SF2A 2017
C. Reylé, P. Di Matteo, F. Herpin, É. Lagadec, A. Lançon, Z. Meliani, F. Royer (eds)

VLTI/GRAVITY OBSERVATIONS OF THE YOUNG STAR β PICTORIS

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Abstract. The nearby young star β Pictoris is surrounded by the archetypal debris disc, which provides a unique window on the formation and early evolution of terrestrial planets. While the outer disc has been extensively studied since its discovery in 1984, very little is currently known about the inner planetary system (<4AU). Recently, accurate squared visibilities obtained with VLTI/PIONIER revealed the presence of resolved circumstellar emission with an integrated brightness amounting to approximately 1.4% of the stellar brightness in H band. However, it is not clear whether this excess emission originates from thermal emission, reflected light from hot dust grains located in the innermost regions of the planetary system, or is simply due to forward scattering by dust grains located further away (but still within the PIONIER field-of-view, i.e., close to the line of sight). In this paper, we present medium-resolution K-band observations of β Pic obtained with VLTI/GRAVITY during science verification. The goals of these observations are to better constrain the temperature of the grains (and hence their location and chemical composition) and to showcase the high-precision capabilities of GRAVITY at detecting faint, close-in circumstellar emission.

Keywords: Exoplanet, planet formation, exozodiacal dust, β Pic, interferometry, VLTI.

1 Introduction

The young ($\sim 12^{+8}_{-4}$ Myr, Zuckerman et al. 2001) A6V-type star β Pic (HD 39060, A6V, 19.3 pc) is surrounded by a famous planetary system, which is a prime target for understanding planetary system formation and evolution. Since its discovery (Smith & Terrile 1984), successive generations of telescopes have reported the detection of an edge-on debris disc with several distinctive features suggestive of a multiple-belt system (Telesco et al. 2005), star-grazing comets ("falling evaporating bodies", Beust et al. 1990), circumstellar gas (e.g., Hobbs et al. 1985; Roberge et al. 2006), and a 9-M_{Jup} planetary companion orbiting at a projected distance of approximately 4.3 AU (Lagrange et al. 2009). The existence of other planets seems likely (Freistetter et al. 2007) and might explain several asymmetries identified in the debris disc, including a warp at $\sim$50 AU (Mouillet et al. 1997; Augereau et al. 2001) inclined by $\sim 4^{\circ}$ with respect to the outer disc (Lagrange et al. 2012).

Over the past few years, the close environment ($\lesssim$ a few AU) of β Pic has been the focus of several studies trying to detect a putative sub-stellar companion. In particular, closure phase measurements with VLTI/AMBER and VLTI/PIONIER excluded the presence of companions a few hundred times as faint as the central star at angular separations up to about 100 mas (i.e., a brown dwarf of about 30 M_{Jup} at β Pic's age, Absil et al. 2010). Whereas no companion has been detected at the current precision level, accurate squared visibilities obtained with VLTI/PIONIER revealed the presence of resolved circumstellar emission with an integrated brightness amounting to approximately 1.4% of the stellar brightness in H band (see left part of Fig. 1, Defrère et al. 2012). An attractive scenario to explain the spectral shape of the measured excess is the scattering of stellar light in the outer disc seen edge-on. However, current models fail at reproducing the total value of this excess and hot material in the innermost region of the planetary system must also be present. The prevailing scenario is the presence of hot exozodiacal dust as proposed for older A-type stars (e.g., Absil et al. 2013; Ertel et al. 2014). However, the exact amount of hot dust, its location, and chemical properties remain unclear, particularly because of the lack of multi-wavelength information.

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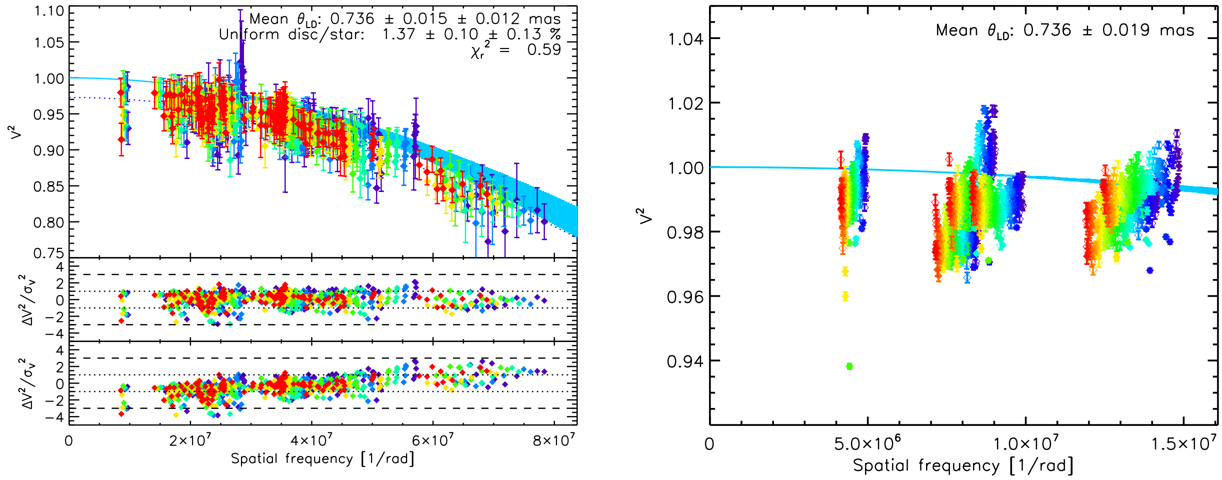

Fig. 1. Left: initial detection of a near-infrared excess around β Pic with VLTI/PIONIER (Defrère et al. 2012). The measured squared visibilities (one colour per spectral channel) are clearly below the expected squared visibility of the limb darkened photosphere (blue solid line). The best-fit model is represented by the dotted blue line with the residuals of the fit given in the middle panel. It corresponds to a limb-darkened photosphere of 0.736 $\pm$ 0.015 $\pm$ 0.012 mas in diameter surrounded by a uniform circumstellar emission of 1.37 $\pm$ 0.10 $\pm$ 0.13% in the H band. The bottom panel gives the residuals obtained by fitting only the stellar diameter (no circumstellar emission). **Right:** detection of a hot excess emission around β Pic with VLTI/GRAVITY (data obtained on September 12th, 2016, during science verification). The presence of an excess can be identified as a drop of squared visibility compared to that expected from the limb-darkened photosphere (blue solid line). Unlike previous observations of this excess obtained at H band with VLTI/PIONIER (Defrère et al. 2012), the K-band excess detected by GRAVITY depends on the wavelength and the baseline orientation. This provides crucial data to reveal the puzzling nature of β Pic's inner planetary system (modelling under progress).

In this paper, we present the first K-band interferometric observations of β Pic obtained with VLTI/GRAVITY during science verification and a preliminary data analysis. Our final goal is to better constrain the morphology and nature of the hot excess resolved around β Pic with VLTI/PIONIER. This will be presented in an upcoming paper.

2 Observations and data reduction

Medium-resolution VLTI/GRAVITY observations of the young star β Pic (HD 39060, A6V, 19.3 pc, $\sim 12^{+8}_{-4}$ Myr) were obtained on September 12th, 2016 using the compact VLTI configuration (A0-B2-C1-D0). Observations of β Pic were interleaved with observations of reference stars to calibrate the instrumental contribution in the observed quantities. Calibrators were chosen close to β Pic, in terms of both position and magnitude, from the catalogue of Mérand et al. (2005). Data were reduced and calibrated using the Python data visualization and reduction tools developed by the GRAVITY consortium (see `http://www.eso.org/sci/facilities/paranal/instruments/gravity/tools.html`). In the following, we focus on the squared visibilities ($\mathcal{V}^2$) to search for circumstellar material using a stellar angular diameter of 0.736 $\pm$ 0.019 mas measured by VLTI/PIONIER (Defrère et al. 2012). After binning the spectral channels by groups of 5, the final calibrated data set ($\mathcal{V}^2$) is shown in the right part of Fig. 1.

3 Data analysis

Figure 1 shows that the measured dispersed squared visibilities are clearly below the expected values from the limb-darkened photosphere (blue solid line). This suggests that VLTI/GRAVITY confirms the presence of a near-infrared excess emission around β Pic. The spectral shape of this excess is however puzzling and suggests that the excess emission is either barely resolved or much fainter at short wavelengths. Further analyses of these data are currently under progress to validate the accuracy and spectral behavior of GRAVITY at this level. If validated, the variation of the squared visibilities with respect to the wavelength and the baseline orientation will be crucial to constrain the morphology and nature of the excess emission.

4 Conclusions

In this paper, we have presented VLTI/GRAVITY observations of β Pic obtained during science verification. This data set confirms the presence of a faint near-infrared excess emission previously detected by VLTI/PIONIER and suggests that the accuracy achieved by GRAVITY is suitable to carry out an exozodiacal dust disk survey. Further analyses are currently under progress to determine whether the measured spectral shape is real or due to unknown instrumental effects.

The author thanks the National Scientific Research Fund (F.R.S.-FNRS) for its support. This work was partly funded by the French Community of Belgium through an ARC grant for Concerted Research Action.

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