EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME PERIOD: **63**

To be submitted only to: proposal@eso.org
Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of COIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title Panel: **O–4**
Physical and Standard Candle Properties of Type Ia Supernovae from a Large, Homogeneous, Nearby Sample

2. Abstract
We propose to use the ESO 3.6m to obtain crucial late-time spectra for ~30 nearby Type Ia supernovae, to be discovered as part of a large international campaign. The goals of this campaign are to determine the luminosity function, investigate known and new photometric and spectroscopic luminosity indicators, determine better lightcurve templates and spectral time series at all optical wavelengths, and calculate the rates, for nearby Type Ia supernovae. This large sample of well-observed Type Ia supernovae, and the resulting improvement in our understanding of their standardized-candle properties, will immediately lower the statistical uncertainties in our current determination of the cosmological parameters, Ω_M and Ω_Λ. The sample will also allow tests for any systematic uncertainties which have not already been accounted for in this measurement.

3.

Run	Telescope	Instrument	Time	Month	Moon	Seeing	Obs. Mode
A	3.6	EFOSC2	3n	apr	d	n	v

4.

Number of nights/hours	Telescope(s)	Amount of time
a) initially requested for this project:	3.6	3
b) already awarded to this project:	3.6	0
c) required to complete this project:	3.6	3

5. Special remarks
Since the preferred dates depend on scheduling of other telescopes PLEASE CONTACT PI BEFORE SCHEDULING.

6. Principal Investigator: C. LIDMAN (ESO, ESO, clidman@eso.org)
CoI(s): I. Hook (ESO, ESO), S. Fabbro (LPNHE, CNRS-IN2P3 & Univ. Paris, F), A. Goobar (Stockholm, S), A. Kim (PCC, CNRS-IN2P3 & College de France, F), R. Pain (LPNHE, CNRS-IN2P3 & Univ. Paris, F), G. Aldering (LBNL, USA), S. Perlmutter (LBNL, USA)

7. Is this proposal linked to the PhD thesis preparation of one of the applicants?

8. Description of the proposed programme

A) Scientific Rationale: The Supernova Cosmology Project (SCP), in alliance with astronomers and physicists from CTIO, the EROS microlensing search, and the QUEST quasar search, is undertaking a large CCD-based program to systematically discover and follow more than 30 nearby Type Ia supernovae (SNe Ia) during the upcoming semester. This is an undertaking of unprecedented scope in the study of nearby SNe, and presents a unique opportunity in which ESO facilities will play a key role. Our focus will be on determining those properties of SNe Ia affecting their use for cosmology, as follows:

- secure the low-z portion of our SNe Ia Hubble diagram (Fig 1) using this large, less biased, sample of nearby SNe Ia.
- obtain $UBVRI$ lightcurves beginning well before maximum — data currently available for only a handful of nearby SNe Ia, and needed to fit the lightcurves of high-z SNe Ia for which we now have extensive data prior to maximum (cf. Fig 2). U-band data is important for comparison with R-band data for SNe with $z > 0.75$.
- test and refine the lightcurve width vs. brightness relation used to standardize SNe Ia luminosities, for which a wide range of lightcurve widths is essential.
- obtain spectral coverage with lightcurve phase, and thereby determine accurate K-corrections as a function of lightcurve width and time (cf. Fig 3).
- test for the existence of abnormal host-galaxy extinction laws.

The resulting dataset will allow detailed exploration of SNe Ia properties which will almost certainly lead to a better understanding of SN physics. In particular, this dataset will enable us to determine

- the intrinsic luminosity function of SNe Ia
- new relations between lightcurve shapes, spectral diagnostics (such as UV continuum slope, SiII 5800Å/6150Å line ratios etc) and luminosity.
- SNe properties in different host galaxy environments (as a surrogate for progenitor age, mass, and metallicity).
- the rates of SNe of all types (presently uncertain by at least a factor of two for nearby galaxies), including rates as a function of host galaxy properties.

The Need for a Better Nearby Sample One of the largest potential sources of systematic uncertainty in our measurement of the cosmological parameters Ω_M and Ω_Λ using SNe at high redshift (Perlmutter et al 1997, 1998a, 1998b) stems from our reliance on the low-redshift SNe Ia dataset from the Calan-Tololo SN survey (Hamuy *et al* 1993, 1996a, 1996b) to anchor the low-redshift portion of the Hubble diagram (Fig 1). This low redshift sample also defines the relation between intrinsic SN luminosity and other properties such as lightcurve shape (or width) and spectral features. The Calan-Tololo survey was conducted by blinking photographic plates so its selection function and biases (i.e. Malmquist bias) are difficult to quantify. This makes it difficult to assess whether or not the statistical properties of nearby and distant supernovae are the same. Trends amongst the Calan-Tololo SNe, such as the presence of SNe with lower-width lightcurves at higher redshift, surprisingly little extinction for most SNe, and a dependence between peak color and luminosity (unrelated to extinction; Tripp 1998), calls for some caution in generalizing conclusions based on the Calan-Tololo SNe Ia. The small number of other SNe Ia for which good data are available are not suitable because they are either too nearby to be in the Hubble flow, have inadequate or heterogeneous photometric coverage, or are heavily reddened. Moreover, few well-observed SNe Ia have been discovered before maximum, meaning that the date of maximum, and pre-max portions of template lightcurves we use to fit the high-z SNe are not well determined.

A Large CCD-based Nearby Supernova Survey
During dark time in January, February, and March 1999 we will use wide-field CCD mosaics at the INT 2.5-m, EROS 1-m, and QUEST 1-m to search for supernovae. We are also cooperating with the CTIO group to help with their KPNO 0.9-m and El Roble surveys as needed, and to ensure follow-up of their SNe discoveries. Each survey will cover 100–400 deg^2 each month, with January observations serving as references for discoveries in February and March. The surveys are optimized to find SNe Ia at redshift $z \sim 0.1$ approximately 10 days before maximum. The surveys will also find other types of SNe, as well as some SNe Ia already past maximum, which will be screened out (but reported in a timely manner so others can follow-up on them) based on spectra taken shortly after discovery. SNe Ia still on the rise (as determined from photometric follow-up and spectroscopic dating) will be imaged in $UBVRI$ every 3–5 days for approximately two months, using a network of queue and classically scheduled 1-m to 2-m telescopes for which some observing time has already been committed. Spectra will also be obtained periodically ($\sim$ once per week) using a network of 2.5-m and larger telescopes (including these proposed ESO 3.6m observations, and possibly including UV spectra from STIS on HST). Based on our rates for SNe Ia at $z \sim 0.3$ (Pain et al 1996) it is expected that the combined searches will contribute ~ 30 SNe per month for two months, yielding ~ 60 SNe, of which more than 30 are expected to be SNe Ia before maximum. Thus, unlike most on-going SNe searches, all of the searching and follow-up for this campaign is concentrated into just a few months, allowing the telescope time for the entire campaign to be classically scheduled and allowing for homogeneous selection and follow-up.
The search and follow-up has been distributed intentionally among several telescopes in geographically diverse locations, in order to make the campaign robust against bad weather or instrument failures. This is an important

8. Description of the proposed programme (continued)

feature given the large amount of time being committed to discover and follow these SNe. All the data will be searched electronically, allowing the discovery efficiencies from each telescope/detector combination to be determined through computer simulations. The faintest SNe will have $B \sim 19$ at maximum light, and will be followed for about 2 months in which time they will fade by 2—3 mag. Hence the need for spectroscopic follow-up on large telescopes. Had we chosen to focus on discovering brighter SNe, the efficiency of the photometric searches would have plummeted due to deadtime (readout, re-positioning) between fields, as presently few of these CCD arrays is sufficiently well aligned to allow drift-scanning.

The well-sampled lightcurves resulting from this intensive follow-up campaign will allow a much better determination of lightcurve properties and how they are related to intrinsic luminosity. Very few nearby SNe have good data prior to maximum light, so these lightcurves will open new avenues of study of both the empirical and theoretical properties of SNe. Most of the SCP high-z SNe have been discovered before maximum (typically by $\sim$ 10 days), so these early, well-sampled lightcurves can be used to create superior templates for use with high-z SNe.

We wish to emphasize the unprecedented size and uniqueness of this campaign for the study of supernovae. Observations from many different observatories are absolutely essential since no one observatory can provide all the necessary follow-up, making this an opportunity and undertaking which is unlikely to come along again in the near future

B) Immediate Objective: The specific goal of the proposed observations is to obtain spectra for approximately 30 Type Ia supernovae at redshifts out to $z \sim 0.1$ during the period 15—35 days after maximum, when they are too faint to observe spectroscopically with smaller telescopes. The ESO 3.6m observations will be complemented by observations using the LCO 2.5m, NOT 2.6m, and Lick 3m when the SNe are brighter, and the KPNO 4m, CTIO 4m, and WHT 4.2m when the SNe are fainter. At the end of this intensive campaign our goal is to have one spectrum per week extending from the date of discovery (typically 1 week before maximum) through to six weeks after maximum for all SNe Ia. The spectra will be used to (a) check each SN individually for spectroscopic peculiarities that would indicate a "non-normal" SN, (b) calibrate peak magnitudes using Nugent *et al.*'s (1995) correlations with spectral features and (c) accurately determine K-corrections as a function of lightcurve phase and lightcurve width. This final goal is very important - when comparing distant and nearby SNe for the purposes of measuring cosmological parameters it is necessary to convert all magnitudes to the same effective bandpass. This requires detailed knowledge of the spectral energy distributions of SNe Ia at all stages in their lightcurves, and for SNe spanning the full range of lightcurve widths.

C) Telescope Justification: We propose to obtain spectra of SNe approximately 30 to 50 days after maximum light. At that phase they will have $21 < B < 22$ and will be too faint to observe with smaller telescopes.

D) Observing Mode Justification (visitor or service): Service mode not offered at 3.6m

E) Strategy for Data Reduction and Analysis: The Supernova cosmology project has active collaborators in Sweden, France, Germany, Chile, U.S.A. and the U.K., and uses the extensive computing facilities available at LBNL, ESO and Paris. Our group has extensive experience with faint object spectroscopy on telescopes around the world. To reduce and analyse spectra, our group has developed techniques that are specific to supernova work.

References:

Hamuy *et al* , 1996a, AJ, 112, 2391.
Hamuy *et al* , 1996b, AJ, 112, 2408.
Pain, R., *et al* , 1996, ApJ, 473, 356.
Perlmutter *et al* , 1997, ApJ, 483, 565.
Perlmutter *et al* , 1998a, Nature.
Perlmutter *et al* , 1998b, ApJ, submitted (see www-supernova.lbl.gov)
Nugent P. et al 1995, ApJL, 455, 147
Tripp, 1998, A&A, 331, 851

8. Attachments (Figures)

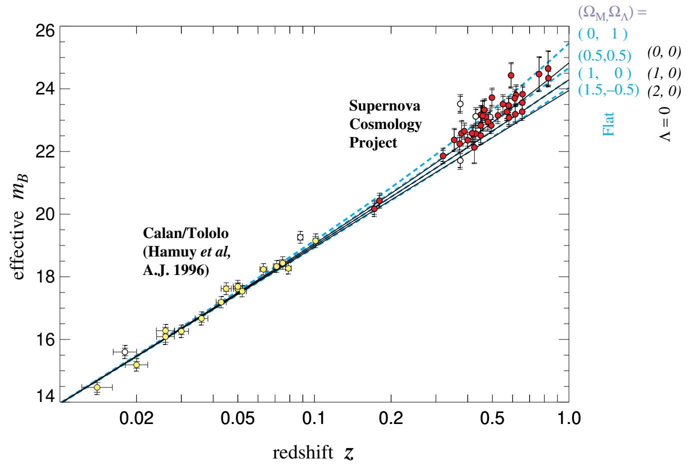

Fig. 1: Cosmological Constraints from Type Ia supernovae

Hubble diagram for 42 high-redshift Type Ia supernovae from Perlmutter *et al* 1998b. At left the low-redshift SNe Ia are those from Hamuy *et al* 1996a which are suitable for analysis using the same methods as used for the high-redshift SNe Ia.

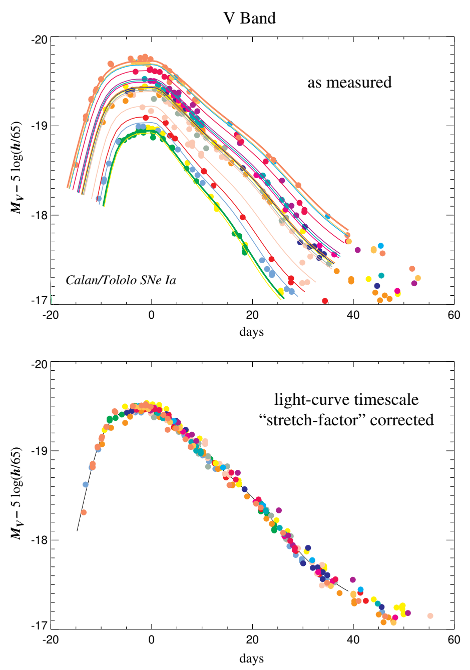

Fig. 2: Photometric and Time Evolution of Type Ia supernovae

V-band lightcurves for nearby SNe Ia from Hamuy *et al* 1996b. The upper panel shows lightcurves for individual SNe Ia (assuming $H_0 = 65$ km/s/Mpc) with fitted template lightcurves from Leibundgut *et al* 1991. Note that the brighter SNe have lightcurves which are broader and decline more slowly. Also notice that very few of these SNe have data well before maximum light. The lower panel shows the superposition of these data after using a linear correction for stretch, S, and scaling the time axis (with maximum at t = 0) by the same stretch-factor.

8. Attachments (Figures)

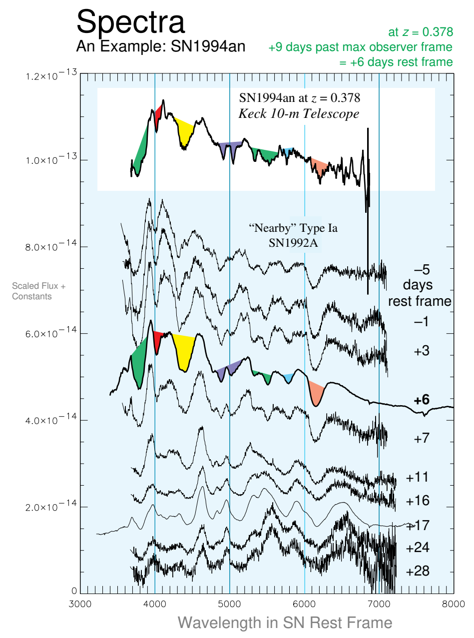

Fig 3: Type Ia SN spectra

The evolution of the spectrum of a Type Ia supernova (SN 92A) as the explosion ages. Sequences such as this are important for determining K-corrections as a function of date, which are needed to compare distant and nearby SNe. The proposed observations will help provide spectral time sequences for SNe with a range of lightcurve widths. At the top is plotted the spectrum of our distant SNe, 1994an, which was obtained at day +6 relative to maximum light. The shaded regions highlight portions of the spectra for comparison. Some of these can also be used as luminosity indicators.

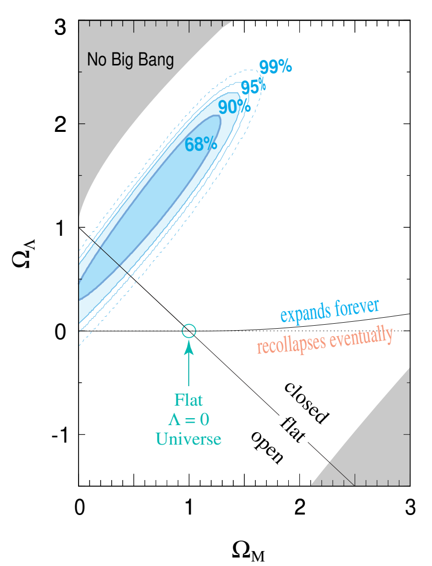

Fig. 4: Cosmological Constraints from Type Ia supernovae

Resulting constraints on Ω_M and Ω_Λ from the SNe shown in Fig.1. The 68%, 90%, and 99% confidence regions for an unconstrained fit for Ω_M and Ω_Λ are shown (see Perlmutter et al 1998b for more details).

9. Justification of requested observing time and lunar phase

Time Justification: During the period 15–35 days after maximum, exposure times of 1–2 hrs per SN are required to provide the necessary accuracy for measuring key spectral features (UV continuum slope, SiII 5800Å/6150Å line ratio, expansion velocity) and constructing accurate spectral series needed to determine K-corrections as a function of lightcurve phase and lightcurve width. To obtain low resolution spectra of 30 SNe at one late-time epoch requires at least 30 hours, leading to our request for 3 nights with EFOSC2 on the 3.6m.

Lunar Phase Justification: The SN spectral features extend down to 3600Å (4000Å at $z = 0.1$, cf. Fig 3). The need for coverage in the blue limits the amount of moonlight that can be tolerated, however, we also wish to avoid a substantial "bright time" gap in our spectral time series. We have determined that our goals can be accomplished during lunar phase as much as 7 days from new moon since there will be a range of brightnesses and relative phases (wrt explosion date) for our sample of SNe.

10. Report on the last use of ESO facilities

61.A-0466 / C. Lidman / Photometry and Spectroscopy of approx 25 Type Ia Supernovae at $\overline{z} \sim 0.6$: Measurement of $Omega_M$ and $Omega_\Lambda$

Telescope	Instrument	Obs. Dates	Completion (%)	Time lost (%)	Reason
3.6	EFOSC	30-32 May 1998	80%	20%	weather

Current status of obtained data: reduced

Remarks: Spectra and lightcurve points obtained at ESO 3.6m over the last 4 periods have played an important role in the follow up of our distant SNe. We are awaiting final reference images for the most recently observed SNe before they can be included in the analysis. Those from previous observing periods have already been included and have contributed to an extensive series of papers (see Publications section).

11. Applicant's publications related to the subject of this application during the past two years

Perlmutter S. et al, ApJ, submitted. Available at www-supernova.lbl.gov and astro-ph: Measurements of Ω and Λ from 42 High-Redshift Supernovae.

Perlmutter S. et al, 1998, Nature, 391, 51: Discovery of a Supernova Explosion at Half the Age of the Universe and its Cosmological Implications.

Perlmutter S. et a, 1997, ApJ, 483, 565: Measurements of the Cosmological Parameters Ω and Λ from the First 7 Supernovae at $z \geq 0.35$.

Kim A. *et al.*, 1997, ApJ, 476, L63: Implications for the Hubble Constant from the First Seven Supernovae of $z > 0.35$.

Pain R. *et al.*, 1996, Astrophysical Journal, 473, 356: The Type Ia supernova rate at $z \sim 0.4$.

Kim A., Goobar A., Perlmutter S., 1996, Publications of the Astronomical Society of the Pacific, 108, 190: A generalized K correction for type Ia supernovae: Comparing R-band photometry beyond $z = 0.2$ with B, V, and R-band nearby photometry.

Perlmutter S et al, 1996, in Thermonuclear Supernovae, NATO ASI, eds. R. Canal, P. Ruiz-LaPuente, and J. Isern 1996: Scheduled discoveries of 7+ high-redshift supernovae: First cosmology results and bounds on q0.

More than 80 discoveries of supernovae, reported in International Astronomical Union Telegrams and Circulars, e.g.:
Twenty High-Redshift Supernovae: Circular 6881, 22 April 1998, Supernova Cosmology Project.

12. List of targets proposed in this programme

Run	Target name	α	δ	Equinox	Mag.	Diam.	Additional information

Target Notes: As described in the scientific case, the ~ 30 targets will be discovered in search runs in February and March. The targets will be found in search fields with declination $\sim 0°$, so that they can be observed by telescopes in both hemispheres, and avoiding regions of high galactic extinction. The final selection of fields depends on the dates scheduled for searching.

13. Scheduling requirements

5. Run special requirement(s)

Run	Special Requirements
A	There must be coordination with other telescopes which are not yet scheduled. Please contact PI before scheduling.

14. Instrument configuration

Telescope	Instrument	Parameter	Value or list
3.6	EFOSC2	Imaging-filters	UBVR
3.6	EFOSC2	Spectro-long-slit	GrismB300eq:338-754
3.6	EFOSC2	Spectro-long-slit	GrismR300eq:602-1034