Fiber Optics in Astronomy

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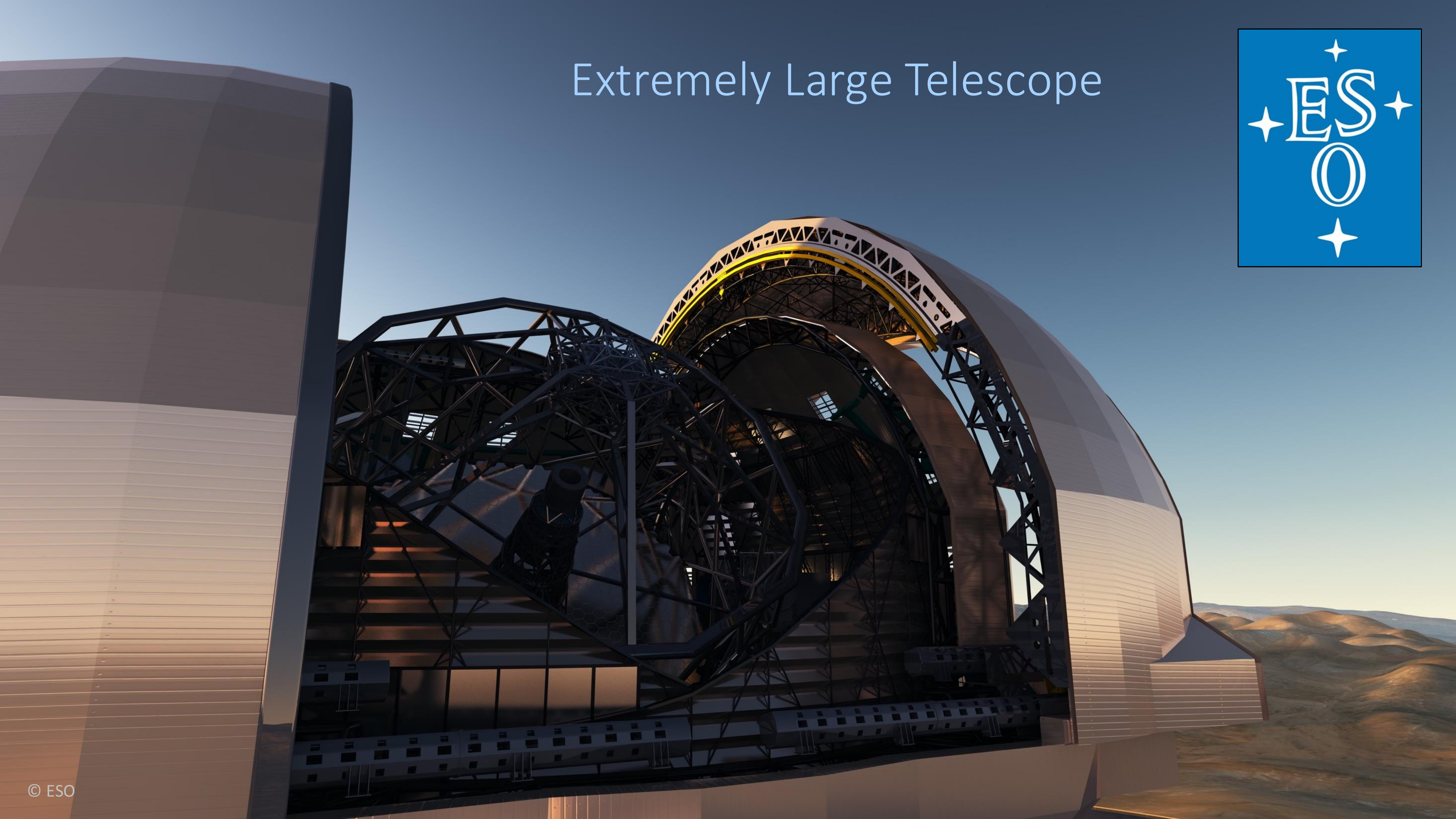
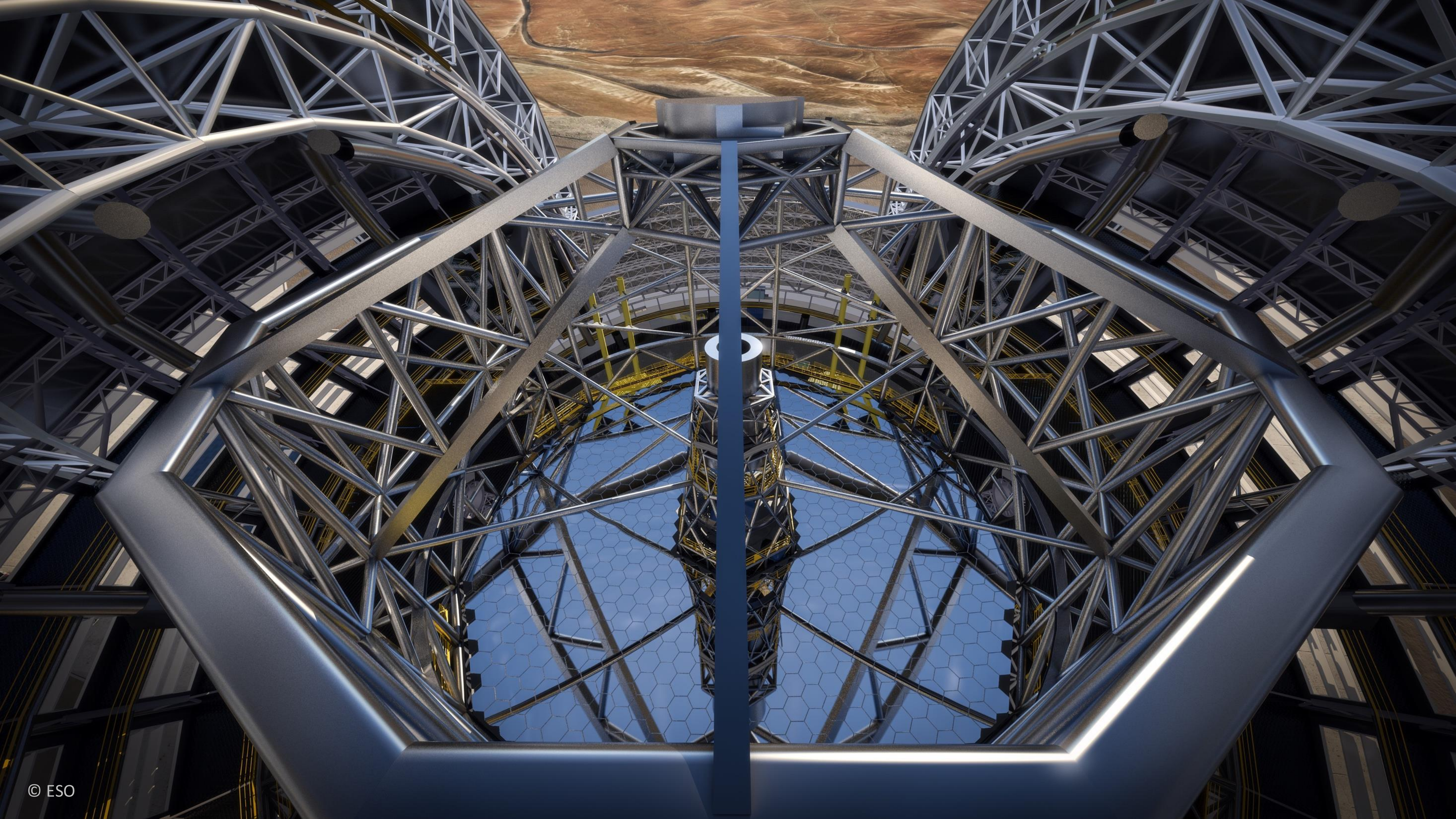
Overview:

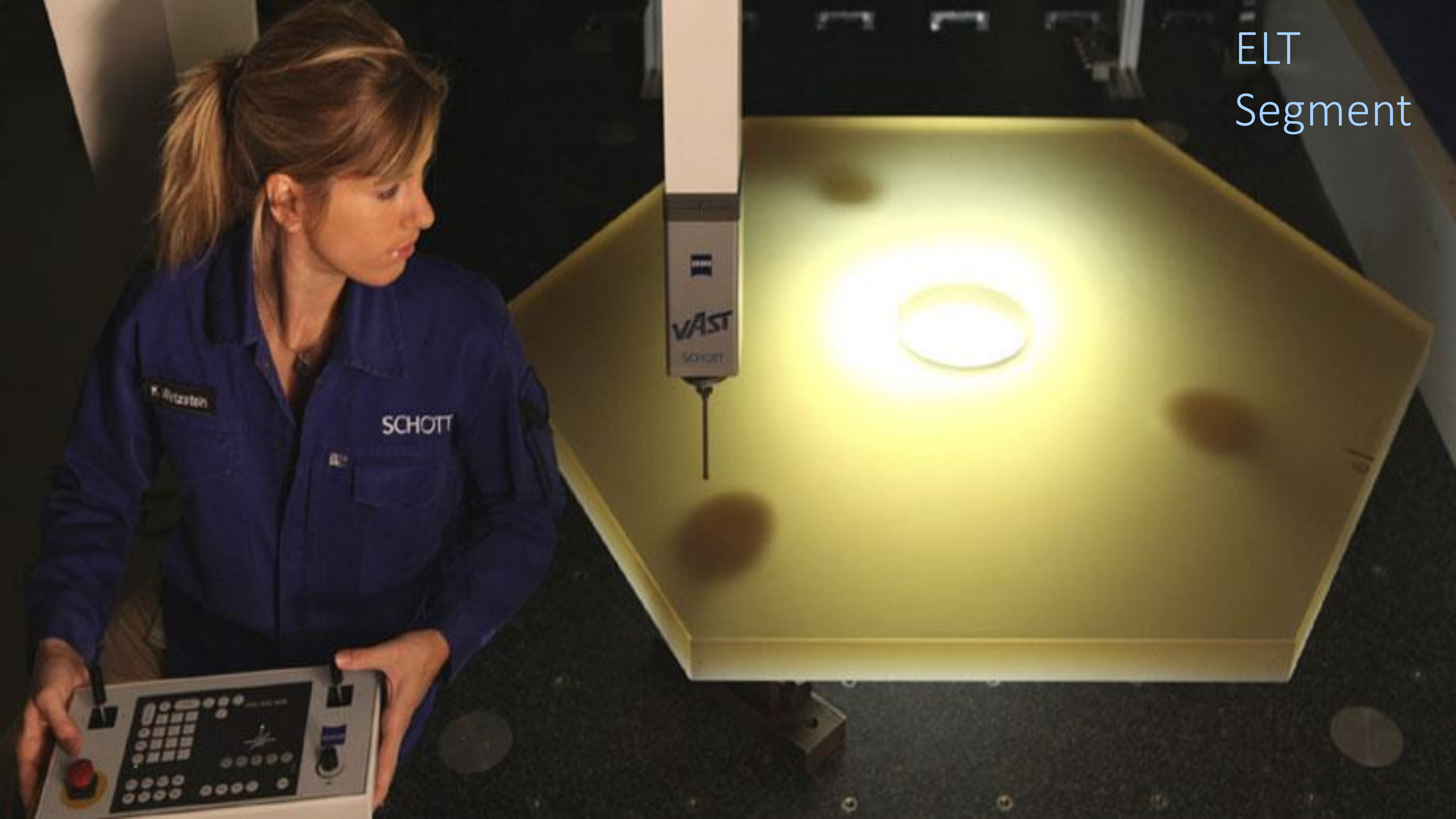
- Instrumentation for Astrophysics
- Intro: Optical Fibers in Astronomy
- Applications
  - High Resolution Spectroscopy
  - Multi-Object Spectroscopy
  - Integral Field Spectroscopy
- Technology Transfer
- Astrophotonics
- Summary

Extremely Large Telescope

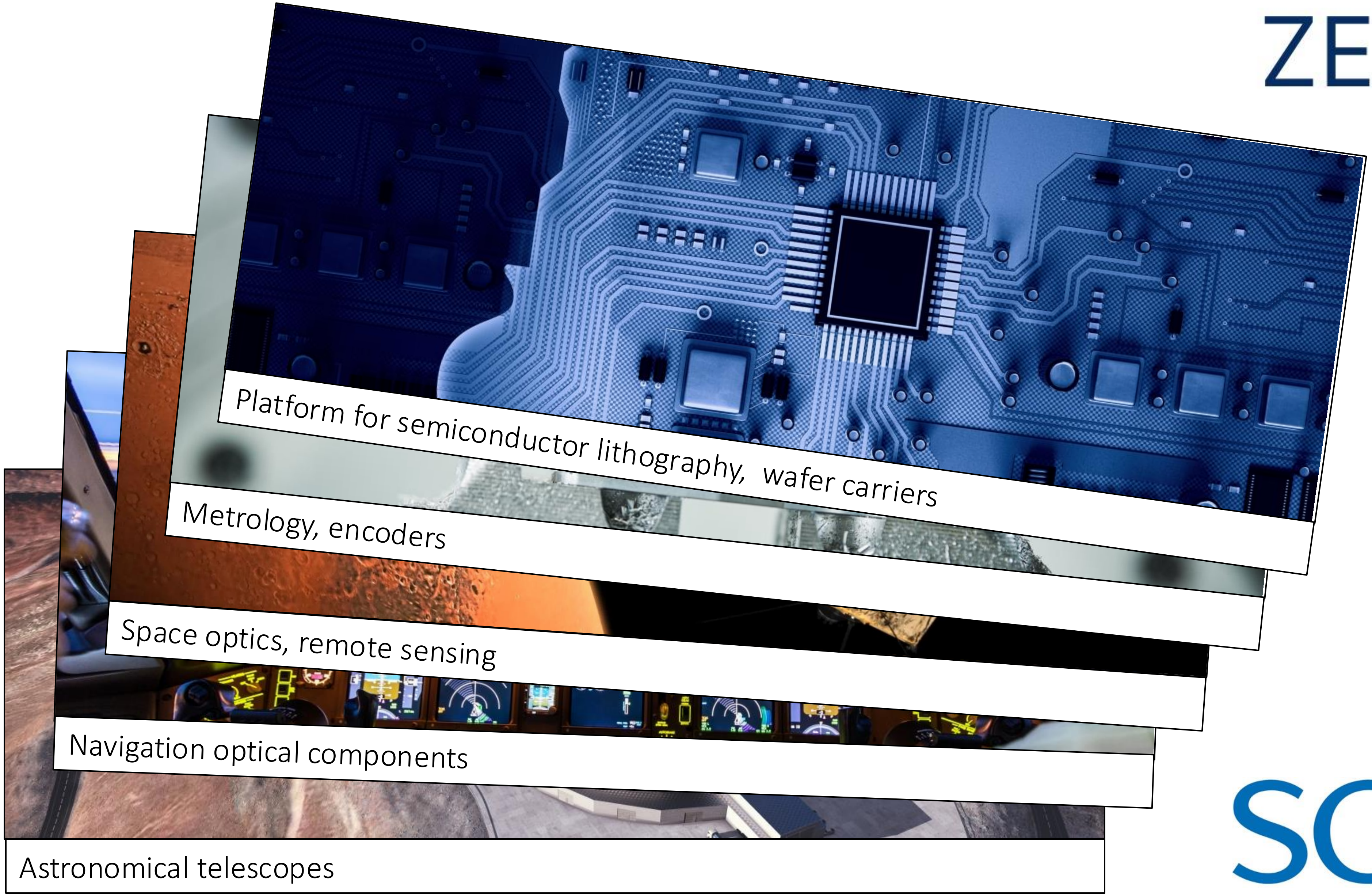




ELT Segment

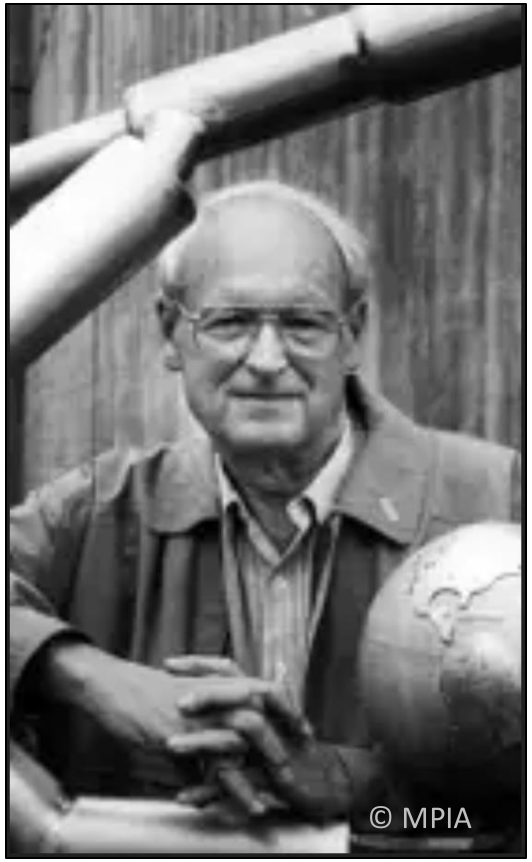


ZERODUR®



SCHOTT

https://www.schott.com/de-de/products/zerodur-p1000269/applications



Hans Elsässer
(1929 – 2003)

ABOUT CONFERENCES + EXHIBITIONS PUBLICATIONS MEMBERSHIP INDUSTRY RESOURCES EDUCATION NEWS

SPIE. The international society for optics and photonics

Low-expansion glass for telescopes

50 years of Zerodur milestones

04 April 2018 Marcus Woo Technology

For a telescope to compete with the world's best, in 1966 Hans Elsässer, director of the observatory at the University of Heidelberg, sought the help of German glass company Schott. Could they, he asked, fabricate a 4-meter telescope mirror? Schott had recently started working with a new class of promising materials called ceramic glass, which S. Donald Stookey of Corning had invented in 1957. It's now a common material found in casserole dishes and other cookware.

After a couple of years, Schott came up with the right ceramic glass for telescope mirrors, and called it Zerodur. In 1968, the company agreed to build a 3.6-meter mirror blank and several smaller mirrors for the Max Planck Institute of Astronomy's Calar Alto Observatory in southern Spain.

Technology transfer from fundamental research to Industry

WLAN (Radio Astronomy)

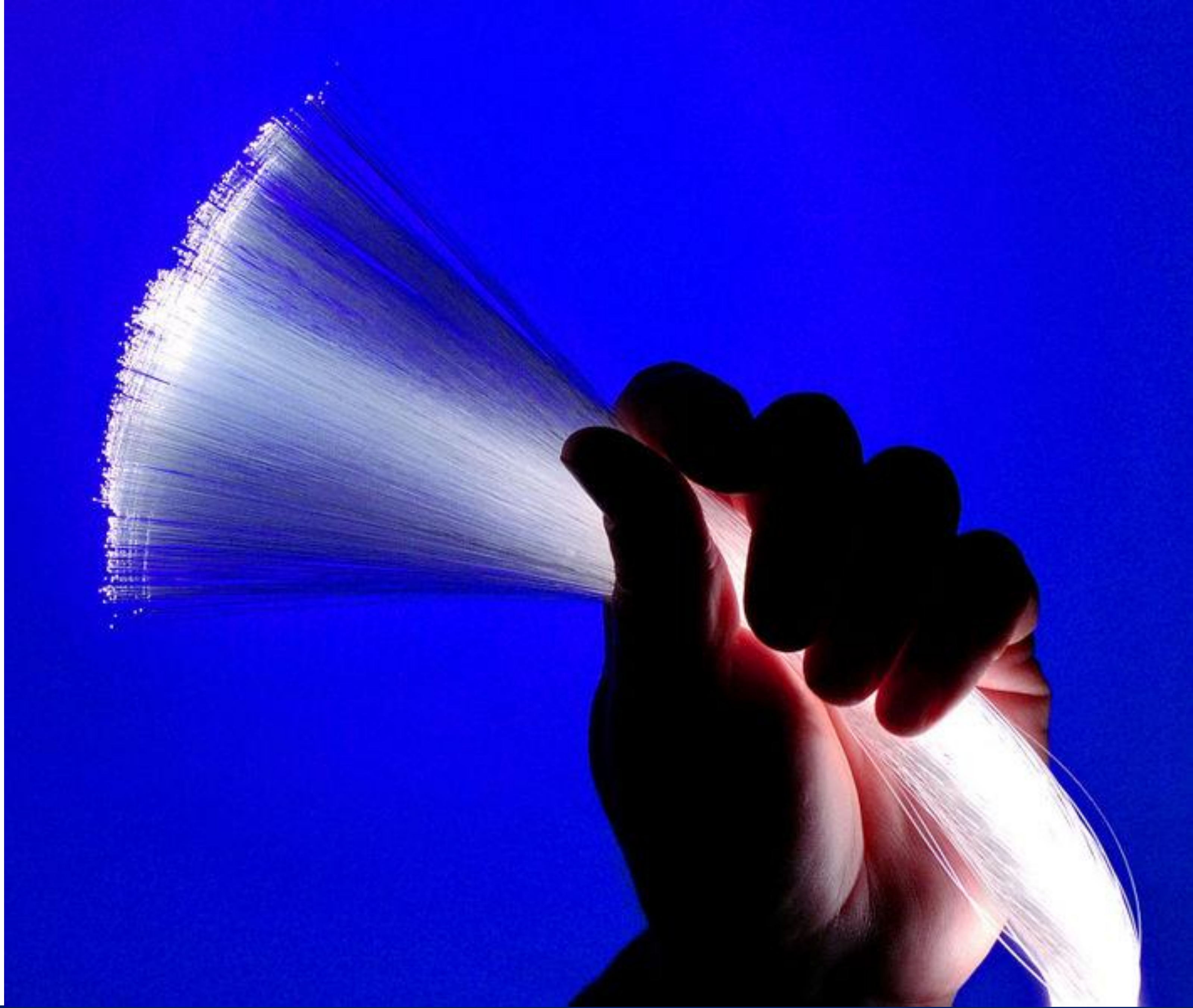
Adaptive Optics (NIR Astronomy)

CMOS Sensor (Optical Astronomy)

CERAN panels (Optical Astronomy)

EUV Optics (Xray Astronomy)

Optical Fibers in Astronomy



Wave Optics

Maxwell Equations

$$\nabla \cdot \mathbf{D} = \rho$$

Gauß' law

$$\nabla \cdot \mathbf{B} = 0$$

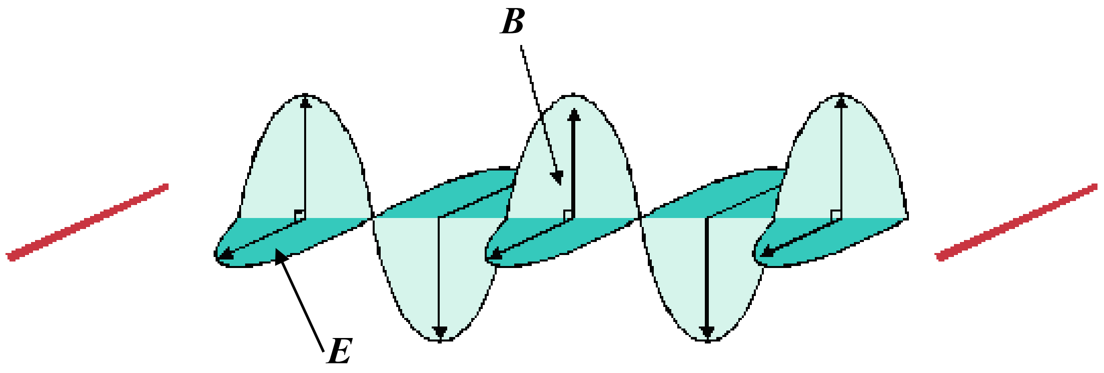
Gauß' law for magnetic field

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Law of induction

$$\nabla \times \mathbf{H} = \mathbf{j} + \frac{\partial \mathbf{D}}{\partial t}$$

Law of magnetic flux



→ Wave Equation

$$\mathbf{B} = \mu_o \mu_r \mathbf{H}$$
$$\mathbf{D} = \varepsilon_o \varepsilon_r \mathbf{E}$$

B: magnetic flux density, ***H***: magnetic field

D: elektrical flux density, ***E***: elektrical field

Helmholtz Equation

$$\nabla^2 \mathbf{E}(\mathbf{r}) e^{i\omega t} - \mu\epsilon\omega^2 \mathbf{E}(\mathbf{r}) e^{i\omega t} = 0$$

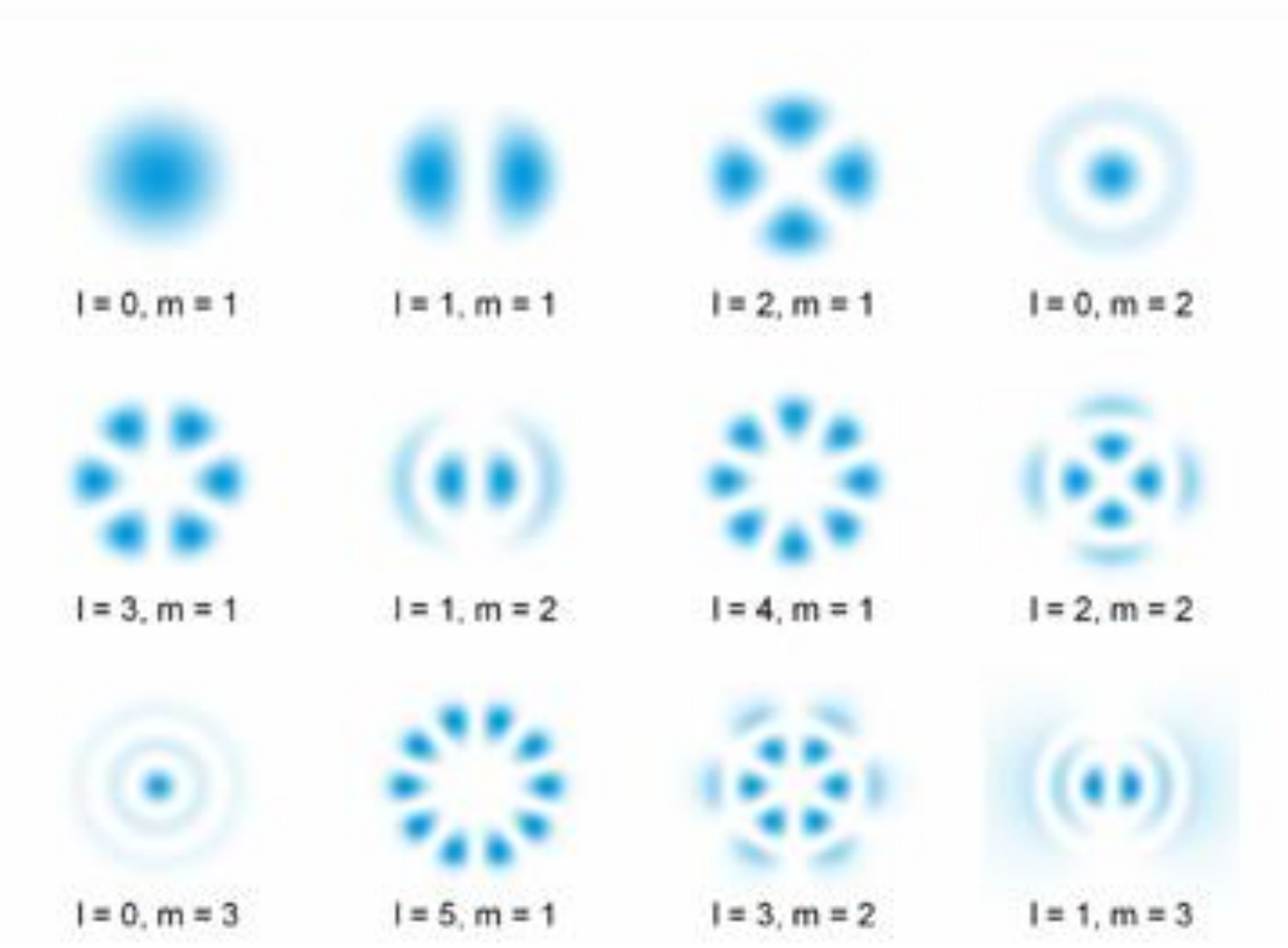
$$n = \sqrt{\mu\epsilon}$$] Index of refraction

$$\nabla^2 \mathbf{E}(\mathbf{r}) e^{i\omega t} - n^2 k^2 \mathbf{E}(\mathbf{r}) e^{i\omega t} = 0$$

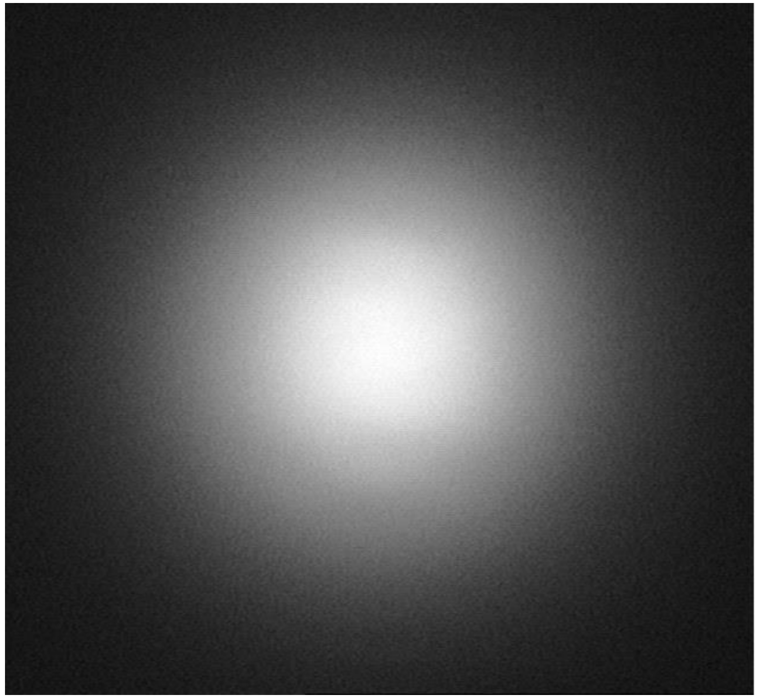
analogous for H field:

$$\nabla^2 \mathbf{H}(\mathbf{r}) e^{i\omega t} - n^2 k^2 \mathbf{H}(\mathbf{r}) e^{i\omega t} = 0$$

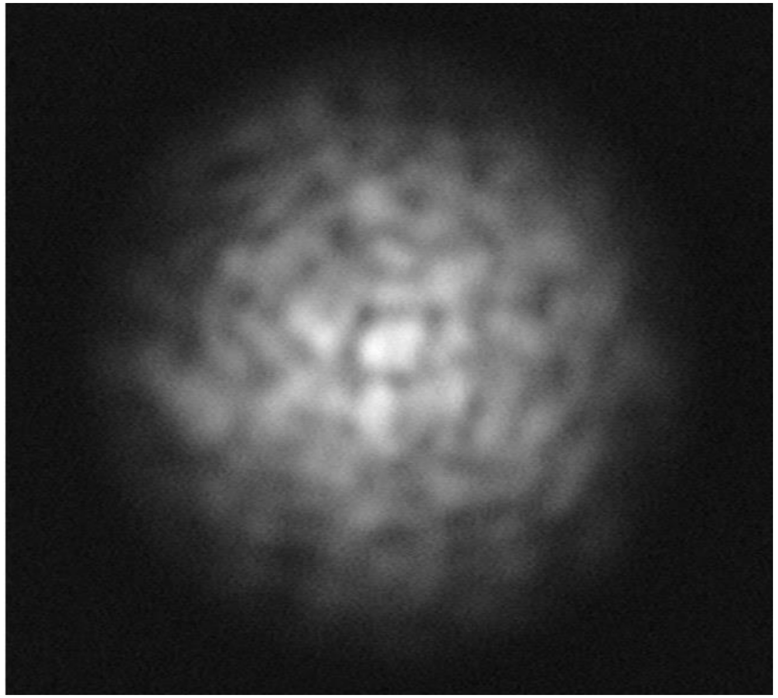
Guided Modes



Guided Modes



Single Mode Fiber (SMF)



Multi Mode Fiber (MMF)

THE ASTROPHYSICAL JOURNAL, **218**:776–782, 1977 December 15

A VERY LARGE OPTICAL TELESCOPE ARRAY LINKED WITH FUSED SILICA FIBERS

J. R. P. ANGEL, M. T. ADAMS, T. A. BOROSON, AND R. L. MOORE
Steward Observatory, University of Arizona
Received 1977 April 15; accepted 1977 June 10

ABSTRACT

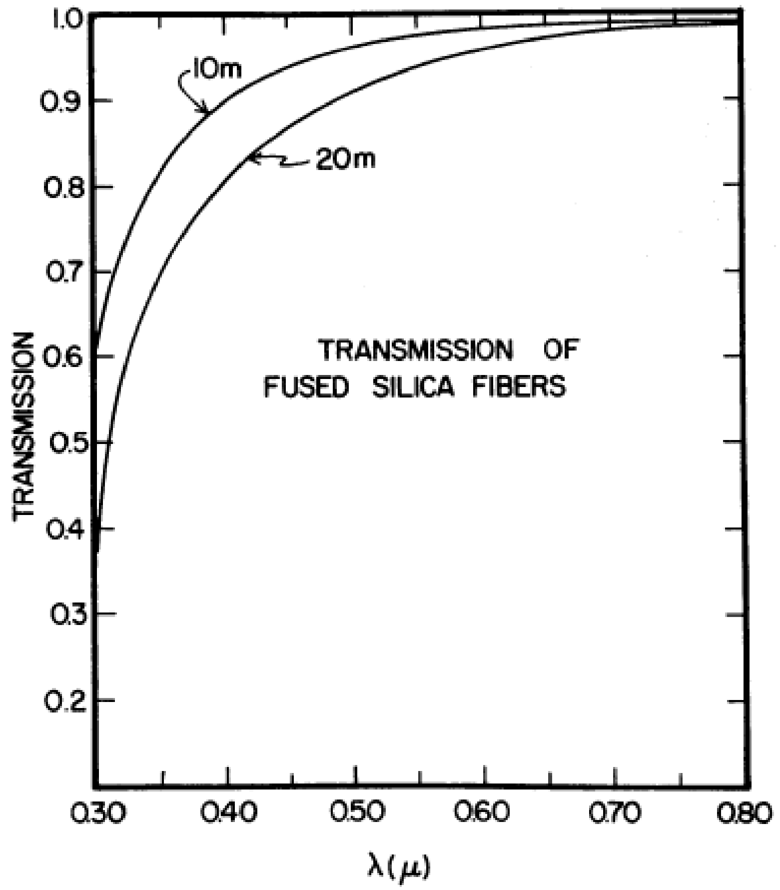
The practical limit in area for single telescope mirrors is around 20 m^2. In order to make much larger telescopes, necessary for the study of very faint objects, light must be collected by more than one mirror. A relatively inexpensive telescope with a collecting area of several hundred square meters can be constructed with fibers to bring together light from many mirrors, each of area ~ 5 m^2. This approach is made possible by the recent development for communications of fused silica fibers which show high transmission in the spectral range 0.3–2 μm over lengths of ~ 20 m, and which do not badly degrade focal ratio over the same distance. Several single fibers at the prime focus of each mirror would each pick up light from an area of a few square arc seconds, matched to the typical seeing disk. This approach is ideally suited for spectroscopy because the fiber ends would be brought directly to a line at the spectrograph slit. We suggest that flexure errors in the mirror support structure be compensated for by moving the fibers at the prime focus, and that the star field at each prime focus as seen by a sensitive imaging detector be used to determine the correction. No lasers or secondary optics are then needed to coalign the mirrors, and the telescope is made useful for deep imaging by summing all the detector outputs.

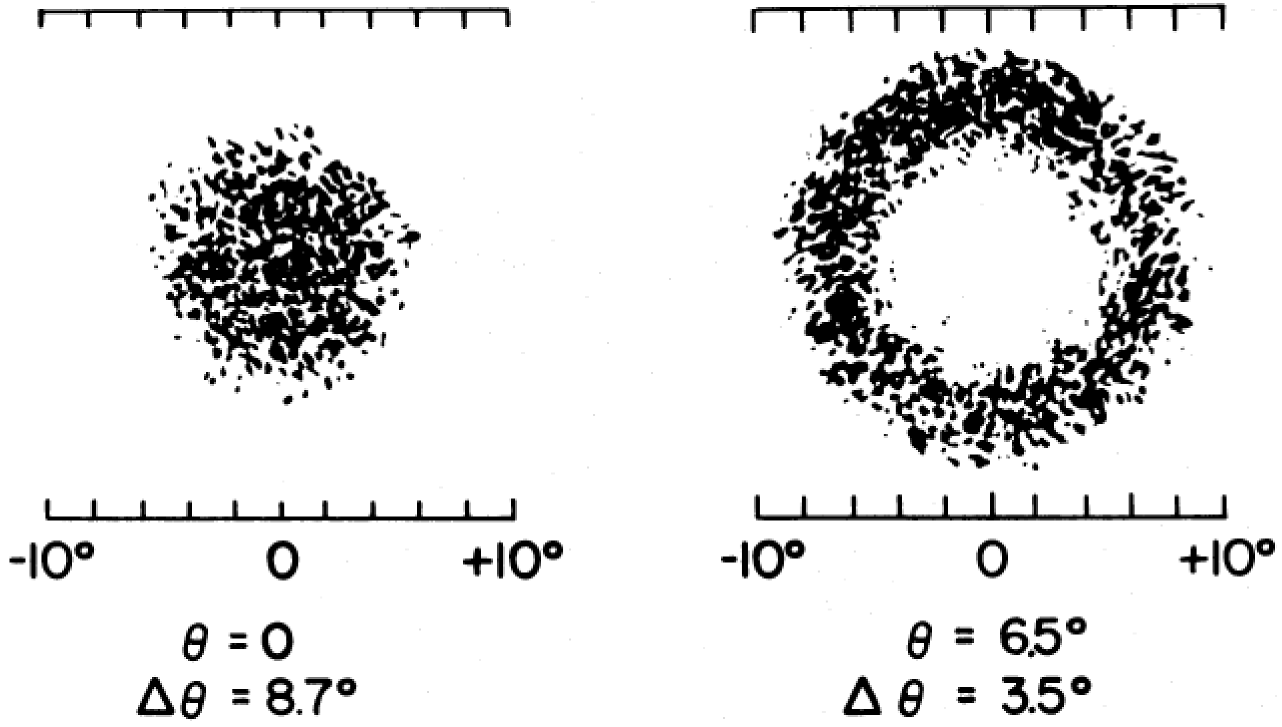
Subject heading: instruments

Roger Angel
© Univ. Arizona

Fiber Transmission

„Focal Ratio Degradation“





Angel J.R.P., Adams M.T., Boroson T.A., Moore R.L., 1977, ApJ, 218, 776

Hill 1988, ASPC 3, 77

Mode expansion theory and application in step-index multimode fibres for astronomical spectroscopy

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[2] *Technische Universität Berlin, HFT4, Einsteinufer 25, 10587 Berlin, Germany*
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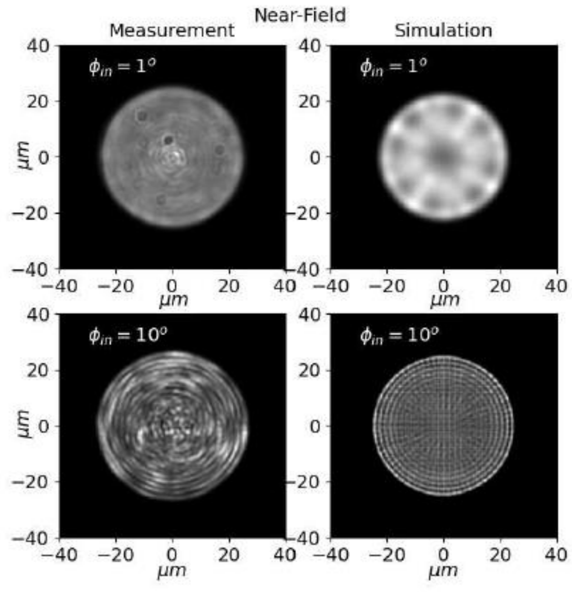
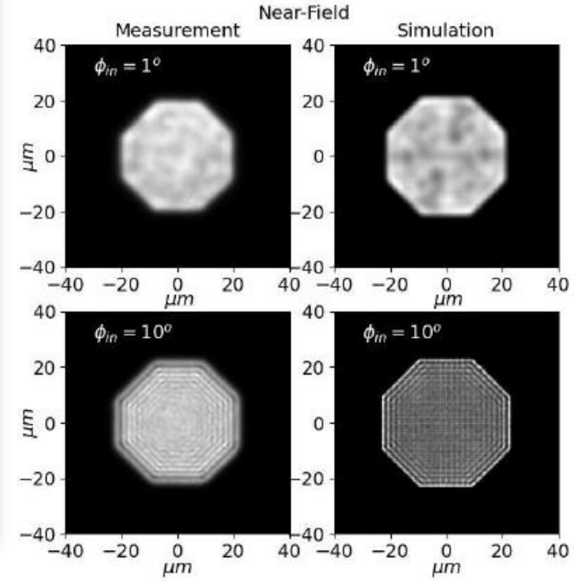
Abstract: In astronomical spectroscopy, optical fibres are abundantly used for multiplexing and decoupling the spectrograph from the telescope to provide stability in a controlled environment. However, fibres are less than perfect optical components and introduce complex effects that diminish the overall throughput, efficiency, and stability of the instrument. We present a novel numerical field propagation model that emulates the effects of modal noise, scrambling, and focal ratio degradation with a rigorous treatment of wave optics. We demonstrate that the simulation of the near- and far-field output of a fiber, injected into a ray-tracing model of the spectrograph, allows to assess performance at the detector level.





Hernandez E., Roth M.M., Petermann K., Kelz A., Moralejo B., Madhav K., 2021, JOSAB, 38, A36

Hill 1988, ASPC 3, 77

Optical Fibers in Astronomy

There are (at least) 3 good reasons

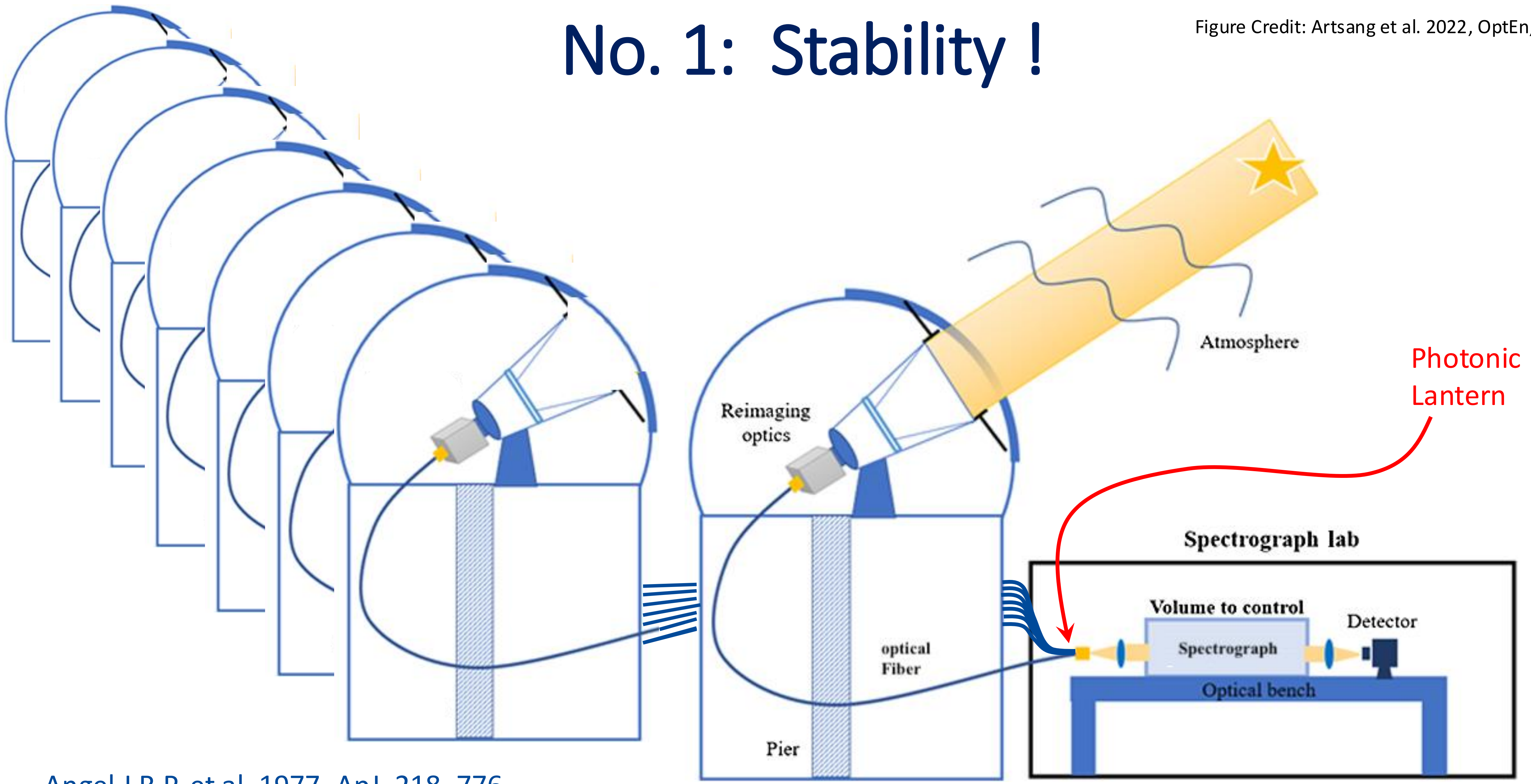
why to couple spectrographs

with optical fibers

Hill 1988, ASPC 3, 77

No. 1: Stability !

Figure Credit: Artsang et al. 2022, OptEn, 61



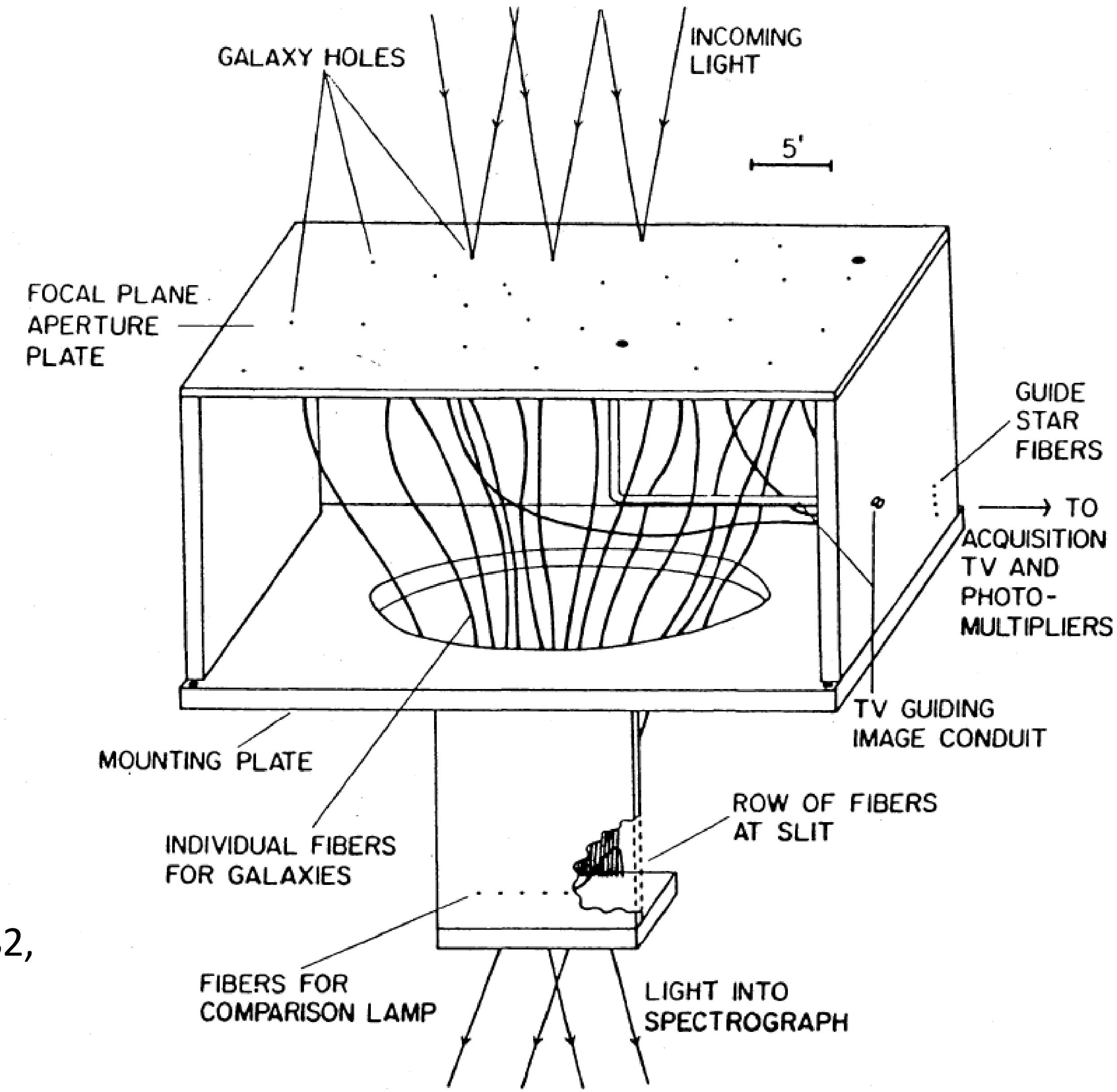
Angel J.R.P. et al. 1977, ApJ, 218, 776

Hubbard E.N., Angel J.R.P., Gresham M.S., 1979, ApJ, 229, 1074

Hill 1988, ASPC 3, 77

No. 2: Multiplex !

Multi-Object Spectroscopy



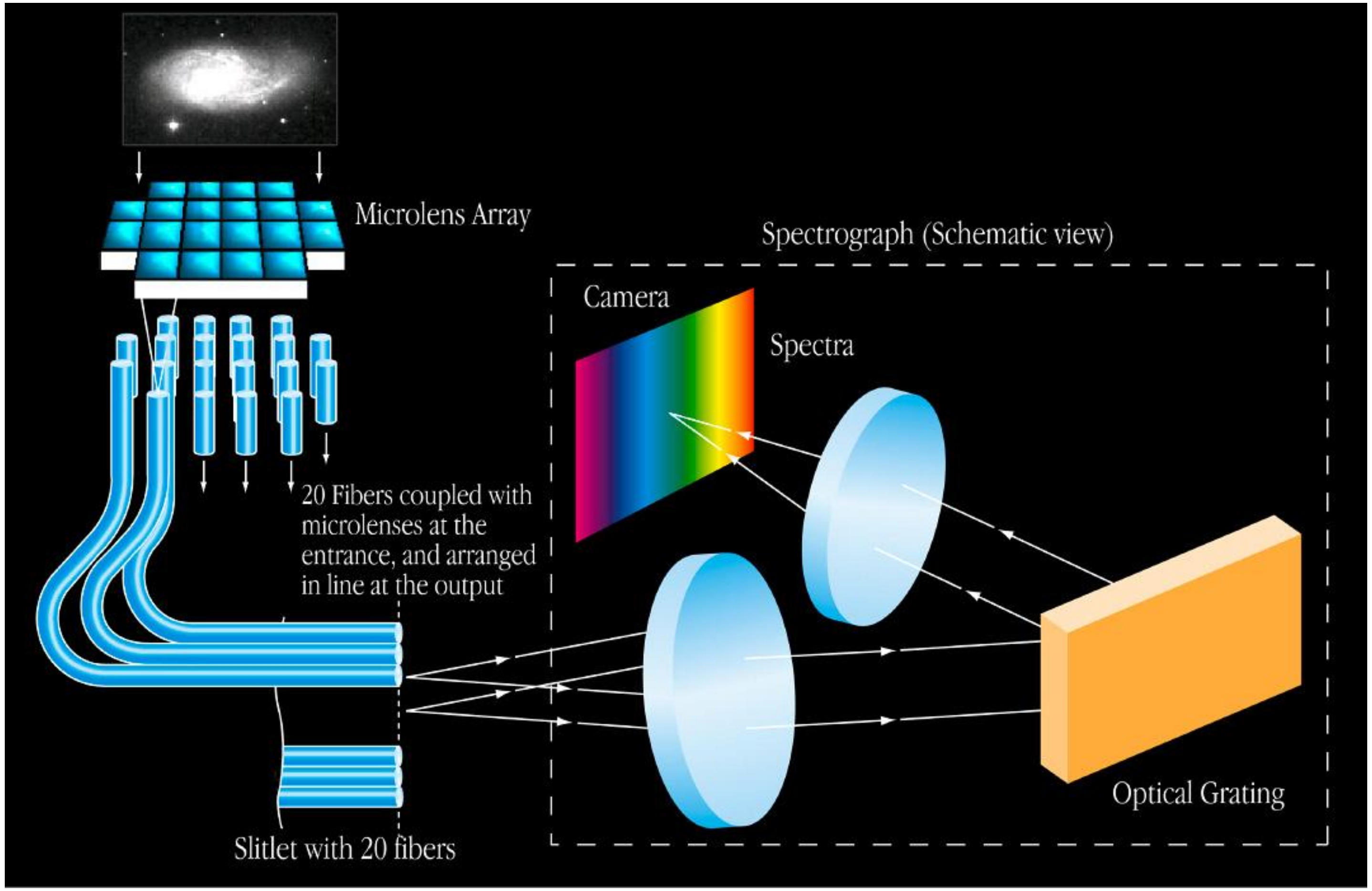
The „MEDUSA" Spectrograph

Hill J.M., Angel J.R.P., Scott J.S., Lindley D., Hintzen P., 1982, SPIE, 331, 279

See also review by Hill J.M., 1988, ASPC, 3, 77

Hill 1988, ASPC 3, 77

No. 3: Imaging Spectroscopy !

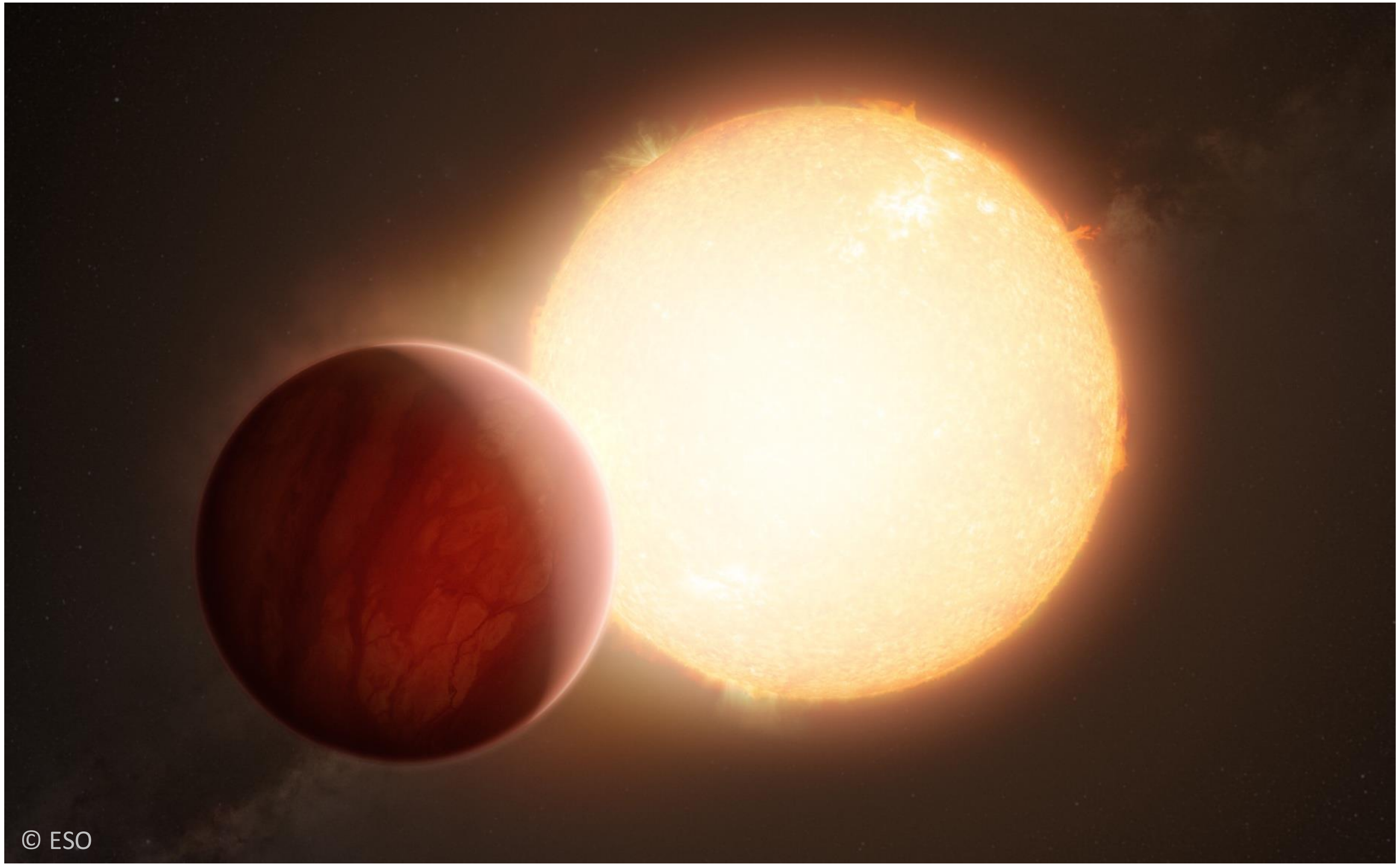


Credit: ESO

Hill 1988, ASPC 3, 77

No. 1: Stability

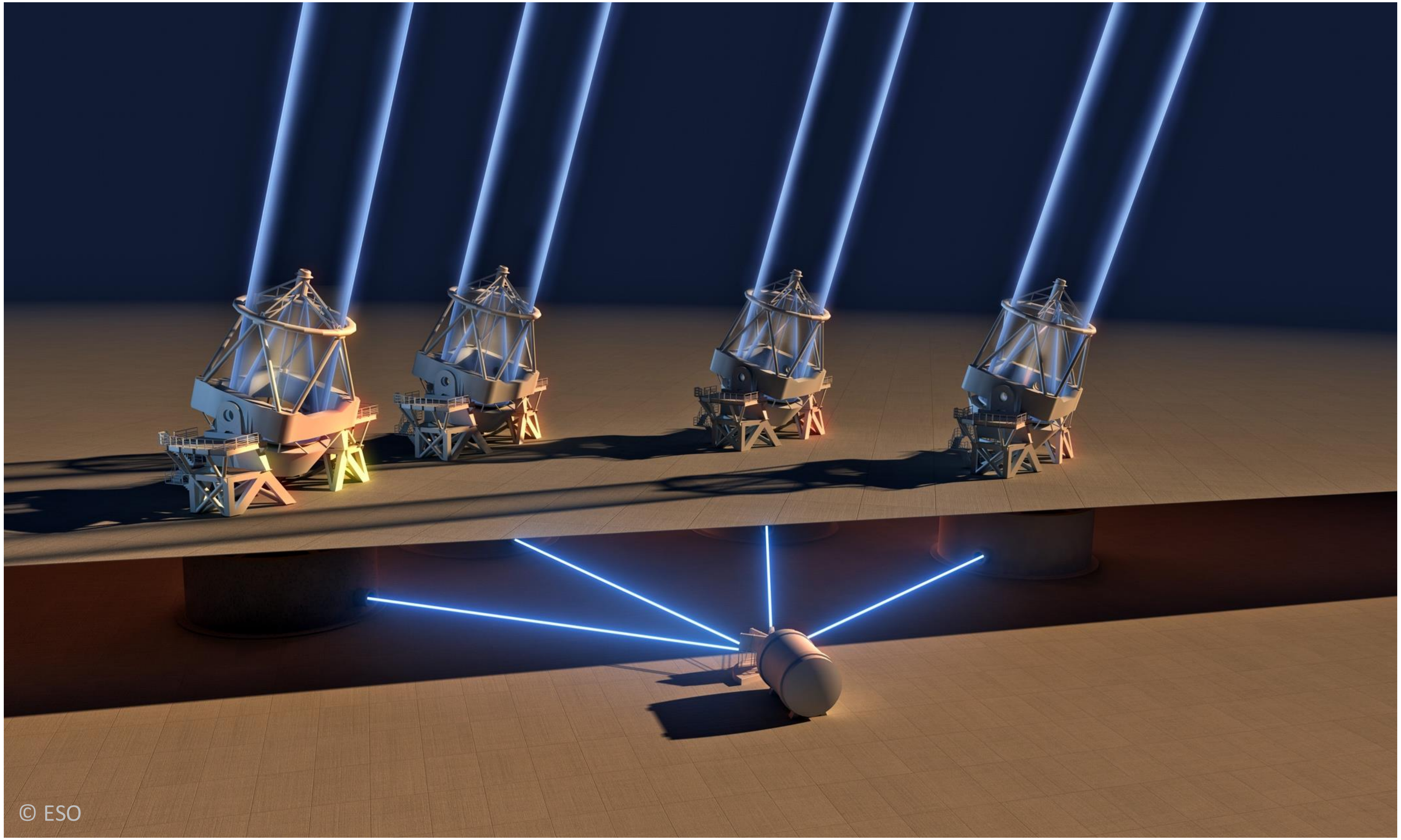
Exoplanet system



Michel Mayor
Nobel Price 2019

Hill 1988, ASPC 3, 77

ESPRESSO @ VLT



Hill 1988, ASPC 3, 77

ESPRESSO @ VLT

	HR (1-UT)	UHR (1-UT)	MR (4-UT)
Wavelength range	380–788 nm	380–788 nm	380–788 nm
Resolving power (median)	140,000	190,000	70,000
Aperture on sky	1".0	0".5	4x1".0
Total efficiency	11%	5%	11%
RV precision (requirement)	**< 10 cm/s**	**< 5 m/s**	**< 5 m/s**
Limiting V-band magnitude*	~17	~16	~20
Binning	1x1, 2x1	1x1	4x2, 8x4
Spectral sampling (average)	4.5 px	2.5 px	5.5 px (binned x2)
Spatial sampling per slice	9.0 (4.5) px	5.0 px	5.5 px (binned x4)
Number of slices	2	2	1

Hill 1988, ASPC 3, 77

ESPRESSO @ VLT

Hill 1988, ASPC 3, 77

ESPRESSO @ VLT

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Hill 1988, ASPC 3, 77

ESPRESSO @ VLT

Hill 1988, ASPC 3, 77

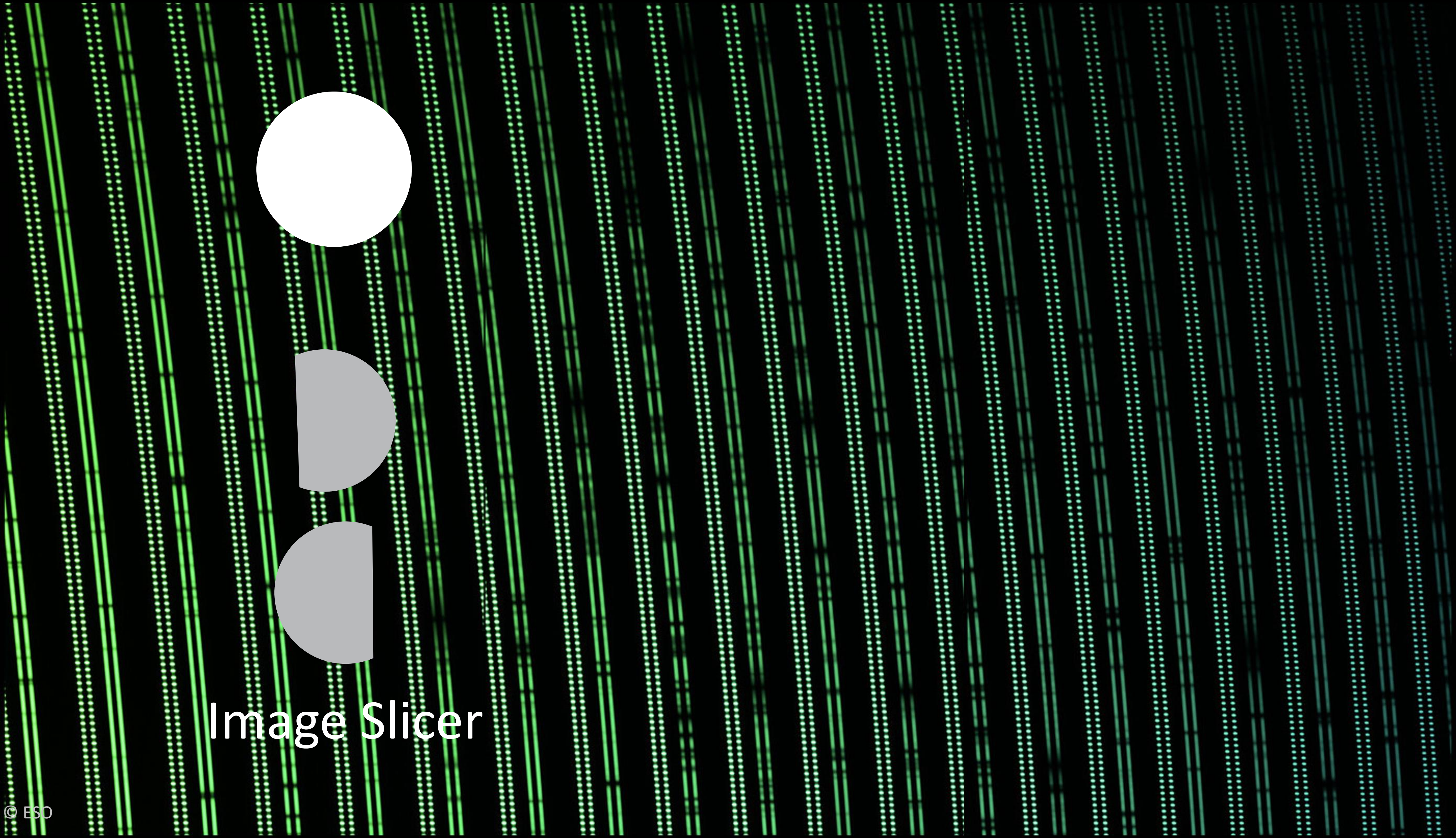
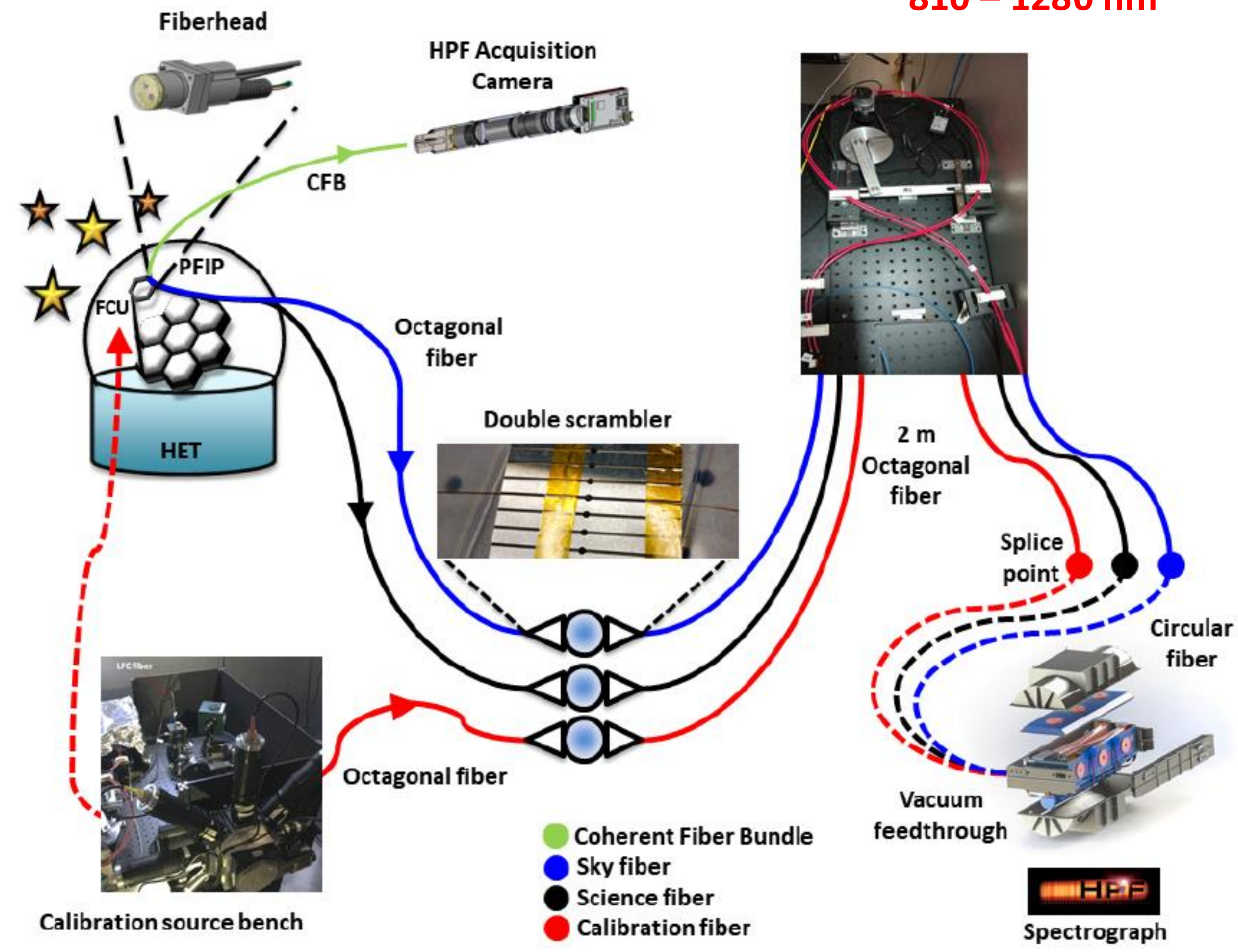
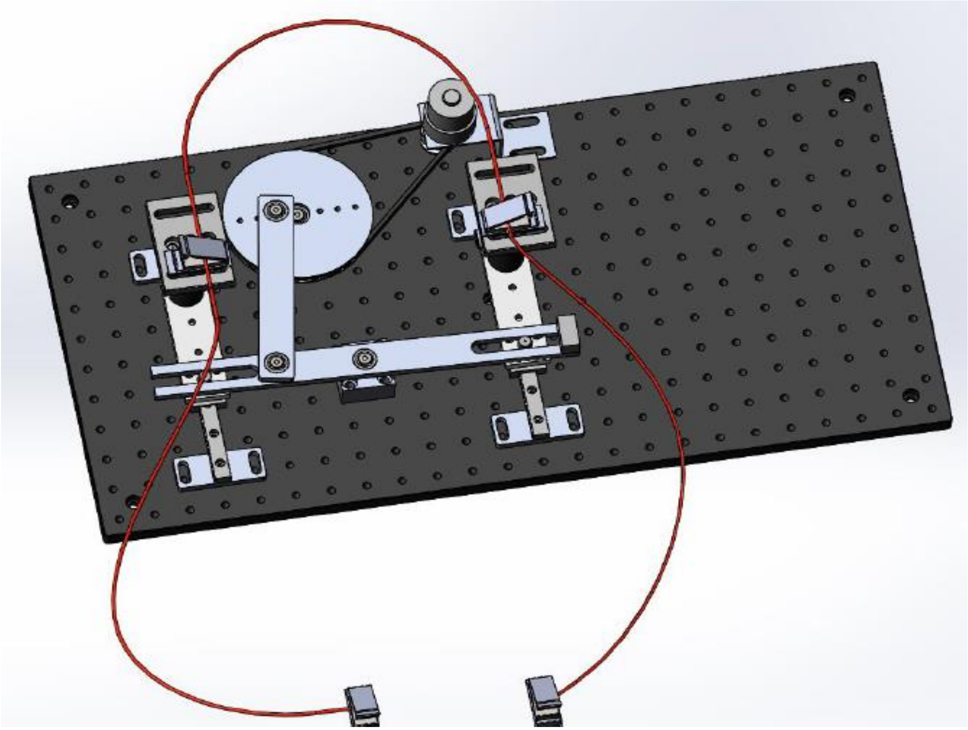


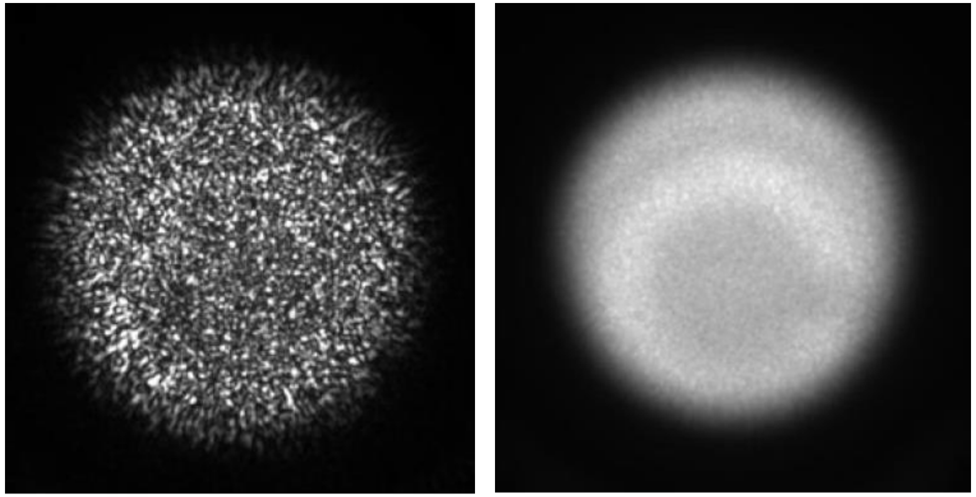
Image Slicer

HPF: Habitable-Zone Planet Finder

810 – 1280 nm







(a) Fiber far field before agitation. (b) Fiber far field after agitation

Kanodia S., Mahadevan S., Ramsey L.W., SJ. et al., 2018, SPIE, 10702, 107026Q

Hill 1988, ASPC 3, 77

CARMENES @ Calar Alto 3.5m

	VIS channel	NIR channel
Wavelength coverage, Δλ*	520-960 nm	960-1710 nm
Detector	1 x 4kx4k e2v CCD231-84	2 x 2kx2k Hawaii-2RG
Wavelength calibration	Th-Ne lamps & Fabry-Pérot etalon	U-Ne lamps & Fabry-Pérot etalon
Working temperature, T_{work}	285.000 ± 0.005 K	140.000 ± 0.005 K
Spectral resolution, R	**94,600**	**80,400**
Mean sampling	2.8 pixels	
Mean inter-fibre spacing	7.0 pixels	
Cross disperser	Grism, LF5 glass	Grism, infrasil
Reflective optics coating	Silver	Gold
No. of orders	55	28
Échelle grating	2 x Richardson Gratings R4 (31.6 mm^{-1})	
Target fibre field of view	1.5 arcsec	
A&G system field of view	3 arcmin	
A&G system band	Approx. *R*	

Hill 1988, ASPC 3, 77

Multi-Object Spectroscopy

Hill 1988, ASPC 3, 77

Multi-Object Spectroscopy

9414 citations in ADS
(as of July 31, 2025)

THE ASTRONOMICAL JOURNAL, 120:1579–1587, 2000 September

THE SLOAN DIGITAL SKY SURVEY: TECHNICAL SUMMARY

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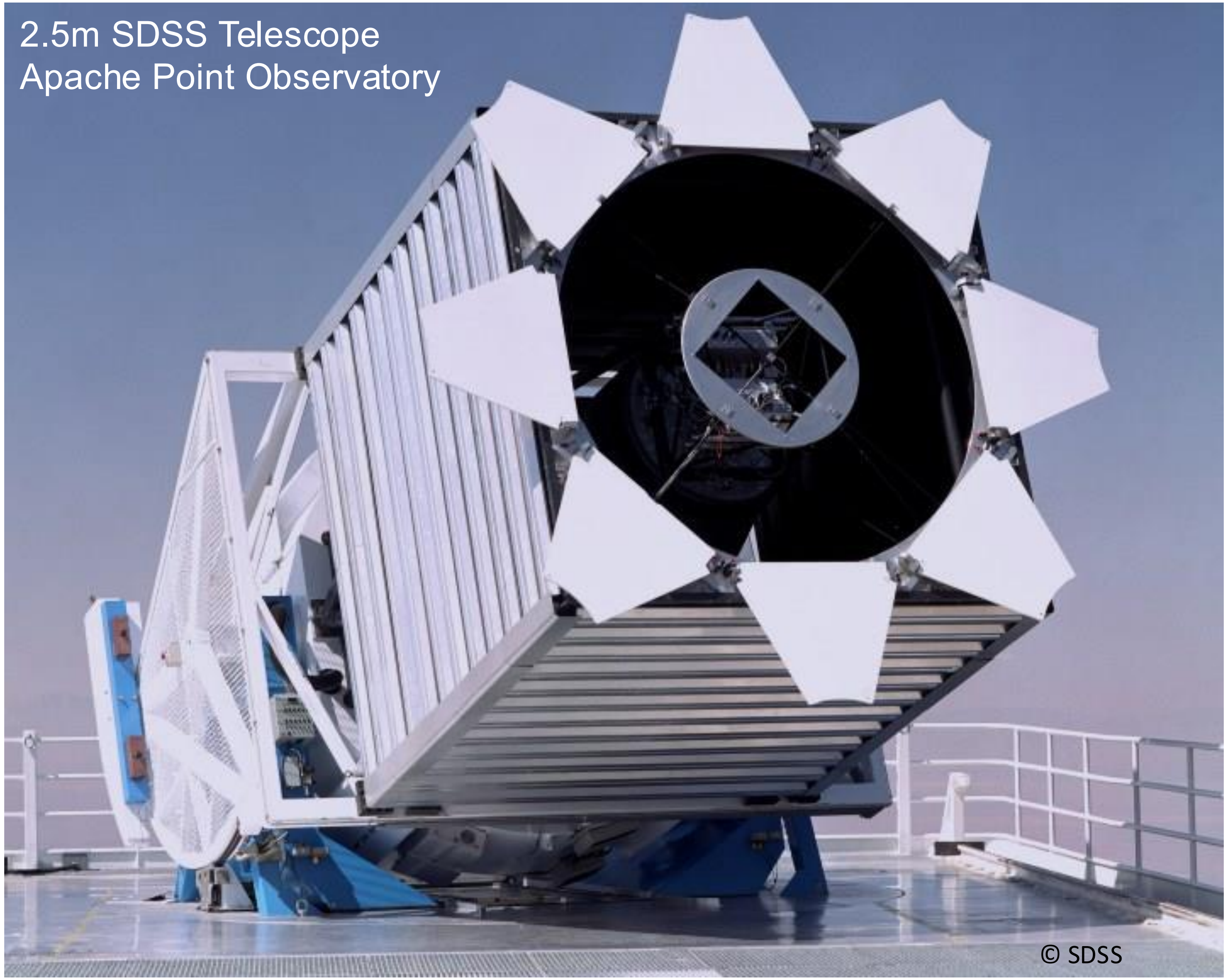
(THE SDSS COLLABORATION)

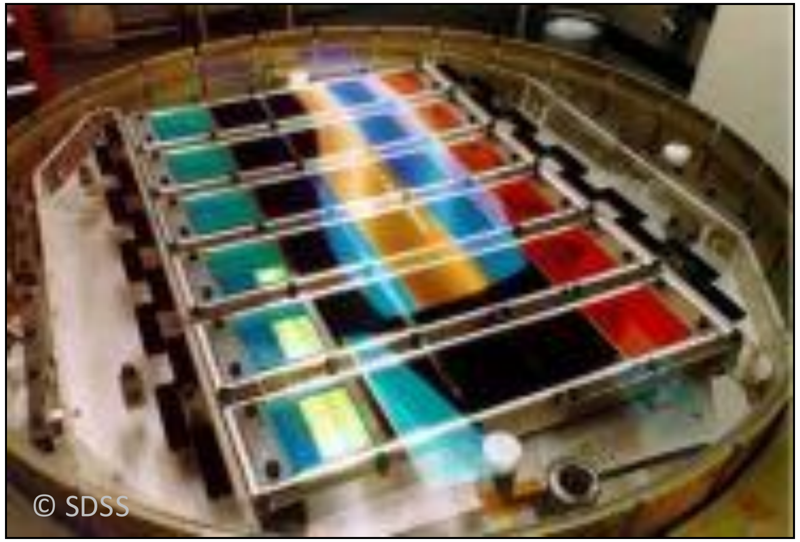
Received 2000 February 13; accepted 2000 June 8

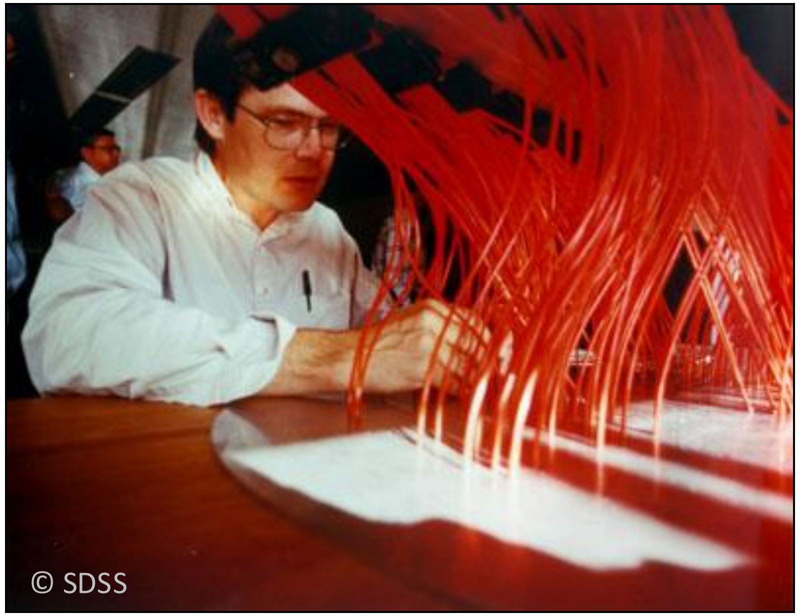
York D.G., Adelman J., Anderson J.E., Anderson S.F., Annis J., Bahcall N.A., Bakken J.A., et al., 2000, AJ, 120, 1579

Hill 1988, ASPC 3, 77

SLOAN Digital Sky Survey



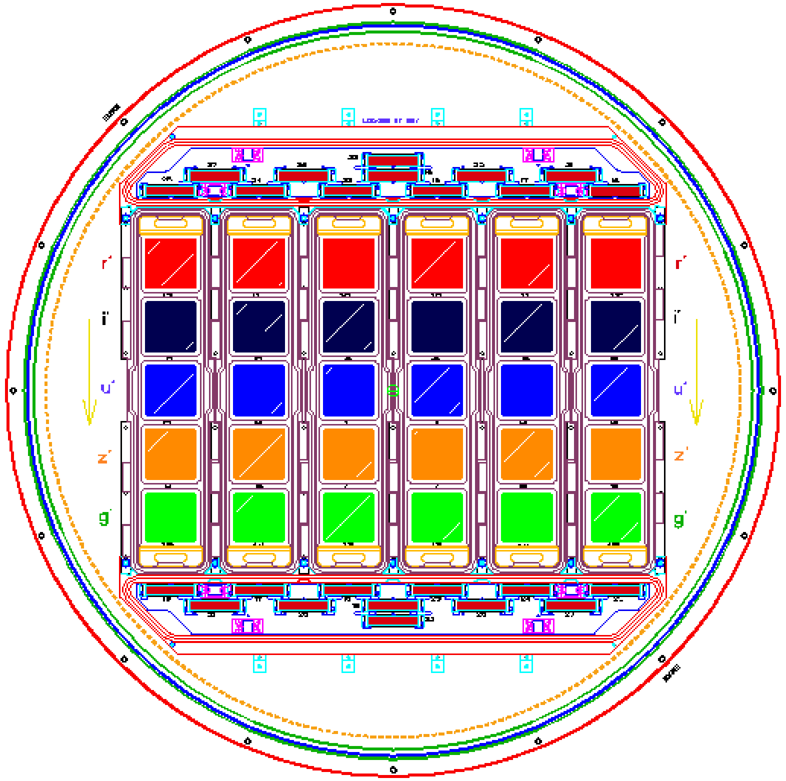




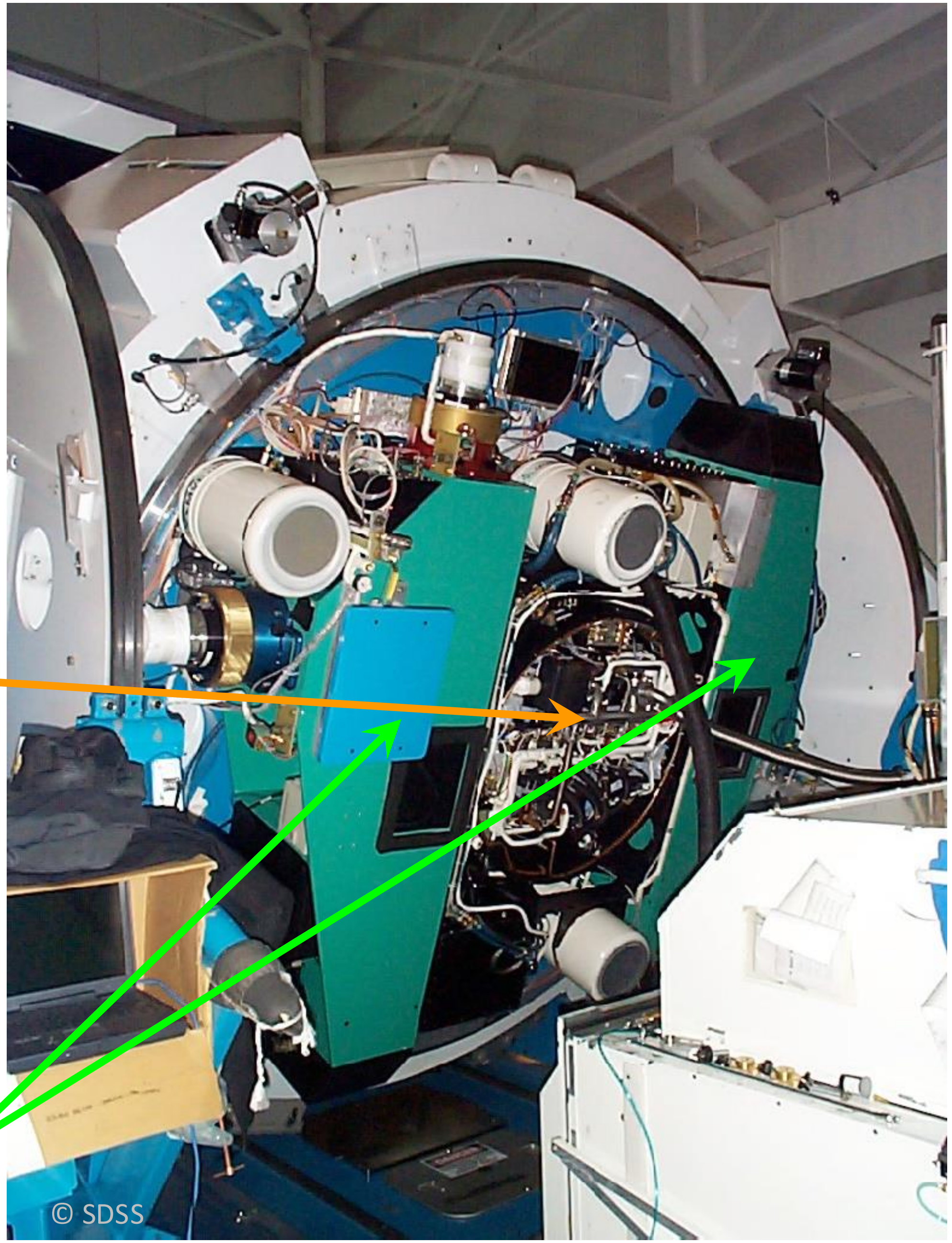
Hill 1988, ASPC 3, 77

SLOAN Digital Sky Survey

Direct imaging CCD camera,
30 x SITe 2048×2048 pixels



two 2-channel-spectrographs (blue/red),
fiber-coupled to the telescope



SLOAN Digital Sky Survey

Combined imaging and spectroscopic survey:

SDSS-I: 2000-2005
SDSS-II: 2005-2008 → DR7
SDSS-III: 2008-2014 → DR8, DR9, DR10

Deep images in 5 filter bands:
u′, g′, r′, i′, z′
359/481/623/764/906 nm

DR8: largest optical survey dataset

- images for >500 million stars and galaxies
- spectra for ~2 million objects
- 8000 square degrees survey area

Telescope and instrumentation (York et al. 2000):
2.5m telescope, f/5, 3° FoV, 0.5m auxiliar telescope (photometric calibration)

- 120 MPixel CCD camera, FoV 1.5 deg^2
- 2 fiber-coupled spectrographs > **600 spectra per exposure**

Hill 1988, ASPC 3, 77

SLOAN Digital Sky Survey

- The discovery of the most distant quasars, powered by supermassive black holes in the early Universe
- The discovery of large populations of sub-stellar objects
- Mapping extended mass distributions around galaxies with weak gravitational lensing
- Systematic characterization of the galaxy population
- The demonstration of ubiquitous substructure in the outer Milky Way
- Demonstration of the common origin of dynamical asteroid families
- Precision measurement of the luminosity distribution of quasars
- Precision measurements of large scale clustering and cosmological constraints
- Precision measurement of early structure with the Lyman-alpha forest
- Detailed characterization of small and intermediate scale clustering of galaxies
- Discovery of many new companions of the Milky Way and Andromeda
- Discovery of stars escaping the Galaxy
- Discovery of acoustic oscillation signatures in the clustering of galaxies
- Measurements of the clustering of quasars over a wide range of cosmic time

→ total of more than 10000 publikations in refereed journals
→ countless dissertations

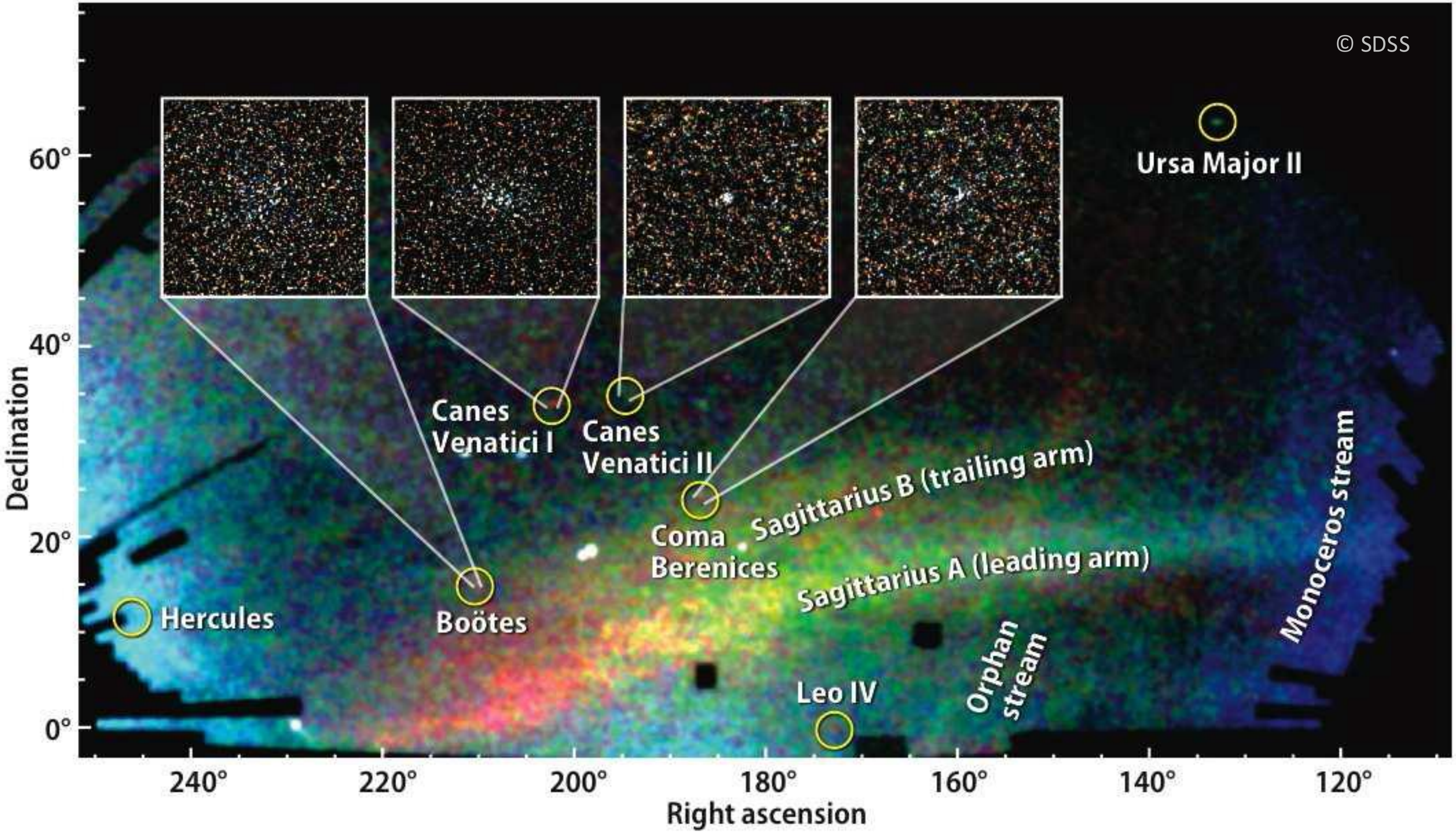
Hill 1988, ASPC 3, 77

SLOAN Digital Sky Survey

Supernovae type Ia

Hill 1988, ASPC 3, 77

SLOAN Digital Sky Survey



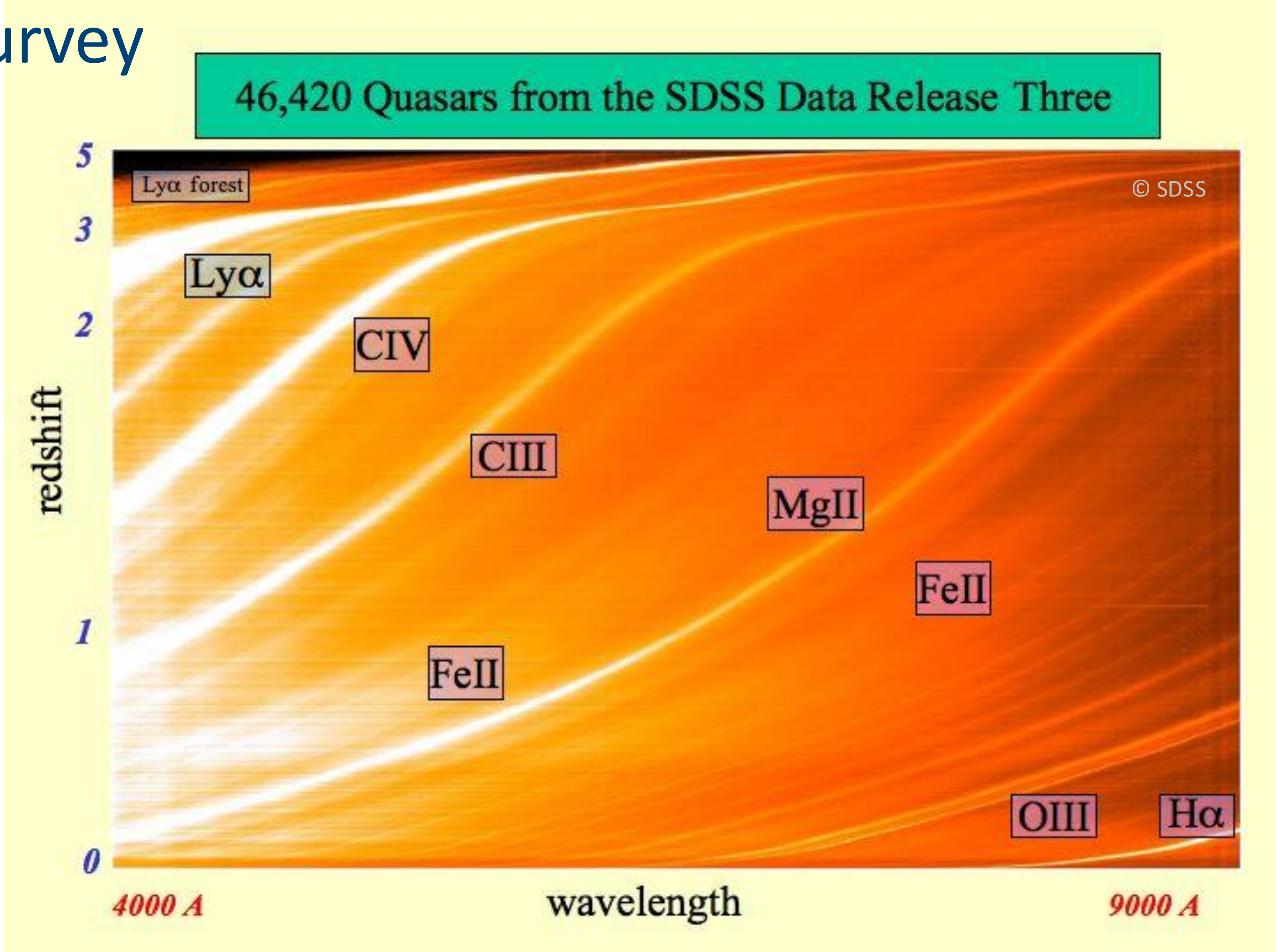
Map of stars in the outer regions of the Milky Way (across 1/5 of the sky). Trails and streams that cross the image are stars torn from disrupted Milky Way satellites (Belokurov et al. 2006).

Four insets: surviving, very faint dwarf galaxies.

The color-coding represents distance, with red being the most distant and blue being the closest.

Hill 1988, ASPC 3, 77

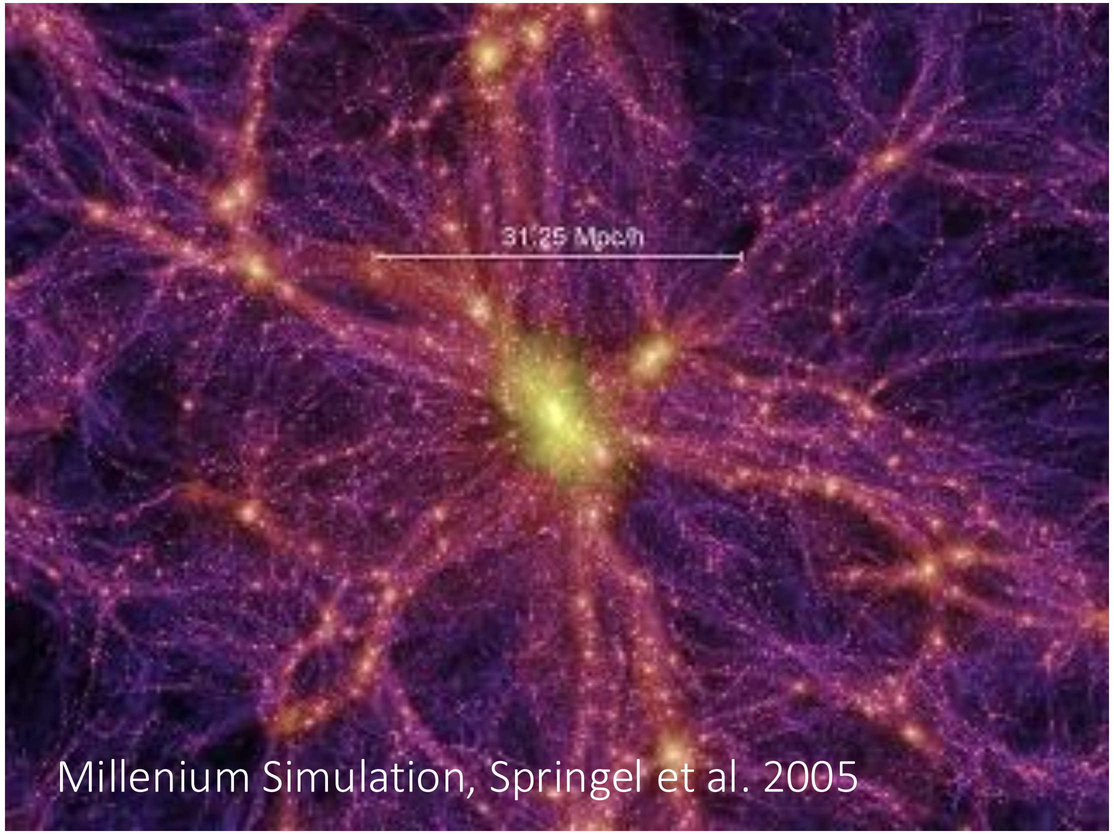
SLOAN Digital Sky Survey

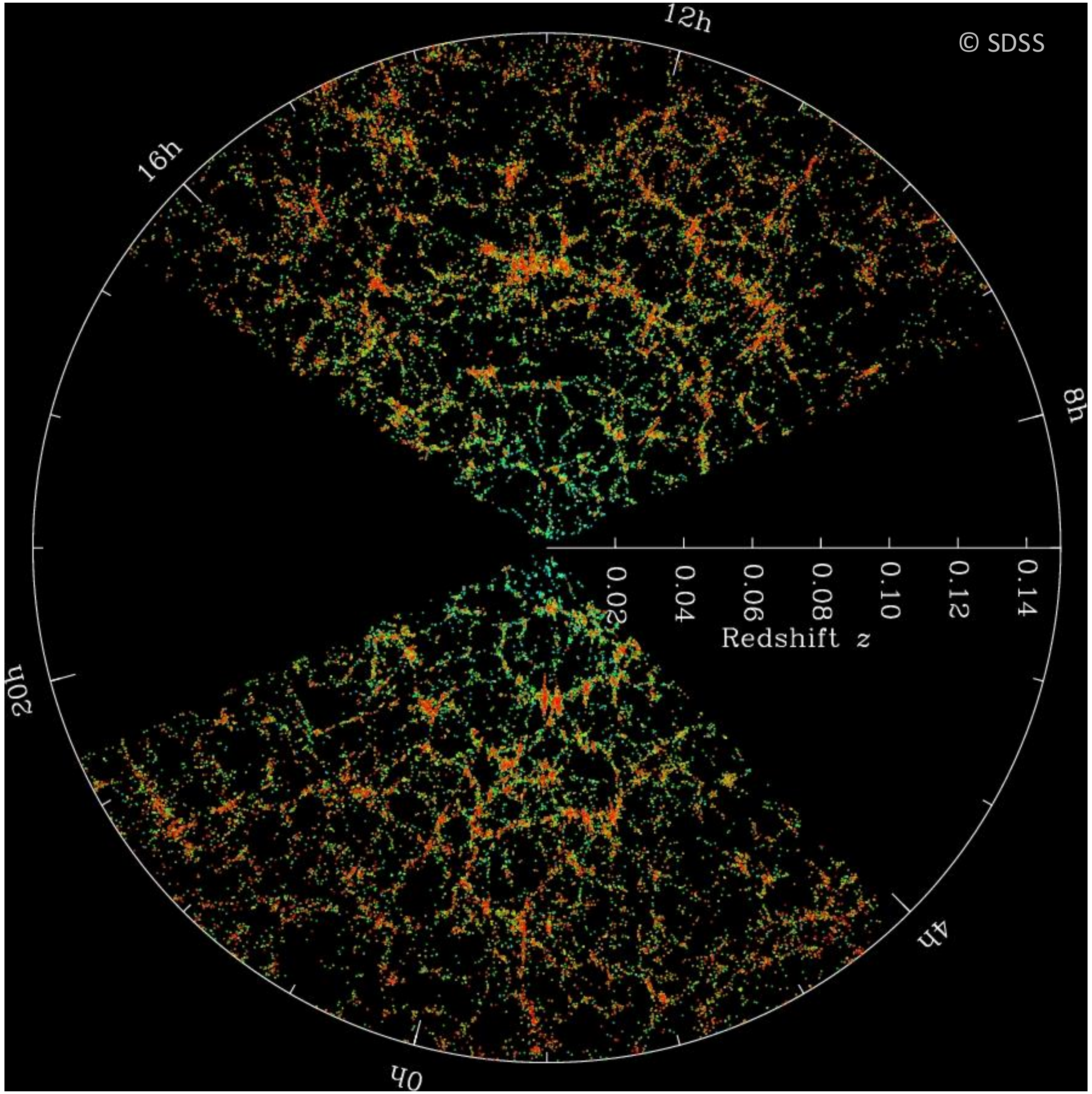


Hill 1988, ASPC 3, 77

SLOAN Digital Sky Survey

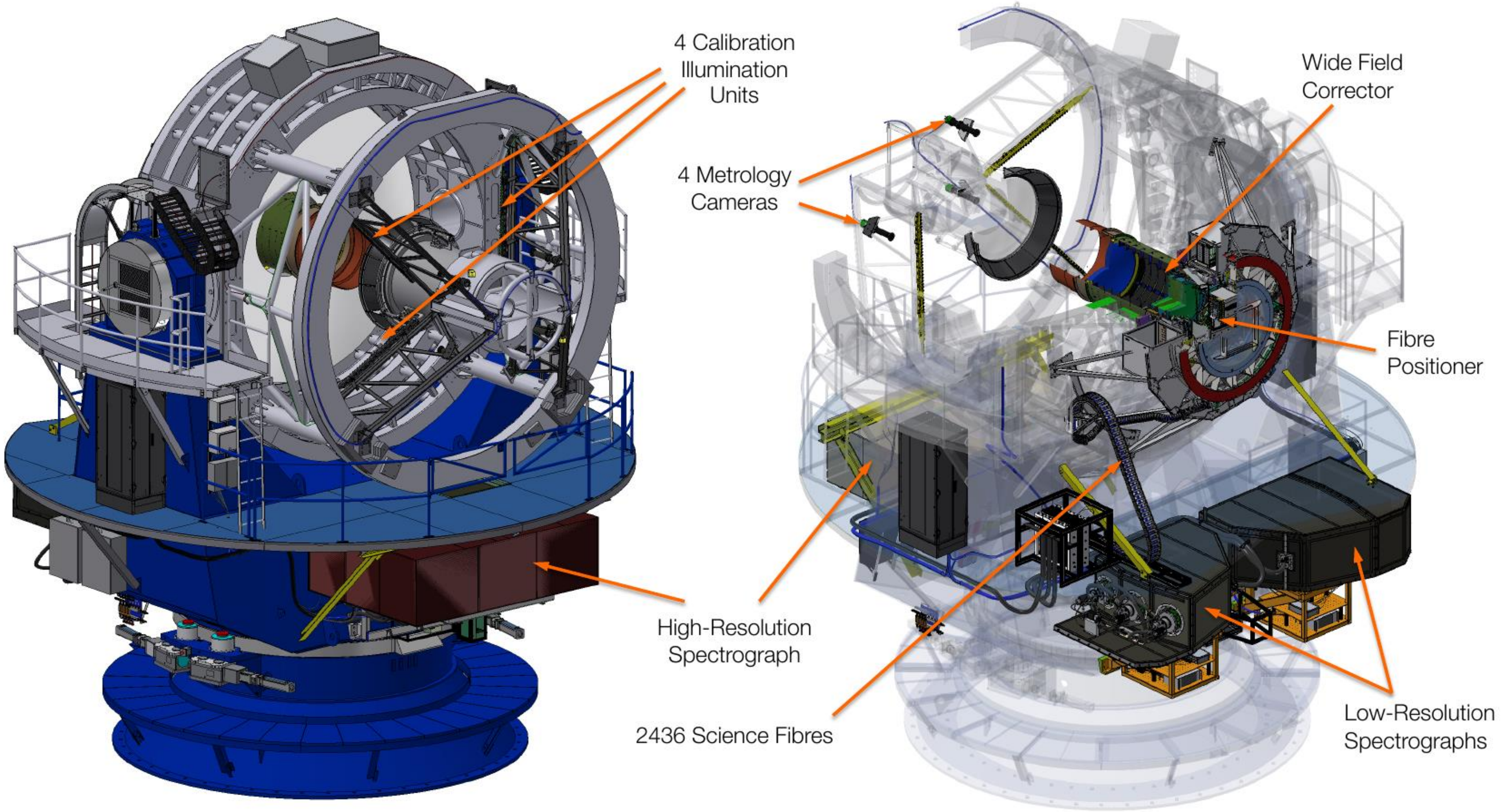
SDSS redshift survey
to test cosmological models





Hill 1988, ASPC 3, 77

4MOST: flagship survey facility for ESO



AIP
Lund University
rijksuniversiteit groningen
University of Bath
AAO
Max-Planck-Institut für Astronomie Heidelberg
University of Cambridge
CRAL
MPE
Universität Hamburg
Durham University
Universität Heidelberg Zukunft seit 1386
EPFL
NOVA
The University of Western Australia
ESO
rijksuniversiteit groningen
University of Bath
Uppsala Universitet

Hill 1988, ASPC 3, 77

4MOST

Requirements

2-hour observation to yield:

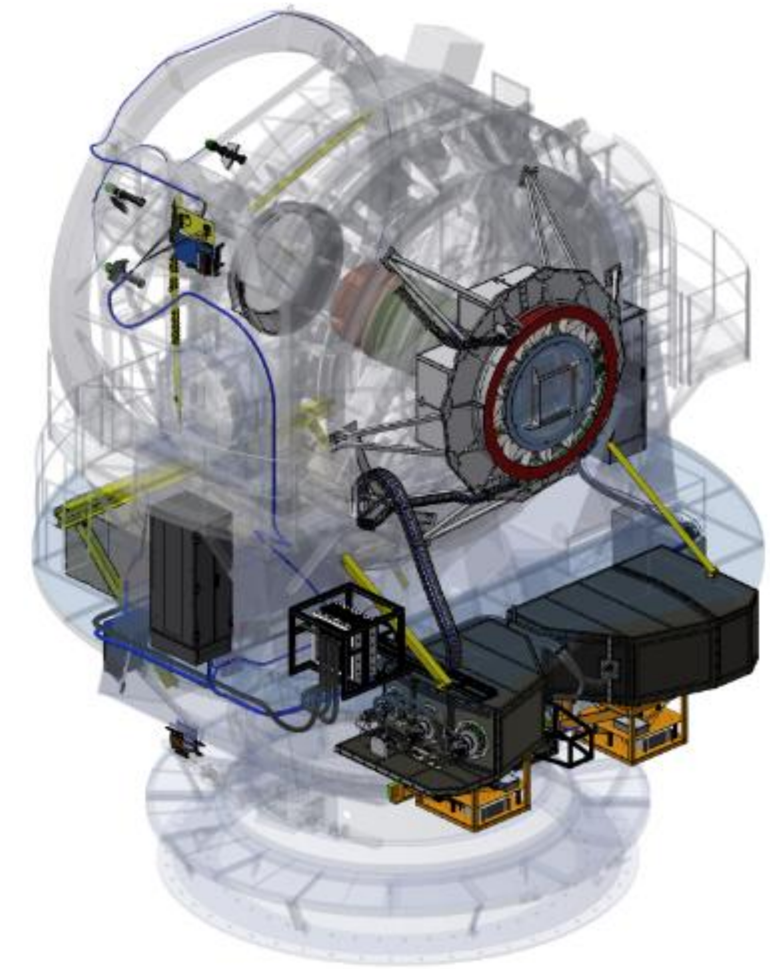
- radial velocities with a precision of better than 2 km/s for any Gaia source (G_{Vega} < 20.5 mag)
- stellar parameters and abundances of up to 15 chemical elements to 15.5 mag, abundances with a precision of better than 0.15 dex for key elements down to 18 mag
- redshifts of r_{AB} < 22 mag galaxies and AGN

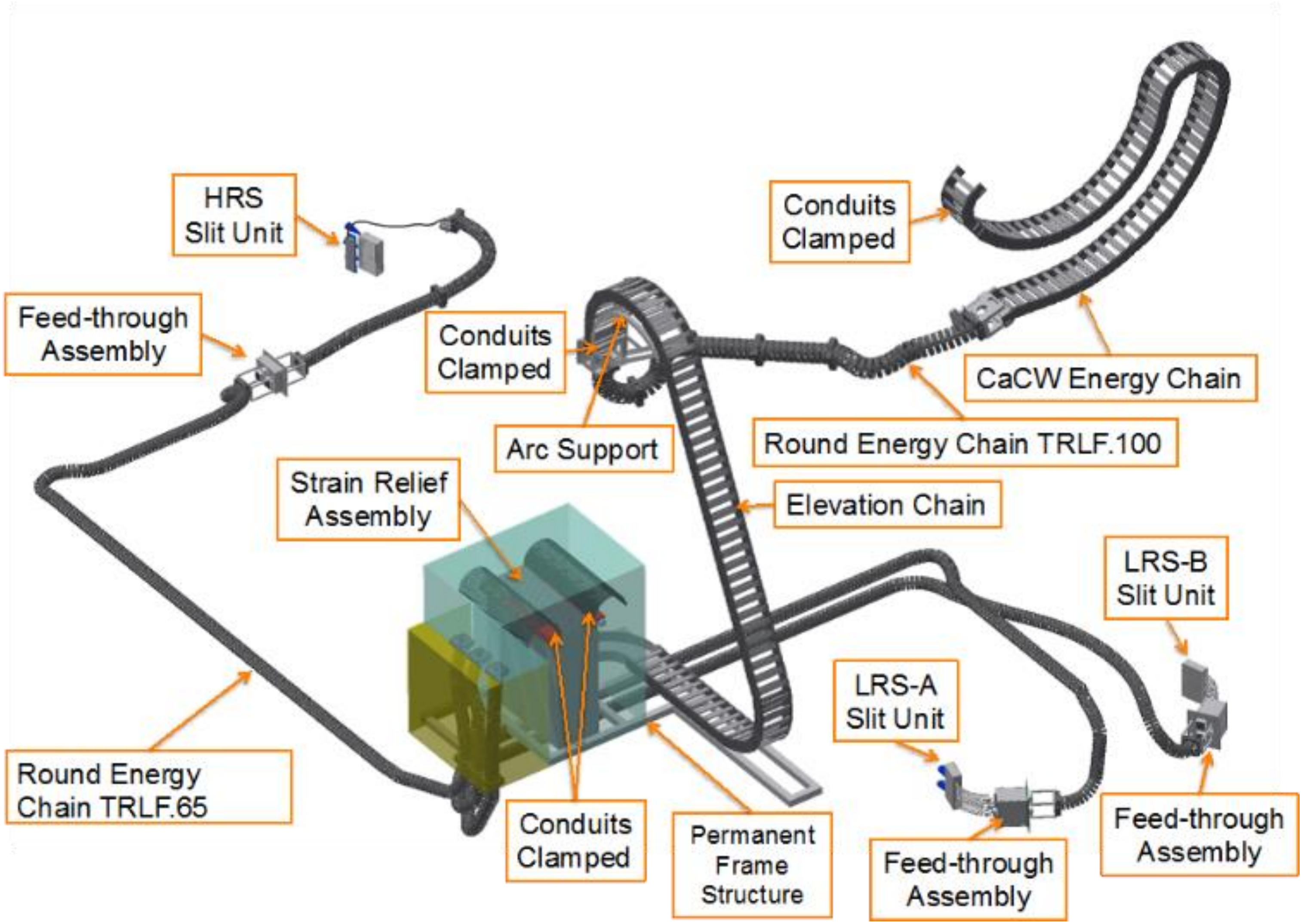
5-year survey: more than 20 million spectra at low resolution and more than 3 million spectra at high resolution.

Field of view	Shape: hexagonal Size: 4.2 deg^2 Diameter: 2.5 deg
Accessible sky (zenith angle < 55°)	30,000 deg^2
Multiplex fibre positioner	2436
On-sky fibre aperture	Shape: circular Size: 1.65 arcsec^2 Diameter: 1.45 arcsec
Minimum distance between fibres	15 arcsec
Expected on-target fibre-hours per year	LRS: 3.2 Mh/yr HRS: 1.6 Mh/yr
Detectors	Readout noise: < 2.3 e^- Readout modes: normal (100 kHz), fast (400 kHz) Binning modes (cross-dispersion × spectral): 1×1, 2×1, 1×2, 2×2, 1×4

Hill 1988, ASPC 3, 77

4MOST Fiberfeed System

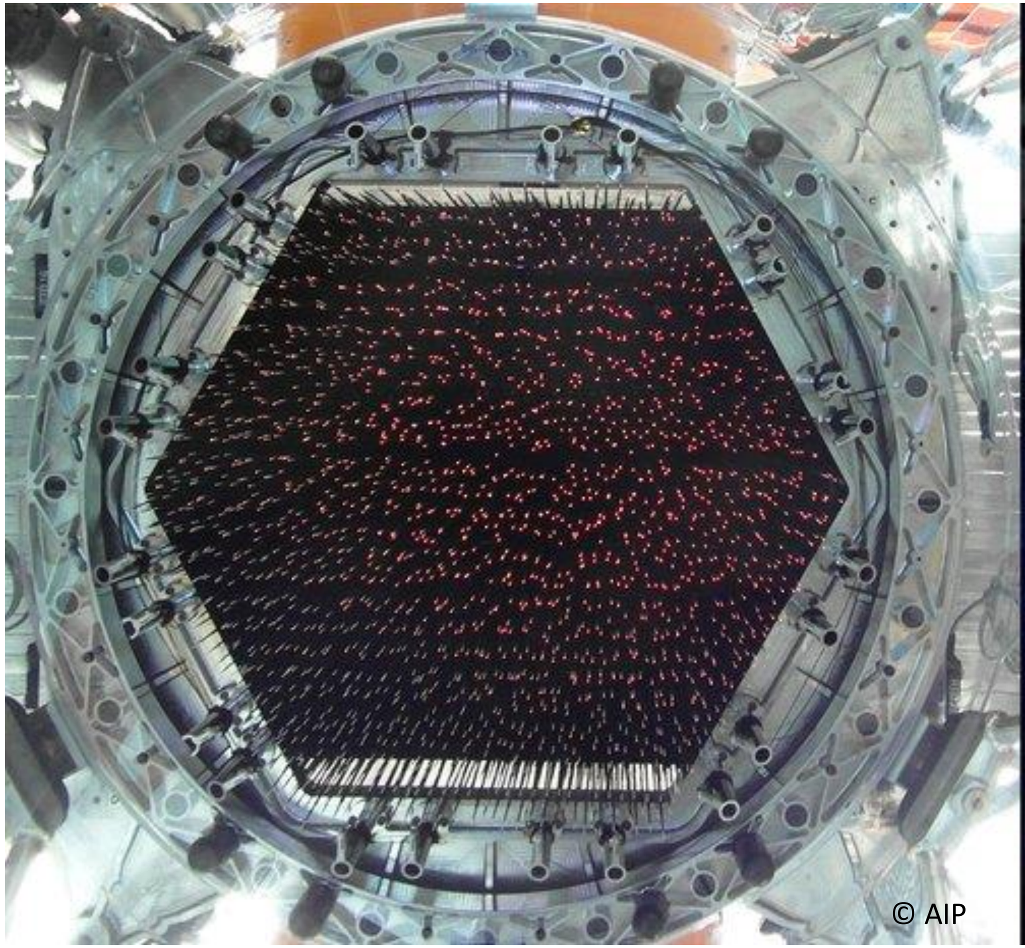


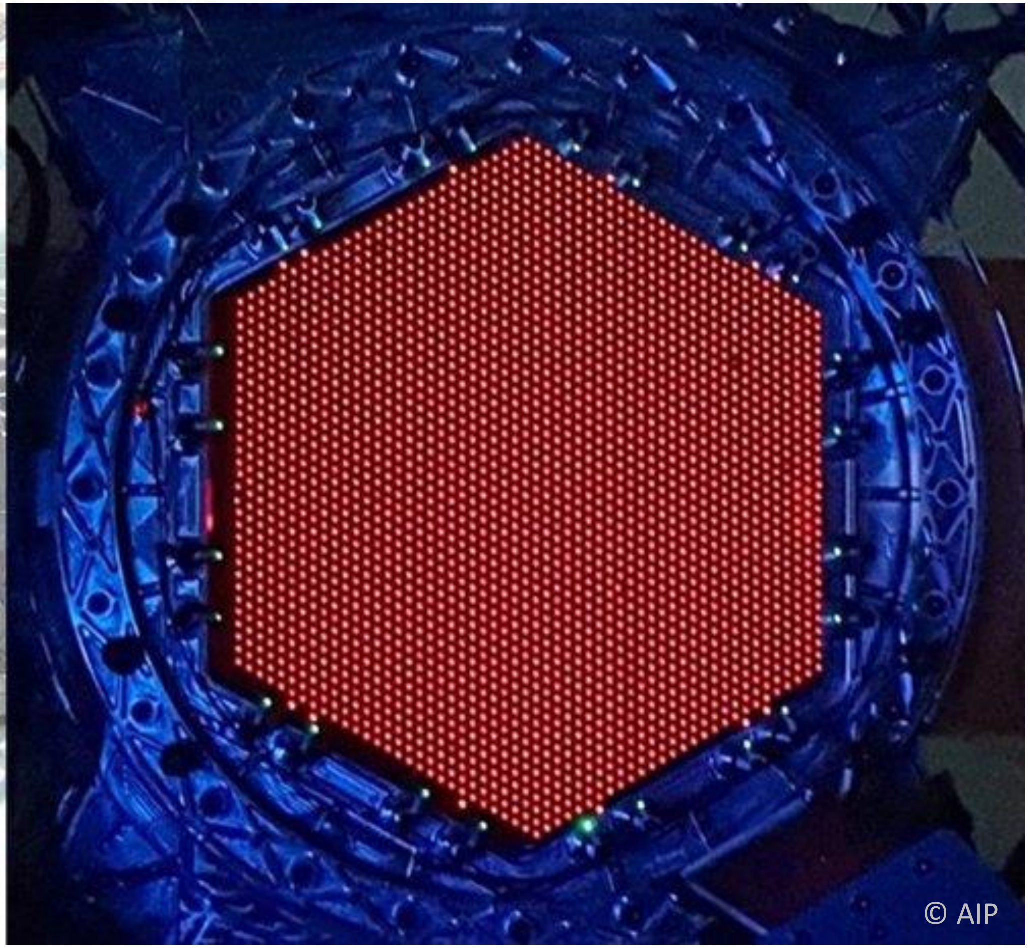


Hill 1988, ASPC 3, 77

4MOST Fiber Positioner „AESOP“

- 2436 movable science fibre spines
- 12 guide fibre bundles
- 24 fixed fiducial fibres



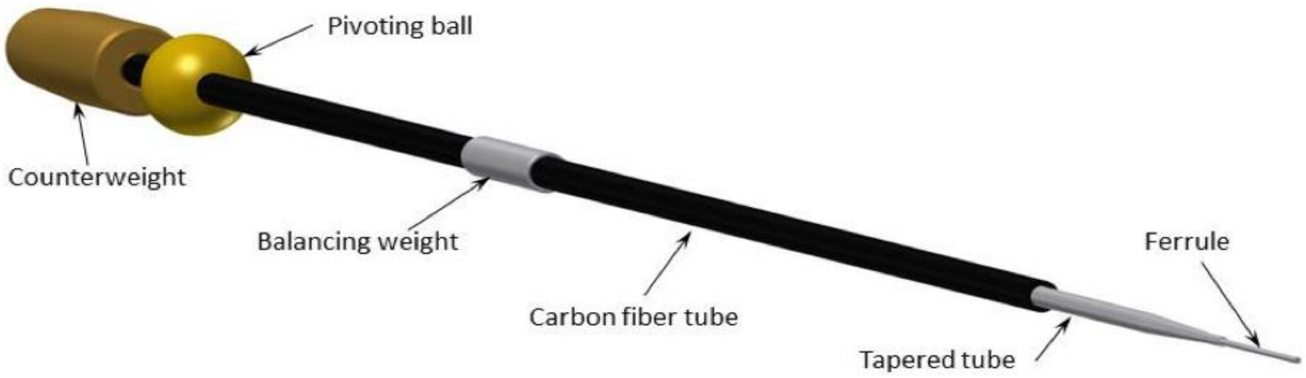


Credit: Andreas Kelz and 4MOST Consortium

Hill 1988, ASPC 3, 77

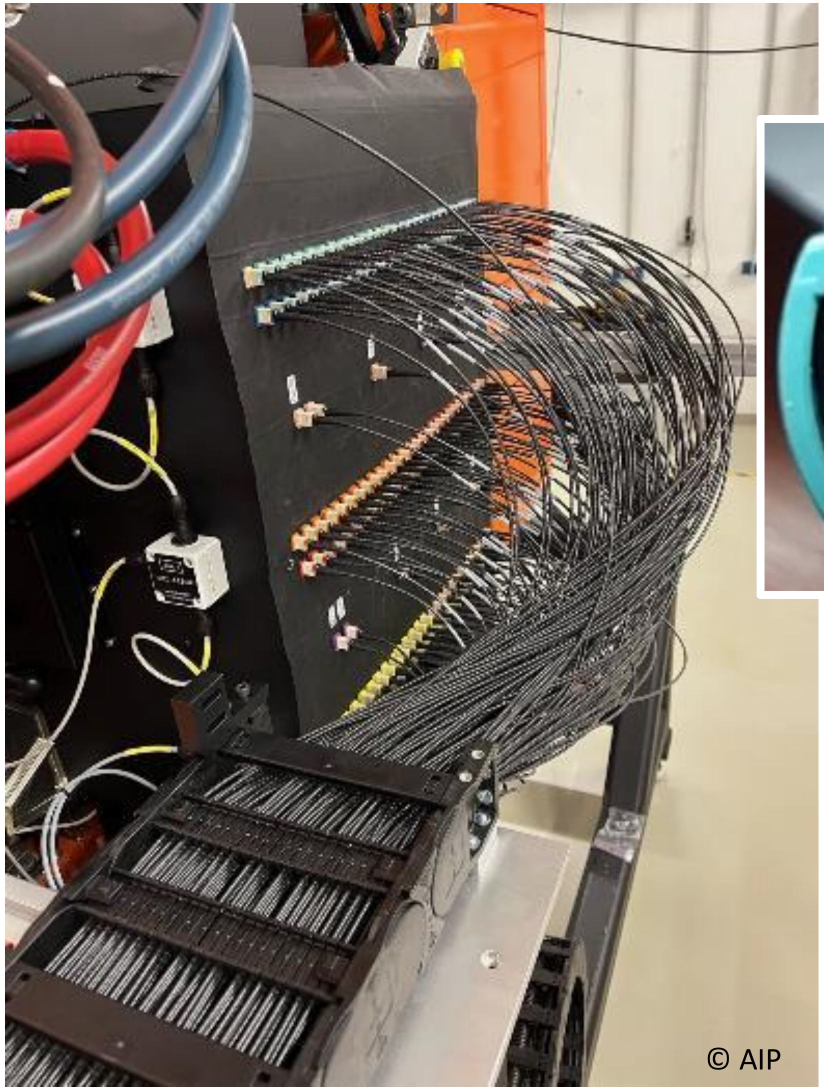
Credit:
Andreas Kelz and
4MOST Consortium

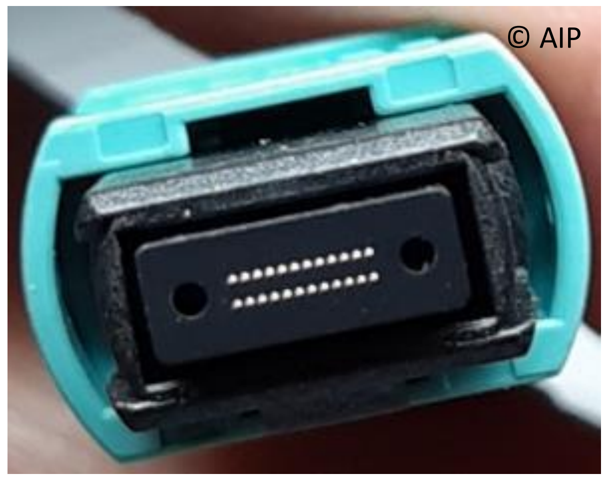
- 2436 Fibers
- Tilting Spine Fiber Positioner
- Positioning with 2 minutes
  over patrol field of
  0.5m diameter



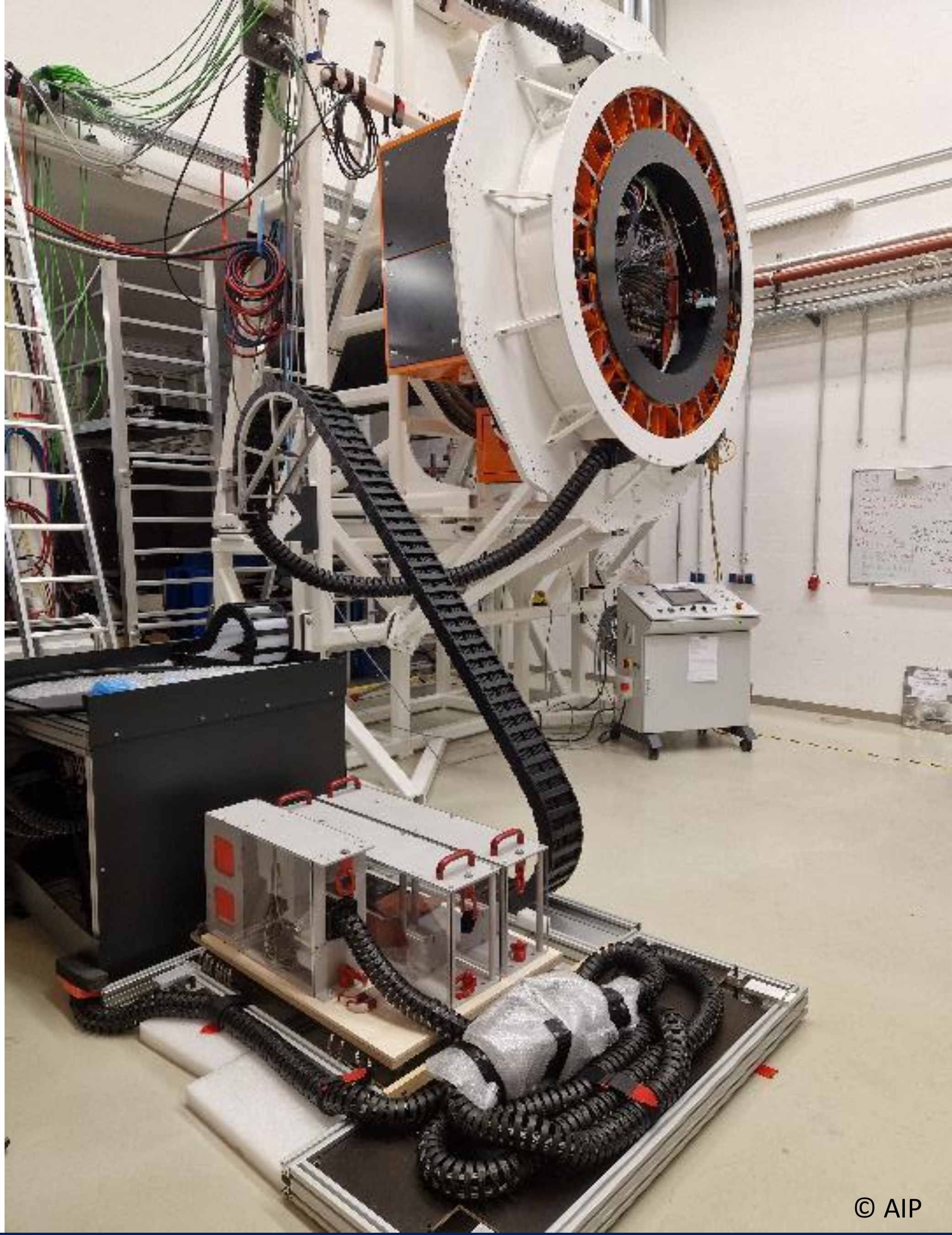
Developed by AAO, Australia

4MOST Fiber Cable Wrap





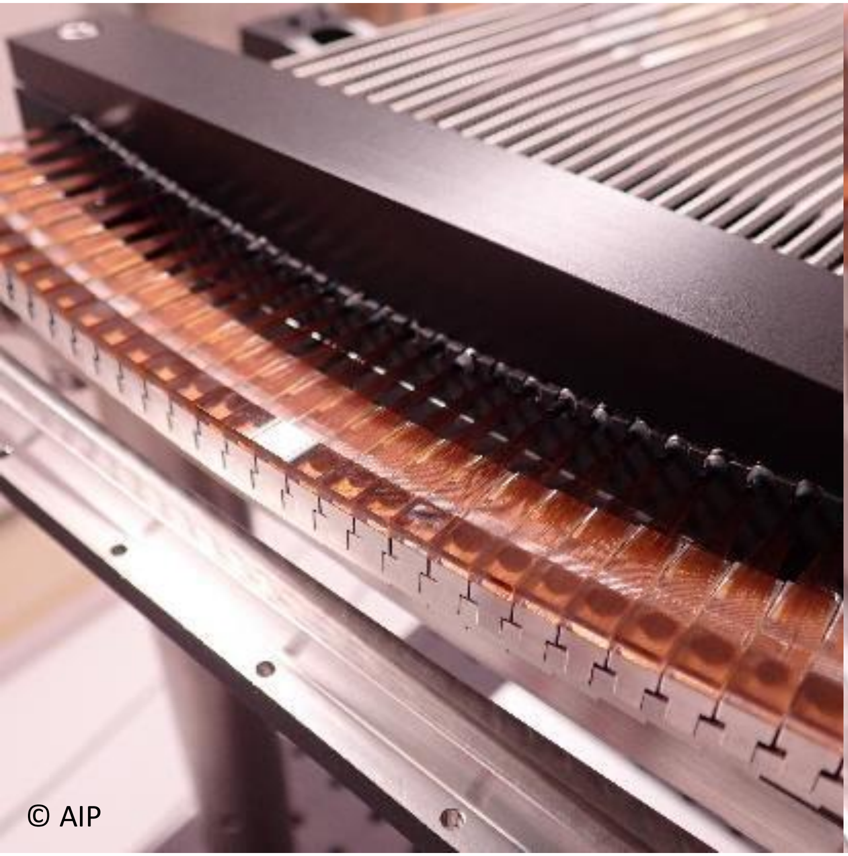
MTP24F Elite connector
(from US Conec)

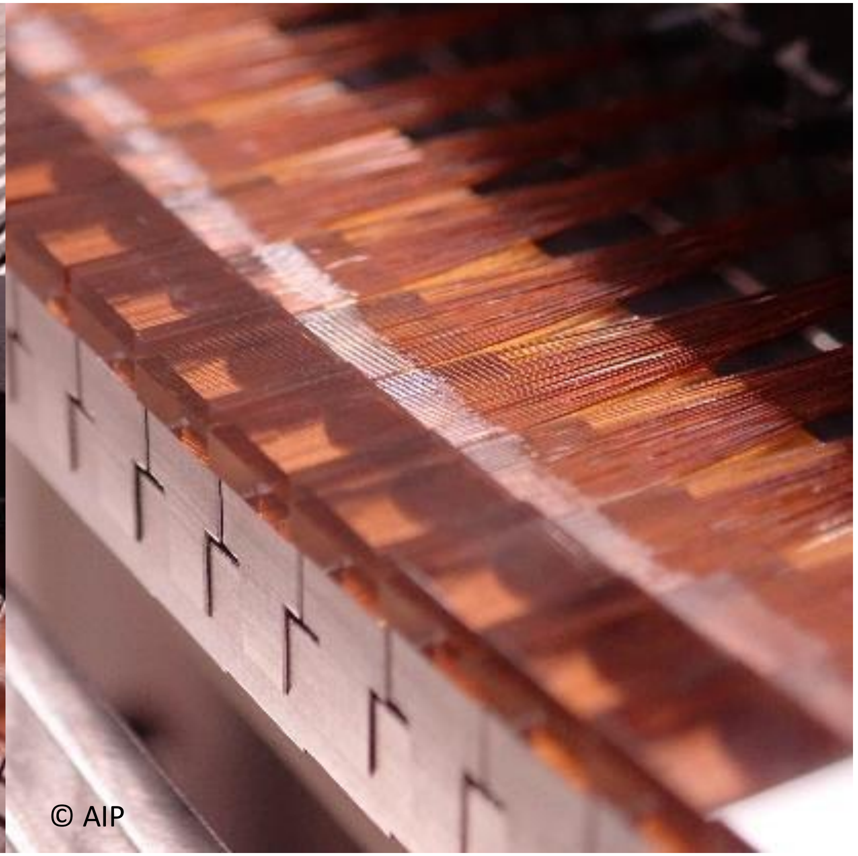


Credit: Andreas Kelz and 4MOST Consortium

Hill 1988, ASPC 3, 77

4MOST Fiber Slit Assembly





Credit: Andreas Kelz and 4MOST Consortium

Hill 1988, ASPC 3, 77

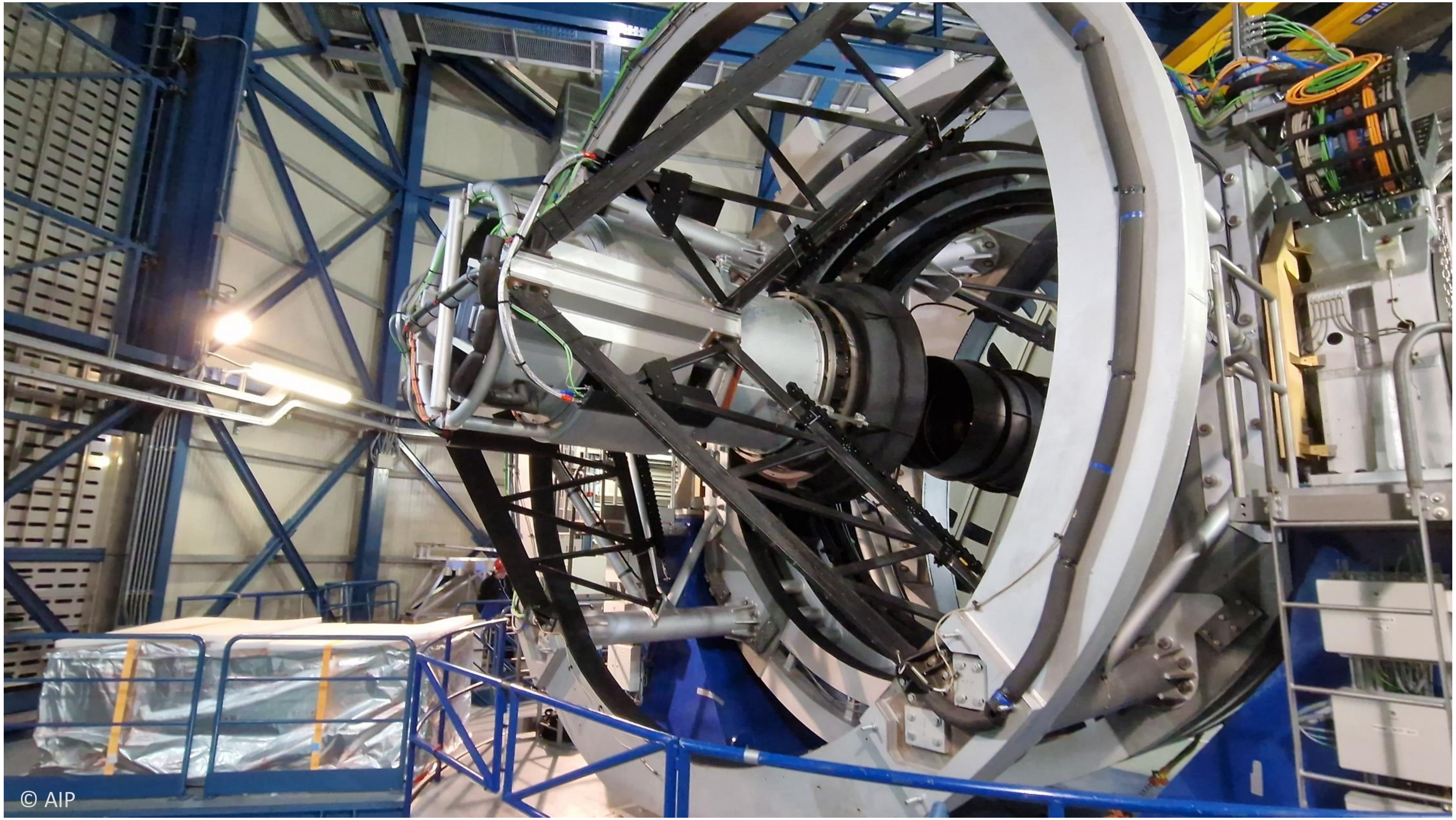
4MOST Commissioning in Chile

Credit: Andreas Kelz and 4MOST Consortium

Hill 1988, ASPC 3, 77

4MOST Commissioning in Chile

Credit: Andreas Kelz and 4MOST Consortium



4MOST Commissioning in Chile

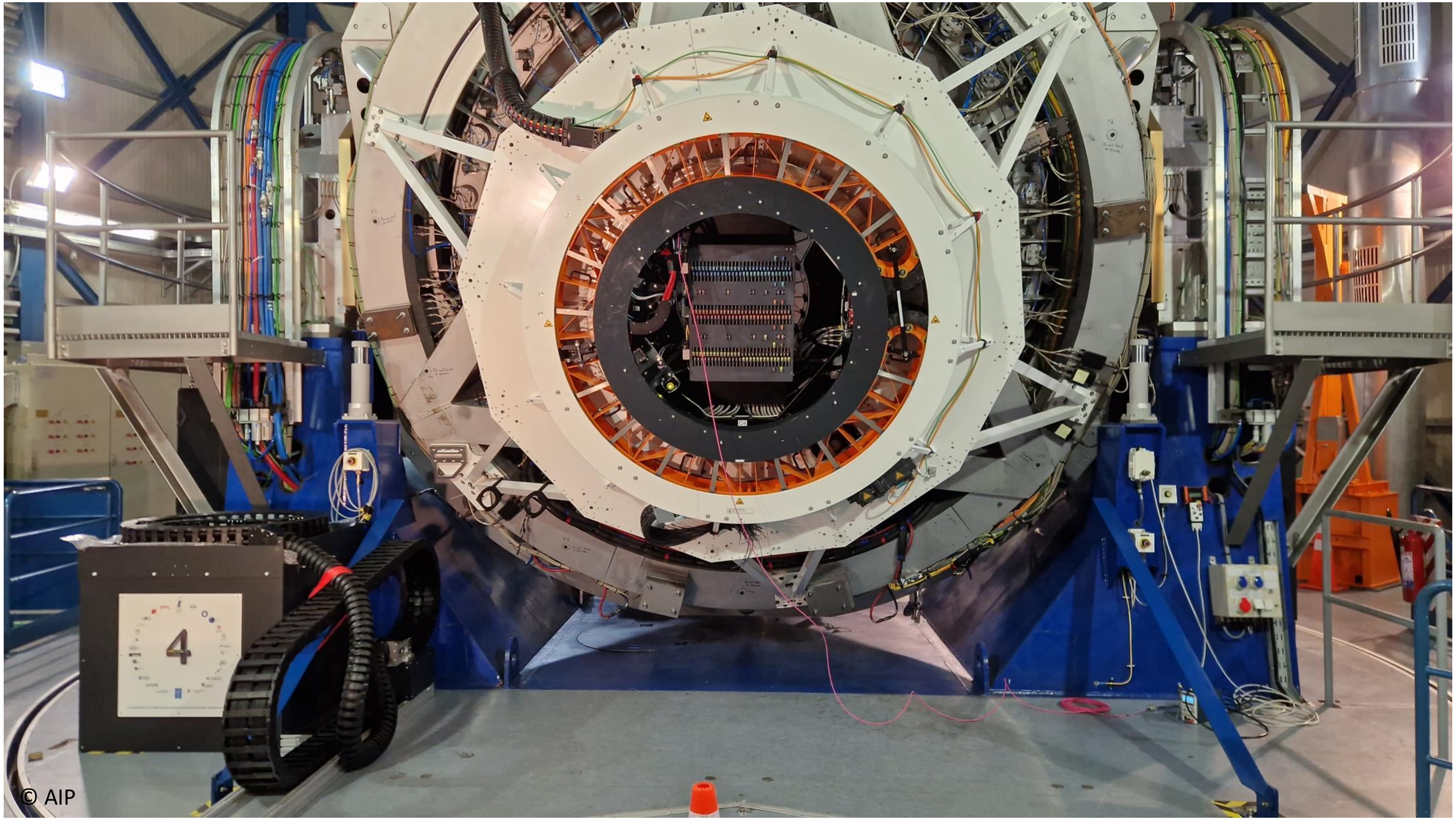
Credit: Andreas Kelz and 4MOST Consortium

4MOST Commissioning in Chile

Credit: Andreas Kelz and 4MOST Consortium

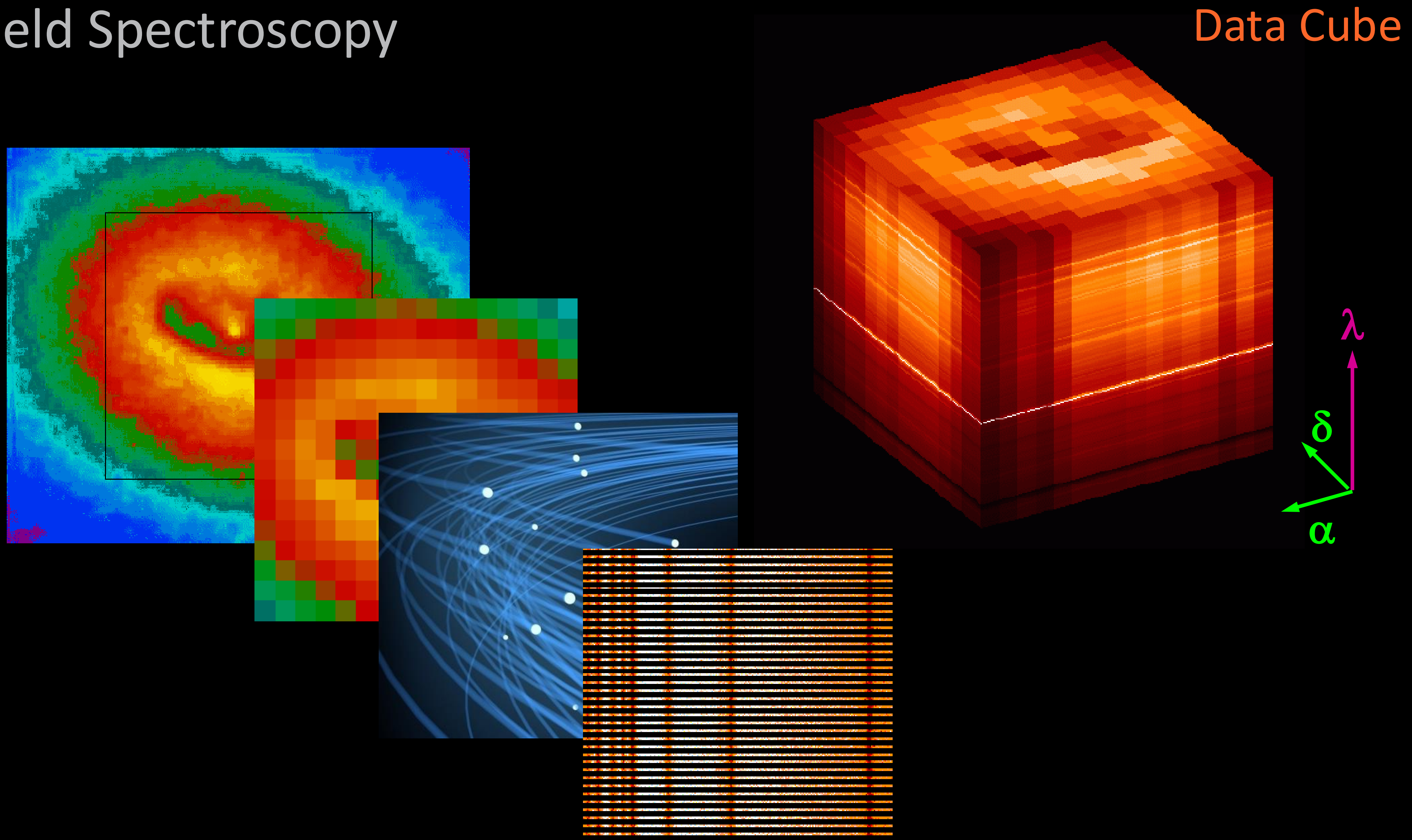
4MOST Commissioning in Chile

Credit: Andreas Kelz and 4MOST Consortium

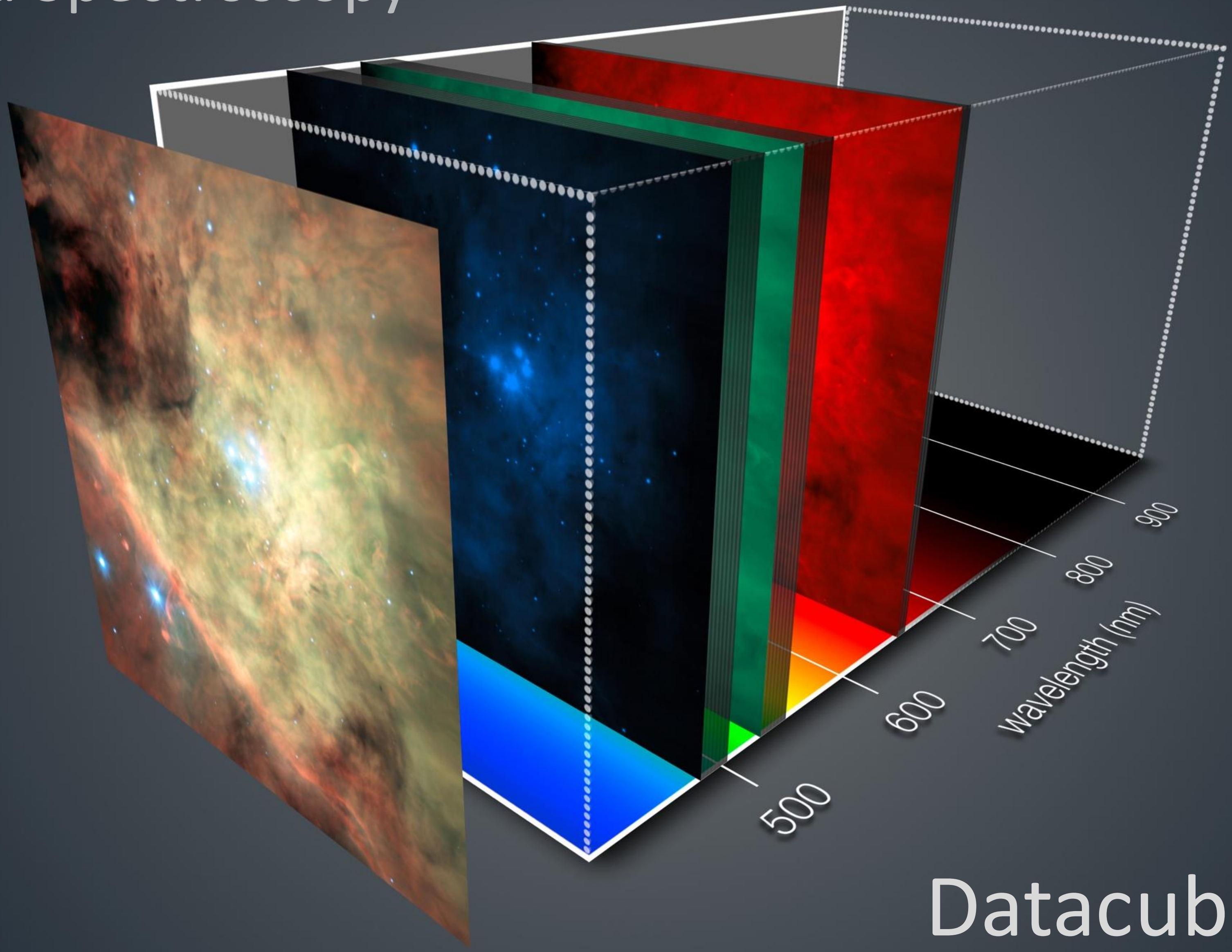


Integral Field Spectroscopy

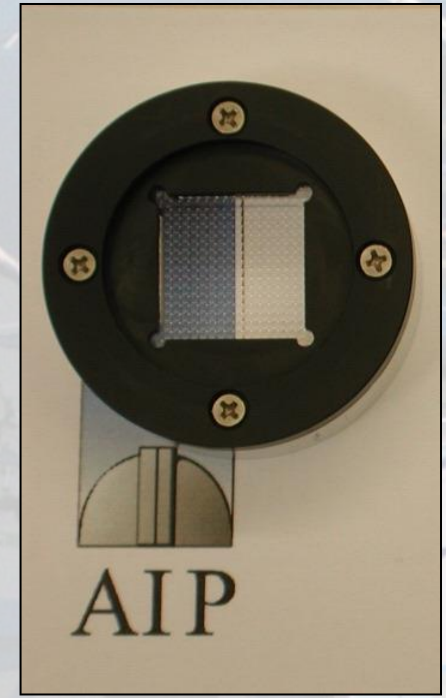
Integral Field Spectroscopy



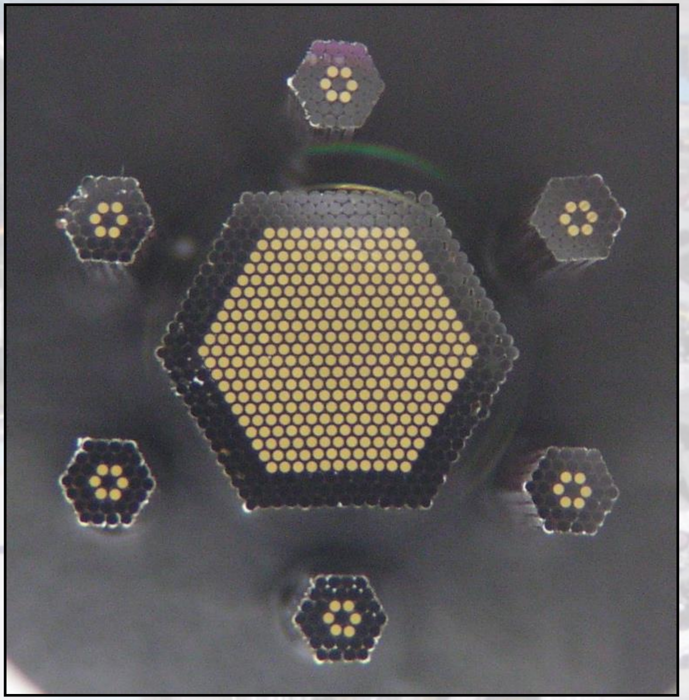
Integral Field Spectroscopy



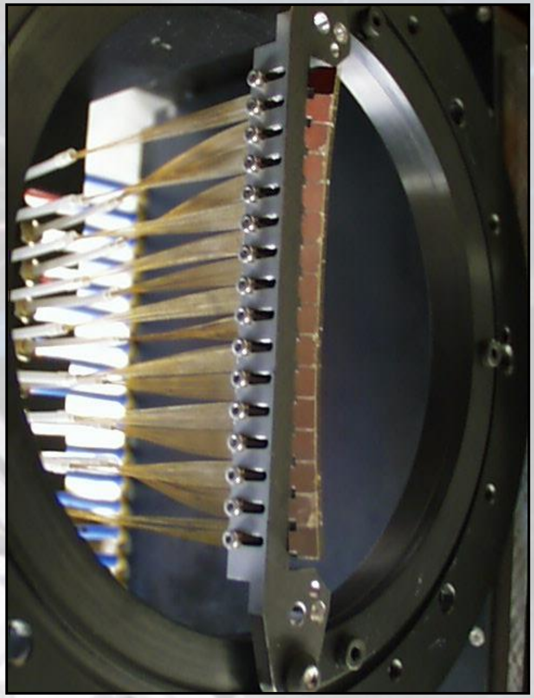
Datacube



LARR IFU



PPak IFU



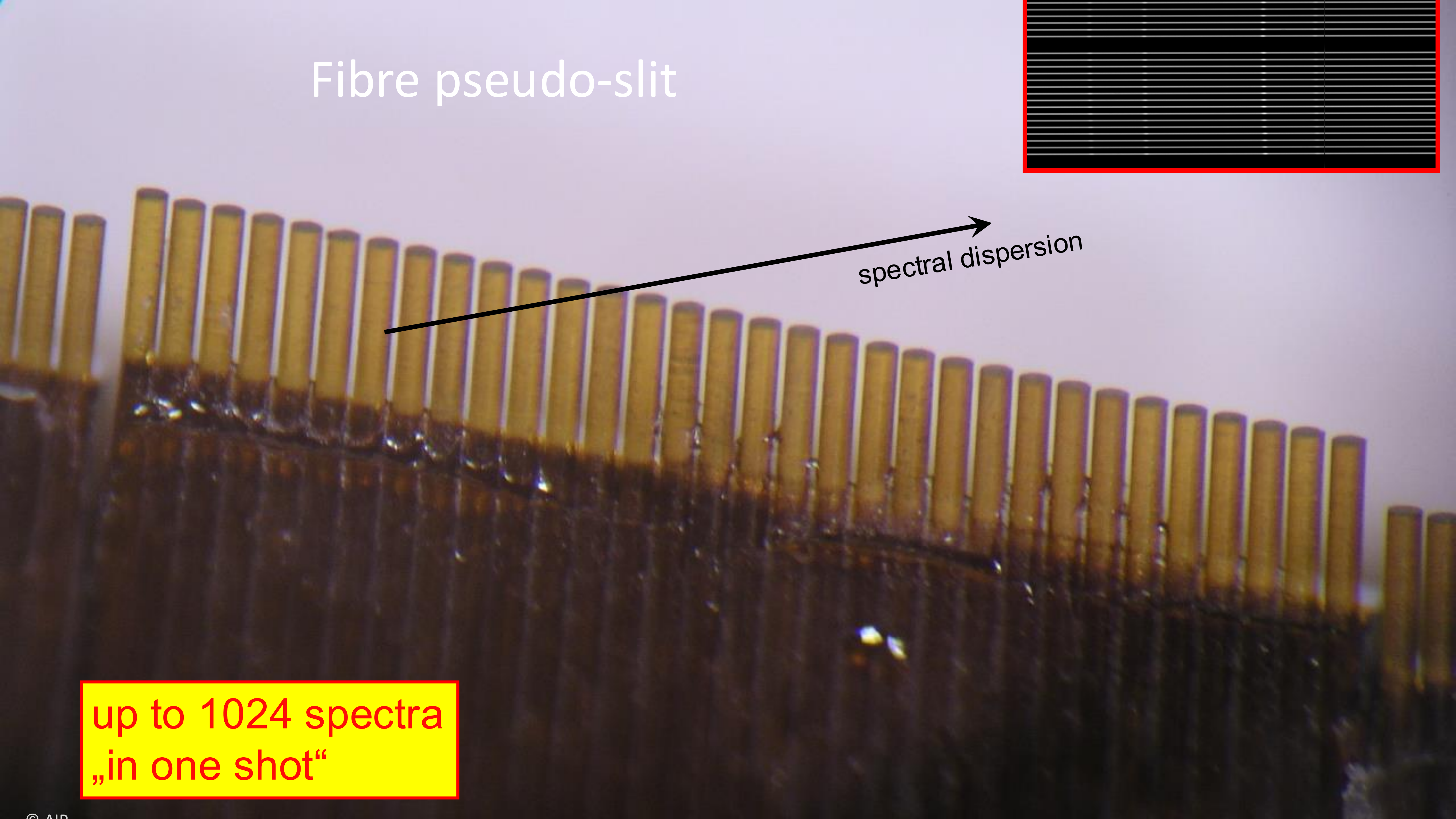
Fiber Slit

MAS

Fiber Optics

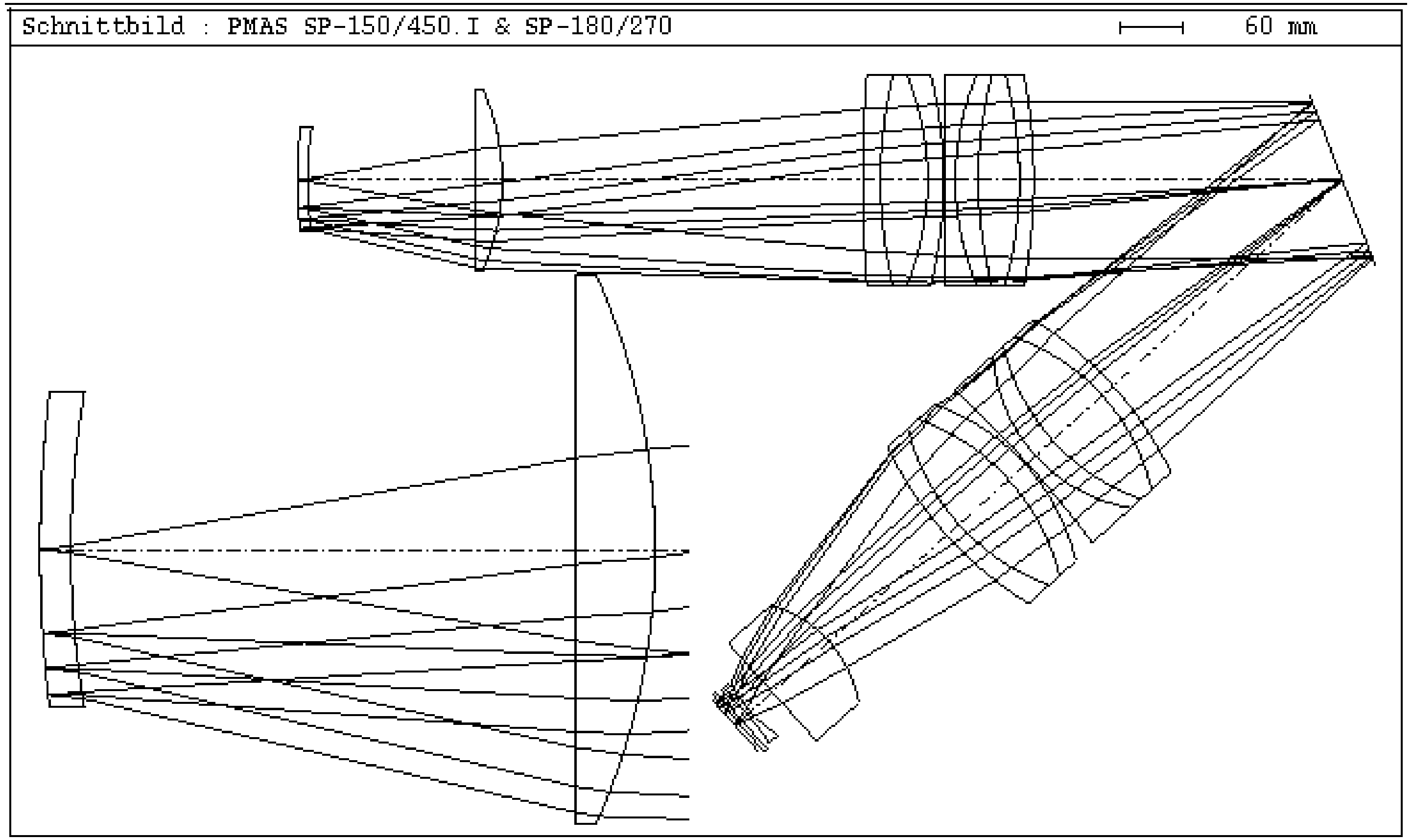
Roth et al. 2005, PASP 117, 620
Kelz et al. 2006, PASP 118, 129

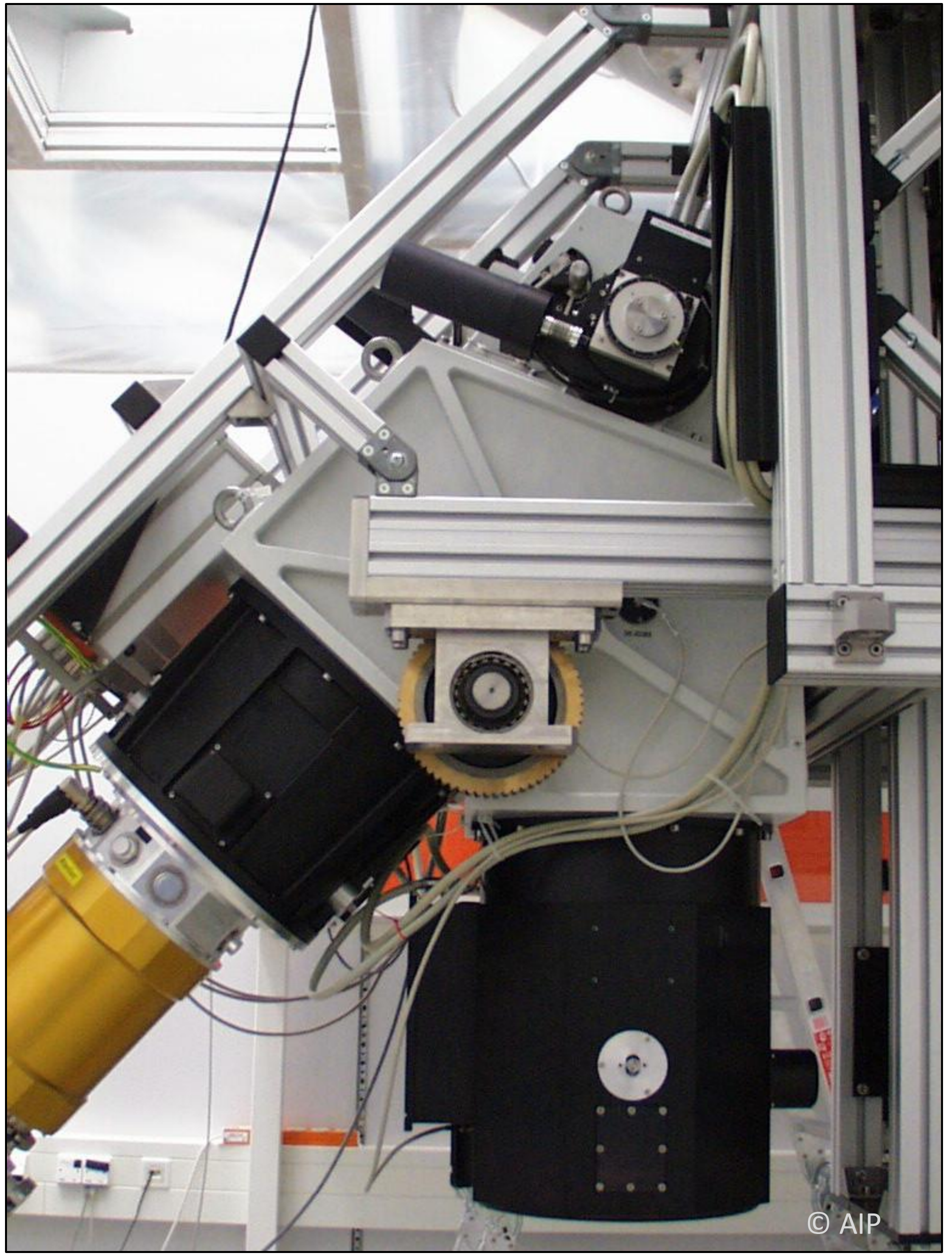
Fibre pseudo-slit



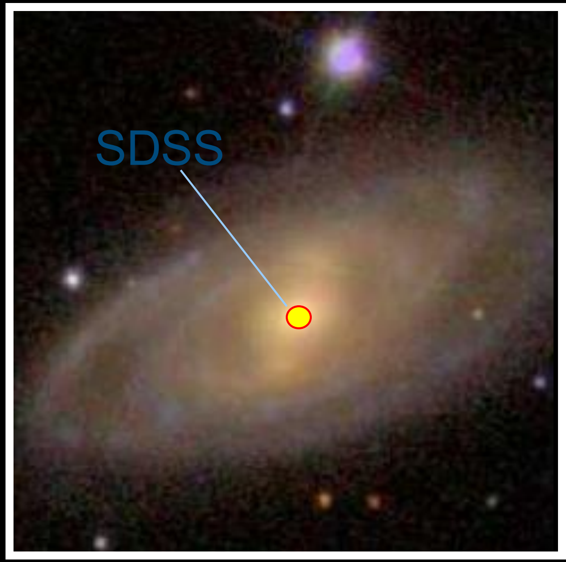
up to 1024 spectra
„in one shot“

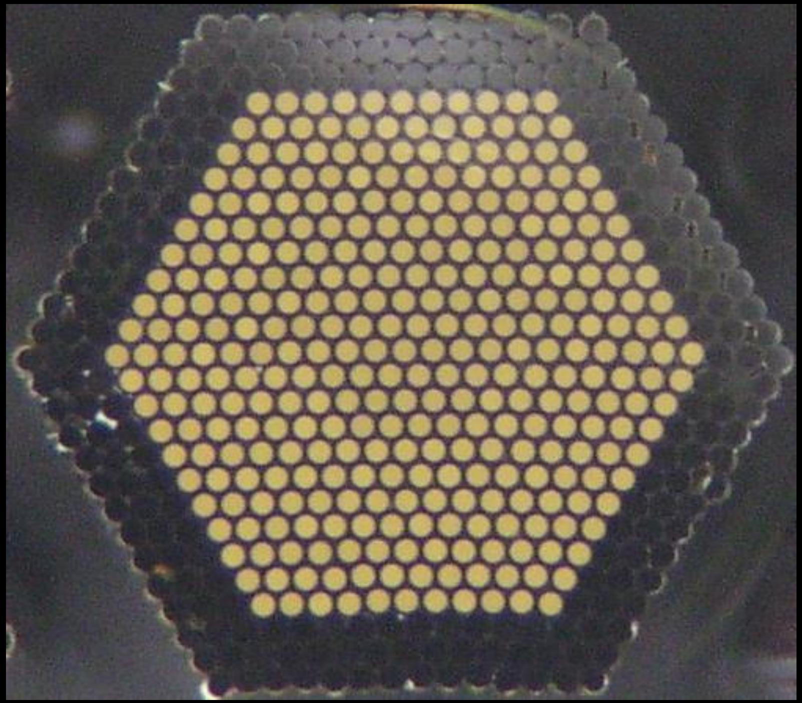
PMAS Fiber Spectrograph

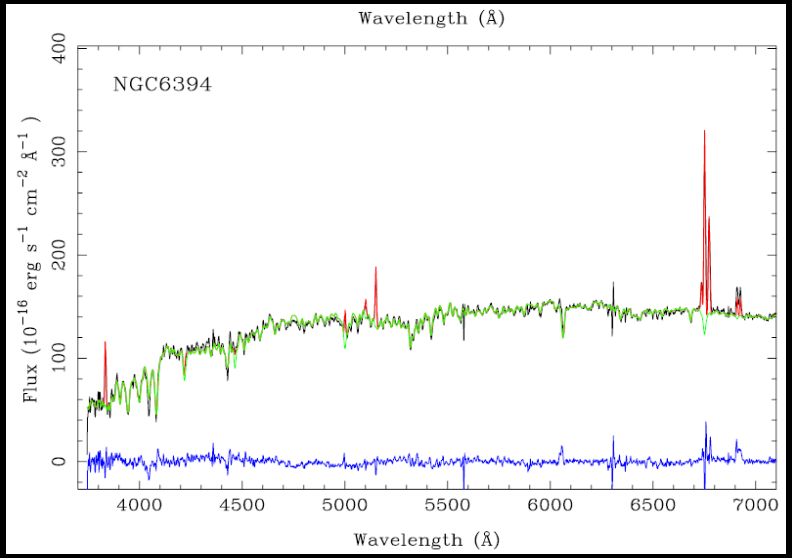




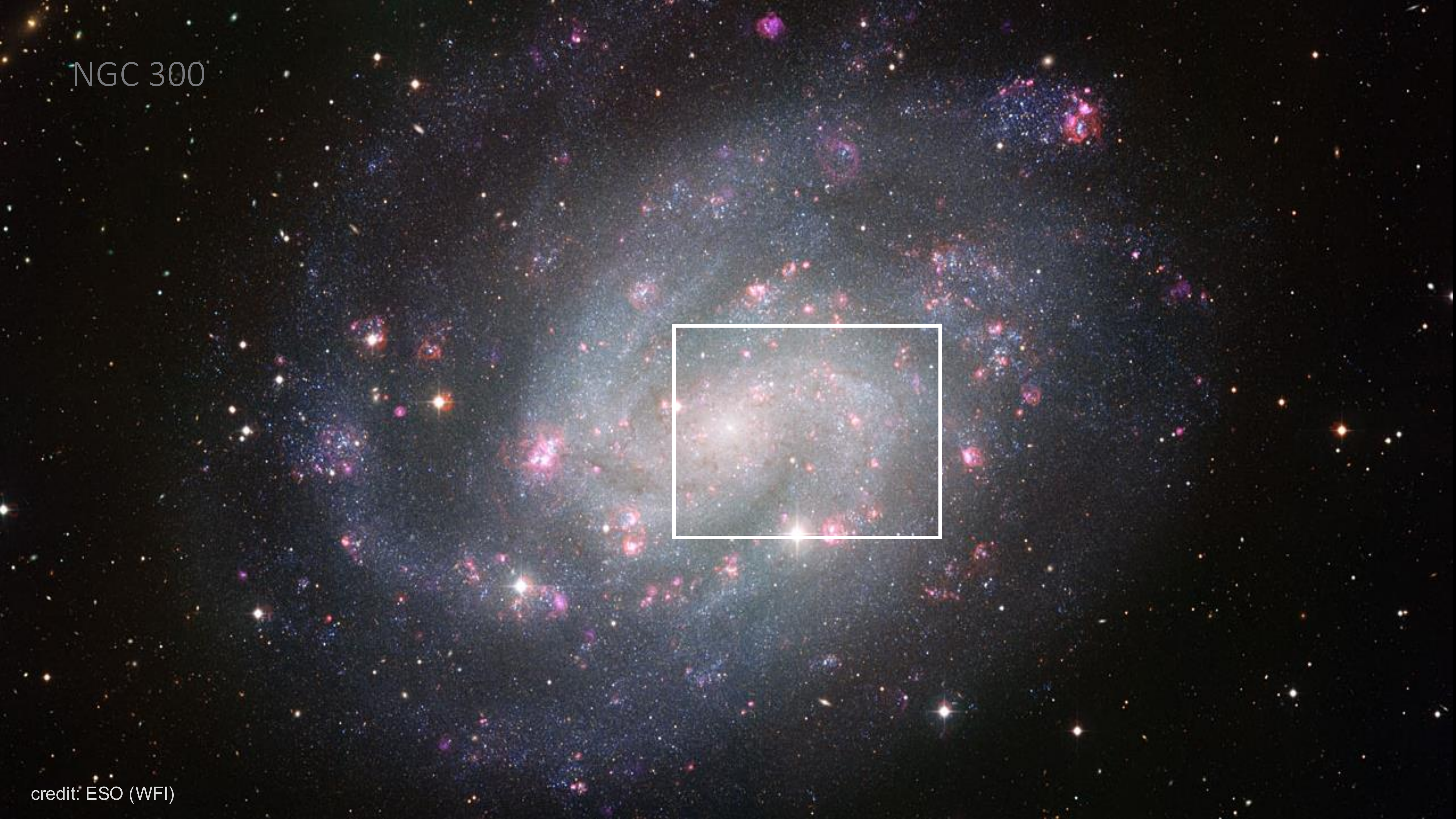
Integral Field Spectroscopy

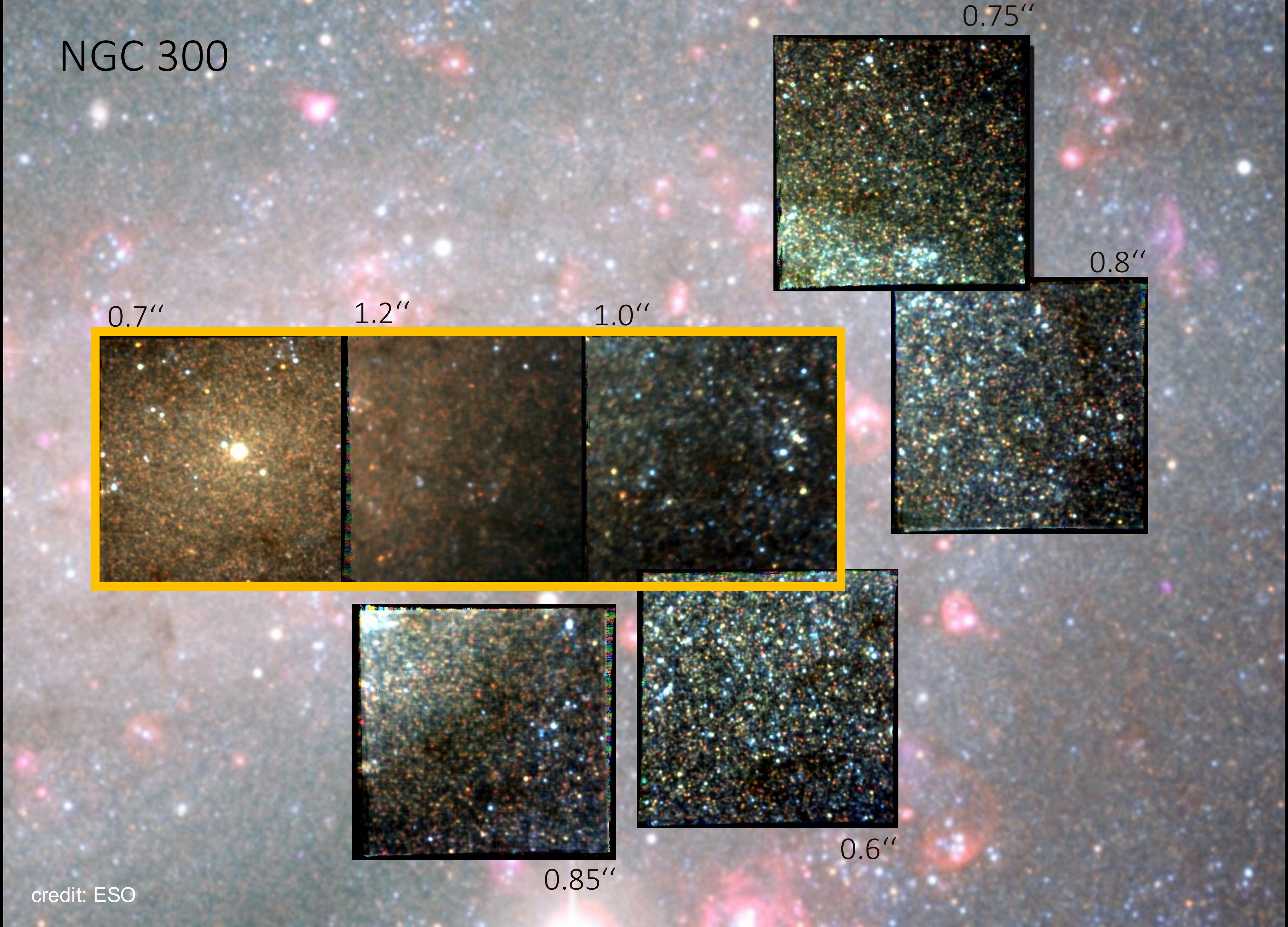




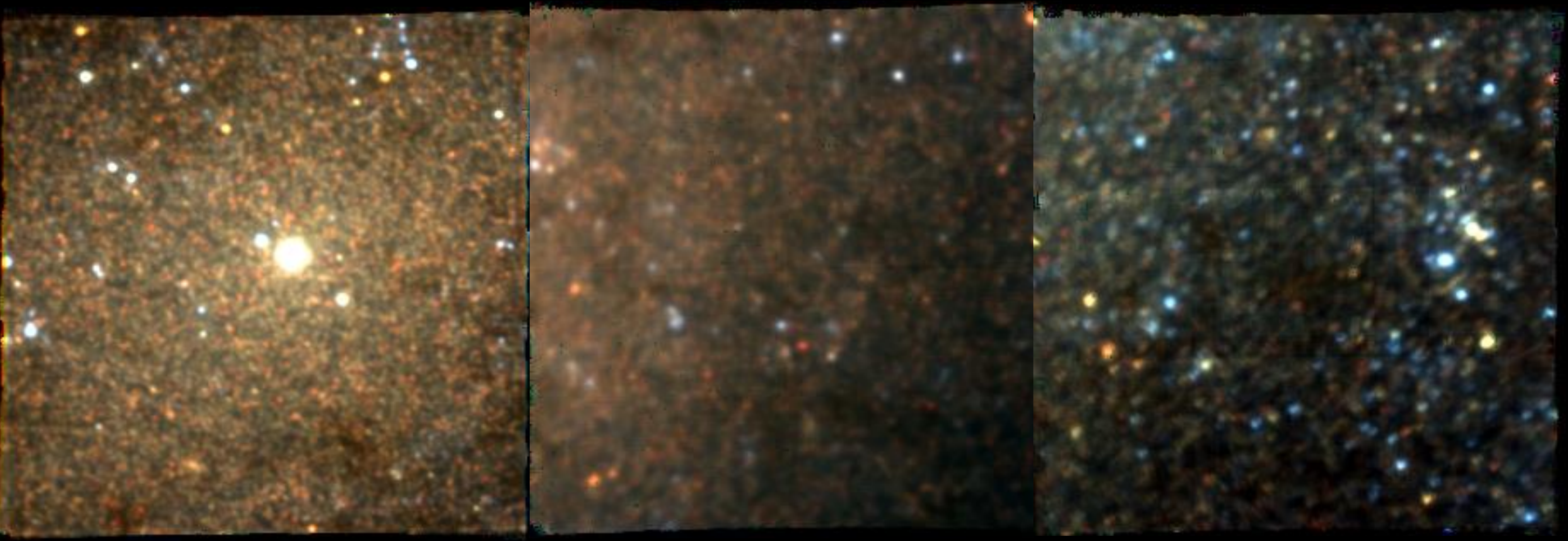



CALIFA SURVEY
Calar Altó Legacy Integral Field spectroscopy Area survey
public access:
www.caha.es/CALIFA
Home
Observed Objects
News
Publications
Contact
Next Events
CALIFA DR1
CALIFA Red Book
CALIFA Collaboration
Members
Structure
Publications
News
News
Next Events
CALIFA Sample
Observed Objects Up-to-Date
SDSS Poststamps: Obs. Sample
SDSS poststamps: Full sample
CALIFA Meetings
6th Busy Week
5th Busy Week
CALIFA 1st DATA RELEASE
NGC6125
NGC1349
NGC4003
NGC5406
UGC07012

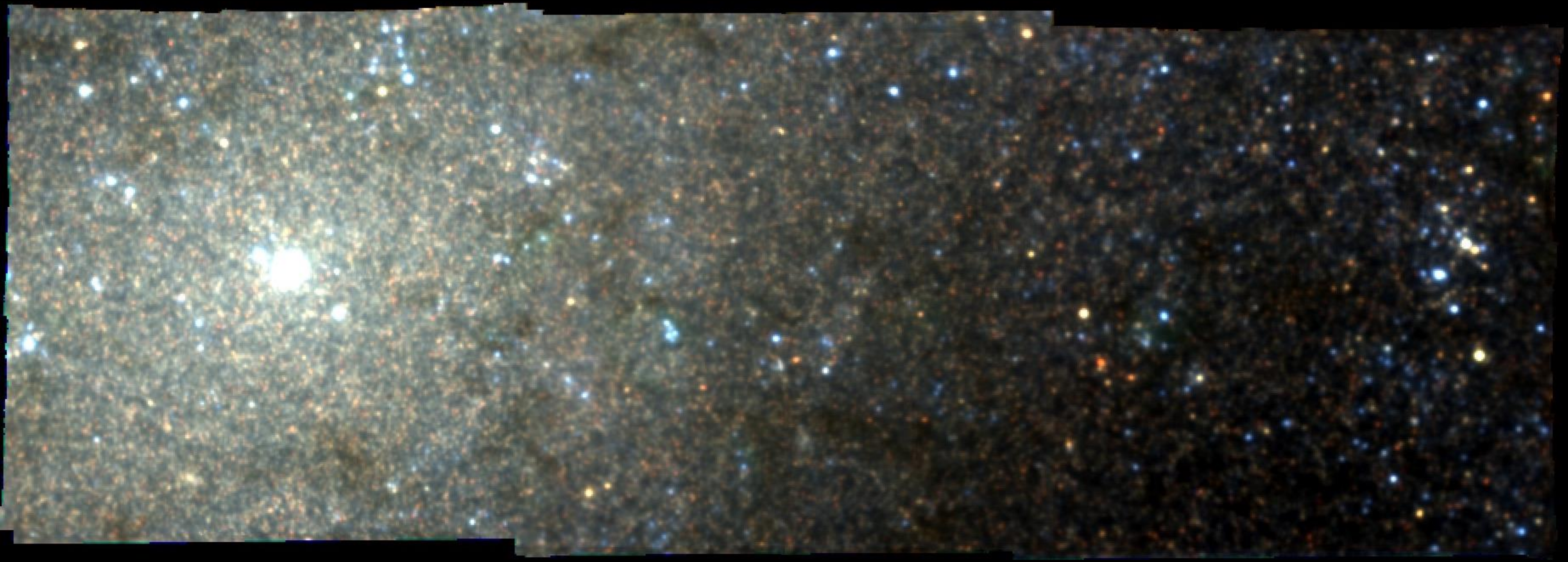

NGC 300
credit: ESO (WFI)


NGC 300
0.75′′
0.8′′
0.7′′
1.2′′
1.0′′
0.85′′
0.6′′
credit: ESO

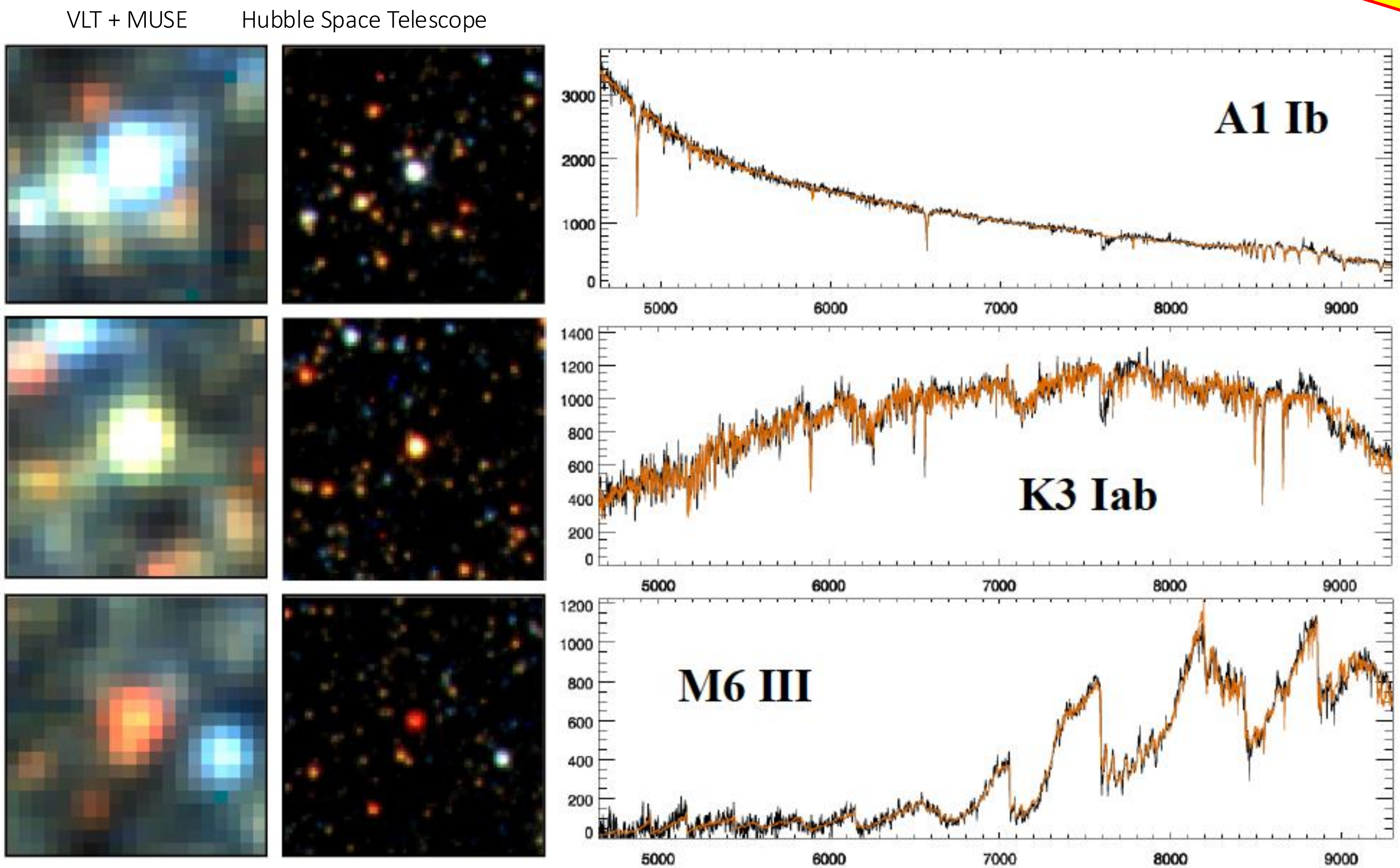
without Adaptive Optics



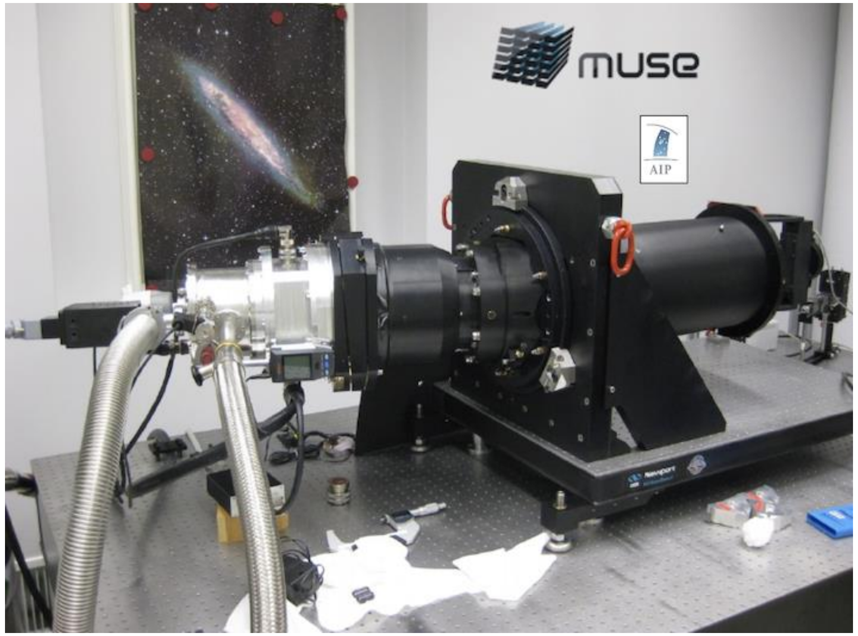
with Adaptive Optics

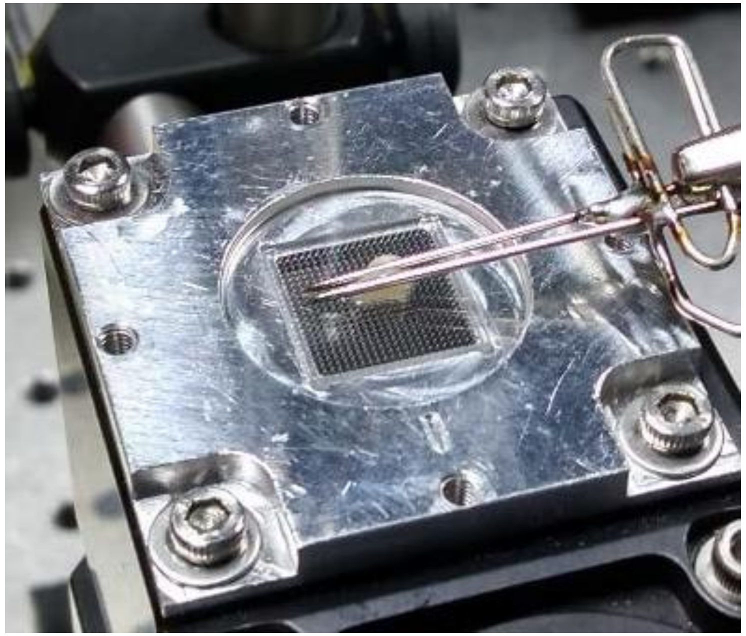


Images and *spectra* of individual stars:

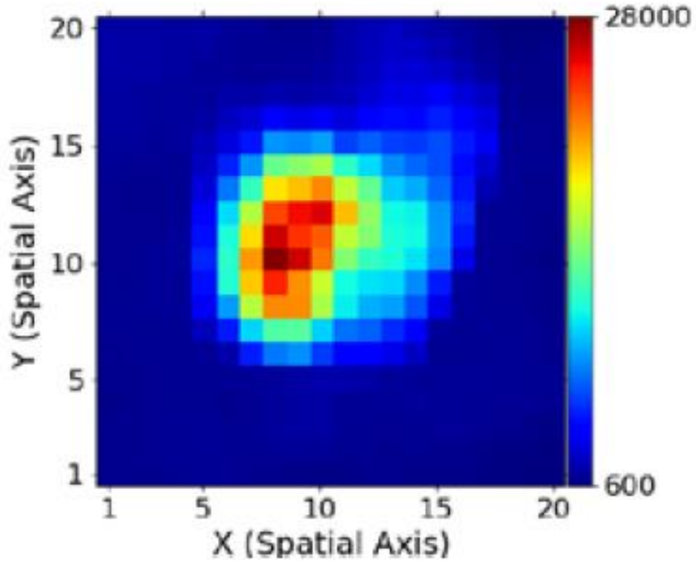


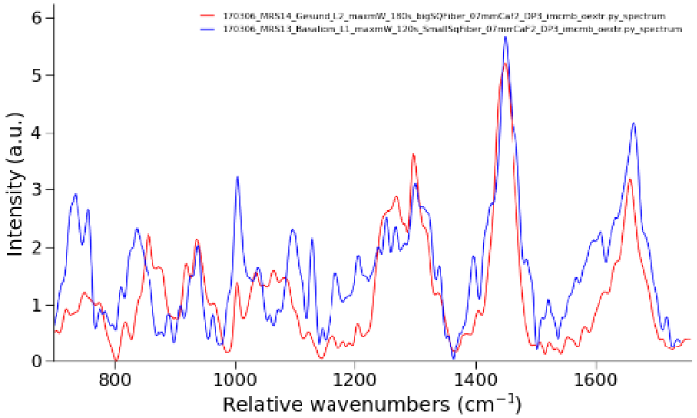
Excursion: Technology Transfer





clinical sample of
basal cell carcinoma (BCC)

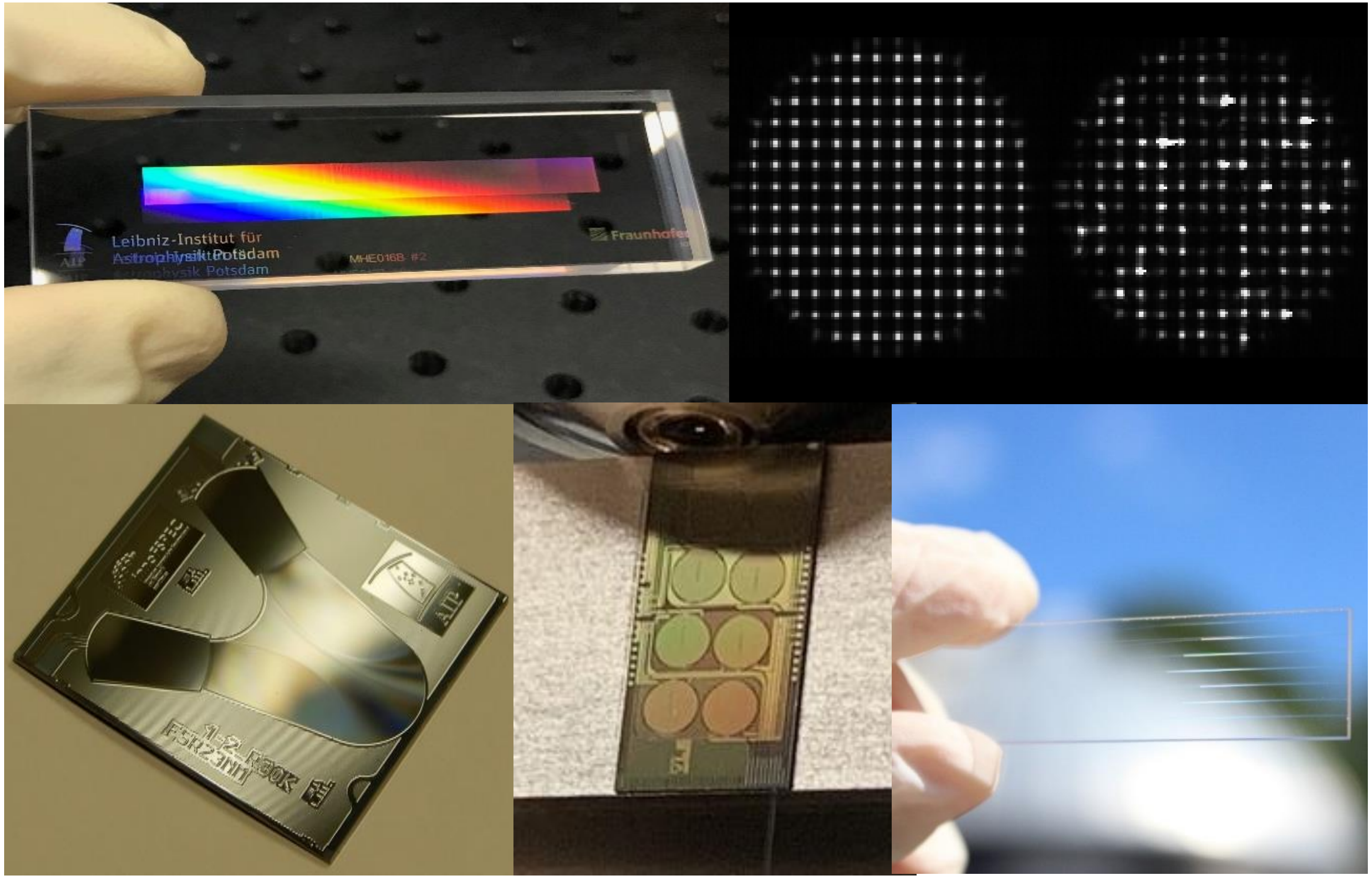




malign tissue
benign tissue

muse
Transfer

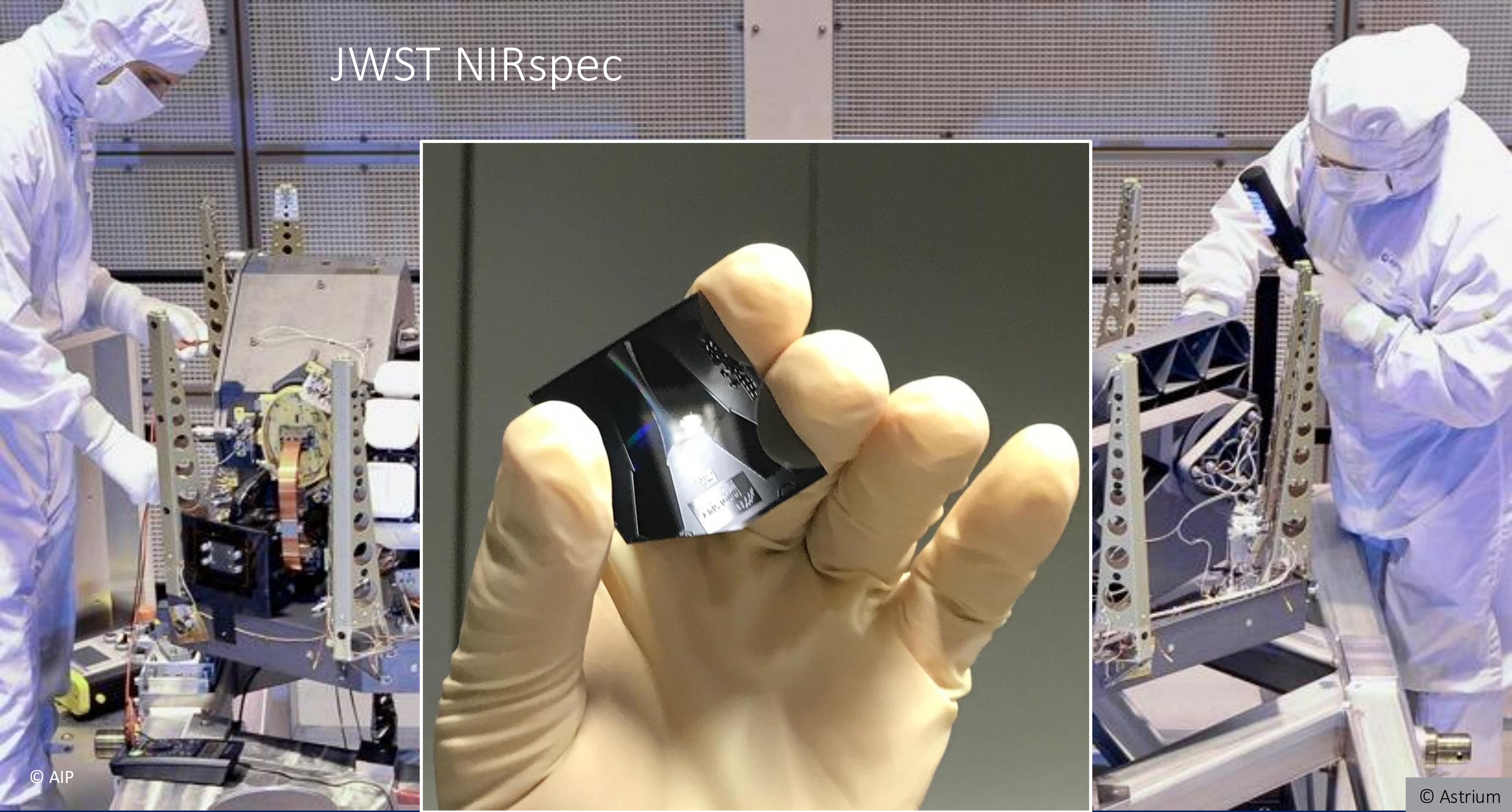
Astrophotonics



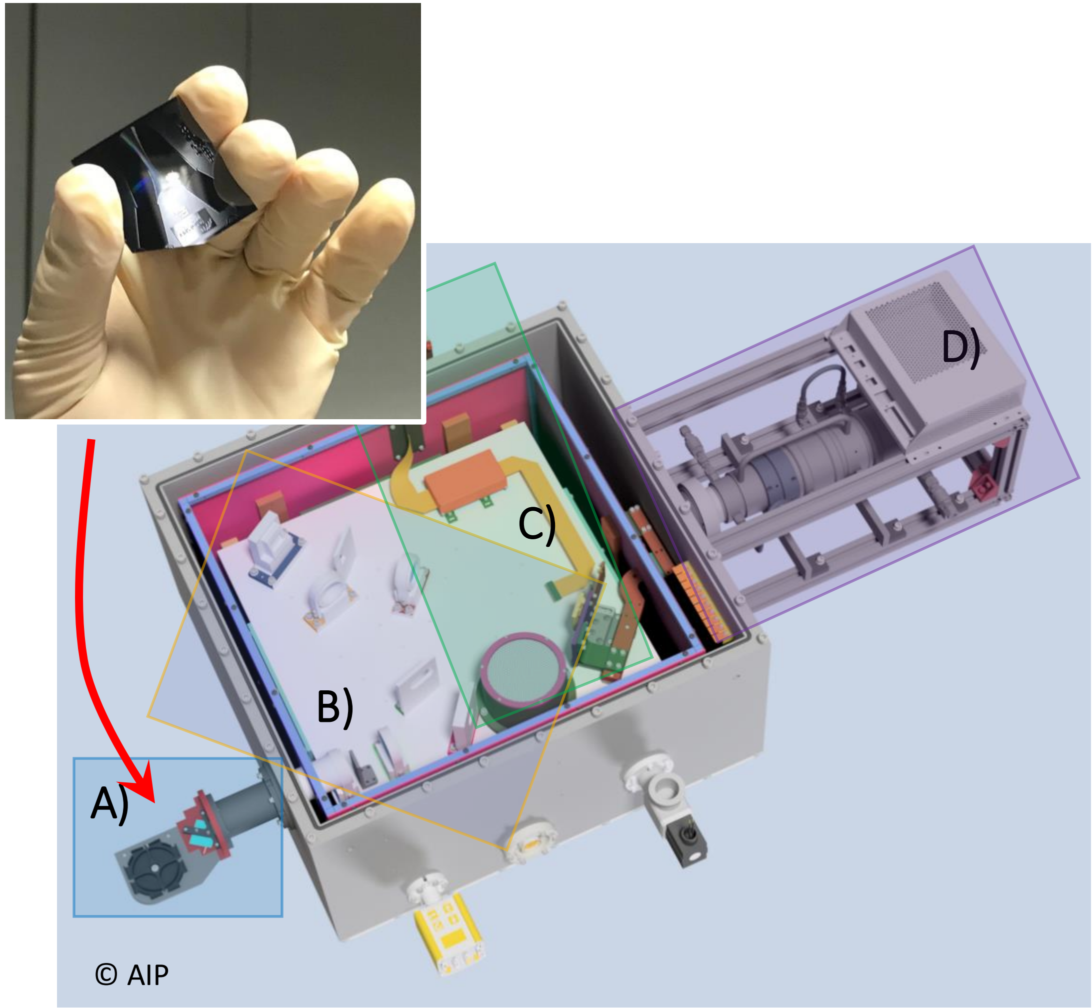
© AIP

1. Complex FBG Filters & Phase Masks
2. Photonic Lanterns for AO & Spectroscopy
3. AWGs for Spectroscopy
4. Ring Resonators for Frequency Combs
5. Beam Combiners for Interferometry

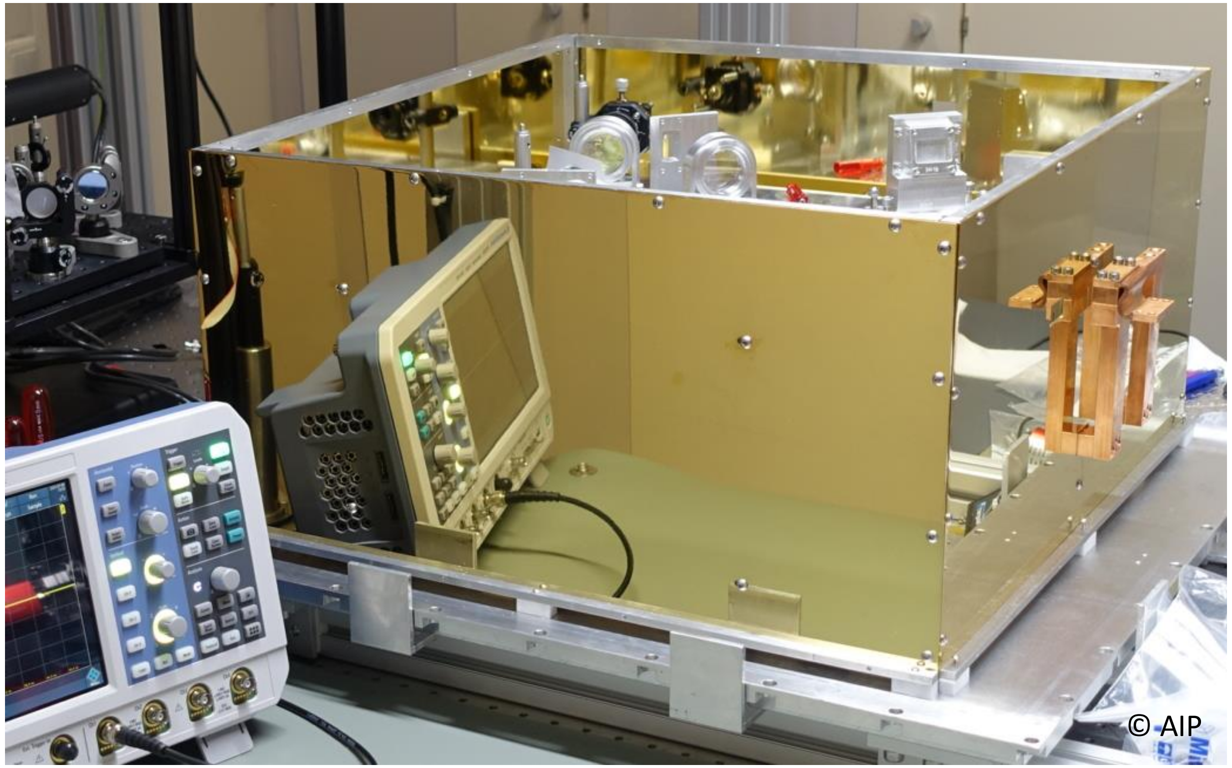
JWST NIRspec



PAWS: Potsdam Arrayed Waveguide Spectrograph



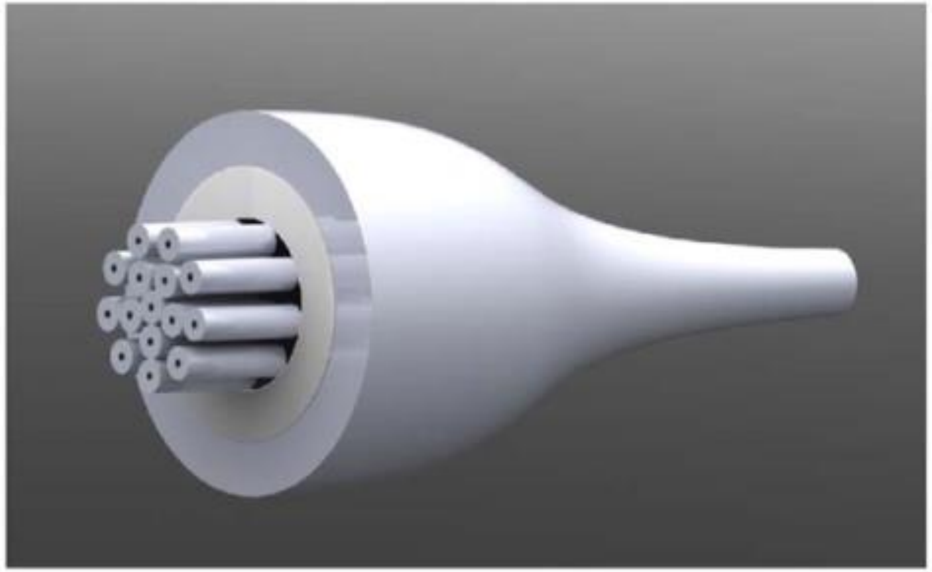
CAD View



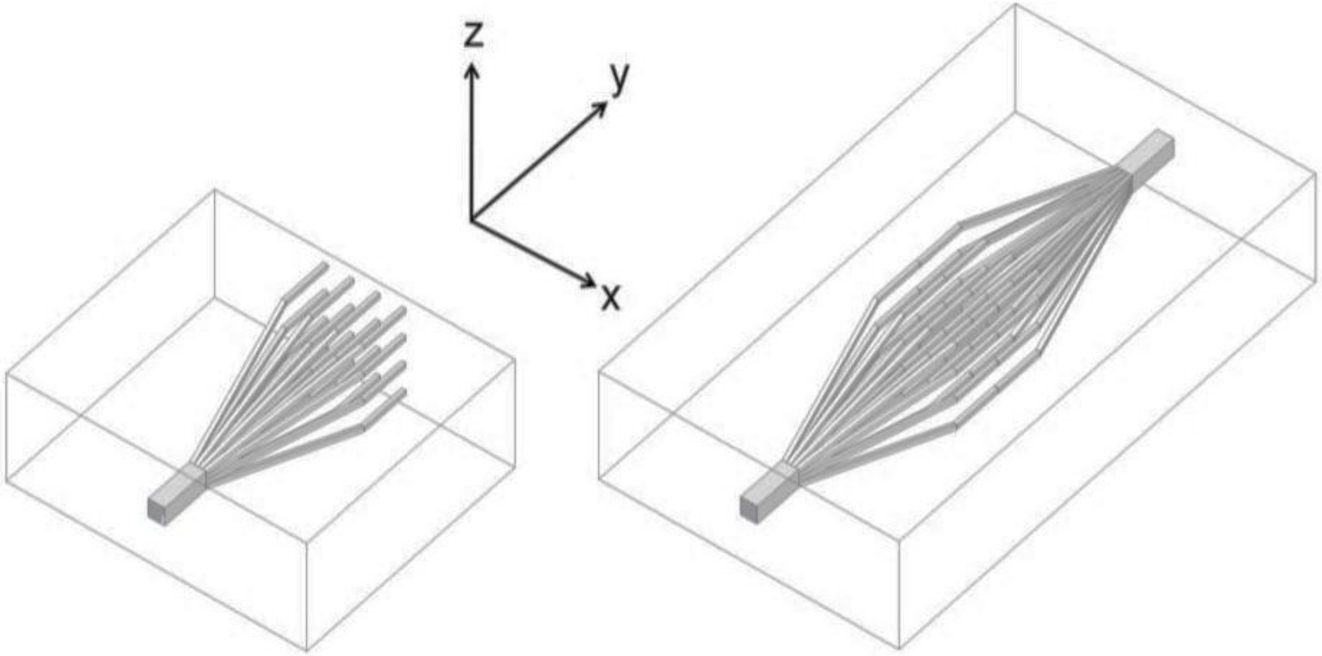
PAWS assembled in the lab

Photonic Lanterns

Mode converter: SMF to MMF, or vice versa

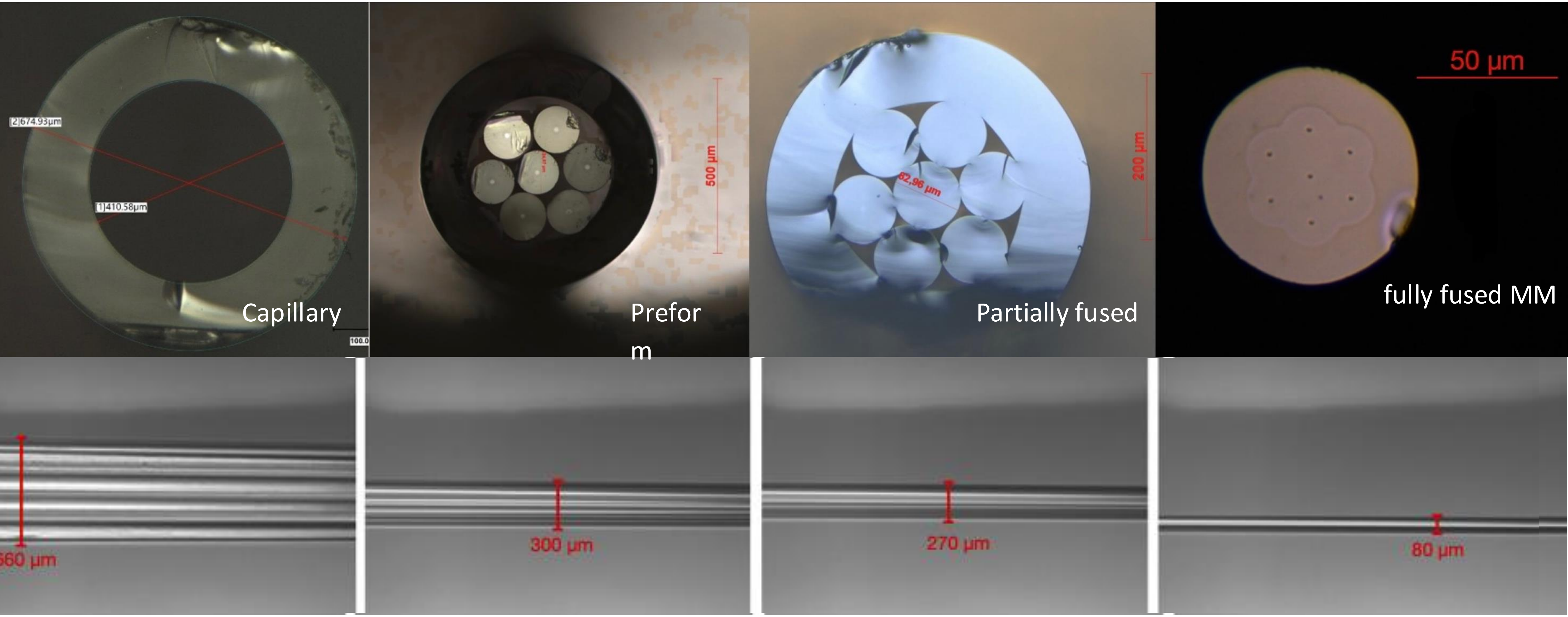


Velázquez-Benítez, et al. 2018



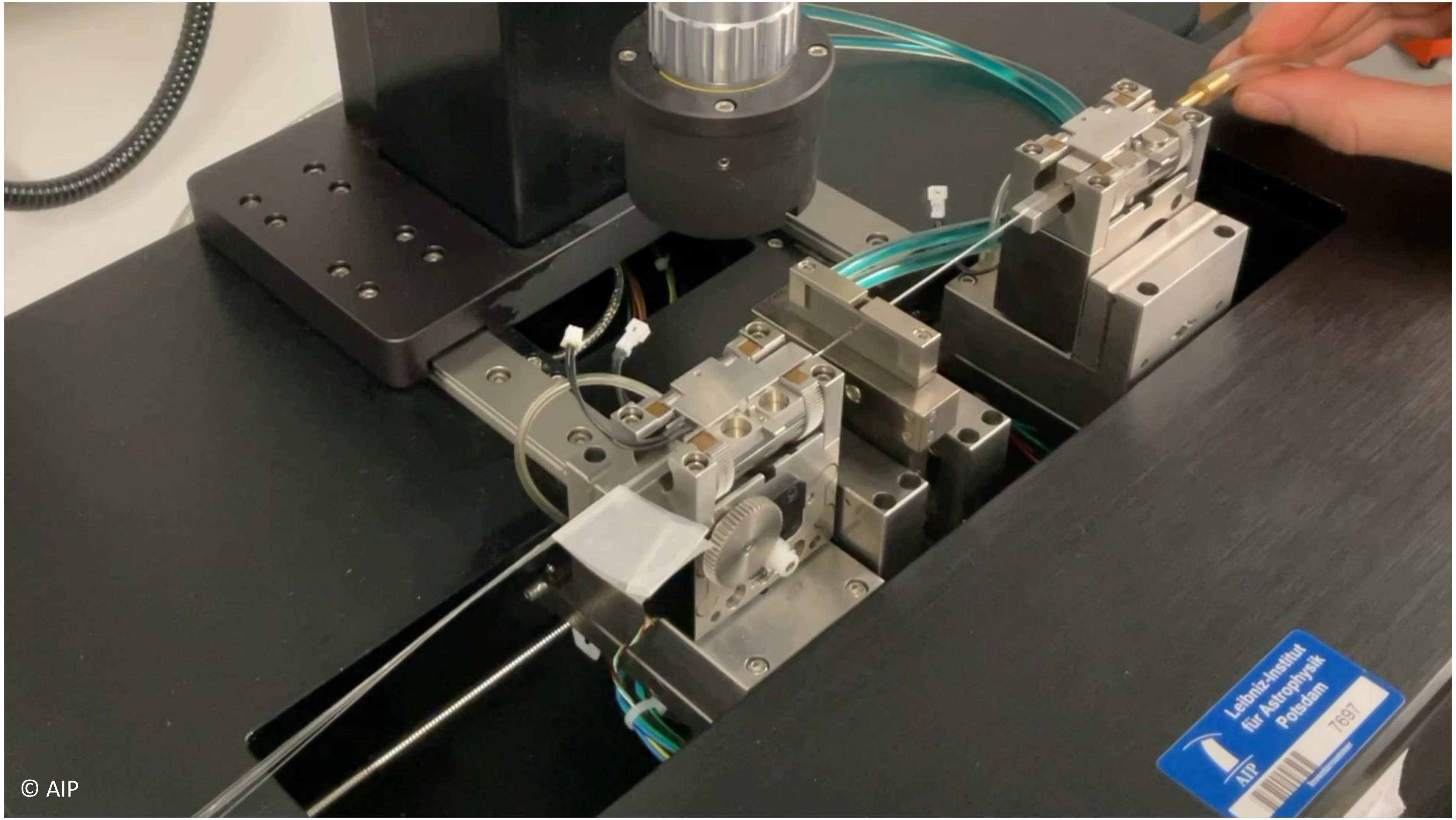
Thomson, R. R. et al. Optics Exp. 19 6 (2011): 5698-705

Photonic Lanterns



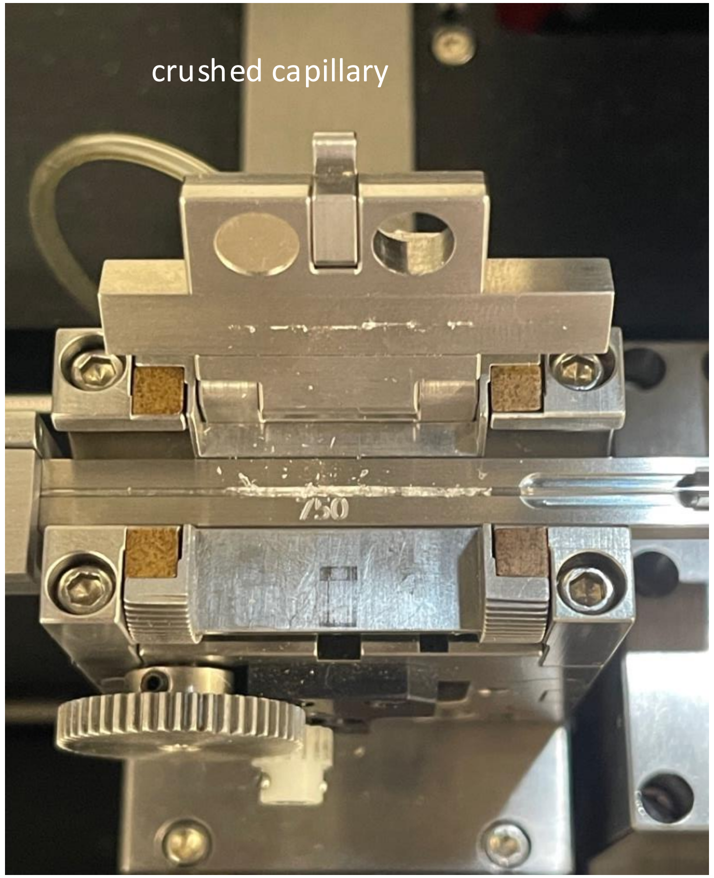
Rypalla J., et al. 2024, Proc. SPIE 13100, 131006P

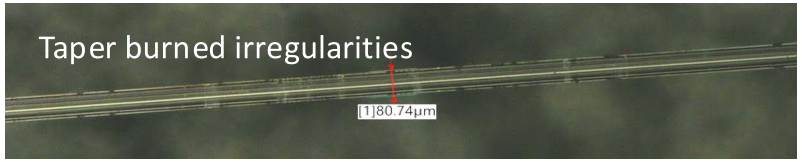
Photonic Lanterns

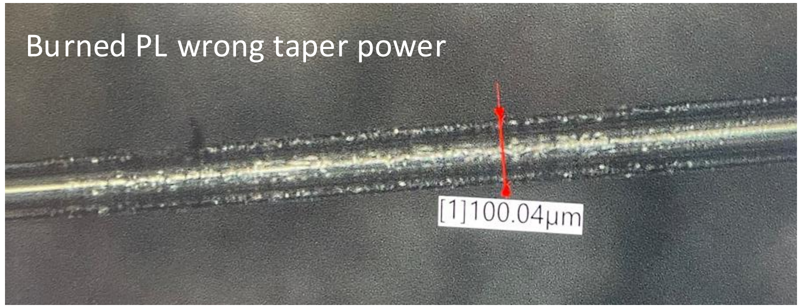


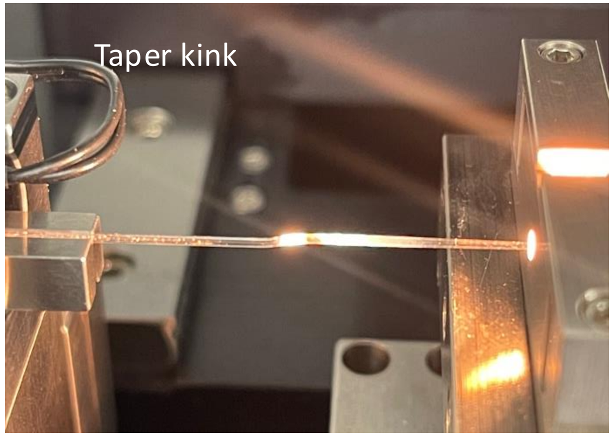
Credit : Julian Rypalla, Kalaga Madhav (AIP)

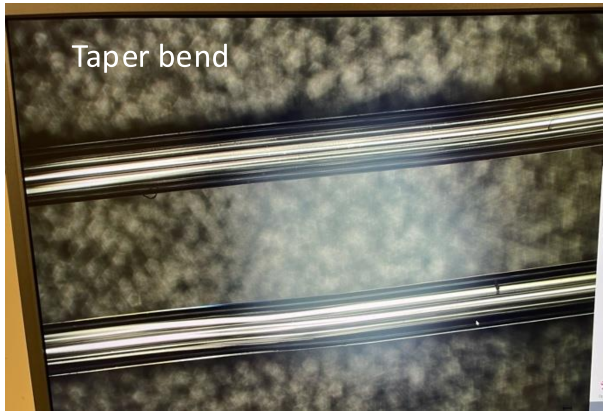
Photonic Lanterns (and what can go wrong…)







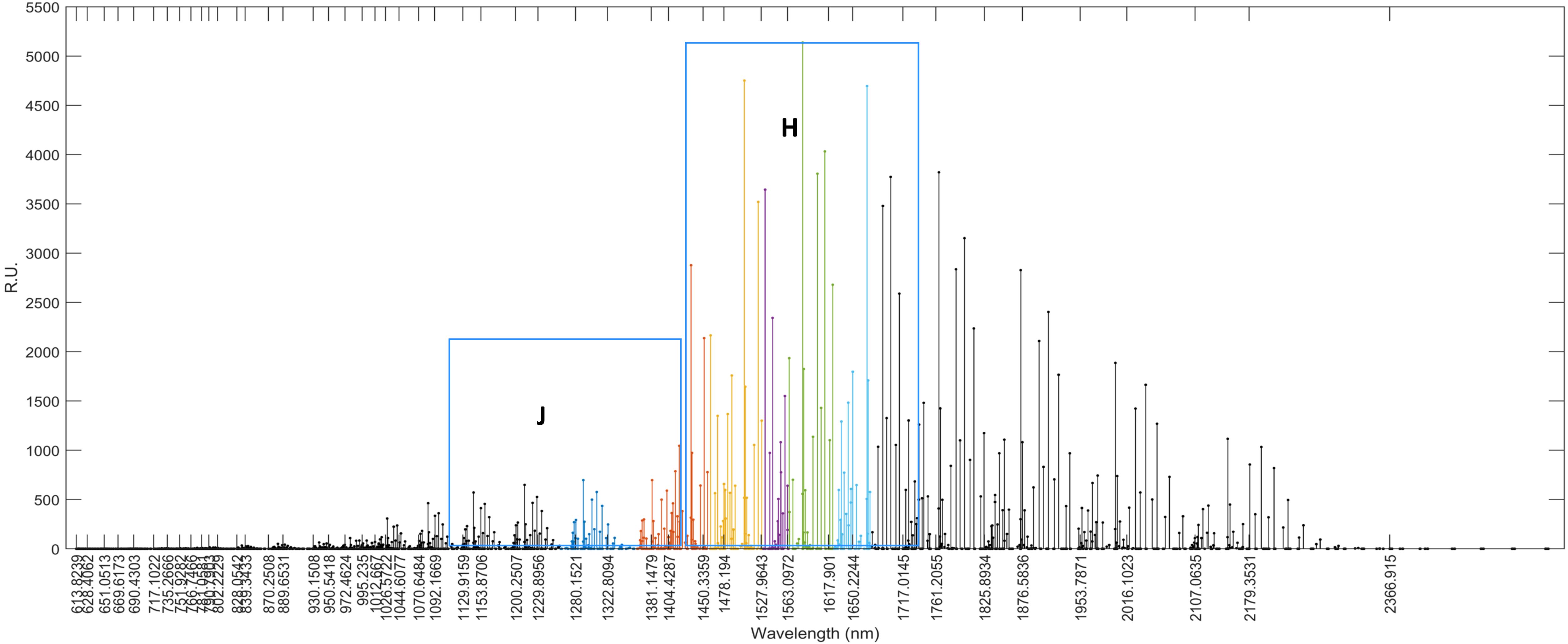




Credit : Julian Rypalla, Kalaga Madhav (AIP)

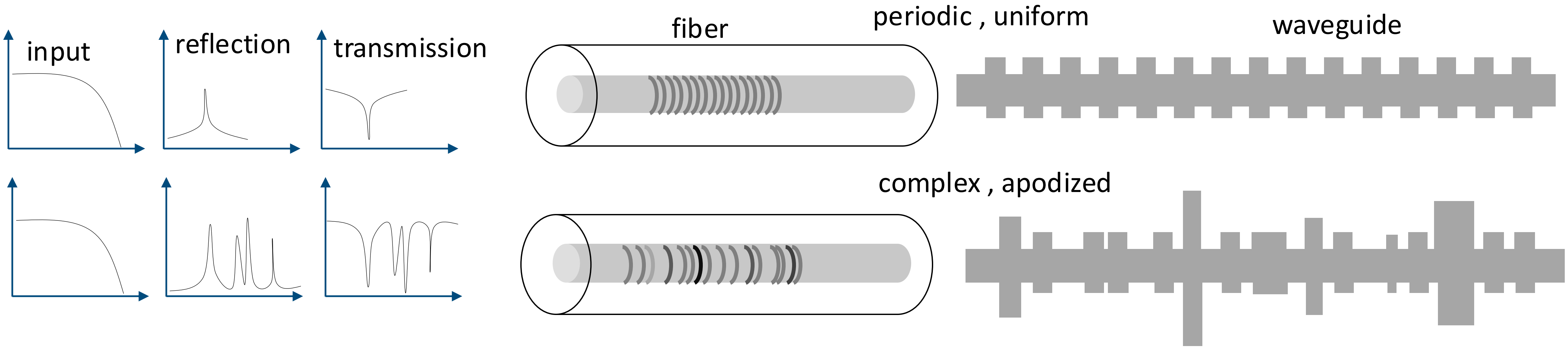
Fiber Bragg Gratings for OH Line Filters

The problem: extremely bright and highy variable OH emission lines in the NIR



Fiber Bragg Gratings for OH Line Filters

Bragg gratings are periodic or aperiodic structures inscribed into a waveguide, typically by changing the refractive index by periodic high power laser inscription



Credit : Aashia Rahman, Kalaga Madhav (AIP)

Fiber Bragg Gratings for OH Line Filters

- Suppress OH lines before light enters spectrograph at high resolution (R = 10,000), maintain high throughput (>80%)

Opt. Express Vol. 12, Issue 24, 5902 (2004)

New approach to atmospheric OH suppression using …

Rec…

m.englu…

-30

The Astronomical Journal, 145:51 (13pp), 2013 February
doi:10.1088/0004-6256/145/2/51

GNOSIS: THE FIRST INSTRUM…

Christopher Q. Trinh[1], Simon C. Ell…
Sergio G. Leon-Saval[3], Keith Shortr…
Kenneth Freeman[6], Hans-Gerd Löhm…
John O'Byrne[1], Stan Miziarski[2], Mart…
[1] Sydney Institute for Astronomy, School…
[2] Australian Astronomical O…
[3] Institute of Photonics and Opt…
[4] Department of P…
[5] Centre for Astrophysics and Supercomp…
[6] Research School of Astronomy ar…
[7] innoFSPEC-Institut für Chemie/Physikalische…
[8] innoFSPEC-Leibniz-Institut…
[9] Department of Astrophysi…
Received 2012 A…

Monthly Notices of the Royal Astronomical Society
MNRAS **492**, 2796–2806 (2020)
Advance Access publication 2020 January 8
doi:10.1093/mnras/staa028

First demonstration of OH suppression in a high-efficiency near-infrared spectrograph

S. C. Ellis,[1,2★] J. Bland-Hawthorn,[2,3] J. S. Lawrence,[1] A. J. Horton,[1] R. Content,[1] M. M. Roth,[4] N. Pai,[1] R. Zhelem,[1] S. Case,[1] E. Hernandez,[4] S. G. Leon-Saval,[2,3] R. Haynes,[5] S. S. Min,[3] D. Giannone,[4] K. Madhav,[4] A. Rahman,[4] C. Betters,[3] D. Haynes,[5] W. Couch,[1] L. J. Kewley,[5] R. McDermid,[6] L. Spitler,[6] R. G. Sharp[5] and S. Veilleux[7,8]

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[2] *Sydney Institute for Astronomy (SIfA), School of Physics A28, University of Sydney, Sydney, NSW 2006, Australia*
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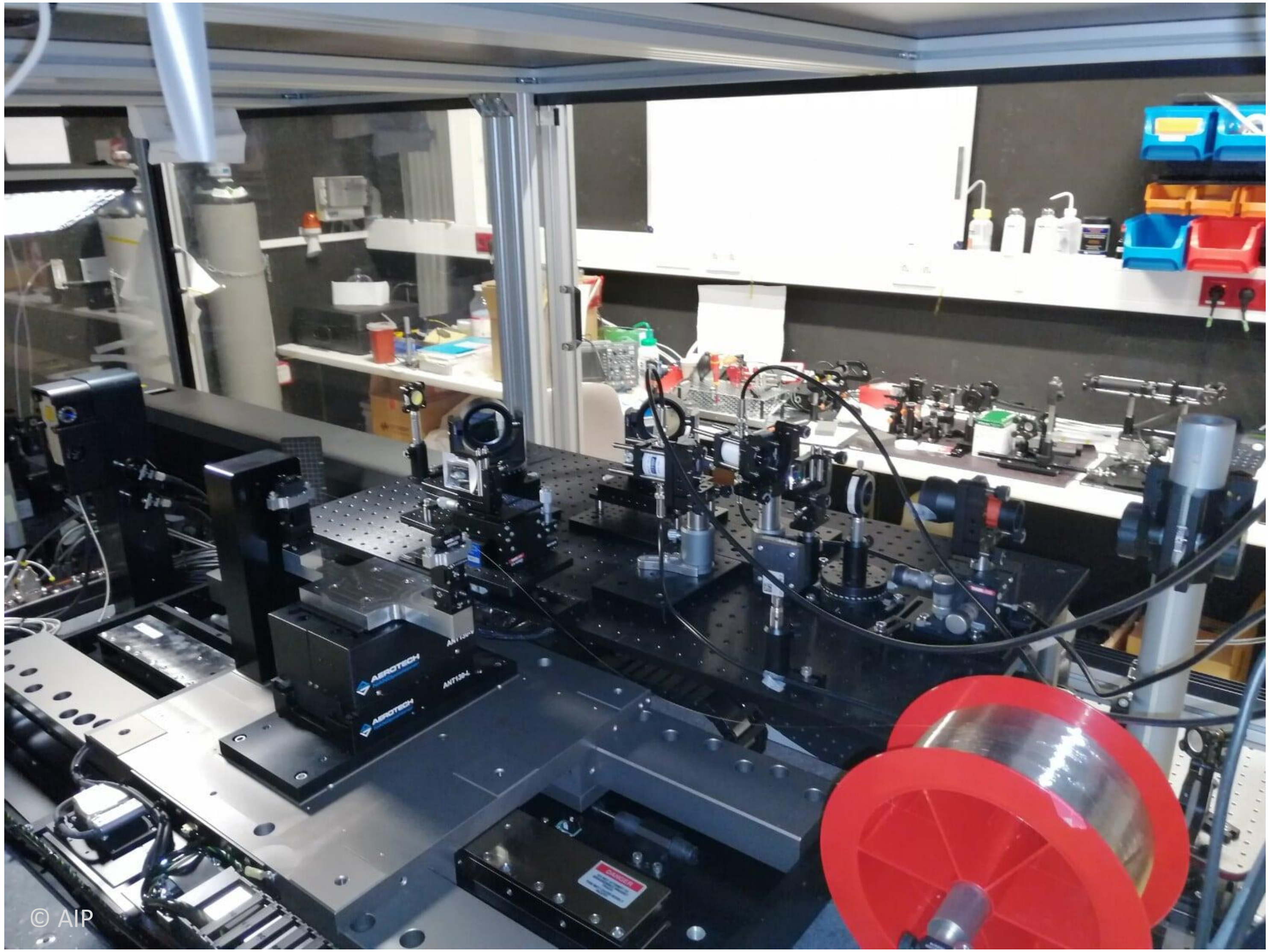
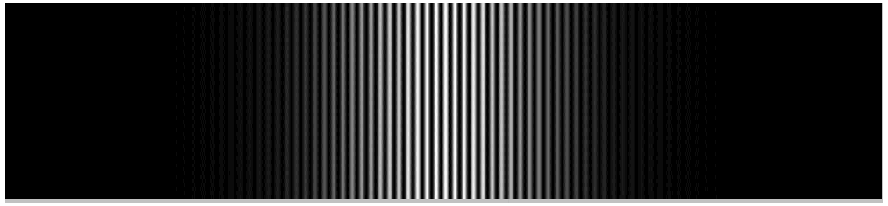
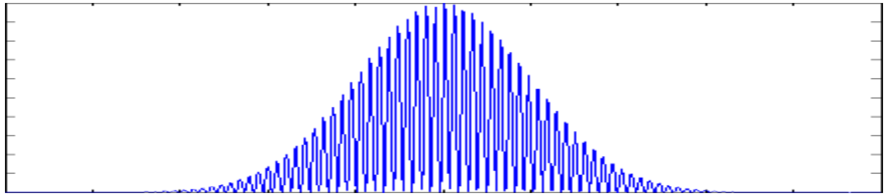
[8] *Joint Space-Science Institute, University of Maryland, College Park, MD 20742, USA*

Fiber Bragg Gratings for OH Line Filters: METI Interferometer



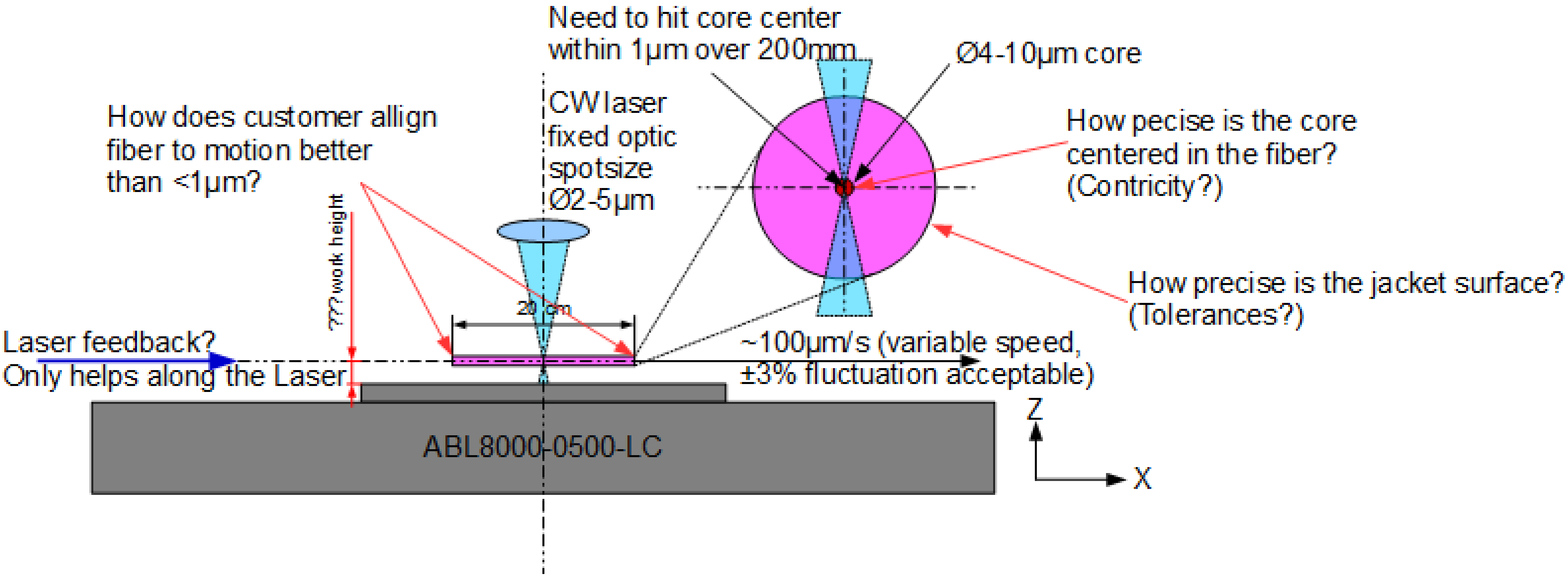




Rahman. A. et. al. 2023, CLEO 2023, Technical Digest Series, paper SF1H.3.

Credit : Aashia Rahman, Kalaga Madhav (AIP)

Fiber Bragg Gratings for OH Line Filters: METI Interferometer

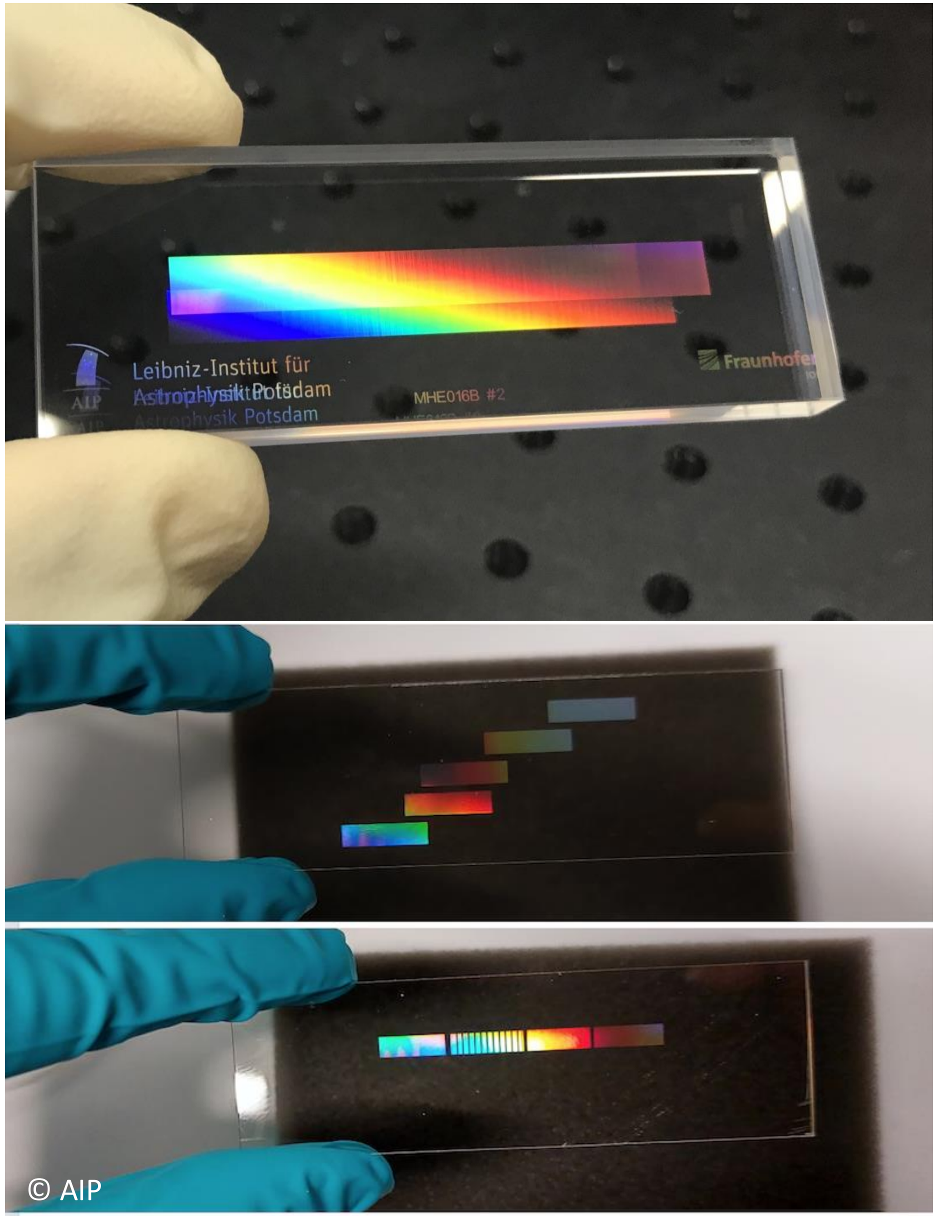


Fiber Bragg Gratings for OH Line Filters

- Complex Phase masks

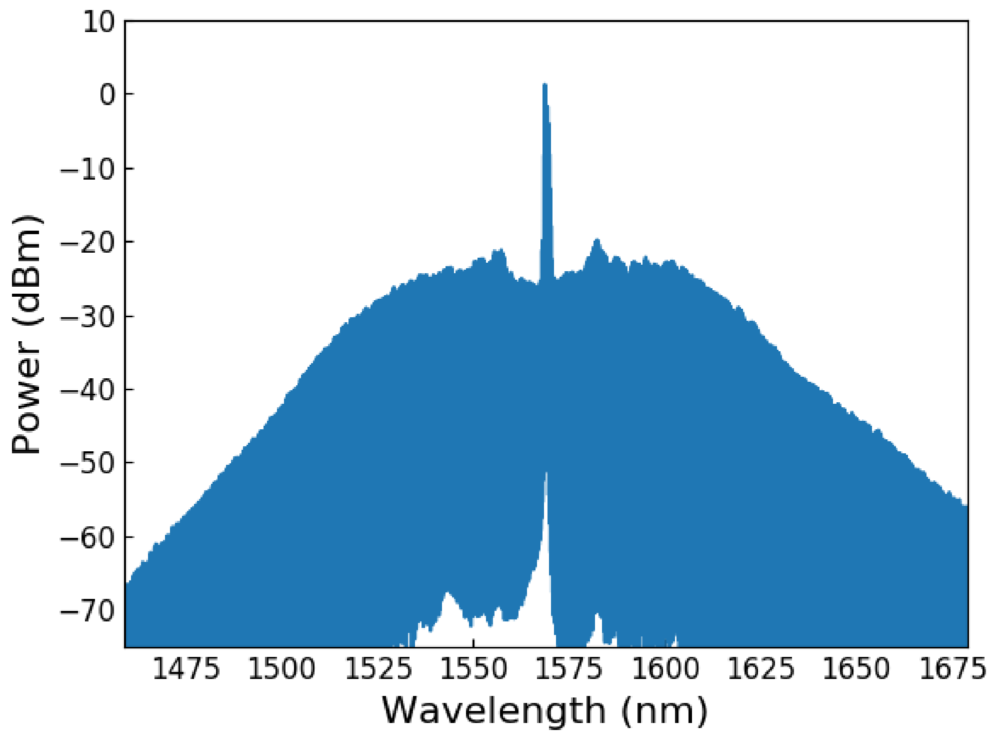
Luo, X. et. al., Proc. SPIE 13100, 1310068

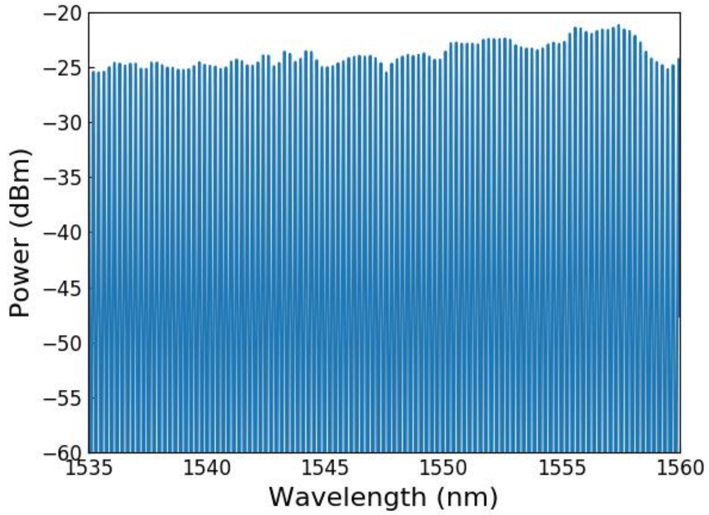
Fraunhofer
IOF

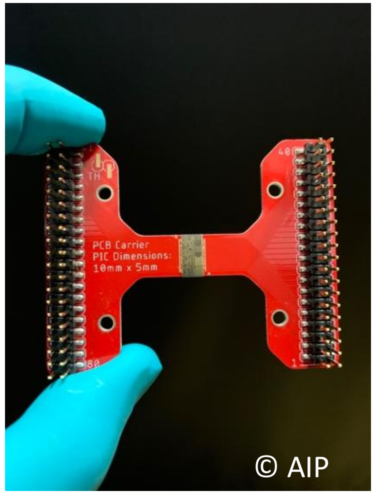


Ring Resonator Frequency Comb „POCO“

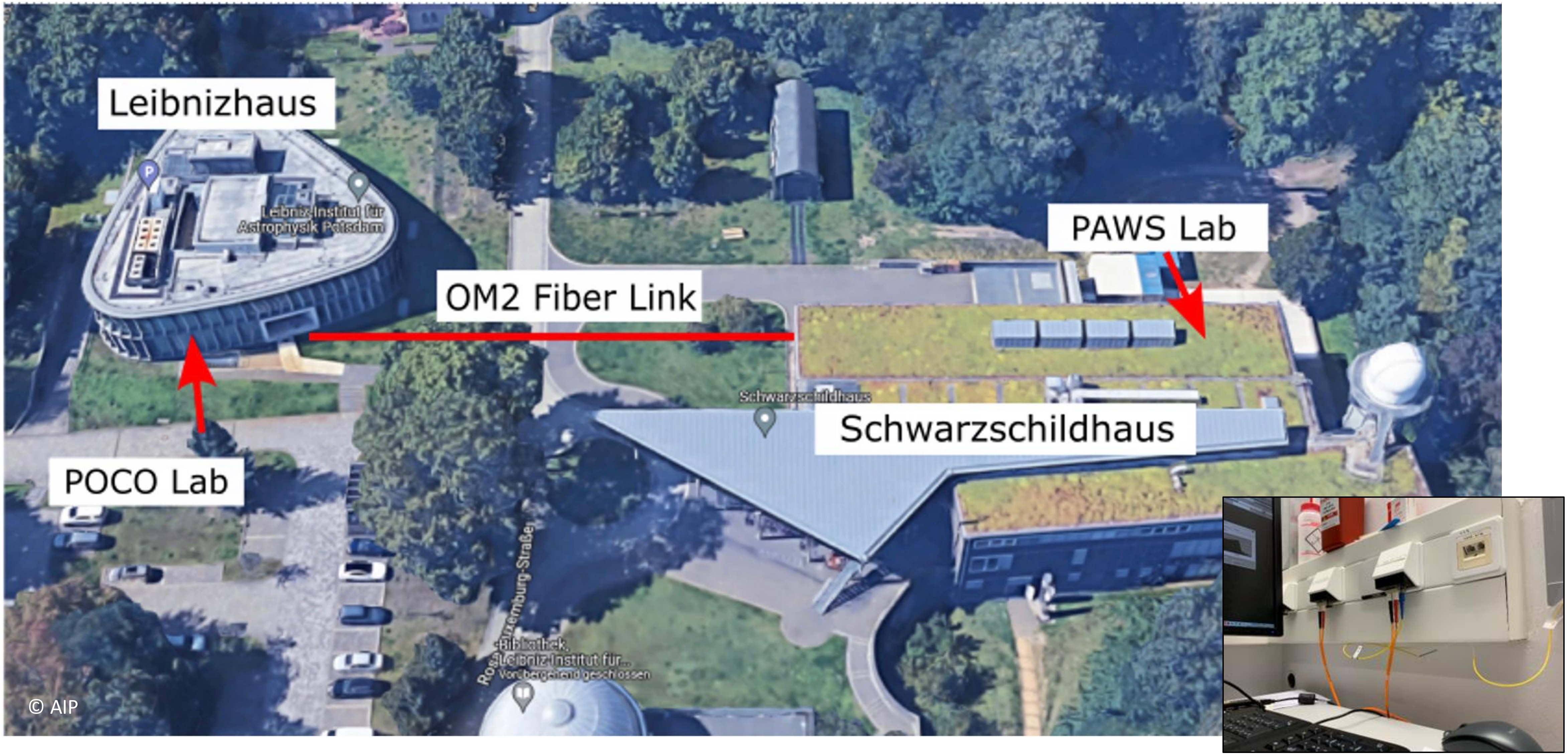
Specification	Typical
Comb spacing (f_{rep})	f_{rep}=28.55 GHz
f_{rep} stability	Δf_{rep} < 1 kHz
f_{CEO} stability (absolute reference)	Δf_{CEO} < 50 kHz
Spectral range	1250-1700nm (NIR) 400nm to 600nm (VIS)
Power per comb line	>0.1 nW @... (VIS)
Line width	1 kHz
Central wavelength	1560nm/1590nm NIR 520nm/530nm VIS
RV stability	25 cm/sec
Form	19” EIA rack
Power	240 VAC@50Hz 1-Phase
Cooling requirements	None
Features	Tuneable





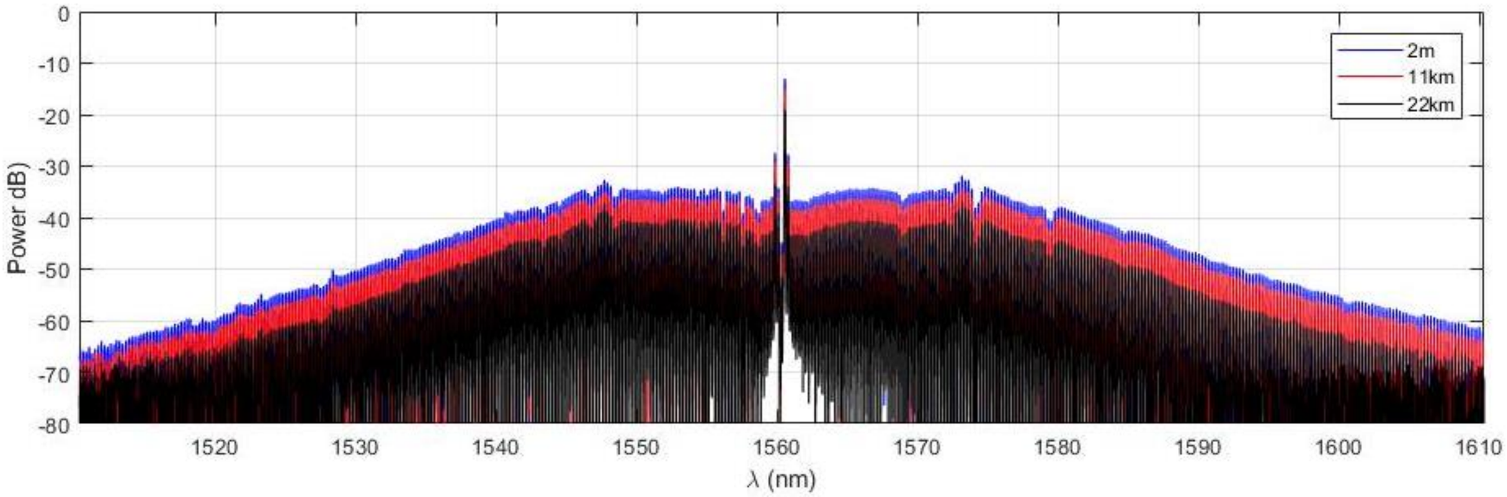


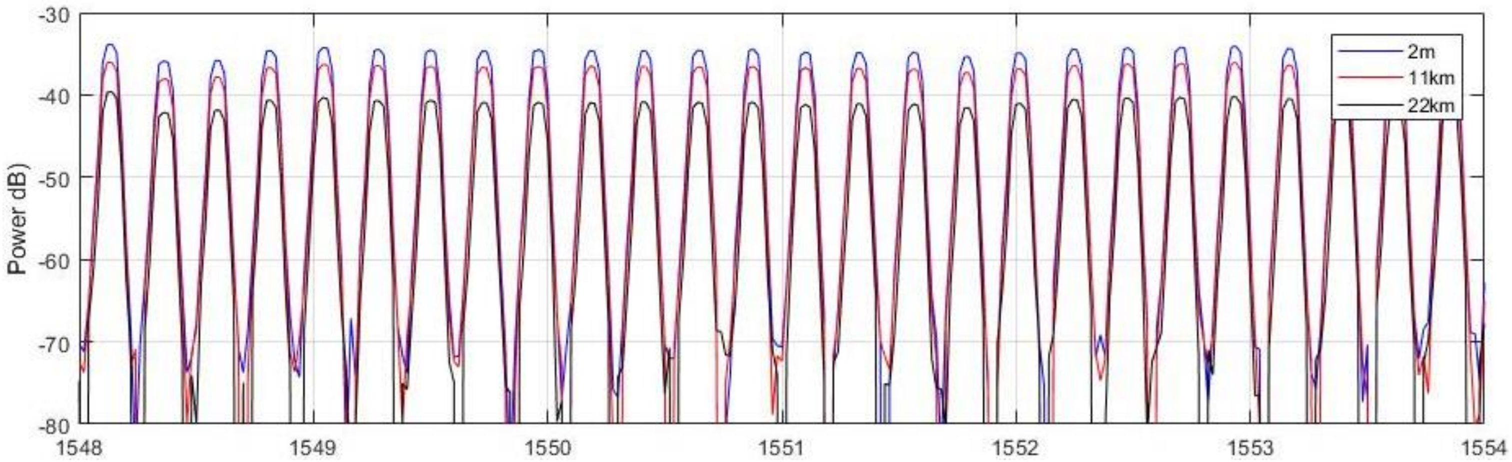
Ring Resonator Frequency Comb „POCO" tested with PAWS



Ring Resonator Frequency Comb „POCO“ tested with PAWS

Comb transmitted over 10s of kms





Summary

Coupling telescopes to spectrographs allows to:

- achieve ultra-high stability, e.g. for exoplanet search
- to observe large statistical samples with multi-object spectroscopy
- realize integral field spectroscopy

Optical fibers couple to photonic devices

Optical fibers can be used as filters, even as spectrographs, and sensors

Acknowledgements

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