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: **76A**

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 — Category: **A–4**

Exploring the Epoch of Deceleration: Putting a new sample of $z \gtrsim 1$ SNe Ia on the Hubble Diagram

2. Abstract

Over the last decade, the Supernova Cosmology Project (SCP) has pioneered the use of the magnitude-redshift relation of Type Ia supernovae (SNe Ia) to measure cosmological parameters. Our analysis of 53 SNe Ia in the redshift interval $z \in [0.18, 0.83]$ showed that the universe is dominated by an unknown form of dark energy and that, at the present epoch, the expansion of the universe is accelerating.
In this proposal, we are asking for 2 nights with FORS2 and 7 hours with ISAAC to complete the necessary observations that will enable us to double the number of $z \gtrsim 1$ SNe Ia on the Hubble diagram, thus enabling us to place tighter limits on cosmological parameters and to test for systematic effects in using SNe Ia as distance probes during the epoch of deceleration.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	76	FORS2	2n	oct	d	$\leq 0.8''$	CLR	v
B	76	ISAAC	7h	any	n	$\leq 0.6''$	CLR	s

4. Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:	FORS2/ISAAC	24h in 169.A-0382(A)/25h in 070.A-0432(A)
b) still required to complete this project:		

5. Special remarks:

6. Principal Investigator: C. Lidman (ESO, ESO, clidman@obspm.fr)

CoI(s): G. Aldering (LBNL, USA), R. Amanullah (Stockholm, S), A. Goobar (Stockholm, S), I. Hook (Oxford, UK), R. Pain (LPNHE, CNRS-IN2P3 and Univ. Paris, F), S. Perlmutter (LBNL, USA), R. Knop (Vanderbilt, USA)

7. Is this proposal linked to a PhD thesis preparation? State role of PhD student in this project

8. Description of the proposed programme

A) Scientific Rationale:

The identity of the mysterious dark energy that is apparently accelerating the universe's expansion is one of the leading scientific questions of our day, and the most direct current approach to this problem remains the measurement of the universe's expansion history using Type Ia supernovae (SNe Ia). Currently, several large efforts are engaged in collecting hundreds of supernovae at low redshifts, $z < 0.1$ for the purpose of refining SNe Ia as cosmological probes (e.g., the Nearby SN Factory and the Lick Observatory Supernovae Search), and at higher redshifts, $0.2 < z < 0.8$, where the acceleration is detected (the CFHT SN Legacy Survey and the ESSENCE project). The very high redshift range, $0.9 < z < 1.5$, which is within the epoch of deceleration, is relatively unexplored.

A sample of SNe Ia in the deceleration epoch allows a direct determination of the curvature of the universe and decoupled measurements of Ω_M and Ω_Λ independently of the constraints set by other experiments. While additional SNe Ia with $z < 0.9$ will improve the current statistical uncertainty by $\sqrt{N}$, additional SNe Ia beyond $z \sim 0.89$ can dramatically shorten the major-axis of the current Ω_M—Ω_Λ error ellipse (cf. Goobar & Perlmutter 1995). Additionally, by including SNe Ia at $z < 0.9$ from previous and ongoing surveys, one can differentiate between competing dark enery theories.

In 1998, we first proposed and demonstrated the possibility of finding and studying such distant supernovae with the discovery of SN 1998eq at $z = 1.2$ (Aldering et al. 1998, Fadeyev et al. 2004). Since this discovery, our team and other groups have performed ground- and space-based searches for additional very distant SNe Ia, but the faintness of these supernovae makes them much more demanding of telescope time. Hence, there are only about a dozen or so such supernovae altogether (see Fig. 1). Current HST work yields only about 10 per year (and requires hundreds of HST orbits).

In a comprehensive 2002 observing campaign, which included VLT follow-up observations with ISAAC, FORS1 and FORS2 (ESO program 169.A-0382), we used the wide-field Suprime-Cam imager on Subaru to discover ∼20 SN Ia candidates in this challenging redshift range (Doi et al. 2003, Yasuda et al. 2003). We were able to confirm less than half of them with spectroscopy performed at the Keck Telescope and the VLT (Lidman et al. 2005), but **all** were followed photometrically through their lightcurves with the Subaru Suprime-Cam, and several were observed with ISAAC (Lidman et al. 2004) and HST. This past year we were able to obtain the final images of the host galaxies after the supernovae had faded, allowing lightcurves for 14 very distant SNe to be constructed. Five of these supernovae have spectroscopically determined redshifts, which allows us to place them on the Hubble diagram (blue points in the lower inset of Fig. 1).

However, nine of these SNe do not have spectroscopically determined redshifts. They do have well sampled light curves, which are shown in Fig. 2. For each of these SNe, we also have R- and z′-band photometry near maximum light, to reject significantly reddened SNe and Type II SNe. The same Type SN II color-rejection technique is used in the HST-based searches that led to the SNe shown in the upper inset of Figure 1, and it has yielded good SN Ia selection.

These SNe, which are shown in red in Fig. 1, are plotted at the redshifts estimated from the time dilation of their lightcurves, assuming that they share the tight lightcurve-width distribution of the other SNe Ia at this epoch. Their exact redshift is not yet known, and, since there is dispersion in the lightcurve timescale of SNe Ia, it can easily vary by the amount shown by the dashed open-circle data point on the lower inset of Fig. 1.

The main aim of this proposal is to obtain the missing spectroscopic redshifts of these nine SNe. As shown in Fig. 1, the full set of 14 new SNe would represent a doubling of the sample size in the decelerating epoch.

References

Aldering G., et al. 1998, IAUC 7046
Commins E., 2004, NewAR 48, 567
Doi M., et al. 2003, IAUC 8119, 8120, and 8121
Fadeyev V., et al. 2004, AAS 205, 6903
Goobar & Perlmutter, 1995, ApJ, 450, 14 Lidman, C. et al. 2004, Messenger, 118, 24
Lidman, C. et al. 2005, A&A, 430, 843
Linder, E. & Holz, D. astro-ph/0412173
Knop R., et al. 2003, ApJ 598, 102
Perlmutter S., et al., 1999, ApJ 517, 565
Riess A., et al. 2004, ApJ 607,665
Yasuda N., et al. 2003, AAS 203, 82.11

B) Immediate Objective: **The culmination of a major scientific program.**

We here propose to complete the final necessary observations of this large campaign by using FORS2 to obtain the redshifts for the host galaxies of nine $z \gtrsim 1$ supernovae.

The proposed observations will complete a comprehensive multi-telescope campaign that has yielded the largest-to-date sample of SNe Ia in the "decelerating" redshift range. This sample will more than double the number of such SNe Ia on the Hubble diagram in this very poorly populated redshift range. In addition to

8. Description of the proposed programme (continued)

constraining cosmological parameters (Ω_M, Ω_Λ and w), this larger sample will, for the first time at these redshifts, make it possible to begin to look for a ridgeline and for outliers, providing tests for non-Ia contamination, and for a residual extinction tail (see Commins 2004). This will be a first step towards measurements of asymmetry in the distribution about the Hubble line that will permit limits to be set on the gravitational lensing, which is statistically expected to skew the distribution with frequent de-amplification and rare amplification of the SN magnitude (see Linder & Holz 2004). Finally, this statistically-significant sample size continues the exploration of this new redshift range, where future projects such as SNAP/JDEM will put significant effort in constraining the dark energy's equation of state and its time variation.

We also propose to obtain the final J-band reference image of one spectroscopically confirmed SNe - SN 2002kn at z=1.03 (one of the red points in Fig. 1.) - with ISAAC. The larger wavelngth span covered by the observed IR-optical colour leads to a more accurate estimate of the extinction and, hence, to smaller errors when extinction corrections are applied.

C) Telescope Justification:

The targets are faint. The R band magnitude of the majority of the objects vary between R=23 and R=24 with a couple that are fainter. Furthermore, we expect that the most of the targets will have redshfts greater than one, so that most of the spectral features that are most commonly used to identify targets at this redshift ([OII], Ca II H and K, etc.) will be around 8000 Å. Hence, an red-optimised low resolution spectrograph on an 8m class telescope is required. This is FORS2.

The IR observations of SN 2002kn (z=1.03) can only be done with ISAAC for two reasons. The SNe was faint (J=23.6) and the host is even fainter. Only ISAAC can detect such objects is a reasonable amount of time. Furthermore, the observations of the SNe with the host were done with ISAAC, so the reference image (host without the SNe) should also be tken with ISAAC.

D) Observing Mode Justification (visitor or service): We request that the FORS2 observations are done in visitor mode. This gives us the possibility of adjusting the exposure time. Since we only need to measure a redshift, we can either end an exposure when the redshift is clar or extend it when it is not. This will lead to increased efficiency.

We request that the ISAAC observations of SN 2002kn are done in service. We request relatively good conditions (seeing ¡ 0.6 in the J band) so that we can match the excellent quality of the data that we currently have for this SN.

E) Strategy for Data Reduction and Analysis:

The observations are straightforward. The PI and the CoIs have extensive experience in faint object spectroscopy (see Lidman et al. 2005 for some examples) and deep IR imaging (Lidman et al. 2004). Fringing at 8000 Åwill not be a limitation. We use frequent dithering along the slit and special reduction procedures (Lidman et al. 2005) to dramatically reduce the systematic error from fringing to negligible levels.

The analysis will be quick, With the exception of the redshifts and the final reference image with ISAAC, which are the subject of this proposal, all the data that are necessary to put these SNe on the Hubble diagram have been taken and fully reduced.

8. Attachments (Figures)

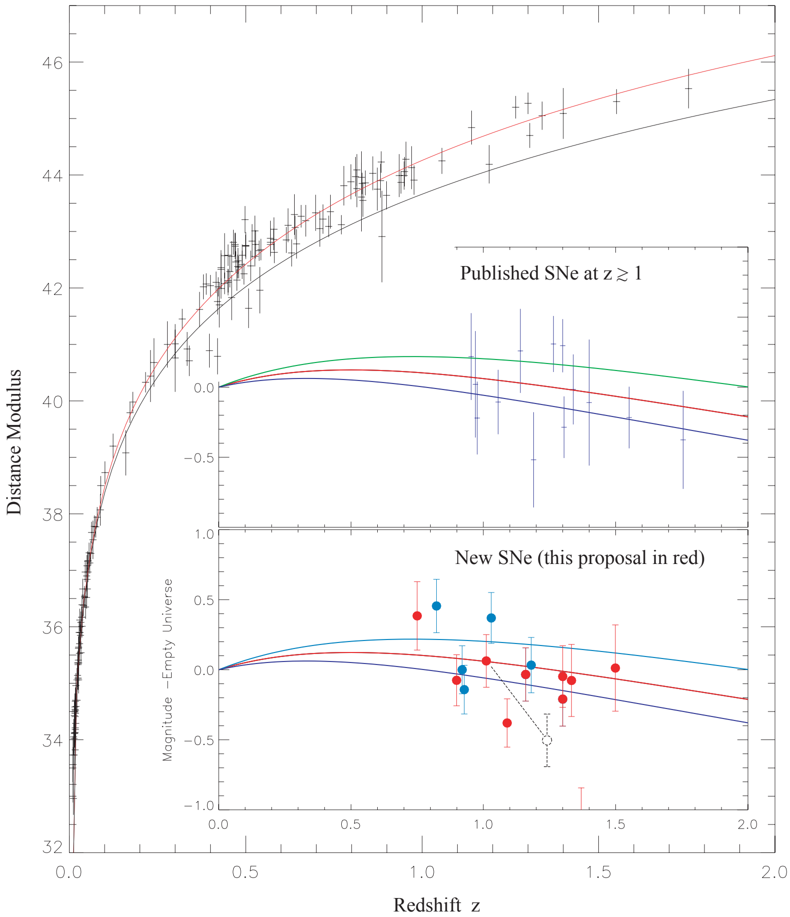

Fig.1 - The SNe Ia Hubble diagram

Fig. 1 The Hubble plot for SN Ia, based on a compilation of SNe in the literature discovered primarily by both the Supernova Cosmology Project and the High-Z SN Search (Riess et al. 2004). The solid curves show flat cosmologies with $\Omega_M = 0.3$ (top) and 1.0 (bottom). At the highest redshifts – in the epoch of deceleration – the plot is very sparsely populated. *Upper Inset:* The magnitude residual from an empty universe ($\Omega_M = \Omega_\Lambda = 0$) for the SNe from this compilation at the highest redshifts. The solid curves show flat cosmologies with $\Omega_M =$ 0.2, 0.3, and 0.4 (top to bottom). *Lower Inset:* The magnitude residual from an empty universe for the new SNe discovered in our Subaru-based search for SNe at these decelerating redshifts. The SN indicated by blue points have spectroscopically measured redshifts, while those indicated with red points are plotted using *approximate* redshifts estimated from the time-dilation of the lightcurve timescale. The dashed-line point shows the $\sim 1\sigma$ range of variation of this redshift estimate, *assuming* the known dispersion of lightcurve timescales (from Perlmutter et al. 1999 and Knop et al. 2003). (This dashed-line point is at the same magnitude as its corresponding solid-line point, but the different assumed redshift gives a very different residual from the empty universe.) We here propose to obtain the exact spectroscopic redshift for the host galaxies of each of these SNe.

8. Attachments (Figures)

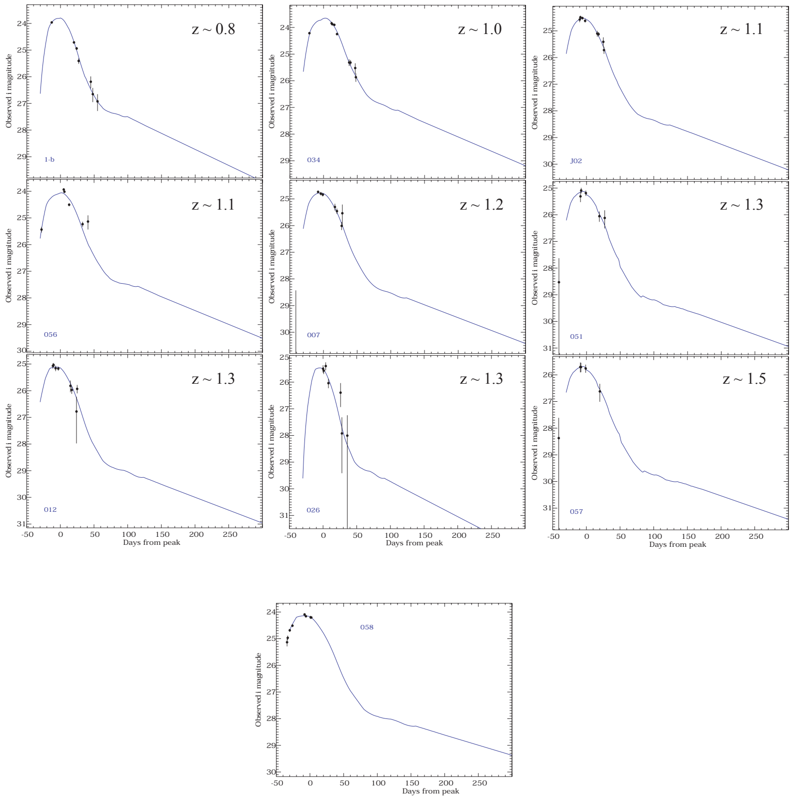

Fig. 2 - The light curves of 9 high redshift SNe Ia

Fig. 2 - The i′-band lightcurves for the nine supernovae targeted by this proposal (red points in the Figure 1 lower inset). Each of these SNe also has R- and z′-band photometry points near maximum light (not shown). Note that for these nine SNe the integrated host galaxy light in a 1′′ aperture is significantly brighter than the SN in almost every case.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: The FORS2 targets are faint, predominantly between R=23 and R=24, so dark time is required. The ISAAC observations can be done with any lunar phase.

Time Justification: (including seeing overhead) From our extensive experience with FORS2 at the VLT and other similar instruments at other facilities, we find that we can determine the redshift in about 2 hours for 80% of the objects we target. The redshift is derived from host galaxy lines, predominantly [OII], Ca II H and K and, in some cases, Balmer absorption lines and is accurate to $\Delta z = 0.001$ (Lidman et al. 2005). Since we expect most of the hosts to have redshift of one and above, we will use the 600I grism with the OG 590 order sorting filter. We request visitor mode, as this will enable us to modify the exposure times on a target by target basis. With 2 hours per target (including overheads) and 9 targets, we'll need 18 hours or 2 nights.
The ISAAC Js imaging observations can be done in service mode. The exposure time is set so that the S/N ratio of the data we currently have (SN+host) is not significantly degraded when the reference image of the host is usbtracted. In a 5 hour exposure, the S/N ratio of the reference subtracted SN will be around 7. With overheads, we need 7 hours.

Calibration Request: Standard calibrations are sufficient.

10. Report on the use of ESO facilities during the last 2 years

DDT program 272.A-5029 2.8 hours. Spectroscopic follow-up of z=5.7 Lyman-alpha emitting galaxies. The program resulted in the successful confirmation of bright Lyman alpha emitting galaxy from the WFILAS survey. See Westra et al. 2005, A&A, 430, L21.
ESO program 071.A-0401 8 hours. A sharp and deep look at the obscured Einstein ring PKS 1830-211. The program resulted in the successful confirmation of a second lensing galaxy. A letter has been submitted to A&A.

11. Applicant's publications related to the subject of this application during the last 2 years

Garavini, G. et al, 2005, AJ, Submitted: The unusual Type Ia SN 1999ac

Noboli, S. et al. 2005, A&A, Submitted: Restframe I-band Hubble diagram for Type Ia SNe Hook, I. et al. 2005, AJ, Submitted: New spectra of high redshift Type Ia SNe and a comparison with their low redshift counterparts

Lidman, C. et al. 2005, A&A, 430, 843: Spectroscopic confirmation of high-redshift SNe with the ESO VLT

Garavini, G. et al. 2004, AJ, 128, 387: Spectroscopic observations and analysis of the perculiar SN 1999aa

Knop, R. et al. 2003, ApJ, New Constraints on $Omega_{\rm M}$, $Omega_{\Lambda}$, and w from an independent set of 11 high-redshift supernovae observed with the Hubble Space Telescope

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT(hrs)	Mag.	Diam.	Additional info	Reference star
A	SuF02-007	02 18 52.4	-05 01 14.0	2.0				
A	SuF02-012	02 18 51.6	-04 47 25.7	2.0				
A	SuF02-026	02 18 51.9	-04 46 57.3	2.0				
A	SuF02-034	02 18 31.2	-05 01 24.5	2.0				
A	SuF02-051	02 17 27.5	-04 40 45.2	2.0				
A	SuF02-056	02 20 00.0	-04 44 20.7	2.0				
A	SuF02-057	02 20 13.9	-05 07 36.2	2.0				
A	SuF02-J02	02 18 42.9	-05 04 12.4	2.0				
A	SXDS_1-b	02 17 09.7	-04 57 47.8	2.0				
B	SN 2002kn	02 16 45.7	-05 09 51.1	7.0				

Target Notes: As most of these targets do not have official names, the internal SCP names are used for the targets. If an IAU name exists, it is used instead.

12b. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If yes, explain why the need for new data.

The data are not in the ESO archive.

13. Scheduling requirements

14. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
76	FORS2	A	LSS	600I + OG 590
76	ISAAC	B	Hawaii Imaging	Js