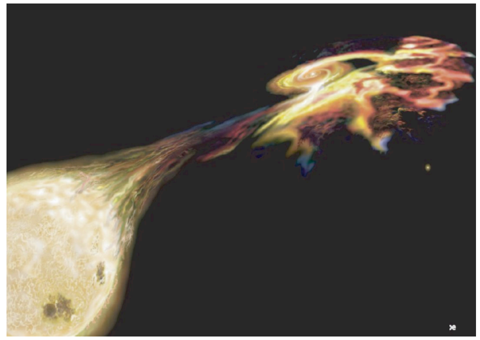
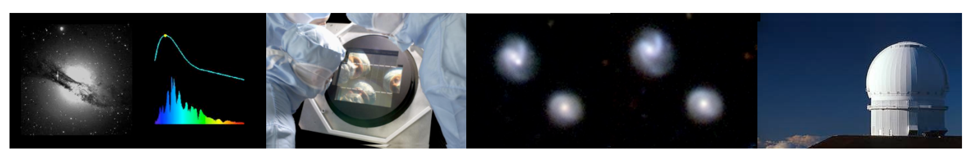
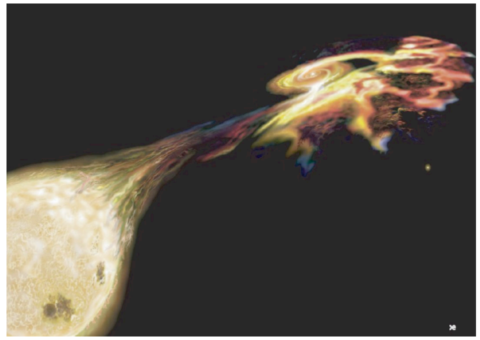


Part III

SNLS

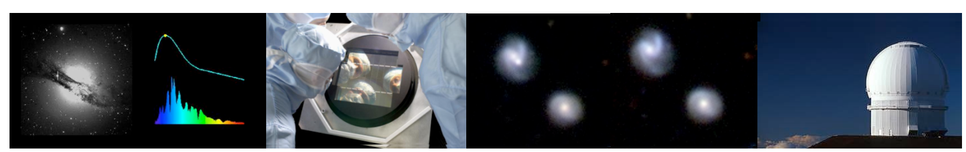
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf





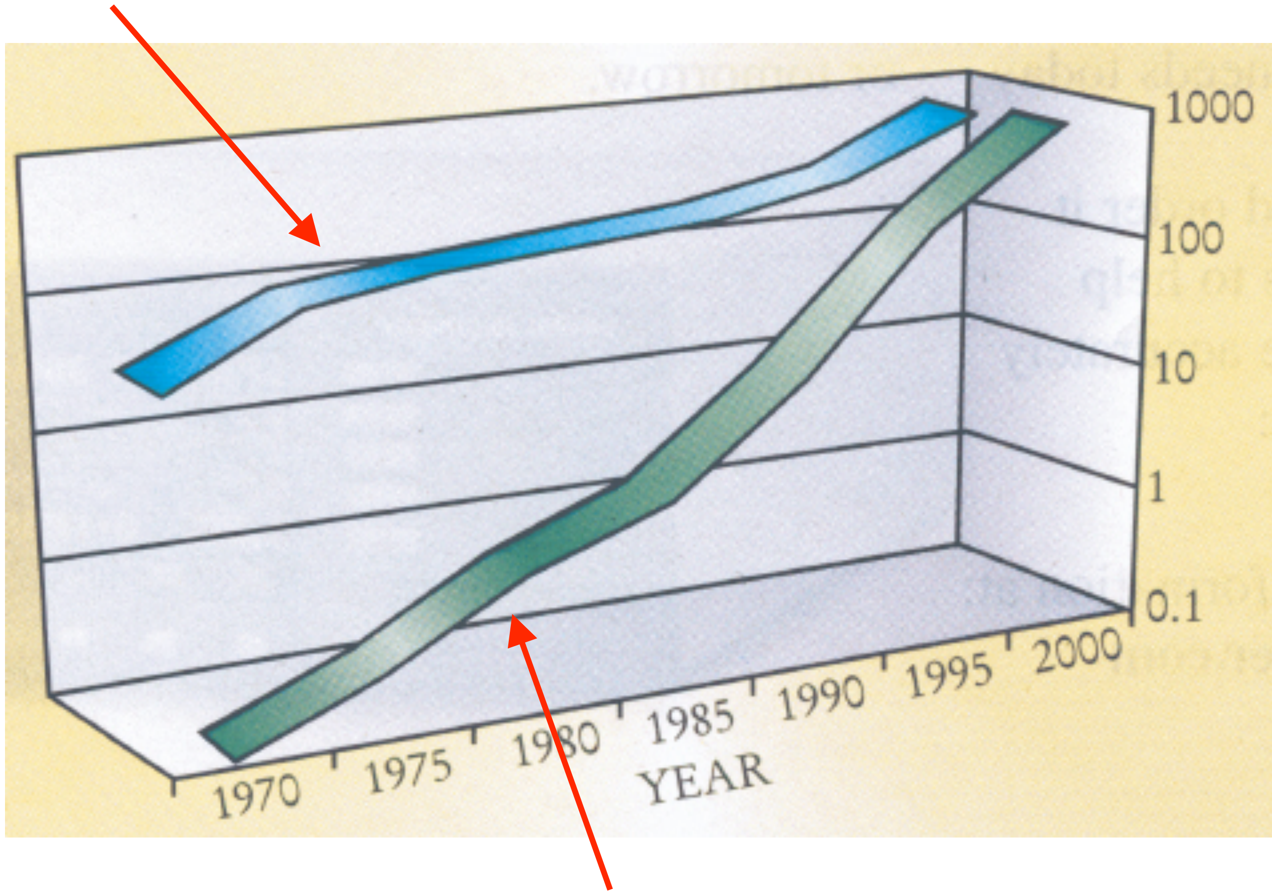
- Background
- Supernova Cosmology
- *SNLS*
- Other SN Science
- Conclusions

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

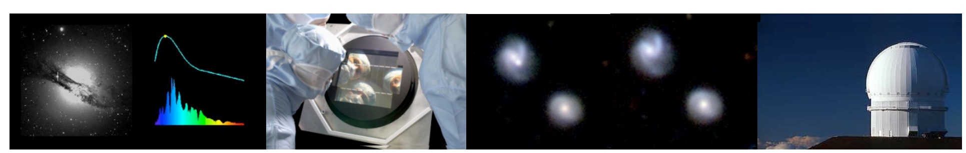


Telescope Aperture vs. Focal Plane Area

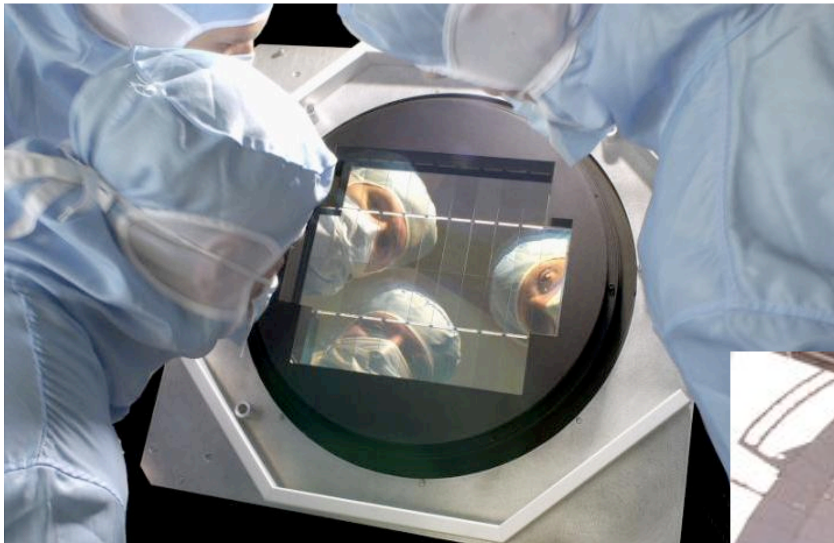
total area in 3m+ telescopes [m^2]



www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



MegaCam at CFHT

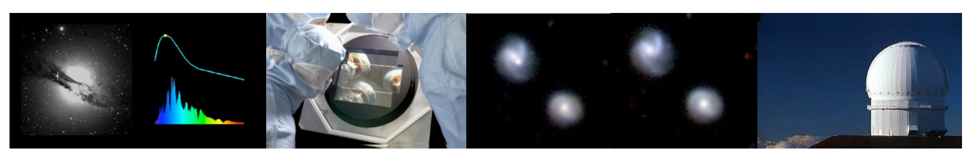


"Size matters ..."

Anon.

- Built by CEA
- 1 deg x 1 deg field
- 40 x (2048 x 4612) chips
  - ~ 400Megapixels
- good blue response

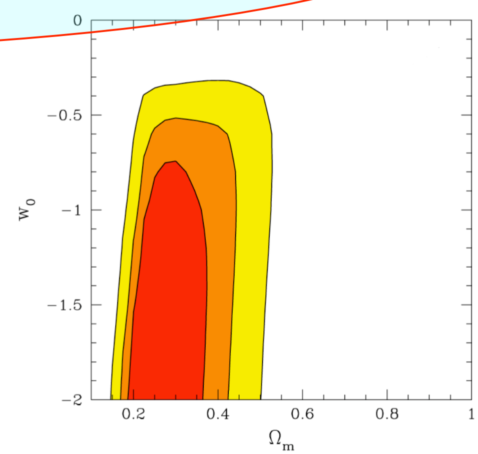
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



CFHT Legacy Survey

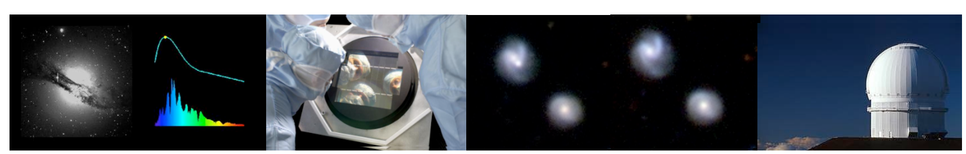
470 nights (dark-grey) over 5 years (2003-2008)

- **SNLS (“supernovae”)**
  - 4 deg², long time sequenced exposures
  - 202 nights
- **Wide (“weak lensing”)**
  - 172 deg² in 3 patches
- **Very Wide *(“KBO”)***
  - 1300 deg², +-2 deg from ecliptic,
  - short exposures
  - Not completed



Hoekstra et al 2006
astro-ph/0511089

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



SNLS in a nutshell

Victoria Group

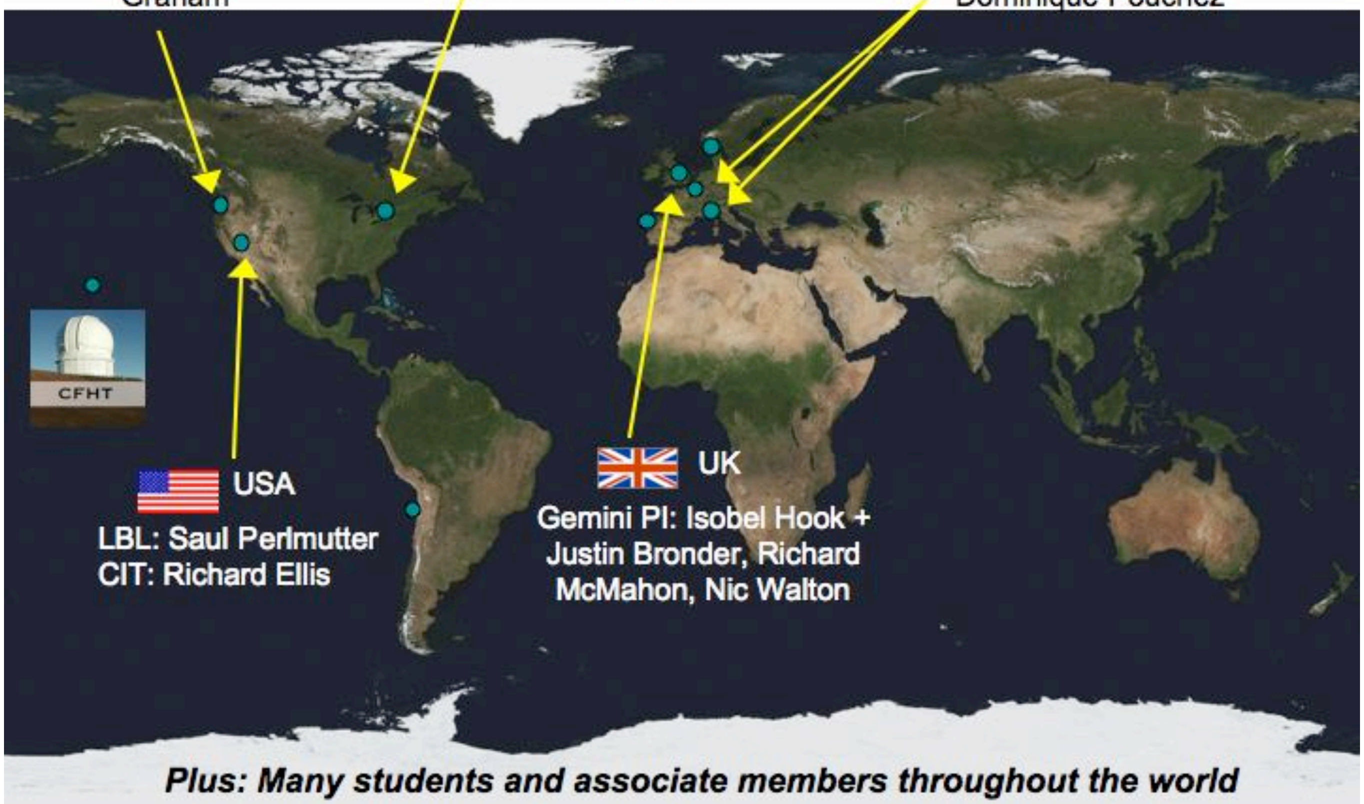
Chris Pritchet, (Don Neill), Dave Balam, Eric Hsiao, Melissa Graham

Toronto Group

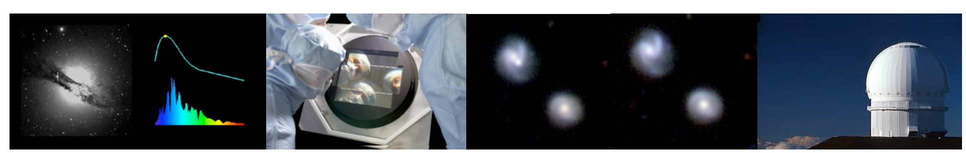
Ray Carlberg, Mark Sullivan, Andy Howell, Kathy Perrett, Alex Conley

French Group

Reynald Pain, Pierre Astier Julien Guy, Nicolas Regnault, Jim Rich, Stephane Basa, Dominique Fouchez

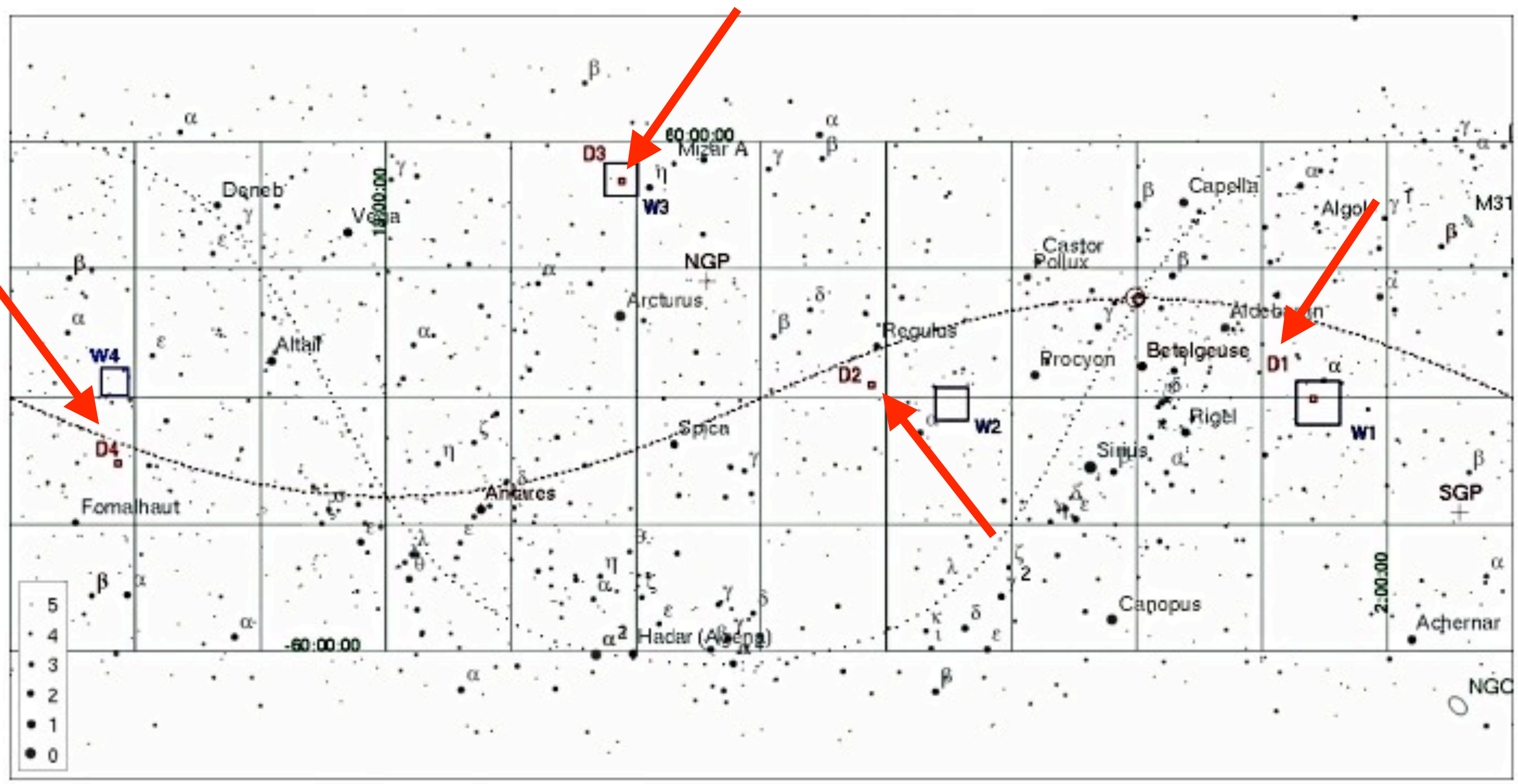


www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

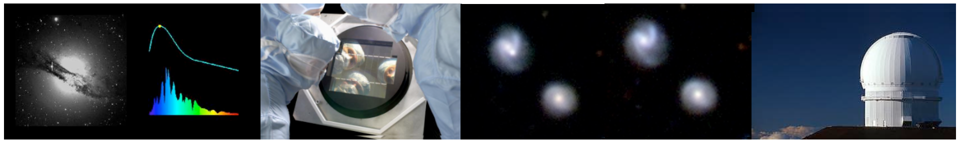


SNLS in a nutshell

- 202 nights over 5 years (part of CFHTLS)
- four 1 deg² fields



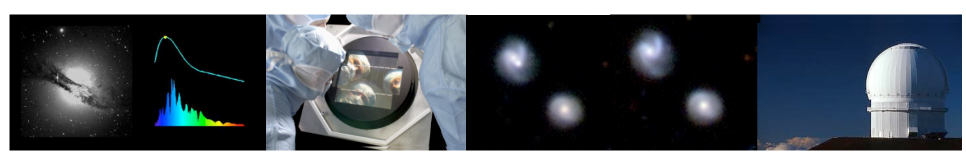
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



SNLS in a nutshell

- ***202 nights over 5 years*** (part of CFHTLS)
- ***four 1 deg² fields***
- queue scheduled obs, ***3-4 day temporal sampling***
- ***griz*** filters (450-950nm)
- spectroscopic followup (VLT, Gemini, Keck, Magellan)
- 2 independent search, photometry, cosmology pipelines
- ***>500 SNeIa*** over 5 yrs with spectroscopic type

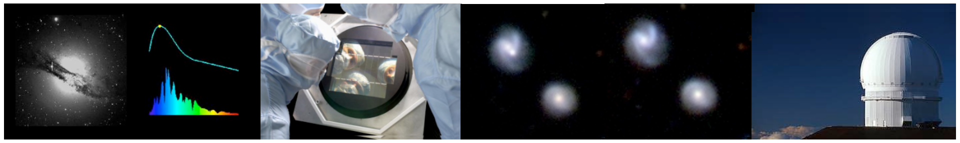
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



SNLS – multiband

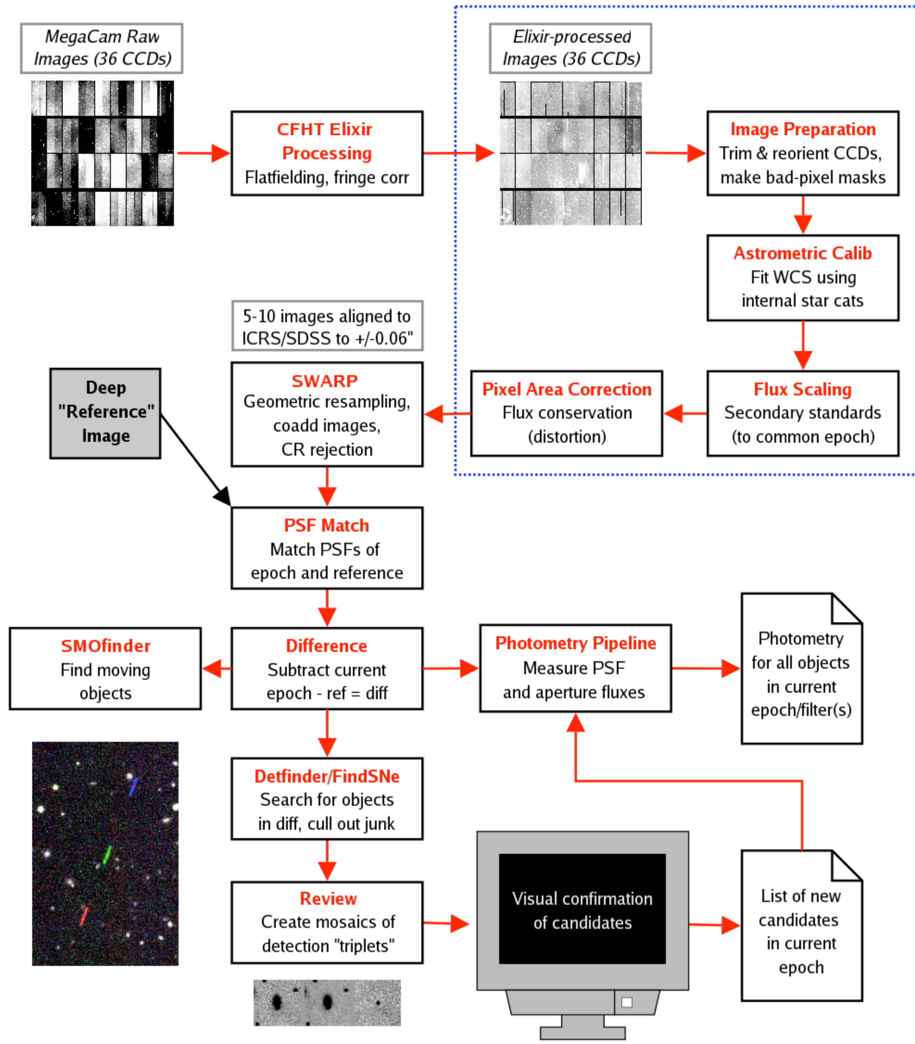
- SNLS provides the definitive high-z SN dataset for the next 5+ years. Multi-band g’r’i’z’ photometry is the key:
  - Wide z range 0.2-0.9
  - Better control over systematics: SN colour evolution
  - Better control over dust: Extinction corrections using rest-frame U-B & B-V
  - Better control over k-corrections: wider wavelength coverage
  - Better estimates of rest-frame *B*-band luminosities

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



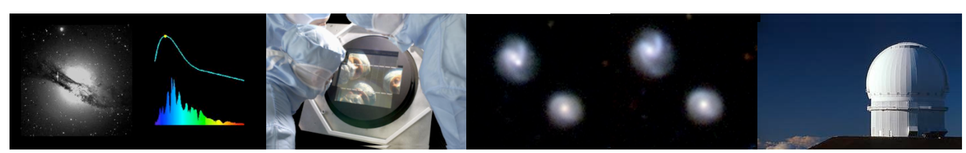
Two Search Pipelines (Ca, Fr)

K. Perrett

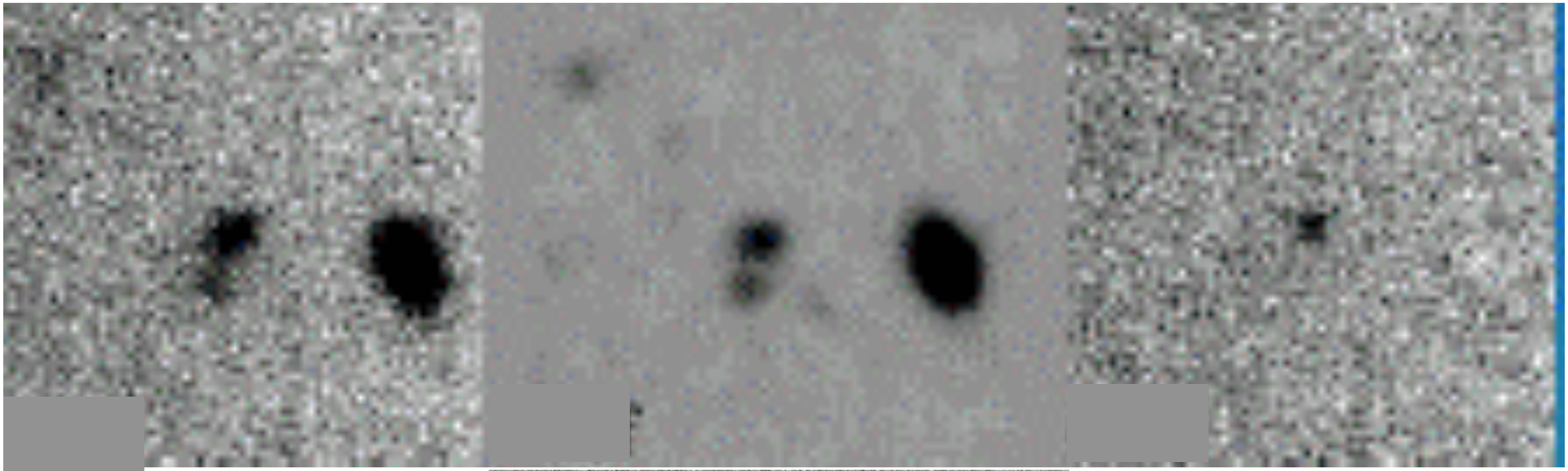


- •2 pipelines
- •Data stays in Hawaii, remote real-time access
- •90% agreement i'~24
- •Short turnaround (6 hr to spec candidates)

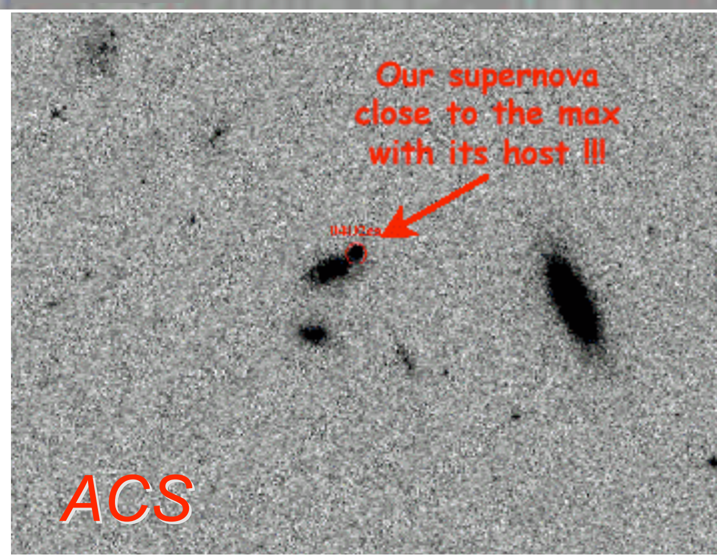
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



Detections

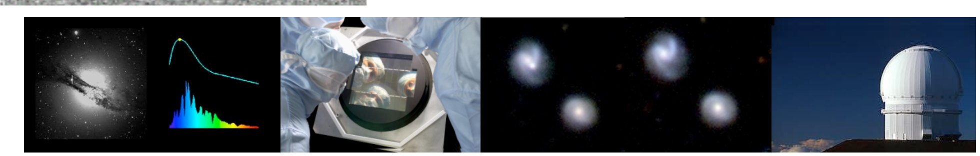


04D2ca
z=0.83 Mar 10



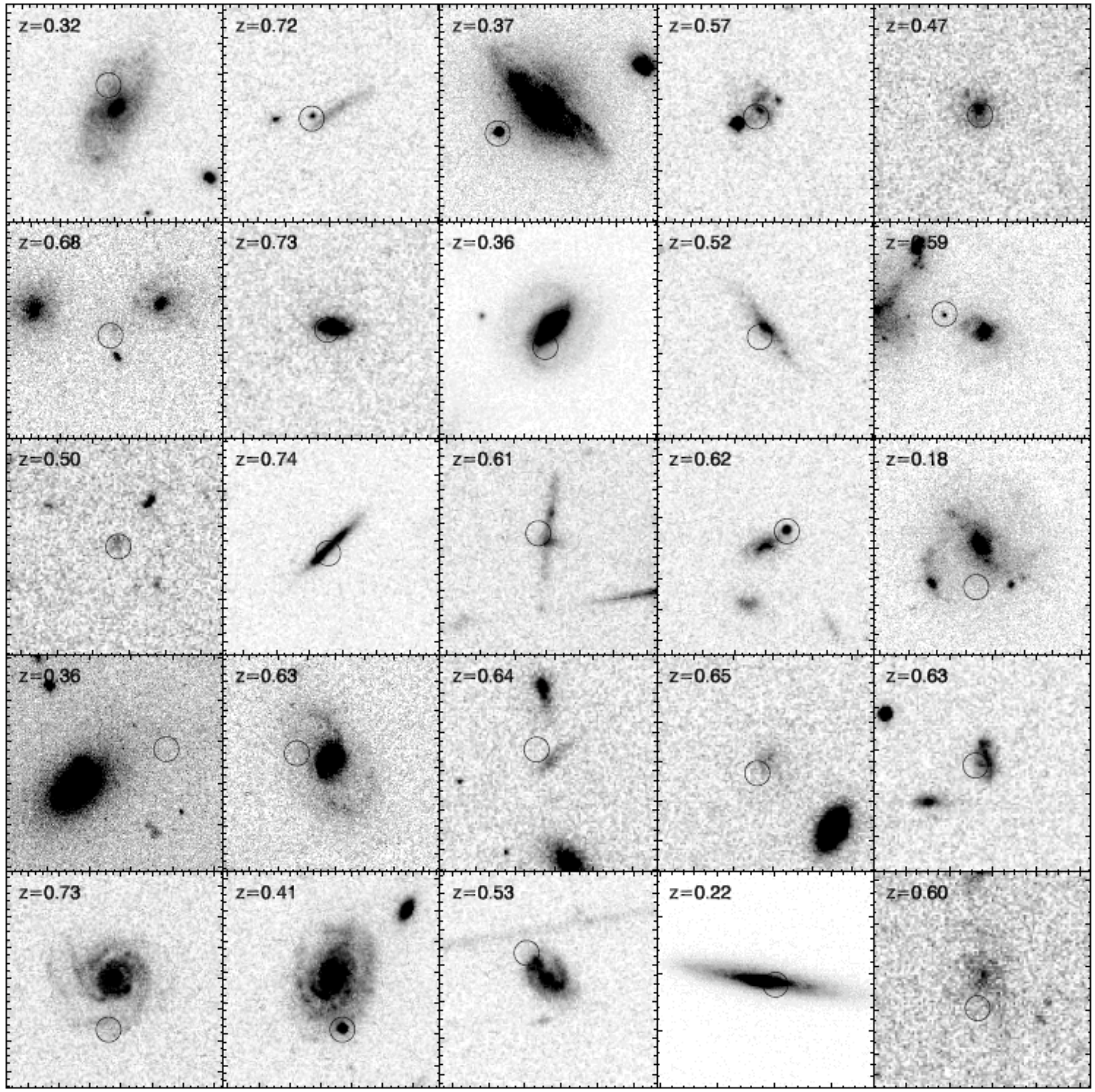
~10^{-4} of total Megacam area

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



- D2
- Cosmos
- ACS imaging
- ~7 x 7 arcsec +-

- Note diversity



www.astro.uvic.ca/~pritchet/SN/A580-2(

Host ID – not trivial

The dependence of SN Ia on their host galaxies 15

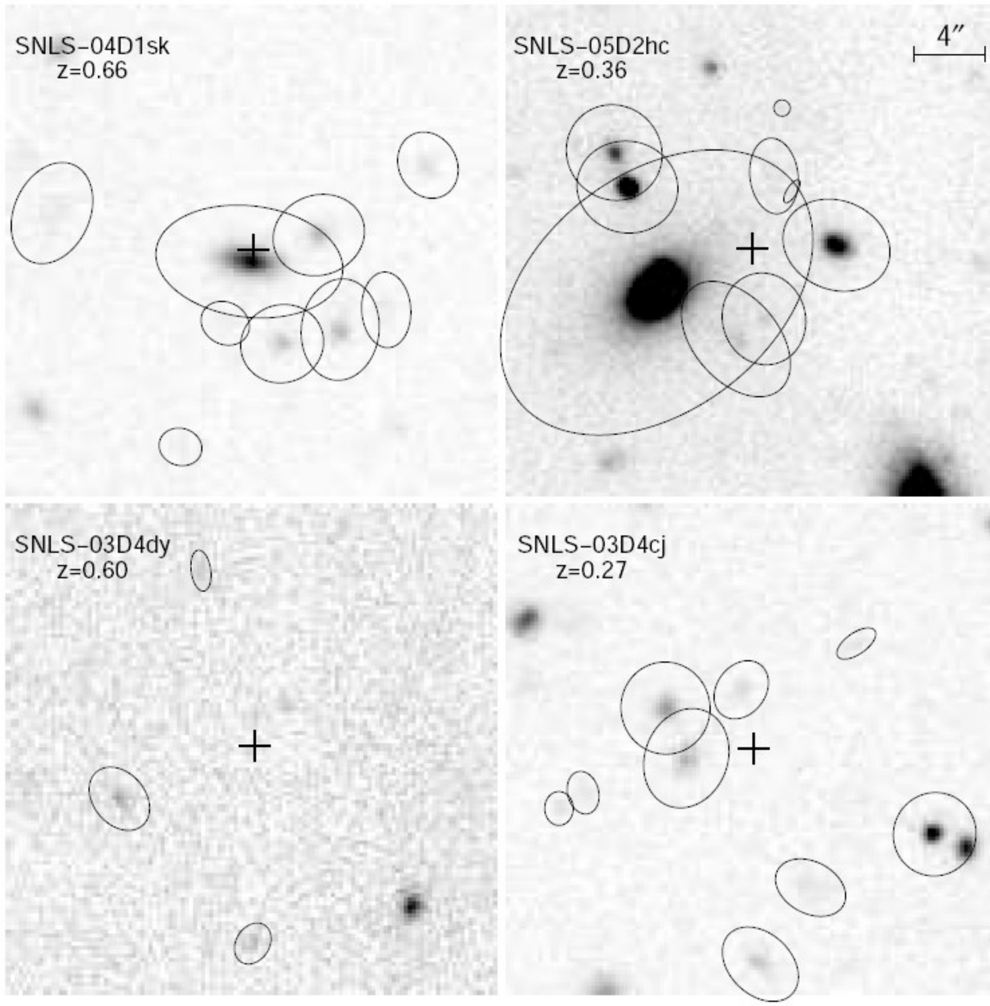


FIG. 1.— Examples of the SN Ia host galaxy identification technique used in this paper (see § 2.3). Four SNe are shown. In each panel, the SN position is marked with a cross, and each candidate host, as detected by SExtractor, has the $5R$ ellipse over-plotted (see § 2.3 for the definition of R). The nearest host in terms of this R parameter is considered to be the correct host; SNe with no hosts inside $5R$ are considered "hostless". Top Left: SNLS-04D1sk, a straightforward case where the identification is unambiguous. Top Right: SNLS-05D2hc, a case where the nearest host in terms of arcseconds is probably not the correct identification. Bottom Left: SNLS-03D4dy, a case where no potential host is found within several arcseconds of the SN position. Bottom Right: SNLS-05D2hc, though several candidate hosts are available, all lie at $R > 5$.

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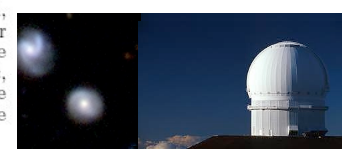
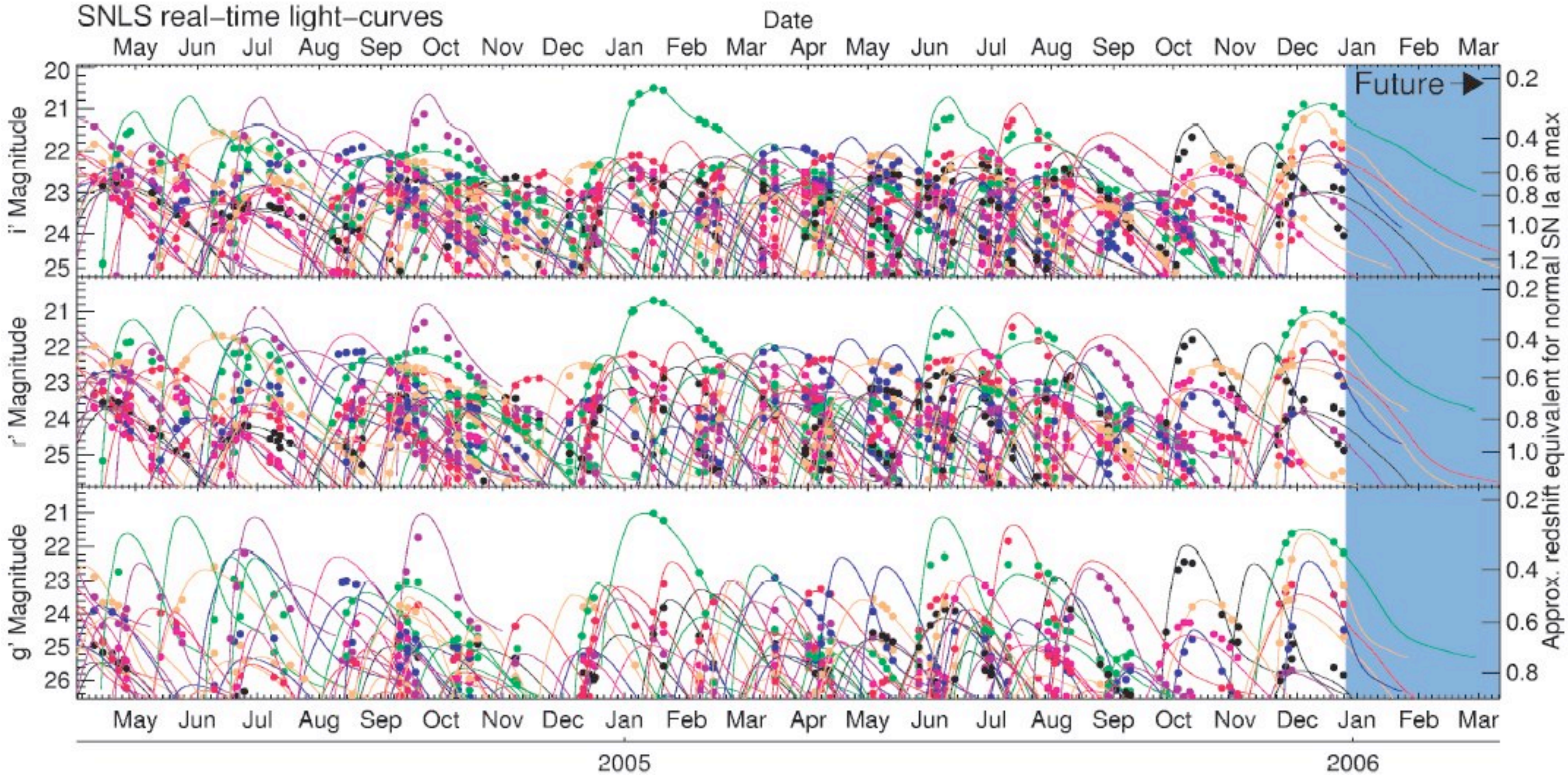
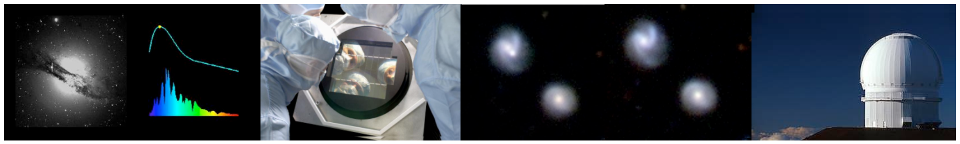


Rolling Search



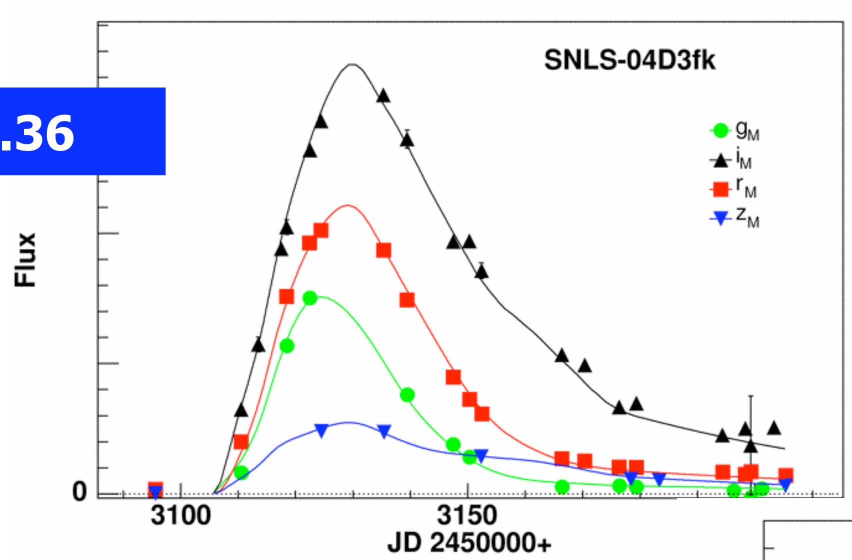
- griz (redshift 0.2-0.9)
- 2-3 day sampling restframe
- 12 month observing

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

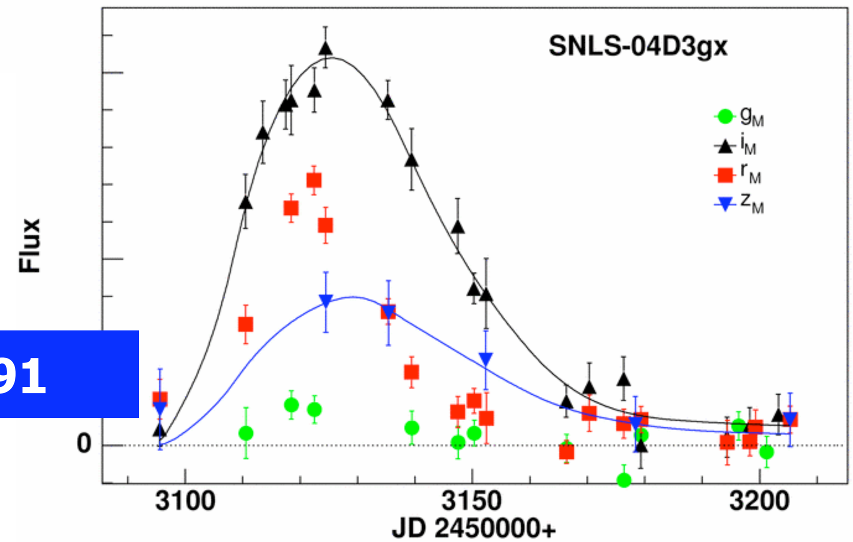


Typical light-curves

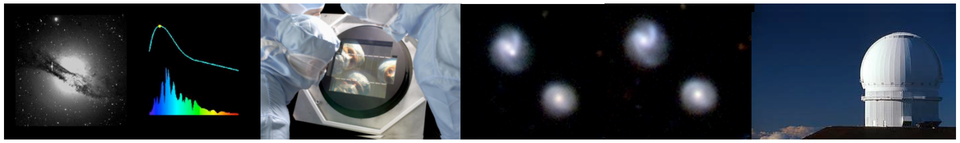
z=0.36



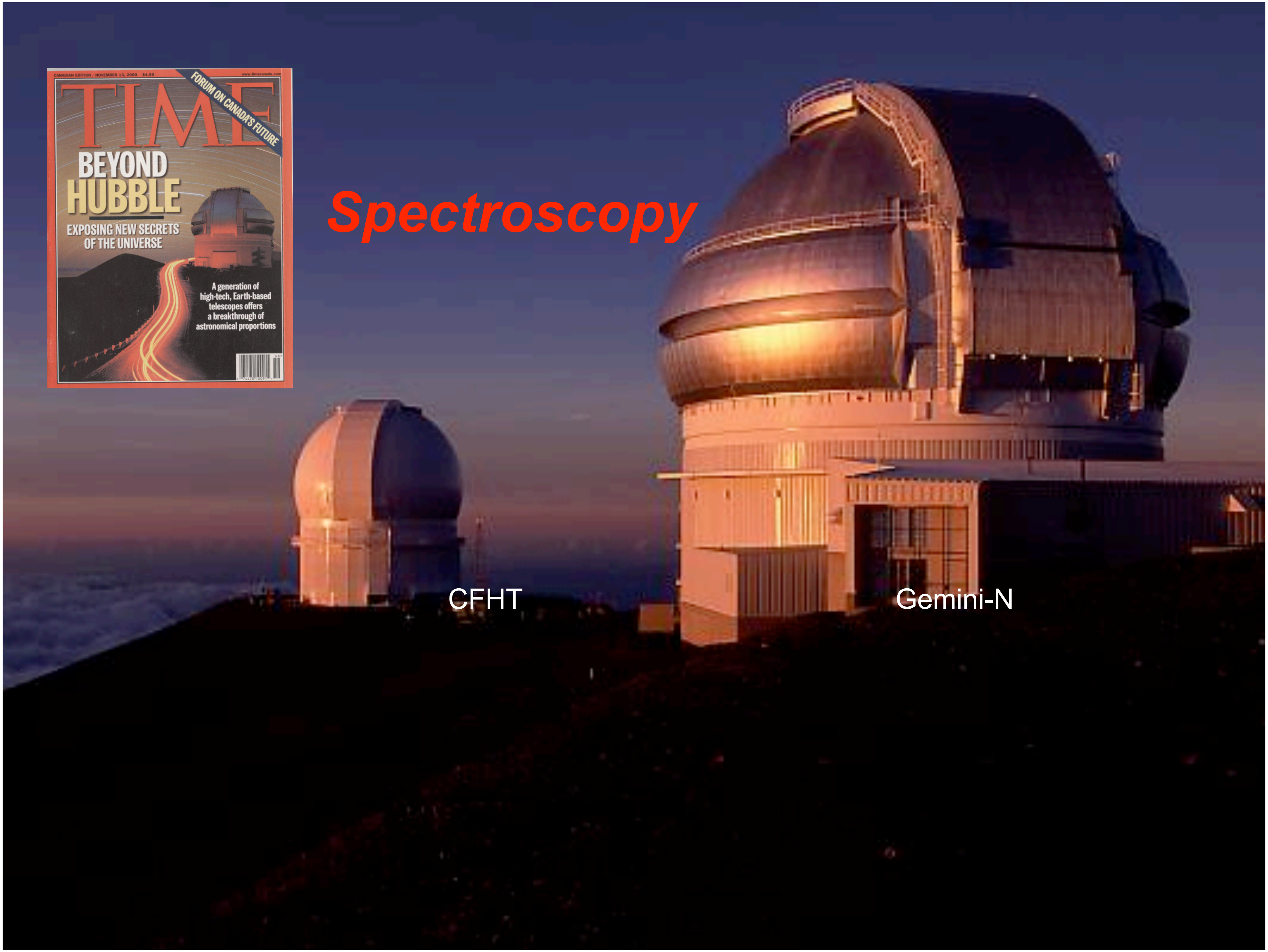
z=0.91



www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



Spectroscopy



Follow-up Spectroscopy (types and redshifts)

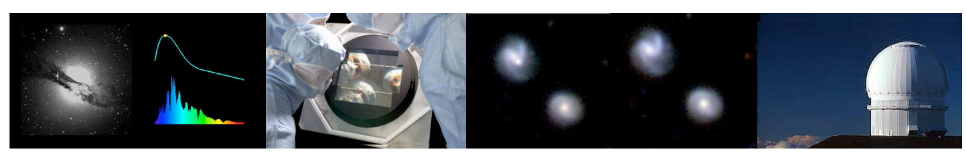
<u>Keck (~8 nights/yr)</u>
Ellis / Perlmutter

More 8-10m time than CFHT time

<u>VLT (120 hr/yr)</u>
France/UK:
FORS1/2 to get types & redshifts for SNe ($0.3 < z < 0.8$)

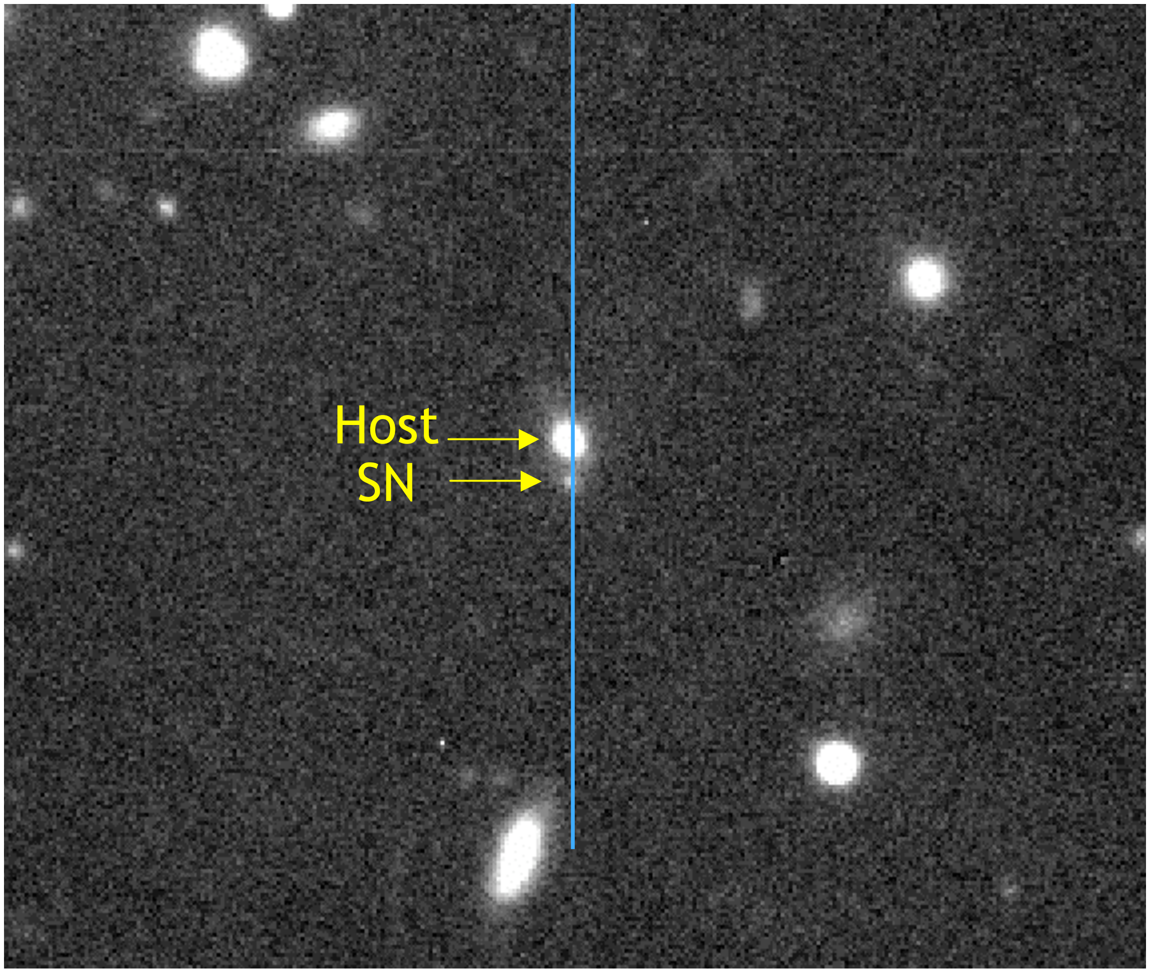
<u>Gemini N & S (120 hr/yr)</u>
Canada/UK/US
GMOS to get types/redshifts for SNe ($0.6 < z < 0.9$)

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

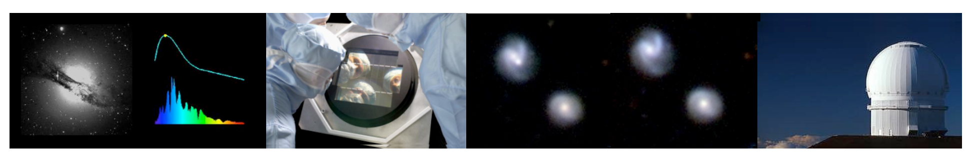


Gemini Acquisition image : 300s in i

Example
i(AB)=24.0

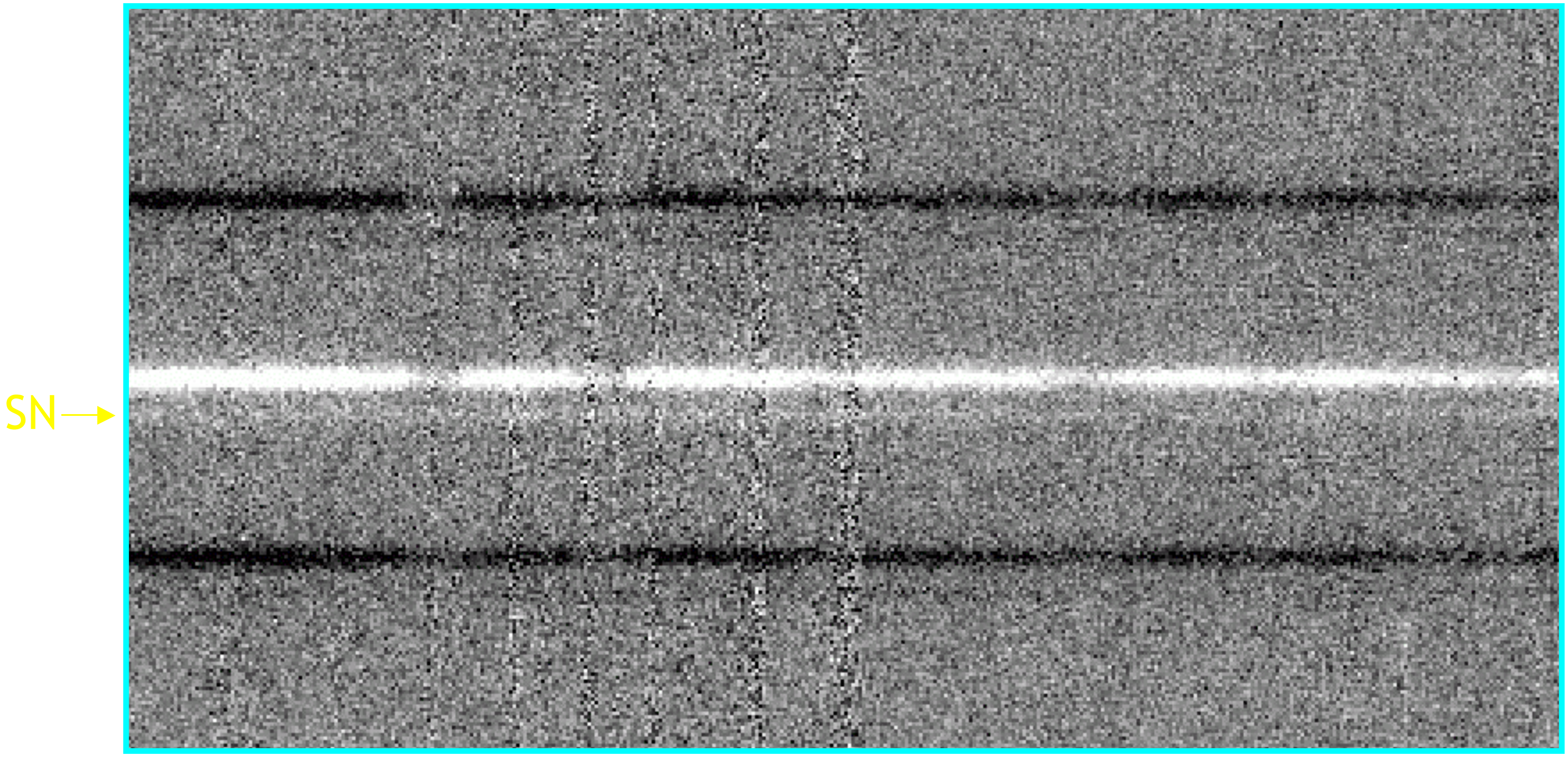


45”

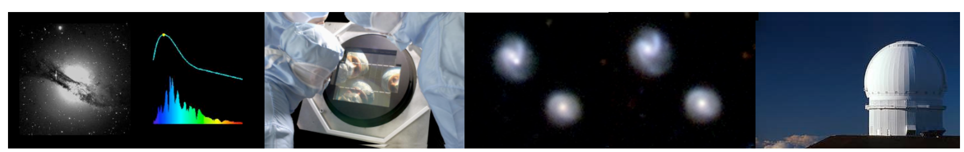


www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

Combined 2 x 4 frames (mosiaced)



www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



Nod and Shuffle – Gemini+GMOS

Long slit

N & S

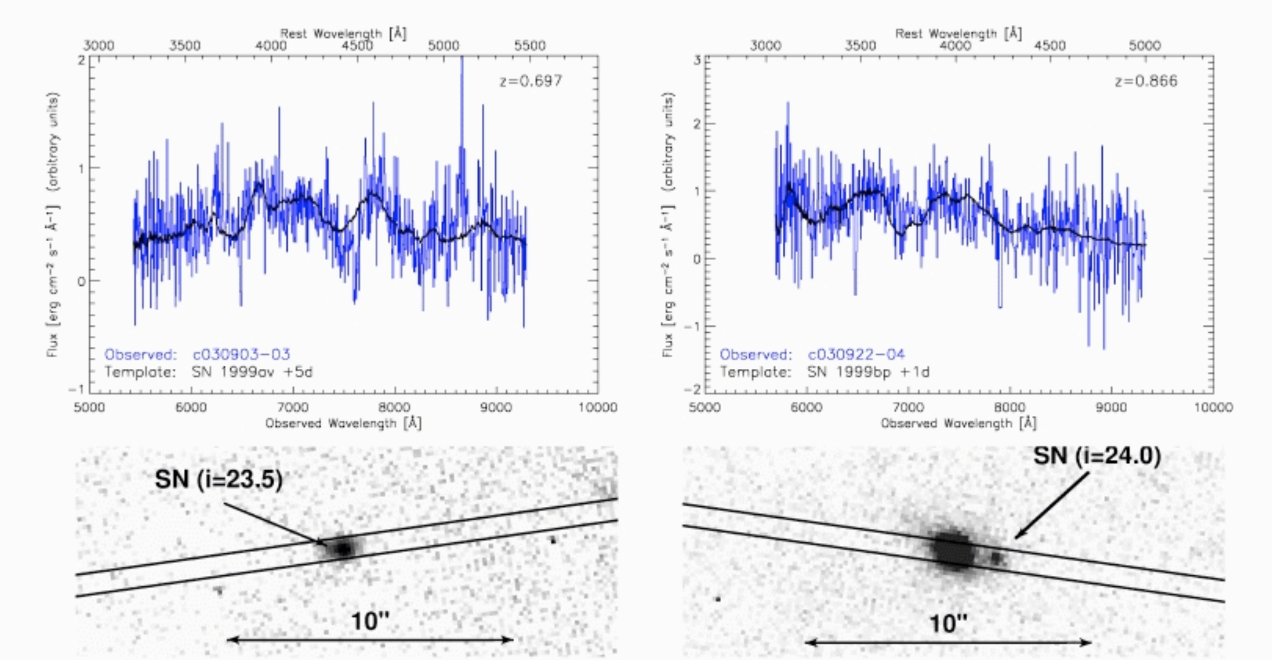
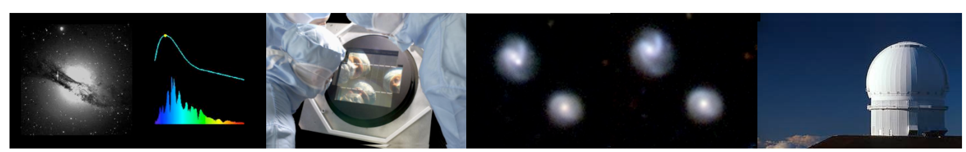


Figure 1: Preliminary spectra from our 2003B September GMOS-N time overplotted with best-fitting local SNe templates. LEFT: A SN Ia at $z = 0.697$ ($i' \simeq 23.5$), RIGHT: A SN Ia at $z = 0.866$ ($i' \simeq 24.0$). Exposure times were 3600s and 4800s, and seeing was $\simeq 0.5''$, allowing the SNe to be clearly resolved. The right hand panel demostrates the power of nod-and-shuffle observations when observing faint events (note the improved sky subtraction when compared to the left-hand spectrum).

- High z at Gemini (nod and shuffle, overheads)

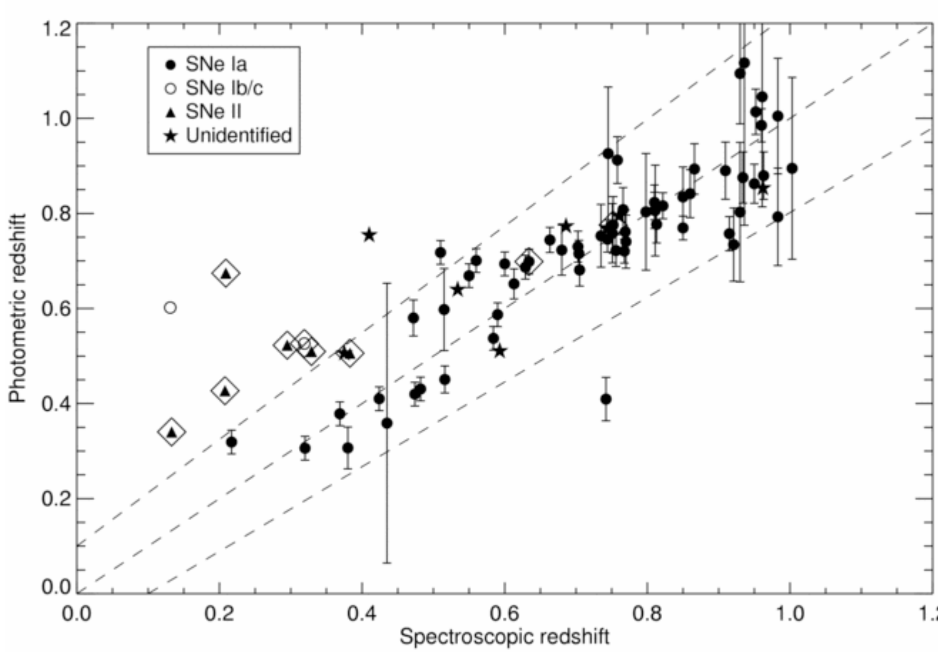
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



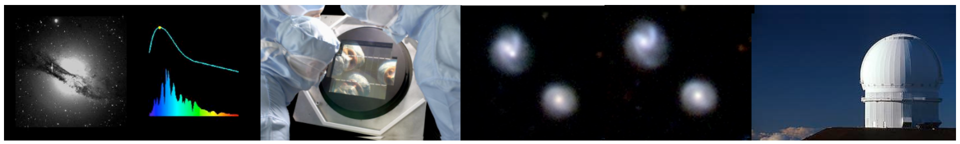
Optimizing follow-up – SN photo-z

- 1000 candidates – how to prioritize for followup? Defines success of survey.
- Photometric pre-selection. Fits early-time SN light-curves, returns probability of the candidate being a SN Ia.

Sullivan et al 2005

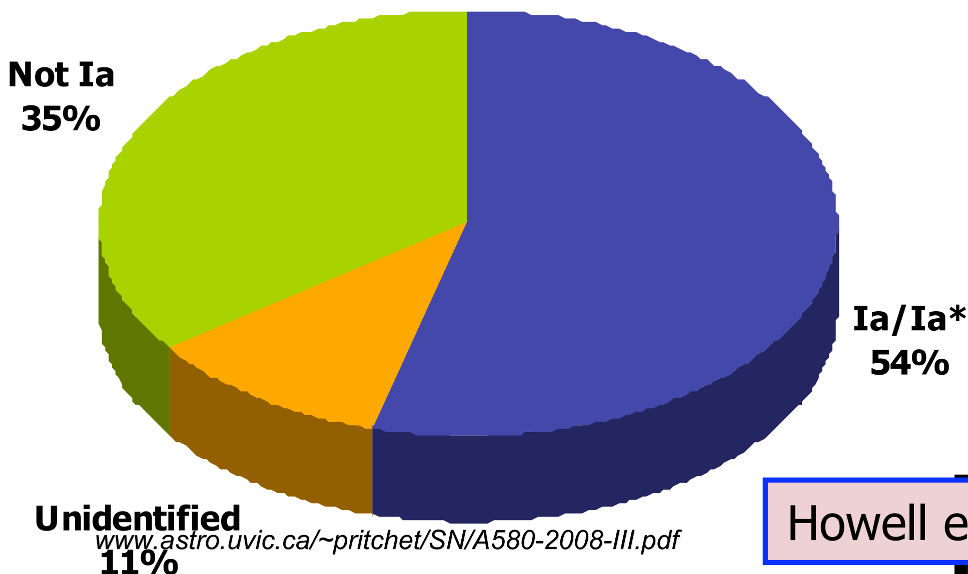


www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



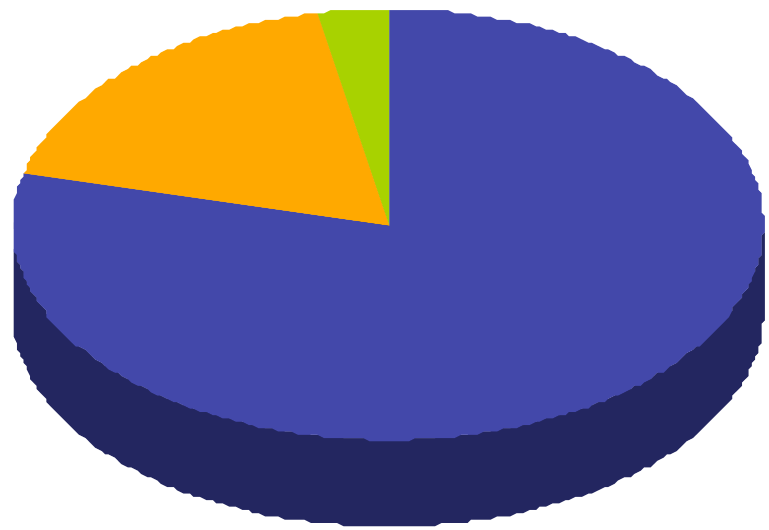
Gemini: success of SN photo-z

- Before implementation:
- Consistent with previously published rates:
  - –Lidman et al. (SCP): 50-62%
  - –Matheson et al. (ESSENCE): 44%
  - –Median z=0.5

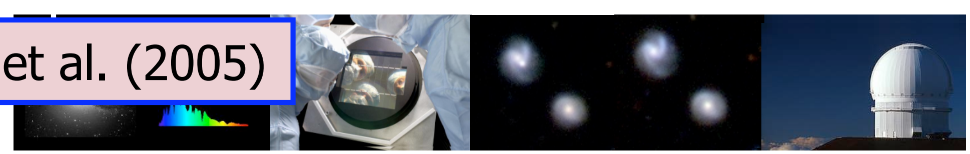


www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

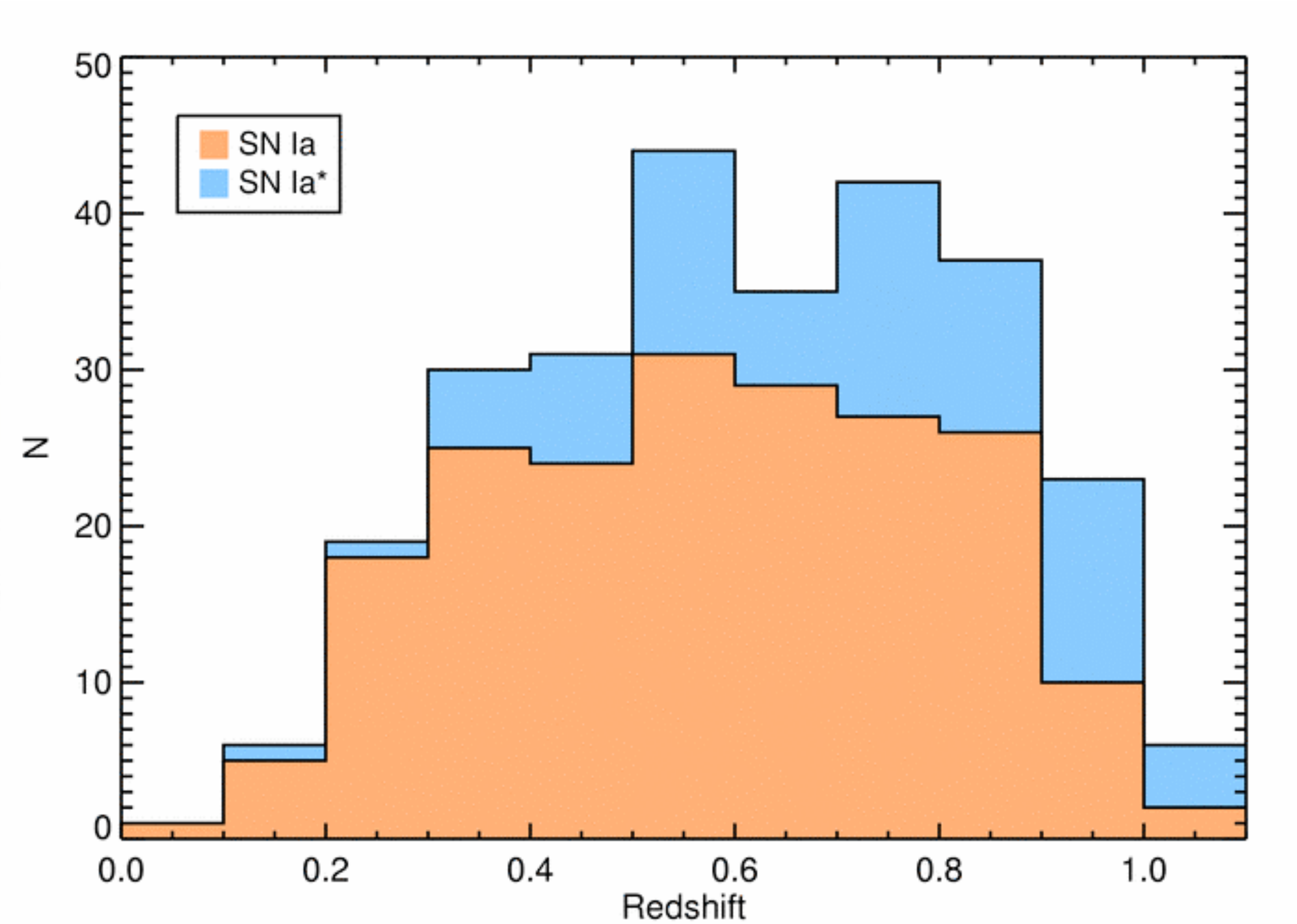
- Using photo-z: ~70-80% confirmed as SNe Ia at Gemini (median z=0.81)
- Only 3% (1/38) non-Ia SNe when using photo-z



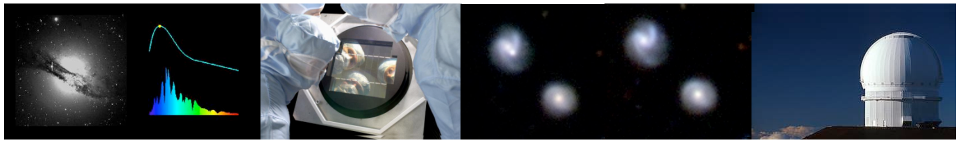
Howell et al. (2005)



N(z) to 2006 (N ~ 300)



www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

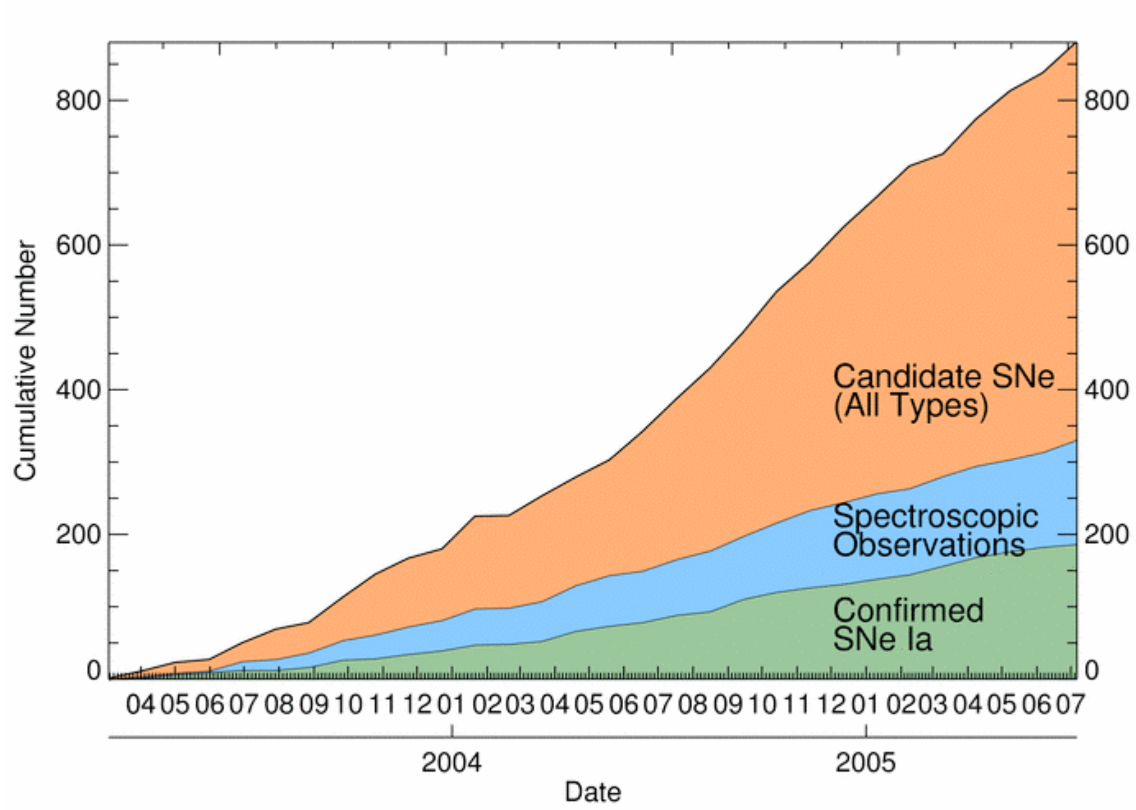


SNLS: Current and projected numbers

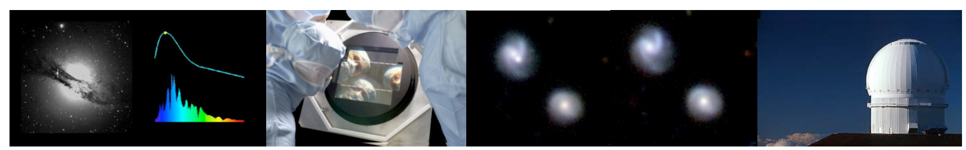
Currently >350 spec confirmed SNe Ia

400-500 spec confirmed SNeIa by survey end

(>1000 total)

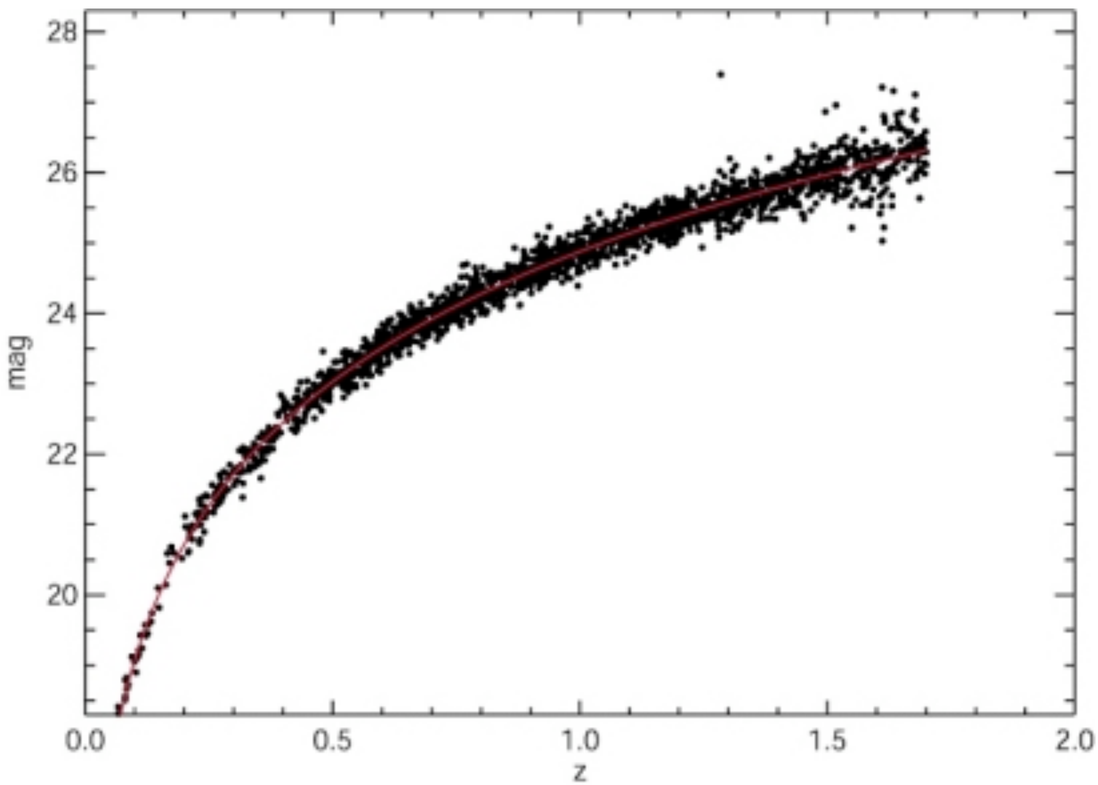


www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



Hubble Diagram - "How To ..."

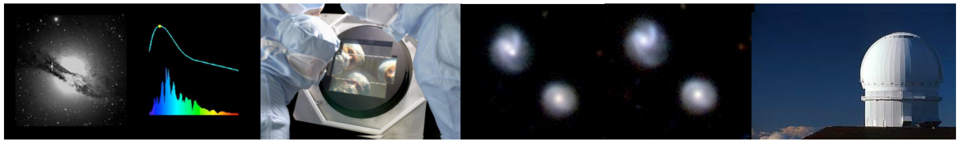
Fake data!



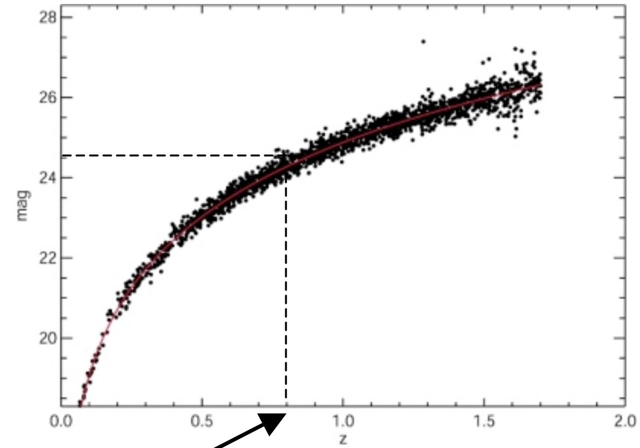
Log apparent brightness

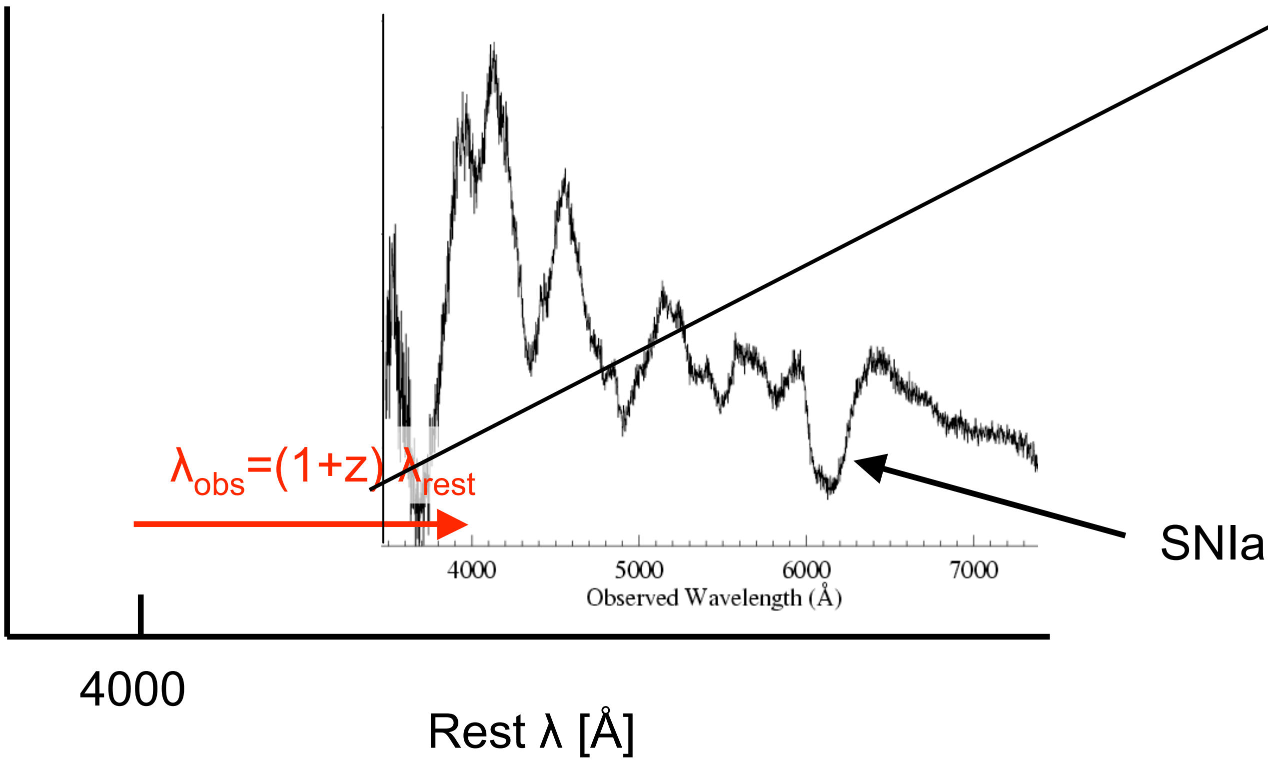
Redshift z=cΔλ/λ

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

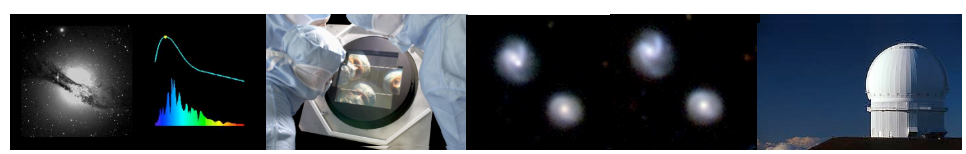


Hubble Diagram
“How To …”

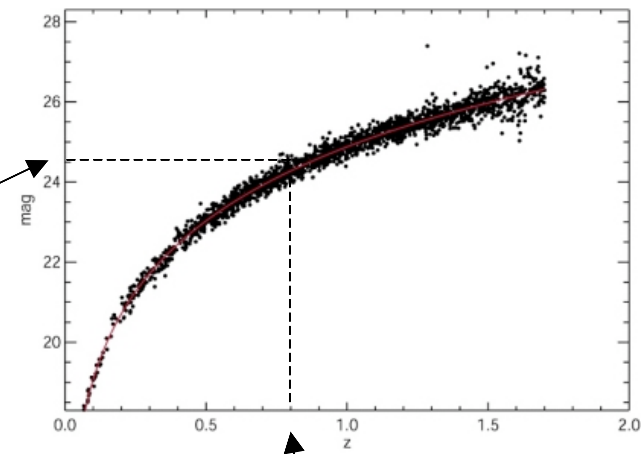


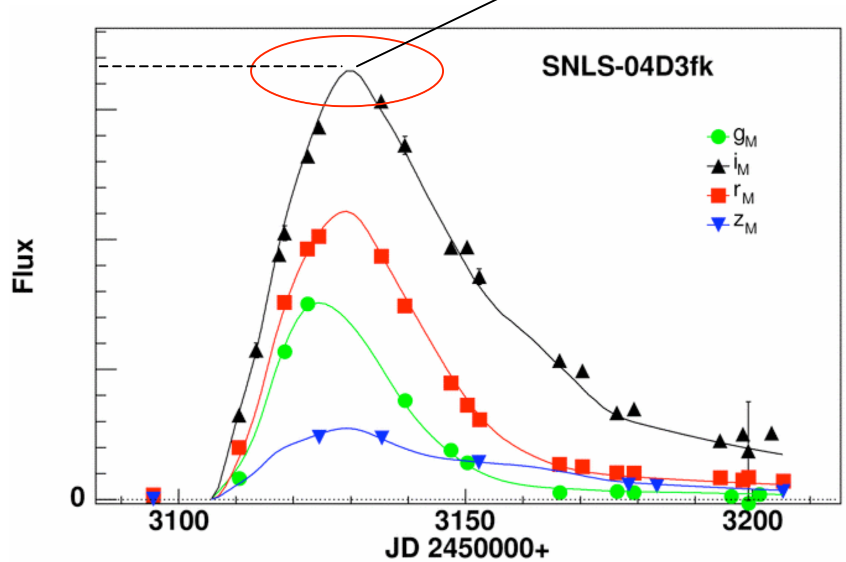


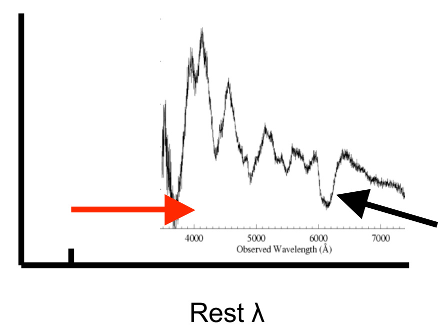
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



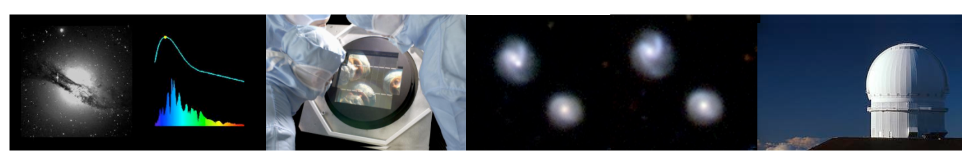
Hubble Diagram "How To …"



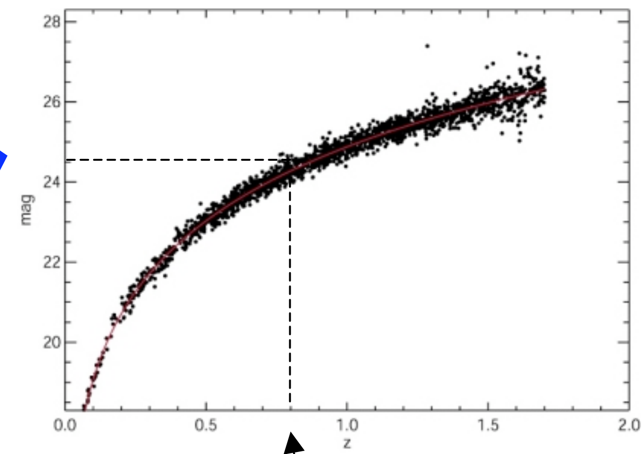




www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf



Hubble Diagram "How To …"



Flux calibration (low z vs high z)

K corrections

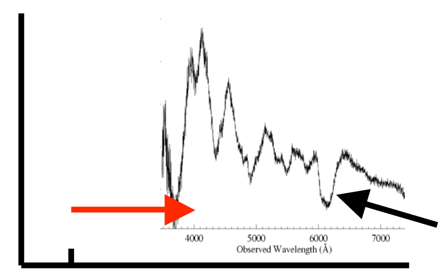
Light curve fit

Distance estimator

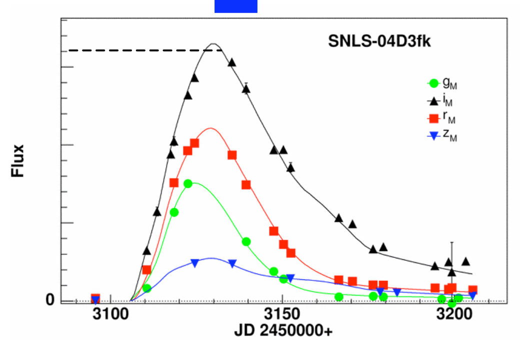
$$\mu_B = m_B - M_B + \alpha(s-1) - \beta \times c$$

s – "stretch" corrects for light-curve shape via α

c – B-V colour corrects for extinction (and intrinsic variation) via β



Rest λ



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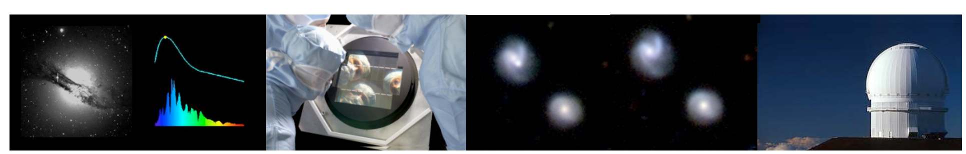

Distance estimator: stretch and colour

- Distance estimator used:

$$\mu_B = m_B - M_B + \alpha(s-1) - \beta \times c$$

s – “stretch” corrects for light-curve shape via α

“c” – B-V colour corrects for extinction (and intrinsic variation) via β

- s, c terms dominate; no need for other terms

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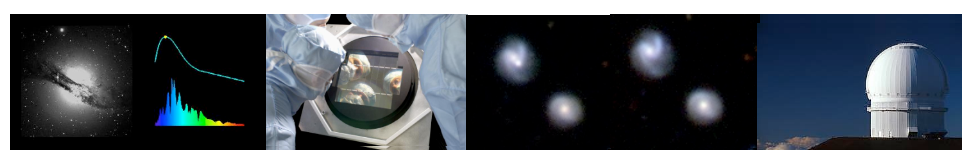
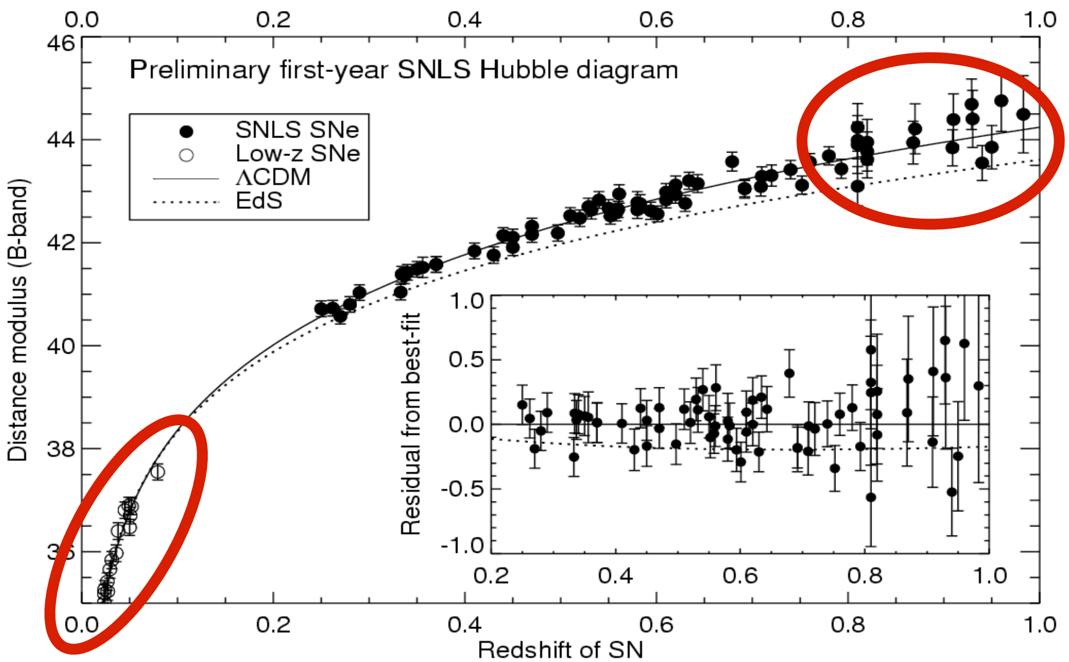


First Year Cosmology (Astier et al. 2006)

Intrinsic disp.: 0.13 ± 0.02

Low-z: 0.15 ±0.02

SNLS: 0.12 ± 0.02



z' errors – now observing 3x longer

First year results (72 SNe Ia) consistent with an accelerating Universe: Ω_M=0.263 in a flat universe

$$\mu_B = m_B - M + \alpha(s-1) + \beta c$$

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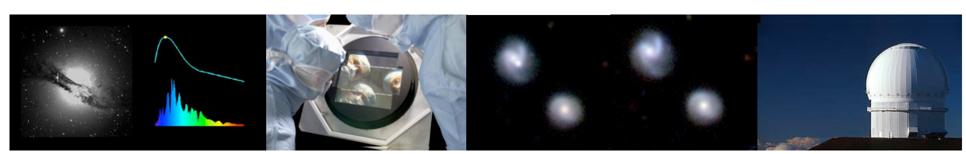
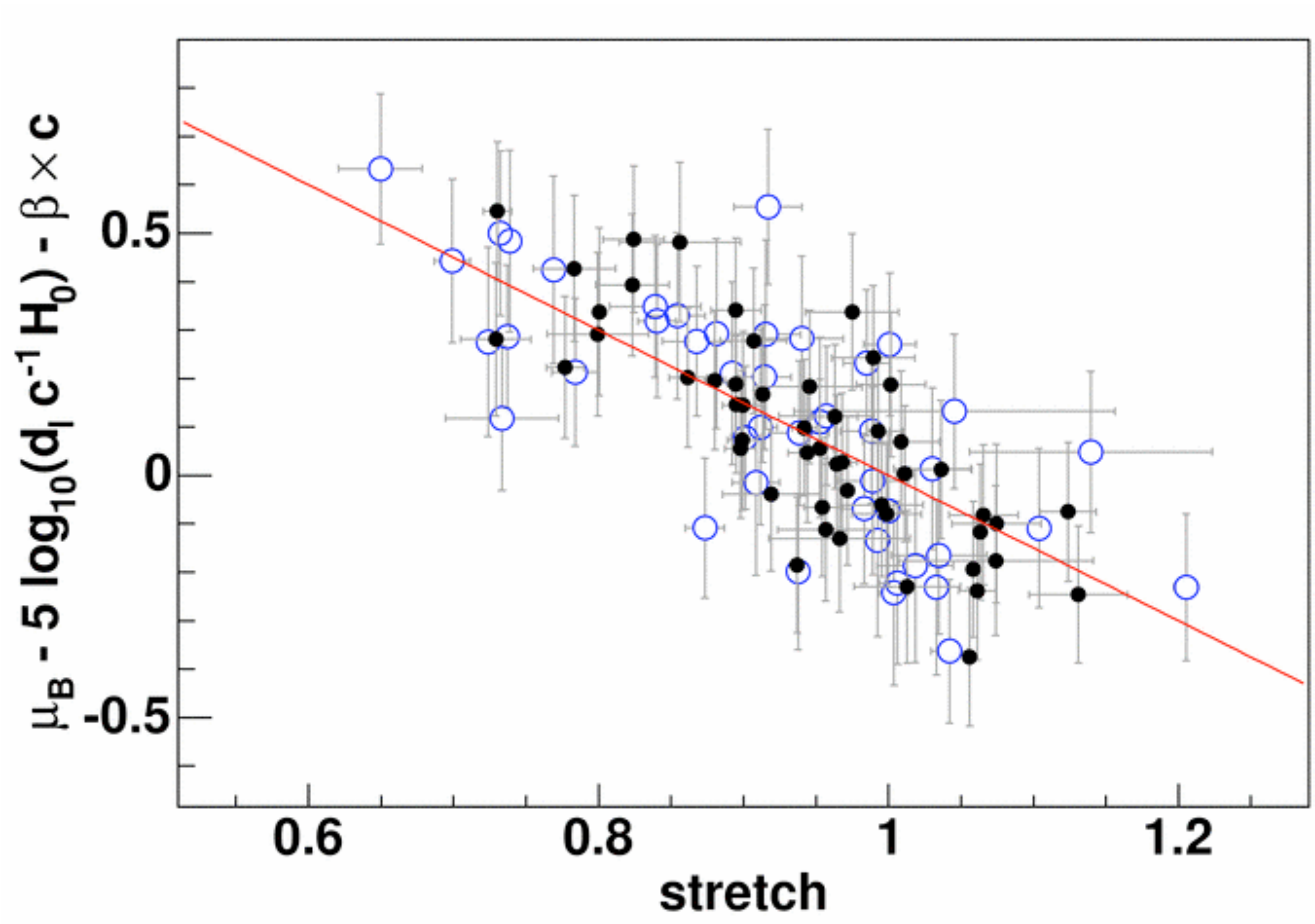


BLUE – nearby

BLACK – SNLS

Residuals by stretch

$$\mu_B = m_B - M + \alpha(s-1) + \beta c$$



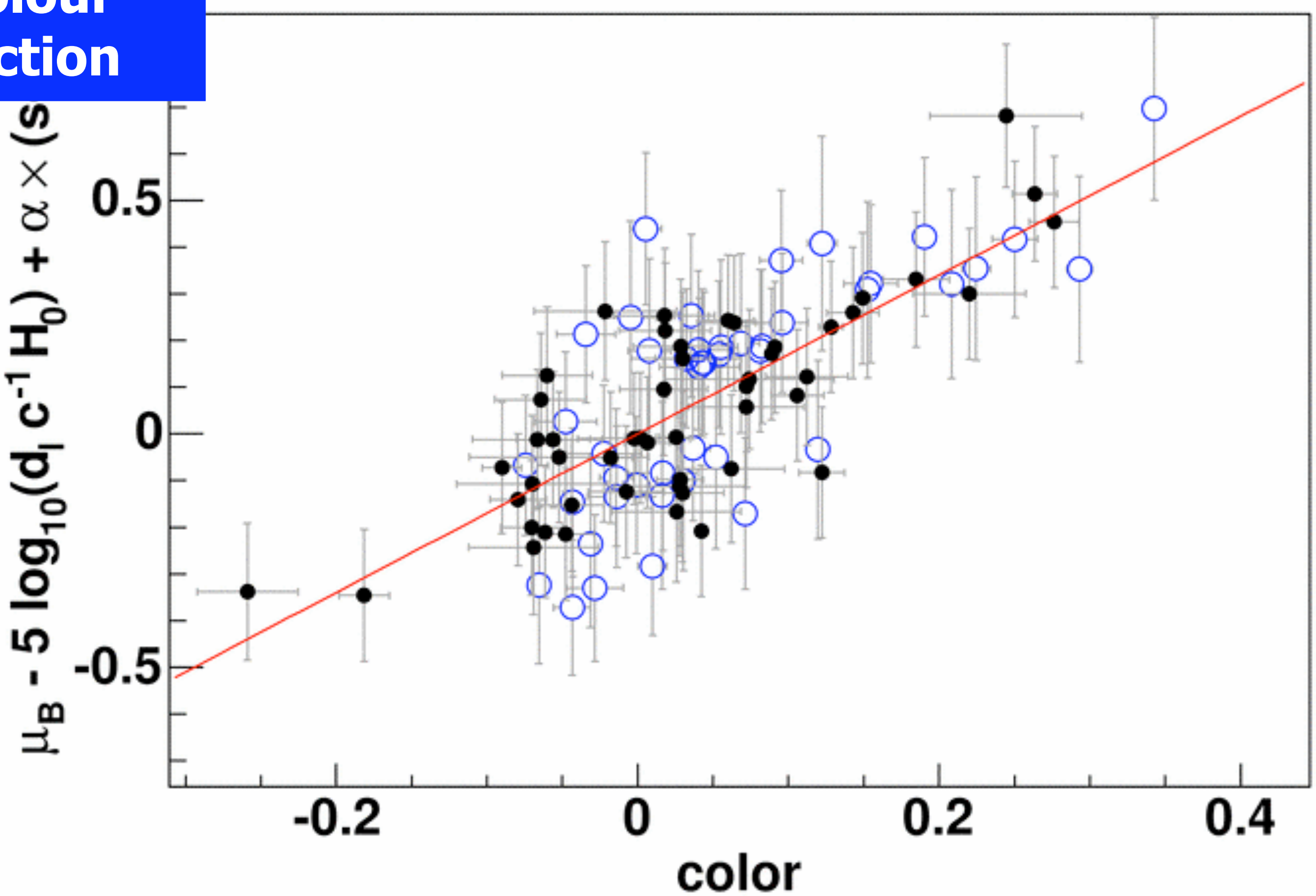
www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

Expected LCS/brightness relationship is seen

Residuals by colour

$$\mu_B = m_B - M + \alpha(s-1) + \beta c$$

No colour correction



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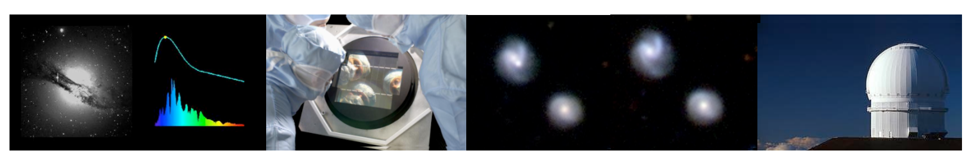
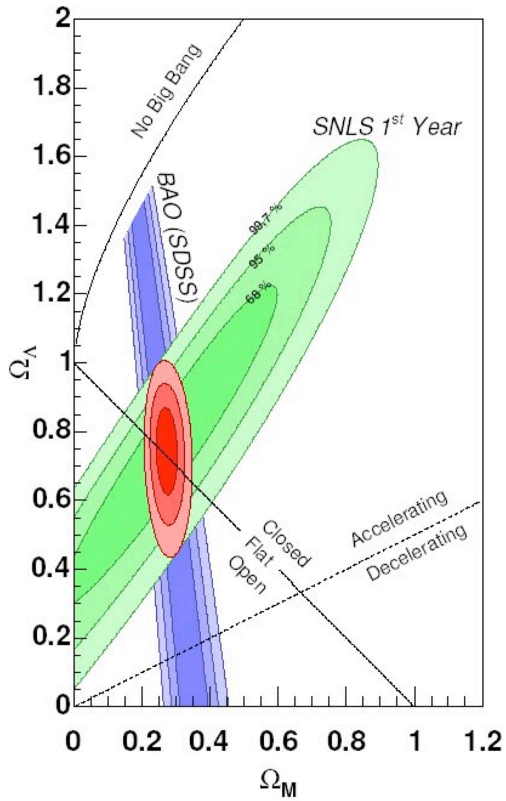
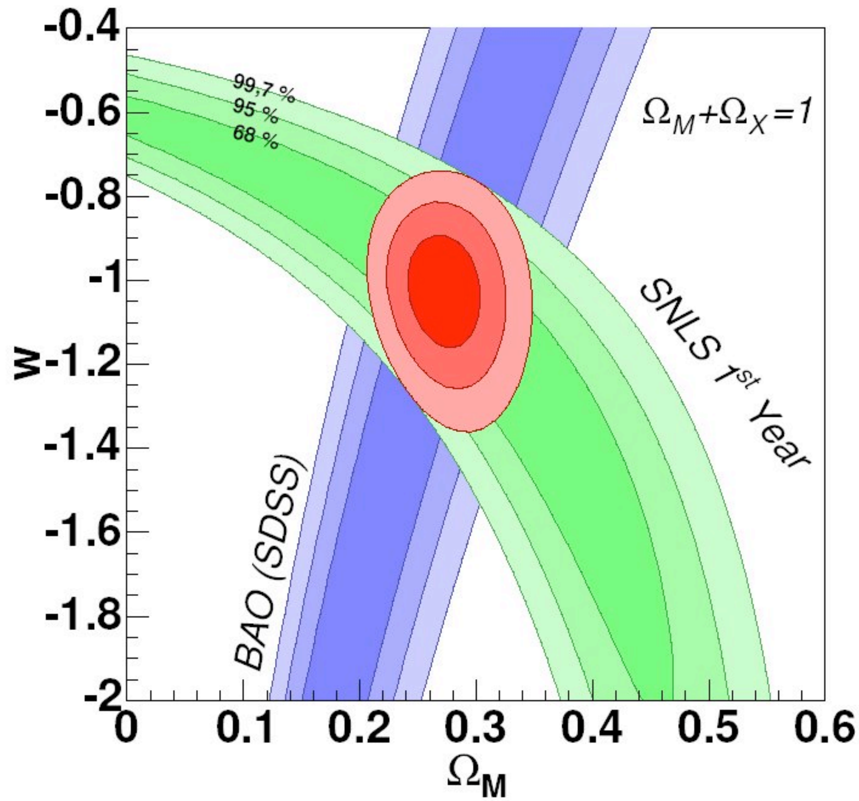


Astier et al 2006

$w = -1.02 \pm 0.09$





- N=71, one year, SNLS+low z only
- w to ~±0.05 by 2008 (why not +-0.03?)

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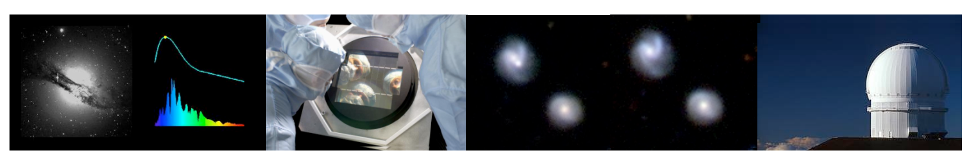
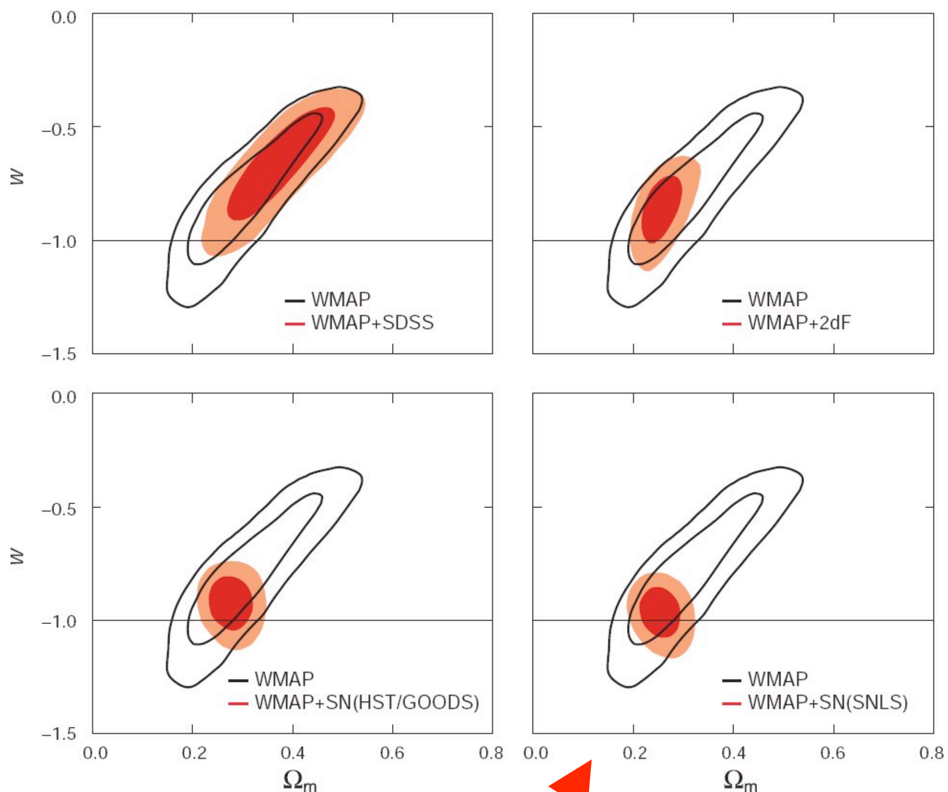


WMAP3 constraints

- Spergel et al 2007



$$w = -0.967^{+0.073}_{-0.072}$$

Assumptions: flat universe, perturbations in dark energy

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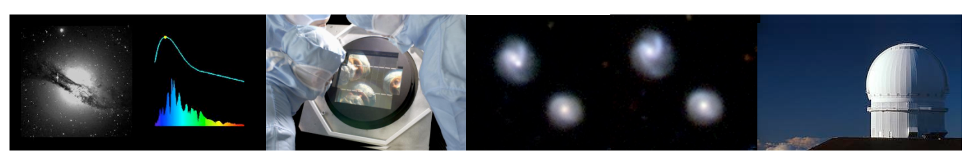
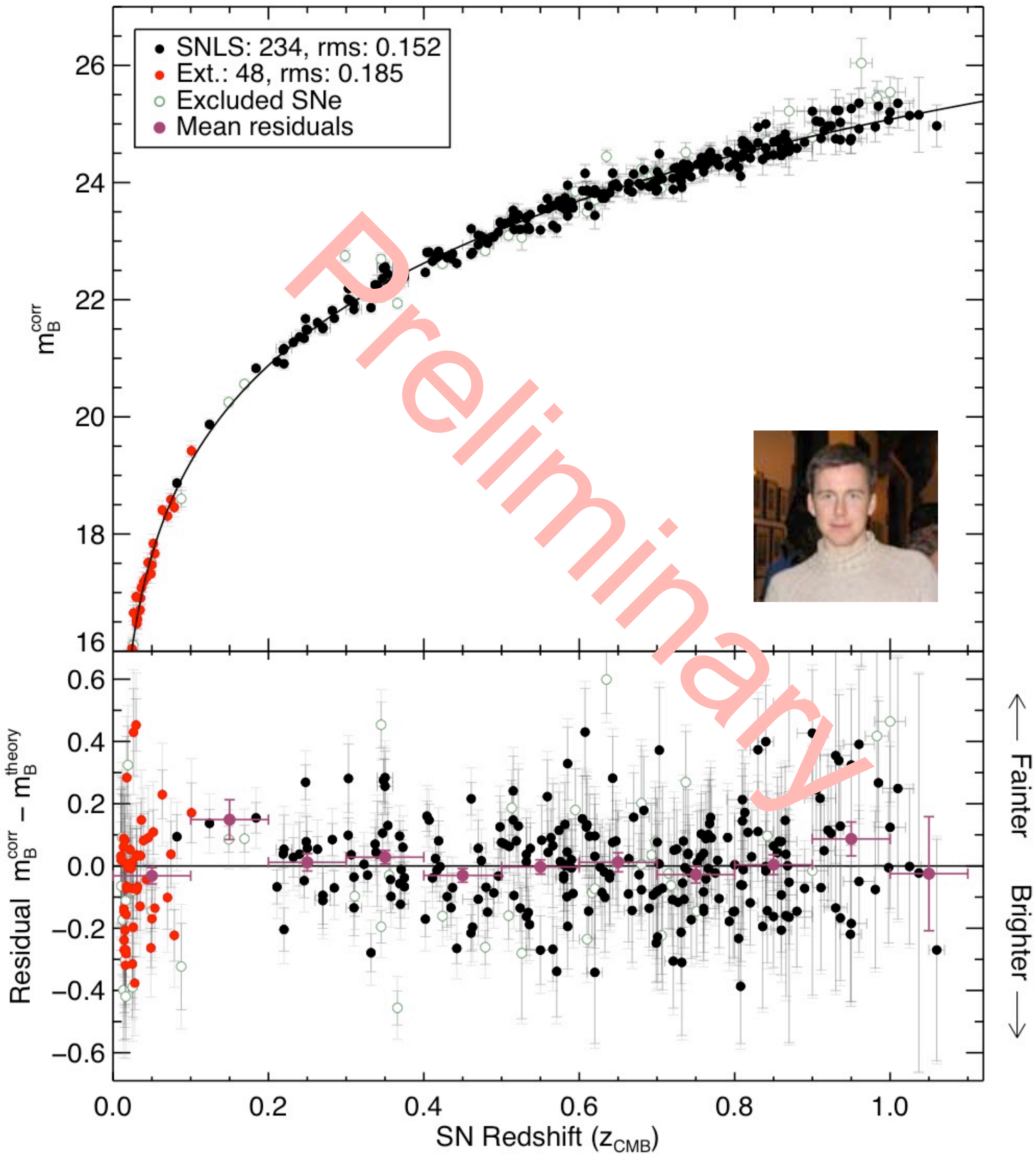


SNLS 3rd year analysis



- **2007** – prelim!
- ~230 out of 270 SNeIa, to Aug 2006
- Fit - w=-1

Cuts:

Stretch 0.75<s<1.25

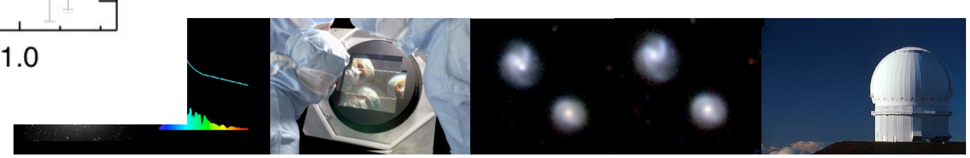
Colour

Light curve coverage

Intrinsic scatter:

SNLS ±0.09

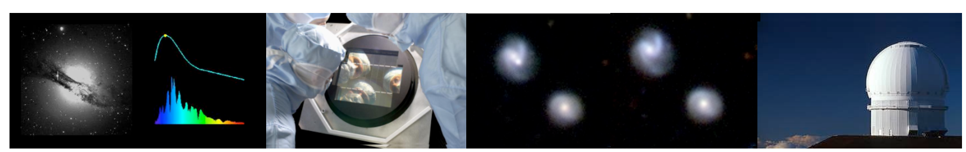
Low z ±0.13



Addressing systematics

- The control of systematics will define how accurately w and especially dw/dz will be determined
- Large sample size of SNLS will allow subsample tests to investigate role of systematics

Largest systematics currently are:



Systematics …

- **ZP uncertainty** ±0.04 in w
  - Improve mosaic uniformity to better than 1% (done)
  - Tie calibration to CALSPEC standards (precise flux standards)
  - Tie low and high z SNe together on uniform photometric system (SDSS-II)

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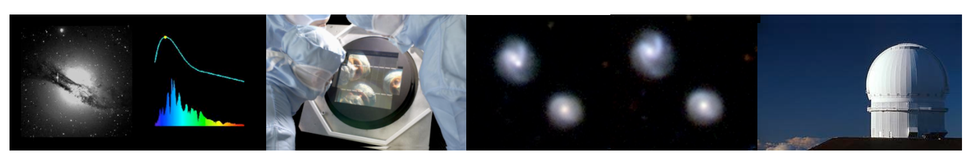

Systematics …

- **k-corrections (Hsiao et al 2007)**

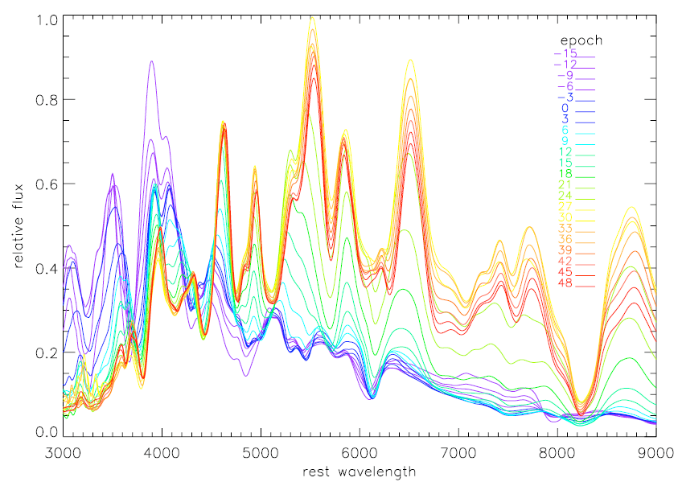

Fig. 5.— An illustration of the time evolution of spectral features of SNe Ia. A spectral template is plotted from $t = -15$ to $t = 48$ relative to maximum B band light. Template spectra at different epochs are normalized to the same B band flux. Spectral features of SNe Ia evolve rapidly around maximum light and slow down pass $t = 20$. This emphasizes the importance of small epoch bins near maximum light.

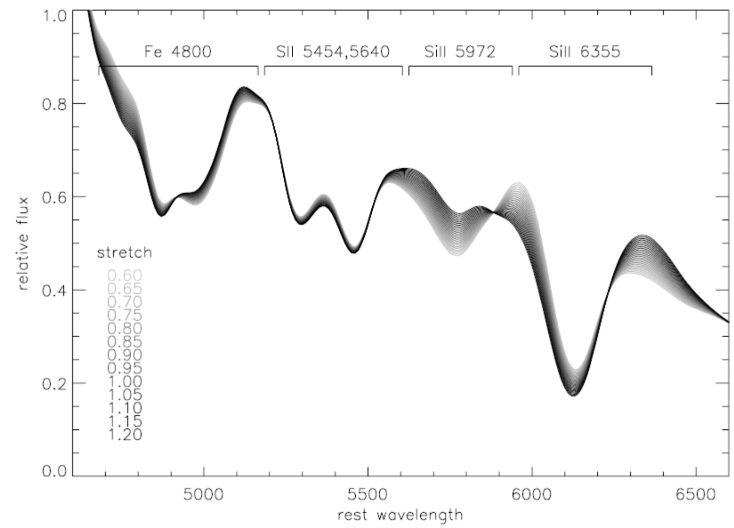

Fig. 14.— The template spectroscopic sequence of Si II λ5972 and Si II λ6355. The template is derived from 24 library spectra of 17 SNe Ia with a wide range of stretch factors. The pattern is prescribed by the principal component analysis of the narrow band color measurements described in Section 5.2.

- Based on 800 individual spectra (Suspect, etc)
- Ellis et al 2007 UV

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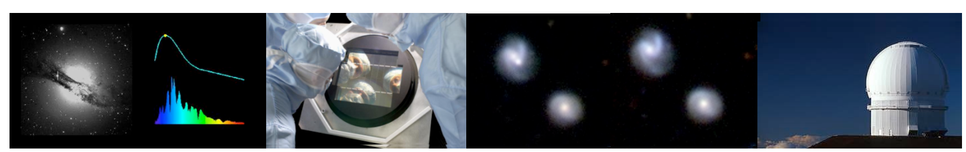

Systematics …

- Malmquist Bias ±0.025 in w (Perrett 2007)

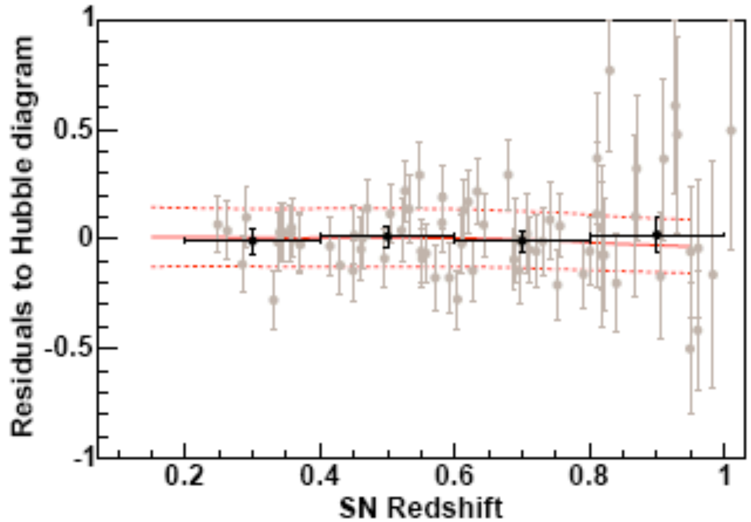

Fig. 13 Stretch, color and Hubble diagram residuals as a function of redshift for SNLS supernovae (gray dots). The black points correspond to average values in redshift bins. The red solid (dashed) lines represent the average (one standard deviation) values obtained with SNe simulations as described in Section 7.4. At large redshifts, since only bright SNe are identified, the average stretch factor is larger and the average color bluer. The average distance modulus is less affected by the se-

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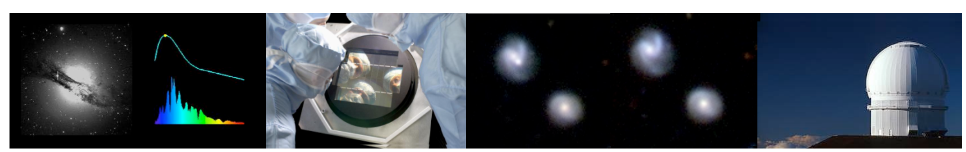
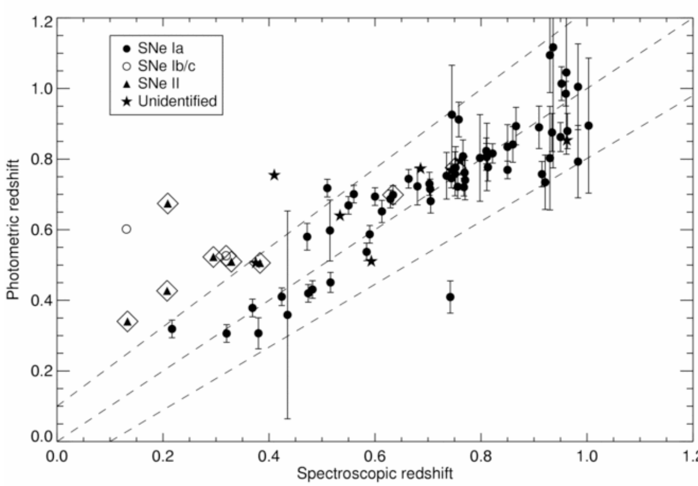


Systematics …

- Redshift dependent population changes
  - come back to - one of the potentially most important astrophysical systematics

- Redshift evolution in SN properties
  - Conley et al, Bronder et al …

Sullivan et al 2005



- Selection by SN photo-z?
  - •1000 candidates – how to prioritize for followup? Defines success of survey.
  - •Photometric pre-selection. Fits early-time SN light-curves, returns probability of the candidate being a SN Ia.

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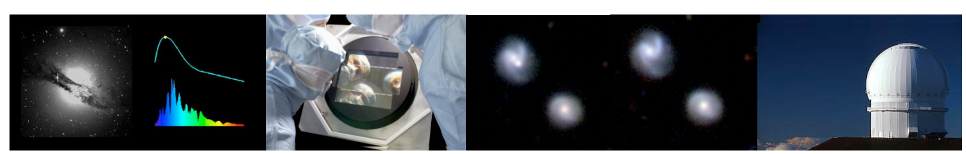
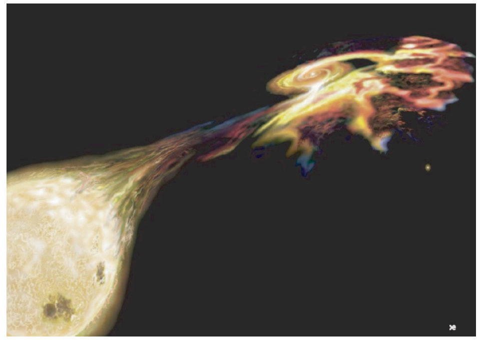
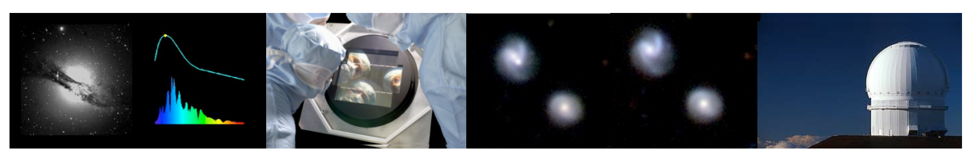
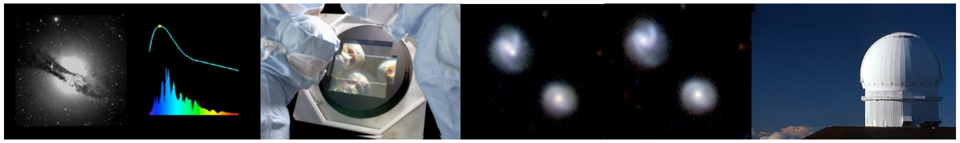




- Historical Background
- Supernova Cosmology
- SNLS
- *Other SN Science*
- Conclusions/Future



SNe II as Standard Candles!



SNe II as standard candles?

Hamuy 2003
astro-ph

Note models show same effect (though offset).

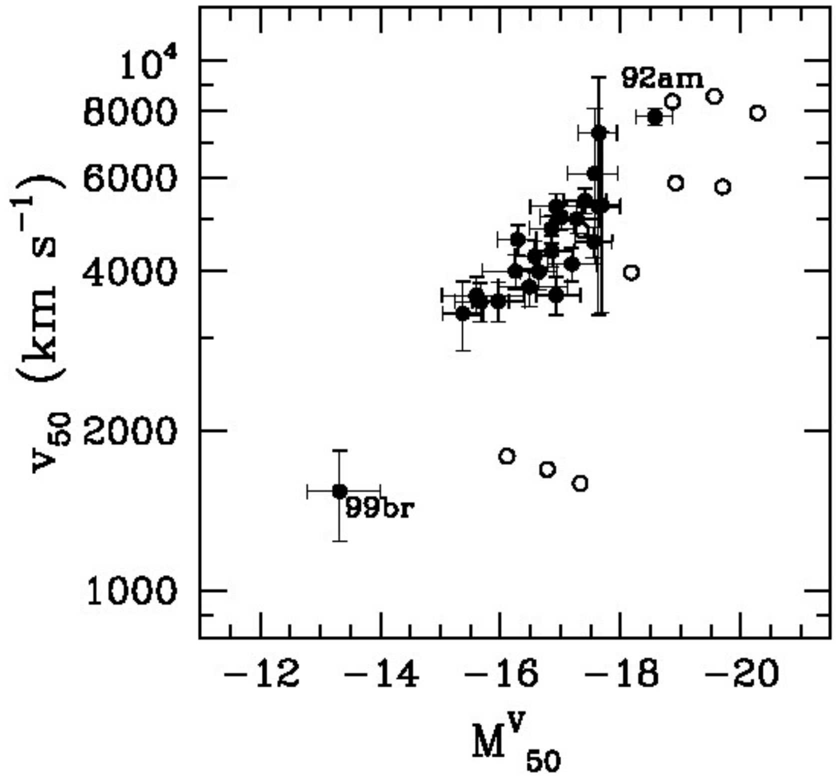


Fig. 1.1. Envelope velocity versus absolute plateau V magnitude for 24 SNe IIP, both measured in the middle of the plateau (day 50) (filled circles). The expansion velocities were obtained from the minimum of the Fe II λ5169 lines. The absolute magnitudes were derived from redshift-based distances and observed magnitudes corrected for dust extinction. Open circles correspond to explosion models computed by Litvinova & Nadezhin (1983, 1985) for stars with $M_{ZAMS} \geq 8\ M_{\odot}$.

www.astro.uvic.ca/~pritchet/SN/A580-2008-III.pdf

SNII Standard Candle (Nugent et al. 2006)

$$M_I = 6.69\left(\frac{V_{FeII}}{5000\ \mathrm{km/s}}\right) - 1.36\left[(V-I)_{50d} - 0.53\right] - 17.49$$

- Keck spectra
- Scatter =0.26 mag
- Fe II correlated with H
- Can be scaled from other than 50 day epoch

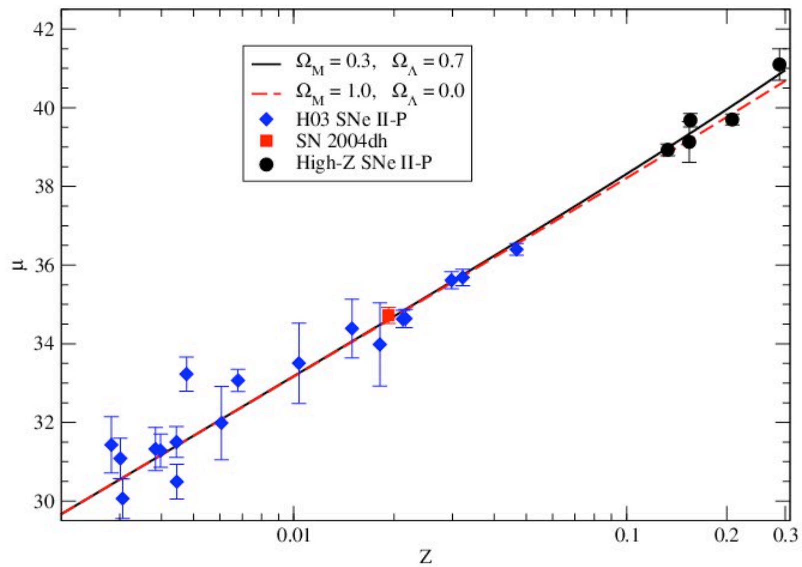
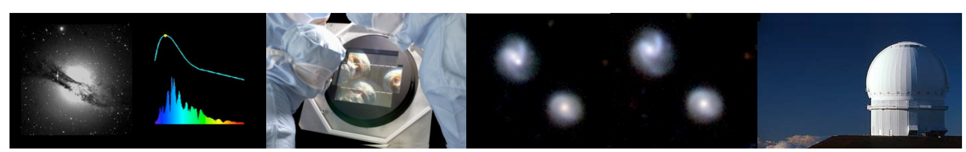
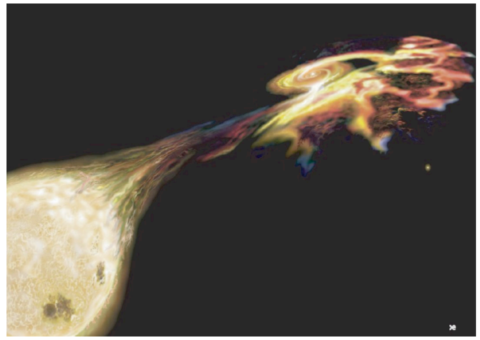


Fig. 13.— The Hubble diagram for both the local SNeII-P (diamonds and square) and the high-redshift SNLS SNeII-P (circles) observed spectroscopically with Keck+LRIS. The observed scatter for the supernova in the Hubble flow is 0.26 magnitudes with a reduced χ^2 of 1.4, which is indicates a small amount of intrinsic uncertainty. To understand the current power of this technique we have over-plotted two differing Hubble lines for a flat cosmology with $\Omega_M = 1$ and 0.3.





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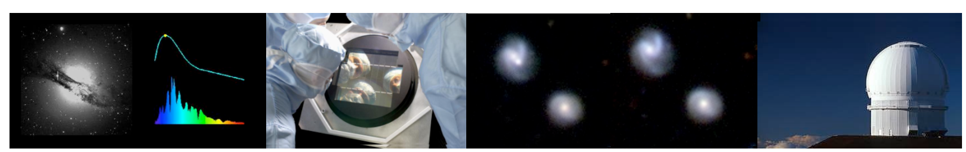

Future

- w = -1±0.06 (preliminary) from 3rd year data (N=230).
  - Dark energy resembles pure cosmological constant (vacuum energy).
  - Most accurate estimate of w yet

- ~400-500 SNeIa with spectroscopy by 2008, >1000 total

- 3rd year analysis (2007), final analysis (2009)
  - Possibility of first estimate of dw/dz (combine data with HST very high z data set and SDSS z=0.2 sample)

- Calibration
  - Current systematics are +-3%
  - Improve to 1% ? (better k-corr, obs of Bohlin CALSPEC standards with MegaCam)

- JDEM!

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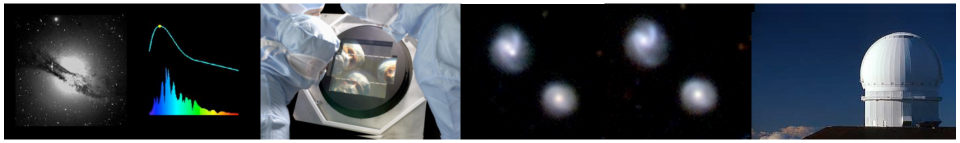
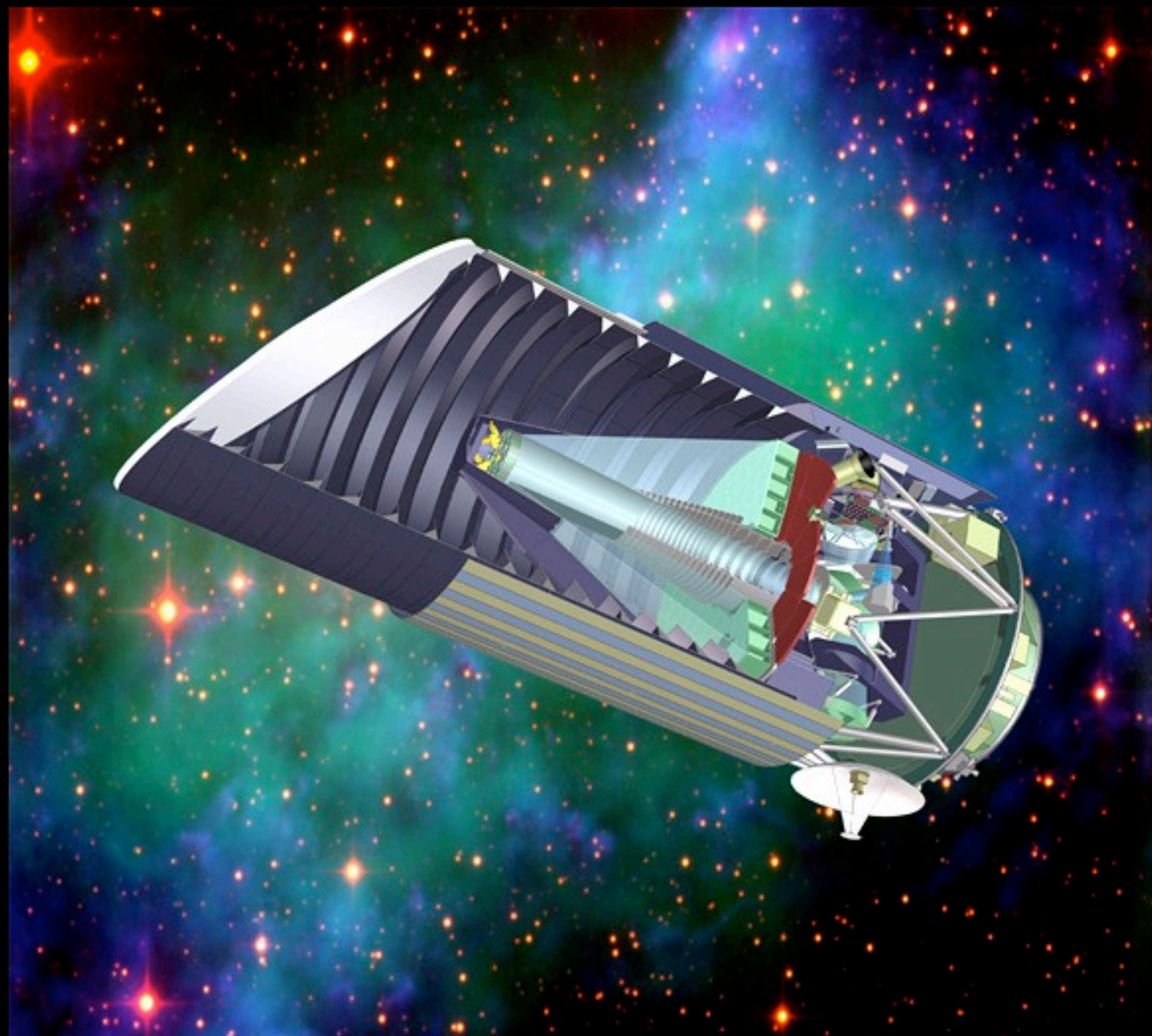


SNAP

Supernova / Acceleration Probe

Studying the Dark Energy of the Universe



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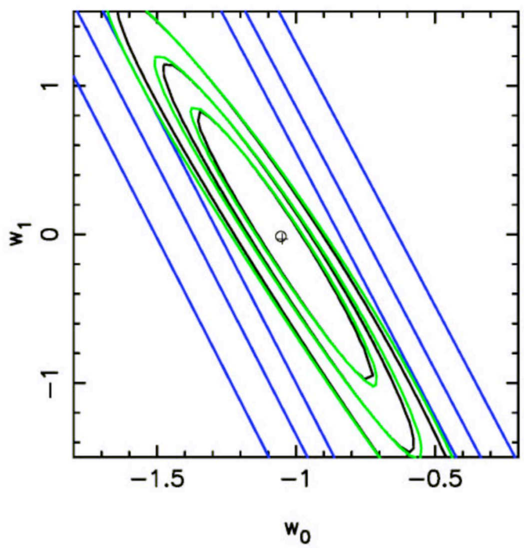
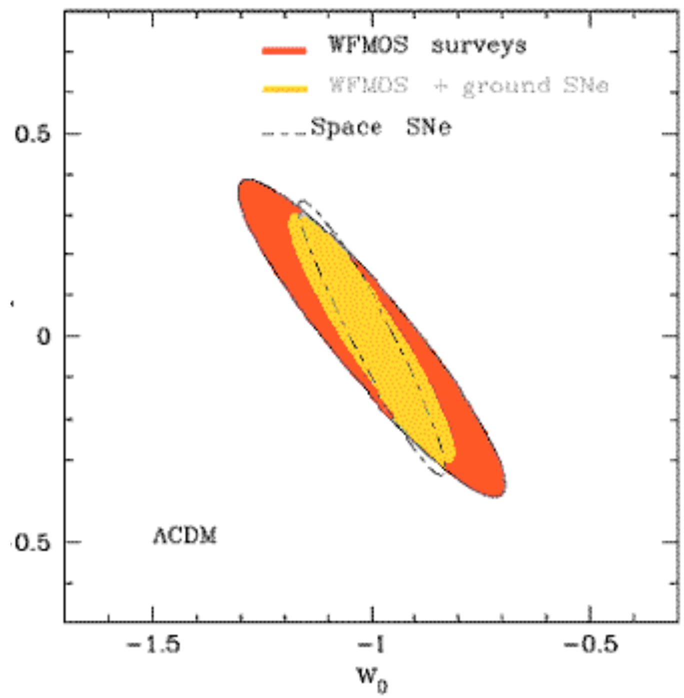
dw/dz - preliminary …





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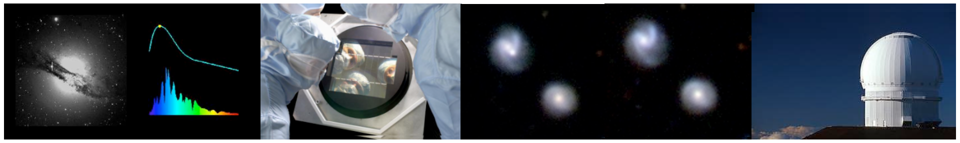
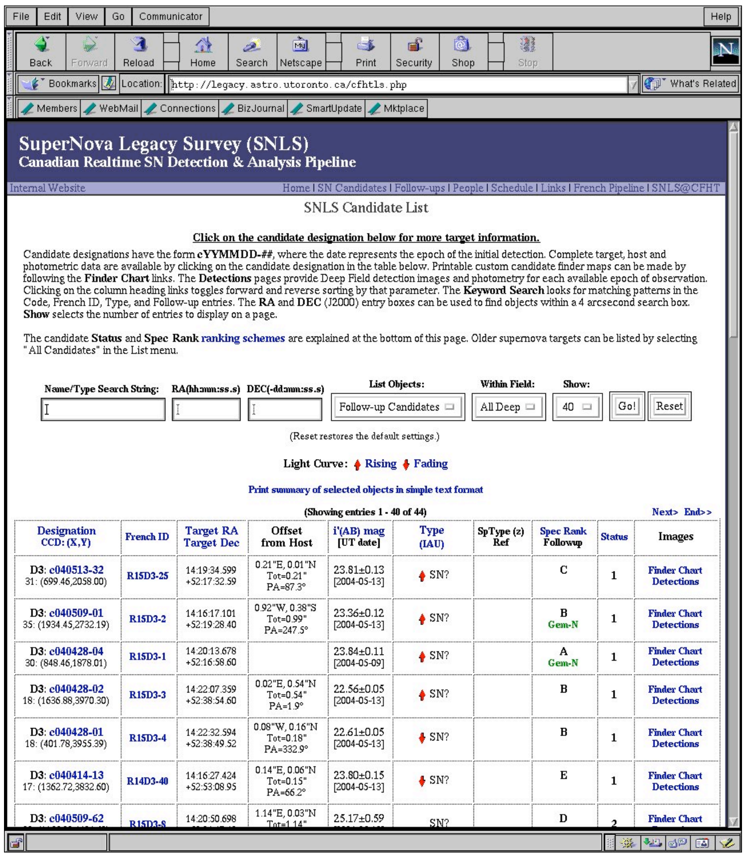


More SNLS information

- [***http://legacy.astro.utoronto.ca/***](http://legacy.astro.utoronto.ca/) *- database (Perrett)*
- ***www.cfht.hawaii.SNLS*** *– people, papers, …*



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SuperNova Legacy Survey (SNLS)
Canadian Realtime SN Detection & Analysis Pipeline

Internal Website — Home | SN Candidates | Follow-ups | People | Schedule | Links | French Pipeline | SNLS@CFHT

SNLS Candidate List

Click on the candidate designation below for more target information.

Candidate designations have the form **cYYMMDD-##**, where the date represents the epoch of the initial detection. Complete target, host and photometric data are available by clicking on the candidate designation in the table below. Printable custom candidate finder maps can be made by following the **Finder Chart** links. The **Detections** pages provide Deep Field detection images and photometry for each available epoch of observation. Clicking on the column heading links toggles forward and reverse sorting by that parameter. The **Keyword Search** looks for matching patterns in the Code, French ID, Type, and Follow-up entries. The **RA** and **DEC** (J2000) entry boxes can be used to find objects within a 4 arcsecond search box. **Show** selects the number of entries to display on a page.

The candidate **Status** and **Spec Rank** ranking schemes are explained at the bottom of this page. Older supernova targets can be listed by selecting "All Candidates" in the List menu.

Name/Type Search String: | RA(hh:mm:ss.s) | DEC(-dd:mm:ss.s) | List Objects: Follow-up Candidates | Within Field: All Deep | Show: 40 | Go! | Reset

(Reset restores the default settings.)

Light Curve: Rising Fading

Print summary of selected objects in simple text format

(Showing entries 1 - 40 of 44) Next> End>>

Designation CCD: (X,Y)	French ID	Target RA Target Dec	Offset from Host	i'(AB) mag [UT date]	Type (IAU)	SpType (z) Ref	Spec Rank Followup	Status	Images
D3: c040513-32 31: (699.46,2058.00)	R15D3-25	14:19:34.599 +52:17:32.59	0.21"E, 0.01"N Tot=0.21" PA=87.3°	23.81±0.13 [2004-05-13]	SN?		C	1	Finder Chart Detections
D3: c040509-01 35: (1934.45,2732.19)	R15D3-2	14:16:17.101 +52:19:28.40	0.92"W, 0.38"S Tot=0.99" PA=247.5°	23.36±0.12 [2004-05-13]	SN?		B Gem-N	1	Finder Chart Detections
D3: c040428-04 30: (848.46,1878.01)	R15D3-1	14:20:13.678 +52:16:58.60		23.84±0.11 [2004-05-09]	SN?		A Gem-N	1	Finder Chart Detections
D3: c040428-02 18: (1636.88,3970.30)	R15D3-3	14:22:07.359 +52:38:54.60	0.02"E, 0.54"N Tot=0.54" PA=1.9°	22.56±0.05 [2004-05-13]	SN?		B	1	Finder Chart Detections
D3: c040428-01 18: (401.78,3955.39)	R15D3-4	14:22:32.594 +52:38:49.52	0.08"W, 0.16"N Tot=0.18" PA=332.9°	22.61±0.05 [2004-05-13]	SN?		B	1	Finder Chart Detections
D3: c040414-13 17: (1362.72,3832.60)	R14D3-40	14:16:27.424 +52:53:08.95	0.14"E, 0.06"N Tot=0.15" PA=66.2°	23.80±0.15 [2004-05-13]	SN?		E	1	Finder Chart Detections
D3: c040509-62	R15D3-8	14:20:50.698	1.14"E, 0.03"N Tot=1.14"	25.17±0.59	SN?		D	2	Finder Chart

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