EUROPEAN SOUTHERN OBSERVATORY

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SINFONI

Pupil Tracking Mode Essential information

To be offered for Period 93

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Date

1 Pupil-Tracking Mode

From P93 onwards, the Pupil-Traking mode will be offered, allowing the S-ADI (Spectrocopic ADI) technique to obtain spectra/images of faint companions. Pupil-tracking mode is available in both service and visitor modes.

1.1 Expected performance

Early performance estimation is based on pupil-tracking observations of a $K = 7.8$ mag B9V star (with no companion), with artificial companion signals injected into the data, and then analysed using standard 2-D ADI reduction techniques. The observations were centred around meridian transit, with a total elapsed time of 1.3 hours (including acquisition), and a total field rotation of 57^{o}, and airmass of $\sim$ 1.0. The observations were done with the 25 mas scale and K band. The ambient conditions were good, with 2.8ms coherence time and a guide star FWHM of 0.5$''$ on the guide probe (in the visible). A DIT of 25s was used, keeping the mean counts to ~ 8000 ADUs for the central spaxel. The time between DITs (i.e. readout time) was 20s.

The data was reduced using the SINFONI pipeline, with the parameters chosen such that the individual data cubes were made from each exposure (rather than all combined into one cube). These are then spatially over-sampled into $256 \times 256 \times 2218$ pixel cubes, from which we extracted 4 sub cubes outside the main telluric absorption bands (at 2.03–2.04 μm, 2.10–2.12 μm, 2.38–2.41 μm and 2.10–2.42 μm). Afterwards, 2-D gaussian PSFs were fitted to measure the PSF x and y positions as a function of time, shown in Fig. 1. This shows that the drift over 1.3 hours was 0.025$''$, roughly the same order of magnitude as the precision for the flexure compensation. Hereafter, the results are reported for the first sub-cube (2.03–2.04 μm); the findings with the other cubes are similar.

Artificial secondaries were injected into the data, which was then processed by filtering out the hot pixels and the primary spectral energy (using a high-pass filter). An anisotropic PSF was also convolved. After recentering, a master PSF was made, and it was subtracted off the individual cubes. Finally the individual frames were re-rotated, re-normalised and median combined.

The artificial secondary was injected into the data covering a range of distances from the primary, with varying polar angles. Different fluxes for the secondary were tested: 100, 10, 1 and 0.5 AUDs, with the primary peak flux at ~ 1300 ADUs. Fig. 2 shows the results of the processed data. At $\Delta m_K = 7.8$, it is still possible to detect the secondary at about 3 – 6 λ/D (0.17$''$ – 0.29$''$) from the primary.

Fig. 3 shows the 5-σ theoretical contrast curve (without secondary injection) as a function of distance (λ/D), while Fig. 4 shows the expected 5-sigma contrast of SINFONI compared with other example contrast curves, showing that medium contrasts between 6 and 8.5 magnitudes (at 5-σ significance) can be expected at distances between 0.17″ and 0.29″ for the 25 mas scale.

Note that the above utilised standard 2-D ADI techniques but it is also possible to combine this with Spectroscopic Differential Imaging (SDI) techniques (e.g. Thatte et al 2007), where the PSF is obtained and subtracted off by scaling the PSF of adjacent wavelength slices. Thus further gains in sensitivity may be possible.

1.2 Important considerations

Pupil-tracking will work with NGS mode only. It can work with all filters and grating combinations. However, at time of writing (September 2013) we have only tested the 25 mas scale (0.8"x0.8" FOV). The 100 mas (3.2"x3.2") and 250 mas (8"x8") scales remain untested, but with these 2 scales the PSF will be under sampled. Therefore for most situations the 250mas scale is not suitable for S-ADI. The 100 mas scale may be usable but one could consider making sub-pixel offsets between exposures to have some some sampling of the PSF (or perhaps it is unnecessary).

The 25 mass scale has the disadvantage that, due to the small FOV ($0.8" \times 0.8"$), if the star is put at the centre of the FOV, then one can only find companions about $< 0.2"$ –$0.4"$ from the primary. One can perhaps increase the distance a by placing the primary near one of the corners of the FOV (or even outside the FOV), but that requires knowing beforehand where the secondary is, and secondly orientating the instrument in such a way that the secondary remains on the FOV during the field rotation. Or one could consider moving the primary off the FOV during the exposure sequence, but to occasionally move it back within the FOV to check its position. This may also be useful for very bright primary stars.

Note there is a difference between the way pupil-tracking is implemented in NACO and SINFONI. For NACO the instrument is automatically rotated in an orientation such that the telescope M2 spiders (i.e. diffraction spikes) are always aligned to the x and y axes of the detector. For SINFONI the rotator of the instrument simply stops (after presetting to a user specified PA on sky), so the telescope spiders can be fixed at any orientation. It gives more flexibility for the user to choose where best to place the secondary, but at the expense of more work in preparation.

The combination of small FOV and the large pixels (spaxels) also means that you will need a fairly large field rotation (> 30 degrees) to avoid self-subtraction. Note also because the spaxels of SINFONI are rectangular (twice as tall as wide), one gets more sampling if the secondary is placed near 12 or 6 o'clock on the FOV. Keeping the secondary moving mainly along an image slice (i.e. moving mainly horizontally on the FOV) also minimise the effects of image distortion and reconstruction.

Another major restriction (compared with NACO) is the need to avoid persistence on the detector; which means one should keep the mean count in the spectral continuum below about 8000 AUDs, or a K mag of $> \sim 4.3$ mag (for the 25mas scale with K and minimum DIT); note that since the 250mas and 100mas scales are used during the acquisition (even if the final scale is 25mas), the actual limit will be closer to $K \sim 6$ mag to avoid causing persistence during the acquisition. Given the minimum DIT is 0.83 seconds and frames are read out individually (i.e. no cube mode), it may be tricky to find targets which are appropriate. There is no coronograph on SINFONI, and persistence must be avoided since in the worst case it can last for many days, ruining the observations of the other observers. One strategy to minimise persistence affecting the observations of other users is to ask for the observations to be done at the end of the night.

Another restriction is that the primary and the companion should not be of comparable brightness. This is because the AO system of SINFONI will take the light from the 2 stars and thinks it is one star and will try to do the AO correction on it. This may result in a weird PSF, plus the field will rotate around the "centre of mass" of the binary. Hence the brightness of the secondary should be pretty insignificant compared to the primary. A back-of-envelope calculation suggests that Δm should be larger than ~ 3.8 mag. Asking for the diameter of the entrance diaphragm for the MACAO system to be manually reduced may also help to block out the secondary star from the AO system.

There will be no pipeline support for the mode, however the existing pipeline can be used to output individual data-cubes by suitable choice of parameters.

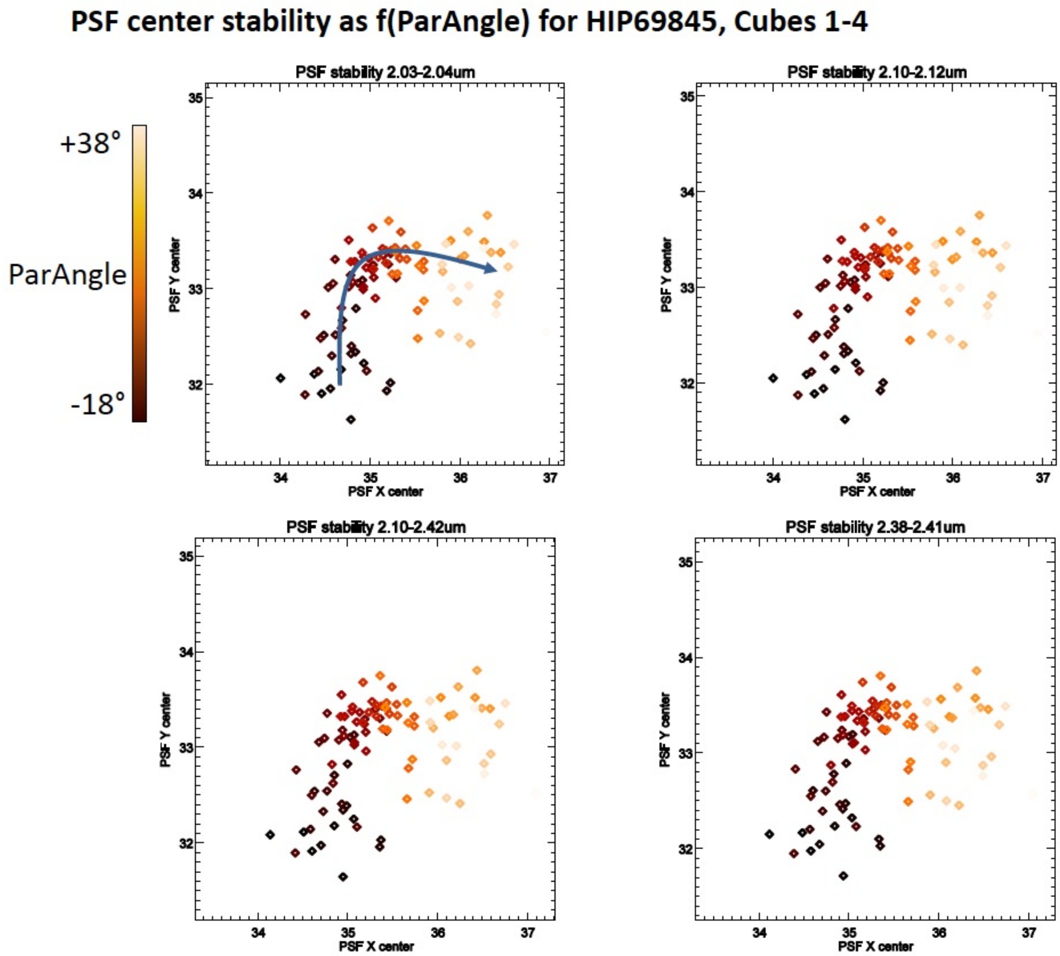

Figure 1: PSF drift over the course of 1.3 hours as a function of position in the FOV, in units of 0.0125″ .

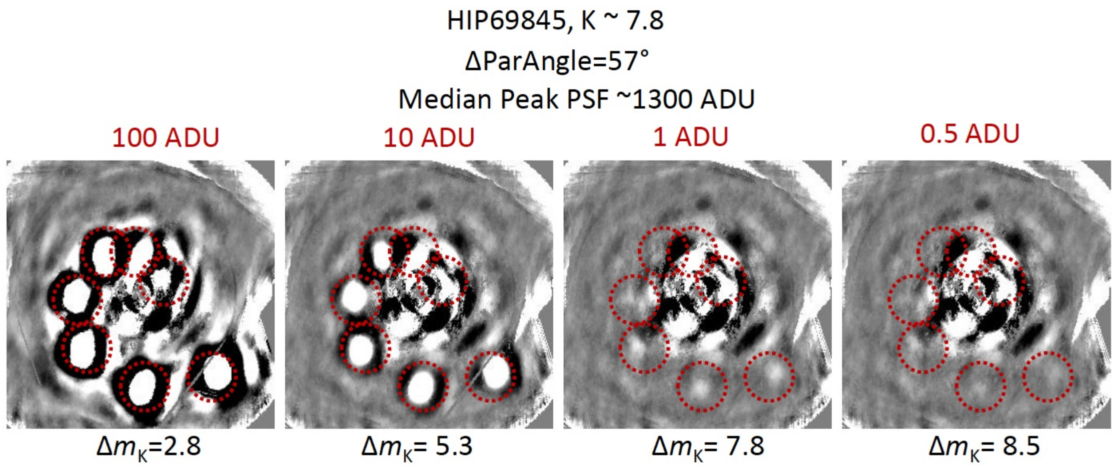

Figure 2: Recovered images after injection of artificial secondary sources of different fluxes and distances. The red circles indicate the expected positions of the artificial secondaries.

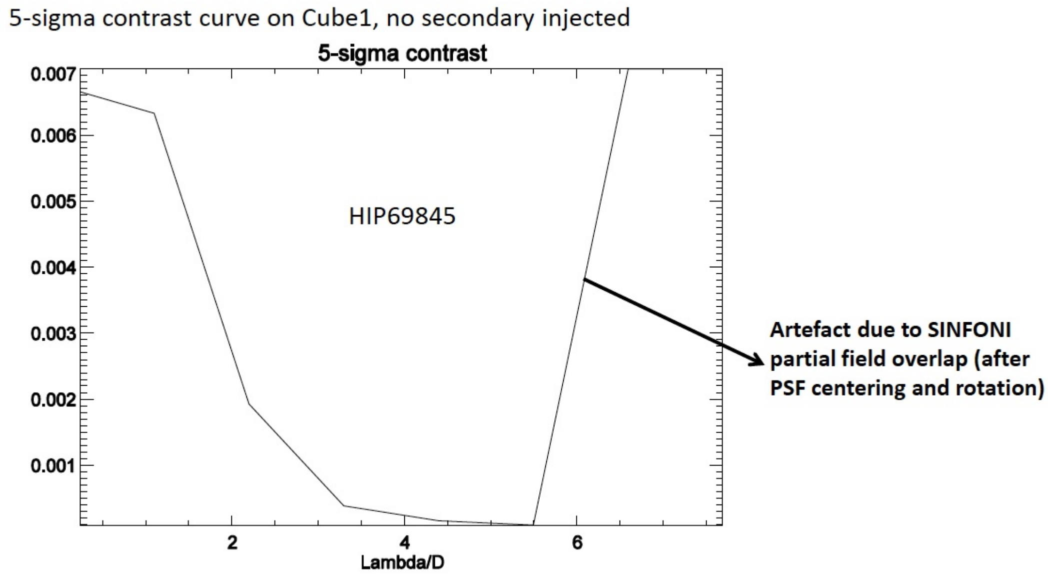

Figure 3: 5-σ contrast curve based on sub-cube # 1, with no secondary injected.

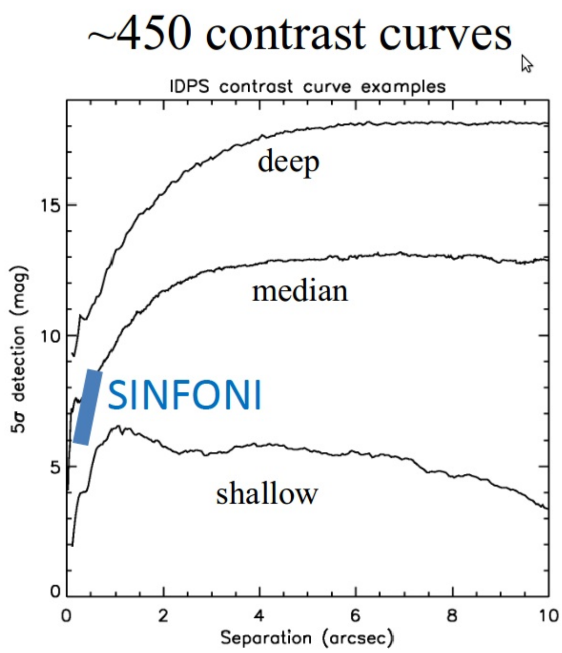

Figure 4: Expected contrasts from SINFONI (blue shaded region) compared to example contrast curves from the International Deep Planet Survey (Galicher et al 2012).