Cosmology with SNe Ia and Gravitational Lensing

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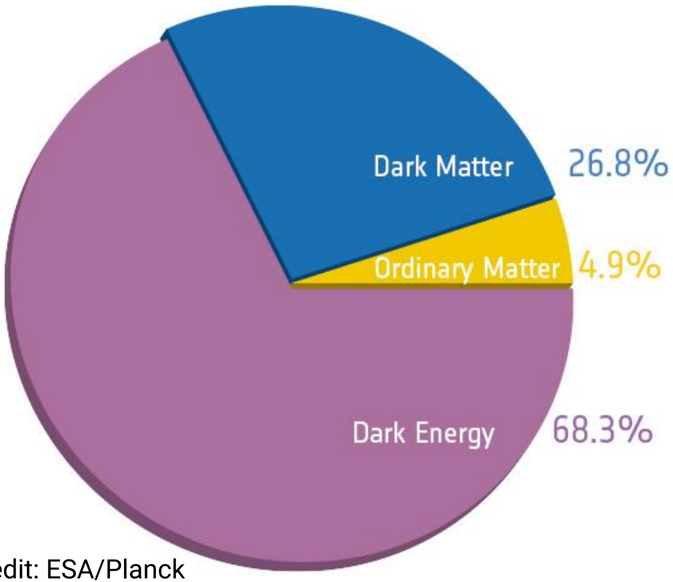
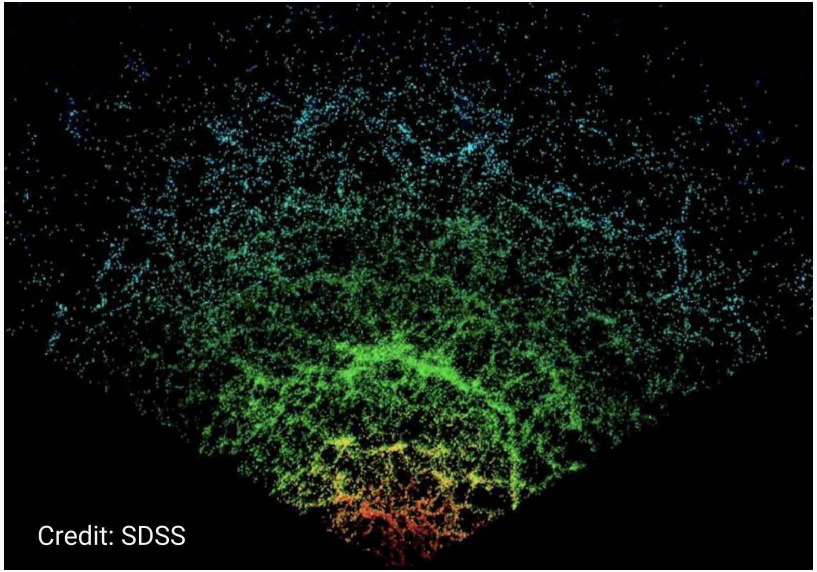
ZTF Team meeting
March 12th, 2019

What is the Universe made of? What forces made it look like this?



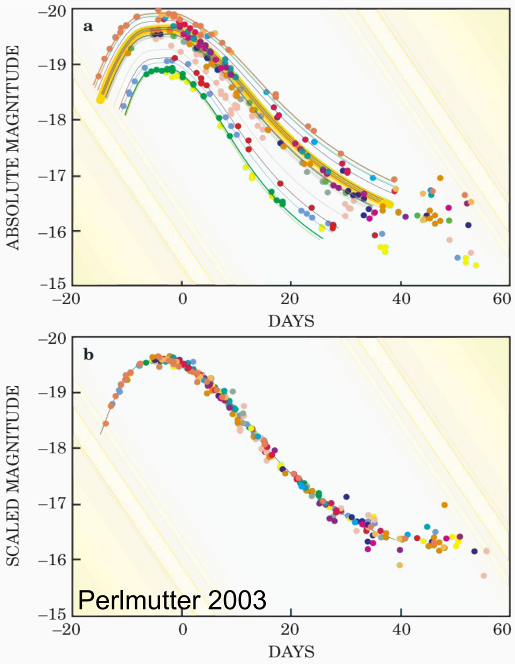
Credit: ESA/Planck

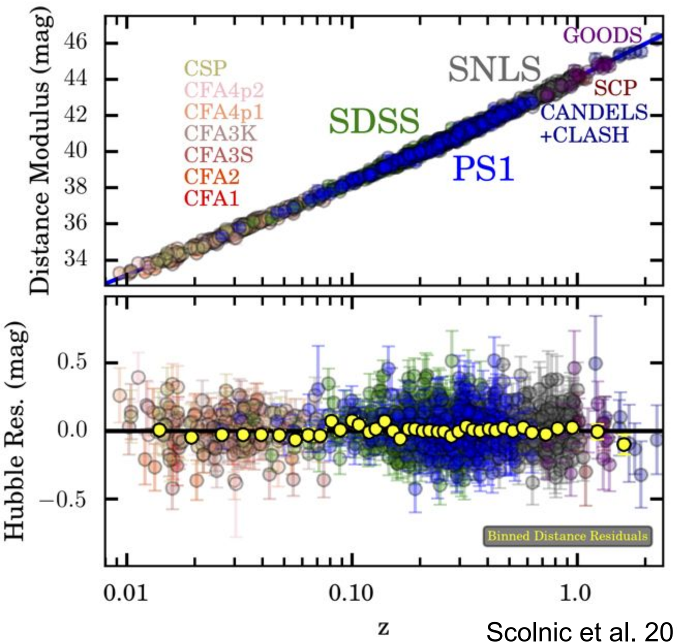


Credit: SDSS

Cosmology with type Ia supernovae

SNe Ia are very precise distance indicators at cosmological distances. Standardized based on lightcurve shape and color.





Scolnic et al. 2018

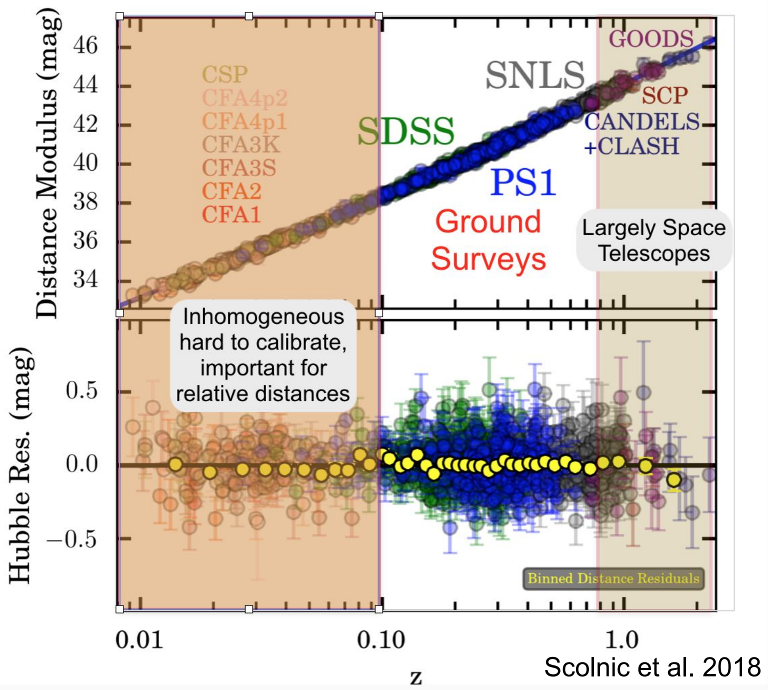
They trace the Hubble-Lemaitre law out to redshifts beyond z = 1, thus we can measure the acceleration of the expansion of the Universe (i.e. dark energy).

SN Ia cosmology with ZTF

Currently the literature low-redshift sample are from various surveys using different telescopes, making it hard to calibrate.

ZTF can find ~ 600 SNe per year that have sufficient lightcurve coverage, which allows us to:

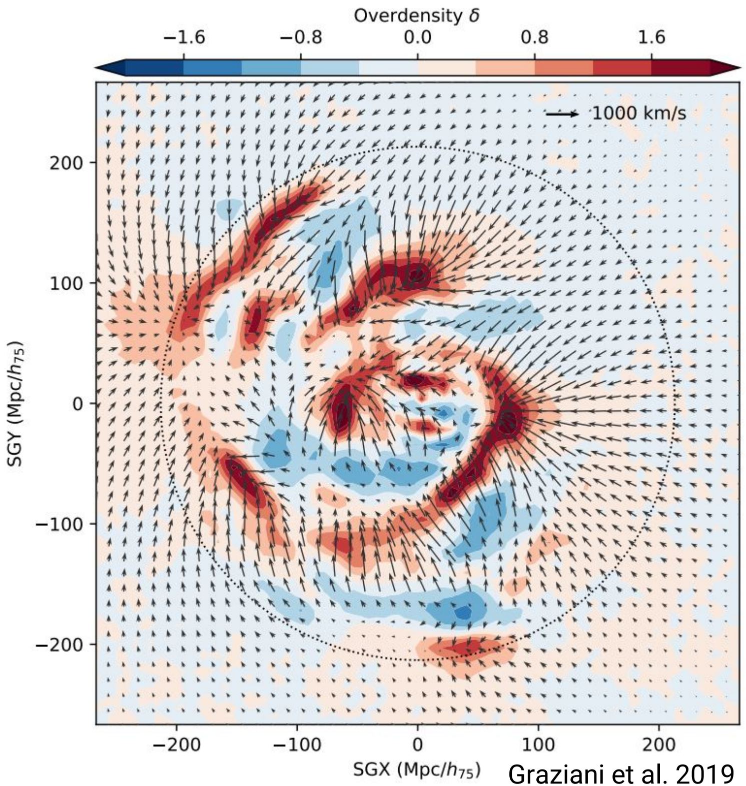
- Anchor the Hubble-Lemaitre diagram for future large samples at mid-to-high redshifts (e.g. from LSST)
- Study the distribution of (dark) matter in the local Universe
- Improve SNe Ia as cosmological probes by better understanding their population (e.g. the color distribution or correlations with host properties)
- Better understand the physics behind them by building large samples of early discoveries



Scolnic et al. 2018

Peculiar velocity studies

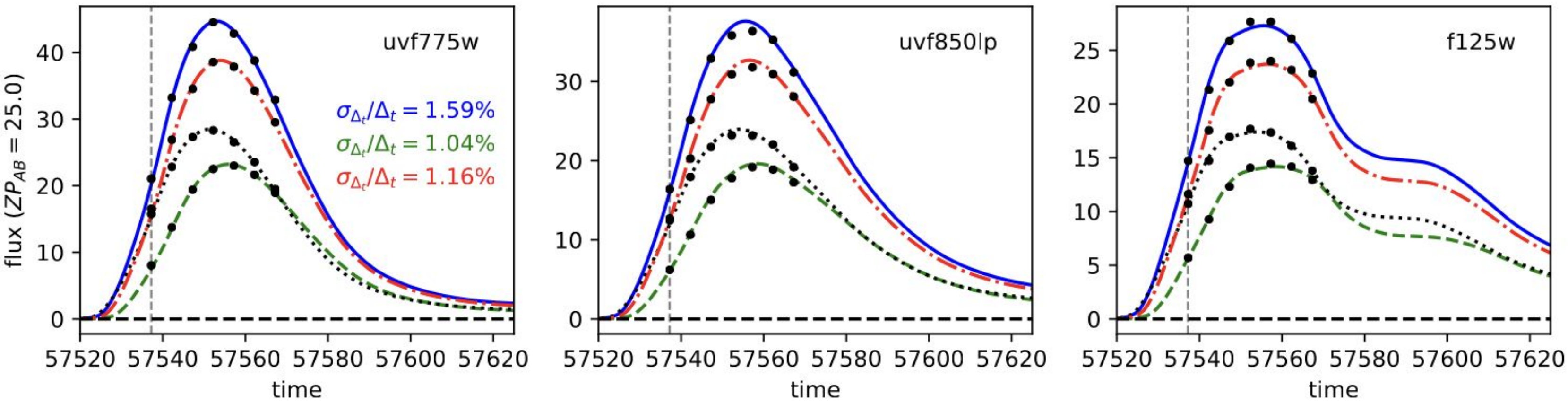
- We will be able to use peculiar velocities in addition to distance measurements
- Can extend velocity catalogs used to reconstruct local structure
- Large coherent motion (bulk flow) in ZTF volume could contradict ΛCDM structure formation
- Further we can measure the growth of structure directly from velocity correlations
- Require ~1000 SNe (statistically equivalent to ~15000 galaxies)



Graziani et al. 2019

H_0 from Lensed Supernovae

Simulation by Danny Goldstein



- ZTF is expected to find ~7 lensed SNe per year in stacked images (see D. Goldstein's talk tomorrow)
- Can measure H0 from the time delay between individual image (requires followup with better resolution)

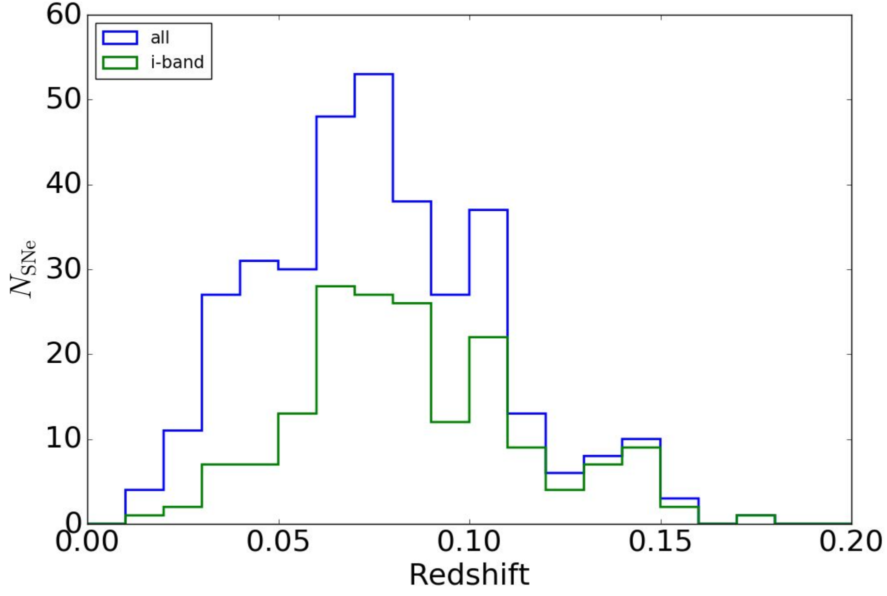
ZTF first year SNIa sample

Currently > 800 SNe Ia have been found by ZTF:

- 347 SNe from year 1 have good lightcurve fits (g/R)
- 177 of those additionally have good i-band coverage

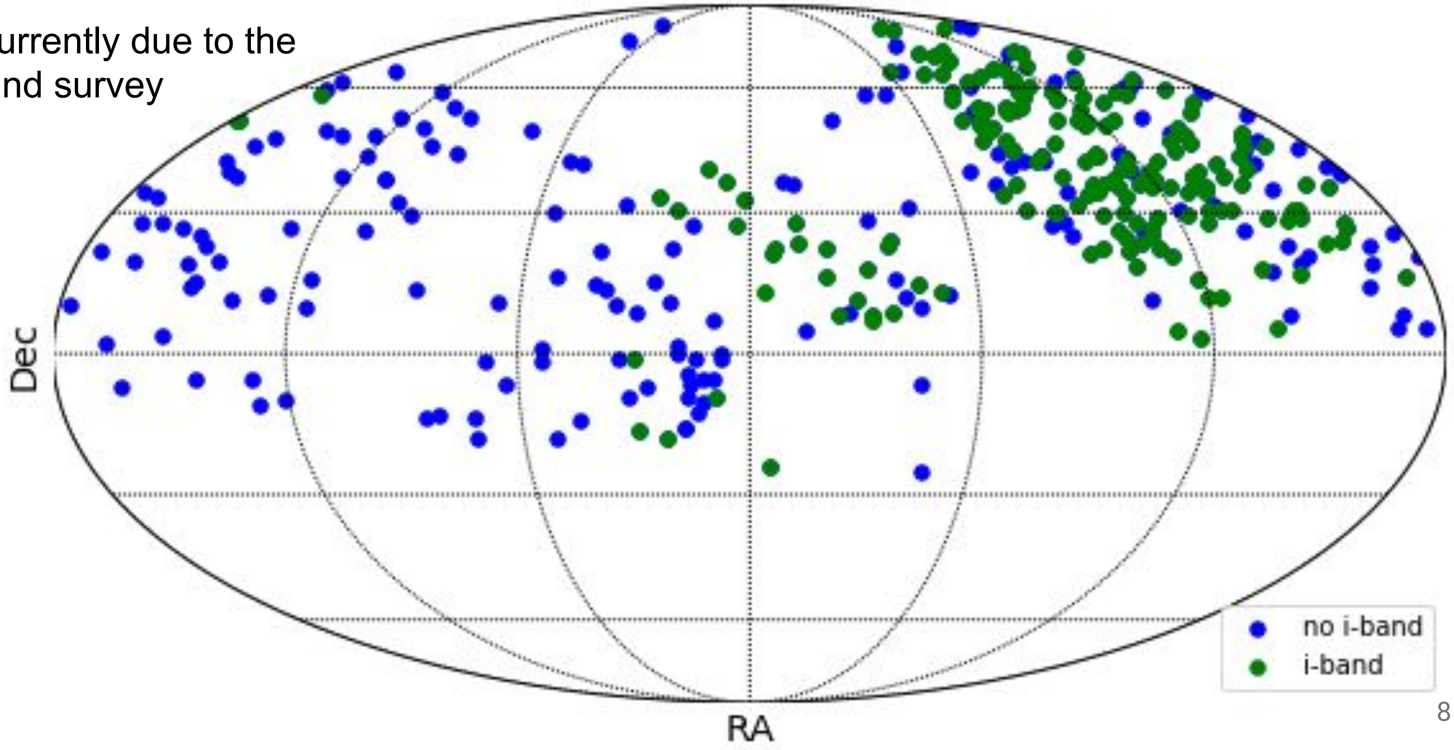
Smaller than potential sample since:

- Alerts were only generated once references were built
- Shorter i-band survey (end of April - September + first half of November)
- Systematic spectroscopic follow-up not working yet (mostly relied on BTS)



Sky coverage

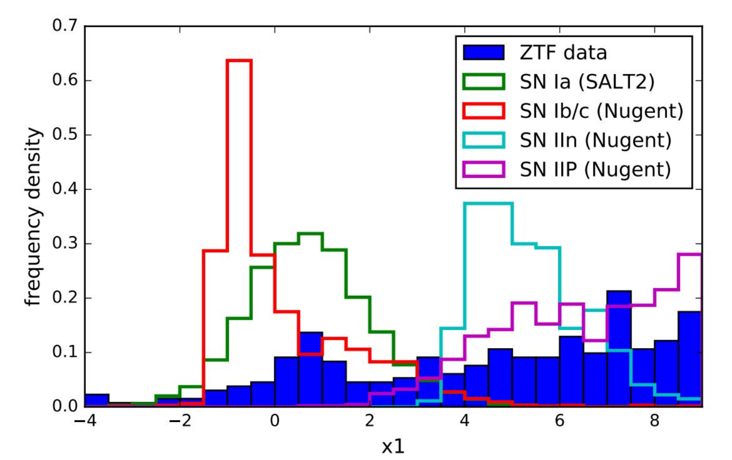
- ZTF will provide a unique SN Ia sample (untargeted and covering the whole northern sky)
- i-band coverage currently due to the shorter year 1 i-band survey

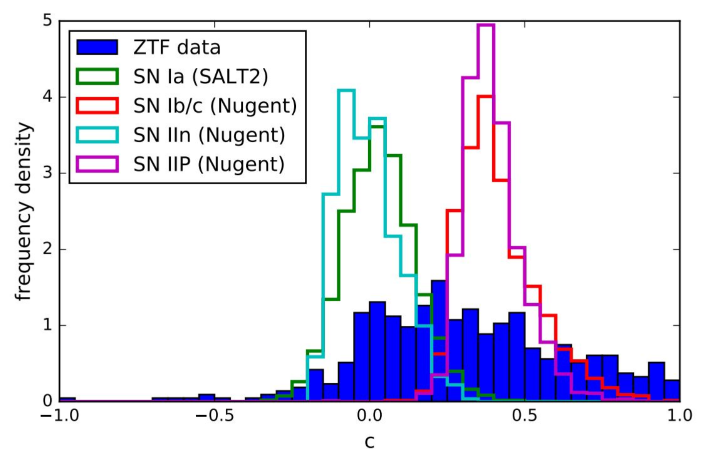


Verifying simulations (and data)

We compared MSIP alerts from July to lightcurve simulations made using `simsurvey` (see arXiv:1902.03923):

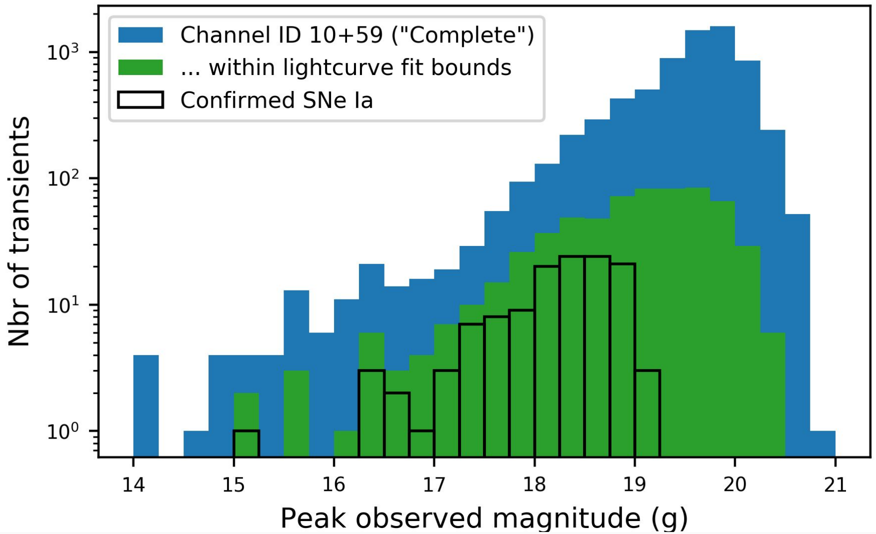
- Limited to 40 fields that had full g and R reference by July 1st
- July had similar very observing conditions to those assumed in simulation
- Run SALT2 lightcurve fit on alerts (using AMPEL) and on simulated SNe (Ia and CC)
- Compared fit parameter distributions as simple photometric typing
- Using a cut in stretch and color, we found 44 SNe Ia in the simulations and 37 ZTF lightcurves (19 SNe Ia, rest not typed)

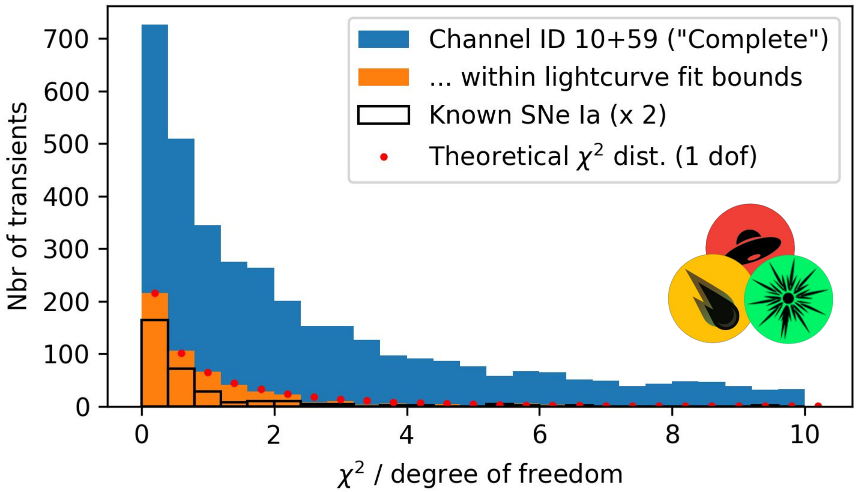




Photometric SN Ia sample

Potential SN Ia sample more similar to photometric sample. Four month `AMPEL` rerun yield 634 photometric SNe Ia, 449 brighter than 19.5. Agrees with `simsurvey` projections and find potential for 1000+ SNe Ia / year





Designing a larger cosmological program

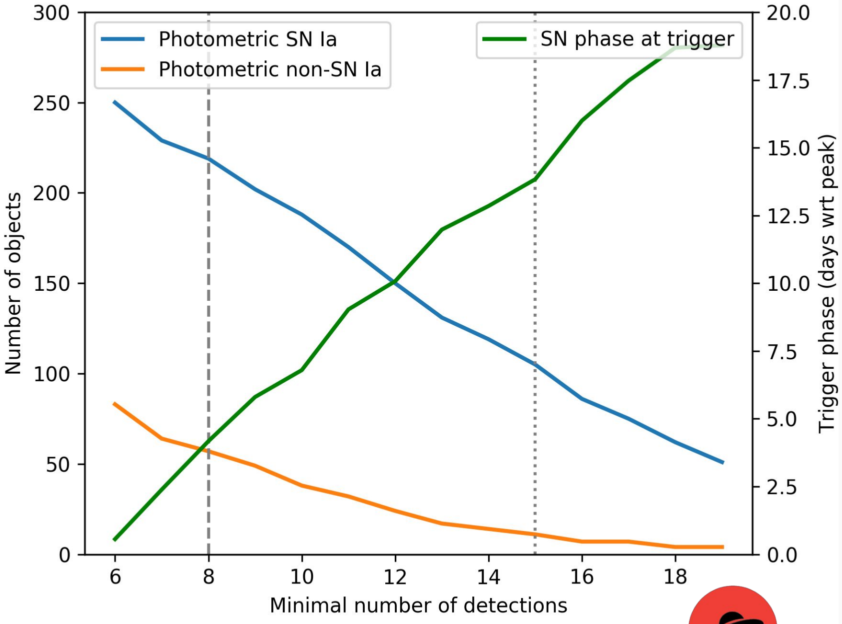
The rerun allows us to (for the first time) directly develop complex follow-up programs.

E.g. for transients with:

- a peak fainter than required for RCF program (18.5)
- a “current” magnitude brighter than 19.5 (instrument limit)
- Lightcurve fit parameters within expected bounds

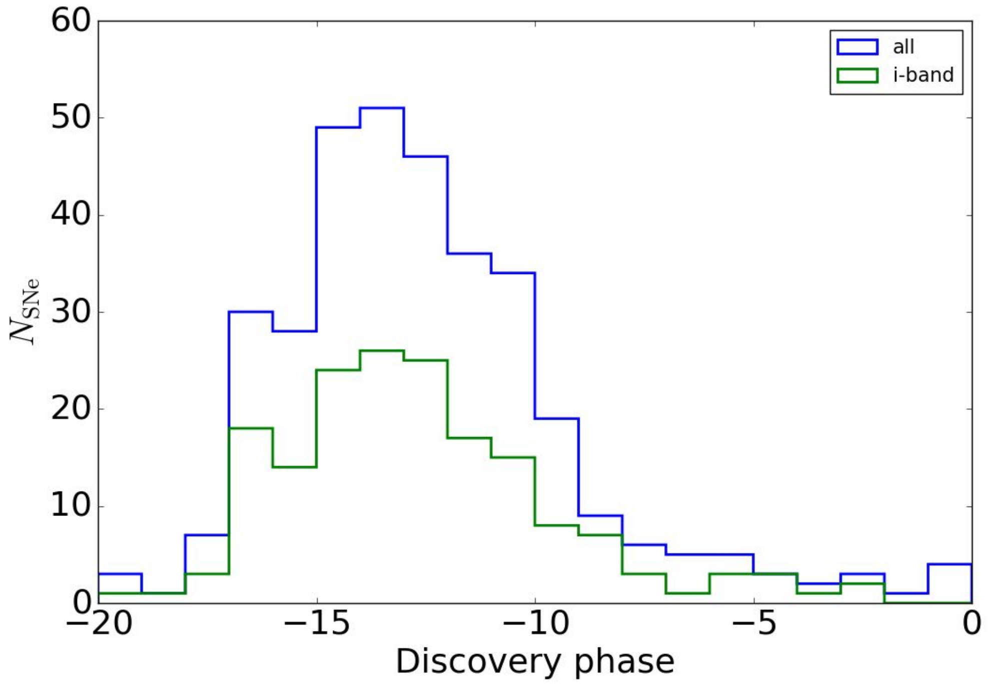
We can phrase the question: “How many detections do I require before I trust that the lightcurve looks sufficiently like a SN Ia, and trigger follow-up?” The obtained sample can be divided based on whether the lightcurve will *eventually* look like a photometric SN Ia (or not).

Requiring 8 detections (+ above) would during four months have produced ~280 triggers, out of which 220 continued developing like SN Ia, with a mean trigger phase of ~4 days.



Early science goals

- Unique among cosmology samples, almost all SNe Ia were discovered more than a week before peak
  - Distinguish progenitor scenarios (talk by P. Nugent)
  - Can use early lightcurve to estimate probability of transient being SN Ia.
  - Standardization by separate rise and fall time can improve standardization (see Hayden et al. 2019)
- Complete SN sample
  - Common ZTF goal
  - Photometric classification
- SN environment correlation



Plans for year 2 and onwards

After year 1 we have real data to show the potential of a ZTF cosmology

- Extended spectroscopic follow-up:
  - Efficient AMPEL filters are already running (real-time or once per day)
  - More spectroscopic resources needed for targets in 18.5<m<19.5 range

- Calibration and extraction of i-band lightcurves
  - Working on getting first i-band information for year 1 SNe
  - Working toward 1% precision calibration (scene modeling and flat fielding)

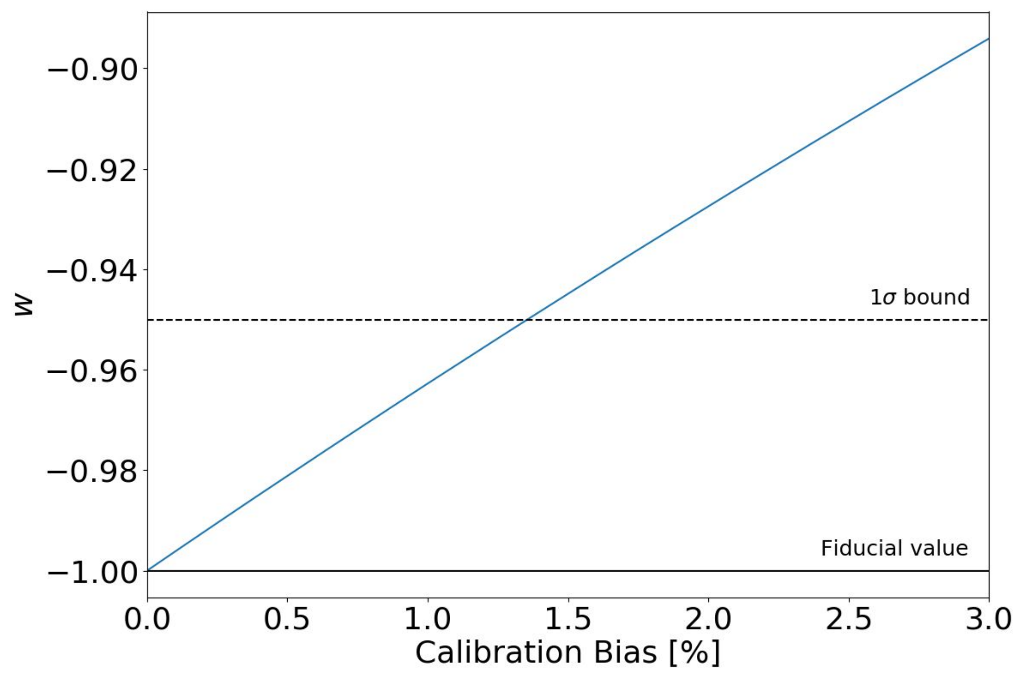
- Obtaining host-redshifts
  - Our science cases require host galaxy redshift (current coverage: ~33%)
  - Working with DESI to obtain redshifts after the end of ZTF

Why is so much WG effort spent on calibration?

The ZTF SN Ia data set will help anchor the Hubble-Lemaitre diagram. A bias in its calibration will have a significant effect on the inference of cosmological parameters.

Thus we are contributing to various calibration efforts in order to get to 1% precision, e.g.:

- Star-flat calibration (see M. Giomi's talk tomorrow)
- PSF modeling (see R. Graziani's talk on Thursday)



Cosmology WG activities

HU

Valéry Brinnel: SN peculiar velocities & environment
Matteo Giomi: star-flat calibration; candidate catalog cross-matching
Nicolas Miranda: Candidate classification; AMPEL interface
Jakob Nordin: Sample selection; calibration; peculiar velocities (DESI WG)
Simeon Reusch: calibration stability

IN2P3

Melissa Amenouche: SN classification with and without spectra.
Romain Graziani: PSF and scene modeling $f\sigma_8$ expectation
Young-Lo Kim: Host identification code, estimating host masse and SFR
Mickael Rigault: SEDM, getting host information
Philippe Rosnet: Dome flat field calibration

OKC

Rahul Biswas: Collecting host information from catalogs
Mattia Bulla: Studies of early discoveries of SNe Ia
Suhail Dhawan: Expectation for non-standard dark energy
Uli Feindt: Survey forecasts/efficiency, typing; GROWTH marshal; anisotropy
Ariel Goobar: Stacked images, lensed SNe; building sample of early SNIa discoveries

Caltech

Danny Goldstein: Stacked images; finding lensed SNe

Summary: ZTF *could* be amazing for cosmology

Year 1 was a already good for SNe Ia:

- We have ~350 Ia's with g/R lightcurves (50% with i-band)
- This year we expect to get several times more than that

The ZTF SN Ia sample could provide the next breakthrough for cosmology:

- Anchor future higher-redshift sample to constrain dark energy precisely
- Measure the local structure to test structure formation

However, much work is required for this:

- Photometric calibration at 1%
- A deeper/larger spectroscopic campaign must be assembled