PIONIER - Imaging combiner for VLTI

Precision Integrated Optics Near-infrared Imaging ExpeRiment

PIONIER in a beautiful 4min movie:
https://youtu.be/7YUSdauRZNk

PIONIER stands for Precision Integrated-Optics Near-infrared Imaging ExpeRiment. PIONIER is a 4-telescope instrument for the VLTI that combines four ATs or four UTs using an integrated optics combiner. It provides low spectral resolution in H band. PIONIER is designed for imaging with a specific emphasis on precision closure-phases and visibilities. PIONIER has been approved by STC at spring 2009 and first science runs started in October 2010.

In P96 and later, PIONIER is now offered to the whole community as a normal ESO instrument thanks to an agreement between IPAG and ESO. Further information can be found in the ESO webpage for PIONIER. The data reduction software can be found in the JMMC website. Data are automatically reduced by the last version of the pipeline and are made available as calibrated science-ready OIFITS in the JMMC OIDB webpage.

PIONIER was exploited as a visitor instrument mostly operated by the PI team until Period 92. In P93 and P94, PIONIER was open to the community in shared risk, delegated visitor mode (deprecated information). Further deprecated information on the science and the system *(deprecated, restricted access)* .

Last news

- 2017-03-02 : A&A highlights the legacy paper of PIONIER about Herbig YSO.
- 2016-03-09 : ESO press release and INSU press release on the first image of RAPID/PIONIER
- 2015-06-15 : ESO press release on the new RAPID detector
- 2015-03-20 : Images from LP Herbig YSO
- 2015-02-26 : PIONIER offered in the ESO Call-for-proposal P96 in service and visitor mode.
- 2014-12-10 : Installation of the RAPID camera. Test on-going.
- 2014-11-03 : Press-release "VLTI Detects Exozodiacal Light" ESO/ OSUG
- 2014-07-01 : OPC answers for P94, about 52 nights scheduled (89 requested).
- 2014-06-10 : First test of the RAPID camera on-sky. Camera is shipped back to IPAG for further improvements.
- 2014-04-01 : PIONIER data serve as reference dataset for the 2014 "Imaging Beauty Contest"
- 2014-01-13 : PIONIER workshop at IPAG (see vlti-pionier.sciencesconf.org).
- 2014-01-01 : OPC answers for P93, about 51 nights scheduled.
- 2013-11-06 : First 4T fringes with RAPID detector at IPAG.
- 2013-07-01 : OPC answers for P92, about 30 nights scheduled (pressure was 3.5 on ATs).
- 2013-02-22 : Failure of the PIONIER workstation (wpnr) -- Replacement done thanks to the great support from Paranal
- 2013-01-01 : OPC answers for P91, about 43 nights scheduled (pressure was 4.8 on ATs).
- 2012-07-10 : OPC answers for P90: about 51 nights scheduled.
- 2012-05-12 : First scientific observations with 4xUTs. Demonstration of sensitivity better than H=10.
- 2012-04-01 : Commissioning of the K-band in PIONIER. Working fine (Kmag~5).
- 2012-01-01 : Failure of the 4T-AC-H combiner, replaced by the older 4T-ABCD-H
- 2011-12-23 : OPC answers for P89, about ~25 nights scheduled.
- 2011-12-07 : Vampire Star Reveals its Secrets (UJF, eso1148, Le Monde, CNRS, Science&Vie).
- 2011-03-17 : First 4xUTs fringes ever, and made with PIONIER (UJF, ESO ann11021).
- 2010-10-27 : First fringes with 4xATs (CNRS, UJF, ESO ann1081, Dauphine Libere).

Sample of publications

- 2021 Nature Astrophysic, Cassan et al., "Microlensing mass measurement from images of rotating gravitational arcs"
- 2019Natur.567..200P Pietrzyski, G et al. "A distance to the Large Magellanic Cloud that is precise to one per cent"
- [...]
- 2016MNRAS.458.3272K Kiefer, F. et al. "Masses of the components of SB2 binaries observed with Gaia - III. Accurate SB2 orbits for 10 binaries and masses of HIP 87895"
- 2017A&A...597A.137K P. Kervella et al. "The radii and limb darkenings of Centauri A and B . Interferometric measurements with VLTI/PIONIER"
- accepted in A&A L. Chen et al. "A study of dust properties in the inner sub-au region of the Herbig Ae star HD 169142 with VLTI/PIONIER"
- accepted in A&A M. Montarges et al. "The convective surface of the red supergiant Antares"
- accepted in A&A C.A. Hummel et al. "Orbit of the Mercury-Manganese binary 41 Eridani"
- accepted in A&A G. Dalla Vedova et al. "VLTI/PIONIER images the Achernar disk swell"
- accepted in A&A M. Wittkowski et al. "Aperture synthesis imaging of the carbon AGB star R Sculptoris"
- accepted in A&A B. Lazareff, J.P. Berger, et al. "Statistical study of Herbig AeBe disks at milliarcsecond scale. A survey in H band using PIONIER-VLTI"
- accepted in MNRAS J.M. Apellaniz, et a., "A close encounter of the massive kind"
- accepted in A&A J.B Le Bouquin, et al., "Resolved astrometric orbits of ten O-type binaries"
- accepted in A&A S. Ertel, et al., "A near-infrared interferometric survey of debris-disc stars. V. PIONIER search for variability"
- accepted in A&A P. Kervella, et al., "The red dwarf pair GJ65AB: inflated, spinning twins of Proxima"
- 2016A&A...587A.117B J. Breitfelder, et al., "Observational calibration of the projection factor of Cepheids. II. Application to nine Cepheids with HST/FGS parallax measurements"
- 2016A&A...588A.130M M. Montarges et al., "The close circumstellar environment of Betelgeuse III. VLTI/PIONIER interferometric monitoring of the photosphere"

- 2016MNRAS.455.3303H J.-L. Halbwachs, H.M.J. Boffin, J.-B. Le Bouquin, F. Kiefer et al., "Masses of SB2 binaries observed with Gaia. II. PIONIER interferometric observations for Gaia validation"
- 2016A&A...586A..11M A. Matter, L. Labadie, J.-C. Augereau, J. Kluska et al., "Inner disk clearing around the Herbig Ae star HD139614: Evidence for a planet-induced gap ?"
- submitted to A&A J.B Le Bouquin, et al., "The limb darkening and featureless surfaces of the yellow supergiants Canopus, Wezen and eps Peg"
- 2015A&A...579A..68G A. Gallenne, et al., "Robust high-contrast companion detection from interferometric observations"
- 2015A&A...576A..64B J. Breitfelder, et al., "Observational calibration of the projection factor of Cepheids I. The Type II Cepheid kappa Pavonis"
- 2015A&A...574A..41A F. Anthonioz, et al., "The VLTI/PIONIER survey of Southern T Tauri stars (I) First results."
- 2014ApJS..215...15S: H. Sana, et al., "Southern Massive Stars at High Angular Resolution: Observational campaign and Companion Detection"
- 2014A&A...570A.128E: S. Ertel, et al., "A near-infrared interferometric survey of debris-disc stars (IV) An unbiased sample of 92 southern stars with PIONIER"
- 2014A&A...570A.127M: L. Marion, et al., "Searching for faint companions with PIONIER (II) 92 main sequence stars from the Exozodi survey"
- 2014AJ....148..114M: P. Mayer, et al., "The three body system delta Circini"
- 2014A&A...568A..94N: A. Nasseri, et al., "HD152246: a new high-mass triple system"
- 2014A&A...569A..10A: A. Domiciano de Souza, et al., "The environment of the fast rotating star Achernar"
- 2014A&A...568A..85P: T. Paumard, et al., "GCIRS7, a pulsating M1 supergiant at the Galactic centre."
- 2014A&A...567A..51C: A. Carmona, et al., "Constraining the structure of the transition disk HD 135344B"
- 2014A&A...565L...2D: E. Di Folco et al., "GG Tau: the fifth element"
- 2014A&A...564A..80K: J. Kluska, et al., "Semi-Parametric Approach for image Reconstruction of Young Stellar objects"
- 2014A&A...564A..93M: J. Menu, et al., "On the structure of the transition disk around TW Hya"
- 2014A&A...564A...1B: H. Boffin et al., "Roche-lobe filling factor of mass-transferring red giants - the PIONIER view"
- 2014A&A...561A.101L: J.B Le Bouquin et al.: "Refined masses and distance of the young binary Haro 1-14 C"
- 2014A&A...561L...3G: A. Gallenne et al., "Multiplicity of Galactic Cepheids from long-baseline interferometry (II) The Companion of AX Circini revealed with VLTI/PIONIER"
- 2014A&A...561A..46C: E. Choquet et al., "The close environment of high-mass X-ray binaries at high angular resolution"
- 2013MNRAS.435.2501L: R. Lachaume and J.P. Berger, "Bandwidth smearing in infrared long-baseline interferometry. Application to stellar companion search"
- 2013A&A...553A.131S: H. Sana, J.-B. Le Bouquin et al.: "Three-dimensional orbits of the triple-O stellar system HD150136"
- 2013A&A...552A..4O: J. Olofsson, M. Benisty et al., "Sculpting the disk around T Chamaeleontis: an interferometric view"
- 2013A&A...551A..121L: J.-B. Le Bouquin, H. Beust, G. Duvert et al, "Masses and age of the Chemically Peculiar double-lined binary Lupi"
- 2012A&A...546L..9D: D. Defrère, J. Lebreton, J.-B. Le Bouquin, A.-M. Lagrange et al, "Hot circumstellar material resolved around beta Pictoris with VLTI/PIONIER"
- 2012MNRAS.423.2711D: De Becker M., Sana H., Absil O., Le Bouquin J-B. et al, "The particle accelerator HD 167971 revealed by long baseline interferometry"
- 2012A&A...540A..76S: Stefl S., Le Bouquin J-B. et al, "Activity in the circumstellar disk of the Be star 48 Lib"
- 2012A&A...541A..89L: Le Bouquin, J.-B.; Absil, O., "On the sensitivity of closure phases to faint companions in optical long baseline interferometry"
- 2012A&A...543A..31L: B. Lazareff, et al., "A novel technique to control differential birefringence in optical interferometers. Demonstration on the PIONIER-VLTI instrument"
- 2011A&A...535A..68A: Absil O., Le Bouquin J-B, et al, "Searching for faint companions with VLTI/PIONIER"
- 2011A&A...536A..55B: Blind N., Boffin H., Berger J-P. et al, "The symbiotic star SS Leporis: Milli-arcsecond imaging with PIONIER/VLTI"
- 2011A&A...534L..11C: Chesneau O., Meilland A., Banerjee K., Le Bouquin et al, "The 2011 outburst of the recurrent nova T Pyx"
- 2011A&A...535A..67L: Le Bouquin J-B, Berger J-P, et al, "PIONIER: a 4-telescope visitor instrument for VLTI"

Sample of conference proceedings and other publications:

- SPIE 2014: Monnier, J. et al., "The 2014 Interferometric Imaging Beauty Contest" (based on PIONIER data)
- 2014IAUS..299..338E: Ertel, S. et al., "Unraveling the Mystery of Exozodiacal Dust"
- 2013prpl.conf1K090R: M. Rabus, R. Lachaume, "Direct determination of physical parameters for main sequence stars"
- 2013EAS.59.41K: Kluska, J.; Malbet, F.; Berger, J.-P., et al, "Imaging the Surroundings of MWC 158 by Optical Interferometry"
- 2013IAUS.290.197C: Choquet, E; Kervella, P; Le Bouquin, JB et al, "Probing the stellar wind geometry in Vela X-1 with infrared interferometry"
- 2012SPIE.8445E..0IL: Le Bouquin, J.-B., Berger, J.-P., Zins, G et al, "PIONIER: a status report"
- 2011 ESO Messenger: Zins G, Lazareff B et al, "PIONIER: A Four-telescope Instrument for the VLTI"
- 2011epsc.conf.1084D: Defrere D., Absil O., Augereau JC., et al, "Imaging the inner regions of debris disks with interferometry"
- 2010SPIE.7734E..99B: Berger, J.-P.; Zins, G.; Lazareff, B. et al., "PIONIER: a visitor instrument for VLTI"

Key science

The instrument is used for a wide range of topics but we particularly focus on the following ones:

- Morphology and time variability of the inner rim of protoplanetary environments around intermediate mass pre-main sequence stars (on-going large program);
- The shape and composition of T Tauri disks (mini-survey finished, data being analyzed);
- Origin, morphology and evolution of hot inner debris discs around main sequence stars (large program finished, data being analyzed, additional observations on-going);
- Multiplicity property of massive stars (large program finished, data being analyzed, follow-up of SB2 binaries on-going);
- Stellar surfaces and interacting binaries.

Sponsors

PIONIER is funded by the Universit\'e Joseph Fourier (now Universit\'e Grenoble Alpes, UGA), the Institut de Plan\'etologie et d'Astrophysique de Grenoble (IPAG), the Agence Nationale pour la Recherche (ANR-06-BLAN-0421, ANR-10-BLAN-0505, ANR-10-LABX56, ANR-11-LABX-13), and the Institut National des Sciences de l'Univers (INSU PNP and PNPS). Its integrated optics beam combiner is the result of a collaboration between IPAG and

CEA-LETI based on CNES R\&T funding, started initially for the VSI project. Wes Traub kindly accepted to ship the IOTA PICNIC camera and optical hardware from PTI to LAOG. The RAPID detector has been developed by the "FUI RAPID", and its installation in PIONIER was supported by the FOCUS LABEX. ESO provides continuous support to the instrument.

Executive team

- Project Manager: Gérard Zins
- System Engineer: Bernard Lazareff / Pierre Kern
- Principal Investigator: Jean-Baptiste Le Bouquin
- Initiator of the projet: Jean-Philippe Berger

PIONIER is on-loan to ESO since March 2015. Therefore it is now the ESO Instrument Operational Team which is in charge of the instrument.

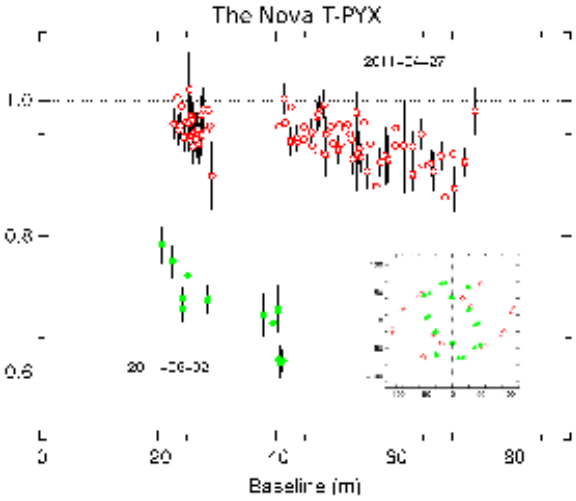
First results

The first results obtained in 2011 include the imaging of the symbiotic binary SS-Lep, the measurement of the size of the recurrent Nova T-Pyx during outburst, the size of the Be star 48-Lib, the detection of the low-mass stellar companion around delta-Aqr...

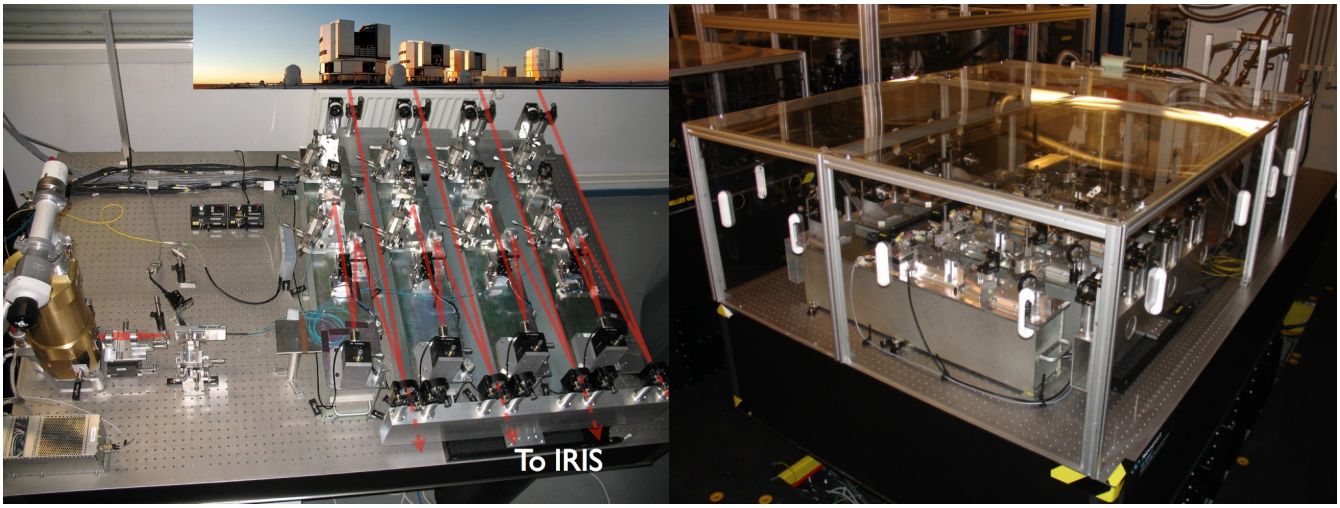
Since 2012, the main contribution of PIONIER are represented by 3 large programs on:

- Debris Disks: >100 main-sequence stars with the compact configuration, to search for diffuse extended material.
- Young Stellar Object: >30 Herbig AeBe?on all configurations to study to morphology of the proto-planetary disks.
- Massive Binaries: >100 O-type stars on the extended configuration to characterize the multiplicity properties.

On each subject the goal is to gather a large sample to allow a breakthrough in our understanding. This is only made possible thanks to the improved sensitivity of PIONIER combined with its excellent operational efficiency.



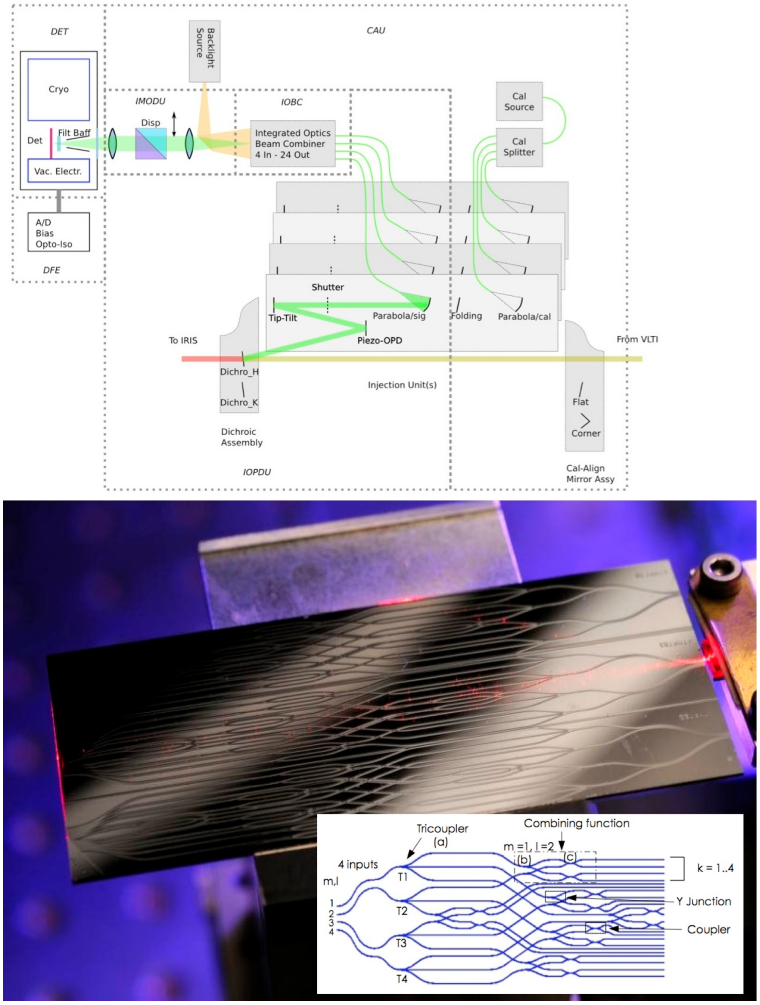
Instrument description



PIONIER has four independent arms that allow the incoming VLTI beams to be injected in fibers. Each arm is equipped tip/tilt and piezo-OPD correction plus shutter. The 4 single-mode fibers guide the light to an integrated optics combiner (IOBC). The IOBC ouput is imaged, through a double doublet + prism onto the detector. The 24 dispersed IOBC outputs are read by the IOTA/IONIC3 PICNIC detector with modified electronics and software.

The alignement units (CAU) allow to 1) to produce coherent beams for internal fringes acquisitions purposes 2) backwards propagate light to ensure alignment to IRIS fast guiding system. One sliding arm with dichroics selects which band (H,K) is forwarded to PIONIER and which one is let through to IRIS. The other sliding arm is used for calibration purposes and has three positions: 1) free: let VLTI beams reach the instrument; 2) mirror: send coherent signal to the instrument; 3) corner-cube: image the input fibers onto IRIS.

The Instrument Software Package is subdivided into the following standard INS software modules: ICS, DCS, OS, MS. Observing templates are executed using the standard ESO BOB tool. Dialog between PIONIER and VLTI (e.g delay lines) is achieved through the VLTI Interferometer Supervisor Software. The architecture has been split into 2 parts; detector system and instrument control system. It is similar to a standard VLTI instrument with an instrument WS, an ICS LCU and a DCS WS, with dedicated tip/tilt and OPD correction facilities. The instrument WS is a standard Linux PC platform supported by the VLT Software. The detector WS is an industrial Linux PC platform equipped with a PCI-7300A board used to generate clock signals and to acquire detector data. It is running under the VLT Software. The instrument LCU is an Embedded PC from BECKHOFF with EtherCAT/fieldbus terminals for I/O.



Left: Fig. 2. PIONIER conceptual scheme. The Injection and Optical Delay Unit (IOPDU) is responsible for the injection of the four beams (either from CAU or from VLTI) in the single mode fibers. It also implements the OPD modulation, the tip-tilt correction and the polarization control. The Integrated Optics Beam Combiner (IOBC) recombines the four beams into 24 interferometric outputs in a pairwise scheme. These outputs are then imaged, and eventually spectrally dispersed, by the Imaging Optics and Dispersion Unit (IMODU) on the detector (DET). The aim of the Calibration and Alignment Unit (CAU) is to provide four interferometric beams that match the size and angle of the VLTI beams. Right: Picture of the optical chip and schematic of the IOBC layout realized by CEA-LETI in collaboration with LAOG (contact: pierre.labeye@cea.fr)