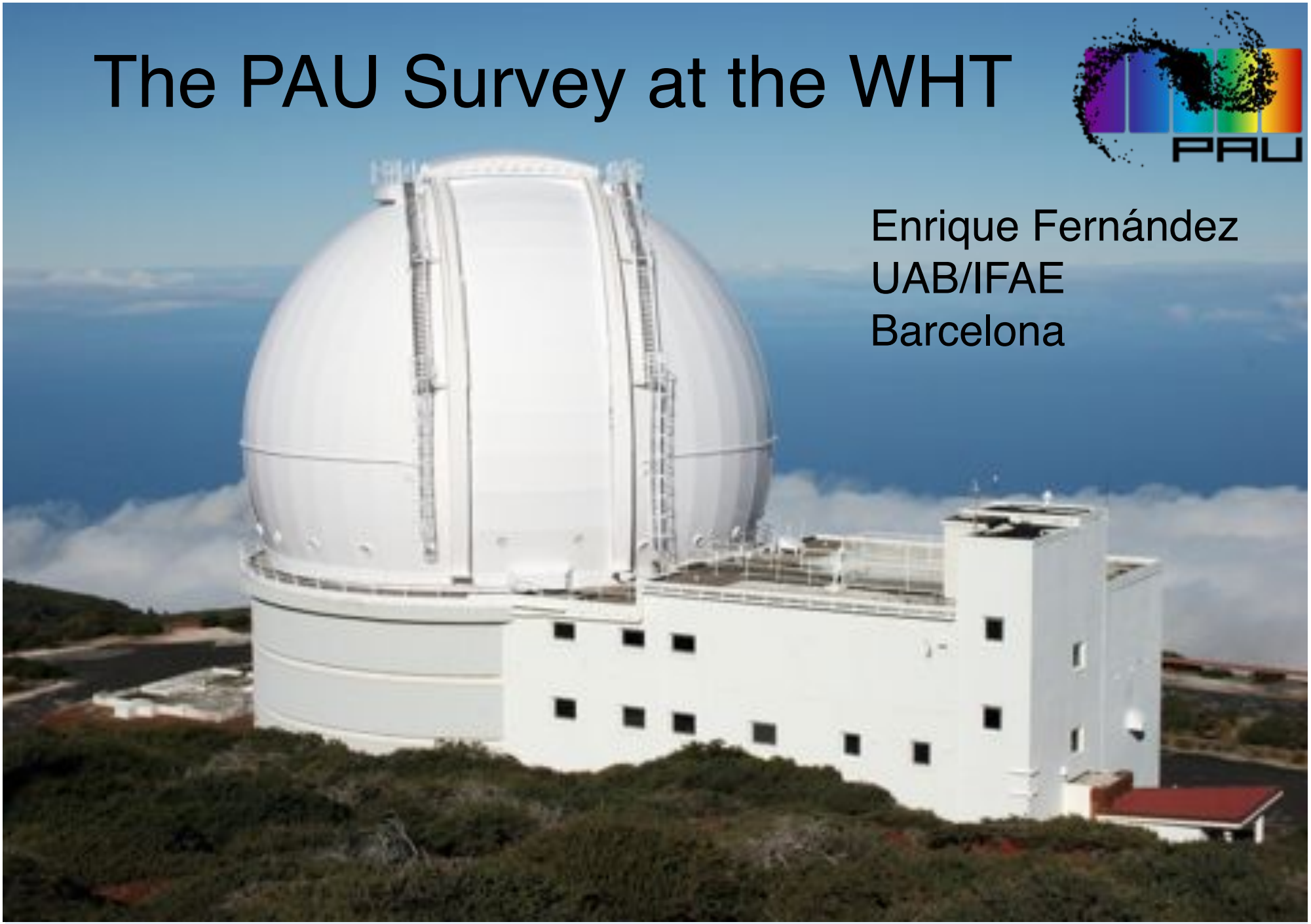
The PAU Survey at the WHT



Enrique Fernández
UAB/IFAE
Barcelona

COSMO-RENATA Meeting in Fuerteventura, 5-6 June 2014

PAU precedents

The PAU Project originated in the Consolider Ingenio 2010 Program of the (former) MICINN.

Project was approved in 2007 (ref. CSD2007-0060).

CIEMAT (Madrid), IAA (Granada), ICE-IEEC (Barcelona), IFAE-UAB (Barcelona), IFIC-UV (Valencia), IFT-UAM (Madrid), PIC (Barcelona).

Effectively started at the beginning of 2008.

PAU precedents

Main ideas:

- To prepare for conducting a large photometric red-shift survey.
- Emphasis in measuring Dark Energy probes.
- To build an appropriate instrument with Consolider funds (PAUCam) for an appropriate telescope (several options).

PAU at the WHT

- Summer 2009: contacted the ING management about possibility of installing PAUCam at the prime focus of WHT. Encouraged to pursue the idea.
- April 2010: submitted detailed proposal to ING board for wide-field camera, equipped with large number of narrow-band filters.
- June 2010: we got further encouragement from the ING board as a visiting instrument.

"The Board has approved the instrument visitor status for now, and is very keen on exploring additional means of access to the telescope that would give you the number of WHT nights needed for the proposed science."

PAU Team (almost 100% correlation with DES-Spain)

Color Code
Senior Scientists
Post-docs
Engineers
Doctoral Students
Technicians

CIEMAT

E. Sánchez, F. J. Rodríguez, I. Sevilla
J. Castilla, J. de Vicente
R. Ponce, F. J. Sánchez

ICE/IEEC

F. J. Castander, E.Gaztañaga, P. Fosalba, A. Bauer, C. Bonnet, M.Crocce, S. Farrens, S.Jouvel
R. Casas, S. Serrano
A. Izard, K. Hoffman, C.López, A. Pujol

IFAE

E. Fernández, R. Miquel, C. Padilla, A. Pacheco, C. Bonnett, J. Aleksić
O. Ballester, L. Cardiel, F. Grañena, C. Hernández, J. Jiménez, L. López, C. Pio
P. Martí, C. Sánchez
C. Arteche, J. Gaweda

PIC

M. Delfino, V. Acín, M. Caubet, J.Flix, C. Neissner, P. Tallada, N. Tonello, E. Planas, J. Carretero

UAM

J. García-Bellido, D. Sapone, S. Nesseris
A. Bueno, D. Alonso

PAU at the WHT

Ever since:

- Have been in close contact with ING/WHT (technical/administrative).

  Agreement signed.
  PAUCam Reviewed by external panel.
  Meeting of Board in Barcelona.

- Preparation of the science of PAU/WHT (PAU Survey at the WHT).

- **Design and construction of PAUCam.**

- Design and construction of the PAUCam data management system.

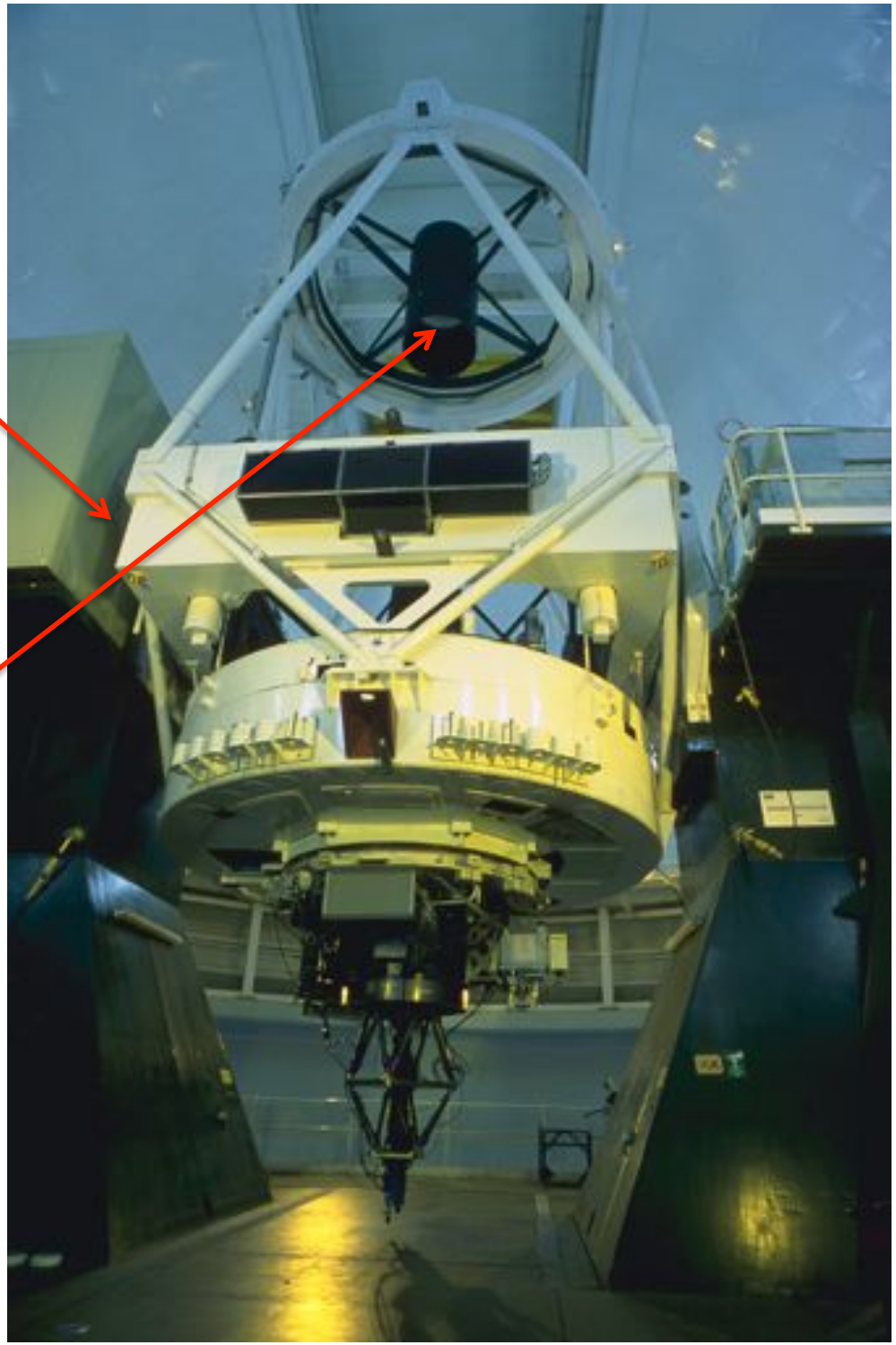
PAUCam at WHT

WHT Telescope

- Diameter: 4.2 m
- Prime focus: 11.73 m
- Focal ratio: f/2.8
- FoV: 1 deg ∅, 40’ unvignetted
- Scale: 17.58’’/mm ⇔ 0.26”/pixel

PAUCam will be mounted at the prime focus:

Strong limitation in the weight: **max. 235 kg**.



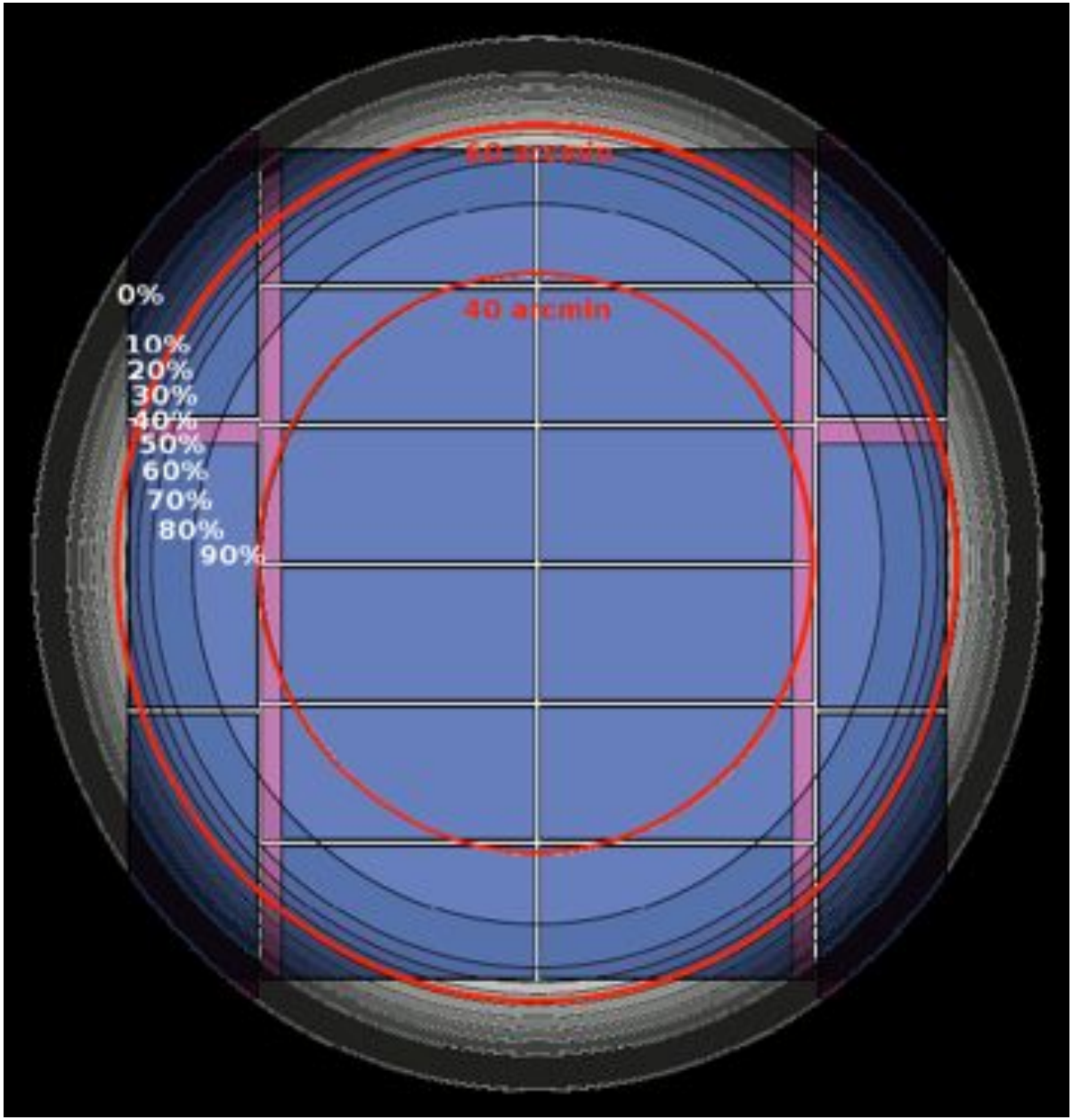
PAUCam focal plane

8 central CCDs with almost 100% exposure for imaging.

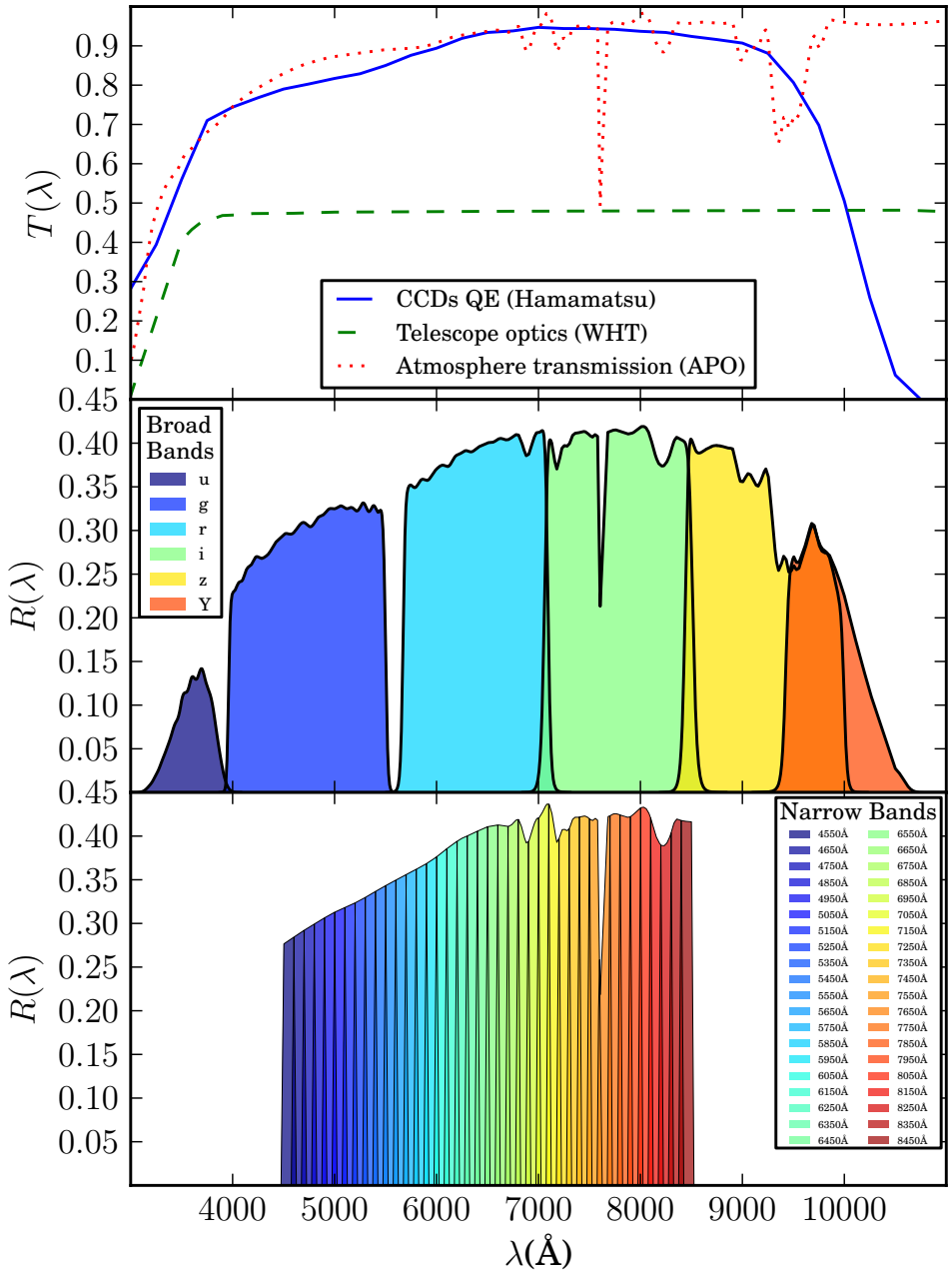
Rest of the CCDs:
2 for guiding
8 for broadbands (calib.)

40 narrow band (10nm) filters covering the range ≈ 450-850 nm
6 BB filters u.g.r.i.z.Y. in separate trays

Optimization: central CCDs will have 8 NB



PAU Filter Transmissions

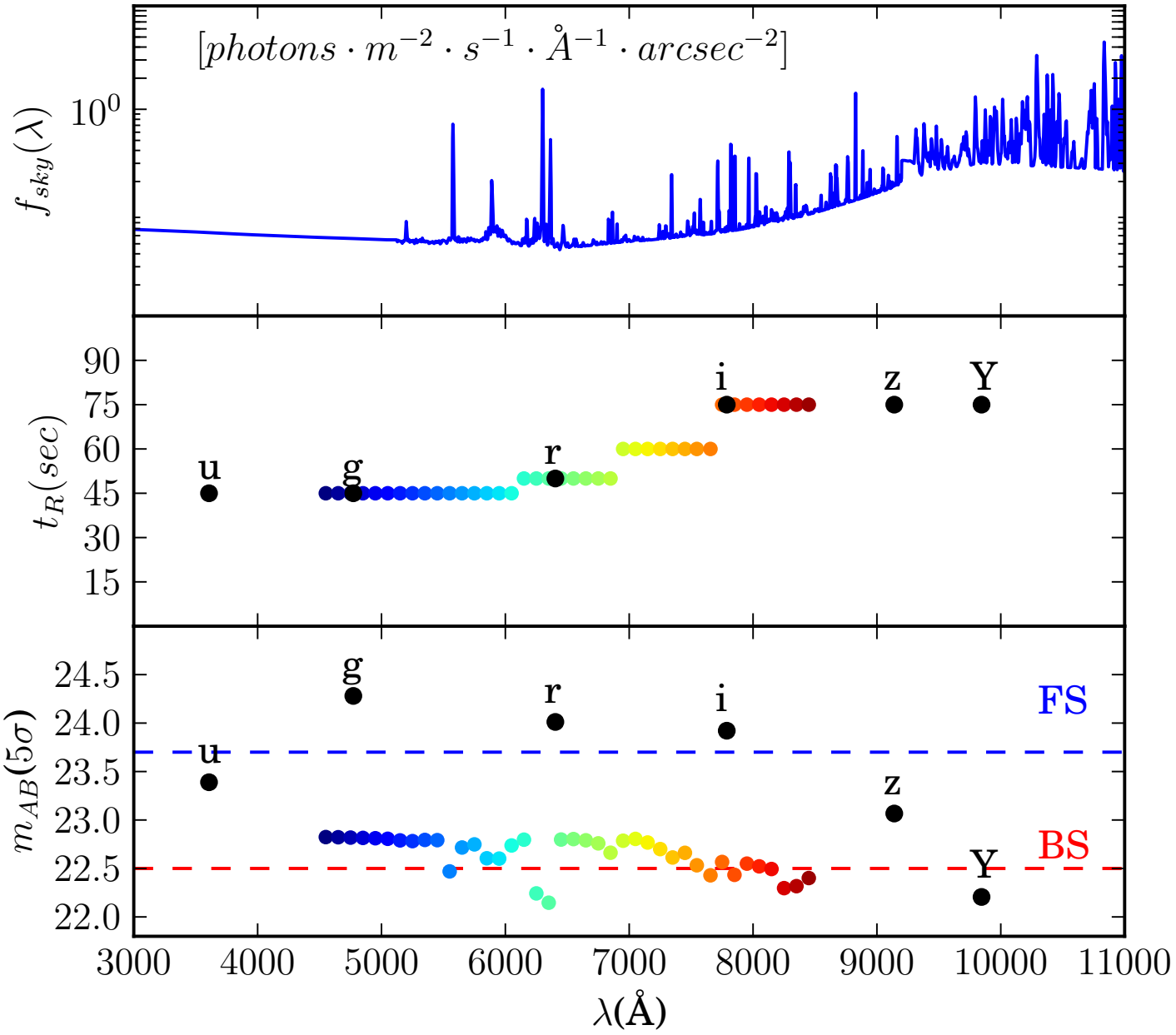


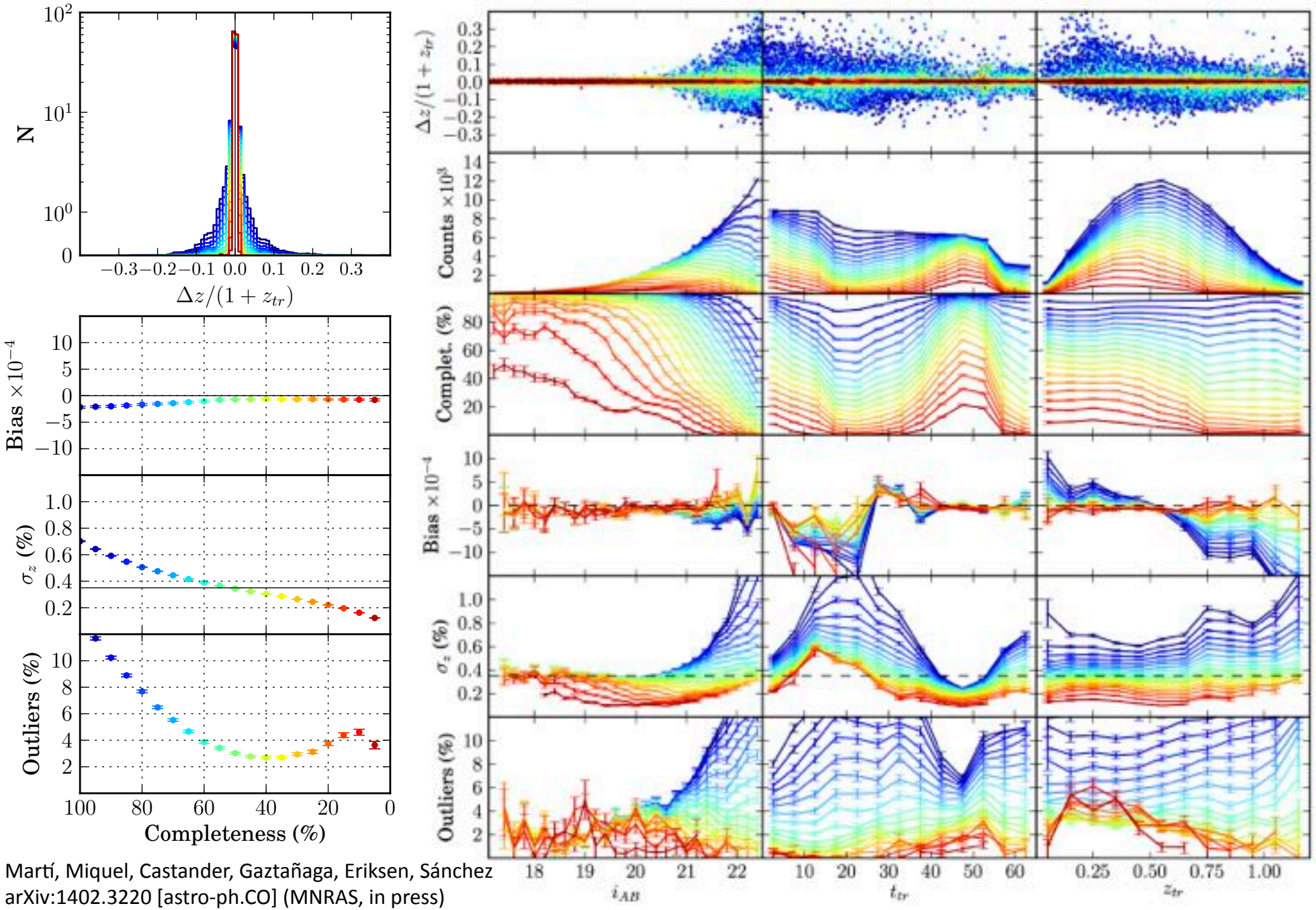
PAU Survey Strategy

- Each central CCDs covers the whole survey area twice.
- With same exposure time, broad bands reach ≈1.4 mag deeper than narrow bands.
- Objects detected in the BB, and flux obtained in the NB.
- Exposure times depend on tray: ≈ 90 s. for bluest, ≈150 s. for reddest.
- Surveying capability: sample 2 deg^2 / night to $i_{AB} < 22.5$ magnitude in all NB, and $i_{AB} < 23.7$ in the BBs

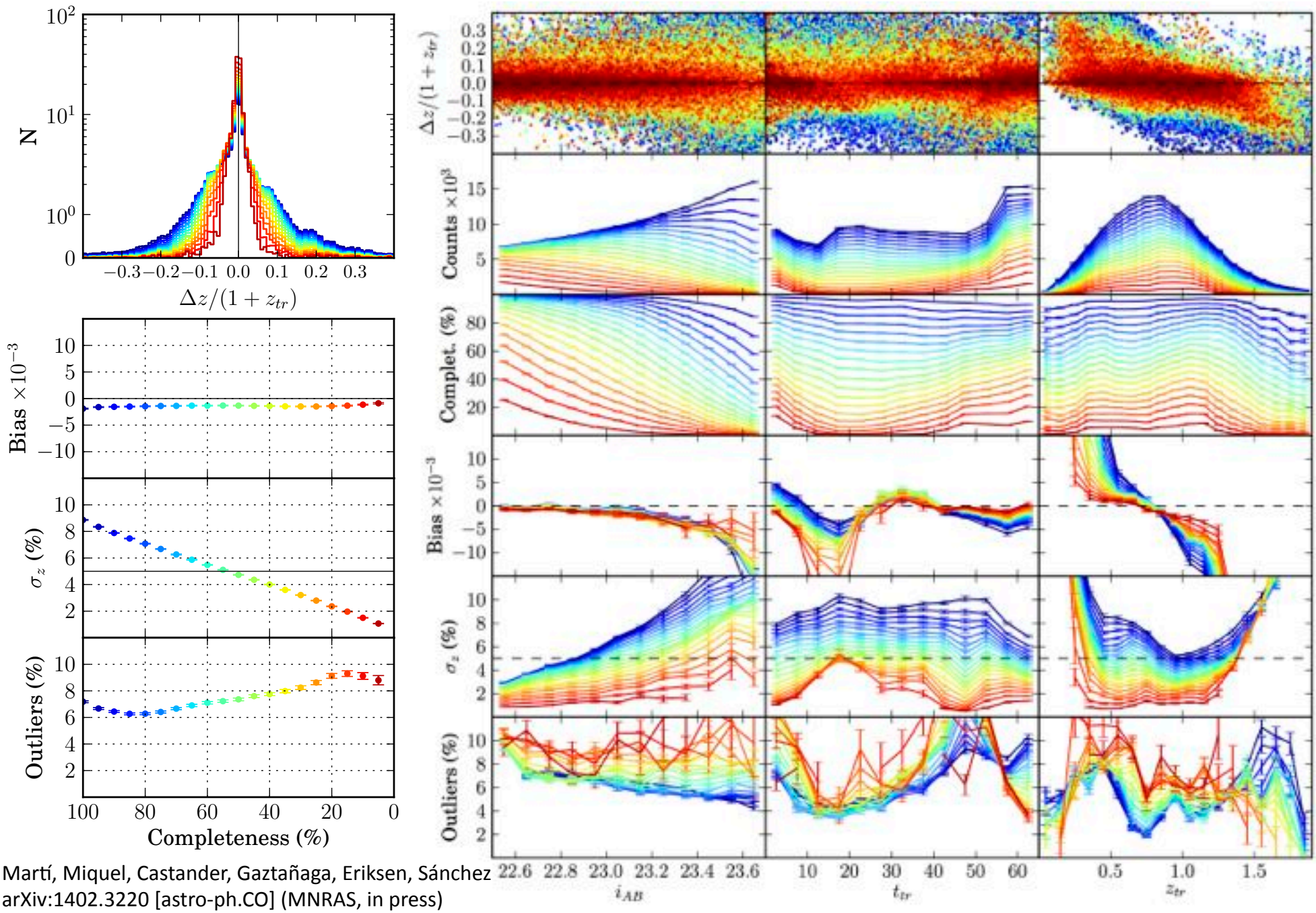
➜ 30000 galaxies, 5000 stars, 1000 quasars /night.

PAU Limiting Magnitudes





Martí, Miquel, Castander, Gaztañaga, Eriksen, Sánchez
arXiv:1402.3220 [astro-ph.CO] (MNRAS, in press)



Martí, Miquel, Castander, Gaztañaga, Eriksen, Sánchez
arXiv:1402.3220 [astro-ph.CO] (MNRAS, in press)

PAUS (PAU-Survey) Scientific Goals

We expect to obtain ≈ 100 nights during the 4-year period 2015-2018. This implies ≈200 deg^2.

Scientific goals for PAU/WHT will focus on measuring

- Red-shift Space Distortions (RSD)
- Weak Lensing Magnification (MAG),

simultaneously over the same sky area, but by making use of two galaxy samples:

- A bright galaxy sample (B) ($i_{AB} < 22.5$) with high redshift resolution of σ_z=0.0035x(1+z).
- A faint sample (F) $22.5 < i_{AB} < 23.7$ with σ_z=0.05x(1+z)

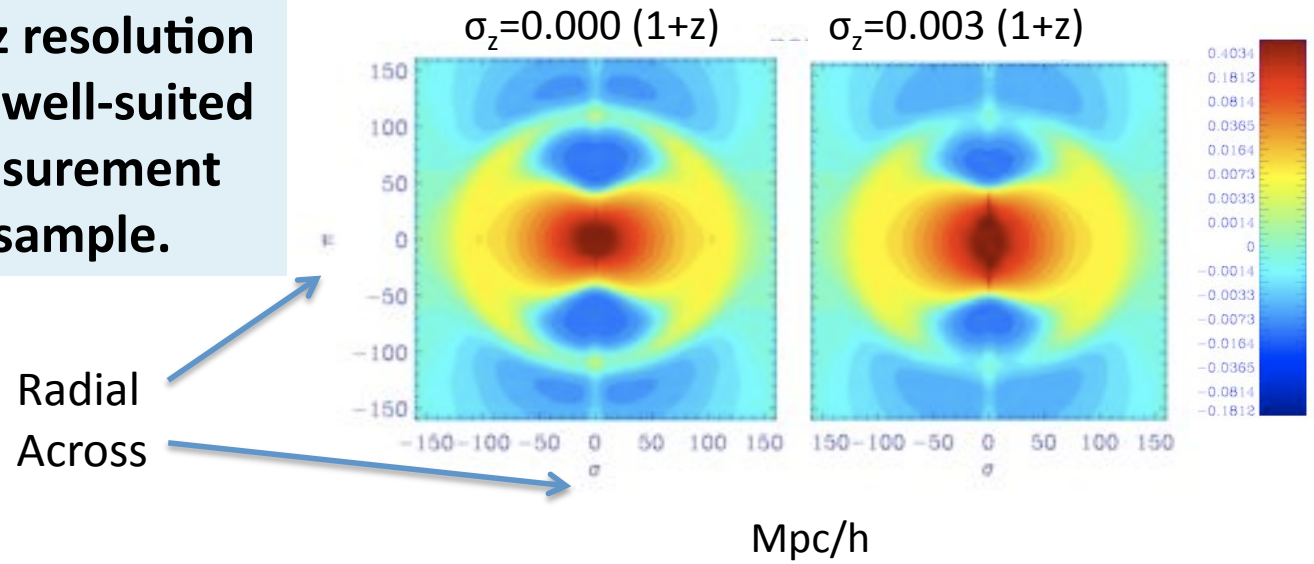
PAUS Scientific Goals

- **Weak-lensing magnification**
  - Lensing changes area of background image → density fluctuations correlated with density fluctuations in the foreground lenses.
  - Very precise photo-z's in foreground lenses allow to perform galaxy-galaxy cross-correlations between well-defined and narrow redshift bins (bin width ≈ 4 times the resolution of the B sample; not critical).

PAUS Scientific Goals

- **Red-shift Space Distortions.**
  - The Hubble relation between redshift and distance in the radial direction is modified by the peculiar velocity of galaxies.
  - Large structures give rise to bulk motions which affect the z-r maps. Galaxies behind over-dense regions will appear nearer, while galaxies in front of dense regions will appear farther ➔ squashing of matter distribution in radial direction at large scales.

PAU photo-z resolution particularly well-suited for this measurement over bright sample.



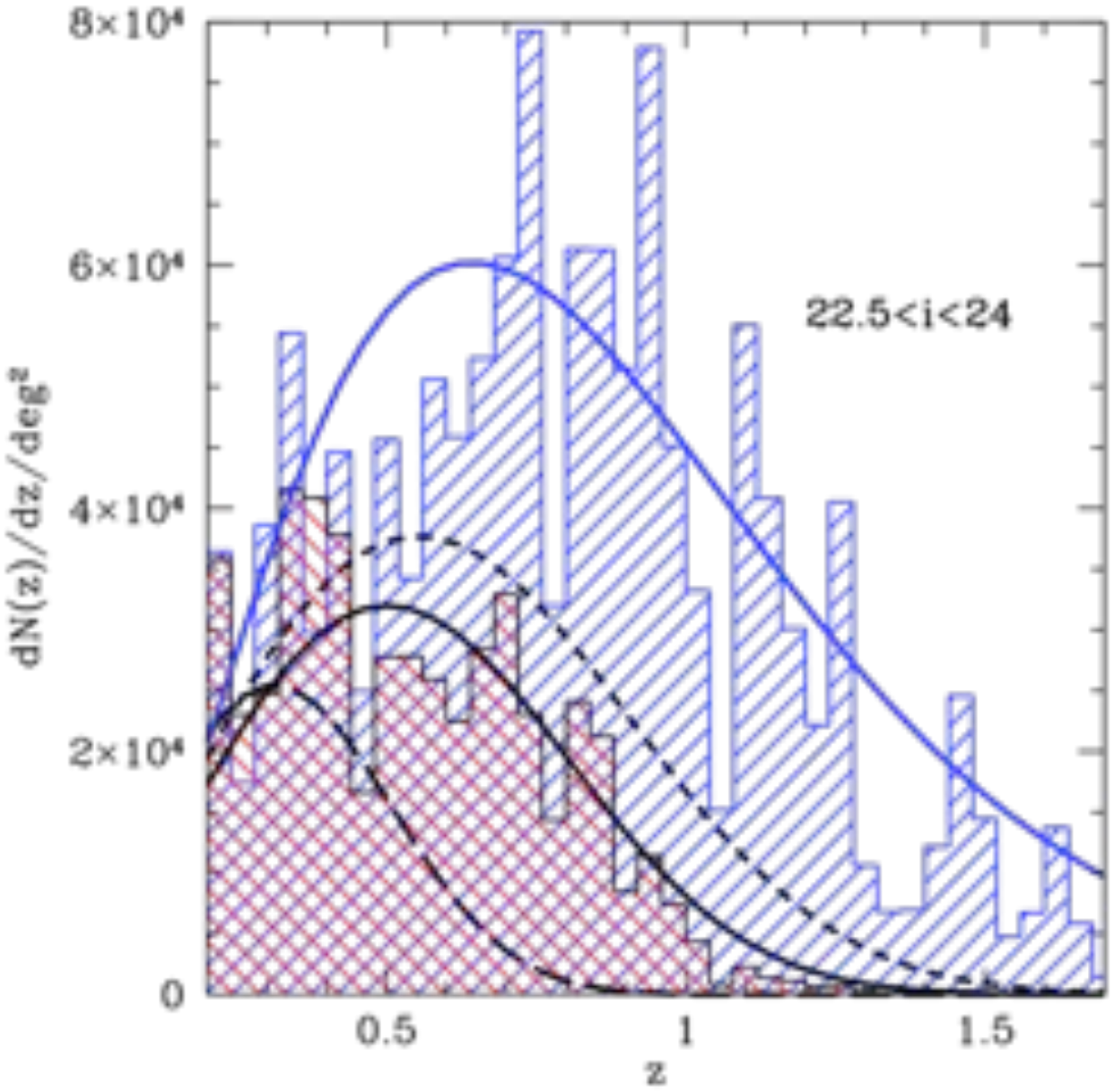
PAUS (PAU-Survey) Scientific Goals

dN(z)/dz /deg^2 for
FAINT (F) and
BRIGHT (B) samples.

6 x 10^6 B galaxies
2 x 10^6 F galaxies
(after 50% efficiency)

F → for W.L. MAG
and/or shear

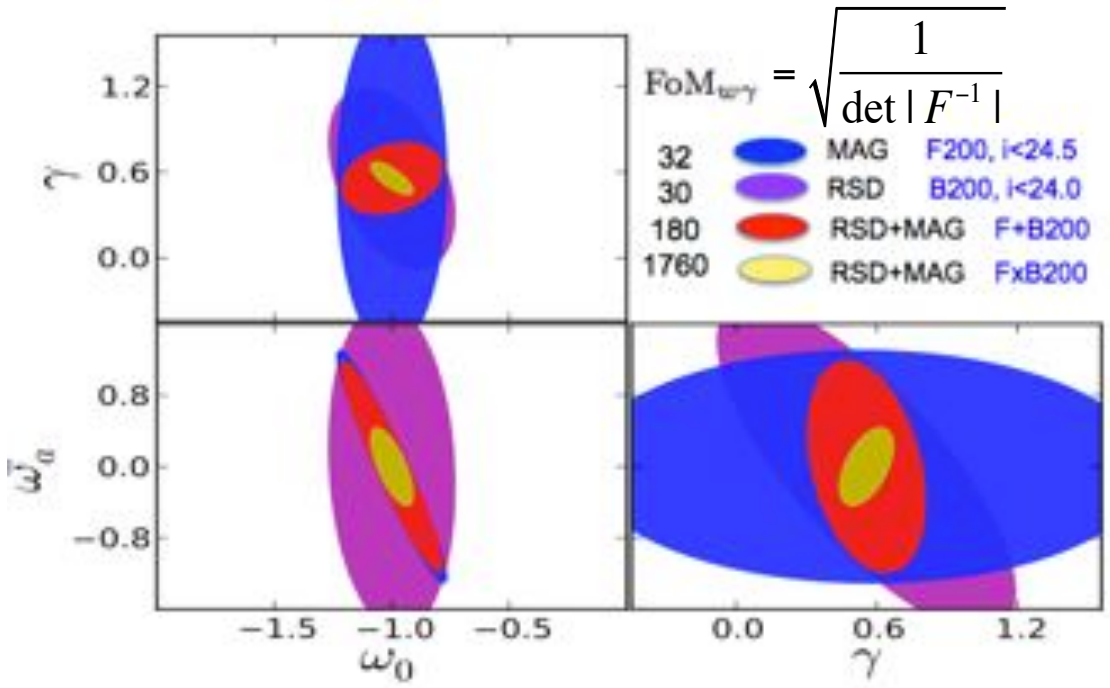
B → for RSD



PAU at the WHT

Effects (MAG and RSD) are sensitive to both the equation of state parameter, $w = w_0 + w_a (1-a)$, and growth of structure parameter γ.

The combination of RSD and MAG in the same dataset is very powerful in breaking degeneracies between cosmological parameters
➔A unique advantage of PAU.



Gaztañaga, Eriksen, Crocce, Castander, Fosalba, Martí, Miquel, Cabré, MNRAS, 422,2904G (2012)

PAU Survey additional science

Although the survey is designed and optimized for DE, many other science topics could be addressed

- Intrinsic alignment of galaxies (main systematic for weak lensing surveys, e.g. Euclid).
- Photo-z calibration of future survey (DES, LSST, Euclid)
- Galaxy evolution
- High redshift galaxies
- Interstellar dust
- Strong gravitational lensing
- Quasars and Lyα systems
- Clusters
- Galactic astronomy
- Stellar populations
- Halo stars
- Local group galaxies
- Serendipitous discoveries

PAUCam
design and construction

PAUCam

To build a complete instrument of these kind, entirely in-house, is a **complex** project. It involves:

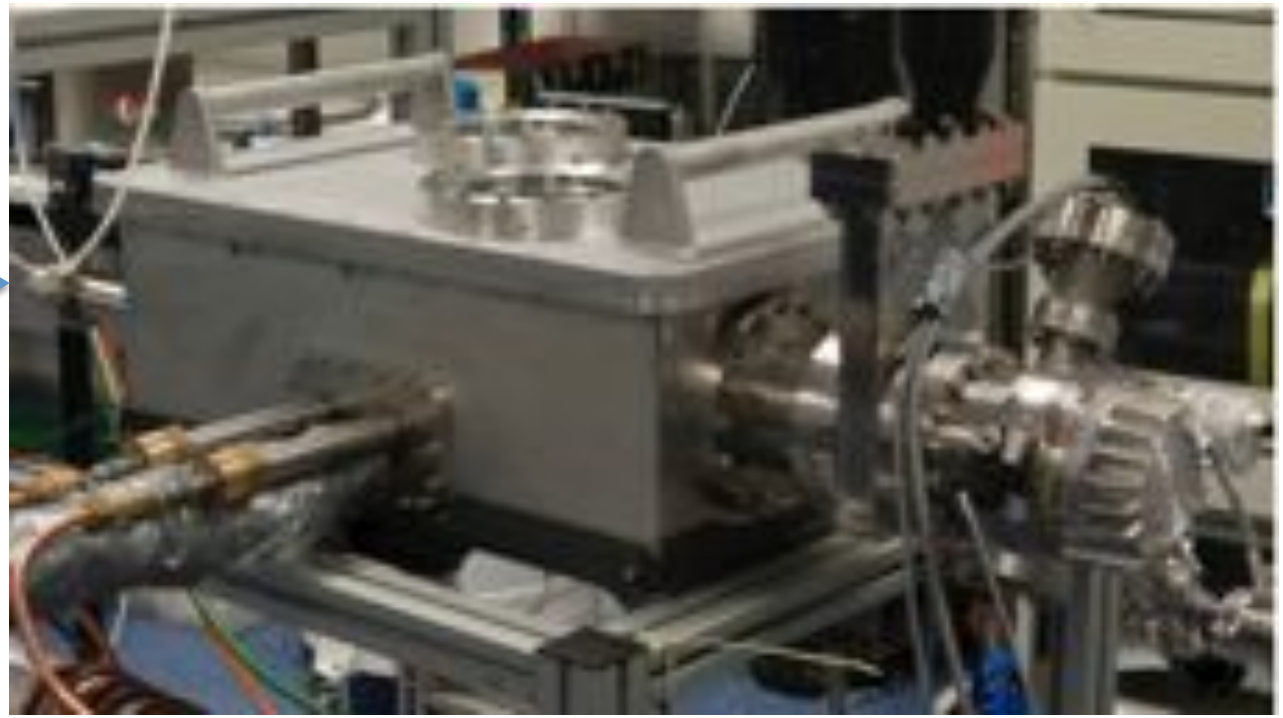
Cryogenics
Vacuum
Low-noise electronics
Precision mechanics
Control systems
"Professional" software
…

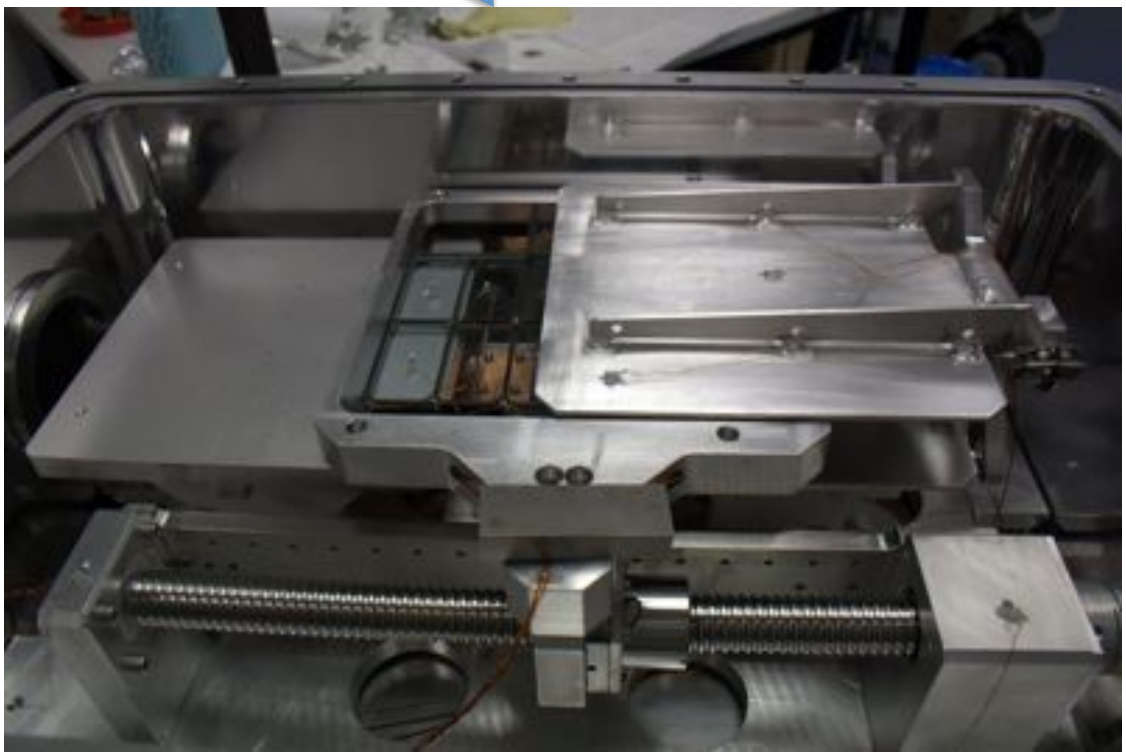
Need a large team of engineers and skilled technicians.

> 20 persons, ≈ 15 FTE

Constraints from the telescope side, especially weight limitations.

PAUCam first full-size prototype





A camera made in Aluminum would be too heavy.

➔

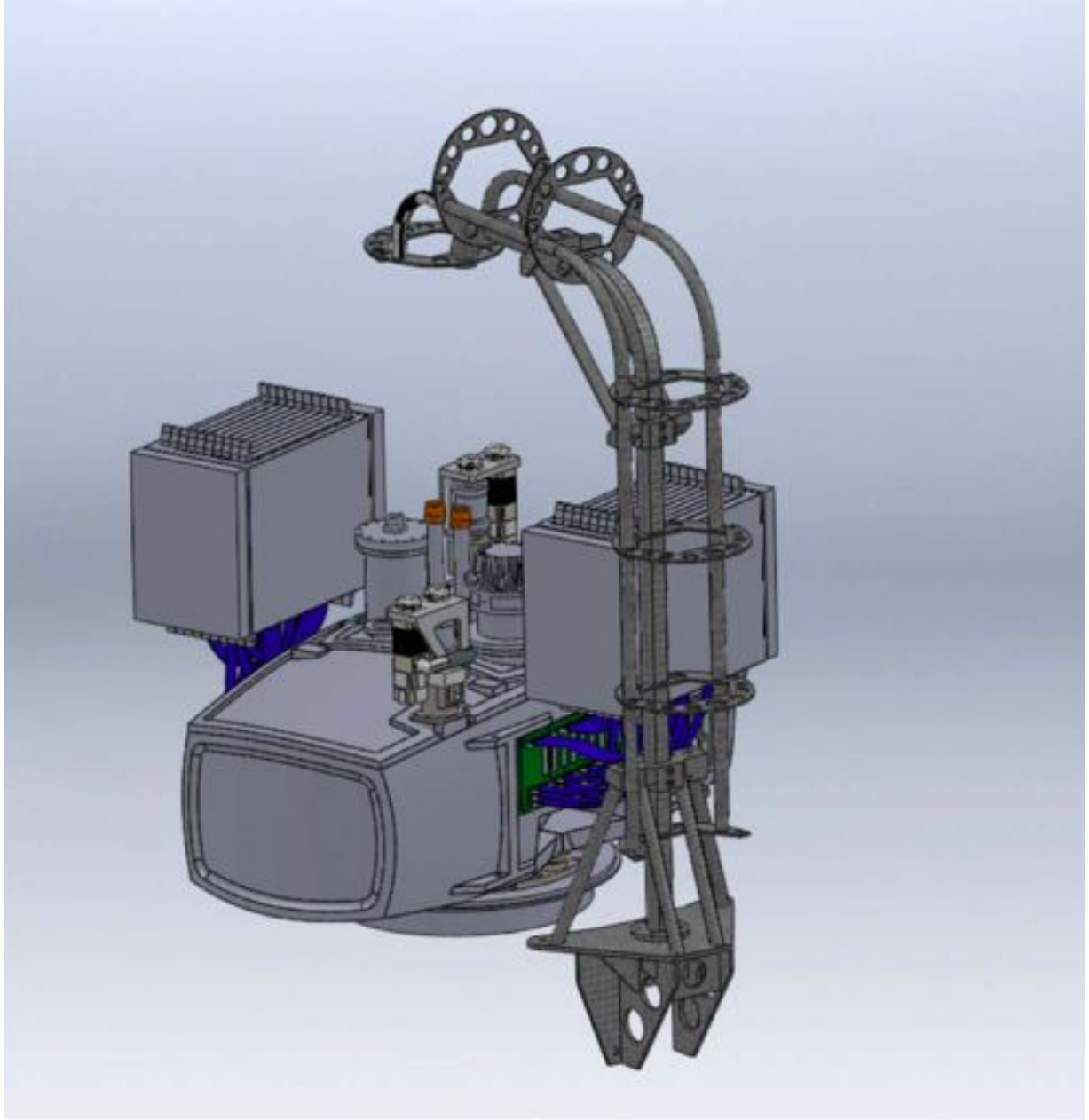
Make it in Carbon Fiber.

PAUCam

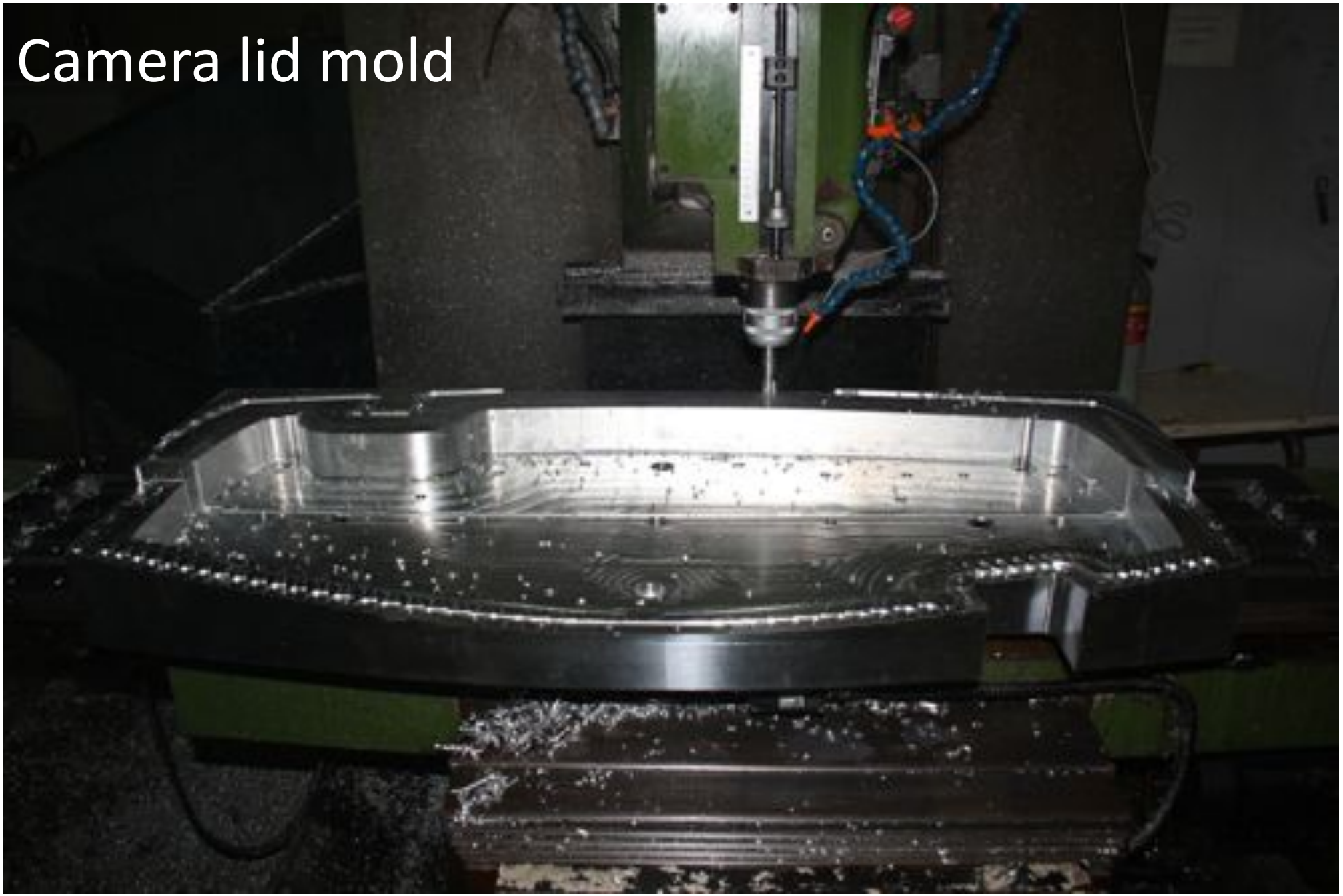
Camera body made of Carbon fiber.

Filter trays inside cryostat (to minimize distance to CCDs).

Large number of filters: several trays that have to be moved remotely, in cryogenic vacuum.



In-house fabrication of camera mold



PAUCam

Camera body made of Carbon fiber. Need to make mold.

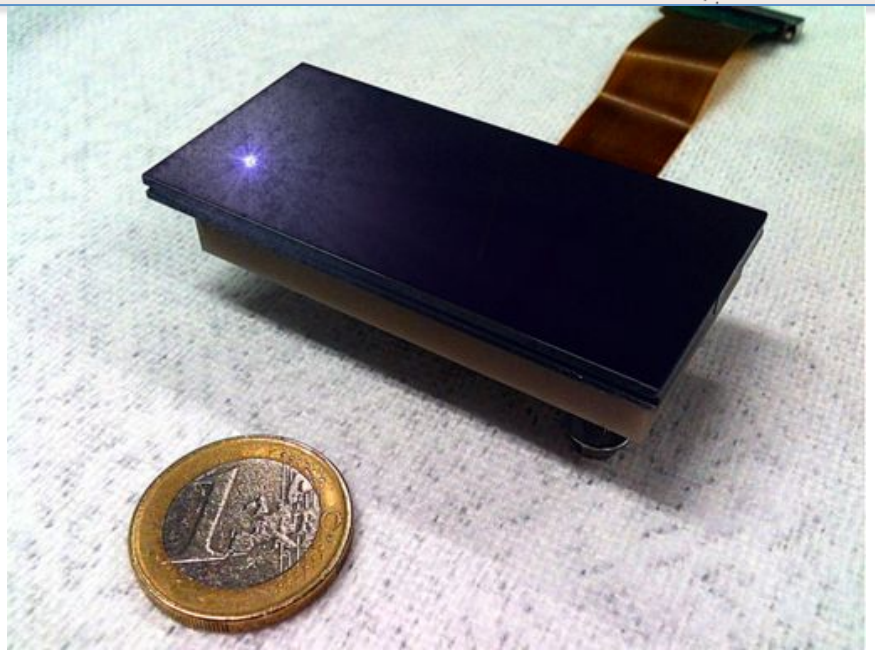
PAUCam assembled mold

PAUCam: part of camera body

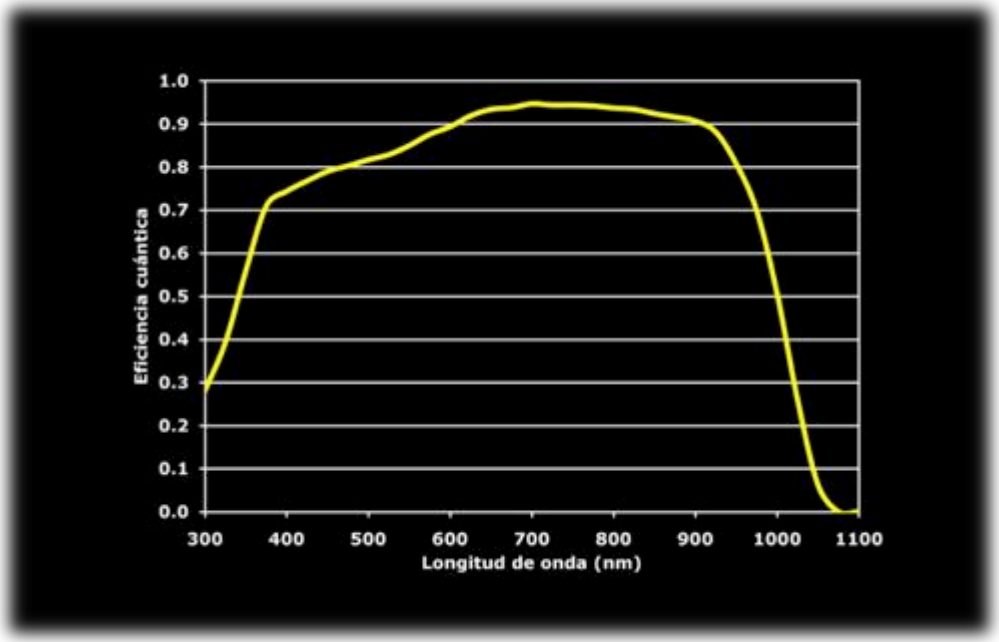
PAU CCDs

CCDs: Hamamatsu photonics (2k X 4k) pixels ($15\mu m^2$) (back-illuminated).

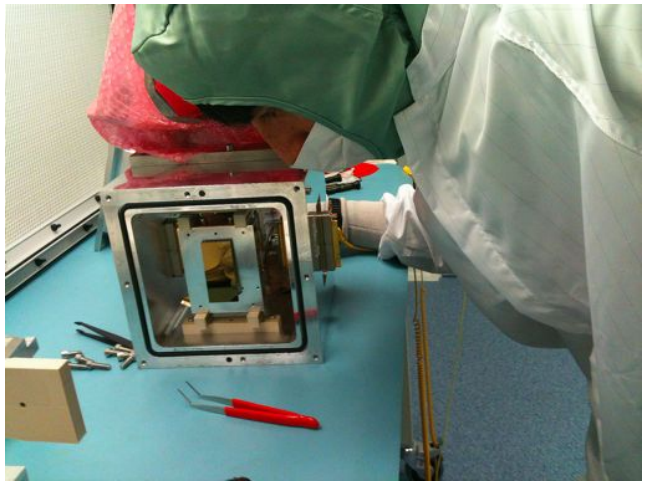
WHT f/2.8 ➔ 0.26” /pixel



Excellence sensitivity from 0.3 - 1 µ

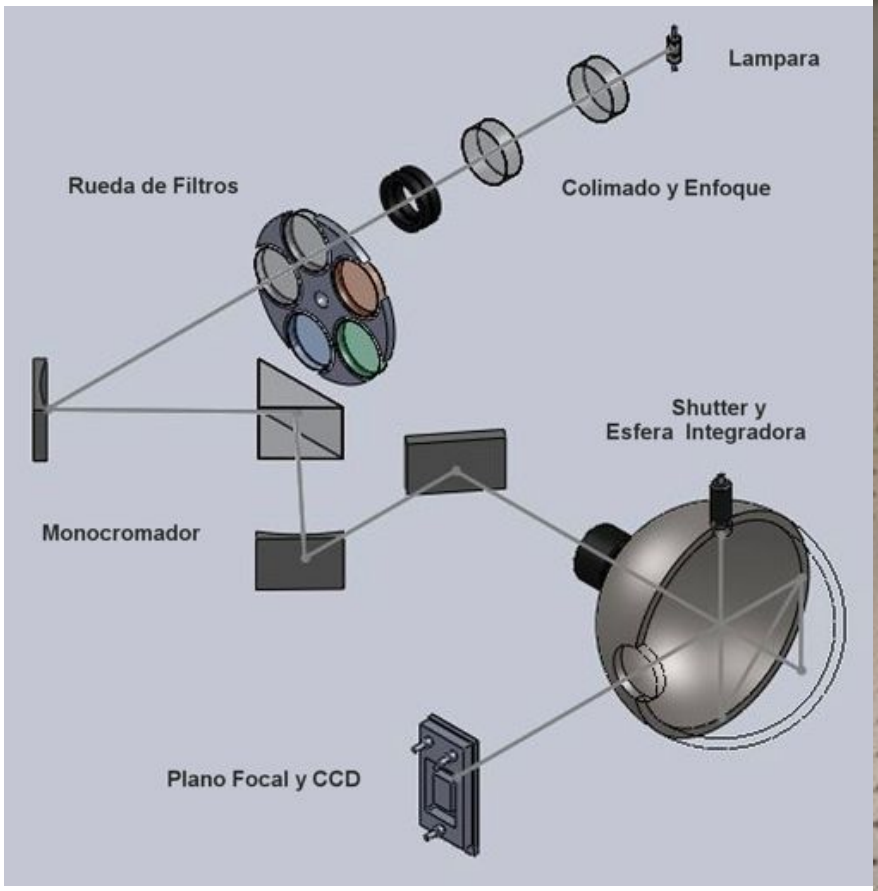


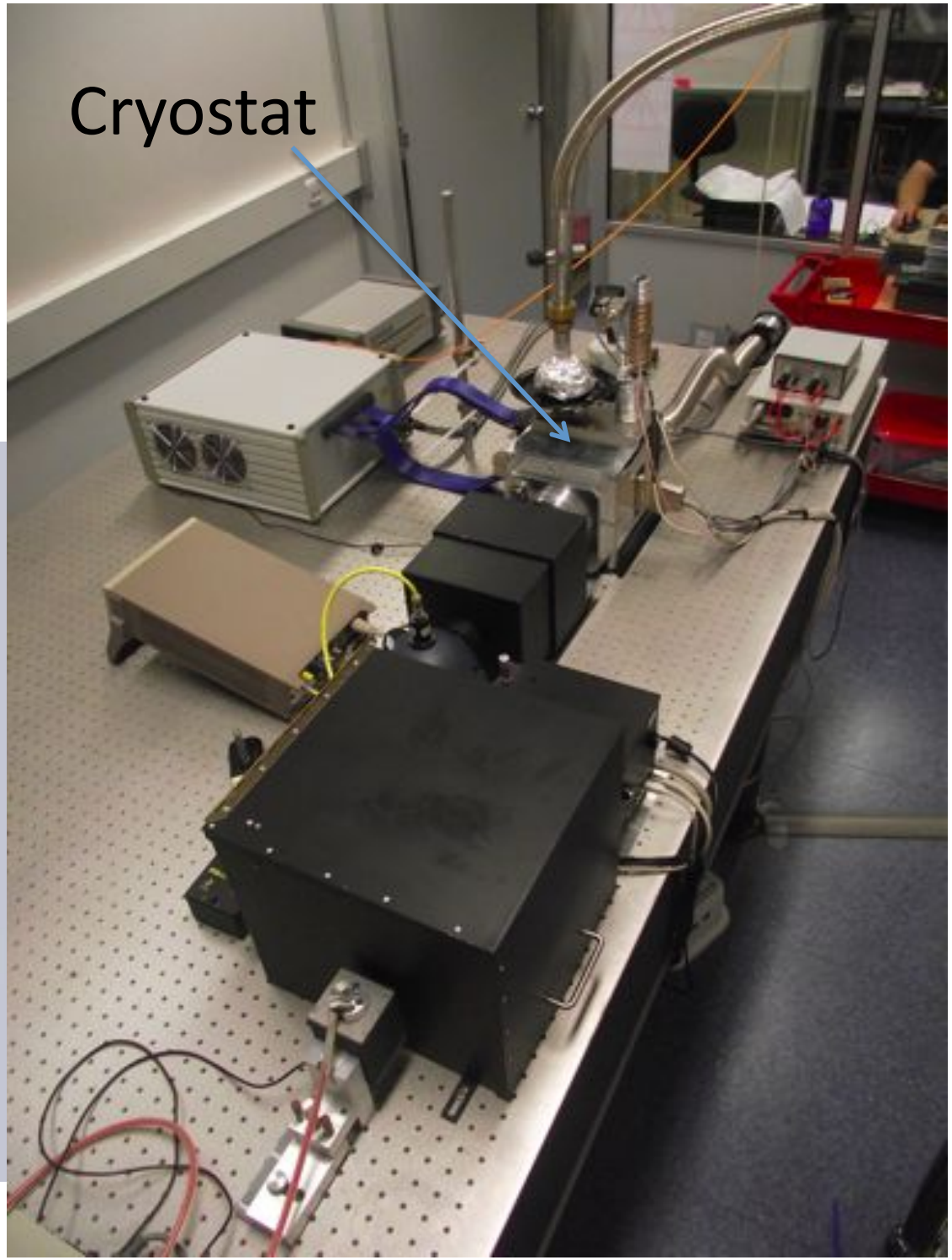
CCD installation in a class-100 clean room.



Characterization:

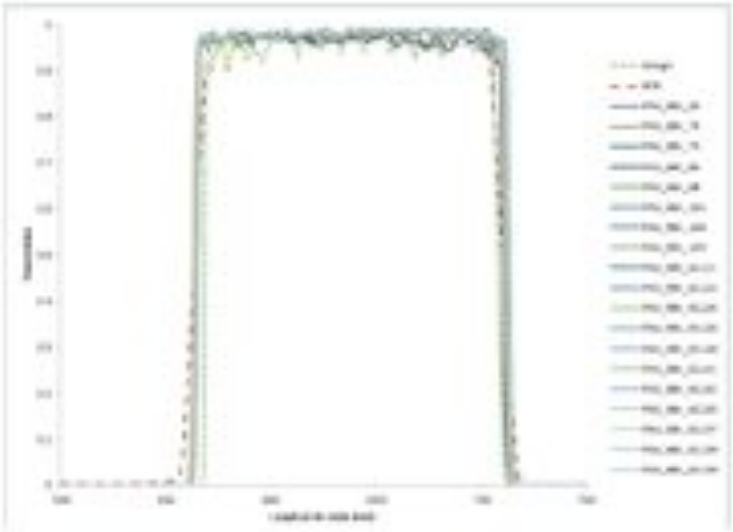
(2 stations, one in Madrid and one in Barcelona)



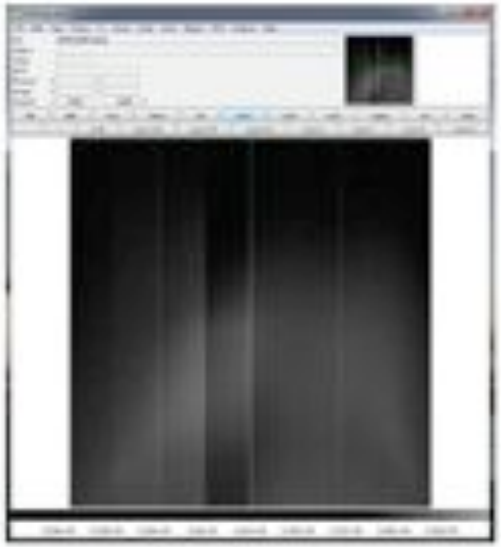


PAU CCDs characterization

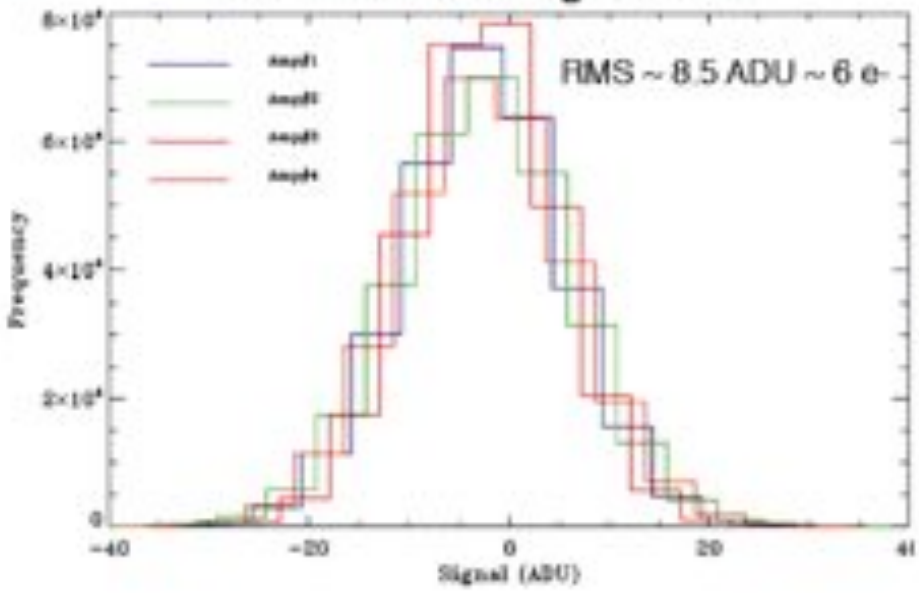
Filter transmission (r-band)



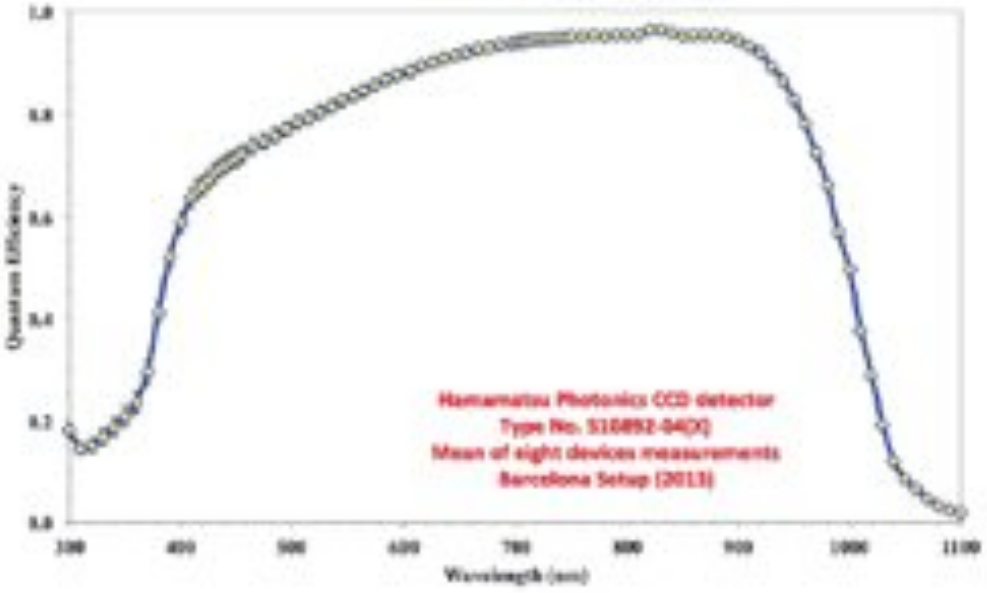
CCD image (30 min dark)



CCD noise reading 2 CCDs

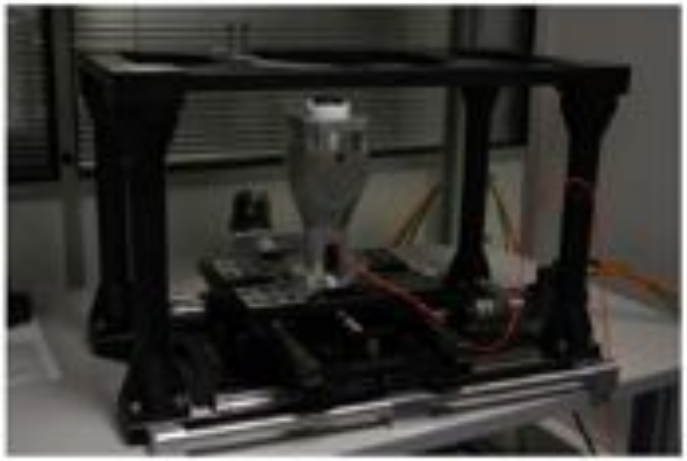


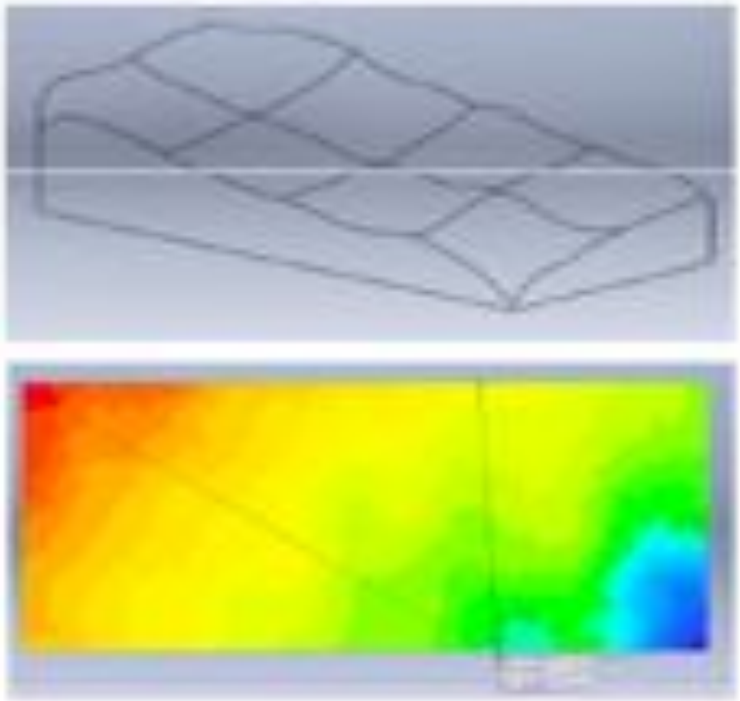
CCD QE



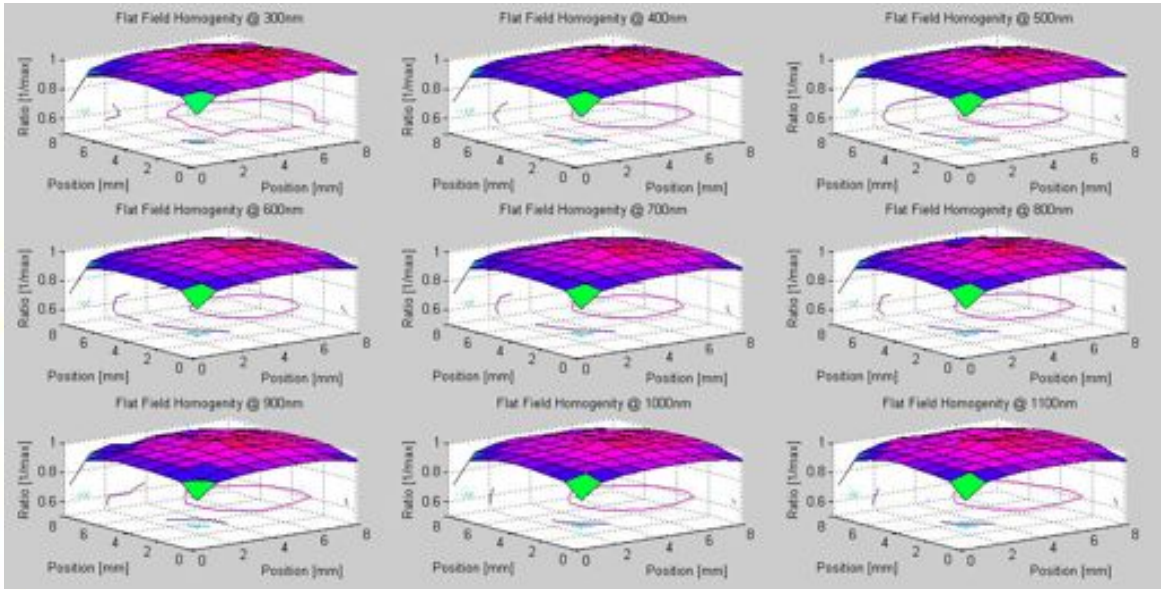
PAU CCD Planarity tests

- PAU: XY Metrology table

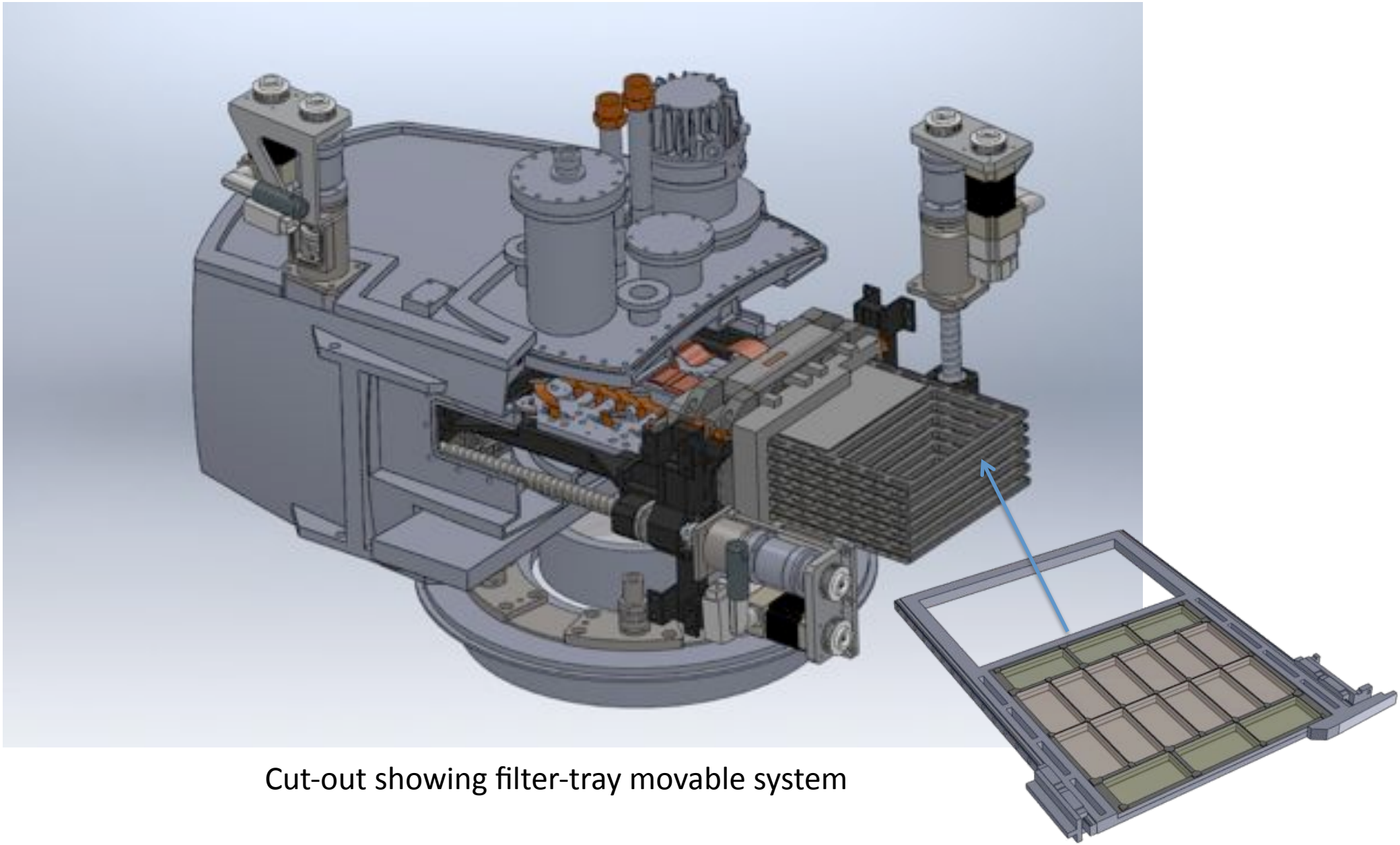




Flat Field Non-Uniformity < 2%



PAUCam



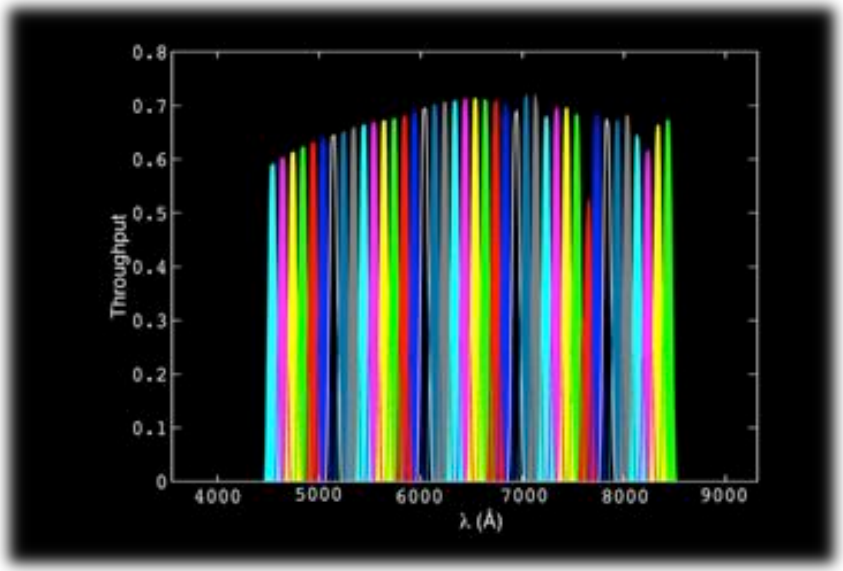
Cut-out showing filter-tray movable system

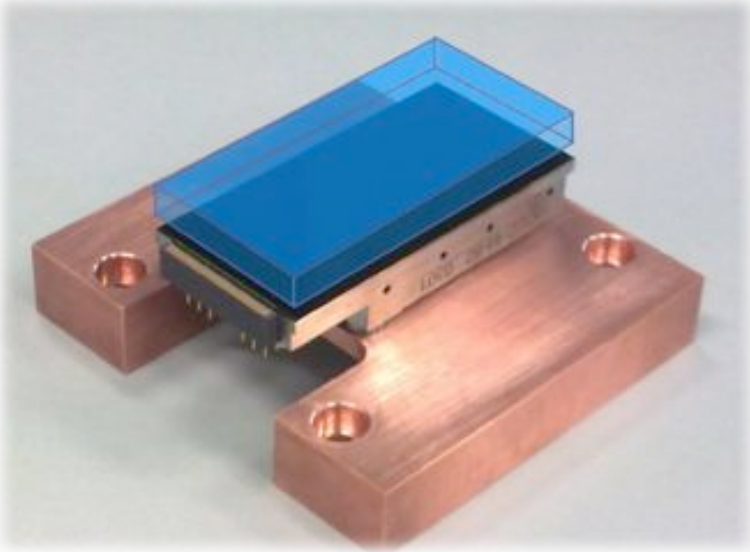
PAU Cam Filters

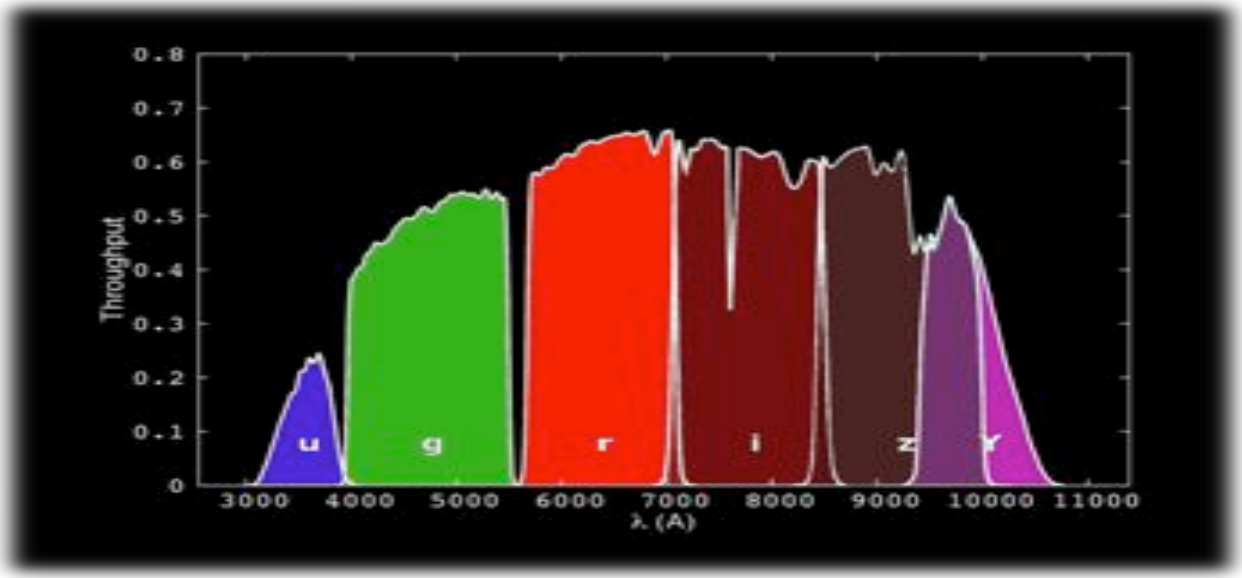
- ~40 narrow-band filters
- FWHM = 100 Å
- Spectral range: λ=4300-8600 Å
- Rectangular transmission profile

- 6 broad-band filters
- ugriZY (SDSS & DES)

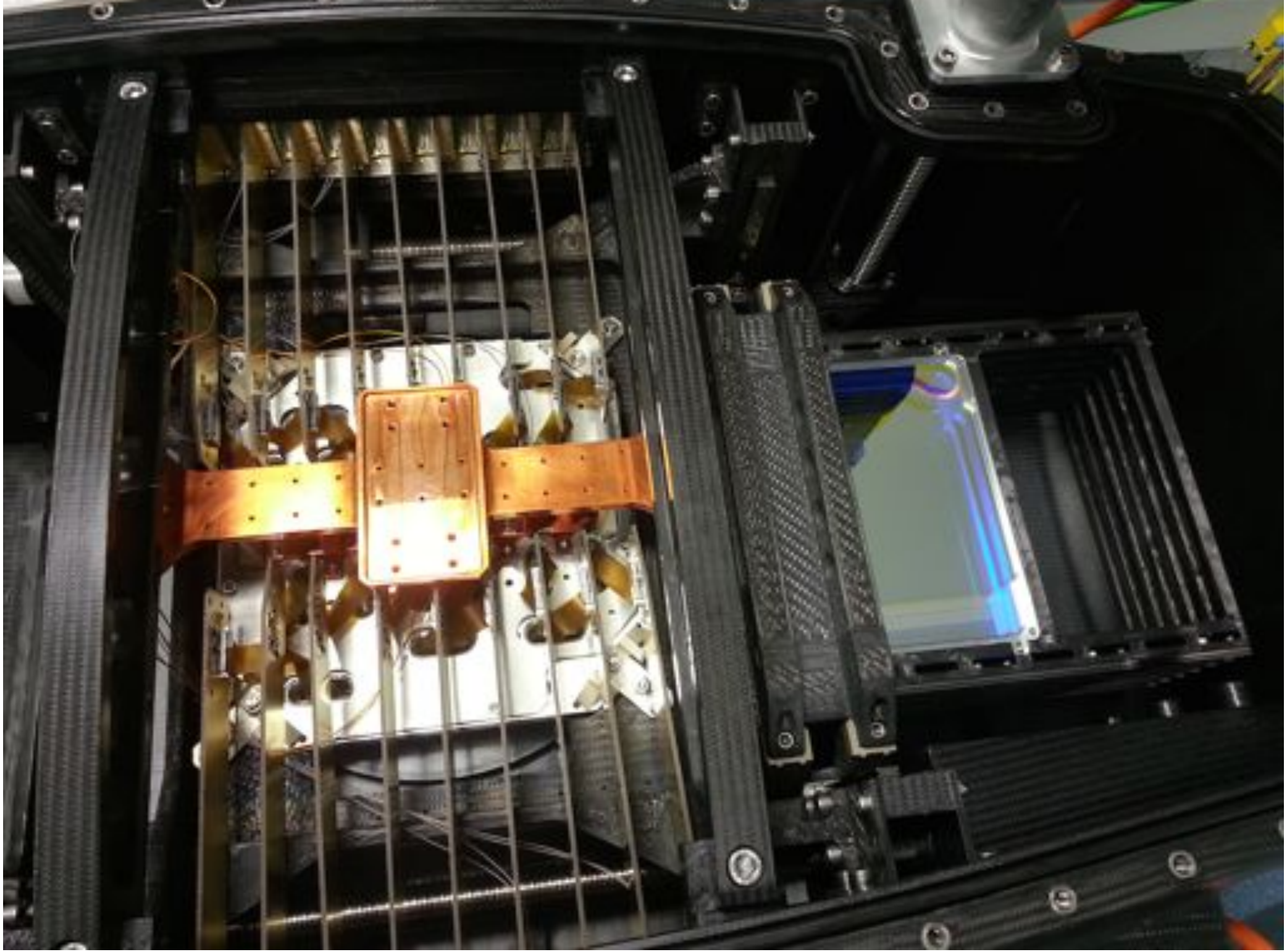
- Additional outside tray for external users.

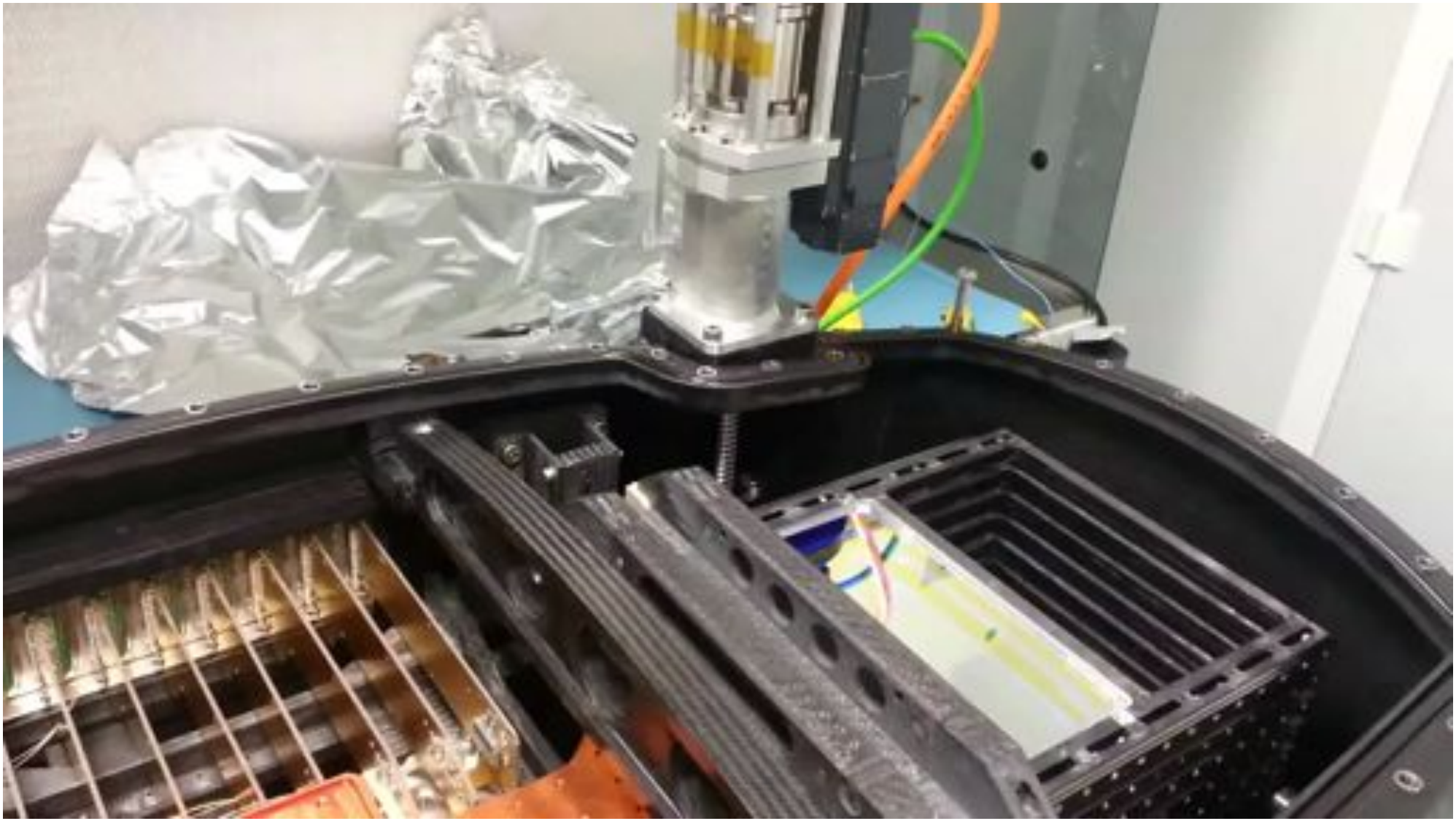




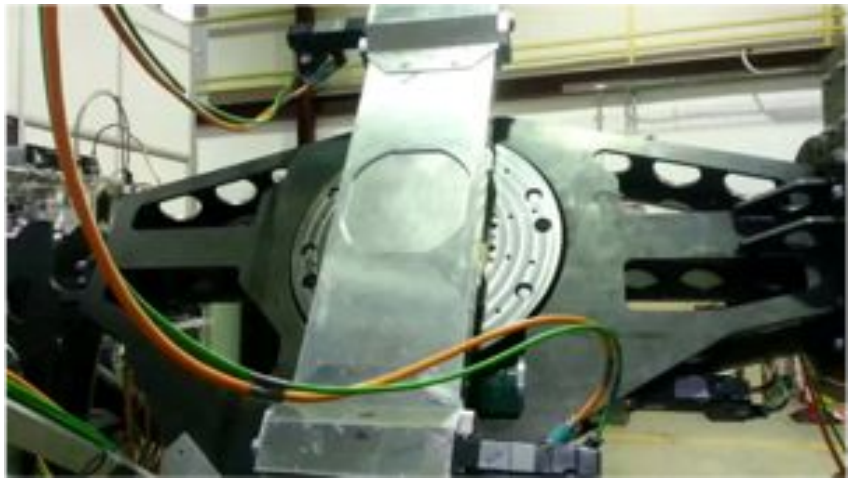


Delivery of filters delayed because of administrative issues.



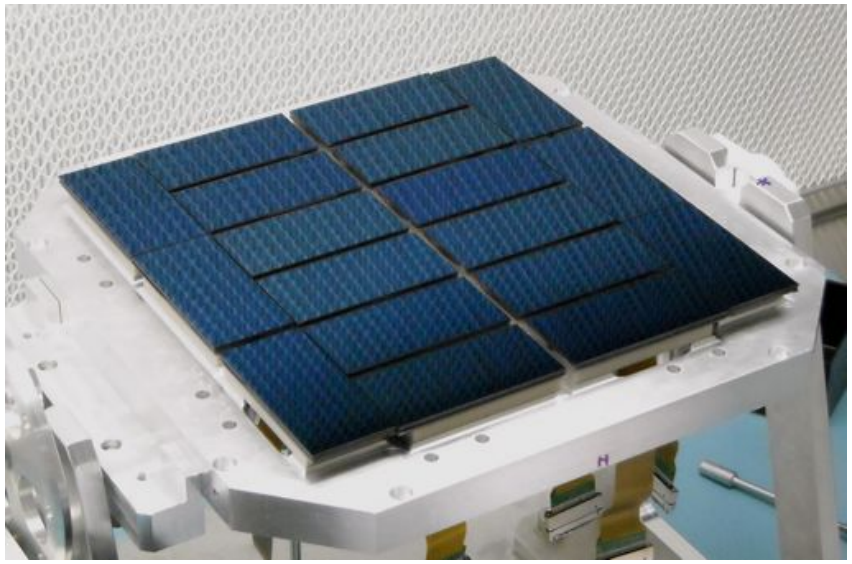


Shutter

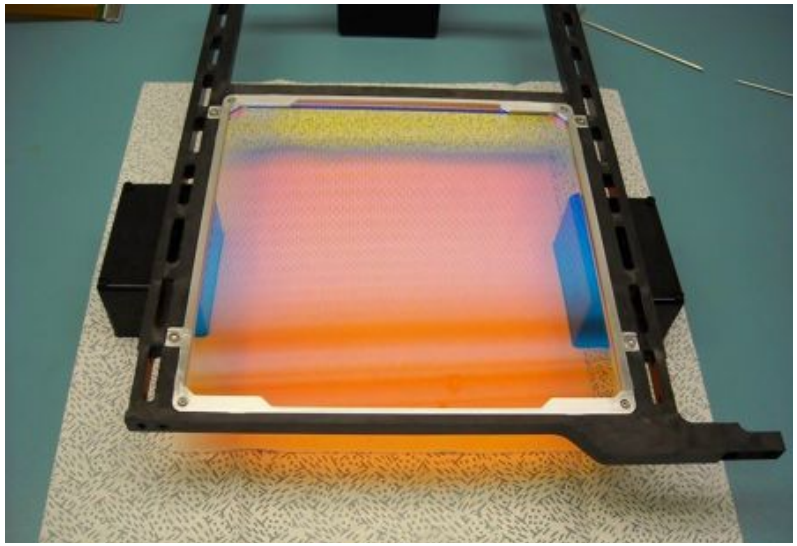


Entrance window

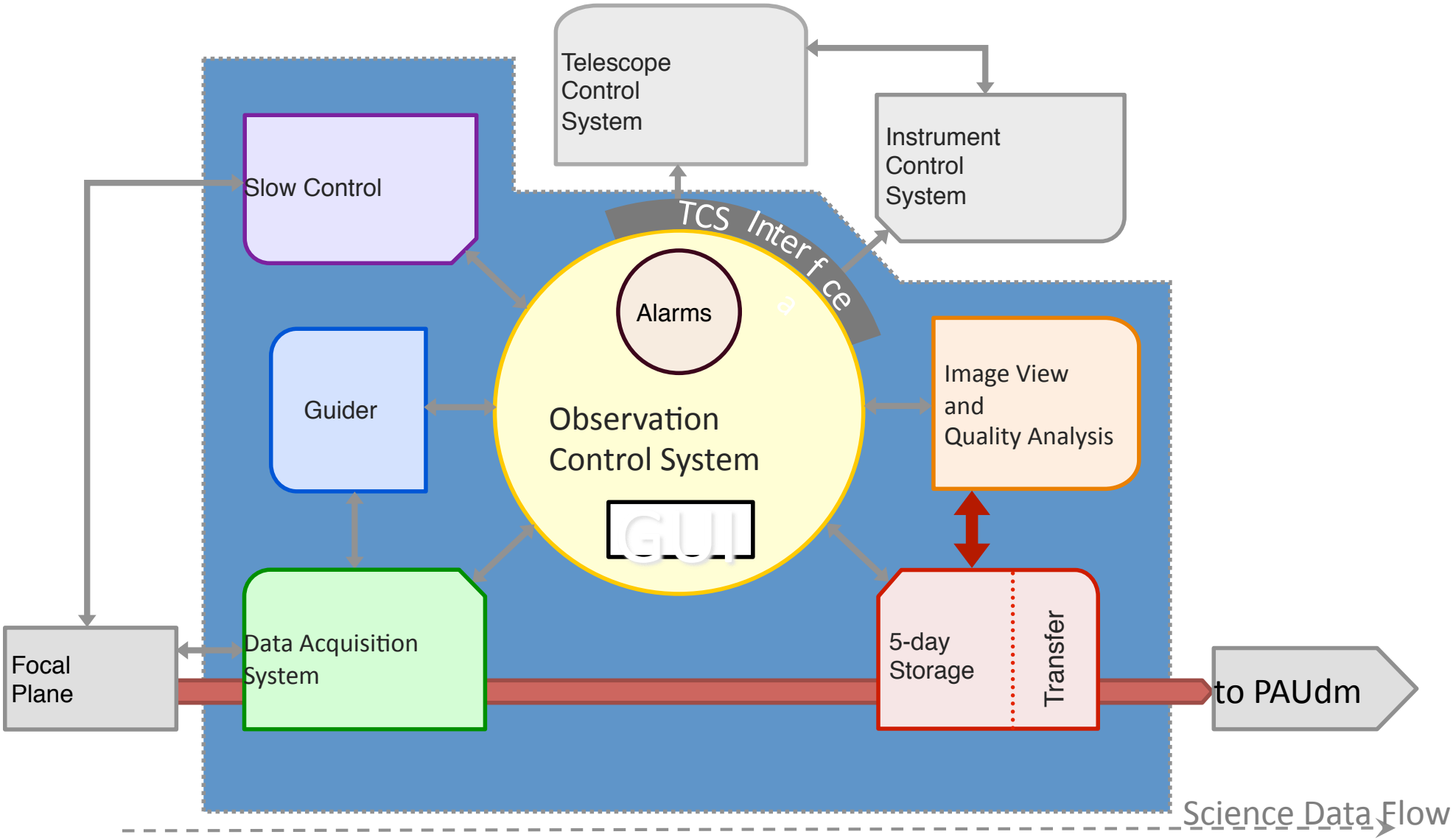
18 CCDs in the focal plane



r-band filter

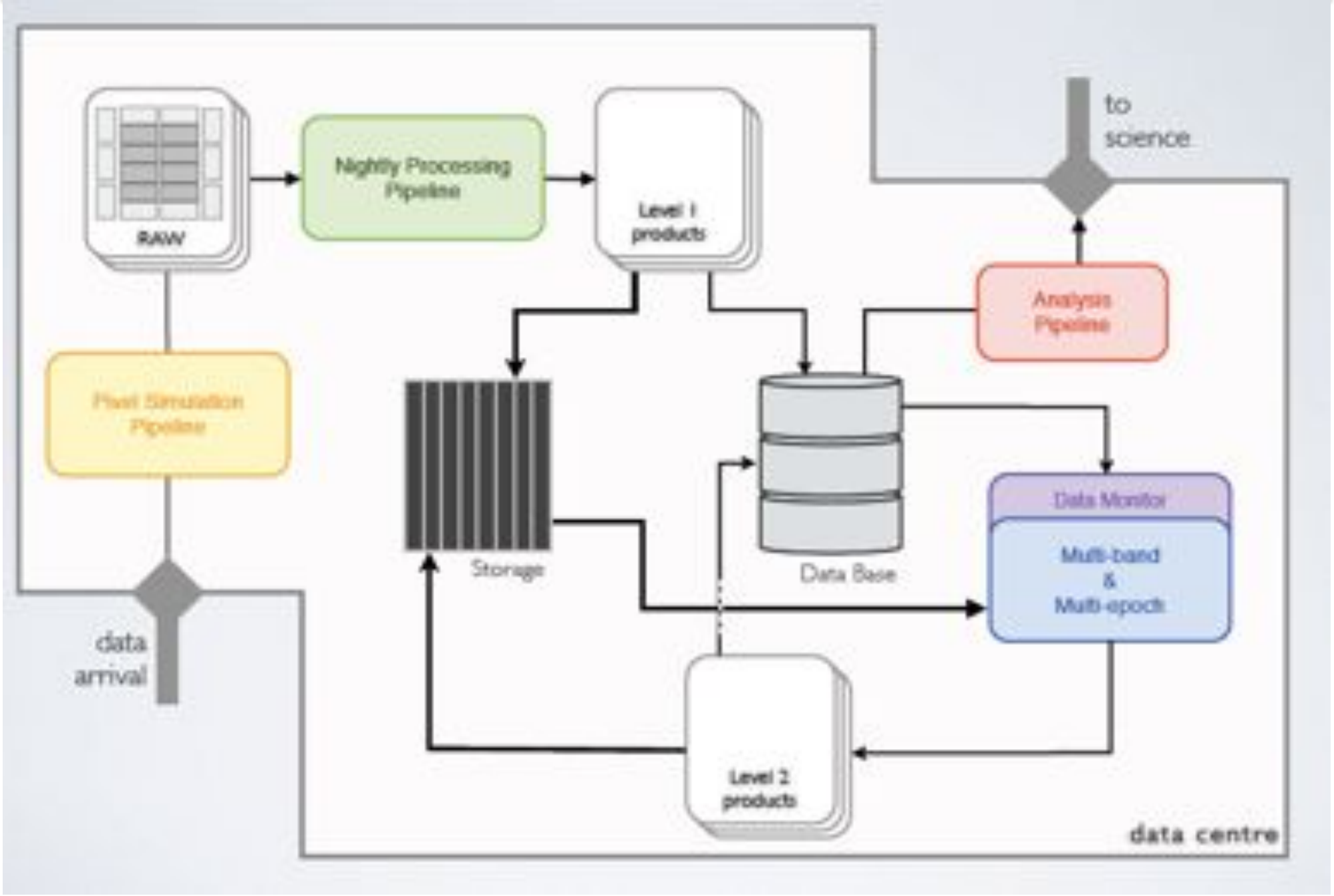


PAUCam Control System

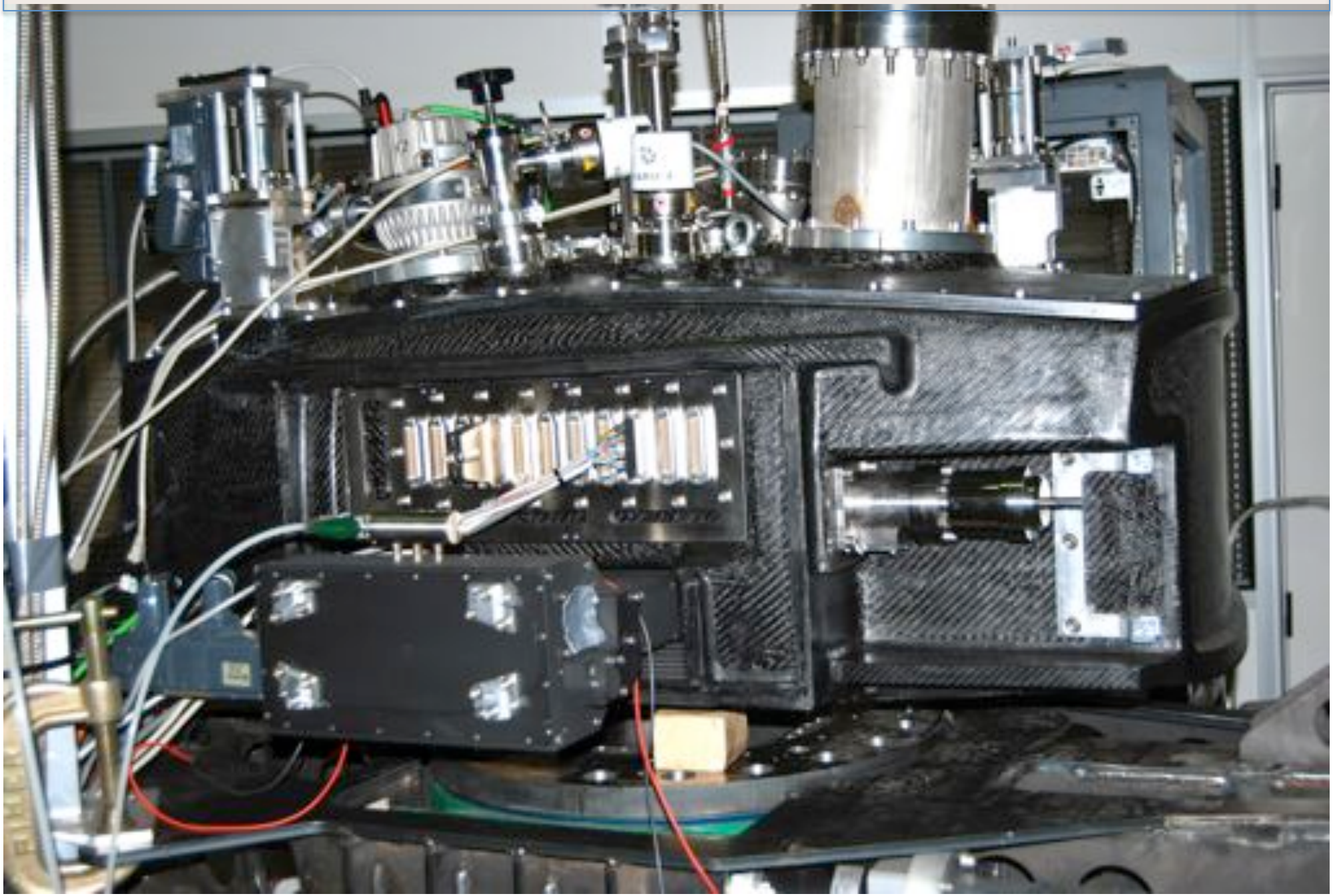


One computer already installed at the WHT. Tests of interface are already taking place.

Data processing Pipelines



PAUCam picture (May, 2014)



Conclusions

PAUCam is essentially completed, with many tests being done.

First commissioning at the beginning of September.

Additional science verification nights later in the fall.

Regular data taking expected by the first observation period of 2015.