The PAU Survey: Early demonstration of photometric redshift performance

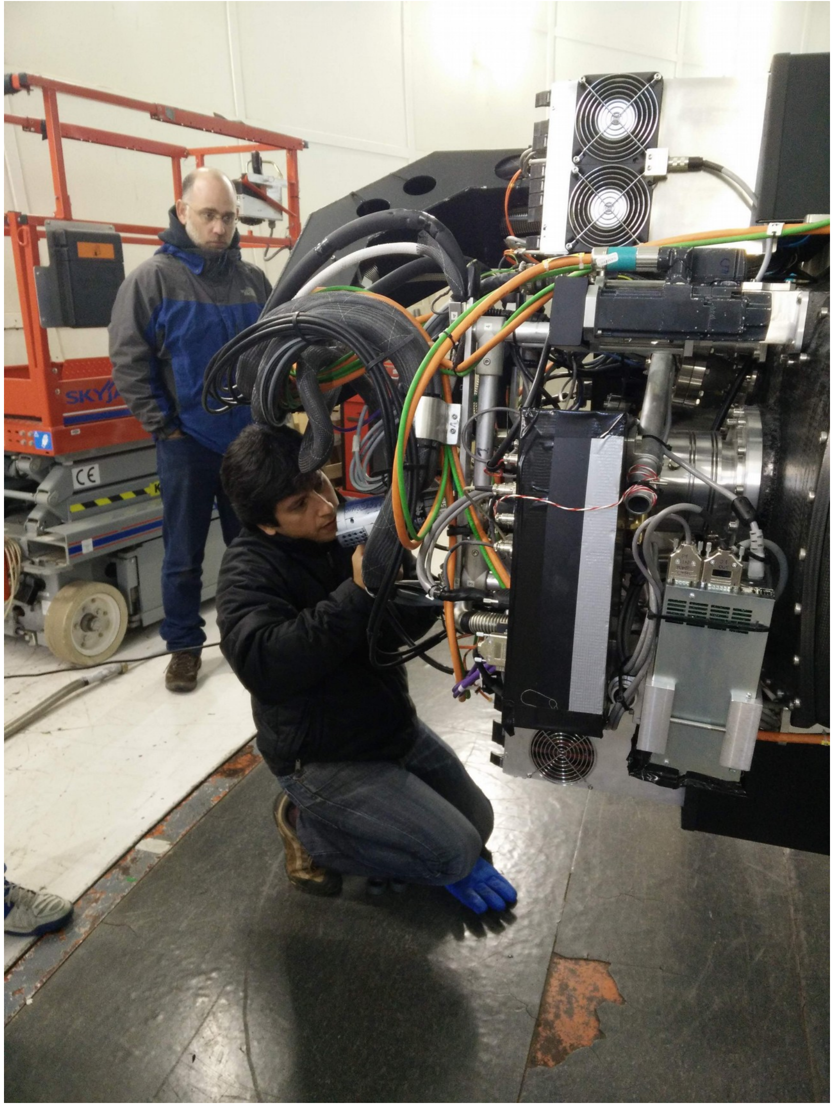
(arXiv:1809.04375)

M. Eriksen, A. Alarcon, E. Gaztanaga, A. Amara, L. Cabayol, J. Carretero, F. J. Castander, M. Delfino, J. De Vicente, E. Fernandez, P. Fosalba, J. Garcia-Bellido, H. Hildebrandt, H. Hoekstra, B. Joachimi, P. Norberg, R. Miquel, C. Padilla, A. Refregier, E. Sanchez, S. Serrano, I. Sevilla-Noarbe, P. Tallada, N. Tonello, L. Tortorelli

- Eight authors with IFAE affiliation, including first author.
- 14 / 25 author on the UAB campus.
- International collaboration: Leiden University, Durham University, UCL, ETH Zurich, Univerity of Bonn.

PAUCam instrument

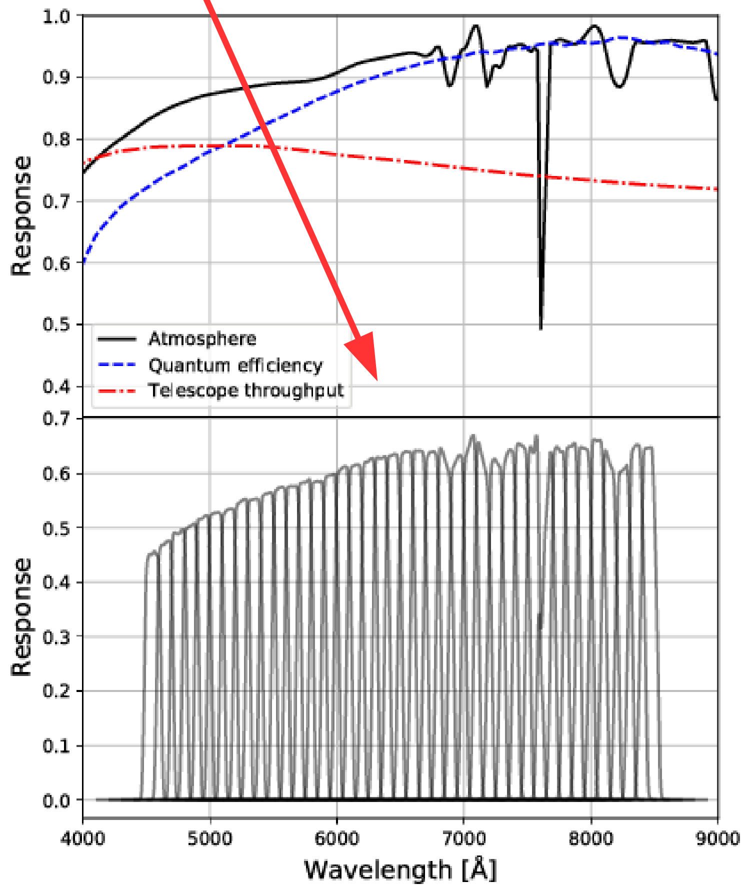
- Installed at William Herschel Telescope (WHT).
- First light in 2015.
- Field of view: 1 deg x 1 deg
- 18 CCD detectors
- 6 wide-band filters: u, g, r, i, z, Y
- 40 narrow-band filters (13 nm wide in steps of 10 nm)
- Time allocated by Spanish, Dutch and UK time allocation committees
- For more info, see: https://www.pausurvey.org/



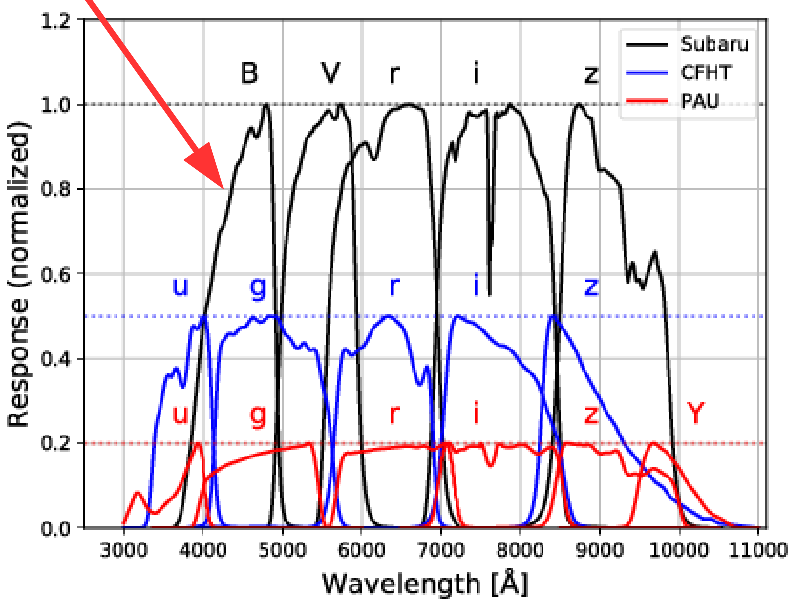
Filter transmission

PAUS narrow bands has a higher wavelength resolution than broad bands filters.

Narrow bands



Broad bands



PAUS Survey

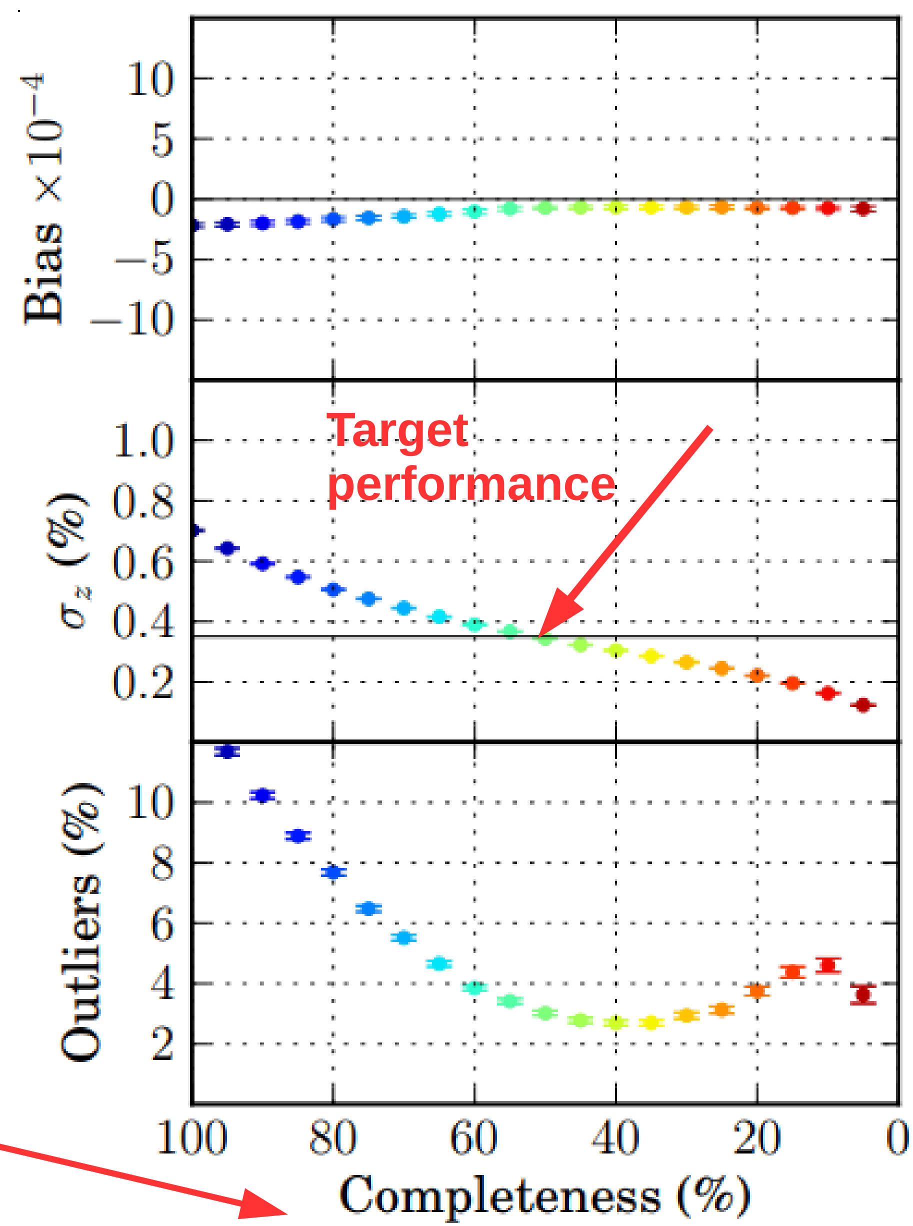
Run	Coverage in 20 bands	Coverage in 40 bands
16A	0,8	2,25
16B	2,9	9,25
17A	8,3	15,65
17B	12,6	21,85
18A	22,1	34,95

- Affected by bad weather.
- More observations in 18B (started!).
- Observing pattern makes the efficiency low in the beginning.

Forecast

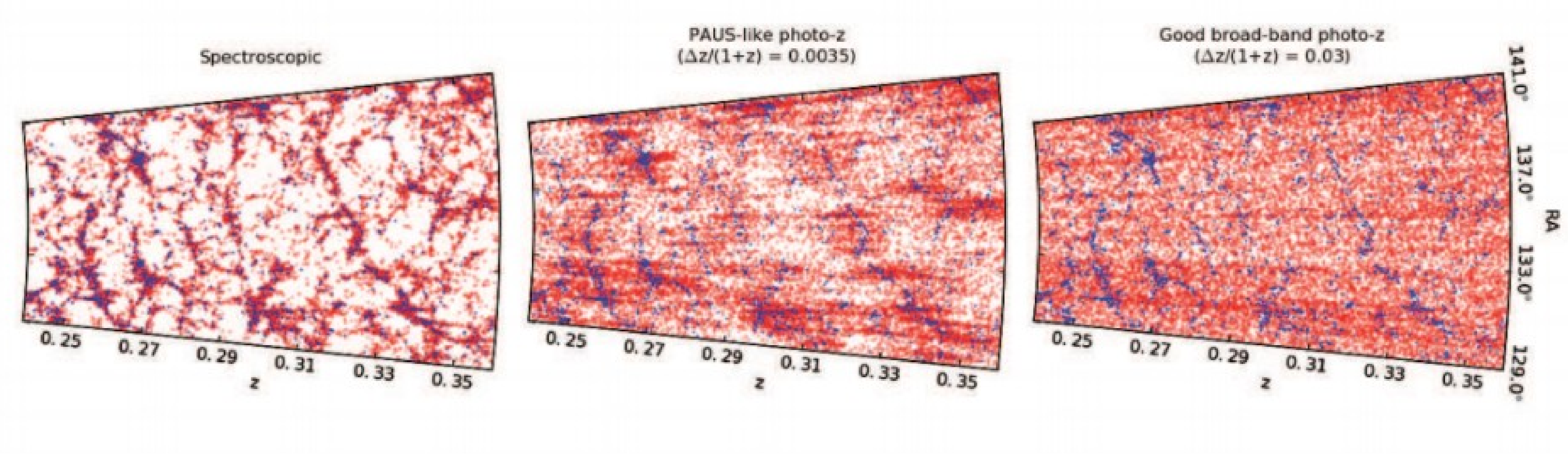
"The Physics of the Accelerating Universe (PAU) survey at the William Herschel Telescope (WHT) will use a new optical camera (PAUCam) with a large set of narrow-band filters to perform a photometric galaxy survey with a quasi-spectroscopic redshift precision of σ(z)/(1 + z) ∼ 0.0035 and map the large-scale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

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



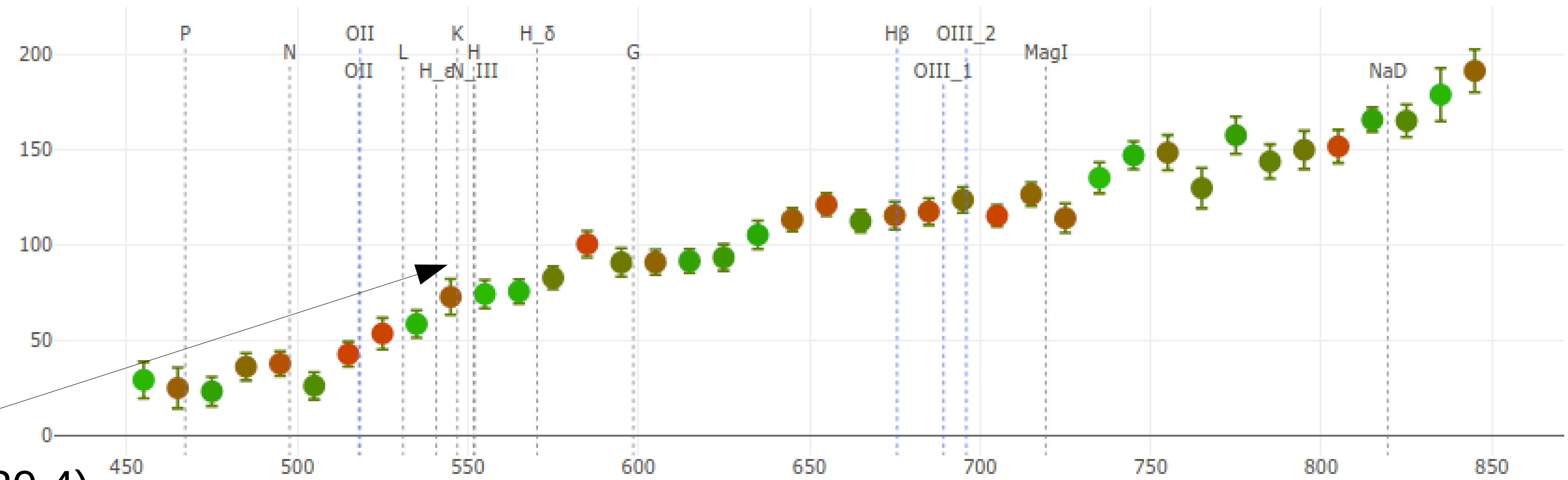
Cut based on fit quality (ODDS).

Large scale structure

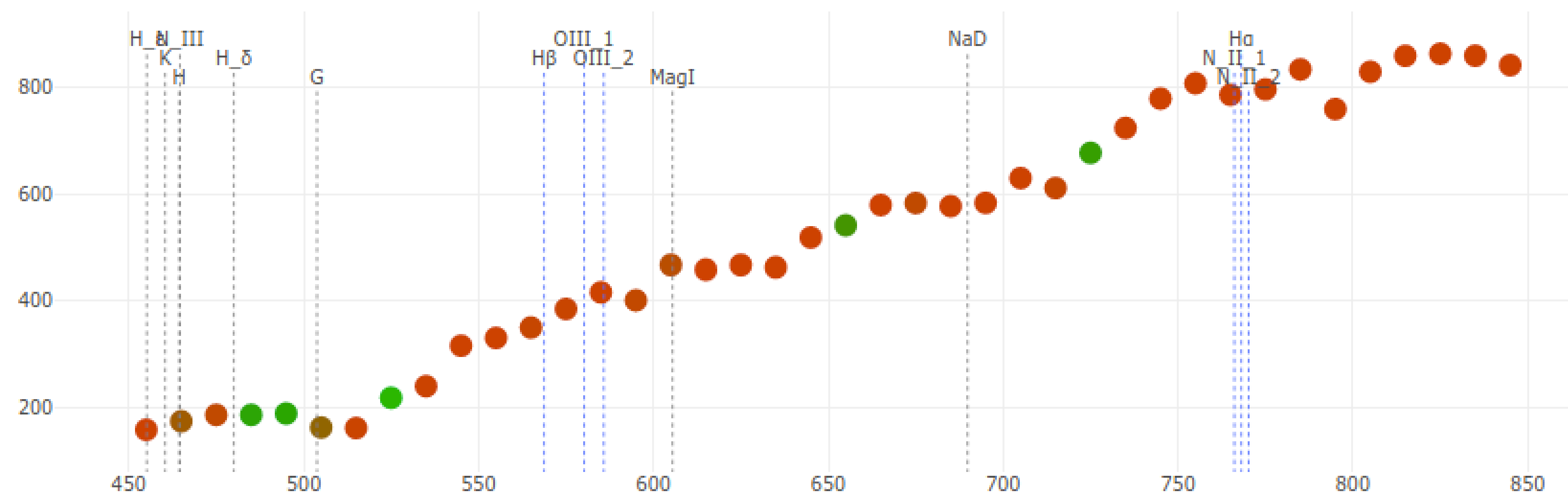


- Blue: Gamma. Red: PAUS
- At z = 0.5 the typical broad band photo-z uncertainty of σ68 /(1 + z) ~ 0.05 translates into a 40% error in the luminosity (or 355 Mpc/h in luminosity distance), while the PAUS photo-z error corresponds to 2.5%.
- Uncertainty in comoving radial distance is reduced by more than an order of magnitude from 171 Mpc to 12 Mpc.
- Original science case of measuring Baryon Acoustic Oscillations Along the Line of Sight. Benitez 2009.
- Later science case on combining galaxy clustering, redshift space distortion and weak lensing. Gaztanaga 2012, Eriksen 2015.

Example spectra



Galaxy (i=20.4)

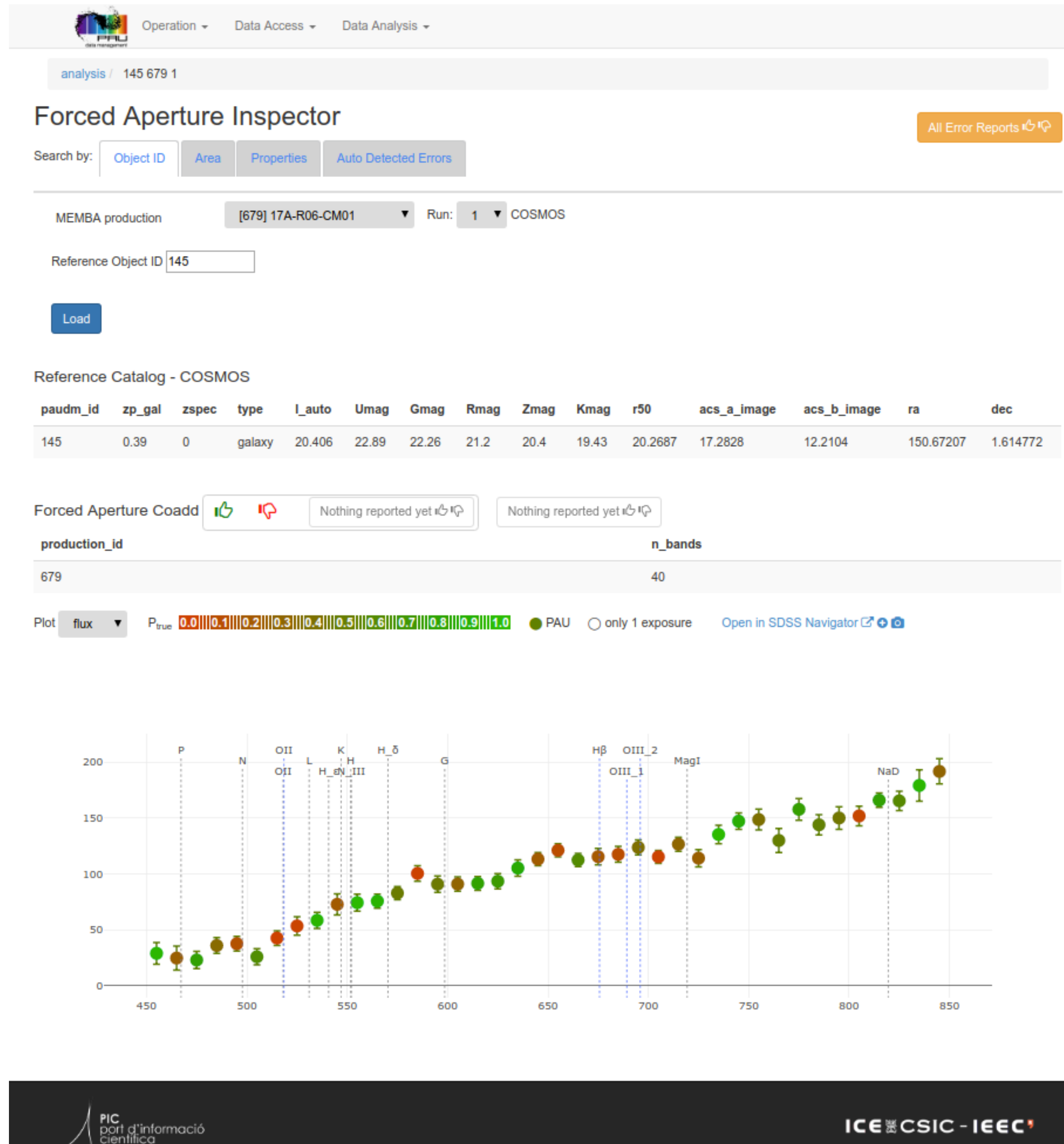


Star (i=18.3)

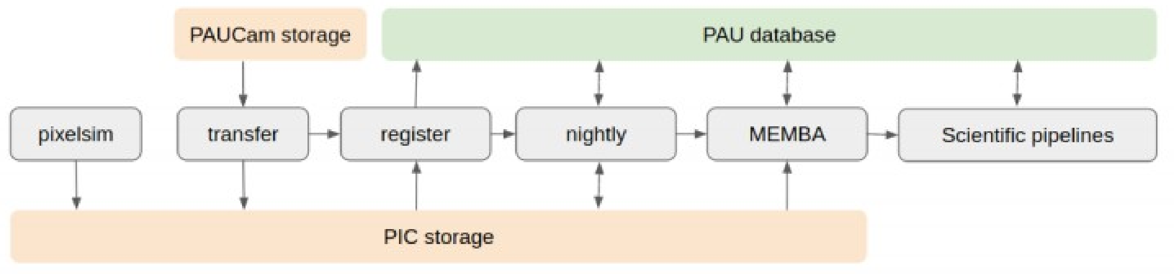
PAUdm - Webpage

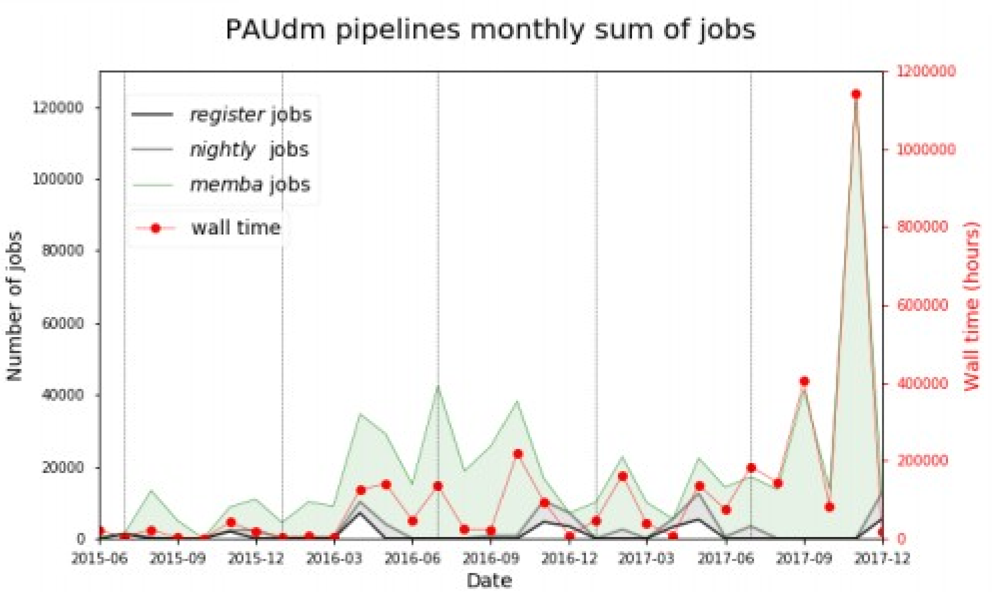
PAUdm, arXiv: 1811.02368

“The PAU Survey: Operation and orchestration of multi-band survey data”



PAUdm - Pipelines

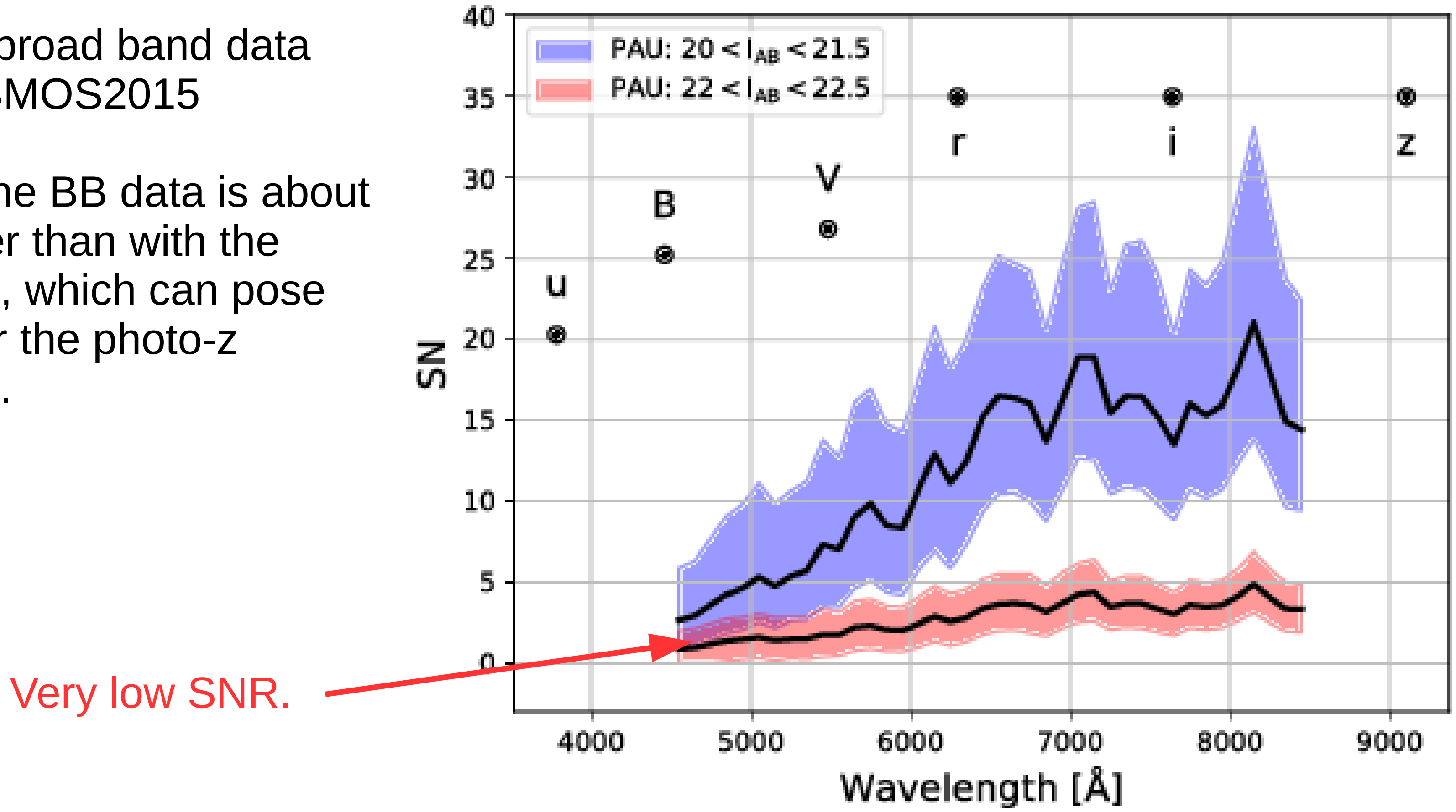




- “Please tell the scientists, the results do not just appear.” Pau Tallada

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.



BCNz2

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

Observed flux

Broad bands

Narrow bands

Zero-point per galaxy

Zero-point per band

Flux error

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

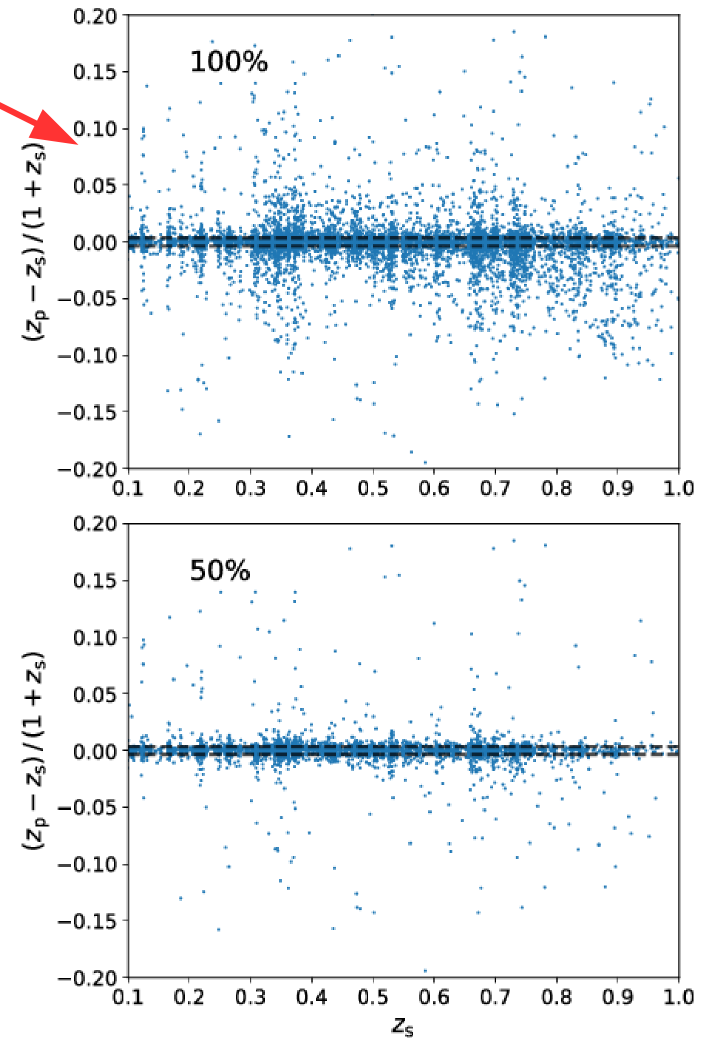
Flux of model **j** in band **i**

Amplitude

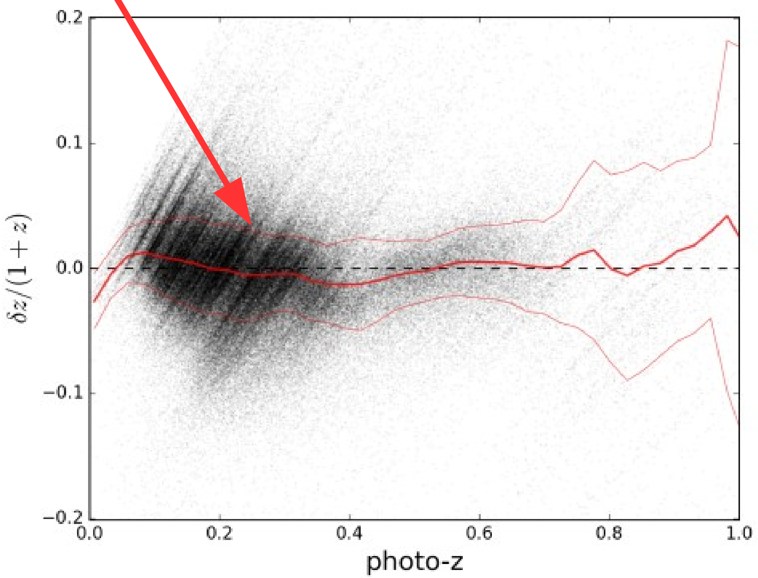
Photo-z scatter

Typical photo-z has sigma68 /(1+z) of 0.03-0.05. PAUS achieves 0.0037

PAUS



KiDS + Viking (NIR)

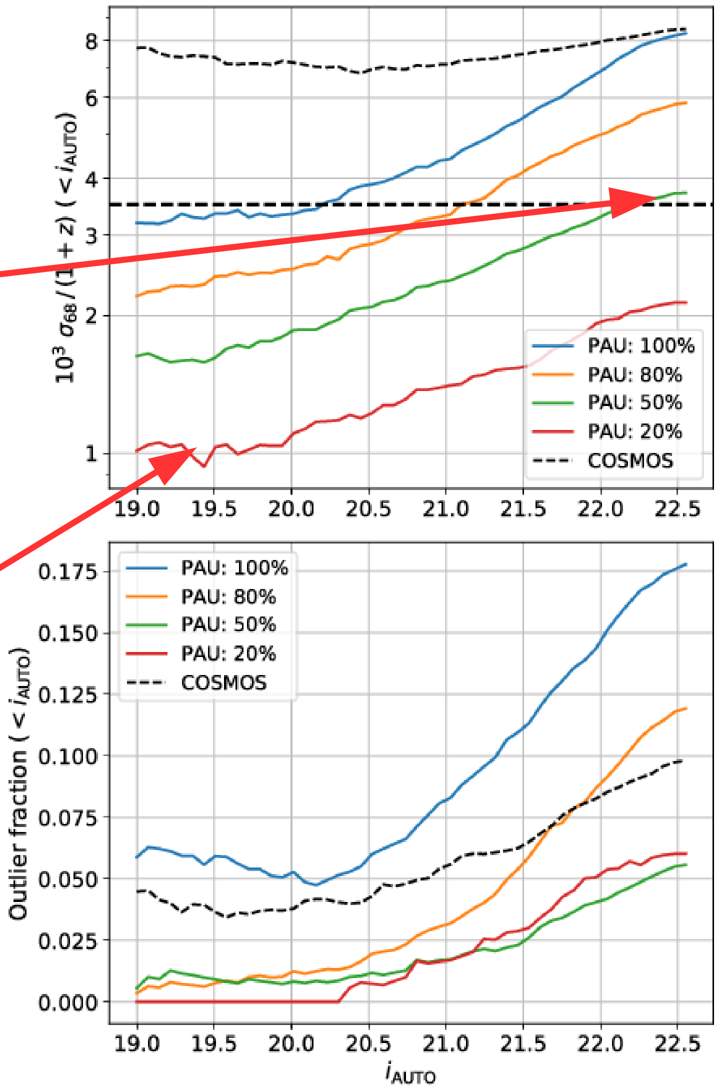


Bilicki et.al. A&A 616, A69 (2018)

Photometric precision

- 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.

- Furthermore, a higher photo-z precision(σ 68 /(1 + z) ∼ 0.001) is obtained for a bright and high quality selection, which is driven by the identification of emission lines.

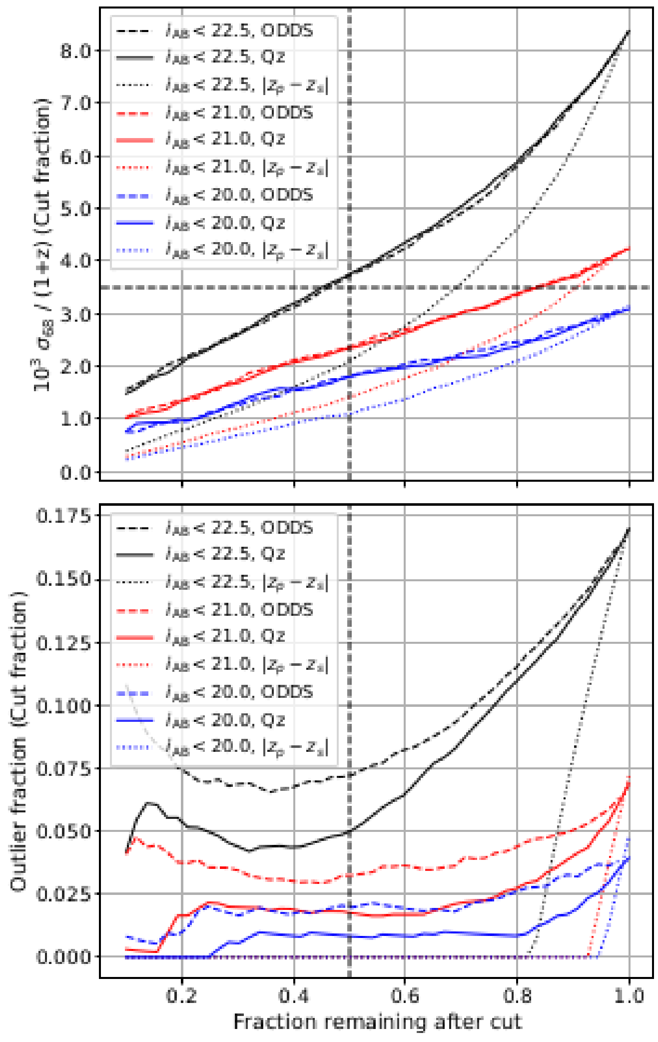


Quality cuts

By default the paper cuts on the Qz parameter.

$$\mathrm{ODDS} \equiv \int_{\mathrm{z_b} - \Delta \mathrm{z}}^{\mathrm{z_b} + \Delta \mathrm{z}} \mathrm{d}z \; p(z),$$

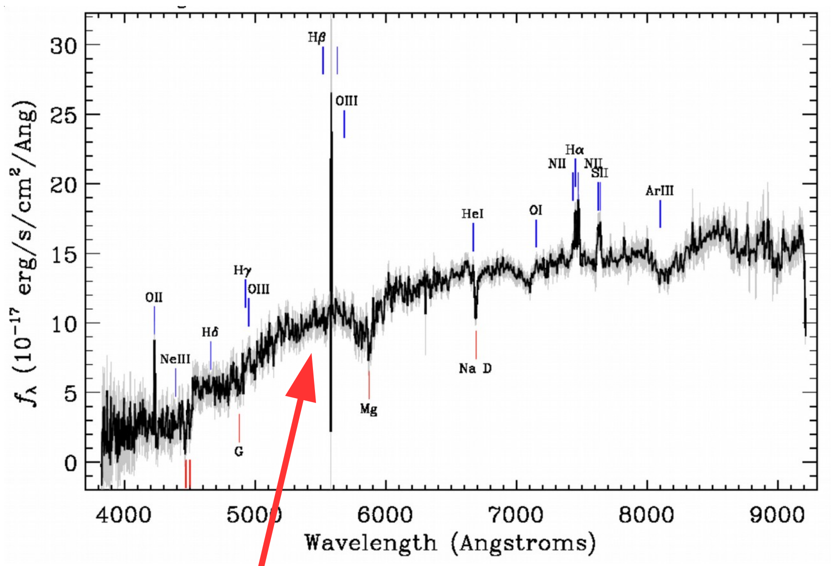
$$\mathrm{Qz} \equiv \frac{\chi^2}{N_{\mathrm{f}} - 3} \left(\frac{z_{\mathrm{quant}}^{99} - z_{\mathrm{quant}}^{1}}{\mathrm{ODDS}(\Delta \mathrm{z} = 0.01)} \right)$$



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.

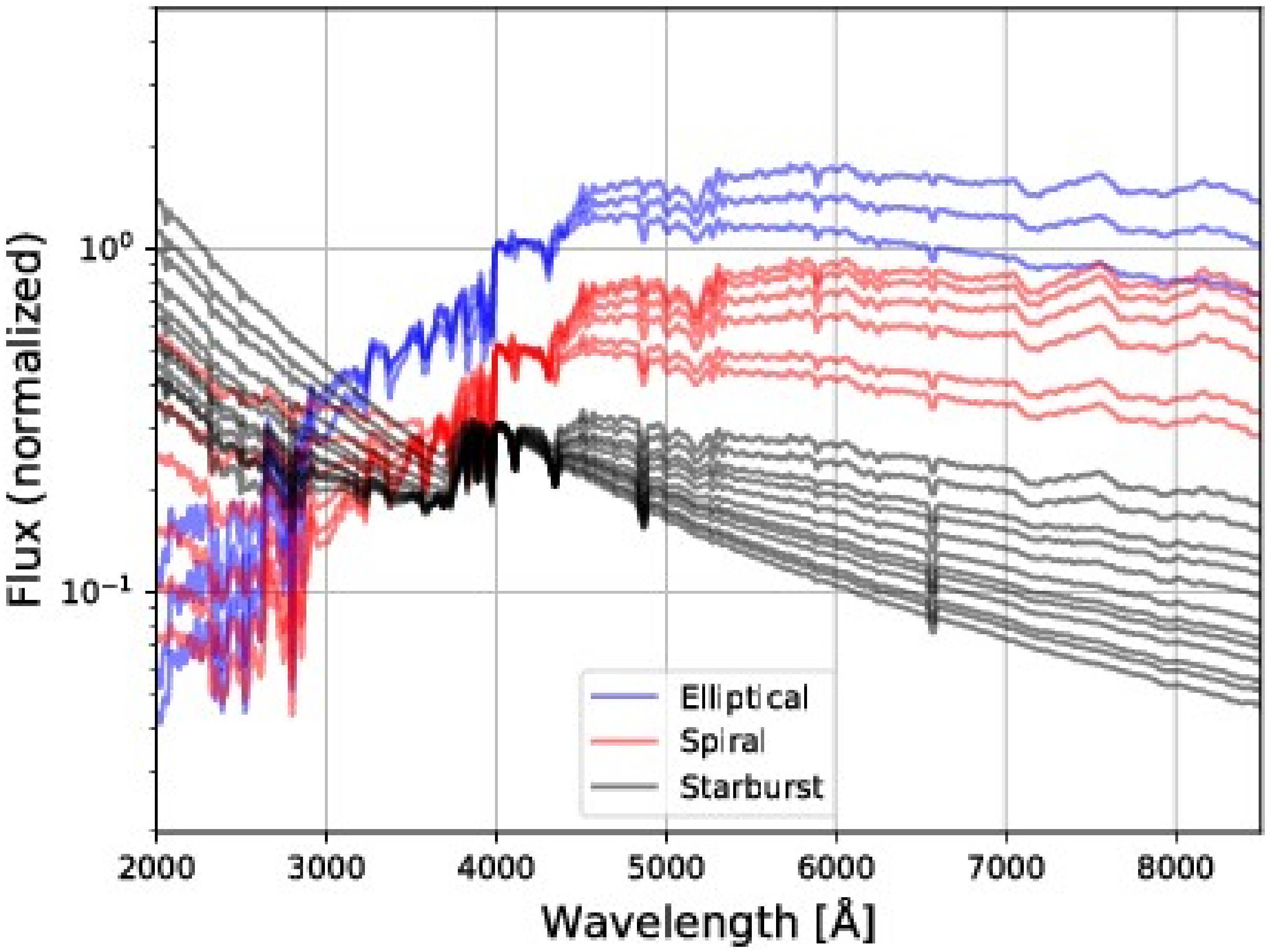
	λ[Å]	Template 1	Template 2
H_α	6563	1.77	-
H_β	4861	0.61	-
Ly_α	1216	2	-
NII_1	6548	0.19	-
NII_2	6583	0.62	-
OII	3727	1	-
$OIII_1$	4959	-	1
$OIII_2$	5007	-	3
SII_1	6716	0.35	-
SII_2	6731	0.35	-



SDSS Starburst spectrum, z=0.13

Source: skyserver.sdss.org

Different SEDs



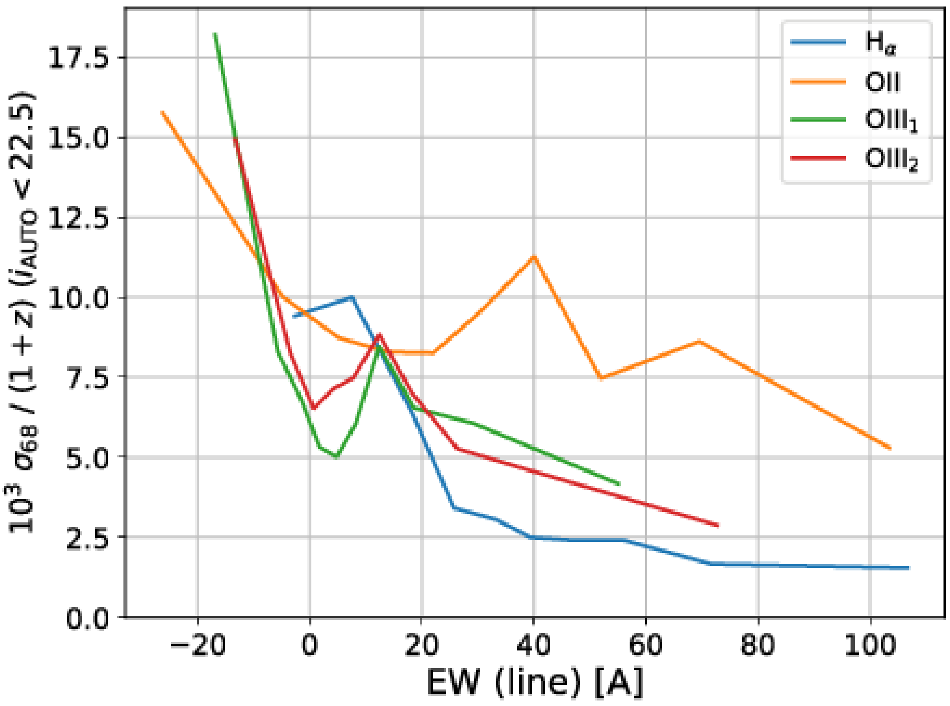
Effect on photometric redshifts

Estimated continuum.

-

$$\mathrm{EW} \equiv 100\text{Å}\,(f^{\mathrm{Obs}} - f^{\mathrm{Cont}})/f^{\mathrm{Cont}}$$

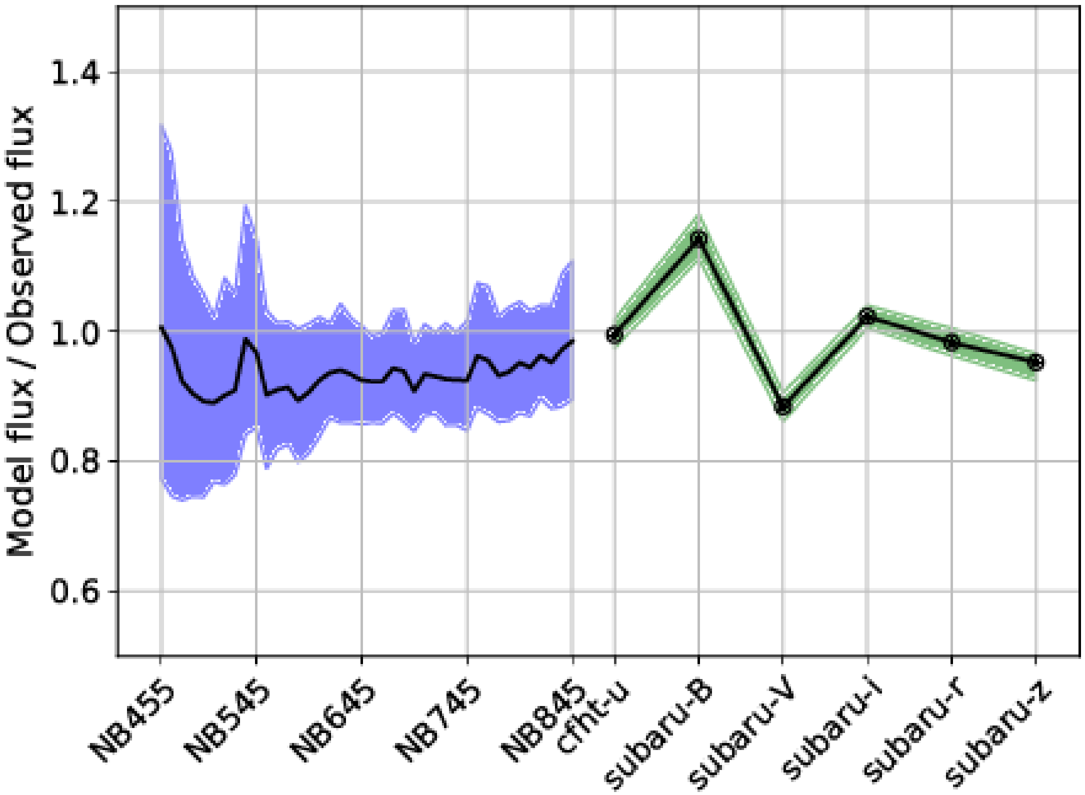
Observed flux



- 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.

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.



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

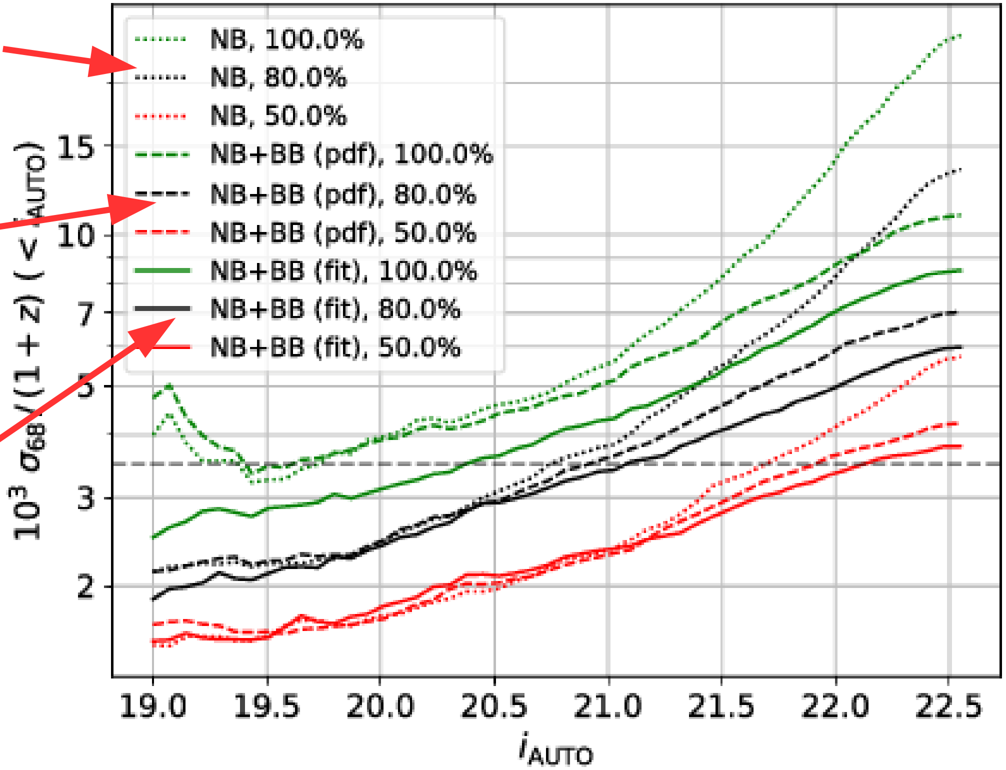
Per band calibration

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:

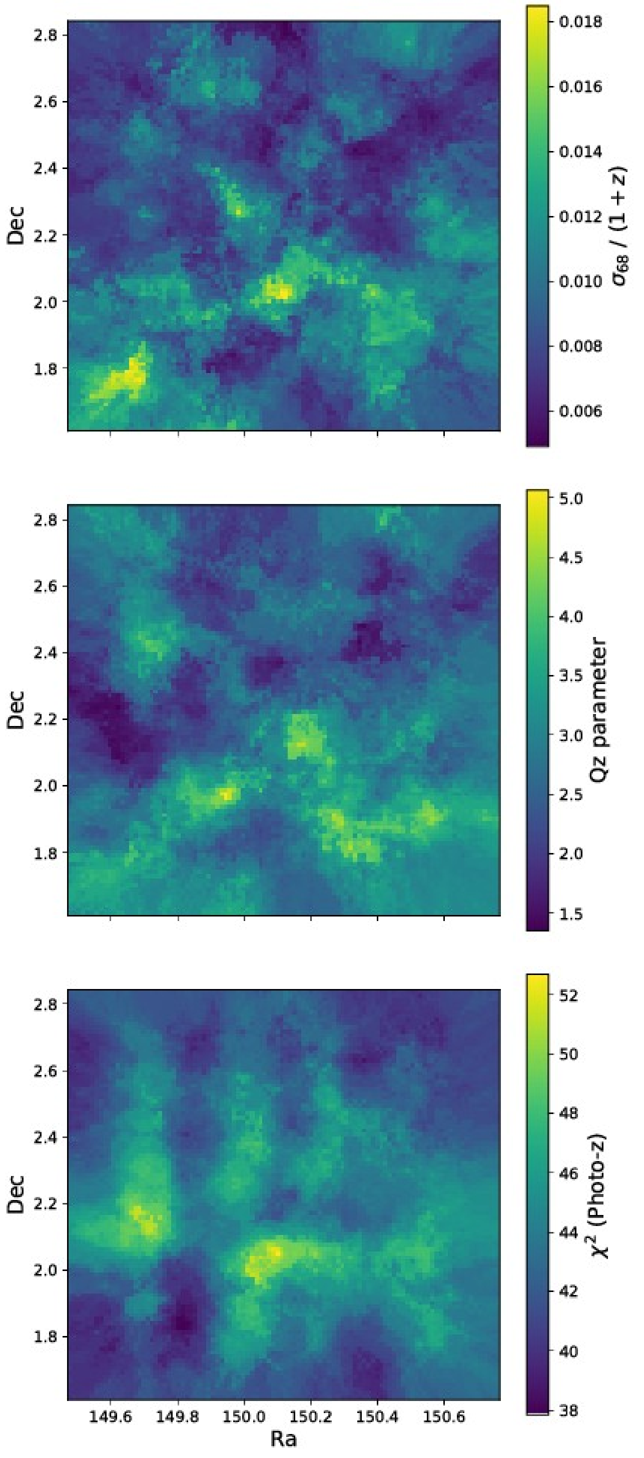
$$p(z) = p_{\mathrm{NB}}(z) \times p_{\mathrm{BB}}(z),$$

- Or properly fitting using both narrow and broad bands.



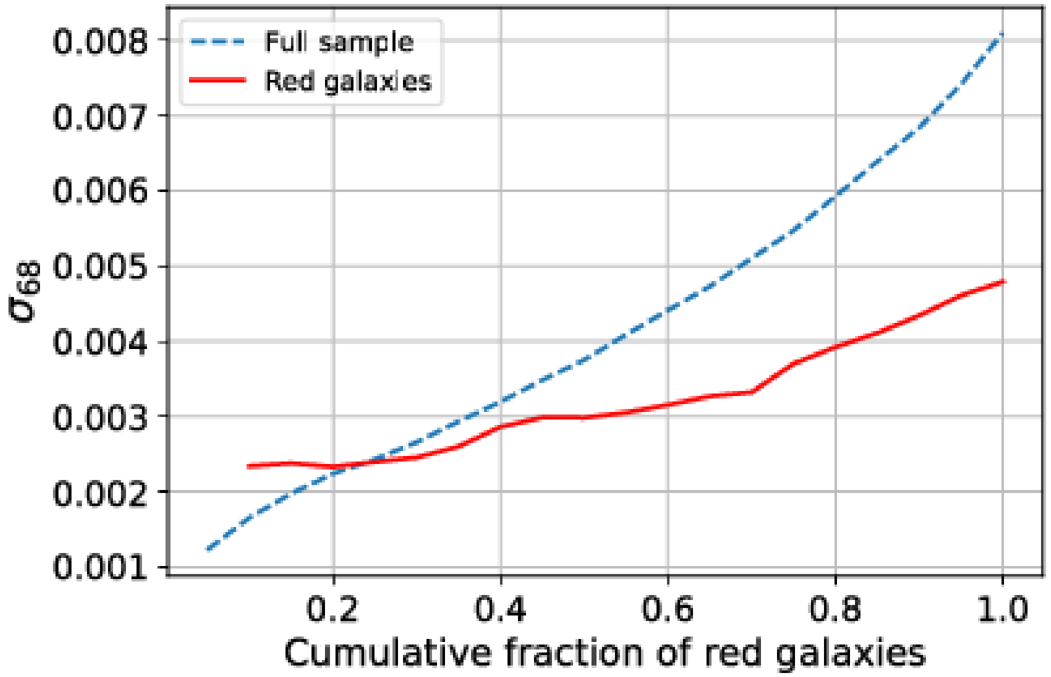
Spatial variations

- 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.



LRGs.

The LRGs are selected by fitting to the SEDs.



PAUS Collaboration – First papers

- - Eriksen et al., 2018, MNRAS submitted (arXiv:1809.04375) “The PAU Survey: Early demonstration of photometric redshift performance in the COSMOS field”
- - Stothert et al., 2018, MNRAS accepted (arXiv:1807.03260) “The PAU Survey: Spectral features and galaxy clustering using simulated narrow band photometry”
- - Cabayol et al., 2018, MNRAS submitted (arXiv:1806.08545) “The PAU Survey: star-galaxy classification with multi narrow-band data”
- - Tortorelli et al., 2018, MNRAS submitted (arXiv:1805.05340) “The PAU Survey: A Forward Modeling Approach for Narrow-band Imaging”

Previous pizza seminar.

Conclusions

It works, good photo-z

- Comparison to secure spectra from zCOSMOS DR3 shows that PAUSachieves 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.

New science

- Unique data set, wider and deeper than many spectroscopic surveys. Better redshift determination than wide broad band surveys. Opens up for new science cases.

Data will eventually get public. Please contact us if Anyone wants to help?

Questions?

Extincition