Deep companion search around β Pictoris down to 1.75 AU with the newly commissioned L'-band vector vortex coronagraph on VLT/NACO

Dimitri Mawet[1], Julien Milli[1,3], Olivier Absil[2], Pierre Baudoz[4], Anthony Boccaletti[4], Gael Chauvin[3], Christian Delacroix[2], Julien H. Girard[1], Anne-Marie Lagrange[3], Jared O'Neal[1], Pierre Bourget[1], Valentin Christiaens[2], Pontus Forsberg[5], Frederic Gontée[1], Serge Habraken[1], Charles Hanot[2], Mikael Karlsson[5], Markus Kasper[6], Jean-Louis Lizon[1], Koraljka Muzic[1], Eduardo Peñna[1], Richard Olivier[7], Nicolas Slusarenko[1], Lowell E. Tacconi-Garman[6], Jean Surdej[2]

[1] European Southern Observatory Vitacura, Alonso de Cordova 3107, Casilla 19001, Vitacura, Santiago 19, Chile
[2] Département d'Astrophysique, Géophysique et Océanographie, Université de Liège, 17 Allée du Six Août, B-4000 Liège, Belgium
[3] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), University Joseph Fourier, CNRS, BP 53, 38041, Grenoble, France
[4] LESIA, Observatoire de Paris, 5 pl. J. Janssen, F-92195 Meudon, France
[5] Department of Engineering Sciences, Ångström Laboratory, Uppsala University, Box 534, SE-751 21 Uppsala, Sweden
[6] European Southern Observatory Headquarters, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany
[7] GDTech s.a., LIEGE Science Park, rue des Chasseurs Ardennais, B-4031 Liège, Belgium

A. Motivation

• Main science driver of adaptive optics imagers/spectrograph is exoplanet science.
• Current exploitation of the park of adaptive optics high contrast imagers has reached its limits.
• Lots of non detections and very few amazing discoveries.
• Need to open a new parameter space.
• Technological breakthrough achieved by
  – second generation instruments (SPHERE, GPI, P3K-P1640, SCExAO)
  – untapped potential of first generation instruments

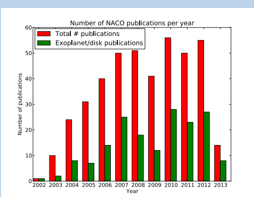

Figure 1: Total number of NACO refereed publications per year (red) and the number of articles related to extra-solar planetary systems imaging and characterization (green). Source: telbib.eso.org

B. Small IWA coronagraph in the L band

L band is a sweet spot for high contrast imaging:
• Star-to-young planet contrast favorable (holds true for older systems).
• ExAO-like Strehl with first generation instruments.
• Loss of resolution completely compensated by the use of small inner working angle (IWA) coronagraph.
• Thermal background increase moderate (typically L' ~ 17 mag).

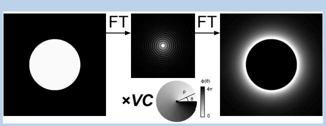

Figure 2: Illustration of the diffraction effect of the vortex phase mask on a filled aperture (left). All of the on-axis coherent light appears outside of the geometric image of the input pupil (right). A circular aperture (Lyot stop) then blocks it all. FT stands for Fourier transform.

C. Vector Vortex Coronagraph

The Vector Vortex Coronagraph (Mawet et al. 2005, Delacroix et al. 2013) is a new generation small IWA phase mask coronagraph with the following properties:
• Demonstrated high contrast
• Broadband
• IWA down to 0.9 λ/D
• Unlimited outer working angle
• High throughput
• 360° unobscured Field of View
• Optical and operational simplicity.

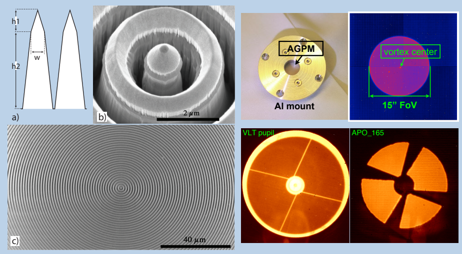

Figure 3. Left panel: scanning electron microscope (SEM) images of the NACO AGPM made from diamond sub-wavelength gratings. a. Structure profile schematic. b. Zoom on the center of the diamond AGPM. c. Overview of the device. Right panel: (i) picture of the fully assembled aluminum mount with a 9 mm clear aperture containing the AGPM. (ii) view from inside CONICA, showing the 15" field of view (diameter). (iii) full oversized stop of CONICA, showing the VLT pupil (including the central obscuration and struts). (iv) APO_165 pupil mask (diameter= 0.87 × Dpup), aligned to cover the diffraction and thermal background from the central obscuration and struts.

D. NACO's AGPM

The monolithic diamond device was installed and validated in November 2012:
• The AR coating is engraved on the substrate itself .
• A cryo-compatible Al mount was manufactured by GD Tech S.A
• Software/template upgrades were implemented.
• Setup optimization suggested the use the use of the Lyot Stop APO165, which covers the central obscuration and spiders, imposing pupil tracking.

Figure 4: Mounting of the AGPM in the Paranal clean room. The component, which looks like a tiny compact disk (10 mm diameter and 0.3 mm thickness), was handled with care and inserted into a dedicated mount (designed in Belgium by GDTech to support a cool down from room temperature to a few tens of Kelvin). The assembly was then mounted onto the "slit/mask" wheel (focal plane) of CONICA.

E. Science Verification on β *Pictoris*

• Date: January 31st 2013
• Duration: half night dedicated to tests + science sequence
• Observing sequence: 3.3 hours
• On-source integration time: ~2 hours
• Total PA variation: ~90°
• Seeing / coherence time: 1", 2ms (mediocre)
• IR WFS
• Variable sky background at L'
• Coronagraph recentering every ~10 minutes

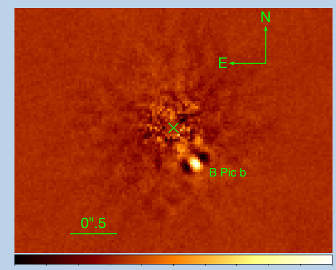

Figure 5. β Pictoris NACO+AGPM L'-band image using angular differential imaging (ADI) and principal component analysis (PCA as in Soummer et al 2012). This figure showcases the potential of the AGPM over a wide range of spatial scales, especially at small angle (down to 0".09, or 1.75 AU). The planet is detected at high SNR (~10).

F. Planet and disk detected

• Astrometry + photometry: fake negative companion technique

• Planet astrometry:
  r = 0".448 +/- 0.01, PA ~ 211° +/- 1°

(error bars to be refined, note that the AGPM ensures a knowledge of the star position to ~4 mas rms for free, simply due to the phase mask requirement to pointing errors)

• Planet photometry: ΔL' = 8 +/- 0.3 mag

• Consistent with Chauvin et al. 2012 and putative orbital elements

• Disk properties: ***see J. Milli's poster 6.28***

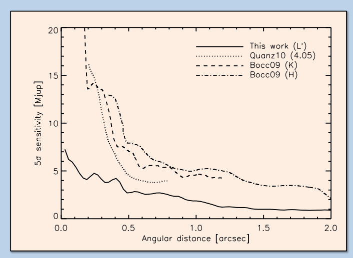

Figure 6. Detection limits in terms of Mjup with the L' NACO AGPM after removing β Picb with the fake negative companion technique. We used the BTSETTL model assuming 12 Myr. These detection limits are the best ever presented. We show recent work at lower wavelengths and with the L' band Apodized Phase Plate for comparison.

G. Detection limits

• No new object is detected close in with sufficient confidence level

• A few hot spots close in and within the disk, to be followed up

• Despite the average to mediocre conditions, the NACO L' AGPM mode provides the deepest detection limits at the smallest IWA ever explored

• ***Results presented and discussed in details in forthcoming paper (Absil et al. 2013, in preparation)***