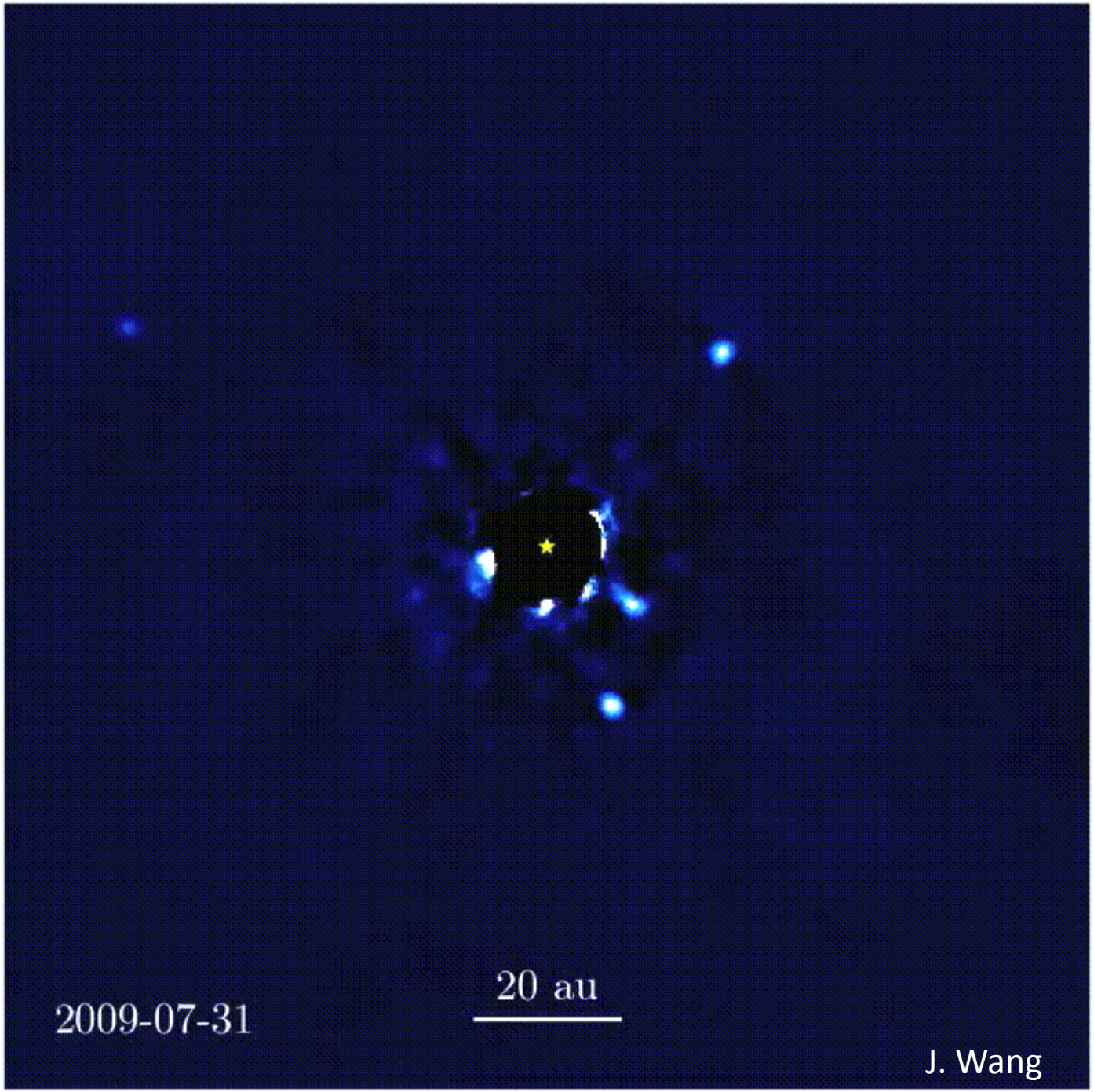
# Leiden EXoplanet Instrument

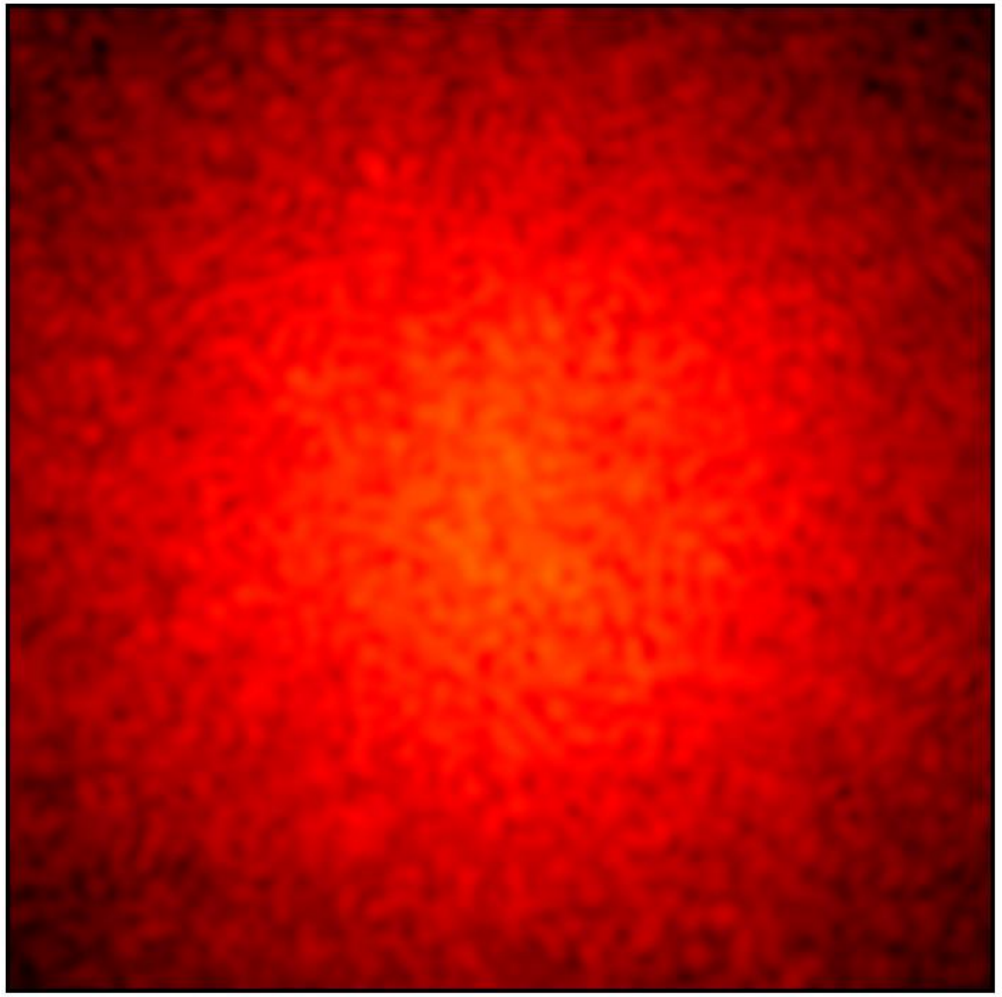
AstroTechTalk, Heidelberg, 22-02-2019

Sebastiaan Haffert, Christoph Keller, Ignas Snellen Leiden Observatory

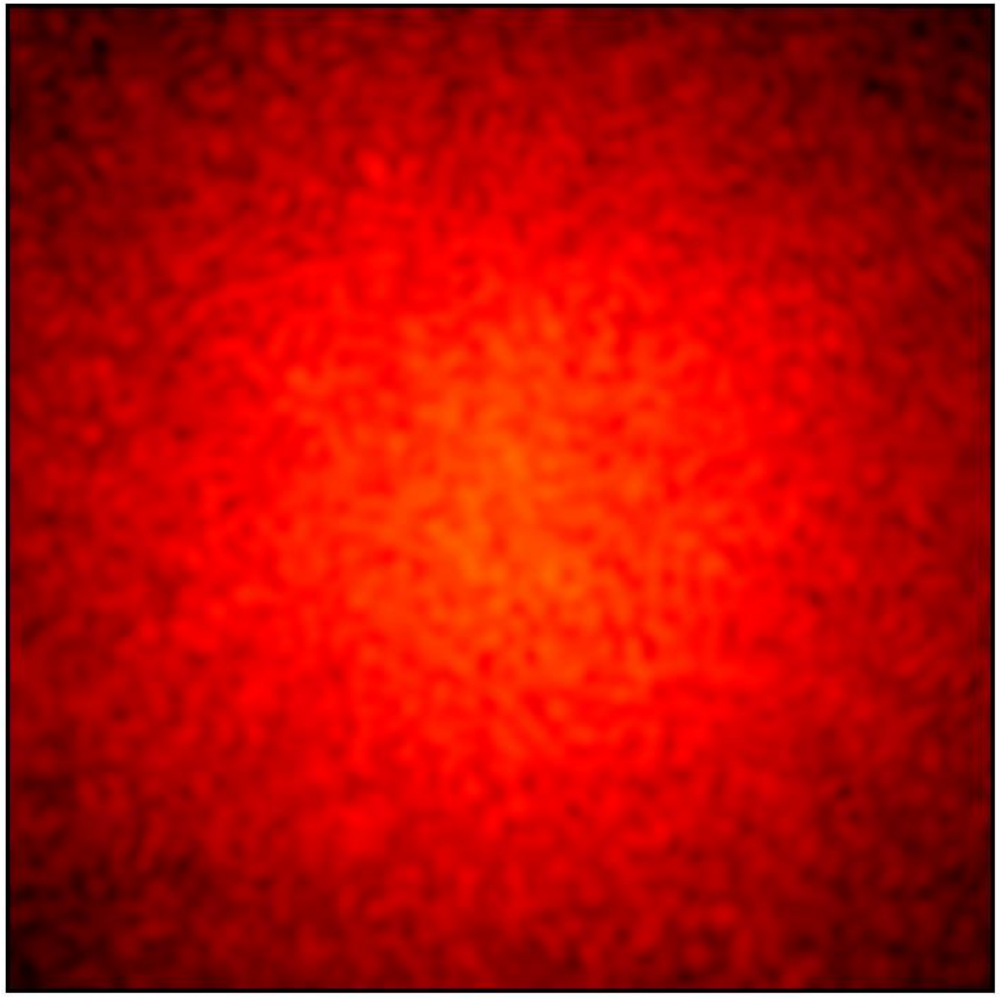

Credits: ESO/M. Kornmesser


2009-07-31
20 au
J. Wang

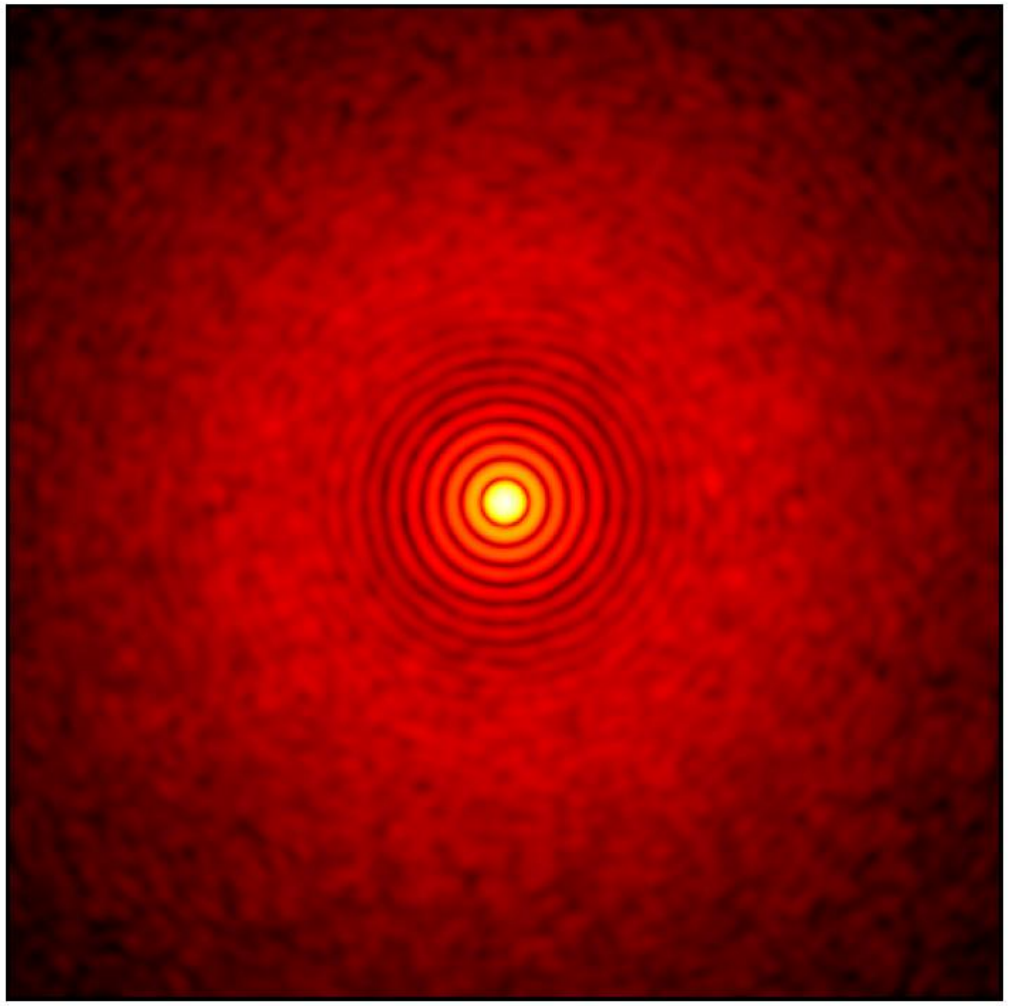
# Imaging through the atmosphere

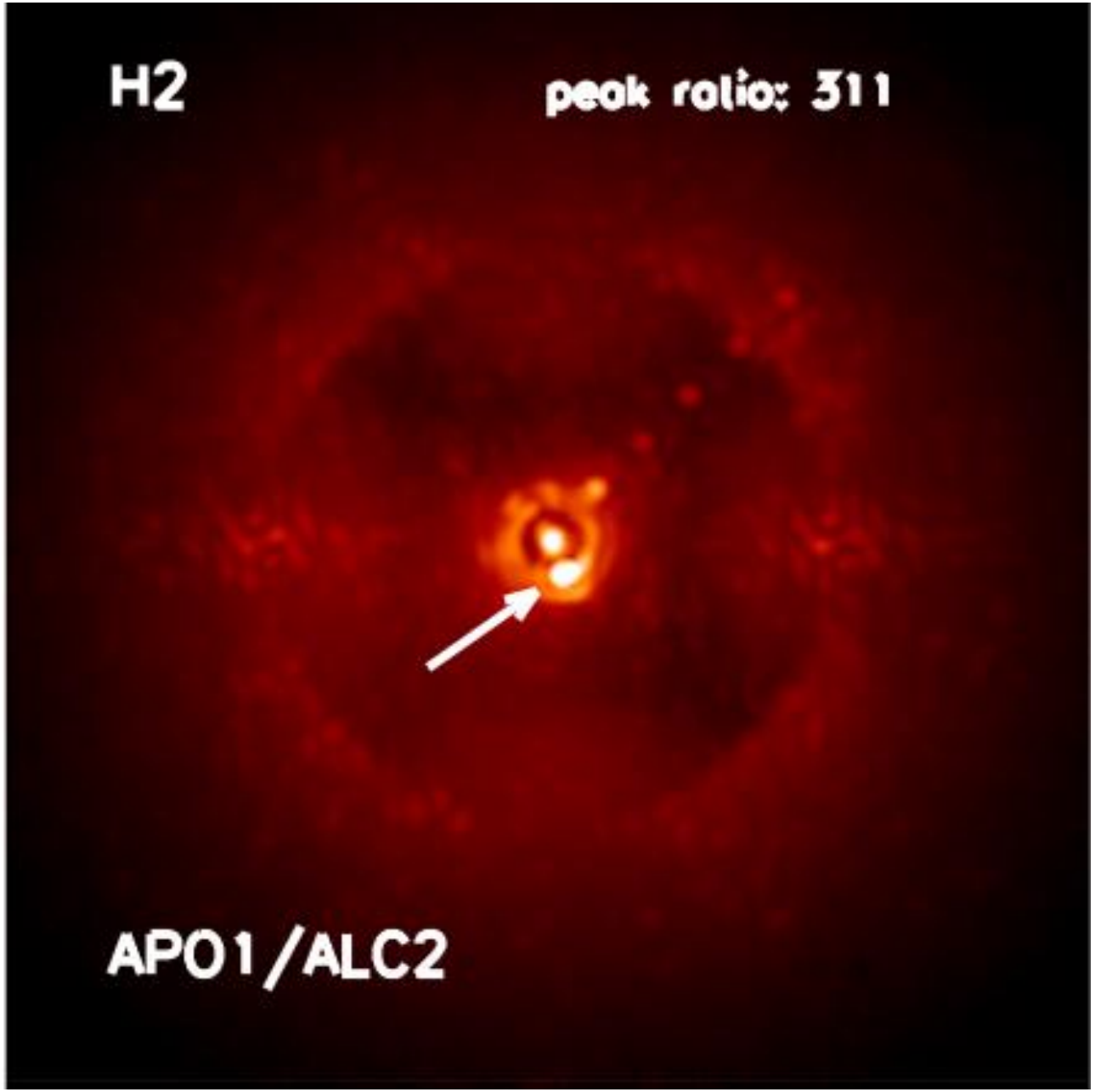


Imaging through the atmosphere

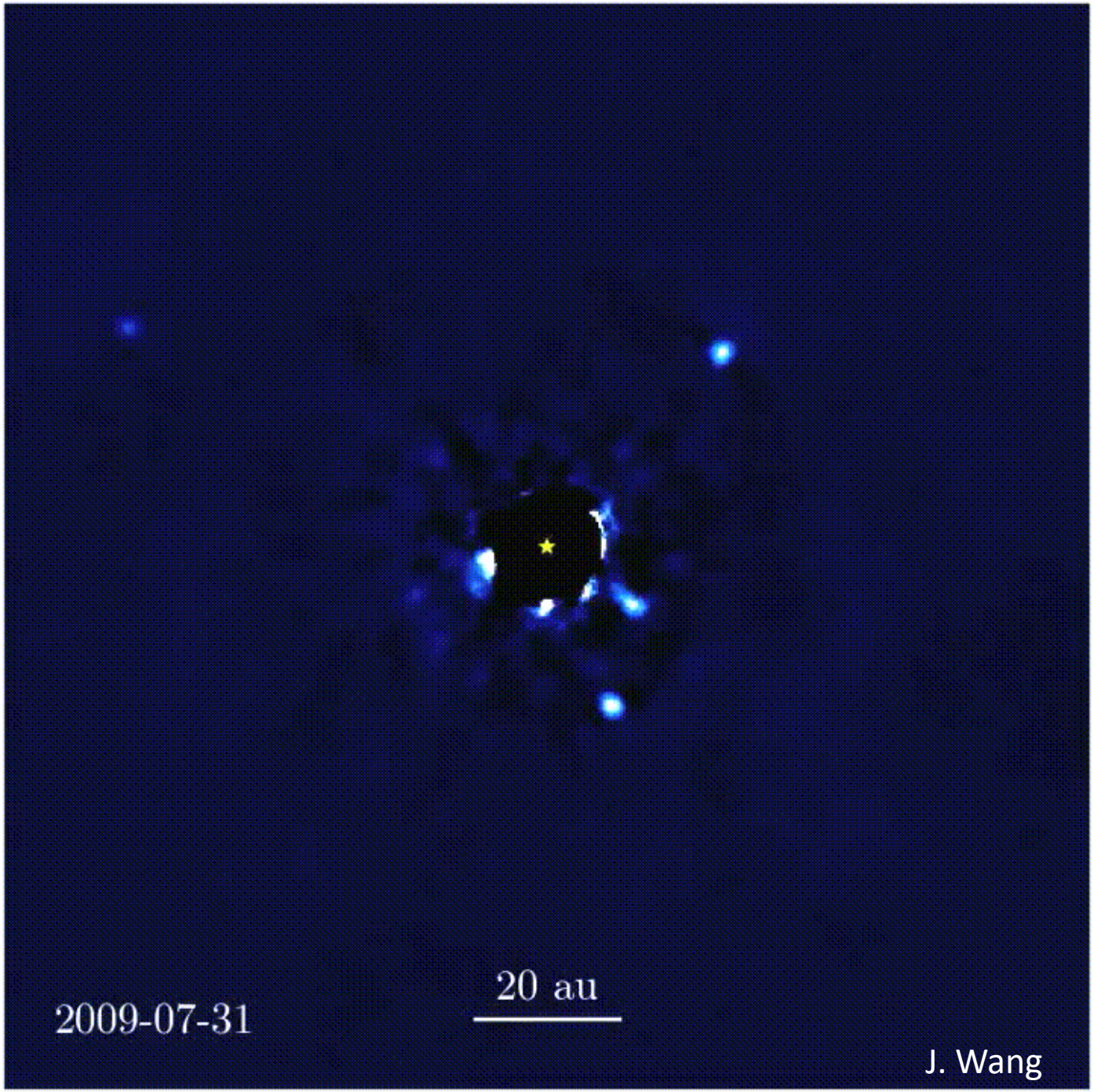


Adaptive optics corrected

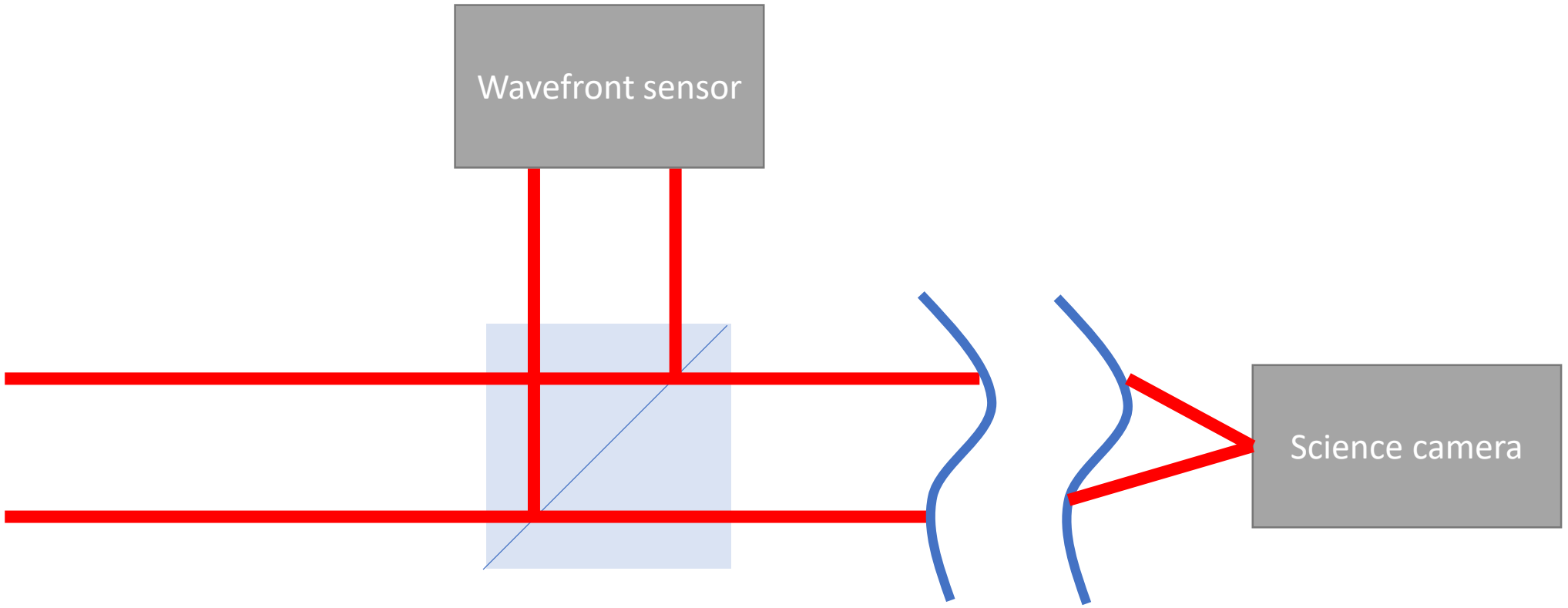





J-L. Beuzit et al 2019

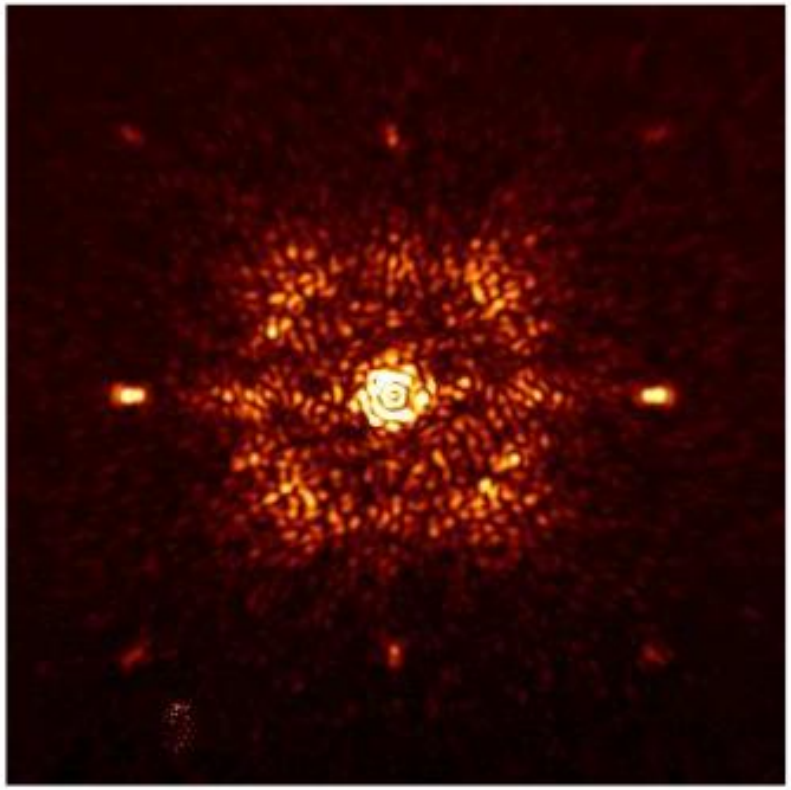

2009-07-31
20 au
J. Wang

# Non-common path abberations

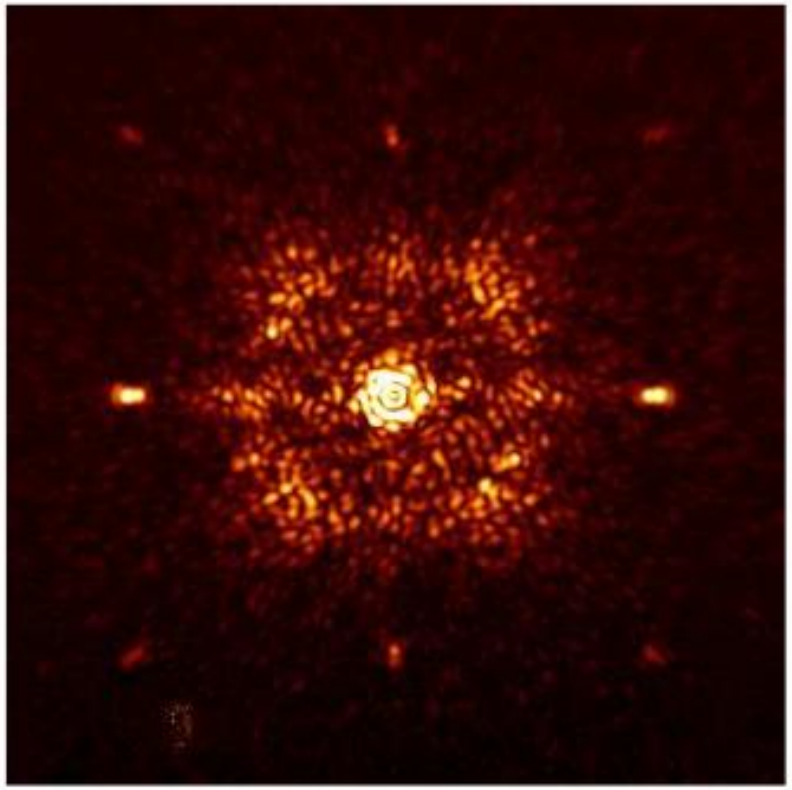


# Temporal stability

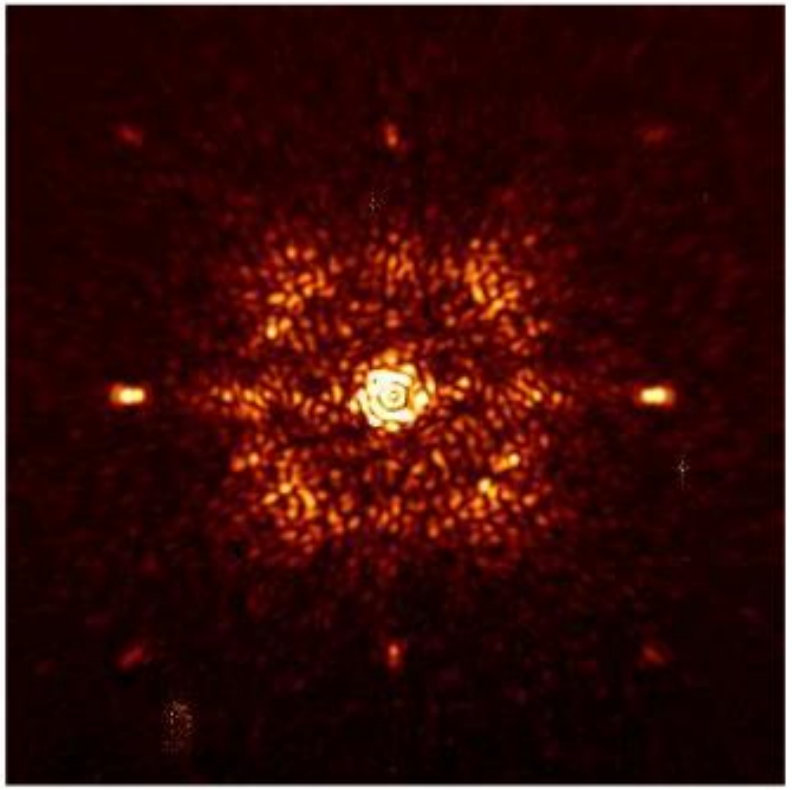
0 min



10 min



100 min

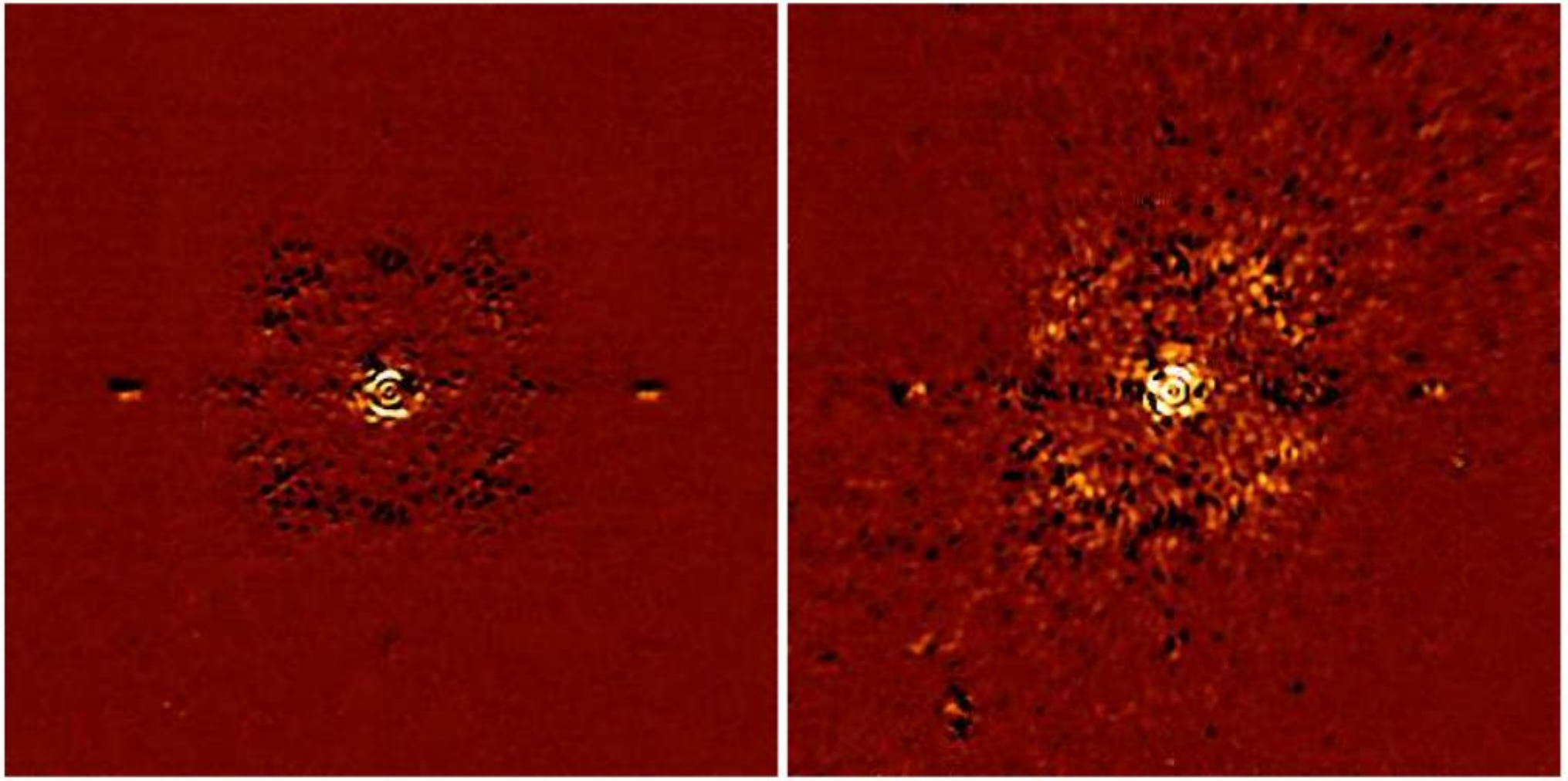


Martinez et al. 2013

# Temporal stability

10 min – 0 min

100 min – 0 min

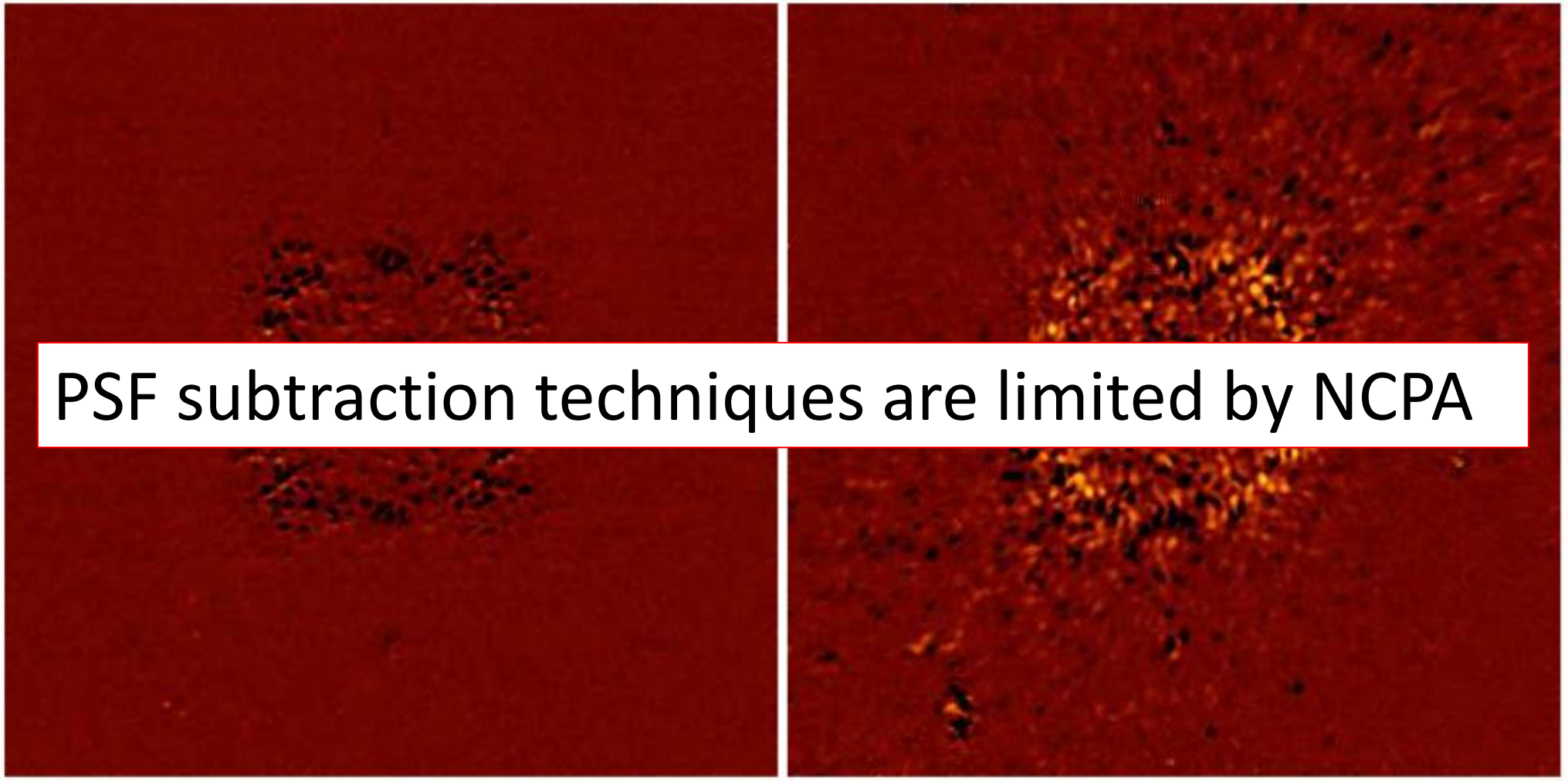


Martinez et al. 2013

# Temporal stability

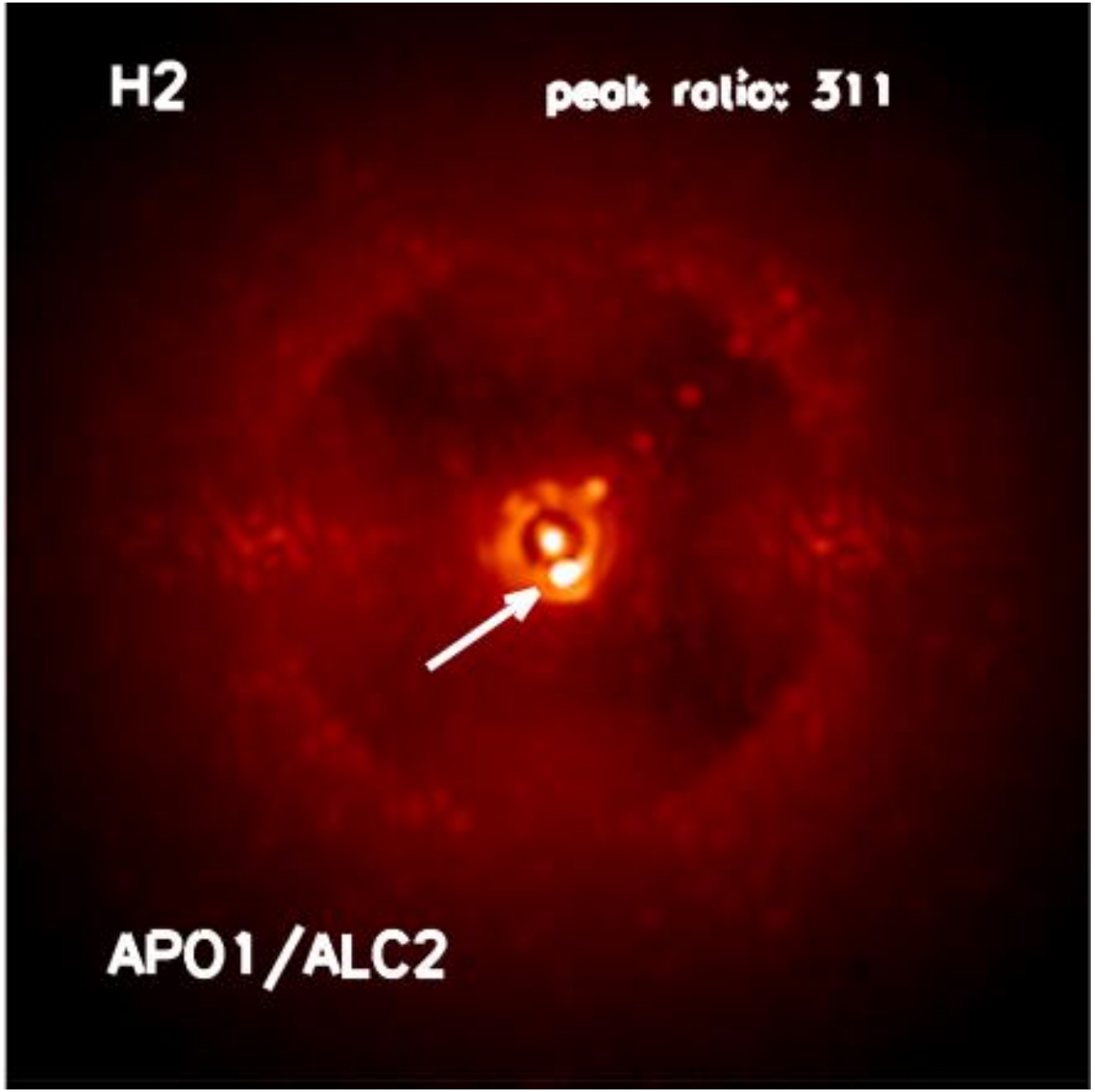
10 min – 0 min

100 min – 0 min

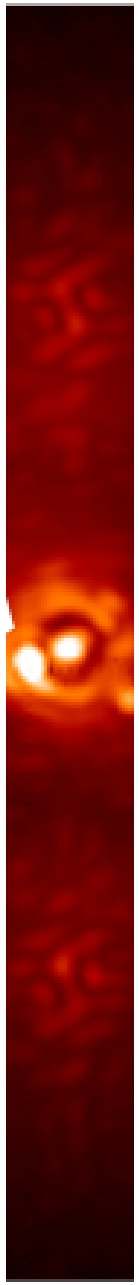


PSF subtraction techniques are limited by NCPA

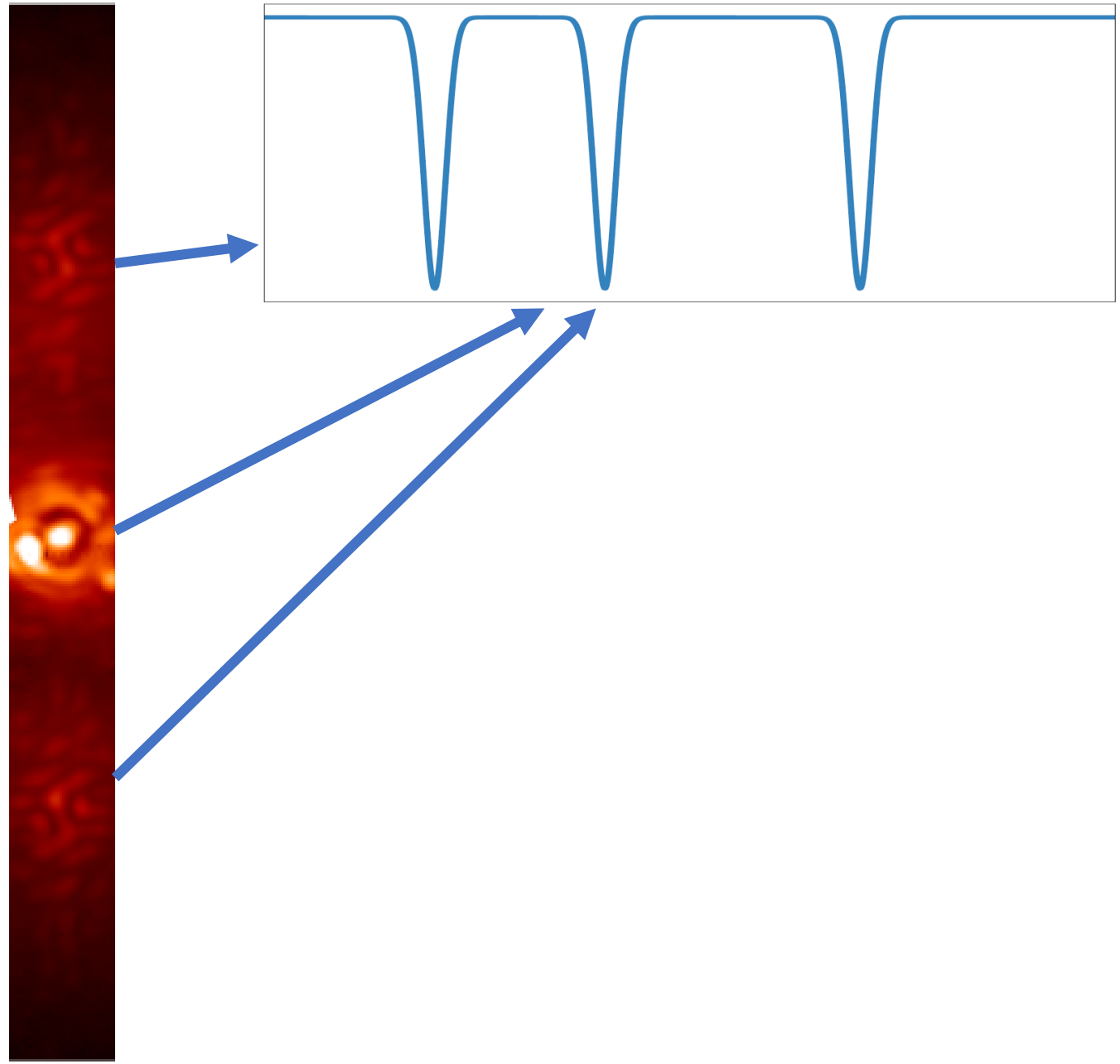
Martinez et al. 2013

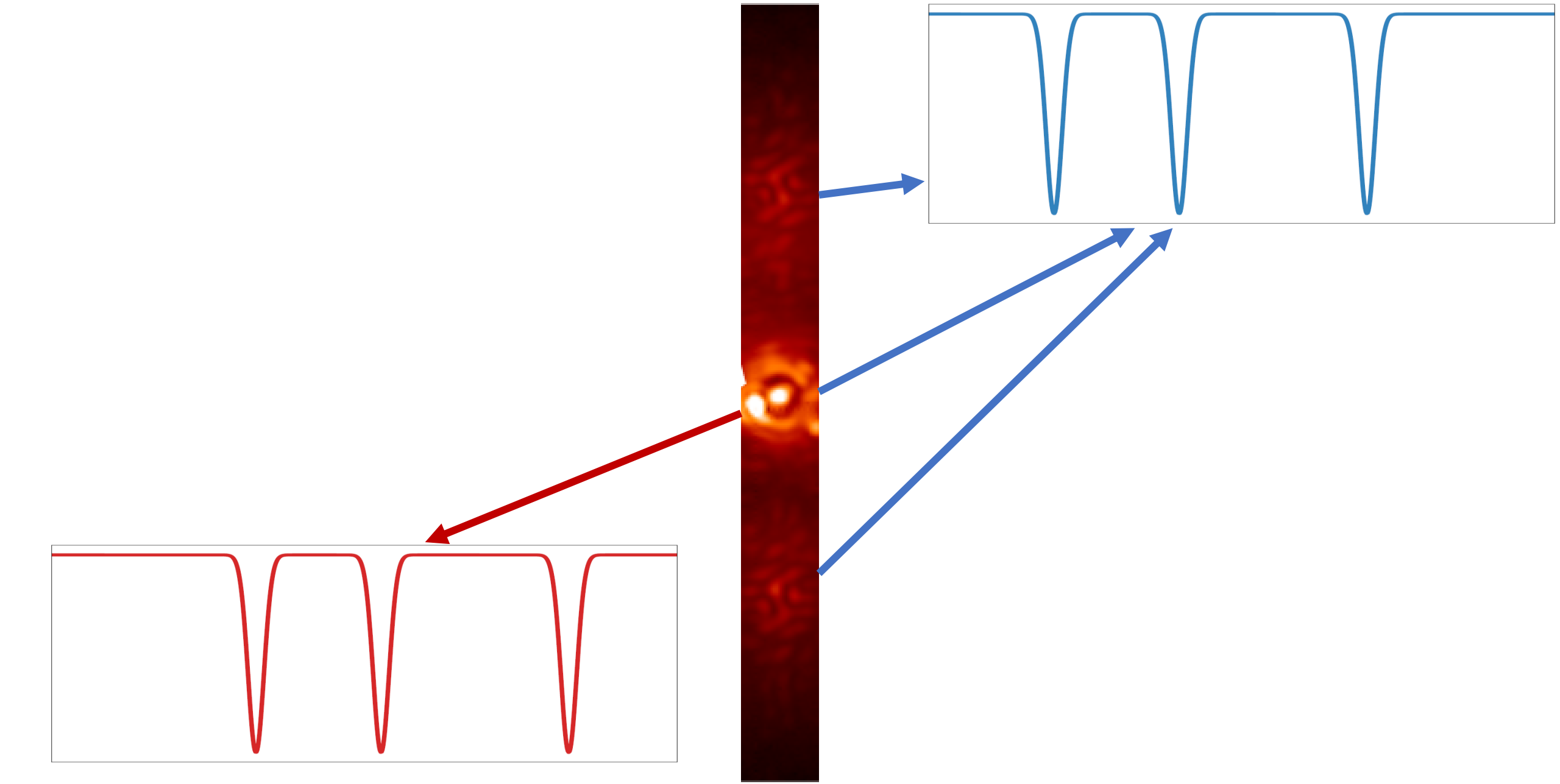



J-L. Beuzit et al 2019



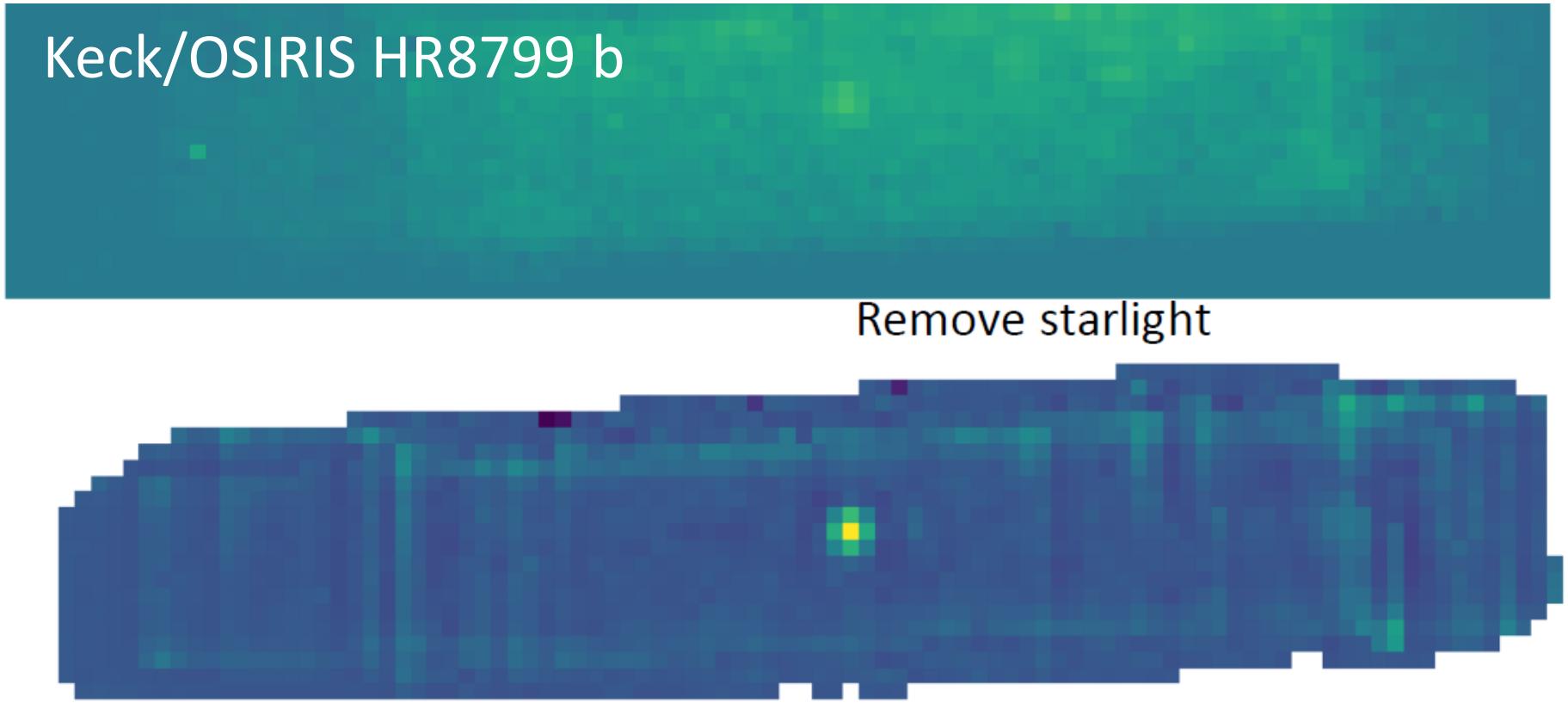
J-L. Beuzit et al 2019

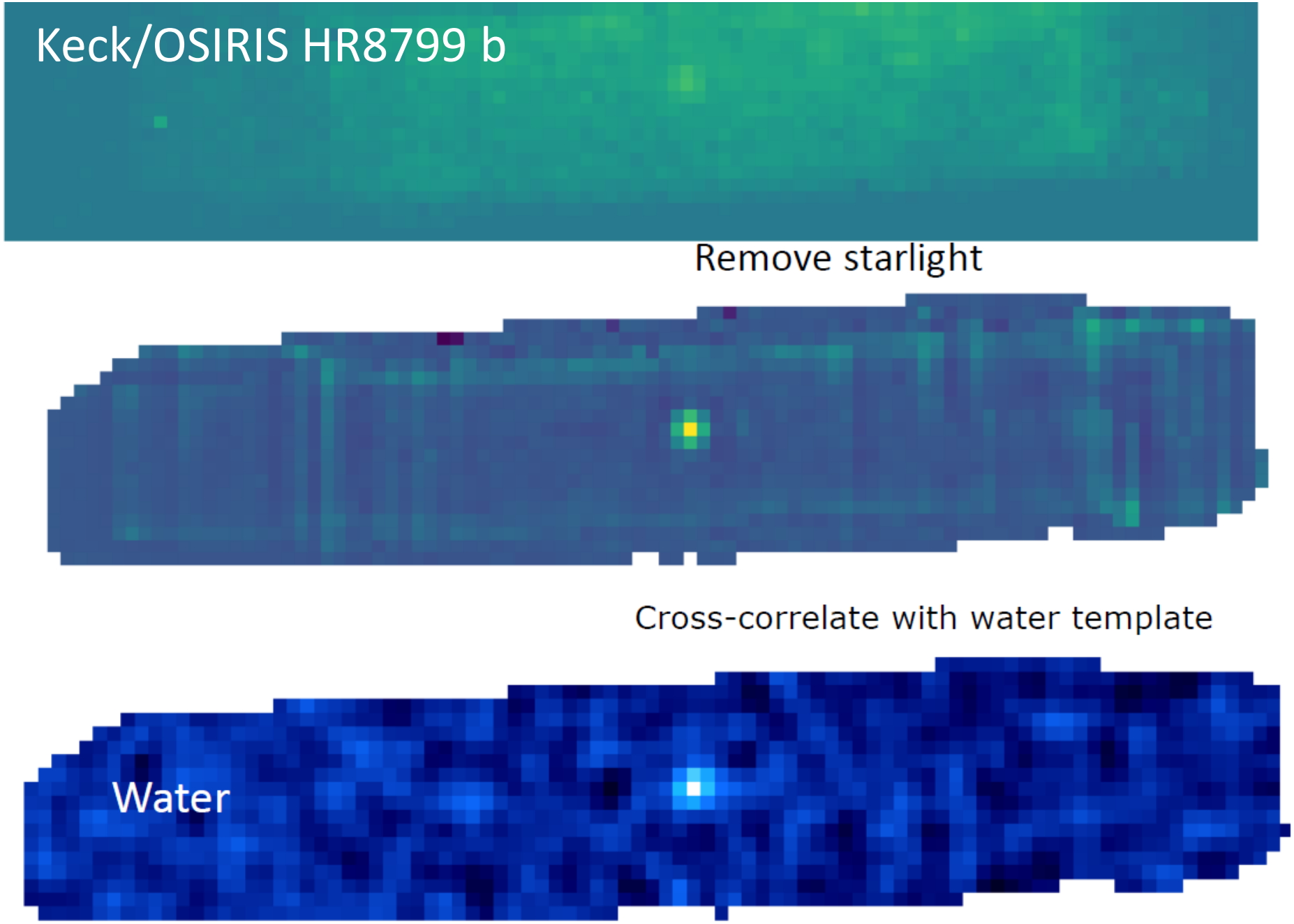




Lets apply this technique

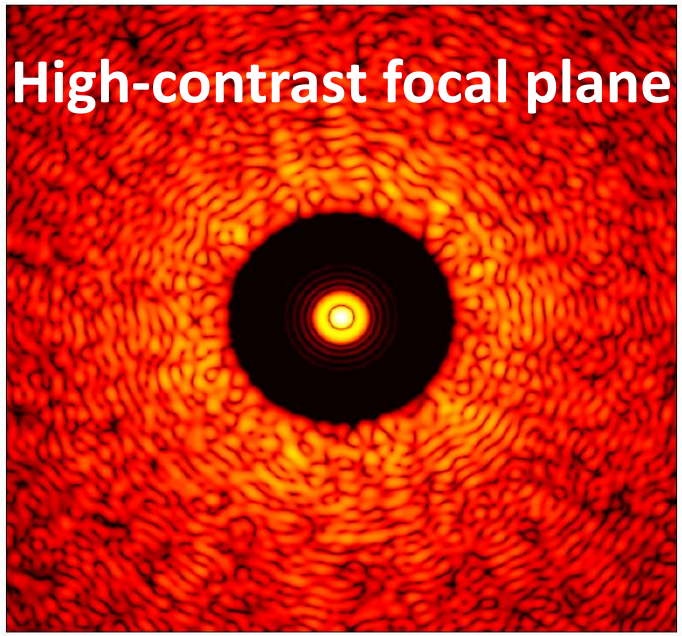
# Keck/OSIRIS HR8799 b


Keck/OSIRIS HR8799 b
Remove starlight

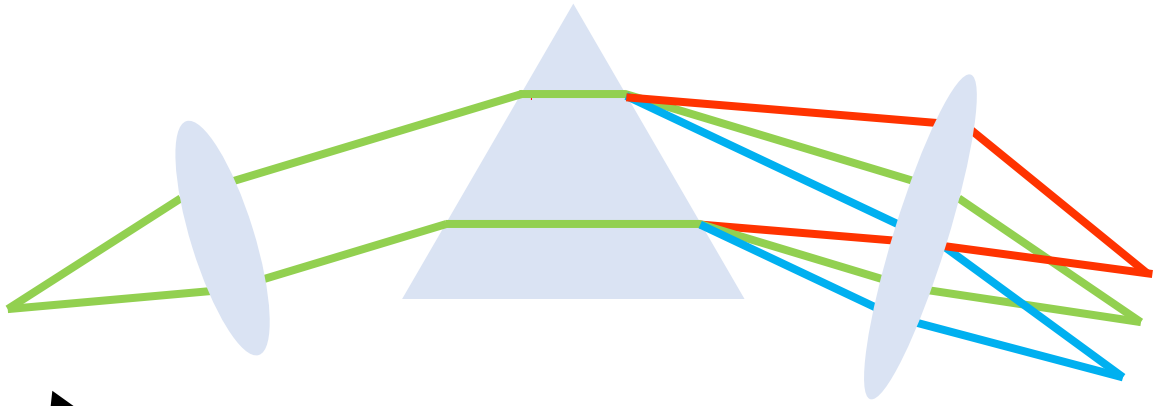



See Hoeijmakers et al 2018, Petit dit de la Roche et al. 2018

# How to couple HCI with HRS



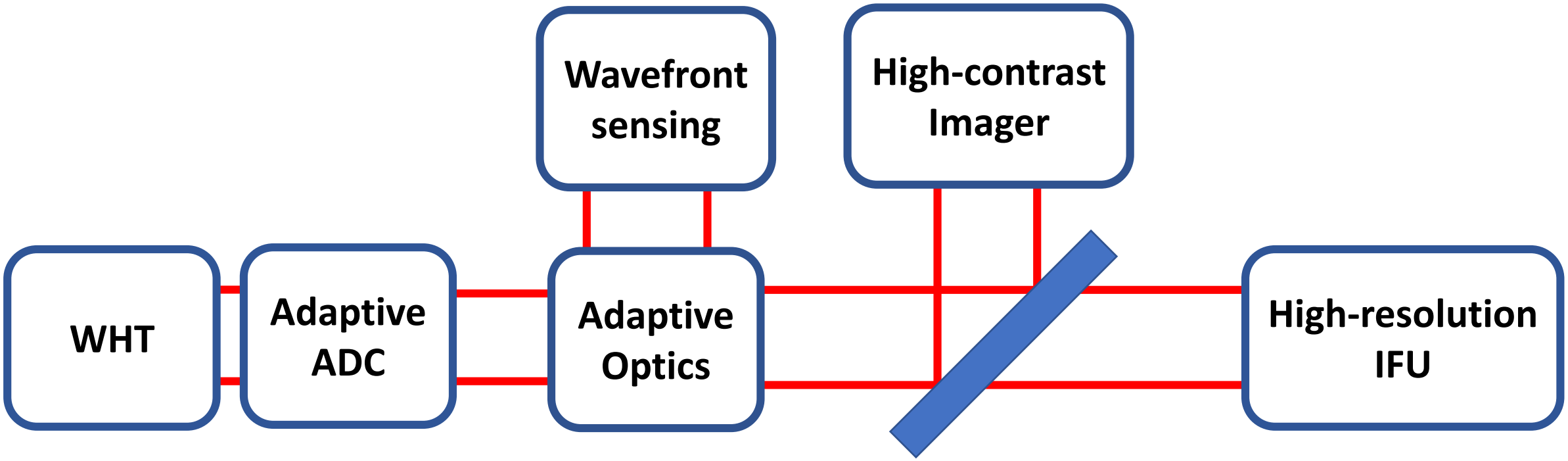

**High-resolution spectrograph**



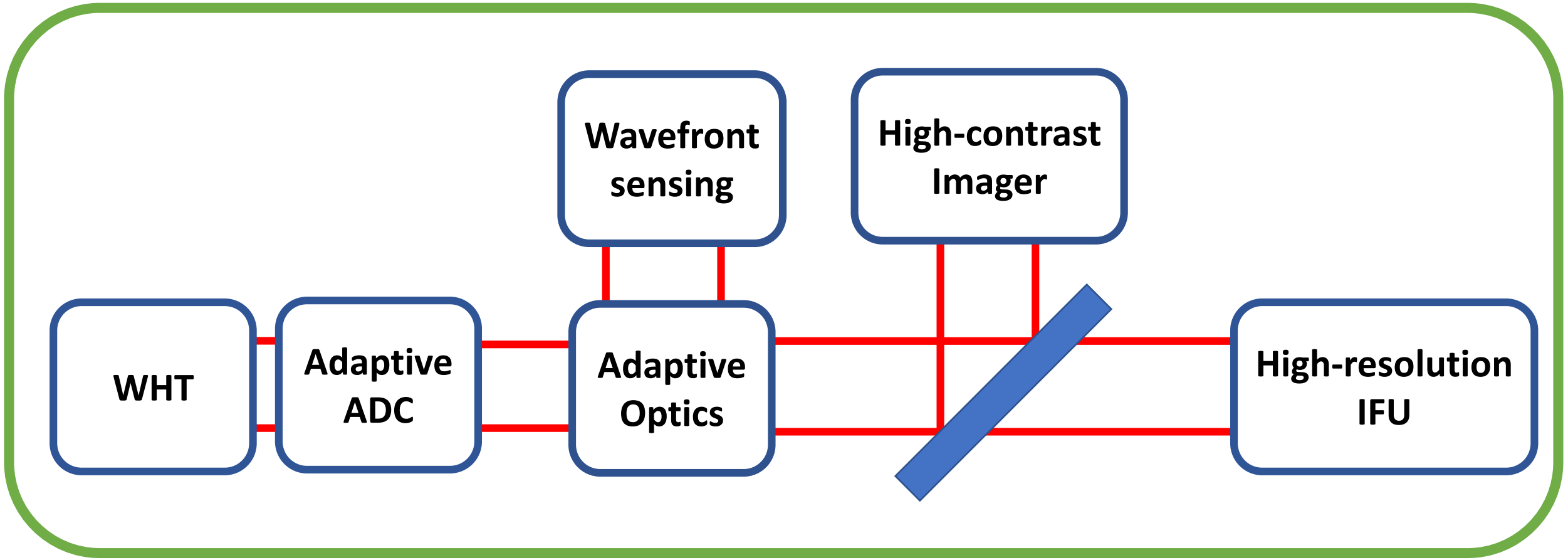
How do we transport the light from our focal plane to the spectrograph?

# The Leiden EXoplanet Instrument

# LEXI


Wavefront sensing
High-contrast Imager
WHT
Adaptive ADC
Adaptive Optics
High-resolution IFU

# LEXI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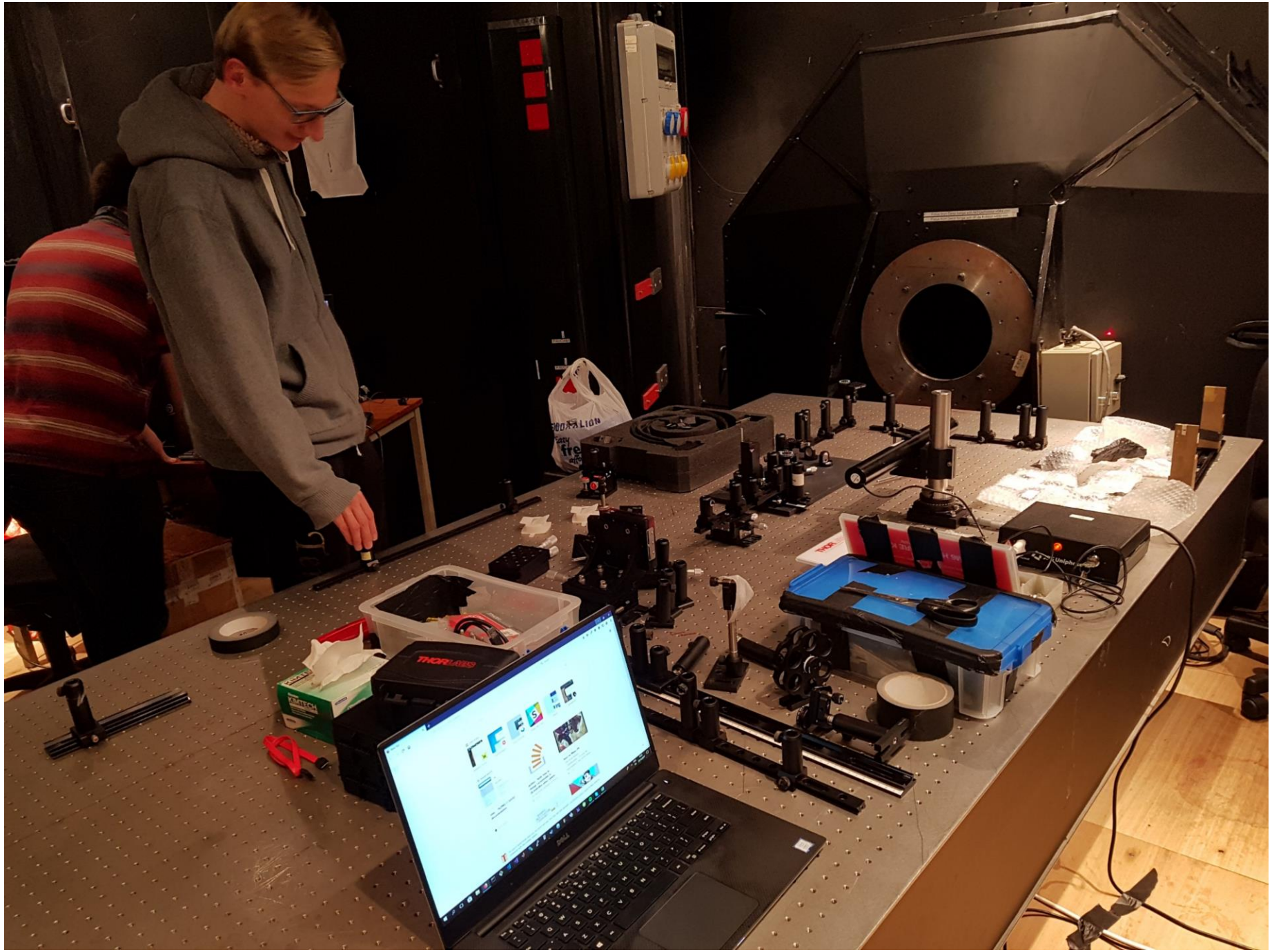
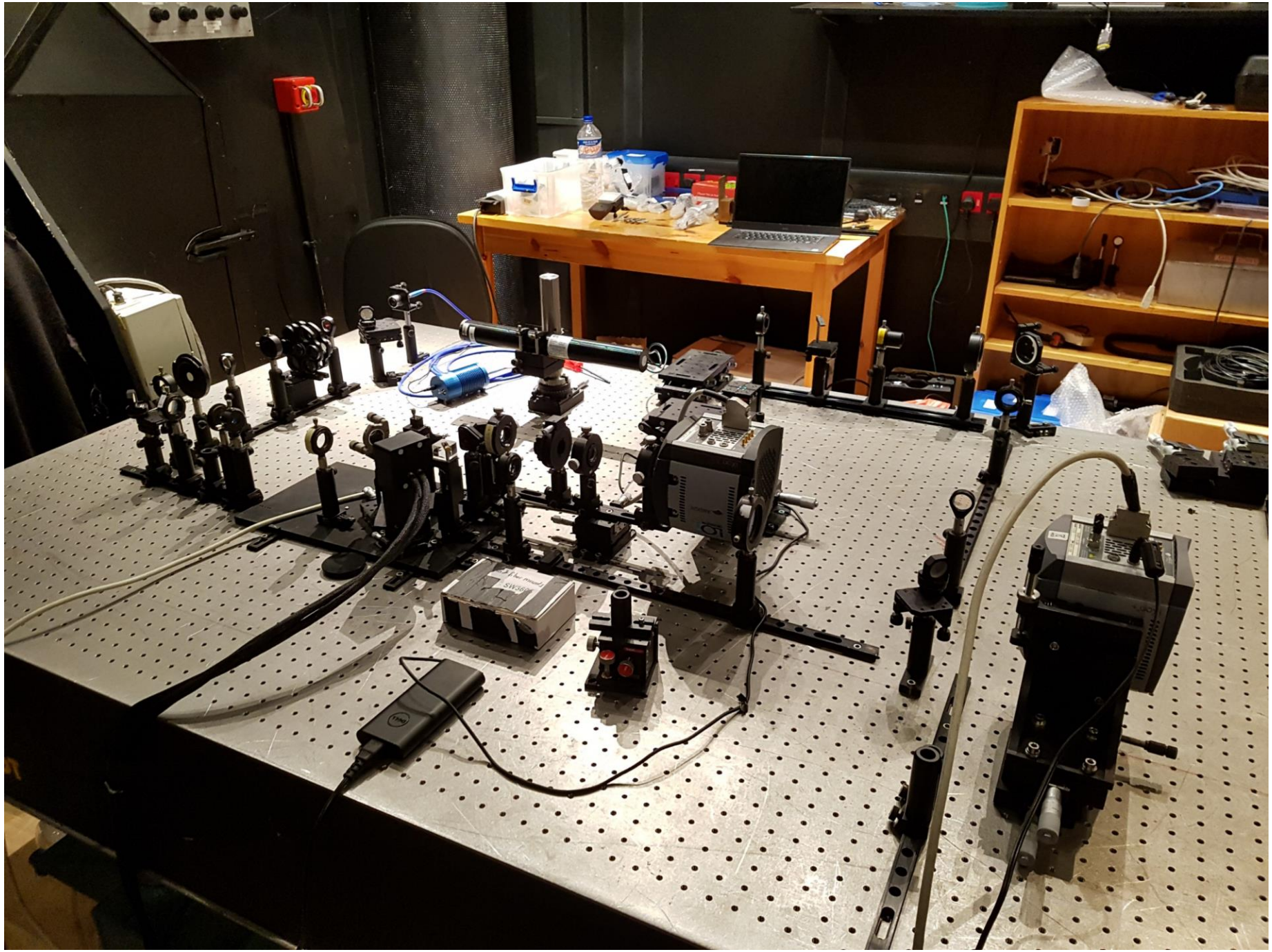
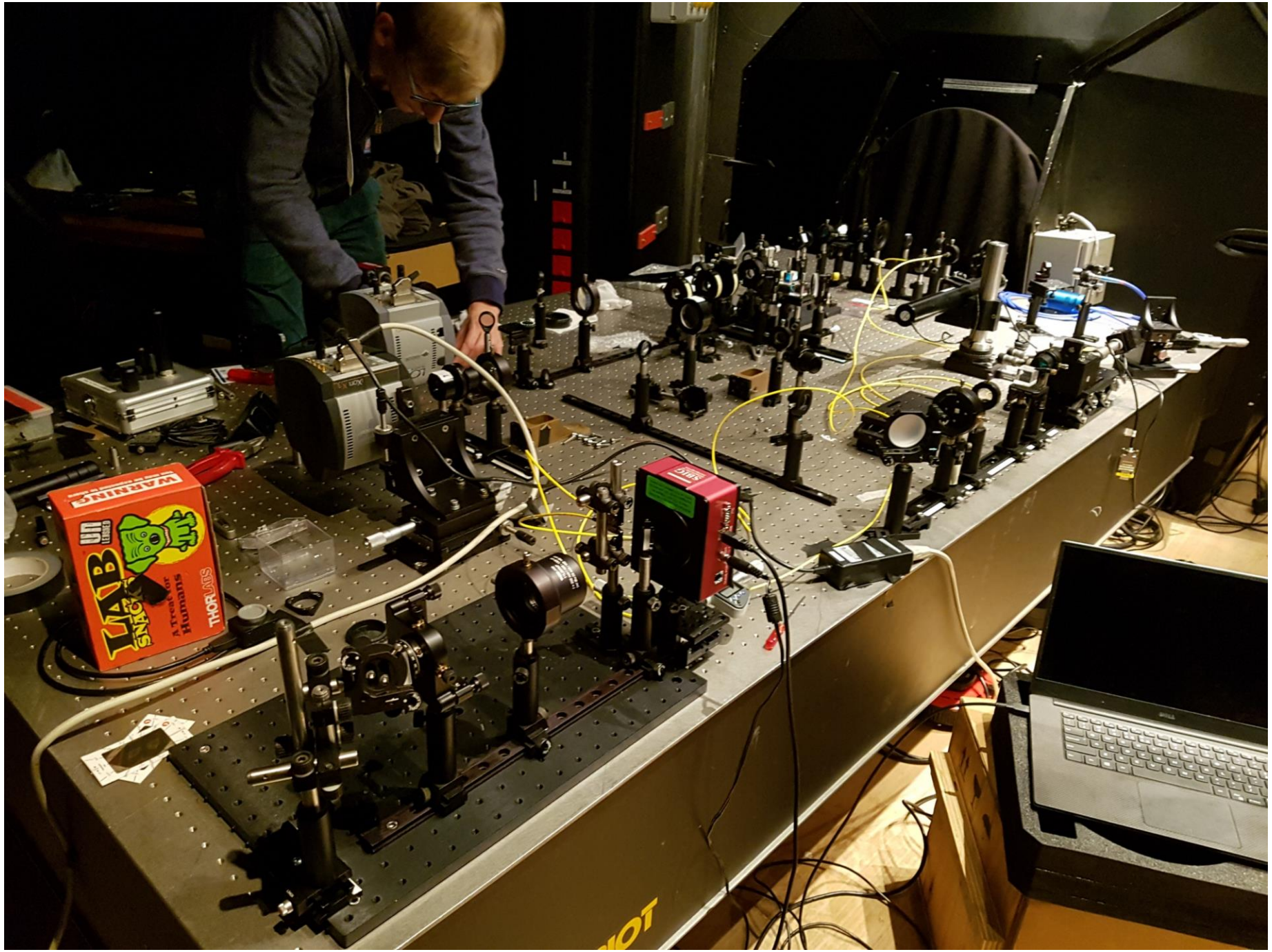
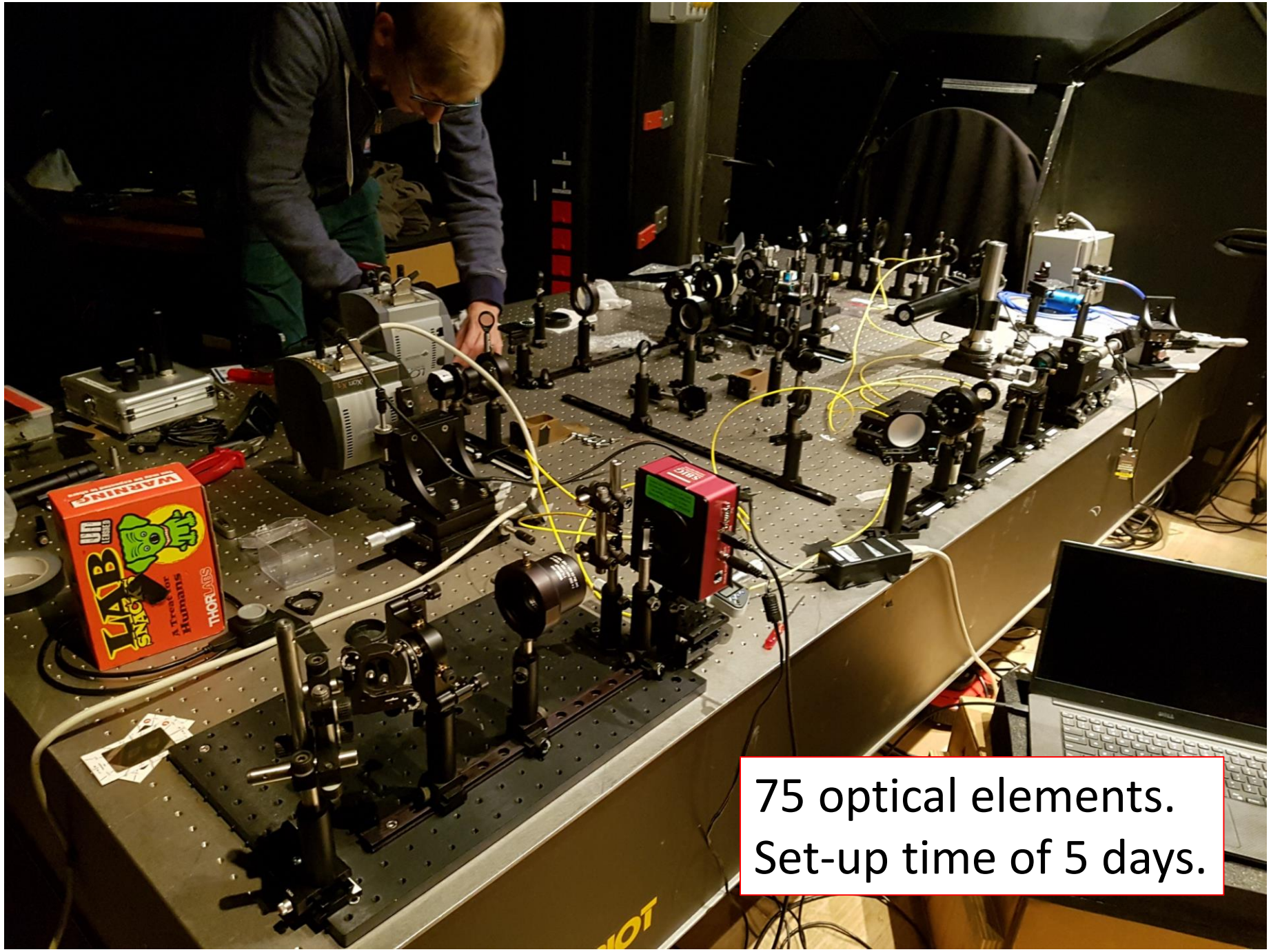

THORLABS


THOR

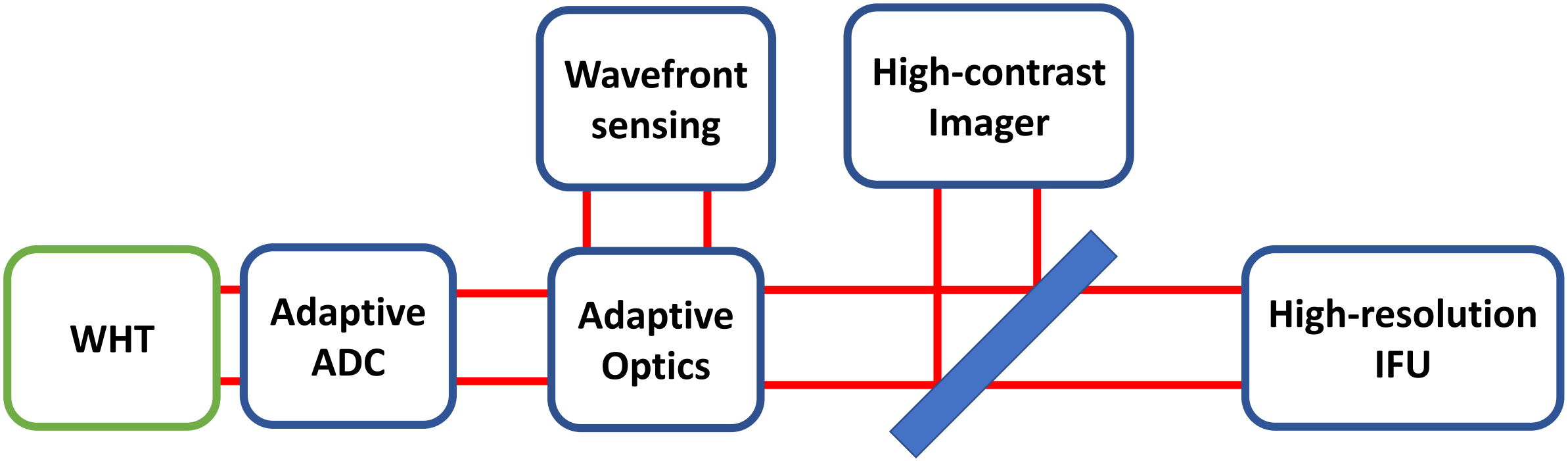



WARNING
LAB SNACK
A Treat for Humans
THORLABS




75 optical elements.
Set-up time of 5 days.

# LEXI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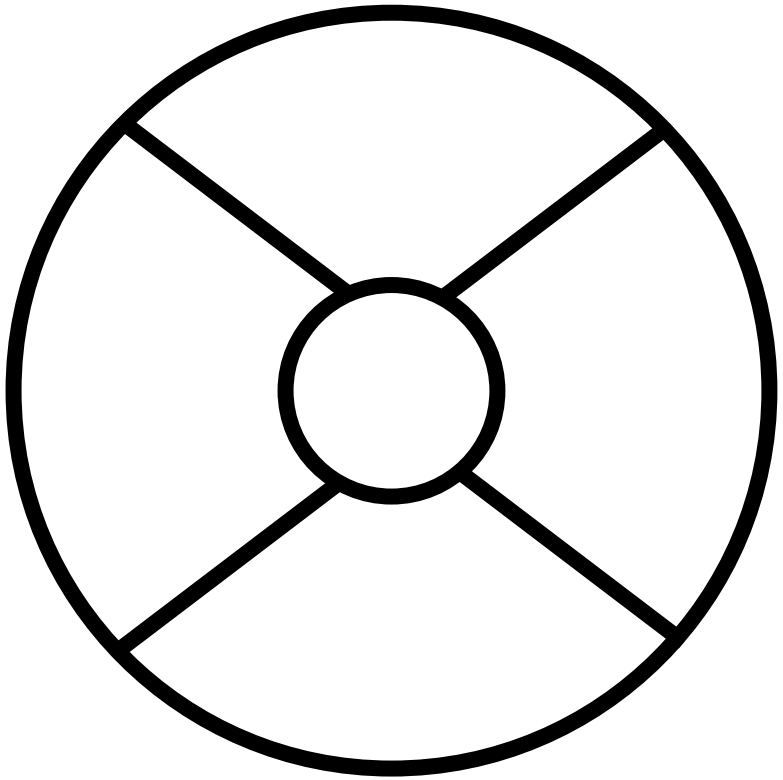
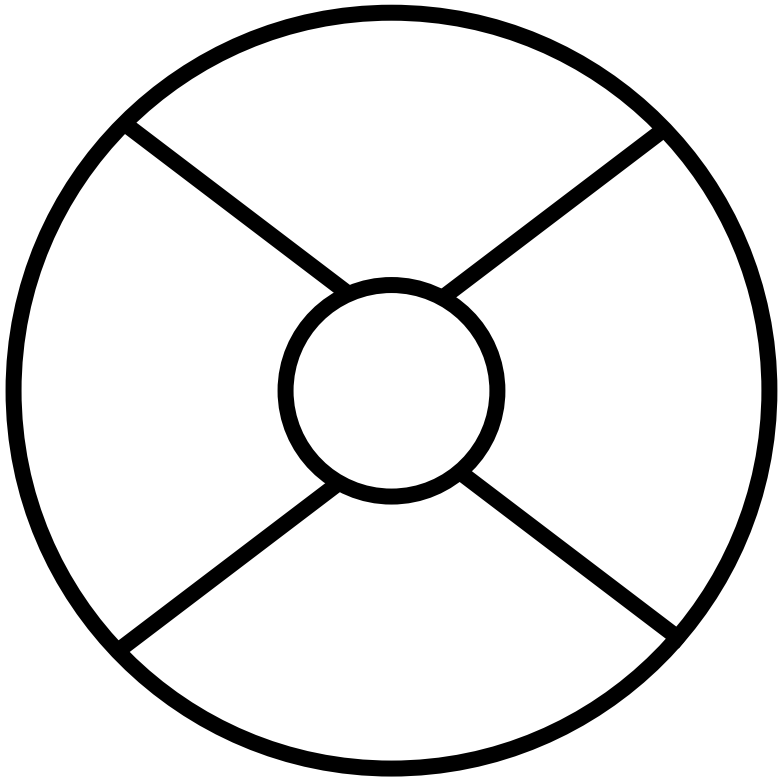
# Evolution of LEXI XAO



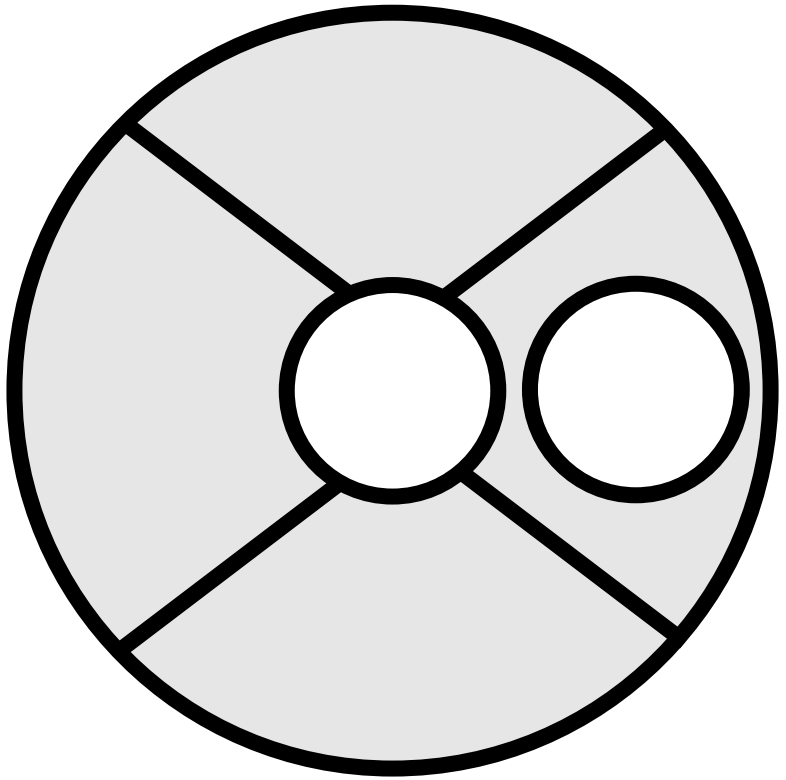
William Herschel Telescope
4.2m diameter
LEXI run June 2016

# Evolution of LEXI XAO



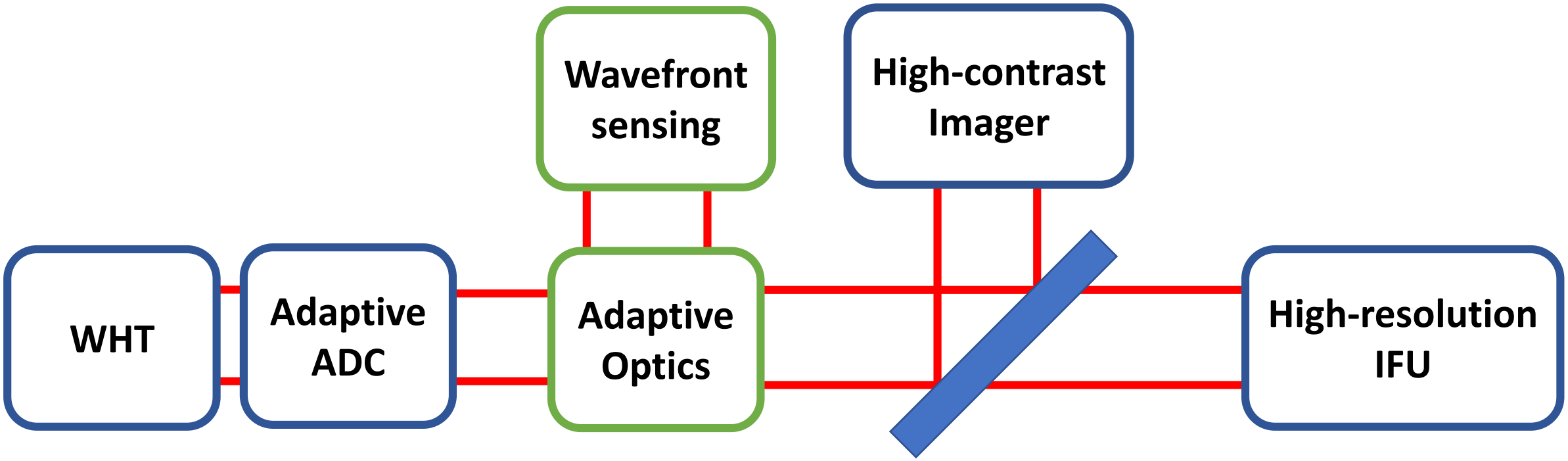
William Herschel Telescope
4.2m diameter
LEXI run June 2016

Palomar strategy:
Downscale aperture to
create an XAO system



William Herschel Telescope
1.2m off-axis segment
LEXI run December 2017/2018

# LEXI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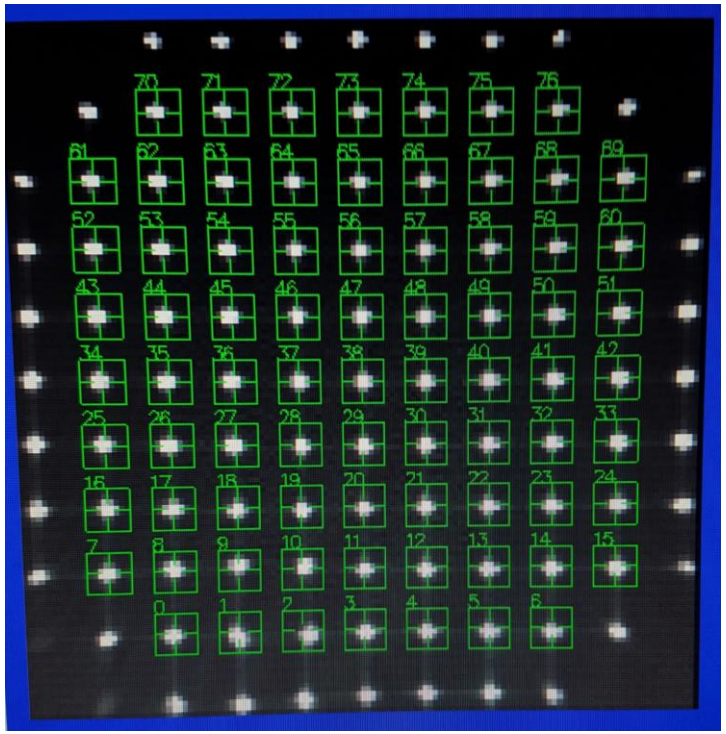
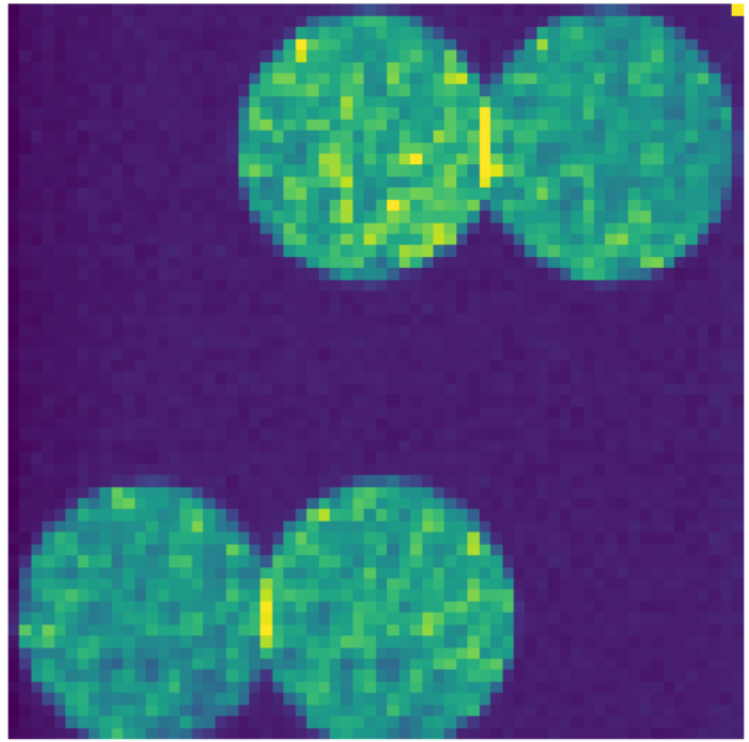
Shack-Hartmann wavefront sensor



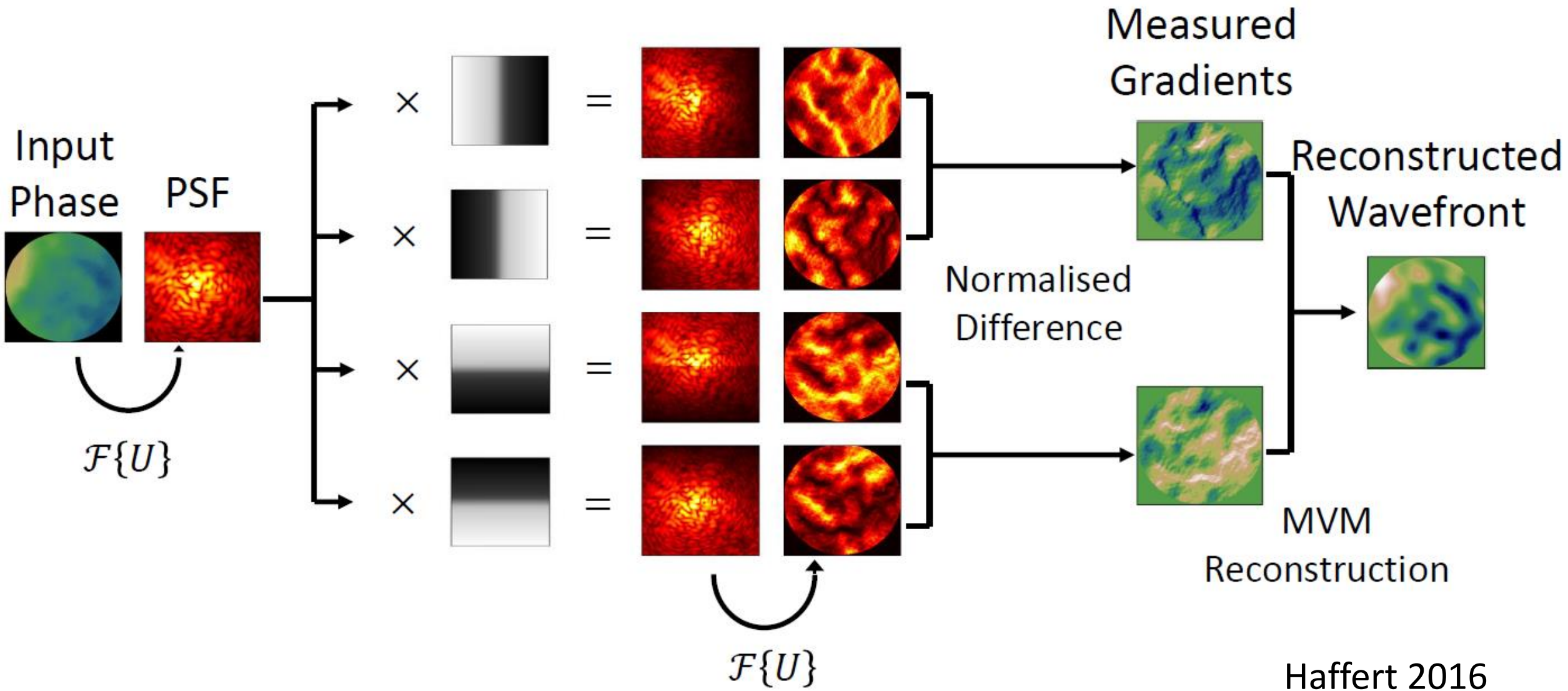
AO speed: 500 Hz
Number of modes: 75-80
Alpao 97-15 DM

generalised Optical Differentiation wavefront sensor



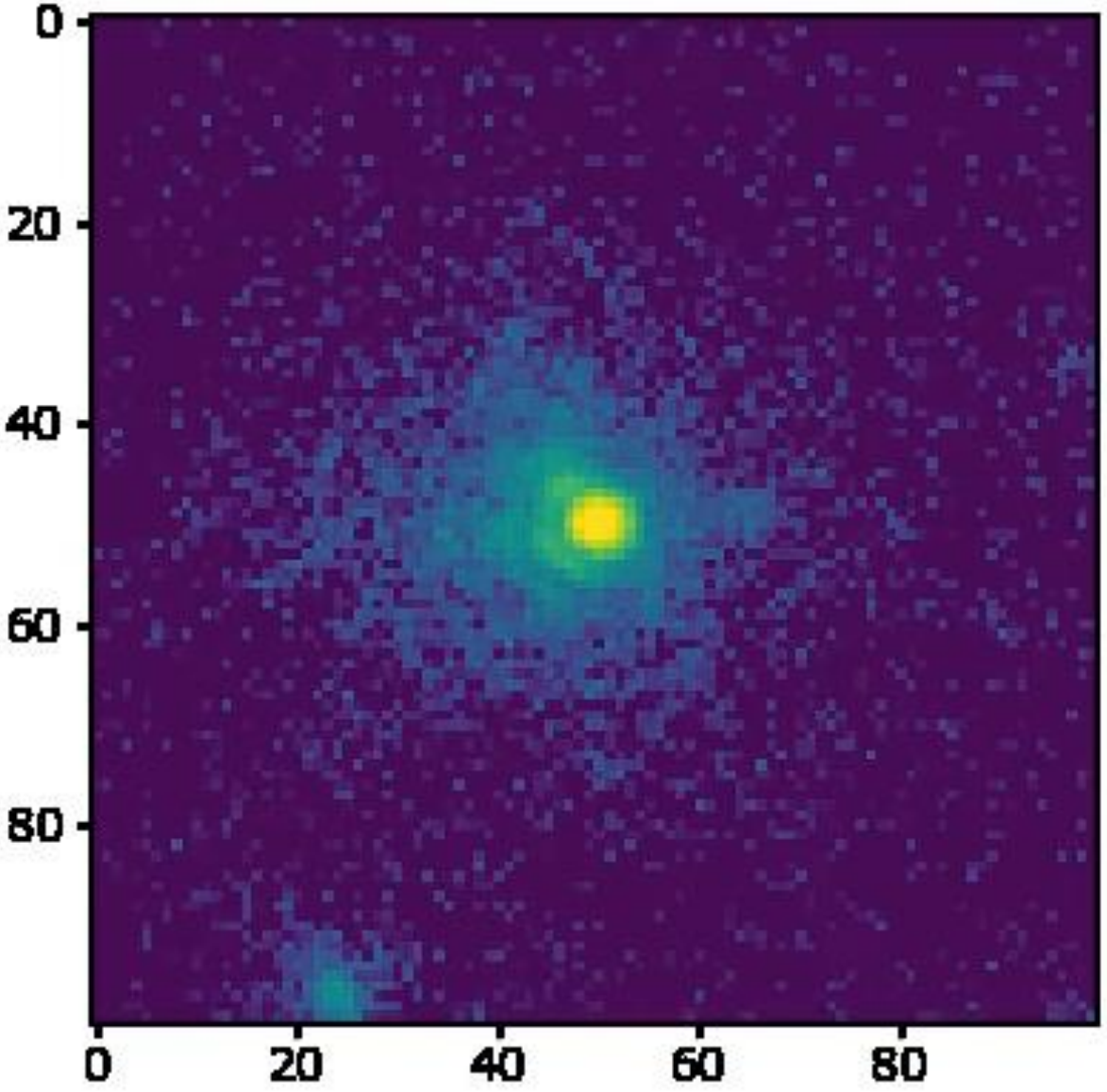
AO speed: 800 Hz
Number of modes: 96
Alpao 97-15 DM

Haffert 2016, Haffert et al. 2019 (in prep)

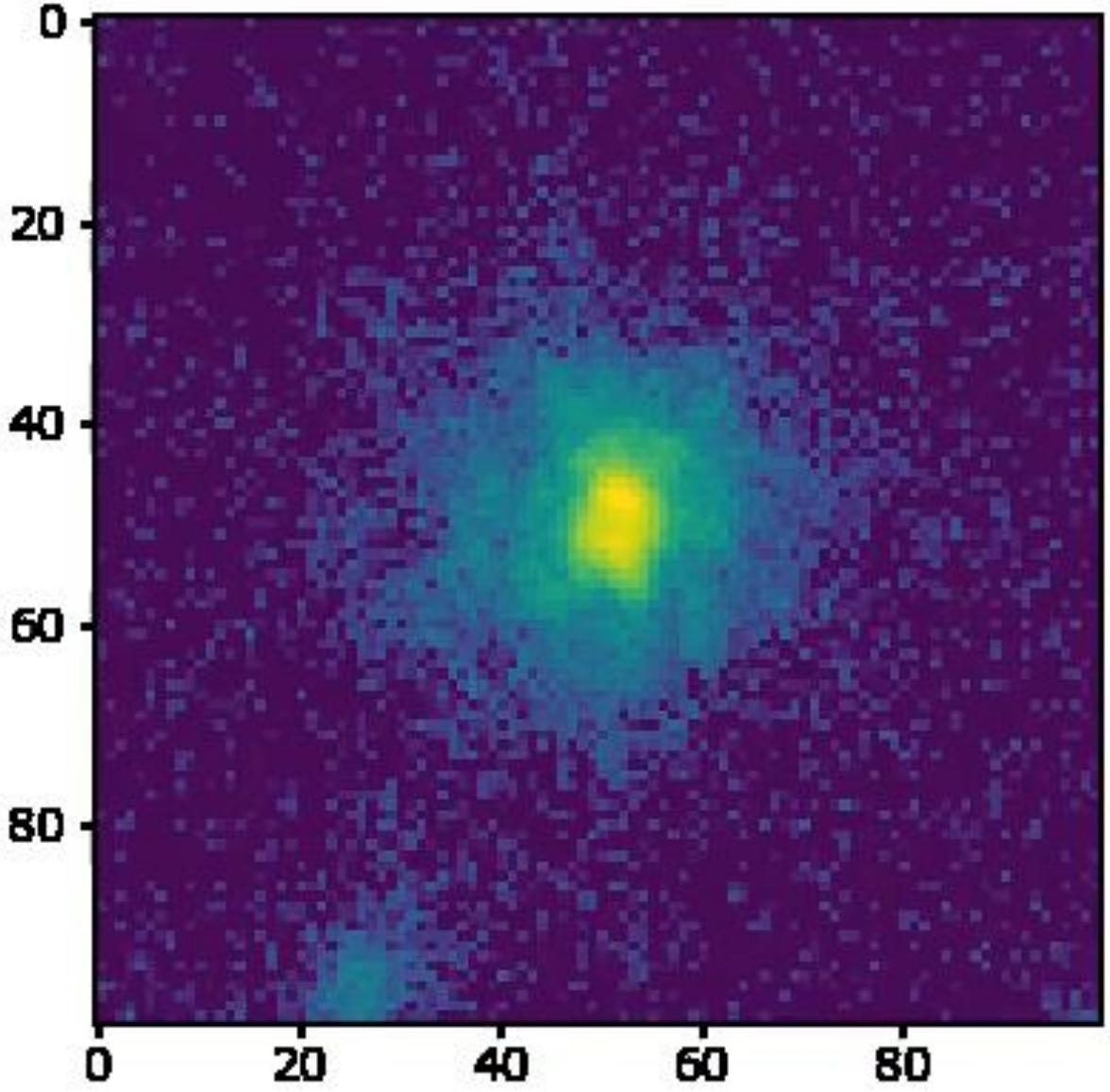



Haffert 2016

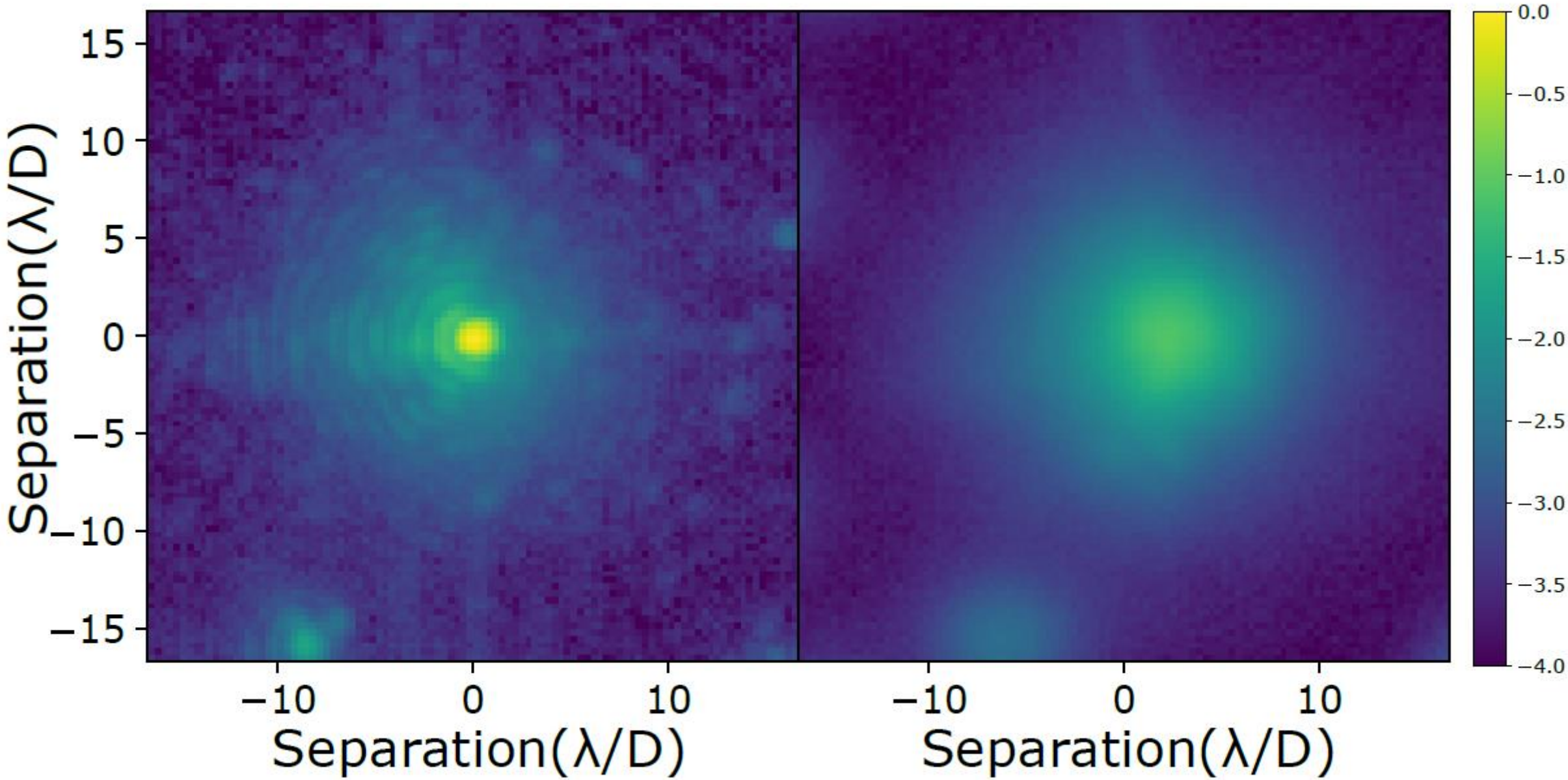
## Adaptive optics on



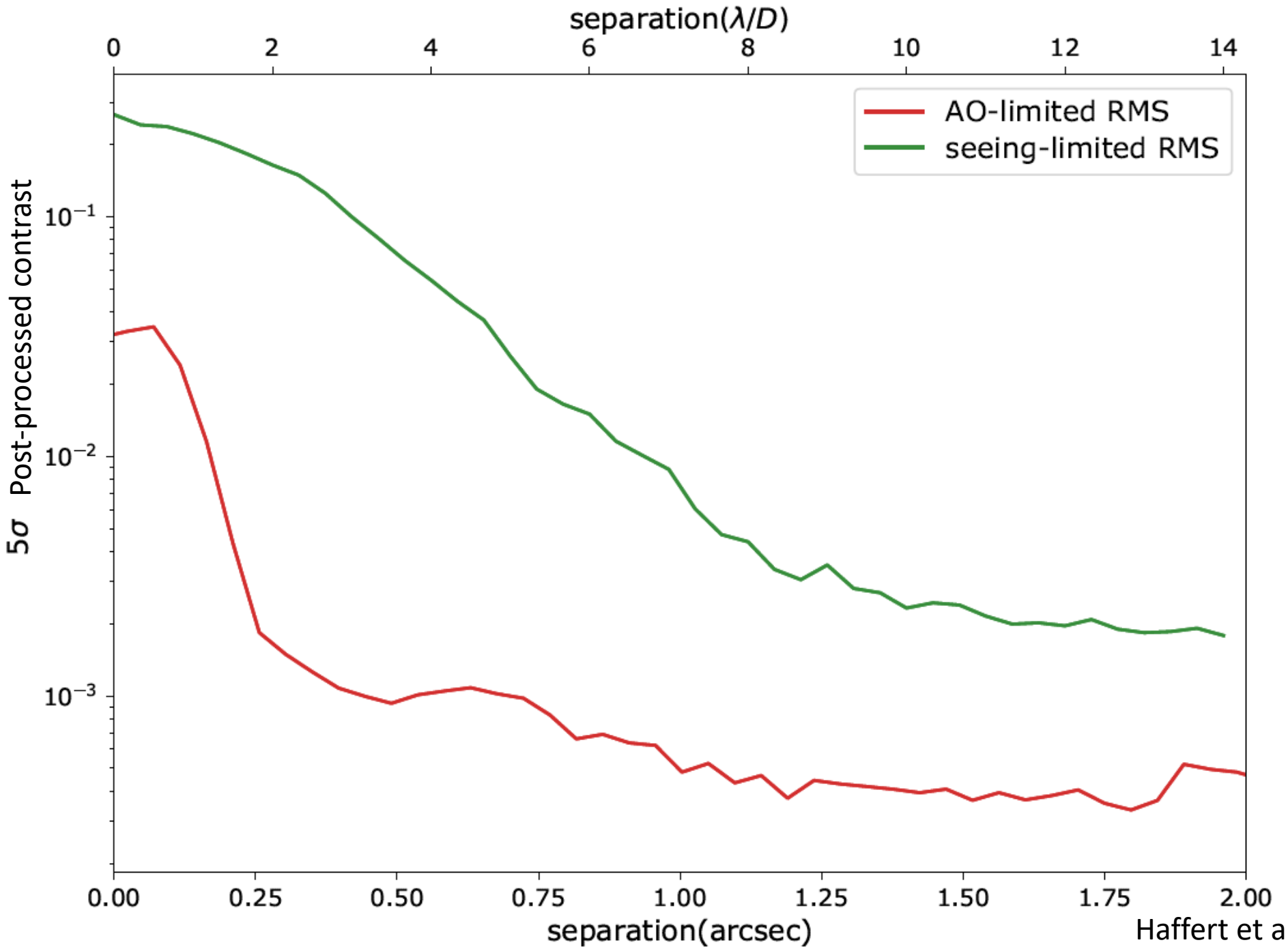

## Adaptive optics off




Haffert et al. in prep

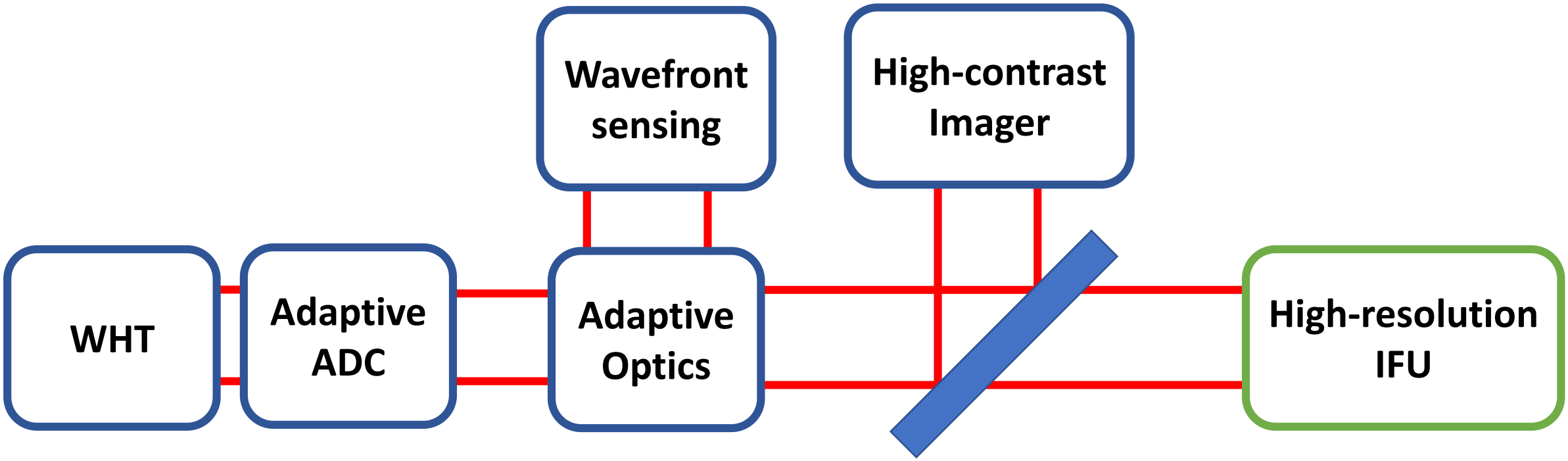



Haffert et al. in prep




Haffert et al. in prep

# LEXI


Wavefront sensing
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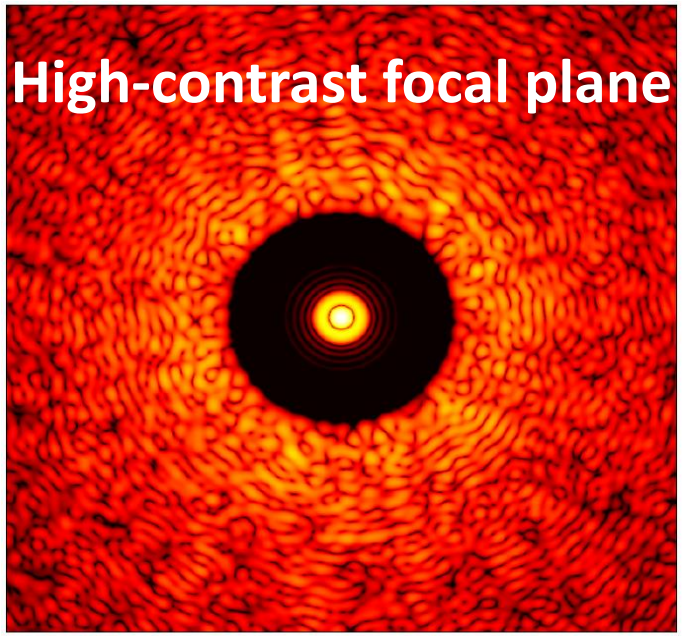
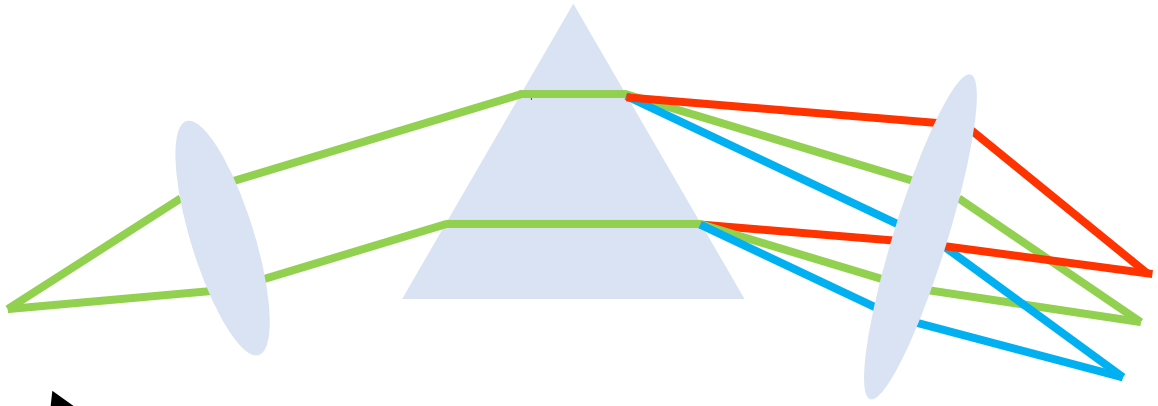
# How to couple HCI with HRS

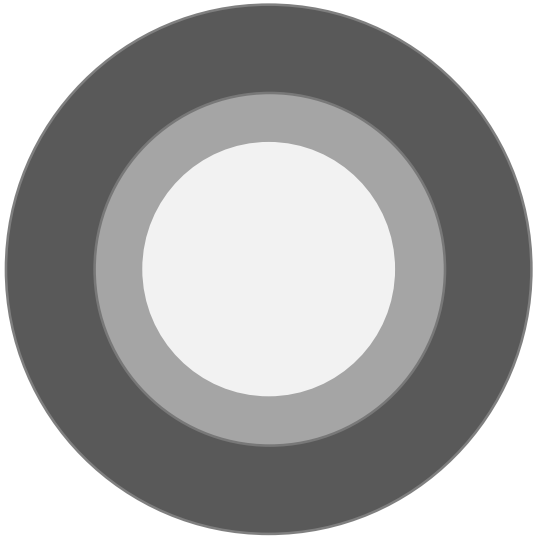



**High-resolution spectrograph**



How do we transport the light from our focal plane to the spectrograph?

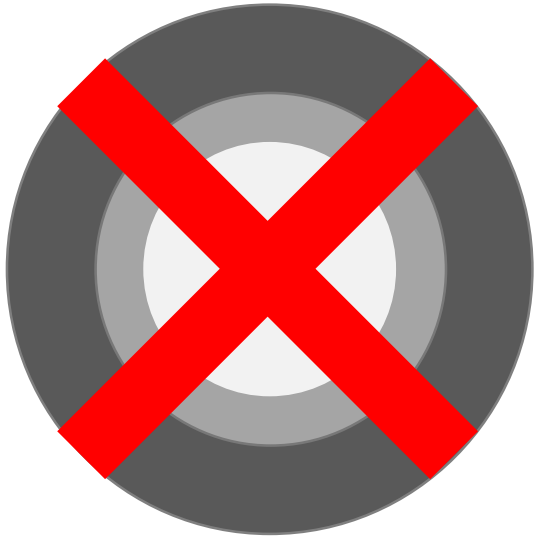
# Fibers



Multi-mode (“seeing-limited”) fiber

Single-mode (“diffraction-limited”) fiber

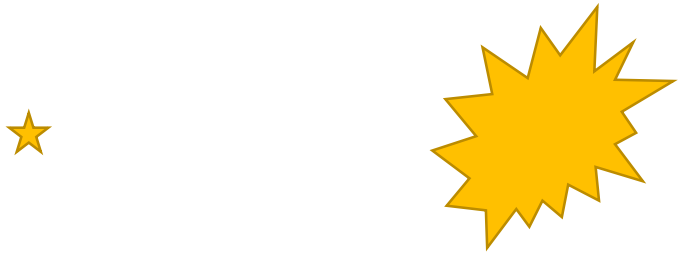
# Fibers



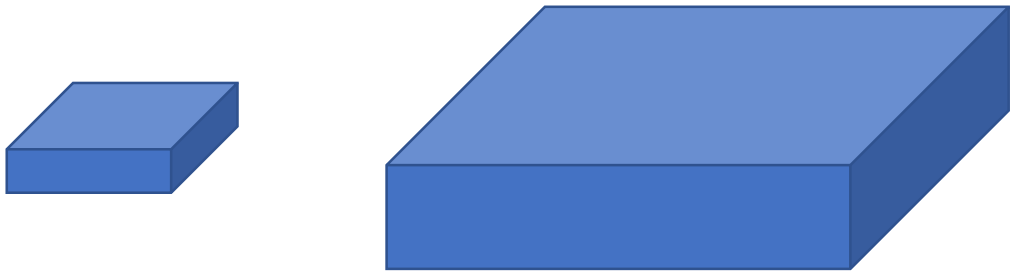
Multi-mode (“seeing-limited”) fiber

Single-mode (“diffraction-limited”) fiber

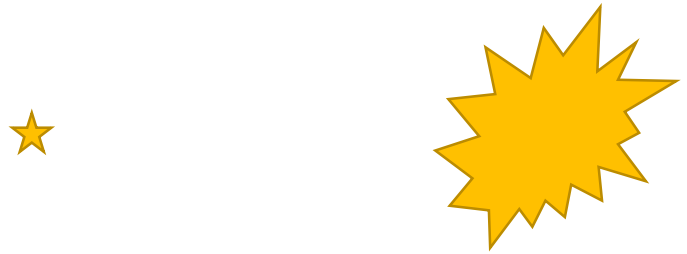
# Advantaged of single-mode fibers



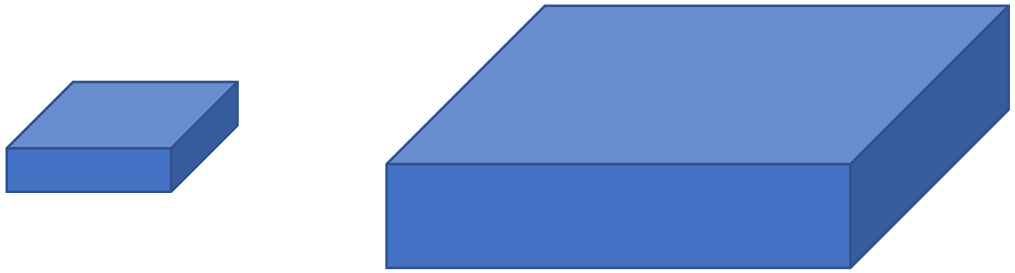
SMFs are diffraction-limited fibers
And spectrographs scale with angular size



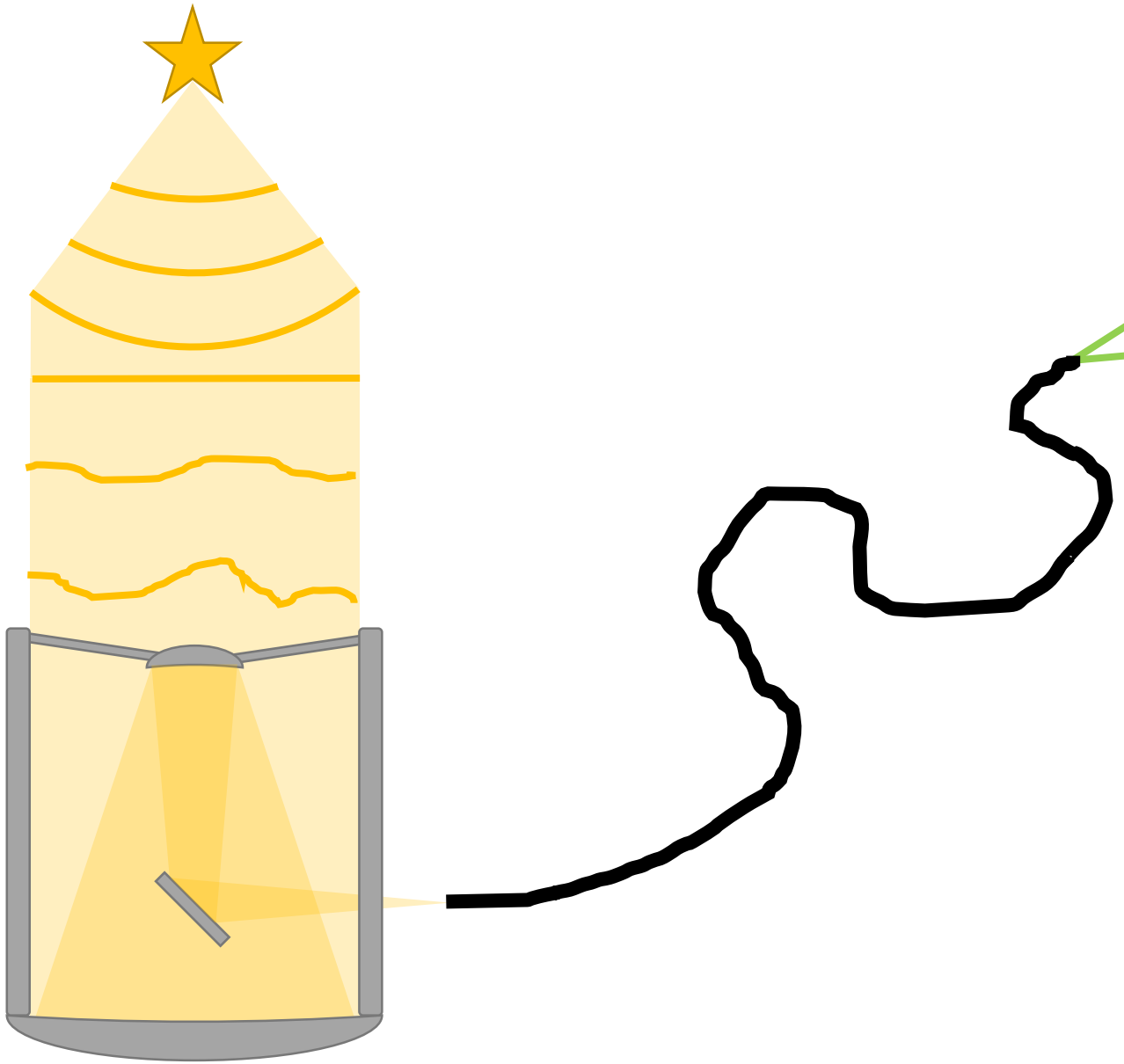
# Advantaged of single-mode fibers

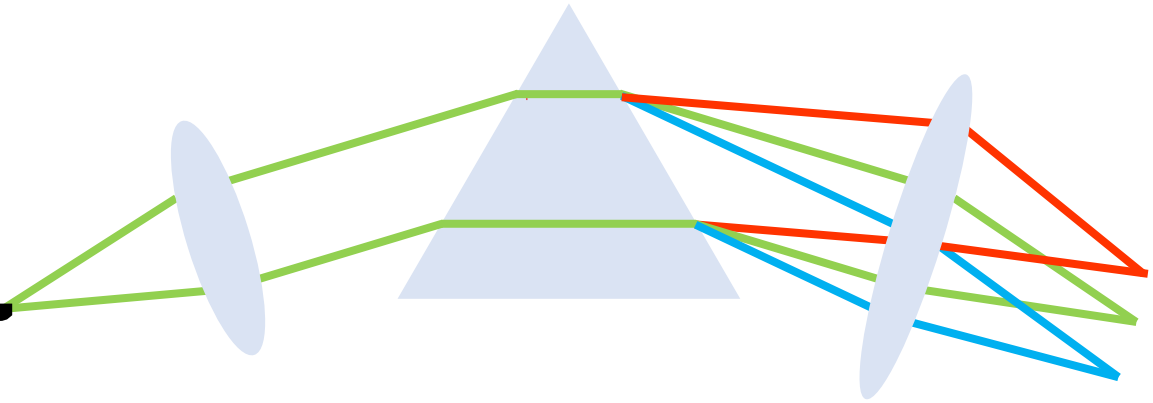


SMF spectrographs are small!



# Advantaged of single-mode fibers

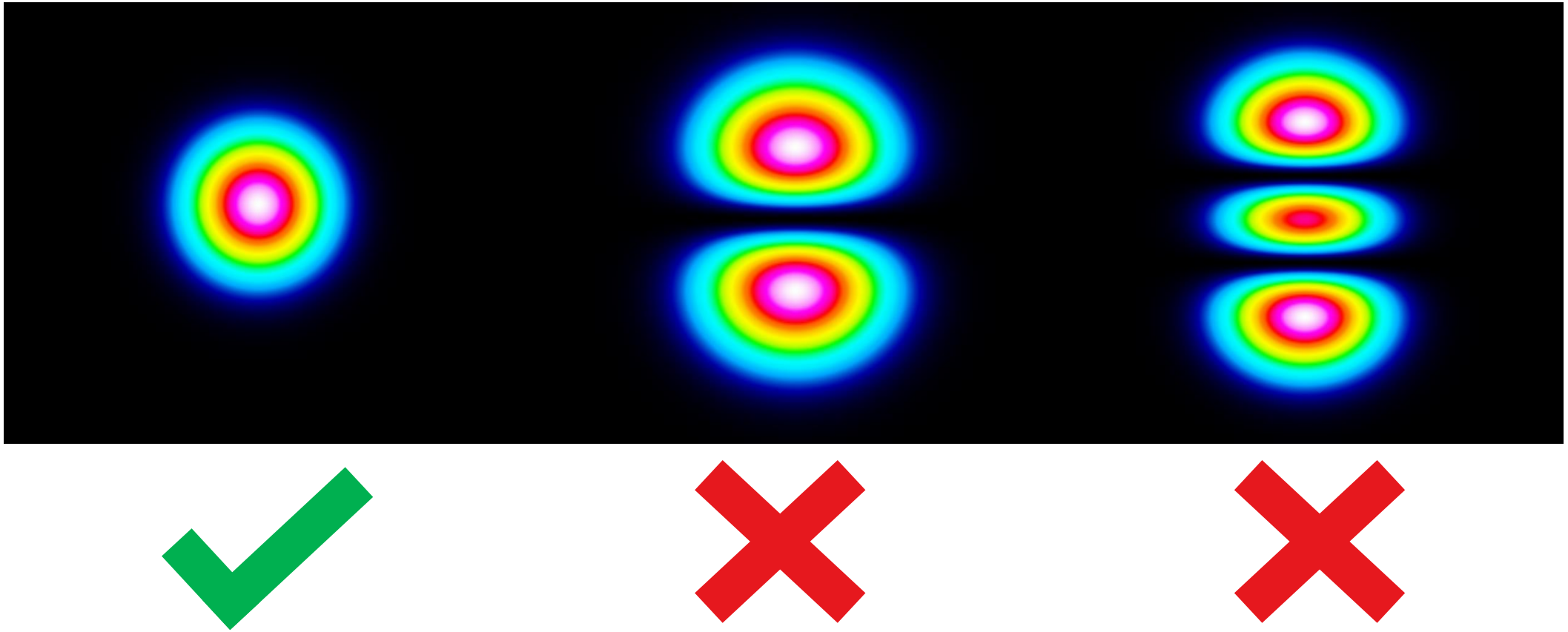




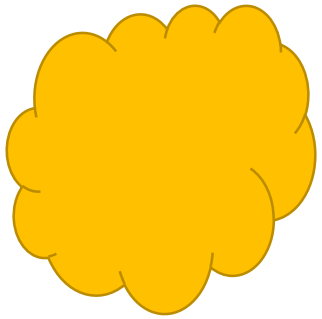
No optical interface! So you can transport any fiber based spectrograph to other telescopes.

It also makes it easy to accommodate wherever there is space.

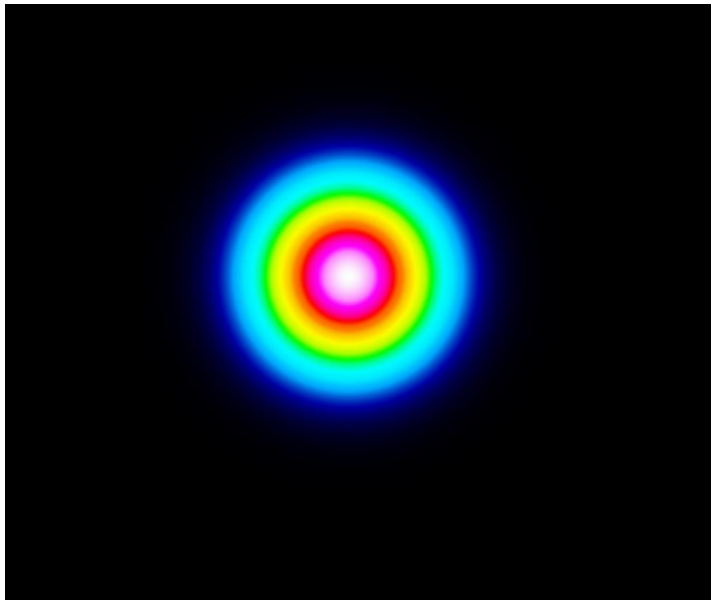
# Advantages of single-mode fibers



# Advantages of single-mode fibers

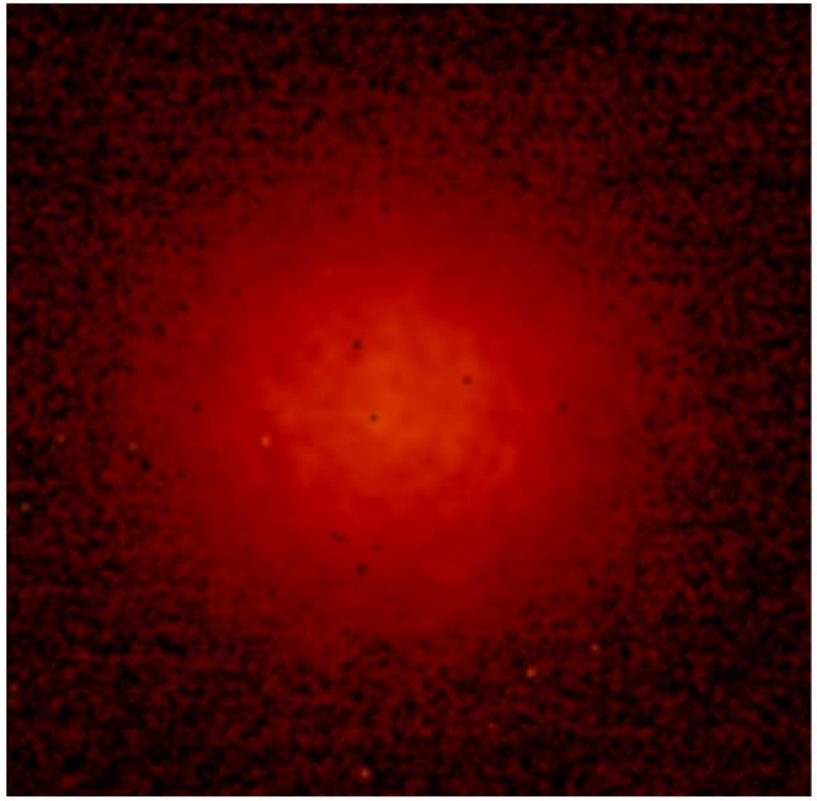


All inputs always transform into a gaussian.



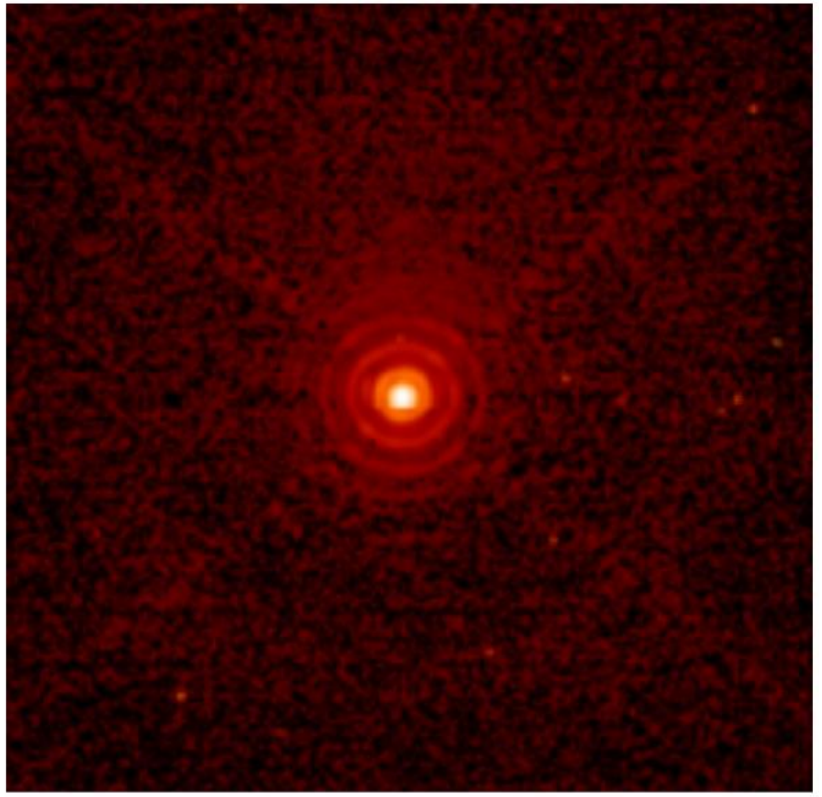
Creates very stable Line Spread Functions.

# Advantages of single-mode fibers



Seeing limited image
$5.2 \pm 2\%$ SR

(a)



AO corrected image
$90.3 \pm 2\%$ SR

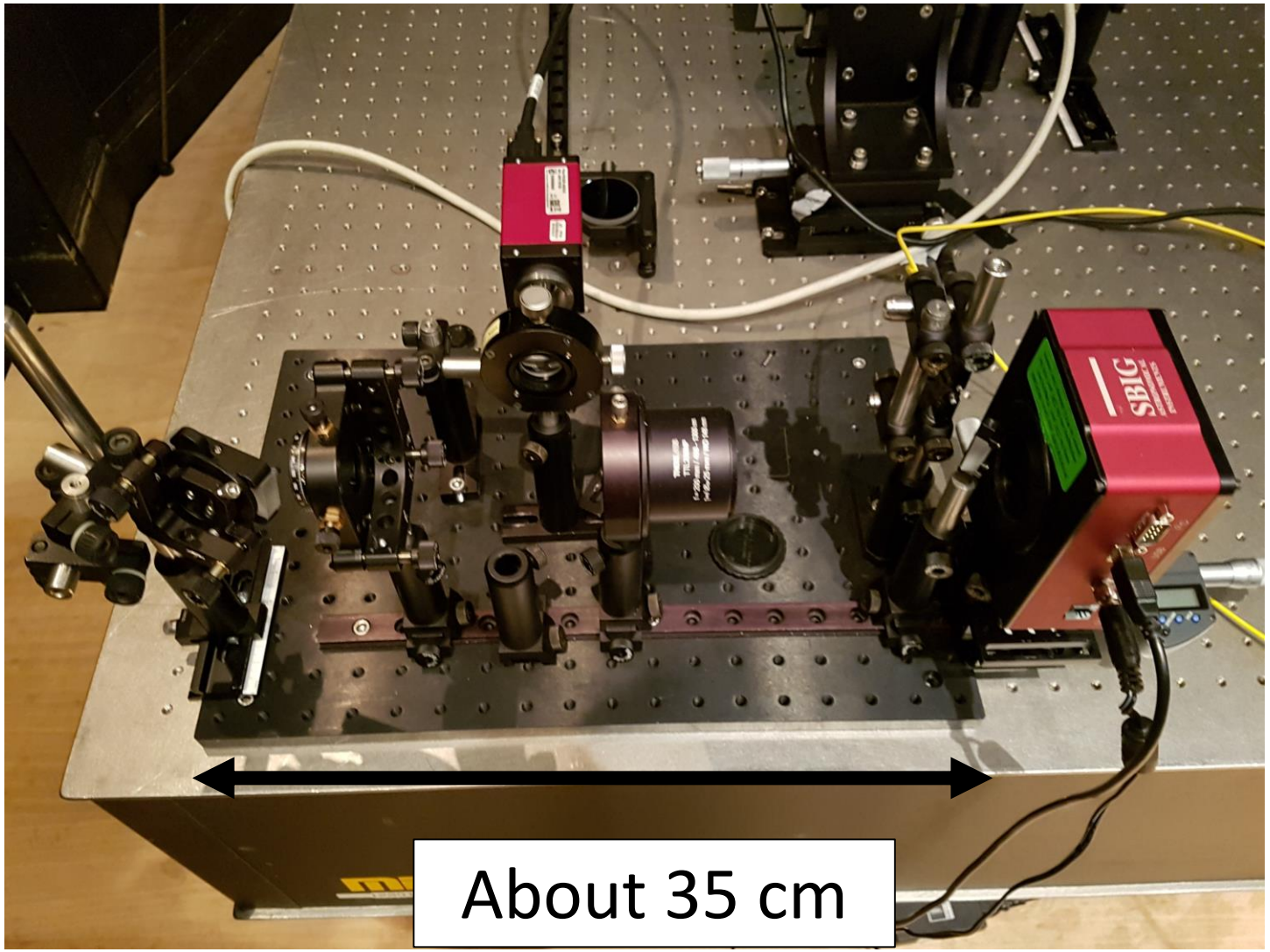
(b)

We put in all the effort to make our instrument diffraction-limited!

Why convert it back to the non-diffraction limit?

Petit et al. 2016

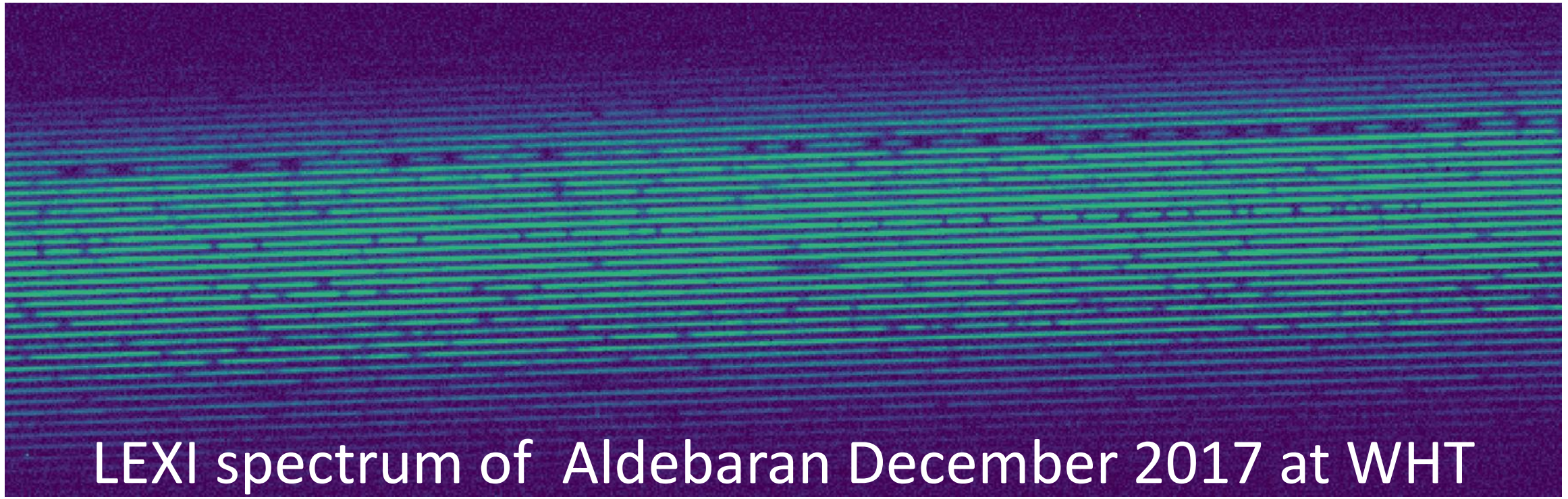
# Compact fiber-fed diffraction-limited spectrograph designs




| Specifications |
| --- |
| R of 100000 |
| 600 to 900 nm |
| 19 fibers |
| Designed with SCAR |
| Off-the-shelf parts |

Haffert et al. 2018 (SPIE)

It is easy to design high-packing efficiencies due to the diffraction-limited spectrograph design.




Haffert et al. 2018 (SPIE)

Now let’s switch to an IFU instead

# Filling a field with single mode fibers.

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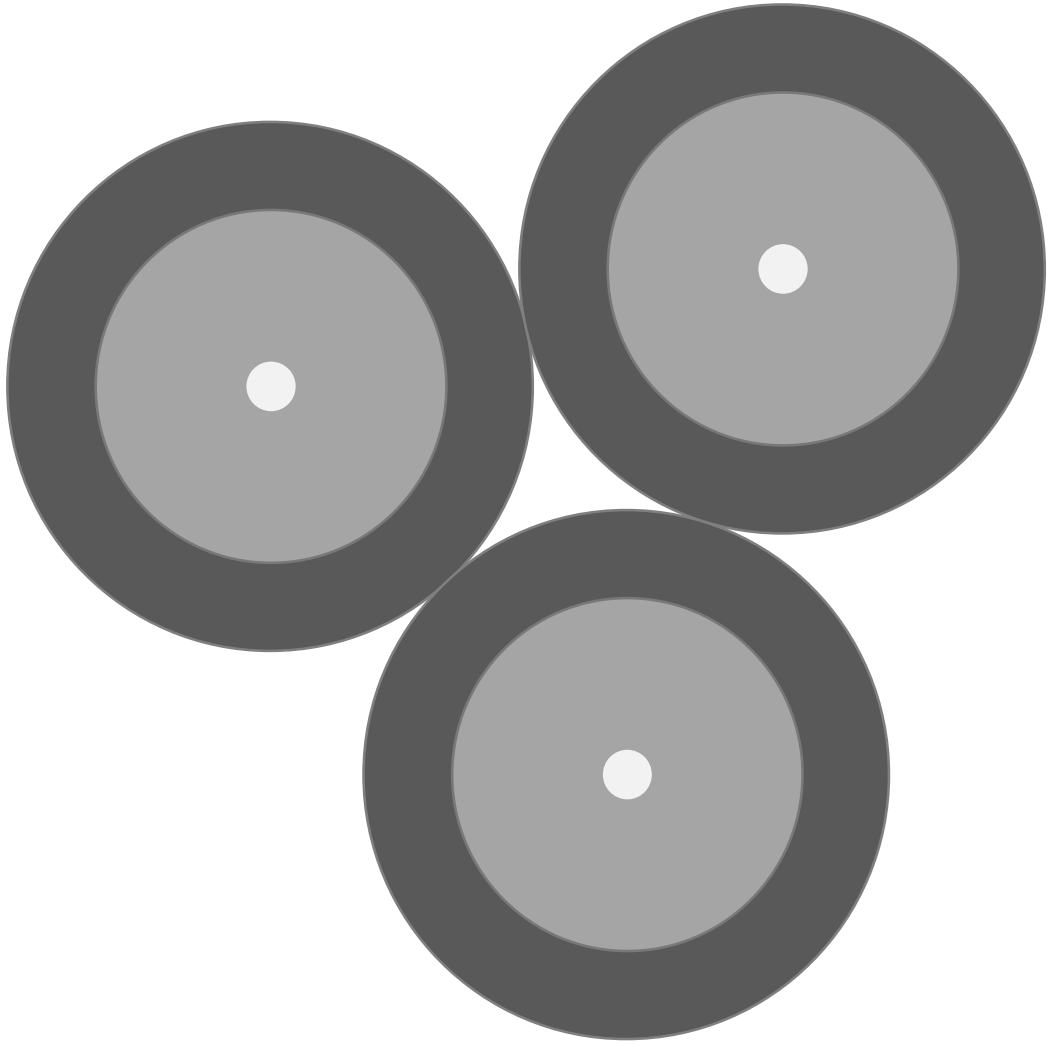

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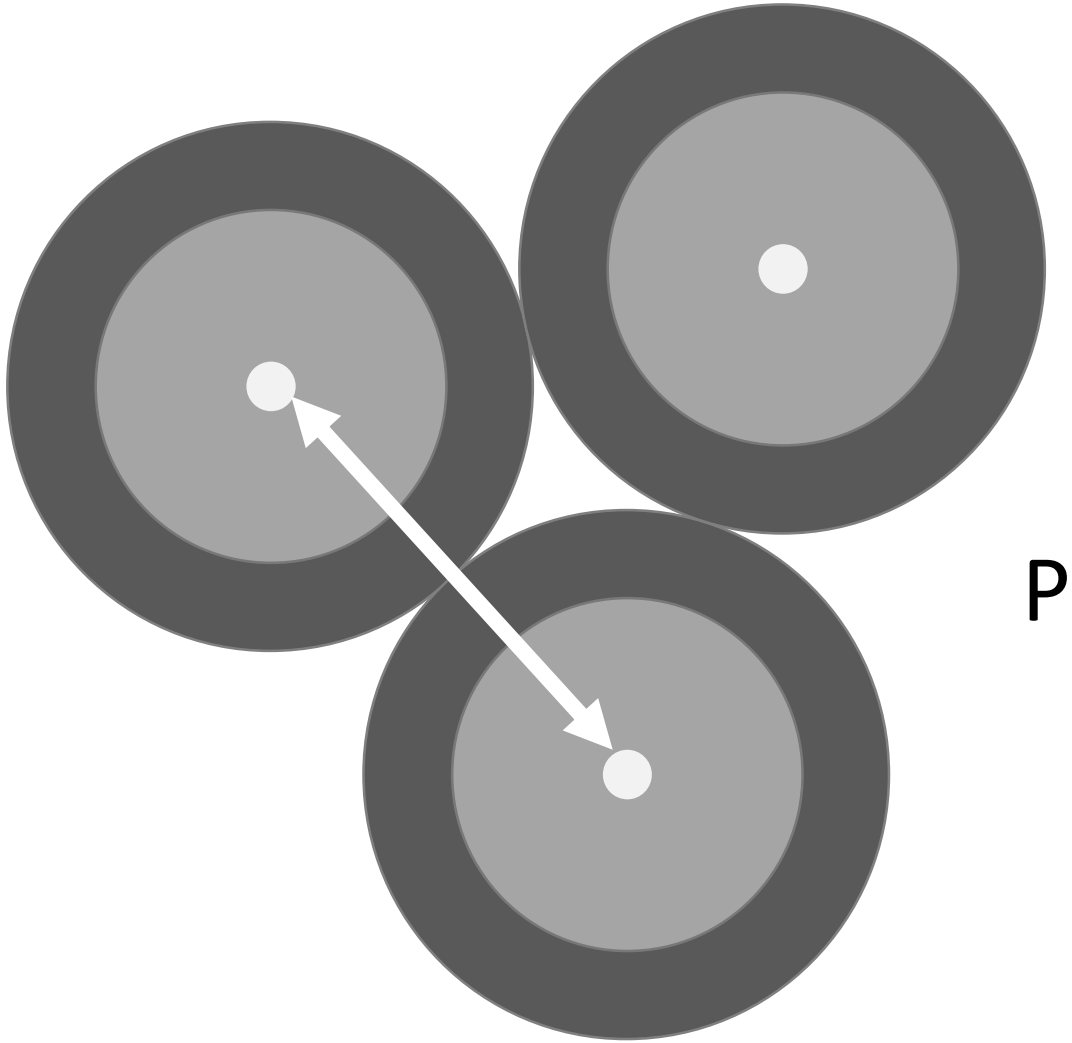
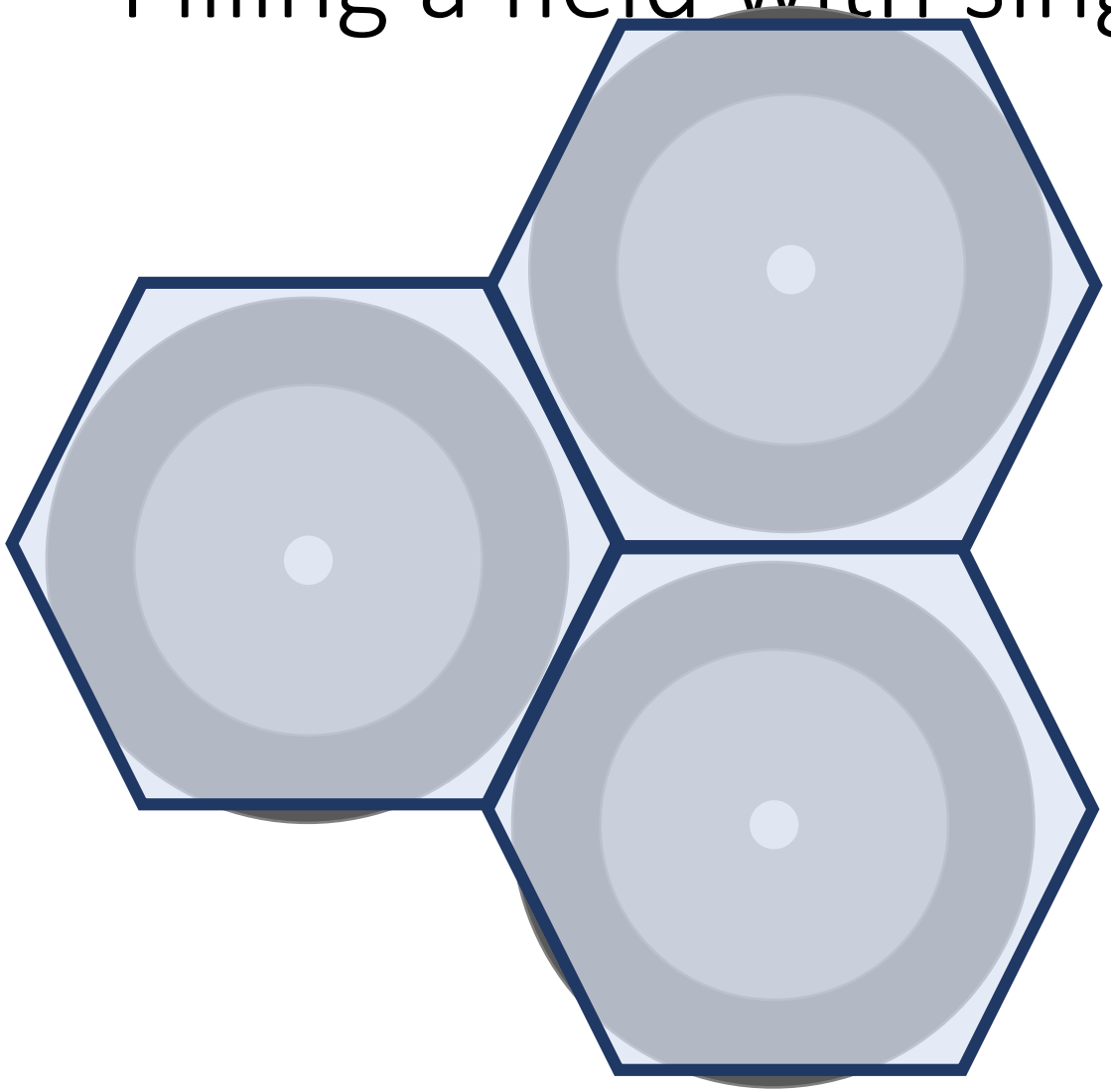


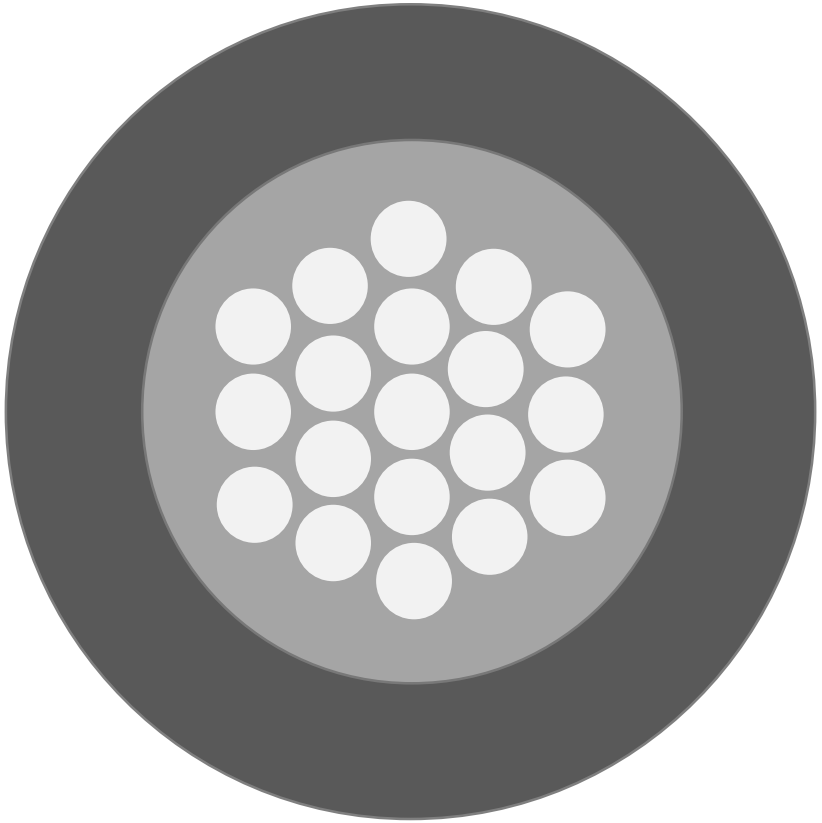
Pitch on order of 200um

# Filling a field with single mode fibers.



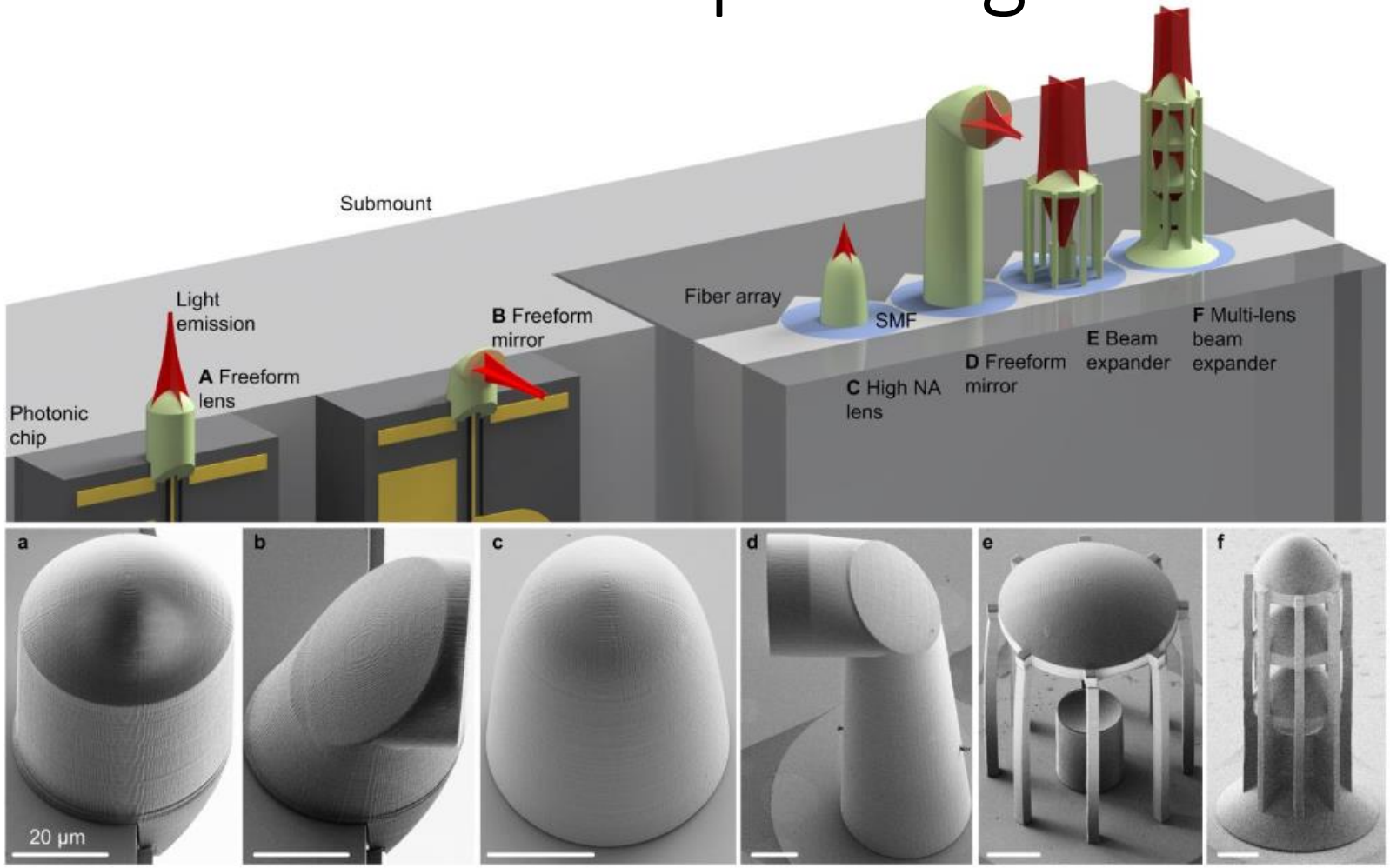
- Micron alignment accuracy
- A MLA is a piece of bulk optic
- Fibers are not in a perfect grid.

# Use a **SINGLE** multi-core fibre



- Excellent core to pitch ratio
- Only a single fiber.
- Dense system.
- Small size is difficult with bulk optics

# In-Situ 3D Nano-printing of freeform optics

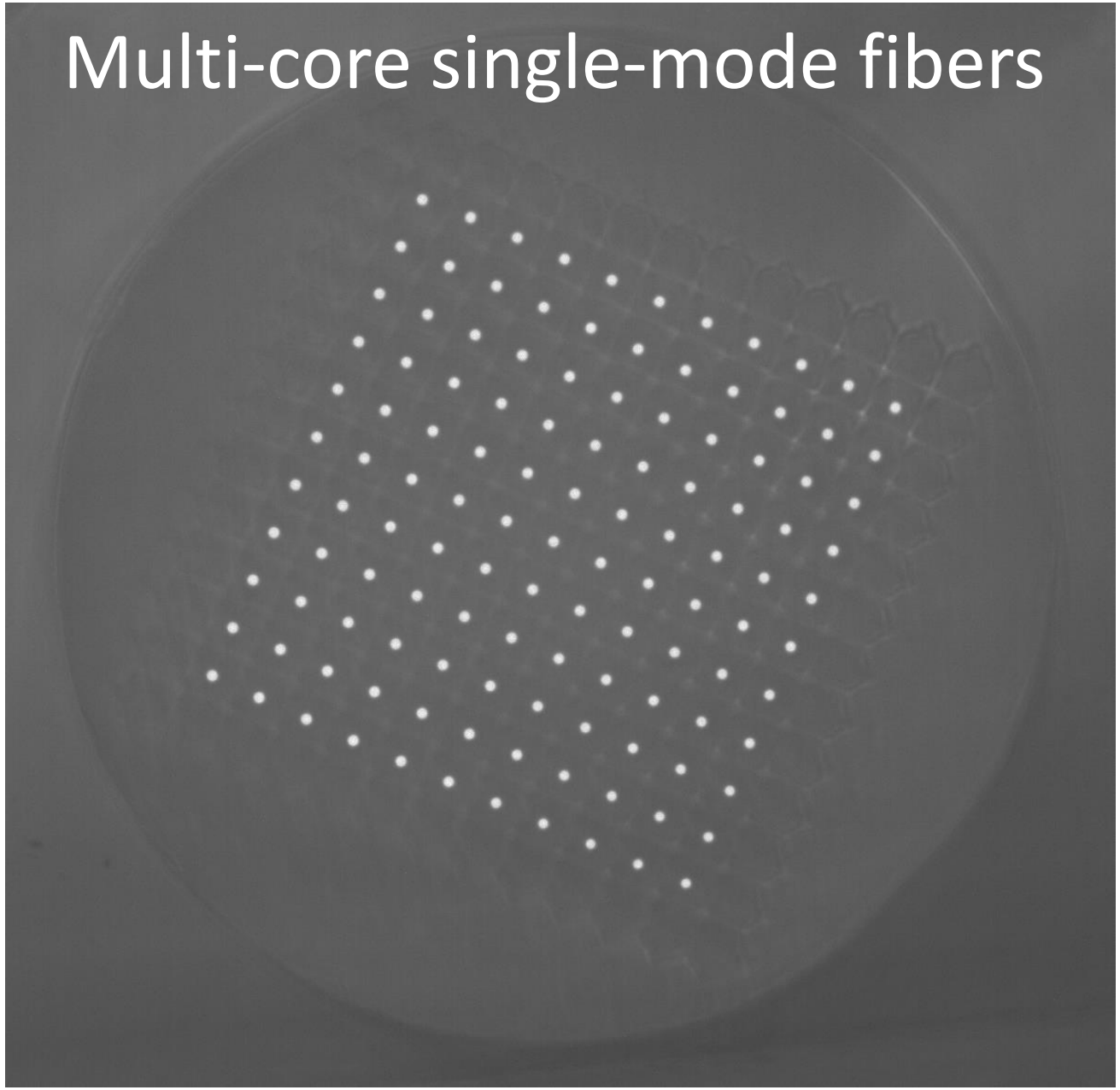



"In-Situ 3D Nano-Printing of Freeform Coupling Elements for Hybrid Photonic Integration" Dietrich et al. 2018

Pitch of 10.5 um

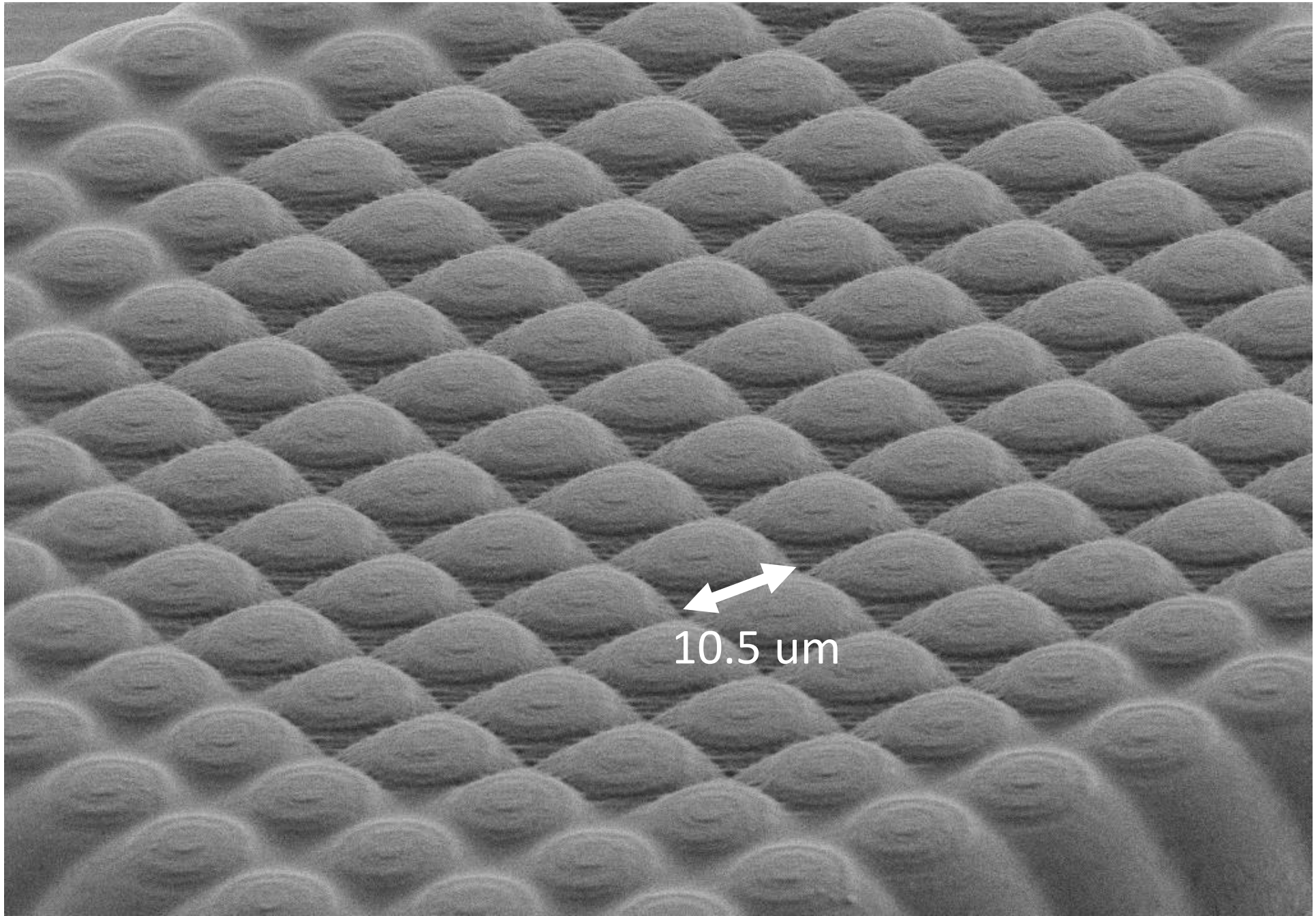
1.83um MFD

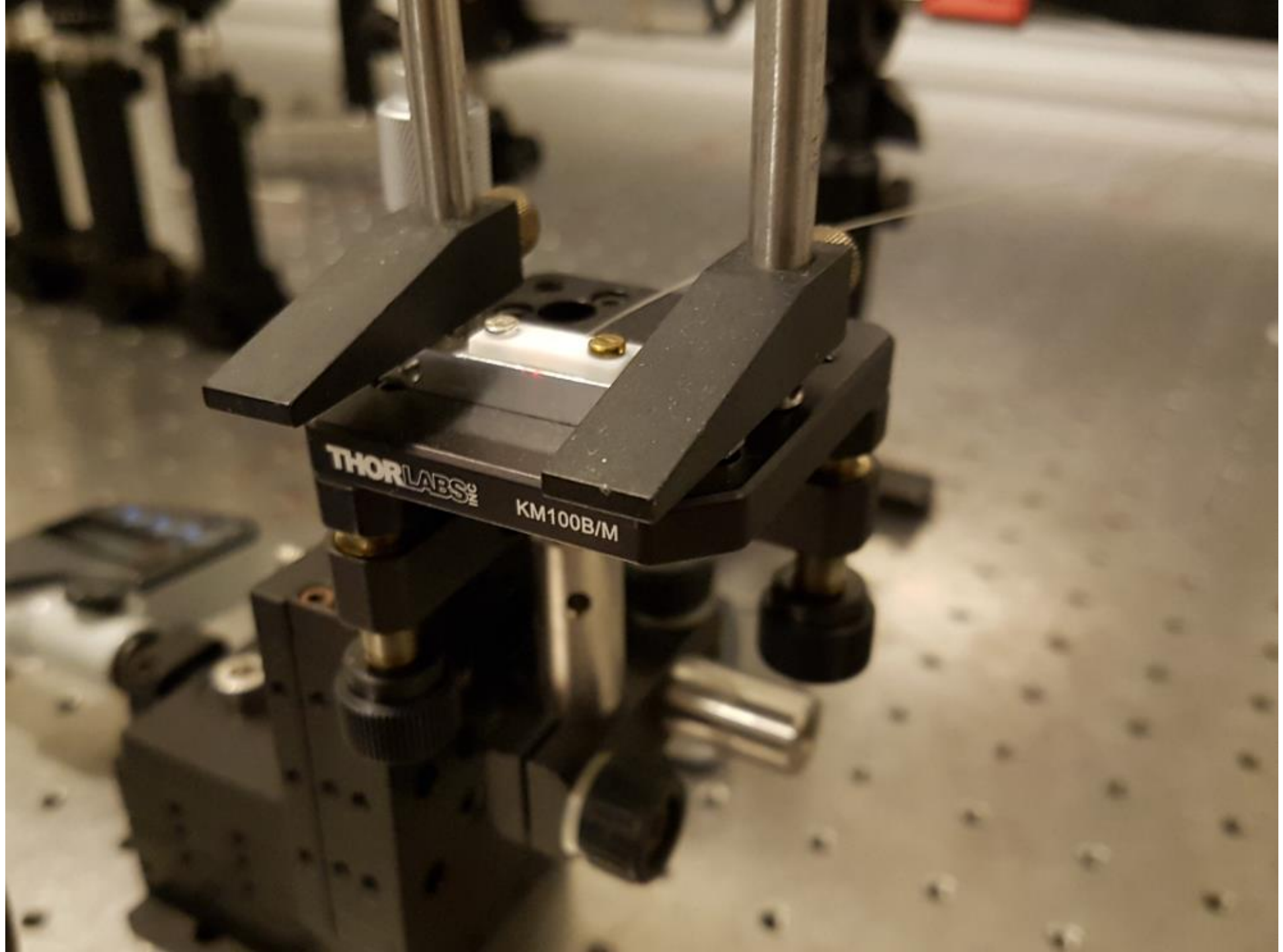
Strict requirements on microlens alignment from SCAR.



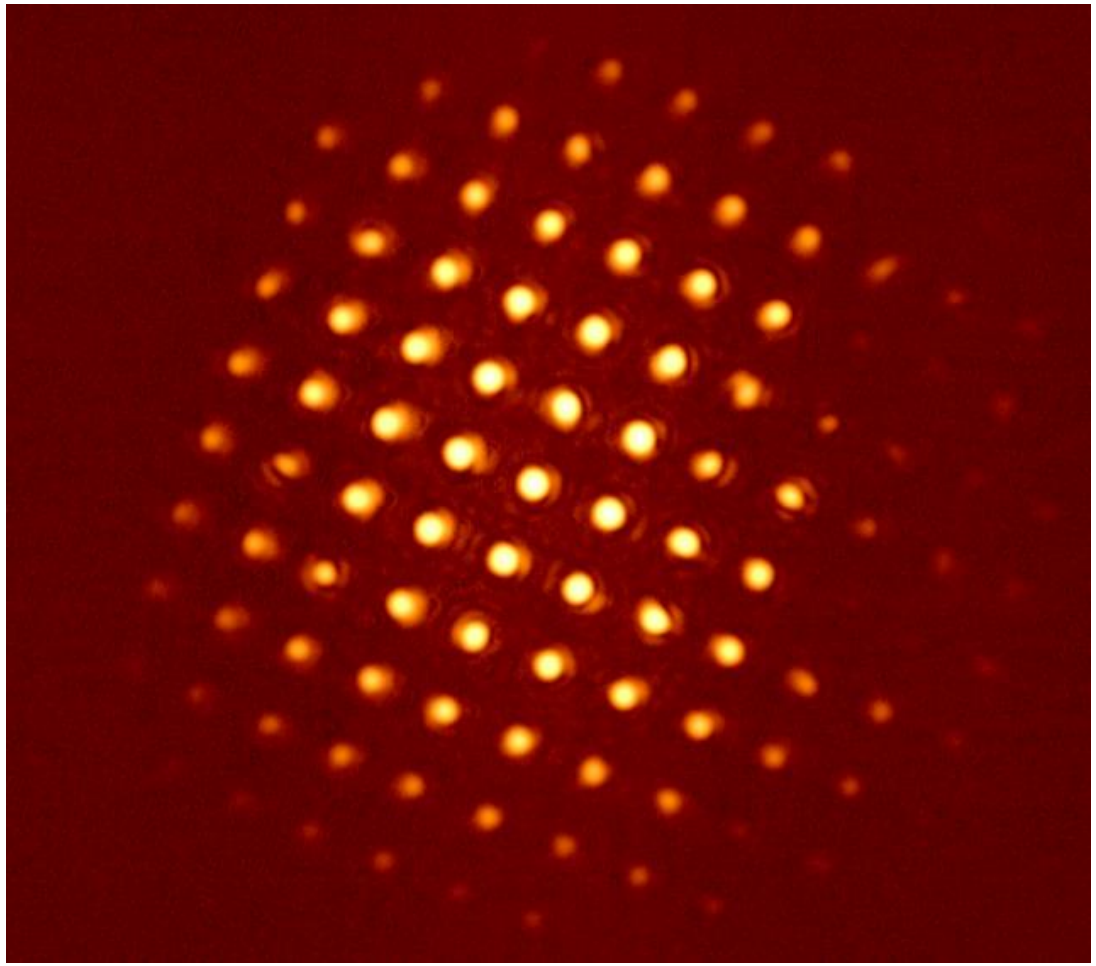

Chandrasekharan et al. 2017 (Bath)


Dietrich et al. 2018 (KIT)
MLA manufactured M. Blaicher


10.5 um


THORLABS
KM100B/M

# Fiber core selection



- I added a slit because the 11x11 MCF has to many fibers.
- Due to the pitch to core ratio of this fiber I can only disperse two columns. There is no room for a third
- So we get an 2x11 area on-sky. This is roughly ~ 0.45x2.5 arcseconds projected on-sky.

Haffert et al. in prep

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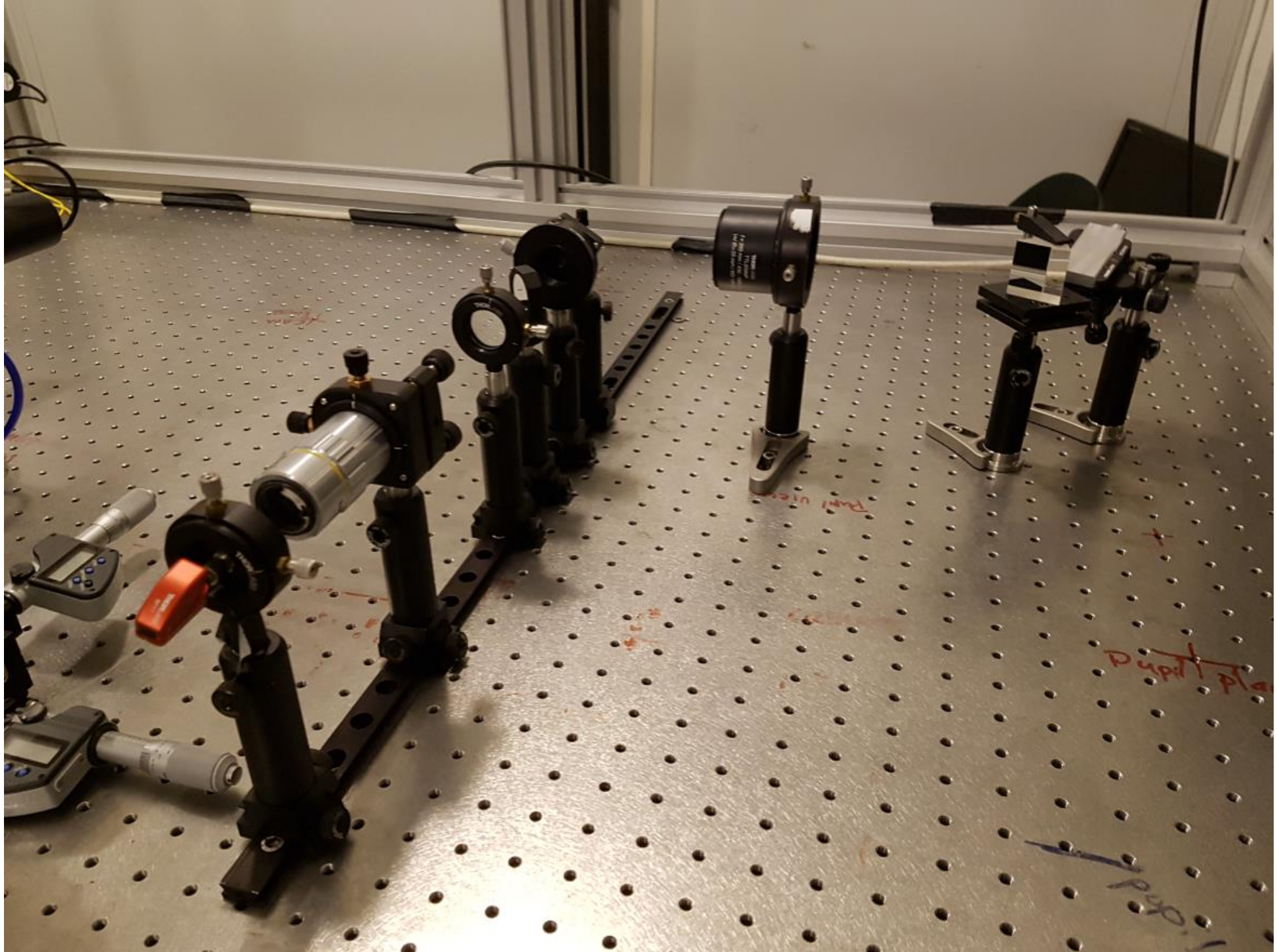
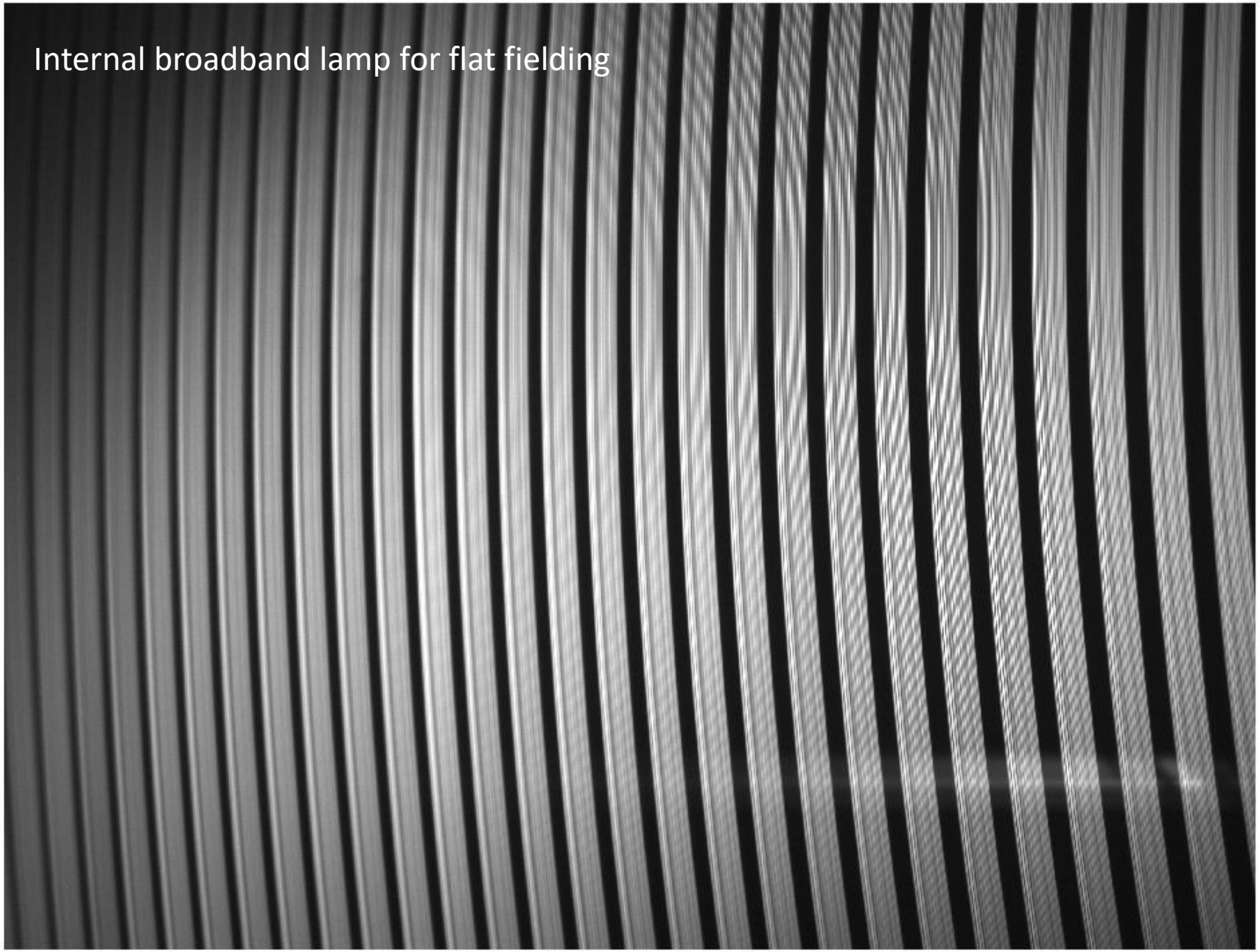
Haffert et al. in prep



# Latest LEXI run at WHT 2018

- Observing from 23$^{rd}$ – 31$^{st}$ of December 2018

- Telescope broke down during our run. We only had 2 half nights.

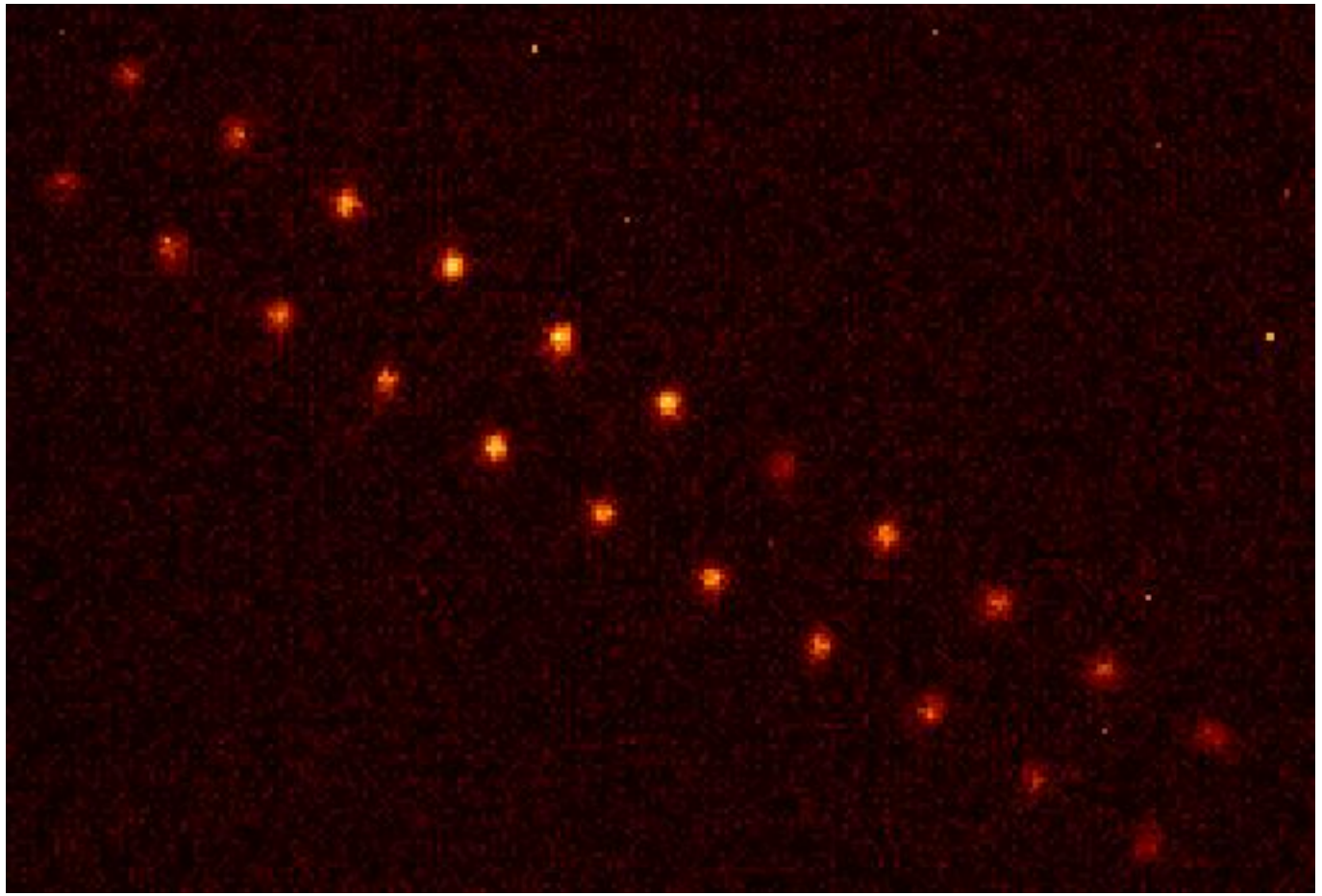



Haffert et al. in prep

# Zoom in of the echellogram

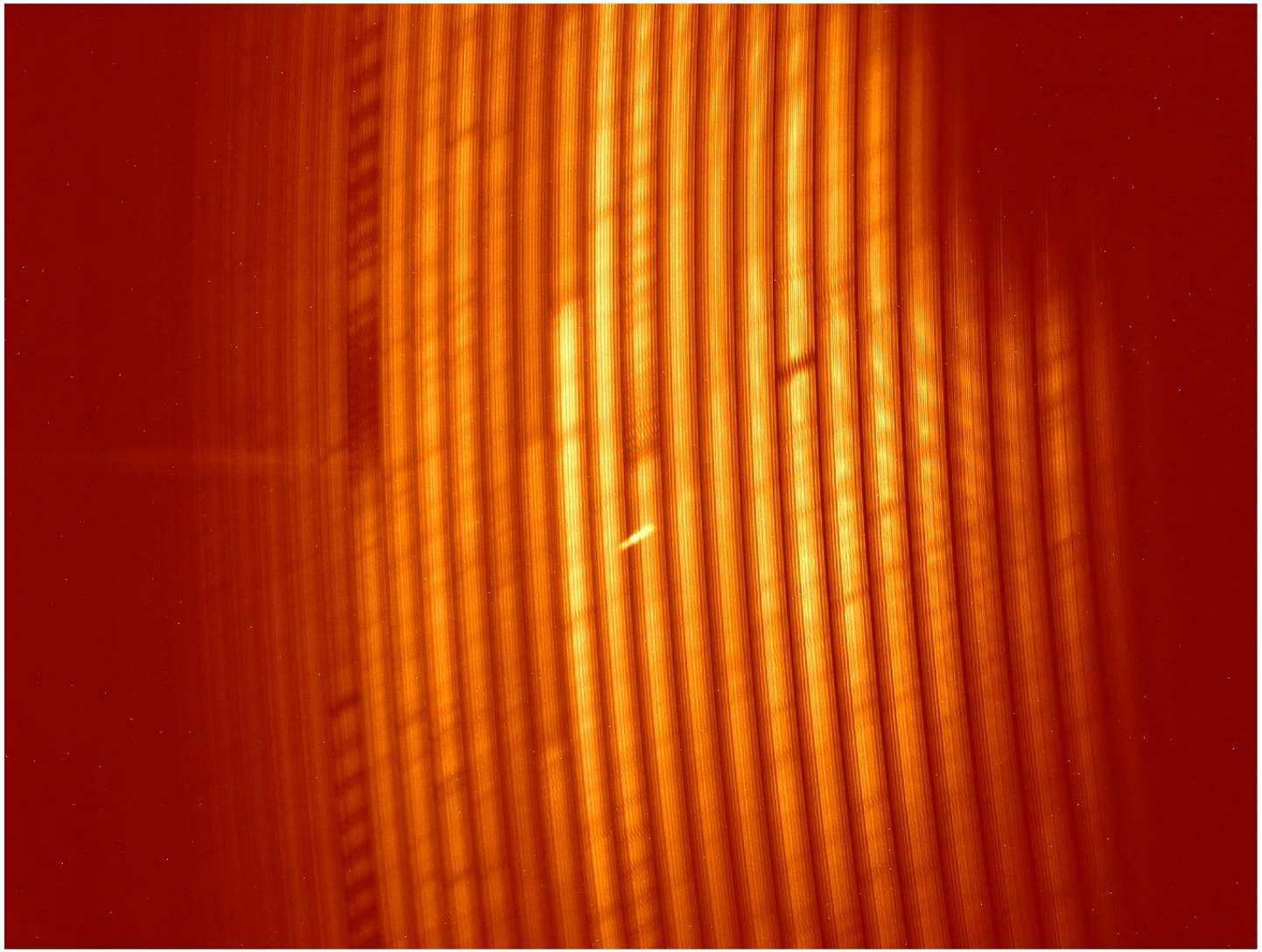
Haffert et al. in prep

# Imaging through the fiber array on Regulus



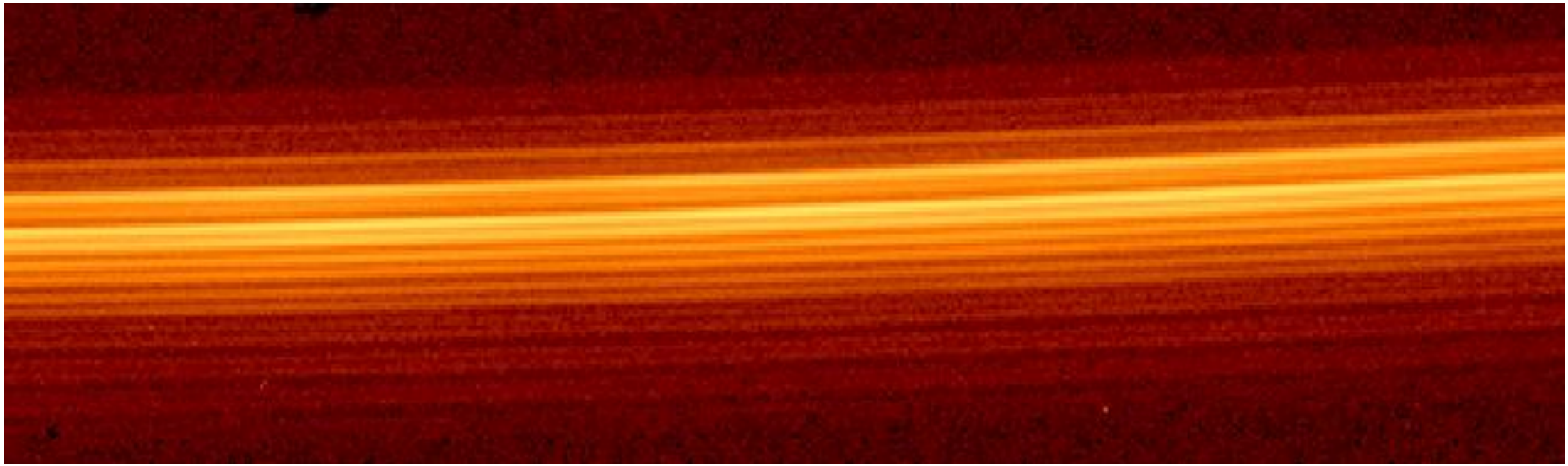
Haffert et al. in prep

# A spectrum of Betelgeuse



Haffert et al. in prep

# A spectrum of Betelgeuse zoom-in



Haffert et al. in prep

# Conclusion

- LEXI has been developed over the past 3.5 years
- The new AO strategy works and delivers high quality PSFs
- Multi-core fibers with the 3D printing works very well for light injection
- With the MCF we can make compact high-resolution IFUs