EUROPEAN SOUTHERN OBSERVATORY

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

VISITING ASTRONOMERS SECTION • Karl-Schwarzschild-Straße 2 • D-85748 Garching bei München • e-mail: visas@eso.org • Tel.: +49-89-32 00 62 23

APPLICATION FOR OBSERVING TIME LARGE PROGRAMME PERIOD: **67**

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 / Total Time Requested

TotalAmountOfTime: 12n/185h TotalNumberOfSemesters: 3

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, at redshifts ranging from $z = 0.18$ to $z = 0.83$, indicates that the universe is dominated by an unknown form of dark energy with negative pressure 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 to obtain a more complete and detailed expansion history of the universe and (b) refining and further testing SNe Ia as tools for cosmological measurements.

We propose to observe during periods 67, 69 and 71 about 20 SNe Ia over the redshift interval $z = 0.5 - -1.2$. These observations will dramatically shrink the major-axis of the error ellipse in the $\Omega_M - -\Omega_\Lambda$ plane, decoupling the measurements of Ω_M and Ω_Λ. Thus, this data set will provide a critical check on the CMB anisotropy measurements on the curvature of the universe. They will place important constraints on the nature of the "dark energy" and *at the same time* assess the systematic effects due to grey dust and evolution of SNe Ia properties.

3.

Run	Telescope	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	UT2	FORS2	3n	apr	d	$\leq 0.8''$	THN	v
A/alt	UT1	FORS1	3n	apr	d	$\leq 0.8''$	THN	v
B	UT2	FORS2	14h	may	d	$\leq 0.8''$	THN	s
B/alt	UT1	FORS1	14h	may	d	$\leq 0.8''$	THN	s
C	NTT	SUSI2	3n	apr	g	$\leq 0.8''$	PHO	v
D	UT1	FORS1	20h	apr	g	$\leq 0.8''$	PHO	s
D/alt	UT2	FORS2	20h	apr	g	$\leq 0.8''$	PHO	s
E	UT1	ISAAC	25h	apr	n	$\leq 0.8''$	PHO	v
F	UT1	ISAAC	4h	jun	n	$\leq 0.8''$	THN	s
G	UT1	FORS1	3h	sep	d	$\leq 0.8''$	THN	s
G/alt	UT2	FORS2	3h	sep	d	$\leq 0.8''$	THN	s

4. Principal Investigator: C. Lidman (ESO-Chile, ESO, clidman@eso.org)

Col(s): A. Goobar (Stockholm, S), R. Pain (LPNHE, CNRS-IN2P3 and Univ. Paris, F), P. Astier (LPNHE, CNRS-IN2P3 and Univ. Paris, F), S. Perlmutter (LBNL, USA), G. Aldering (LBNL, USA), P. Nugent (LBNL, USA), I. Hook (ROE, UK), G. Folatelli (Stockholm, S), G. Garavini (Stockholm, S), S. Nobili (Stockholm, S), D. Harding (LPNHE, CNRS-IN2P3 and Univ. Paris, F), S. Fabbro (LPNHE, CNRS-IN2P3 and Univ. Paris, F)

5. Description of the proposed programme

A) Scientific Rationale:

The Supernova Cosmology Project has developed an approach to measuring the mass density Ω_M and energy density associated with the cosmological constant Ω_Λ using the magnitude-redshift relation of SNe Ia (Goobar & Perlmutter 1995, Perlmutter et al 1997, 1998, 1999). Our recent 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 yet undetermined form of "dark energy" and that, at the present epoch, the expansion of the universe is accelerating (Perlmutter et al 1999). 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.

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 2000) 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 (see Fig.2a).

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 proposed 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 $\sim 7\%$. The resulting estimate of Ω_M, for *any* Ω_Λ, is still accurate to ± 0.2 in this simulation and would be a first check on the CMB measurements that indicate a flat geometry.

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); the proposed VLT observations will address this need.

(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 two issues. This work seeks to take advantage of an almost unique characteristic of SNe Ia as cosmological tools: they can be studied individually by their light curves and time-varying spectra and hence calibrated individually, not simply statistically.

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 type Ia SNe in the 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

3 to 5 well observed SNe Ia at these redshifts. During a recent pilot study we discovered and spectroscopically confirmed a SN Ia at the highest redshift yet, $z = 1.2$ (SN1998eq, IAU Circular 7046). The success of that study paves the way for this proposed much larger search aimed at building up a statistically significant sample of SNe with redshifts greater than one.

Secondly, the ubiquitous nature of dust, even grey dust, is that it reddens if the observed baseline is long enough. In what is the only available 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. Our proposed 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) would be able to detect this amount of reddening.

It is natural to expect that there is, at some level, evolution of SNe Ia properties with redshift. However, there is indirect evidence that it is not a major problem. Nearby SNe Ia are observed in a wide variety of galaxy environments, from massive ellipticals to star forming spirals. They all lie on the same peak-magnitude vs. stretch correlation. It is expected that distant SNe Ia will also come from a similar range of environments and that they will also lie on the same relationship. Thus, it is reasonable to expect that any evolution in type Ia progenitors can be accounted for by the peak magnitude vs. stretch relationship. However, indirect evidence is not as certain as direct observational proof. We will focus on two observational tests.

1) A spectral-feature luminosity indicator. The spectral ratios of Ca II and SiII show a tight relationship with the lightcurve timescale parameter (Fig 3a) and may therefore be used as an alternative luminosity indicator (Nugent et al. 1995). These spectral ratios have not yet been exploited at high-z. Measurement of these features for SNe Ia at $z \sim 0.5$ will allow a better than 3σ detection of evolutionary effects which could sufficiently alter the SN brightness to make the current datasets consistent with a flat, $\Omega_M = 1$ universe.

2) A UV metallicity indicator. Metallicity is an important parameter governing radiative transfer in SN photospheres, and thus it is important to develop a direct measure for metallicity in a given SN Ia. The positions of the iron-peak blends (Co and Fe of varying ionisations) at restframe ∼2890 and 3165 Å have FWHM of ∼100 Å and shift by 60 Å when going from 0.1 solar to 10 times solar metallicity (see Fig. 3b). Measurement of this shift is relatively insensitive to host-galaxy spectral contamination or reddening.

In the upper half of Fig 4. we show the spectrum of a SN Ia at $z = 0.54$, which we have nicknamed Beethoven, that was taken with FORS1 on UT1. As a comparison, in the lower half Fig. 4 we show the spectrum of a type Ia SN at $z = 0.55$ taken with EFOSC1 on the ESO 3.6m. The difference in the signal-to-noise ratio between the two spectra is a factor of 6. The VLT allows us to make the transition from qualitative statements, such as "It looks like a SN Ia," to quantitative measurements of line strengths and comparisons with nearby objects.

Beethoven appears to be a perfectly normal type Ia SNe that was observed about 5 days before maximum light (rest frame). As exciting as the spectrum of Beethoven is, it will be through the study of several SNe Ia at $z = 0.5$ that the question of evolution can be addressed. Our success with using the VLT to obtain the spectrum of Beethoven has convinced us that studying several SNe Ia at z=0.5 in detail is now feasible and necessary.

Conclusion

By concentrating our effort on two large campaigns (*and not requesting time on the alternate Semesters, i.e. period 68 and 70.*), we can most effectively pursue the goal of a well-measured SNe Ia Hubble diagram at the highest redshifts, and directly study the cosmological parameters, curvature, and dark energy.

These SNe also refine our evolution/dust checks on systematics. Having pioneered these techniques, we see this large VLT-led campaign as the next key step.

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, 2000, submitted Phys. Rev. Lett.
Lidman, C, et al., 2000, Messenger, In Press.
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., 2000, 536, 62.
Weller, J. and Albrecht, A., submitted to Phys. Rev. Lett.

B) Immediate Objective:

5. Description of the proposed programme (continued)

The aim of this project is to observe a sample of 20 type Ia SNe with redshifts ranging between $z = 0.5$ and $z = 1.2$ to place constraints on the nature of the dark energy and to comprehensively evaluate and quantify the effects of grey dust and the role that evolution plays in using SNe Ia as distance indicators. This is complex program that requires substantial amount of time on ESO telescopes. We plan to observe 10 SNe Ia during period 67 and a further 10 SNe Ia during period 69. Final reference images will have to be taken during periods 69 (for SNe discovered in period 67) and 71 (for SNe discovered in period 69).

The observations are structured as follows:

Run A - The confirmation run and high S/N spectra of 3 $z = 0.5$ SNe
3 visitor nights with FORS2. 2.2 nights will be used for spectroscopic confirmation of candidates found with MOSAIC on the CTIO 4m and 12kx8k camera on CFHT. We estimate that we will discover about 5 SNe Ia in the redshift interval $z = 0.4$ to 0.8, 6 SNe Ia in the redshift interval $z = 0.8$ to 1.0, and 5 SNe Ia with redshifts greater than one. These observations are essential. Only confirmed SNe Ia will be followed. The remaining 0.8 nights with FORS2 will be used for moderate S/N observations of three SNe Ia with $z \approx 0.5$. These spectra will be taken before maximum light. At this stage, the spectra of SNe Ia gives us insight to the progenitor of the supernovae since the spectrum is produced in the outer layers of the atmosphere which are mostly left unburned during the supernova's thermonuclear explosion.

Run B - Late time spectra of 3 $z = 0.5$ SNe
14 hours of FORS2 service time to take late time spectra of the 3 $z = 0.5$ SNe observed in run A. Moving ahead in phase one can see deeper into the atmosphere probing the explosion physics by examining the elements synthesized during the explosion and the velocities with which they were ejected. We will examine both broad and narrow Fe II features. The iron in the atmosphere is a product of the radioactive decay of Ni^{56} to Co^{56} to Fe^{56}, and is the source of energy for the light curve of the supernova. Thus we will, for the first time, be able to probe the physics which powers a supernova at high redshift.

Run C/D - Optical Lightcurves
Three NTT visitor nights and 20 hours of FORS1 service time to monitor five SNe, including the three SNe observed above, in the R and I bands. This data will be used to obtain the light curves of the SNe at $z = 0.5 - 0.8$. Optical observations of SNe with $z > 0.8$ can only be done with HST, for which we have been awarded 76 orbits. The light curve allows us to calibrate the peak magnitude of SNe Ia and to place the them on the Hubble diagram. The data, together with run E, will also be used to measure the restframe $B - I$ color and will allow us to test for the presence of grey dust.

Run E - Using IR peak magnitudes to set limits on the amount of grey dust
25 hours of ISAAC service time to measure the peak magnitudes of 10 SNe Ia over the redshift interval $z = 0.5$ to 1.2 . For the SNe at $z \approx 1.0$, the rest frame V band corresponds to the near IR J-band. Together with data from the HST, this will be used to measure host galaxy extinction. Then, we can place the SN on the Hubble diagram and test for intergalactic grey dust. For the SNe at $z \approx 0.5$, the observed $R - J$ colour corresponds to rest frame $B - I$ and will also allow us to test for presence of grey dust.

Run F/G - Final reference images for two SNe Ia
During periods 64 and 65, we followed one SN Ia at $z = 0.85$ with FORS1 and another SN Ia at $z = 0.54$ with ISAAC. We request 3 hours with FORS1 and 4 hours with ISAAC to obtain final images. These images are used to correct for the contribution of the galaxy host in the photometry.

All SNe that will be observed in runs C, D and E, will require final reference images. These images are taken when the SNe have faded from view, which is usually one year later. Thus, we will need to take images during period 69 for the SNe discovered during period 67 and images during period 71 for the SNe discovered during period 69. This will require 40 hours of ISAAC time and 20 hours of FORS1 time during periods 69 and 71.

C) Telescope Justification: The observations consist of moderate S/N ($\approx 10 - 20$) observations of SNe that have magnitudes that range between 22.5 to 25 in R and 22 to 24 in J. For the bulk of the observations, only the VLT can obtain the S/N we require. For those observations that can be done on 4m class telescopes, we have requested the NTT.

D) Observing Mode Justification (visitor or service): Some of our observations require visitor mode, since we will have to observe within a specific time frame. Service mode observations cannot guarantee this no matter what priority the program has. Furthermore, spectral confirmation of SNe candidates requires a great deal of flexibility, including quick reduction at the telescope in order to classify candidates on the fly. Other observations, particularly the optical followup over six weeks are best done in service mode.

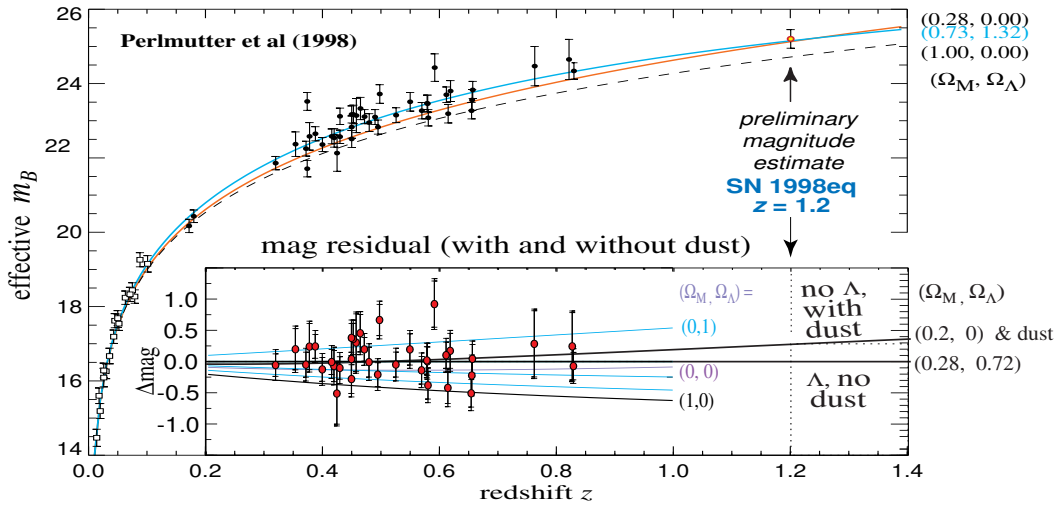

Fig.1 - The SNe Ia Hubble diagram

Fig.1: Hubble diagram for 42 high-z SNe (Perlmutter et al. 1999). The best-fit world model with $(\Omega_M, \Omega_\Lambda) = (0.73, 1.32)$ is drawn through the data (grey line). The Einstein-de Sitter case (1.0, 0.0) is strongly excluded by the current data (dashed line). The case $(\Omega_M, \Omega_\Lambda) = (0.28, 0.00)$ indicates that some contribution from a cosmological constant is required for values of Ω_M favored by dynamical measurements. The magnitude difference between the best-fit world model and suitable ones with Ω_Λ=0 show redshift dependencies which would be very hard to mimic with SNe evolution or grey dust (see inset panel). By extending our survey to $z > 1$, the *shape* of the curve alone would become sufficient evidence to support a cosmological constant. The preliminary magnitude estimate of our highest redshift SN 1998eq at $z = 1.2$ is suggestive, but more analysis and more SNe at this redshift are necessary.

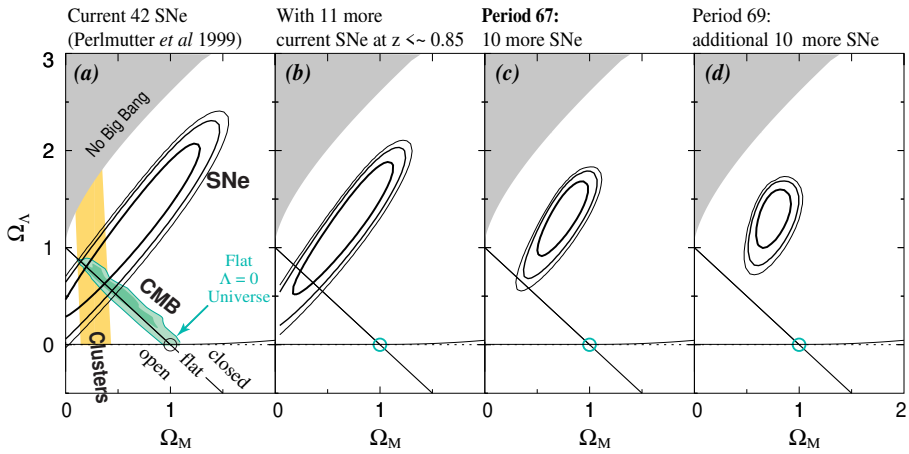

Fig.2 - Confidence regions

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. These results indicate $\Omega_\Lambda > 0$, in agreement with the overlap of the recent combined CMB results (Jaffe et al. 2000) with the Ω_M measurements from galaxy clusters. *(b)* Expected confidence region after including our additional 11 $z < 0.85$ SNe Ia currently under analysis. *(c)* Confidence region expected from the observations requested for period 67, including two at $z \sim 1.2$. *(d)* Future confidence region after period 69. 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)*.

5. Attachments (Figures)

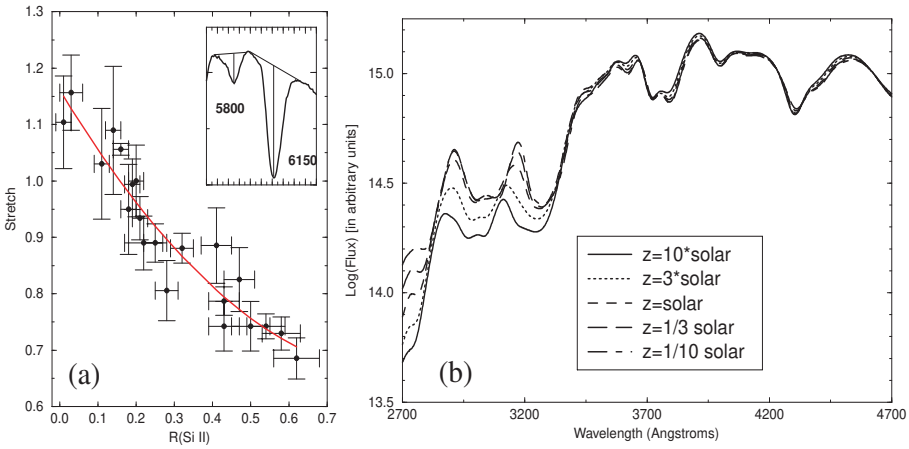

Fig.3 - Luminosity and metallicity indicators

Fig.3: (a) The tight relationship between the spectroscopic ratio $\mathcal{R}$(SiII) and the lightcurve timescale stretch for well-observed low-redshift SNe Ia (see N95 for a similar $\mathcal{R}$(CaII) plot). The inset shows how this spectral ratio is measured. (b) Maximum light spectrum synthesis models of W7 (a deflegration SN Ia model by Nomoto et al.) with varying metallicities in the outer C+O layer. Note the change in both the strength of several restframe UV features and the wavelengths of their minima (which we propose to measure for three $z \sim 0.5$ SN Ia).

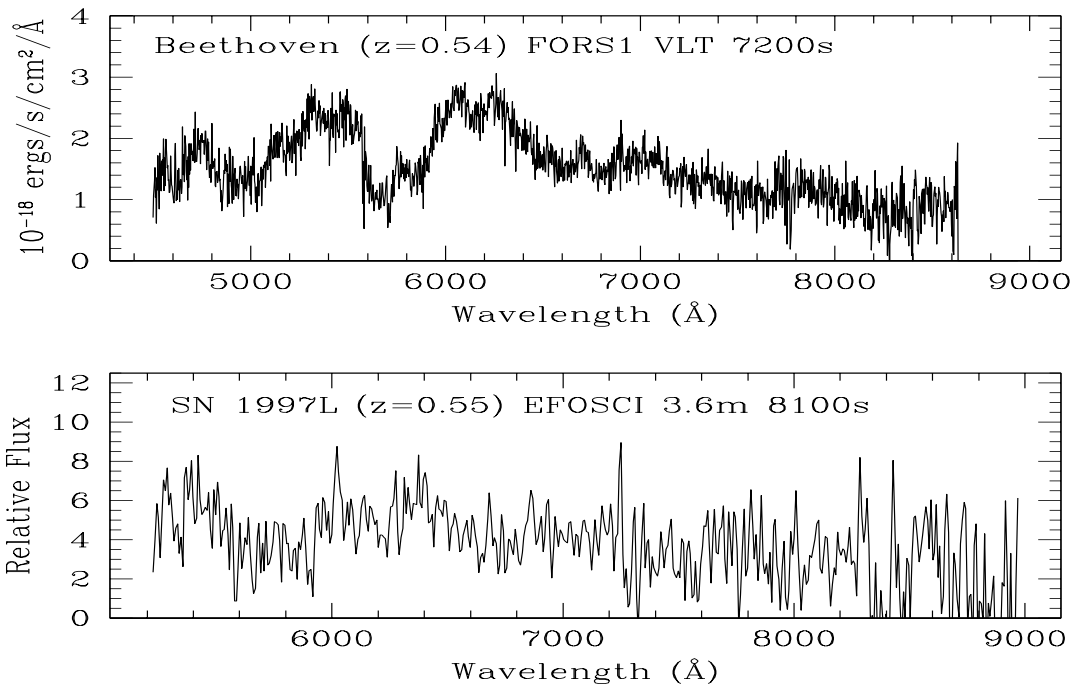

Fig.4 - Beethoven and SN 1997L

Fig.4: A comparison between the spectra that one can obtain of a distant SNe Ia with a 4m class telescope (SN 1997L) and a 8m class telescope (Beethoven). The VLT allows us to make the transition from qualitative statements, such as "It looks like a SN Ia" to quantitative measurements of line strengths and comparisons with nearby objects.

6. Experience of the applicants with telescopes, instruments and data reduction

The Supernova Cosmology Project has repeatedly demonstrated its ability to

a) discover large numbers of high–z SNe Ia (> 20 per observing run) 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 $z = 1.20$.

We have been a frequent user of ESO facilities. During periods 58, 59, 60, 61, 62 and 63 over 60 distant and 13 nearby SNe Ia were observed by our group using the ESO 3.6m. During period 64, we used FORS1 to follow a SN Ia at $z = 0.85$. During period 65, we used ISAAC and FORS1 on UT1 to obtain detailed IR imaging and optical spectroscopic followup of a type Ia SN at $z = 0.54$ (Lidman et al, 2000). All of this data has been reduced and much of it published. It usually takes a little over one year after the initial discovery and a few months after the final reference images to publish the results.

The PI, Aldering, Hook, Pain and Perlmutter are all experienced observers. The PI is a service observer at UT1 and UT2 and has observed almost 200 nights since operations began. He is very experienced in all aspects of FORS1, FORS2 and ISAAC and is very knowledgeable in data reduction techniques. The co-Is of the proposal have all participated in our previous discovery and follow-up runs and are experts in faint object imaging, spectroscopy and data reduction.

A. Goobar and P.Nugent guide the group in designing the optimal observing strategy and developing tools to make best use of the data.

7. Resources available to the team, such as: computing facilities, research assistants, etc.

The Supernova Cosmology Group (SCP) is an international Collaboration that is spread over five geographical locations.

In Sweden, the group, which consists of one senior researcher and three Phd students, is headed by A. Goobar. This group, together with I. Hook, will be responsible for reducing and analyzing the spectroscopic data.

In France, the group, which consists 2 senior researchers, 2 post-docs and one Phd student, is headed by of R. Pain. this group will co-ordinate the search and discovery run at the CFHT and perform the photometry.

In the USA, the group, which consists 2 senior researchers, 3 post-docs and 2 Phd students, is headed by S. Perlmutter. They will co-ordinate the search and discovery run at CTIO and they serve as the data center.

The SCP has extensive computing resources in the USA, Sweden and France.

The PI lives and works in Chile and will co-ordinate the ESO observations once the SNe have been discovered.

The Supernova Cosmology Group has a proven track record. To date, we have discovered and observed over 100 distant SNe Ia.

8. Special remarks

This is an international collaboration that uses several telescopes. It uses the CFHT 12kx8k and the CTIO MOSAIC cameras to discover SNe Ia candidates. It uses the VLT and the Keck telescope to spectroscopically confirm SNe Ia. It uses the VLT and NTT to follow most SNe both spectroscopically and photometrically over a period of two months. It uses HST (76 orbits already awarded) to do photometric follow-up of the most distant SNe, a task that only HST can perform.

The key to our success has been that we have been able to get time on each of these facilities. No single telescope, no single observatory, including ESO, can hope to collect the data we wish to obtain. However, ESO facilities play the *key-role* in our observing campaign. *Without the requested time at ESO telescopes we will be unable to achieve any of the aims set out in the scientific rationale.*

The data we propose to collect will be used by four European Phd students for their thesis.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: For the spectroscopy with FORS2, dark time is essential. For the followup imaging in the optical, grey time is acceptable. For the IR observations, there is no restriction.

Time Justification: We have used the exposure time calculators (v2.5.1). The following table lists the broad band magnitudes of a type Ia SNe at $z = 0.5$ (R-band) and $z = 0.85$ (I-band) and the required exposure times.

Day past Max (obs frame)	0	10	20	30	40
z=0.5 (R-band)	22.4	22.7	23.3	23.9	24.6
SUSI2 Exp. time (S/N=20, IQ=0.8")	140s	230s	660s	1900s	6900s
z=0.85 (I-band)	23.2	23.4	23.8	24.4	25.1
FORS1 Exp. time (S/N=20, IQ=0.8")	500s	700s	1500s	4500s	16000s

To observe 5 $0.5 < z < 0.85$ SNe Ia during 4 epochs, we ask for 3 nights (0.5+0.5+1.0+1.0) with SUSI2 and 20 hours with FORS1. We also want to take spectra of 3 of these SNe at maximum light and 30 days after maximum light with FORS2. To reach a S/N of 5-10 with the 300V grism, we require 2 hours for the first epoch and 4 hours for the second. In total, we would require 0.8 visitor nights and 14 hours of service respectively. The following table lists the peak J band magnitude of a type Ia SN at four different redshifts.

Redshift	0.5	0.85	1.0	1.2
J-band magnitude	22.4	23.2	23.5	23.9
ISAAC exposure time (S/N=20, IQ=0.6")	2600s	10000s	11000s (S/N=15)	10000 (S/N=10)

To measure the peak magnitude of 10 type Ia SNe over this redshift interval, we need 25 hours, including overheads.

Calibration Request: Standard Calibration

Convert to a normal programme? Yes

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

Goldhaber, G. et al., 2000, ApJ, Submitted: Type Ia Supernova Lightcurves: Composite B Lightcurve, Turn-on Behaviour and $1 + z$ Lightcurve Broadening.

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

Bergström, L.,Goliath, M., Goobar, A., & Mörtsell, E., 2000 A&A, 358, 13: Lensing Effects in an Inhomogeneous Universe.

Aldering, G., Nugent, P., & Knop, R. 1999, AJ, 119, 2110: The Rise Times of High- and Low-Redshift Type IA Supernovae Are Consistent

Perlmutter S. et al., 1999, ApJ, 517, 565: Measurements of Ω and Λ from 42 High-Redshift Supernovae.

Gilliland, R., Nugent, P. & Phillips, M. M., 1999 ApJ, 521, 30: High-Redshift Supernovae in the Hubble Deep Field,

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

More than 100 discoveries of supernovae, reported in International Astronomical Union Telegrams and Circulars, including announcement of a $z = 1.2$ SNIa, IAUC 7046.

11. List of targets proposed in this programme

Run	Target/Field	α	δ	Equinox	Mag.	Diam.	Additional information
A	Type Ia SNe	00 00 00	-00 00 00	J2000	24		
B	Type Ia SNe	00 00 00	-00 00 00	J2000	24		
C	Type Ia SNe	00 00 00	-00 00 00	J2000	24		
D	Type Ia SNe	00 00 00	-00 00 00	J2000	24		
E	Type Ia SNe	00 00 00	-00 00 00	J2000	24		
F	Ravel	03:03:17.5	+00:03:06.6	J2000			SNe Ia at z=0.85
G	Beethoven	13:59:26.9	4:58:09.40	J2000			SNe Ia at z=0.54

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

12. Scheduling requirements

1. Run Splitting

Run	splitting
C	0.5n,0.5n,1n,1n

5. Run special requirement(s)

Run	Special Requirements
A	and B,C,D, and E. These runs have to be co-ordinated with the search runs that will occur in March and April 2000. The PI must be contacted before the schedule is made.

13. Instrument configuration

Telescope	Instrument	Parameter	Value or list
UT1	FORS1	IMG	R and I Bessell filters
UT1	ISAAC	SWI	SZ and J filters
UT2	FORS2	LSS	G300V
NTT	SUSI2	Imaging-filters	R and I Bessell filters