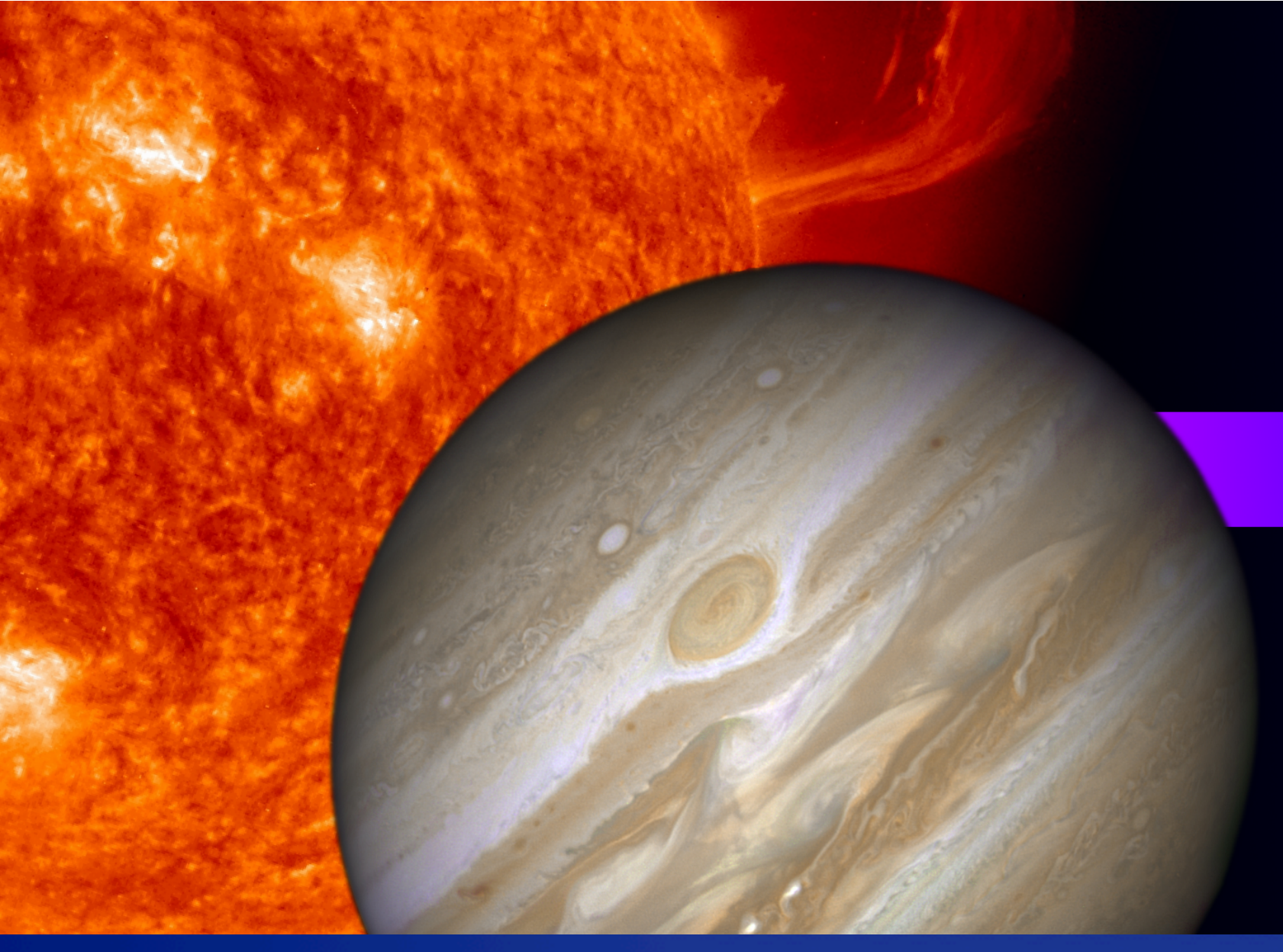


SPHERE / ZIMPOL

Characterization of the ZIMPOL PSF

H.M. Schmid[a], J. Milli[b], J.H. Girard[b], D. Mouillet[c],
J.L. Beuzit[c], and the SPHERE team[d,e,f,g,h,i]

[a]ETH Zurich, Institute for Astronomy
[b]European Southern Observatory, Santiago
[c]Univ. Grenoble Alpes, CNRS, IPAG
[d]INAF, Osservatorio Astronomico di Padova
[e]Max-Planck-Institut für Astronomie, Heidelberg
[f]NOVA Optical-Infrared Group at ASTRON
[g]Aix-Marseille Univ., CNRS, LAM
[h]University of Amsterdam
[i]Obs. Astronomique de l'Université de Genève

Introduction

The Zurich Imaging Polarimeter (ZIMPOL) is one of the three focal plane instruments of the SPHERE / VLT "planet finder". ZIMPOL is designed for imaging, angular differential imaging, dual beam imaging (mainly for the Hα line), and polarimetric differential imaging. SPHERE includes also an extreme AO system, visual and near-IR coronagraphs, the near-IR integral field spectrograph (IFS) and the dual beam imager (IRDIS).

The ZIMPOL system is a special imager, because it is optimized for high precision polarimetry using a fast modulation – demodulation principle using specially masked CCD detectors. The polarization modulator and polarizer (polarization beam splitter) convert the degree-of-polarization signal into a fractional modulation of the intensity, which is then measured in a demodulating detector system by a differential intensity measurement between the two modulator states. For this "every second row" of the CCD is masked so that photo-charges created in the unmasked row during one half of the modulation cycle are shifted for the second half of the cycle to the next masked row, which is used as a temporary buffer storage. It has been demonstrated that ZIMPOL reaches a very good polarimetric sensitivity, ideal for the investigation of the reflected and therefore polarized light from circumstellar disks and the search of scattered (polarized) light from extra-solar planets.

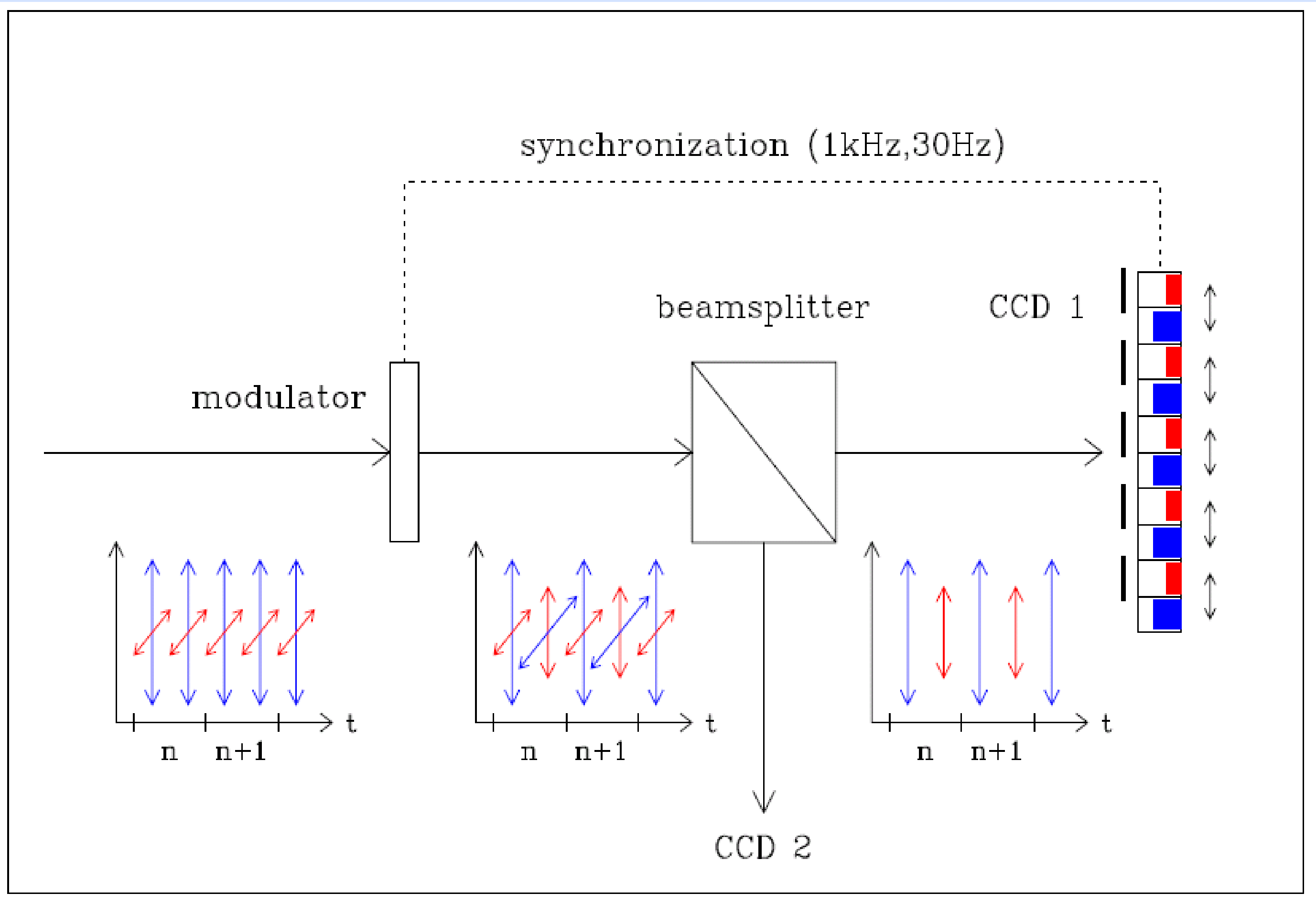


Figure 1: Illustration of the ZIMPOL principle with the convertion of the polarization signal into an intensity modulation and the on-detector demodulation

The ZIMPOL PSF vs wavelengths

In Figure 2 we compare the flux normalized point spread functions (PSFs) for V- and I-band (N_I-filter) of ZIMPOL-SPHERE for observations taken under good conditions. It is clearly visible that the AO-control radius is larger in the I-band and the contrast inside the control radius is much deeper. Figure 3 shows azimuthally averaged PSF profiles for the different bands and a comparison with diffraction-limited profiles.

For the flux normalized PSFs (Fig. 3 left) the peak flux is essentially color independent but the Strehl ratio $S=F_{Obs}(r=1)/F_{VLT}(r=1)$ depends strongly on color with S=0.095 for V, 0.14 for N_R, and 0.23 for N_I. The enhanced PSF widths (Fig. 3 right) are at least partly caused by residual jitter (5 mas) in the system (telescope and instrument).

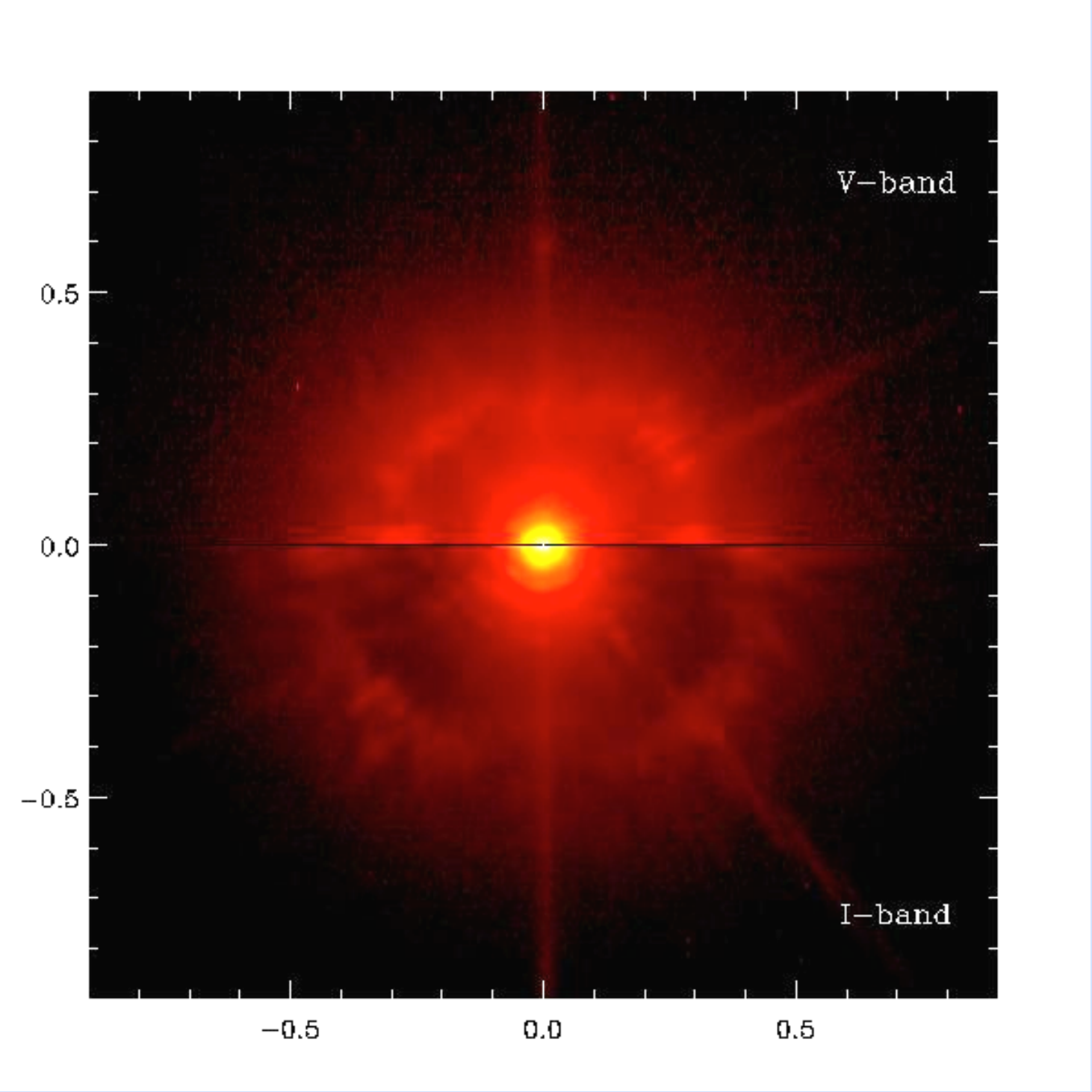


Figure 2: Comparison of the ZIMPOL PSF in V- (top) and I-band (bottom)

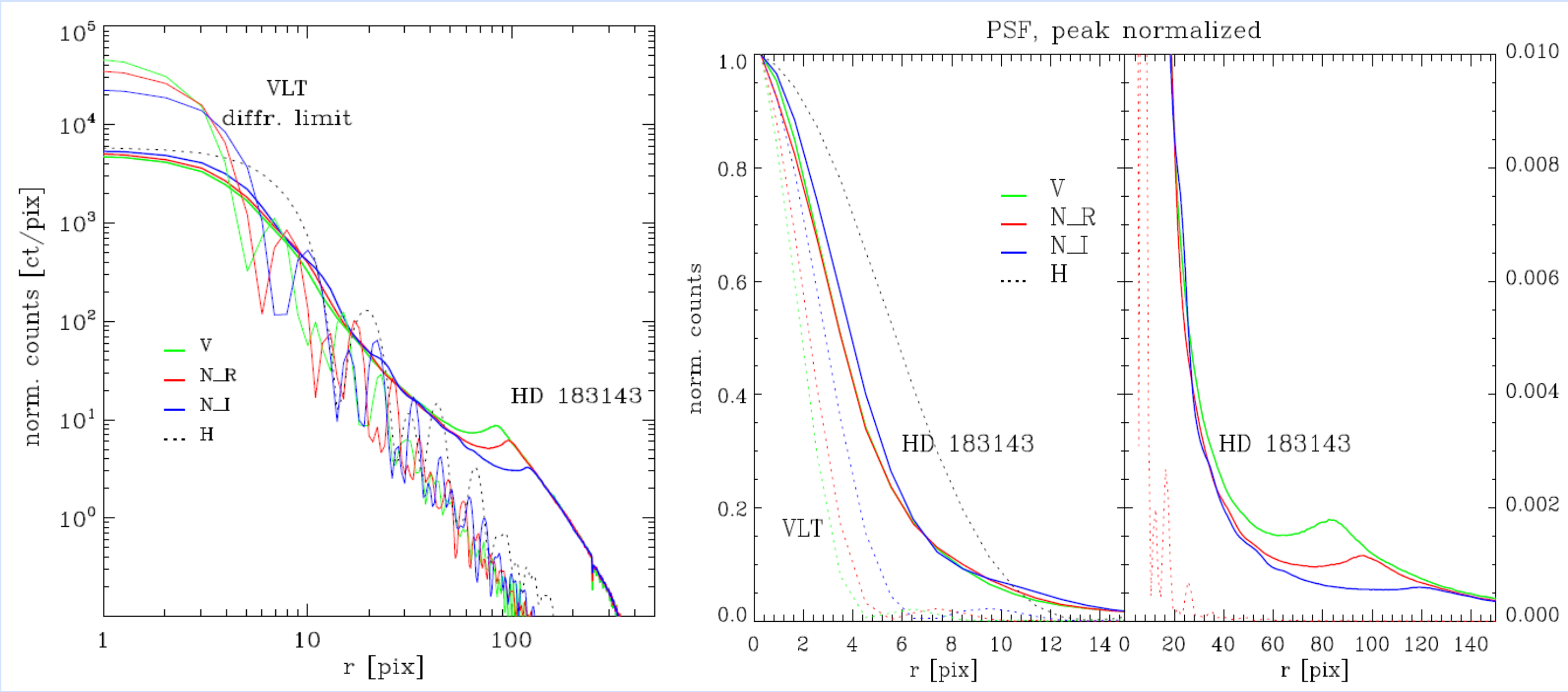


Figure 3: Comparison of the V, N_R, and N_I PSF with the expected diffraction limited PSF in a log-log, flux-normalized (total $=10^6$ cts) plot (left), and a linear, peak-normalized plot (middle and right). One pixel corresponds to 3.6 milli-arcsec.

PSF dependence on turbulence

The PSF of SPHERE-ZIMPOL depends strongly on atmospheric conditions. Figure 4 gives the ratio of two flux-normalized PSFs, one taken under good seeing conditions (0.70", τ_0=8ms) and one under bad conditions (1.2", τ_0=1.4ms). The "good PSF" has a peak, which is twice stronger and a residual flux level within the control radius which is half when compared to the "bad PSF". This demonstrates that the atmospheric conditions are essential for high-contrast observations in the visual.

The strong spider feature is probably due to the illumination by the moon.

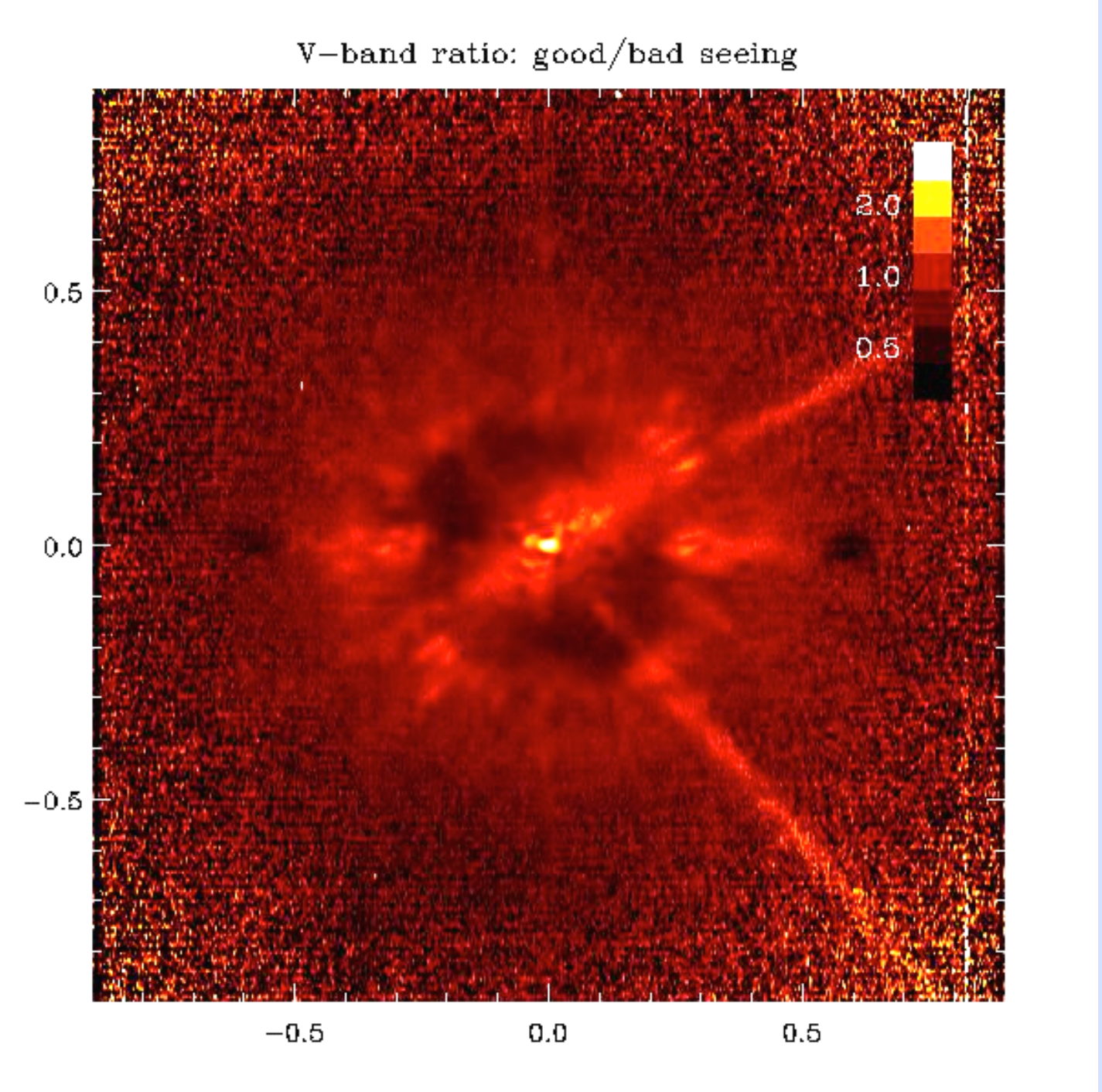


Figure 4. Ratio between a good and bad V-band PSF.

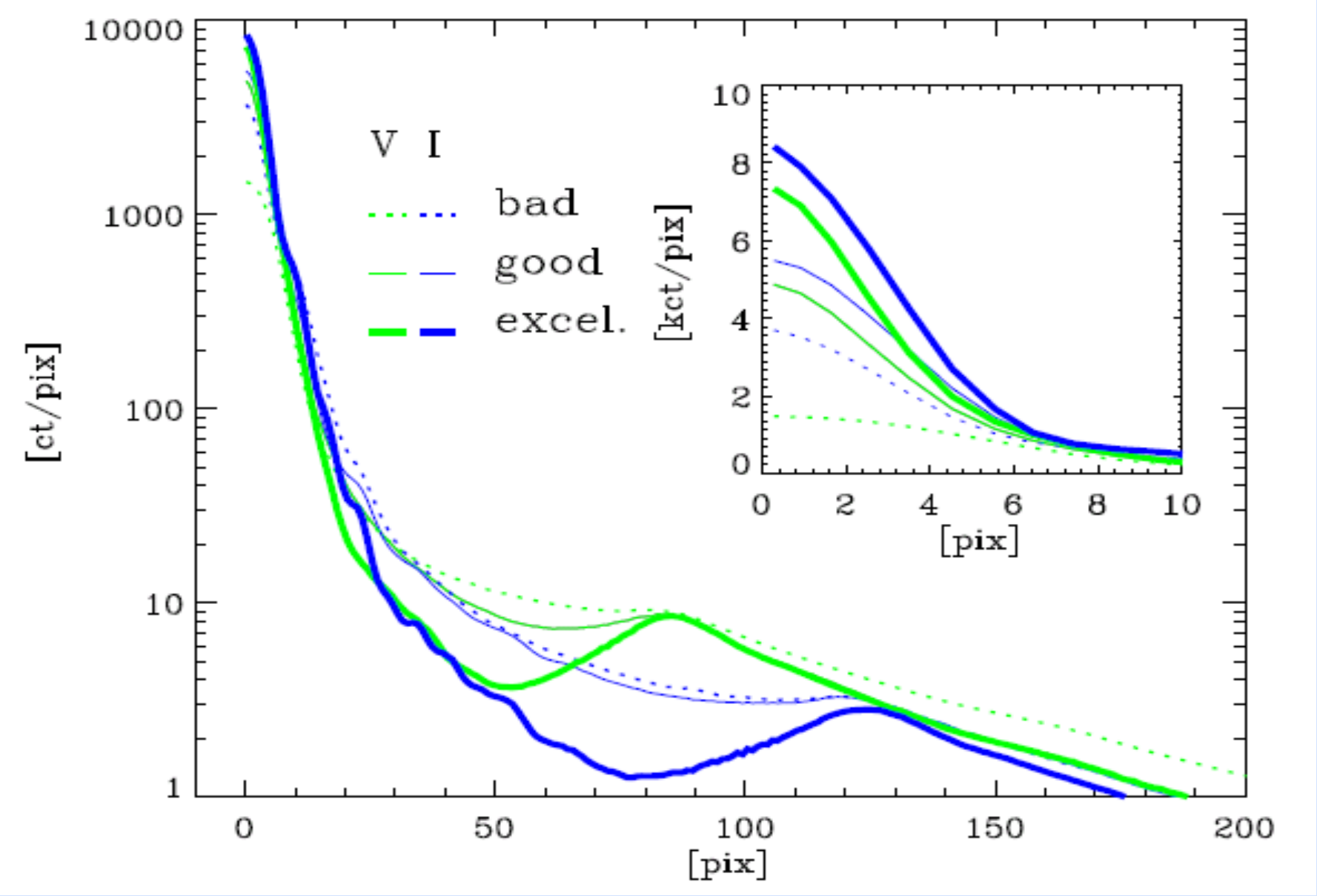


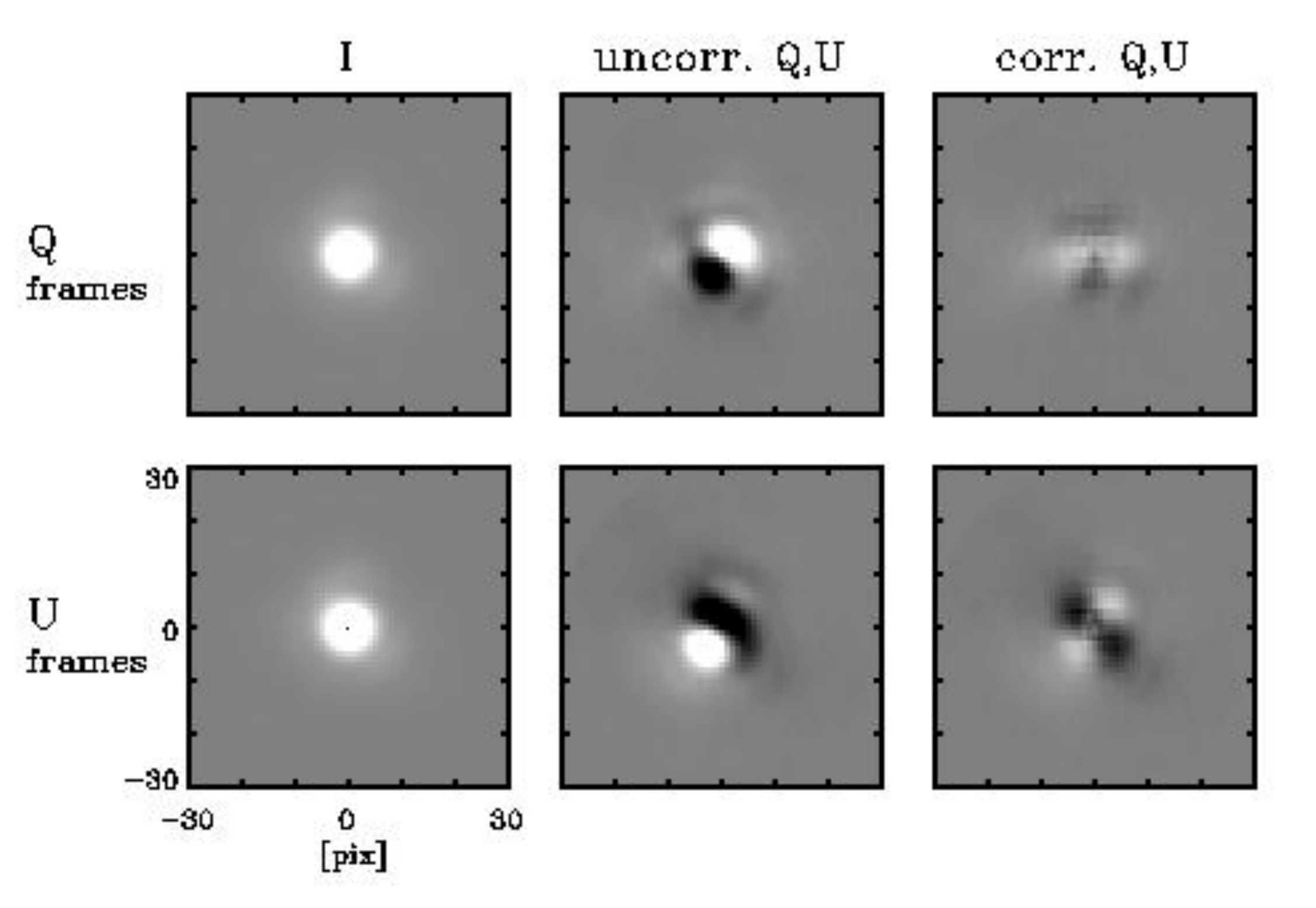
Figure 5. Flux normalized, radial profiles in the V- and N_I-band filters for stars observed under "bad", "good", and excellent conditions.

Differential beam shift in polarimetry

We detected after the integration of ZIMPOL into the SPHERE instrument a polarimetric differential beam shift, i.e. the two polarization directions of one simultaneous polarimetric measurement are offset by 0.5 to 1 mas. This effect, which originates mainly from the inclined mirrors of the telescope and the image derotator, has an important impact on the high-precision polarimetric measurements for which ZIMPOL was designed for.

Figure 6 shows the effect for R Aqr which was used as test target. The first column shows the stellar PSF of the intensity images based on the Q and U frames. In the second frame the differential linear polarization $Q=I_0-I_{90}$ and $U = I_{45}-I_{135}$ are given showing positive and negative residuals of about 1% of the I-peak value because of the small differential shift. However, this effect can be corrected in the data reduction process by a realignment of the I_0 with the I_{90} and I_{45} with the I_{135} images before the polarimetric combination. The third column shows the corrected polarimetric signal for the PSF. The residual polarization pattern can even be attributed to the circumstellar scattering in the wind of the Mira variable R Aqr.

Figure 6. Beam shift effect as observed for R Aqr in the Cnt820 filter. The black minima and white maxima in the middle column are about 1% of the peak flux of the intensity PSF. The residual polarization in the beam shift corrected panels look like the expected signal from circumstellar scattering.



Conclusions

The ZIMPOL/SPHERE subsystem is a unique concept that provides high-contrast high-resolution observations in the optical thanks to the AO module of SPHERE and dedicated polarisation components. The Strehl ranges typically from 10 to 30% depending on the wavelength. The PSF depends much more strongly on the atmospheric conditions than in the near-infrared, hence the need for PSF calibrators observed in the same turbulence conditions (for PSF subtraction or deconvolution for instance). The calibration of the linear polarization is made thanks to the concept of differential polarimetry with a fast modulation technique. An unexpected effect called the beam shift was discovered on the telescope and can be corrected in post-processing.