Adaptive Coronagraphy

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Purpose

In this paper, we introduce the use of adaptive masks in a coronagraphic set up. These masks are binary versions of the instantaneous degraded instrument point spread function, so that they are transparent except at those points in which the PSF intensity is higher than a fixed threshold. Although this technique has been developed to be implemented on ground-based telescopes, it can also be applied to detect faint companions immersed in a temporally evolving perturbing medium.

Adaptive Mask

The goal of this paper is to use a coronagraphic mask able to cancel out not only the central PSF core but also the most brilliant part of the surrounding speckled halo. Although a circular mask that changes its radius as a function of atmospheric seeing has already been used, no conclusive results have been reported [1].

A threshold, above the companion peak intensity, is applied to the registered instantaneous PSF (figure 2b). The positions of pixels with intensity values above the threshold are recorded.

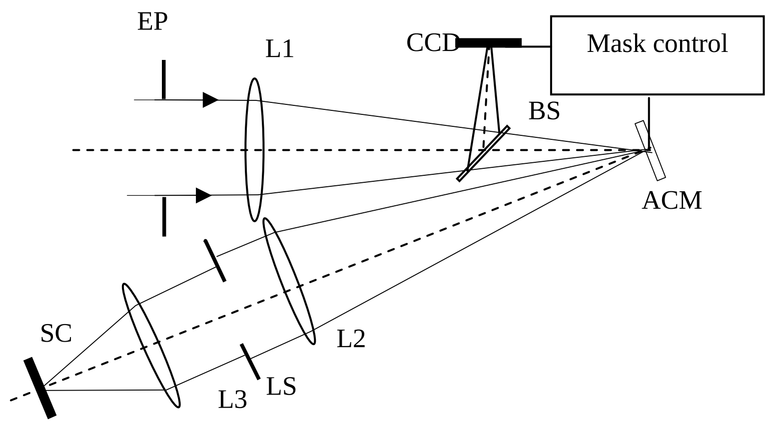


Fig. 1. Adaptive coronagraph. EP: Entrance pupil, L1: telescope, BS: beam splitter, CCD: camera, ACM: reflecting adaptive mask, L2 and L3: 4-f system, LS: Lyot stop and SC: scientific camera.

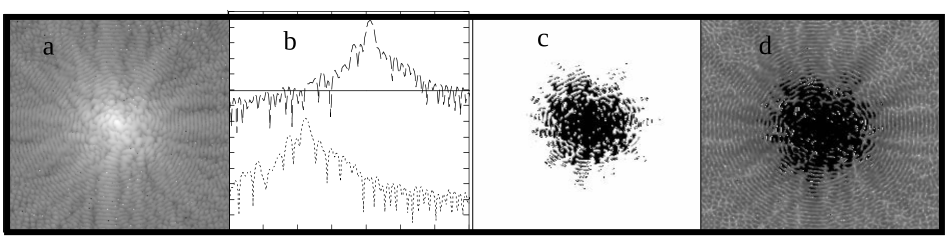


Fig. 2. a) Instantaneous star PSF log scaled. b) Transversal cut of the PSF (dashed) and threshold used to determine the adaptive mask shape (solid). The companion PSF (dots) is below the threshold. c) Binary adaptive mask obtained from the PSF shown in 2b. d) Star PSF times adaptive mask.

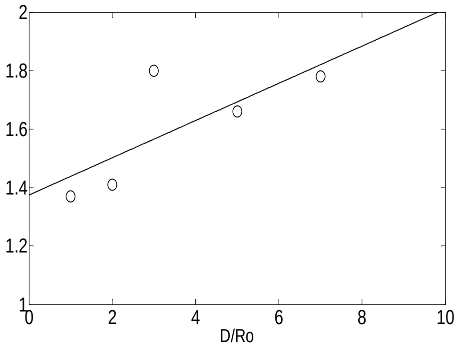
The adaptive mask is generated by placing dark pixels at the set of positions previously recorded (figure 2c). This requires an exact correspondence between pixels in the camera and those of the device used to create the adaptive mask. Masked PSF (figure 2d) is obtained by reflection on the ACM. An array of micro-mirrors may perform the binary reflective mask, since it can be modulated at several kHz. Since atmosphere fluctuations take between 10 ms and 50 ms to occur an appropriate sample rate could be around 30 ms that allows us a good balance between the need of freezing the atmosphere and the need of a high signal to noise ratio.

The parameter used to determine the mask performance was the distance (ρ) between the star and the nearest point in which the ratio between the companion and the star intensities is larger than 5, measured at the scientific camera plane. So far, the circular hard edge mask (CHEM) is the best performing option for uncompensated ground-based detection, as it was shown by Crepp et al. [2]. So, we will compare ACM results with those of the CHEM. We restrict our analysis to those cases in which the atmospheric degradation is not too severe: $1 \leq D/r_0 \leq 7$.

Results

The first result is that to attain the same star light extinction rate the CHEM needs an area much larger than the ACM. Figure 3a shows the ratio between the occluded area using the CHEM and that occluded by the ACM when both of then provide the same extinction. For all the D/r_0 range the ratio is over 1.4. This means that using ACM closest objects could be detected.

By comparing CHEM to ACM (fig. 3b) we see that there is a noticeable reduction (in percent) of the distance, since $\rho_{HE} > \rho_{AC}$ for the whole range of D/r_0 values analyzed. That is, ACM allows us to detect a faint companion in a position closer to the star. What is more, a very relevant advantage of the ACM is that its performance is not affected by pointing errors.



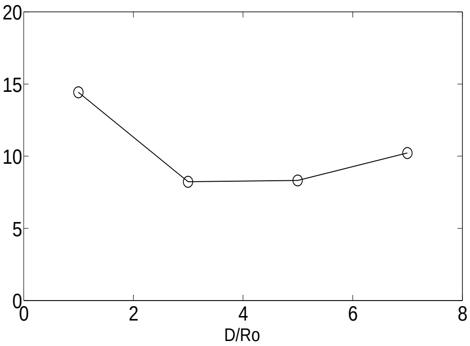


Fig. 3. a: Ratio between the area of CHEM and that of ACM. b: Distance reduction in per cent ($\Delta\rho=100*(\rho_{HE} - \rho_{AC}) / \rho_{HE}$) as a function of D/r_0.

Conclusions

In paper we have proposed a new technique able to improve current results in ground-based coronagraphy which opens new ways to alternative techniques. The ACM allows detecting faint companions in points closer to the star and, at the same time, it is not sensitive to pointing errors.

This technique can easily be applied to detect a faint object which is very close to a much brighter one and both of them immersed in a turbid medium.

References

1. P. Bourget, R. Vieira Martins, F. Colas, P. Assus and A. Irbah, in Direct Imaging of exoplanets, Science and Techniques, C. Aime and F. Vakili eds. (Cambridge Univ. Press 2006) 461.

2. J.R. Crepp, A.D. Vanden Heuvel , and J. Ge, “Comparative Lyot Coronagraphy with Extreme Adaptive Optics Systems,” Astrophys. J. 661 1323-1331 (2007).