Palomar Transient Factory and the Search for Progenitors Channels of SNe Ia

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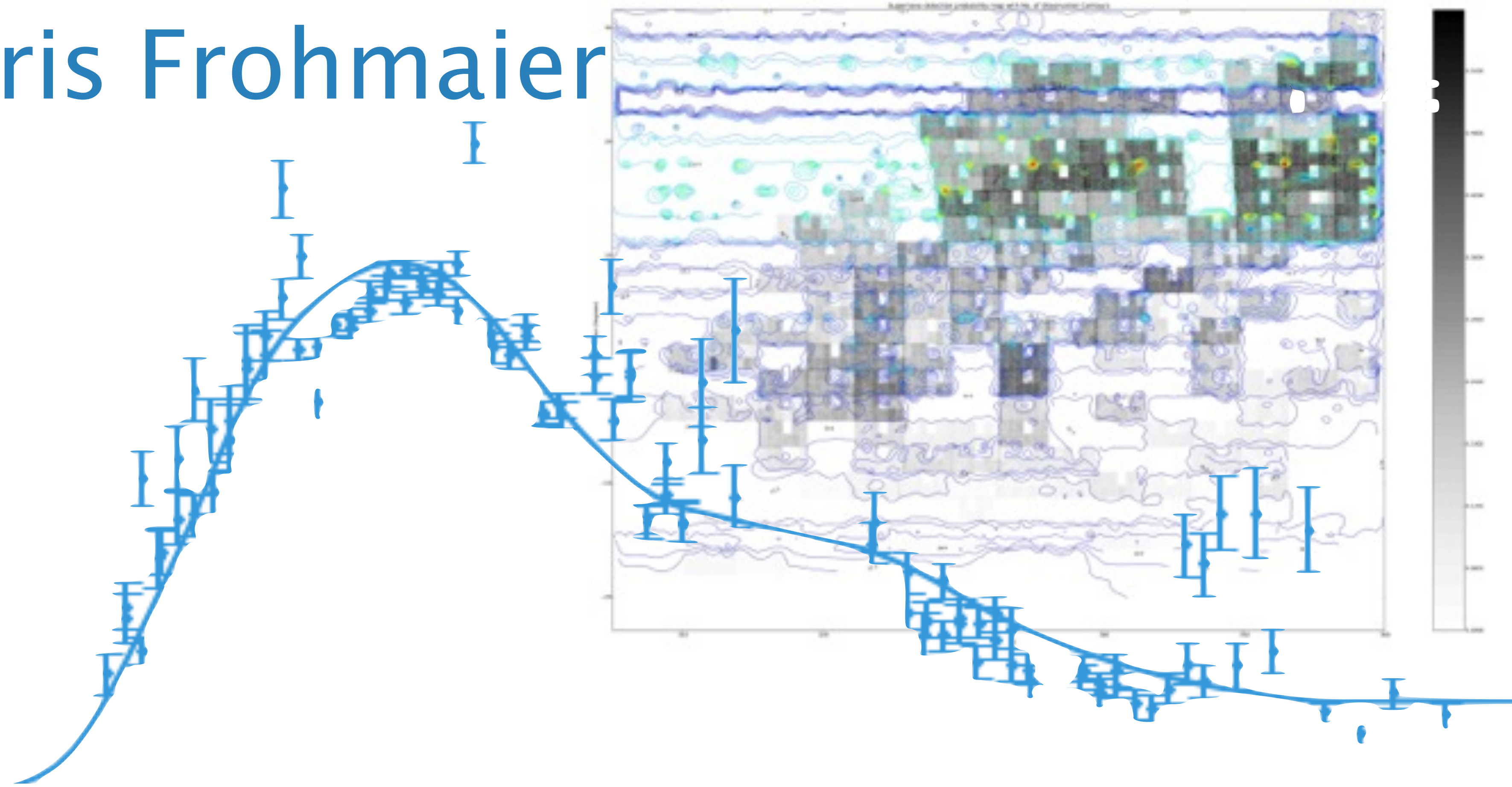

UNIVERSITY OF Southampton

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Motivation

- SNe govern the heavy element production of the Universe and cycle matter in galaxies.
  - A SN rate provides insight into metal enrichment on a cosmic timescale.
  - Are Supernovae responsible for dust in Galaxies?
- Shockwaves inject energy into the ISM.
- Used as a test of stellar evolution models.
- Insight into the birth rate of compact objects.
- A delay-time-distribution from the Ia rate can constrain progenitor models for this sub-class.

Rate Equation

$$r(v) = \frac{1}{V}\sum_i \frac{1+z_i}{\epsilon_i \Delta T_i}$$

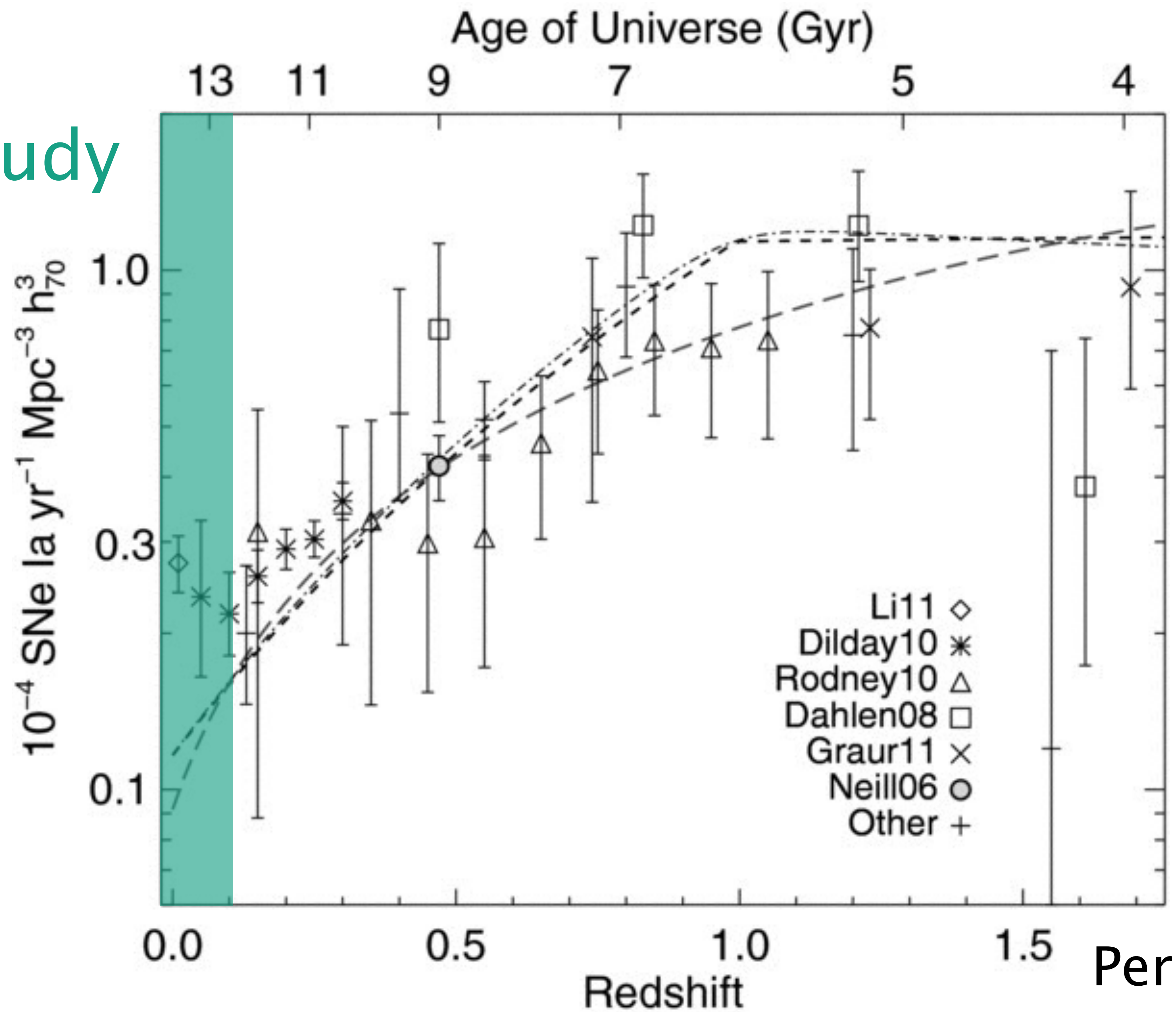
ϵ - Efficiency in detecting each supernova

T - Time window in which search was done

V - Volume surveyed

Previous Rates

Our study

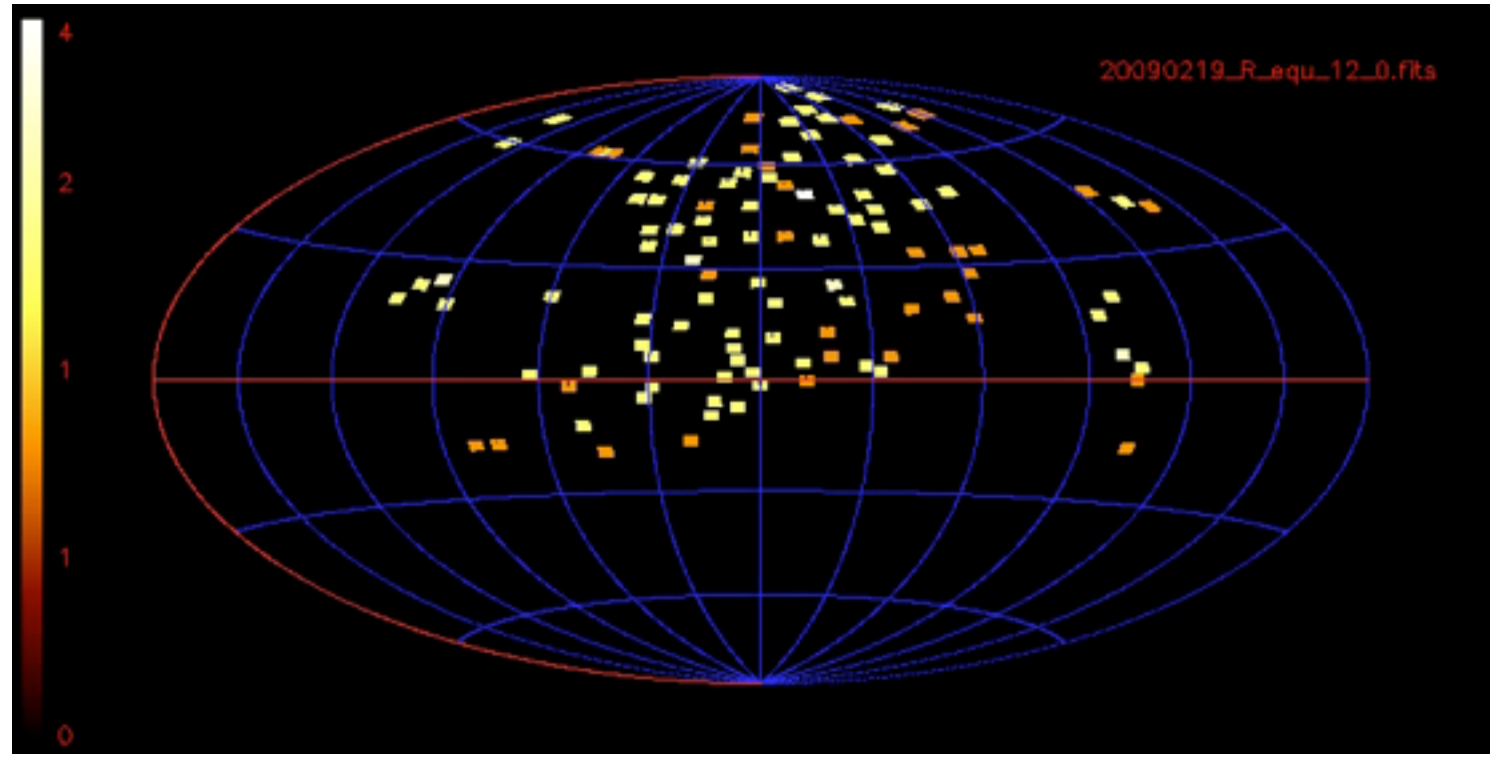


Perrett et al. 2012

Dashed lines are evolution models of the cosmic star formation history.

Palomar Transient Factory

- Largest unbiased sky survey
- 3-5 day mean cadence
- >100GB data per night
- ~7.26°^{2} FOV, 1.01” per pixel



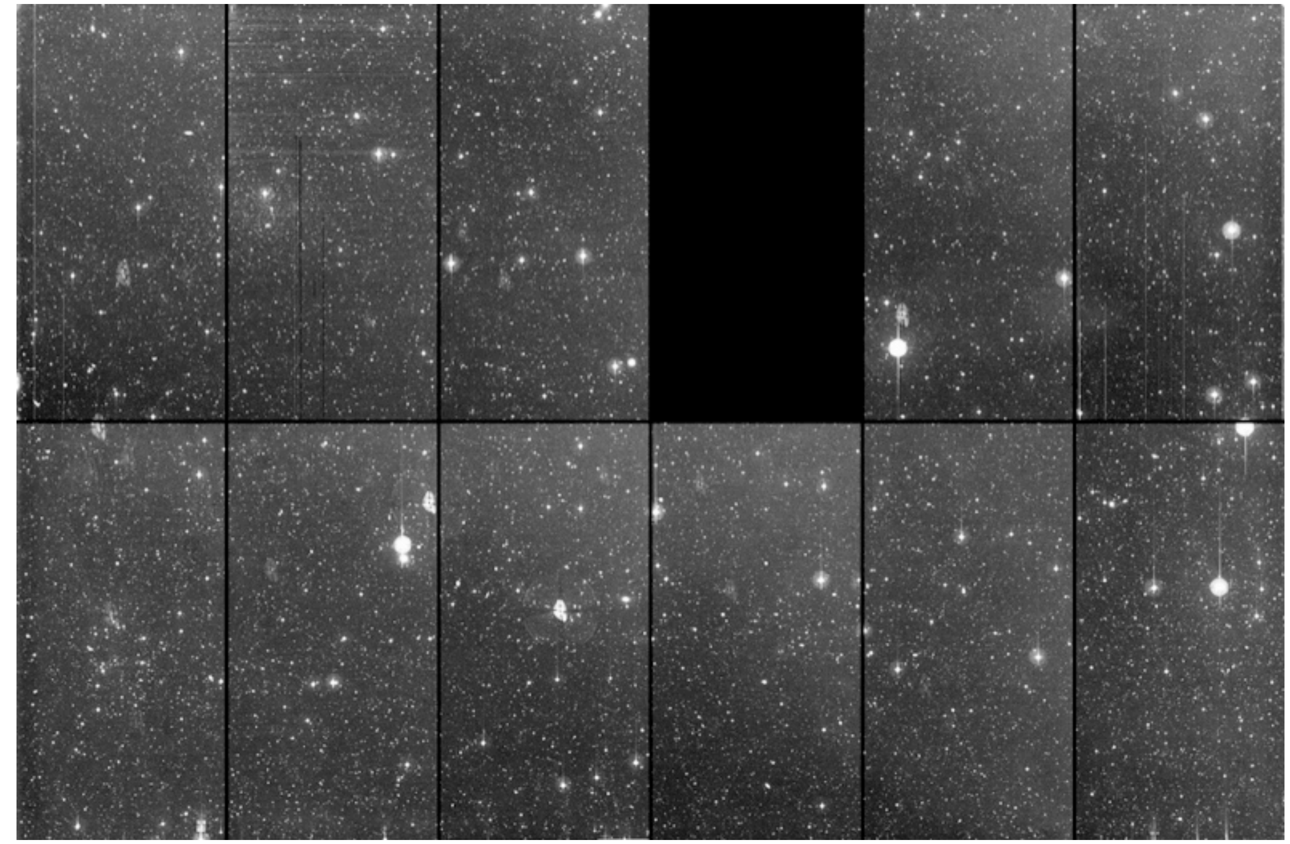
- Provides excellent low redshift statistics:

    Perfect for a SN rate…hopefully. But a lot of hard work!

PALOMAR TRANSIENT FACTORY

Palomar Transient Factory

	R-band	g-band
images	1.82M	305k
subtractions	1.52M	146k
references	29.2k	6.3k
Candidates	890M	197M
Transients	42945	3120



All in 851 nights between 2009 and 2012.

An image is an individual chip (~0.7 sq. deg.)

The database is now 1 TB.

PALOMAR TRANSIENT FACTORY

Palomar Transient Factory

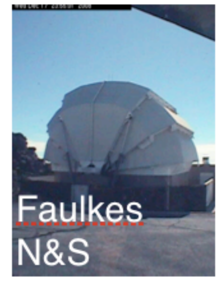
PTF Key Projects	
Various SNe	Dwarf novae
Transients in nearby galaxies	Core collapse SNe
RR Lyrae	Solar system objects
CVs	AGN
AM CVn	Blazars
Galactic dynamics	LIGO & Neutrino transients
Flare stars	Hostless transients
Nearby star kinematics	Orphan GRB afterglows
Type Ia Supernovae	Eclipsing stars and planets
Tidal events	H-alpha ½ sky survey

The power of PTF resides in its diverse science goals and follow-up.

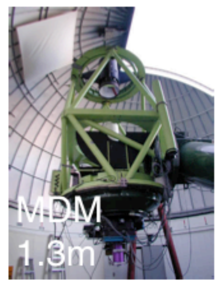
PALOMAR TRANSIENT FACTORY

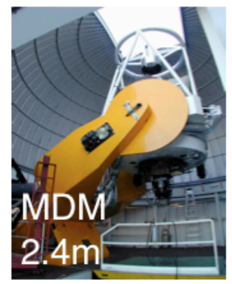
Palomar Transient Factory

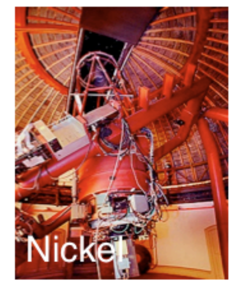
▼▶ Detected transients will be followed up using a wide variety of optical and IR, photometric and spectroscopic followup facilities.

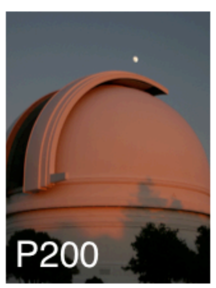


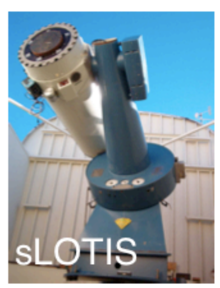
Liverpool Telescope

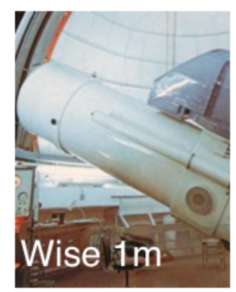












LCOGT.net

The power of PTF resides in its diverse science goals and follow-up.

i.e. Everyone chipped in to get spectroscopy for everyone else…

PALOMAR TRANSIENT FACTORY

Palomar Transient Factory

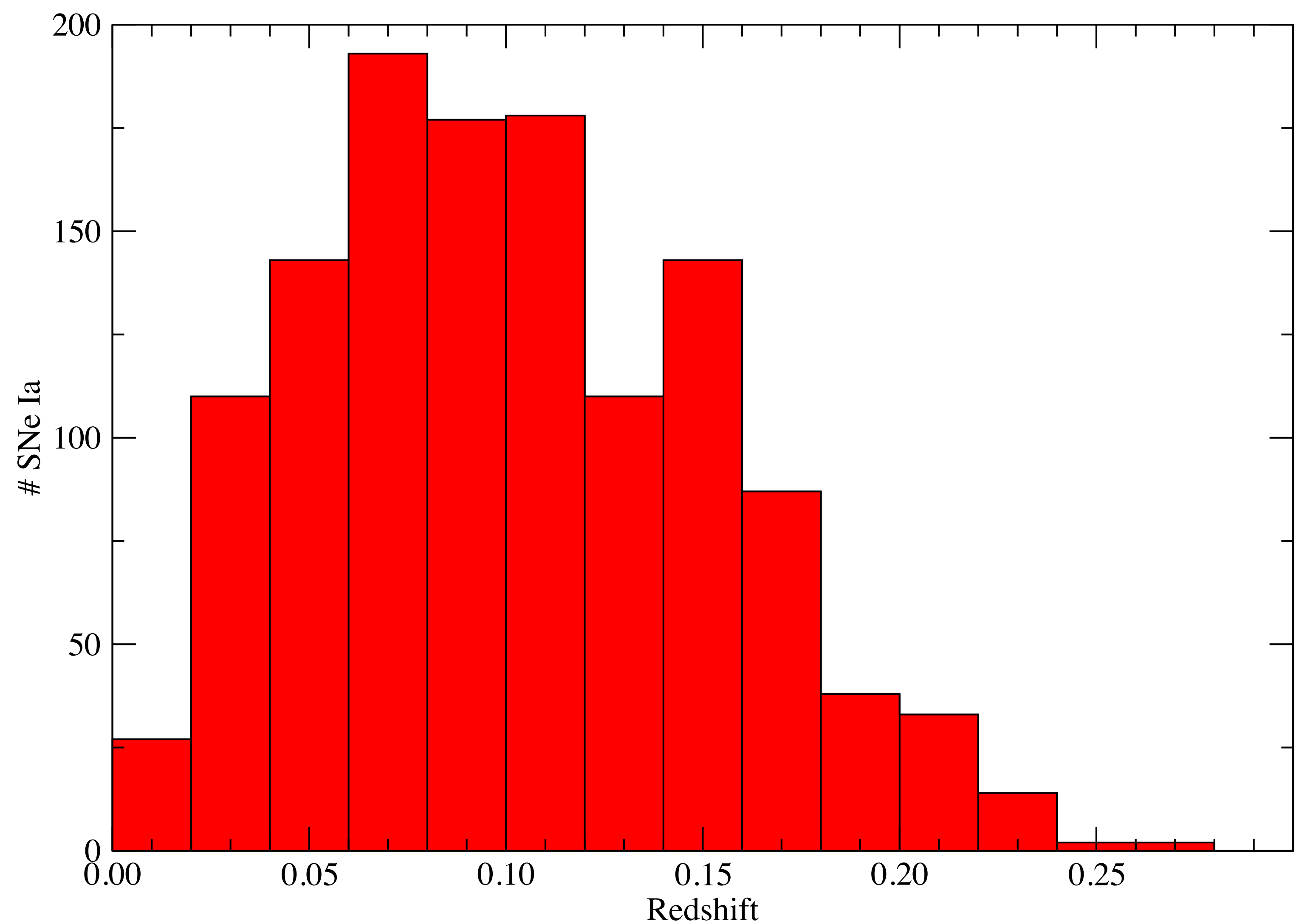
Stat Sheet:

- 1793 SN discovered and spectroscopically confirmed between 2009-2012
- 1258 SNe Ia over this time period (6 Mpc < d < 800 Mpc)

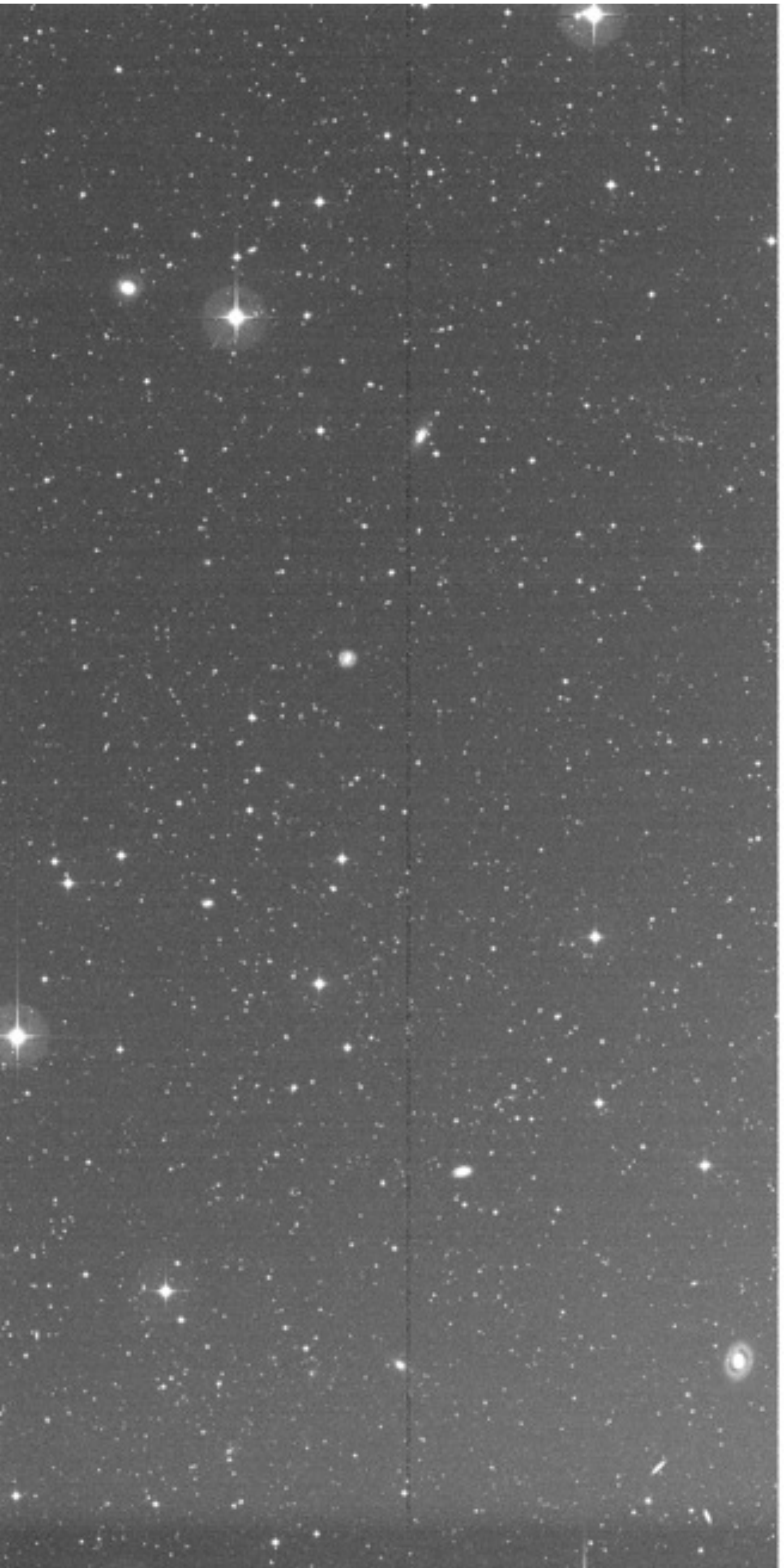
Of these SNe Ia we found:

22 which were 91bg-like,
46 which were 91T-like,
6 SN 2002ic-like,
6 SN 2002cx-like and
5 Super-Ch's.

And a variety of oddballs like PTF09dav, PTF10ops, PTF11kx,…

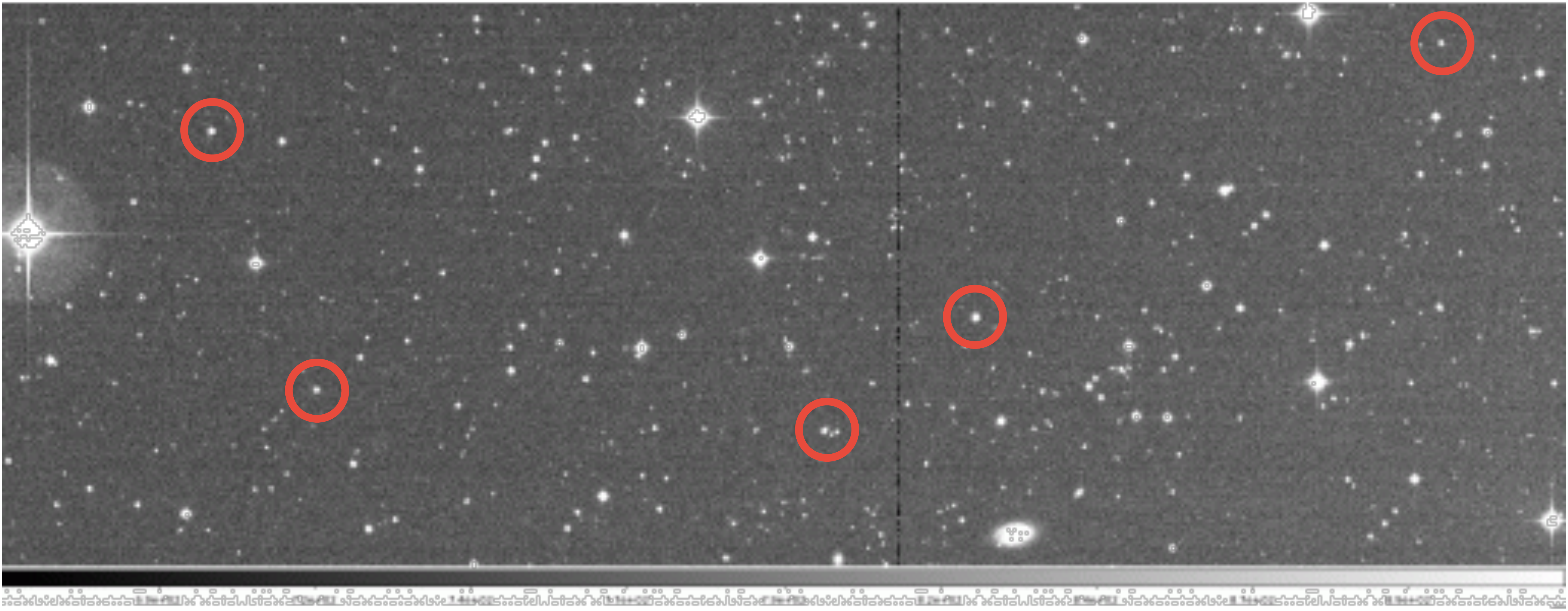


PTF Observation Sample



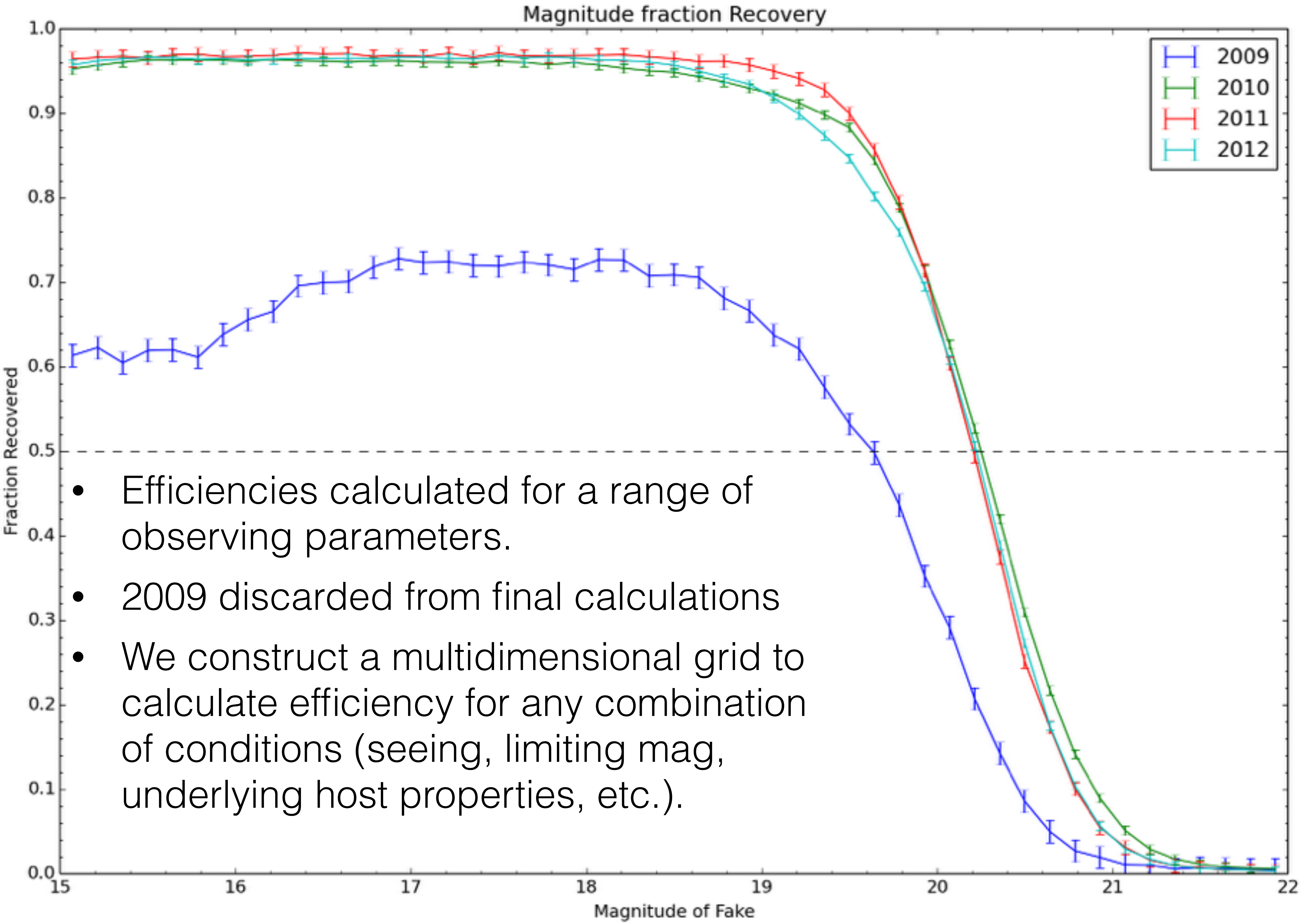
- 13,500 raw images from 2009–2012
- Representative sample of the conditions over the entire survey.
- 60 fakes stars placed in each image
  - 90% in galaxies
  - 10% hostless
- 7,000,000 fake stars added
- Store fake star parameters in PSQL database

Image subtraction and Machine Learning



- Replicate the real-time PTF transient detection pipeline
- Run machine learning on all candidates (Bloom et al. 2012)
- Store candidates in PSQL database
- Compare recovered candidates to fake stars

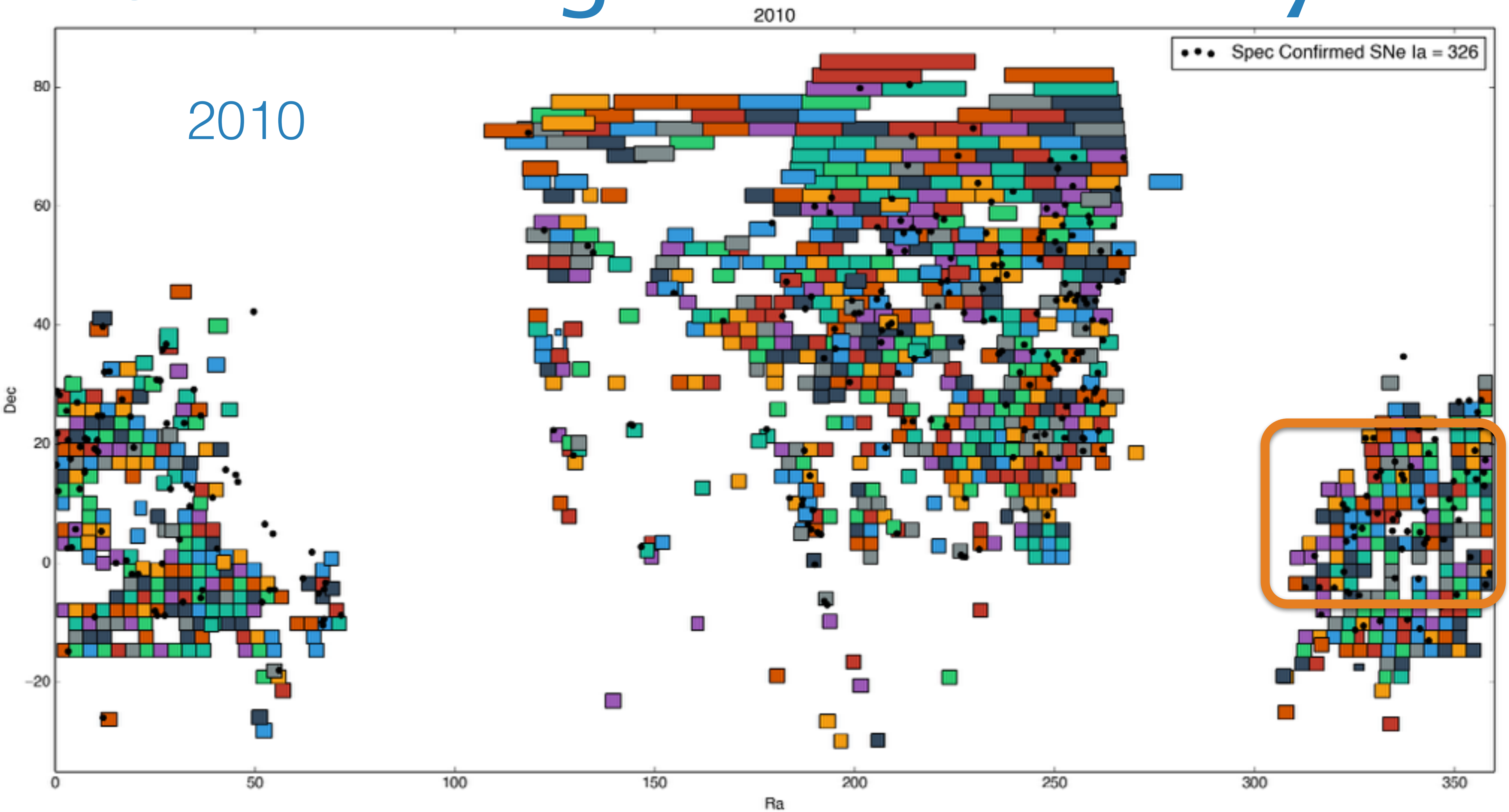
Recovery Efficiencies



- Efficiencies calculated for a range of observing parameters.
- 2009 discarded from final calculations
- We construct a multidimensional grid to calculate efficiency for any combination of conditions (seeing, limiting mag, underlying host properties, etc.).

Simulating the PTF survey

2010



E(B-V)<0.1

326 Spectroscopically confirmed Ia

Simulating Supernovae

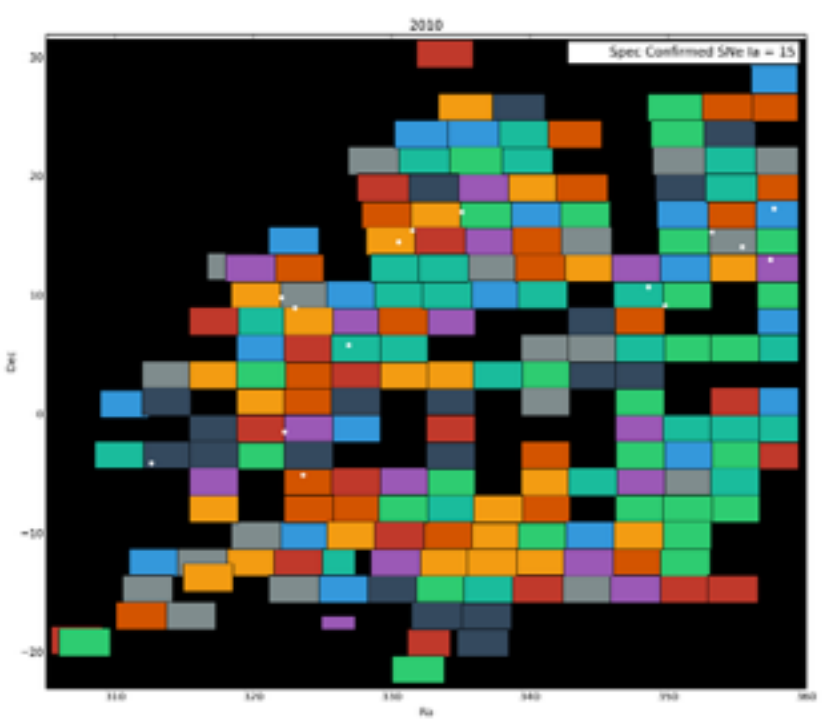
sncosmo
A Python Library for Supernova Cosmology

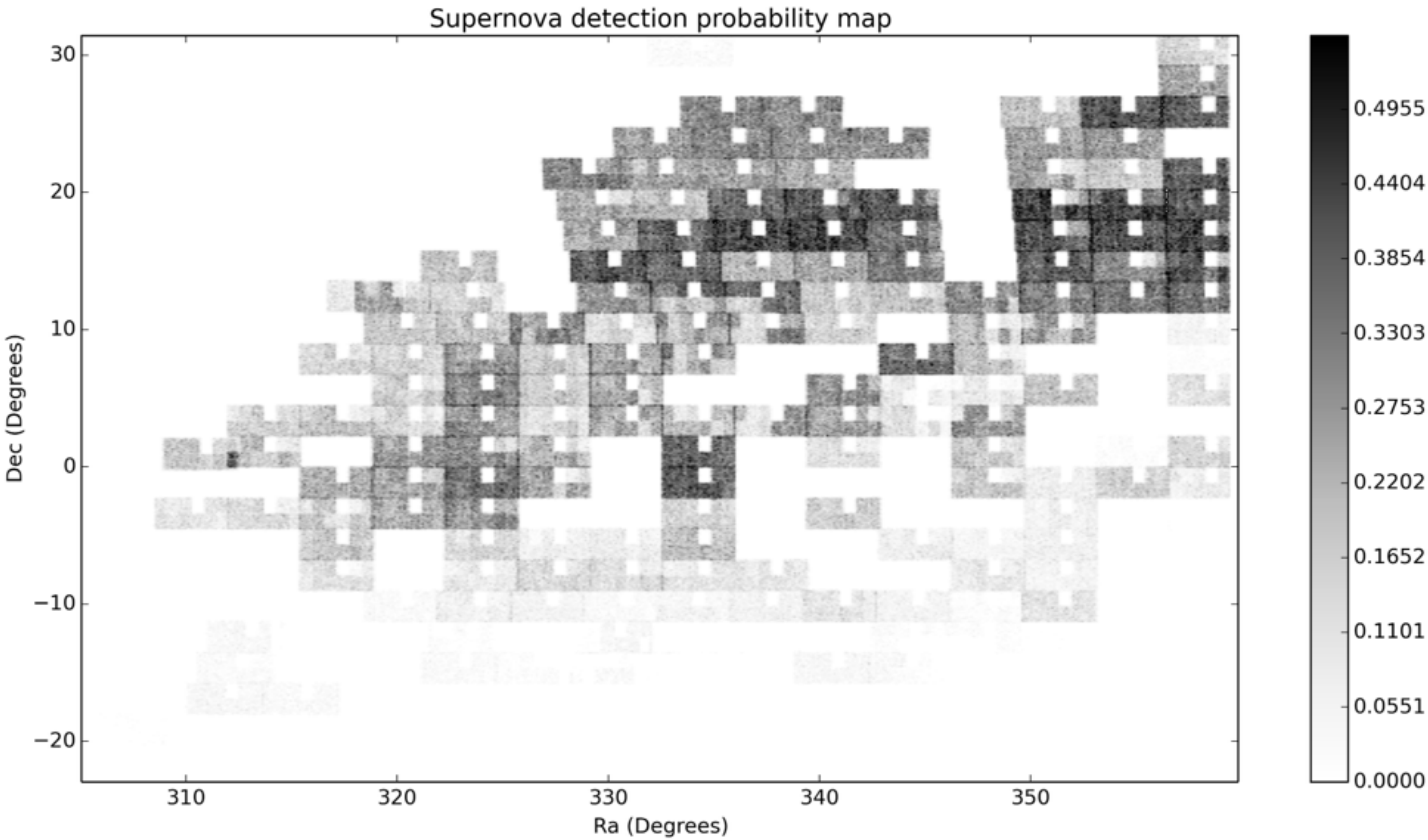
- Use sncosmo python library to generate lightcurves
- Follow a SALT2.4 model
- Parameters from Betoule et al. 2014
- $\alpha = 0.141$
- $\beta = 3.101$
- σ_{int} : Drawn from Gaussian of width 0.15
- x_1: Flat, –3 to 3
- c: Flat, –0.3 to 0.3
- z: Flat, 0 to 0.1

$$M = -19.05 - \alpha x_1 + \beta c + \sigma_{int}$$

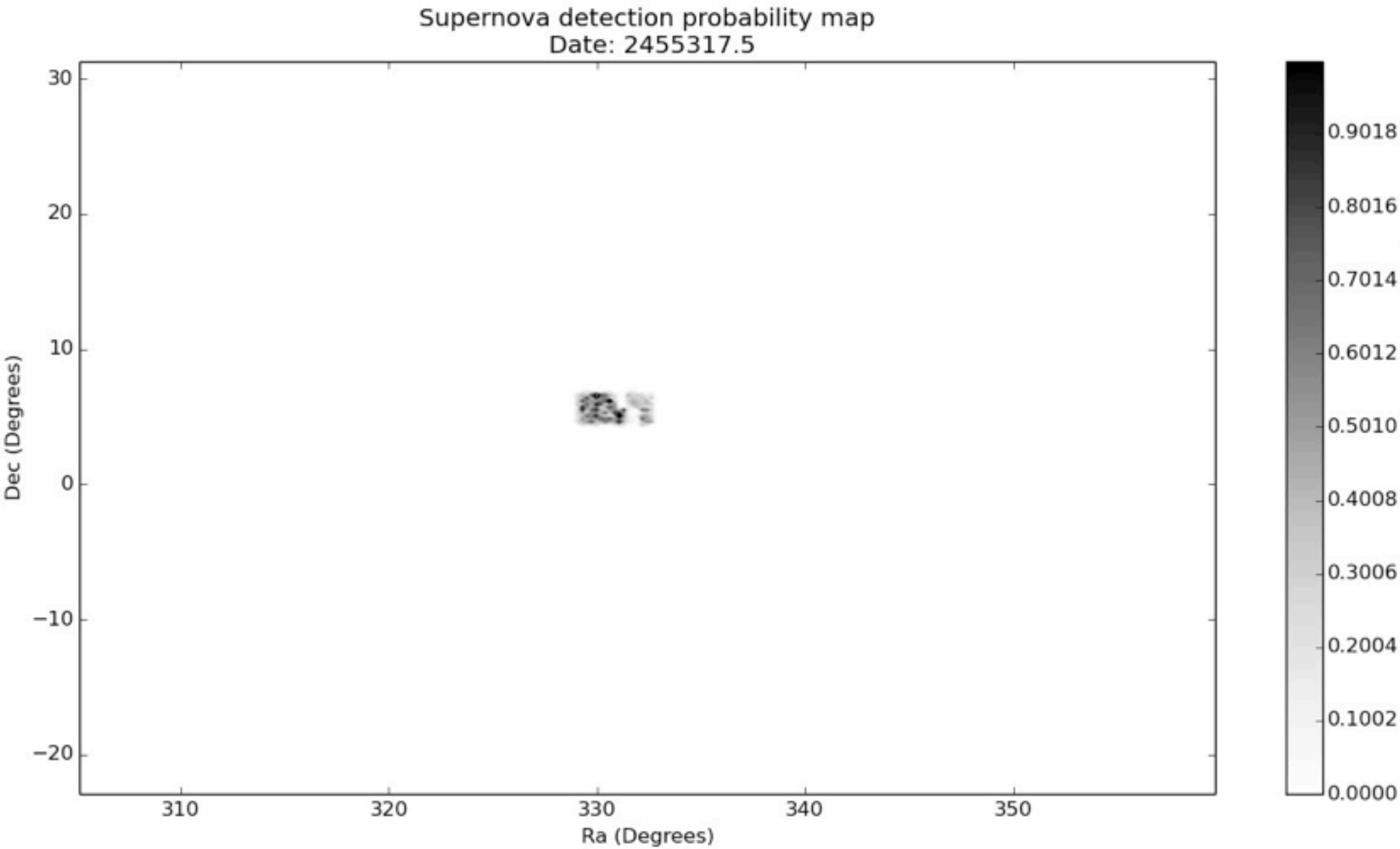
Simulated Lightcurves

- Use Iridis4 supercomputer
- Simulated 104.5 million supernovae
- ~3,000 deg^2 sky
- z<0.12
- Simulate PTF survey between 1 May 2010 and 31st October 2010





Supernova detection probability map
Dec (Degrees)
Ra (Degrees)
30
20
10
0
−10
−20
310
320
330
340
350
0.4955
0.4404
0.3854
0.3303
0.2753
0.2202
0.1652
0.1101
0.0551
0.0000

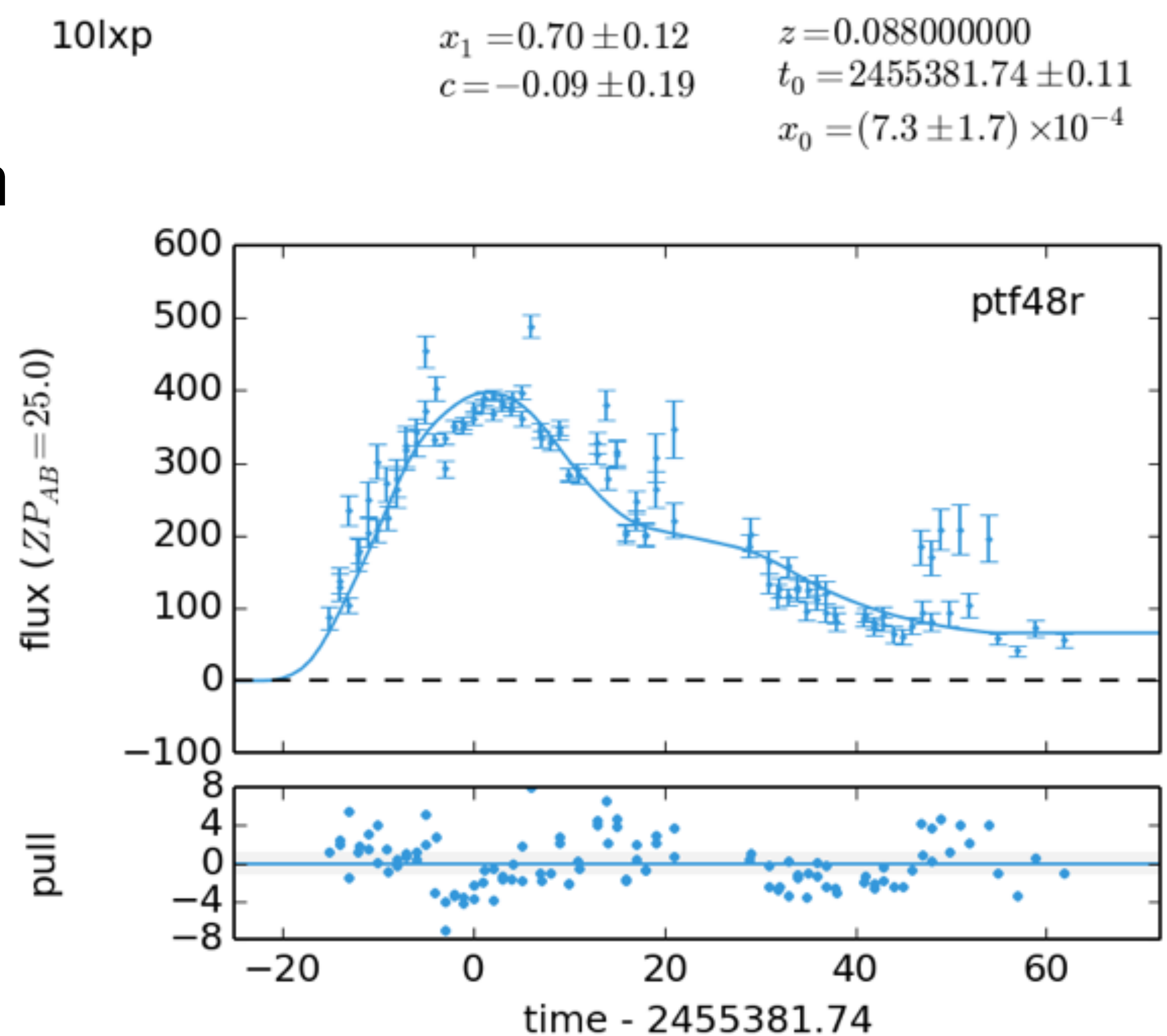


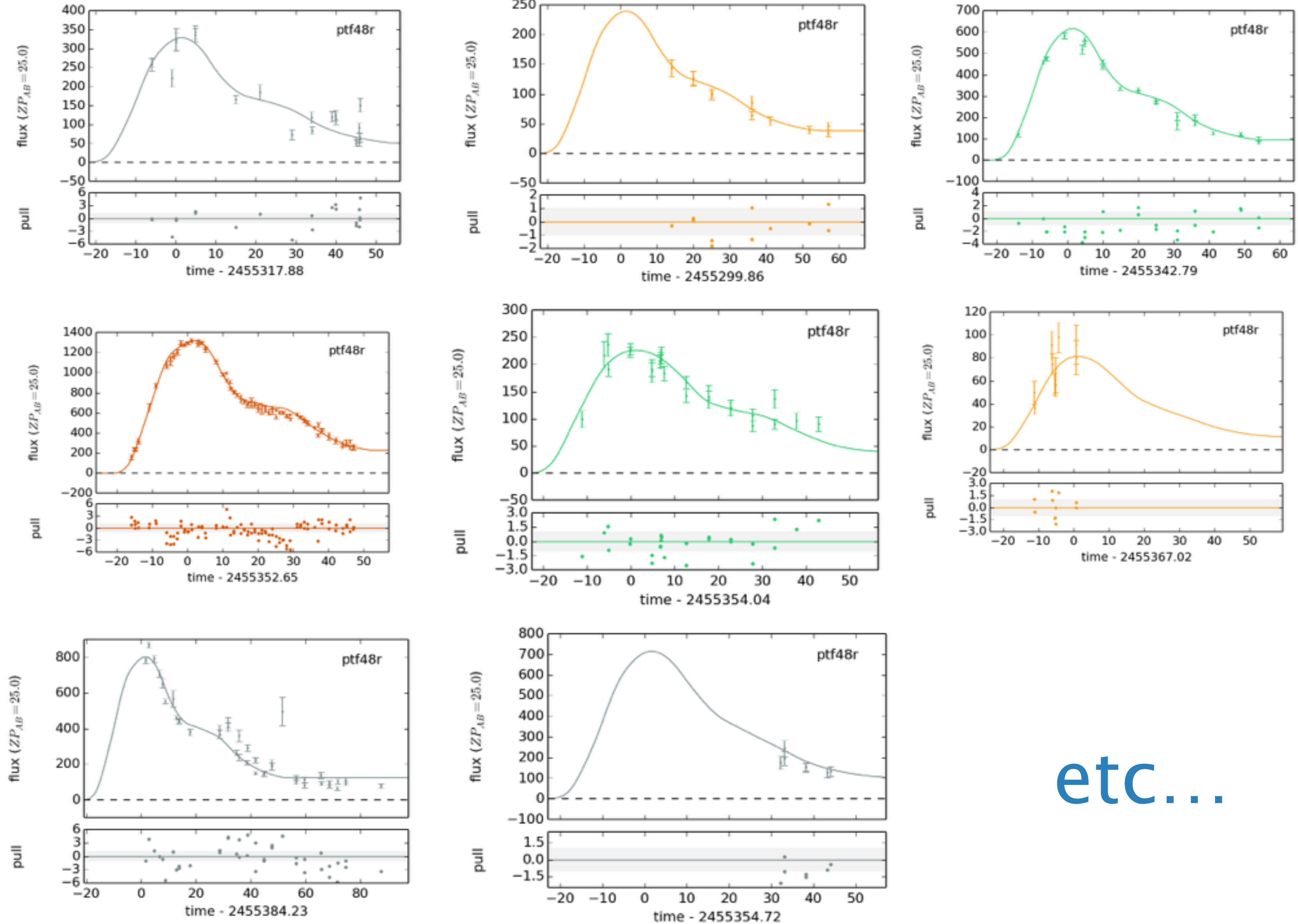
Supernova detection probability map
Date: 2455317.5
Dec (Degrees)
Ra (Degrees)
30
20
10
0
−10
−20
310
320
330
340
350
0.9018
0.8016
0.7014
0.6012
0.5010
0.4008
0.3006
0.2004
0.1002
0.0000

Spectroscopically Confirmed Sample

sncosmo
A Python Library for Supernova Cosmology

- 27 spectroscopically confirmed SNe Ia
- 12 pass redshift and observational cuts with a requirement of 5+ points total separated by 4+ days
- Lightcurves fit with sncosmo
- Fits parameters interpolated on to find efficiency




ptf48r
flux ($ZP_{AB}=25.0$)
pull
time - 2455317.88
time - 2455299.86
time - 2455342.79
time - 2455352.65
time - 2455354.04
time - 2455367.02
time - 2455384.23
time - 2455354.72

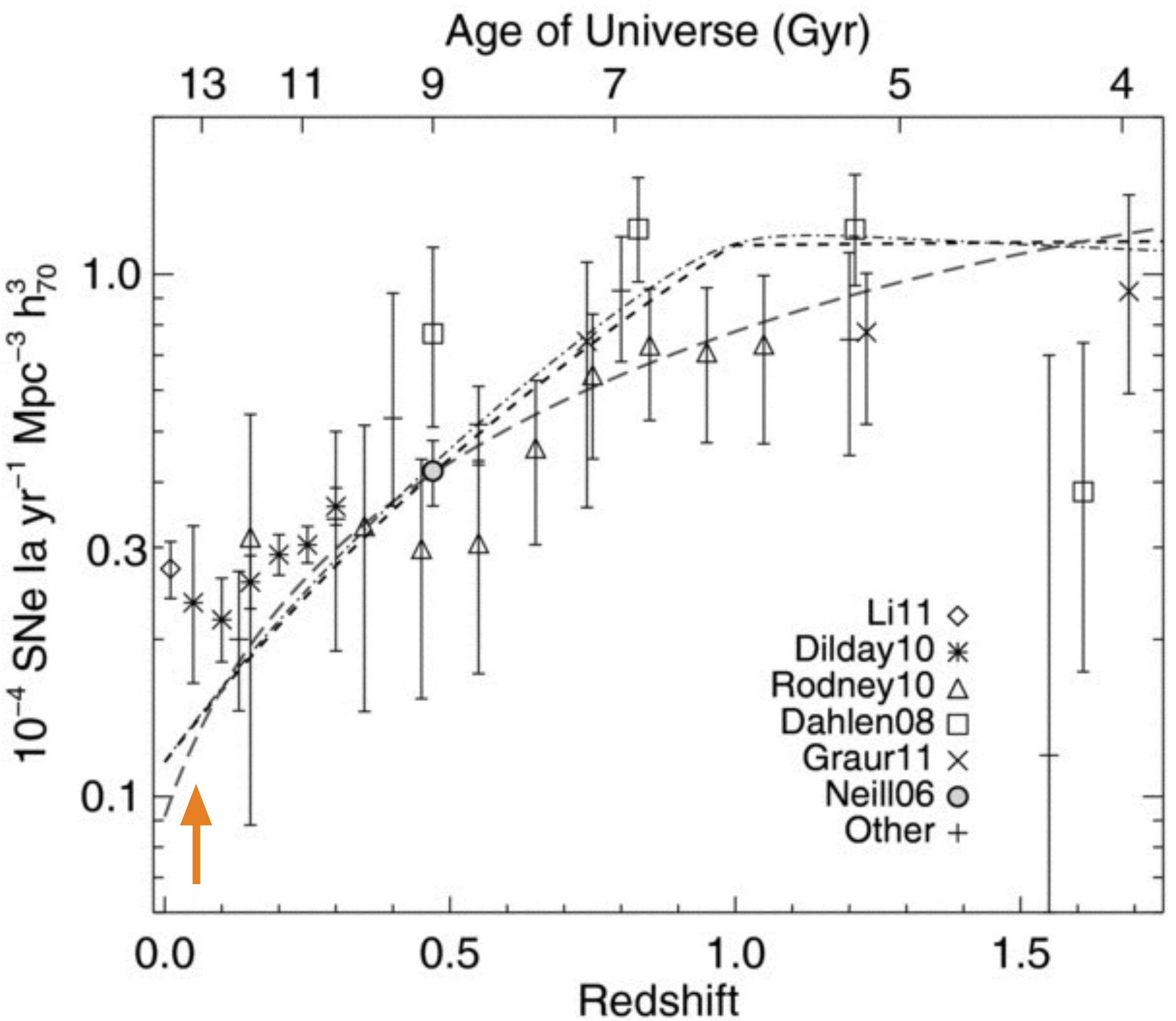
etc...

Preliminary Result

- Simulation finished 19th June

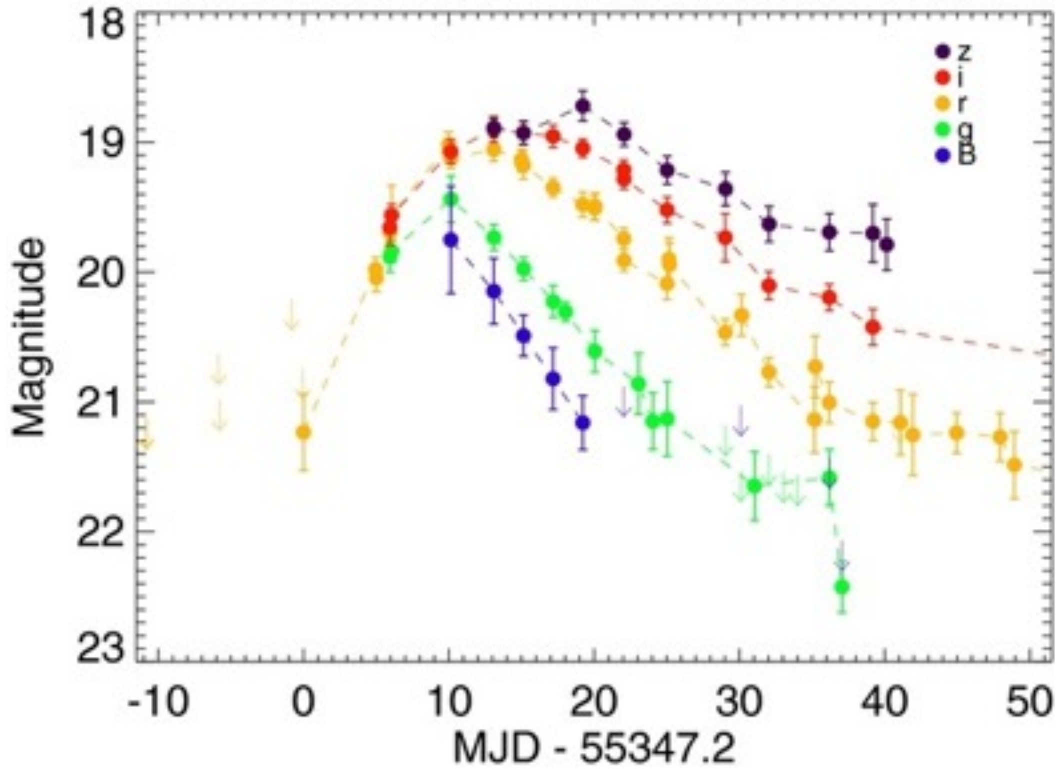
$$1.1 \times 10^{-5} \mathrm{SNe\ Ia\ Mpc}^{-3}\,\mathrm{yr}^{-1}$$

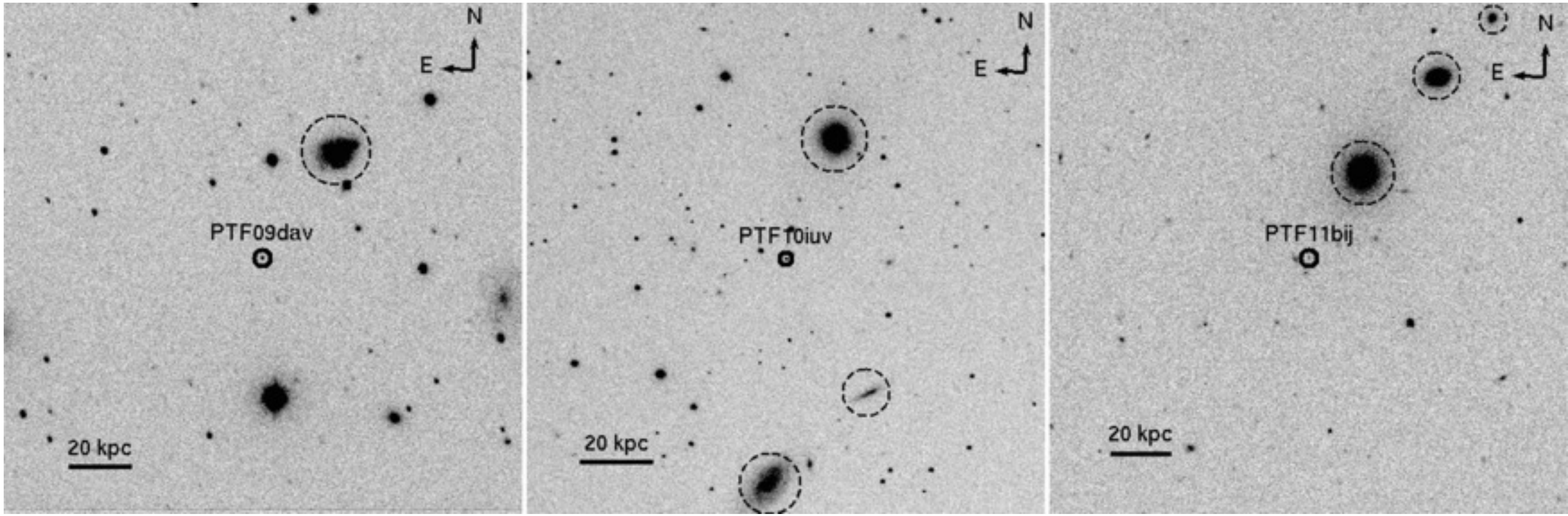
- ~2x lower than other rates
  - Lower limit as this is just a spectroscopic sample (assumes we have missed nothing)
  - Small fraction of our total survey area



Early Applications: Calcium Rich Transients

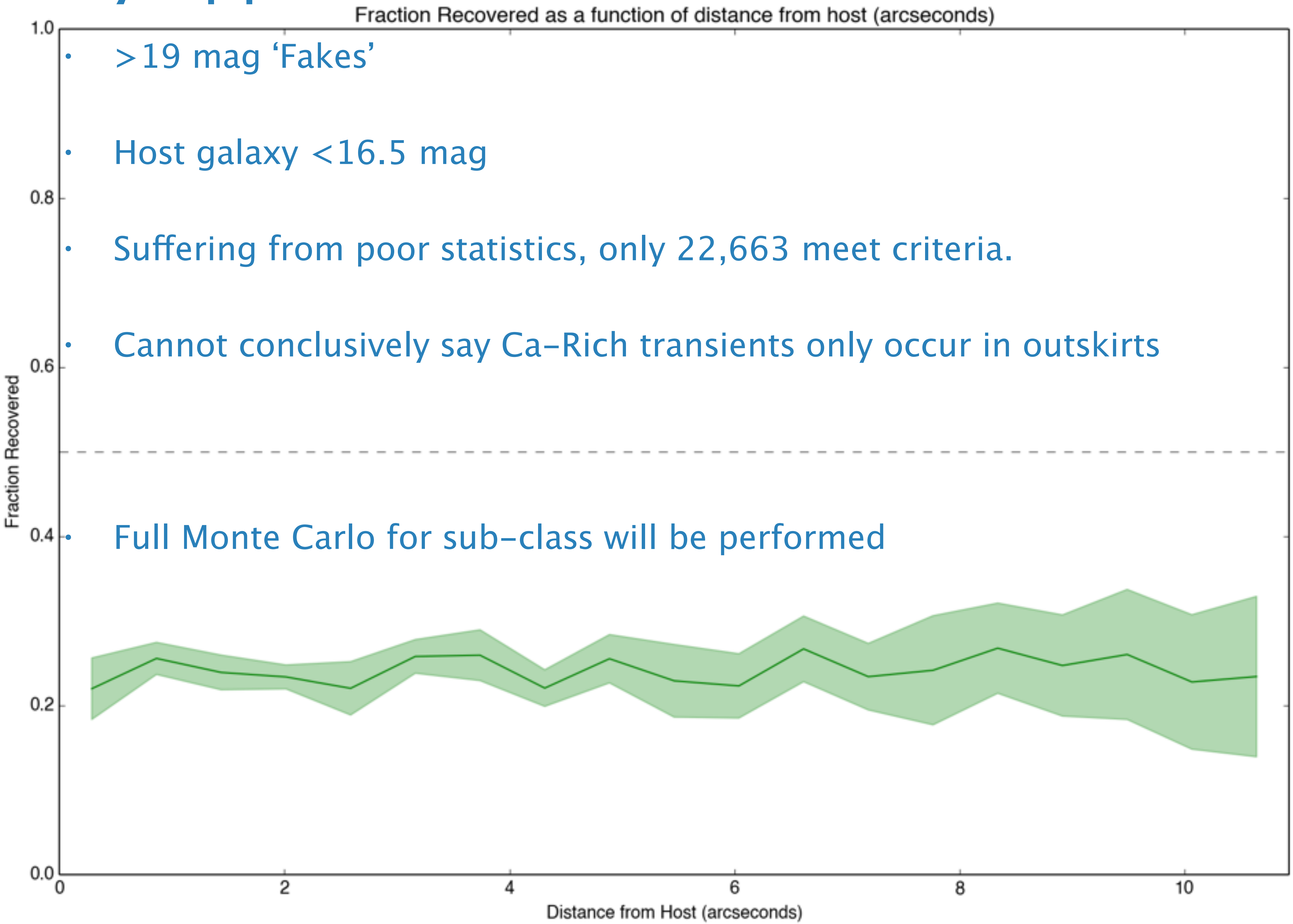
- Nebular spectra dominated by Calcium.
- Rapid rise, t_{rise}~ 12– 15 days
- M_R=–15.5 to –16.5
- Appear offset from their hosts
  - >33kpc
- Kasliwal et al. 2012
- TD around IMBH, Triple system?? (Sell et al. 2015)



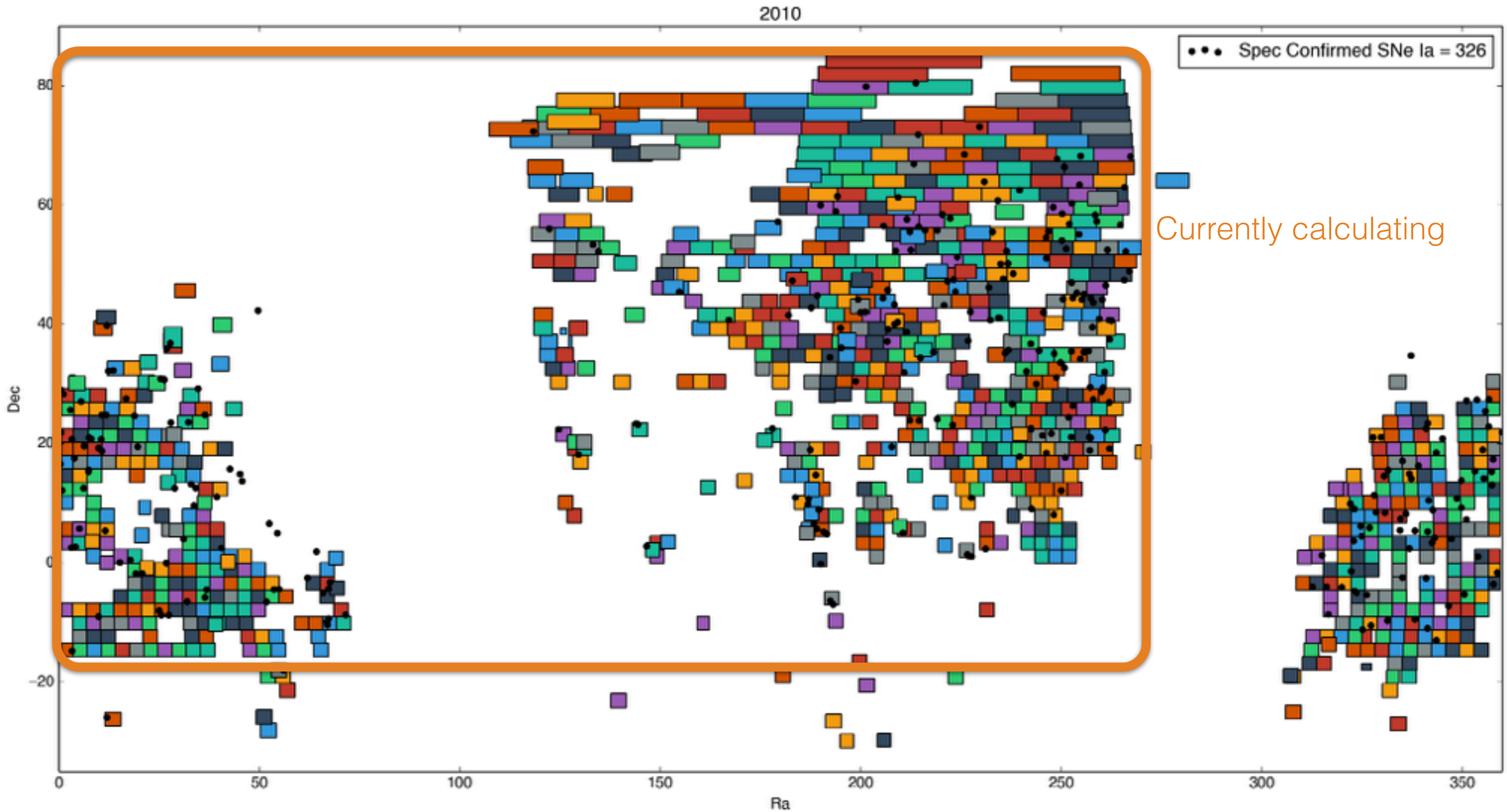


Early Applications: Calcium Rich Transients

- >19 mag ‘Fakes’
- Host galaxy <16.5 mag
- Suffering from poor statistics, only 22,663 meet criteria.
- Cannot conclusively say Ca-Rich transients only occur in outskirts
- Full Monte Carlo for sub-class will be performed



Pushing on…



Next up – the rest of 2010 and then everything else…

Major Challenges…

We found a lot, but…. in several ways we didn't make it easy on ourselves for doing the rates.

- We switched between g & R, but almost rarely on the same fields – thus there are large gaps in each.
- Constantly building new references throughout the year and would typically stay on a field for ~2 month maximum.
- Daily cadence fields had higher priority than 3-5 day cadence fields, thus there were often large gaps in the latter.
- Picked fields near equator, so moon hammered them
- AGN suck…

Criteria Moving Forward

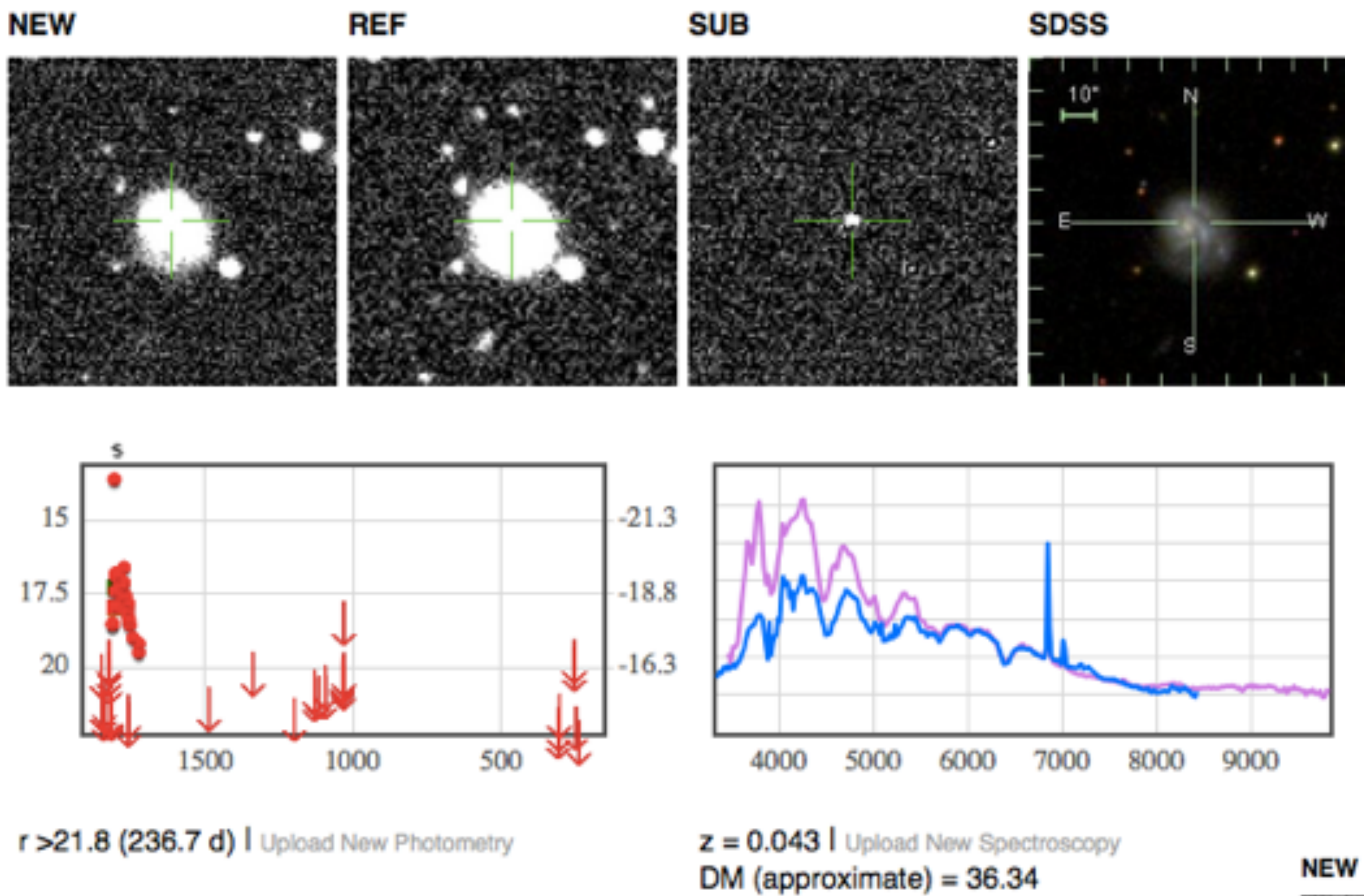
Current criteria (everything will be done through database):

- March 1 2010 - October 31 2010 in SDSS DR10 fields
- 5+ candidates within 3” spread out over 3+ days with a non-detection ahead of first detection and all detection brighter than 20th mag and with a decent real-bogus score.
- No negative detections during this timeframe
- Not within 5” of a known SDSS star (< 19th mag)

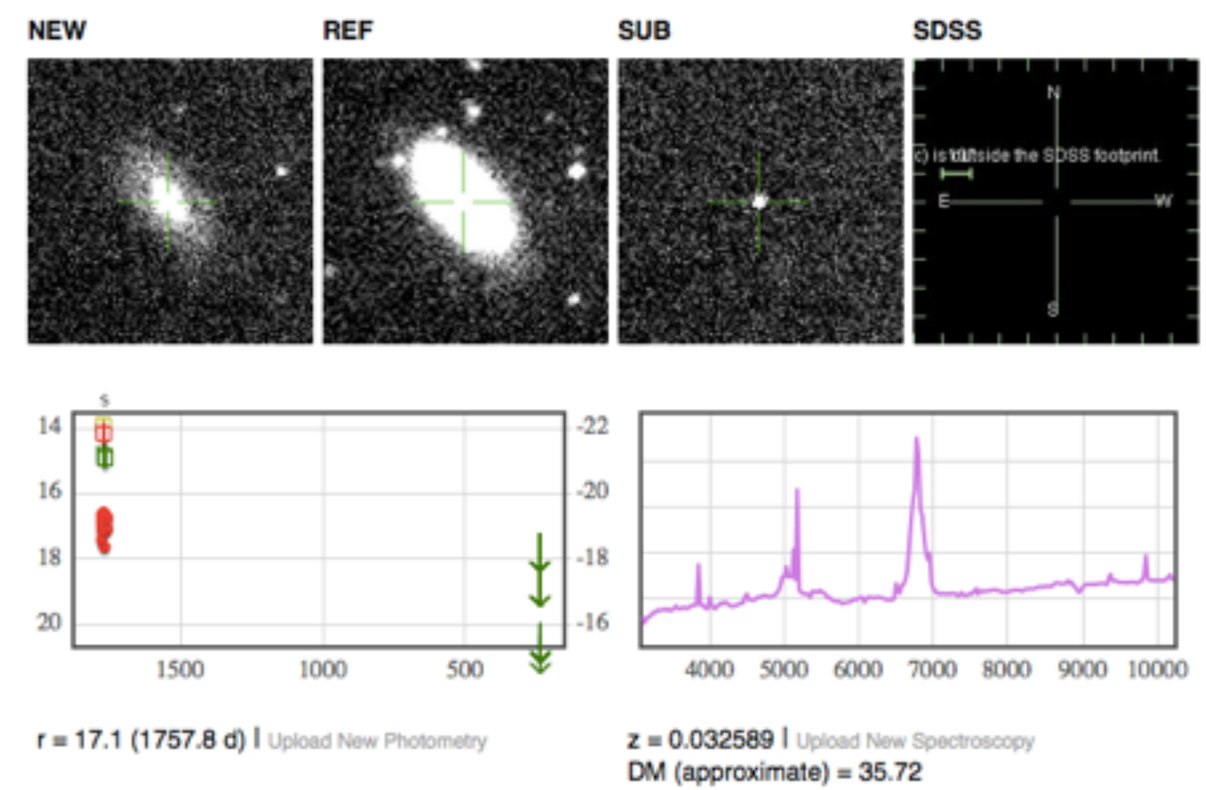
246,765,552 detections get whittled down to 15k potential SN candidates we “missed”.

501 SNe Ia in all of 2010 get trimmed down to 97 which pass cuts.

AGN suck…



Nice SN Ia – too close to host center…which happens to be active.



Lovely AGN which we happened to build a reference for during a quiescent phase…

Question:

What should we calculate next (02ic, 02cx, etc.) ?