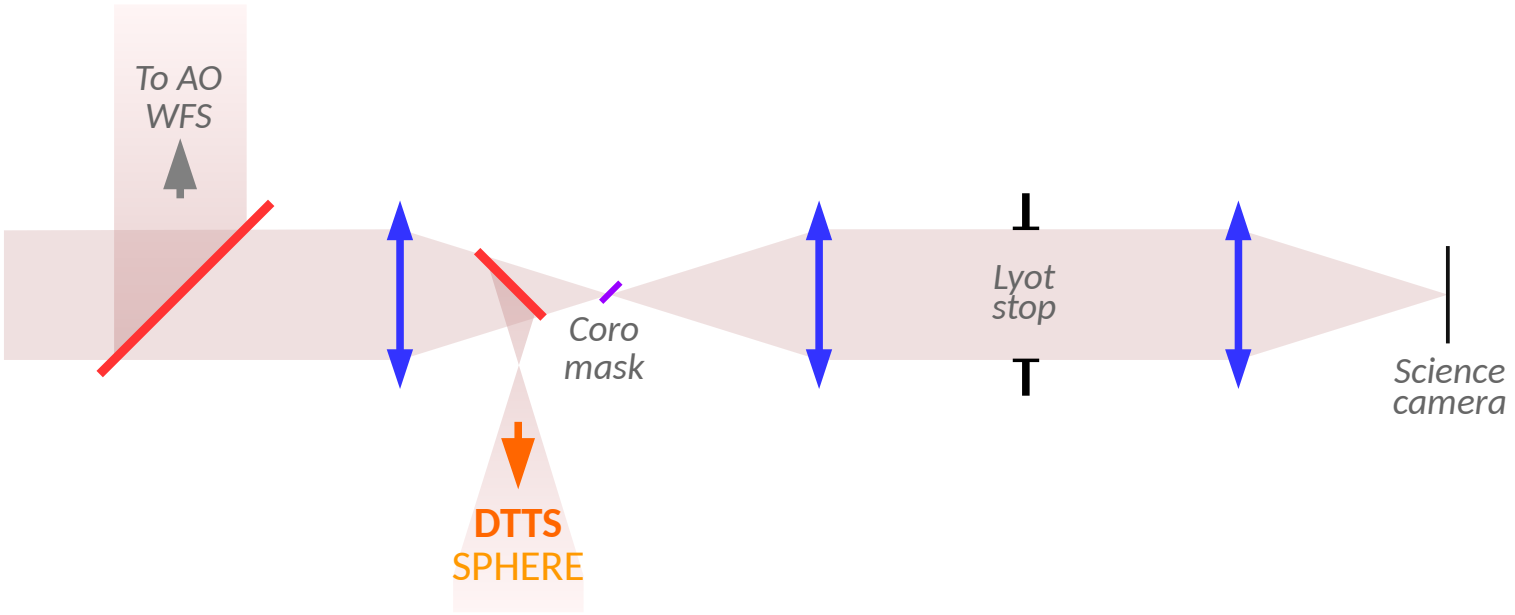
QACITS: a focal-plane tip-tilt sensing technique

E. Huby, P. Baudoz
LESIA, Observatoire de Paris
VORTEX team
(U. Liège, Caltech, Uppsala University)

- Short review of different existing LOWFS techniques
- Description of the QACITS principle
- Possible integration in SPHERE+

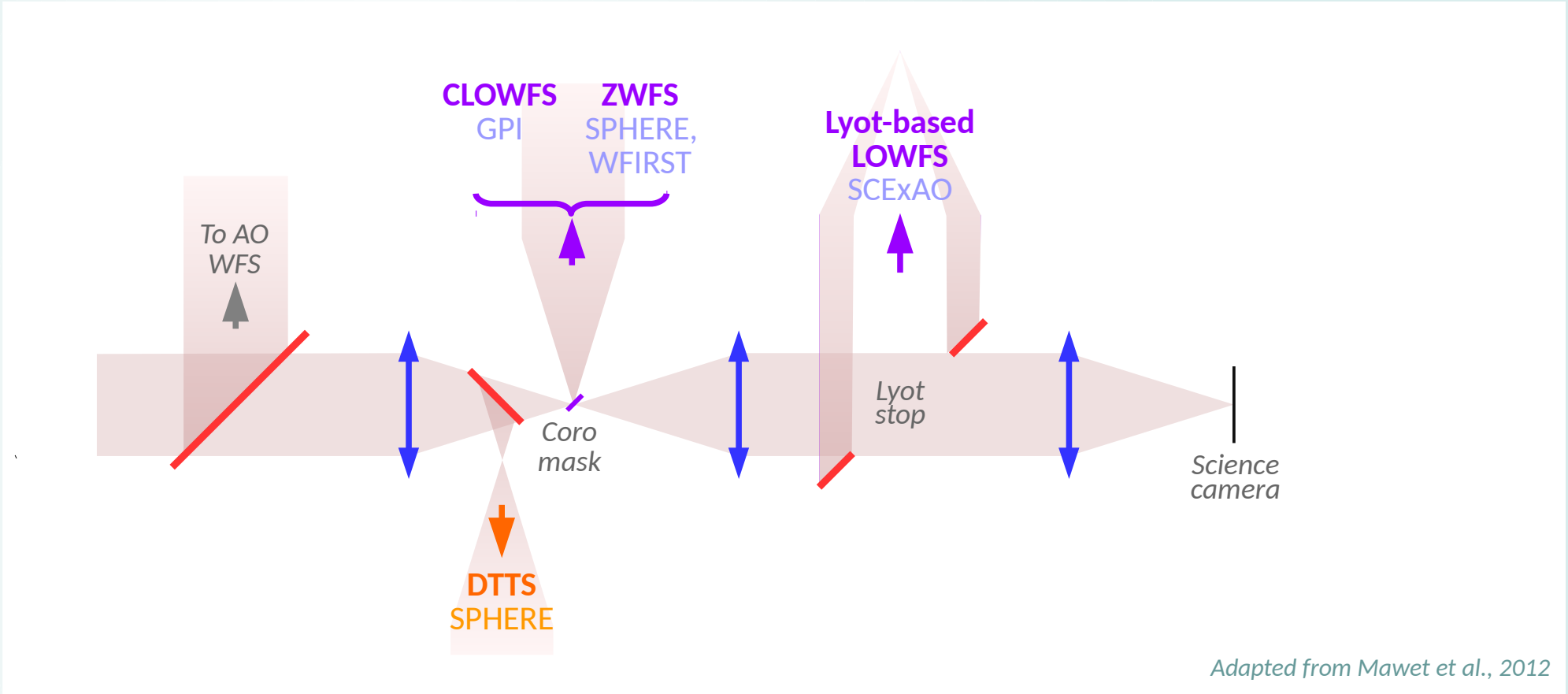
LOWFS techniques - locations



Adapted from Mawet et al., 2012

Beamsplitter **DTTS** : Differential Tip-Tilt Sensor

LOWFS techniques - locations



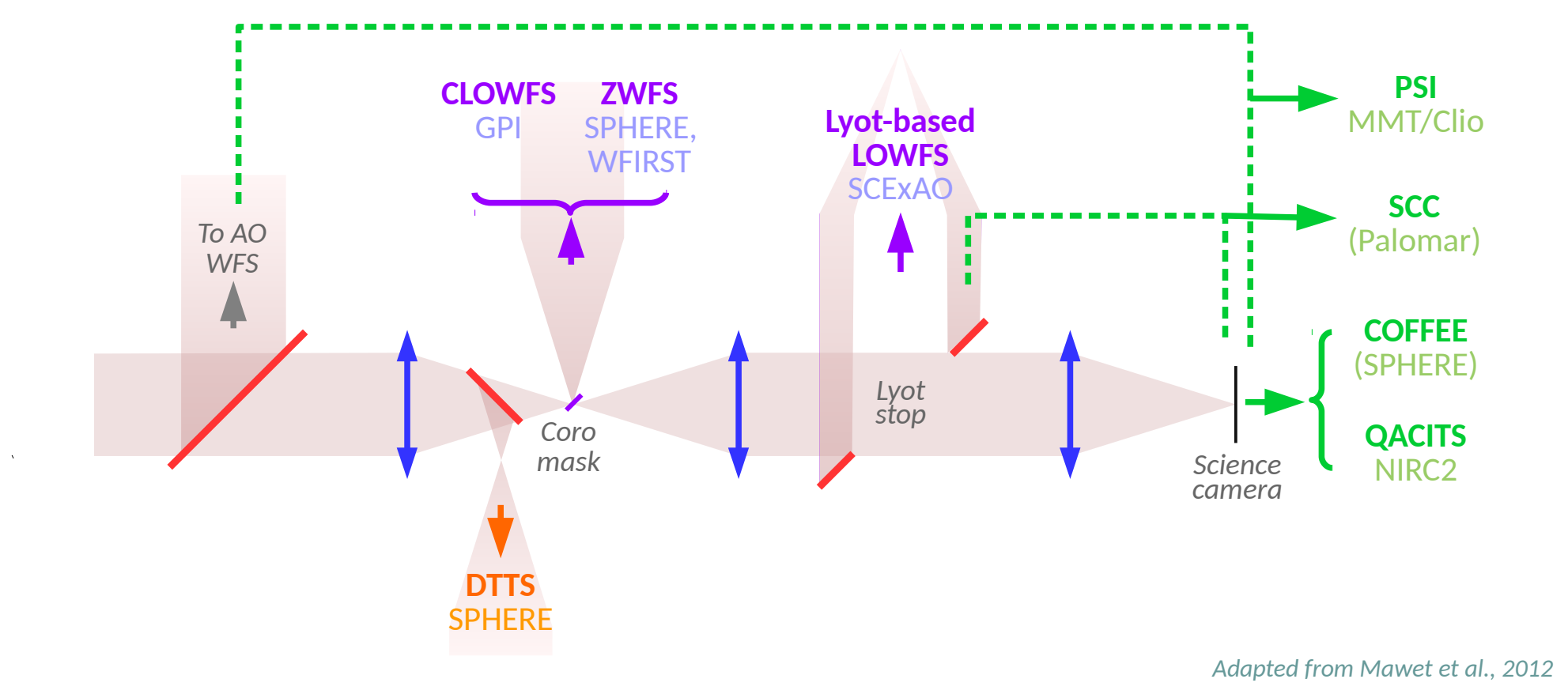
Beamsplitter

DTTS : Differential Tip-Tilt Sensor

Light rejected by the coronagraph

- **ZWFS** : Zernike Wave-Font Sensor
- **CLOWFS** : Coronagraphic Low-Order Wave-Front Sensor
- **LLOWFS** : Lyot-based Low-Order Wave-Front Sensor

LOWFS techniques - locations



Beamsplitter

DTTS : Differential Tip-Tilt Sensor

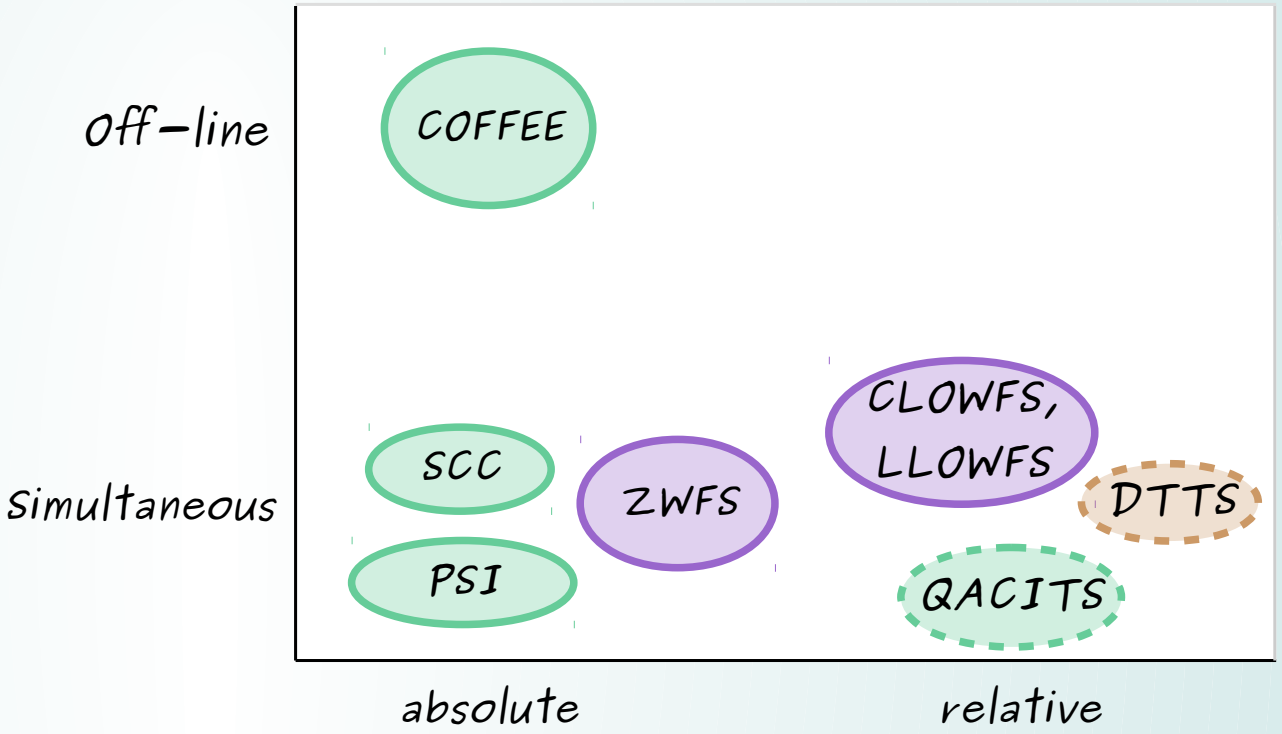
Light rejected by the coronagraph

- **ZWFS** : Zernike Wave-Font Sensor
- **CLOWFS** : Coronagraphic Low-Order Wave-Front Sensor
- **LLOWFS** : Lyot-based Low-Order Wave-Front Sensor

Analysis of the science image

- **COFFEE** : Coronographic Focal-plane wave-Front Estimation for Exoplanet detection
- **QACITS** : Quadrant Analysis of Coronagraphic images for Tip-tilt Sensing
- **PSI** : Phase Sorting Interferometry
- **SCC** : Self-Coherent Camera

LOWFS techniques - measurements



Beamsplitter

DTTS : Differential Tip-Tilt Sensor

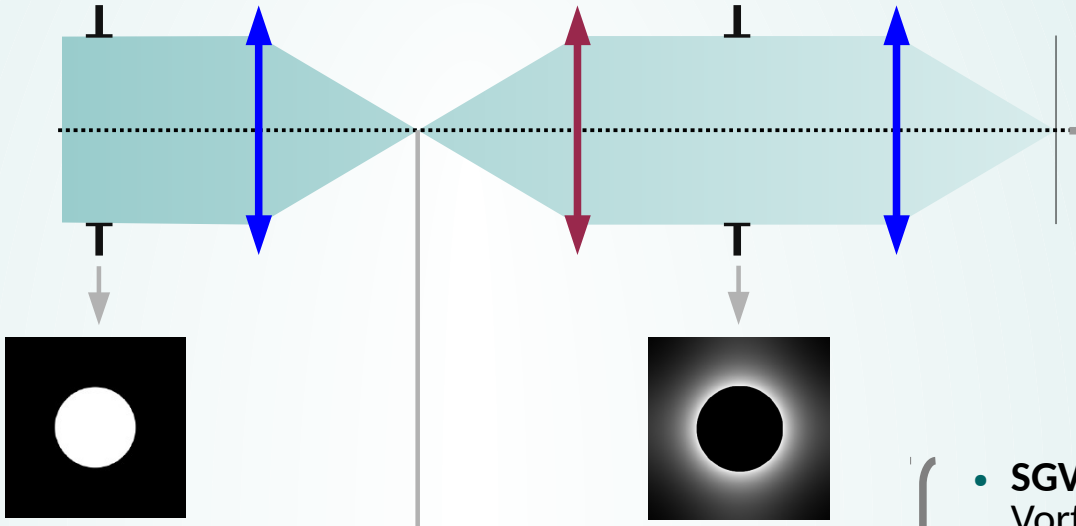
Light rejected by the coronagraph

ZWFS : Zernike Wave-Font Sensor
CLOWFS : Coronagraphic Low-Order Wave-Front Sensor
LLOWFS : Lyot-based Low-Order Wave-Front Sensor

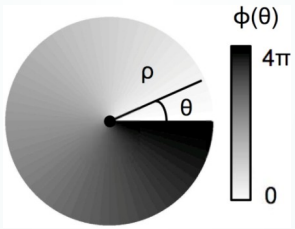
Analysis of the science image

COFFEE : Coronographic Focal-plane wave-Front Estimation for Exoplanet detection
QACITS : Quadrant Analysis of Coronagraphic images for Tip-tilt Sensing
PSI : Phase Sorting Interferometry
SCC : Self-Coherent Camera

The Vector Vortex Coronagraph

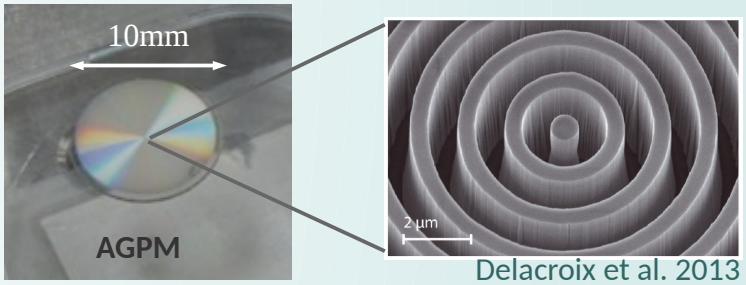


Theoretical perfect starlight extinction
(for an unobstructed pupil)



Phase mask

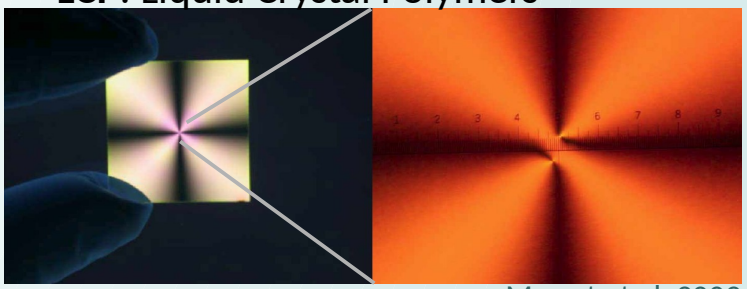
- **SGVC2**, **SGVC4**: Sub-wavelenth Grating Vortex Coronagraph of charge 2, 4...



Delacroix et al. 2013

Note:
SGVC2 = AGPM (Annular Groove Phase Mask)

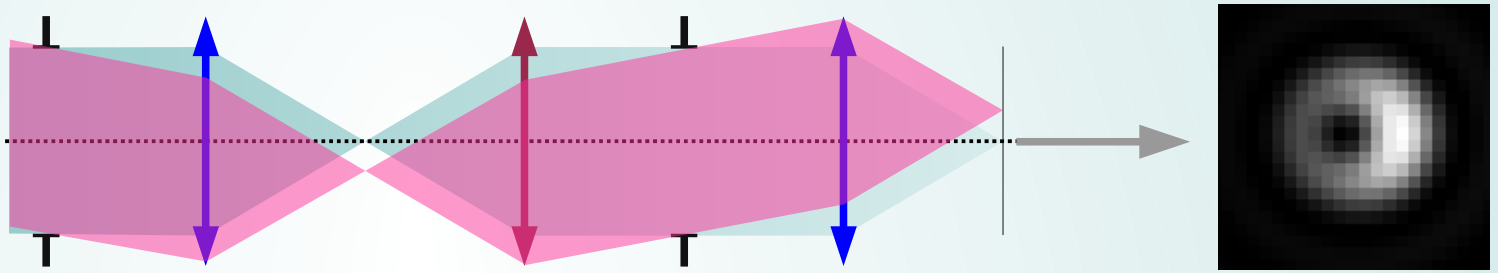
- **LCP**: Liquid Crystal Polymers

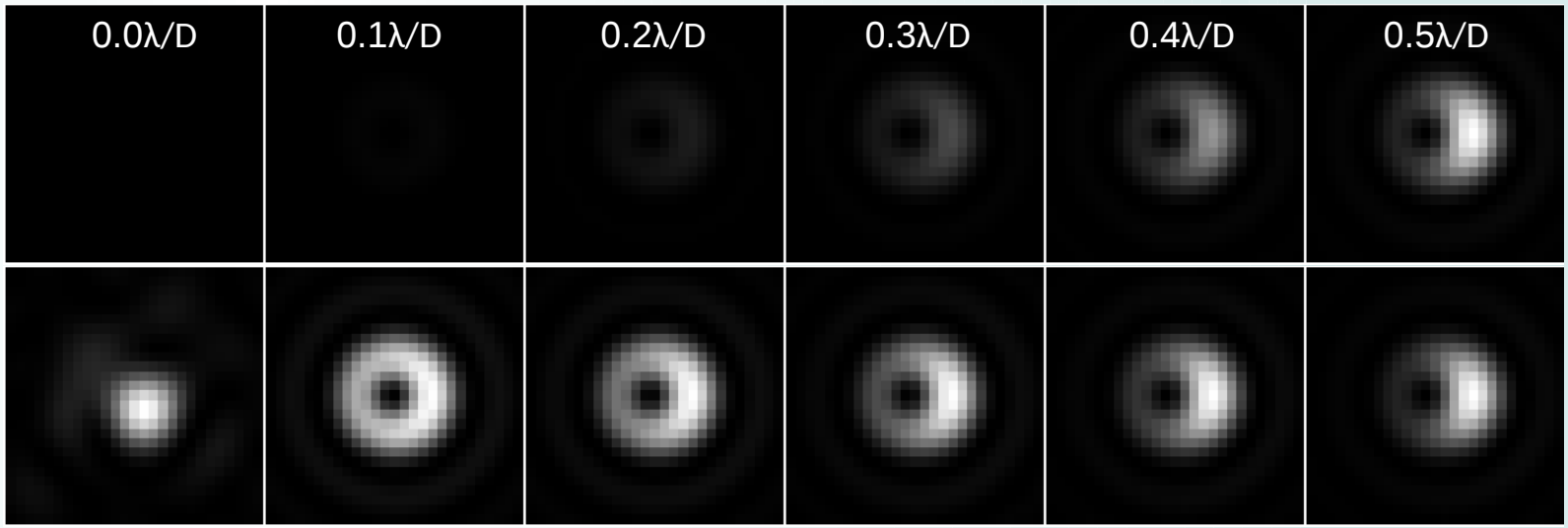


Mawet et al. 2009

Effect of a pointing error

Unobstructed pupil case



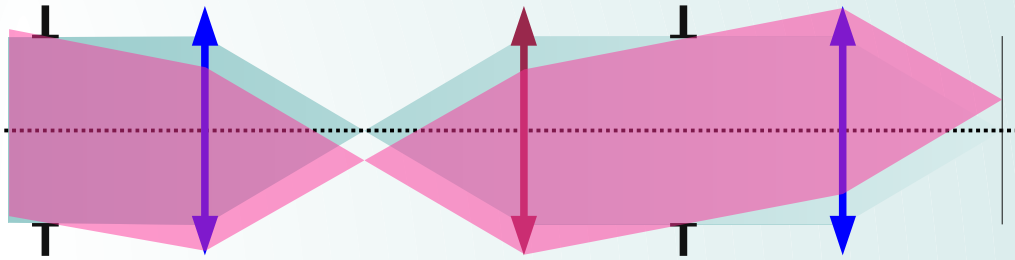


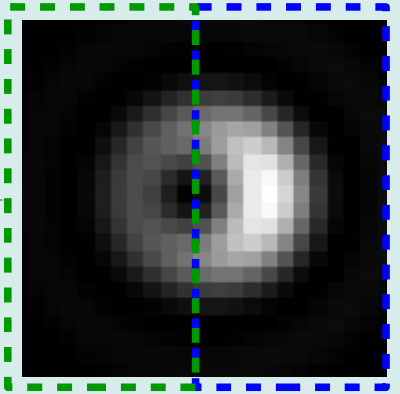
$$I_{det} = \quad \ldots \quad + 2\,T_x^3 \cos(\theta)\,\frac{J_2(\alpha)}{\alpha}\,\frac{J_3(\alpha)}{\alpha}$$

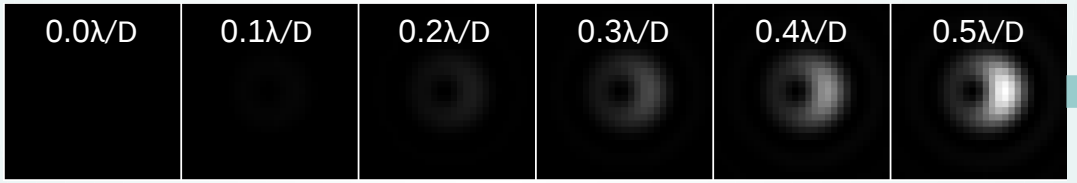
FQPM: Mas, Baudoz et al. 2012
VVC: Huby, Baudoz et al. 2015
Huby et al. 2017

Principle of QACITS

Unobstructed pupil case



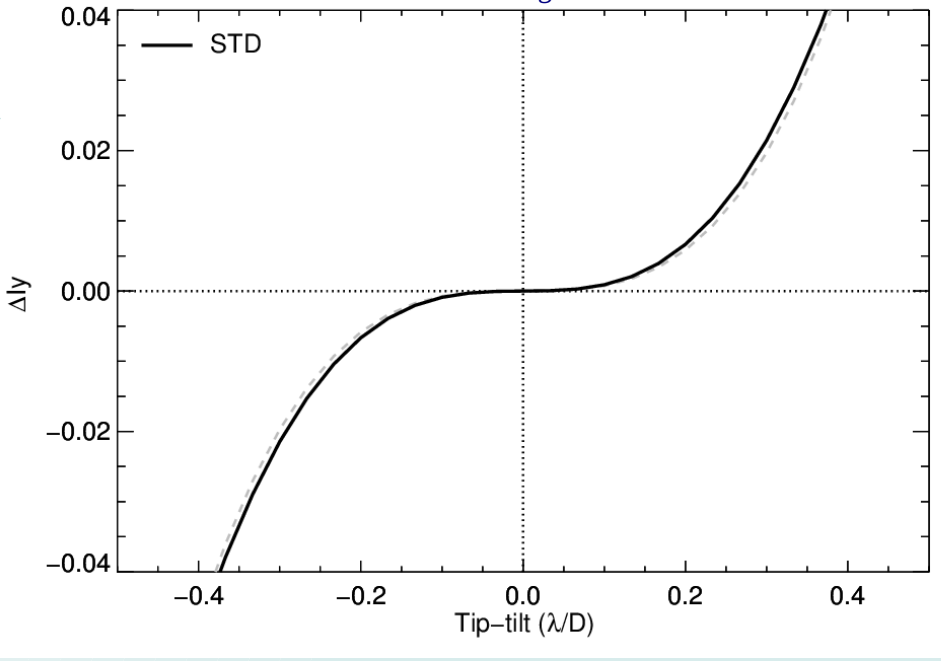




Estimation of the tip-tilt:

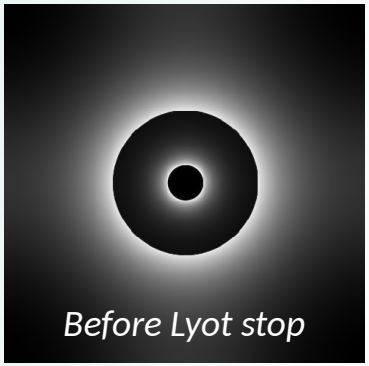
$$T_x = \left(\frac{\Delta I_x}{\beta} \right)^{1/3}$$

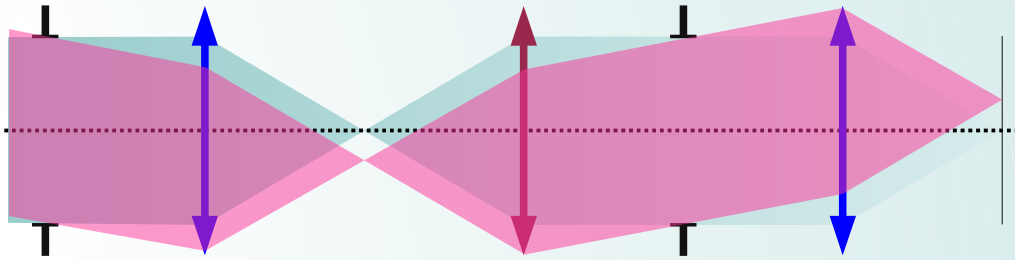
$$\Delta I_x = I_{\text{right}} - I_{\text{left}}$$

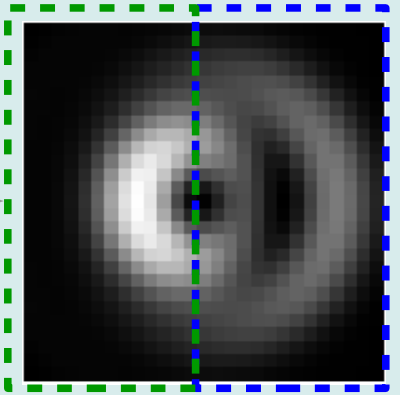


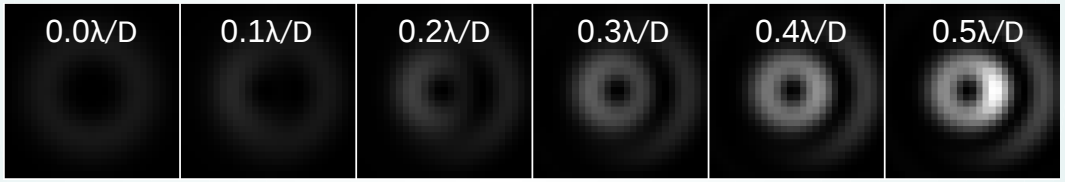
Principle of QACITS

Centrally obstructed pupil case

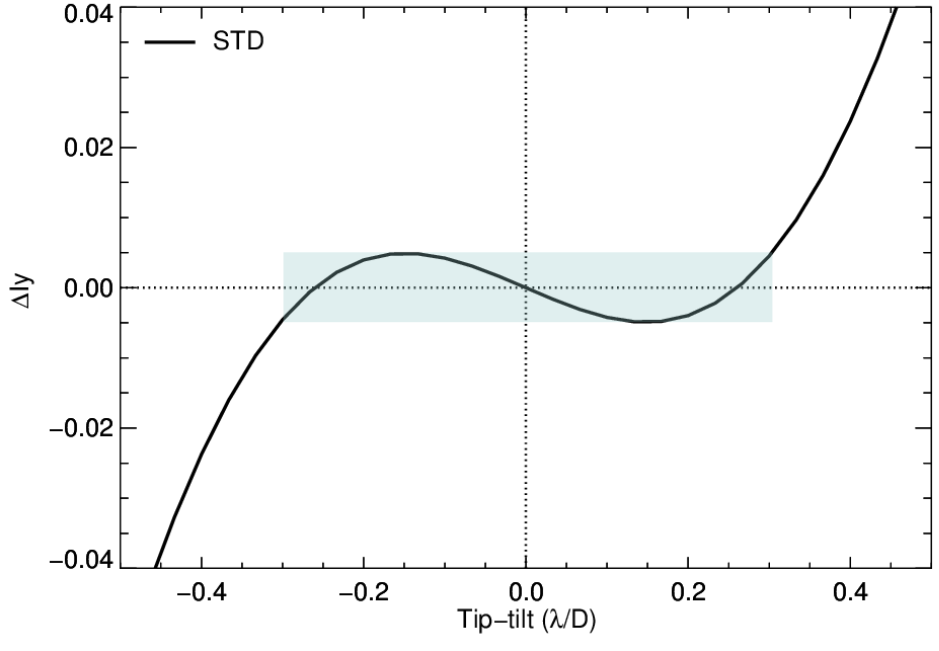






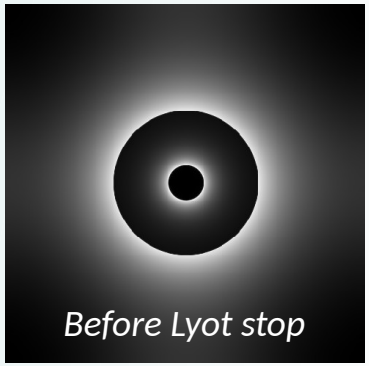


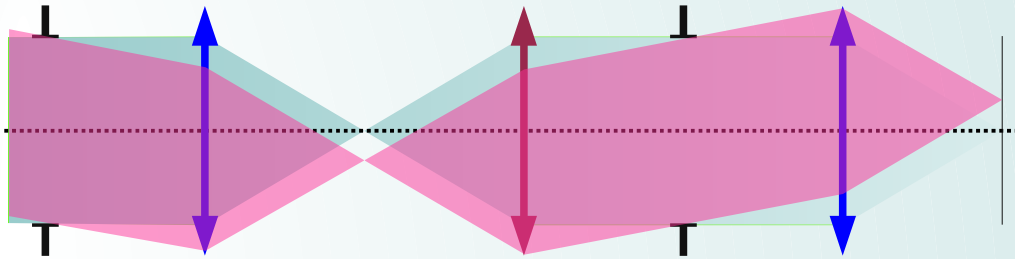
$$\Delta I_x = I_{\text{right}} - I_{\text{left}}$$

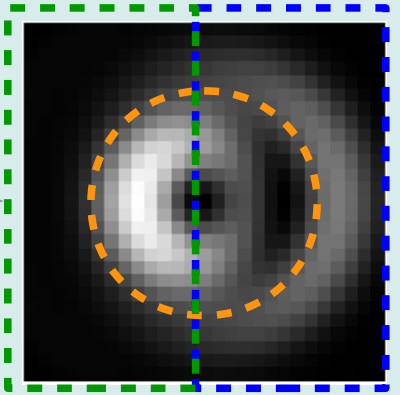


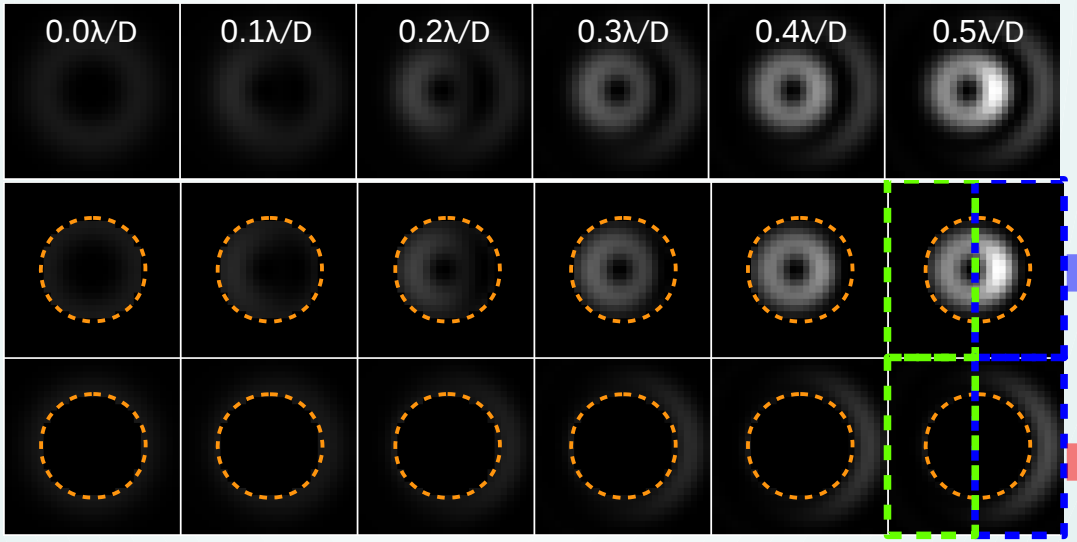
Principle of QACITS

Centrally obstructed pupil case

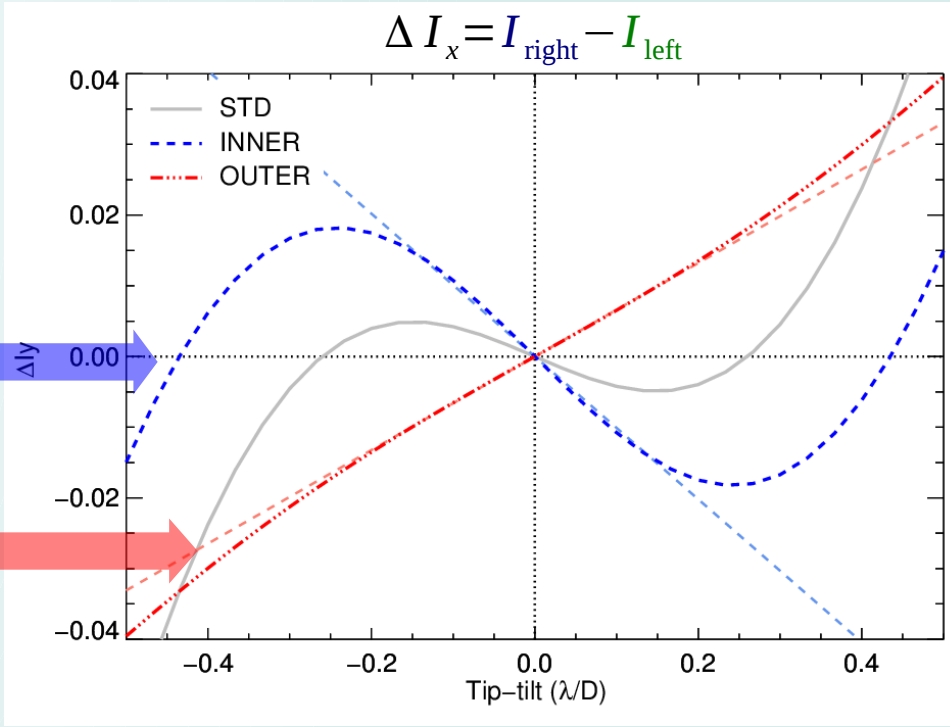








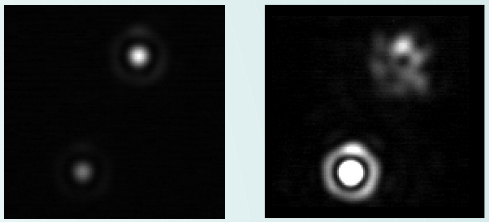
$$\Delta I_x = I_{\text{right}} - I_{\text{left}}$$

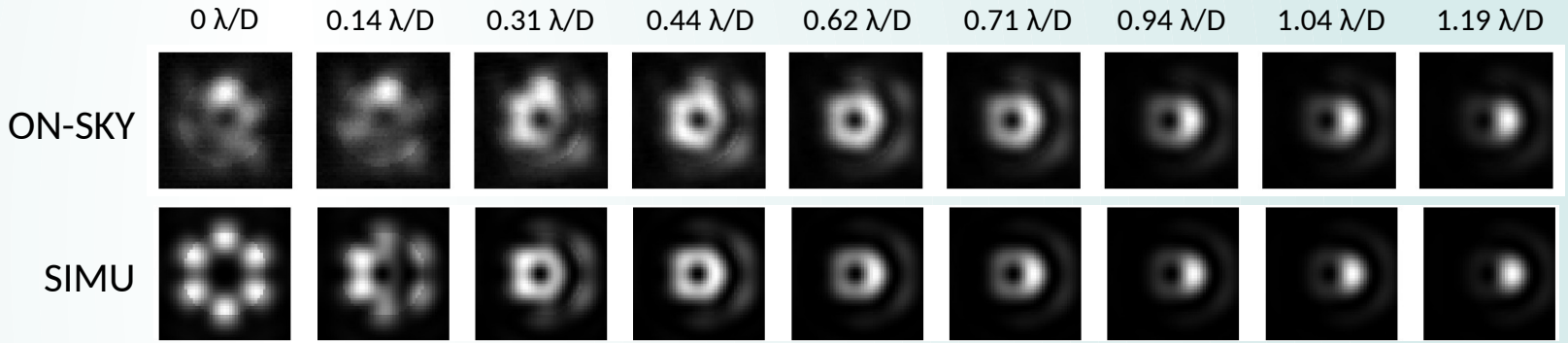


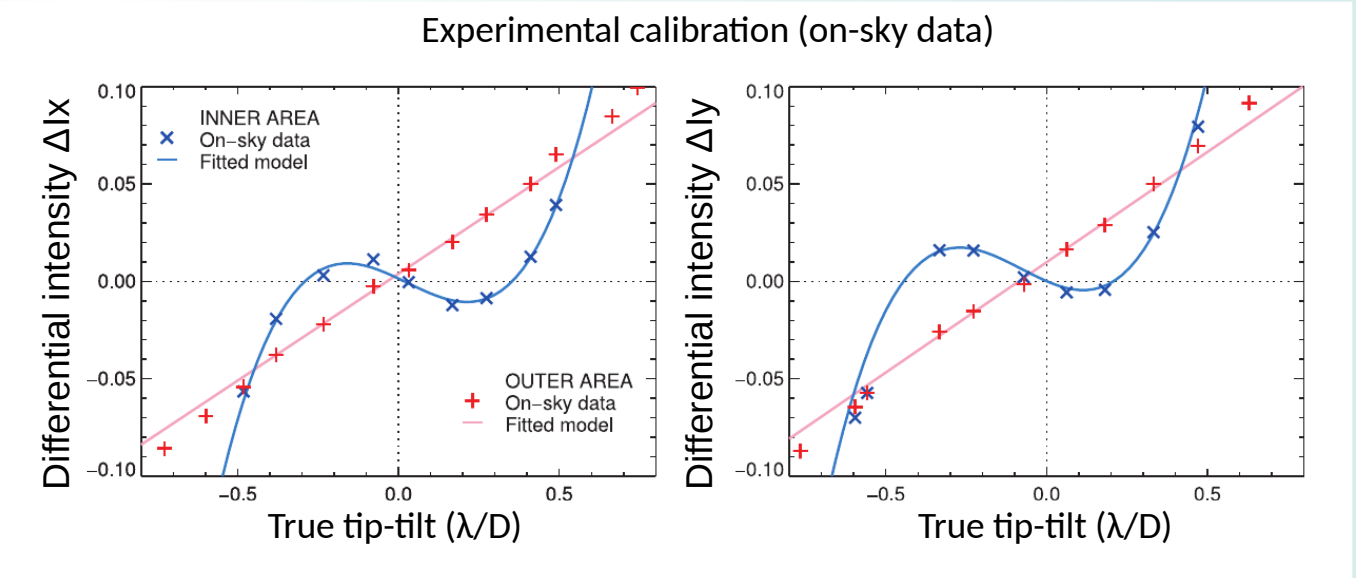
Implementation on Keck/NIRC2

On-sky model validation

- Calibration with observations of a binary system



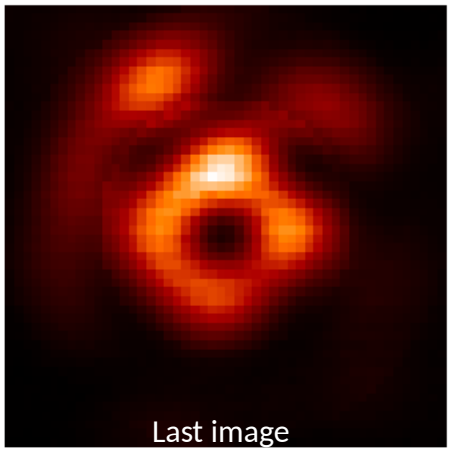


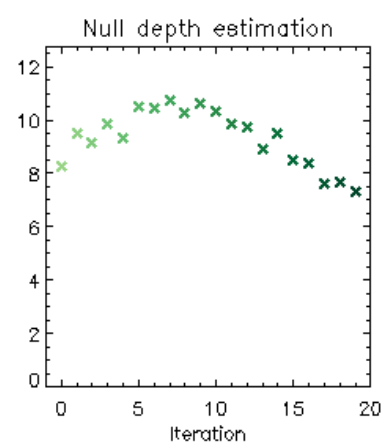


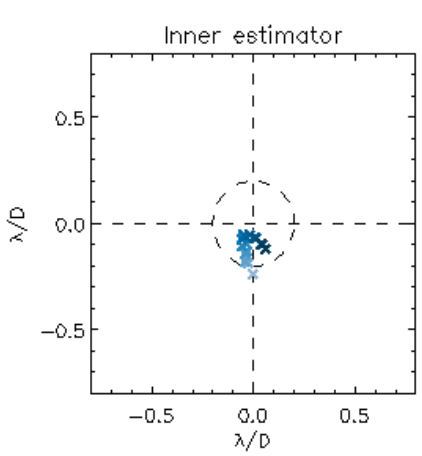
Implementation on Keck/NIRC2

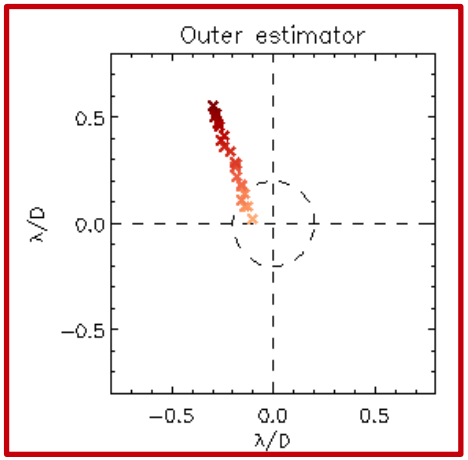
Without QACITS

Data sequence : **UT2015-06-09 HR 8799** (~20min)





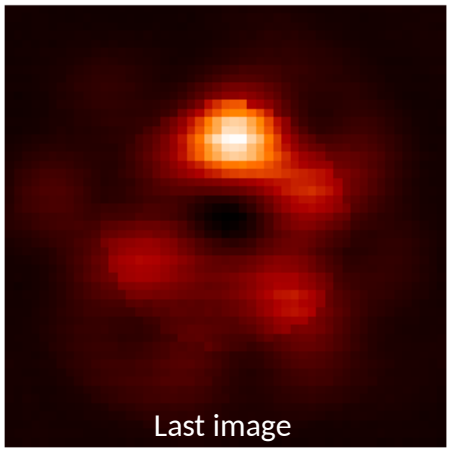


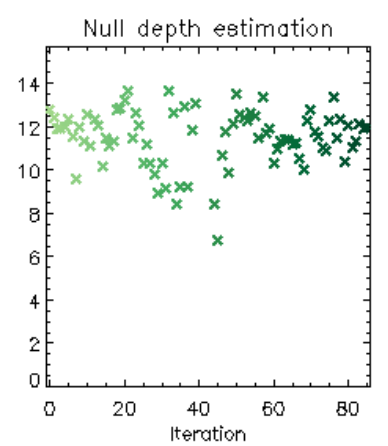


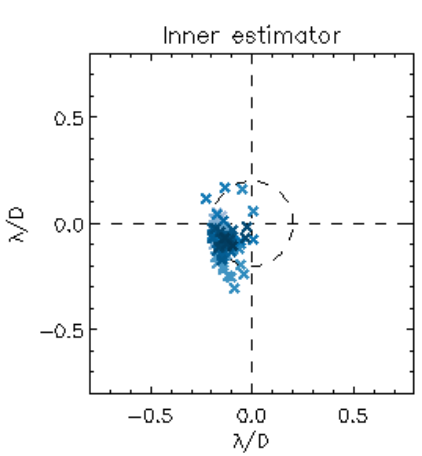
Drift rate:
~3 mas per minute

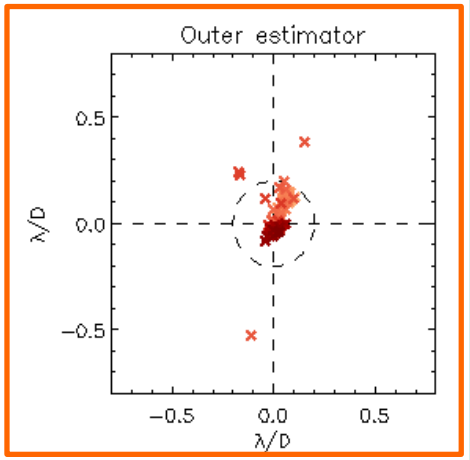
With QACITS

Data sequence example: **UT2015-10-24 HR 8799** (~90min)



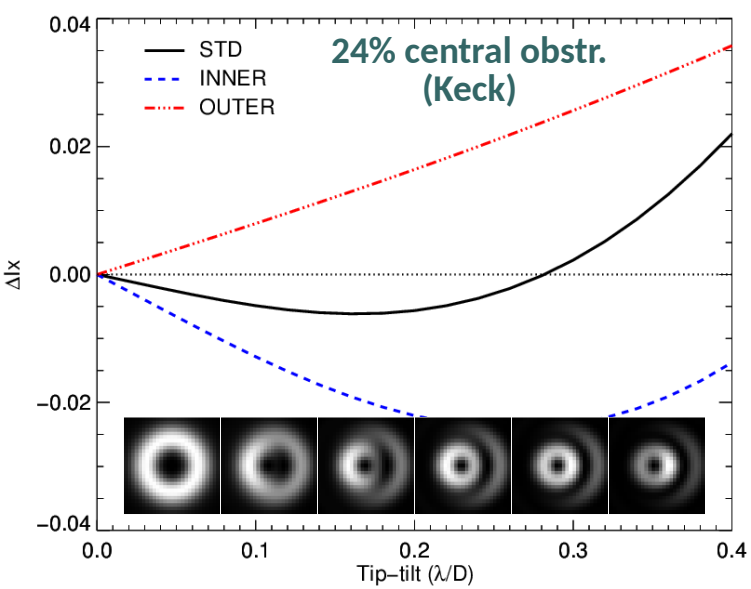


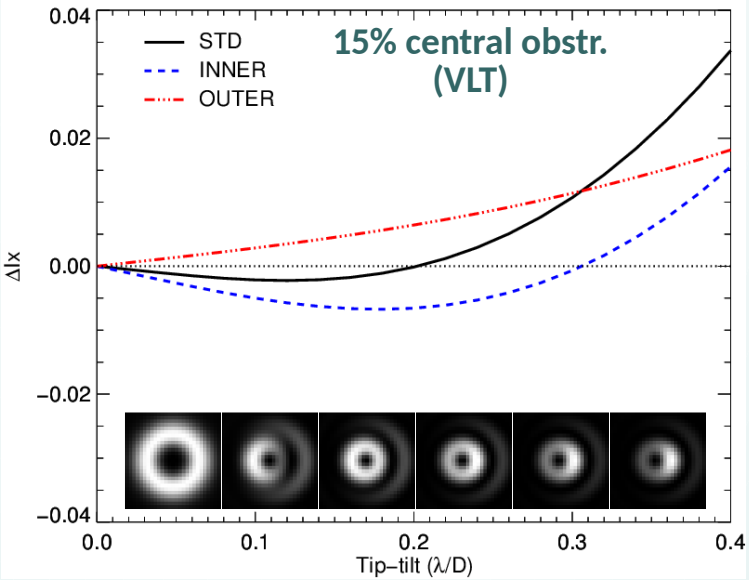




Current "*limitations*"

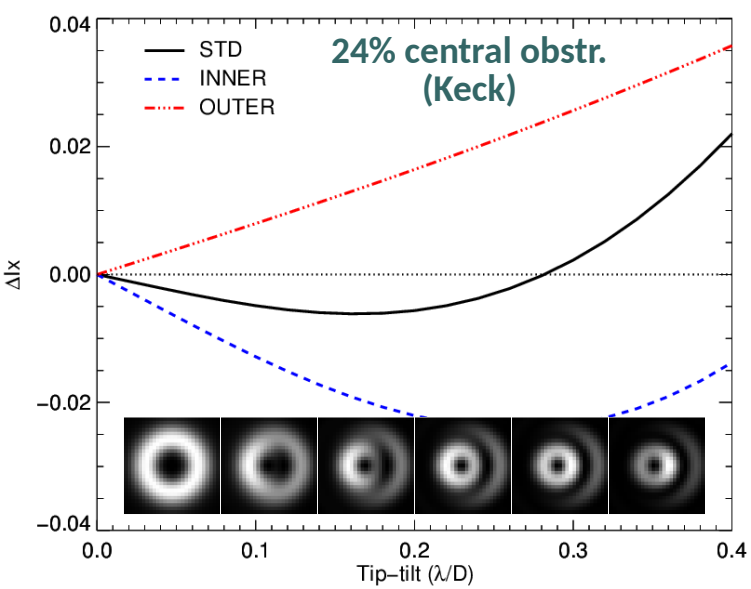
- Model dependency on central obstruction dimension

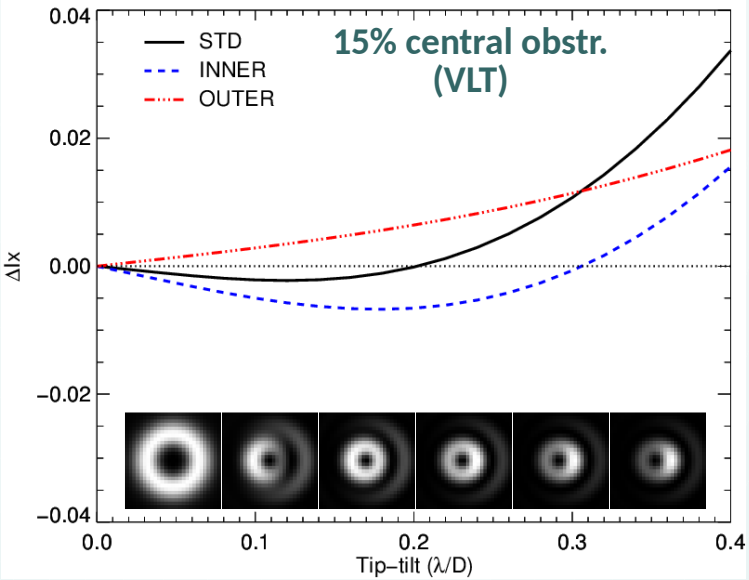




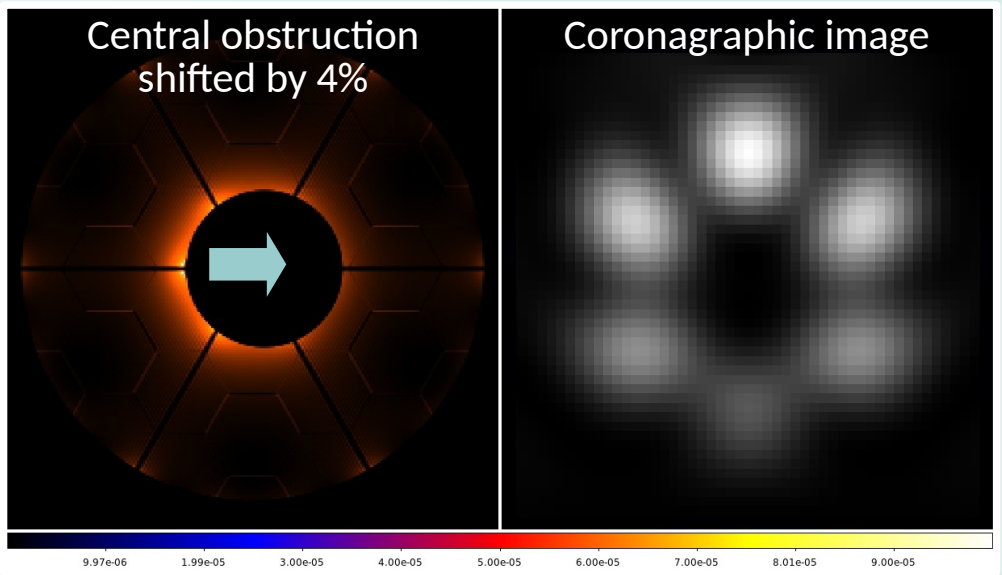
Current "*limitations*"

- Model dependency on central obstruction dimension

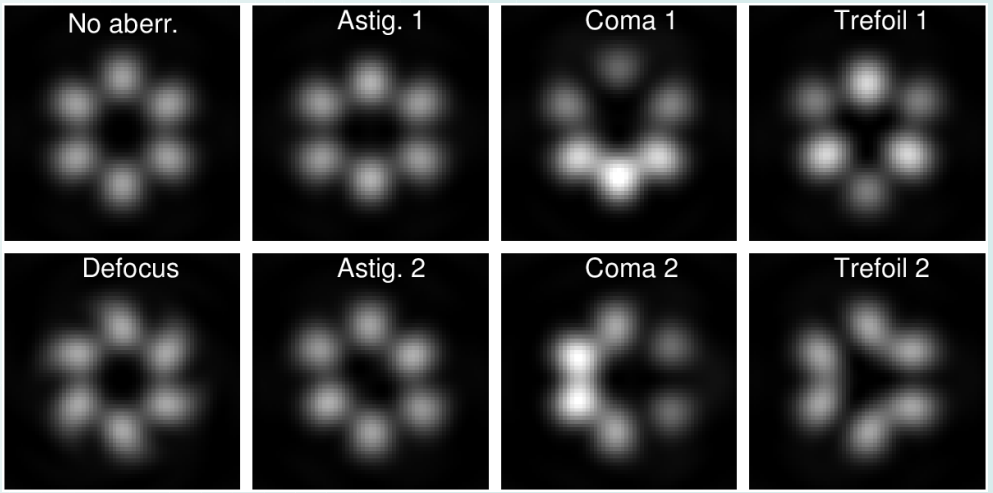




- Sensitivity to Lyot stop shift



- Sensitivity to other aberrations



Integration of QACITS in SPHERE?

- **Key features of QACITS:**
  - ✔ Based on science image: **fully common path**
  - ✔ **Non-invasive method:** no need for a modification of the setup
  - ✔ Only requirements: possibility to read science images and send feedback
  - ✔ On-line, **simultaneous** measurement
  - ✔ Complement to DTTS for faint targets
  - ✔ **Models** can be analytically derived for various coronagraphs

- **Possible upgrades of QACITS:**
  - ➢ **More modes**? (projection on a basis like in CLOWFS/LLOWFS)
  - ➢ **Smart reference** adjustment
  - ➢ Sensitive to **Lyot stop alignment**