CanariCam@GTC

Recommissioning & Lessons Learned

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C. Packham – Univ. of Texas at San Antonio; C. Alvarez – Keck Observatory

The organization http://www.gtc.iac.es/GTChome.php

- GTC telescope is an initiative of the Instituto de Astrofísica de Canarias (IAC)
- Funded by Spain (90%), México (5%), and the University of Florida (2.5-5%). In the process of defining the participation of China as new member.
- Belongs to the set of Spanish *Unique Scientific & Technical Infrastructures*
- Construction started in 2000, first light in 2007, operations started in 2009
- GRANTECAN is the company that built, operates, maintains and upgrades GTC
- GTC operates in a multi-instrument queue mode
- Public Data Archive: http://gtc.sdc.cab.inta-csic.es/gtc/index.jsp

Latitude: 28º 45’ 24’’ N
Longitude: 17º 53’ 31’’ W
Elevation of about 2300 masl

Outline

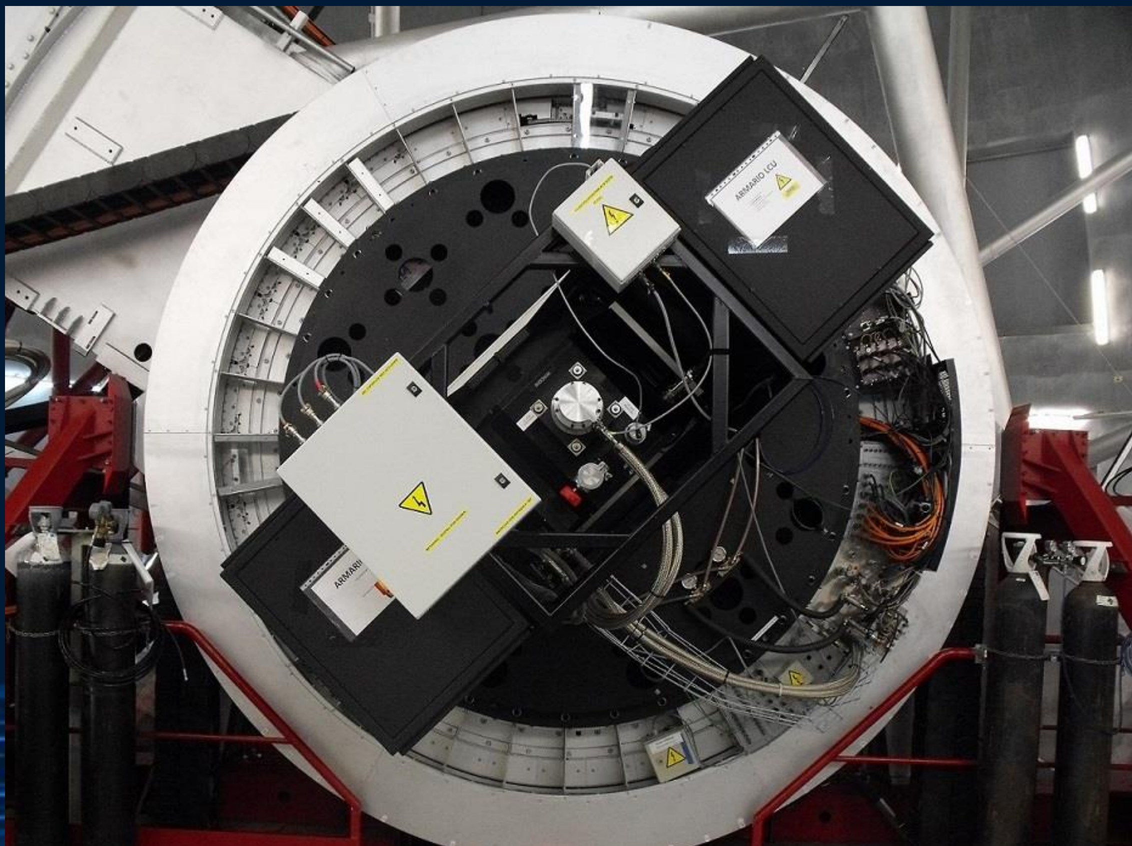
- CanariCam@Nasmyth (Mar 2012 -> Mar 2016)
    - Instrument Overview
    - Science Results and Productivity
    - Performance (sensitivity)
- Upgrade Project (Apr 2018 - > Dec 2019)
    - Motivation and Scope
    - Challenges, risks and opportunities
    - Outcome
- CanariCam@Folded-Cass (Dec 2019 - > Dec 2020??)
    - Recommissioning
    - Current status and results
    - Lorentz Center workshop follow-up experiments
- Future Prospects??
- Conclusions and Lessons Learned from CanariCam/GTC
- Q&A slides (following up discussions on Slack)

CanariCam@Nasmyth
(Mar 2012 -> Mar 2016)

CanariCam@Nasmyth

Instrument Overview http://www.gtc.iac.es/instruments/canaricam/

CanariCam is the facility multi-mode mid-IR (7.5-25 um) camera on the 10-m Gran Telescopio CANARIAS (GTC) on La Palma, Spain. Designed and built by the University of Florida, it provides imaging, spectroscopic and unique polarimetric capabilities near the diffraction limit of the telescope.



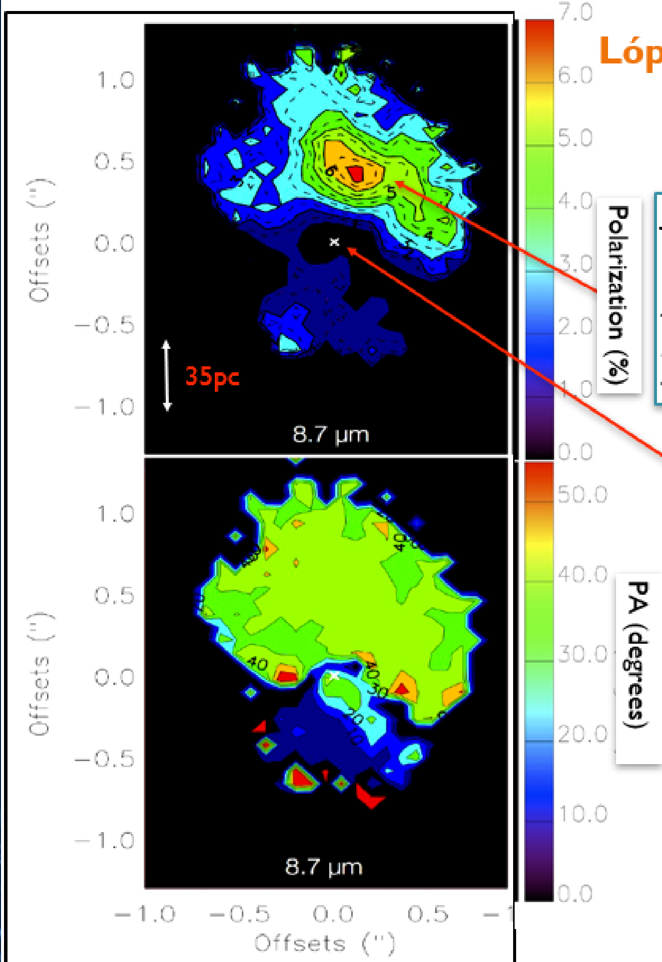
Spectral Range	7.5-25 µm
Detector	Raytheon 320x240 Si:As (cooled to 9K)
Plate Scale	0.08 arcsec pix^{-1}
Field of view	26 x 19 $arcsec^2$
Imaging modes	broad/narrow band, polarimetry
Spectroscopic modes	long-slit, polarimetry
Spectral resolution	175 to 1300

CanariCam@Nasmyth

Science Domain - AGNs

MIR polarization of NGC1068 does not peak at the AGN position

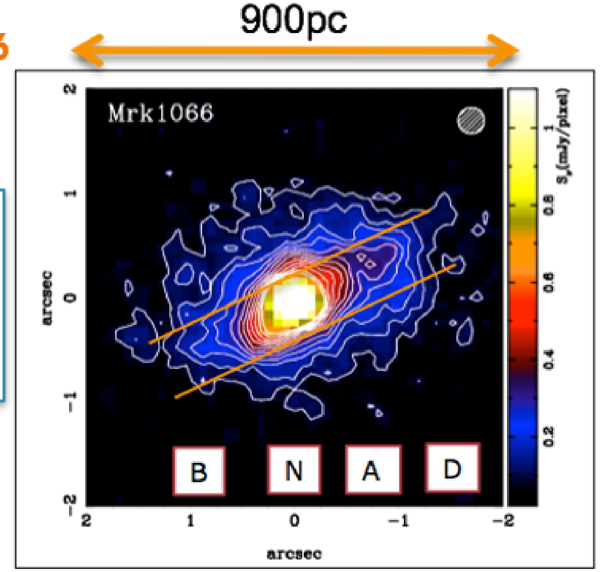
López-Rodríguez+2016



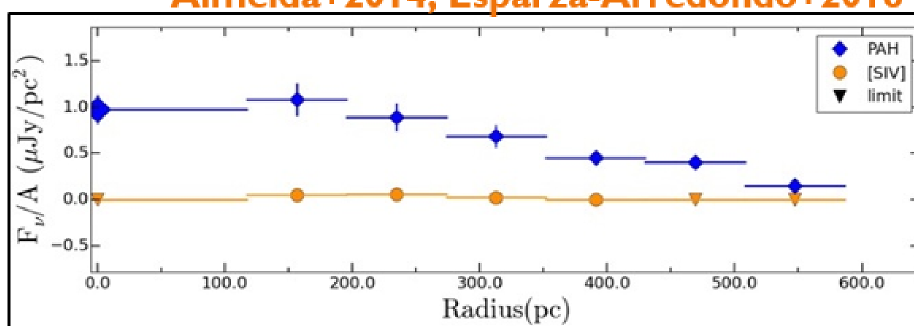
Jet-molecular cloud interaction in northern ionization cone: No silicate feature in polarized light: **dust grains different from those in ISM?**

AGN location <0.3% polarization from the torus

PAHs are not destroyed and are spatially resolved in the nuclear regions of AGN



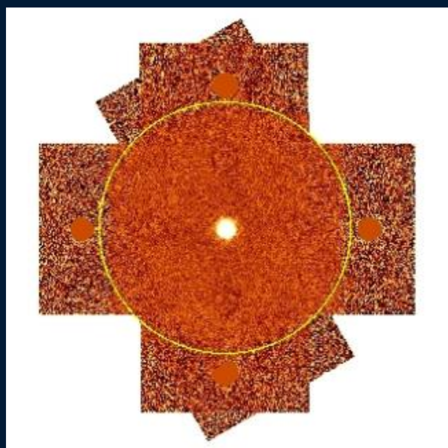
Alonso-Herrero+2014, Ramos Almeida+2014, Esparza-Arredondo+2018

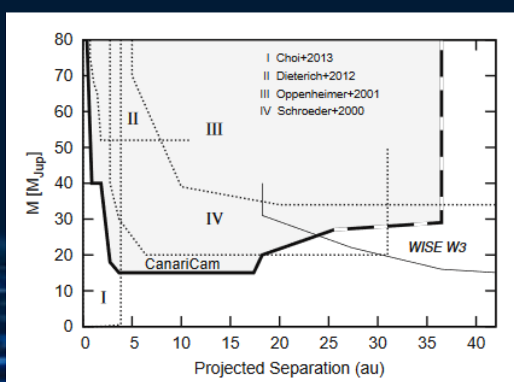


CanariCam@Nasmyth

Science Domain – Substellar Objects

Constraining the presence of substellar companions around the Barnard's star (Gauza+2015)





Thermophysical modelling of Apophis (Licandro+2015)

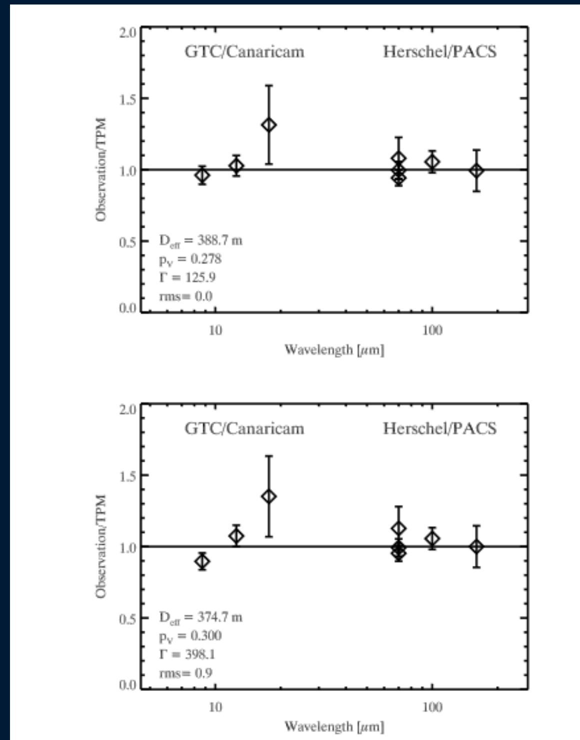


Fig. 3. Observed GTC/CanariCam (this paper) and Herschel/PACS (from Müller et al. 2014) divided by model fluxes for the two extreme cases with roughness slope angles *rms* = 0.0 (*upper*) and 0.9 (*lower*). Notice that observed-to-modeled fluxes of the GTC/CanariCam data are particularly sensitive to roughness and worsen for larger roughness, which led us to favor the solutions with low surface roughness in our analysis

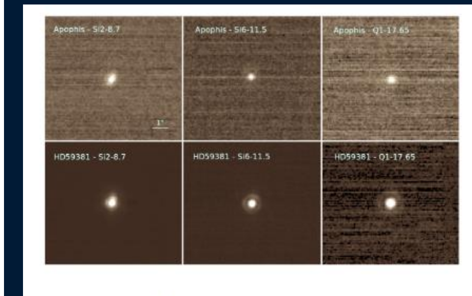
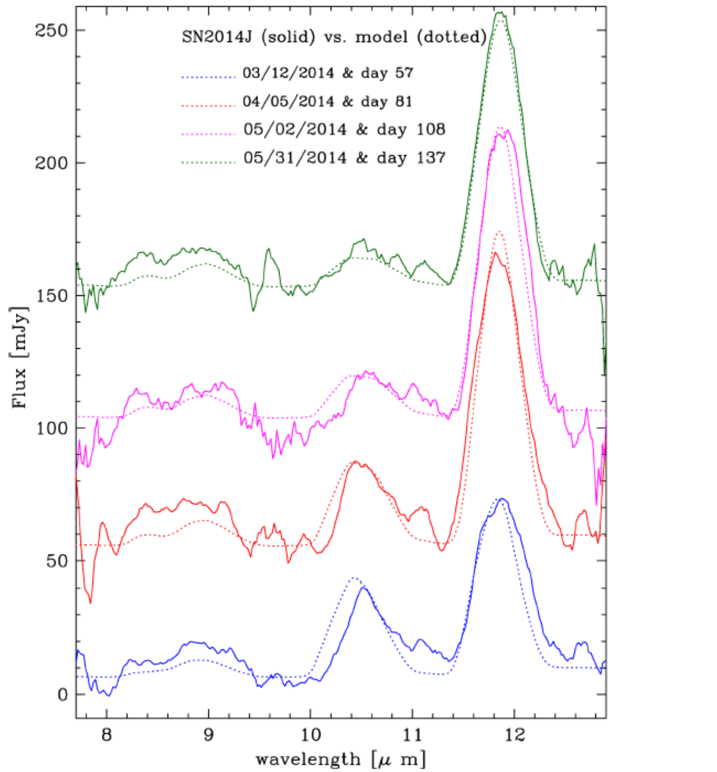


Fig. 1. Composed images of Apophis (upper panels) and HD59381 flux standard star (lower panel) in the three filters used.

CanariCam@Nasmyth

Broad Science Domain - Supernovae, lensed Quasars...



ABSTRACT

We present a time series of 8–13 μm spectra and photometry for SN 2014J obtained 57, 81, 108, and 137 days after the explosion using CanariCam on the Gran Telescopio Canarias. This is the first mid-IR time series ever obtained for a Type Ia supernova (SN Ia). These observations can be understood within the framework of the delayed detonation model and the production of $\sim 0.6\, M_\odot$ of ^{56}Ni, consistent with the observed brightness, the brightness decline relation, and the γ-ray fluxes. The [Co III] line at 11.888 μm is particularly useful for evaluating the time evolution of the photosphere and measuring the amount of ^{56}Ni and thus the mass of the ejecta. Late-time line profiles of SN 2014J are rather symmetric and not shifted in the rest frame. We see argon emission, which provides a unique probe of mixing in the transition layer between incomplete burning and nuclear statistical equilibrium. We may see [Fe III] and [Ni IV] emission, both of which are observed to be substantially stronger than indicated by our models. If the latter identification is correct, then we are likely observing stable Ni, which might imply central mixing. In addition, electron capture, also required for stable Ni, requires densities larger than $\sim 1 \times 10^9$ g cm^{-3}, which are expected to be present only in white dwarfs close to the Chandrasekhar limit. This study demonstrates that mid-IR studies of SNe Ia are feasible from the ground and provide unique information, but it also indicates the need for better atomic data.

Mid-IR spectroscopic follow-up of type Ia SN 2014J in M82 (Telesco+2014)

Lensed Quasar Q2237+0305 (Vives-Arias+2016)

Flux Ratios:
B/A= 0.99 ± 0.10
D/A= 0.69 ± 0.10
D/A= 0.84 ± 0.10

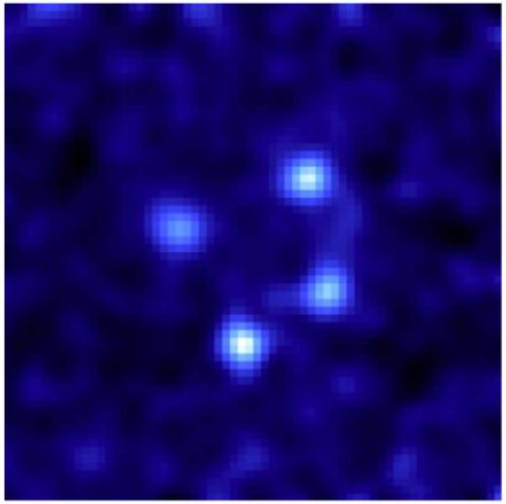


Figure 1. Quadruple lens system Q2237+0305 at 11.6 μm using data taken with CanariCam at GTC on 2013 September 18 and 19 (UT). The pixel scale is 0.″08 pixel^{-1}, and the image subtends 5.″12. North is up, east is left, and the quasar images are, starting from top right and moving clockwise, B, D, A, and C, respectively. This image has been smoothed with a Gaussian kernel of σ = 0.″12 in order to improve the contrast relative to the noise.

CanariCam@Nasmyth

Science Domain - Polarimetry

Magnetic Field in the GC
by Roche+2018

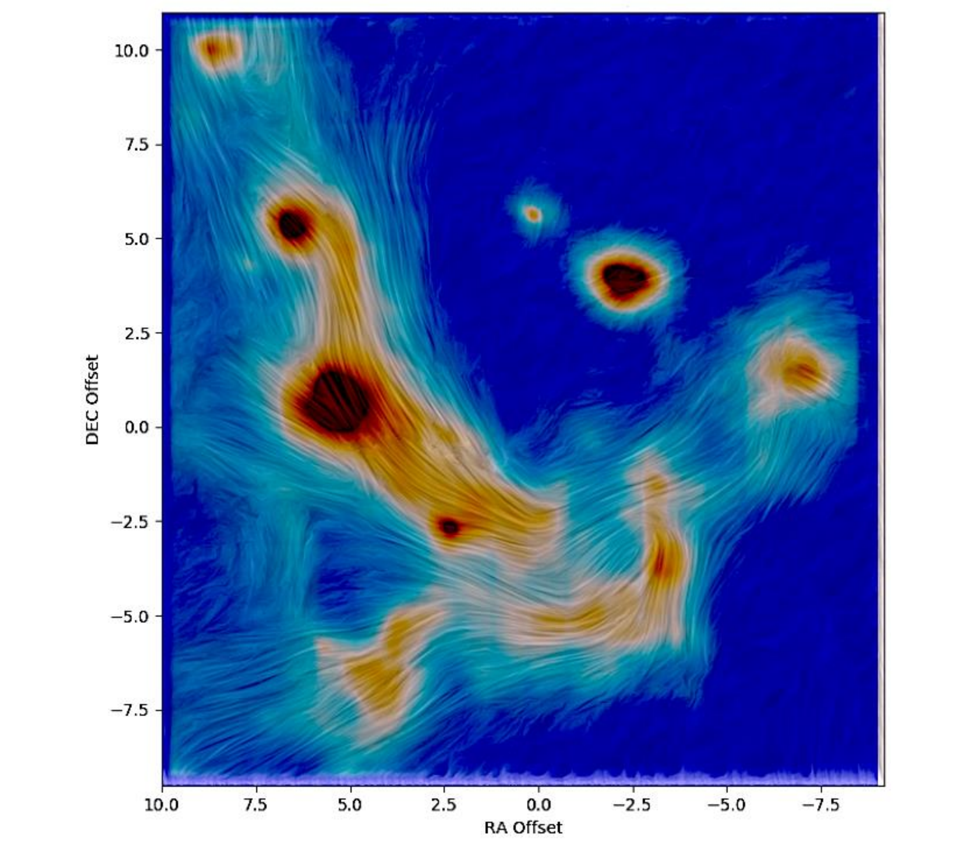


Figure 3. The polarization map of the central 0.75 parsec produced with a line integral convolution to emphasise the coherent structures.

First-ever spectropolarimetry of protoplanetary disks in thermal-IR (WL-16) by Zhang+2016

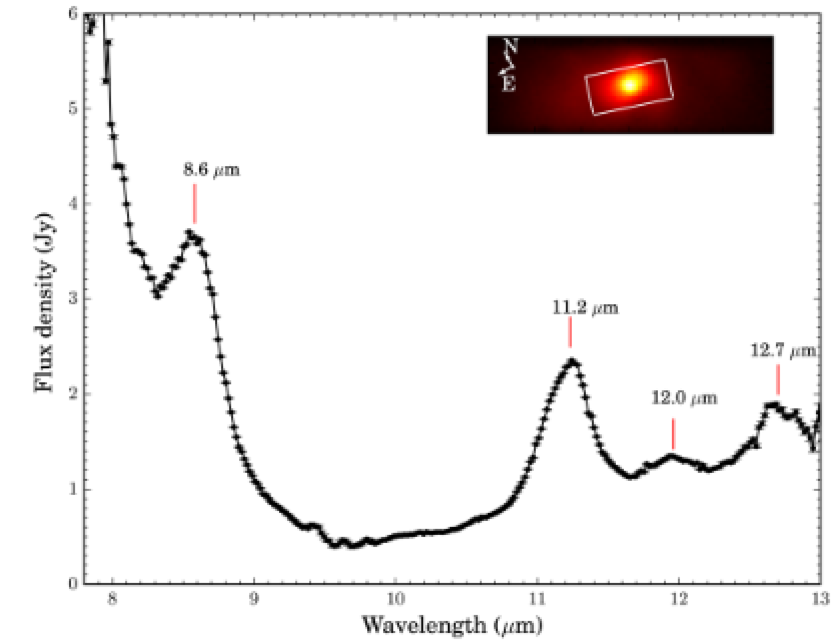


Figure 3. The low-resolution ($R \approx 50$) spectrum of the brightest central 1.6 arcsec (21 pixel) region of WL 16. The slit (white rectangle) is shown on the inset image of WL 16 at 8.7 μm. The raw data were smoothed with a boxcar of 3 pixel (0.06 μm) in width. PAH emission features are seen at 8.6, 11.2, 12.0, and 12.7 μm. The 8.6 μm feature originates from C–H in-plane bending. The 11.2, 12.0, and 12.7 μm features originate from C–H out-of-plane bending.

CanariCam Productivity – 43 papers so far

Year	Authors	Title	Country	Journal	Volume	Page	Instrument	adsLink
2014	Russell et al.	The multiwavelength polarization of Cygnus X-1	ES	MNRAS	438	2083	CANARICAM	http://adsabs.harvard.edu/abs/2014MNRAS.438.2083R
2014	Alonso-Herrero et al.	Nuclear 11.3 mum PAH emission in local active gala...	ES	MNRAS	443	2766	CANARICAM	http://adsabs.harvard.edu/abs/2014MNRAS.443.2766A
2014	López-Rodríguez et al.	Polarized Mid-infrared Synchrotron Emission in the...	US	APJ	793	81	CANARICAM	http://adsabs.harvard.edu/abs/2014ApJ...793...81L
2014	Ramos Almeida et al.	A mid-infrared view of the inner parsecs of the Se...	ES	MNRAS	445	1130	CANARICAM	http://adsabs.harvard.edu/abs/2014MNRAS.445.1130R
2014	Mori et al.	Near- to mid-infrared imaging and spectroscopy of ...	JP	PASJ	66	93	CANARICAM	http://adsabs.harvard.edu/abs/2014PASJ...66...93M
2015	Telesco et al.	Mid-IR Spectra of Type Ia SN 2014J in M82 Spanning...	US	APJ	798	93	CANARICAM	http://adsabs.harvard.edu/abs/2015ApJ...798...93T
2015	García-Bernete	The nuclear and extended infrared emission of the ...	ES	MNRAS	449	1309	CANARICAM	http://adsabs.harvard.edu/abs/2015MNRAS.449.1309G
2015	González-Martín et al.	Nuclear obscuration in LINERs. Clues from Spitzer/...	ES	AA	578	74	CANARICAM	http://adsabs.harvard.edu/abs/2015A%26A...578A..74...
2015	Gauza et al.	Constraints on the substellar companions in wide o...	ES	MNRAS	452	1677	CANARICAM	http://adsabs.harvard.edu/abs/2015MNRAS.452.1677G
2015	Lopez-Rodriguez et al.	Near-infrared polarimetric adaptive optics observa...	US	MNRAS	452	1902	CANARICAM	http://adsabs.harvard.edu/abs/2015MNRAS.452.1902L
2015	Barnes et al.	Magnetic field structures in star-forming regions:...	US	MNRAS	453	2622	CANARICAM	http://adsabs.harvard.edu/abs/2015MNRAS.453.2622B
2015	Martínez-Paredes et al.	A deep look at the nuclear region of UGC 5101 thro...	MX	MNRAS	454	3577	CANARICAM	http://adsabs.harvard.edu/abs/2015MNRAS.454.3577M
2015	Pereira-Santaella et al.	Sub-arcsec mid-IR observations of NGC 1614: Nuclea...	ES	MNRAS	454	3679	CANARICAM	http://adsabs.harvard.edu/abs/2015MNRAS.454.3679P
2016	Alonso-Herrero et al.	A mid-infrared spectroscopic atlas of local active...	ES	MNRAS	455	563	CANARICAM	http://adsabs.harvard.edu/abs/2016MNRAS.455..563A
2016	Licandro et al.	GTC/CanariCam observations of (99942) Apophis	ES	AA	585	10	CANARICAM	http://adsabs.harvard.edu/abs/2016A%26A...585A..10...
2016	González-Martín et al.	X-ray long-term variations in the low-luminosity A...	MX	AA	587	1	CANARICAM	http://adsabs.harvard.edu/abs/2016A%26A...587A...1...
2016	López-Rodríguez et al.	Mid-infrared imaging- and spectro-polarimetric sub...	US	MNRAS	458	3851	CANARICAM	http://adsabs.harvard.edu/abs/2016MNRAS.458.3851L
2016	Alonso-Herrero et al.	The complex evolutionary paths of local infrared b...	ES	MNRAS	463	2405	CANARICAM	http://adsabs.harvard.edu/abs/2016MNRAS.463.2405A
2016	García-Bernete et al.	The nuclear and extended mid-infrared emission of ...	ES	MNRAS	463	3531	CANARICAM	http://adsabs.harvard.edu/abs/2016MNRAS.463.3531G
2016	Vives-Arias et al.	Observations of the Lensed Quasar Q2237+0305 with ...	ES	APJ	831	43	CANARICAM	http://adsabs.harvard.edu/abs/2016ApJ...831...43V
2016	Li et al.	An Ordered Magnetic Field in the Protoplanetary Di...	ES	APJ	832	18	CANARICAM	http://adsabs.harvard.edu/abs/2016ApJ...832...18L
2017	López-Rodríguez et al.	Infrared polarimetry of Mrk 231: scattering off ho...	US	MNRAS	464	1762	CANARICAM	http://adsabs.harvard.edu/abs/2017MNRAS.464.1762L
2016	Riaz et al.	A Multiwavelength Characterization of Proto-brown-...	DE	APJ	831	189	CANARICAM	http://adsabs.harvard.edu/abs/2016ApJ...831..189R
2017	Zhang et al.	The mid-infrared polarization of the Herbig Ae sta...	US	MNRAS	465	2983	CANARICAM	http://adsabs.harvard.edu/abs/2017MNRAS.465.2983Z
2017	Ruschel-Dutra, D. et al.	Star formation in AGNs at the hundred parsec scale...	ES	MNRAS	466	3353	CANARICAM	http://adsabs.harvard.edu/abs/2017MNRAS.466.3353R
2017	Martínez-Paredes et al.	The dusty tori of nearby QSOs as constrained by hi...	MX	MNRAS	468	2	CANARICAM	http://adsabs.harvard.edu/abs/2017MNRAS.468....2M
2017	Zhang et al.	Detection of Polarized Infrared Emission by Polycy...	US	APJ	844	6	CANARICAM	http://adsabs.harvard.edu/abs/2017ApJ...844....6Z
2017	García-González et al.	A mid-infrared statistical investigation of clumpy...	ES	MNRAS	470	2578	CANARICAM	http://adsabs.harvard.edu/abs/2017MNRAS.470.2578G
2018	Li et al.	Mid-infrared polarization of Herbig Ae/Be discs	US	MNRAS	473	1427	CANARICAM	http://adsabs.harvard.edu/abs/2018MNRAS.473.1427L
2018	Díaz-Luis et al.	GTC/CanariCam Mid-IR Imaging of the Fullerene-rich...	ES	AJ	155	105	CANARICAM	http://adsabs.harvard.edu/abs/2018AJ....155..105D
2018	Roche et al.	The magnetic field in the central parsec of the Ga...	UK	MNRAS	476	235	CANARICAM	http://adsabs.harvard.edu/abs/2018MNRAS.476..235R
2018	Taha et al.	The spatial extent of polycyclic aromatic hydrocar...	DE	AA	612	15	CANARICAM	http://adsabs.harvard.edu/abs/2018A%26A...612A..15...
2018	Esparza-Arredondo et al.	Circumnuclear Star Formation and AGN Activity: Clu...	MX	APJ	859	124	CANARICAM	http://adsabs.harvard.edu/abs/2018ApJ...859..124E
2018	López-Rodríguez et al.	The origin of the mid-infrared nuclear polarizatio...	US	MNRAS	478	2350	CANARICAM	http://adsabs.harvard.edu/abs/2018MNRAS.478.2350L
2019	Saikia et al.	Modelling the mid-infrared polarization in dust ar...	IN	MNRAS	484	3582	CANARICAM	http://adsabs.harvard.edu/abs/2019MNRAS.484.3582S
2019	Fernández-Ontiveros et al.	A compact jet at the infrared heart of the prototy...	ES	MNRAS	485	5377	CANARICAM	https://ui.adsabs.harvard.edu/abs/2019MNRAS.485.53...
2019	Martínez-Paredes et al.	Quantifying Star Formation Activity in the Inner 1...	MX	APJ	871	190	CANARICAM	https://ui.adsabs.harvard.edu/abs/2019ApJ...871..1...
2018	Maucó et al.	Herschel PACS Observations of 4-10 Myr Old Classic...	MX	APJ	859	1	CANARICAM	https://ui.adsabs.harvard.edu/abs/2018ApJ...859......
2018	Díaz-Luis et al.	Study of Fullerene-based Molecular Nanostructures ...	ES	PASP	130	994	CANARICAM	https://ui.adsabs.harvard.edu/abs/2018PASP..130l70...
2017	González-Martín et al.	Hints on the Gradual Resizing of the Torus in AGNs...	MX	APJ	841	37	CANARICAM	https://ui.adsabs.harvard.edu/abs/2017ApJ...841......
2019	Benítez et al.	Multiwavelength observations of the triple-peaked ...	MX	MNRAS	490	5521	CANARICAM	https://ui.adsabs.harvard.edu/abs/2019MNRAS.490.55...
2020	Roche et al.	High resolution imaging of the magnetic field in t...	UK	P&SS	183	104578	CANARICAM	https://ui.adsabs.harvard.edu/abs/2020P%26SS..1830...

841,67 h delivered

Despite the inherent lower efficiency in ground-based thermal-IR observing, the ratio is good at **19.5 h/paper**

(23 h/paper for TAC programs, 6 h/paper for DDT, 12 h/paper for ESO-GTC large program)

CanariCam@Nasmyth

Instrument Performance

http://www.gtc.iac.es/instruments/canaricam/

Sensitivity Estimates (from commissioning and science programs)

	Accumulation		Shift and add →		
Filter	FWHM (")	Sensitivity (mJy, 5-σ in 30min on-source)	FWHM (")	Sensitivity (mJy, 5-σ in 30min on-source)	PWV (mm)
Si1-7.8	0.24	6.94	0.24	5.42	7.2
Si2-8.7	0.25	2.15	0.25	1.01	7.2
Si3-9.8	0.25	3.00			
Si4-10.3	0.28	2.69			
Si5-11.6	0.30	3.02			
Si6-12.5	0.34	6.43			
Q1-17.65	0.44	22.81			
PAH1-8.6	0.25	2.03			
ArIII-8.99	0.26	5.29			
SIV-10.5	0.29	5.02			
PAH2-11.3	0.33	3.38			
SiC-11.75	0.32	3.57			
NeII-12.8	0.33	8.46			
NeII_ref2-13.1	0.34	8.73			
QH2-17.0	0.44	50.10			
Q4-20.5	0.50	33.32			
Q8-24.5	0.59	95.62			

"Shift&Add" used with bright point sources to overcome IQ inestabilities and **the lack of Fast Guiding** (until late 2015)

CanariCam: Sensitivity vs. long integrations from ESO/GTC large programme

Examples with long integrations with the Si2-8.7 filter using aperture photometry measured with 1"-diameters. PWV values are old uncalibrated ones

EXTENDED SOURCES:

NGC5793 – on-source 15minutes, flux 18.2+/-0.7mJy (SNR=26), 5σ 3.5mJy => 30 minutes on-source, 5σ 2.5mJy **PWV=4.5-5**

UGC5101 – on-source 20minutes, flux 54+/-0.4mJy (SNR=135), 5σ 2mJy => 30 minutes on-source 5σ 1.6mJy (no point-source corr.) PWV=5.9

POINT SOURCES:

NGC5347 – on-source 15 minutes 91.9+/-0.6mJy, 114 mJy point source (SNR=190), **5σ 3mJy => 30 minutes on-source 5σ 2mJy PWV=4.5-5**

NGC3227 – on-source 15 minutes 150.1+/-0.5mJy, 225 mJy point source (SNR=450), **5σ 2.5mJy => 30 minutes on-source 5σ 1.8mJy PWV=5.9**

Alonso-Herrero et al.

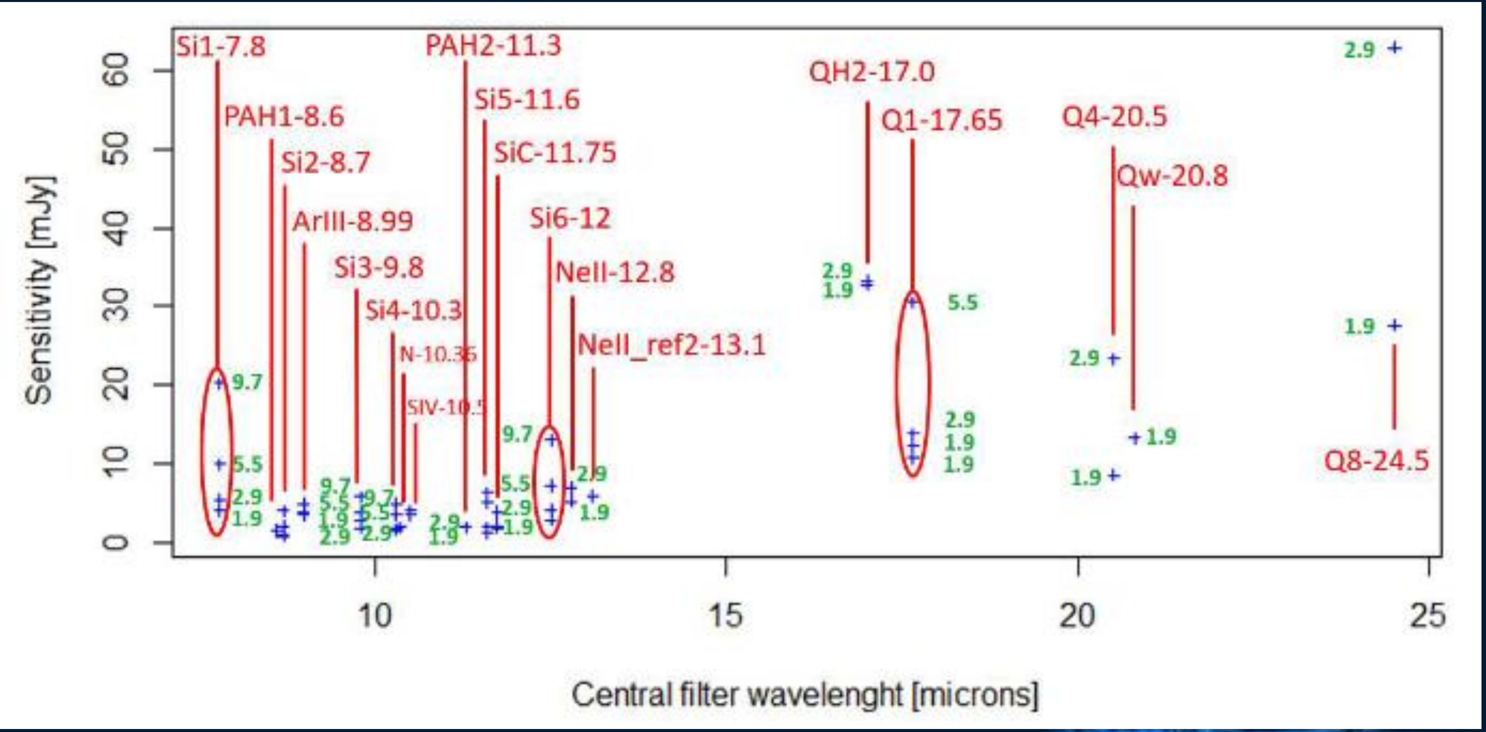
CanariCam@Nasmyth

Instrument Sensistivity vs PWV (corrected calibration)

Sensitivity Estimates (from commissioning and science programs)

Perez-Jordan 2018

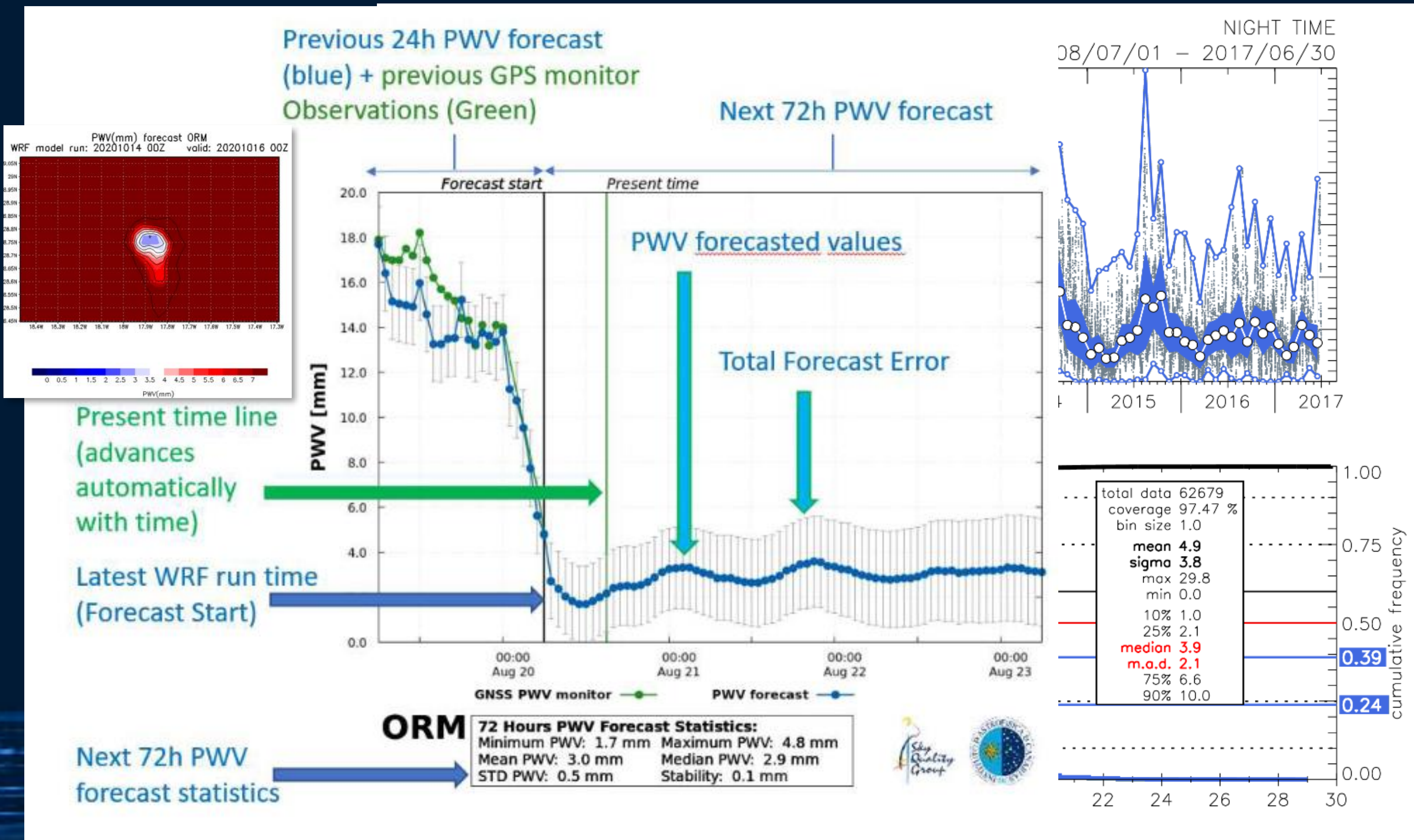
(Master Thesis available in the CanariCam web page)



CANARICAM estimated sensitivity (in mJy) for a 5-σ detection in a 30-min on-source time as a function of wavelength and night mean measured PWV. Data points are stacked up at each filter central wavelength, as shown in the figure in red (filter name and central wavelength). For a certain filter, the sensitivity values correspond to different dates with different PWV measured by the GPS monitor (PWV values in milimeters in green colour), with higher values of sensitivity (thus, poorer) at higher PWV. For the sake of clarity, the PWV has been included only for certain points

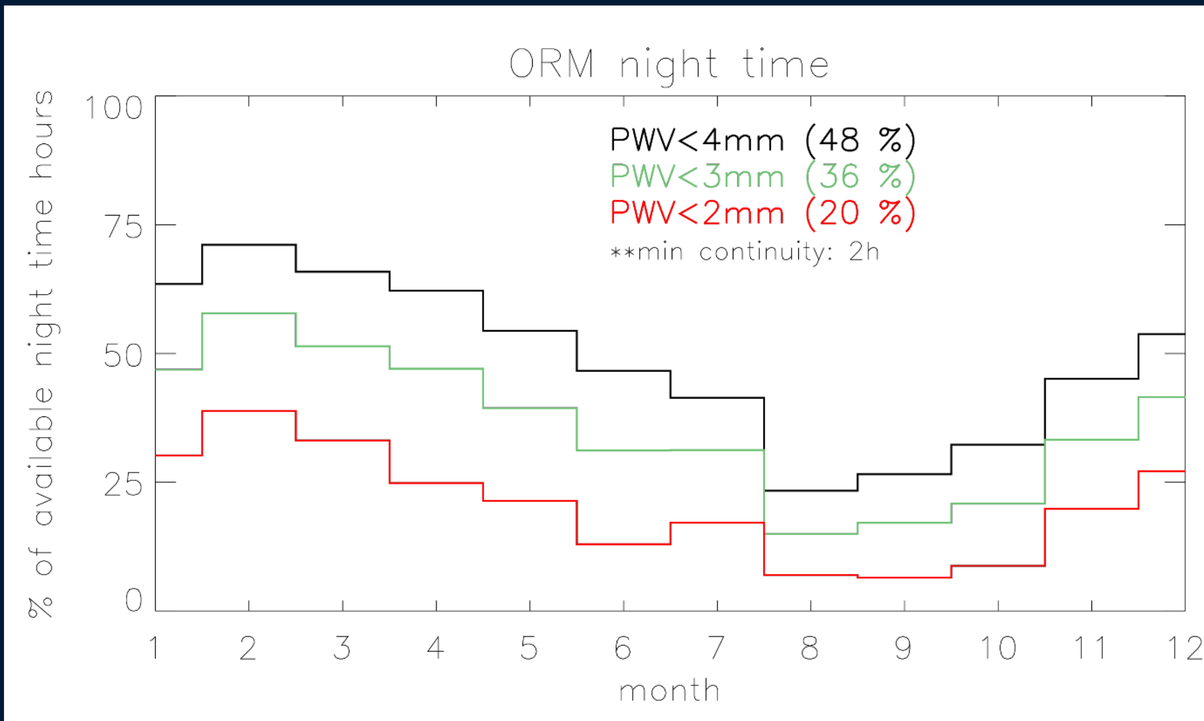
CanariCam@Nasmyth

PWV monitoring and forecasting at the ORM site –> Flexible queue scheduling



CanariCam@Nasmyth

PWV stability



			GPM_OT		GPM_ORM	
Threshold	Synoptic	Stability	Time availability			
(mm)		(h)	(h/a)	(%)	(h/a)	(%)
< 2	optimal	0.5	959	30	836	24
< 2	optimal	2	877	27	731	20
< 2	optimal	6	603	18	471	13
< 3	excellent	0.5	1471	46	1358	39
< 3	excellent	2	1367	42	1263	36
< 3	excellent	6	1089	33	989	28
< 4	valid	0.5	1790	56	1776	51
< 4	valid	2	1766	55	1710	48
< 4	valid	6	1496	46	1437	41

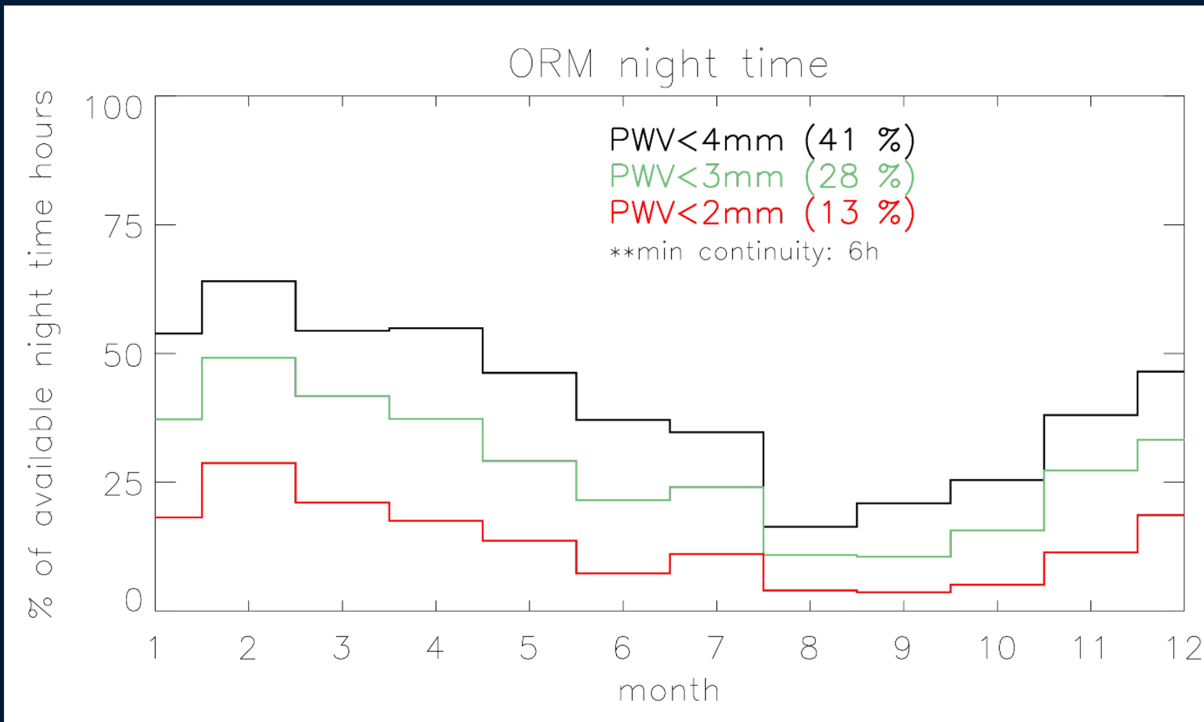
TABLE 5.1: Stability yearly times by thresholds for GPM_OT and GPM_ORM.

Information provided by the IAC Sky Quality Group (2018)

For further information about this system (monitoring and forecasting), its calibration and results, see Perez-Jordan+ 2015 and 2018, Castro-Almazan+ 2016

CanariCam@Nasmyth

PWV stability



Threshold (mm)	Synoptic	Stability (h)	GPM_OT Time availability (h/a)	(%)	GPM_ORM (h/a)	(%)
< 2	optimal	0.5	959	30	836	24
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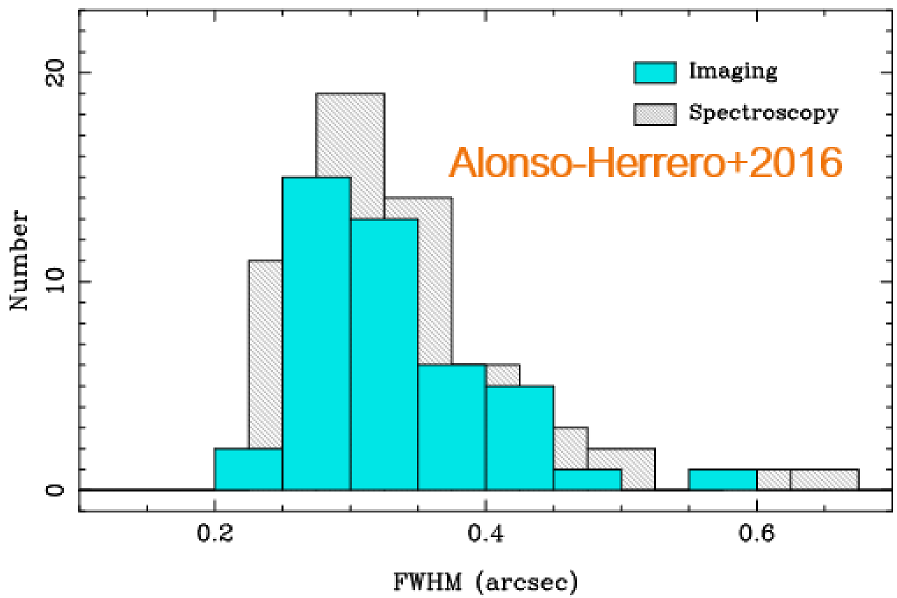
CanariCam@Nasmyth

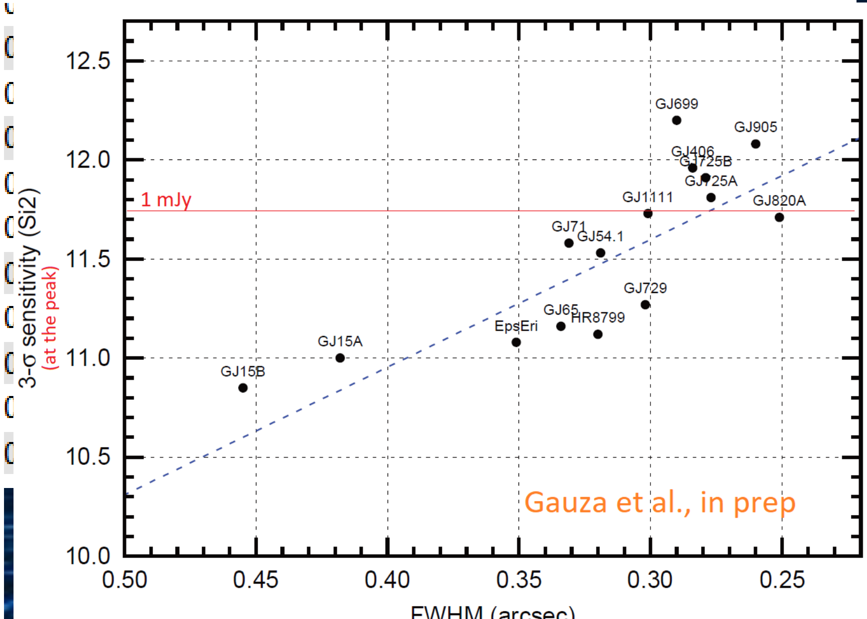
Instrument sensitivity vs IQ

8” chop-nod – 2 seconds saveset

	Accumulation		
Filter	Ellip.	FWHM (")	Strehl
Si1-7.8	0.04	0.24	0.21
PAH1-8.6	0.05	0.25	0.24
Si2-8.7	0.04	0.25	0.29
ArIII-8.99	0.05	0.26	0.22
Si3-9.8	0.03	0.25	0.39
Si4-10.3	0.03	0.28	0.32
SIV-10.5	0.06	[illegible]	0.27

Chopping	Reduction	FWHM	Sensitivity (mJy)
Symmetric 20"	Stacking	0.32	1.05
Asymmetric 20"	Stacking	0.40	1.75
Symmetric 10"	Stacking	0.27	0.86
Asymmetric 10"	Stacking	0.39	1.47
Symmetric 20"	Registration	0.26	0.63
Asymmetric 20"	Registration	0.35	1.15
Symmetric 10"	Registration	0.26	0.62
Asymmetric 10"	Registration	0.31	0.79





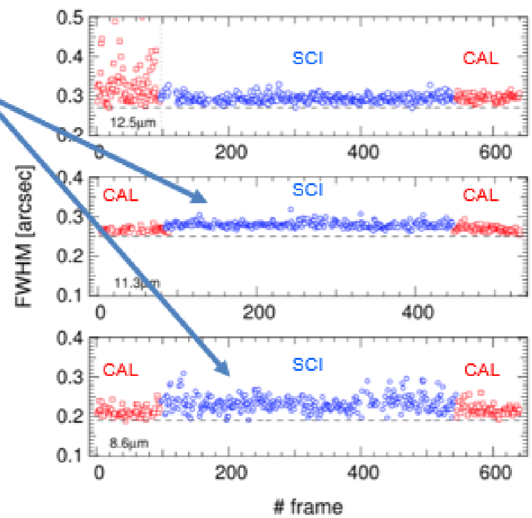
CanariCam@Nasmyth

Science with demanding IQ constraints still possible

Taha, Labadie, Pantin et al., A&A 612, A15 (2018)

- **PAHs** Observations with CanariCam/GTC in the **PAH-1** (8.7µm), **PAH-2** (11.3µm) and **Si-6** (continuum, 12.5µm)
- Seeing of 0.5″ to 0.6″ delivers **~90% Strehl** with FWHM ranging from 210 mas to 300 mas and d(HD179218) = 290pc

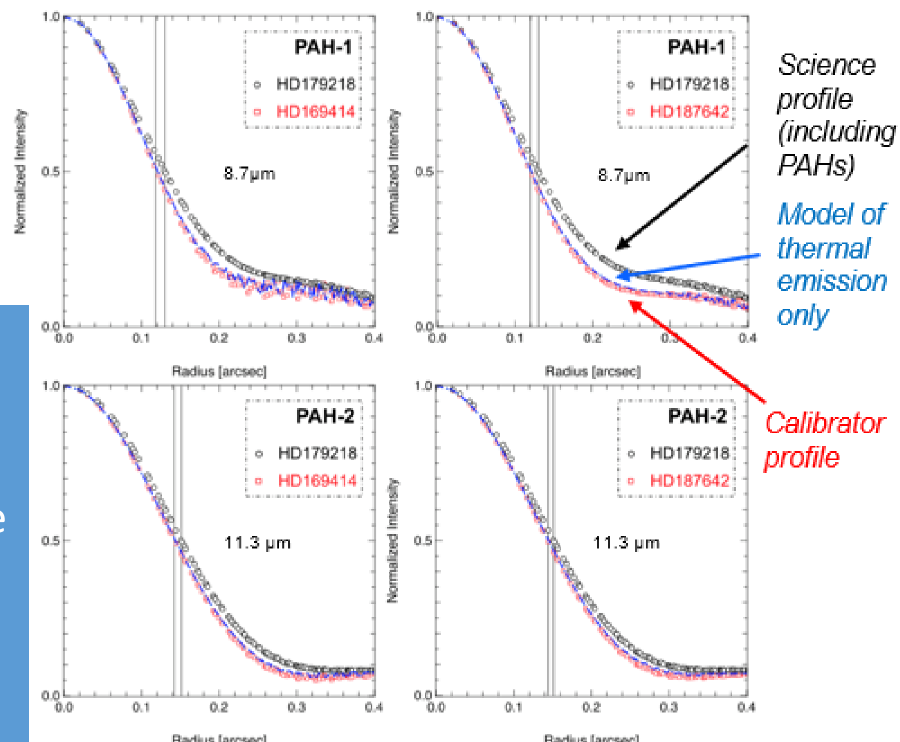
Distribution of FWHM from individual frames with T_int = 2s



Filter	$FWHM_{sci} - FWHM_{cal}$	$3\sigma_{tot}$	Resolved
PAH-1	0.019/0.022 (Cal 1)	0.005/0.004	Y
PAH-1	0.015/0.021 (Cal 2)	0.005/0.004	Y
PAH-2	0.013/0.016 (Cal 1)	0.002/0.002	Y
PAH-2	0.012/0.013 (Cal 2)	0.002/0.002	Y
Si-6	0.001/0.002 (Cal 2)	0.002/0.004	N

PAH emission is spatially resolved

Thermal emission is unresolved

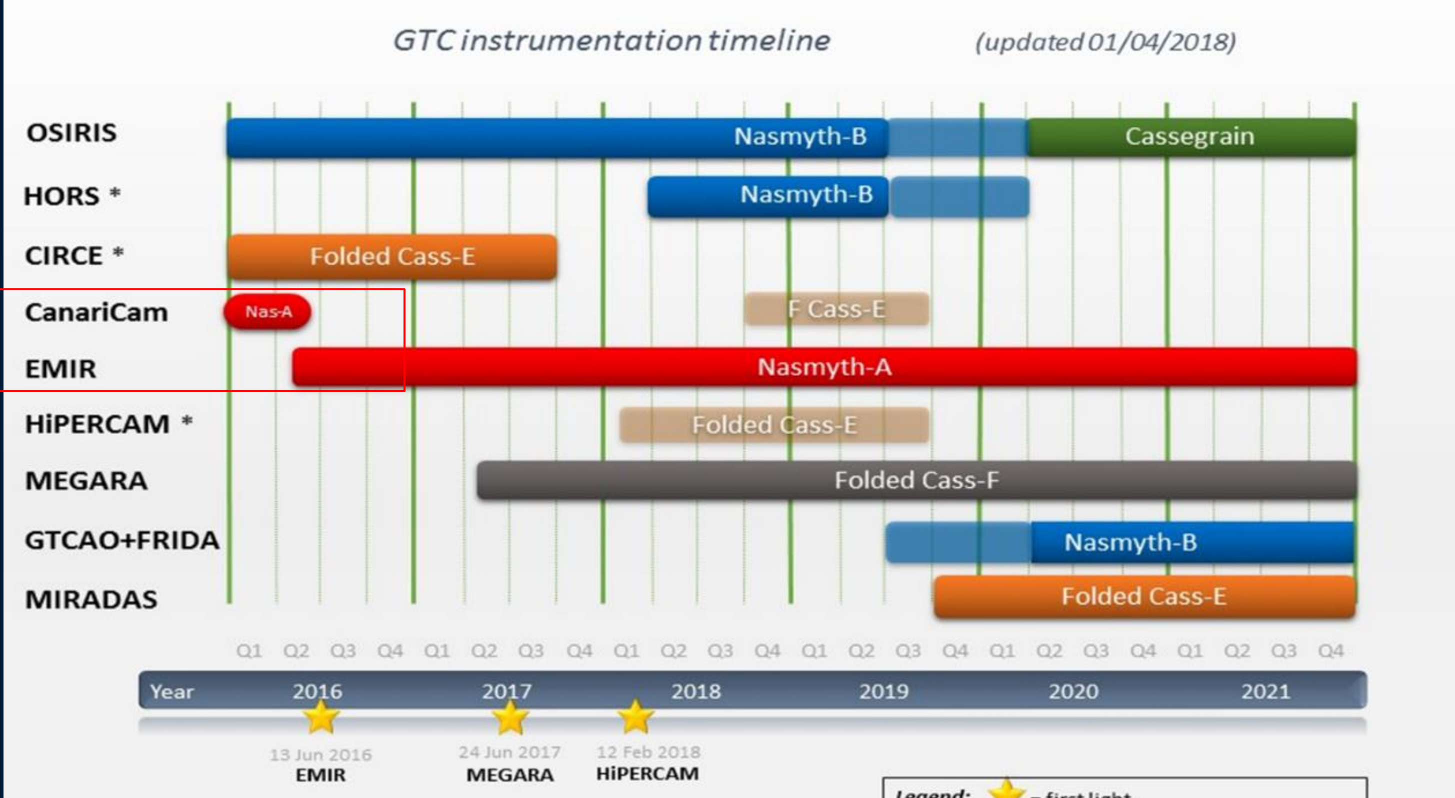


This study has exploited the high-resolution capabilities of CanariCam/GTC to explore the spatial distribution of the PAHs species in the archetypal disk of the Herbig star HD179218 and put that in relation with the predominant charge state of these particles (neutral vs. ionized) as probed by spectroscopy

CanariCam@Nasmyth

Decommissioning in April 2016

To make room for EMIR

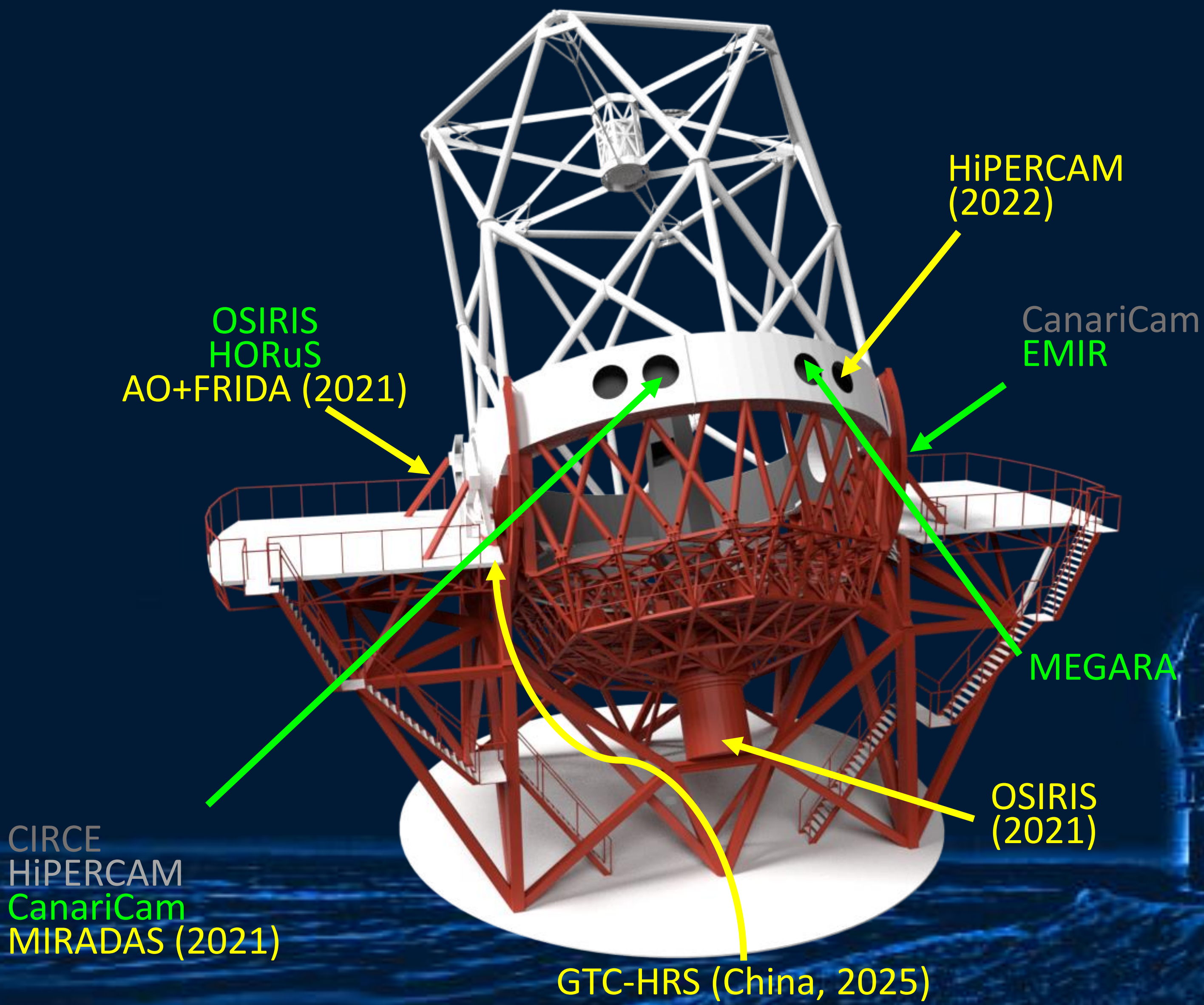


Demanding Instrumentation Program!

(7 instruments in the first decade + 3 coming)

The GTC focal stations and scientific instruments

Staffing Level ~ 60-70 FTE including astronomers, engineers (operations and development), technicians and administrative (LP & TF)



CanariCam Upgrade Project
(2018-2019)

Upgrade Project - Motivation

- New Focal Station:
  - Nasmyth-A → Folded-Cass-E (smaller & tight envelope)
- Fix issues
  - Engineering (reliability & FMECA analysis) => Main technical problem with CanariCam was the cryocooler and the He infrastructure!!! (maintenance every 3-4 months)

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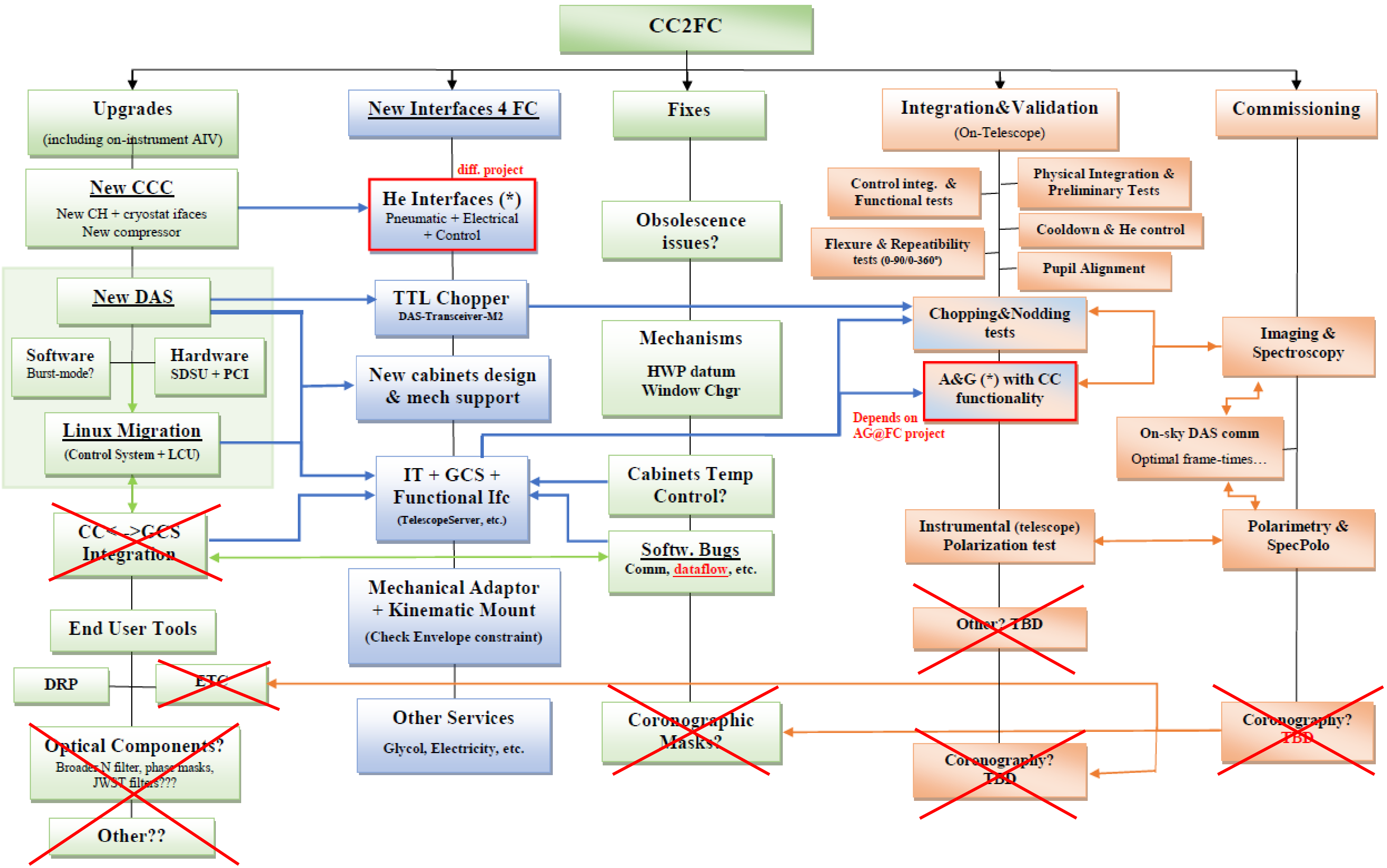
  - Other operational problems and pitfalls: fault reports analyzed to prioritize their possible solutions
- Obsolescence
  - Old detector electronics (MCE heritage from T-ReCS from the 90's)
  - Obsolete COTS
- New science/modes
  - Burst-mode, coronography, additional filters (JWST), etc.

Upgrade Project - Conceptual WBS



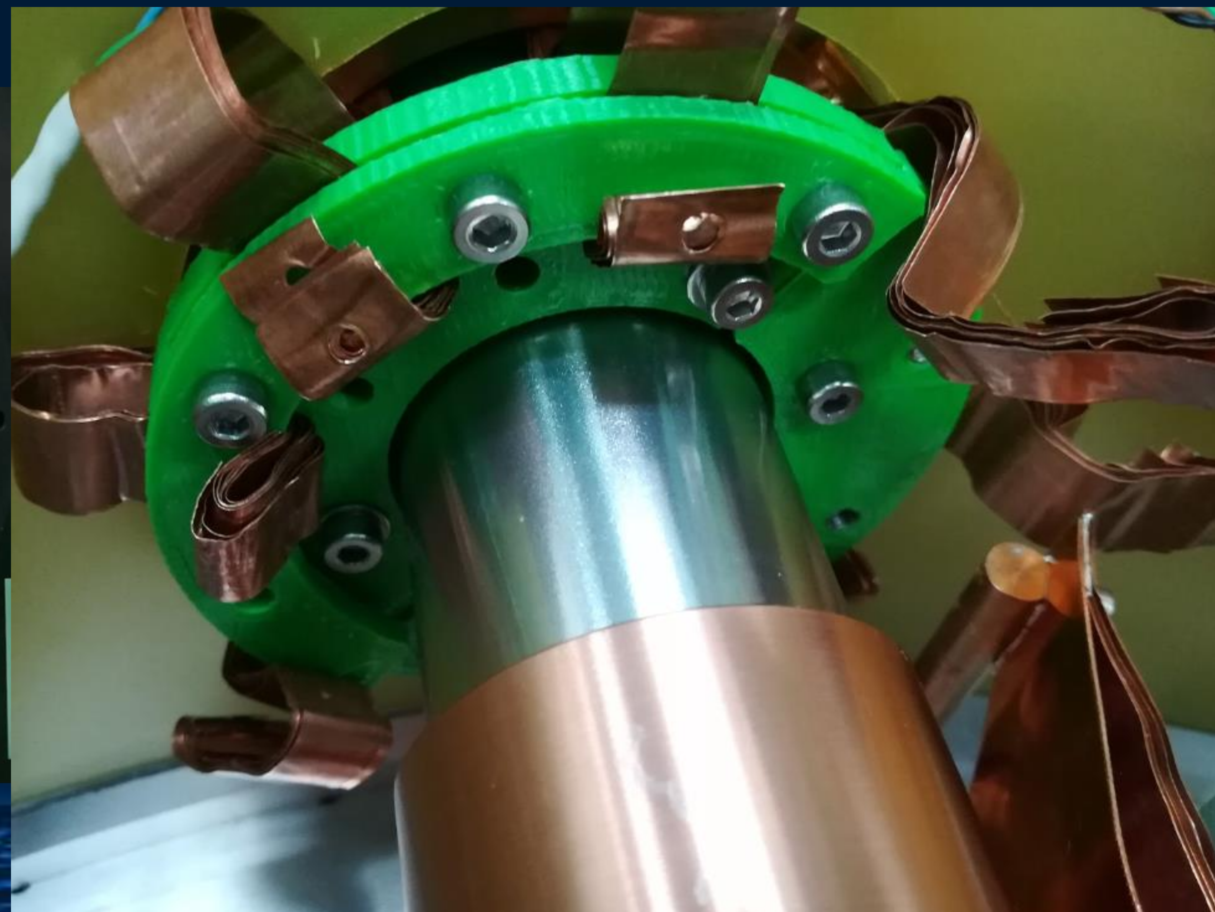
Upgrade Project - Collaboration Agreement signed with UF

- Project Constraints
  - ITAR (IR detectors ~ munition): CanariCam Export License from the US
  - Limited Resources at GTC => need for outsourcing
  - Time (funding delay left small opportunity window) => de-scoping options
  - Contracting/Funding applicable Policies
- Sole-Source "contract" => Collaboration Agreement signed with UF (in April 2018)
  - Requirements (Non-Profit, common goal and shared contribution)
  - WPs distribution based on expertise, availability of resources, constraints and minimizing external interfaces
  - SOW
- Major Risks and challenges
  - Distributed work on a common (remote) system => shared interfaces
  - "Shared" responsibilities
  - Timeframe => shortcut adopted; from CoD to FD and Realization altogether
- Opportunities
  - Close Collaboration (and it worked well to its full extent, and beyond…)

Upgrade Project - Collaboration Agreement

- New SUMITOMO Cryocooler (SRDK-415)

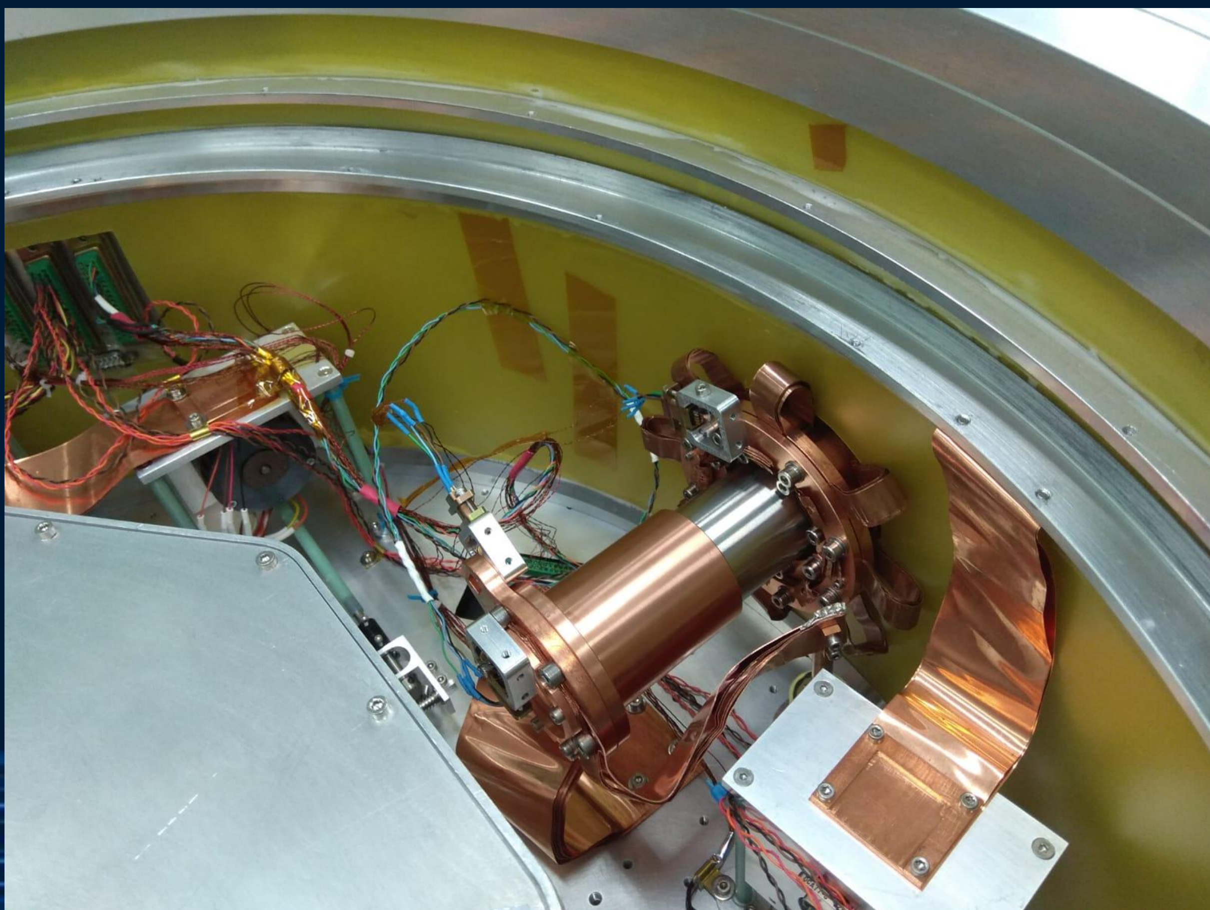
Mechanical and thermal interfaces designed by UF+GTC. 3D-printed parts to fine-tune and validate them before fabrication in the US (thermal conductance vs clearance).



Upgrade Project - Collaboration Agreement

- New Cryocooler + (monitoring, safety and automatic control system)

Successful SUMITOMO RDK-415D 4K coldhead (+ F-50H compressor). It has been operating **1+ year trouble-free with excellent performance** (<4K).



Sensor Name	Temperature		Plot
Detector	+06.835	K	☐
Cold Finger	+06.664	K	☐
Cold Head #2	03.884	K	☐
Cold Plate in ...	10.231	K	☐
Dark Box Wall	11.219	K	☐
Cold Plate Ce...	11.796	K	☐
Cold Head #1	32.700	K	☐
Lyot Motor	06.121	K	☐
Grating Motor	62.091	K	☐
Passive Shield	234.61	K	☐
Pressure	1.37E-08	Torr	☐

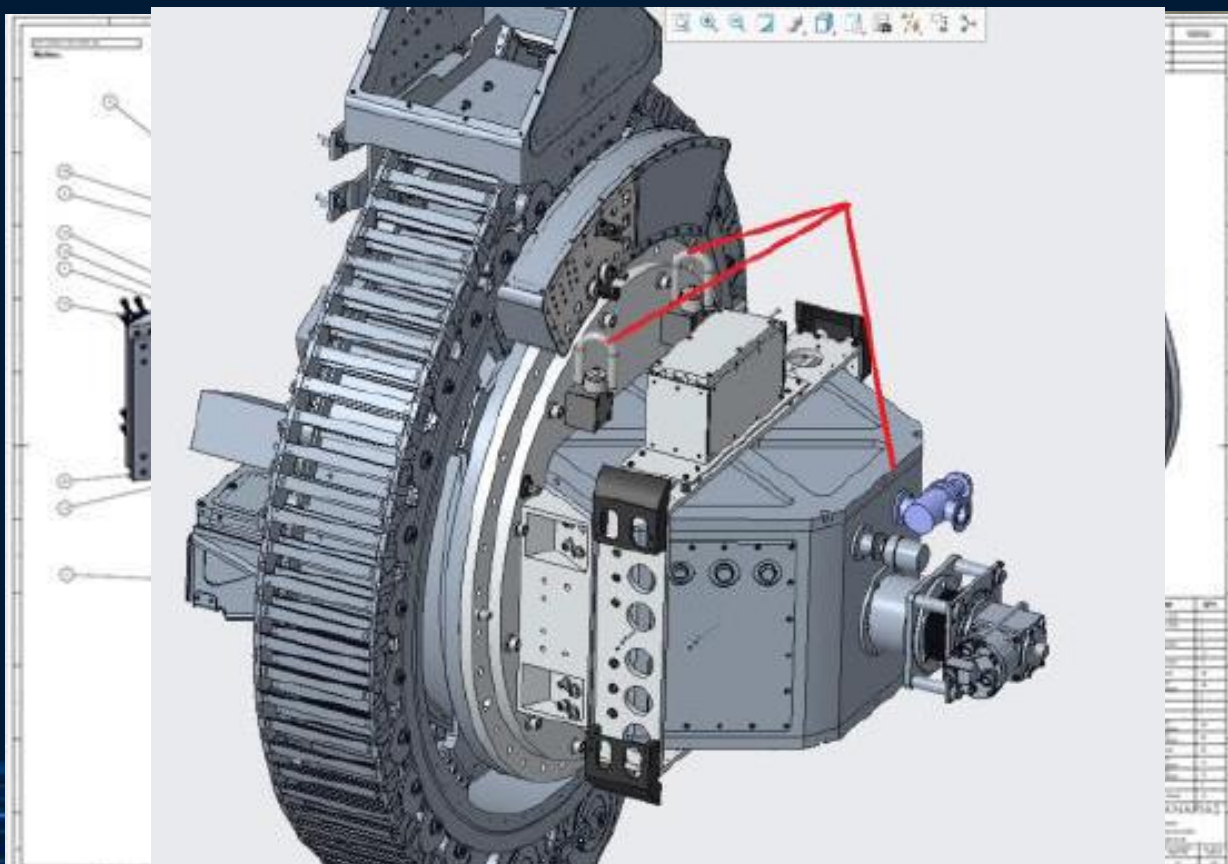
Red == Warm, OK to o...
Orange == In Transition
Blue == Cold, OK for o...

☐ Auto Scale
☑ Show Grid

Upgrade Project - Collaboration Agreement

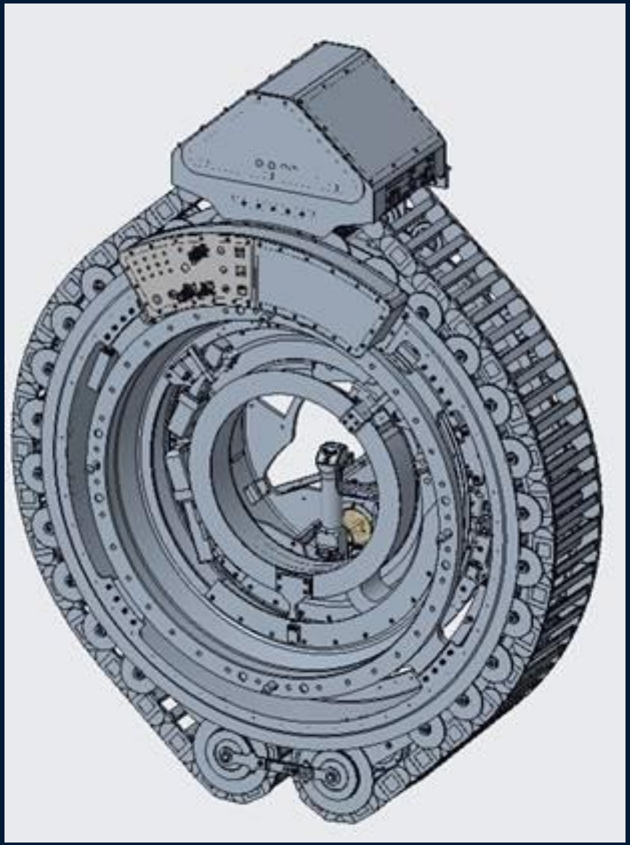
- New Flange for Folded-Cass (+ Handling Cart not anticipated at CoDR)

New (opto)mechanical interface with tip/tilt adjustment mechanism required new handling cart (to ensure quick&repeatable pupil alignment).



Upgrade Project - Collaboration Agreement

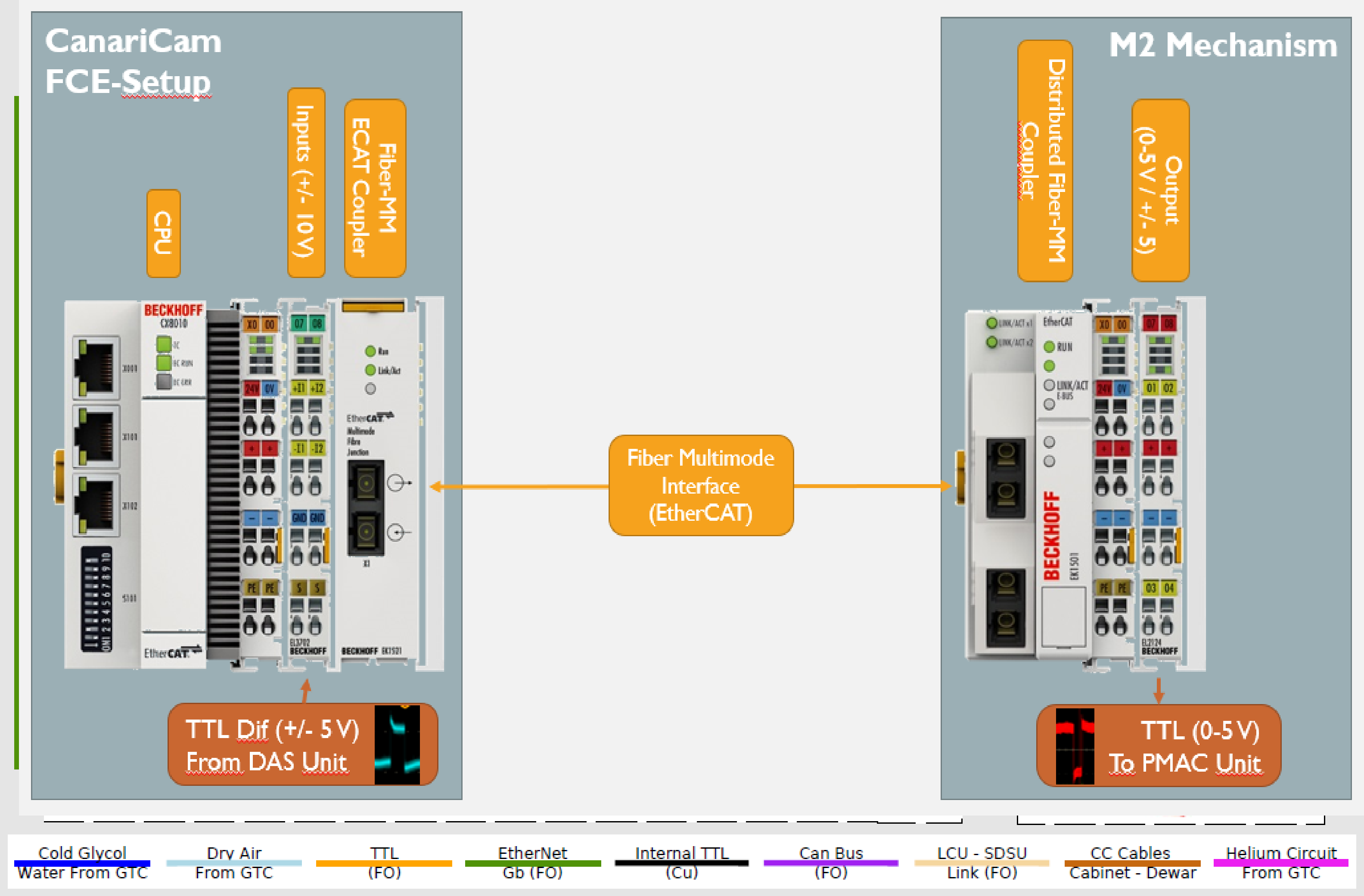
- Reduction of Window Changer envelope (to avoid interference with AG arm)



Upgrade Project - Collaboration Agreement

- New Chopper Interface (CPU prototype / TTL transceiver)

Compatible with old and new DAS from any place within the facility



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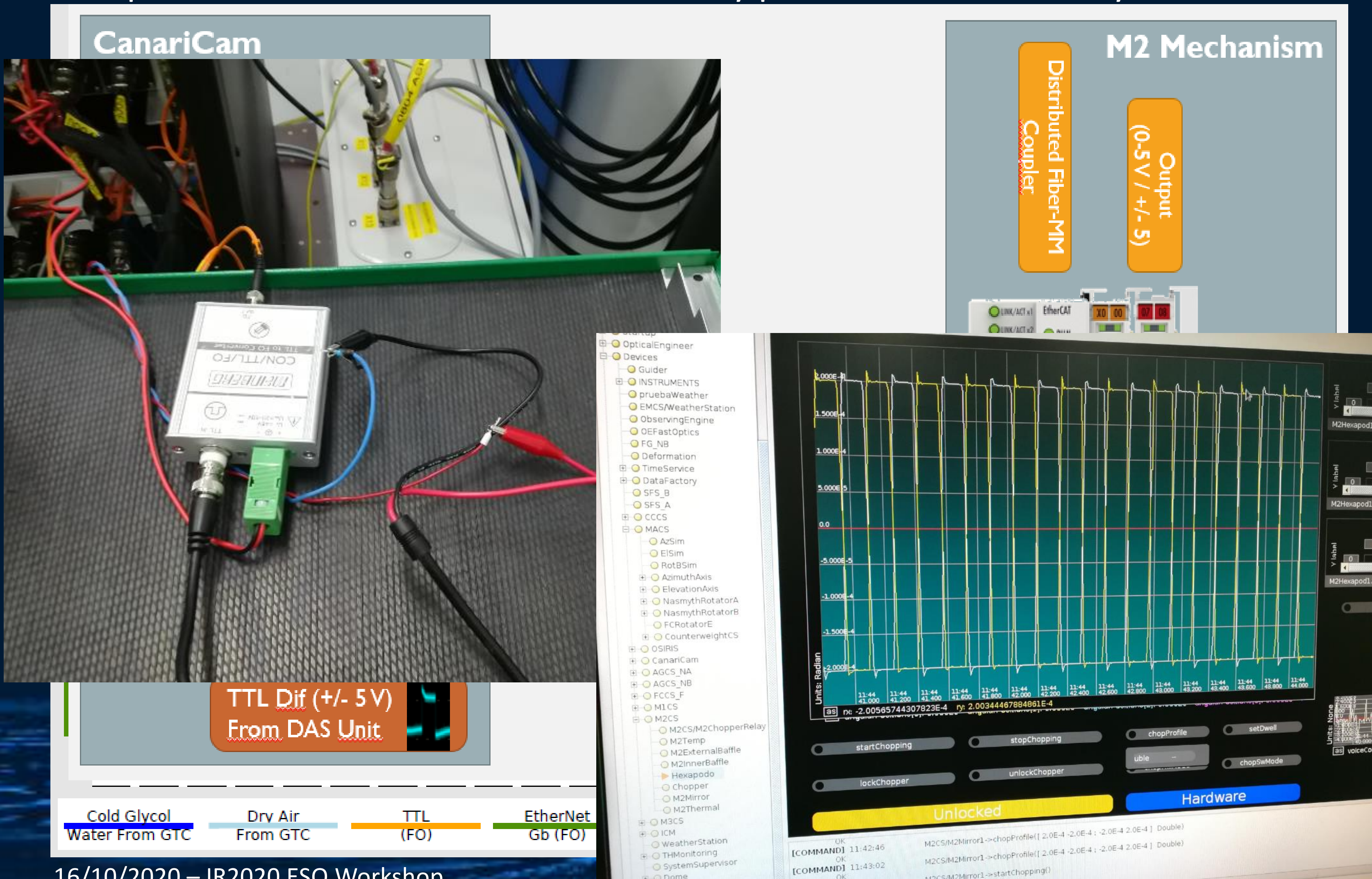
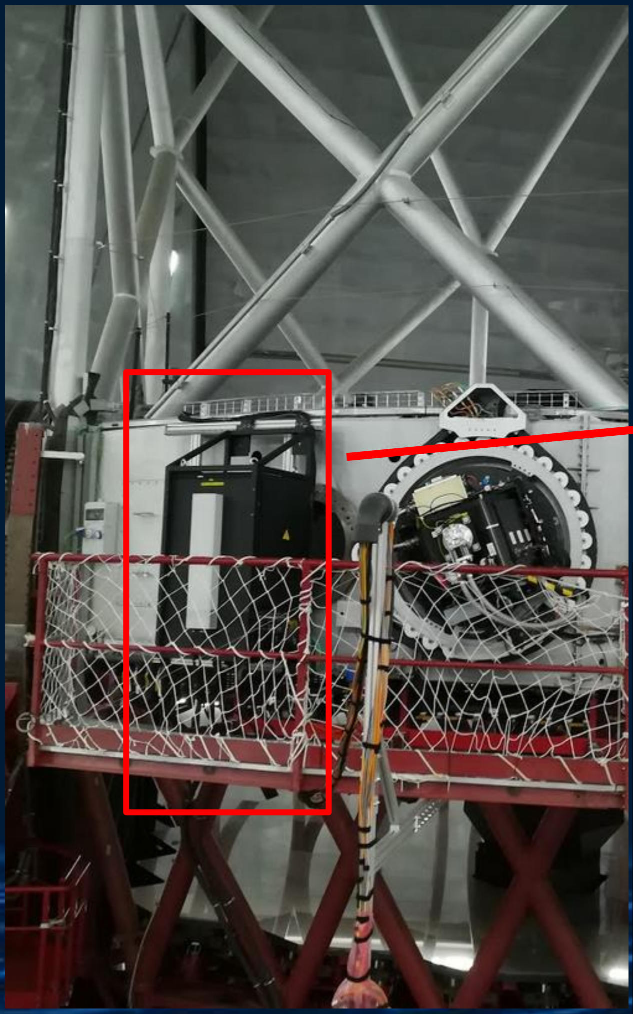
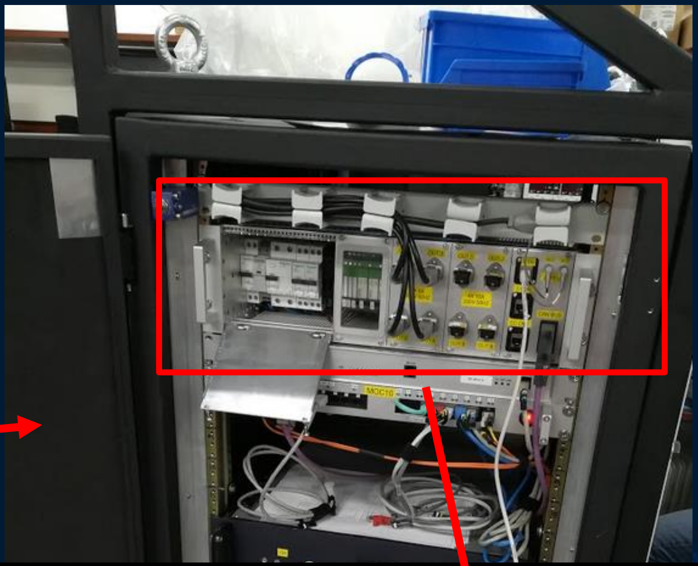
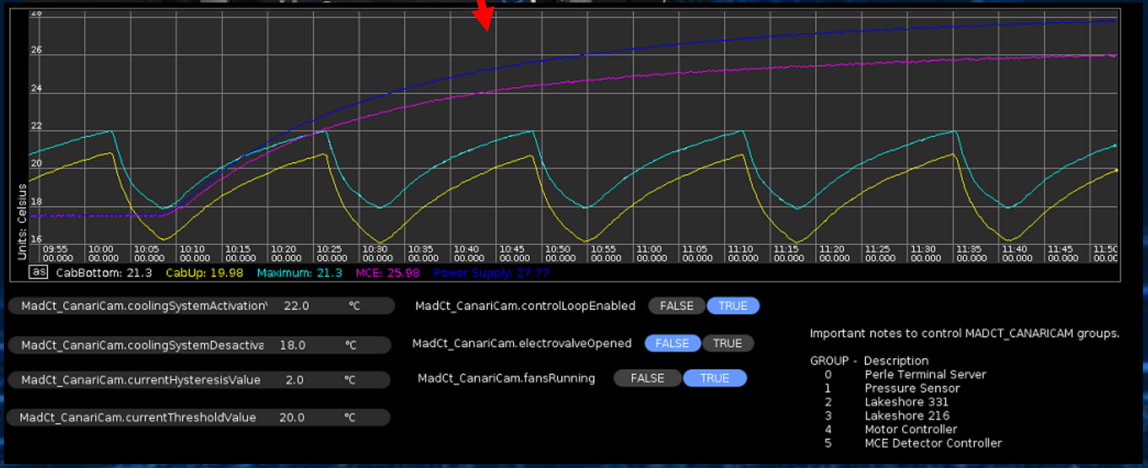


Upgrade Project - Collaboration Agreement

- New Fixed (non-rotating) Cabinet and MADCT device (Thermal Control and Remote Power unit – prototype for future systems based on Beckhoff PLCs)





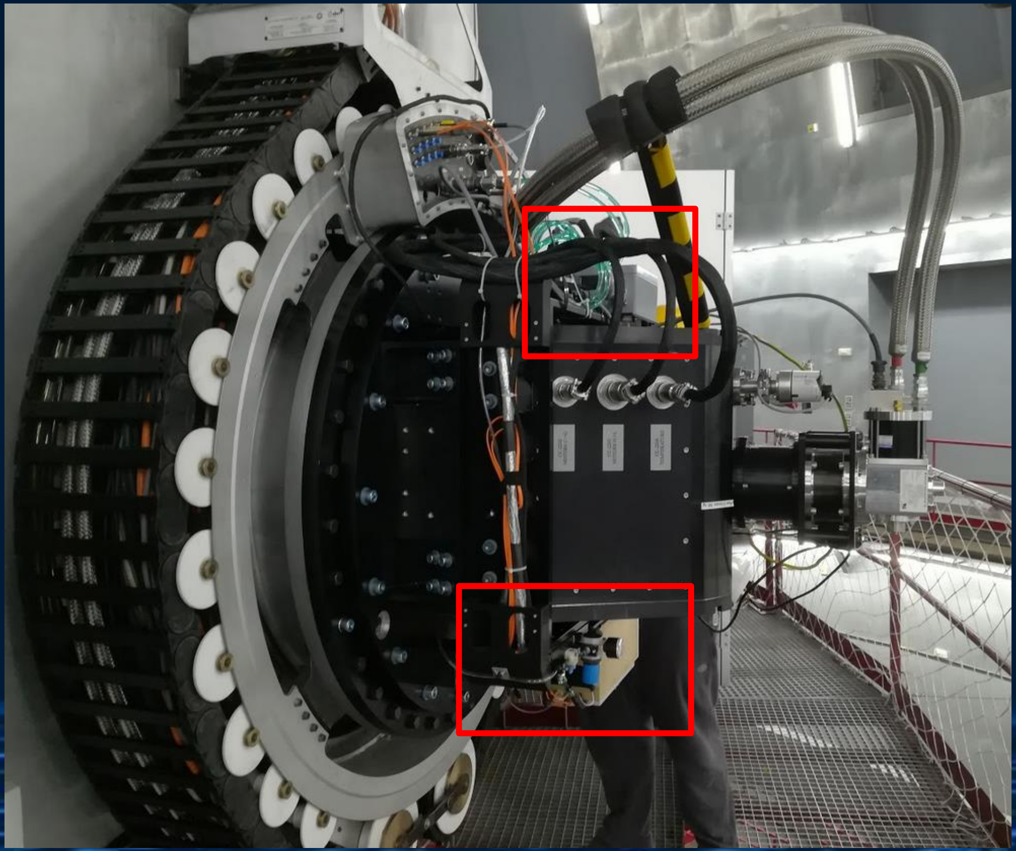


Upgrade Project - Collaboration Agreement

- New DAS (SDSU Detector Controller + x86 Linux)

Its development took much longer than anticipated (installed on telescope in Sep2019)

MCE sweet point -> SDSU tuning was troublesome (noise & artifacts!)



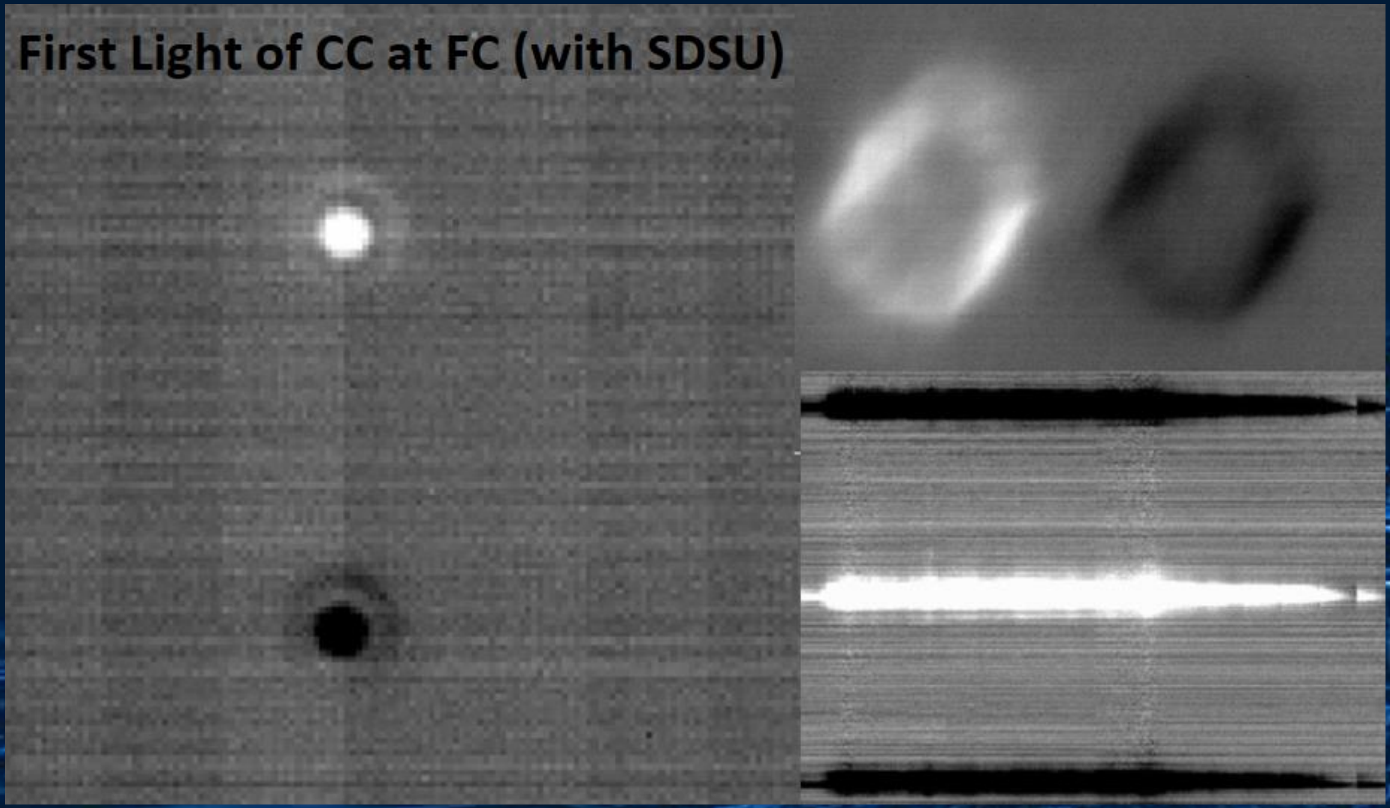
Remaining issues/features:

- CDS (S1R1-CR) only (not CQS S1R3)
- Horizontal stripes and pickup noise
- Shallow well only
- Poorer linearity and lower dynamic range (only uncovered during commissioning)

Upgrade Project - Collaboration Agreement

- New DAS (SDSU Detector Controller + x86 Linux) recommissioning #1 (oct2019)

- Burst-Mode (saving all individual frames down to 18ms) worked well!
- Chopping-Nodding worked well out-of-the-box and with Fast Guiding!
- Shot noise dominated for most science cases, and post-processing technique was available to eliminate patterns of CDS readout… <u>except for Polarimetry!</u>



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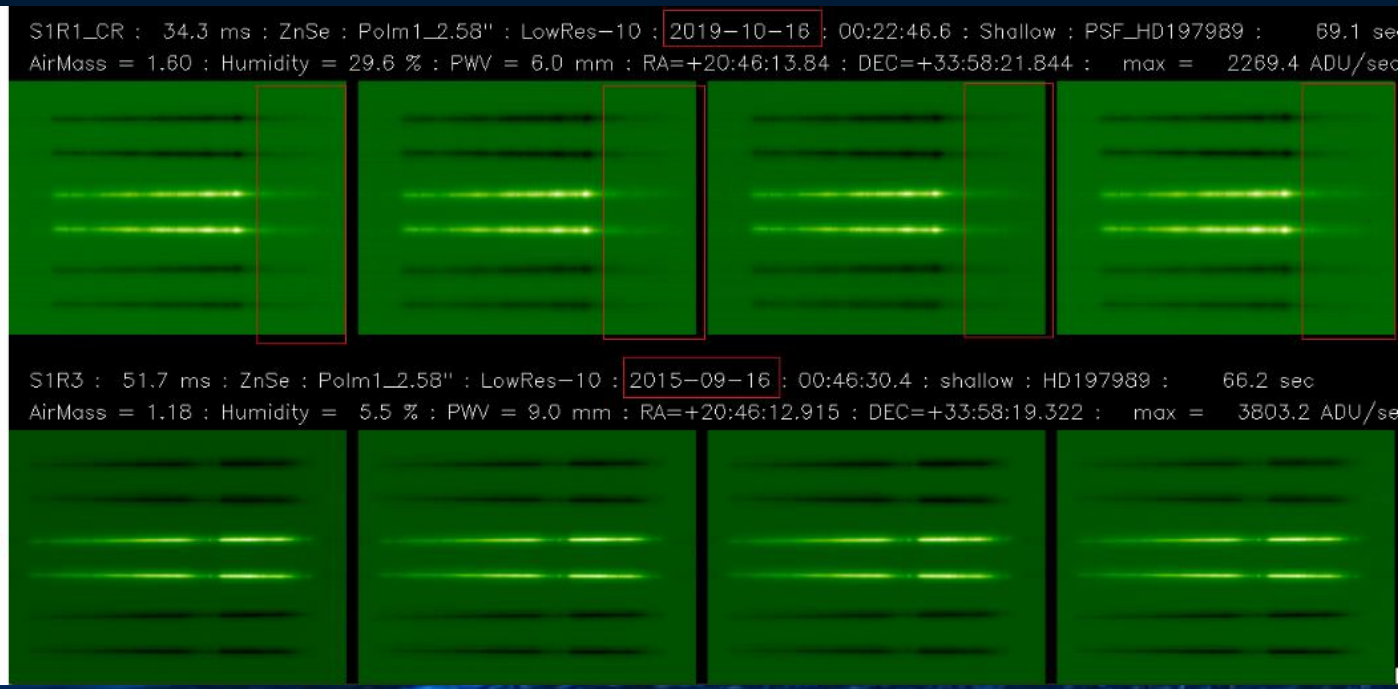
- Shot noise dominated for most science cases, and post-processing technique was available to eliminate patterns of CDS readout… except for Polarimetry!
- Uncovered Linearity issue not detected in the LAB setup! Lower Dynamic Range, that would jeopardize science quality (specially for Spectroscopy)

New data with ARC, taken in Oct2019. Abnormal shape

Reference data taken in 2015 with the MCE



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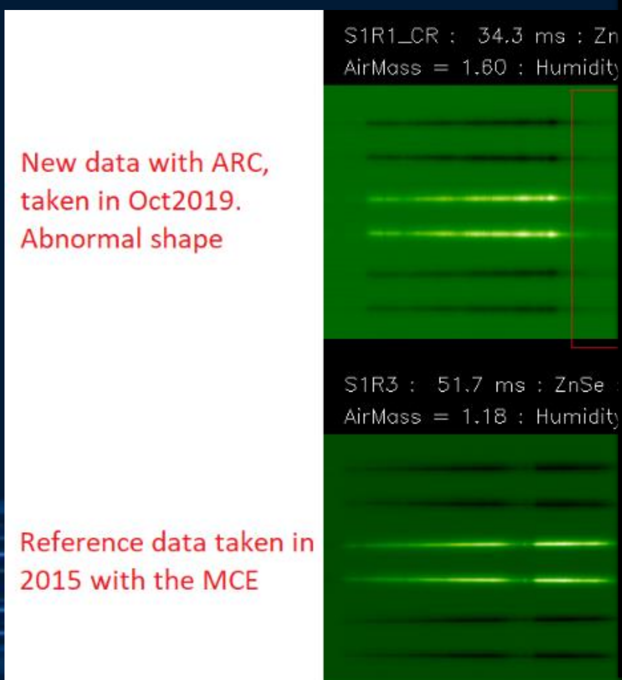
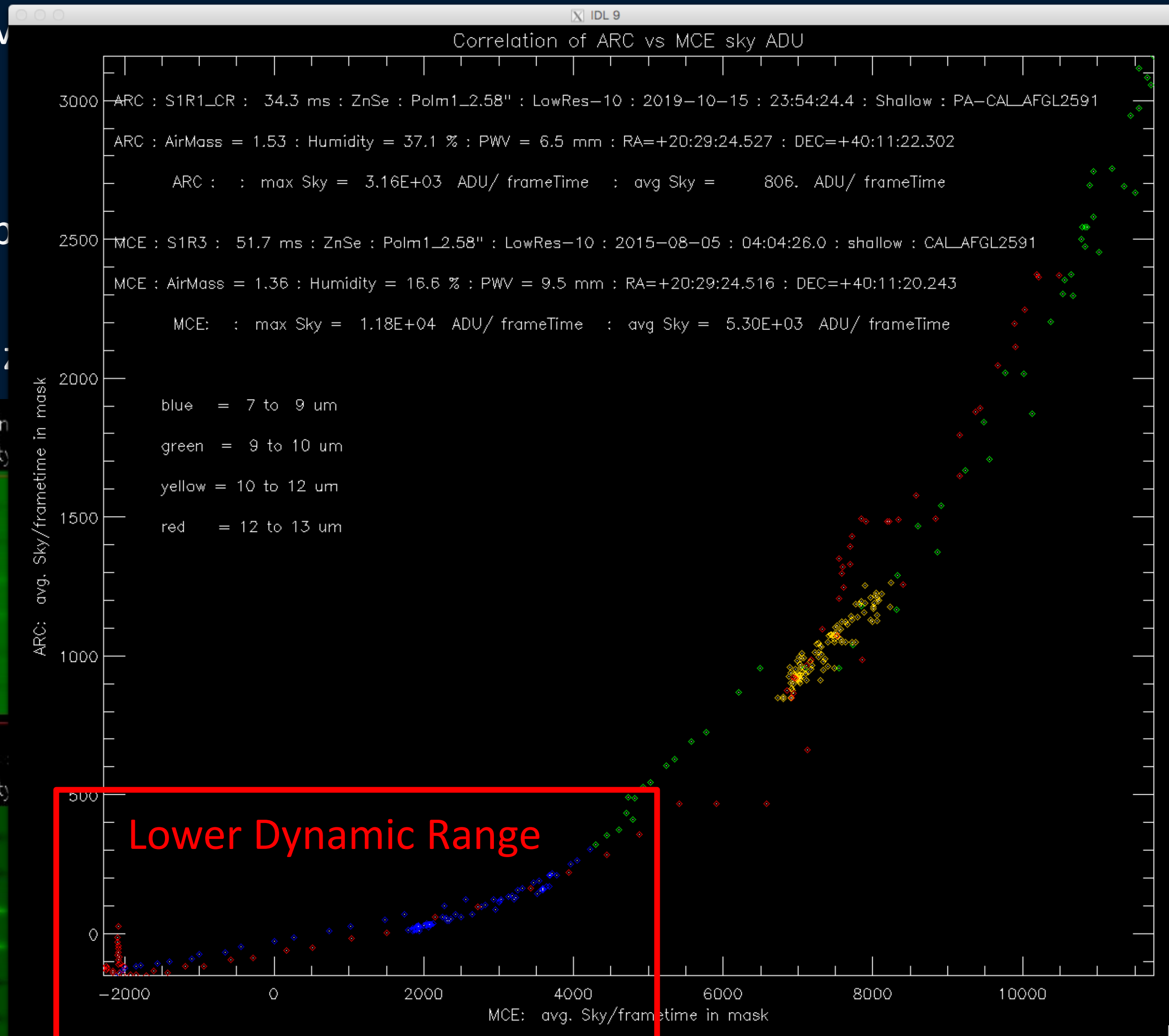
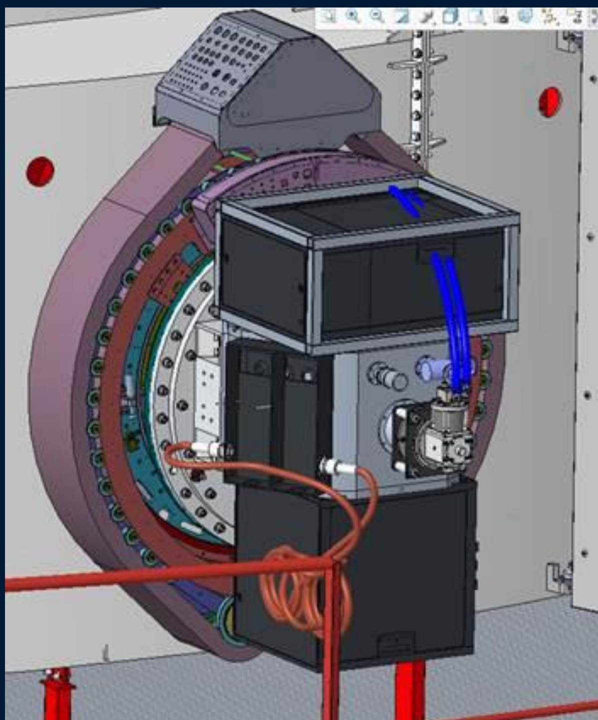
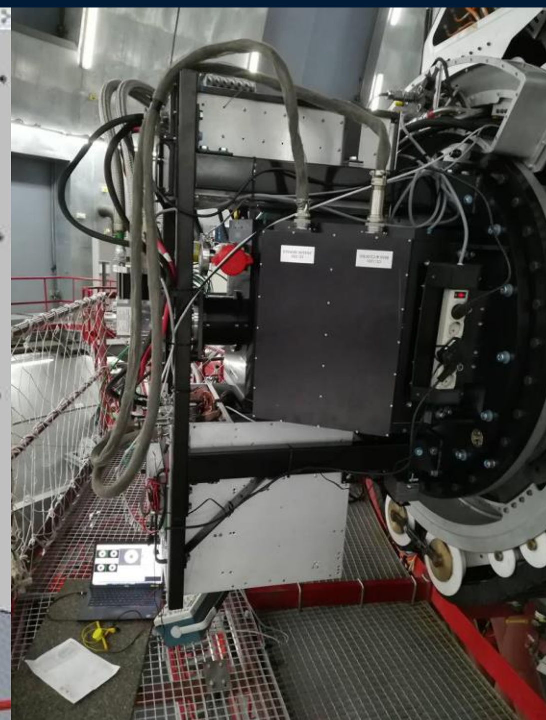




Upgrade Project - Collaboration Agreement

- Contingency Plan – modified MCE => Commissioning and Science <u>in dec2019</u>

- MCE adapted for the FC envelope and thermal control

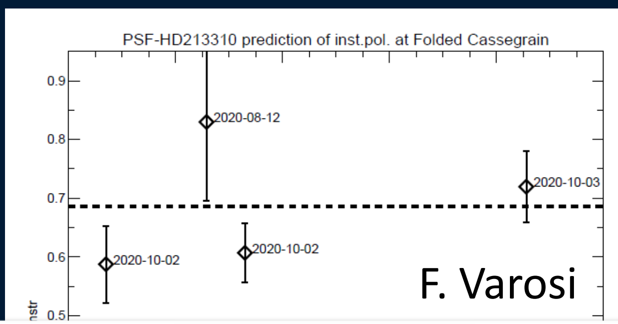



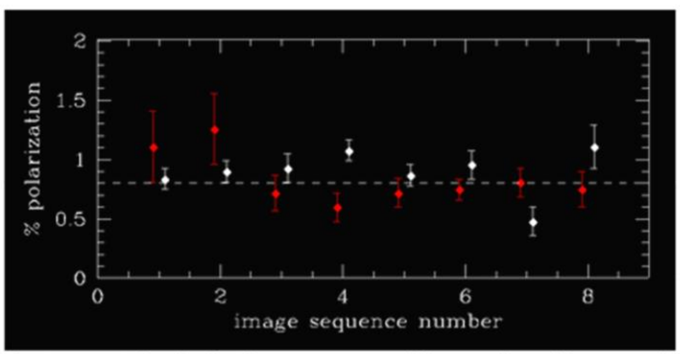

From concept (September) to Tests (05dec2019) and to final on-sky tests (14dec2019)

CanariCam@Folded-Cassegrain (2019-2020)

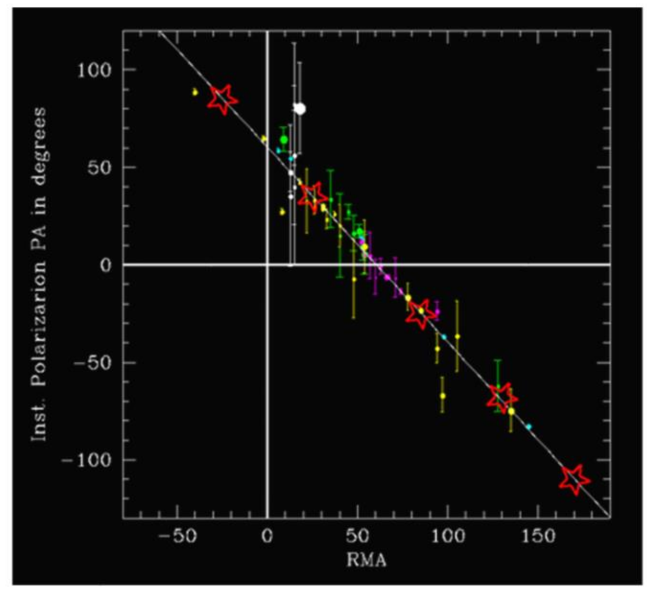
CanariCam@FC - Current status

- Commissioning
  - Basic and limited on-sky commissioning (in December 2019)
  - Polarimetry as high-priority and completed just before the lockdown in March 2020. Results as expected and in good agreement with previous knowledge/performance metrics: http://www.gtc.iac.es/instruments/canaricam/cc_upgrade.php





Canaricam instrumental polarization as measured in a series of images of Pollux (re points) and Sirius. The average value is fully consistent with the value measures bef the instrument upgrade. The dashed line indiicated the 0.8% polarization level.

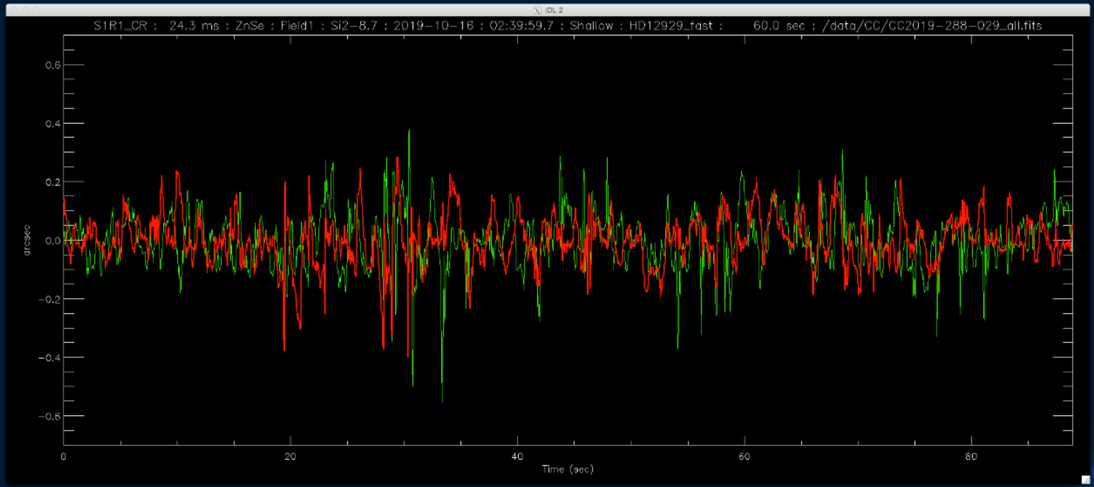


Canaricam instrumental polarization position angle at folded cassegrain focus. Compared to the previous situation, now the dependence on elevation disappeared and the polarization position angle only change according to the rotator position angle RMA. In this figure the old data from Nasmyth focus have been transformed setting elevation = 90 and adding 180 because the instrument is now mounted upside down. The five big stars represent the measurements obtained during the last commissioning run (March 2020). The line is the relation PA = 60.4-RMA.

CanariCam@FC - Current status

○ Commissioning&Technical wish-list

- Further test/analyze the benefit of using Fast guiding with CanariCam under different conditions and for different chopping configurations.
    - Burst-mode allowed to measure an improvement of 20% in image stability.



0.118” vs 0.15” rms

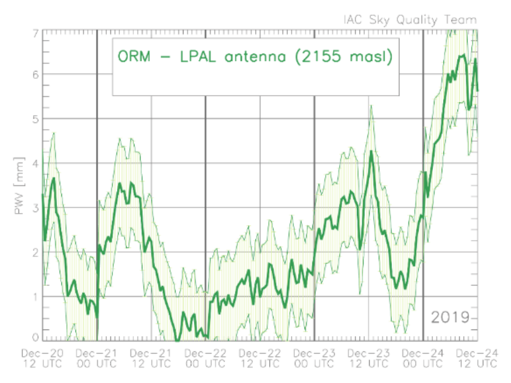
Credit: Frank Varosi

- Better assess instrument sensitivities in all modes and under different atmospheric conditions (IQ, PWV, etc.).

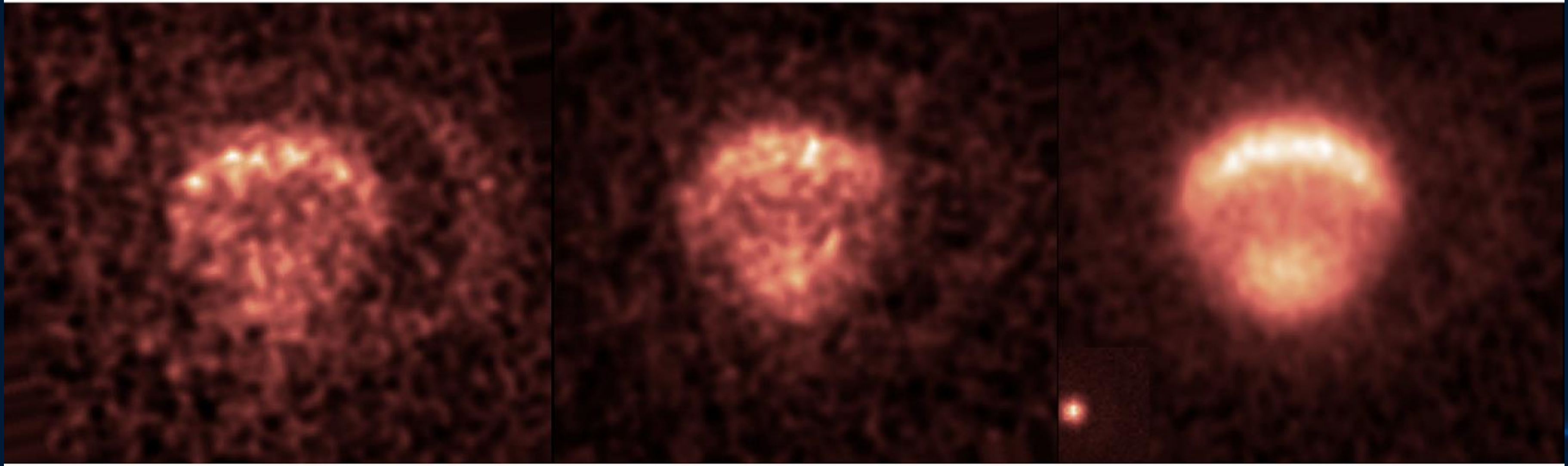
- Further test the Lorentz Center Workshop “Experiments”

CanariCam@FC - Current status

- Science Observations started in December



Uranus Observations - Roman et al., Manuscript in preparation

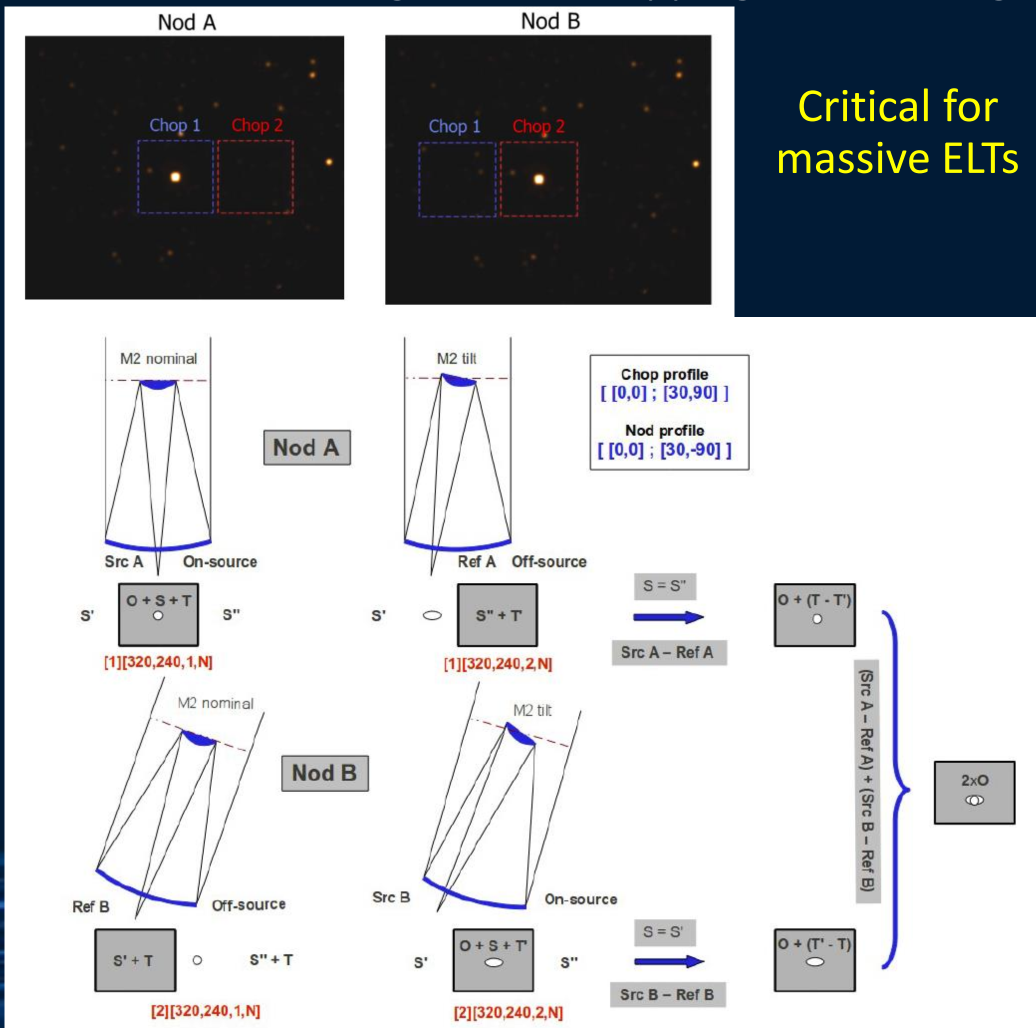


Q1 (17.65um) Q4 (20.5um) Q8 (24.5um)

CanariCam@FC – Experiments for the Future Instruments

- Drift-Scanning & Radiative Offset

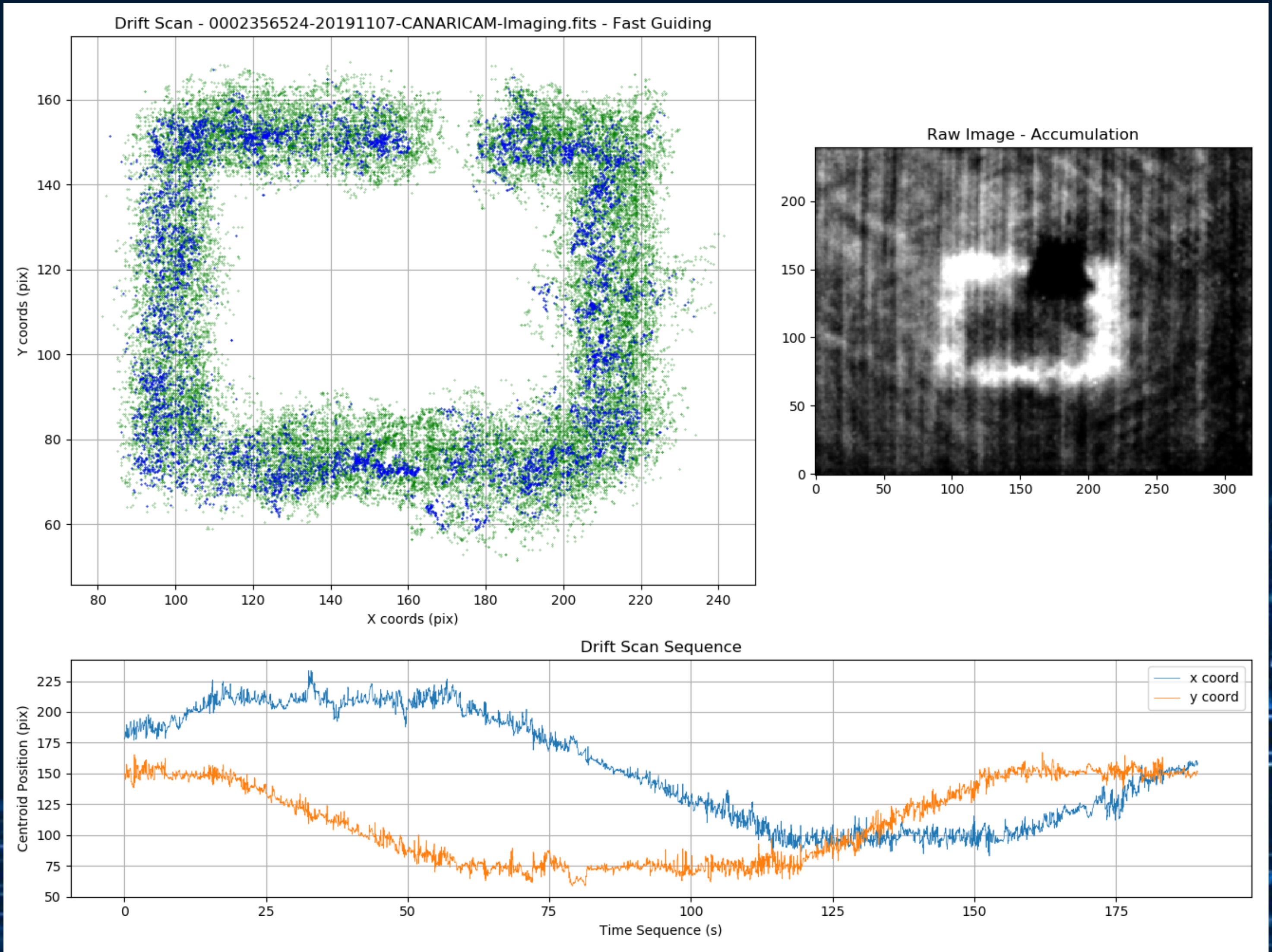
… or how to get rid of chopping and nodding



Critical for massive ELTs

CanariCam@FC – Experiments for the Future Instruments

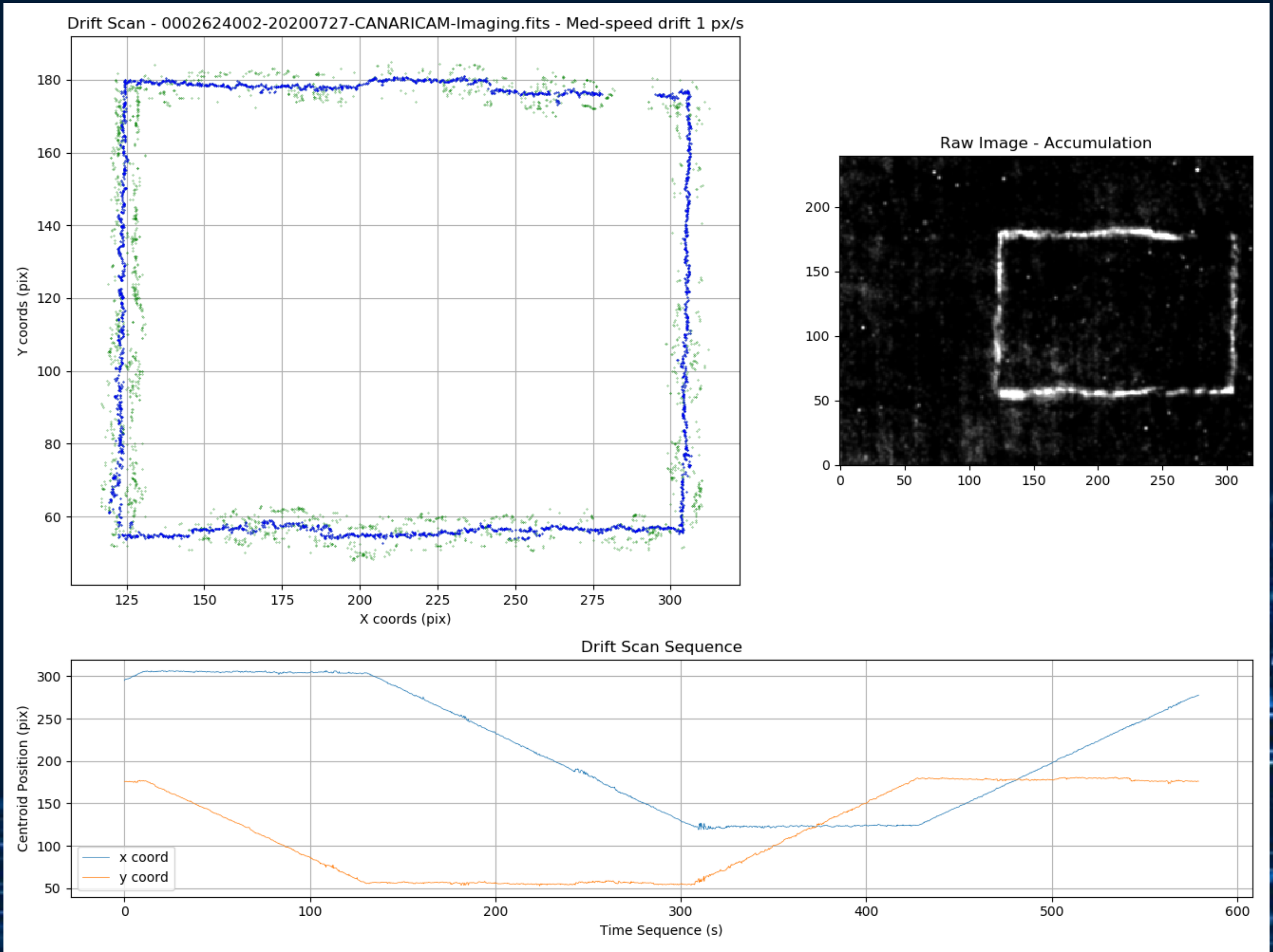
- Drift-Scanning



Using the Non-Sidereal Guiding functionality and custom ephemeris files to drift along/across channels at different drift rates

CanariCam@FC – Experiments for the Future Instruments

- Drift-Scanning

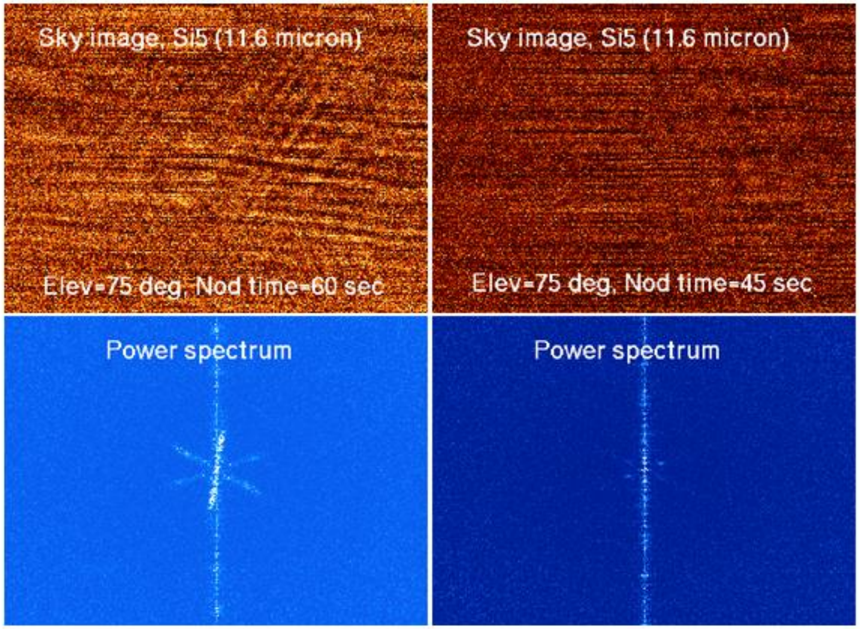


Sensitivity gain is being estimated and will be presented at SPIE (poster - TBC)

Packham, Torres-Quijano & Fernandez-Acosta in prep.

CanariCam@FC – Experiments for the Future Instruments

- Radiative Offset
  - Residual thermal background from the telescope.



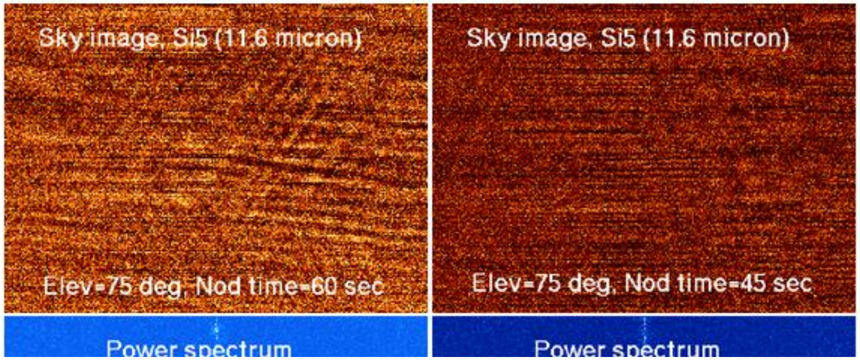
The diagonal wavy pattern noise seen in the top left image is the radiative offset residual, which can be seen much clearer in the Fourier space (bottom left panel). The pattern almost disappears (both, in the image and Fourier space) when a nod dwell time of 45 seconds instead of 60 seconds is used. By measuring the radiative offset residual at different elevations, we found out that the residual can be removed reasonably well with a nod dwell time of 45 seconds at all elevations. It would be possible to nod faster, but the gain in offset removal is counterweighted by a lower observing efficiency, which is 91%, 88% and 84% for nod dwell times of 60, 45 and 30 seconds, respectively. It would also possible to nod slower than 45 seconds at low elevations, but this would add unnecessary complexity to the observation. **Therefore, the nominal nod dwell time for radiative offset minimization in CanariCam is 45 seconds at all elevations.**

What does it depend on?
&
How stable is it?

TinTin Collaboration
(Images from Subaru, ESO and GTC)

CanariCam@FC – Experiments for the Future Instruments

- Radiative Offset
  - Residual thermal background from the telescope.



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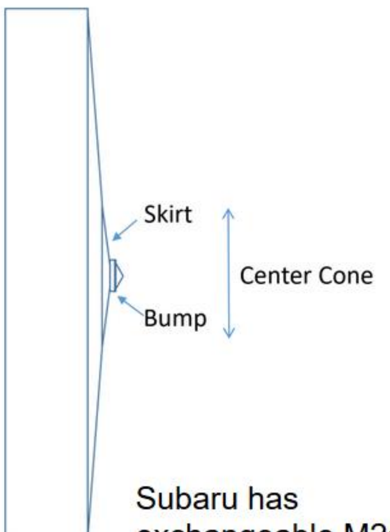


Subaru has exchangeable M2s (for optical / IR)

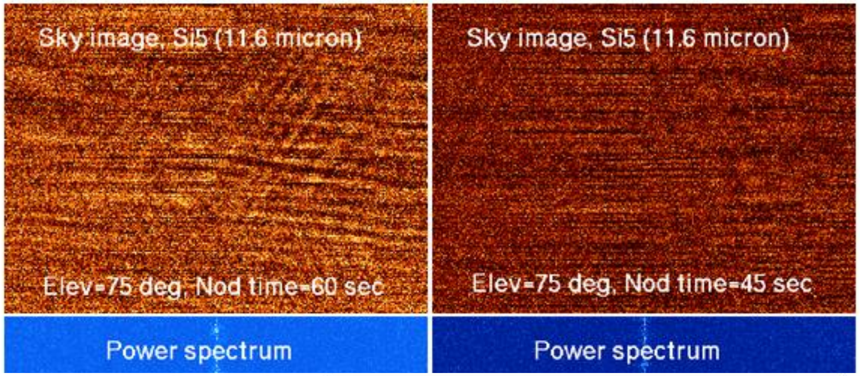
GTC has a hole in the M2

VLT/UT3 M2 (seen from Cassegrain while VISIR was removed)

TinTin Collaboration
(Images from Subaru, ESO and GTC)

CanariCam@FC – Experiments for the Future Instruments

- Radiative Offset
  - Residual thermal background from the telescope.



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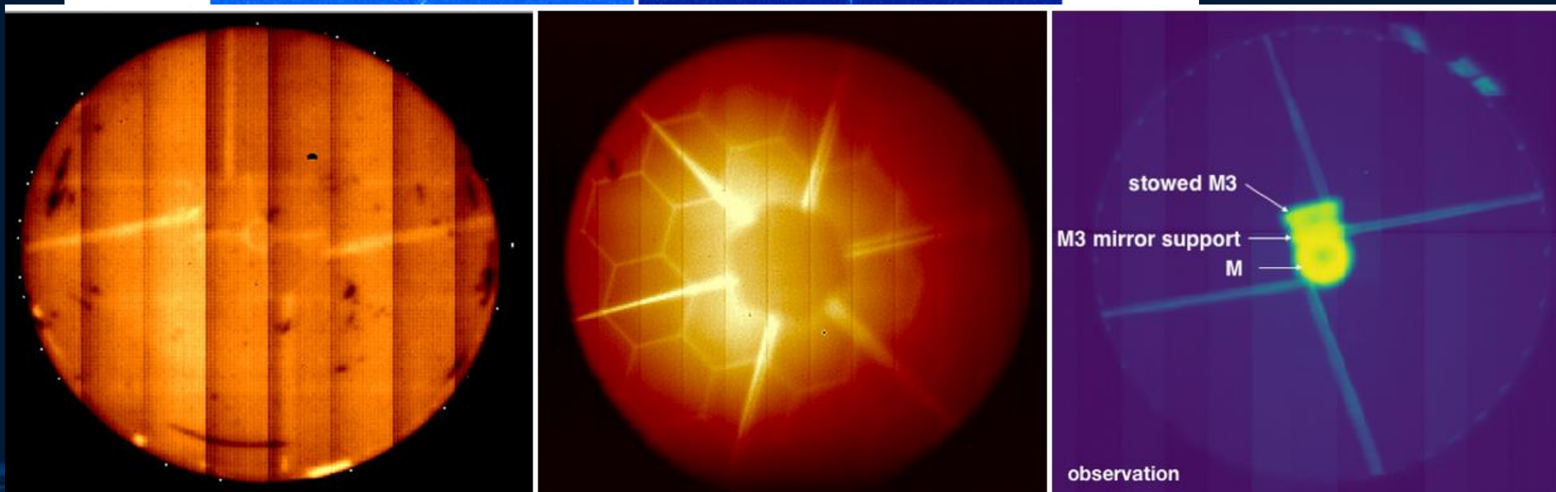
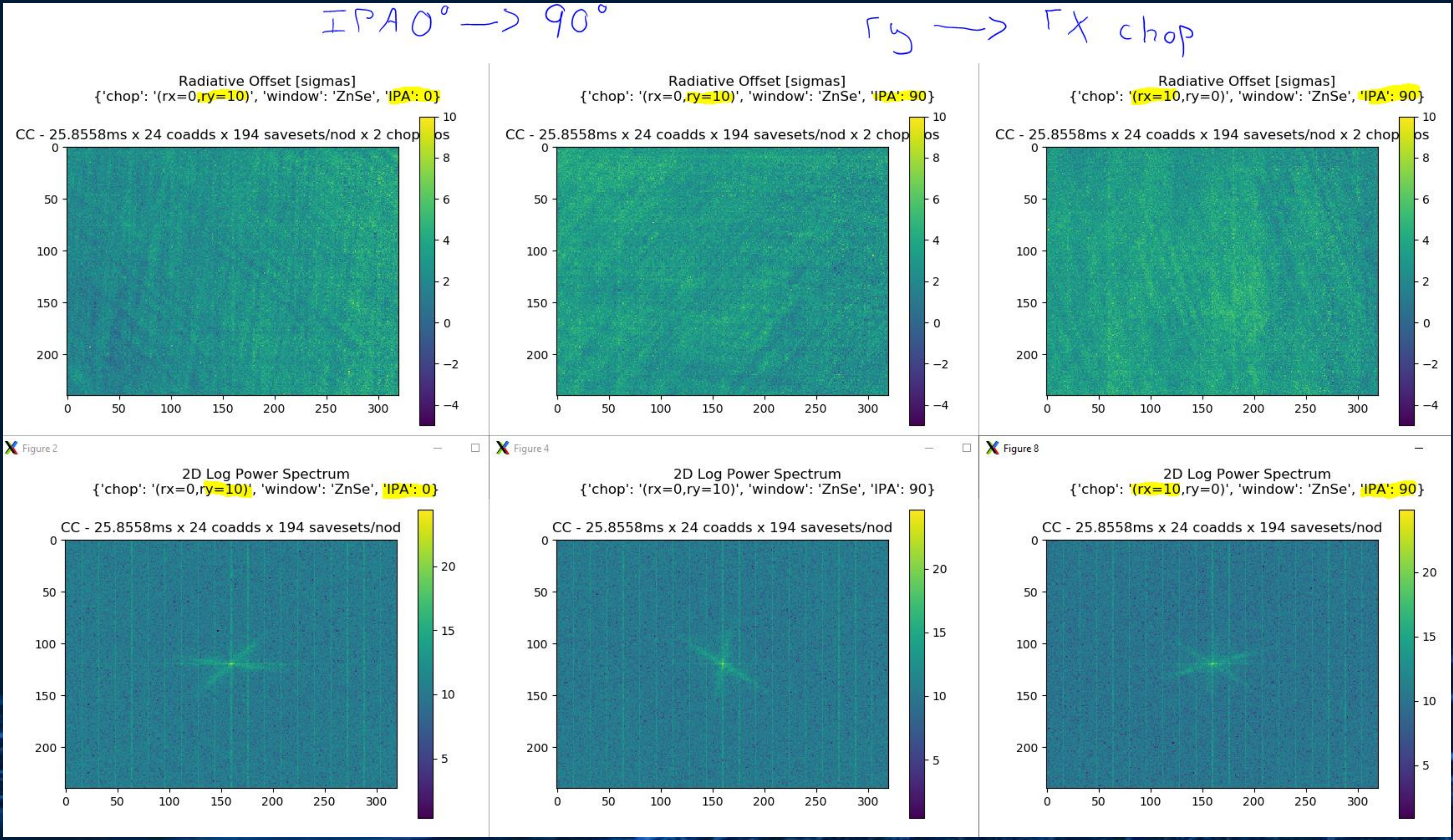


Subaru CanariCam VISIR

TinTin Collaboration
(Images from Subaru, ESO and GTC)

CanariCam@FC – Experiments for the Future Instruments

- Radiative Offset : Instrument Orientation vs Chopping Orientation



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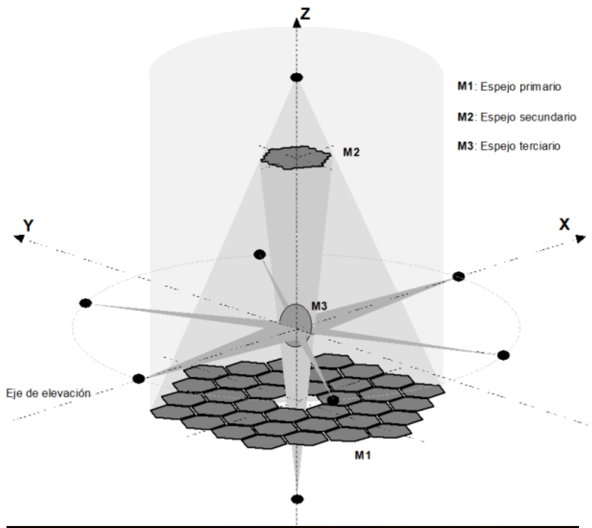
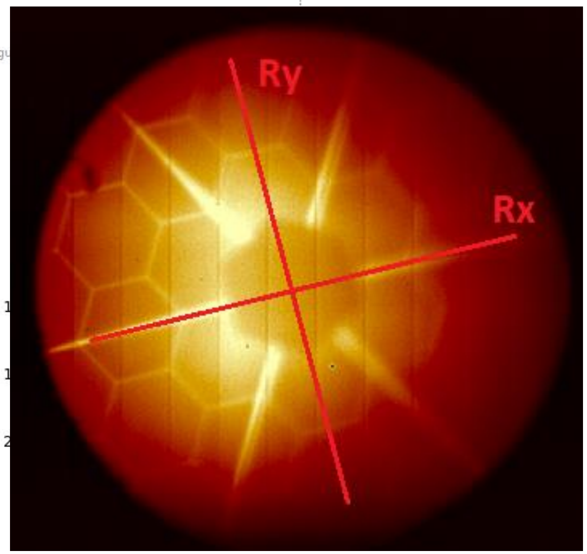
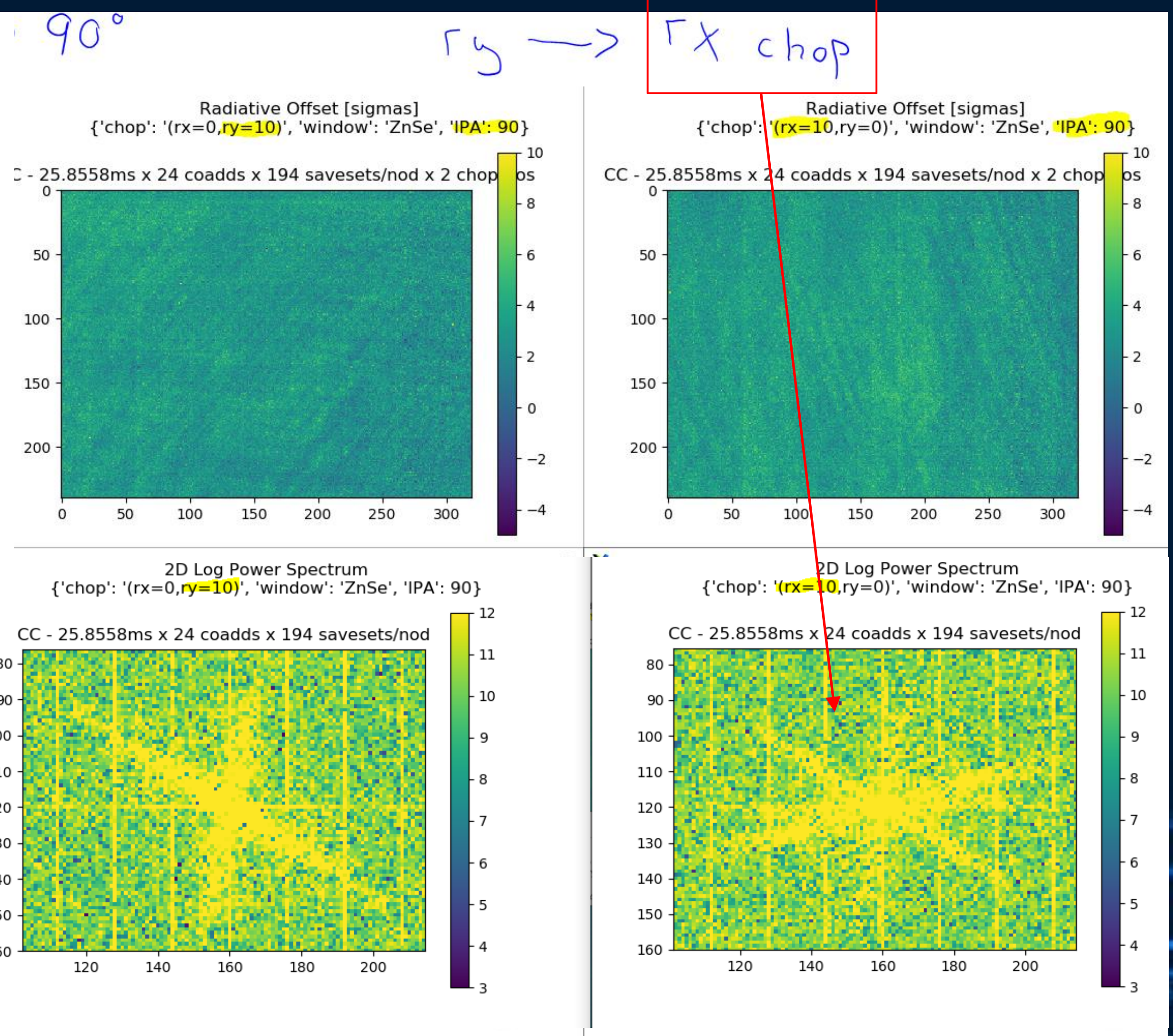
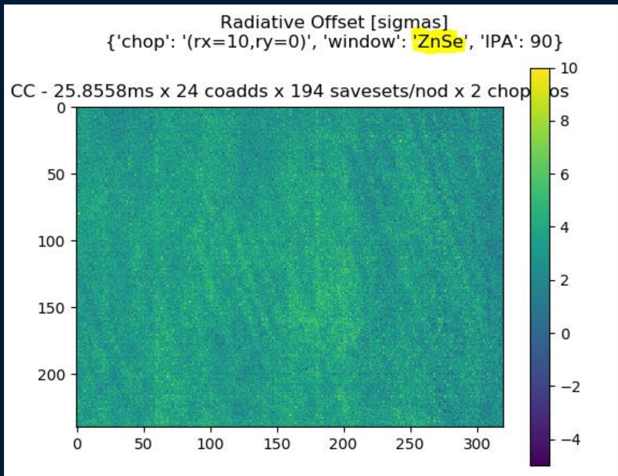


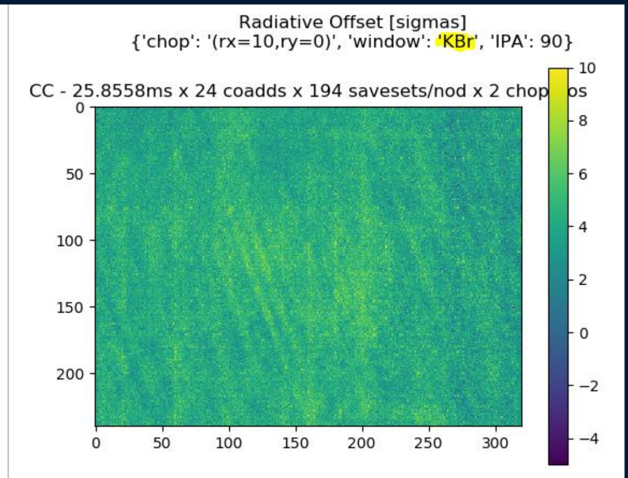


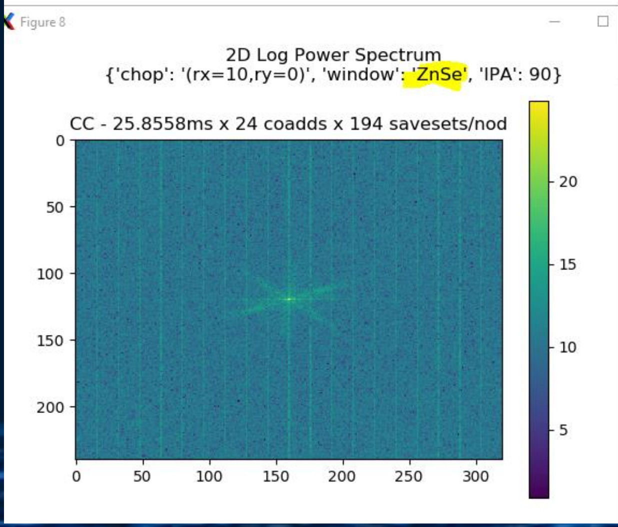


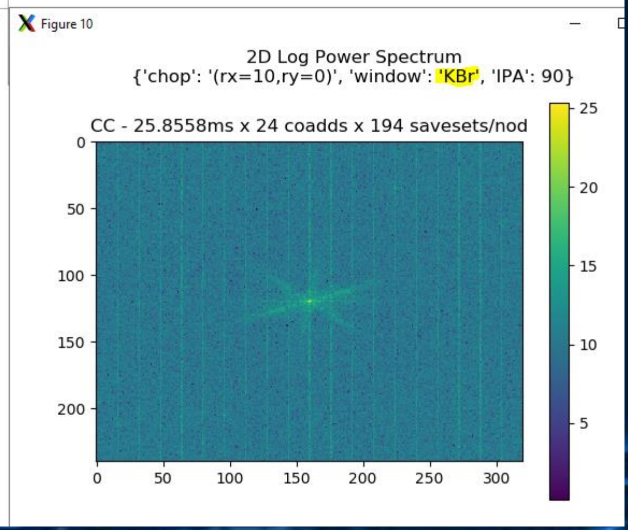
CanariCam@FC – Experiments for the Future Instruments

- Radiative Offset : Entrance Window

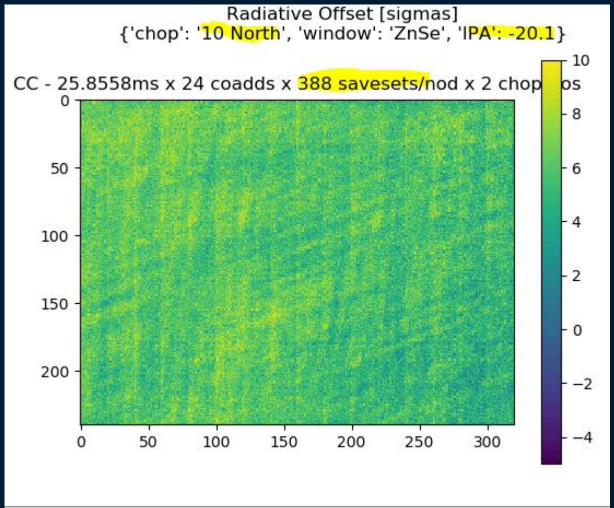


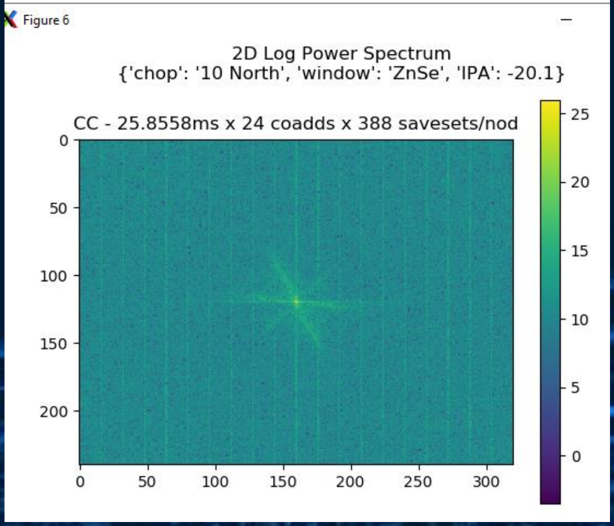






Radiative Offset : Time stability?



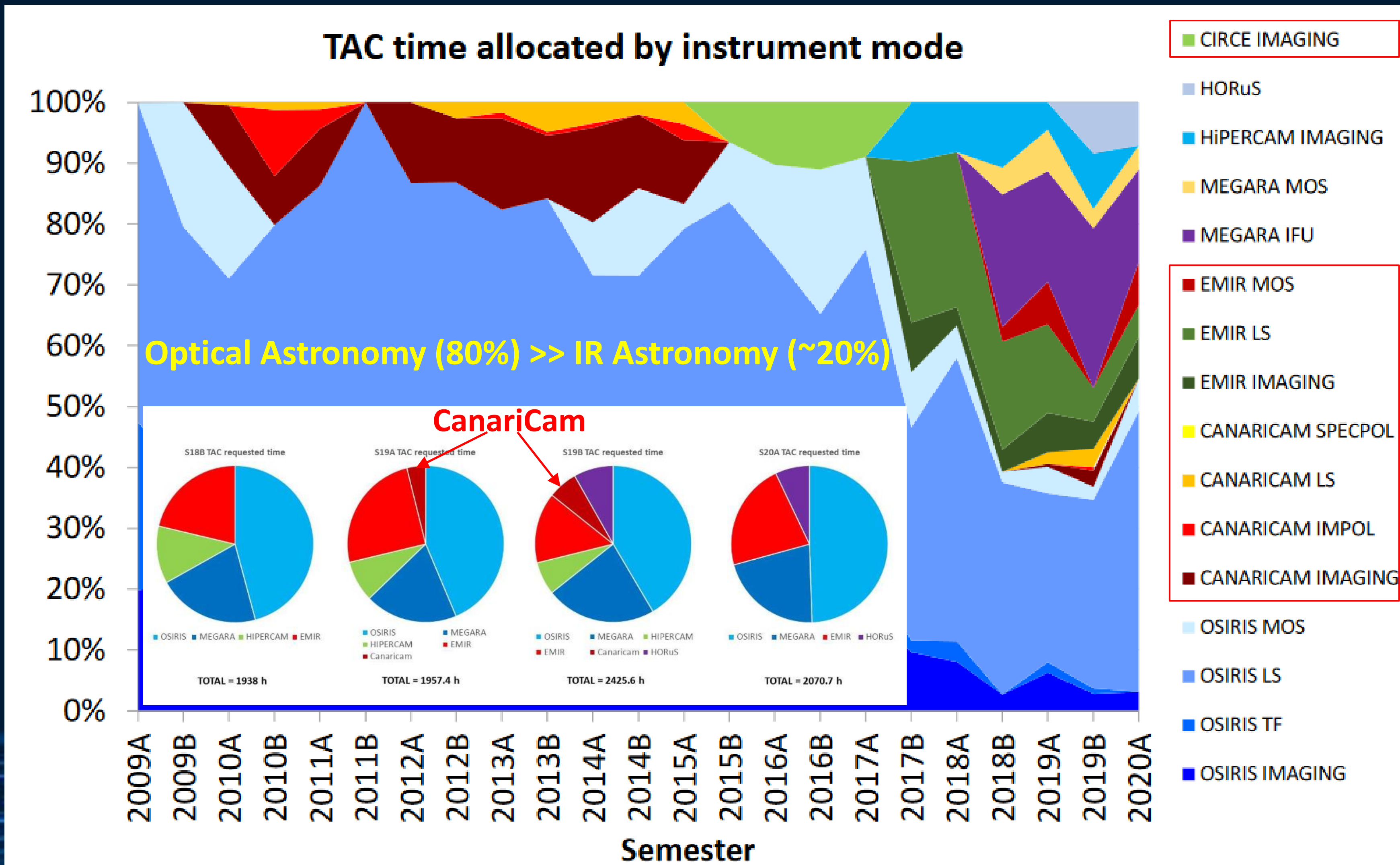


elapsed = 600 sec

Future???

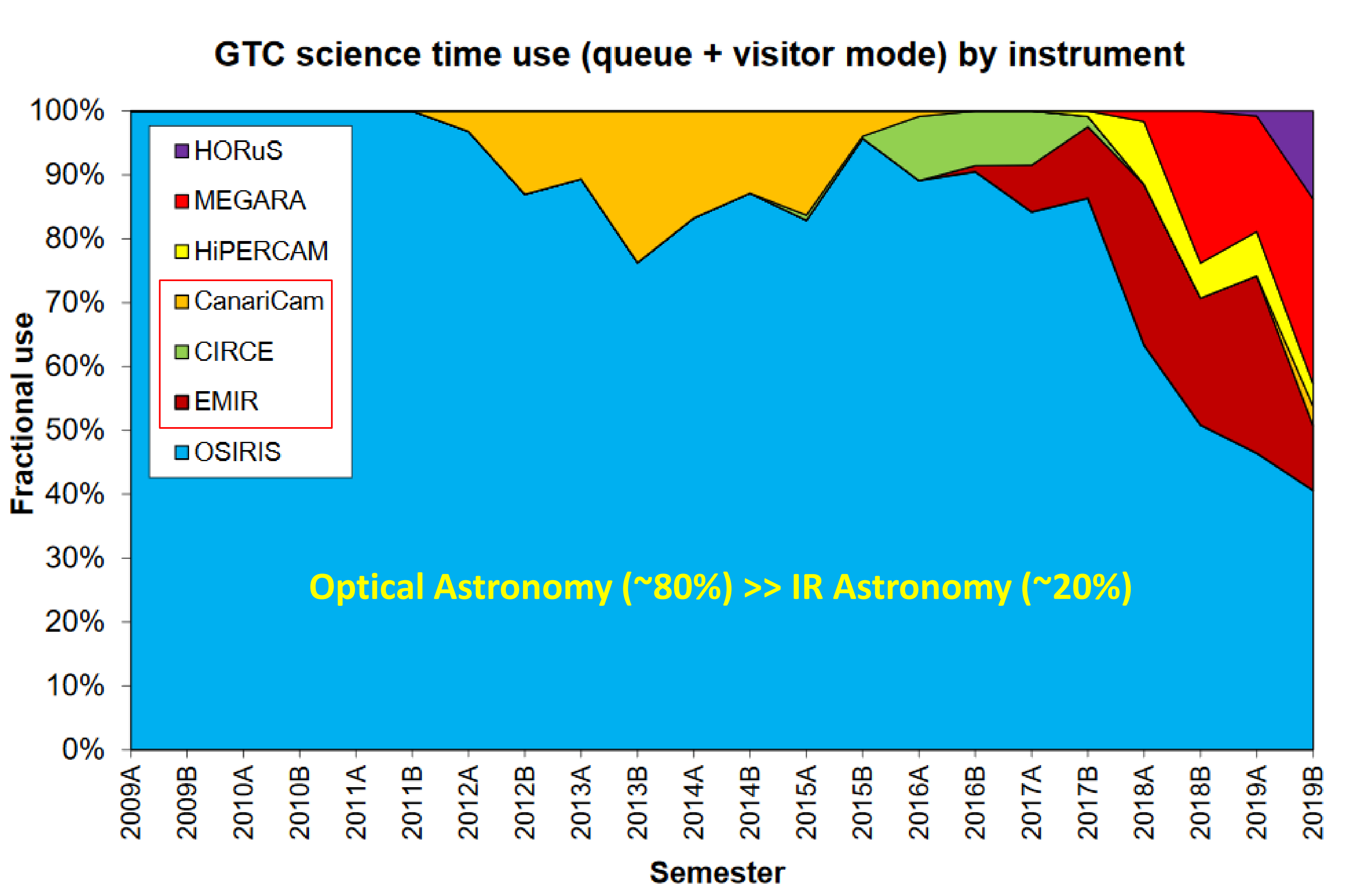
CanariCam Future

Place of CanariCam within the Instrumentation Program and our community

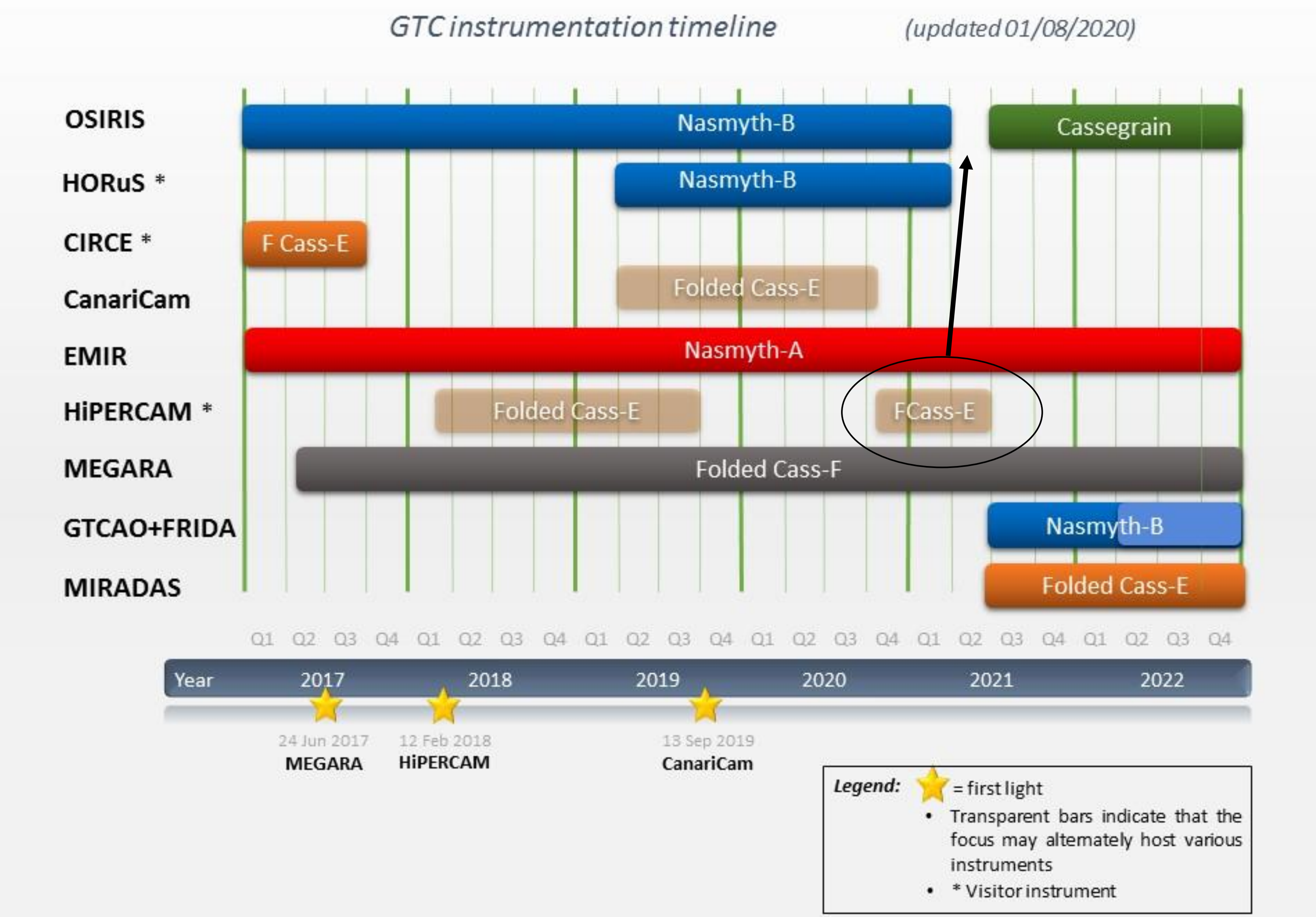


CanariCam Future

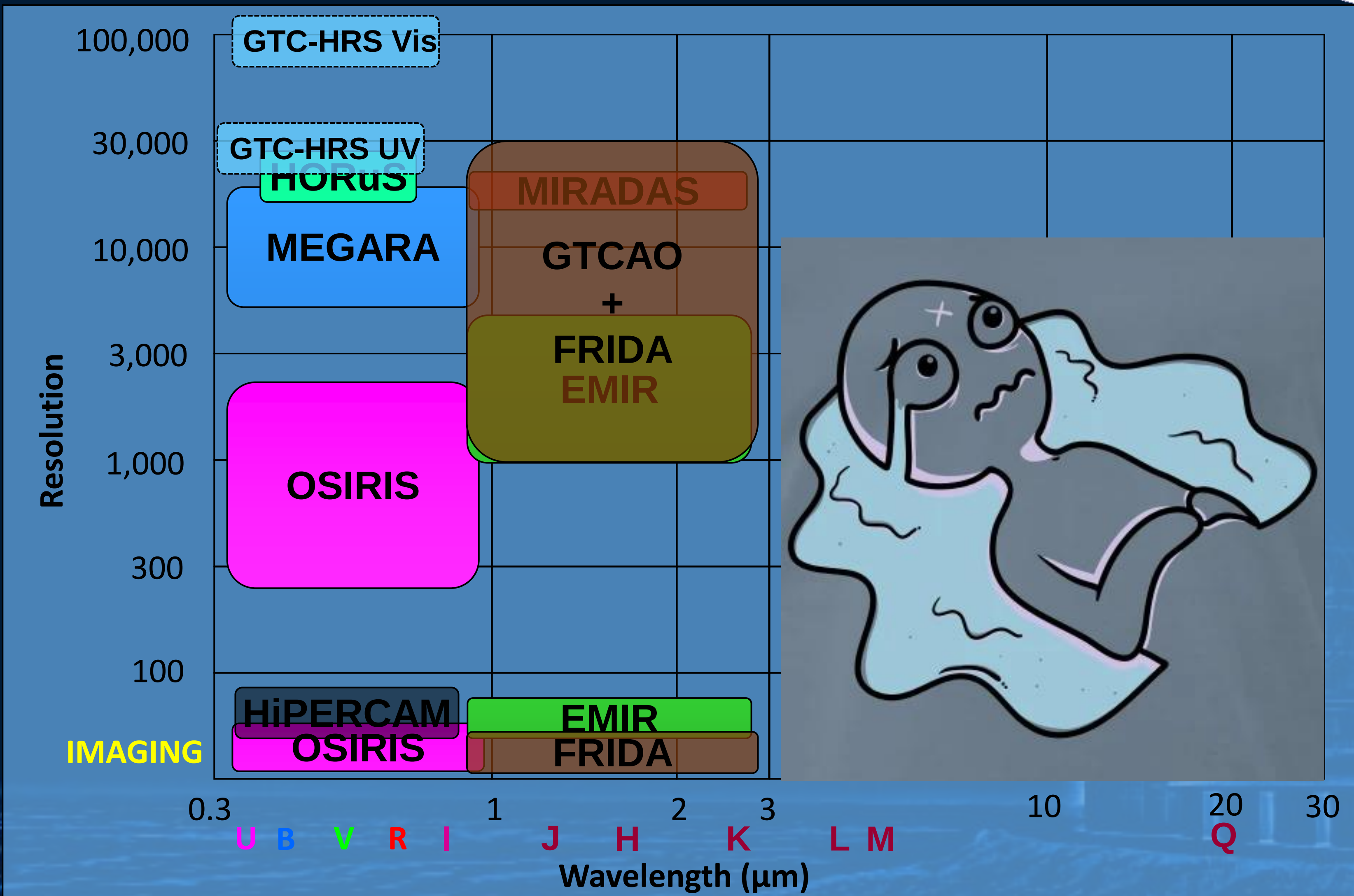
Place of CanariCam within the Instrumentation Program and our community



The GTC focal stations and scientific instruments



Instrumentation plan (more info at www.gtc.iac.es)



Conclusions and Lessons Learned

CanariCam – Conclusions and Lessons Learned

- The challenge of Thermal-IR instruments in a single-telescope observatory

  Usually perceived as too expensive to maintain wrt to delivered science (quantity-wise). Competing with Optical and NIR facility instruments.

  - Design and build a robust instrument (must follow space industry standards)
  - Build and maintain a large/committed enough scientific and technical community behind the instrument to support/demand it (pipelines, etc.). Keep the expertise as ESO

- General
  - 4K cryogenics is challenging (benefit of gravity invariant vs gravity variant approaches)
  - Polarimetry will be challenging with the ELT given its complex optical design with several folding mirrors, but it is a very powerful tool enabling unique science cases
  - Image Quality (stable PSF and high strehl ratio) is a must (chopping, AO, vibrations…)
  - Background subtraction will continue to be a challenge: PWV forecasting and flexible scheduling can help, and of course innovative observational/reduction techniques
  - Better Detectors are needed
- CanariCam
  - Unique thermal-IR spectropolarimeter , but being decommissioned
  - Main "issues" with CanariCam "1" were the IQ and the cryocooler.
  - Main problem with the upgrade project were:
    - Small opportunity window => tight schedule led to shortcuts
    - Technical risk of the DAS upgrade was underestimated
    - Development on remote system (though common nowadays)
    - Full V&V of individual WPs/subsystems was not feasible

http://www.gtc.iac.es/GTChome.php

THANKS!!!!

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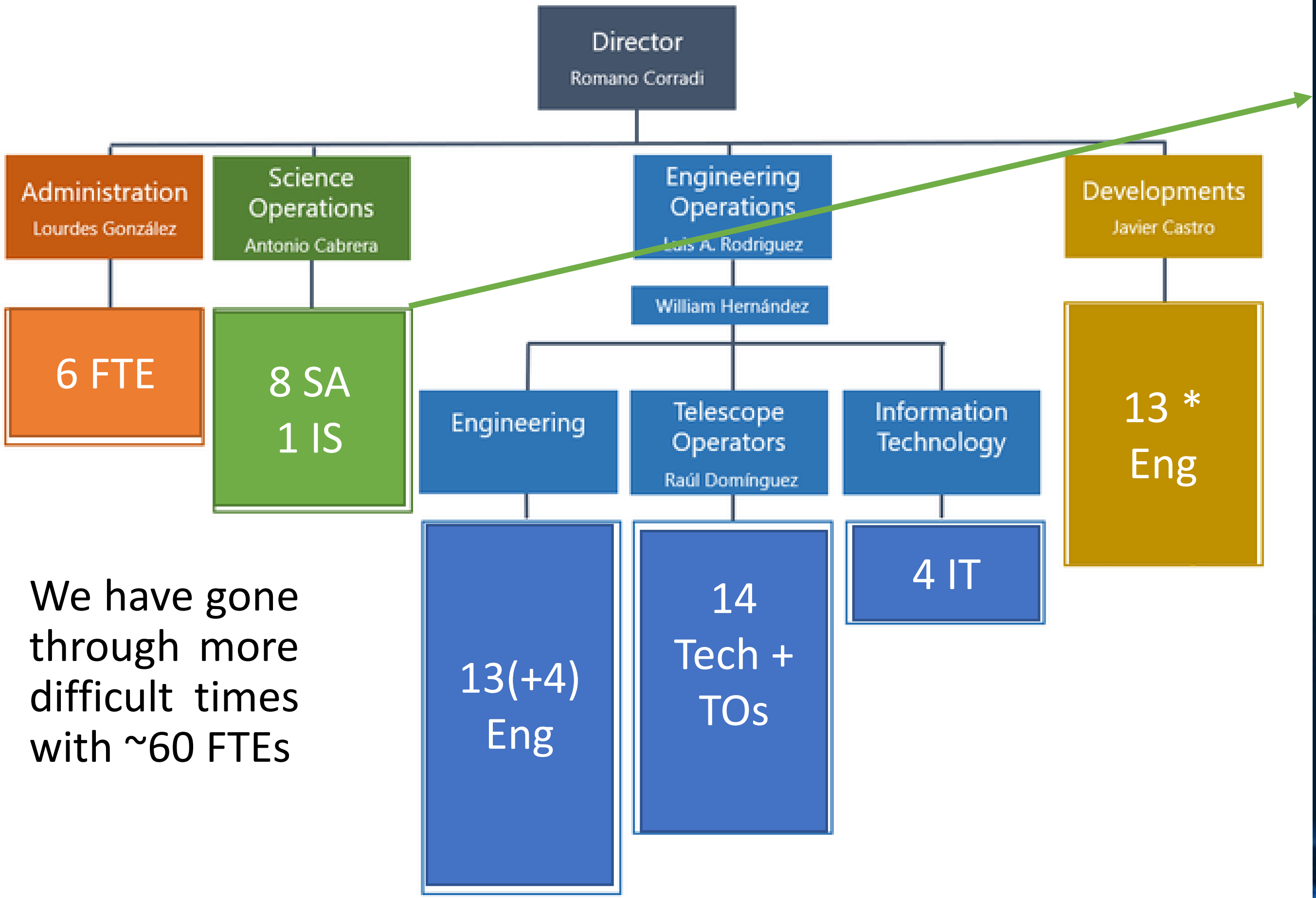
GTC Context and Future Instrumentation – Q&A session

http://www.gtc.iac.es/gtc/transparency.php



We have gone through more difficult times with ~60 FTEs

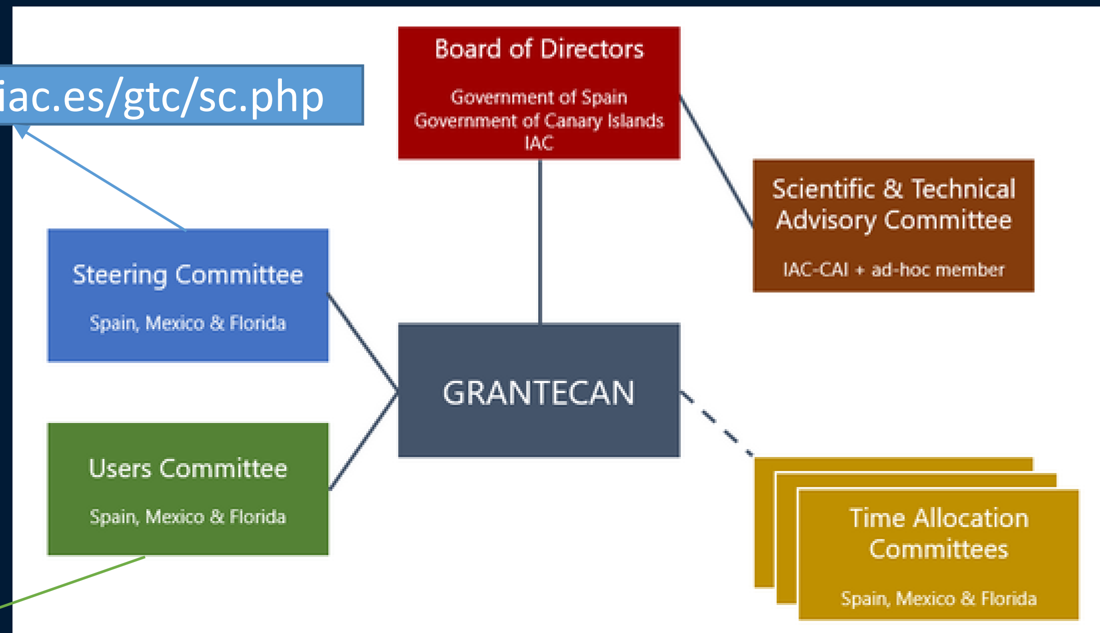
Reminder:

GTC is a highly-flexible multi-instrument queue observatory with a planned suite of 10+ instruments (5 + 2 instruments in a given night)

GTC Context and Future Instrumentation – Q&A session

http://www.gtc.iac.es/gtc/transparency.php

http://www.gtc.iac.es/gtc/sc.php



GUC's Presentations (20-21 Jul 2020)

- Director's Report
- GTC Science Operations Status Report
- GTC Engineering Operations Status Report
- GTC Developments Division Status Report
- GTC Next Generation Instruments
- GTC Archive Report

GUC's Reports

- 21st GUC summary report of 10-11 February 2020
- 20th GUC summary report of 29-30 July 2019
- 19th GUC summary report of 20-21 February 2019
- 18th GUC summary report of 19-20 September 2018
- 17th GUC summary repo
- 16th GUC summary repo
- 15th GUC summary report of 17-18 March 2017
- 14th GUC summary report of 26-27 July 2016
- 14th GUC summary report of 26-27 July 2016
- 13th GUC summary report of 04-05 February 2016
- 12th GUC summary report of 13-14 July 2015
- 11th GUC summary report of 10-11 February 2015
- 10th GUC summary report of 10-11 July 2014
- 9th GUC summary report of 27-28 January 2014
- 8th GUC summary report of 25-26 June 2013
- 7th GUC summary report of 29-30 Jan 2013
- 6th GUC summary report of 27-28 June 2012
- 5th GUC summary report of 24-25 Jan 2012
- 4th GUC summary report of 5-6 July 2011
- 3rd GUC summary report of 28 Jan 2011
- 2nd GUC summary report of 20 July 2010
- 1st GUC summary report of 25-26 Feb 2010

http://www.gtc.iac.es/gtc/guc.php

Operations financed by the European Regional Development Fund (ERDF)

Financing	Description
Scientific Infrastructure Operational Programme (1994-1999)	Parts of the construction project of GTC
REGIS II Community Initiative (1994-1999)	Parts of the construction project of GTC
Programa Operativo de Infraestructura Científica (2000-06)	Parts of the construction project of GTC
Technology Fund Operational Programme (2007-2013)	Folded Cassegrain
Programa Operativo de Canarias (2007-2013)	Project for the construction of two multi-object spectrographs
Technology Fund Operational Programme (2007-2013)	Improvements of the GTC Dome Shutters
Programa Operativo de Canarias (2007-2013)	Extension of the GTC equipment. Phase 1 (2013-2015)
Programa Operativo de Canarias (2007-2013)	Adaptive Optics System for the GTC
Programa Operativo de Canarias (2014-2020)	Extension of the GTC equipment. Phase 2 (2014-2019)
Programa Operativo Plurirregional de España 2014-2020	Mejora de la ICTS Gran Telescopio Canarias (2016-2020)
Programa Operativo FEDER Canarias 2014-2020	Optimización de las observaciones infrarrojas del Gran Telescopio Canarias (IR_GTC)
Programa Operativo Plurirregional de España 2014-2020	Mejora y consolidación del Gran Telescopio Canarias (MECON_GTC)

GTC Context and Future Instrumentation – Q&A session

http://www.gtc.iac.es/instruments/instrumentation.php

Instrumentation developments for GTC

- Summary
- Day-one instruments
- Visitor instruments
- Second generation instruments
- Third generation instruments
- Next generation instruments

+ GTC-HRS (China)

http://www.gtc.iac.es/instruments/media/Doc-GTC-Informe-final-del-New-Instrumentation-Working-Group.pdf

http://www.gtc.iac.es/instruments/media/Instrumentation_Review_Panel_Report_2013.pdf

http://www.gtc.iac.es/instruments/media/PublicCallGTCinstrumentation2018.pdf

Role of GTC in the era of the ELTs and multi-Messenger Astronomy??

By 1 December 2018, we have received up to five "Concept papers" for new science instruments for the GTC. At the conference VI meeting on Science with GTC, there will be a special session with oral presentations of these Concept Papers to conduct a general discussion on the different designs described.

On the next table, a summary of the new instruments proposed is given:

Instrument	GTCAO?	Wavelength range	Observing modes	FOV	Spectral Resolution	Budget
BATMAN	No	0.36 - 1.0 µm	Imaging Multi-Object Spectroscopy	2.3 x 1.2 arcmin (DMD-based) 6.0 x 6.0 arcmin (MIRA-based)	500 - 4000 (for 1-0.2 arcsec slits)	10 MEUR
GATOS	No/Yes	0.37 - 2.35 µm (simultaneous)	Imaging Long Slit Spectroscopy High time-resolution IFU Spectropolarimetry	3 x 3 arcmin or 4.2 arcmin (diameter) 3 arcmin long slit 9.7 x 6.8 arcsec IFU 2.5 x 3.6 arcsec IFU (with AO)	4000	9.7 MEUR
GTCMCAO	Yes (MCAO)	0.9 - 2.4 µm	Adaptive Optics Facility	40 x 40 arcsec	-	4.1 MEUR
MAGAM	Yes (MCAO)	0.9 - 2.4 µm	Diffraction limited Imaging	85 x 85 arcsec	-	43 MEUR
NEREA	No/Yes	0.8 - 1.7 µm	Fiber-fed Spectroscopy	-	R > 70000 (req.) R = 110,000 (goal)	4 - 5 MEUR

White papers Scientific evaluation (GTC STAC + ad-hoc external committee

Final decisión on instrument(s) to be developed by CSUG (TBD)

CanariCam – is there a chance for a third life?

- Discussion raised during the workshop

  Given the unique and compelling science that CC-Pol enables, is there a chance for a third live of CanariCam:

  - For future short campaigns at GTC?
  - What kind of support could the community provide?
  - Is it possible to adapt it to another telescope?

  Strong science cases are needed to support it.

- Technically speaking, what would be needed for another life?
  - Refurbish cryocooler
  - Refurbish Wollaston mechanism (parts are already available)
  - MCE definitive enclosure or debugging the new controller
  - Modifications to interface with a different telescope? (optomechanics, software, etc.)
  - Recommissioning