Leibniz-Institut für Astrophysik Potsdam

AIP

Astrophotonics

Bringing Integrated Photonic Components to the Telescope

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innoFSPEC research and innovation center at AIP

Multi-Channel Spectroscopy

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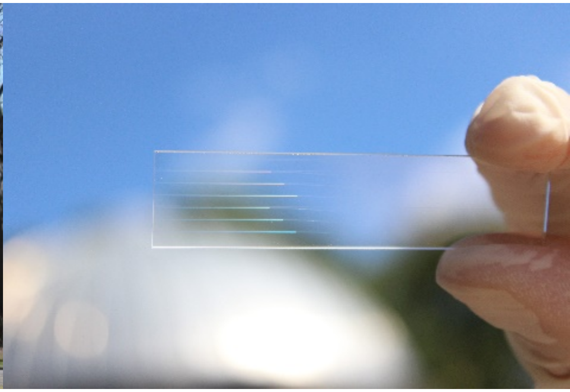
Astrophotonics

Group leader: Dr. Kalaga Madhav: kmadhav@aip.de





Images: AIP, AIP/R. Arlt, AIP/A. Dinkelaker, Leibniz-Institut für Astrophysik Potsdam

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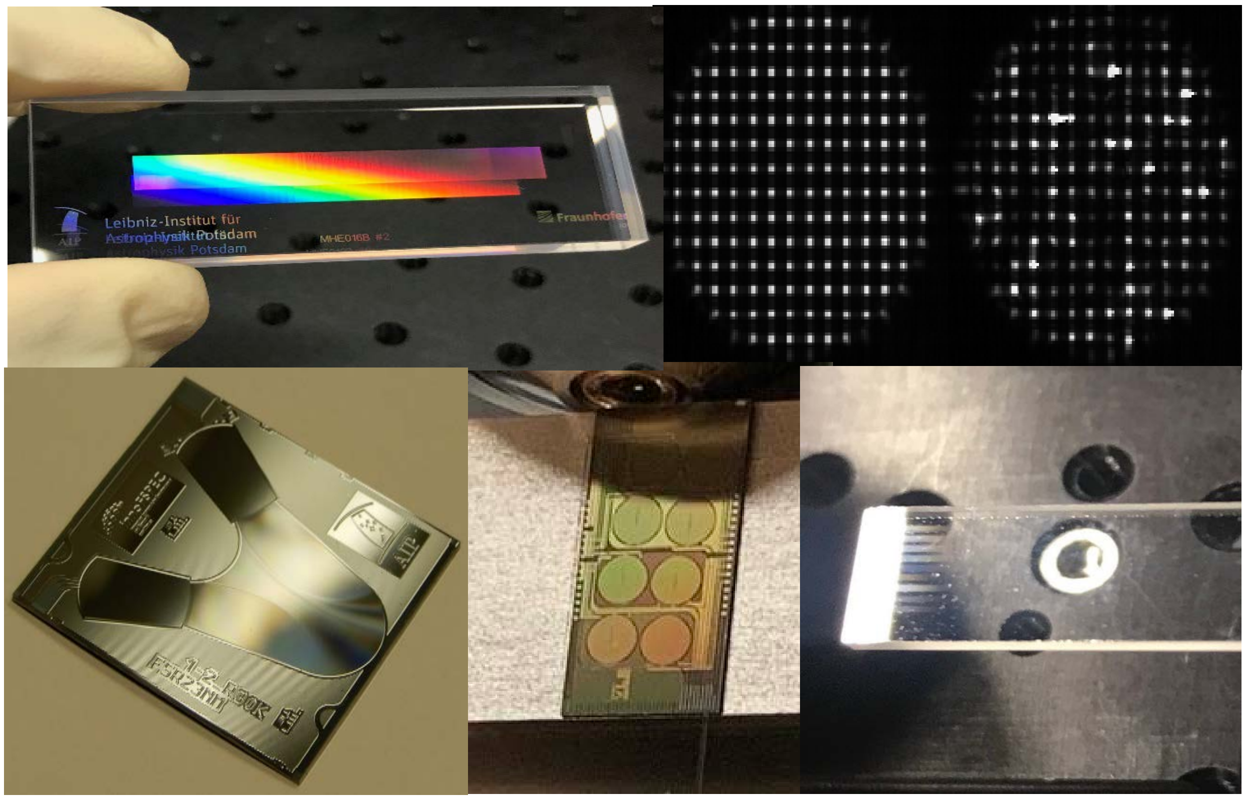
Innovative faseroptische Spektroskopie und Sensorik

Astrophotonics at AIP

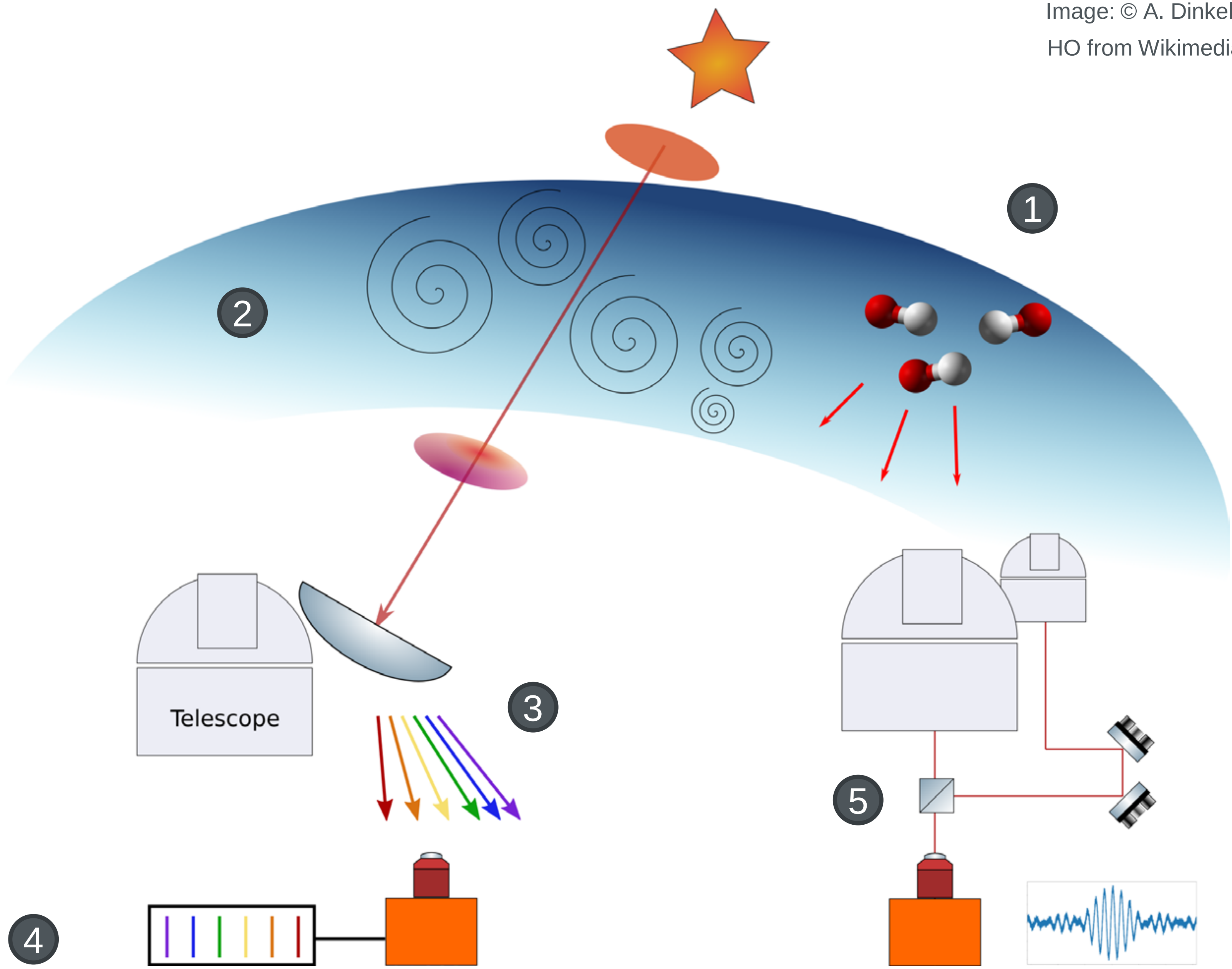
Fiber and chip based photonics for astronomy, telescopes and telescope arrays



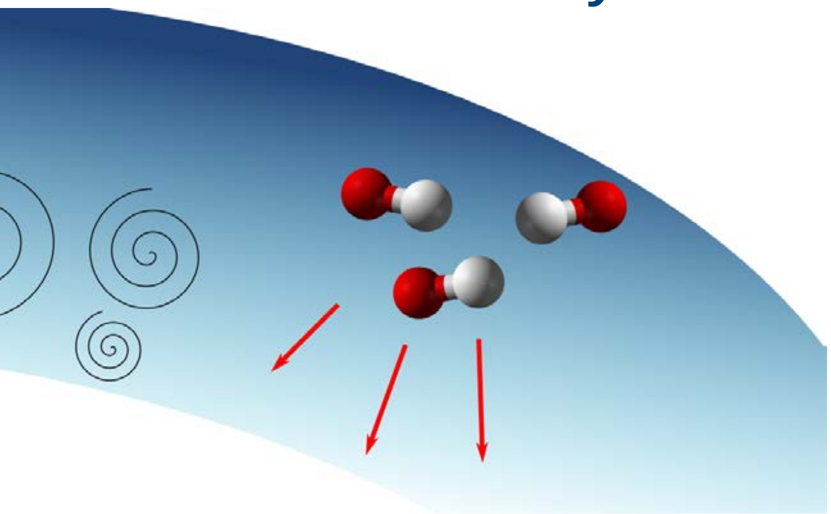
1. OH Suppression Filters & Phase Masks
2. Adaptive Optics & Photonic Lanterns
3. Arrayed Waveguide Gratings
4. Frequency Combs
5. Pupil Remappers & Beam Combiners

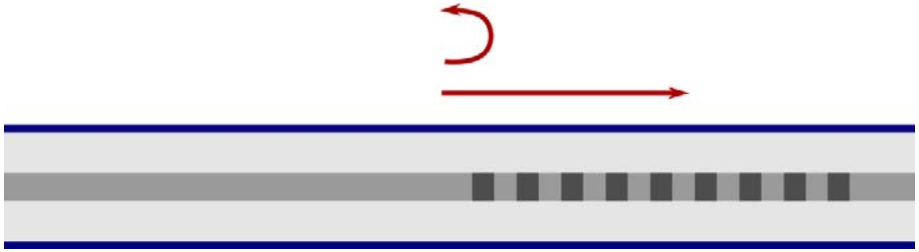
Images from AIP. Top left image from Rahman et al., Optics Express (2020)

Image: © A. Dinkelaker (AIP)
HO from Wikimedia Commons



Sky OH-Suppression Filters





Bright OH-emission lines from the atmosphere in NIR

Filter requirements:

- Multi-Notch
- Deep suppression
- Narrow line-width

AIP develops such OH suppression filters using **Fiber Bragg Gratings** (FBG)

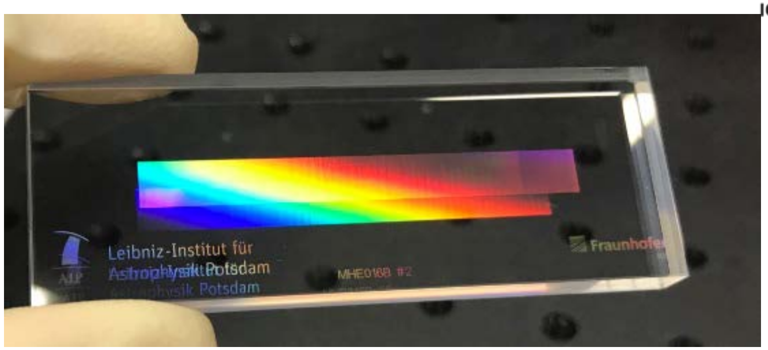
Applications e.g. for the multi-object spectrograph ELT-MOS/MOSAIC

OH-Suppression Fiber Bragg Gratings

Manufacturing Complex Bragg Grating at AIP using 244 nm UV inscription

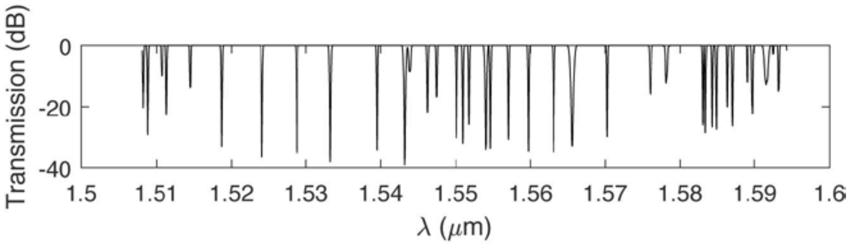
1. Complex, aperiodic phase-mask

   Design for 37 filter lines
   Fabrication by Fraunhofer IOF
   Repeatable, direct FBG inscription



2. Modified Elliptical Talbot Interferometer

   Real-time fabrication
   Tunable chirp



Contact:
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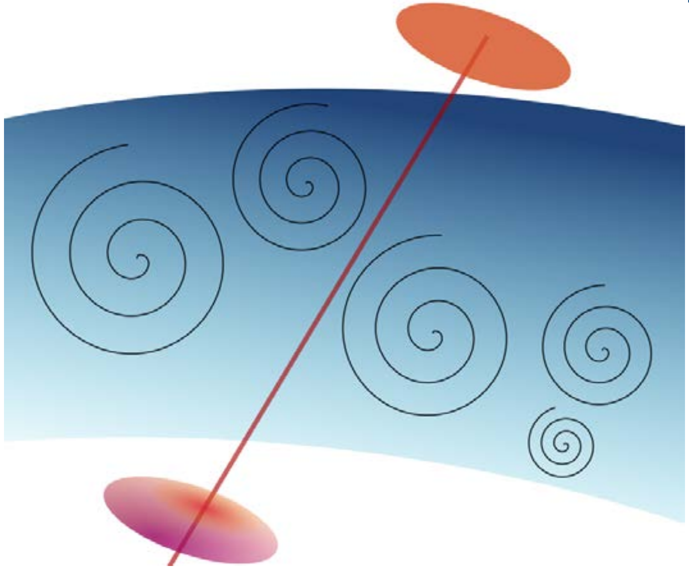
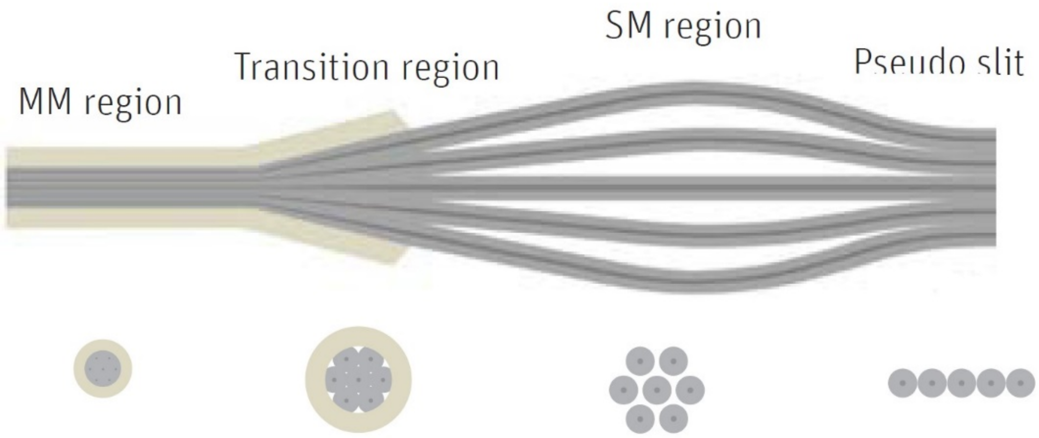
Images: A. Rahman, K. Madhav, and M. M. Roth: “Complex phase masks for OH suppression filters in astronomy: part I: design”, Optics Express, Vol. 28, Issue 19, pp. 27797-27807 (2020)

Adaptive Optics and Photonic Lanterns



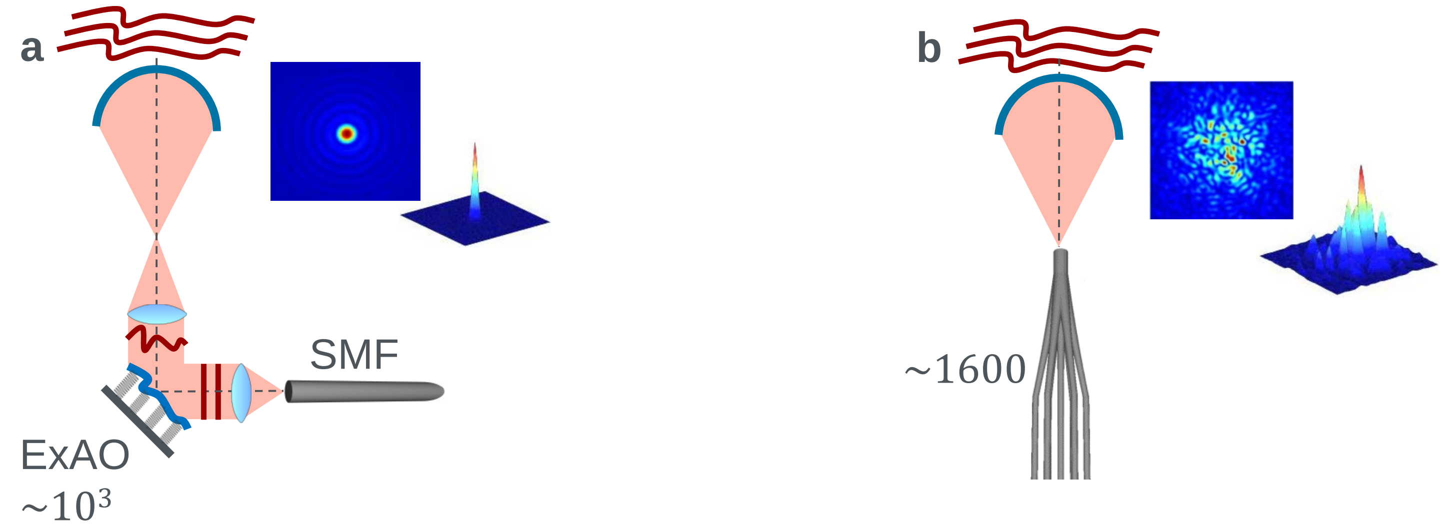


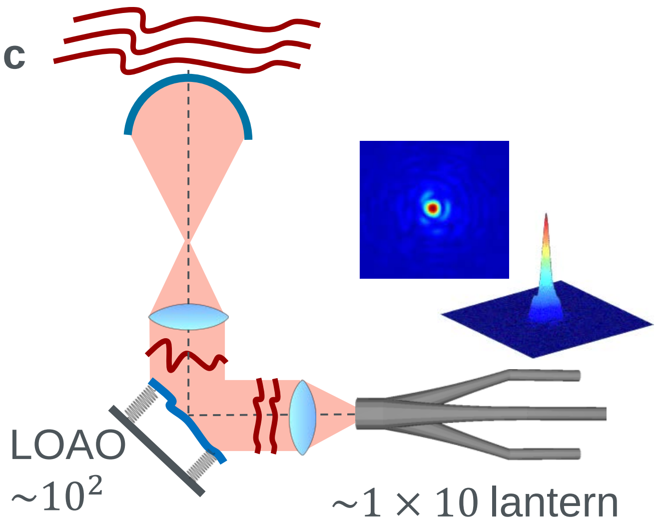
Atmospheric turbulence distort the optical wavefront → precludes efficient coupling of light into photonic devices.

Adaptive optics systems & **photonic lanterns (PL)**.

- Transition from a multi-mode (MM) to many single-mode fibers (SM).
- Development of photonic lanterns reformatters at AIP.
- SMFs are stacked and tapered, where SMF claddings fuse to form the MMF core.

Adaptive Optics and Photonic Lanterns





Alternative techniques for efficient SMF coupling

Trade-off: number of modes of AO system & number of channels of photonic lantern

Models and experiments at AIP

M. Diab et al., submitted to MNRAS

Images: M. Diab (AIP)

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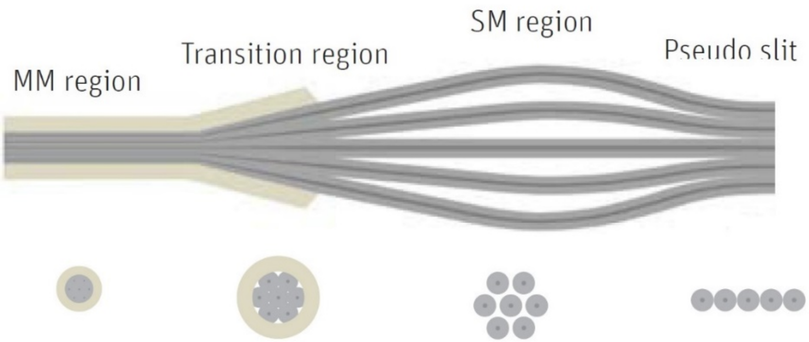
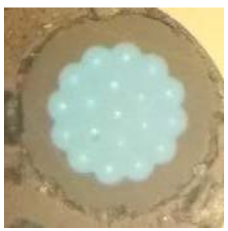
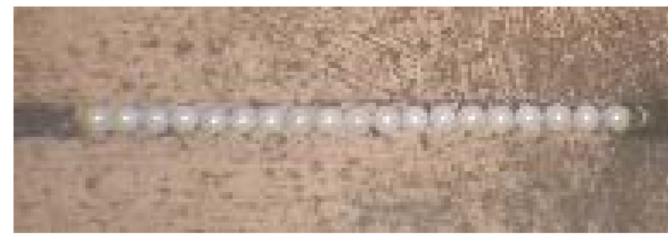
Adaptive Optics and Photonic Lanterns







On-sky test for MMF–SMF photonic lanterns planned at WHT

Photonic lanterns can also be used for MMF to MMF

Novel manufacturing method at AIP, patent no.: ePa20188489.7

Application: Combine telescope arrays into single spectrograph for MARCOT.

PL Images: © J. Davenport (AIP)

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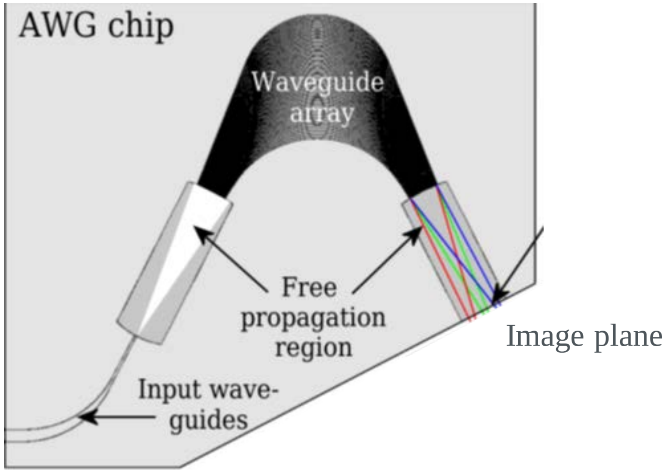
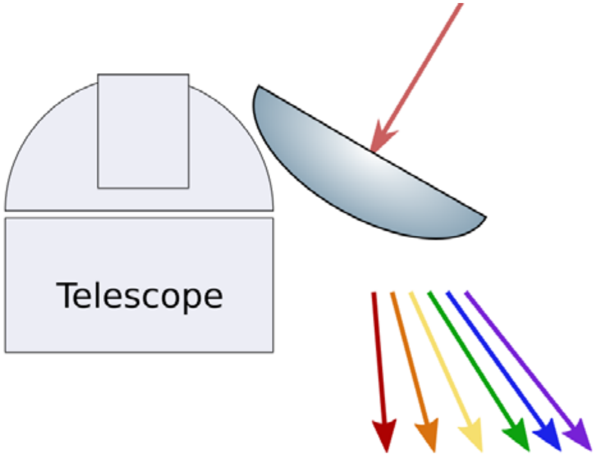
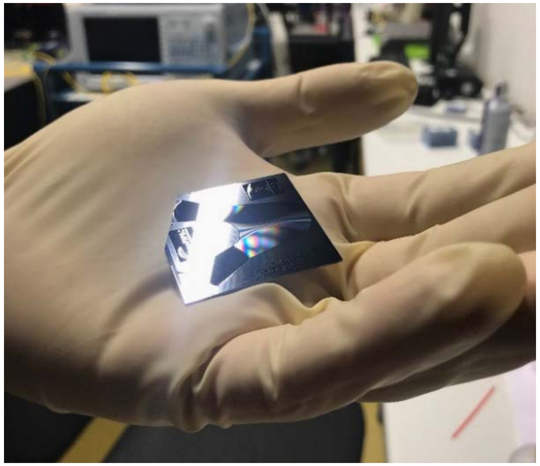
Compact Spectrograph – Arrayed Waveguide Grating







First Arrayed Waveguide Gratings (AWG) designed specifically for astronomy at AIP.

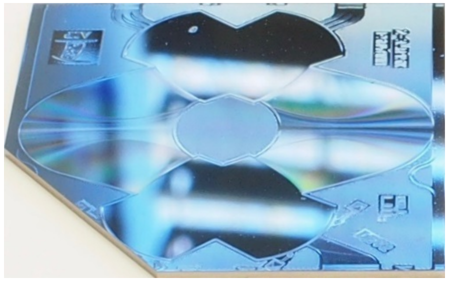
Devices developed for H-band (1500 nm–1800 nm).

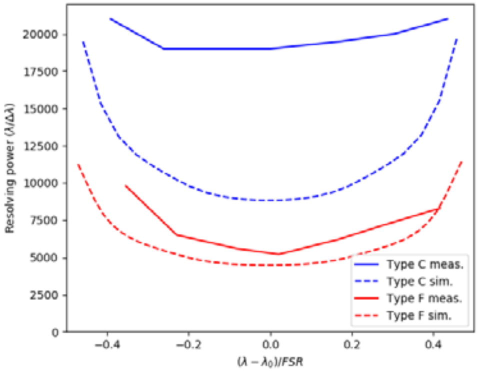
Silica-on-silicon technology, <3 dB insertion loss

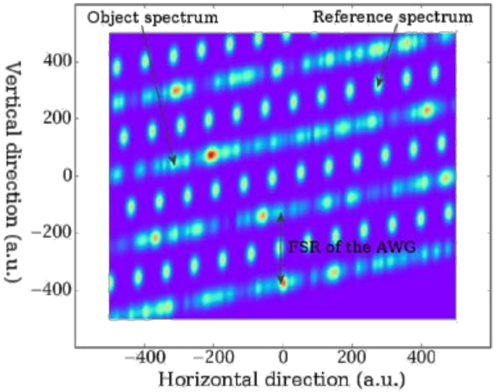
~500 - 700 waveguides in array

Image AWG: A. Stoll, Z. Zhang, R. Haynes and M. Roth: "High-Resolution Arrayed-Waveguide-Gratings in Astronomy: Design and Fabrication Challenges", Photonics 2017, 4(2), 30

Compact Spectrograph – Arrayed Waveguide Grating







Measurements and laboratory tests:

Grating diffraction efficiency: 86%
Spectral resolving power: 5,000 –20,000
Free spectral range: 16 – 48 nm

Packaging design and integration at AIP to build compact spectrograph.

Calibration source input, require high line density → Frequency comb

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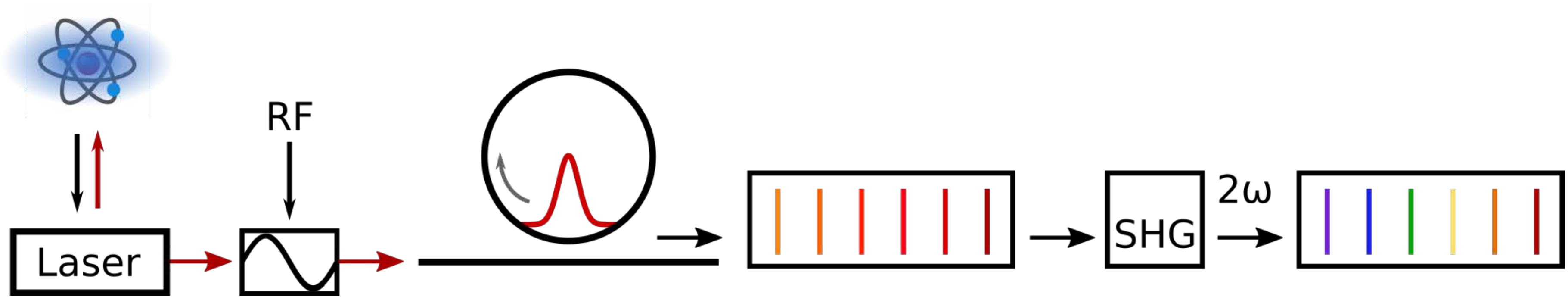
Alan Günther: aguenther@aip.de
Eloy Hernandez: ehernandez@aip.de

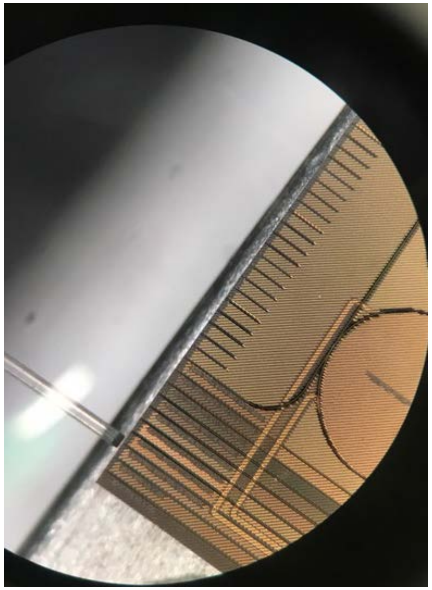
Images: A. Stoll & K. Madhav (AIP). Right: A. Stoll et al. 2018

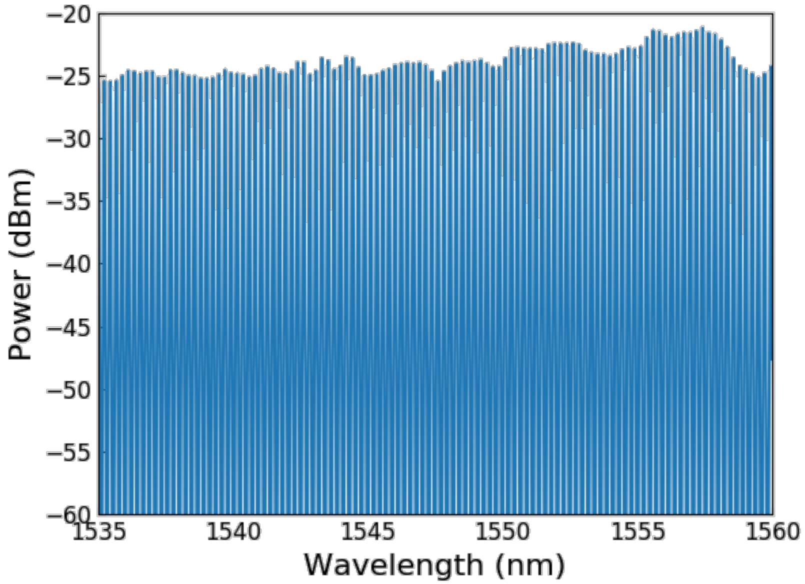
Chip-based frequency comb (Astrocomb)



Spectra with f_{rep}=28.55 GHz,
Expected stability Δf_{CEO} < 50 kHz

Silicon-Nitride Chip (SiN-Chip)





Comb image and data: D. Bodenmüller & J. Chavez-Boggio (AIP).
See also: Chavez Boggio et al., Proc. SPIE (2020), Bodenmüller et al., Proc. ANZCOP (2019). Further reading: Lo Curto et al. in The Messenger 149 (2012). Schematic: © A.Dinkelaker (AIP)

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Daniel Bodenmüller: dbodenmueller@aip.de

Frequency Comb for STELLA Échelle Spectrograph

STELLA: two robotic telescopes on Tenerife to monitor stellar activity

STELLA Échelle Spectrograph (SES): upgrade planned with high-resolution spectrograph in VIS (390 nm – 870 nm)

- R ~55000 → ~8.6 GHz per resolution element
- Desired Doppler accuracy ~2 m/s → Δf ~3.2 MHz
- Frequency comb for calibration

On-sky test at STELLA in 2021

Image: M. Weber, K.G. Strassmeier and T. Granzer: „The STELLA échelle spectrograph, five years ofrobotic high-resolution spectroscopy", Second Workshop on Robotic Autonomous ObservatoriesASI Conference Series, 2012, Vol. 7, pp 165 – 170, see also: M. Weber, T.Granzer, K.G.Strassmeier: "STELLA: 10 years of robotic observations on Tenerife", Proc. SPIE 9910, Observatory Operations: Strategies, Processes, and Systems VI, 99100N (15 July 2016), and https://www.aip.de/en/research/facilities/stella/

Photonic Beam Combiners for Interferometry

High angular resolution astronomy

“virtual“ large telescope with $\Delta\theta \propto \lambda/B$

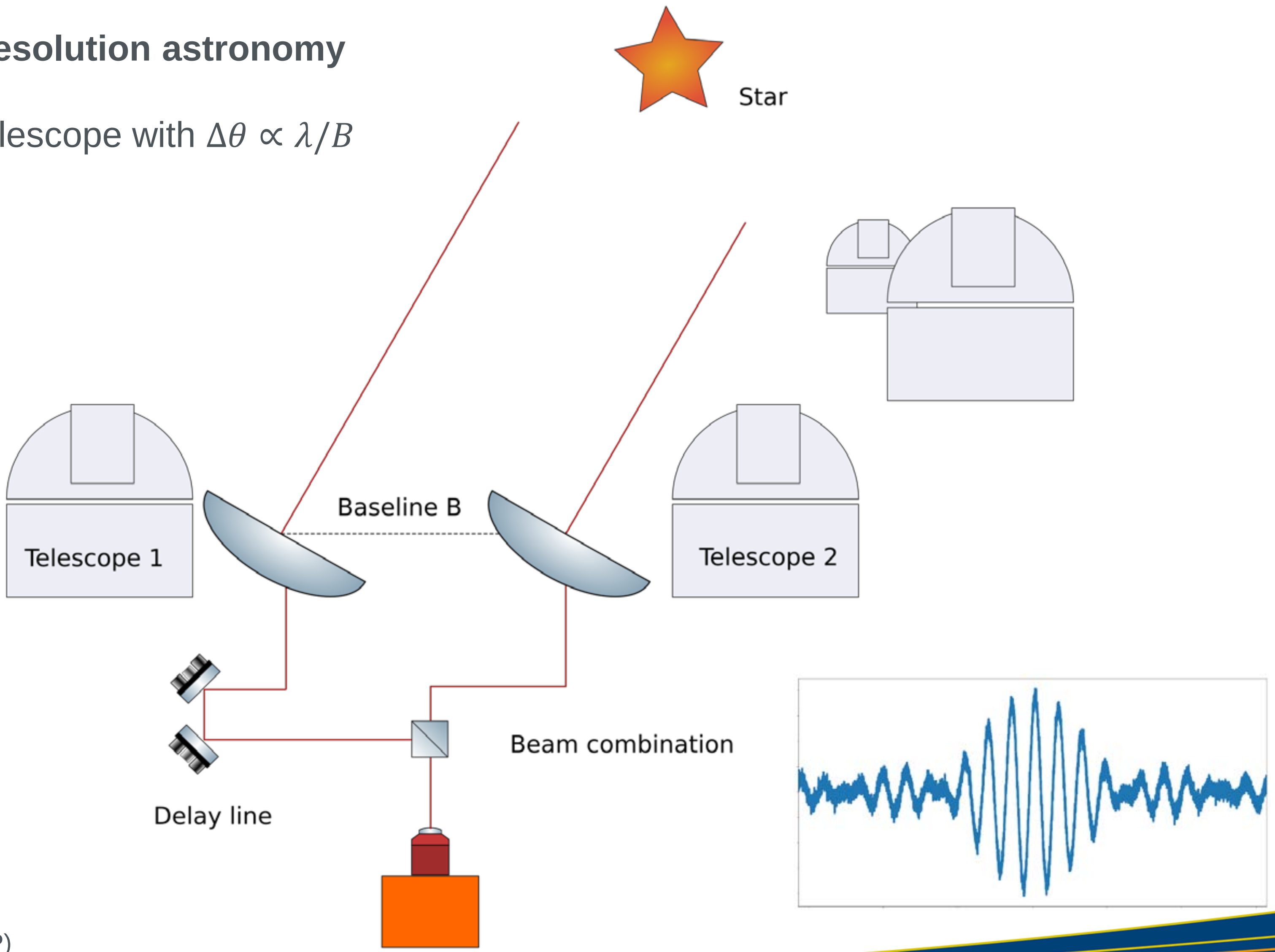
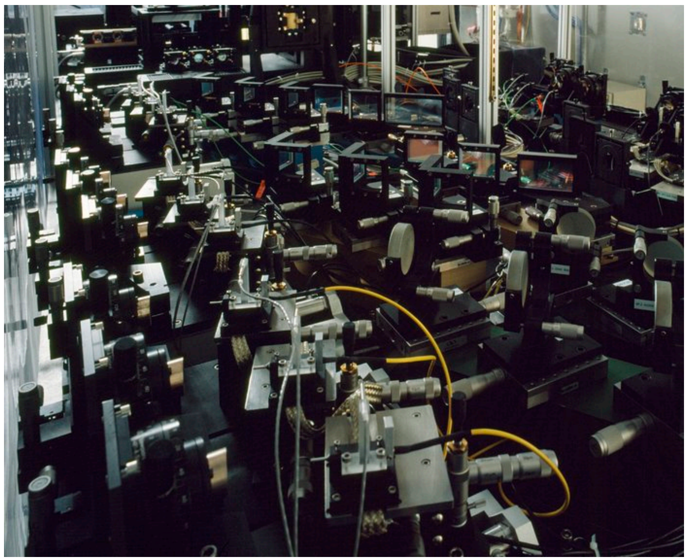


Image: © A. Dinkelaker (AIP)

Photonic Beam Combiners for Interferometry

Free space optics

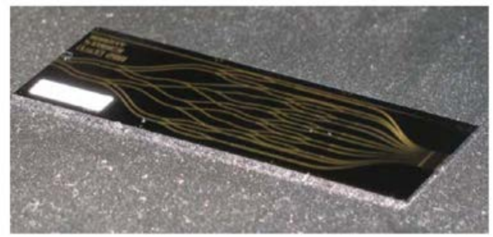
Beam combination at the AMBER instrument

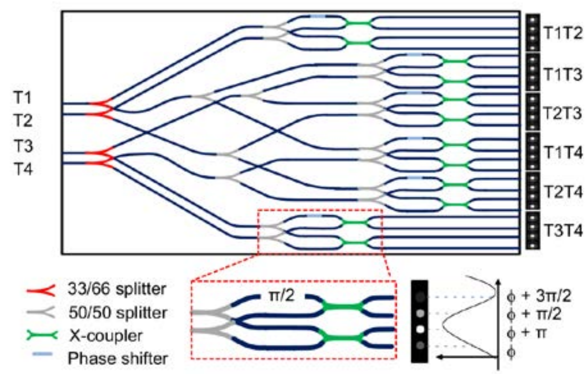


Integrated optics

2D

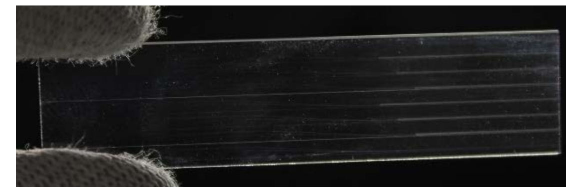
GRAVITY beam combiner





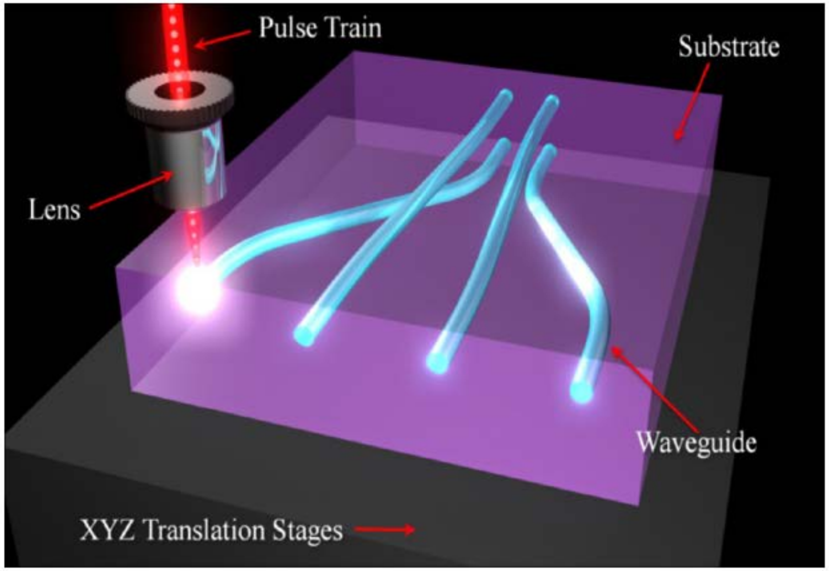
3D

Discrete beam combiner at AIP

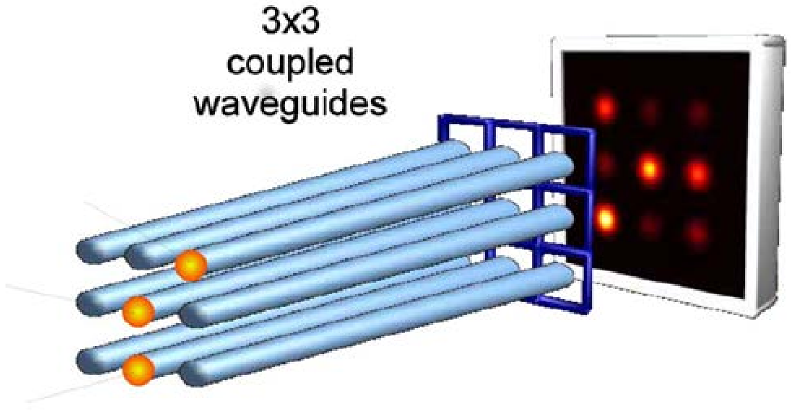


AMBER: Image credits: ESO, https://www.eso.org/public/images/eso0706a/ , GRAVITY: Image credits: GRAVITY collaboration, "First light for GRAVITY: Phase referencing optical interferometry for the Very Large Telescope Interferometer"; A&A 602, A94 (2017), 3D Beam combiner: manufactured by Politecnico Milano, Image credits: top: AIP/Dinkelaker, bottom: Pedretti+ 2018 (arxiv 1809.01260v1)

Ultrafast laser inscription

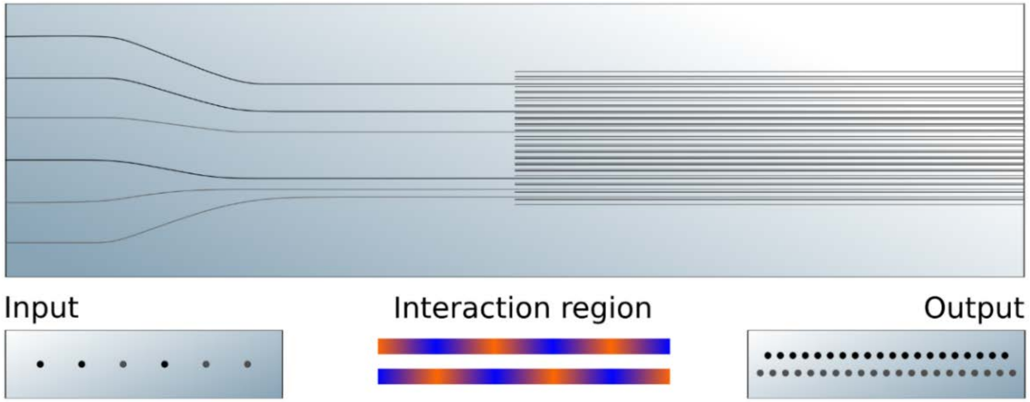


Astrophotonics containing 3D waveguide structures and arrays



Picture: Lee+ 2012: “Performance of volume phase gratings manufactured using ultrafast laser inscription”. For ULI see also: Thomson+ 2011 (Opt. Express, 19, 5698). Waveguide array image (modified) from: Minardi+ 2010 (Opt. Lett. 35, 3009).

Discrete Beam Combiners (DBC)



Reformatter at input

Array of evanescently coupled waveguides

For N telescopes:
N inputs and M > N x N outputs

Can simultaneously retrieve the complex visibility of each baseline

Devices for J- (1250 nm) and H- (1550 nm) Band

Contact:
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Abani Nayak: anayak@aip.de

Photograph of a chip with laser-written 3D beam combiners (image: AIP / Dinkelaker, Chip fabricated by Politecnico Milano). Image of schematic: © A. Dinkelaker (AIP). For ULI pupil remapper, see also: Jovanovic+2012 (MNRS). For multi-telescope ULI beam combiners, see also: Diener+2017 (Optics Express), Pedretti+2018 (arxiv 1809.01260v1), Saviauk+2013 (Applied Optcs), Minardi+2010 (Opt. Lett. 35, 3009).

Discrete Beam Combiners (DBC)

Characterization of 6-input beam combiners

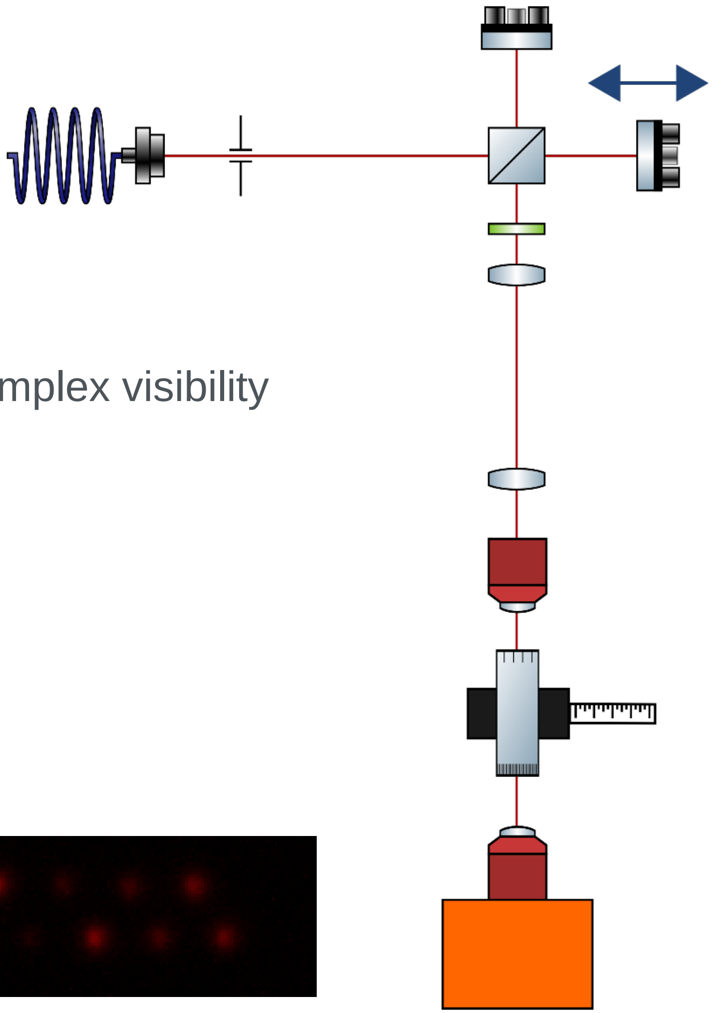
Michelson interferometer

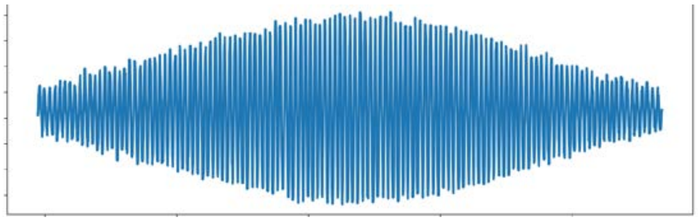
- Movable mirrors
- Delay line

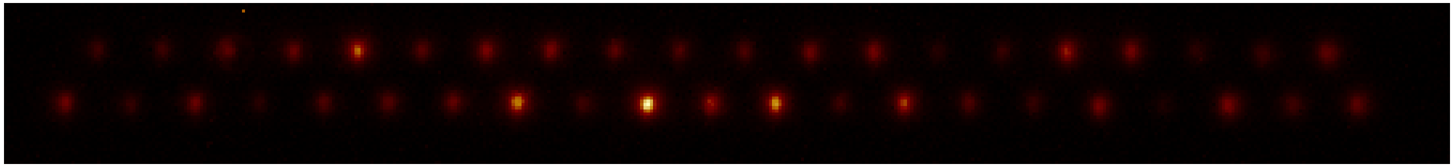
Couple 2 inputs (I_1, I_2) simultaneously

Monitor fringes at all 41 output waveguides and extract complex visibility

Characterize transfer function of the DBC for all baselines





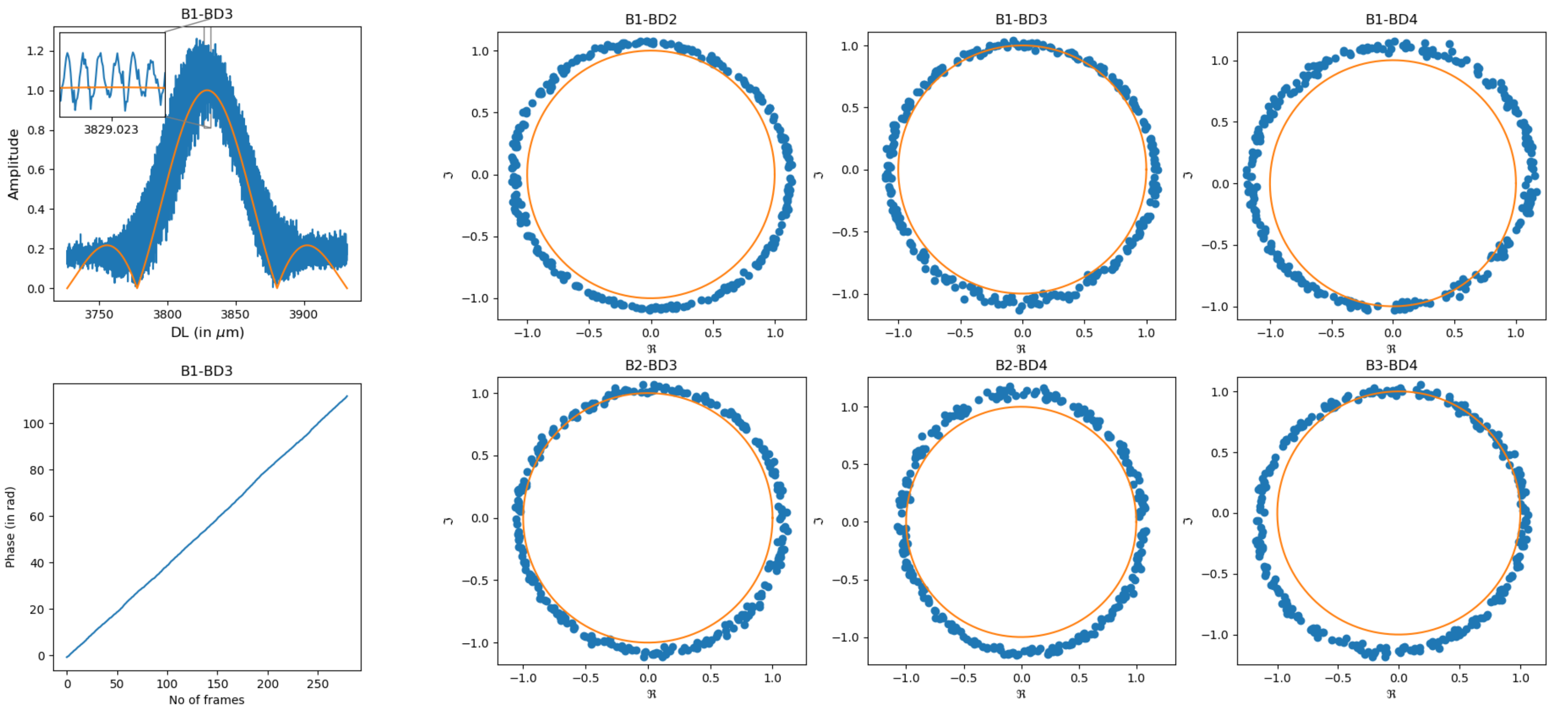


See also Lacour+ 2008: “Characterization of integrated optics components for the second generation of VLTI instruments”
Images: A. Dinkelaker (AIP)

Discrete Beam Combiners (DBC)

4-telescope DBC for H-Band

Characterize V2PM in lab. Inverse (P2VM) allows extraction of visibilities for science targets



See also Lacour+ 2008: “Characterization of integrated optics components for the second generation of VLTI instruments”
Data and plots: A. Nayak (AIP)

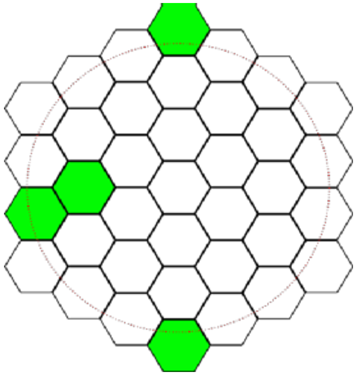
Pupil remapping with DBC

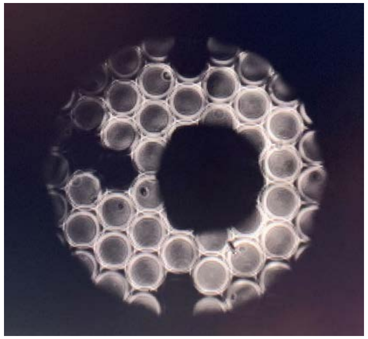
Pupil remapping with a 4-input beam combiner

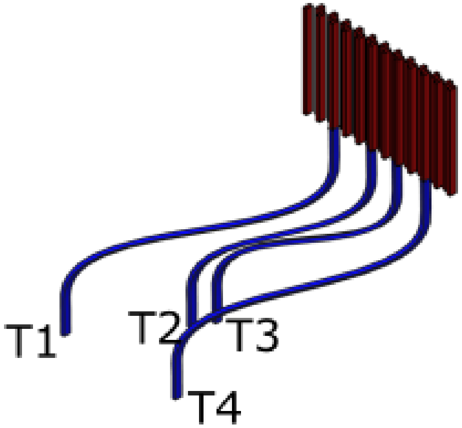
Deformable mirror for characterization and input selection

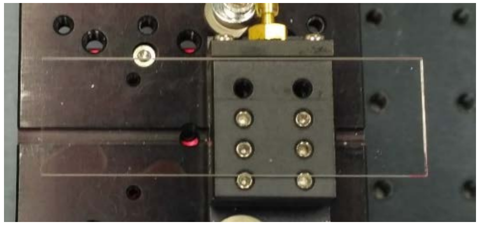
Couple 4 inputs simultaneously

Aperture masking and spatial filtering in integrated photonics









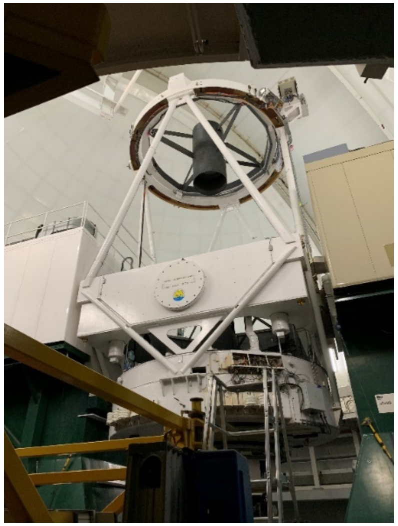
4T beam combiner tested with pupil remapping at William Herschel Telescope

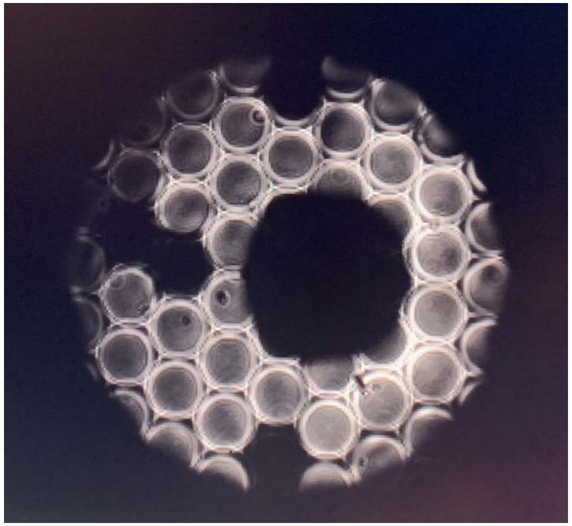
A.S. Nayak et al., publication in preparation (SPIE)

Pupil remapping at WHT

August 2019: first-light experiments at William Herschel telescope (WHT).

CANARY AO for active adaptive optics (AO) correction.
Stellar light coupled into the device from Vega, Altair, 47Cygni, βCyg and psiPeg.





9 August 2019 - First Light of DBC from Vega

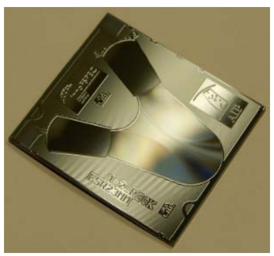
Images: http://www.ing.iac.es/Astronomy/telescopes/wht/ (left), AIP (center, right)

Summary

Chip and fiber-based photonic devices can be used at various points in the telescope.

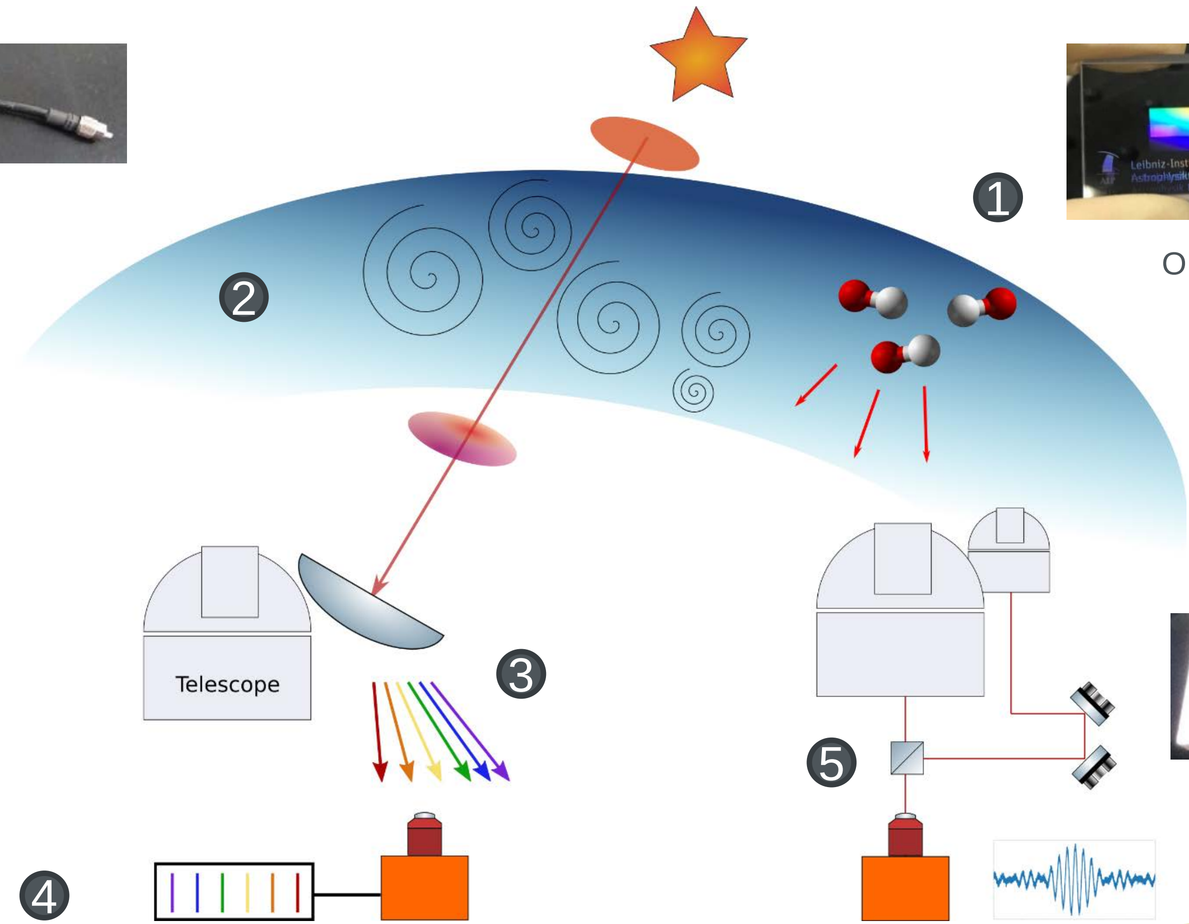
Astrophotonic devices developed at AIP are getting ready for on-sky tests.

Photonic Lanterns



AWG

Frequency Combs



OH Suppression Filters

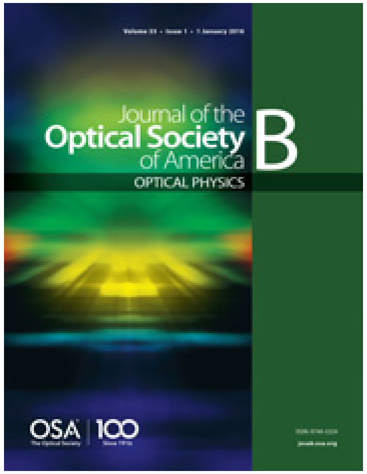
Beam Combiners

Astrophotonics Feature Issue

Submit your astrophotonics papers to JOSA B and Applied Optics

Lead Editor: Joss Bland-Hawthorn, The University of Sydney, Australia

Journal of the Optical Society of America B **and** ***Applied Optics*** **Feature Announcement**



Astrophotonics

Submission Opens: 1 November 2020

Submission Deadline: 5 January 2021

https://www.osapublishing.org/josab/journal/josab/feature_announce/astrophotonics.cfm

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Thank you

Astrophotonics Group at innoFSPEC Potsdam, AIP

https://innofspec.de/en/research-focus/astrophotonics

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Dr. Aline Dinkelaker: adinkelaker@aip.de

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