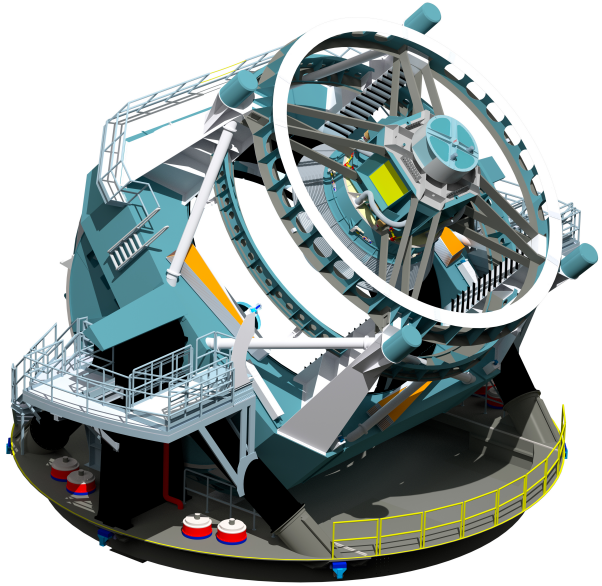
European Research Council
Established by the European Commission

Spectroscopic Follow-up

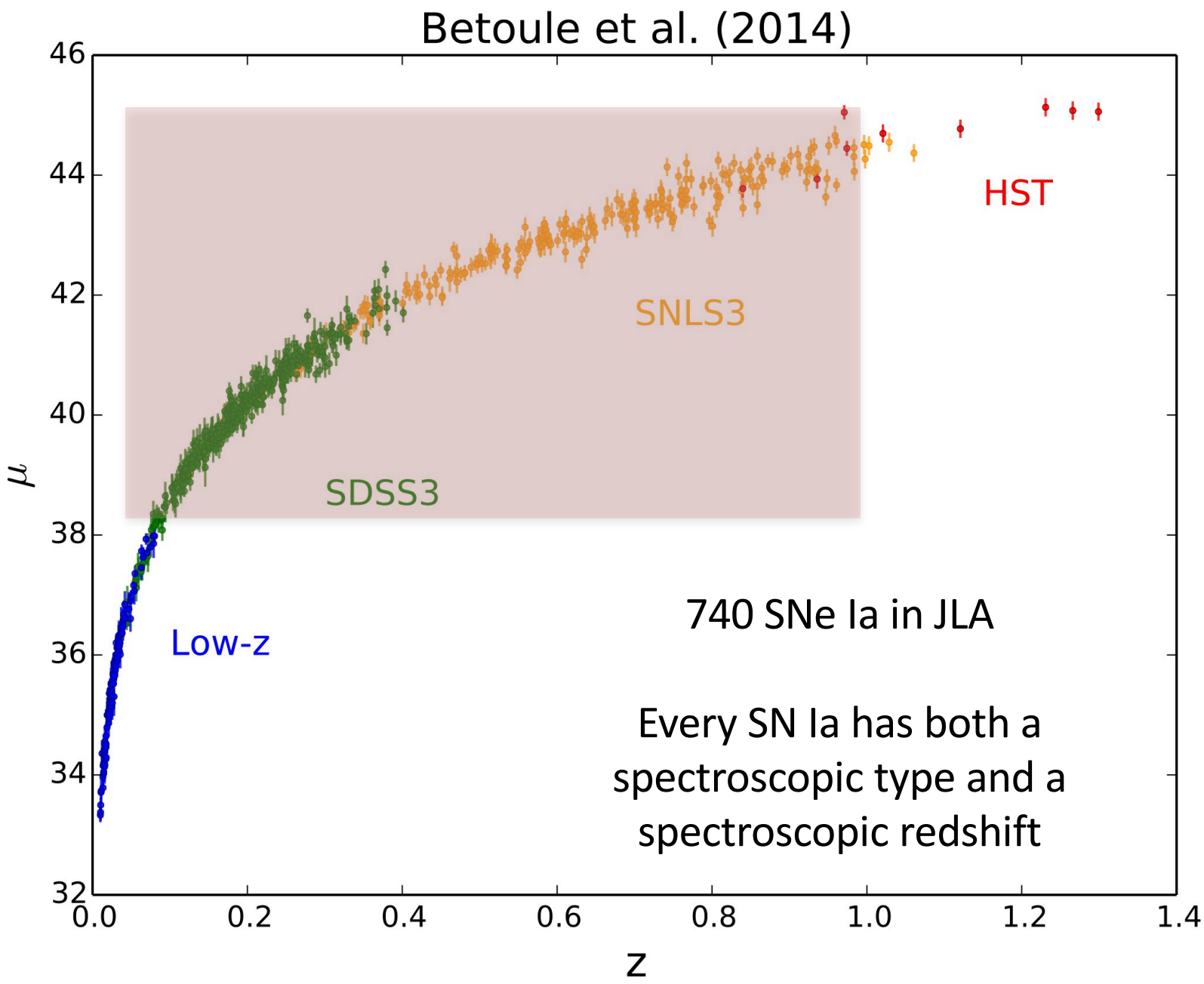
Mark Sullivan, Southampton



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)
HST
SNLS3
SDSS3
Low-z
740 SNe Ia in JLA
Every SN Ia has both a spectroscopic type and a spectroscopic redshift
μ
z
46
44
42
40
38
36
34
32
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

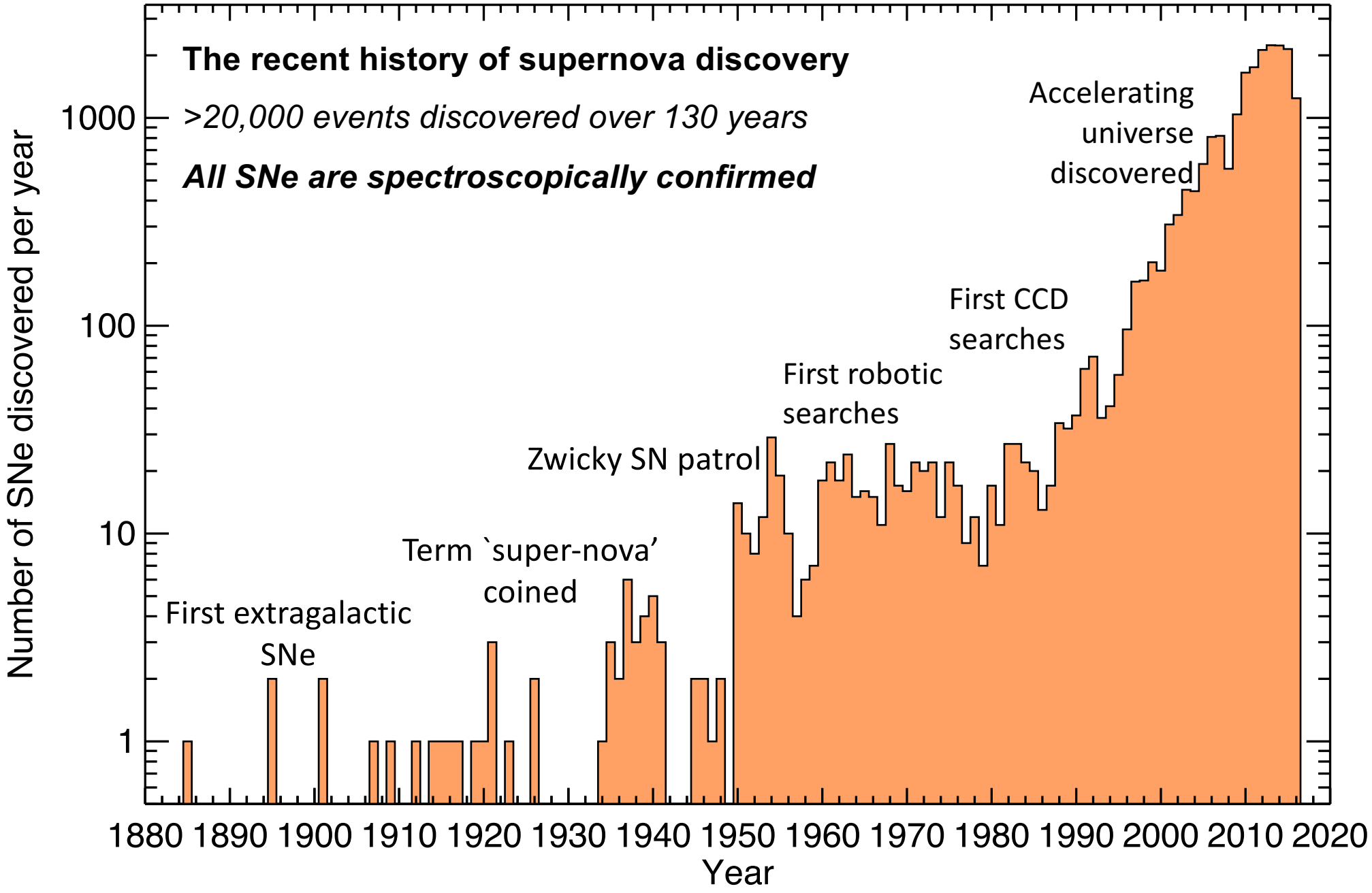
Simplified SN systematic-error budget ("JLA")

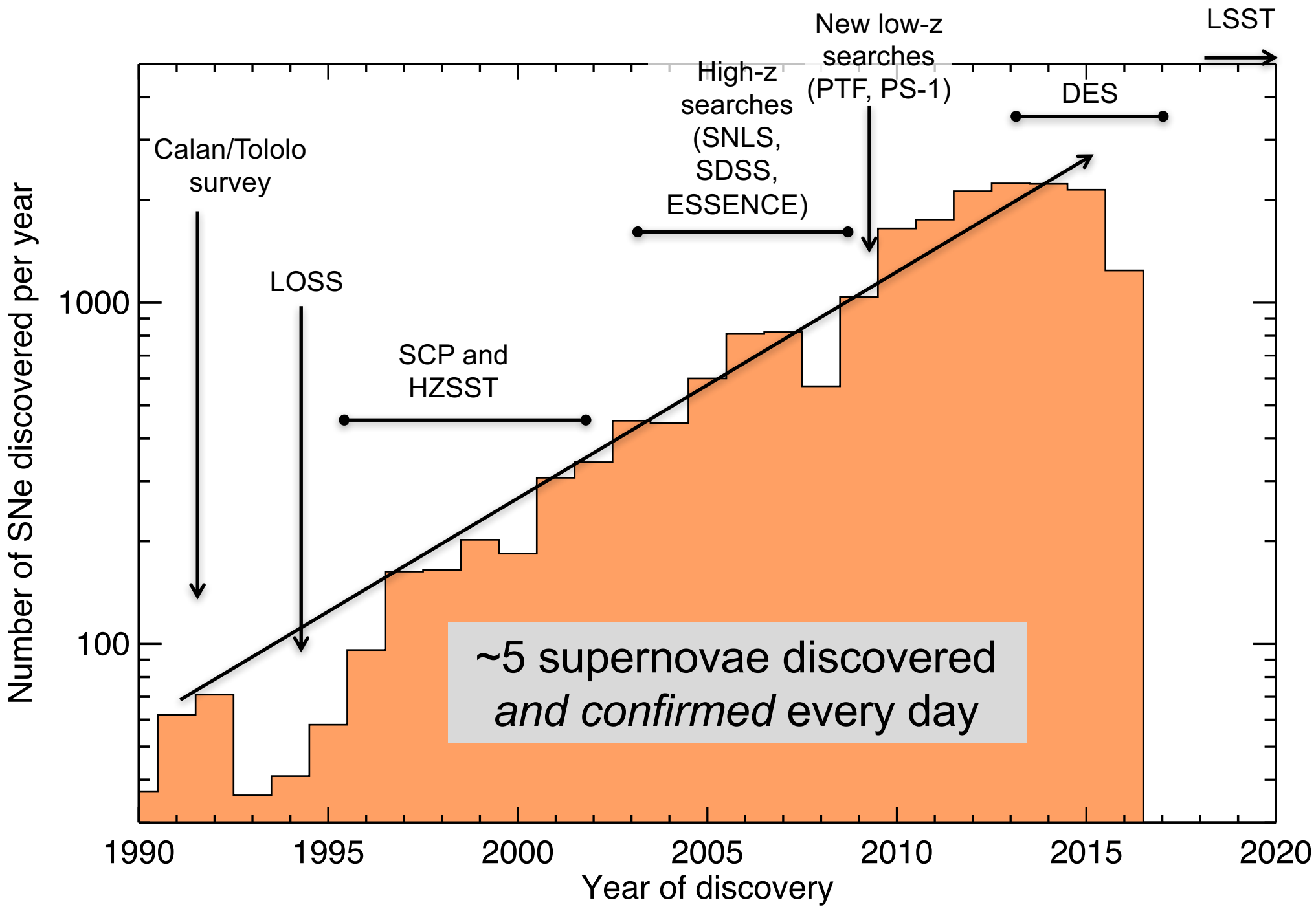
Uncertainty sources	$\sigma_x(\Omega_m)$	% of $\sigma^2(\Omega_m)$
Calibration	0.0203	36.7
Milky Way extinction	0.0072	4.6
Light-curve model	0.0069	4.3
Bias corrections	0.0040	1.4
Host relation[a]	0.0038	1.3
Contamination	0.0008	0.1
Peculiar velocity	0.0007	0.0
Stat	0.0241	51.6

Photometric calibration is (by far) the dominant systematic uncertainty

Betoule et al. 2014

Number of SNe discovered per year



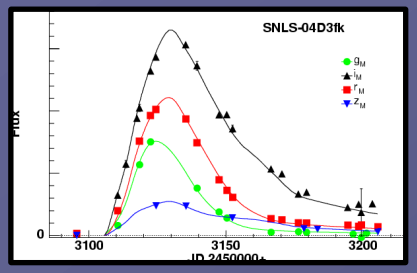

Number of SNe discovered per year
LSST
New low-z searches (PTF, PS-1)
High-z searches (SNLS, SDSS, ESSENCE)
DES
Calan/Tololo survey
LOSS
SCP and HZSST
~5 supernovae discovered *and confirmed* every day
Number of SNe discovered per year
1000
100
1990
1995
2000
2005
2010
2015
2020
Year of discovery

Supernova Legacy Survey: 2003—2008

Imaging

Distances from light-curves

Discoveries

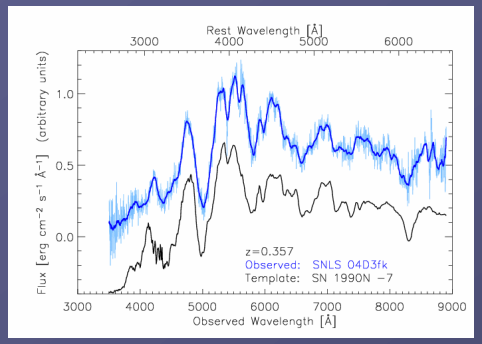


Lightcurves

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)

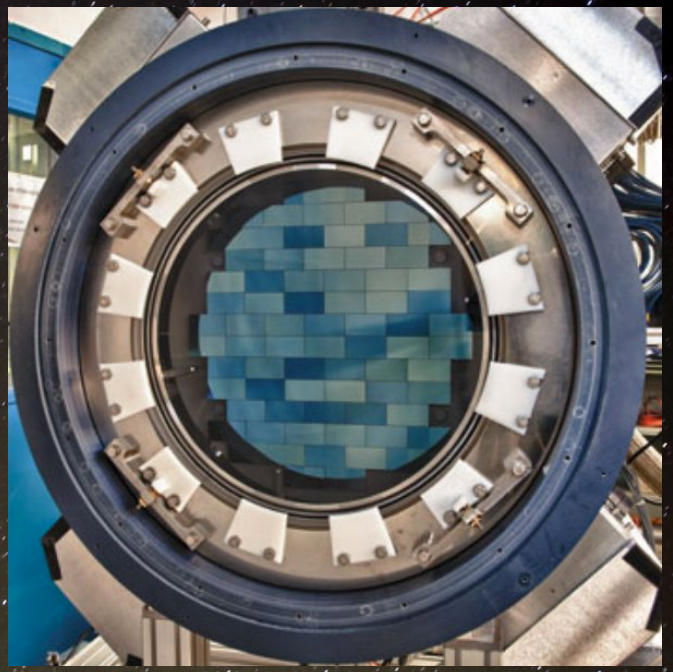
Keck (8 n/yr)

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 deg^2 in *grizY*: r_{AB} ~ 24.3, i_{AB} ~23.5 (10σ)
- Large Scale Structure; Weak Lensing; Galaxy Cluster

DES-SN

- ~ 6-day cadenced *griz survey* over 27 deg^2
- Type Ia Supernovae

Probes of both Distance vs. Redshift & Growth of Structure

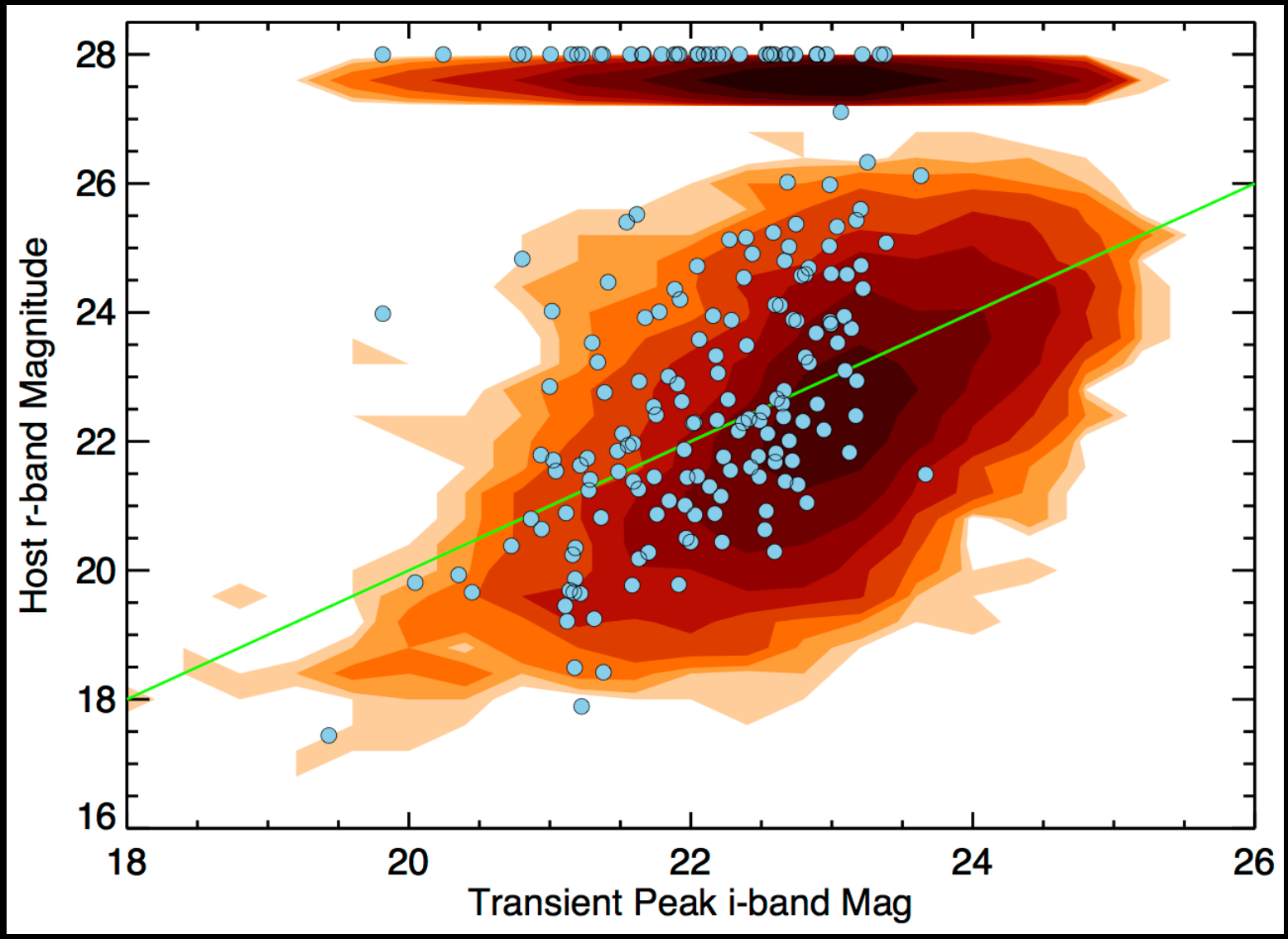
UK DES Collaboration

Cambridge ❖ Edinburgh ❖ Nottingham ❖ Portsmouth ❖ Sussex ❖ UCL

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

- 520 Mpx camera; 3 deg^2 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

After the fact
Thousands of events

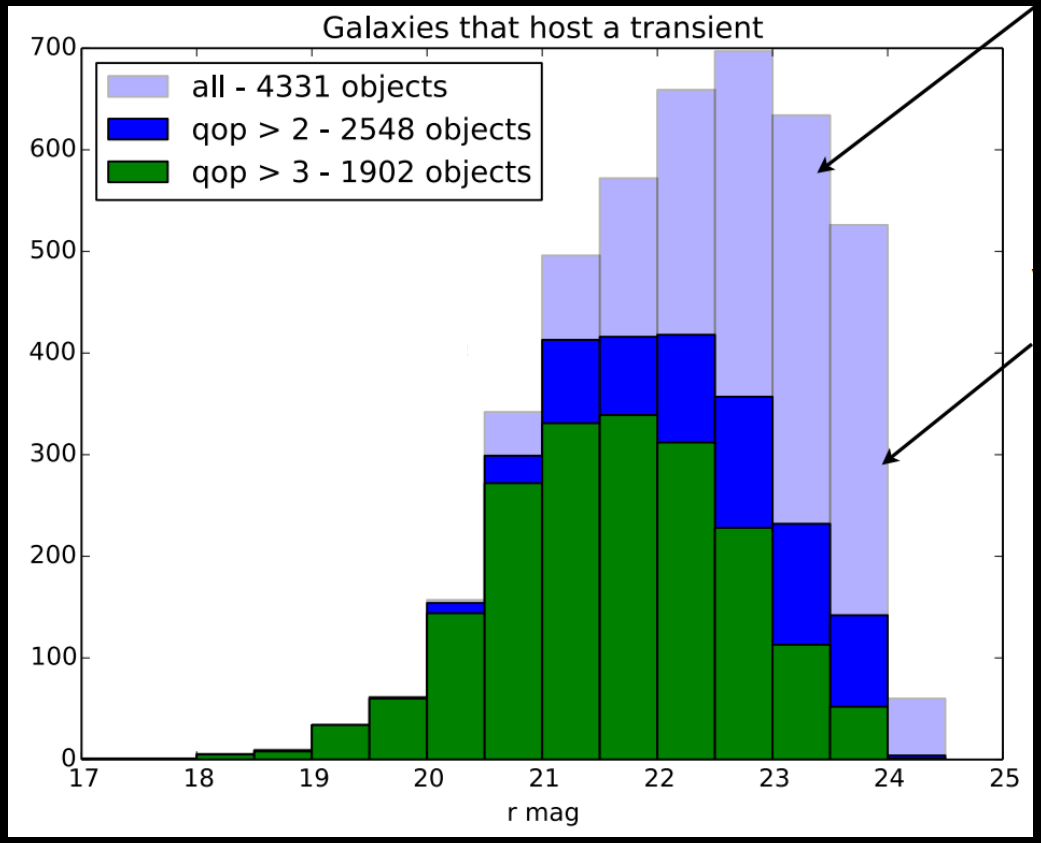
- SNe in Faint Host Galaxies
  - Redshifts for faint hosts; unbiased sample
- Representative sample
  - Tuned to cover parameter space expected from photometric-cosmology sample
- Complete sample
  - Measure SN population demographics at low-z
  - Unbiased sample
- Ancillary programs (SN Physics, weirdos)

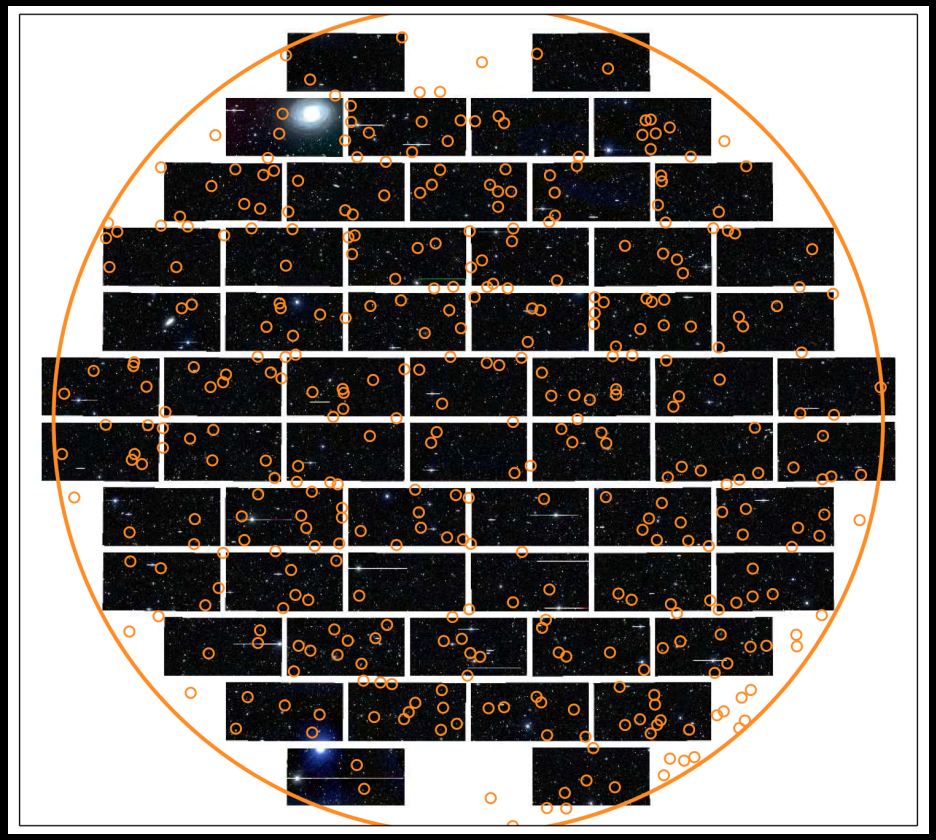
Live
Hundreds of events

AAT: OzDES

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

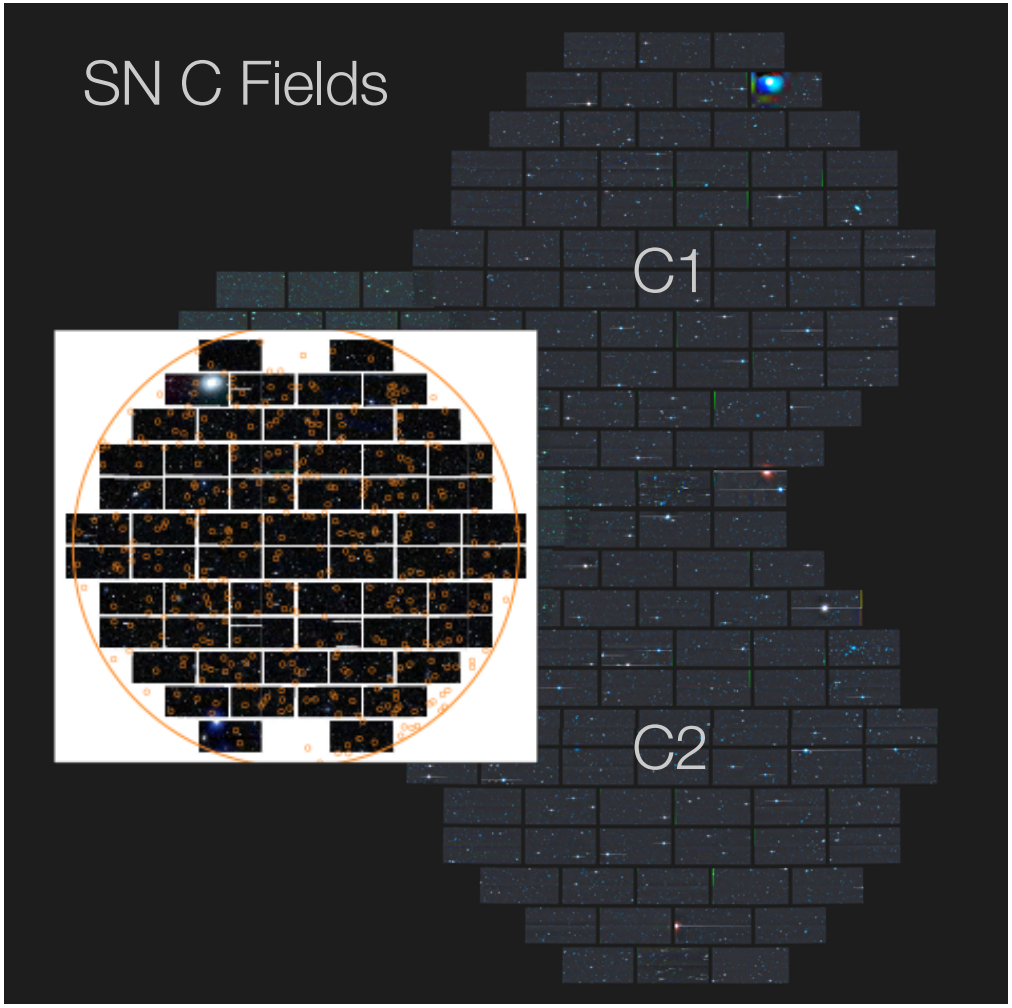
On target for ~4000 SN host redshifts

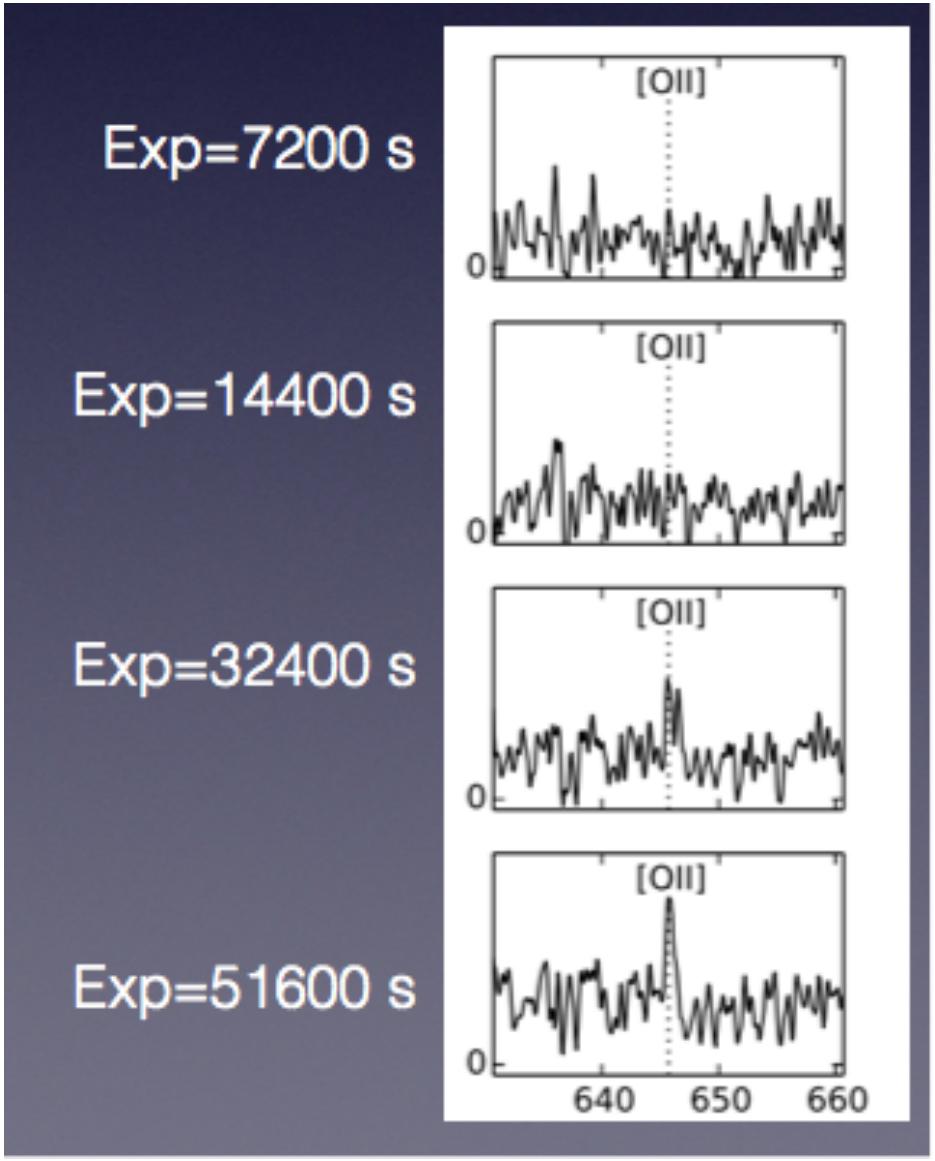




Courtesy C. Lidman

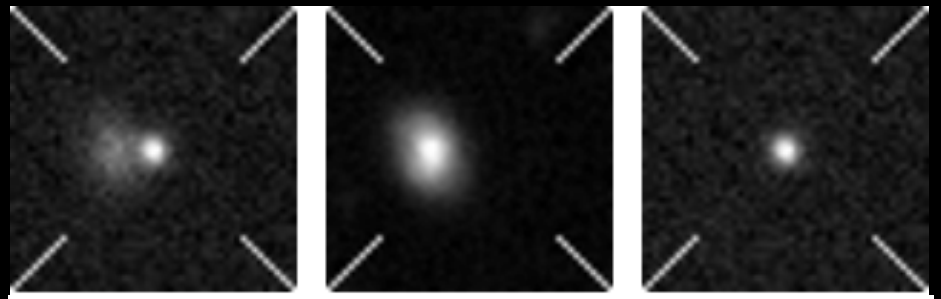
Large MOS follow-up of SN hosts

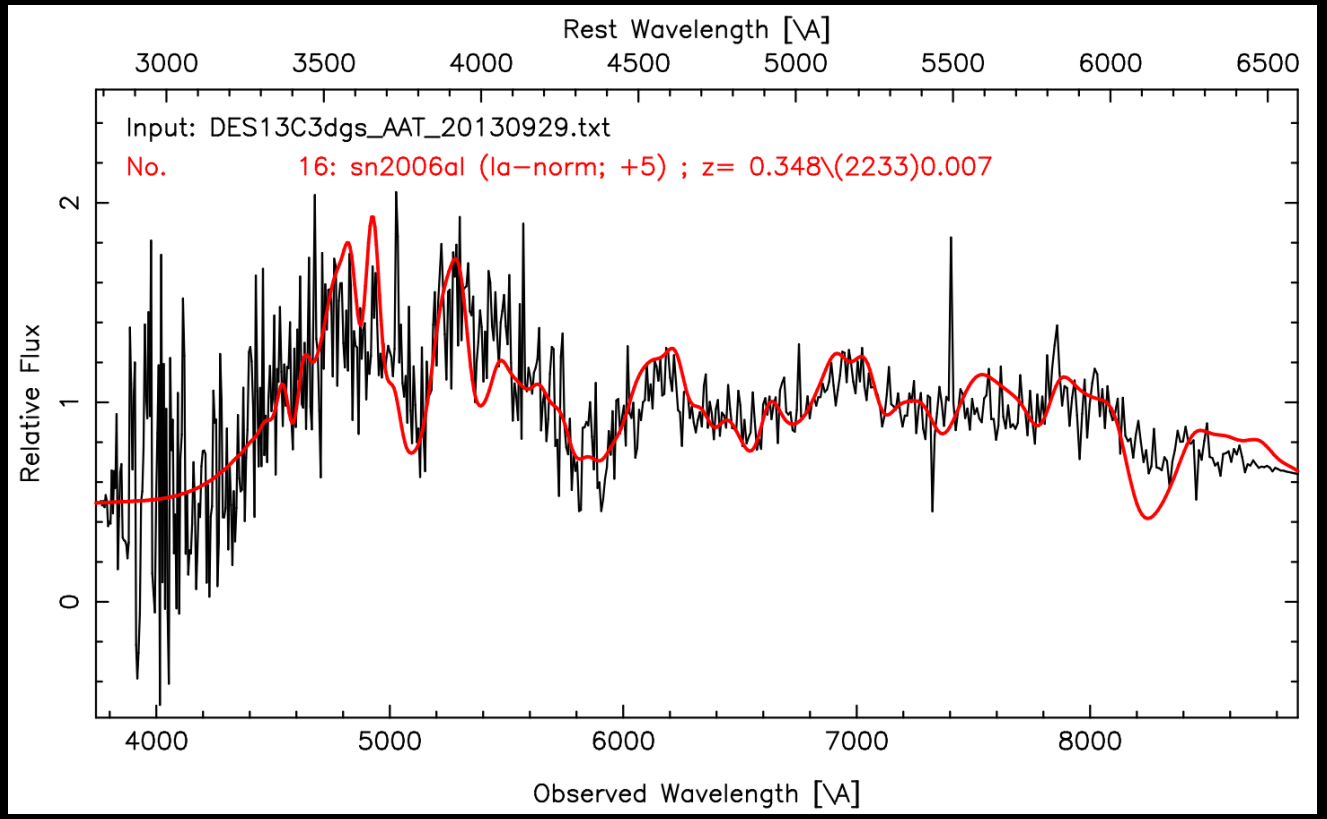




OzDES Live SNe!

20130909-r Peak r=21.5

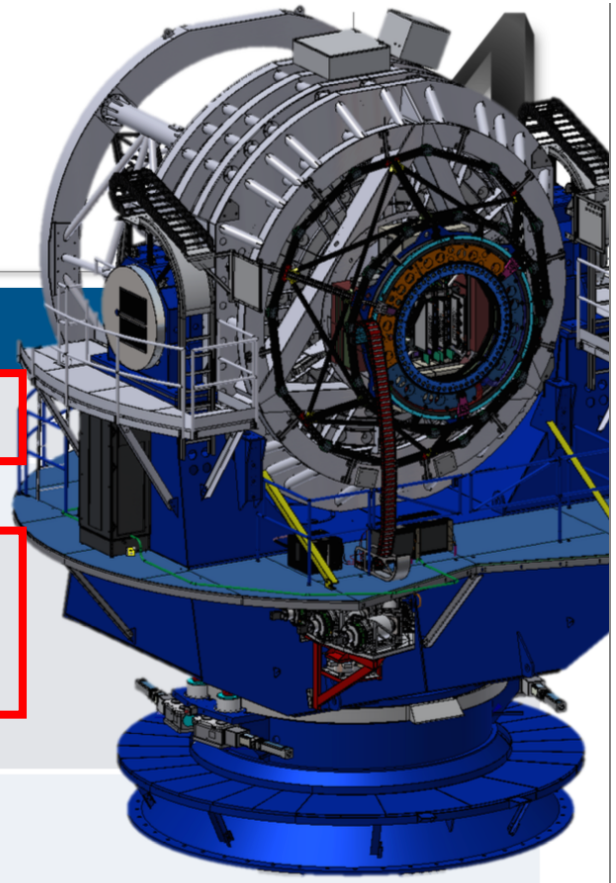




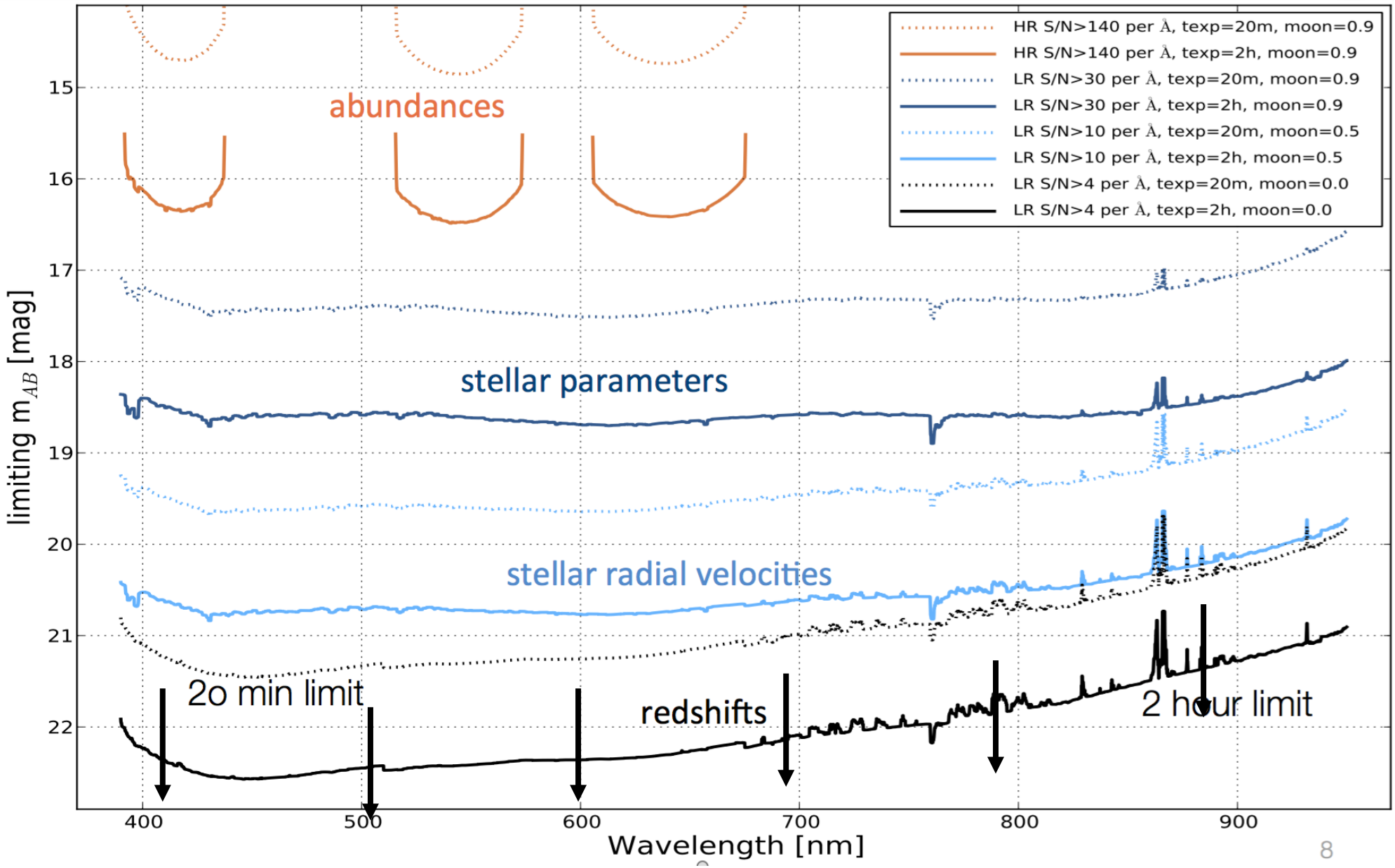
4MOST: A multi-fibre spectrograph for the ESO VISTA telescope

Instrument Specification

Specification	Design value
Field-of-View (hexagon)	~4.1 degree^2 (ø**>2.5°**)
Multiplex fiber positioner	~2436
Medium Resolution Spectrographs (2x) # Fibres Passband	R~4000–7000 812 fibres (2x) 370-950 nm
Velocity accuracy	< 1 km/s
High Resolution Spectrograph (1x) # Fibres Passband Velocity accuracy	R~20,000 812 fibres 392.6-435.5, 516-573, 610-679 nm < 1 km/s
# of fibers in ∅=2' circle	>3
Fibre diameter	∅=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 deg^2, 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 SNeIa
- Note: LSST rate uncertainty !
- Doesn’t include non-Ia hosts (contamination)
- Doesn’t include LSST Deep drilling fields (or other TiDES science cases)

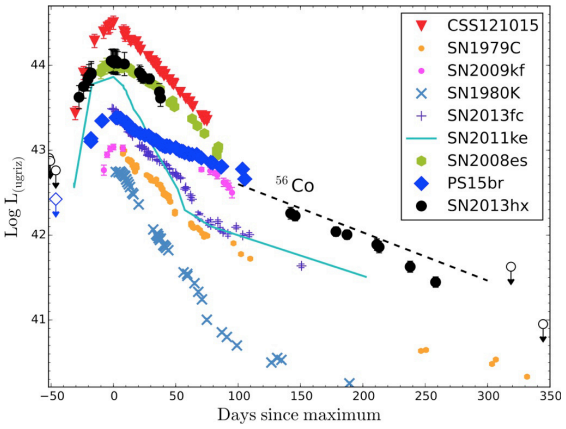
TiDES survey strategy: deeper observations

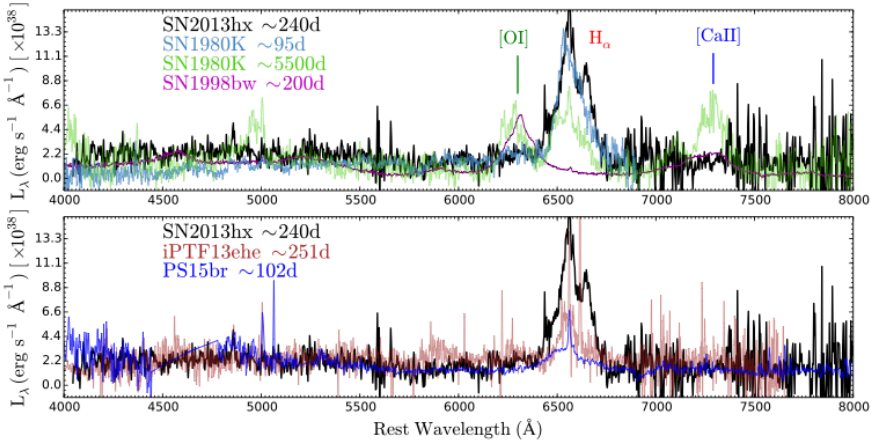
- ~10% of 4MOST sky visited more than twice because of overlaps between adjacent pointings
- 4MOST Deep fields build-up signal on faintest hosts and live SNe.
  - Dynamic scheduling – once sufficient signal-to-noise is obtained, move fibre to another source (cf. Similar to OzDES)
  - 4MOST's deep fields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