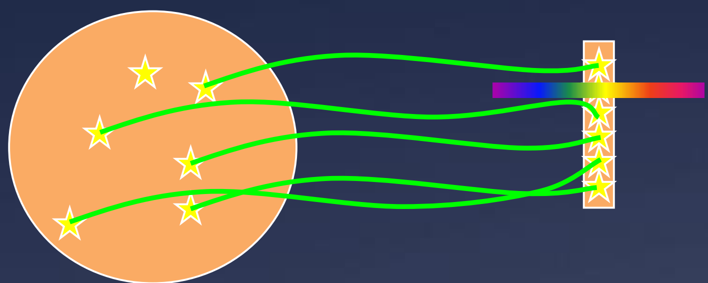
Astrophotonics: the ideal toolkit for Antarctic Observatories

N. Jovanovic,
O. Guyon, N. Cvetojevic, C. Schwab, B. Norris, S. Gross, S. Leon-Saval, P. Tuthill, F. Martinache

Subaru Telescope, National Astronomical Observatory of Japan
The University of Sydney
Macquarie University
Observatoire de la Cote d'Azur

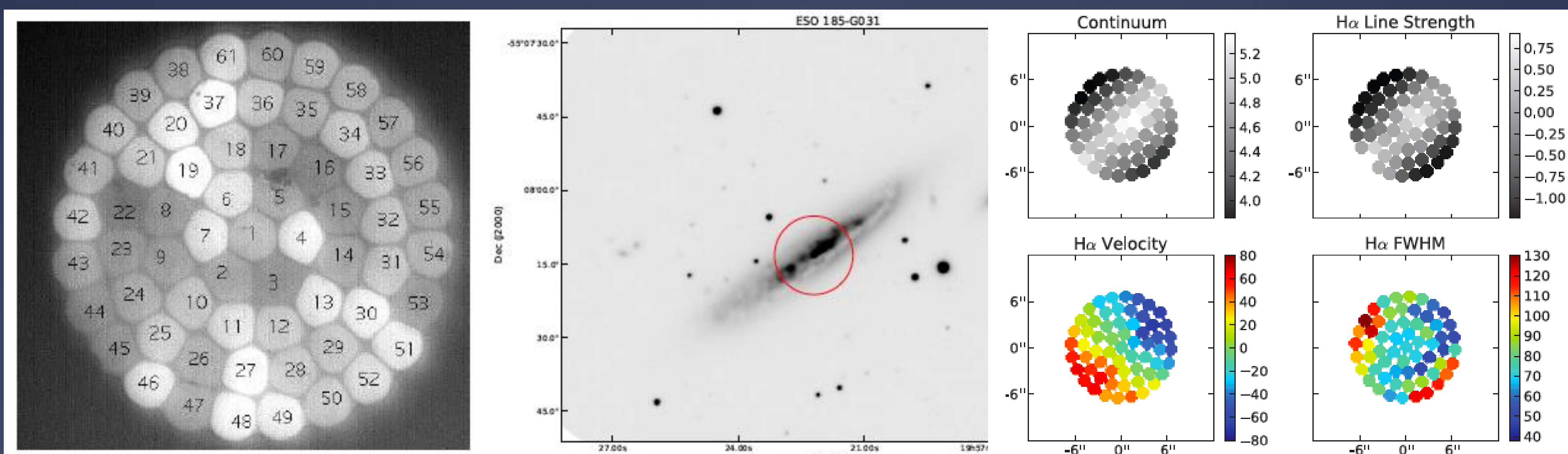
Key areas of Astrophotonic developments

Most common use of photonics: multimode fiber transport to spectrographs.



MMF based instruments:

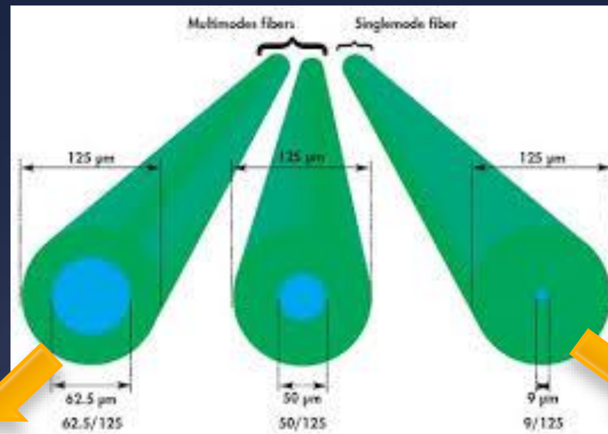
- PRAXIS
- SAMI
- 2DF/AAOmega
- HEXDET
- SDSS
- HARPS N/S
- FMOS



J. J. Bryant et al, MNRAS, 415, 2173 (2011)

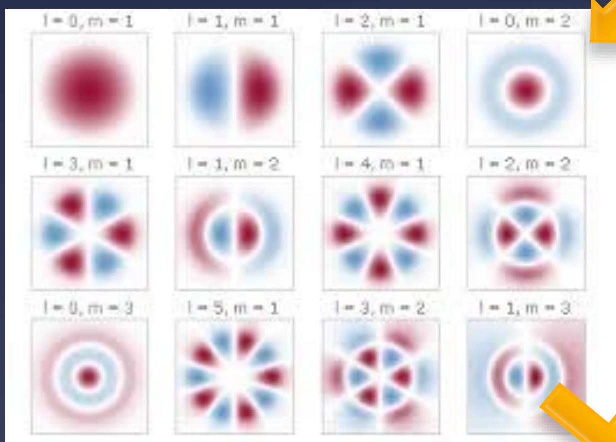
Fogarty et al, http://arxiv.org/pdf/1211.0352.pdf

The two photonic categories



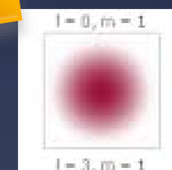
MMF - Bucket of light

Easy to inject light efficiently

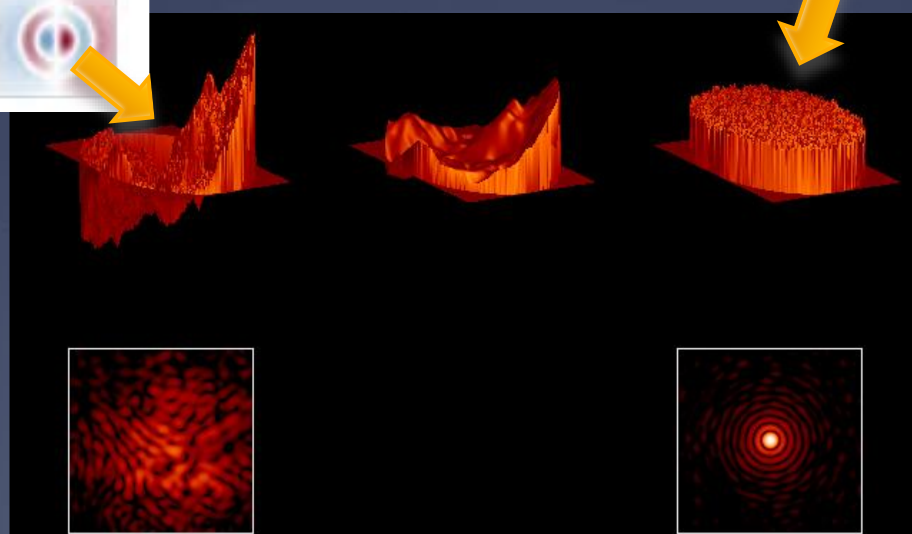


SMF – Spatial filter

Difficult to inject light efficiently

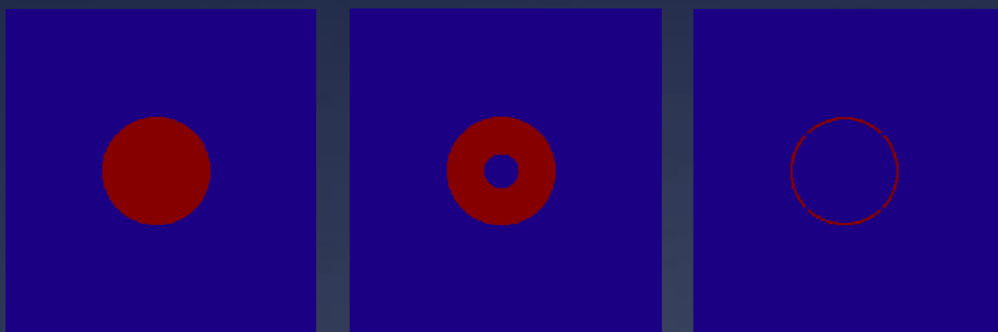


- Flat wavefront
- Gaussian intensity profile

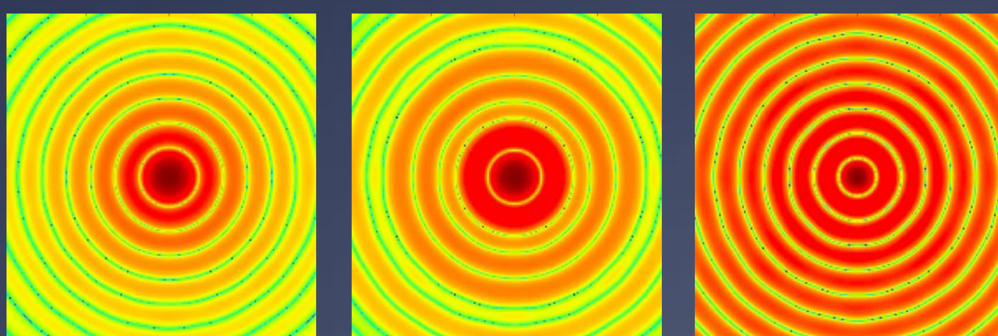


Coupling with an Airy pattern

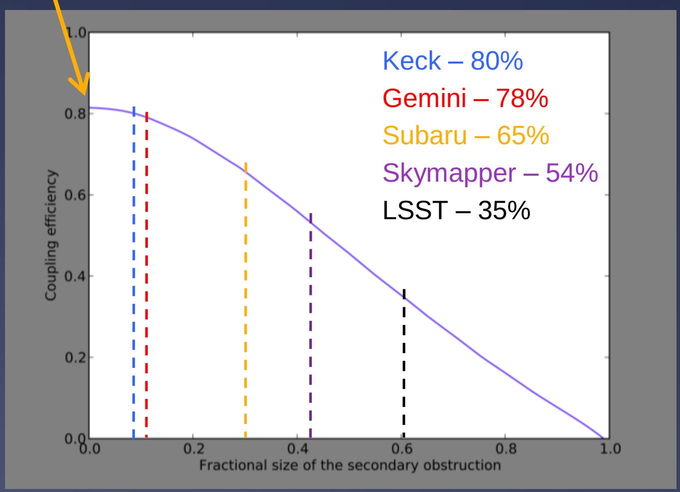
Pupil geometry



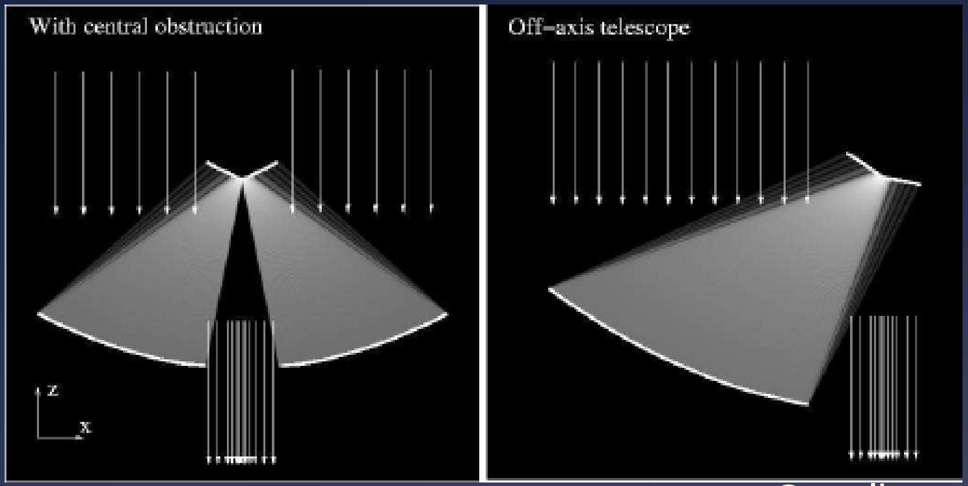
PSF



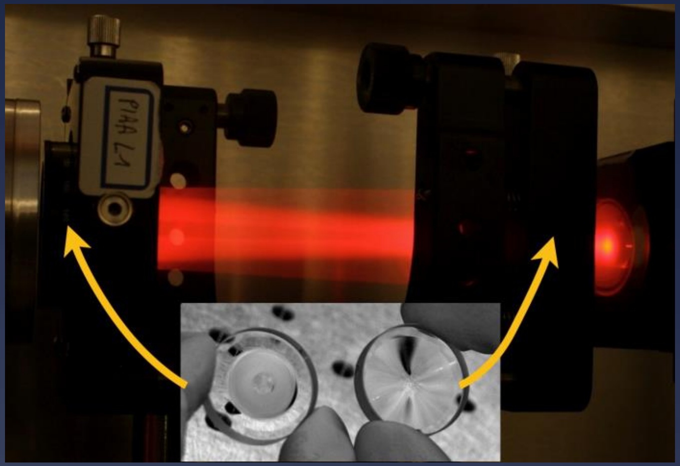
No central obstruction limit is 81%



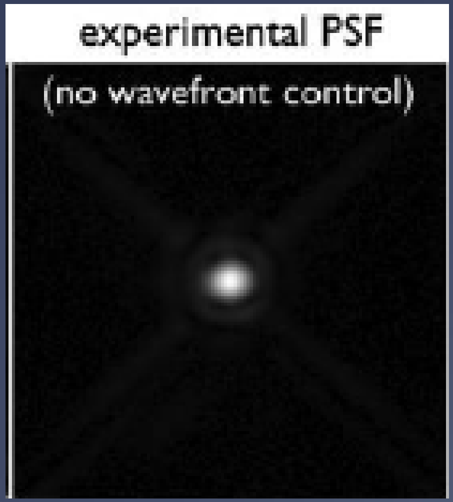
Matching the PSF profile:
Phase induced amplitude apodisation



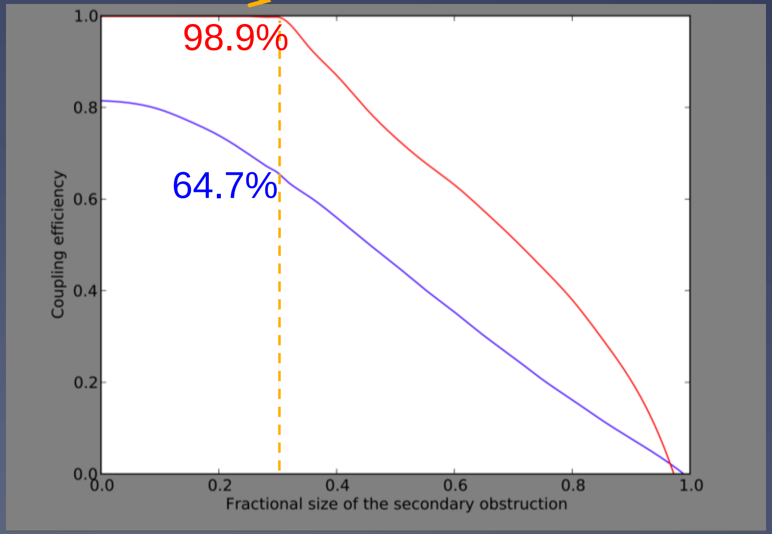
Guyon et al, A&A, 404, 379 (2003)



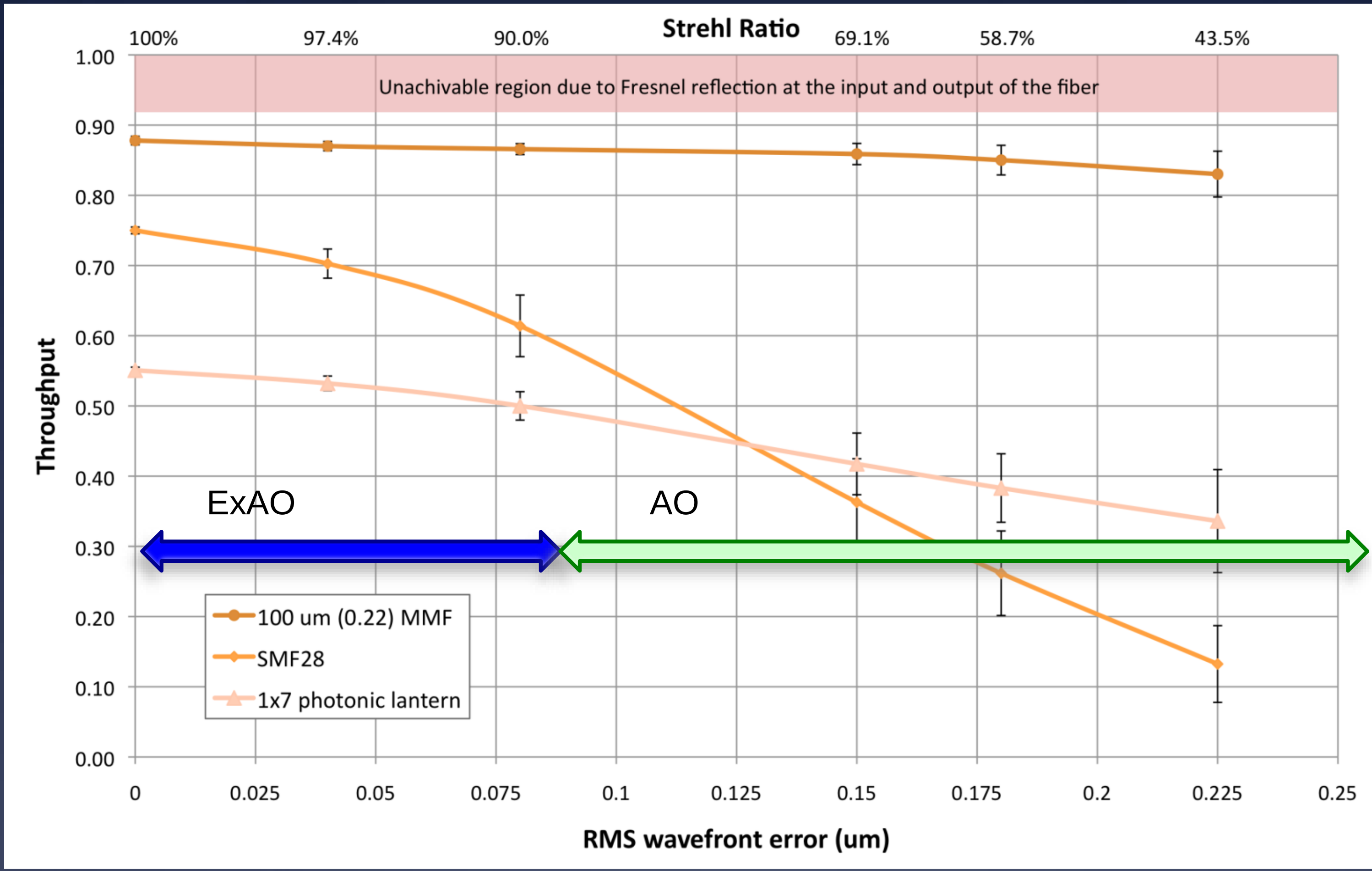
Lozi et al, PASP, 121, 1232 (2009)



Coupling perfect
with PIAA up to
…..



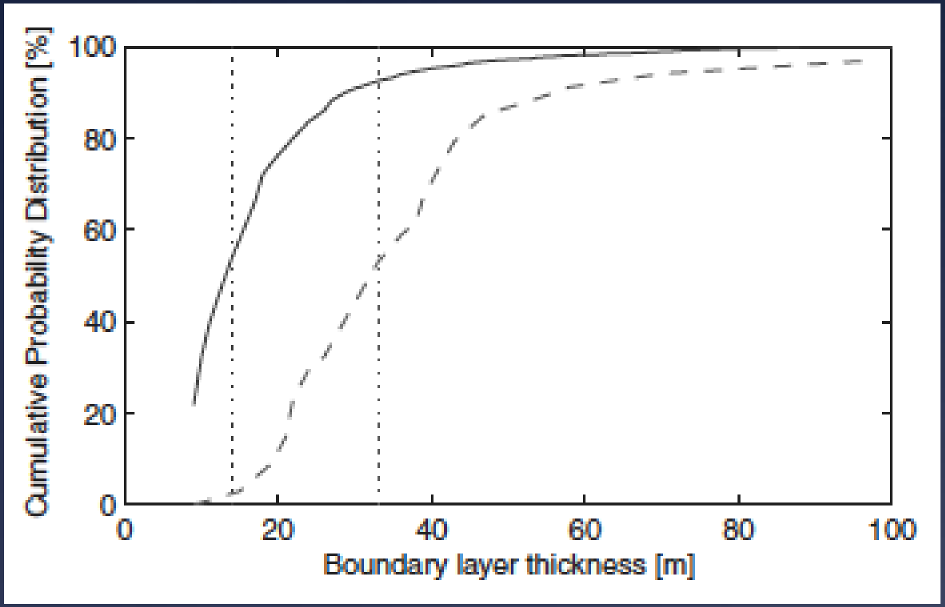
Measured coupling efficiency:



Laboratory experiments:

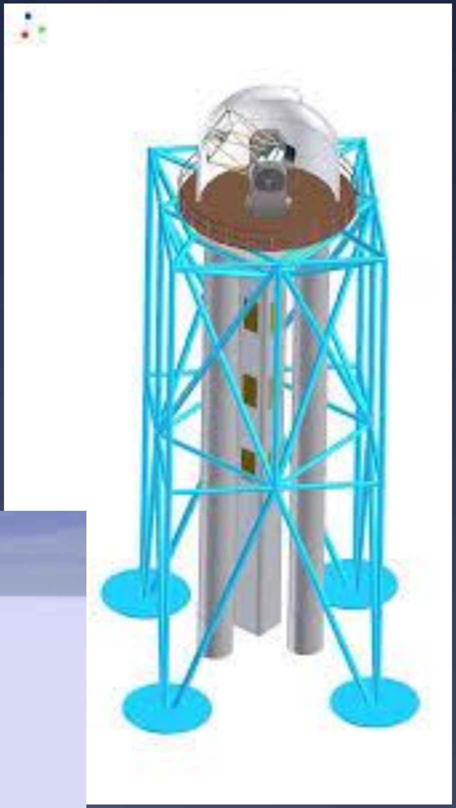
- H-band (1550 nm)
- PIAA lenses used
- Turbulence simulator used and RMS wavefront error and low spatial frequencies varied. Windspeed fixed at 10 m/s.
- Power measured at the input and output of the fiber (not simultaneously)

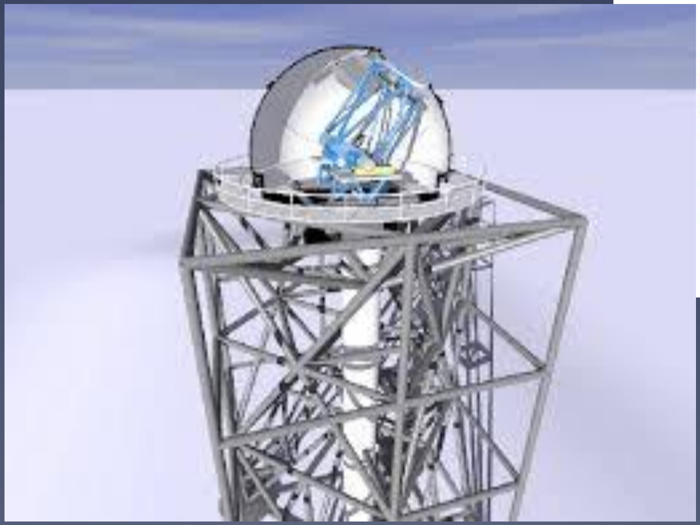
Measured coupling efficiency:



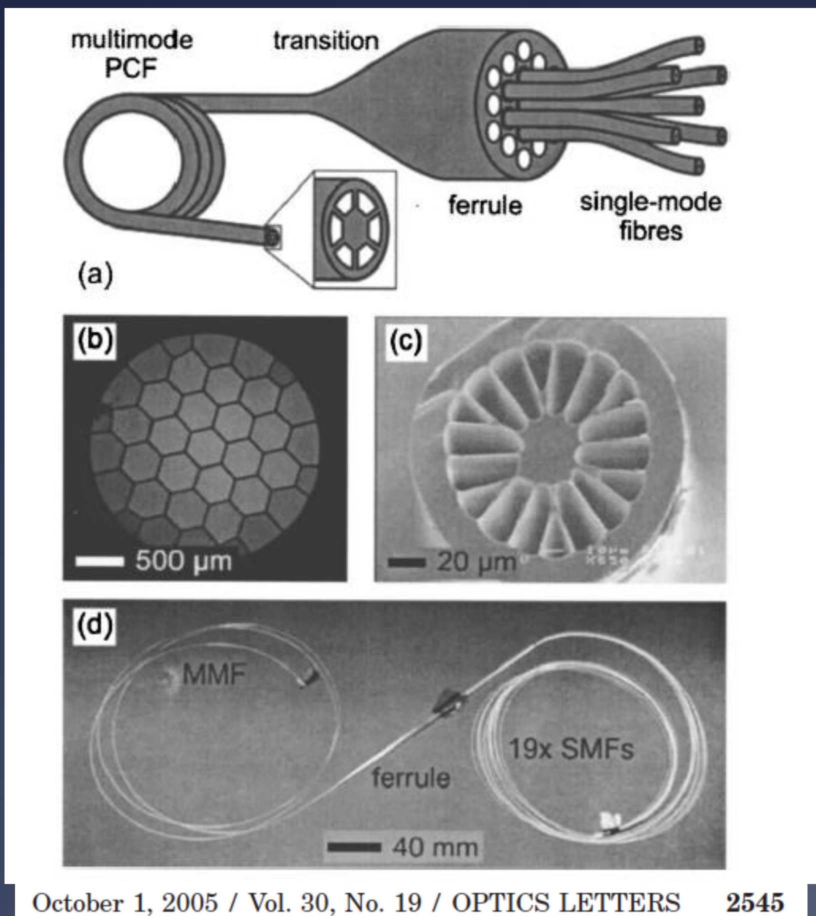
Bonner et. al., *PASP,* 122,1 122 (2009)

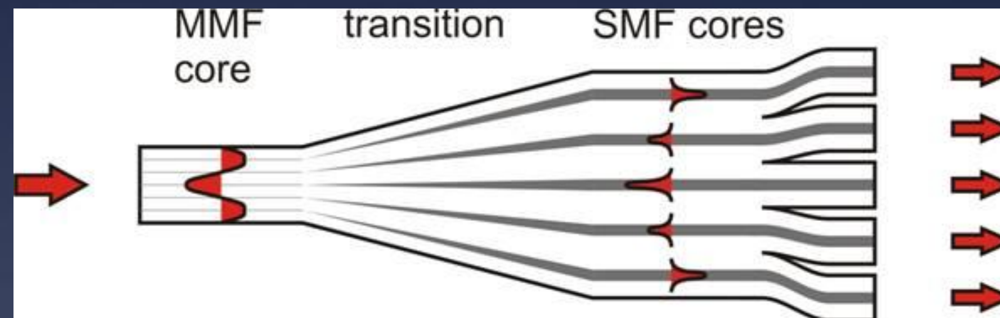
Free seeing ~0.27” on average!





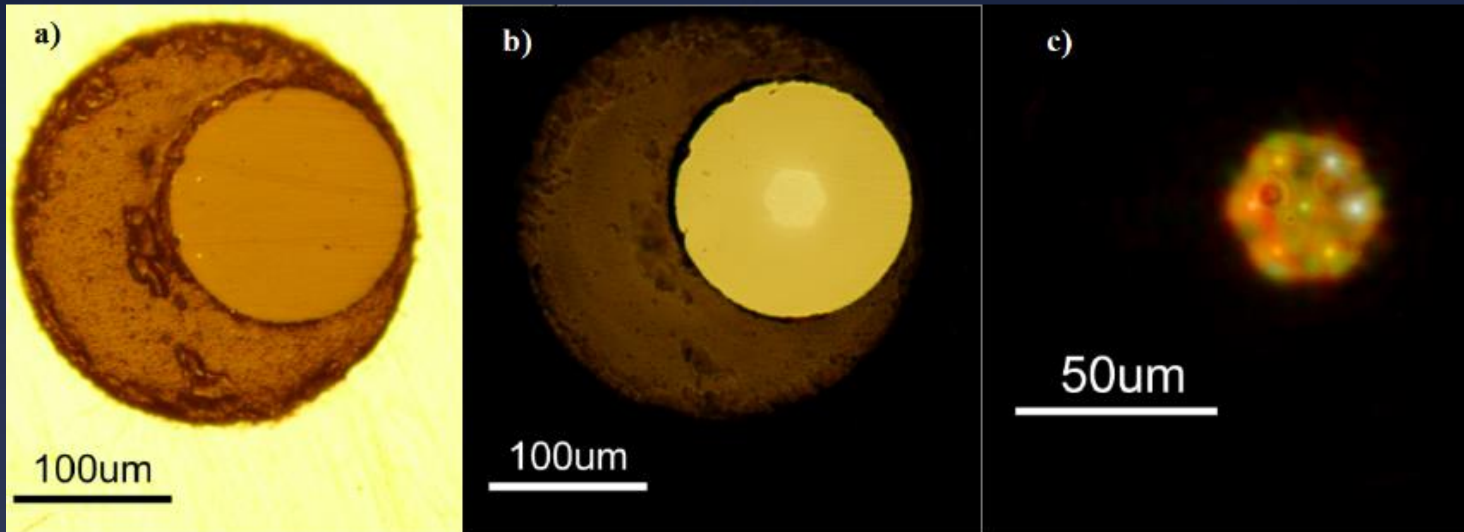
Reformatting when wavefront isn't perfect

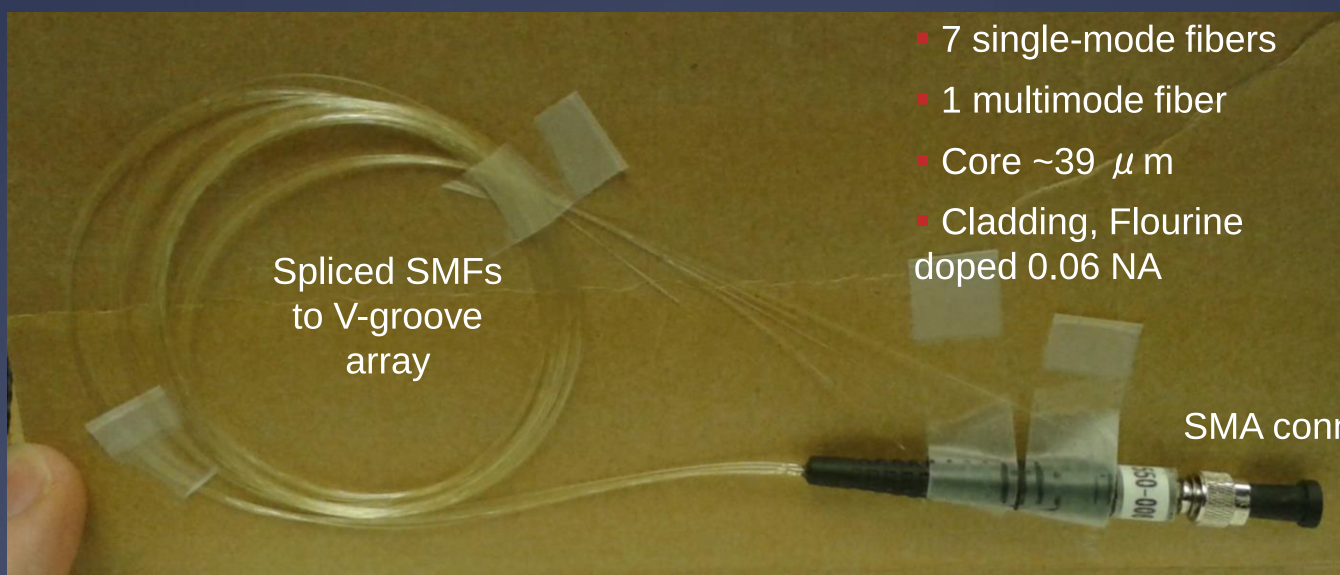




Photonic lantern

1x7 fiber lantern:

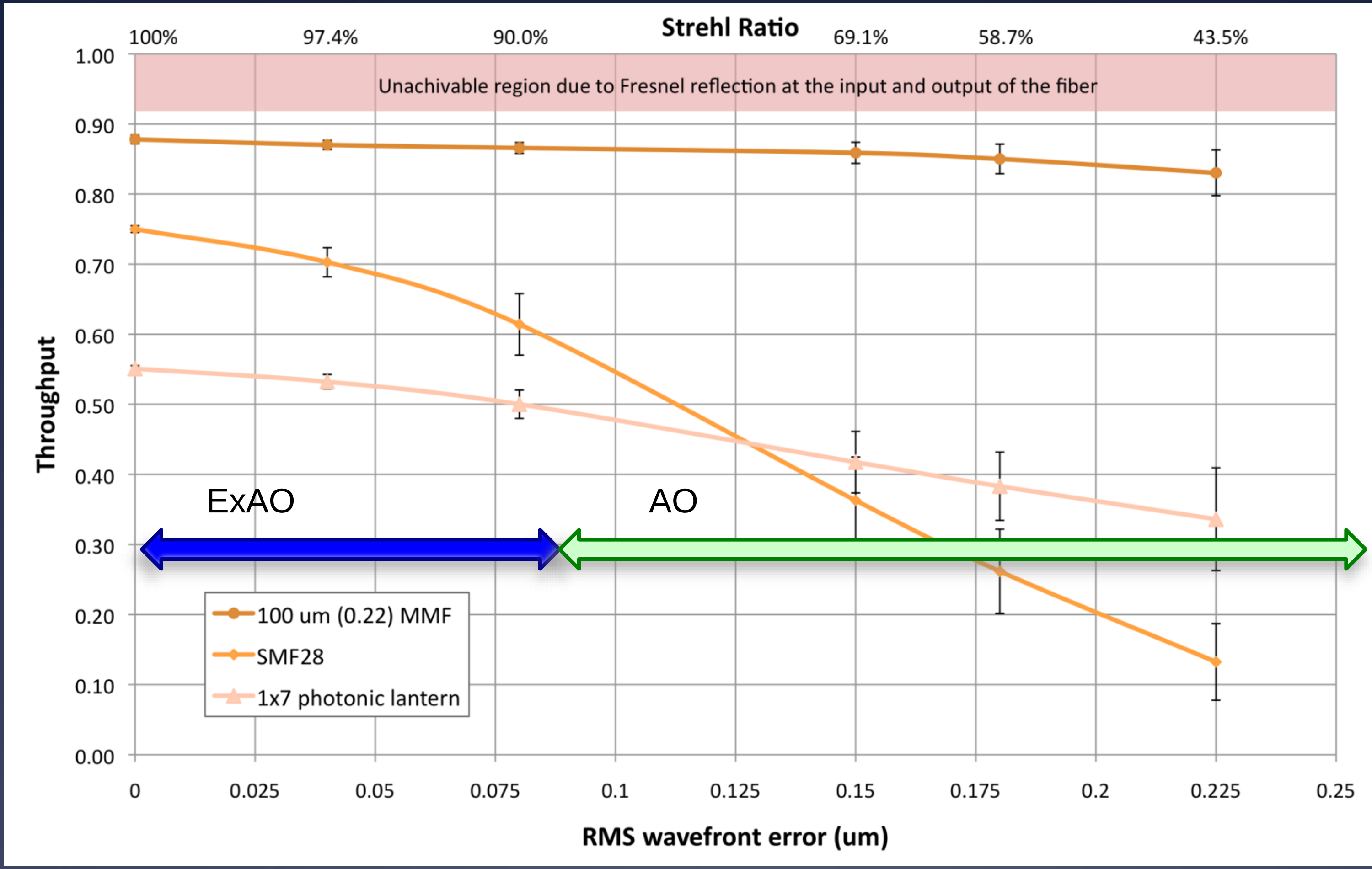




- 7 single-mode fibers
- 1 multimode fiber
- Core ~39 μm
- Cladding, Flourine doped 0.06 NA

Courtesy: Sergio-Leon Saval, USyd

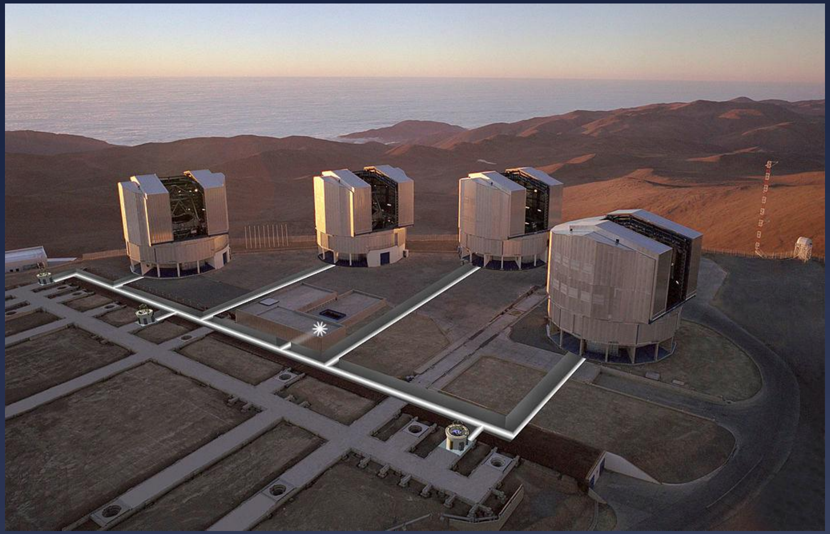
Measured coupling efficiency:



Laboratory experiments:

- H-band (1550 nm)
- PIAA lenses used
- Turbulence simulator used and RMS wavefront error and low spatial frequencies varied. Windspeed fixed at 10 m/s.
- Power measured at the input and output of the fiber (not simultaneously)

Advantages of single-mode devices



AMBER & MIDI: Long baseline interferometer

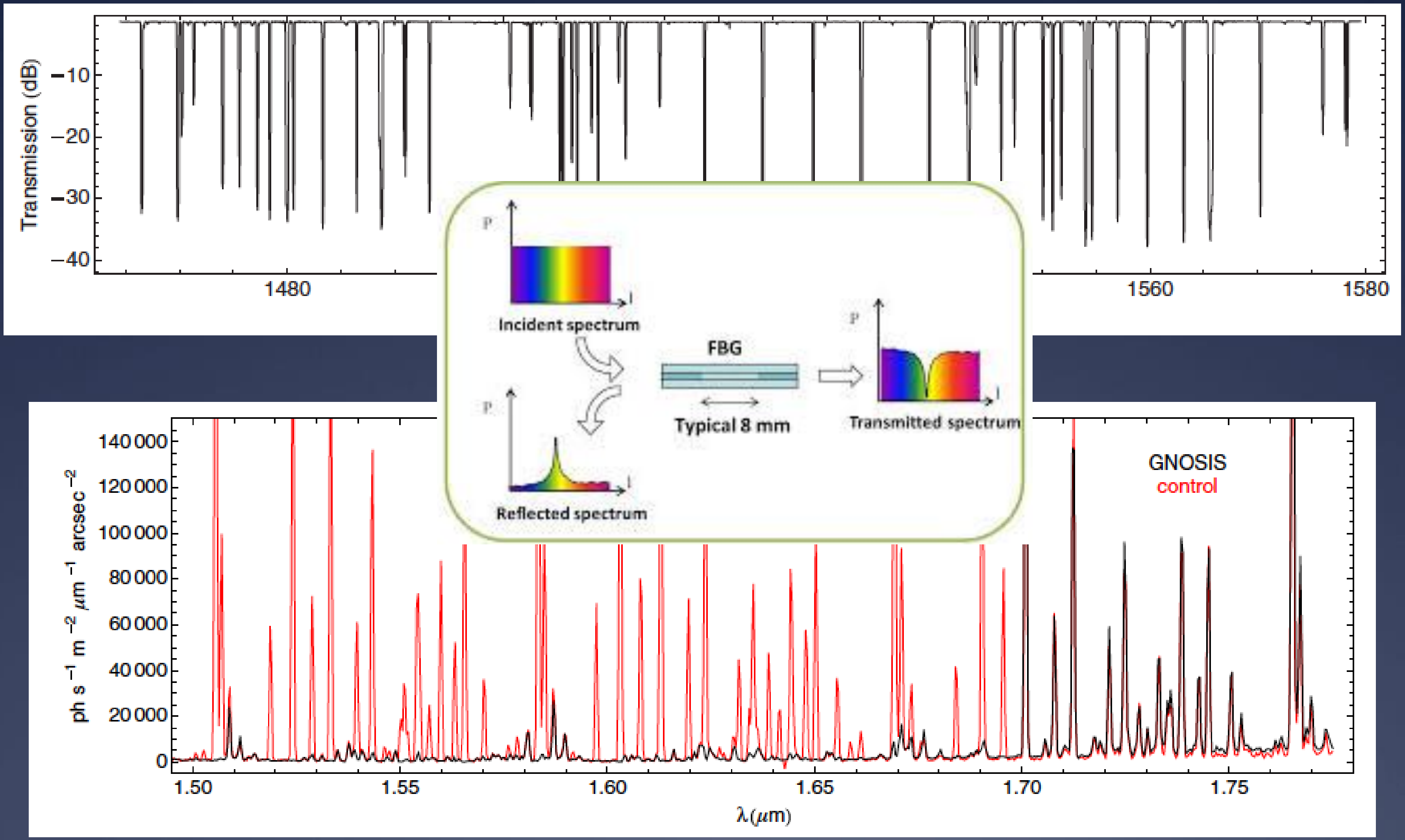
SMF based instruments:

- Amber
- MIDI
- PIONIER
- GRAVITY
- DRAGONFLY
- FIRST

Diffraction-limited photonics have a lot to offer:

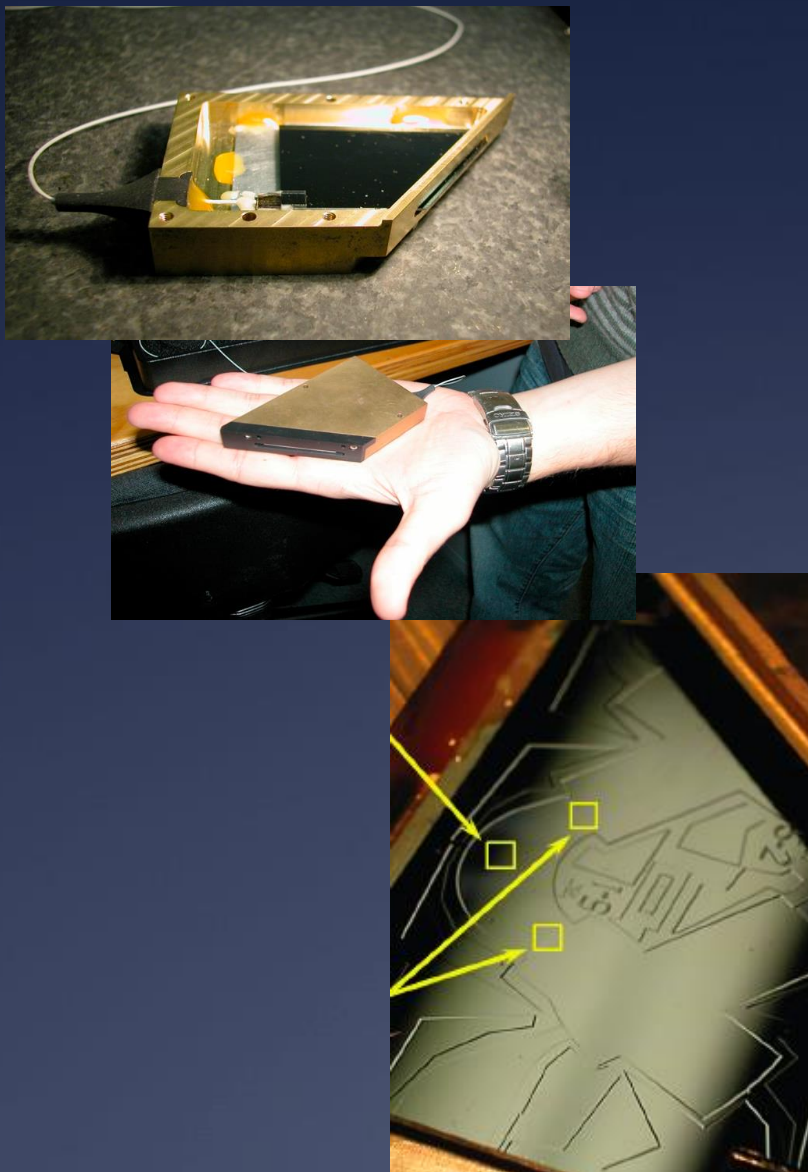
- **Spatial filtering** (flattening the wavefront)
- **Spectral filtering** (via FBGs, ring resonators)
- **Temporally invariant output PSF** (eliminates modal noise, allows high contrast fringes to be formed)
- Potential gains in terms of size/volume and stability

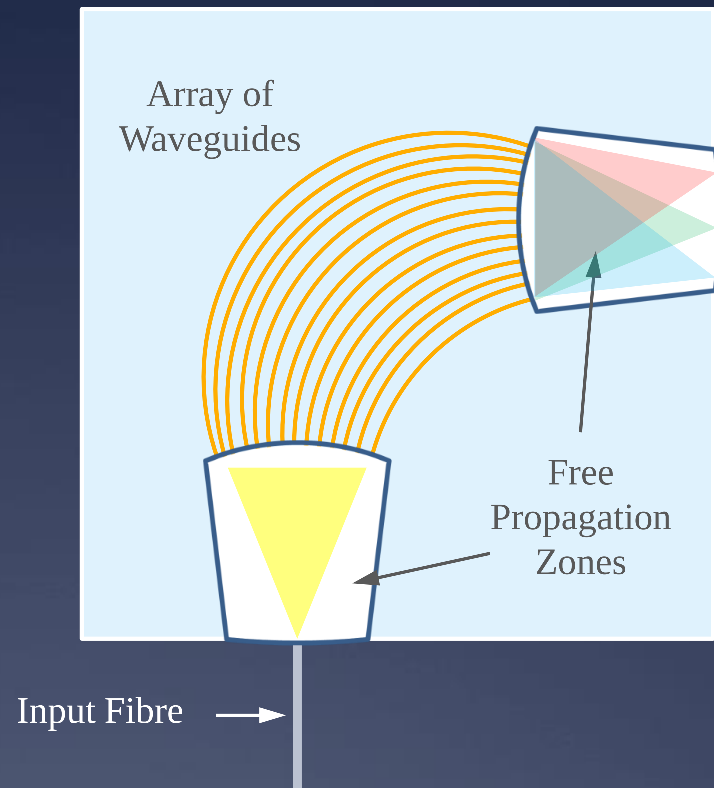
Spectral filtering with photonics



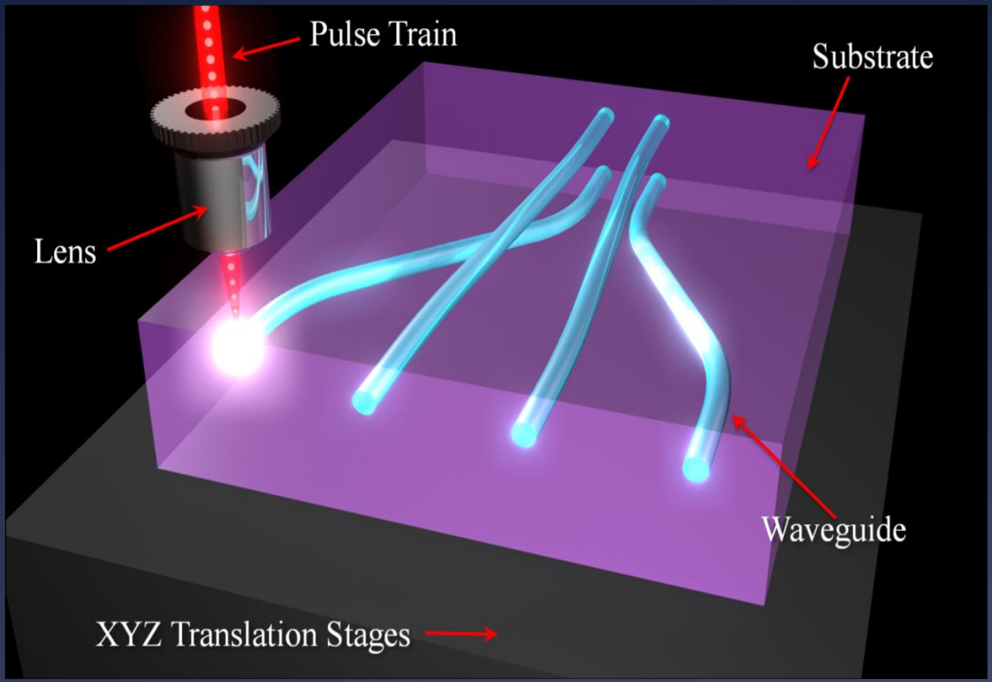
C. Trinh et al, Astron. J., 145, 51 (2013)

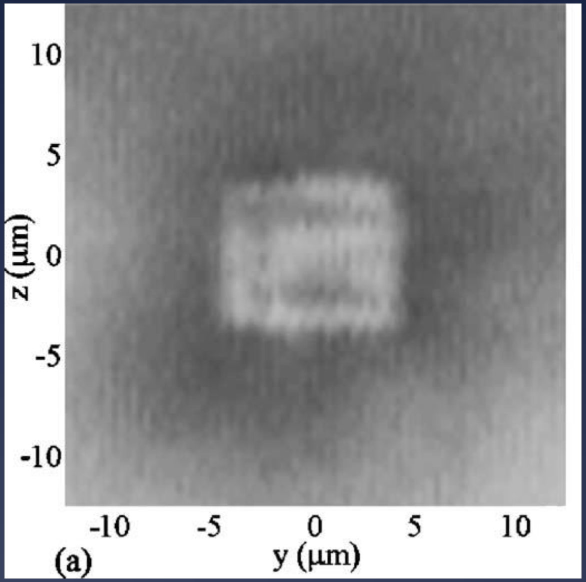
Photonic spectrographs





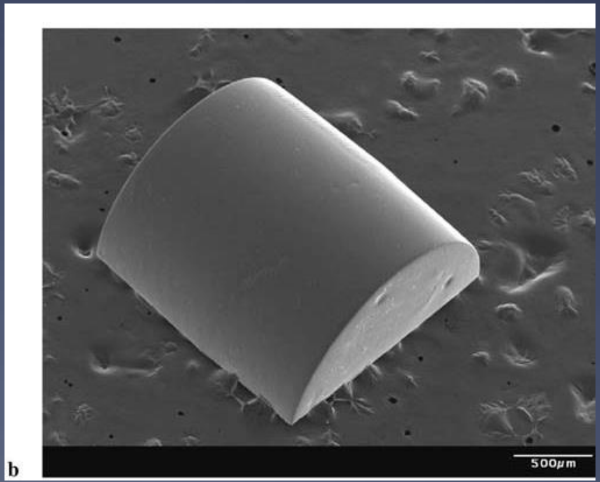
3D photonic fabrication





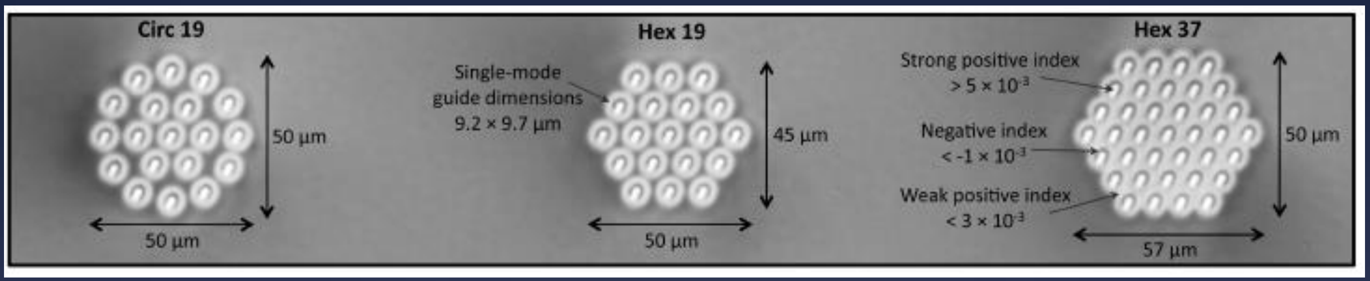
Psaila et al, Appl. Phys. Lett. 90, 131102 (2007)

- Unique fabrication capabilities:
- 3D optical waveguides.
- Micro-optics, -mechanics and -fluidics.
- ULI is material flexible.
- ULI is a direct-write technology.



Cheng et. al., *Appl. Phys. A.* 85, 11 (2006)

Integrated multimode waveguides



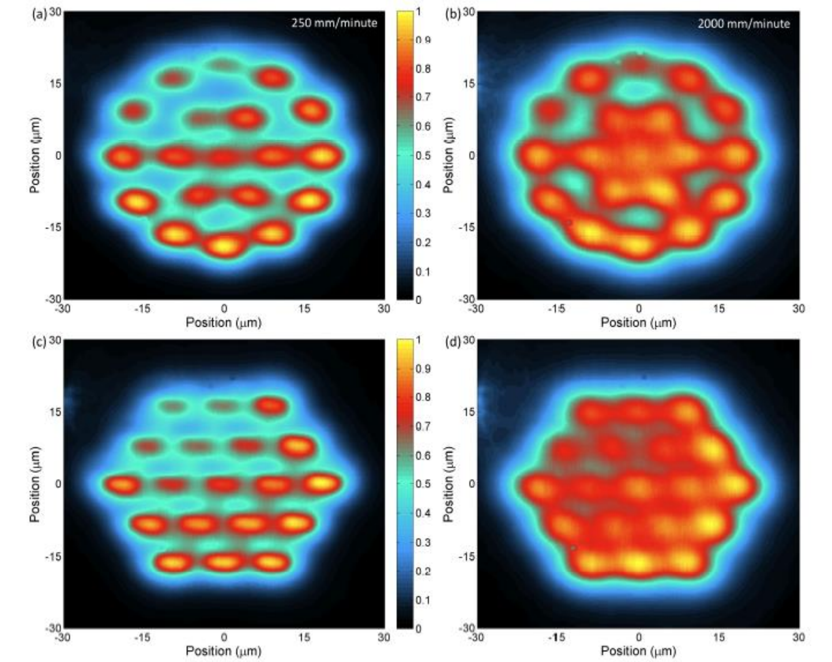
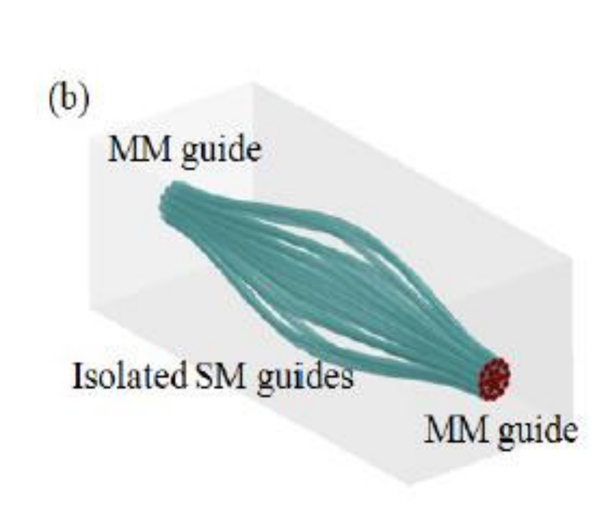
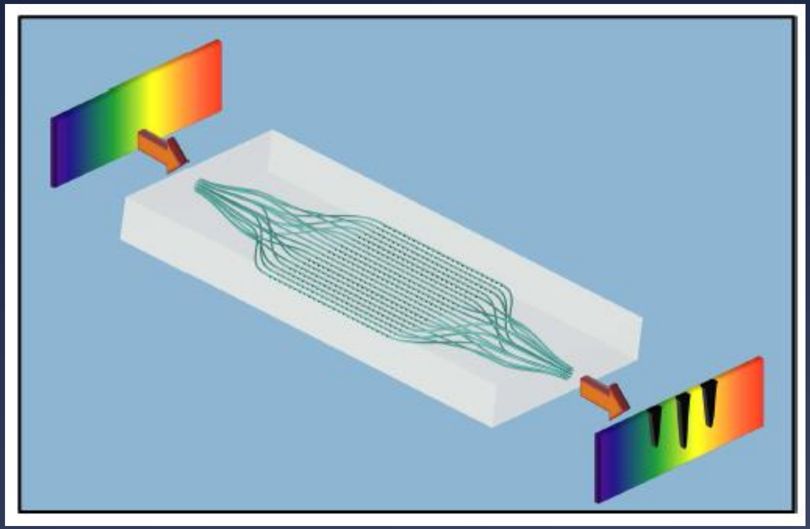


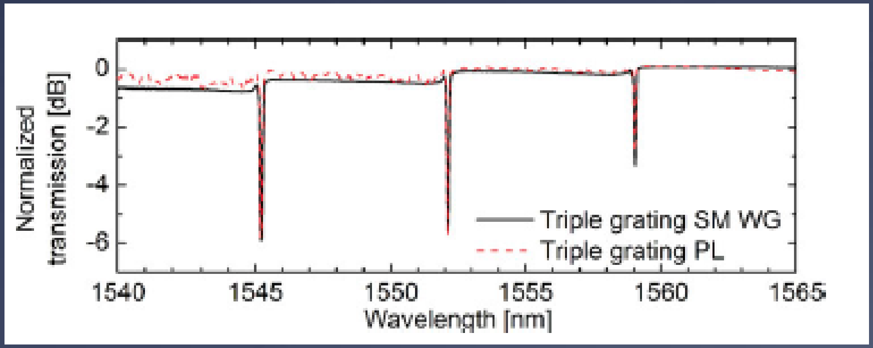
Fig. 10. Near-field intensity distributions for Circ 19 structures ((a) and (b)) and Hex 19 structures ((c) and (d)), for two translation speeds of inscription; 250 mm/minute ((a) and (c)) and 2000 mm/minute ((b) and (d)).

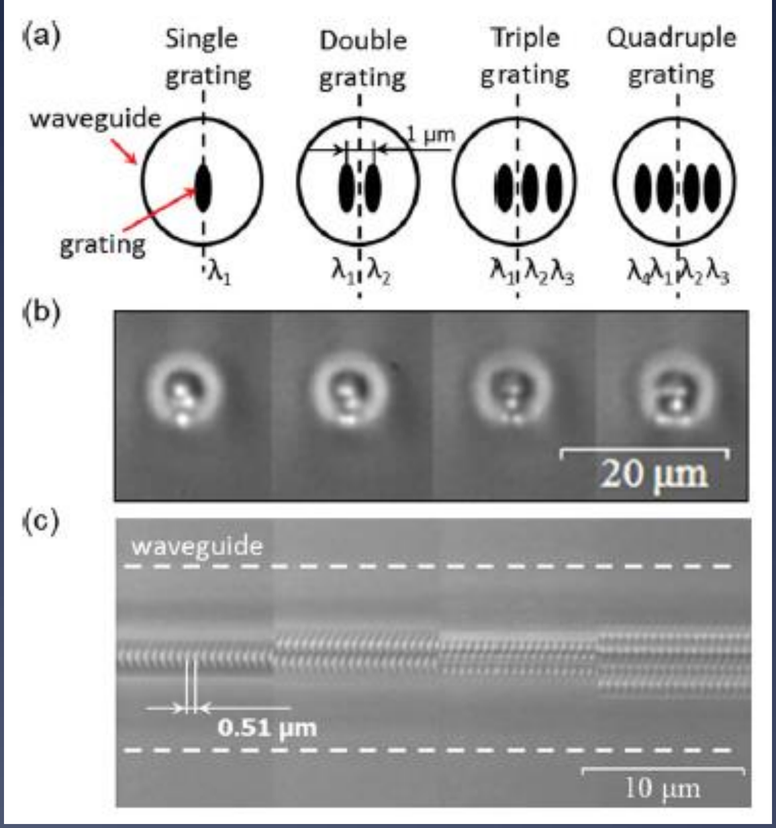


Jovanovic et. al., *Opt. Exp.* (20012)
Spaleniak et, al. Opt Exp. (2013)

On-chip multiband processing

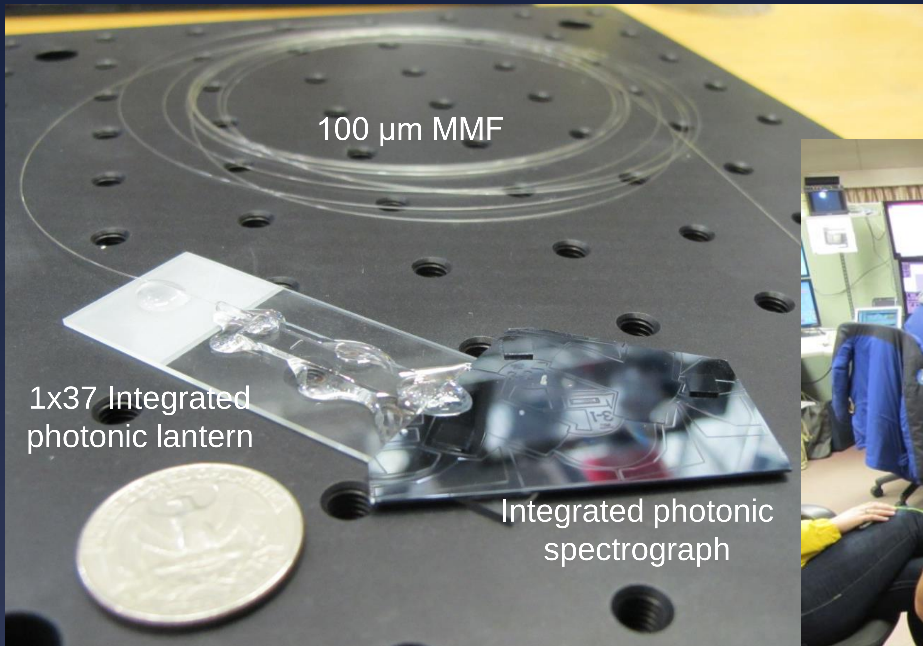


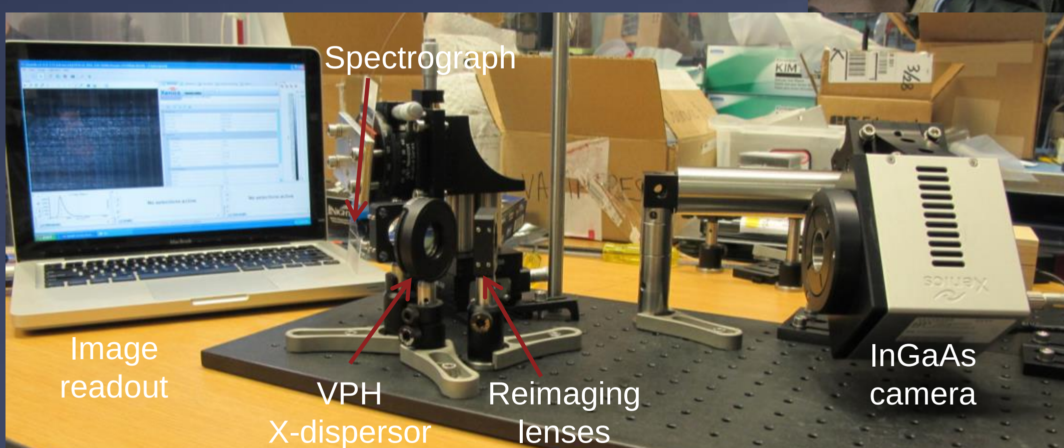




Laser Photonics Rev. **8,** No. 1, L1–L5 (2014) / **DOI** 10.1002/lpor.201300129

On-sky data: Photonic spectroscopy

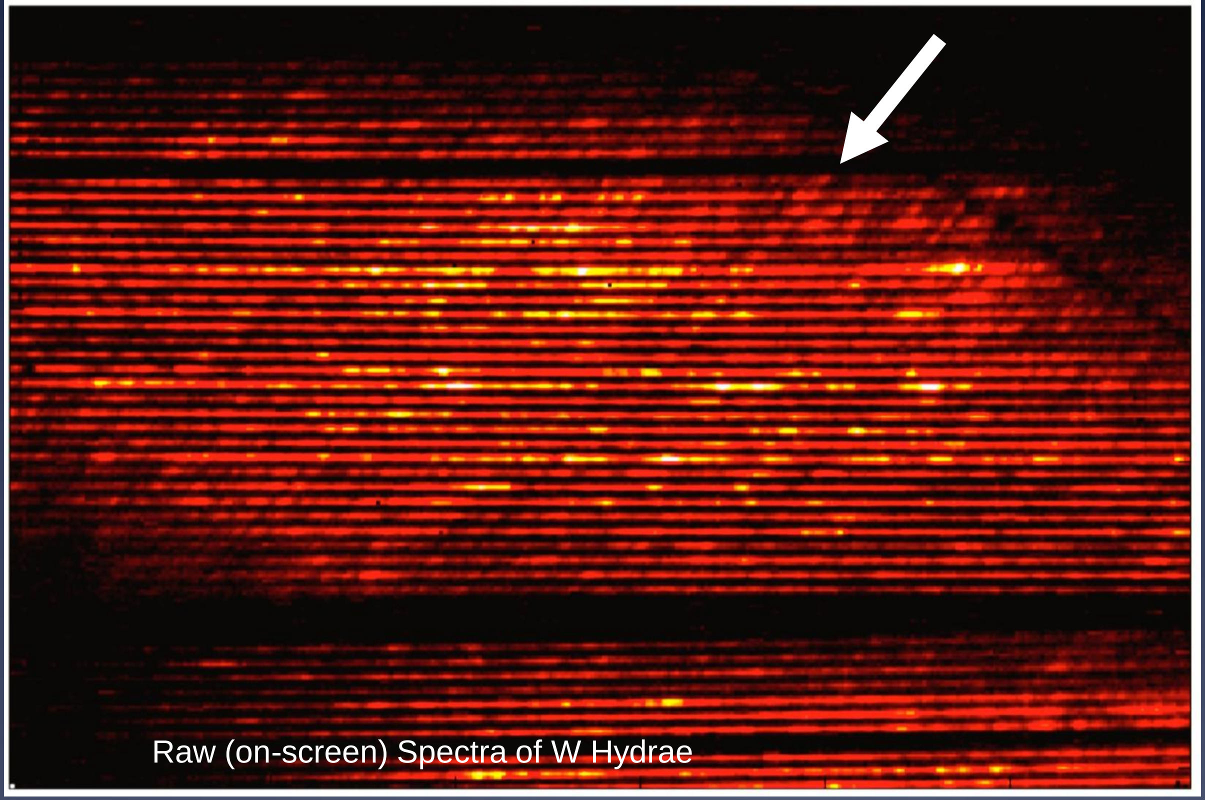




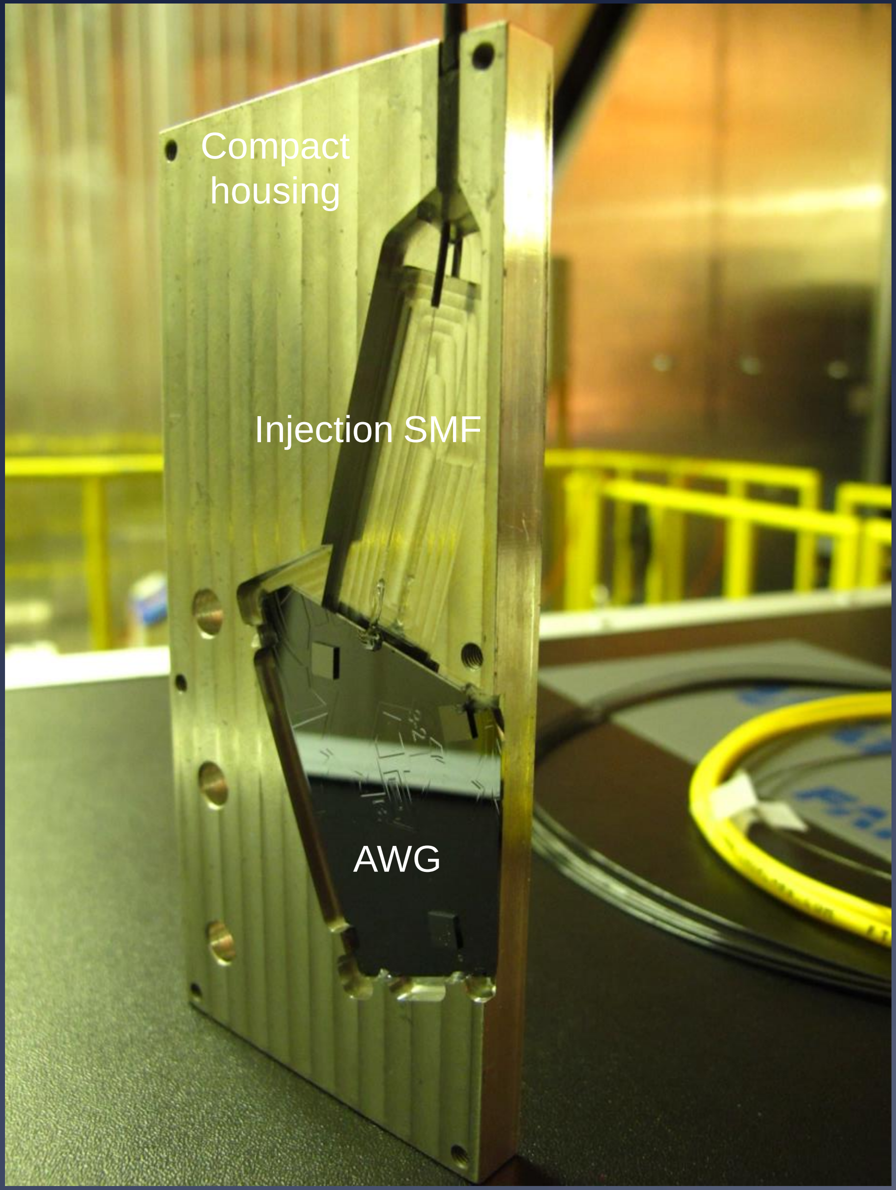
Specs:

- R~3000
- λ~1550 nm
- FSR~50 nm

On-sky data: Photonic spectroscopy

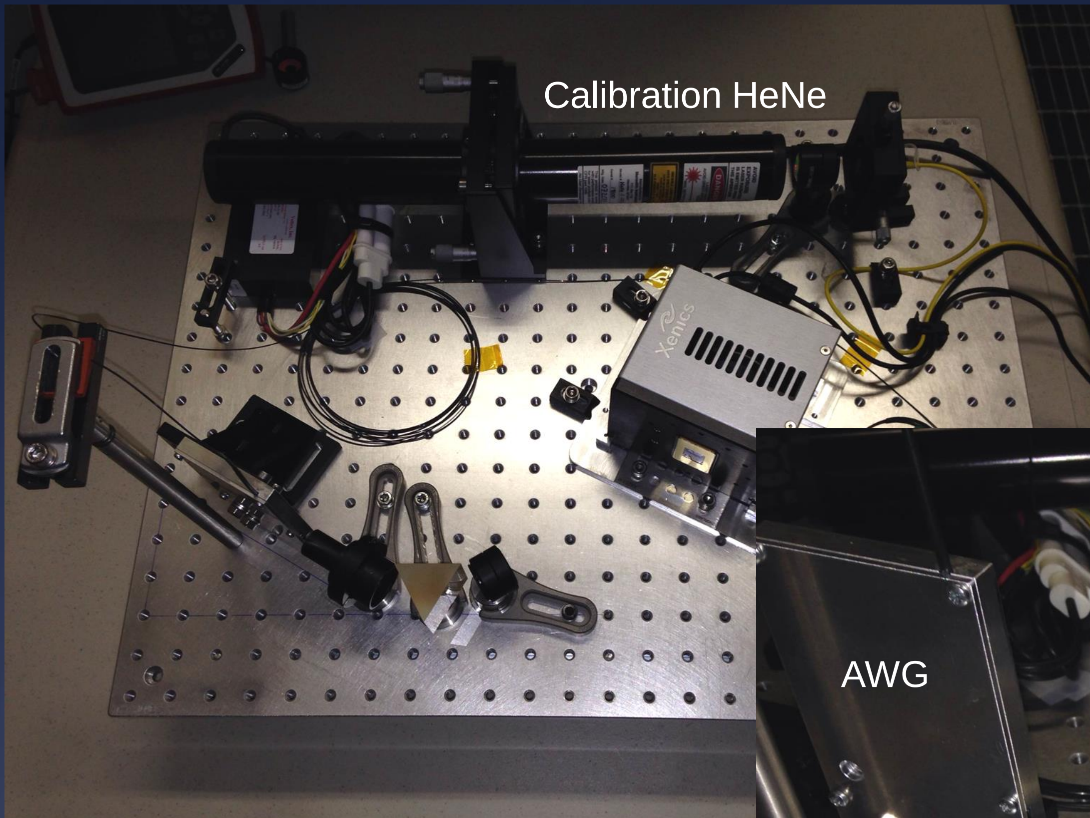


On-sky: SM fiber-fed spectrograph



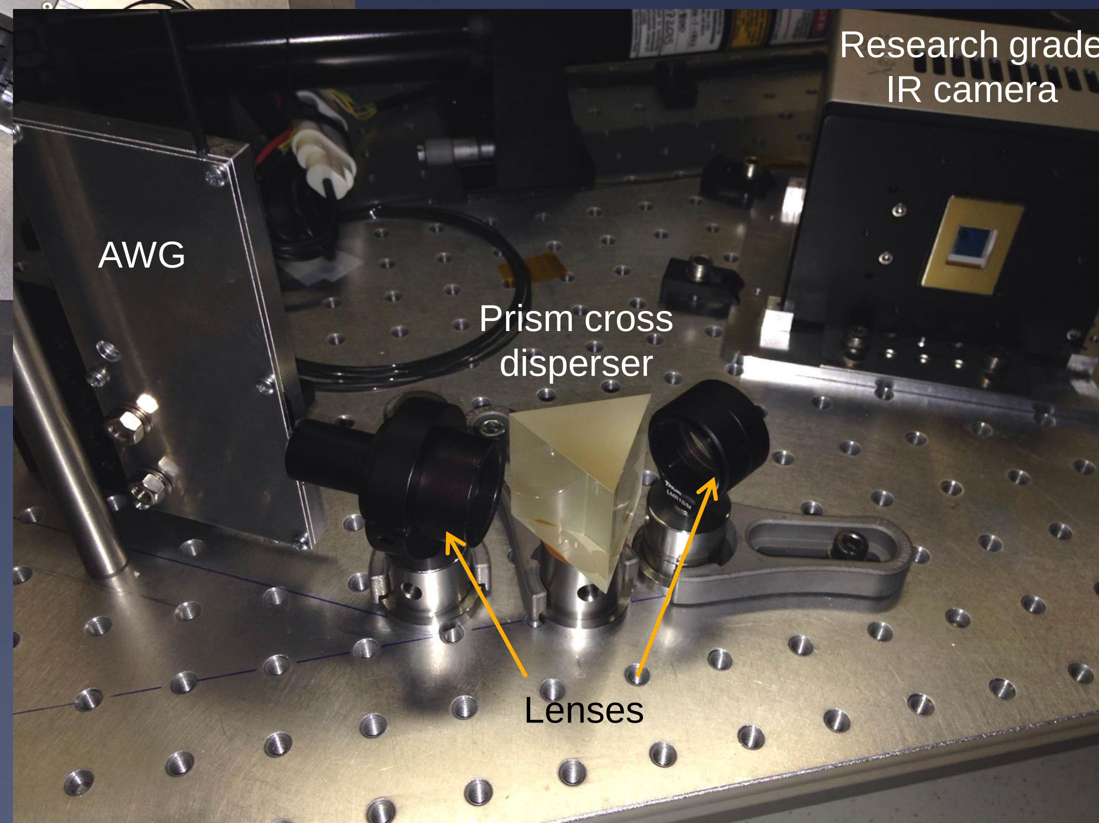
- Extremely compact
- Light weight
- Easy to transport
- Easy to stabilize
- No realignment needed
- R=7000, more possible

On-sky: SM fiber-fed spectrograph

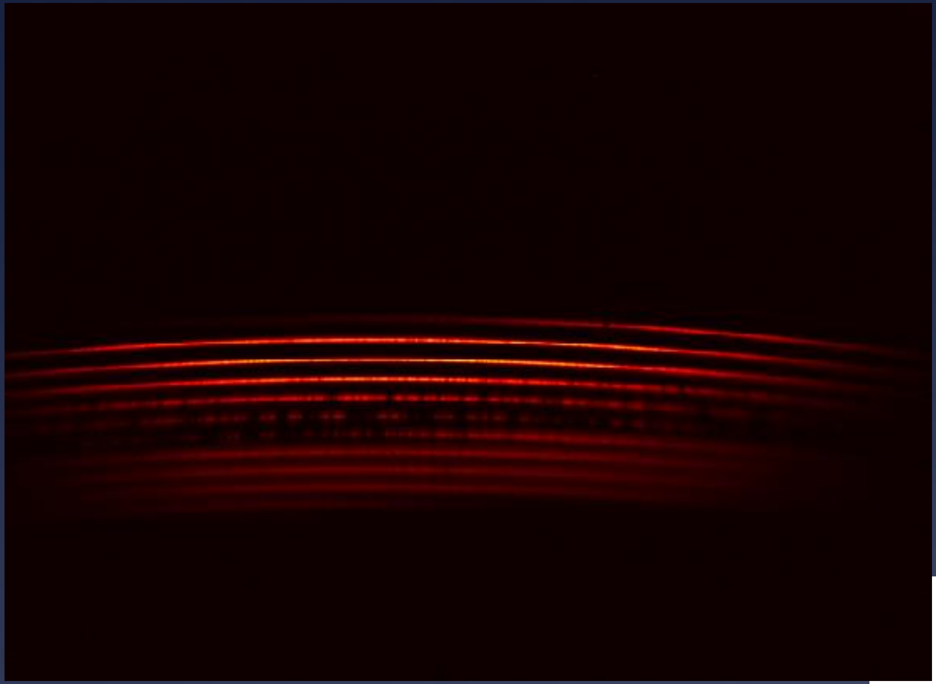


R = 3000-4000

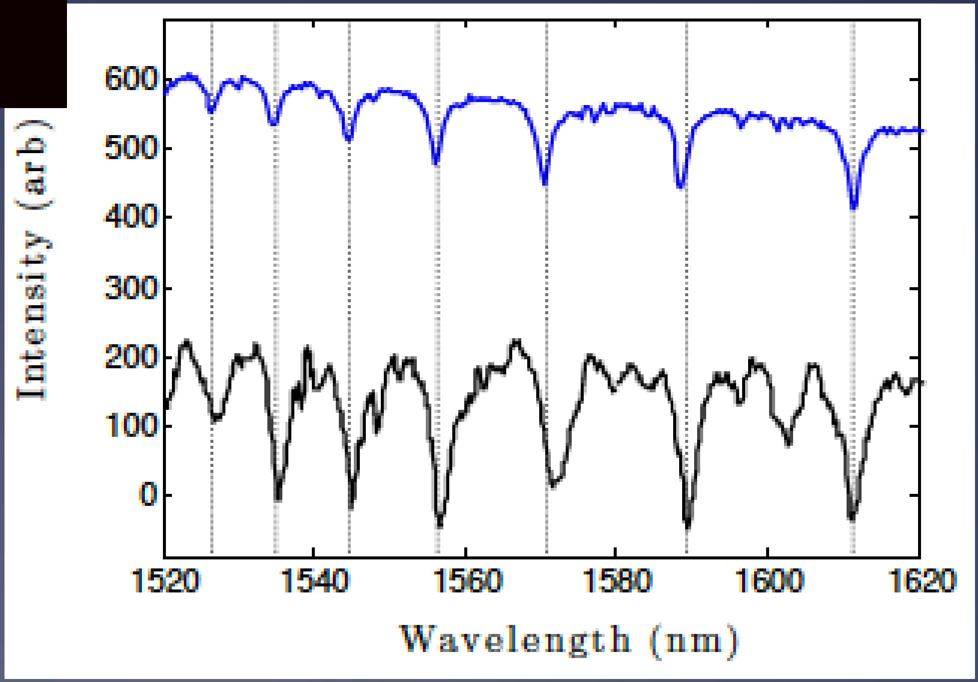
J and H band



On-sky: Results

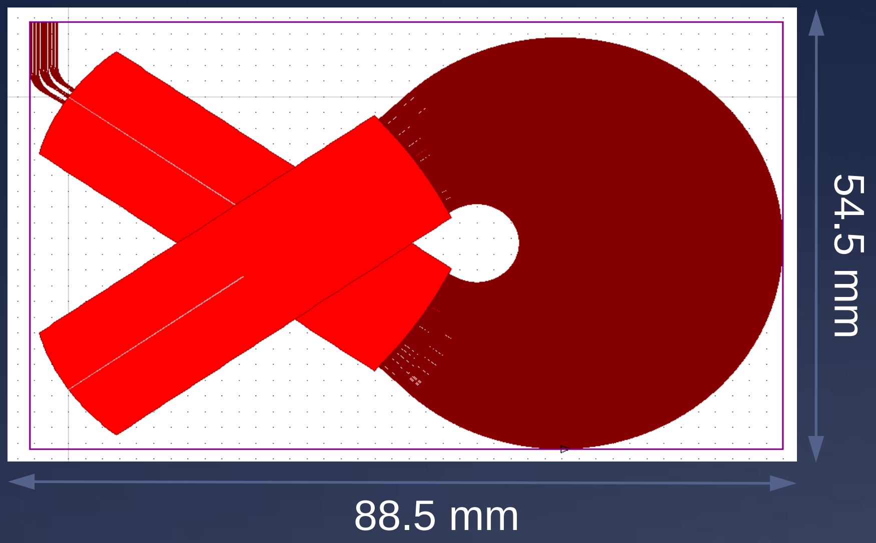


Preliminary data reduction

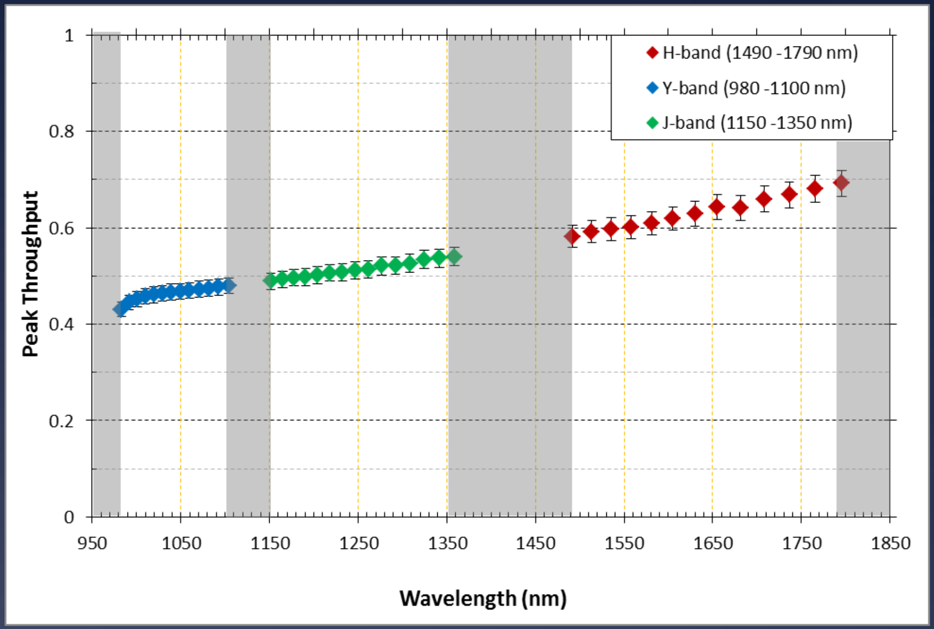


Photonic spectrographs

New AWG circuit design



- Array Waveguides = 960
- Resolution = ~65,000 (0.025 nm)
- Central Wavelength = 1630 nm
- Central operating order = 101
- FSR = ~ 16 nm (changes w.r.t. grating order)



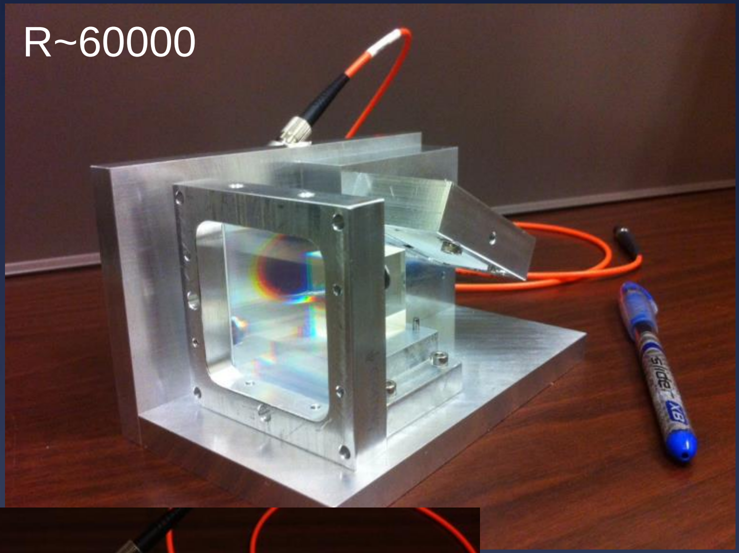
Cvetojevic, N. PhD thesis and paper in preparation

Throughput is 2-3 times better than traditional disperser technologies!

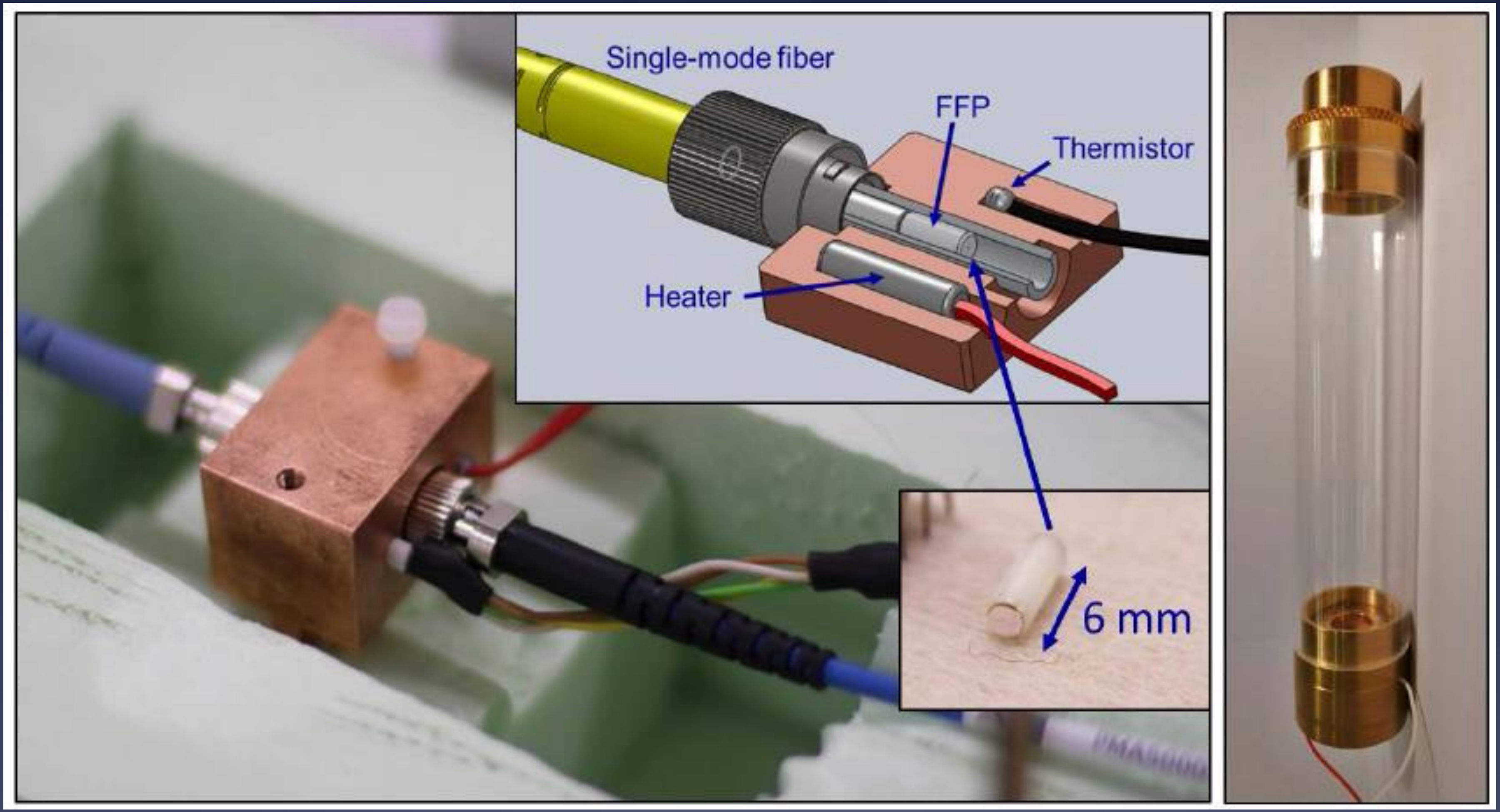
No polarization dependence, throughput is equal for *s* and *p*

Bulk optic spectrographs

- Traditional optical elements: Grating (Echelle, lenses)
- Several independent components which need to be stabilized.
- Can be very compact, simple and relatively inexpensive.

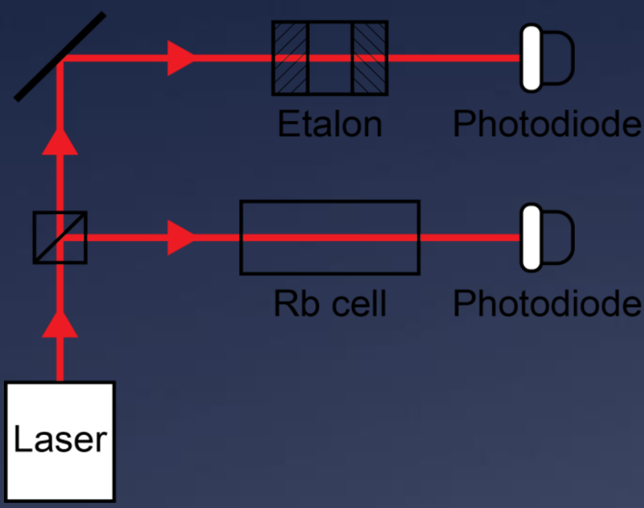


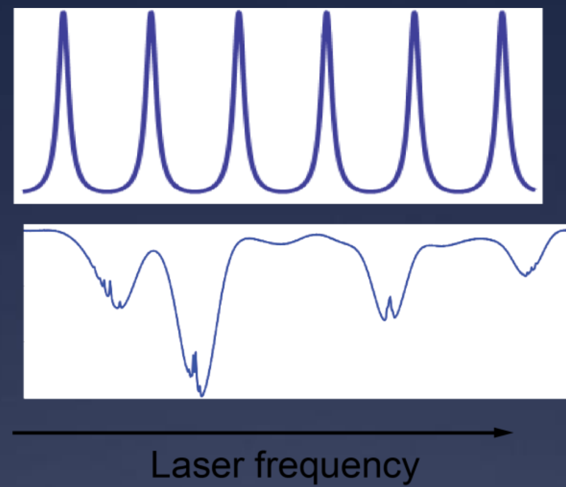
Fiber Fabry-Perot & confocal etalon

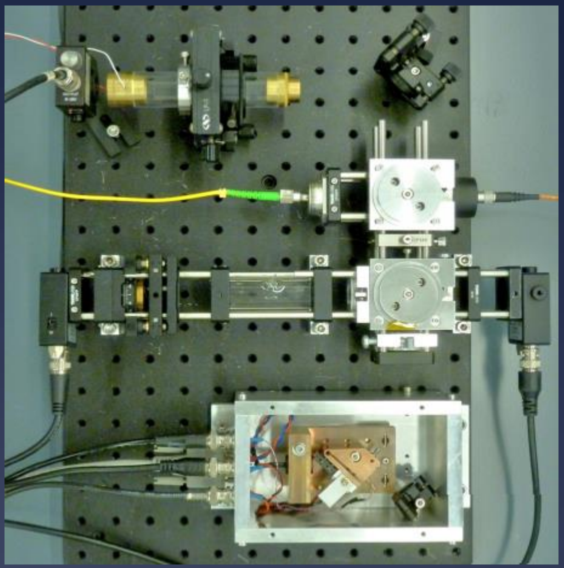


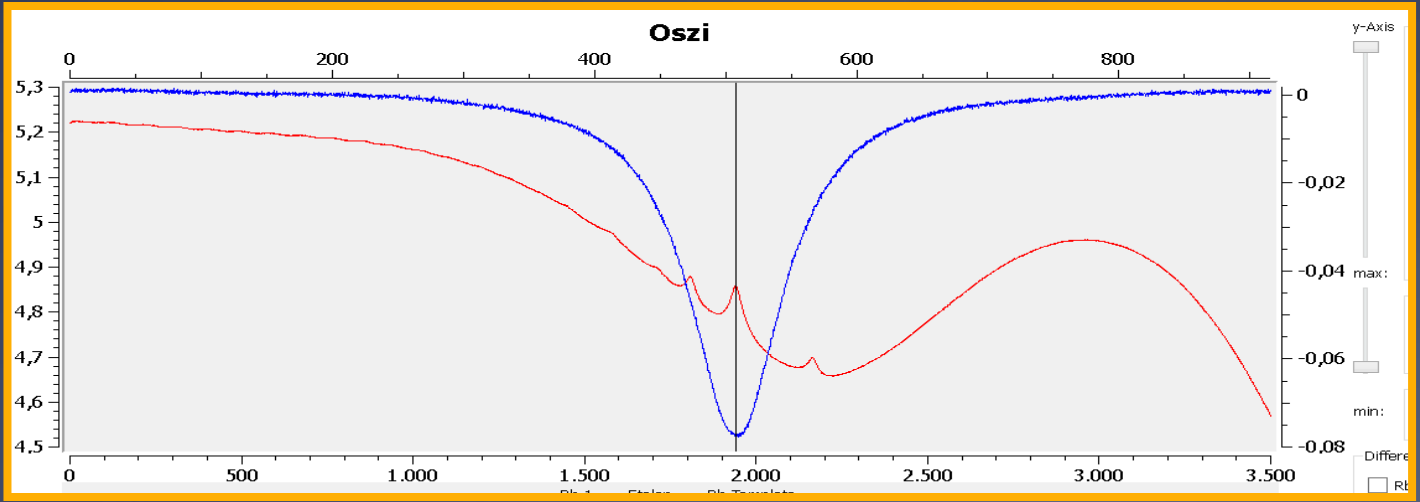
Halverson et al, Proc. SPIE 8446, 84468Q (2012).
Halverson et al, arXiv: 1403.6841v1 [astro-ph.IM].

Laser-locked etalon



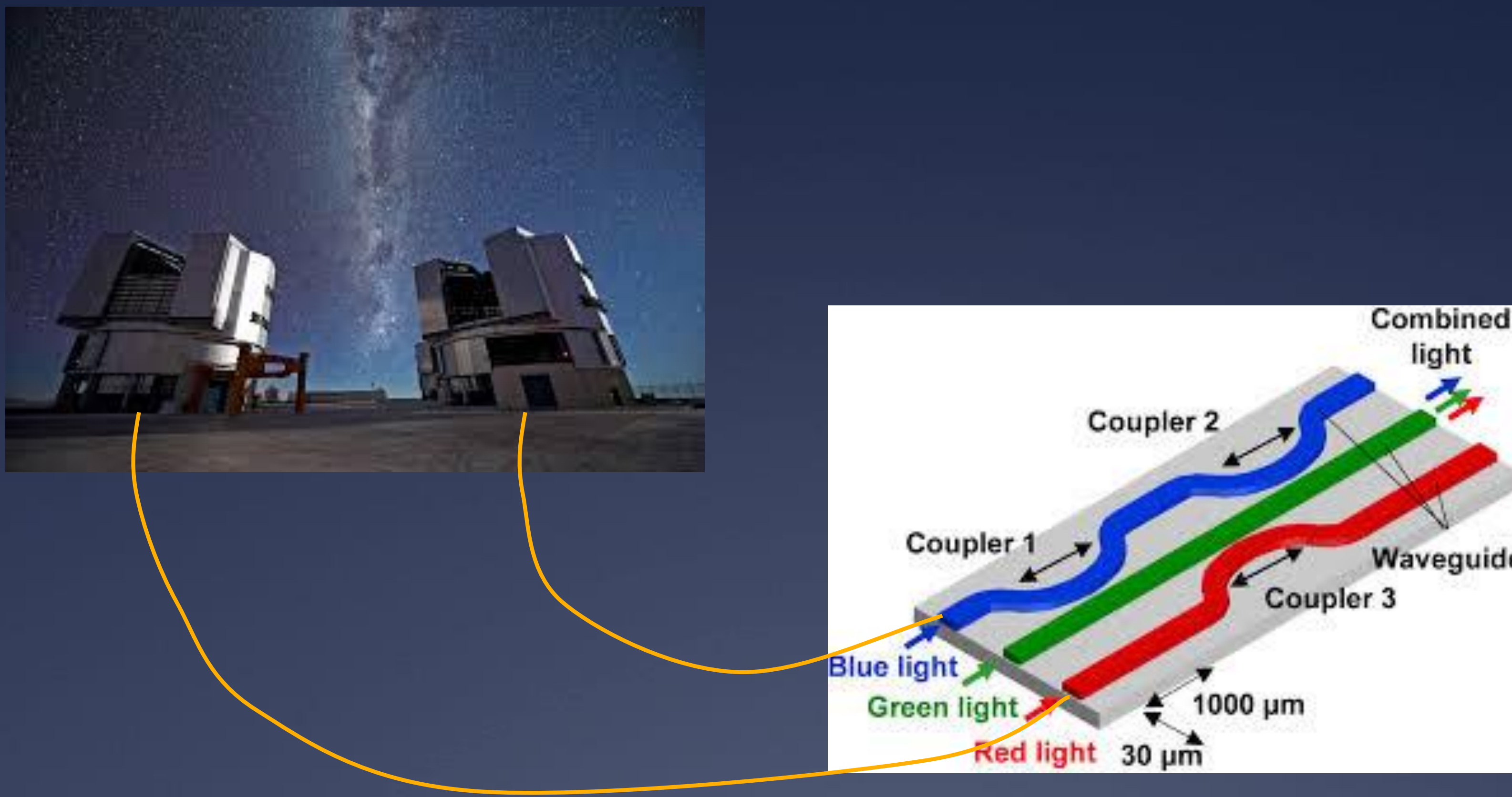




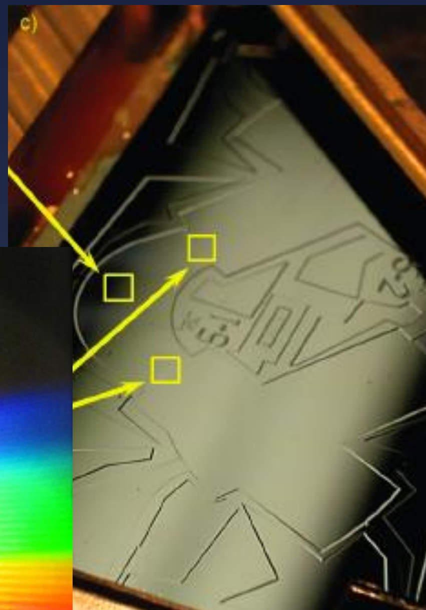


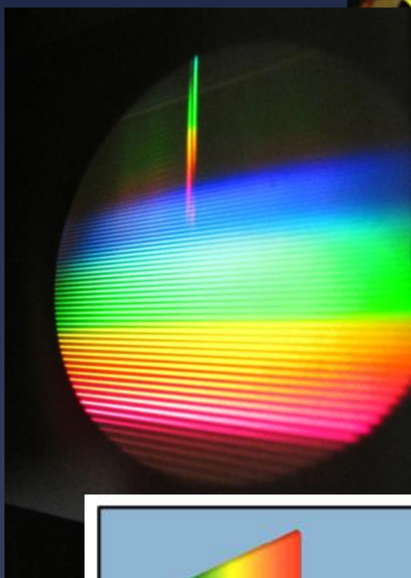
RTC Software

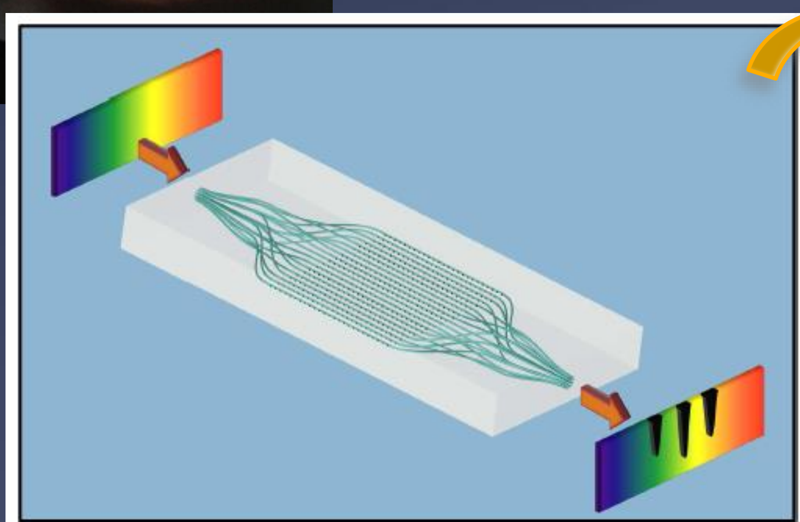
Interferometry with photonics



Photonics in Antarctica?







- Extremely compact
- Light weight
- Easy to transport
- Easy to stabilize
- No realignment needed
- No moving parts
- Advanced functionalities

Certainly promising for remote sites

What can SCAR do for my research?

1) By Promoting of photonic technologies and techniques
2) Getting people interested in the technology who will then help with logistical getting prototype instruments to Antarctica
3) Helping us apply for funding to get the project moving and to Antarctica
4) Database of Antarctic researchers/area and site testing results.


Contact us:
nem@naoj.org