Multi-core fibre-fed integral-field unit (MCIFU)

Overview and first-light

Sebastiaan Y. Haffert [a,b], Robert J. Harris [c,l], Alessio Zanutta[d], Fraser A. Pike [e], Andrea Bianco [d], Edoardo Redaelli [d], Aurelien Benoıt [e], David G. MacLachlan [e], Calum A. Ross [e], Itandehui Gris-Sanchez [f,m], Mareike D. Trappen [g,h], Yilin Xu [g,h], Matthias Blaicher [g,h], Pascal Maier [g,h], Giulio Riva [d], Baptiste Sinquin [i], Caroline Kulcsar [i], Nazim Ali Bharmal [j], Eric Gendron [k], Lazar Staykov [j], Tim J. Morris [j], Santiago Barboza [l], Norbert Muench [l], Lisa Bardou [j], Leonard Prengere [i], Henri-Francois Raynaud [i], Phillip Hottinger [c], Theodoros Anagnos [c,n], James Osborn [j], Christian Koos [g,h], Robert R. Thomson [e], Tim A. Birks [f], Ignas A. G. Snellen [a], Christoph U. Keller [a], Laird Close [b], and Jared R. Males [b]

Abstract

The Multi-Core Integral-Field Unit (MCIFU) is a new diffraction-limited near-infrared integral-field unit for exoplanet atmosphere characterization with extreme adaptive optics (xAO) instruments. It has been developed as an experimental pathfinder for spectroscopic upgrades for SPHERE+/VLT and other xAO systems. The wavelength range covers 1.0 um to 1.6um at a resolving power around 5000 for 73 points on-sky. The MCIFU uses novel astrophotonic components to make this very compact and robust spectrograph. We performed the first successful on-sky test with CANARY at the 4.2 meter William Herschel Telescope in July 2019, where observed standard stars and several stellar binaries. An improved version of the MCIFU will be used with MagAO-X, the new extreme adaptive optics system at the 6.5 meter Magellan Clay telescope in Chile. We will show and discuss the first-light performance and operations of the MCIFU at CANARY and discuss the integration of the MCIFU with MagAO-X.

The Multi-core fibre-fed integral-field unit (MCIFU)

Parameter	
Spectral resolution	7000 (H), 8500 (J), 10000 (Y)
Single-shot spectral range	1.0 to 1.6 µm
Field of view	0.860" (0.096 per spaxel)

The MCIFU is a medium to high-resolution (R=8000) single-mode integral-field spectrograph that covers the spectral range from the Y-band to the H-band (1.0 to 1.6 µm). The spectral range was set by the properties of the available fiber (lower wavelength limit) and the available detector (upper wavelength limit). This spectral range contains interesting spectral features from molecules such as methane, carbon-monoxide and water and accretion-driven emission lines from hydrogen and helium.

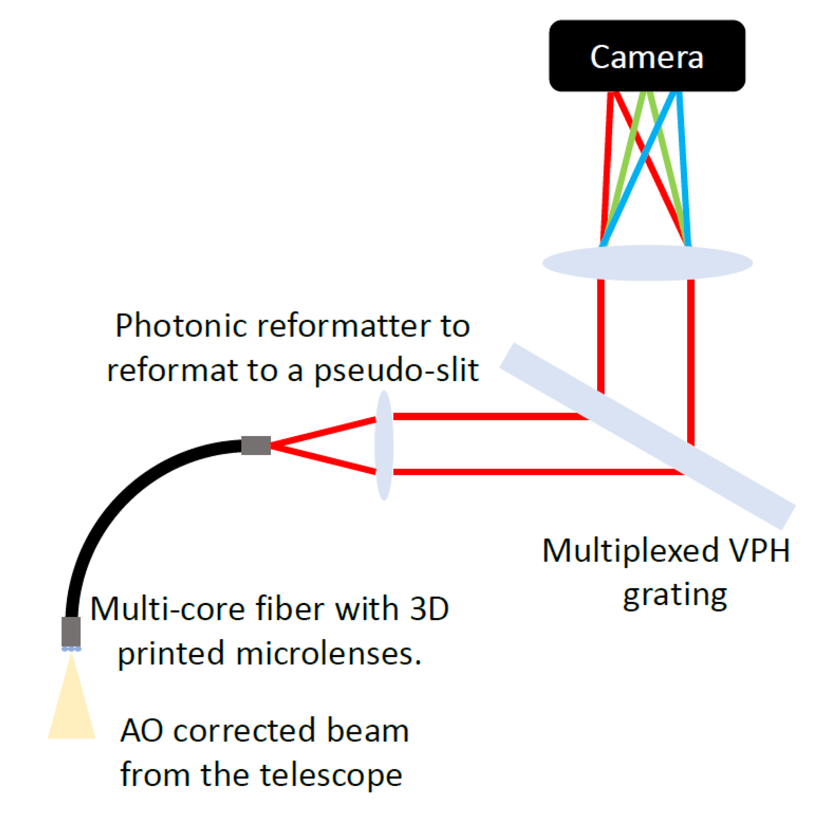


Figure 1. An overview of the multi-core integral field unit (MCIFU). The telescope beam is imaged onto a microlens array that is written on top of a multi-core fiber. The output of the multi-core fiber is rearanged into a pseudo-slit by the photonic reformatter to make it dispersable. And finally a triple multiplexed grating is used to disperse a broad wavelength range into three orders at a resolving power higher than $R=5000$. The spectrograph itself is used in a first-order manner, where a lens is used to collimate the light onto a grating and a second lens is used to image the spectrograph focal plane.

The novel fiber link

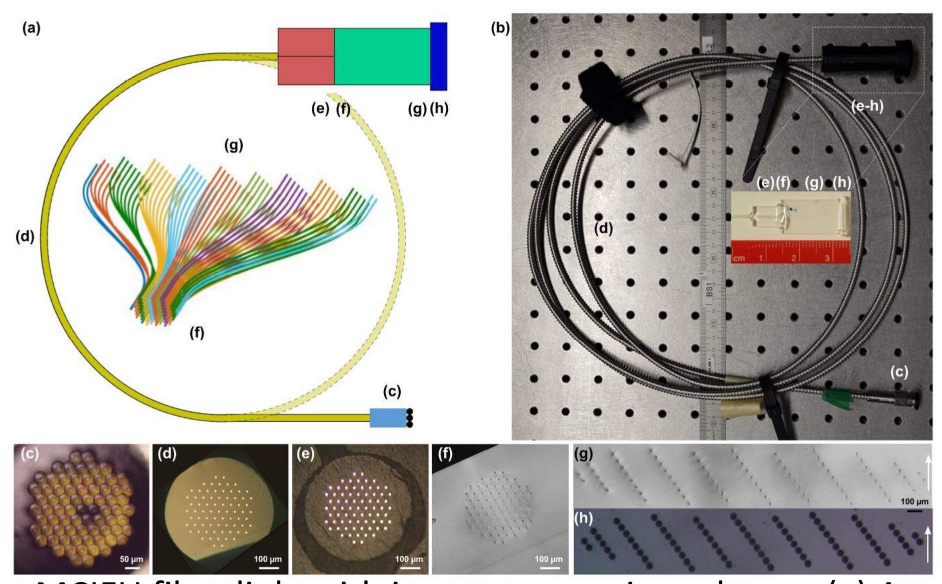


Figure 2. The MCIFU fiber link, with important sections shown. (a) A schematic representation of the fiber link, (b) photograph of the complete packaged fibre-link comprising all the elements from the microlens array, (c) the 3D printed microlenses, (d) the bare fiber, (e) the bare fiber in a v-groove, (f) the input of the chip reformatter. (g) The output of the reformatter (h) The output mask. The white arrow in (g/h) indicates the dispersion direction. Inset in (b): scale picture of the full reformatter.

Results of the MCIFU with CANARY

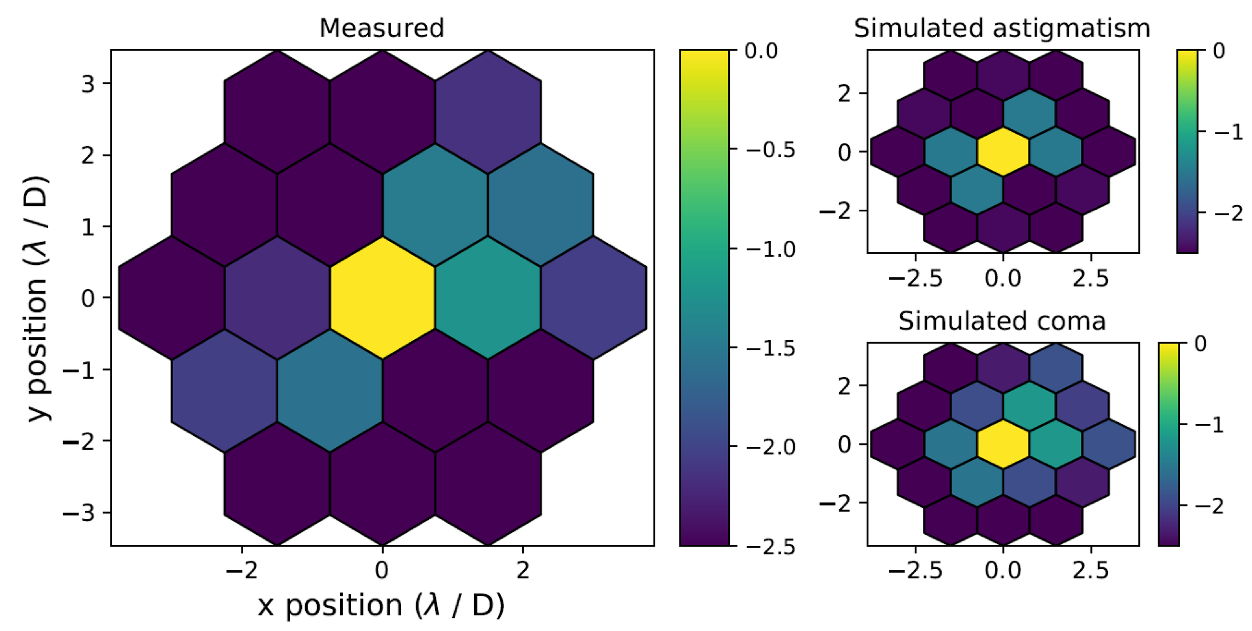


Figure 3. The monochromatic post-fiber contrast on a logarithmic scale as measured with a 1550nm laser (left). A comparison of the asymmetry in the illumination with simulations (right) hints on the presence of 0.5 radians rms residual astigmatism and/or coma.

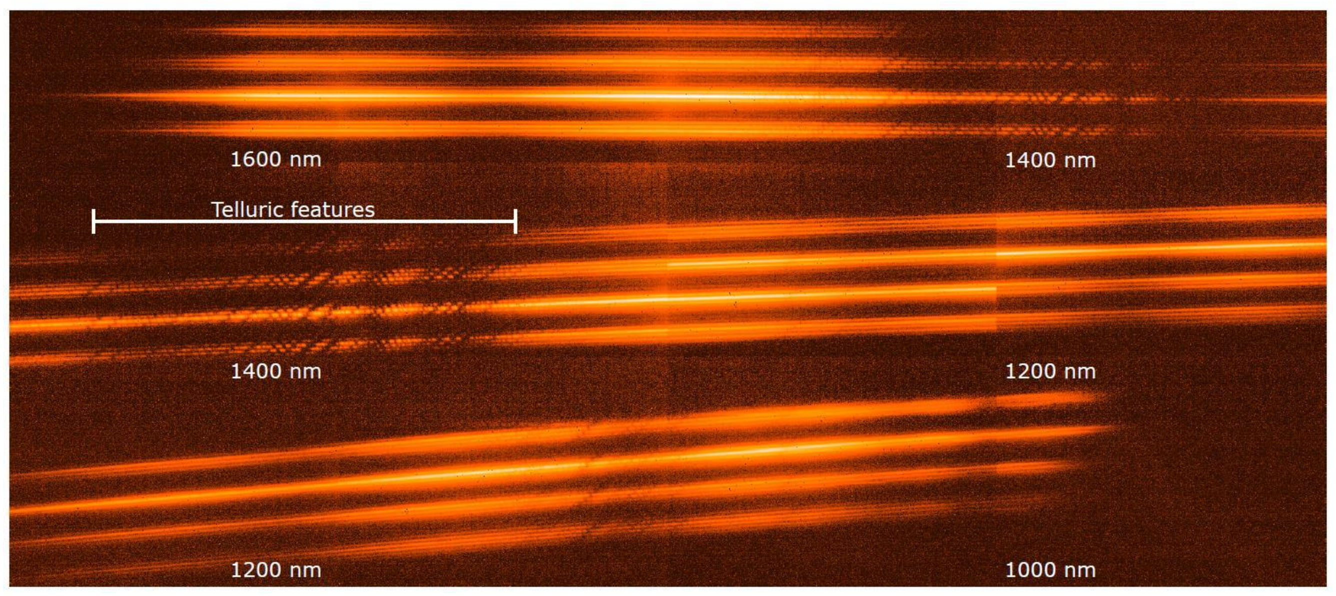
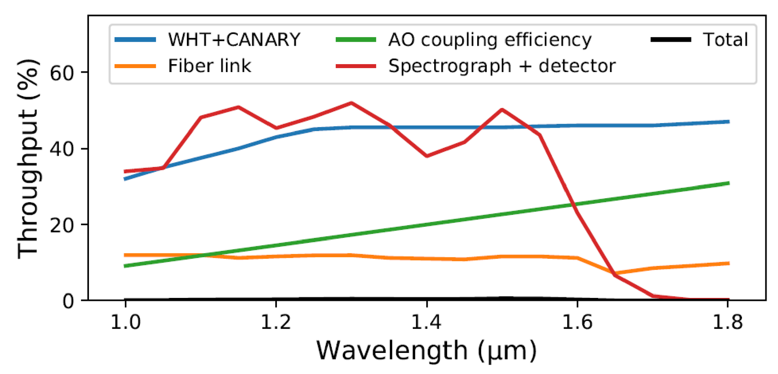
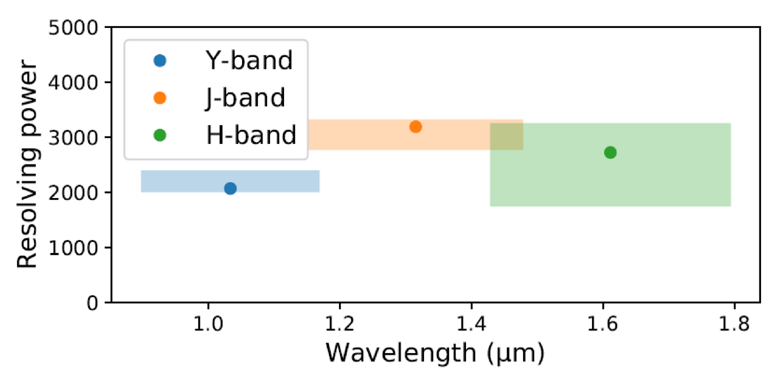


Figure 4. The full spectrograph output on a log scale of Vega after stitching 12 detector positions together. Each fiber captures a different part of the PSF at the input. The main features that are visible are the telluric lines imprinted into the spectrum of Vega. Abrupt changes in the continuum of the individual cores are visible because the full image was reconstructed from 12 observations.

Performance of the spectrograph

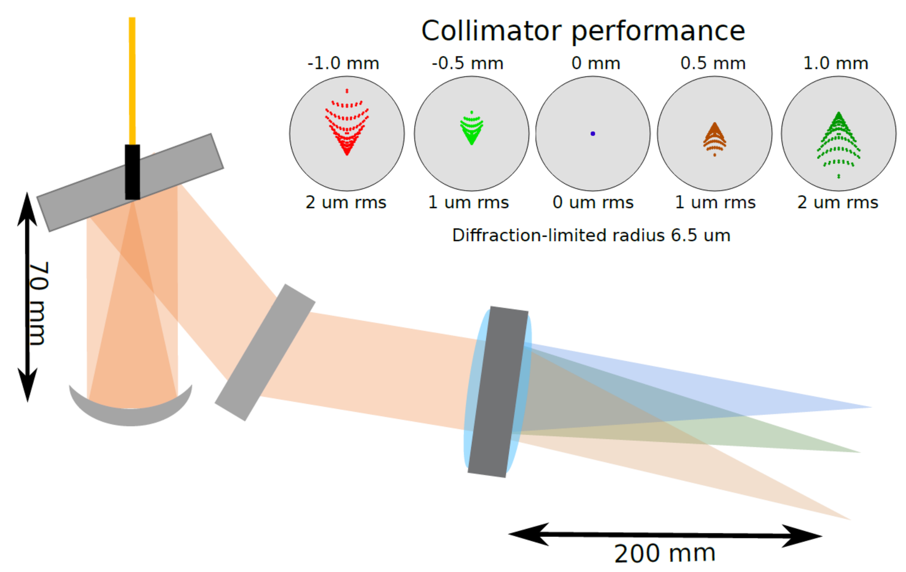


- The throughput is around 0.5 percent. Main limiting factors are AO performance and the interface losses in the fiber link. The fiber-link itself has a throughput of 8% to 25% of its theoretical maximum.



- The measured resolving power is between 2000 and 3000. This is most likely due to the aberrations from the collimator which has strict alignment tolerance.

New design of the spectrograph



Here we propose a new design of the spectrograph. The refractive collimator is replaced by an on-axis parabolic mirror. This is easy to align and has a diffraction-limited performance over the full length of the reformatter output.

Conclusion

- The MCIFU has been demonstrated on-sky to work. We have a resolving power of 3000.
- There are several issues that we want to alleviate with a new spectrograph design.
- We will integrate the MCIFU into MagAO-X in spring 2021 and we plan to go on-sky in 2021. MagAO-X will have a Strehl above 90% in the NIR. This will increase our throughput by a factor of 3 to 6.

Affiliations and reference

Haffert, S. Y., Harris, R. J., Zanutta, A., Pike, F. A., et al. (2020). Diffraction-limited integral-field spectroscopy for extreme adaptive optics systems with the Multi-Core fiber-fed Integral-Field Unit. *arXiv preprint arXiv:2009.03529*.

[a] Leiden Observatory, Leiden University
[b] Steward Observatory, University of Arizona
[c] Zentrum fur Astronomie der Universitat Heidelberg, Landessternwarte Konigstuhl
[d] INAF - Osservatorio Astronomico di Brera
[e] SUPA, Institute of Photonics and Quantum Sciences, Heriot-Watt University
[f] Department of Physics, University of Bath
[g] Institute of Microstructure Technology, Karlsruhe Institute of Technology
[h] Institute of Photonics and Quantum Electronics, Karlsruhe Institute of Technology
[i] Universite Paris-Saclay, Institut d'Optique Graduate School
[j] Department of Physics, Durham University
[k] LESIA, Observatoire de Paris
[l] Max-Planck-Institute for Astronomy
[m] ITEAM Research Institute, Universitat Politecnica de Valencia (current affiliation)
[n] Department of Physics and Astronomy, Macquarie University

Sebastiaan Haffert
shaffert@email.arizona.edu

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NASA Hubble Fellowship Program

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