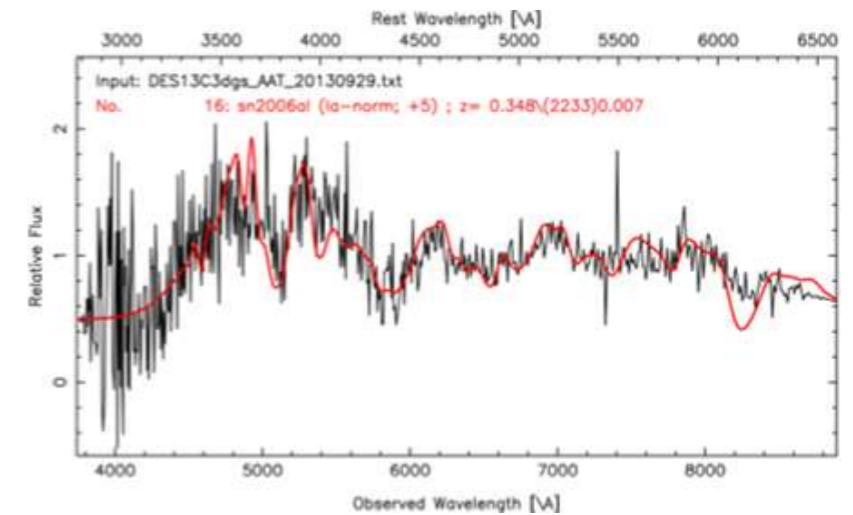
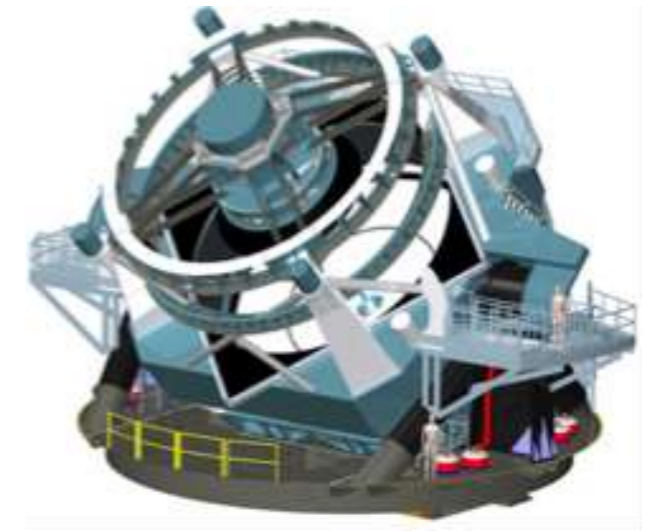


The Time-Domain Extragalactic Survey

LSST & 4MOST

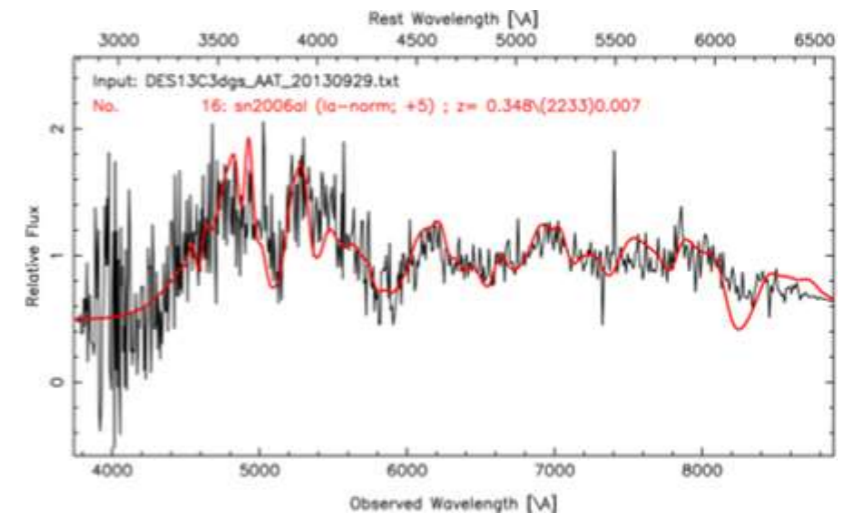
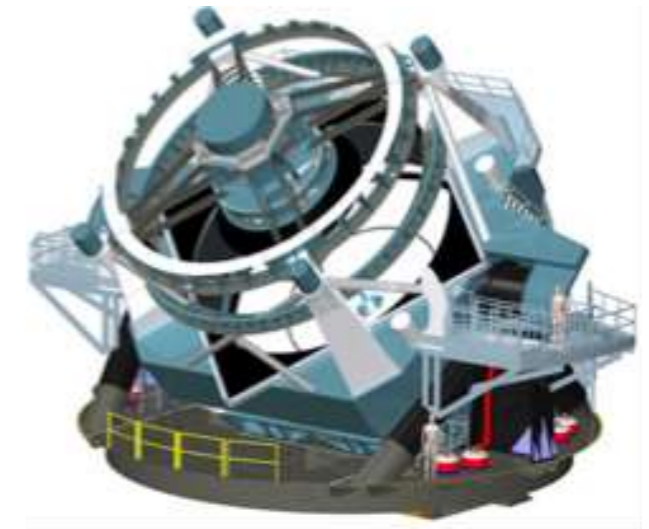
Elizabeth Swann
Institute of Cosmology and Gravitation

On behalf of the TiDES team: Mark Sullivan (PI)
tides@4most.eu



The Time-Domain Extragalactic Survey

LSST & 4MOST

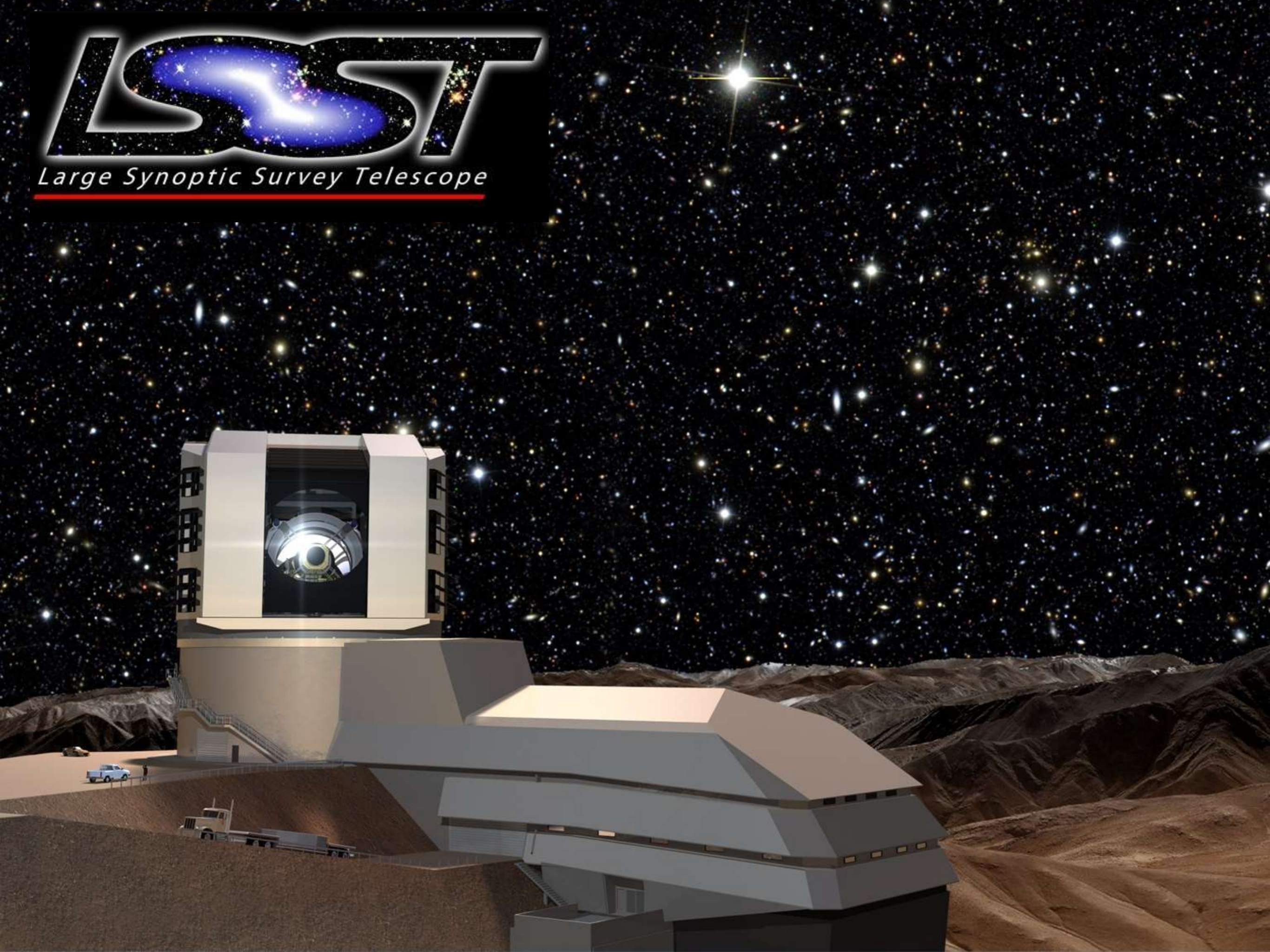


Overview: Part 1

- Transient Science in the LSST era
- LSST and Supernovae (SNe) Cosmology
- Why Spectroscopic Follow-up?
- 4MOST and Time Domain Extragalactic Survey (TiDES)
- Current simulations
- Hand over to Mark Sullivan – Phase B (Part 2)

LSST

Large Synoptic Survey Telescope



The Large Synoptic Survey Telescope

- LSST will be an enormous transient machine scanning the entire southern sky ~ every 3ish nights
- Under construction for science first light in 2021
 - 8.4 primary meter mirror
 - 3.2 giga-pixel CCD camera (largest digital camera ever constructed)
 - Will produce 1.2 petabytes of raw data a year, needing 250 teraflops of computing power to process

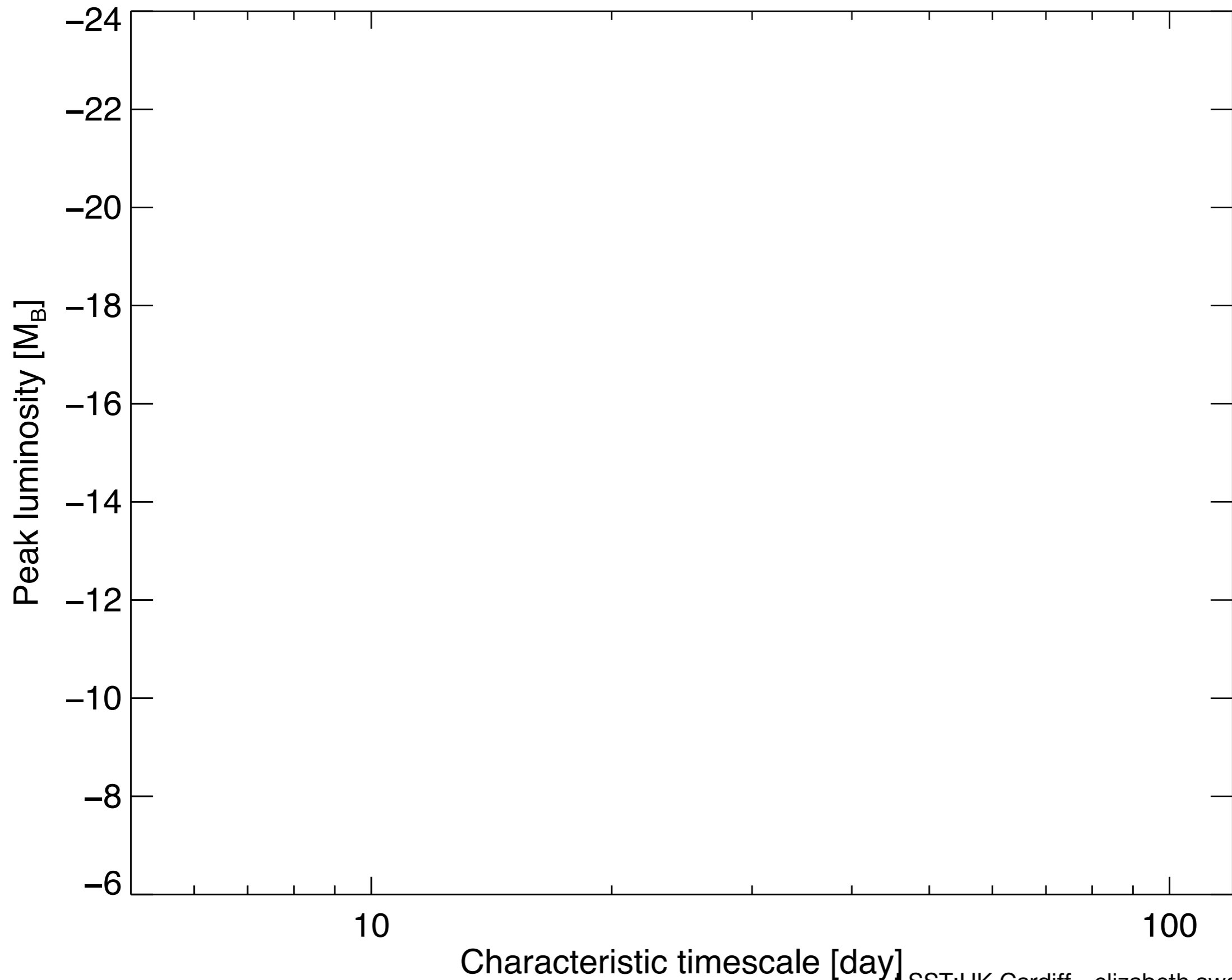


Image from Cerro Pachon Camera and KICP website

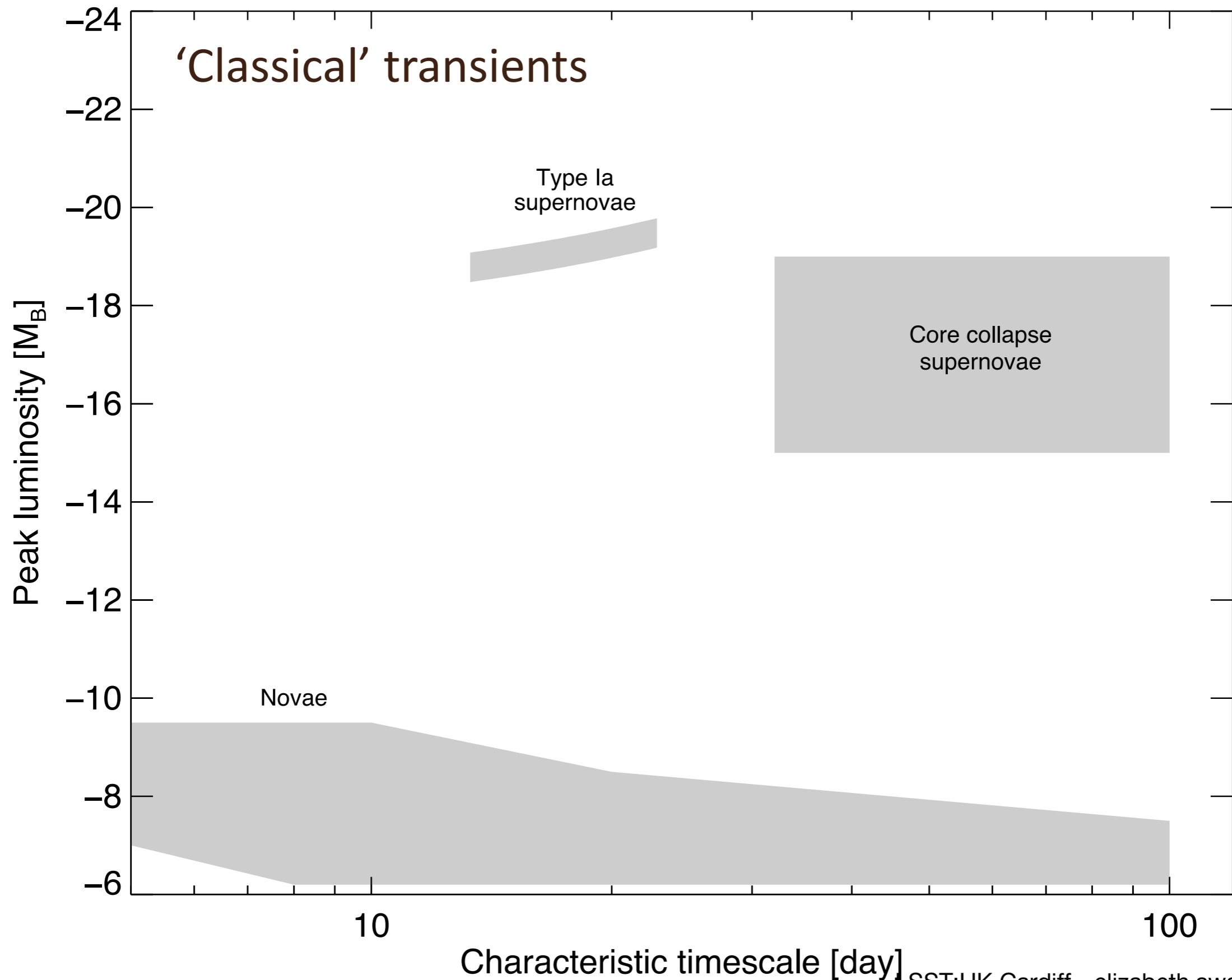


LSST:UK Cardiff - elizabeth.swann@port.ac.uk

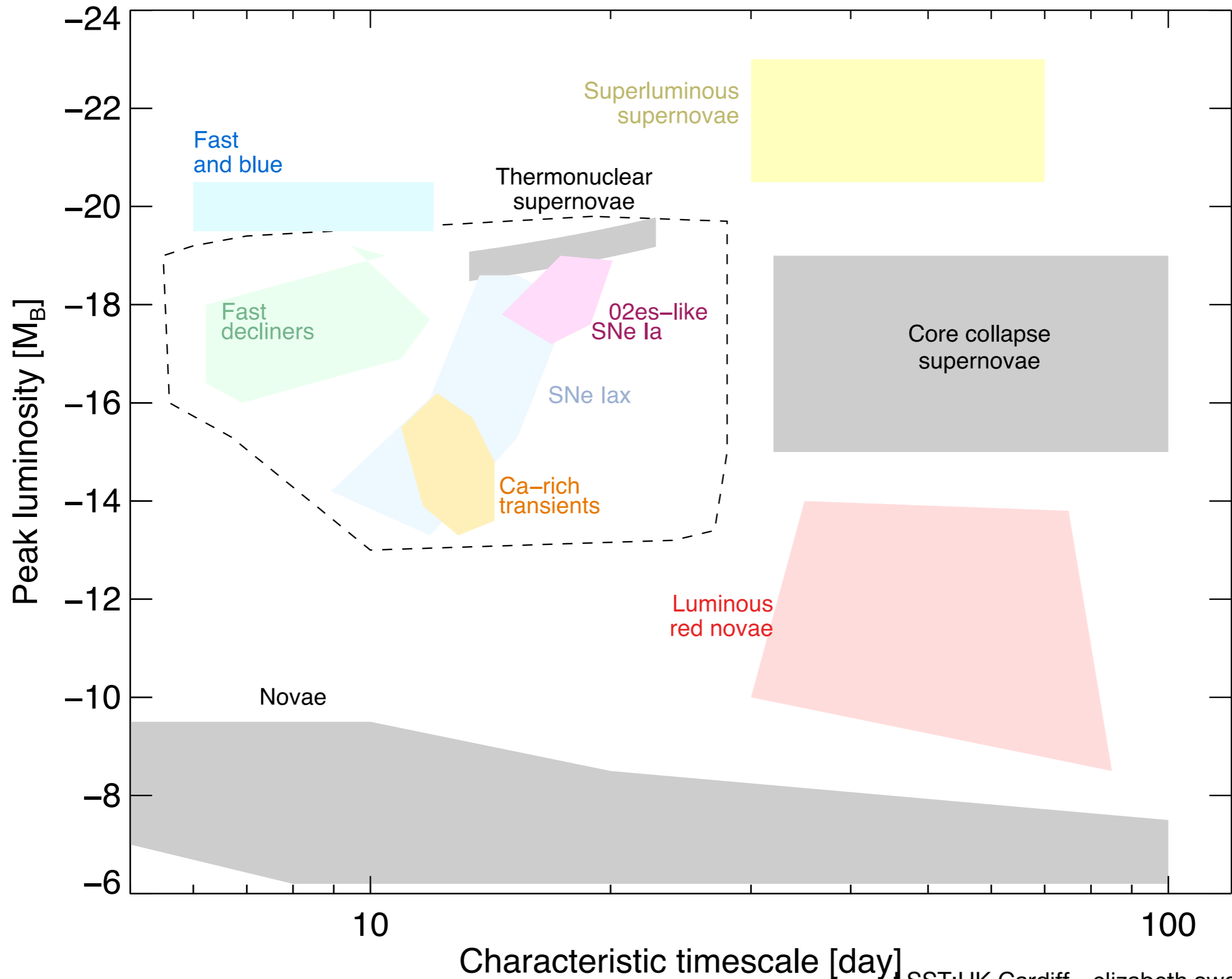
Explosive transient parameter space



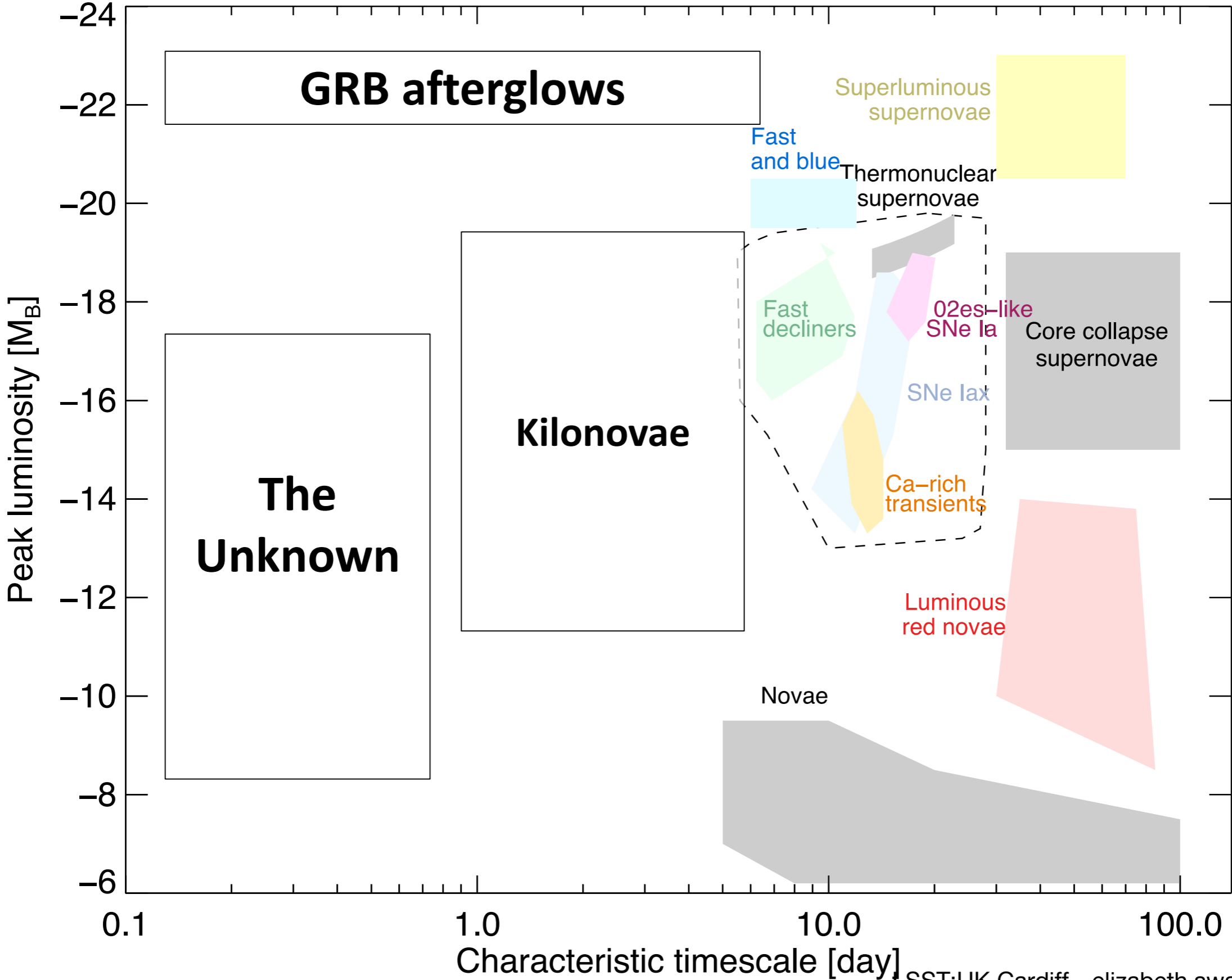
Explosive transient parameter space



Explosive transient parameter space



Explosive transient parameter space

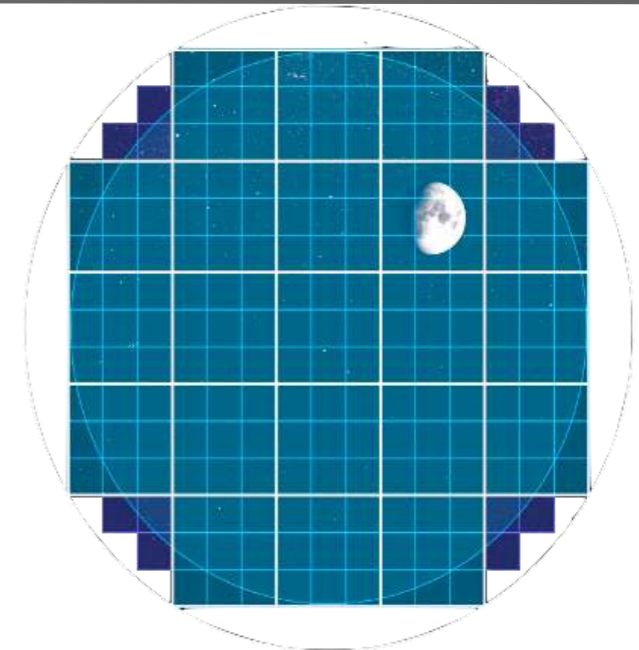


LSST and SN Cosmology

LSST will discover **vast quantities of supernovae:**

- 50,000 cosmologically useful SNe Ia p/year (LSST white paper)
z~0.7 (main survey)
z~1 (deep drilling fields)
- 10,000 SLSNe (Scovacricchi et al 2016)
- AGN, GRBs, TDEs, GW optical counterparts

Possibly objects we've never seen or thought of before!

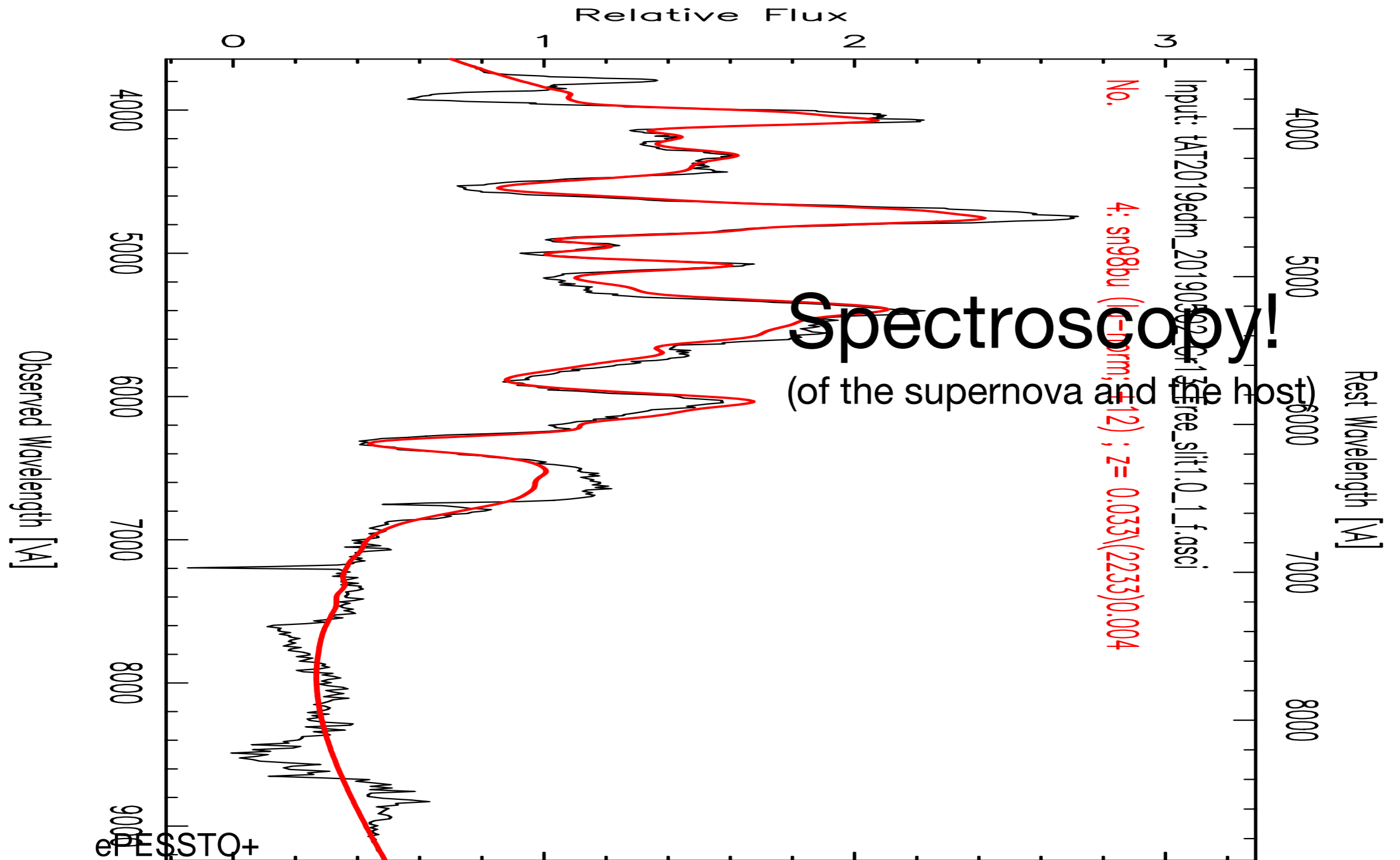


LSST 9.6 deg² FoV



The key to exploiting LSST SNe science?

The key to exploiting LSST SNe science?



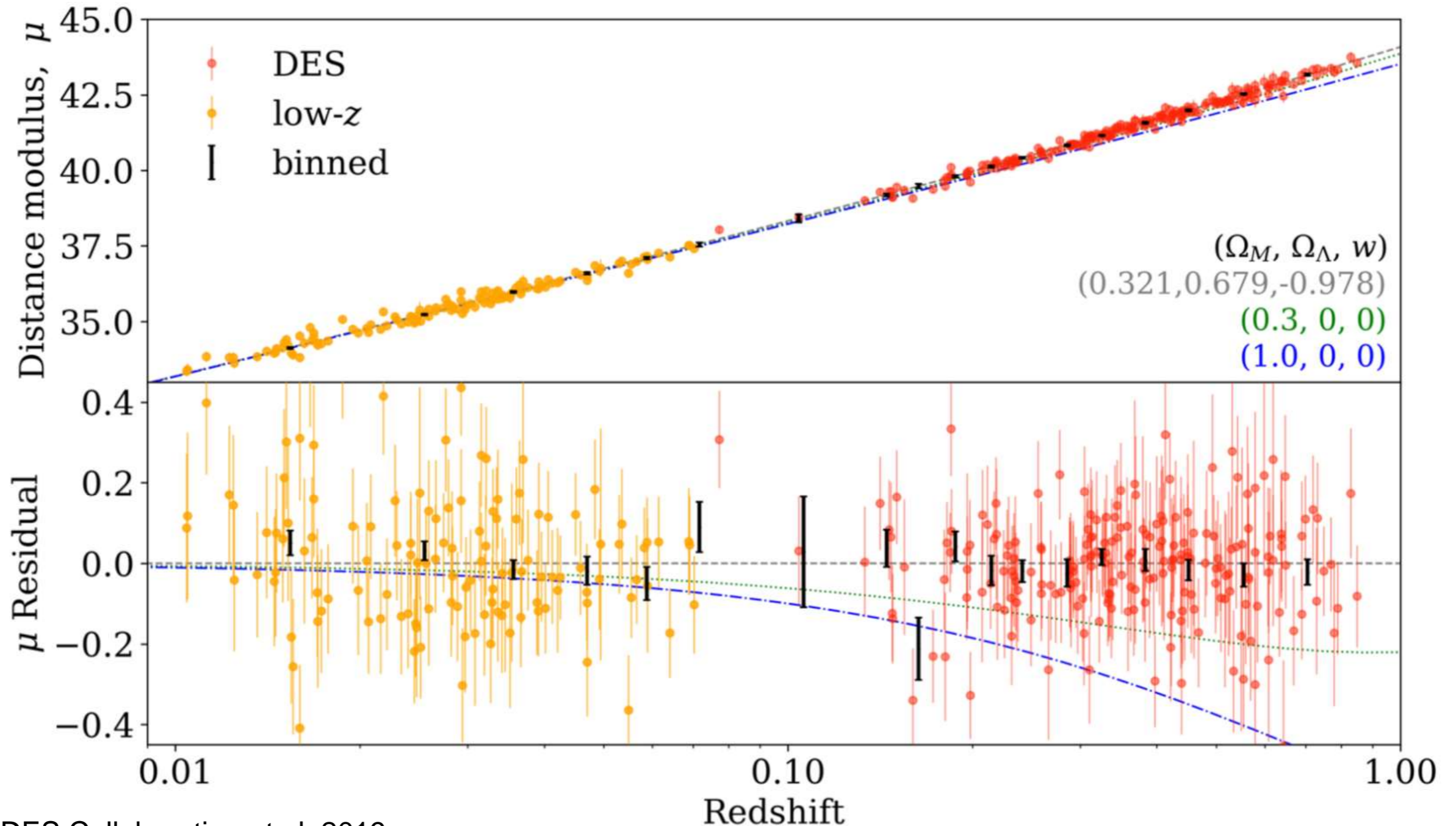
Spectroscopy!

(of the supernova and the host)

Why spectroscopy?

Why spectroscopy?

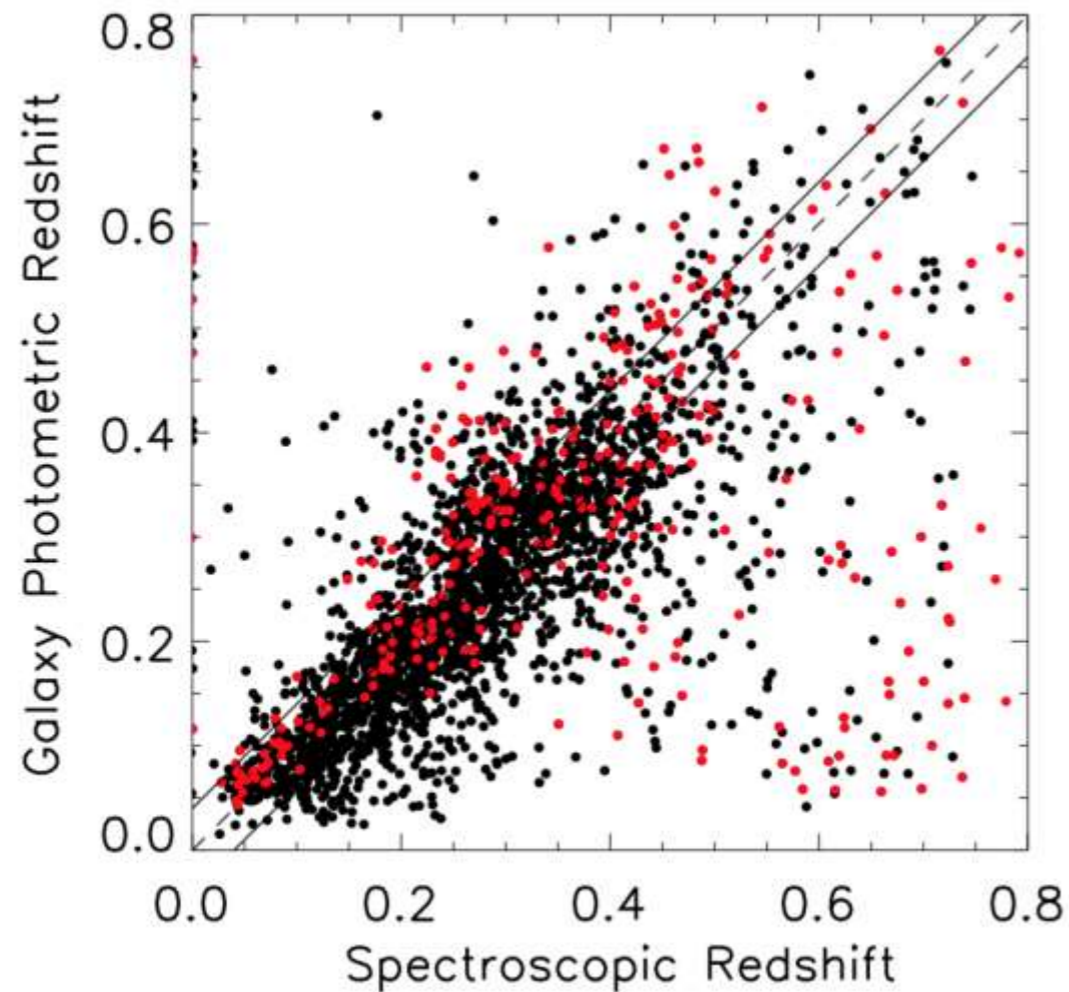
Allows for precision supernovae cosmology



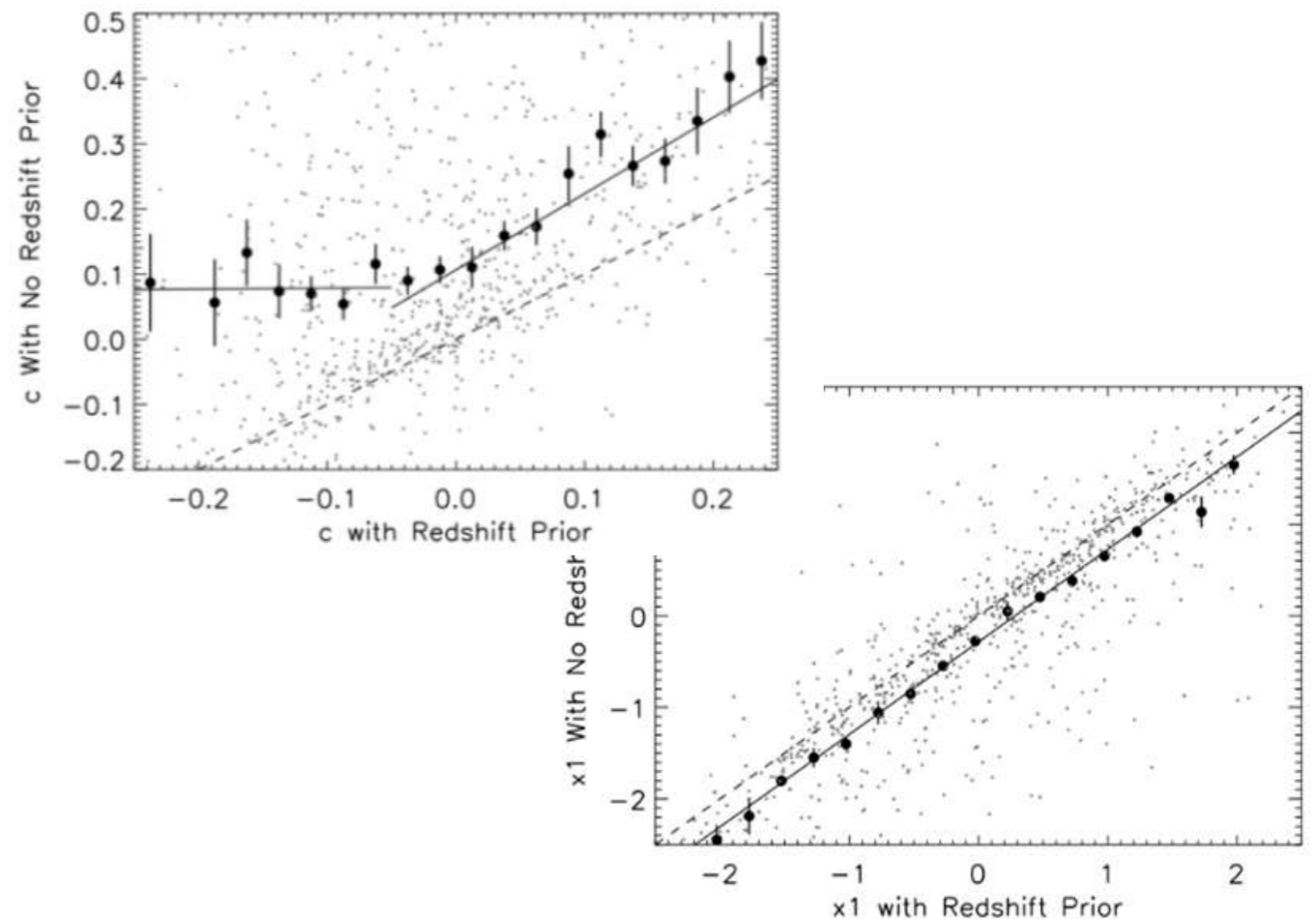
Why spectroscopy?

Allows for precision supernovae cosmology

Systematic bias favouring **lower photometric redshift** estimates and **redder colours** in the limit of low S/N data. (Olmstead et al 2014)



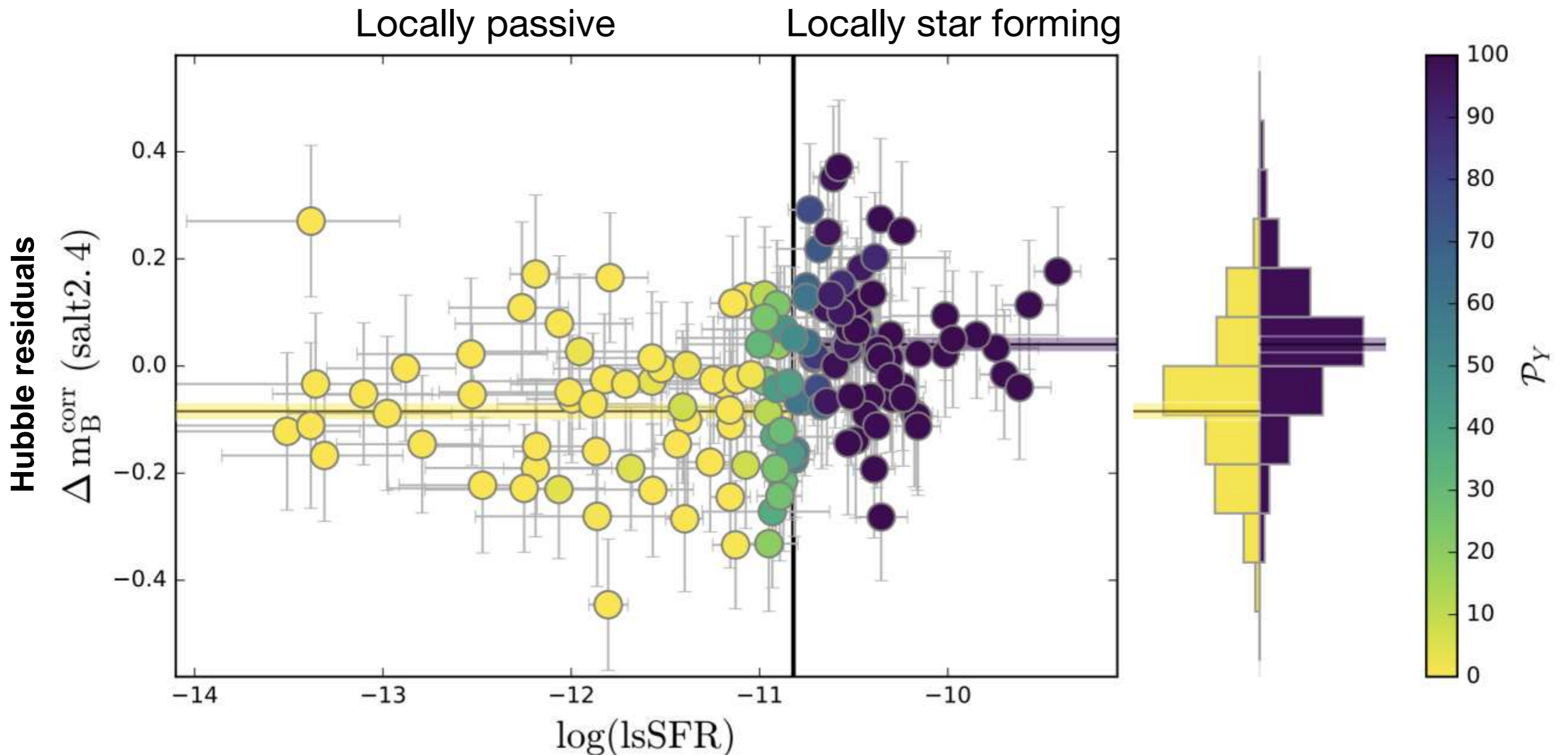
The difference between photometric redshift estimates and a spectroscopic redshift



Differences between derived SN parameters when using & not using a spectroscopic redshift

Why spectroscopy?

Measure correlations between HR and host galaxy properties

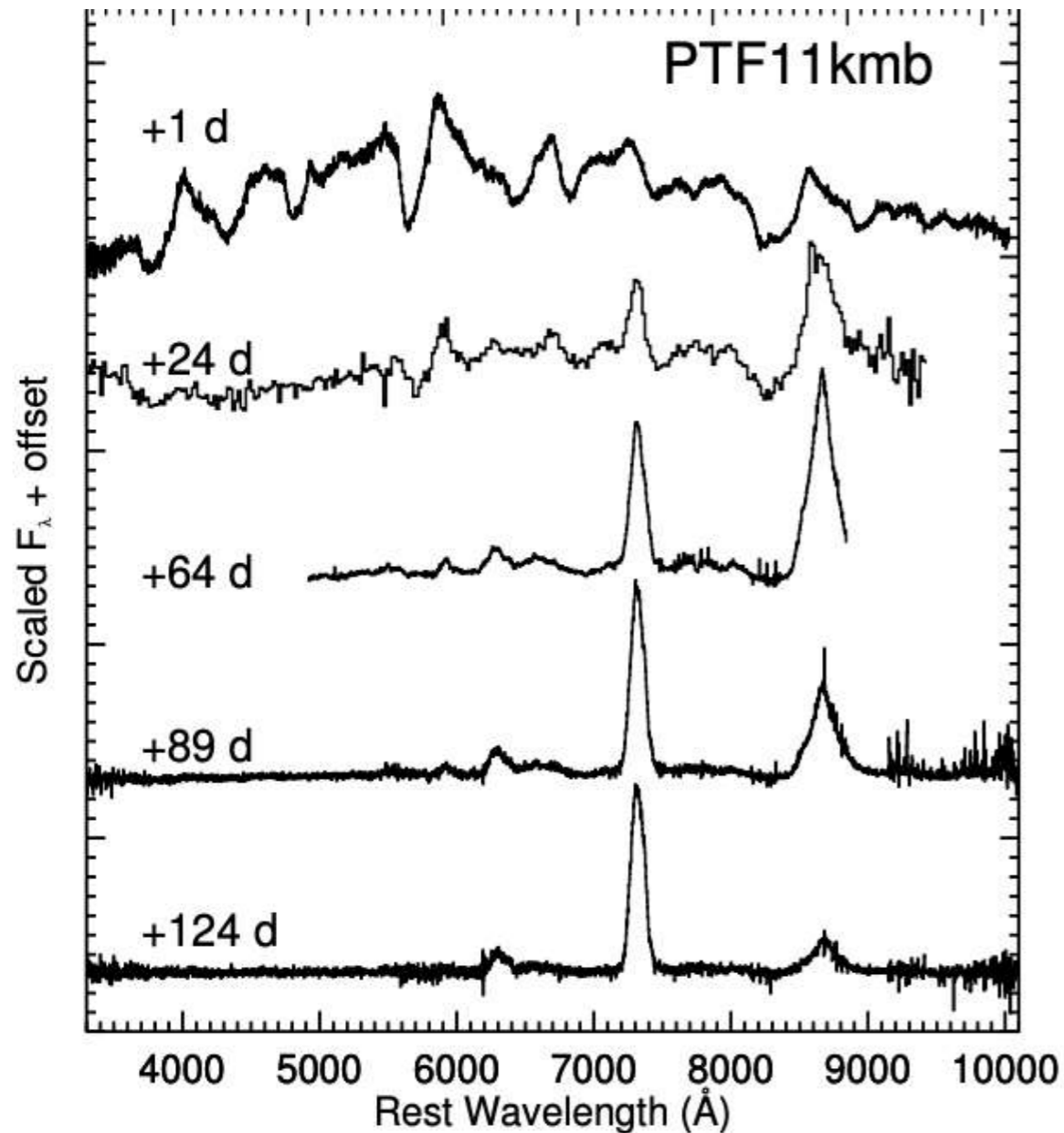


Rigault et al. (2018)

Local specific star formation rate of host galaxy

Why spectroscopy?

Allows for nearly all 'astrophysics' measurements



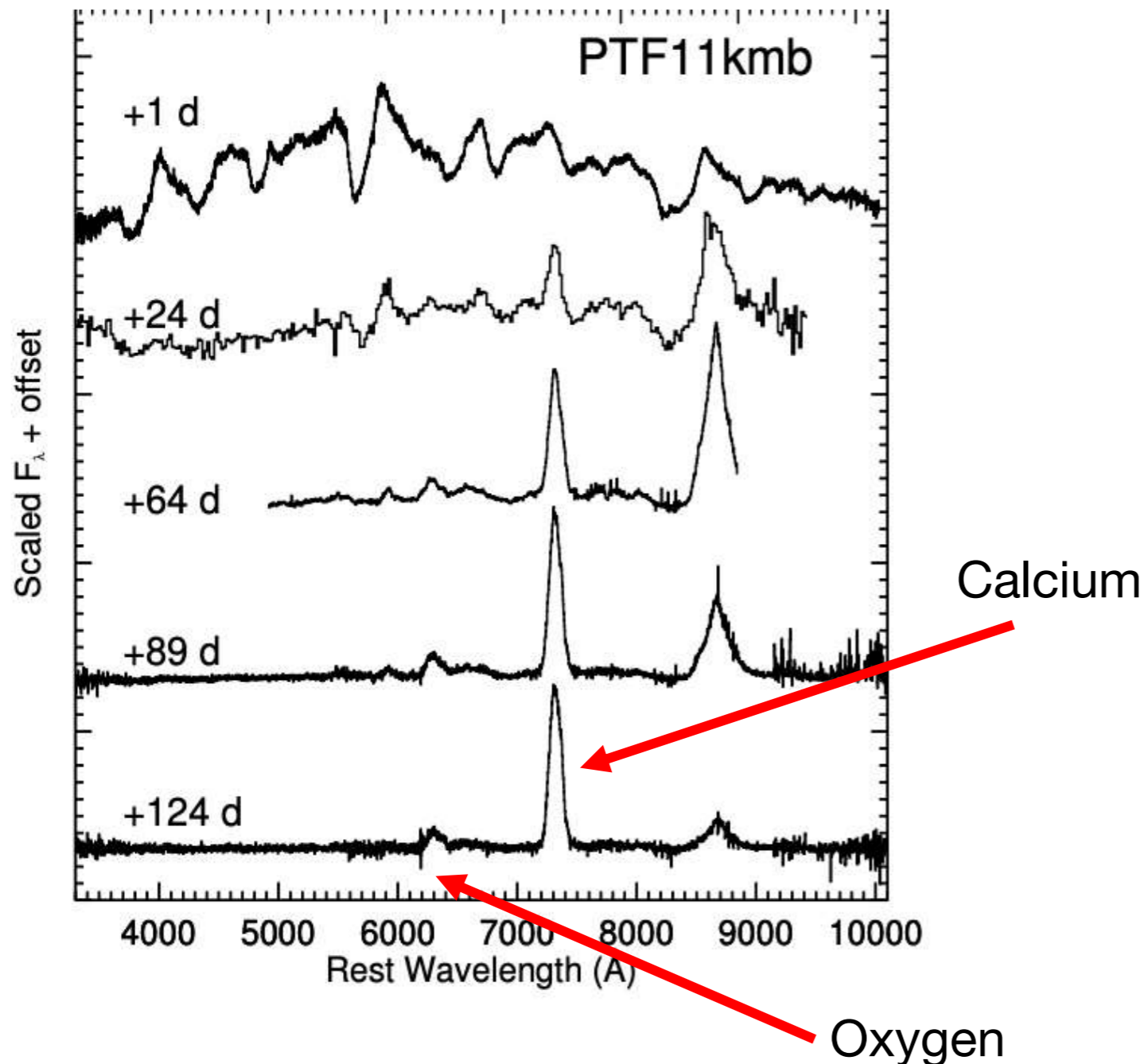
Why spectroscopy?

Allows for nearly all 'astrophysics' measurements

Example: Calcium rich SN

Spectroscopy allows for:

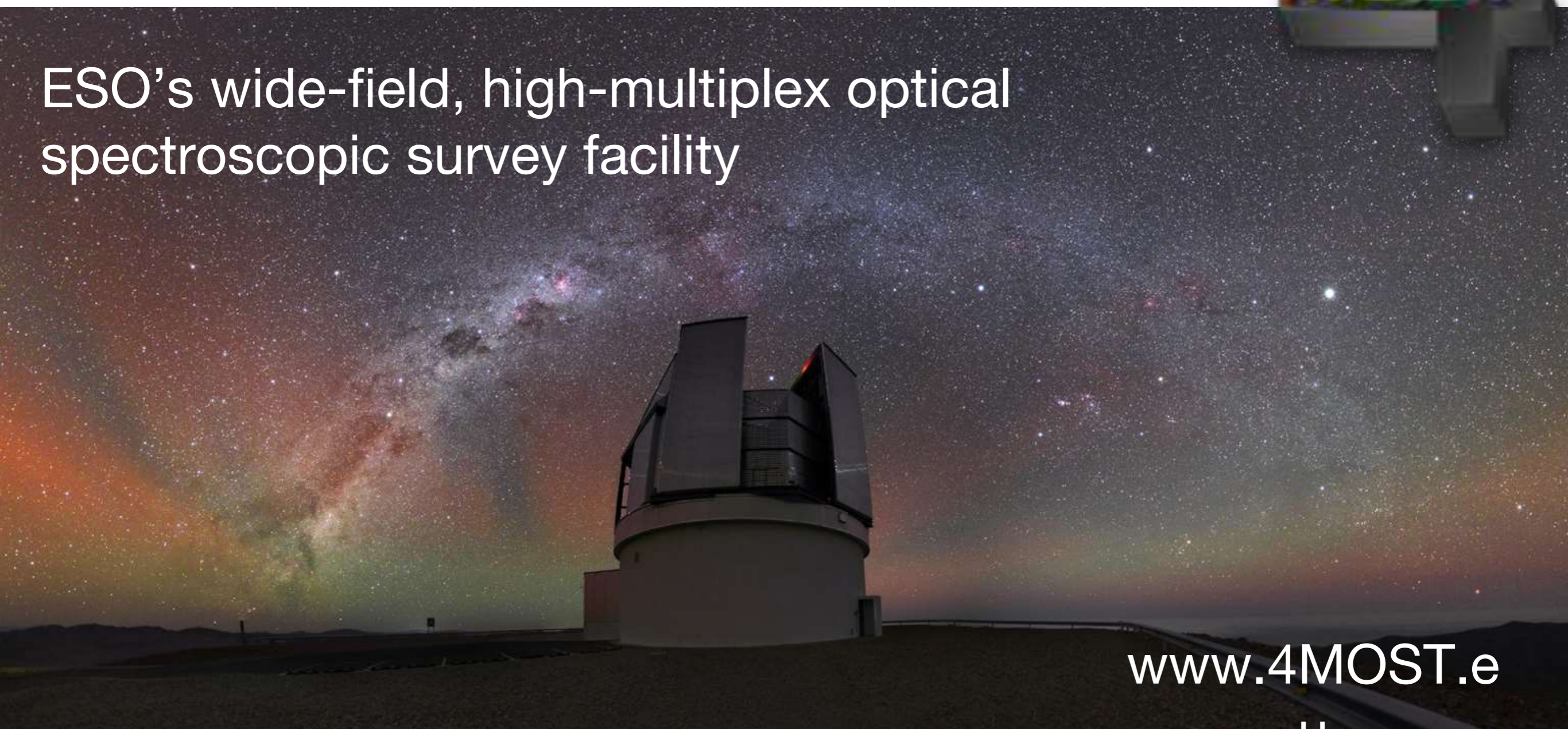
- Chemical abundance estimates
- Ejecta mass estimates
- Velocity measurements
- + many other measurements



4MOST – 4m Multi-Object Spectroscopic Telescope



ESO's wide-field, high-multiplex optical spectroscopic survey facility

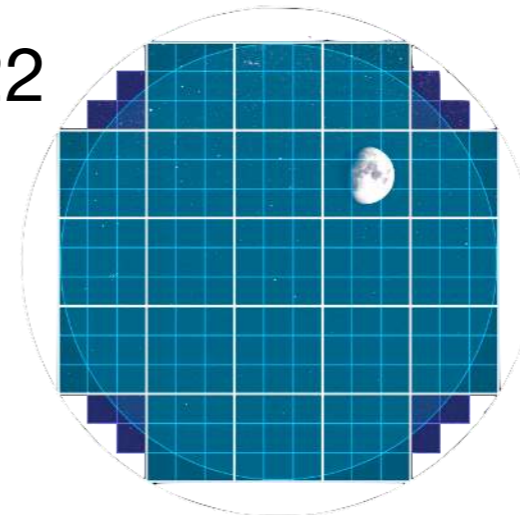


www.4MOST.e

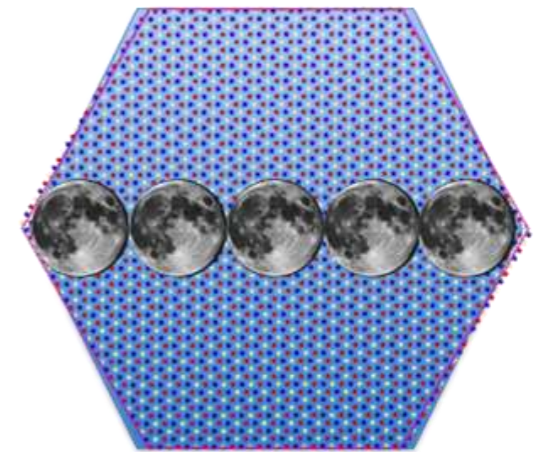


4MOST – 4m Multi-Object Spectroscopic Telescope

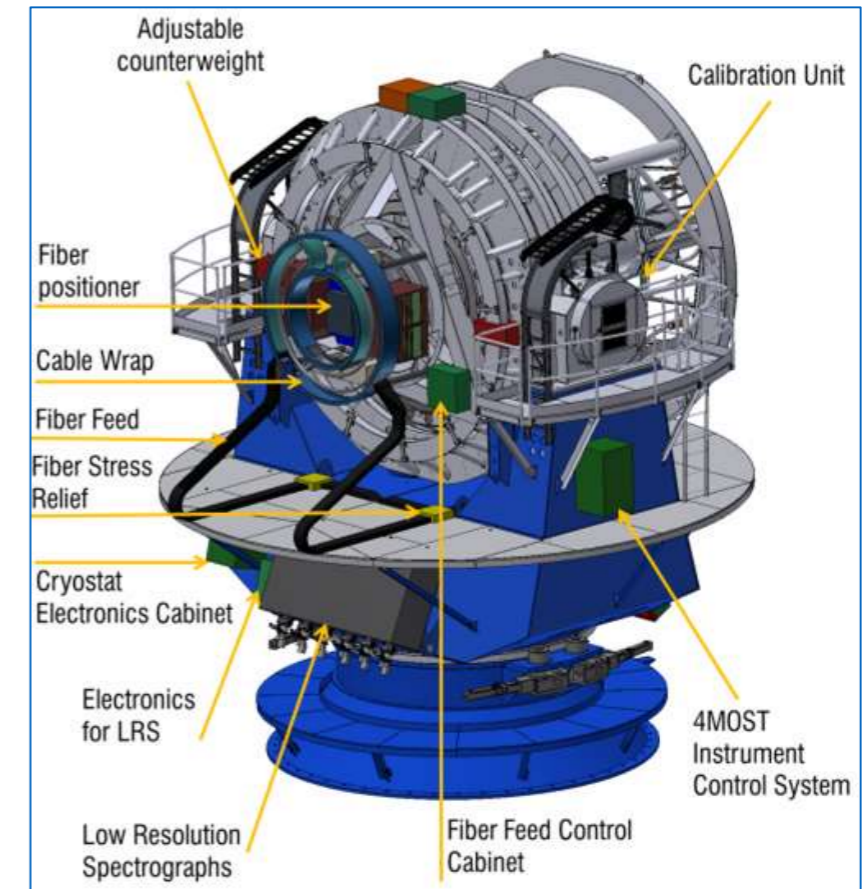
- Instrument to be in operation by 2022
- Optical Range (390-930nm)
- Wide field of view (4.1 sq deg)
- ~ 2400 fibres
- Will survey the southern sky over 5 years with repeat visits to deep fields
- **4MOST well matched to LSST** in terms of:
 - Sensitivity
 - Location
- It is the premier **wide spectroscopic facility** in the southern hemisphere (30 sq deg p/night)



LSST 9.6 deg² FoV



4MOST 4.1 deg² FoV



The Time Domain Extragalactic Survey

TIDES

- 250,000 fiber hours guaranteed
- Aim to target 30,000+ live transients

Live Transients:

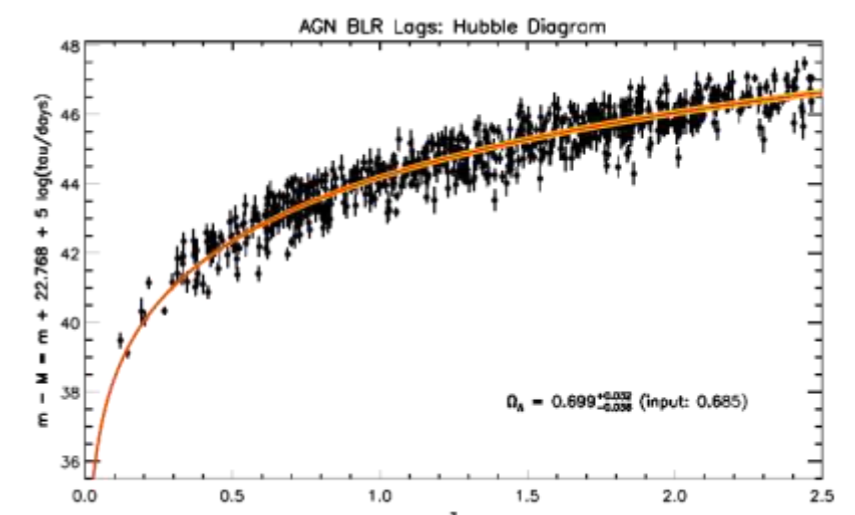
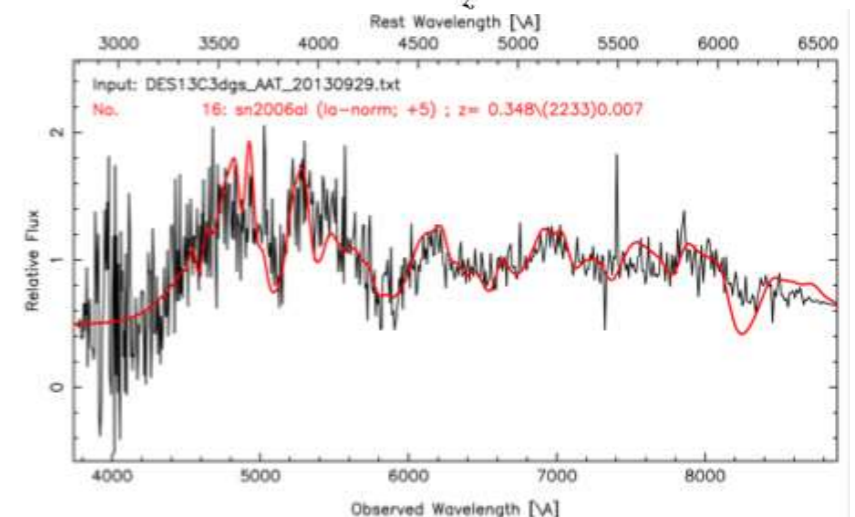
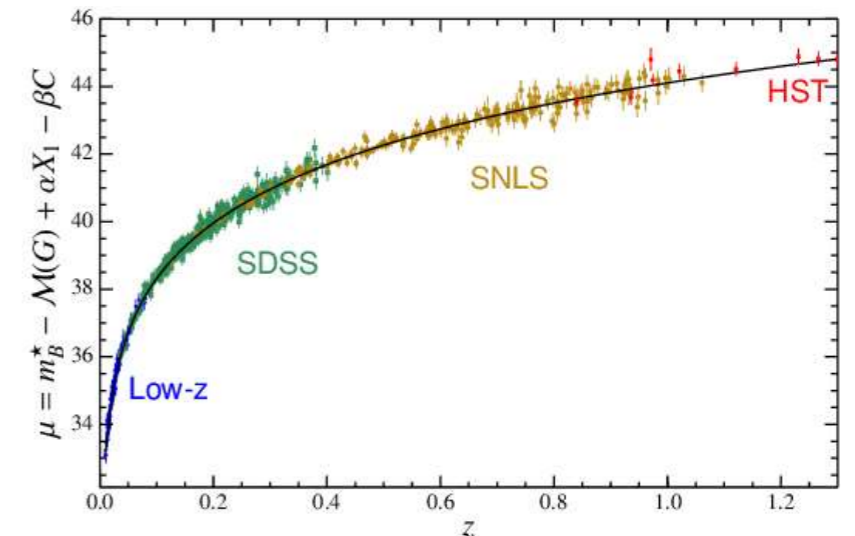
- Rapid (3-4 day) follow-up of LSST transients
- Spectroscopic classification & redshifts

Host Galaxies of Type Ia's:

- Spectroscopic redshifts of hosts
- Allows detailed host galaxy studies

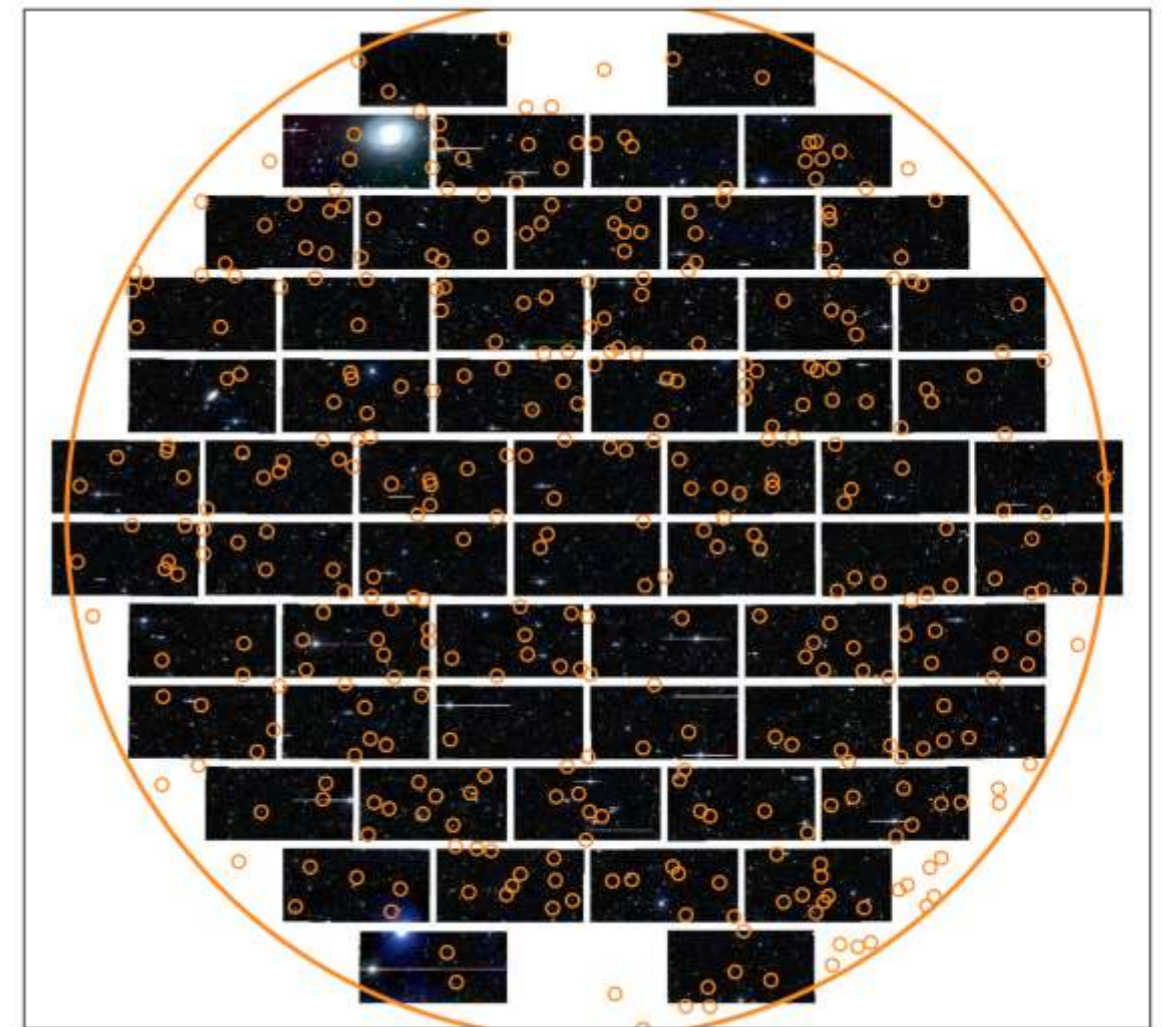
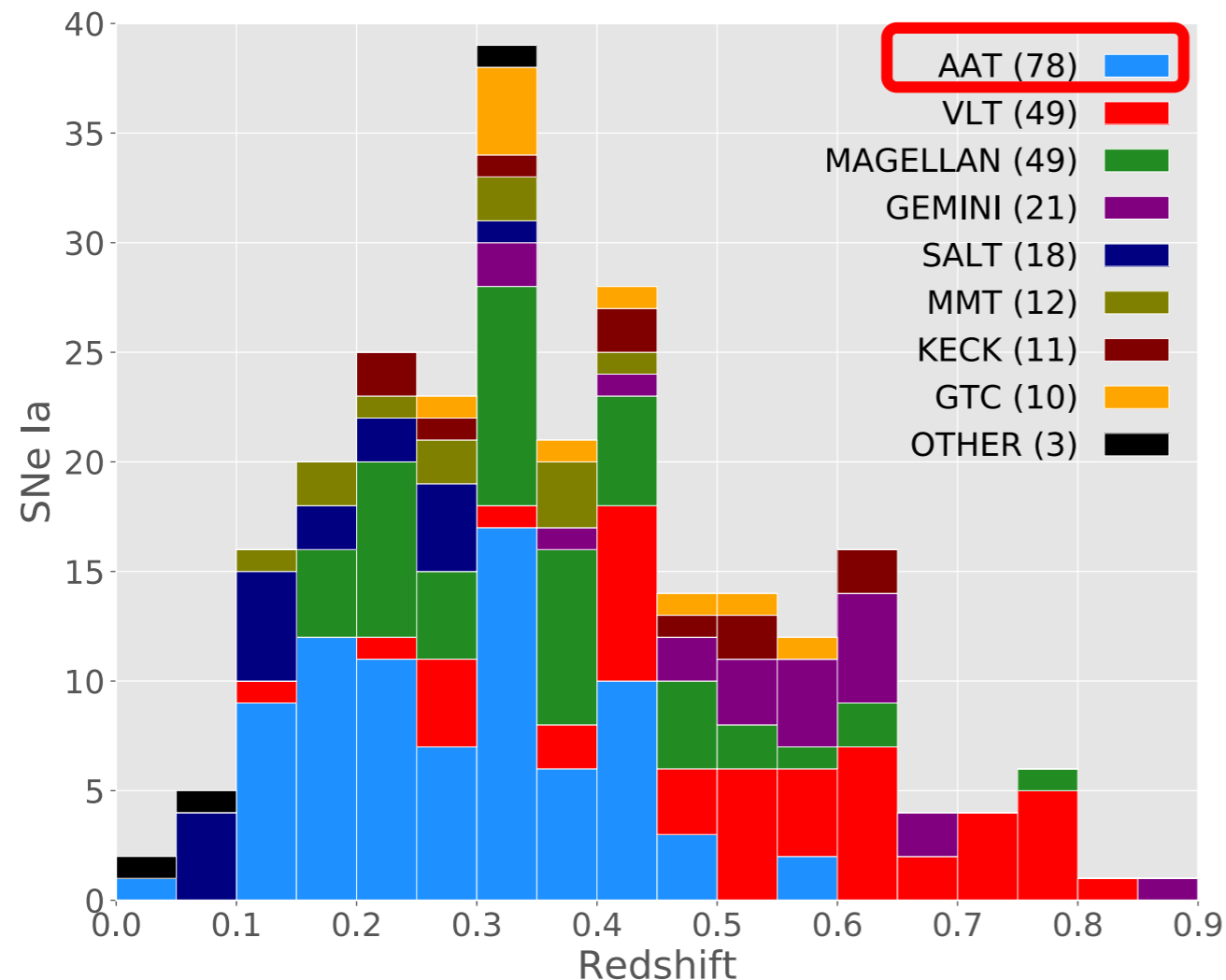
AGN Reverberation Mapping:

- Black Hole masses and Hubble Diagram to $z \sim 2.5$



Influenced by OzDES on the AAT

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

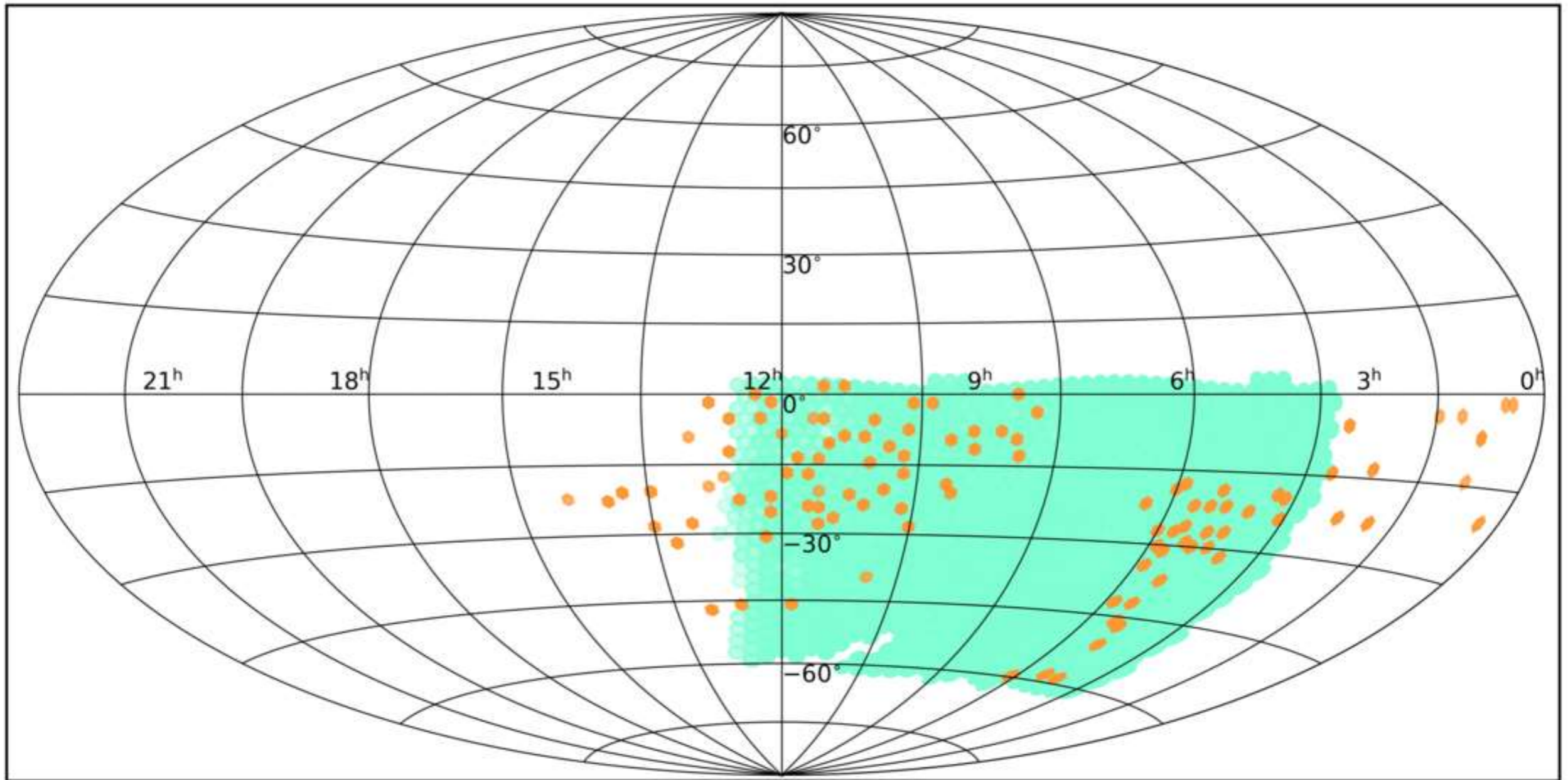


Black: DES CCD's

Orange: AAT Field of view and example fiber placement

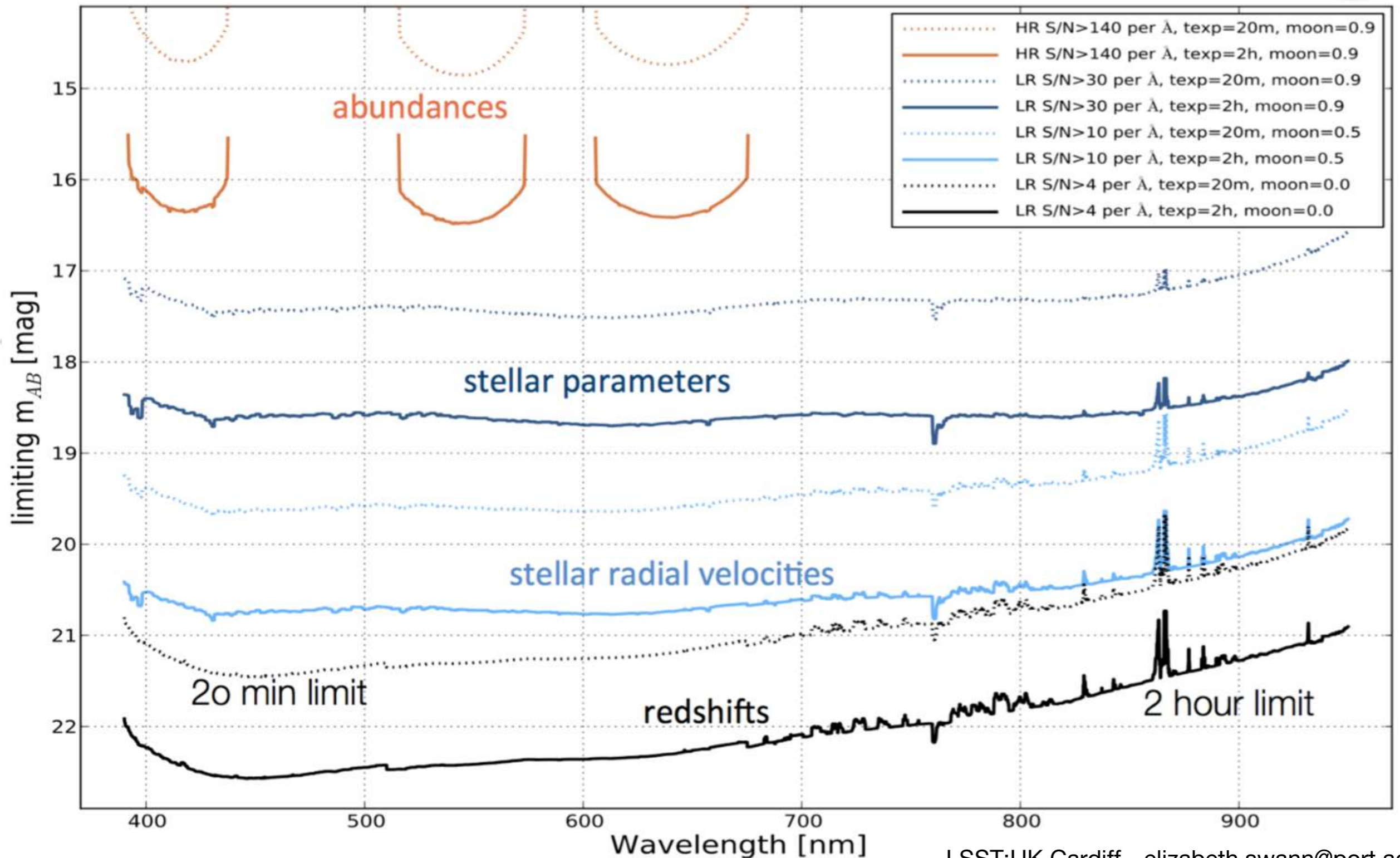
LSST & 4MOST synergy

2022-02-10

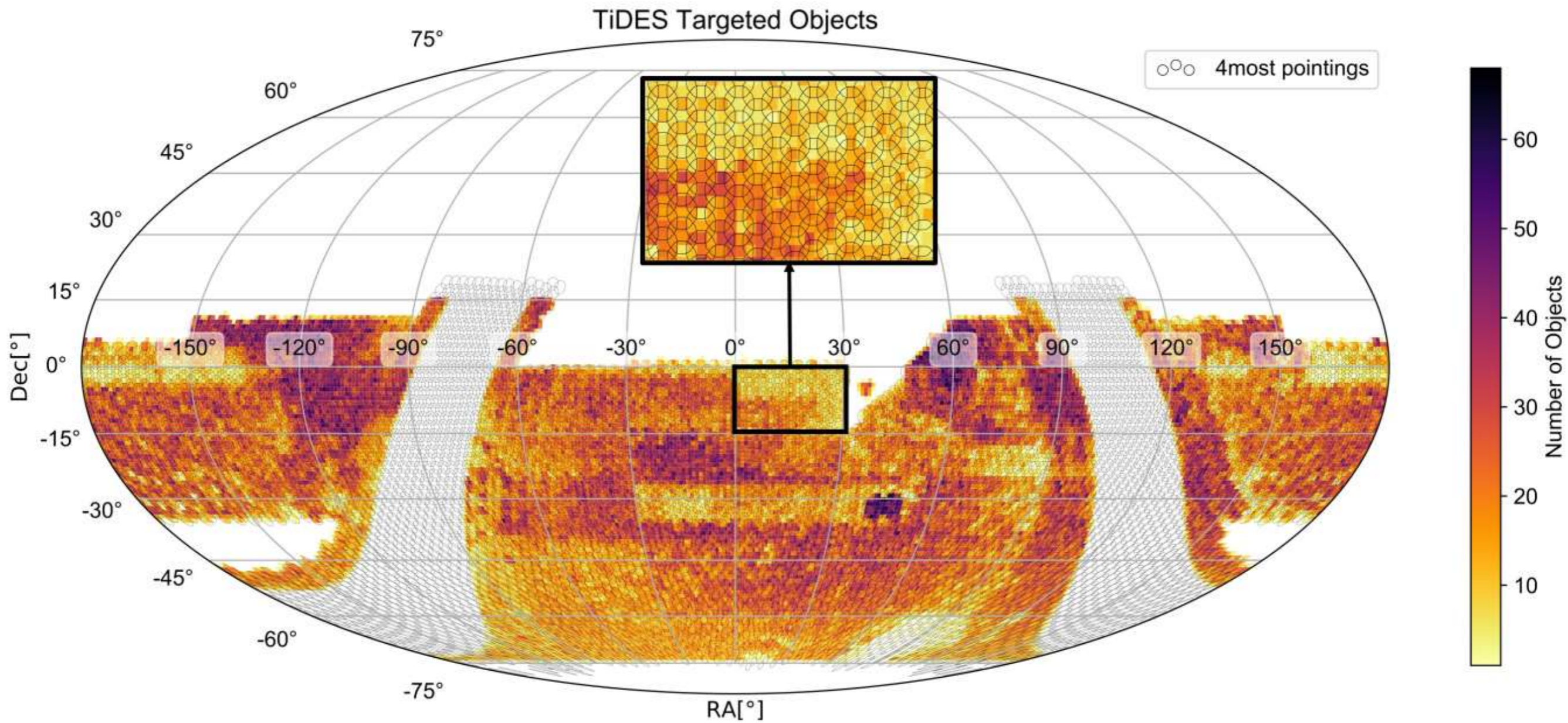


Example spatial and temporal overlap for SNe Ia at $z \sim 0.25$

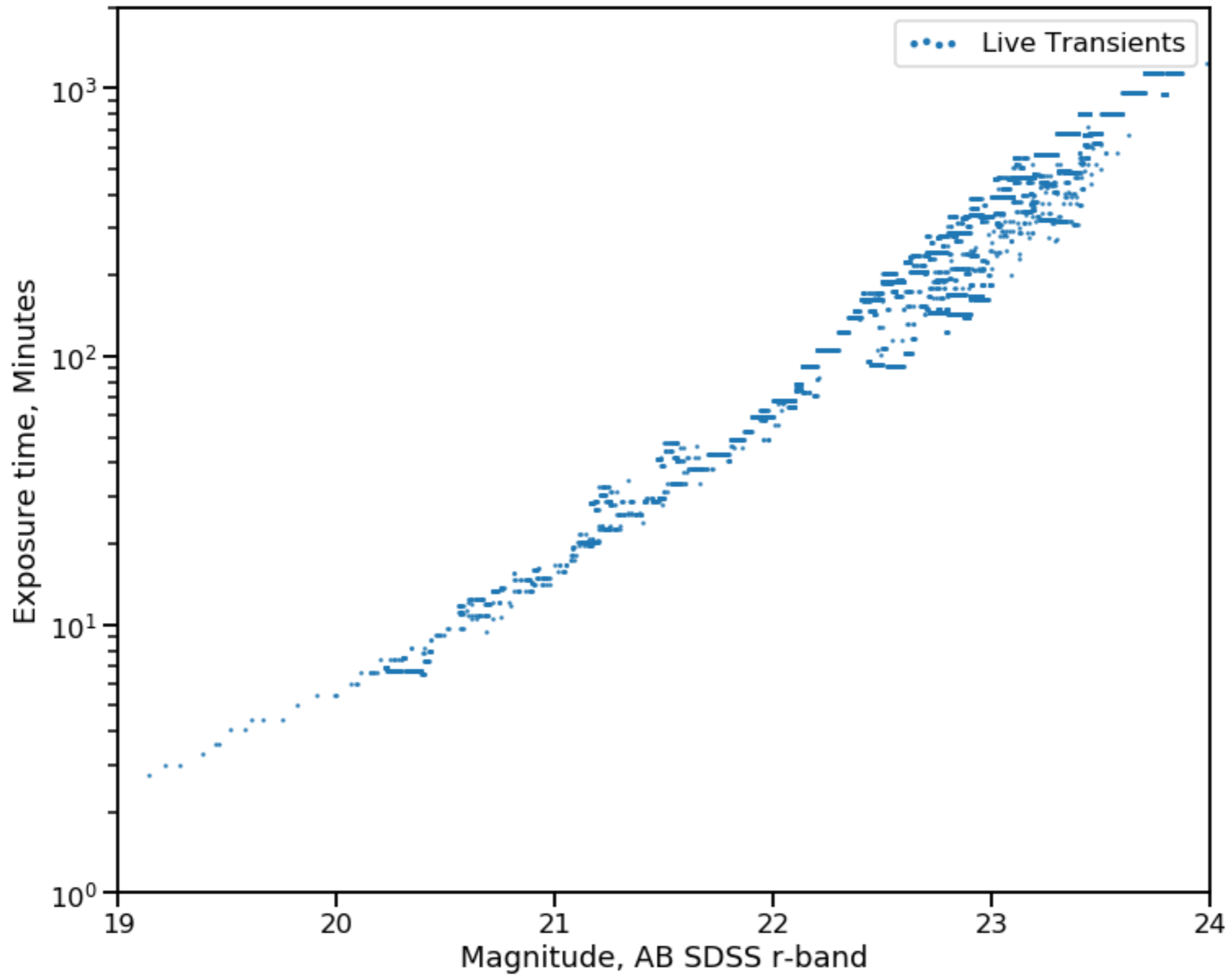
Magnitude Limits for Typical Science Cases



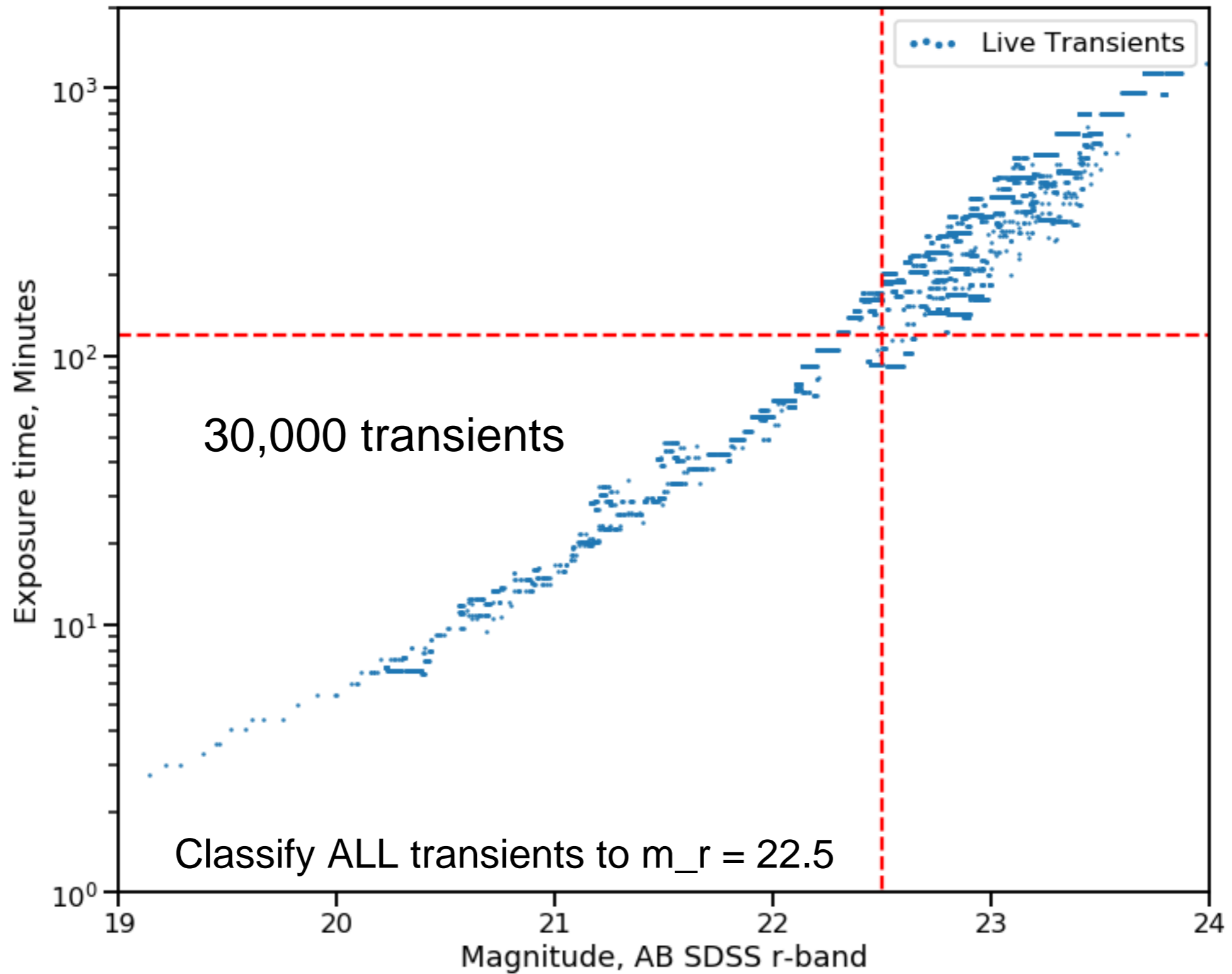
Current Simulations



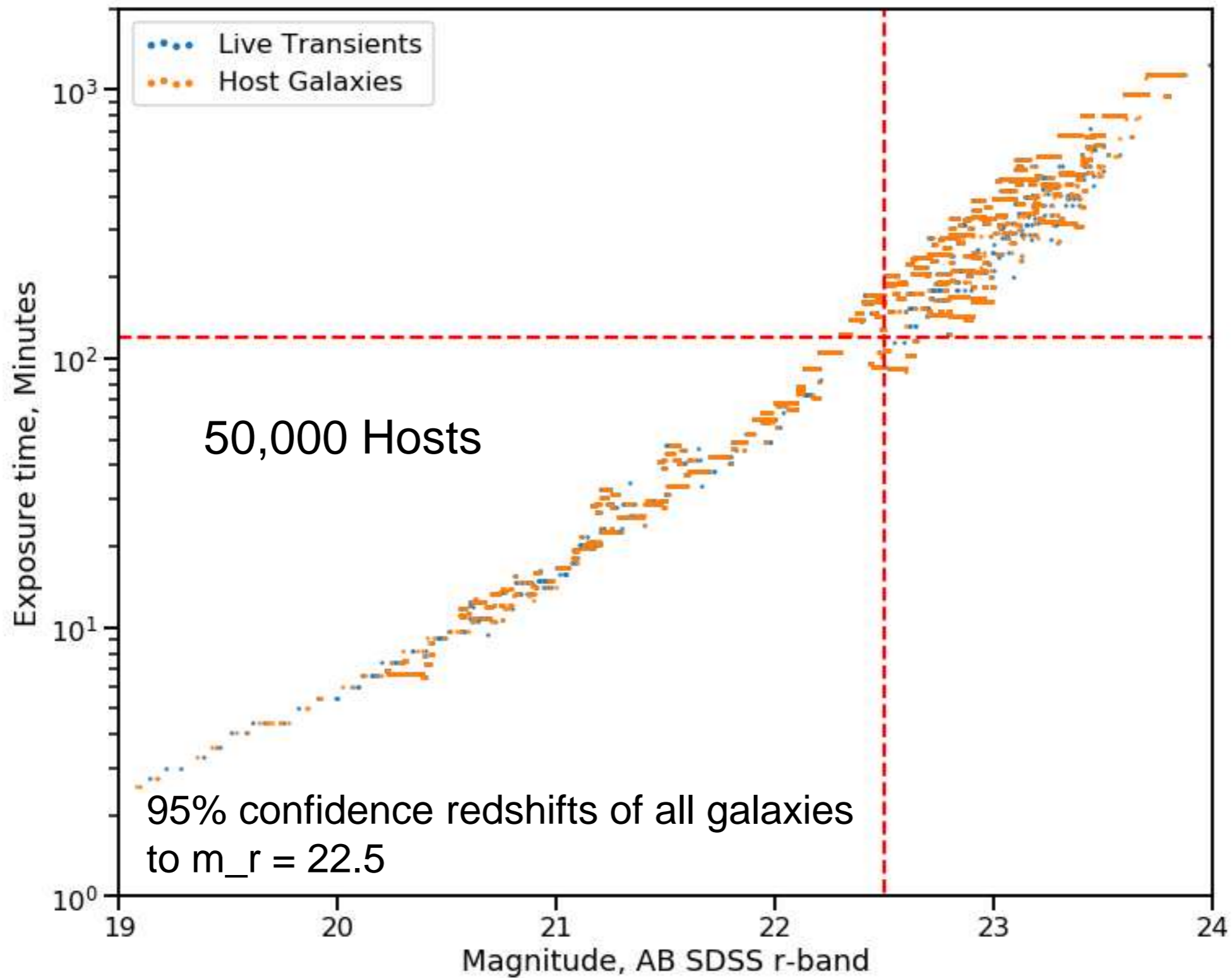
Current Simulations



Current Simulations



Current Simulations



Conclusions: Part 1

TiDES has three science goals:

- Precision Type Ia Supernovae Cosmology
- Explore the diversity of transients
- AGN reverberation mapping

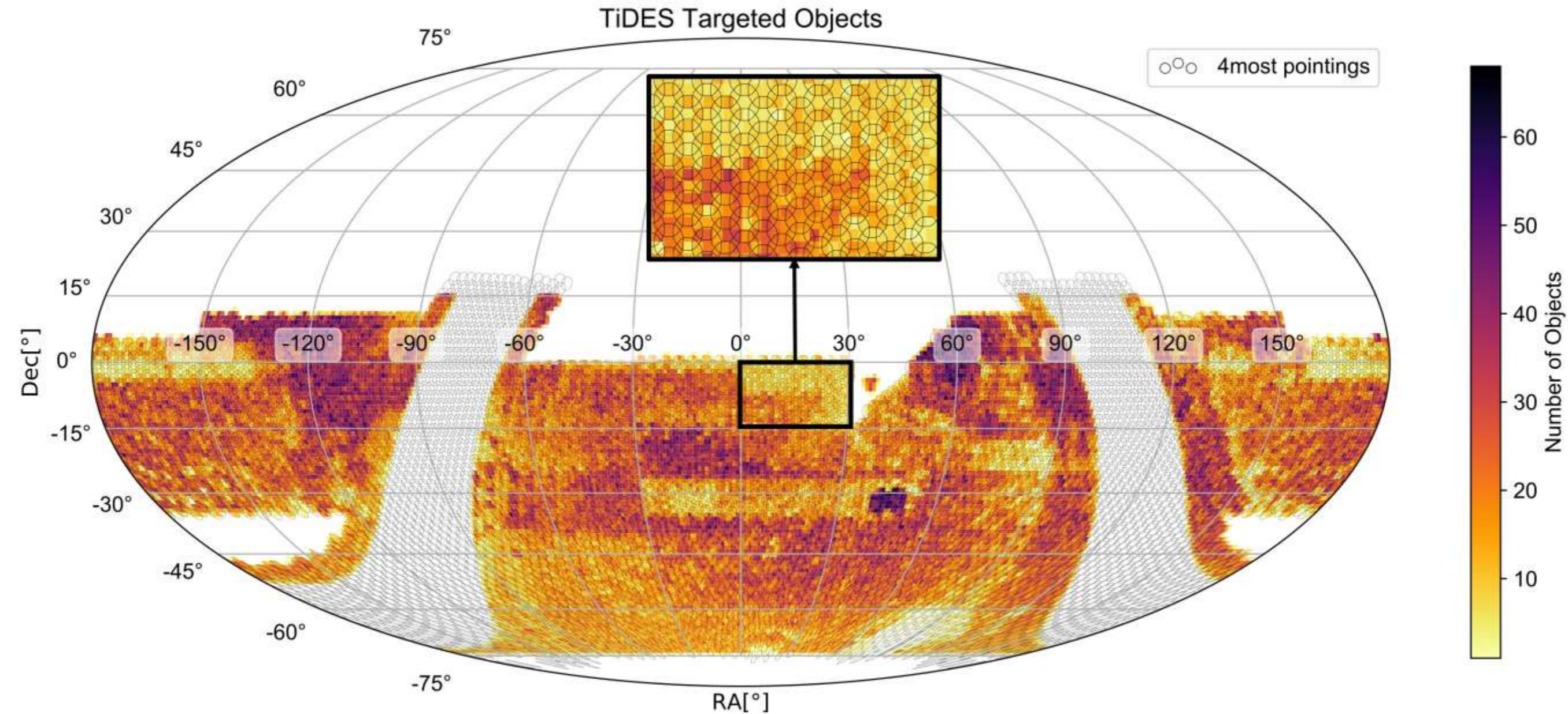
Simulations have shown:

- Classify **30,000** live transient spectra, (**~80%** Type Ia spectra)
- Redshifts for **50,000+** host galaxy spectra
- **700** AGN monitored over **5+** years

This will be the largest **ever** cosmological sample of
Type Ia Supernovae

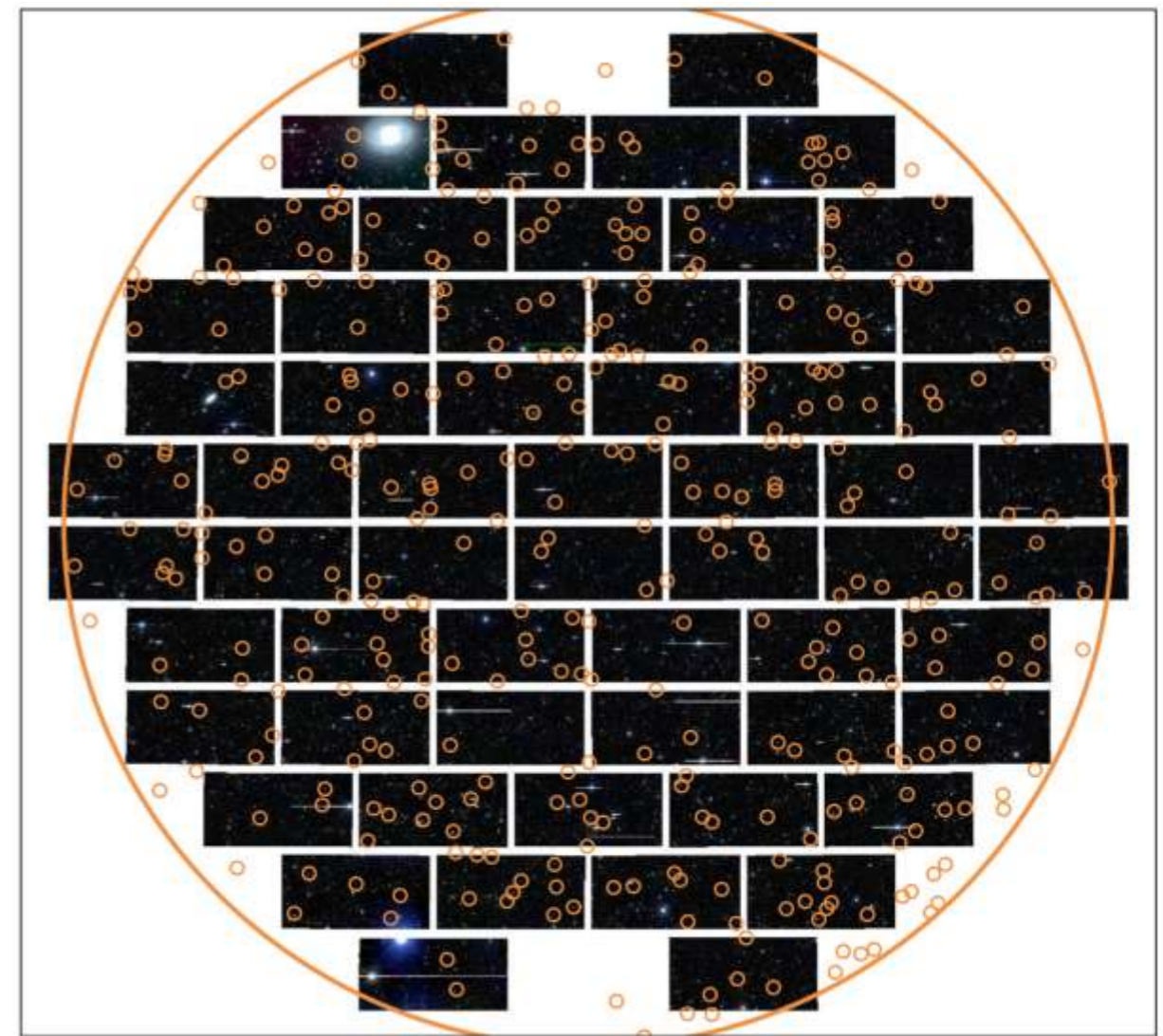
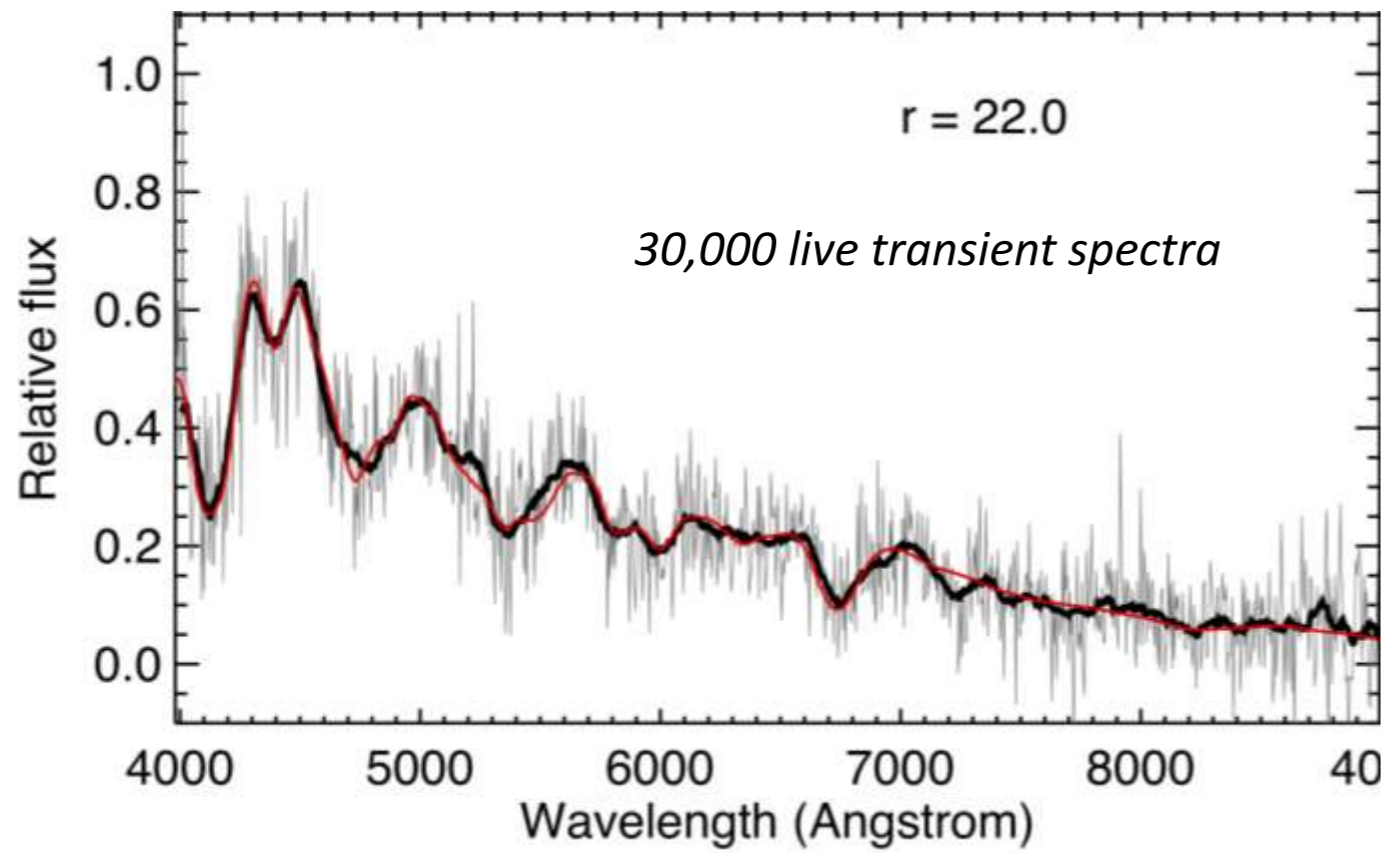
~~Phase B~~ / Future Work

How to convert:

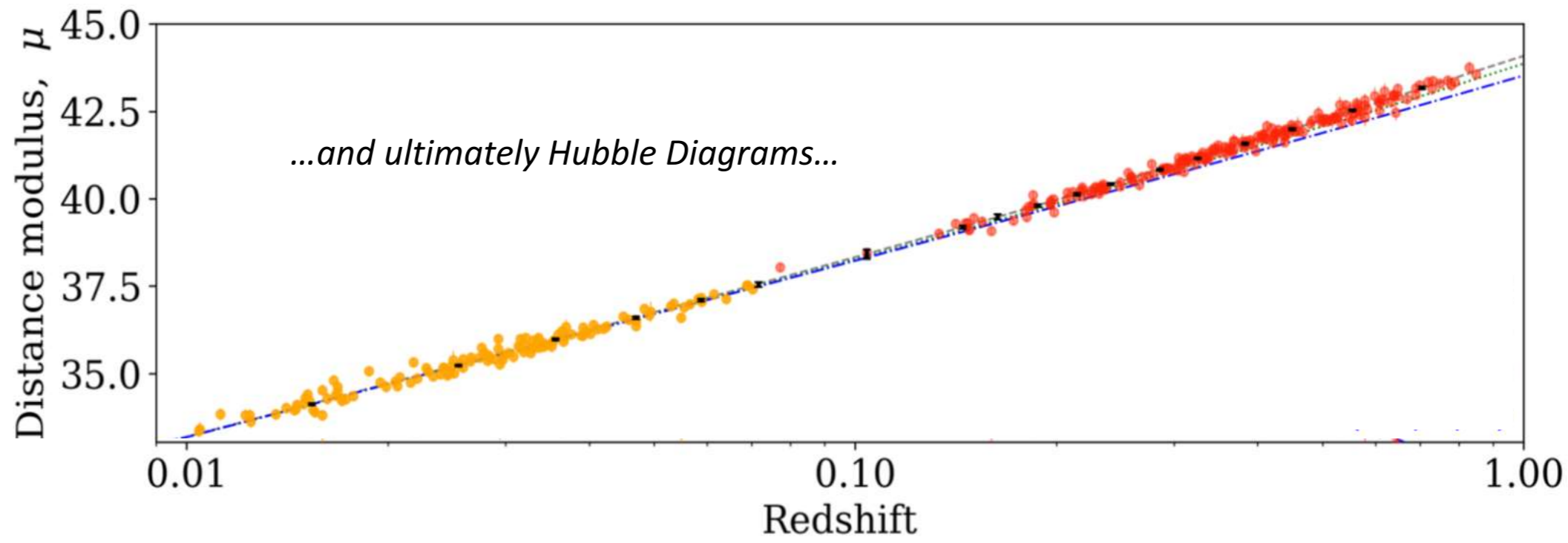


Example distribution of LSST SNe, with 4MOST observing pattern overlaid

...into...

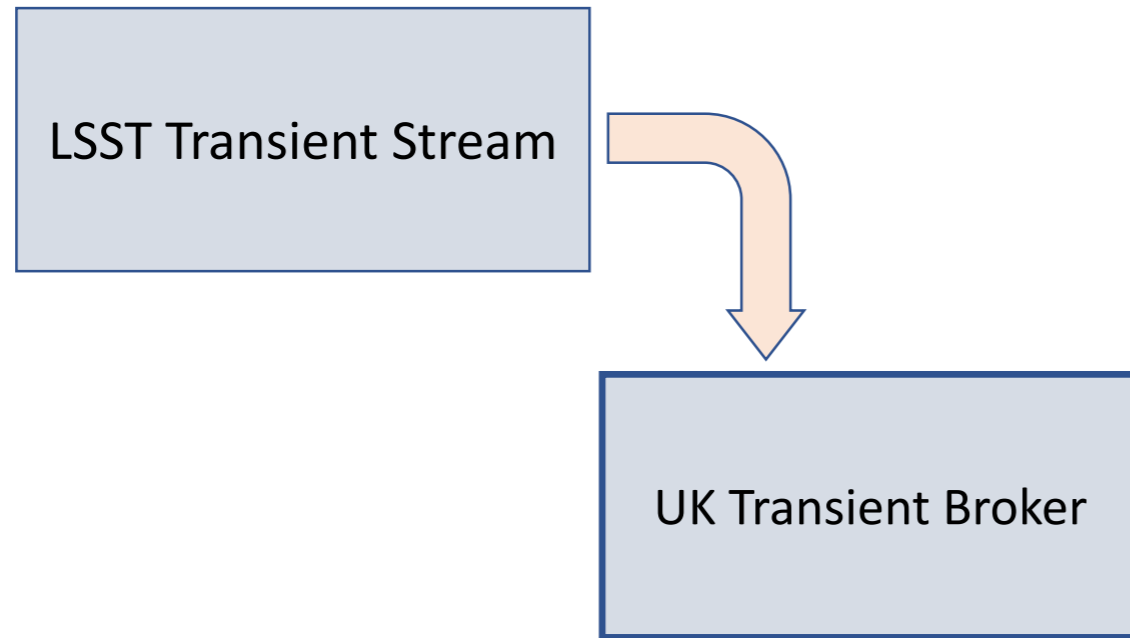


50,000 transient host spectra

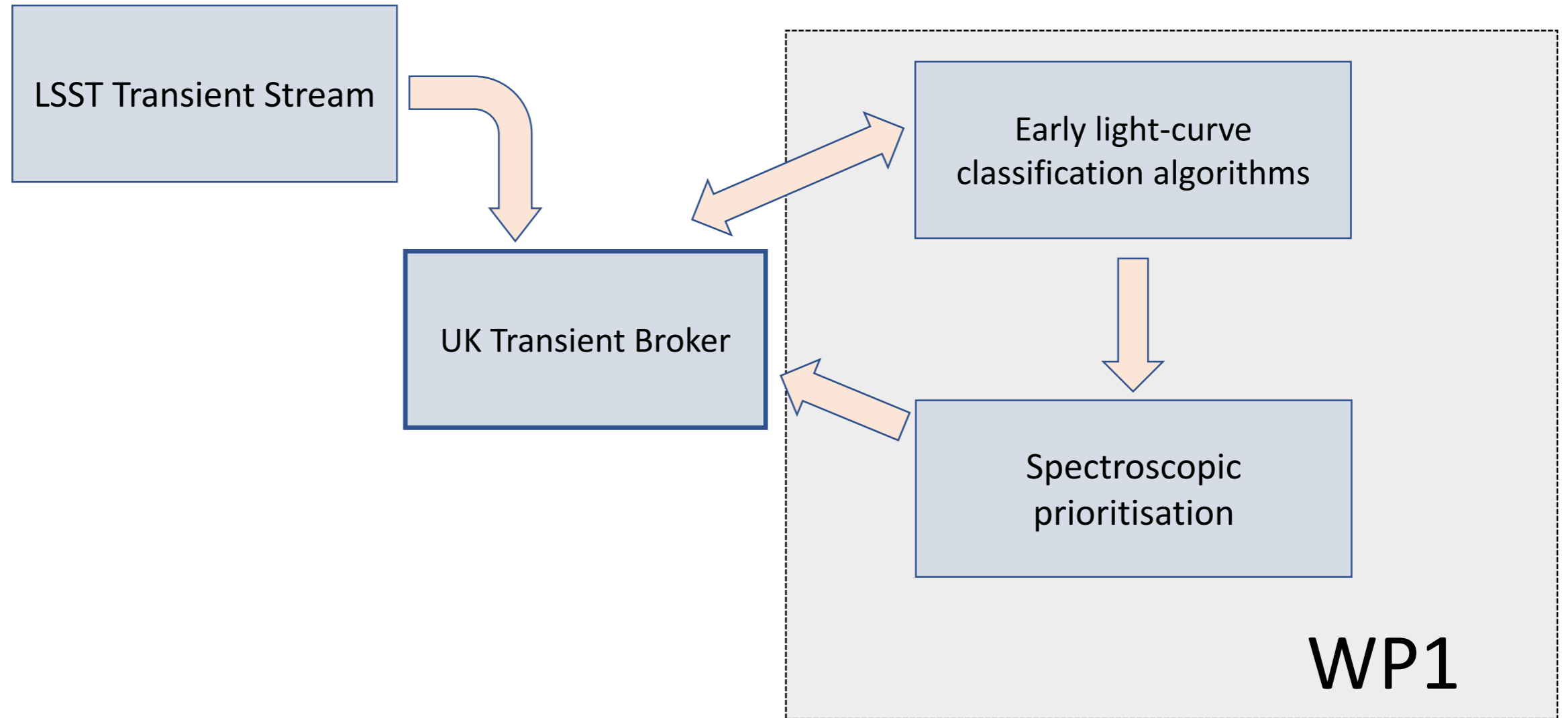


Infrastructure needed

Infrastructure needed

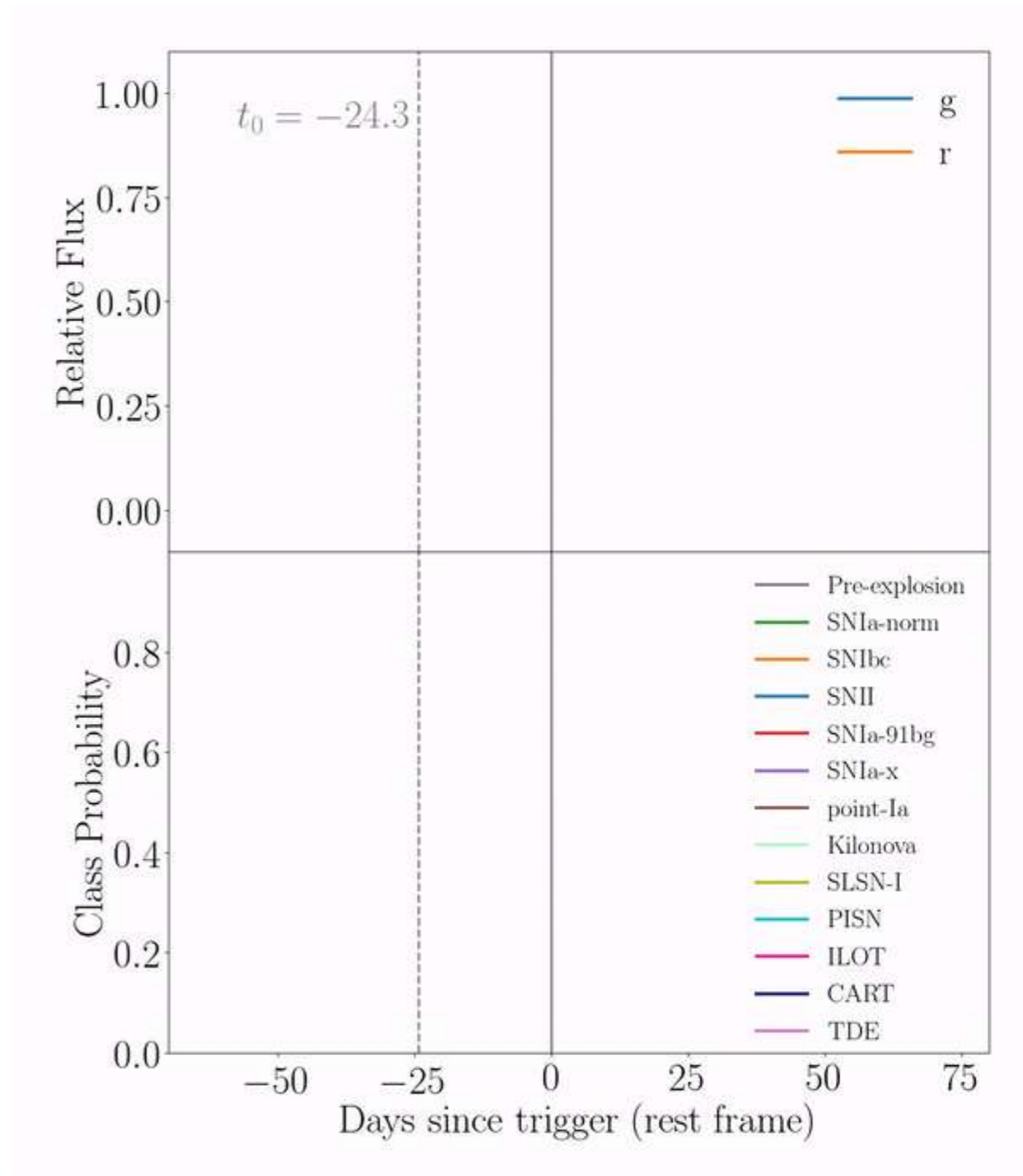


Infrastructure needed

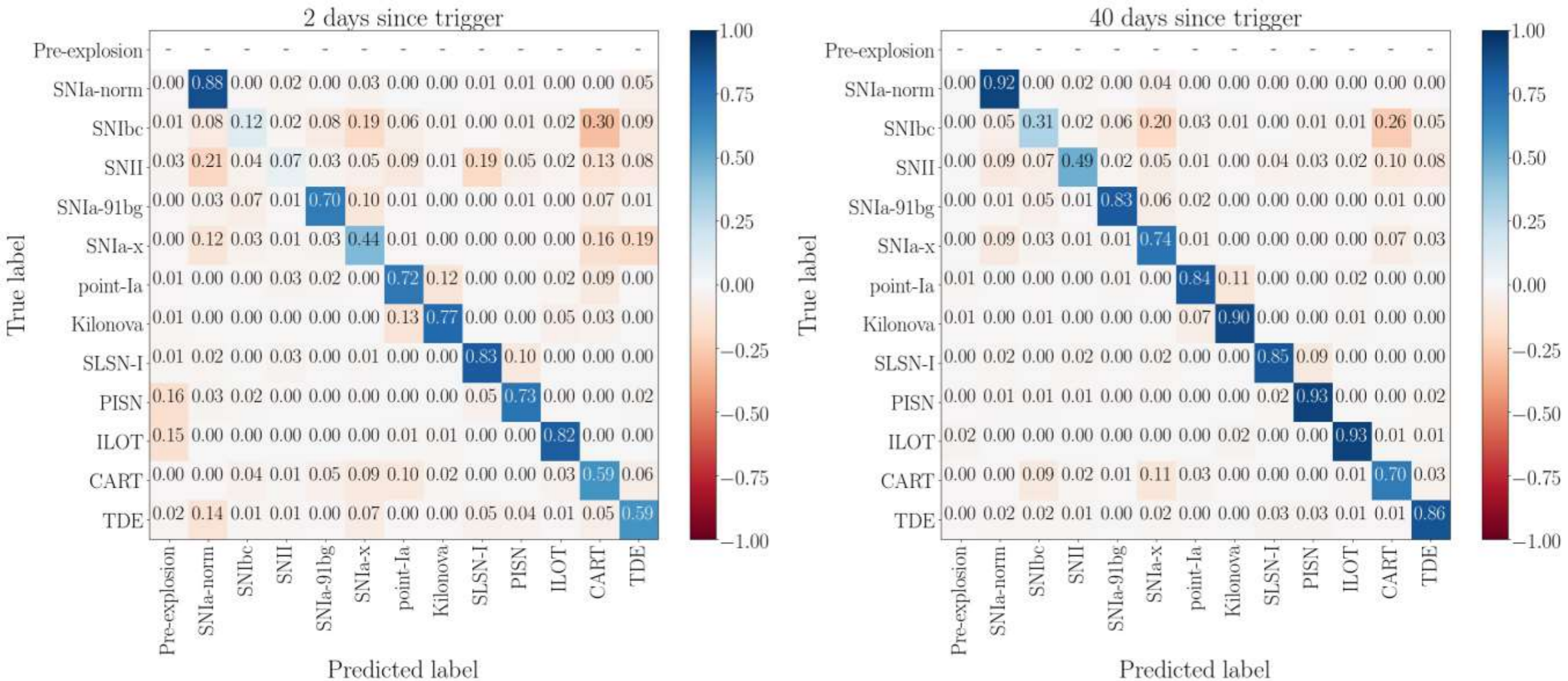


How to prioritise based on limited data?

- Example: RAPID
- Automatically identify transients from day of alert to full light curve
- Needs to be tested on LSST-type data and new templates

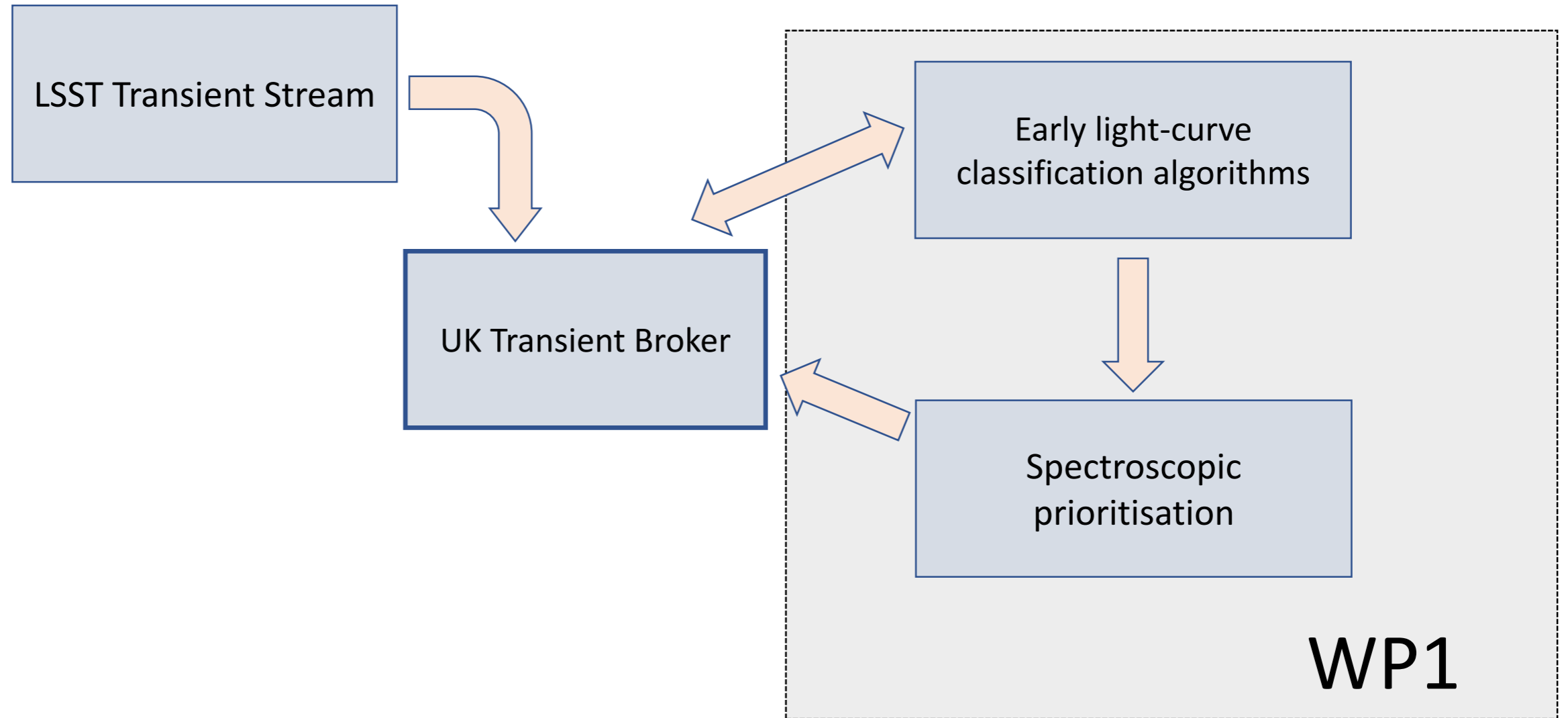


How to prioritise based on limited data?

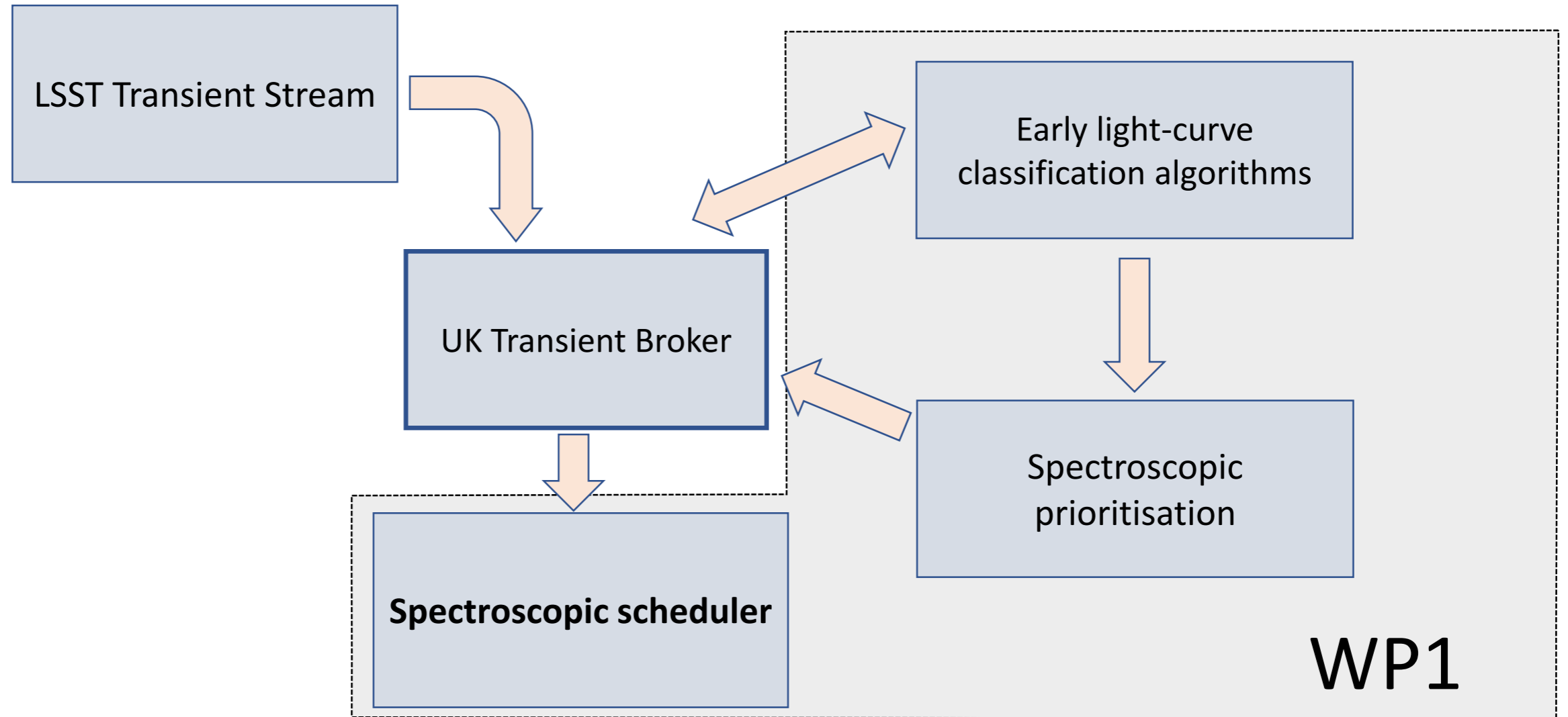


- Need better simulations for testing with increased diversity
- Need to tests on commissioning data

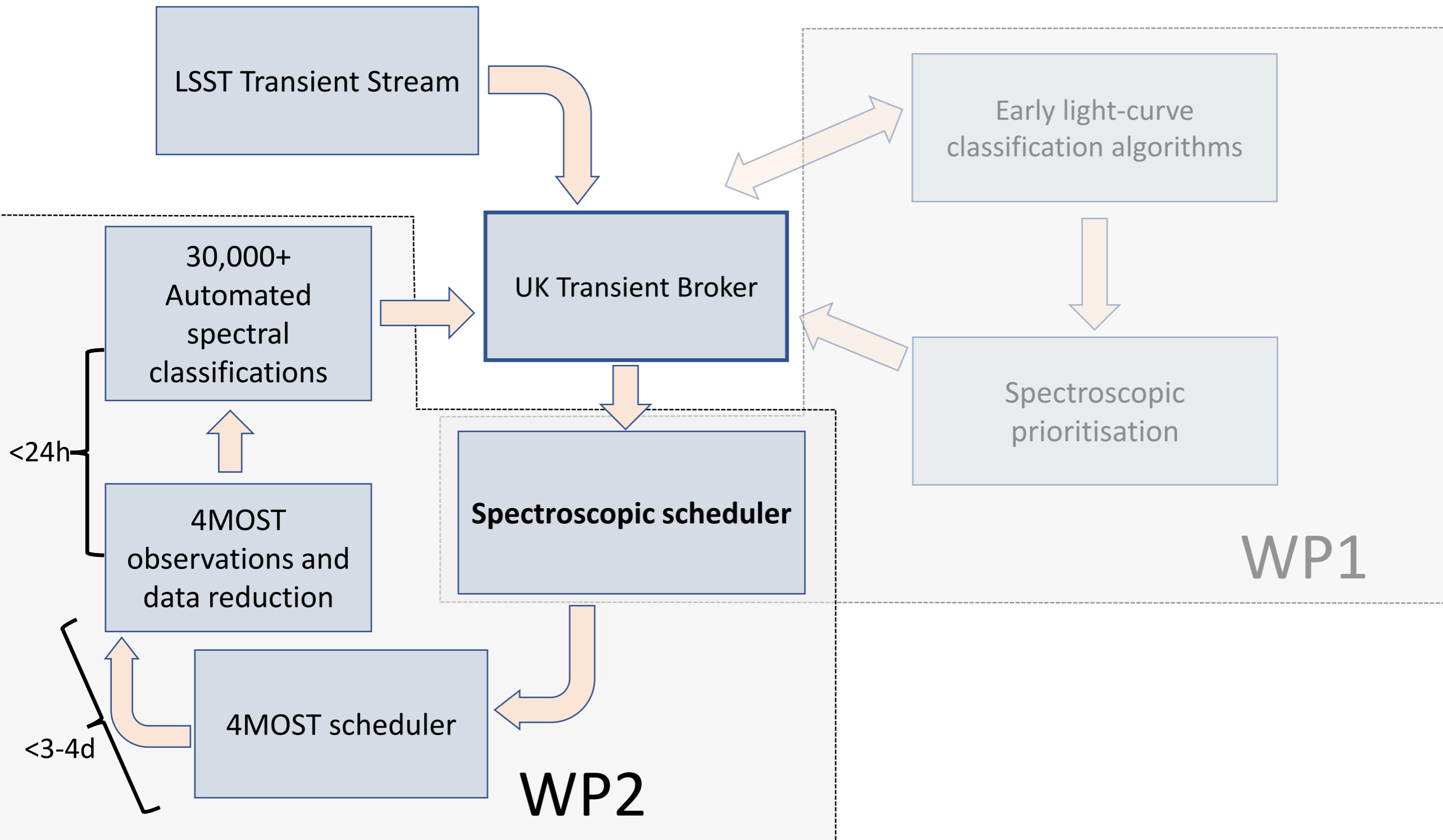
Infrastructure needed

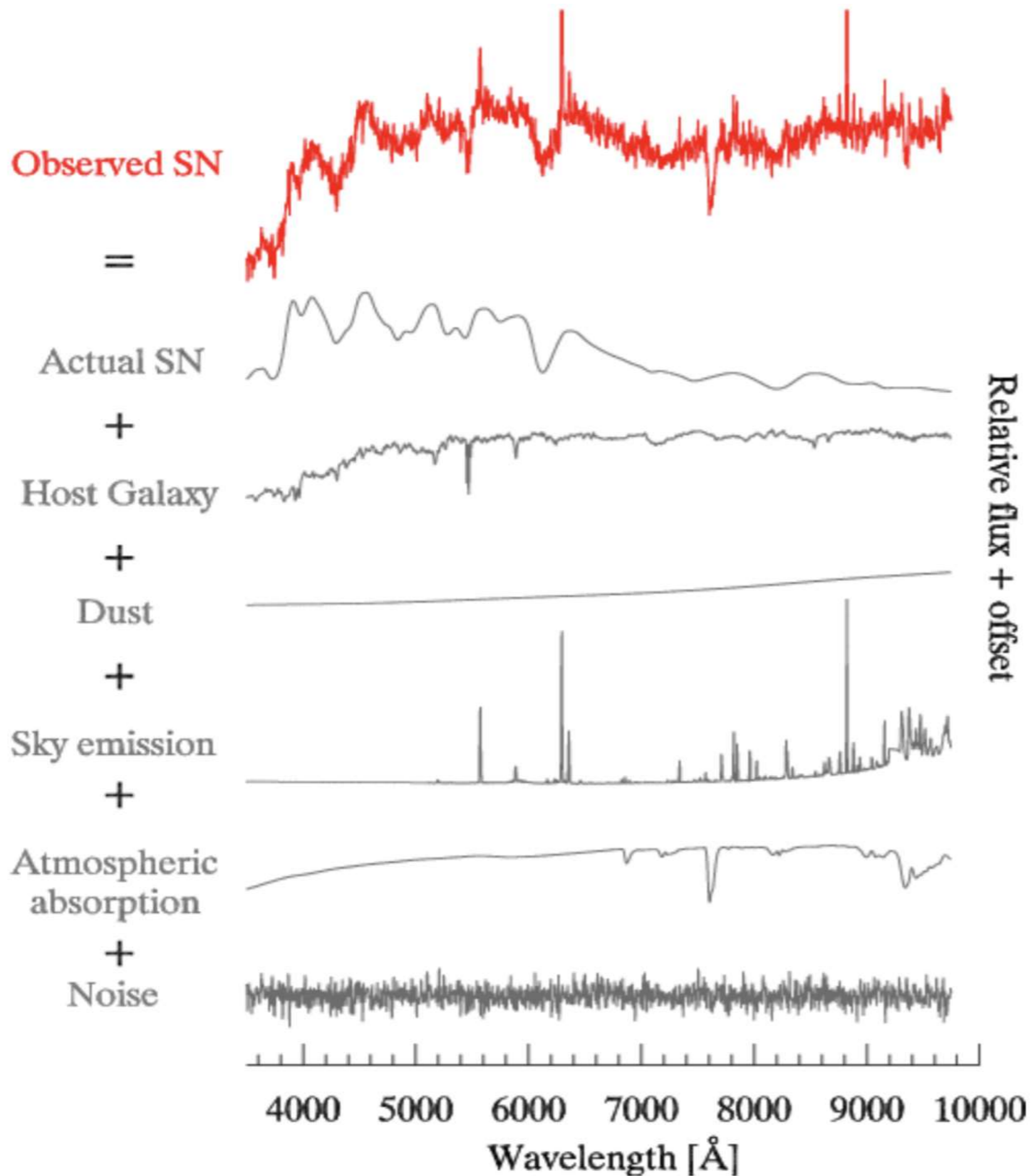


Infrastructure needed



Infrastructure needed





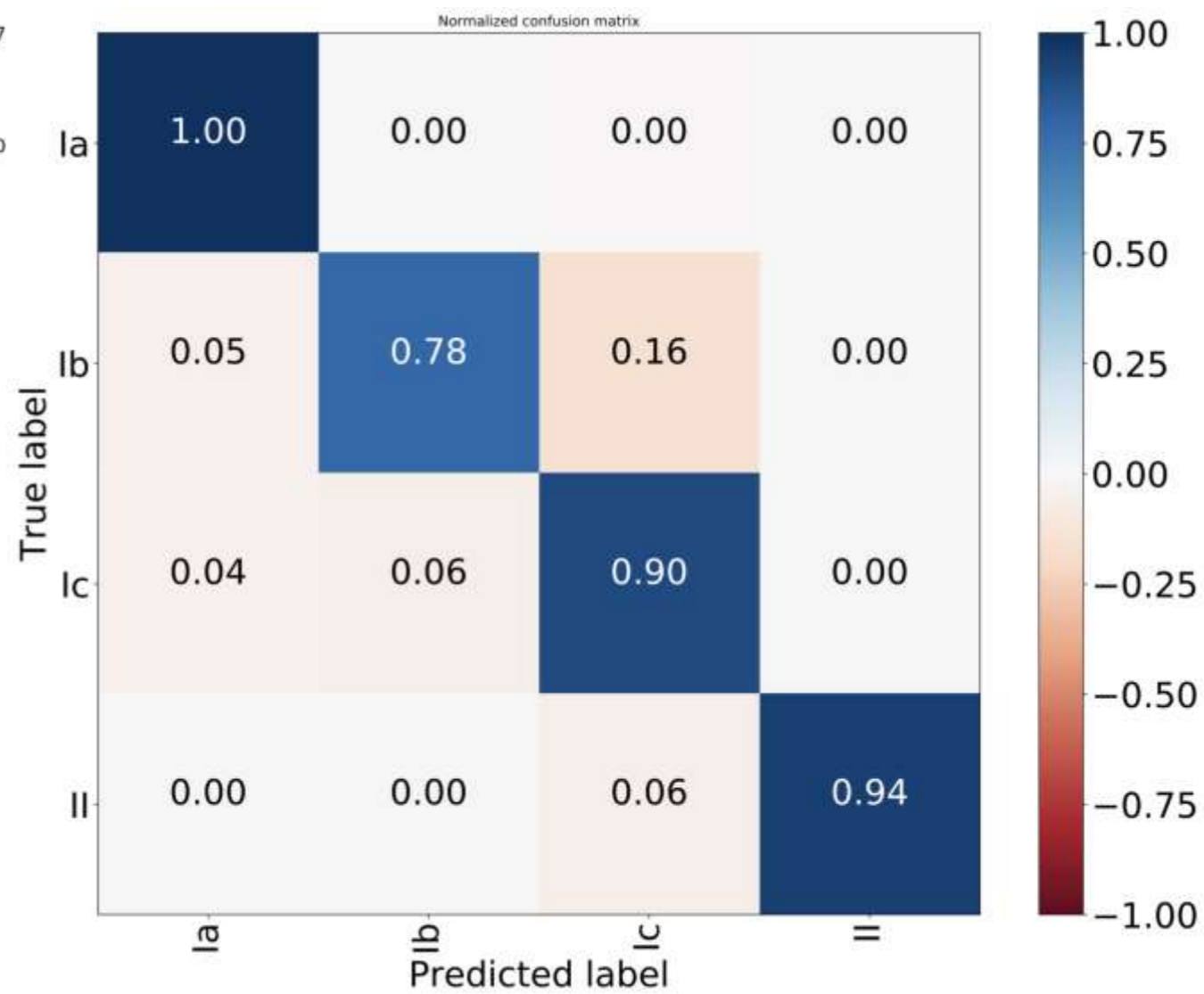
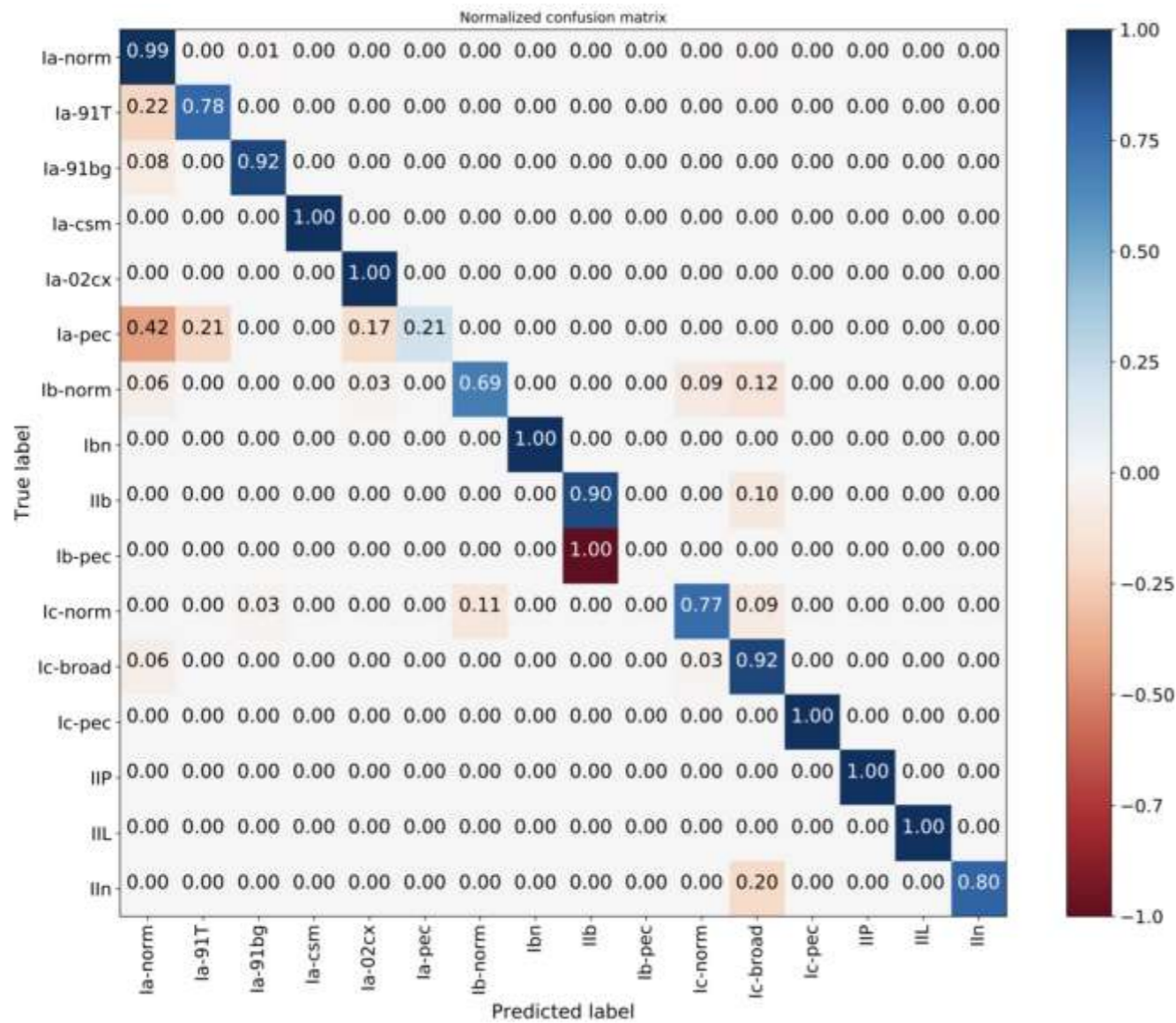
Need to classify 30-40 transients each and every night:

- Labour intensive
- Subjective

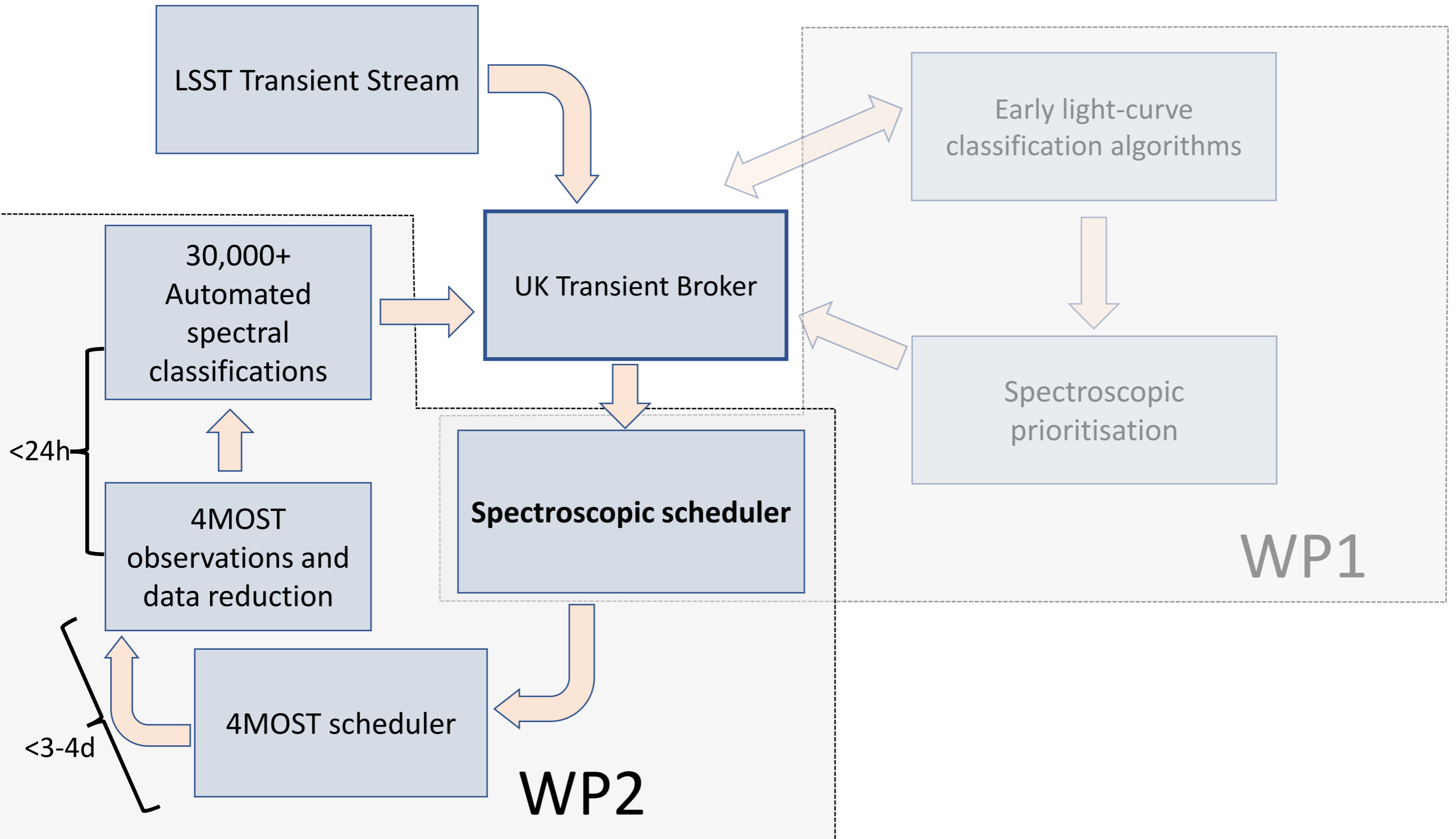
Promising techniques based on deep learning – but are not yet working autonomously in real-time

Getting this working will release 30,000 classifications to the community in real time

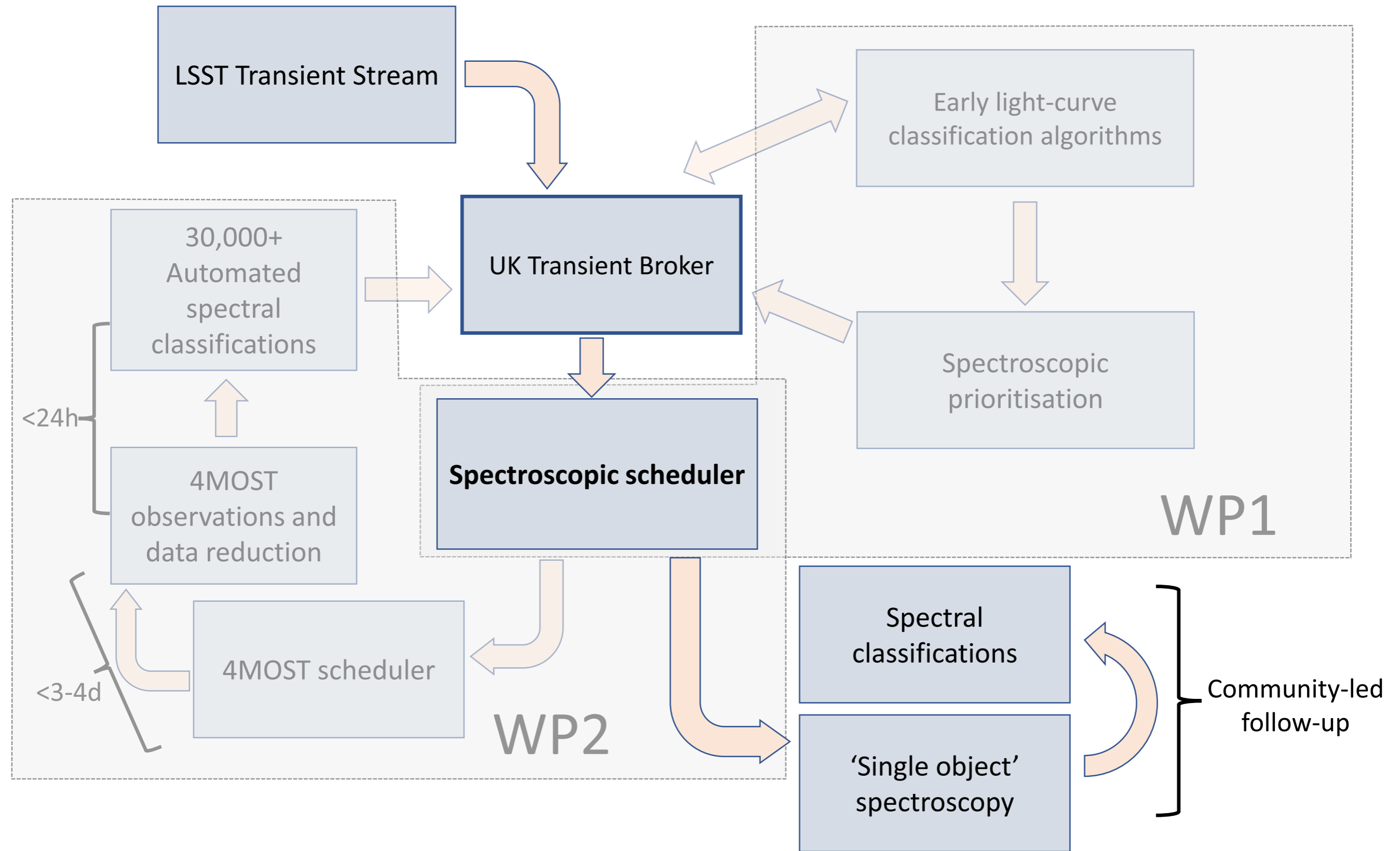
Plot from Daniel Muthukrishna



Infrastructure needed



Infrastructure needed

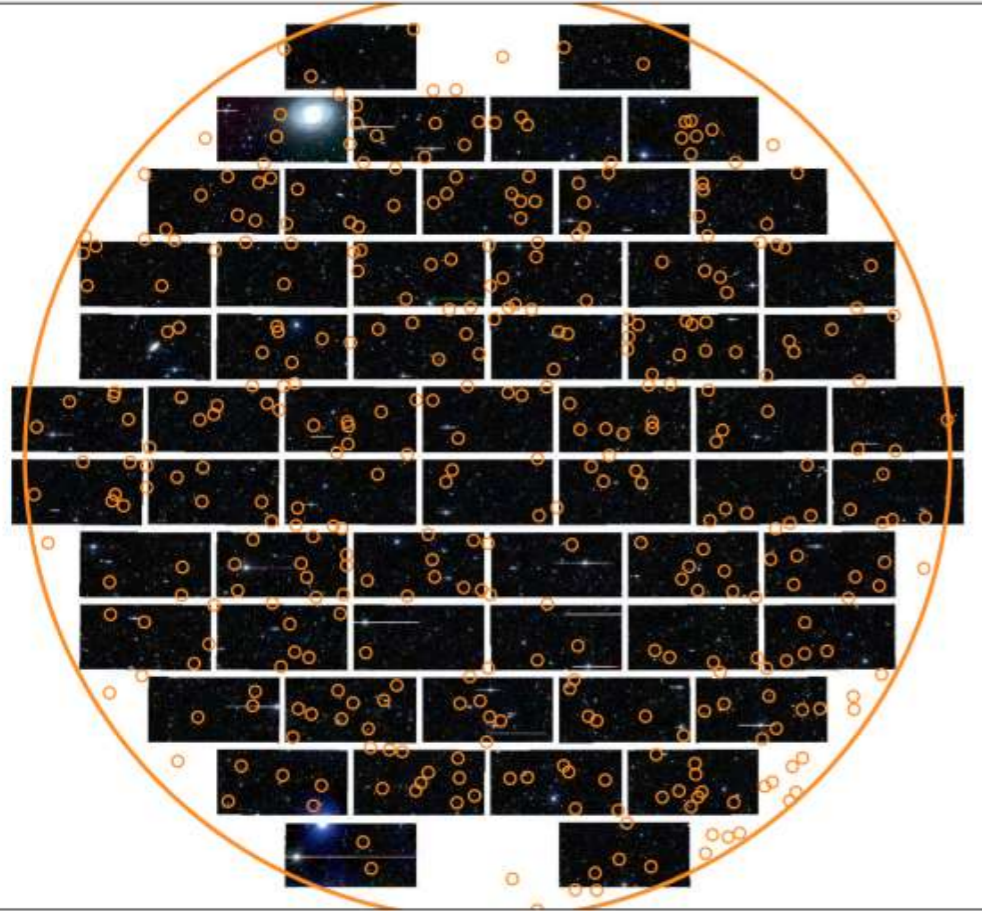


Entire system needs to be tested using:

- Phase A simulations (Vincenzi et al.)
 - Captures full diversity of SN population
 - Test classifications based on actual LSST cadences

- Commissioning data
 - Exercise system using ComCam / LSSTCam
 - Possible pilot programs using AAT/2dF (cf. OzDES)

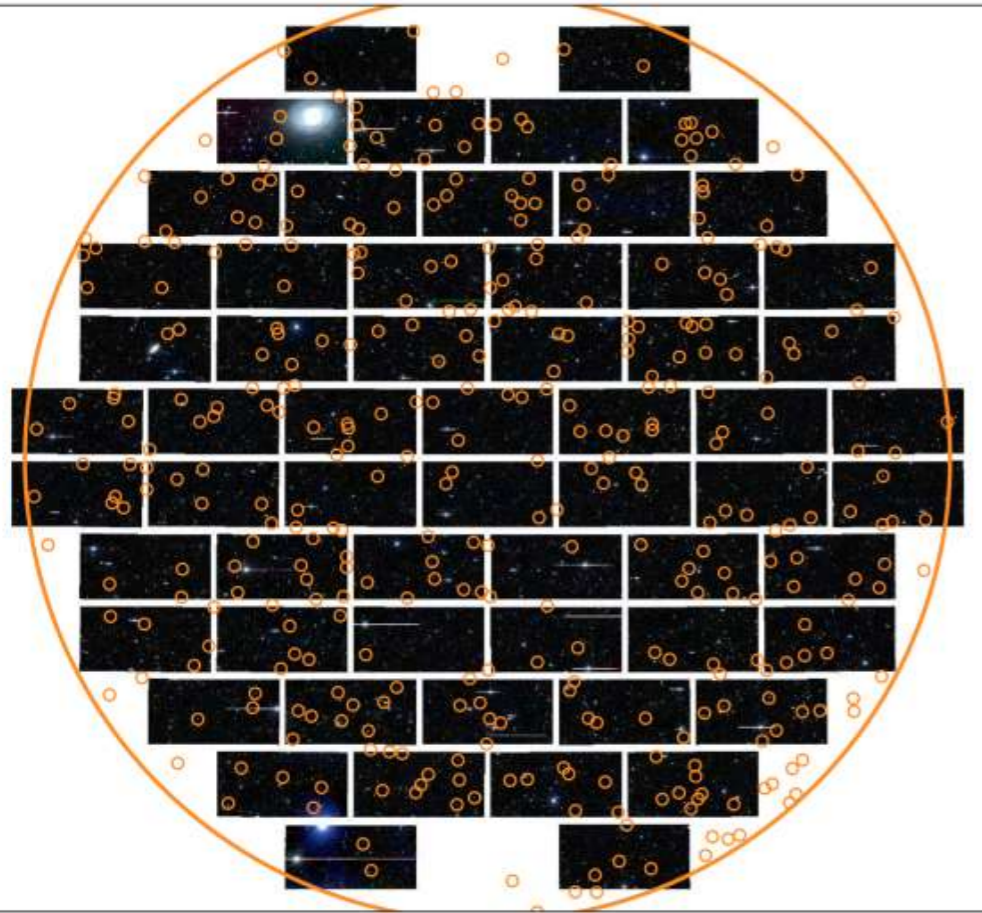
Time Domain Extragalactic Survey (TiDES)



- Wherever 4MOST points, there will be previously-discovered LSST transients
- Put fibre on host galaxy to get a redshift
- Observe live transients; find/schedule in <4 days

- Release 30,000 classifications to the UK community
- Consolidate leadership in SN Ia cosmology and TVS
- No other group/facility currently planned competes with TiDES

Time Domain Extragalactic Survey (TiDES)



- Wherever 4MOST points, there will be previously-discovered LSST transients
- Put fibre on host galaxy to get a redshift
- Observe live transients; find/schedule in <4 days

- Using 250,000 fibre hours over 5 years:

- *Capability of 30,000 live SNe: x30 improvement over DES*
- *Capability of 50,000 SN hosts: x20 improvement over DES*
- *Monitor 700 AGN to $z=2.5$ in Deep Fields to measure lags*

See TiDES
White Paper
– Swann et
al. 2019