Achromatic stellar interfero-coronagraphy with variable rotational shear

Pavel Frolov (1), Ilmir Akhmetov (2), Alexander Rodin (1), Oleg Korablev (1), Alexander Tavrov (1)
1: IKI-RAS Space Research Institute of RAS, Profsoyuznaya ul. 84/32, Moscow 117997, Russia
2: MPEI Moscow Power Engeneering Institute,Krasnokzrmennaya ul.14, Moscow, Russia

Keywords: interferometry, polarization, high-contrast astro-imaging

1. Abstarct (Introduction)

In the present communication we propose a common-path nulling interfero-coronagraph containing an image rotator with variable shear to optimize a coronagraphic contrast by the different observable combinations of the apparent stellar size and the star-to-planet separation.

Despite of all efforts spent on the detection of extra-solar planets (called exoplanets), both the direct imaging and the spectral study of an Earth-like exoplanet remains very challenging. The reason for the sort of situation is the critical combination of huge brightness contrast between the star and the planet (10^6 in the mid-IR and 10^9 in the visible) and the small angular separation between sources (typically 0.5…0.1 arcsec). Stimulated by these requirements, stellar coronagraphy has become a rapidly evolving field with many enhanced alternatives to the classical Lyot coronagraph. The achromatic interfero-coronagraph (AIC) has a high performance due to its widest achromaticity compared to the other types of stellar coronagraphs, and also due to the inner-working angle (IWA) of $0.38{\cdot}\lambda/D$ (according to the IWA definition: the moment when the throughput is reduced at the 50% of its maximum). In AIC, the nulling interferometer produces a localized dark field of destructive interference for the symmetric on-axis image component (star). Simultaneously, an off-axis asymmetric image component (e.g. planet, circumstellar or debris disc, etc.) interferes non-destructively with its copied achromatic image. The latter is superimposed by the lateral shear set by the apparent off-axis separation between the star and the planet.

At small IWAs, an AIC does not obtain the required high coronagraphic contrast due to the star leakage effect. The latter effect appears due incompletely suppressed the stellar light, the reason is the finite diameter of the star. For example, consider a Solar-sized star with a $0.01{\cdot}\lambda/D$ apparent stellar size that is being observed from 5 parsec by means of a $D = 1$ m diameter telescope at a λ=1 μm wavelength. Initial AICs with a 180º fixed angular shear angle could theoretically reach a coronagraphic contrast no greater than $4{\cdot}10^4$, due to the star leakage effect. An initial AIC principle is advantageous at the planet-to-star separation $\leq 1{\cdot}\lambda/D$, with the optimal separation being $\sim 1{\cdot}\lambda/D$, in this case the images of the companion and its copy do not destructively interfere.

With larger telescopes we can observe an exoplanet that is separated by several Airy radii from its parent star. For this case, an initial AIC principle was proposed to be incorporated to the achromatic rotation-shearing coronagraph (ARC) and to the absolute position interfero-coronagraph (APIC). They are based on a two-beam interferometer that has an optimized variable angle of rotational shear. That lets us to achieve the maximum of coronagraphic contrast for the desired combination of the apparent stellar size and the star-to-planet separation.

For modest telescope diameters of 0.5 m to 1.5 m., a tandem common path (TCP)-AIC, uses an effective four-beam interference with a 90° rotational shear of four copied stellar images. It can obtain a 10^{10} coronagraphic contrast for a $0.01{\cdot}\lambda/D$ apparent stellar size at $\sim 1{\cdot}\lambda/D$ planet-to-star separation.

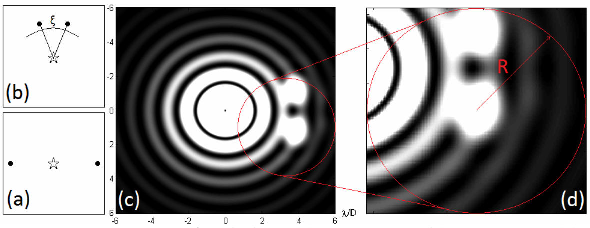

Fig 1: ARC images in focal plane (a) AIC image (b) ARC image (c) ARC image with stellar residual background (d) companion area

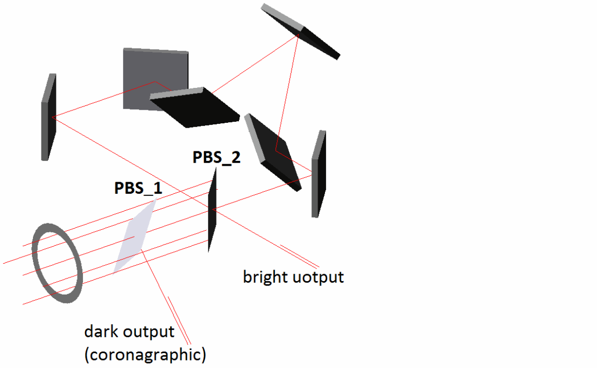

Fig 2: Scheme of CP-ARC

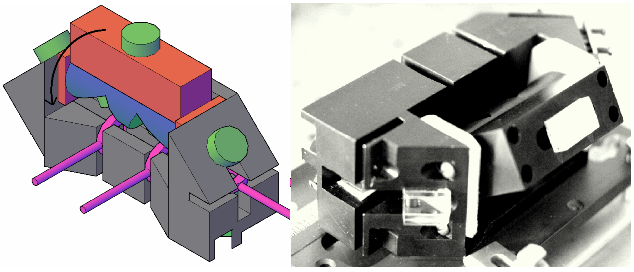

Fig 3: CAD design and laboratory photo of CP-ARC

2. References

[1] O. Guyon, E. Pluzhnik, M. Kuchner, B. Collins, S. Ridgway, ApJS **167**, 81 (2006).

[2] P. Baudoz, Y. Rabbia, J. Gay, Astronomy and Astrophysics Suppl. Ser. **141**, 319-329 (2000).

[3] A. V. Tavrov, Journal of Experimental and Theoretical Physics, **108**, No. 6, 963., 2009.

[4] C. Aime, G. Ricort, A. Carlotti, Y. Rabbia, J. Gay, Astronomy and Astrophysics **517**, A55 (2010).

[5] J. Nishikawa, L. Abe, N. Murakami, and T. Kotani, Astronomy and Astrophysics **489**, 1389 (2008)