Opportunities in SN Ia Cosmology With LSST

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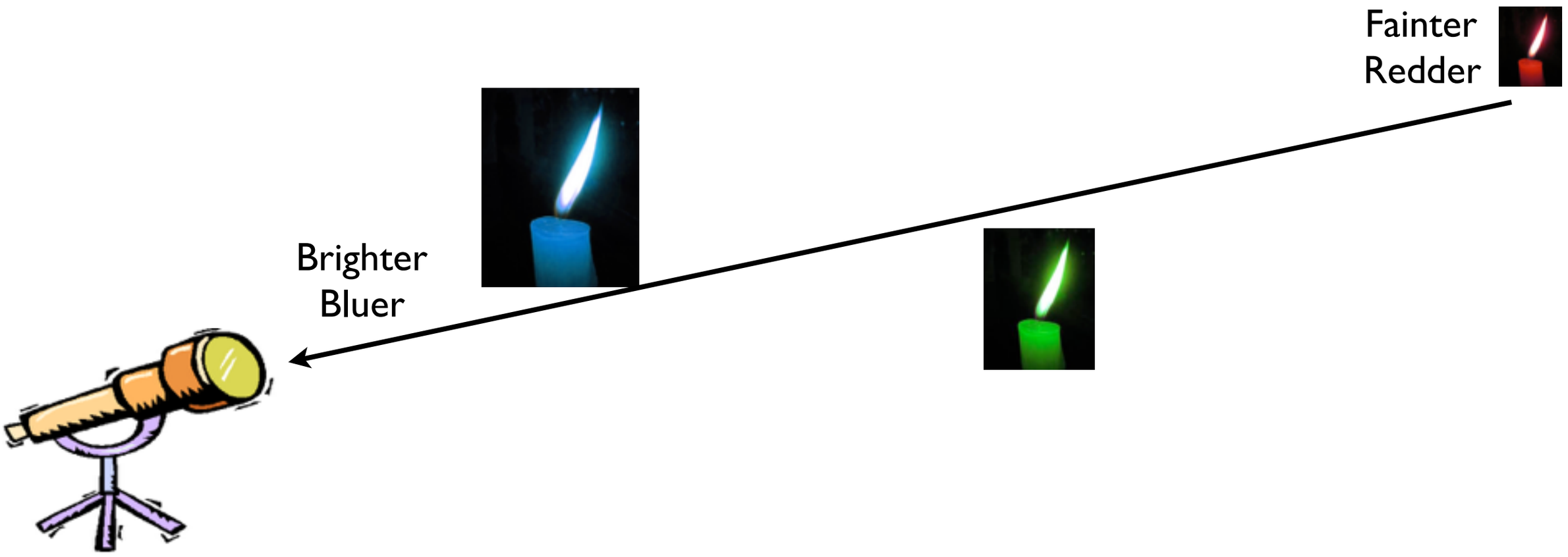
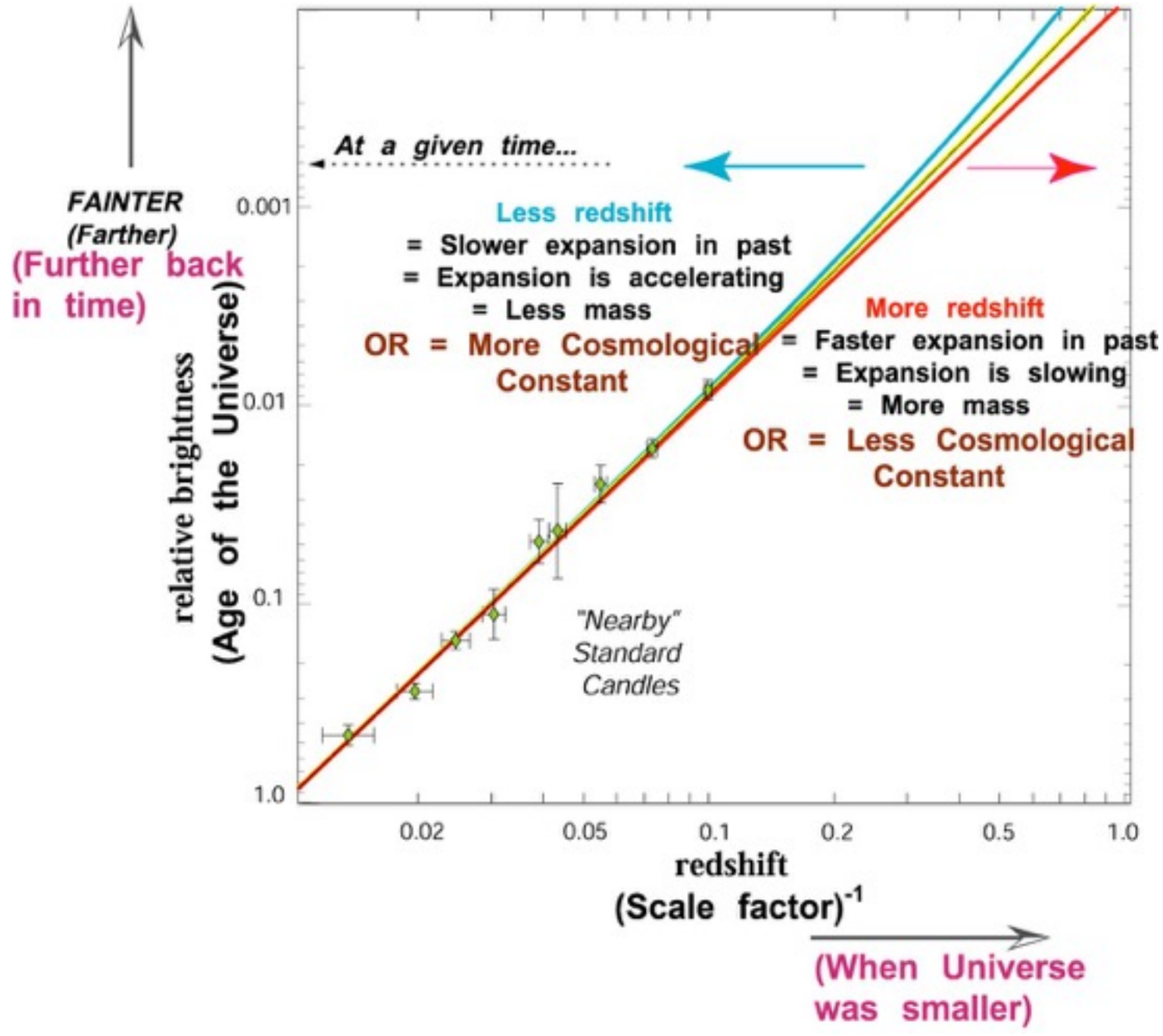
LSST-Dark Energy Science Collaboration

Standard Candles To Cosmology: Measurement



- For a set of standard candles of luminosity L
  - Measure flux f
  - Measure redshift z

Standard Candle Hubble Diagram: Expansion History if the Universe



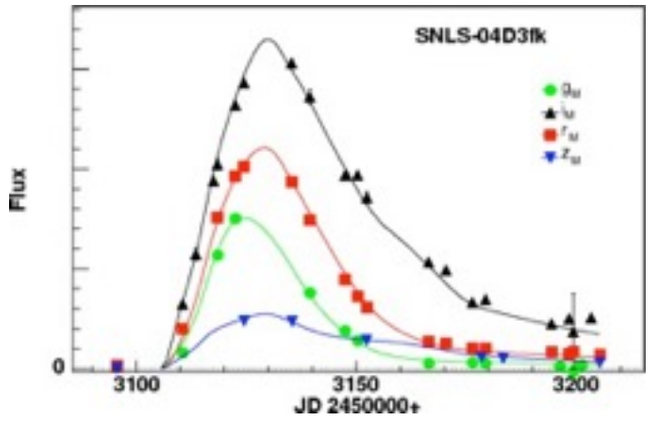
Type Ia Supernovae To Cosmology: Measurement

Fainter
Redder

Brighter
Bluer

For Type Ia supernovae (standardizable candle)

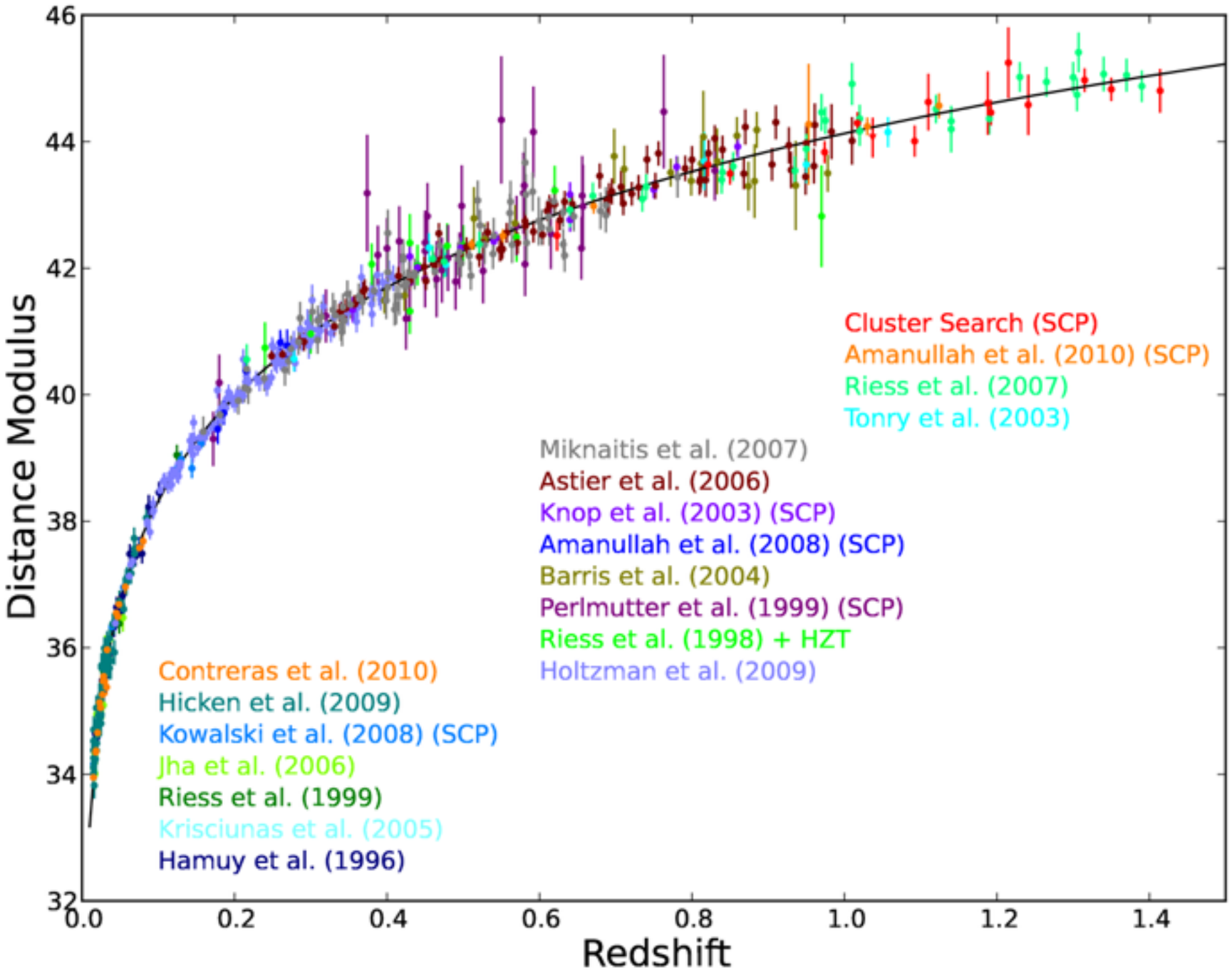
- Measure flux f at different times and wavelengths
- Luminosity L of each supernova encoded in the shape and colors of multi-band light curves



→ Luminosity

- Measure redshift z of supernova or host galaxy

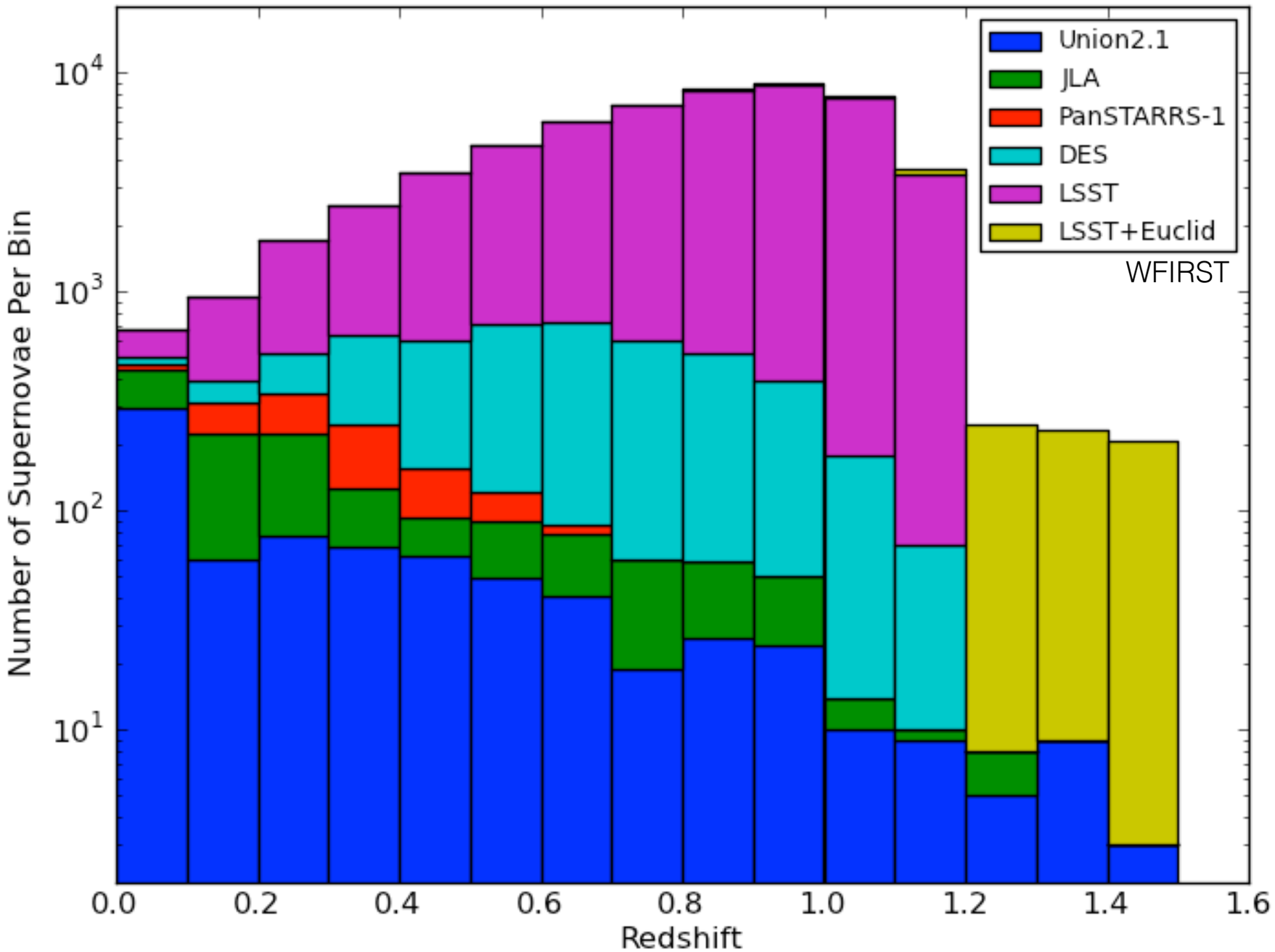
Supernova Hubble Diagram: Expansion History if the Universe



LSST: The Next Generation of Ground-Based Cosmological SN Surveys

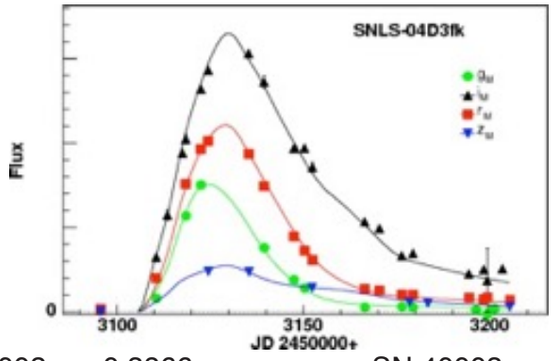
	DES SN		LSST	
	Wide	Deep	Main	Deep Drilling
Duration	5 CTIO Semesters		10 years	
Effective Mirror Diameter	3.6 m		6.7 m	
Solid Angle	8x3 sd	2x3 sd	18,000 sd	O(5)x9.6 sd
Depth/visit	24 *griz*	25 *griz*	24/25/24/23/22 *u/gr/i/z*	26.5/26/25.5/24.5 *gr/i/z/y*
Cadence	5 days/band	5 days/band	3 days	4 days/band
Numbers	2500	500	1,000,000	50,000

Current and Upcoming Surveys Redshift Distributions



Numbers Do Not Tell the Entire Story: Light Curve Quality

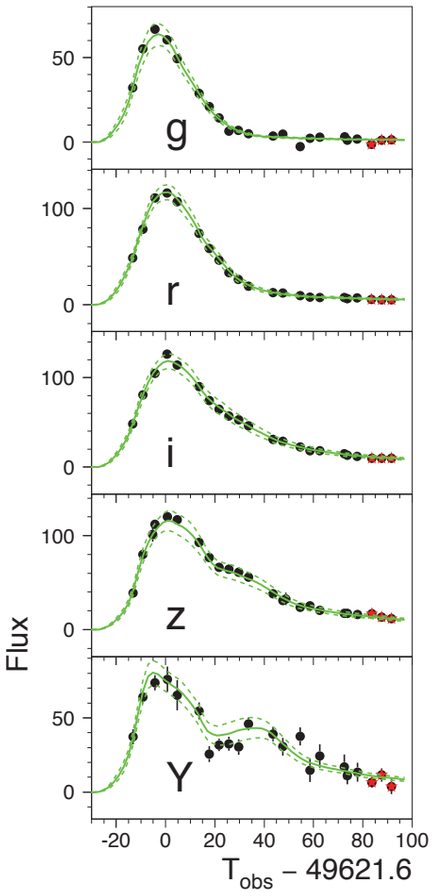
- Recall that light curve shapes and colors give the luminosity



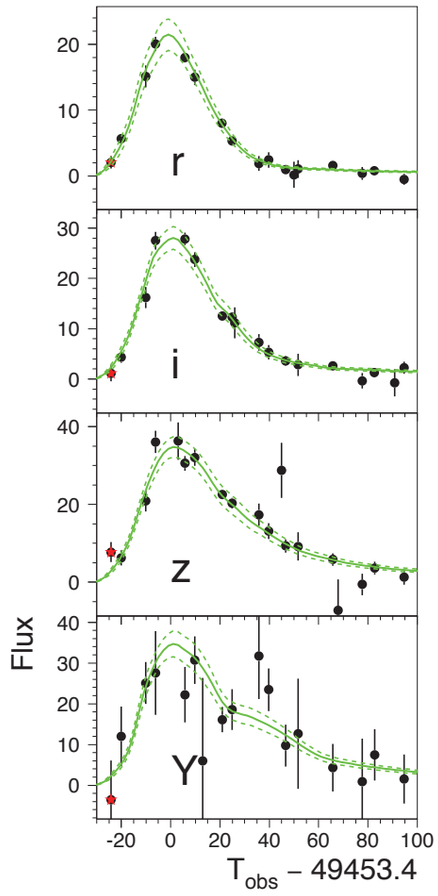
Luminosity

Luminosities

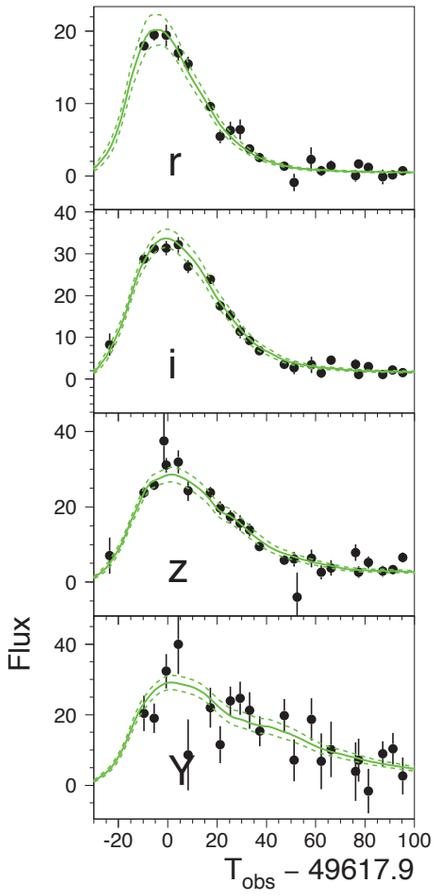
SN 40002 z=0.3866



SN 40003 z=0.598



SN 40006 z=0.8065

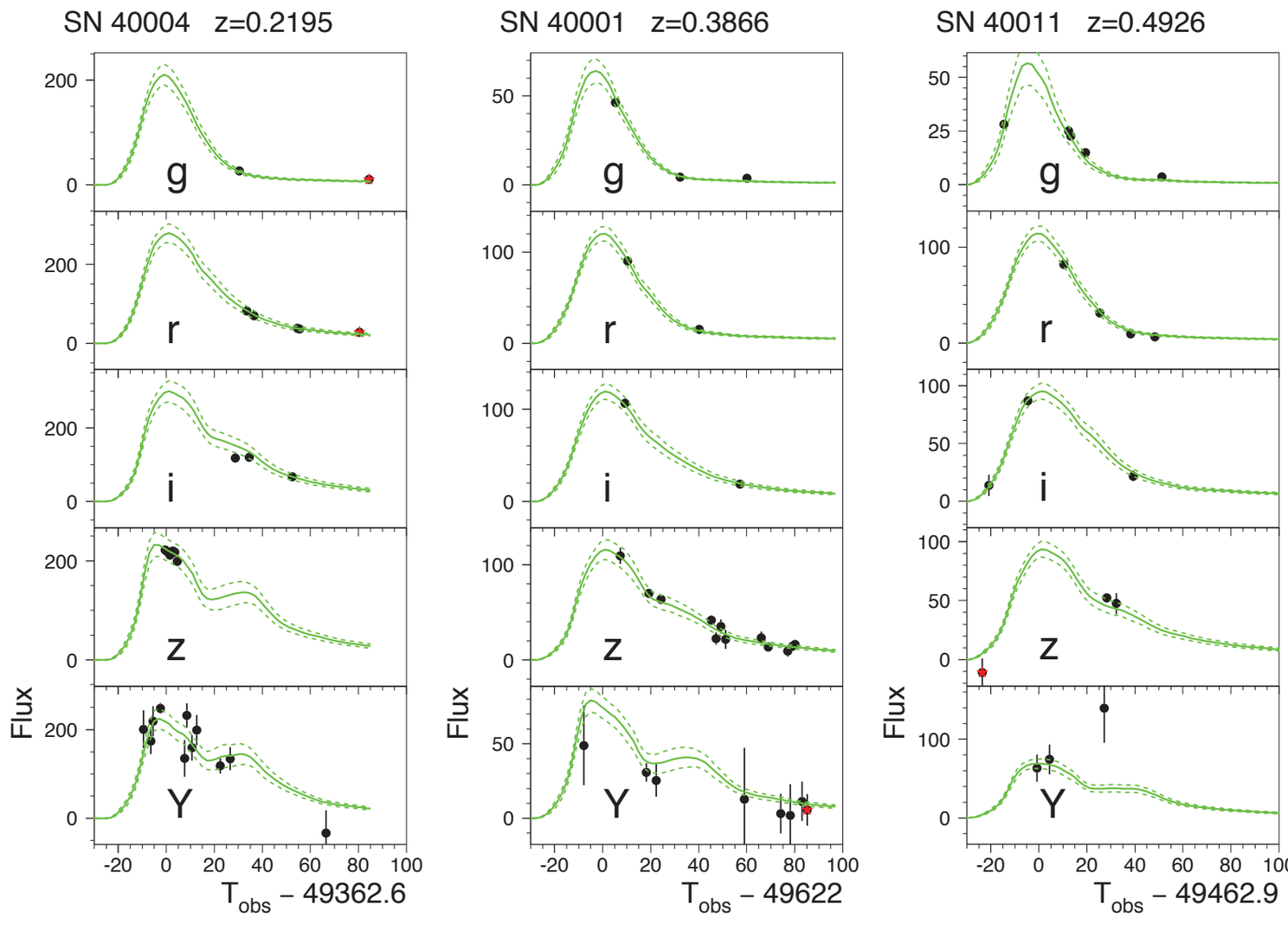


Simulated SN Ia Light Curves in the Deep Drilling Field
LSST Science Book v2.0

Numbers Do Not Tell the Entire Story: Light Curve Quality

- Supernova discovery not sufficient to give accurate luminosity
- Shown are examples of SNe that are found but give poor luminosity determinations

Simulated SN Light Curves Wide Survey

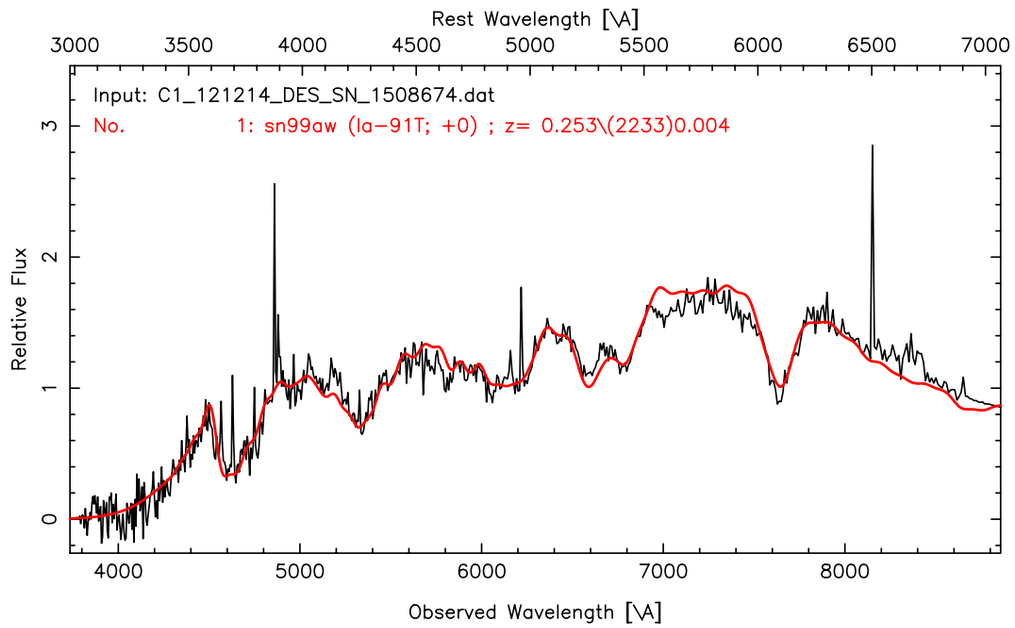


LSST Science Book v2.0

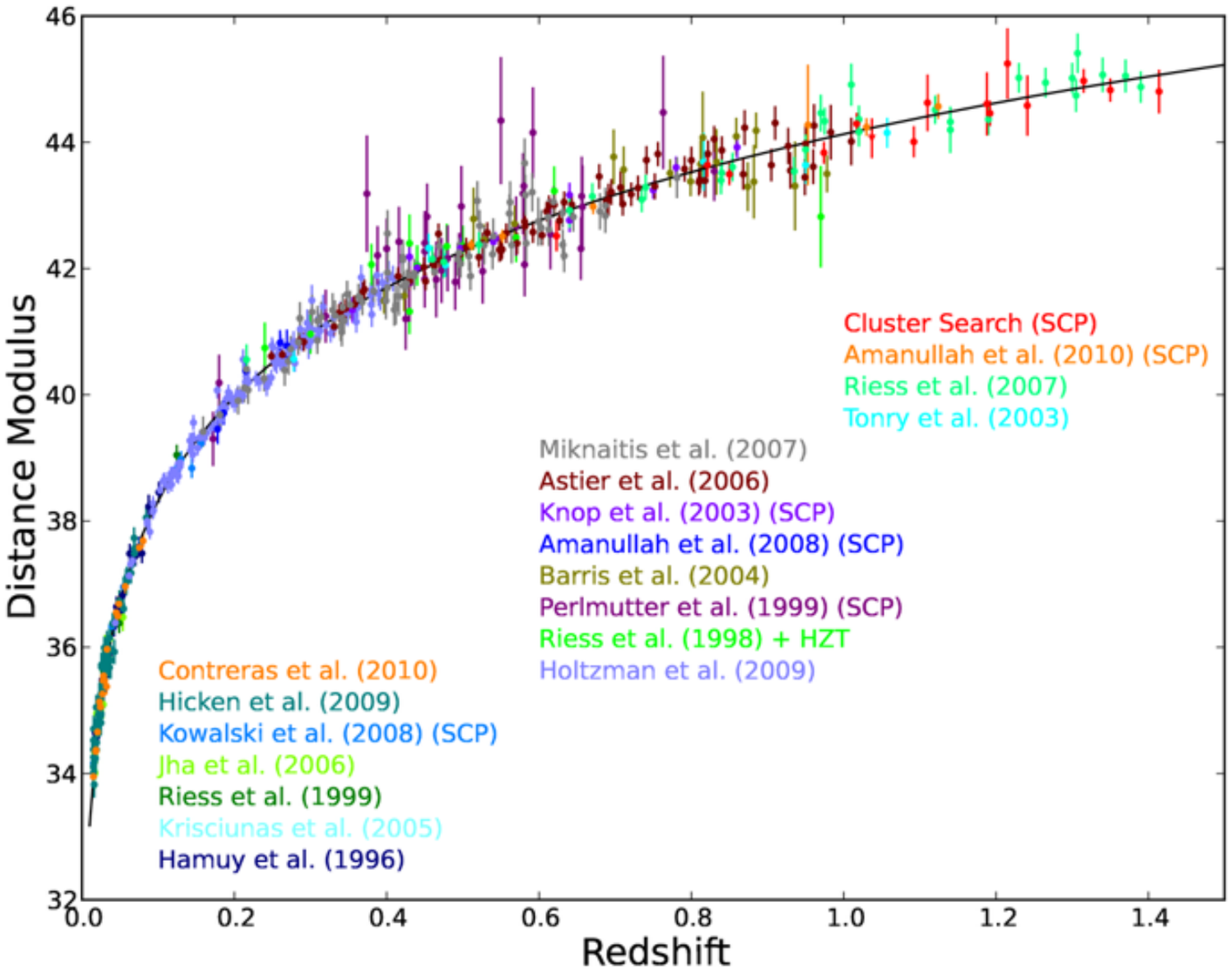
Numbers Do Not Tell the Entire Story: Incomplete Spectroscopy

- Spectroscopy (not part of the imaging DES or LSST surveys) gives
  - Transients typed as SNIa
  - Host galaxies identification
- Highly precise redshift

OzDES spectrum of DES Type Ia Supernova



Numbers Do Not Tell the Entire Story: Incomplete Spectroscopy



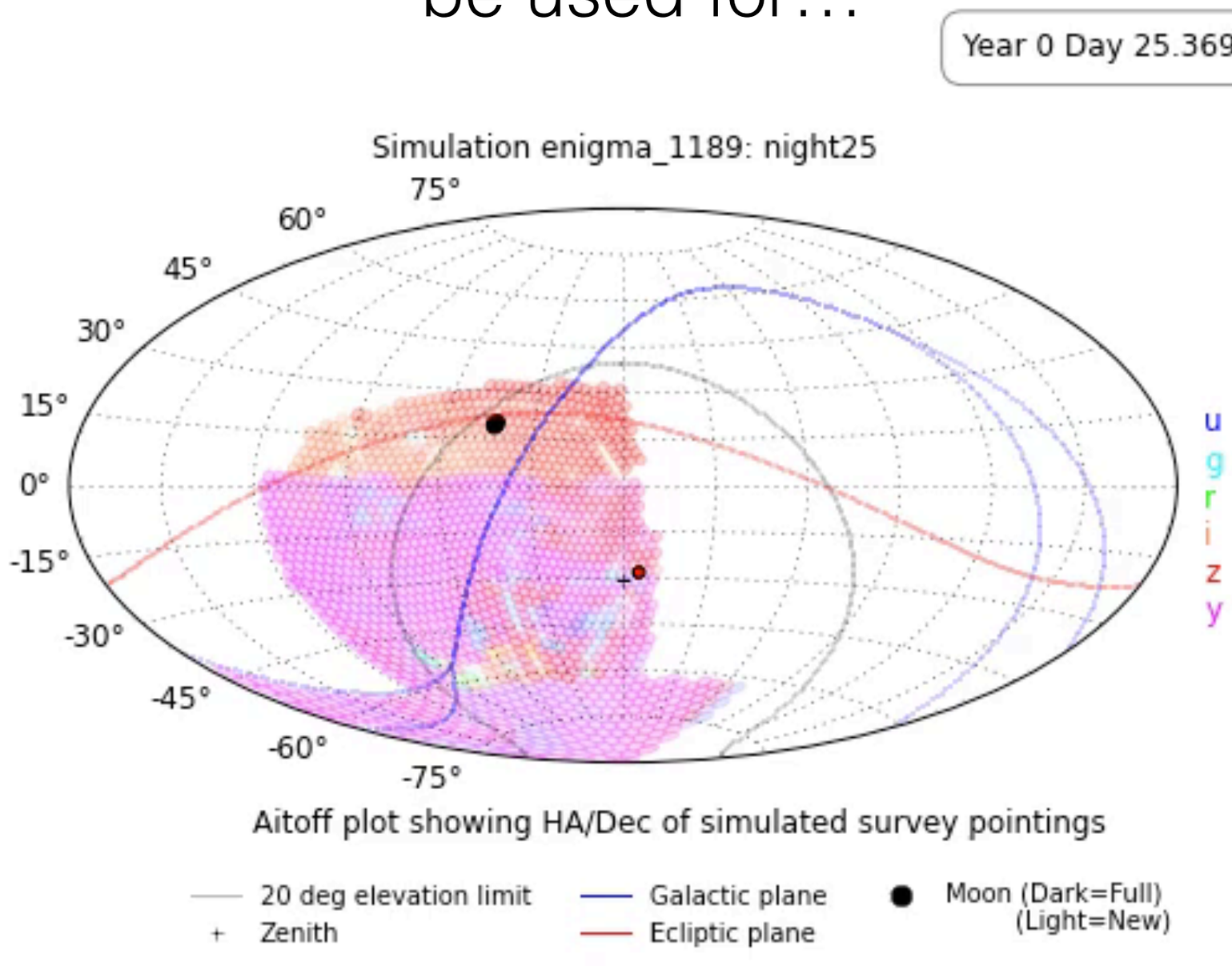
- DES Hubble Diagram (very preliminary!!)
  - has an impressive number of transients
  - is an impressive mess
- Mess is due to lack of spectroscopic completeness
  - Contamination from non-Ia's
  - Host galaxies misidentified
  - Highly uncertain redshifts
- It has NOT been established whether systematic uncertainties can be constrained to yield precision cosmology from these data

Opportunities To Work on LSST Today!

- Optimize LSST observing strategy to produce accurate supernova luminosities
- Develop analysis methods for when there is no spectroscopic typing
- Organize the supernova spectroscopy program: Large-aperture telescopes (e.g. GMT) required for success
- Synergy with DESI
- Synergy with WFIRST
- Novel Physics! strongly lensed SNe, isotropy studies, peculiar velocities, cross-correlation with other tracers, intrinsic transient properites…

Survey Strategy Leads To Light Curve Sampling

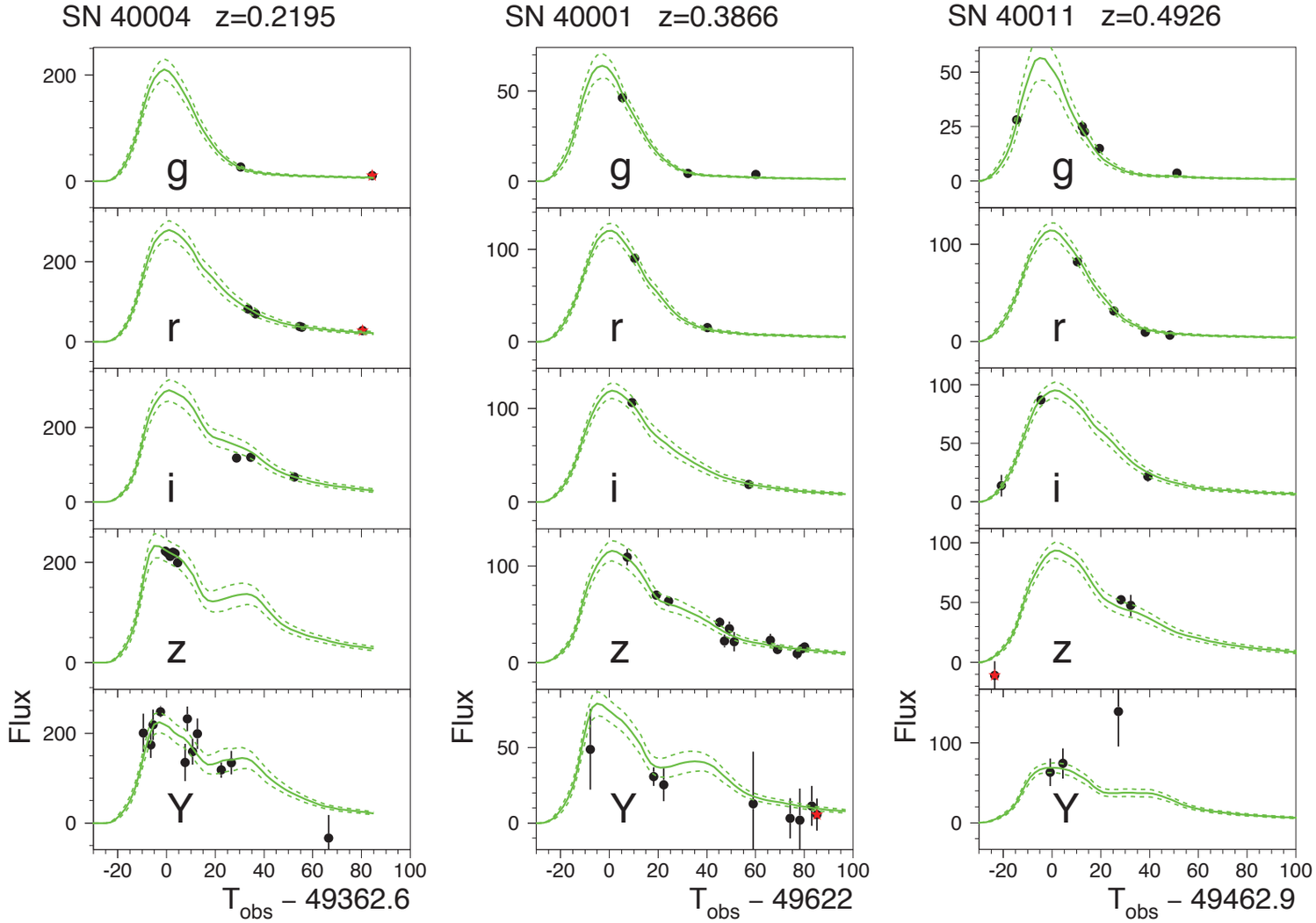
The LSST Project makes simulations of observations that can be used for…



Survey Strategy Leads To Light Curve Sampling

The LSST Project has makes simulations of observations that can be used for…

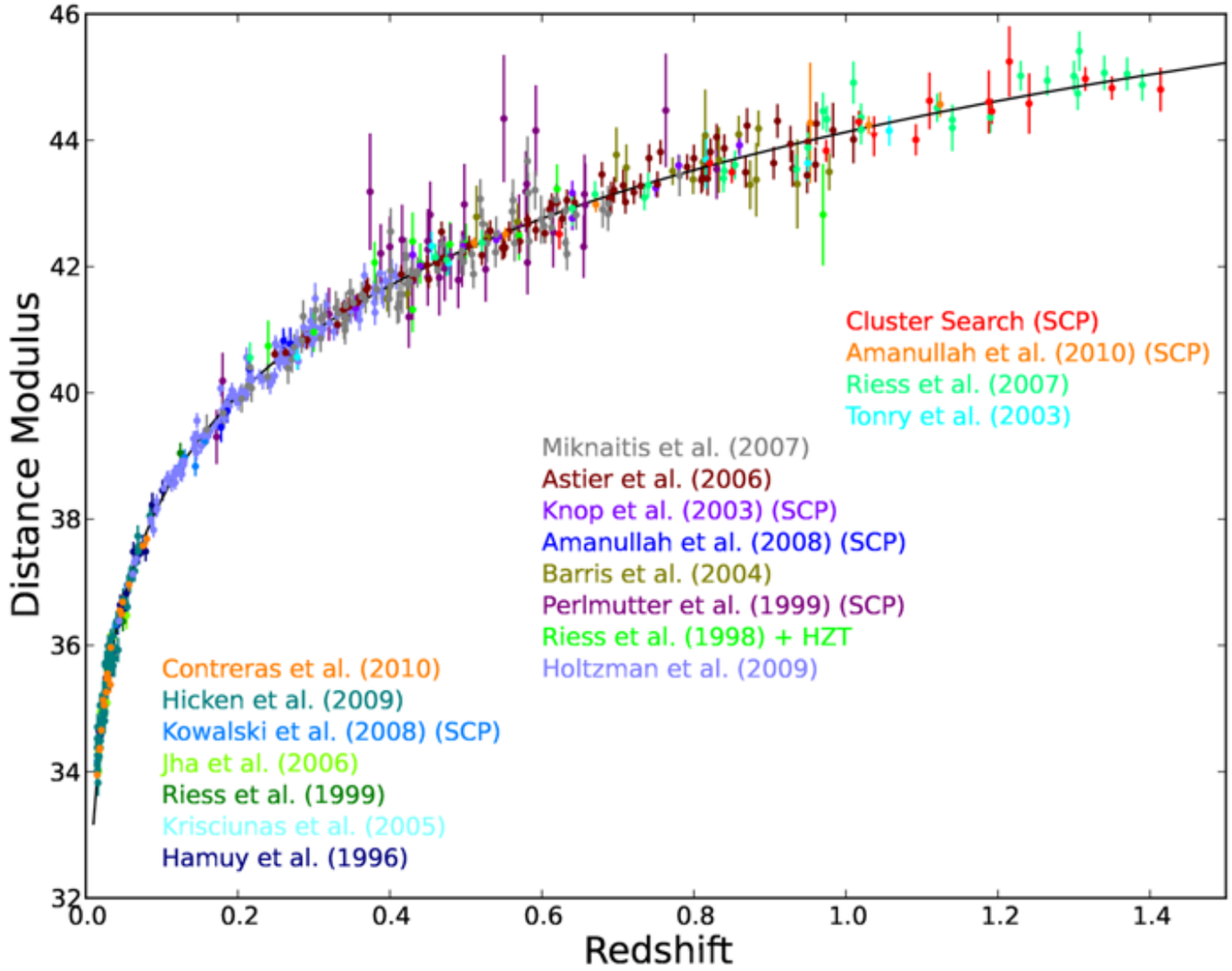
simulating observed supernova data



Survey Strategy Leads To Light Curve Sampling

The LSST Project has makes simulations of observations that can be used for…

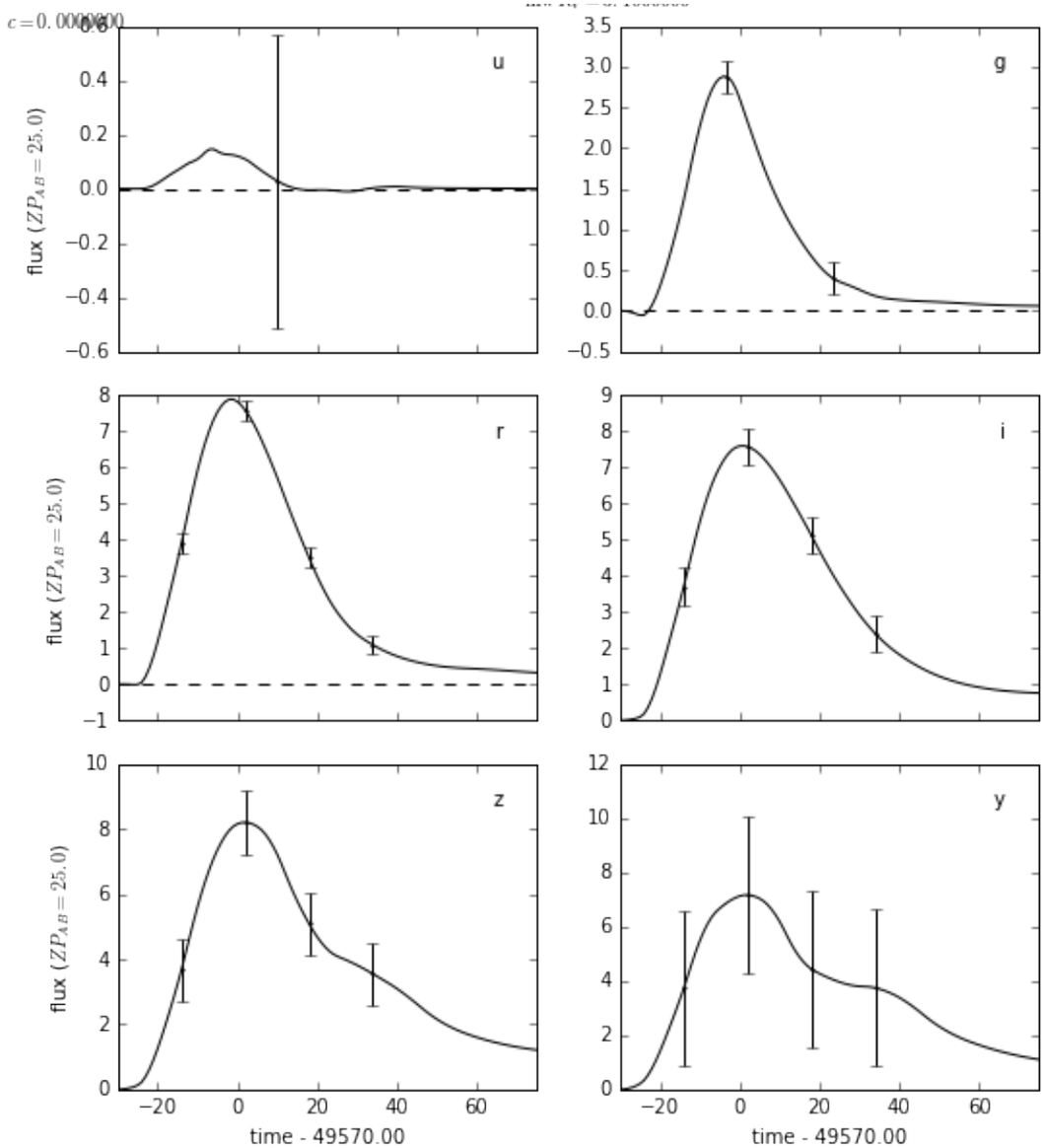
determining distance precisions from the data



Survey Strategy Optimization: SN Cosmology Cadence Whitepaper

- LSST Project solicits metrics for science performance
    - http://lsstsciencecollaborations.github.io/ObservingStrategy/
- Project provides framework that takes simulated LSST observations and returns metric
    - https://confluence.lsstcorp.org/display/SIM/MAF+documentation
- SN Cosmology Group actively developing metrics, alternative observing strategy
    - led by R. Biswas, M. Lochner, Jeonghee Rho

Nominal LSST Wide Survey

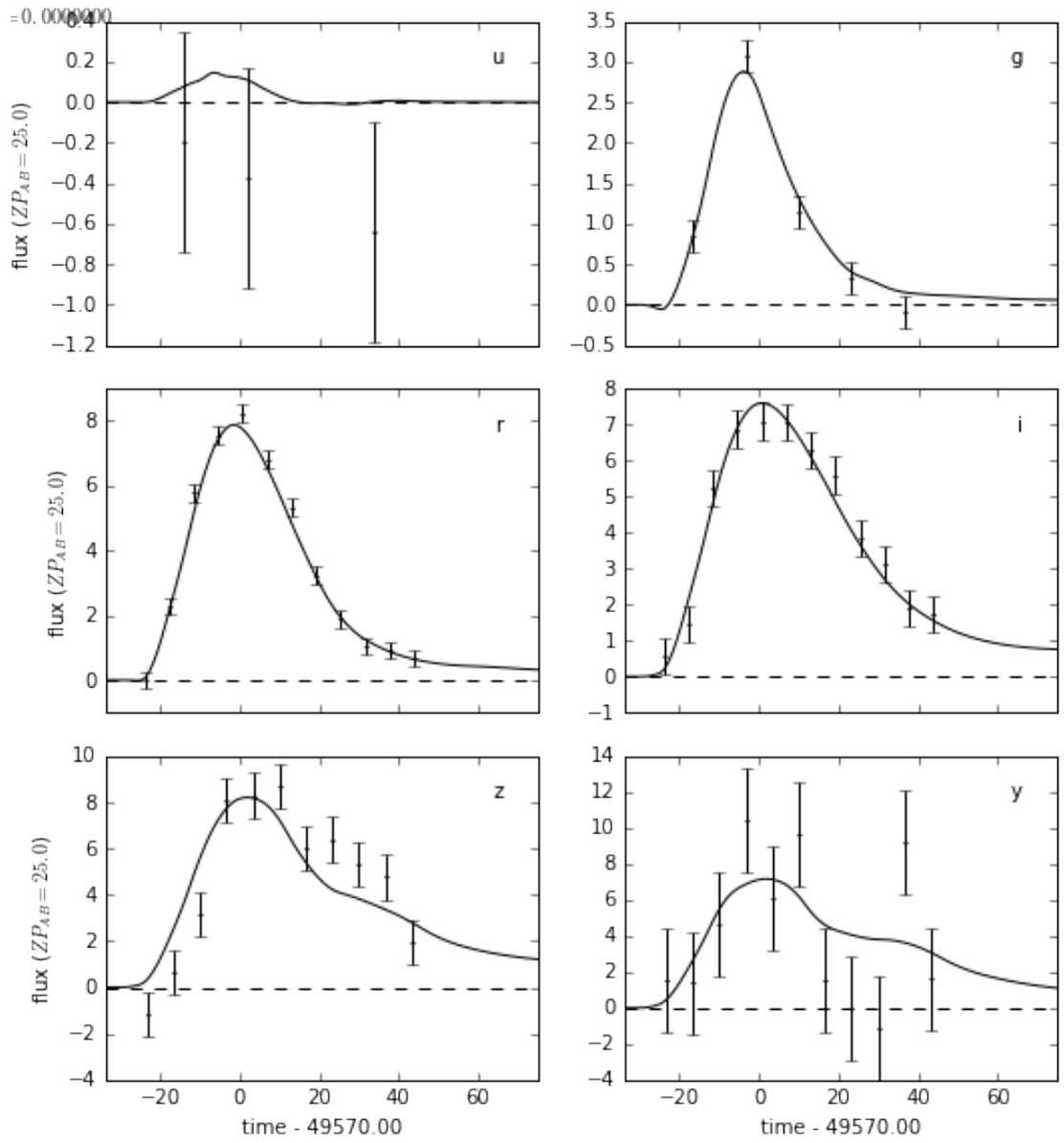


- Wide survey designed to cover 18,000 degrees of extra-Galactic sky
- Continuous monitoring over the 10 years of the survey
- Sky revisited ~3 days on of the filters
- Result: Poorly sampled supernova light curves

Rho 2016 LSST-DESC Collaboration Meeting

Wide Survey Alternative Plan

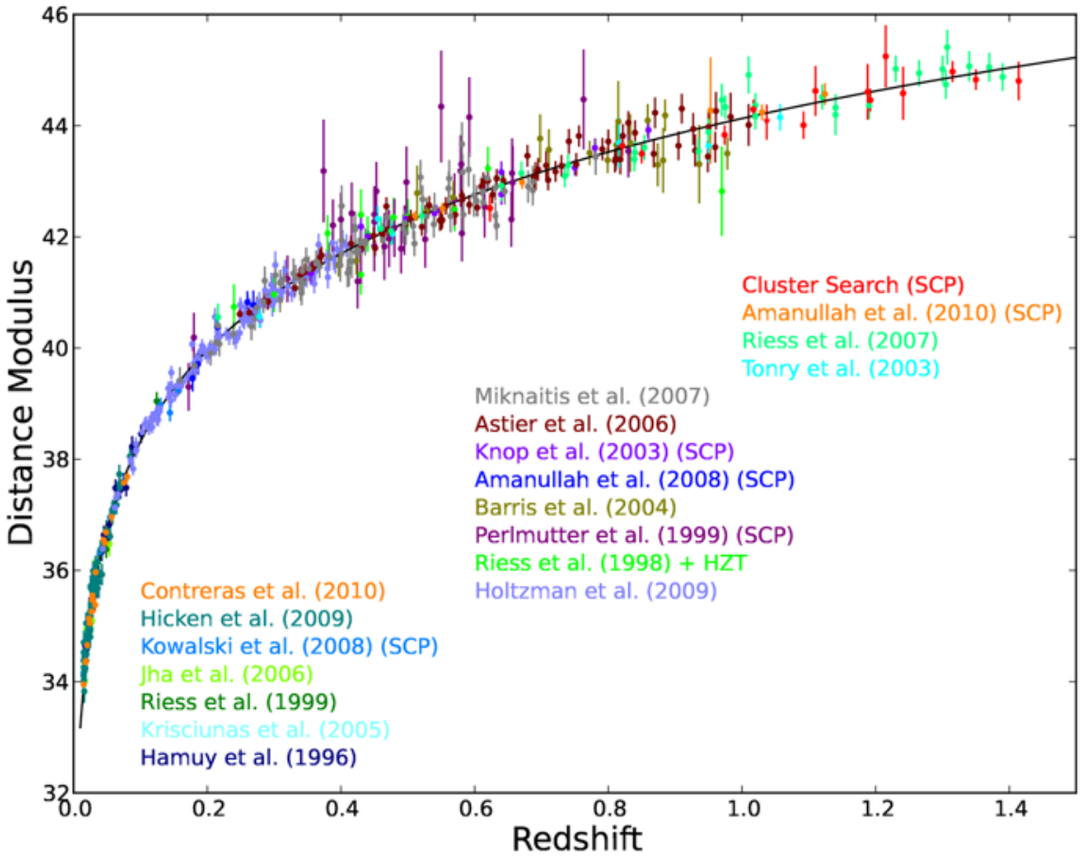
- Wide survey designed to cover 18,000 degrees of extra-Galactic sky
- Monitoring every other year during the survey
- Sky revisited ~1.5 days on of the filters
- Result: Better sampled supernova light curves



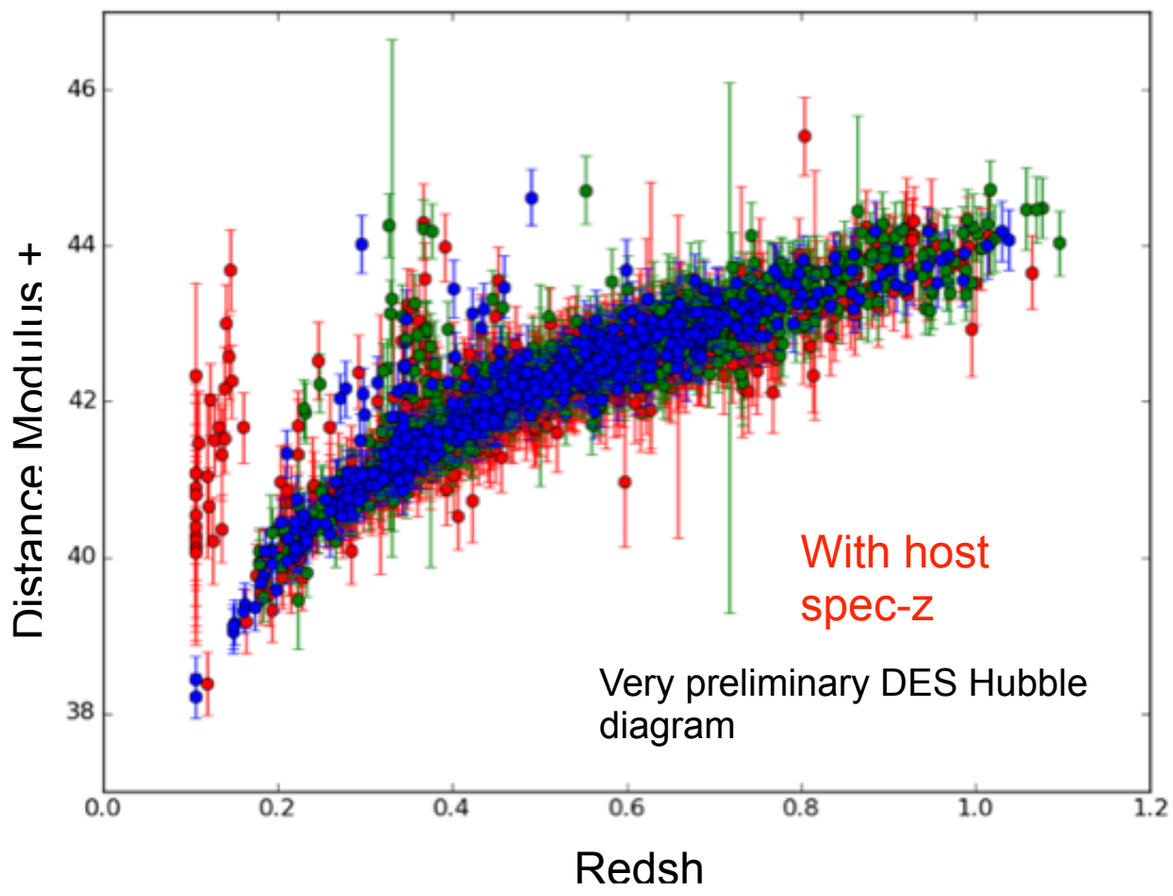
Rho 2016 LSST-DESC Collaboration Meeting

LSST Requires a Different Kind of Hubble Diagram Analysis

Pre-DES, LSST



DES, LSST



UNIVERSAL

INDIVIDUAL SN

OBSERVATORY

DATA

SNe Ia, Populations

Cosmology

Pre-DES, LSST

Distance

Luminosity

Flux

Type Subtype$_o$

Redshift$_o$ Phot & Spec

Host Properties$_o$ Phot & Spec

Photometry$_o$

SNe $i = 1, \cdots, N_{SN}$

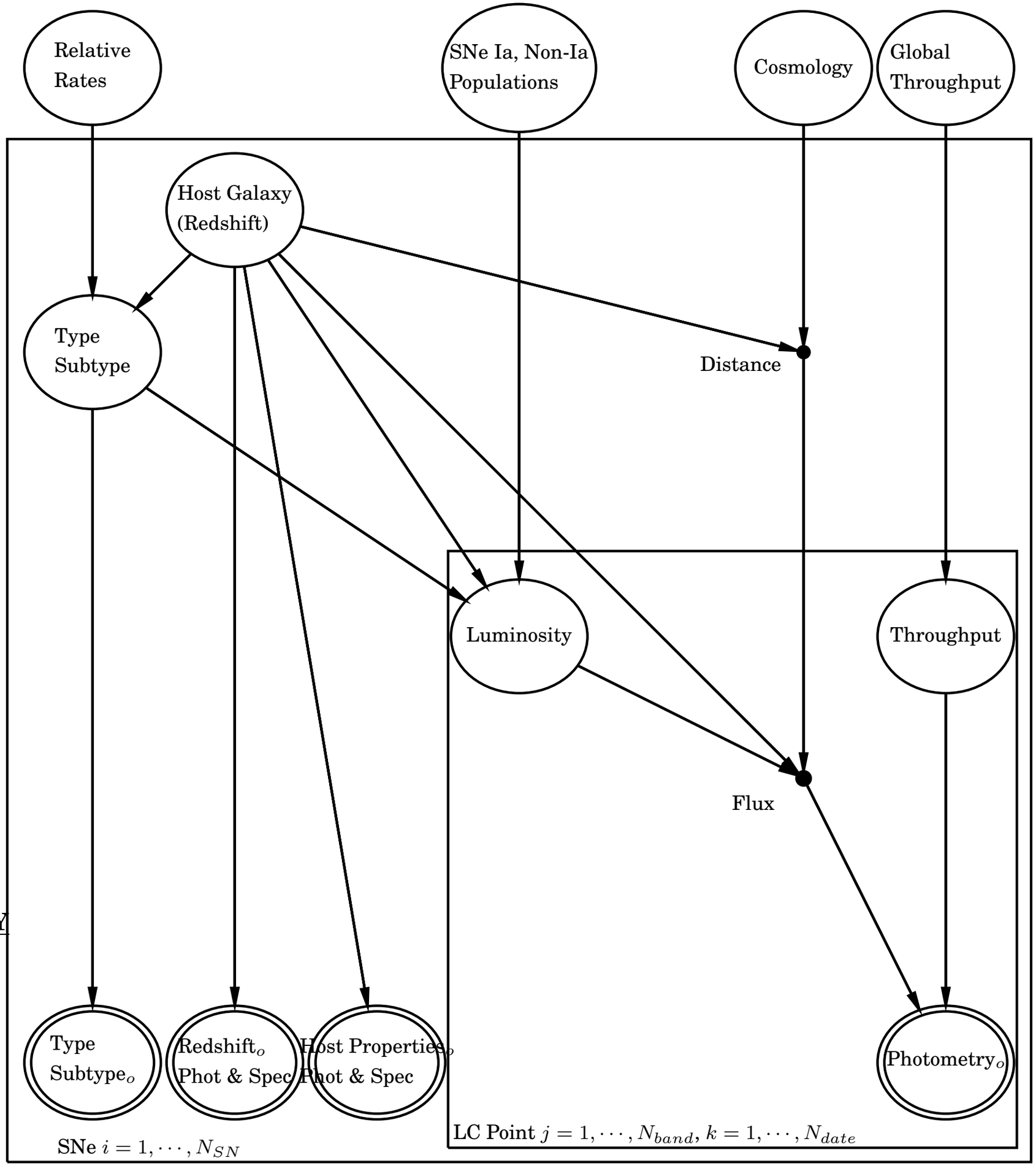
LC Point $j = 1, \cdots, N_{band}$, $k = 1, \cdots, N_{date}$

UNIVERSAL

INDIVIDUAL SN

OBSERVATORY

DATA



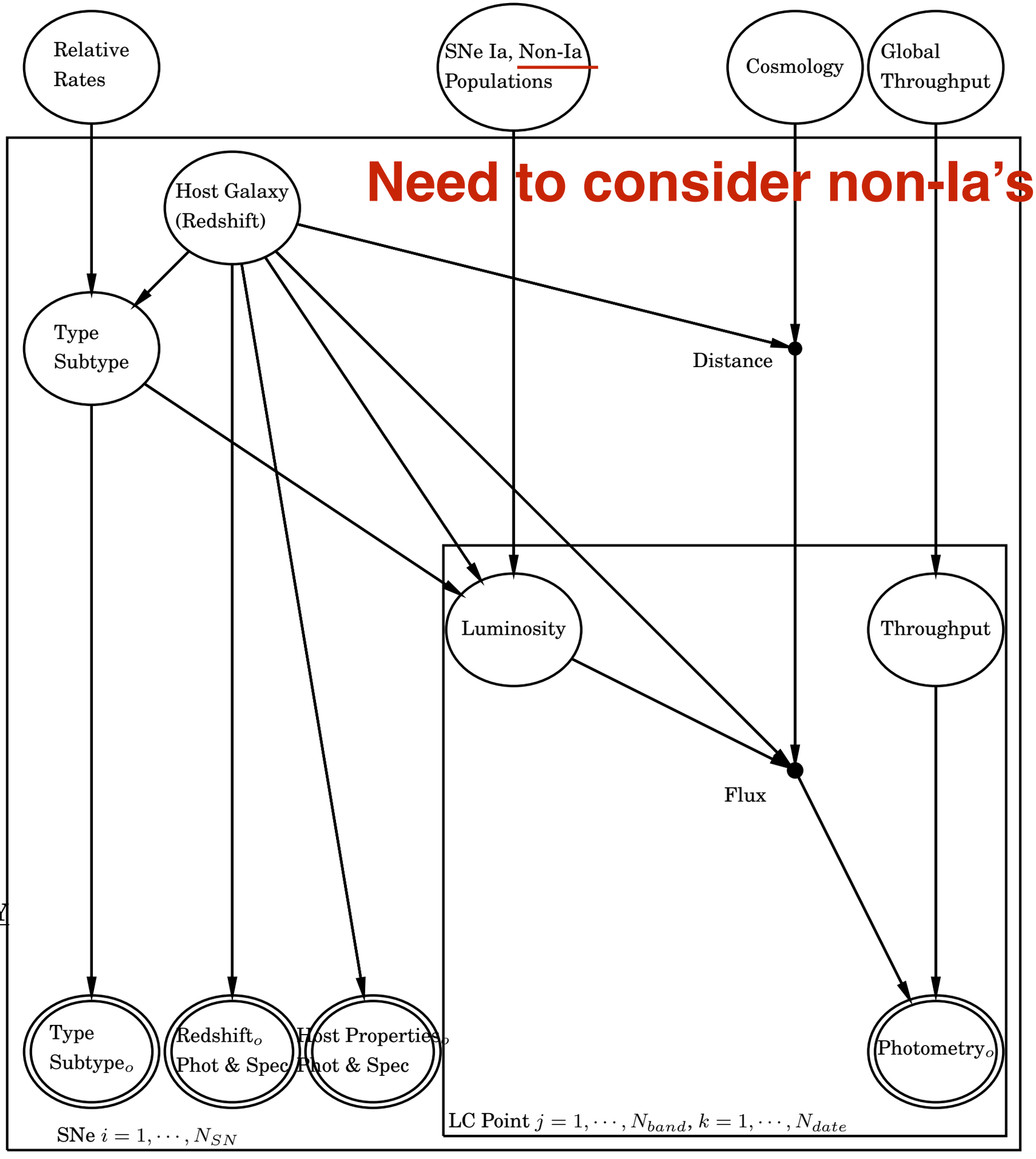
DES, LSST

UNIVERSAL

INDIVIDUAL SN

OBSERVATORY

DATA



Need to consider non-Ia's

DES, LSST

UNIVERSAL

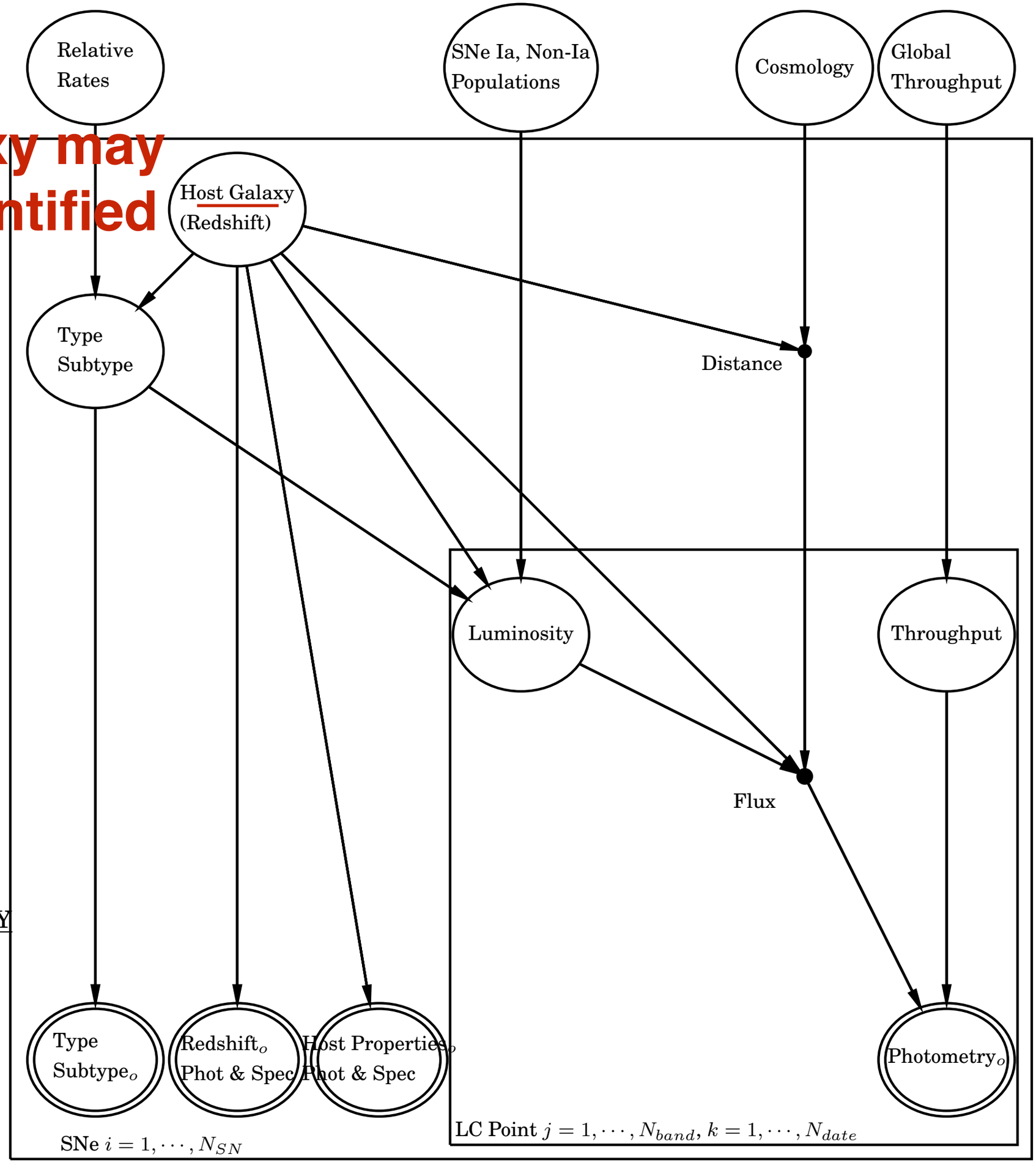
INDIVIDUAL SN

OBSERVATORY

DATA

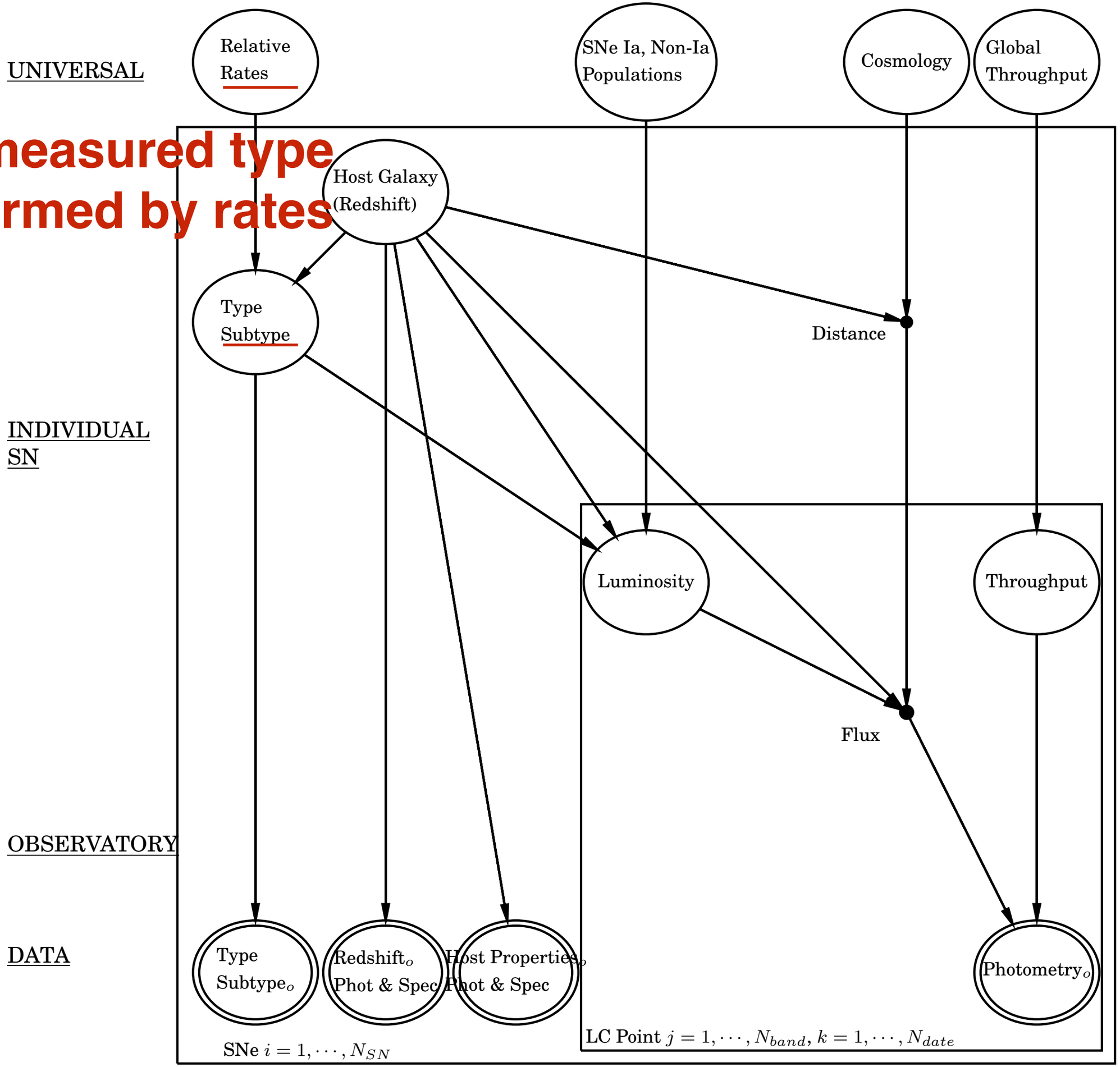
Host galaxy may be misidentified

DES, LSST



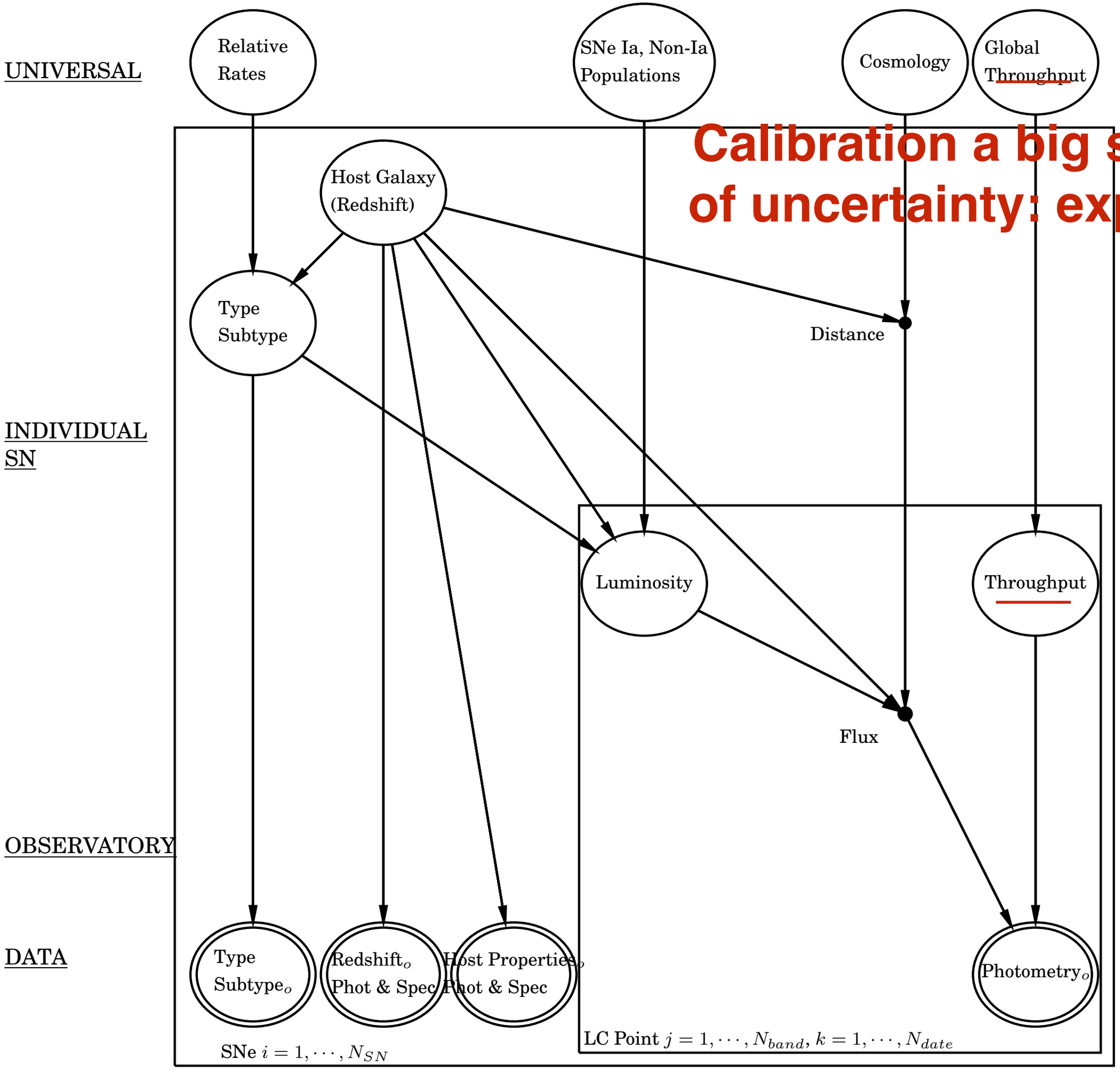
Unmeasured type informed by rates

DES, LSST



DES, LSST

Calibration a big source of uncertainty: expose it

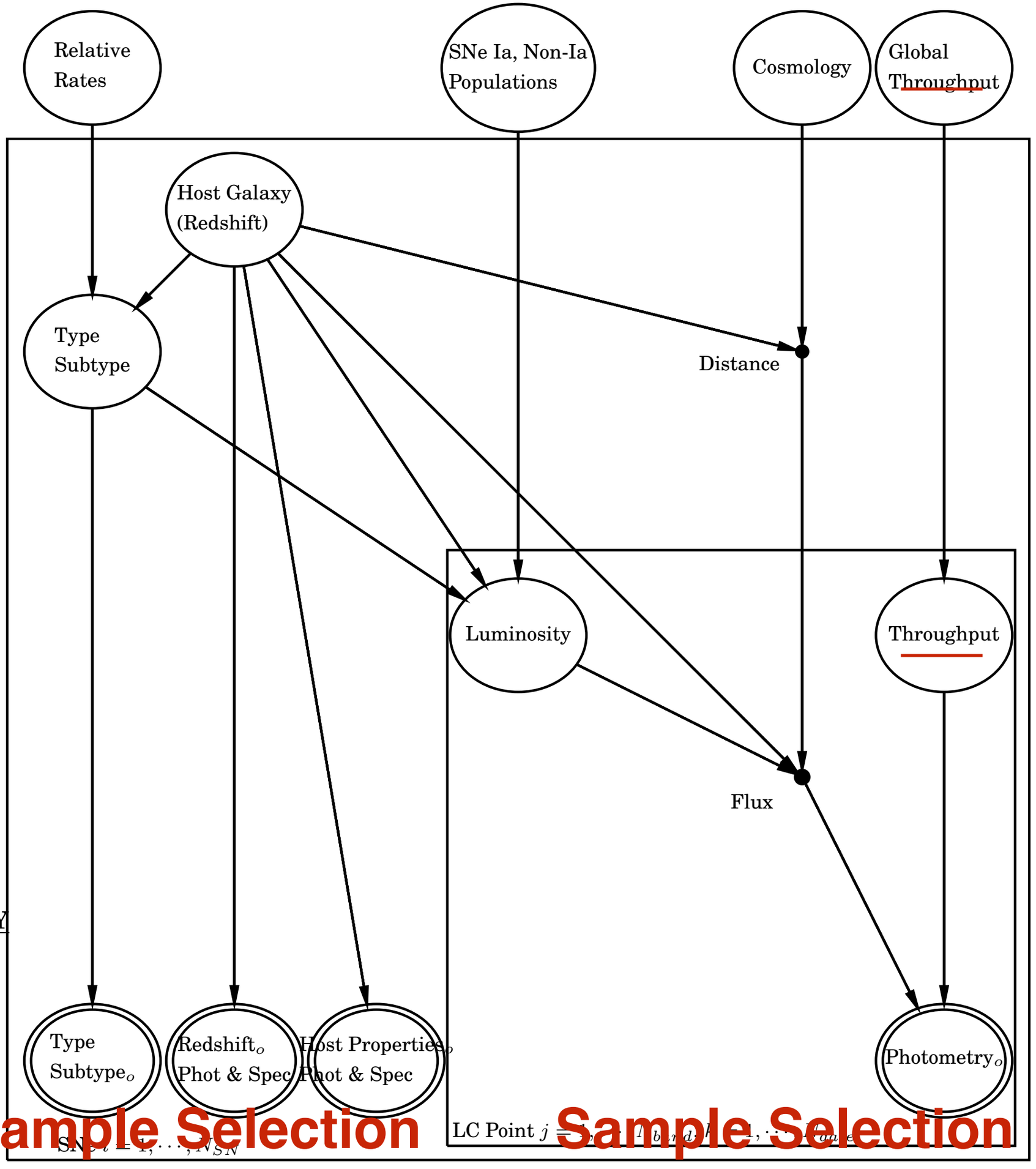


UNIVERSAL

INDIVIDUAL SN

OBSERVATORY

DATA

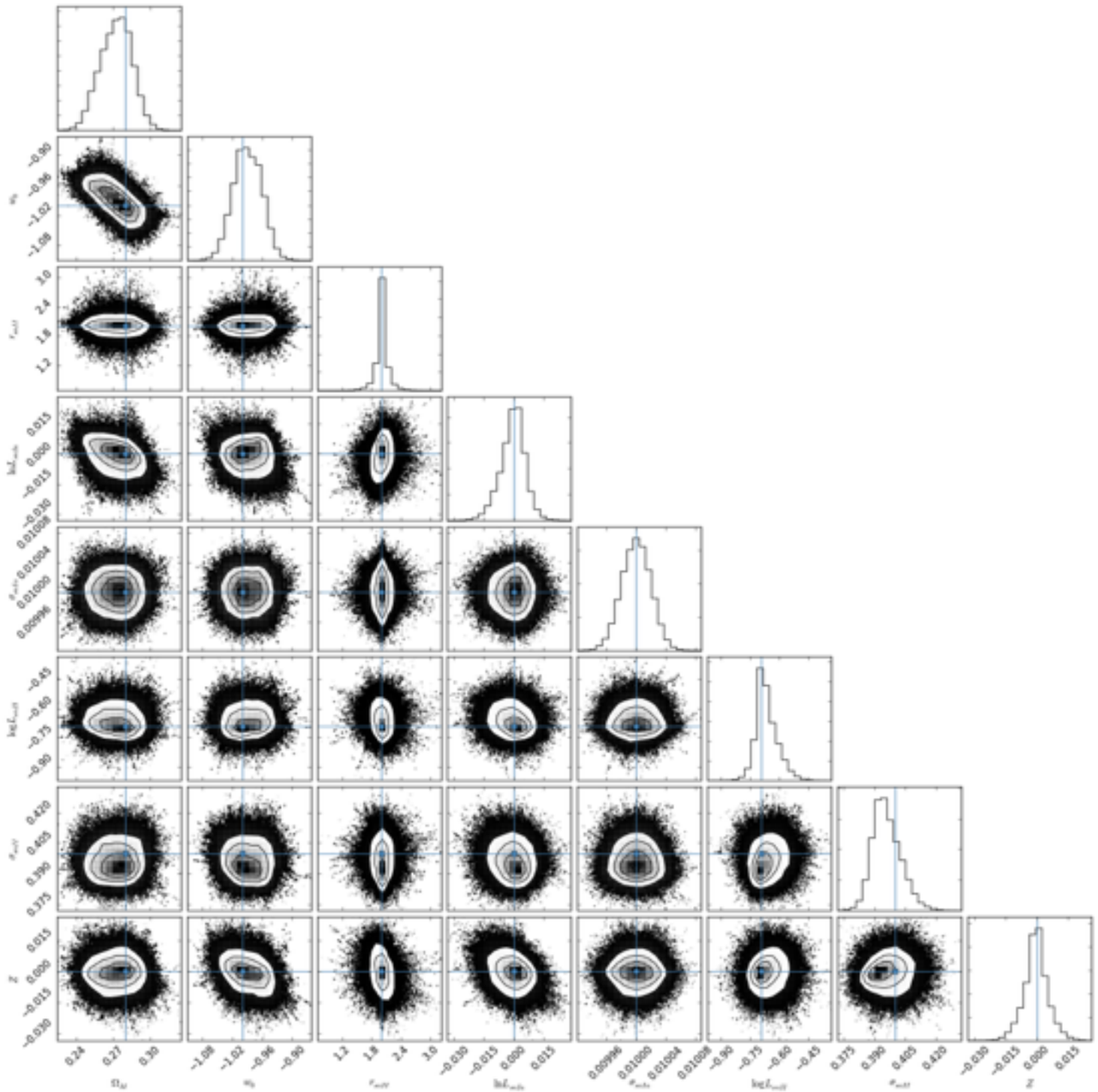


DES, LSST

Sample Selection Sample Selection

Determining the PDF is a Computational Challenge

- Able to construct parameter PDF's for ~100 SNe using Affine Invariant MCMC (emcee) but…

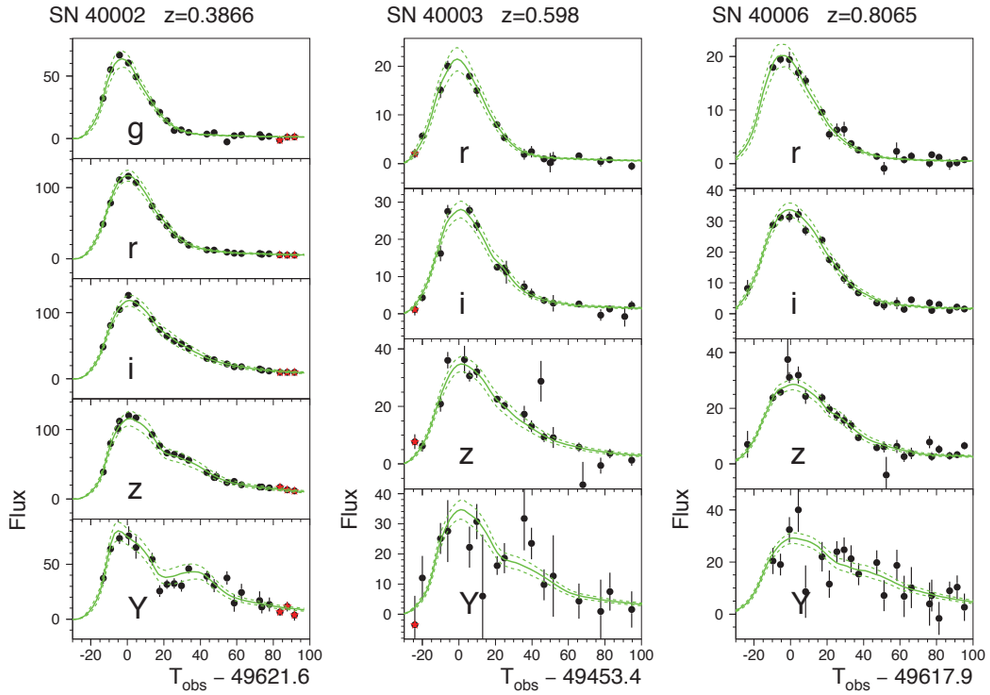


Determining the PDF is a Statistical Challenge

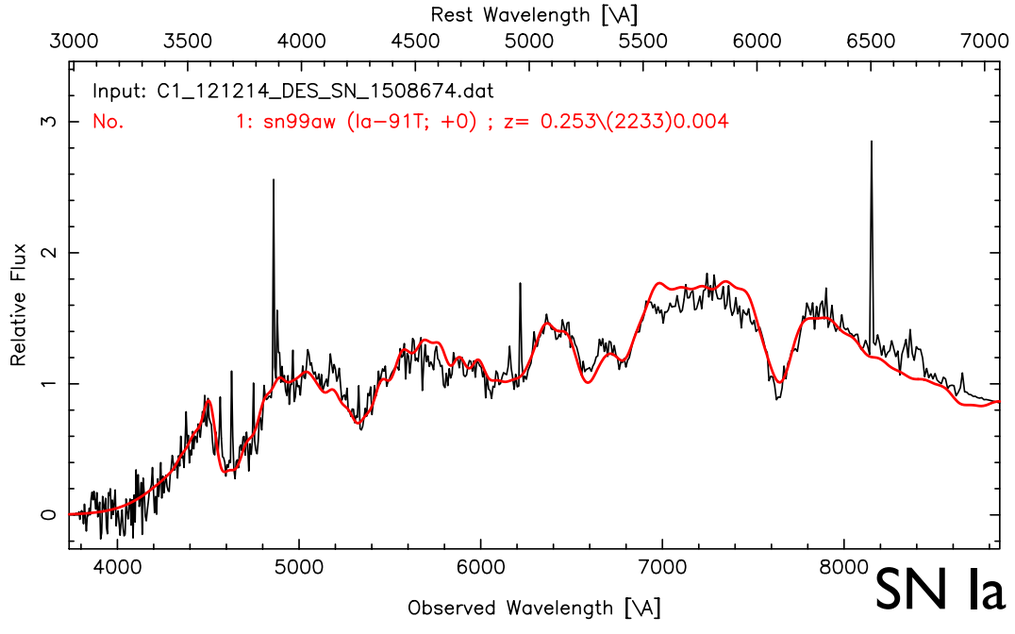
- LSST produces >10^4 SNe!
  - Each SN is associated with several parameters
- Curse of dimensionality for Metropolis-Hastings MCMC algorithms
- Hamiltonian Monte Carlo is the only algorithm (I know of) that successfully handles such huge parameter sets …
  - … but due to an integral in the likelihood I have not got one to work
- A problem for other cosmological probes

Supernova Spectroscopy Follow-up Program

- LSST provides photometry only
- Spectroscopy is critical for SN cosmology
  - Redshift, Classification
  - Where to get it?
- Needs
  - Wide-field MOS: DESI
  - Next-generation large-aperture telescopes: GMT



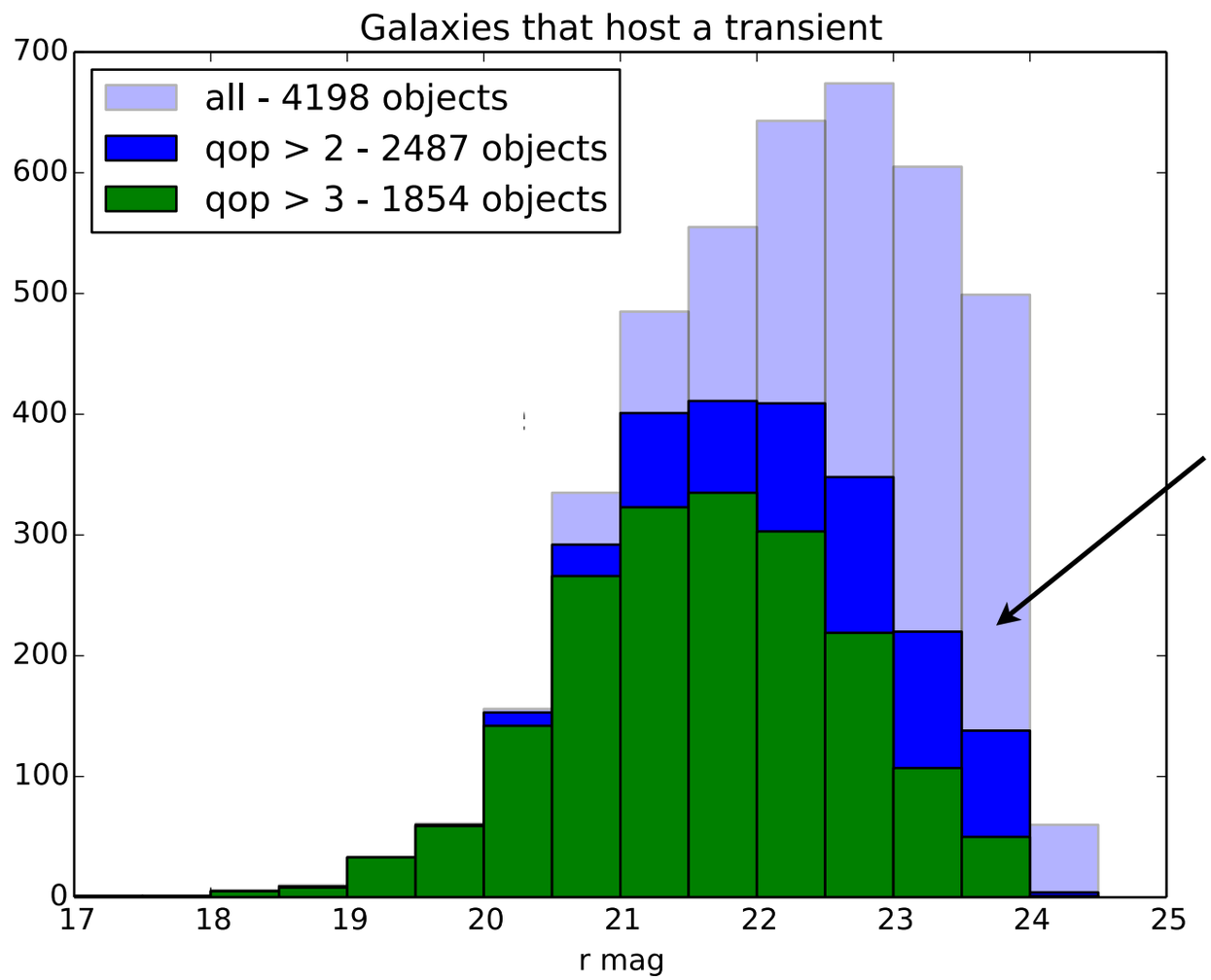
OzDES spectrum of DES Supernova



OzDES: A Collaboration Created To Serve DES Spectroscopy Needs

- Spectroscopic follow-up of DES deep fields with the 4m Anglo-Australian Telescope, AAOmega-2df
- AAT AAOmega-2df allows 392 fiber-fed optical spectroscopy
- 2 square degree closely matches 2.2 s.d. field of view of DECam
- 5-year survey started 2013
- 100 nights of AAT time

AAT gets the redshift



Completeness towards r=24
will increase
as we re-observe hosts

AAT provides part of the sample for training

More than 100 SNe spectroscopically confirmed

Most are Type Ia SNe (up to z~0.6)

Several Type Ibc SNe

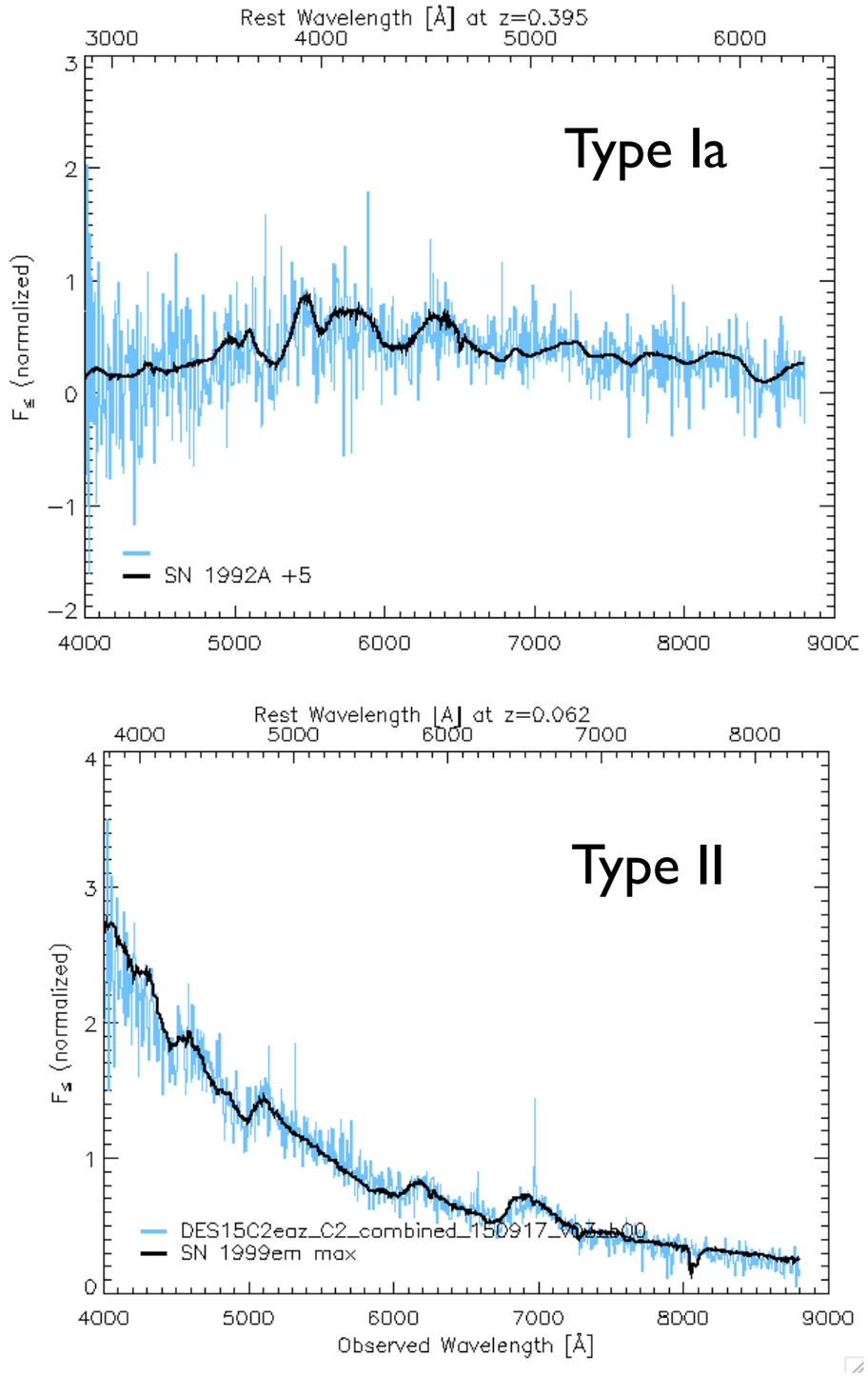
A dozen Type II SNe

Two super-luminous supernova

Published in 16 ATels

More to come as we reanalyse data from earlier runs

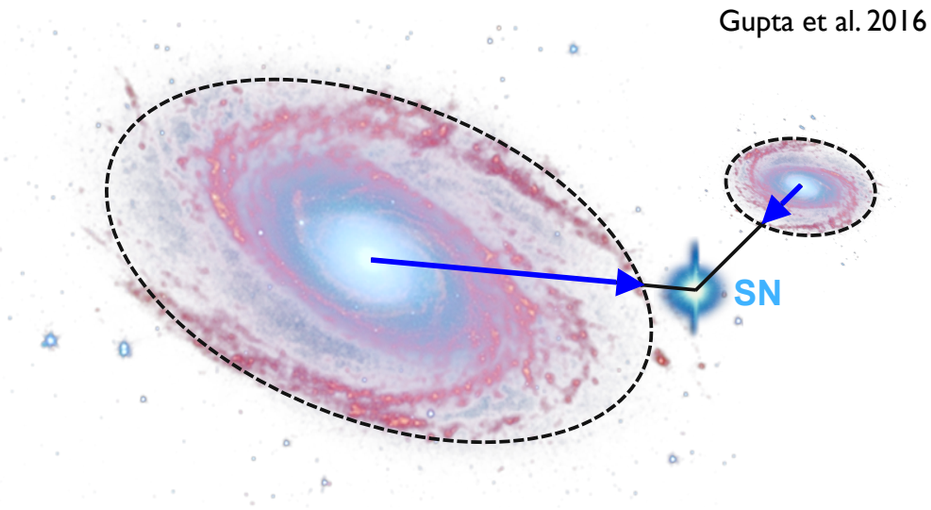
90% of DES transient types from OzDES



Host Identification

Issues

- The wrong host was identified



Gupta et al. 2016

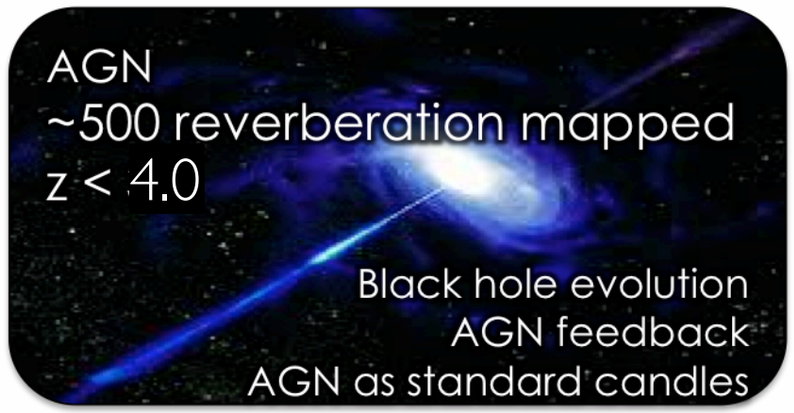
Simulations suggest an accuracy of 97% with 98% accuracy

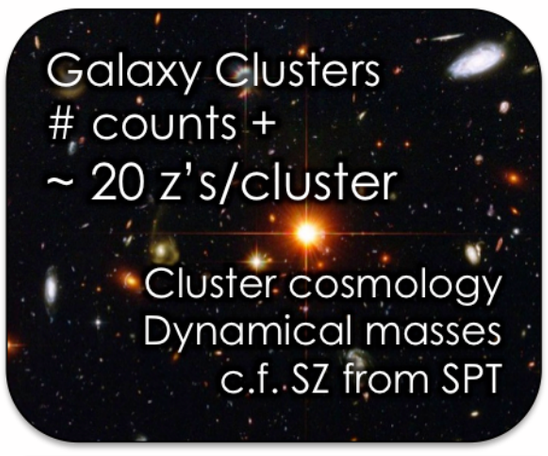
At the AAT, we can target multiple hosts.

- Some SNe are hostless. These will be lost from SN Hubble Diagram

- Properties of the SN correlate with the properties of the host

Other OzDES Science Goals



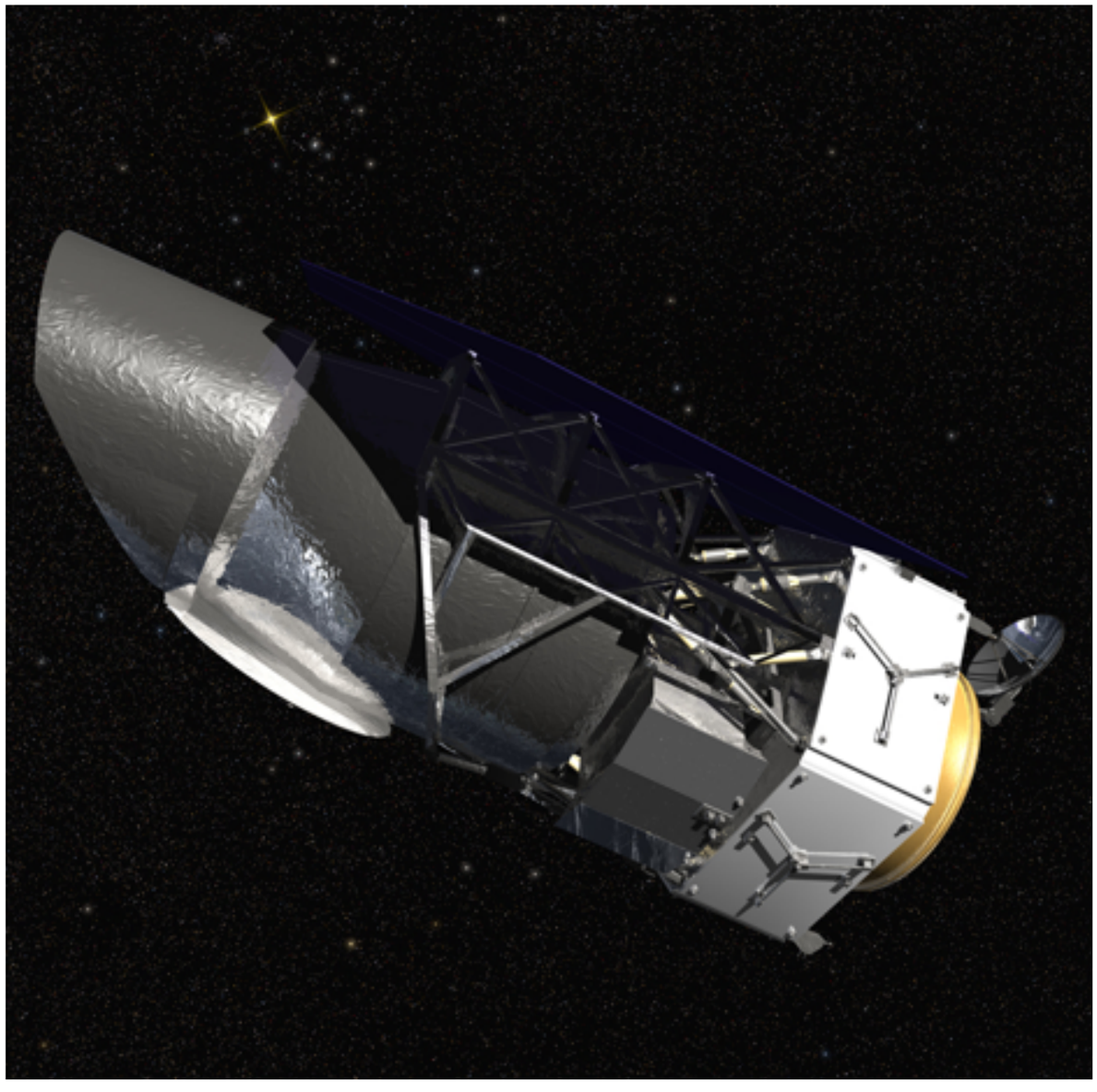


Other transients
+ the unexpected!

Photo-z calibration
One of the reasons DES wants us

There are many more fibers than supernova targets

WFIRST SN Program



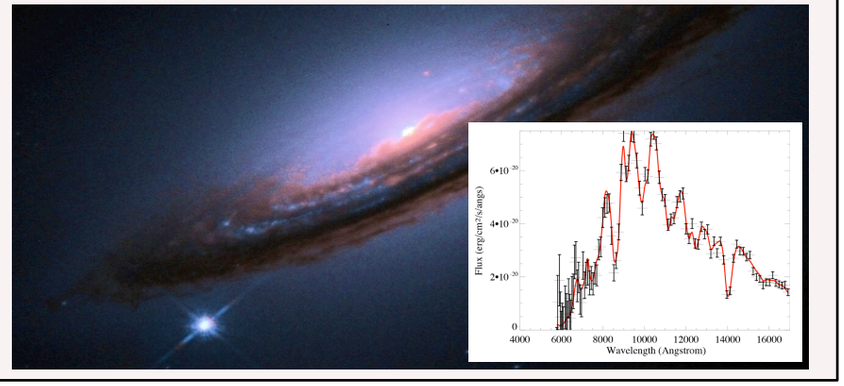
Supernova Survey

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

↓

standard candle distances
z < 1 to 0.20% and z > 1 to 0.34%



WFIRST SN Program

Increase number of supernovae by letting LSST do the discovery!

Supernova discovery

Supernova Survey

~~wide,~~ medium, & deep imaging

+

IFU spectroscopy

~~2700~~ type Ia supernovae

3200 z = 0.1–1.7

↓

standard candle distances

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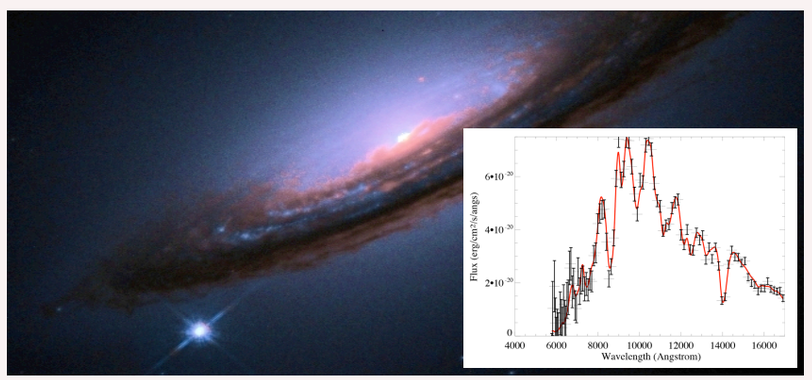


Supernova chromatic light curves

LSST-WFIRST Synergy

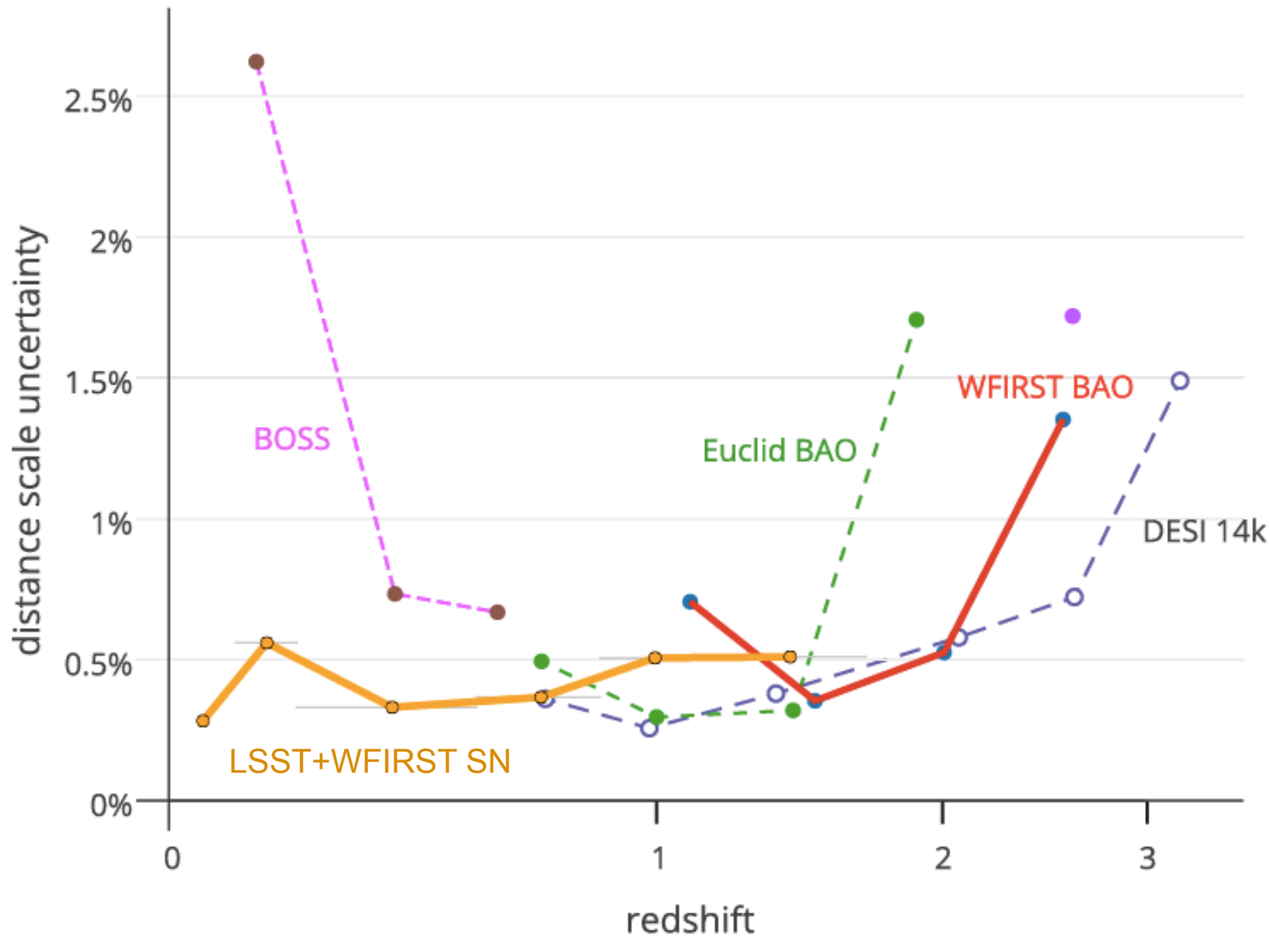
This is a mutual LSST-WFIRST win-win:

Current SN program concepts with and without LSST discoveries at z < 0.8.

Program Concept	**Number of SNe**			**FoM** (±~10)	
z =	0.1--0.4	0.4--0.8	0.8--1.7	*Without Rv drift syst.*	*With the systematics*
2-band **WFIRST imaging discovery** and lightcurves. Spectrophotometric time series.	420	912	606	350	300
LSST & WFIRST imaging discovery and lightcurves. Spectrophotometric time series.	591	1,712	909	460	360

Note: These numbers are based on full simulations with more optimal exposure time/ redshift distributions, correlation-accounted systematics, host-galaxy light, and vetted ETCs, ***not*** *the straw-man SDT notional program.*

LSST-WFIRST Synergy



Perlmutter 2016 LSST-DESC Collaboration Meeting

Designing a Joint LSST/ WFIRST SN Survey

- Timing
- Fields
- Exposure times and cadence
- Serious study has not yet begun!

Conclusions

- Type Ia Supernovae remain a powerful probe of dark energy into the next decade
- LSST is the next survey that will discover overwhelmingly huge numbers of SNe Ia
- Lots of work necessary to ensure that those discoveries are used effectively
- Opportunities for new projects and participation in existing ones