LSST-UK Phase B Dev: Work Package 3.5

~~Multi-wavelength~~

Near-infrared data fusion and LSST

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(WP 3.5 PI; LSST:UK Infrared Liaison; LSST: Galaxies WG Co-Chair)

and co-Is

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Matt Jarvis (Oxford),

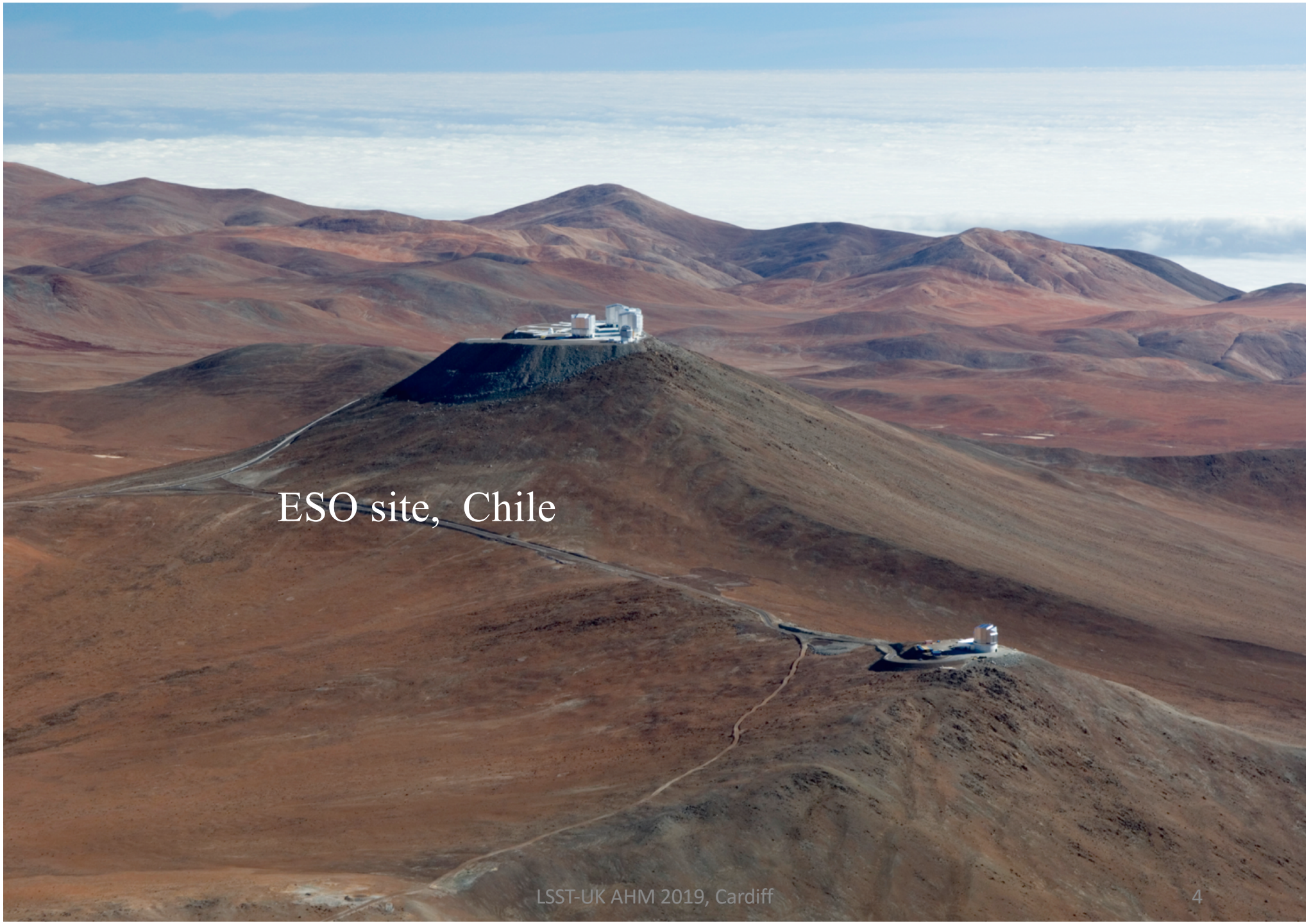
Graham Smith (Birmingham; LSST –UK Commissioning Scientist)

Outline

- Scientific motivation
- Key datasets - focusing mostly on the infrared but also significant UK leadership at many other wavelengths
- Phase B Work Package Description

Science Case for combining LSST data with other wavelengths (mainly near IR from VISTA)

- Improved photometric redshifts for Dark Energy and galaxy evolution science
- Epoch of Reionization: identification of high-redshift (z>6.5) galaxies and quasars; drop-outs at optical (grizy) wavebands, detected in the near IR wavebands.
- High-redshift (z>1) galaxy clusters
- Identification and characterization of AGN in X-ray, IR, radio; could also feed into better photometric redshifts for the galaxy population since unaccounted AGN contribution biases redshift estimates.
- More robust stellar masses and star formation rates for LSST galaxy evolution science


ESO site, Chile

The VISTA Mirror

ESO Press Photo 10c/08 (16 April 2008)

4.1 m diameter f/1 primary

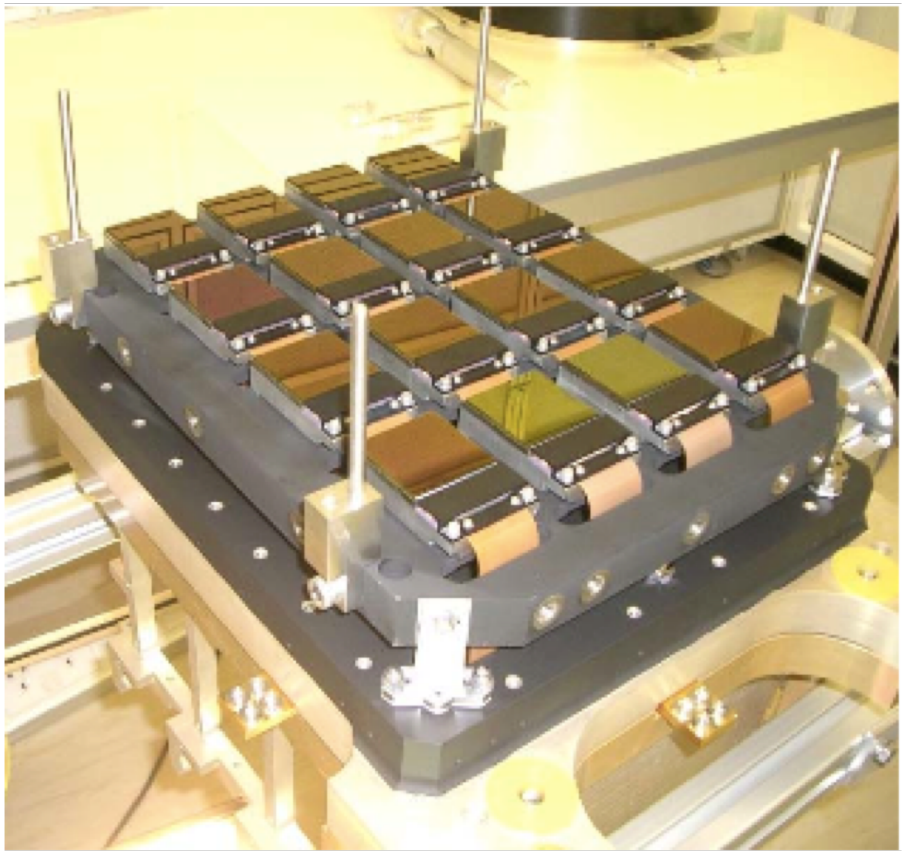
Visible and Infrared Survey Telescope for Astronomy (VISTA)

- **VISTA summary**

- **Location**: ESO, Paranal, Chile
- **Aperture:** 4.1 m diameter f/1 primary
- **Field of view**: 1.65 degree diameter
- **Instrumentation**: VIRCAM — Sparse fille 8k x 8k mosaic
- **Detectors**: 16 x 2k x 2k pixel (Raytheon VIRGO HgCdTe); 67 megapixels

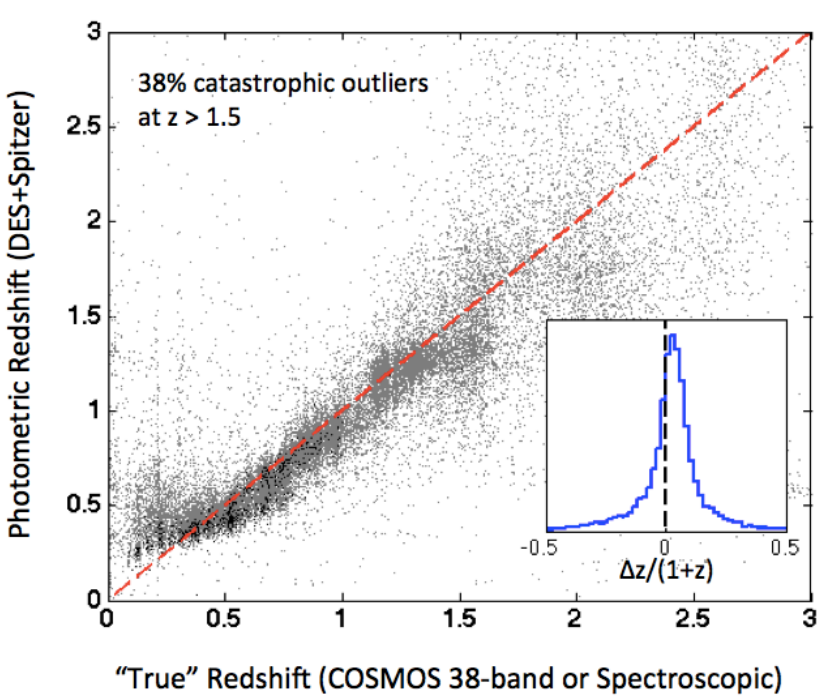
- **Wavelength range**: 0.84–2.5 microns
- **Pixel scale**: 0.34 arcseconds/pixel

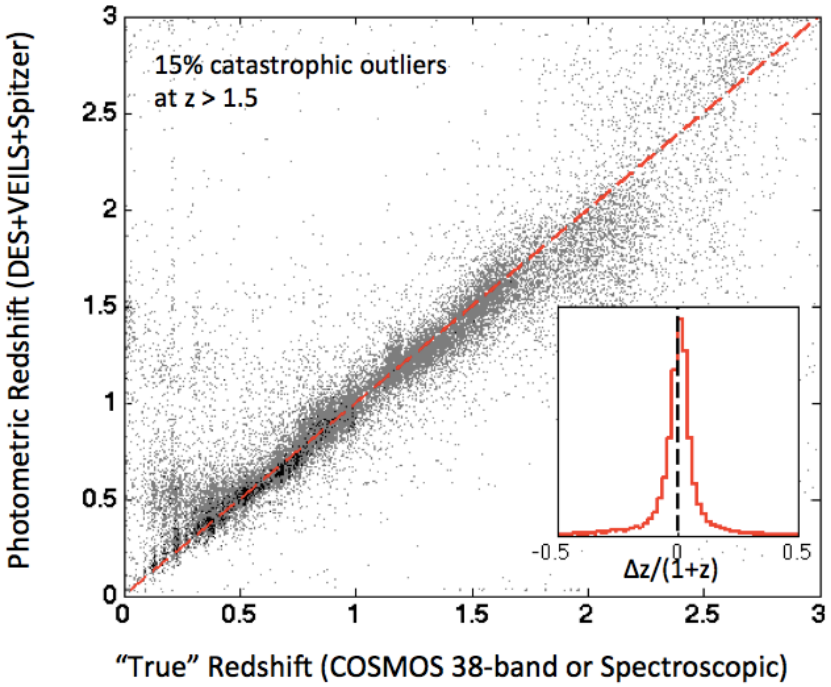
- **Surveys started: March 2010**



Sparse filled mosaic 90%, 42% spacing

Photo-z predictions for DES-Deep



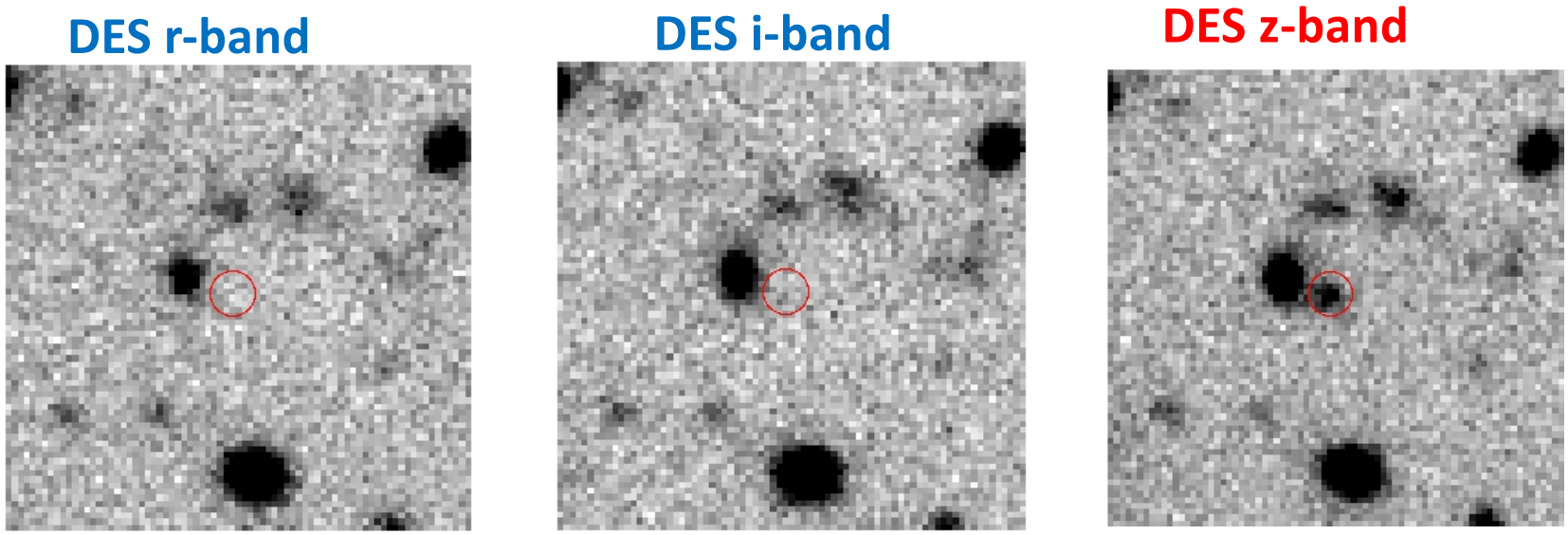


Taken COSMOS 38-band photometric redshift catalogue (Muzzin et al. 2013) as a proxy for spectroscopic redshift and degraded the photometry/removed filters in order to simulate data from DES (deep), VISTA VIDEO+VEILS and Spitzer SERVS + DeepDrill

Significantly reduced outlier fraction in photo-z estimates at z > 1.5

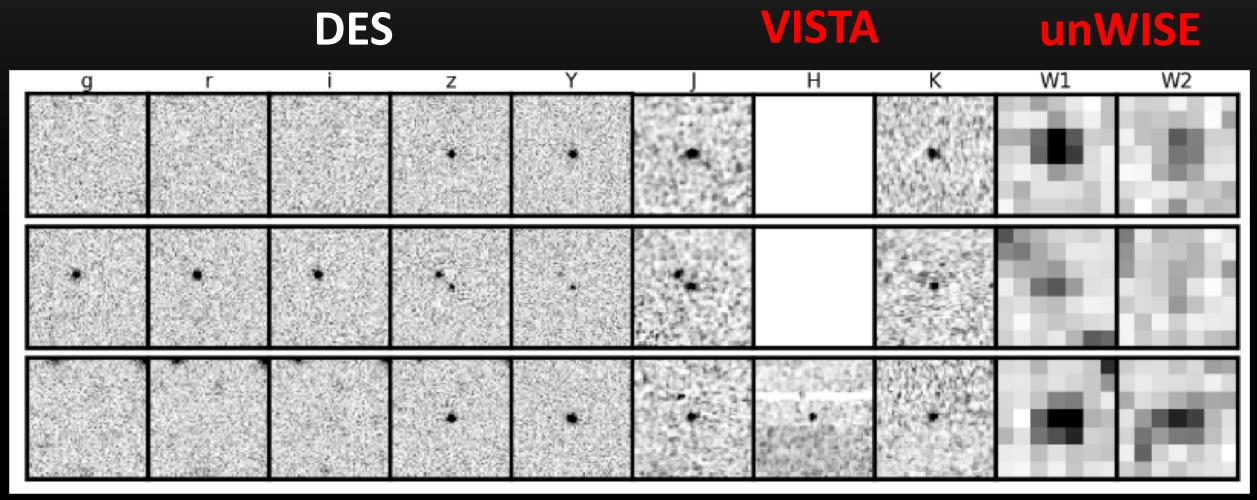
High-redshift galaxies

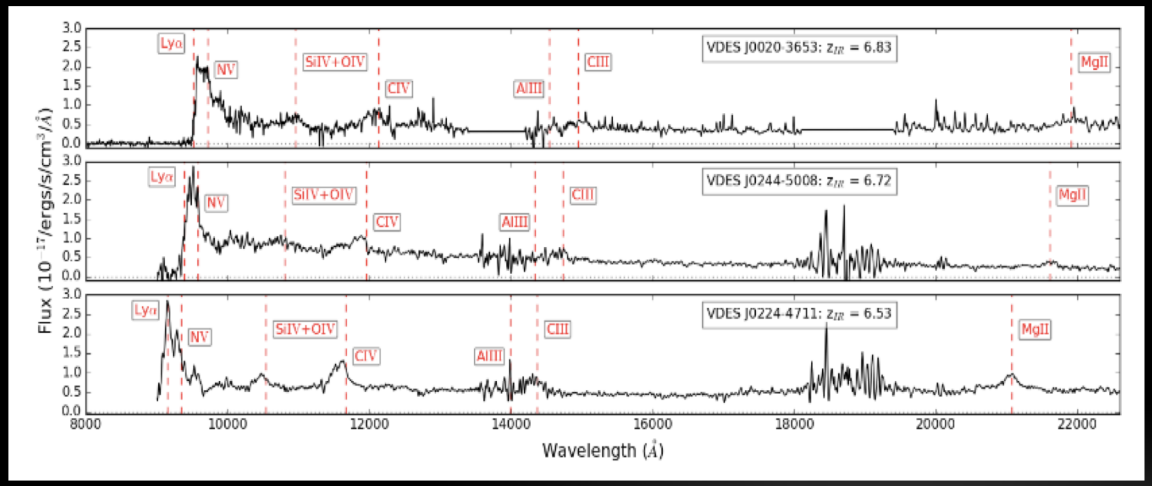
- The most distant galaxies and quasars at z > 6.5 will be undetected in most of the LSST passbands but will appear in the corresponding infrared surveys e.g. VISTA, Euclid
- Finding highest-z galaxies with LSST also requires near IR imaging observations to select and reduce foreground contamination from lower redshift galaxies.



Spectroscopically confirmed z=6.07 galaxy in the DES deep fields (DES Collaboration)

Luminous Quasars in the Epoch of Reionization





From Reed, **Banerji**+19

Wide-field surveys such as PANSTARRS, DES, VISTA,, WISE now used to identify most distant, luminous quasars at z > 6.5

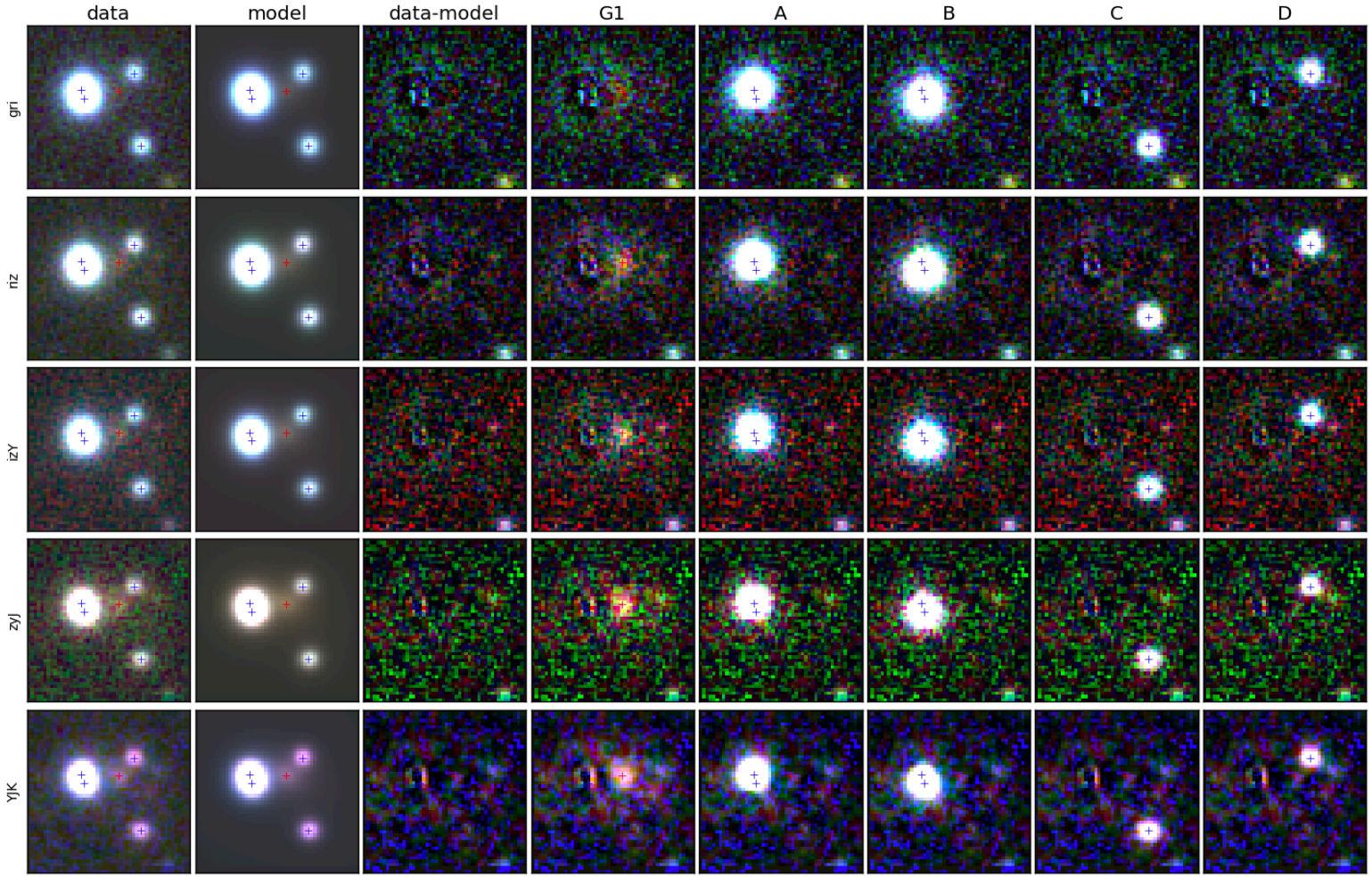
Large black-hole masses of 10^8 – 10^9 M_0. High Eddington ratios

LSST + VISTA should discover 50+ z>6.5 quasars in LSST Mini-survey and 500+ in DR1; 15-30 with z>7.0

Spectroscopically confirmed z=2.17 Quadruply gravitationally lensed quasar Lemon et al, in prep)

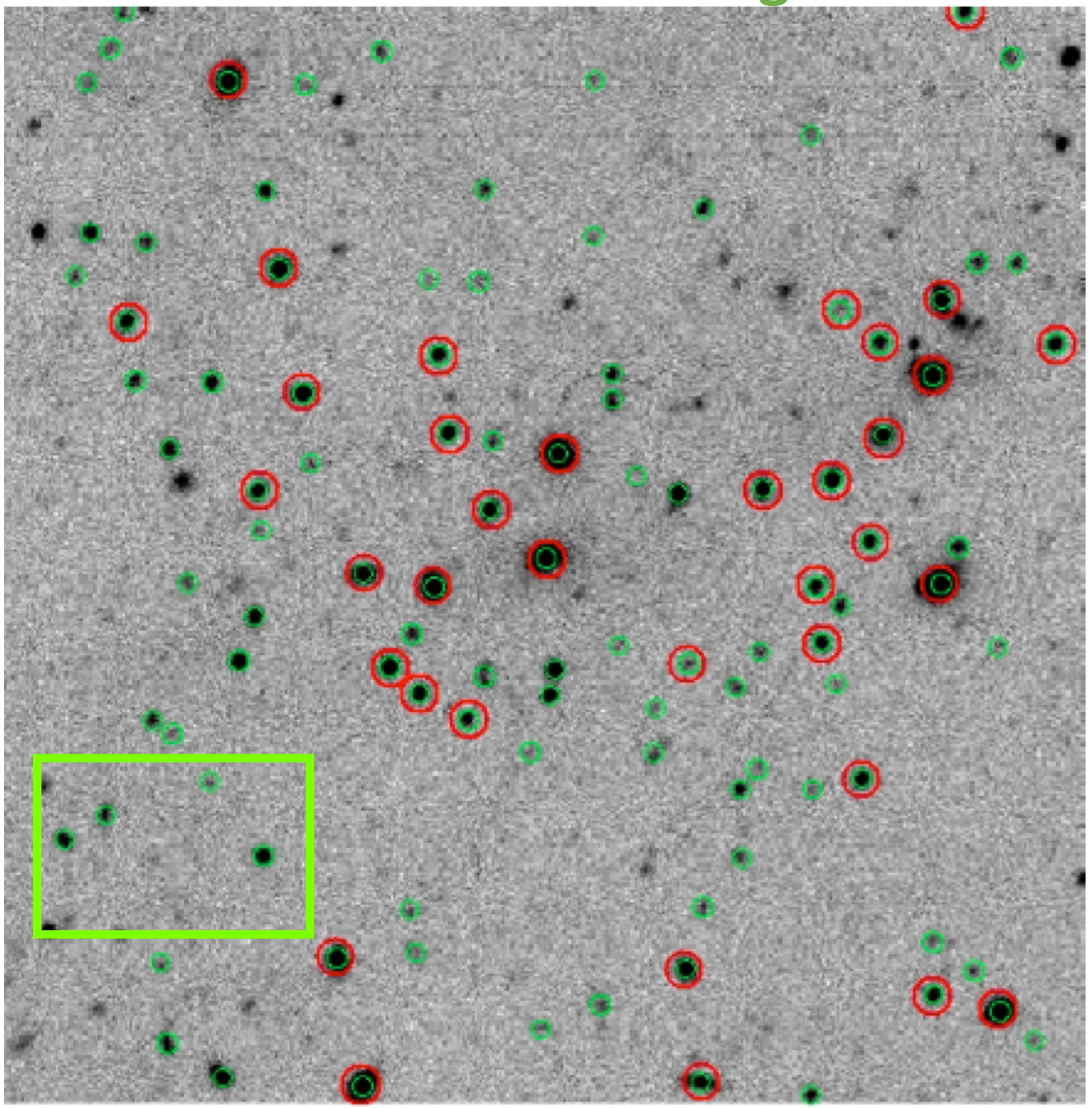
[DES + VISTA photometry: grizYJK SED analysis to detect lensing galaxy prior to spectroscopy; Gaia + WISE selection]

Einstein radius = 2.5”



Forced Photometry DES -> VHS

DES r-band image



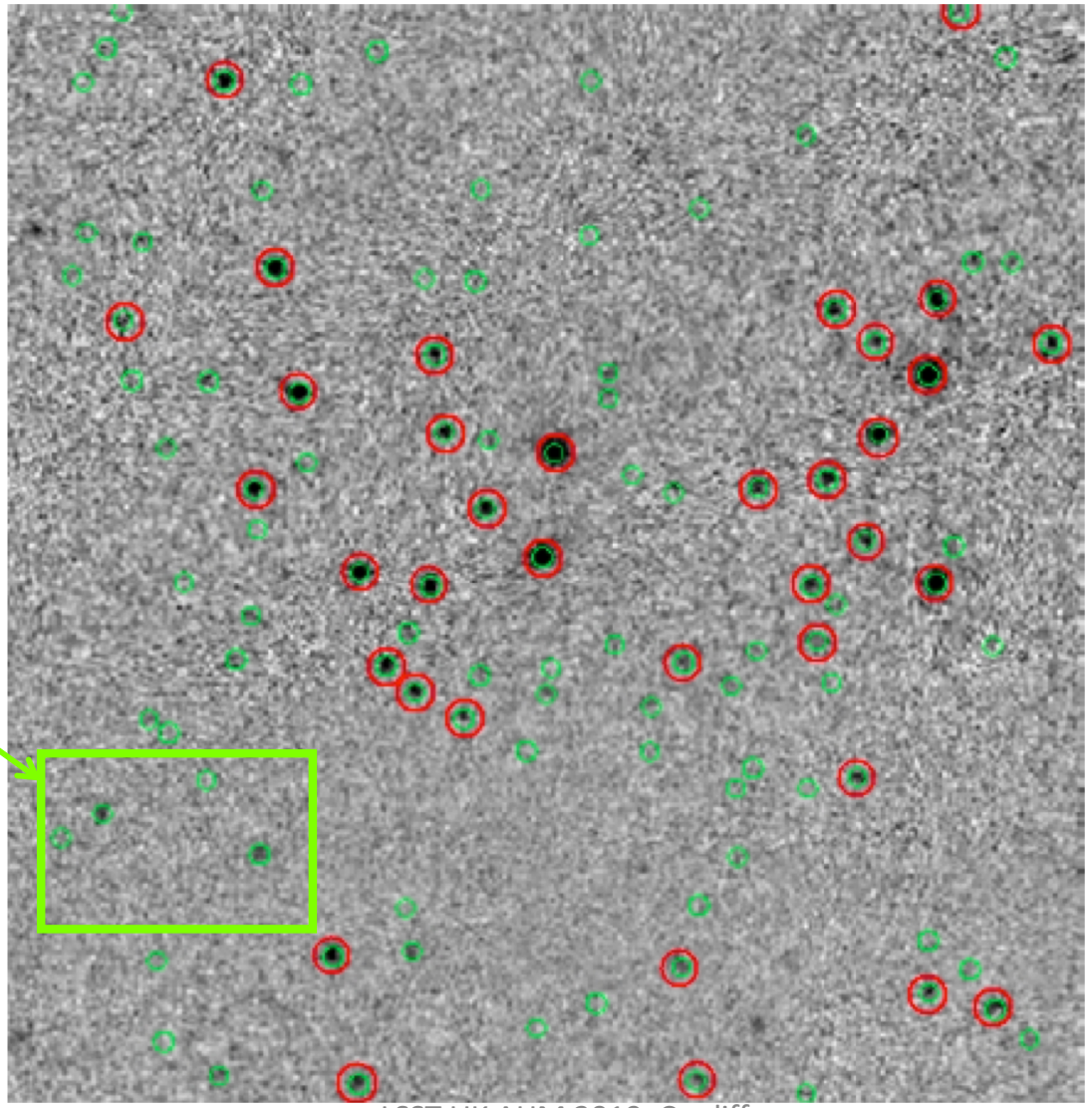
Red = in VHS catalogues

Green = in DES catalogues

Banerji et al. 2015

Forced Photometry DES -> VHS

VHS K-band



Red = in VHS catalogues

Green = in DES catalogues

Clear excess in pixel value at DES position even for sources not in VHS catalogues

Banerji et al. 2015

Key Datasets 1: The VISTA Imaging Surveys (NIR)

ESO VISTA Public Surveys: Cycle 1: 2010-2017

UK PI

Acronym	Short Title	PI	Area (deg^2)	Filters and Depth Measure (mag (10σ, AB))	Depth (mag)
Ultra-VISTA	An Ultra Deep Survey with VISTA	J. Dunlop	0.73 (ultra-deep)	5σ, AB	Y=26.7 J=26.6 H=26.1 K_s=25.6 NB=26.0
VIKING	The VISTA Kilo-degree Infrared Galaxy Survey	A. Edge, W.Sutherland	1500	5σ, AB	Z=23.1 Y=22.3 J=22.1 H=21.5 K_s=21.2
VMC	The VISTA near-infrared survey of the Magellanic System	M.R. Cioni	184	10σ, Vega	Y=21.9 J=21.4 Ks=20.3
VVV	Vista Variables in the Via Lactea	D. Minniti	520	5σ, Vega	Z=21.9 Y=21.2 J=20.2 H=18.2 K_s=18.1
VHS	The VISTA Hemisphere Survey	R. McMahon	20 000	5σ, AB	Y=21.2 J=21.2 H=20.6 Ks=20.0
VIDEO	VISTA Deep Extragalactic Observations Survey	M. Jarvis	12	5σ, AB	Z=25.7 Y=24.6 J=24.5 H=24.0 K_s=23.5

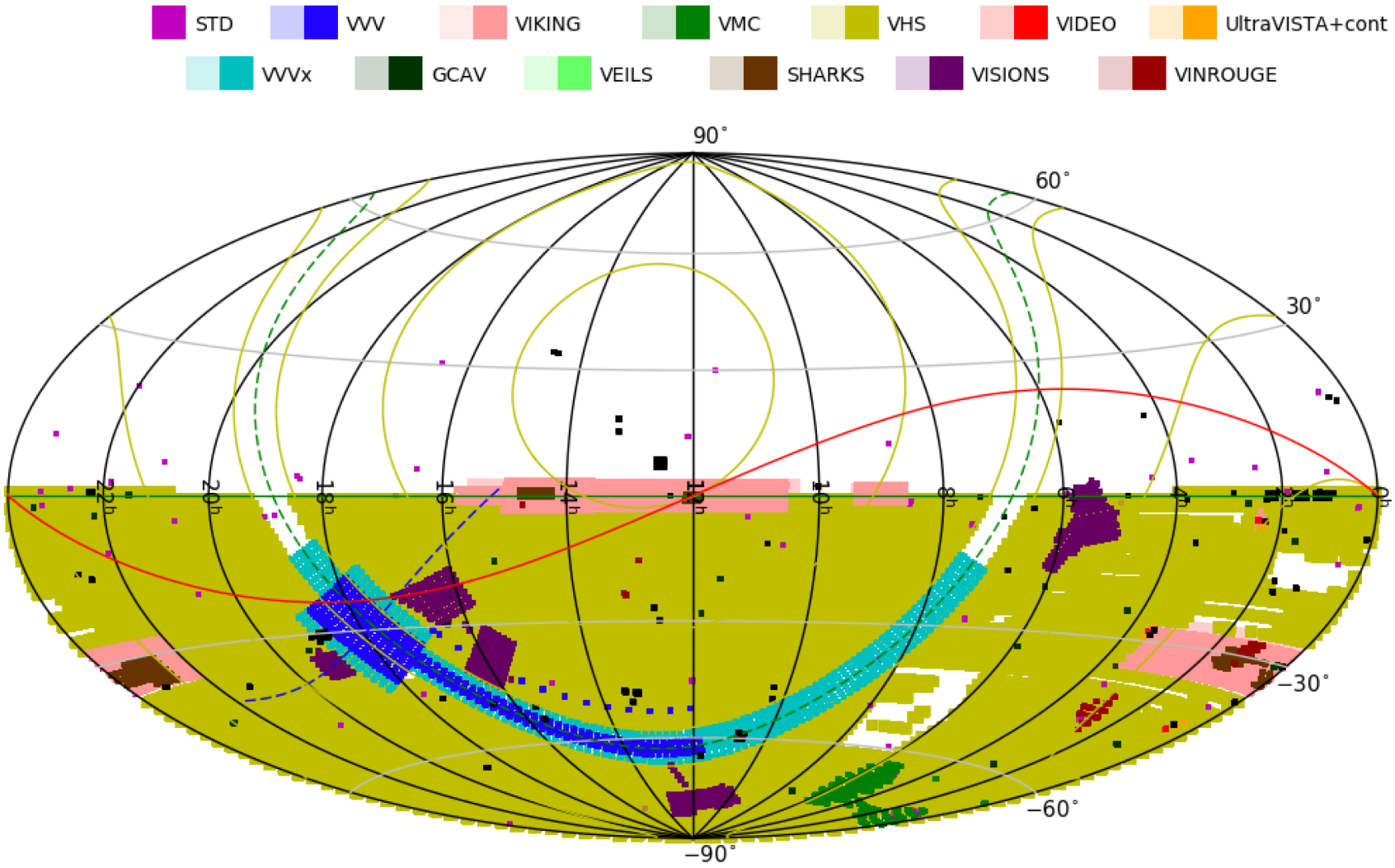
Key Datasets 1: The VISTA Imaging Surveys (NIR)

ESO VISTA Public Surveys: Cycle 2: 2017-

UK PI

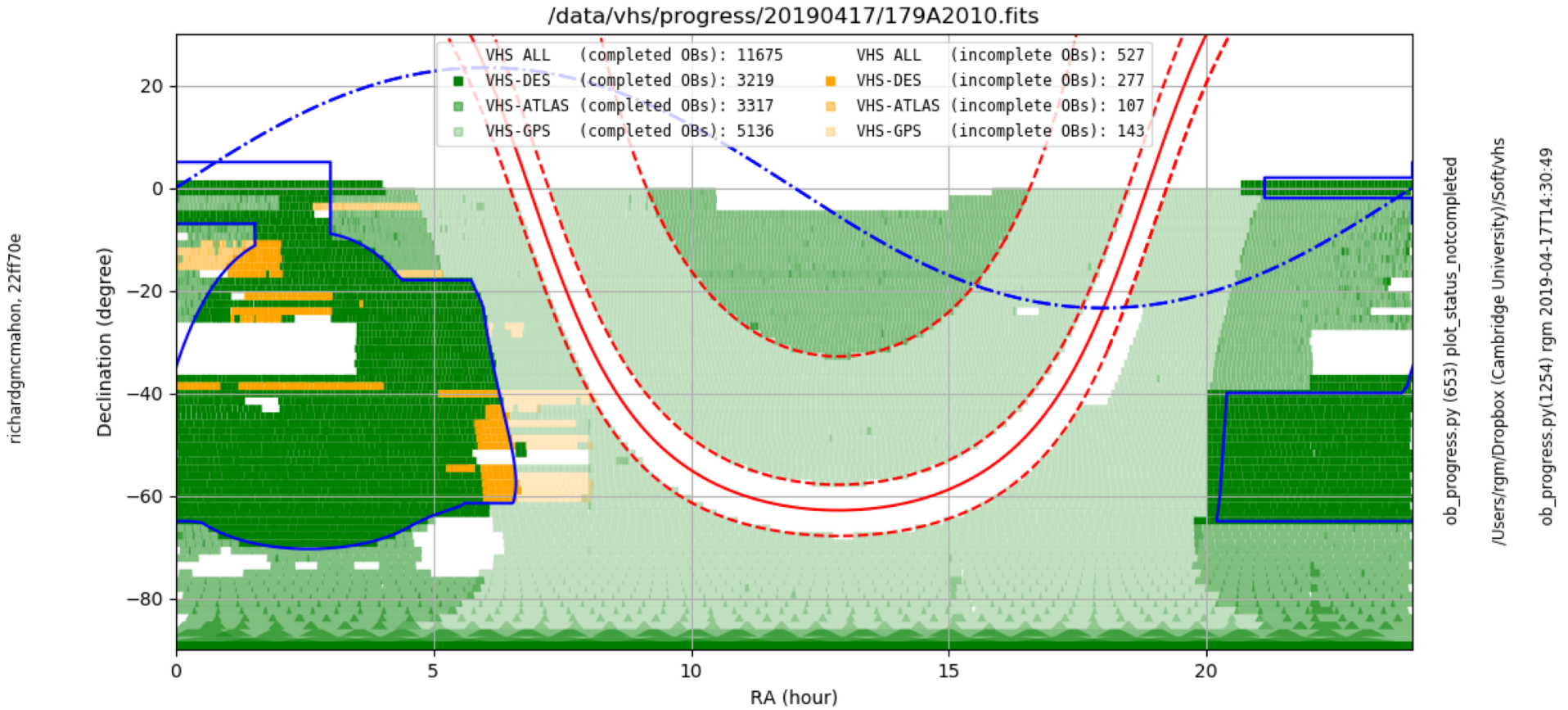
Acronym	Short Title	PI
VINROUGE	Kilonova counterparts to Gravitational wave sources	N. Tanvir
Cont. UltraVISTA	Completing the legacy of UltraVISTA	J. Dunlop
VVVX	Extending VVV to higher Galactic latitudes	D. Minniti
VEILS	VISTA Extragalactic Infrared Survey	M. Banerji
GCAV	Galaxy Clusters at VIRCAM	M. Nonino
VISIONS	VISTA star formation atlas	J. Alves
SHARKS	Southern Herschel-Atlas Regions K-band survey	J. Oteo

The VISTA Imaging Surveys



Vista Hemisphere Survey (VHS) current coverage status

DES footprint; DES DR1 now public



THE ESO VISTA EXTRAGALACTIC INFRARED LEGACY SURVEY (VEILS)

Co-PIs: Manda Banerji, Sebastian Hoenig

- Main science goals:
  - **Pinning down faint AGN space density in the EoR**
  - **Understanding massive galaxy formation at early times – what fraction of star-forming galaxies at z > 4 host AGN?**
  - Cosmology with Type 1a SNe and AGN dust reverberation

- ESO Public Survey using VIRCAM on VISTA to obtain *wide and deep* near infra-red imaging over DES, HSC and LSST deep fields:
  - 21 sq-deg down to J,K < 23-24 mag when combined with VISTA VIDEO (Euclid-Wide depths)
- Almost 1200 hours allocated to the survey over 3 years starting in 2017
- Observations are cadenced to enable transient science

Work Package 3.5 Description

WP 3.5.1: Data Management and DAC Delivery:

1. Ingestion of relevant datasets within the UK DAC (IRIS). Both pixel and catalogue-level data from optical and IR surveys need to be ingested including re-formatting of meta-data to comply with LSST stack processing requirements.
2. VISTA data ss the primary dataset as well as potentially HST data as a test-bed for ingesting upcoming datasets e.g. Euclid. Currently available optical pixels from surveys such as DES and Subaro HSC will also be ingested together with their associated catalogues to serve as proxy training set for LSST.
3. The outputs from our dual photometry pipeline using near IR and optical as priors respectiverly (WP3.5.2) will be ingested into a queryable database and made easily accessible to the community.

Work Package Description continued

WP 3.5.2: Dual Photometry Pipeline Development

1. Pipeline will be based on the forced-photometry module within the LSST software stack. This module will be configured to perform photometry on VISTA IR images based on LSST detections and vice versa. i.e. positional and shape priors from LSST and vice versa

WP 3.5.3: Pipeline Benchmarking

1. Existing photometry pipelines (e.g. Sextractor , imcore_list) used by current surveys such as DES and VISTA, will also be implemented in order to support validation and allow benchmarking
2. The workflow will also be ported onto generic High Performance Computing (HPC) systems e.g. DIRAC/IRIS
3. **IRIS (https://www.iris.ac.uk/); 7000 cores; 5PB of storage for LSST-UK shared with Particle Physics, SKA, LIGO etc; Distributed over multiple STFC sites. Around 10% for LSST.**

Work Package Description continued

WP 3.5.4: Pipeline Commissioning on LSST data

1. Pipeline commissioning and testing will overlap with the Commissioning and Science Verification phases of the LSST survey, allowing LSST pixels to be directly processed and combined with the VISTA data during this phase.
2. Need to ensure fields with good IR coverage are observed in LSST Commissioning and Science Verification. This will be facilitated by the LSST:UK Commissioning Coordinator (Graham Smith).

Work Package Description continued

WP 3.5.5: Scientific Validation

LSST-UK collaboration will be invited to validate the deliverables

Initially the data products will be multi-wavelength catalogues produced by combining current optical photometric surveys such as DES and Subaru HSC with VISTA, while LSST pixels will be combined with IR pixels towards the end of Phase B.

The key scientific validation steps will be:

1. Assessment of noise properties, depths, seeing FWHM, stellar and galaxy colours produced using different approaches to photometry;
2. Assessment of the utility of IR data in improving star-galaxy separation, by exploiting the new colour information from the IR;
3. Other key multi-wavelength datasets: The UK also has strong interests in other multi-wavelength datasets, which can be combined with LSST during science validation. e.g.
   - X-ray (e.g. XMM-Newton, Chandra, NuSTAR, e-ROSITA),
   - Mid-IR (e.g. Spitzer/WISE)
   - Far-IR (e.g. Herschel) and
   - Radio (e.g. MeerKAT, ASKAP) Your science here

Science validation will be overseen by Matt Jarvis

May 2019 Various Timelines

LSST (2019 May)

- ComCam Data Release: 2021 Dec (images)
- Mini-surveys start: 2021 Dec
- Survey Starts: 2022 Oct 1st
- LSST-UK Phase B ends: 2023 Mar
- DR1: 2023 Oct (15, 000deg^2)
- DR2: 2024 Oct (20,000deg^2)

Euclid (2018 Dec)

- Launch: 2022 June (T0 = Launch + 6 months)
- DR1: 2025 Jan (2500deg^2) [T0 + 2 years]

4MOST (2019 Mar)

- Survey Starts: 2022 Nov

The End

- Questions

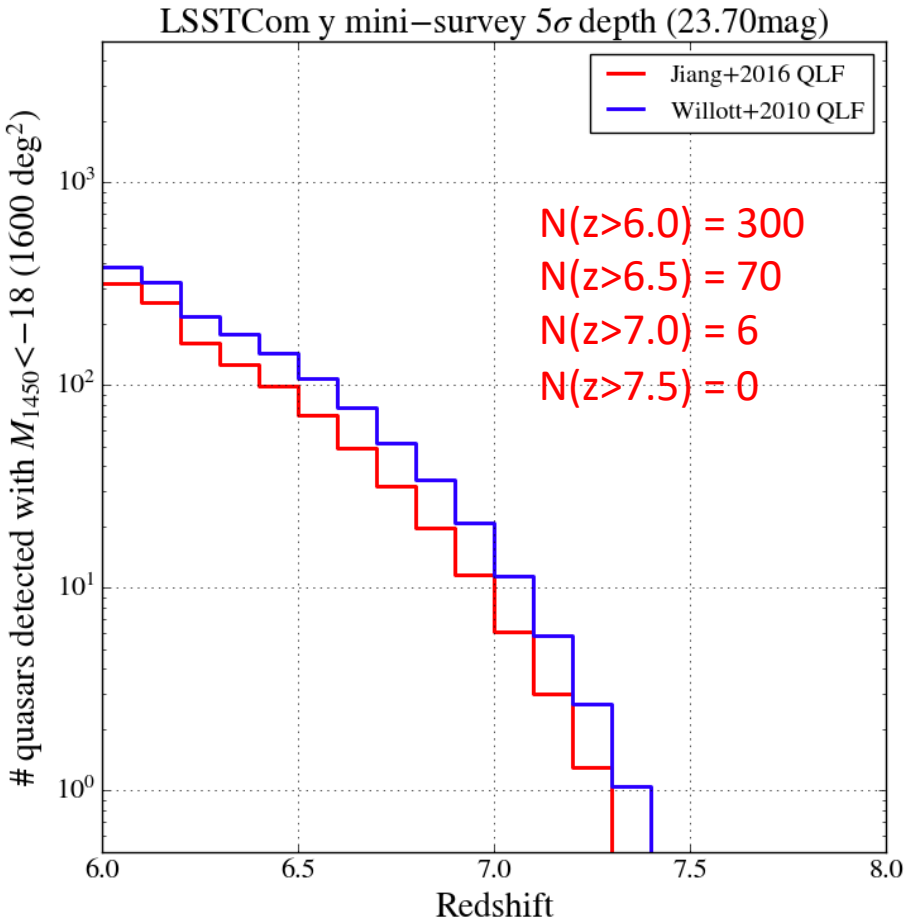
Extra

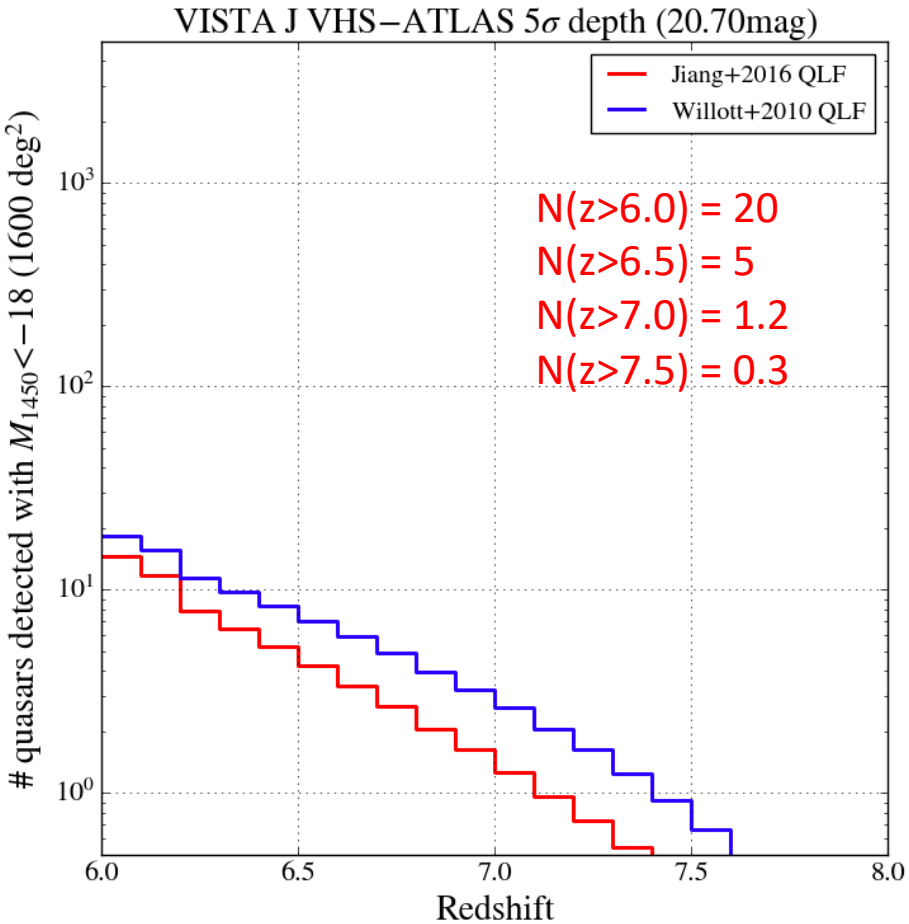
VHS DR5

Survey	Area (deg^2)	5σ point source depth (AB mag)				
		Z	Y	J	H	K_s
VHS_DR5	**16,700**		**21.1**	**20.8**	**20.5**	**20.0**
1. VHS-DES 120 secs per band	4200	*23.4*	*22.2*	21.4	(20.7)	20.3
2. VHS ATLAS 60 secs per band	4800		21.1	20.8	(20.3)	20.0
3. VHS-GPS (5° <|b|<30°) 60 secs per band	7700			20.65		19.9
VIKING	**1,500**	**23.1**	**22.3**	**22.1**	**21.5**	**21.2**
VVV (Galactic Centre)	520	22.4	21.8	21.1	19.6	20.0
VMC (Magellanic Clouds)	184		23.3	23.1		23.0

DES depth provenance; DR1 (Y3A1), Abbott+2018

Forecast for LSST Commissioning Mini-survey 1

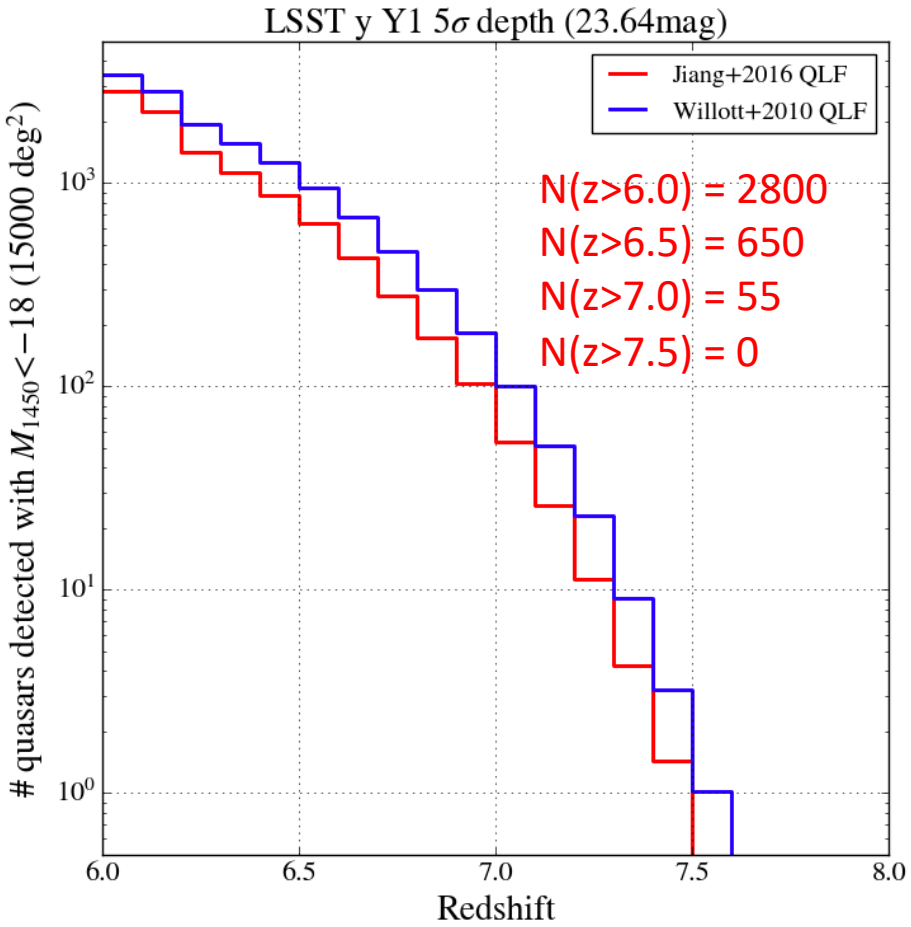


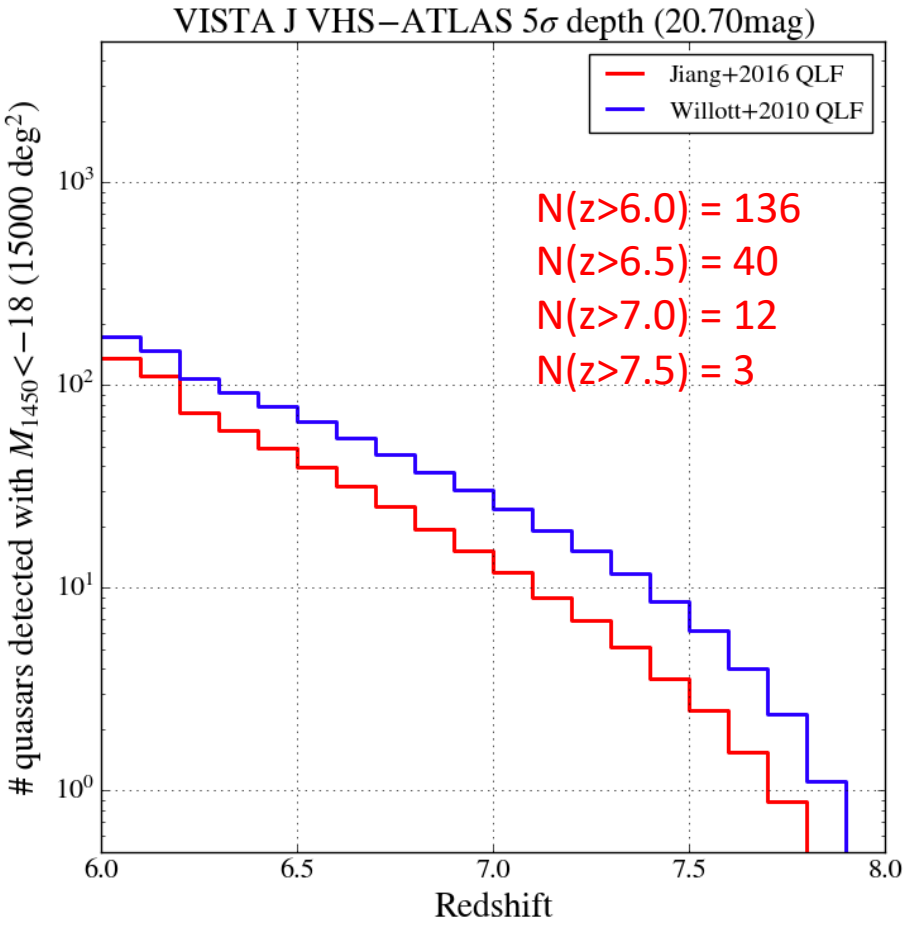


Near IR needed to remove Galactic foreground due to low mass LT dwarf stars.

Based on Pons et al, 2019

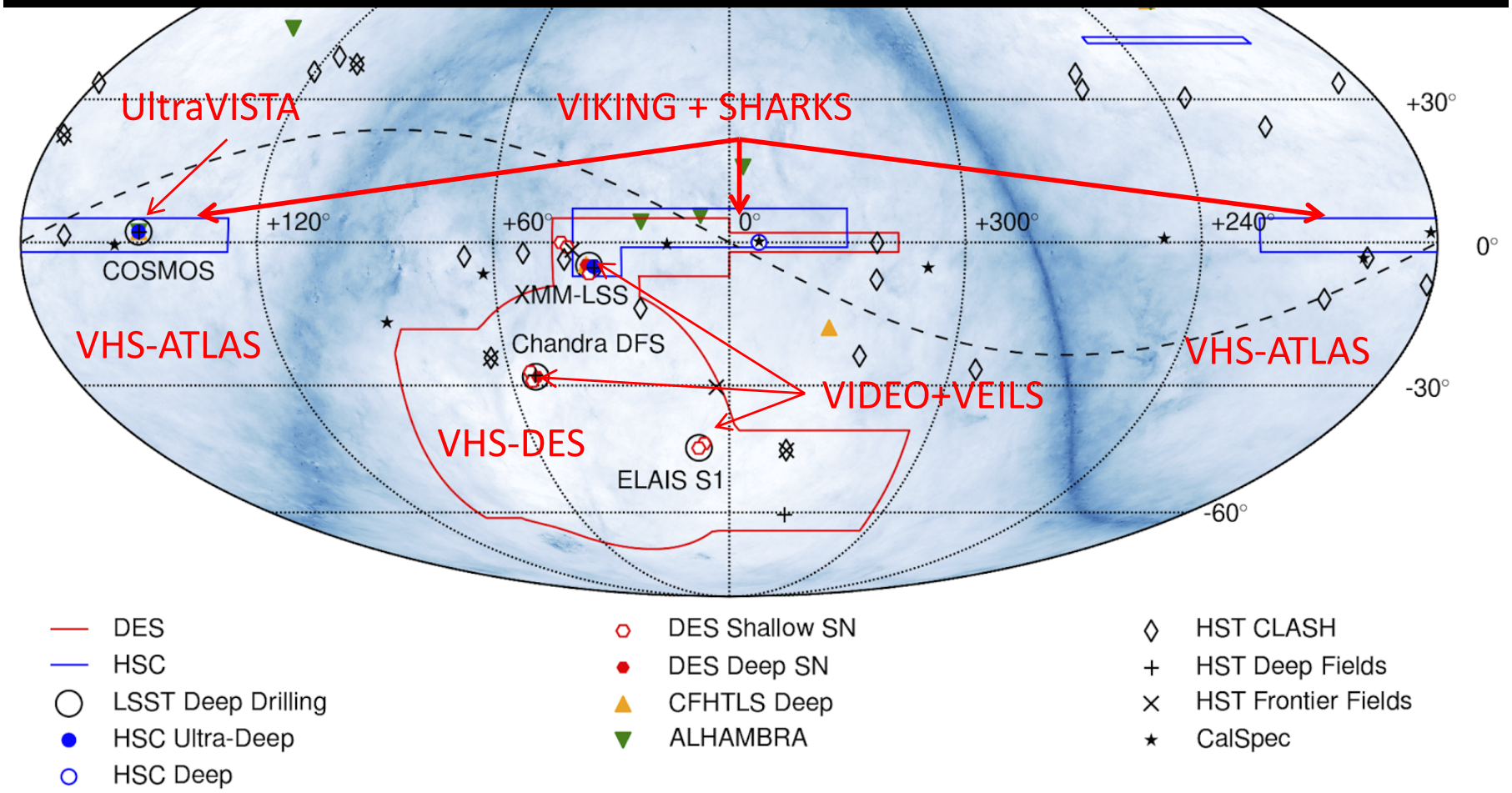
Forecast for LSST Year 1 (15,000 deg^2)





Candidate reference fields/area for LSST Commissioning Observations

Eventually Euclid but will likely not cover entire LSST footprint and also wont have K-band. More importantly can leverage UK VISTA leadership



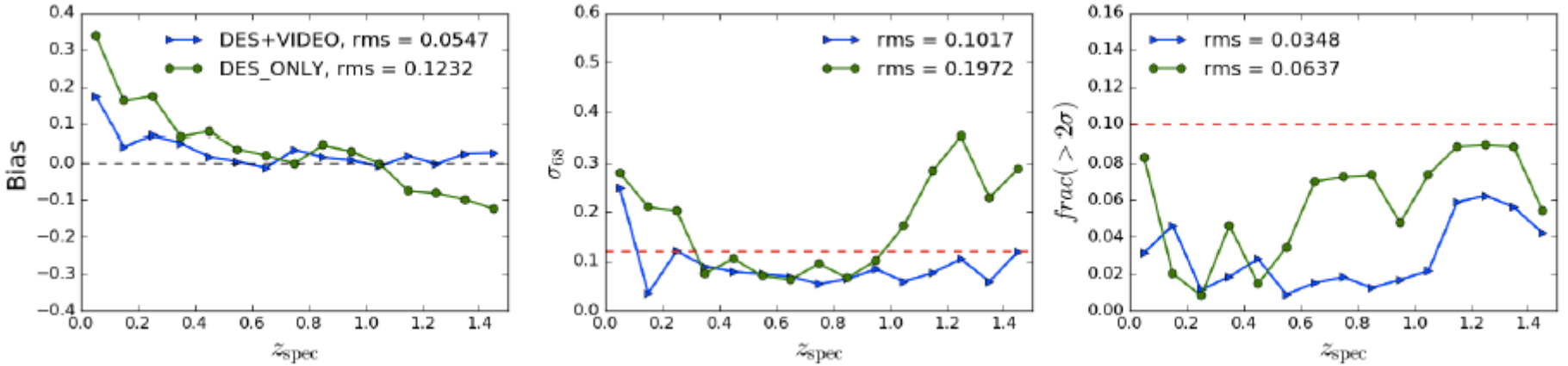
Taken from presentation by C. Claver & B. Wilman

Key Datasets (II) Spitzer Warm

SURVEY	PI	TOTAL AREA
SPLASH/SPLASH2	P. Capak	3.6 sq-deg
SHELA	C. Papovich	28 sq-deg
SERVS+DeepDrill	M. Lacy	40 sq-deg
SSDF	S. Stanford	100 sq-deg
SPIES	G. Richards	175 sq-deg

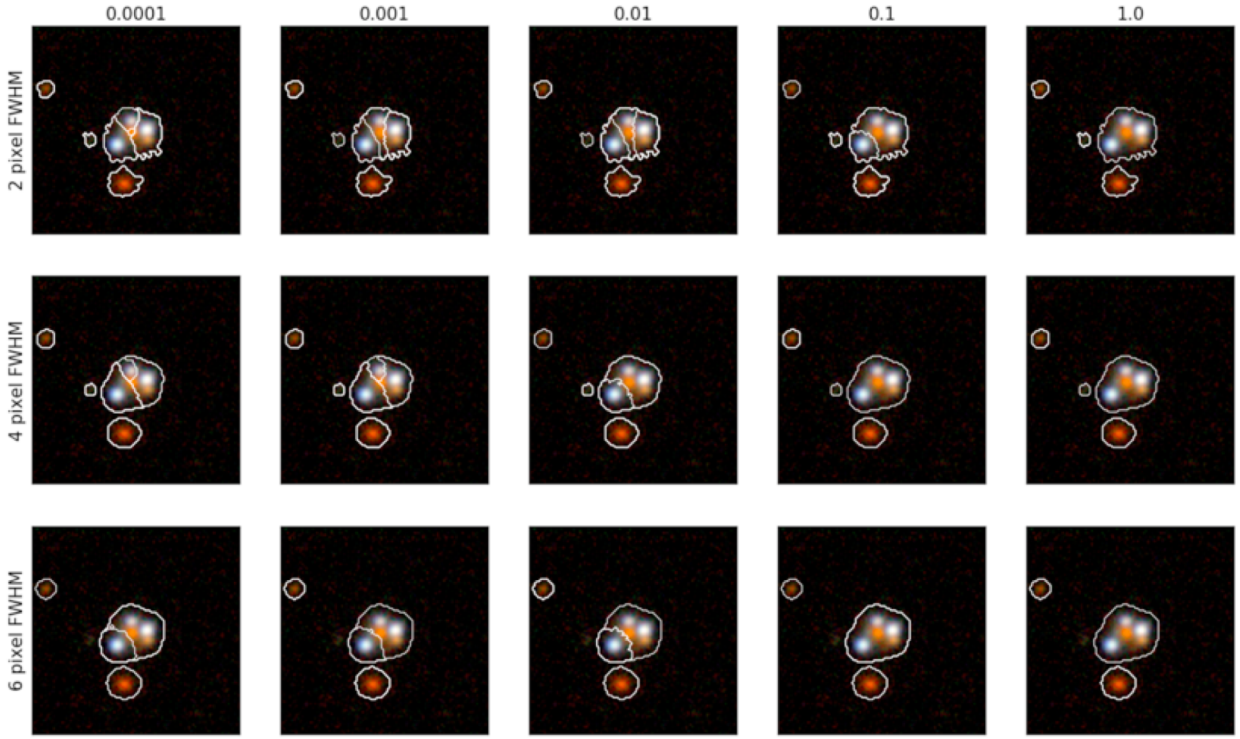
Photo-z performance: DES + VISTA

Schooneveld, Banerji+ in prep



Significantly improved bias, scatter and outlier fraction when IR data from VISTA is added to DES, particularly at high redshifts (z>1) (see also Banerji+08, Jarvis+13, Bezanson+16)

De-blending



C. Lemon, R. McMahon et al.

Example of de-blending for a lensed quasar system in DES using different de-blending parameters, kernels etc and across different wavelengths.

Need to be especially careful when combining this with low-resolution data e.g. from WISE to produce multi-wavelength SEDs.

Work package Requirements continued

WP 3.5 will provide:

- R5.08: Results of running benchmarking tests on the pipeline in order to scope out future computational requirements.
- R5.09: Reports on scientific validation of catalogues produced by the pipeline in the form of scientific presentations and/or publications.

WP 3.5 should provide:

- R5.10: An analysis pipeline that is easily reconfigured to process future datasets e.g. Euclid

- R5.11: A modular pipeline structure such that new algorithms for joint pixel-level processing of LSST data and other multi-wavelength datasets (e.g. Spitzer, WISE) can be easily implemented within it.

Work package requirements

WP 3.5 shall provide:

- R5.05: A joint pixel-level analysis pipeline for the combined processing of optical and ground-based near infra-red imaging surveys of comparable seeing together with comprehensive documentation detailing the full pipeline implementation.

- R5.06: Optical + near infra-red (NIR) catalogues produced by joint pixel-level analysis of LSST pre-cursor surveys (DES, HSC) and ground-based near infra-red imaging surveys (UKIDSS-LAS, VHS, VIKING, VIDEO, VEILS).

- R5.07: Optical+near infra-red (NIR) catalogues produced by joint pixel-level analysis of LSST commissioning and science verification data and ground-based near infra-red imaging surveys (UKIDSS-LAS, VHS, VIKING, VIDEO, VEILS).