Extreme coronagraphy with an adaptive hologram

Simulations of exo-planet imaging
Summary

- Traditional coronagraphy: the Lyot Coronagraph
- The idea: combining the coronagraph with an hologram
- Software simulations
- Results
The classical Lyot Coronagraph

Planet (off axis)

Star (on axis)

Lyot Mask (2-3 rings)

Lyot Stop (~95% of the pupil)

CCD
Lyot Coronagraph + hologram

Star (on axis)

Lyot Mask (microprism)

Lyot Stop

Direct beam

Reference beam

Deviating prism

Planet (off axis)

-1

0

CCD

Hologram
Detail of the microprism

Planet (off axis)

Star (on axis)

Direct beam

Reference beam
Star residuals \( \approx \) Reference beam

Recording the hologram

Orders diffracted

Dephasing of \( \pi \)

Order 0 of the star, not dephased

Order +1 of the reference beam, dephased of \( \pi \)

Addiction in complex amplitude

Wow, a planet!
The order $+1$ of the ref. beam interferes destructively with the order $0$ of the star. The order $-1$ of the ref. beam is said the "twin wave."
Using an apodized pupil

Aspherical mirrors

Non-apodized telescope beam

Non-apodized beam

Lyot Mask

Apodized beam

Apodized beam

Star (on axis)

The flux is concentrated within the peak, increasing the effect of the Lyot mask
Testing the performances of...

- Classical Lyot coronagraph
- Apodized Lyot coronagraph
- Apodized Lyot coronagraph + adaptive hologram
- Apodized Lyot coronagraph + adaptive hologram and after the subtraction of the twin wave
  - Perfect conditions
  - $\lambda/20$ and $\lambda/100$ mirror imperfections
  - $\lambda/20$ and $\lambda/100$ imperfections + photon noise
Performances with wavefront bumpiness

cla

B) Apodized Lyot coronagraph

apo

C) Apodized coronagraph with hologram, apodized reference beam

apo + holo

D) Apodized coronagraph with hologram, without twin wave

apo + holo - twin

$10^{3.0}$  $10^{5.5}$  $10^{6.5}$  $10^{4.0}$  $10^{6.5}$  $10^{7.5}$
Performances with wavefront bumpiness

\( \lambda/20 \)

\( \lambda/100 \)

Graphs showing the S/N ratio versus \( F_s/F_p \) for different configurations:
- Hol. apodized ref, without twin wave
- Hol. apodized ref.
- apo
- cla
- Lyot
- apo + holo
- apo + holo - twin
Performances with wavefront bumpiness and photon noise

$\lambda/20$

- Wavefront bumpiness: $\lambda/20$
- $m_v < 15$
- $m_v = 17$
- $m_v = 19$
- $m_v = 21$
- $m_v = 23$

$\lambda/100$

- Wavefront bumpiness: $\lambda/100$
- $m_v < 11$
- $m_v = 15$
- $m_v = 17$
- $m_v = 19$
- $m_v = 21$
- $m_v = 23$

S/N ratio vs. Fs/Fp

apo + holo + twin
<table>
<thead>
<tr>
<th></th>
<th>Ideal</th>
<th>$\lambda/100$</th>
<th>$\lambda/20$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical coronagraph:</td>
<td>$10^{3.2}$</td>
<td>$10^{3.2}$</td>
<td>$10^{3.1}$</td>
</tr>
<tr>
<td>Apodized coronograph:</td>
<td>$10^{9.5}$</td>
<td>$10^{5.0}$</td>
<td>$10^{3.4}$</td>
</tr>
<tr>
<td>Apodized coron. + hologram:</td>
<td>$10^{10.0}$</td>
<td>$10^{7.8}$</td>
<td>$10^{6.0}$</td>
</tr>
<tr>
<td>Apodized coron. + hologram – twin wave:</td>
<td>$10^{11.0}$</td>
<td>$10^{11.0}$</td>
<td>$10^{7.0}$</td>
</tr>
</tbody>
</table>
Extreme coronagraphy with an adaptive hologram
Simulations of exo-planet imaging

D. Ricci¹,* , H. Le Coroller², and A. Labeyrie³

¹ Département d’Astrophysique, Géophysique et Océanographie, Bât. B5C, Sart Tilman,
Université de Liège,
B-4000 LIEGE 1, Belgium
e-mail: ricci@astro.ulg.ac.be

² Observatoire de Haute Provence,
F-04870 Saint Michel l’Observatoire (France)
e-mail: herve.lecoroller@oamp.fr

³ Collège de France,
11, place Marcelin Berthelot
75231 Paris Cedex 05
e-mail: antoine.labeyrie@obs-azur.fr

...submitted...