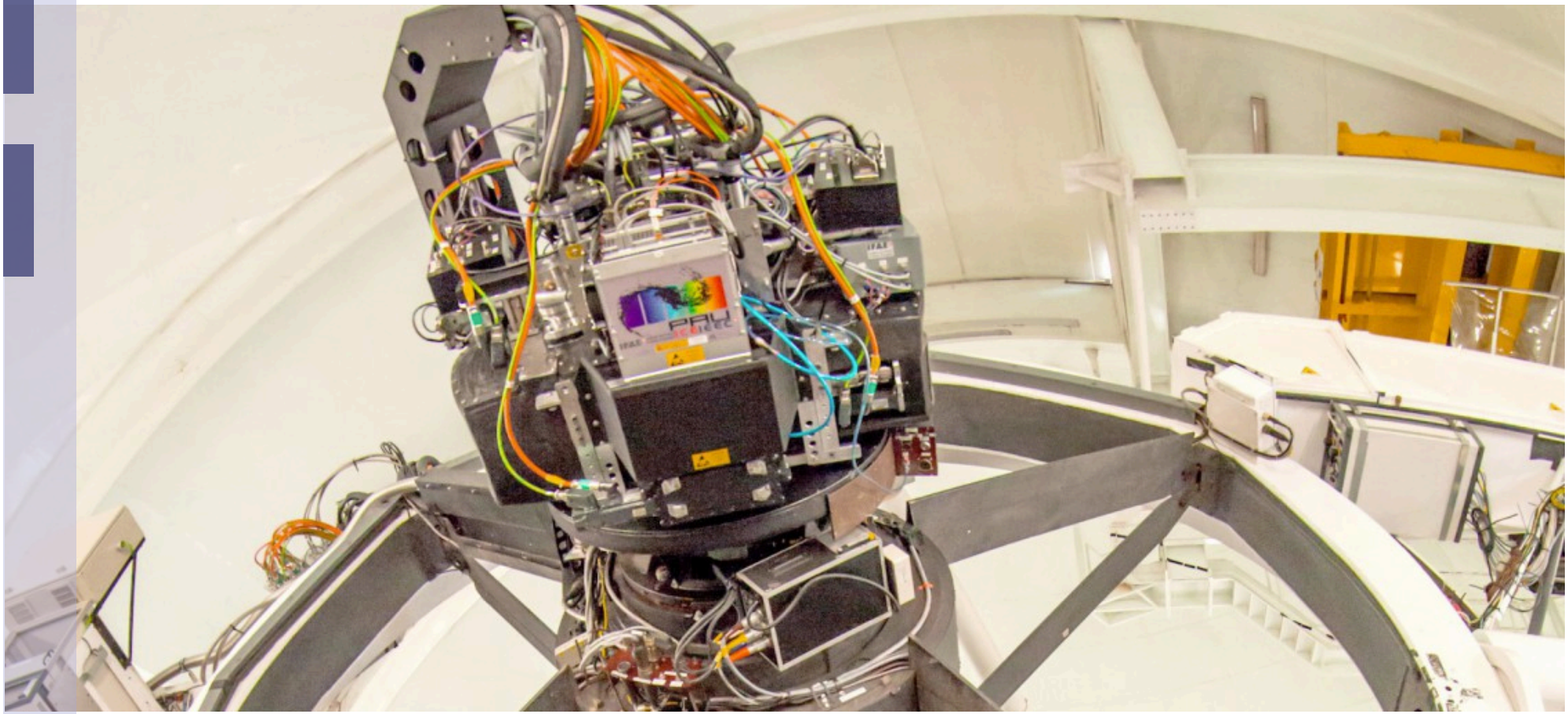
PAUS: the Probe of the Accelerating Universe Survey



Peder Norberg (ICC & CEA, Durham University)
for the PAUS Team

EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

PAUS: the collaboration

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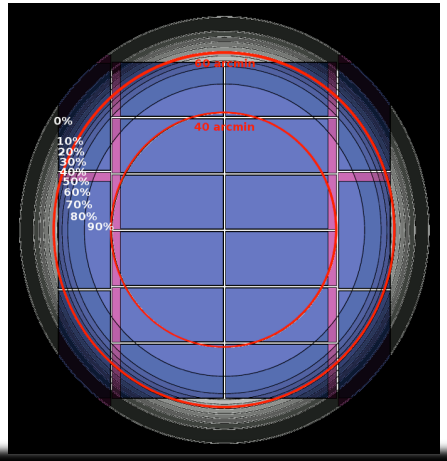
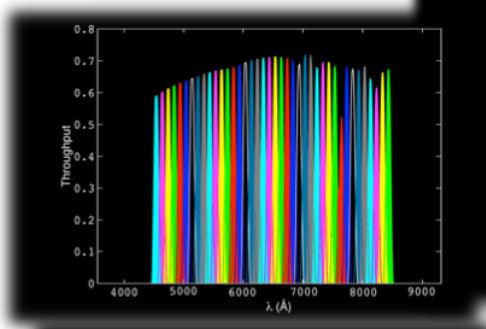
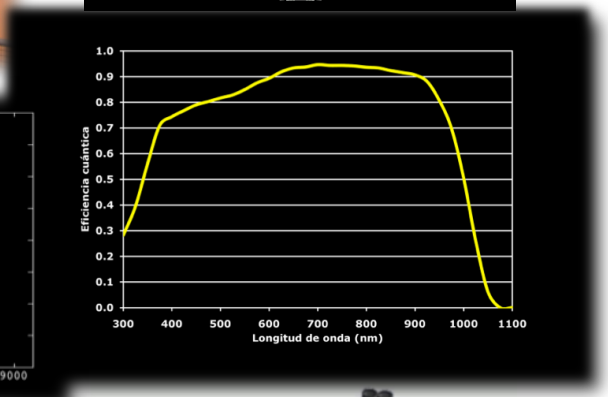
PAUCam in a nutshell

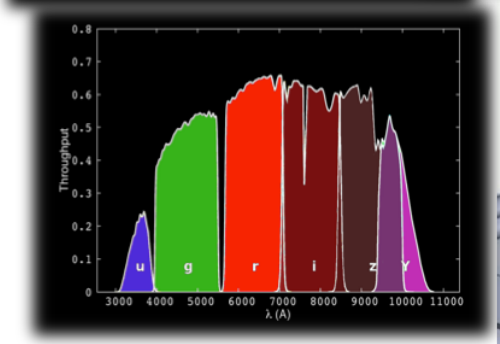
- New camera for WHT with 18 2k x 4k CCDs covering ~1 deg ∅ FoV.
- 40 x130Å-wide NB filters covering 4500-8500 Å (100Å steps) in 5 movable filter trays, which also include standard ugrizY BB filters.
- Survey camera: aims to cover ~0.7 deg^2 per night in all filters to i~22.5-23.0 , i.e. ~15k galaxies per night!
- Provide low-resolution spectra ($\Delta\lambda/\lambda$ ~ 2%, or R ~ 50)
- Expected photometric galaxy redshift accuracy:

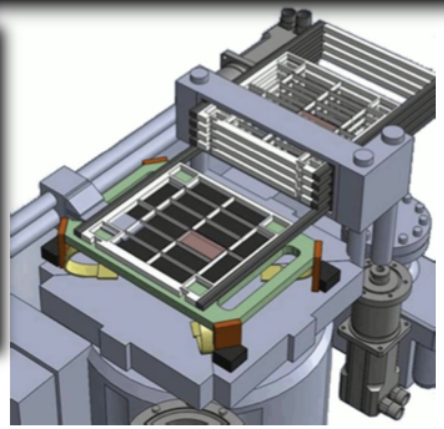
$$\sigma(z) \sim 0.0035\times(1+z)$$



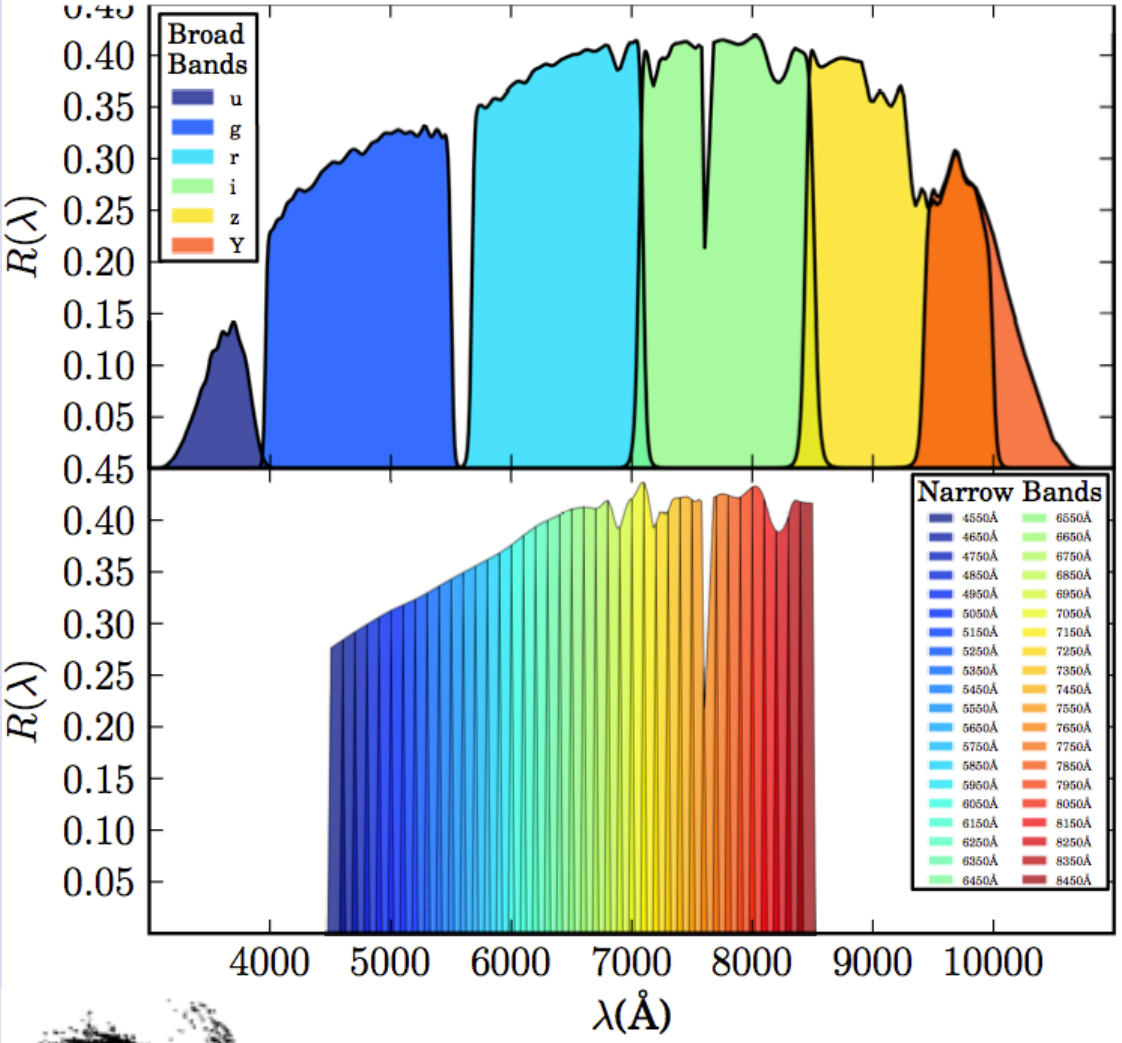


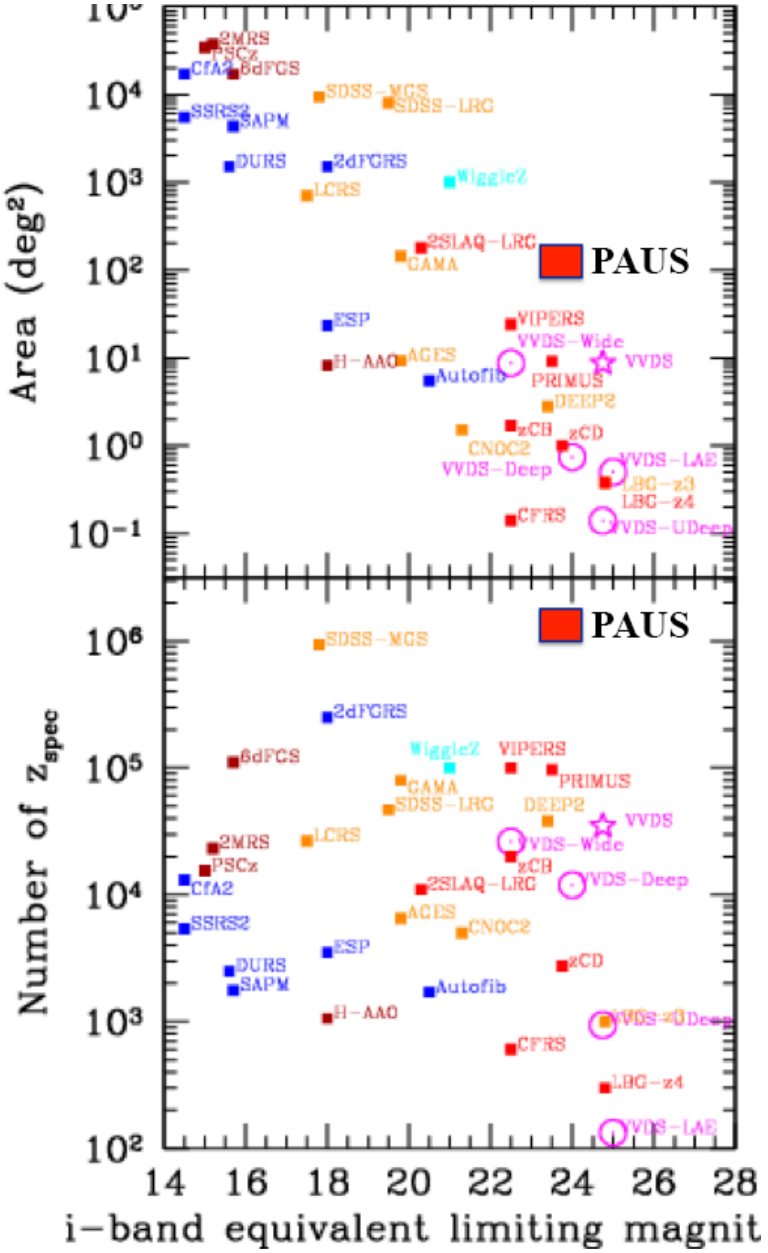




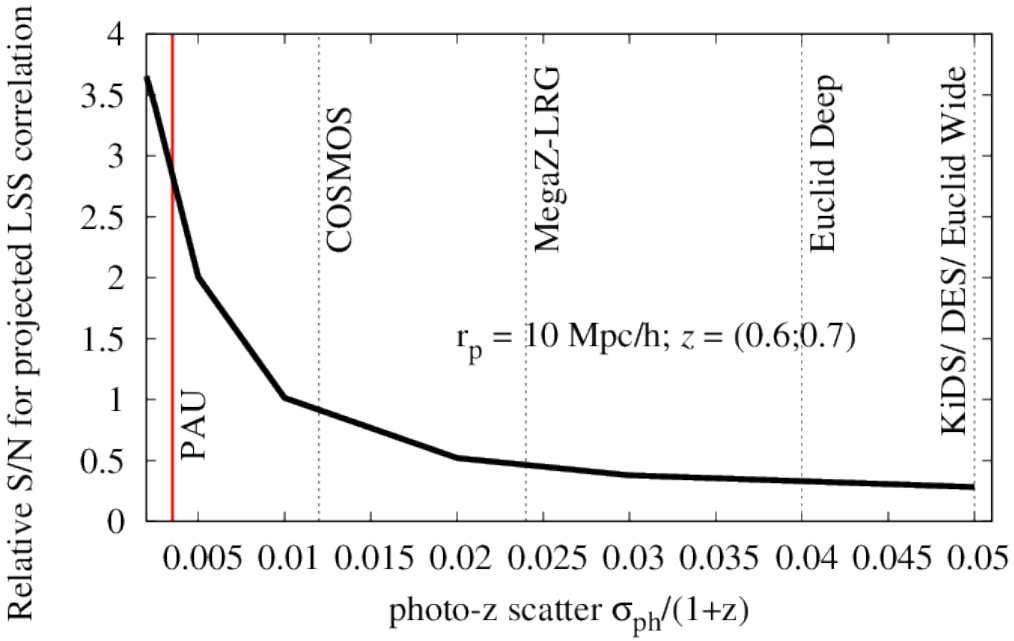


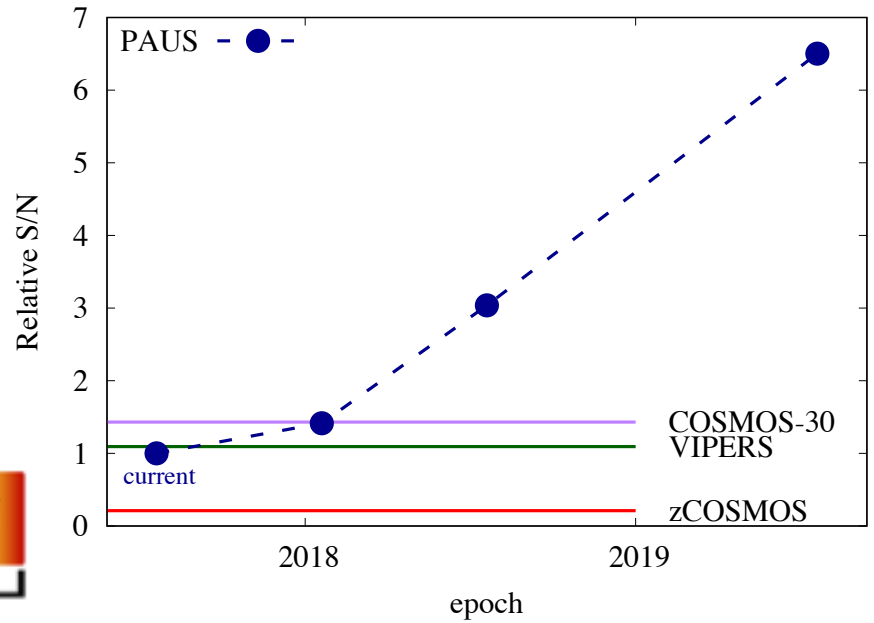
40NB filters and PAUCam Survey parameter space





Proposed intrinsic alignment science with PAUS





Relative S/N of projected large-scale structure clustering correlation functions (applicable to intrinsic alignment and galaxy clustering) as a function of photo-z accuracy.

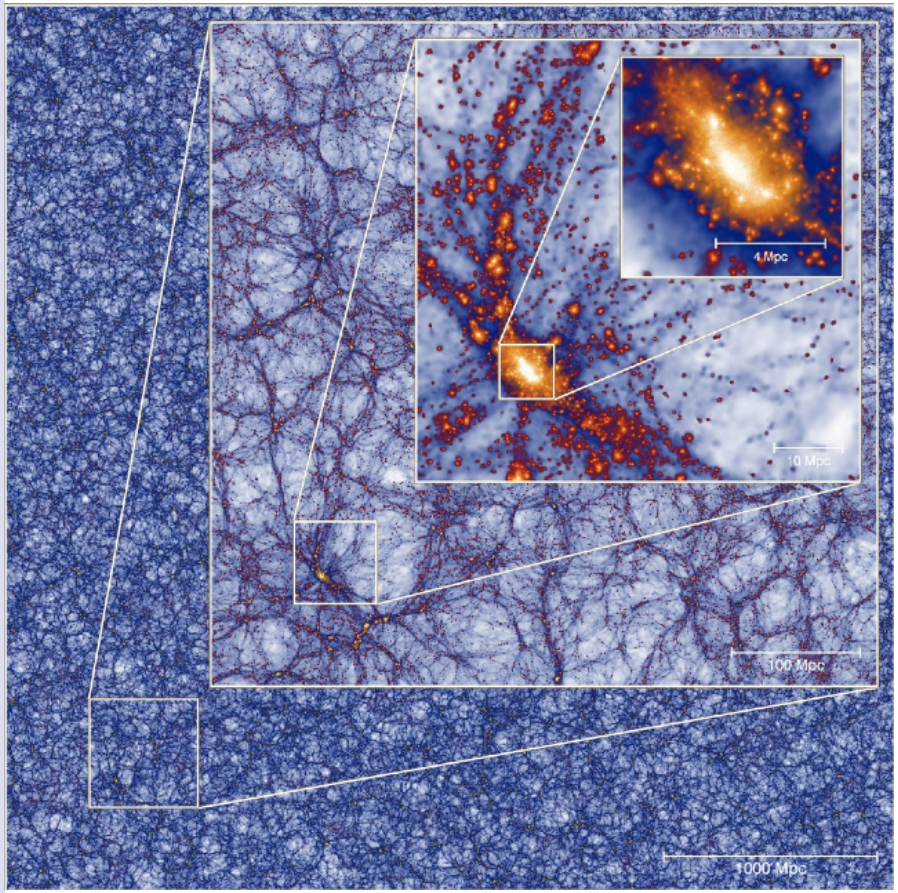
Since intrinsic alignments and galaxy clustering are local effects, redshift uncertainty quickly degrades the signal. A 75sq.deg. PAUS will be competitive with KiDS and DES despite the 20-80 times smaller area!

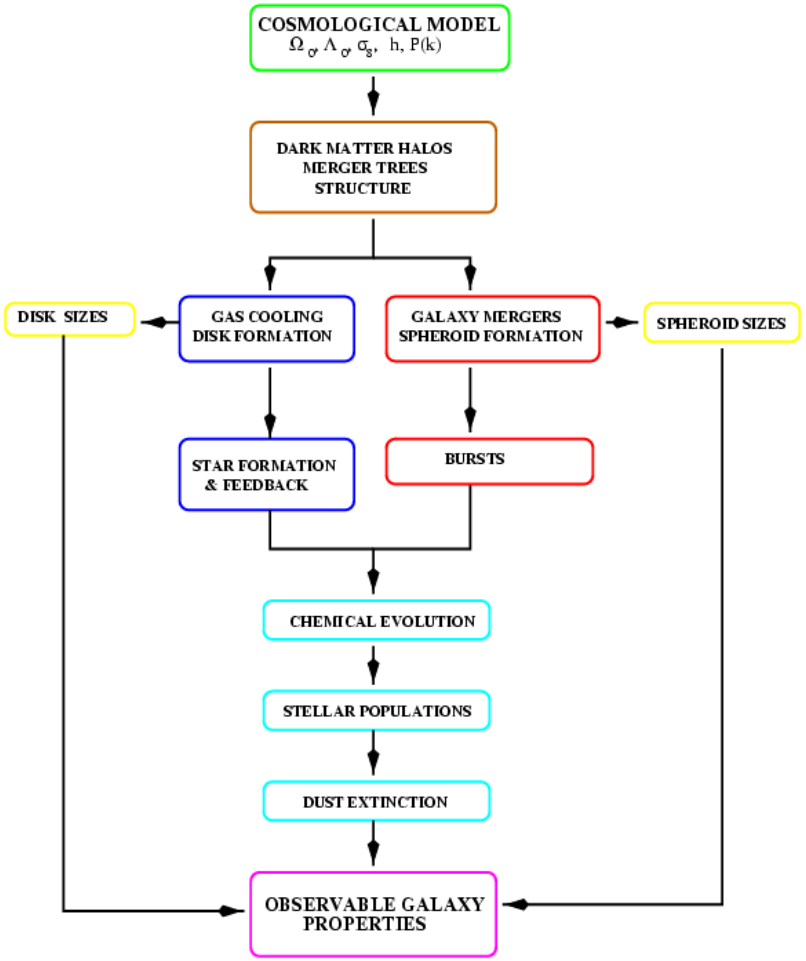
PAUS is already competitive compared to other available surveys

By end 18A with CFHTLS-W3 completed, PAUS will provide more than double the S/N of COSMOS-30.

PAUS TAC applications 2017A/B, 2018A/B

Galform mock for PAUS projections





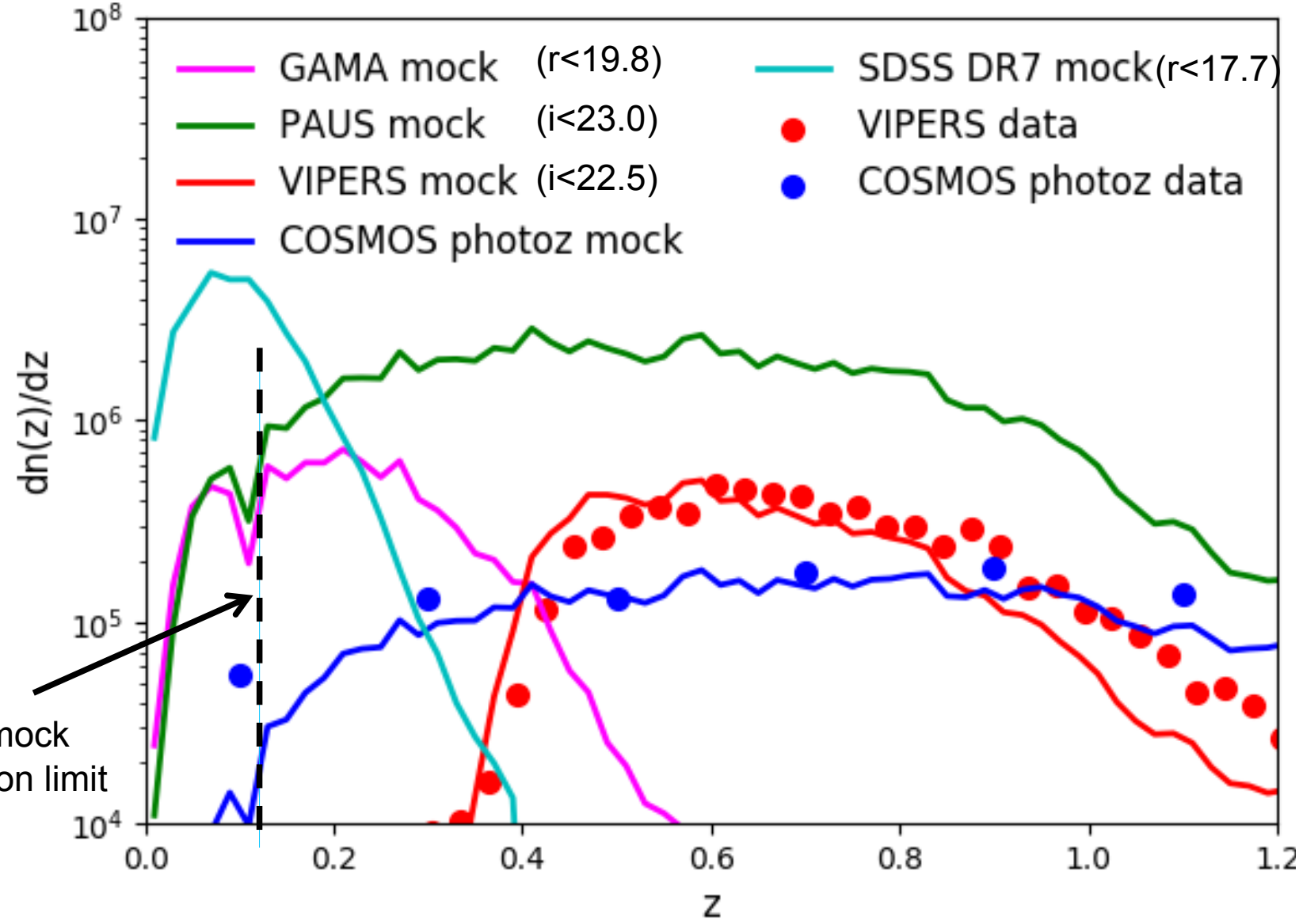
N-body Simulation + Galaxy Formation Model

MR7: $(500\text{Mpc/h})^3$ box with $m_p \sim 10^9$ Msol/h (Guo et al. 2011, with Dhalo merger-trees)

Gonzalez et al. (2014) matches low-z data (but not at the percent level – far from that!)

Stothert et al. (submitted)

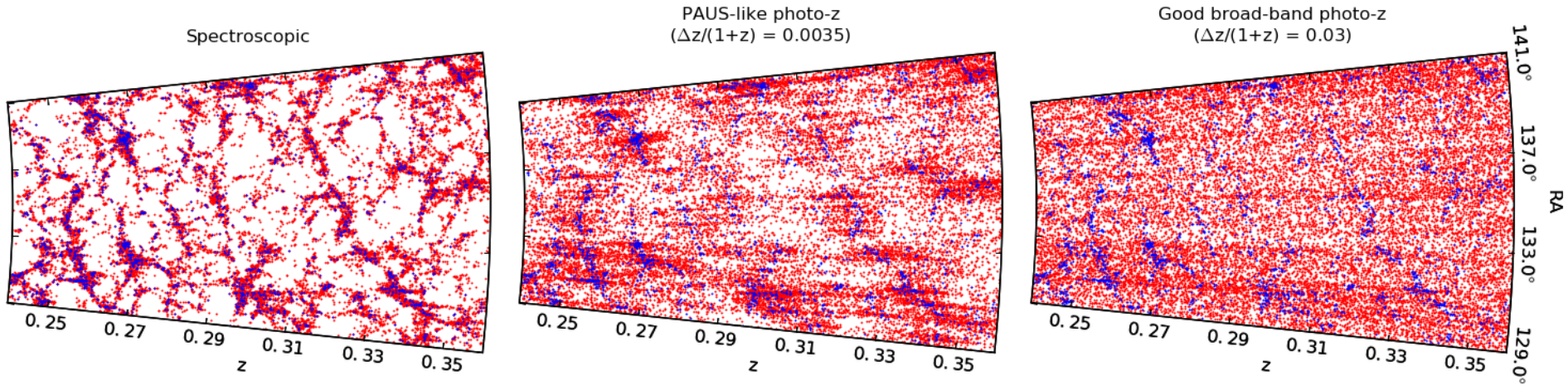
Expected PAUS redshift distribution (60 sq.deg.)

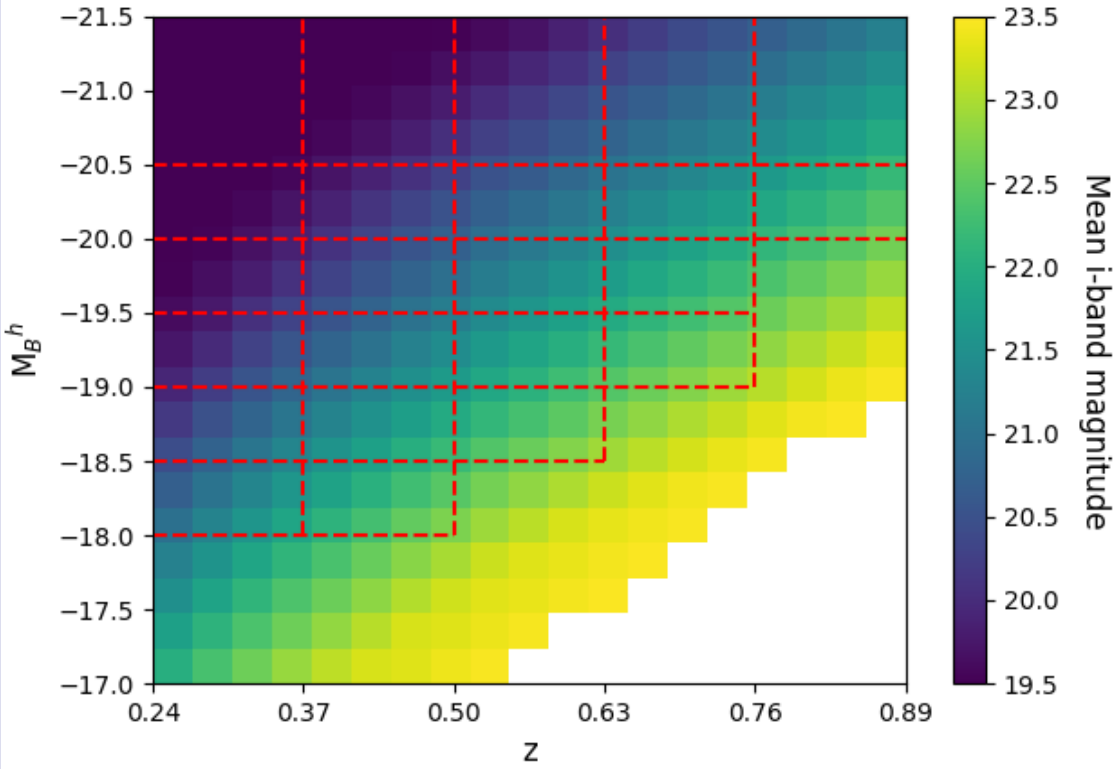


VIPERS mock includes VIPERS sampling rate and colour cuts

Stothert et al. (submitted)

Proposed science parameter space with PAUS





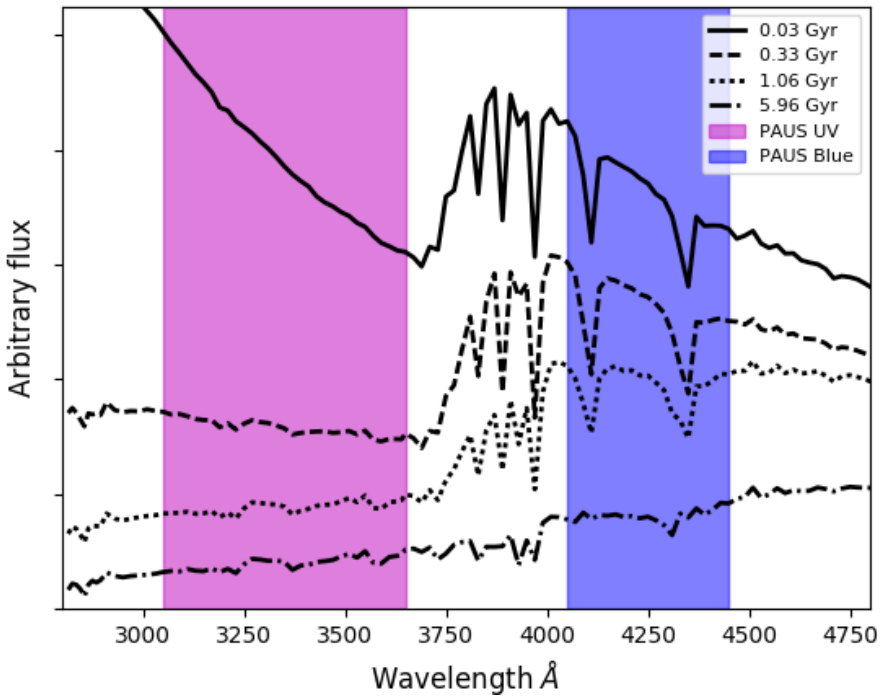
Galaxy groups:
- combination of bright spec-z and faint photo-z

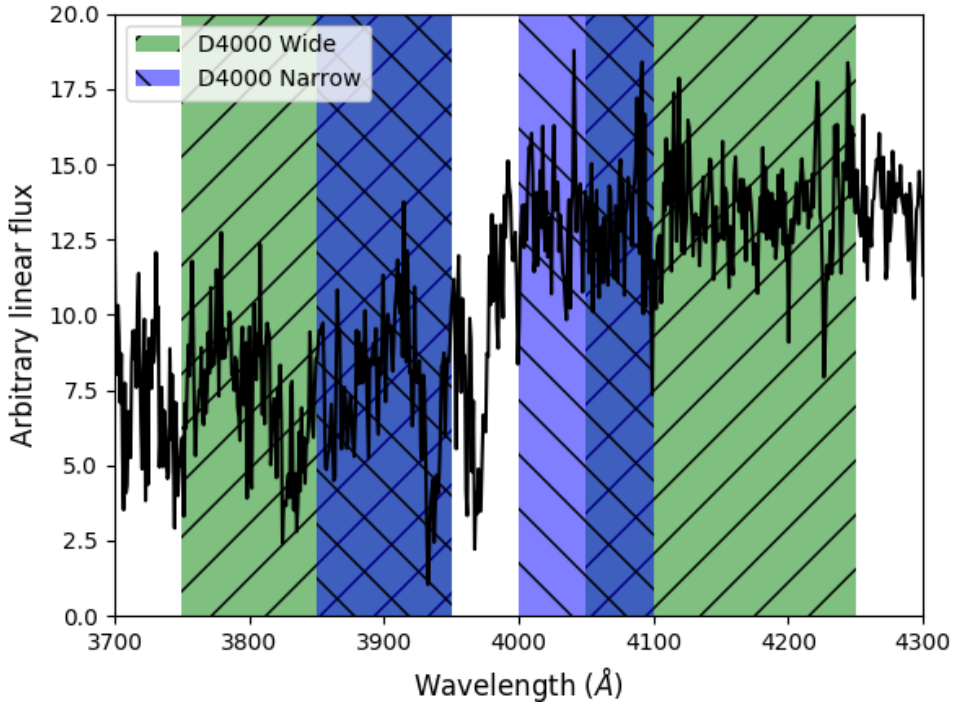
key question: how much fainter than bright spec-z sample?

Galaxy evolution:
- rest-frame properties for ~15k galaxies per night to i~22.5-23
- clustering studies to halo occupation distributions content…

Stothert et al. (submitted)

Projected science parameter space with PAUS: directly inferred rest-frame properties





Rest-frame UV

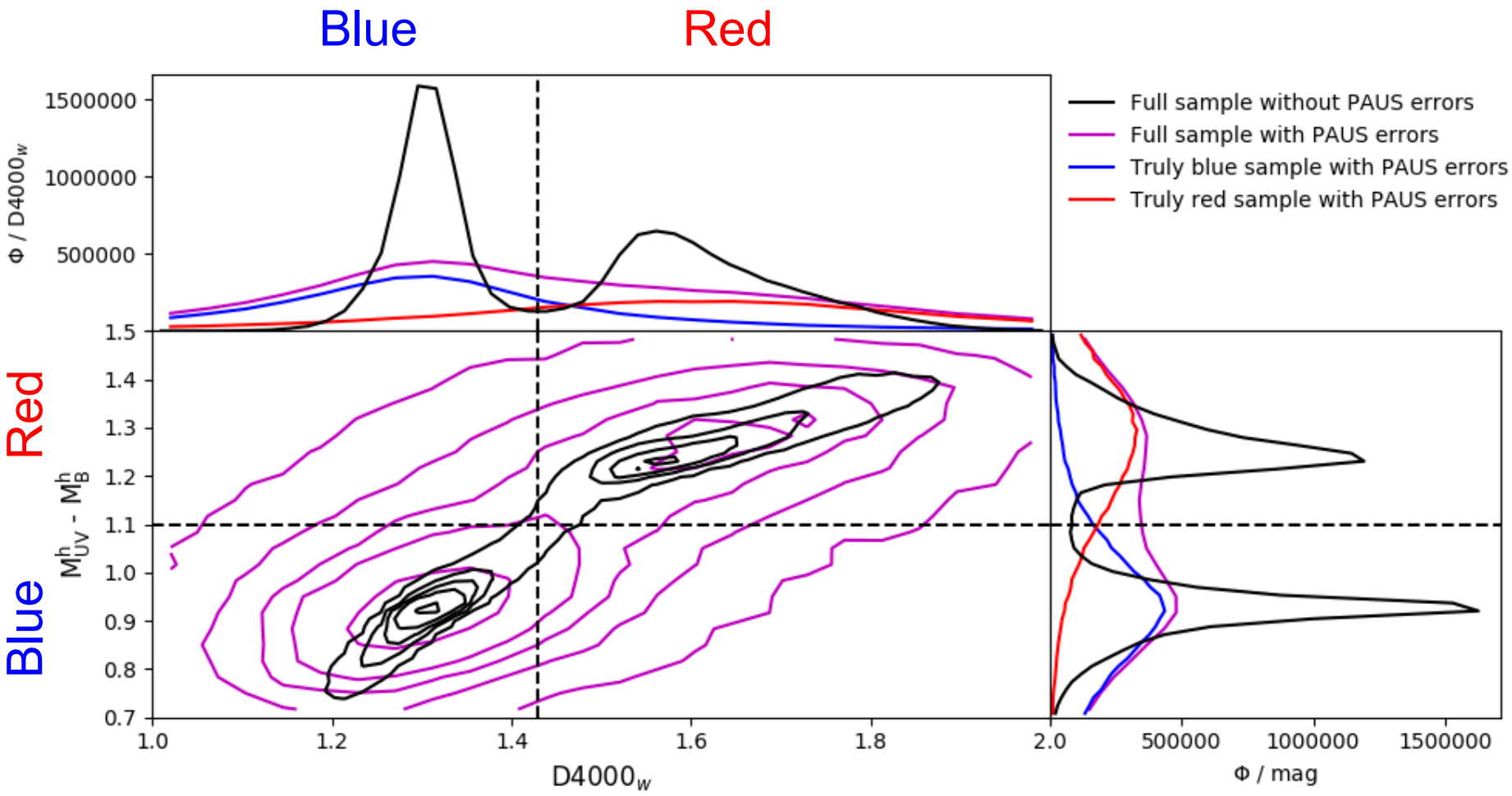
Rest-frame Blue

D4000
(ratio of flux above and below 4000A break)

Feature	Wavelength Range Å	Redshift Range
$D4000_N$	3850-3950 , 4000-4100	0.17 - 1.07
$D4000_W$	3750-3950 , 4050-4250	0.20 - 1.00
PAUS UV (M^h_{UV})	3050-3650	0.48 - 1.39
PAUS Blue (M^h_B)	4050-4450	0.11 - 0.90

Stothert et al. (submitted)

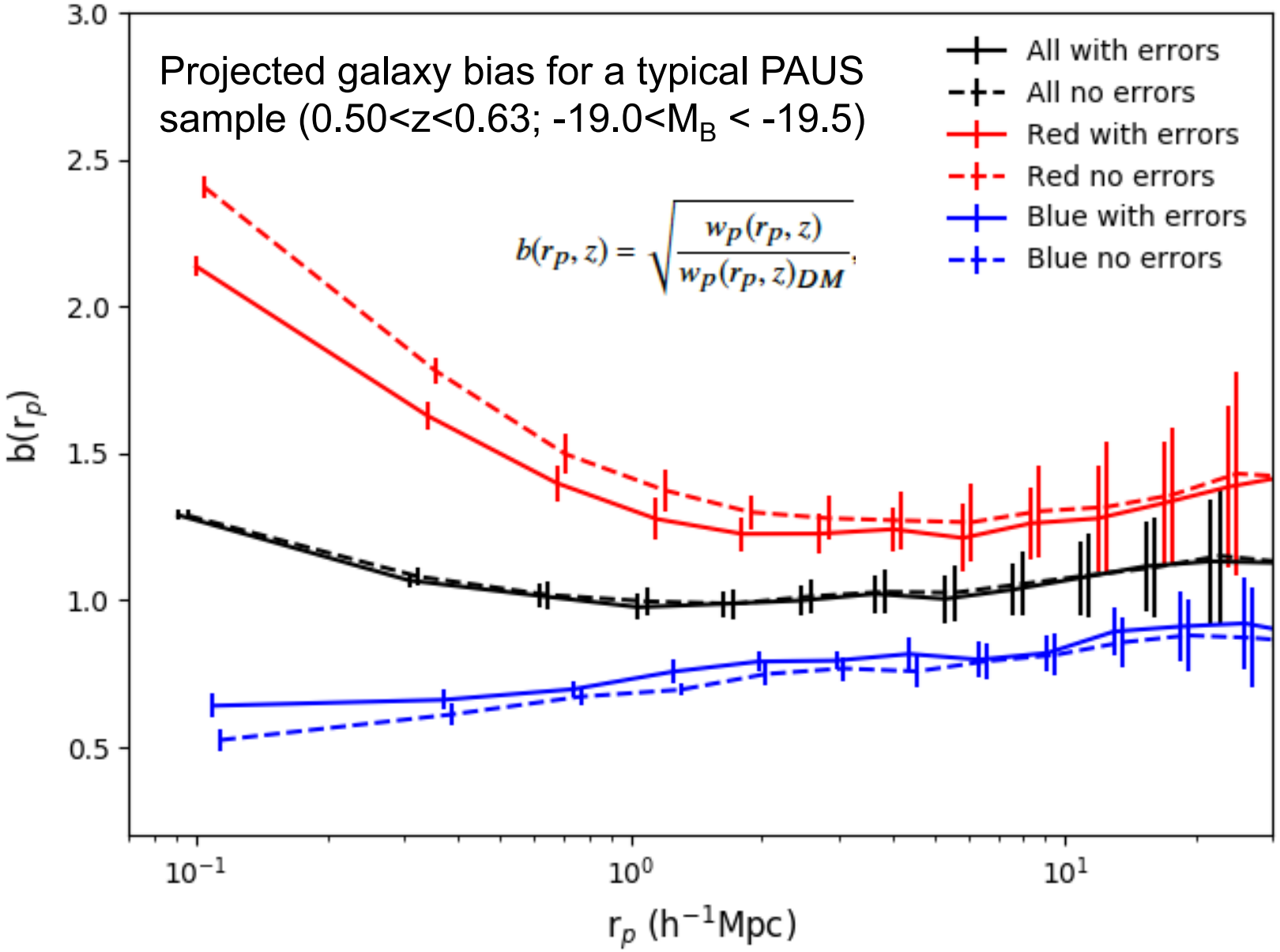
Projected science parameter space with PAUS: directly inferred rest-frame properties



Correlation between rest-frame properties
with and without typical PAUS errors
(photometric & photo-z)

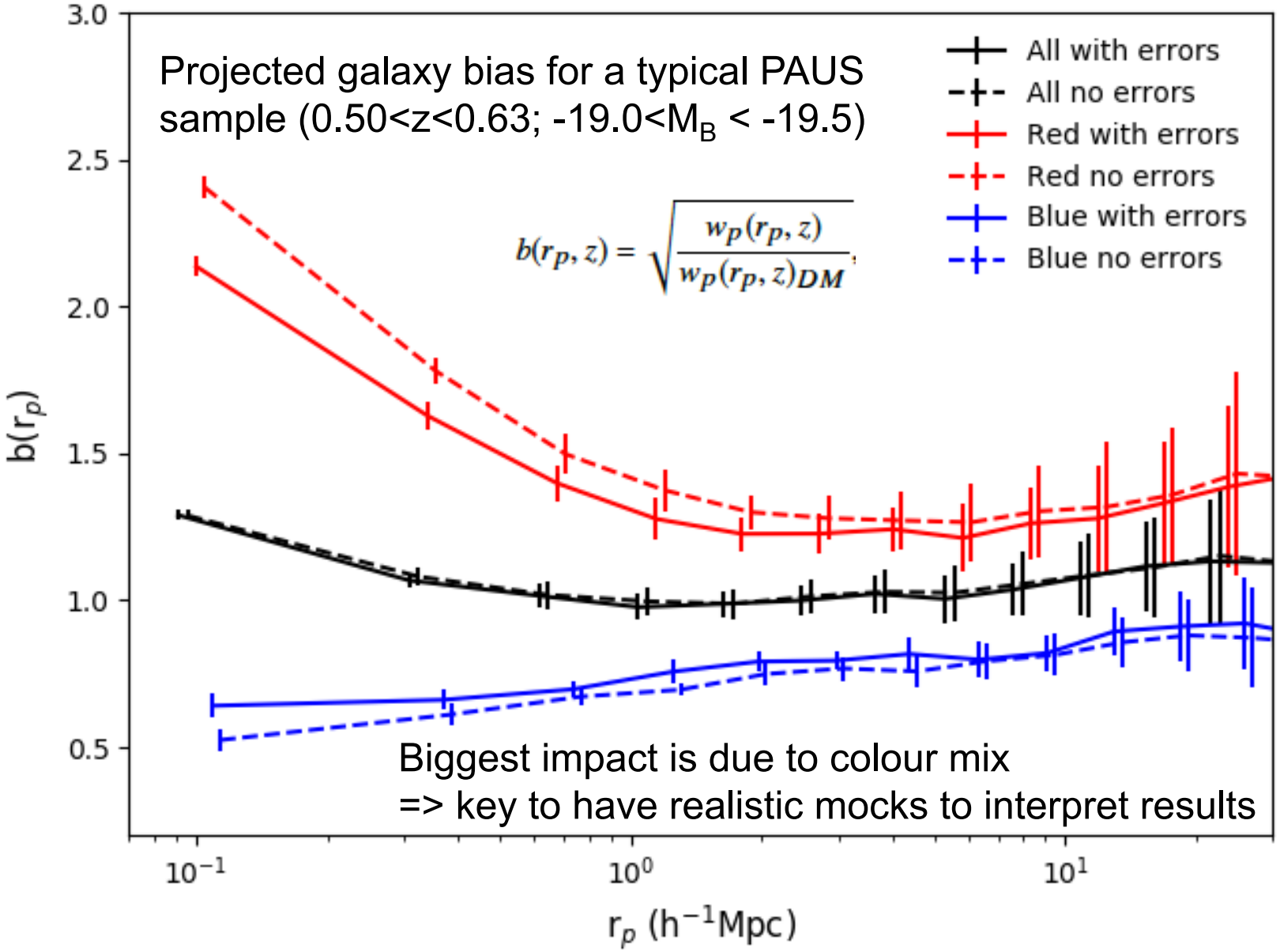
Stothert et al. (submitted)

Clustering with directly inferred rest-frame properties



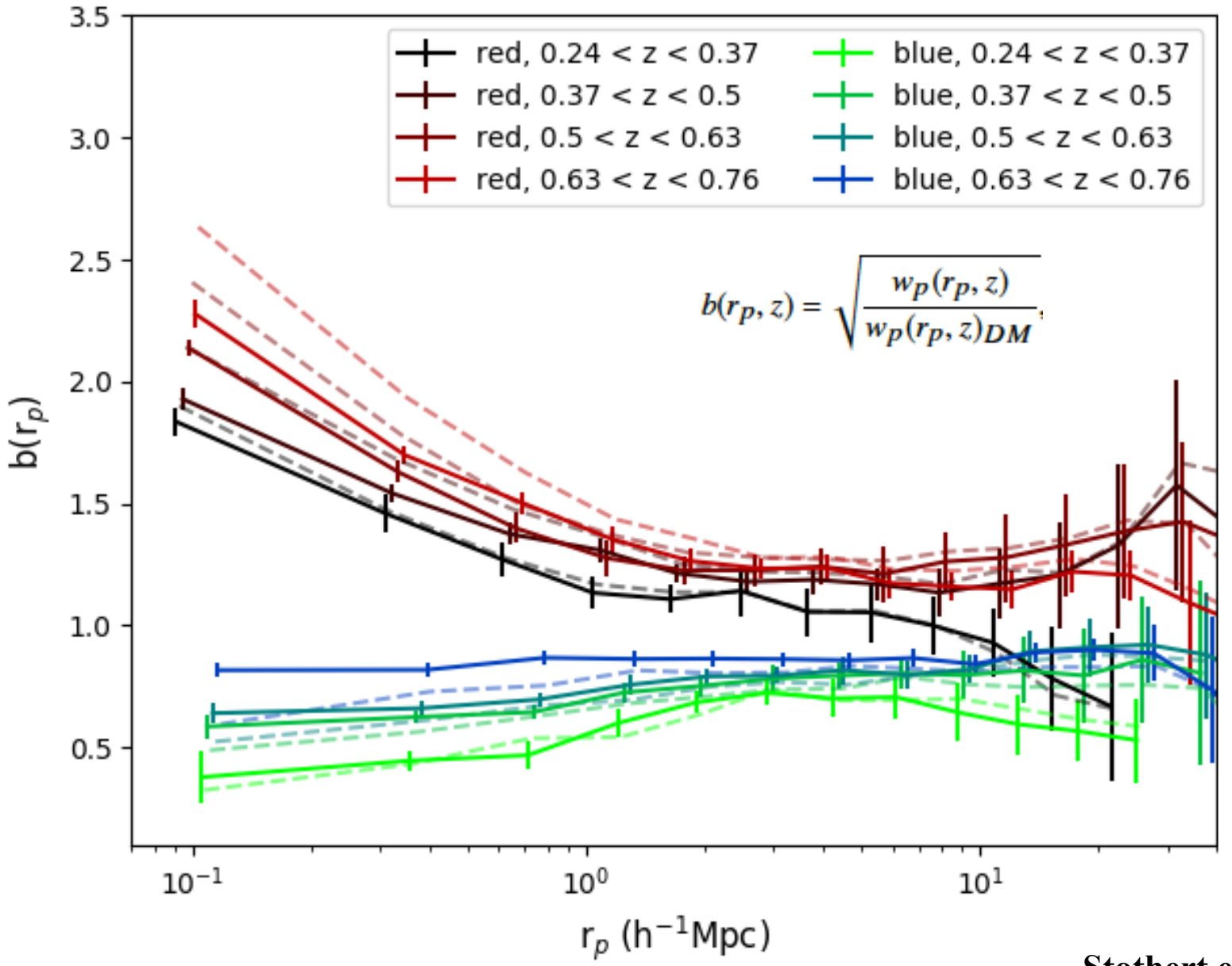
Stothert et al. (submitted)

Clustering with directly inferred rest-frame properties



Stothert et al. (submitted)

Clustering with directly inferred rest-frame properties as function of redshift

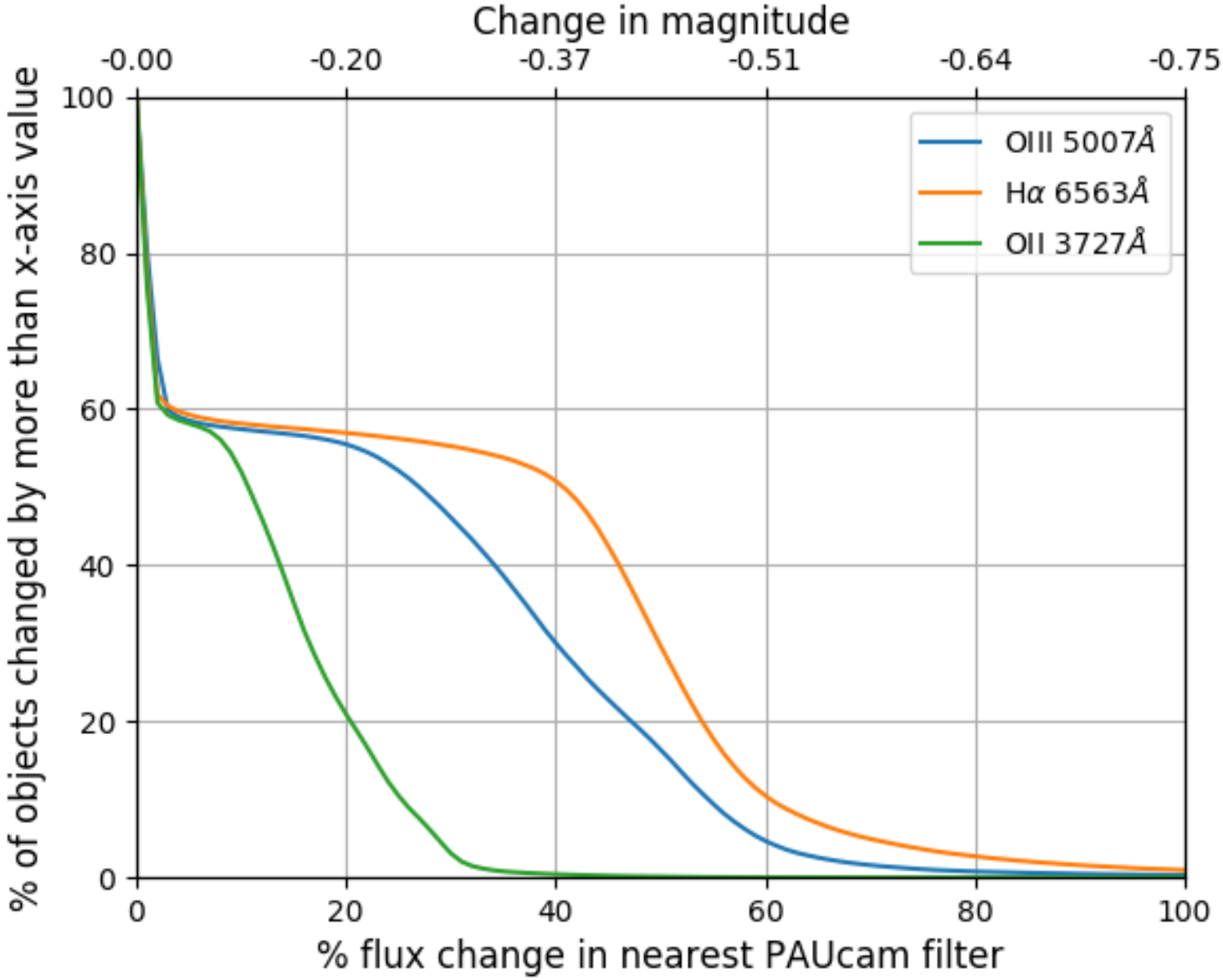


PAUS improves on GAMA, by going fainter, and on VIPERS, by probing continuously to z<0.5 (and slightly fainter).

PAUS overall completeness is more key for group studies.

Stothert et al. (submitted)

PAUS: projected impact of emission lines (mocks)



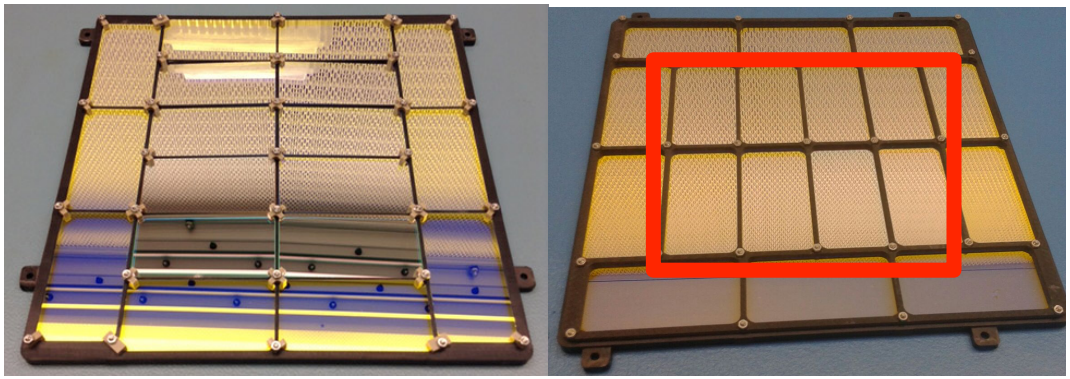
Stothert et al. (in prep)

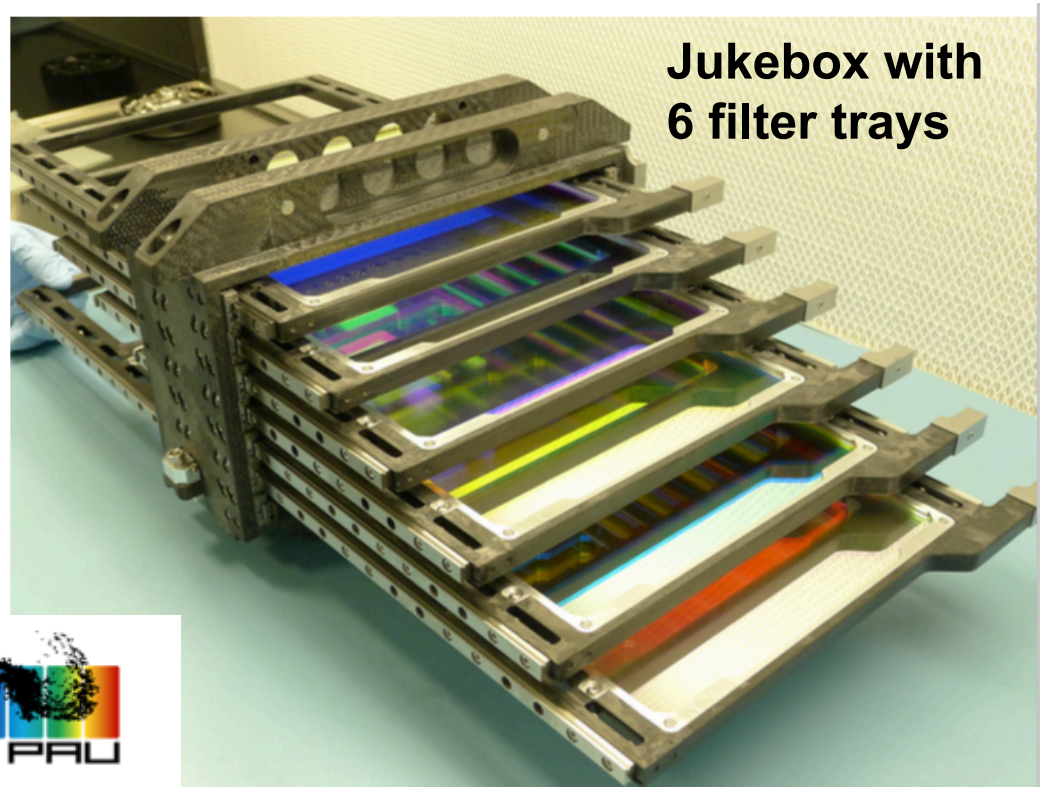
Projections are one thing, what about the real PAUS data?

- Summary of survey progress to date:
  - Survey strategy
  - Survey coverage
- Some first results:
  - Flux calibrated low resolution spectra
  - Photo-z accuracy

Survey strategy & PAUCam design: closely related

Filter arrangement: 8 centrally located NB filters

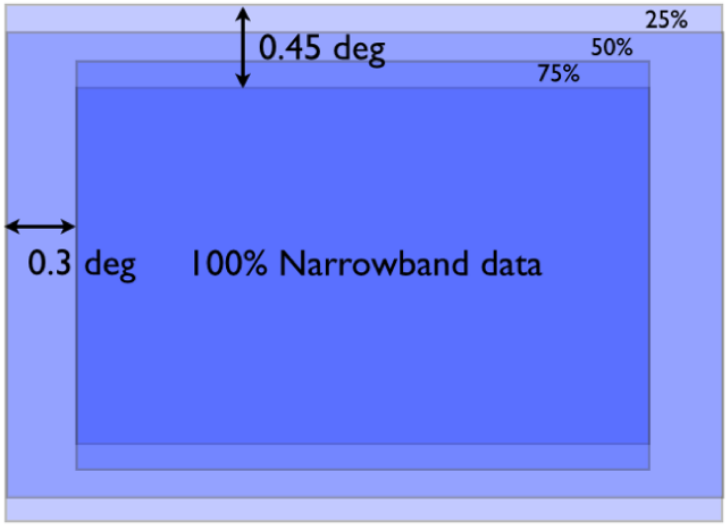




PAUS Survey Strategy

Exposures times

	1 455-525	2 535-605	3 615-685	4 695-765	5 775-845	total	total w overhead
commissioning	90	100	120	120	120	550	610
2015B & 2016A	3*70	3*80	3*90	3*110	3*130	1440	1740
2016B & 2017A	3*90	3*90	3*100	3*100	3*120	1500	1800



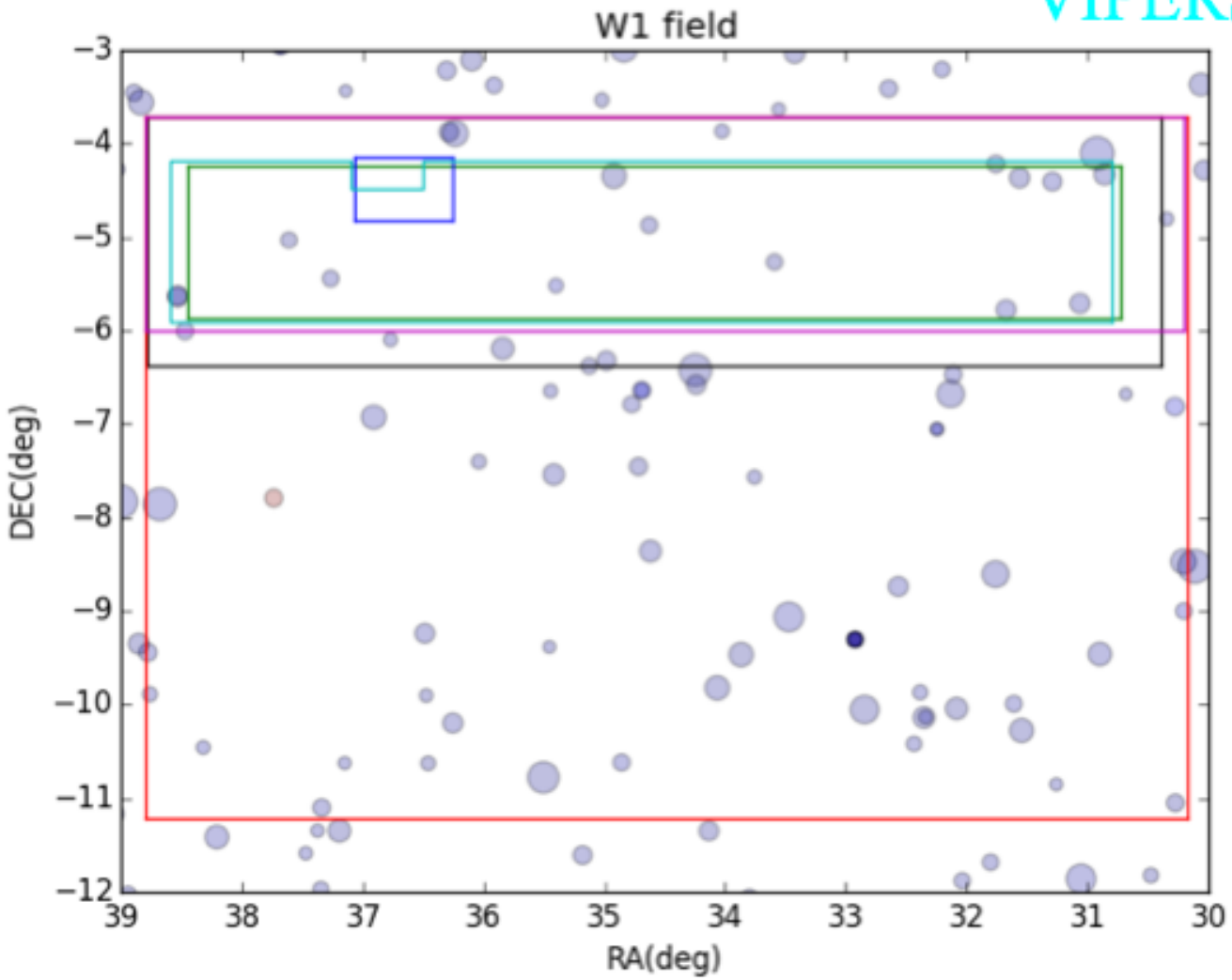
72	73	74	75	76	77	78	79	80
71	42	43	44	45	46	47	48	49
70	41	20	21	22	23	24	25	50
69	40	19	6	7	8	9	26	51
68	39	18	5	0	1	10	27	52
67	38	17	4	3	2	11	28	53
66	37	16	15	14	13	12	29	54
65	36	35	34	33	32	31	30	55
64	63	62	61	60	59	58	57	56

Castander , Serrano et al.

Survey Strategy

Field coverage

CFHT-Lens red
VVDS blue
GAMA magenta
VIPERS cyan

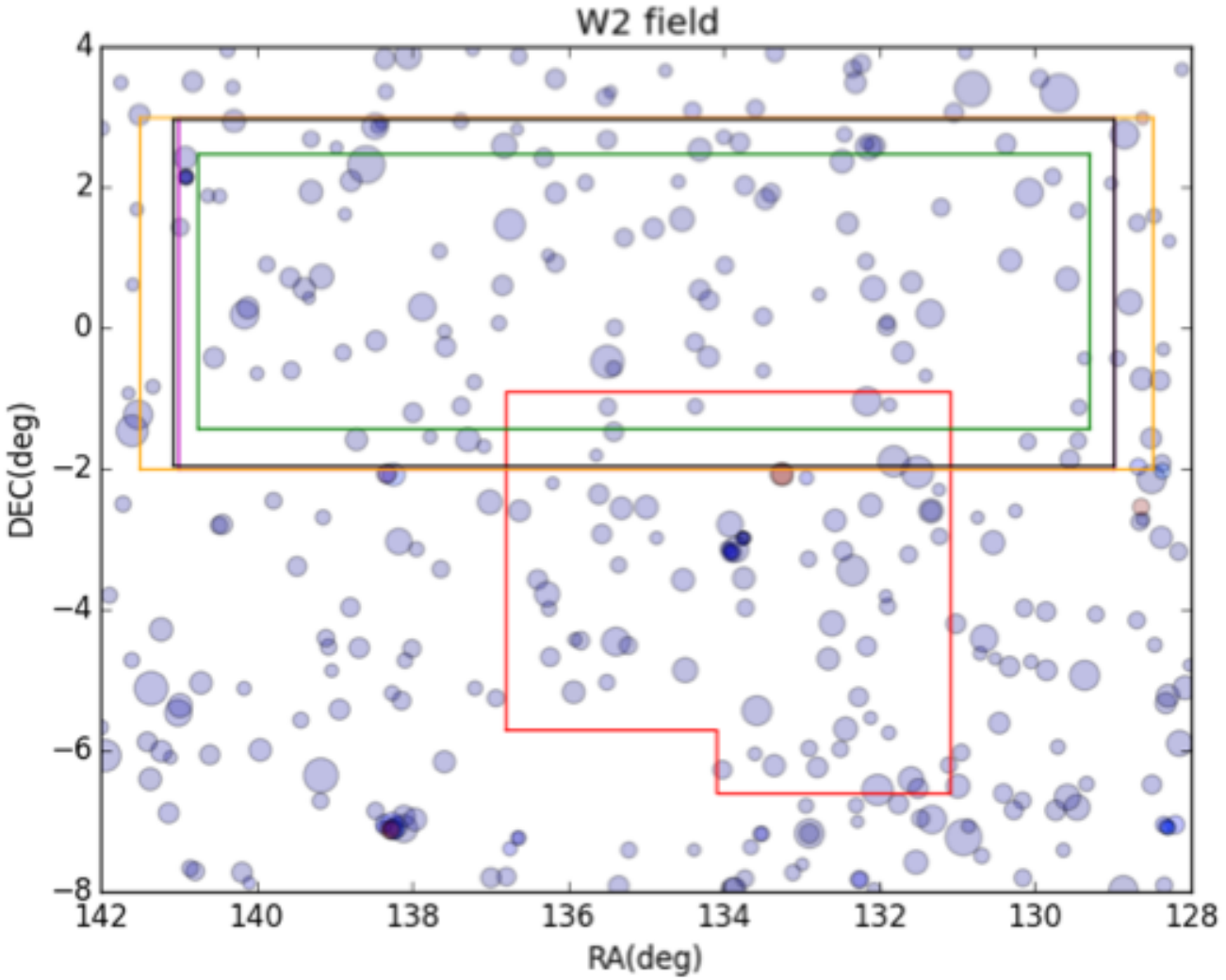


Castander , Serrano et al.

Survey Strategy

Field coverage

CFHT-Lens red
KiDS orange
GAMA magenta



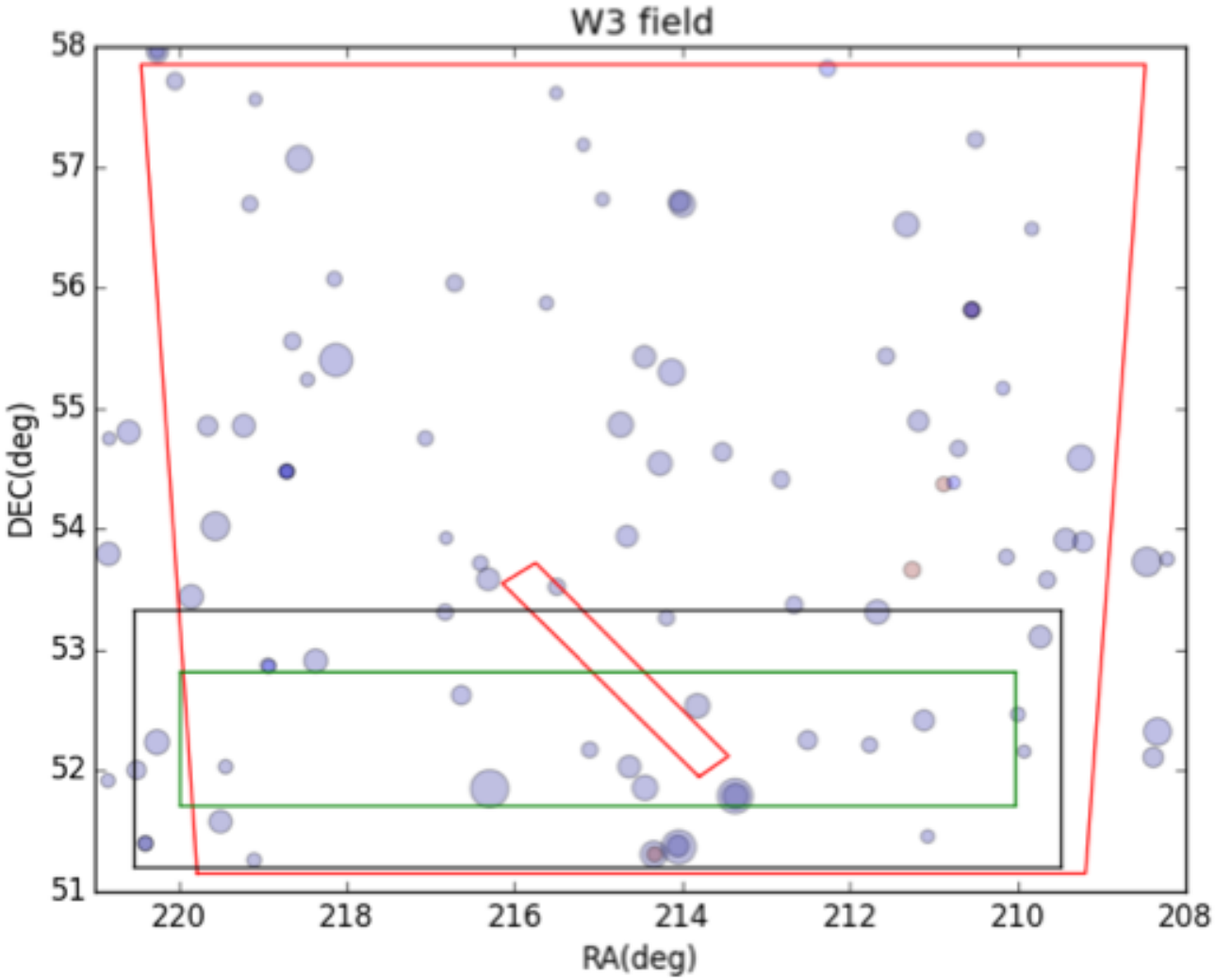
Note for GAMA/KiDS folks: W2 should be read/understood as G09….

Castander , Serrano et al.

Survey Strategy

CFHT-Lens red
DEEP2 red

Field coverage

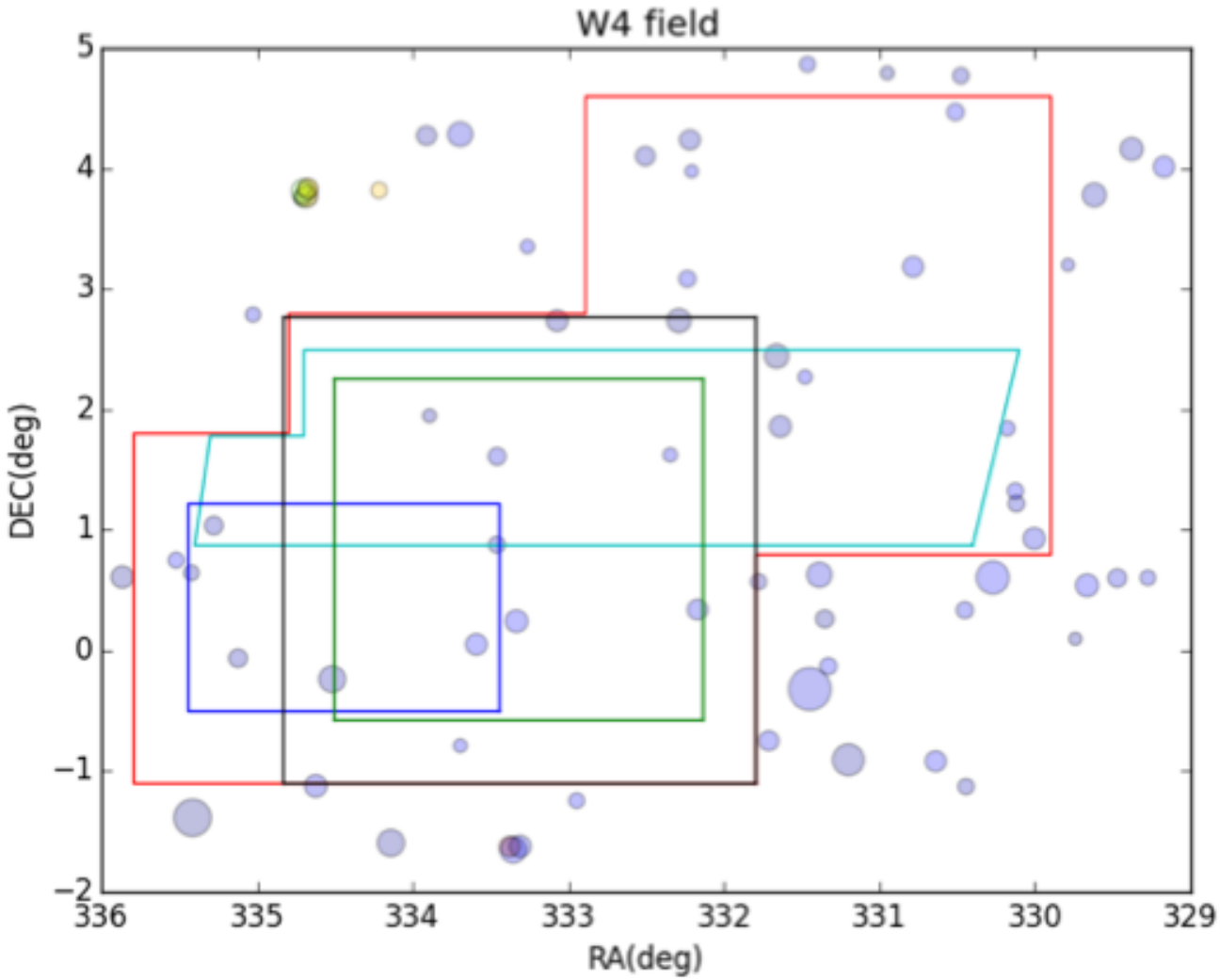


Castander , Serrano et al.

Survey Strategy

CFHT-Lens red
VVDS blue
VIPERS cyan

Field coverage



Note: W4 is considered by the PAUS Team as a spare/extra field
(observed only when no other PAUS field is available)

Castander , Serrano et al.

PAUS: Survey Status after 18A (June 2018)

Observing conditions matters…

Until the last run, the total # of bad nights exceeded the total # of good nights
(with good = dome open, i.e. not the same as good conditions!!)

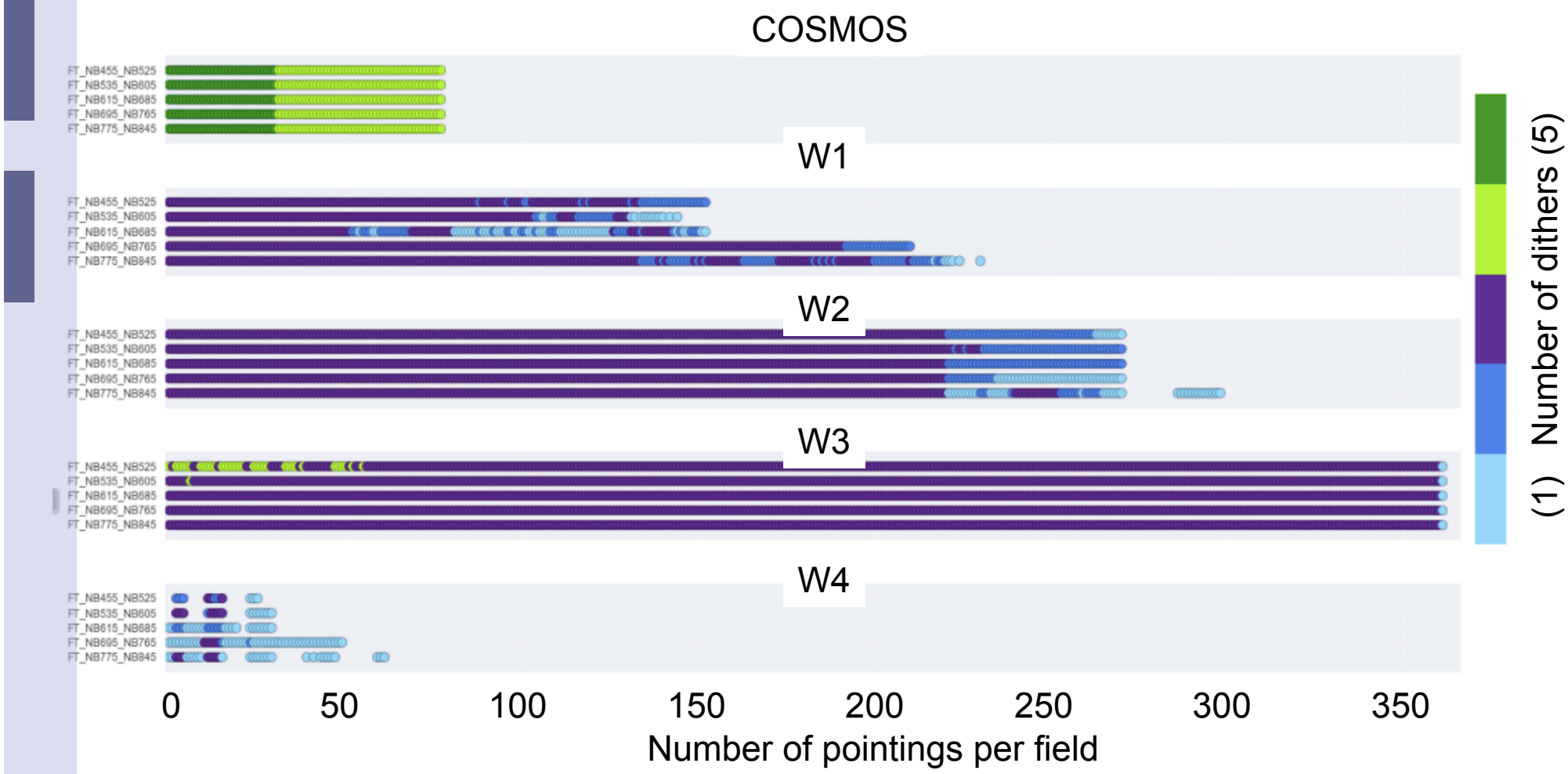
	nights	BAD	POOR	GOOD	TECHNICAL	LOST TECH	GOOD DATA
2015B	10	4	3	3	2.2	1	2
2016A	13	5.7	1.5	5.8	0.8	0.0	5.8
2016B	20.5	10.6	2.2	7.7	0.9	0.8	6.9
2017A	27.5	7.8	3.4	16.3	4.1	2.4	13.9
2017B	28	13.2	4.5	10.3	1.0	0.7	9.6
2018A	24.5	6.1	2.9	15.5	0.1		15.5
All	123.5	47.4 (38%)	17.5 (14%)	58.6 (47%)	9.1	4.9	53.7 (43%)

2018B: 37 nights scheduled (with UK TAC time for once…)

IF weather and observing conditions cooperate (!), we can expect:

W1 (~20 deg^2), W2 (~20 deg^2), W3 (~12 deg^2) (by end 18B)

PAUS Survey Status after 18A (June 2018)



Castander , Serrano et al.

PAUS Survey Status after 18A (June 2018)

Area [sqdeg] with:	40NB filters	30NB filters	20NB filters	10NB filters
Cosmos	1,8	2,2	3,2	3,8
W1	3,1	4,6	6,2	8
W2	7	8,4	10,6	12,2
W3	10,2	11,5	14,2	16
W4	0	0,3	0,7	1,5
Total	22,1	27	34,9	41,5

Until May 2018, we have focused our PAUS data reduction efforts on COSMOS data, so no W1/W2/W3 analysis presented today… W3 data reduction is now underway!

Hereafter only results from PAUCam observations in the COSMOS area

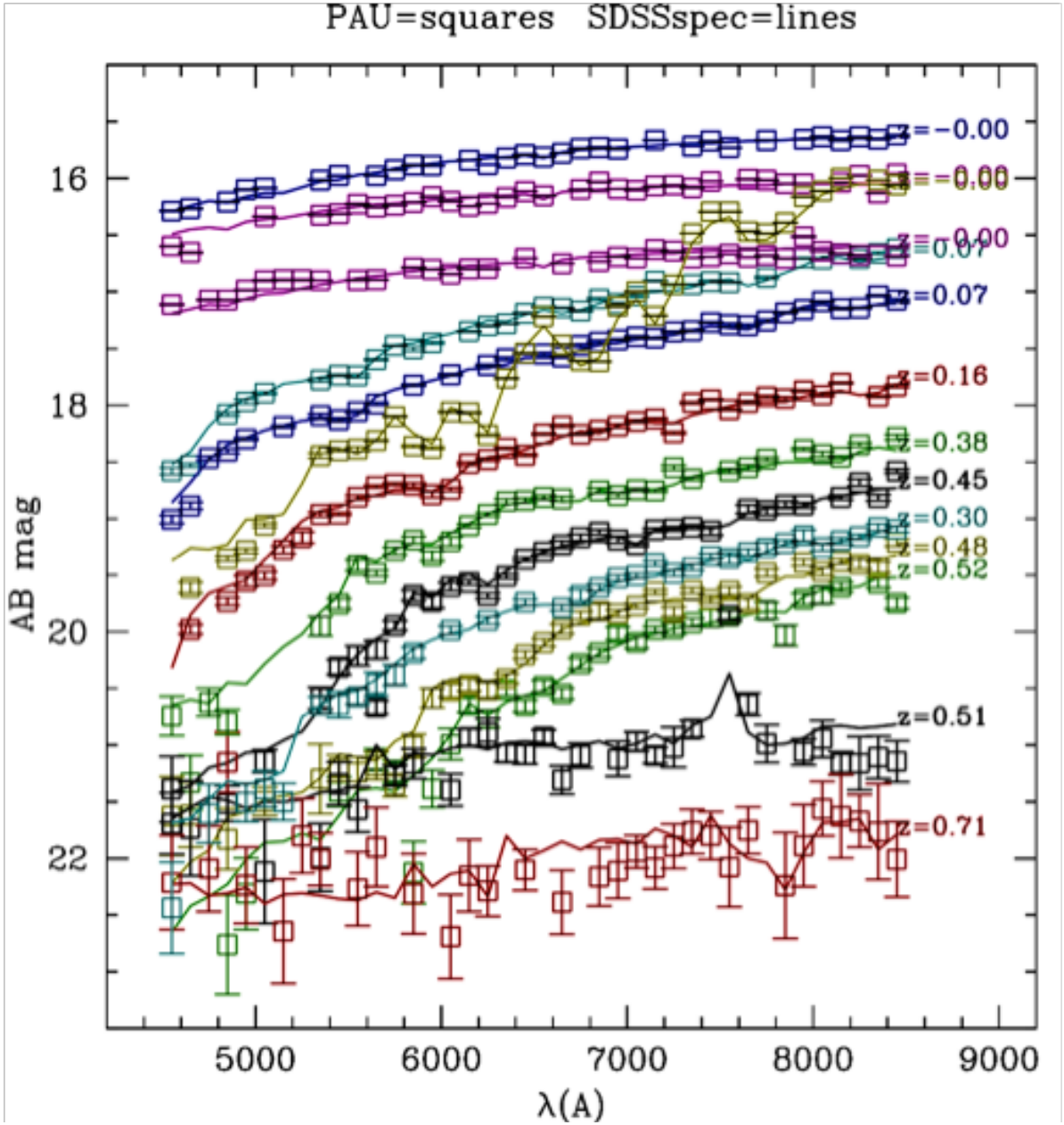
NB: the very good weather in 2018A more than doubled the available W3 area!

PAUS: example low resolution spectra (early data)

Each PAU spectra consist of up to 200 (40x5) independently calibrated flux measurements

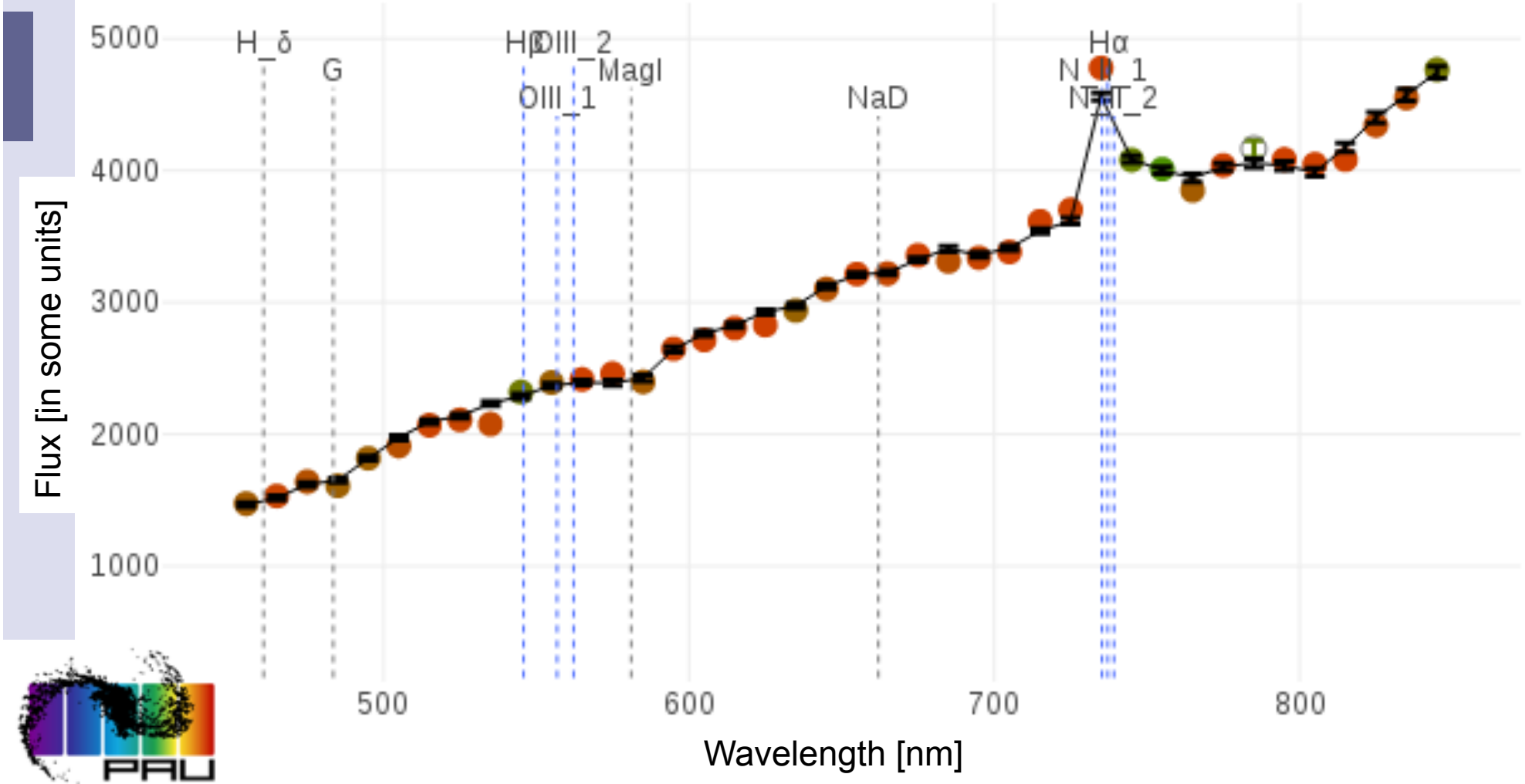
Here we use 12 pixel diameter apertures, best for bright galaxies.

Noise is for large aperture photometry (limiting error could be much smaller for faint galaxies)

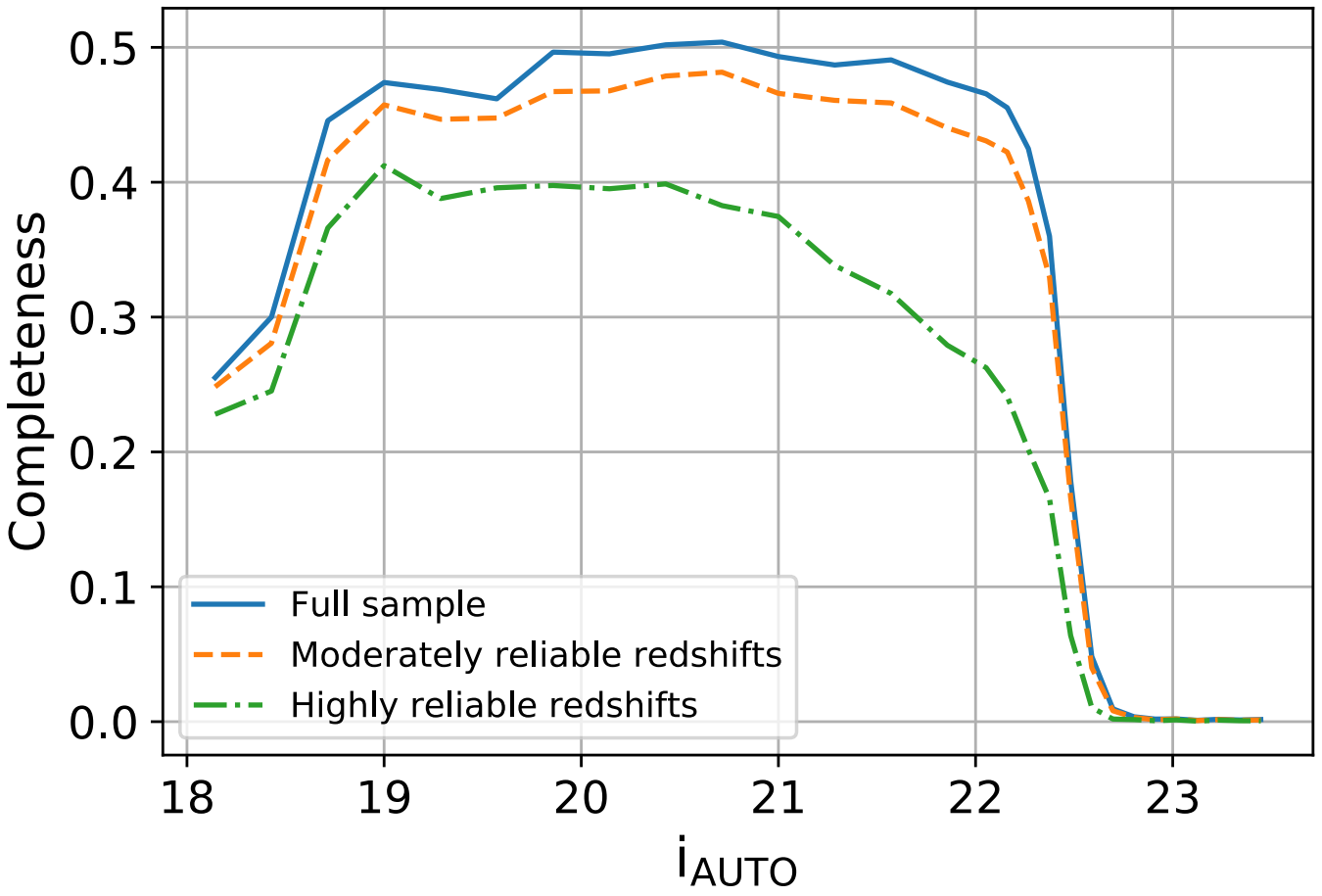


PAUS: emission lines impact NB filter fluxes

Example of a bright galaxy: I_auto 16.658, zspec 0.123



PAUS photo-z: the spec-z COSMOS sample

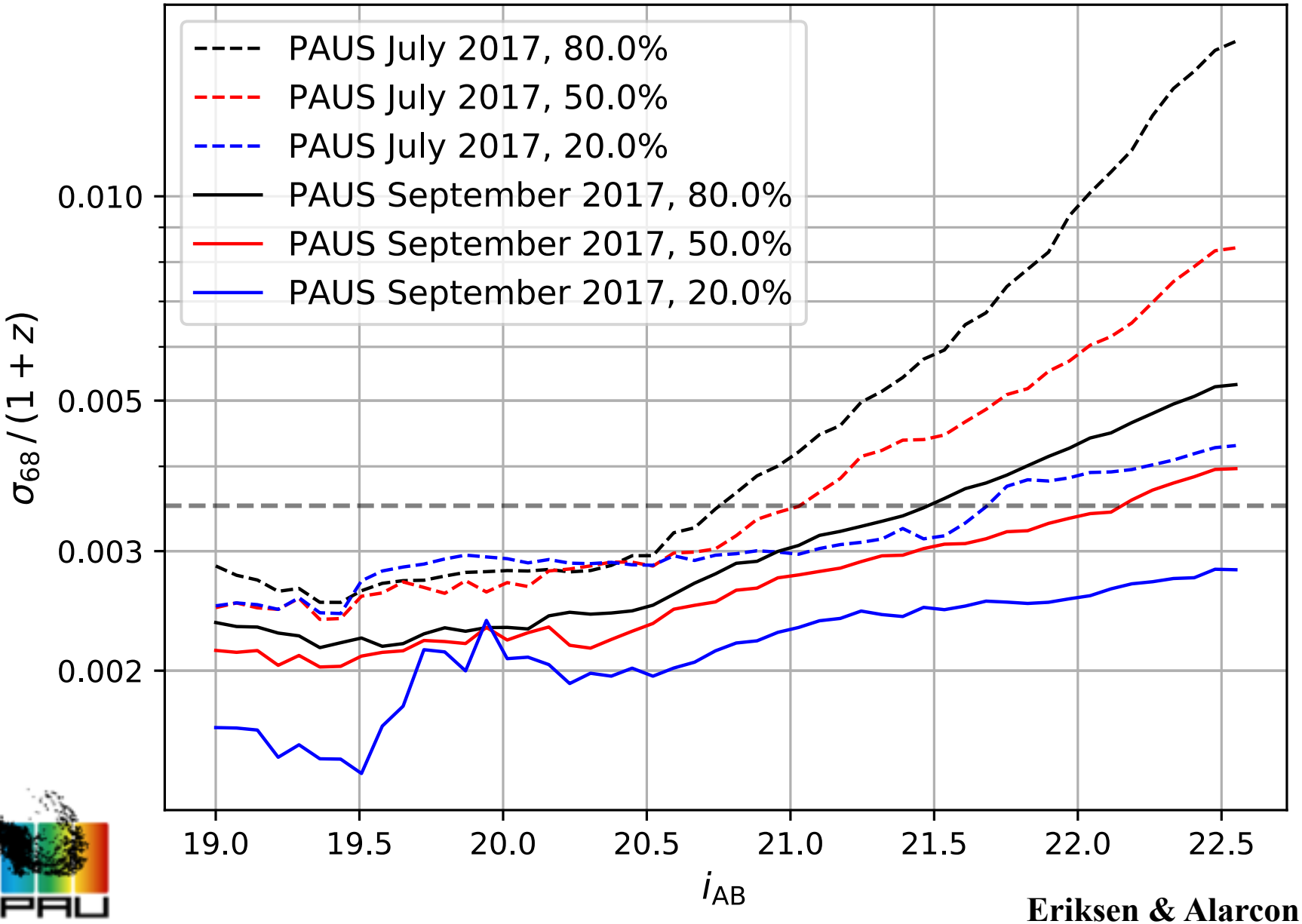


Completeness of spec-z reference sample:
we only compare to the highly reliable spec-z sample (3.x, 4.x)
=> Warning: this is clearly not a fair sample of all galaxies at a fixed flux (but currently the best we have to compare against)

Eriksen & Alarcon et al.

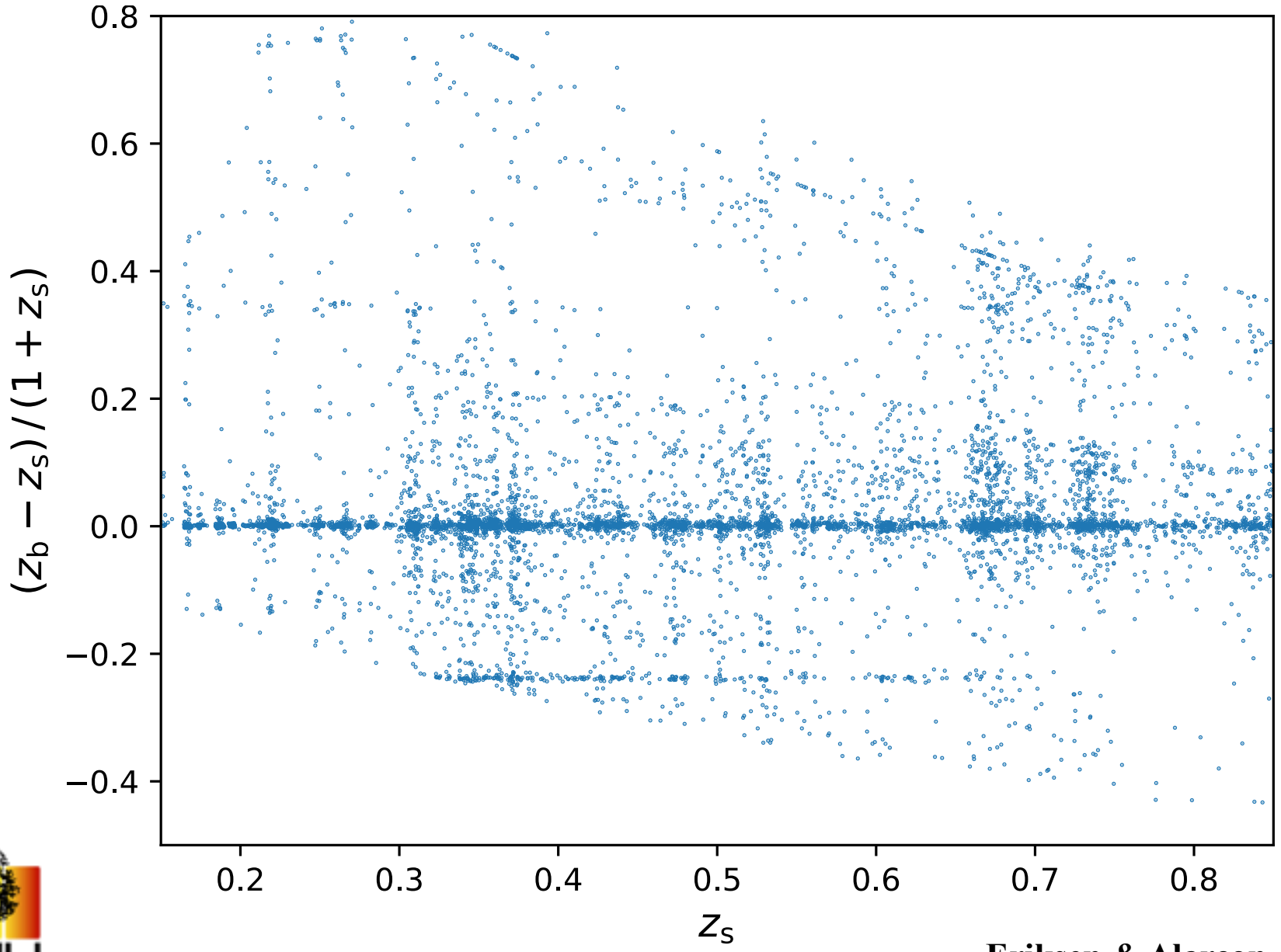
PAUS photo-z: status with NB only (2017)

impact of improvements in photometry (data reduction) and photo-z analysis



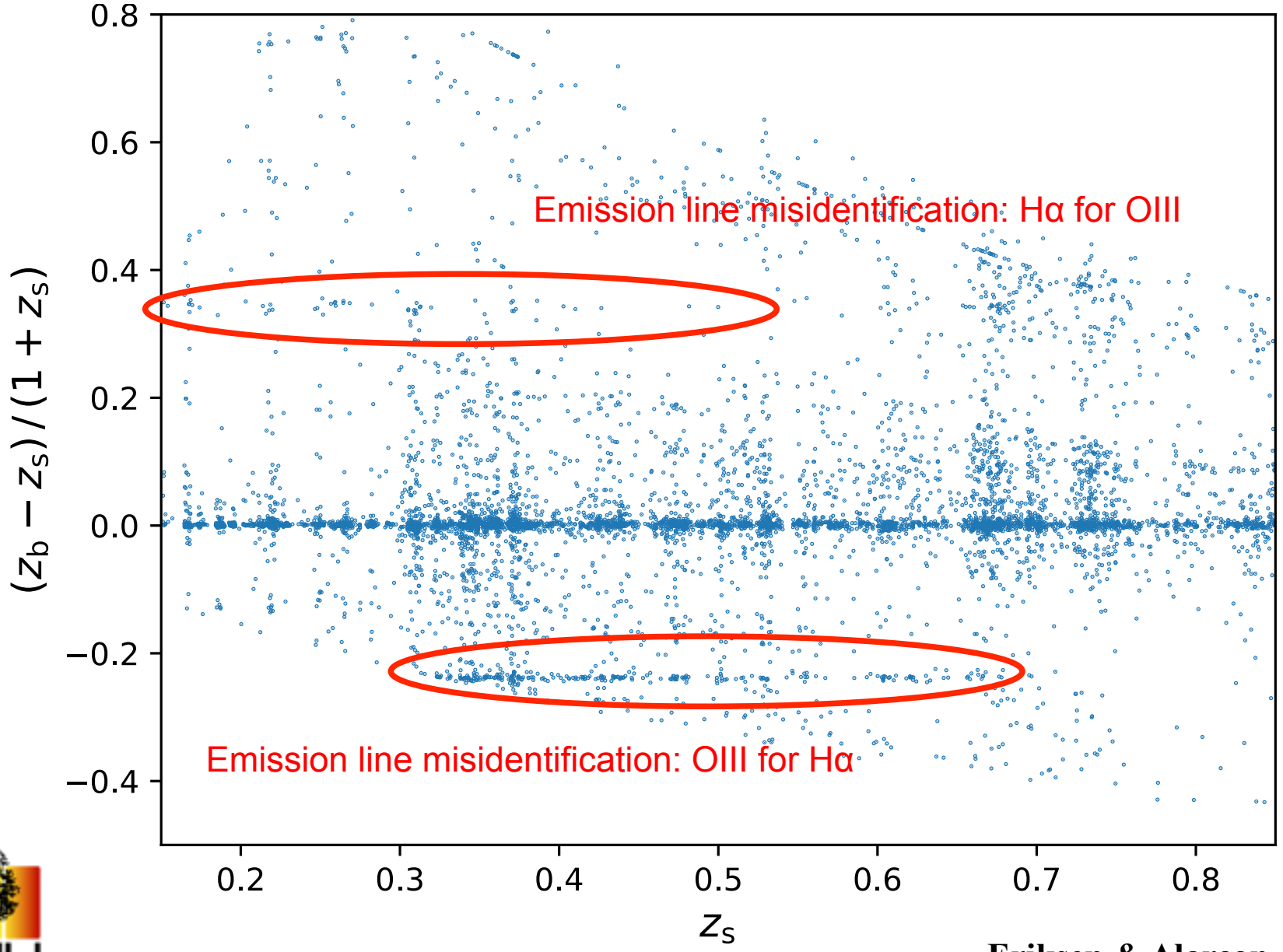
Eriksen & Alarcon et al.

PAUS photo-z status on COSMOS with NB only (2017)



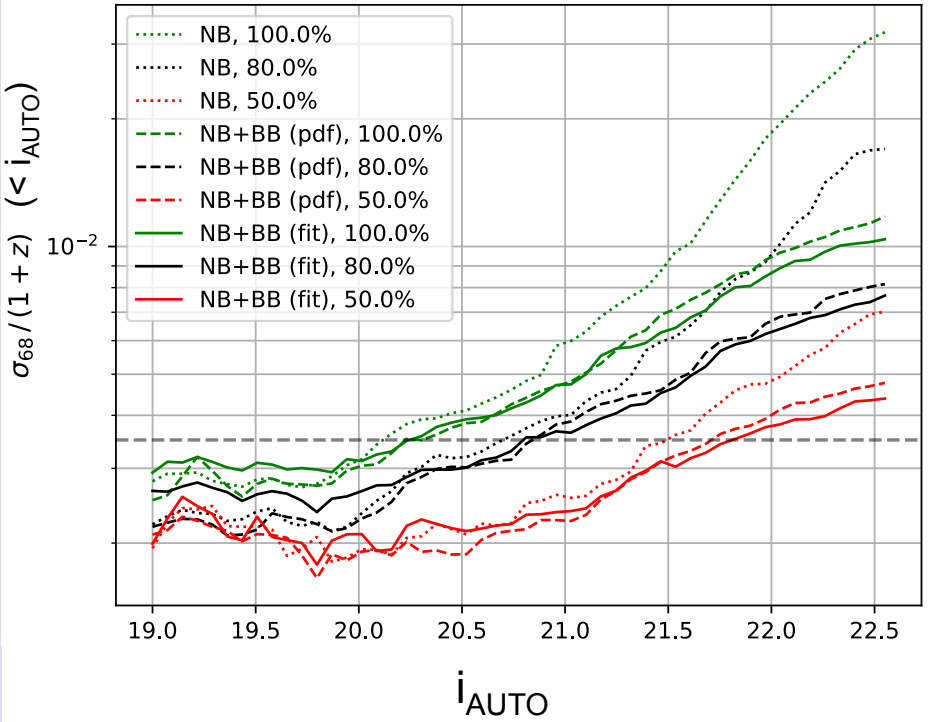
Eriksen & Alarcon et al.

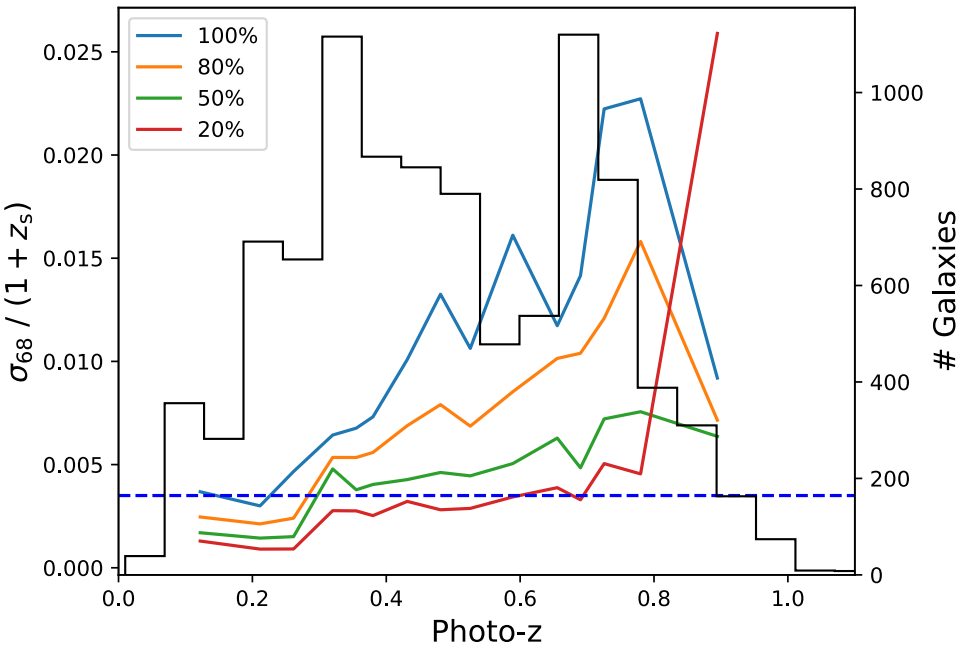
PAUS photo-z status on COSMOS with NB only (2017)



Eriksen & Alarcon et al.

PAUS photo-z: current accuracy as function of magnitude and redshift





Current photo-z accuracy:

- pushing towards PAUS goal of 0.35% for 50% of the galaxies.
- Improvements include better modelling of emission lines
- Main improvements needed at the faintest magnitudes
- Important differences in results in how BB and NB are combined (new territory for NB surveys)

Eriksen & Alarcon et al.

PAUS: papers to come out shortly

https://www.pausurvey.org/pausurvey/publications/

- The PAU Survey: Early demonstration of photometric redshifts
  M.Eriksen, A.Alarcon et al. (in preparation)

- The PAU Survey: Photometric Calibration of Narrow Band Images
  F.J.Castander et al. (in preparation)

- The PAU Survey: Data Reduction of Narrow Band Images
  S.Serrano et al. (in preparation)

- The PAU Survey: Operation and orchestration of multi-band data
  N.Tonello, P.Tallada et al. (in preparation)

- The PAU Survey: Measuring spectral features and galaxy clustering using NB photometry
  L.Stothert et al. (MNRAS submitted)

- The PAU Survey: star-galaxy classification with multi narrow-band data
  L.Cabayol et al. (arXiv:1806.08545)

- The PAU Survey: A Forward Modeling Approach for Narrow-band Imaging
  L.Tortorelli et al. (arXiv:1805.05340)

Series of science papers with early data in the COSMOS field to follow...

PAUS: some conclusions

- PAUcam is a new instrument on the WHT 4.2m telescope in La Palma
- PAUcam has 40 130A wide narrow band filters over 4500-8500A and broad band UGRIY with a FoV of ~1 deg^2 (~0.5 deg^2 without distortions).
- PAUS has acquired ~50 good nights (15B-18A) (& 37 more in 18B):
    - ~20 deg^2 with 40NB to i_{AB}~22.5-23.0
    - ~40 deg^2 with 10NB to i_{AB}~22.5-23.0
- PAUS: very accurate photo-z (below 0.35%), but currently too many outliers.
- PAUS provides new ways to calibrate photometric surveys (e.g. DES, KIDS, Euclid, LSST, WFIRST, WAVES,…):
    * accurate and complete redshift samples to train and validate photo-z on
    * dense galaxy samples to apply cross-correlation clustering N(z) calibration
    * understand spectroscopic target selection and incompleteness
    * calibrated templates as a function of z, mag, inclination, morphology,…
- PAUS ideal to probe 1-20 Mpc/h scales over different environments
- PAUS SED are flux calibrated and have the potential to open a new window in statistical studies of galaxy evolution and stellar SED templates.