Apodized Pupil Lyot Coronagraph, working without Lyot stop

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Abstract

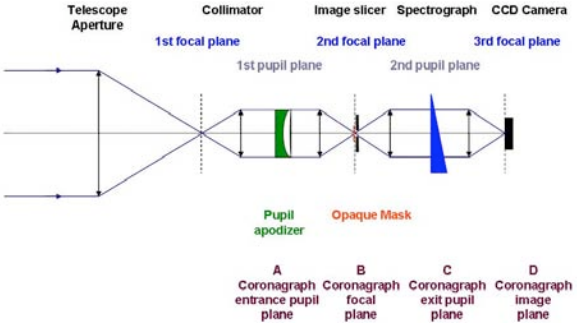
In this work, we propose to leave the Lyot stop off from the **Apodized Pupil Lyot Coronagraph (APLC)**, proposed by Soummer (2005). It is shown that a good bright star extinction can be reached. This configuration proves to be very interesting for instruments in progress, like FRIDA (inFRared Imager and Dissector for the Adaptive optics system of the 10.4m *Gran Telescopio Canarias [GTC]*), in which a stellar coronagraph would be installed.
In FRIDA, there are some mechanical constraints which prevent from putting a Lyot stop within their second pupil plane, namely the spectrograph pupil.

Coronagraph feasibility study for the FRIDA instrument

Frida Kahlo (1907-1954) Artista pintora mexicana

FRIDA (López et al. 2006) is being designed as a diffraction limited instrument with broad and narrow band imaging and integral field spectroscopy (IFS) capabilities to operate in the wavelength range 0.9-2.5 μm. FRIDA is a collaborative project between the main GTC partners, Spain, México and Florida, USA.

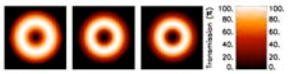
In our work, we study the possibility of introducing a coronagraph in the FRIDA optical scheme, represented below. An opaque or a phase mask can be placed in the 1st focal plane and Lyot stop in the following pupil plane. The coronagraphic image is obtained with a CCD camera in the 2nd focal plane in image mode and in the 3rd one in IFS mode.



FRIDA optical scheme in IFS mode. Here, it is represented with APLC w/o Lyot stop.

In our case, a classical APLC cannot be inserted because of the presence of the spectrograph in the 2nd pupil plane, which prevents from putting a Lyot stop in the same plane.
That is the reason why we're getting interested in how an APLC works without Lyot stop.

Apodized Pupil Lyot Coronagraph



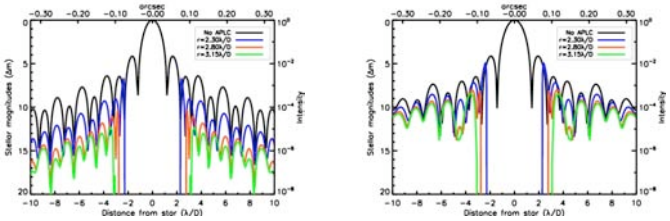
From left to right: Apodizer throughput used for a 12% central obstruction input pupil for a 2.30, 2.80 and 3.15 λ/D opaque mask radius. The apodizer could be done with a doublet of lenses (in prep.)

The Apodized Pupil Lyot Coronagraph, proposed by Soummer (2005) is a combination of an apodization placed at the input pupil, an opaque mask at the following focal plane and a Lyot stop at the coronagraph exit pupil to block the rejected starlight that is left outside the exit pupil.
As this rejection reaches reasonable values without any Lyot stop inserted, we propose not to use it at all.

In the following section, λ denotes the wavelength of study and D the telescope diameter (10.4m for the GTC).

Results with the APLC w/o Lyot stop

Below, we represent the residual intensity profile obtained with APLC w/o Lyot stop for different opaque mask radius for an on-axis monochromatic point source (λ= 1.65 μm) and a 12% centrally obstructed circular aperture.
On the left, the results are obtained for a perfect instrument (FRIDA+GTC) working in space.
On the right, the study is done for the GTC equipped with its Adaptive Optics system (GTCAO) and FRIDA, simulated with CAOS (Carbillet et al. 2005).



We worked with 12 statistically independent phase screens and we choose a "standard seeing scenario": r_0=20cm at λ= 0.5 μm and a turbulent velocity of 10m.s^{-1}. We used an on axis-bright guide star at null zenith angle. The simulation considered the following deformable mirror (DM) and subaperture geometry: 21 actuators and 20 subapertures placed across the long axis of the telescope pupil. The wavefront sensor measurements were considered perfect (ideal detector). The achieved Strehl ratio in H band was 0.74.
A significant theoretical gain can be reached, in stellar magnitudes: 1.5 to 2.0 for ground based telescopes and 3.0 to 6.5 in the case of a space based instrument. These values are achieved at an angular distance of 3.5λ/D from the main optical axis.

Interest for FRIDA and future instruments…

For FRIDA, the interest is that when working in IFS mode, APLC w/o Lyot stop allows to increase the signal's dynamic range and therefore avoid any detector saturation.
These results are encouraging as we later want to reduce the speckles contribution by using the Simultaneous Spectral Differential Imaging (SSDI) technique proposed by Marois et al. (2004). We think that the combination "AO system + coronagraph + differential imaging technique" is feasible with FRIDA and very promising for the detection and study of faint companions (imaging and spectroscopy). The latter statement is supported by some astronomers (Thatte, E-ELT conf. 2006).