Latest results with LBTI’s VORTEX coronagraph

D. Defrère
University of Liège

LBT user meeting -- Florence – June 23rd
Which planets?
The birth of a concept

- FQPM $\rightarrow$ sub-wavelength gratings $\rightarrow$ Annular Groove PM

- Advantages of the AGPM
  - Inner working angle $\approx 1\ \lambda/D$
  - Clear $360^\circ$ discovery space
  - Achromatic (SG design)
  - Easy to implement

Mawet, Riaud, Absil & Surdej 2005
Grating design and optimization

L band. Period = 1.42 µm, angle = 3.00°

Delacroix et al. 2013
Etching on synthetic diamond

• Inductively coupled plasma etching
  o N band (grating period = 4.6 µm)
  o L band (grating period = 1.4 µm)

N band (Nov 2009)  N band (Feb 2012)  L band (Sep 2012)

• Parameters close to optimal ... need to test!
High performance

Peak rejection

L band


Delacroix et al. 2013
Installation at VLT, LBT, and Keck
Installation at VLT, LBT, and Keck

Don’t break a priceless device
Science highlights

HD 169142 @ VLT/NACO

HIP 79124 @ Keck/NIRC2

MWC 758 @ Keck/NIRC2

Biller et al. 2014, Reggiani et al. 2014

Serabyn et al. (2017)

Reggiani et al. (in prep)

Beta Pic @ VLT/NACO

HIP 141569 @ Keck/NIRC2

Absil et al. 2013
The observing challenge

VORTEX coronagraphy at the LBT

LBT has two 8.4-m mirrors mounted on a single structure (collecting area of a single 11.8-m aperture)

Resolution
Beam combination provides the equivalent resolution of a 22.7-m telescope.

High Contrast
The AO system creates an image with a Strehl of >90% at 3.8 µm.

Sensitivity
# LMIRCam specifications

<table>
<thead>
<tr>
<th></th>
<th>LMIRcam</th>
<th>AGPM+LMIRCAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Coverage (µm)</td>
<td>J,H,K,L,M (1.5-5.1)</td>
<td>L&amp;M (3.2-5.1)</td>
</tr>
<tr>
<td>Throughput</td>
<td>&gt;30%</td>
<td>&gt;30%</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>0.011”</td>
<td>0.011”</td>
</tr>
<tr>
<td>FOV</td>
<td>40x40”</td>
<td>5x5”</td>
</tr>
<tr>
<td>Minimum Strehl</td>
<td>90% (3.8 µm)</td>
<td>90% (3.8 µm)</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>350</td>
<td>40 (with IFU)</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>40 mas @ L’</td>
<td>40 mas @ L’</td>
</tr>
</tbody>
</table>
Several possibilities

Single AO+AGPM imaging

Binocular AO+AGPM imaging

*New mode*

Single IFU+AO+AGPM imaging
AGPM: easy to install

New optimized Lyot stop

2015 (AGPM-L4&B8D2)
Nov. 2013: first-light observations

- First-light observations on October 17, 2013 (AGPM-L4, 1 telescope):

  Peak rejection ~35:1 (far from optimal)

  Gomez et al. 2017
Nov. 2013: first-light observations

Gomez et al. 2017
Comparison with other instruments

- NACO (1h54, 83deg, L=3.4)
- NIRC2 (30min, 168deg, L=5.2)
- LMIRCam (1h20, 96deg, L=5.2)
VIP library: [http://github.com/vortex-exoplanet/VIP](http://github.com/vortex-exoplanet/VIP)

VIP - Vortex Image Processing package

**Attribution**


**Introduction**

VIP is a package/pipeline for angular, reference star and spectral differential imaging for exoplanet/disk detection through high-contrast imaging. VIP is being developed in Python 2.7.

VIP is being developed within the VORTEX team @ University of Liege (Belgium). Most of VIP’s functionalities are mature but it doesn’t mean it’s free from bugs. The code will continue evolving and therefore all the feedback and contributions will be greatly appreciated. If you want to report a bug, suggest or add a functionality please create an issue or send a pull request on the github repository.

**Jupyter notebook tutorial**

VIP tutorial (Jupyter notebook) is available in this repository and can be visualized online [here](http://). If you are new to the Jupyter notebook application read the beginner guide. TL;DR download the tutorial from its repository and from the terminal run:
New improvements

(Huby et al. 2015)

• 1. Real-time star centroiding using QACITS
New improvements

- 2. New optimized Lyot stop

![Graph showing contrast vs. angular separation with different Lyot stop configurations.]
New improvements

- 3. New AGPM+IFU mode

First AGPM+IFU image (beta Aur)  
Spectral image cube (2.8 – 4.2 microns, R~20)

Data processing by Jordan Stone (UoA)
Latest observations

- Planet formation at small angular separation (preliminary)
Summary

• LMIRCam+AGPM for L’ high-contrast imaging

• New optimized Lyot stop and two AGPMs for binocular observations

• New IFU + AGPM mode (R=40)

• New real-time tip/tilt loop (improve efficiency and contrast)

• Want to use it?
  • AGPM contact: ddefrere@ulg.ac.be
  • LMIRCam contact: jstone@as.arizona.edu
Backup
Recent results

- Squeezed in ~1 hour of AGPM engineering in December 2016 (during ALES commissioning)
  - New double Lyot stop shows no issue
  - Alignment went smoothly;

No Lyot stop

With new double Lyot stop
AGPM misaligned

- Both AGPMs fit nicely LMIRCam’s field-of-view;
- The center of the right AGPM doesn’t seem to appear at the center of the AGPM => mount cover has rotated.
- Example of clocked mount cover (left). Last picture before closing the cryostat (right):
The LBT interferometer (LBTI)
ALES (Arizona Lenslet for Exoplanet Survey)

Wavelength ranges / spectral resolutions:
2.8-4.15 (R~40)
3-5 (R~20)
2.2-3.7 (R~40)
2.0-2.3 (R~150)
3.1-3.5 (R~100)

FOVs / spaxel scales (the finest scales are for dual-aperture interferometry)
0.45x0.45" (6x6 mas spaxels)
0.9x0.9" (12 mas spaxels)
1.8x1.8" (25 mas spaxels)
3.6x3.6" (50 mas spaxels)