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AstroTech Talk
Haus der Astronomie, Heidelberg
8.12.2017

Tip-Tilt Sensing & SMF Coupling

Using 3D-Printed Microlens-Arrays

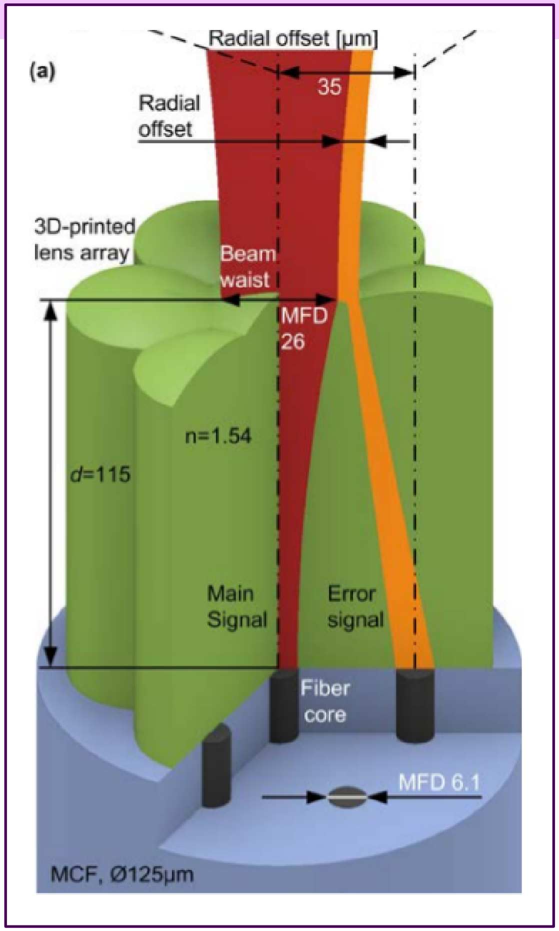
Contributions

LSW Astrophotonics:
A. Quirrenbach, **R. Harris**,
T. Anagnos, **P. Hottinger**

3D Printing: *Karlsruhe Institute of Technology (KIT)*
(C. Koos, P. Dietrich, M. Blaicher)

Lab: *KOOL Collaboration*
MPIA, ISYS Stuttgart, LSW

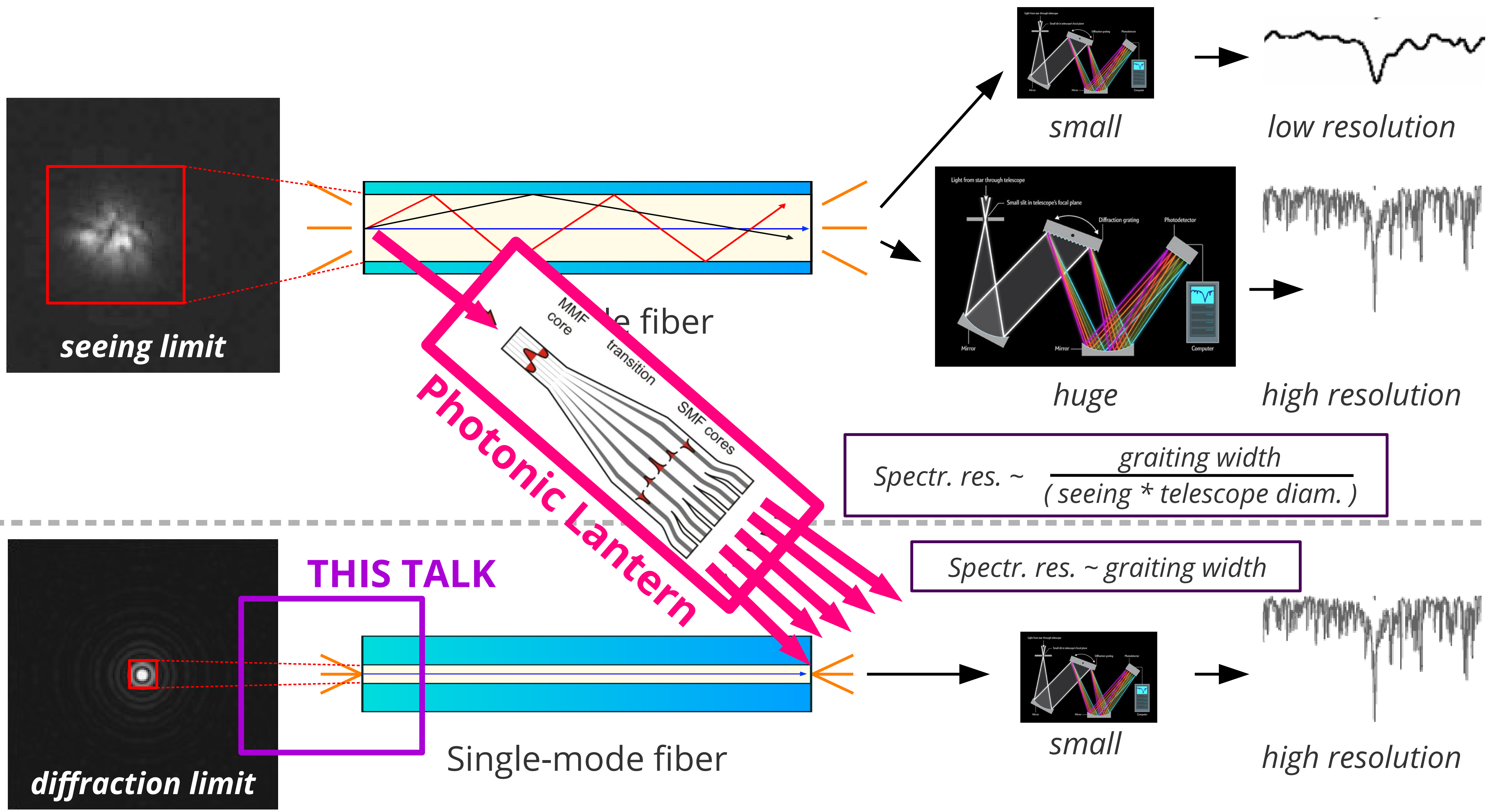
iLocater Spectrograph: *Notre-Dame*
(A. Bechter, J. Crass)



MLA on MCF
(Dietrich & Harris et al., 2017)

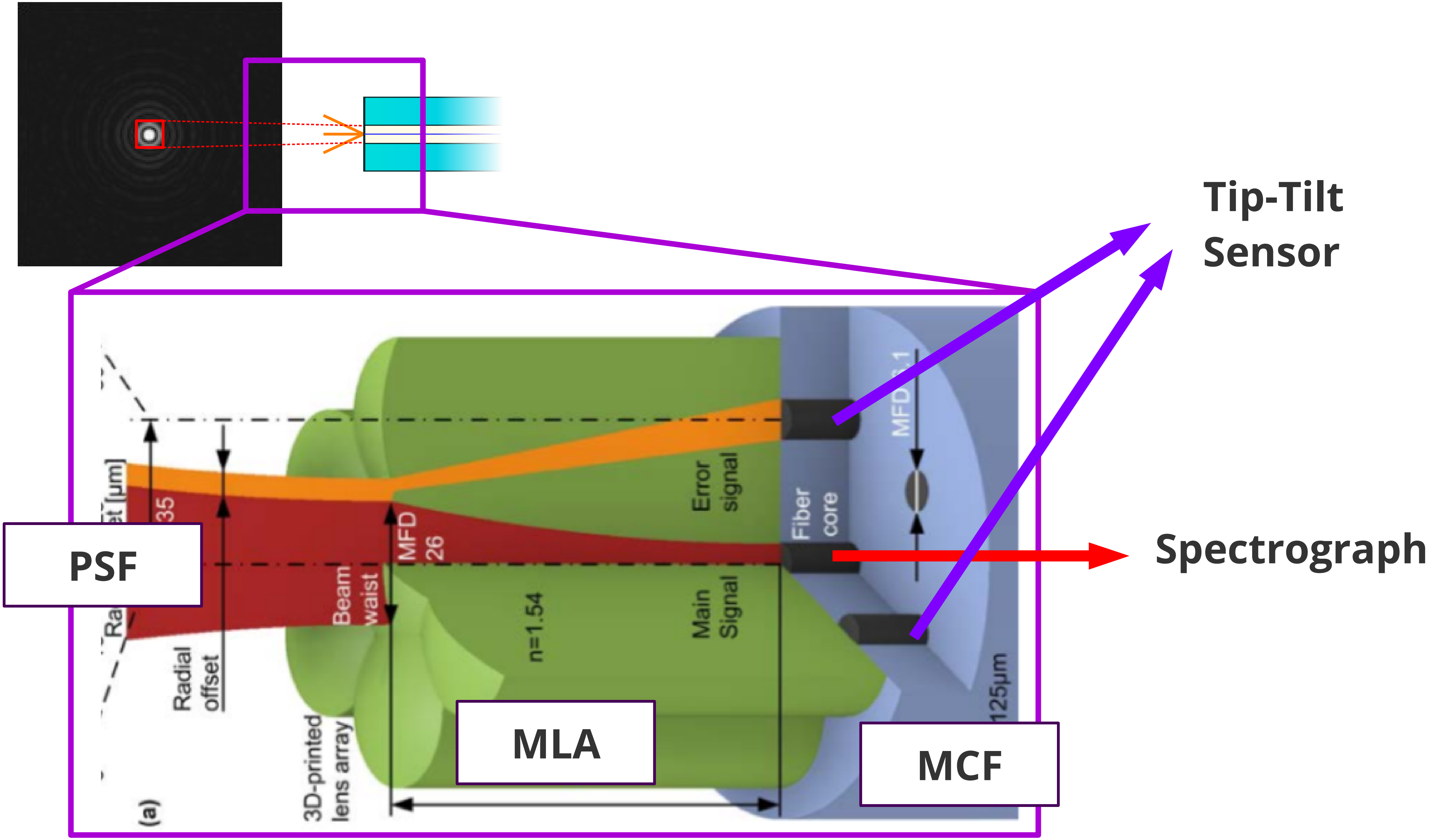
LSW Astrophotonics: Principles

PSF | **Light propagation** | **Spectrograph** | **Spectrum**



Credit: PSF: astrosurf.com/cavadore/optique/turbulence; Fiber: https://en.wikipedia.org/wiki/Optical_fiber, with modification; Lantern: Leon-Saval et al, 2005; Spectrograph: George Retseck, www.scientificamerican.com/article/ancient-stars-how-does-spectrograph-work; Spectra: Cincunegui & Mauas, 2014

Single-Mode Fiber Coupling with Tip-Tilt Sensor

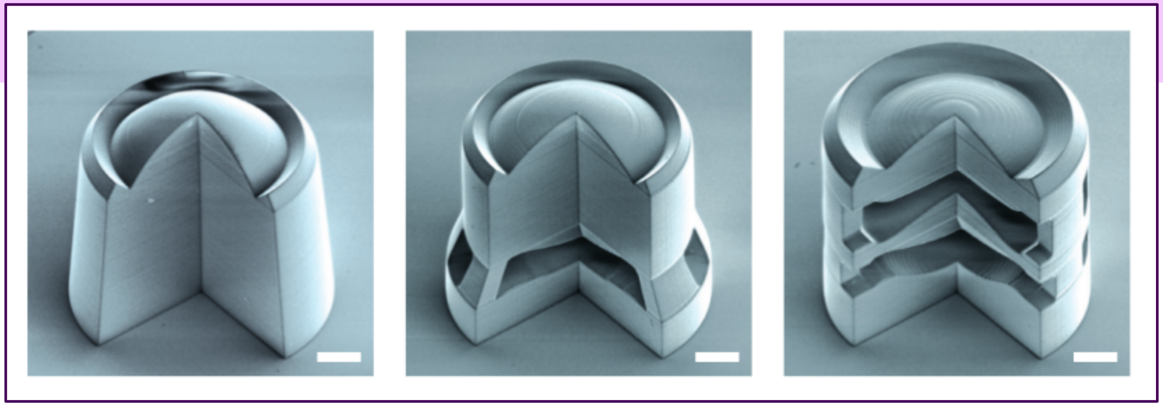


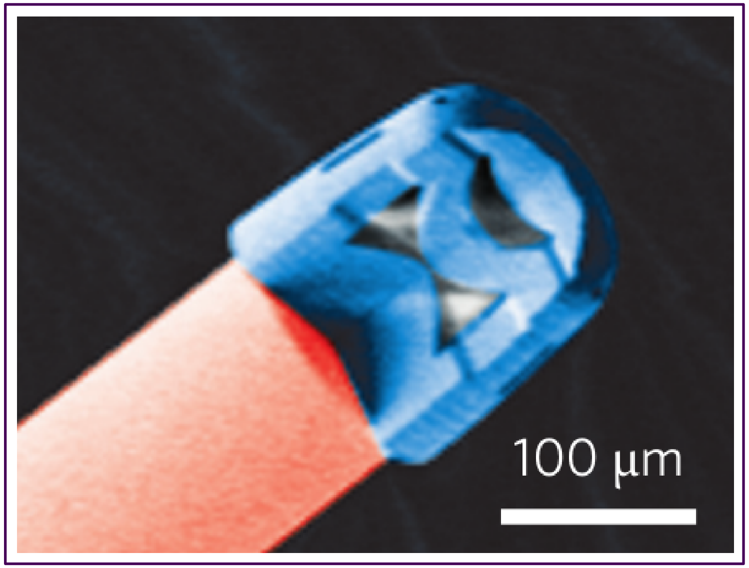
Outline

- **Introduction**
  - 3D-Printed Lenses
  - Microlens-Array as Tip-Tilt Sensor
- **Development**
- **Application**
- **Conclusion**

3D - Printing

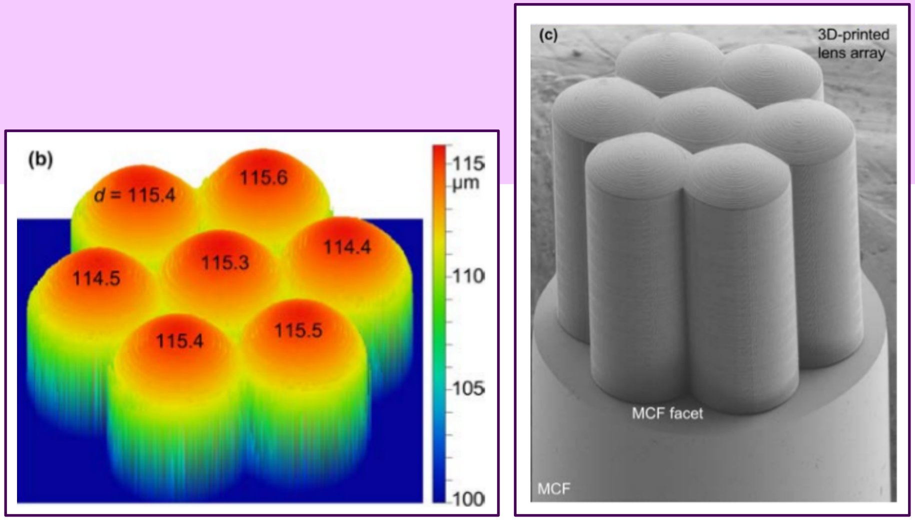
- 3D polymerization of commercial resist
- Two leading groups: Karlsruhe (KIT), Stuttgart (SCoPE)
- Printing directly on any structure
  → Good alignment & specialization
- Free-form printing, eg.
  - Singlets, doublets, triples
  - Microlens-array (MLA)
- Application: fiber coupling





Top: 3D printed singlet, doublet , triplet
Bottom: Triplet on SMF
(Gissibl et al., 2016)

MLA Prototype

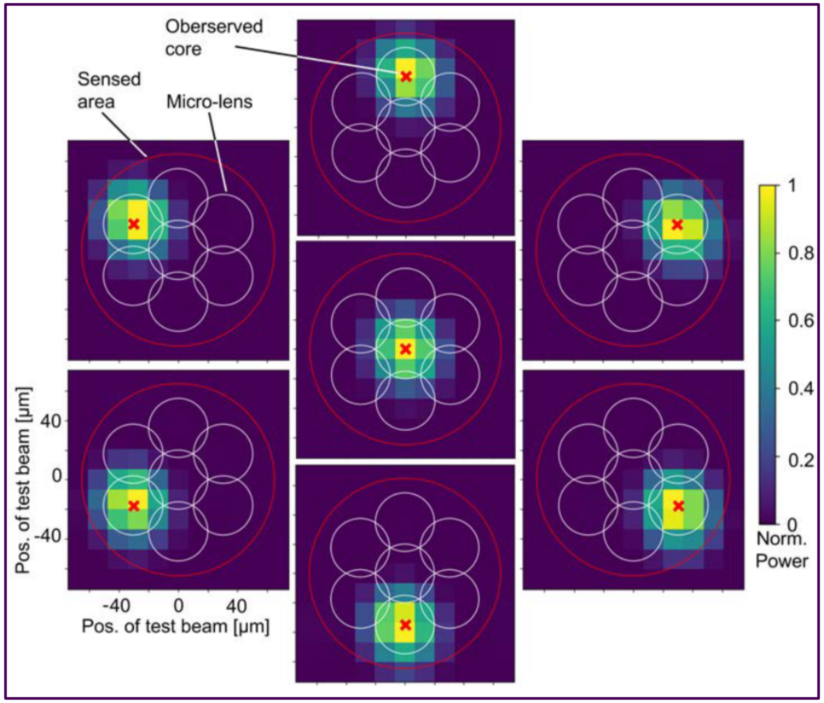


MLA on a MCF

Dietrich & Harris et al., 2017

- MLA printed on MCF
  - 7 SM cores, 35µm pitch
- First prototype device for demonstration
- First lab tests tests at 1.55µm
  - 73% coupling efficiency (21% loss due to cleaving)
- Suggestion: use as tip-tilt sensor & SMF coupling

→ **Further tests and optimization**

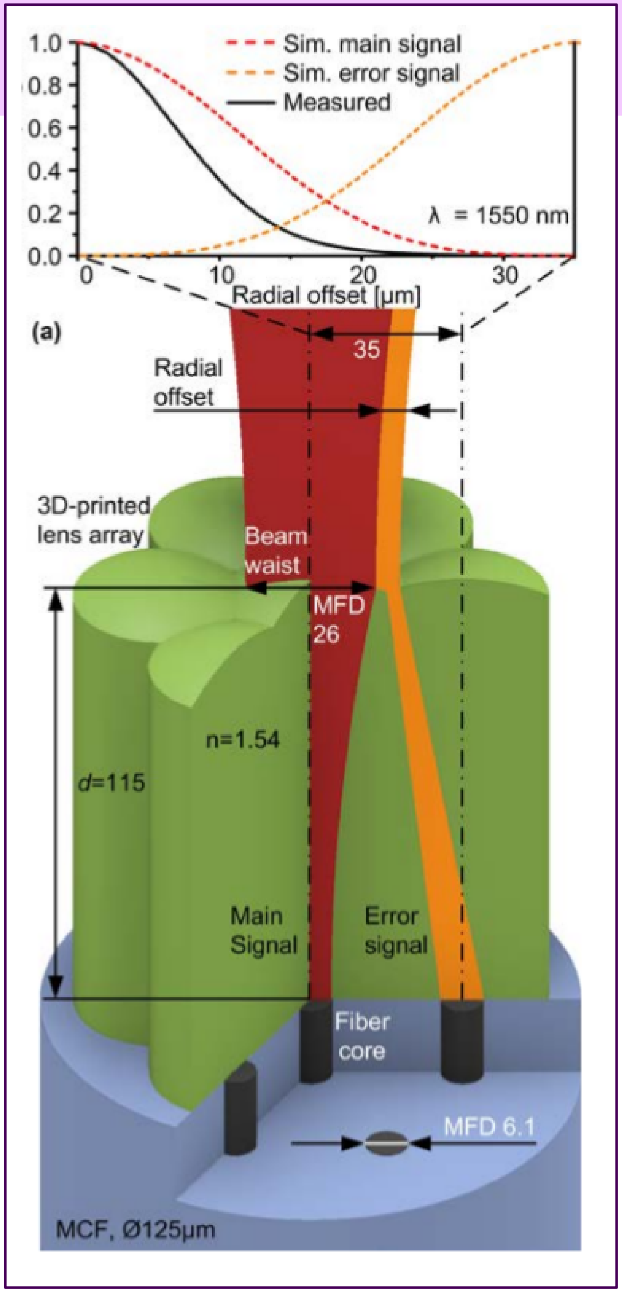


Coupling efficiency as function of beam position

MLA as Tip-Tilt Sensor

with integrated fiber coupling

- MLA printed on MCF
  - 7 SM cores, 35μm pitch
  - MLA design adjusted to actual core positions
  - Rigid alignment to cores
- Central "science" fiber
  - Feeding SM-spectrograph
- Outer sensor fibers
  - Read out by photometers
- When beam is aligned, all light goes through science fiber



Microlens array on a MCF
(Dietrich, Harris et al., 2017)

Advantages of Tip Tilt Sensor

Conventional options

- WFS of AO system
- Acceleration measurement (Martin Glück)
- Pinhole
- Separate CCD / quad-cell

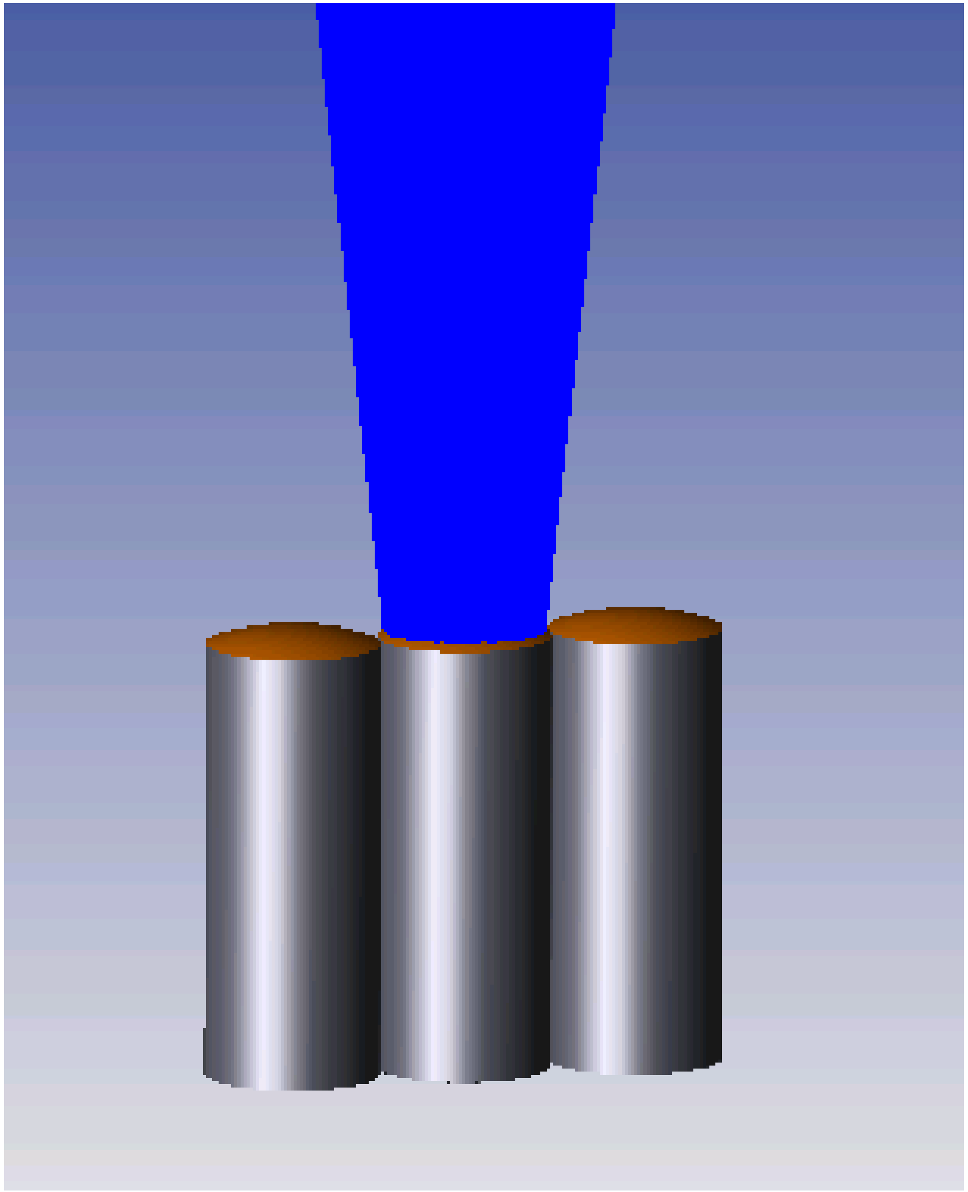
Why MLA?

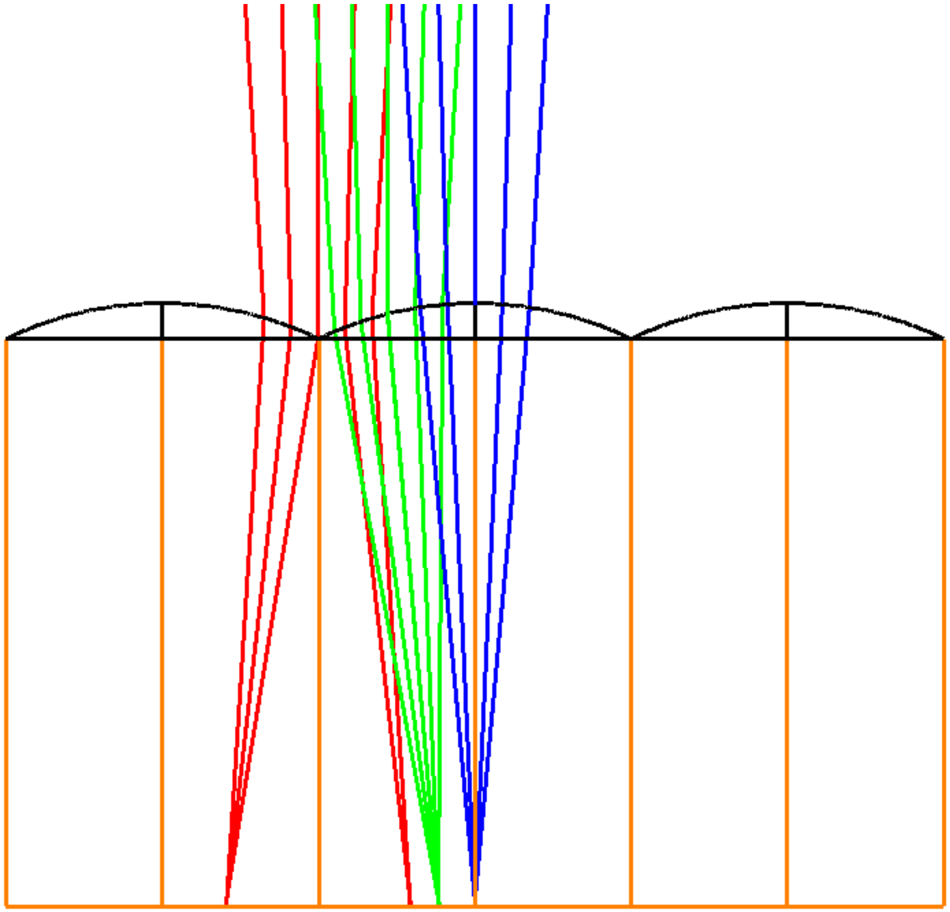
- Integrated alignment to SMF
- No additional losses
- Compact design
- Adjustable to requirements
  - imperfections of system
  - flexibility in design
- Increase coupling tolerances

Outline

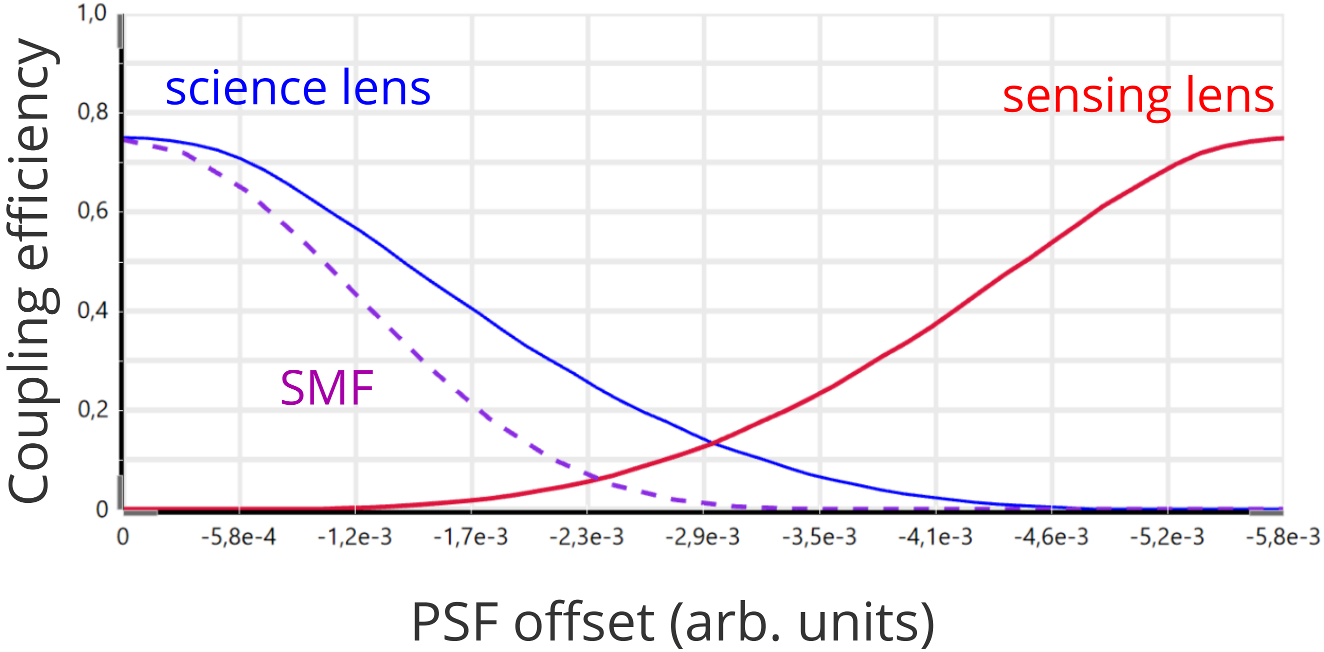
- **Introduction**
- **Development**
  - Optimization & Design
    - Modeling
    - Finding Suitable MCF
  - Testing & Characterization
    - at KOOL Laboratory
- **Application**
  - *iLocater Spectrograph at LBT*
- **Conclusion**

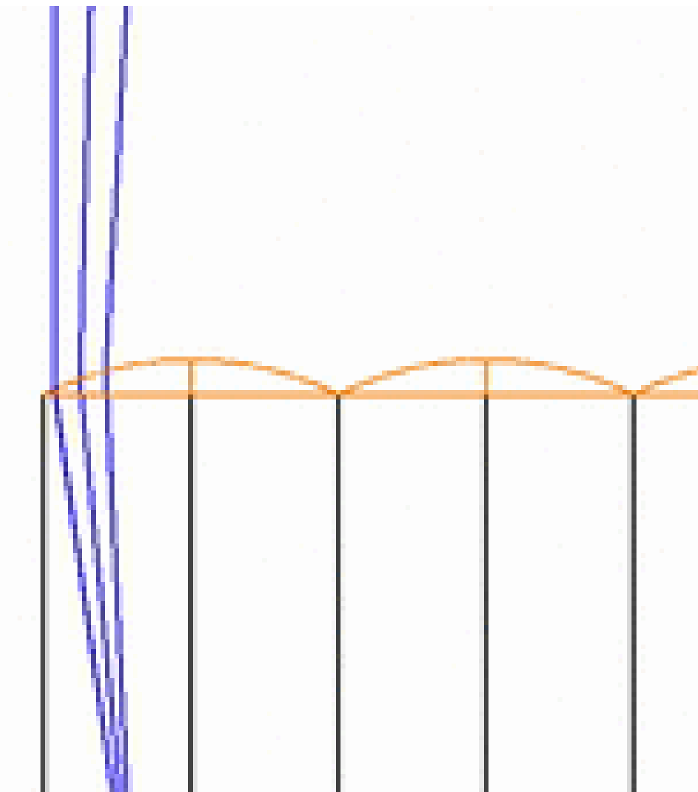
Modeling: Zemax





Modeling: Zemax





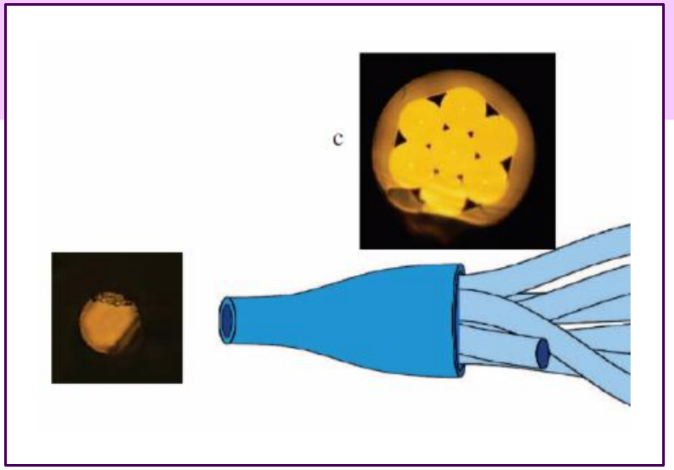
Multi-Core Fiber

Requirements

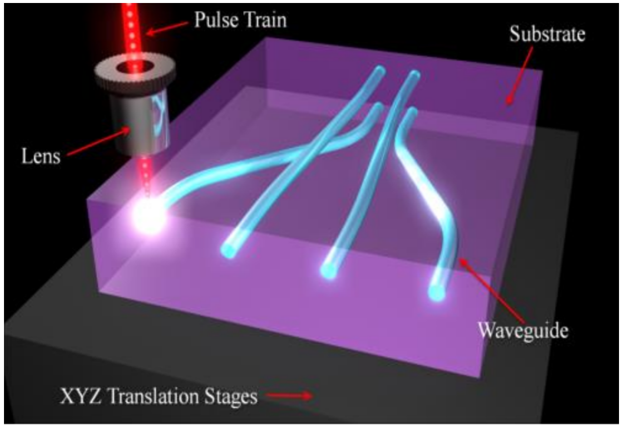
- Central specialized SM science fiber
- Fibers need to be accessed separately
- Small pitch between cores
- No (little) coupling between fibers
- Additional outer (back-illuminated) alignment fibers?

Options

- Fiber bundle
  - Etch away cladding → Coupling?
- MCF with reformatter
  - Loss at reformatter?



Fiber bundle
(Yerolatsitis et al., 2016)



Ultrafast laser inscription of waveguides as reformatter
(Birks et al., 2015)

Lab: KOOL Collaboration

Königstuhl Observatory Opto-mechatronics Laboratory

- Adaptive optics testbed
- New collaboration
  - **MPIA**: Jörg-Uwe Pott
  - **Institute for System Dynamics Stuttgart (ISYS)**: O. Savodny, Martin Glück
  - **LSW**: A. Quirrenbach, Rob Harris, Philipp Hottinger

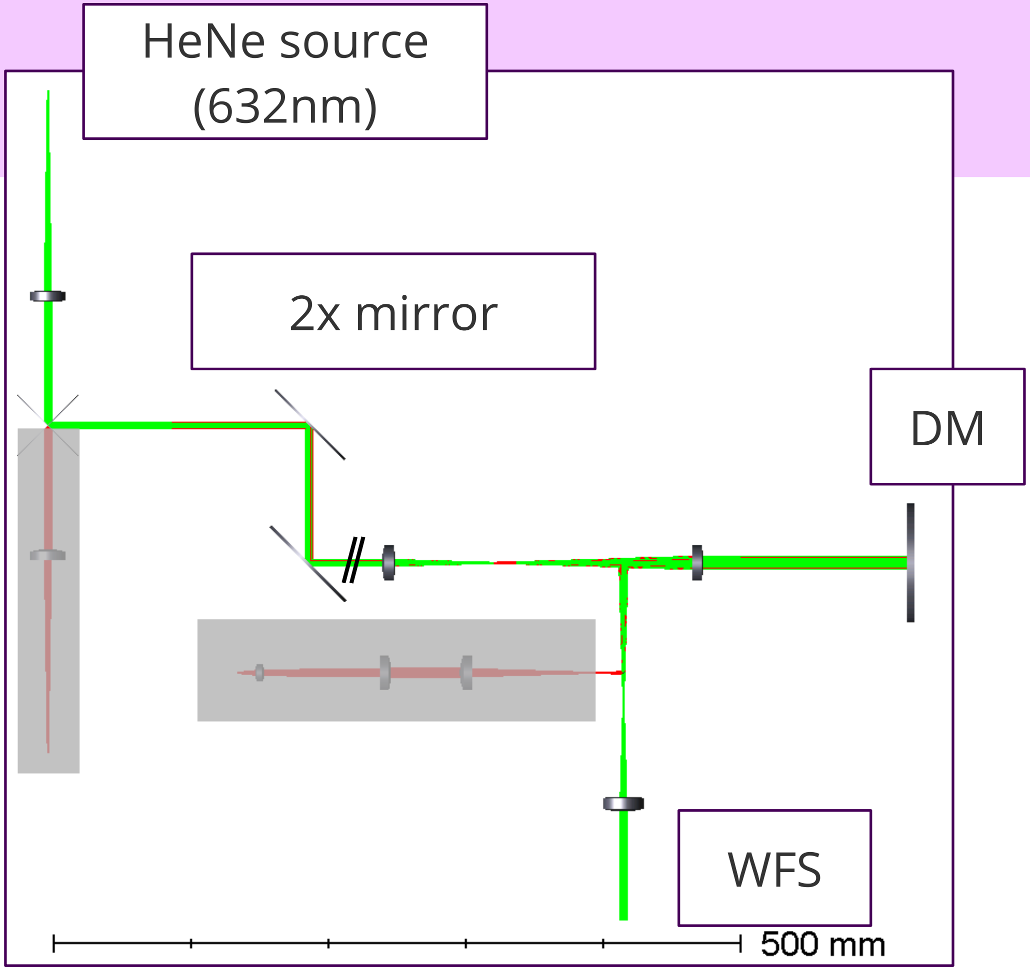
KOOL: Testbed

Components

- Vibration mirror
- Tip-tilt mirror
- DM (and WFS)
- Can all be used for injecting and correcting disturbances

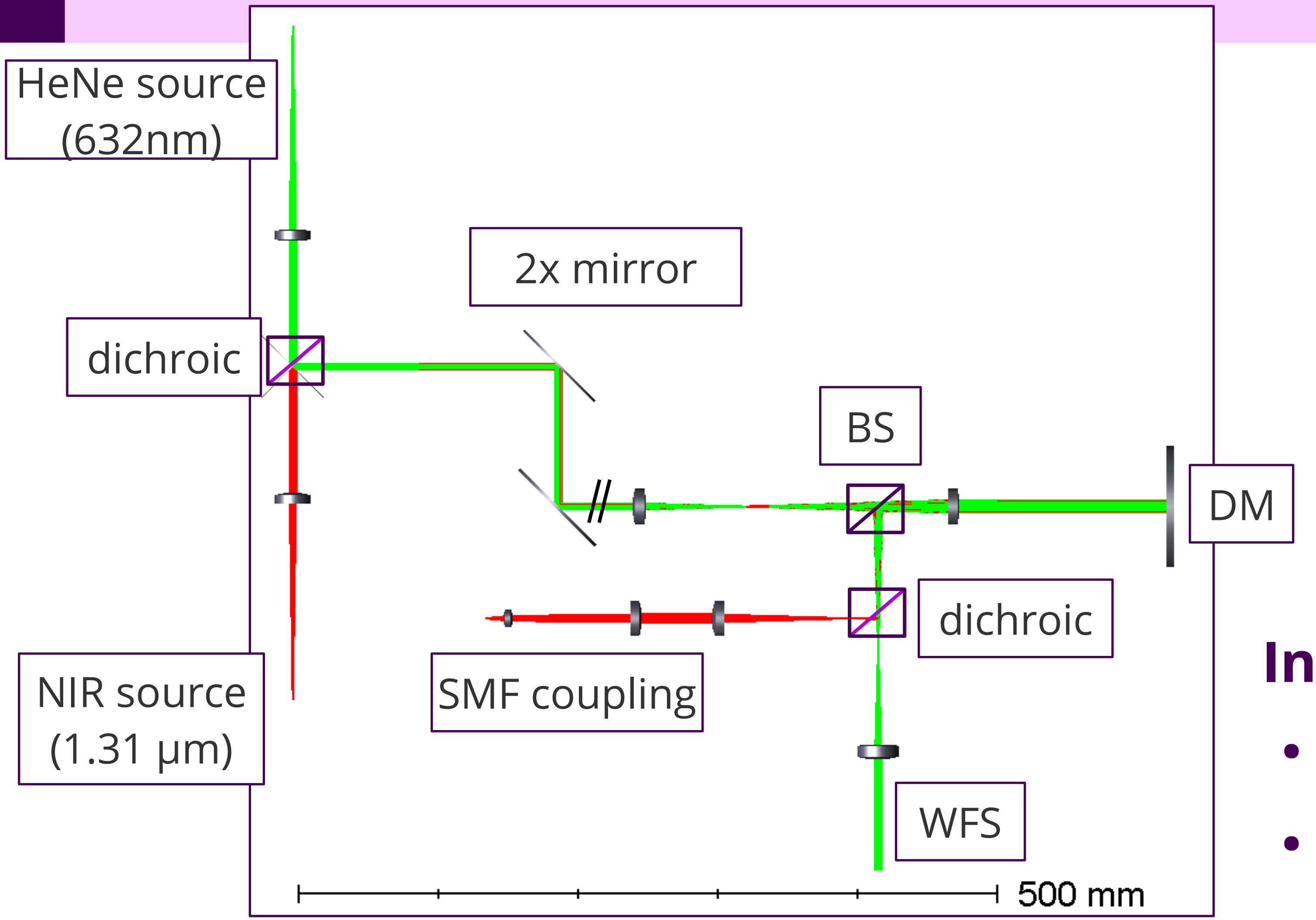
Setup from Martin Glück:

- *LBT vibration simulation*
- Sensing of vibrations with accelerators
- 632nm (HeNe) fiber-fed source



KOOL: Optical setup
(Zemax model)

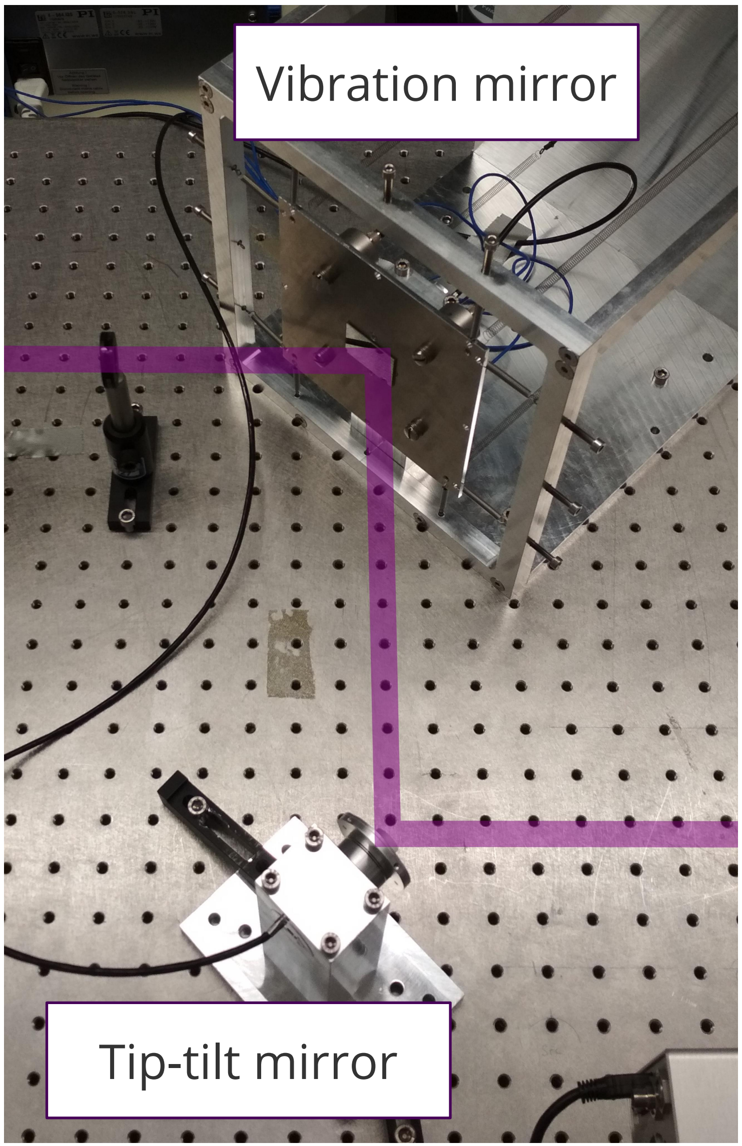
KOOL: Zemax Model

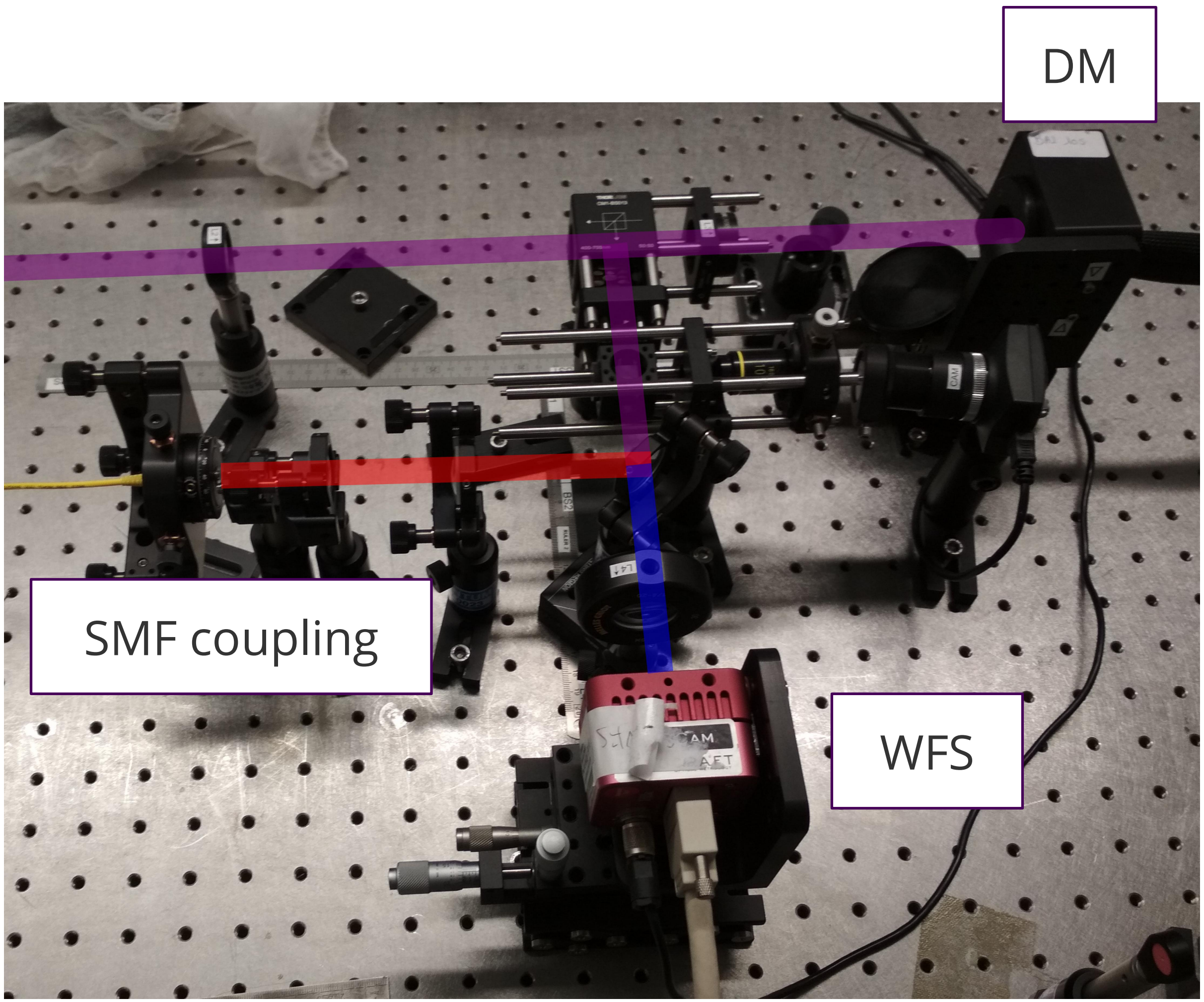


Including MLA

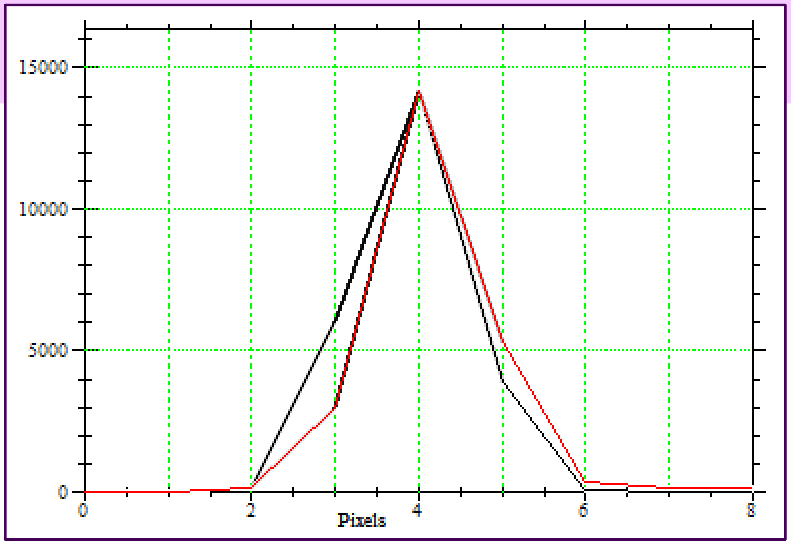
- 1310nm source
- DM introducing telescope realistic abberations

KOOL Lab Setup





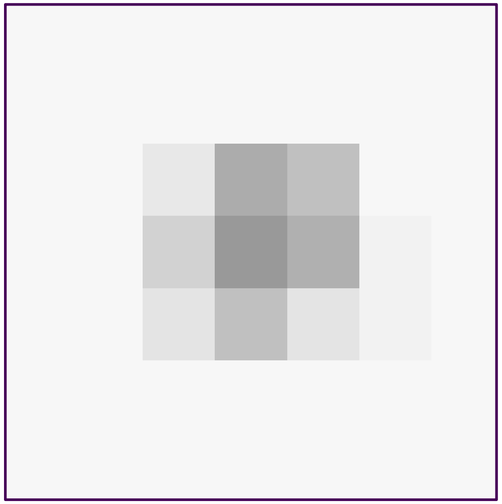
Lab: First Results



PSF cross section

Challenges

- System efficiency< 0.1%
  - 3x lenses,
    2x beamsplitter,
    2x mirrors
- Achromaticity
- Different conjugate planes



Preliminary PSF
at fiber coupling plane

Next steps:

- SMF coupling
- WFS-less optimization

Outline

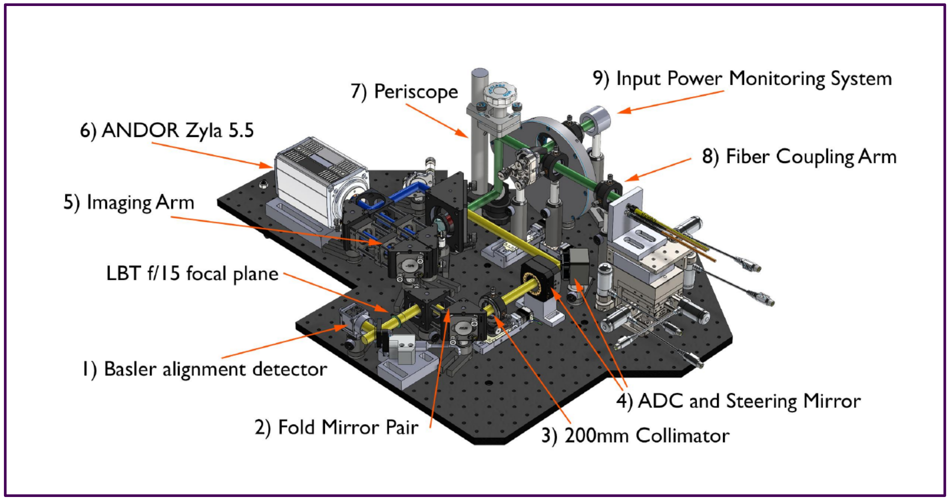
- **Introduction**
- **Development**
- **Application**
  - iLocater Spectrograph at LBT
  - Outlook
- **Conclusion**

iLocater Spectrograph

J. Crass & A. Bechter at Nodre-Dame

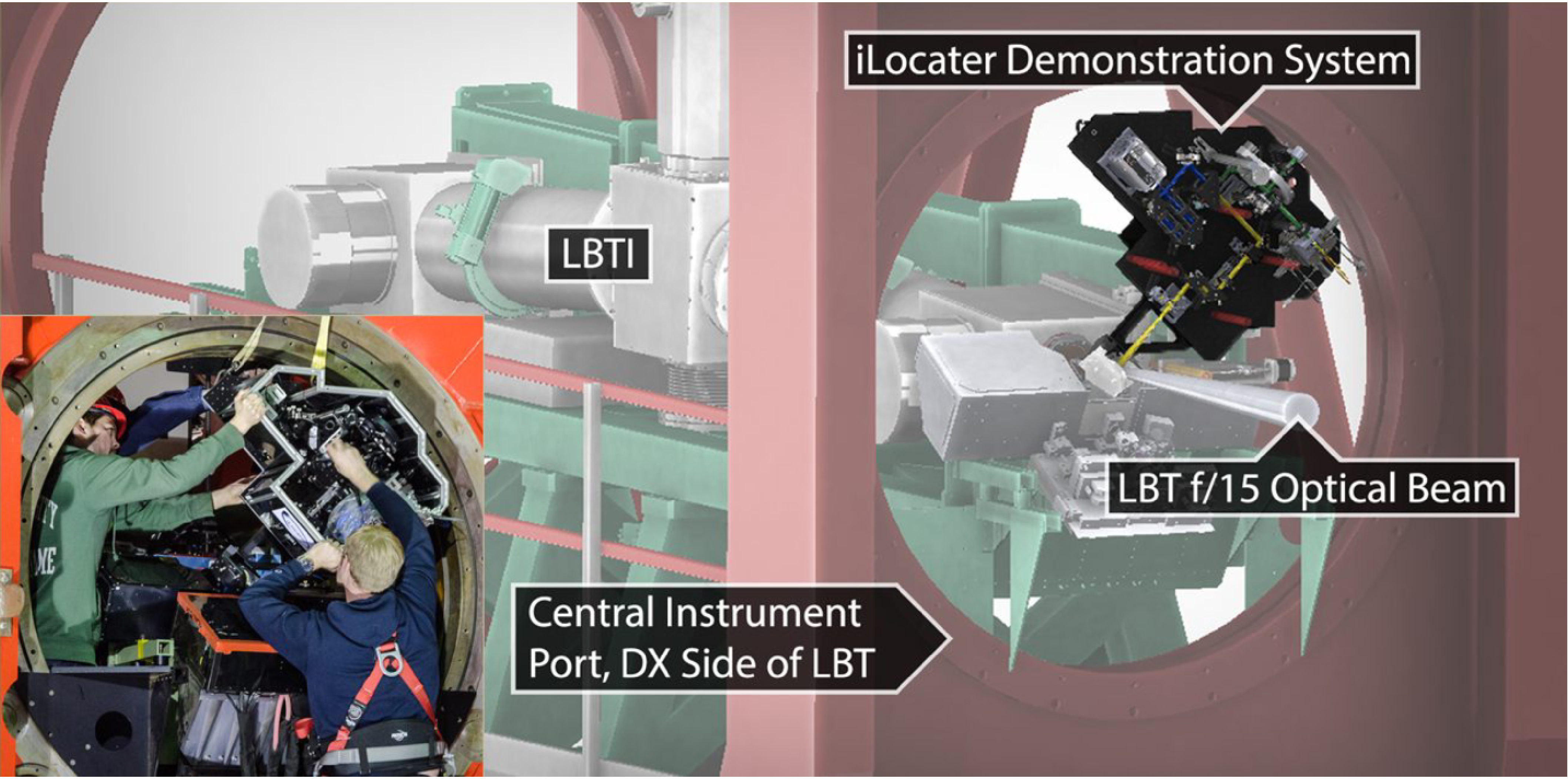
(infrared Large Binocular Telescope exoplanet reconnaissance)

- LBTI AO working at diffraction limit in NIR
- SM-fed spectrograph
- Possibilities to test (astro-)photonic devices
- Y- and J-Band (0.97µm-1.31µm)
- R ~ 150,000-260,000



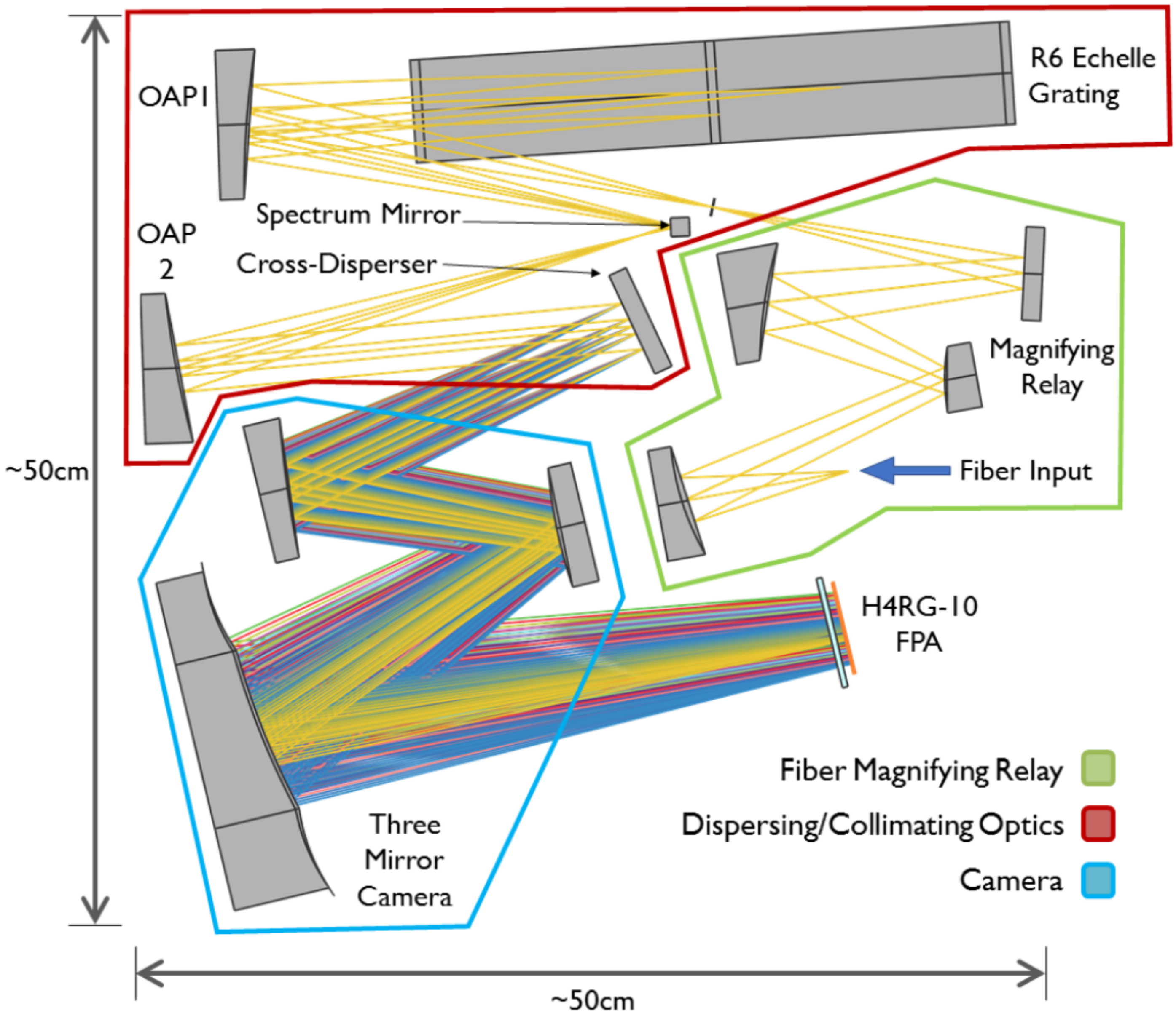
iLocater fiber coupling prototype design *(Bechter et al., 2016)*

iLocater: Fiber Coupling



iLocater fiber coupling prototype at LBTI
(Bechter et al., 2016)

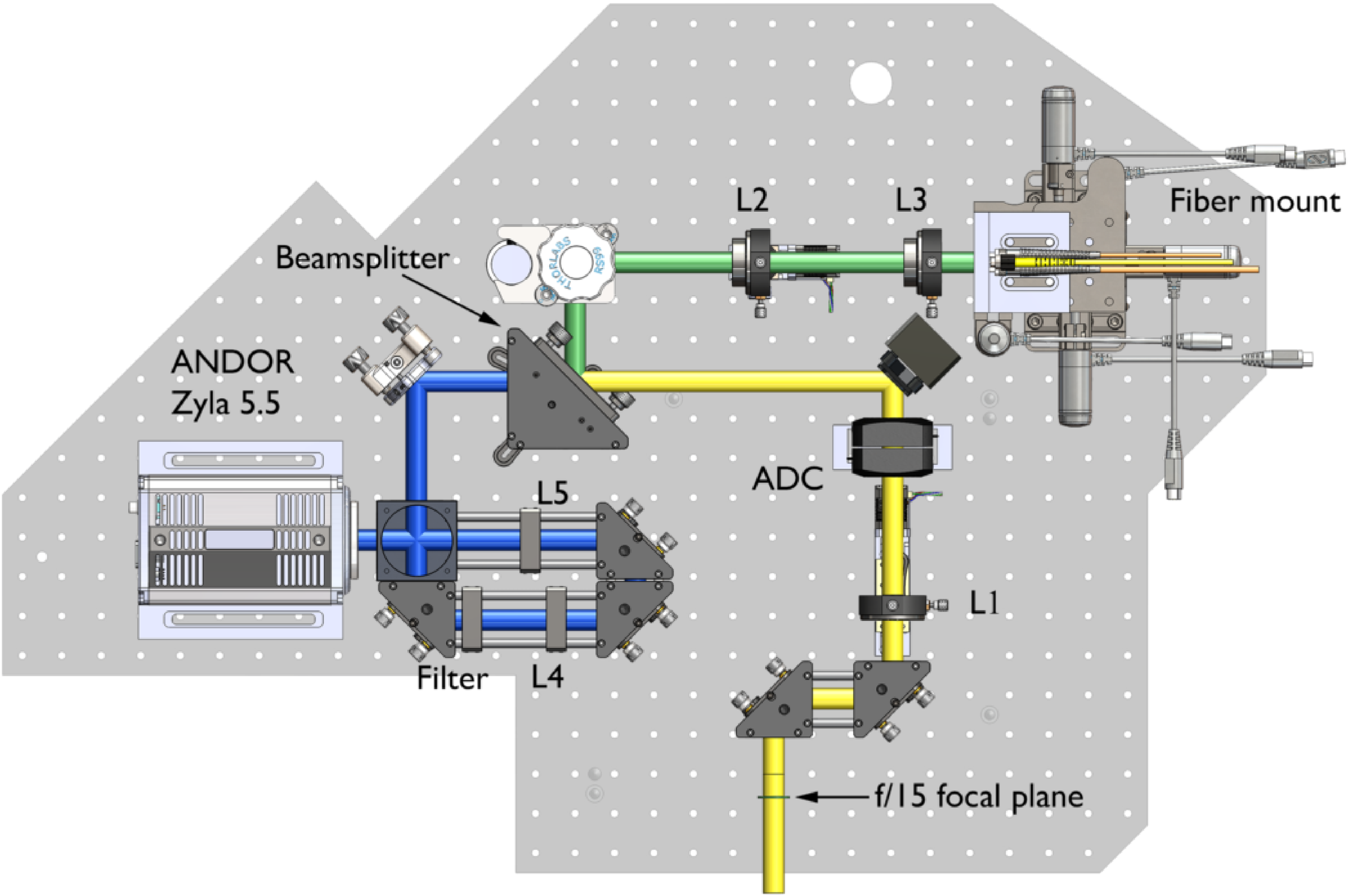
iLocater Spectrograph: Fiber Coupling



iLocater spectrograph design

(Crepp et al., 2016)

iLocater: Fiber Coupling



early iLocater fiber coupling prototype design

(Bechter et al., 2015)

LBT Vibrations

- Diffraction limited PSF
- But tip-tilt motions
  → Difficult to couple into SMF
- Current idea: use quad cell for tip-tilt sensing

On-sky testing of an optimized MLA next year

LBT vibrations at iLocater
(J.Crass / A.Bechter)

Outlook

On-sky testing of an optimized MLA next year

testing → optimizing → final design → on-sky testing

Other applications with MLA on MCF

- IFU Spectrograph
- Photonic lantern alternative
  (coupling diffr. limited PSF into several SMFs)
- etc.

Recap & Conclusion

- 3D-printed MLA as tip-tilt sensor
- Ongoing designing
- Testing & characterization
  - KOOL testbench
- On-sky testing at iLocater spectrograph

Credits and References

in order of appearance

MLA on MCF: Dietrich & Harris et al., 2017 [Dietrich, P.-I., Harris, R. J., Blaicher, M., Corrigan, M. K., Morris, T. J., Freude, W., … Koos, C. (2017). Printed freeform lens arrays on multi-core fibers for highly efficient coupling in astrophotonic systems. Optics Express, 25(15), 18288. https://doi.org/10.1364/OE.25.018288]

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Spectrograph: George Retseck [accessed on 22.11.2017 at https://www.scientificamerican.com/media/inline/ancient-stars-how-does-spectrograph-work_2.jpg]

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iLocater spectrograph design: Crepp et al., 2016 [Crepp, J. R., Crass, J., King, D., Bechter, A., Bechter, E., Ketterer, R., … Zhao, B. (2016). iLocater: a diffraction-limited Doppler spectrometer for the Large Binocular Telescope. In C. J. Evans, L. Simard, & H. Takami (Eds.) (p. 990819). https://doi.org/10.1117/12.2233135]

Early iLocator fiber coupling prototype design: Bechter et al., 2015 [Bechter, A., Crass, J., Ketterer, R., Crepp, J. R., King, D., Zhao, B., … Bechter, E. (2015). Design of the iLocater acquisition camera demonstration system. In S. Shaklan (Ed.), Proc. of SPIE 9605 (Vol. 9605, p. 96051U). https://doi.org/10.1117/12.2188426]

LBT vibrations at iLocater: J.Crass / A.Bechter, with permission