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: **70A**

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: **A–4**

Distant type Ia SNe and Cosmology: Constraining the nature of the dark energy and assessing the importance of dust and evolution.

2. Abstract

Over the last decade, the Supernova Cosmology Project has pioneered the use of the magnitude-redshift relation of Type Ia supernovae (SNe Ia) to measure cosmological parameters. Our analysis of 42 SNe Ia in the redshift interval $z \in [0.18, 0.83]$ indicates 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. There are now two important directions to pursue with the SN Ia cosmology work: (a) filling in the SN Ia Hubble diagram; and (b) refining and further testing SNe Ia as tools for cosmological measurements.

In this proposal, we are asking for 50 hours time on ISAAC (25 hours in period 70 and an additional 25 hours in period 72) to image 2 SNe Ia at maximum light. This proposal is linked to the large program 169.A-0382, which was split over two periods.

3.

Run	Telescope	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	UT1	ISAAC	25h	nov	n	$\leq 0.6''$	PHO	s

4.

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:	UT1/UT3/UT4/NTT	7n/125h
b) still required to complete this project:	UT1	25h

5. Special remarks

The OPC split program 169.A-0382 over two periods. This caused a mismatch between runs. All the IR time was awarded for P69, and none was awarded for P70. In order to maximize the scientific use of the time awarded for P70, we are asking for additional time with ISAAC.

6. Principal Investigator: C. Lidman

(ESO-Chile, ESO, clidman@eso.org)

CoI(s): A. Goobar (Stockholm, S), G. Folatelli (Stockholm, S), G. Garavini (Stockholm, S), S. Nobili (Stockholm, S), R. Amanullah (Stockholm, S), R. Pain (LPNHE, CNRS-IN2P3 and Univ. Paris, F), P. Astier (LPNHE, CNRS-IN2P3 and Univ. Paris, F), J. Raux (LPNHE, CNRS-IN2P3 and Univ. Paris, F), K. Schahmaneche (LPNHE, CNRS-IN2P3 and Univ. Paris, F), I. Hook (Oxford, UK), S. Perlmutter (LBNL, USA), G. Aldering (LBNL, USA), P. Nugent (LBNL, USA), R. Knop (Vanderbilt, 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 has developed an approach to measuring cosmological parameters using the magnitude-redshift relation of SNe Ia (Goobar & Perlmutter 1995, Perlmutter et al. 1997, 1998, 1999). Our results based on 42 fully-analysed SNe with $0.18 < z < 0.83$ show that we live in a universe that is dominated by a unknown form of "dark energy" and that, at the present epoch, the expansion of the universe is accelerating (Perlmutter et al 1999; also Riess et al. 1998). A Hubble diagram based on our HST and ground-based observations is shown in Fig. 1. For a flat universe, where the "dark energy" is due to the cosmological constant, we find $\Omega_M = 0.28^{+0.09}_{-0.08}$, and constrain the combination $0.8\,\Omega_M - 0.6\,\Omega_\Lambda$ to -0.2 ± 0.1 for any universe.

This evidence has been increasingly strengthened, both by tests and improvements of the supernova measurements and by independent, cross-cutting cosmological measurements. In particular, the recent balloon-based CMB measurements (Jaffe et al. 2001) have strongly indicated that the geometry of the universe is flat, reinforcing the evidence for an accelerating universe by eliminating the possibility of a low-density open universe.

There are now two important directions to pursue with the SN Ia cosmology work: (a) filling in the SN Ia Hubble diagram to obtain a more complete and detailed expansion history of the universe and (b) refining and further testing the SNe Ia as tools for cosmological measurements.

(a) FILLING THE HUBBLE DIAGRAM TO z=1.2: THE NATURE OF THE DARK ENERGY

We currently have the opportunity to obtain a Hubble diagram that will be of long-lasting value as a record of the expansion history of the universe over the last 10 billion years. The redshift range that we propose to populate ($0.5 < z < 1.2$) is aimed at addressing several of the most important scientific questions of our time.

First, it allows a determination of the curvature of the universe and decoupled measurements of Ω_M and Ω_Λ. While additional SNe Ia with $z < 0.85$ will improve the current statistical uncertainty by $\sqrt{N}$, additional SNe Ia beyond $z \sim 0.85$ can dramatically shorten the major-axis of the current Ω_M—Ω_Λ error ellipse (cf. Goobar & Perlmutter 1995 and Fig. 2). With these observations we will be able to rule out $\Omega_\Lambda = 0$ at better than 3σ. For a flat universe, Ω_M and Ω_Λ could be constrained to $\sim 6\%$. The resulting estimate of Ω_M, for *any* Ω_Λ, is still accurate to ± 0.15 in this simulation and would be a first check on the CMB measurements that indicate a flat geometry (Fig. 2).

Second, the Hubble diagram out to $z \sim 1$ provides one of the only known ways to constrain the physics of the "dark energy" that apparently is accelerating the universe's expansion. The simplest measurement to characterize this dark energy is the effective equation-of-state ratio, $w \equiv p/\rho$. The current constraints on w are consistent with a very wide range of dark energy theories, including Einstein's Cosmological Constant (for which $w = -1$) (Perlmutter et al. 1999, Garnavich et al. 1998). The proposed data set, together with data now being analyzed, can tighten these constraints by 40%, potentially ruling out several contending theories if the current w value holds. Recent work by Weller and Albrecht (2000) has shown that dark energy theories can be further differentiated on the Hubble diagram at $0.3 < z < 1$ by their behavior *over the range* of z. This requires better photometry measurements than previously obtained in this redshift range (with 4-m telescopes).

(b) SNE IA SYSTEMATIC UNCERTAINTIES: GREY DUST AND EVOLUTION

Perlmutter et al (1997, 1999) provide extensive discussion of possible systematics in the measurement of Ω_M and Ω_Λ; we find that uncertainties due to K-corrections, gravitational lensing amplification, and Malmquist bias, are quite small compared to the statistical error. Remaining sources of systematic uncertainty that we showed are unlikely, but possible, are SNe Ia evolution and abnormal dust within, or even between, galaxies. To proceed with the SN cosmology studies, we have identified a series of refinements and tests that will "sharpen" this cosmological measurement tool, by addressing these issues.

It is unlikely that dust, as we normally consider it, causes SNe Ia to be too dim. The effects of such dust would have already been apparent (Reiss et al. 2000, Perlmutter et al. 1999). This has led some to hypothesize the existence of grey dust (Aguirre, 1999; Aguirre & Haiman 2000), which would not have been detected in the current data sets. If grey dust were the cause of the dimming, then there are two ways it can be detected.

Firstly, the difference between the apparent magnitudes of SNe Ia in a model dominated by dark energy (Ω_M,Ω_Λ) = $(0.3, 0.7)$ and those in an open universe with dust becomes significant for SNe Ia with $z > 0.9$ (See Fig. 1). At $z = 1.2$, the difference amounts to 0.3 magnitudes, and this should be measurable with 5 well-observed (optical and near-IR observations) SNe Ia at these redshifts. During 2001 we discovered and followed SN 2001gn ($z = 1.1$), see Fig. 3, and SN 2001gp ($z = 1.067$); in 1998 we discovered and followed SN 1998eq ($z = 1.2$). We now wish to observe another 2 such SNe Ia (the aim of this proposal) during period 70.

Secondly, the ubiquitous nature of dust, even grey dust, is that it reddens. In one grey dust model (Aguirre, 1999), SNe Ia should be reddened by $E_{(\mathrm{B-I})} = 0.14$ magnitudes if dust were the cause of the dimming. Precise observations of several SNe at $z = 0.5$ in the near IR J band (rest frame I-band) and optical R-band (rest frame B band) should be able to detect this amount of reddening. During 2000 and 2001 we observed SN2000fr at z=0.54 (see Fig. 4). We plan to observe 2 $z \approx 0.5$ SNe Ia during the ISAAC time allocated for the large program 169.A-0382 during P69 (run H).

8. Description of the proposed programme (continued)

References

Aguirre, 1999, ApJ, 525, 593.
Aguirre & Haiman, 2000, ApJ, 532, 28.
Garnavich et al. 1998, ApJ., 509, 74.
Goobar & Perlmutter, 1995, ApJ, 450, 14.
Jaffe, A. H. et al, 2001, Phys. Rev. Lett. 86, 3475.
Knop, R., et al., 2000, B.A.A.S., 197, 950.
Lidman, C, et al., 2000, Messenger, 101, 18.
Nugent et al., 1995, ApJ. Lett., 455, 147.
Perlmutter S. et al., 1997, ApJ, 483, 565.
Perlmutter S. et al., 1998, Nature, 391, 51.
Perlmutter S. et al., 1999, ApJ, 517, 565.
Riess, A. G., et al., 1998, AJ, 116, 1009.
Riess A. G. et al., 2000, 536, 62.
Riess, A. G., et al., 2001, ApJ, in press.
Weller, J. and Albrecht, A., 2001, Phys. Rev. Lett. 86, 1939.

B) Immediate Objective:

We propose to observe two $z \approx 1$ SNe with ISAAC on the VLT during period 70 and to re-observe them one year later (reference images), when the SNe have faided from view. These observations, together with space based optical folloup and ground based spectrsopy, will enable us to put these SNe on the Hubble diagram which will enable us to measure the cosmological parameters and to test the grey-dust hypothesis. The ground based spectroscopic follow up has been approved as part of a ESO large program (169.A-382(A)) and the HST optical follow-up has been approved.

The ground based IR data is vital as it is combined with space based optical data to measure the colour of the SNe and hence determine if there is any redenning whether it be from normal or grey dust.

We had planned to observe two z 1 SNe Ia during P69 as part of the approved large program 169.A-0382; however, the OPC split the runs of this program over two periods, with the spectroscopic, optical and IR follow-up of CFHT discoverd SNe Ia occuring in P69 (runs B, F and H) and the spectrscopic followup of Subaru discovered SNe Ia occuring during P70 (Run A). Unfortunately, all the IR time (run H) was awarded in P69 and none of it was awarded in P70. The z 1 SNe will be found from only the Subaru search. The CFHT search will find SNe Ia at a median redshift of $z \approx 0.5$ and we do not expect it to discover SNe Ia at $z \approx 1$.

C) Telescope Justification: The observations consist of moderate S/N ($\approx 10-20$) observations of SNe that have magnitudes that range between $23 < J < 24$. Only ISAAC on the VLT can obtain the S/N we require.

D) Observing Mode Justification (visitor or service): We require good image quality and good weather. Service is strongly preferred.

E) Strategy for Data Reduction and Analysis:

The search for SNe Ia at $z \approx 1$ is scheduled to occur with SuprimeCam on Subaru during October and November. After candidates have been identifed, they will be spectroscopically confirmed with FORS2 (Run 169.A-0282(A)). Only spectroscopically confirmed candidates are then followed at optical and IR wavelengths.

The optical data are used to place the supernovae on the Hubble diagram and the IR data are used to determine the colour of the SNe and then assess the importance of extinction, whether it be from normal or grey dust.

The Supernova Cosmology Project has repeatedly demonstrated its ability to: (a) discover large numbers of high–z SNe Ia while they are still on the rise; (b) obtain spectroscopic follow-up within a few days of discovery to confirm the SN type and redshift; (c) acquire ground-based and HST light curve photometry; and (d) analyze the data to obtain peak magnitudes and measure Ω_M and Ω_Λ.

We have demonstrated this capability out to $z = 1.20$.

8. Attachments (Figures)

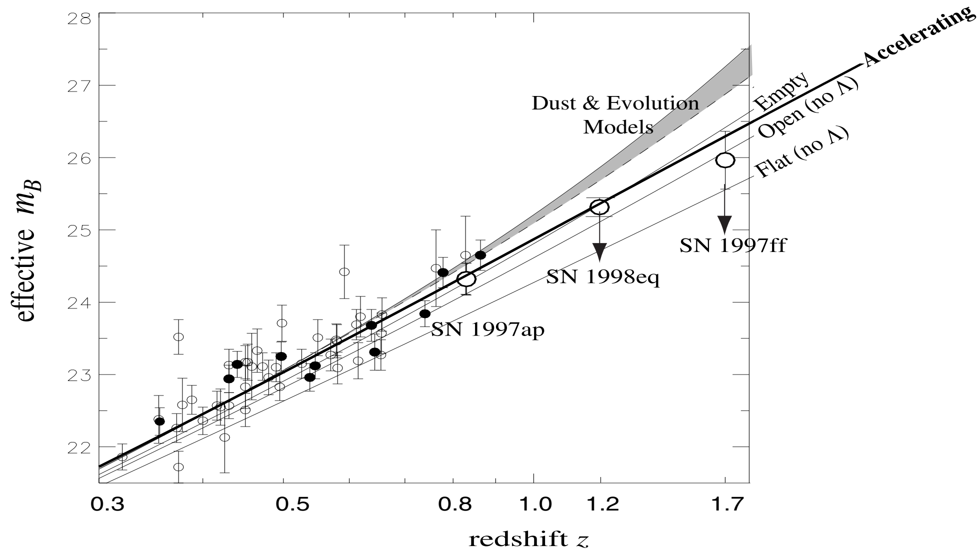

Fig. 1 The Hubble diagram for 42 high-z SNe, plotted as open circles (Perlmutter et al. 1999), 11 more recently observed SNe, plotted as filled circles (Knop et al. 2000) and three high redshift SNe, plotted as large open circles (SN 1997ap, SN1998eq and SN1997ff). The magnitude difference between the best-fit "Accelerating" world model $(\Omega_M, \Omega_\Lambda) = (0.28, 0.72)$ and suitable ones with Ω_Λ=0 show redshift dependencies which would be very hard to mimic within the context of SNe evolution or grey dust hypotheses (the grey shaded region is an example model with uniform dust). By extending our survey to $z = 1.2$, the *shape* of the Hubble diagram alone would become sufficient evidence to support a cosmological constant. The preliminary magnitude estimate of SN1998eq at $z = 1.2$ is suggestive (as is the serendipitous data for SN1997ff at $z = 1.7$), but more analysis and more SNe Ia at these redshifts, and better(planned, not serendipitous) measurements, as proposed here are necessary.

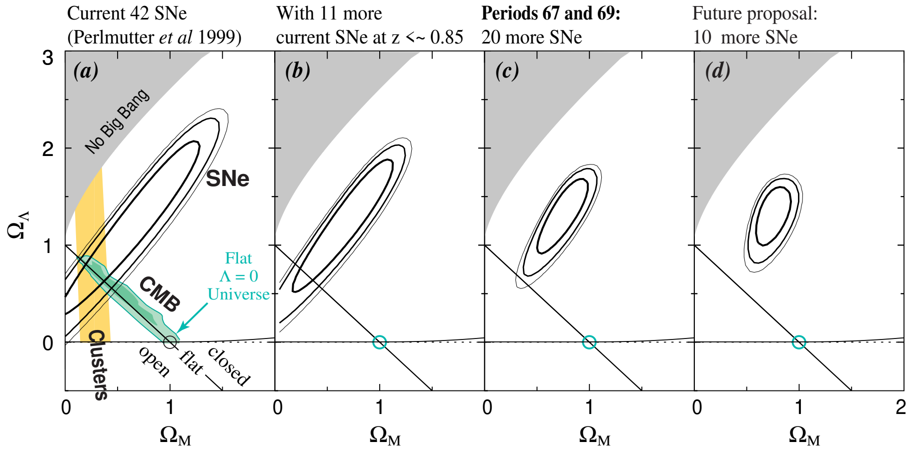

Fig.2: *(a)* 68%, 90%, and 99% confidence regions in the Ω_M—Ω_Λ plane from the 42 distant SNe Ia in Perlmutter et al. 1999. *(b)* Expected confidence region after including our additional 11 $z < 0.85$ SNe Ia currently under analysis. *(c)* Confidence region expected from the observations taken during periods 67 and 69, including four SNe Ia at $z \sim 1.1$. *(d)* The confidence region with observations of a future proposal, which includes 2 additional SNe Ia at z=1.2. These simulations show that our proposed program can check the curvature of the universe found by the CMB program; we dramatize the point by showing a scenario in which the universe is *not* flat, e.g., using the central Ω_m,Ω_Λ value of panel *(a)*.

8. Attachments (Figures)

Fig. 3: An ISAAC image of SN 2001gn at $z = 1.1$. With a S/N ratio of 15, this image demonstrates what ISAAC on the VLT can do in good seeing (0.5 arc seconds FWHM) and long exposures times (8 hours).

Fig. 4: The temporal evolution in the restframe B-I colour of SN 2000fr. Also plotted are the colours SN 2000fr should have if the dimming of distant SNe is due to cosmology or grey dust. With only one SNe, a clear distiction between the two models cannot be made.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: No lunar phase restriction - IR observation

Time Justification: The peak magnitude of a SNe Ia at $z = 1.1$ is J=23.9. In 0.5 arc second seeing we need 12.5 hours with the Js filter to reach S/N $\approx$ 15 in the *reference subtracted image*, and this includes overheadsw. To observe 2 SNe Ia, we need 25 hours.

Calibration Request: Standard Calibration

10. Report on the last use of ESO facilities

67.A-0361 / C. Lidman / Distant type Ia SNe and Cosmology.

Telescope	Instrument	Obs. Dates	Completion (%)	Time lost (%)	Reason
UT1	FORS1	21-23 Apr 2001	40%	60%	weather
UT1	FORS1	Apr May 2001	100%	0%	
UT1	ISAAC	Apr May 2001	100%	0%	

Current status of obtained data: paper-in-press/published

Remarks: Very successful program to identify and follow high redshift SNe, see IAUC 7763. Two articles published and several more in preparation.

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

S. Noboli et al. 2001, AAS, 199.1611N : Type Ia Supernovae: Tests for evolution and grey dust. Ground and space based follow up of a SNe Ia at z=0.543. (See also AAS 199.2402E, 199.2401P, 199.1612S, 199.1610B and 199.1607K)

R. Pain et al., 2001, submitted: The distant Type Ia supernova rate.

A. Goobar, and L. Bergström, 2001, ApJ, Accepted, (see also astro–ph/0103489): Determining the Fraction of Compact Objects in the Universe Using Supernova Observations

M. Goliath, R. Amanullah, P. Astier, A. Goobar, and R. Pain, 2001, A&A Submitted (see also astro–ph/0104009): Supernovae and the Nature of the Dark Energy

E. Mörtsell, C. Gunnarsson, and A. Goobar, 2001, ApJ, Accepted (see also astro–ph/0105355): Gravitational Lensing of the Farthest Known Supernova SN1997ff.

A. Goobar, L. Bergström and E. Mörtsell, 2001, A&A Submitted: Measuring the properties of dust with high-redshift supernovae.

Goldhaber, G. et al., 2001, ApJ, 558, 359: Timescale Stretch Paramerterisation of Type Ia Supernova B-band Light Curves.

Reiss et al., 2001, astro-ph/0109070: Farthest Known Supernova: Support for an Accelerating Universe and a Glimpse of the Epoch of Deceleration.

Lidman, C., Goobar, A., & Pain, R. 2000, Messenger, 101, 18: Type Ia supernovae, cosmology and the VLT.

More than 100 discoveries of supernovae, reported in International Astronomical Union Telegrams and Circulars. The latest circular is IAUC 7736.

12. List of targets proposed in this programme

Run	Target/Field	α	δ	Eq.	Mag.	Diam.	Additional info	Reference star
A	Type Ia SNe	00 00 00	-00 00 00	J2000	J=24			

Target Notes: SNe will be found during a dedicated search run.

13. Scheduling requirements

14. Instrument configuration

Telescope	Instrument	Parameter	Value or list
UT1	ISAAC	SWI	Js