UNIVERSITÄT BERN

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
EU Framework Programmes

erc European Research Council Established by the European Commission

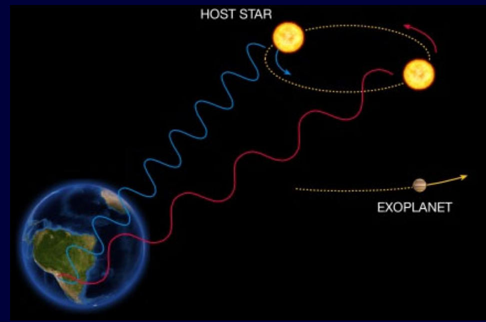
PI: **Jonas Kühn**

PlanetS **Project C.7**

PACE

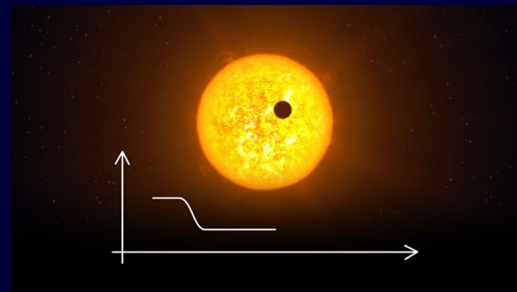
Rapid Active Coronagraphy Experiment from a Ground-based Observatory

Detecting exoplanets…
Why Direct Imaging?



> 1000 found !

- **Radial velocity (RV) → provide mass**

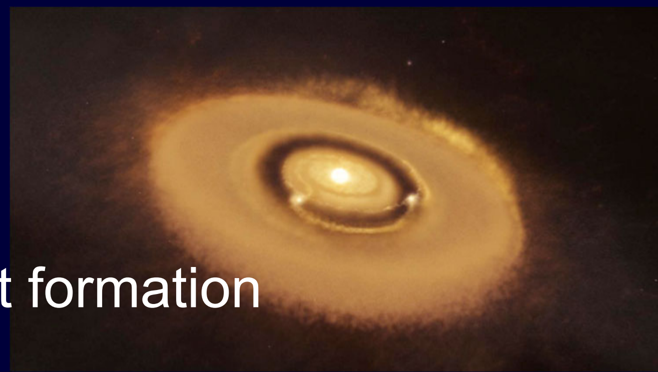


> 3,700 found !

- **Transit → provide size, possibly transmission atmospheric spectroscopy**

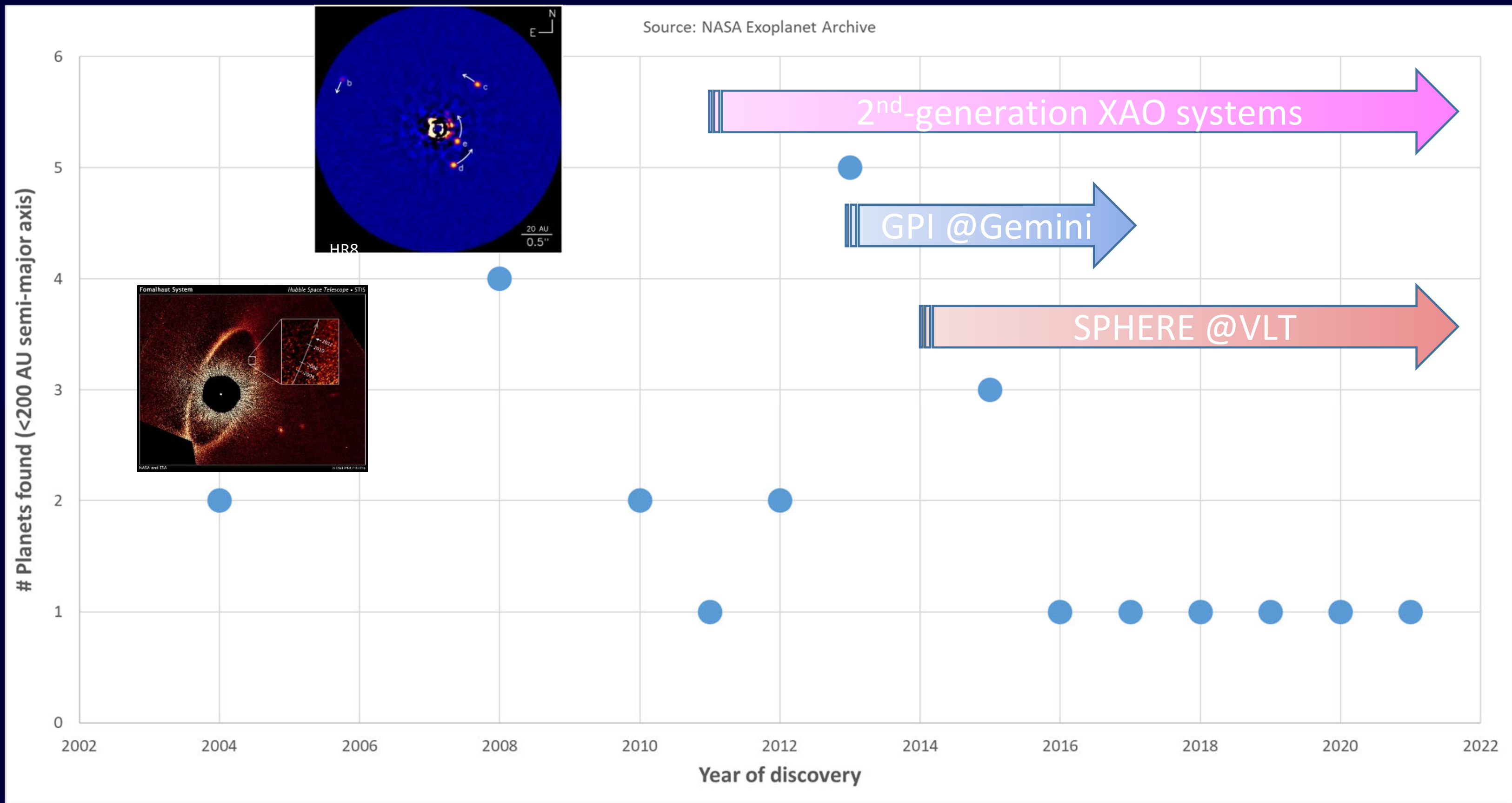
~ 30 found…

- **High-contrast Direct Imaging:**
  - Probe wider orbits
  - High-resolution spectroscopy of the atmosphere
  - Interaction between planets and disks, i.e. planet formation

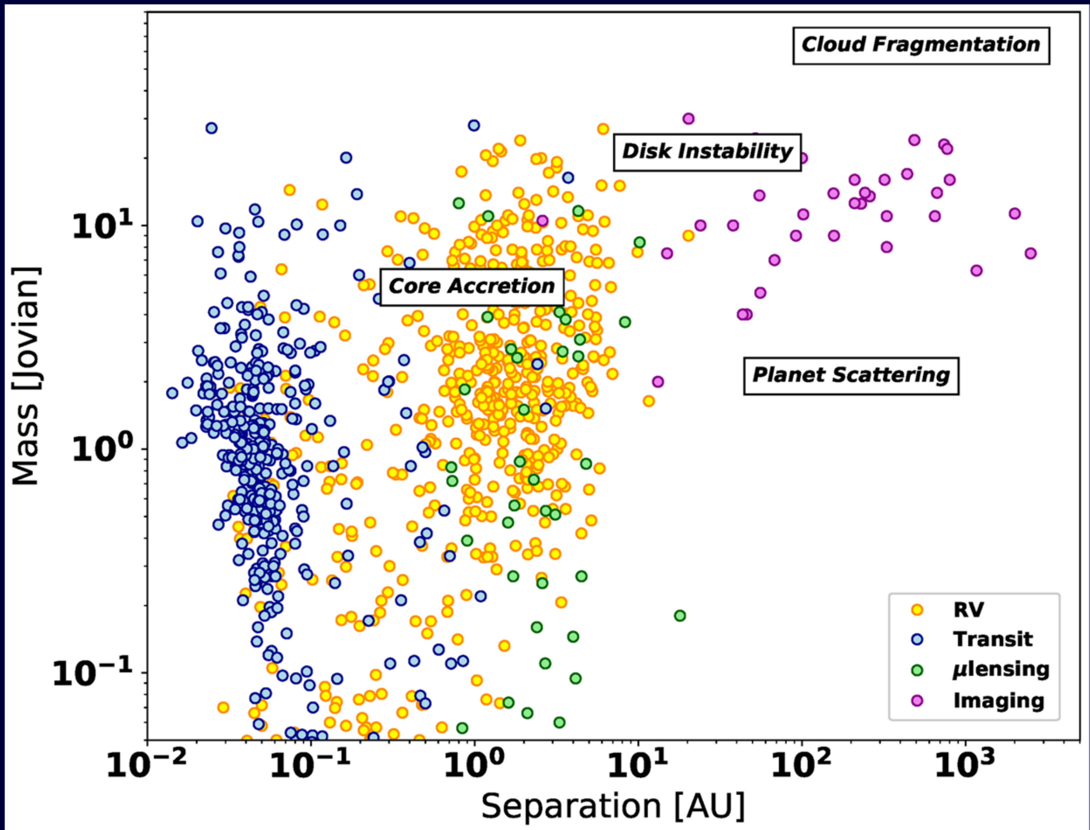


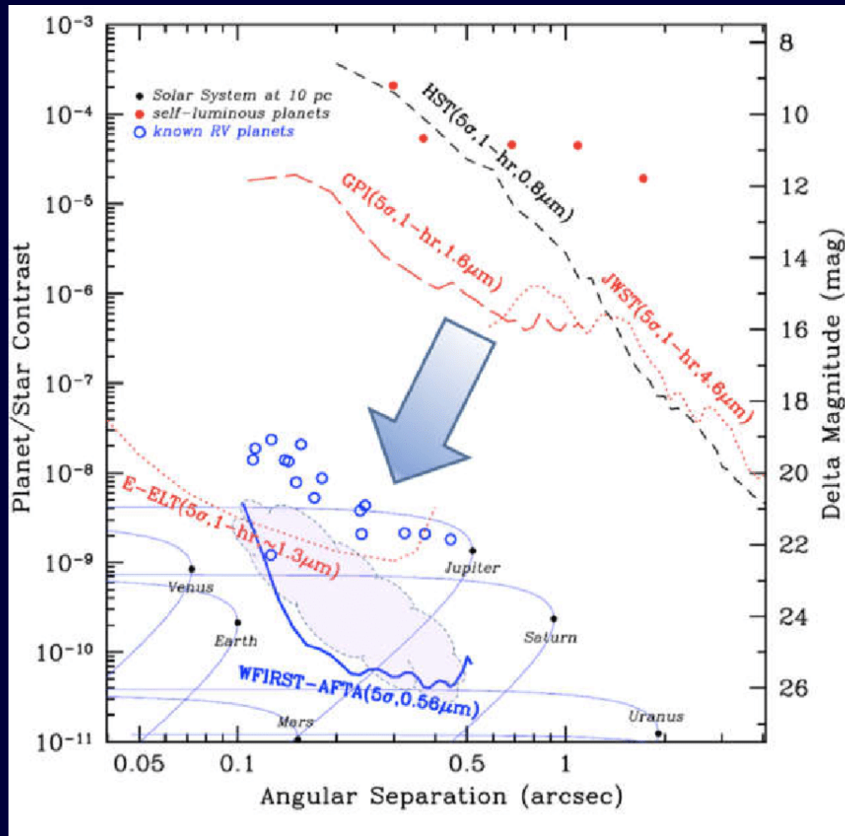
Source: exoplanets.eu (as of April'23)

High-contrast Imaging yield over time



The population bottleneck

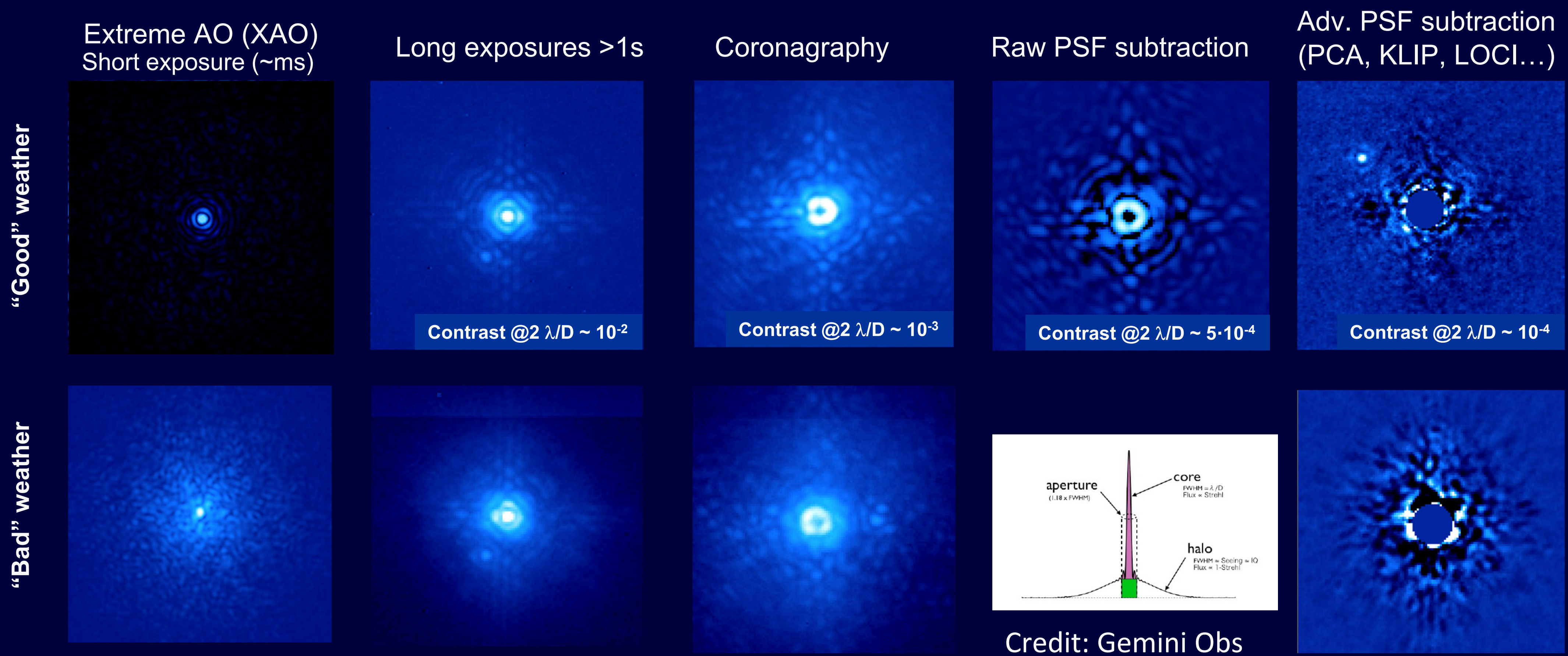




https://doi.org/10.3390/galaxies6020051

Gomez de Castro 2018

The technology bottleneck



Credit: Gemini Obs

Objectives of RACE – GO project

"Rapid Active Coronagraphy of Exoplanets from a Ground-based Observatory"

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erc
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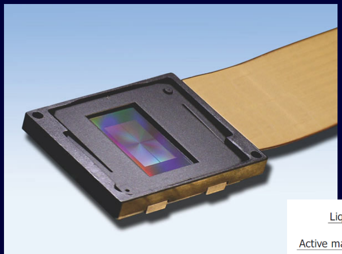
Established by the European Commission

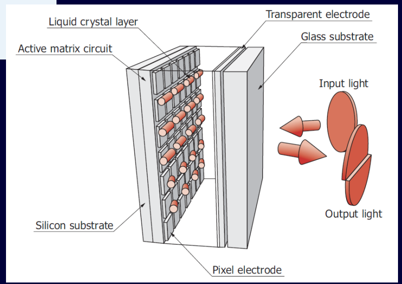
- **Breakthrough on direct imaging instrument capabilities** by
  - Developing a viable scheme for **Coherent Differential Imaging (CDI)**
  - **Use latest technology** to do it at speed relevant to the atmospheric coherence time (< 10 ms)

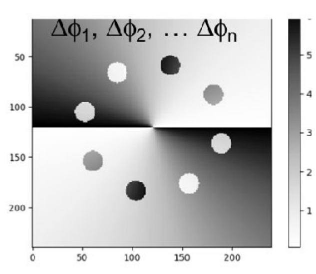
- **Validate and exploit the approach on-sky with 60 GTO nights** on a 4-m telescope equipped with a XAO system

Coherent Differential Imaging (CDI): How To



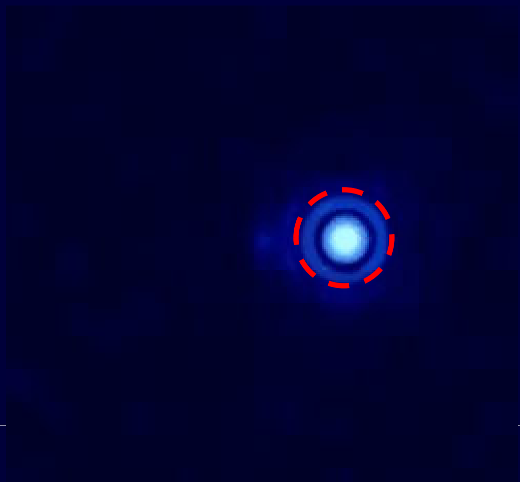
SLM = liquid crystal Spatial Light Modulator





SLM phase pattern at instant t

- **Each pixel of a SLM can locally delay the optical path** (phase) of incoming light
  - Dynamically adjustable **birefringence**
  - **Only works with polarized light**
- Any **phase pattern can be programmed**
  - µm-sized pixels provide excellent sampling, also in the focal-plane
  - Video-rate or beyond



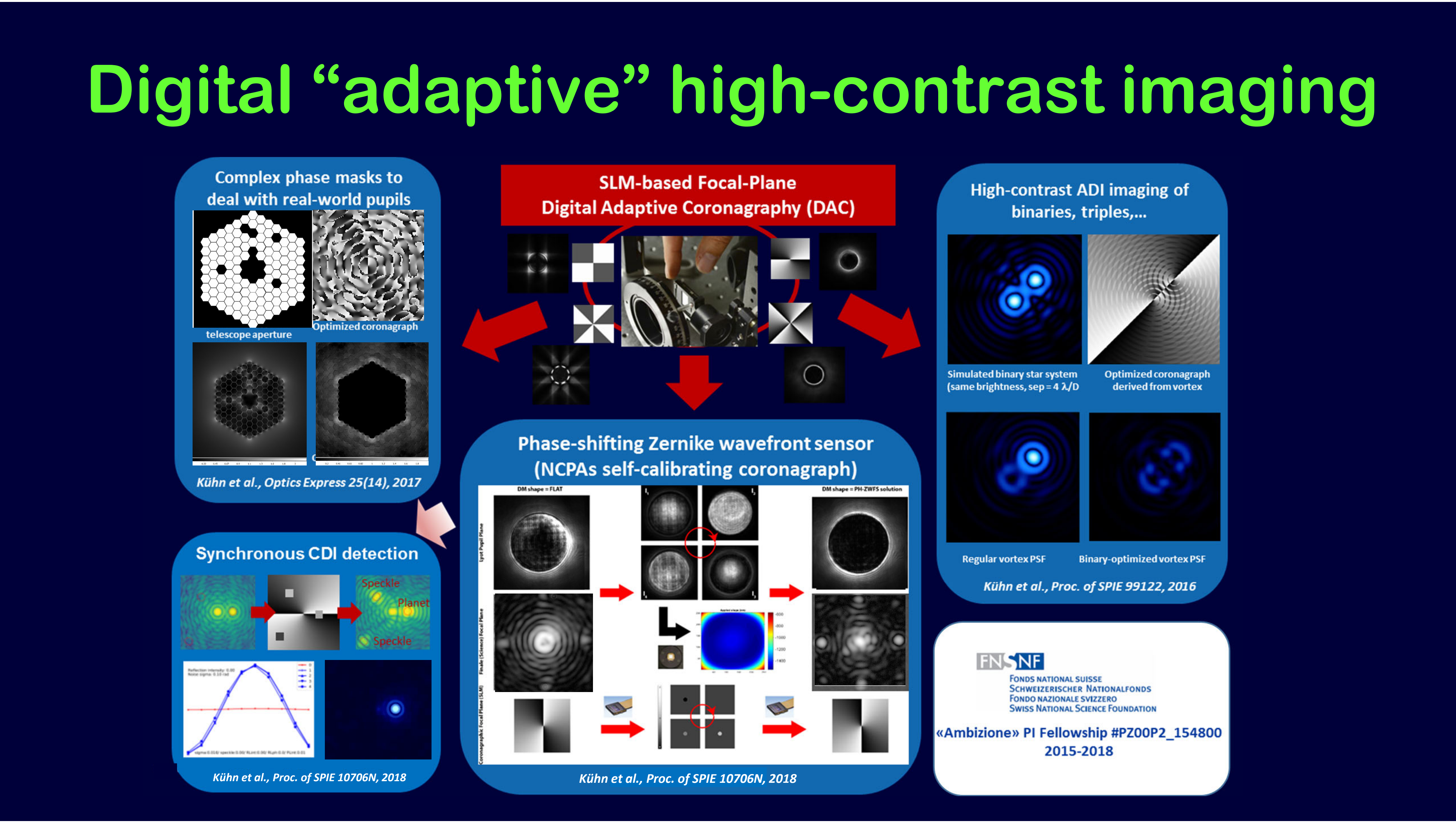
Latest technology for millisecond CDI

Speed

NEW SINCE 2021 !
High-speed > 200 Hz SLMs

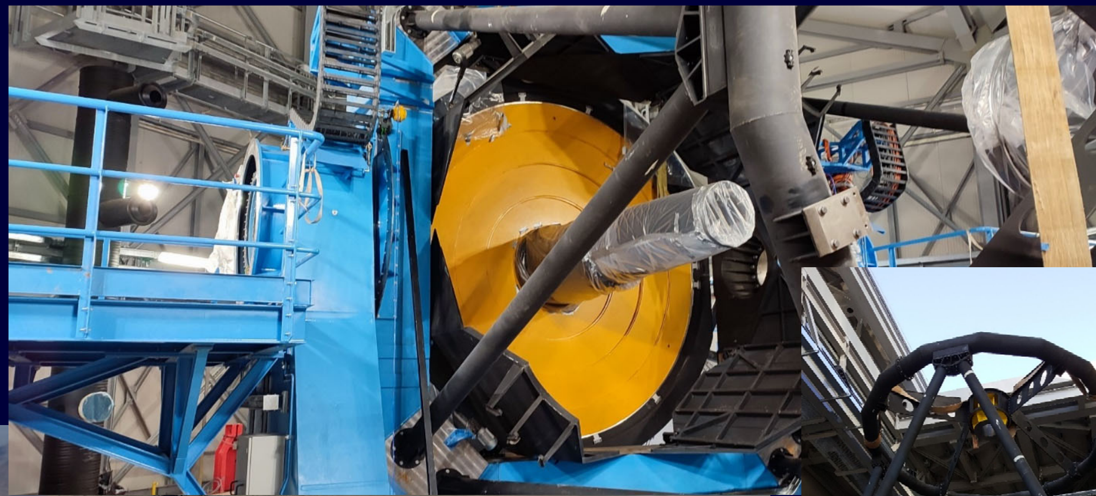
Speed, Sensitivity

SINCE 2019 !
Ultra low-noise SWIR camera w/ 3,500 FPS


Digital “adaptive” high-contrast imaging
Complex phase masks to deal with real-world pupils
telescope aperture
Optimized coronagraph
Kühn et al., Optics Express 25(14), 2017
SLM-based Focal-Plane Digital Adaptive Coronagraphy (DAC)
High-contrast ADI imaging of binaries, triples,...
Simulated binary star system (same brightness, sep = 4 λ/D
Optimized coronagraph derived from vortex
Regular vortex PSF
Binary-optimized vortex PSF
Kühn et al., Proc. of SPIE 99122, 2016
Phase-shifting Zernike wavefront sensor (NCPAs self-calibrating coronagraph)
DM shape = FLAT
DM shape = PH-ZWFS solution
Kühn et al., Proc. of SPIE 10706N, 2018
Synchronous CDI detection
Speckle
Planet
Speckle
Kühn et al., Proc. of SPIE 10706N, 2018
FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation
«Ambizione» PI Fellowship #PZ00P2_154800
2015-2018

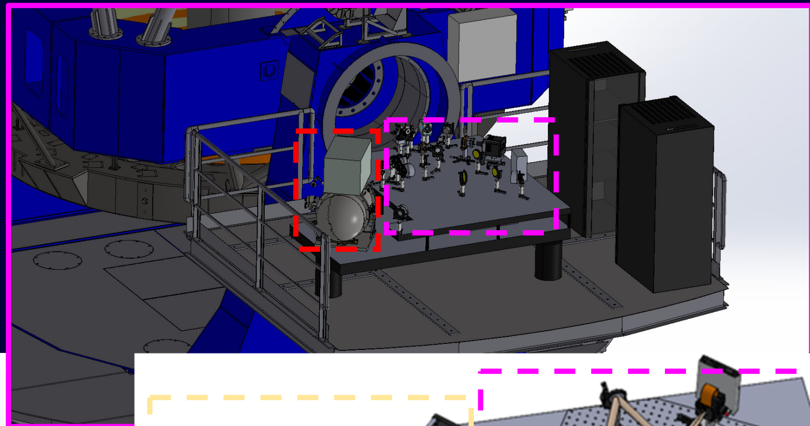
Getting on-sky: the 4-m DAG telescope

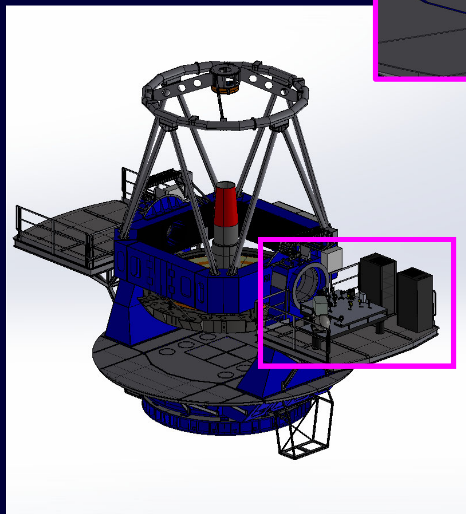
- **East Anatolia Observatory (DAG) is the new national observatory of Turkey**
  - Ritchey-Chrétien architecture
  - **4-m primary mirror** and two Nasmyth foci
  - Established near Erzurum (altitude: 3100m)
  - First light in fall 2023

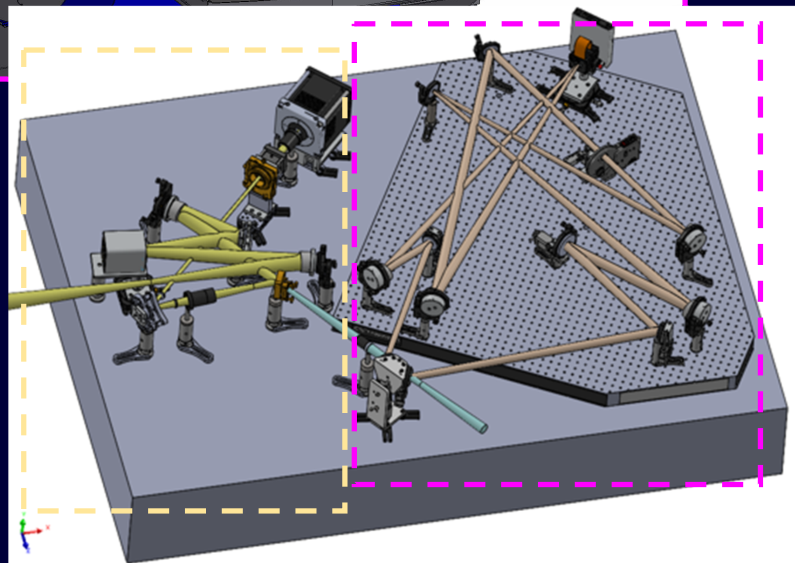


The PLACID instrument

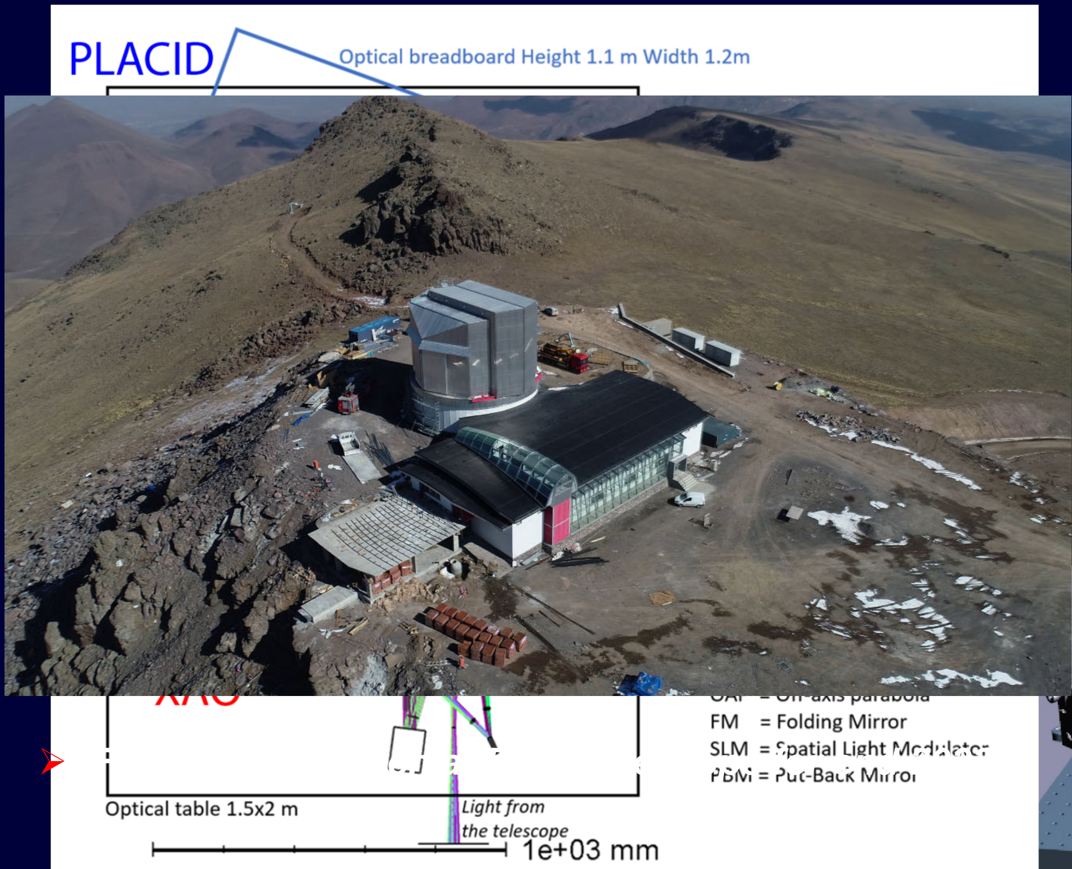
- PLACID stands for “Programmable Liquid-crystal Active Coronagraphic Imager for the DAG telescope”
  - **World’s first SLM-based active high-contrast instrument**
  - H-band (1.65 μm) and Ks-band (2.2 μm)
  - Versatile instrument ideal for prototyping and mentoring
  - Final Design Review (FDR) passed in Dec 2021
  - **First light by end of 2023**
- PLACID will operate downstream of TROIA
  - «TuRkish adaptive Optics system for Infrared Astronomy»
  - **Extreme AO with pyWSF and 468-DM from AlpAO**
- … and upstream of DIRAC
  - «DAG InfRAed Camera»
  - **HAWAII-2RG detector**



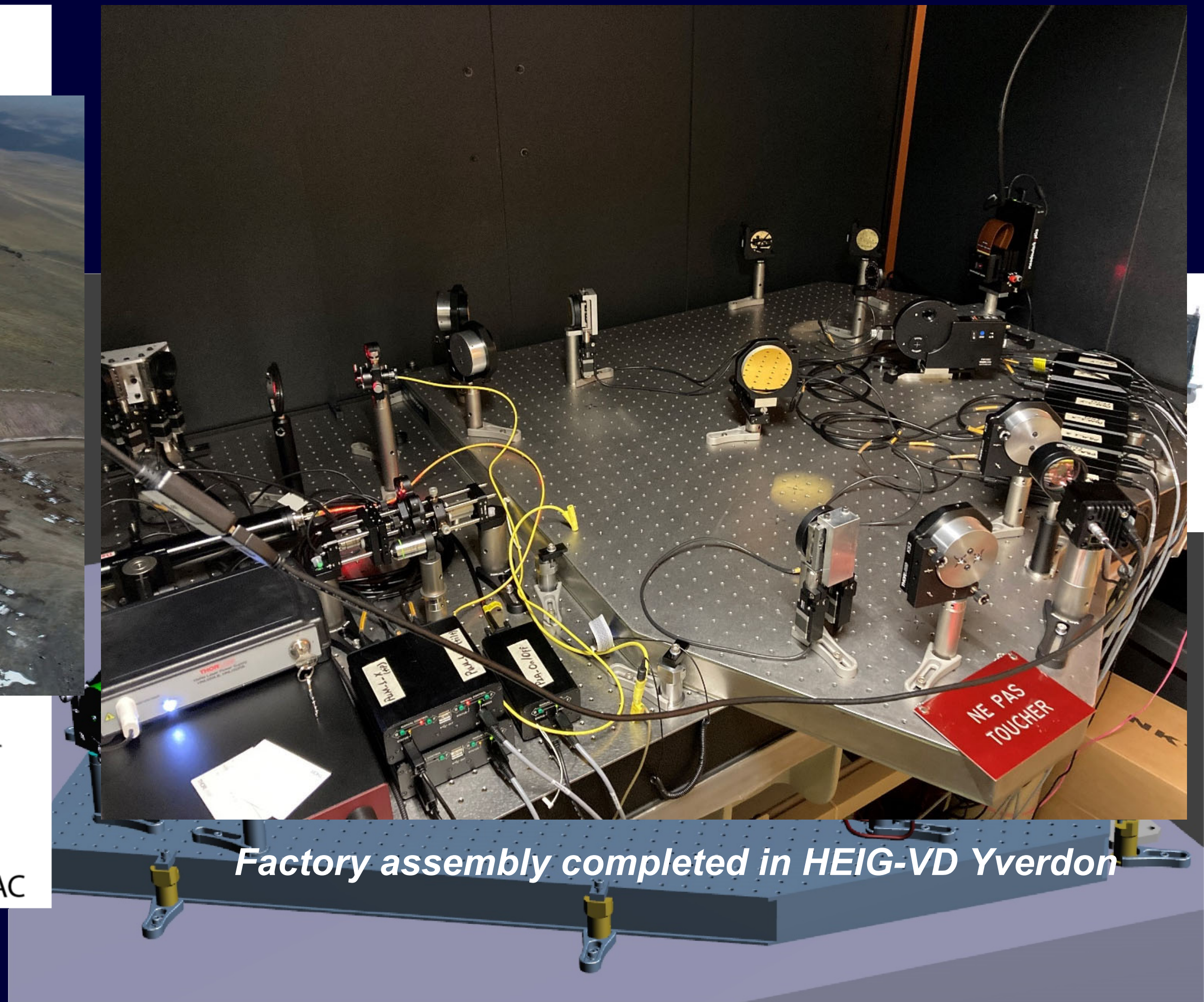




PLACID design & assembly



FDR optical design of PLACID, with its interfaces with TROIA and DIRAC



Factory assembly completed in HEIG-VD Yverdon

- ***Factory Acceptance Review on May 2-3, 2023 !***

60 GTO nights

- **RACE-GO shall be allocated 60 "Guaranteed Time Observing" (GTO) nights**
  - Letter of Intent signed by the DAG telescope managing organization (ATASAM)
  - **The 60 nights are spread over 2 years**

- In exchange the RACE-GO project would
  - Upgrade the PLACID instrument
  - Transfer ownership of the upgrade equipment
  - Provide staff training and technical support

Letter of Intent - Exchange of DAG observing nights for the full access to PLACID upgrades

ATASAM manages and operates the Eastern Anatolia Observatory (DAG), a 4-m class telescope on the Erzurum Plateau, which will equip the PLACID high-contrast exoplanets imager instrument by late 2022/early 2023.

Dr. Jonas Kühn is the lead proposer of an ERC (European Research Council) Consolidator grant application due April 20th, 2021, called RACE-GO ("Rapid Active Coronagraphy of Exoplanets from a Ground-based Observatory"), which is aimed at funding a major upgrade of the PLACID instrument, for an equipment value in excess of 570,000.00 Euros.

By the present, both undersigned parties proclaim their intention to negotiate an "Agreement" for the exchange of:

- (From the ATASAM side) 60 guaranteed time observing (GTO) nights spread over a period of 2 years, with staff support for operations and access to facilities
- (From Dr. Kühn's side) Transfer of ownership of the PLACID upgrade equipment funded by the ERC RACE-GO grant, and staff training and support for the corresponding 2-years period

It is understood that negotiation and signature of said "Agreement" is entirely conditional and subject to the successful funding of the RACE-GO project proposal by the ERC.

In such an outcome, the negotiation on said "Agreement" will start immediately after acceptance notification from the ERC panel (foreseen around May 2022), and will take place between ATASAM and Dr. Kühn's host academic institution at the time.

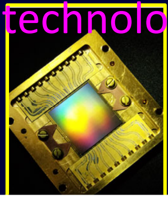
Agreed upon,

Timeliness

- ➢ **Most of the technology is just in !**
- ➢ **Collaboration to bring the technology to the Subaru 8-m Telescope SCExAO instrument (PI: O. Guyon)**
- ➢ **E-ELT Planetary Camera and Spectrograph (PCS)**
  - ❖ Originally planned as EELT 2nd-gen. instrument
  - ❖ Phase-A not started yet due to several technological milestones still to be cleared…

C-RED One available

MKIDS available



PCS concept and challenges

To achieve its scientific goals, PCS must provide an imaging contrast of ~ 10^{-8} at 15 milliarcseconds angular separation from the star and 10^{-9} at 100 milliarcsec-onds and beyond. In addition, it must

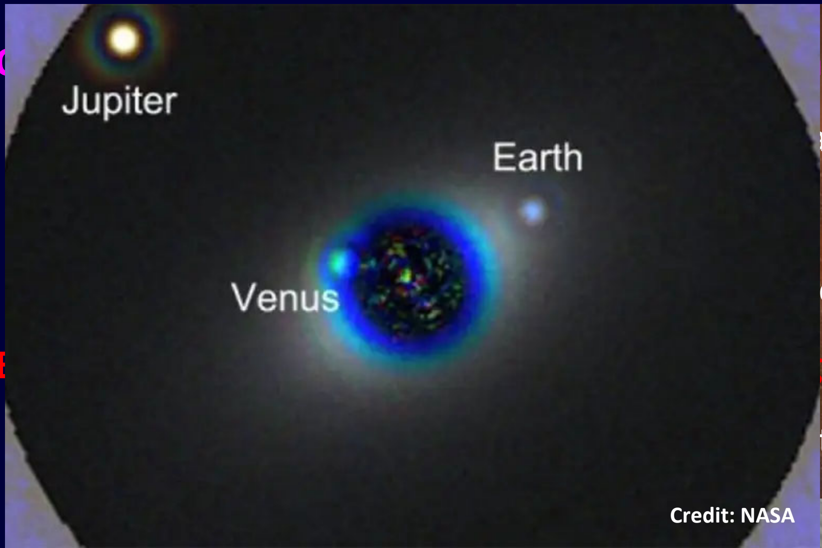
https://elt.eso.org/instrument/

Instrument	Main specifications			Schedule				
	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (μm)	Phase A	Project start	PDR	FDR	First light
MICADO	Imager (with coronagraph) 50.5″ × 50.5″ at 4 mas/pix 19″ × 19″ at 1.5 mas/pix	*I, Z, Y, J, H, K* + narrowbands	0.8–2.45	2010	2015	2019		
	Single slit	*R* ~ 20 000						
MAORY	AO Module SCAO – MCAO		0.8–2.45	2010	2015			
HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L, M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L, M, N* + narrowbands	3–13	2010	2015	2019		
	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
	IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L, M* bands *R* ~ 100 000						
HIRES	Single object	*R* ~ 100 000	0.4–1.8 simultaneously	2018				
	IFU (SCAO)							
	Multi object (TBC)	*R* ~ 10 000						
MOSAIC	~ 7-arcminute FoV ~ 200 objects (TBC)	*R* ~ 5 000–20 000	0.45–1.8 (TBC)	2018				
	~ 8 IFUs (TBC)	*R* ~ 5 000–20 000	0.8–1.8 (TBC)					
PCS	Extreme AO camera and spectrograph	TBC	TBC					

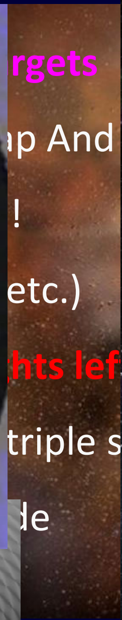
1 milliarcsecond (mas) = 0.001″

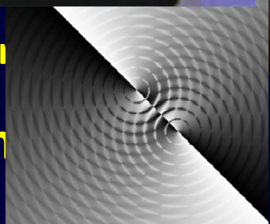
Kasper et al. 2021

Expected results / New Science

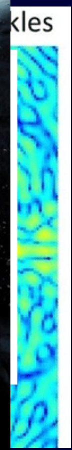


Credit: NASA





Kühn et a

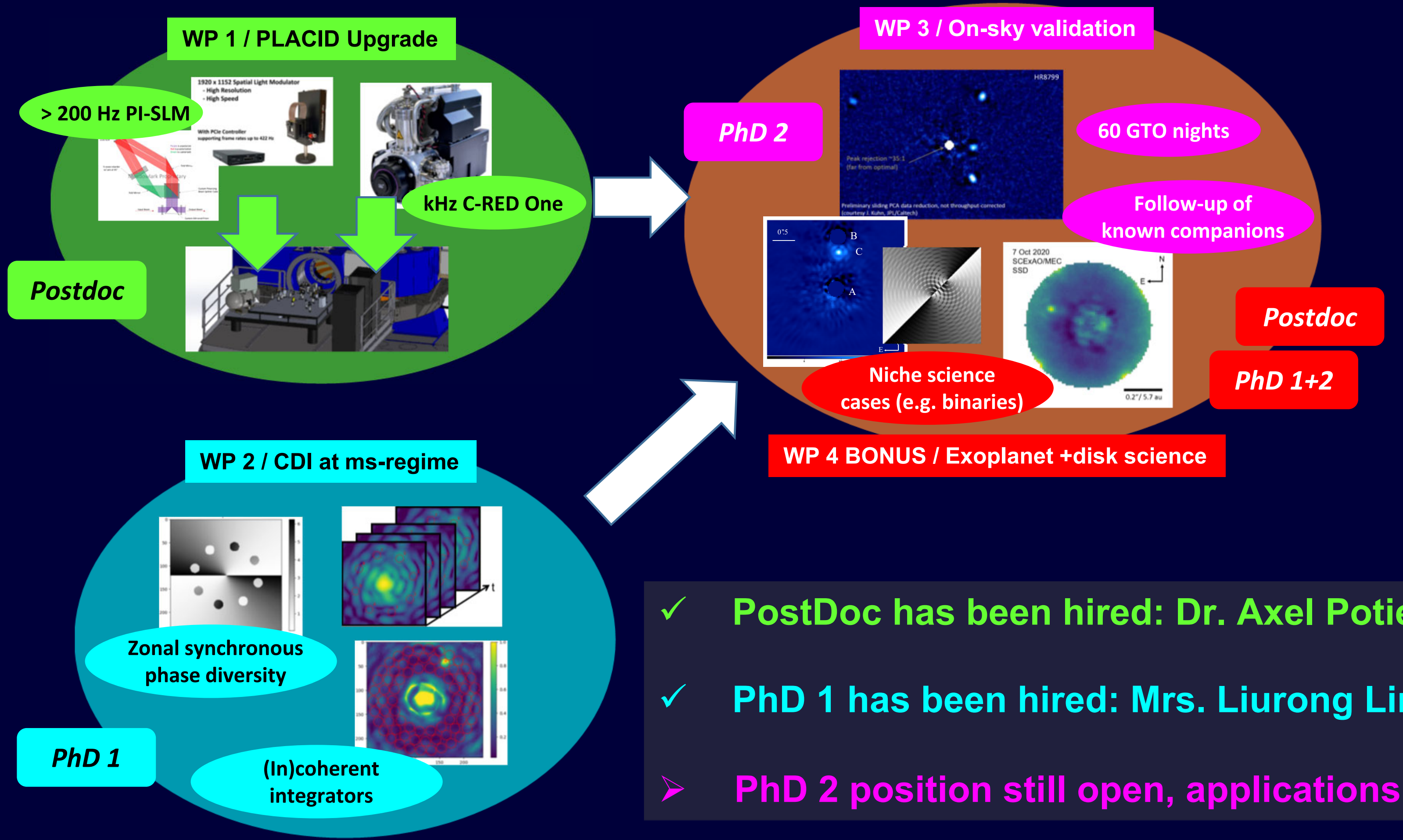


Miller et al., 2017

❖ RACE-GO on E-ELT PCS, and other

⇒ Imaging solar system

Work Breakdown Structure and Hiring



- ✓ PostDoc has been hired: Dr. Axel Potier (JPL), starts in Aug’23
- ✓ PhD 1 has been hired: Mrs. Liurong Lin (Leiden), starts in May’23
- ➢ PhD 2 position still open, applications due by April 30, 2023