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SHAPING THE LIGHT

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SHAPING THE LIGHT

Turbulence mitigation without AO

How can we compensate turbulence with an MPLC? A Focus on pointing error

David ALLIOUX

Product manager

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

45 employees
(**18** PhDs)

16.6 M€ ++
raised

References:

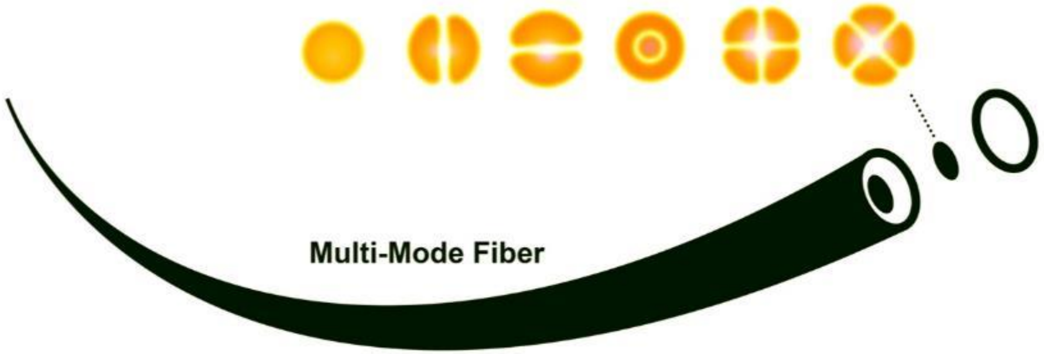
SAFRAN
tellabs
KDDI
NOKIA
Amplitude

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



Leadership in complex beam shaping
Telecom and beyond

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MPLC technology

CANUNDA BY CAILABS	AROONA BY CAILABS	PROTEUS BY CAILABS	TILBA BY CAILABS	Cailabs inside
Improve laser material processing	Future-proof fiber infrastructure of LANs	Invent the optical networks of the future	Ensure the reliability of LaserCom	Integrate tailored optical solutions

References:

Amplitude · tellabs · KDDI · NEC · SAFRAN

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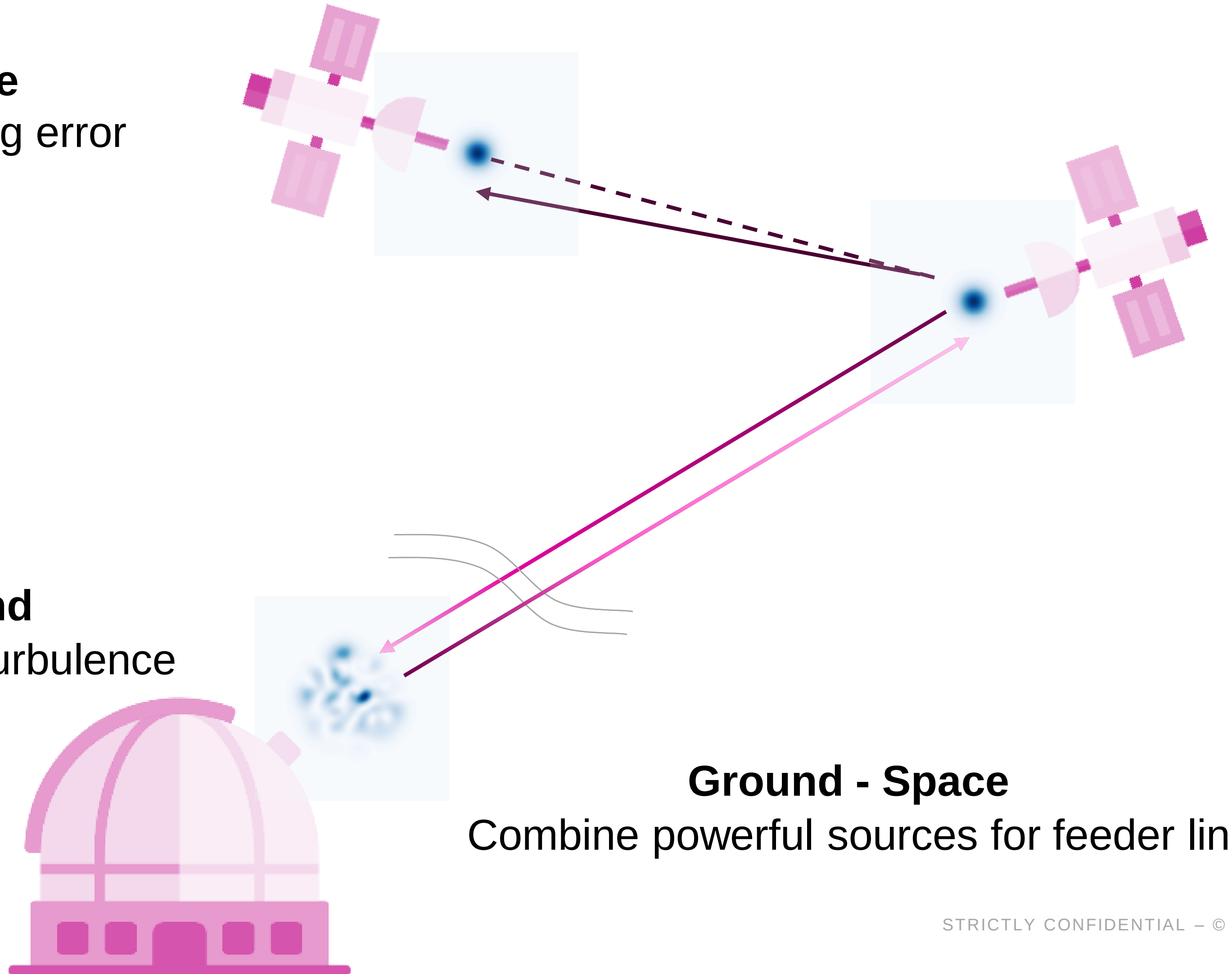
How do we operate LaserCom?
Improving multiple sides of optical links

Space - Space
Compensate pointing error



Space - Ground
Mitigate atmospheric turbulence

Ground - Space
Combine powerful sources for feeder links

How do we operate LaserCom?
Improving multiple sides of optical links

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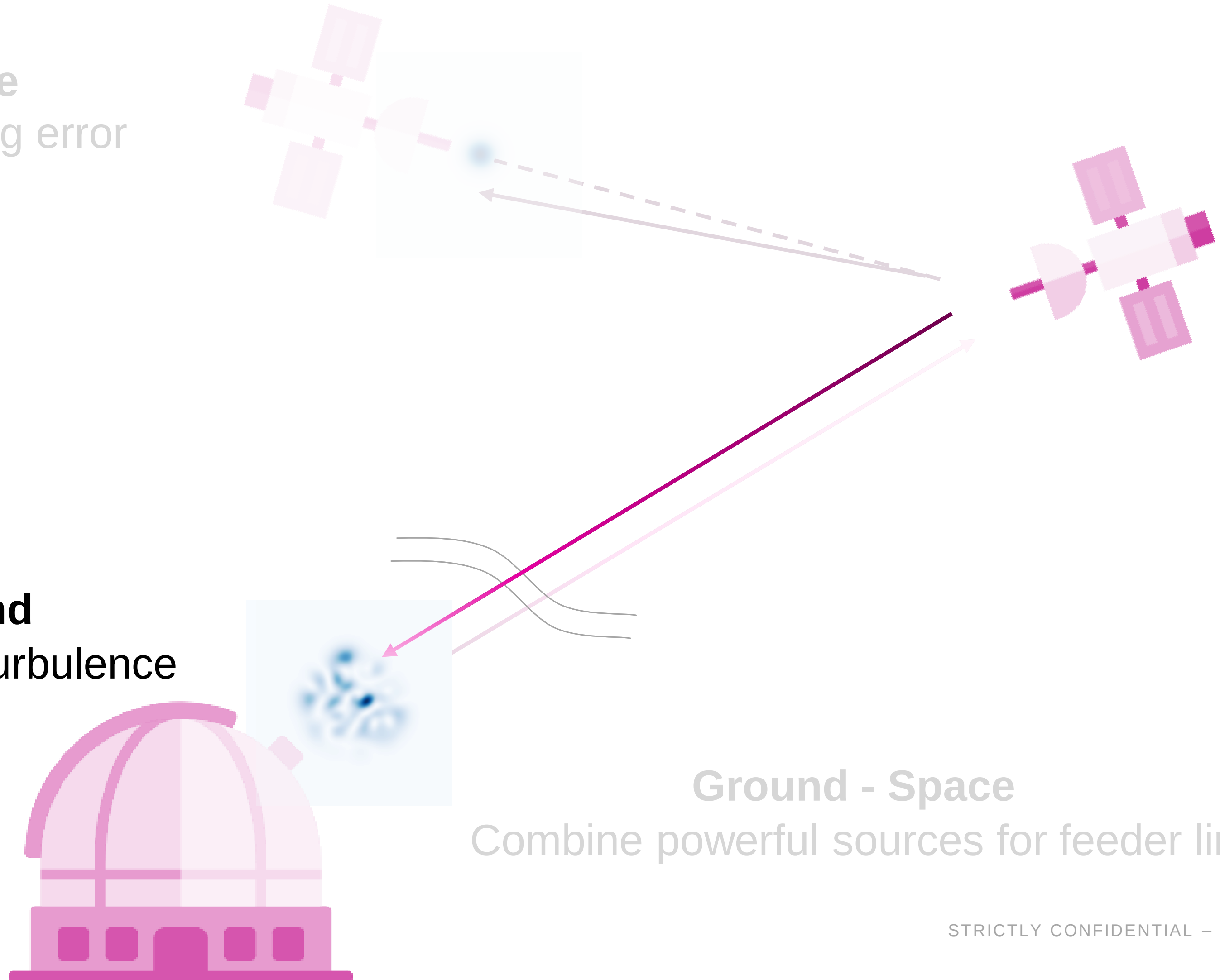
Space - Space
Compensate pointing error



Space - Ground
Mitigate atmospheric turbulence

Ground - Space
Combine powerful sources for feeder links

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MPLC for LaserCom

State-of-the-art beam shaping and spatial multiplexing

Multi-Plane Light Conversion (MPLC)
Take-home message

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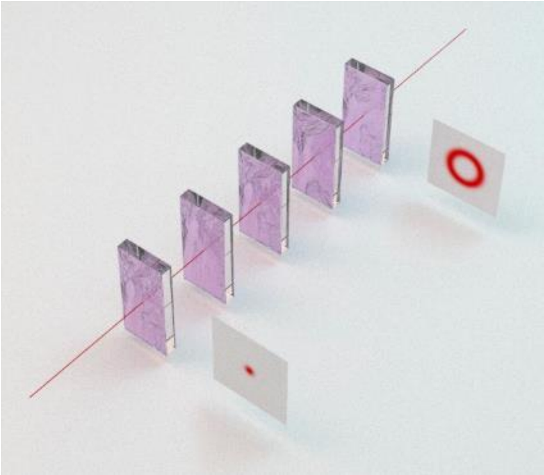
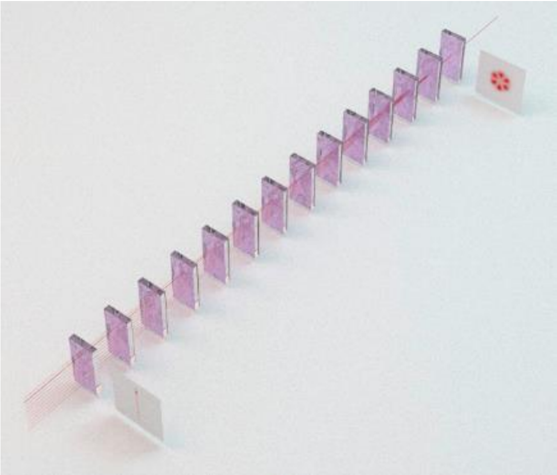
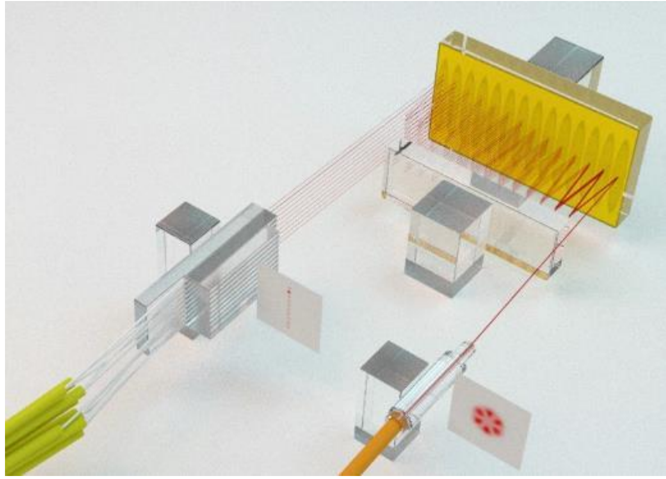
- Derived from quantum optics at French Kastler Brossel Lab
- Complex beam shaping through succession of spatial phase profiles
- Passive optical beam shaping with no intrinsic loss nor moving elements

Morizur & al. JOSA A 2010; US PATENT

Multi-Plane Light Conversion
A spatial multiplexer in a small box

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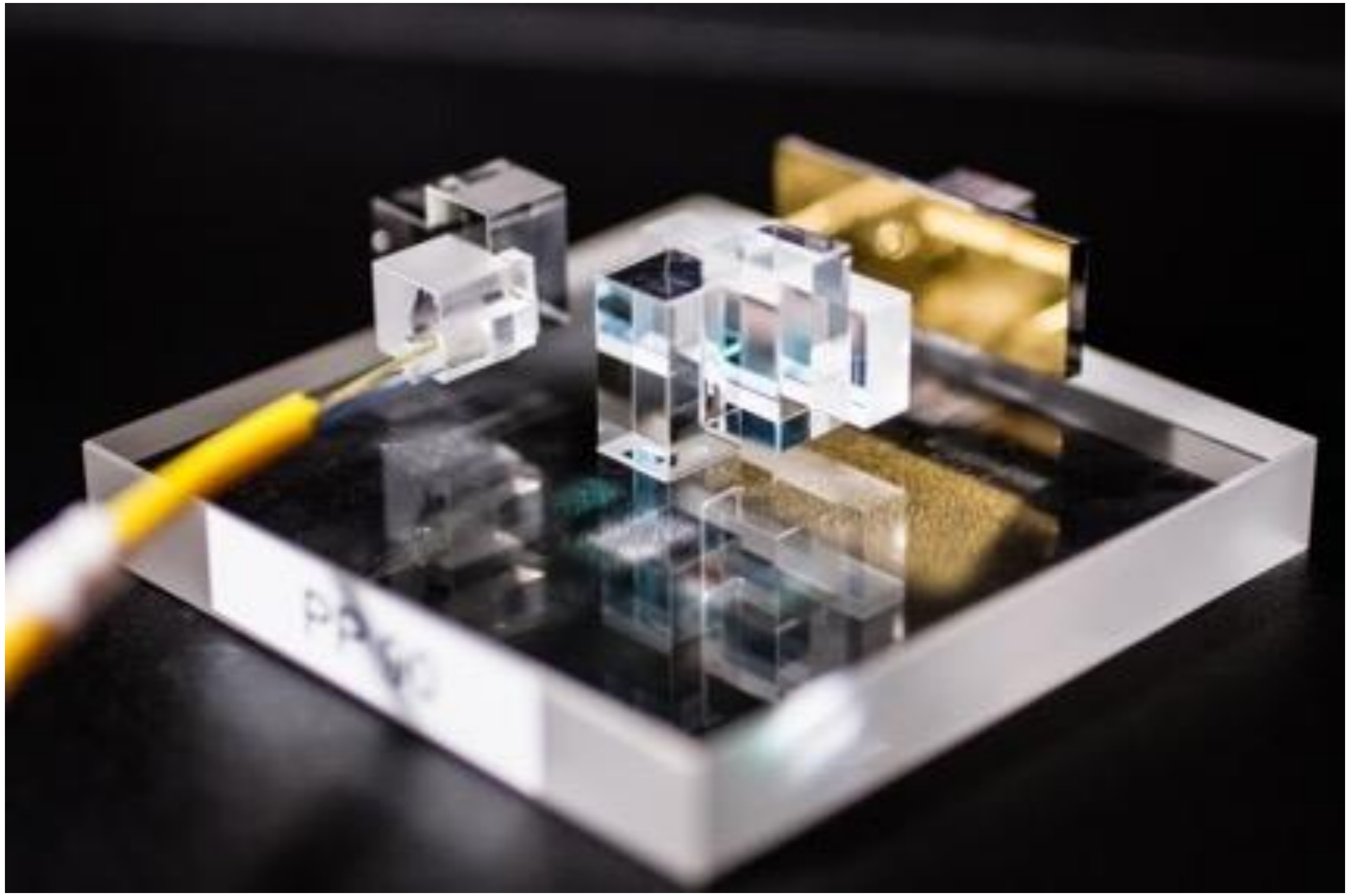
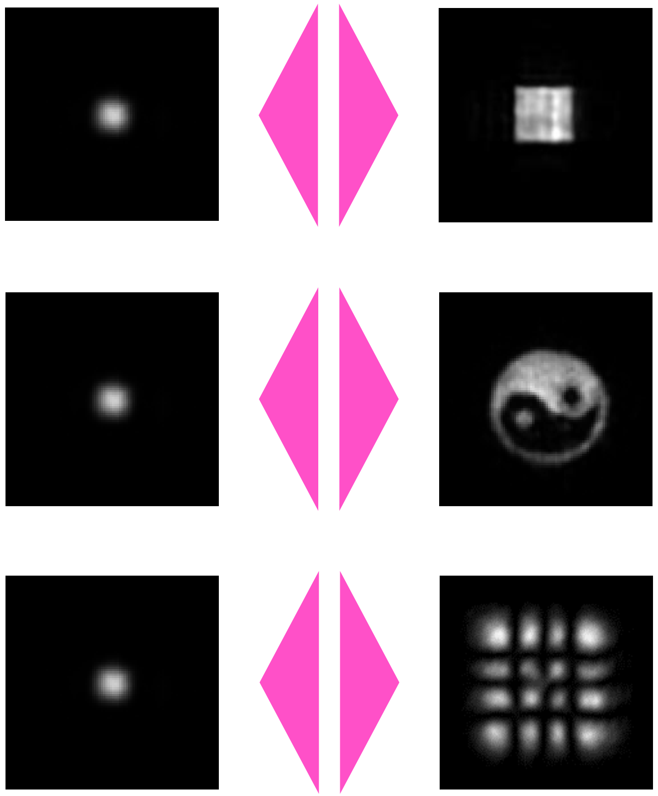
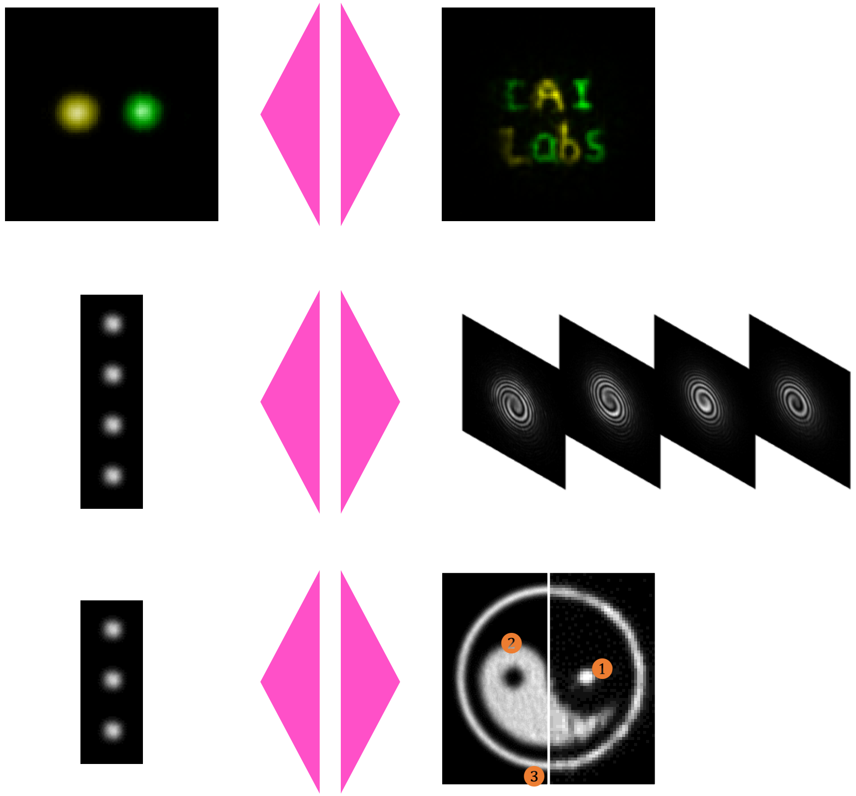


Multi-Plane Light Conversion
Flexible and versatile beam shaping

Mono-mode transform



Multi-mode transform



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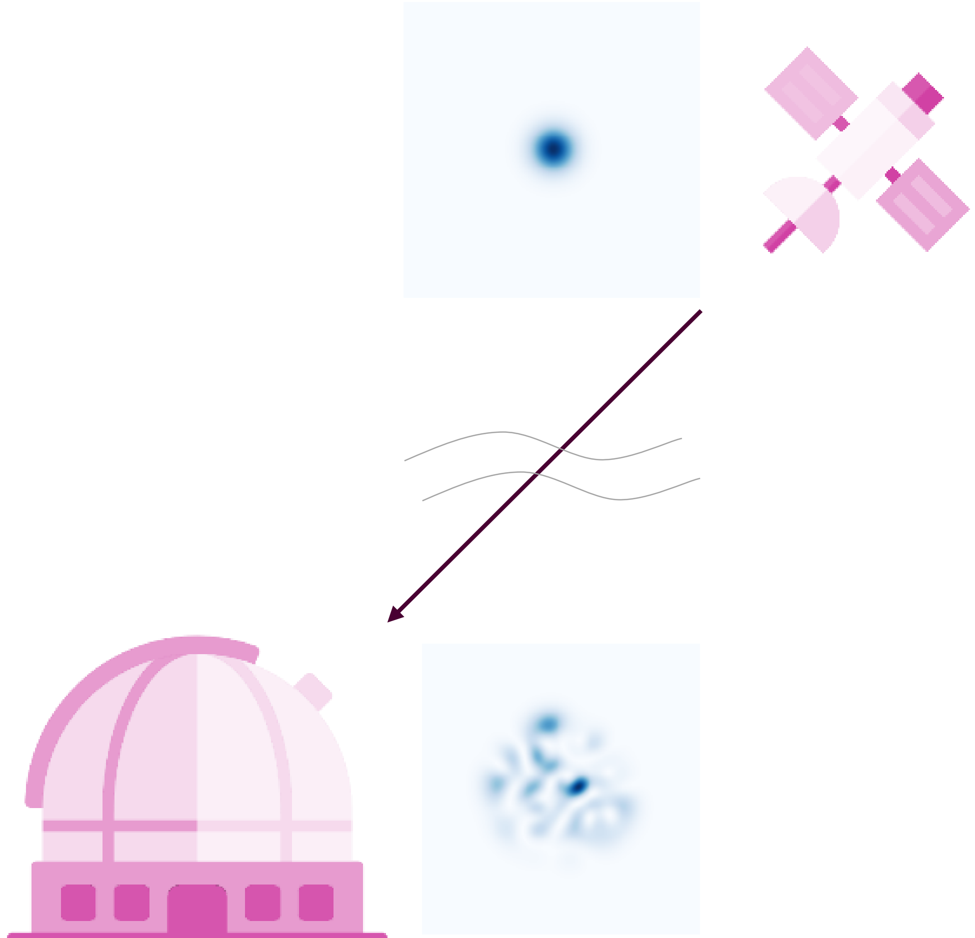
Mitigating turbulence with an MPLC

How to do adaptative optics with a passive component?

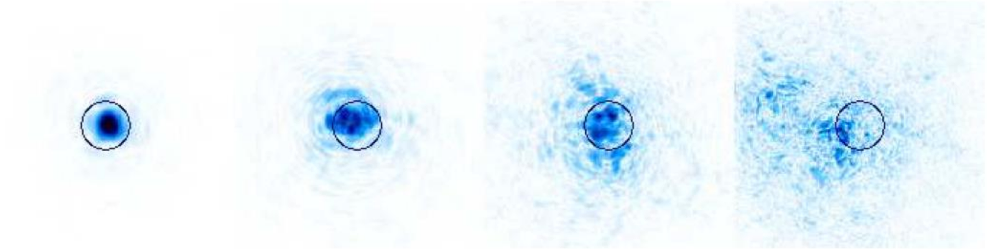
Space-to-ground: mitigating turbulence at reception

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: adaptative optics

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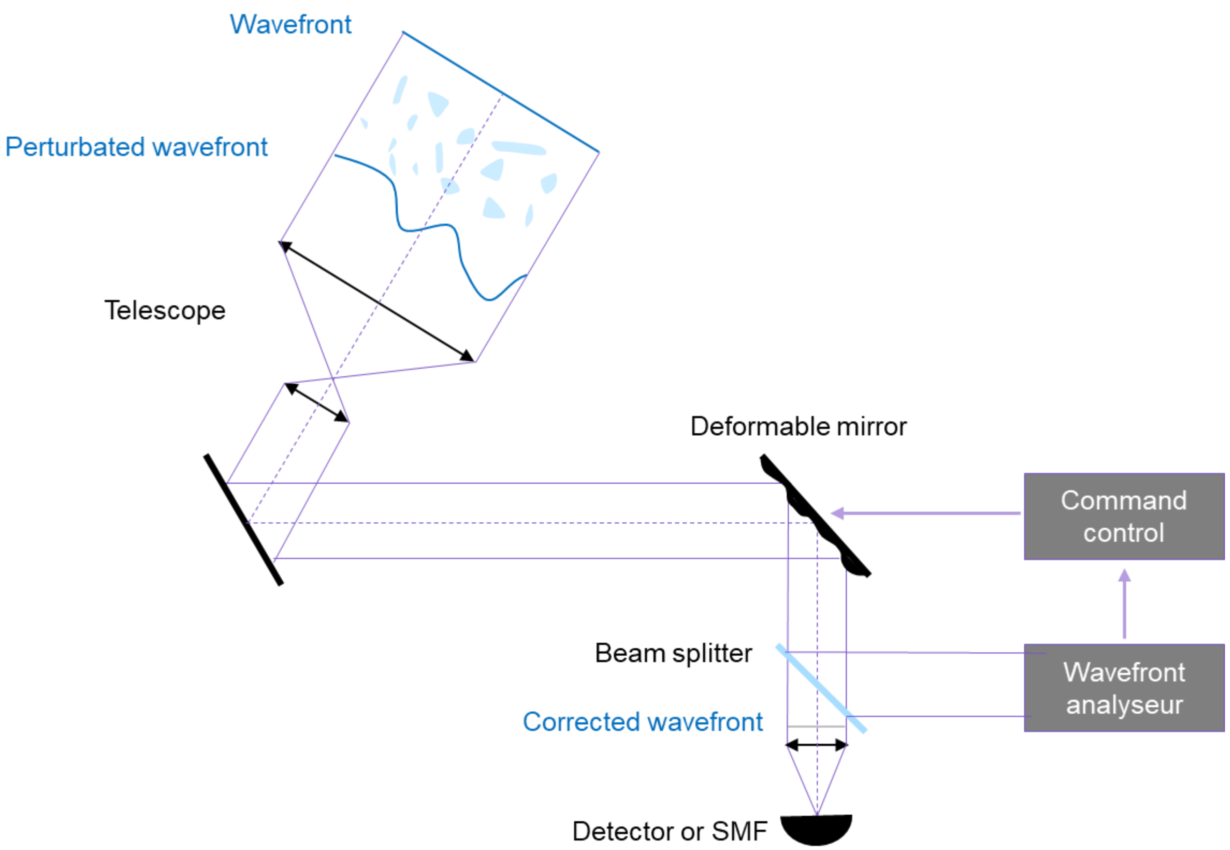

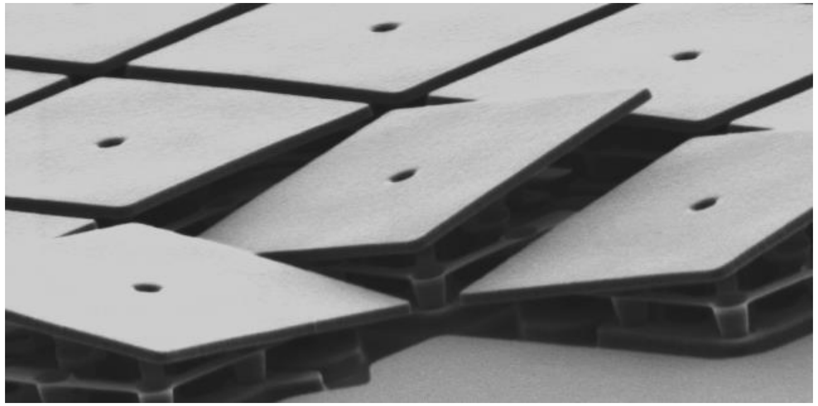

Drawbacks:

- Are expensive
- Need feedback loop
- Display moving elements

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

Mitigating turbulence and pointing errors

A similar function with a different approach

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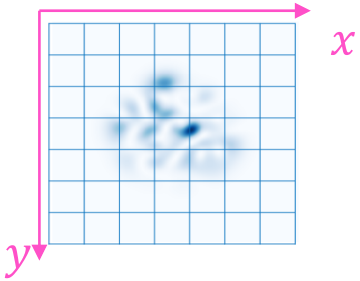
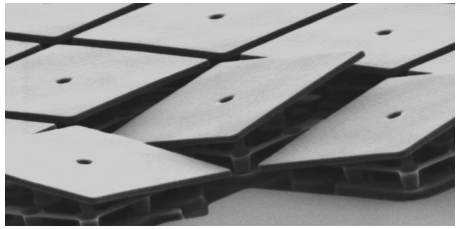
ADAPTATIVE OPTICS

Cartesian basis

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



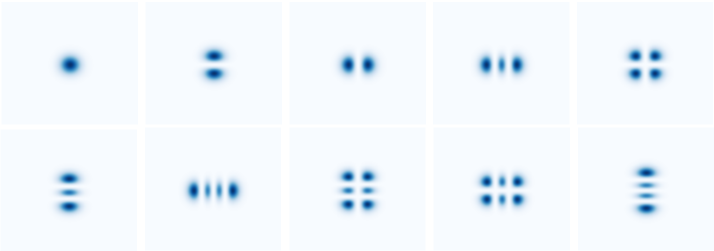


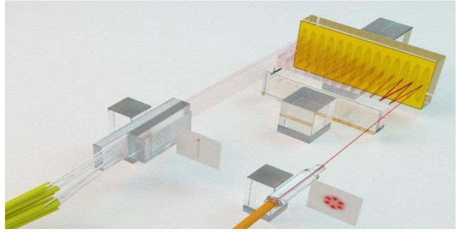
Deformable mirrors

SPATIAL DEMUX

Mode basis

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

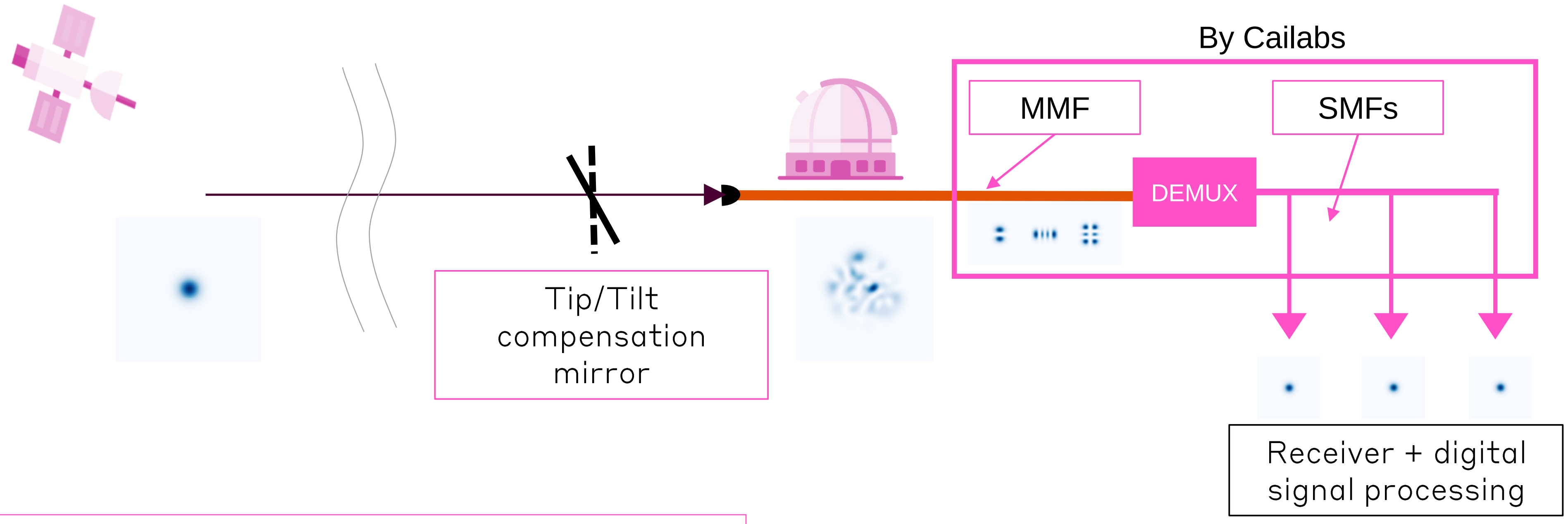




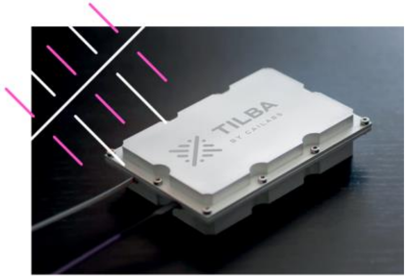
MPLC

Space-to-ground: mitigating turbulence at reception

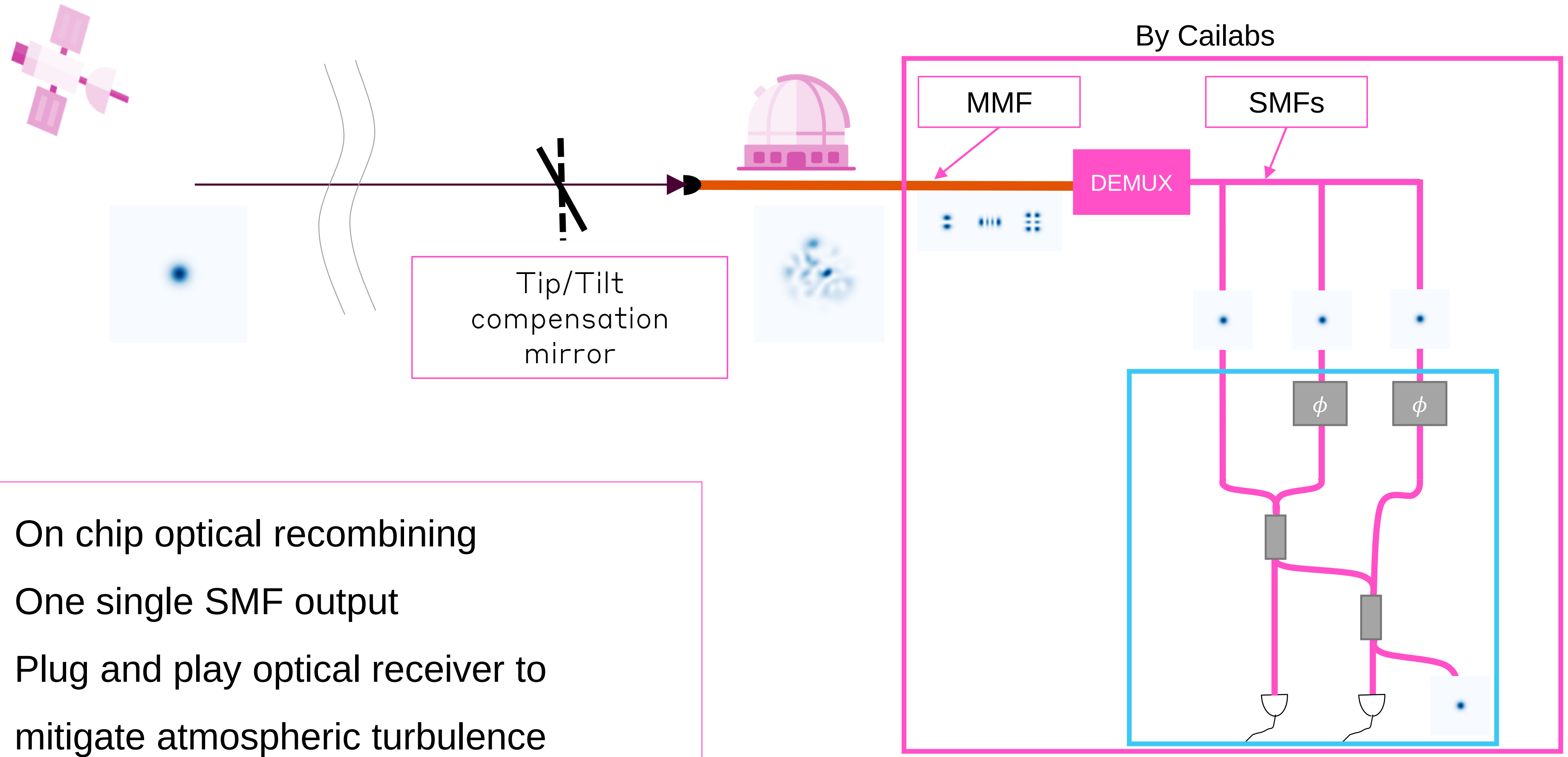
Decomposing the incident beam



- ✓ 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



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

Space-to-ground: mitigating turbulence at reception
Experimental results: x5 increased reception

NEC

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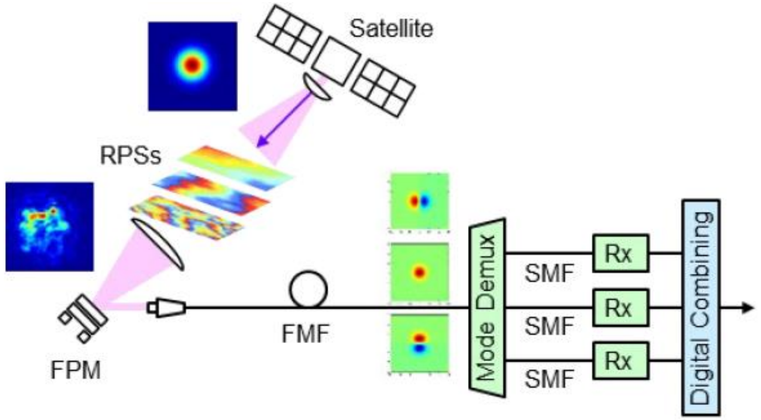
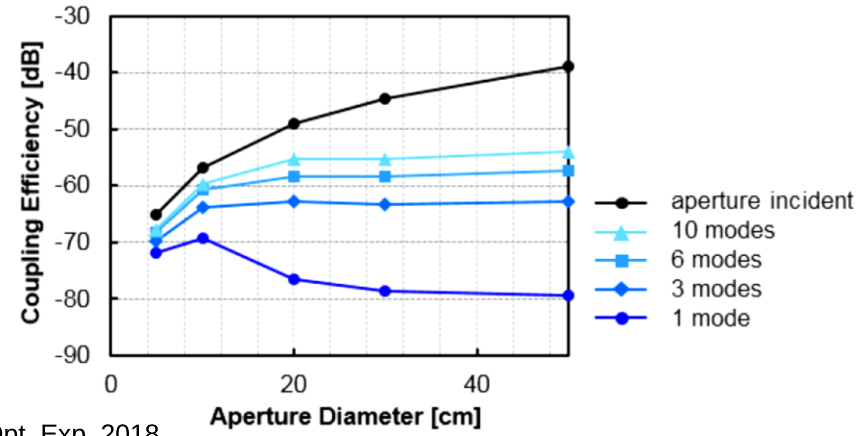
LEO-to-ground communication

✓ **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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Playing with the modes

Focus on the pointing error

Mitigating pointing errors
Hypothesis

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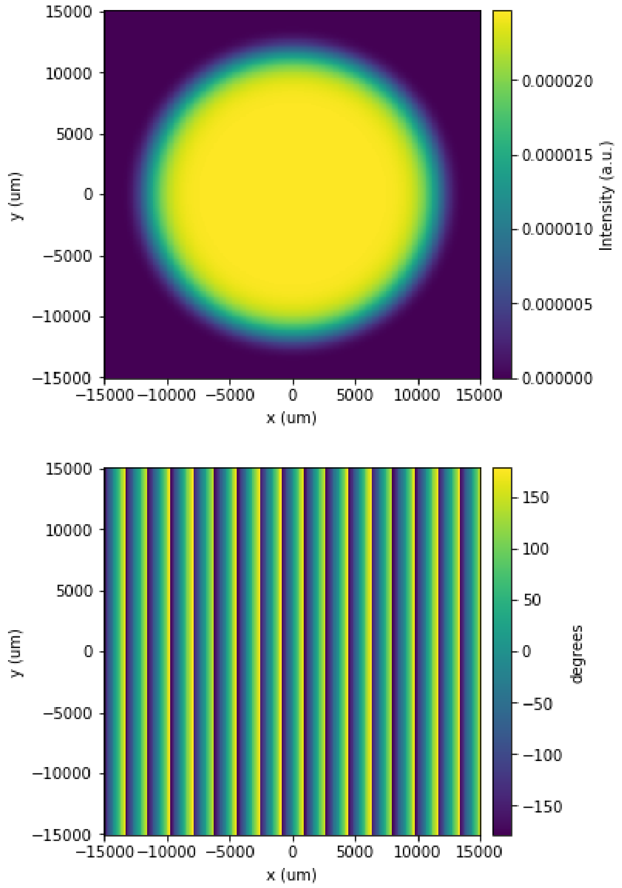
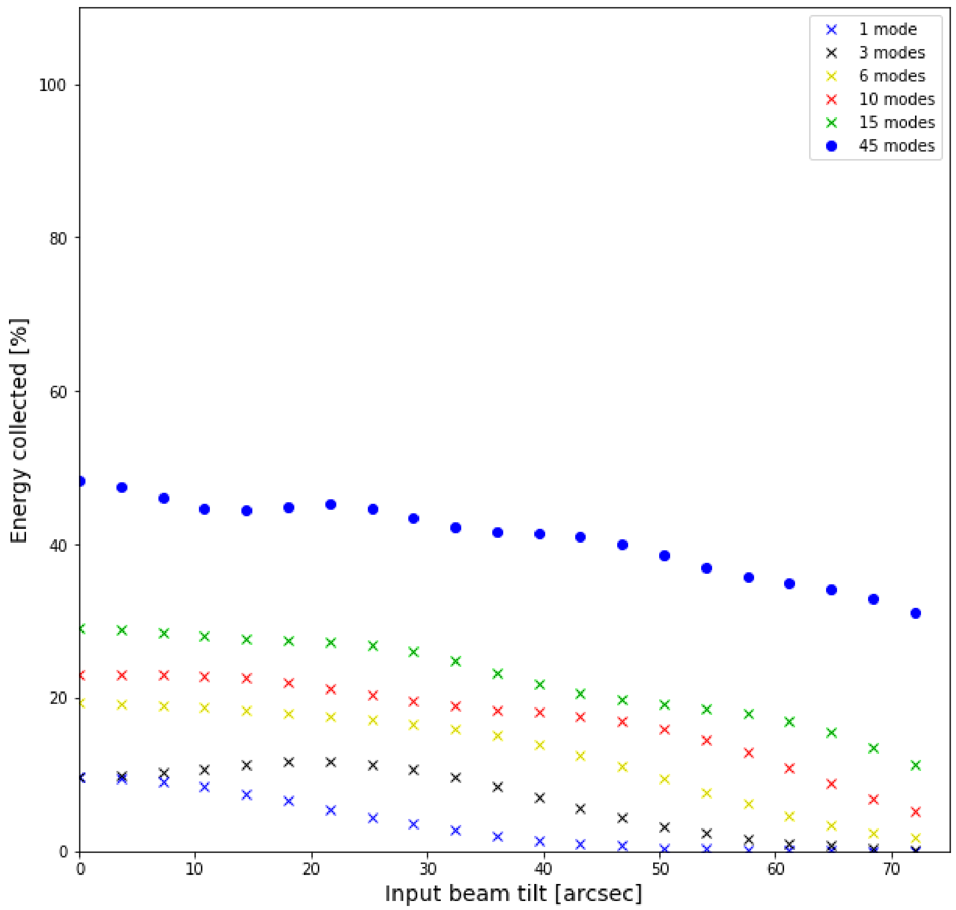
Input

- Super-Gaussian beam (3rd order)
- 25 mm pupils
- Plane phase
- Free space input

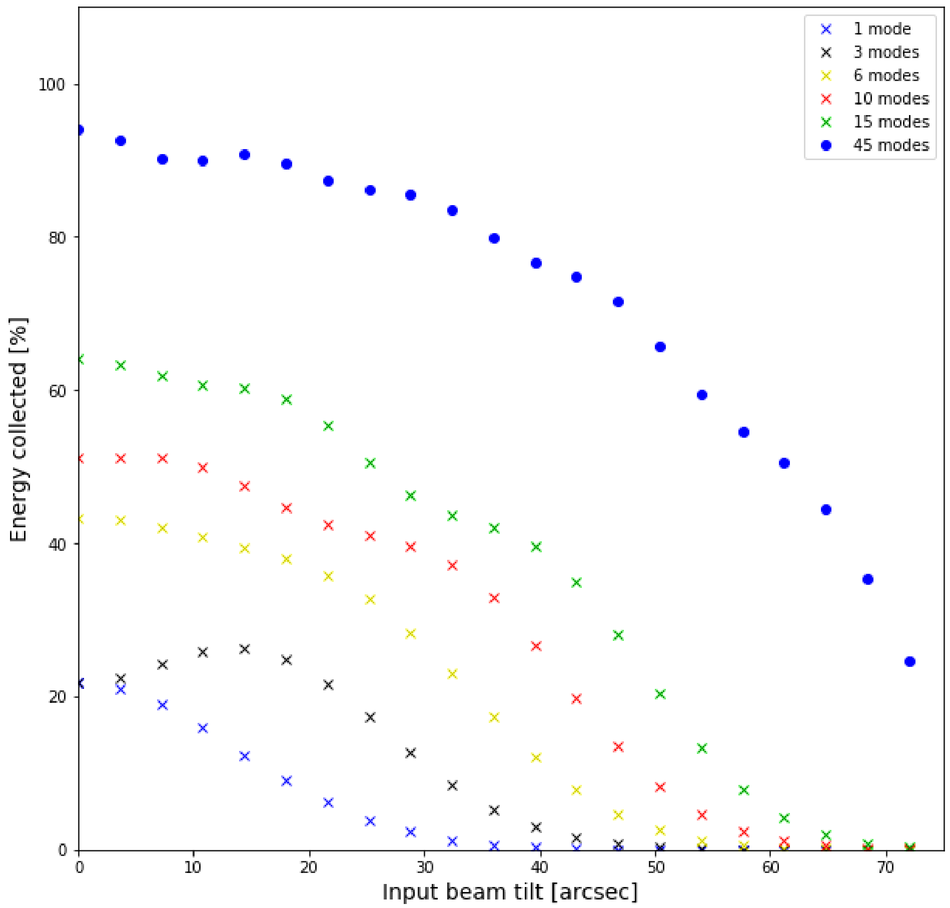


Results with HG modes
Small beam waist

MPLC with 2.5 µm waist



MPLC with 3.75 µm waist



Results with HG modes
Large waist

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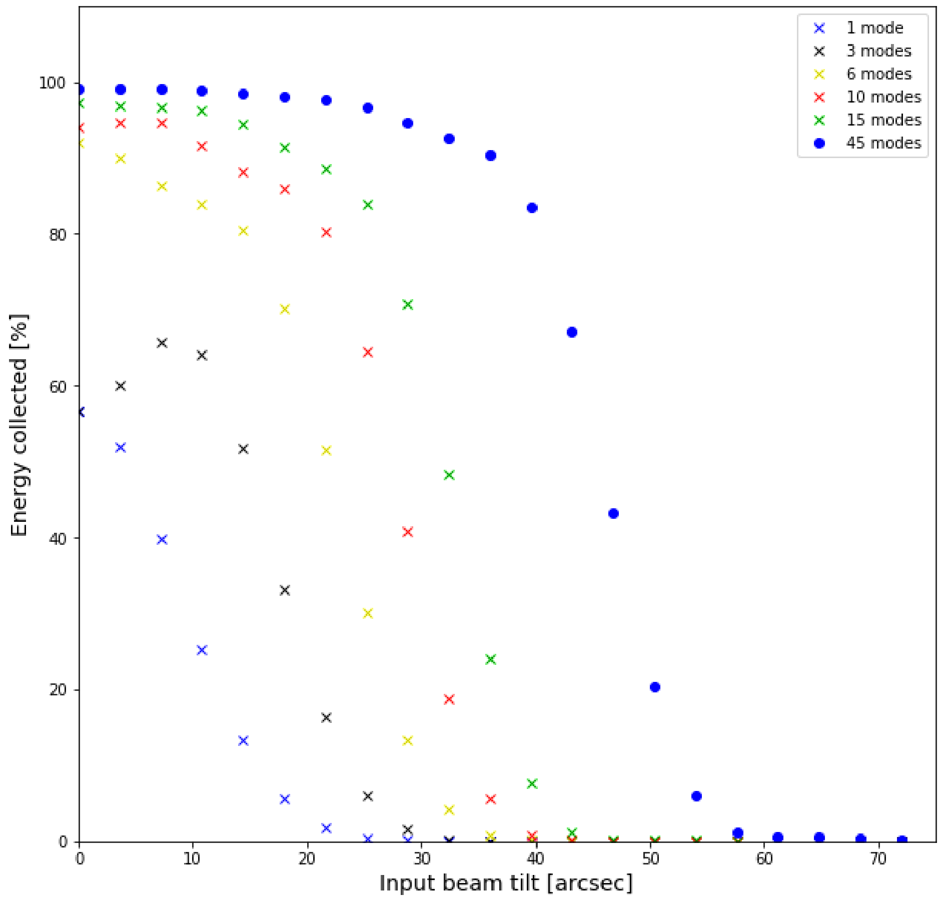
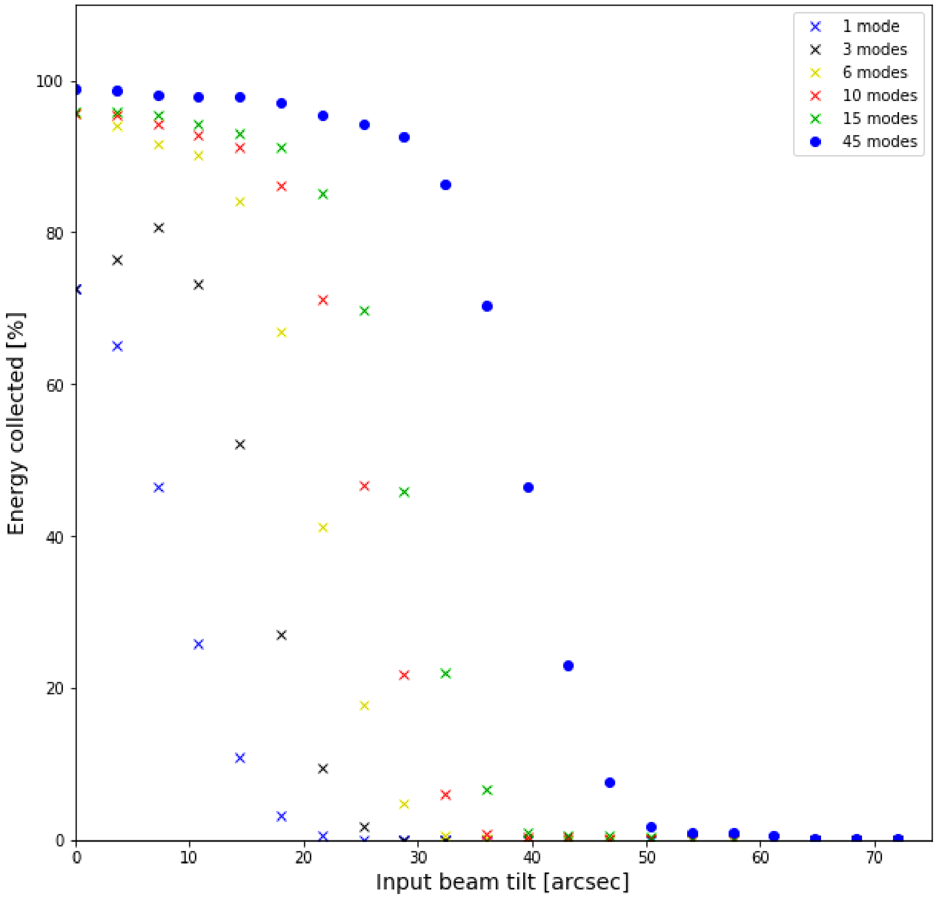
MPLC with 5 µm waist



MPLC with 7.5 µm waist



Results with HG modes
Finding the good compromise

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2 possible compromise:

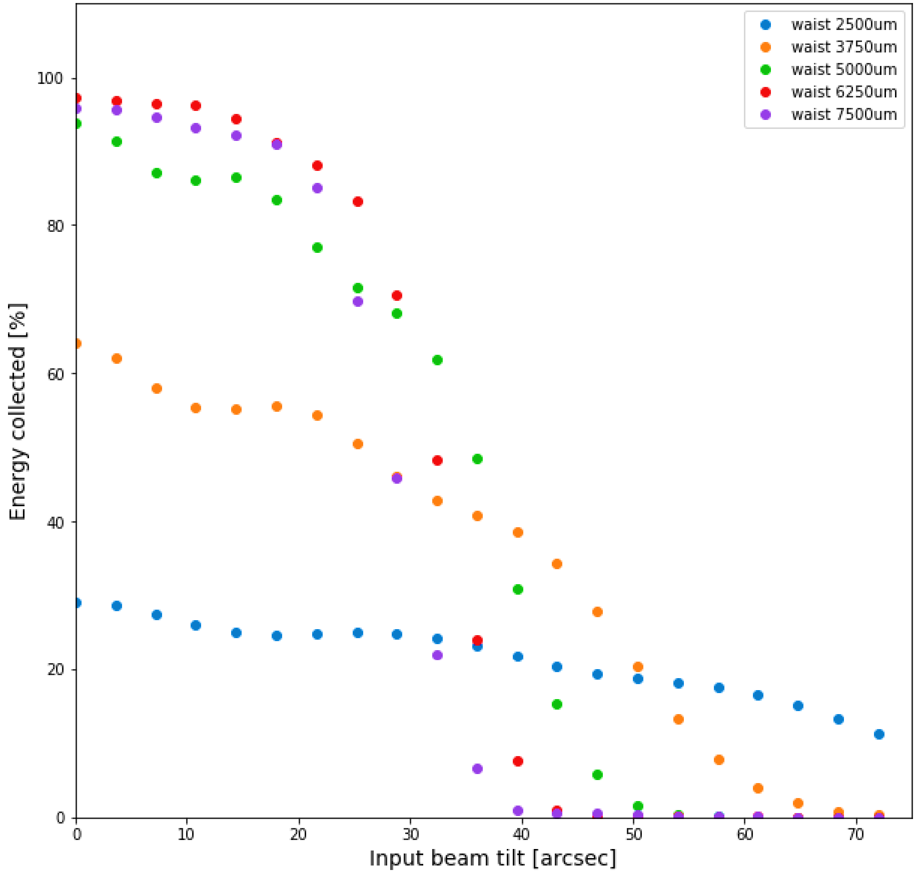
- **Large angle compensation with moderate collection efficiency:**

Blue and orange curve

- **Low angle compensation with very high effiency:**

Green, red and violet cuves

Compensation with 15 modes



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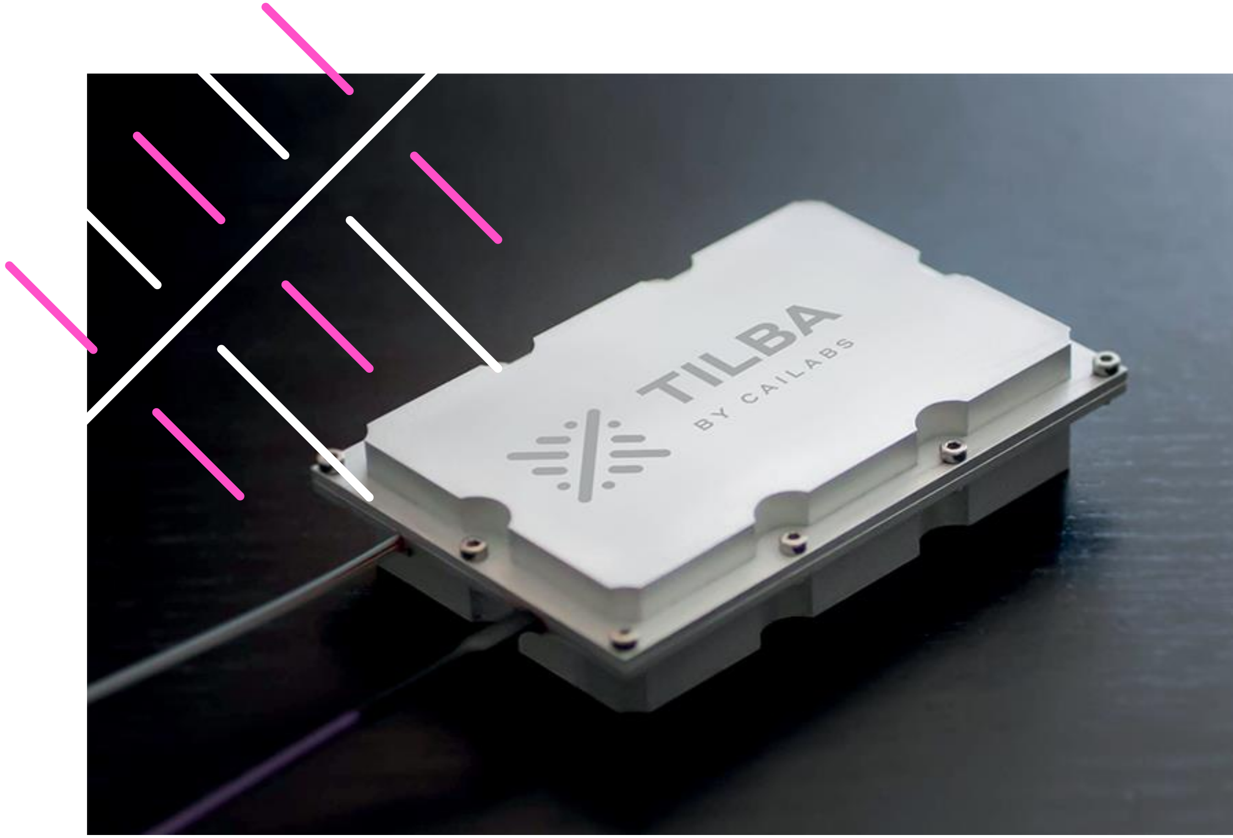
Built a custom MPLC



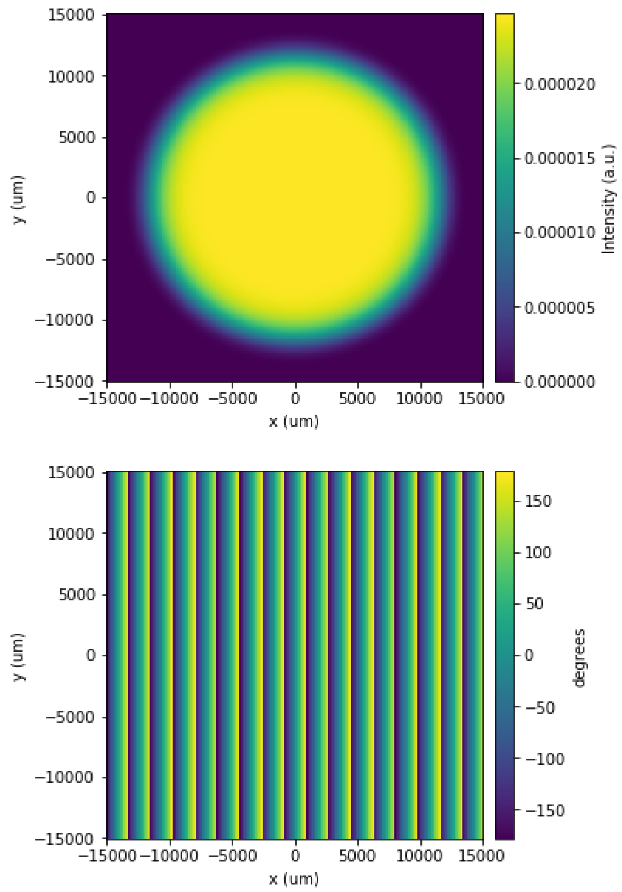
An SVD approach

Optimal approach
What is it?

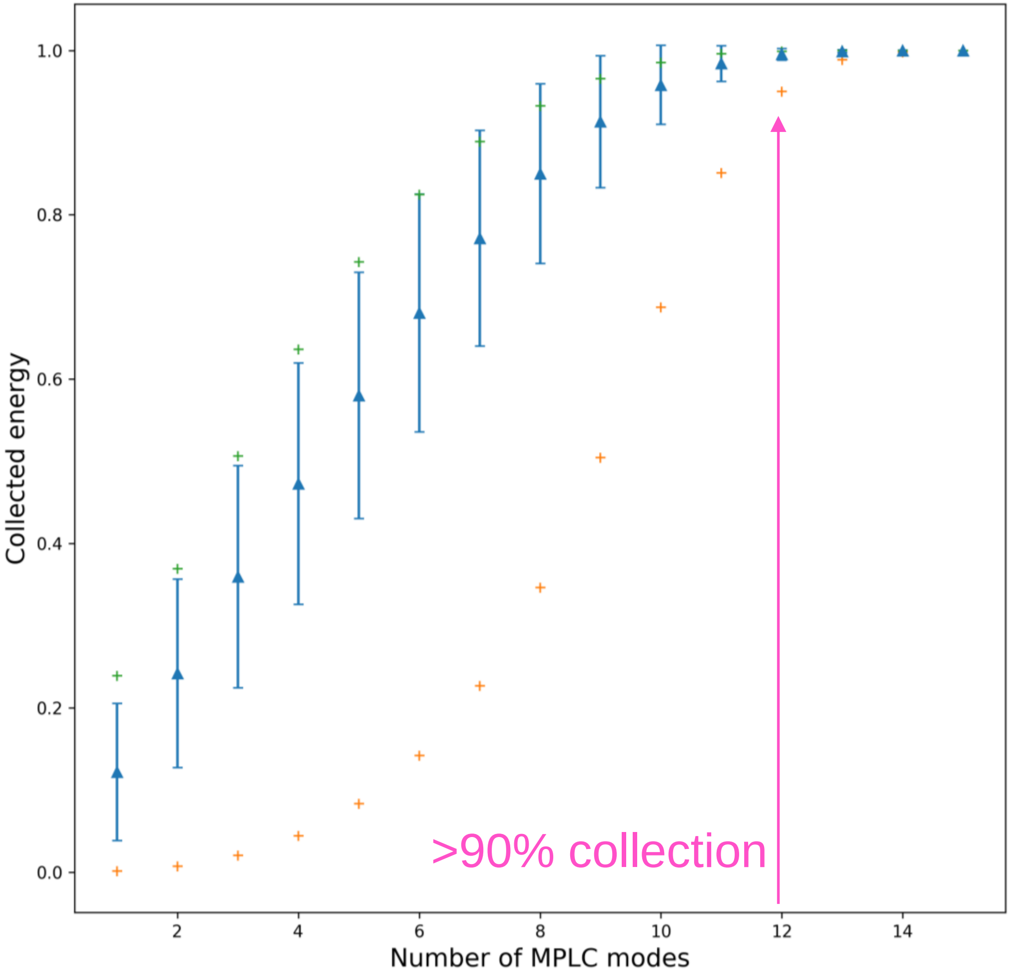
Problem:

- >200 PSFs
- Collect them with an MPLC with 3 to 45 modes.

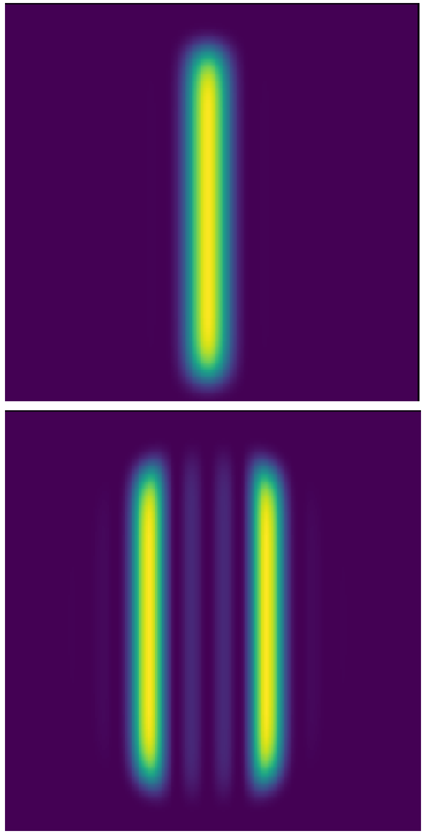
What is the best collection mode bases?



1D depointing: +/- 72 arcsec
Optimal bases



Intensity mode profiles



1D depointing: +/- 180 arcsec
Optimal bases

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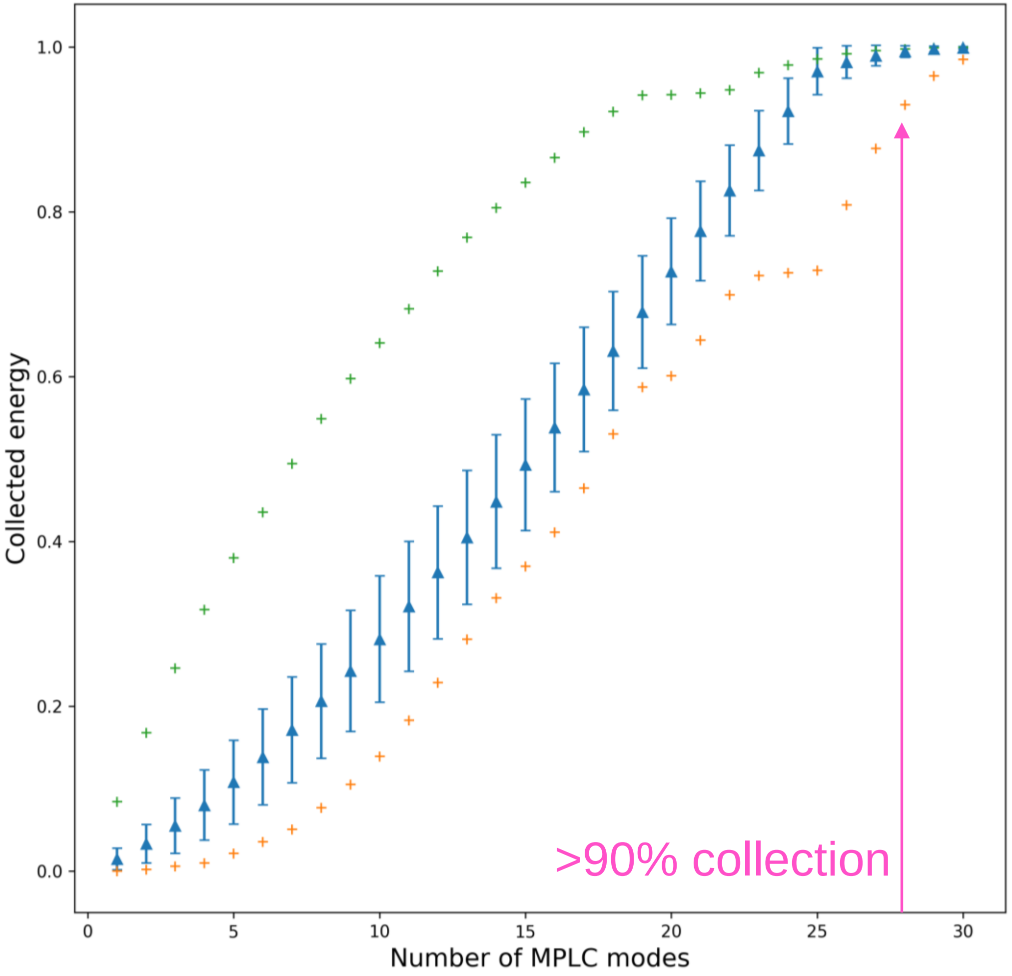
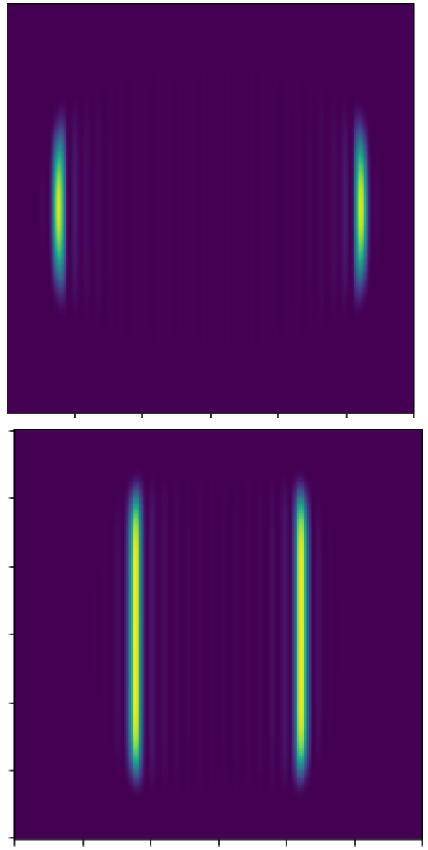


Intensity mode profiles



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2D depointing: +/-36 arcsec

Select the best modes for pointing error compensation

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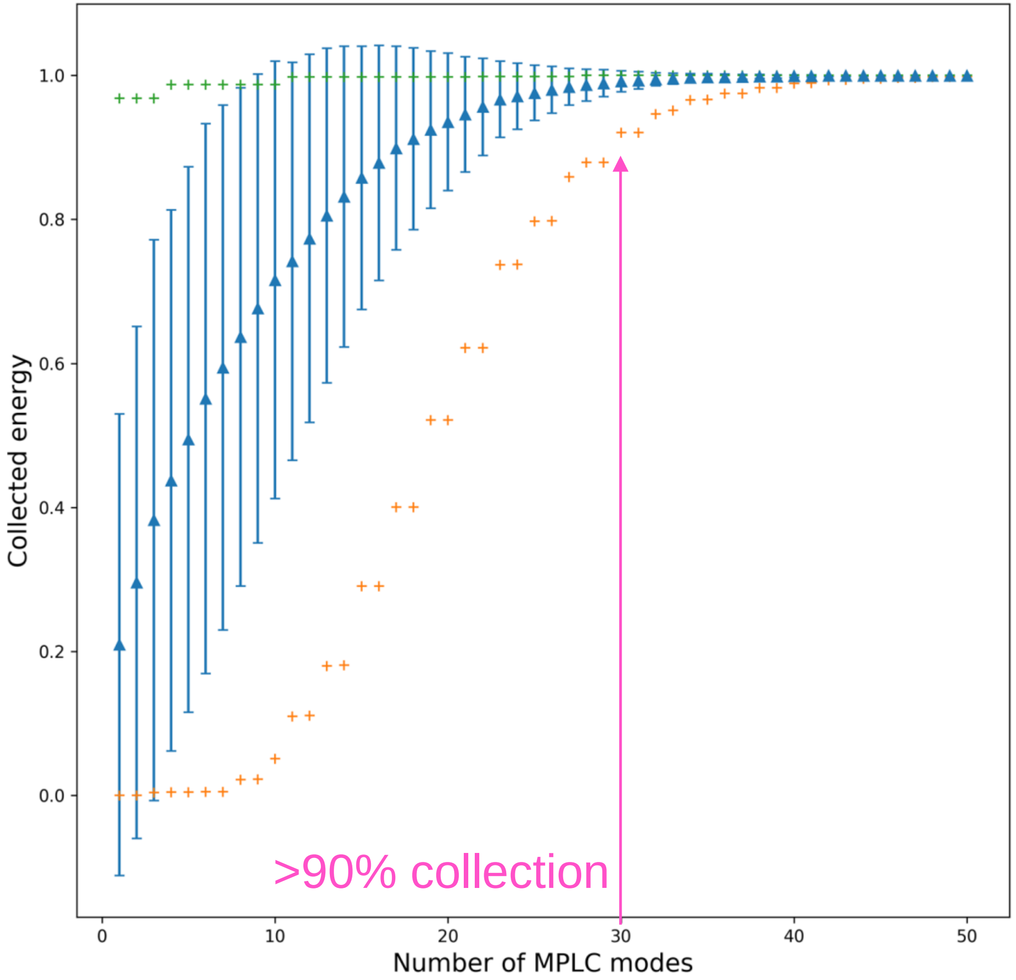
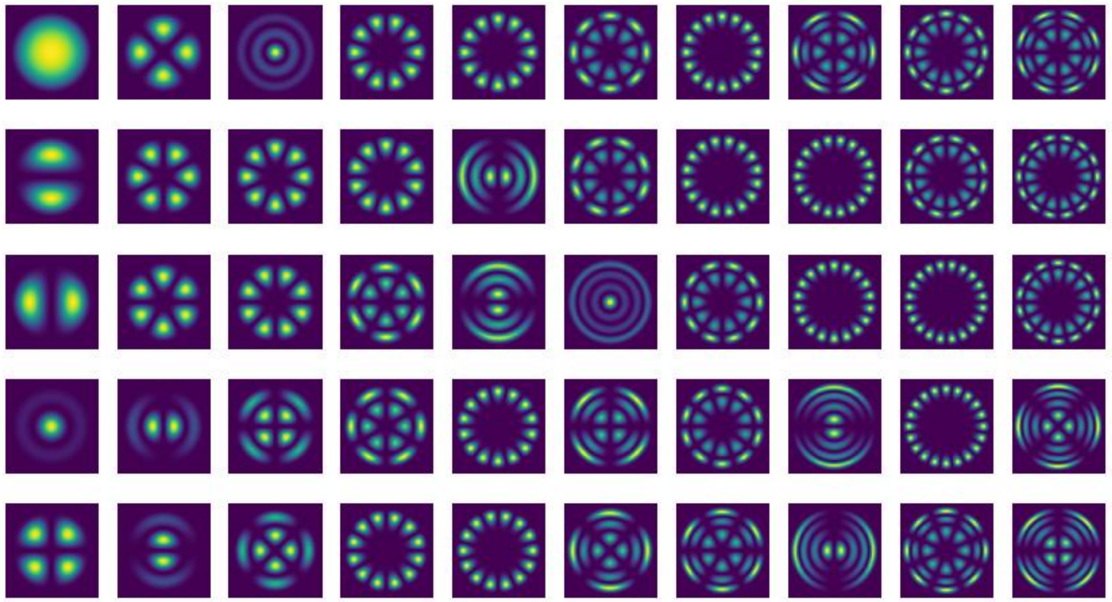


Modes close to LG modes



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Conclusion and Roadmap

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Improves Lasercom at the reception:

- Pointing errors
- Turbulence mitigation

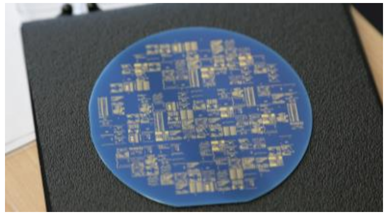
Improves Lasercom at the emission:

- Coherent combining
- Potential for precompensation

Roadmap

2019 | 2020 | 2022 | >2024

Ground station
Field test



Silicon Photonic Chip

Commercial Turbulence
mitigation

Aircraft LaserCom
Network

Thank you for your attention

David@cailabs.com

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