(Single-mode) Photonics in ground based Astronomy

Oliver Pfuhl

European Southern Observatory

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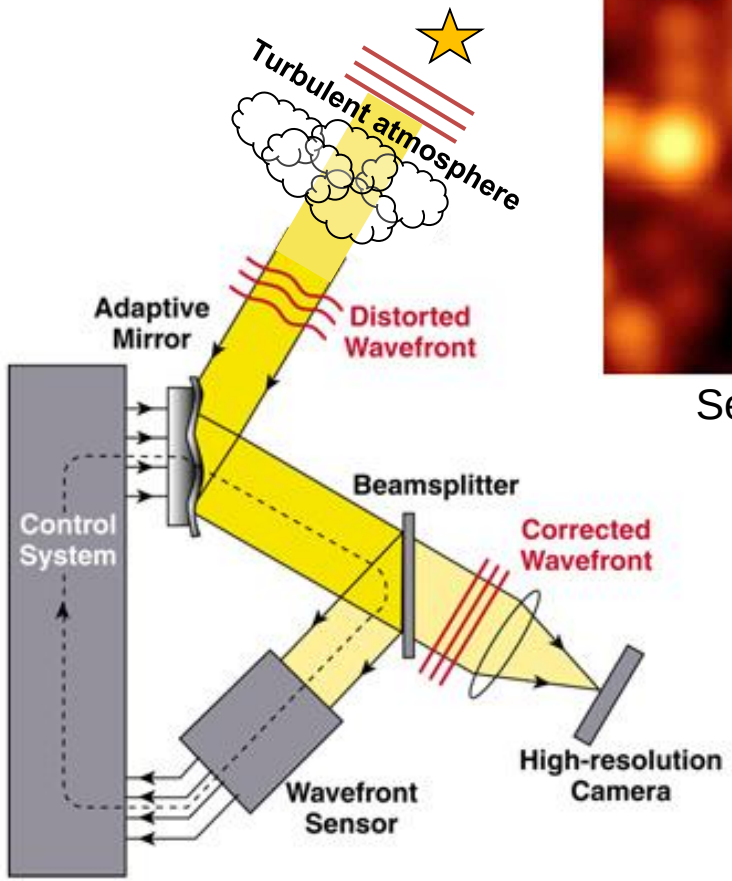
European Southern Observatory

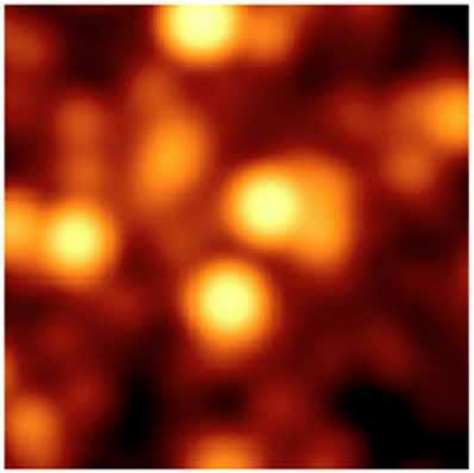
The European Southern Observatory (ESO) is the pre-eminent intergovernmental science and technology organisation in astronomy. It carries out an ambitious programme focused on the design, construction and operation of powerful ground-based observing facilities for astronomy, in order to enable important scientific discoveries. ESO also plays a leading role in promoting and organising cooperation in astronomical research.

16 European nations + Chile, 3 observatories, largest telescope (40m) under construction

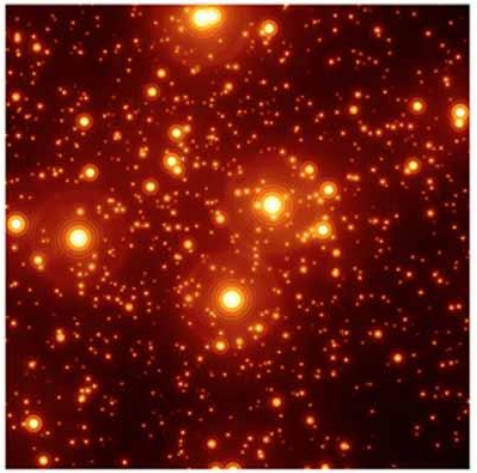
Ground based problems



Feedback loop: next cycle corrects the (small) errors of the last cycle



Seeing limited

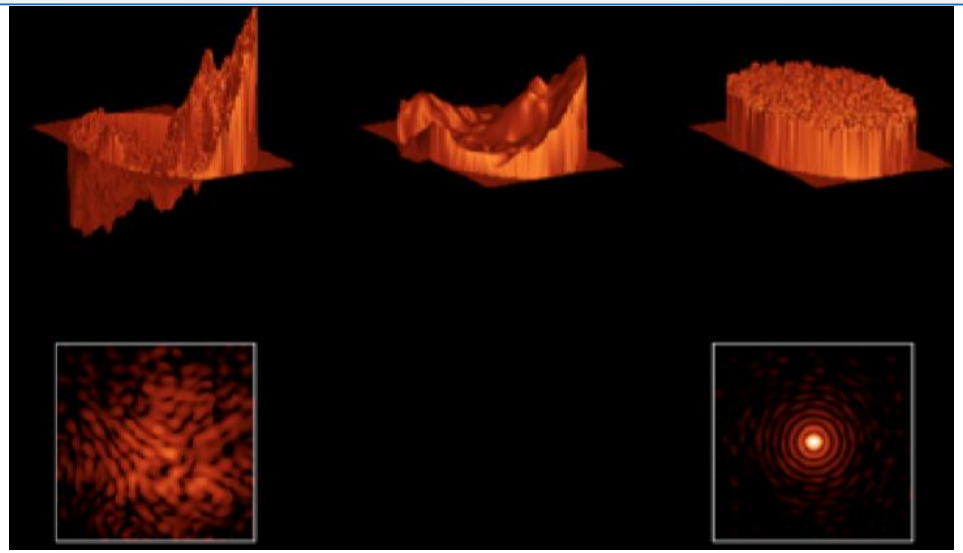


Adaptive Optics corrected

Multi-mode / Single-mode

Number of modes in telescope P
oint Spread Function

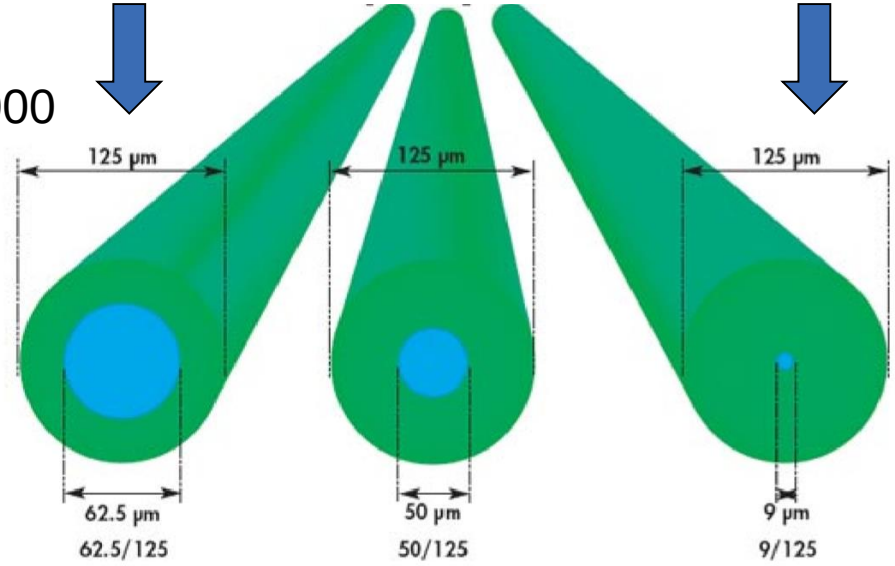
$$M \approx \left(\frac{\pi\theta D}{4\lambda}\right)^2$$



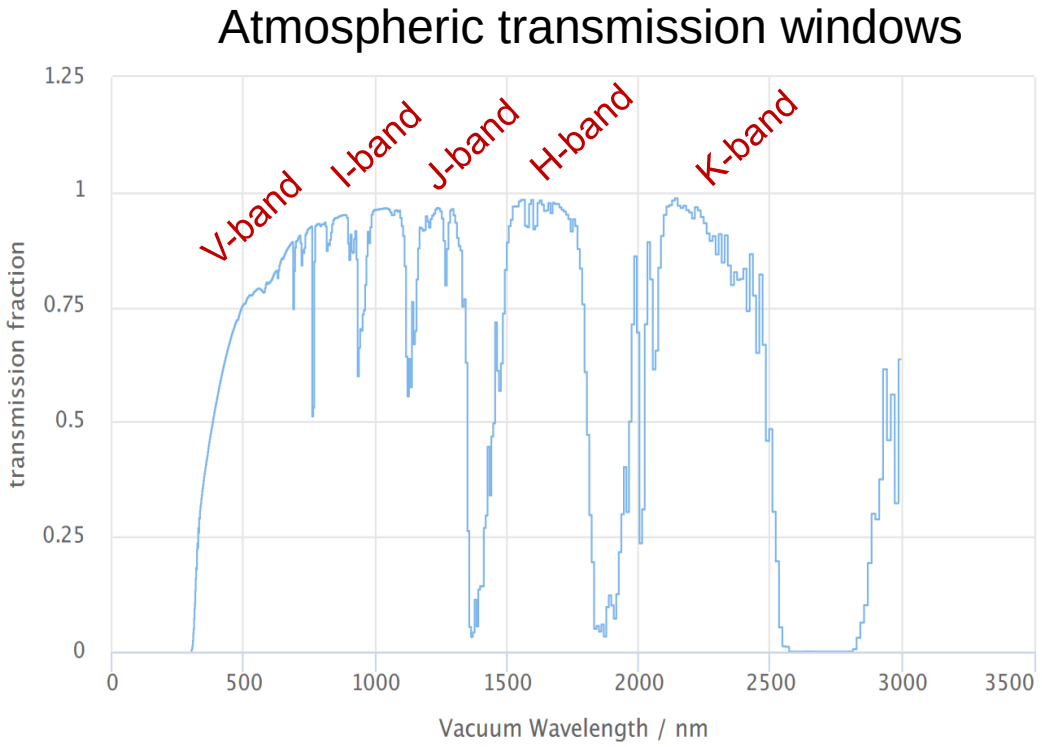
Diffraction limited: $\theta \sim \lambda/D$ => $M \approx 1$

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)



Sweet spot for SiO2 single mode components



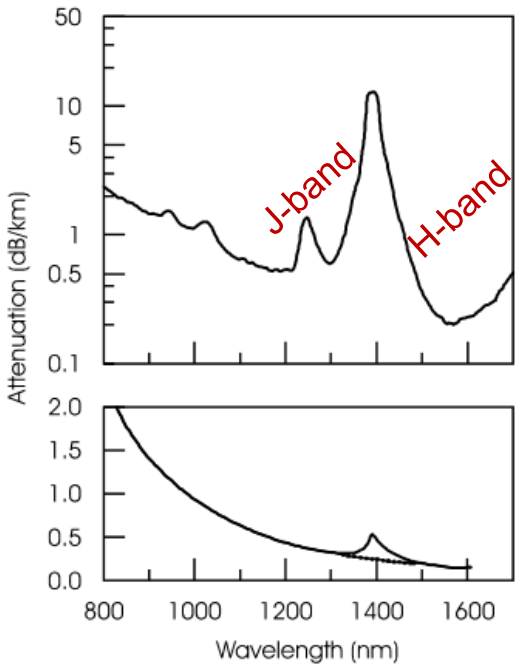
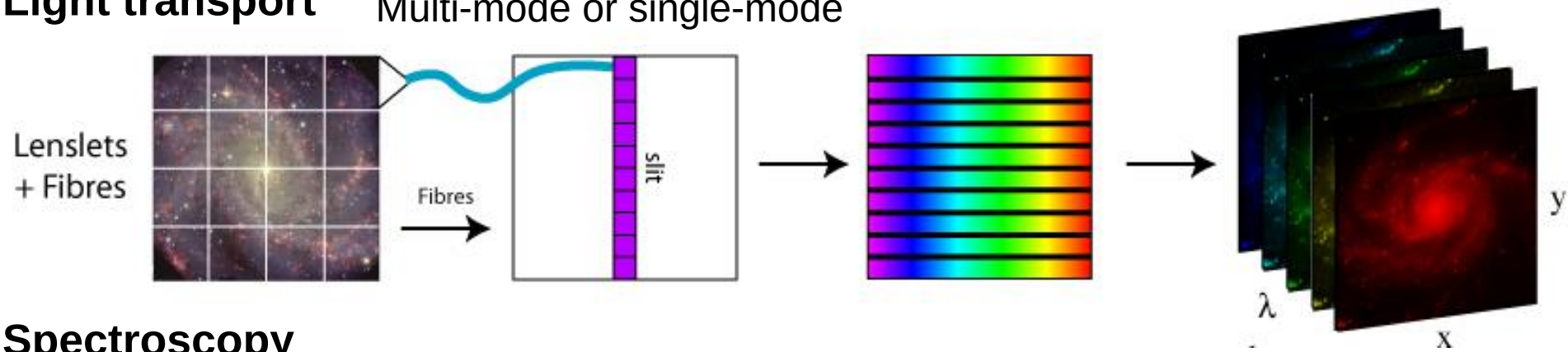


Fig. 0.1. Transmission characteristics single-mode optical fibres. Upper part: data given in Ref. 4, lower part: Corning SMF-28™ optical fibre (*full line*), SMF-28e™ (*dotted line*)

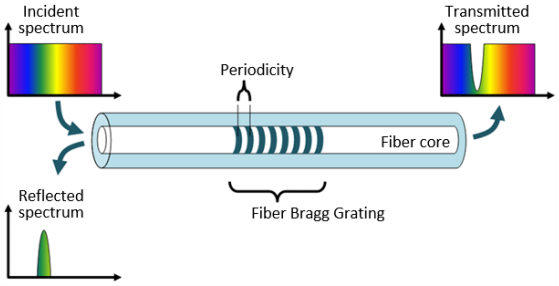
Waveguide applications in Astronomy

Light transport

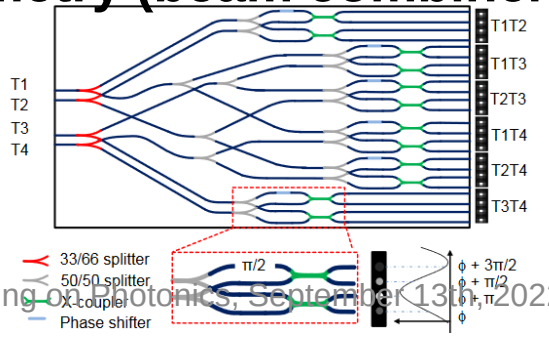
Multi-mode or single-mode

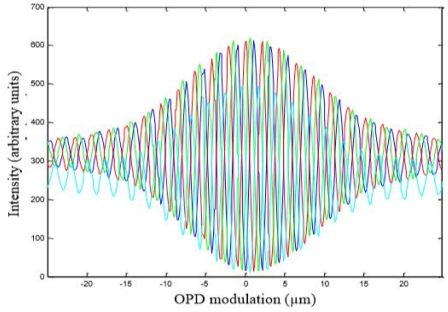


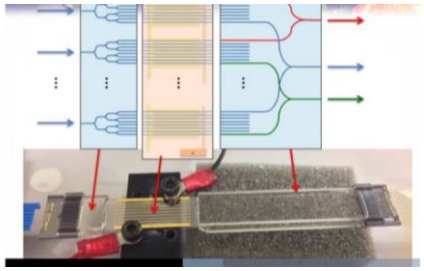
Spectroscopy



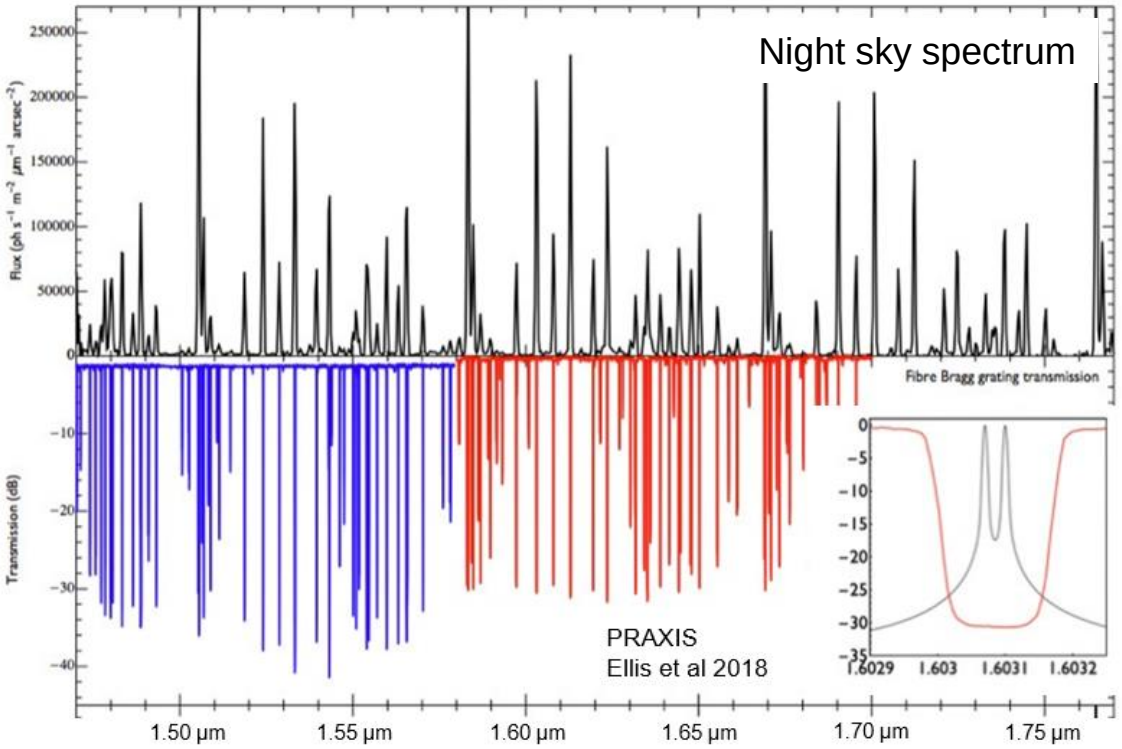
Interferometry (beam combiners, phase-shifters)

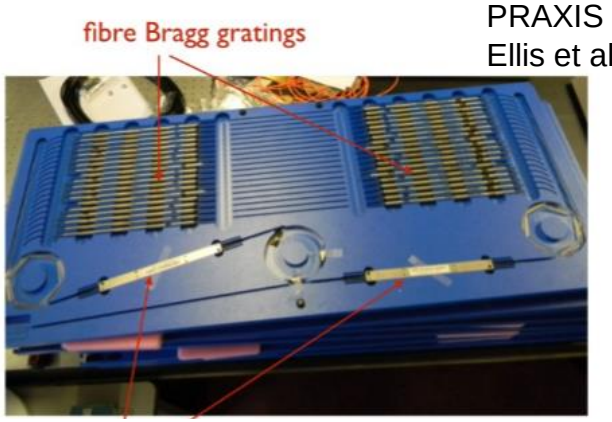


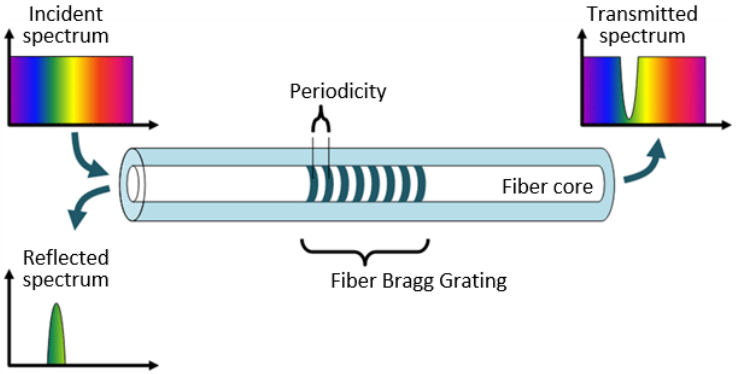




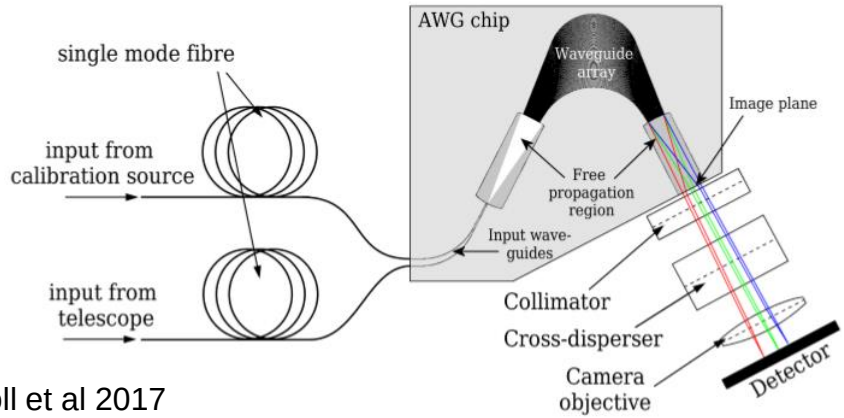
OH suppression



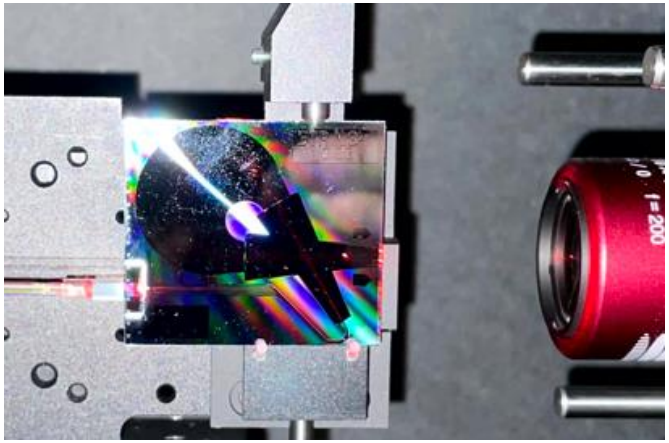




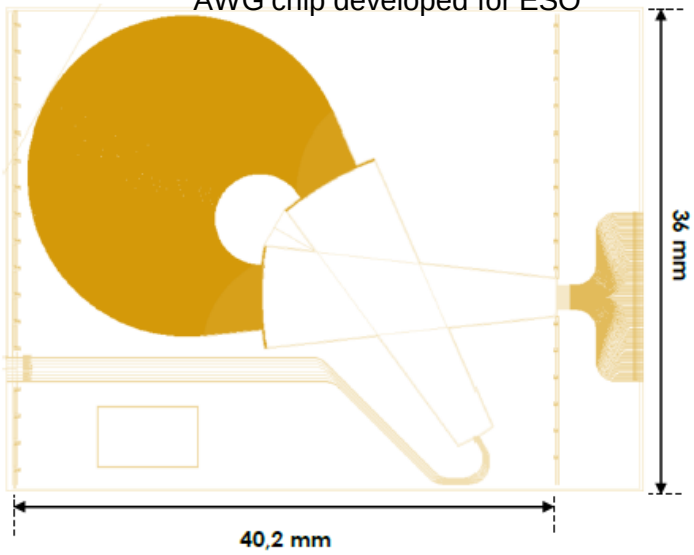
Photonic Spectrometers

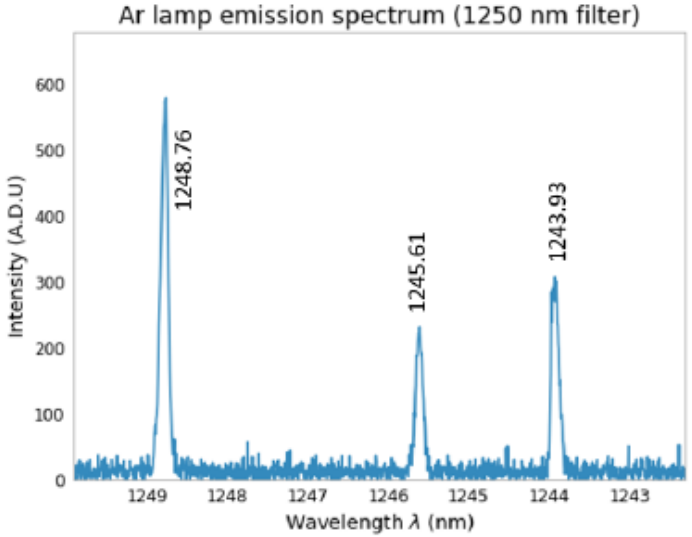


Stoll et al 2017



AWG chip developed for ESO

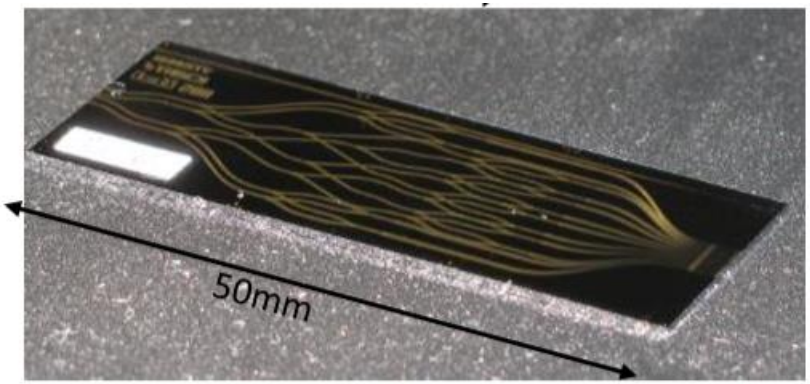


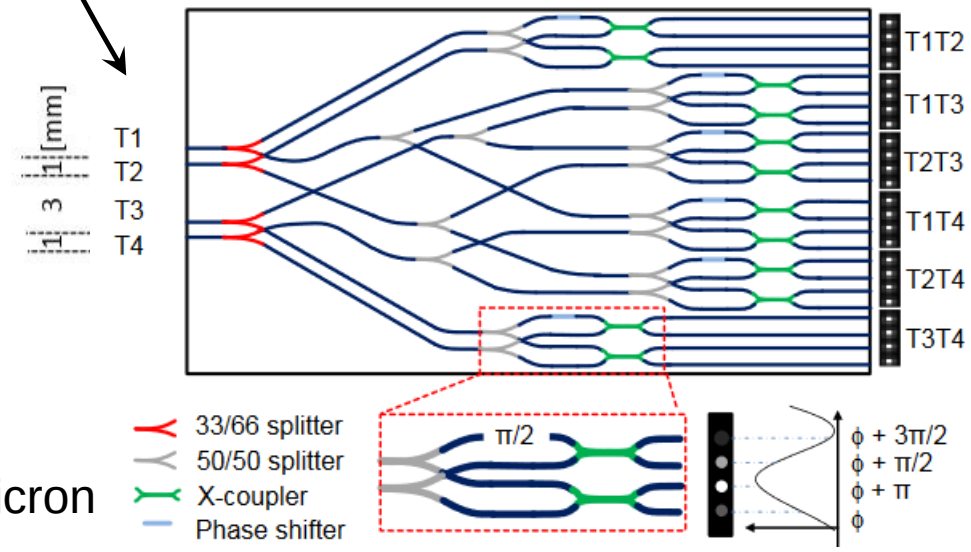


- Spectral resolution R=10,000
- Bandwidth 1150-1350nm
- FSR: 10nm

Application in interferometry

GRAVITY beam combiner





- Beam combiner working at 1.9-2.45micron
- Working at 200K
- Monolithic design => excellent stability

Perraut et al 2018

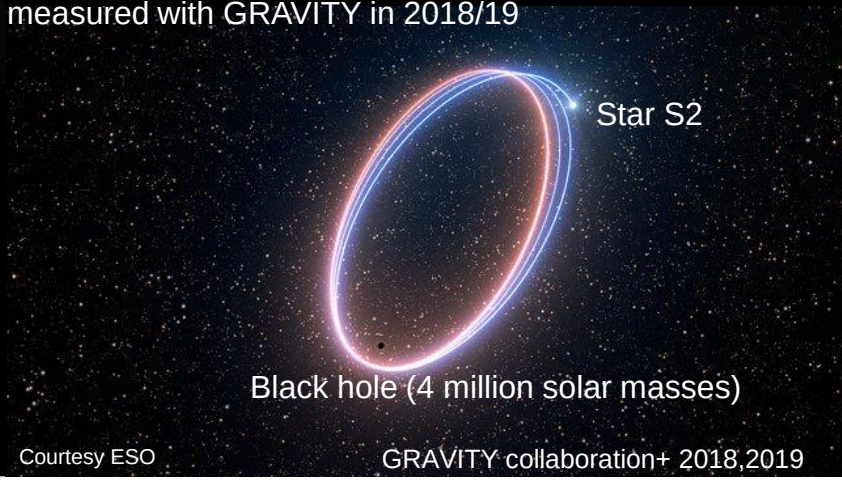
Astrophotonics breakthrough

GRAVITY instrument

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"

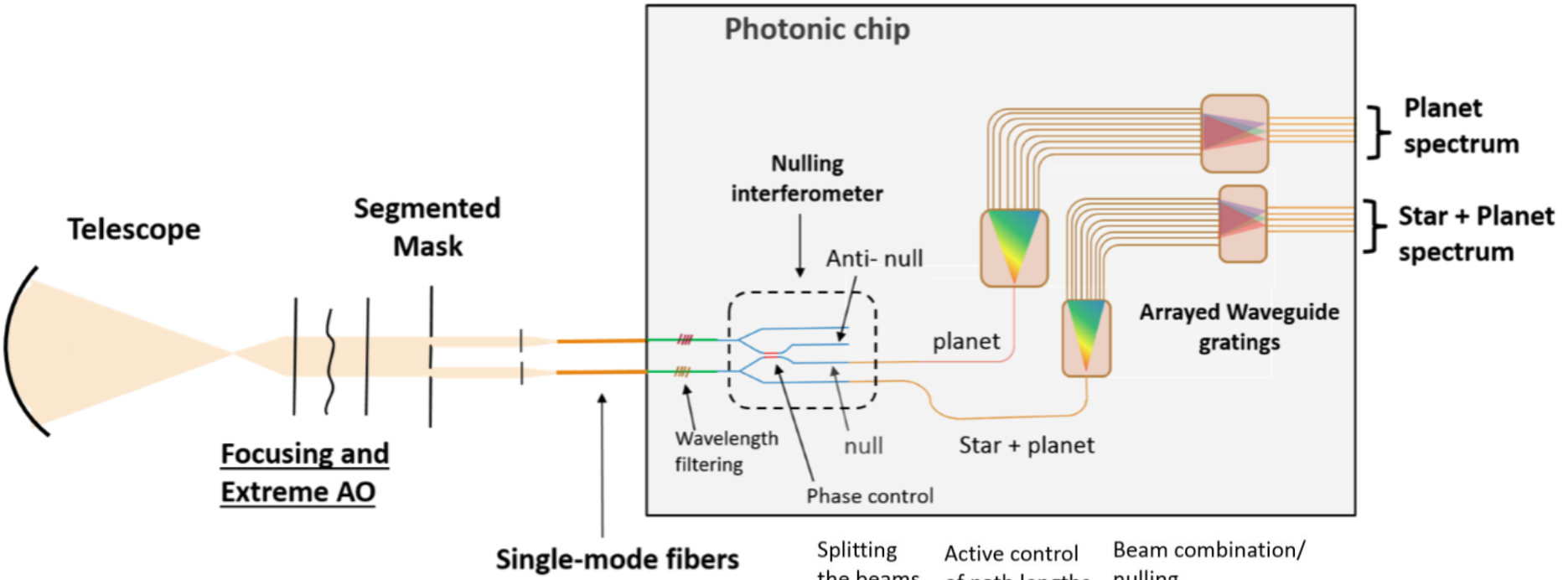
Gravitational redshift and Schwarzschild precession measured with GRAVITY in 2018/19



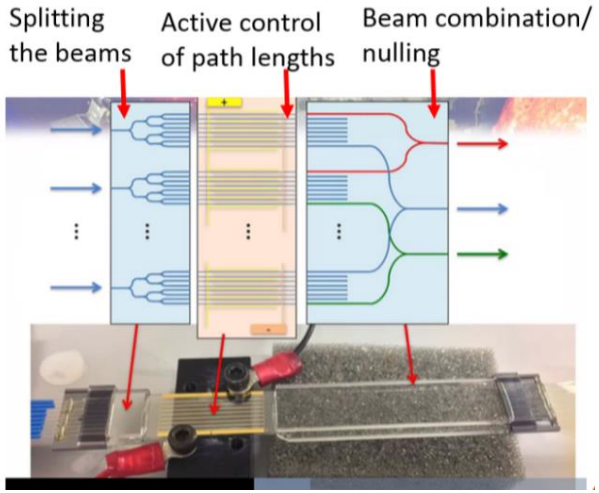
Courtesy ESO

GRAVITY collaboration+ 2018,2019

Outlook

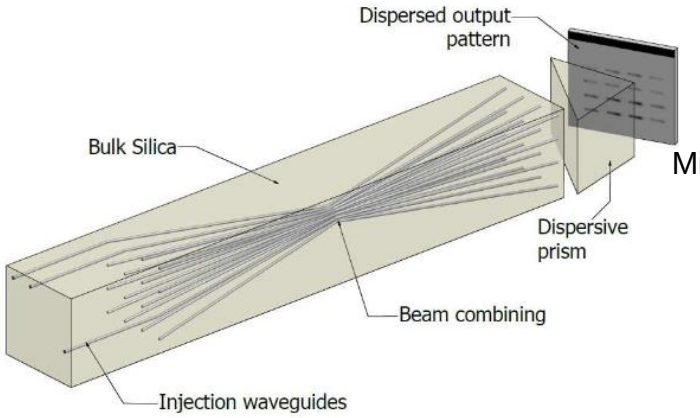


Gatkine et al 2019



What is needed in the future?

- **Off-the-shelf components, which can be readily combined**
- **3D photonic components (e.g. beam combiners, re-formatters)**
- **Components/materials working in the mid-IR (3-5μm)**
- **Reduction of coupling losses (combination of components)**
- **Improvements in transmission and bending losses**

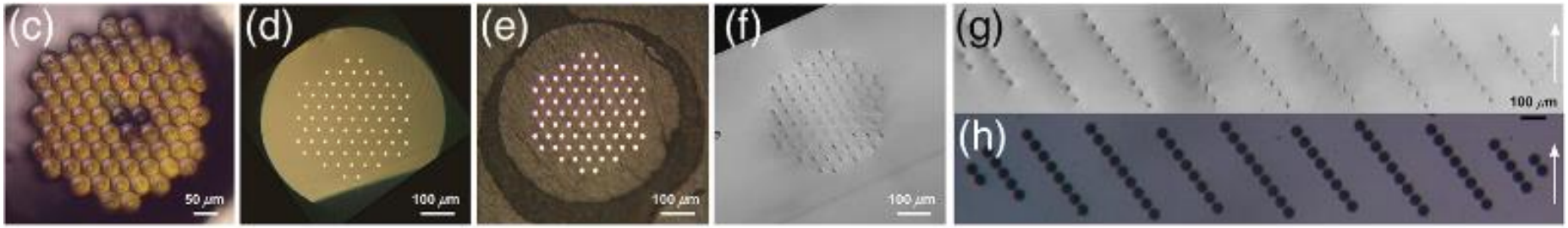


Minardi+ 2012

3D reformatter

Printed micro-lenses

Multi-core fibers



Haffert+ 2021

Conclusion

- Advantages of single mode photonics
  - Extremely compact (~few cm) & stable (no flexure, temperature gradients etc)
  - Can be combined with filters, active components (OH etc.) in a monolithic design
  - Can be directly fed with calibration sources (LFC etc)
  - Diffraction limited -> $R = \frac{A\, d_{coll}}{r}$ (independent of telescope, i.e. spectrograph volume does not scale with telescope)

- Disadvantages
  - Works best with diffraction limited PSF
  - Limited bandwidth
  - Technology only mature in NIR (J/H-band and K-band) due to adaption from telecommunication

Thank you