CHARA/SPICA
General introduction

OCA/Lagrange +IPAG & LESIA: D. Mourard, P. Bério, N. Nardetto, C. Bailet, J. Dejonghe, P. Fedou, L. Jocou, S. Lacour, S. Lagarde, I. Lapassat, D. Lecron, A. Meilland, F. Millour, F. Morand, F. Patru, K. Perraut, S. Rousseau

+ CHARA group (Theo, Judit, Nils, Laszlo, Matt, Chris, Gail…)

+ MIRCx/MYSTIC group (N. Anugu, S. Kraus, JB Le Bouquin, J. Monnier)

Support from PNPS/ASHRA/LAGRANGE

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Two emblematic examples

DIRECT MEASUREMENT OF THE RADIUS AND DENSITY OF THE TRANSITING EXOPLANET HD 189733b WITH THE CHARA ARRAY

Ellyn K. Baines,[1] Gerard T. van Belle,[2] Theo A. ten Brummelaar,[1] Harold A. McAlister,[1] Mark Swain,[3] Nils H. Turner,[1] Laszlo Sturmann,[1] and Judit Sturmann[1]

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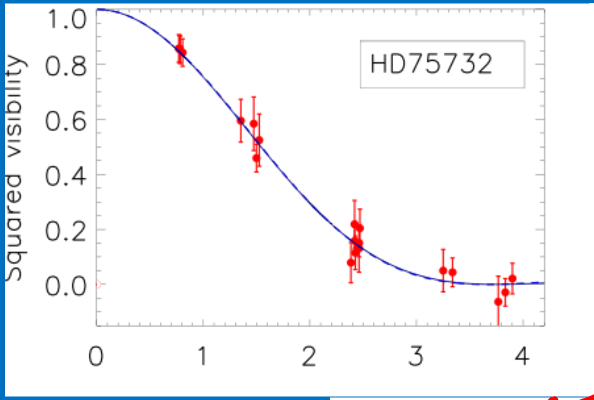
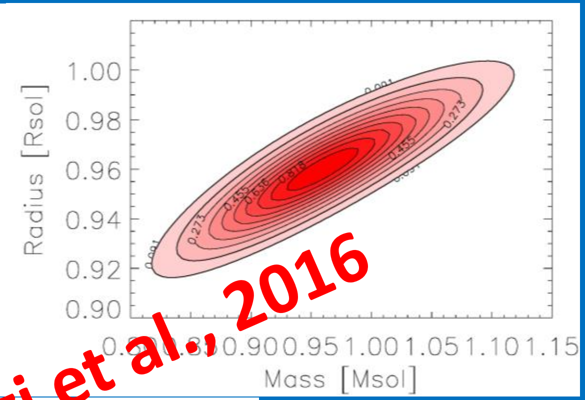
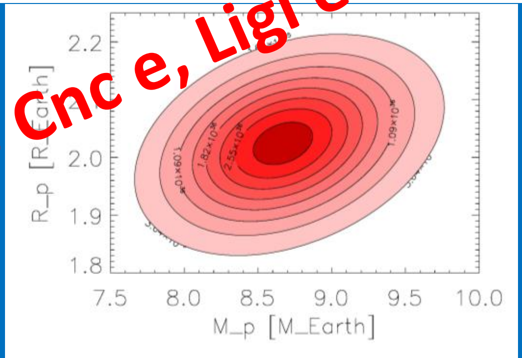
ABSTRACT

We have measured the angular diameter of the transiting extrasolar planet host star HD 189733 using the CHARA optical/IR interferometric array. Combining our new angular diameter of 0.377 ± 0.024 mas with the *Hipparcos* parallax leads to a linear radius for the host star of 0.779 ± 0.052 $R_\odot$ and a radius for the planet of 1.19 ± 0.08 R_{Jup}. Adopting the mass of the planet as derived by its discoverers, we derive a mean density of the planet of 0.91 ± 0.18 g cm^{-3}. This is the first determination of the diameter of an extrasolar planet through purely direct means.

Baines et al., 2007





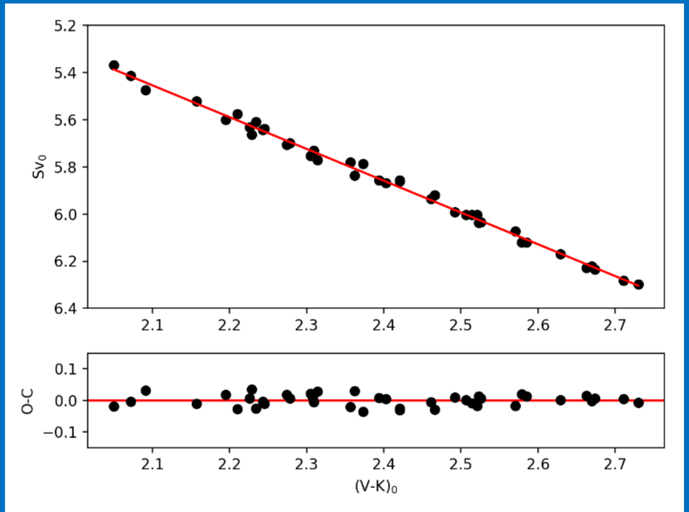


55 Cnc e, Ligi et al., 2016

A one per cent distance determination to the Large Magellanic Cloud

G. Pietrzyński[1], D. Graczyk[1], A. Gallenne[2], W. Gieren[3], I. B. Thompson[4], B., Pilecki[1], P. Karczmarek[5], M. Górski[3], K. Suchomska[5], M., Taormina[1], B. Zgirski[1], P. Wielgórski[1], Z. Kołaczkowski[1], P. Konorski[5], S. Villanova[3], N. Nardetto[7], P. Kervella[8], F. Bresolin[9], R. P. Kudritzki[9], J. Storm[10], R. Smolec[1], W. Narloch[1]

Pietrzynski et al., 2019



SBCR + eclipsing binaries

Definition of the main objectives

Measuring a large number of angular diameters

- To support the exoplanet researches through direct characterization of the host star.
- To support, e.g., the direct determination of extragalactic distances through accurate and homogeneous SBC relationships, but also to permit precise and accurate angular diameter estimations for many different purposes.
- Many other projects (see Nicolas' talk)

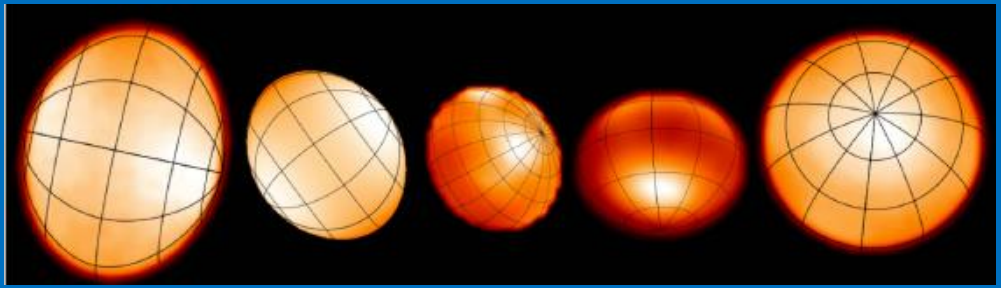
Very timely with the new space missions (TESS, CHEOPS, PLATO) and their objectives of measuring brighter stars than with the first generation of space missions (CoRoT, KEPLER)

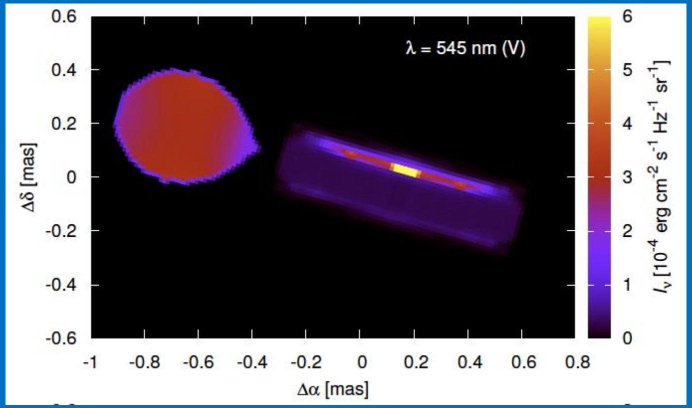
What means *large number* and *angular diameters* ?

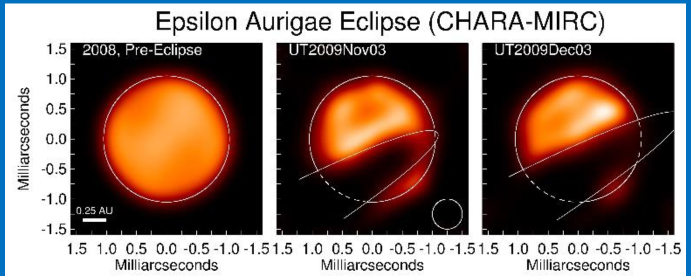
- Large Number:
  - In the past a few tens of objects only (PIONIER, CHARA)
  - For the SBC relations, 5 LC, 7SP → few hundreds of stars for a good sampling of the HR diagram and to improve the precision and accuracy.
  - Almost 200 exoplanet host stars accessible to CHARA.

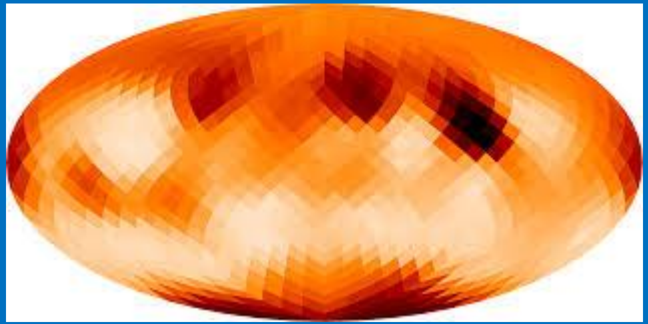
→ ***~1000 stars***

- Angular Diameters





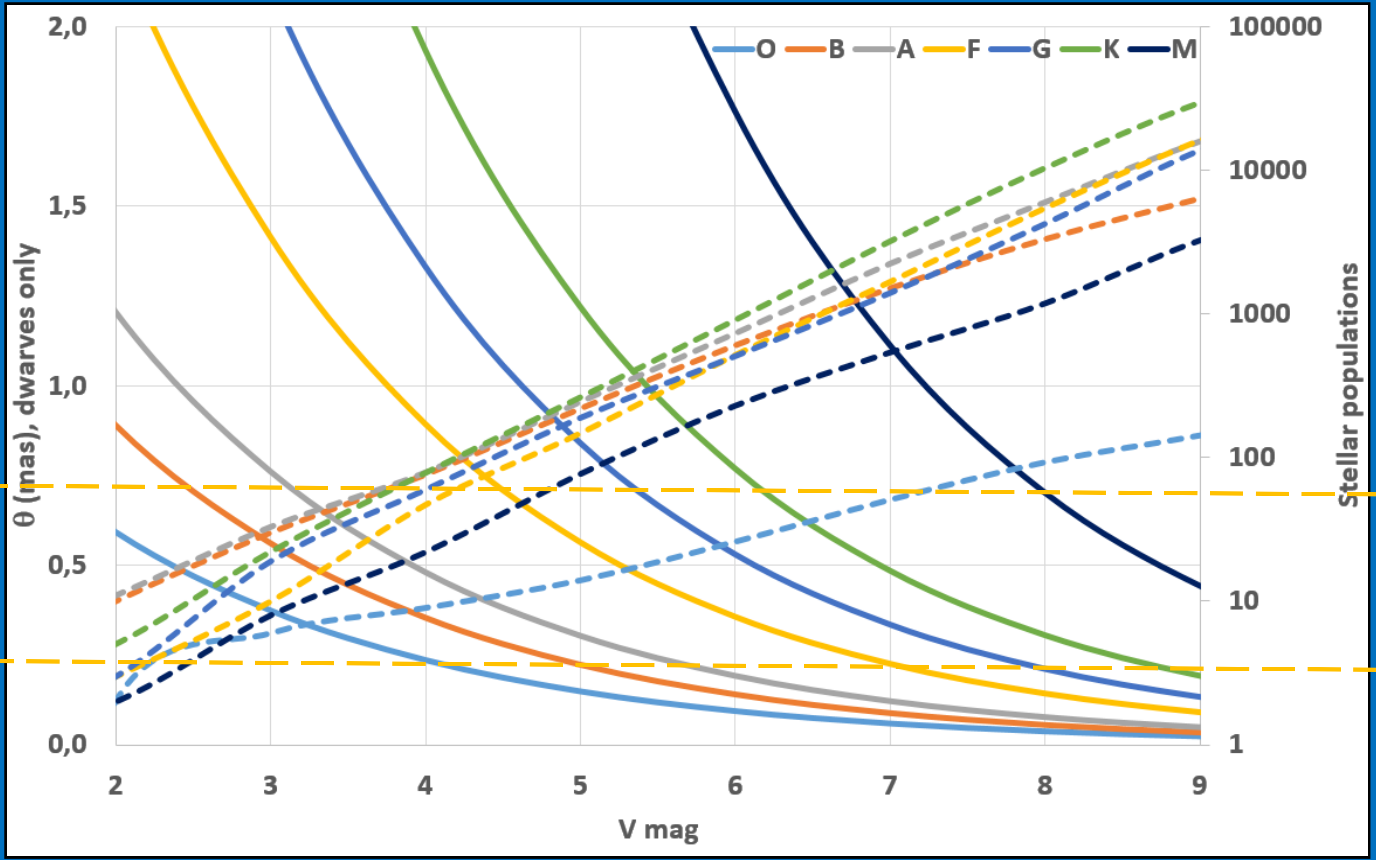




Statistics of the CHARA sky

θ>0.7mas

θ>0.2mas



	O	B	A	F	G	K	M
Limiting magnitude for θ>0.2mas	4.3	5.2	5.9	7.2	8.2	8.8	10.6
Number of stars with θ>0.2mas	10	266	646	2128	5420	23904	8377
Limiting magnitude for θ>0.7mas	1.5	2.5	3.3	4.5	5.4	6.2	8.0
Number of stars with θ>0.7mas	0	19	40	86	277	1153	1168

High level requirements
Diameters:

- magR=8 (but at low V^2)
- High precision, high efficiency (6T)
- R=300 (LR mode)

Imaging

- magR=5 (but at low V^2)
- UV coverage (6T, +Supersynthesis)
- R=3000 (MR mode)

Main scientific requirements

~1000 stars

- ➔ θ down to 0.2mas
- ➔ 300m and visible wavelengths is mandatory

Magnitude around 8 for the angular diameter measurements, around 4-5 for the surface imaging

SNR considerations ➔ long exposures are mandatory to reach the sensitivity

Limiting magnitude defined as S/N=10 per spectral channel in 10mn of integration

Group delay only (DIT=10ms)

	R=140	R=3000
V^2=0.25	8.7	5.4
V^2=0.01	5.5	2.3

Phase delay tracking

	R=140	R=3000
V^2=0.25, DIT=0.2s	10.1	6.7
V^2=0.01, DIT=0.2s	6.7	3.5
V^2=0.25, DIT=30s	10.4	7.1
V^2=0.01, DIT=30s	7.0	4.0

These estimations use the same S/N calculator of FRIEND, validated on-sky

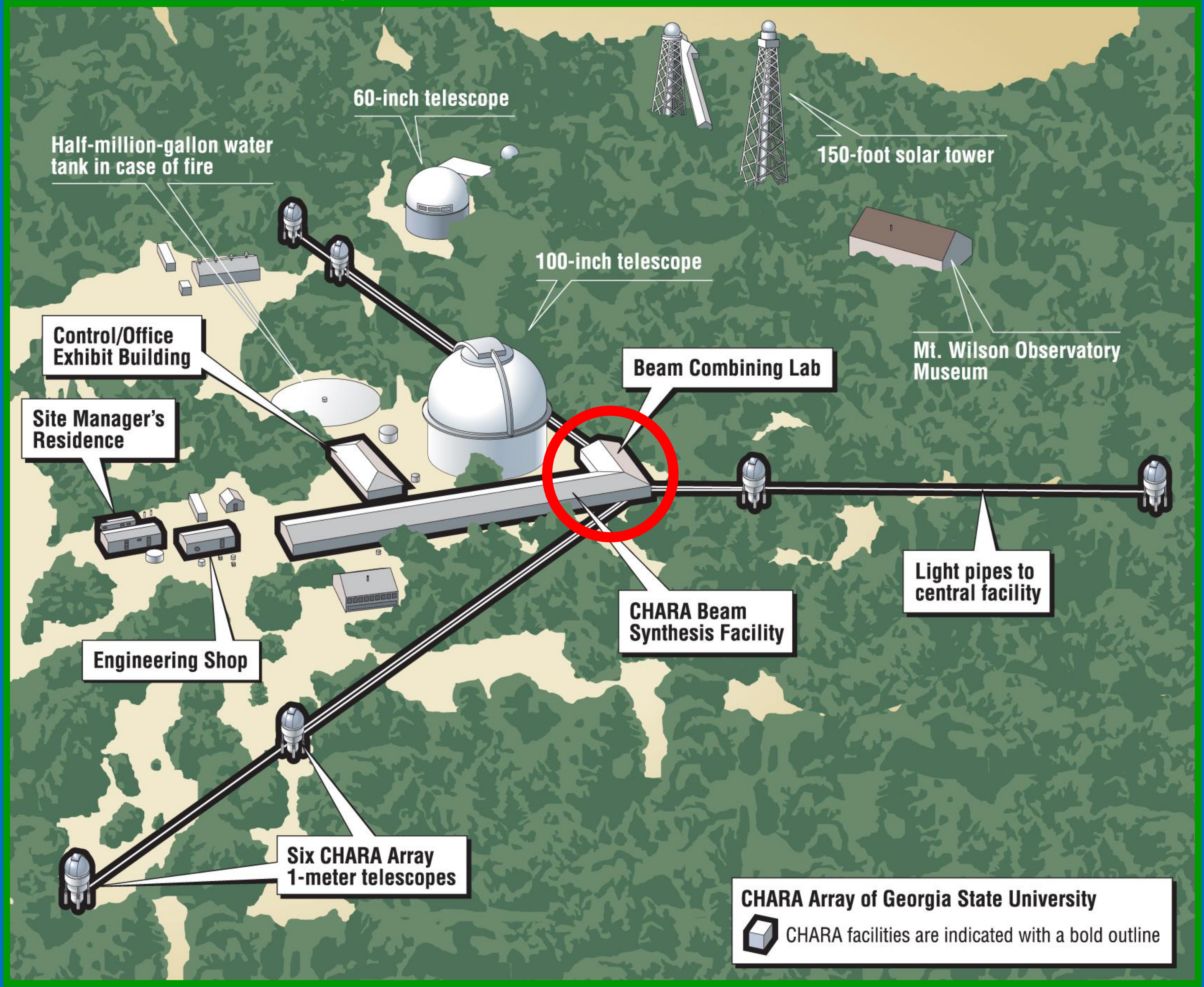
CHARA/SPICA: 3 core activities

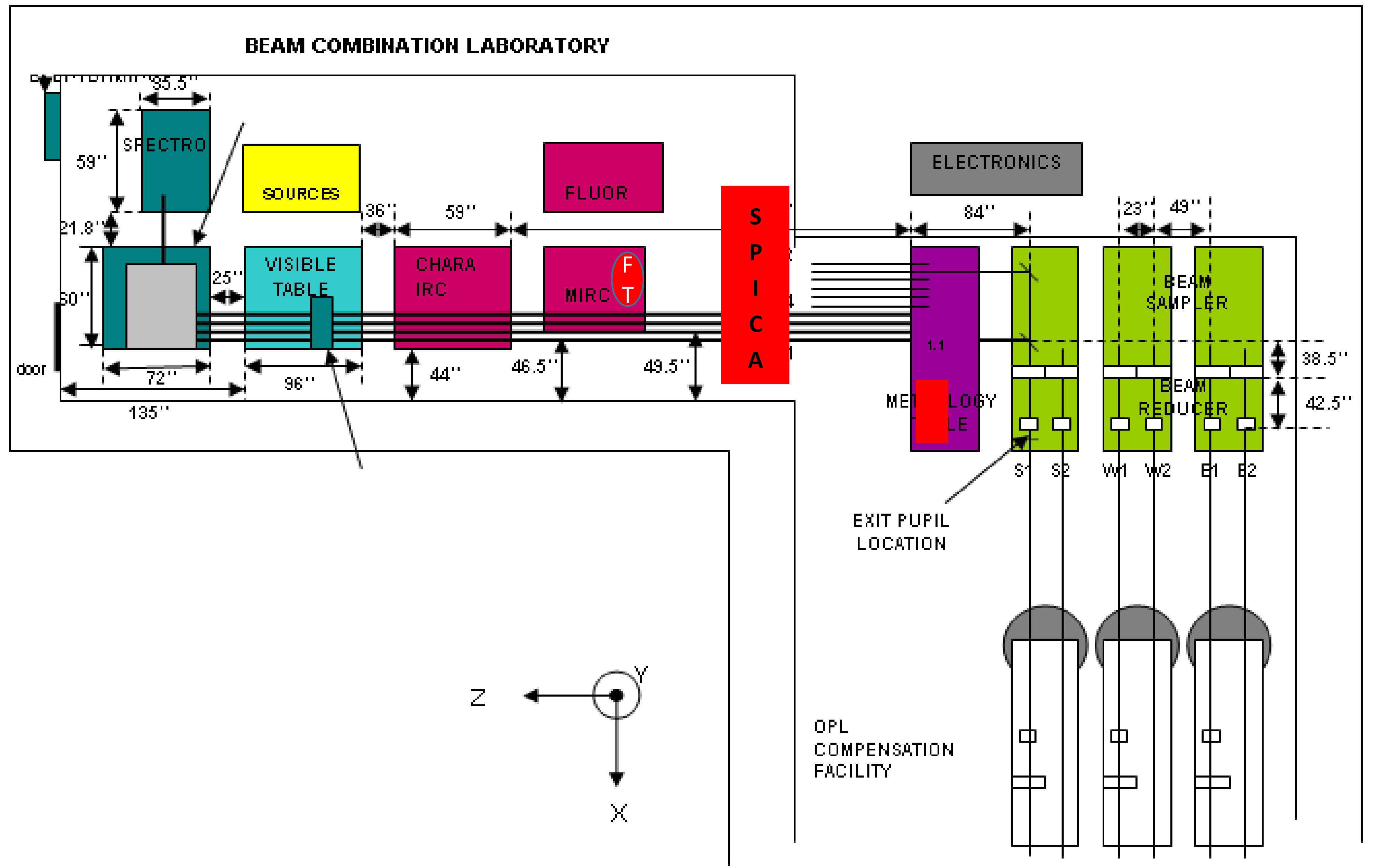
- Science Group
  - Definition of the lists of targets
  - Definition of the observing strategy (survey management)
  - Definition of the automatic pipeline + archive of processed data
  - Definition of the sorting criteria
  - Definition of the methods for extracting the high level products (R, M, Age, Teff…)
  - Definition of the statistical analysis
  - … and manage the science products!

- A visible instrument SPICA-VIS

- A near-infrared fringe tracker SPICA-FT

The CHARA Array - Mount Wilson Observatory




BEAM COMBINATION LABORATORY
35.5''
59''
SPECTRO
SOURCES
FLUOR
ELECTRONICS
21.8''
36''
59''
84''
23''
49''
25''
VISIBLE
TABLE
CHARA
IRC
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A
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BEAM
SAMPLER
60''
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72''
96''
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46.5''
49.5''
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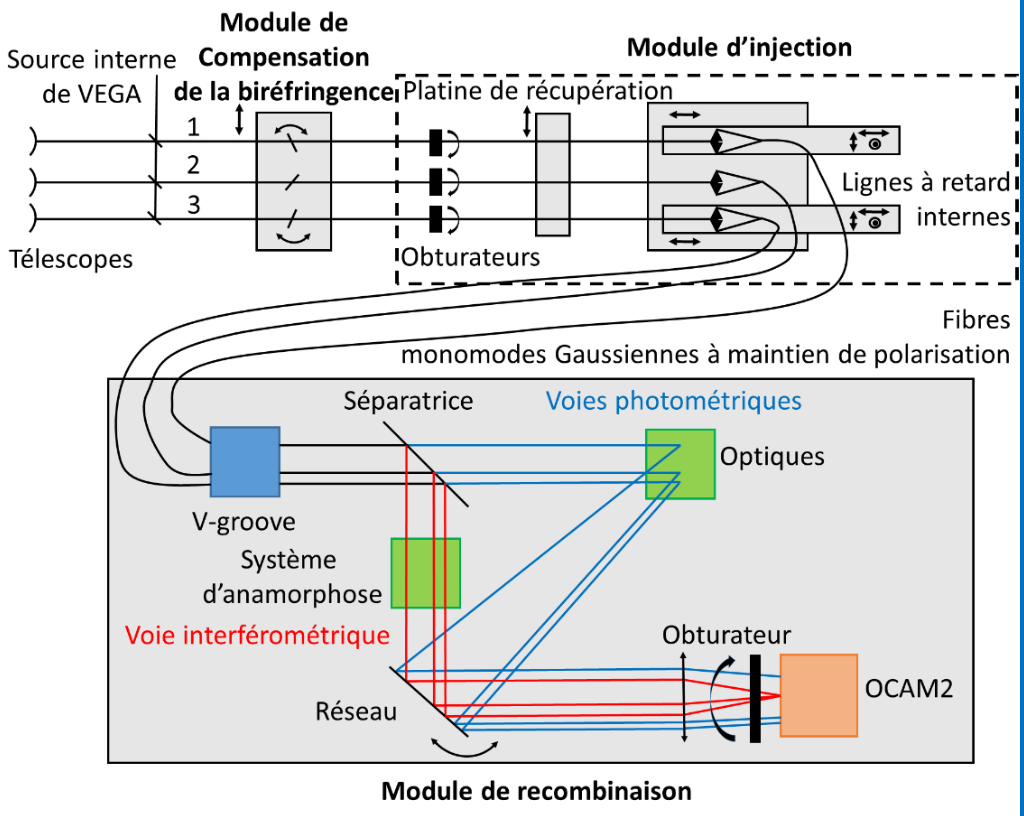
BEAM
REDUCER
42.5''
S1
S2
W1
W2
E1
E2
EXIT PUPIL
LOCATION
Z
Y
X
OPL
COMPENSATION
FACILITY

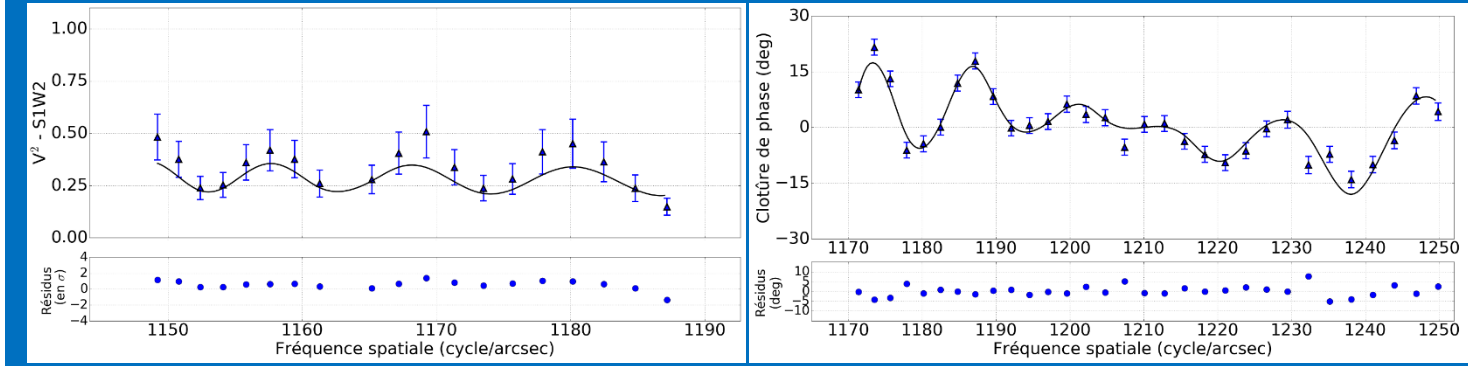
SPICA-VIS: The FRIEND prototype

Limitations of VEGA + AO on CHARA
➔ opportunity for fibered interferometry in the visible
➔ Prototype for know-how and expertise in Nice



Lessons learned on:

- Visible fibres and injection with partial AO
- Birefringence correction
- EMCCD detector
- Data processing with fibered combiner: V^2 and Cϕ



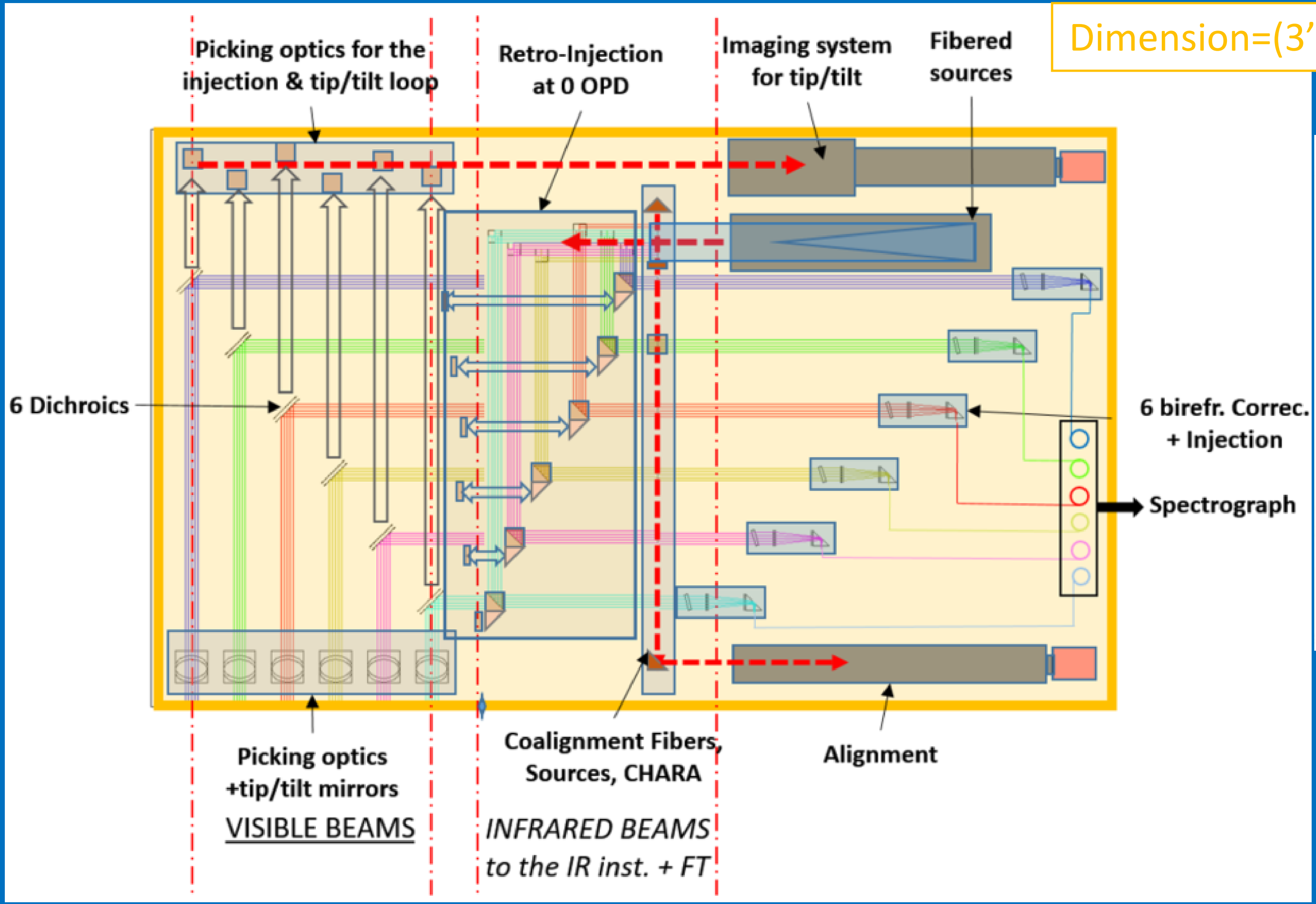
Martinod et al., 2018

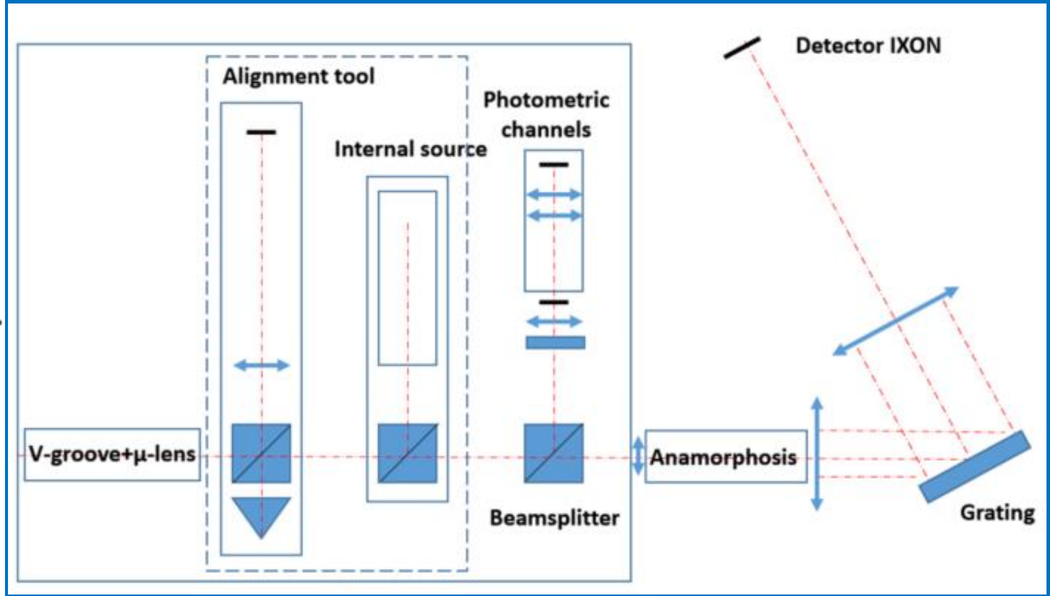
A short historical recreation

- Winter 2011/2012: Philippe Bério: first idea of guided optics in visible after VEGA
- Nov 2012: first test of OCAM² detector
- Dec 2014: First light of FRIEND on CHARA
- March 2015: First talk at CHARA meeting on & Visible 6T BC
- July 2015: DM+AM: structuration of the Project
- Progress meetings in 2016/2017
- First funding requests in 2016/2017

Optical design of SPICA

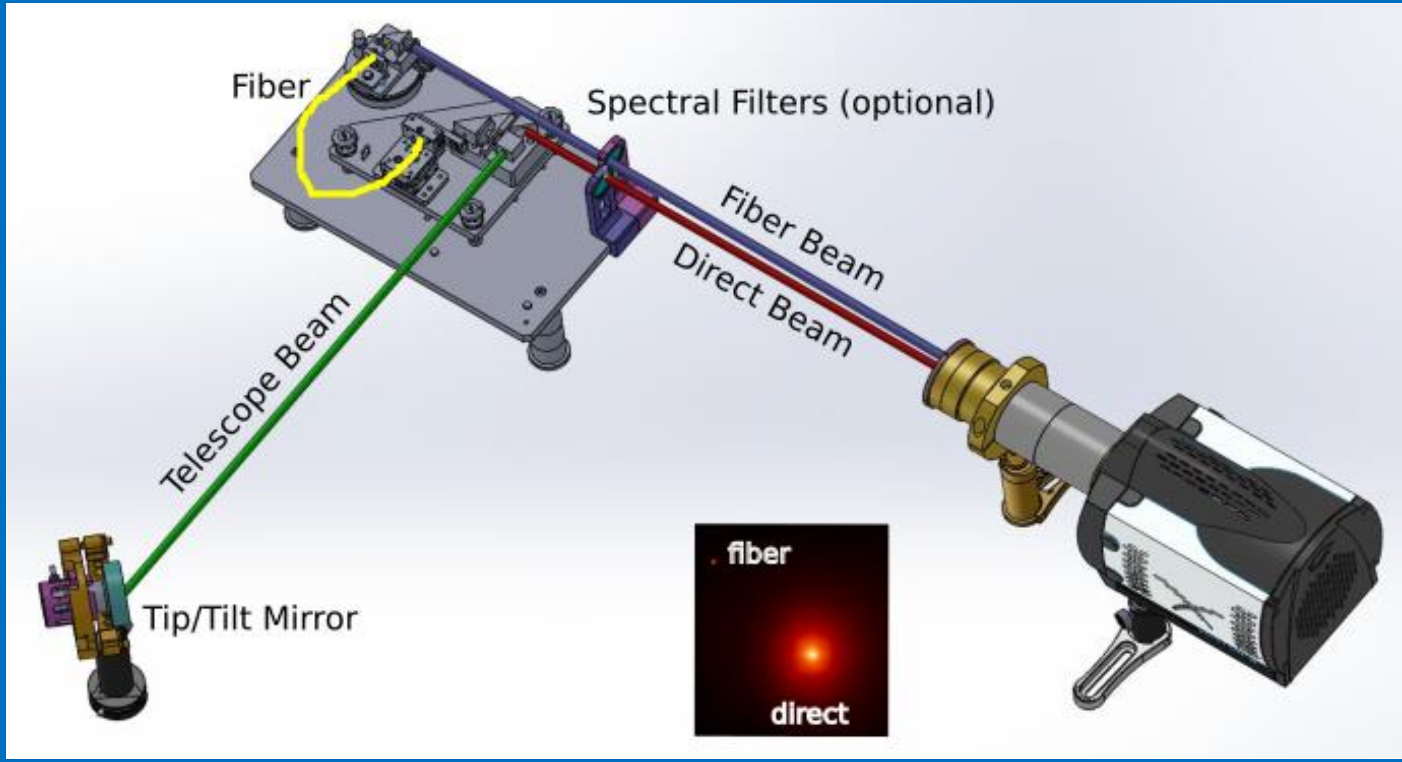
Dimension=(3'x5')

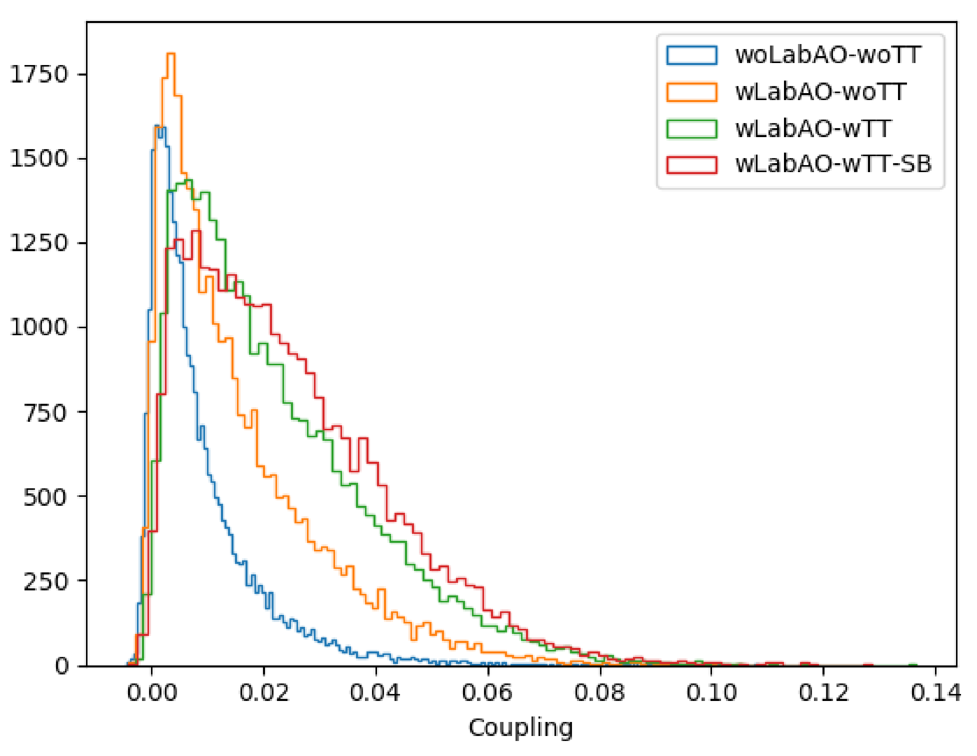




The two main difficulties are:
- Injection in SM fibres in partial AO correction
- Phase tracker for long exposure capabilities

CESAR : Coupling Efficiency Statistical Analysis and Recording

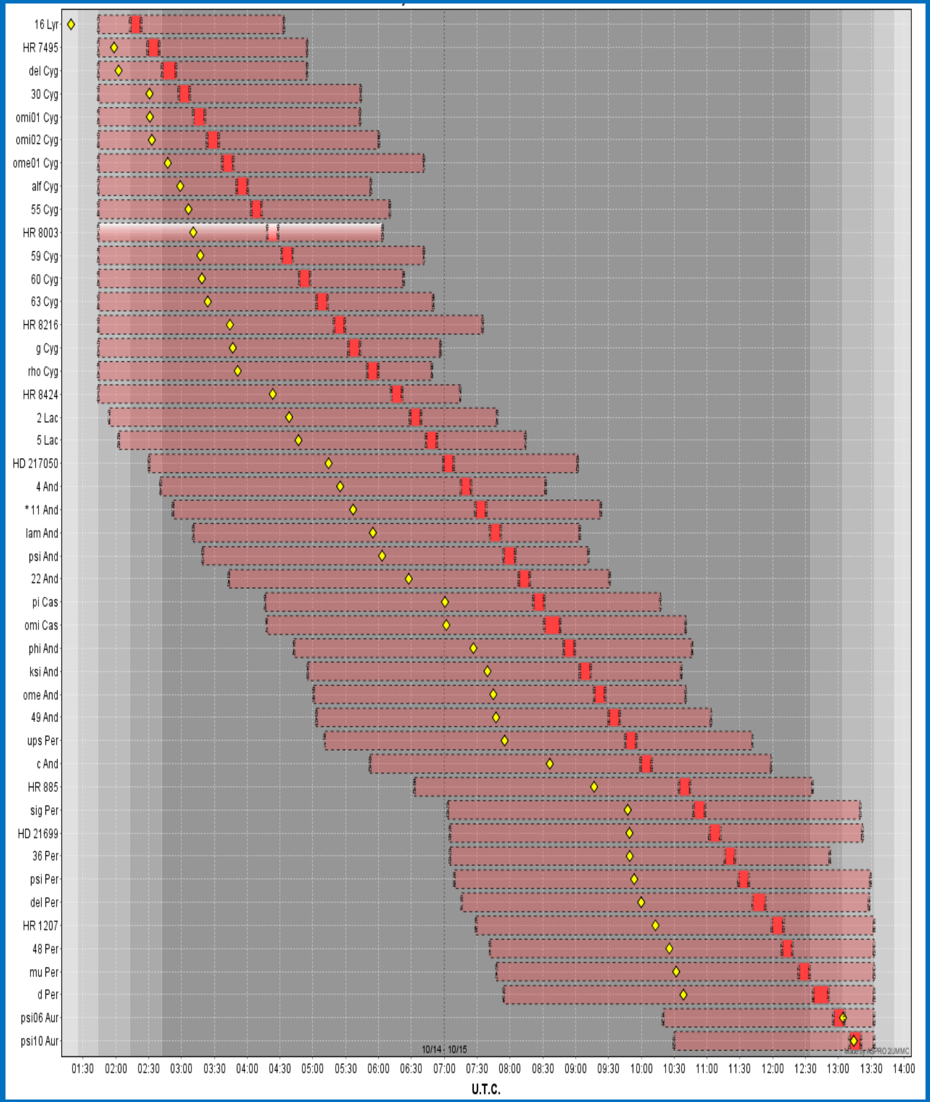


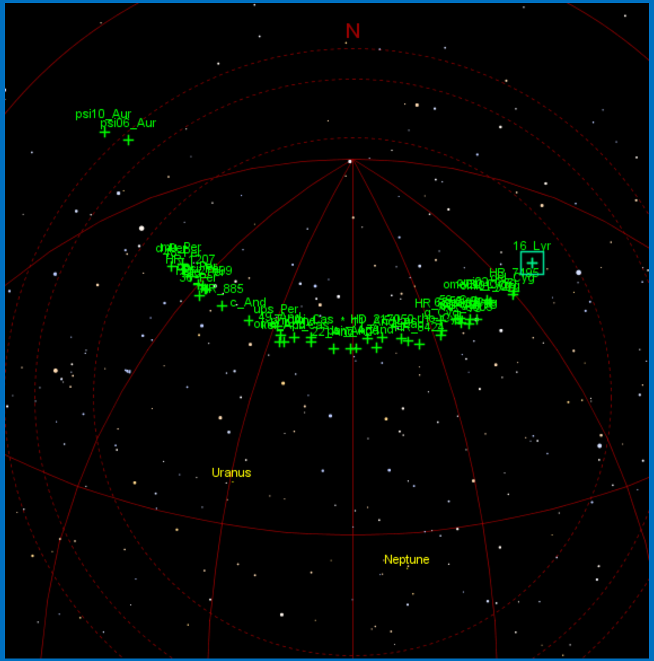


Test of injection stability (% of images with CE>1%)	
Without LABAO, without TT	30
With LABAO, without TT	54
With LABAO , with TT (V1)	71
With LABAO, with TT (V2)	76

Coupling x3
Stability x2.4

Survey mode testing with VEGA+CLIMB 2017-10-15





10mn per star, every 15mn. Clear identification of overheads (actions in progress)

Night=115Gb ⇔ SPICA~1Tb…

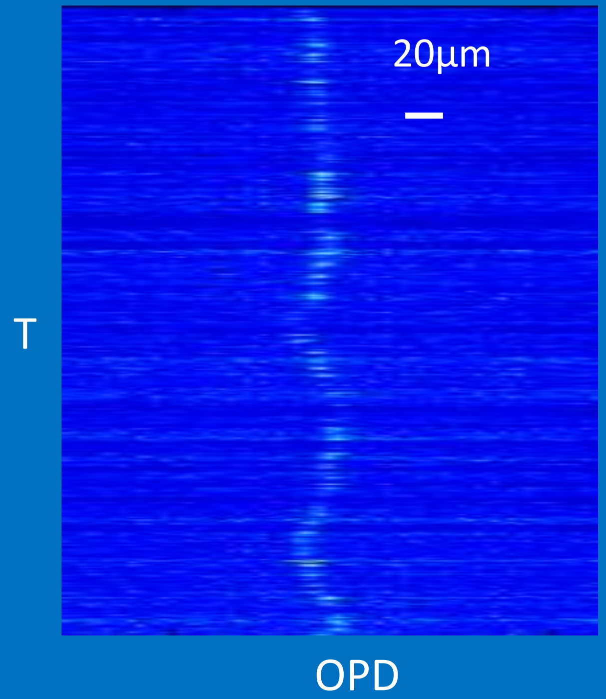
No fringes drift (150µm over the night), no pupil drifts. Only 1 NIRO alignment after a crash

SPICA/CHARA FT: guiding principles and baseline solution

- Do not re-invent the wheel: lessons learned from CHAMP, GRAVITY-FT
- Minimization of the development
- Full integration inside the CHARA infrastructure: a general-purpose FT if possible

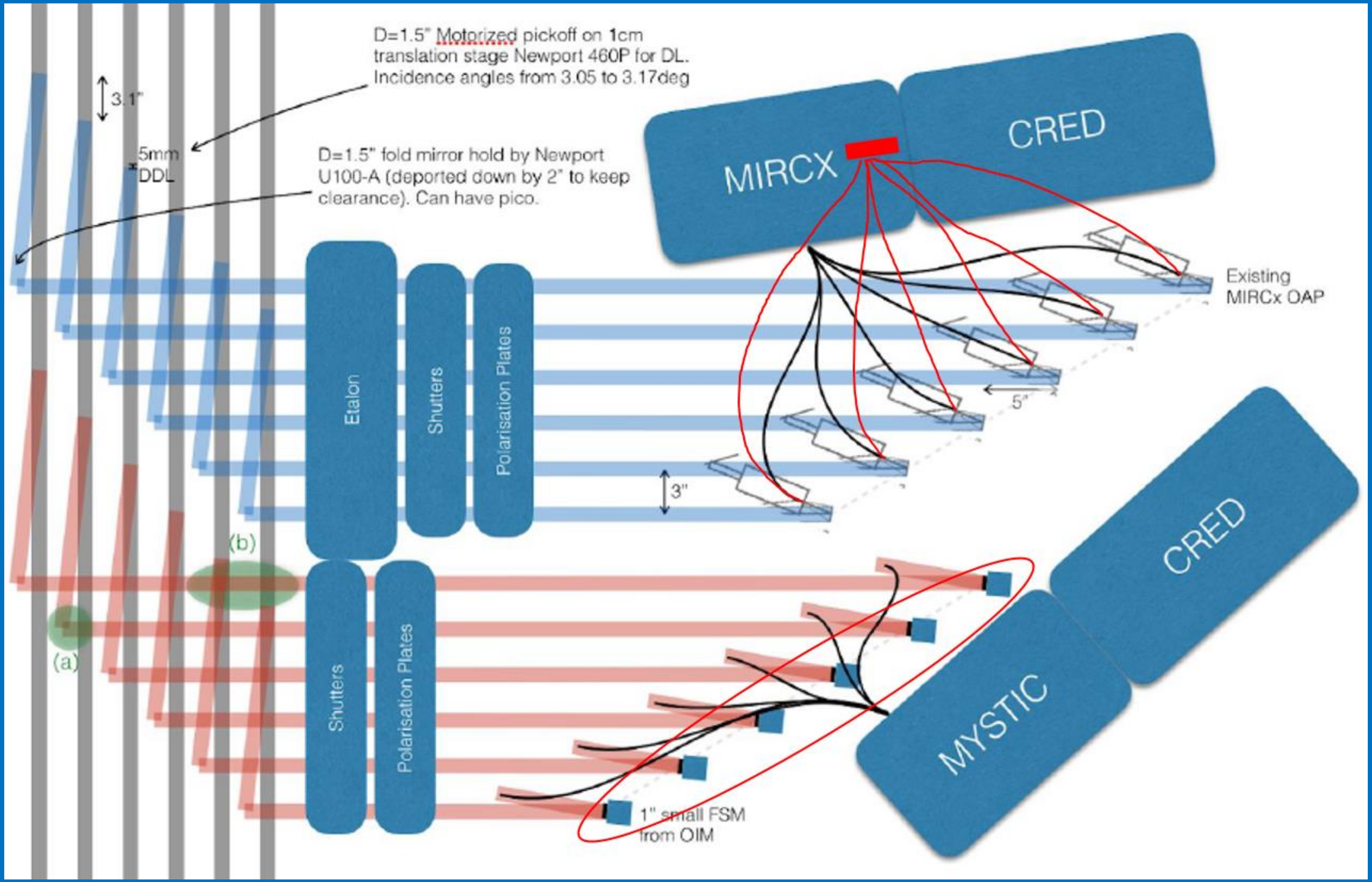
➢ ABCD all pairs
➢ IO device, H band Silicium technology
➢ Fast and low noise detector

FRIEND Oct. 2015

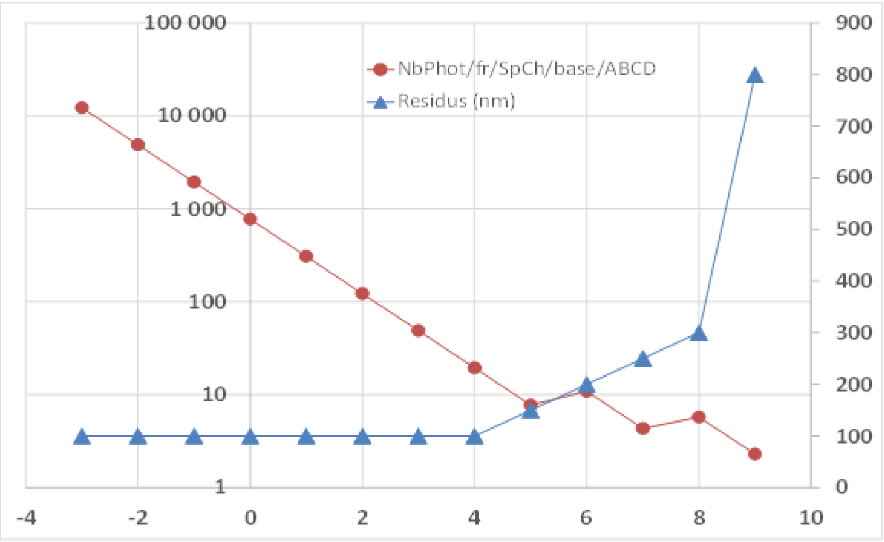


The solution:
- Use the H-band MIRCx fibres to feed a 6T ABCD IO component that will feed the MIRCx Selex detector
- Develop a real-time phase sensor software + a state machine to control the CHARA DL

SPICA-FT inside MIRCx

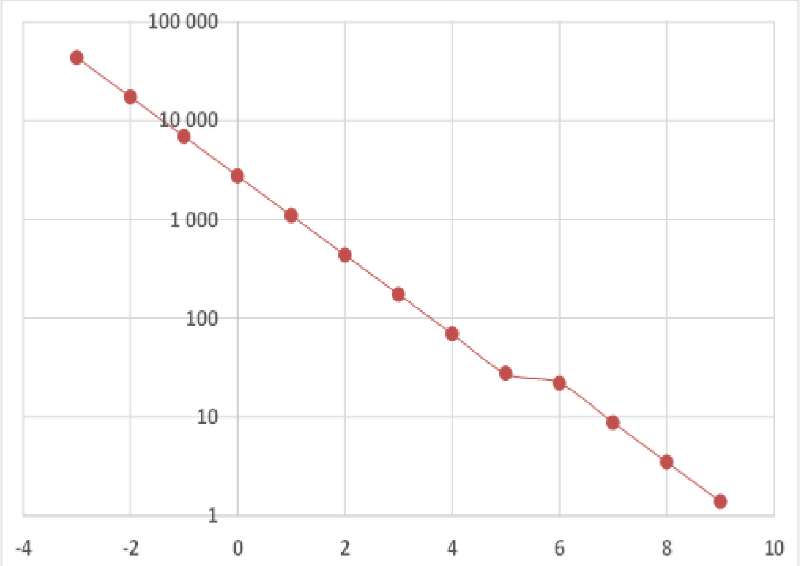


Estimation of performance for a H-band CHARA FT

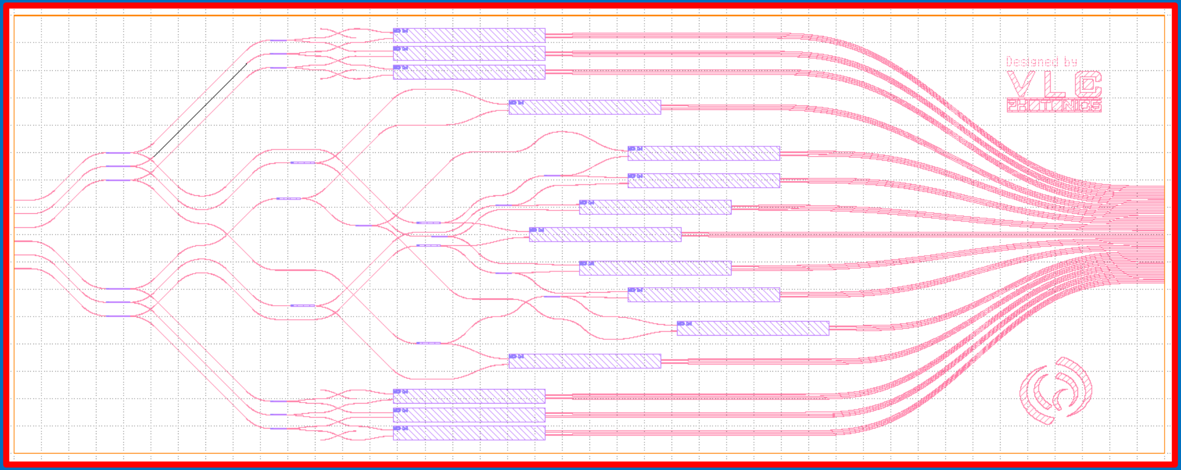


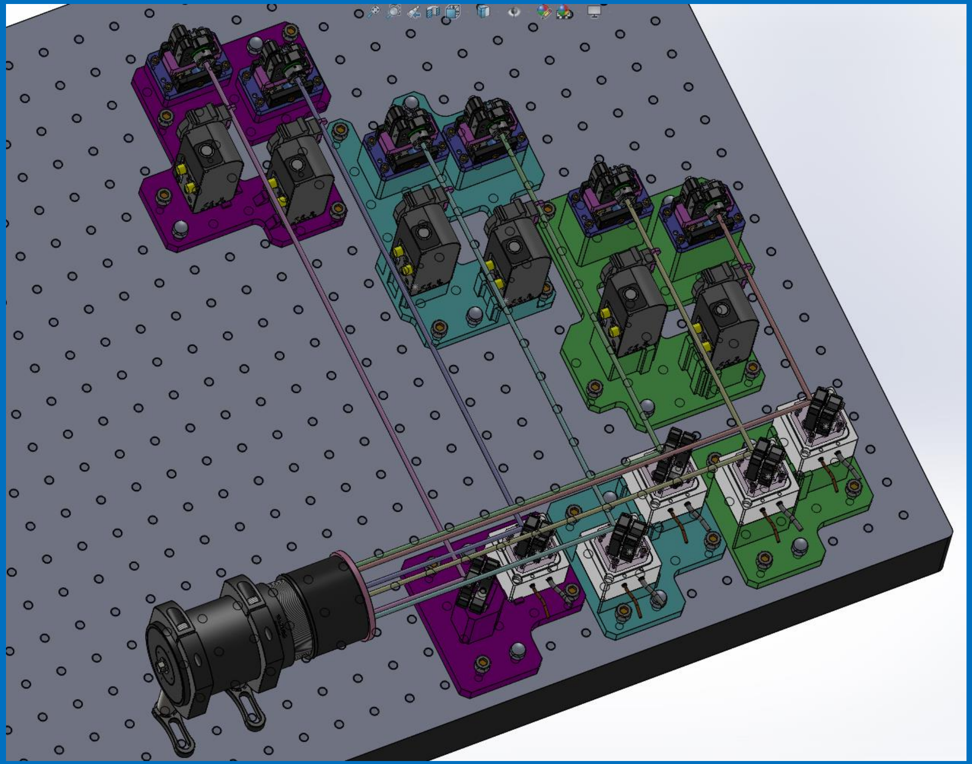
VLTI-GRAVITY FT performance

H band FT, 5 SpCh, 6T ABCD, Selex detector. T0=10ms , Texp=5/10ms



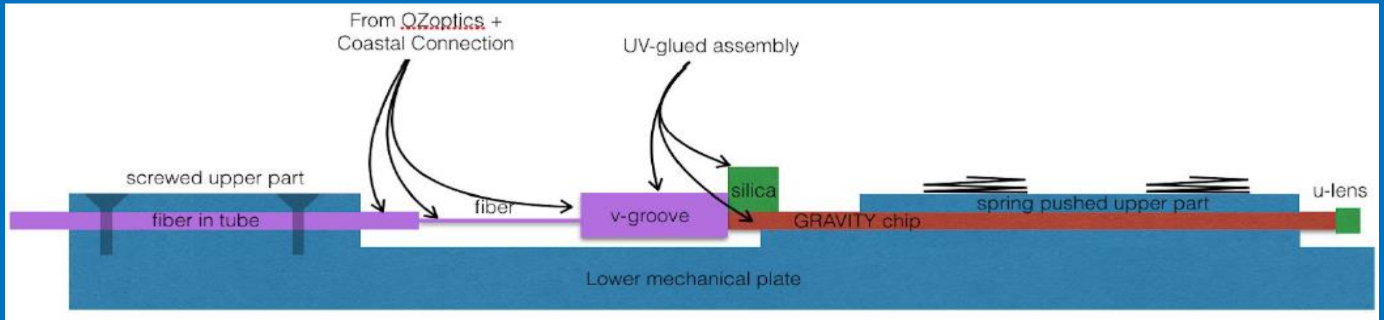
IO component for 6T-ABCD fringe sensor





Design and fabrication by VLC photonics

- *Technology is mature*
- *T between 35% and 50%*
- *Delivery ~end of Feb 2019*
- *Order of MLA has been placed, as well as for the fibers and V-groove to feed the IO chip*
- *Qualification at IPAG March-April*
- *Integration in Nice May to summer 2019*



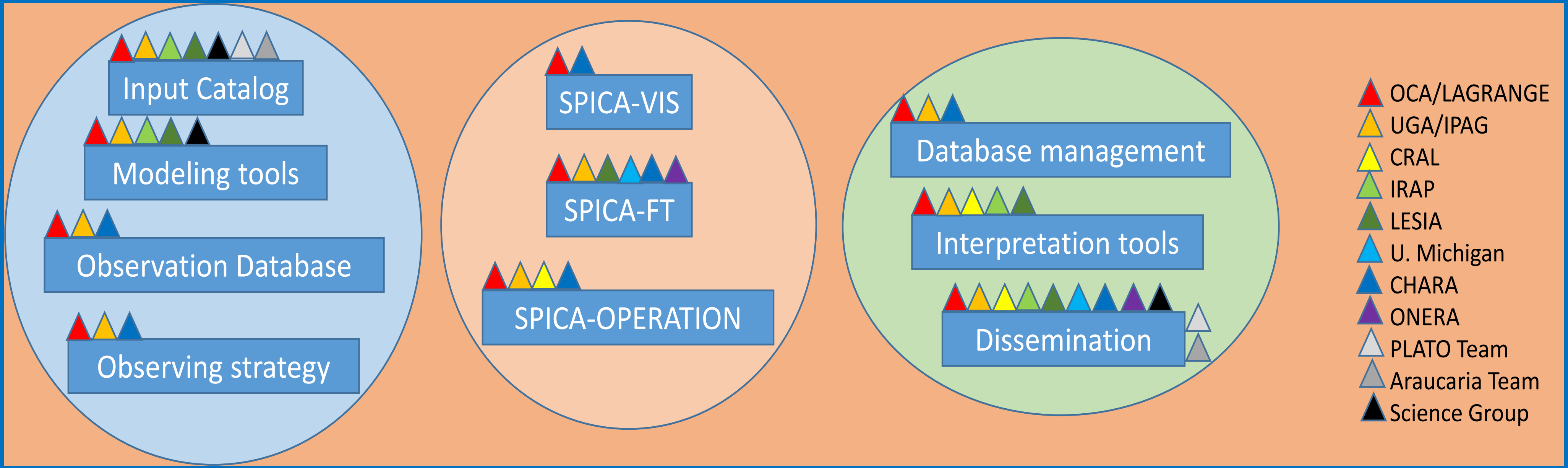
Summary SPICA-VIS & SPICA-FT

- SPICA-VIS
  - With VEGA: test of survey mode, observing strategy…
  - With FRIEND: testbed for fibres, birefringence, EMCCD (OCAM ^{2} → ANDOR Ixon), pipeline. Sky demonstration, precision of measurements.
  - With FRIEND and CESAR: optimisation of the injection
  - Preliminary design ok
  - Funding for FRIEND, CESAR, ANDOR. No funding for SPICA-VIS for the moment
  - ANR ISSP submitted in Oct. 2018…: SPICA-VIS (250k€) + SG activities

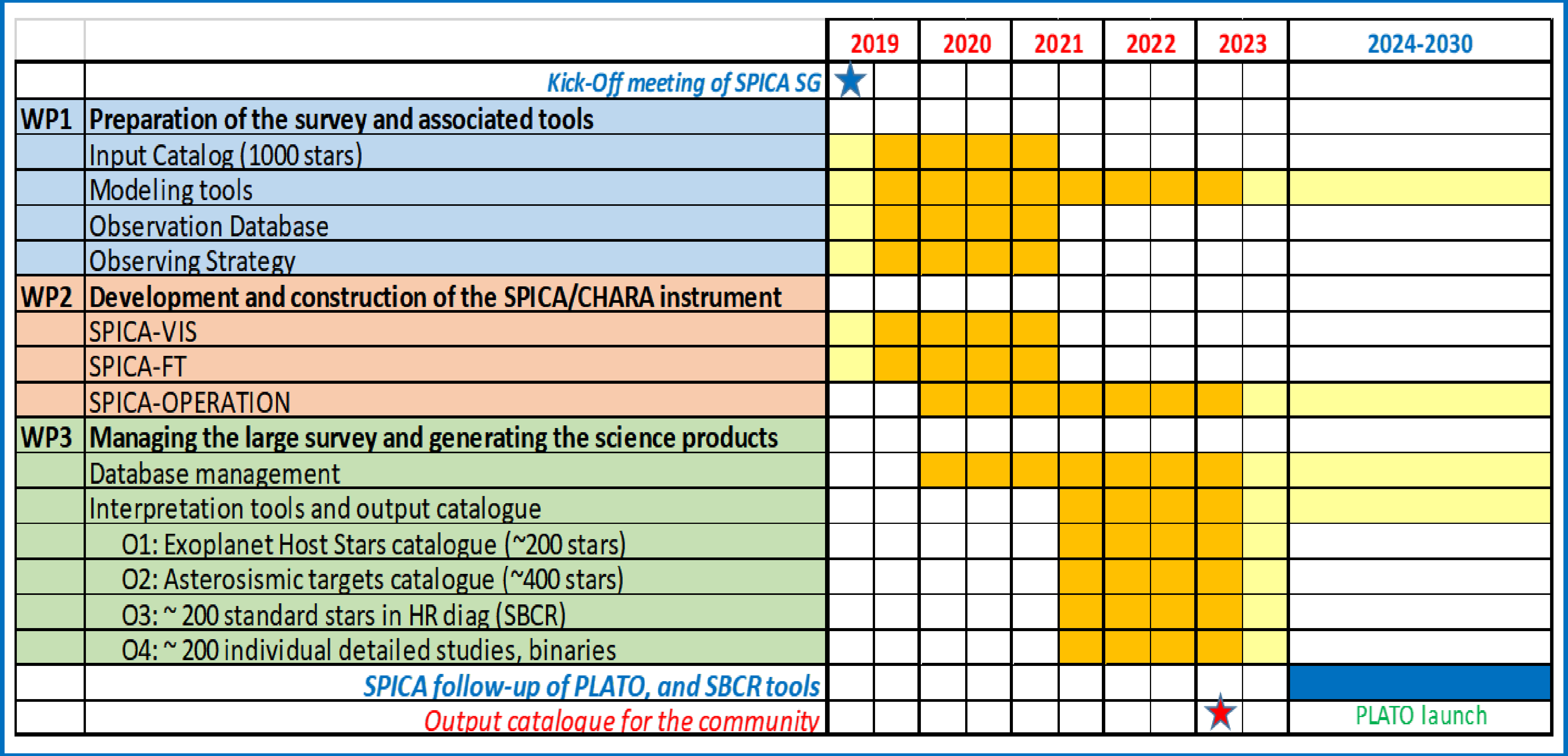
- SPICA-FT
  - Funding CNRS/INSU (68.5k€) and UCA (111k€). H2020 Opticon 2yr postdoc (Vis. Interferometry: CHARA/SPICA + iVis/VLTI) + Lagrange & OCA.
  - Fabrication in progress (VLC, Aμs, Leukos), lab and software activities.
  - First light expected for T4/2019

ANR Interferometric Survey of Stellar Parameters

Design to fund the activities of the Science Group and the construction of the visible instrument (2019-2023)



ANR Interferometric Survey of Stellar Parameters



Conclusion – Objectives of the WS

- SPICA/FT well on track - SPICA/VIS well explored - SG in extension

- The Science Group kick-off meeting:
  - Direct support for the ANR ISSP Phase 2 preparation (end of March. Hopefully…)
  - Start of the activities to tune the specifications of SPICA/VIS

  - Consolidation of the science objectives, possible extensions.
  - Analysis of:
    - the short-term needs: definition of targets and associated tools;
    - The mid-term needs: observing strategy, pipelines needs, database definition;
    - The long-term needs: the science tools for individual and statistical activities.

- Informal discussions about a possible Plan B for the funding if ANR KO.