

LAGRANGE

Robust high-contrast imaging with segmented telescopes in space: on-going R&D at Lagrange

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General [Lagrange] context

Instrumental R&D expertise at Lagrange

Interferometry - high-contrast imaging - adaptive optics - atmospheric optics

Strong historical expertise in coronagraphy

CIA - APLC & DZPM - PKC - Apodization - Starshades

Implication in former and current projects

VLT/SPHERE - coronagraph (APLC) - numerical simulator (CAOS) - Other science program

JAXA/SPICA - participation to the coronagraph instrument (testbed DIAMS)

Subaru/SCEXAO - participation to the instrument development (Project Scientist)

On-going R&D

SPEED - high-contrast imaging at small IWA w/ segmented telescope

ERC KERNEL - synergy between interferometry & high-contrast imaging at small IWA

HIPIC-CIAO - on-sky AO-based platform (1-m telescope at C2PU)

SIA - Stable Imaging in Astronomy (instrumental overall stability efforts, project unrelated)
& *related researches* (cophasing sensors - wavefront sensors - coronagraphs, etc.)

C4PO (Center for planetary origin)

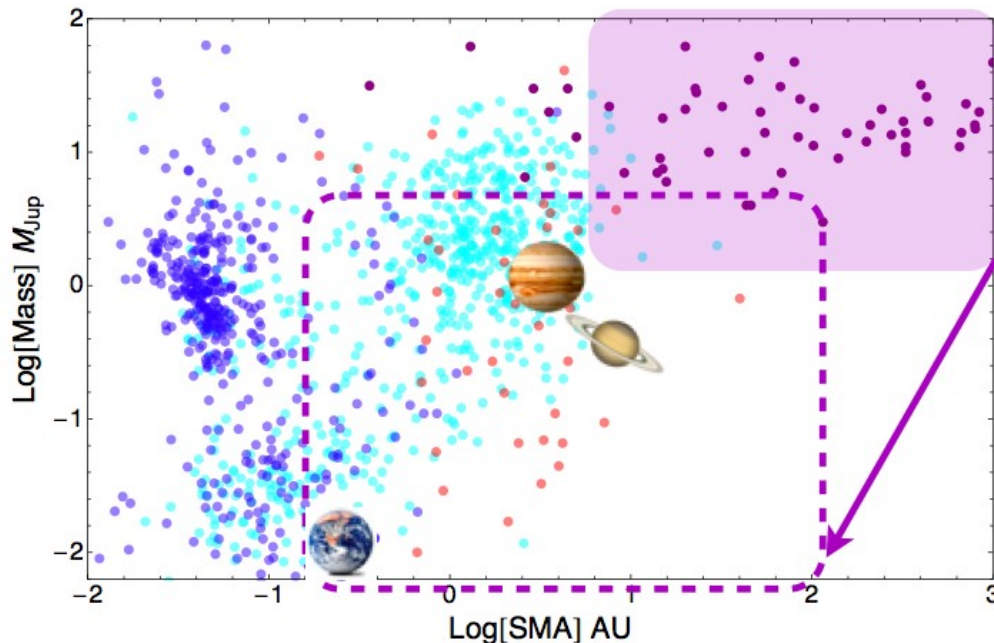
Structural project gathering people from instrumentation/planetology/fund. Physics

Exoplanets detection down to Earth-like planets

⇒ Understanding of formation and evolution of planetary systems

Ground-based observatories: VLT/SPHERE - Gemini/GPI - Subaru/SCEXAO, etc.
Space missions: HST - JWST - WFIRST/AFTA

LUVOIR: natural gain in sensitivity and angular resolution



Sensitivity and angular resolution are not good just for exoplanets... (see yesterday presentation)



On-going relevant projects at Lagrange



On-going R&D SPEED: the Segmented Pupil Experiment for Exoplanet Detection

SPEED (Martinez et al.)

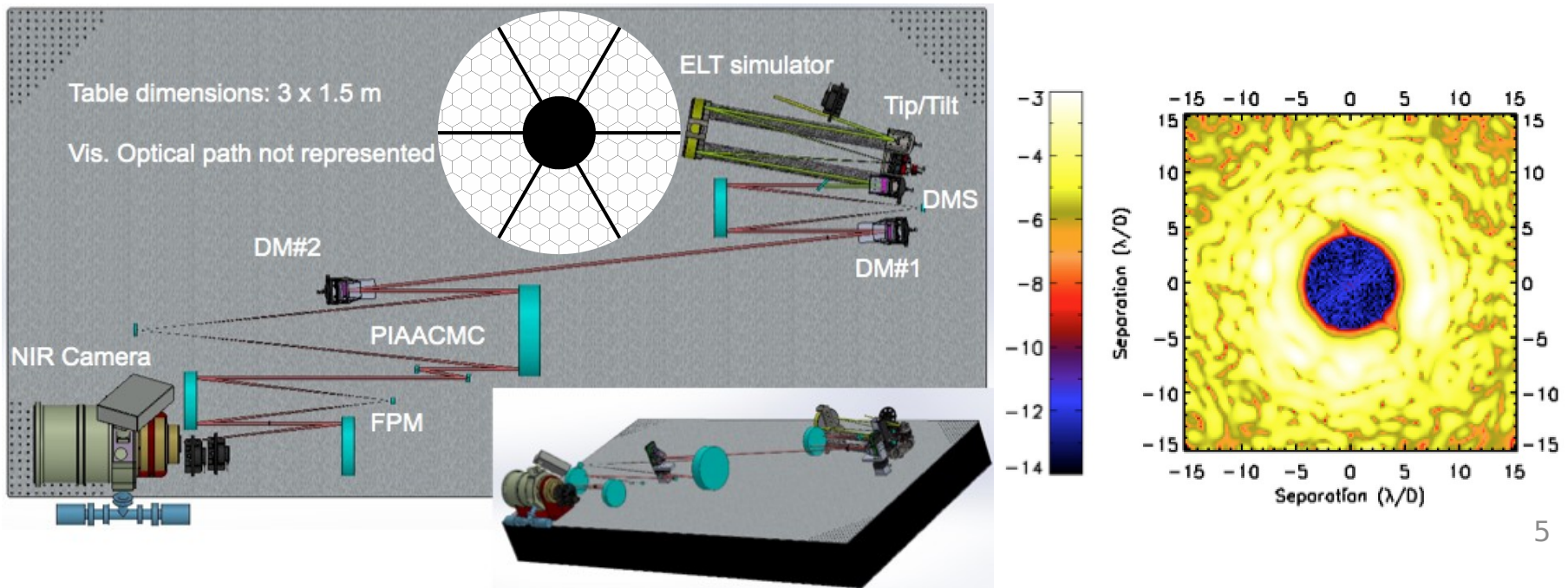
Project: 700 k€ (hardware wo/ manpower), 2 PhDs (2014-2017), 1 PhD (2017-2020)

High-contrast imaging @ $1 \lambda/D$ with up to 163 segments (modulable) in the telescope pupil
Vis. path (cophasing sensors) and NIR path (science)

Instrumental and contrast design (PIAACMC, multi-DMs, EFC, etc.)

Martinez et al. SPIE 2014-2016, Beaulieu et al. MNRAS submitted 2017

Collaborations: LESIA (SCC-PS - Fresnel/Talbot optical design) - O. Guyon (PIAACMC) - LAM (ZELDA)



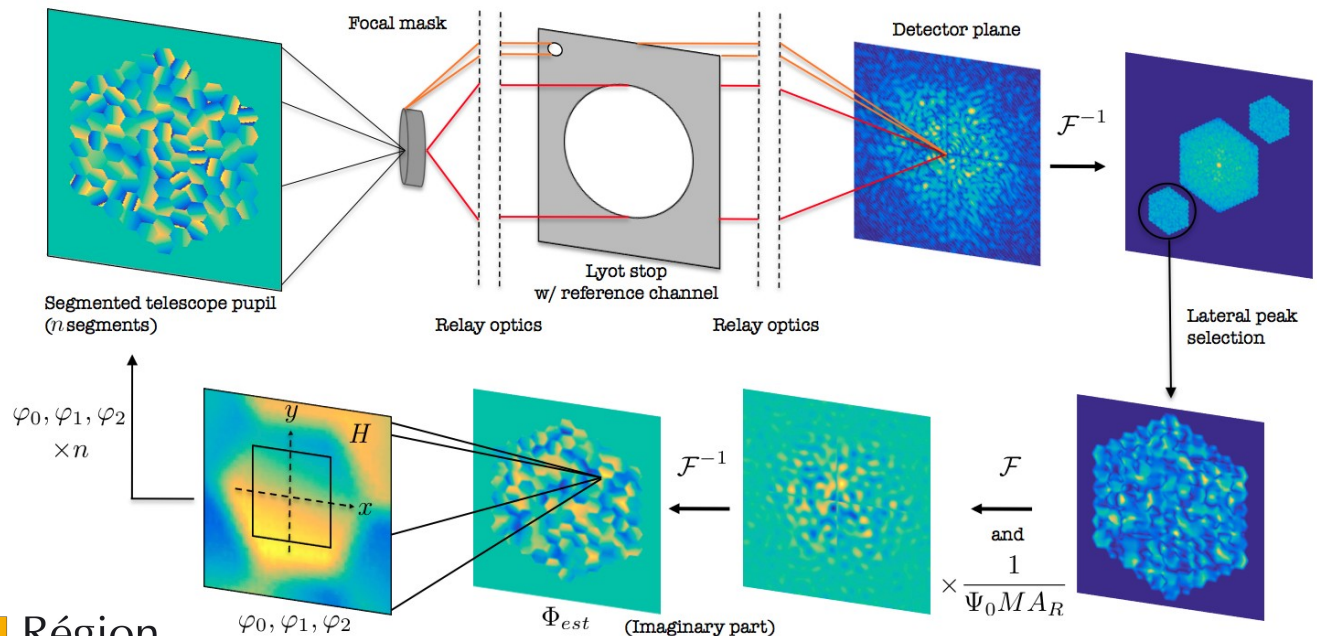
On-going R&D

Cophasing segmented apertures: SCC-PS “the LESIA connection”

SCC-PS: Self-Coherent Camera-Phasing Sensor - based on the **SCC** concept (LESIA)
 (SCC is a fine wavefront sensor: **Baudoz et al. 2006, Galicher et al. 2008, Mazoyer et al. 2013**)

Novel focal plane phasing sensor from coronagraphic image => monitoring during observations
Janin-Potiron et al. A&A 2016

Novel broad capture range cophasing solution (DWCT, Dual Wavelengths Coherence Technique)
Martinez & Janin-Potiron A&A L 2016



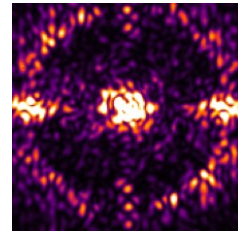
On-going R&D

Cophasing segmented apertures: ZELDA-PS “The LAM connection”

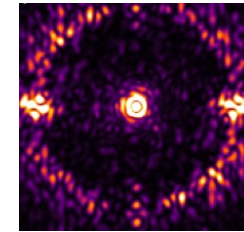
ZELDA: non-common path aberrations correction

Pupil plane fine wavefront sensor (nanometric measurements from intensity analysis in the pupil)...

N’Diaye et al. A&A 2013 - 2016



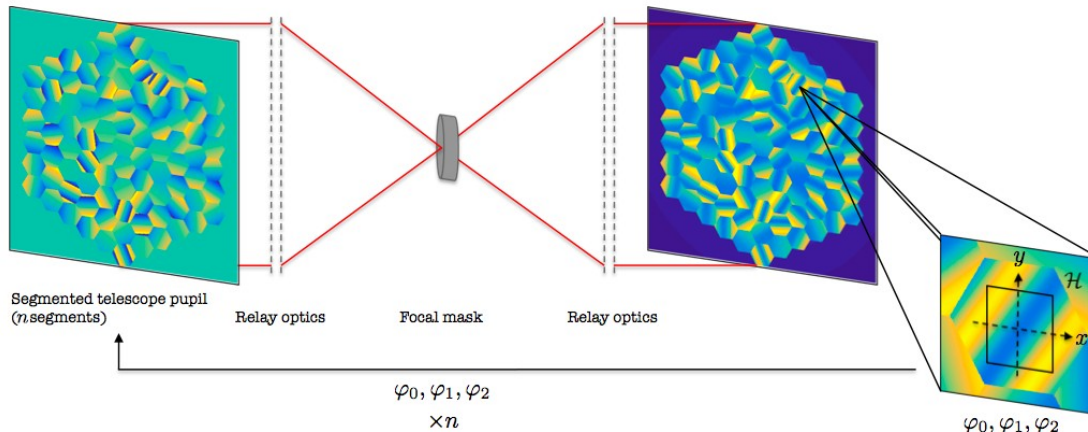
ZELDA

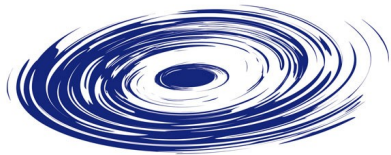


(SPHERE images)

...towards a fine pupil plane phasing sensor (**ZELDA-PS**: ZELDA-Phasing Sensor)

Janin-Potiron et al. A&A 2017 in prep.





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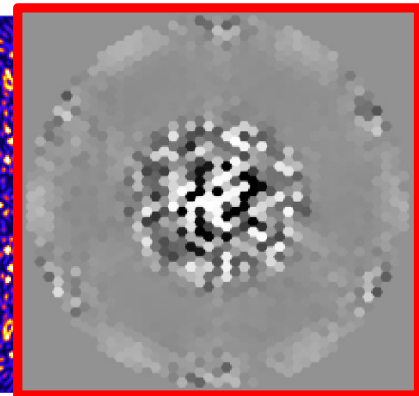
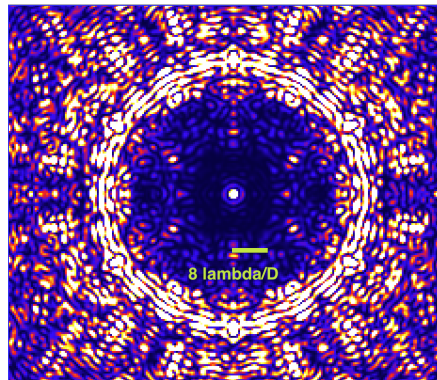
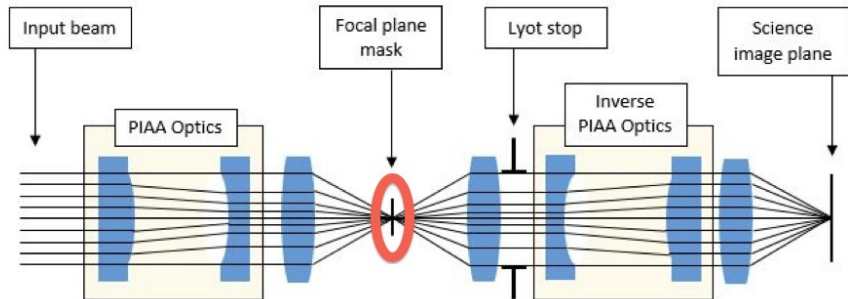
On-going R&D

Robust coronagraph concepts: “The STScI & Subaru connections”

PIAACMC development in collaboration w/ O. Guyon (Subaru)



- Optimized for the SPEED pupil (correction of pupil discontinuities) & stellar flux extinction
- Towards very small IWA ($1\lambda/D$ or sub- λ/D , w/ $C = 10^{-7}$ a IWA)



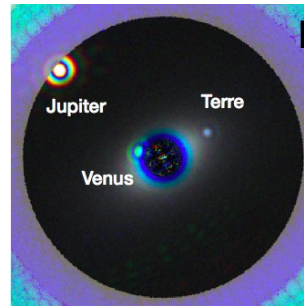
Merging APLC & Shaped Pupil in collaboration w/ STScI

- Post-JWST development (NASA Segmented Design Coronagraph & Analysis - SCDA)
- Achromaticity & stellar angular size robustness

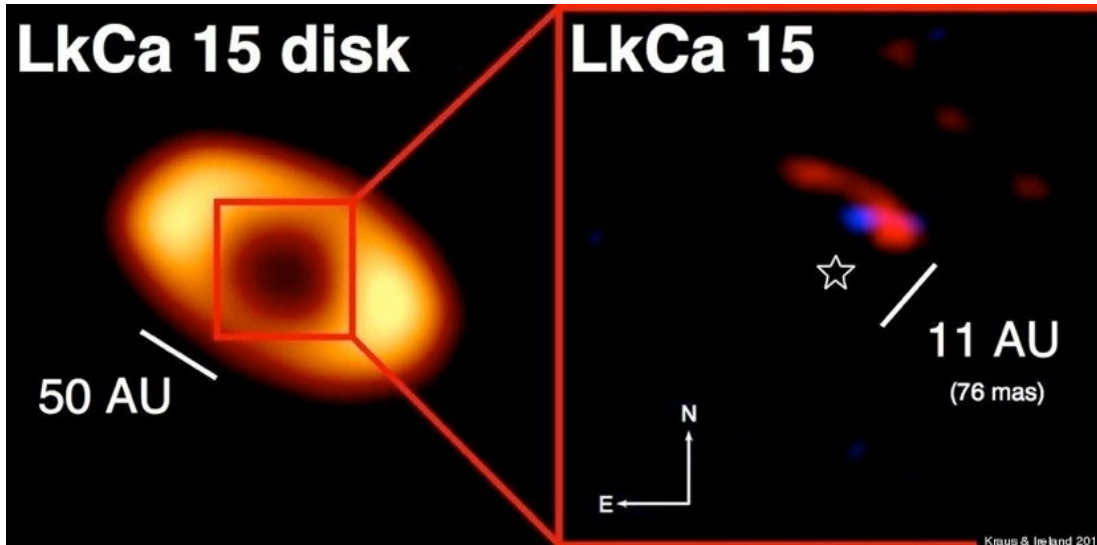
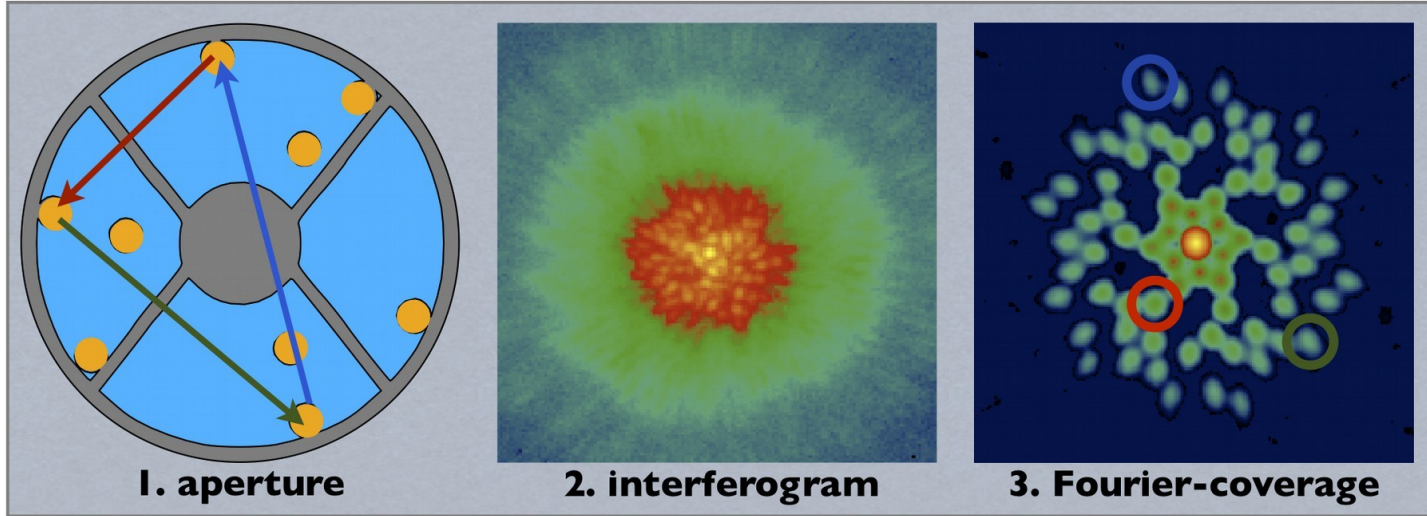


Binary shaped pupil for APLC

Solar System @ 13pc in 40h



N'Diaye et al. ApJ 2015 - 2016



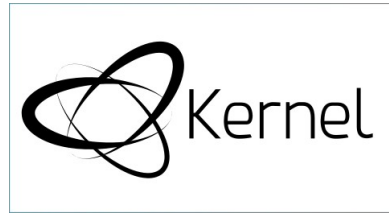
Super resolution !

Collaborations :
STScI, Usydney,
LESIA, Subaru Telescope



On-going R&D

KERNEL: merging inteferometry and high-contrast imaging



European Research Council

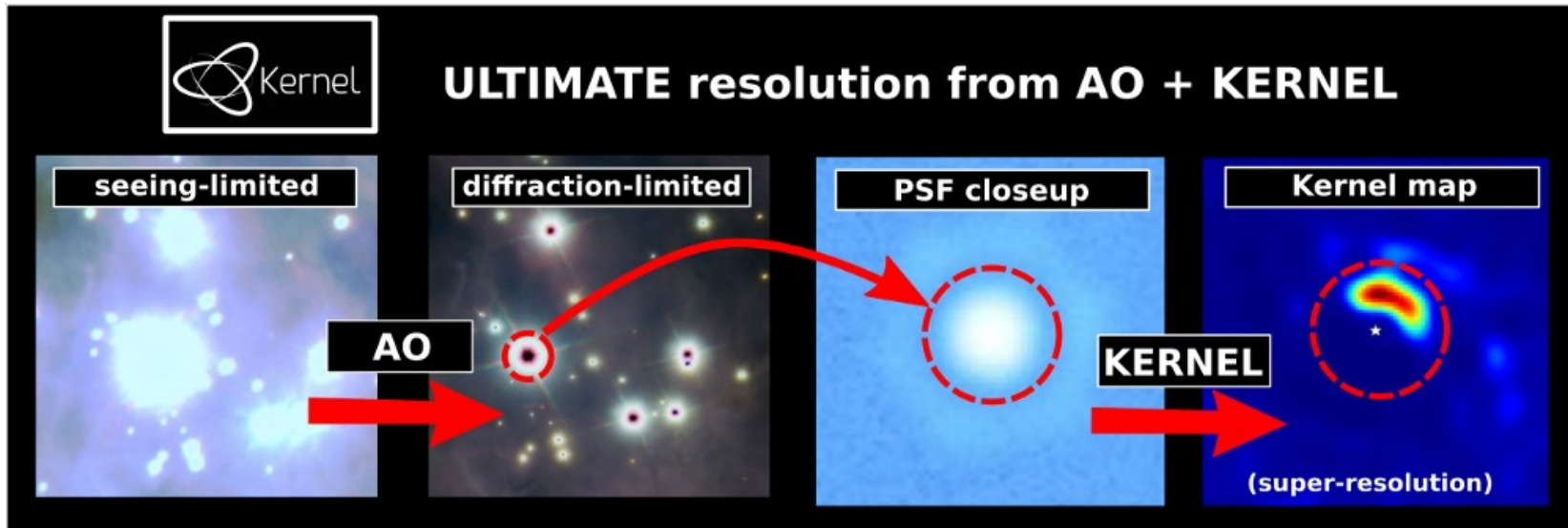
Established by the European Commission

Supporting top researchers
from anywhere in the world

KERNEL (Martinache et al.)

ERC #683029, 1.7 M€ Period 2016 - 2021 including 4 PhD + 5 years Postdoc
Interferometric methods adapted to classical apertures

- ✓ Focal plane wavefront sensor (EIGEN PHASES)
- ✓ Scientific exploitation (KERNEL-PHASES)





Lagrange Lab. propositions & collaborations for LUVOIR



Lagrange propositions & collaborations

LUVOIR telescope cophasing

Guaranty the telescope full optical capacity and performance
⇒ propose an integrated cophasing & fine wavefront sensor solution

Monitoring & stability

SCC-PS - APFWS

Fine phasing

SCC-PS - ZELDA-PS - APFWS

Coarse phasing

SCC-PS - ZELDA-PS
(coupled w/ multi- λ or coherence-based methods)

Broad phasing

DWCT (ground-based application so far...)

Non-common path errors

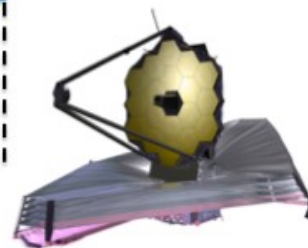
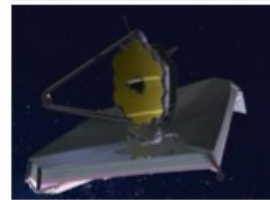
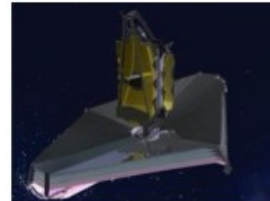
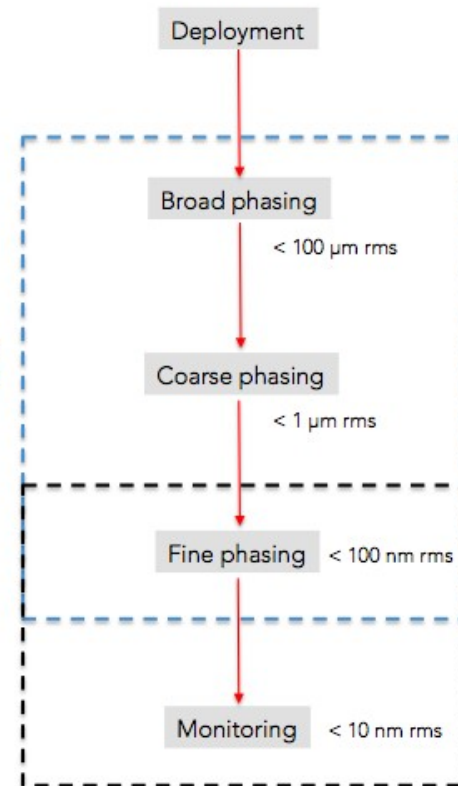
SCC / ZELDA

SPEED facility for devel., testing, & comparison

Collaborations: LESIA - LAM - STScI

Commissioning

Maintaining





Lagrange propositions & collaborations

LUVOIR high-contrast imaging

Guaranty the instrument high-contrast imaging capacity and stability
⇒ propose an integrated wavefront control/shaping and coronagraphic solution

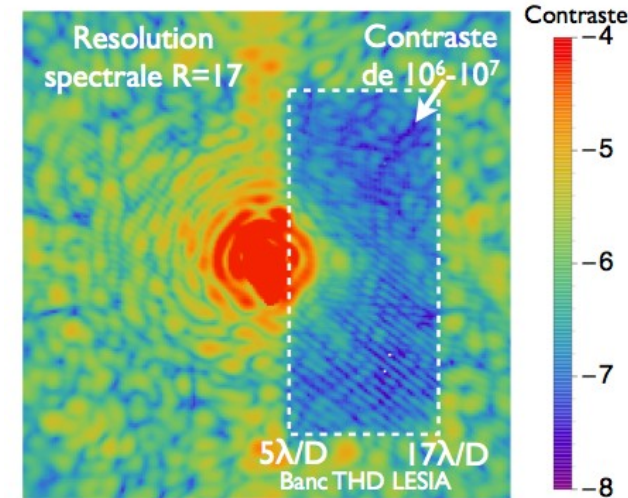
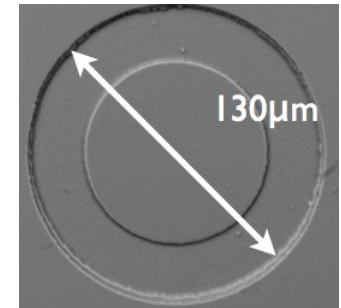
PIAACMC development for SPEED (Supported by the **CNES**)

Multi-DM wavefront shaping architecture dedicated to small IWA (SPEED)

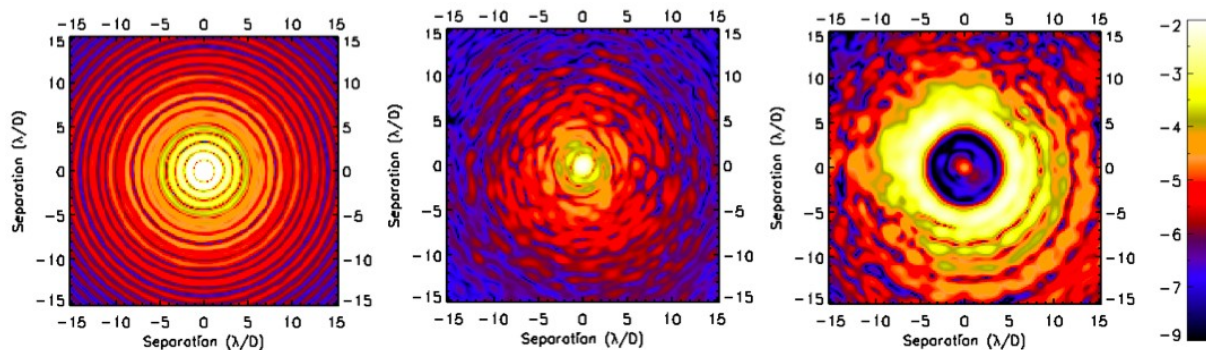
Fine wavefront sensor development (KERNEL, etc.)

Optical components: apodization, phase mask, etc.

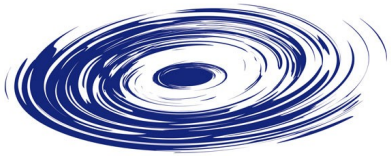
Collaborations: LESIA - LAM - IPAG - STScI



DZPM tests @ THD (LESIA)



Simulations of performance w/ SPEED

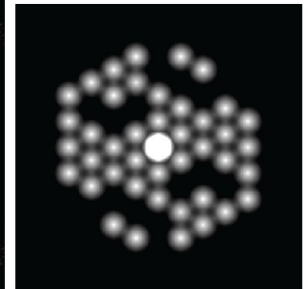
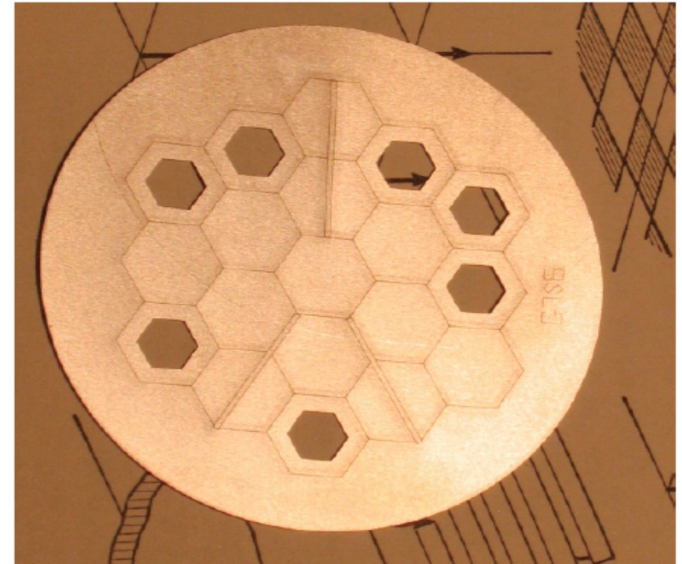
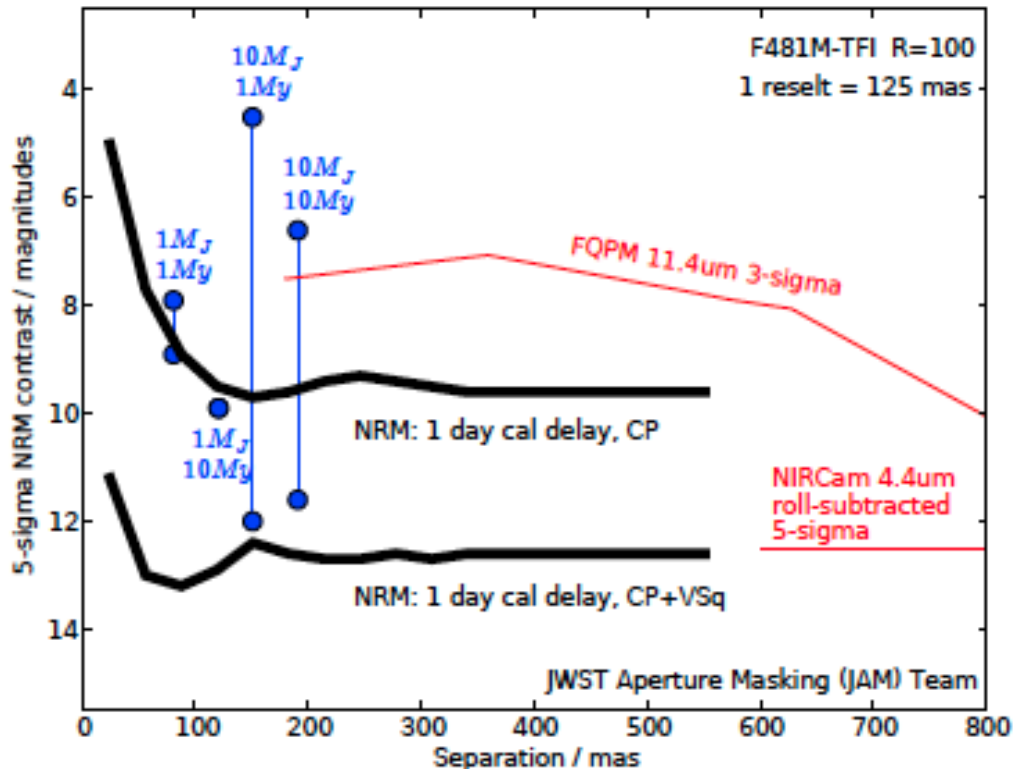


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Lagrange propositions & collaborations

LUVOIR performance evaluation

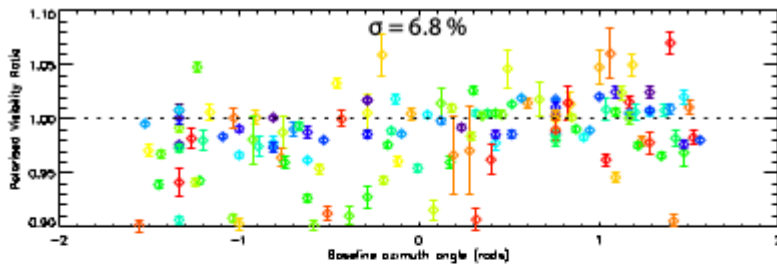
Performance prediction NRM & co. w/ KERNEL testbench?
(LESIA, STScI)



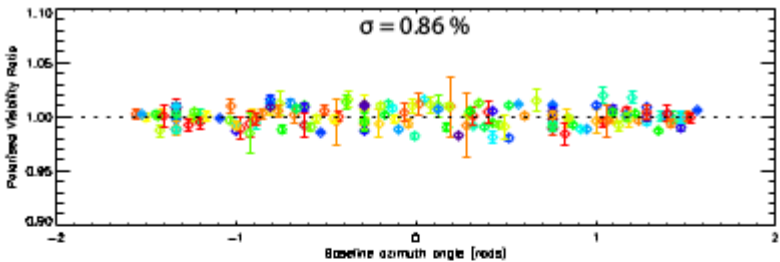
20"

NRM contrast detection limits (JWST NIRISS)

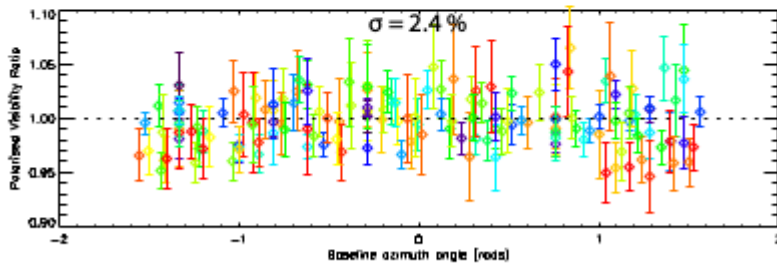
Polarimetric interferometry w/ LUVOIR (USydney, Subaru)



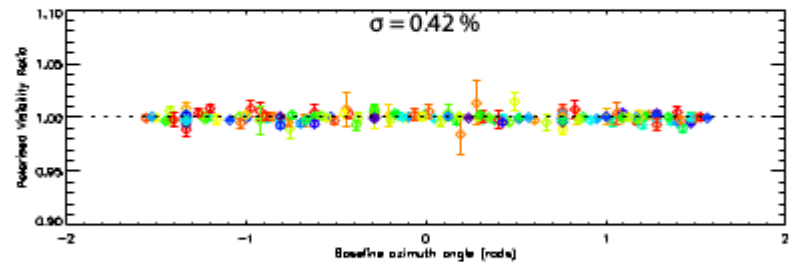
a) 1 tier - Wollaston prism only. No temporal variation leads to small error bars, but strong systematic errors (from non-common path) dominate.



c) 2 tiers - Wollaston + LCVR. The Wollaston and LCVR cancel each others errors. Systematic errors are still visible.



b) 1 tier - LCVR only. No non-common path error, and the mean is ~ 1.0 . However since switching is slower than seeing temporal errors lead to large error bars.



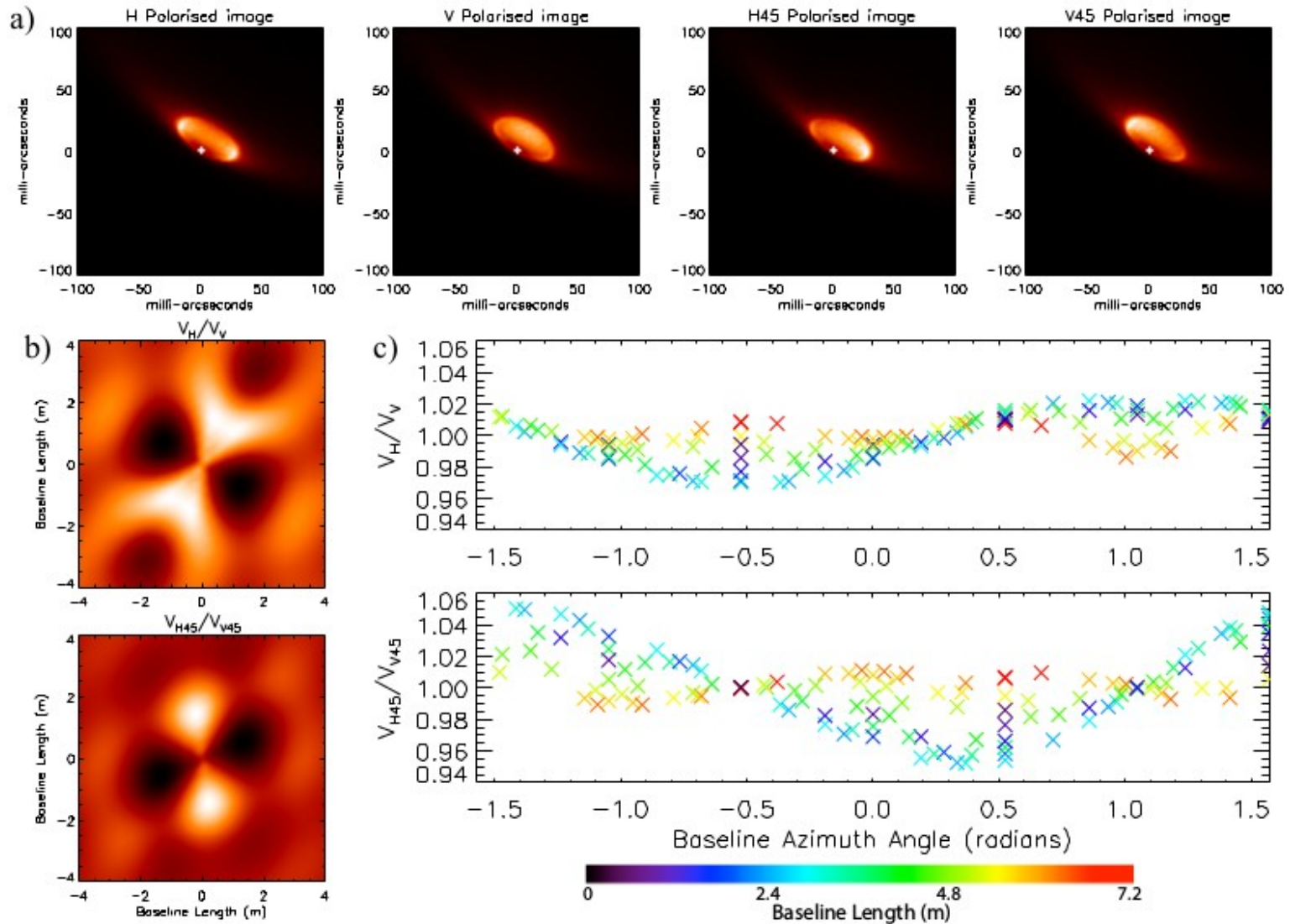
d) 3 tiers - Wollaston + LCVR + HWP. The HWP cancels out static systematic errors (such as those arising from instrumental effects). Here precision is limited by random error; additional integration time would improve precision further.

On-sky polarimetric visibilities (SCExAO / VAMPIRES)



Lagrange propositions & collaborations

Polarimetric interferometry with LUVOIR

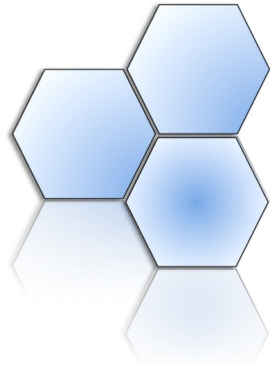




Lagrange propositions & collaborations

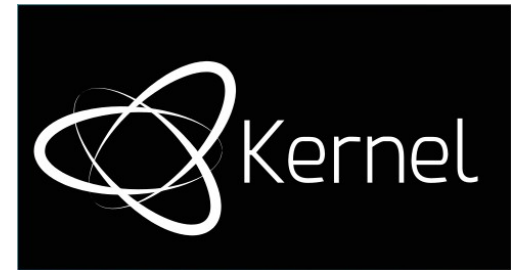
Resources and coordination

Projects at Lagrange in connection w/ LUVOIR



SPEED

Segmented-Pupil Experiment for Exoplanet Detection



SPEED & KERNEL can participate in fields identified as of critical importance in the NASA roadmap for LUVOIR through 2 major topics:

⇒ telescope full optical performance

⇒ instrument high-contrast imaging capabilities

Manpower (preliminary)

M. Beaulieu, F. Martinache, P. Martinez, M. N'Diaye, L. Abe

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