Cosmological Synergies with Time Domain Astronomy

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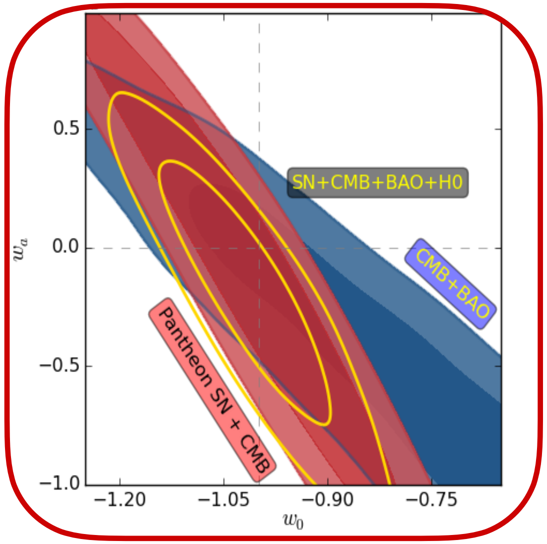
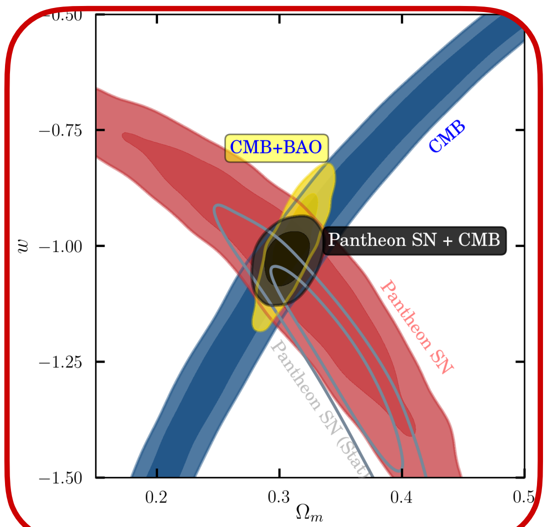
Cosmological Synergies in the Upcoming Decade,
IAP , Paris Dec 9-12, 2019

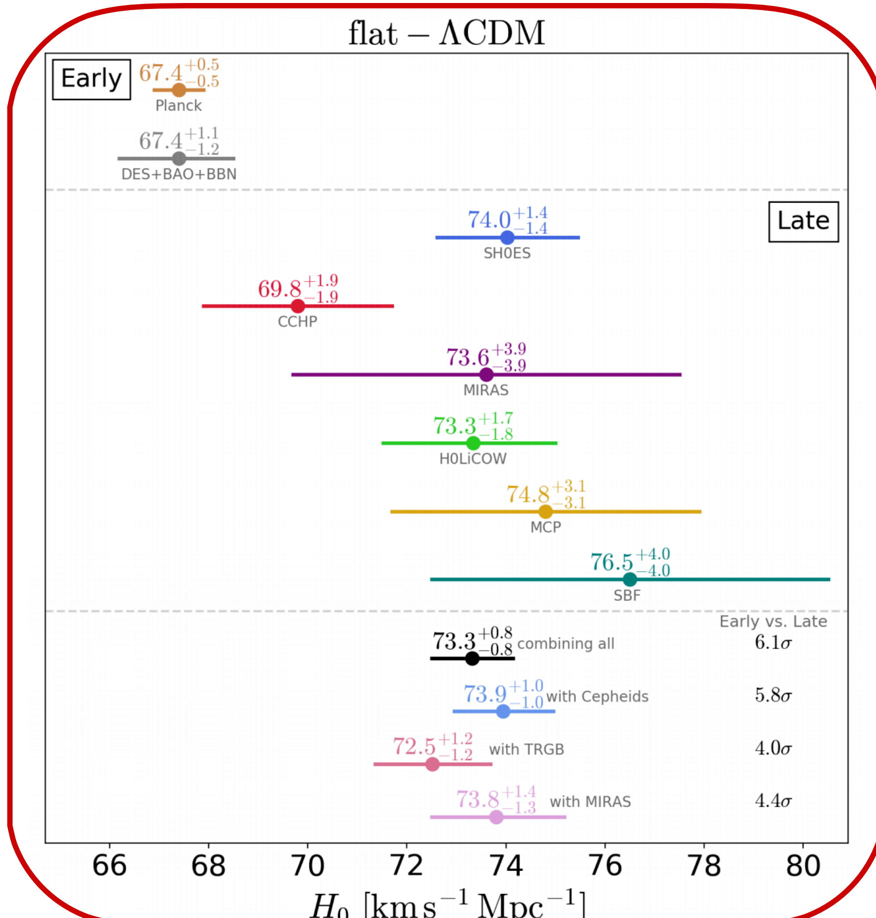
Synergies in Cosmology

- Synergies between different cosmic probes
- Synergies between surveys for Time Domain Astronomy (TDA)
  - photometric and spectroscopic followup of TDA sources
  - photometric TDA & galaxy spectroscopy
  - Different kinds of TDA surveys (co-observing or not)

TDA as Complementary Geometric Probes







Verde, Treu & Riess, 2019

Pantheon, Scolnic ++, 2018

Feeney, Rigault Talks today

Upcoming decade: Advent of Wide Field Surveys

- Large volume: rare objects
  - eg. time delay cosmography: GLSN

    Ooguri++ 2010, Goldstein ++ 2018

  - with GW: kilonovae

- SNIa : large scale structure tracer with precise distances

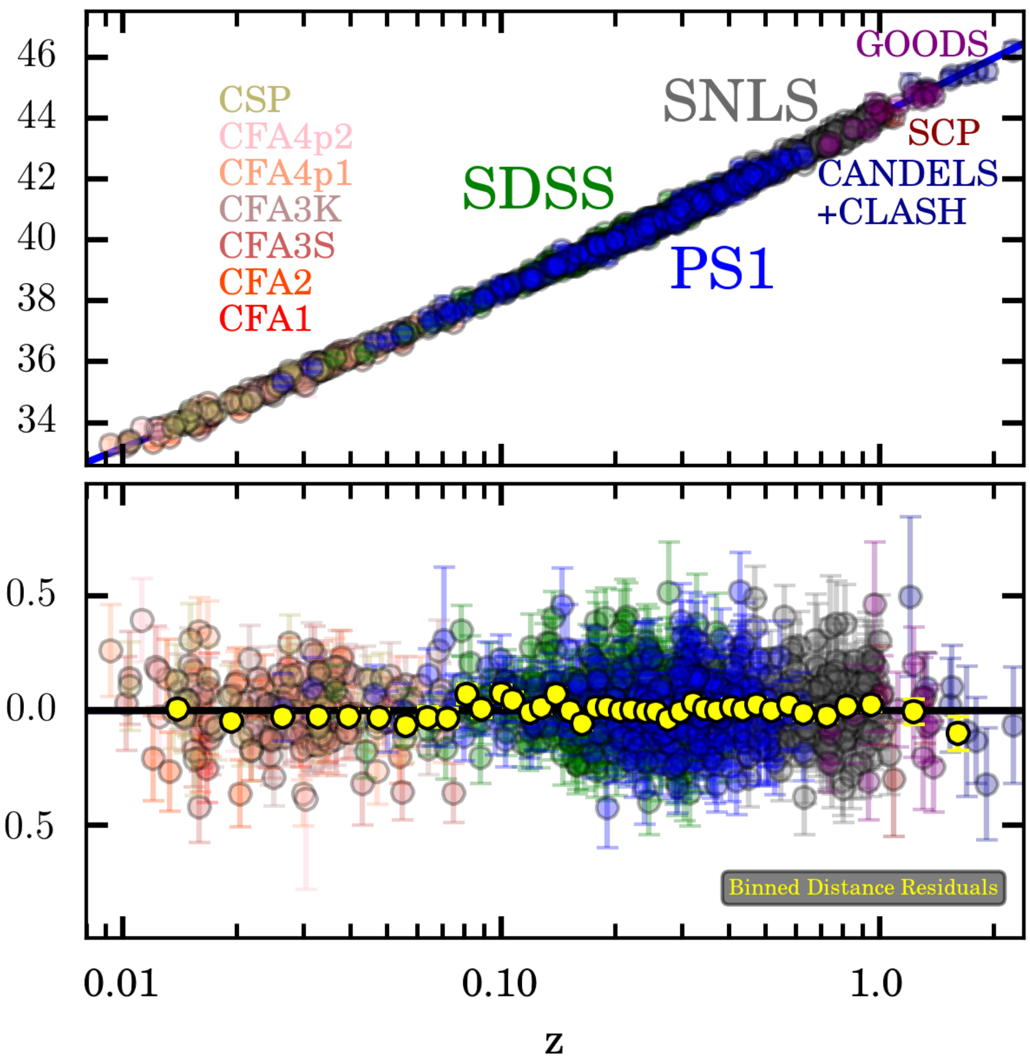
  Bhattacharya++ 2011, Feindt++ 2013,Howlett++ 2017, Graham++ 2019, Mukherjee++ 2018, Kim++ 2019,

- Properties of Dark Matter

  Niikura ++ 2019, Zumalacárregui++ 2018, Dhawan++ 2018

Supernova Cosmology (spectroscopic): State of the Art

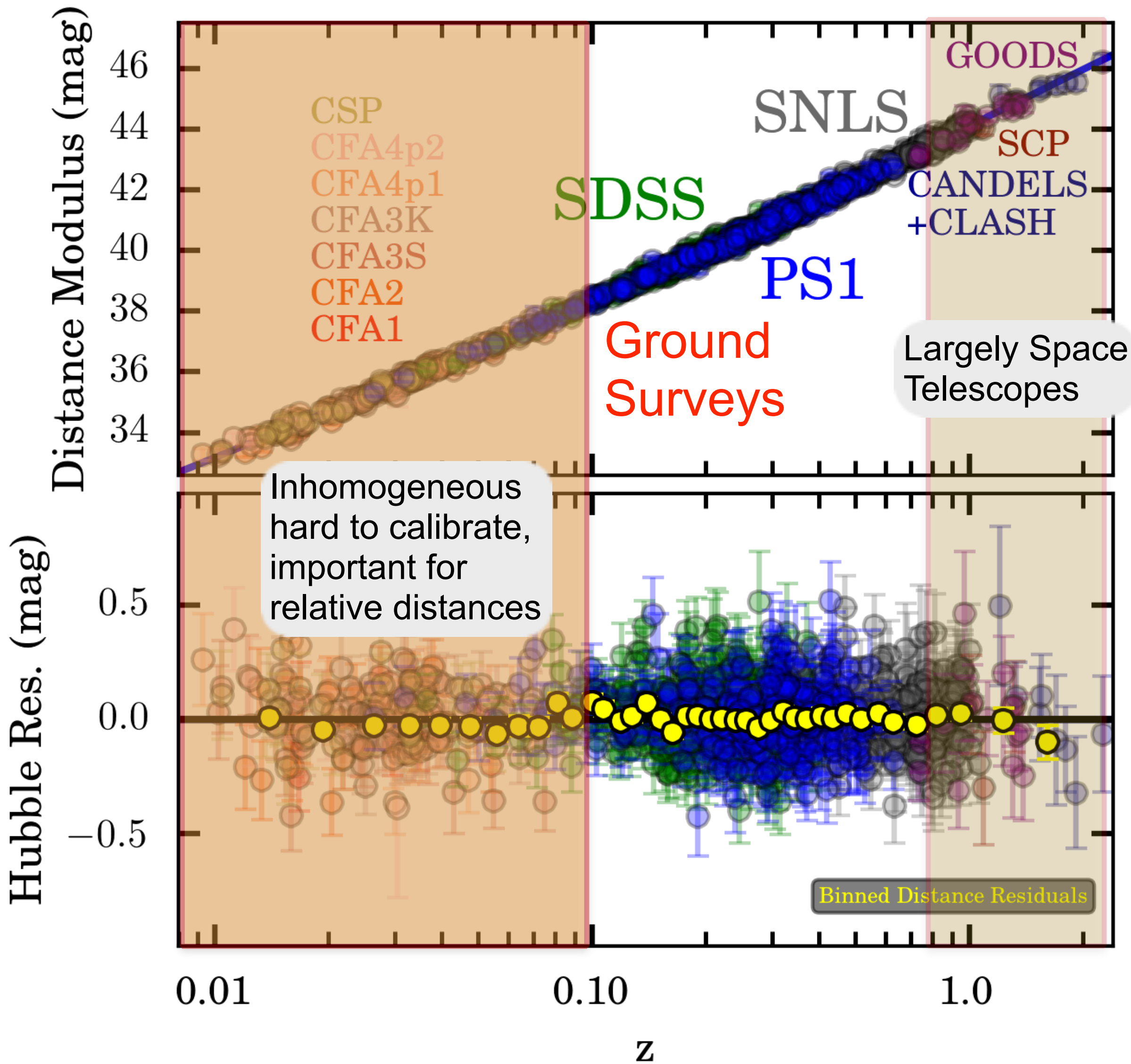
Scolnic et al, 2018 (Pantheon)



Probing expansion history of the universe

- Properties of Dark Energy ($z \lesssim 1.7$)
- Local expansion history of the universe ($z \lesssim 0.1$)

Supernova Survey Landscape



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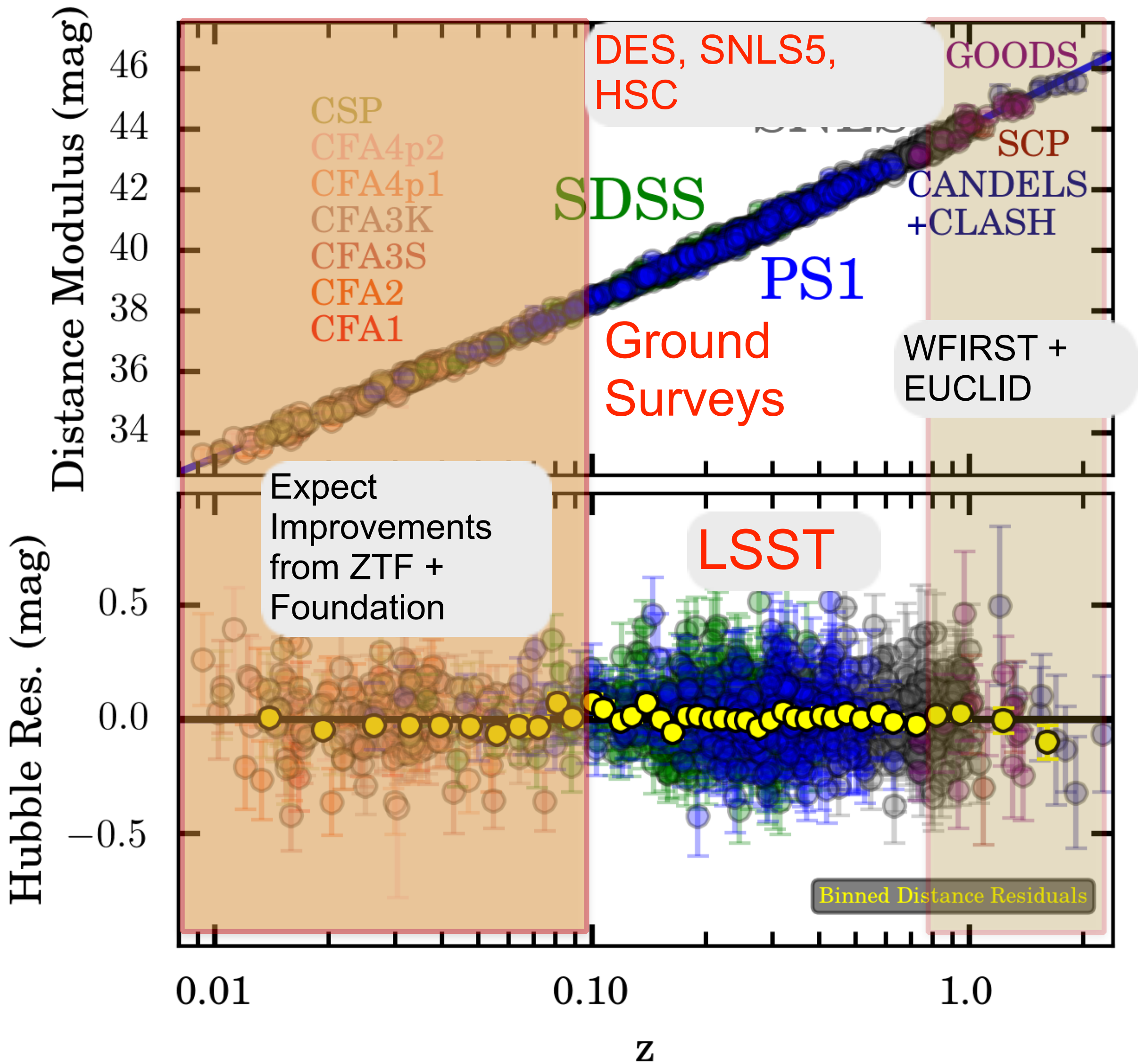
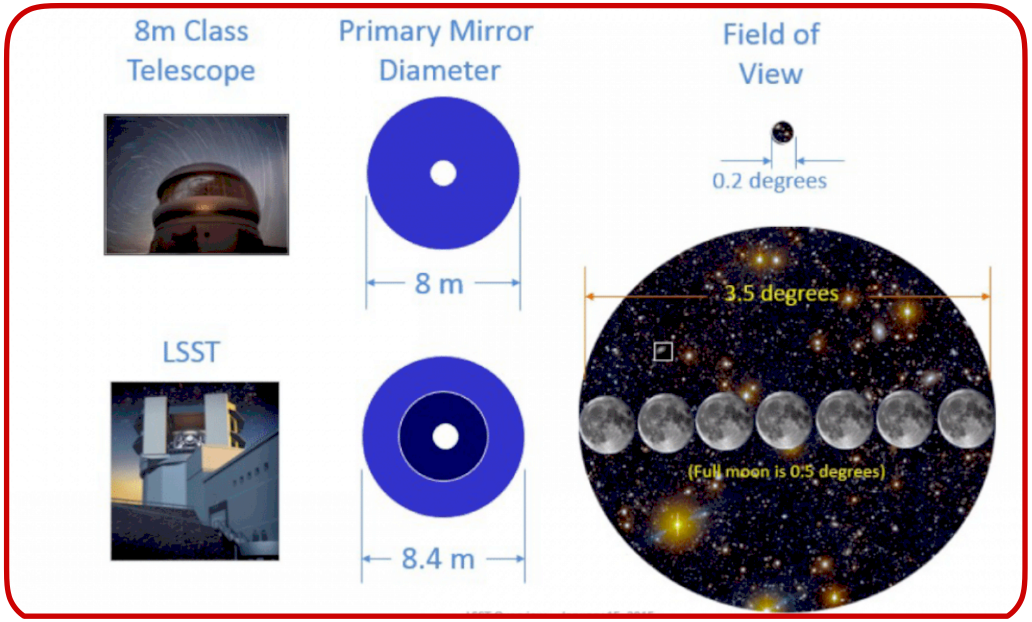


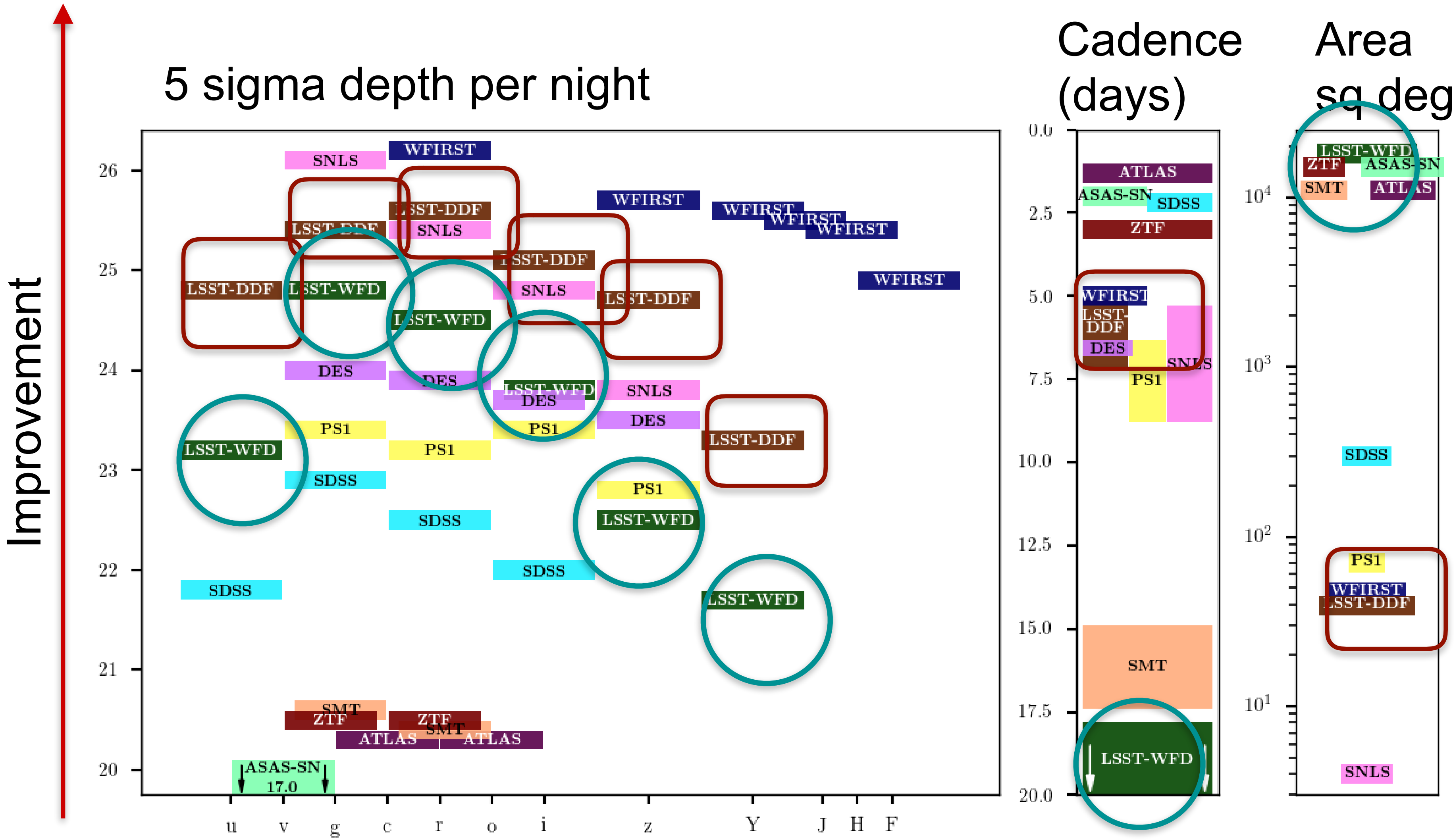
Large Synoptic Survey Telescope

- 10 year, ugrizy band photometric survey
- ~ 24.3 in r band
- Revisits in ~3 days, WFD ~ 18K sq degrees, DDF ~ 4-10 sq deg



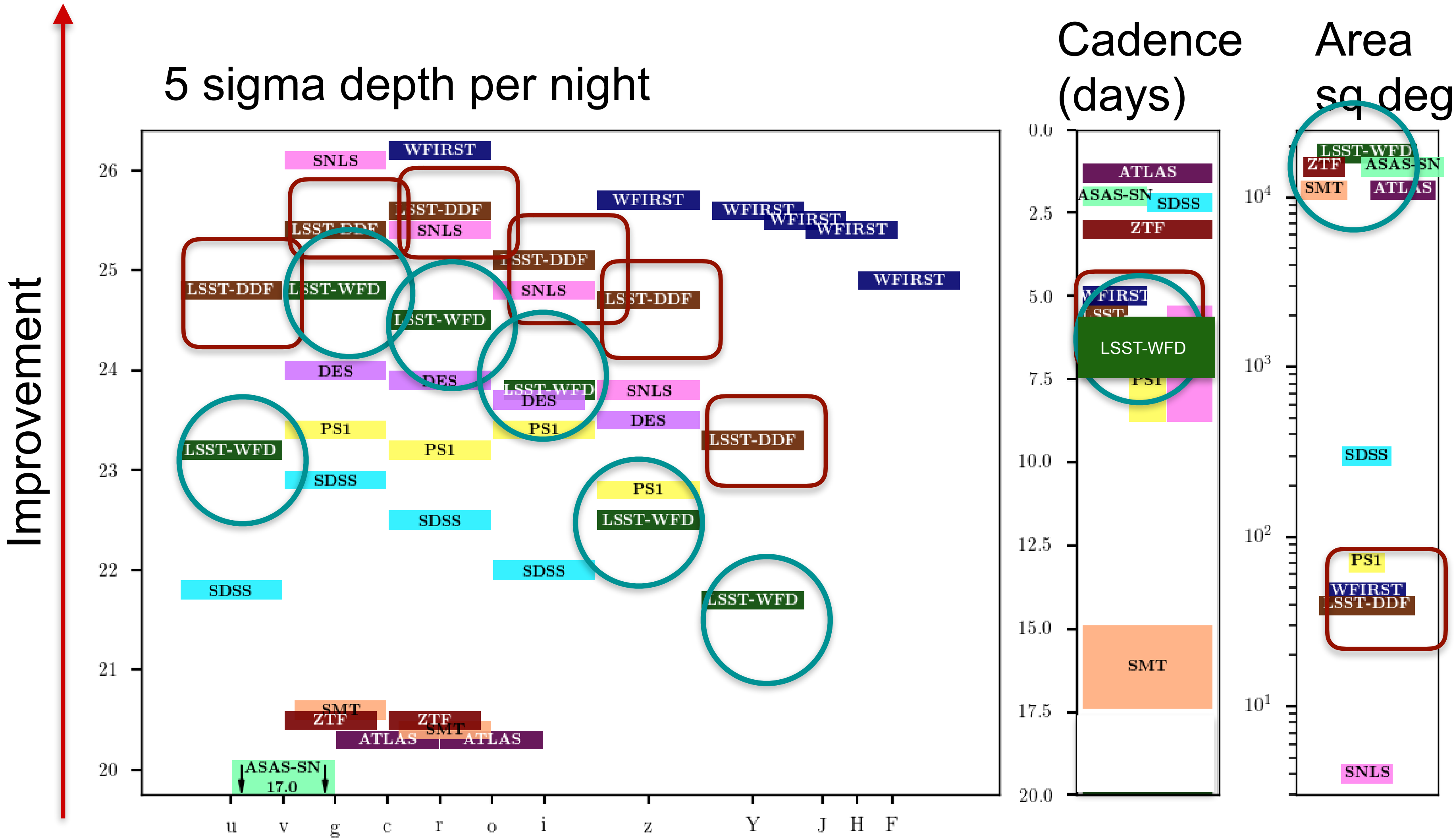
LSST Facility (Dec 07, 2019 webcam)

LSST in the context of SN Surveys



Scolnic et al. 2018 + RB

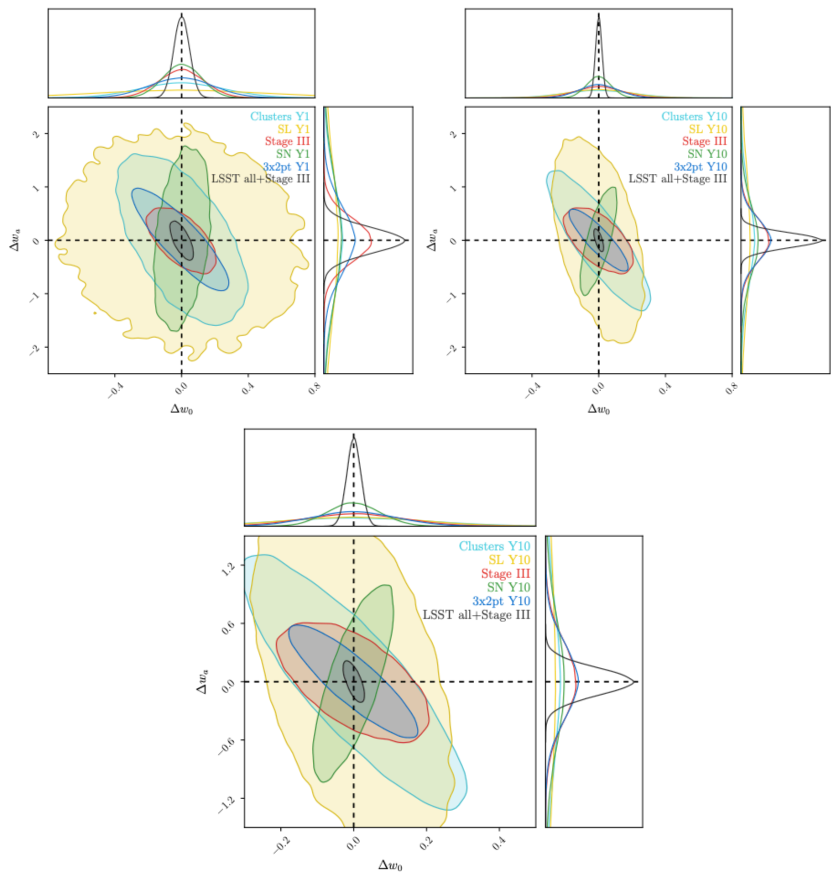
LSST in the context of SN Surveys



Ongoing work in LSST Project + DESC +Science Collaborations

LSST DESC Forecasts: SN constraints play critical role

- Critical role in the joint DESC constraints
- External low sample from Foundation and/or ZTF.
- included if spectroscopically followed up hosts
- Further realism to be incorporated (eg. classification impurities)



DESC SRD arXiv:1809.01669
(Mandelbaum et al., 2018 , SN Holzek, Scolnic, RB)

In flux, but an improved reference over the Science Book

SN Cosmology is systematics limited

Joint LightCurve Analysis

Table 11. Contribution of various source of measurement uncertainties to the uncertainty in Ω_m.

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

Betoule ++ RB 2014

Pantheon Analysis

Table 9.

	w shift	σ_w^{syst}	Fraction of $\sigma_w^{(\text{stat})}$
Stat. Uncertainty	+0.000	0.031	1.000
Total Sys Uncertainty	+0.031	0.025	0.814
Calibration			
SALT2 Cal	-0.002	0.014	0.457
Survey Cal	+0.006	0.009	0.285
HST Cal	-0.006	0.006	0.177
Supercal	+0.002	0.003	0.098
SN Modeling			
Selection	+0.010	0.007	0.233
Intrinsic Scatter	+0.019	0.005	0.170
β Evol.	-0.001	0.007	0.238
γ Evol.	-0.002	0.000	0.000
m_{step} Shift	-0.002	0.002	0.064
External			
MW Extinction	+0.010	0.008	0.262
Pec. Vel.	+0.000	0.003	0.103

Notes: The dominant systematic uncertainties in the Pantheon SN sample with respect to w while solving for a wCDM model. The w shift is defined relative to the statistical value and σ_w^{syst} is defined to be $\sqrt{\sigma_w^2 - \sigma_{w-stat}^2}$ when a specific systematic uncertainty is applied.

Scolnic ++ 2018

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Scolnic ++ 2018

Non-leading but non-negligible contribution from SNIa Standardization and Population Model

Accounting for Selection Bias

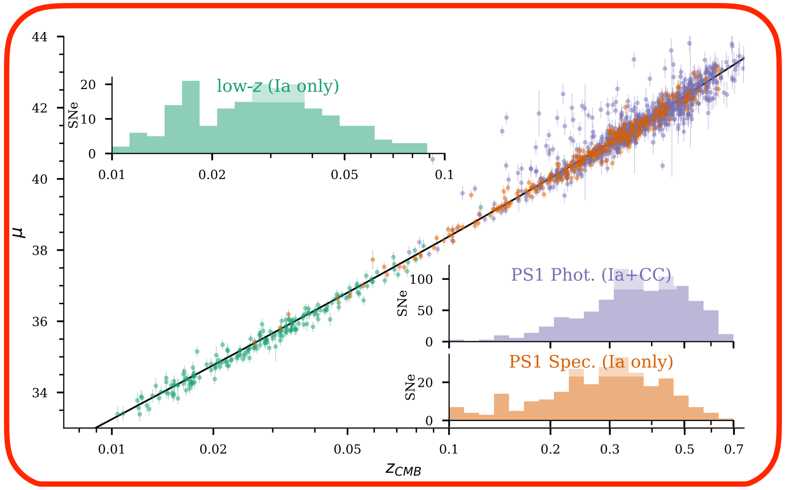
- Correct (marginalize) for selection bias

- JLA implementation: Mosher, et al + RB, 2014

- DES, Pantheon: "BBC" implementation (Kessler et al, 2017)
  - based on populations from SNLS+SDSS+lowz (Scolnic et al, 2016)

Photometric Classification

- Spectroscopic follow-up of LSST transients limited



- Like PANSTARRS, DES: photometric cosmology

State of Art : (PANSTARRS) Jones et al. 2018 host specz + classification + Bayesian analysis

- Numerous algorithms, PLaSTicc challenge

How can classification be approached?

- Statistical Hypothesis testing
- Bayesian Model selection : Evidence calculation
- 'Information Theory' Criteria : AIC/BIC like measures

Need a good model & relative abundances

- Machine Learning methods (Feature Engineering + classification)
- Deep learning methods : (Choice of architecture)

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- Statistical Hypothesis testing
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Need good training sets / Understand Population

- Machine Learning methods (Feature Engineering + classification)
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Sample Building

- Cosmology Sample: photometric SNIa + identified host galaxies with spectroscopy (photoz for expanded sample) of host galaxies
- Standardization Training Sample : Training sample used in standardization
- Classification Training Sample : Spectroscopically identified , likely of different distribution than cosmology sample
- Classification Verification Sample: Spectroscopically identified SNIa, Must be representative of the cosmology sample but smaller than cosmology sample

Large Spectroscopic Samples

- Large transient samples : high volumetric survey rate
- Large spectroscopic sample now: 1-1.5 m spectroscopy => <18 19 mag
- Large Field of View

Bellm, 2018

Zwicky Transient Facility

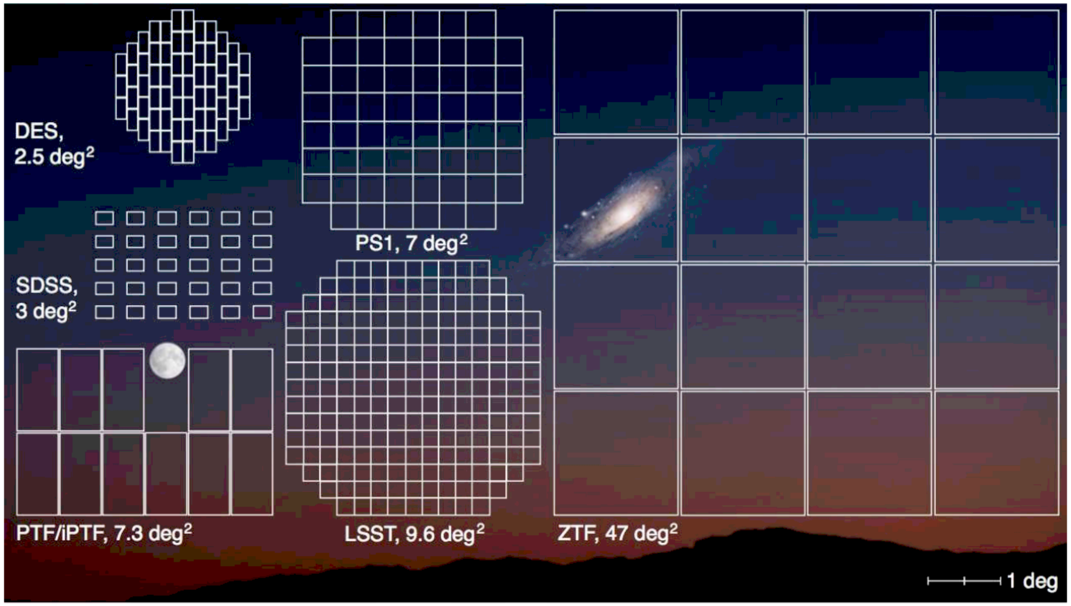


Figure 1. Field of view of the ZTF camera compared to that of other large-survey cameras. The Moon and the Andromeda Galaxy (Messier 31) are shown to scale. (With the permission of Joel Johansson.)

Laher ++, 2019

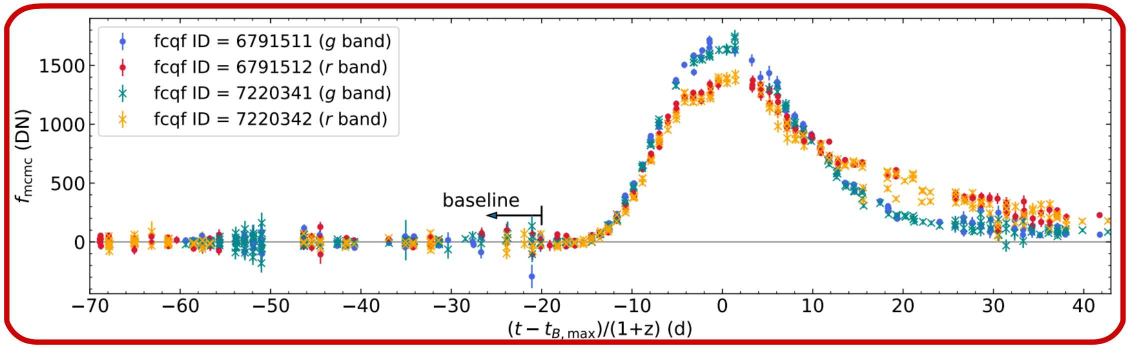
Large fraction followed up with SED machine on P60

Rigault++ 2019

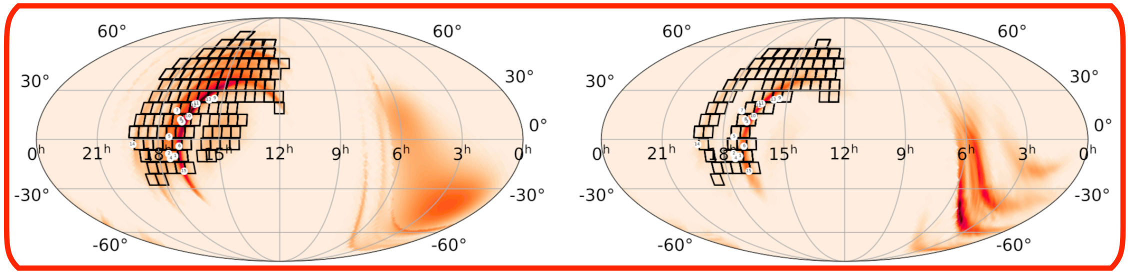
- Public survey in g+r, 30 sec exposures with ~3 day cadence in each band + partnership data + Caltech Time
- Median depth of ~ 20.5 mag in gr
- Partnership time: science specific surveys (eg. High cadence, i band, ToO etc.)

ZTF highlights

- Largest number of SN spectroscopically identified by a single survey (3000+)



Yao++ 2019



Coughlin++   2019

S190425z

ZTF Cosmology

Current

- GLSNIa : Time delay cosmography
- SNIa: tracer of LSS at low z
- EMGW: LIGO triggers
- Distance ladder : SN in Hubble flow
- SNIa Rates: progenitors

Synergies with future surveys

- Low z anchor for improved DE measurements
- Knowledge of rate and population

SNIa Population Models from ZTF : Bright Transient Survey Data

- Bright (< 18.5 mag) public transients (2 detections)
- SedMachine on 1.5m telescope P60 + others
- **Objective** follow-up criteria
- **High success rate** at mag < 18.5 (called Bright Transient Survey)

- large Unbiased, spectroscopically identified dataset
- less sensitive to fluctuations in observational noise

Fremling ++, 2019

SNIa Population Models

- Parametrized population models of SNIa : General eg. Gaussian mixture, along with abundance

- Regression Problem : Simultaneous Bayesian inference of parameters of population models from ZTF Bright Transeint Survey + SED Machine spectra

- Selection effects: survey simulations => library of selection effects over time, sky location and SN properties

- Low redshift, combined with host properties

Biswas et al (In Prep)
with Peiris, Goobar, Mortlock + ZTF Collaborators

Summary

- Synergies of Time Domain Astronomy with cosmological probes :
  - LSST, WFIRST improves SN cosmology
  - Novel prospects: MMA, Time delay cosmography, LSS
- Synergy between different TDA surveys
  - ZTF : large, unbiased, spec sample enabling new science
  - significantly helps SN cosmology in future (LSST/WFIRST)