GEMINI OBSERVATORY

observing time request summary

Semester: 2007A **Observing Mode:** queue

Instruments: GMOS North **Gemini Reference:** **Time Awarded:**

Title: **The Nature of Dark Energy from Type Ia Supernovae**

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Partner Submission Details *(multiple entries for joint proposals)*

Partner	Partner Lead Scientist	Time Requested	Minimum Time Requested	NTAC Reference Number	NTAC Reco-mmended Time	NTAC Minimum Time Reco-mmended	NTAC Rank
UK	Hook	20.0 hours	20.0 hours		0.0	0.0	
USA	Perlmutter	10.0 hours	10.0 hours		0.0	0.0	
Canada	Pritchet	30.0 hours	30.0 hours		0.0	0.0	
	Total Time	*60.0 hours*					

Abstract:

Type Ia supernovae (SNe Ia) currently provide the most direct evidence for an accelerating Universe and for the existence of an unknown "dark energy". The 5-year Supernova Legacy Survey (SNLS) is generating a definitive dataset with well-sampled g'r'i'z' light curves and spectroscopic confirmation, which together allow precise measurement of the cosmological parameters. We are now entering the final 18 months of this highly successful survey. With the full, final sample we expect to determine the cosmological equation of state parameter "w" to a statistical precision of +/-0.05 or better, testing theories for the origin of the universal acceleration. The amount of spectroscopic follow-up performed is central to the success of the survey. Approximately 500 SNe Ia will be spectroscopically confirmed in a coherent program involving Gemini, VLT and Keck. Nod-and-shuffle observations at Gemini play a pivotal role. The goal for Gemini this semester is to obtain types and redshifts for ~30 SN Ia candidates with redshifts 0.6-0.9, contributing to a dataset superior to any existing - or planned - sample. This is a continuing QR (quick response) proposal for GMOS-N.

Science Justification

The Hubble diagram for high-redshift Type Ia supernovae (SNe Ia) provides the most direct evidence for the accelerating expansion of the Universe. The "first generation" of SN Ia cosmology work led to astonishing results ruling out a flat, matter-dominated Universe (Riess et al. 1998; Perlmutter 1999). This indicated the presence of a new "dark energy" driving cosmic acceleration.

One of the most pressing questions in cosmology now is: "What is the nature of this dark energy?". There is a fundamental difference between a Cosmological Constant and other proposed forms of dark energy -- the former being equivalent to the vacuum energy (constant in time and space) as opposed to a slowly-varying scalar field (e.g. "quintessence" models). The distinction can be addressed by measuring the dark energy's average equation-of-state parameter, <w>= <pressure/density>, where w=-1 corresponds to a Cosmological Constant -- most scalar-field models predict values different from -1.

The importance of improving measurements to the point where <w>=-1 could be excluded led our collaboration to set up the Supernova Legacy Survey (SNLS, described below). Our over-arching goal is to constrain <w> by building an order-of-magnitude larger sample of SNe in the redshift range z=0.3-0.9, where <w> is best measured. With this sample, we aim to answer the key question: Is the dark energy something other than Einstein's Lambda?

The recent analysis of the 3rd year WMAP CMB data (Spergel et al., 2006) highlights the power of SNe Ia data in determining cosmological parameters: indeed the tightest constraints on w are obtained when the WMAP data are combined with our 1st year SNLS results (which were published in Astier et al., 2006).

SNLS: AN UNPRECEDENTED SN Ia DATASET TO MEASURE DARK ENERGY

The CFHT Legacy Survey (http://cfht.hawaii.edu/SNLS/ and http://legacy.astro.utoronto.ca/) is an ambitious, repeat-imaging wide-field survey conducted in 4 filters (g'r'i'z'). The full five-year SNLS began operation in August 2003 and completion at CFHT is assured. The final dataset will be the definitive high redshift SN dataset for the next decade.

Our first year results already represent the largest homogeneous SNe Ia sample for cosmological measurements (Astier et al 2006, and Fig 1). We aim to submit our year 2&3 results paper by the end of the year, but only with the final 5-year sample will we reach the full potential of the survey. Simulations indicate that with our final sample of 500 well-measured SNe Ia plus a few hundred nearby SNe from current & upcoming nearby searches, combined with current constraints from WMAP or Baryon Acoustic Oscillation (BAO) constraints from SDSS (Percival et al 2006), we will determine w to a statistical precision of +/-0.05 or better, distinguishing between w>-0.8 and w=-1 at more than 3-sigma. SNLS's superior control of systematic effects (see below) may also allow us to place constraints on the variation in w with time (by measuring w at z=0.5 and z=0.9), an important discriminant between the cosmological constant and other dark energy models. Furthermore, future experiments such as Planck will have the most powerful, complementary dataset with which to combine results.

SYSTEMATIC UNCERTAINTIES

Though uncertainties due to K-corrections, gravitational lensing and Malmquist bias were small compared to the statistical error of previous SN samples, the SNLS is reducing statistical errors to the point where some systematics may again become important. Understanding systematic effects is also key to planning future dark energy experiments, as highlighted by the recent report by the U.S. "Dark Energy Task Force" (astro-ph/0609591). The SNLS dataset allows powerful tests and places constraints on several potential systematics. e.g.:

Multi-colour lightcurves: SNLS is generating the first large high-redshift SN Ia dataset with complete colour coverage throughout the lightcurves. This enables comprehensive extinction studies since all the SNe are sampled over a wide rest-wavelength baseline.

High-statistics subsamples: By dividing the sample into subsets based on host galaxy type, we are now able to begin comparisons of the nearly dust-free subset of SNe Ia (those in E/S0 hosts) with the subset that has been corrected for extinction (those in spiral hosts). To do such tests at the required precision requires a large number of SNe in each subgroup, only achievable with the full, end-of-survey sample.

Tests for evolution: We are able to test for systematic effects due to evolution of SNe Ia by comparing their properties in different redshift bins. Our Gemini spectra have proved to be of high enough quality to allow quantitative comparisons of spectral features between low and high-z SNe (Figs 2 and 3, also Bronder, PhD thesis and paper in prep). We have also tested the uniformity of the lightcurve shape and find spectacular uniformity across the redshift range of SNLS, and furthermore that the rise-time of SNLS SNe is consistent with that of low-z SNe Ia (Conley et al 2006 and Fig 3).

PARALLEL SCIENCE

Although the main goal of SNLS is measurement of w, the vast amount of high-quality data, collected in a uniform way, allows a wealth of related studies on supernova properties, their environments and rates. Recent examples include a measurement by Neill et al (2006) of the SNIa rate at $\langle z \rangle=0.47$ based on 73 SNLS SNe. Intriguingly, after normalizing for host mass, we find that the SNe Ia rate in active star-forming galaxies is a factor of about 10 higher than in quiescent galaxies such as E/S0's (Sullivan et al, 2006b and Fig 3). These studies, coupled with our unparalled data set for studying supernova astrophysics at high redshift (eg supernova 03D3bb - Howell et al 2006, Nature) have profound implications for our understanding of progenitors and explosion mechanisms for SNe Ia.

CONCLUSIONS

This continuing proposal focuses on the extraordinary science opportunities presented by the CFHT Legacy Survey. We are now entering the final 18 months of the survey - we will not submit any real-time supernova spectroscopy proposals beyond 08A for SNLS. The large improvement in statistics and control of systematics provided by the final sample is crucial for studying the cosmological parameters and the nature of dark energy. By supporting this program Gemini will continue to play a leading role in this fundamental science.

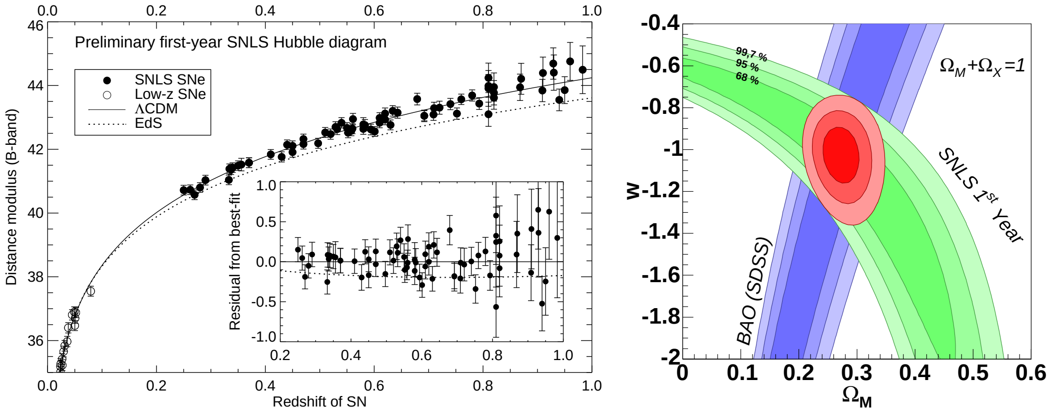
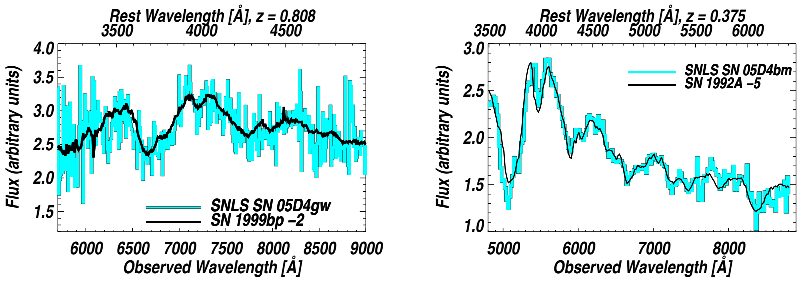
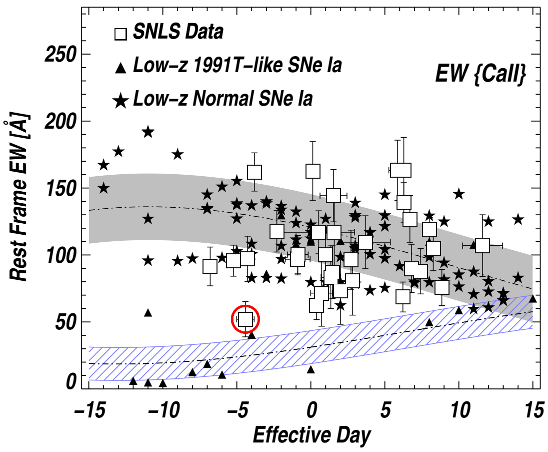


Figure 1: SNLS cosmological results. **Left:** The SN Ia Hubble diagram from the first full year of data (71 high-redshift SNe; Astier et al. 2006), only a quarter of the current SNLS sample, yet already the largest homogeneous SN sample. Inset shows the residuals from the best-fitting cosmology. The best-fit flat cosmology is Ω_M=0.263 ±0.042 (*stat*) ±0.032 (*sys*) (Astier et al. 2006). **Right:** Constraints in $\Omega_{\rm M}$ versus w. Solid lines show the current 1, 2 and 3σ confidence limits. The current constraint is $w = -1.023 \pm 0.090$ (*stat*) ±0.054 (*sys*) when combined with the SDSS baryon acoustic oscillations result (Eisenstein et al. 2005). Similar results are obtained when SNLS is combined with the 3rd year WMAP data. The end-of-survey results will provide a statistical error on w of ±0.05 or better.

Figure 2: Example spectra of SNLS candidates obtained during the 06A Gemini observing campaign. The light-blue lines show the data after host galaxy subtraction (if necessary), re-binned to 10Å. Over-plotted in black are best-fitting SN templates. The spectra are confirmed by Gemini to be Type Ia SNe.





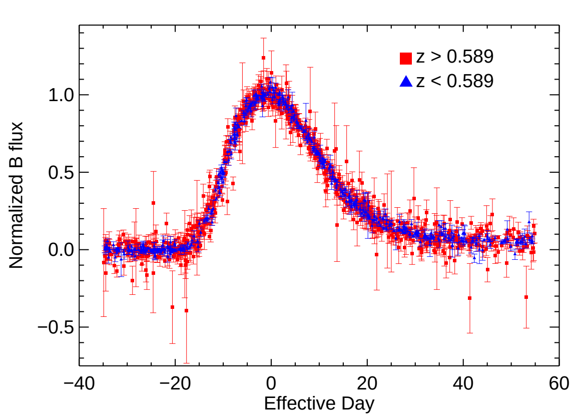
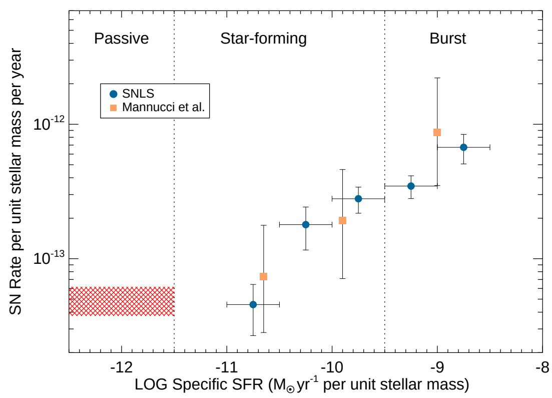


Figure 3: A selection of science results from the SNLS. **Above:** A comparison of equivalent width measurements of the Ca II absorption feature in local SNe Ia spectra with those observed by Gemini for the SNLS (Bronder et al. 2006). The dashed line and grey shaded area is the mean and $\pm 1\sigma$ dispersion for nearby SNe Ia; the striped region denotes the same trend for unusual '1991T-like' SNe. This test identifies peculiar SNe Ia in the SNLS sample (red circle) and tests the high-z SNe Ia for evolution (no difference from the local SNe is seen). **Above Right:** The result of the study of the rise-times of SNLS SNe Ia from Conley et al. (2006). Shown is the normalised and light-curve-width corrected rest-frame B-band SNLS SN Ia light-curves. Blue triangles are SNe at lower redshift, red squares those at higher redshifts. The rise-times of the two samples are consistent. Furthermore, the consistency in the shape of the light-curves is spectacular across our entire redshift range. **Lower Right:** The rate per unit stellar mass as a function of host galaxy type from Sullivan et al. (2006b). The SN Ia rate per unit mass is around ten times higher in strongly star-forming galaxies than in passive systems, a surprising result with implications for the nature of the SN Ia progenitor system. Gemini plays a crucial role in defining the highest redshift data set allowing tests for evolution such as those described here.



Technical Justification

SNLS STATUS -- REAL-TIME ANALYSIS

SNLS has proved to be a highly focused, productive survey and routinely identifies ~40 SN candidates per month. Completion of the Legacy Survey is assured at CFHT following a successful review by the CFHT SAC, thus the size of our confirmed SN Ia sample will be limited only by the amount of spectroscopic follow-up time available. At the current rate of about 8 confirmed SNe Ia per month, we will have approximately 500 confirmed SNe Ia by the end of the survey (293 to date).

We have developed a reliable technique to optimise our spectroscopic follow-up. Using the real-time g'r'i'z' photometry, we are able to predict candidate redshift and phase -- as well as a probability that the candidate is a SN Ia -- after only two or three epochs of CFHT data (Sullivan et al., 2006a). These predictions allow us to schedule follow-up time when a SN is at maximum light and efficiently reject AGN, variable stars and SNe II from our follow-up program (Howell et al. 2005).

We note that the SN photo-zs cannot be used for the purposes of cosmology because the pre-screening method makes use of a weak cosmological prior. Galaxy photometric redshifts are also insufficiently reliable at present, and would bias the sample to SNe with bright hosts. One of the goals of SNLS is to assess the non-Ia contamination fraction and the possibility of using photo-zs for future surveys. However at this stage spectroscopic redshifts and spectroscopic confirmation of SN types remain essential for the foreseeable future.

GMOS OBSERVATIONS

The Gemini Observatory plays the leading role in the observations of the highest-redshift targets. In the range $0.6<z<0.9$ (where Gemini observations are focused), the key SNIa features are redshifted into the region of the spectrum dominated by sky emission. Nod and shuffle (available only at Gemini) virtually eliminates the systematic errors associated with sky subtraction, allowing reliable identification of the SN type.

The overheads associated with Gemini observations make deep exposures an efficient use of telescope time (brighter candidates are observed at VLT). Gemini targets have i'=23-24.2, and we use GMOS exposures of between 1 and 2 hr. Assuming an average exposure time of 1.5 hr, and 30 minute overhead per object for setup and Nod & shuffle overheads, we again request 60hr (total from all partners) in order to observe approximately 30 SN candidates this semester. This is in line with our observations to date. Although longer exposures would give better signal-to-noise, our priority is identification and redshifts of as many targets as possible. The exposure times that we use have proved sufficient for this goal and also allow quantitative statistical studies of the spectra themselves (Bronder, PhD thesis and paper in prep).

All observations use a 0.75" slit, the R400_G5305 grating, and OG515 order sorting filter, with one of two central wavelengths depending on the predicted redshift of the target. The slit PA is chosen to pass through both SN and host galaxy to obtain a SN type and a host redshift. Our experience shows that the dispersion of the R400 grating (~2A/pix) gives excellent nod and shuffle sky subtraction, and we rebin the data ~10x afterwards for SN typing.

SCHEDULING AND LOGISTICS

As SNe Ia will be discovered throughout the semester, observing time should be spread throughout 2007A. We obtain SN detections in real time at CFHT (<24 hr turnaround), and the Phase-II definition is updated frequently during each dark period. The coordinates quoted here are those for the search fields- exact coordinates will be entered into the Phase-II when known. This is a QR (quick response) proposal, for which the triggers are SN discoveries from SNLS.

As for last semester, we request all our time on GMOS-N. The poorer red response and fringing of the GMOS-S detectors is an important factor in this choice.

INTERNATIONAL COLLABORATION

Spectroscopy on 8m class telescopes is essential for this project to succeed; the total amount of spectroscopic time needed is well beyond the reach of any one group or nation. We are applying for 60 hrs of Gemini time this semester (30 hrs Canada, 20hrs UK, 10 hrs US).

Our VLT large program (REF 176.A-0589, PI Pain) has been approved for the period 2005B-2007A inclusive (120 hrs per year). I.H. will continue as PI and principal contact for our Gemini program. The co-investigators on this proposal are a subset of the full collaboration; see http://snls.in2p3.fr/people/snls-members.html for a complete list.

SNLS SCIENCE USING GEMINI DATA - PUBLICATION PLAN

We have obtained spectroscopy of 140 candidates in 288 hours of observations at Gemini since 2003B. The spectra are reduced as soon as they become available, and we post types and redshifts on our website. The first year Gemini spectroscopy is published (Howell et al 2005). Analysis of the 2nd and 3rd year Gemini spectra up to May 2006 is complete (Bronder, PhD thesis submitted) and these spectra will be presented by Bronder et al (2006 in prep).

We are able to produce Hubble diagrams, including Gemini-observed SNe, within 5-6 months of the spectroscopic observations (the SNe must be followed for around two months after maximum light to fit their light-curves). Our first-year cosmological results have been published (Astier et al 2006) and several papers on related topics are in press or in preparation (see science case). Our next paper on cosmological parameters, based on 3 years of data (up to July 2006), is planned for submission at the end of 2006. Our collaboration has committed to publish the full lightcurve photometry and spectroscopic measurements approximately one year after the corresponding cosmological results. Additional papers on parallel science will continue to be written as the dataset grows.

REFERENCES

--Percival et al, 2006, ApJL submitted (astro-ph/0608635) --Perlmutter et al., 1999, ApJ 118, 1766 --Riess et al., 1998, AJ 116, 1009 --Riess et al., 2004, ApJ 607, 665 --Spergel et al., 2006, ApJ, submitted (astro-ph/0603449) --Sullivan et al., 2003, MNRAS 340, 1057 (References for SNLS publications can be found in the "Publications" section).

Observation Details

Observation	**RA**	**Dec**	**Brightness**	**Total Time** *(including overheads)*
CFHTLS-D3	14:19:28.01	+52:45:41	i=22-24	20.0 hours
GSC0385900245(oiwfs)	14:19:43.781	52:46:17.69	13.48 mag	separation 2.46
Observing conditions: SN Spec		resources: GMOS North		
CFHTLS-D2	10:00:28.60	+02:12:21.0	i=22-24	20.0 hours
GSC0024401641(oiwfs)	10:00:30.266	2:09:07.49	14.44 mag	separation 3.25
Observing conditions: SN Spec		resources: GMOS North		
CFHTLS-D4	22:15:31.67	-17:41:05.7	i=22-24	20.0 hours
GSC0638100228(oiwfs)	22:15:17.758	-17:42:09.76	12.94 mag	separation 3.48
Observing conditions: SN Spec		resources: GMOS North		

Observing Conditions

Name	**Image Quality**	**Sky Background**	**Water Vapor**	**Cloud Cover**
SN Spec	70 %	50 %	Any	50 %

Resources

- Gemini North
  - GMOS North
    - Focal Plane Unit
      - Longslit 0.75 arcsec
      - Nod and Shuffle 0.75 arcsec
    - Filter
      - GG455_G0305
      - OG515_G0306
      - i_G0302
      - r_G0303
    - Disperser
      - R400_G5305

Scheduling Information

Scheduling constraints and non-usable dates

- (impossible):
- (optimal):
- (synchronous):

Aditional Information

Keyword Category: extraGalactic
Keywords: Cosmological distance scale
Survey

Allocations:

Reference	Time	% Useful	Status of previous data
GN-2006B-Q-10	60.0 hours	%	Observations underway (band 1)
GN-2006A-Q-7	60.0 hours	60%	Follow up of CFHTLS supernovae. Successful semester (in band 1). 20 candidates observed (limited by poor weather). Data reduced. Data up to May 2006 to be published in Bronder et al 2006.
GN-2005B-Q-7	45.0 hours	93%	Follow up of CFHTLS supernovae. Successful semester (in band 1).19 candidates observed. Data reduced - to be published in Bronder et al 2006
GS-2005B-Q-6	15.0 hours	89%	Follow up of CFHTLS supernovae. Successful semester (in band 1). 6 candidates observed. Data reduced - to be published in Bronder et al 2006.
GN-2005A-Q-11	45.0 hours	91%	Follow up of CFHTLS supernovae. Successful semester (in band 1). 18 targets observed. Data reduced - to be published in Bronder et al 2006.
GS-2005A-Q-11	15.0 hours	65%	Follow up of CFHTLS supernovae. Successful semester (in band 1). 5 targets observed. Data reduced - to be published in Bronder et al 2006.
GN-2004B-Q-16	45.0 hours	100%	Follow up of CFHTLS supernovae. Successful semester (program in Band 1) - 23 targets observed. Results up to October 2004 are published in Howell et al (2005). The remaining spectra have been reduced - to be published in Bronder et al 2006.
GS-2004B-Q-31	15.0 hours	15%	Follow up of CFHTLS supernovae. The program was in band 2 at GS. competition with other programs resulted in only 2.25hrs of data being taken (1 target). Data reduced - to be published in Bronder et al 2006.
GN-2004A-Q-19	43.0 hours	100%	Follow up of CFHTLS supernovae. Successful semester (program in band 1). 22 targets observed. Results presented in Howell et al (2005).
GS-2004A-Q-11	17.0 hours	7%	Follow-up of CFHTLS supernovae. Weather and competition with other Band 1 programs led to a lower than expected completion rate (1 target observed in 1.2hrs). Results presented in Howell et al (2005).
GN-2003B-Q-9	45.0 hours	100%	Follow-up of CFHTLS supernovae. Successful semester (program in band 1). 22 targets observed. Results presented in Howell et al (2005).
GS-2003B-Q-8	15.0 hours	63%	Follow-up of CFHTLS supernovae. Weather and competition with other Band 1 programs led to a lower than expected

			completion rate. 3 targets observed in 9.5hrs. Results presented in Howell et al (2005).

Related proposal information:

ESO VLT 176.A-0589 : French + other European collaborators time on FORS1 (VLT) for CFHTLS SN followup. 120 hr allocated on FORS1/FORS2 each year from 05B to 07A. The PI is R. Pain.

Publications:

- Howell A. et al (SNLS), 2006, Nature, 433, 308 "The type Ia supernova SNLS-03D3bb from a super-Chandrasekhar-mass white dwarf star"
- Conley A. et al. (SNLS), 2006, AJ, 132, 1707 "The Rise Time of Type Ia Supernovae from the Supernova Legacy Survey"
- Sullivan et al (SNLS), 2006b, ApJ, 648, 868, "Rates and Properties of Type Ia Supernovae as a Function of Mass and Star Formation in Their Host Galaxies"
- Neill J. D. et al (SNLS), 2006, AJ, 132, 1126 "The Type Ia Supernova Rate at z~0.5 from the Supernova Legacy Survey"
- Astier P. et al (SNLS), 2006, "The supernova Legacy Survey: Measurements of Omega_M, Omega_Lambda and w from the First Year Data Set.", A&A, 447, 31
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- Sullivan M. et al. 2003, "The Hubble Diagram of Type Ia Supernovae as a Function of Host Galaxy Morphology", MNRAS, 340, 1057
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- Perlmutter S. et al, 1998 "Discovery of a supernova explosion at half the age of the Universe and its cosmological implications", Nature 391, 51.
- Perlmutter S. et al 1997 "Measurement of the cosmological parameters Omega and Lambda from the first 7 supernovae at z>0.35", ApJ, 483, 565