The Nearby Supernova Factory

Beginning a New Era of
Supernova Cosmology Experiments

Participating Scientists

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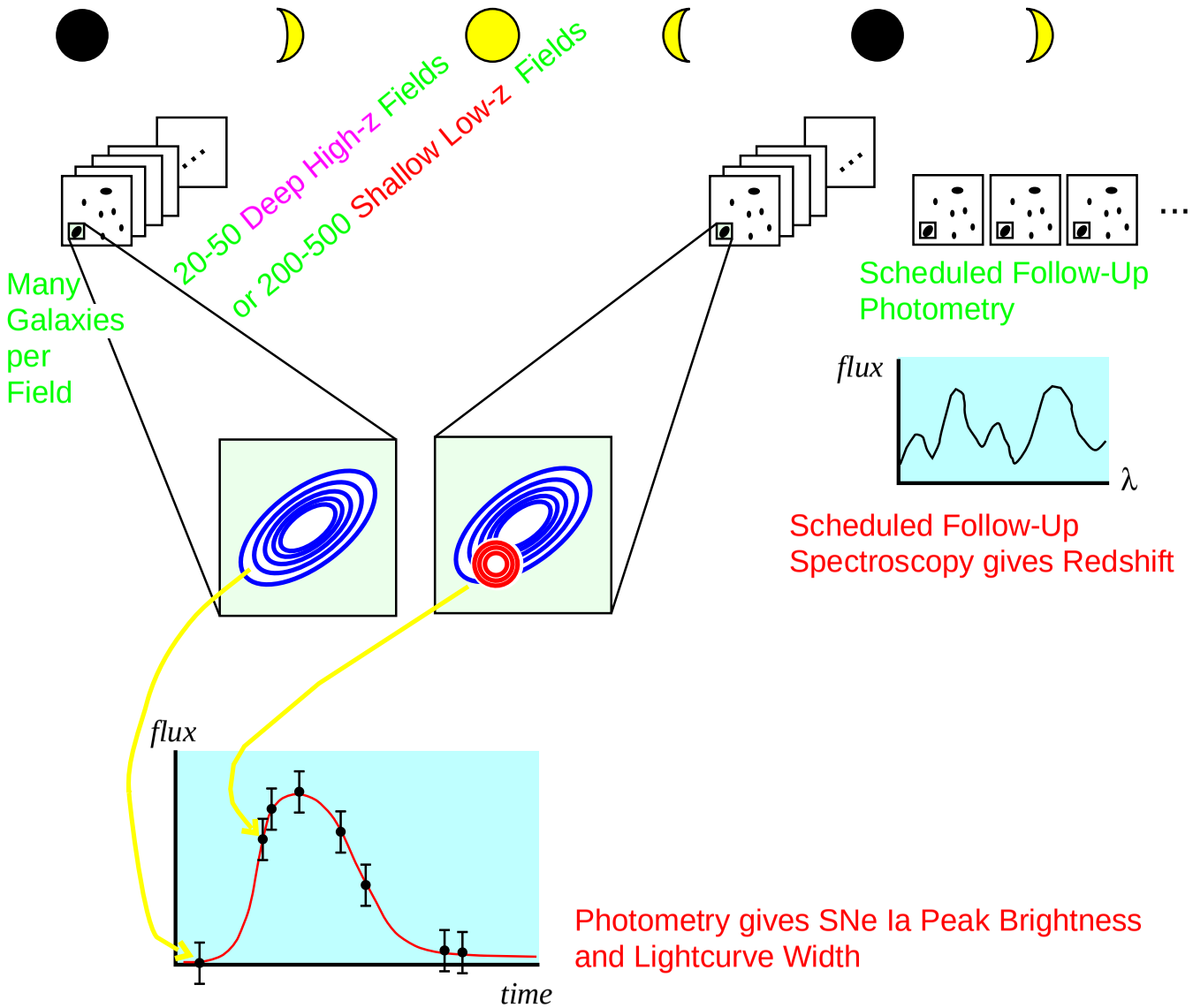
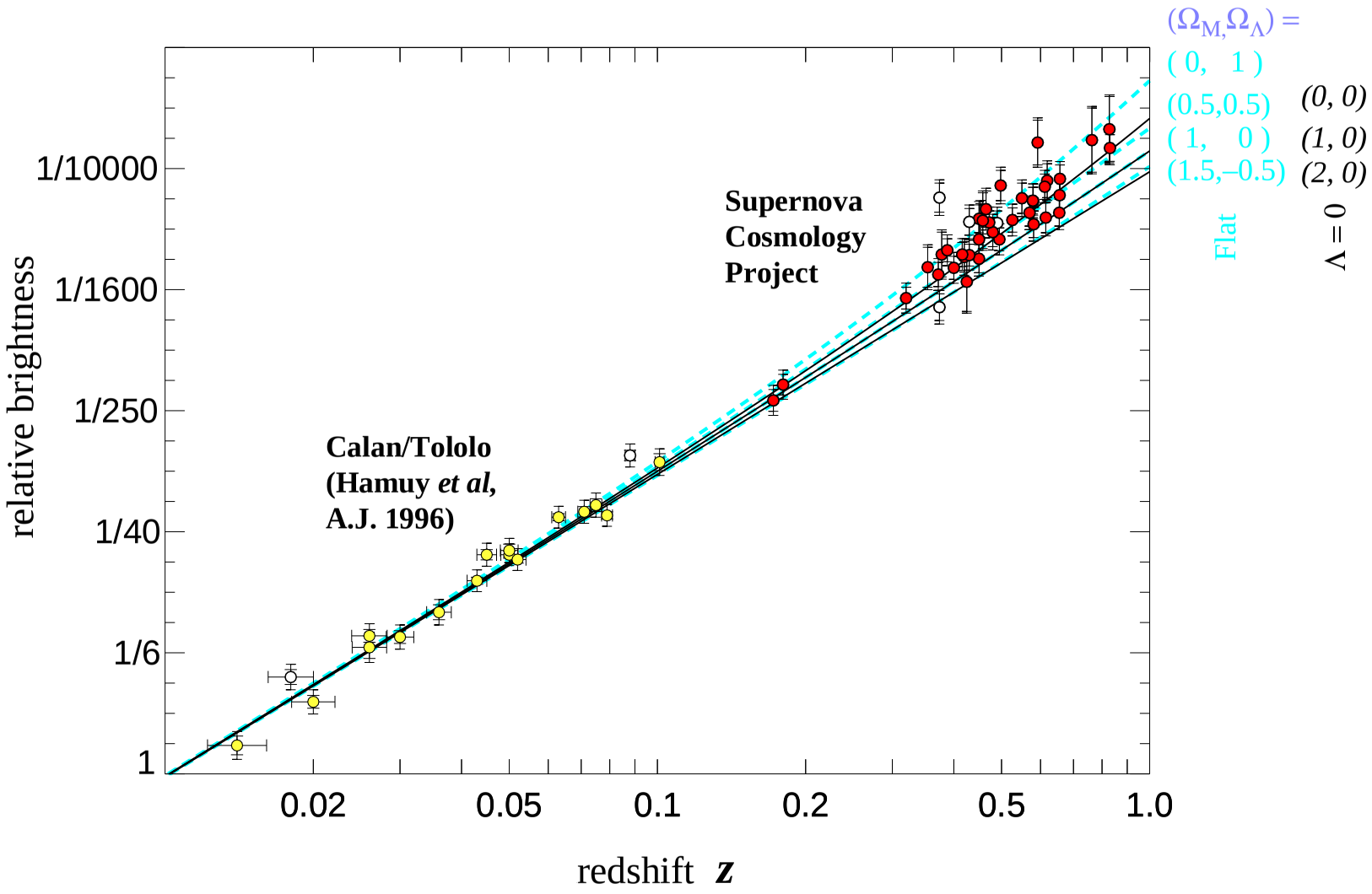
Institut de Physique Nucleaire de Lyon (IPNL)

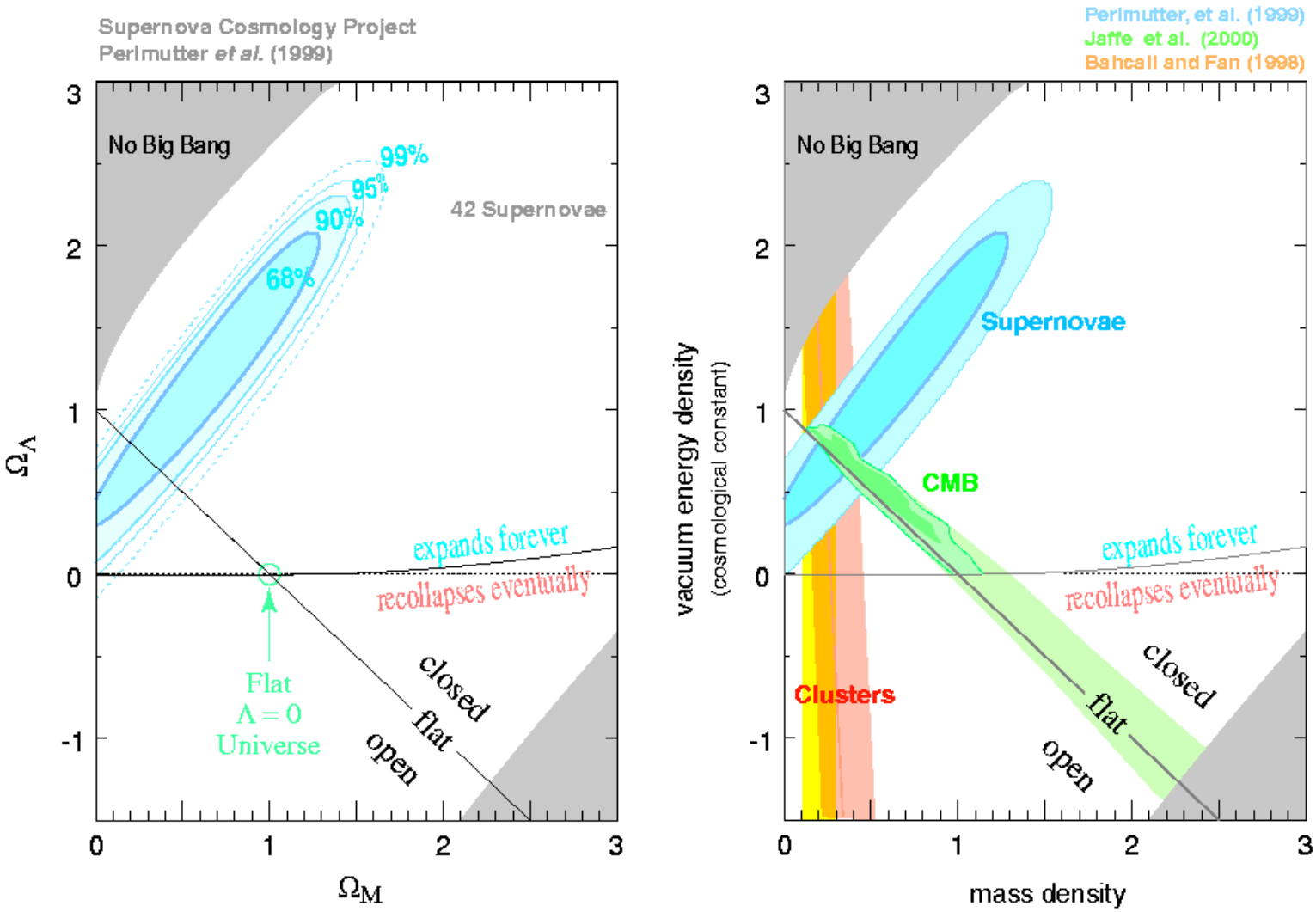
Gilles Adam, Roland Bacon, Emmanuel Pecontal
Centre de Recherche Astronomique de Lyon (CRAL)

How Type Ia SNe are Used



SCP Type Ia Supernova Hubble Diagram




Supernova Cosmology Project
Perlmutter et al. (1999)
No Big Bang
99%
95%
90%
68%
42 Supernovae
expands forever
recollapses eventually
closed
flat
open
Flat
Λ = 0
Universe
Ω_Λ
Ω_M
Perlmutter, et al. (1999)
Jaffe et al. (2000)
Bahcall and Fan (1998)
No Big Bang
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
vacuum energy density
(cosmological constant)
mass density

70% of the Universe Doesn't Fit the Standard Model

Naive estimate: $\frac{\Lambda}{8\pi G} \sim m_{Planck}^4$ off by 120 orders of magnitude!

"This is the worst prediction in all of physics."

— Michael Turner

Points to possible new physics.

A basic property of Dark Energy is its Equation of State:

$$w = p_u/\rho_u$$

For the Cosmological Constant, $w = -1$.

If Dark Energy is not the Cosmological Constant it may evolve with time:

$$w = w_0 + w_1 z + ...$$

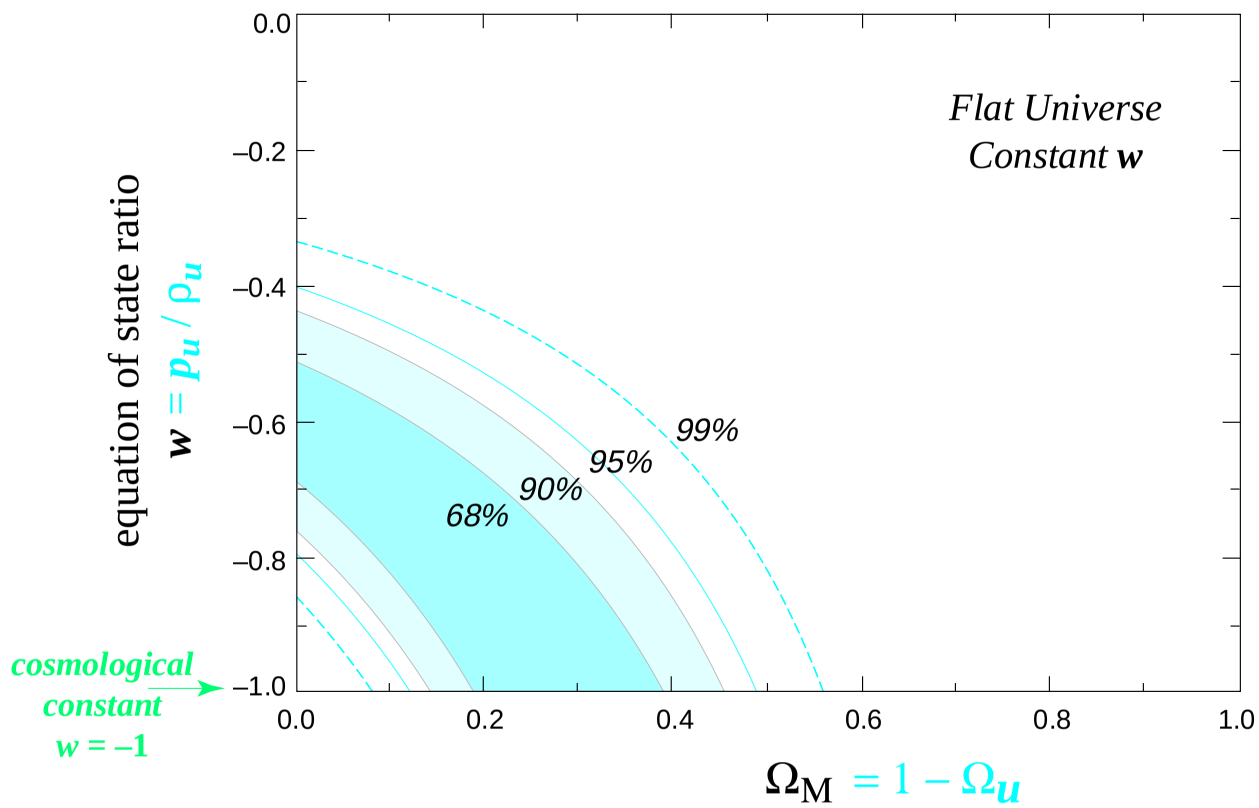
Possible candidates are Dynamical Scalar Fields, Branes, etc.

These are fundamentally different than the Cosmological Constant

Determination that $w_0 \neq -1$ would be profound

Unknown Component, Ω_u, of Energy Density

Perlmutter *et al.* (1999)



c.f. Garnavich et al. (1998)

Dark Energy is both Exciting and Baffling

"... Maybe the most fundamentally mysterious thing in basic science."

— Frank Wilczek

"Right now, not only for cosmology but for elementary particle theory, this is the bone in our throat."

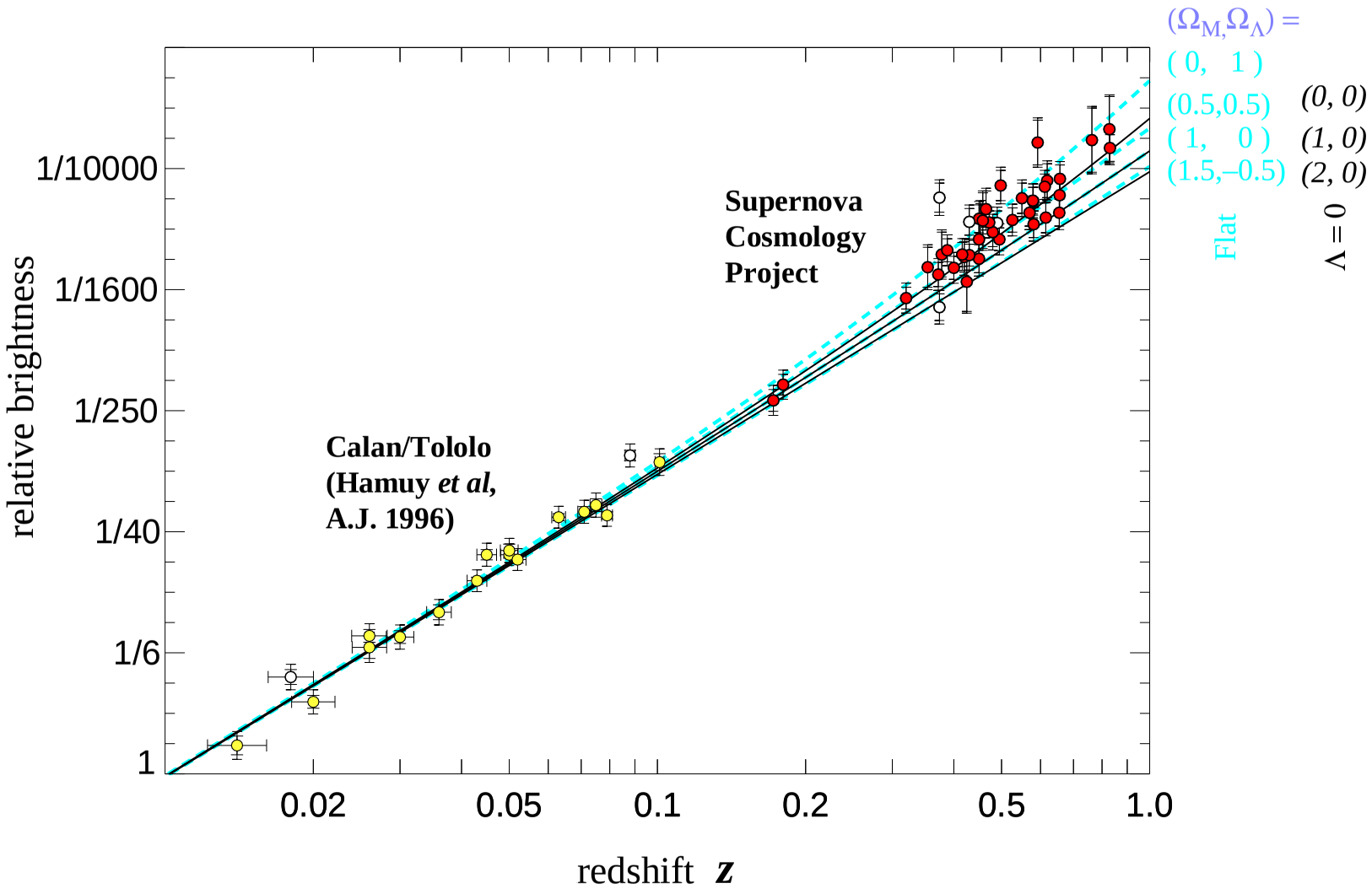
— Steven Weinberg

"... Would be No. 1 on my list of things to figure out."

— Edward Witten

Statistical Power of Nearby Supernovae

How Can Nearby Supernovae Help?



Current & Future SN Cosmology Experiments

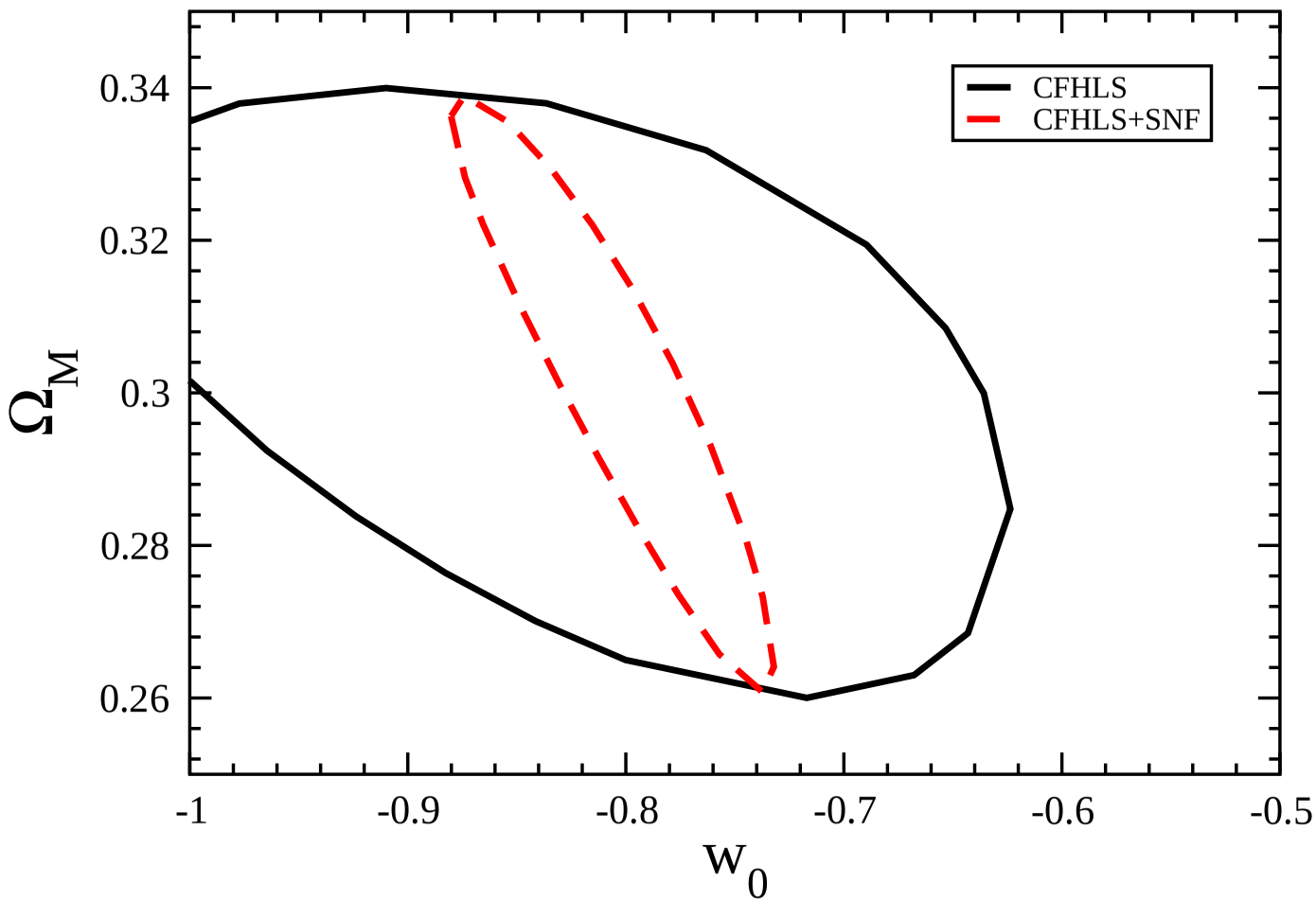
SCP-I	42 Type Ia supernovae collected during 1992 through 1997 spanning $0.2 < z < 0.83$, but concentrated near $z \sim 0.5$. Observations in two filters for most.
SCP-II	11 HST-observed Type Ia supernova collected during 1997 through 1998 spanning $0.3 < z < 0.83$. Excellent color measurements for all
SCP-III	40 Type Ia supernova collected from late 1998 through 2002 spanning $0.3 < z < 1.2$. Excellent color measurements for all. Roughly 1/3 observed with HST.
CTIO-SS	200-300 Type Ia supernova to be collected between 2002 and 2007, spanning $0.3 < z < 0.7$ with full lightcurves in two filters for all. (In proposal stage.)
CFHT-LS	750 Type Ia supernova spanning 4□$^\circ$to be collected between 2003 and 2008, spanning $0.3 < z < 0.9$ with full lightcurves in four filters for all.
SNAP	2000 Type Ia supernova to be collected between 2009 and 2011, spanning $0.3 < z < 1.7$, with full lightcurves in up to nine filters for all. (In proposal stage.)

Statistical Uncertainties with & without the *SNfactory*

Experiment	$\Omega_M\|^{flat}_{w_0=-1}$		$\Omega_M\|_{w_0=-1}$		$w_0\|^{flat}_{w_1=0}$	
	without	with	without	with	without	with
SCP	0.09	0.07	< 1	< 1	< 0.4	< 0.4
CTIO/CFHTLS	0.05	0.05	0.12	0.06	0.29	0.11

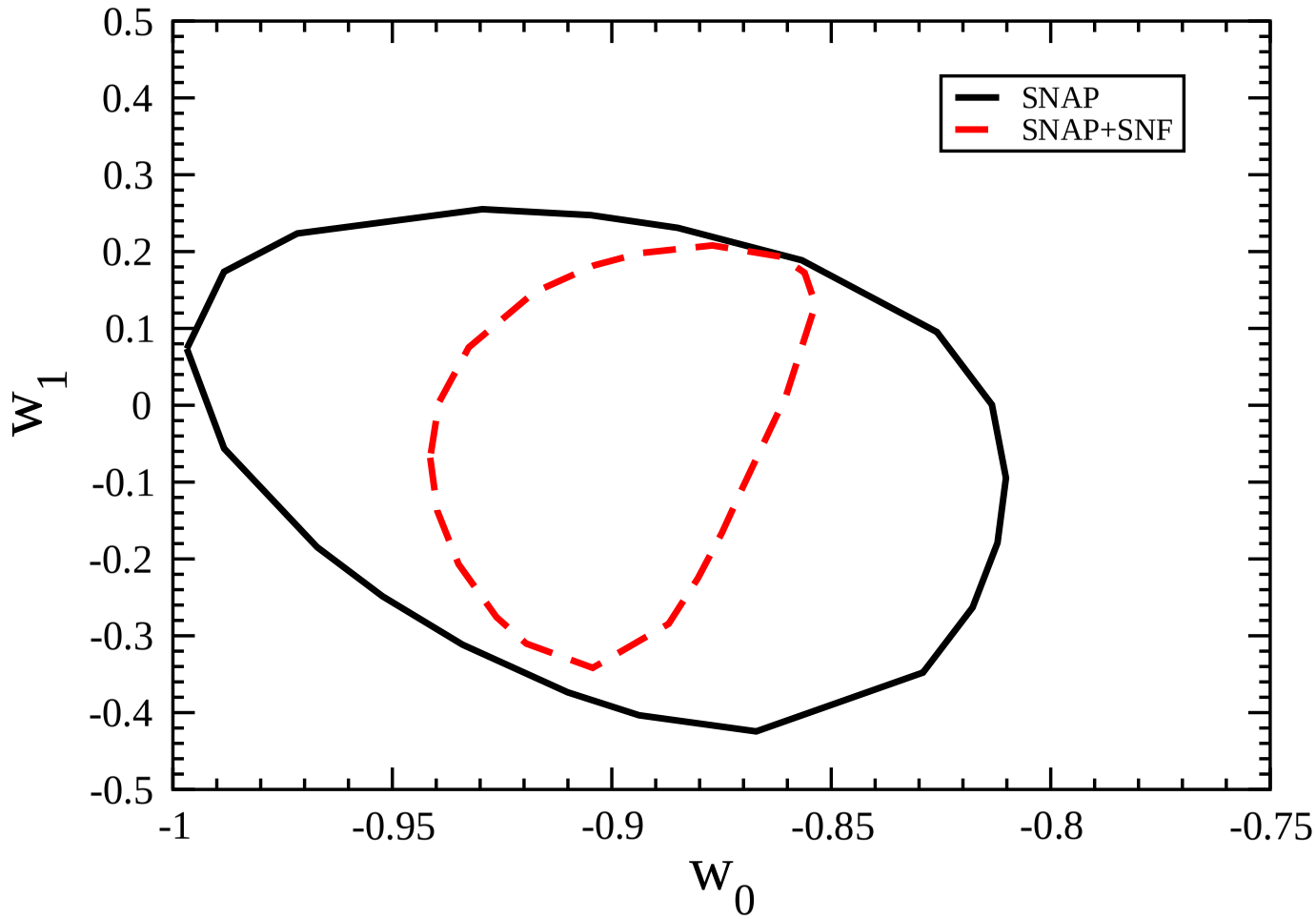
Impact on CFHT Legacy Survey

$$w \equiv w_0$$



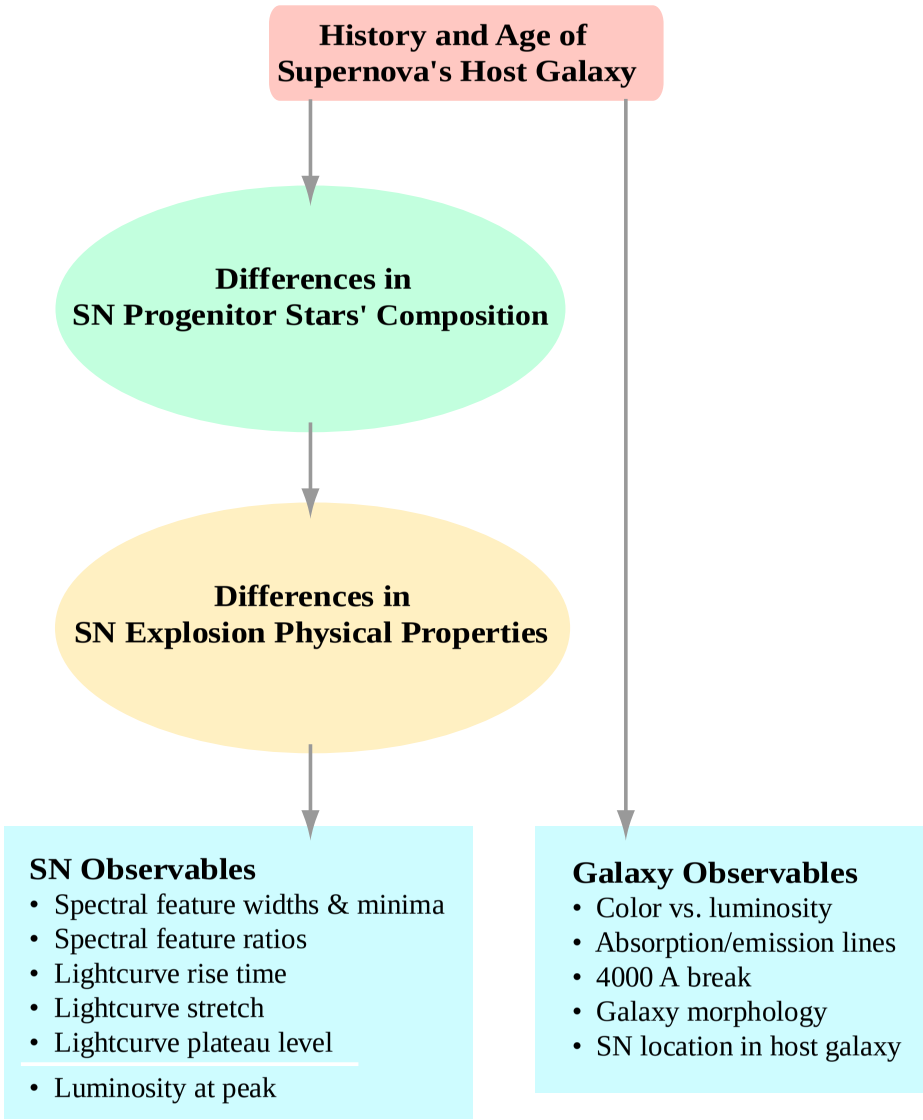
Impact on SuperNova/Acceleration Probe

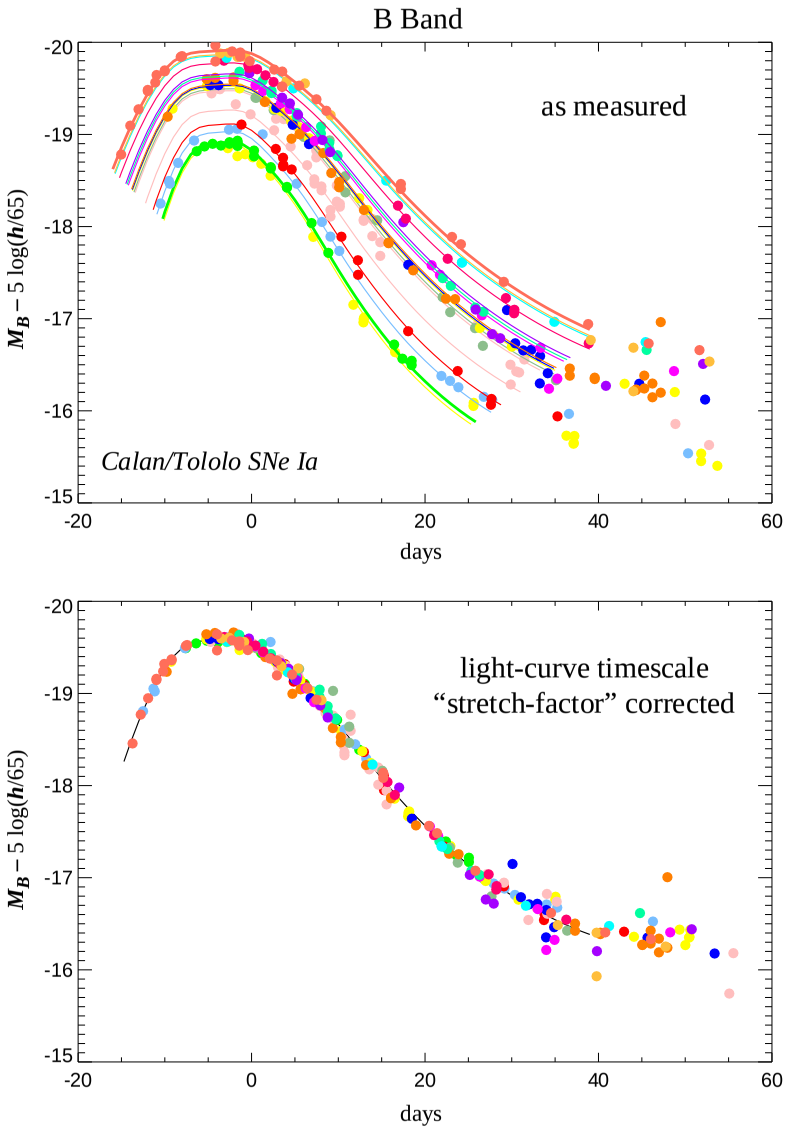
$$w \equiv w_0 + w_1 z$$



Systematics Improvements

Matching SN Evolutionary States

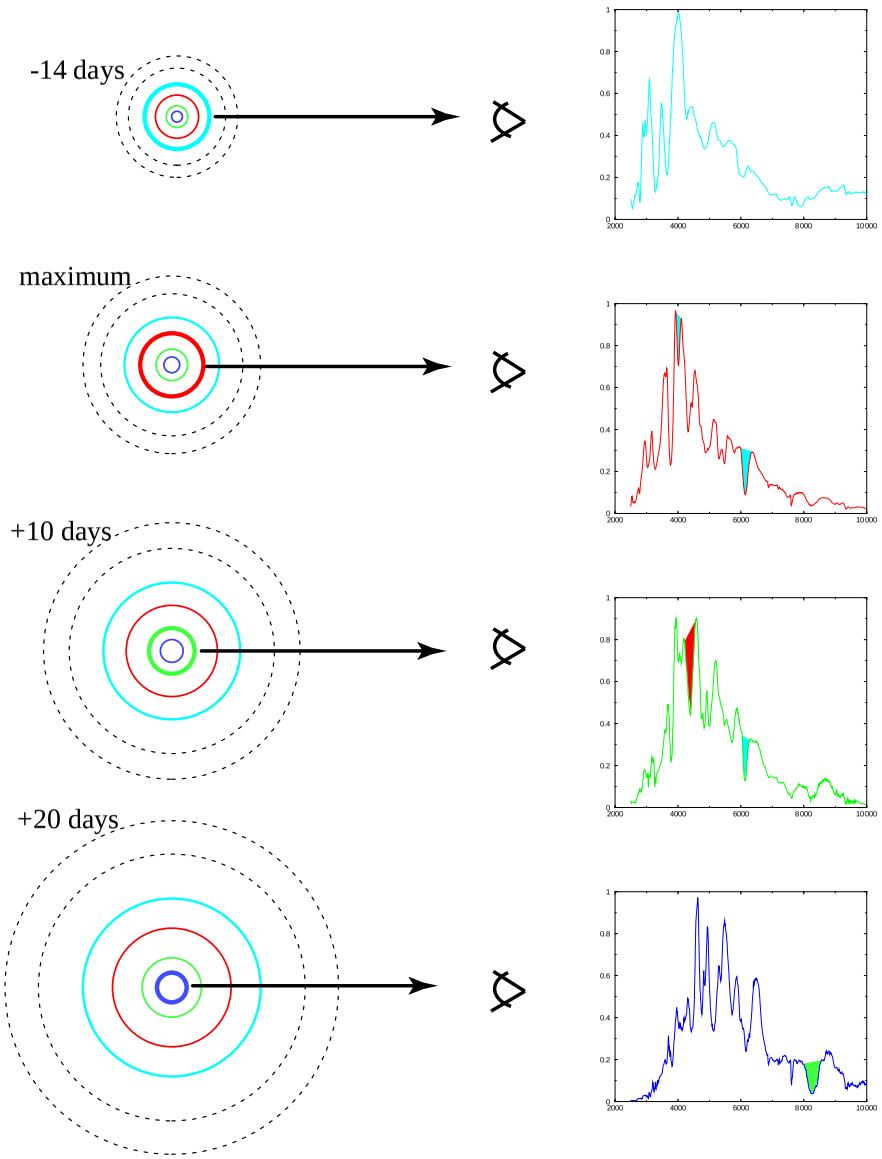




Stretch-Luminosity relation appears to homogenize Type Ia Supernovae

If true, then "average" SN lies on Stretch-Luminosity relation, and can be corrected at any redshift

The time series of spectra is a “CAT Scan” of the Supernova



SNfactory Explores SN Parameter Space

1

Sort into Like Subsets

Group A:
* Si II in spectrum: type Ia
* elliptical host
* bright UV: low metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

⋮

Group B:
* Si II in spectrum: type Ia
* in core of late-type spiral host
* faint UV: high metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

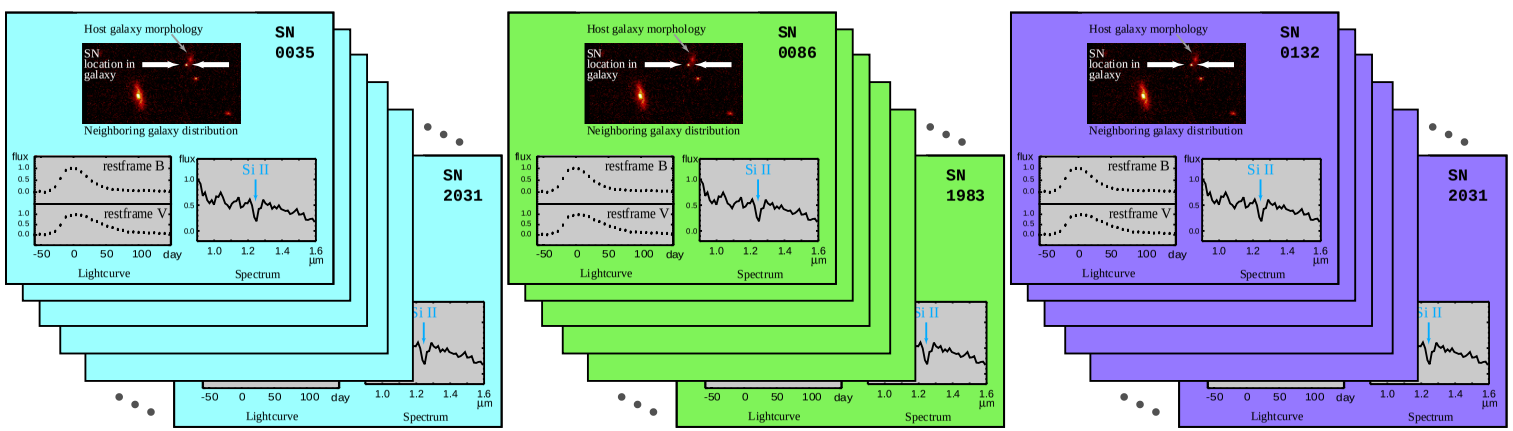
⋮

Group C:
* Si II in spectrum: type Ia
* in outskirts of late-type spiral host
* bright UV: low metallicity
* long rise time: high Ni56 mass
* spectral feature velocities
  8000 < v < 9500 km/s

⋮

•••

Group C:
* Si II in spectrum: type Ia
* in coreof late-type spiral host
* bright UV: low metallicity
* short rise time: high Ni56 mass
* spectral feature velocities
  8000 < v < 9500 km/s



Matching Likes to Likes

Each subset gets its own extinction-corrected Hubble diagram:

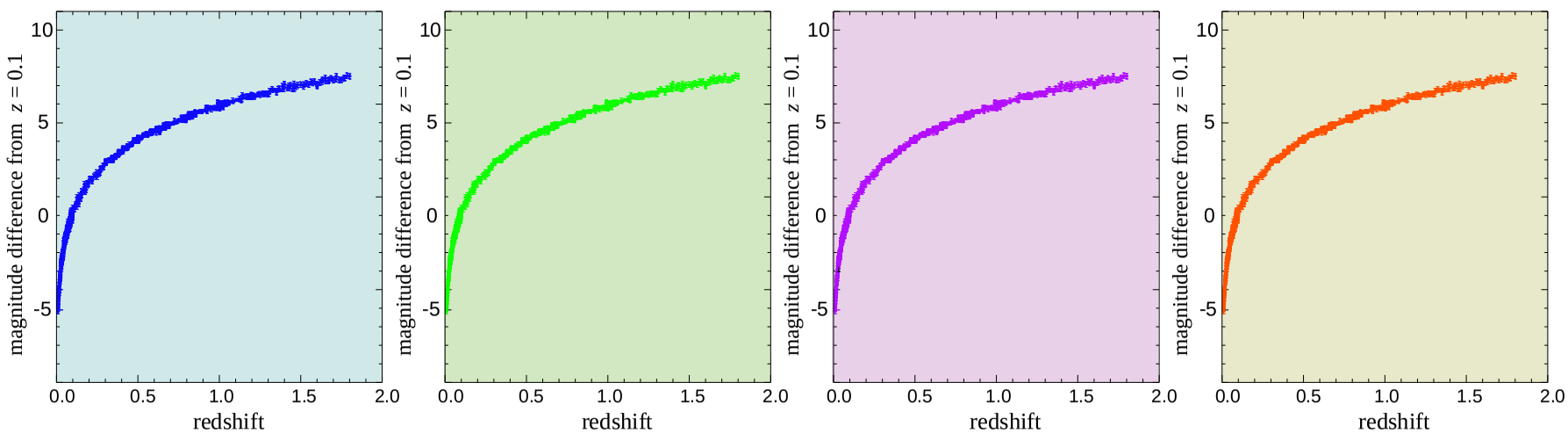
Group A:
* Si II in spectrum: type Ia
* elliptical host
* bright UV: low metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

Group B:
* Si II in spectrum: type Ia
* in core of late-type spiral host
* faint UV: high metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

Group C:
* Si II in spectrum: type Ia
* in outskirts of late-type spiral host
* bright UV: low metallicity
* long rise time: high Ni56 mass
* spectral feature velocities
  8000 < v < 9500 km/s

• • •

Group C:
* Si II in spectrum: type Ia
* in coreof late-type spiral host
* bright UV: low metallicity
* short rise time: high Ni56 mass
* spectral feature velocities
  8000 < v < 9500 km/s



SNfactory Implementation

SNfactory Fills a Key Niche

The Issues:

- The technique of Type Ia supernovae is the only method developed well enough to begin probing w.
- Low-redshift SN searches fundamentally incompatible with high-redshift searches
  (deep & narrow field vs. shallow & wide field)
- Current low-redshift SN searches concentrate on galaxies which are too nearby
- Most low-redshift SN searches revisit fields infrequently so most SN are after maximum light
- Intensive & homogeneous spectroscopy essential, but rarely done

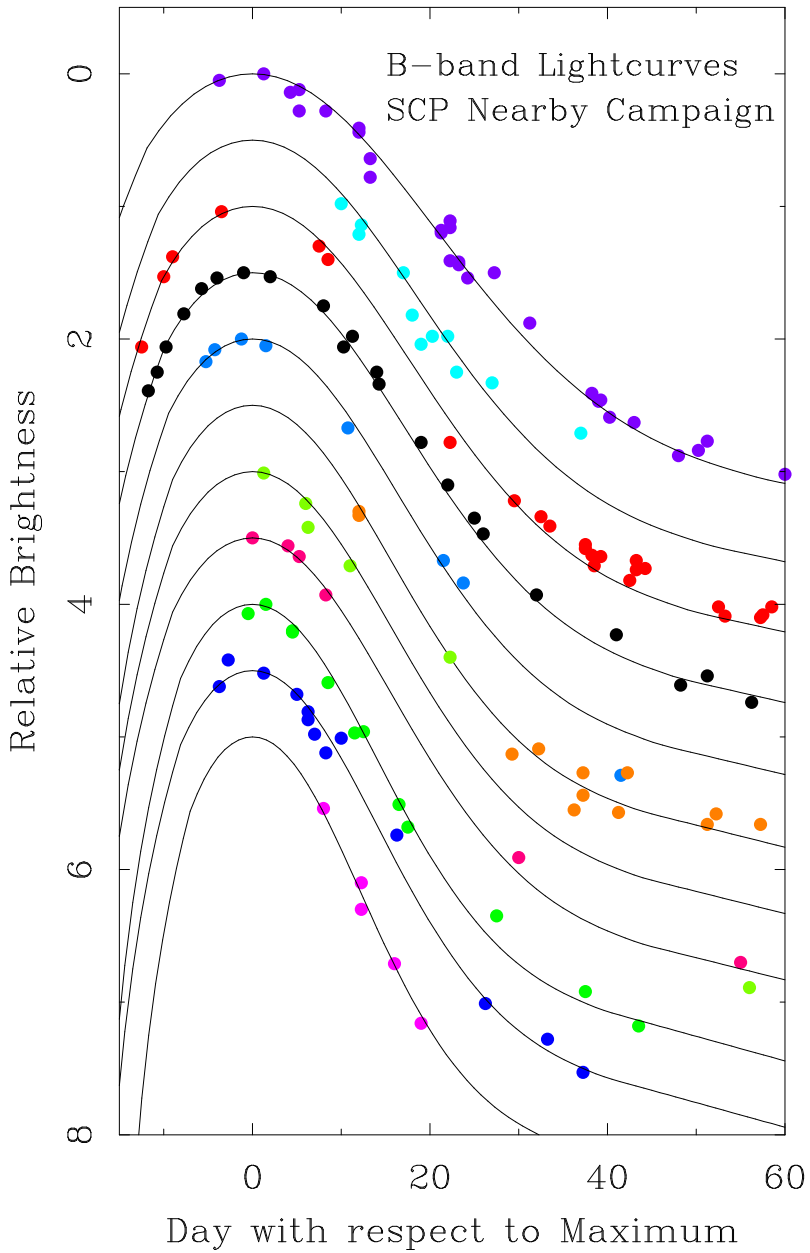
A solution: The Nearby Supernova Factory

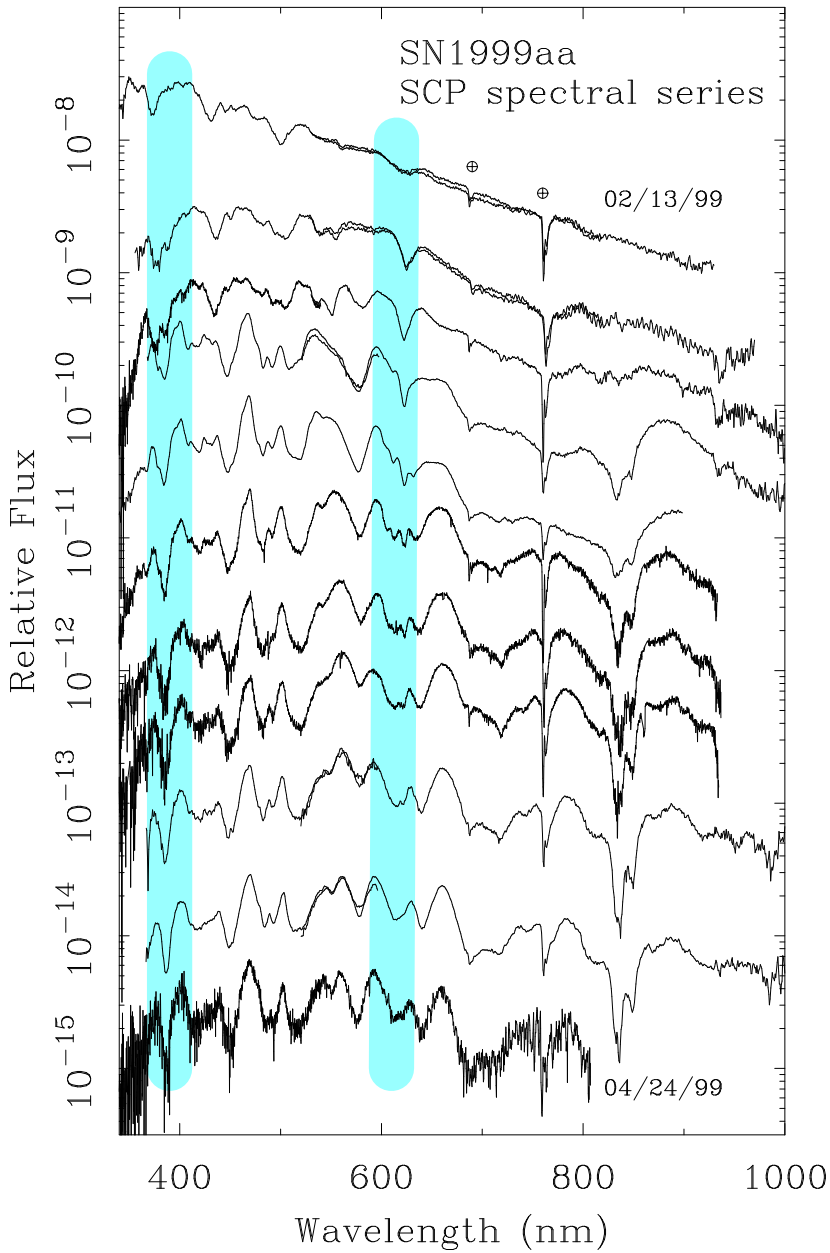
- Very wide-field search to $z \sim 0.08$ with weekly repeats
- Dedicated spectrograph optimized for SN work with access several times each week

Primary Nearby Supernova Factory Goals

- calibrate SN brightness using low-z portion of Hubble diagram
- test and refine the standard lightcurve stretch—brightness relation
- refine K-corrections as a function of lightcurve phase
- determine intrinsic (unreddened) SNe Ia color-curves
- test for abnormal host-galaxy dust extinction laws
- construct early template lightcurves

The Pilot Program: The SCP Spring 1999 Nearby Campaign





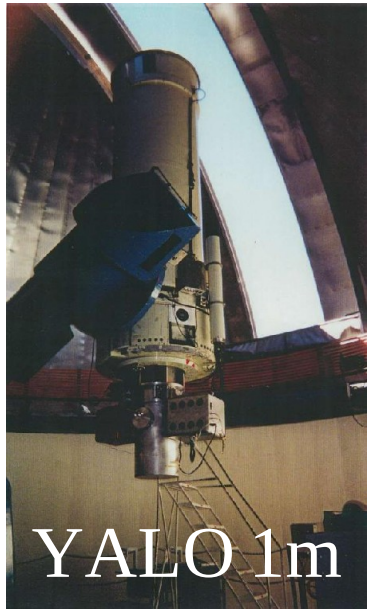
SNfactory Baseline Program

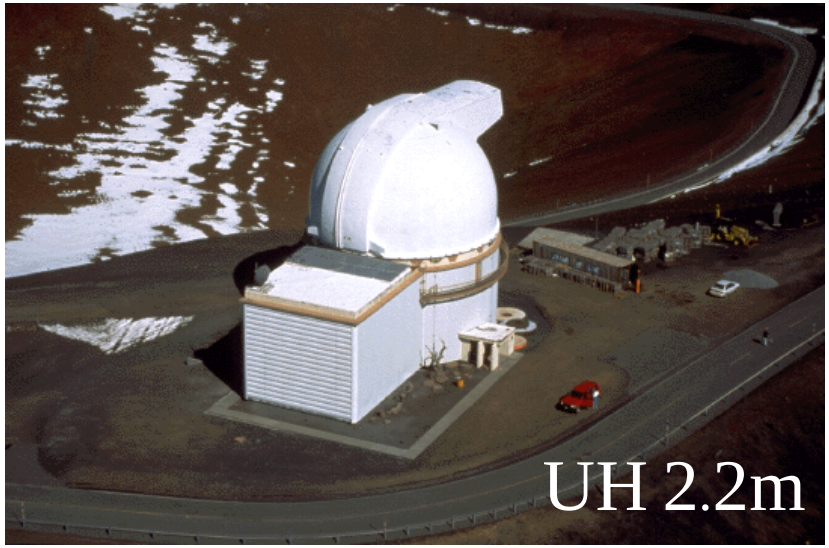
- 300 Type Ia supernova over 3.5 yrs
- Discovery via blind, wide-field CCD search
- Concentrate on nearby smooth Hubble-flow $0.03 < z < 0.08$
- Early discovery, 10–15 days before maximum

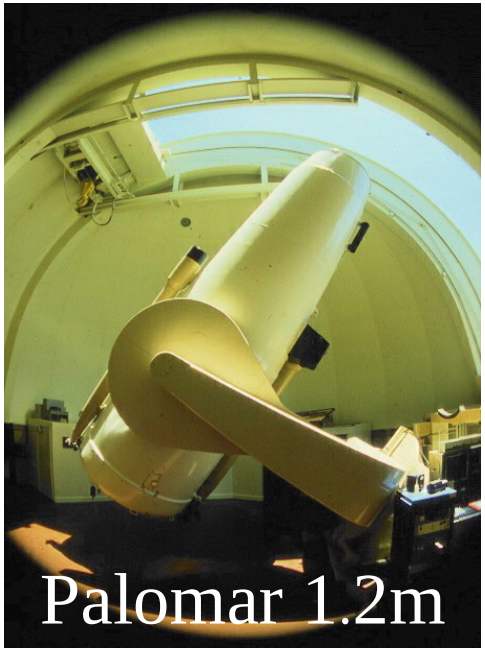
  - Flux-calibrated optical spectroscopy every 3–5 days
  - Follow-up from -15 to $+45$ days; more for nearer SNe
  - Lightcurve follow-up for $0.03 < z$ for peculiar velocities

- UV spectroscopy for small subset using Hubble Space Telescope
- Near-infrared lightcurves and/or spectra for small subset

SNfactory Observing Facilities



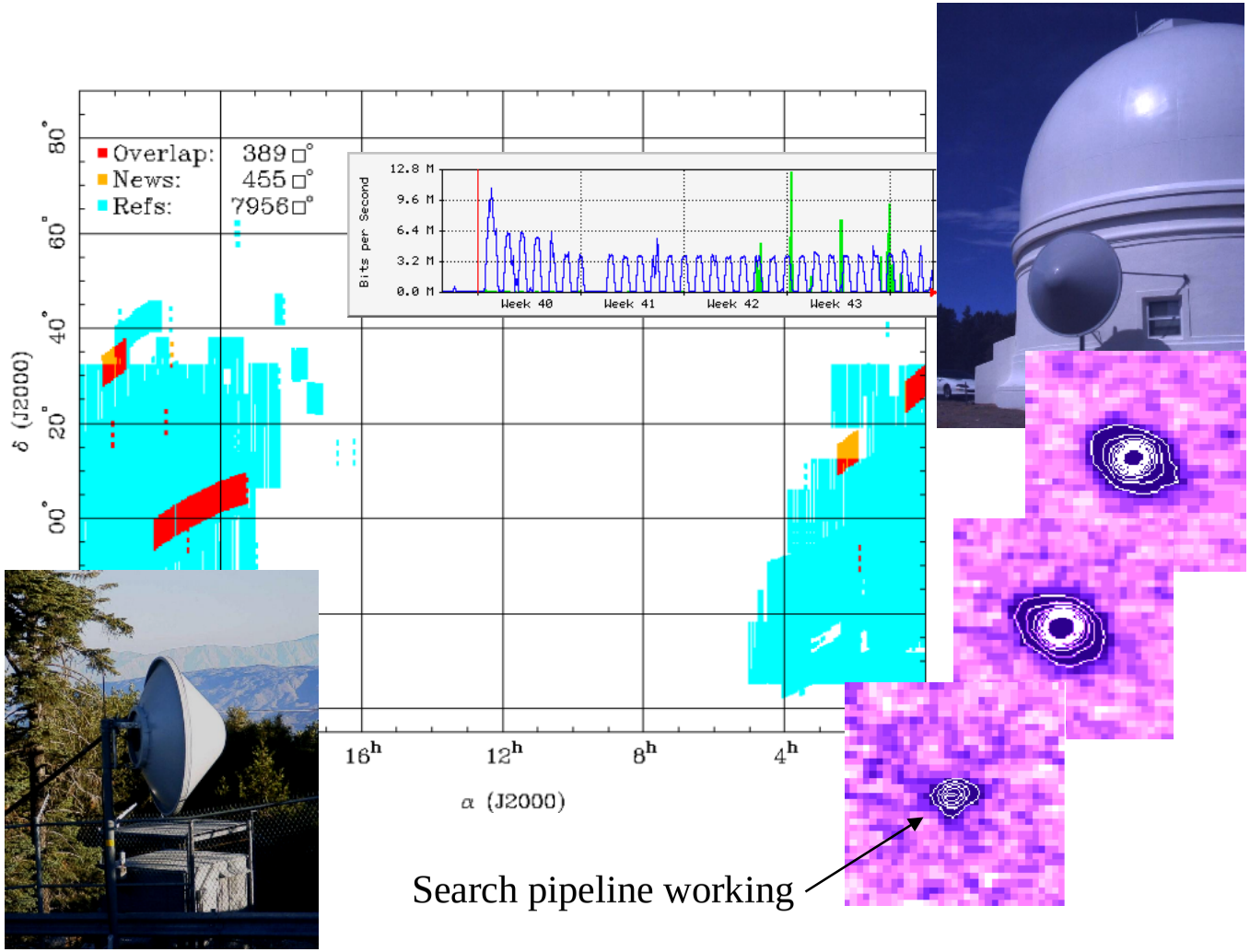




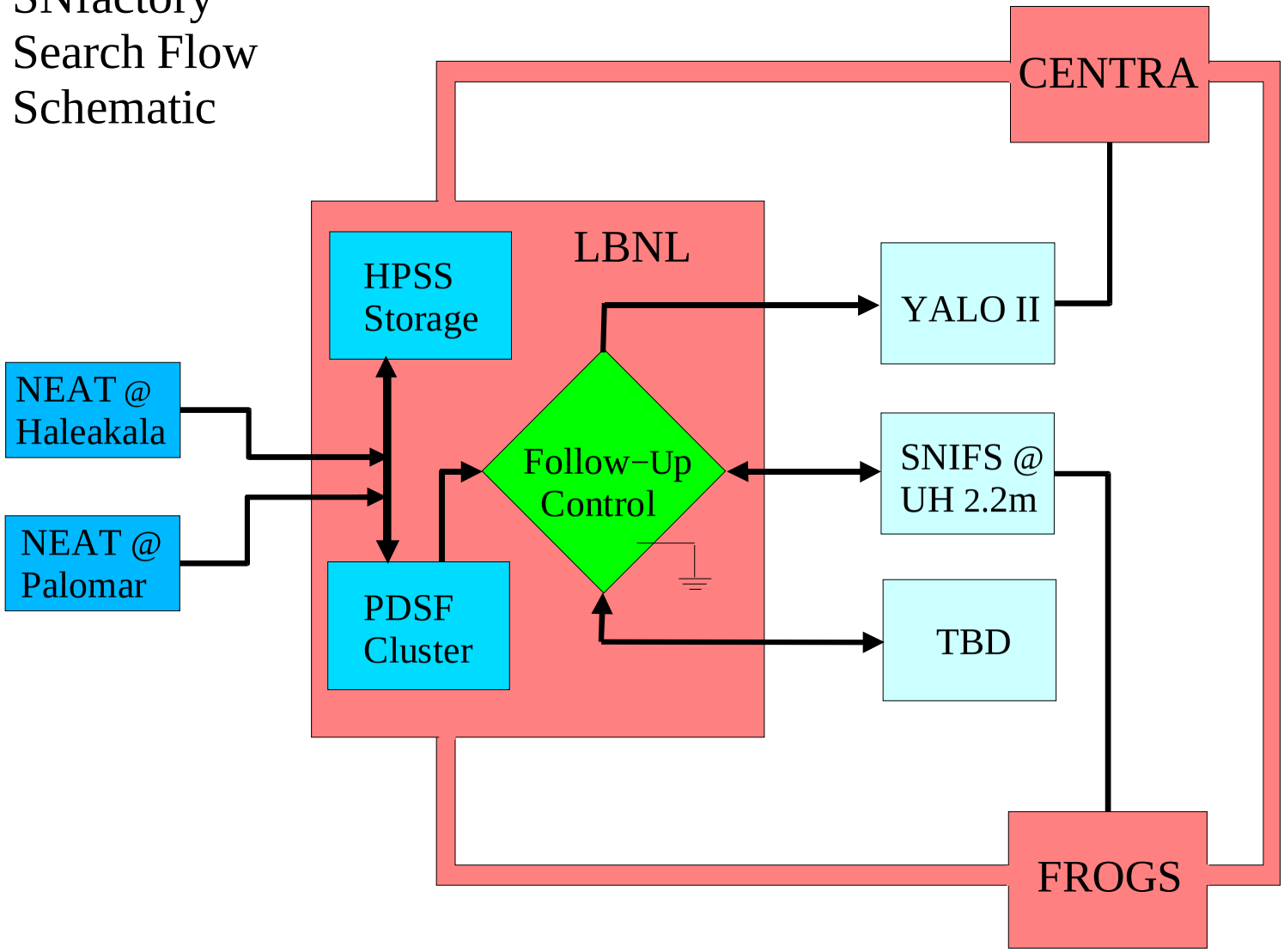
NEAT Search Facilities

Site:	Haleakala	Palomar I	Palomar II
Aperture:	1.2m	1.2m	1.2m
Nights/Month:	18 dark/gray	18 dark/gray	9 dark/gray
Imager Format:	$4k \times 4k$	$3 \times 4k \times 4k$	$112 \times 2.4k \times 0.6k$
Imager Scale:	$1.33''$/pixel	$1.01''$/pixel	$0.87''$/pixel
Field of View:	$1.5^\circ \times 1.5^\circ$	$1.1^\circ \times 3.4^\circ$	$2.3^\circ \times 4.0^\circ$
Filters:	open	open	open
Exposures:	3×20 sec	3×60 sec	TBD
Readout:	20 sec	20 sec	40 sec
Nightly Coverage:	$300\square^\circ$	$500\square^\circ$	$(1000\ \square^\circ)$
Start:	Mar 2000	Apr 2001	$\sim$Aug 2002
Data (compressed):	12 Gbyte/night	40 Gbyte/night	(80 Gbyte/night)

Data Streamed to LBNL via Wireless

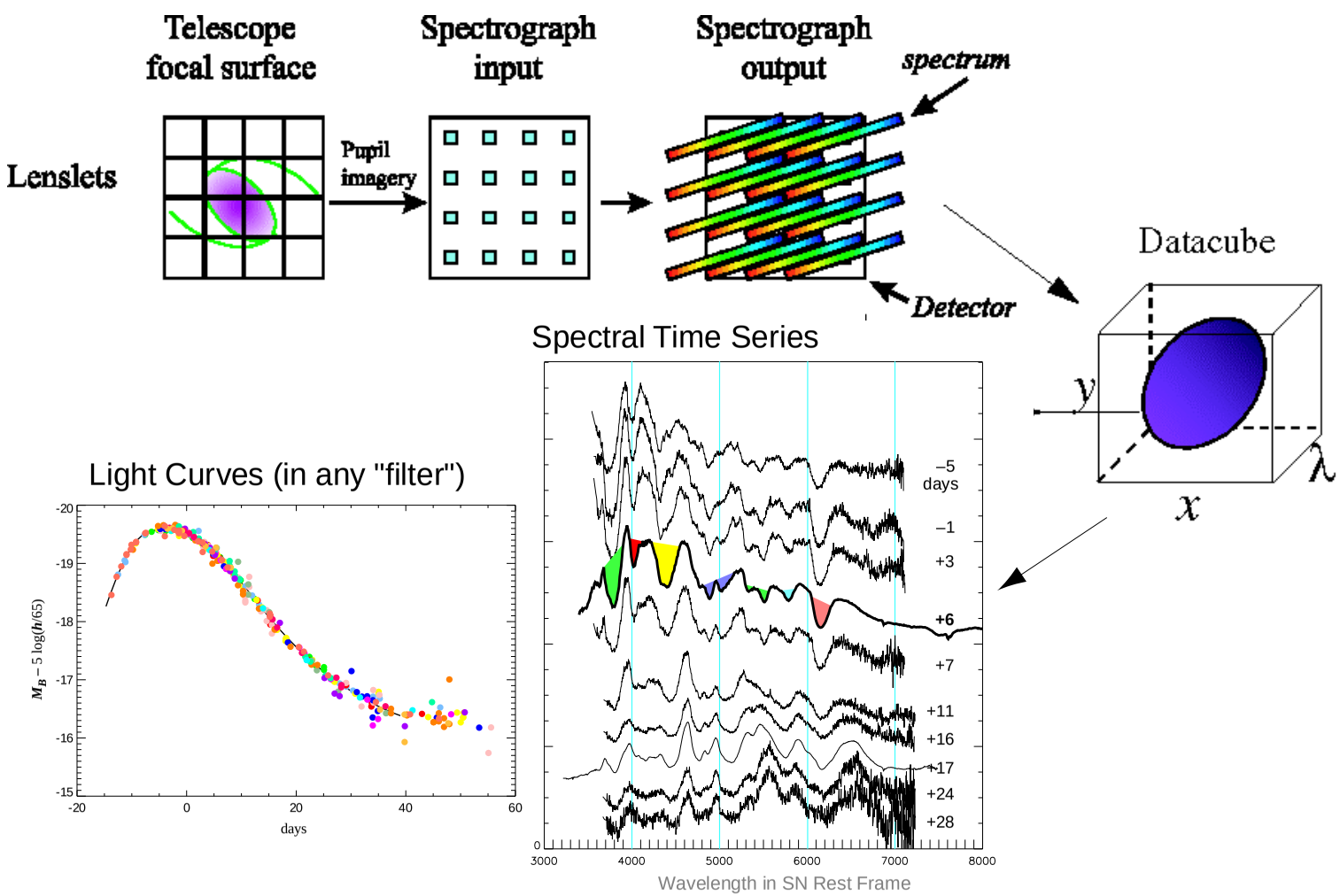


SNfactory
Search Flow
Schematic



Integral Field Unit Operating Principle

"Integral Field Unit" Spectrograph



SuperNova Integral Field Spectrograph Specifications

Integral Field Unit

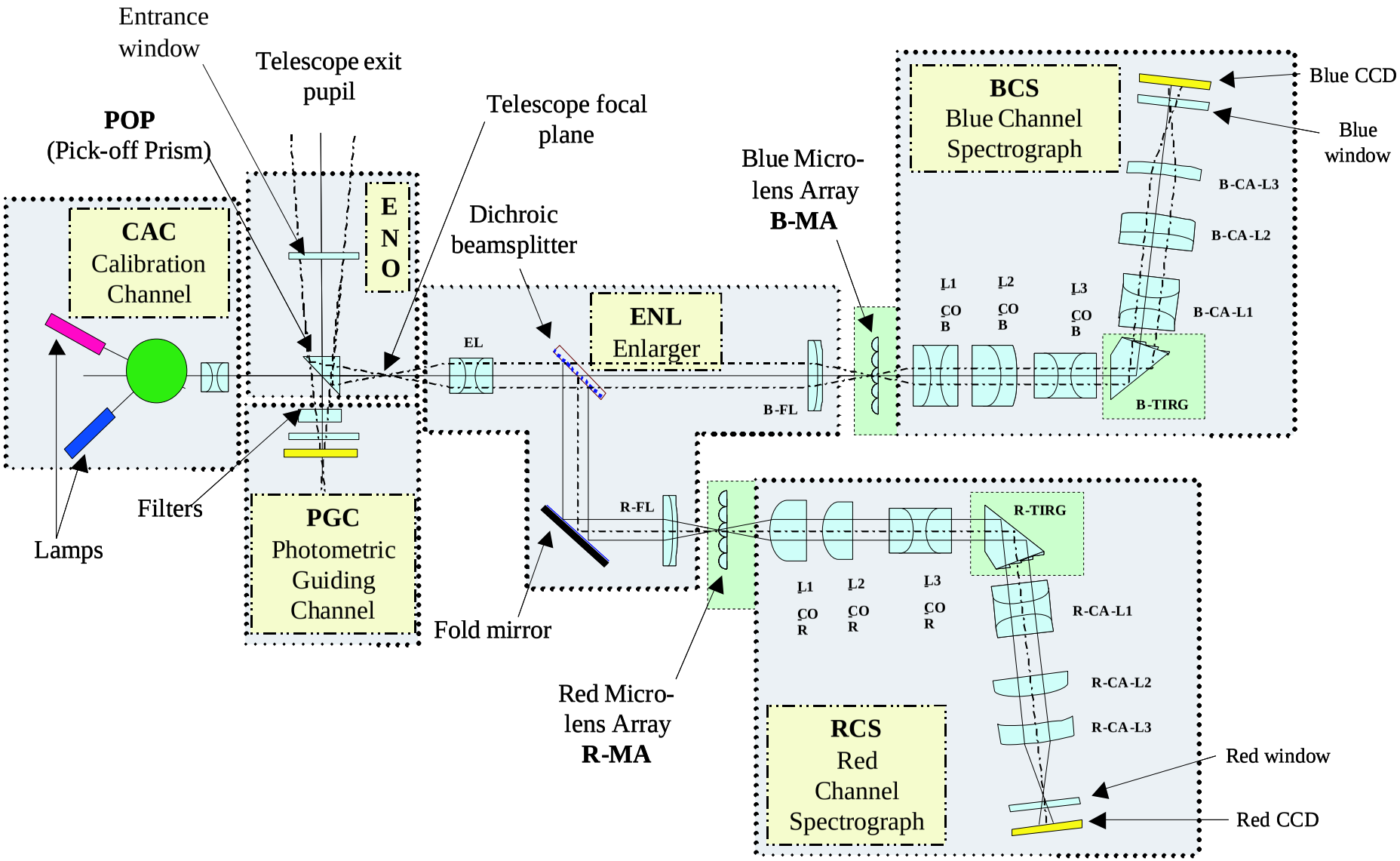
Scale	$0.4''$/lens
Field of View	$6'' \times 6''$

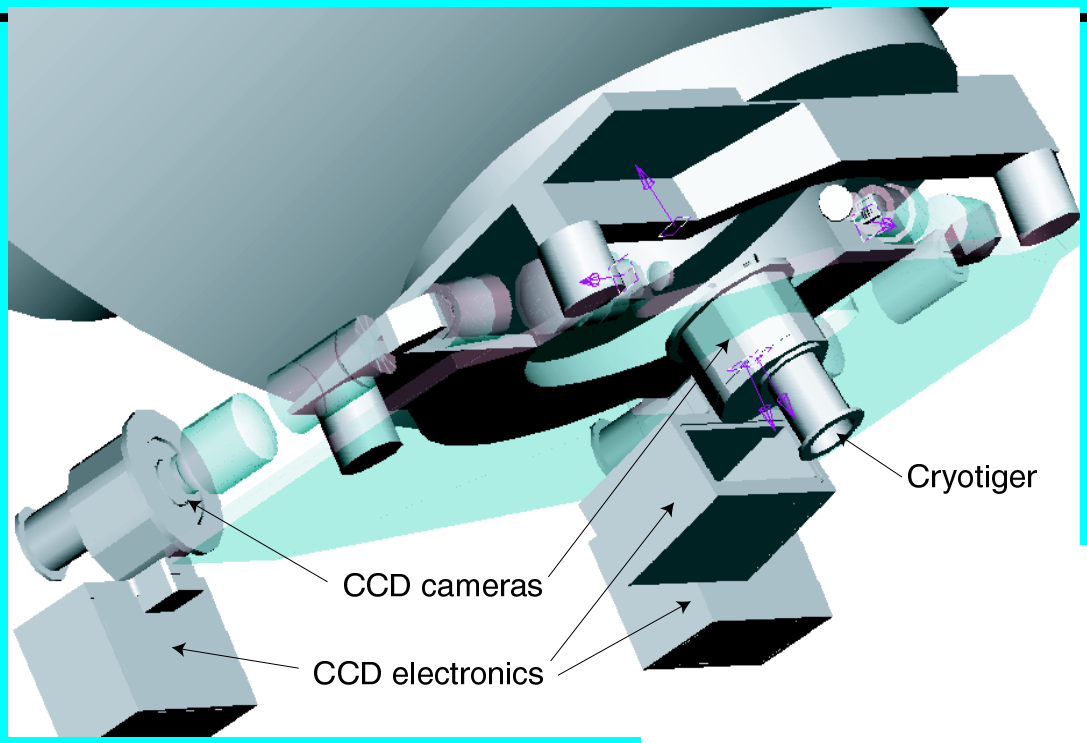
Spectrograph

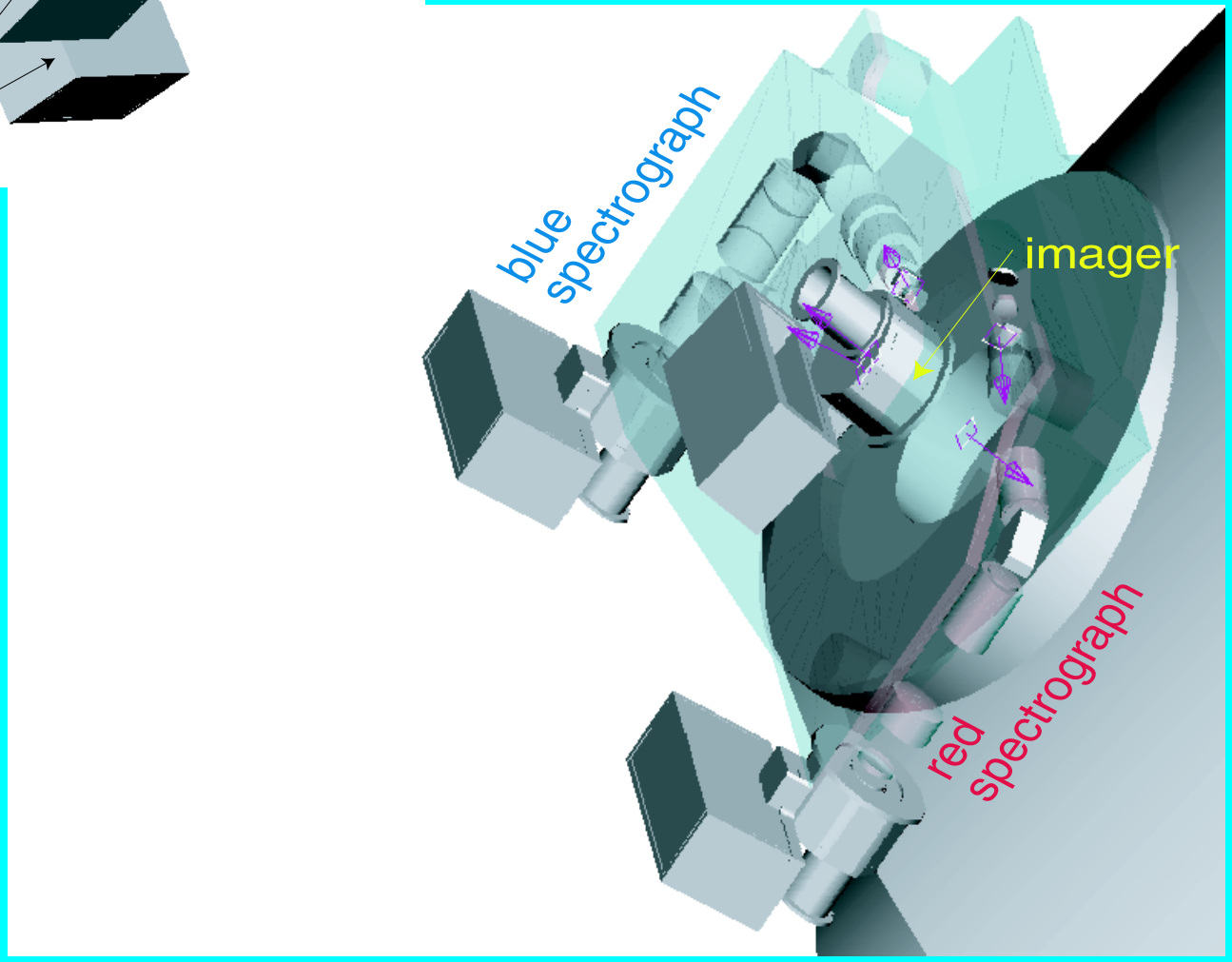
Channel	Blue	Red
Coverage	3200–5500Å	5500–10000Å
Spectral Dispersion	2.3Å/pixel	3.3Å/pixel
Grism	300 l/mm $\lambda_B = 4200$Å	300 l/mm $\lambda_B = 6500$Å
Detector	Marconi 2k $\times$ 4k	LBNL 2k $\times$ 4k
Calibration	He/Hg/Cd + flat	Ne/Ar/Xe + flat

Auxillary Camera & Guider/Focuser Camera

Scale	$0.14''$/pixel
Field of View	$4.7' \times 9.4'$
Detector	LBNL 2k $\times$ 4k
Filters	u,g,r,i,z,extinction monitor


Entrance window
Telescope exit pupil
POP
(Pick-off Prism)
Telescope focal plane
Dichroic beamsplitter
Blue Micro-lens Array
B-MA
BCS
Blue Channel Spectrograph
Blue CCD
Blue window
B-CA-L3
B-CA-L2
B-CA-L1
B-TIRG
L1 CO B
L2 CO B
L3 CO B
CAC
Calibration Channel
E N O
ENL
Enlarger
EL
B-FL
Filters
Lamps
PGC
Photometric Guiding Channel
R-FL
Fold mirror
Red Micro-lens Array
R-MA
R-TIRG
L1 CO R
L2 CO R
L3 CO R
R-CA-L1
R-CA-L2
R-CA-L3
RCS
Red Channel Spectrograph
Red window
Red CCD


Cryotiger
CCD cameras
CCD electronics


blue spectrograph
imager
red spectrograph

Project

SNfactory Major Project Milestones

Date		Milestone
Summer	1999	Project inception
Spring	2003	*SNfactory* operations begin
Spring	2006	Discovery stage completed (final refs continue)
Spring	2007	Observing operations completed
Spring	2008	Analysis operations completed

SNfactory Project Construction Milestones

Date		Milestone
Summer	2000	*SNIFS* conceptual design begun
Summer	2001	Agreement for use of UH 2.2-m reached
Summer	2001	Palomar telecommunications established
Fall	2001	Preliminary search pipeline operational
Summer	2002	Preliminary spectral reduction pipeline operational
Summer	2002	Final search pipeline operational
Fall	2002	Completion of *SNIFS* CCD cameras
Fall	2002	Completion of *SNIFS* optical fabrication
Winter	2002	*SNIFS* integration & test (Lyon)
Winter	2002	Final data reduction pipeline operational
Winter	2002	*SNIFS* integration & test (Hawaii)

SNfactory Management

Person	Role	Position
G. Aldering	Exec Comm / Project Leader	LBNL Staff Scientist
R. Pain	Exec Comm / French Spokesperson	LPNHE Staff Scientist
S. Perlmutter	Exec Comm	LBNL Sr. Staff Scientist
P. Antilogus	Computing Scientist	IPNL Staff Scientist
E. Pecontal	*SNIFS* Instrument Scientist	CRAL Staff Scientist
J. P. Lemmonier	*SNIFS* Project Manager	CRAL Sr. Engineer
S. Loken	LBNL Project Manager	LBNL Sr. Staff Scientist

SNfactory Additional Scientific Manpower

Person	Role	Position
G. Adams	instrument design	CRAL staff scientist
P. Astier	software	LPNHE staff scientist
R. Bacon	instrument oversite	CRAL director
S. Bongard	simulations	IPNL graduate student
C. Bonnaud	simulations	CRAL graduate student
Y. Copin	spectrum software	IPNL postdoc
G. Goldhaber	scanner supervision	UCB professor
D. Hardin	data analysis	LPNHE staff scientist
D. A. Howell	SN matching software	LBNL postdoc
J. M. Levy	data analysis	LPNHE staff scientist
P. Nugent	SN Theory	LBNL staff scientist
R. Quimby	acquistion software	LBNL pre-graduate student
G. Smadja	simulations	IPNL sr. staff scientist
G. Sainton	spectral reductions	LPNHE graduate student
K. Schamananeche	observing control	LPNHE staff scientist
W. Wood-Vasey	search software	UCB graduate student

SNfactory Additional Technical Manpower

Person	Role	Position
C. Aufranc	computing	CCIN2P3 computing scientist
D. Boudon	fabrication	CRAL machinist
L. Capoani	mechanical	CRAL mechanical engineer
R. Godon	electronics	CRAL electrical engineer
F. Henault	optics	CRAL engineer
D. Imbault	fabrication	IN2P3 mechanical engineer
A. Pecontal-Rousset	instrument software	CRAL computing scientist
M. Rouxel	instrument Control	CRAL technician

LBNL SNfactory Budget

Fiscal Year	Amount	Source	Purpose
2000	$300K	LDRD	PD + commercial CCD
2001	$300K	LDRD	PD + 2 GSRA + 1 camera
2002	$300K	LDRD	PD + 2 GSRA + 2 cameras
2003	$488K	Phys Div	UH 2.2m + 2 PD + 2 GSRA + S&E
2004	$675K	Phys Div	UH 2.2m + 2 PD + 2 GSRA + S&E
2005	$675K	Phys Div	UH 2.2m + 2 PD + 2 GSRA + S&E
2006	$583K	Phys Div	UH 2.2m + 2 PD + 2 GSRA + S&E
2007	$415K	Phys Div	UH 2.2m + 2 PD + 2 GSRA + S&E
2008	$340K	Phys Div	2 PD + 2 GSRA + S&E
Total	$4.08M		
Outyear Funds	$3.18M		

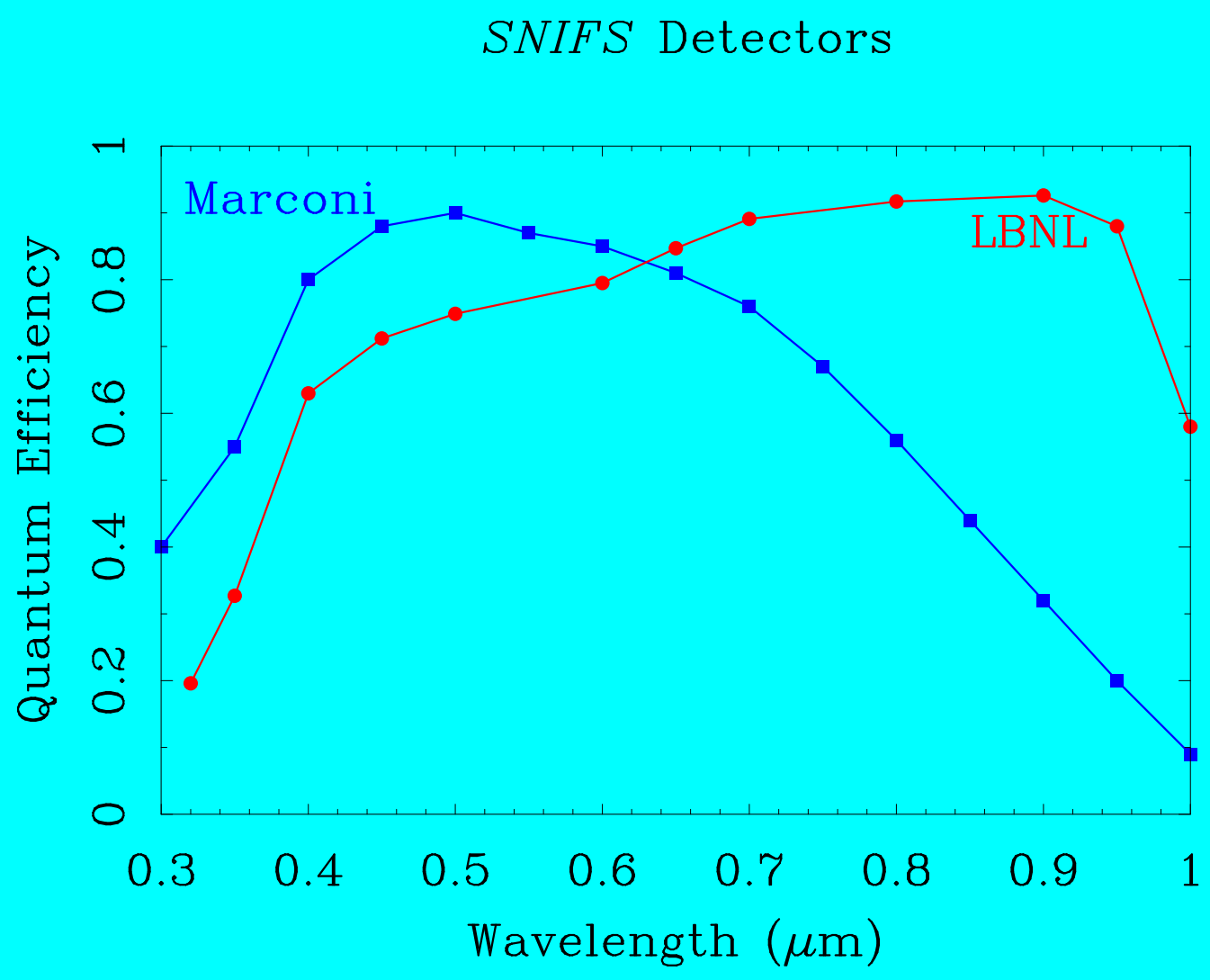
During 2003-2007 roughly half is for pro-rated telescope maintenence.

The other half goes towards PD's and GSRA's.

In France: $400K for *SNIFS*, 1 PD, 3 GSRA's, 8 Tech's, plus scientists.

LBNL Deliverables

- 4 CCD's (1 commercial & 3 LBNL)
- 3 cameras (CCD's, cryostats, electronics, & coolers)
- UH 2.2-m telescope access (20% share)
- NEAT data access
- HPSS storage of NEAT dataset (via NERSC)
- SN search pipeline
- Parallel Distributed Systems Facilities (PDSF) access
- SNIFS target acquisition software
- SNIFS spectral classification software
- Follow-up control & monitoring pipeline
- Expertise in science analysis (inc. lightcurve & spectral analysis)


SNIFS Detectors
Marconi
LBNL
Quantum Efficiency
0
0.2
0.4
0.6
0.8
1
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Wavelength (μm)

Summary

- Dark Energy is a profound mystery for particle physics
- SNfactory doubles accuracy on w_0 for next-gen SN tests for $w_0 \neq -1$
- SNfactory doubles accuracy on w_0 for 3rd-gen SN tests for $w_1 \neq 0$
- SNfactory is a tremendous asset for addressing systematics
- Implementation plan in place & “construction” begun
- On the air in Spring 2003

Endorsements from Non-Cosmologists

"Obtaining a uniform photometric and spectroscopic database for a large number of supernovae certainly is the best way to advance our understanding of which stars explode, and how they do it ... [and to] advance the use of supernovae as precision distance indicators for cosmology."

— David Branch, Professor, University of Oklahoma

"I am an enthusiastic supporter of this project. We still have alot to understand both about supernovae themselves and their application to cosmology... There are the rare events that may prove quite critical in understanding novel kinds of supernovae and their relation to gamma-ray bursts."

— Stan Woosley, Professor, University of California at Santa Cruz

"I strongly support the goals of the Supernova Factory."

— J. Craig Wheeler, Regents Professor, University of Texas at Austin

"The SNfactory will provide an excellent set of data with which we will confront the theoretical models with observations and perfect the laboratory experiments."

— Bruce A. Remington, Hydrodynamics Group Leader, LLNL

"The Supernova Factory data set will be a gold-mine for understanding the nature of supernovae and for studying their use in observational cosmology."

— Edward Baron, Professor, University of Oklahoma

"... Supernovae are perfect laboratories to test physics, e.g. nuclear reactions, combustion physics, radiation hydrodynamics, systems out of thermodynamical equilibrium ... We need a project such as the Supernovae Factory."

— Peter Hoeflich, Research Scientist, University of Texas at Austin

Other supporters: Tony Mezzacappaa (ORNL), Dimitri Mihalas (LANL), Mario Hamuy (OCIW), ...

LBNL Budget Breakdown

Fiscal Year	UH	PD's	GSRA's	S&E	Total
2003	$150K	$200K	$100K	$38K	$488K
2004	$300K	$200K	$100K	$75K	$675K
2005	$300K	$200K	$100K	$75K	$675K
2006	$225K	$200K	$100K	$58K	$583K
2007	$75K	$200K	$100K	$40K	$415K
2008	$0K	$200K	$100K	$40K	$340K

SNIFS Construction Costs

Item	Amount
Optics	$350K
Calibration Assembly	$50K
Marconi CCD	$87K
Camera #1 (w/ electronics & cooler)	$85K
Camera #2 (w/ electronics & cooler)	$85K
Camera #3 (w/ electronics & cooler)	$85K
Total	$742K