Date: September 21, 2000   Category: Large Scale Structure, Cosmology   Proposal: F593

CFHT
OBSERVING TIME REQUEST
Semester: 2001A   Agency: France

1. Title of the Program *(may be made publicly available for accepted proposals)*:

Cosmology with high redshift type Ia supernovae

2. Principal Investigator: **Reynald Pain**

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Saul Perlmutter et al	Institute: LBL, Berkeley	E-mail: saul@lbl.gov

4. Summary of the Program *(may be made publicly available for accepted proposals)*:

We propose to use the CFH12k camera to discover type Ia supernovae at $z \in [0.8, 1.2]$ for the purpose of independently determining the mass density $\Omega_{\rm M}$ and vacuum energy density Ω_Λ of the Universe and hence its curvature. The proposed observations are a continuation of the program started in semester 1999B. Distant type Ia supernovae have been used as calibrated standard candles out to z=0.8 ($\bar{z} \simeq 0.55$) to measure the combination $\sim (\Omega_{\rm M} - \Omega_\Lambda)$ using the classical magnitude-redshift relation. Extending the redshift range will reduce and eventually break the $(\Omega_{\rm M}, \Omega_\Lambda)$ degeneracy, and will also enable to discriminate the effects of a non-zero cosmological constant from that of hypothetical intergalactic light dimming by grey dust. We also propose to discover about 10 supernovae at $0.5 < z < 0.8$ for both cosmology and systematics study. CFHT with the CFH12k camera is currently the best available instrument to detect a sufficient number of supernovae at redshifts around 1. These observations will be coordinated with other ground-based and space observations to identify (Keck) and follow-up (HST, Gemini and VLT) the most promising supernovae that will be discovered. This coordinated effort is done within the *Supernova Cosmology Project (SCP)* international collaboration.

5. Summary of the Observing Run Requested:

Instrument	Detector	Moon (d)	Filters	Grisms
CFH12K	EEV1	7	I, R	

Time Req.	Service/Queue?	Queue Mode	Image Quality	Opt. LST	Min. LST	Max. LST
6 nights	No	—	—	12:00	08:00	16:00

6a. Is this a joint proposal? NO   6b. If yes, total number of nights or hours requested from all agencies? —

7a. Is this a Thesis Project? YES   7b. If yes, indicate supervisor: R. Pain

8. Special instrument or telescope requirements:

9. Scheduling constraints:

The observations at the second epoch have to be scheduled before new moon (in order for the spectroscopy to take place at new moon), and roughly 3 weeks after the first epoch of observations, which we envisage either in March or April. It is crucial to contact P.I. before scheduling to coordinate with other telescopes.

10. Scientific Justification *(science background and objectives of the proposed observations: 1 page maximum)*:

The Hubble diagram for Type Ia supernovae (SNe Ia), extended to redshifts well beyond $z = 0.25$ (Fig. 1), provides perhaps the most direct current measurement of the expansion history of the universe—and hence the most direct evidence for an accelerating expansion. We developed an approach to this measurement that resulted in a determination, based on 42 SNe at $0.18 < z < 0.83$, of $\Omega_M = 0.28^{+0.09}_{-0.08}$ for a flat universe (Perlmutter et al. 1999, Riess et al. 1998). 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) strongly indicate that the geometry of the universe is flat, reinforcing evidence for an accelerating universe by eliminating the possibility of a low-density open universe (Fig. 2a). There are now two important directions to pursue in this proposal:

(1) Extending and filling a SN Ia Hubble diagram to $z \sim 1.2$. We currently have the opportunity to obtain a Hubble diagram of longlasting value as a record of the expansion history of the universe over the last 10 billion years. Significant improvements are now being made in the systematic uncertainties in SN measurements, and it is therefore now useful to reduce the statistical uncertainty by almost a factor of two — that is, by studying an additional ~100 SNe Ia. This is a key task, and we are therefore proposing a concerted effort in semester 2001A to discover and study 15 SNe Ia, with the most distant to be followed with 76 HST awarded orbits. Only HST observations can provide photometric accuracy at these higher redshifts, and the wide-field capabilities of the CFHT are crucial to discover these SNe.

This Hubble diagram redshift range that we propose to populate is aimed at addressing several of the more important scientific questions of our day. First, it allows a determination of the curvature of the universe and decoupled measurements of Ω_M and Ω_Λ: 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). After our proposed observations in semester 2001A, $\Omega_\Lambda = 0$ could be ruled out at better than 3σ. For a flat universe, Ω_M and Ω_Λ could be constrained to $\sim \pm 0.07$. 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 "dark energy" that apparently is accelerating the universe's expansion —by measuring its 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 a Cosmological Constant ($w = -1$) (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. This requires better (and more) photometry measurements than previously obtained in this redshift range (with 4-m telescopes). With this proposal, all CFHT SNe discovered will have the necessary photometric accuracy (either from the HST, for the higher redshifts, or from the new generation of 8-m telescopes, for $z < 0.85$) to address this fundamental science.

(2) Refining and testing SNe Ia as a cosmology tool. We have shown (Perlmutter et al. 1997, 1999) that possible systematics in the measurement of Ω_M, Ω_Λ 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 SN Ia evolution and abnormal dust extinction. For this proposal, we have identified a series of refinements and tests that will "sharpen" this cosmological measurement tool, by addressing these two issues: As shown in Fig. 1, the form of the Hubble diagram at high-z expected for a Λ-dominated universe would be hard to mimic by systematic effects such as intergalactic gray dust or evolution in SN Ia peak magnitudes. Comparing the proposed high-signal-to-noise measurements of SNe Ia at $z \sim 0.85$ and at $z > 1$ will provide a direct test for such possible systematics. A further test, made possible with a set of well-measured high-z SNe, is to check for the increased dispersion in absolute magnitude expected from evolution or abnormal dust extinction.

Conclusion. By concentrating our year's effort on one large campaign (*and not requesting time next semester*), 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 CFHT-led campaign as the key next step.

11. References *(1 page maximum)*:

Aguirre, A. 1999, ApJ, 525, 583.
Jaffe, A.H et al., 2000, astro-ph/000733, submitted to Phys. Rev. Lett.
Garnavitch, P. et al., 1998, ApJ, 509, 74.
Goobar, A. and Perlmutter, S. 1995 ApJ, 450, 14.
Pain., R. et al., 1996, ApJ, 473, 356.
Pain., R. et al, 2000, to be published.
Perlmutter, S. et al., 1997, ApJ, 483, 565.
Perlmutter, S. et al., 1999, ApJ, 517, 565.
Riess, A. et al., 1998, AJ, 116, 1009.

12. Figures *(all figures must appear on a single page)*:

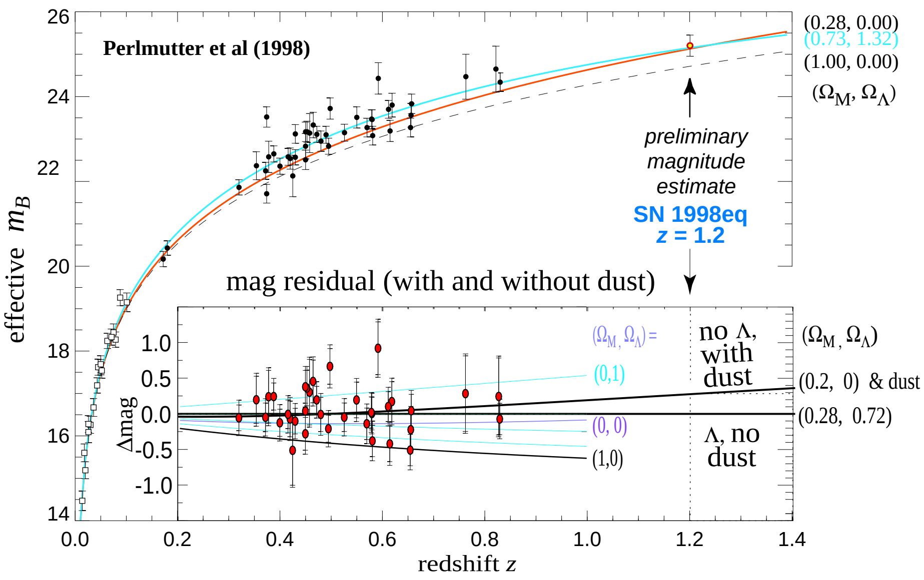

Figure 1: Hubble Diagram for 42 high z SNe. The best-fit model is drawn through the data (full grey line), which strongly exclude $(\Omega_\mathrm{M}, \Omega_\Lambda) = (1.0, 0.0)$ (dashed line). The inset shows the difference in magnitude to the best-fit for flat models. A model resorting to dust rather than Ω_Λ is also plotted: it can be detected with the proposed observation of SNe at z=[0.8-1.2]. It is also difficult for evolution of supernovae to mimic the exact shape of the best fit cosmological model at high redshift. The preliminary measurement from sn 1998eq is suggestive of no significant evolution or dust.

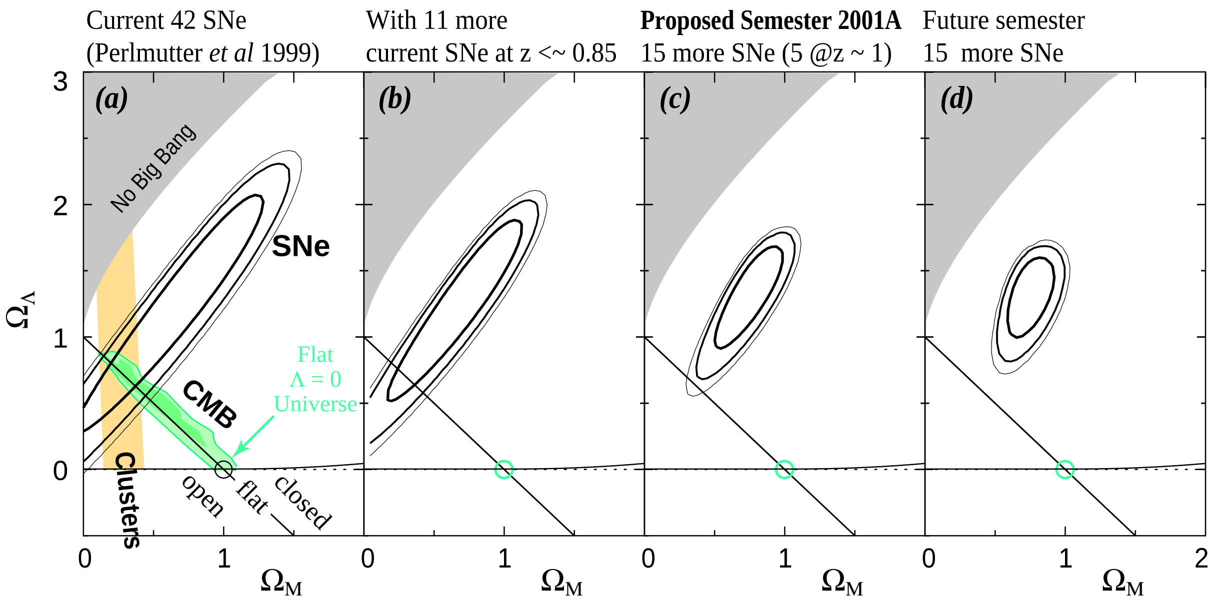

Figure 2: 68%, 90% and 99% confidence contours in the $(\Omega_\mathrm{M}, \Omega_\Lambda)$ plane from the present 42 high-z SNe from Perlmutter *et al.* Also show are the recent results from Jaffe *et al* using CMB anisotropies and constraints from galaxy clusters. (b) adding the 11 already collected SNe at $z < 0.85$. (c) the effect of the proposed campaign, and (d) of a second similar one. These simulations show that we can check the CMB curvature measurements; we emphasize this by using a non-flat scenario, e.g. using the central $(\Omega_M, \Omega_\Lambda)$ value of panel (a).

13. Technical Justification

(provide technical details of the proposed observations; justify the use of the CFHT, the requested instrument configuration, and the amount of telescope time requested: 1 page maximum):

The basic requirements of our high-z SNe Ia program are deep imaging at two epochs in a single bandpass (for detection via image subtraction), spectroscopy of SN candidates a few days after the 2nd epoch, and deep photometry of confirmed SNe Ia for construction of the light curve and measurement of its width. To find sufficient SNe Ia over the entire $0.5 < z < 1.2$ range, both deep imaging covering modest area and shallow imaging covering a larger area are needed. In order to ensure that SNe Ia are discovered prior to maximum, the two imaging epochs must be scheduled 3–4 weeks apart. *Significant time on other telescopes (76 HST orbits, VLT, Keck) relies on the results of this search.*

Imaging depth: Our deepest imaging will reach SNe Ia at $z = 1.2$ having $I = 24.5$ at maximum. To allow for discovery 0.4 mag below maximum (pre-max) and a dispersion of 0.3 mag, we aim at detecting $I = 25.2$ on the subtraction. With CFHT12k under average conditions (i.e lunar phase 0—7 days, airmass 1.0—1.5, seeing $0.8''$) $I = 25.2$ point sources are detectable at 6 σ *after subtraction* with 4.2 hours of integration. Note that a 6 σ threshold is necessary to suppress spurious candidates given the 10^7 independent samples present in such large images, and the great expense of spurious candidates targeted for spectroscopic follow-up.

For the shallow search ($0.5 < z < 0.8$), we aim at detecting a $z = 0.8$ SN Ia 10 rest-frame days before maximum at 7 σ. This requires images reaching $R = 24.2$. This depth can be achieved in less than 10 minutes. Split exposures are needed to veto cosmic rays and asteroids.

Areal coverage: Using our rate determinations (Pain et al 1996, 2000), we have conducted Monte-Carlo simulations to estimate the number of pre-max SNe detectable a search to $I = 25.2$ with a 3-week spacing between epochs. The rate is based on actual observations (conducted the same way as envisioned here), so it already includes detection inefficiencies. (e.g. due to SNe buried within galaxy cores). These simulations showed that we should detect ~ 4.5 SNe Ia/$\square^\circ$ before maximum with $0.8 < z < 1.2$ (median z=1). In order to discover 5 SNe Ia with $0.8 < z < 1.2$ to be followed with HST, four CFHT12k pointings (1.33 $\square^\circ$) are required.

Note that HST requires target coordinates to within 1° three weeks *prior to discovery* of our SNe Ia. Since the SNe Ia locations are not known yet, all of our deep search fields must be located within a single 1° radius on the sky. The result is that the deep field can be observed for at most 6 hrs per night.

For the shallow search, 10 pre-max SNe Ia to be followed with VLT are desired. Our simulations indicate that 20 pointings reaching $R = 24.2$ are required to meet this target. For many of these objects, the S/N will be good enough for the photometry on the detection image to contribute significantly to the light curve, especially because early discovery helps constrain measurement of the light curve width.

The need for two close epochs: Only SNe Ia discovered at or before maximum produce useful light curves. Therefore the two imaging epochs must be separated by 3—4 weeks since the time from explosion to 7 rest-frame days before peak is 3 weeks at $z = 0.5$ and 4 weeks at $z = 1.0$. Since each faint SN-candidate requires ~4 hrs on Keck or VLT, spectroscopy of post-max SNe is an expensive waste of large-aperture telescope time. Larger epoch spacings can result in up to 60% of candidates being post-max. For this reason we must request CFHT time for deep imaging for both epochs during this semester. The discovery (2nd epoch) images must be completed several days prior to new moon so that confirming spectroscopy at Keck and VLT and follow-up photometry from VLT (and HST) can commence by new moon.

Summary of the observing time request: The deep search requires four pointings of 4.2 hrs exposure (plus 0.4 hrs of overhead) in I-band at two epochs. The deep search region is visible for only 6 hrs per night (see above), so 3 nights (4×4.6 hrs/6 hrs visibility per night = 3 nights) at each epoch. The balance of each night will be used to conduct the shallow search, which requires twenty pointings of 10 mn in R-band at two epochs. *3 nights per epoch for two epochs brings our total request to 6 nights.*

Subtraction technique: We have previously discovered SNe with CFHT12k and were able to flatfield, defringe, and run the subtractions within the day after the observations. Subtraction systematic residuals were ~1% on the core of bright objects, and the noise was exactly that expected from photon statistics.

Resources: We have support from the Programme National de Cosmologie to buy, install and run computing equipment at the CFHT HQ to search for SNe in CFH12k images just after the observations.

14. Targets:

Object/Field	α	δ	Epoch	Mag/Flux	Comment

15. General Target Information:

We will observe 4 pointings in I (4.2 hours each) and 20 pointings in R (2 times 5 minutes each). The 4 pointings have to be in a circle of 1 degree in radius to meet HST constraints. The actual targets coordinates will be choosen according to the actual dates scheduled.

16. Is this program conducted in relation with other observations (optical, radio, space)?

YES: This program is conducted in relation to proposals on the Keck, VLT, Gemini and HST (where 76 orbits are already awarded to this project)

17. How many additional nights or hours at CFHT would be required to complete this project? 6 nights

18a. Is an extension of the one-year proprietary period required? NO

18b. If yes, justify the request for an extension:

19. Recent Allocations on CFHT and Other Telescopes:

- cfht 99b: 2x1.5 nights on cfh12k. 2 pointings searched (1 bad half night on the second epoch), 14 candidates found, spectra at Keck for 8 of them, and followed-up one at VLT. Unfortunately HST went out of service after the search. VLT photometry data is reduced.
- cfht 2000a: 2x2.5 hours on cfh12k. High sky background. 1 candidate at z=0.54 found very early (about 14 days before maximum) followed at HST, VLT and Keck with high signal-to-noise photometry and spectroscopy for systematics study.

20. Publications Resulting from CFHT Observations *(only the 12 most recent contained in the database are displayed)*:

C. Lidman, A. Goobar and R. Pain, 2000, ESO messenger, accepted
S. Fabbro et al., on behalf of the SCP, 1999, IAUC, 7311, accepted

Disclaimer: *In submitting this application, I acknowledge that I am aware of CFHT's policy concerning public access to data after a proprietary period of one year. I recognize that each individual reacts differently to working at high altitude and that some individuals may experience potentially severe altitude sickness or other medical problems. I agree that observers proposing to work at Mauna Kea should be medically fit for such work and not have conditions which would be inconsistent with work at high altitude. I understand and agree that Canada-France-Hawaii Telescope Corporation and those acting in its behalf have no liability with respect to the risks associated with work at the telescope by observers or others, and that every participant in an observing run at Mauna Kea should follow the policy of his or her own employer or sponsoring agency with respect to medical examinations and other requirements for work at high altitude.*

Signature: signed via "POOPSY"

21. **Experimental Design** *(additional scientific and technical details for large programs: 2 pages maximum)*:
