New NIR spectro-polarimetric modes for the SCExAO instrument

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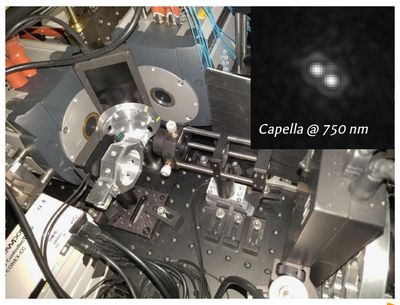
I. LEGACY: VISIBLE DUAL CAMERA POLARIMETRY WITH VAMPIRES



VAMPIRES module in the visible bench of SCExAO.

VAMPIRES PERFORMANCES

- VAMPIRES uses the AO corrected visible PSF to achieve <10 mas resolution images of polarized sources.
- It can either use a full pupil, or non-redundant masks (7 holes, 9 holes, 18 holes or annulus masks).
- Operating wavelengths: 600-800 nm.
- VAMPIRES rotates a half-wave plate in front of AO188.

DUAL CAMERA SYSTEM

- A second EMCCD camera was installed, one for each polarization mode, for differential imaging.
- A Ferroelectric Liquid Crystal (FLC) is used for a fast switch of the polarization.
- A field stop was installed to allow small sub-window mode for kHz fast acquisition.

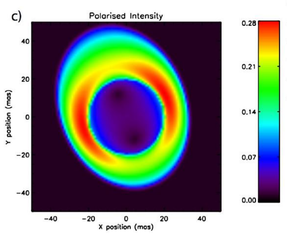
Hα IMAGING MODE

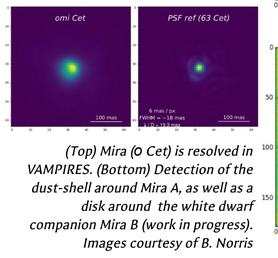
- The polarization splitting cube can be changed with a 50/50 splitting cube.
- A filter wheel between the two cameras allow to do a slow switch (~1 Hz) between continuum and Hα filters.

VAMPIRES detection of inner mass-loss dust-shell around μ Cep, at milliarcsecond scale.
Inner radius: 9.3 ± 0.2 mas (~ Rstar)
Scattered-light fraction: 0.081 ± 0.002
PA of major axis: 28 ± 3.7 °
Aspect ratio: 1.24 ± 0.03

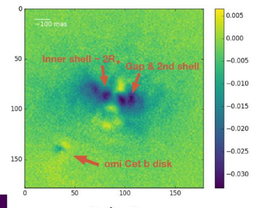
SCIENCE RESULTS

- VAMPIRES observed known disks and mass-loss dust shells around red giant stars.
- A careful calibration of the instrumental polarization is necessary to measure accurately the stokes parameters of the polarization.

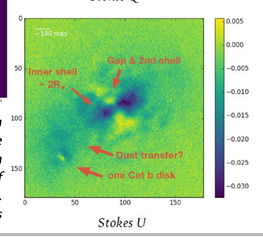




(Top) Mira (ο Cet) is resolved in VAMPIRES. (Bottom) Detection of the dust-shell around Mira A, as well as a disk around the white dwarf companion Mira B (work in progress). Images courtesy of B. Norris



Stokes Q

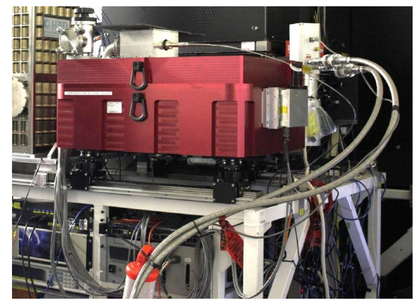


Stokes U

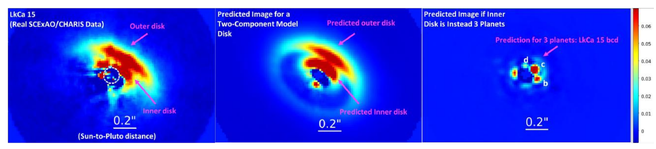
II. NOW AVAILABLE: NIR SPECTRO-POLARIMETRY WITH CHARIS

CHARIS PERFORMANCES

- CHARIS is the IFS installed behind SCExAO since 2016.
- CHARIS provides the main science output of the SCExAO instrument.
- Field of view: 2.07"x2.07"
- HAWAII-2RG Detector
- Wavelength coverage: J to K-band
- Low-res mode (R~19, broadband) and High-res mode (R~70-90, single band) available.



CHARIS IFS installed behind SCExAO.

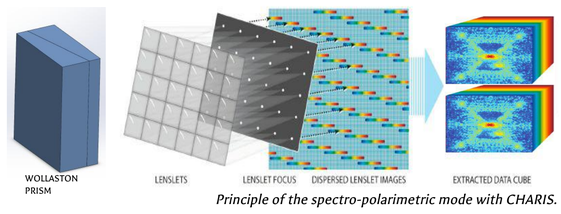


Example of disk observed with CHARIS in regular observing mode (SDI+ADI): LkCa15 (Currie et al. 2019) .

Wollaston prism deployed between the CHARIS pickoff wheel and the enclosure.

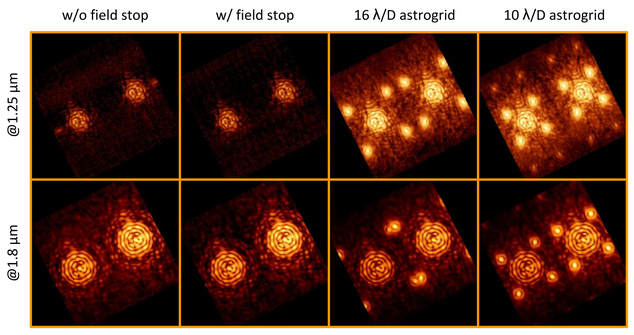
SPECTRO-POLARIMETRIC MODE

- A Wollaston prism was installed in front of CHARIS, inside SCExAO, splitting the light into two polarizations before entering CHARIS.
- A field stop limits the field of view to half the image plane of CHARIS (1"x2").
- This mode is compatible with the low-res and high-res modes of CHARIS.



Principle of the spectro-polarimetric mode with CHARIS.

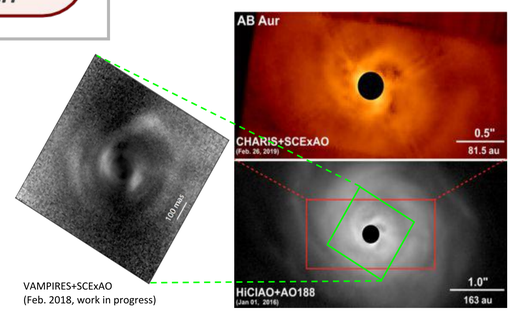
- The field stop removes any cross-contaminations between polarizations.
- The Wollaston can be rotated by 90° manually.
- A tighter speckle grid can be used for astrometric/photometric calibration.



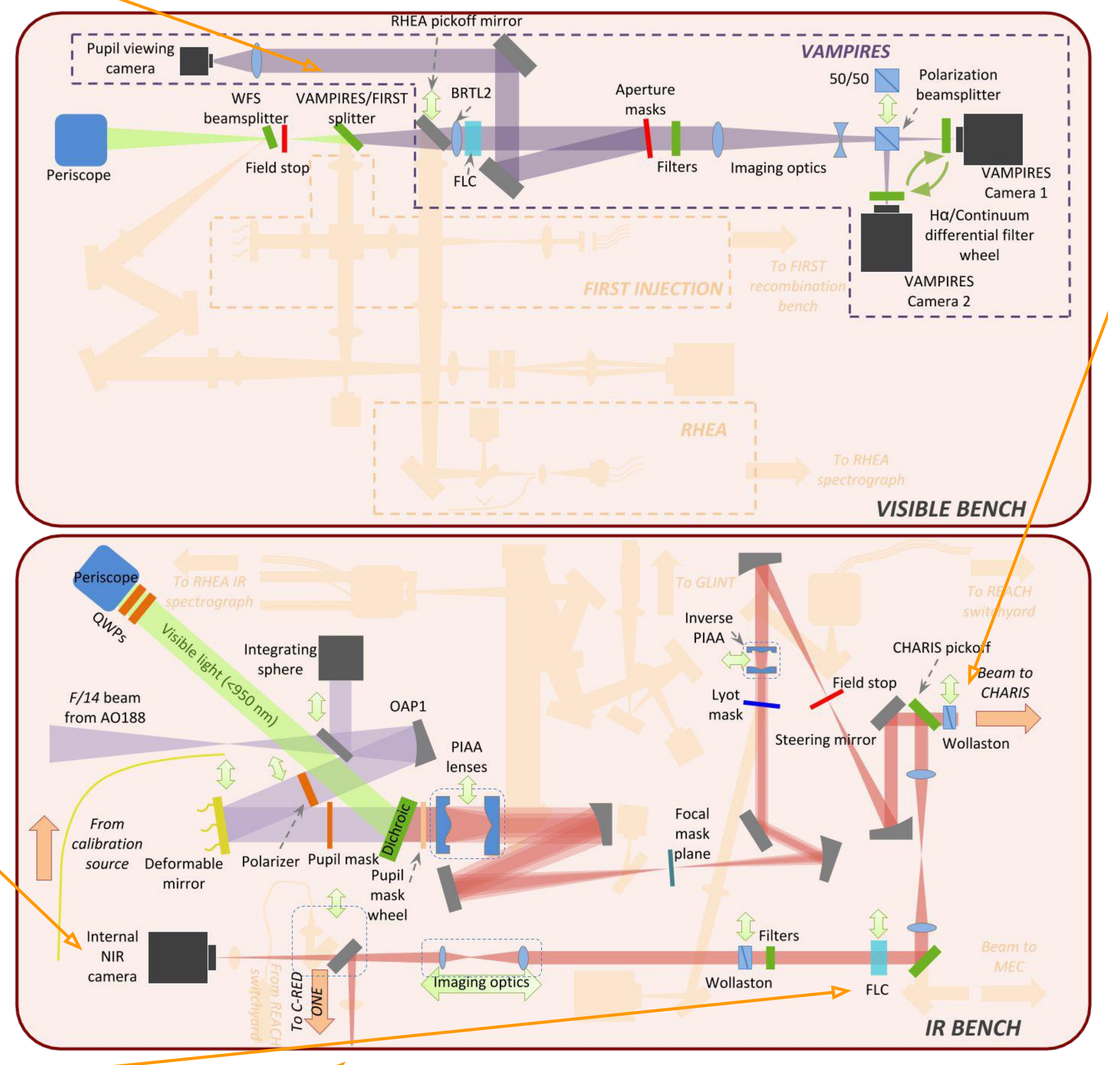
Laboratory images taken with the internal source and a Lyot coronagraph.

ON-SKY RESULTS

- The new PDI mode was tested on-sky at the beginning of 2019, on known disks previously observed with the PDI mode of HiCIAO and/or the SDI mode of CHARIS.
- VAMPIRES is driving the HWP in front of AO188, synchronized with the CHARIS images.
- A careful calibration of the instrumental polarization, is in progress. ***See Poster #11447-402 (R. van Holstein)***
- The mode is now open for Open-Use observations.



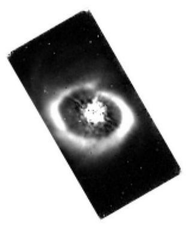
Comparison of the observation of AB Aurigae with HiCIAO (2016), VAMPIRES (2018), and the spectro-polarimetric mode of CHARIS (2019). Images courtesy of B. Norris and T. Kudo.

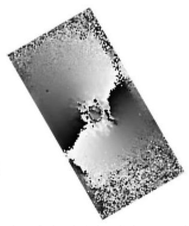


III. IN DEVELOPMENT: FAST NIR POLARIMETRY

POLARIMETRY WITH THE FIRST LIGHT IMAGING C-RED 2

- A second Wollaston prism, identical to the CHARIS one, was installed in the common path between the internal C-RED 2 camera and the SAPHIRA port.
- Despite the wider field of view of the camera, since the Wollaston is the same, the field of view of the polarization mode is the same as CHARIS: 2"x1".
- The camera can look at wavelengths between y-band and H-band (950 nm to 1.7 um), using band filters or in broadband mode.
- In Fast-PDI mode, the camera is synchronized with the FLC to switch the polarization between each frame, for frequencies between 1 and 500 Hz. This mode is limited to H-band by the FLC.
- The Wollaston prism can be rotated manual with increments of 45°, depending on the desired orientation. Matching field stops can be inserted depending on the orientation.

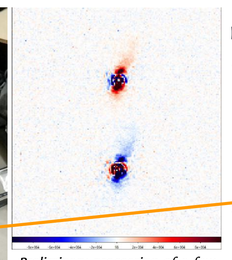




Polarization intensity and angle of the bright disk around HD 34700A in broadband mode (no FLC) . Courtesy J. Zhang

New C-RED 2 camera used as SCExAO's internal NIR camera.

Ferroelectric Liquid Crystal (FLC) device installed on a manual rotation mount, now installed inside SCExAO.



Preliminary processing of a few minutes of data on the variable star R Aqr taken at high speed, synchronized with the FLC. A double difference was performed to highlight the dust around the star. Courtesy O. Guyon.

FIRST ON-SKY RESULTS

- Some preliminary on-sky testing were performed on bright polarized sources using the C-RED 2 running at a few tens of Hz, first without the FLC.
- Earlier this year, we tested the FLC synchronized with the C-RED 2 camera for frequencies between 1 and 500 Hz.
- With the FLC, similarly to VAMPIRES, three levels of subtractions are now possible. At high speed, atmospheric speckles are more effectively subtracted.

C-RED ONE CAMERA

- The C-RED ONE will be shared with a new NIR PyWFS for AO188, until we acquire a second one.
- The camera was integrated on the side of SCExAO, where IfA's SAPHIRA camera used to be. A pickoff mirror reflects the light towards this camera instead of the C-RED 2.
- The camera was successfully tested on-sky, showing better sensitivity than the C-RED 2. Tis test was performed without the FLC for now.

NEXT STEPS

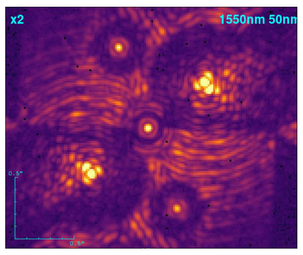
- The last step to complete the Fast PDI mode with the C-RED ONE is to implement the synchronization between the acquisition and the FLC, similarly to what we have done for the C-RED 2.

First Light Imaging C-RED ONE installed on the side of SCExAO, where IfA's custom SAPHIRA camera used to be for testing. In the future, the camera will also be able to use another port on the side of AO188, to be used as a NIR PyWFS.

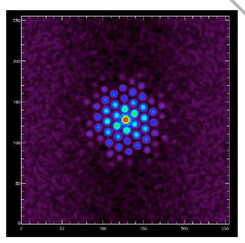
IV. FUTURE WORK

FAST POLARIMETRY WITH C-RED ONE

- A synchronization of the C-RED ONE camera and the FLC is in the works.
- We are looking into purchasing another Wollaston prism to increase the field-of-view by a factor two, to 2x4 arcsec.
- The fast-PDI mode should be available for Open-Use in 2021.



vAPP already installed on SCExAO, using a grating to separate the dark zones.

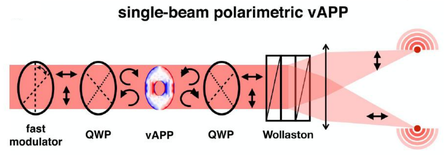


χ Cyg power spectrum with NRM (star is resolved). Courtesy B. Norris.

FUTURE POLARIZATION PROJECTS

- Non-redundant masks will be added to the instrument, to provide the same option as VAMPIRES (with the added spectral resolution of CHARIS).
- A polarimetric vAPP will be added in the pupil plane, surrounded by two QWPs. The two dark zones will then be separated by the Wollaston prism.

single-beam polarimetric vAPP



Principle of the polarimetric vAPP using the available FLC and Wollaston prism. Courtesy S. Bos.

- Another envisonned upgrade will be to add the capacity of measuring circular polarizations instead of linear polarizations, by adding QWPs in the instrument.
- Finally, the Wollaston will be used as a beamsplitter for spectral differential imaging for the Paβ line.

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