Type Ia supernova cosmology with ZTF: DR1 and First results

Cosmology and Lensed SN SWG update

ZTF Collaboration Meeting, Caltech, 20 October 2020

Outline

- Motivation for low-z Type Ia supernova

- Hubble diagram
    - Summary statistics
    - Comparison to the literature
    - Future applications

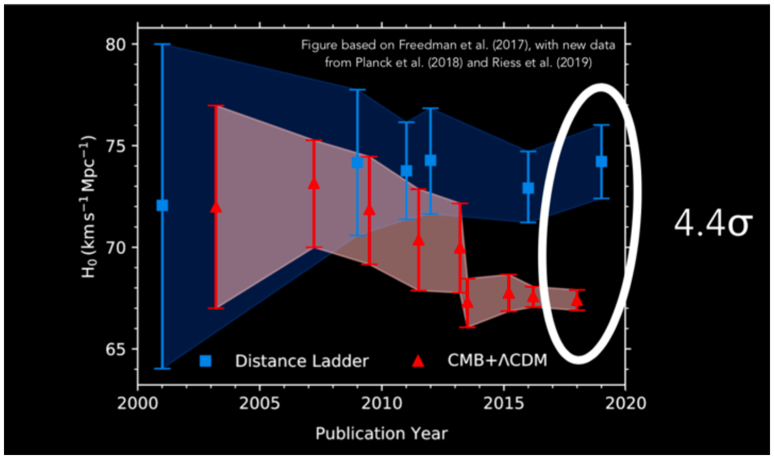
- Spectroscopic data

- Ongoing work on calibration

- Investigations with Y1 sample

SN cosmology: low-z sample

Ideal sample to measure H₀, dark energy and growth of structure



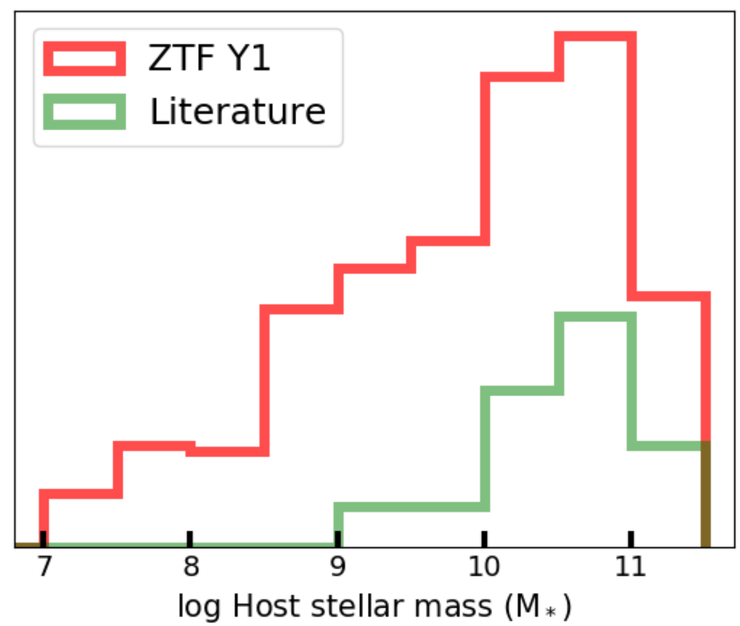
- Hubble tension: New cosmology or astrophysical bias?

- Nature of dark energy: low-z sample largest systematics

- Future competitive probe of growth of structure

ZTF DR1 already comparable to all low-z *combined*

Untargeted => test environmental bias



Hubble Diagram

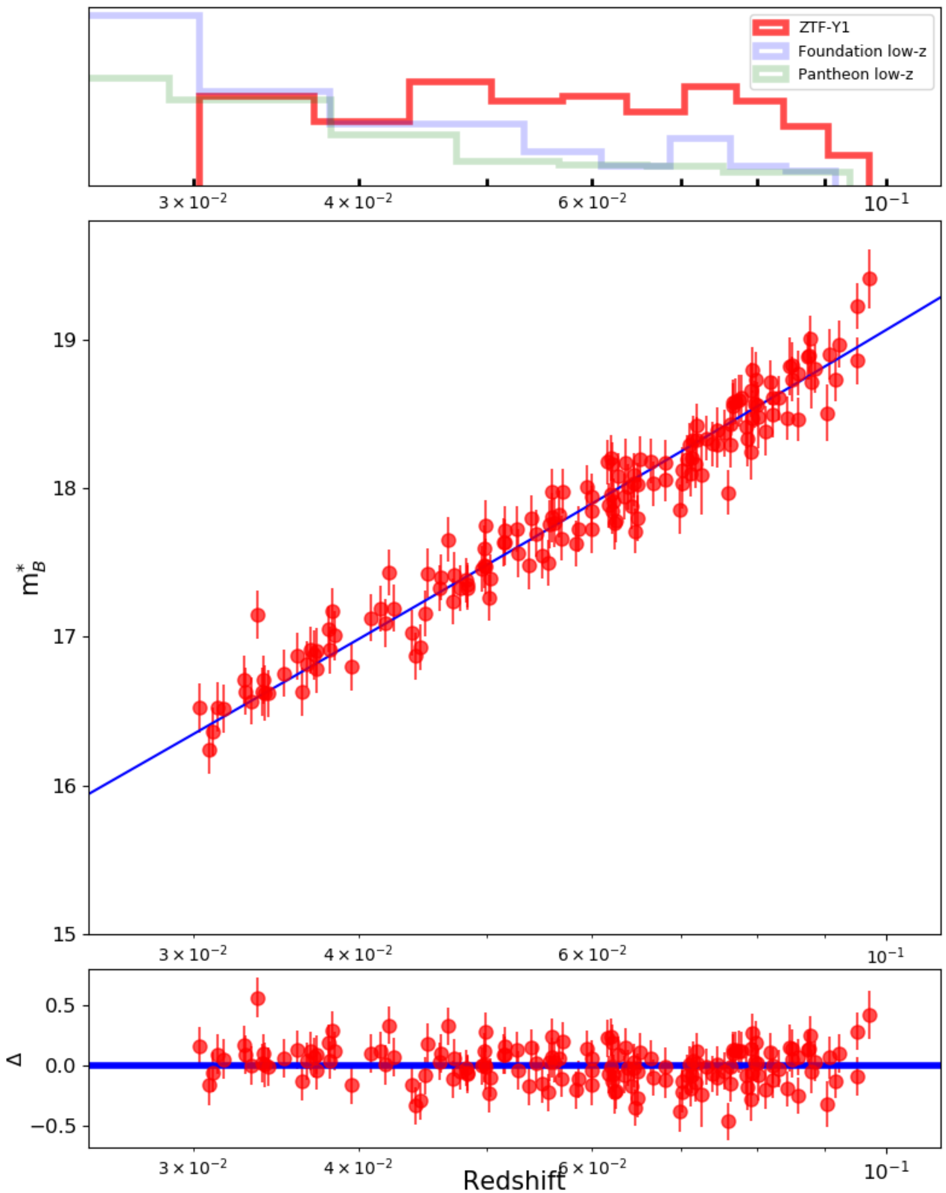
- 157 SNe in "gold" sample -> host redshift

Greater than *all lowZ combined*

- ZTF σ_{rms} = 0.16 mag
- Foundation σ_{rms} = 0.17 mag
- LowZ σ_{rms} = 0.20 mag

- ZTF <z> = 0.062
- Foundation <z> = 0.029
- LowZ <z> = 0.031

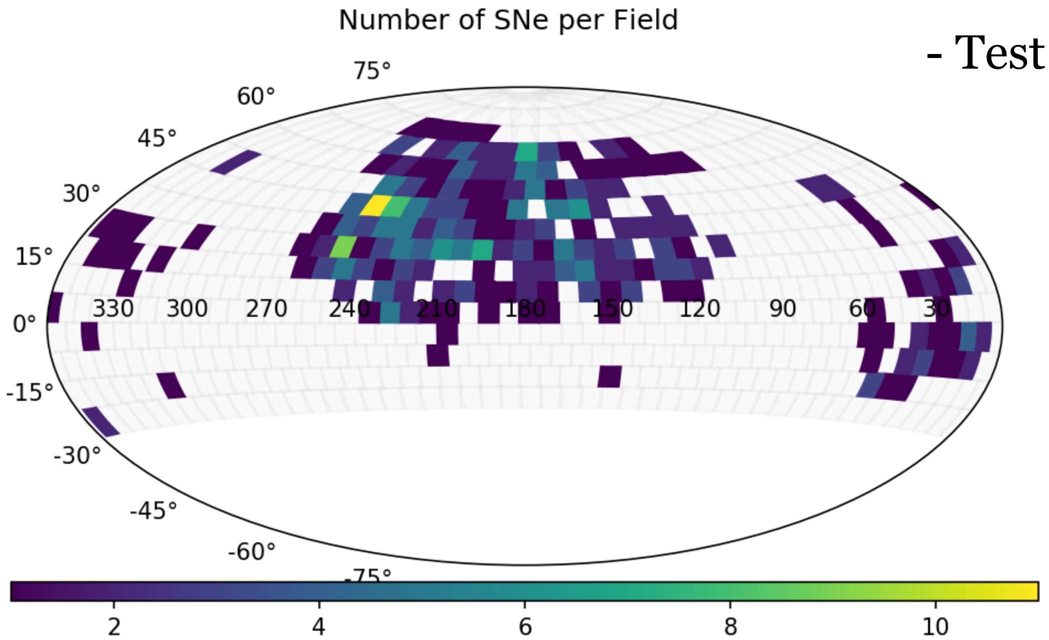
- Host-z required; SN-z sample 3 X



Year 1 sample

Dhawan et al. in prep

- Sky distribution of Year 1 sample
  - High cadence fields have > 1 SN
- Important for growth of structure
- Test directional dependence, e.g. H_0



Sample selection + lightcurves

Dhawan et al. in prep

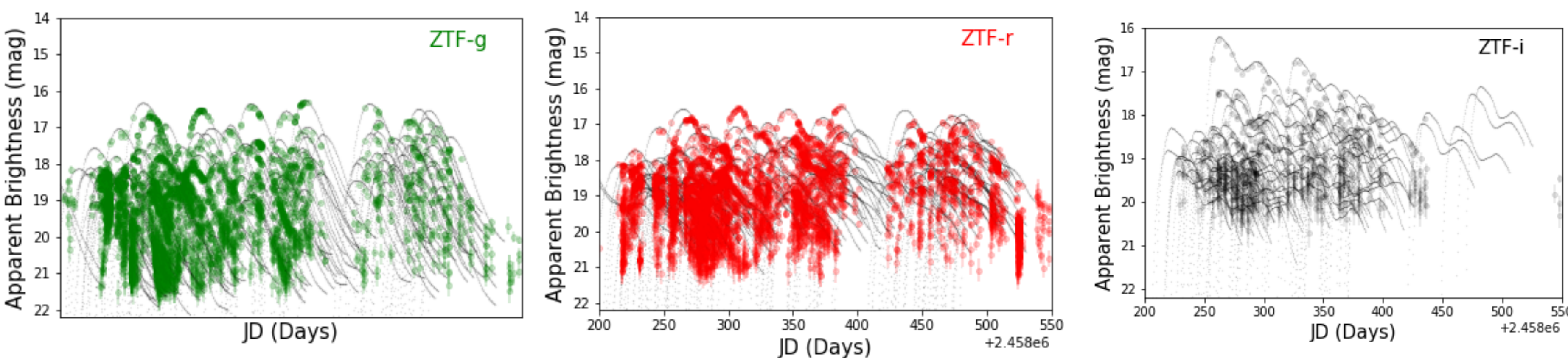
Cut	# SNe Ia	SNe rejected
2018 Cosmo-Marshal	799	
Host redshift	301	498
Duplicate/not '18/not Ia	290	11
Peculiar	273	17
Phase Coverage	230	43
Redshift cut	200	30
Cosmo cut (salt param)	**156**	44

- Pipeline developed for ZUDS

- Custom reference for each SN/field

z <= 0.015 for future Cepheid distances

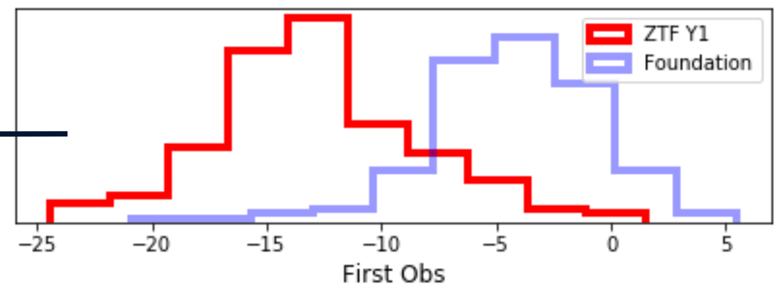
Use z >= 0.1 using selection function model



Model Fitting
toward an upgrade

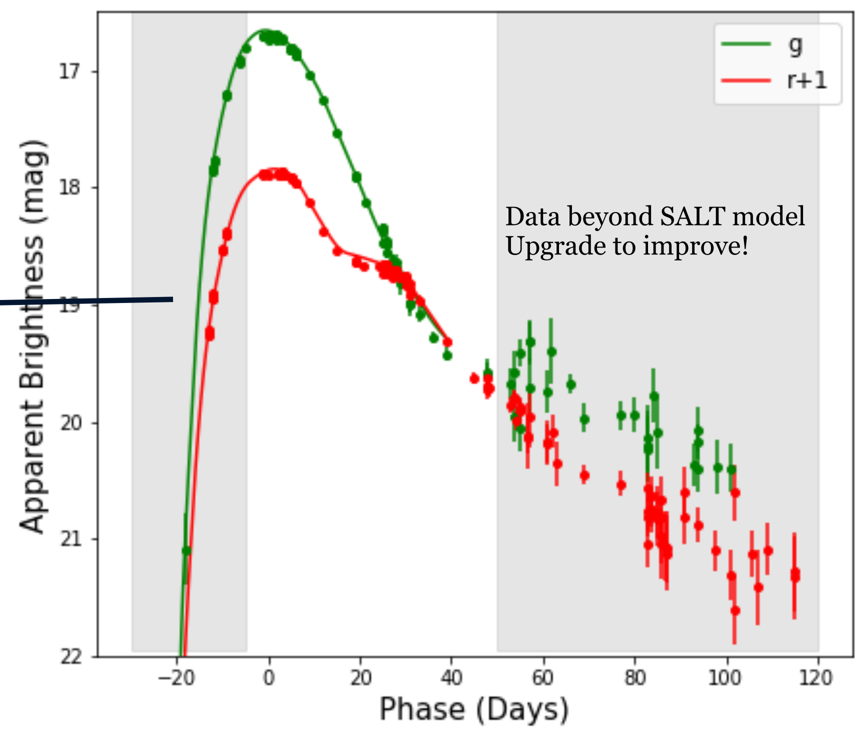
Dhawan et al. in prep

Much earlier discoveries than the literature



- for z <= 0.05, lc beyond +100 days
- Improve existing model

Early light curve for improving distances



i band tests

Ongoing

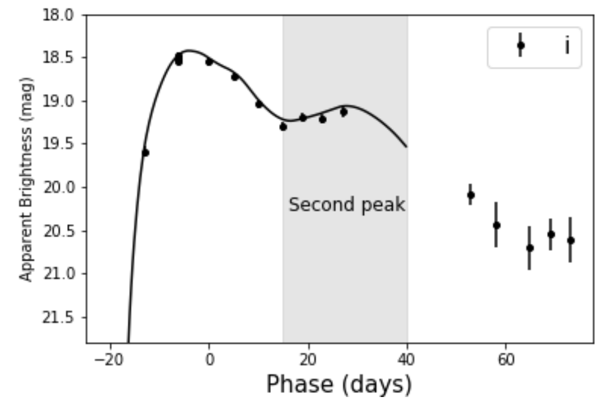
Dhawan et al. in prep

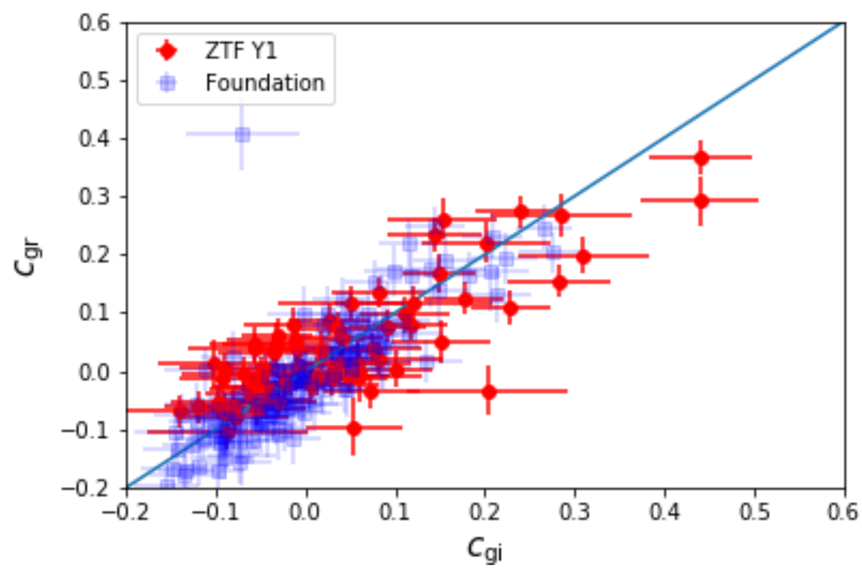
- Colour calibration tests
    - Fewer outliers than Foundation
    - Need to improve scatter

- Independent i-band Hubble diagram

- Improve photo-classification

- Second peak => explosion properties

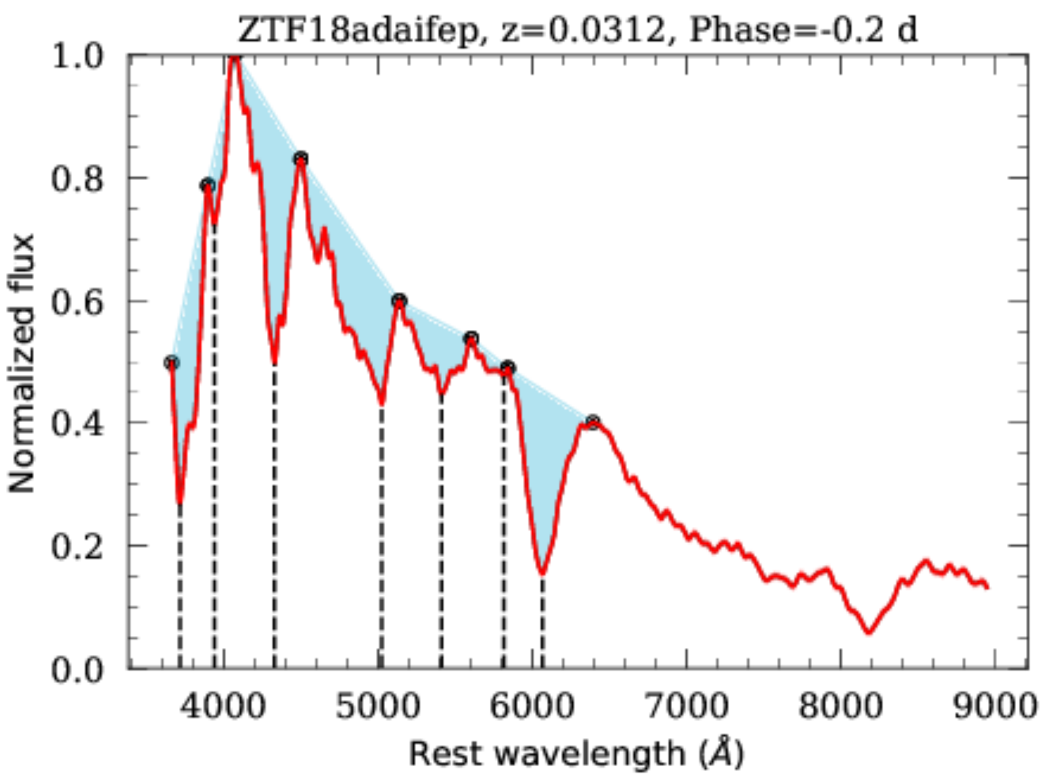




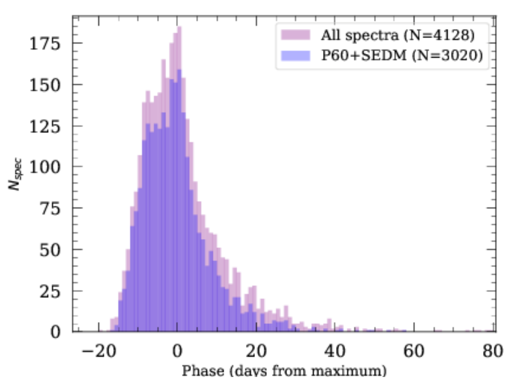
Ongoing

Spectra for DR1

- Do subclasses (e.g. high/low velocity) have smaller scatter?



Credits: J. Johansson



SEDm data yield accurate velocities!
High-velocity SN (> 5 σ determination)

NIR follow-up in ZTF2

Ongoing

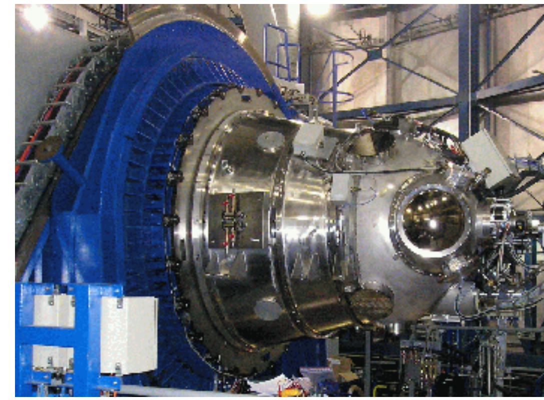
- SNe Ia are almost standard candles in the NIR

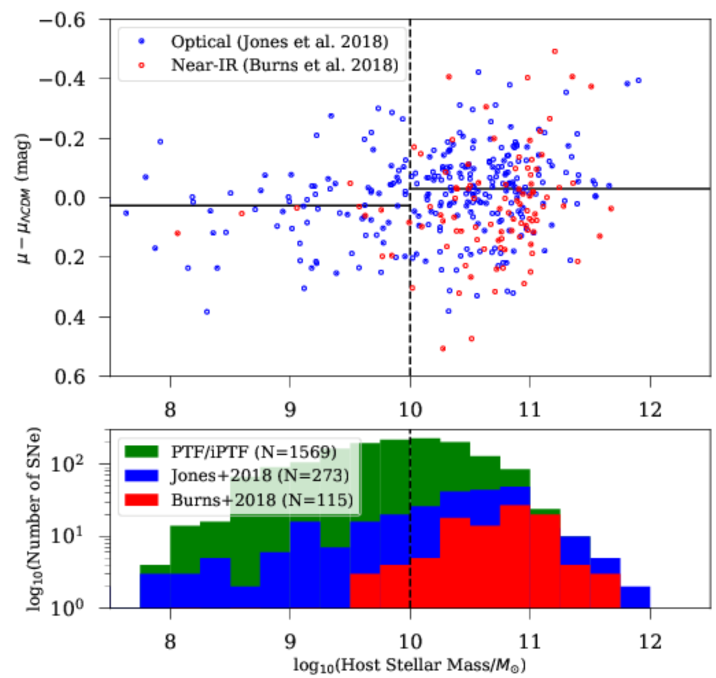
- "Snapshot" distances: single/two epochs of observing
  - Use well-studied templates to get peak

- HAWK-I **approved** proposal (PI: Dhawan)
  - Target sample of 200 in 3 semesters

- Test host galaxy mass step in the NIR

- Debate about poorly known extinction properties
  - NIR provides a wide wavelength coverage



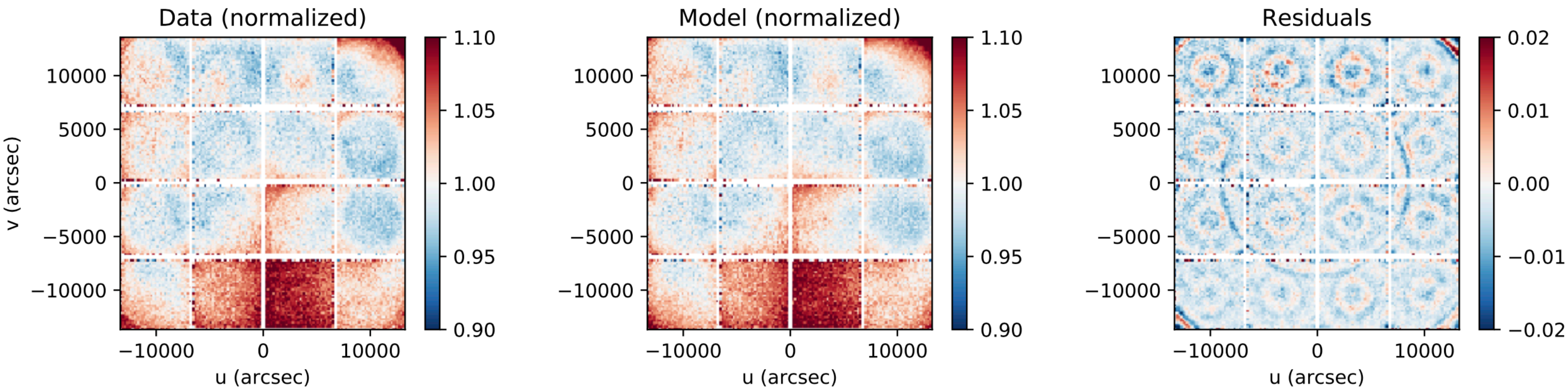


Ongoing work: Calibration

New PSF model dev by IN2P3 team (from PIFF)

Ongoing

(1/2 days average | *g band 1st of March 2019*)



Relative PSF size residual (arcsec)

1 arcsec error = 1% error in flux

see also Andrew Drake's talk on Monday

Projected Cosmology Improvement

Sample	Hubble Constant	Dark energy	Unique addition
Gold sample Y1 (157 SNe)	30% better than current SN sample	50% improvement compared to LSST alone	Environmental dependence + single system
ZTF-I 3Yr sample (1800 SNe)	2.5 X smaller error	2 X improvement compared to LSST alone	Directional dependence tests Subpopulation studies
ZTFI+II sample (4000 SNe)	3 X smaller error	3 X improvement compared to LSST alone	Growth of structure at 5% ZTF-only calibrators

Ongoing + future works

Projects Ongoing with DR1 sample

- Local distance ladder H_0
- Measuring the CMB dipole
- Directional dependence of the Hubble constant
- Properties of dust around reddened SNe Ia
- Spectroscopic subclasses based on line velocities
- SNIa clustering (see Ariel's talk)
- Characterising the SN population (see Rahul's talk)

Summary + Conclusions

- Complete cosmology sample ~ 2000 SNe Ia
- DR1 sample: Already greater than combined low-z in the literature
- Excellent rise and late phase coverage
  - Test new standardisation methods
  - Extend existing SALT2 model

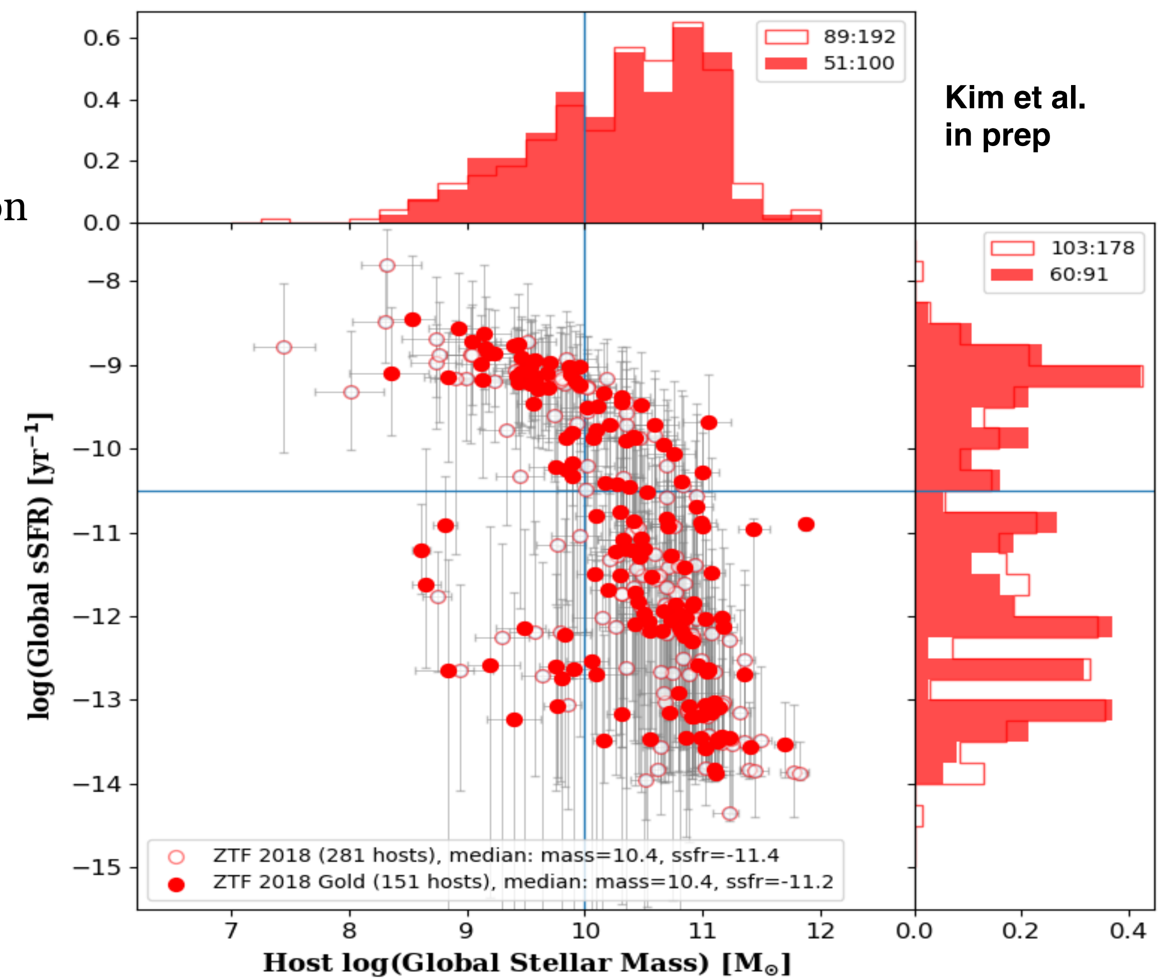
- Low intrinsic scatter of 0.15 mag
- Follow-up cosmology studies: H_0, CMB dipole, directional dependence
- Sample of reddened SNe used to constrain extinction properties
  - NIR follow-up of ZTF2 SNe
- Lensed SN search: skyportal instance setup and in development
  - New simulations on expected rate of glSNe

Host galaxy Analysis

Ongoing

Yr1 sample: 281 hosts in SDSS
- 151 from the gold sample

Samples the underlying distribution
- Unlike the current low-z



Kim et al. in prep

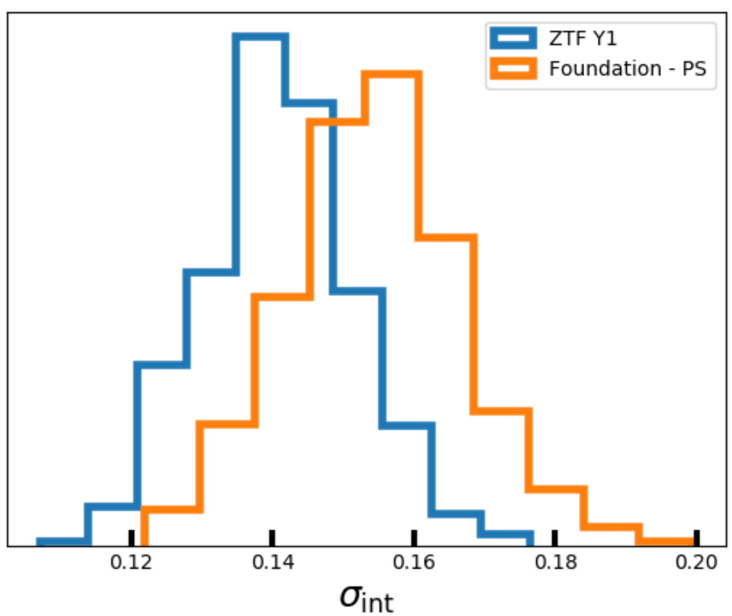
Intrinsic scatter

- Compare scatter to the literature
    - Foundation is on PS1 system
    - rms of 0.17 mag
- ZTF Y1 has rms scatter of 0.16 mag

- Intrinsic scatter including fit error
    - No systematics included
- σ_{int} = 0.15 mag (Foundation), 0.14 mag (ZTF Y1)

MR: REMOVE IT

posterior distribution of intrinsic scatter from fitted Hubble diagram



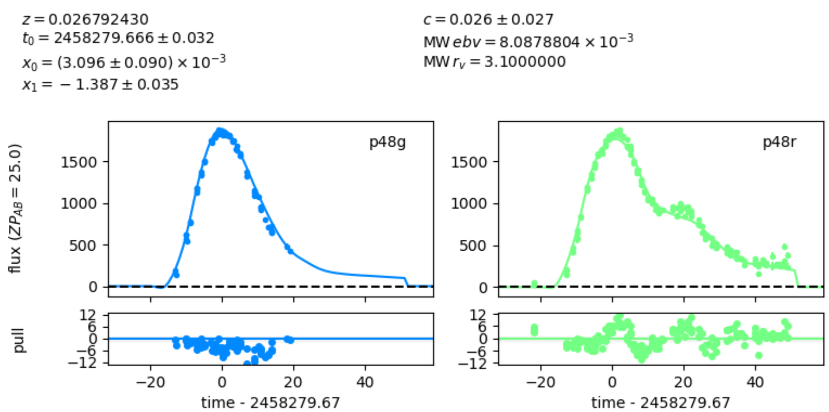
glSN monitoring search

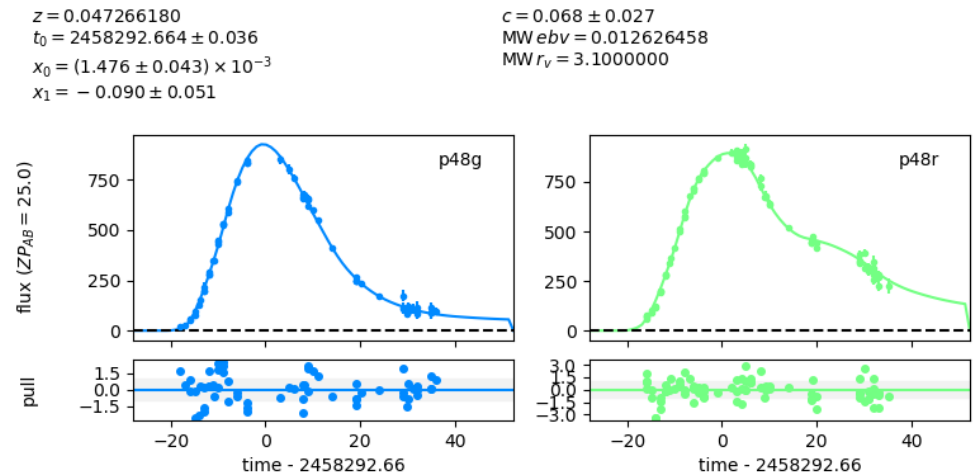
- AMPEL has several useful filters and provides an API for new filters

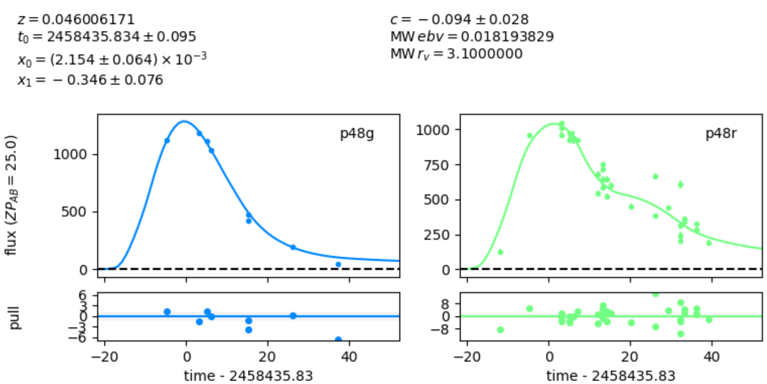
- Use SkyPortal instance to engage GLSN group to look at the alert stream for only GLSN filtered candidates

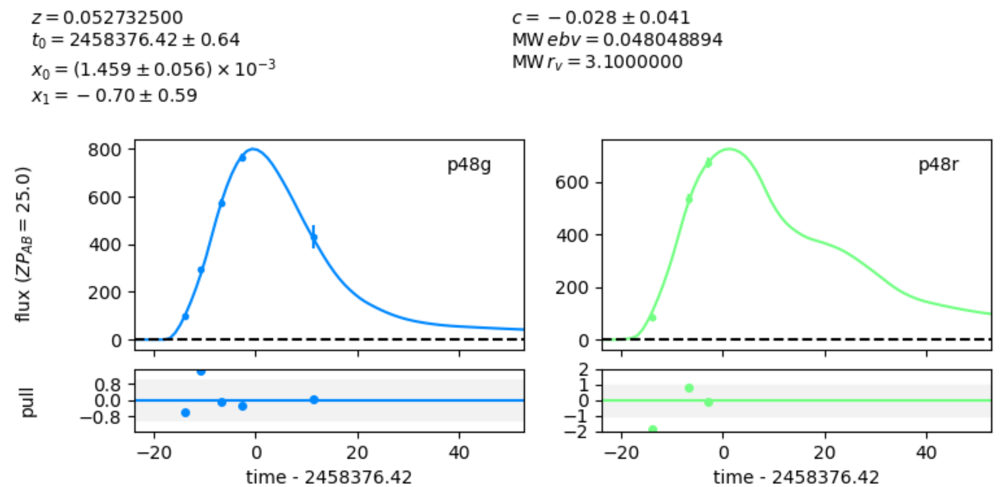
- Objective : set up a sufficient stream with relatively limited resources for rare transients

Lightcurve examples



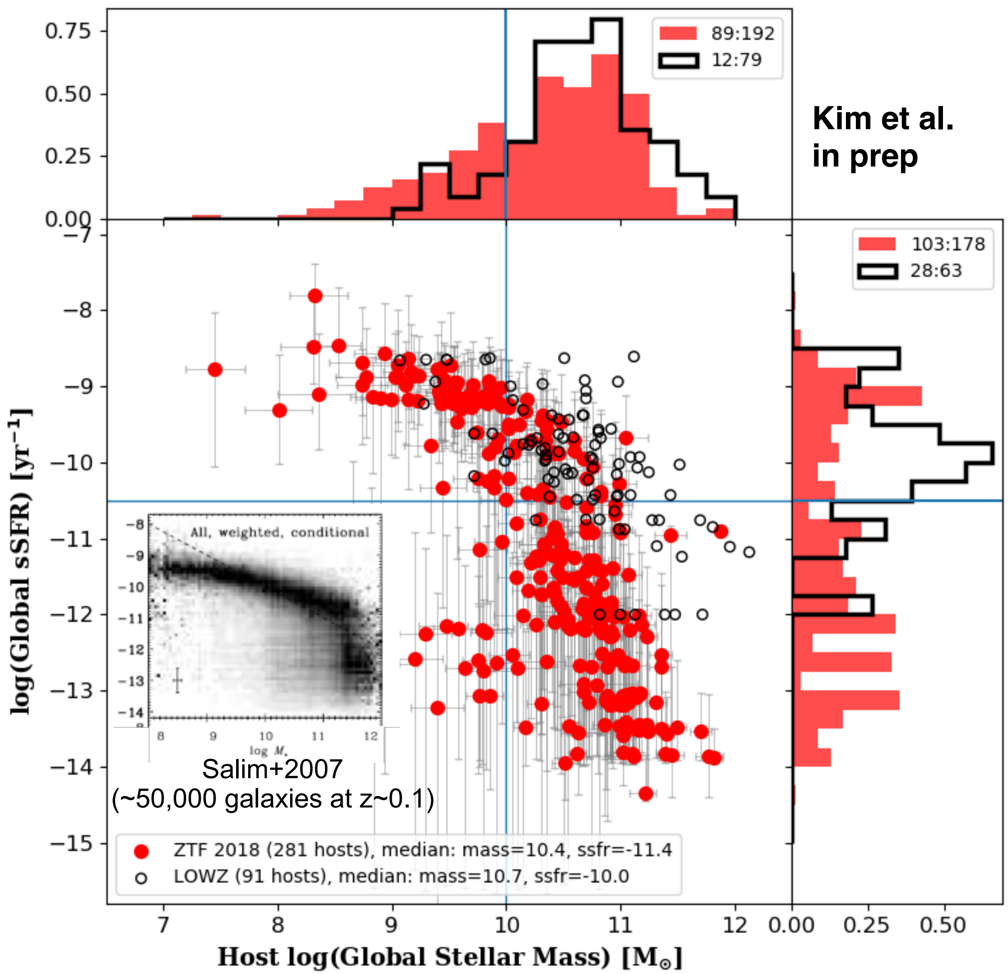






ZTF is untargeted!

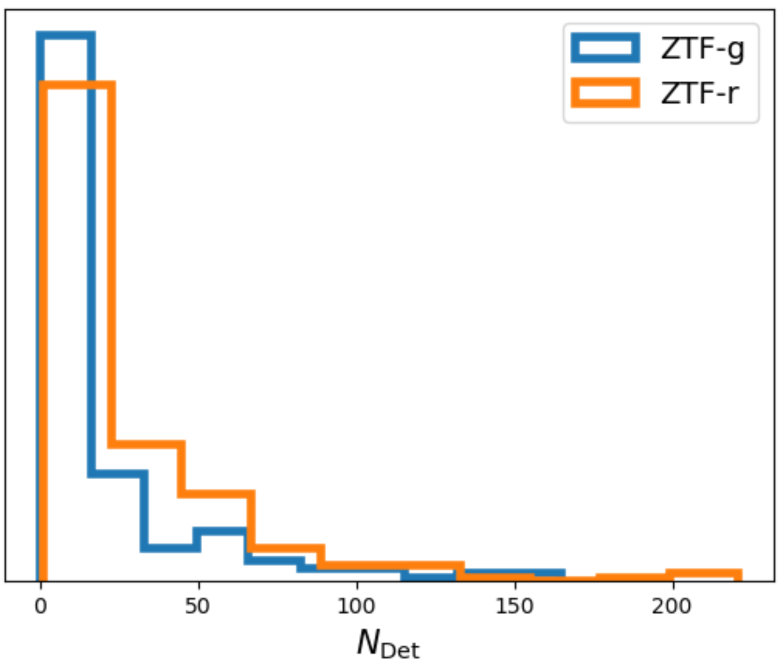
- Host properties => impact DE/H0 constraints
- Underlying cause unknown
  - Different dust properties?
  - Intrinsic 56Ni difference?
- SDSS ugriz photometry fitted
  - LePHARE for fitting 281 hosts
  - Pan-STARRS to increase sample
- Symmetric distribution in mass
  - Low-z data is asymmetric (e.g. Kim et al. 2019)
  - Important to test selection effects

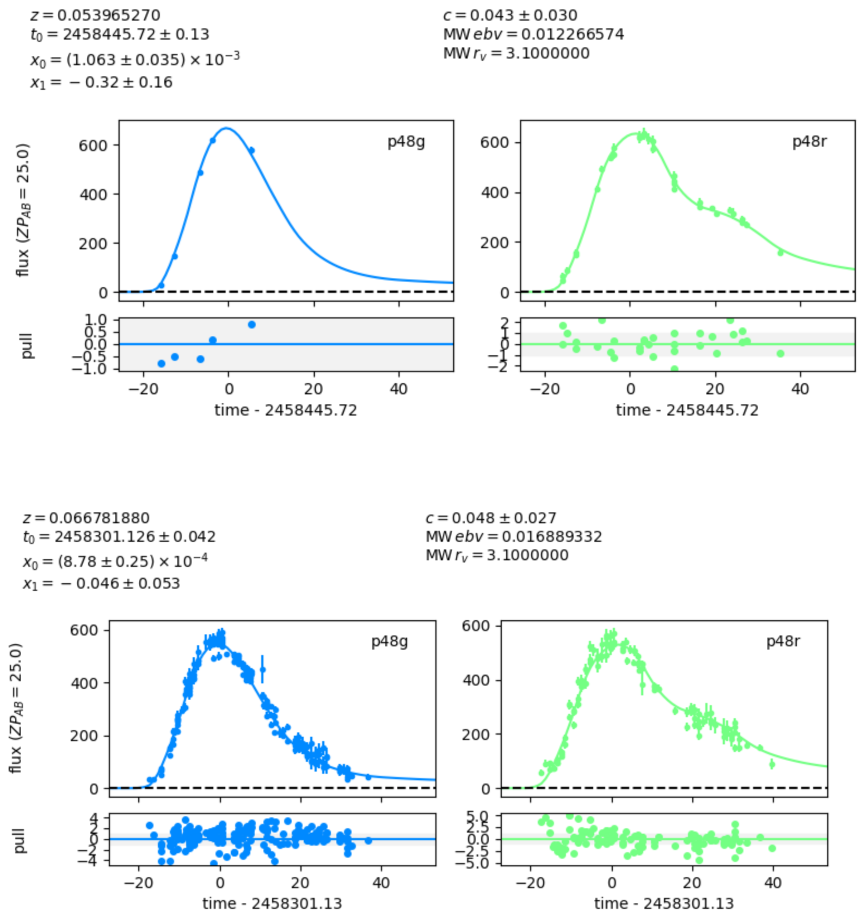


Kim et al. in prep

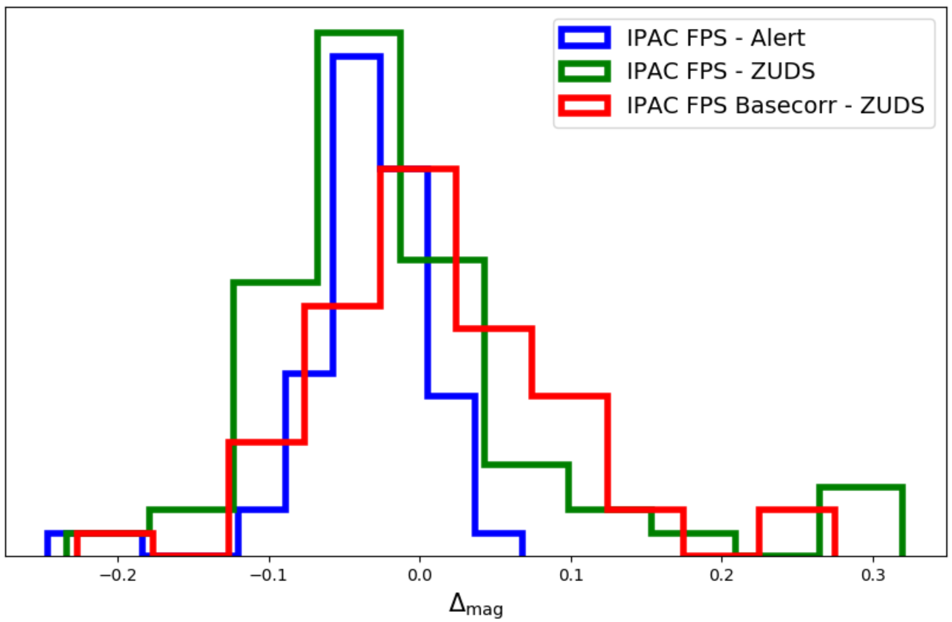
ZUDS Summary Stats

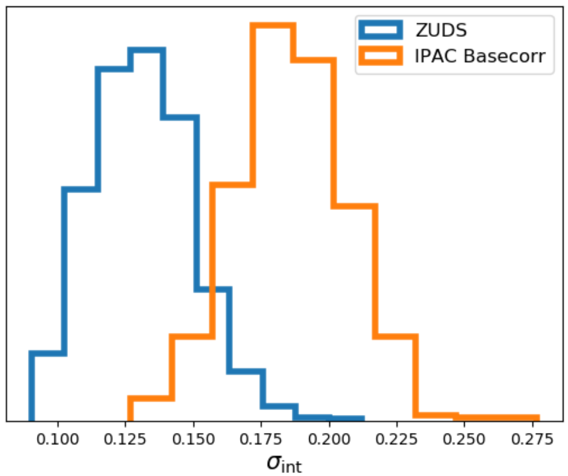
- N detections > 3σ
  - Median g-band 8 observations
    - Need to process late time tail for ~ 1/2 g-band data
  - Median r-band 15 observations





Comparison with IPAC FPS

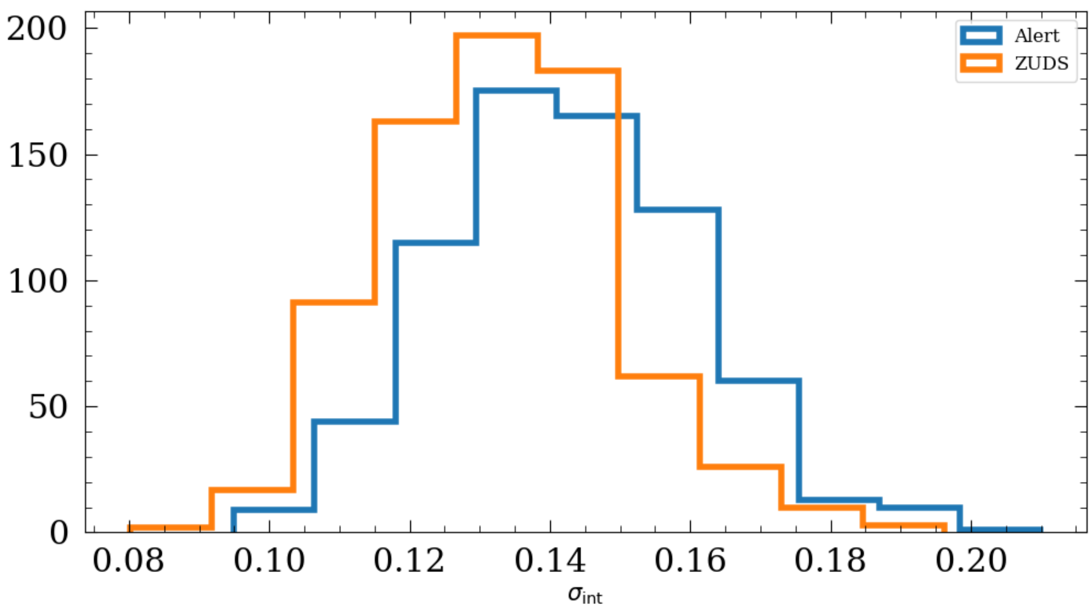


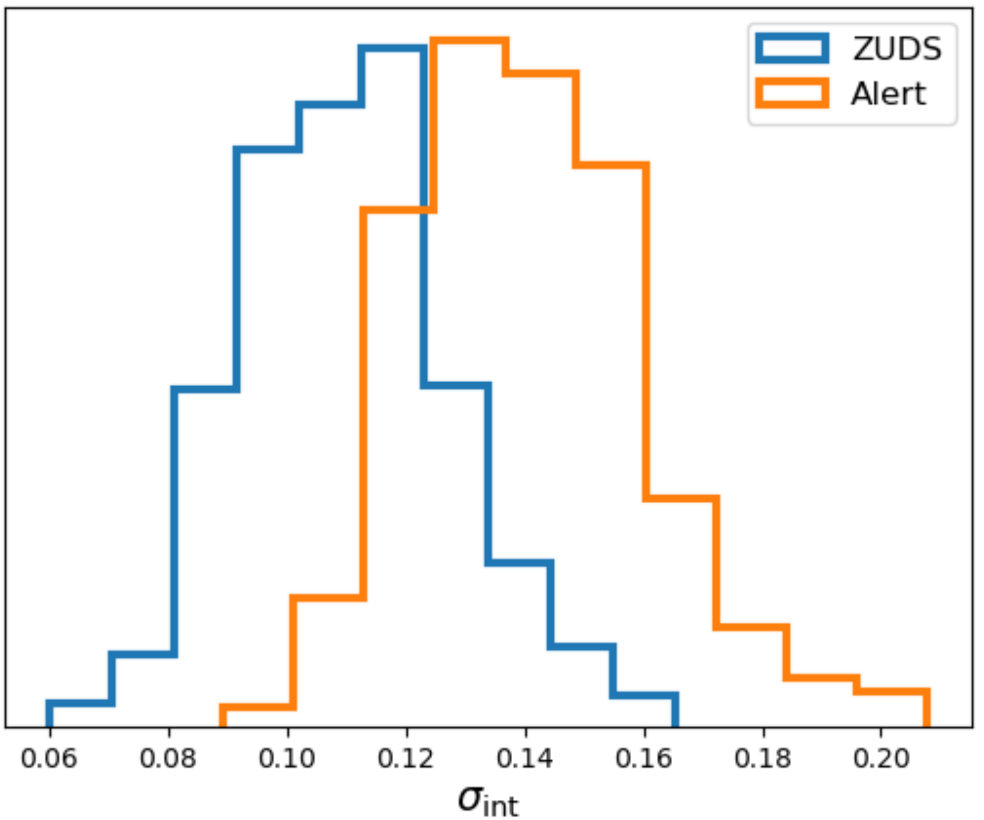


55 SNe in common
IPAC FPS-Basecorr is 0.188 mag
ZUDS is 0.132 mag

Comparison with alert

72 SNe in common
IPAC Alert is 0.142 mag
ZUDS is 0.132 mag




ZUDS
Alert
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
$\sigma_{\rm int}$

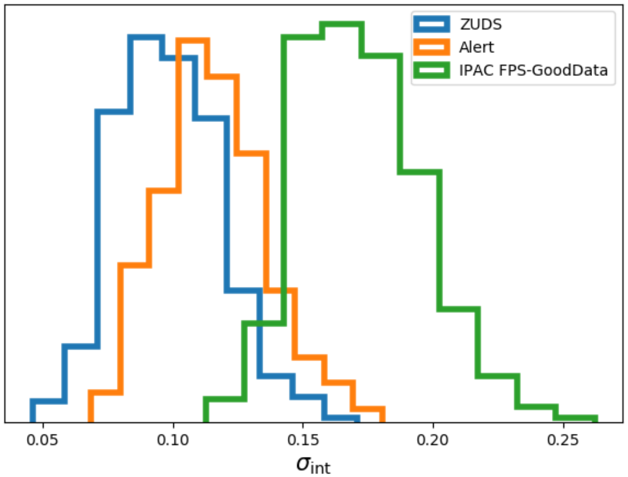
Pipeline Comparison

- ZUDS: custom references, subtractions i-band photometry, lowest scatter, lightcurve where there are no alert photometry points

- Alert: with checks from IPAC, no i-band, flux in reference, still low scatter for ones with good g+r

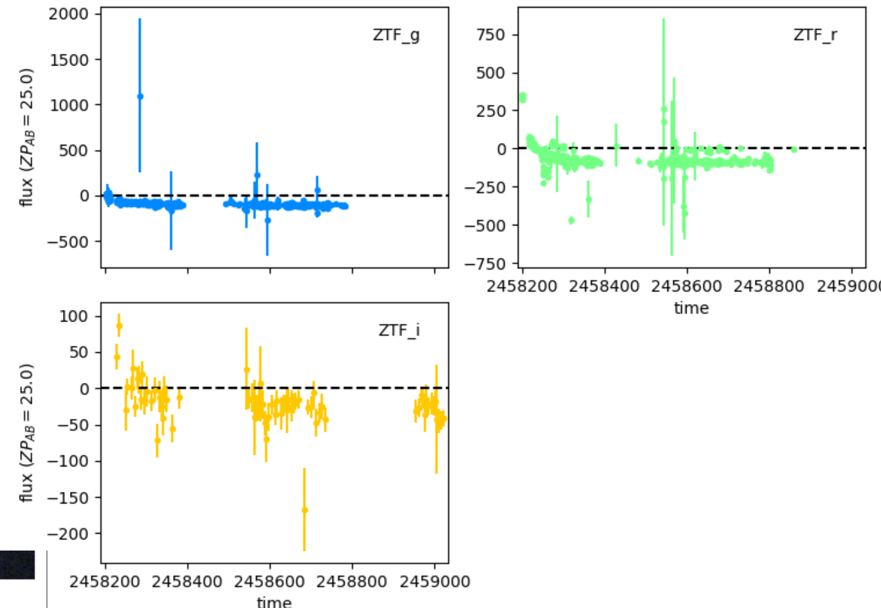
- IPAC FPS: good to check number of detections, long baseline, Frank doesn't trust over alert photometry

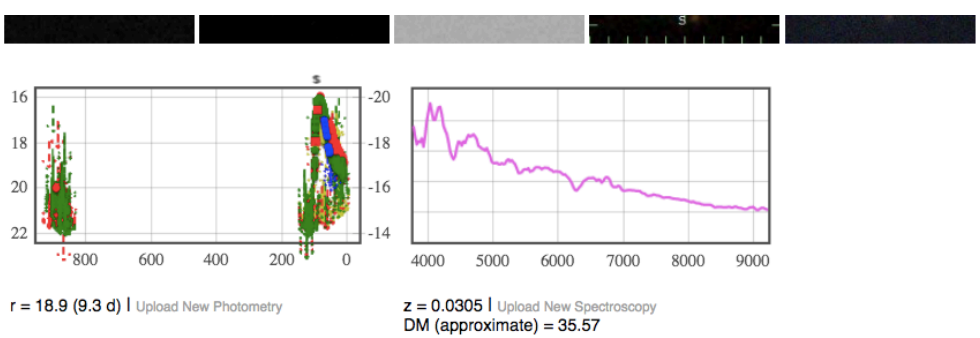
standard deviation from best fit
ZUDS - 0.13 mag
Alert - 0.14 mag
IPAC FPS - 0.18 mag



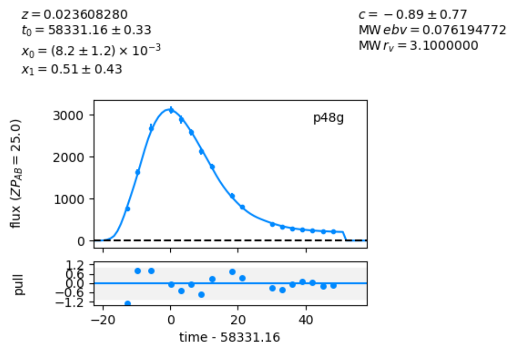
Sample Update

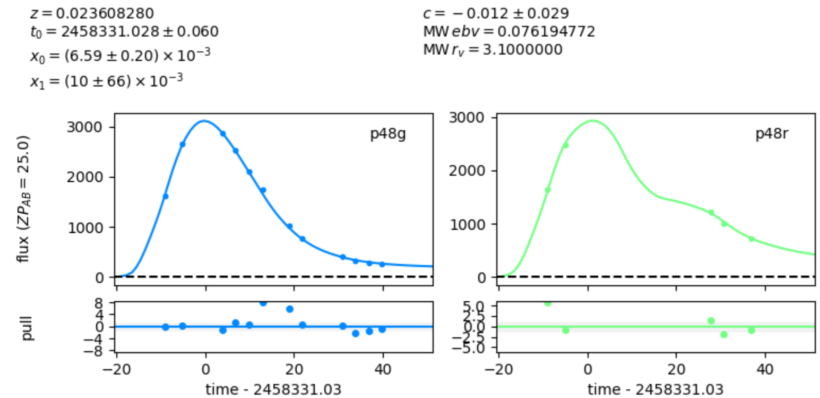
- All light curves made: Some hurdles/incompletion
  - Corrupt files, especially for SNe on two fields
  - Some are all on the secondary grid
  - Too early to get an estimate of tmax
  - Alert in 2018 but SN is from 2020
  - ZUDS removes good seeing data
    - Use epochs with seeing < 1.7”

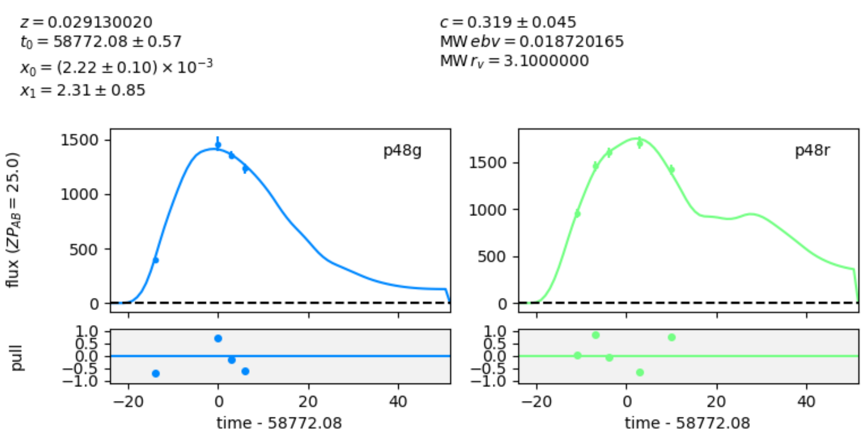


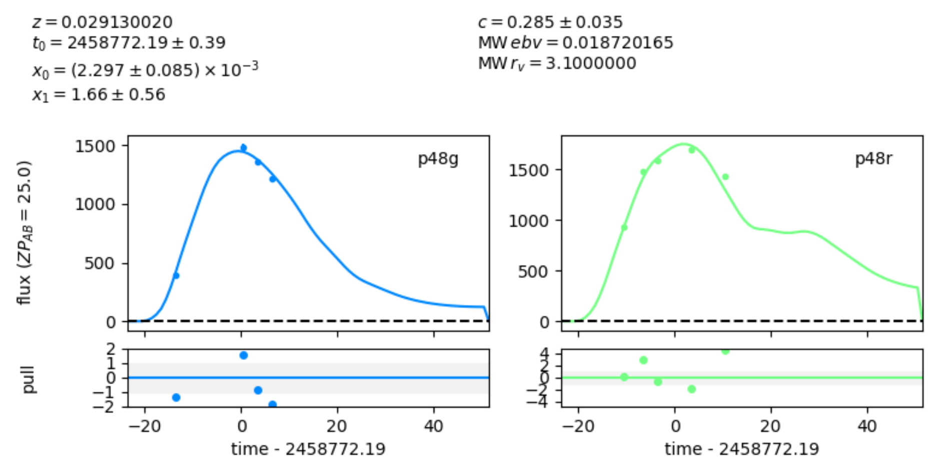


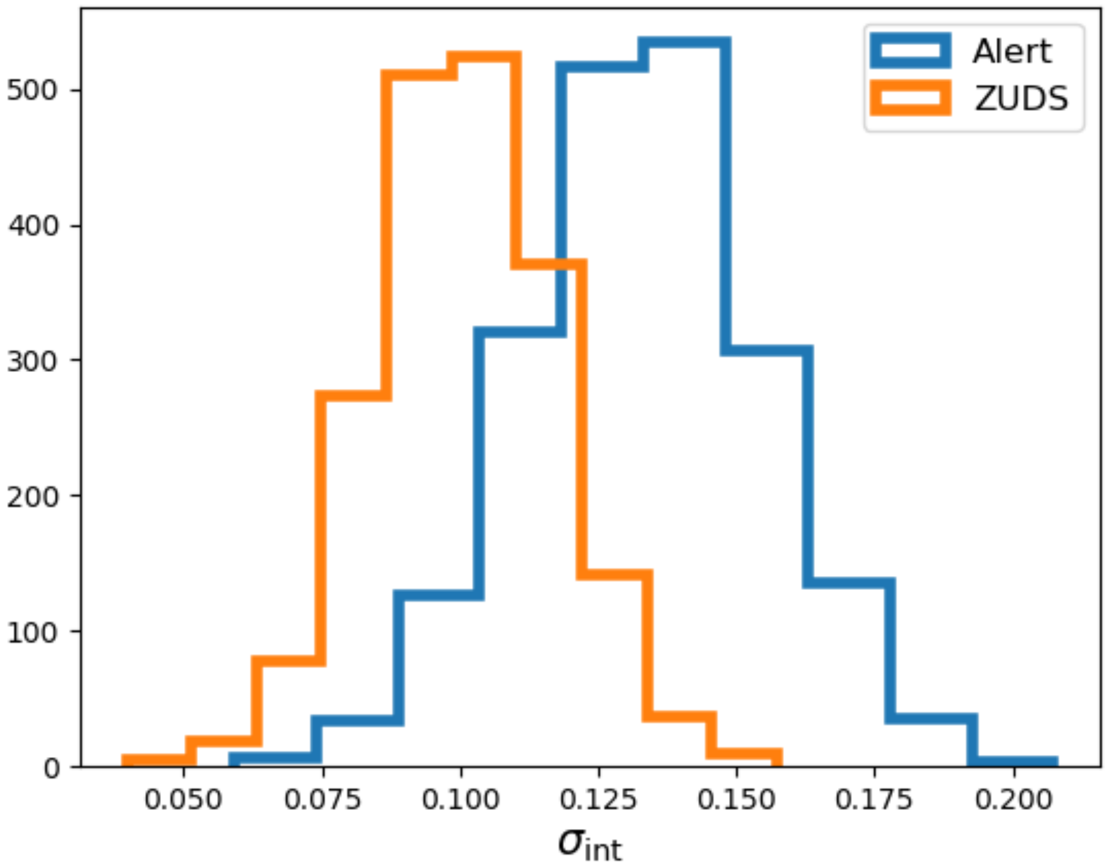
Alert versus ZUDS







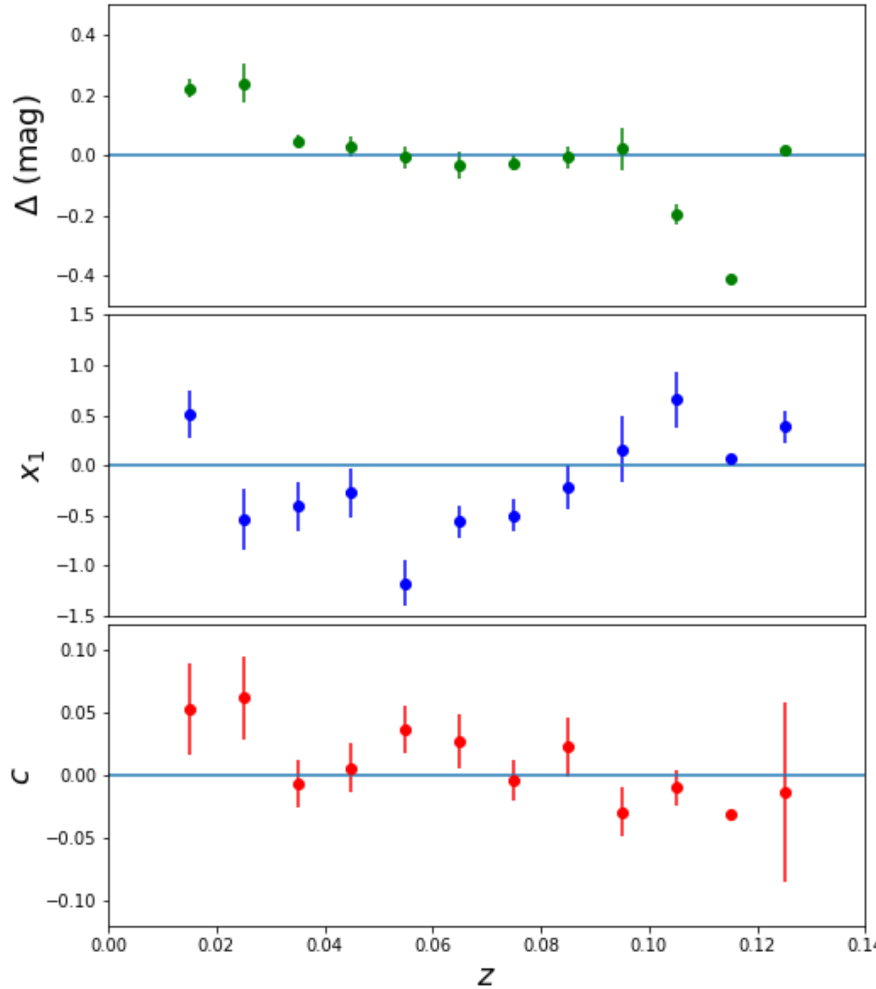




Alert
ZUDS
500
400
300
200
100
0
0.050
0.075
0.100
0.125
0.150
0.175
0.200
σ_{int}

Redshift upper limit

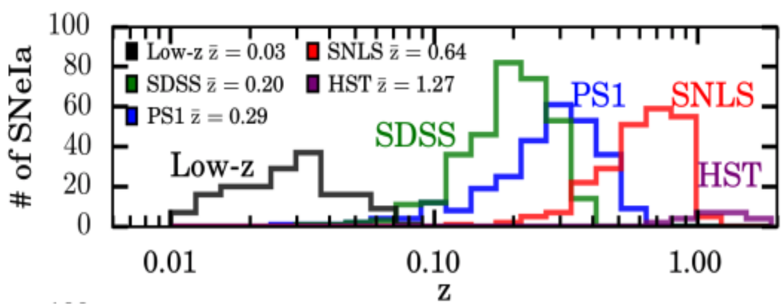
- After what z are the residuals brighter?



Low-z Anchor : State of the art

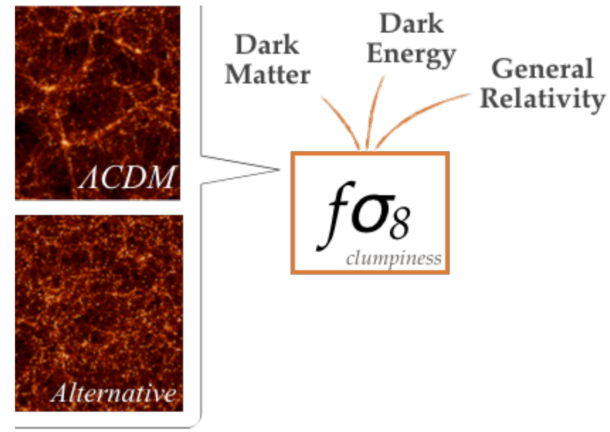
Table 4.

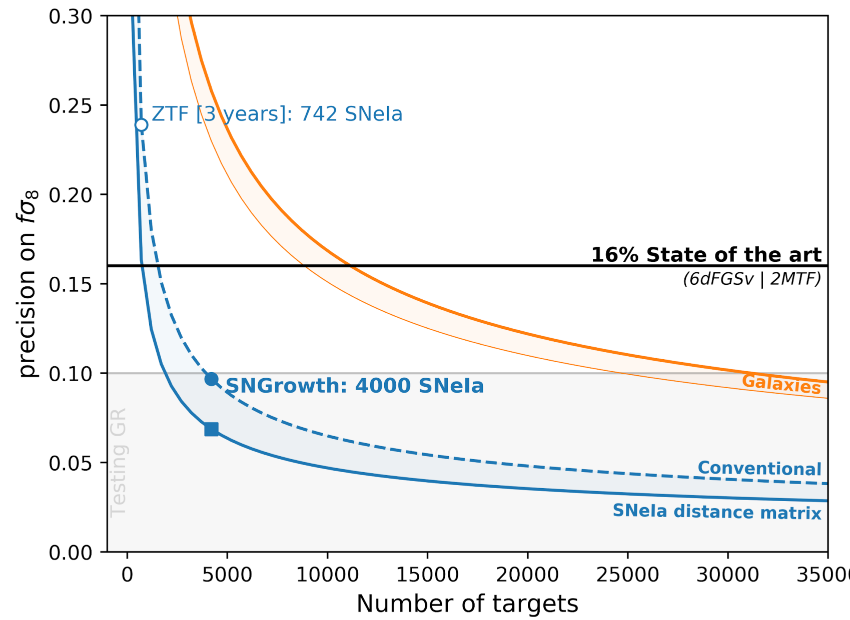
Sample	Number	Mean z
CSP	26	0.024
CFA3	78	0.031
CFA4	41	0.030
CFA1	9	0.024
CFA2	18	0.021
SDSS	335	0.202
PS1	279	0.292
SNLS	236	0.640
SCP	3	1.092
GOODS	15	1.120
CANDELS	6	1.732
CLASH	2	1.555
Tot	1048	



Growth of structure

- Measure growth of structure from velocity correlations
- Independent probe of σ_8 tension
- Require few thousand SNe (statistically equivalent to ~15000 galaxies)
- Large coherent motion (bulk flow) in ZTF volume could contradict ΛCDM structure formation
- ZTF 1+2 will provide ideal sample





Sample statistics

- Redshift 0.03 < z < 0.1
    - Low impact of peculiar velocities
    - z >= 0.1 Malmquist biased
        - SNe are bluer and wider than average
- Median > 15 observations in g+r
    - Subset with ~ 100 points around peak
- Early discoveries: novel constraints on the rise