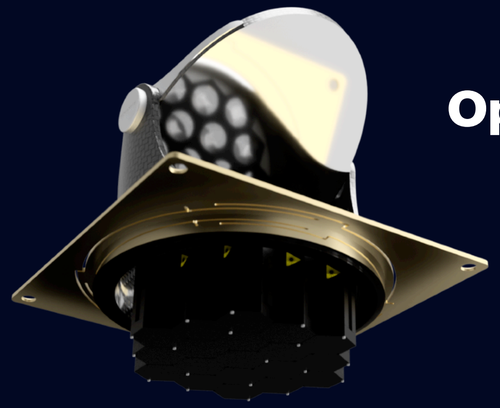
Disruptive Technologies Innovation Fund

# Domains of Expertise: Space & Defence

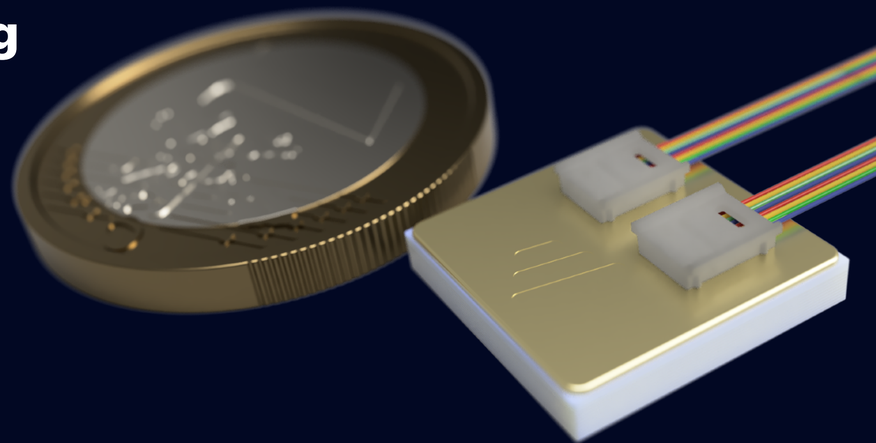
## Optical & Secure Communications

## Space Situational Awareness

## PNT

## Optics & Photonics Engineering Services, Research & Development



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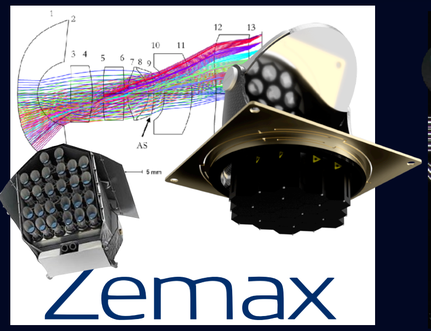
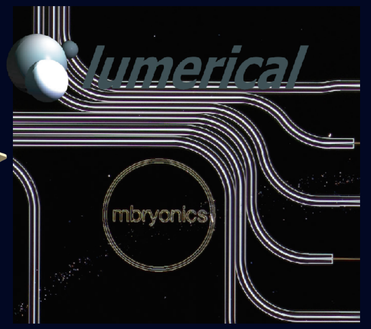
# Photonics & Optical System Integrators:

Design, Engineering, Manufacturing, Assembly, Integration, Measurement & Test

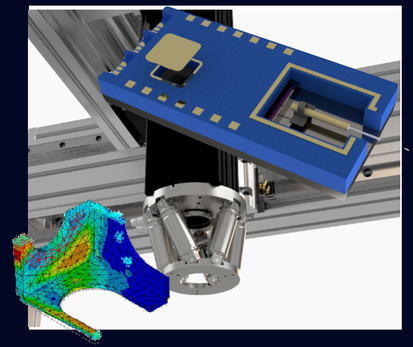
## Our Core Capabilities:



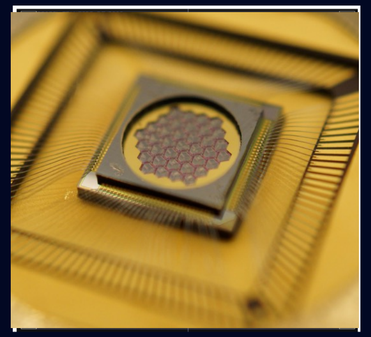

**Optical & Mechanical Design MAIT**



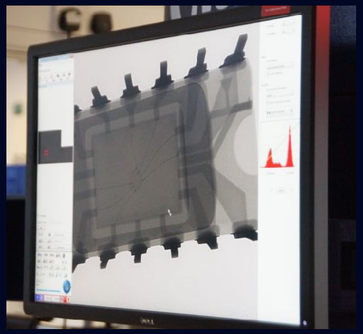

**(PIC) Photonic Integrated Circuits Design**



**Photonics System Design MAIT**



**Electro-optical systems & ASIC**



**Component Qualification & Upscreening**

**ISO 17025 for Photonics Components**

# Satcom Overview

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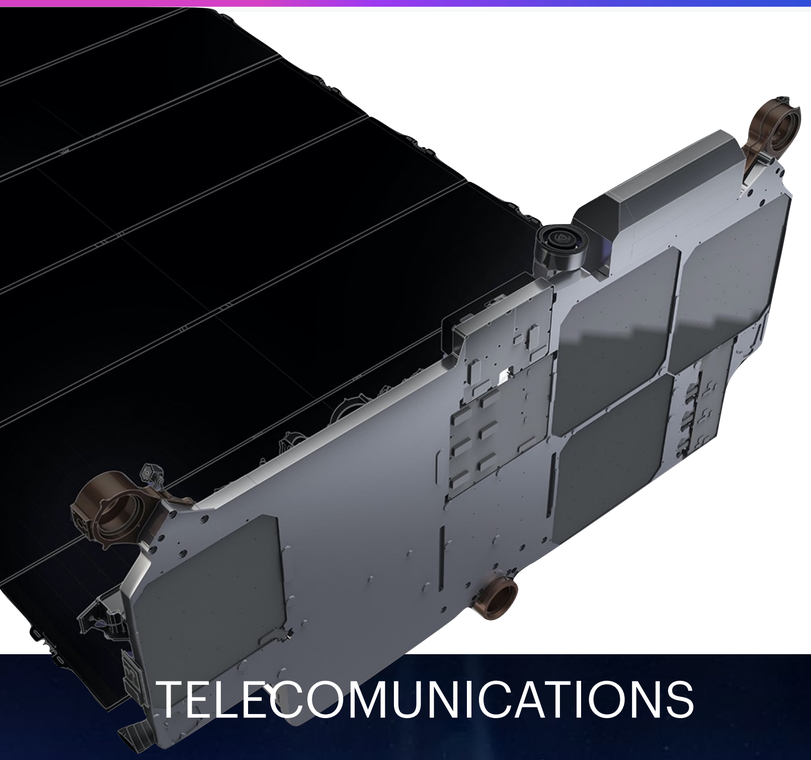
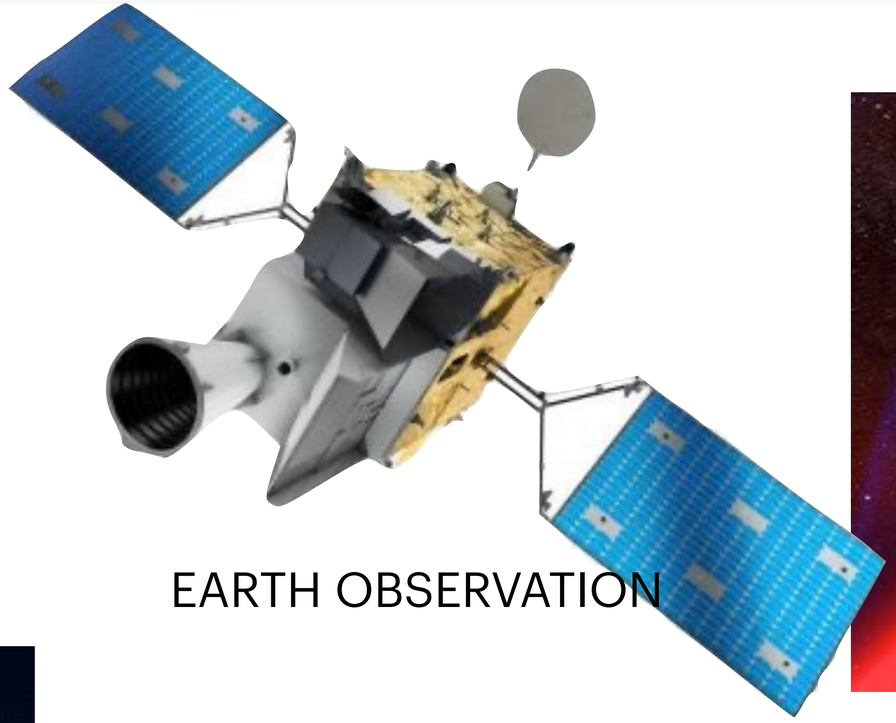
# Space Applications

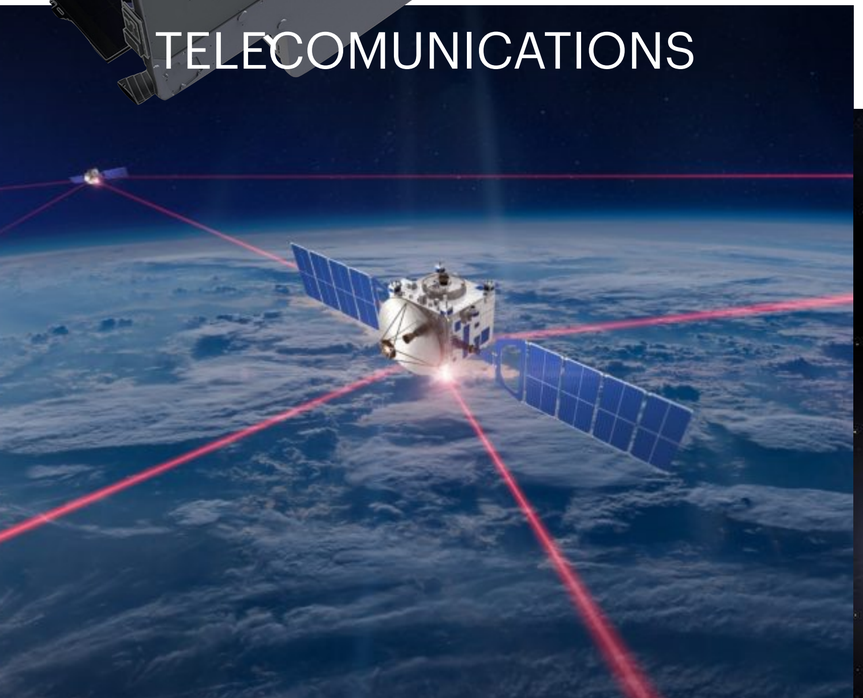


TELECOMUNICATIONS



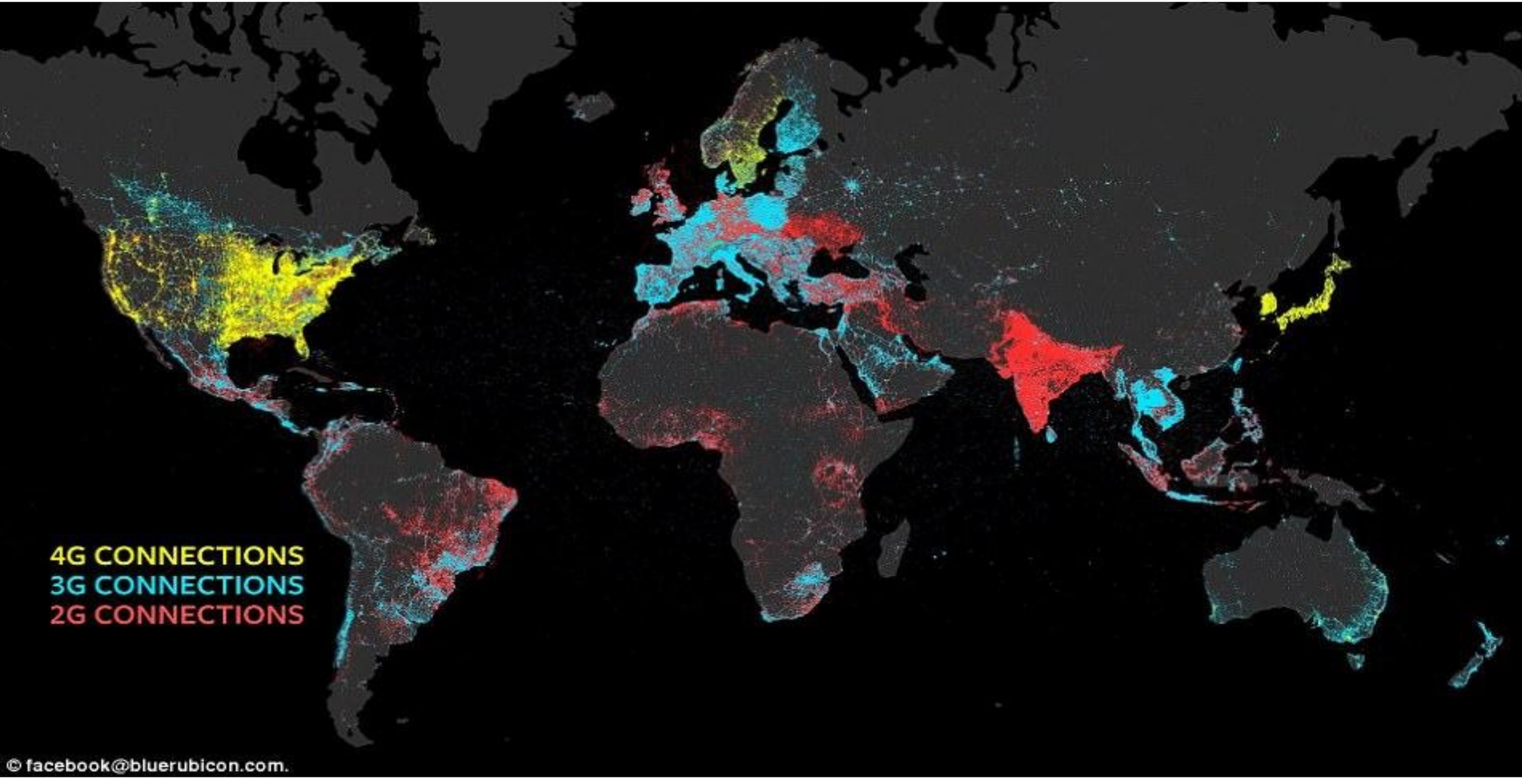
EARTH OBSERVATION

SCIENCE MISSIONS



GNSS


amazon
PROJECT KUIPER
STARLINK
iridium
Viasat
OneWeb
TELESAT™
> 50,000 satellites over the next 10 years


4G CONNECTIONS
3G CONNECTIONS
2G CONNECTIONS
© facebook@bluerubicon.com.

Optical

GEO Access

RF Gateway

RF Access

Metro-core Optical Network and fixed wireless Access

**GEO SATELLITE**
(36,000 km)

**Antenna FOV**
(40 - 90º)


**MEO SATELLITE GNSS**
(1000-30,000 km)

**LEO SATELLITE**
(400-1,000 km)

**Optical Gateway**
1064 - 1550 nm

SATELLITE BACKHAUL

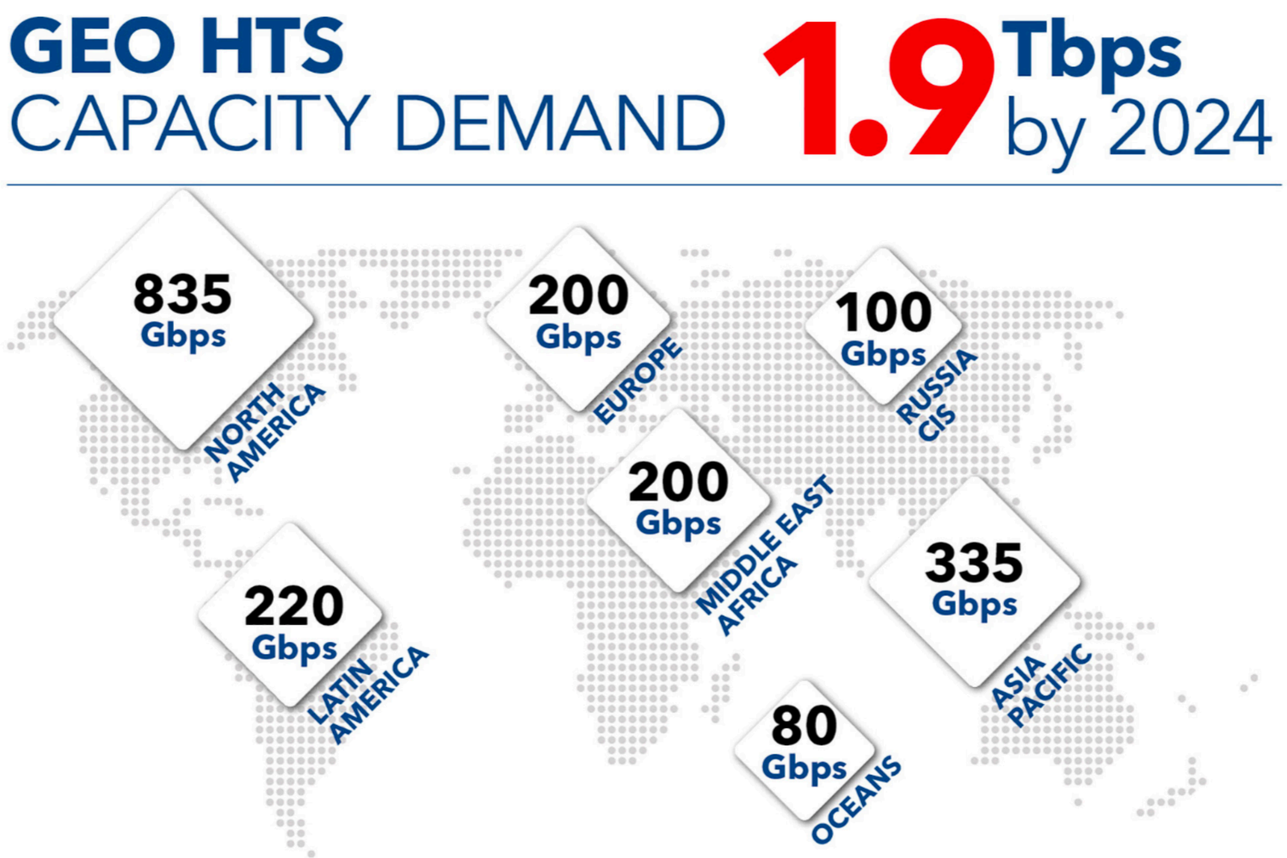
**Ka, Ku, Q or V band Gateway**
(20 - 60 GHz)

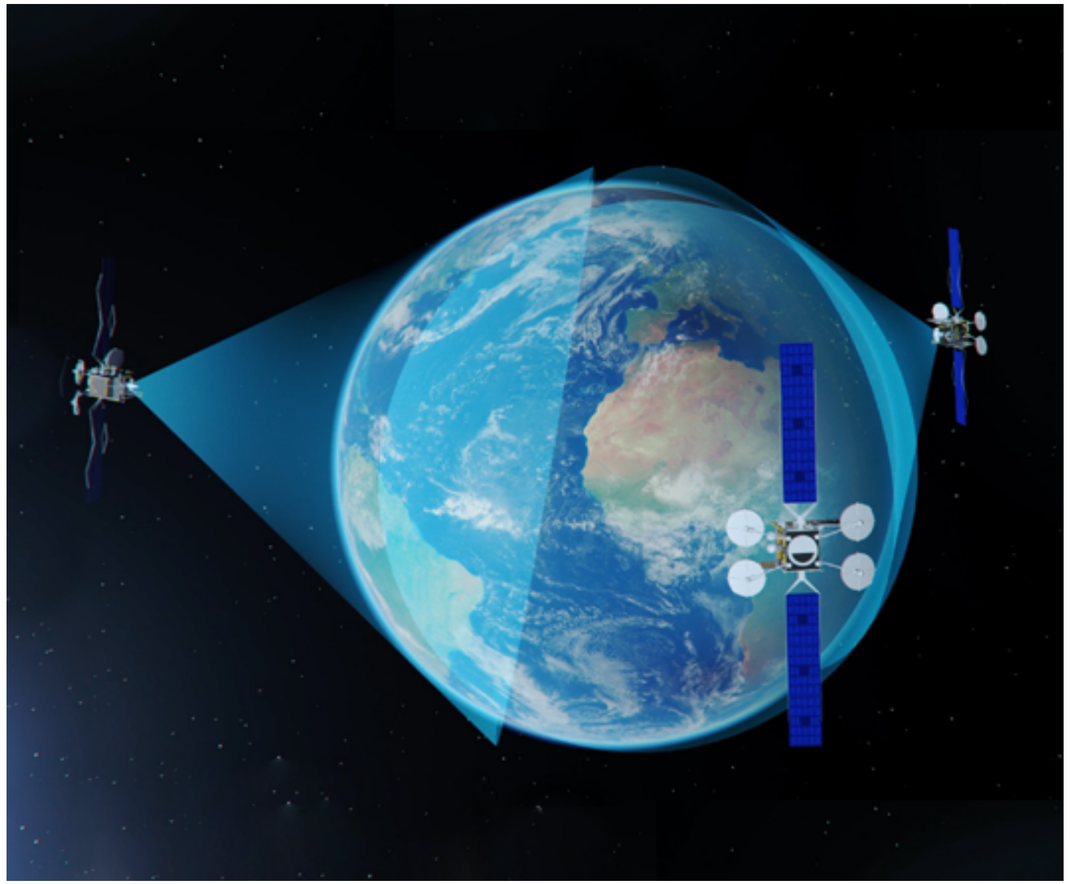
**PSEUDO SATELLITE**
(20 - 60 km)

URBAN ACCESS

SATELLITE REMOTE ACCESS USERS

# GEO Telecoms



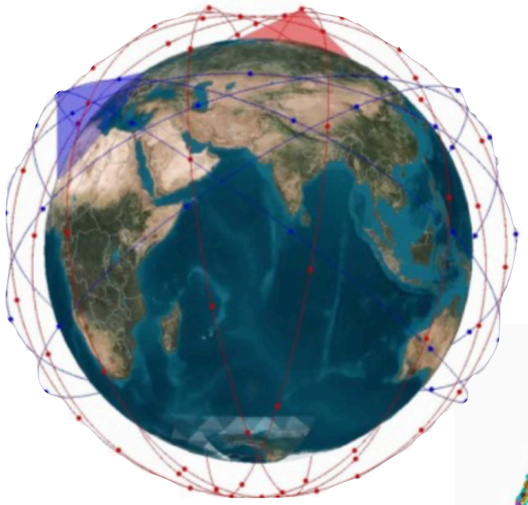



**Remote broadband, shipping, in flight connectivity**

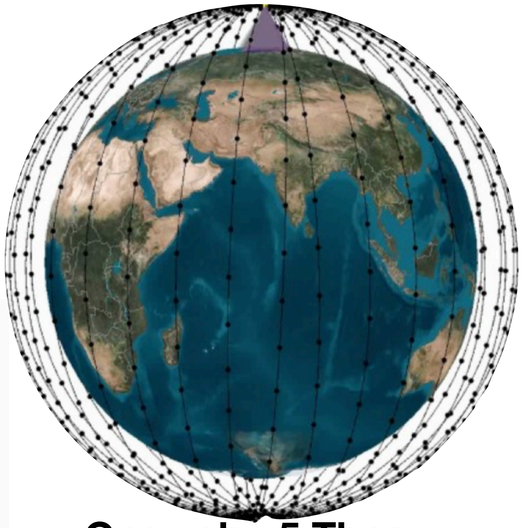
**ViaSat V3**
**(3 satellites @ 36000km)**

# LEO Telecoms

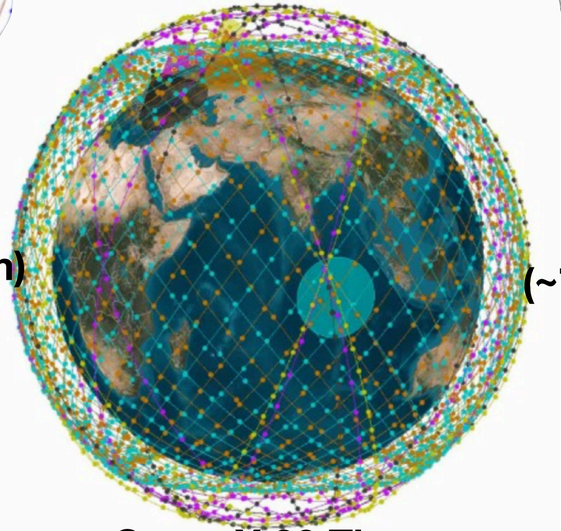
Iridium Next 75



Telesat 1-3 Tbps
(~292 satellites @ < 1200km)

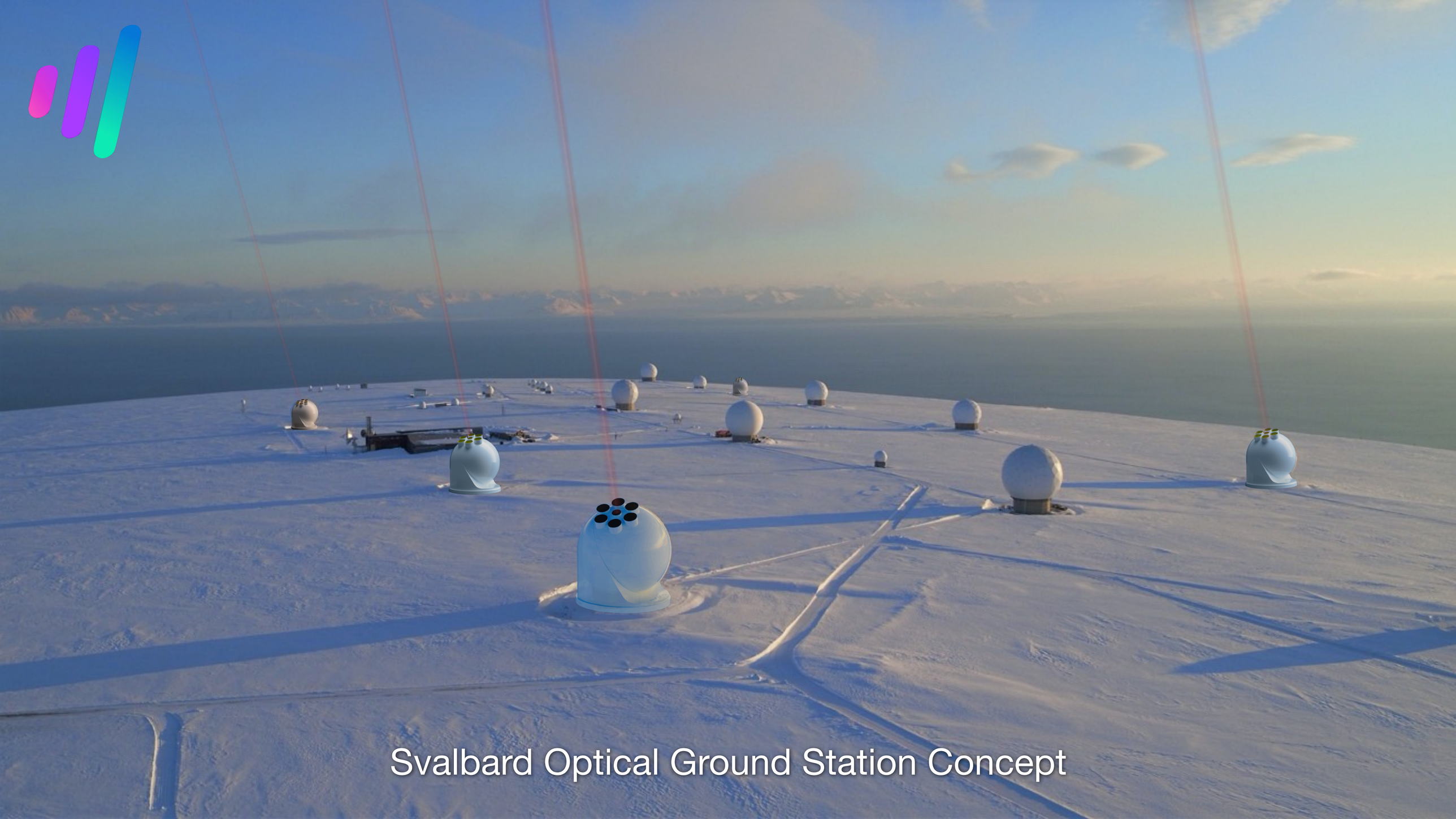


Oneweb >5 Tbps
(~720 satellites @ < 1200 km)

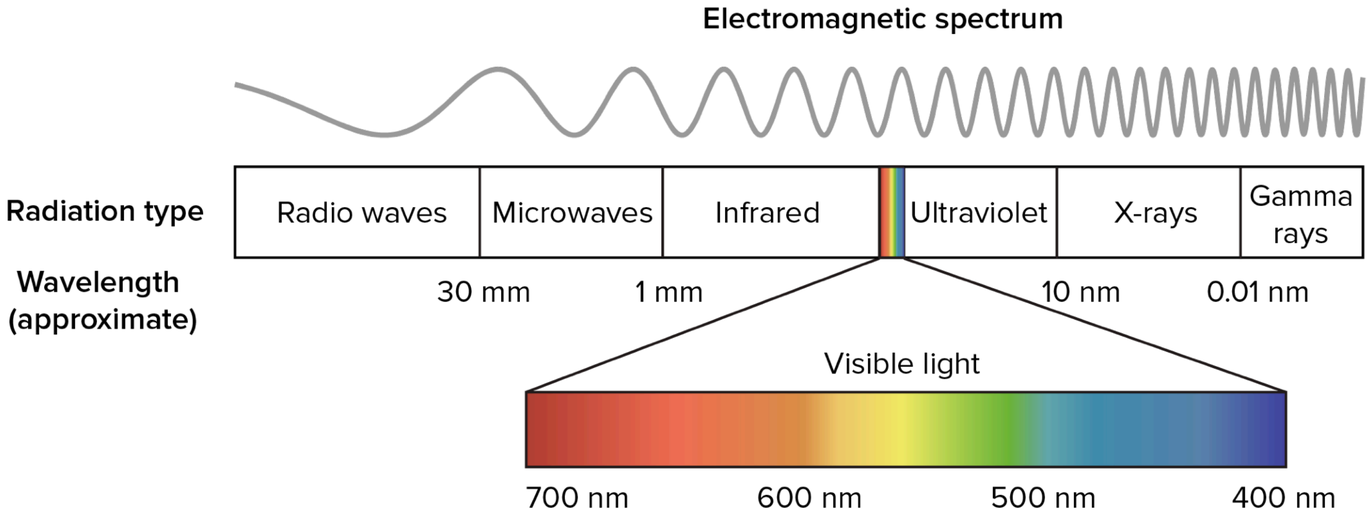


SpaceX 80 Tbps
(~a lot of satellites @ < 550km)

Optical ISL and feeder links are going to be critical for these large networks to deliver the ExaBytes of total backhaul traffic generated monthly.


Svalbard Optical Ground Station Concept

# BENEFITS OF OPTICAL COMMUNICATIONS



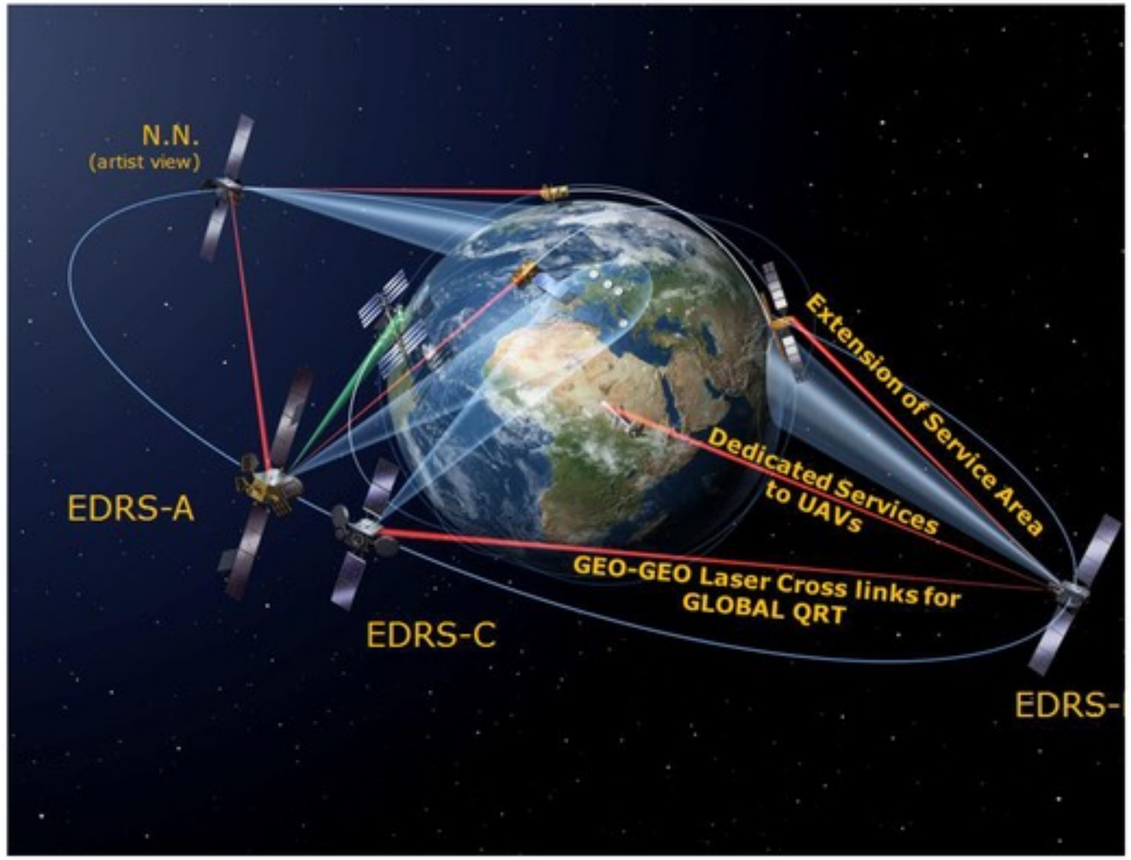


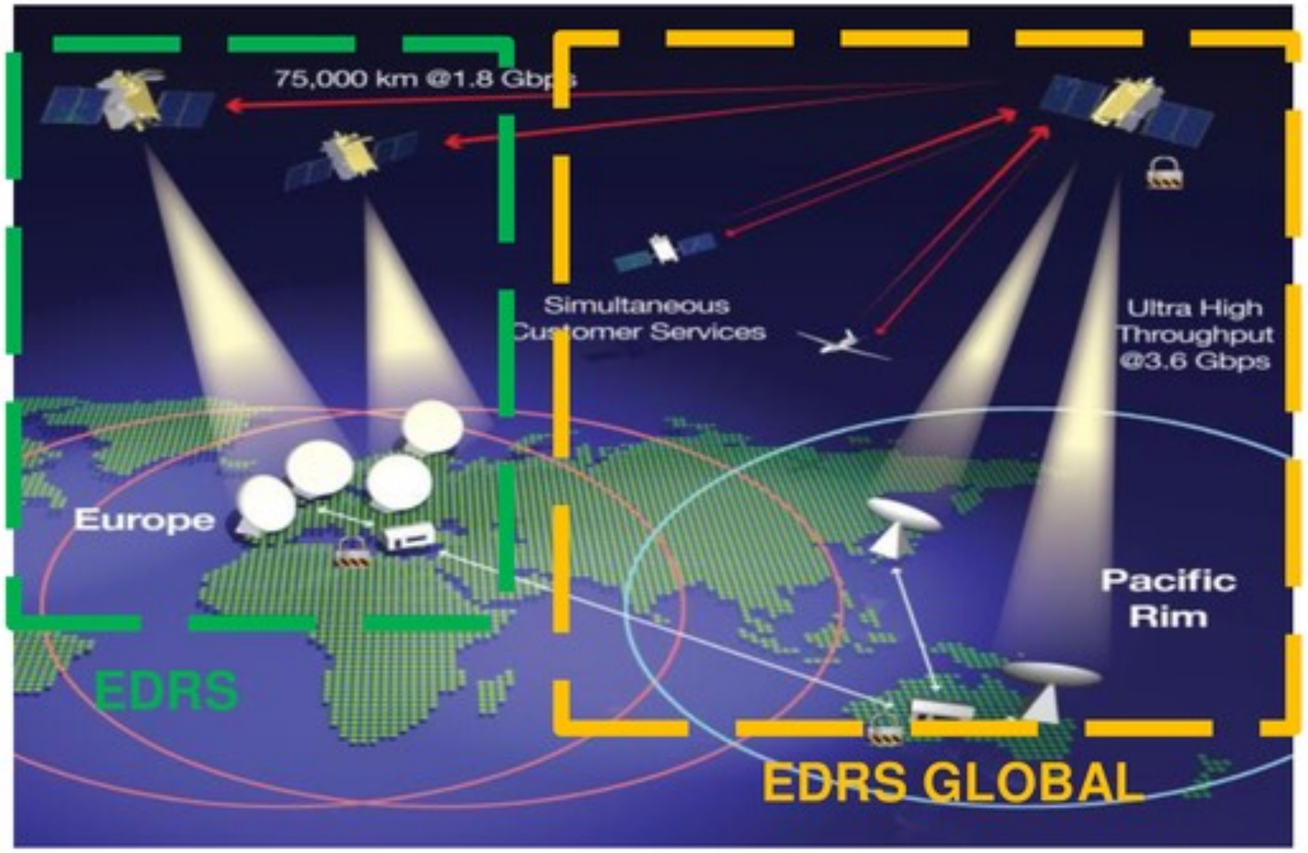
## Key Benefits of laser communications:

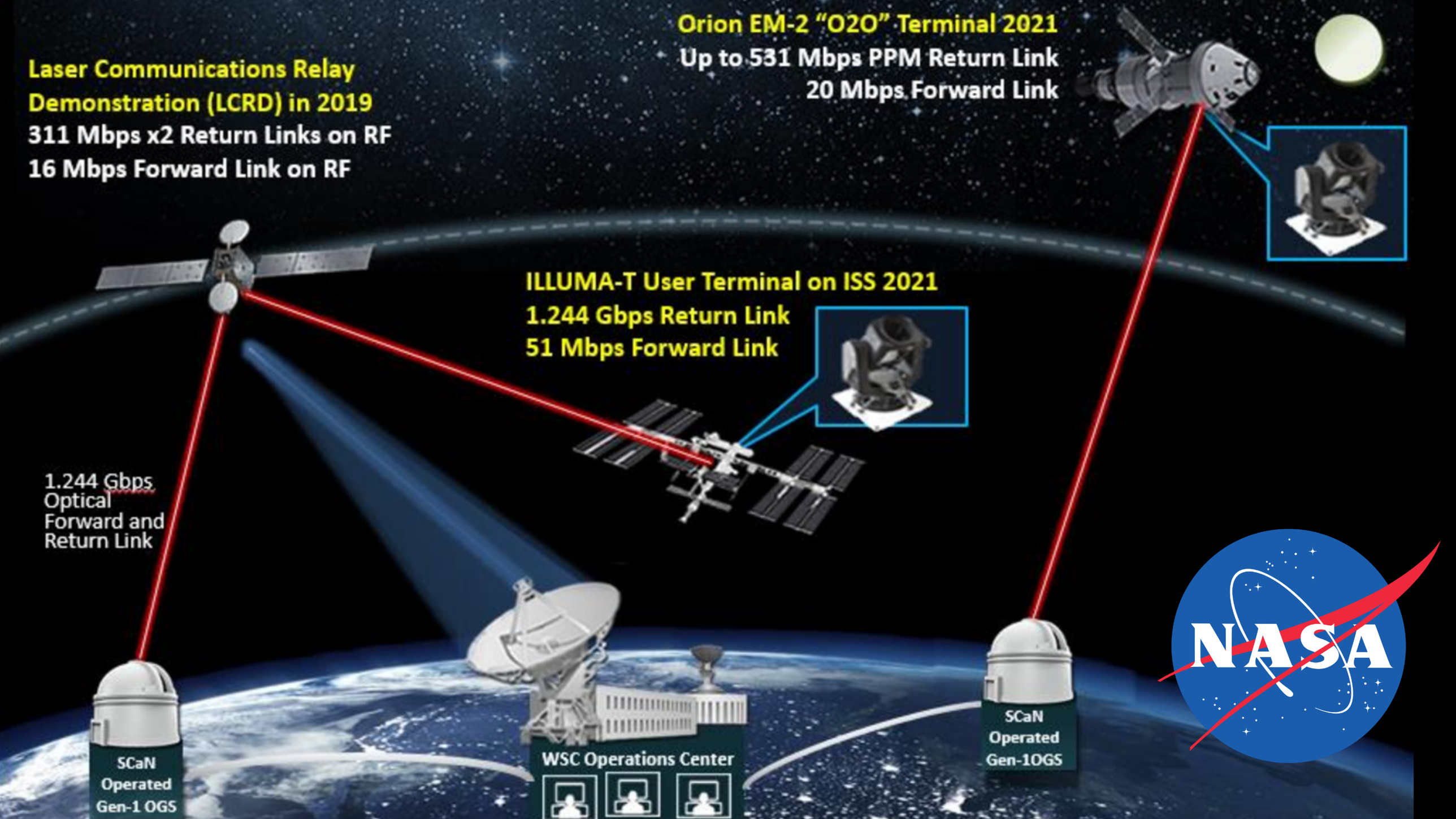
- Data Rate: Tbps data rates possible
- Security: Narrow directional beam difficult to intercept and potential for quantum encryption using QKD.
- Unregulated Spectrum: No spectrum co-ordination necessary (to date)
- SWaP-C advantages for space and ground segments

# Satellite Optical Communications in use today: European Data Relay System

## “Space Data Highway”: Optical LEO/GEO → GEO; RF GEO → Earth

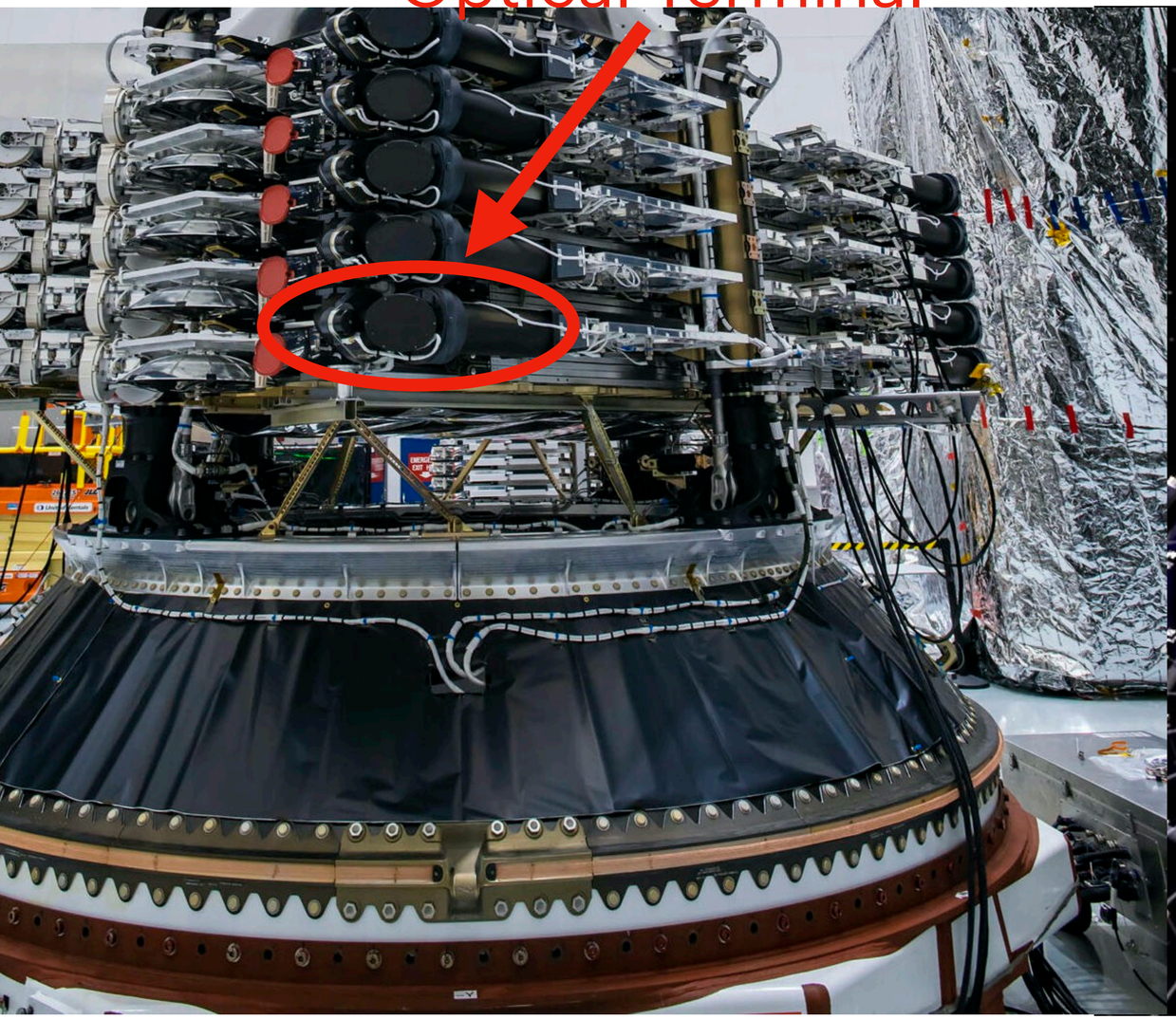


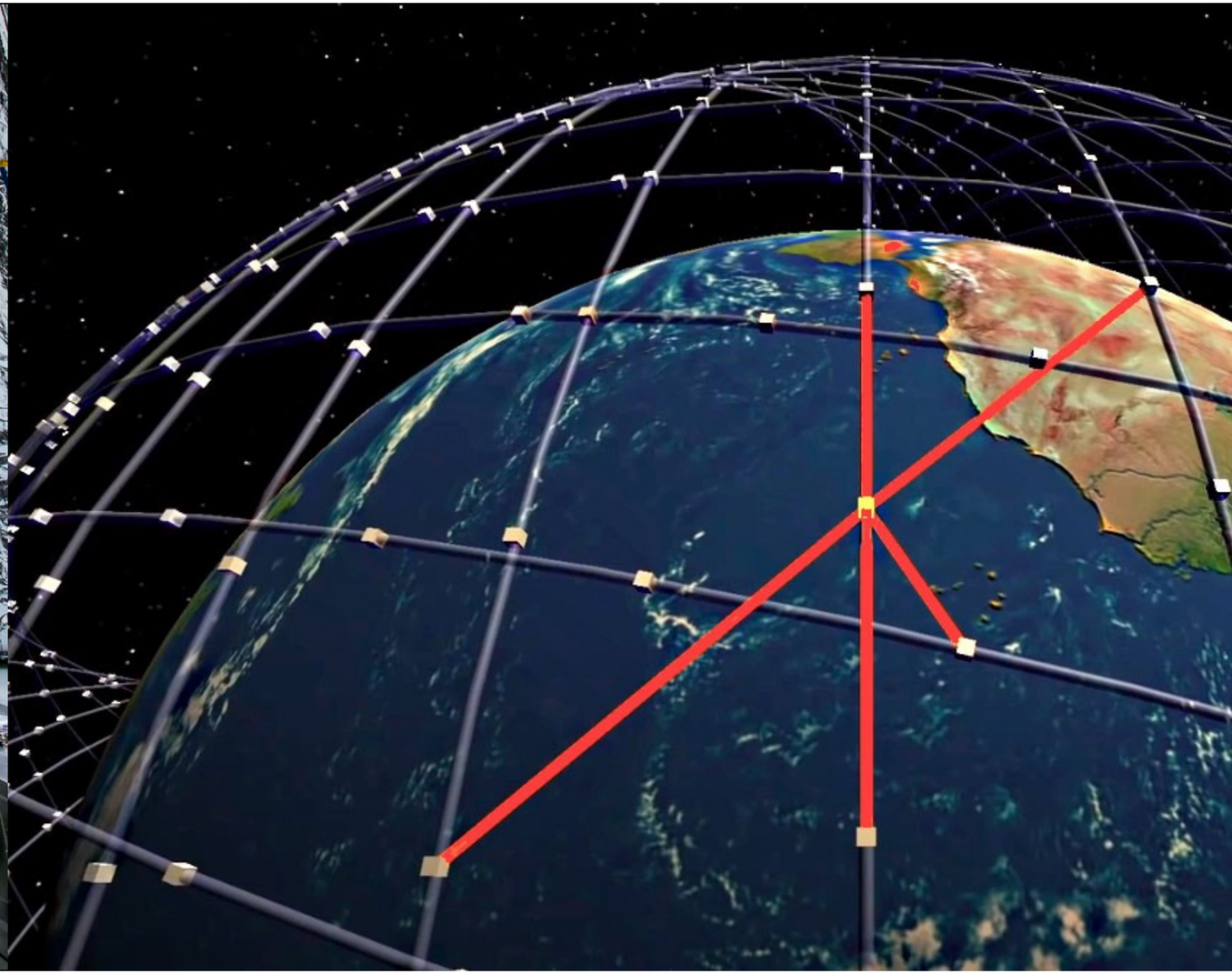




Orion EM-2 "O2O" Terminal 2021
Up to 531 Mbps PPM Return Link
20 Mbps Forward Link
Laser Communications Relay Demonstration (LCRD) in 2019
311 Mbps x2 Return Links on RF
16 Mbps Forward Link on RF
ILLUMA-T User Terminal on ISS 2021
1.244 Gbps Return Link
51 Mbps Forward Link
1.244 Gbps Optical Forward and Return Link
SCaN Operated Gen-1 OGS
WSC Operations Center
SCaN Operated Gen-1OGS
NASA

# Satellite Optical Communications Commercial Systems

Optical Terminal





# InterSatellite Laser links

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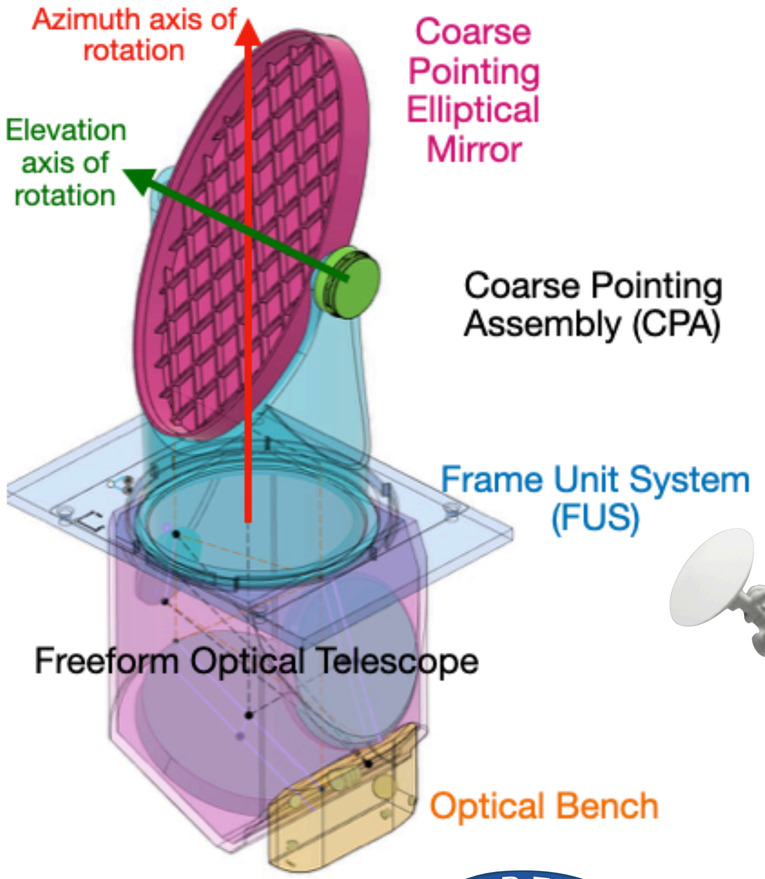
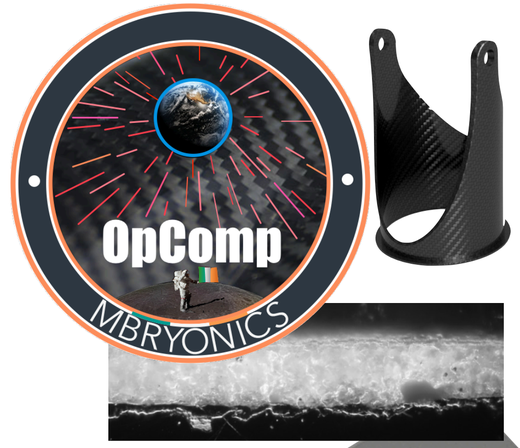
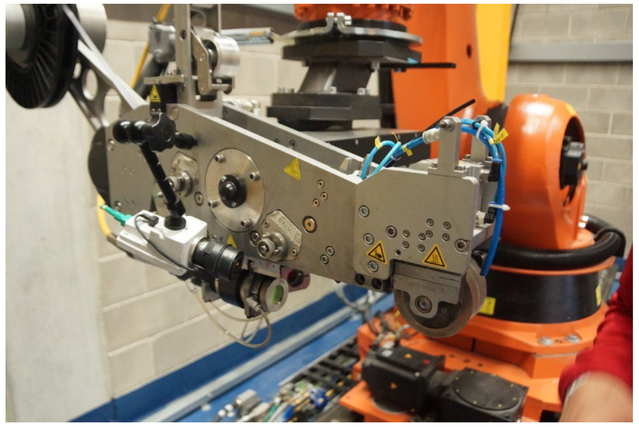
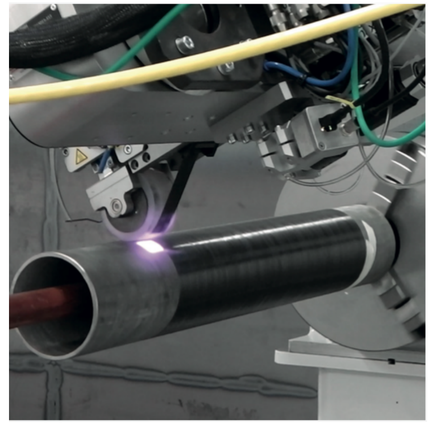
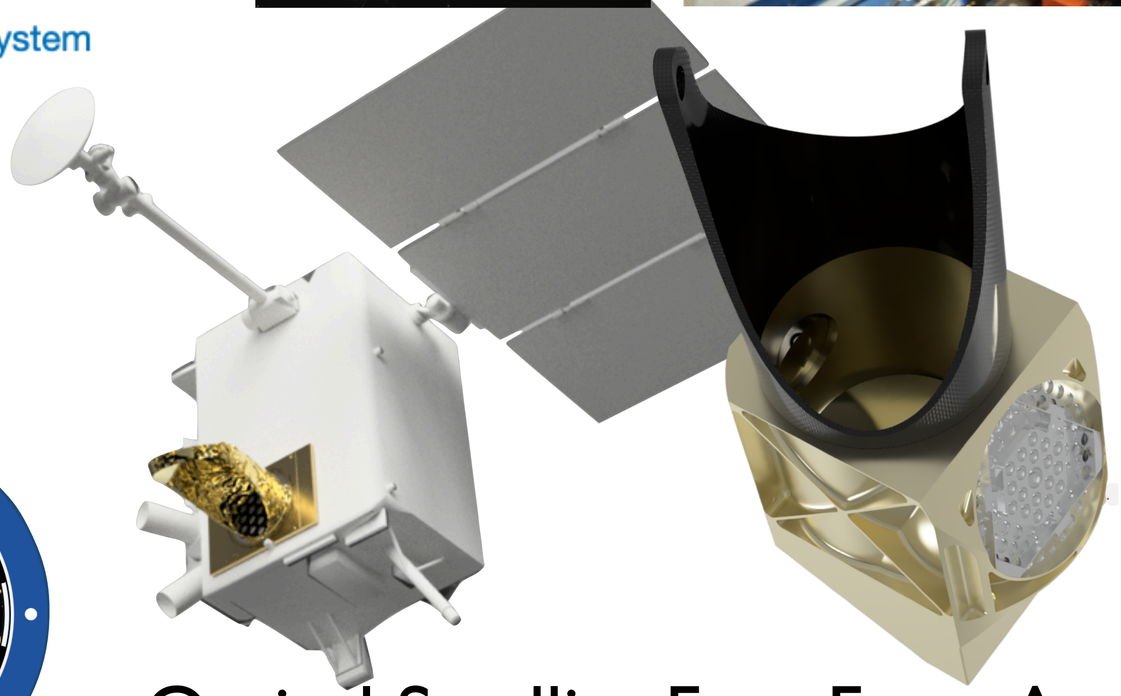
# Satellite Optical Terminal Overview

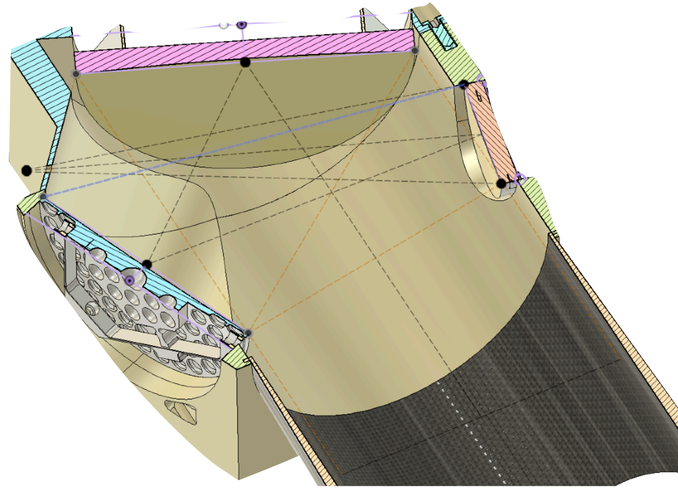


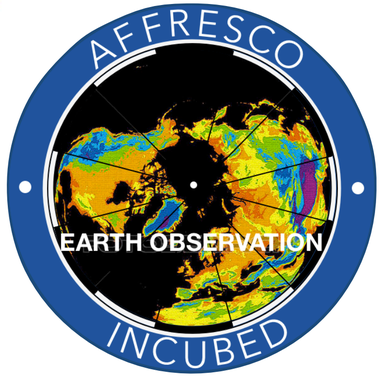









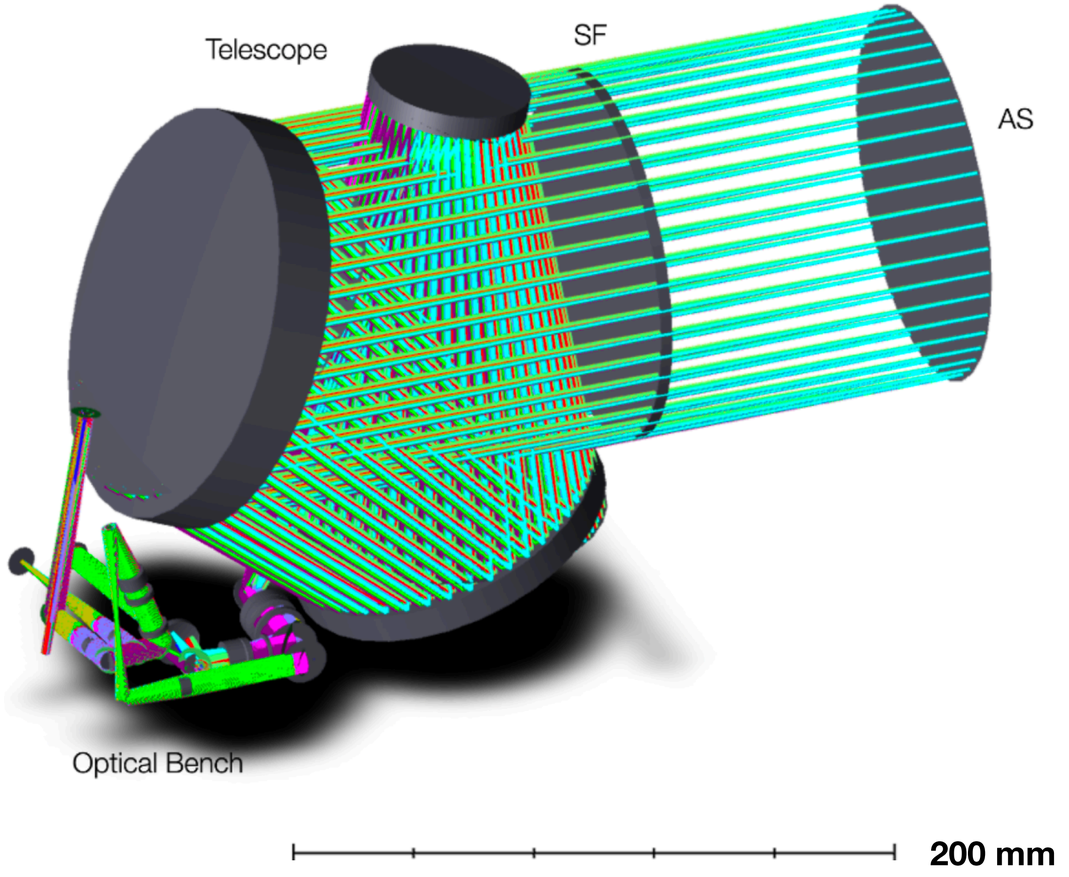



esa

## Optical Satellite Free Form Antenna

# Satellite Optical Terminal Overview

- Unobscured Aperture of 124 mm
- Compact design enabled by two freeform mirrors and one aspheric.
- F/3.88 folded reflective system
- Compact relay optical bench
- Combined system circular polarisation preserving >99%.
- Mirror design to minimise sensitivity to launch.



# FreeForm Optics

***What is freeform optics?***

Optical surfaces/elements that lack symmetry about a common optical axis

***Why use freeform?***

Complex optical surface can replace multiple elements reducing the optical system mass and volume

***Research in FFO is evolving worldwide***

- Optical design has a very active FFO research field
- Manufacturing only coming of age
- Metrology is difficult and is not yet well established

***Key Challenges in Manufacture***

- Metrology for large deformations but need nanometer resolution

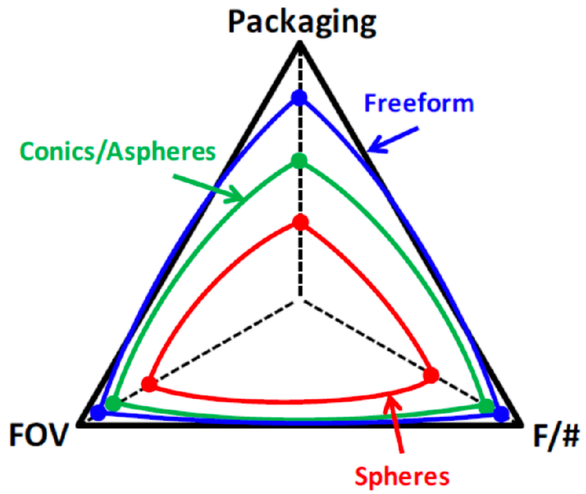



Image source: K. Fuerschbach. Freeform, ϕ-polynomial optical surfaces: optical design, fabrication and assembly. PhD thesis, Institute of Optics, Rochester, 2014

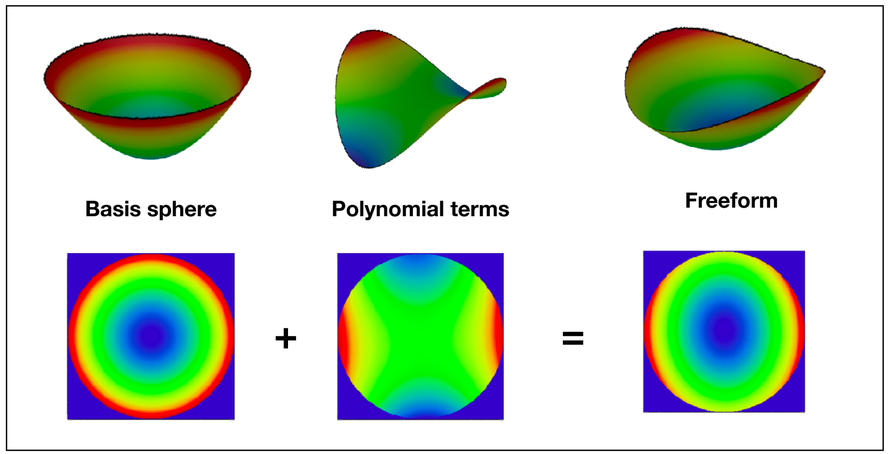
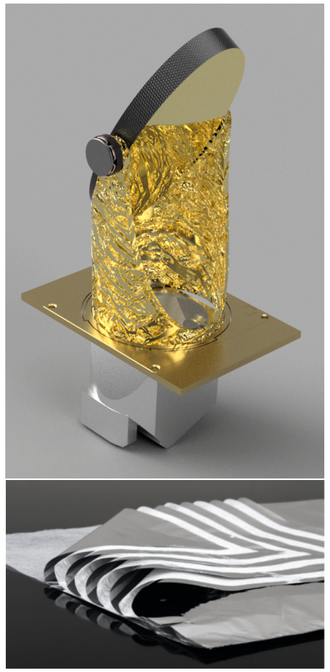
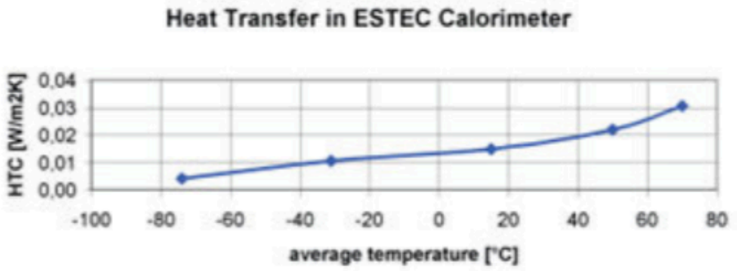
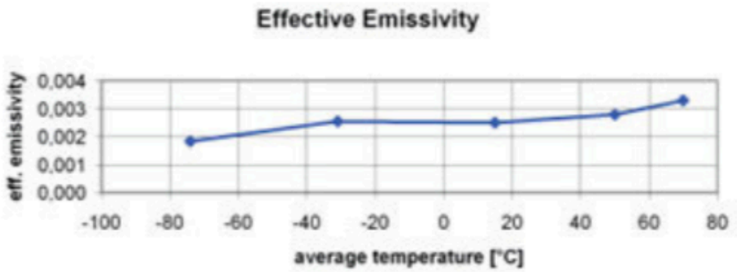


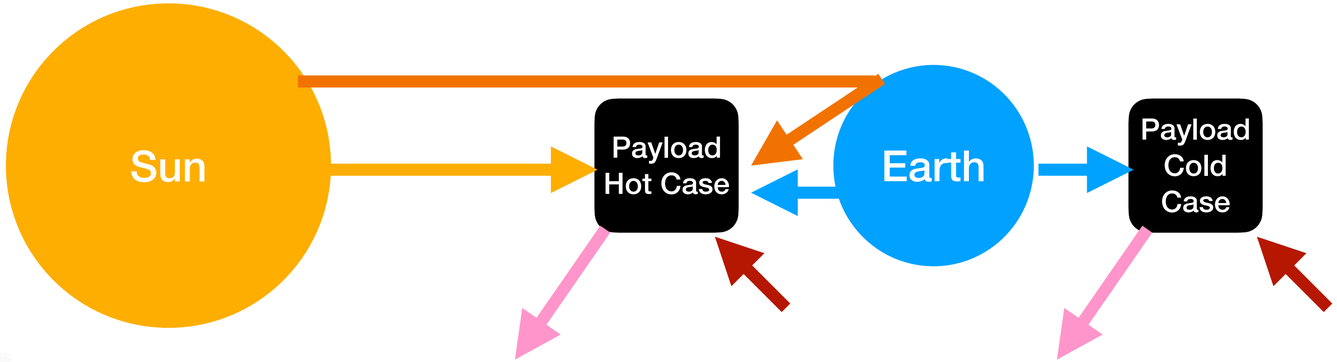

Image source: N. Fitzgerald, mBryonics, internal documentation (2019)

# Satellite Optical Terminal Design

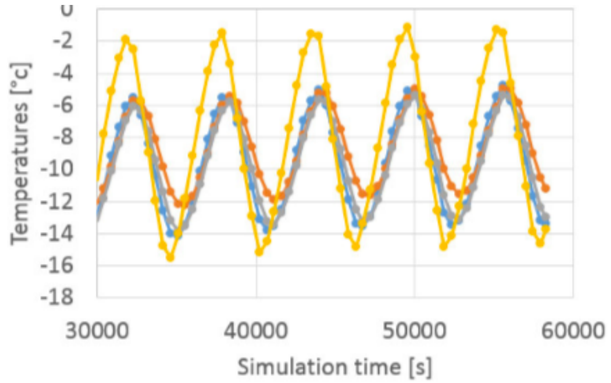




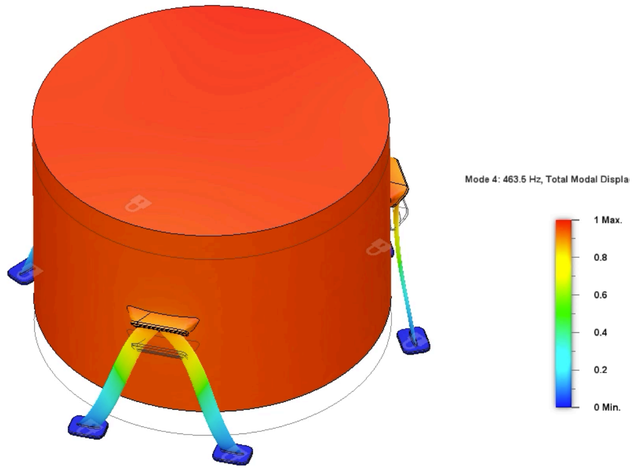



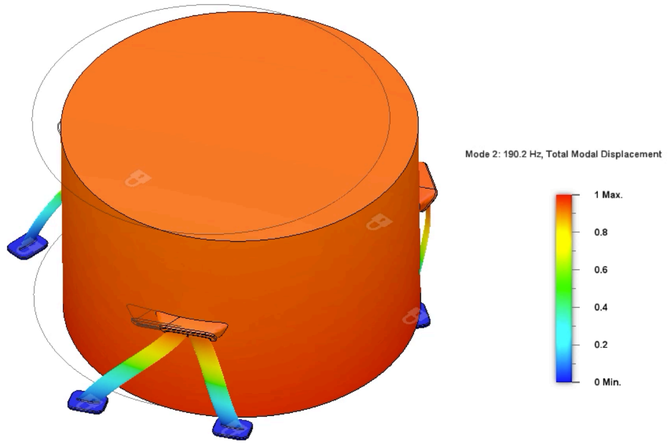

| Direct Solar Flux 1367 W/m² | Albedo 410 W/m² | Bus interface Min/Max: 50 - 2000 W/m² | Earth IR 240W/m² | Emitted radiation (2.7K) |
|---|---|---|---|---|

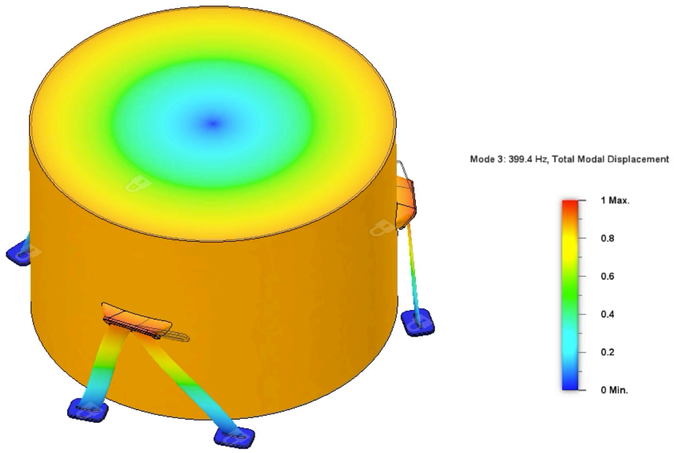


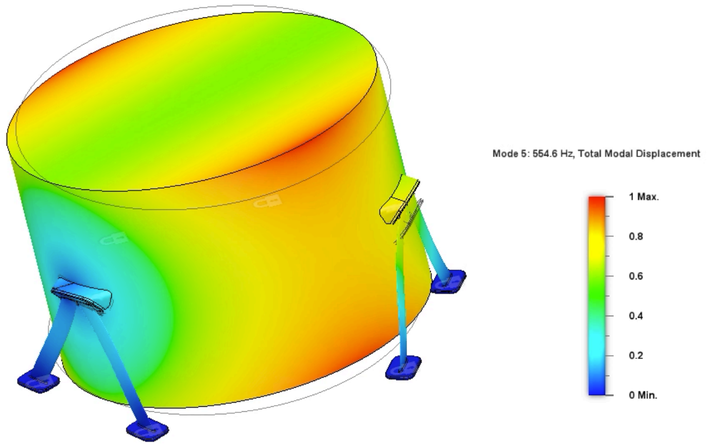
# Vibration and Thermal Decoupling

## Isostatic Bipod Mounts Modal Simulations of Dummy Mass Excitation

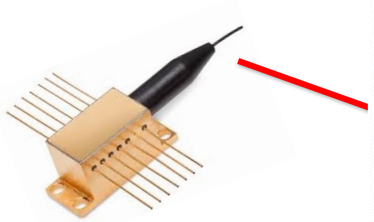


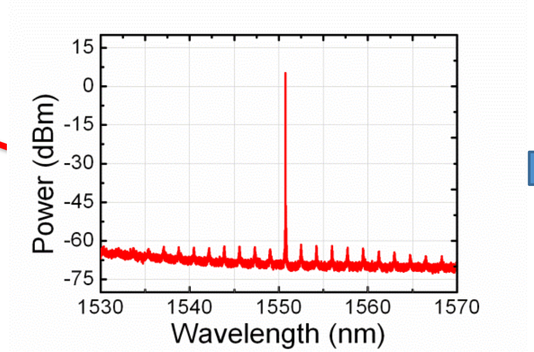



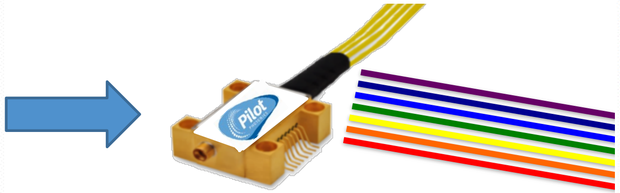



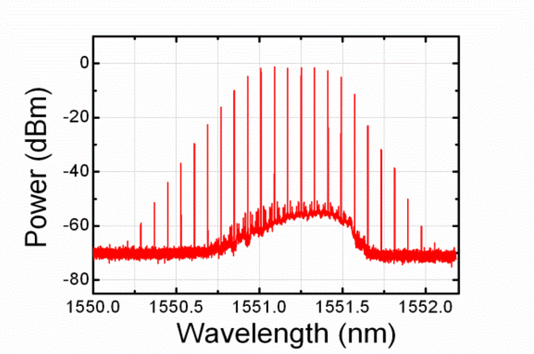



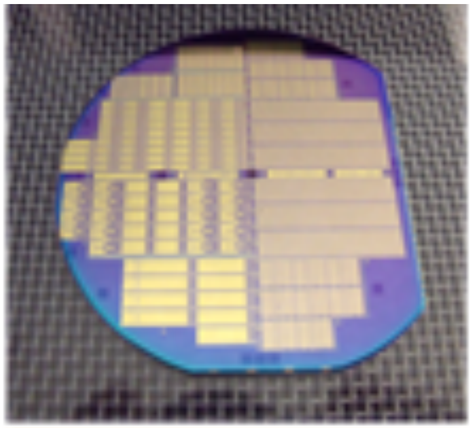
# Coherent Optical Inter-satellite Links



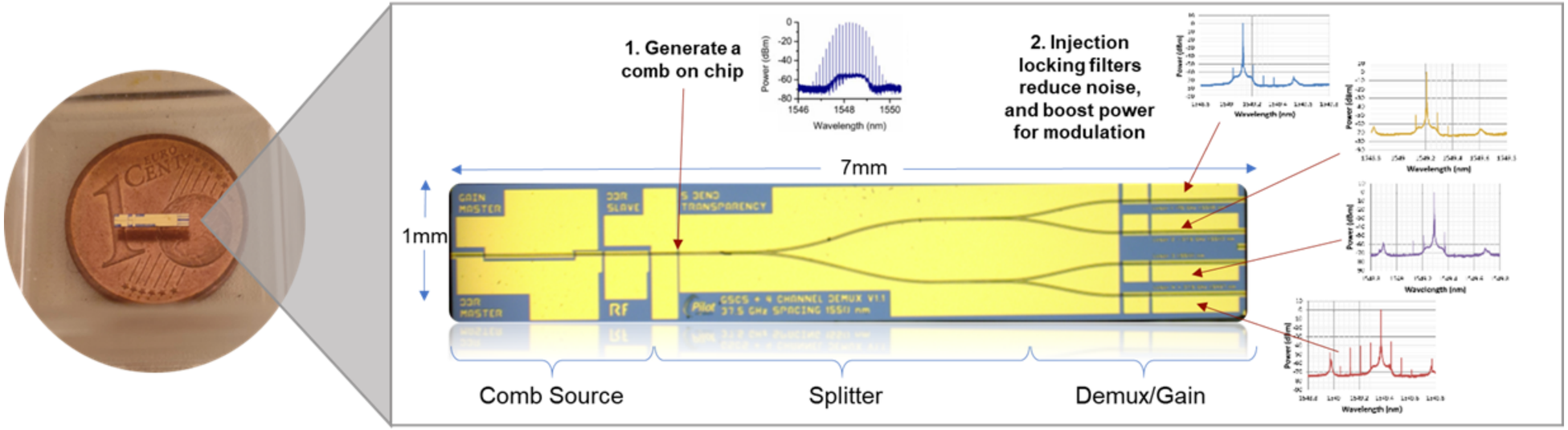


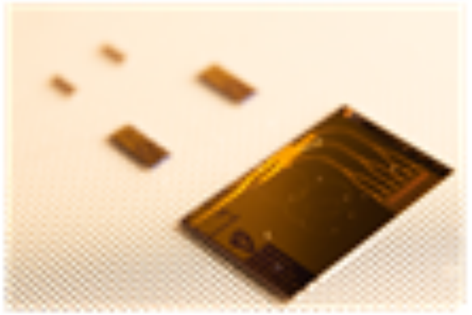



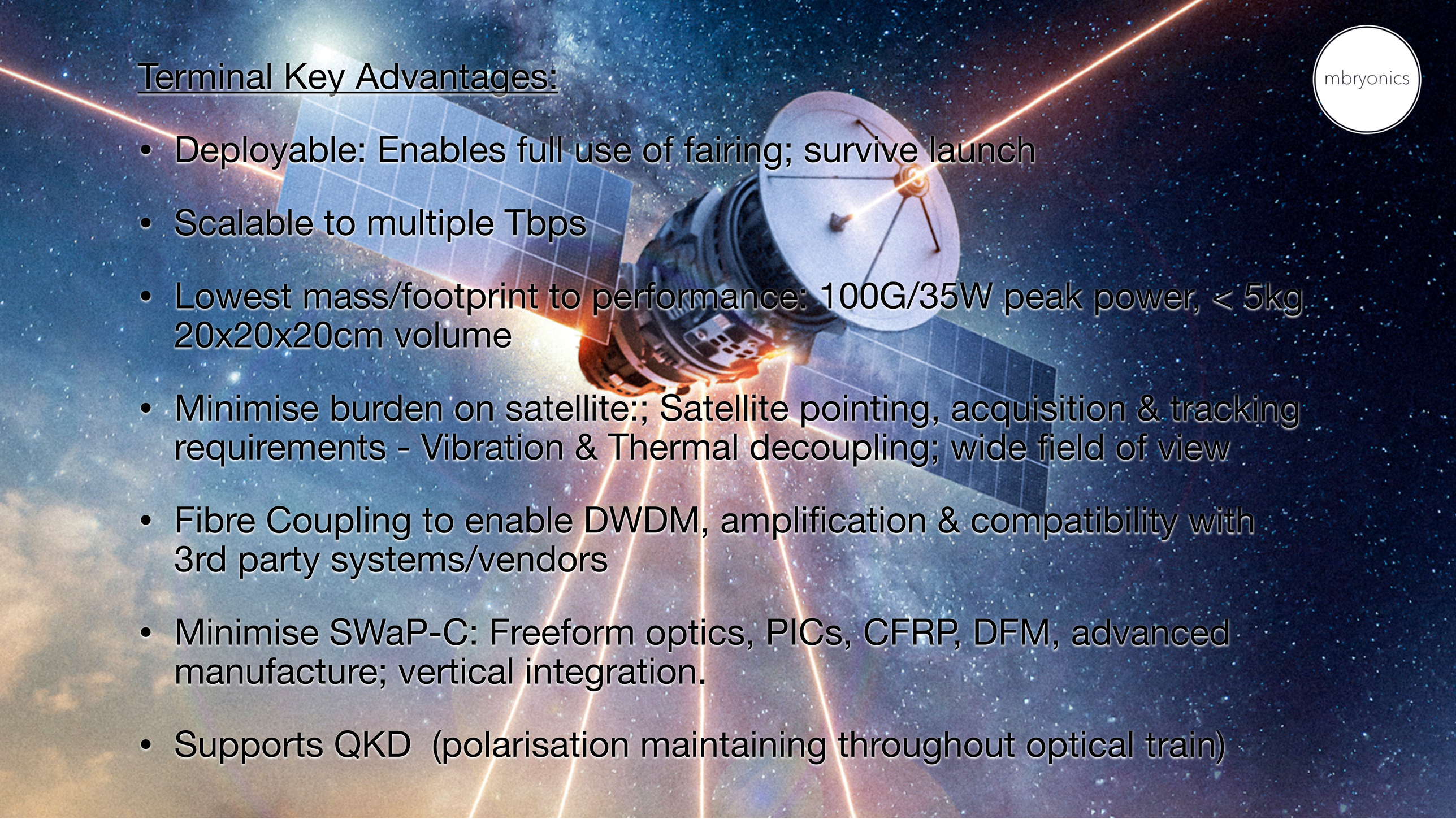



# Pilot Photonics



(above) A processed wafer of Pilot's Photonic Integrated Circuits and (below) individual PICs after coating & dicing



mbryonics

## Terminal Key Advantages:

- Deployable: Enables full use of fairing; survive launch
- Scalable to multiple Tbps
- Lowest mass/footprint to performance: 100G/35W peak power, < 5kg 20x20x20cm volume
- Minimise burden on satellite:; Satellite pointing, acquisition & tracking requirements - Vibration & Thermal decoupling; wide field of view
- Fibre Coupling to enable DWDM, amplification & compatibility with 3rd party systems/vendors
- Minimise SWaP-C: Freeform optics, PICs, CFRP, DFM, advanced manufacture; vertical integration.
- Supports QKD  (polarisation maintaining throughout optical train)

# Atmospheric Free Space Optical Communications

MBRYONICS


esa
European Space Agency
ESA
SAPPHIRE
SCYLIGHT

# LASER COMMUNICATIONS CHALLENGES

**Cloud Cover / Physical Obstacles / Horizon**

Laser Communication requires Line-of-Sight

**Background Sunlight**

Communication receivers are sensitive in the Infra Red (IR) wavelength range.

Background light from the sun and sky background is a noise source that can be of similar in strength to signal strength, and requires narrow band filtering or spatial filtering.

**Atmospheric Turbulence**

Turbulence causes beam spreading, beam wander and scintillation causing large random signal fades.

**Fine Pointing Requirements**

The narrow laser beam requires accurate pointing and tracking (~μrad pointing)

**Platform Motion & Vibration**

Motion close to the laser source is translated into beam pointing error.

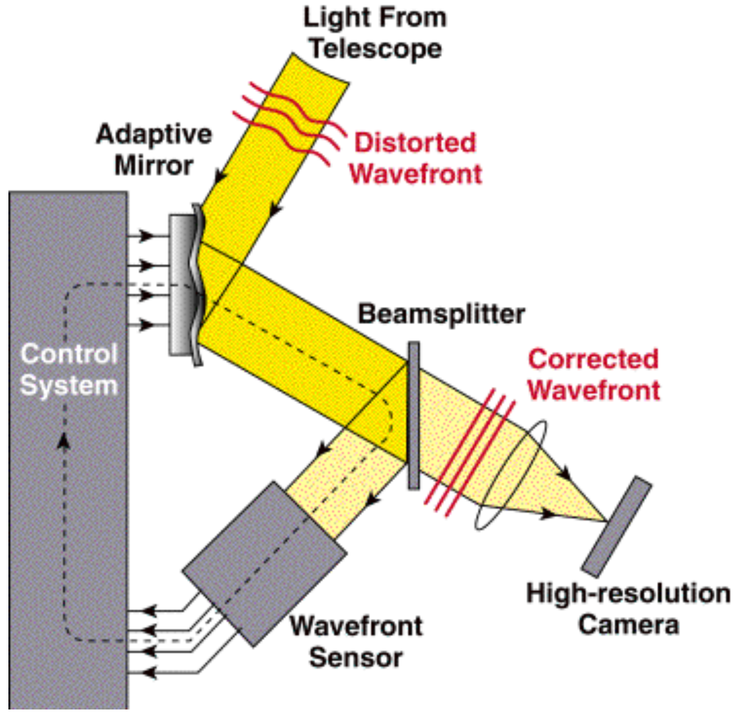
Platform motion will also affect the receiver.

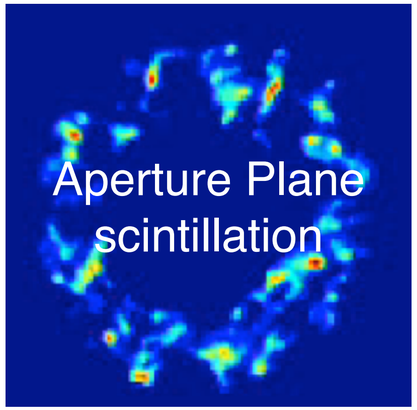
# The Atmospheric Channel

The characteristics of the atmospheric channel can be defined in terms of two parameters:

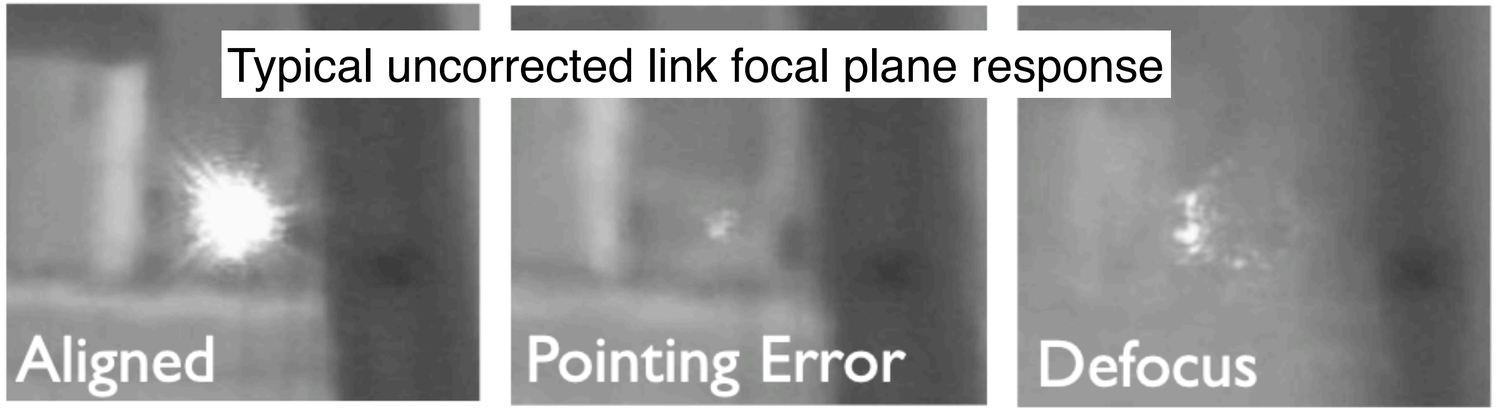
- the Fried parameter, $r_0$ (equivalent antenna diameter)
- the scintillation index, $\sigma_I^2$

Atmosphere effect is typically compensated with DSP, which results in high latency, also impossible to use fibre photonics components without compensation of atmospheric channel.

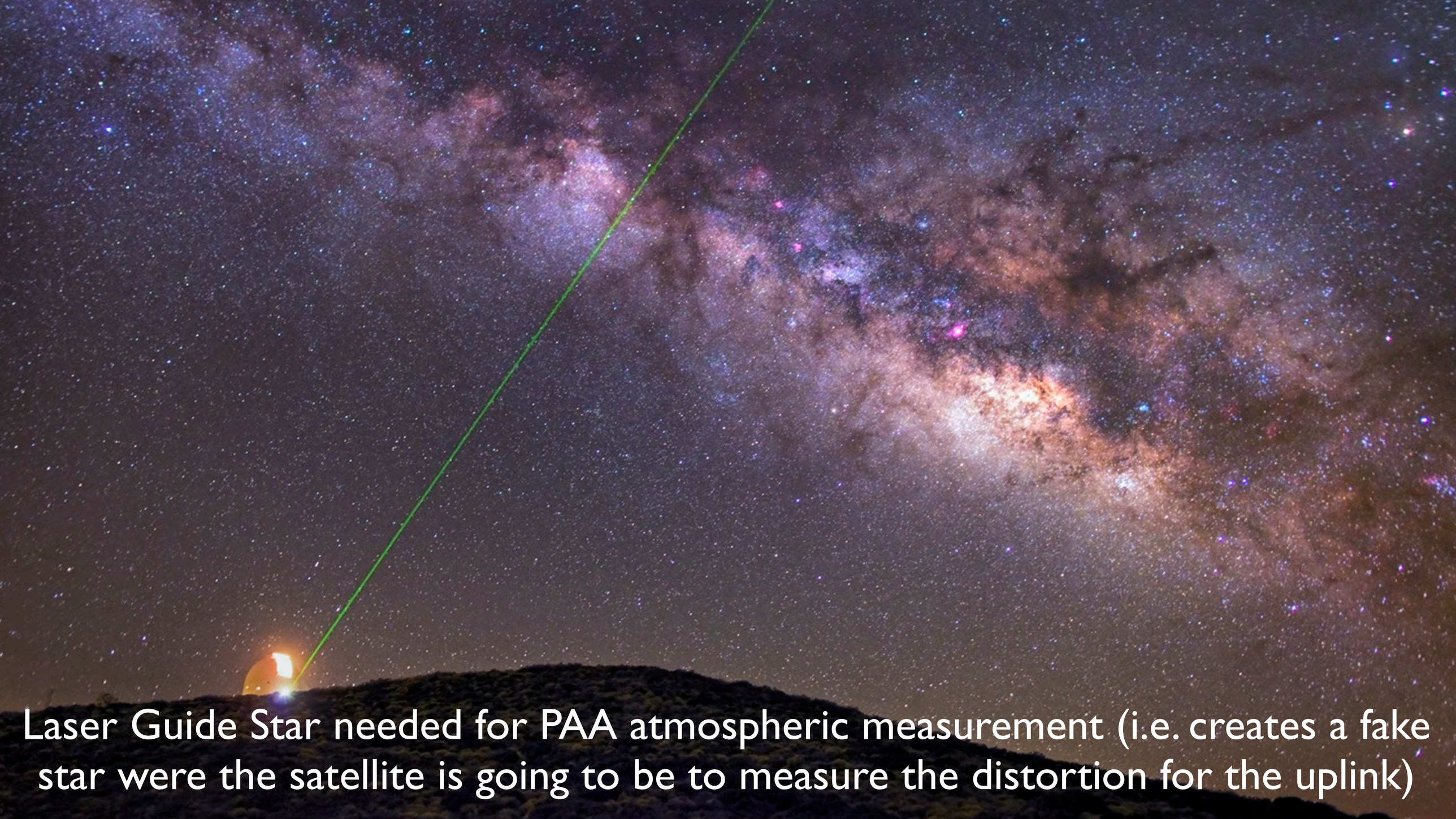



Typical uncorrected link focal plane response

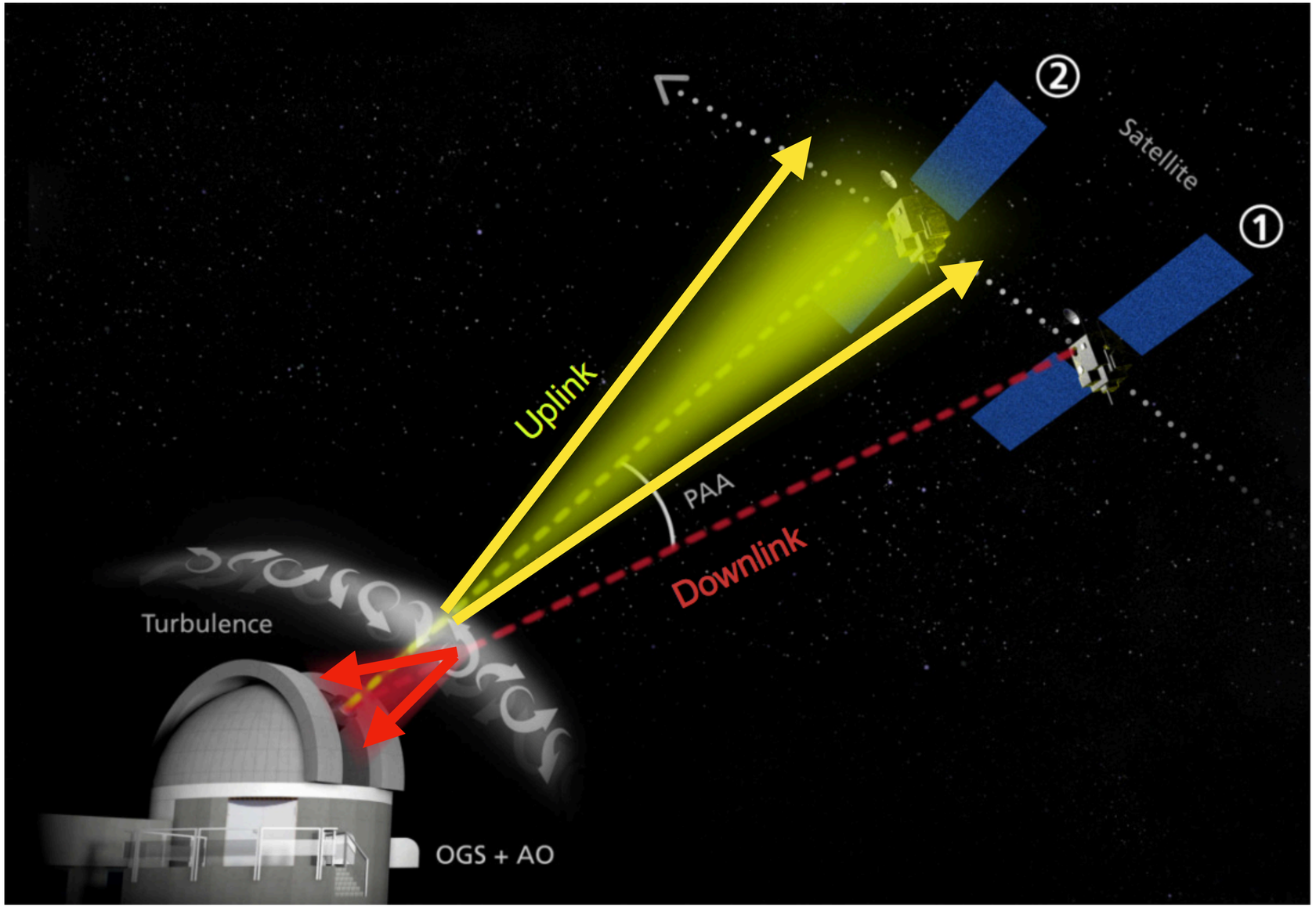


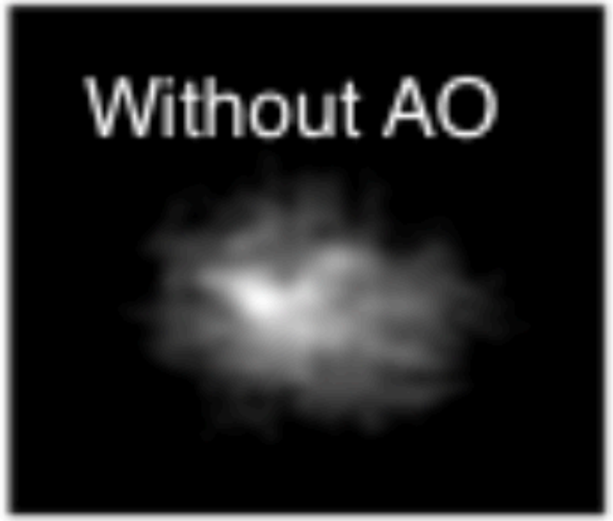

*DSP: Digital Signal Processing*

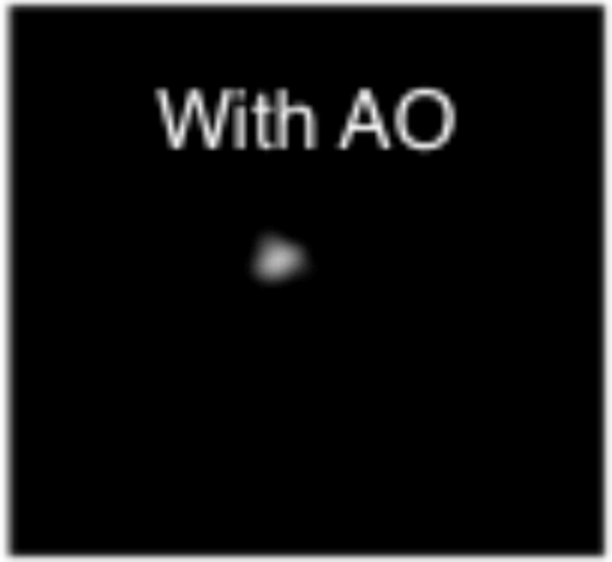


Laser Guide Star needed for PAA atmospheric measurement (i.e. creates a fake star were the satellite is going to be to measure the distortion for the uplink)

# Optical Links in Atmospheric Turbulence



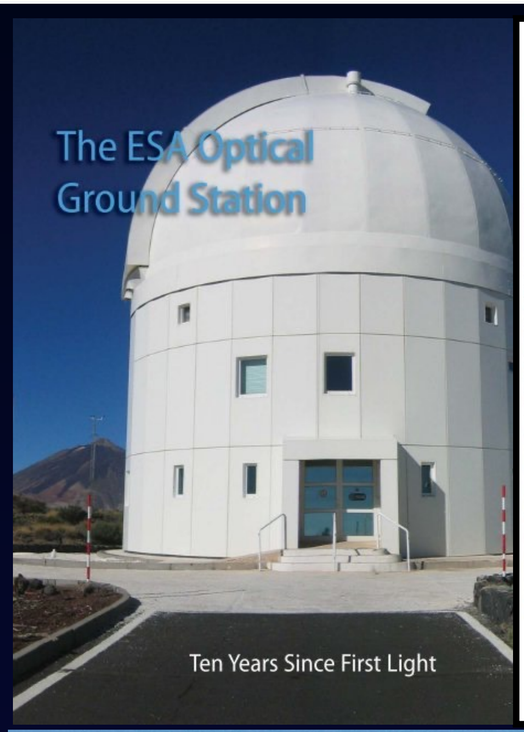




Nina Leonhard, "Real-time adaptive optics testbed to investigate point-ahead angle in pre-compensation of Earth-to-GEO optical communication," Opt. Express 24, 13157-13172 (2016)

# Optical Ground Stations in use today

- Limited to mountain top operations
- Large, bulky systems: 1 metre aperture telescopes
- Not ruggedised: Multiple free space optical elements
- Limited data rates: Not fibre coupled
- Adaptive optics integration requires multi-element optics and laser guide star



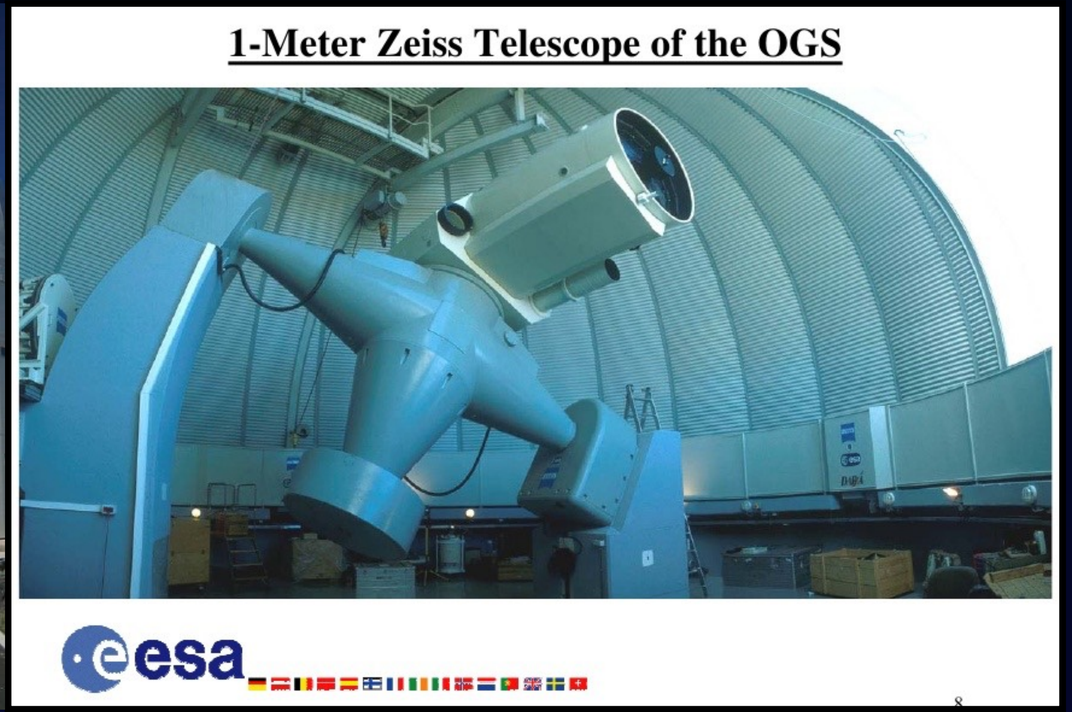




Image Credits: ESA

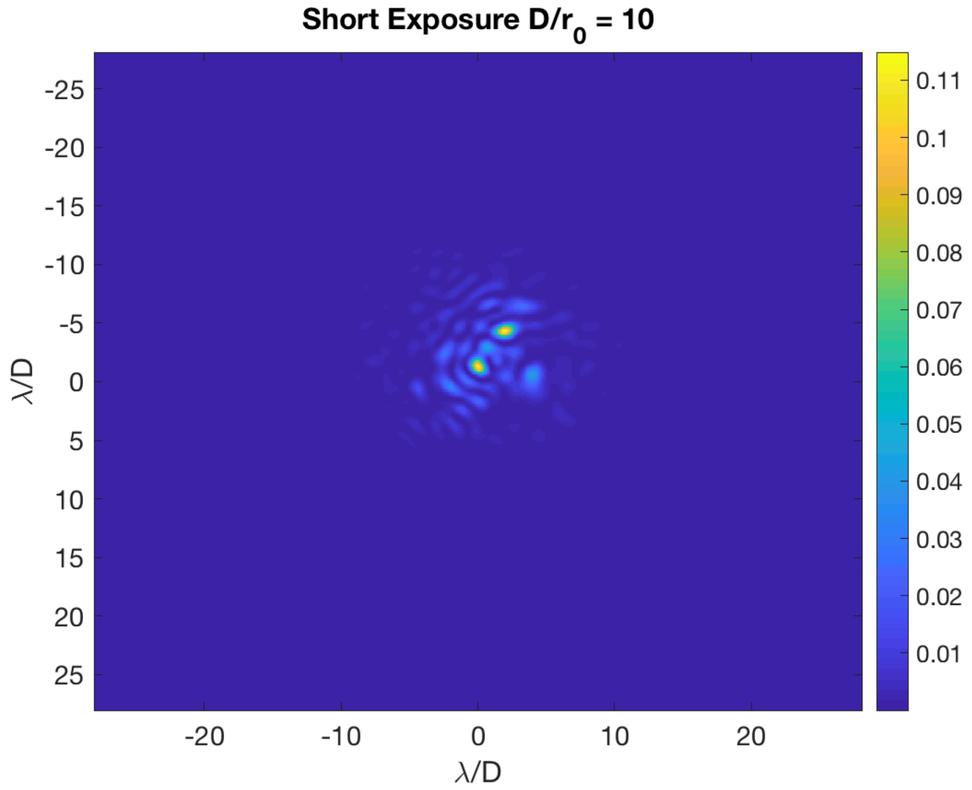
Mount Teide, Tenerife, Image Credits: Canary Geo

MBRYONICS

Taking a top down approach to optimise Antenna Gain versus Distortion Correction Bandwidth

<u>Critical Design parameters:</u>

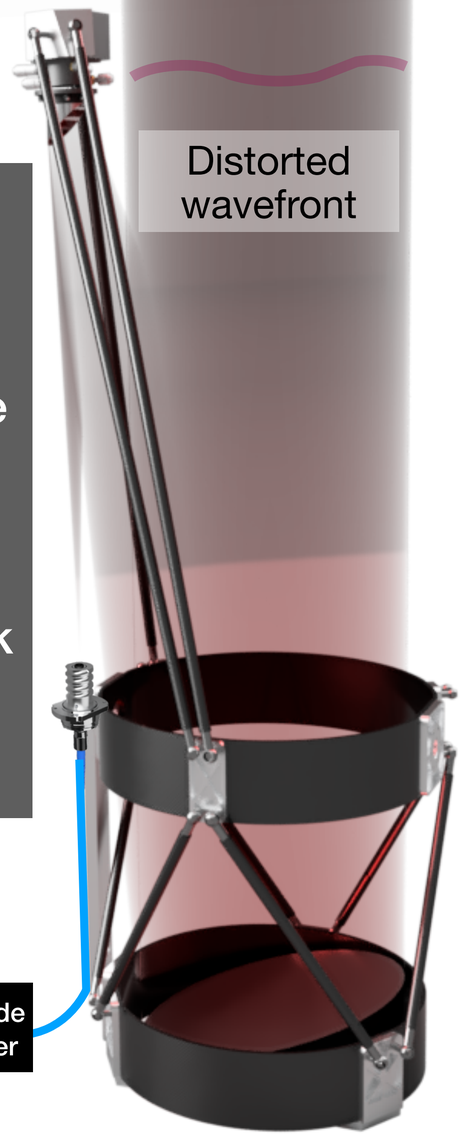
- Telescope Diameter (influences tip tilt range and bandwidth, Lantern modes, co-phasing bandwidth)
- Atmospheric parameters
- Downlink Orbit



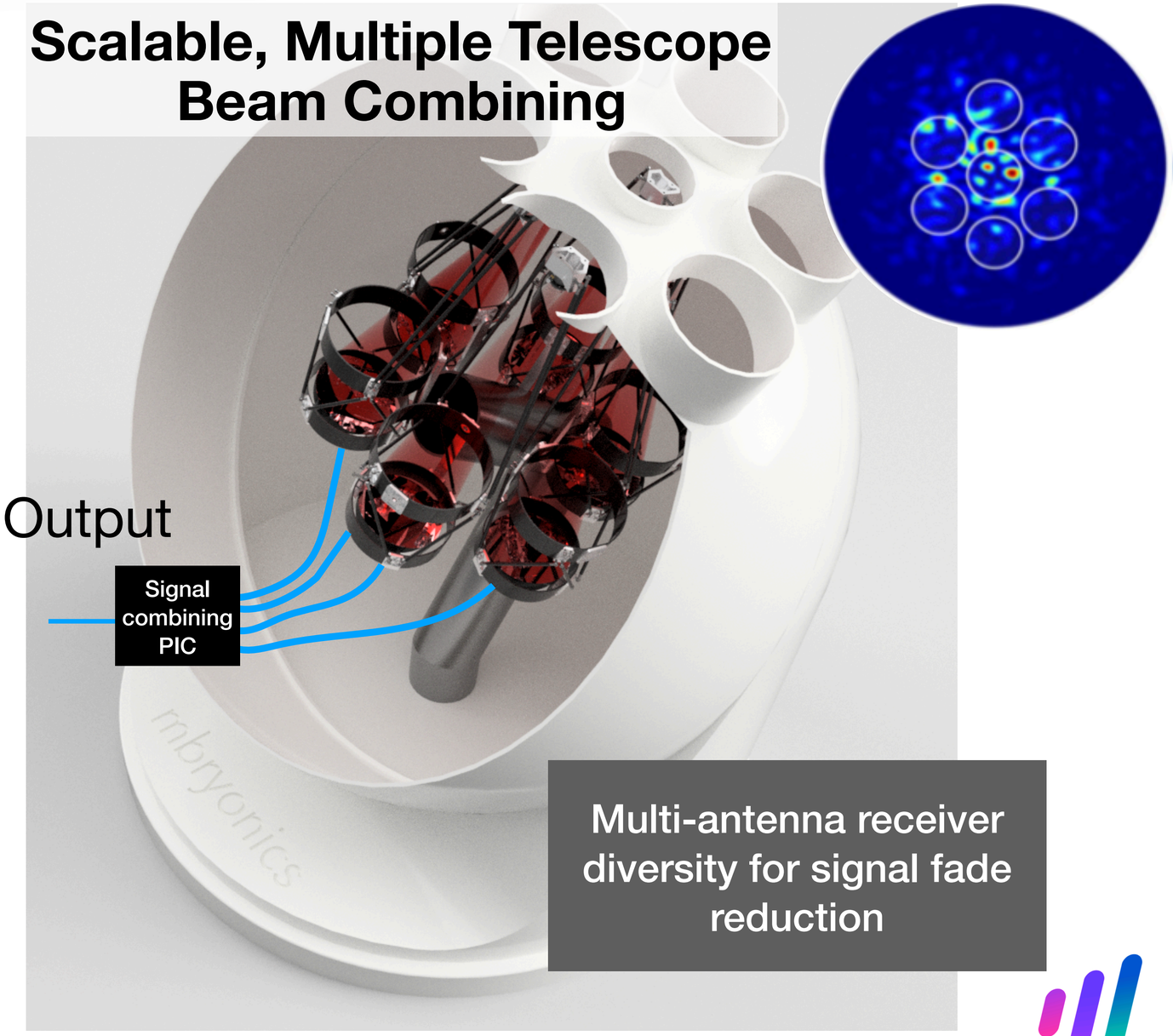
# Optical Ground Station

## Single Telescope

SkyLark active and passive focal plane atmospheric mitigation photonics for robust fibre coupling, utilising a photonics multi-mode beam combiner to move away from traditional bulk optical adaptive optics systems



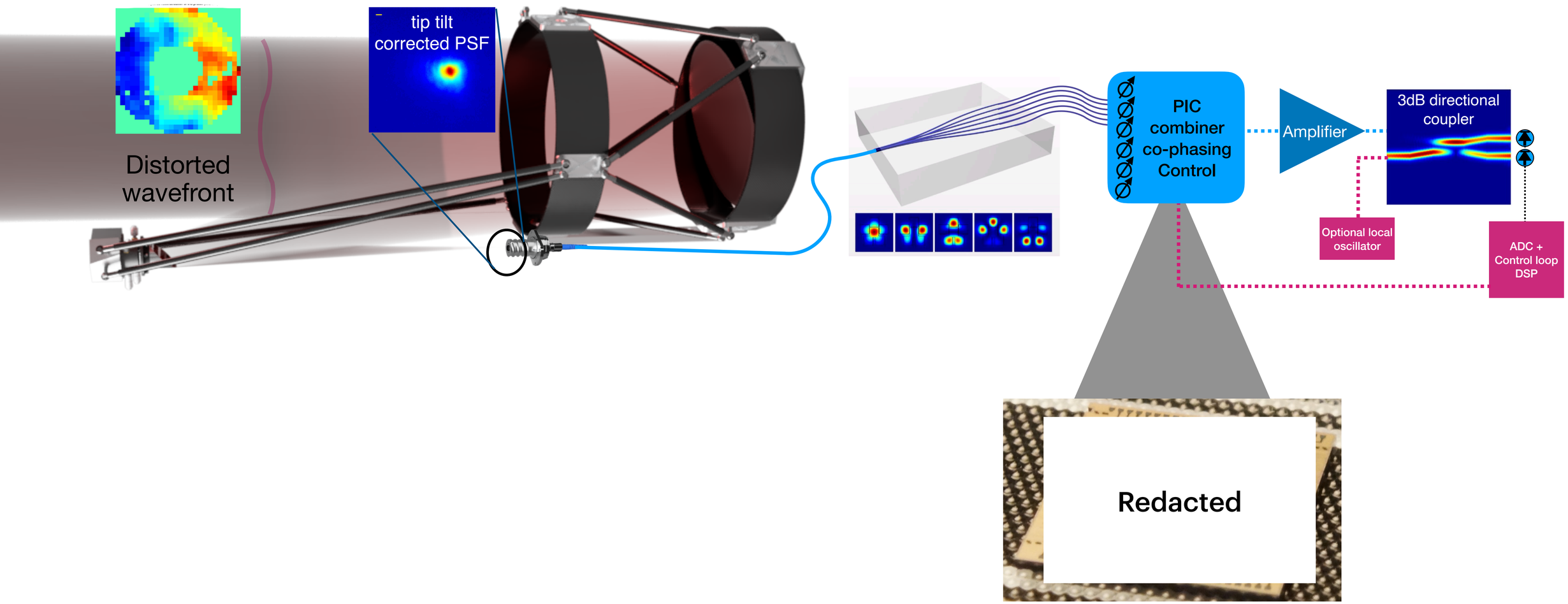

## Scalable, Multiple Telescope Beam Combining

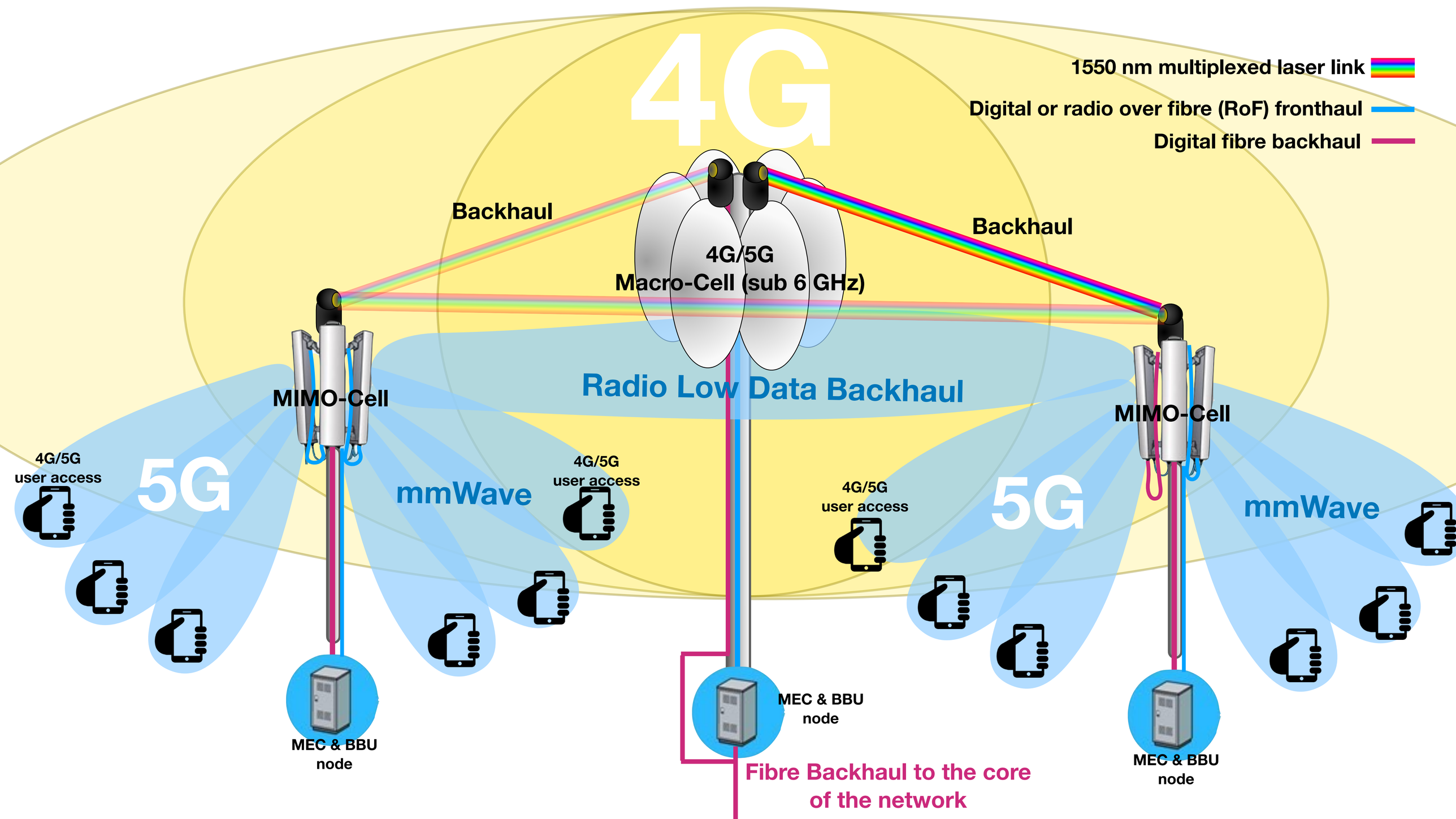



Multi-antenna receiver diversity for signal fade reduction

# Optical Antenna

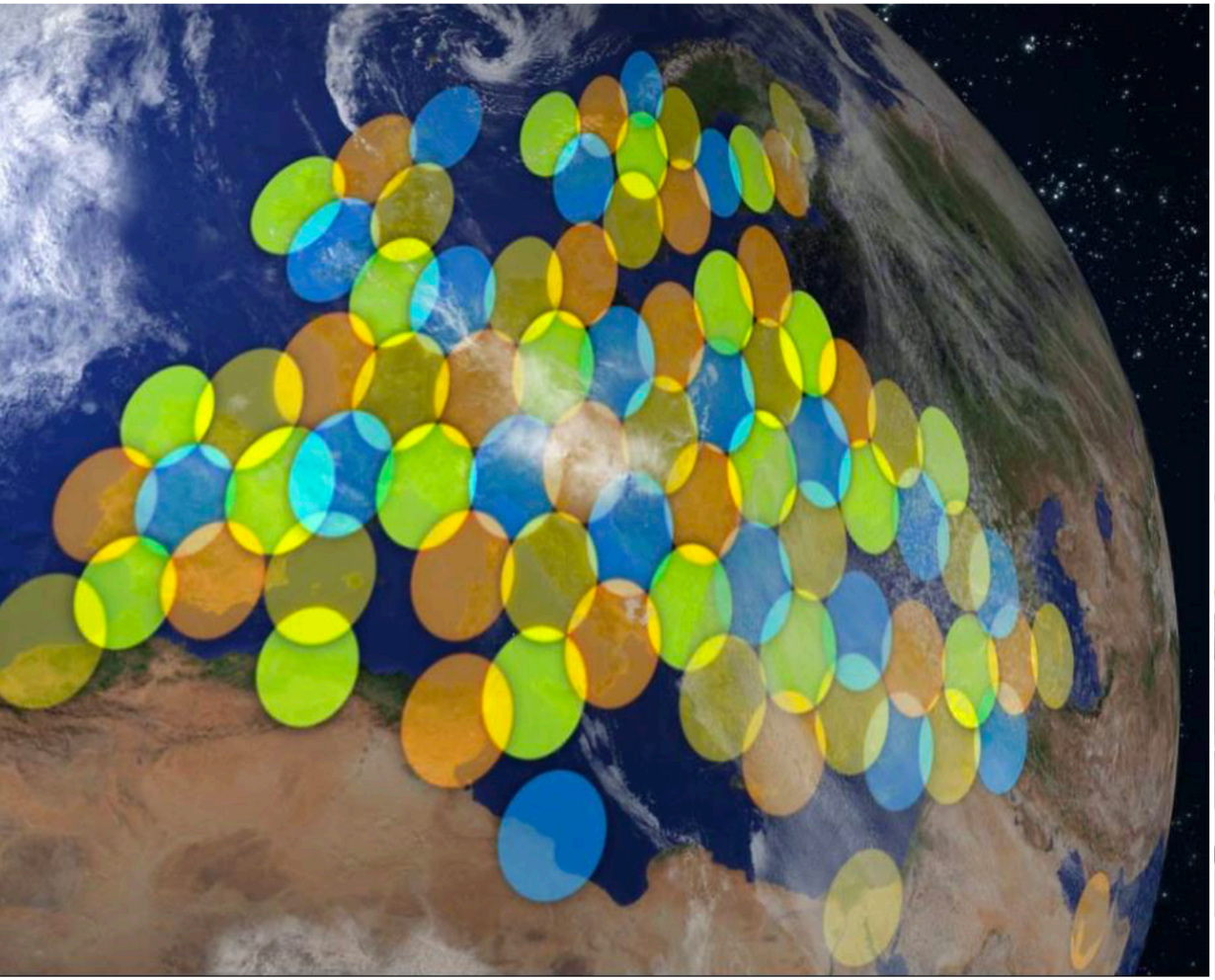
System architecture works best with a beacon channel

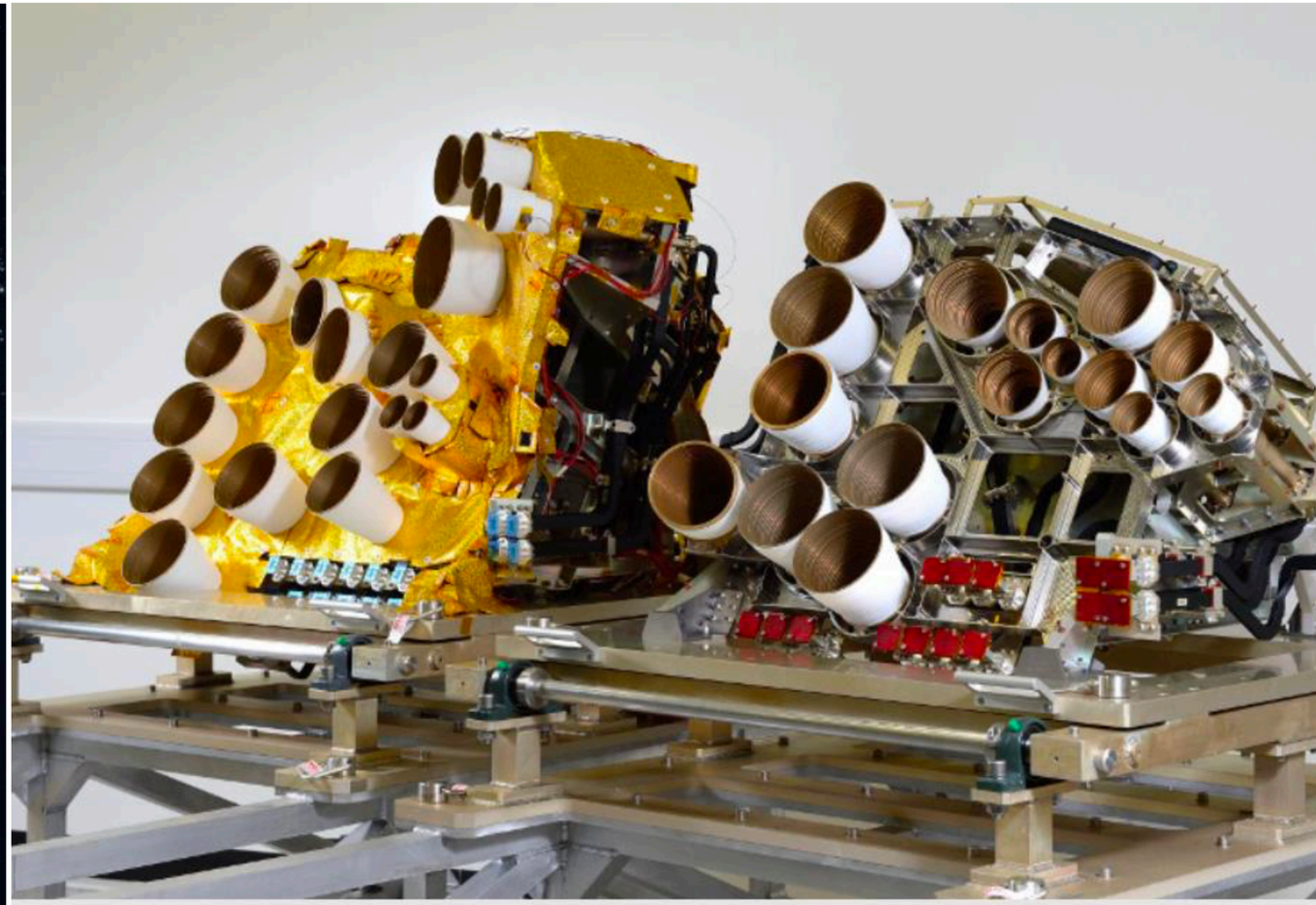



4G
1550 nm multiplexed laser link
Digital or radio over fibre (RoF) fronthaul
Digital fibre backhaul
Backhaul
Backhaul
4G/5G
Macro-Cell (sub 6 GHz)
Radio Low Data Backhaul
MIMO-Cell
MIMO-Cell
4G/5G
user access
5G
mmWave
4G/5G
user access
4G/5G
user access
5G
mmWave
MEC & BBU
node
MEC & BBU
node
MEC & BBU
node
Fibre Backhaul to the core
of the network


Space Photonics

# Photonics Satellite Applications



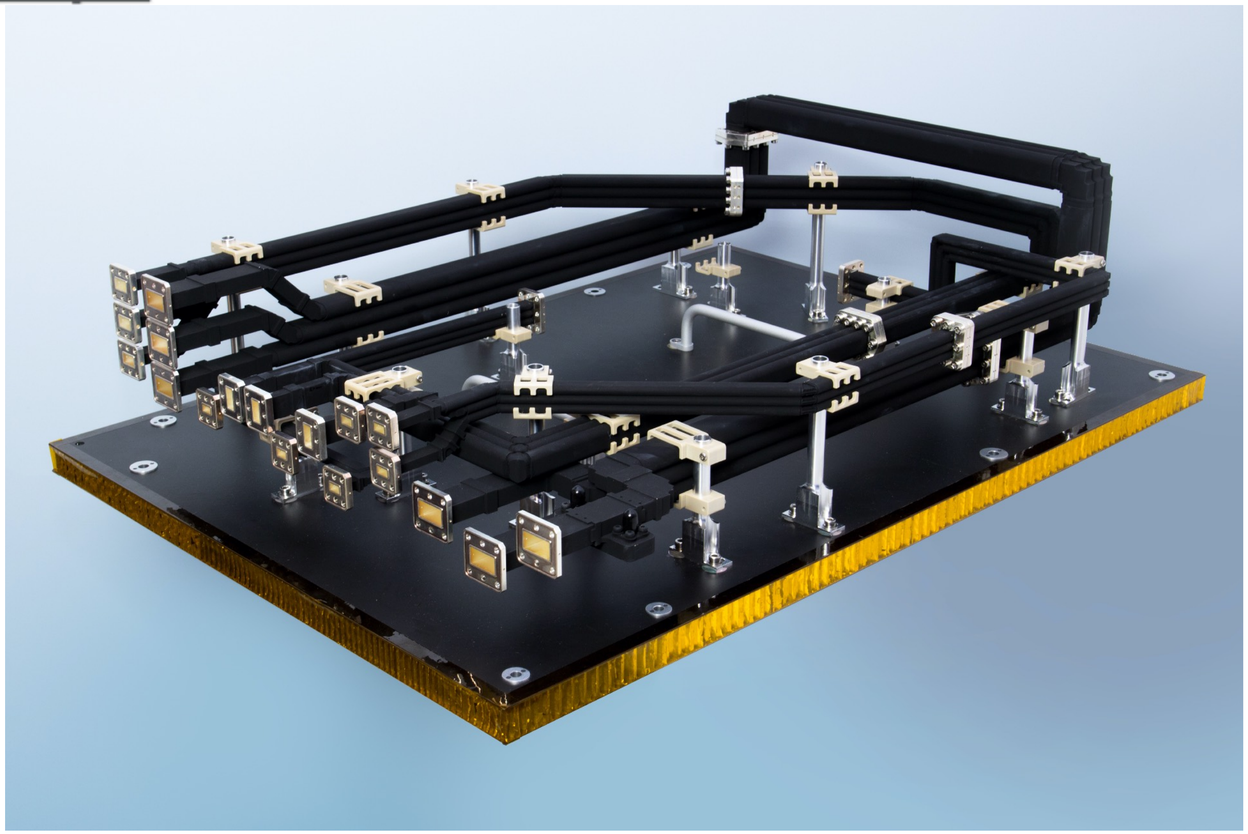


Airbus Defence & Space's new Large Multiple-spot Feed Array. Credit: AD&S

Spot beam antennas allow for spectrum reuse

# Photonics Satellite Applications

## 2 types of Payloads with clearly defined roadmaps:



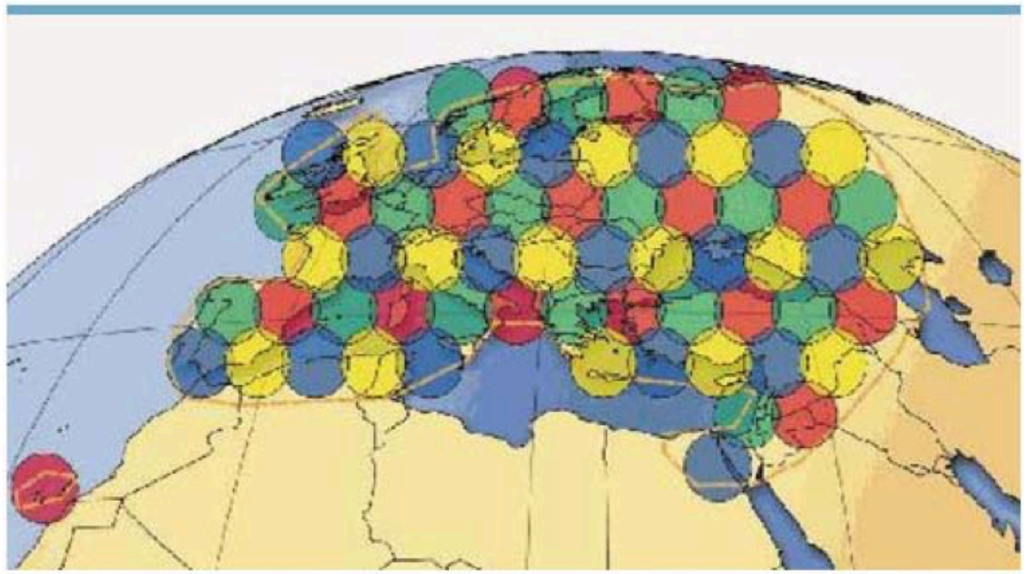
### Analog Payloads

- Photonic distribution of RF LOs (2018)
- Photonic Frequency Generation Unit (2020)
- Photonic Frequency Conversion Unit (2020)
- Photonics Routing Unit (2020)
- Photonic RF Filtering (2023)
- Photonic Beam Forming (2023)

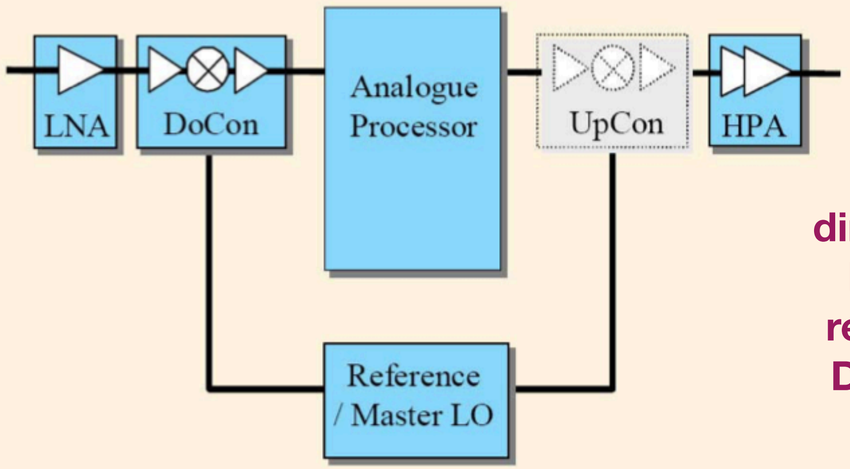
### Digital Payloads

- Optical Interconnects @25 Gbps (2018) & @56 Gbps (2020)
- ASICs with co-packaged/embedded optical I/Os (2023)
- Electro-photonic Direct Sampling ADC/DAC (2020)

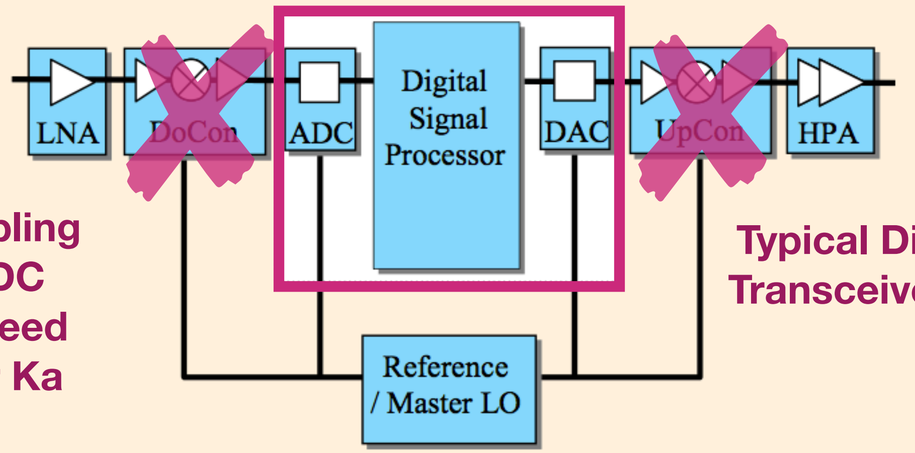
# Photonics Satellite Applications



*(Alcatel RT 2Q2006)*



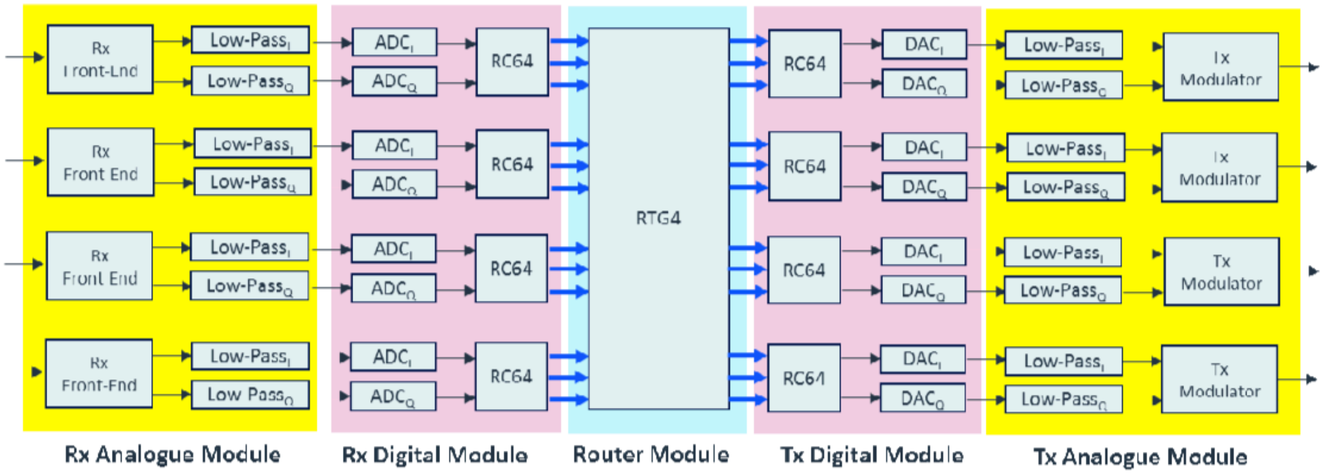

**direct sampling DAC & ADC removes need DoCon for Ka Band**



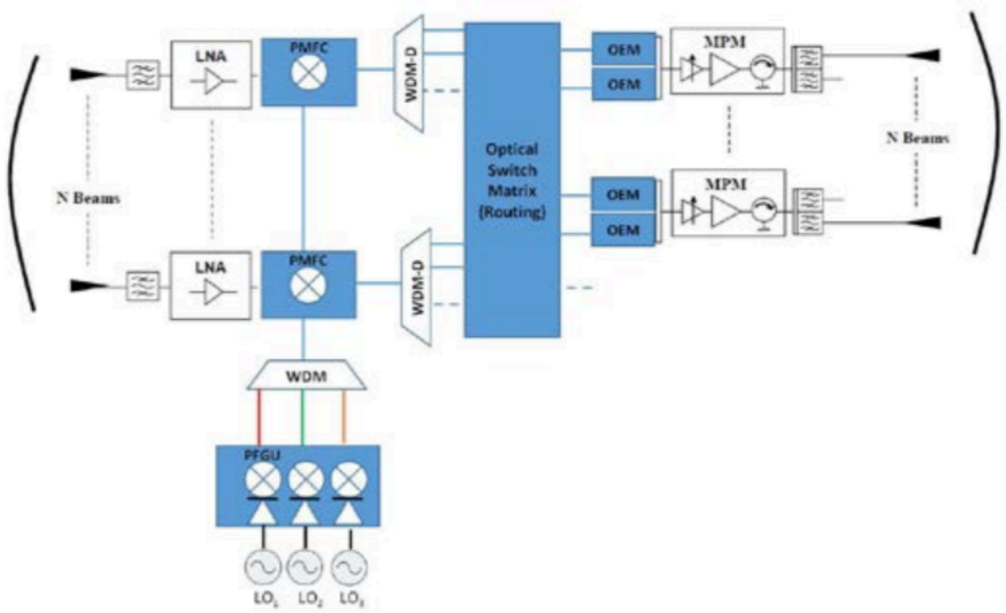

**Typical Digital Satellite Transceiver Application**

# Photonics Satellite Applications

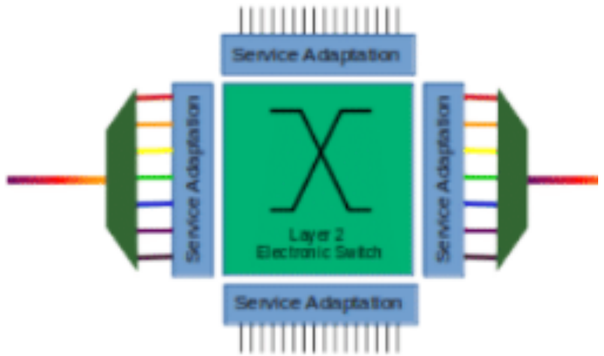
## TAS




## Airbus OPTIMA



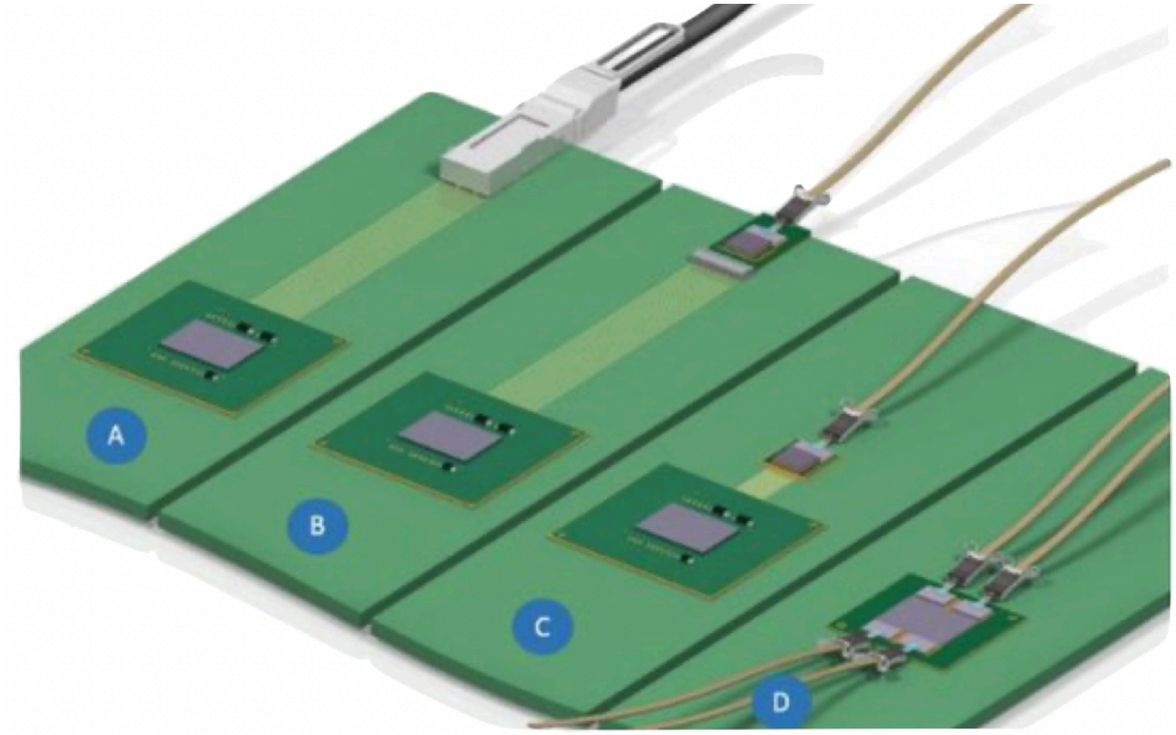

MODULAR PAYLOAD SOLUTIONS FOR SECURITY AND FLEXIBILITY NEEDS ON SMALL TO LARGE SIZE PLATFORMS

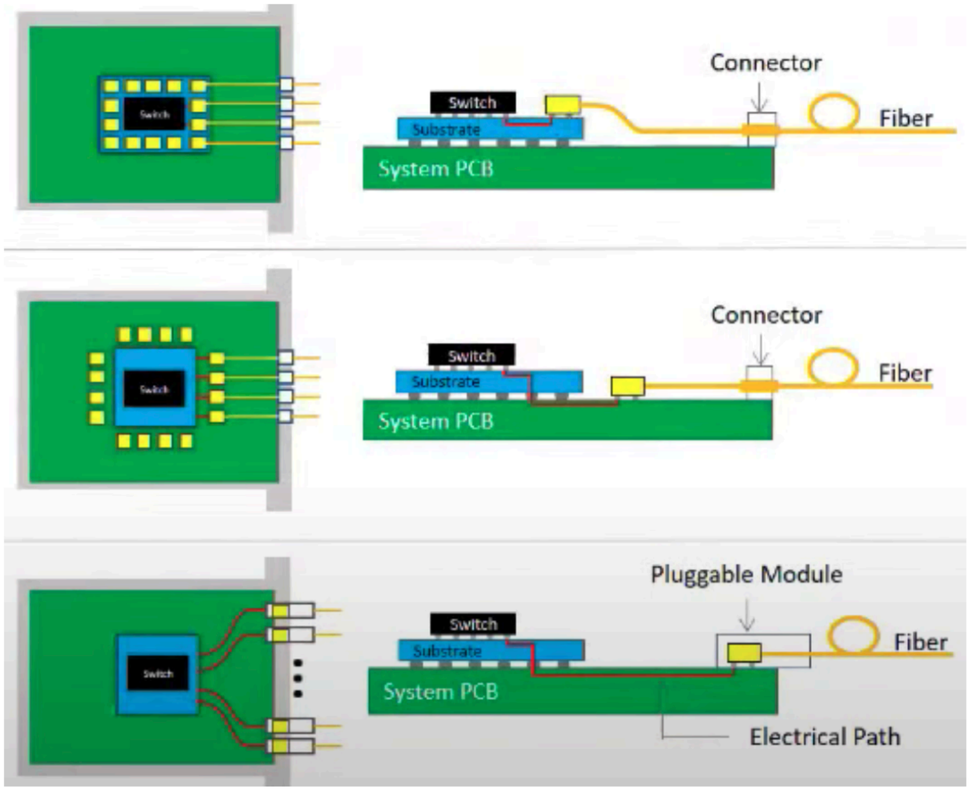



Digital Packet & optical switching

# HSSLs Review Summary

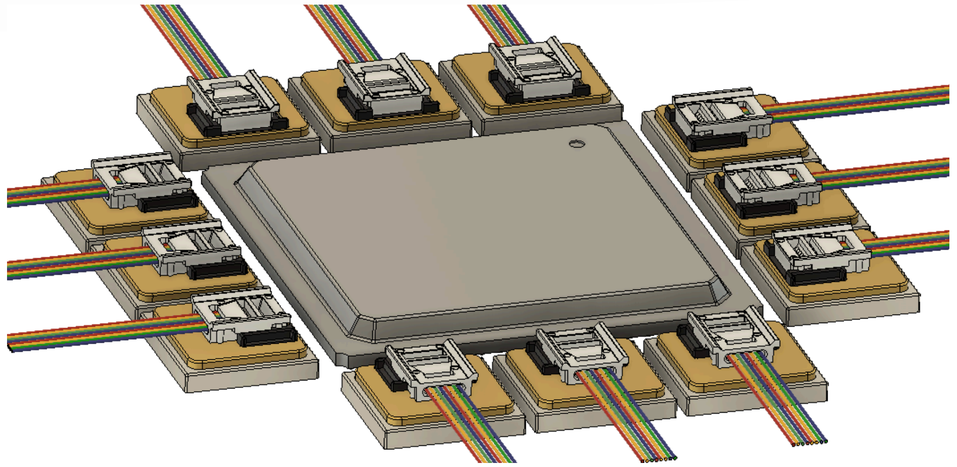
- However the use of DSP and moving to PAM4 modulation has continued to increase power consumption - recent trends in data centres developments are moving towards reduced SerDes link distances



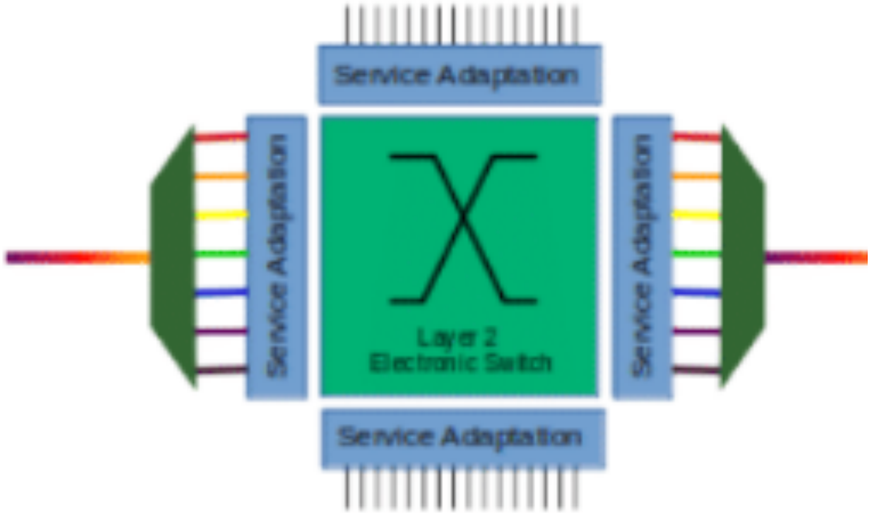




Pluggable optical transceivers → Co-packaged optical Transceivers

# Packet Optical Switching Co-packaging HSSI



Showing proposed Co-packaging example
> 5Tb





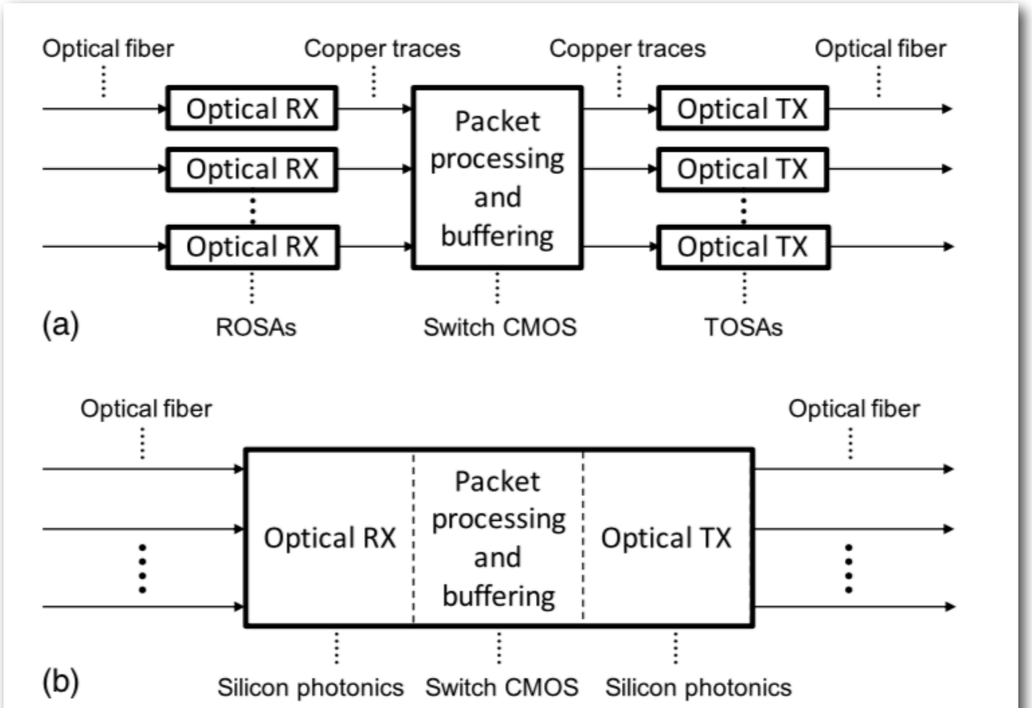
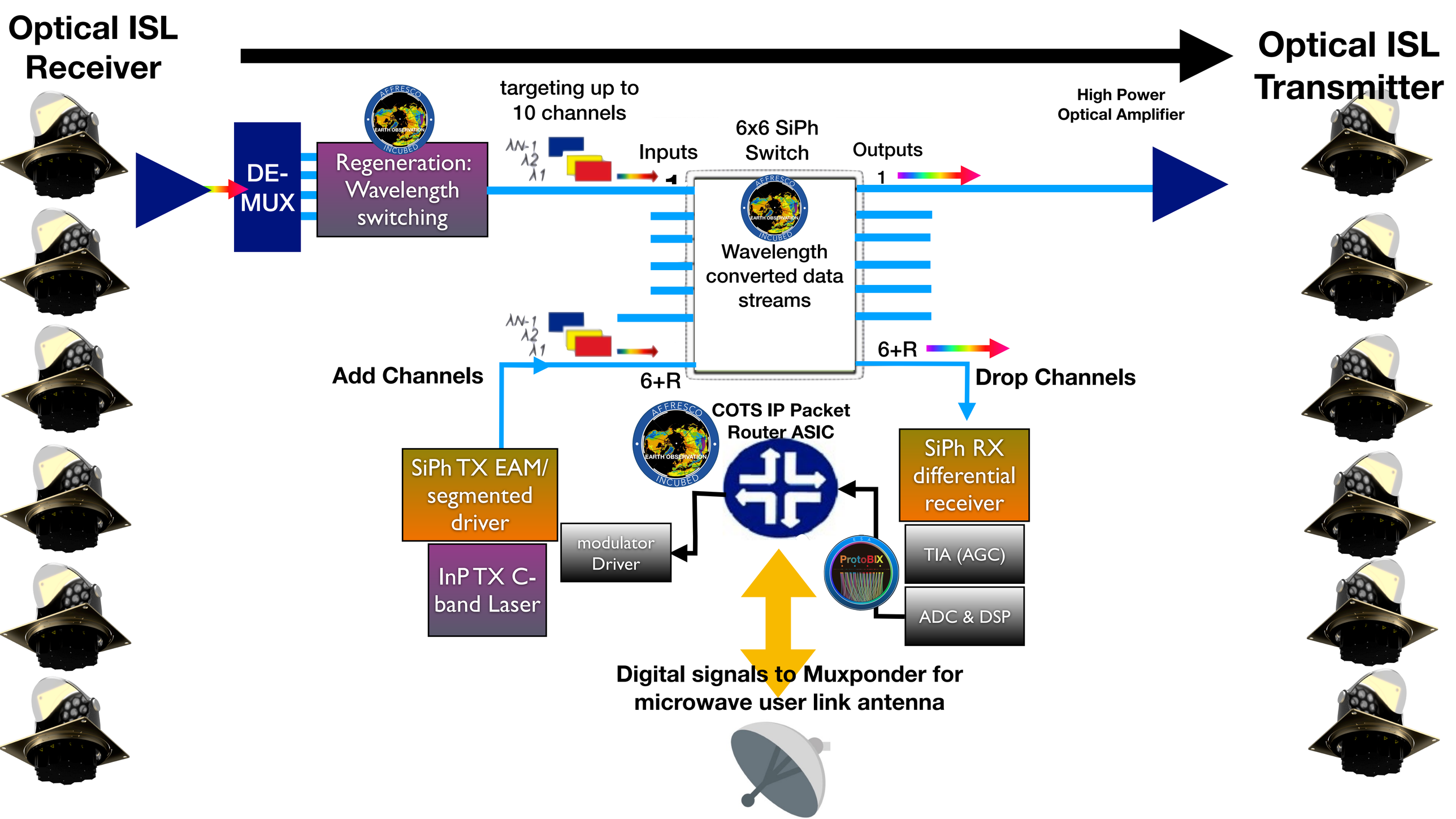
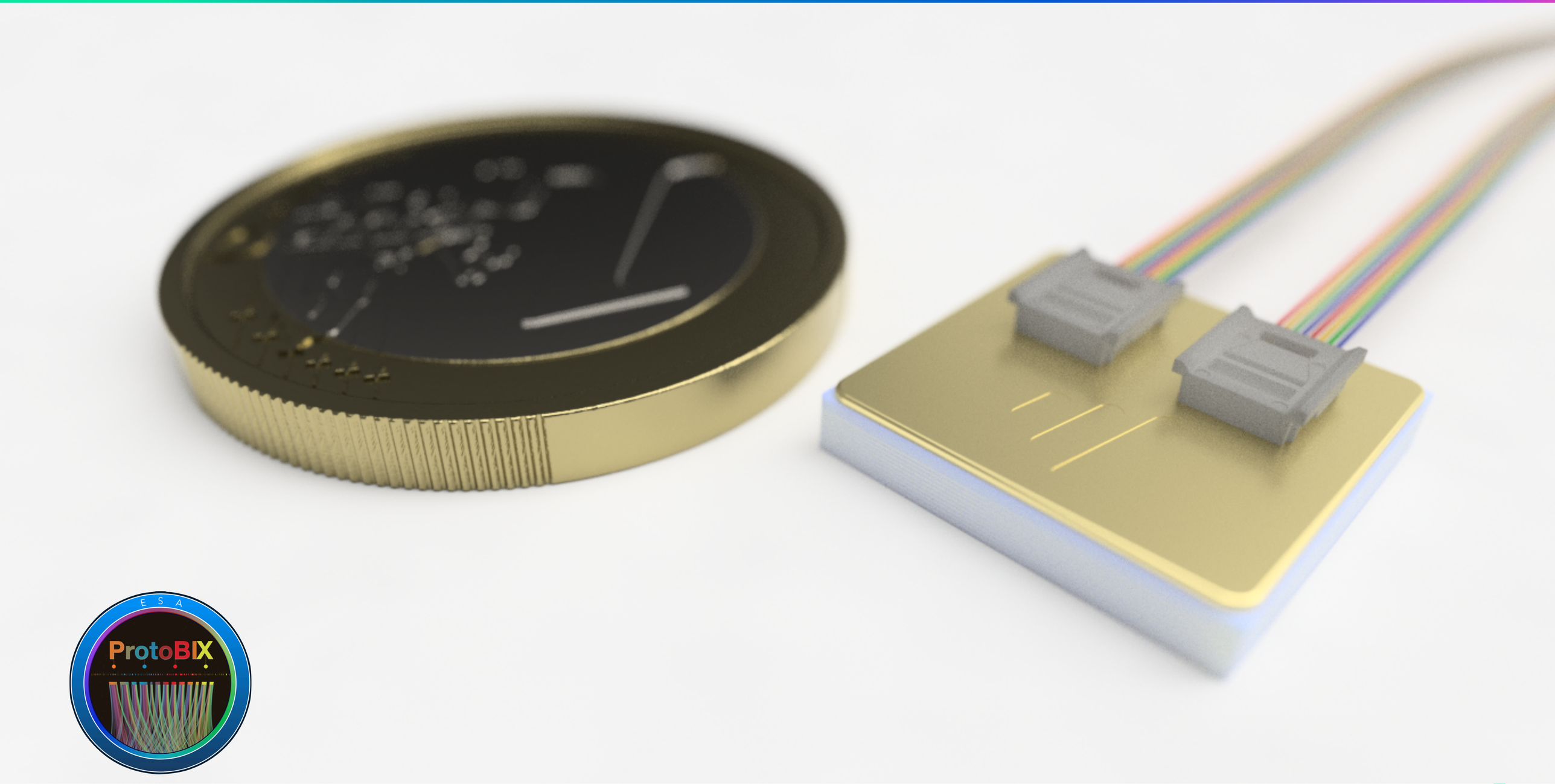



Fig. 1. (a) Traditional switch ASIC with separate optical transceivers. TOSAs and ROSAs (transmitter/receiver optical sub assemblies) are separated for clarity. (b) Switch optoASIC. Integration of CMOS and silicon photonics reduces cost and power consumption and increases I/O density. Thick black lines represent expensive packaging boundaries.


Optical ISL Receiver
Optical ISL Transmitter
DE-MUX
Regeneration: Wavelength switching
targeting up to 10 channels
λN-1 λ2 λ1
Inputs
6x6 SiPh Switch
Outputs
1
High Power Optical Amplifier
Wavelength converted data streams
λN-1 λ2 λ1
Add Channels
6+R
6+R
Drop Channels
COTS IP Packet Router ASIC
SiPh TX EAM/ segmented driver
InP TX C-band Laser
modulator Driver
SiPh RX differential receiver
TIA (AGC)
ADC & DSP
ProtoBIX
Digital signals to Muxponder for microwave user link antenna

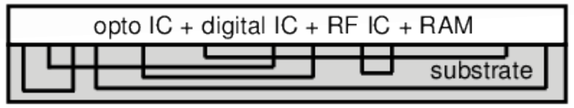


# Packaging

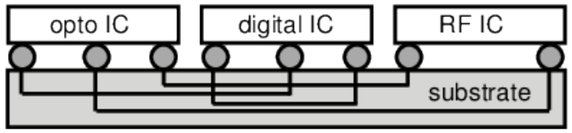
MBRYONICS

# Electronic & Photonics Packaging Technologies

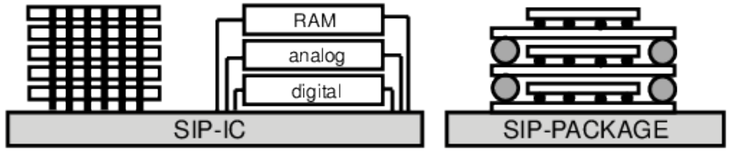
**SOC**
complete system
on one chip



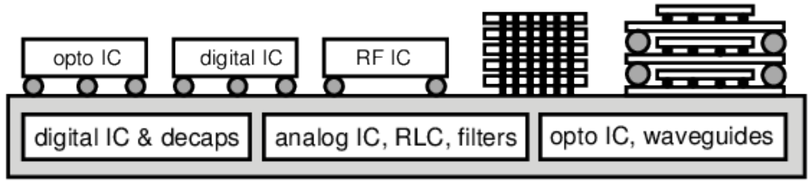

**MCM**
interconnects
components



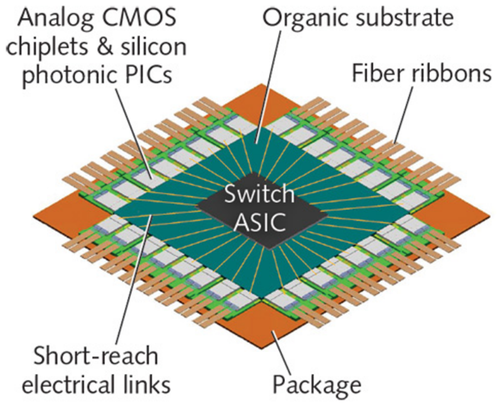

**SIP**
stacked chips
or packages

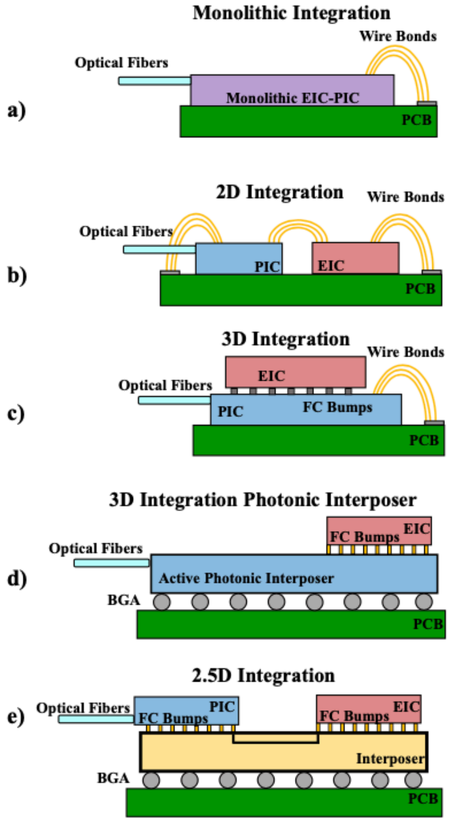


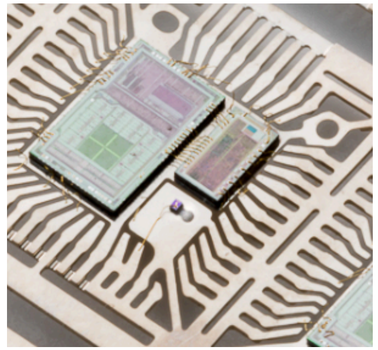

**SOP**
optimizes btw
chip/package

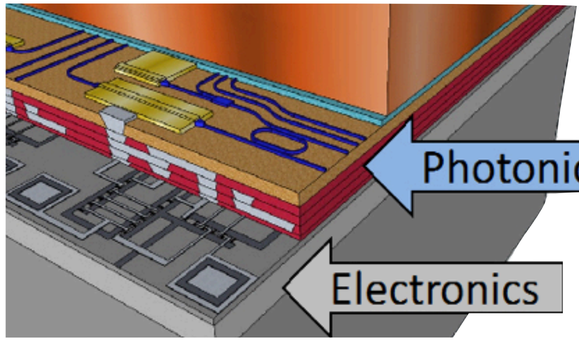



## Co-packaged photonics

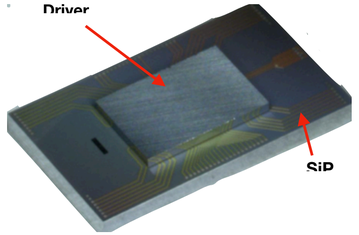


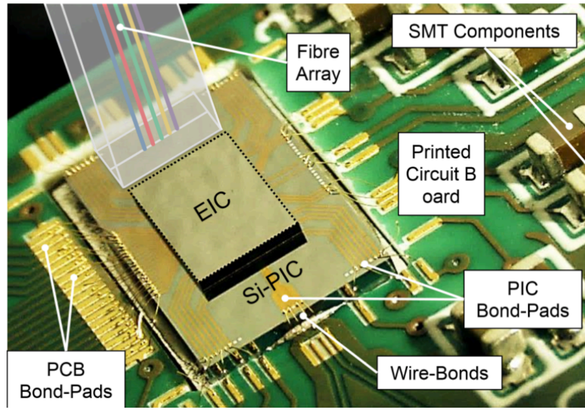





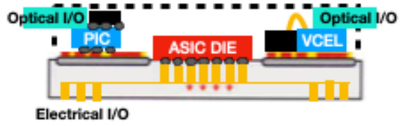




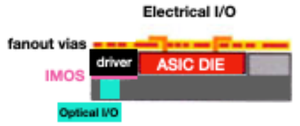





**Multi-Chip-Module (MCM) or System in Package (SiP)**



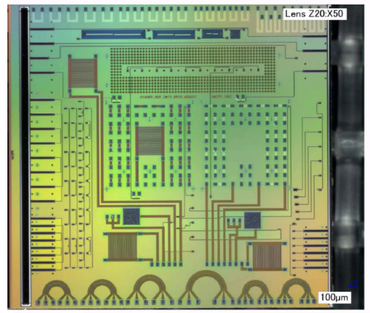

**2D System in Package (SiP) & hybrid Photonics**




**2.5D multiple die Wafer Level fan-out package & photonics with integrated electronics (IMOS)**

# Photonics & Optics Systems Design, Engineering, Integration

## Optics & Photonics Workflow:




### PIC Design

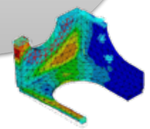
lumerical LUCEDA PHOTONICS Nazca design™

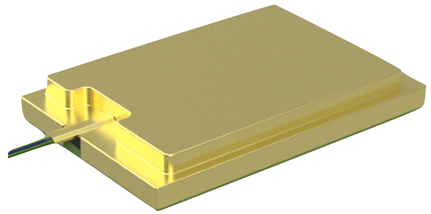
### Process Design

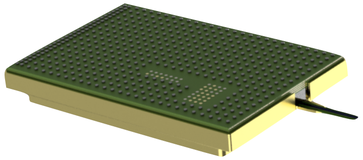
Lower TRL Packaging Process R&D

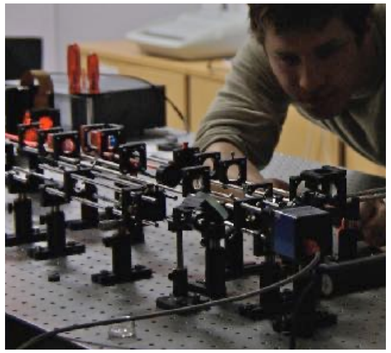
### Package Design

Zemax NASTRAN SIMULIA ABAQUS









SMART PHOTONICS Independent InP Foundry

LIGENTEC

HHI

imec

VTT

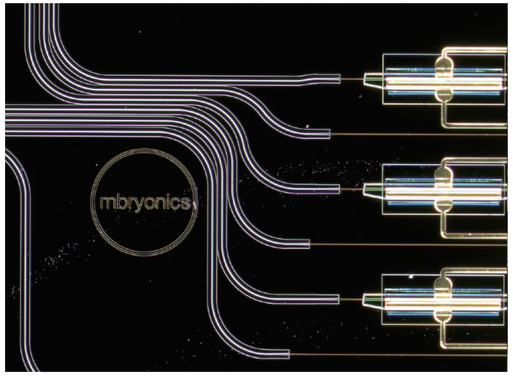
**PIC fabrication in Foundry**

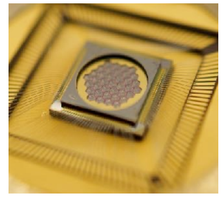
Silicon
Indium Phosphide
Silicon Nitride
Gallium Arsenide

**Industrialisation of R&D**

**Package process automation for AIT**

**Manufacturing Ramp Packaging Integration and Test**



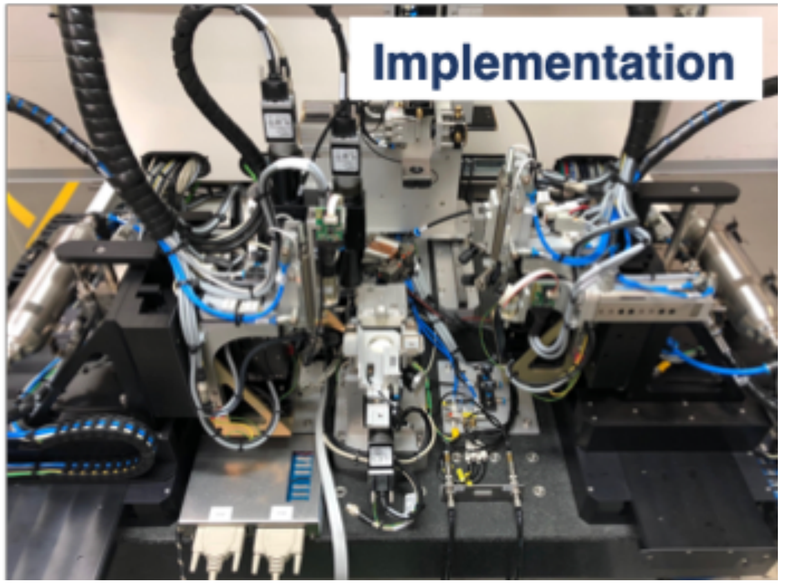



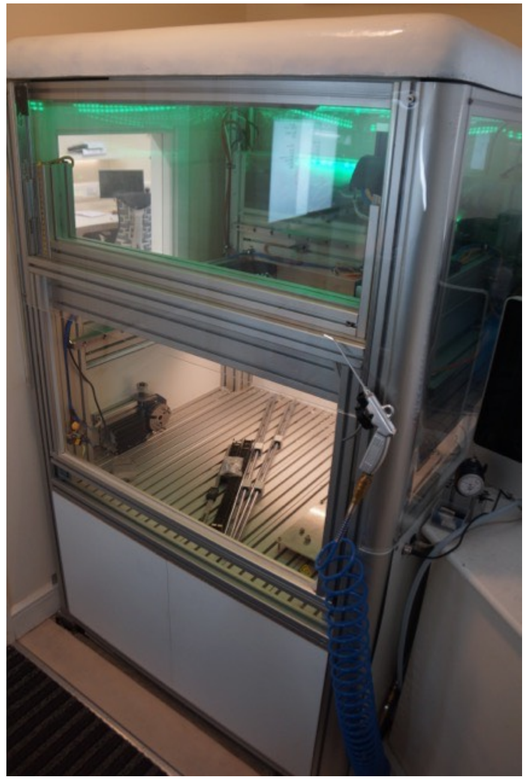
# DTIF - Advanced Manufacture For Photonics Automated AIT

mbryonics

PIXAPP
Photonic Packaging
Pilot Line

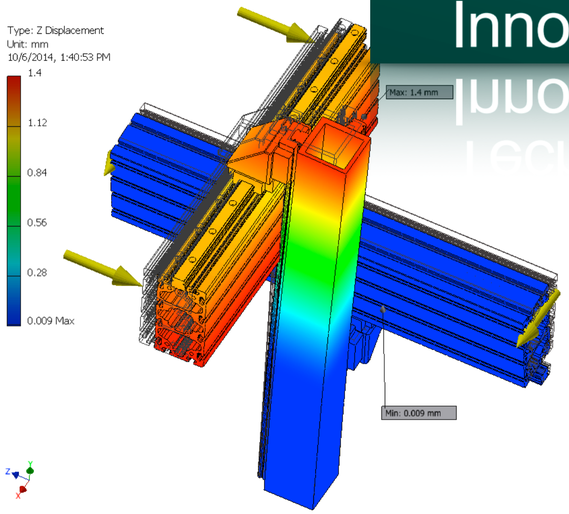




Rialtas na hÉireann
Government of Ireland

Disruptive
Technologies
Innovation Fund

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