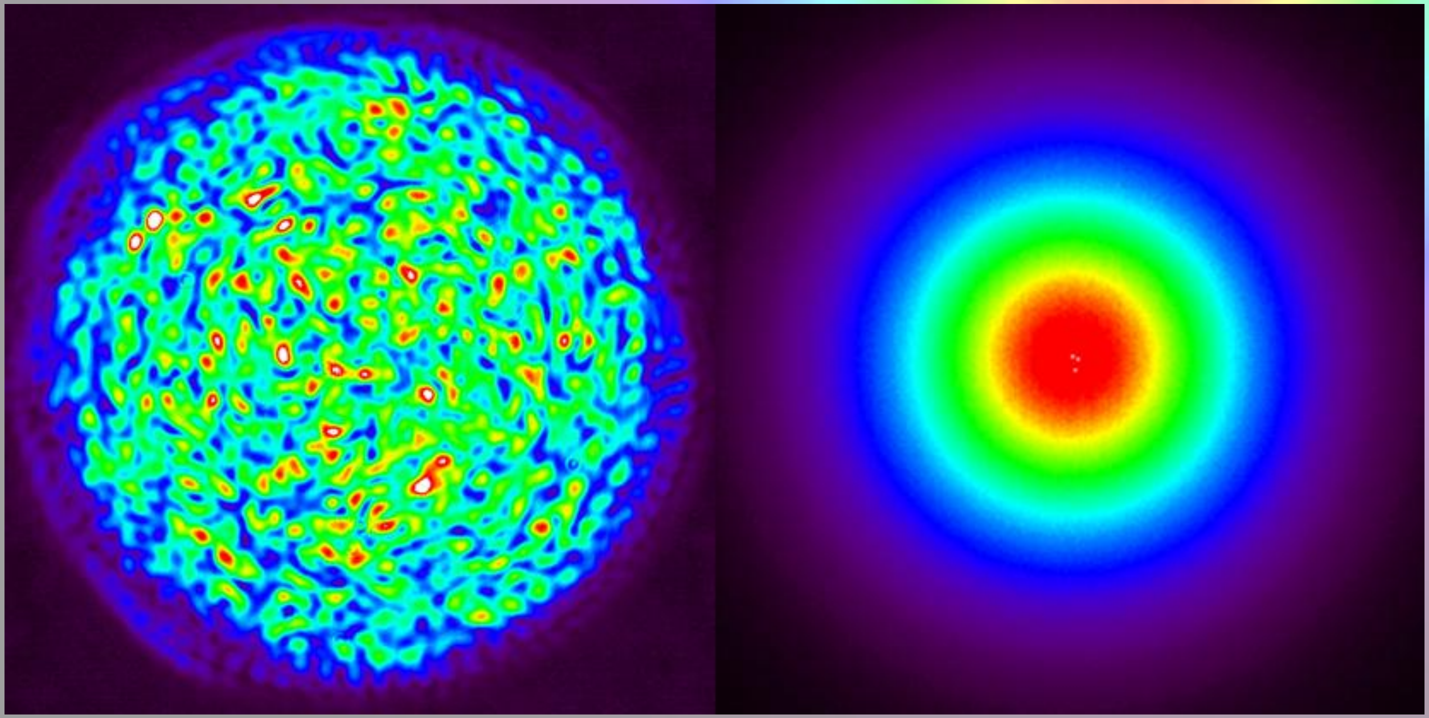
# Extreme precision single mode Doppler spectrographs in the NIR

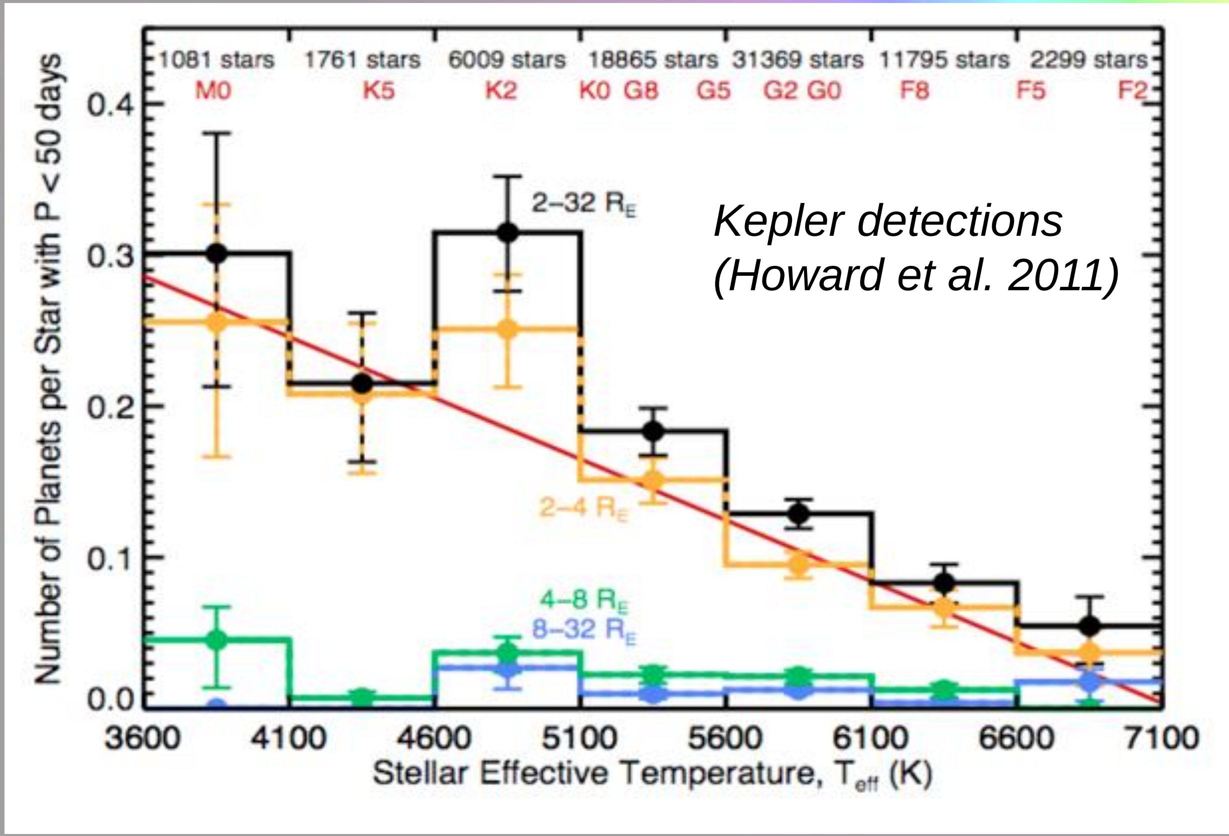


# M Dwarfs as targets

- Low masses mean higher reflex velocities
- Small radii mean deeper transits
- Long lifetimes mean stability for biological evolution
- Habitable zones are shorter period orbits
- Very common stars

# M Dwarfs as targets

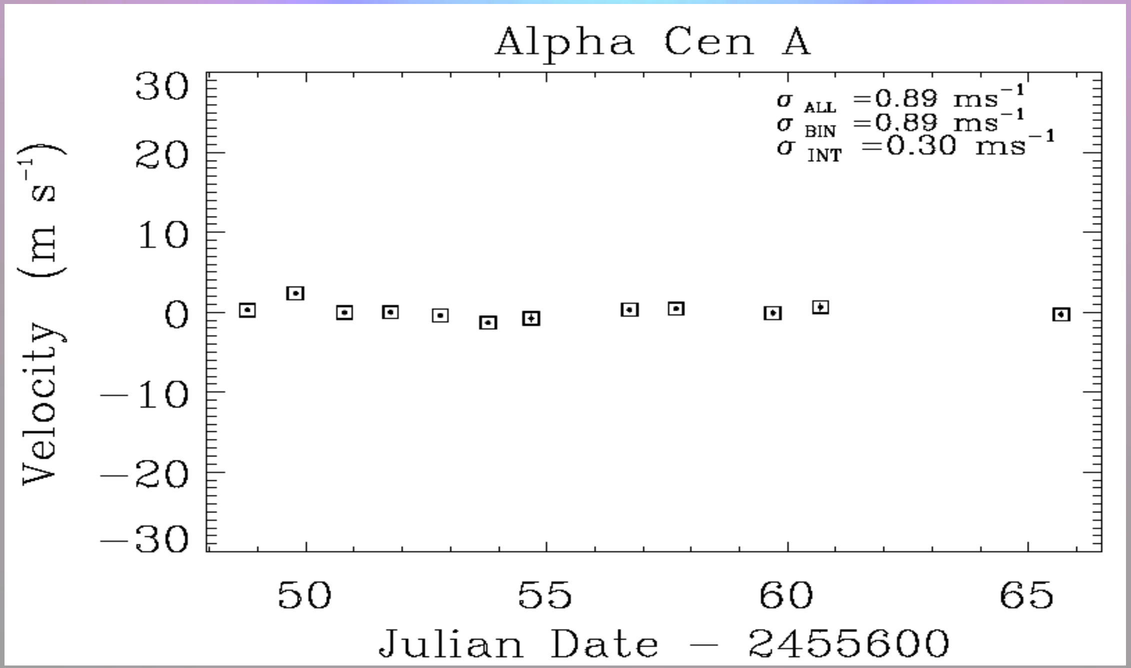
Evidence for many low mass planets (at least around M0-M5V) from Kepler observations and Doppler measurements. (e.g., Howard et al. 2011, Johnson et al. 2008, Bonfils et al 2011, Delfosse et al. 2012, Butler et al. 2006)



# RV precision requirements

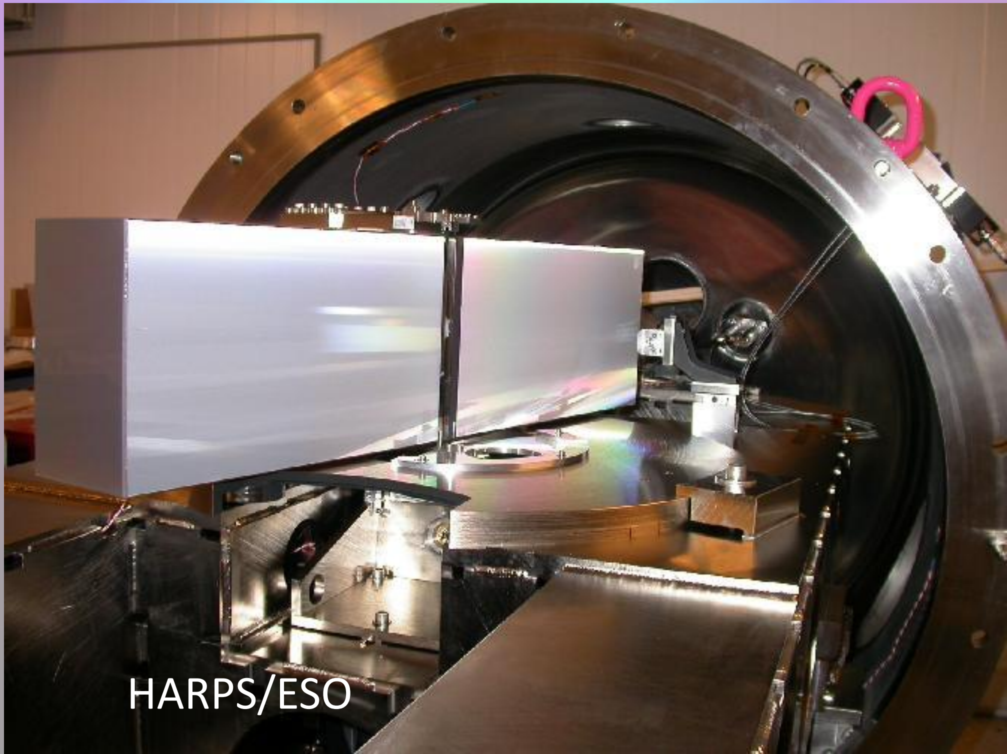
- Order 1m/s: relative precision of 3x 10^-9
- Stellar spectra are fully resolved for R>60.000
- At 2px sampling, 1 px is 2.5km/s > 15 micron pixels > 6 nm spectral shift on detector!

CHIRON: 0.9 m $s^{-1}$ RMS
(First 2 weeks of data)



# PRV spectrograph state-of-the-art

- Astronomical Echelles: Richardson ruling engine, 1965
- Fiber coupling: 80's. (eg. AURELIE 1989)
- HIRES: 1993
- HARPS 2003



# PRV spectrograph state-of-the-art

- Current Echelle spectrographs are refined, optimized, fine-tuned version of 80's/90's technology… PRV v1.3.
- PRV 1.99 (beta):
  - Non-circular fibers
  - LFCs
  - … Slicers, VPH's…

Geoff Marcy '95 (?)

# What about PRV spectrograph 2.0?

- Compact, cheap(er), ultra-stable.
- user-friendly, sleek, and everyone has the same- *iSpectrograph?*

# Photonics

*SMF feeds can push precision!*

- Illumination stability: PSF and far field
- Diffraction limited source:
  match PSF disc to pixel size: f/30
- Ideally suited for SM calibrators
- *Resolving power = resolution:* 1 inch beam!

  → More stable bench

  → Wide choice of optical designs & materials

  → Superior image quality

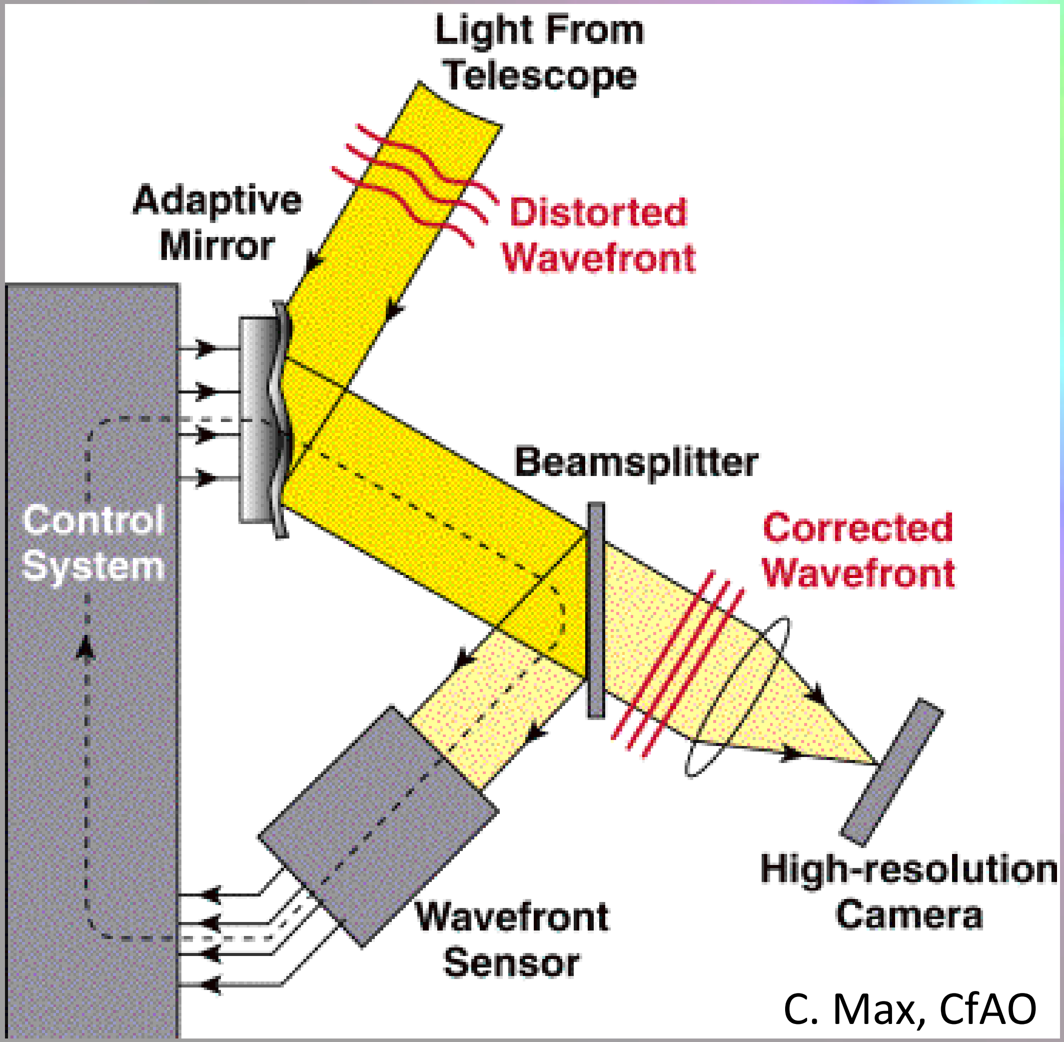
  → Easier T and P control

# Coupling SMF to the telescope

- Can't rely on high Strehl
- Every optical engineer working on astronomical spectrographs wants a funnel!

Heisenberg et al: You can NOT funnel light!

# Enabling technology: Adaptive Optics




- Science target is NGS
- Most simple case for AO system
- All major facilities develop AO

# LBT natural guide star AO: results

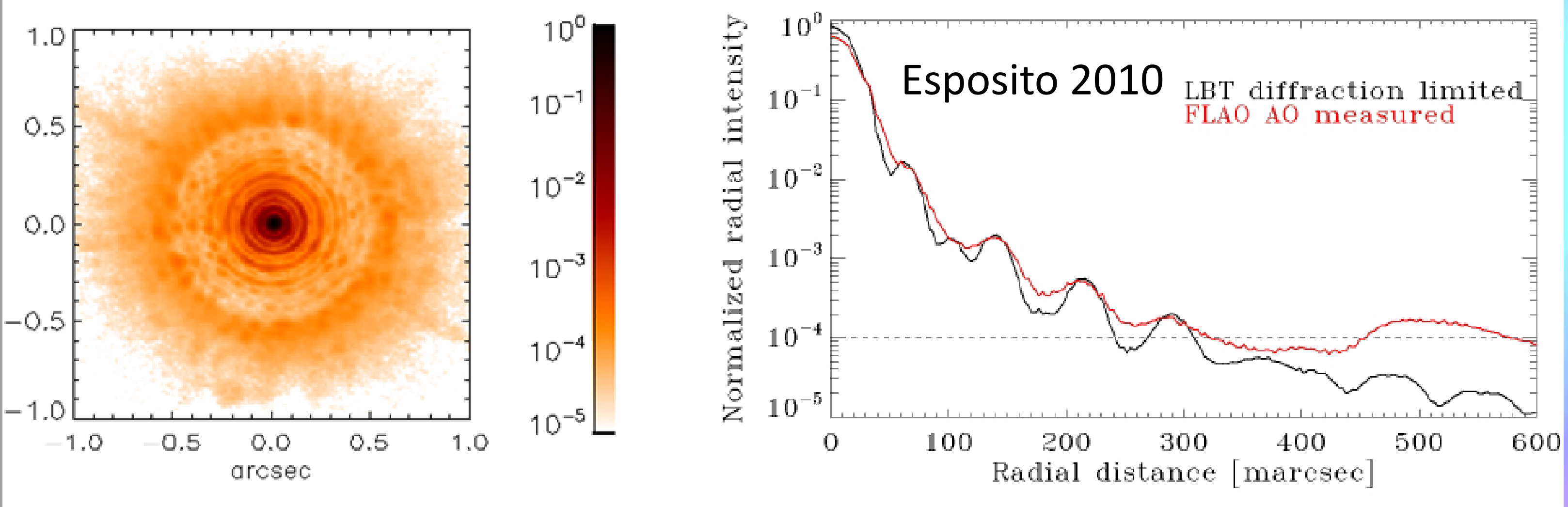
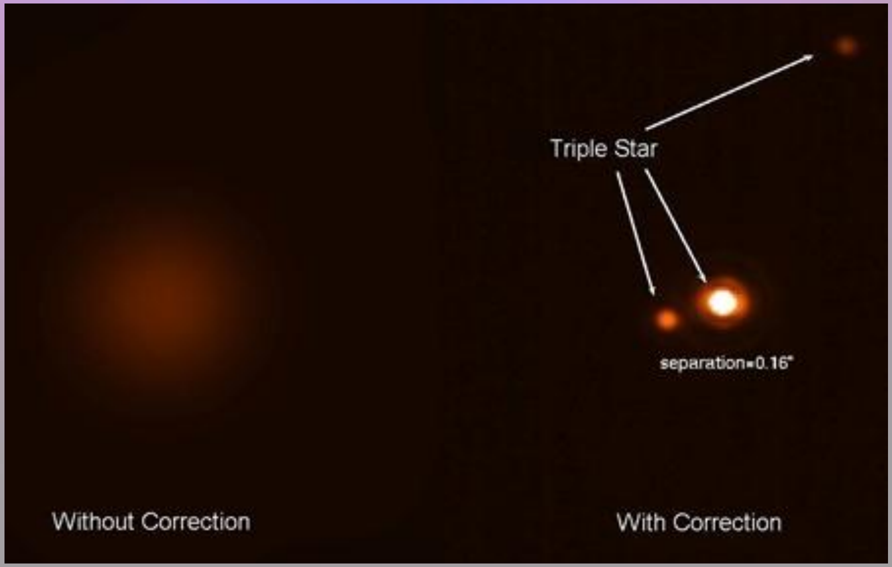
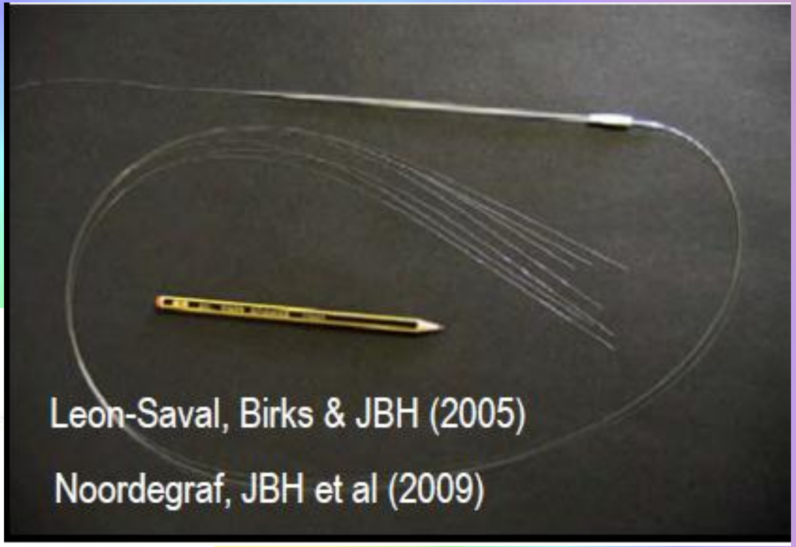



Figure 5. (*Left*) High-order AO-corrected PSF using a bright star ($M_R$ = 6.5) under median seeing conditions

# Photonic lanterns



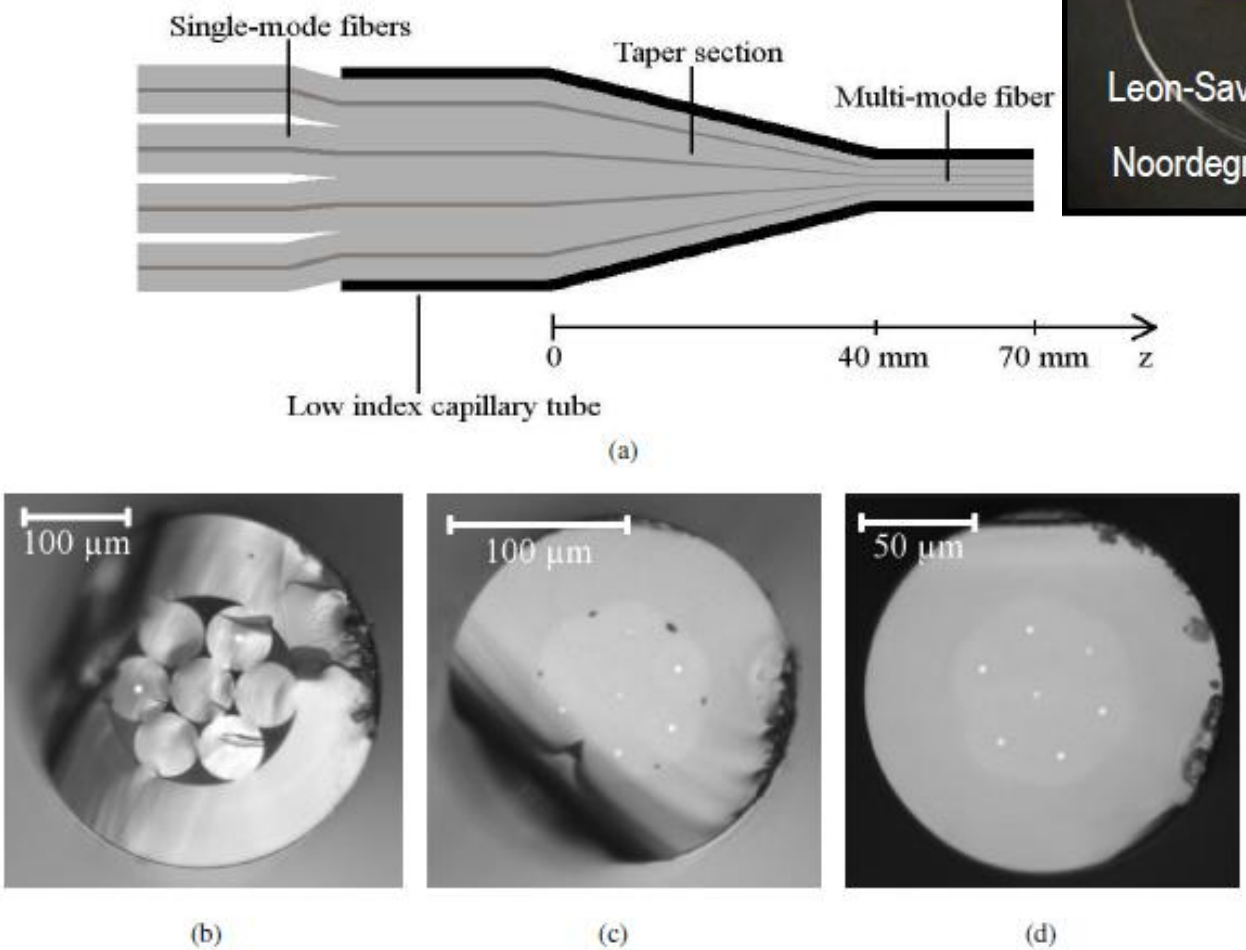
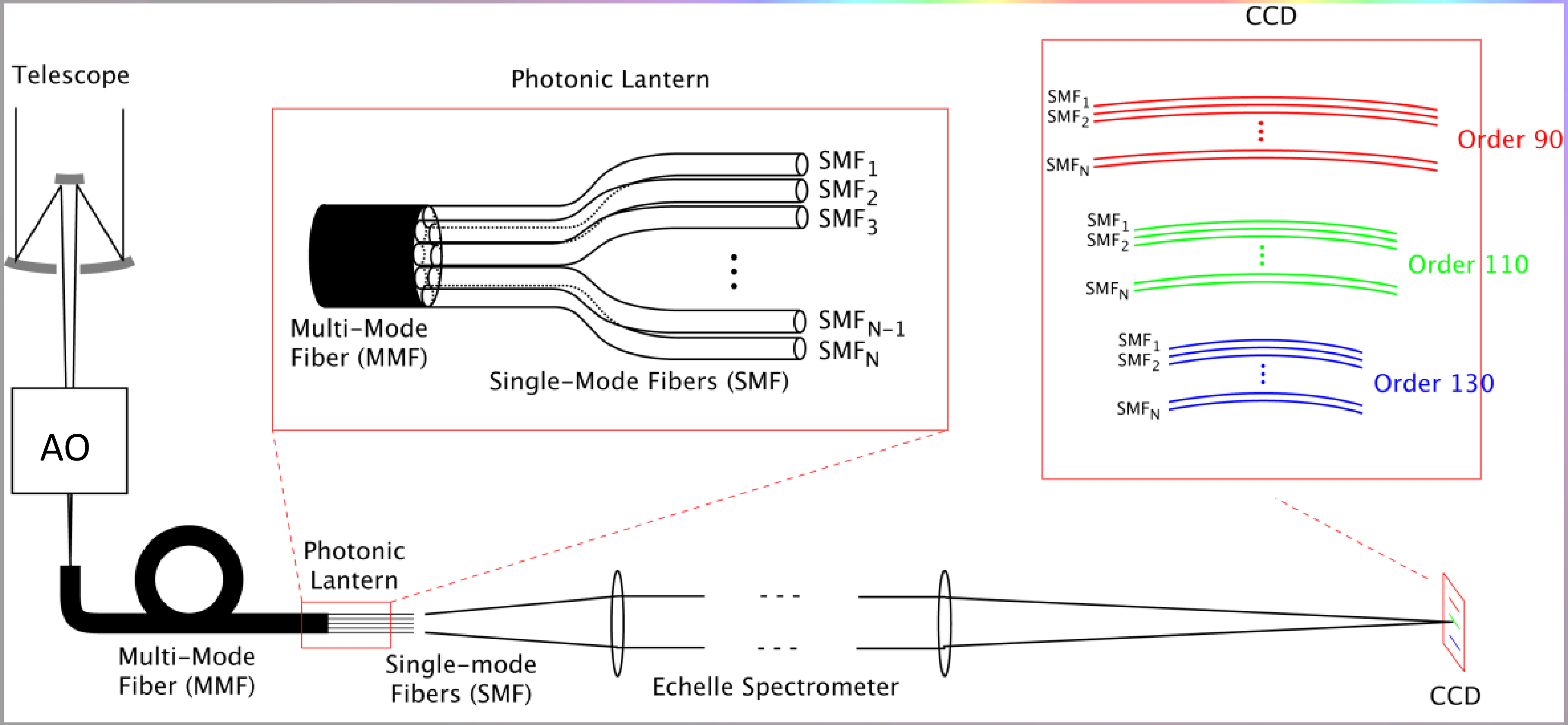




Fig. 1. Schematic illustration of the photonic lantern. (b)-(d) Microscope pictures of the fiber bundle cross section at different positions in the taper transition, at z=5 mm, z=20 mm and z=25 mm, respectively.

# Lantern-fed echelle



# SNR and number of modes

Number of fibres permitted is set by

- Manufacturing: current limit is 160 fibers..
- Read out noise / SNR

*Example: 20 SMFs,*

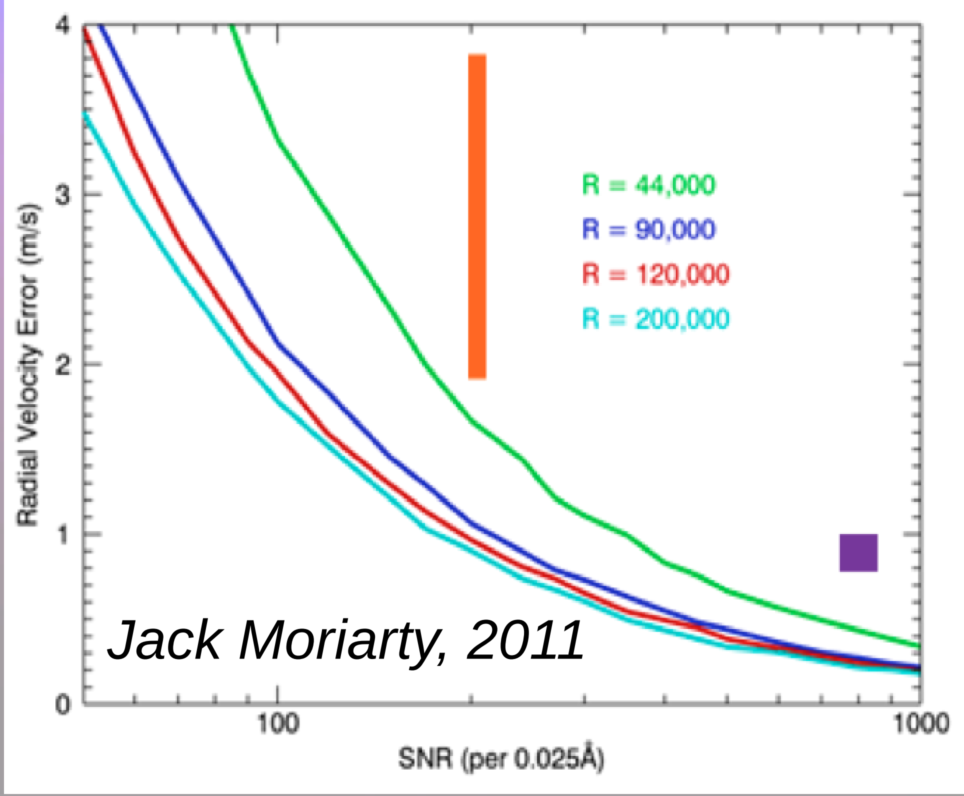
*SNR of 200 per res. element*

*4x 10^4 photons divided onto*

*20 fibres: 2000 ph/fibre*

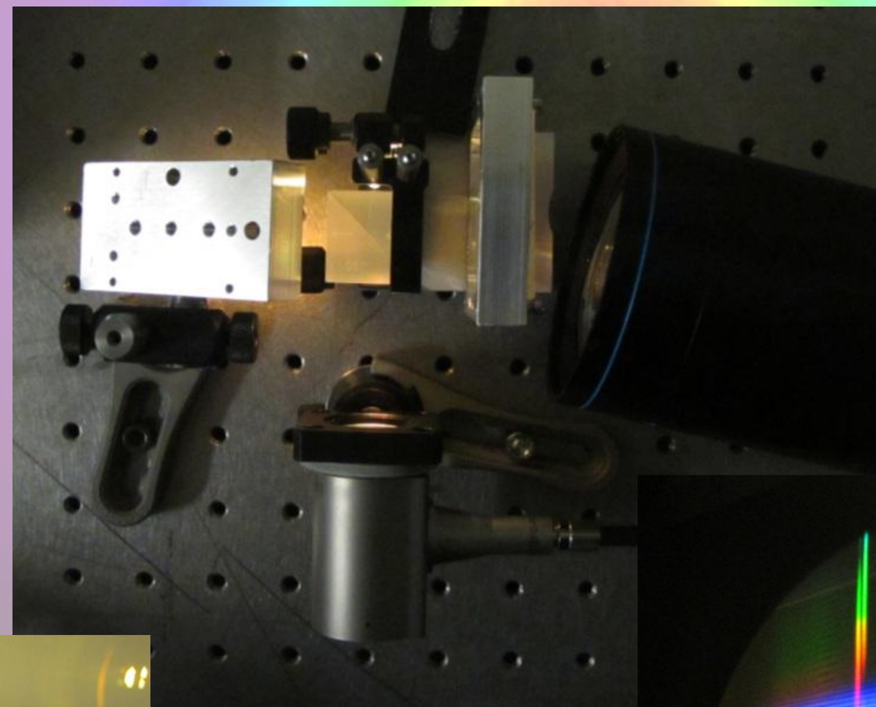
*4 pixels per fibre (2x2):*

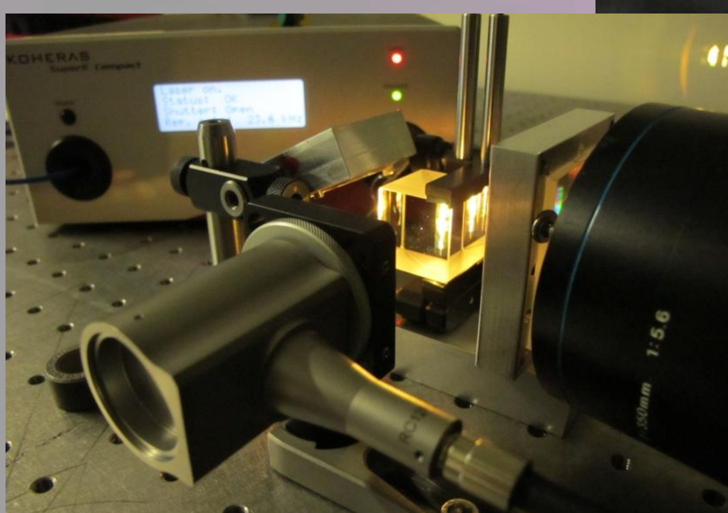
*500 ph/px.*

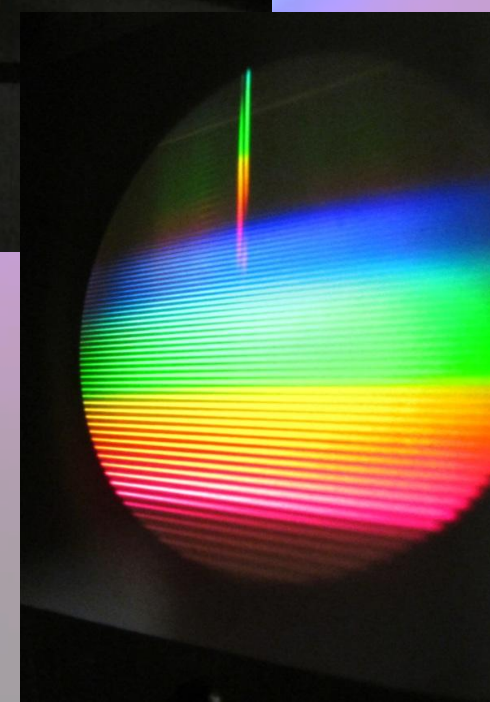


# Lab tests

- 25 mm beam SMF spectrograph
- COTS components
- Similar to RHEA@Maquarie





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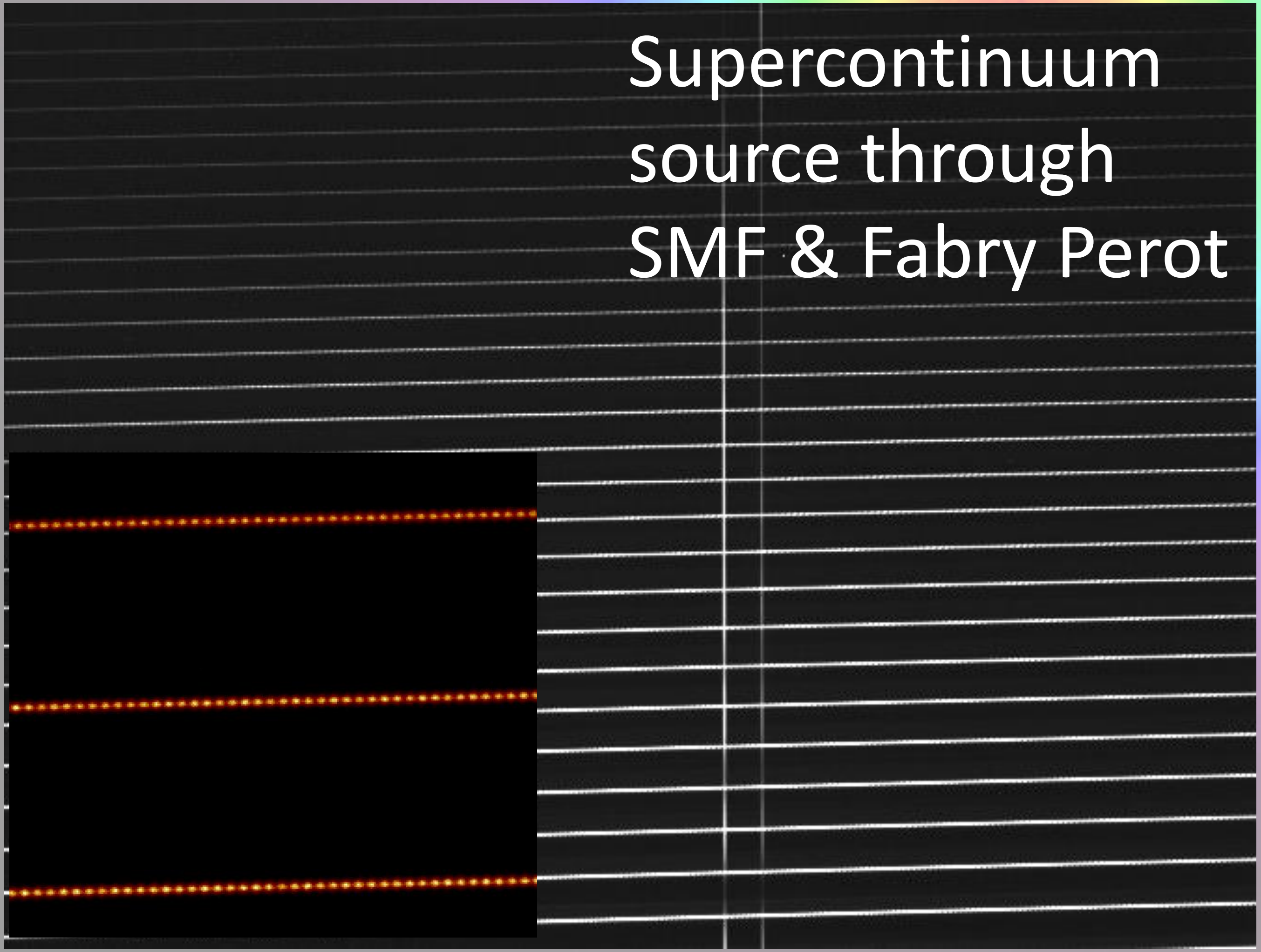

# Conclusions

- *iPRVspec 2.0* might look very different
- Tremendous technology developments in the past decade
- For a particular science case, astrophotonics will provide the next step in precision
- Very similar spectrograph for any telescope