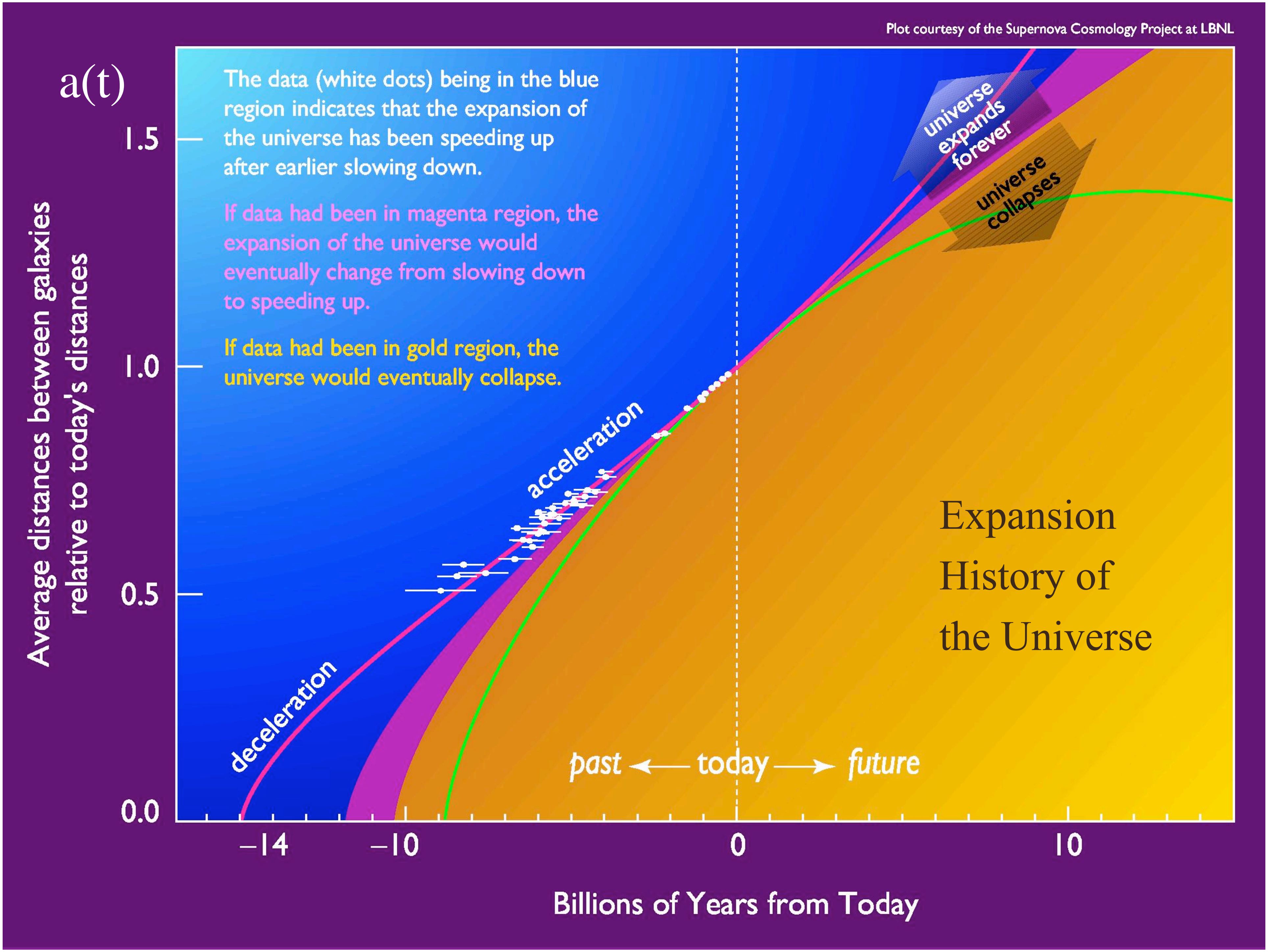
SDSS II Supernova Survey

- The SN Program: goals and plans
- Progress since the NSF proposal was submitted (6/04)
- Synopsis of remaining development work



Plot courtesy of the Supernova Cosmology Project at LBNL
a(t)
The data (white dots) being in the blue region indicates that the expansion of the universe has been speeding up after earlier slowing down.
If data had been in magenta region, the expansion of the universe would eventually change from slowing down to speeding up.
If data had been in gold region, the universe would eventually collapse.
universe expands forever
universe collapses
acceleration
deceleration
Expansion History of the Universe
past ← today → future
1.5
1.0
0.5
0.0
−14
−10
0
10
Average distances between galaxies relative to today's distances
Billions of Years from Today

Dark Energy and the Accelerating Universe

Brightness of distant Type Ia supernovae, along with CMB and galaxy clustering data, indicates the expansion of the Universe is accelerating, not decelerating.

This requires *either* a new form of stress-energy with negative effective pressure *or* a breakdown of General Relativity at large distances:

DARK ENERGY

Characterize by its effective equation of state: $w = p/\rho$

and its relative contribution to the present density of the Universe: Ω_{DE}

Special case: cosmological constant: $w = -1$

Type Ia Supernovae & Cosmology

Advantages:

- small dispersion in peak brightness (standard candles)
- single objects (simpler than galaxies)
- can be observed over wide redshift range (bright)

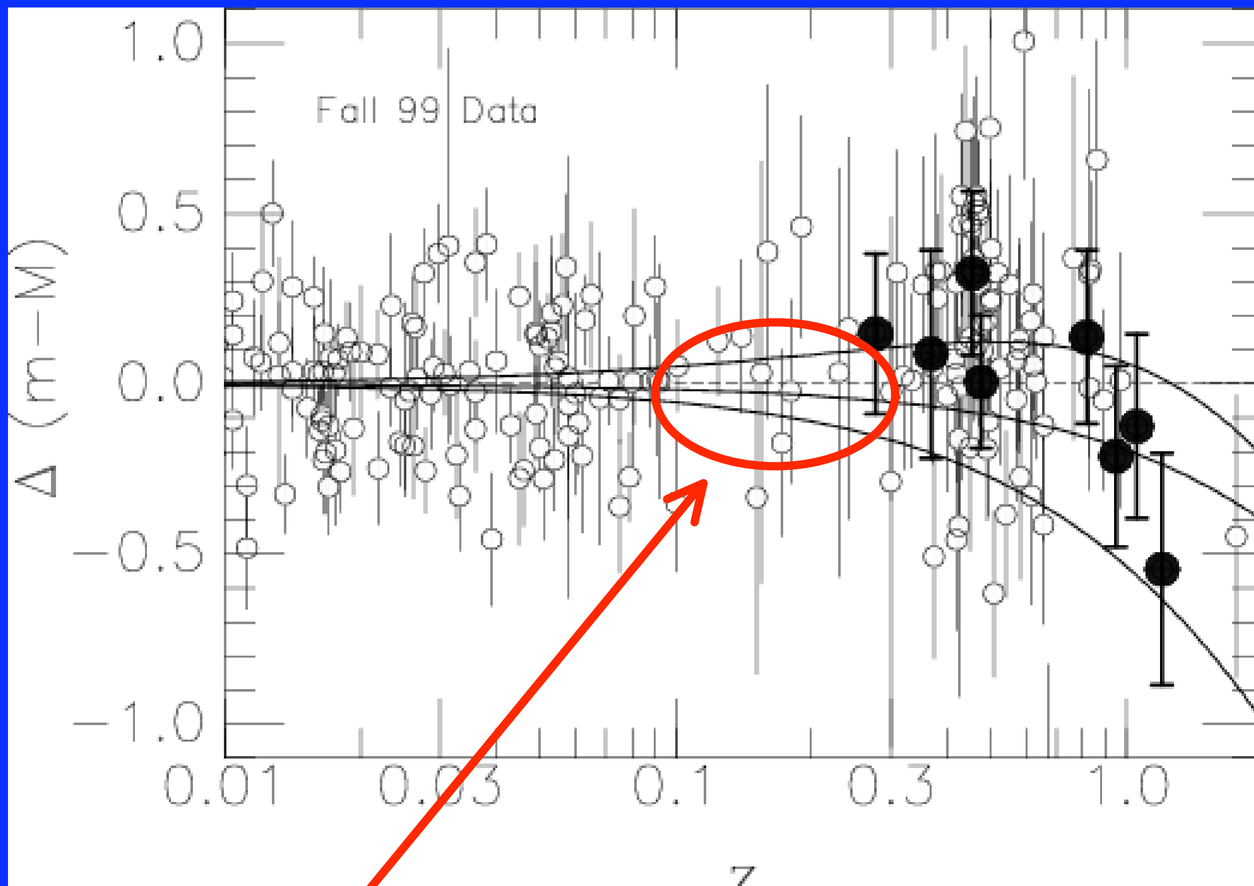
Challenges/Systematic concerns:

- dust extinction in host galaxy
- chemical composition variations/evolution
- evolution of progenitor population
- photometric calibration
- Malmquist bias
- environmental differences
- K correction uncertainties

Need new SN surveys for statistics and systematics

Compiled Supernovae Ia Sample

Brightness relative to empty Universe: ($\Omega_m = \Omega_\Lambda = 0$)



Ω_m Ω_Λ

0.3, 0.7

0.3, 0.0

1.0, 0.0

`Gold' sample of 157 SNe included only 6 between z = 0.1-0.3; SDSS naturally fills this gap

Tonry etal '03
Riess etal '04

Science Goals

- Measure ~200 *high-quality,* multi-band, densely sampled SN Ia light-curves in the redshift desert z = 0.05 – 0.35: continuous Hubble diagram from low to high redshift
- Probe Dark Energy in z regime less sensitive to evolution and more orthogonal to CMB and LSS constraints than deeper surveys, produce data that complements/strengthens deeper surveys
- Study SN Ia systematics (critical for SN cosmology) with high photometric accuracy and large statistical sample
- Search for additional parameters to reduce SN Ia dispersion
- Determine SN/SF rates/properties vs. z, environment
- Rest-frame u-band SN Ia templates for z >1 surveys
- Database of rare SN light-curves: 5-band photometry, large survey volume allow color selection of unusual type II, Ibc, etc., for further study

SDSS SN Program: 2.5m Imaging

- Repeat *ugriz* imaging of ~2.5°x100° deg. region along celestial equator (SDSS stripe 82) for three 3-month runs (Sep-Nov. 05-'07)
- Alternate every other night between strips 82N and 82S → dense sampling, early detection: high-quality light-curves
- Why stripe 82?
  - repeated imaging in SDSS I → veto catalog of variables; more accurate photometry for calibration; deeper template
  - Use Fall months: complement Legacy+SEGUE
- Frame subtraction in SDSS *gri* → SN Ia selection in 24 hrs
- Rapid release of candidates and data: enable other time domain studies

SDSS SN Program: Spectroscopy

- Rationale: SN typing, redshift, multi-epoch spectrophotometry for improved K-corrections

- Resources (per year):

  ARC 3.5m: will request ~40 half-nights from ARC institutions

  HET 9.2m: ~50 hours (queue) committed from Stanford KIPAC, additional expected from Texas, Penn State

  MDM 2.4m: 30 nights committed from Ohio State (w/ new high-throughput spectrograph)

  Subaru: JPG collaborators submitting proposal

  ESO: Portsmouth leading European proposal for large program on VLT, NTT

  Monte Carlo simulation indicates committed resources adequate for up to 4 epochs of spectroscopy at g' < 22

OSU Supernova Spectrograph for MDM

- Currently, SN K-corrections rely on interpolating and `warping' a small number of nearby SN spectra to match observed colors --> distance uncertainties
- Goal: multi-epoch spectrophotometry to g'~22
- R~300, sufficient to resolve & study SN features
- Better than 5% relative spectrophotometric accuracy over at least 400-800 nm
- Single-chip instrument with high throughput (~50%)
- Undergoing final design

SDSS SN Program: Follow-up Imaging

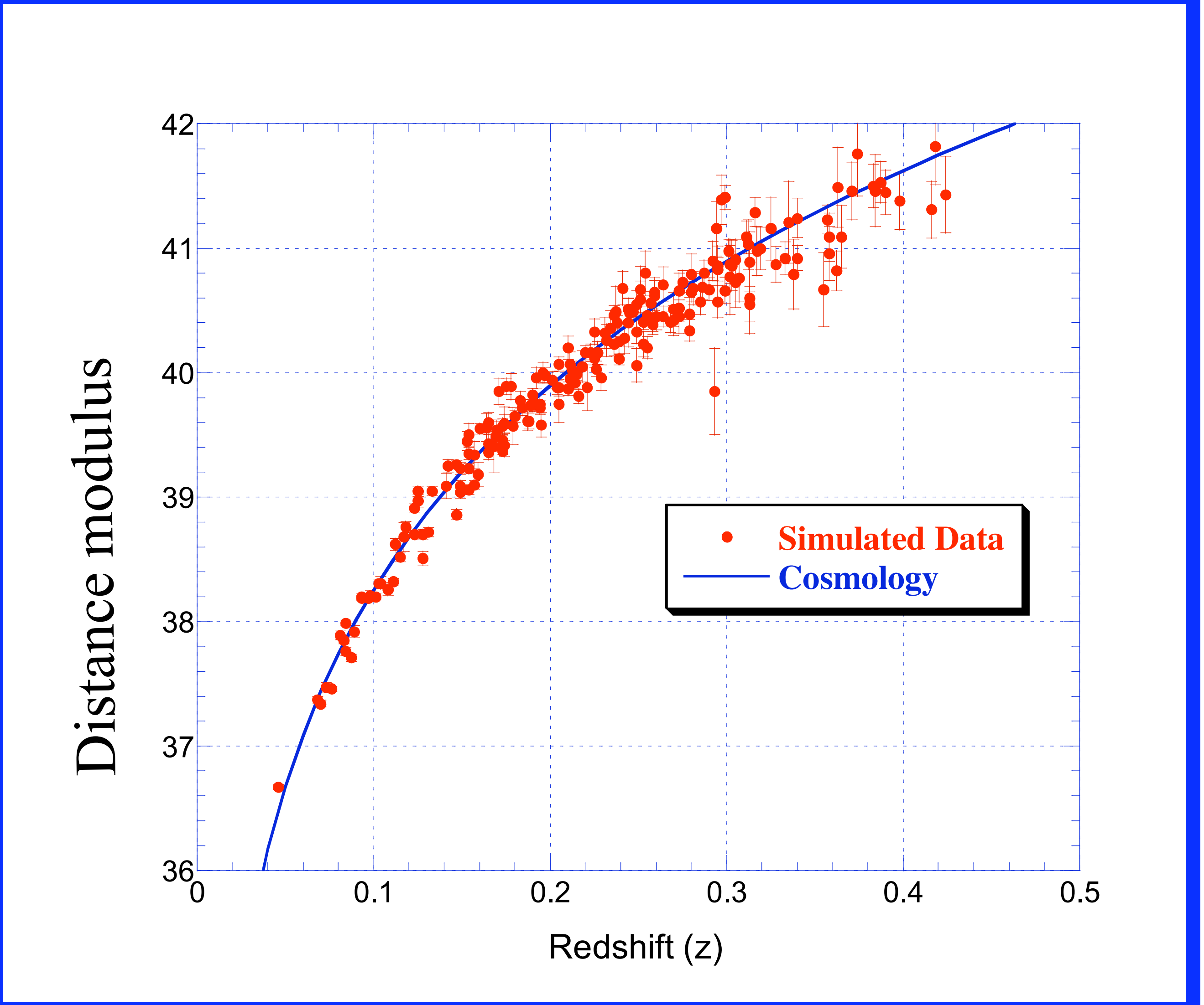
- NIR imaging: extinction/reddening and lightcurves
- Optical imaging: fill in/out lightcurves as needed (weather, dimming, end of season)

- Resources:
- NIR imaging: Carnegie Supernova Project at LCO:
  - z<0.2: NIR lightcurves YJHK (1-m, 2.5-m)
  - z>0.2: NIR coverage near peak YJ (6.5-m)
  - Europeans also exploring Calar Alto
- Optical imaging: NMSU 1m robotic (gri)
  - ARC 3.5m (SDSS bands)
  - ESO proposal to follow higher-z sample

Monte Carlo Data

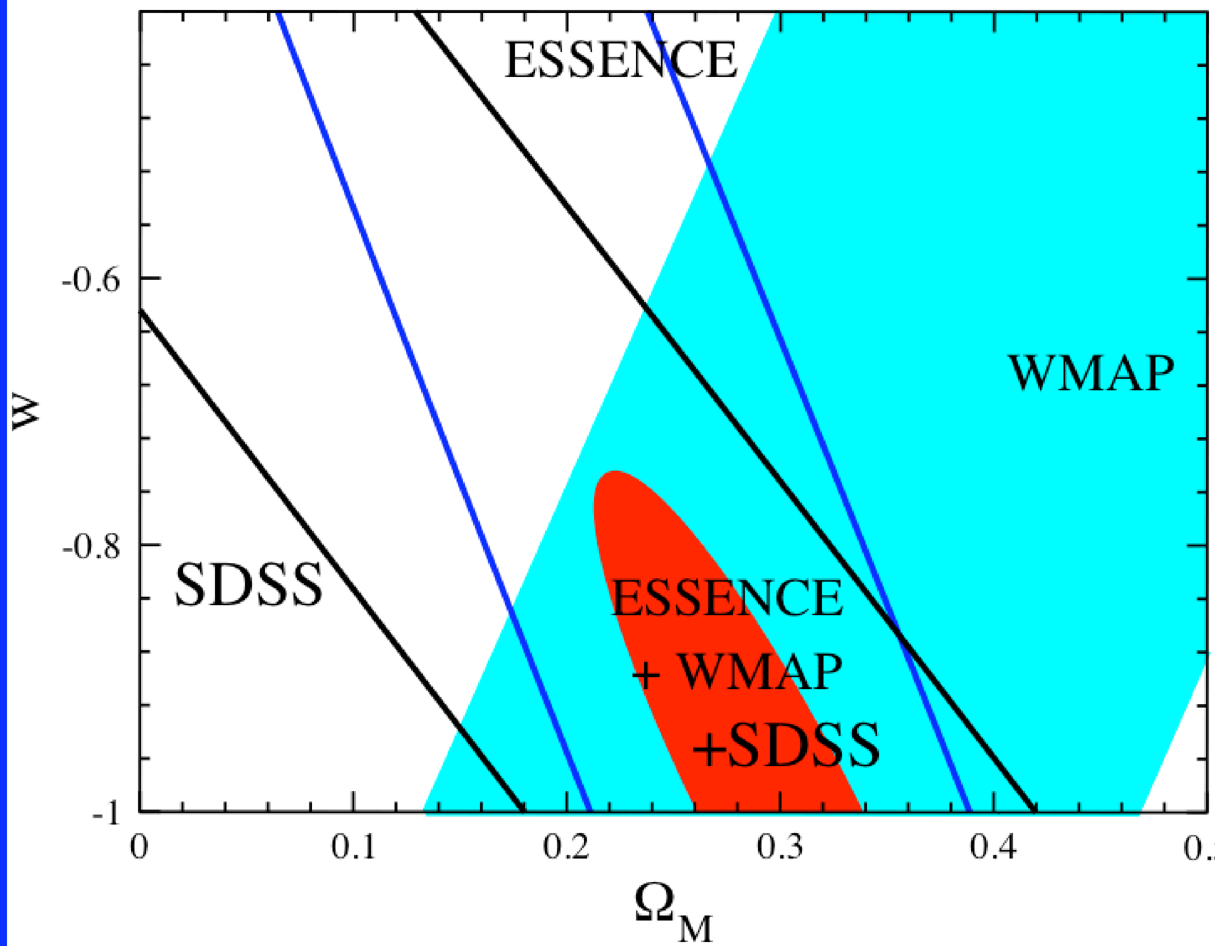
Simulated redshift distribution and photometric errors for completed SDSS SN sample (here assumed Ω_Λ=0.7=1–Ω_m H_0=72)

Note: moony & non-photometric data modeled; needed for survey efficiency



Forecast Cosmological Constraints

Combining SDSS and ESSENCE leads to improved constraints, due to broader redshift leverage.



$\sigma(w)$ = 0.16 from SDSS+WMAP+LSS

= 0.10 from SDSS+ESSENCE+WMAP+LSS

(statistical errors only, constant w, flat Universe)

Data Quality and Control of Systematics

- Current cosmological constraints from SNe are systematics-limited
- Need high data quality to control systematics:
- Uniformly calibrated, well-characterized photometric system on a single instrument whose response is regularly monitored
- Multi-wavelength optical and NIR imaging (control extinction/reddening)
- Densely sampled and early lightcurves for improved LC fitting
- Follow-up spectroscopy and multi-epoch spectrophotometry for improved K-corrections

Fall 2004: Early Science & Test Run

- Imaging: 20 nights of SDSS 2.5m scheduled every other night late Sept.-mid Nov., covered half the survey area (82N): 11 nights were useable (including moony & non-photometric nights)
- Follow-up spectroscopy: ARC 3.5m, HET 9.2m
- Follow-up imaging (during/after run): NMSU 1m, ARC 3.5m
- Science Goal: ~10 well-measured SN Ia light-curves with confirmed spectroscopic types and redshifts.
- Yield: 16 confirmed Ia's: $0.05<z<0.32$ with $\langle z \rangle = 0.15$,

  5 Type II, 1 luminous Type Ic; 8 Ia's found before peak
- Engineering goals met:
- Rapid processing and selection of candidates on-mountain using prototype compute cluster
- Coordinated follow-up observations
- Study detection efficiency and photometric accuracy under varying conditions

SN Data Processing Software

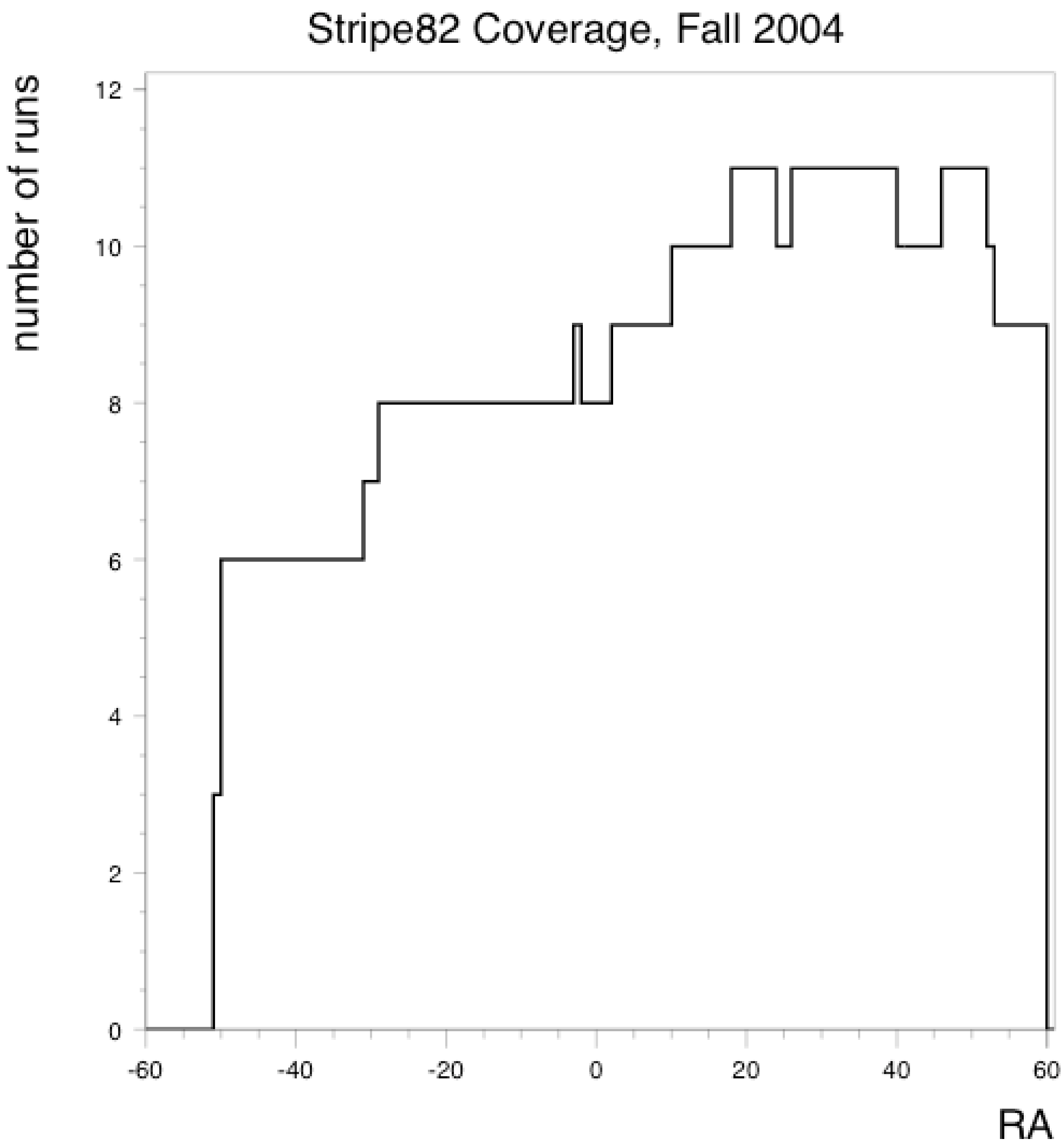
- Spool data from tape to SN compute cluster disk
- PHOTO through corrected frames
- Frame subtraction (modified version of code developed for ESSENCE):
  - match (position and PSF) and scale to template image, subtract, identify objects in subtracted image
- Candidates database (hosted at FNAL):
  - positional match of *g,r* candidates to veto asteroids
  - veto stars and variables, bright star masks, from previous catalogs
  - match objects over nights
  - store photo-z for host galaxy, if available from catalogs
- GUI for human inspection/selection of candidates for follow-up (ds9, www)
  - results stored in database
- Generate finding charts
- Candidate info. displayed dynamically on web, including spectroscopic follow-up
- Final photometry pipeline (off-line): aperture, PSF
- All imaging processing scripted

SN Data Processing Hardware

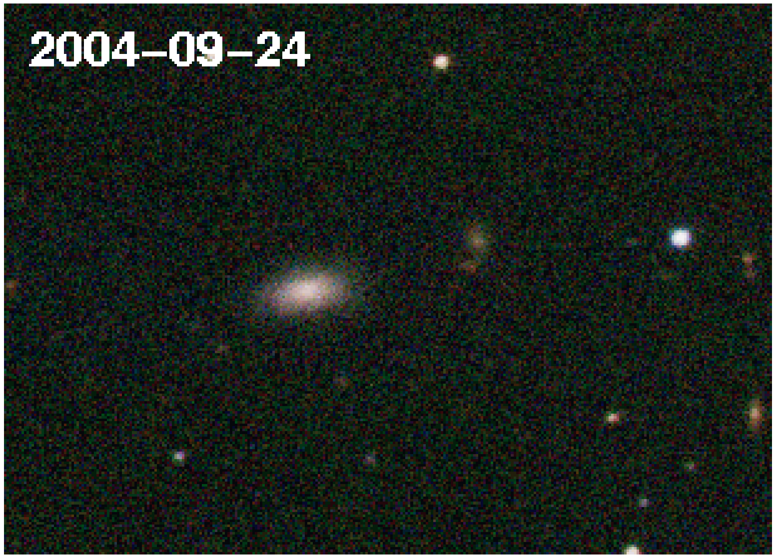
- Fall 2004: Compute cluster configured at FNAL using decommissioned machines, then shipped to APO: 7 dual processors (1 for each camera column + database server), ~7 Tb disk, and 8 tape drives.
- Processed full nights of imaging data through *gr* frame subtraction in ~48 hours
- Main concern: hardware and network stability (having at least one team member on-shift at APO + APO sysadmin support was critical)
- SDSS II: upgrade to ~10 faster dual processors: process *gri* in 24 hours. Benchmark testing underway this month at FNAL.

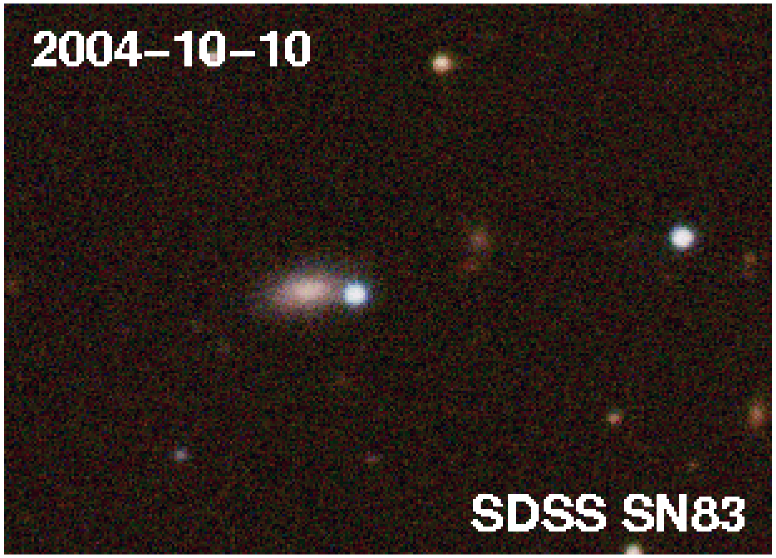
Fall 2004 Campaign: Follow-up

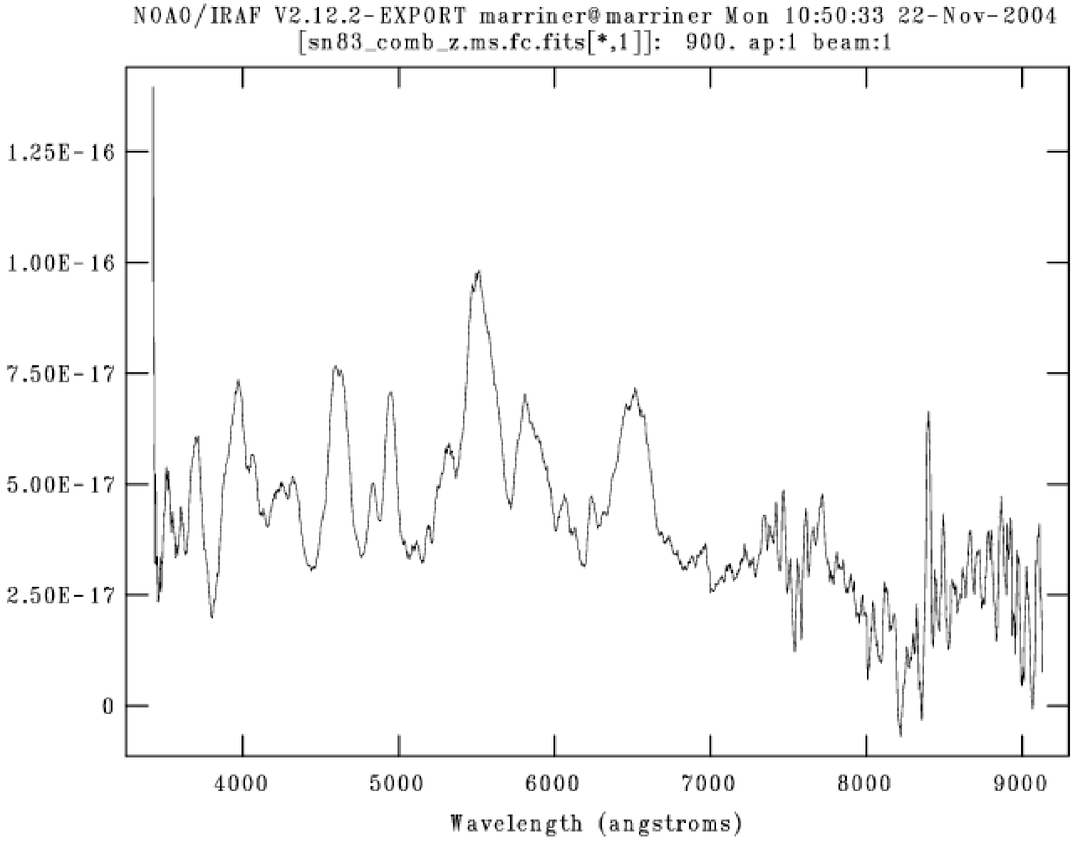
- Spectroscopy:
- 15 half-nights scheduled ARC 3.5m (UC) + 3 half-nights (PU) for host spectra
- 11+12.5 hours allocated (queue-scheduled) on HET (Stanford time)
- 23 SNe confirmed; 12 additional objects observed but not typed
- 1 object followed up by SNF
- NIR imaging:
- 4 hours scheduled on Liverpool Telescope (2m robotic), data not taken
- Optical imaging (fill in/out lightcurves since the run was short):
- 4 half-nights scheduled ARC 3.5m (UW)
- multiple targets repeatedly observed on NMSU 1m


Stripe82 Coverage, Fall 2004
number of runs
12
10
8
6
4
2
0
-60
-40
-20
0
20
40
60
RA

sn2004ie



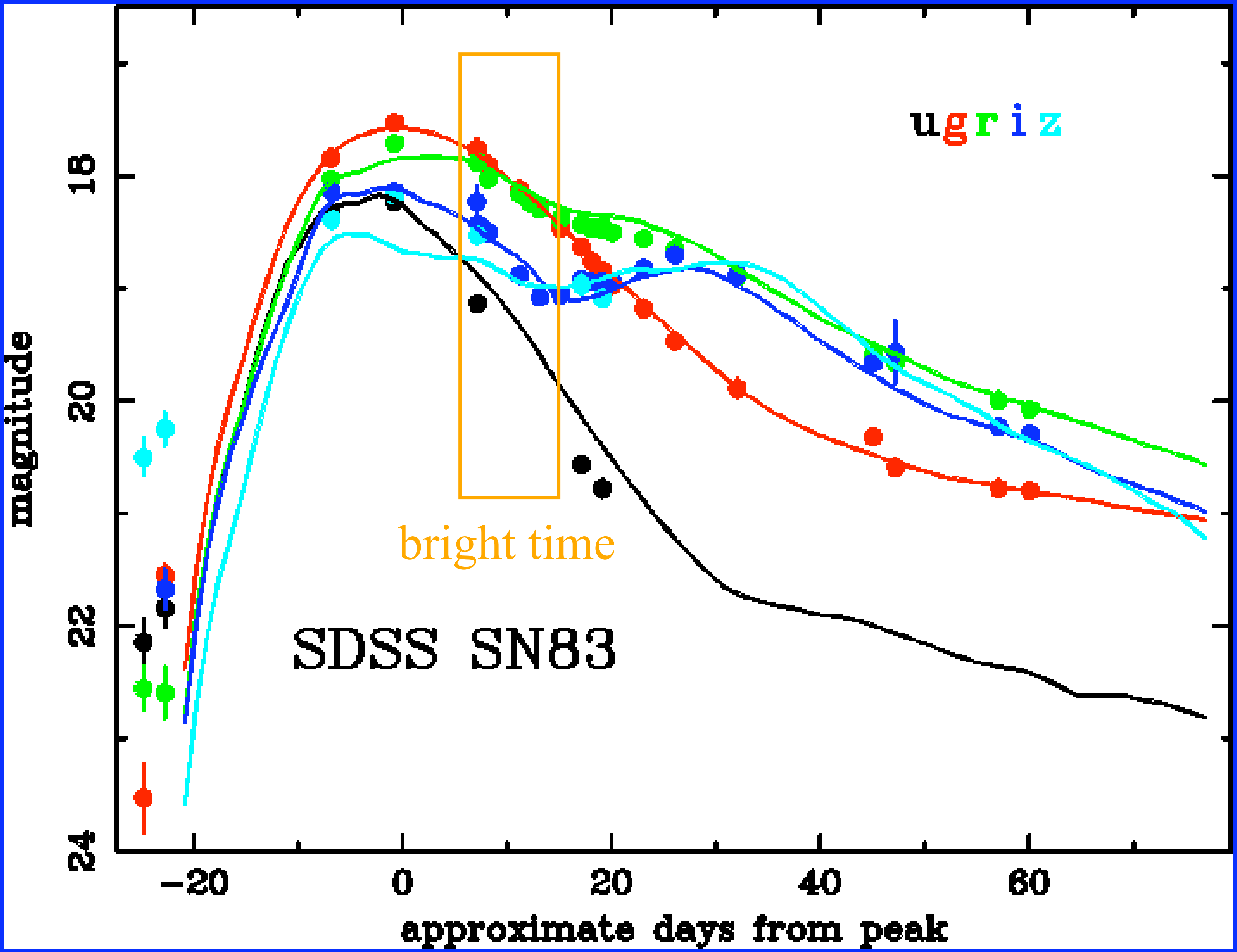




SN Ia z=0.0513

3 epochs of ARC spectroscopy

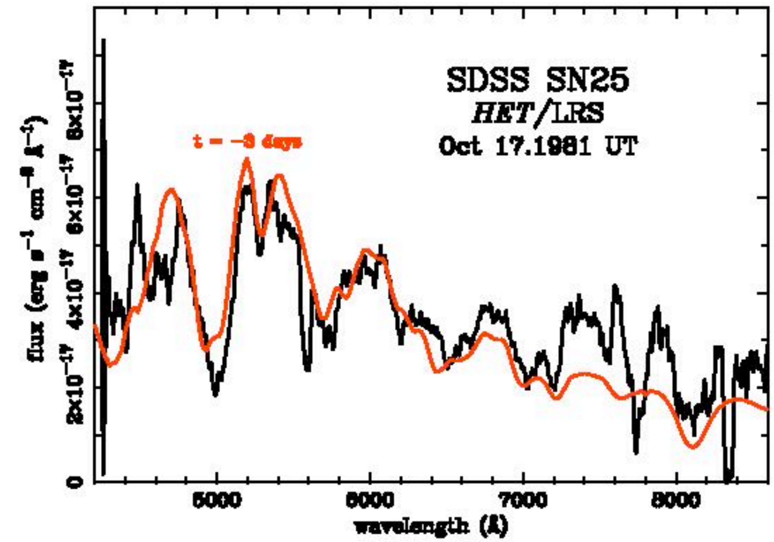
2004ie: Observed vs. Synthetic Light-curves (very preliminary)

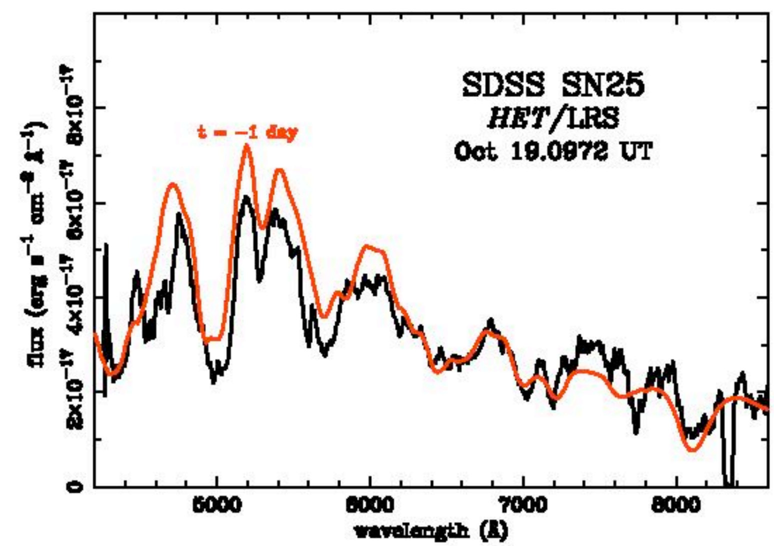


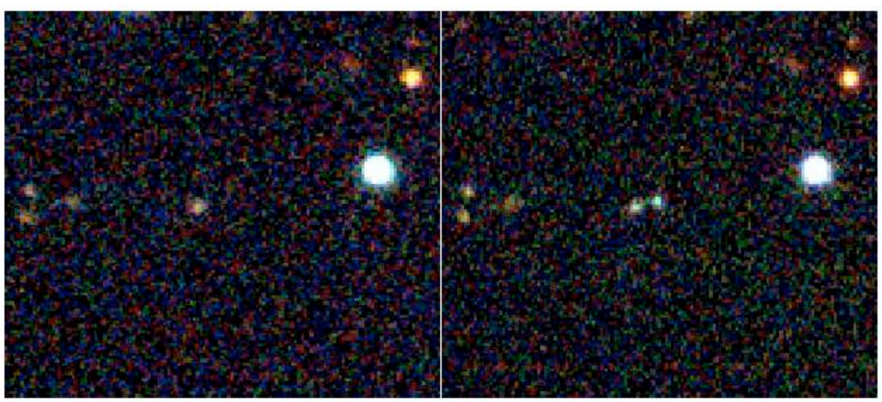
SN25

sn2004if

- Highest redshift Ia from this sample:
  z=0.32
- Luminous Ia: $M_r \sim -20$
- Cross-correlation analysis yields best-fit Ia spectral templates separated by 2 days, in excellent agreement with data



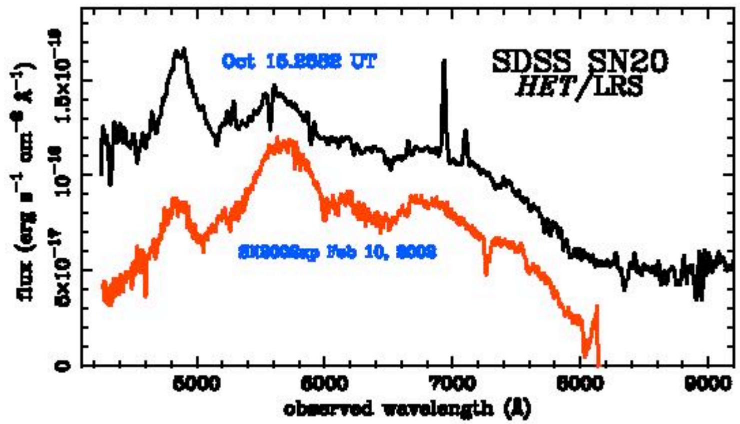


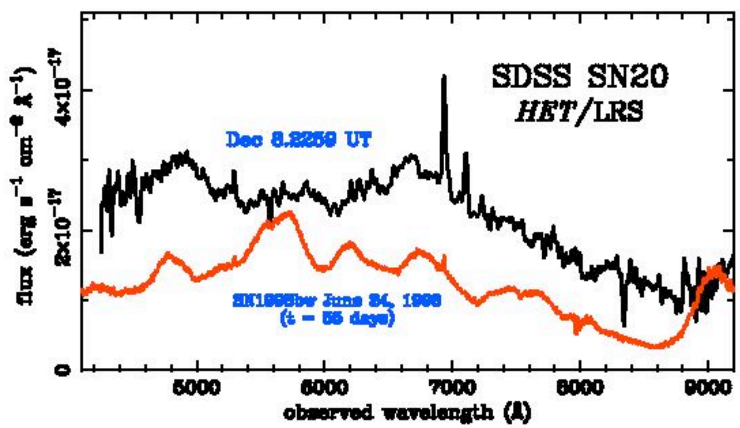


2004ib

SN20

Type Ic

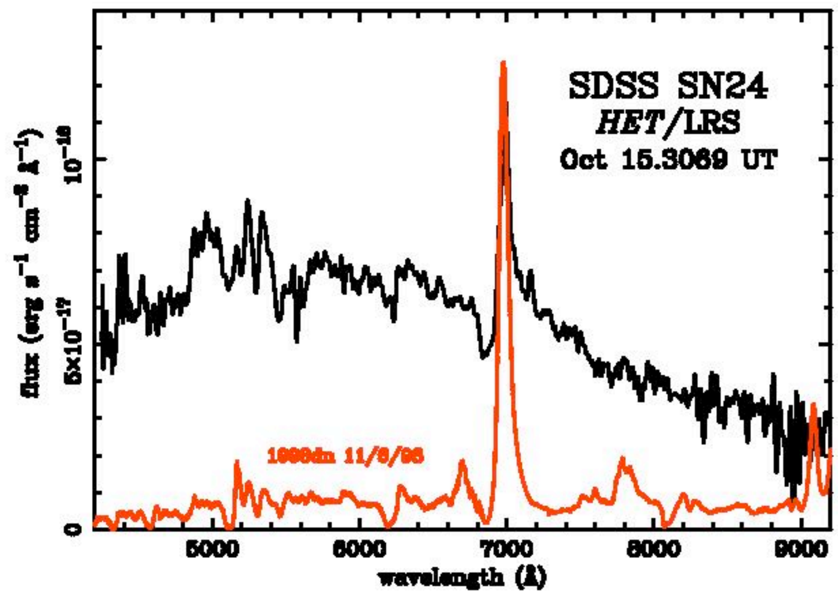




Additional visit on 1/2/05

SN24

2004ht



Type II

Fall 2004: Lessons Learned

- Demonstrated basic feasibility of the program:
  - data rate (weather) consistent with MC expectations
  - prototype software & hardware functioned adequately to achieve goals
  - gained operational experience carrying out the program
  - photometric accuracy of moony and non-photometric conditions: validated usefulness of imaging taken during normally `spectroscopic' conditions; will likely propose operations through ~1/2 of bright time periods

- Detection efficiency:

  effective threshold for object detection was 10σ in *g,r*, skewing sample to lower redshift: changes to frame sub

Development for SDSS II

- Software Development Highlights:
  - Requirements draft, Work Plan (WBS) in place
  - Frame subtraction: improved diagnostics, remapping, masked pixels, PSF determination, convolution, object finding, co-added template images (goal, not requirement)
  - Database: improved veto & star catalogs
  - Implement `real-time' efficiency tests with artificial SNe
  - Implement multi-color SN target selection
  - Improve webserver for candidate selection and tracking
  - Public webserver for candidates
- Plan: critical improvements in place & tested by 6/05

SDSS II SN Development Team

Fermilab: Jen Adelman-McCarthy, Fritz DeJongh, Juan Estrada, Hubert Lampeitl, John Marriner, Chris Stoughton, Doug Tucker

U. Chicago: Ben Dilday*, Rick Kessler

U. Washington: Andy Becker, Gajus Miknaitis* (--> FNAL), Craig Hogan

Portsmouth: Bob Nichol

NMSU: Jon Holtzman

APO: SDSS + 3.5m observing specialists (test run and spectroscopy)

JPG: Mamoru Doi, Naoki Yasuda, Naohiro Takanashi*

Stanford: Roger Romani, Masao Sako, Jared Kaplan**

Ohio State: Darren Depoy, Jennifer Marshall*

JHU/STScI: Adam Riess SF State: Dennis Lamenti**

External Collaborators/consultants: Lifan Wang (LBL), Peter Hoeflich (Texas), Wendy Freedman (Carnegie), list will grow

*graduate student **undergraduate

Note shared human resources w/ other SN surveys

SN Data Release Plans

- SN candidates:

  essential info. needed for follow-up will be rapidly posted to a public website and in IAU circulars

- Stripe 82 data will be processed through PHOTO at FNAL; corrected frames and catalogs with relative calibration will be released ~once per month through the Fall campaigns