PAUS: The physics of the accelerating universe survey

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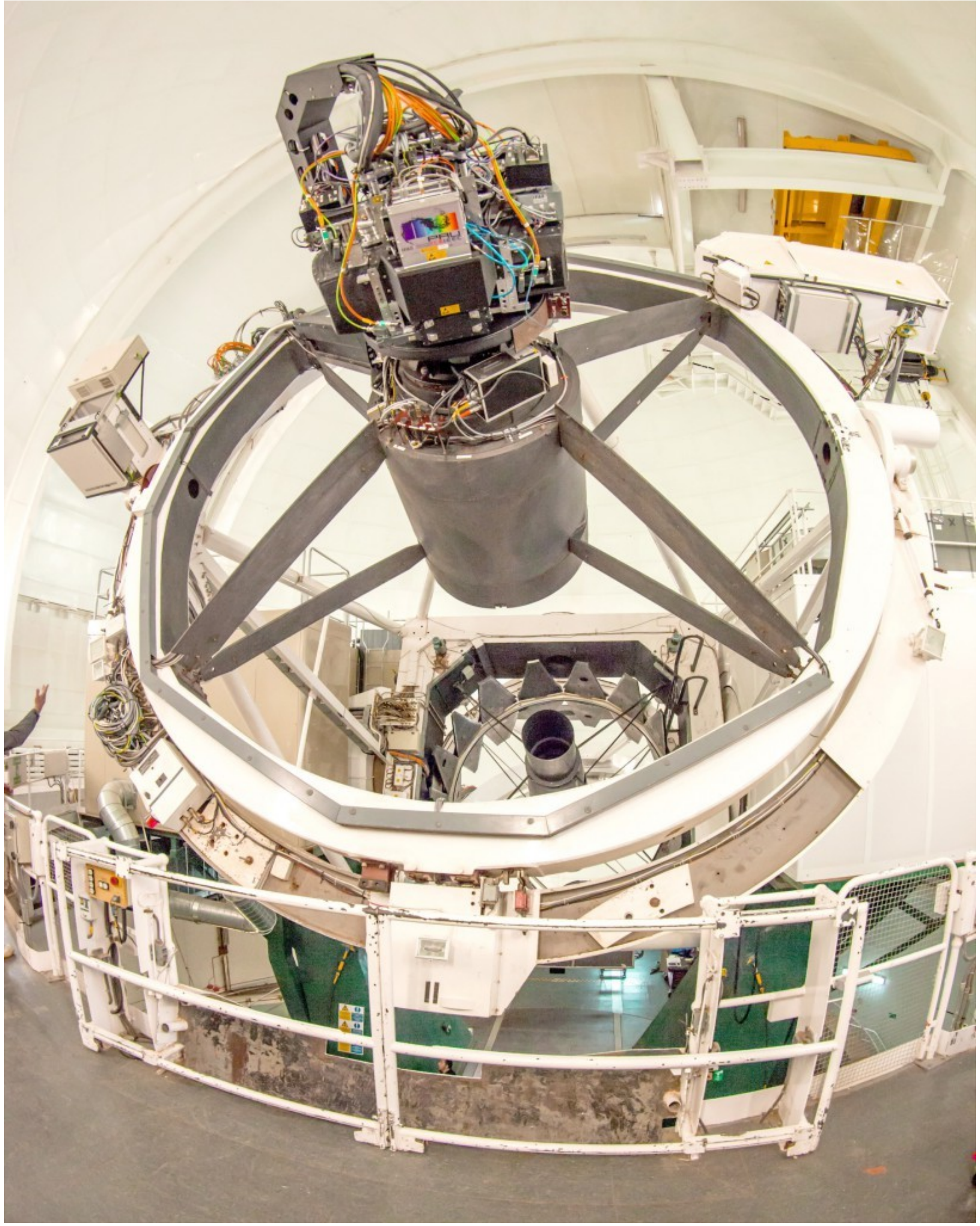
PIC port d'informació científica

PAUCam instrument

- Installed at William Herschel Telescope (WHT).
- First light in 2015.
- Field of view: 1 deg x 1 deg
- 18 CCD detectors
- Time allocated by Spanish, Dutch and UK time allocation committees
- For more info, see: https://www.pausurvey.org/



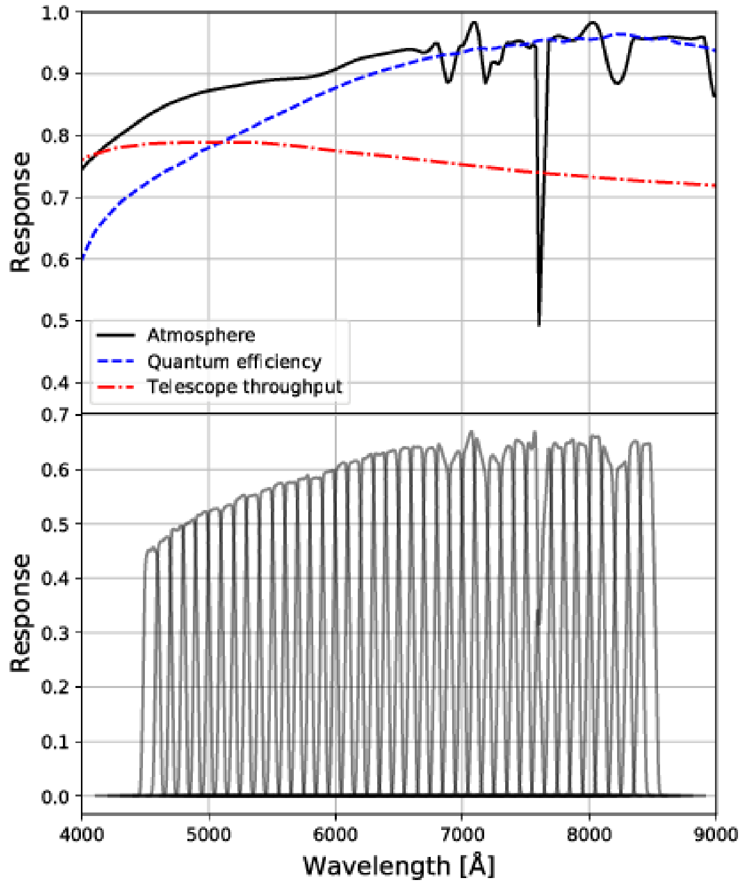
Filter transmission

- 40 narrow-band filters (13 nm wide in

steps of 10 nm

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

Narrow bands



Broad bands

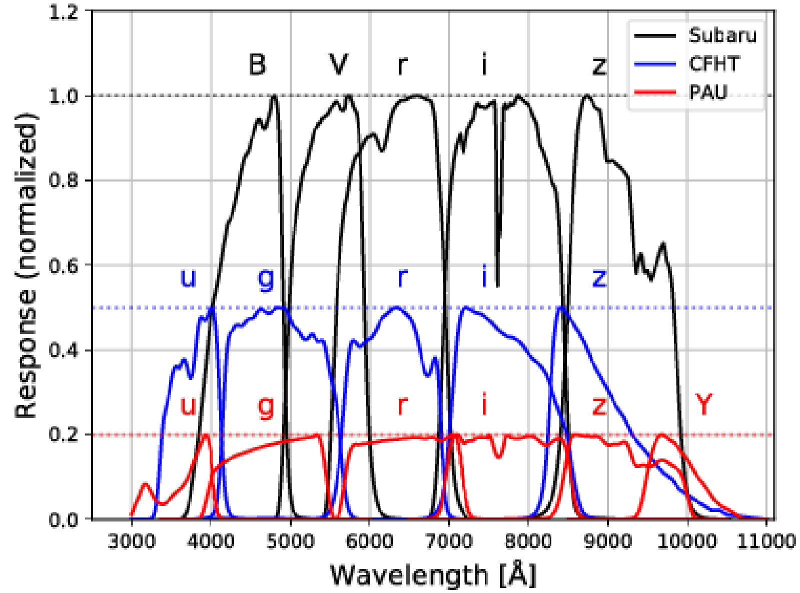
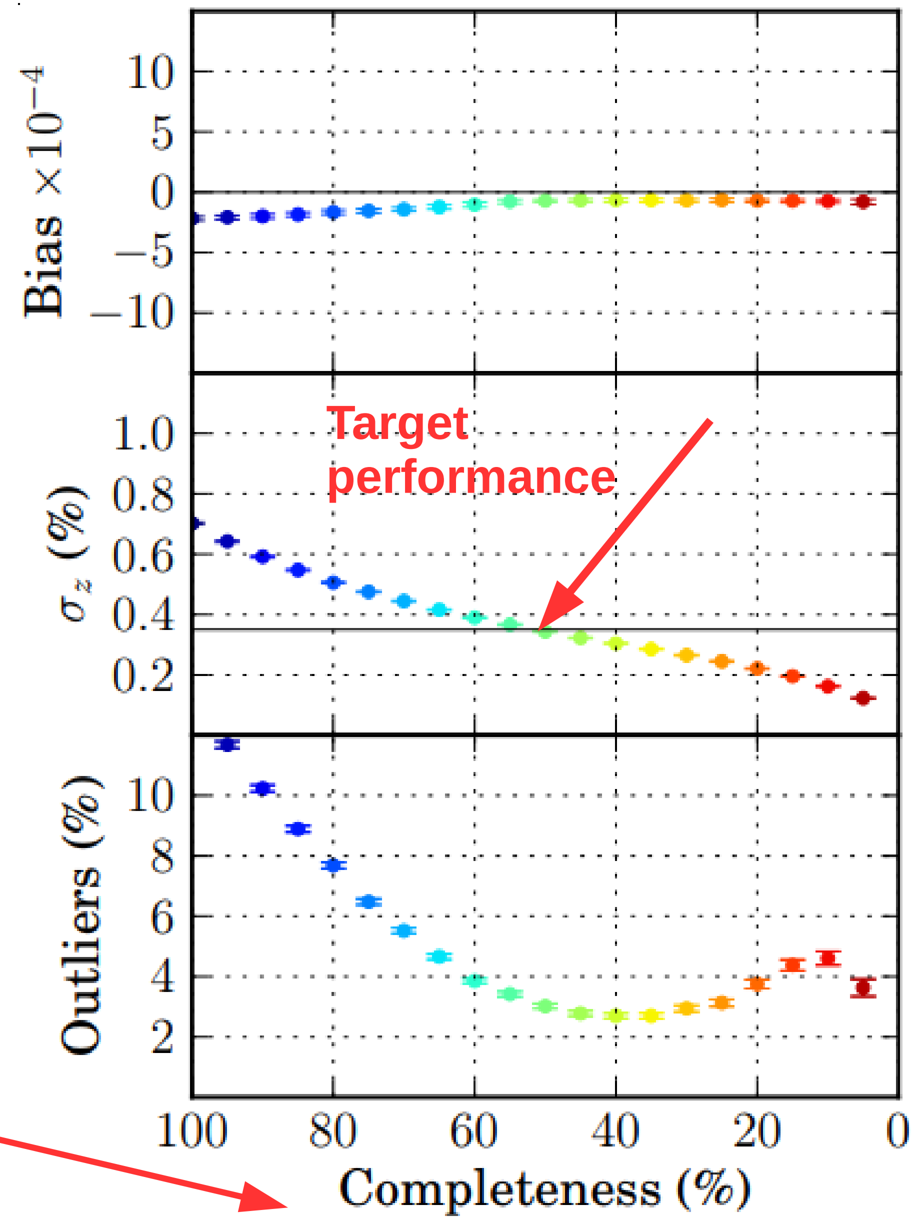


Photo-z forecast

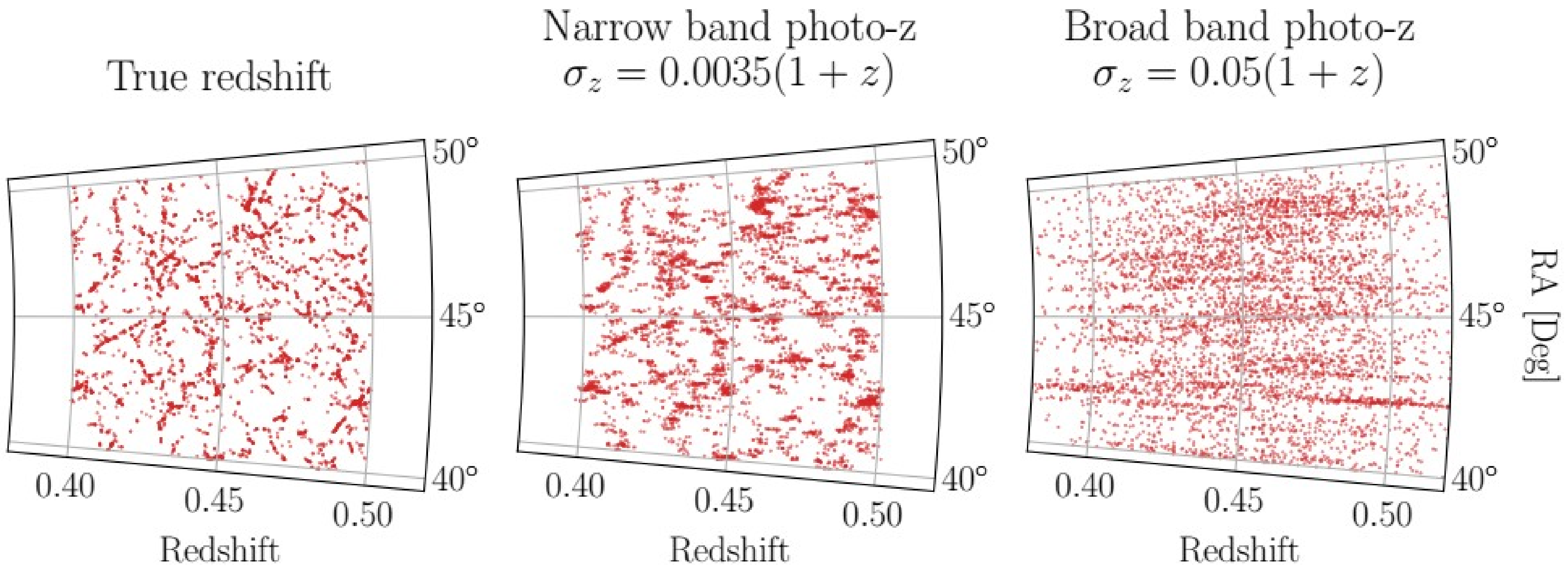
“The Physics of the Accelerating Universe (PAU) survey at the William Herschel Telescope (WHT) will use a new optical camera (PAUCam) with a large set of narrow-band filters to perform a photometric galaxy survey with a quasi-spectroscopic redshift precision of σ(z)/(1 + z) ∼ 0.0035 and map the large-scale structure of the universe in three dimensions up to i < 22.5-23.0.”

Marti et.al. Mon. Not. R. Astron. Soc. 442 (2014) 92



Cut based on fit quality (ODDS).

Large scale structure



- At z = 0.5 the typical broad band photo-z uncertainty of σ68 /(1 + z) ~ 0.05 translates into a 40% error in the luminosity (or 355 Mpc/h in luminosity distance), while the PAUS photo-z error corresponds to 2.5%.
- Uncertainty in comoving radial distance is reduced by more than an order of magnitude from 171 Mpc to 12 Mpc.
- Ideal for measuring intrinsic alignments, which require good pairwise distances for a larger area.

Survey progress

- PAUS is mapping weak lensing wide fields in CFHT-LS: W1 (2h), W2 (9h), W3 (14h) and W4 (22h).

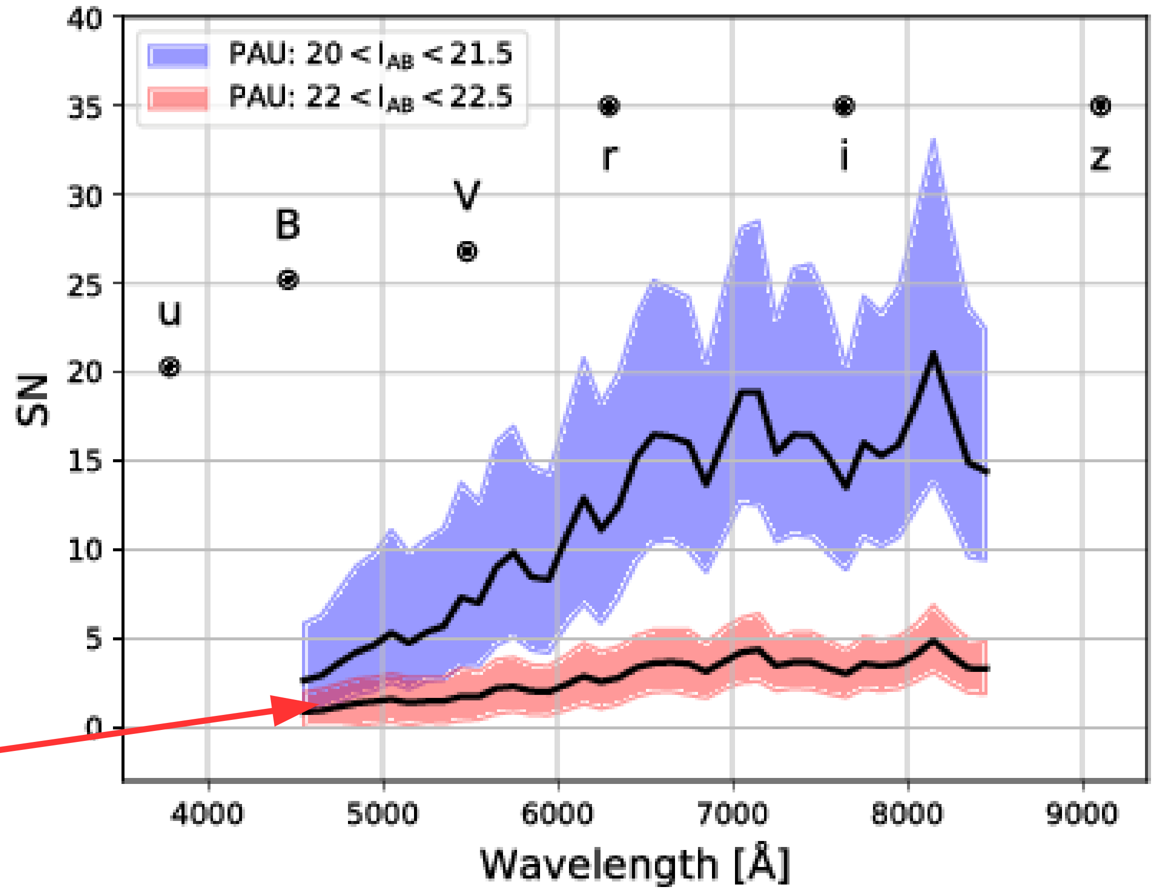
- The survey area coverage so far with 40 (20) Bands is:
  W1 9.2 deg2 (12.6 deg2),
  W2: 12.2 deg2 (16.5 deg2),
  W3: 10.2 deg2 (14.2 deg2),
  W4: 0.2 deg2 (0.4 deg2),
  COSMOS: 1.8 deg2 (3.2 deg2),
  TOTAL: 33.6 deg2 (47.3 deg2).

- Time with good conditions: 45%

- Efficiency of 0.6 sq.deg per night.

BCNz2: Low SNR regime

- We used the broad band data from the COSMOS2015 catalogue.
- The SNR of the BB data is about **8 times** higher than with the narrow bands, which can pose challenges for the photo-z determination.

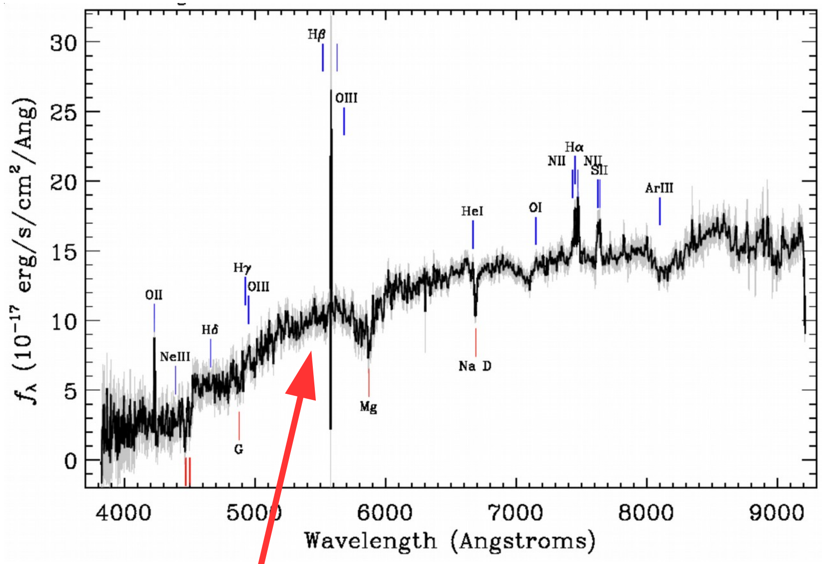


Very low SNR.

BCNz2: Emission line modelling

- Add the emission lines as two templates.
- The third column contains the main emission line template, with flux ratios relative to OII.
- In the last column is the OIII template, normalized relative to OIII 1.

	λ[Å]	Template 1	Template 2
H_α	6563	1.77	-
H_β	4861	0.61	-
Ly_α	1216	2	-
NII_1	6548	0.19	-
NII_2	6583	0.62	-
OII	3727	1	-
$OIII_1$	4959	-	1
$OIII_2$	5007	-	3
SII_1	6716	0.35	-
SII_2	6731	0.35	-



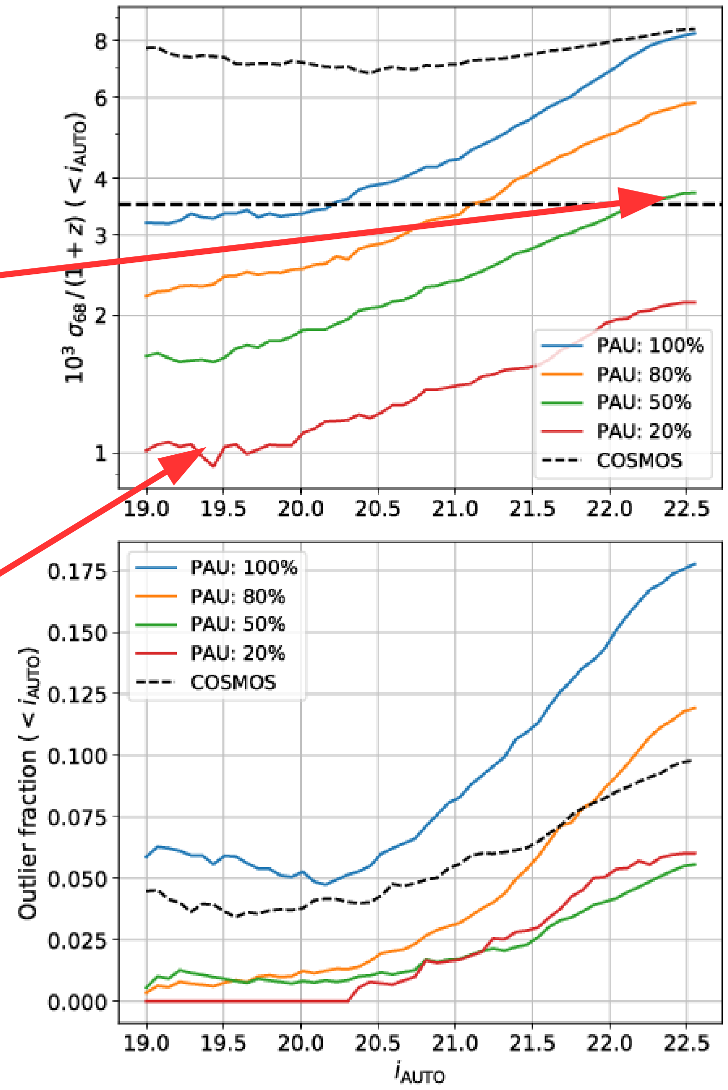
SDSS Starburst spectrum, z=0.13

Source: skyserver.sdss.org

PAUS photo-z in the COSMOS field.

- Result on data published in Eriksen et. al. 2019.
- Comparison to secure spectra from zCOSMOS DR3 shows that PAUS achieves σ /(1+z) = 0.0037 to i < 22.5 when selecting the best 50% of the sources based on a photometric redshift quality cut.

- Furthermore, a higher photo-z precision(σ /(1 + z) ∼ 0.001) is obtained for a bright and high quality selection, which is driven by the identification of emission lines.



Effect on photometric redshifts

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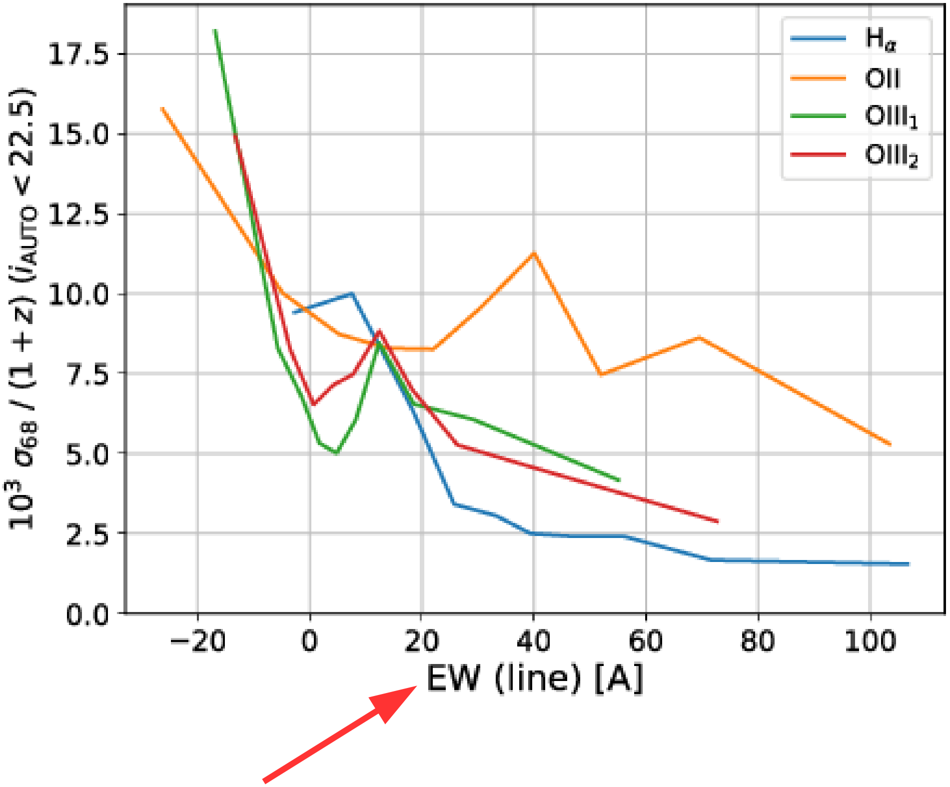
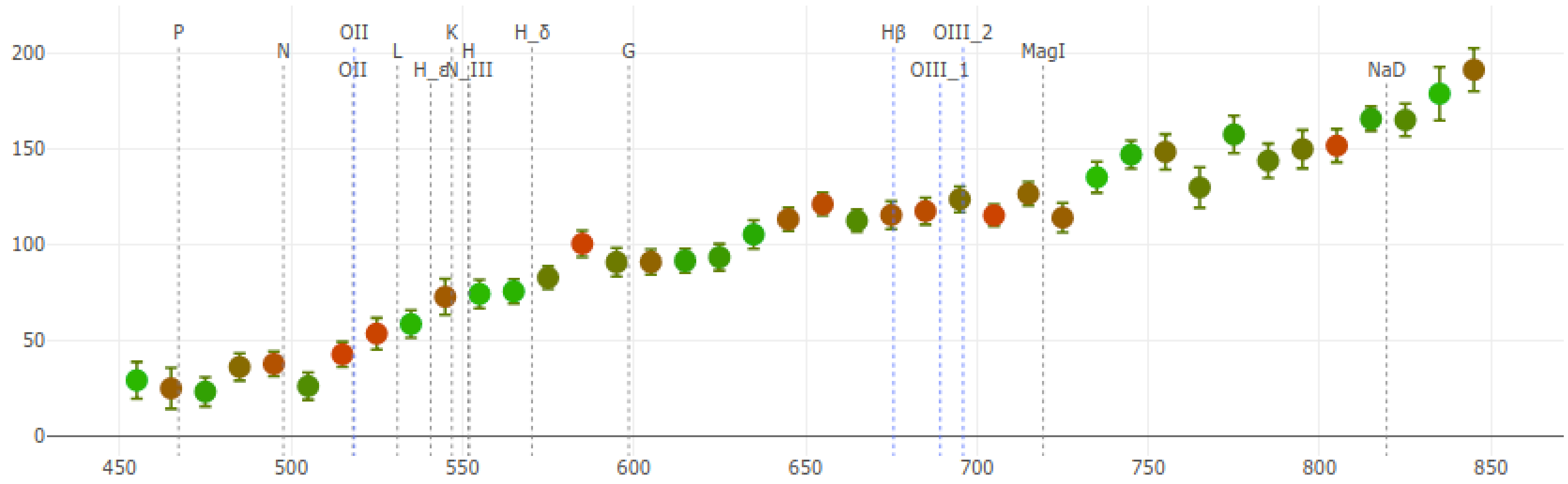
- For higher emission line strengths, σ68 / (1 + z) decreases for all lines.
- A negative emission line strength occurs when overestimating the continuum, e.g. by underestimating the extinction.



High EW means a strong emission line.

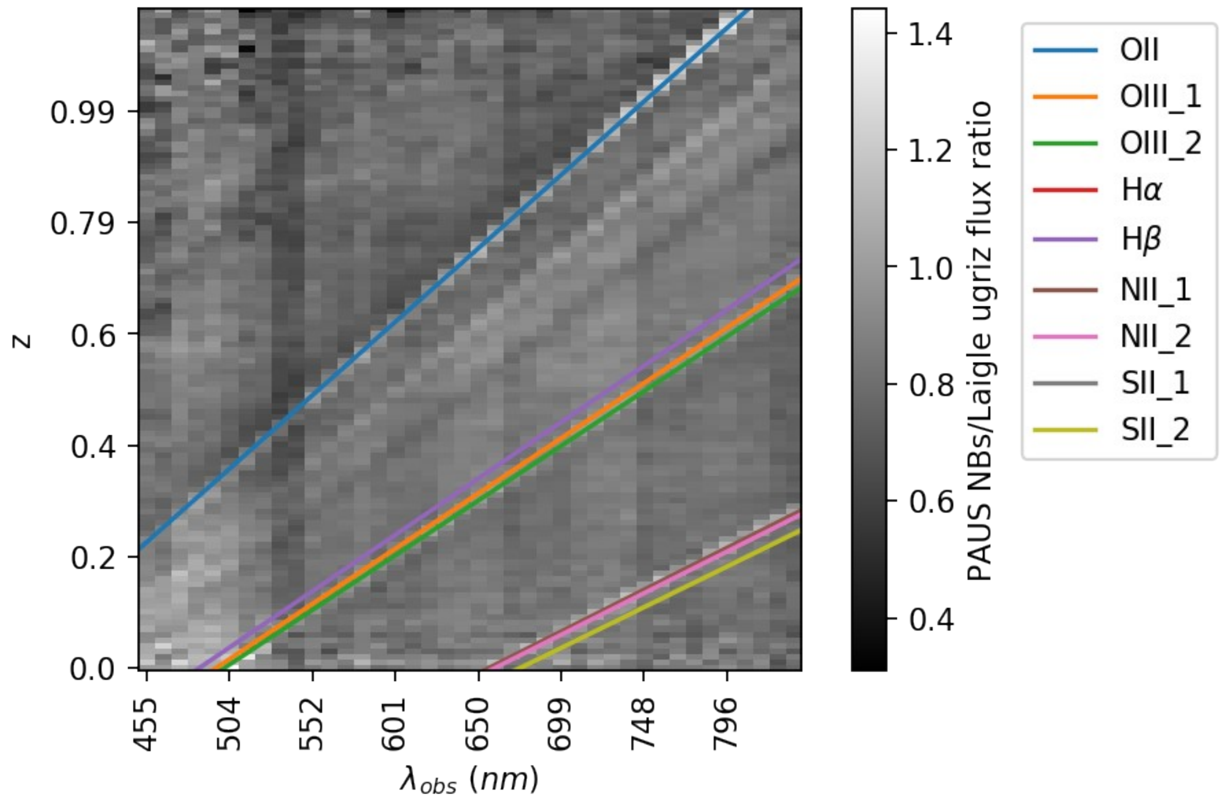
PAUS example “spectra”

Galaxy (i=20.4)



Emission lines for stacked SEDs

- Stack the SED in the observed frame for different redshifts.
- Use ubvriz from Laigle 2015 to estimate the continuum.
- **Diagonal lines**: Emission or absorption lines
- **Vertical lines:** Data issues, possible calibration

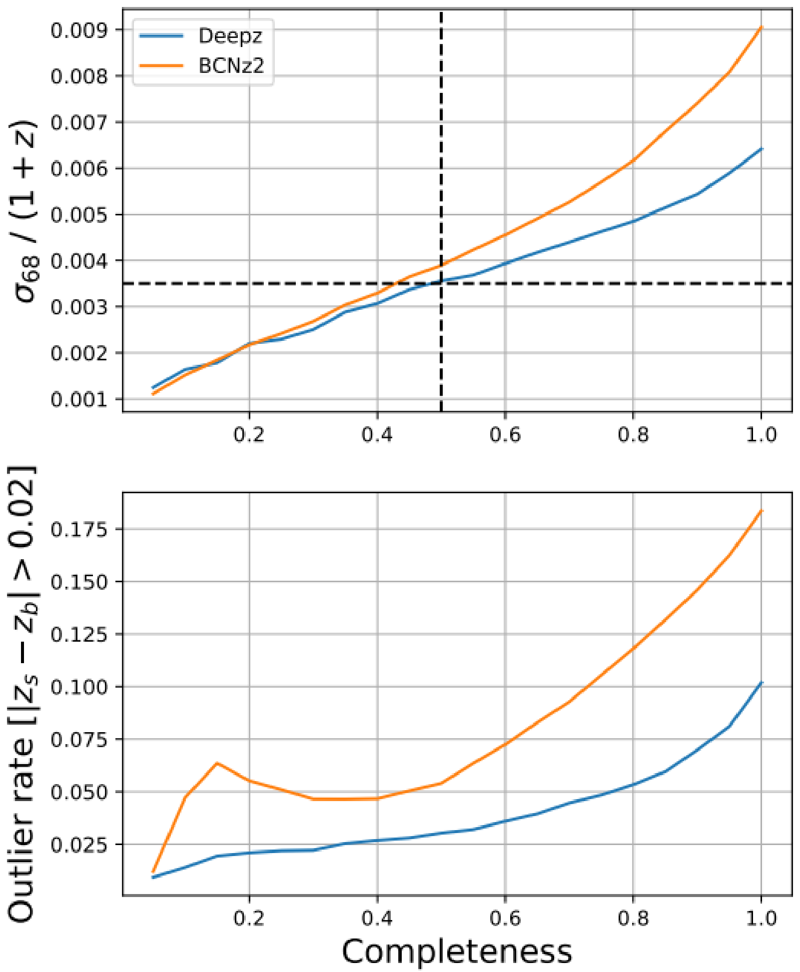


Renard et.al. (in prep)

Deep learning photo-z

- Template fitting require an increasingly complex modeling to work.
- Have now also a machine learning code working.
- Uses a deep neural network and various tricks.

- **See also** talk/poster on PAUS background estimation using deep learning by Laura Cabayol.



Eriksen et.al (in prep)

Conclusions

- Comparison to secure spectra from zCOSMOS DR3 shows that PAUS achieves σ 68 /(1+z) = 0.0037 to i AB < 22.5 when selecting the best 50% of the sources based on a photometric redshift quality cut.
- We conclude that PAUS meets its design goals, opening up a hitherto uncharted regime of deep, wide, and dense galaxy survey with precise redshifts that will provide unique insights into the formation, evolution and clustering of galaxies, as well as their intrinsic alignments.
- Unique data set, wider and deeper than many spectroscopic surveys. Better redshift determination than wide broad band surveys. Opens up for new science cases.

Thanks for your attention.

BCNz2

Observed flux

Broad bands

$$\chi^2[z, \boldsymbol{\alpha}] = \sum_{i,NB} \left(\frac{\tilde{f}_i - l_i k f_i^{\mathrm{Model}}}{\sigma_i} \right)^2 + \sum_{i,BB} \left(\frac{\tilde{f}_i - l_i f_i^{\mathrm{Model}}}{\sigma_i} \right)^2$$

Narrow bands

Zero-point per galaxy

Zero-point per band

Flux error

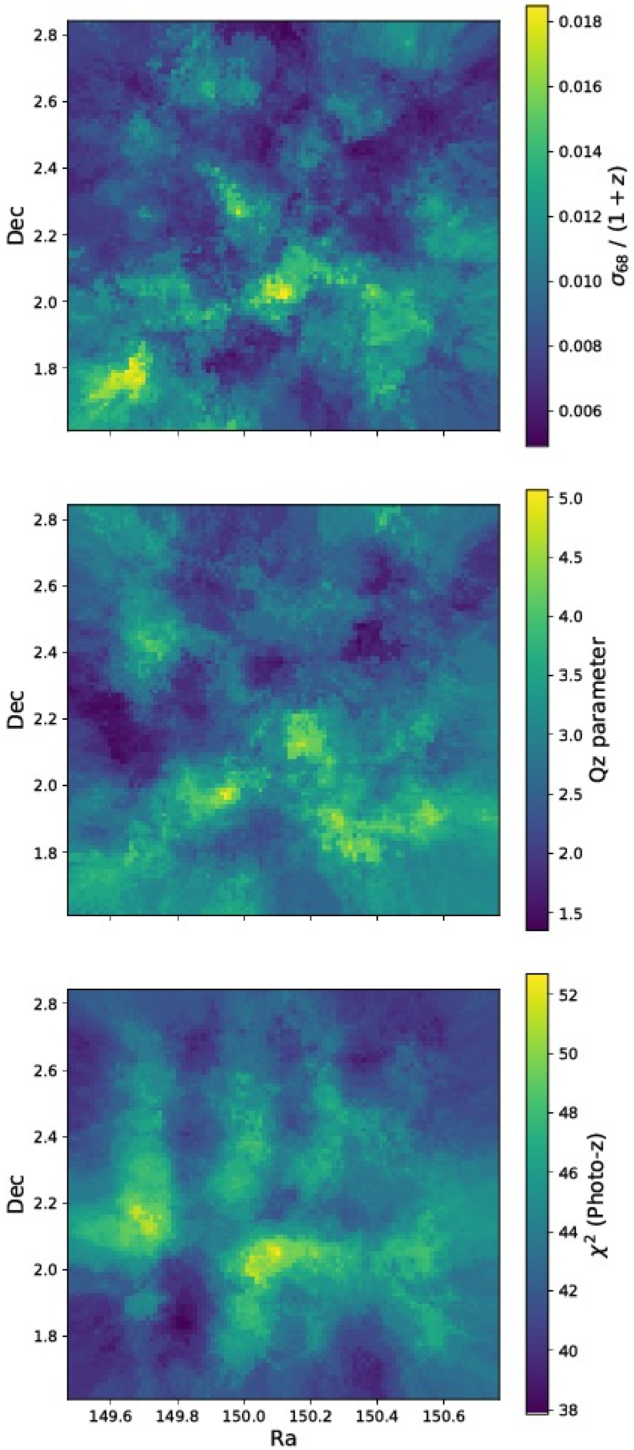
Flux of model **j** in band **i**

$$f_i^{\mathrm{Model}}[z, \boldsymbol{\alpha}] \equiv \sum_{j=1}^{n} f_i^j(z) \boldsymbol{\alpha}_j$$

Amplitude

Spatial variations

- Here there are no quality cuts, so the absolute numbers are higher.
- Yes, doing cuts **will** introduce clustering patterns.
- Method for correcting for this effect shown in “Photo-z quality cuts and their effect on the measured galaxy clustering”. Marti et.al. 2014, Volume 437, Issue 4, p.3490-3505.
- One should however be very careful when starting to measuring a clustering signal.

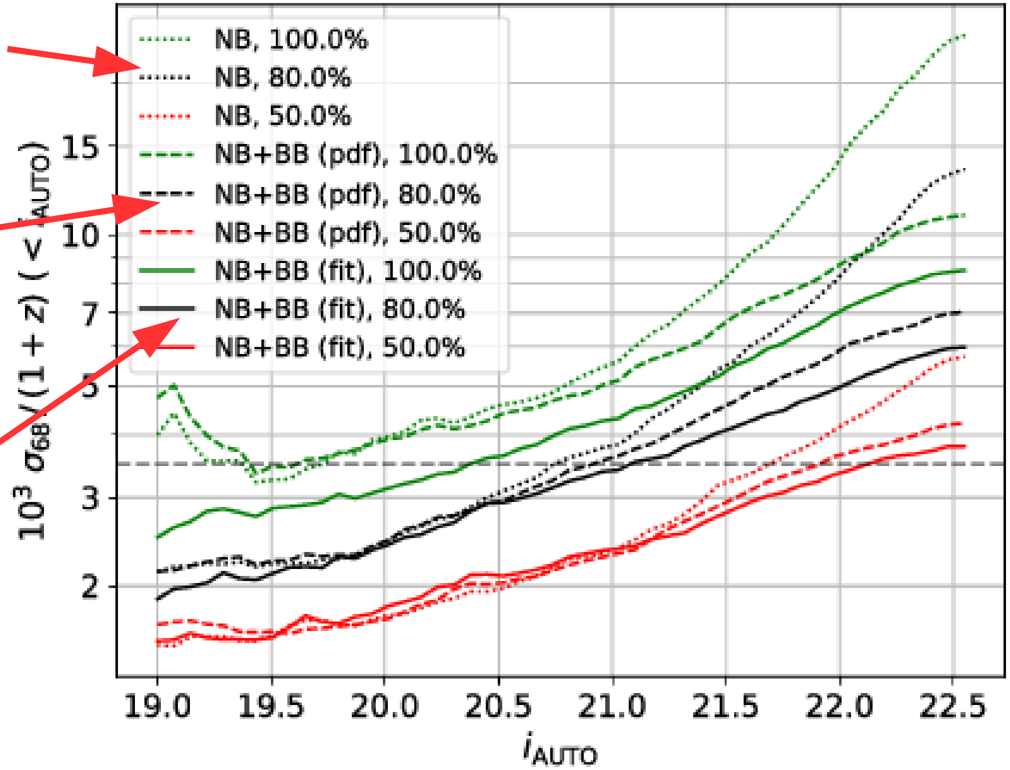


Effect of adding broad bands.

- The final photo-z performance combines narrow and broad bands.
- Show the effect of running with NB alone.
- Or combining the pdfs:

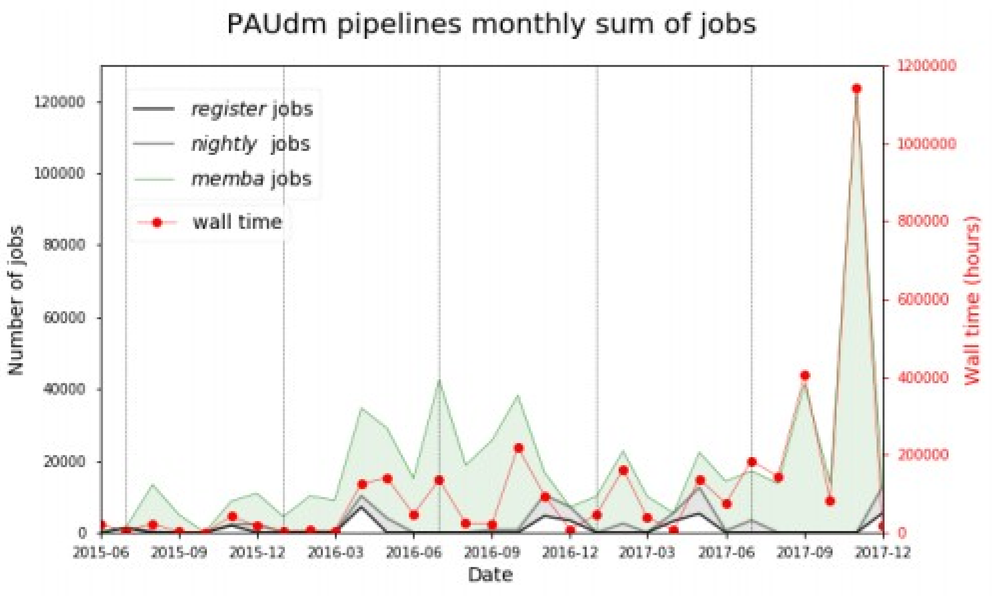
$$p(z) = p_{\rm NB}(z) \times p_{\rm BB}(z),$$

- Or properly fitting using both narrow and broad bands.

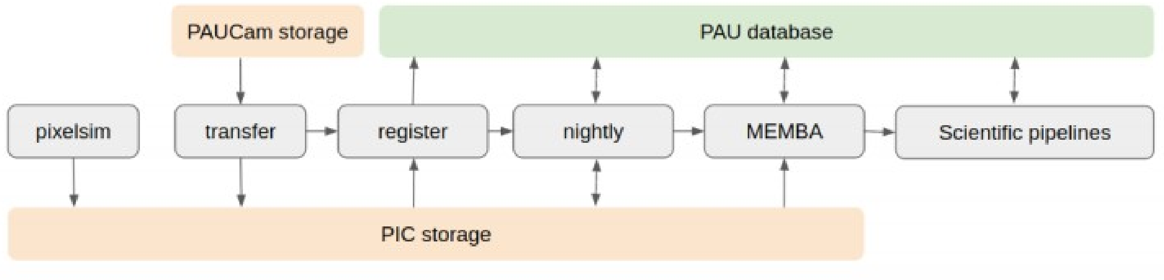


PAUdm operations

“Please tell the scientists, the results do **not** just appear.” Pau Tallada

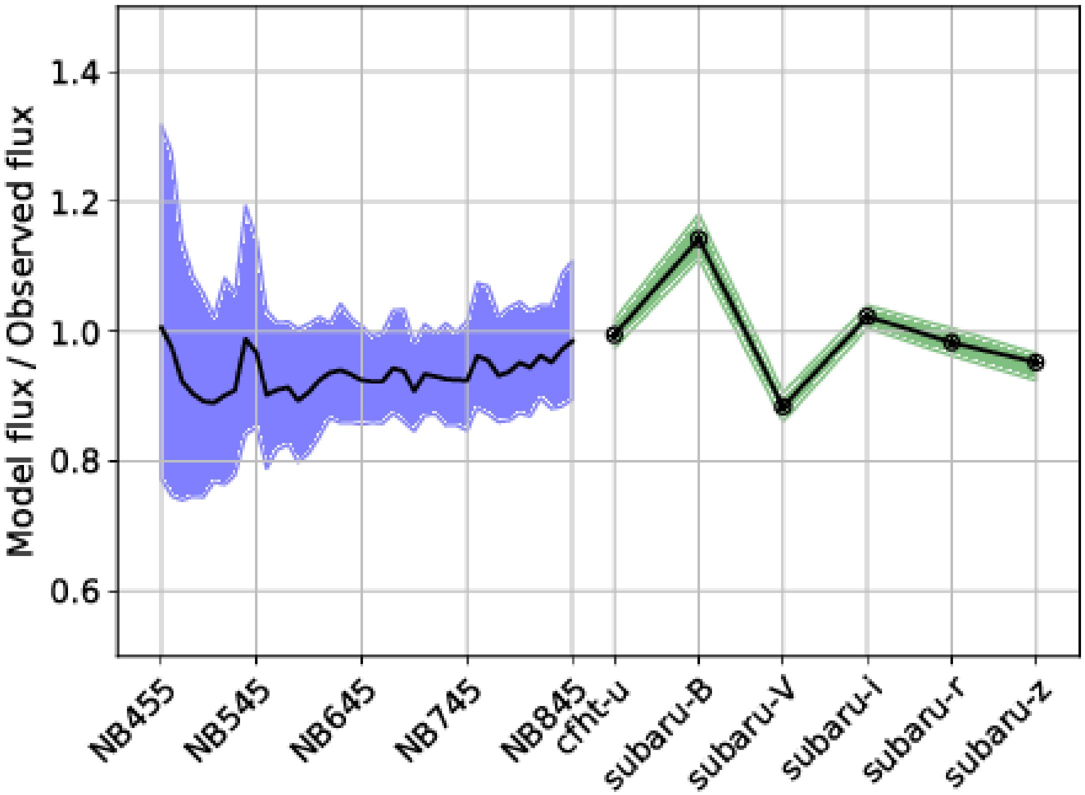


Tonello et. al. 2018



Added zero-points.

- Additional calibration needed to achieve good photo-z.
- We are using external broad band catalogs, which needs to be calibrated relative to PAUS.
- We run the photo-z at the spectroscopic (zs) redshift to determine the correct offset.
- Repeat this procedure 20 times..
- The bands show the 16-84 percentiles for the full catalogue, while the line shows the median.



$$l_i = \text{Median}[f^{\text{Model}} / f^{\text{Obs}}]$$

Per band calibration