SF2A 2019
P. Di Matteo, O. Creevey, A. Crida, G. Kordopatis, J. Malzac, J.-B. Marquette, M. N'Diaye, O. Venot (eds)

ACHILLES: ASTRONOMICAL HETERODYNE IN INFRARED-OPTICAL WITH MULTIAPERTURES

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Abstract. We present a low-cost heterodyne near-IR interferometry instrument (H-band), which is being largely made only by Chilean students. It is aimed to work with kilometric baselines to allow further detailed studies of the stars of our galaxy (including exoplanets), as well as finally widen the field of action of the Optical Long-Baseline Interferometry (OLBI) to extragalactic objects. As this instrument is obviously of great technical complexity, this paper can only outline the main parts that it is composed of and how it basically works.

Keywords: instrumentation: interferometers, instrumentation: high angular resolution, techniques: interferometric, infrared: stars

1 Introduction

ACHILLES is an interferometer prototype based on commercial 1.55 μm fiber components. As the most crucial component of it we characterized a novel sub-shot noise correlation detection system for two receivers, and are about to extend it to three receivers. To accomplish this, we acquired a 2^{nd} Generation Reconfigurable Open Architecture Computing Hardware (ROACH2) platform for the correlator with the capacity to digitize four parallel 1.25 GHz bandwidth receivers, so that phase closure measurements will be possible. We extend the stabilization of the local oscillator (LO) phase between the telescopes to cover the whole acoustic perturbation range. For the telescope to single-mode fiber coupling under atmospheric perturbation, we develop a fiber actuator lock-loop for small telescopes and good seeing, and test an adaptive optics approach for mediocre seeing and/or larger telescopes. We constructed also a frequency comb based laser synthesizer system to include tests on multi-frequency band measurements towards ultra-broad band dispersed heterodyne detection systems finally useful for the Planet Formation Imager (PFI; Monnier et al. 2018b,a).

We develop this concept with the motivation to reach kilometric baselines for larger groups of telescopes. Indeed, as a comparison example, a single telescope with a diameter $D = 40cm$ at a wavelength $\lambda \approx 1.55\mu m$ offers an angular resolution $\theta \approx 10^3\,mas$, where, at the same λ, the Very Large Telescope Interferometer (VLTI) at Paranal/Chile with its maximum baseline $B_{max} \approx 200\,m$ offer $\theta \approx 1.5\,mas$, while the PFI with its expected $B_{max} \approx 10\,\mathrm{km}$ could reach (always at the same λ) a $\theta \approx 3 \times 10^{-2}\,mas$. In addition, the noise temperature of a cross-correlation heterodyne detection system may be under the quantum limit (Michael & Besser 2018).

2 General concept

Based on commercial 1.55μm-fiber technology, ACHILLES works in the H-band (λ =1.4-1.8μm) with more than 95% of transmission through the earth's atmosphere. Conceived as a mobile instrument, it may be connected to any group of existing less-used medium size optical telescopes (e.g. at La Silla, Las Campanas or Tololo, Chile). Our instrument is designed for high-precision phase control for kilometric baselines and nulling interferometry; e.g. using the $14^{\prime}$ Goto-Dobsonians with the ALMA buried fibers to run a demonstration experiment. As well as ACHILLES could be used as development-platform forwards Planet Formation Imager (PFI) relevant techniques (Broadband heterodyne detection, Phase tracking). Figure 1 below depicts our current scheme of a static two-telescope interferometer.

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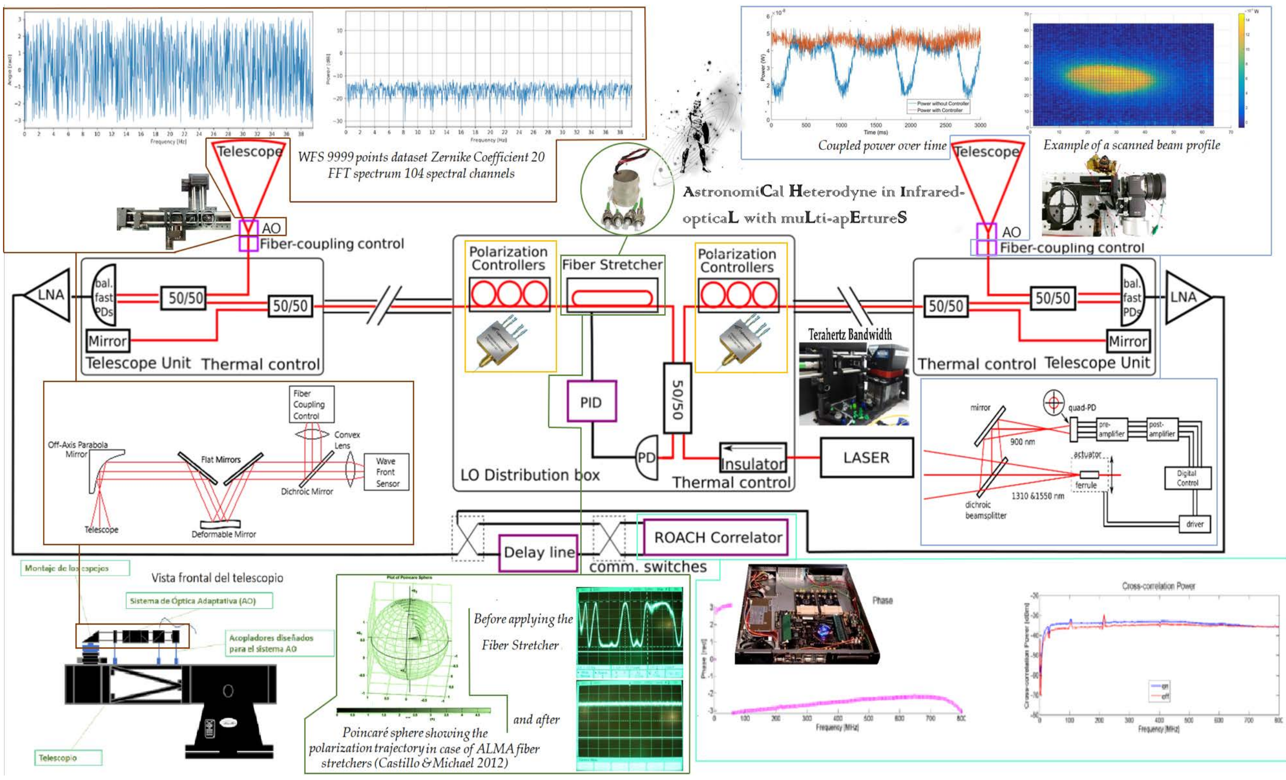

Fig. 1. Actual test setup of a static two-telescope interferometer (Besser et al. 2016, 2018). We added some real pictures and plots of main components of ACHILLES, where farmed; in brown the Adaptive Optics (AO), in blue the Coupling Control (Ramos et al. 2017), in green the Fiber Stretcher (Castillo & Michael 2012), in cyan ROACH (Besser et al. 2016) and in yellow the Polarization Control. Note that two opposite waves don't influence each other in a linear medium, which is the case at the low intensities we have in the fibers (superposition principle). LO-power distribution limit for the heterodyne interferometer: $PL \leq 500$ Wm, i.e. 1000W for 5m and 100mW for 5 km.

2.1 *Main components of ACHILLES*

ACHILLES is mainly composed of:

2.1.1 Adaptive Optics

For a better coupling efficiency we use a lens and mirror arrangement to have a "CLEAN" wavefront to be coupled to the fiber, a piezoelectric deformable mirror DMP40M-P01, which counteracts in real time the effects of Earth's atmosphere, and a wavefront sensor WFS20-14AR/M.

2.1.2 Fiber Coupling Control and Tip-Tilt Correction

Our fiber coupling controller is an amateur guiding camera for telescope coarse auto-guiding and fine guiding through an original control design. Indeed, our small telescope (35 cm diameter) needs only tip-tilt correction under good seeing, where the tip-tilt correction is done with a CD pick-up actuator, thanks to a Digital control based on dsPIC33EP device (Ramos et al. 2017).

2.1.3 Fiber Stretcher and Polarization Control

In order to keep the same phase between the two receivers, we use a fiber stretcher and a PID (Proportional-Integral-Derivative) controller. While, we correct the polarization affected by the stretching of the fiber, to ensure a constant polarization at the telescope, especially maintain parallel polarizations at all telescopes and so maximize the cross-correlations (Castillo & Michael 2012).

2.1.4 Terahertz Bandwidth

This important optional component consists in a comb-generator-based LO-system for future experiments to introduce a spectral LO step-tunability over a bandwidth of a terahertz, while fine-tuning is provided over the thermal control of the Koheras fiber laser. Additionally, it is planned for future experiments where signal and comb lines will be spectroscopically dispersed in special photonics to multiple parallelized receivers.

2.1.5 ROACH-based Correlator

The current ROACH-board is a Xilinx FPGA-board with two 3 GSPS iADC cards. It allows us a compilation of open-source correlator models with Xilinx Simulink in Matlab/Linux environment, and development of own improved models. It has also its own extension of the correlator model by a second integration block, enabling chopped ON/OFF measurements (so-called Dicke-switching in radio-astronomy).

3 Conclusions

Our short-term goals are: To obtain "first light" on a star; by finish improving the control frequency of the coupling control loop and the adding an adaptive optics system to correct higher mode turbulences. As well as to finish developing a heterodyne dispersed receiver based on an optical comb, without forgetting to manage the polarization control of the electromagnetic waves. Then proceed to the next step of implementing a 3-telescope interferometer to get closure phase. While our aims at long term are: to run tests at the ISI (Infrared Spatial Interferometer; Townes et al. 1998; Hale et al. 2000) or at the VLTI interferometer, and to achieve a test bench for mid-infrared receivers for the PFI.

Special thanks go to the project grants ESO-MIXTO funds 2018, CONICYT-ALMA funds N^{o} 31090018/31140025, QUIMAL N^{o} 150010 and CATA-Basal PFB-06.

References

Besser, F. E., Ramos, N., Rates, A., et al. 2018, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 10701, Proc. SPIE, 107012L

Besser, F. E., Rates, A., Ortega, N., et al. 2016, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 9907, Proc. SPIE, 99072L

Castillo, J. A. & Michael, E. A. 2012, IEEE Photonics Journal, 4, 2390

Hale, D. D. S., Bester, M., Danchi, W. C., et al. 2000, ApJ, 537, 998

Michael, E. A. & Besser, F. E. 2018, IEEE Access, 6, 45299

Monnier, J. D., Ireland, M., Kraus, S., et al. 2018a, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 10701, Proc. SPIE, 1070118

Monnier, J. D., Kraus, S., Ireland, M. J., et al. 2018b, Experimental Astronomy, 46, 517

Ramos, N., Ortega, N. M., Michael, E. A., Rates, A., & Besser, F. E. 2017, in 2017 CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON), 1–5

Townes, C. H., Bester, M., Danchi, W. C., et al. 1998, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 3350, Proc. SPIE, ed. R. D. Reasenberg, 908–932