Photonics in ground based astronomy

Oliver Pfuhl

Sylvestre Lacour, Vishaal Gopinath, Norbert Hubin, Steffan Lewis, Samuel Leveque

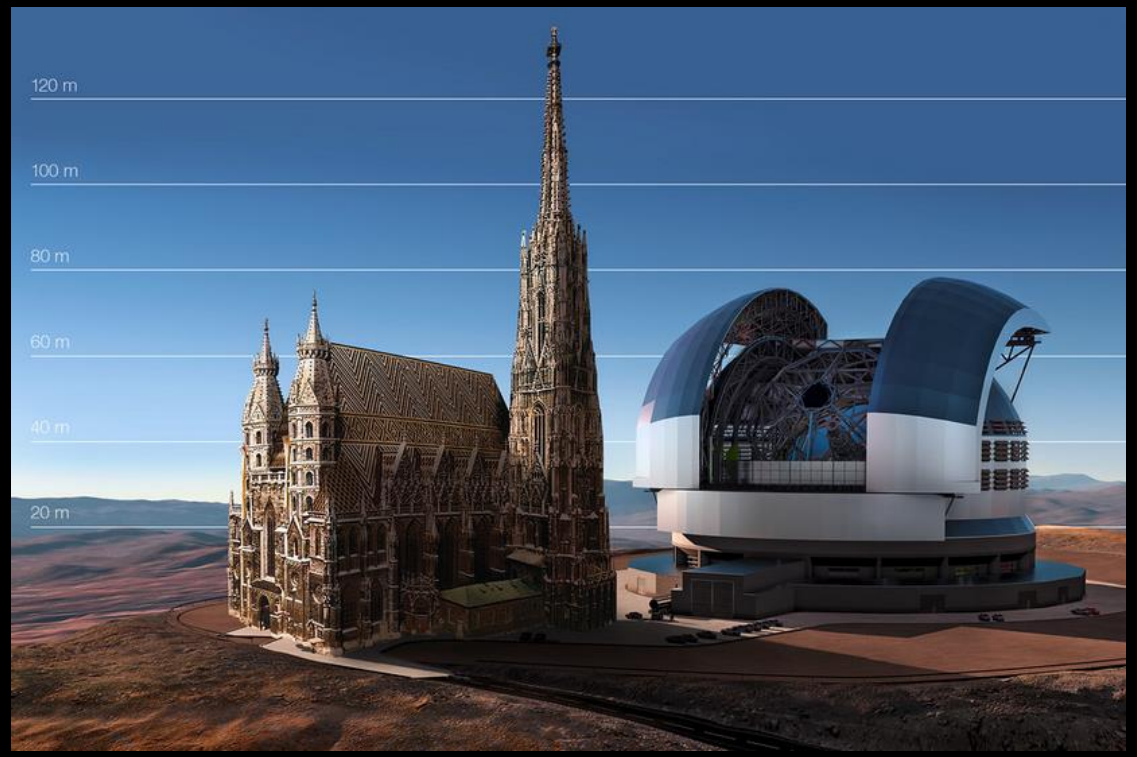
European Southern Observatory

16 European nations + Chile, 3 observatories, largest telescope (39m) under construction

The European Southern Observatory (ESO) is an intergovernmental science and technology organization in astronomy. We focus on the design, construction and operation of powerful ground-based observing facilities for astronomy

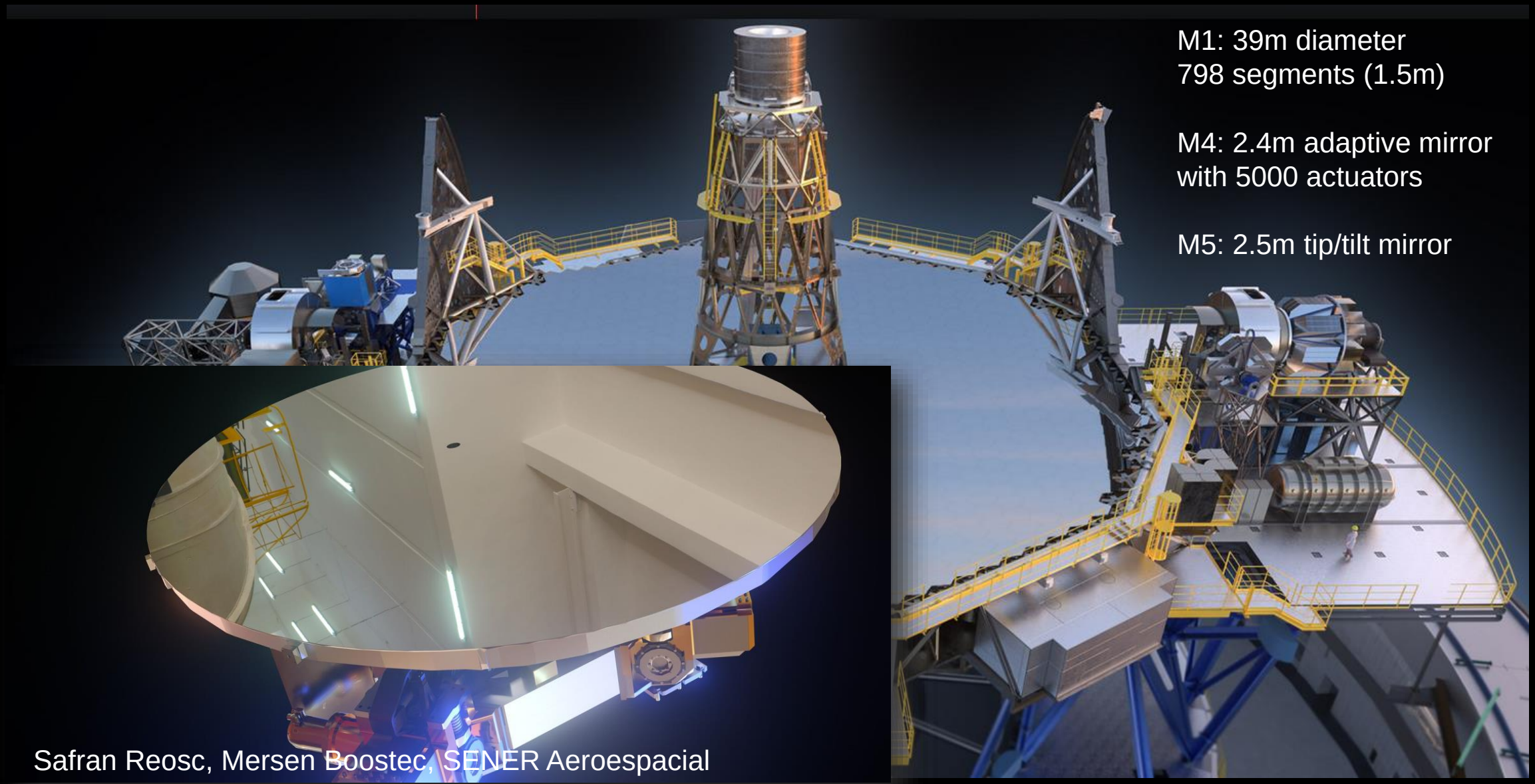
European Southern Observatory

VLT @ Cerro Paranal, Atacama desert, Chile



ELT @ Cerro Armazones, Atacama desert, Chile

ESO ELT



M1: 39m diameter
798 segments (1.5m)

M4: 2.4m adaptive mirror
with 5000 actuators

M5: 2.5m tip/tilt mirror

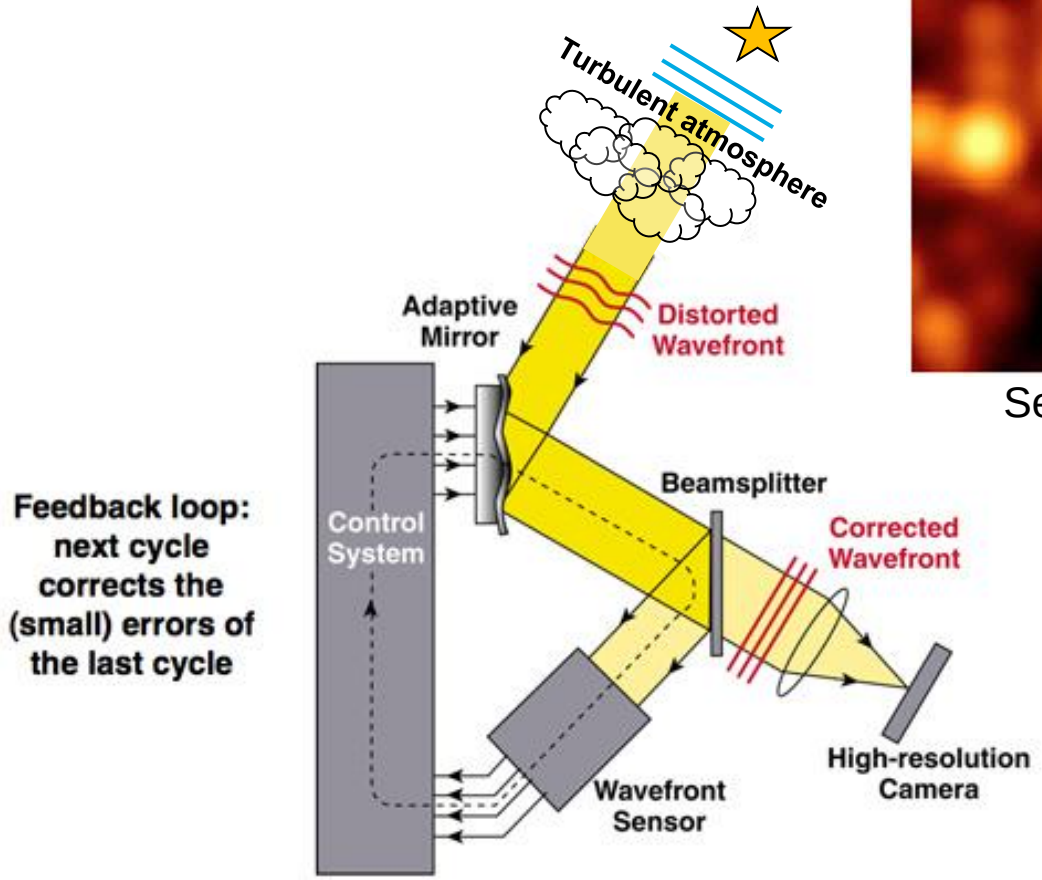
Safran Reosc, Mersen Boostec, SENER Aeroespacial

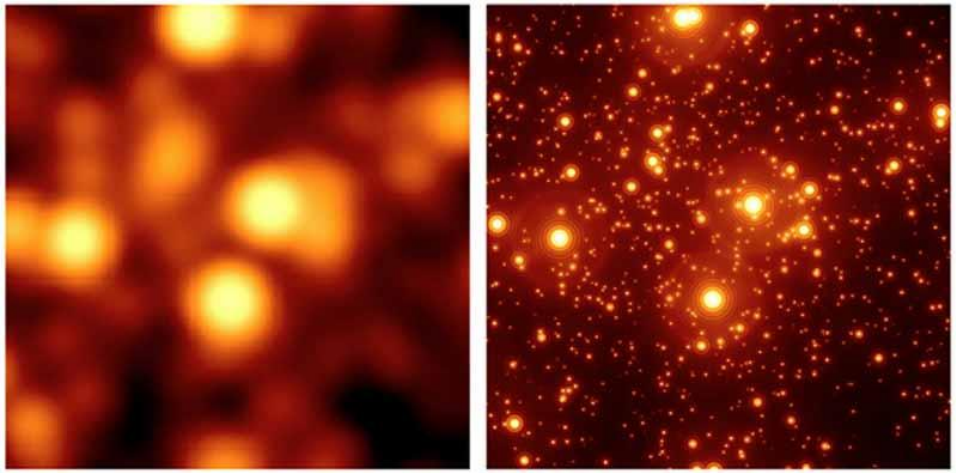
European Southern Observatory

Cerro Armazones, 11th of September 2023, 2 AM

https://elt.eso.org/about/webcams/

Observing through the atmosphere





Seeing limited

Adaptive Optics corrected

Matching the etendue

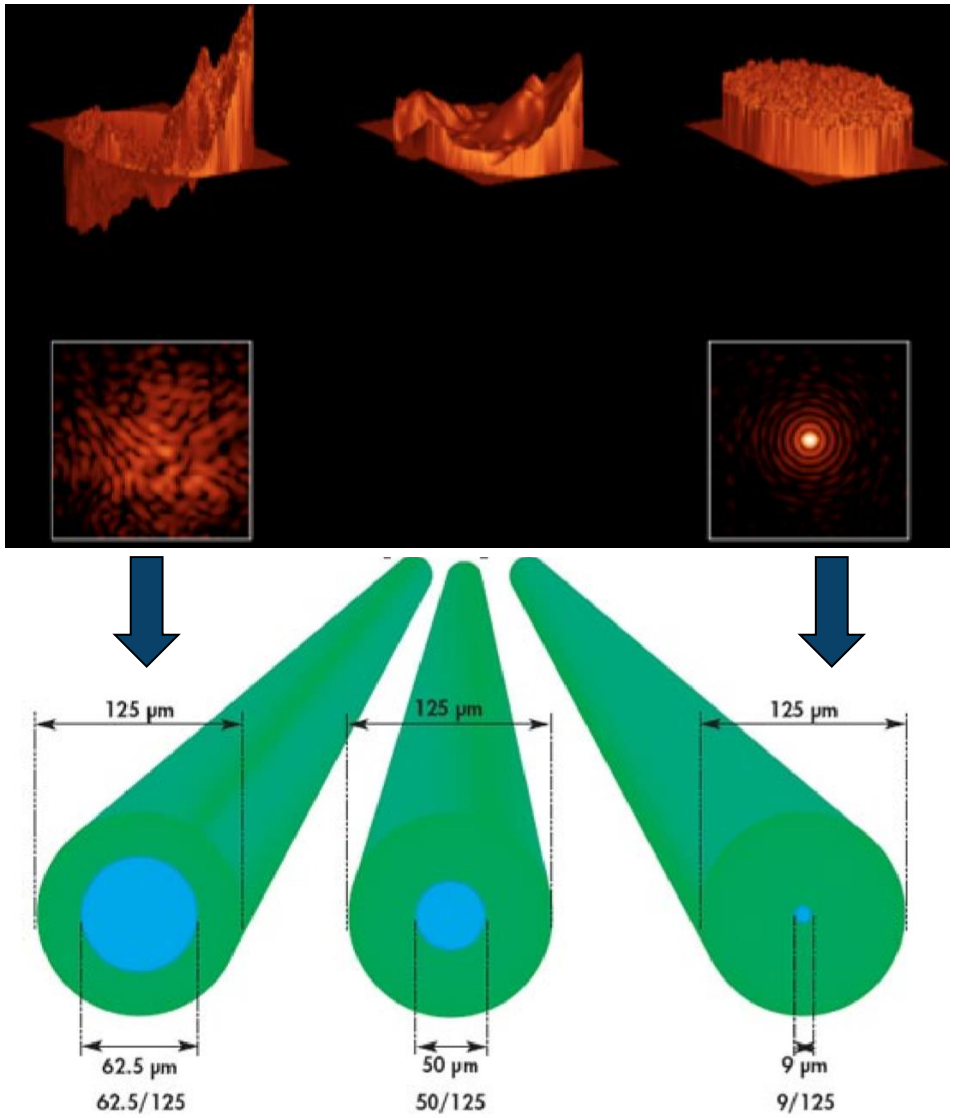
Number of modes equivalent to telescope Point Spread Function

$$M \approx \left(\frac{\pi\theta D}{4\lambda}\right)^2$$

Diffraction limited: $\theta \sim \lambda/D$ => $M \approx 1$

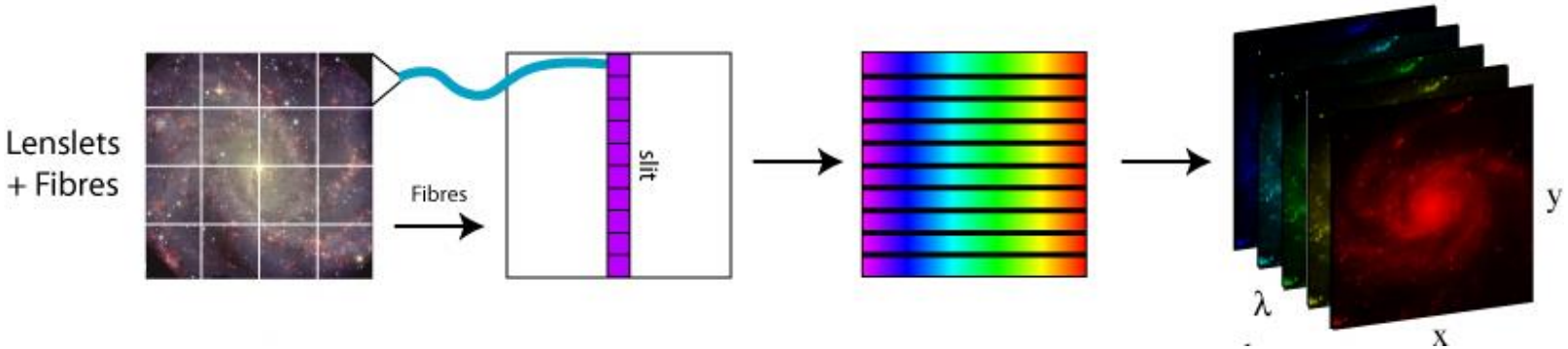
Seeing limited: $\theta \sim \lambda/r_0$ => $M \approx \left(\frac{D}{r_0}\right)^2$ ~100-1000

r0~0.2m (@500nm); r0~0.8m (H-band)

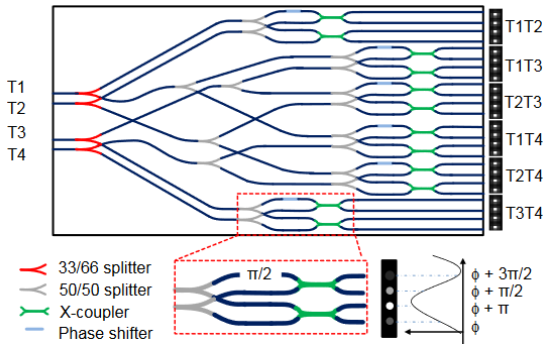


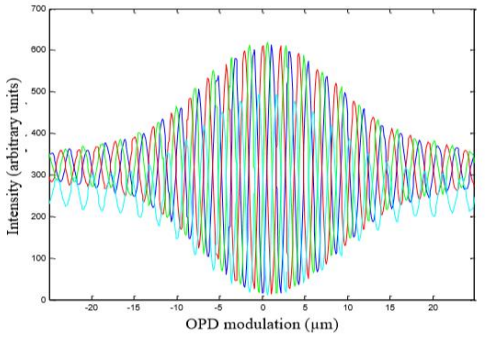
Photonics in Astronomy

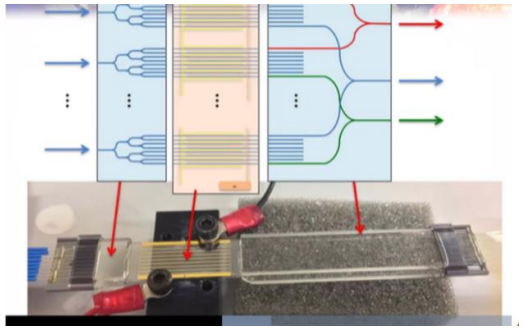
Light transport
multimode / single mode



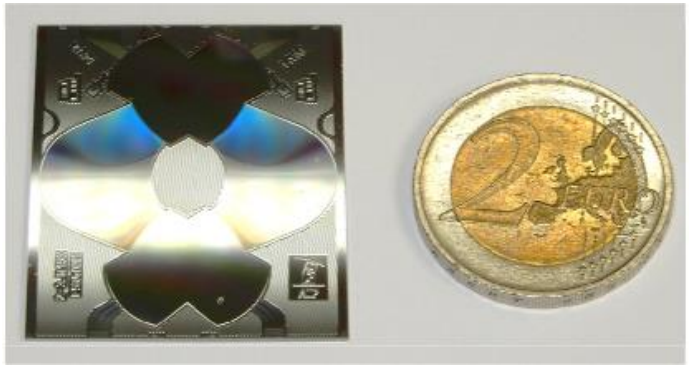
Interferometry
beam combiners, phase-shifters

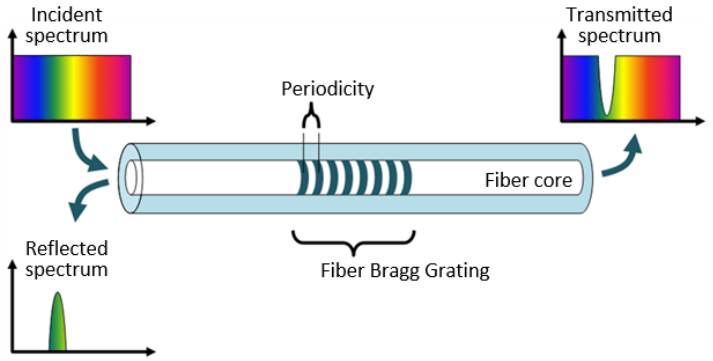






Spectroscopy
gratings / filters





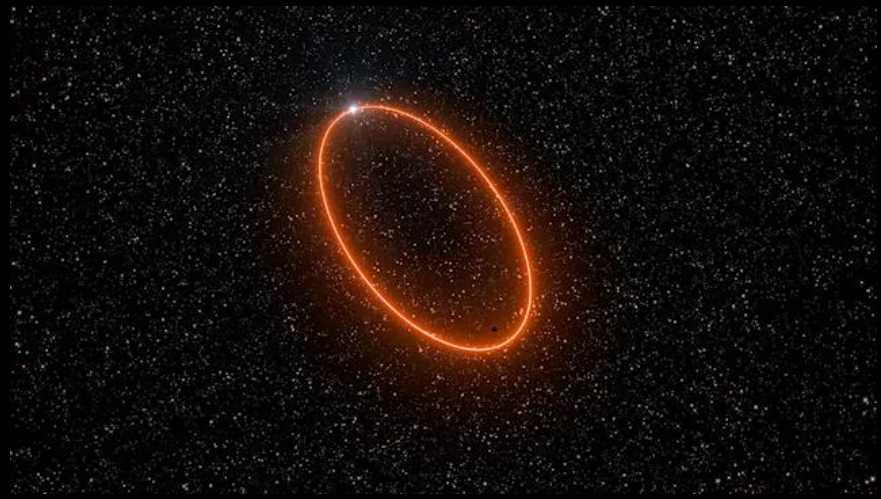
Astrophotonics breakthrough

Nobel prize in physics 2020

GRAVITY collaboration+ 2017

The Nobel Prize in Physics 2020 to Reinhard Genzel and Andrea Ghez for the "discovery of a supermassive compact object at the centre of our galaxy" and to Roger Penrose "for the discovery that black hole formation is a robust prediction of the general theory of relativity"

Gravitational redshift and Schwarzschild precession measured with GRAVITY in 2018/19

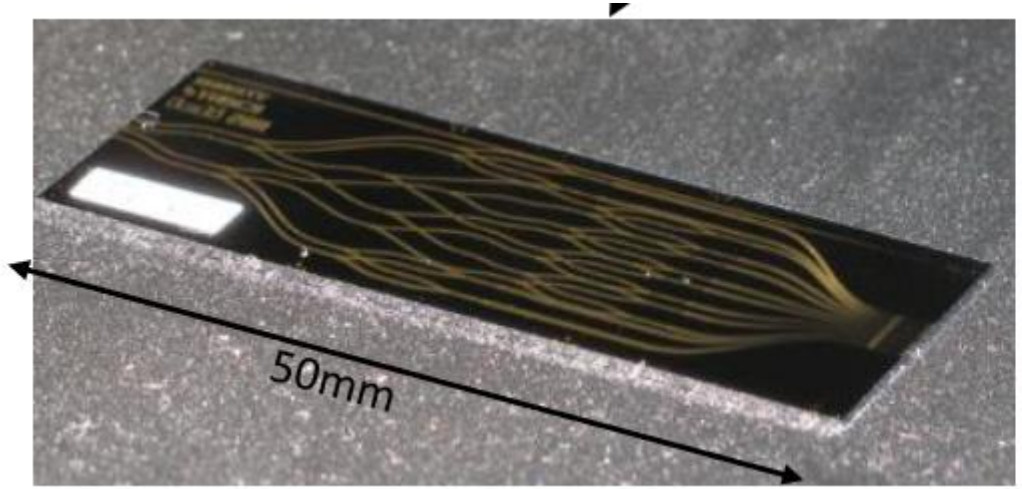


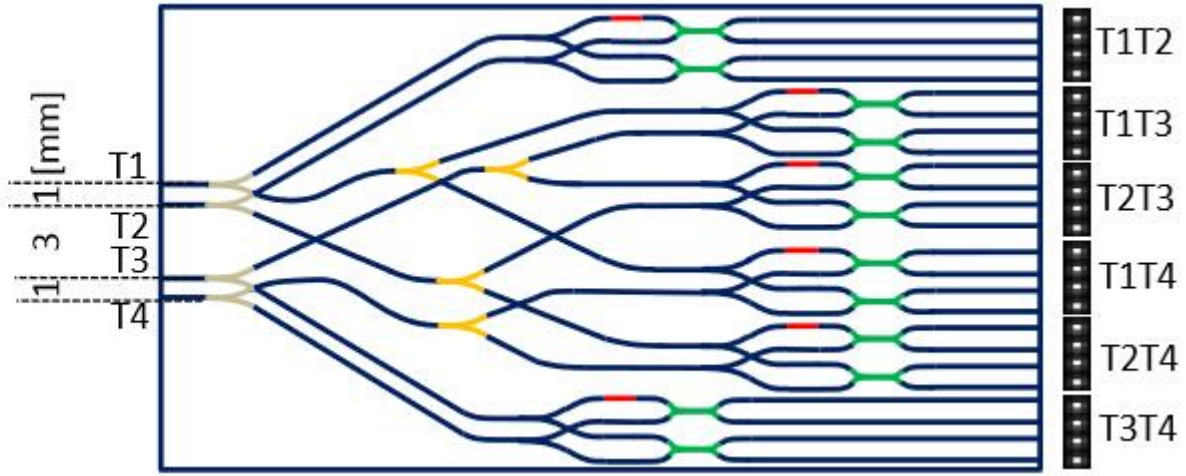
Courtesy ESO

GRAVITY collaboration+ 2018,2019

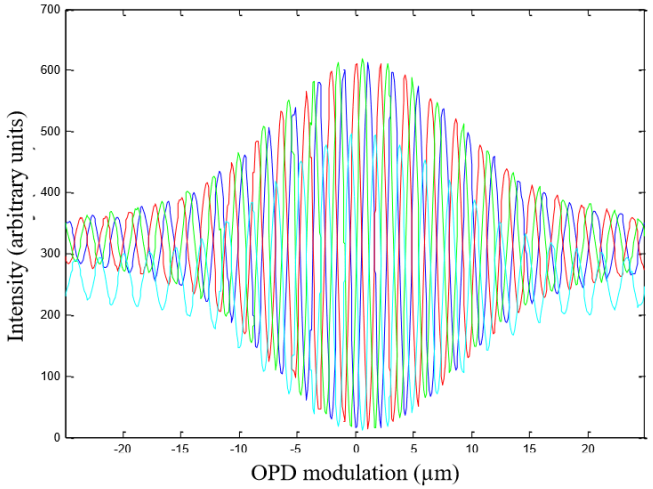
Beam combiner chip

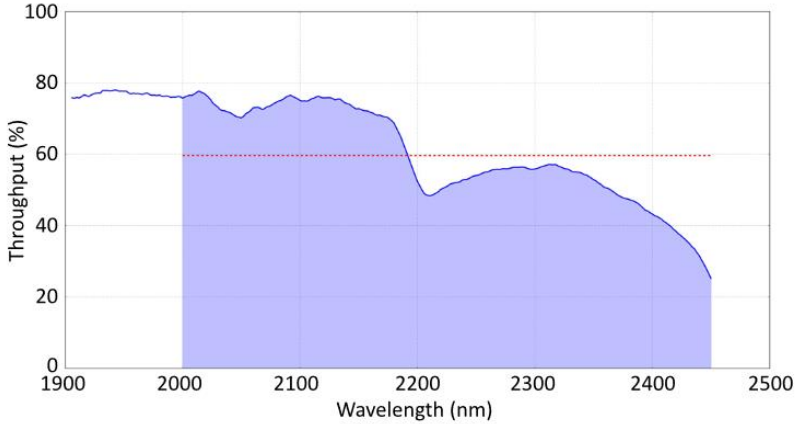
Stability is key



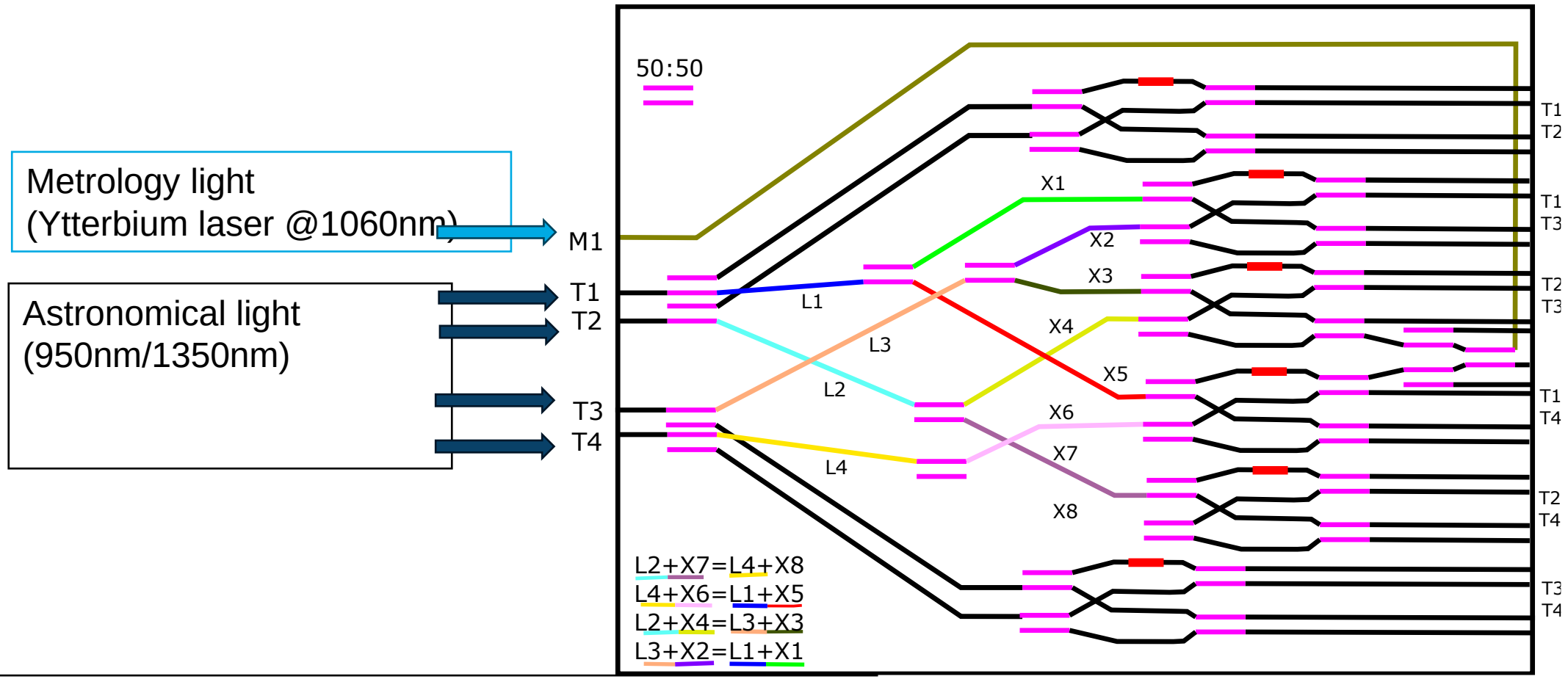


- Silica-on-Silicon chip
- 4 telescope beam combiner
- Wavelenght range: 1.9-2.45 um
- Fed by ZBLAN fibers

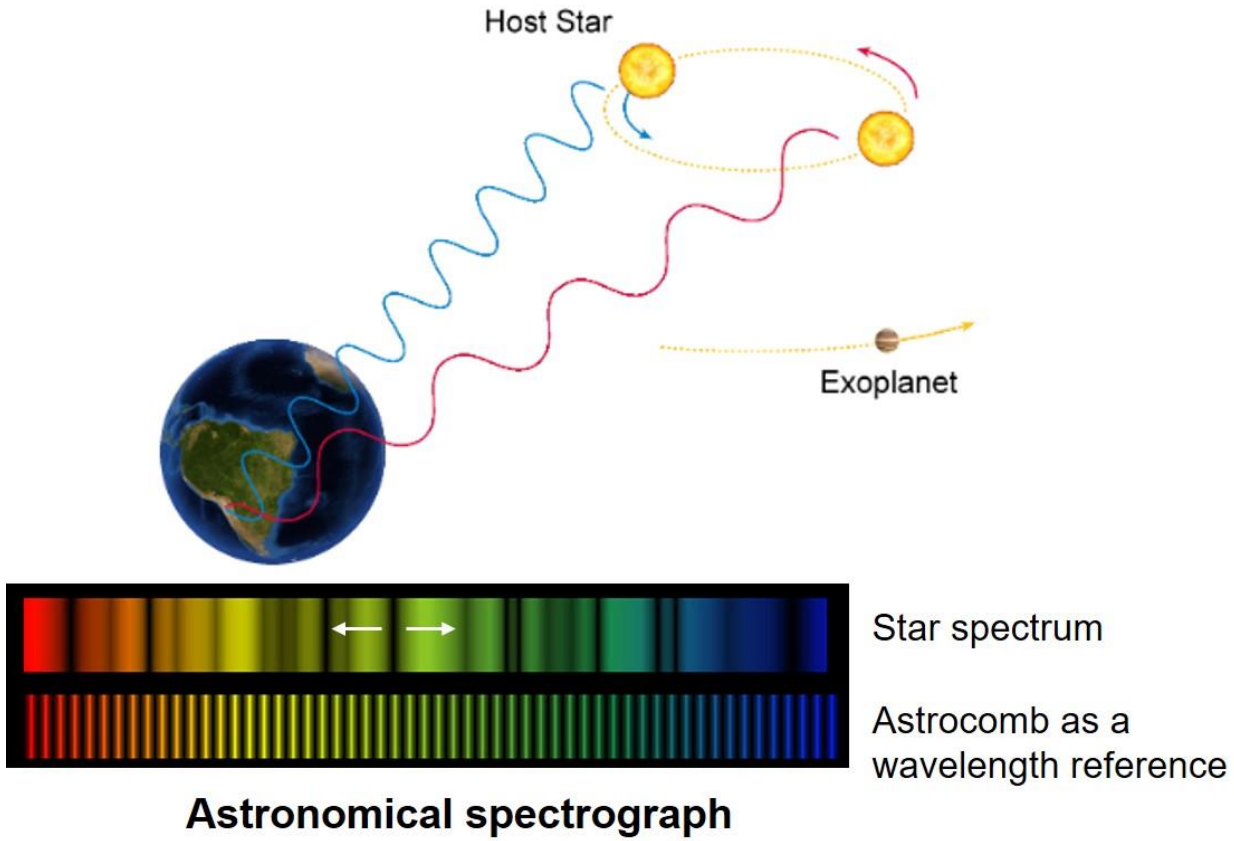


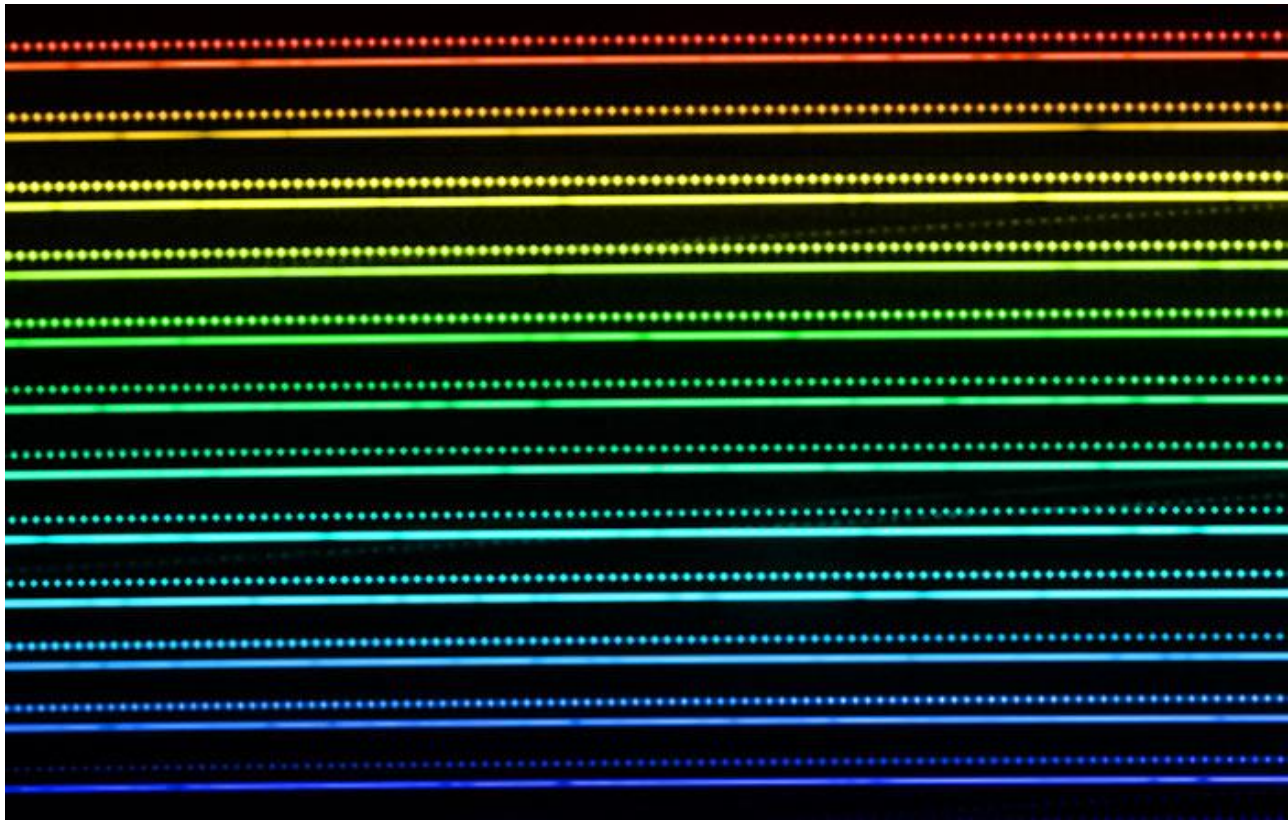


J band interferometry with internal metrology



Astrocombs
Laser Frequency Combs for Astronomy

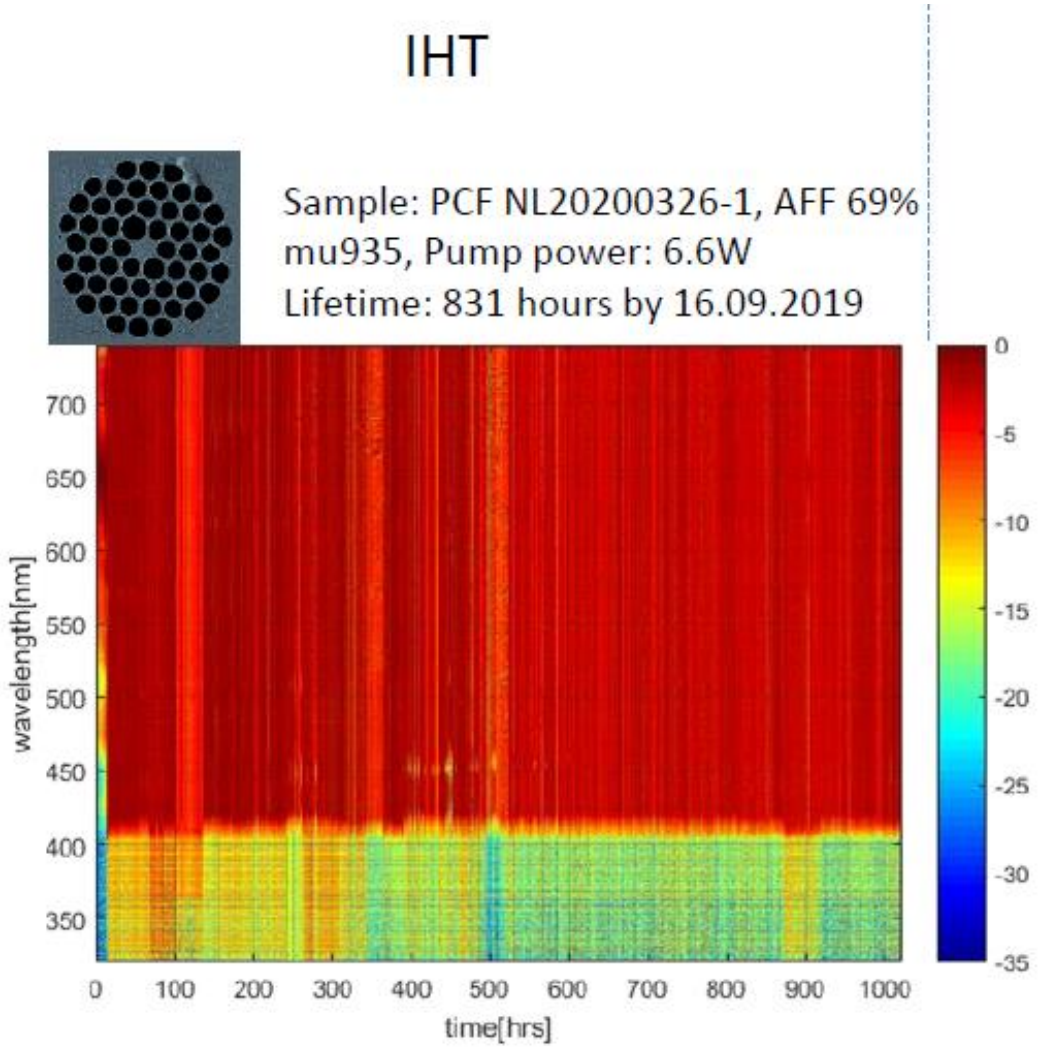




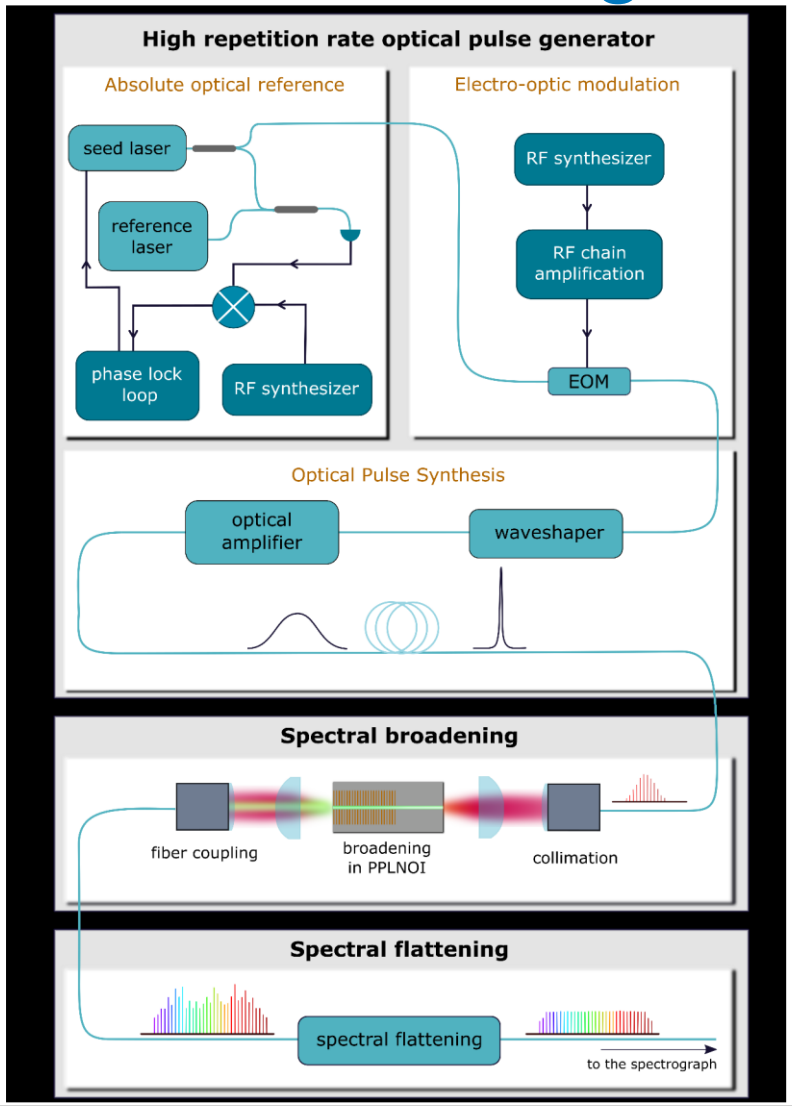
Δv ~ 10cm/s for earth revolving around the sun
$(df/f = 3 \cdot 10^{-8})$

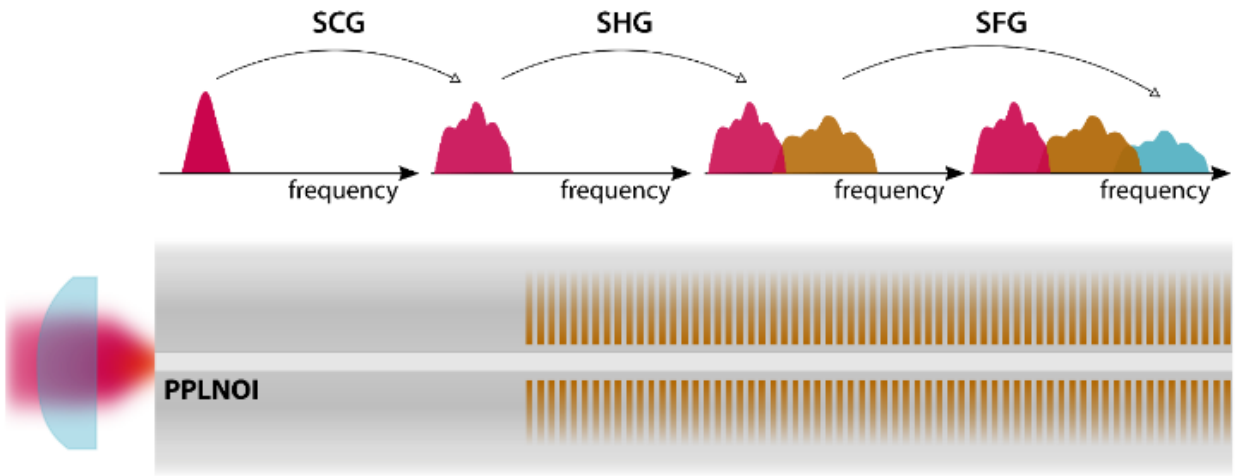
Astrocombs
Laser Frequency Combs for Astronomy

MenloSystems



ASTROCOMB 2nd generation

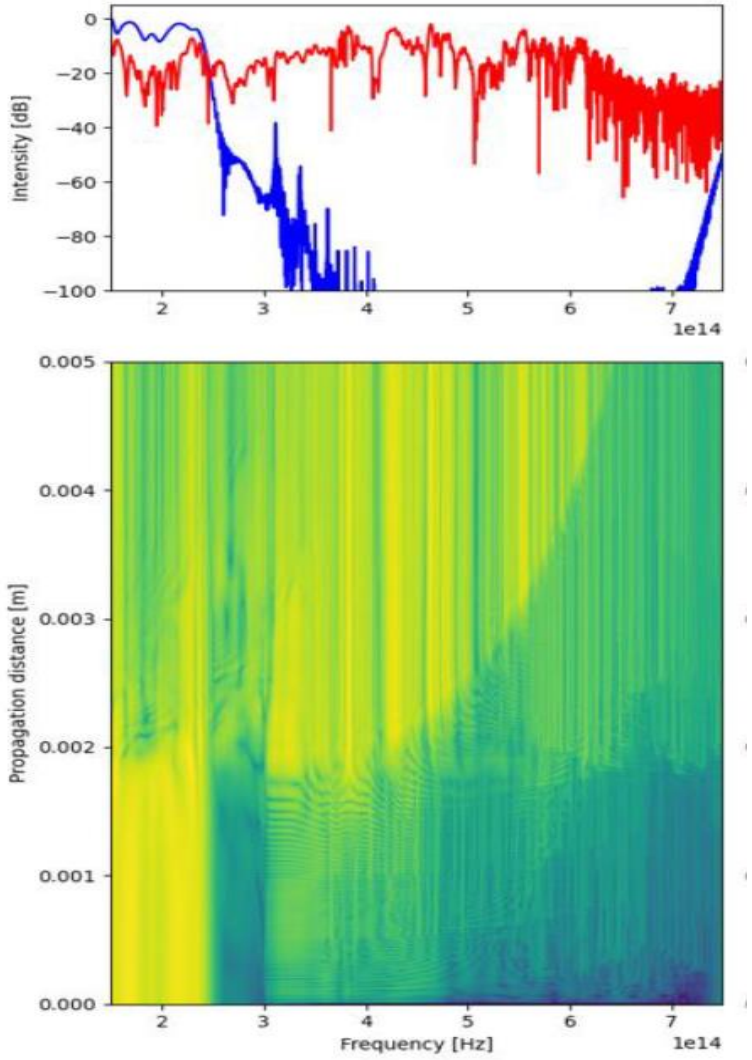




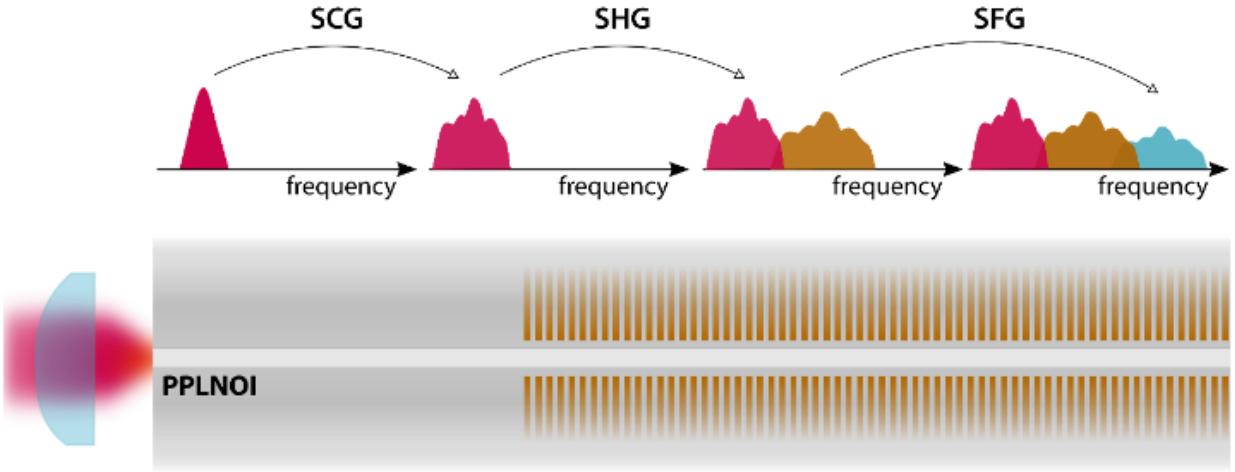
Under study:
3 step broadening in single LiN chip

- Super continuum generation
- Second harmonic generation
- Sum-frequency generation

ASTROCOMB 2nd generation



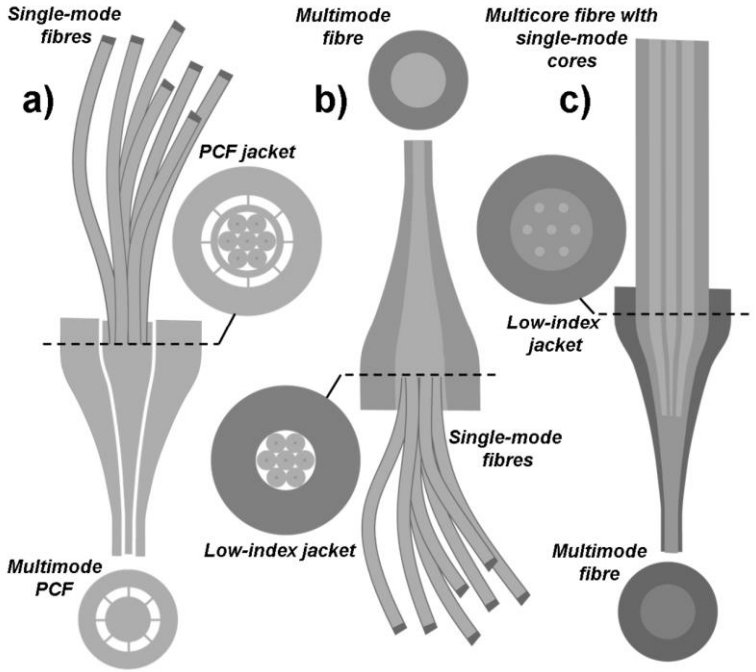
Simulation
T. Herr, DESY



- Wavelength range: 0.4 – 1.8um

Visible Photonic Lantern on SCExAO / Subaru telescope

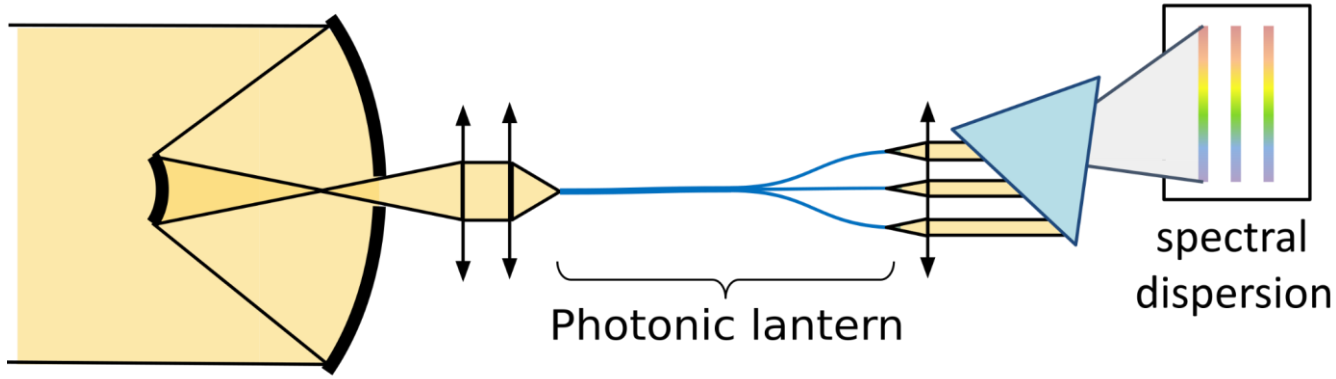
Photonic lanterns for more photons



*Schematics representation of three different approaches for the fabrication of Photonic Lanterns; a) PCF technique; b) Standard single-mode fiber combiner/splitter technique; and c) Multicore fibre approach. From Leon-Saval et al. "*Photonic Lanterns: a study of light propagation in multimode to single-mode converters*" OSA 2010*

Photonic Lantern = Fibered device with Multi-Mode (MM) input and several Single-Mode (SM) outputs

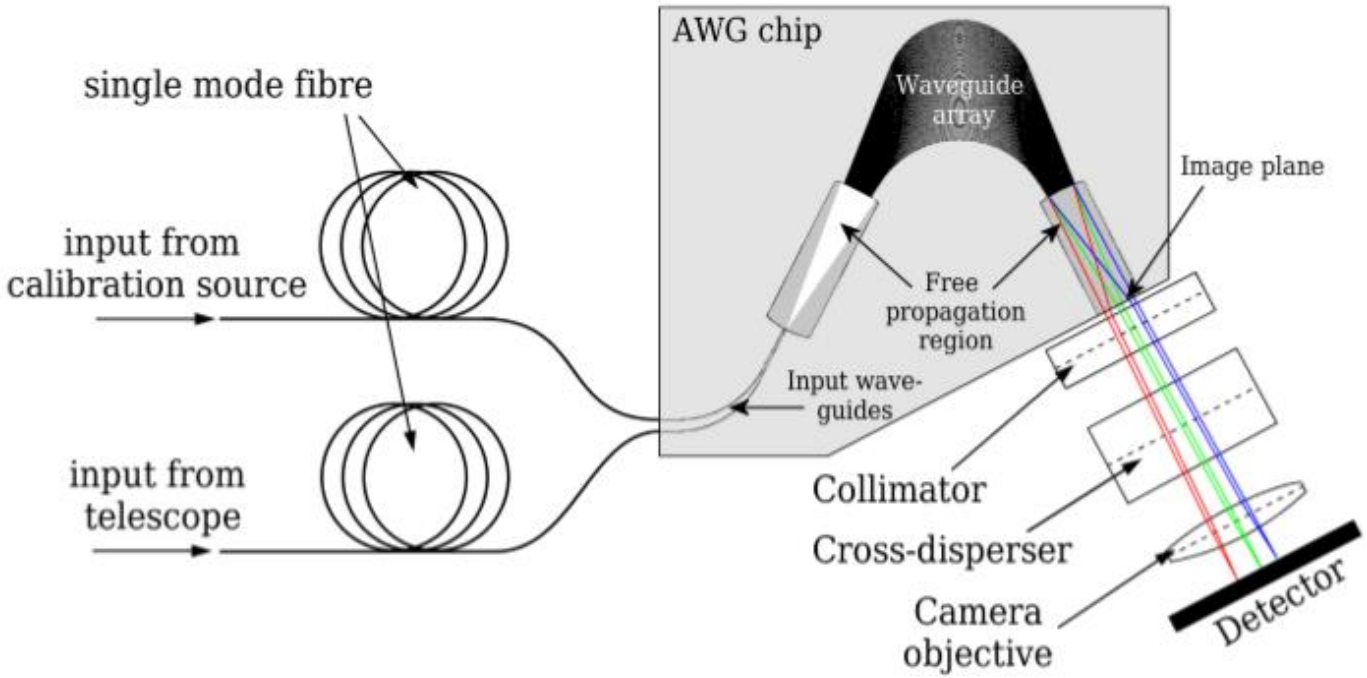
- Adiabatic transition between MM to SM mode
  very efficient (>90%, Birks et al. 2015)
- Allows for SMF-fed spectroscopy with high throughput

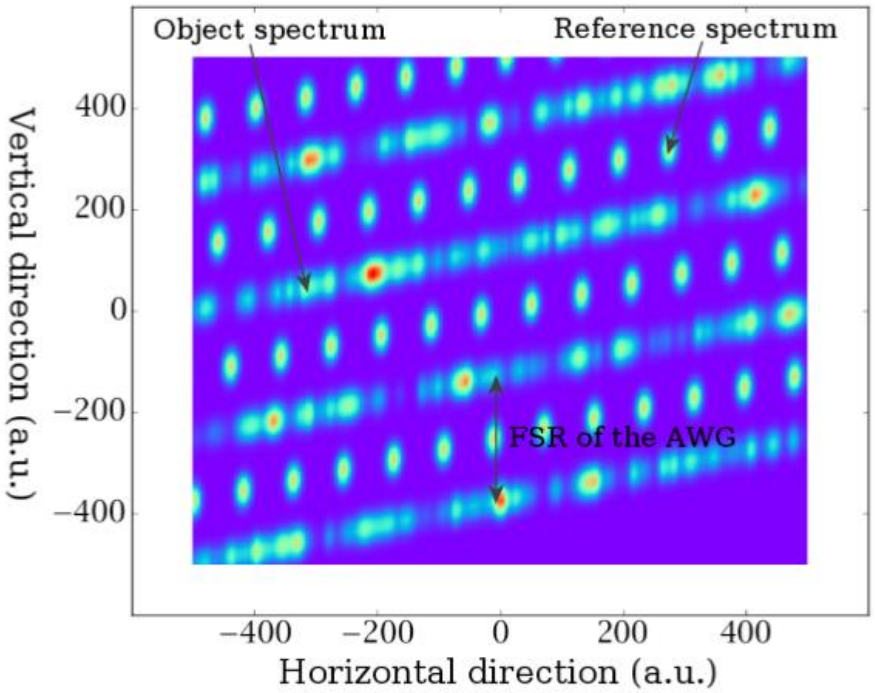


Photonic Lantern spectroscopy instrument concept

Sébastien Vievard, Manon Lallement, Sergio Leon-Saval, Olivier Guyon, Elsa Huby, Sylvestre Lacour, Nemanja Jovanovic

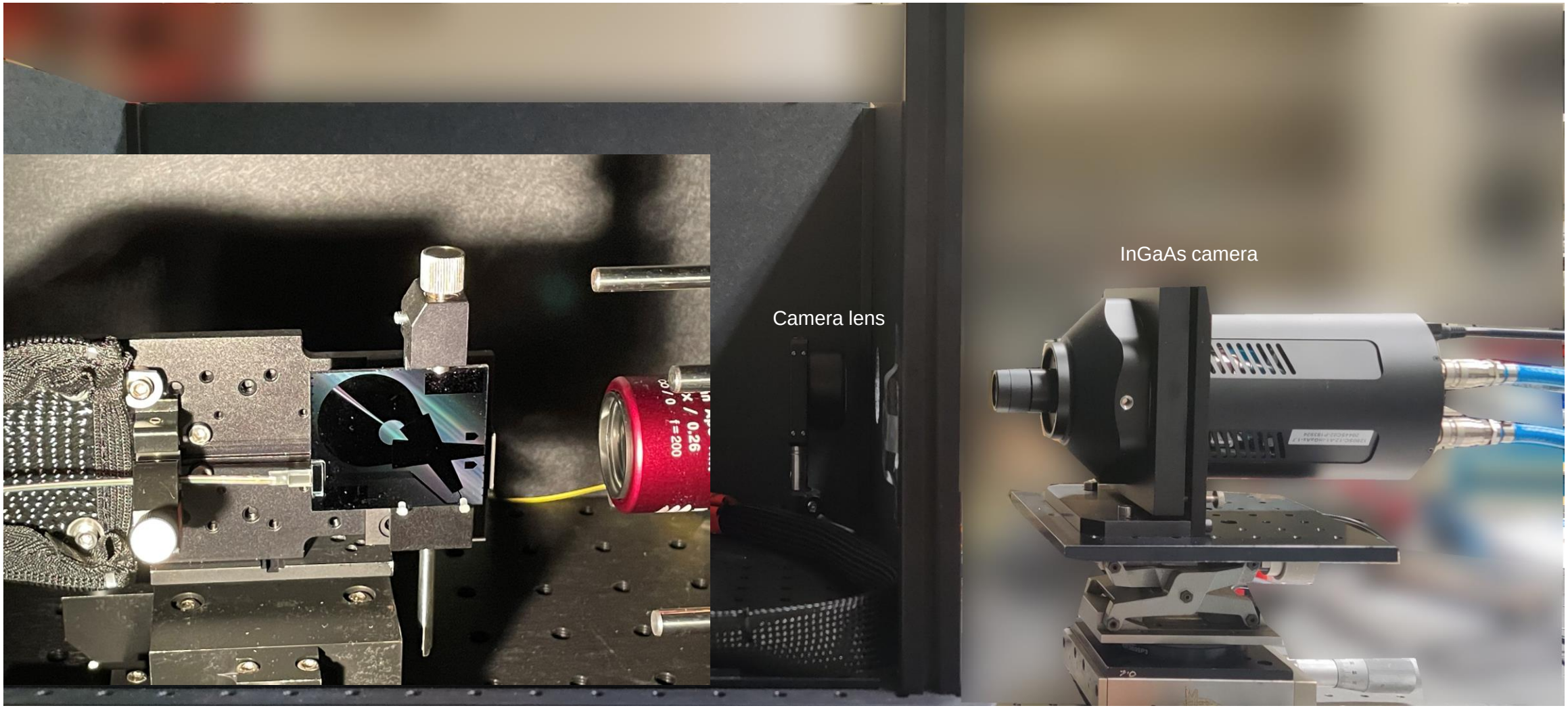
Photonic spectrograph



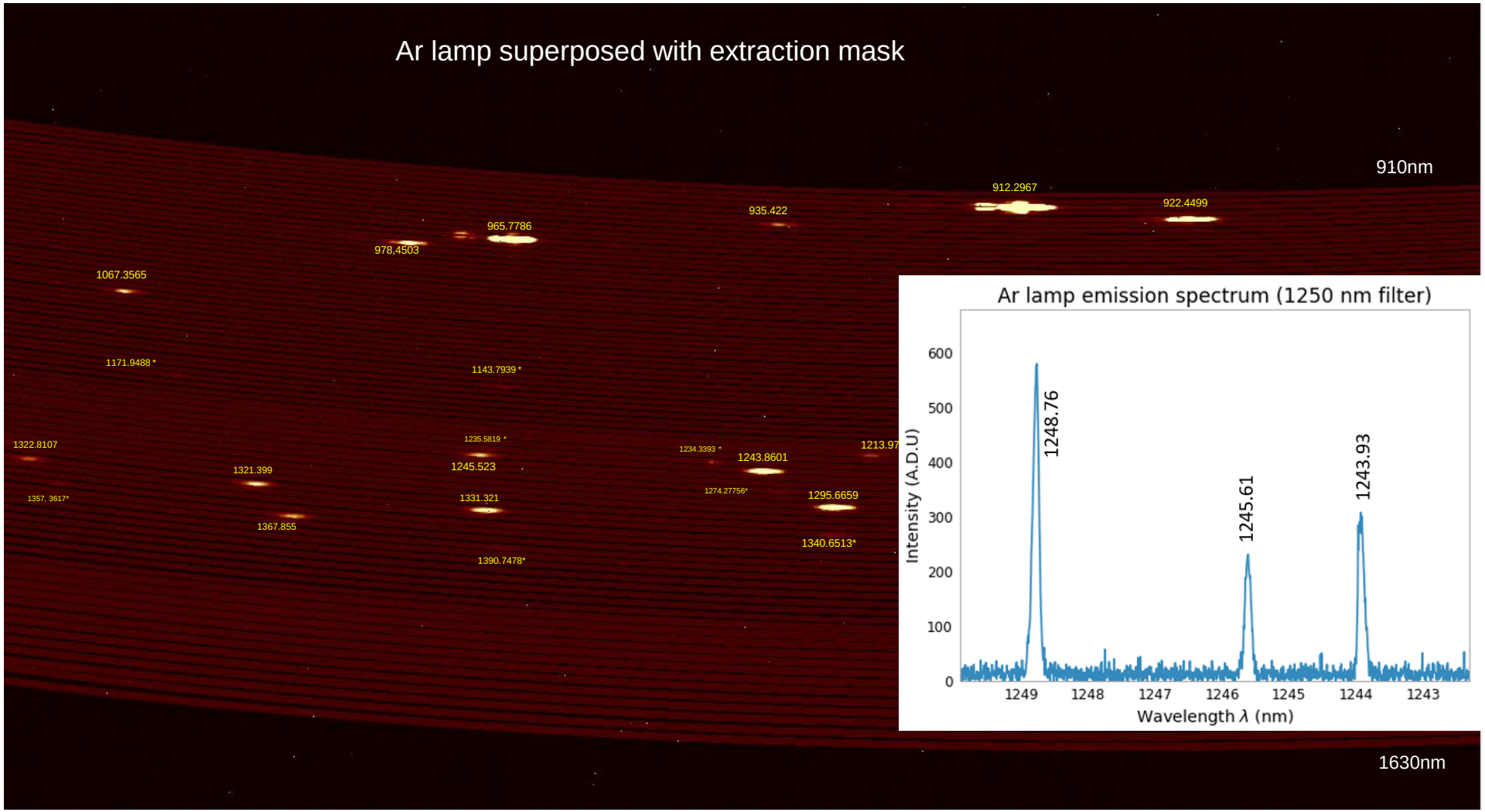


Stoll et al 2017

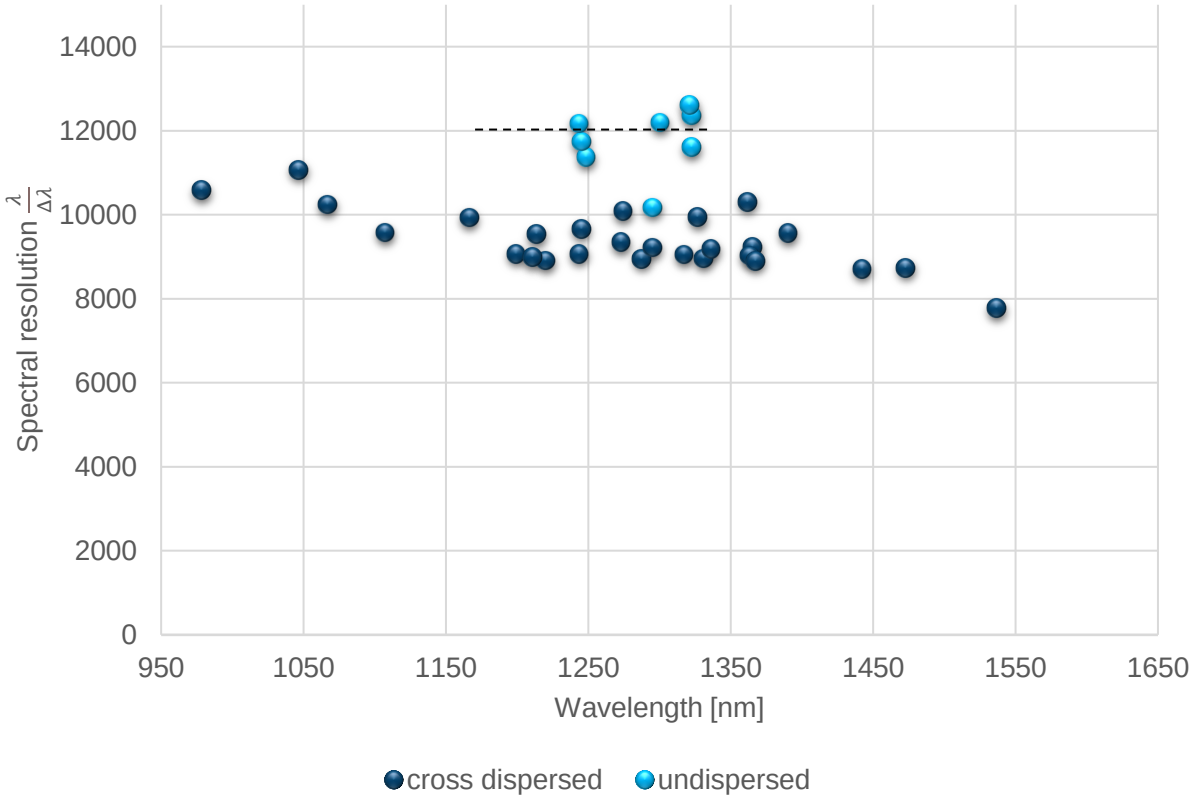
AWG test

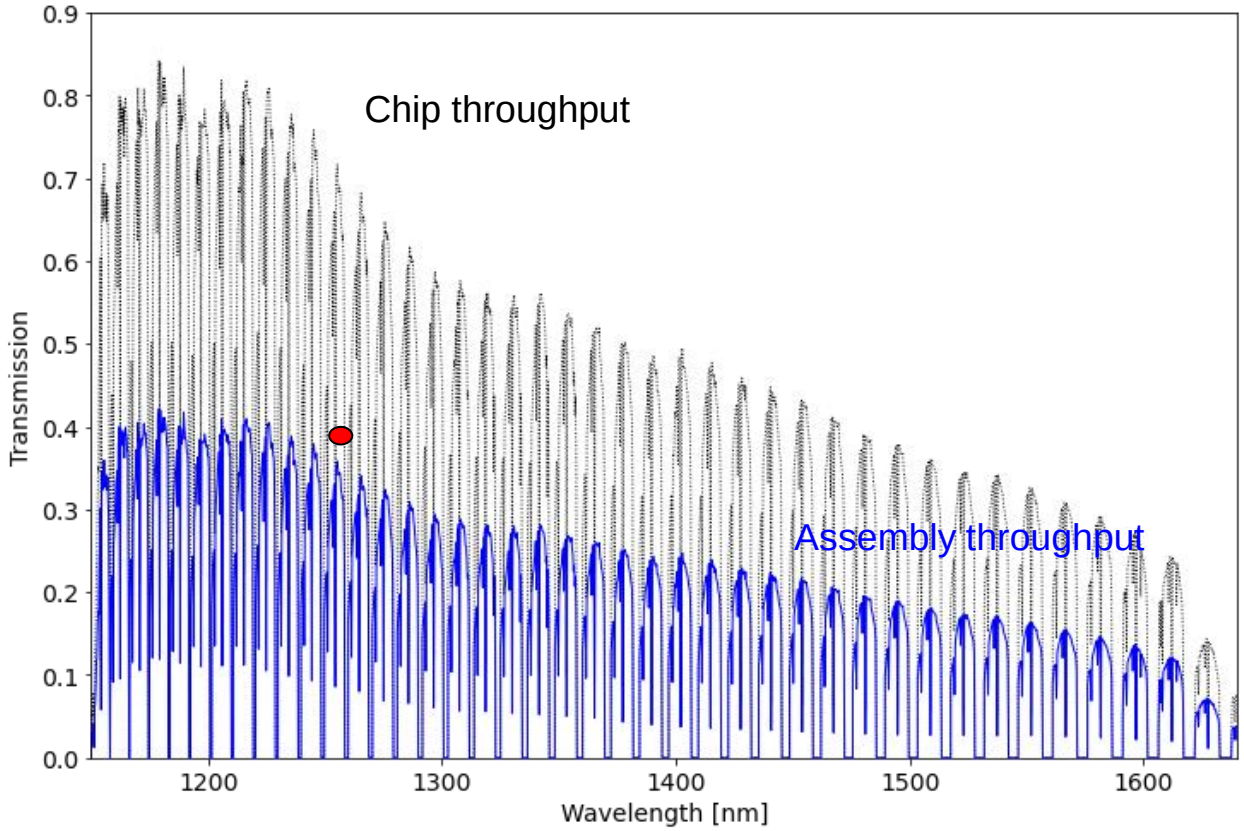


AWG cross-dispersed



AWG performance

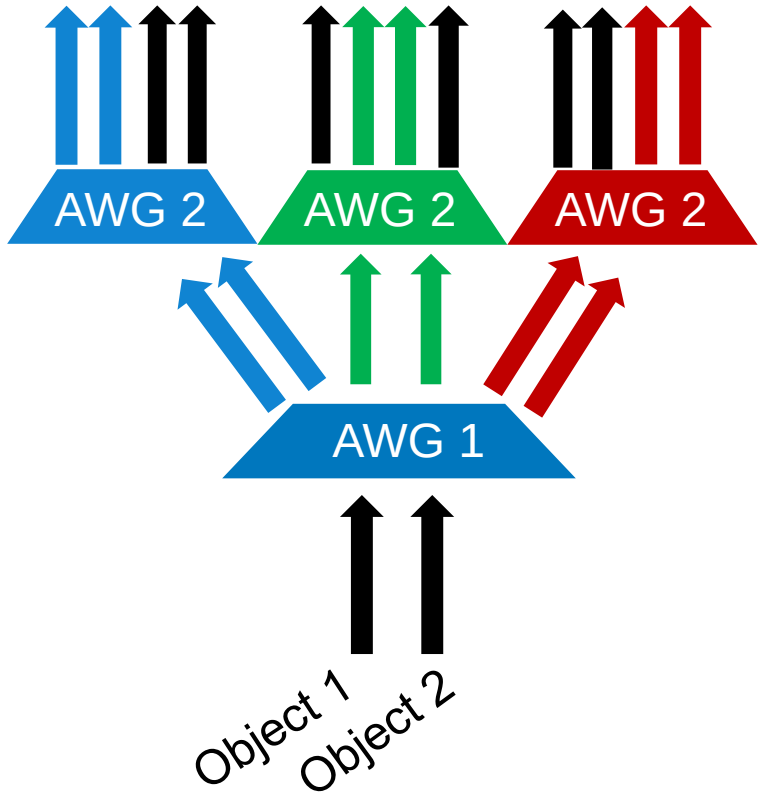




Wishlist for photonic components

Spectroscopy

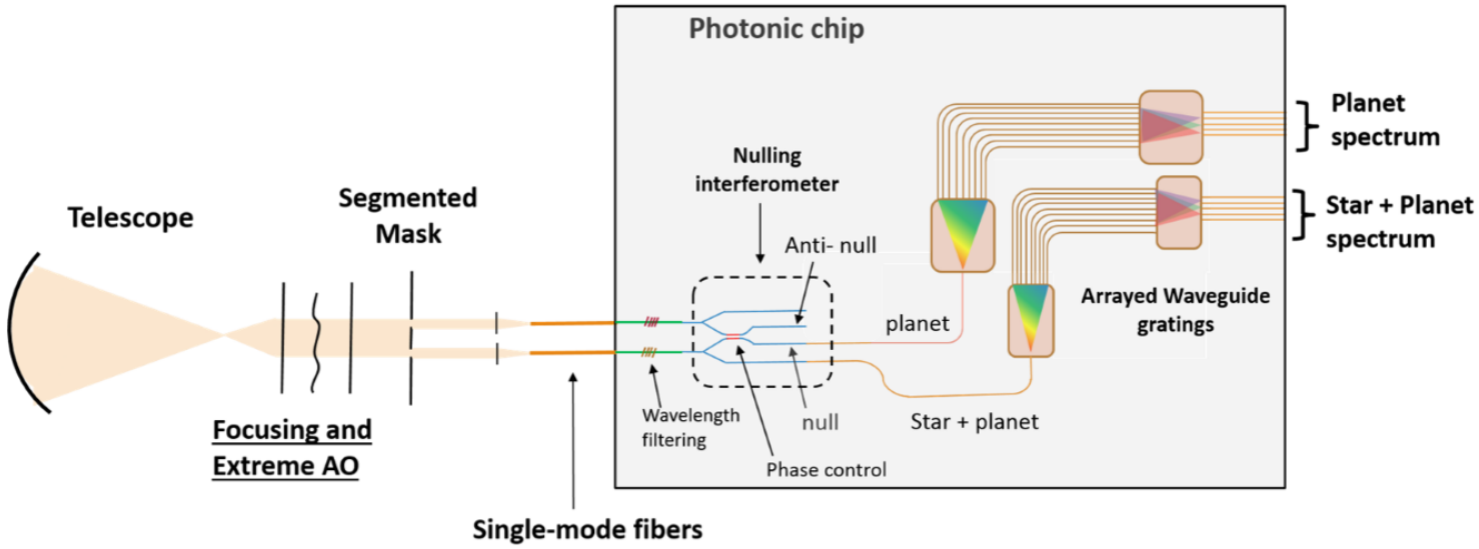
- High spectral resolution (R~100,000)
- Wide wavelength range 1-2.4um (e.g. cascaded AWGs)
- High throughput (incl. injection efficiency)
- Multiplexing capability



Wishlist for photonic components

Interferometry on a chip

- Beamcombiner
- EO phase shifters
- AWGs
- On a single chip

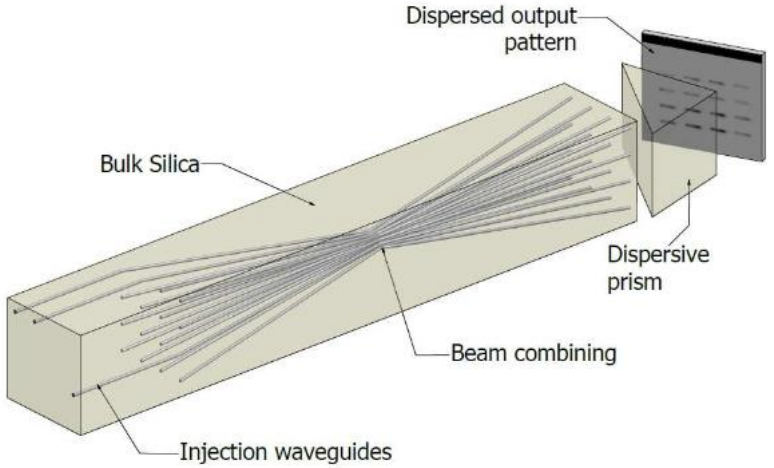


Gatkine et al 2019

Wishlist for photonic components

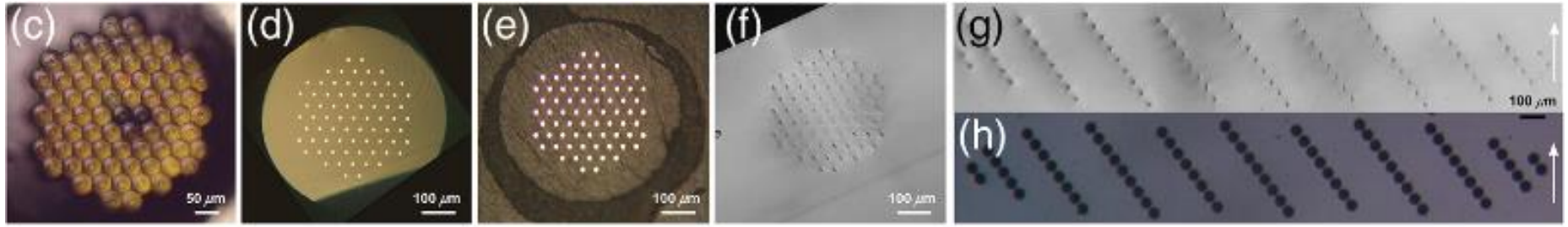
3D photonic components

- Reformat e.g. multi-core fibers to linear arrays



Minardi+ 2012

3D reformatter



Haffert+ 2021

Thank you!

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