15 High dynamic range thermal infrared imager for the VLTI

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High dynamic range imaging provides a key technique to observe, characterize, and understand extrasolar planetary systems. While current XAO-assisted 10-m class telescopes provide very high-contrast images (up to 10^{-7} beyond 0.3'' in the H band), their angular resolution is generally insufficient to study directly the inner planetary region. Interferometric instruments can circumvent this limitation by observing within the diffraction limit of a single aperture but generally at much reduced contrasts. Currently, the most precise instrument at the VLTI (i.e., PIONIER) achieves a contrast of a few 10^{-3} in the near-infrared and second-generation instruments are not designed to improve that limit. Based on the experience gained with PIONIER, as well as with mid-infrared nulling instruments (KIN, LBTI), and thanks to recent advent of new data reduction techniques, the VLTI could reach the next level of high-dynamic range observations at small angular separation with a nulling interferometric instrument operating in the thermal infrared, a sweet spot to image and characterize young extrasolar planetary systems. Technical and science motivations for such an instrument are described in this chapter.

The development of high dynamic range capabilities has long been recognized as one of the top priorities for future interferometric instruments (e.g., Ridgway et al. 2007) and for the VLTI in particular (e.g., Léna et al. 2006). In the early 2000s, pushed by the need to prepare the way for future space-based infrared interferometric missions, a concept for such an instrument was designed and studied in detail for the VLTI (Absil et al. 2006). This study demonstrated the feasibility of reaching a contrast of 10^{-4}, approximately one order of magnitude better than what is achievable with the current and second-generation VLTI instrument suite. While this project did not materialize in an actual instrument, the key scientific questions that it was supposed to address remain, and high-contrast infrared interferometry is still nowadays the best option to answer them. New scientific questions that would benefit from such an instrument have also appeared in the last 10 years, making the case even stronger. Today, recent advances in interferometric data reduction (the so-called Nulling Self Calibration or NSC, see Mennesson et al. 2011), beam combination architecture (Lacour et al. 2014a), and mid-infrared lithium niobate beam combiners (Lacour et al. 2014b) offer new possibilities to bring the VLTI to the next level of high dynamic range observations at small angular separation.

With an anticipated contrast of 10^{-4}, the VLTI would significantly contribute to three main areas related to extrasolar planetary science: exo-planets, exo-zodiacal discs, and planet-forming regions. First, it would be sensitive to young self-luminous or irradiated gas giant planets at angular separations smaller than what future extremely large telescopes will be capable to resolve. Low-resolution spectroscopic observations of such planets (e.g., τ Boo b, Gliese 86d, or HD 69830b) in the thermal infrared (3.5-4.5 µm) are ideal to derive the radius and effective temperature of the observed planets and provide critical information to study the non-equilibrium chemistry of their atmosphere via the CH_4 and CO spectral features. Second, a contrast of 10^{-4} would allow faint exo-zodiacal disc emissions to be detected around nearby main-sequence stars, at the ~50 zodis level. Such observations are crucial to unravel the mystery of hot dust (e.g., Ertel et al. 2014) and to constrain the faint-end of the exo-zodiacal disc luminosity function (complementarity with the KIN and LBTI survey in the Northern hemisphere). Finally, the improved dynamic range in the thermal infrared would open a new observational window on planet-forming regions and would allow studying the physics of planet formation at higher contrasts, including forming proto-planets. Other major fields that make use of interferometric observations such as stellar physics and the study of AGN would also benefit from a higher dynamic range.

Besides these scientific motivations, a new high dynamic range imager at the VLTI would also serve as a technology demonstrator and scientific precursor for future interferometric instruments such as PFI, or for TPF/Darwin-like missions if a nulling architecture is selected. Technology demonstration would include key technologies and detection strategies like four-telescope NSC, the combination of closure phases and nulling, and mid-infrared integrated optics components for interferometric combination. Heterodyne techniques using laser frequency combs could also be considered (Ireland et al. 2014). Scientific preparation would include for instance exo-zodiacal dust reconnaissance for southern stars that will be targeted by future exo-Earth characterization missions. Note also that the VLTI offers at L band an angular resolution which is similar to that of ALMA in its most extended configuration or that of future ELTs in the near-infrared (i.e., ~5 mas or 0.1 AU at 20 pc). Hence the VLTI can be used to trace complementary dust species and molecular lines in ALMA-detected circumstellar discs or to get complementary information on ELT-detected planets, possibly on much less-solicited telescopes such as the ATs, which could also be more easily used to carry out large surveys. New discoveries could then be followed up with ELTs or ALMA.

References

1. *Ridgway S. et al., "Workshop on the Future Directions for Ground-based Optical Interferometry", 2007*
2. *Léna P., Absil. O, Borkowski V., et al., Bulletin de la Société Royale des Sciences de Liège, Vol. 74, 203-229, 2005*
3. *Absil O, den Hartog R., Gondoin P., et al., A&A 448, 787-800, 2006*
4. *Mennesson B., Hanot C., Serabyn, et al., ApJ 743, 2011*
5. *Lacour S., Tuthill P, Monnier J.D., et al., MNRAS 439, 2014b*
6. *Lacour S., Lapeyrère V., Gauchet L., et al., SPIE 9143, 2014a*

7. *Ertel S., Absil O., and Defrère D., A&A 570, 2014*
8. *Ireland M. and Monnier J., SPIE 9146, 2014*