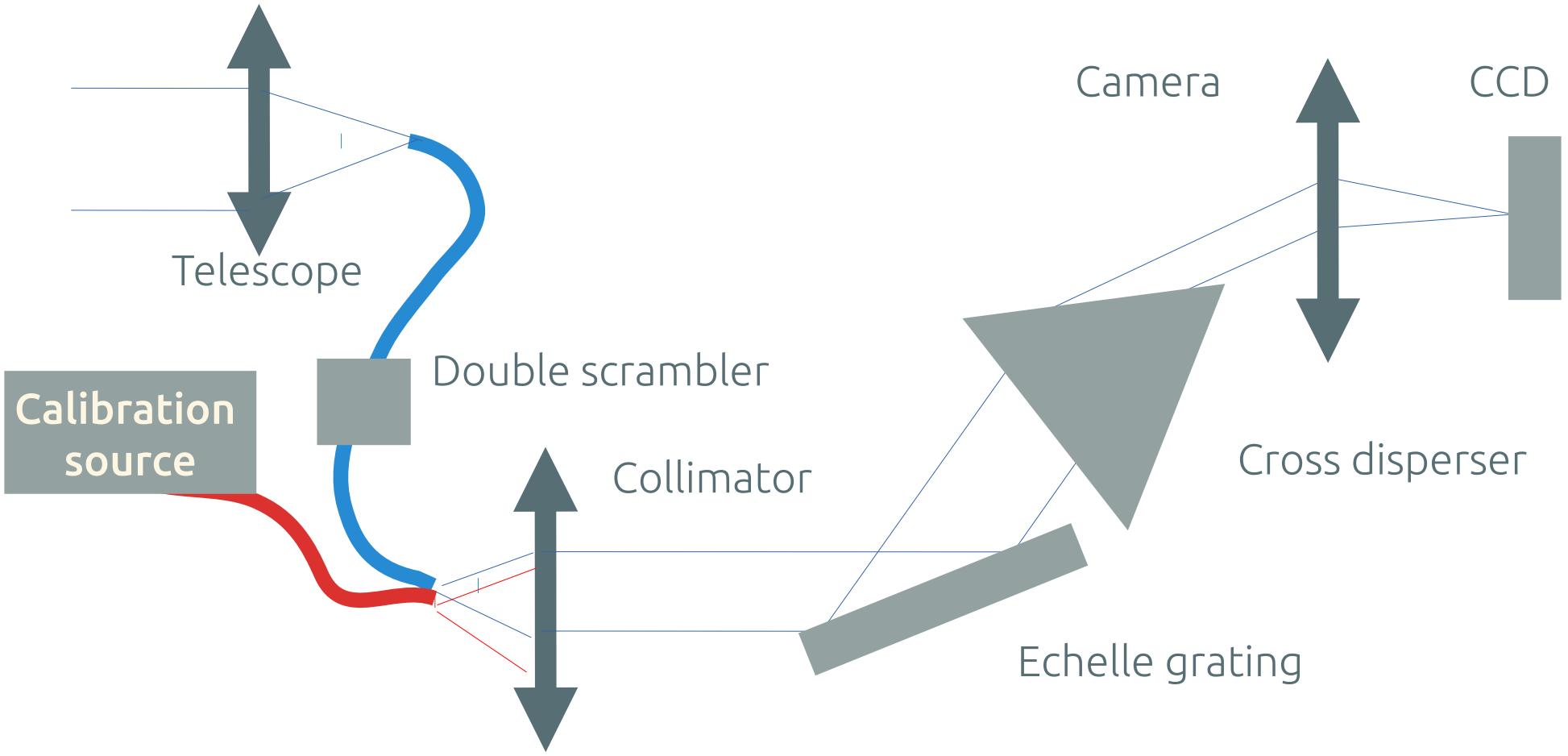
Light injection into EPRV spectrographs

Bruno Chazelas,
Observatory of Geneva

EEPRV4 Grindelwald

Typical EPRV Instrument

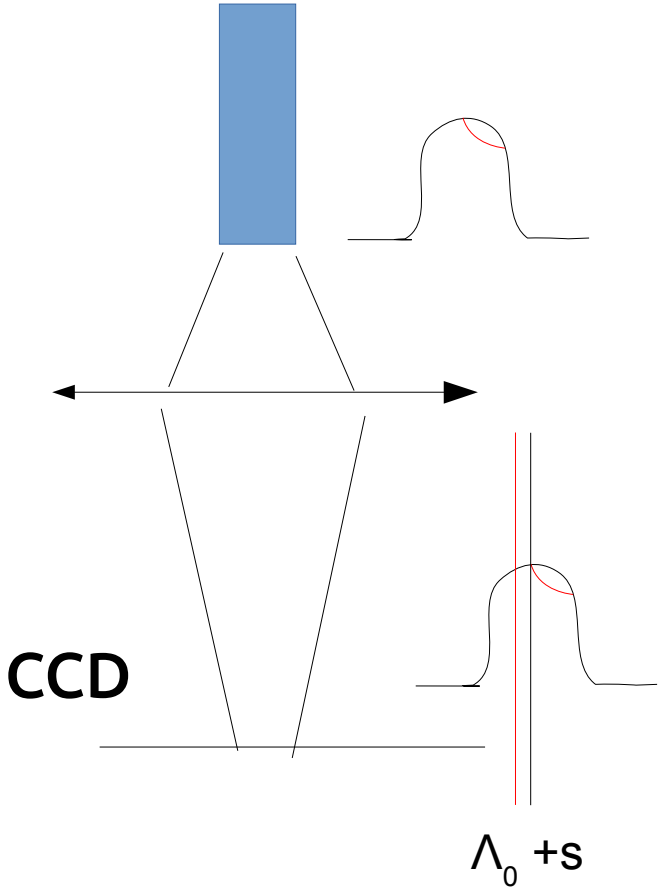


What do we want

- Tons of photons
- But the good ones

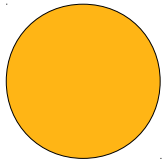
What are we fighting

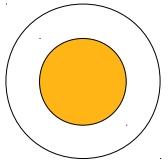
Near field effects



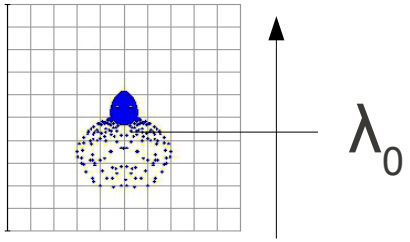
Far field effects

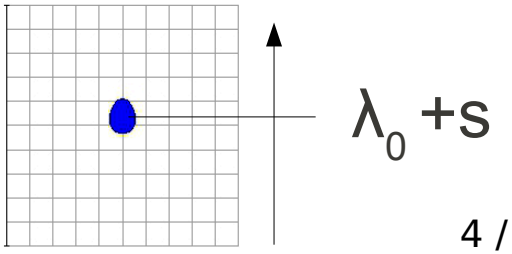
Instrument pupil illumination



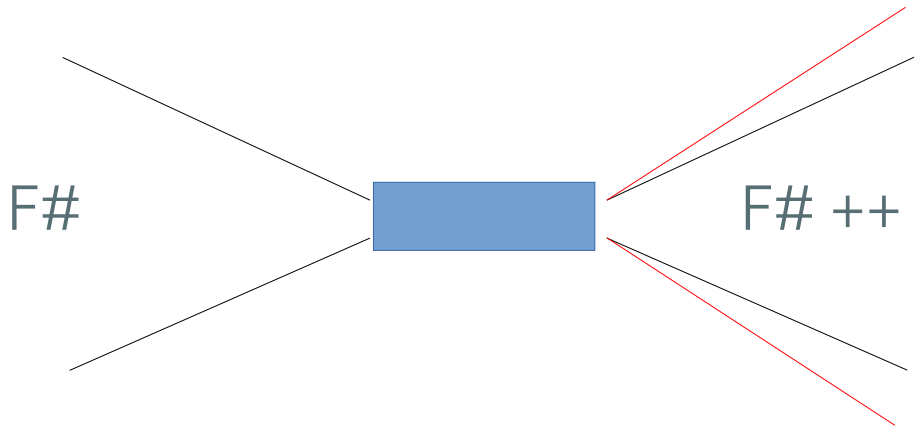


Instrument profile





Focal Ratio Degradation (FRD)



FRD is an increase of the beam etendue.

Etendue is already an issue with large telescopes thus it is lost light.

FRD comes from :

→ Fiber extrusion process (roughness/micro-bending)

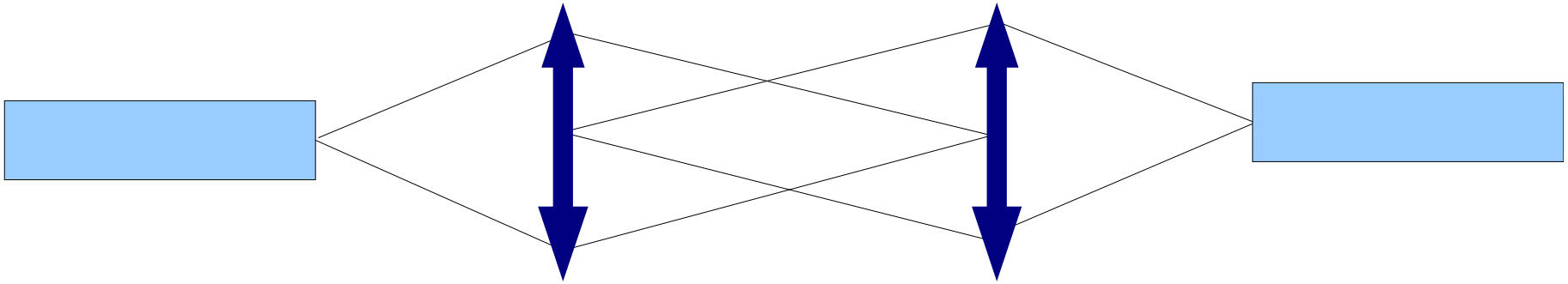
→ Connectorization

Round fibers / Non circular

- Round fiber do (Heacox 1986,1987) :
  - azimuthal scrambling in **near** and **far** field
- Non circular fiber do (Chazelas+ 2010/2012):
  - « perfect » near field scrambling
  - Azimuthal scrambling

Double scrambler

(Hunter and Ramsey 1992)

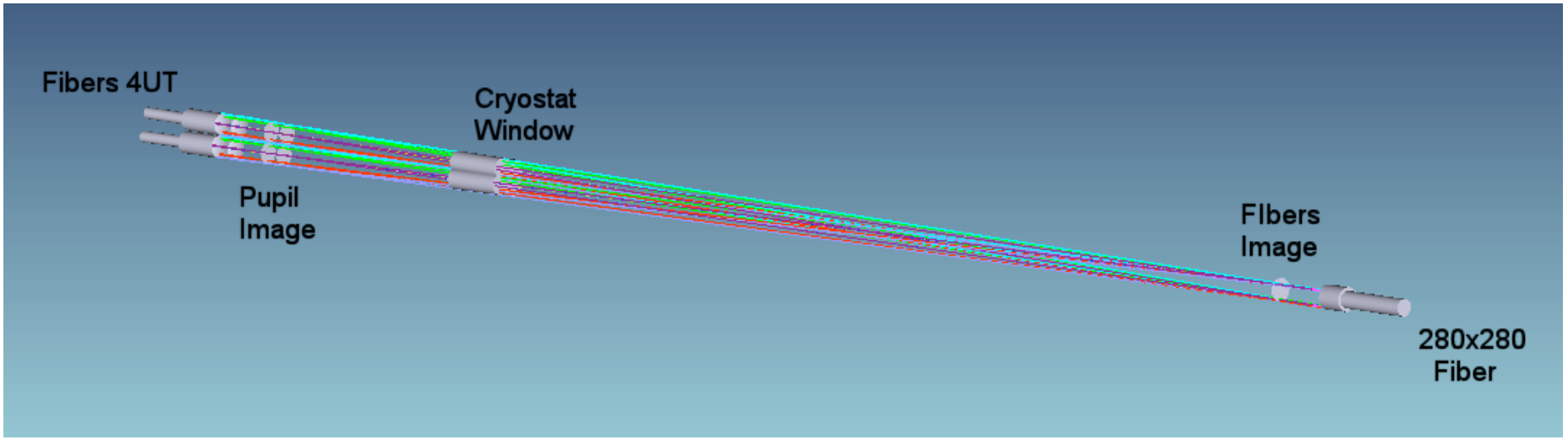


- Imagined to use the stability of the pupil of the instrument
- Exchange The near field and far field
- Cost a bit of transmission (FRD)

XL aperture telescopes

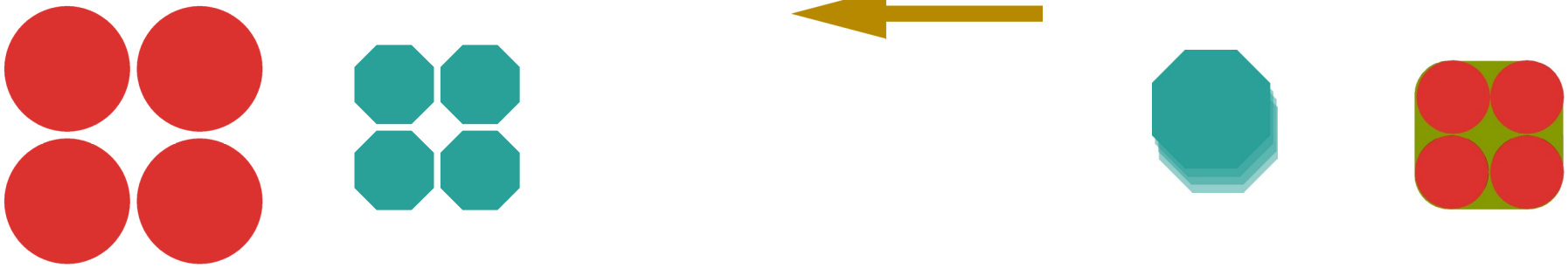
- Etendue is so big that one needs new tricks
  - Slicing image (KPF,HPF,...)
  - Slicing pupil (SPIRou, ESPRESSO,G-CLEF,MAROON-X ...)

ESPRESSO Image combiner / SCRISER



(Témich + 2018)

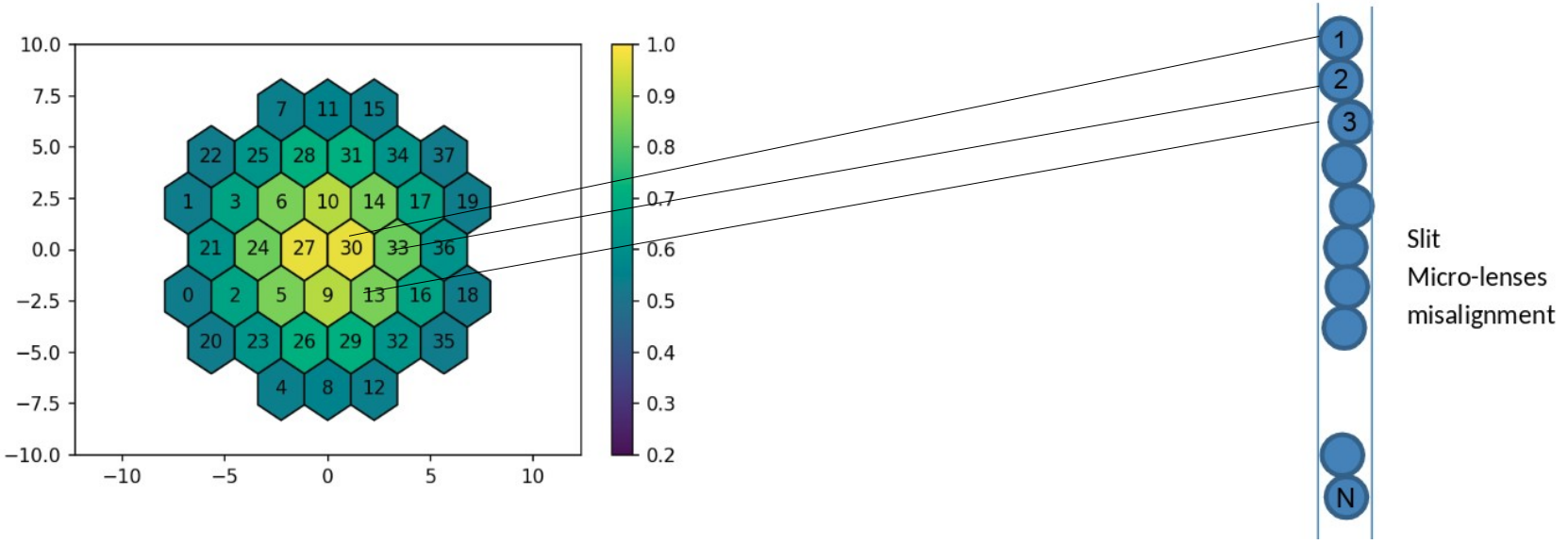
Scrambling image slicer



Scrambling image combiner

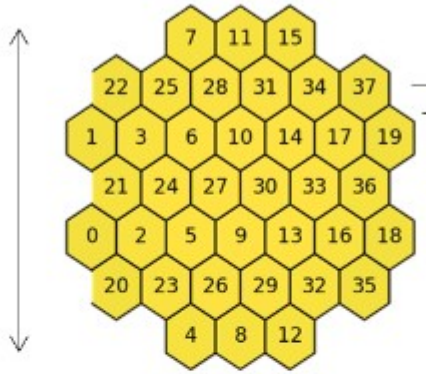
Case of HIRES

- Reformat PSF/ Pupil into a long slit
- Need for an inter-fiber scrambling technique for high stability science

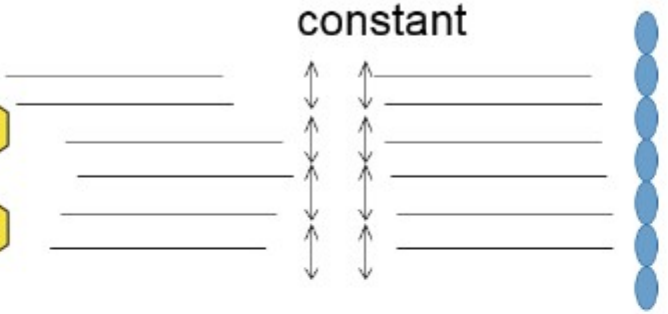


Case of HIRES

Projection of the pupil on the
new fiber bundle / microlens array



double scrambler on each fiber
+ non circular fiber
Will make the spectrographe illumination
constant



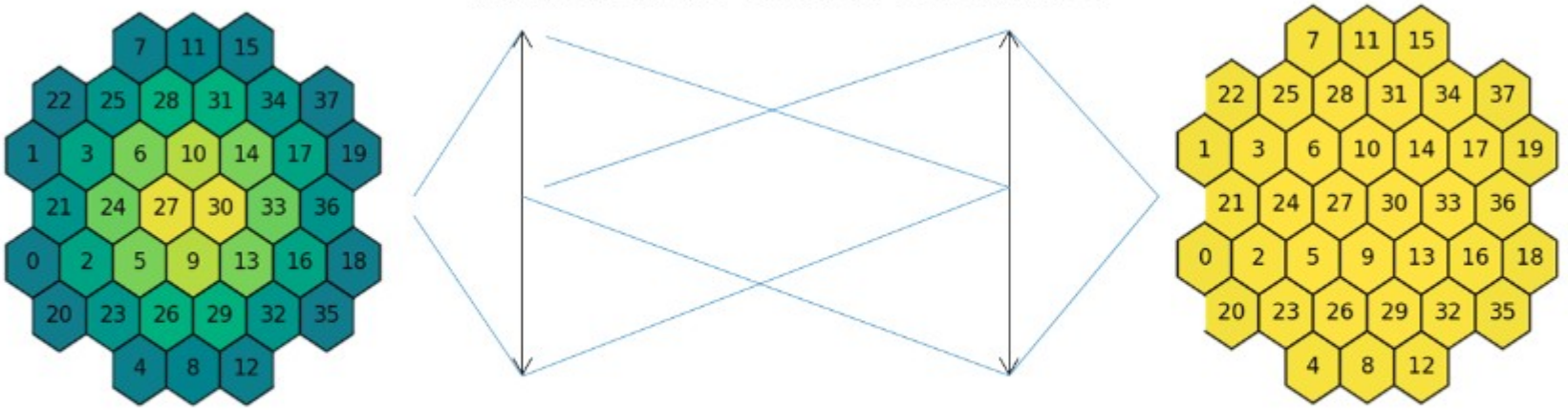
All fiber have an illumination independant of guiding and seeing
However they have the far field that will change with
These parameter

Case of HIRES

Dicing in the image space

Near field stable and flux distributed evenly

Inter bundle double scrambler



Far field stable (Pupil of telescope)

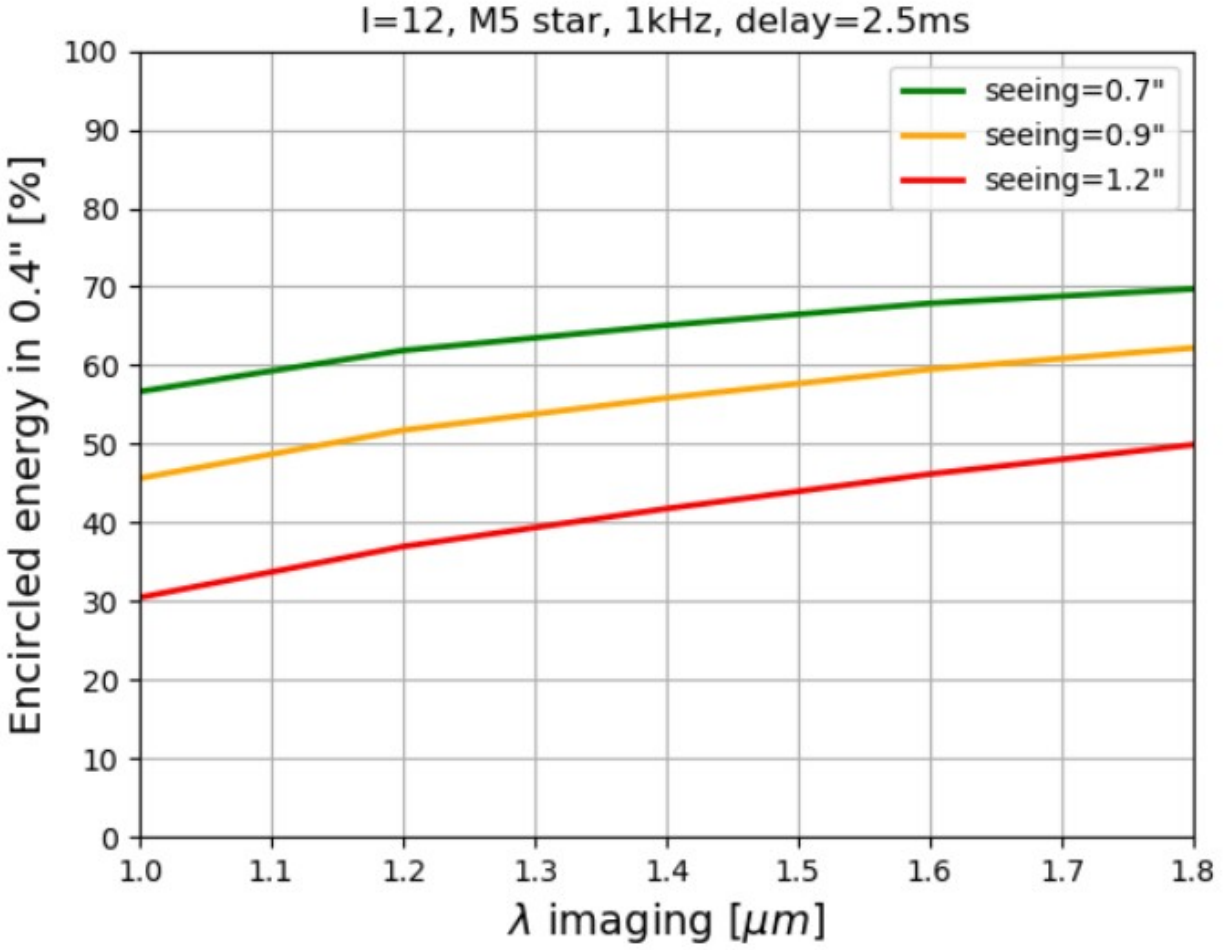
Far field is the flux averaged the power

AO assisted spectrograph

- Reduce the Etendue :
  - Smaller spectrograph (ILocater , NIRPS, ...)
  - Higher resolution (Ge + 1998)
  - Recover spatial information (HIRES, ...)

AO assisted spectrograph

4m Class Telescope

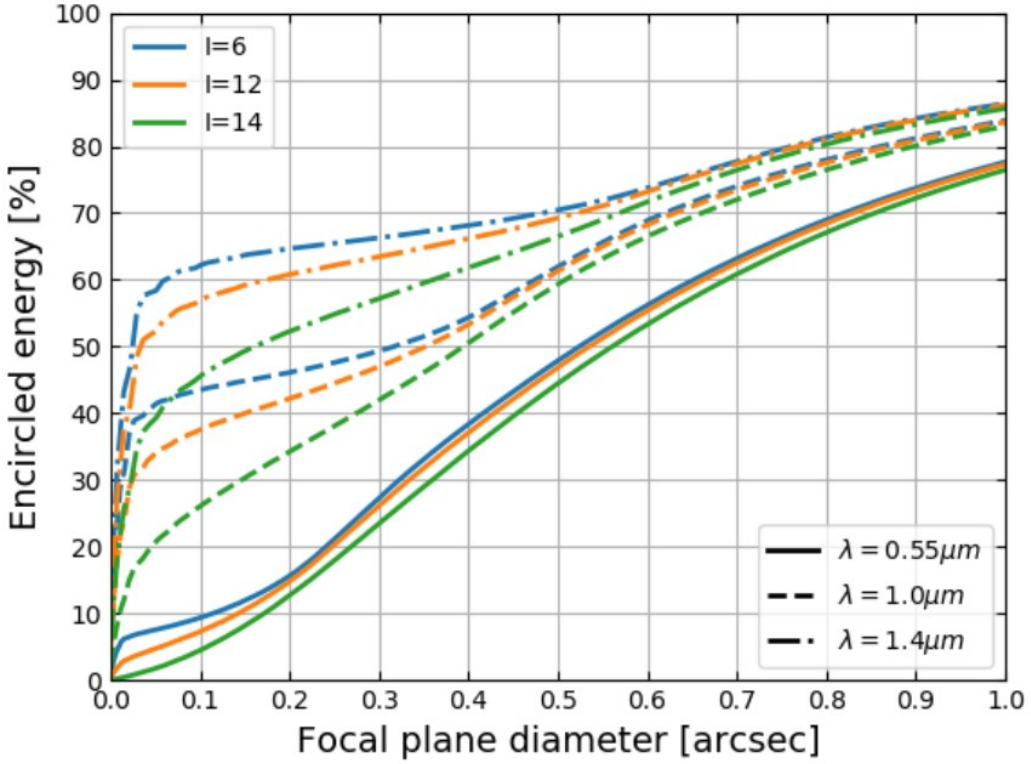


Conod+ 2019 submitted

- NIRPS AO coupling performances

AO Assisted spectrograph

39m Class Telescope



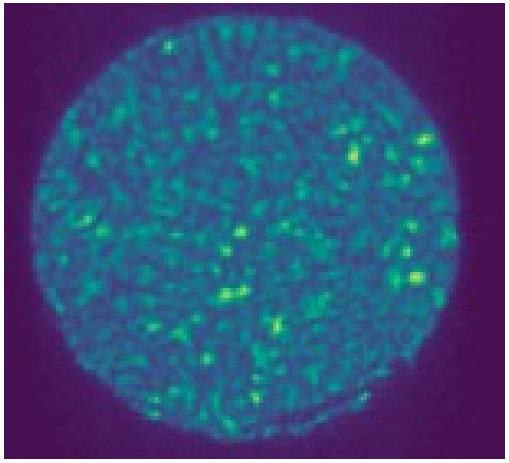
Conod 2018
Phd Thesis

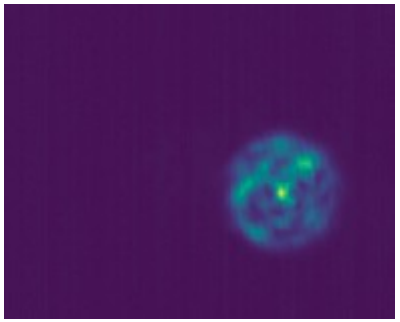
- ELT with SCAO and only M4 actuators

Mono-mode instruments

- Single mode fiber on theory are the perfects scrambler
  - Hard to couple light into it (AO)
    - But maybe achievable on 8m class telescope with XAO
  - Still some issues like polarization (Halverson + 2015)

Modal Noise





- Geometrical optics do not work any more if radius is small / or wavelength is long
- Illumination dominated by speckles
- Photometric « speckles » noise
- LSF variations

Fight Modal noise

Correction :

- Time averaging (Phase)
- Occupy a constant number of mode
  - Seeing
  - Tip-tilt
  - Fiber bending agitating ….
  - Increasing Etendue
- Keep the mode shape constant

Fighting Modal noise

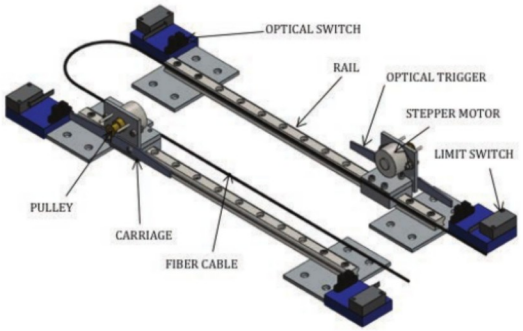
- Calibration source : LFC, FP
  - Agitation, Rotating diffusers, Integrating spheres

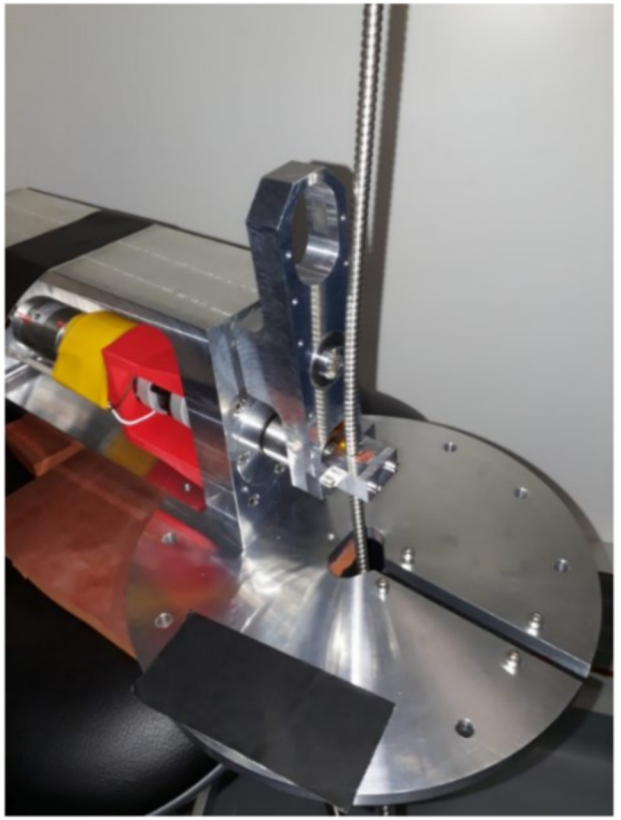
=> you can lose a lot light (**easy, but necessary**)

- Stellar light :
  - You can’t afford to loose photons !!

Agitators

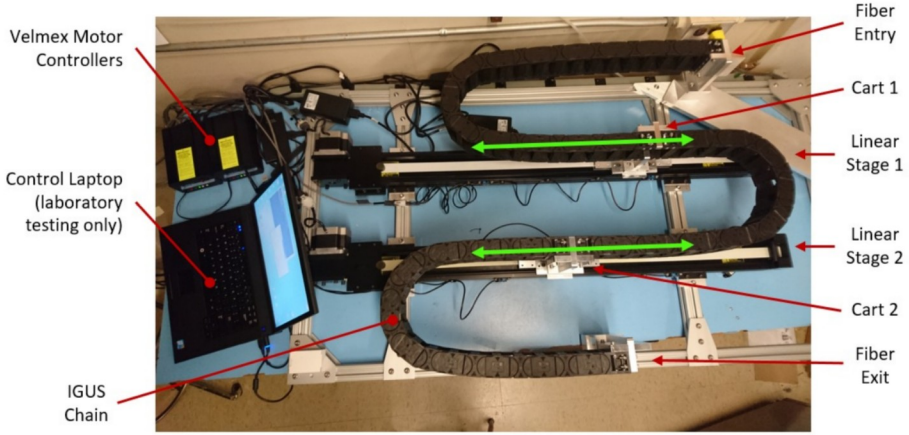
HPF Roy + 2014



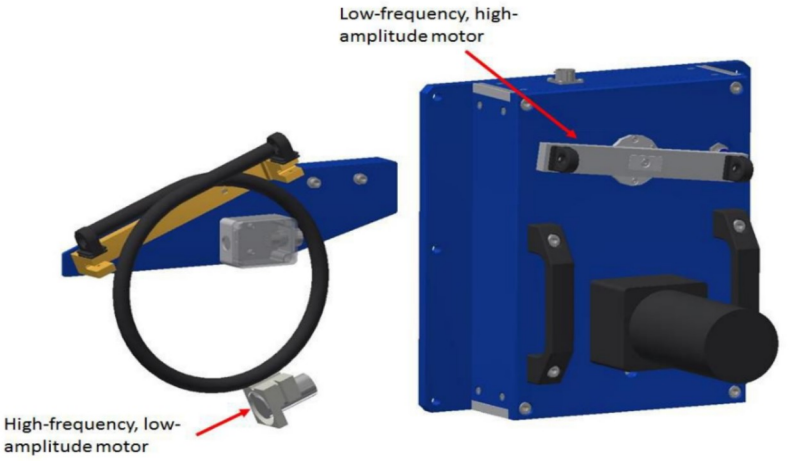


SPIRou Micheau + 2018

KPF Sirk + 2018

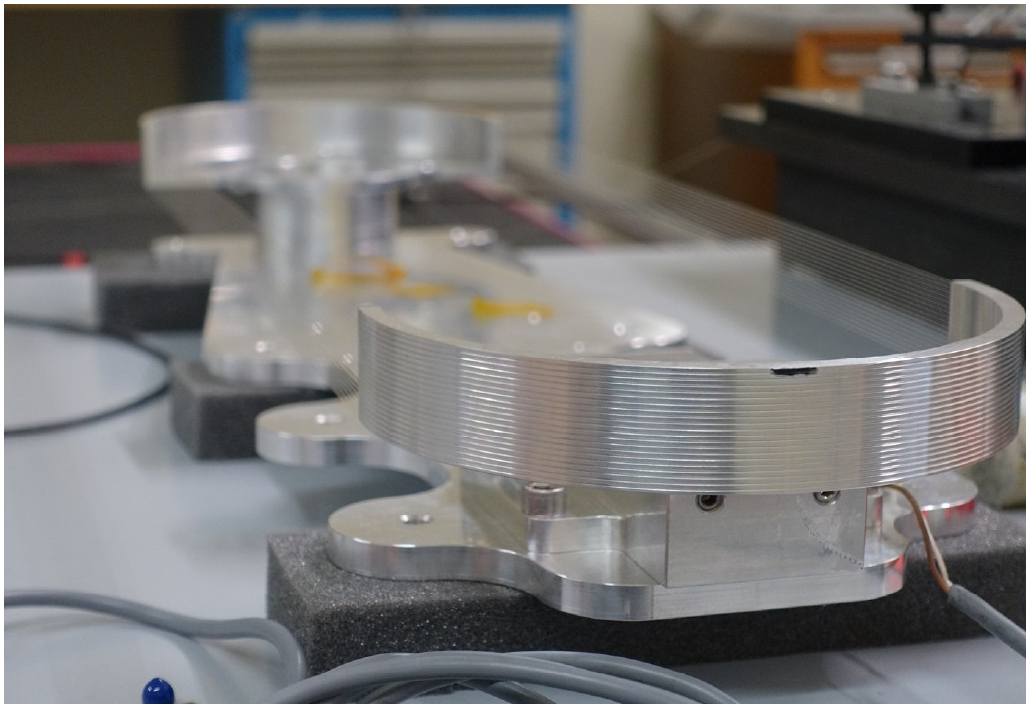


Veloce Tinney + 2018



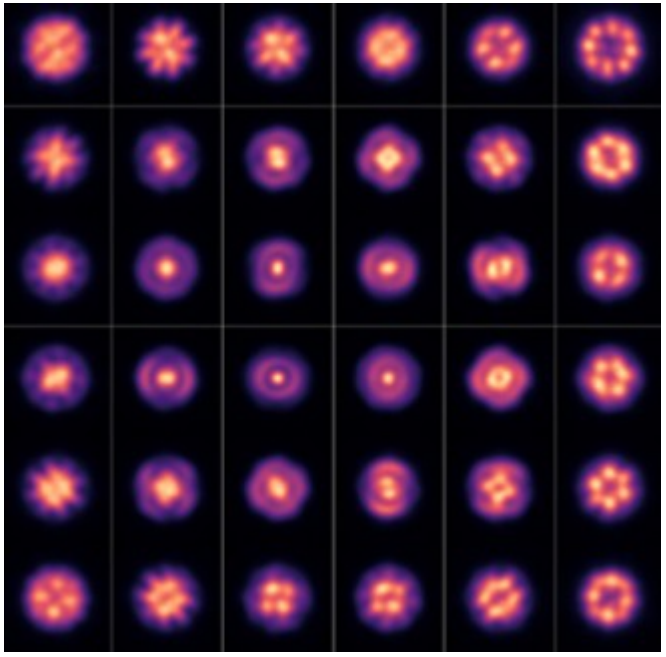
How to control Phase

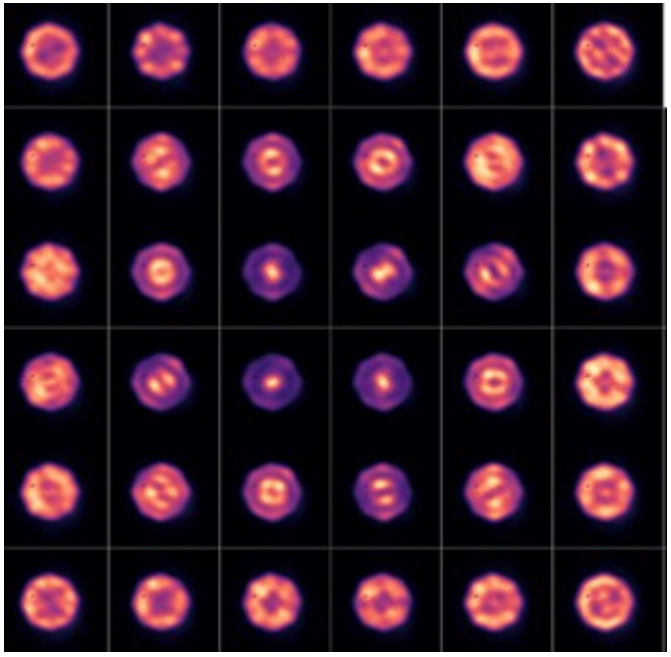
- Using a stretcher to change length of fiber
  - Used in telecom
  - Uses on GRAVITY as delay lines
  - PRV :
    - ACES spectrograph (Reynolds + 2004)
    - NIRPS (Wildi + 2017)



How to populate the modes

NIRPS Fiber, near field and far field, if a point source is moving across its entrance face



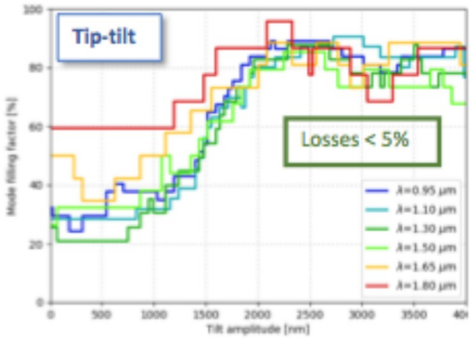


Courtesy N. Blind

Few modes modal noise mitigation

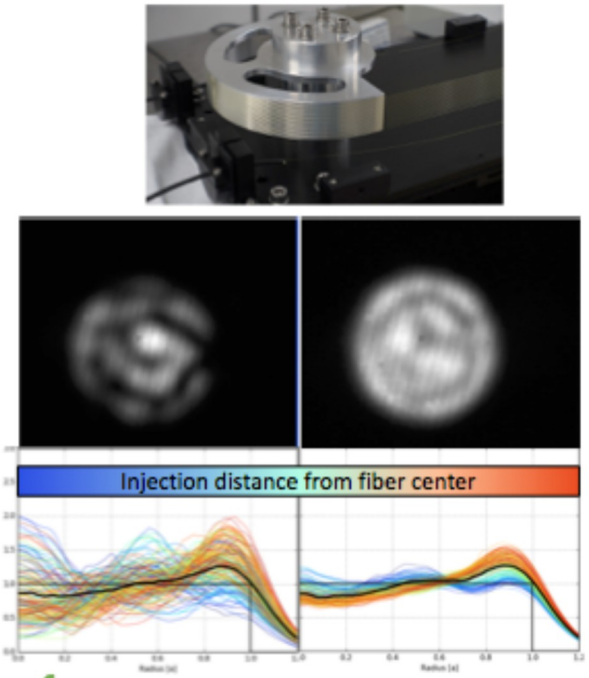
Modal noise mitigation

At injection: fill the modes with AO system



✓ Efficient with tip-tilt

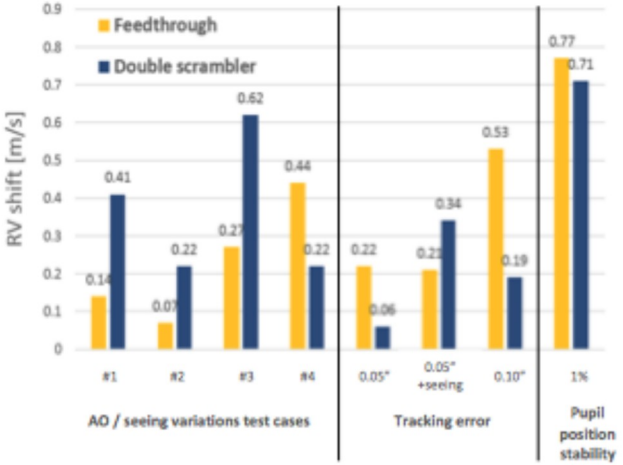
In fiber: modulate the phase with fiber stretcher



✓ 8mm stretch ➡ dT > 50K over 30m

Double scrambler

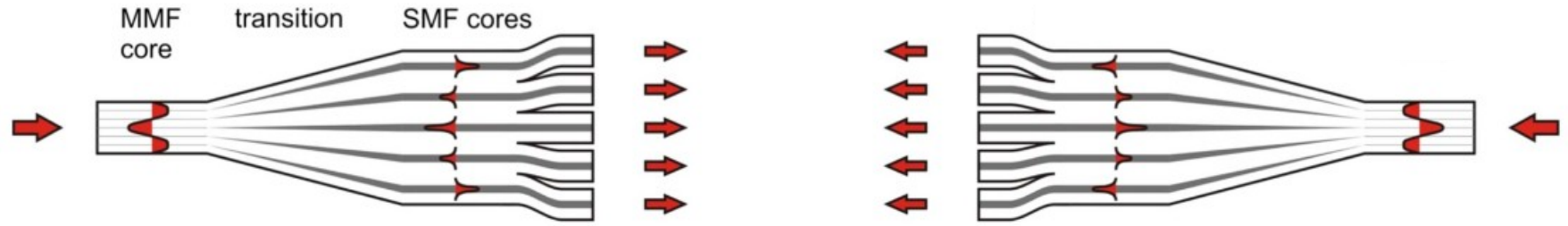
NF & FF measurements injected in spectrograph design, with various perturbations



✗ No clear gain
Costs photons (NF / FF mismatch)

Courtesy N. Blind

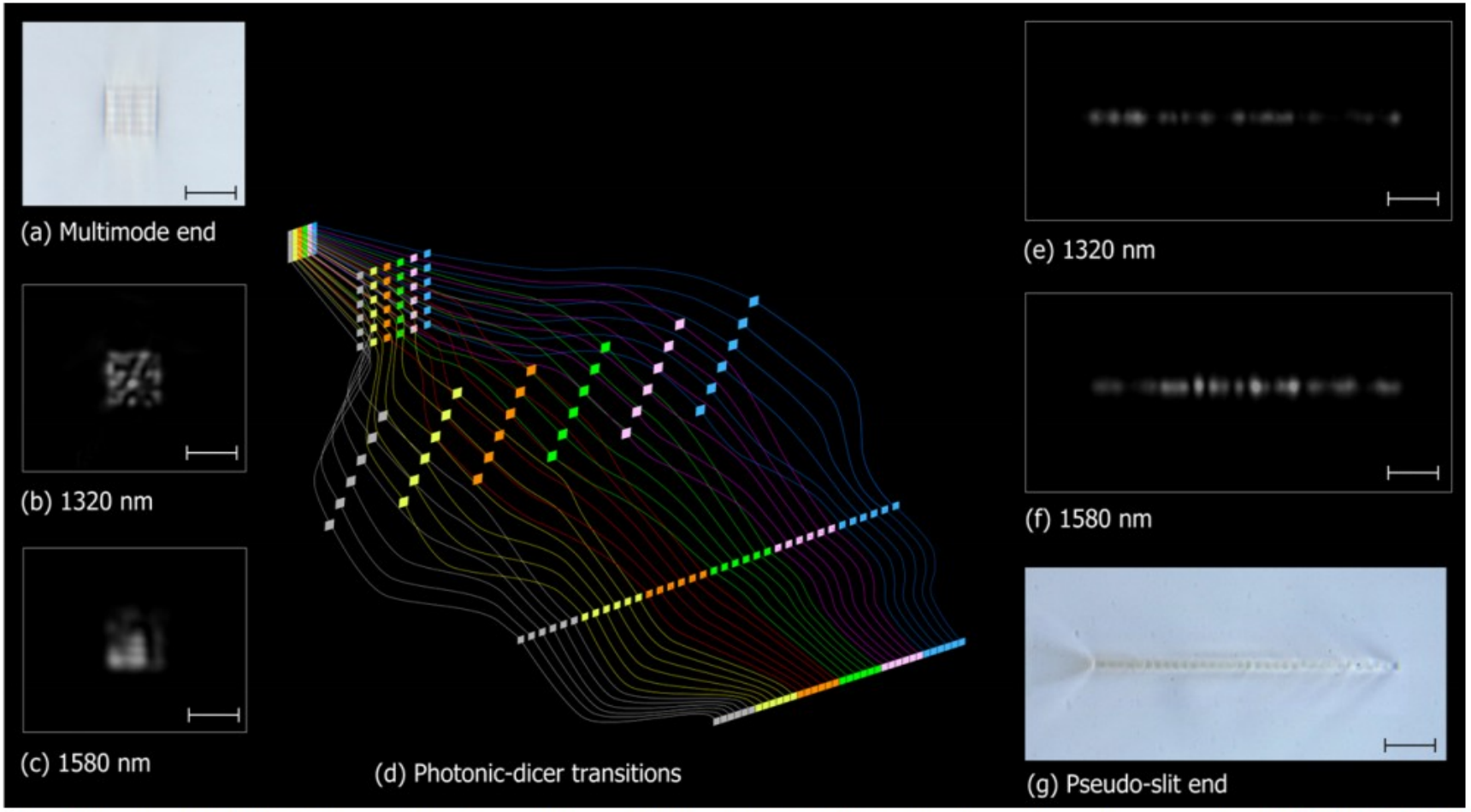
Photonic lanterns



Birks + 2015

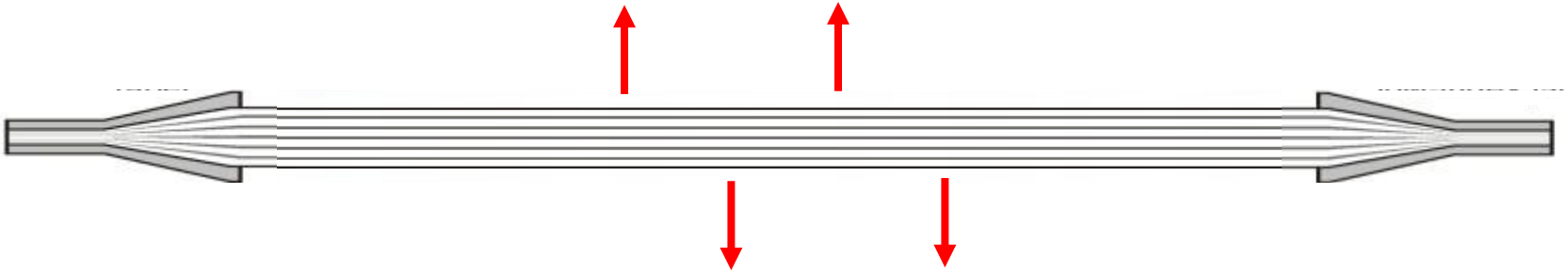
- Smooth transition from multi-mode to individual mono-mode individual guides
- Lots of possibilities

Monomode Reformater

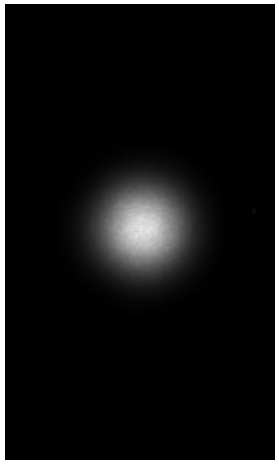


R. J. Harris et al, "Photonic spatial reformatting of stellar light for diffraction-limited spectroscopy" - arXiv:1402.2547

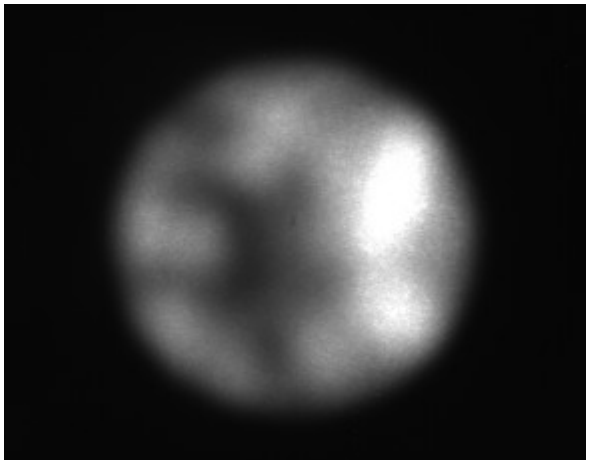
Modal noise scrambling



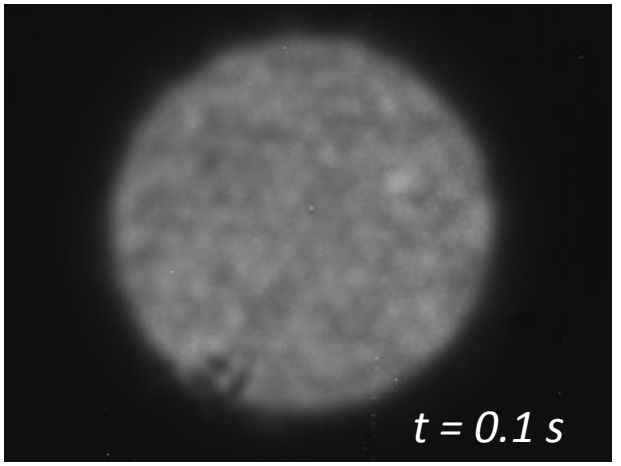
Mode scrambler:



input



step-index MMF



MCF with lanterns

TA Birks et al, Opt Express 20 (2012) 13996

Summary

- Illumination control is mandatory for PRV
- Non circular fibers are the state of the art for geometric scrambling
- Modal noise in the infrared needs extra-work
- Some more development in the future with XXL telescopes
- AO can be the baseline for a PRV instrument
- Mono-mode instrument nearly perfect for illumination control