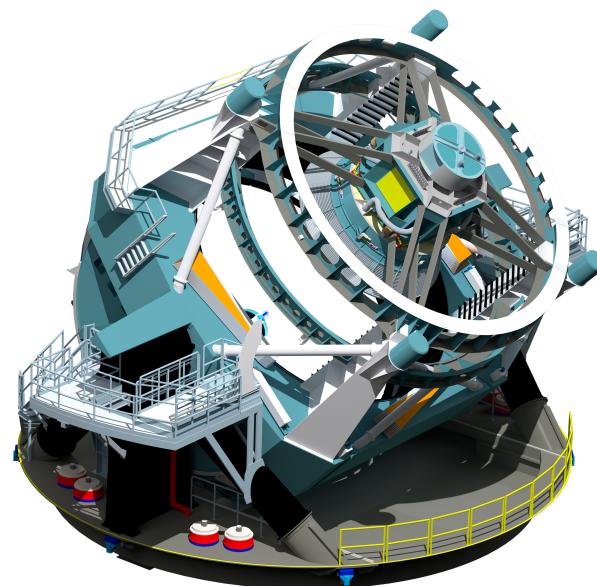




European Research Council
Established by the European Commission

Spectroscopic Follow-up

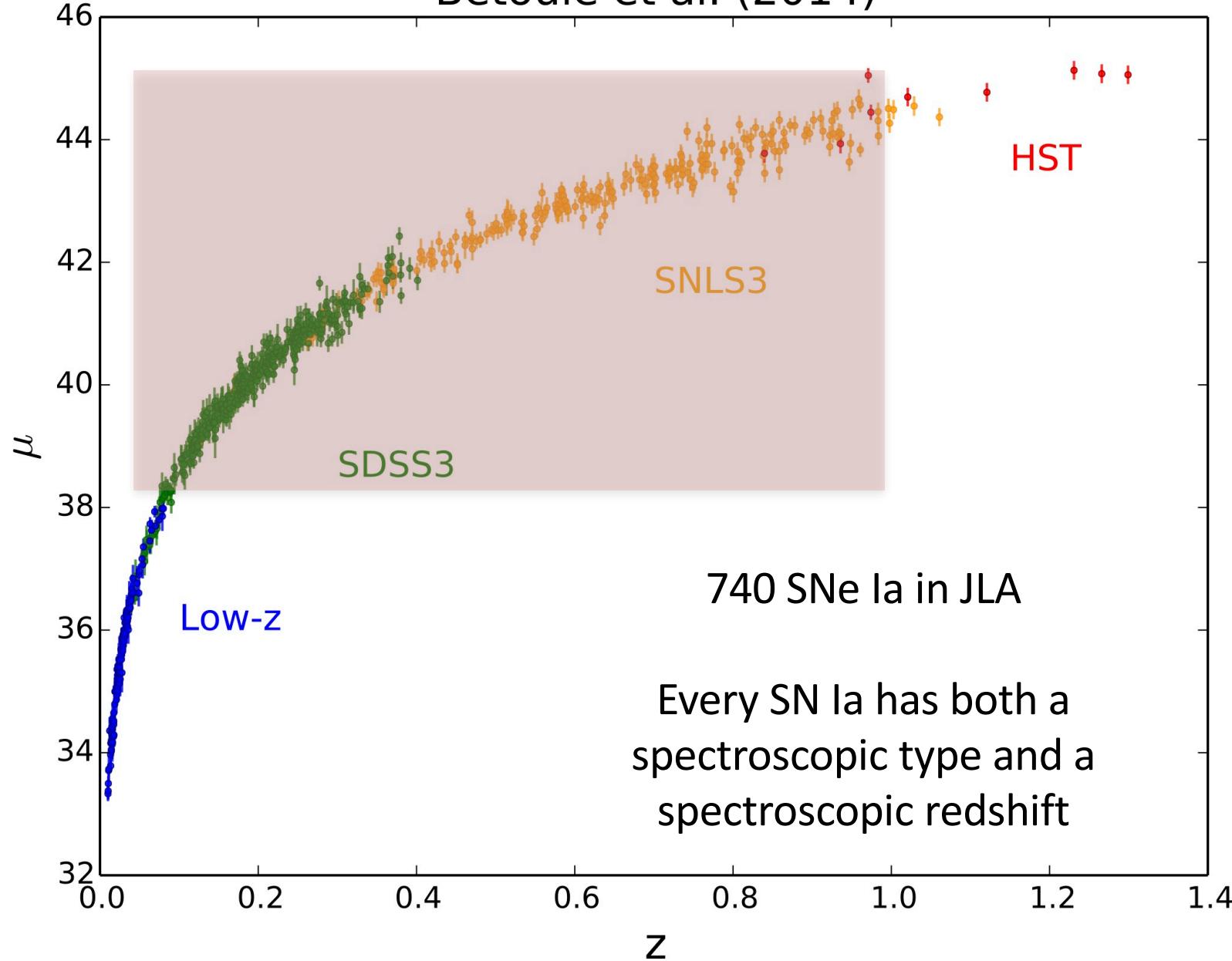
Mark Sullivan, Southampton



Why do spectroscopy?

- Why not?
 - Samples of 50,000 SNe easily within grasp
- Systematics/biases in photometric-redshift cosmology unquantified
- Spectroscopy provides reliable training samples
- Enables ‘science’
- Enables reliable environment studies

Betoule et al. (2014)

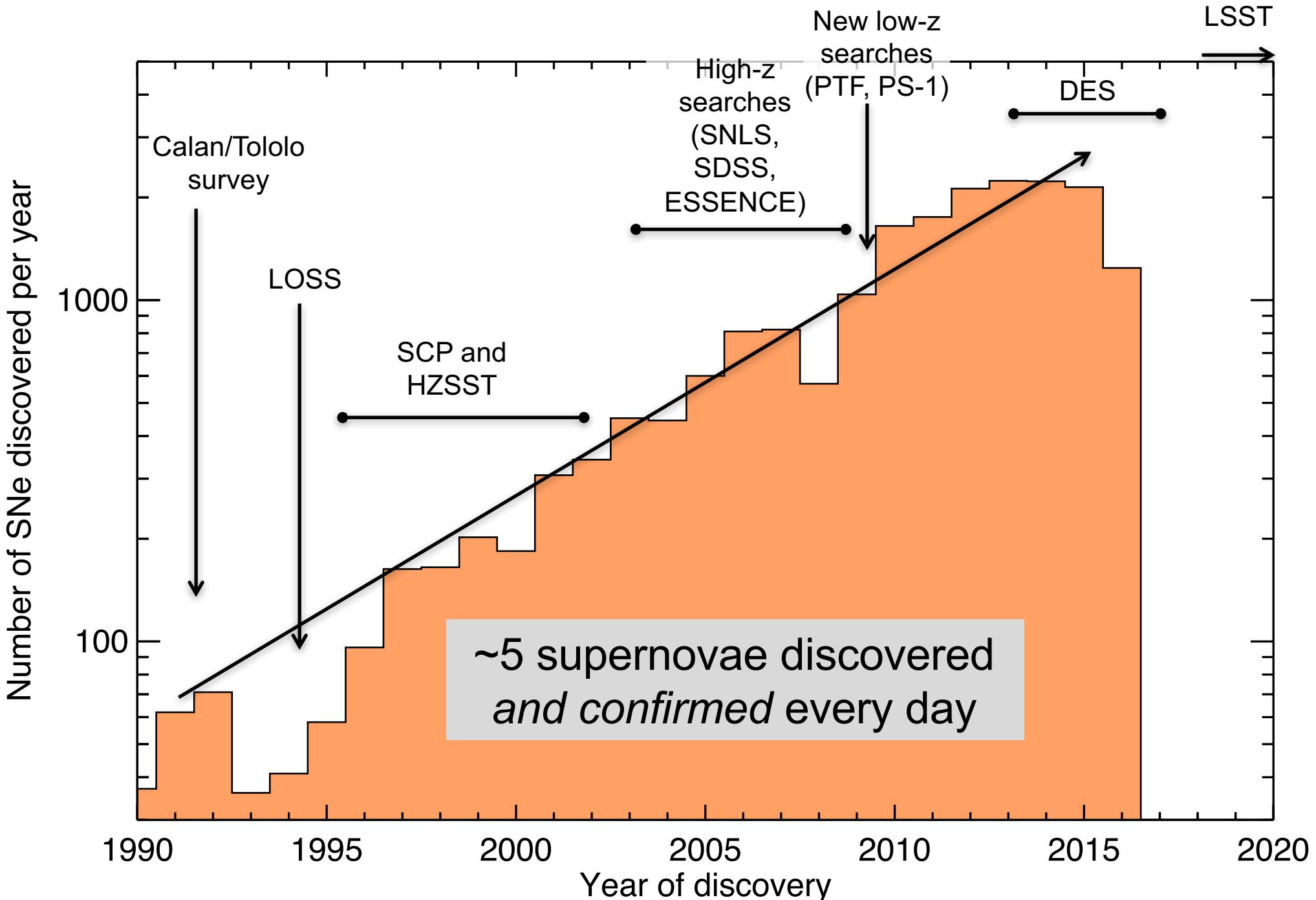


Simplified SN systematic-error budget (“JLA”)

Uncertainty sources	$\sigma_x(\Omega_m)$	% of $\sigma^2(\Omega_m)$
Calibration	0.0203	36.7
Milky Way extinction	0.0072	4.6
Light-curve model	0.0069	4.3
Bias corrections	0.0040	1.4
Host relation ^a	0.0038	1.3
Contamination	0.0008	0.1
Peculiar velocity	0.0007	0.0
Stat	0.0241	51.6

Photometric calibration is (by far) the dominant systematic uncertainty

Number of SNe discovered per year



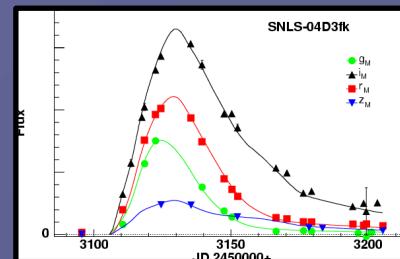
Supernova Legacy Survey: 2003—2008

Imaging

Distances from
light-curves



Discoveries



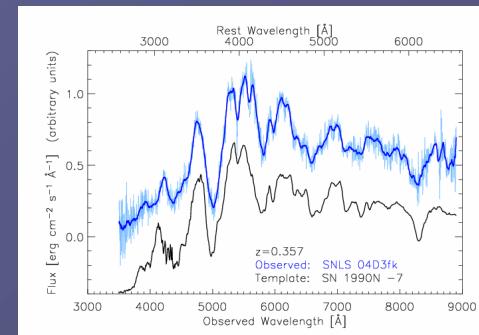
Lightcurves



g'r'i'z' every 4 days
during dark time

Spectroscopy

Redshifts →
Distances from
cosmological model



Gemini N & S
(120 hr/yr)



VLT
(120 hr/yr)



Keck
(8 n/yr)

*More 8m-class telescope time (~1600h)
than CFHT time (~1200h)*

*Led to ~750 spectra
~440 SNe Ia*

THE DARK ENERGY SURVEY

Multi-component survey designed to probe **dark energy** and origin of cosmic acceleration

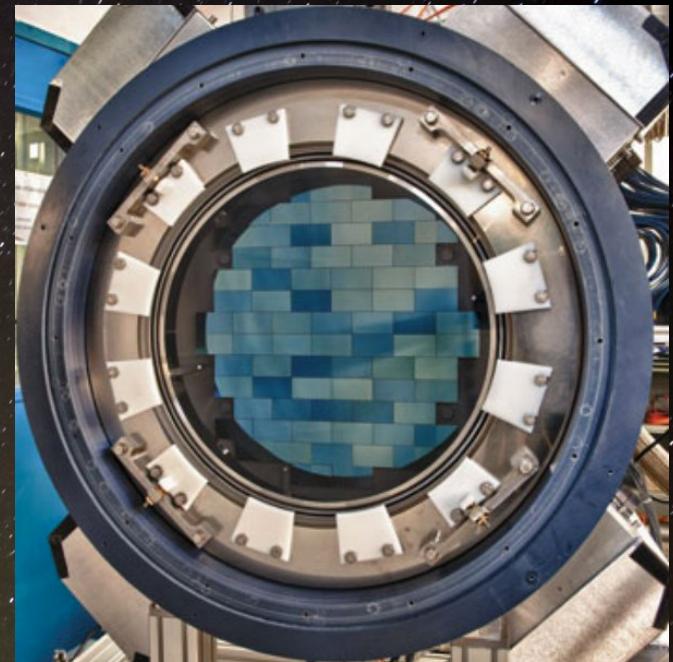
DES-Wide

- 5000 deg² in grizY: $r_{AB} \sim 24.3$, $i_{AB} \sim 23.5$ (10σ)
- Large Scale Structure; Weak Lensing; Galaxy Cluster

DES-SN

- ~ 6-day cadenced griz survey over 27 deg²
- Type Ia Supernovae

Probes of both Distance vs. Redshift & Growth of Structure



UK DES Collaboration

Cambridge ♦ Edinburgh ♦
Nottingham ♦ Portsmouth
♦ Sussex ♦ UCL



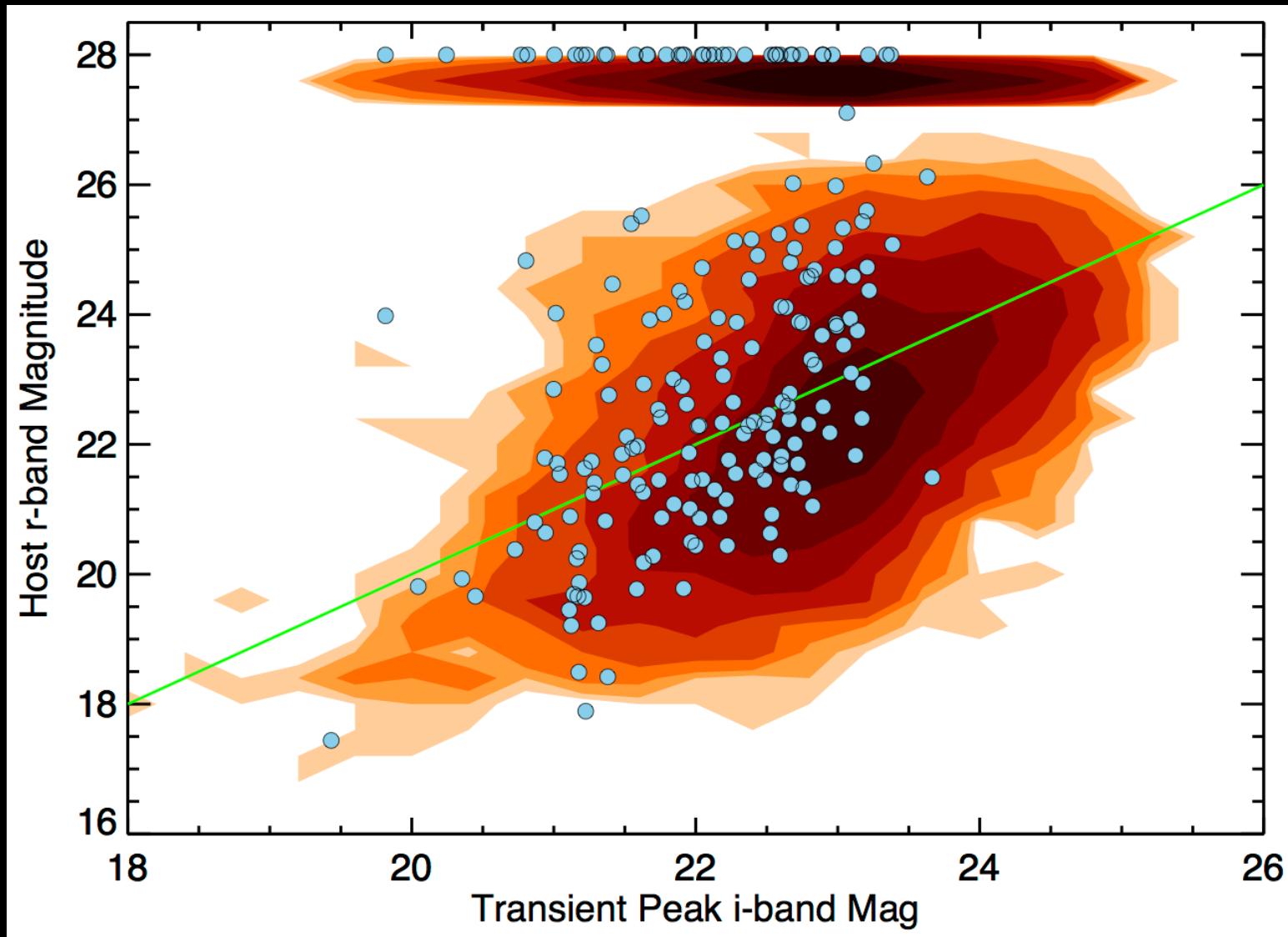
Dark Energy Camera (DECam) on 4m Blanco Telescope at CTIO

- 520 Mpx camera; 3 deg² FoV; deep-depleted LBNL CCDs
- Allocated 525 nights over 5 observing seasons (Aug - Feb, 2013 - 2018)
 - **DESY4 starts 13 August 2016**

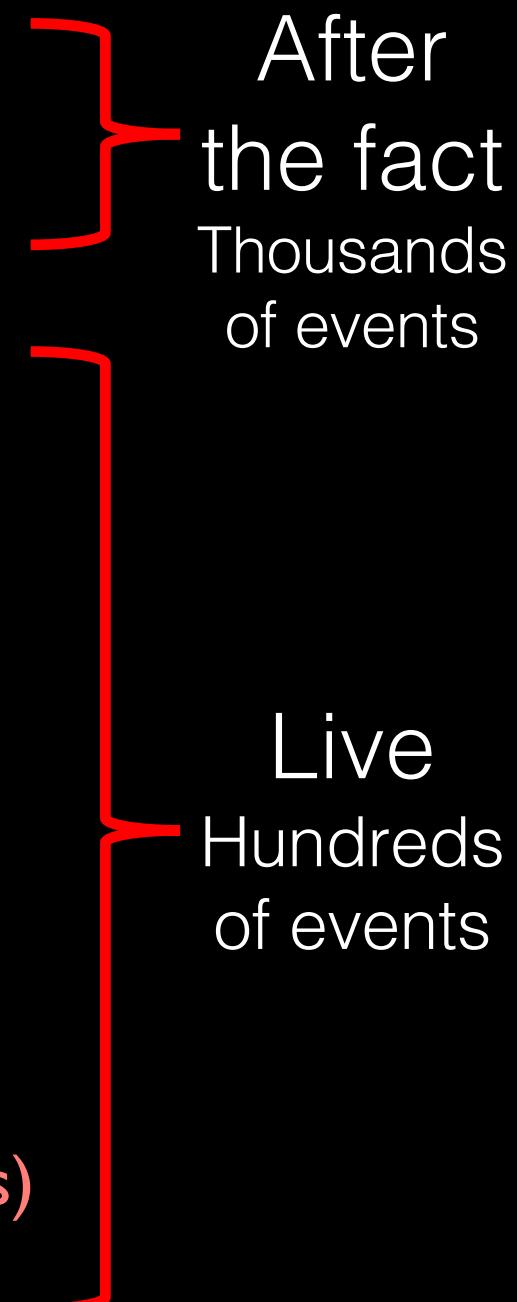


DES HOST/TRANSIENT MAGNITUDE

PARAMETER SPACE



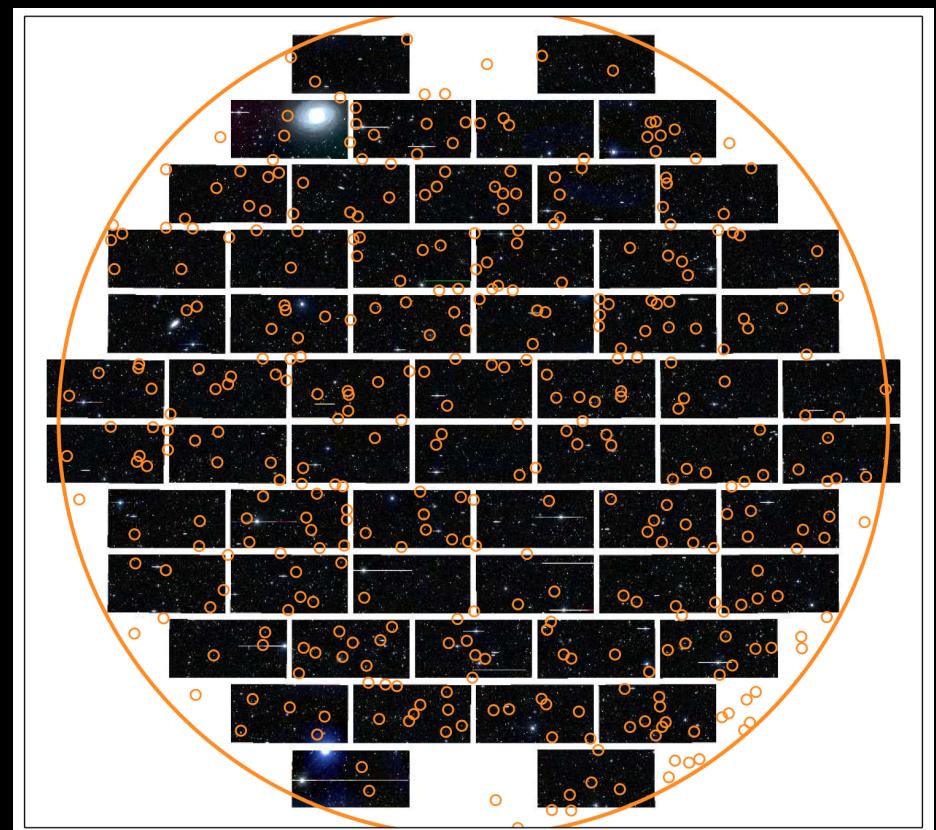
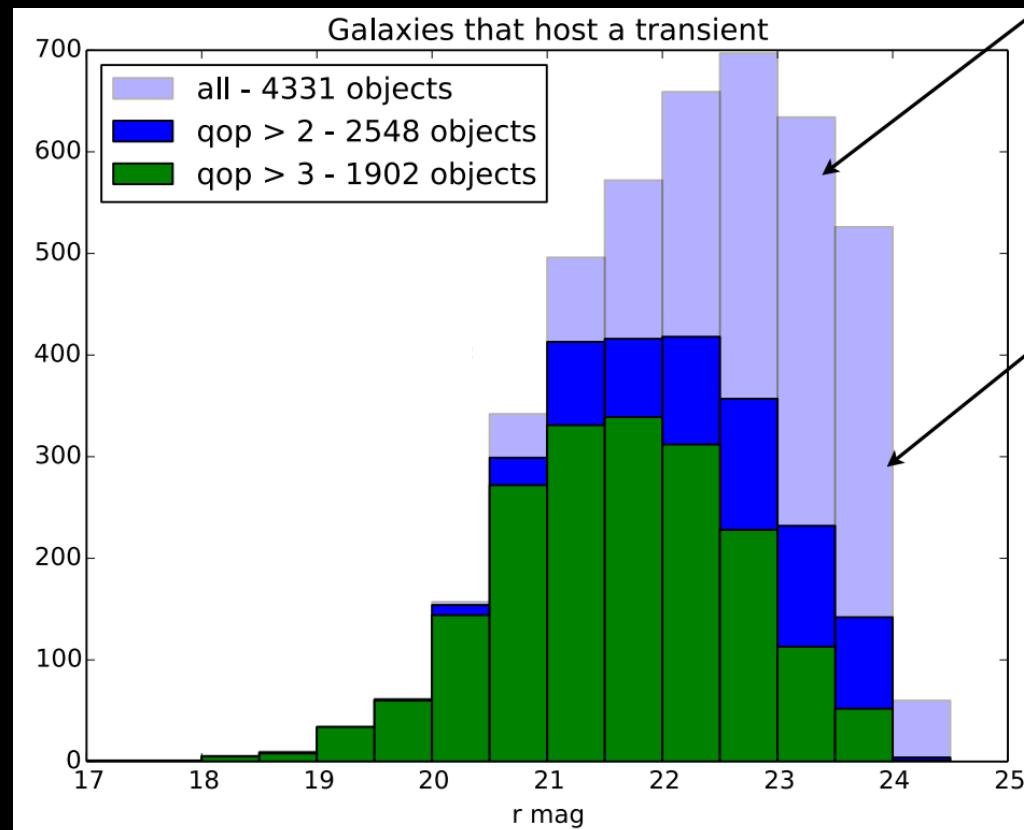
DES-SN SPECTROSCOPIC PROGRAMS

- Host-Galaxy Redshifts
 - Bright hosts
 - Photometric Classification
 - SNe in Faint Host Galaxies
 - Redshifts for faint hosts; unbiased sample
 - Representative sample
 - Tuned to cover parameter space expected from photometric-cosmology sample
 - Complete sample
 - Measure SN population demographics at low-z
 - Unbiased sample
 - Ancillary programs (SN Physics, weirdos)
- 

AAT: OzDES

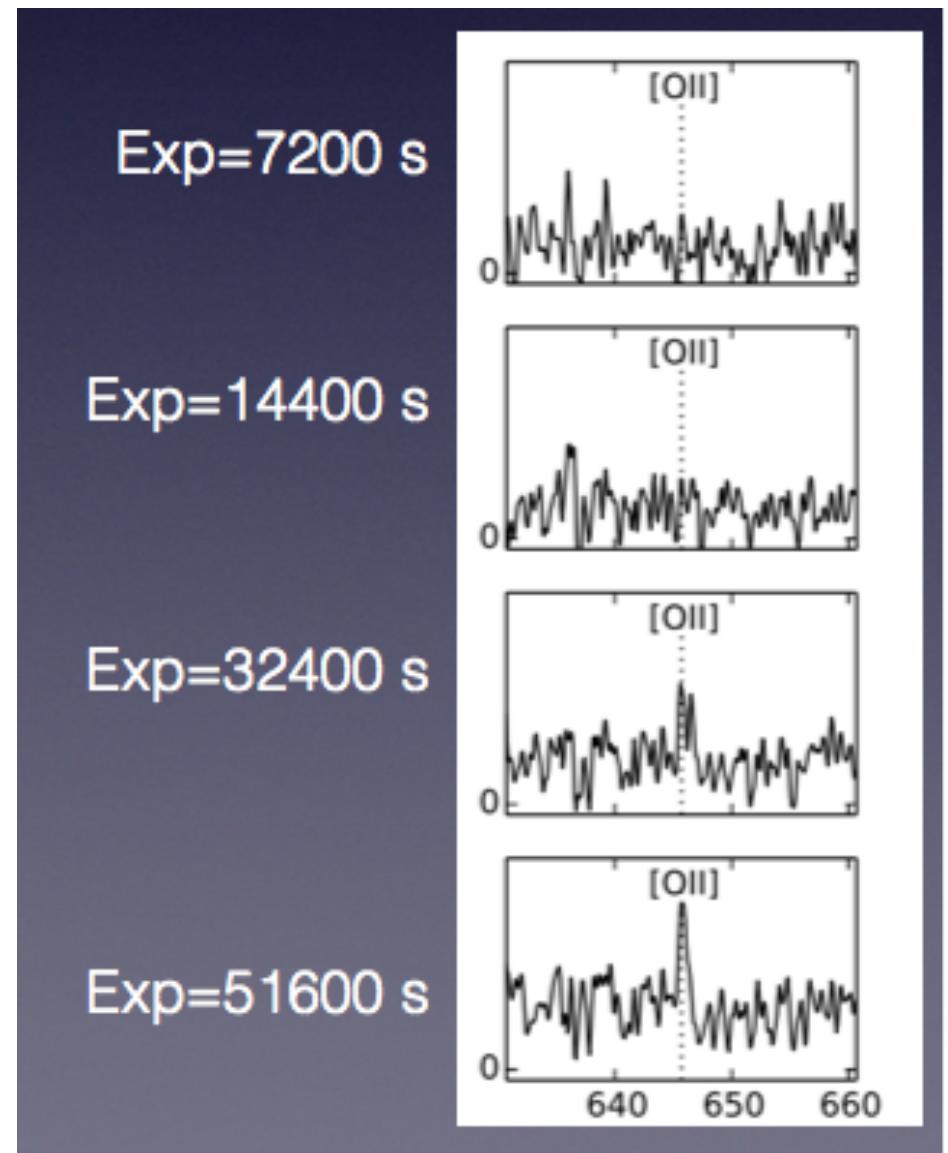
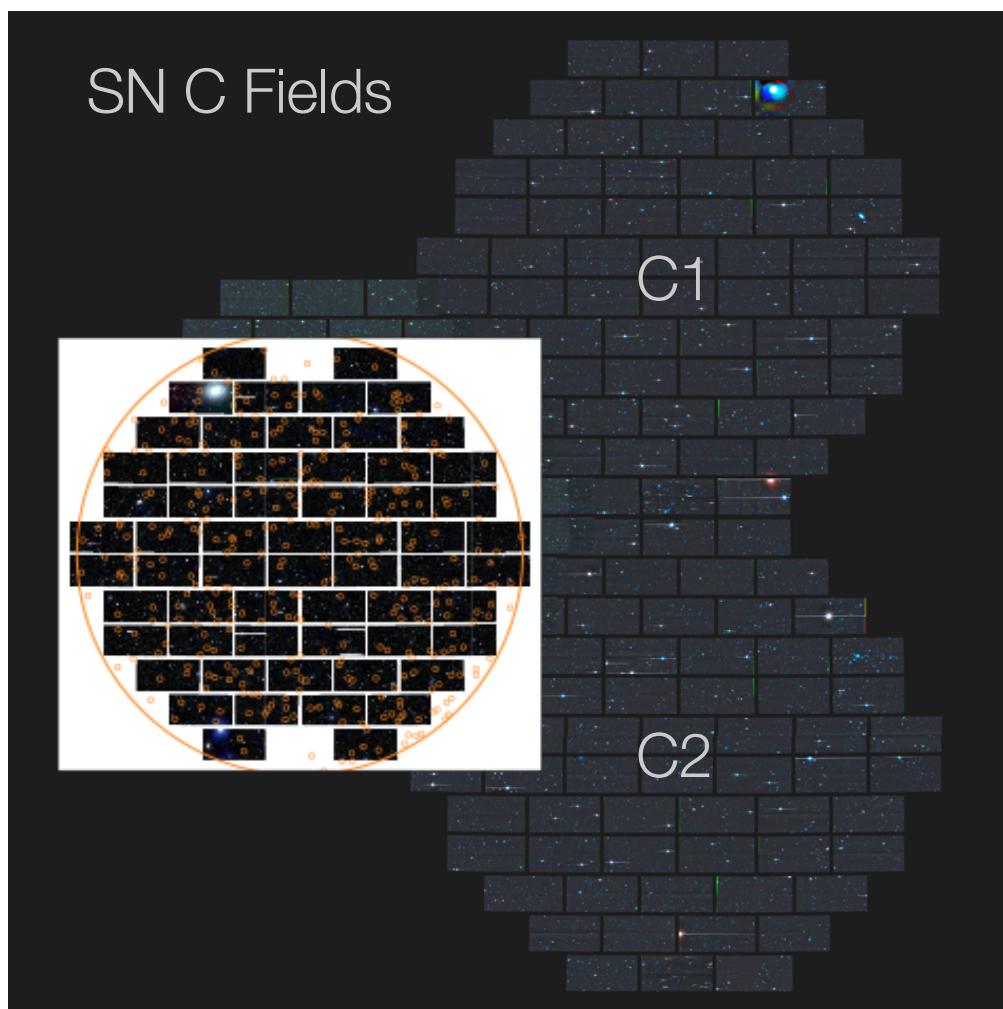
- 100 night program over 5 years overlapping with DES
- SN Hosts repeatedly targeted to build up depth;
Live transients targeted as well

On target for \sim 4000 SN host redshifts



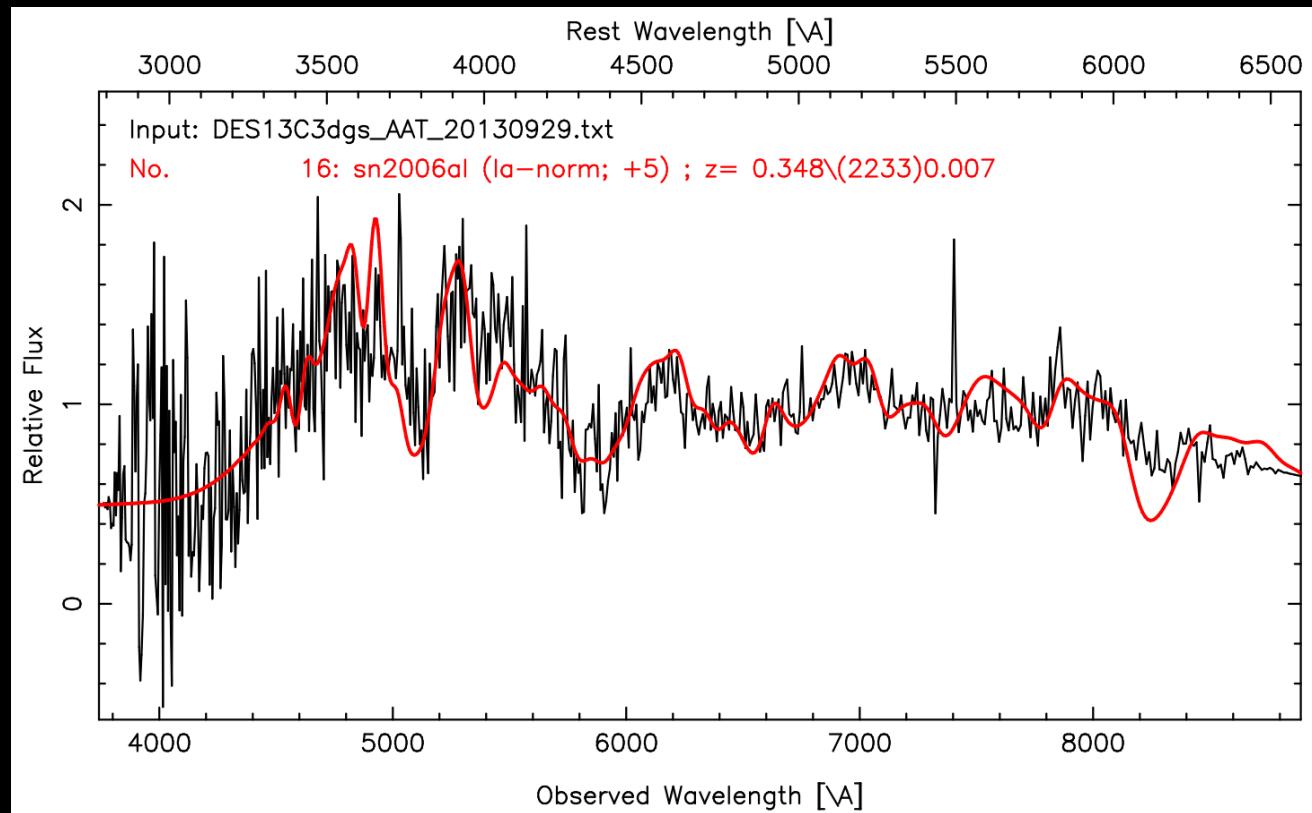
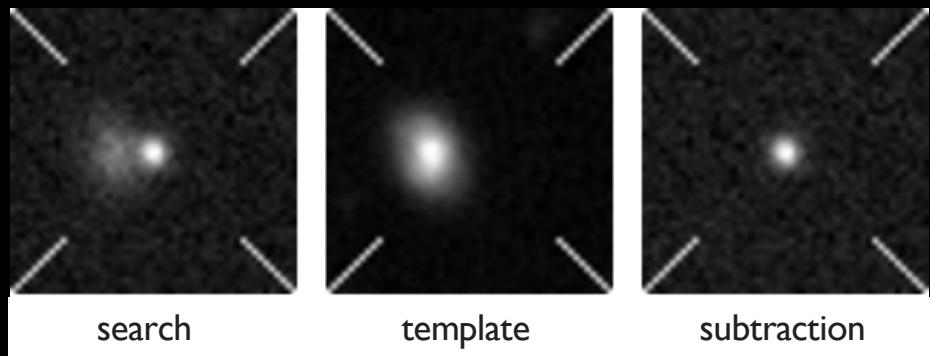
Courtesy C. Lidman

Large MOS follow-up of SN hosts

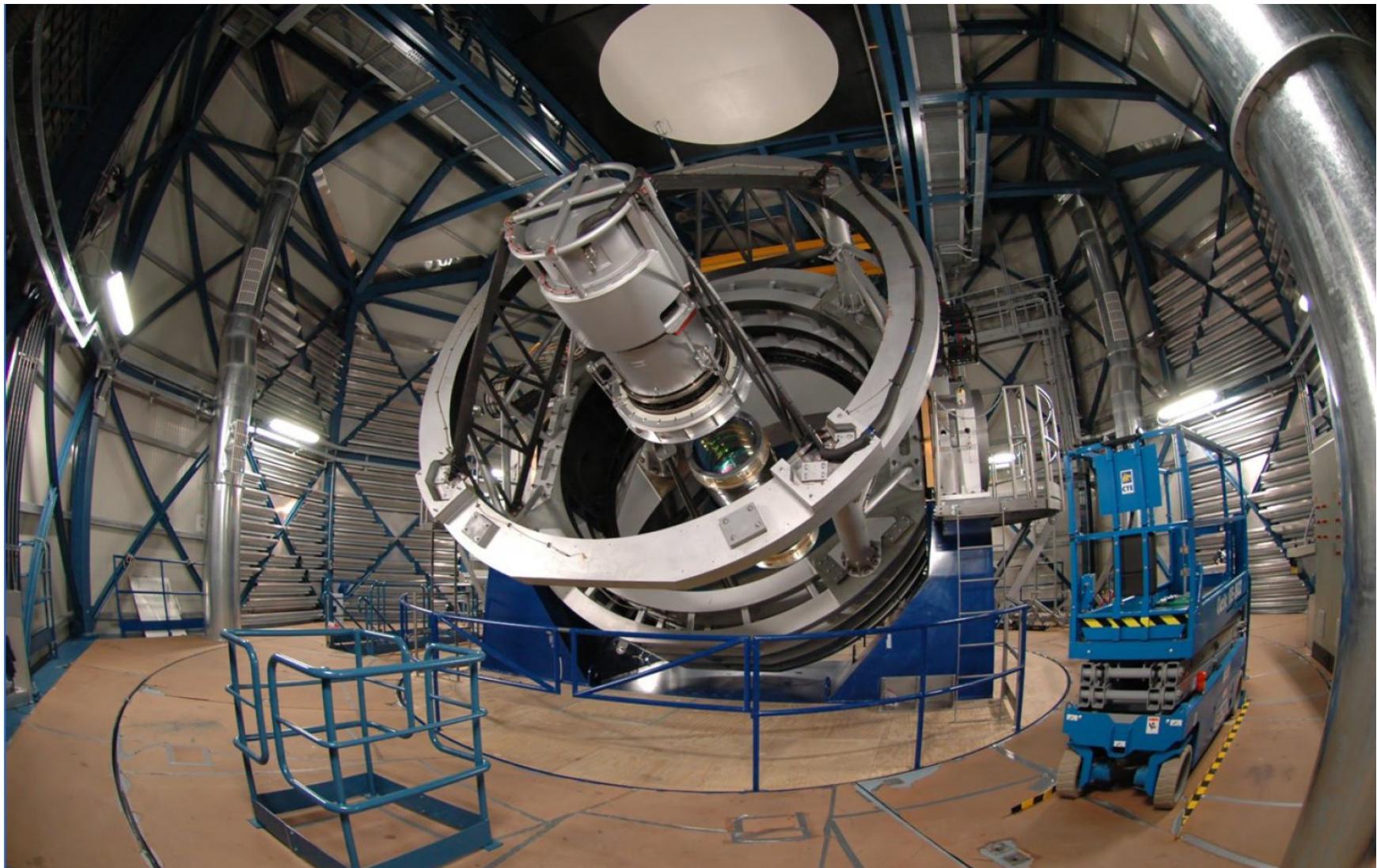


OZDES LIVE SNE!

20130909-r Peak r=21.5

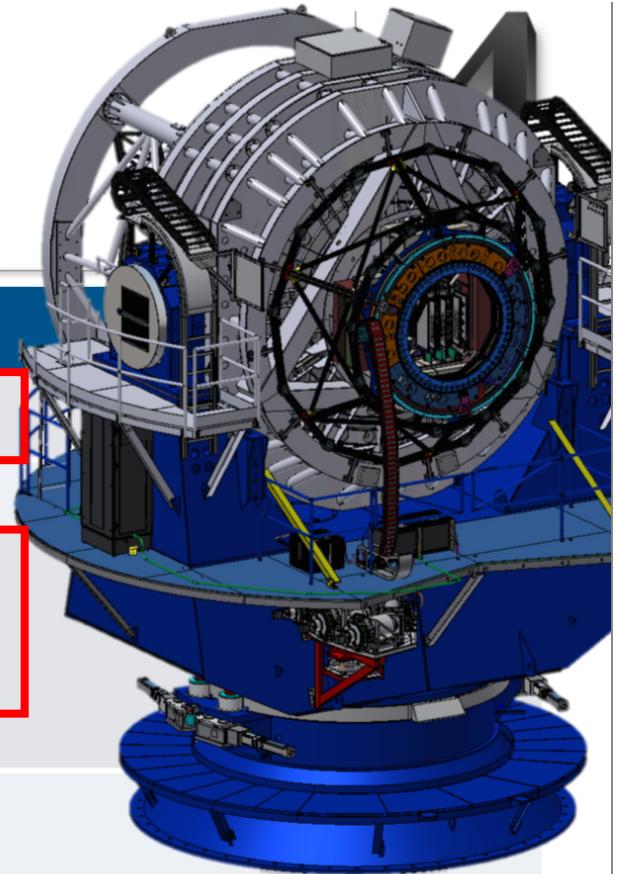


4MOST: A multi-fibre spectrograph for the ESO VISTA telescope

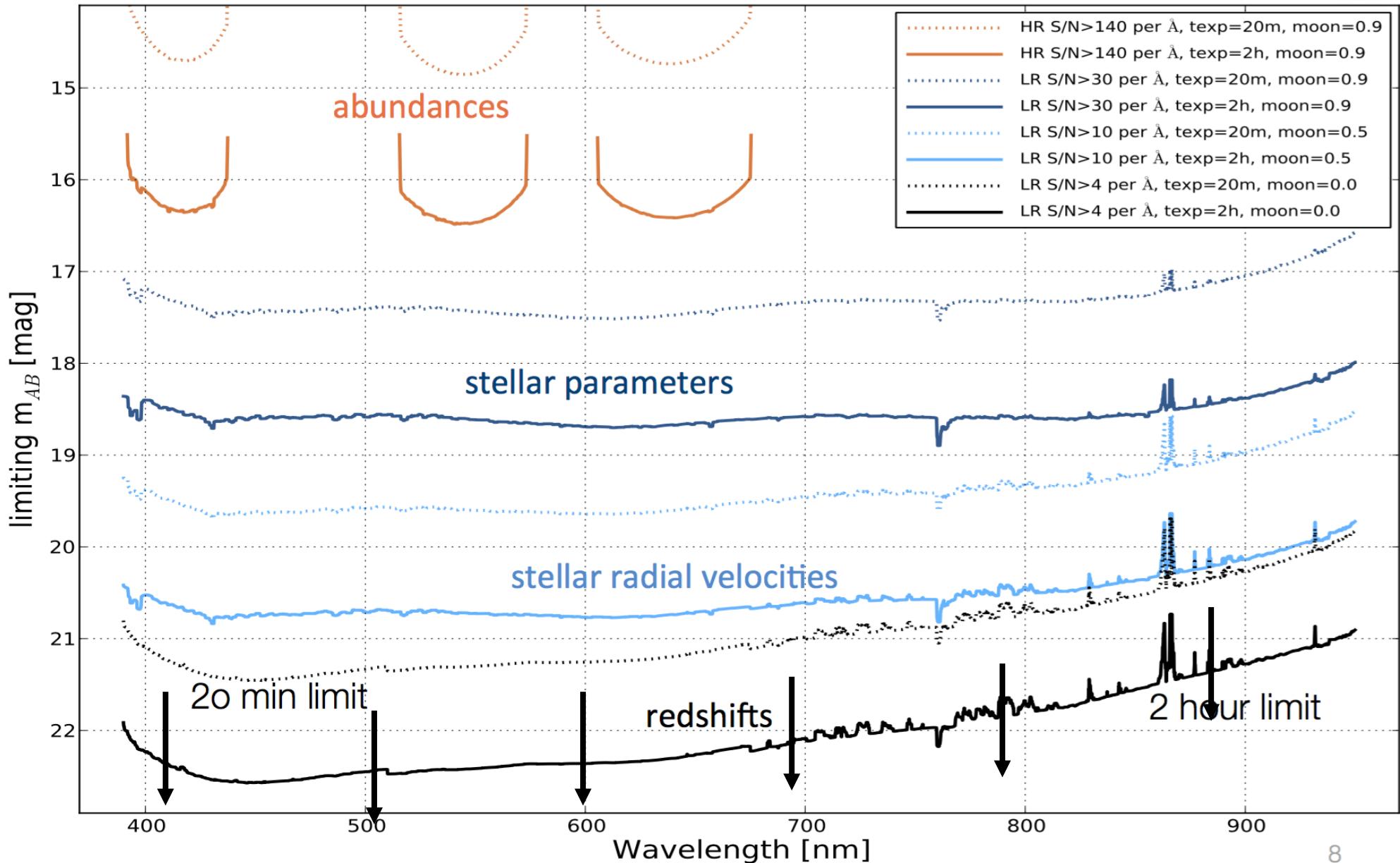


Instrument Specification

Specification	Design value
Field-of-View (hexagon)	~4.1 degree ² ($\phi > 2.5^\circ$)
Multiplex fiber positioner	~2436
Medium Resolution Spectrographs (2x)	R~4000–7000
# Fibres	812 fibres (2x)
Passband	370-950 nm
Velocity accuracy	< 1 km/s
High Resolution Spectrograph (1x)	R~20,000
# Fibres	812 fibres
Passband	392.6-435.5, 516-573, 610-679 nm
Velocity accuracy	< 1 km/s
# of fibers in $\phi=2'$ circle	>3
Fibre diameter	$\phi=1.45$ arcsec
Area (first 5 year survey)	>2h x 18,000 deg ²
Number of science spectra (5 year)	~75 million of 20 min



Magnitude limits for typical science cases



4MOST / TiDES Survey

- *Time Domain Extragalactic Survey (TiDES)*
- 250,000 fibre hours over 5-years
 - Average 2.5% of fibres in any pointing
 - 32 fibres/pointing x 8 pointings x 150 dark nights ~ 50,000 spectra/yr
- Can be live transients or host galaxies
- Scheduling 1-7 days in advance (TBD)
- Envisage sensible overlap of 4MOST calibration fields and LSST Deep Drilling fields

TiDES broad strategy SN Ia host galaxies

- Rationale: Wherever 4MOST points, LSST will have previously discovered SNe. Put a 4MOST fibre on the host galaxy to get a redshift.
- How many fibres do we need for this?
- **Assumptions**
 - On average LSST produces 0.5 SNeIa/yr/sq deg to $z=0.5$ **that are suitable for cosmology (depends on light-curve quality)**. **Large uncertainty!**
 - LSST starts operation in 2021 (...)
 - 4MOST starts operation in 2022
 - 4MOST covers 18,000 deg², visiting each area of sky at least twice, in first 5 years
 - Each 4MOST visit is 1 hour (3 x 20 mins).
 - Each host must be observed twice to reach sufficient S/N

Rough numbers for LSST SN hosts

Year	New 4MOST area covered (sq deg)	Number of known LSST SNe hosts in that area
2022	4,000	4,000
2023	4,000	6,000
2024	4,000	8,000
2025	4,000	10,000
2026	4,000	12,000
Total	20,000	40,000

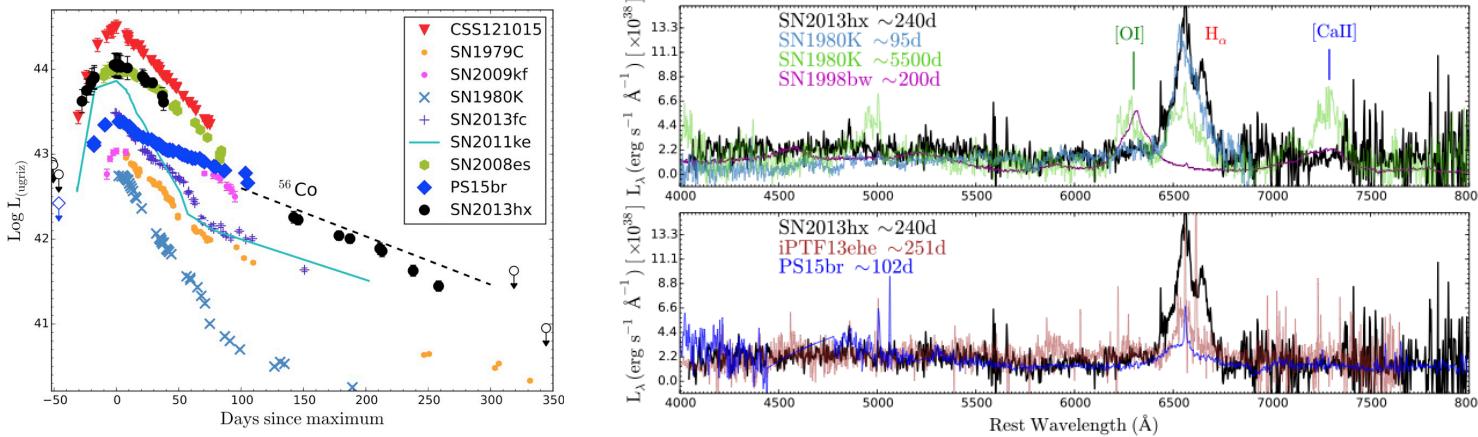
- We require 2hrs x 40,000 fibres = 80,000 fibre-hours
- Final sample = 40,000 SNels
- Note: LSST rate uncertainty !
- Doesn't include non-Ia hosts (contamination)
- Doesn't include LSST Deep drilling fields (or other TiDES science cases)

TiDES survey strategy: deeper observations

- ~10% of 4MOST sky visited more than twice because of overlaps between adjacent pointings
- 4MOST Deep fields build-up signal on faintest hosts and live SNe.
 - Dynamic scheduling – once sufficient signal-to-noise is obtained, move fibre to another source (cf. Similar to OzDES)
 - 4MOST's deep fields should coincide with those of LSST: higher redshift SNe with better LSST lightcurves

Live transients:science goals

- Classification: Hostless SNe and training samples
 - R=22.5 AB == a normal SN Ia at z=0.5
 - Expect 3-4 live SNe per 4MOST pointing; 15000-20000 over 5 years
- *Screening: triggering follow-up on other facilities*
- *Outliers: find rare events (e.g., very luminous events)*
- *Rates, environments, correlations with host galaxy properties*
- *Transient physics (from 4MOST and follow-up elsewhere)*
- *SLSNe to z~2; possible standard candles for cosmology*



Two Hydrogen-rich SLSNe, screened with PESSTO (2-4m telescopes) and followed with VLT. (Inserra et al 2016)

DES HOST/TRANSIENT MAGNITUDE

PARAMETER SPACE

