Precision Integrated Optics Near-Infrared Experiment

Le Bouquin, Berger, Lazareff, Zins, Traub, Jocou, Kern, Haguenauer, Absil, Augereau, Benisty, Blind, Bonfils, Delboulbe, Feautrier, Germain, Gitton, Guieu, Labeye, Lizon, Monin, Magnard, Malbet, Maurel, Menard, Micallef, Michaud, Montagnier, Morel, Moulin, Perraut, Popovic, Rabou, Rochat, Roussel, Roux,

Stadler, Tatulli, Ventura...

+ CRISTAL and FOST teams from IPAG



PIONIER in a nutshell



VLT-I ELT

- Combines four telescopes of VLTI (4 UTs or 4 ATs)
- Near-infrared 1.6µm H-band with small spectral resolution ≈20
- Based on integrated optics technology
- Provides sensitive imaging capabi high spatial resolution ≈2mas





A PIONIERing interferometer In a grand display of astrophotonics, the light from

at the Very Large Telescope Interferometer (VLTI) in Chile was cor bined in late October for the first time, by the Precision Integrate Optics Near-infrared Imaging ExpeRiment (PIONIER). The visiting instrument, developed at the Laboratoire d'Astrophysique de Grenoble (LAOG) in France, complements the two existing VLTI instruments that combine light from two and three telescopes. Before even reaching PIONIER, the light paths from the four 1.8-meter auxiliary telescopes at the VLTI had to be controlled to less than a micron. Each of PIONIER's four alignment units, seen above in the foreground, focuses one of the incoming VLTI beam into an optical fiber. The fibers channel the light into the heart of the instrument: an integrated optics beam combiner, developed

Illed at the focus of VLTI as of 2010

PIONIER in a nutshell

ANR 2006 (R&D IO)	240 k€
Univ. JF - Grenoble	115 k€
ANR 2010 (Exozodi)	37 k€
PNPS	40 k€
PNP	23 k€
Labex OSUG	8 k€
Labex FOCUS	20 k€
Salaries (2009-2014)	≈500 k€
Total consolidated	≈1 100 k€

- Proposition made in 2009 by IPAG to ESO
- First Light and Science in Oct. 2010
- Exploited as a visitor-instrument 2010-2014

- Total consolidated cost is approximately 1 million euros
- Project initiated by local funding (UJF)
- National funding (ANR, INSU) support the project and the operations

PIONIER and stellar formation

Multiplicity of O stars

Proto-planetary disks of Herbig AeBe stars

Hot debris disks around AFGK stars

Low-mass pre-main sequence



1. Multiplicity of Massive Stars



- Massive stars are key component of stellar feedback on the Univers.
- The 1-50 AUs is an uncharted territory for multiplicity.

- 107 O-type stars observed with PIONIER
- 45 companions detected < 100mas (only 5 were known)
- Overlap between RV and Visual Binaries
- 9 O+O systems are followed to measure accurate dynamical masses and distances

1. Multiplicity of Massive Stars



Kratter+ 2010





Most massive stars are born as part of a close binary system.

→ Early trends are compatible with disk fragmentation through gravitational instabilities.



- Global multiplicity is 0.87 before un-biasing.
- 100% of luminosity classe V are close binaries (versus 80% and 60% and for class III and I).

Sana+ 2014, submitted



Given the multiplicity property, almost all massive stars will interact with a companion.

→ Fundamental aspect of the stellar feedback.

2. Circum-stellar disks of Herbig stars







- So far, spatially resolved observations mostly probed size/luminosity relation, but not the morphology.
- Driver for modern optical interferometry (VLTI), but not achieved because of sensitivity issue.
- The main goal of the PIONIER consortium.

2. Circum-stellar disks of Herbig stars



Kluska+ 2013

50 Herbig stars observed with all VLTI configurations

- 12 targets with intensive imaging campaign
- Statistical analysis on-going

Interferometric imaging (PIONIER)



Radiative Transfer modelling (PRODIMO)



- Unexpected extended emission in some stars (scattering on outer disk ?)
- Comparison with detailed modelling for the most resolved targets

3. Hot debris disks around AFGK stars

Kalas+ 2005, Boley+ 2012



- Cold, outer debris disks are observed at all wavelengths.
- EXOZODI refers to the hot and warm dust in the inner regions of planetary systems
- In the solar system, the zodiacal dust has a tiny mass but dominates the luminosity.



- FLUOR, K-band, 42 stars, 8 year survey
- PIONIER, H-band, 88 stars, 1 year survey
- Unveil any near-IR excess >0.75%

3. Hot debris disks around AFGK stars





- Hot and cold dust not correlated
- No clear age dependence
- Flat color of the excess suggests important contribution from scattering

- Radiative transfer modelling favours very small grains accumulated to the sublimation radius (0.5AU)...
- ... hard to replenish efficiently such a population over the stellar life-time.
- A possible scenario involves a link with the outer planetary system.

4. Pre-main sequence of low-mass stars



- Model-independent masses and distance 0.90 $\pm 0.05~M_{\odot}$ and 0.30 $\pm 0.01~M_{\odot}$
- Flux ratio in near-IR bands
 f = 0.239 ±0.004

- Comparison with models is limited by the accuracy on T_{eff}
- GAIA will provide the flux ratio in visible... allowing to compute the V-H and V-K colors of each component.

More about PIONIER results

- 21 articles published/submitted, all in stellar physics
- 12 articles from peoples outside the initial science team.
- The most important studies are still in preparation



Accommodation Sponsors

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Practical Information

- submitted: H. Sana, et al., "Southern Massive Stars at High Angular Resolution: Observational submitted: J. Menu, et al., "TW Hya: multi-wavelength interferometry of a transition disk" submitted: J. Kluska, et al., "Semi-Parametric Approach for image Reconstruction of Young Ste submitted: A. Carmona, et al., "Constraining the structure of the transition disk HD 135344B" accepted in A&A: H. Boffin et al., "Roche-lobe filling factor of mass-transferring red giants - the 2014A&A...561A.101L: J.B Le Bouquin et al.: "Refined masses and distance of the young binar 2014A&A...561L...3G: A. Gallenne et al., "Multiplicity of Galactic Cepheids from long-baseline in 2014A&A...561A..46C: E. Choquet et al., "The close environment of high-mass X-ray binaries a 2013MNRAS.435.2501L: R. Lachaume and J.P. Berger, "Bandwidth smearing in infrared long-t 2013A&A...553A.131S: H. Sana, J.-B. Le Bouquin et al.: "Three-dimensional orbits of the triple-2013A&A...552A..4O: J. Olofsson, M. Benisty et al., "Sculpting the disk around T Chamaeleonti 2013A&A...551A..121L: J.-B. Le Bouquin, H. Beust, G. Duvert et al, "Masses and age of the Ch 2012A&A...546L..9D: D. Defrère, J. Lebreton, J.-B. Le Bouquin, A.-M. Lagrange et al, "Hot circi 2012MNRAS.423.2711D: De Becker M., Sana H., Absil O., Le Bouquin J-B. et al, "The particle 2012A&A...540A...76S: Stefl S., Le Bouquin J-B. et al, "Activity in the circumstellar disk of the B 2012A&A...541A..89L: Le Bouquin, J.-B.; Absil, O., "On the sensitivity of closure phases to fain 2012A&A...543A...31L: B. Lazareff, et al., "A novel technique to control differential birefringence 2011A&A...535A..68A: Absil O., Le Bouquin J-B, et al, "Searching for faint companions with VL" 2011A&A...536A..55B: Blind N., Boffin H., Berger J-P. et al, "The symbiotic star SS Leporis: Mill 2011A&A...534L..11C: Chesneau O., Meilland A., Banerjee K., Le Bouquin et al, "The 2011 out
- 2011A&A...535A..67L: Le Bouquin J-B, Berger J-P, et al, "PIONIER: a 4-telescope visitor instruition instruition in the second sec

- Workshop in Grenoble in January 2014
- <u>http://vlti-pionier.sciencesconf.org</u>
- http://ipag.osug.fr/pionier

A glimpse on other stellar physics studies

Imaging the symbiotic binary SS Lep



"PIONIER has provided a new view on symbiotic stars" (H. Boffin, ESO)

Observations of the fast-rotator Altair



"PIONIER/VLTI does not have enough spatial resolution to probe the gravity darkening" (A. Merand, ESO)

"To understand the complex environment of AGB stars, imaging large samples of stars and/or time series are needed" (C. Paladini, Belgium)



"No change of mass-loss over the last 15 years and no strong binary effect at apastron". (J. Groh, Geneva Obs.)

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Imaging the Mira star R For