PAUS
(Physics of the Accelerating Universe Survey)
and
PAUCam
at the William Herschel Telescope

Enrique Fernández (UAB/IFAE)
on behalf of the PAU Survey collaboration

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Ramon Miquel (ICREA/IFAE/UAB)
on behalf of the PAU Survey collaboration

PAU precedents

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

Effective start beginning of 2008.

PAU precedents

Main ideas:

- Conduct large photometric redshift survey.
- Emphasis in measuring Dark Energy probes.
- Build appropriate instrument with Consolider funds (PAUCam).

PAU at the WHT

- Fall 2009: approached the ING management about the possibility of installing PAUCam at the prime focus of WHT (4.2 m). 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."

- February 2012: an MoU has been signed between the director or the ING and the director of IFAE.

PAU at the WHT

Among other things the MoU establishes that:

- PAUCam will be a visitor instrument **also available for public use**. The camera will have 42 narrow-band filters and 6 wide-band filters (u, g, r, i, z, Y).

- We will station a “scientific postdoc” at La Palma integrated with the WHT personnel.

- We will also provide a public data-reduction pipeline.

PAU at the WHT

We appointed an External Review Panel of the design of PAUCam (193 pg. document), which convened in December 2010.

Members: D. Baade, O. Boulade, M. Riva, O. Iwert, R. Sharples, F. Zerbi.
Also attended: M. Balcells (ING Director) and D. Cano (WHT chief engineer).

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From the report:

> The Board wishes to compliment the PAUCam team for the great amount of work done in the definition and preliminary study of the instrument, as well as in the assembly of a complete and comprehensive document such as the one the Board examined.
>
> The Board wishes to underline the very well shaped and focussed Science Case for PAUCam presented in the document under scrutiny. The science objectives are indeed well defined and worthwhile. The Board is convinced that the Team has deep and active expertise at the engineering level for most of the areas related with this specific instrument design and construction.

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, J. Jiménez, F. Madrid, S. Serrano
J. Asorey, M. Eriksen, A. Izard, K. Hoffman, C.López, A. Pujol

IFAE
E. Fernández, R. Miquel, C. Padilla, A. Pacheco, (S. Heinis, starting in September)
O. Ballester, L. Cardiel, F. Grañena, C. Hernández, L. López, M. Maiorino, C. Pio
P. Martí, C. Sánchez
C. Arteche, J. Gaweda

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

UAM
J. García-Bellido, D. Sapone, S. Nesseris
Alicia Bueno, David Alonso

PAUS (PAU-Survey) scientific goals

- We expect to observe for ~100 nights during the 4-year period 2013-2016.
- Scientific goals for PAU/WHT will focus on measuring:
  - Redshift-Space Distortions
  - Weak Lensing Magnification
- To exploit these, we will measure (over the same area):
  - Bright galaxy sample ($i_{AB} < 22.5$) with high redshift resolution of $\sigma_z \sim 0.0035\ (1+z)$ to $z \sim 1$
  - Faint galaxy sample ($22.5 < i_{AB} < 24$) with $\sigma_z \sim 0.035\ (1+z)$ to $z \sim 1.8$

PAUCam will use 42 narrow-band (10 nm) filters covering the region ~ 470-830 nm.

PAUS scientific goals

- **Redshift-Space Distortions.**
  - The Hubble relation between redshift and distance in the radial direction is modified by peculiar velocities of galaxies, which trace the matter density field
  - Anisotropies on the galaxy 2-point correlation function measure the growth of structure at a given redshift: probe of dark energy
  - Relevant scales are ~10 Mpc/h, well matched to PAUS' z precision

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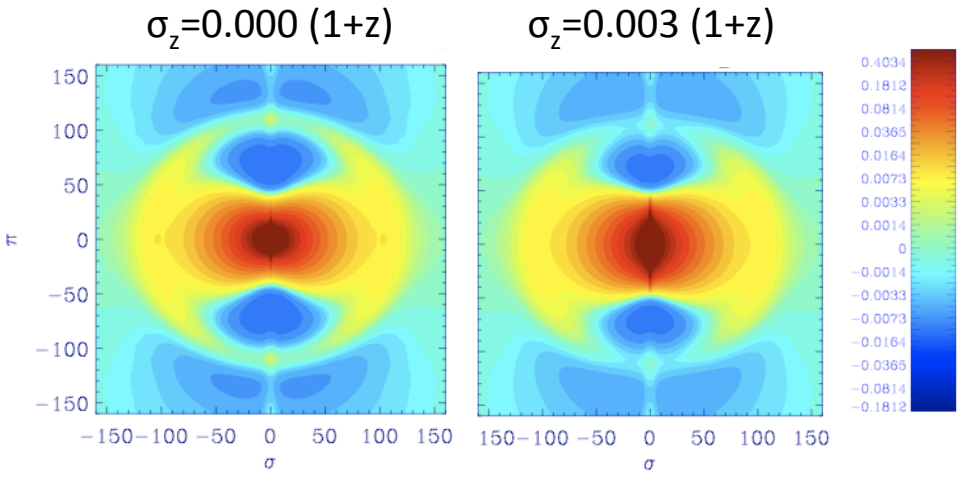
PAU photo-z resolution particularly well-suited for this measurement over bright sample.



Mpc/h

PAUS scientific goals

- **Weak-lensing magnification**

  - Lensing magnifies measured fluxes and alters the area observed, therefore changing the number of observed objects in a magnitude-limited survey.

  - Density fluctuations in background galaxies are correlated with density fluctuations in foreground lenses.

  - Very precise photo-z's in foreground lenses allow PAUS to perform cross-correlations between well-defined narrow redshift bins.

  The combination of RSD and MAG in the same data set is very powerful in breaking degeneracies between cosmological parameters ➔ a unique advantage of PAUS.

PAUS scientific goals

Quantitative study accepted for publication (arXiv:1109.4852, MNRAS in press):

Cross-Correlation of spectroscopic and photometric galaxy surveys: cosmology from lensing and redshift distortions

Enrique Gaztañaga[1], Martin Eriksen[1], Martin Crocce[1], Francisco J. Castander[1], Pablo Fosalba[1], Pol Marti[2], Ramon Miquel[2,3], Anna Cabré[4]

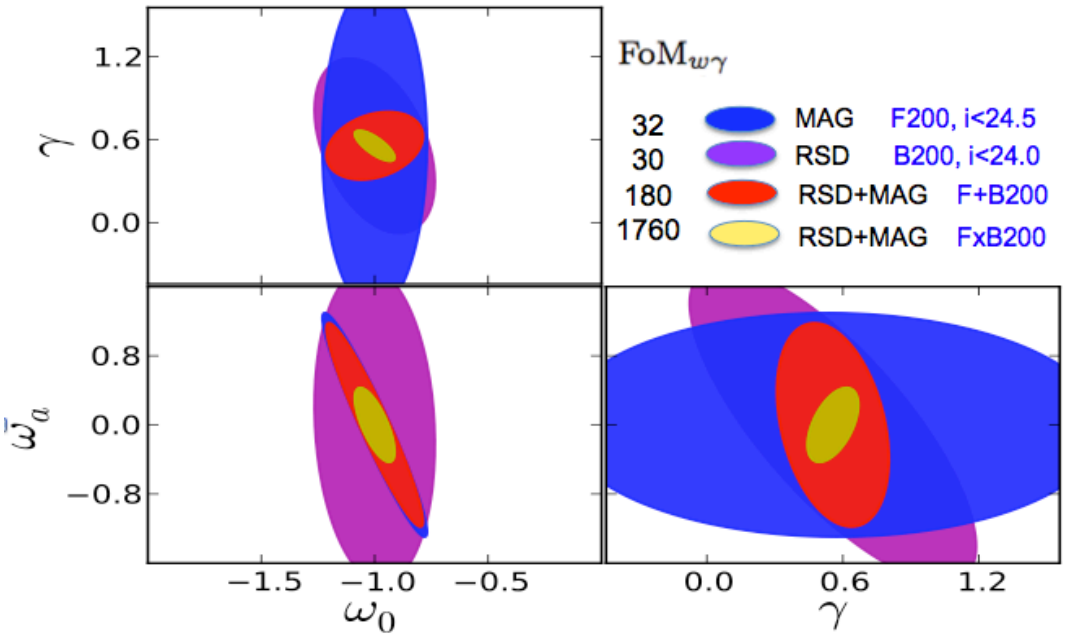
[1] *Institut de Ciències de l'Espai (IEEC-CSIC), E-08193 Bellaterra (Barcelona), Spain*
[2] *Institut de Física dAltes Energies (IFAE), E-08193 Bellaterra (Barcelona), Spain*
[3] *Institució Catalana de Recerca i Estudis Avançats (ICREA), E-08010 Barcelona, Spain*
[4] *University of Pennsylvania, Philadelphia, USA*

Observables are sensitive both to the expansion rate of the universe and to the rate of structure growth.

Figure of Merit for w_0, w_a and growth factor γ:

Combination of

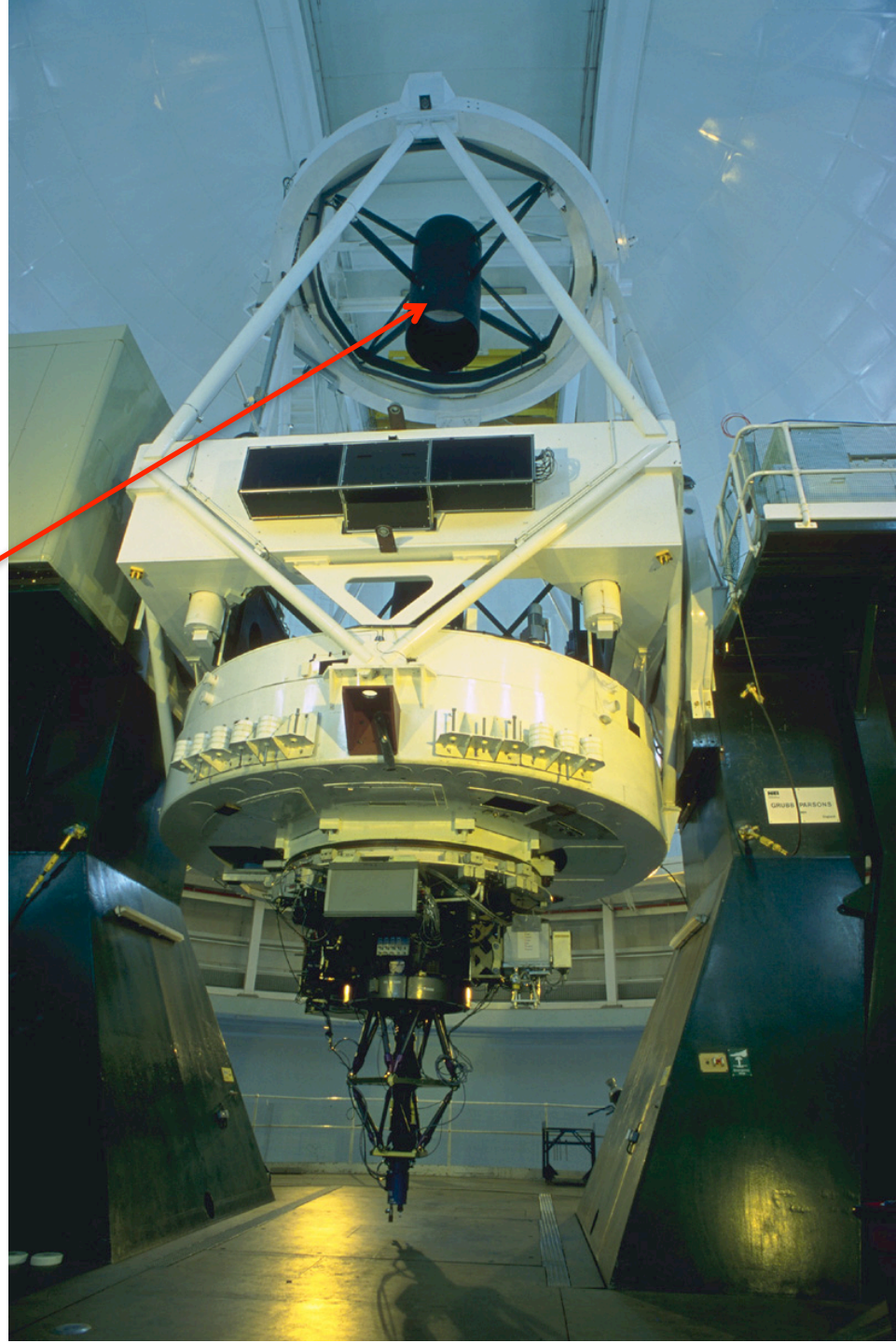
1. 3D galaxy clustering, which is degenerate with galaxy biasing.
2. Weak lensing magnification, which is unbiased but 2D.
3. Redshift space distortions, which also measure galaxy bias and growth.



PAUCam

PAUCam will be mounted at the prime focus of the WHT:

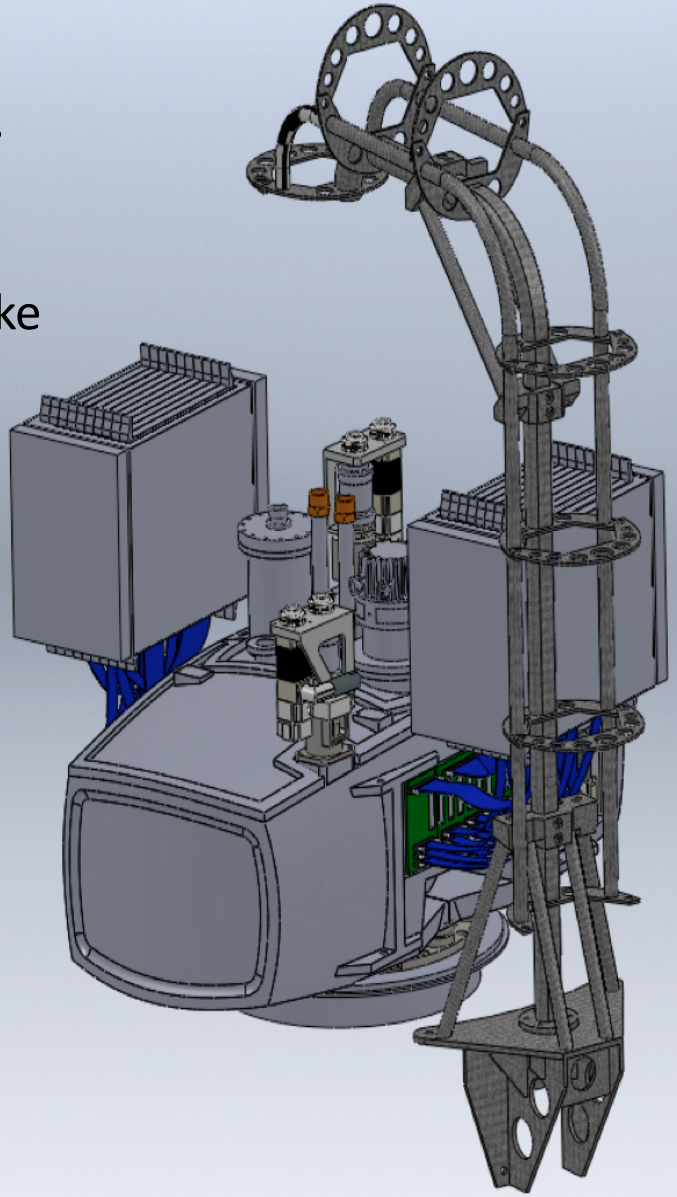
Strong limitation in weight: max. 235 kg.



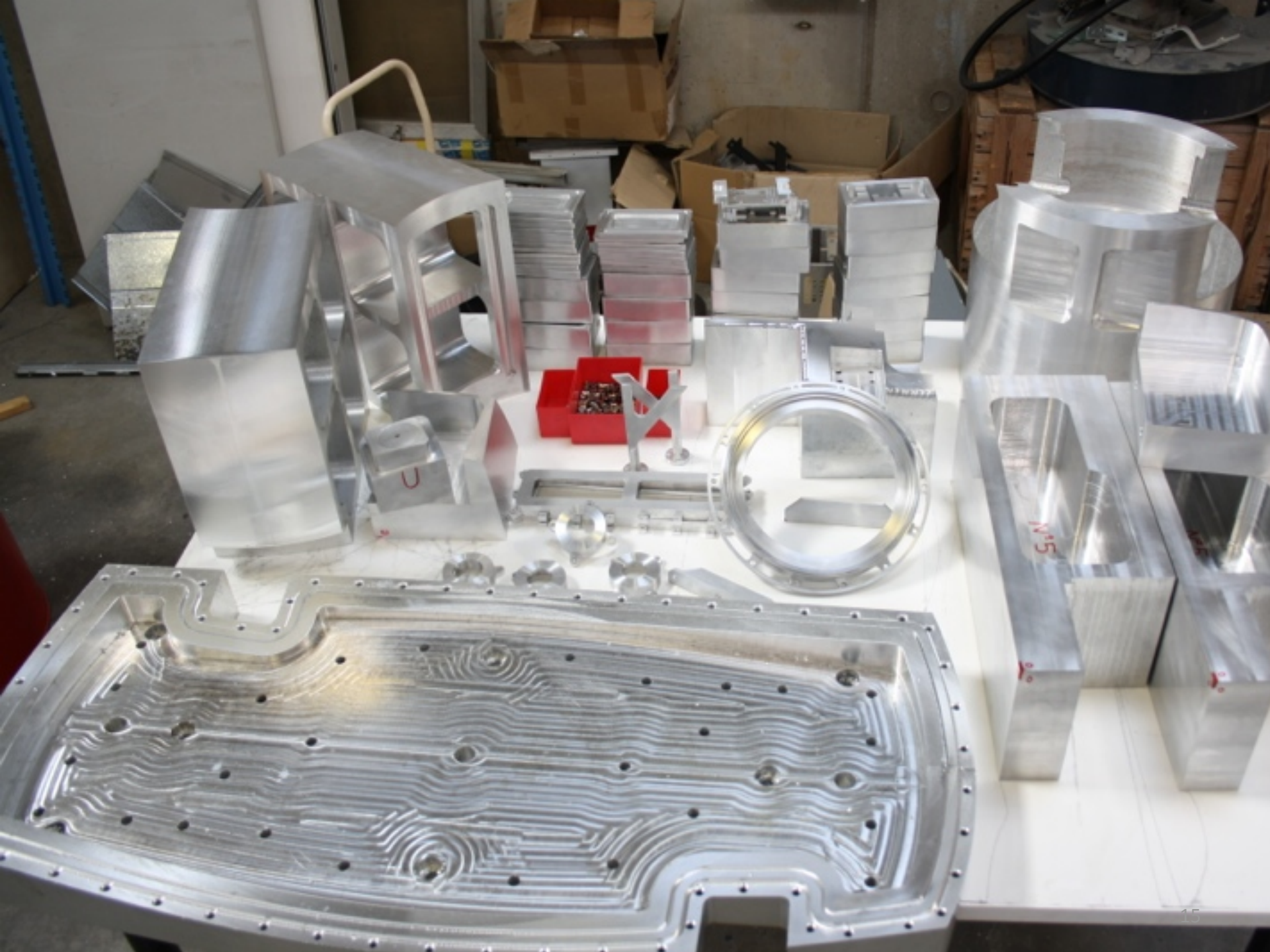
PAUCam

Many pieces are ready.

Mold being fabricated.
Takes 2-3 weeks to make enclosure.



Body of camera made of carbon fiber, shaped to minimize wall thickness



PAUCam focal plane

8 central CCDs with almost 100% illumination.

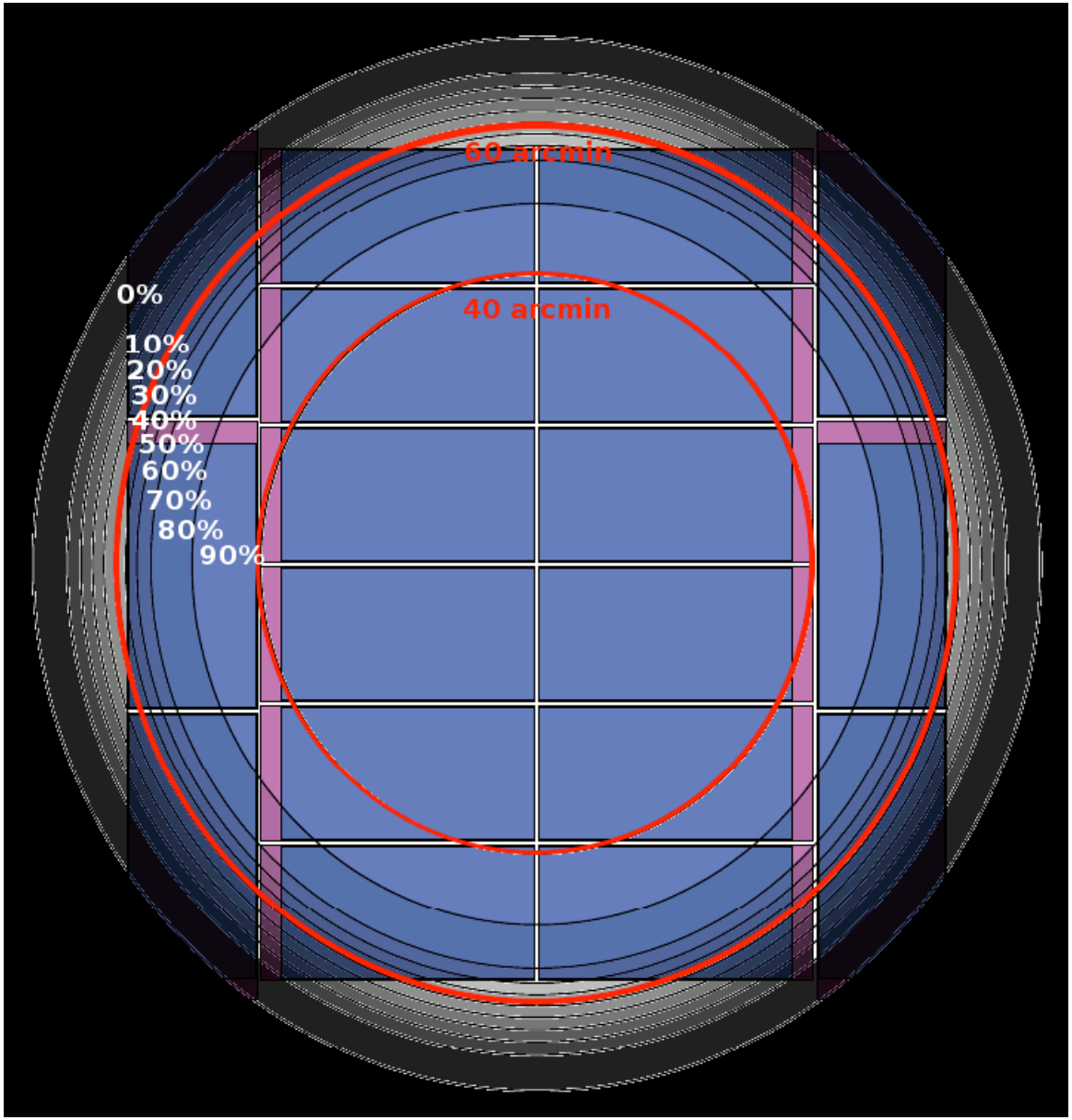
Rest of the CCDs:

- 2 for guiding
- 8 for additional photons

42 narrow band (10nm) filters covering the range ~ 470-830 nm

6 wide band filters u, g, r, i, z, Y

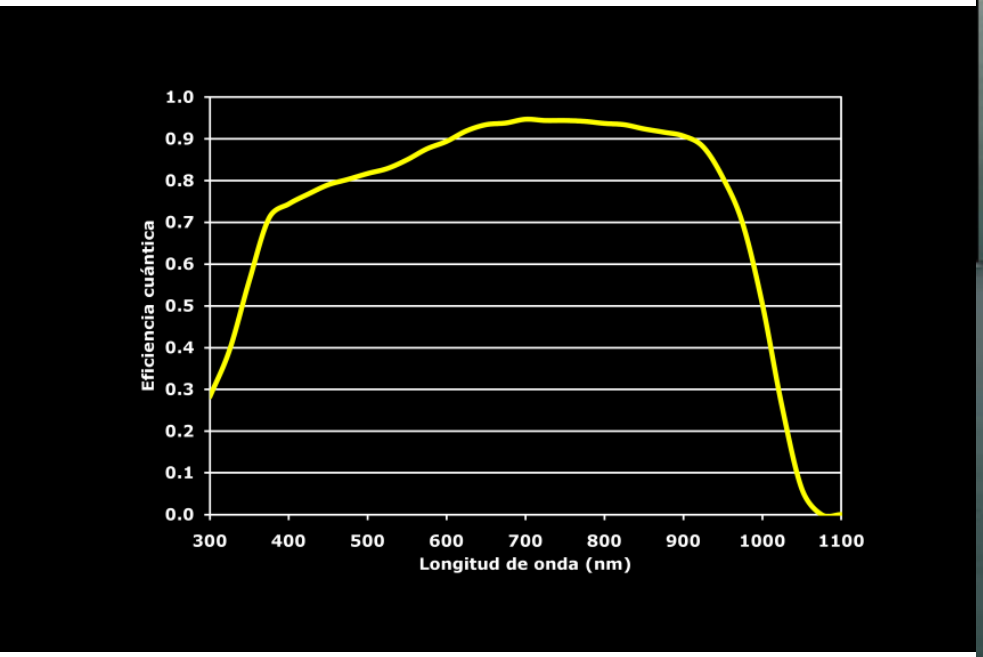
Optimization of filter arrangement: 7 narrow bands and 1 broad band in central CCDs.

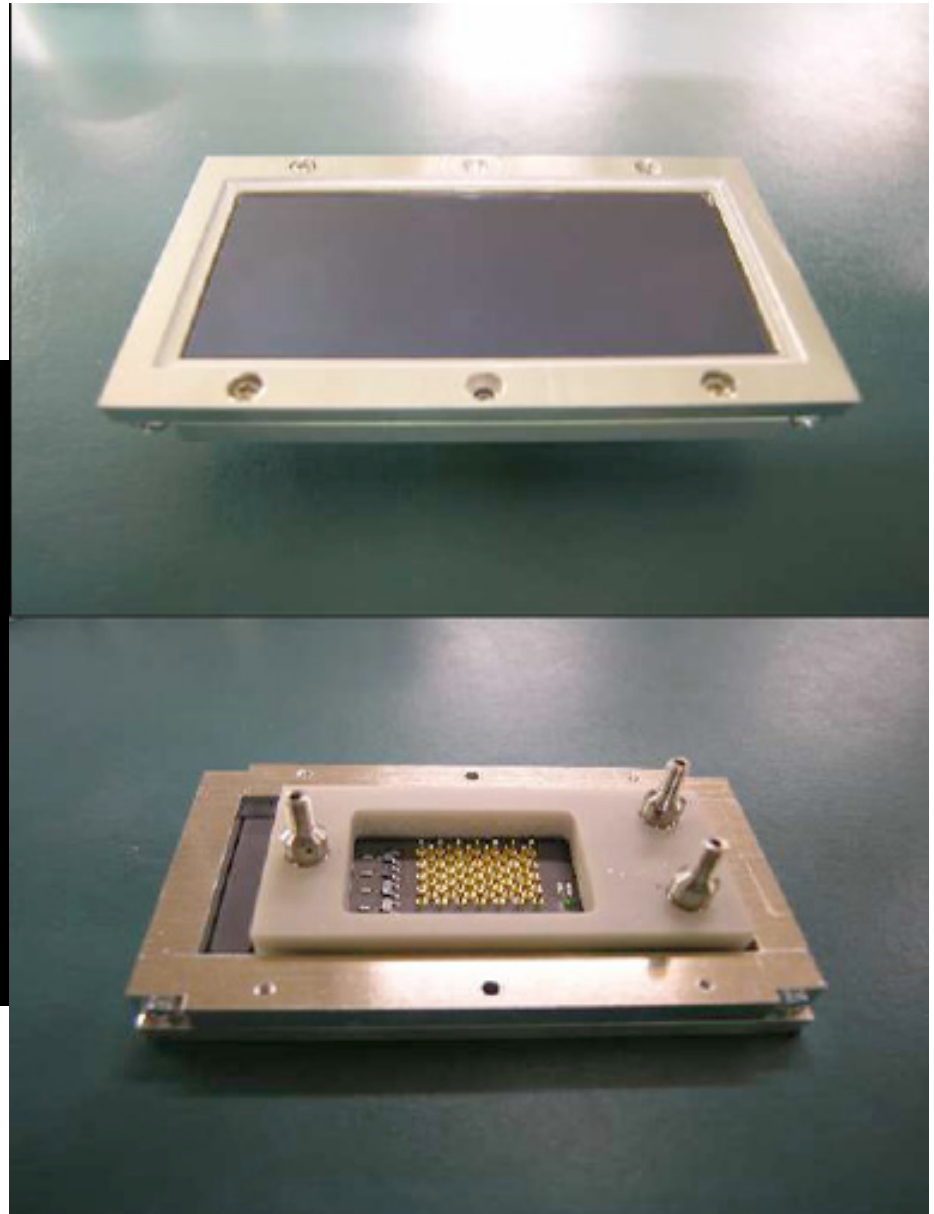


PAUCam CCDs

Detectors

- Hamamatsu photonics
  (2k × 4k) 15µm pixels
- Telescope f/2.8 ➜ 0.26”/pixel





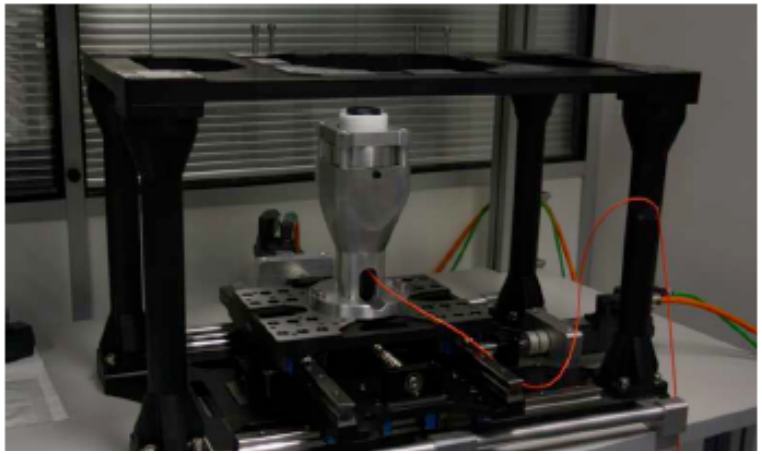
All CCDs are already in our labs, being characterized.

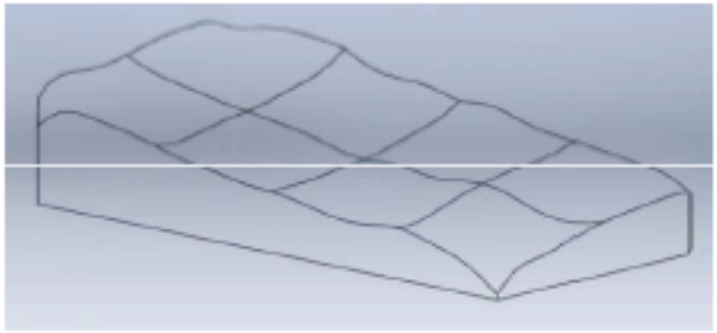
PAUCam CCDs

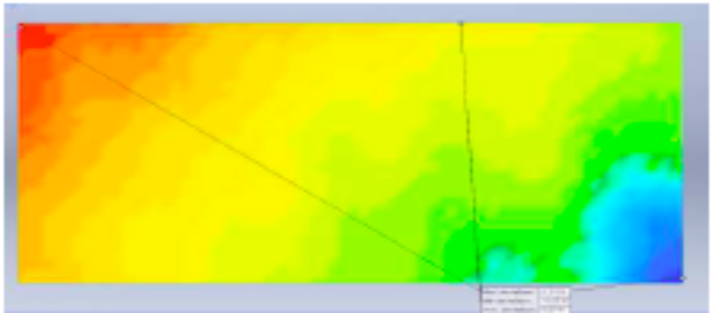
Two set-ups to characterize CCDs are ready, including software, one at CIEMAT, the other at IFAE/IEEC.

CCD testing station at CIEMAT

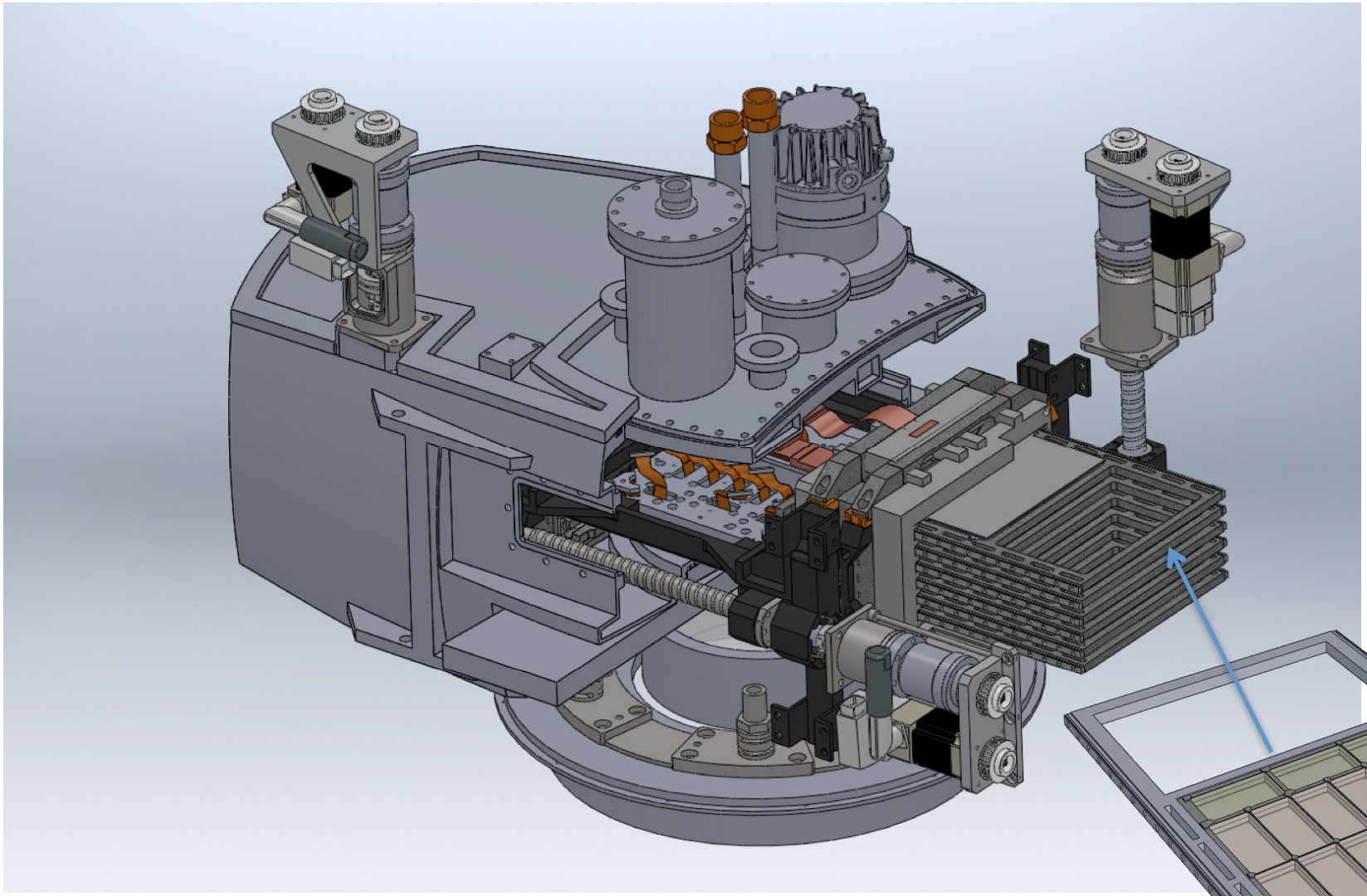
PAU XYZ metrology table





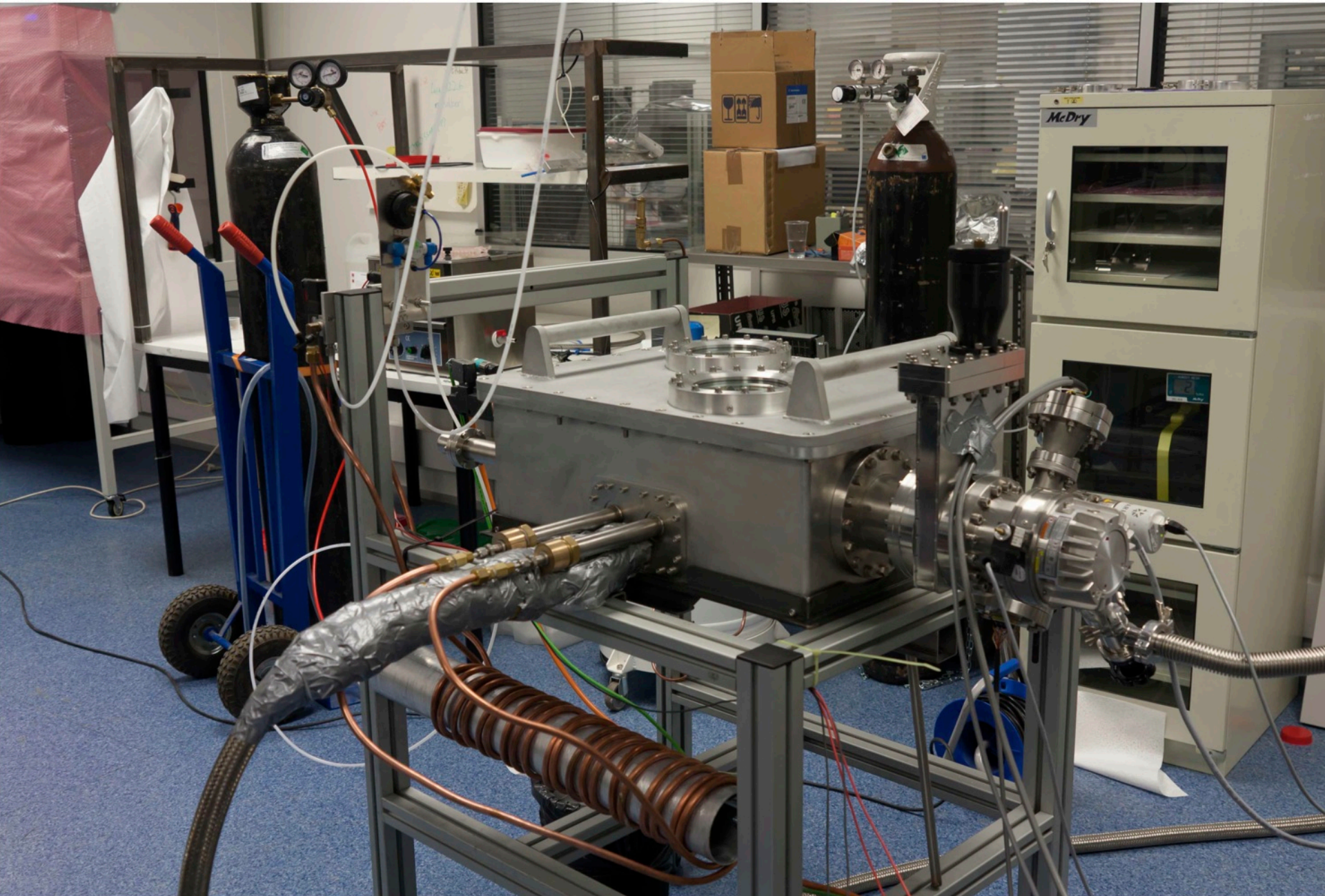


PAUCam filter trays

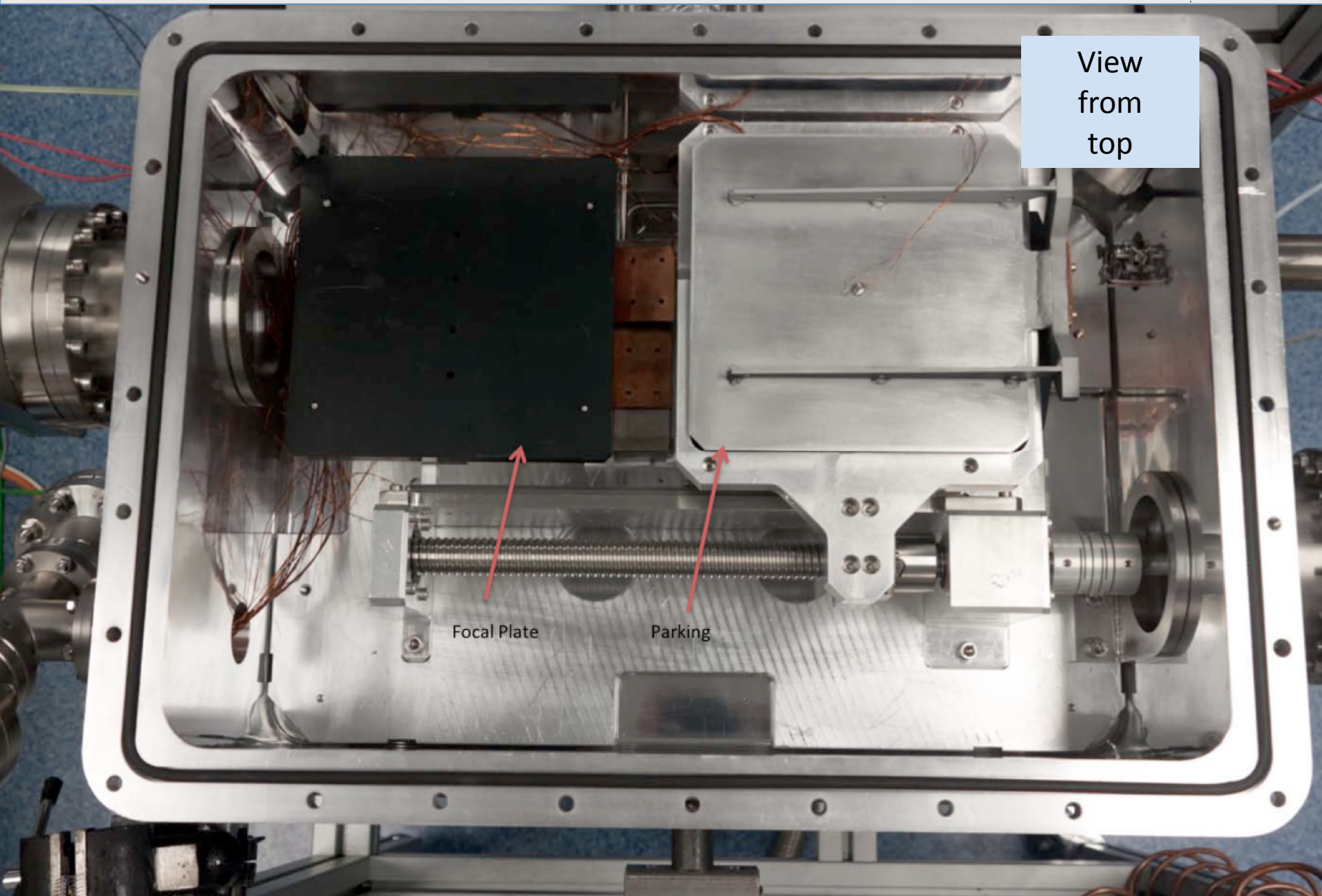


Cut-out showing filter-tray movable system

PAUCam (set-up as of summer 2011)



PAUCam set-up



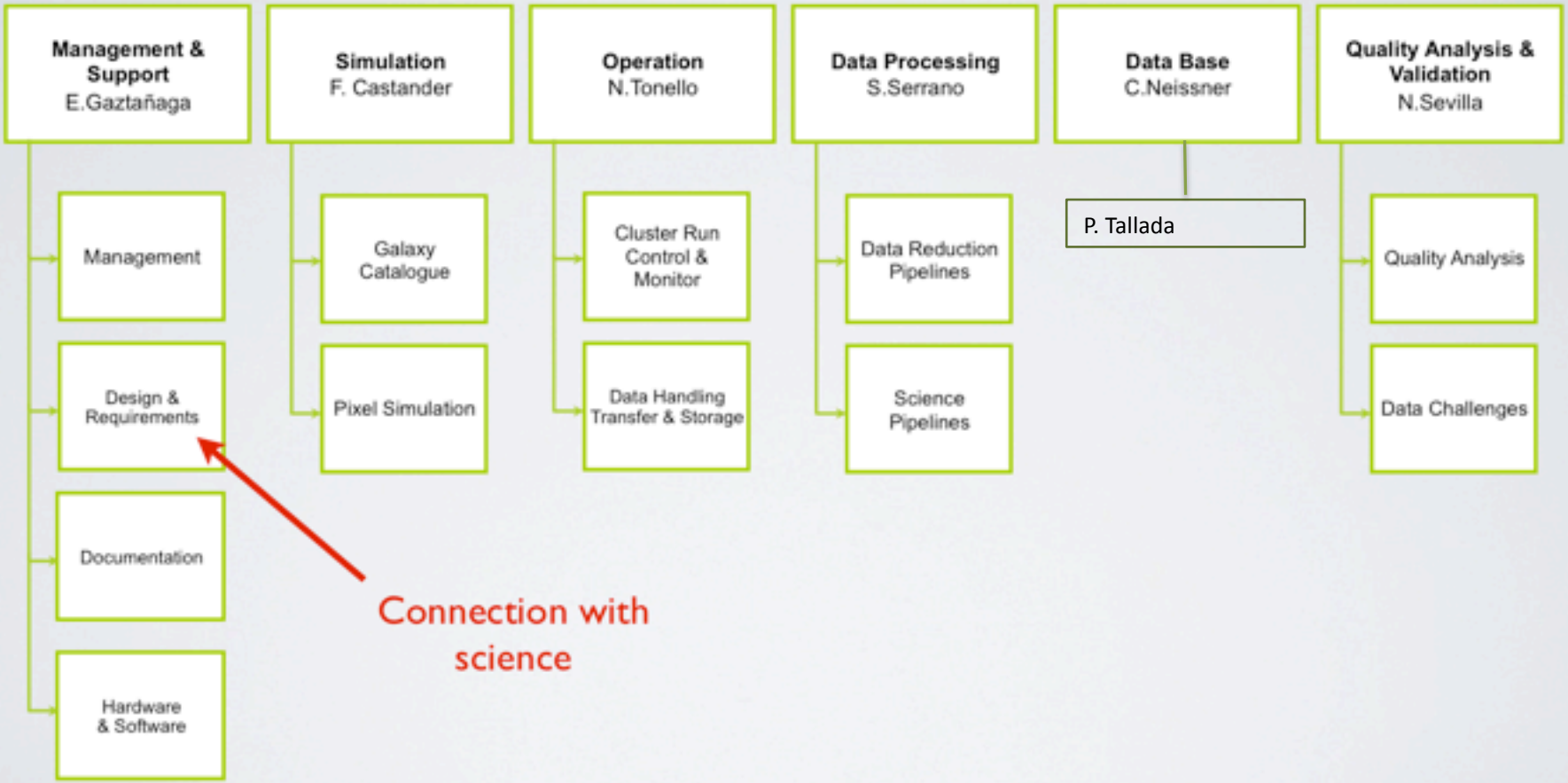
PAUCam status

Many other elements of the camera are either ready or being fabricated. Examples:

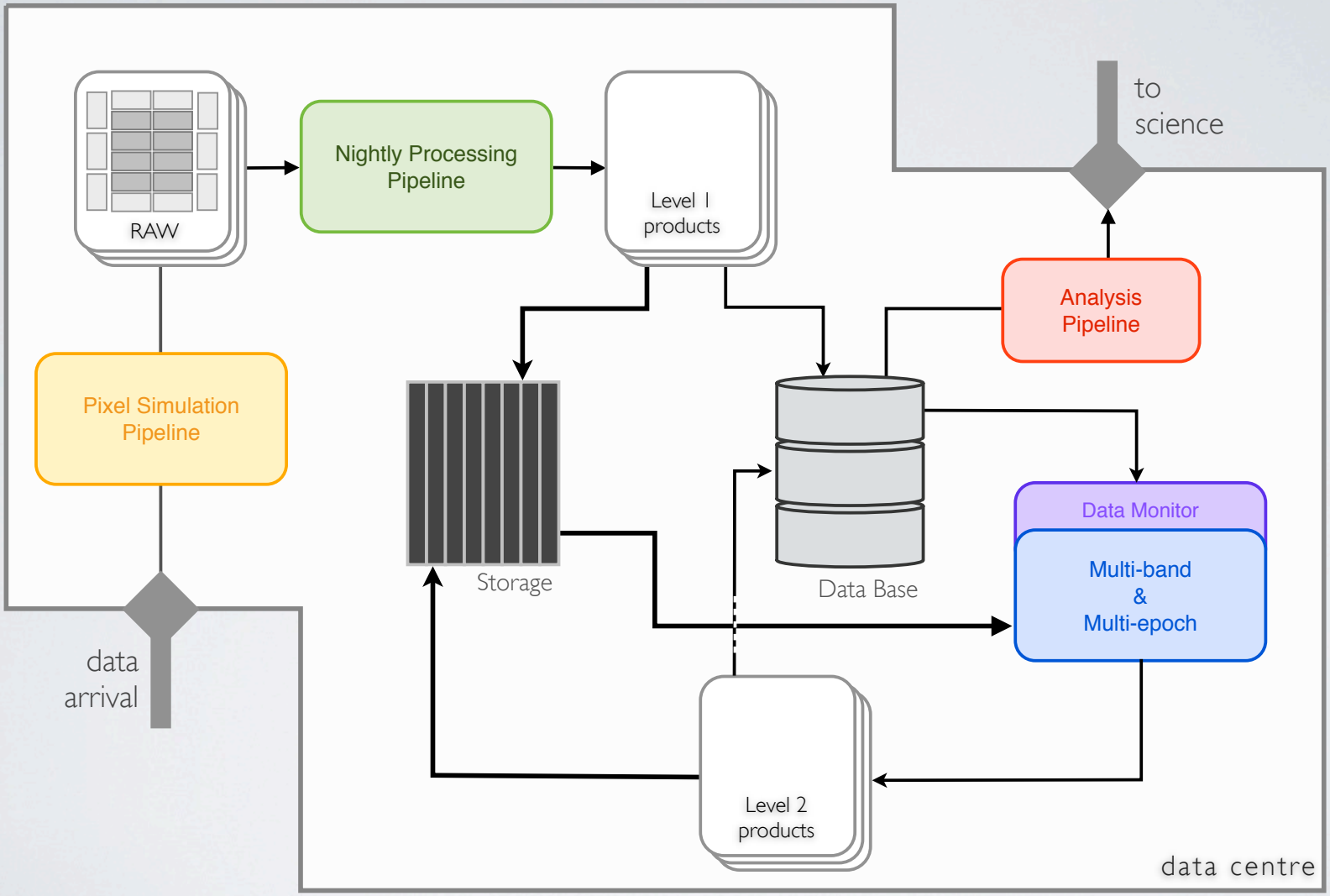
- Optics (entrance window): study done by FRACTAL. Ordered.
- Shutter: design ready, contract will go out soon.
- Cryotigers: one received, first tests show excellent behavior.
- Assembly done in house. Clean room (an important infrastructure) is ready.

PAUS data management

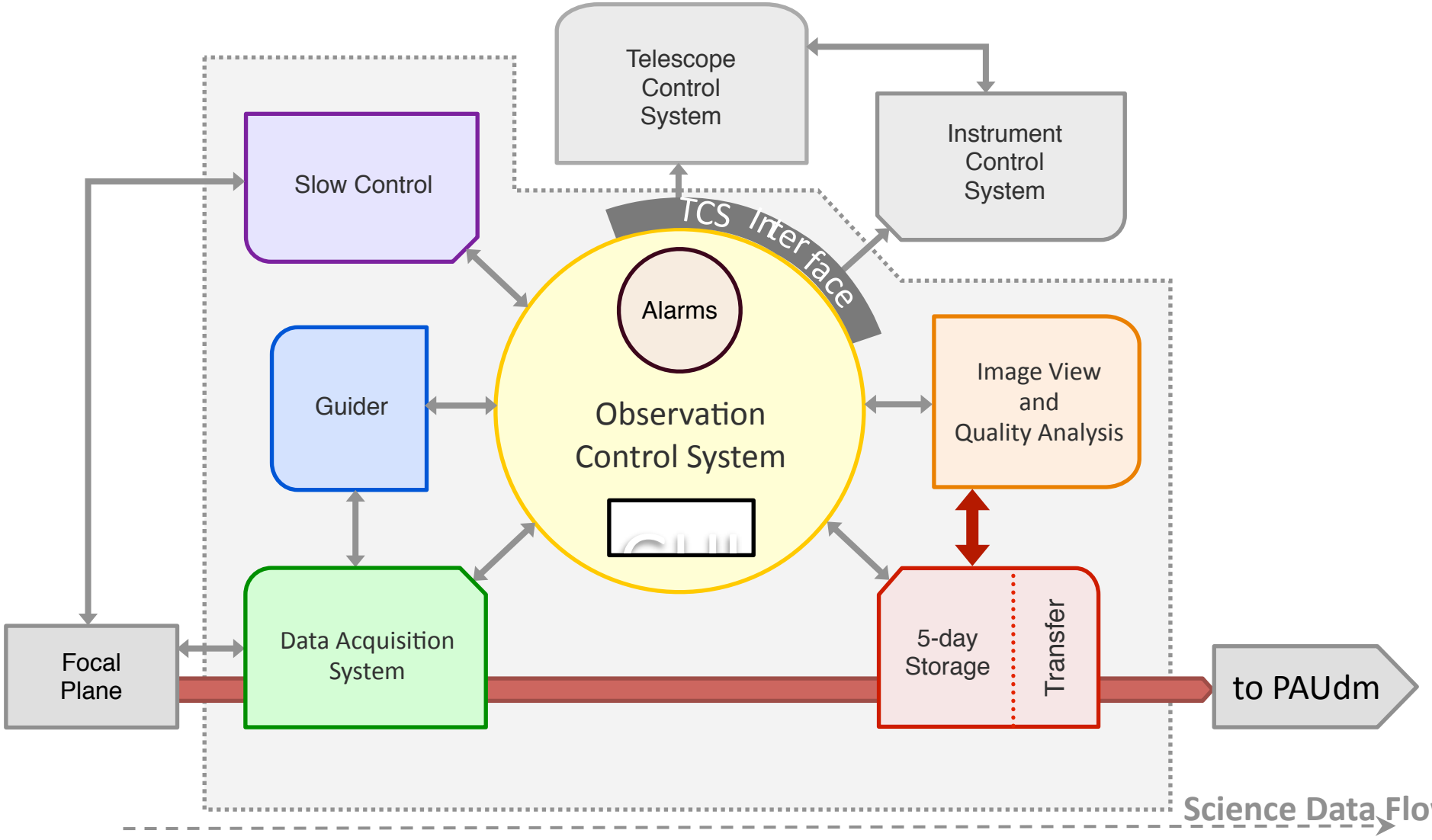
PAUdm Working Packages



Data processing pipeline



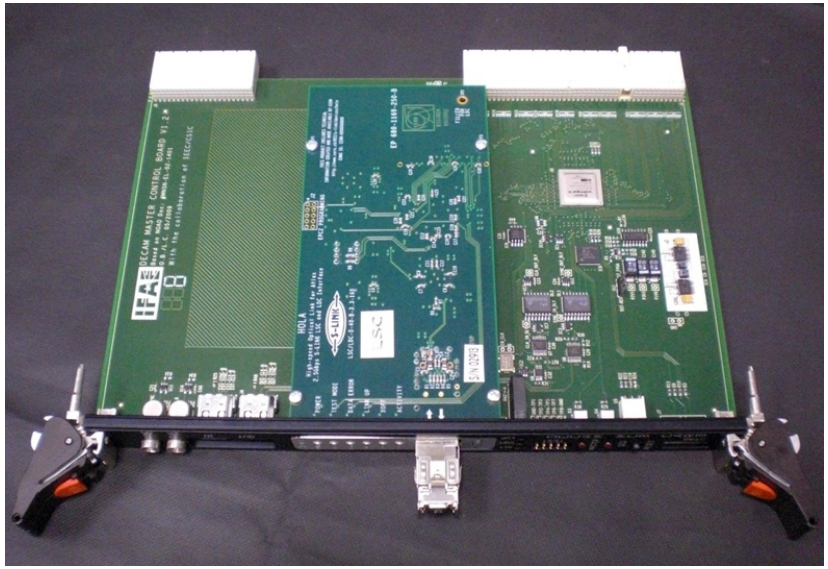
PAUCam camera control system

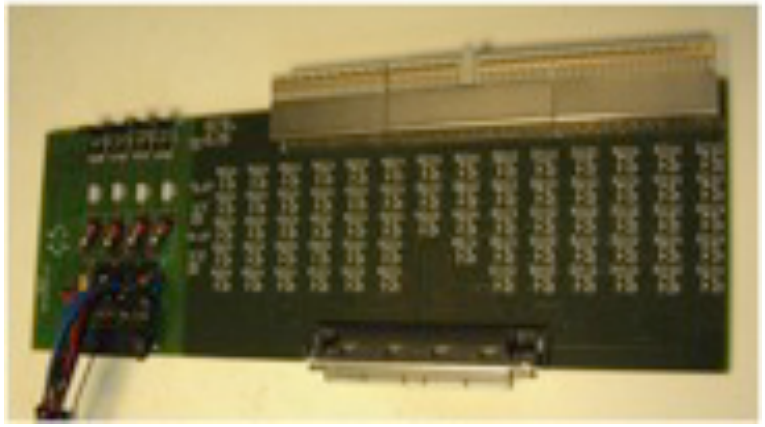


One computer already installed at the WHT. Tests of interface are already taking place.

PAUCam electronics

- Electronics follows the Monsoon (NOAO) standard. The group has delivered the entire electronics of DECam, based on Monsoon.





DES Clock & Bias Board

← DES Master Control Board

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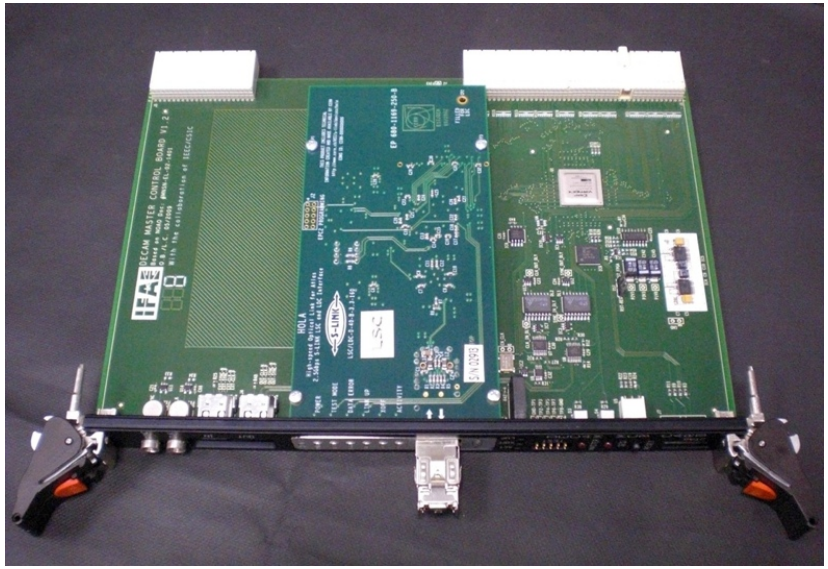

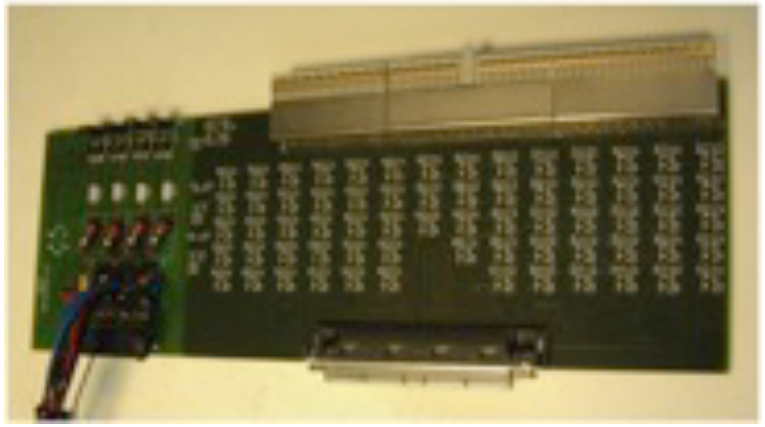

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The aim is to have a working instrument ready by the end of 2012

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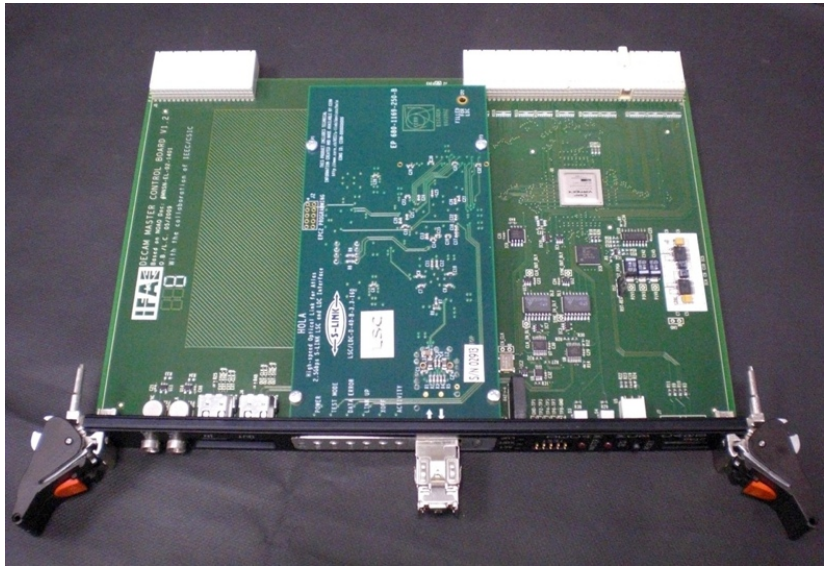

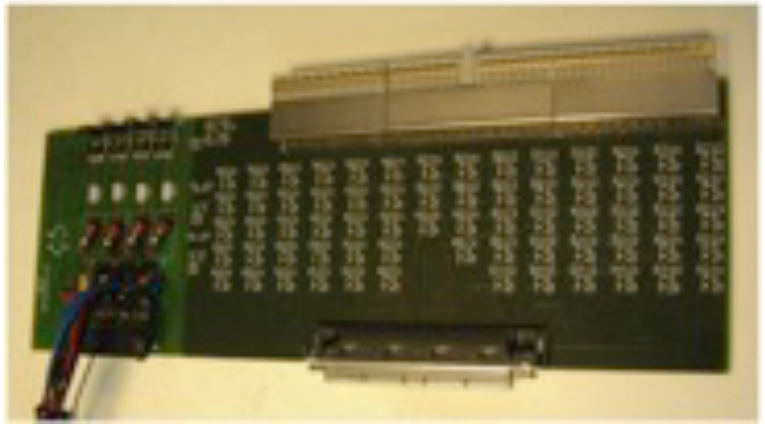

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The aim is to have a working instrument ready by the end of 2012

Final verification, installation, calibrations... Much work remains to be done

PAUS capabilities

- ~2 deg^2 per night in all filters (42 narrow-bands + ugrizY).
- It will deliver in one night "low-resolution spectra" (R~50) for:
  - 30,000 galaxies
  - 5,000 stars
  - 1,000 quasars
  - 10 galaxy clusters

PAUS additional science

Although the survey is designed and optimized for dark-energy science, many other science topics could be addressed:

- Galaxy evolution
- High redshift galaxies
- Interstellar dust
- Quasars and Lyα systems
- Clusters
- Weak gravitational lensing
- Strong gravitational lensing
- Galactic astronomy
- Stellar populations
- Halo stars
- Local group galaxies
- Serendipitous discoveries

Thank you