

Characterization of NIRPS Guiding Camera for Close Visual Binaries

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Abstract

Close visual binaries are common among nearby stars and can bias high-precision radial-velocity measurements when companion light leaks into the spectrograph fiber. This work aimed to characterise the Near InfraRed Planet Searcher (NIRPS) guiding-camera capability to detect close companions and to quantify the resulting contamination of the 0.4" High-Accuracy science fiber. We analysed adaptive-optics-corrected guiding-camera images acquired in fiber-offset and fiber-centered configurations. We measured the point-spread function (PSF) from fiber-offset images, derived detection limits with an injection–recovery analysis, and computed the companion flux entering the fiber by shifting and scaling the measured PSF over separation and magnitude contrast. The PSF is well represented by a compact core plus extended wings, with a best-fit core full width at half maximum of 7.3 pixels (0.26" at 35 mas/pixel) and wings extending to angular scales of order 1". The 95% completeness contrast curve closely matches the fixed 5σ curve and reaches a plateau of mag 9.6-9.8 beyond 2.5", corresponding to a guiding-camera limiting magnitude of $m_{lim} = 13.5$ for this dataset. Contamination decreases steeply with separation and becomes weakly dependent beyond $\approx 3''$, but companions at or below the guiding-camera detection limit can still induce contamination of 10^{-3} to 10^{-5} at separations below 1-2". These results show that guiding-camera non-detections do not imply negligible fiber contamination and that detectability constraints must be combined with contamination estimates when assessing binary-star impact on NIRPS observations.

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1 Introduction

1.1 Search for exoplanet in binaries

A large fraction of stars belong to binary or multiple systems (Raghavan et al., 2010), making the detection and characterization of exoplanets in such environments essential for deriving unbiased planet occurrence rates. For radial-velocity surveys in particular, a nearby companion can compromise measurement reliability when its light partially overlaps the target within the instrument entrance aperture, even if the companion is not clearly resolved in acquisition images. This effect becomes more critical for modern high-precision, fiber-fed spectrographs, which use small on-sky fibers to stabilize illumination and suppress background light. In the presence of close visual binaries, the relevant observational question is therefore not only whether a companion is detectable in guiding images, but also under which conditions it can contribute non-negligible flux to the science fiber. Quantifying these detectability and contamination limits for the NIRPS guiding system is the focus of this work.

1.2 Detectability and contamination of nearby companions

When observing visual binary systems with a fiber-fed spectrograph, two distinct questions must be addressed: (i) can a nearby companion be detected in the guiding images, and (ii) if not detected, can it still contribute flux to the science fiber. Detectability is typically quantified with a contrast curve, which gives the limiting magnitude difference as a function of angular separation from the target (Reggiani et al., 2022). At each separation, it defines the faintest companion that can be recovered by the adopted detection pipeline.

Companions brighter than the contrast-curve limit are expected to be identified in the guiding-camera images, whereas fainter companions may remain undetected. However, an undetected companion can still contribute light to the fiber through the extended wings of the AO-corrected point spread function, and may therefore remain absent from the images while still imprinting a measurable contribution in the recorded spectrum (Cunha et al., 2013).

For this reason, detectability must be complemented by an estimate of flux contamination (Fig. 1). We express contamination as

$$\text{contamination} = \frac{F_{\text{comp}}^{\text{fiber}}}{F_{\star}^{\text{fiber}}}, \quad (1)$$

where $F_{\text{comp}}^{\text{fiber}}$ is the companion flux entering the fiber and $F_{\star}^{\text{fiber}}$ is the target-star flux entering the fiber, both measured within the same on-sky fiber aperture.

Together, the contrast curve and contamination estimate define the region of separation and magnitude contrast over which nearby companions are either detectable in the guiding images or capable of affecting the spectroscopic measurement.

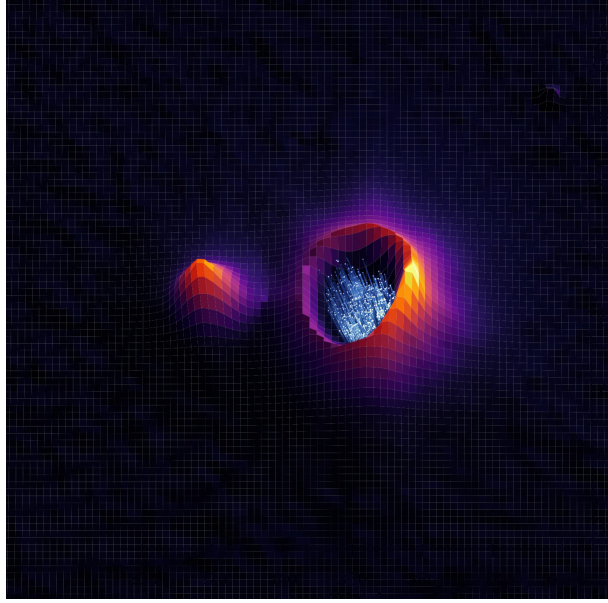


Figure 1: Illustration of a close visual binary observed with a fiber-fed spectrograph. The science fiber is centred on the primary star, while the secondary lies at small angular separation, illustrating the geometry relevant for flux contamination.

1.3 The NIRPS instrument

1.3.1 NIRPS overview and general design

The Near-InfraRed Planet Searcher (NIRPS) is a high-resolution, high-stability, fiber-fed near-infrared spectrograph installed on the ESO 3.6 m telescope at La Silla Observatory (Chile). It was designed for precise radial-velocity measurements and exoplanet characterisation, with continuous spectral coverage of the Y, J, and H bands from 972.4 to 1919.6 nm. NIRPS provides two observing modes: High Accuracy (HA; $R \sim 90\,000$) and High Efficiency (HE; $R \sim 75\,000$). In this work, we use the HA configuration, which corresponds to a science-fiber diameter of $0.4''$ on sky. NIRPS can be operated simultaneously with HARPS, enabling broad visible–near-infrared spectral coverage (Bouchy et al., 2025).

A key design element of NIRPS is its adaptive-optics-assisted fiber injection, which concentrates and stabilises the stellar image at the fiber entrance and enables efficient coupling into a small on-sky fiber. This design improves isolation of the target star, but also makes observations more sensitive to flux leakage from nearby companions, motivating the detectability and contamination analysis presented in this report.

1.3.2 Adaptive optics system, PSF structure, and stellar halo

NIRPS uses an adaptive optics (AO) system to correct atmospheric turbulence and stabilise the stellar image at the fiber entrance. The AO system sharpens the point spread function (PSF), increasing the fraction of light in a compact core and improving coupling into the small HA fiber.

After AO correction, the PSF is typically composed of a sharp central core surrounded by an extended halo (Fétick et al., 2019). While the core dominates the encircled energy,

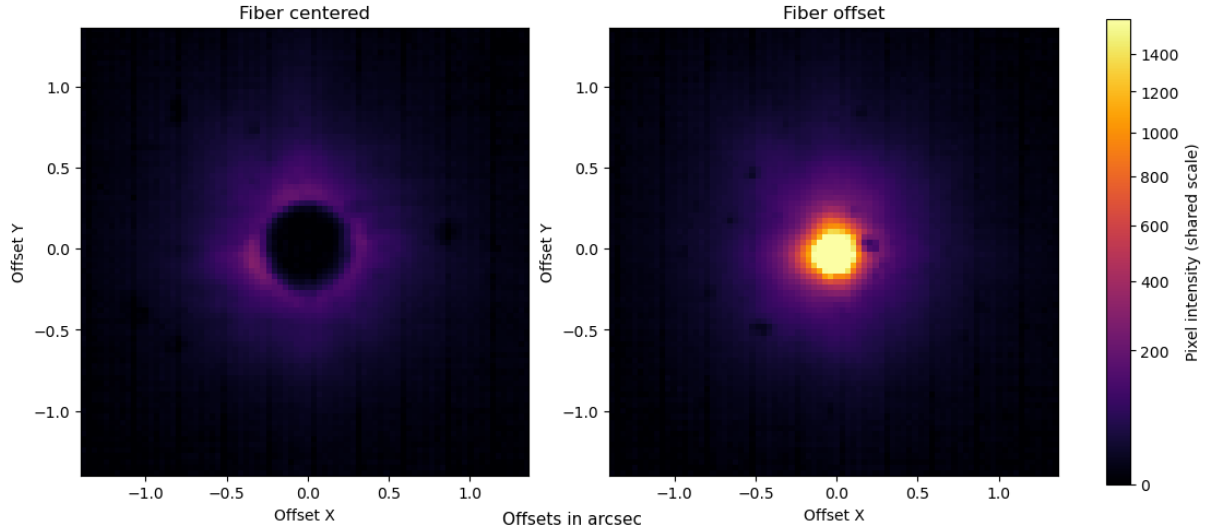


Figure 3: Guiding-camera images in the fiber-centred (left) and fiber-offset (right) configurations, shown on a shared intensity scale. The fiber footprint is visible as a central obscuration in the fiber-centred image, while the stellar PSF is unobscured in the fiber-offset case.

2 Data and Methods

2.1 Images obtained with the NIRPS guiding camera

All data used in this work were obtained with the NIRPS near-infrared guiding camera and correspond to standard, pre-reduced products archived within the NIRPS raw FITS files. For each NIRPS exposure, the guiding-camera data are provided as a single stacked image, formed by averaging typically $N=100$ short-exposure frames, corresponding to a total integration time of approximately one minute. All analyses presented here therefore rely on these archived averaged images. Two types of guiding-camera images are used in this study, as illustrated in Fig. 3. fiber-centered images correspond to the nominal observing configuration, in which the science fiber is aligned with the target star and the stellar core is partially affected by the fiber-hole geometry. fiber-offset images are obtained by intentionally displacing the fiber from the target position, allowing the full adaptive-optics (AO) corrected point spread function (PSF) core to be observed. The fiber-offset images are used to characterise the PSF and to construct the PSF template required for the contrast-curve analysis and for estimating flux contamination from nearby companions.

2.2 Point spread function of the AO-corrected images

The stellar point spread function (PSF) is measured on fiber-offset guiding-camera images, where the PSF core is unobscured. For each image, the stellar centroid is determined and an azimuthally averaged radial intensity profile $I(r)$ is extracted from concentric annuli centred on the centroid.

The radial PSF is modelled with a two-component Moffat profile, describing the compact core and the extended halo (Fétick et al., 2019). The one-dimensional Moffat function is

written as

$$I(r) = A \left[1 + \left(\frac{r}{\alpha} \right)^2 \right]^{-\beta} + C, \quad (2)$$

where A is the peak amplitude, r is the radial separation from the centroid, α is a scale parameter, β controls the wing slope, and C is a constant background. The corresponding full width at half maximum (FWHM) is given by

$$\text{FWHM} = 2\alpha\sqrt{2^{1/\beta} - 1}. \quad (3)$$

In practice, the inner Moffat component is fitted to the core-dominated region and the outer component to the halo-dominated region, with the transition radius determined during the fitting. Model parameters are estimated via non-linear least-squares minimisation using `SciPy` (Virtanen et al., 2020). The resulting PSF widths and FWHM values are used to set the photometric aperture, to tune the filtering and matched-filter kernels in the contrast-curve pipeline, and to compute the fiber-contamination estimates.

2.3 Contrast curve

2.3.1 Overview

To quantify the sensitivity of the NIRPS guiding camera to faint companions, we derive contrast curves as a function of angular separation using an injection–recovery approach based on 95% completeness. The methodology is inspired by the companion-detection framework developed for the Gemini NICI planet-finding campaign (Wahhaj et al., 2013), but is substantially adapted to the NIRPS guiding-camera data. In particular, the pipeline is tailored to single-wavelength images without angular or spectral differential imaging and accounts for the specific properties of the adaptive-optics (AO) corrected PSF, pixel scale, and observing configuration of NIRPS.

2.3.2 Basic reduction and calibration

Each dataset is calibrated to correct for detector systematics. A master dark frame is constructed from stacked dark exposures using a sigma-clipped mean and is subtracted from the guiding-camera images. A bad-pixel map is generated by combining the available high- and low-value masks into a single binary mask. Flagged pixels are corrected by replacing their values with the median of the surrounding valid pixels.

The calibrated images are then separated into fiber-centred and fiber-offset datasets, which are processed consistently in the subsequent analysis.

2.3.3 Centering and artifact mitigation

Accurate centering is required to compute radial quantities and to inject simulated companions. For each image, the stellar position is estimated and recorded. In fiber-centred images, where the PSF core is partially obscured by the fiber, the centroid is determined from the outer PSF regions after masking the central area.

2.3.4 Filtering

The calibrated images are filtered to suppress large-scale stellar halo light and detector artefacts while enhancing compact, star-like signals. All filtering parameters are scaled from the reference values adopted in Wahhaj et al. 2013 to match the NIRPS guiding-camera pixel scale and the measured size of the AO-corrected PSF. The filtering sequence consists of the following steps:

- *Broad Gaussian convolution (halo modelling)*. Each image is convolved with a broad Gaussian kernel with a full width at half maximum of $\text{FWHM}_{\text{halo}} = 18.7 \text{ px}$ to model the large-scale stellar halo.
- *Unsharp masking (halo subtraction)*. The halo model is subtracted from the original image:

$$I_{\text{unsharp}} = I - I_{\text{halo}}. \quad (4)$$

- *Narrow Gaussian convolution (noise suppression)*. The halo-subtracted image is convolved with a narrower Gaussian kernel with $\text{FWHM}_{\text{noise}} = 4.7 \text{ px}$ to reduce pixel-scale noise while preserving signals at the scale of the PSF core.
- *Azimuthal subtraction (inner region)*. Residual radial PSF structure is suppressed by subtracting an azimuthally averaged intensity profile centred on the star. This operation is applied only within a radius of $r_{\text{max}} = 40 \text{ px}$.
- *Vertical stripe correction (outer region)*. Low-level vertical striping is corrected by subtracting the median value of each image column. This correction is applied only outside a central exclusion region of radius $r = 40 \text{ px}$.

This filtering sequence suppresses residual halo light and instrumental artefacts while preserving PSF-scale features, thereby improving sensitivity to faint companions.

2.3.5 Construction of the radial noise curve and 1σ contrast

Noise is estimated on the same spatial scale used for companion photometry (Jensen-Clem et al., 2018). With a measured PSF $\text{FWHM} \simeq 7 \text{ px}$, we adopt a circular aperture of radius $r_{\text{ap}} = 3.5 \text{ px}$. From the final filtered image, an aperture-flux map is constructed by replacing each pixel value with the summed flux within an aperture of radius r_{ap} centred on that pixel.

The radial noise profile $\sigma(r)$ is computed as the standard deviation of the aperture-flux values within concentric annuli at separation r from the stellar centroid. The corresponding 1σ contrast curve is defined as

$$C_{1\sigma}(r) = \frac{\sigma(r)}{F_{\star}}, \quad (5)$$

where $F_{\star}$ is the stellar reference flux measured with the same aperture on a fiber-offset image using `Photutils` (Bradley et al., 2020).

2.3.6 Detection map and matched filtering

A signal-to-noise (S/N) map is constructed from the filtered image. For each pixel (x, y) at radial separation

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2}, \quad (6)$$

from the stellar centroid (x_0, y_0) , the S/N is defined as

$$\text{S/N}(x, y) = \frac{I_{\text{filt}}(x, y)}{\sigma(r)}, \quad (7)$$

where $I_{\text{filt}}(x, y)$ is the filtered image intensity.

The S/N map is convolved with a circular, normalised top-hat kernel of radius r_{PSF} , chosen to be comparable to the photometric aperture size. Candidate companions are identified as local maxima in the matched-filtered S/N map.

2.3.7 False positive detection threshold

Before injection–recovery, a conservative detection threshold corresponding to zero false positives is defined. The analysed data are assumed to contain no detectable astrophysical companions. Local maxima in the matched-filtered S/N map of the non-injected images are identified, and the highest peak value is adopted as the detection threshold.

2.3.8 Injection–recovery tests and completeness-based contrast curve

Detection sensitivity is quantified using injection–recovery tests with simulated companions. Artificial companions are generated from a PSF template built from fiber-offset images and injected from $r_{\text{min}} = 5 \text{ px}$ to $r_{\text{max}} = 200 \text{ px}$ in steps of $\Delta r = 10 \text{ px}$. The position angle is incremented by $\Delta\theta = 137.5^\circ$ between successive injections.

The full injection sequence is repeated for 20 different starting angles, spanning 0° to 342° in steps of 18° . A 95% completeness level corresponds to successful recovery of 19 out of 20 injected companions at a given separation.

For each injection position (r, θ) , the injected signal strength is parameterised by a dimensionless factor X in units of the local noise $\sigma(r)$. Injections start at $X = 20$ and are reduced in steps of 0.5σ until recovery fails. The lowest recovered value defines $X_{\text{lim}}(r, \theta)$.

At each separation, the 95th percentile of the X_{lim} distribution defines $X_{95}(r)$. The limiting flux and contrast are

$$F_{\text{lim}}(r) = X_{95}(r) \sigma(r), \quad (8)$$

$$C(r) = \frac{F_{\text{lim}}(r)}{F_\star}, \quad \Delta m(r) = -2.5 \log_{10} C(r). \quad (9)$$

For comparison, a fixed-threshold contrast curve is also computed using a 5σ criterion.

2.3.9 Two-dimensional detection limit map

In addition to the radial contrast curve, a two-dimensional detection limit map is derived from the injection–recovery results. Each recovered injection provides a local detection limit at a specific position in the image.

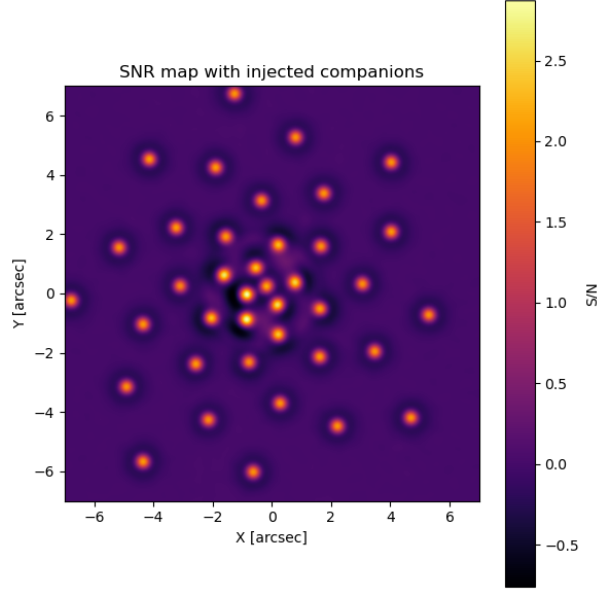


Figure 4: Signal-to-noise (S/N) map with injected synthetic companions. Artificial sources are injected at multiple angular separations and position angles to probe the spatially varying detection sensitivity of the guiding-camera images. The colour scale indicates S/N.

Injection positions are converted from pixel coordinates to angular offsets using the guiding-camera plate scale. The discrete detection-limit measurements are then interpolated onto a regular grid using a radial basis function interpolation, yielding a two-dimensional map of the detection sensitivity across the field of view.

2.4 Contamination estimate

The contamination is defined as the fraction of flux from a secondary star that enters the science fiber relative to the flux from the primary star.

The stellar reference flux is measured on a fiber-offset image using circular aperture photometry with a diameter matching that of the science fiber ($0.4''$). A copy of the measured stellar PSF is then used to simulate a companion by shifting it to different angular separations from the fiber center. For each separation, the companion flux falling within the fiber aperture is measured.

This procedure is repeated after scaling the companion PSF to different magnitude contrasts, allowing the contamination to be evaluated as a function of both angular separation and relative brightness. The contamination fraction is defined as

$$C_{\text{cont}}(r, \Delta m) = \frac{F_{\text{comp}}^{\text{fiber}}(r, \Delta m)}{F_{\star}^{\text{fiber}}}, \quad (10)$$

where $F_{\text{comp}}^{\text{fiber}}(r, \Delta m)$ is the companion flux entering the fiber at separation r and magnitude contrast Δm , and $F_{\star}^{\text{fiber}}$ is the primary-star flux measured within the same fiber aperture.

Table 1: Best-fit parameters of the two-component Moffat PSF model.

Component	FWHM (")	α	β	Normalisation
Core	0.26	4.41	134.89	2817.26
Wings	0.44	1.82	1.00	343.43

3 Results and discussion

3.1 Point spread function characteristics

3.1.1 Radial profile and empirical modeling

The guiding-camera PSF was characterised on fiber-offset images of q Vel, for which the stellar core is not occulted by the science fiber. The azimuthally averaged radial profile shows a steep inner decline followed by a slower outer decay, consistent with a compact core plus extended wings (Table 1). Several analytical models were tested, including Gaussian, Moffat, Gaussian+Moffat, and Moffat+Moffat descriptions. Only the two-component Moffat model reproduces the observed radial profile. The transition radius is set to $r = 9$ px.

3.1.2 Quantitative PSF properties

The best-fit parameters of the two Moffat components are reported in Table. 1. The core component has a FWHM of 7.3 px ($0.26''$ at 35 mas px^{-1}), significantly narrower than typical seeing-limited images at La Silla ($\sim 1''$), but broader than the near-infrared diffraction limit of the 3.6-m telescope ($\sim 0.10''$), consistent with partial AO correction.

The wing component extends to angular scales of order $\sim 1''$ and dominates the radial profile outside the transition radius, despite containing only a small fraction of the total flux.

3.1.3 Interpretation

The two-component morphology matches the expected structure of AO-corrected images: the compact core traces the corrected wavefront, while the extended wings arise from residual uncorrected turbulence and scattered light. Although the core contains most of the flux, the wings set the intensity distribution at larger separations and are therefore the relevant component for off-axis contamination.

3.1.4 Implications for detectability and contamination

The HA science fiber has a $0.4''$ diameter ($0.2''$ radius), comparable to the measured PSF core FWHM ($0.26''$). Core-dominated contamination by a companion therefore requires the companion to lie within, or extremely close to, the fiber footprint. Such configurations would generally produce a detectable spectroscopic signature unless the companion is very faint relative to the primary.

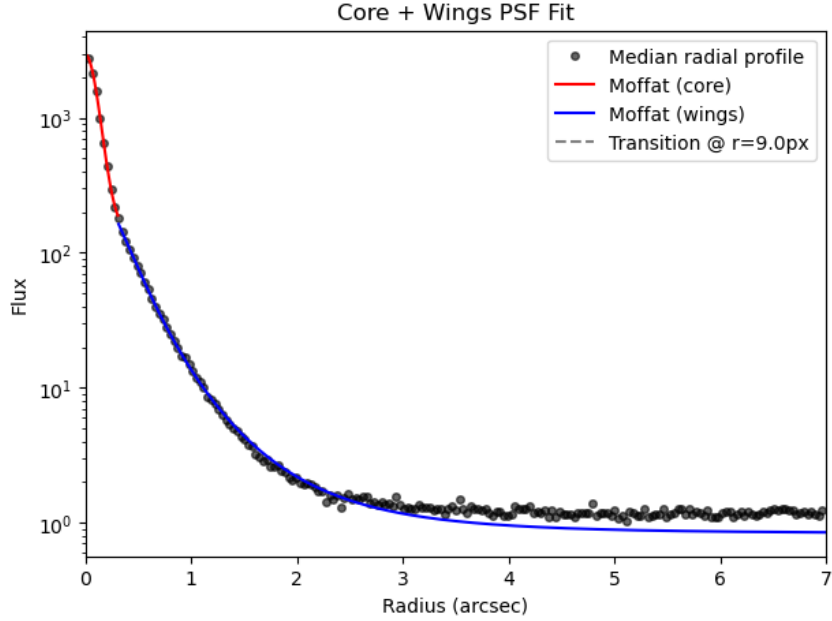


Figure 5: Azimuthally averaged radial PSF profile measured from fiber-offset guiding-camera images (black points), together with the best-fit two-component Moffat model. The inner component (red) describes the PSF core, while the outer component (blue) represents the extended wings. The transition happens at $r = 9$ px.

Conversely, companions faint enough (or close enough) to evade spectroscopic identification are also likely to remain below the guiding-camera detection threshold, making core-dominated contamination by unseen companions uncommon. At larger separations, contamination is instead driven by the PSF wings, which can contribute flux inside the fiber even when the companion is not detected in the guiding images. This halo-dominated regime motivates the contamination analysis presented in Sect. 3.3.

3.1.5 Limitations

This PSF characterisation is based on a single target observed during one night and does not probe variations with seeing, stellar magnitude, or AO performance. A larger sample is required to quantify PSF stability and to propagate these variations into contamination estimates.

3.2 Contrast curve characteristics

3.2.1 Radial contrast curve

Figure 6 shows the radial contrast curve derived from the injection–recovery analysis, comparing the 95% completeness limit with the conventional 5σ contrast. The contrast is expressed as the magnitude difference relative to the primary star (Δmag) as a function of angular separation. The achievable contrast improves rapidly at small separations and reaches an approximately constant regime beyond $\simeq 2.5''$, where the detection limit is set primarily by the noise floor of the processed image rather than by residual stellar halo.

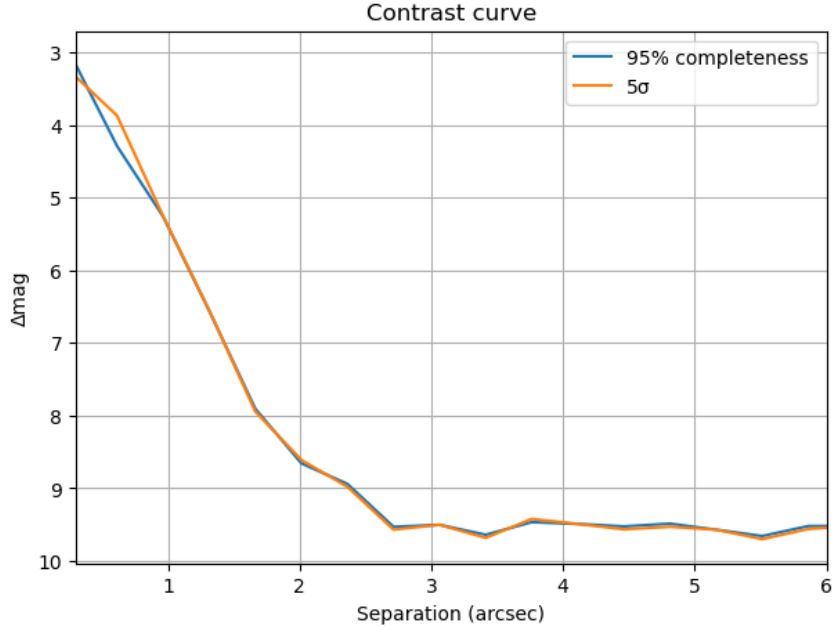


Figure 6: Radial contrast curve derived from the injection–recovery analysis. The solid blue curve shows the 95% completeness limit, while the orange curve indicates the conventional 5σ detection threshold. The contrast is expressed as the magnitude difference relative to the primary star as a function of angular separation.

The limiting magnitude is obtained by combining the measured contrast with the catalogued near-infrared magnitude of the target, $m_J = 3.78$ (Centre de Données astronomiques de Strasbourg (CDS), 2024), and applying a standard atmospheric extinction correction (Sitko and Stolker, 2023). For this dataset, the plateau contrast of $\Delta\text{mag} \simeq 9.6\text{--}9.8$ corresponds to a limiting guiding-camera magnitude of $m_{\text{limiting}} \simeq 13.5$. This value is specific to the observing conditions and exposure time of the present dataset.

3.2.2 Comparison between 95% completeness and 5σ contrast

The 95% completeness contrast curve closely matches the fixed 5σ contrast over the full range of separations considered, indicating that the radial detection sensitivity is well described by a fixed-threshold criterion for this dataset. The completeness-based curve nevertheless provides a more robust estimate, as it accounts for spatial variations in sensitivity and the actual recovery probability of injected companions.

3.2.3 Two-dimensional detection limit map

To quantify spatial variations in detection sensitivity, a two-dimensional detection-limit map was constructed from the injection–recovery results (Fig. 7). The map reports the minimum detection strength required for recovery in units of the local noise standard deviation σ , with lower values indicating higher sensitivity.

The central circular region corresponds to the science-fiber footprint (radius $\simeq 0.2''$), within which companion detection is not possible. A darker annulus at $\simeq 0.7''$ reflects locally enhanced sensitivity produced by halo subtraction and filtering near the stellar

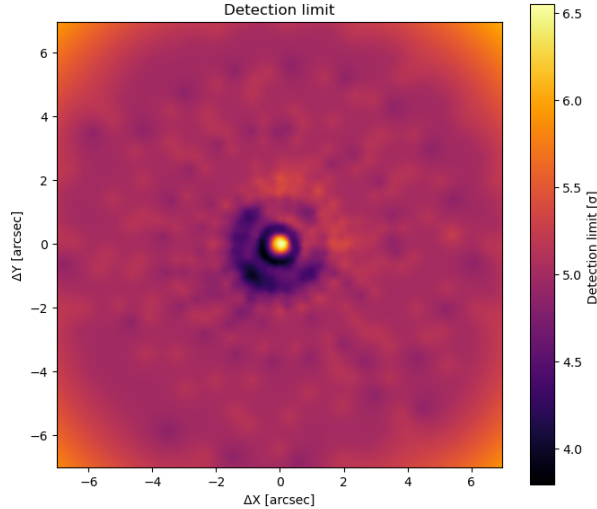


Figure 7: Two-dimensional detection-limit map in units of the local noise standard deviation σ as a function of angular offset from the primary star. Lower values indicate higher sensitivity, the central region corresponds to the science-fiber footprint.

core. A second radial feature at $\simeq 1.7''$ coincides with the outer limit of the azimuthal subtraction region in the filtering pipeline, beyond which the stellar halo is no longer explicitly modelled, resulting in a change in the residual noise properties.

The map exhibits moderate azimuthal asymmetry, attributed to slight fiber mis-centering relative to the stellar PSF, leading to anisotropic residuals after halo subtraction. A weak square-like pattern is also present and is attributed to non-astrophysical effects introduced by the reduction and reconstruction process.

3.2.4 Interpretation and limitations

The radial contrast curve and two-dimensional detection-limit map show a transition from a stellar-halo-limited regime at small angular separations to a noise-limited regime at larger separations. The close agreement between the 95% completeness and 5σ contrast curves indicates stable and reproducible detection performance for this dataset.

These results are based on a single observation obtained under specific observing conditions and exposure time. The achievable contrast and limiting magnitude are expected to vary with target brightness, AO performance, background level, and integration time. A larger dataset covering multiple targets and observing conditions is required to fully characterise the contrast performance of the NIRPS guiding camera.

3.3 Estimation of the contamination level of a nearby star on the fiber hole

3.3.1 Contamination as a function of separation and companion brightness

Figure 8 shows the fractional contamination of the science fiber as a function of angular separation for companions of different magnitude contrasts relative to the primary star. Contamination is defined as the fraction of companion flux entering the fiber relative to

the flux from the primary star measured within the same fiber aperture.

For all contrasts, contamination decreases rapidly with increasing separation. At small separations, it is dominated by the PSF core and inner halo, resulting in significant contamination even for moderately faint companions. With increasing separation, the contribution from the companion PSF wings declines steeply, and beyond $\simeq 3''$ the contamination curves flatten, indicating a regime dominated by the far PSF wings and only weakly dependent on separation.

At a fixed separation, the contamination level scales strongly with companion brightness, with brighter companions producing significant contamination over a wider range of separations. Fainter companions contribute appreciably only at small angular separations. Nevertheless, contamination levels of order 10^{-3} – 10^{-4} can still occur below $\simeq 1''$, emphasising the importance of accounting for flux leakage from close, undetected companions in visual binary systems.

3.3.2 Relation to guiding-camera detectability

The black dashed curve in Figure 8 indicates the contamination expected from a companion at the guiding-camera detection limit, as derived from the contrast-curve analysis in Sect. 3.2. Companions below this curve are, by definition, not detectable in the guiding-camera images.

This comparison shows that companions undetected by the guiding camera can still induce measurable contamination of the science fiber, particularly at small angular separations. Below $\simeq 1''$, companions at the detection limit can contribute contamination at the level of 10^{-2} – 10^{-3} , depending on separation. Conversely, companions producing contamination well above this curve are sufficiently bright to be detected in the guiding-camera images and can therefore be identified and accounted for observationally.

3.3.3 Core-dominated versus halo-dominated contamination

Core-dominated contamination requires the companion to lie within, or very close to, the fiber footprint. In such cases, a companion bright enough to contribute significant core flux would typically produce a detectable spectroscopic signature, while companions that are both extremely close and very faint are also likely to remain undetected in the guiding-camera images.

The contamination regime of primary practical relevance is therefore halo-dominated contamination. Companions at separations from a few tenths of an arcsecond to a few arcseconds can contribute flux through the extended PSF wings, even when they remain below the guiding-camera detection threshold. This regime encompasses the dominant contamination scenarios for close visual binaries observed with NIRPS.

3.3.4 Practical implications and limitations

These results demonstrate that guiding-camera non-detections do not guarantee negligible contamination of the science fiber. Companions at or below the guiding-camera contrast limit can still introduce contamination at levels relevant for high-precision radial-velocity measurements, depending on separation and brightness. In this context, complementary

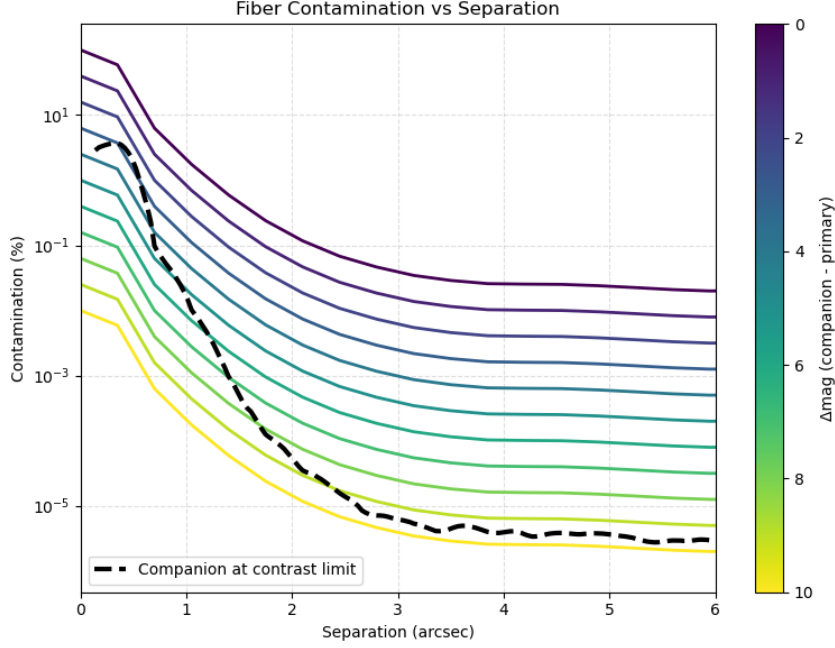


Figure 8: Fractional contamination of the science fiber as a function of angular separation for companions of different magnitude contrasts relative to the primary star. The dashed black curve indicates the contamination expected for a companion at the guiding-camera detection limit derived from the contrast-curve analysis.

constraints from the spectrograph detection limits would be valuable to further bound the parameter space in which a binary companion remains undetectable while still contributing measurable contamination.

The contamination estimates presented here are based on a single dataset and assume that the companion PSF is well represented by the primary-star PSF measured in fiber-offset images. Variations in AO performance, observing conditions, stellar brightness, and spectroscopic sensitivity are not explored. A broader analysis spanning multiple targets, nights, and observing configurations will be required to fully characterise contamination levels and their variability.

4 Conclusions

This work aimed to characterise the NIRPS guiding-camera performance for detecting close visual companions and to quantify the level of companion-light contamination entering the $0.4''$ science fiber in High-Accuracy mode. The focus was on the regime where companions may remain unseen in guiding images but still bias fiber-fed spectroscopic observations.

The main results are as follows:

- The AO-corrected guiding-camera PSF is well described by a two-component structure consisting of a compact core and extended wings. The best-fit core width is $\text{FWHM} = 7.3 \text{ px}$, corresponding to $0.26''$ at 35 mas px^{-1} , while the wing component extends to angular scales of order $\sim 1''$ and dominates the radial profile outside the transition radius.

- Contamination decreases steeply with separation and becomes only weakly dependent on separation beyond $\simeq 3''$, consistent with a far-wing-dominated regime.
- Even relatively faint companions can contribute contamination at the 10^{-3} – 10^{-4} level at separations below $\simeq 1''$.
- When compared to the guiding-camera detection limit, companions that are not detectable in guiding images can still produce contamination at the level of 10^{-3} to 10^{-5} at separations below $\simeq 1$ – $2''$.

These results show that guiding-camera non-detections do not imply negligible contamination of the science fiber. The relevant regime is halo-driven flux leakage, which can remain significant at sub-arcsecond to few-arcsecond separations. This motivates combining guiding-based detectability limits with spectrograph-based detection limits to identify configurations in which a companion remains undetected while still contaminating the spectroscopic signal.

This study is limited by the use of a single dataset, and variations with AO performance, observing conditions, and target brightness are not yet quantified. Future work should extend the analysis to multiple targets and nights, include High-Efficiency mode observations, and evaluate frame-to-frame variability using individual guiding frames when available. A practical next step is to derive joint constraints from guiding-camera contrast limits and spectrograph detectability limits in order to bound the parameter space in which contamination can occur without an identifiable companion signature.

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