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 64 73

APPLICATION FOR OBSERVING TIME — PERIOD: **77A**

To be submitted only to: proposal@eso.org — **ToO**

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**

Decelerating and dustfree: using Type Ia SNe in high redshift galaxy clusters to constrain the dark energy equation of state and its evolution with time.

2. Abstract

We propose to make the first unbiased measurement of the dark energy equation of state and its evolution with time by using a Hubble diagram of Type Ia supernovae (SNe Ia) in elliptical galaxies. By choosing SNe Ia in elliptical galaxies, we elimiante the largest source of statistical and systemmatic error - the correction for extinction from dust within the host. A single SNe Ia in an elliptical galaxy is statistically worth nine SNe Ia in other galaxies.

We have been awarded 219 HST orbits to discover and follow SNe Ia with elliptical hosts. We target rich galaxy clusters with redshifts ranging from z=0.9 to 1.5 to maximise our chances of finding such SNe. To date, two z=1 SNe Ia with elliptical hosts have been discovered. In this proposal, we ask for 16 hours of FORS2 time to measure the redshifts of these host galaxies and to type the supernovae.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	77	FORS2	8h	any	d	$\leq 0.8''$	CLR	s
B	77	FORS2	8h	any	d	$\leq 0.8''$	CLR	s

4. Number of nights/hours — Telescope(s) — Amount of time

a) already awarded to this project:

b) still required to complete this project:

5. Special remarks:

Run A is a ToO run consisiting of 4 triggers. Run B is a normal service mode program.

6. Principal Investigator: C. Lidman (ESO, ESO, clidman@eso.org)

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)

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: A key goal of observational cosmology this decade is to characterise and identity the dark energy through the detailed and accurate measurement of the entire expansion history, from deceleration through to acceleration, of the universe. Of the small number of known measurement techniques, only Type Ia supernovae (SNe Ia) have actually been developed to the point of routine use. Initial studies of the decelerating universe using SNe at $z \gtrsim 1$ by both the Higher-Z Team (Riess et al. 2004) and the Supernova Cosmology Project (Fadeyev et al. 2004) clearly point to host galaxy extinction correction as the most dominant source (dramatically so at $z > 1$ (see Fig. 1)) of both statistical and systematic error for SNe distances and the derived cosmological parameters.

The color uncertainties for well-measured SNe at $z > 1$ is $0.08 - 0.1$ in $B - V$, leading to uncertainties in extinction correction (after accounting for intrinsic color uncertainty) of >0.4 mag! This dispersion grows worse, $\sigma \approx 0.5$, after accounting for the uncertainty in the dust reddening coefficient, $R_B \equiv A_B/E(B-V)$, which Draine (2003) notes can vary from the fiducial value 4.1 by ± 0.5. Recent studies of nearby SNe Ia (Altavilla et al. 2004, Reindl et al. 2005) are consistent with large dispersions of R_B. (Note that the actual dispersion about the Hubble-line fit for $z > 1$ SNe Ia corrected for extinction matches this 0.5 mag value.)

These large dispersions in extinction correction have been dealt with, e.g. in Riess et al. (2004), by applying a strong Bayesian prior to the extinction distribution, assuming knowledge of the dust and SN distribution in the $z > 1$ host galaxies (shaded contour of Fig. 2). However, such Bayesian priors are necessarily one-sided (no negative reddening) and hence are known to introduce systematic biases when the error bars are larger at high-redshift than low-redshift (Perlmutter et al. 1999), which is generally the case. This bias can be seen in Fig. 2 as the difference between the long-dashed contour and the solid contour. This approach to the extinction analysis is also subject to other obvious sources of systematic biases, for example if the mean value of R_B drifts from low to high redshift, as shown by the short-dashed contour of Fig. 2.

Sullivan et al. (2003) have demonstrated that the dispersion (including ground-based measurement error) about the Hubble diagram for elliptical-hosted SNe is 0.16 mag — three times smaller than just the measurement uncertainty for extinction-corrected SNe Ia at $z > 1$ — primarily due to the absence of dust. Thus, each SN Ia in an elliptical host is statistically worth *nine times* that of SNe in spirals when making cosmological measurements,

By studying SNe Ia discovered specifically in elliptical galxies, where extinction is low, we can remove this primary uncertainty. We have been awarded one of the largest ever HST programs (219 orbits) to use this new approach in this difficult decelerating redshift range.

Our Cycle 14 (July 2005 – June 2006) HST search is expected to yield ~ 10 Type Ia SNe in $z \gtrsim 1$ elliptical hosts (to date we already have discovered and confirmed two). The trick is to observe massive galaxy clusters at $z = 0.9 - 1.5$, something that has only recently become possible with the identification of such clusters from large-field, deep near-infrared surveys such as RCS2 (on CFHT), mid-infrared surveys such as IRAC (on Spitzer), and X-ray surveys (such as XMM and Chandra). This sample should achieve statistical constraints equivalent to $\sim$90 SNe in later-type hosts, and avoid the aforementioned systemtic errors. The $z = 0.9 - 1.5$ redshift range provides key leverage on the cosmological model. In particular, this will provide a test of the small, suggestive shift from a cosmological constant model seen in Riess et al. 2004 (the shaded contour in the middle panel of Fig. 2).

Our HST program consists of repeated photometry (F850LP) of 22 clusters of galaxies ($0.9 < z < 1.5$) with HST/NICMOS2 followup photometry (F110W). The resolution of HST/ACS will also provide the resolved host morphology as well as high signal-to-noise light curves. We will discover $\sim$30 SNe among which $\sim$10 SNe Ia in elliptical hosts are expected. Up until September 2005, we had already discovered and confirmed 2 SNe Ia in elliptical hosts (both of which are in the same cluster).

Although evidence for dust is found in about 50% of nearby elliptical galaxies, the quantity of dust is generally very small and confined to a central disk where its cross-section is very small. The clearest line of evidence that dust has little effect on stars in elliptical galaxies comes from the tightness of the color-magnitude relation. The dispersion in the colors of early-type galaxies has long been known to be very small in clusters ranging from Coma to intermediate redshifts (Bower et al. 1992; Ellis et al. 1997; Stanford, Eisenhardt & Dickinson 1998; van Dokkum et al. 2001; Blakeslee et al. 2003, Nakata et al. 2005). Recent results from HST imaging show the same strikingly small dispersion in color extends to redshifts $z \gtrsim 1$.

There are number of systematic surveys of SNIa for nearby and intermediate redshifts (e.g. SDSS-II, SN Factory, ESSENSE, SNLS) which will give such "clean" SN Ia sample at these redshifts. But in order to measure the cosmological expansion over last 10 Gyr, including the time when the universe was decelerating, we need SNe Ia at higher redshifts.

The emphasis on high redshift and attention to systematics are the opening steps in bringing to maturity cosmological methods of the next generation, and this program will serve as a bedrock scientific legacy for dark energy studies.

References

8. Description of the proposed programme (continued)

Altavilla, G. et al. 2004, MNRAS, 349, 1344
Blakeslee, J. P. et al. 2003, ApJL, 596, L143
Bower, R. et al. 1992, MNRAS, 254, 589
Draine, B.T. 2003 ApJ, 598, 1017
Ellis, R. et al. 1997, ApJ, 483, 582
Fadeyev, V. et al. 2004, AAS
Lidman, C. et al. 2005, A&A, 430, 843
Perlmutter, S. et al. 1999, ApJ, 517, 565
Nakata, F. et al. 2005, MNRAS, 357, 1357
Riess, A. et al. 2004, ApJ, 607, 665
Reindl, B. et al. 2005, astro-ph/0501664
Stanford, S. et al. 1998 ApJ, 492, 461
Sullivan, M. et al. 2003, MNRAS, 340, 1057
van Dokkum, P. et al. 2001, ApJ, 552, 101

B) Immediate Objective:
FORS2 spectroscopy is requested to obtain redshifts of the SNe and/or their host galaxies, and to confirm which SNe are of Type Ia. Our HST time did not include a request for spectroscopic follow-up because our experience is that this is possible from the VLT (Lidman et al. 2005).

The spectroscopy observations proposed here are the key gound-based component of a very large approved HST program using a known approach to SN measurements which will provide the first significant *and unbiased* measurement of w_0 vs. w'.

For run A, we aim to take low resolution spectroscopy of the host galaxy and the supernova when the supernova is close to maximum light. Hence, for this run we apply for ToO status as we need to observe the supernova within a given time interval and we do not know ahead of time when this will be, although we expect that we will initiate most of our triggers during the first two months of period 77.

When the supernovae have faded from view, we will take a spectrum of the host without the supernova. For this part of the proposal ToO observations are not needed. In total, we plan to observe 4 targets. We will have observed about 6 targets with other facilities by the time period 77 begins.

Since the supernovae will be considerably fainter than their hosts (the hosts are mostly bright (I 22) elliptcals), we need the second spectum of the host without the SNe so that we can remove the host from the first spectrum and unambiguously identify the spectral type of the supernova. The redshift will be obtained from H and K lines of the hosts.

C) Telescope Justification: Supernovae at $z \sim 1$ are faint, typically I=24, and the peak of the spectral energy sitribution is at 8000Å. Hence, we need an intrument with good red sensitivity and a telescope with a large aperture. FORS2 on the UT1 is clearly the best instrument for this type of work. FORS1 is much less efficient in the red and the fringing in the red make the reductions more complex.

D) Observing Mode Justification (visitor or service): As this is a ToO request, these observations can only be done in service mode.

E) Strategy for Data Reduction and Analysis: The reduction of the spectra is straightforward. The PI of the proposal has the experience (see Lidman et al. 2005), the tools and the time to reduce the data.

8. Attachments (Figures)

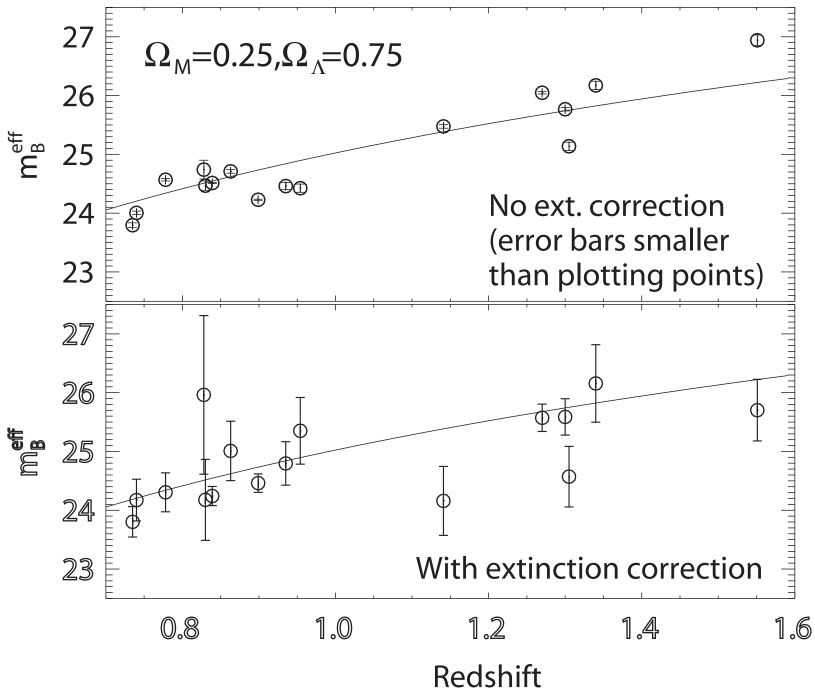

Fig. 1:The Hubble diagram, before and after extinction correction, for a mixture of SNe Ia in all host types. The uncertainty in the B-V color propogates to an error of ~ 0.5 magnitudes for SNe at $z \gtrsim 1$, consistent with the scatter seen.

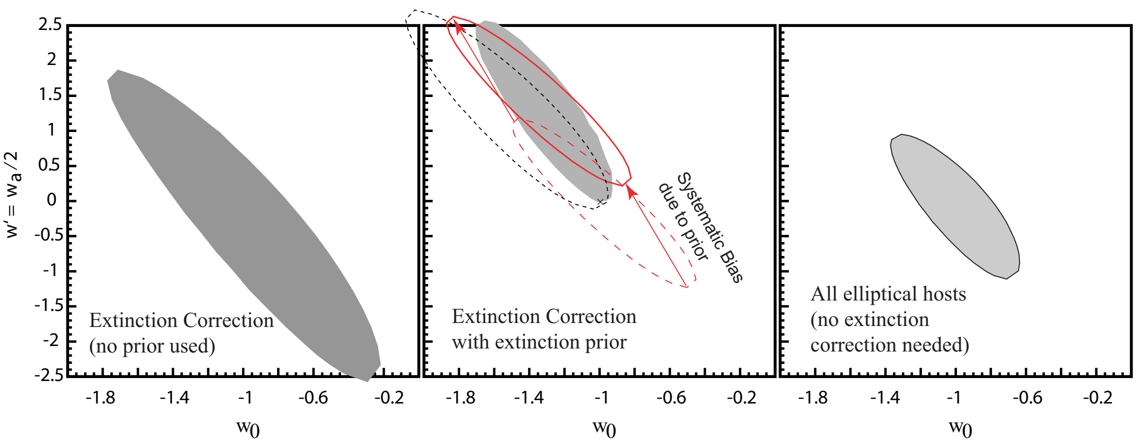

Fig. 1: **Left Panel:** Simulated 68% confidence region on w' vs w_0 for SNe Ia in the literature, simulated with an underlying cosmology ($w_0 = -1$; $w' = 0$). The parameters are poorly constrained because color errors are magnified by $R_B \approx 4$. **Middle Panel:** The solid red contour shows reduced uncertainties (excluding systematic bias) using a Baysian prior on the extinction distribution to suppress color errors. If the errors are larger at high z than at low z (as is the case with the actual data), this introduces systematic biases. The filled gray contour is from Riess et al. 2004 using this prior. The short-dashed contour shows that this approach is also sensitive to shifts in R_B with redshift; the example shifts from 4.1 to 2.6. **Right Panel:** The goal of this proposal is shown as a confidence region for a simulated new sample of ~ 10 $z \gtrsim 1$ SNe Ia found in cluster ellipticals, together with 5 in ellipticals from other HST (GOODS) searches, and 120 SNe Ia in ellipticals at the lower redshifts from the ground-based CFHT SN Legacy Survey, the CTIO Essence survey, and the Nearby SN Factory. A SN Hubble diagram in ellipticals avoids the large statistical error problem of panel (a) and the large systematics problem of panel (b).

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: Targets are extremely faint (I=24). We can tolerate a small amount of moon since we are mostly working at 8000 Å., but the lunar illumination should be below 0.4

Time Justification: (including seeing overhead) The peak I band magnitude of a Type Ia SNe at z=1.2 (the median redshift of our clusters) is around 24. With the 300I grism and OG590 order sorting filter, we expect to get a S/N ratio of 2-3 in 6000 seconds per 3.2 nm. Since SN features are broad, we rebin the data to 20 or 40 Angstrom bins and this is usually sufficient to identify the supernova type. The host galxies are going to be a magnitude or two brighter, so the S/N ratio will be around 10-20, which is more than adequate to obtain a redshift. Allowing for overheads, we estimate 2 hours per target. With 4 targets and two visits (runs A and B) per target, we request 16 hours.

Calibration Request: Standard Calibration

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

DDT program 275.A-5012 The redshift, mertallicity and age of one of the brightest Lyα emitting galaxies at $z = 5.7$. The program has been completed, the data was recieved and the analysis is in progress.
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. See Courbin et al. A&A, 438, 37.

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

Garavini, G. et al, 2005, AJ, In press: Spectroscopic Observations and Analysis of the Unusual Type Ia SN 1999ac

Noboli, S. et al. 2005, A&A, 437, 789: Restframe I-band Hubble diagram for Type Ia SNe

Hook, I. et al. 2005, AJ, In press: 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, 598, 102: New Constraints on Ω_M, Ω_Λ, 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	Mag.	Diam.	Additional info	Reference star
AB	High z cluster	00 00 00	00 00 00	16				

Target Notes: Since this is a ToO request, we've entered zero for the co-ordinates

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
77	FORS2	A	LSS	300I
77	FORS2	B	LSS	300I