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Argonne Dark Energy Survey Group: Supernova Research

J. P. Bernstein, S. Kuhlmann, H. Spinka, R. Talaga

HEP Division, Argonne National Laboratory

DOE Site Visit, September 24, 2009

High Energy Physics Division

Argonne National Laboratory

Outline

- Summary of ANL HEP Division supernova (SN) research
- Dark Energy Survey (DES) activities
- Sloan Digital Sky Survey II (SDSS) activities
- Large Synoptic Survey Telescope (LSST) activities
- Researching the origin of Type Ia supernova (SN Ia) light curves

Summary of ANL HEP Division Supernova Research

DARK ENERGY SURVEY

- SNANA: ***S***uper***N***ova ***ANA***lysis package
  - Most sophisticated SN analysis code: used by DES, SDSS, LSST
  - Bernstein, Kuhlmann: members of core development group
- ANL DES group
  - Leading the effort to optimize the SN search
  - Leading the production of the optimization journal paper
- ANL SDSS group
  - Bernstein, Kuhlmann, Spinka: external collaborators
  - Key involvement in SN cosmology analysis using all 3 years of data
- ANL LSST group
  - Bernstein, Kuhlmann: SN science collaboration members
  - Key involvement in effort to forecast LSST SN sample
  - Authors on two sections of the LSST Science Book
- Bernstein, Kuhlmann: 2 of 5 people world wide in DES, SDSS, & LSST SN
- Forefront SN Ia light curve/white dwarf explosion model study w/ D. Lamb et al.

SNANA: SuperNova ANAlysis Package

(Kessler et al. 2009, PASP, 121, 1028 http://adsabs.harvard.edu/abs/2009PASP..121.1028K)

DARK ENERGY SURVEY

- R. Kessler (U. Chicago), J. P. Bernstein, S. Kuhlmann (ANL), and others
- Public URL: http://www.sdss.org/supernova/SNANA.html
- Used by DES, SDSS, & LSST
- Software for simulating (both SN Ia & non-Ia) and fitting SN light curves
- Uses various models (e.g. MLCS2k2, SALT-II, stretch, etc.)
- Simulation steps
  - Generate rest-frame luminosity and fluctuations
  - Apply host galaxy dust extinction
  - Make redshift correction
  - Apply Milky Way dust map based on line of sight
  - Apply observatory weather history effects, sky noise, and detector effects

SNANA webpage created and maintained by J. P. Bernstein; #1 hit on Google search “snana”

SNANA

Welcome to the SuperNova ANAlysis software homepage

Install Guide | SNANA Manual | Overview Paper | Legal Notice

SNANA Download | Mailing List | Contact Form

SNANA contains a light curve fitter and simulation that can be applied to any supernova (SN) model and to any data set. This website provides installation instructions, a user manual, and a software package download area.

Example DES SNANA Simulated SN Ia Light Curves

$1+z \equiv \lambda_{obs}/\lambda_{emit}$

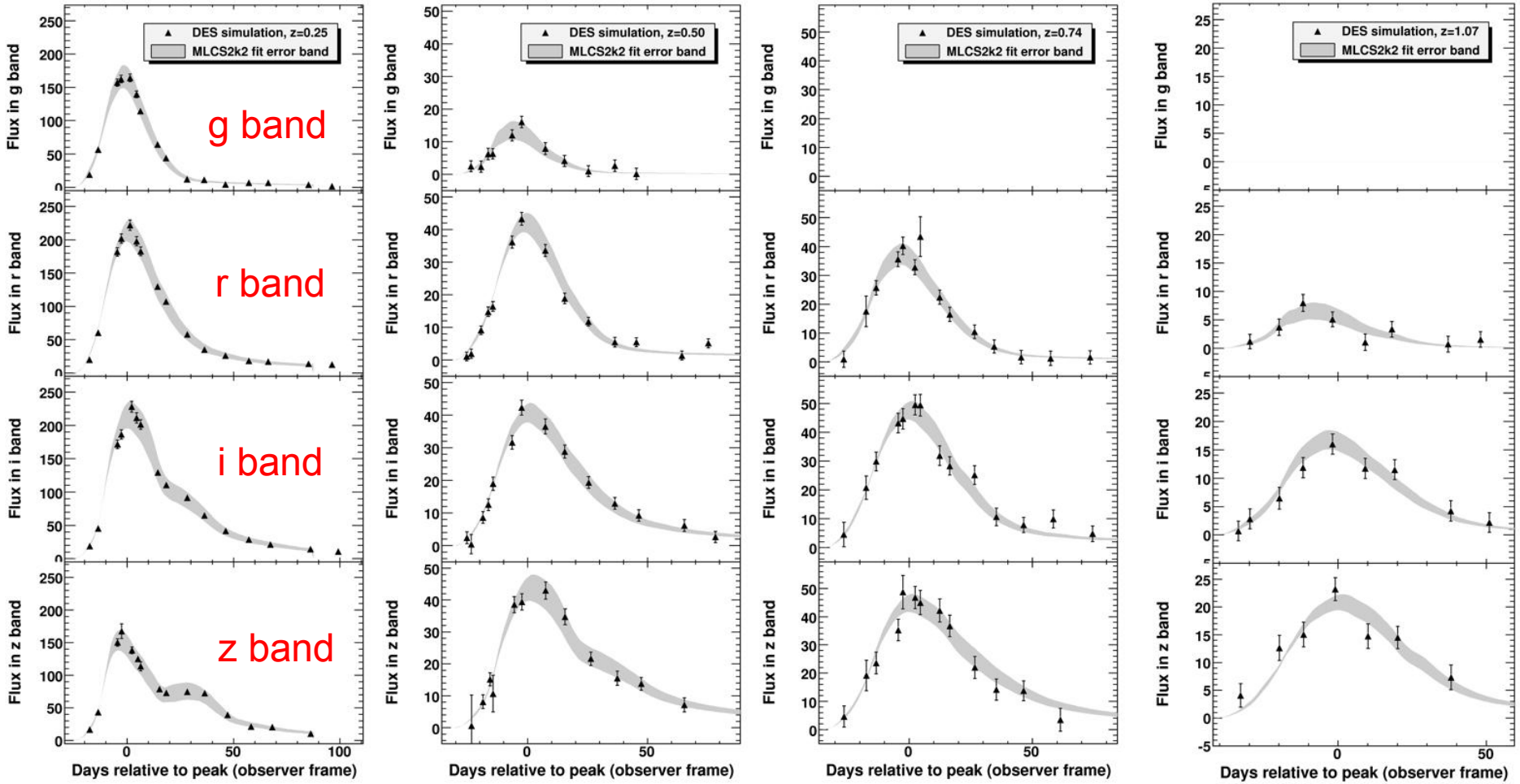
$z \equiv$ *redshift*

λ_{obs} = observed wavelength

λ_{emit} = emitted wavelength

NB. distance $\propto$ func(z,Ω)

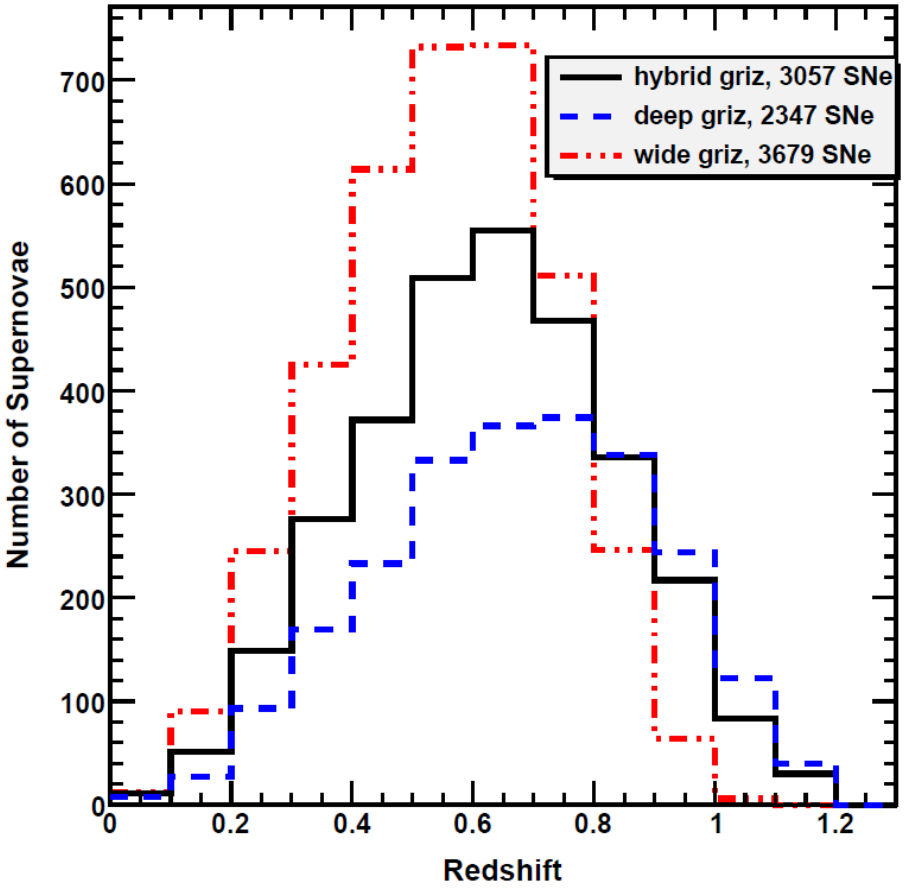
Redshift 0.25 | Redshift 0.50 | Redshift 0.74 | Redshift 1.07

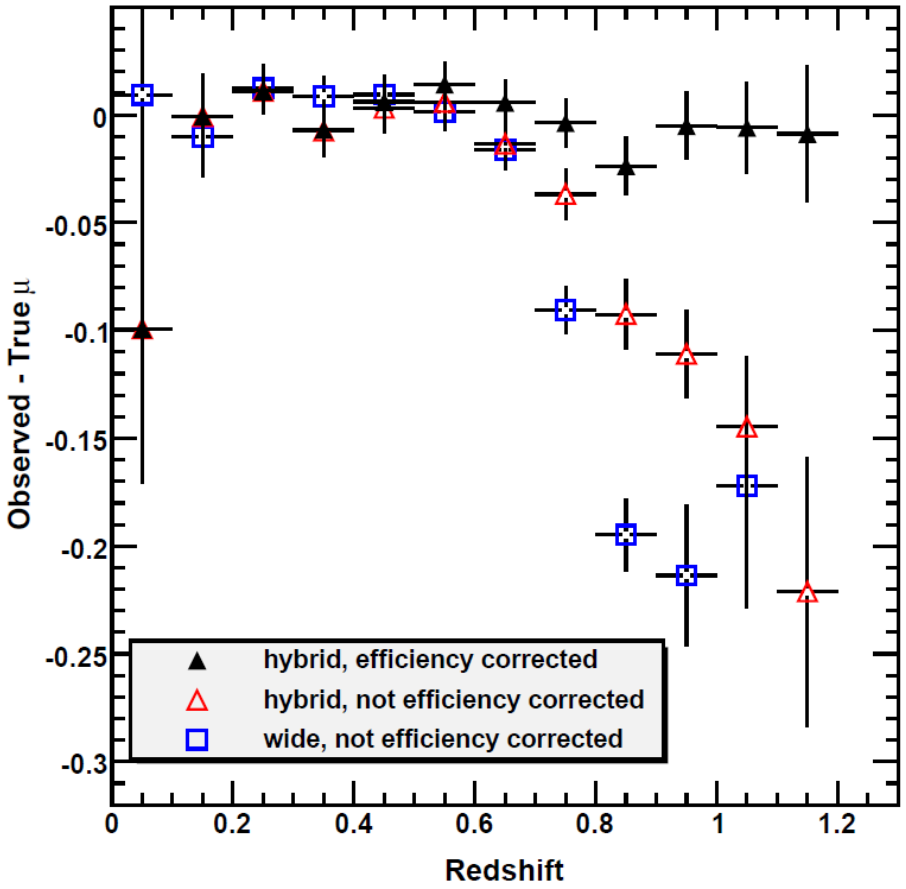


g band: 400 – 550 nm | r band: 560 – 710 nm | i band: 700 – 850 nm | z band: 860 – 1000 nm

DES Type Ia Supernova Sample SNANA Forecast

DARK ENERGY SURVEY





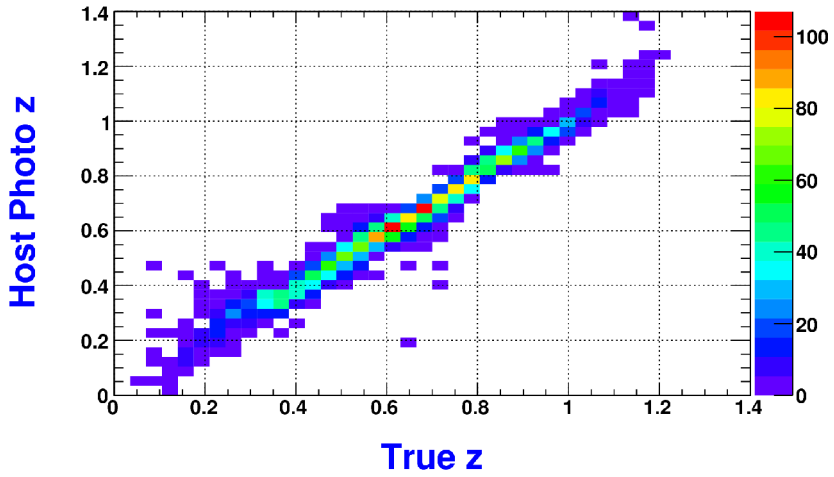
Distance modulus: $\mu = 5\log_{10}(d/10\ \mathrm{pc})$

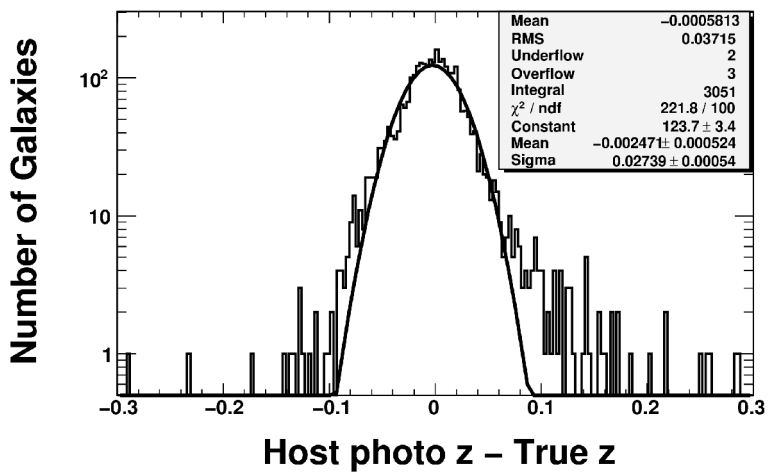
d = distance (1 pc = 3.09×10^{16} m)

Photometric Redshifts

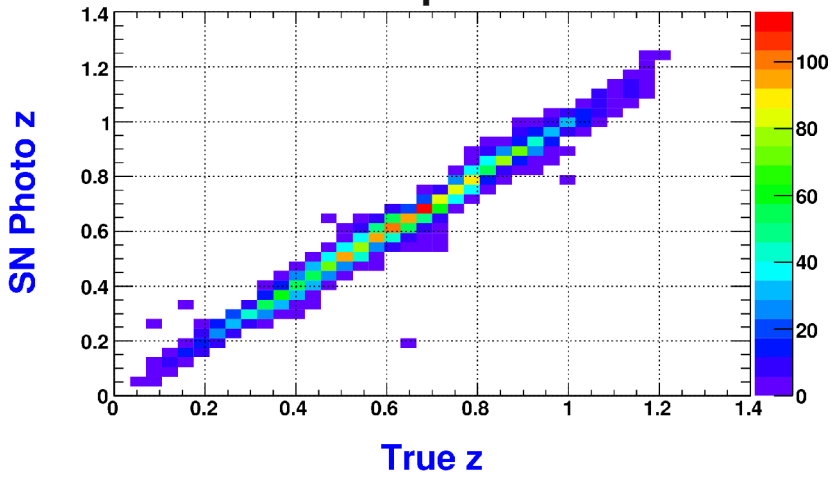
DARK ENERGY SURVEY

"Host" = galaxy in which SN exploded

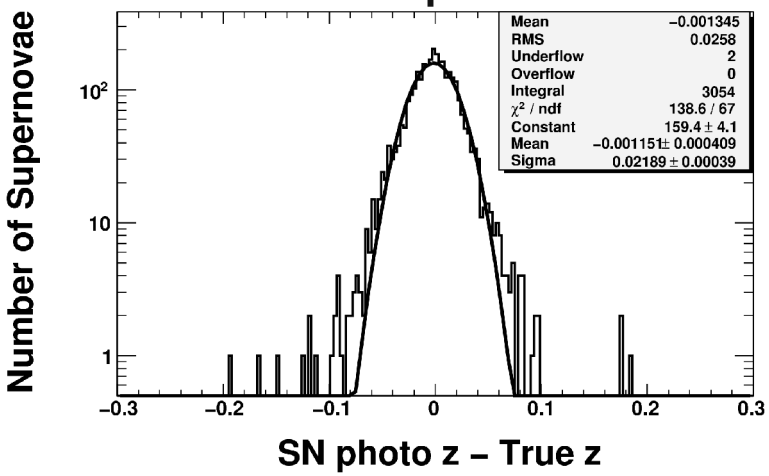




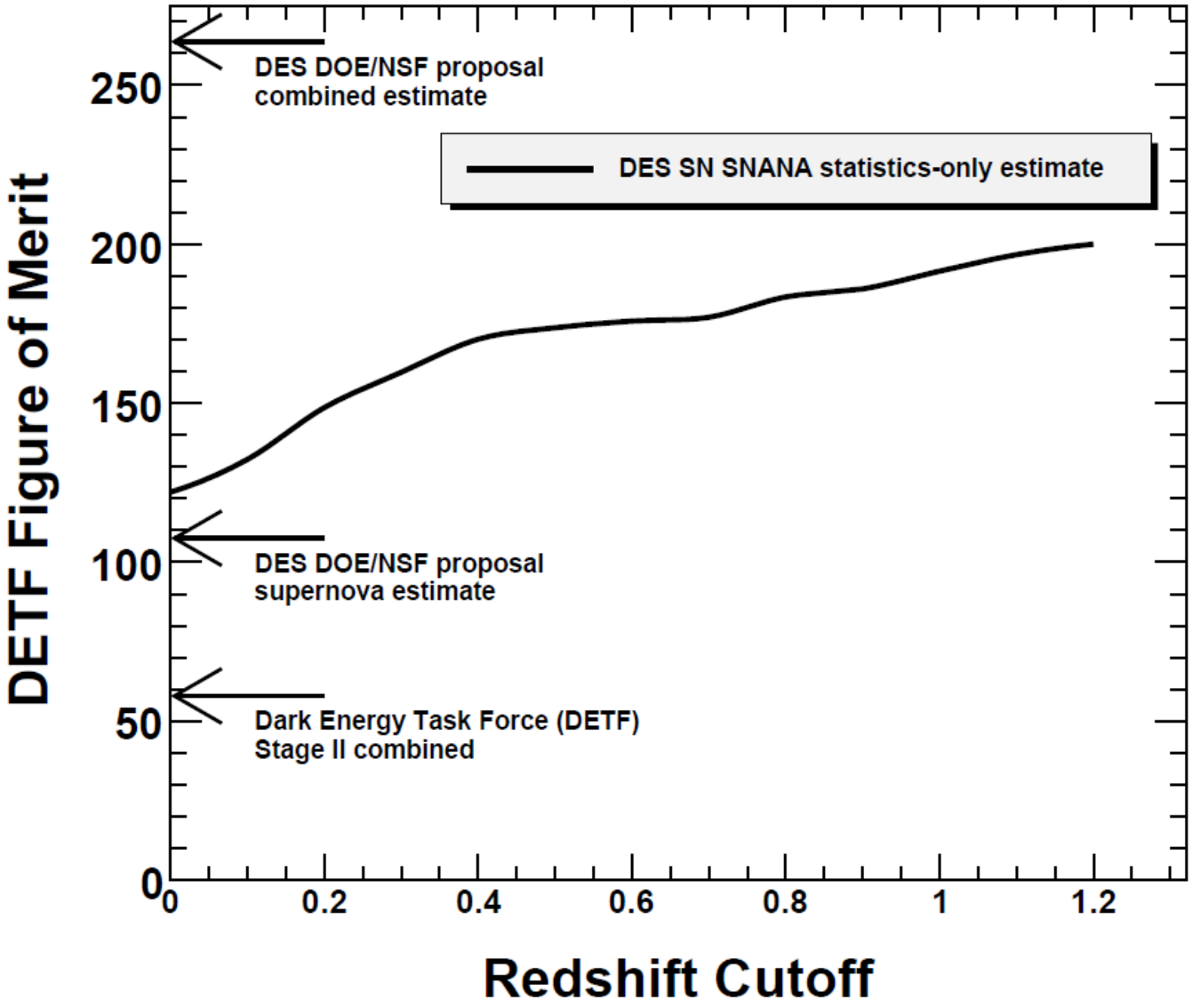
Host z used as prior



Host z used as prior



Dark Energy Task Force (DETF) Figure of Merit



SNANA Forecasted Contamination of DES SN Ia Sample

DARK ENERGY SURVEY

Assume 100% host galaxy spectra		
Type	# SNe passing default cuts	# SNe passing default cuts + fit prob. > 0.1
Ia	3066	2954
Ibc	486	183
IIP	775	10
IIL	112	10
IIn	1417	26

Default cuts: at least

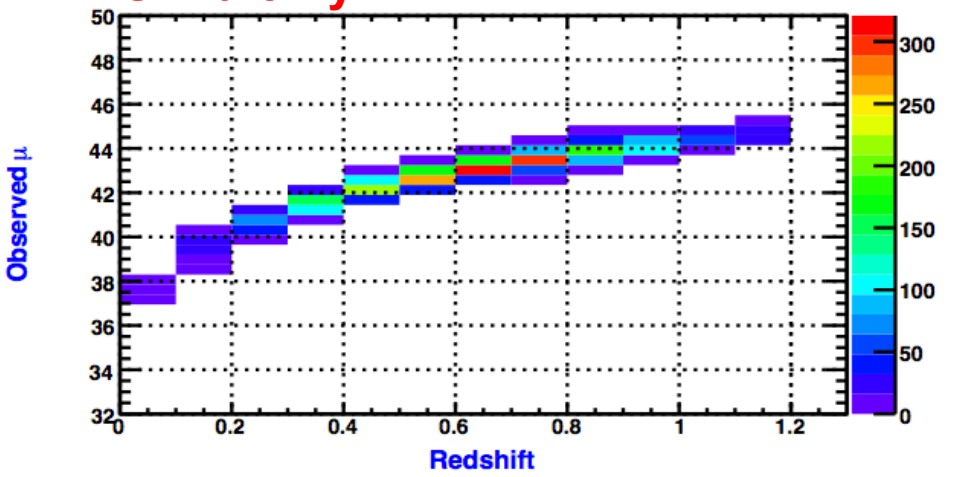
- Five total epoch above a small, but non-zero signal to noise (SNR) threshold
- One epoch before B-band peak and at least one ten days after B-band peak
- One filter measurement with SNR > 10 and two additional with SNR > 5

- 1000,664 total SNe generated, 9344 SN Ia
- About 7% core collapse "contamination" with fit probability cut > 0.1
  - Biases cosmology fit by about 6 standard deviations!
- Fit probability cut > 0.5 reduces contamination to about 2%
  - Also reduces bias to less than 2 standard deviations
  - Trade off is loss of about 20% of the SN Ia sample

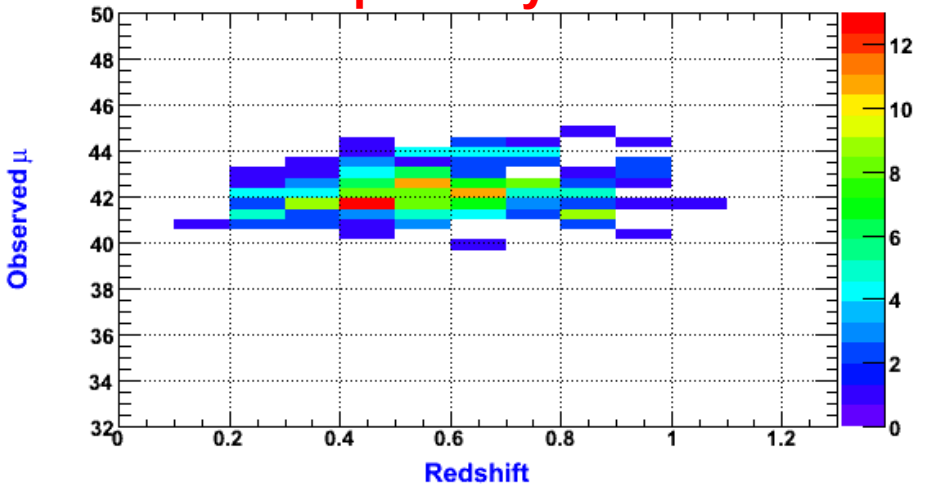
Two Component Fit: Alternative to Fit Probability Cut

DARK ENERGY SURVEY

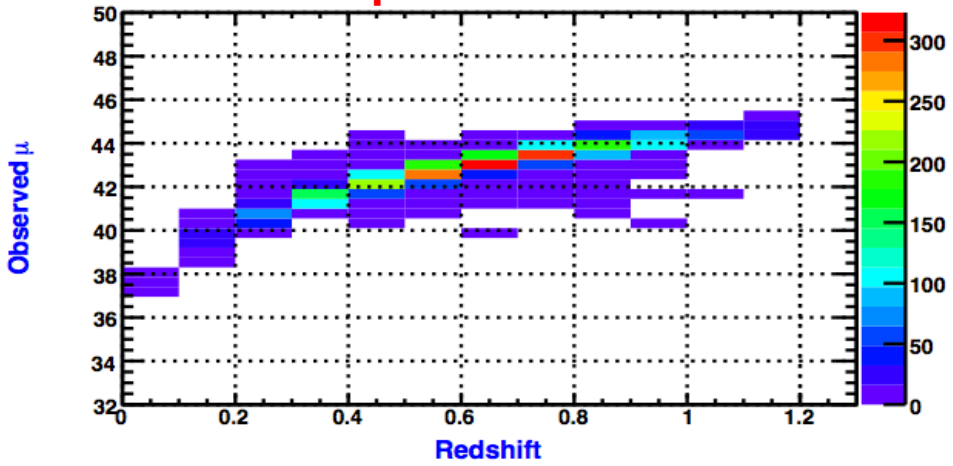
SN Ia only



Core collapse only



Entire sample

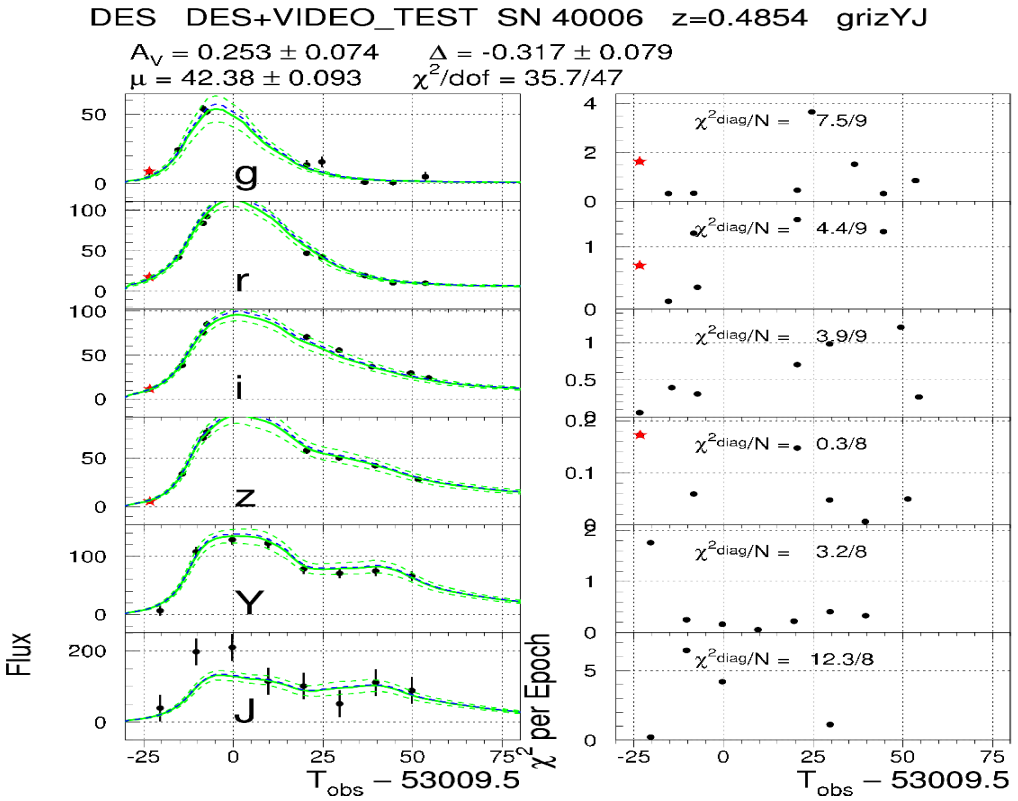


Undergraduate students Tara Hufford (Loyola U. Chicago) & Ian Crane (U. Illinois) are actively working on studies of two component fits and a student research poster presentation is anticipated at the 215th Meeting of the American Astronomical Society 3–7 January, 2010, in Washington, D.C.

Exploring DES+VIDEO Optical/Infrared SN Ia Light Curves

DARK ENERGY SURVEY

- VIDEO is a new infrared survey
- DES–VIDEO overlap presents an outstanding opportunity
- Extension of optical SN Ia light curves to the infrared
  - Enables more accurate colors due to the larger leaver arm
  - Provided by the increased wavelength range
- Germane as SN cosmology on cusp of being limited by systematics



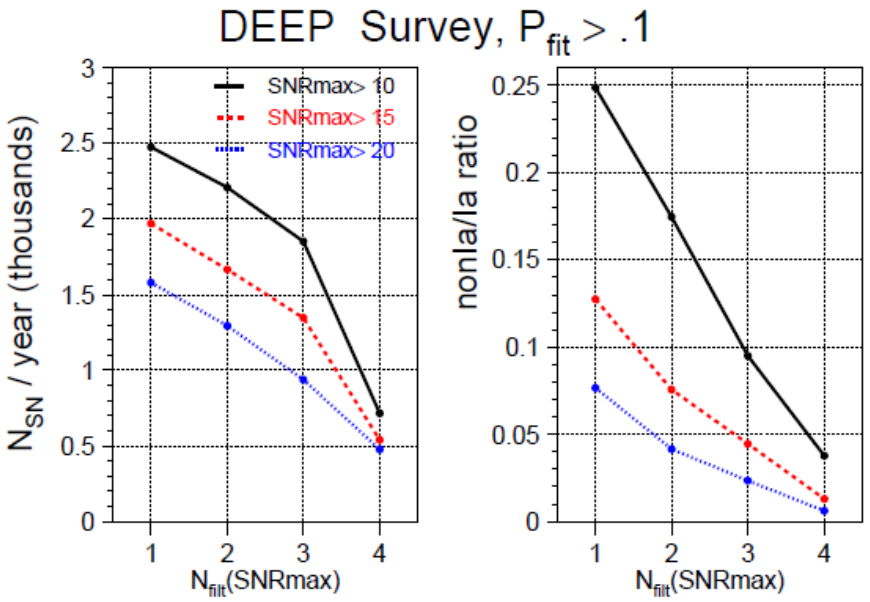
SDSS SNANA Studies

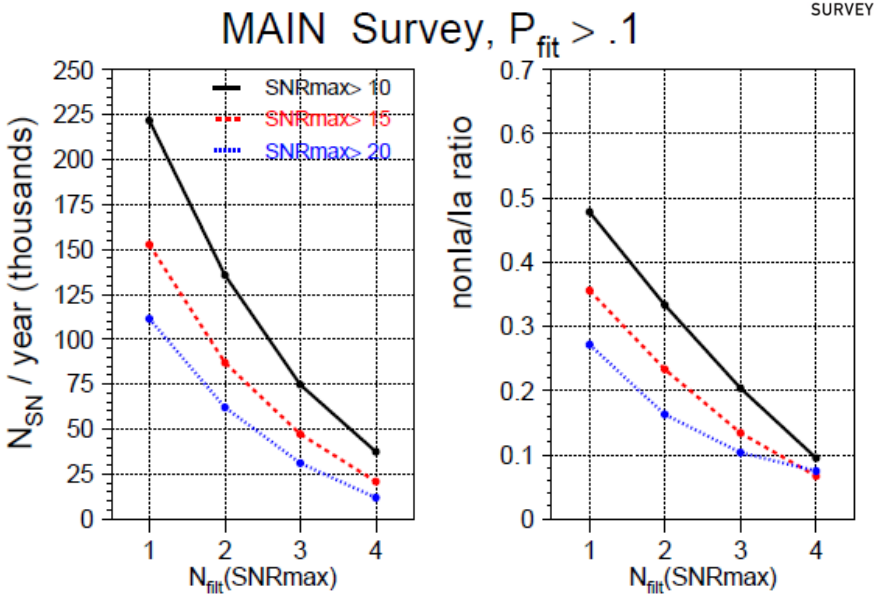
DARK ENERGY SURVEY

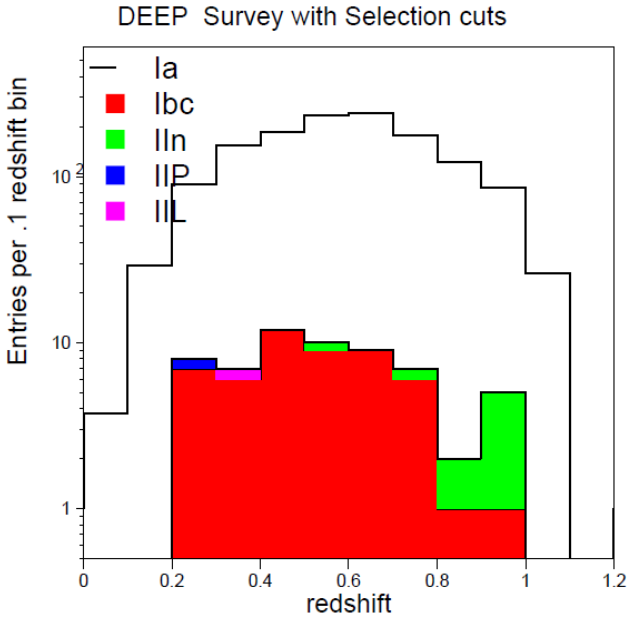
Upgrading the low redshift SN anchor dataset to include the CFA3 sample: a key element of the full SDSS SN cosmology analysis based on the 3-year sample

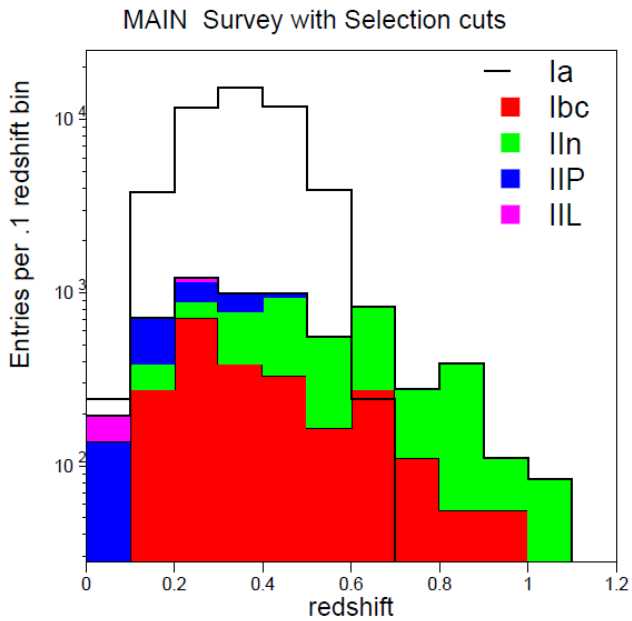
Dataset	w	sig_w +	sig_w -	OM	sig_OM
SDSS+SNLS+ESSENCE*	-0.711	0.088	0.082	0.319	0.025
Old LOWZ fits					
LOWZ+SDSS*	-0.915	0.133	0.122	0.273	0.028
SDSS+LOWZ+SNLS+ESSENCE*	-0.765	0.08	0.07	0.306	0.021
SDSS+LOWZ+SNLS+ESSENCE+HST*	-0.757	0.071	0.064	0.308	0.019
LOWZ+ESSENCE+SNLS*	-0.779	0.083	0.082	0.302	0.022
***Matches SNCOSMO09 paper**					
New low-z (CFA3) fits					
CFA3+SDSS	-0.845	0.11	0.105	0.287	0.026
SDSS+CFA3+SNLS+ESSENCE	-0.742	0.07	0.065	0.311	0.02
SDSS+CFA3+SNLS+ESSENCE+HST	-0.738	0.061	0.059	0.312	0.019
CFA3+ESSENCE+SNLS	-0.733	0.07	0.07	0.313	0.021

LSST SNANA Studies





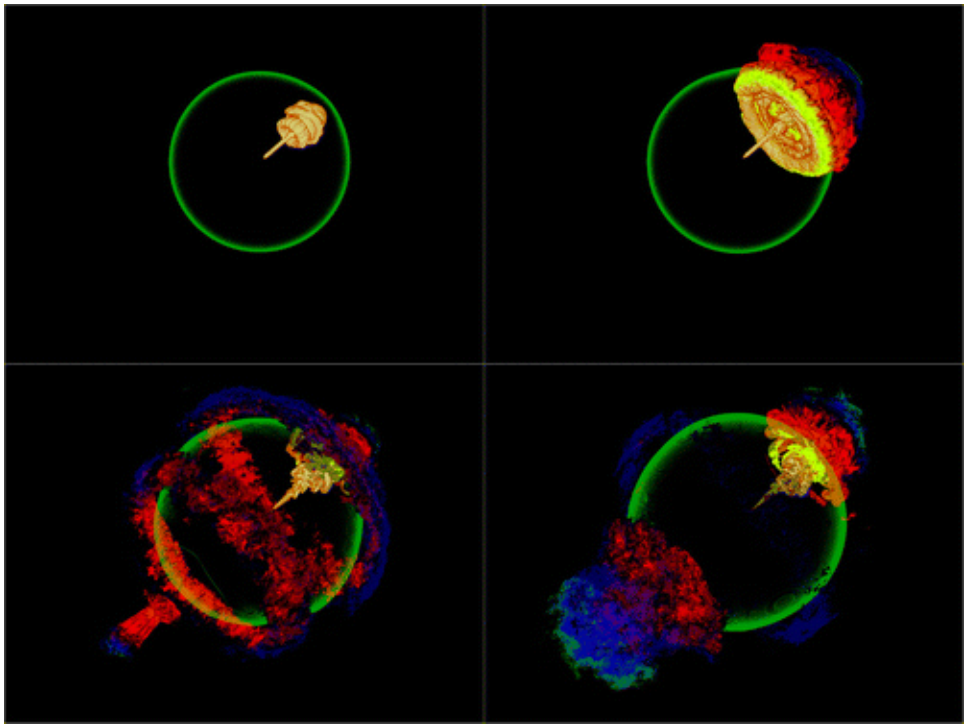




Researching SN Ia Light Curve Origins

DARK ENERGY SURVEY

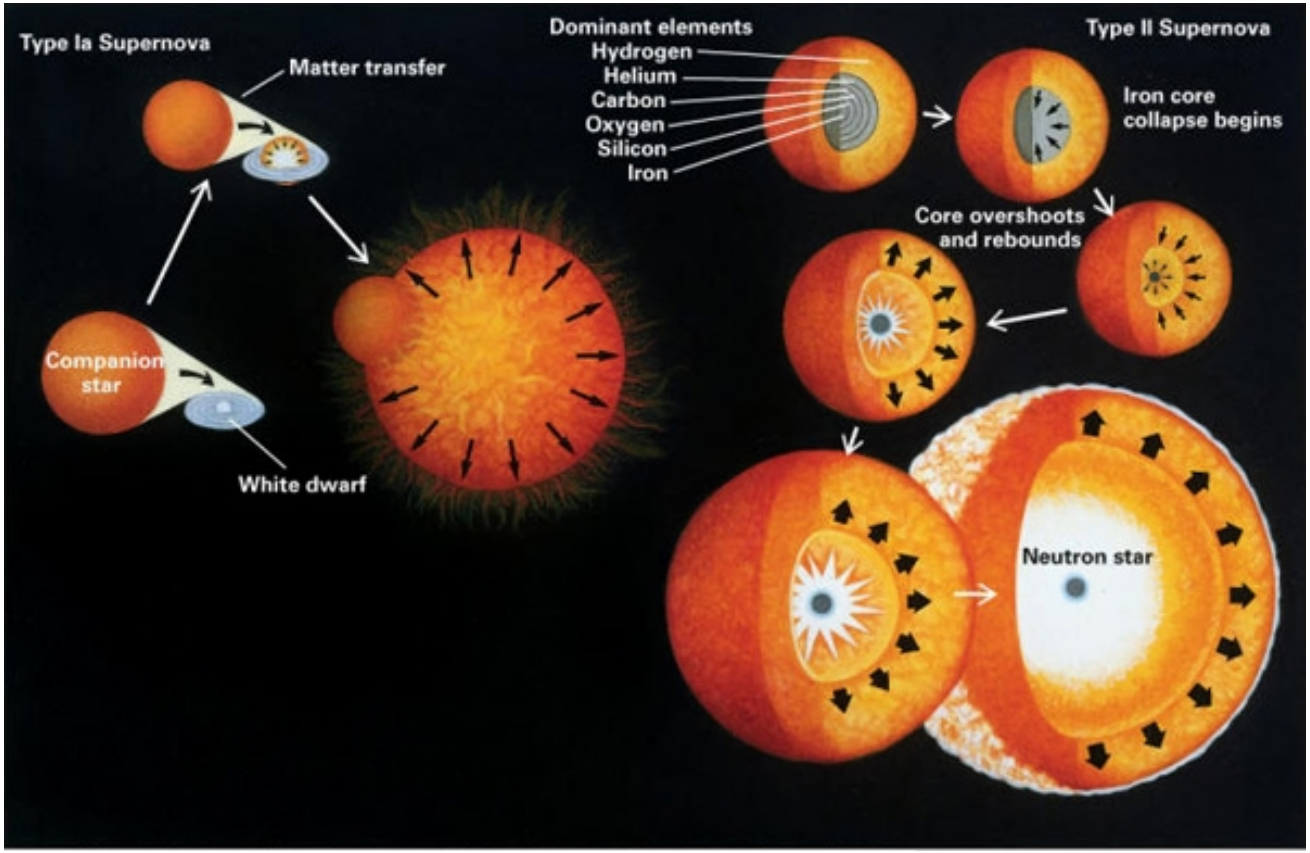
- Difficulties tracing SN Ia light curves to white dwarf detonation persist
- Requires reliance on parametric light curve models
  - For example, MLCS2k2 & SALT-II
  - First principles elusive
- Kuhlmann & Bernstein joined FNAL and U. Chicago (UC) scientists
  - Successful UC/FNAL/ANL seed grant research proposal
  - Study utilizes SDSS light curves & FLASH simulated SN Ia explosions



Jordan et al. 2008, ApJ, 681, 1448

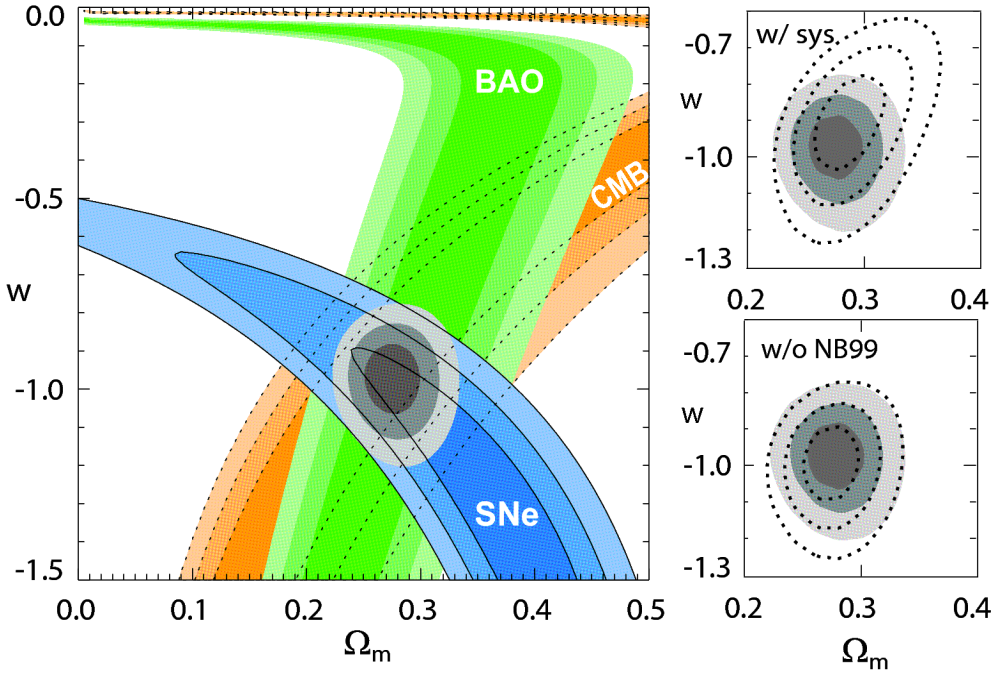
Backup Slides

Supernova Explosions

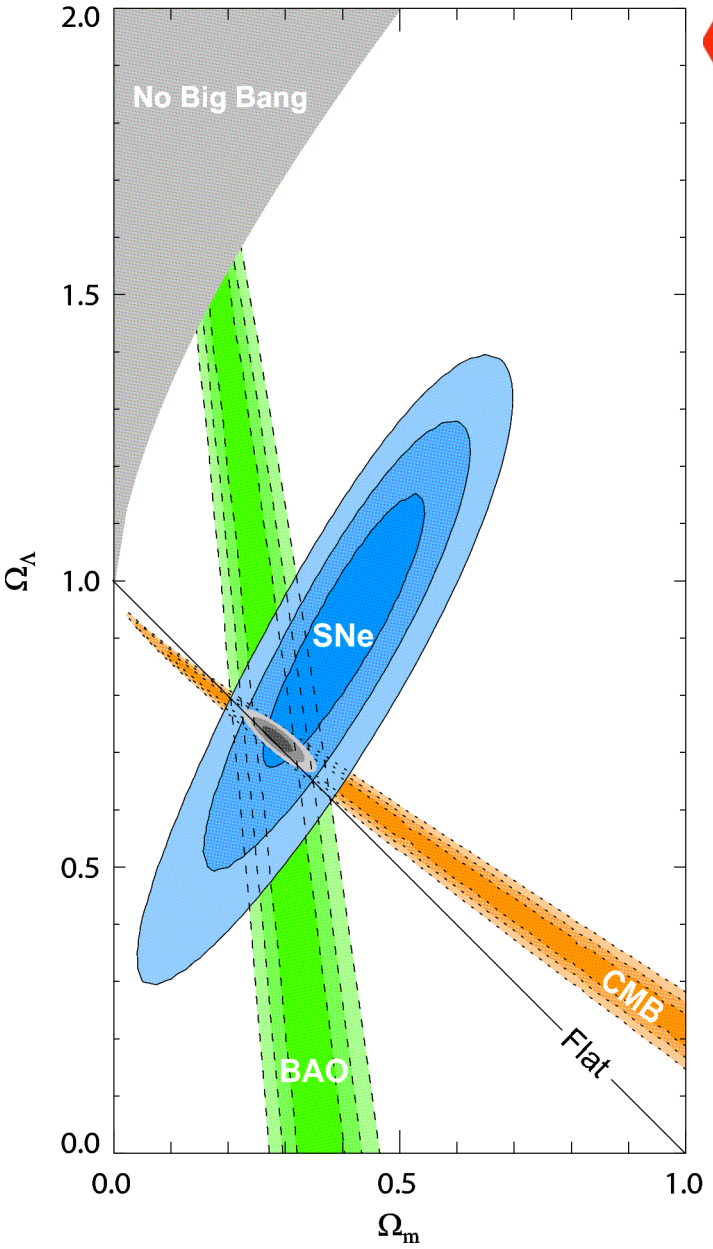


Courtesy Encyclopedia Britannica

Current Cosmology Constraints



Kowalski et al. 2008, ApJ, 686, 749



DARK ENERGY SURVEY

Multicolor Light Curve Shape Model

(MLCS2k2; Jha, Riess, Kirshner 2007, ApJ, 659, 122)

DARK ENERGY SURVEY

- Light curve model magnitude m_x for passband x at given epoch:

$$m_x = M_x + \mu_0 + \Xi_{x,MW} + \Xi_{x,H}(R_v, A_{v0}) + P_x\Delta + Q_x\Delta^2$$

- 4 free parameters:
  - t_0: epoch of maximum light in B-band
  - μ_0: distance modulus
  - Δ: luminosity/light curve shape parameter
  - A_{v0}: extinction in magnitudes by host dust; $R_v = A_{v0} / E(B\text{-}V)$, initially set to 3.1*
- Provided by MLCS2k2 SN data training (Jha,Riess,Kershner 2007):
  - M_x: rest-frame magnitude w/ $\Delta = A_{v0} = 0$
  - P_x & Q_x: describe change in shape & luminosity as function of Δ
  - Ξ_x: extinction functions; "MW" for Milky Way & "H" for host galaxy

*Cardelli, Clayton, Mathis 1989, ApJ, 345, 245, and references therein

Spectral Adaptive Lightcurve Template Model

(SALT-II; Guy et al. 2007, ApJ, 466, 11)

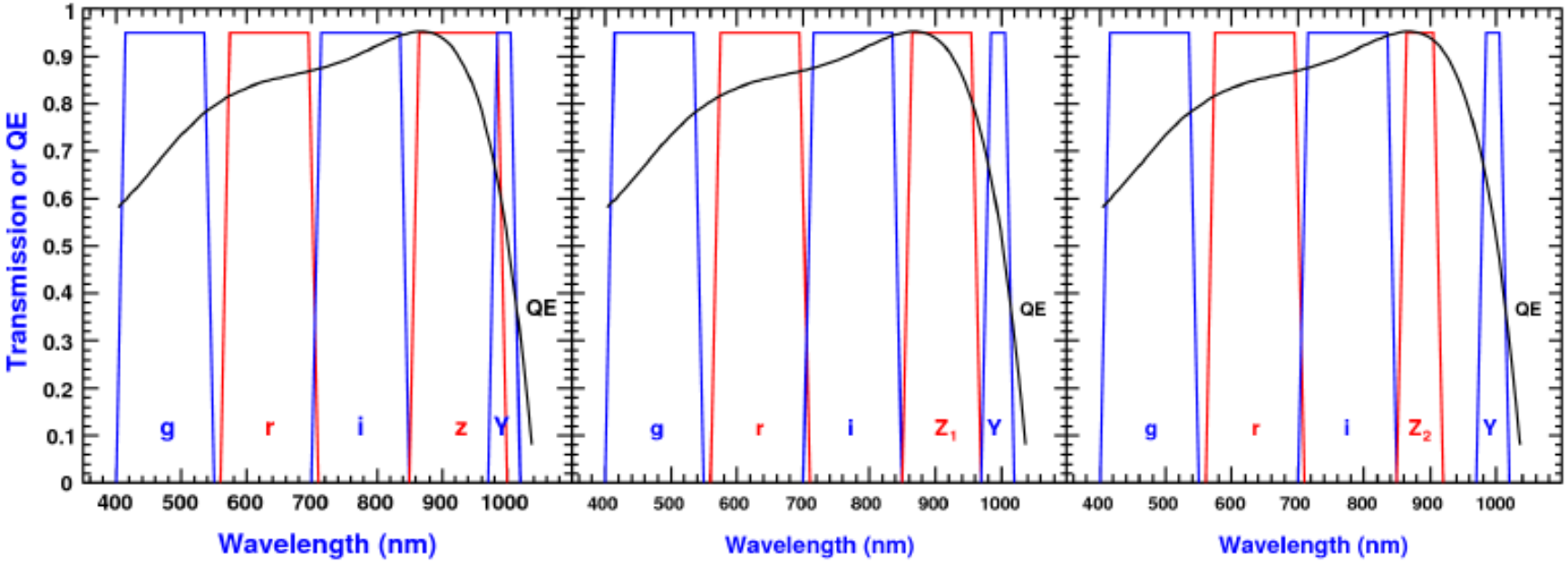
DARK ENERGY SURVEY

- Light curve model flux F:

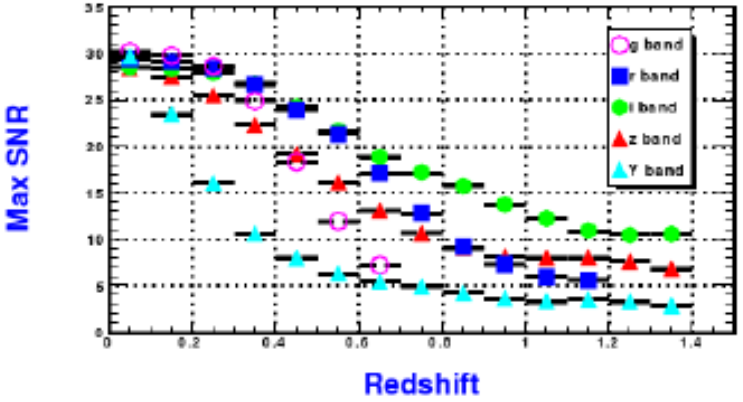
$$F(p, \lambda) = x_0 \times [M_0(p, \lambda) + x_1 M_1(p, \lambda) + \ldots] \times \exp[cCL(\lambda)]$$

  - p is the rest-frame time since the date of maximum B luminosity
  - λ is the wavelength in the SN rest-frame
  - x_0 is normalization of the SED sequence
  - $x_{k>0}$ are the intrinsic parameters of SN (such as a stretch)
  - $M_0(p, \lambda)$ is the average spectral sequence
  - $M_{k>0}(p, \lambda)$, are additional components describing main variability
  - $CL(\lambda)$ is average color correction law
  - $c = (B - V)_{MAX}$ MAX $- (B - V)$ = color offset wrt max B luminosity
- M_k and CL are properties of the global model
- x_k and c are parameters of a given SN

Original DES Filter Options



- SN Filters: g, r, i, z or Z_1 or Z_2 , Y ?
- DES has selected z & DES SN will NOT use Y
- Hybrid deep field griz exposure times: ~300s, 1200s, 1800s, 4000s
- Hybrid wide fields have 1/3 exposure times



RA: 52.500000 DECL: -27.500000 NOBS: 130 MWEBV: 0.000 PIXSIZE: 0.270

#	MJD	IDEXPT	FLT	CCD GAIN	CCD NOISE	SKYSIG	PSF1 (pixels)	PSF2	PSF2/1 RATIO	ZPTAVG	ZPTSIG	MAG
S:	52889.191	10000000	g	1.00	10.00	79.89	2.26	0.00	0.000	32.97	0.033	1.000
S:	52892.312	10000001	g	1.00	10.00	142.97	2.58	0.00	0.000	32.71	0.033	1.000
S:	52900.172	10000002	g	1.00	10.00	47.63	1.57	0.00	0.000	32.92	0.033	1.000
S:	52902.281	10000003	g	1.00	10.00	47.63	2.21	0.00	0.000	31.72	0.032	1.000
S:	52907.305	10000004	g	1.00	10.00	47.63	1.48	0.00	0.000	32.94	0.033	1.000
S:	52915.238	10000005	g	1.00	10.00	57.17	1.35	0.00	0.000	33.04	0.033	1.000
S:	52928.254	10000006	g	1.00	10.00	80.51	1.14	0.00	0.000	33.07	0.033	1.000
S:	52934.148	10000007	g	1.00	10.00	47.63	2.44	0.00	0.000	31.82	0.032	1.000
S:	52935.160	10000008	g	1.00	10.00	47.63	1.86	0.00	0.000	32.19	0.032	1.000
S:	52941.121	10000009	g	1.00	10.00	47.63	1.53	0.00	0.000	32.67	0.033	1.000
S:	52942.102	10000010	g	1.00	10.00	50.21	1.68	0.00	0.000	32.57	0.033	1.000
S:	52943.105	10000011	g	1.00	10.00	53.16	1.49	0.00	0.000	32.79	0.033	1.000
S:	52944.129	10000012	g	1.00	10.00	58.26	1.29	0.00	0.000	32.81	0.033	1.000
S:	52948.109	10000013	g	1.00	10.00	106.51	2.82	0.00	0.000	32.87	0.033	1.000
S:	52949.109	10000014	g	1.00	10.00	125.68	2.81	0.00	0.000	32.87	0.033	1.000
S:	52950.109	10000015	g	1.00	10.00	146.40	2.05	0.00	0.000	32.94	0.033	1.000
S:	52951.094	10000016	g	1.00	10.00	167.13	1.85	0.00	0.000	32.94	0.033	1.000
S:	52956.070	10000017	g	1.00	10.00	47.63	2.21	0.00	0.000	32.93	0.033	1.000
S:	52957.070	10000018	g	1.00	10.00	47.63	2.19	0.00	0.000	32.93	0.033	1.000
S:	52958.070	10000019	g	1.00	10.00	47.63	1.54	0.00	0.000	32.95	0.033	1.000
S:	52959.098	10000020	g	1.00	10.00	47.63	1.61	0.00	0.000	32.85	0.033	1.000
S:	52960.266	10000021	g	1.00	10.00	55.45	1.31	0.00	0.000	32.77	0.033	1.000
S:	52971.125	10000022	g	1.00	10.00	50.39	1.27	0.00	0.000	32.90	0.033	1.000
S:	52974.082	10000023	g	1.00	10.00	67.07	1.16	0.00	0.000	32.19	0.032	1.000
S:	52986.160	10000024	g	1.00	10.00	77.16	1.50	0.00	0.000	32.90	0.033	1.000
S:	52994.160	10000025	g	1.00	10.00	47.63	1.28	0.00	0.000	32.87	0.033	1.000
S:	53001.152	10000026	g	1.00	10.00	47.63	1.49	0.00	0.000	32.94	0.033	1.000
S:	53002.199	10000027	g	1.00	10.00	47.63	1.44	0.00	0.000	32.94	0.033	1.000
S:	53030.043	10000028	g	1.00	10.00	52.36	2.81	0.00	0.000	32.94	0.033	1.000
S:	53034.125	10000029	g	1.00	10.00	78.09	1.37	0.00	0.000	32.50	0.032	1.000
S:	53046.086	10000030	g	1.00	10.00	47.63	1.45	0.00	0.000	32.93	0.033	1.000
S:	53054.055	10000031	g	1.00	10.00	47.63	1.94	0.00	0.000	32.94	0.033	1.000
S:	53063.070	10000032	g	1.00	10.00	67.94	2.24	0.00	0.000	32.98	0.033	1.000

DARK ENERGY SURVEY

Example Simulation Library File (g-band section only)

Effect of

Moon

ESSENCE PSF variation

ESSENCE Zeropt variation

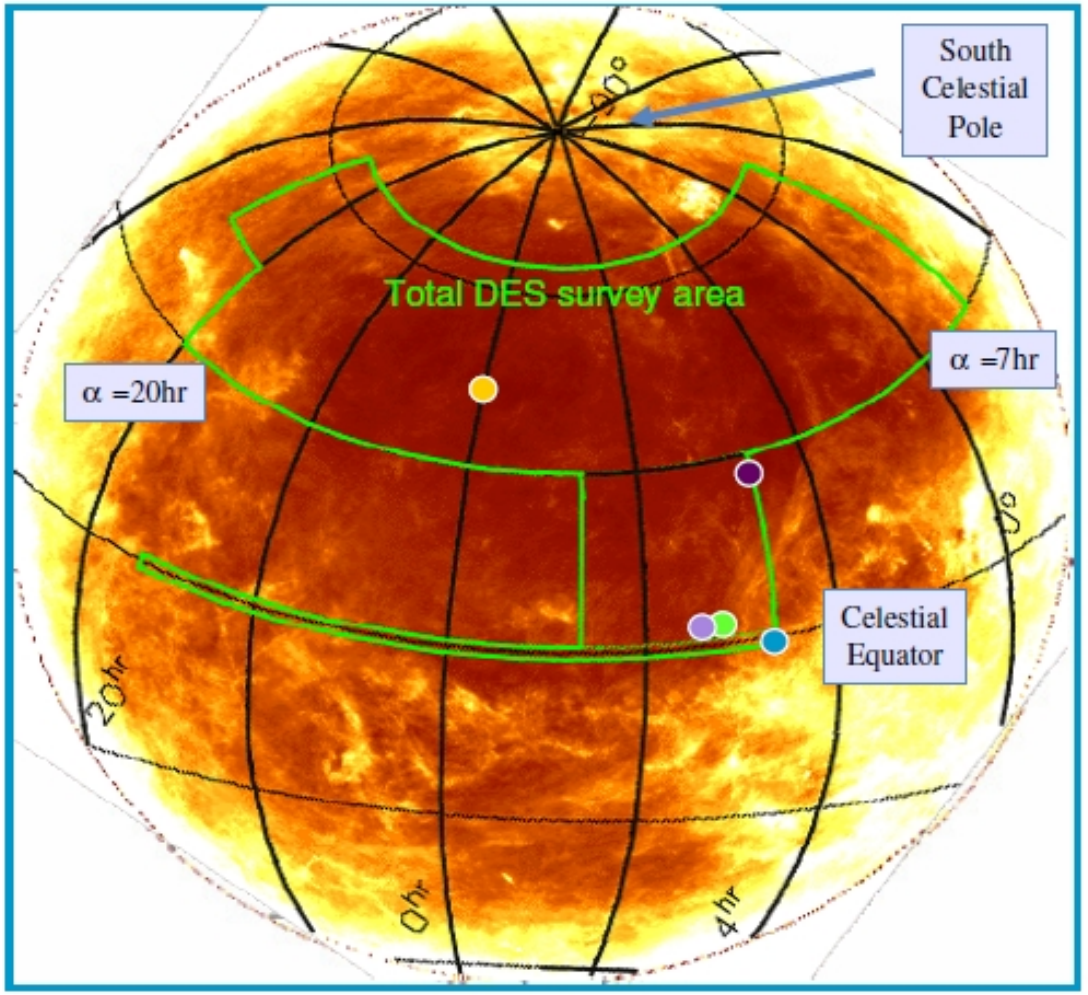
Currently Favored DES SN Fields

DARK ENERGY SURVEY

- Chosen to maximize:
  - visibility from DES site
  - past observation history
  - visibility from, e.g, Hawaii

Chandra Deep Field – South
Sloan Stripe 82
SN Legacy Survey (SNLS) D1
XMM-Newton LSS
ELIAS S1

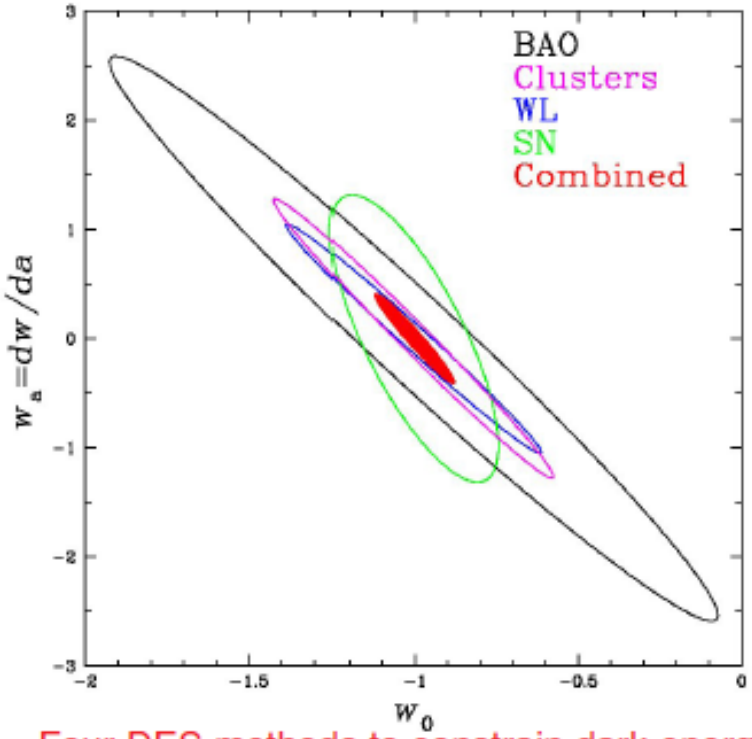
From a study by Peter Nugent



Dark Energy Task Force Figure of Merit (FoM)

DARK ENERGY SURVEY

- Dark Energy Task Force (DETF) FoM: inverse size of $w_a - w_o$ error ellipse
  - $w(a) = w_o + (1-a)\,w_a$
  - a = scale factor
  - w_o = w at present epoch
  - w_a = rate of change of w with a
- Inverse area means bigger is better



Four DES methods to constrain dark energy (plot from NSF/DOE proposal including Planck priors but NOT the DETF Stage II constraints)

DES–VISTA Synergy

DARK ENERGY SURVEY

- Motivation: simulate VISTA light curves
  - 4-m class wide field survey telescope
  - southern hemisphere
  - near IR camera (1.65 deg diam FOV)
  - 67 million pixels of mean size 0.339"
  - broad band filters at Z, Y, J, H, K_s
  - narrow band filter at 1.18 micron

http://www.vista.ac.uk

Summary of ANL HEP Division Supernova Research

DARK ENERGY SURVEY

- SNANA: ***S***uper***N***ova ***ANA***lysis package
  - Most sophisticated SN analysis code: used by DES, SDSS, LSST
  - Bernstein, Kuhlmann: members of core development group
- ANL DES group
  - Leading the effort to optimize the SN search
  - Leading the production of the optimization journal paper
- ANL SDSS group
  - Bernstein, Kuhlmann, Spinka: external collaborators
  - Key involvement in SN cosmology analysis using all 3 years of data
- ANL LSST group
  - Bernstein, Kuhlmann: SN science collaboration members
  - Key involvement in effort to forecast LSST SN sample
  - Authors on two sections of the LSST Science Book
- Bernstein, Kuhlmann: 2 of 5 people world wide in DES, SDSS, & LSST SN
- Forefront SN Ia light curve/white dwarf explosion model study w/ D. Lamb et al.