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SHAPING THE LIGHT

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SHAPING THE LIGHT

Enabling competitive high throughput LaserCom

Improves both ends of LaserCom links with MPLC technology

Jean-François Morizur

CEO Cailabs

Cailabs, a deep-tech company
Develop, manufacture & sell innovative optical components

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Unique technology (MPLC)
and **expertise** in beam shaping

19
patent families

43 employees
(**18** PhDs)

8.6 M€ ++
raised

References:

SAFRAN   tellabs   KDDI   NOKIA   Amplitude

Placing Cailabs
Tailored beam shaping is photonics’ next disruption enabler

Beyond the usual properties …

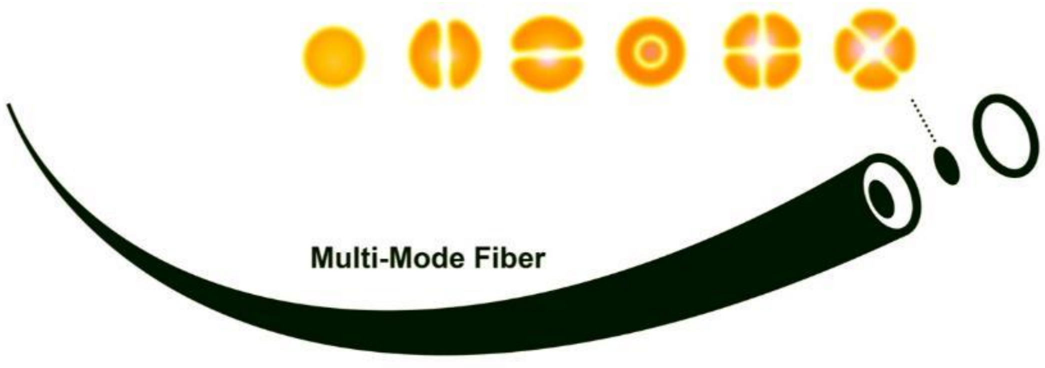

Power


Wavelength


Polarization


Phase

… we control the shape of the light



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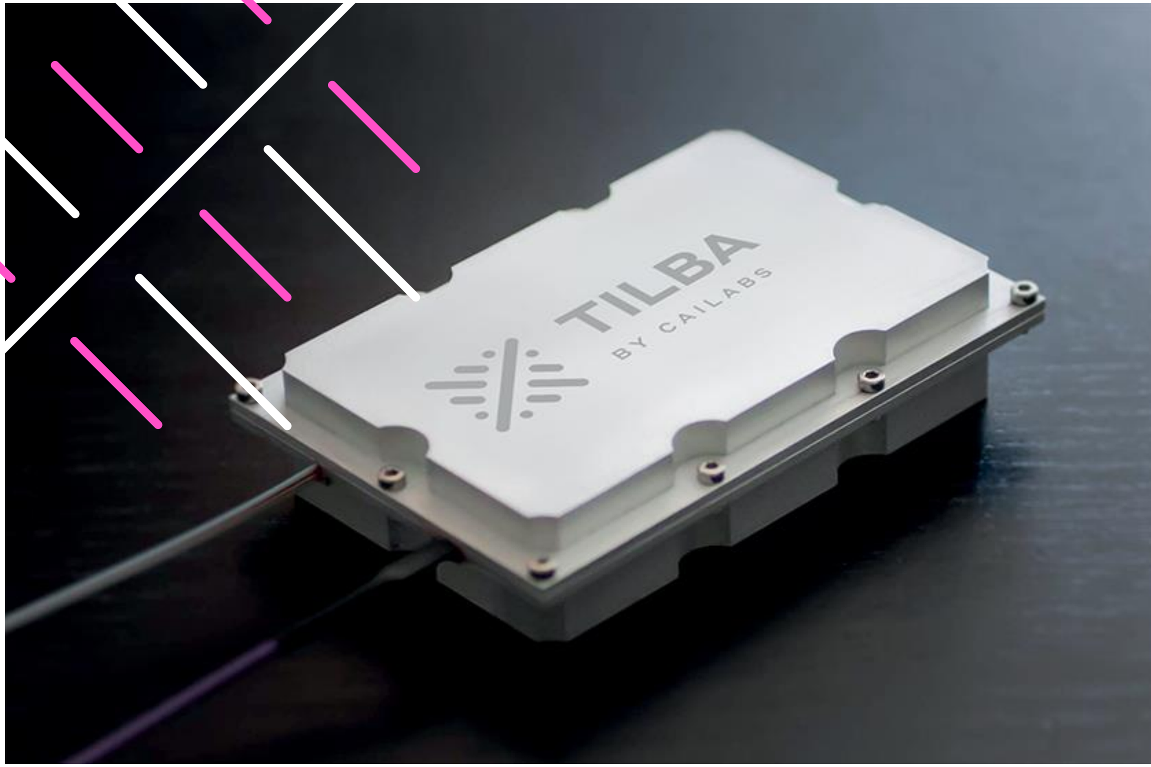
Lasercom : why & when?



Why LaserCom?
New needs for data high-speed transmission

A growing number of aircrafts and spacecrafts…

- **23.600 airplanes**[1]
- **2.062 satellites**[2]
- + UAV

…with new booming data consuming needs…

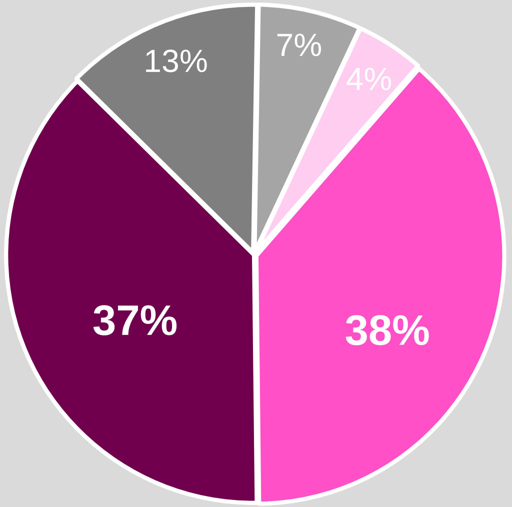
- **Earth observation**
- **Telecommunication coverage** of remote areas
- **In-Flight Entertainment**

…but hindered by the current data transferring technology

- RF is too slow and too energy-intensive (<4Gbps)
- **Data transmission is becoming a bottleneck**

Spacecraft illustration

75% of active satellites need to transfer important and growing amounts of data



Active satellite applications

- Earth Observation
- Communications
- Technology Development
- Navigation/Global Positioning
- Space Science

1. Ascend 2. UCS

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Why LaserCom?

LaserCom: a better SWaP and throughput

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Optical communication over RF:

ADVANTAGES:

- **Very High Throughput**
- **Better SWaP (Size, Weight and Power)**
- **Unlicensed spectrum**
- **High security**

DRAWBACKS:

- Require **tight PAT** (Pointing, Acquisition and Tracking)
- Impaired by the **atmosphere**

Link	Optical		RF	
GEO-LEO				
Antenna Diameter	10.2 cm	(1.0)	2.2 m	(21.6)
Mass	65.3 kg	(1.0)	152.8 kg	(2.3)
Power	93.8 W	(1.0)	213.9 W	(2.3)
GEO-GEO				
Antenna Diameter	13.5 cm	(1.0)	2.1 m	(15.6)
Mass	86.4 kg	(1.0)	145.8 kg	(1.7)
Power	124.2 W	(1.0)	204.2 W	(1.6)
LEO-LEO				
Antenna Diameter	3.6 cm	(1.0)	0.8 m	(22.2)
Mass	23.0 kg	(1.0)	55.6 kg	(2.4)
Power	33.1 W	(1.0)	77.8 W	(2.3)

Comparison of **SWaP** for GEO and LEO links using optical or RF communication systems – *underlined figures are ratios*

H. Kaushal & G. Kaddoum, IEEE Com Surveys & Tutorial (2017)

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When LaserCom?

Intersatellite and ground-to-satellite links should be mature around 2022

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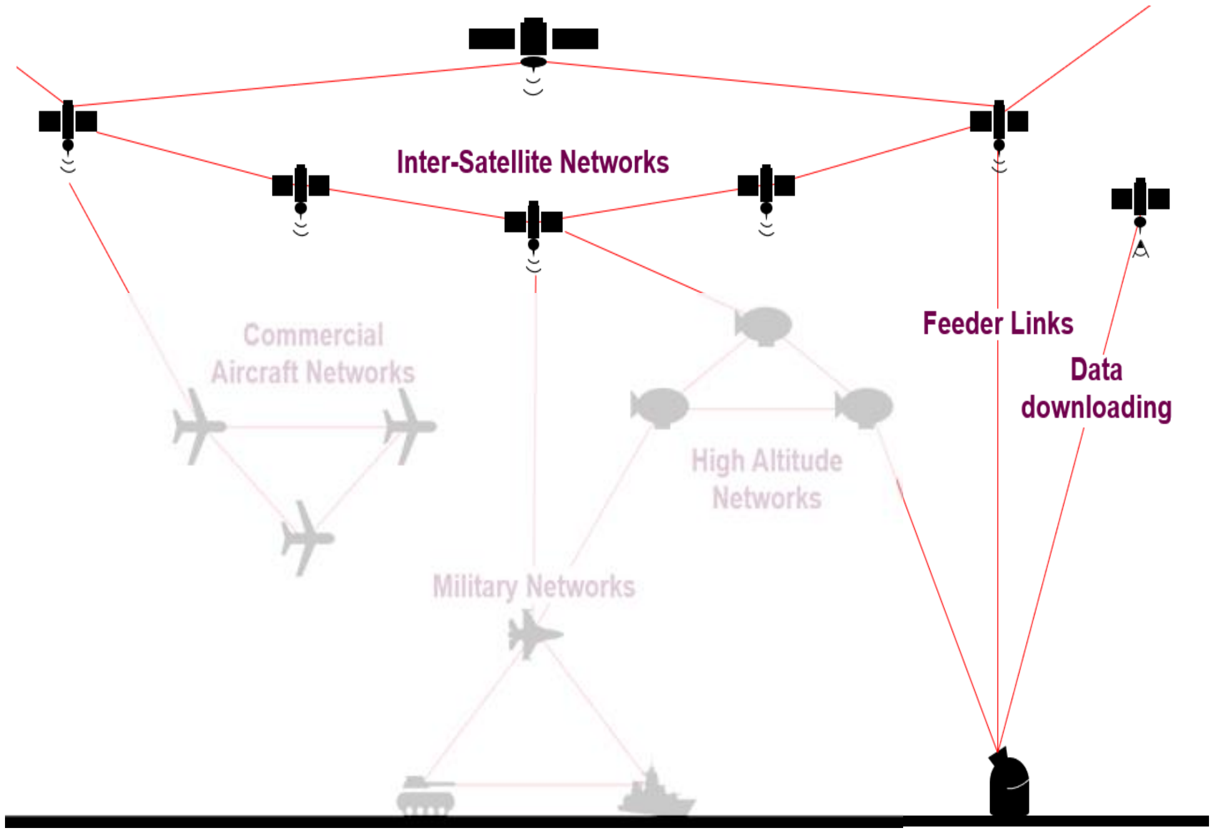
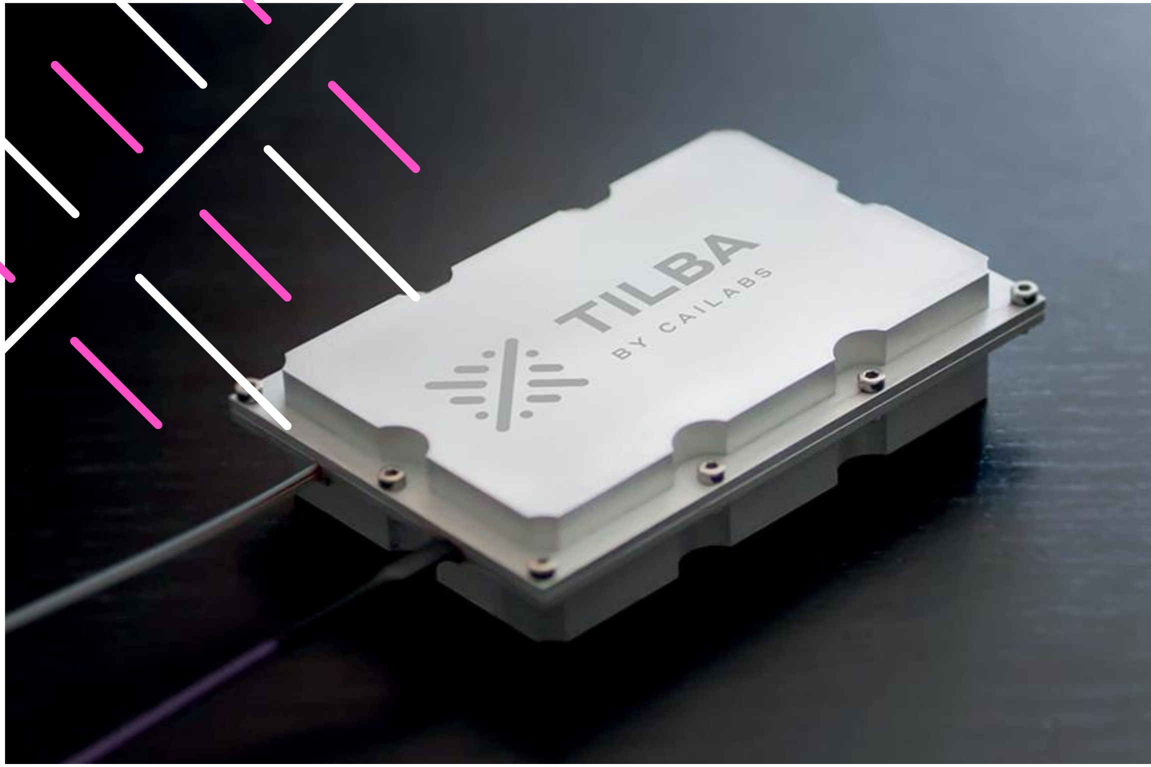


Satellites architectures will be the first one to emerge :

- 2020: Ground station with **adaptive optics**[1]
- 2022: **Mega-constellations** with ISL
- 2025: Terabit/s-throughput optical **feeder link**[1]

1. Hydron roadmap

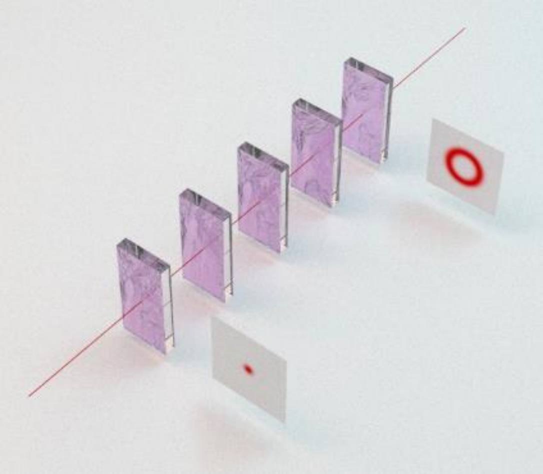
Multi-Plane Light Conversion

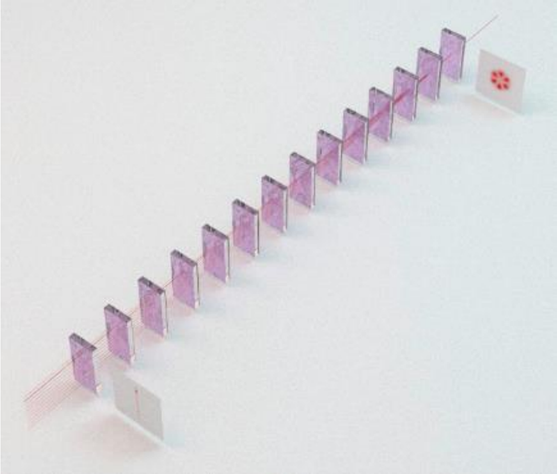


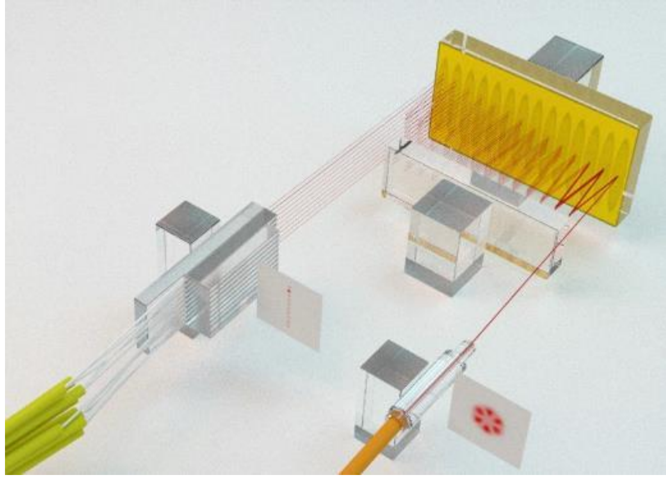
Multi-Plane Light Conversion
Take-home message about MPLC

Multi-Plane Light Conversion (MPLC)

- Derived from quantum optics at Laboratoire Kastler Brossel
- Complex beam shaping through succession of spatial phase profiles
- Passive optical beam shaping with no intrinsic loss nor moving elements







Multi-Plane Light Conversion
Compact implementation

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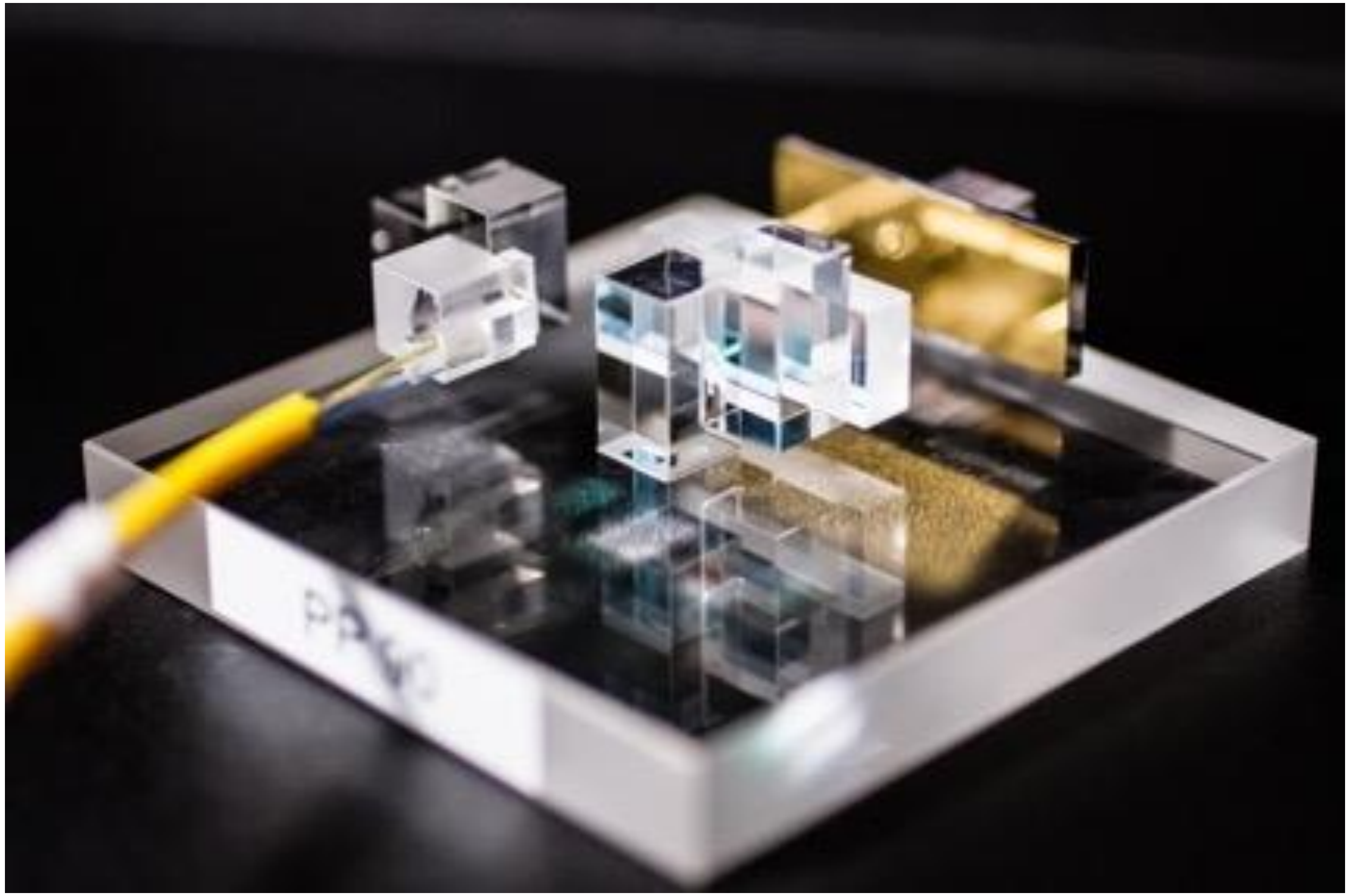

Multi-Plane Light Conversion
Spatial mutliplexer

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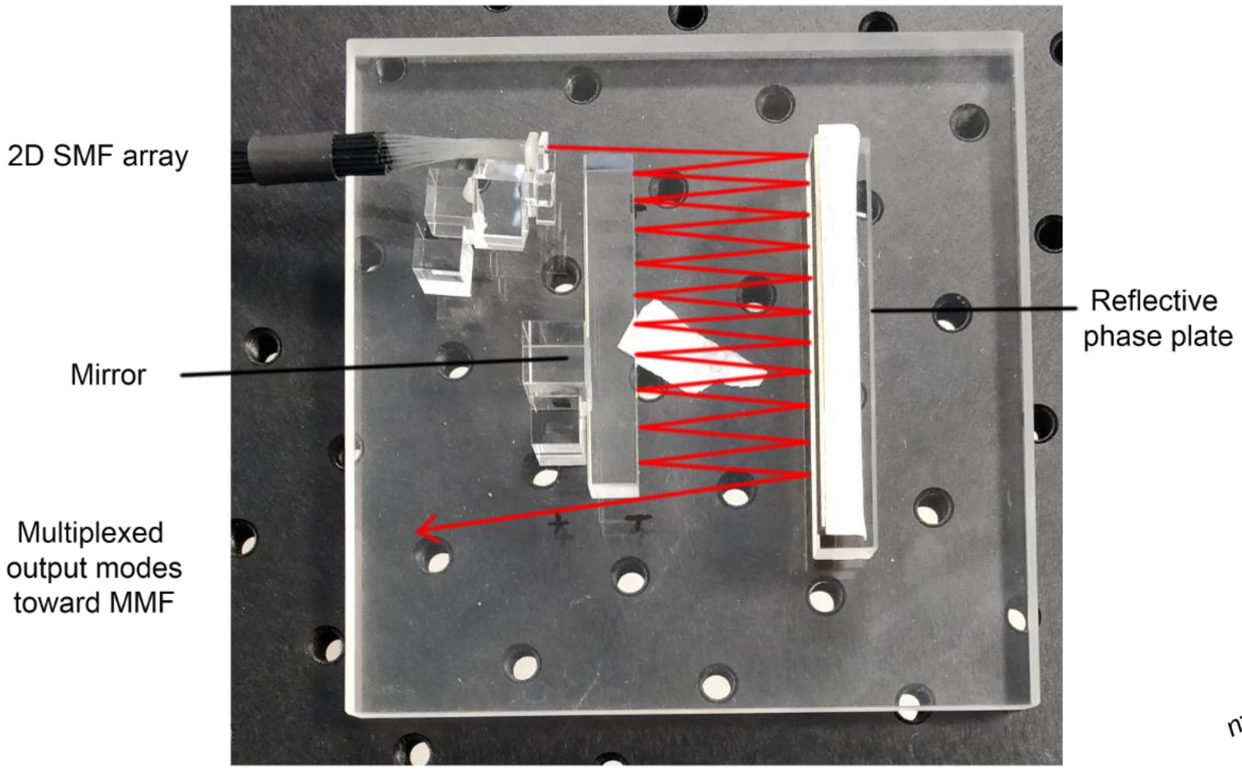

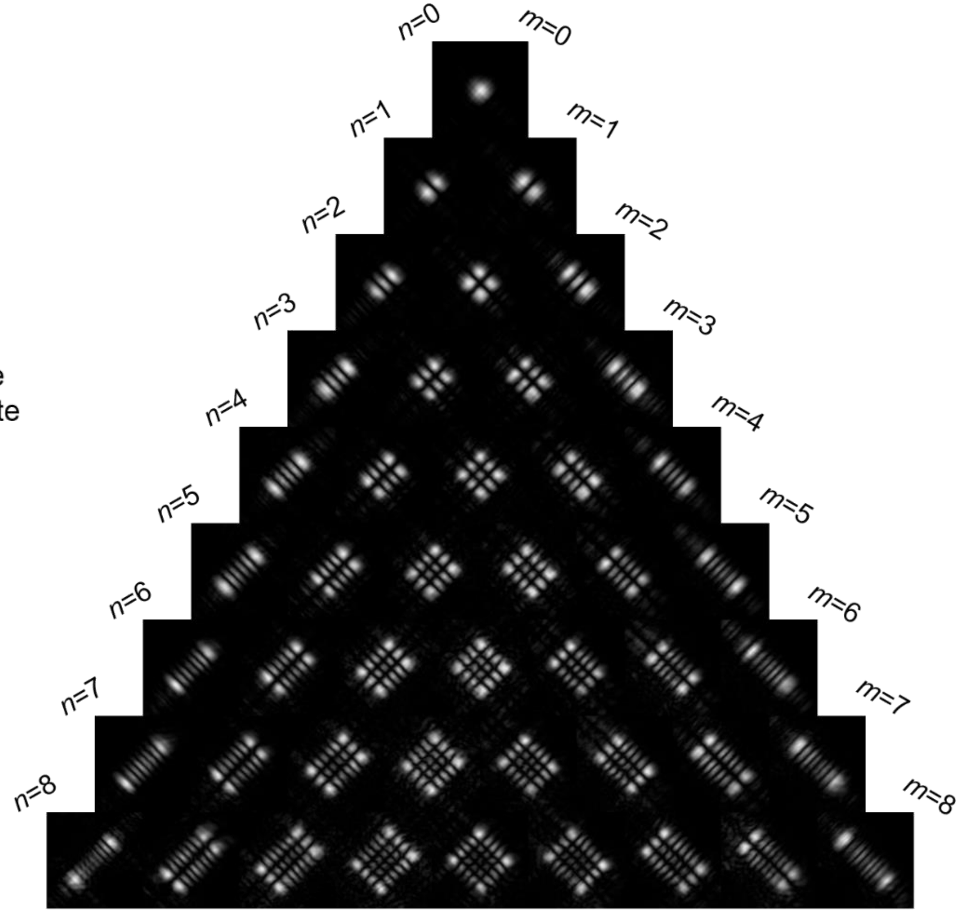

S. Bade & al., PDP OFC 2019

Addresses optical drawbacks

Improve Space-to-Space & Space-to-Ground optical links

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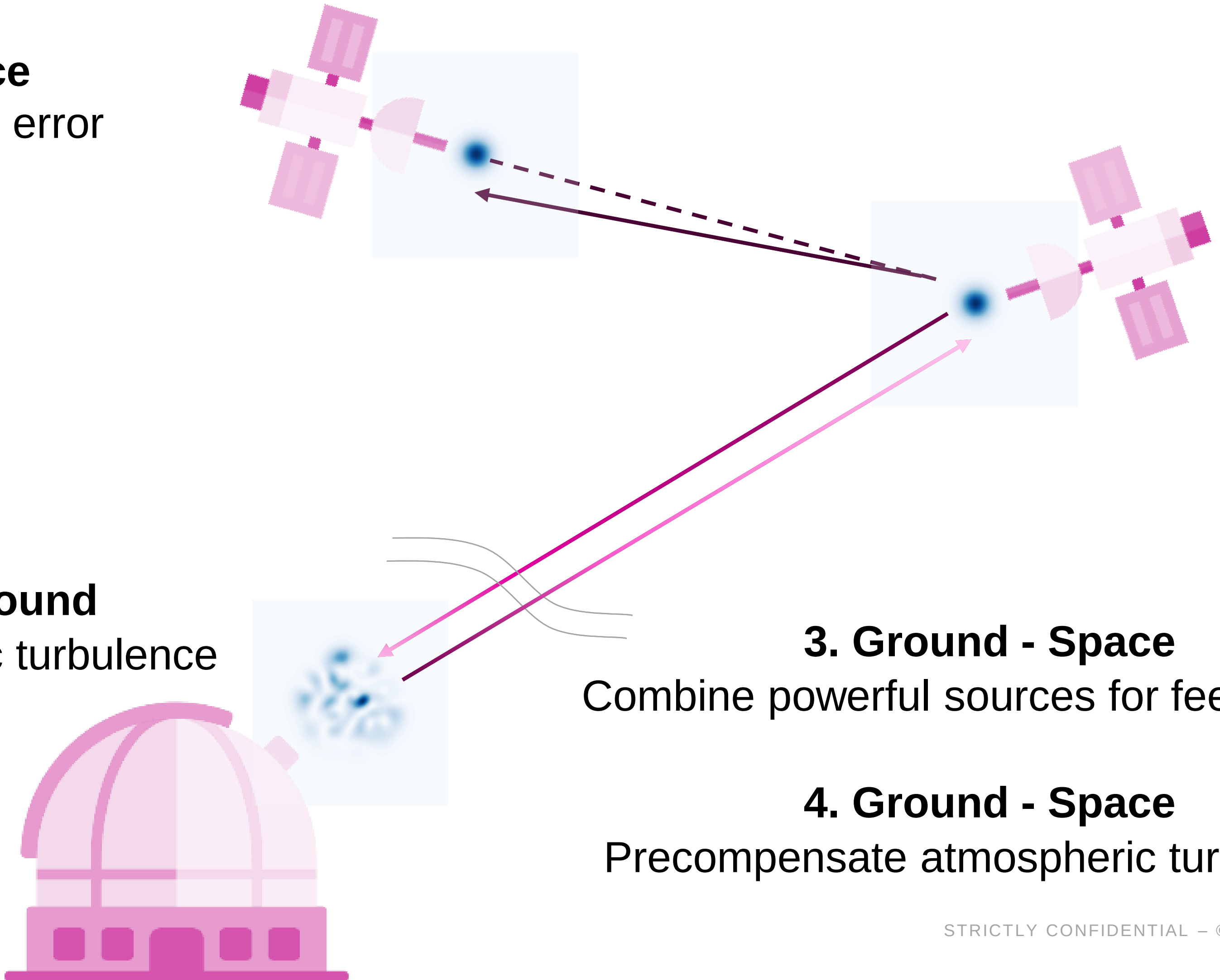
1. Space - Space
Compensate pointing error

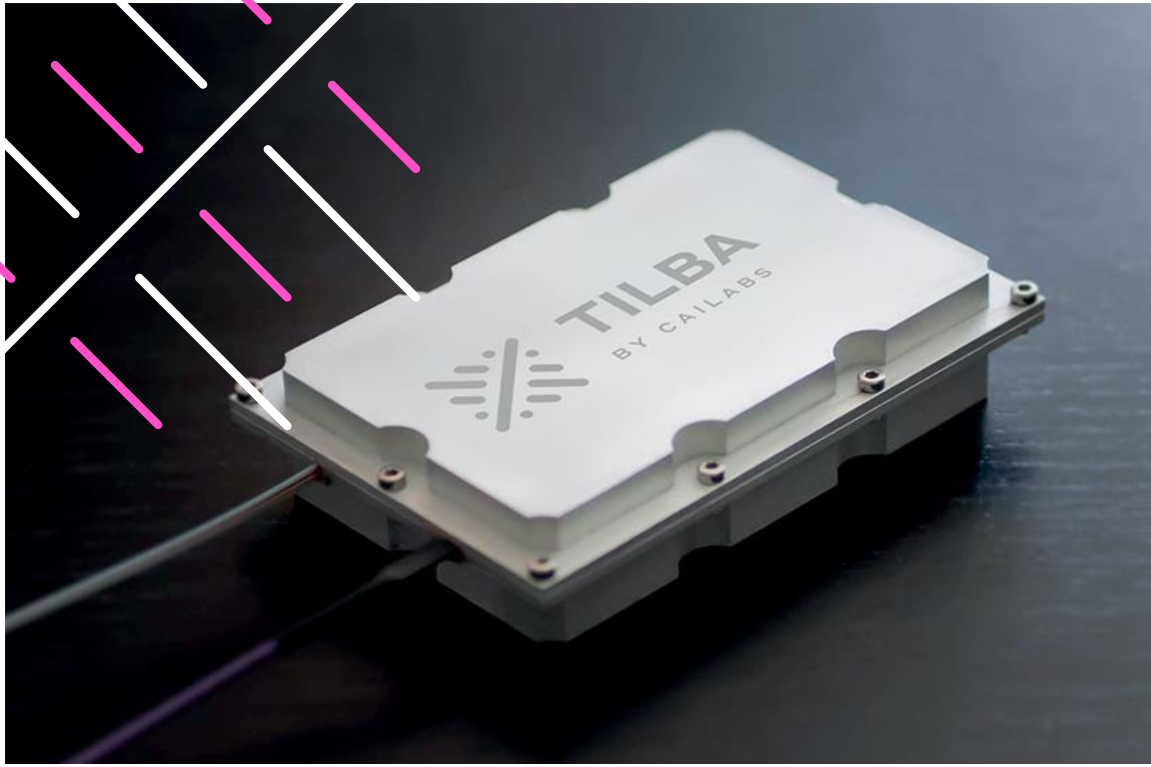


2. Space - Ground
Mitigate atmospheric turbulence

3. Ground - Space
Combine powerful sources for feeder links

4. Ground - Space
Precompensate atmospheric turbulence

Space-to-space: mitigate pointing errors



Remove pointing errors with no moving parts

Space-to-space: mitigate pointing errors
Pointing errors degrade inter-satellite communication

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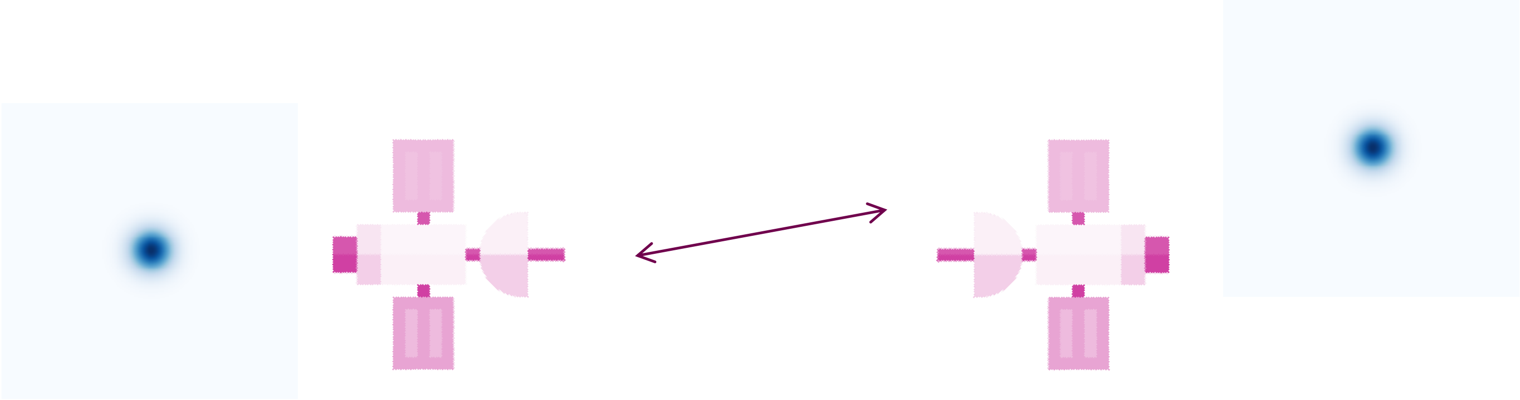
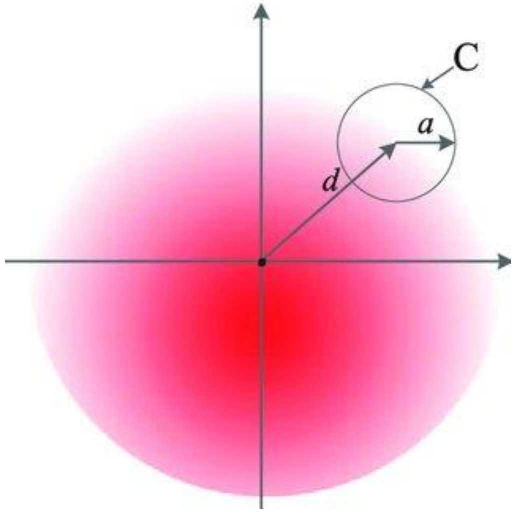
Pointing errors





Degrade dramatically the performance of the entire network

T. Song & al. JLT (2017) ; S. Arnon & N.S. Kopeika (1997)

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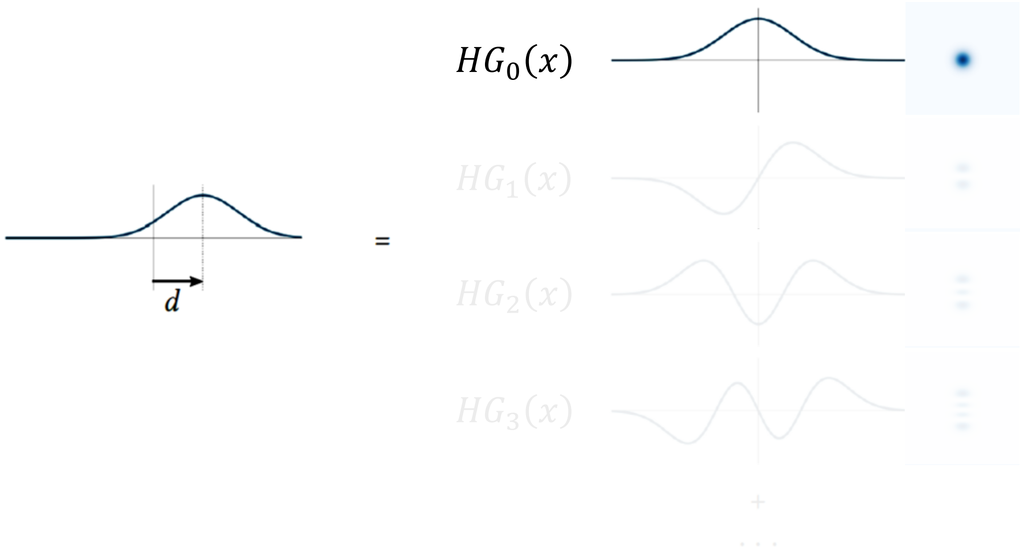
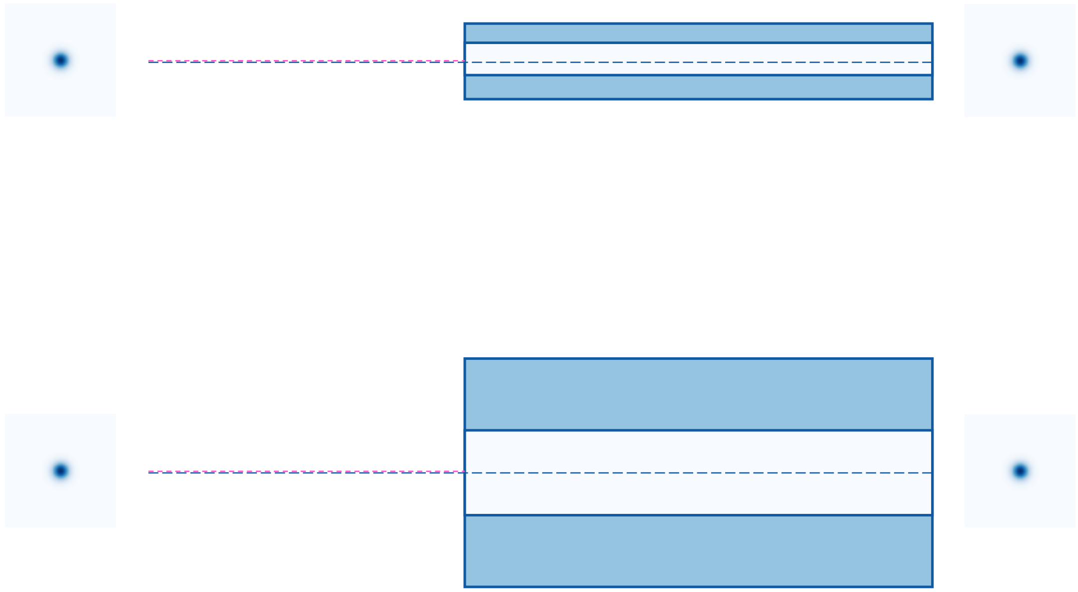
Space-to-space: mitigate pointing errors

Mode decomposition of a mislagnment

Tilt:

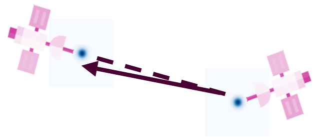
$$E_0\Big|_{x+\delta x} = \varepsilon_0\left[HG_0\Big|_x + \frac{i\delta x}{w_0}\times HG_1\Big|_x + o\left(\frac{\delta x}{w_0}\right)\right]$$





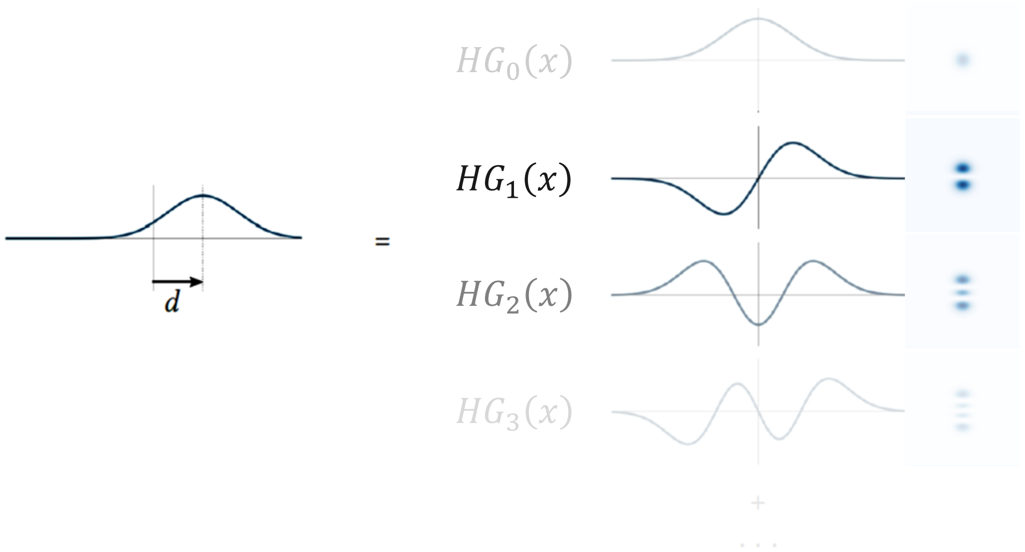
P. Boucher & al. Opt. Exp (2018)

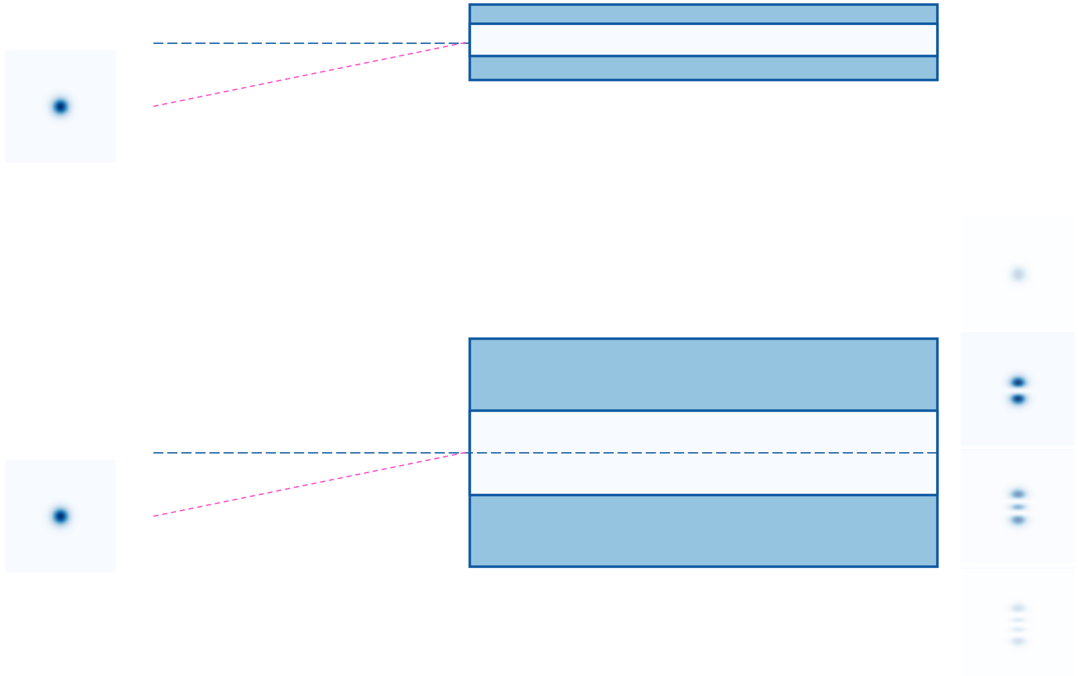
Space-to-space: mitigate pointing errors
Mode decomposition of a mislagnment



Tilt:

$$E_0\Big|_{x+\delta x} = \varepsilon_0\left[HG_0\Big|_x + \frac{i\delta x}{w_0}\times HG_1\Big|_x + o\left(\frac{\delta x}{w_0}\right)\right]$$

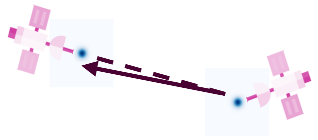




P. Boucher & al. Opt. Exp (2018)

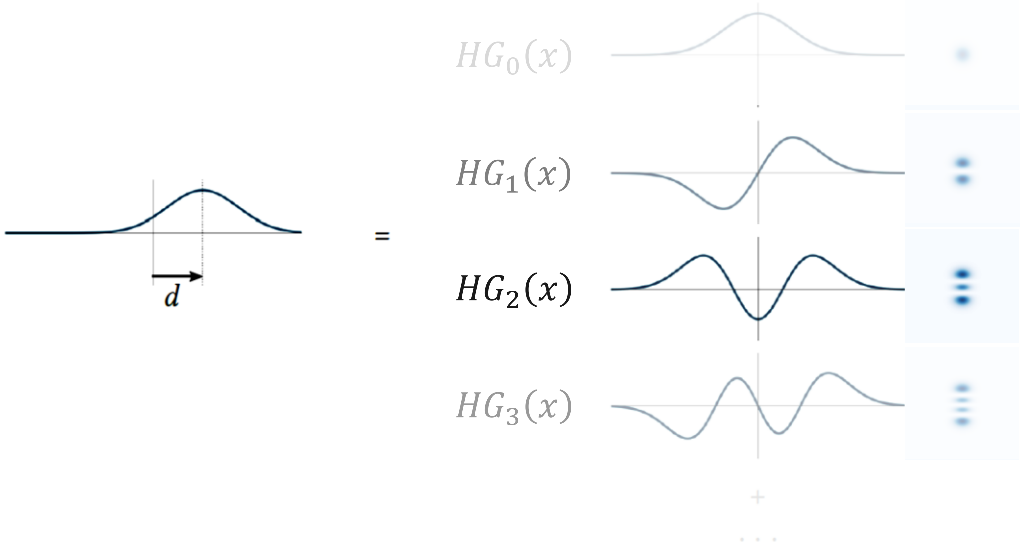
Space-to-space: mitigate pointing errors

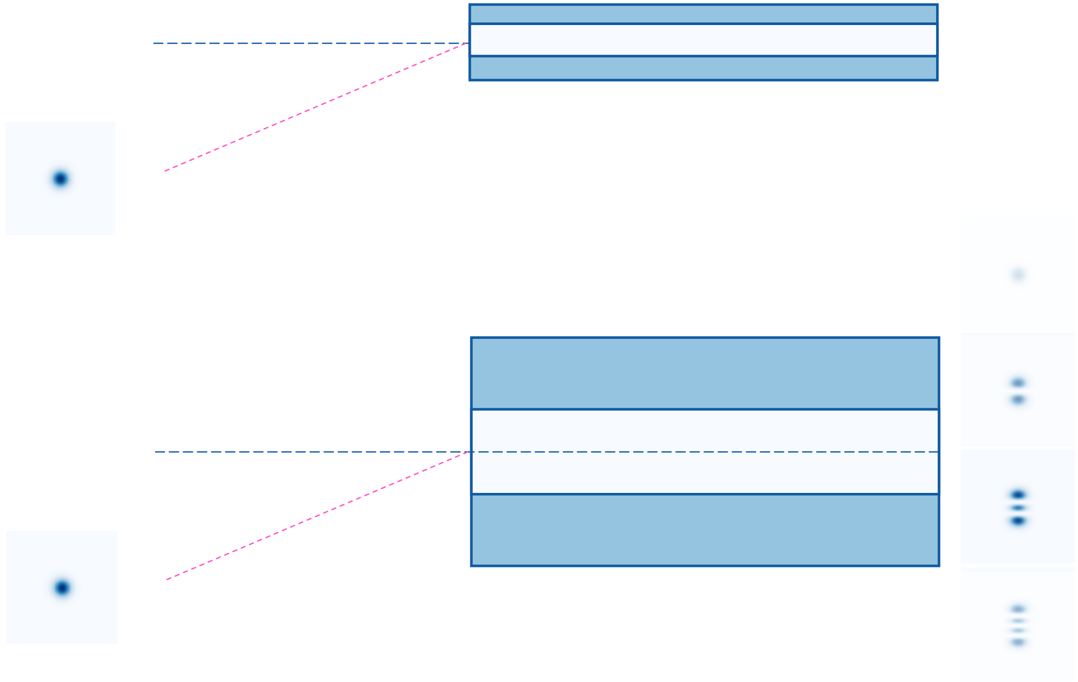
Mode decomposition of a mislagnment



Tilt:

$$E_0\Big|_{x+\delta x} = \varepsilon_0\left[HG_0\Big|_x + \frac{i\delta x}{w_0}\times HG_1\Big|_x + o\left(\frac{\delta x}{w_0}\right)\right]$$





P. Boucher & al. Opt. Exp (2018)

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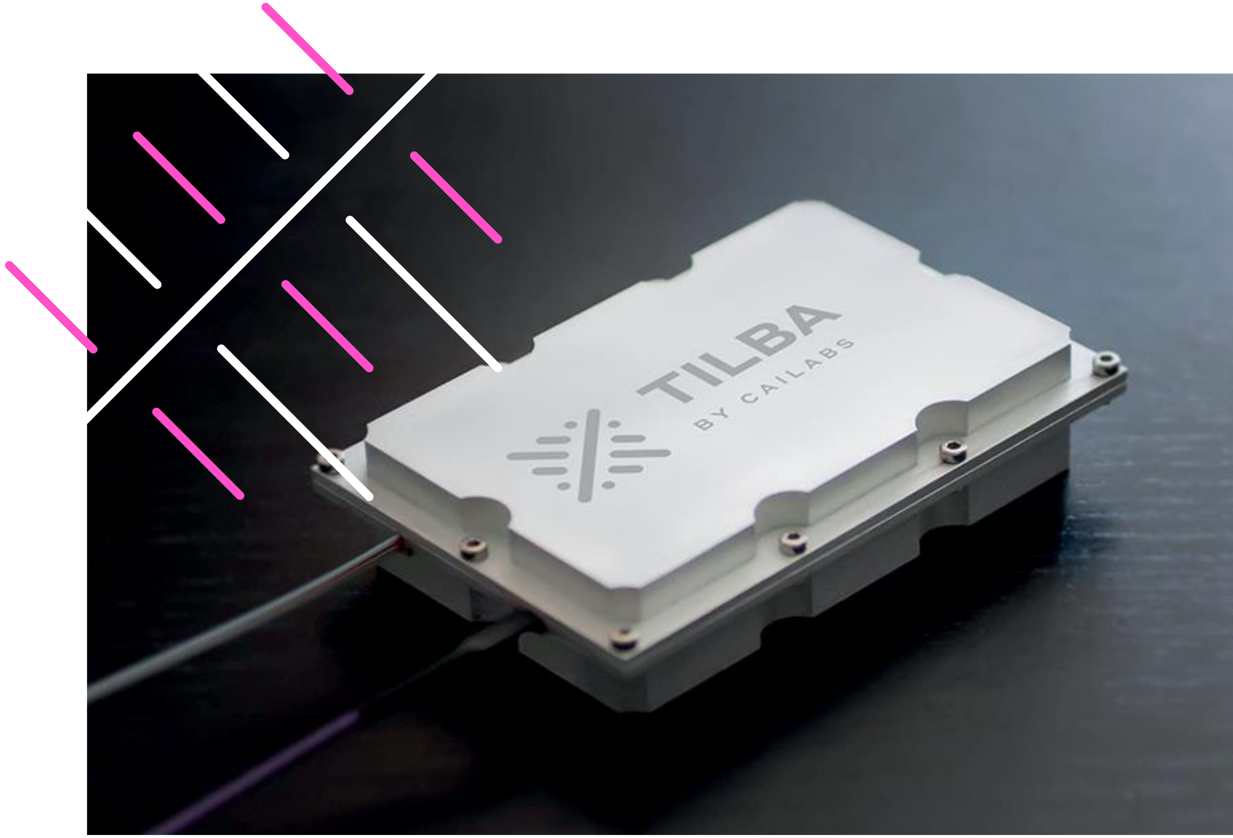
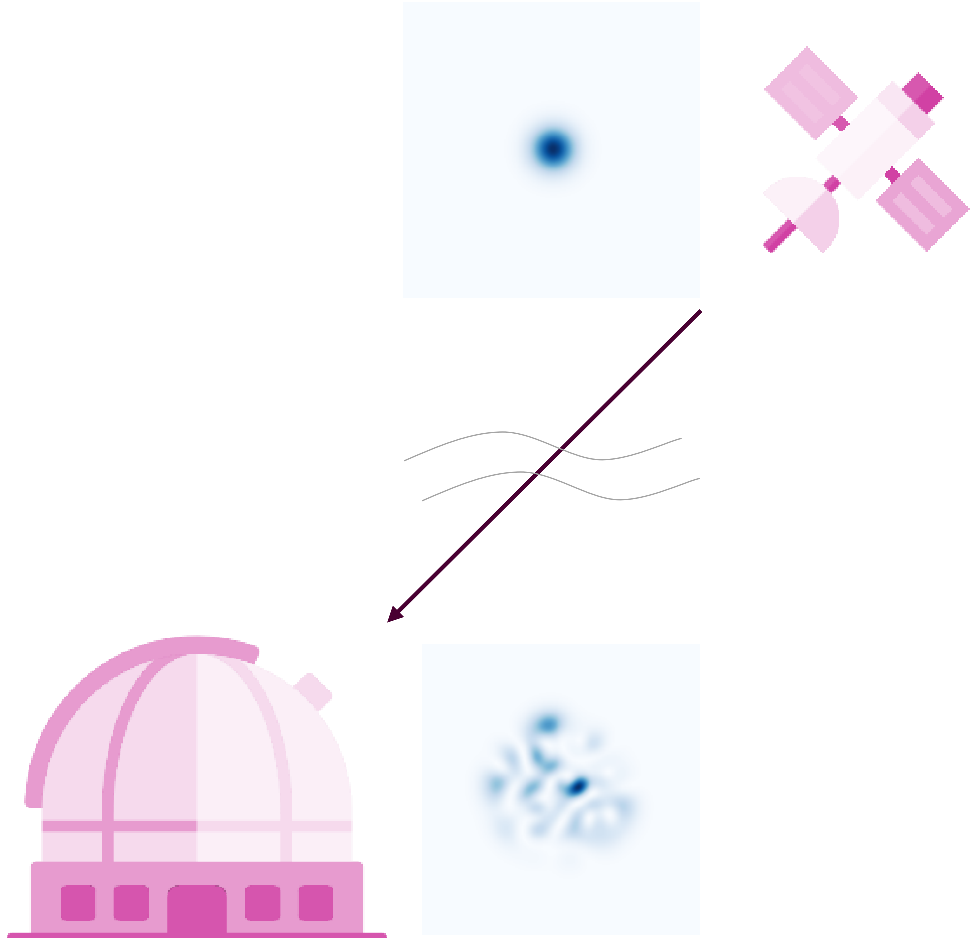
Space-to-ground: Mitigating turbulence at reception



Adaptive optics in a chip

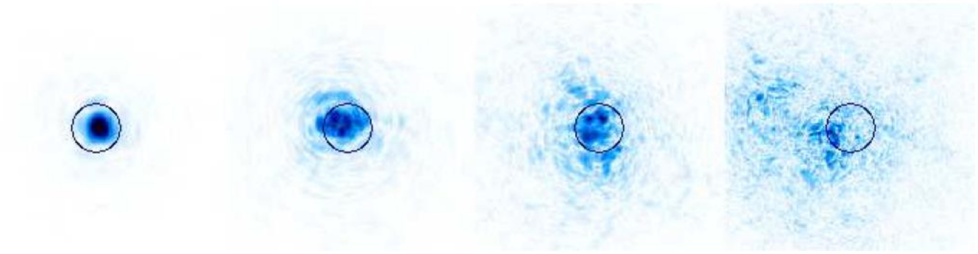
Space-to-ground: Mitigating turbulence at reception

Atmospheric turbulence deteriorates LaserCom links



Effects of turbulences :

- **Beam spreading – Defocusing**
- **Beam wander - Tilt**
- **Scintillation**



Impact on LaserCom:

- **Less persistent link** (milliseconds fades)
- **Lower throughput** (higher BER)

N. Schwatz PhD 2009

Space-to-ground: Mitigating turbulence at reception

Existing solutions are complex and expensive

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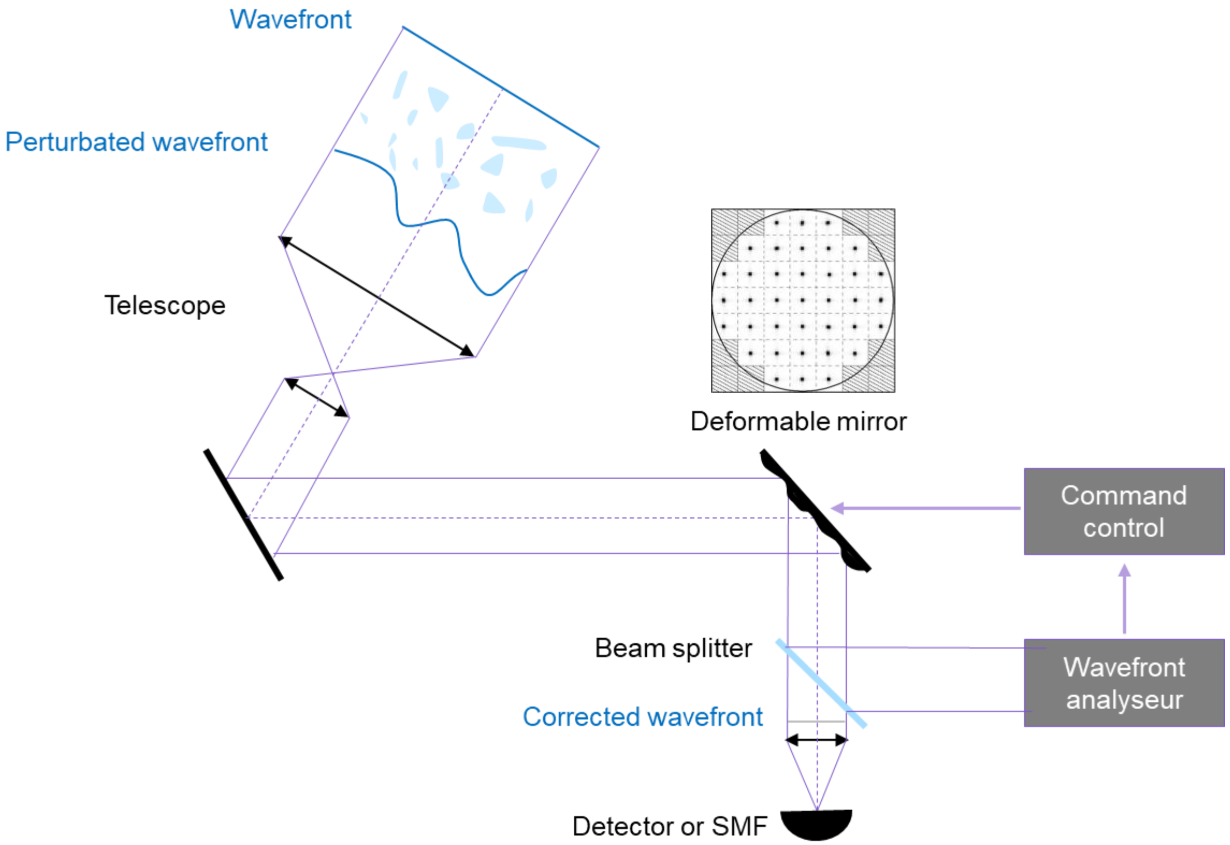
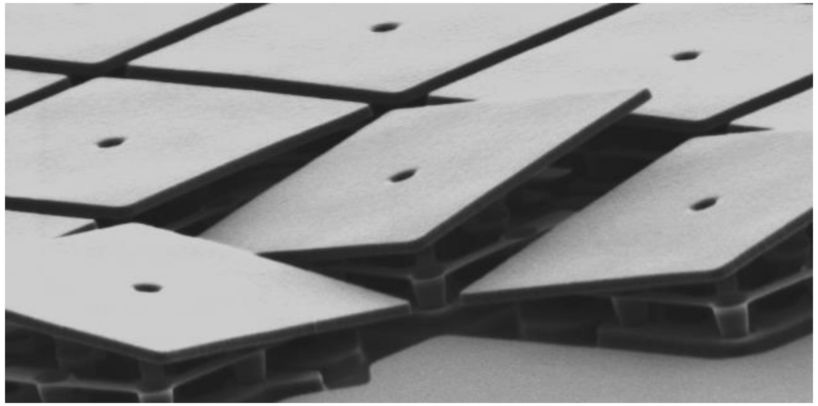
ADAPTATIVE OPTICS





But:

- Are expensive
- Need feedback loop
- Display moving elements

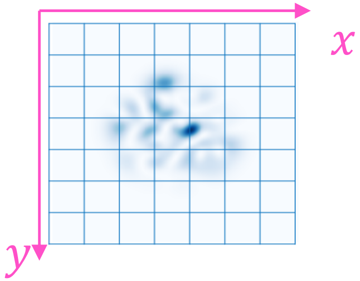
Images: [1] Mignardi 2016 e2e.ti.com [2] N. Schwatz PhD 2009

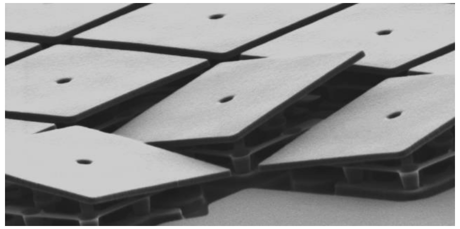
Space-to-ground: Mitigating turbulence at reception
A similar function with a different approach

ADAPTATIVE OPTICS

Cartesian basis

$$\sum A(x,y)\mathrm{e}^{\mathrm{i}\psi(x,y)}$$



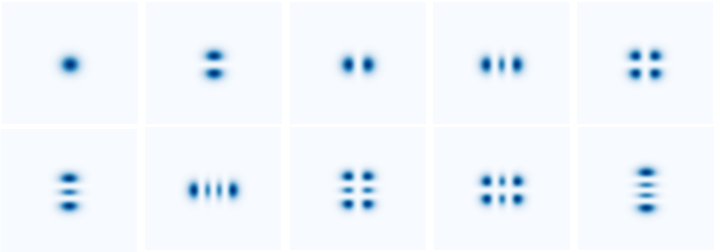


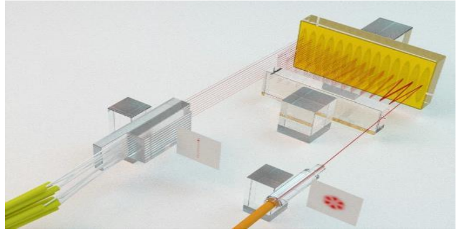
Deformable mirrors

SPATIAL DEMUX

Mode basis

$$\sum \alpha_{n,m}\mathrm{HG}_{\mathrm{n,m}}\mathrm{e}^{\mathrm{i}\psi_{\mathrm{n,m}}}$$





MPLC

Space-to-ground: Mitigating turbulence at reception
Decomposing the incident beam

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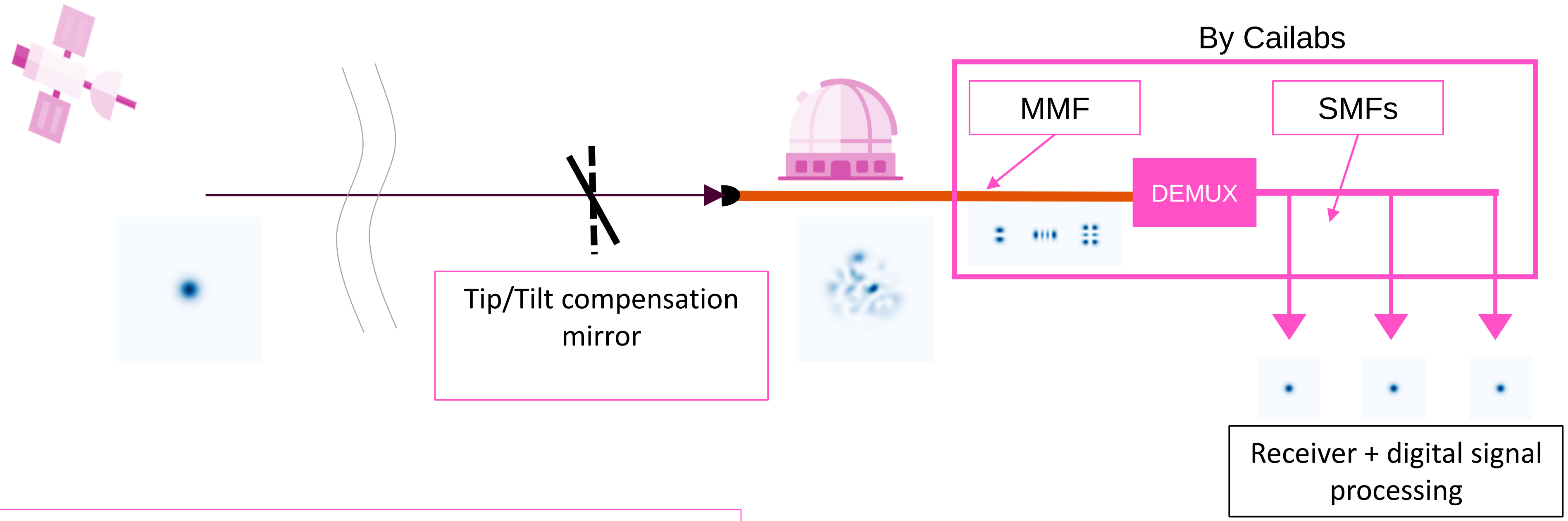
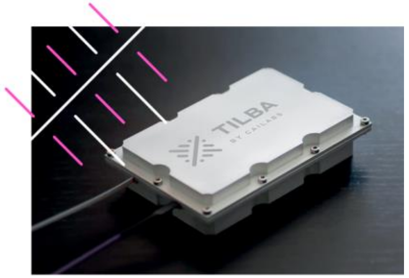


- ✓ Collect more incident light
- ✓ Modal diversity
- ✓ WDM compatible
- ✓ Passive component



Space-to-ground: Mitigating turbulence at reception
A photonic integrated chip to recombine the outputs

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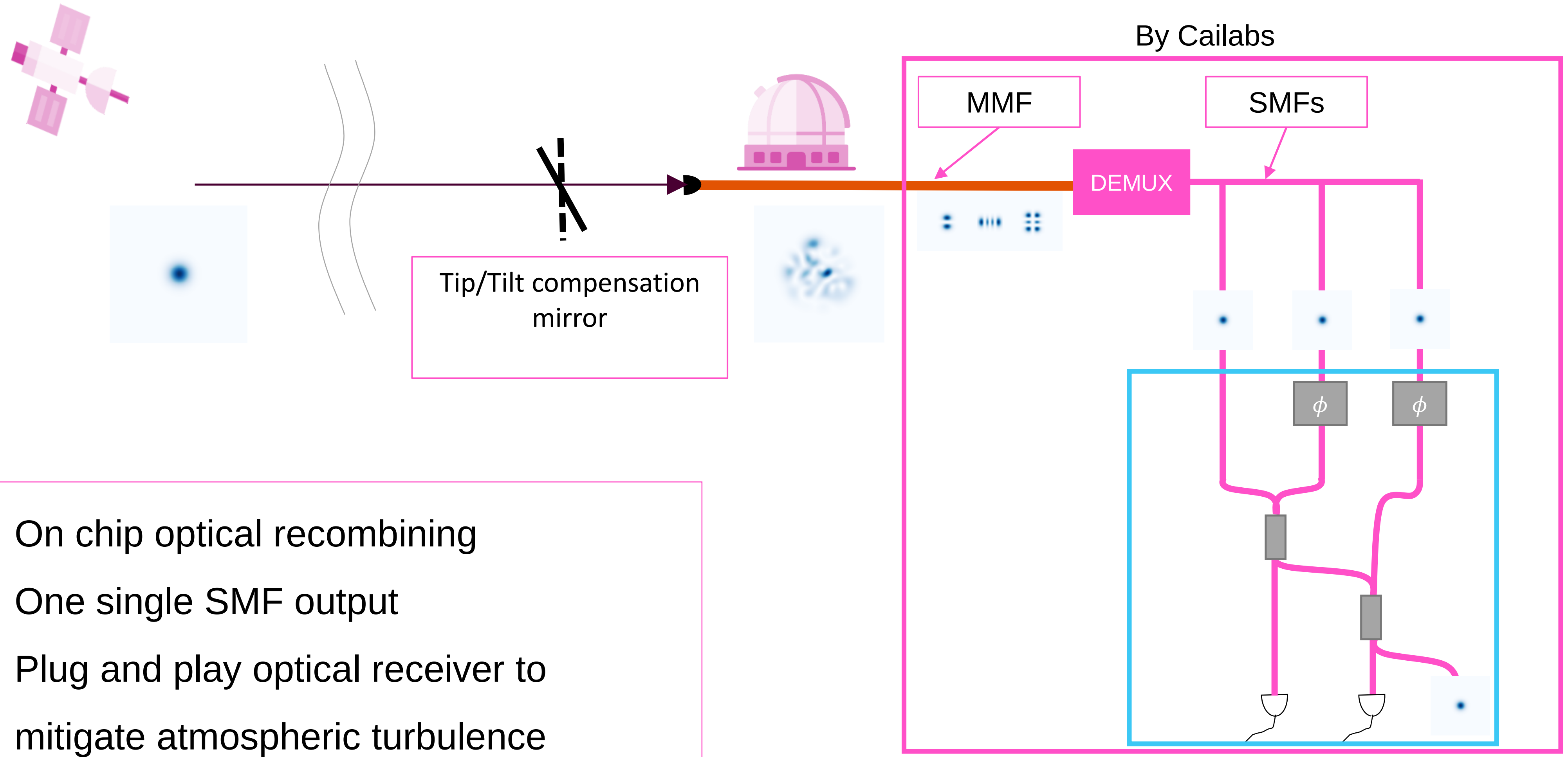

- On chip optical recombining
- One single SMF output
- Plug and play optical receiver to mitigate atmospheric turbulence

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Space-to-ground: Mitigating turbulence at reception

Experimental results: x5 increased reception

NEC

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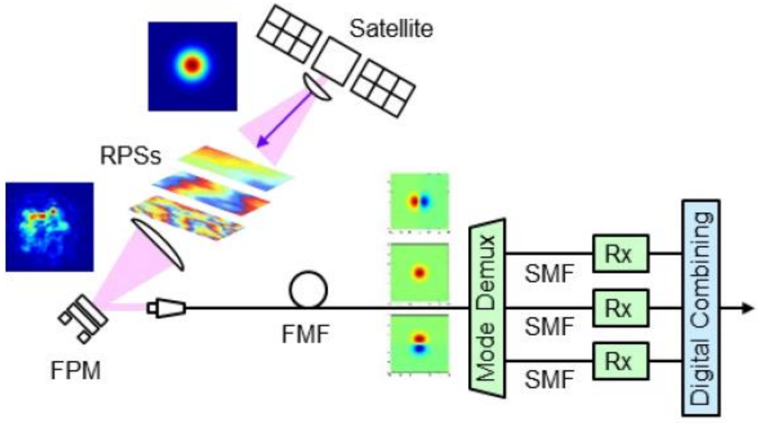
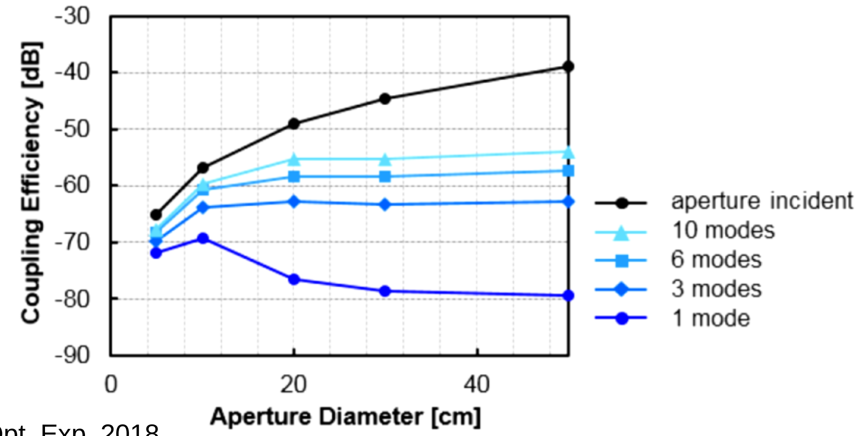
LEO-to-ground communication

✓ **10 Gb/s over 400 km**
Simulation of LEO-to-ground link

✓ **Up to x5 (+7 dB) coupling efficiency**
in 5% worst cases of strong turbulence

✓ **Passive optical component**
No use moving parts





References : [1] Arikawa & al. Opt. Exp. 2018
[2] Arikawa & al. SPIE Proc 2018

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Space-to-ground: Mitigating turbulence at reception

Experimental results: x5 increased reception

NEC

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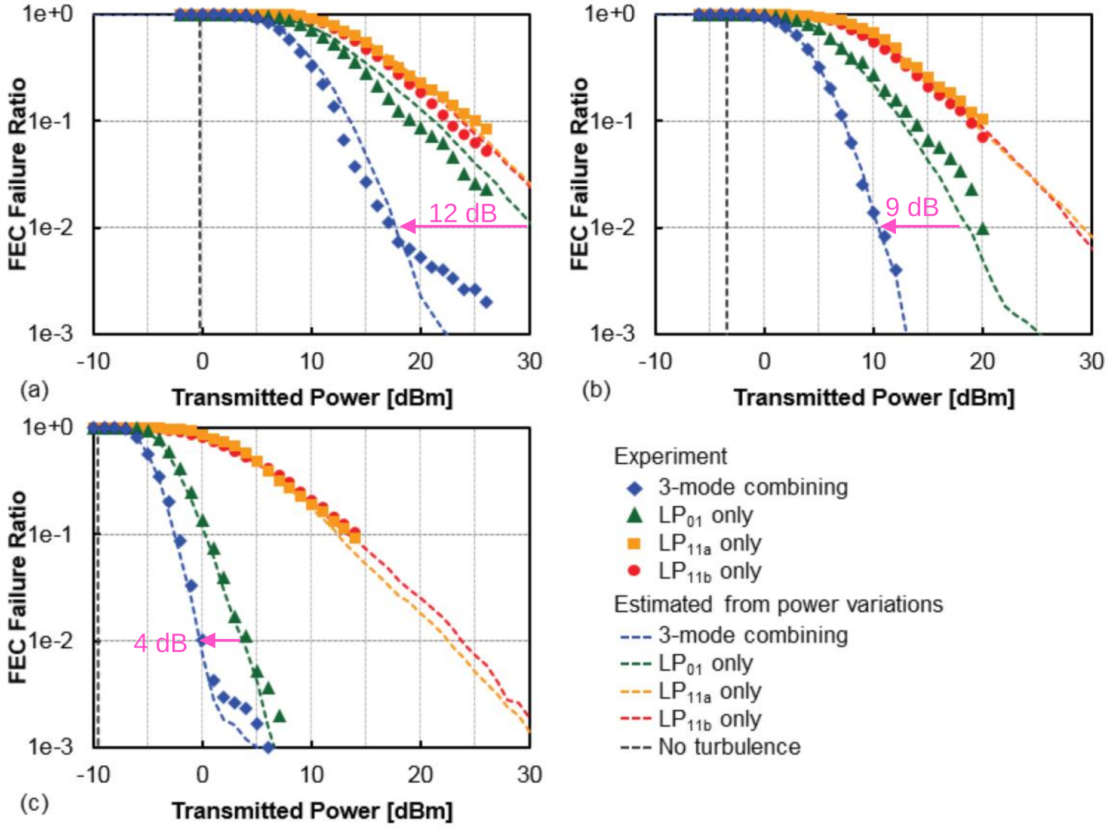
Ratio that BER exceeds FEC threshold against the transmitted power, at the condition of elevation angles of (a) 20°, (ab) 30° and (c) 90°

LEO-to-ground communication

- ✓ **Three mode digital combining**
  10 Gb/s QPSK

- ✓ **Relax the transmitted power by:**
  12 dB at 20°, 9 dB at 30° and 4 dB at 90°
  For 1% FEC error

- ✓ **Passive optical component**
  No use moving parts



References : [1] Arikawa & al. Opt. Exp. 2018
[2] Arikawa & al. SPIE Proc 2018

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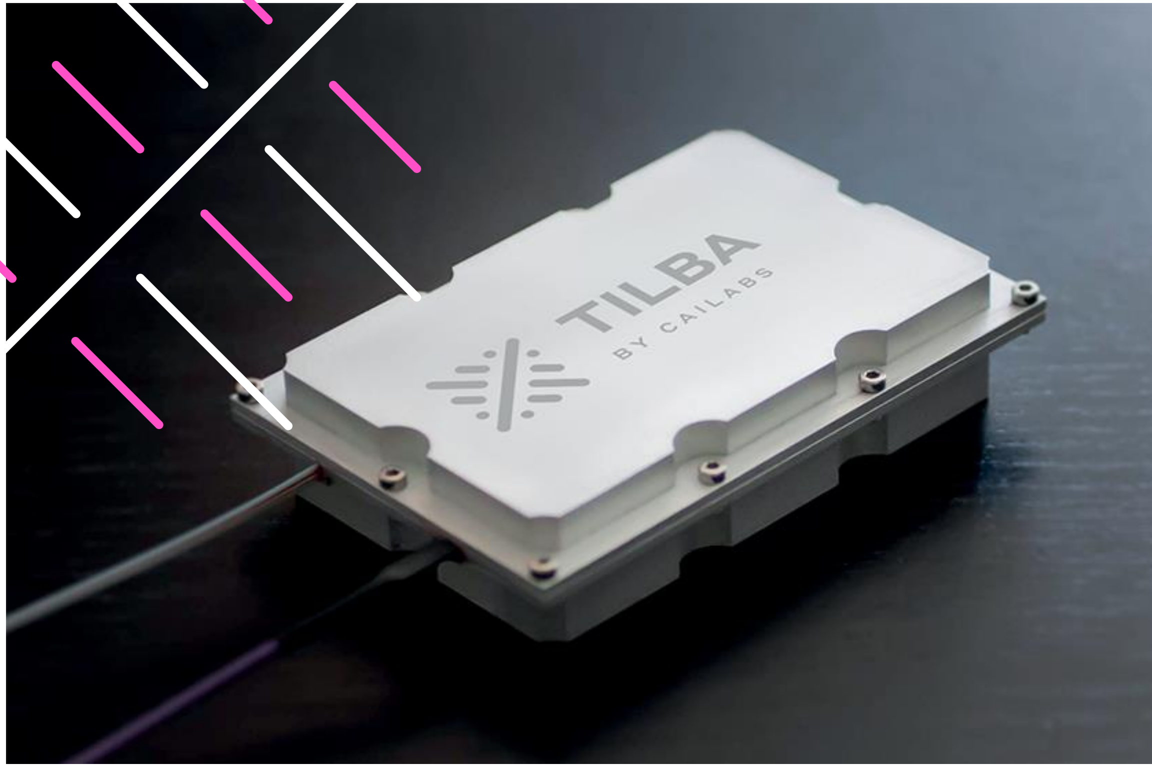
Ground-to-space: Increase power at the emission

Coherent combination across wide spectrum



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Ground-to-space: Increase power at the emission

Combining to increase source power - coherent

Very High Throughput Satellites

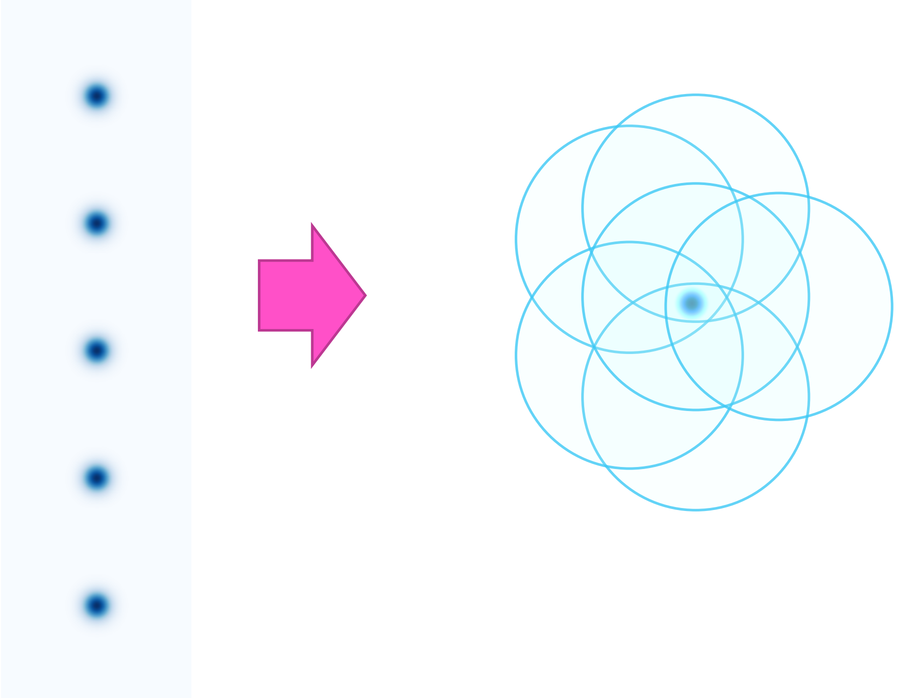
Telecom constellations

Powerful feeder links needed

Need to handle high power (>100W) and high throughput

Need to be WDM compatible

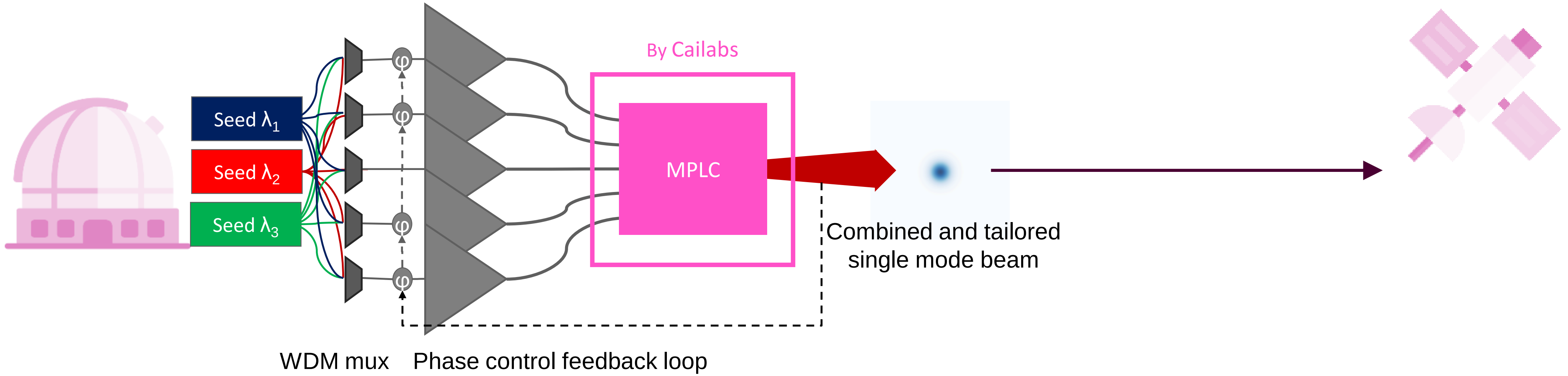
TILBA beam shaping enables **more tolerant coherent combination thanks to constructive interferences**



3. TILBA-T-Combine

Combine coherently high-power sources for feeder links (Tbits)

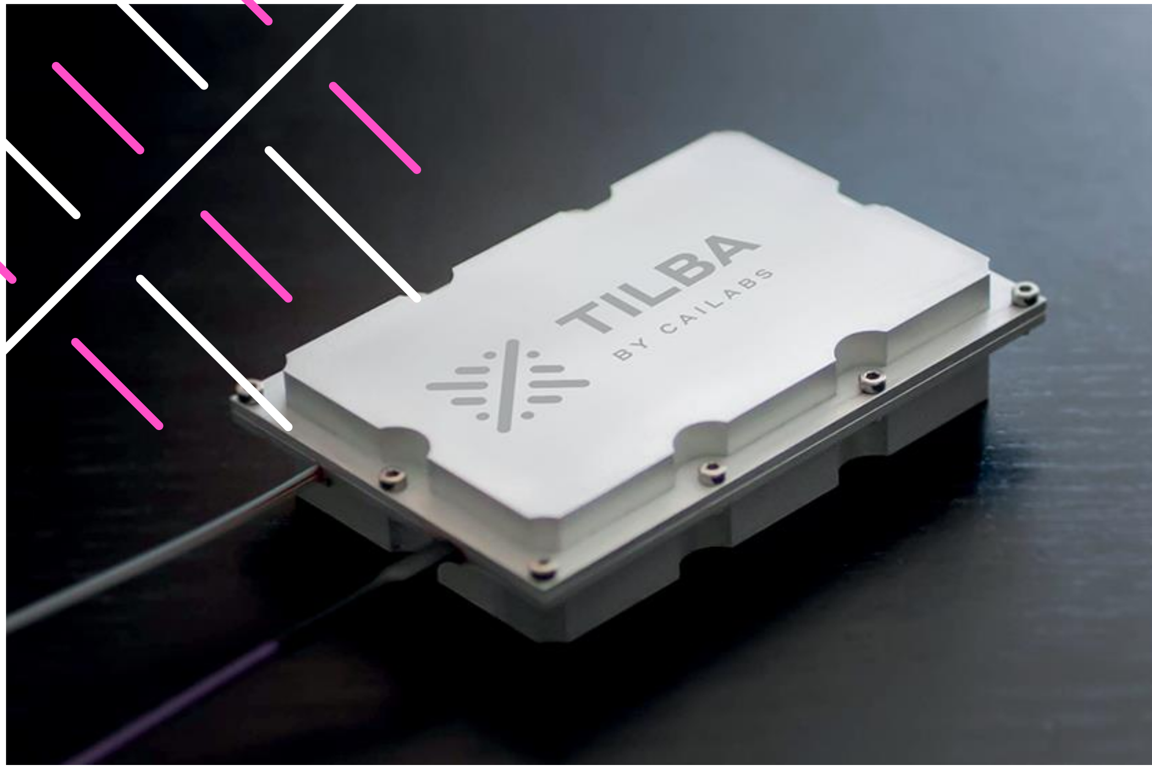
TILBA BY CAILABS



- ✓ **High efficiency**
- ✓ **High power handling**
- ✓ Combination of **up to 45 coherent sources**
- ✓ **WDM compatible**

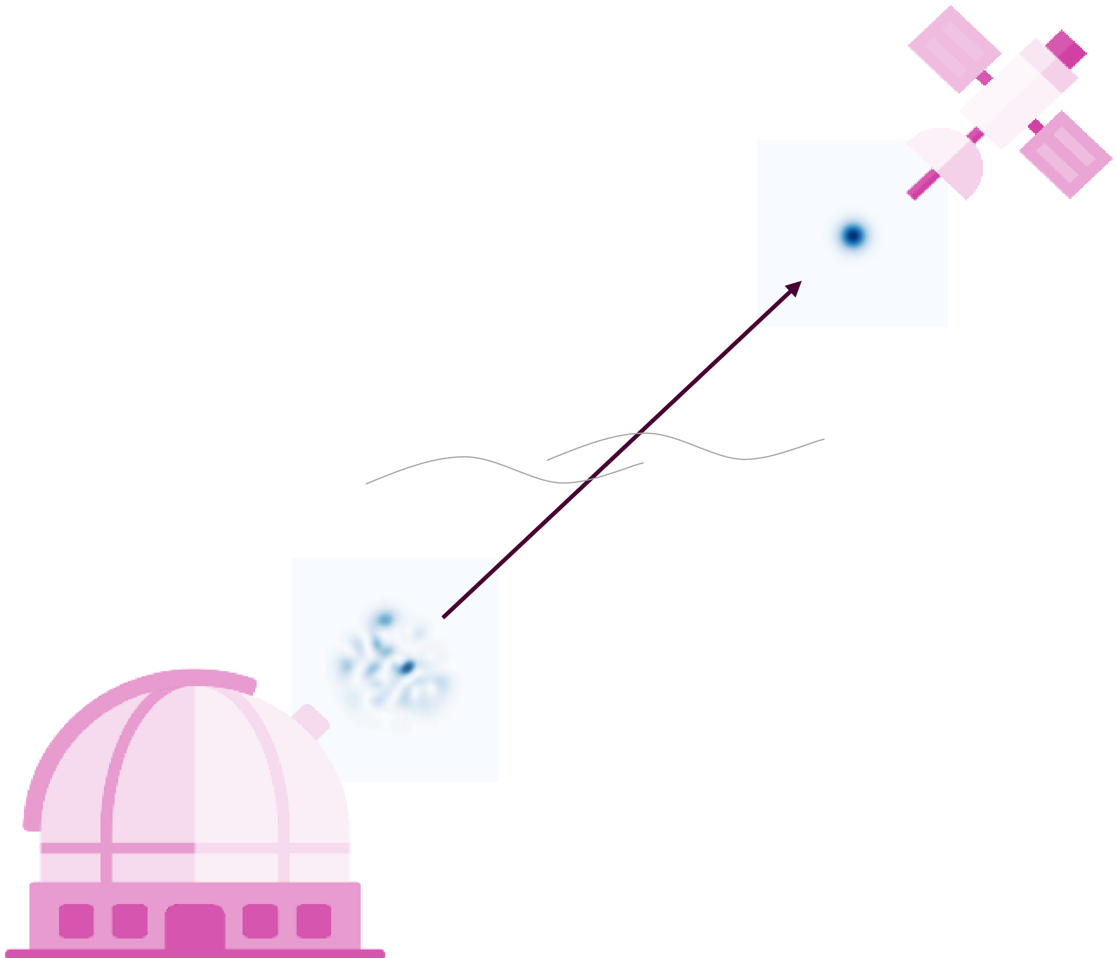
Ground-to-space: Pre-compensate the turbulence

What if we could pre-compensate the atmospheric turbulence?



Ground-to-space: Pre-compensate the turbulence

Shape the emitted beam to precompensate atmospheric turbulence



1. **Analyse the turbulence**
2. **Decompose it analytically on the MPLC bases**
3. **Send the corrected beam**

Take home message

Improves the Space-to-Space & Space-to-Ground links

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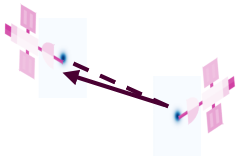
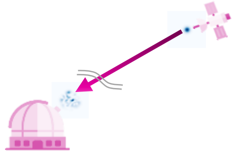
Improves LaserCom **at the reception :**

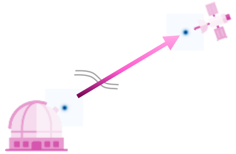


pointing errors

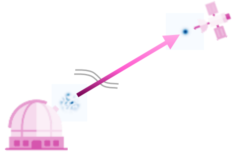


Turbulence mitigation

Improves LaserCom **at the emission :**



Coherent combining

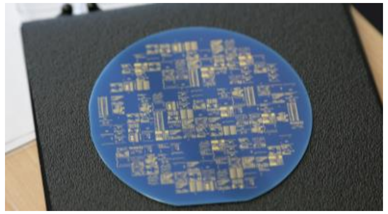


Precompensation

TILBA roadmap

2019	2020	202?	>2024

Ground station Field test



Silicon Photonic Chip

Satellite Tip-Tilt compensation

Aircraft LaserCom Network

Thank you for your attention

Environment validation
Temperature, pressure, humidity, vibration

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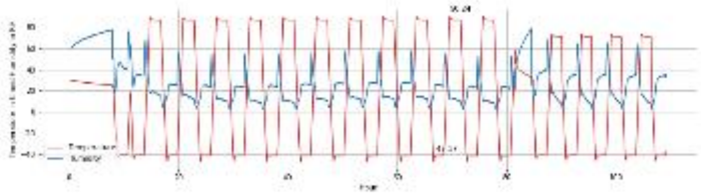
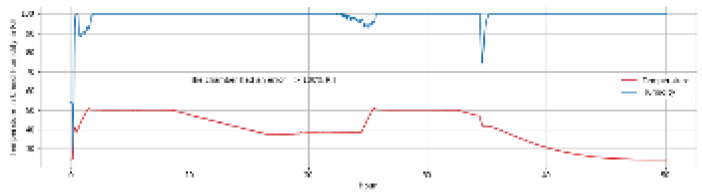
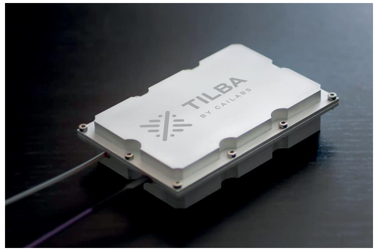
- Specific validation of novel optical components critical in aircraft context
  - Validate specific environmental conditions
  - Avoid the « concept » trap
- Temperature
  - Operation from -40 to 85 °C
  - Operation +- 2°C / minute
- Pressure
  - Operation from 0.1 Bar to 1 Bar
- Humidity
  - Operation at 50°C, 95% RH
- Vibration
  - Vibration, operation at 4.12g RMS
  - Shock, operation at 6g for 11ms
- Cabling
  - No impact of bending radius 2 cm







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