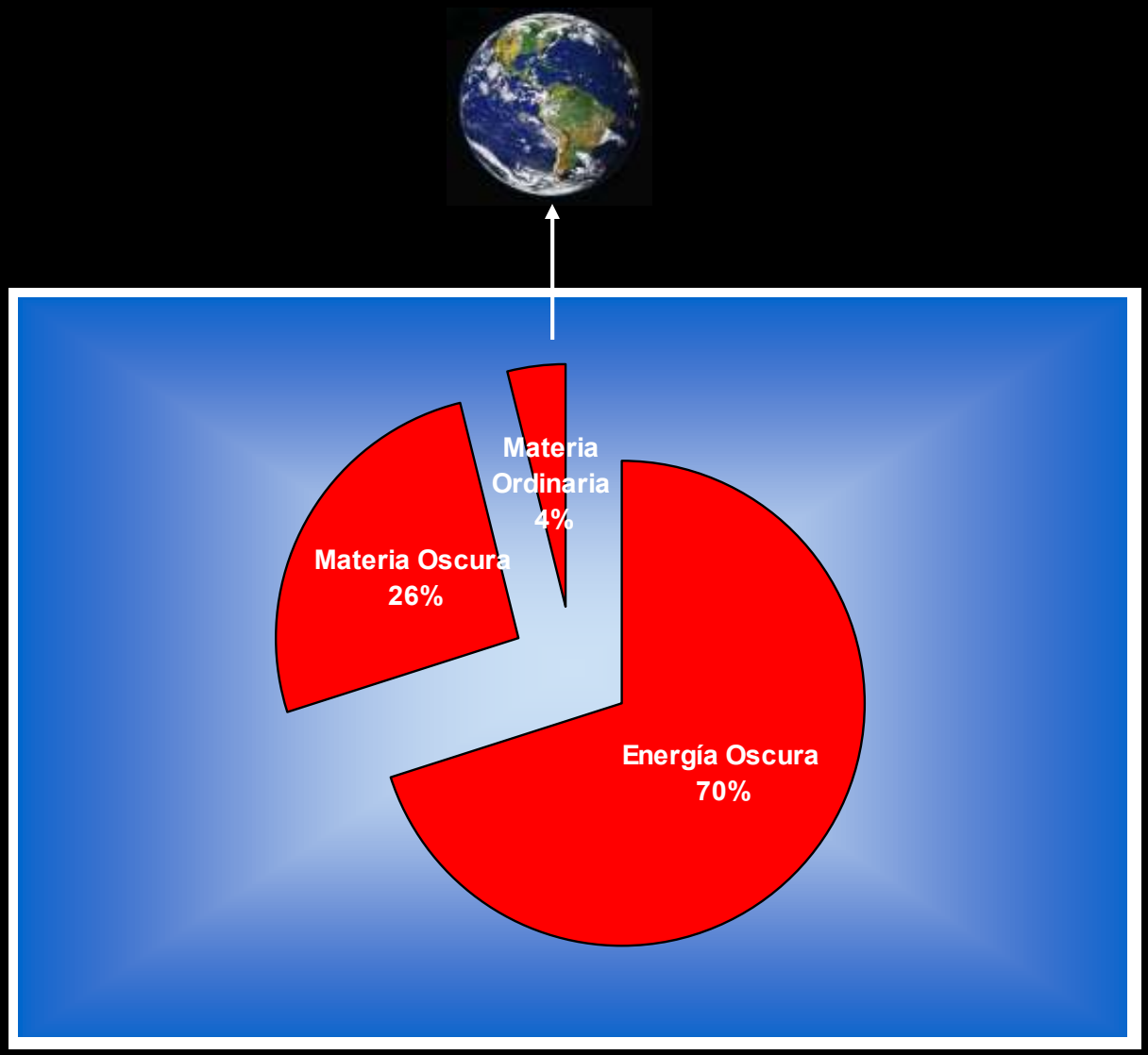
The acceleration of the Universe in the light of supernovae

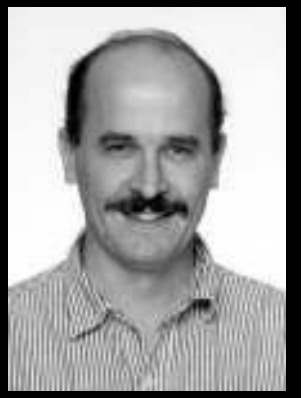
The key role of CTIO

- Mario Hamuy
- Universidad de Chile

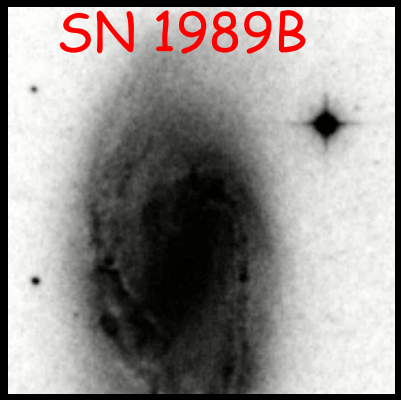
Composition of the Universe

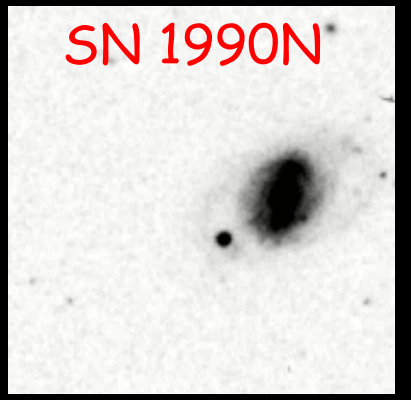


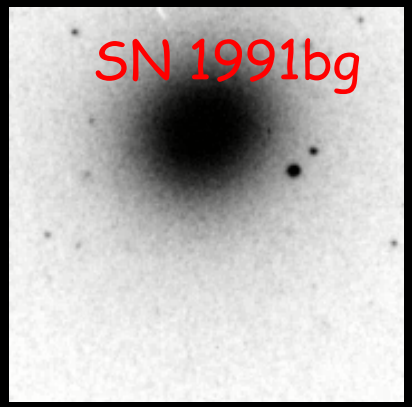
The Tololo Nearby Supernova Survey

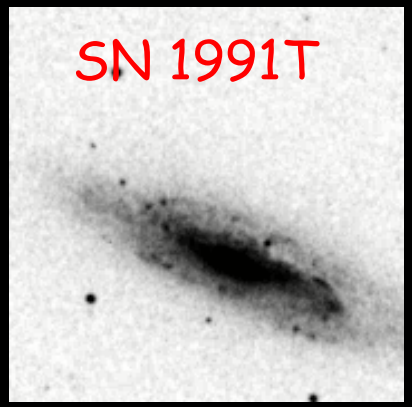


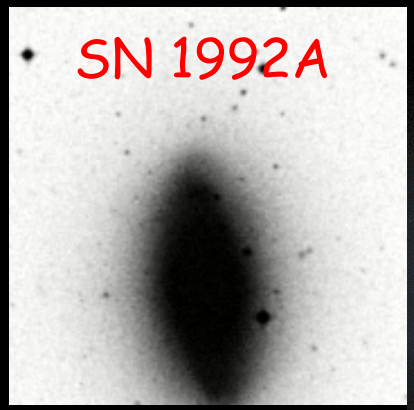
First digital light curves of supernovae
(cz < 2000 km/sec)

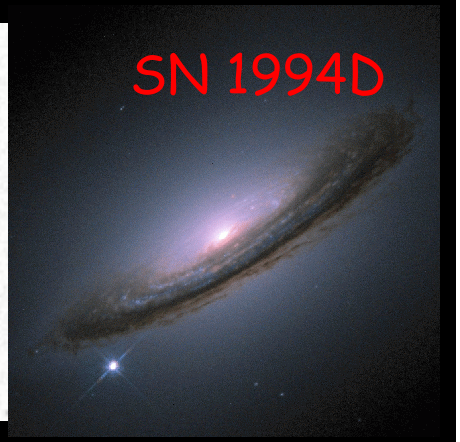




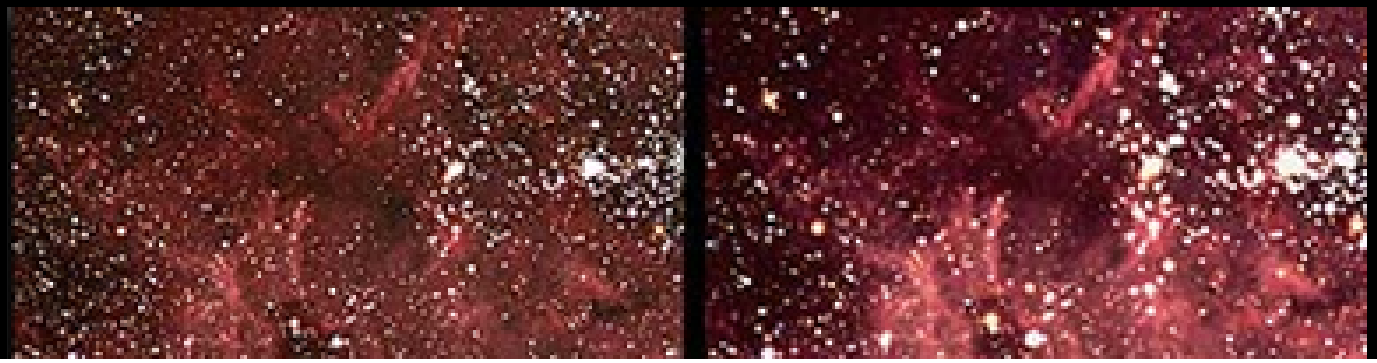






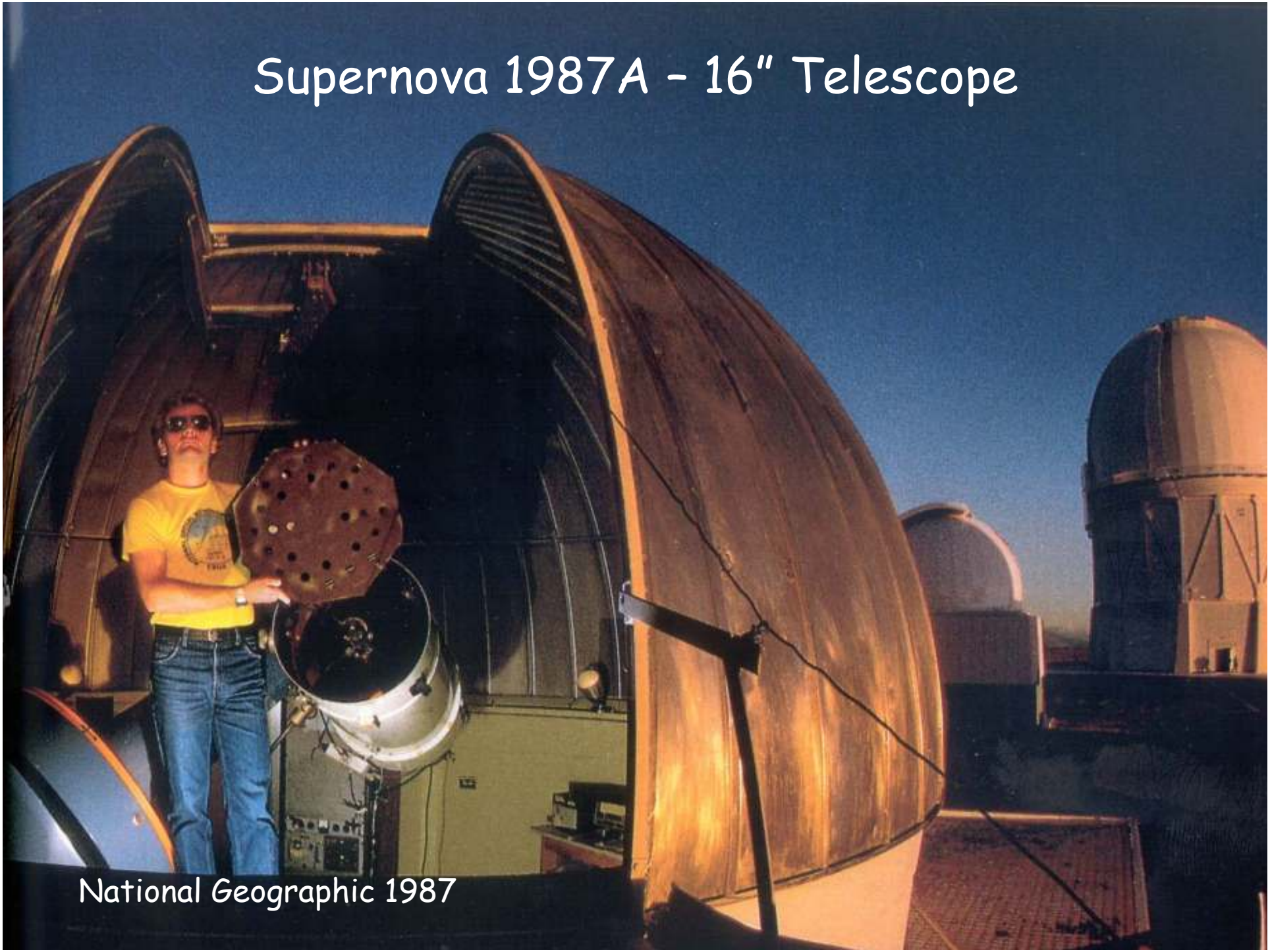


Supernova 1987A



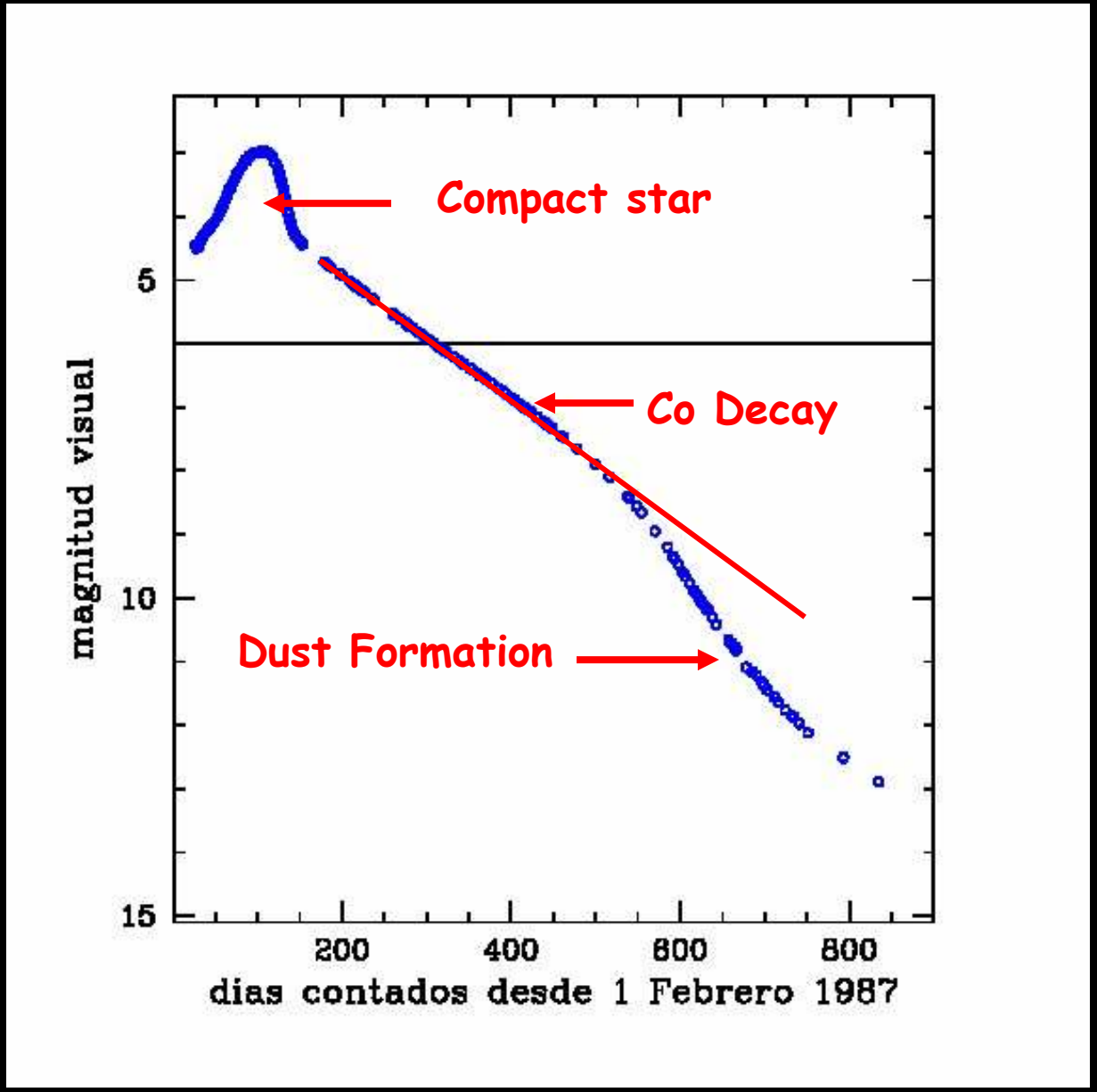
M1:The scientific career is full of surprises

Supernova 1987A – 16" Telescope



National Geographic 1987

Supernova 1987A – Observations from Tololo



Workshop Santa Cruz – California - 1989

Workshop Santa Cruz – California - 1989

Supernovae Ia as Standard Candles

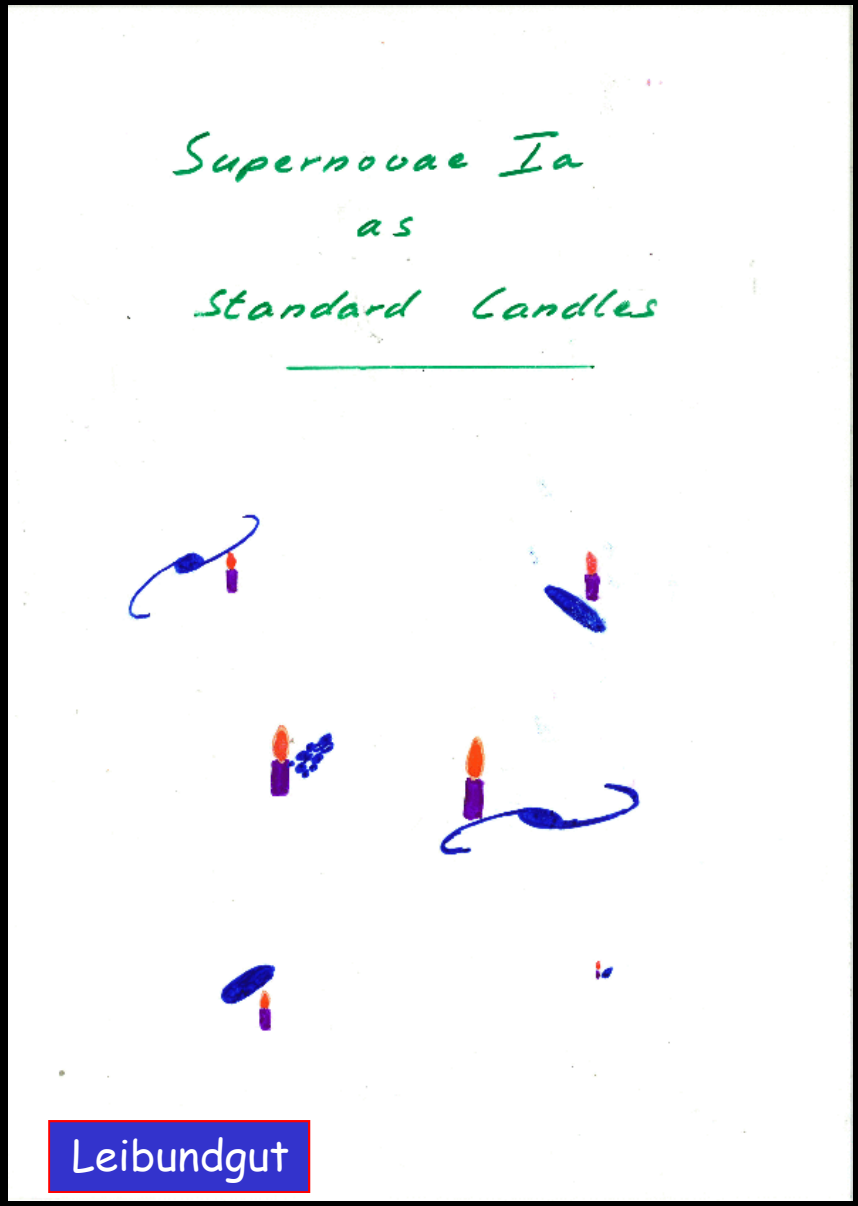
Bruno Leibundgut

1. Introduction

The use of Supernovae (SNe) as a mean of distance measurements was proposed already in the early times of supernova research. An extensive study by Baade (1938) of all available data at that time illustrates how SNe were used to infer cosmological parameters.

Although the recognition of various subtypes of SNe (Minkowski 1964, Kirshner et al. 1973, Oke and Searle 1974, Wheeler and Levreault 1985, Uomoto and Kirshner 1985) hampers the use of SNe In general for distance determinations, the possibility remains of using SNe of type II as "custom yardsticks" (Kirshner and Kwan 1974, Höflich 1987, Wagoner 1988, Eastman and Kirshner 1989) and SNe of type Ia as standard candles (Tammann 1982, Leibundgut 1988, Leibundgut and Tammann 1989). The second method needs, of course, a good calibration of SNe Ia as objects with equal, if not identical, evolution of their light emission. Spectroscopic studies of SNe Ia have shown differences between individual events (Branch et al. 1988), but the photometric observations have exhibited astonishing uniformity (Leibundgut 1988). The exceptional case of the well studied SN 1986G in the peculiar galaxy NGC 5128 (Cen A; Phillips et al. 1987, Frogel et al. 1987, see also Canal et al. 1988) poses a strong challenge to the significance of standard candles for SNe Ia. We would like to understand what caused the differences, for instance in the infrared light curves of SN 1986G compared to standard SNe Ia like SNe 1972E, 1981B, 1980N (Leibundgut 1988) and the dispersion of the expansion velocities in SNe Ia (Branch et al. 1988), before we really may rely on distances from SNe. The little knowledge on extinction in external galaxies complicates accurate determinations even further, but as will be shown below, it might still be acceptable to neglect this contaminating effect for most SNe Ia.

We will first demonstrate the photometric uniformity of SNe Ia and then outline their possible uses for cosmology. The observations of SN 1988U (Norgaard-Nielsen et al. 1989) provide a first test of the predictions.



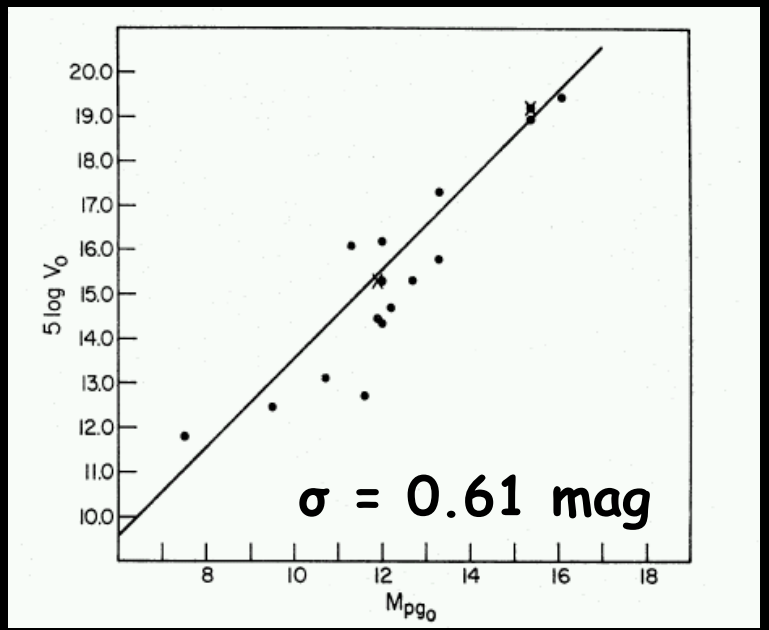
Leibundgut

The absolute magnitudes of supernovae

Baade 1938 -> Mpg = -14.3 +/- 1.1 mag

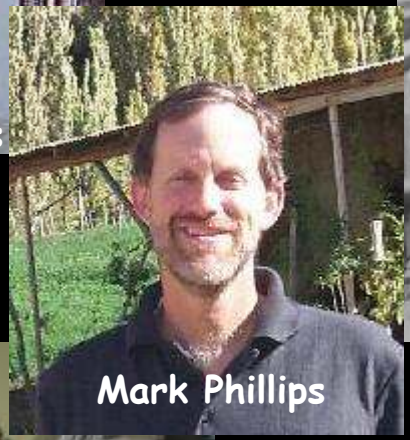
Van den Bergh 1960 -> Mpg = -18.7 +/- 1.1 mag (Type Ia)

Kowal 1968 - First Hubble Diagram

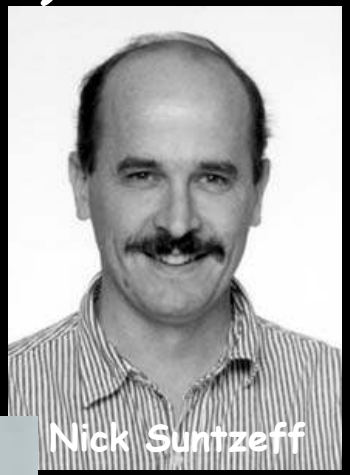


The Calán/Tololo Project (1989-1996) - Members


Roberto Avilés


Mark Phillips


Bob Schommer


Nick Suntzeff


Mario Hamuy


Roberto Antezana


José Maza

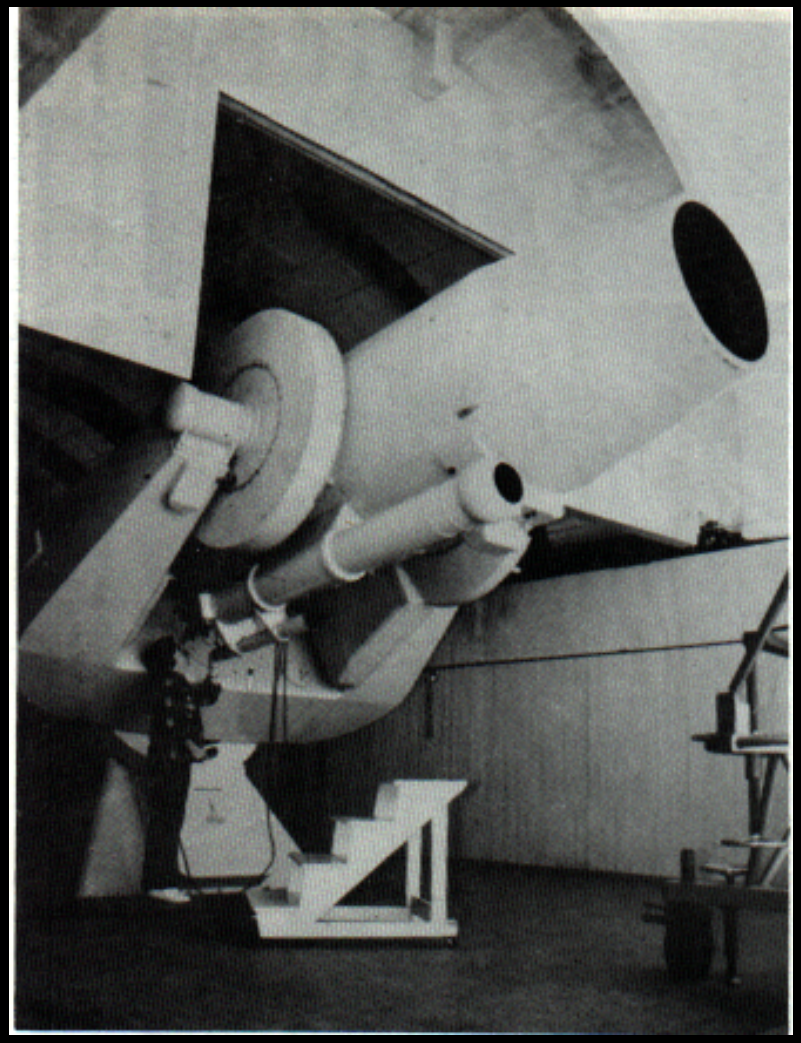

Lisa Wells


Marina Wischnjewski


Luis González


Paulina Lira

Cerro El Roble Supernova Search (1979-1984)



Maksutuv Telescope at El Roble Observatory

José Maza
Marina Wischnjewsky
Luis González
Juan Parra
Pedro Hernández

50 supernovae!
SN 1980N (Fornax A)
SN 1983K

Apoyo de:
Enrique d'Etigny
Claudio Anguita
Hugo Moreno

UNIDADES EJECUTORAS DE LA (S) INSTITUCION (ES) PATROCINANTE (S)

INSTITUCION/FACULTAD/DEPARTAMENTO

1.	OBSERVATORIO INTERAMERICANO DE CERRO TOLOLO.
2.	UNIVERSIDAD DE CHILE / DEPARTAMENTO DE ASTRONOMIA.
3.	
4.	
5.	
6.	
7.	

RESUME eda esta página)

M2:If you lose a competition, you must persevere!

We propose to start a photographic search for supernovae in the southern hemisphere for a period of three years. The survey will be carried out using the Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory (CTIO) with IIaO plates. A careful review of the plates will be performed at the Department of Astronomy of the University of Chile (Cerro Calán). According to previous tests of the Calán/CTIO survey performed between June 1990-June 1991, we should be able to find one supernova brighter than B=19 every month. We will obtain follow-up photometry and spectroscopy of these objects using other CTIO telescopes for spectral classification and the measurement of the light curves. In the course of the three years we expect to find 20-25 Type Ia events in the redshift range 0.005-0.1, which will be used to study the Hubble diagram for these objects at this redshift range. A more detailed monitoring will be obtained for 1-2 bright supernovae per year, in the optical and infrared wavelengths.

Calán/Tololo - Search

Cámara Curtis-Schmidt
Cerro Tololo

La Serena → Santiago

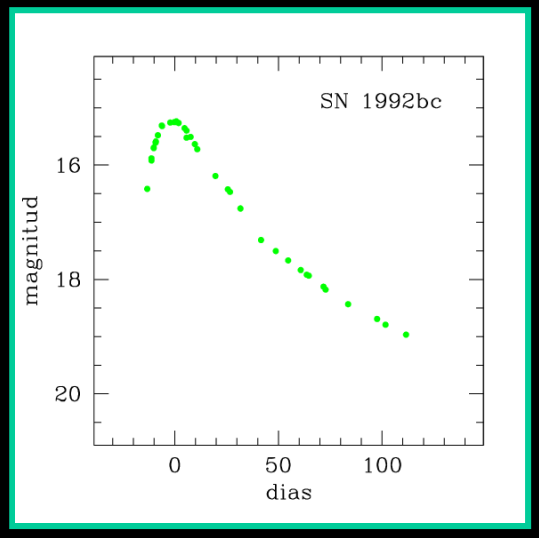
Photographic Plate

Blink Comparator
Cerro Calán

Supernova!

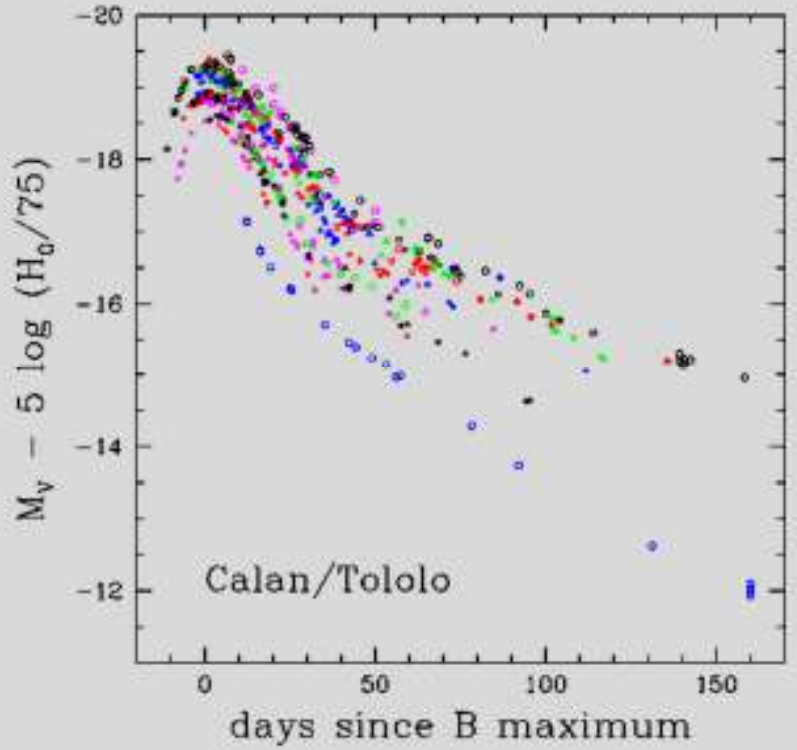
Santiago → La Serena

Calán/Tololo - Followup



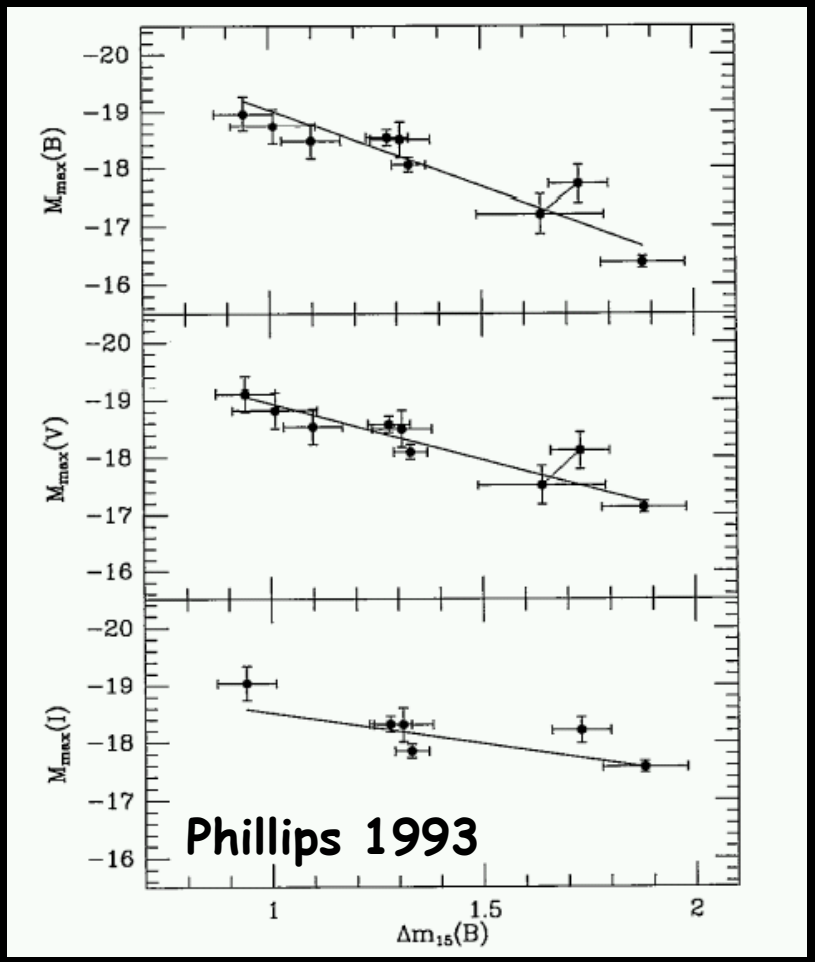
(1) The discovery of 29 Type Ia supernovae in the Hubble flow

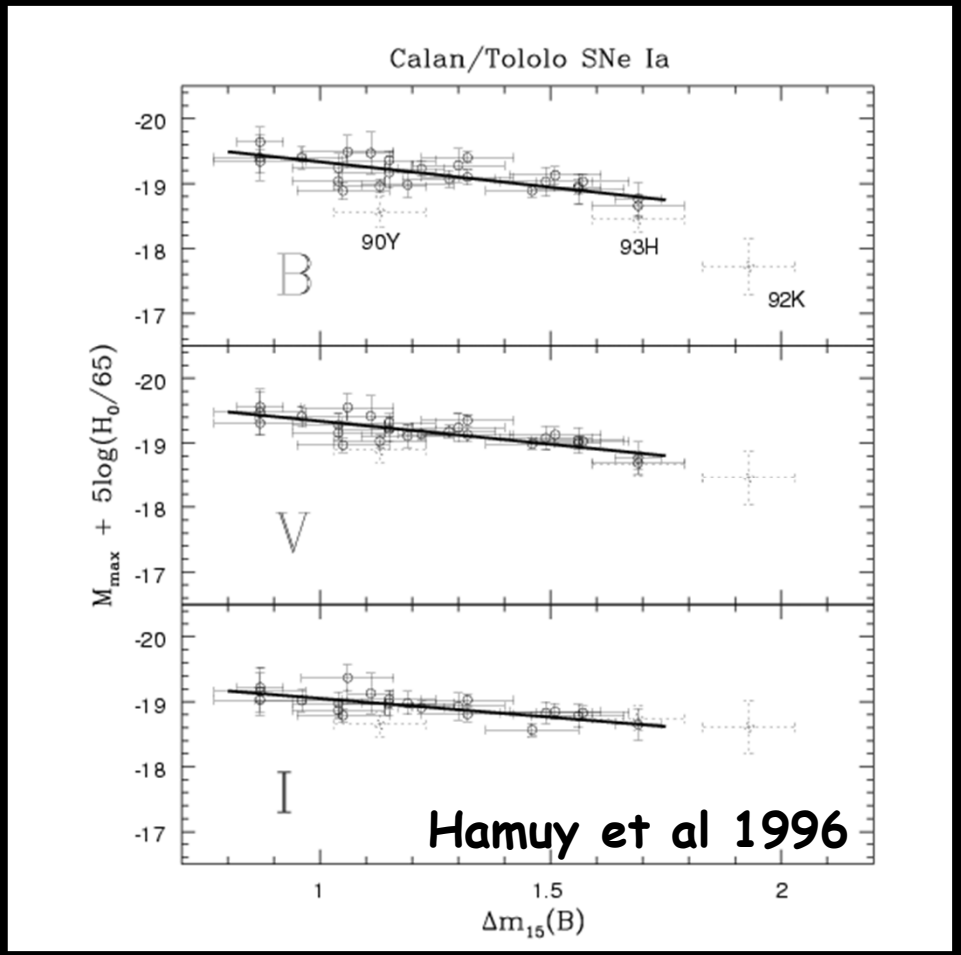
(2) The recording of the most precise light curves ever obtained at that time thanks to the CCD technology



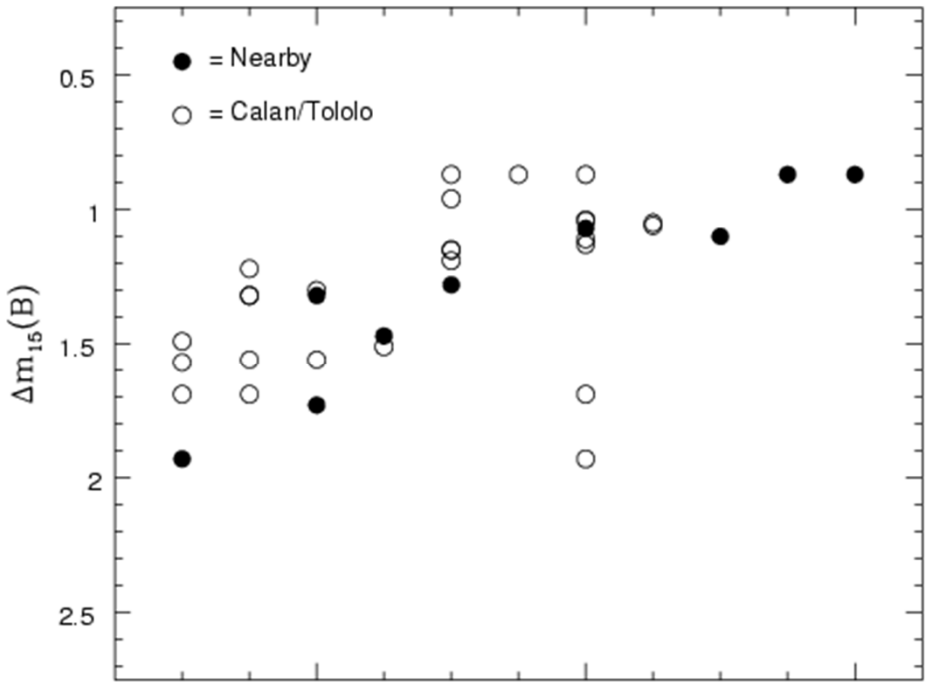
(3)
The proof that
Type Ia
were not perfect
standard candles

(4) The demonstration that Phillip´s relationship was qualitatively correct

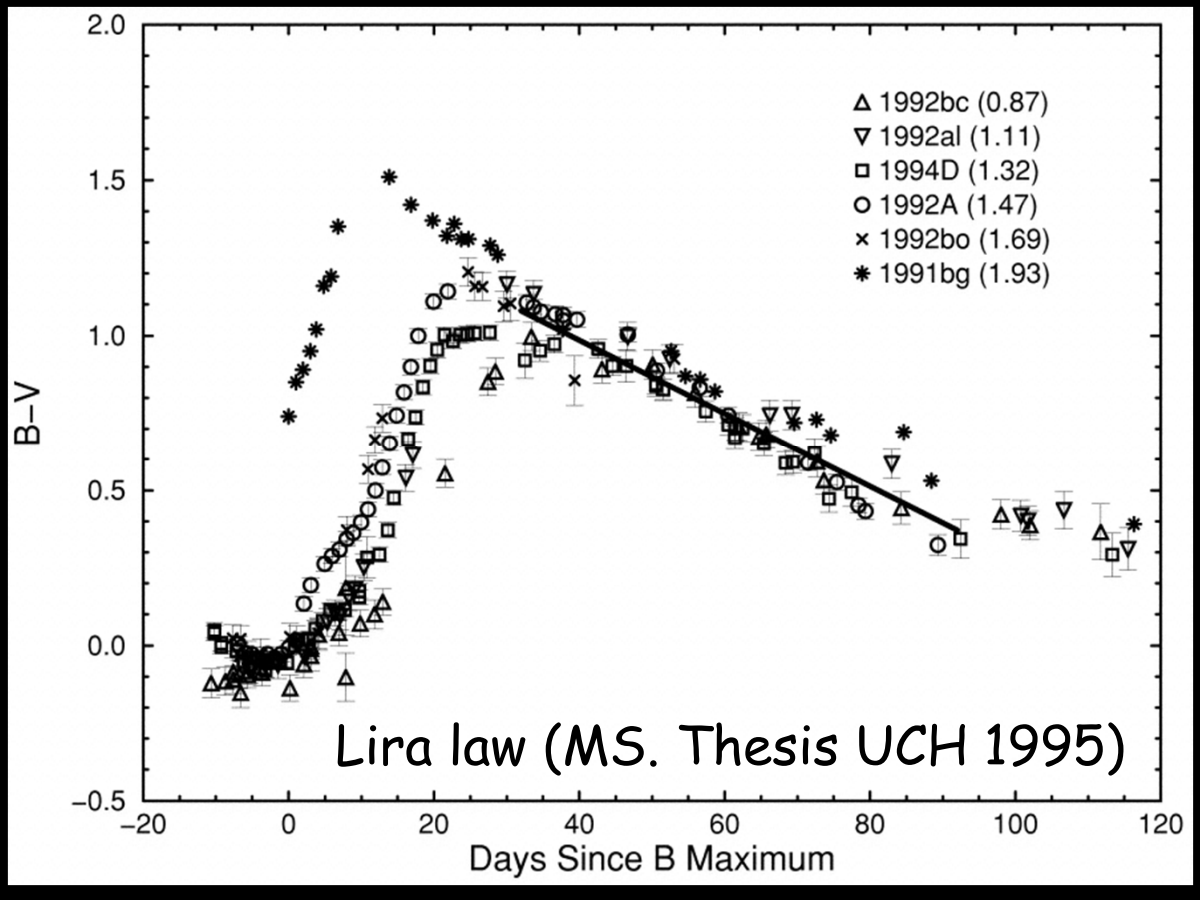




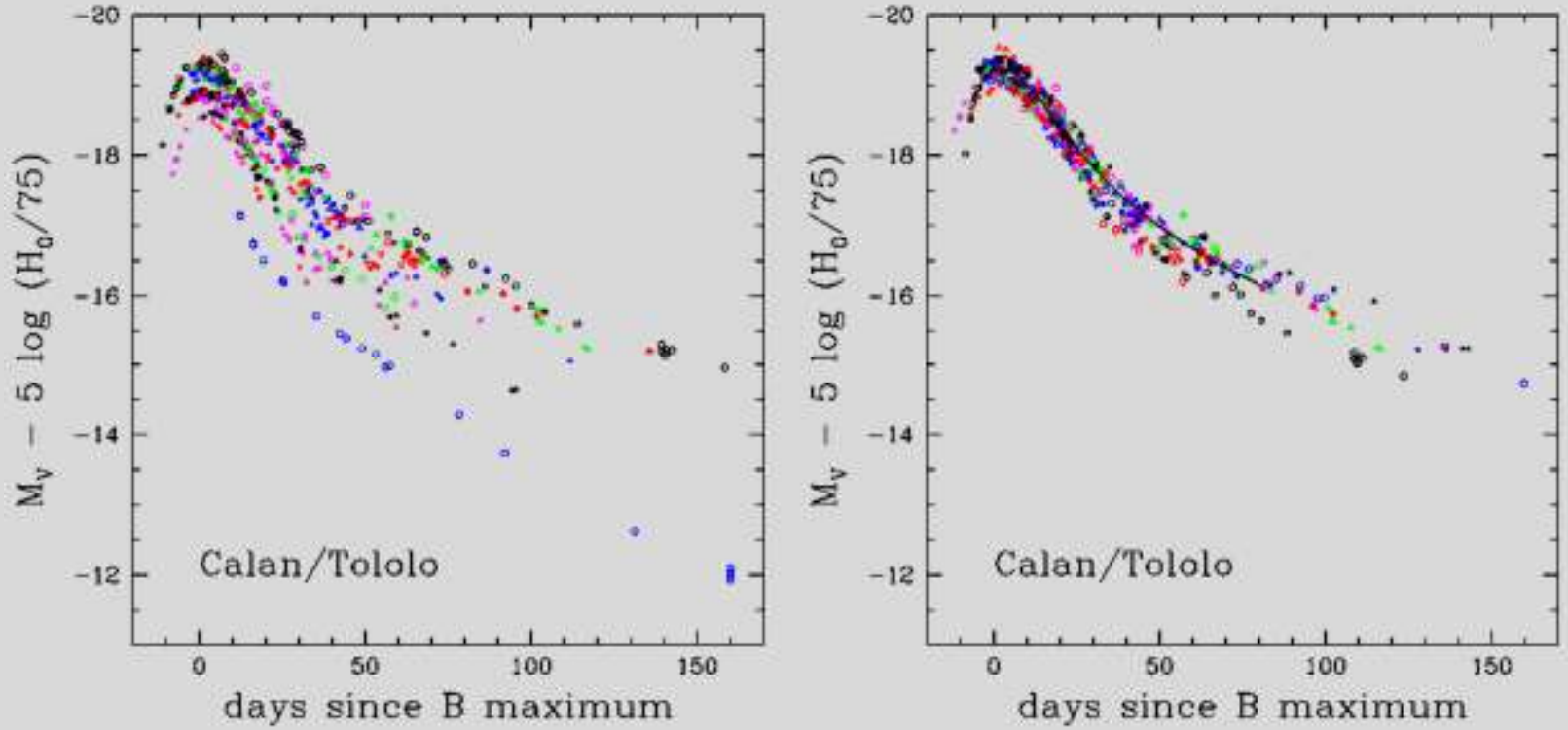
(5) The dependence of supernova luminosities with host galaxy Hubble types



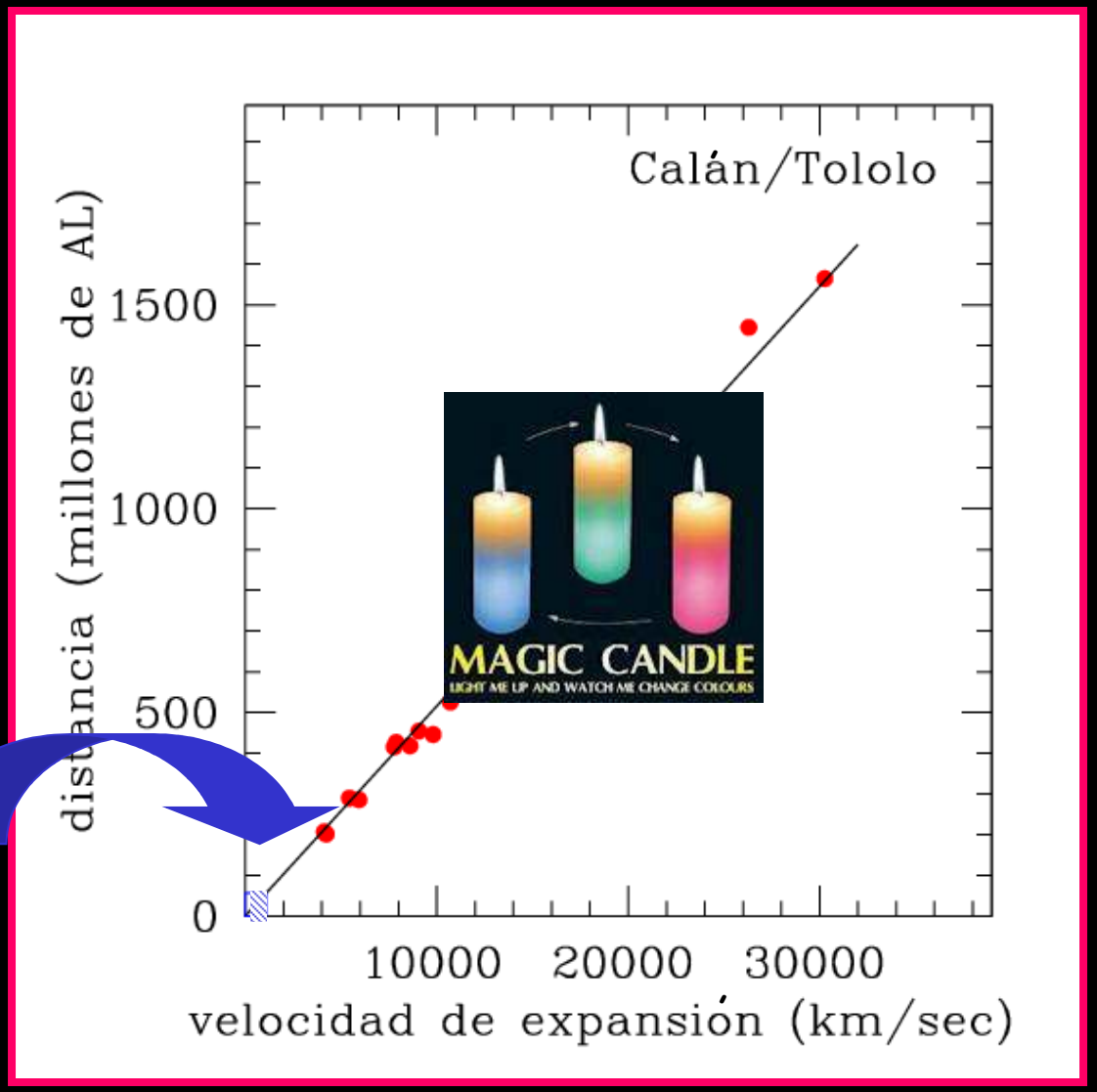
(6) The establishment of a method to correct supernova luminosities for host-galaxy reddening



(7) The most precise calibration of the supernova luminosities at that time (1994-1996)



(8) The establishment of key tools to measure distances with a precision never reached before



Hubble

OBSERVING TIME REQUEST
CERRO TOLOLO INTER-AMERICAN OBSERVATORY

Prepare in duplicate and send one form each to: CTIO, Casilla 603, La Serena, Chile **AND** CTIO Support Office, NOAO, P.O. Box 26732, Tucson, AZ 85726. Alternatively, the TEX file may be sent directly to CTIO by E-mail to ctiosked@noao.edu. **DEADLINES:** The proposal must be received in **Chile** by Sept. 30 for the next Feb.–July period and Mar. 31 for the next Aug.–Jan. period. The E-mail deadline is 5 days earlier.

Title: The Calan/Tololo Supernovae Search Program

Date: September 30, 1993

Principal Investigator: Mario Hamuy Telephone: 56-51-225415
Address: CTIO - Casilla 603 - La Serena - Chile
Email: mhamuy@noao.edu
Other Investigators: Name, Address and Phone
Nicholas Suntzeff, Mark Phillips, Christopher Smith, Roberto Aviles, Mauricio Navarrete, CTIO
Jose Maza, Marina Wischnjewsky, Roberto Antezana, Univ. Chile

Investigators planning to observe at CTIO (limit of 2): M. Hamuy, R. Aviles
Grad. student? no Is proposed research part of Ph. D. thesis? no

Travel support, as specified in the *CTIO Facilities Manual*, will automatically be awarded to qualifying principal observers.

Graduate Students: Applications will not be accepted unless accompanied by a letter from a responsible faculty member certifying observational competence and academic standing.

1) Abstract of Scientific Justification:

The Calan/Tololo SN survey is a project to discover supernovae of all classes near maximum light in the redshift range ($0.01 \leq z \leq 0.1$). The goals of the project are to explore the general characteristics of supernovae near maximum light, to study the homogeneity of the subclasses of supernova types, and to study the use the supernovae as distance indicators. To date, we have discovered ~30 Type Ia SNe, and have light curves to $B = 22$ for 12 objects. In order to finish the light curves for the remaining objects, we need to obtain deep CCD frames of their parent galaxies with the 0.9-m telescope for galaxy subtraction purposes. In addition, we propose to continue our observations of nearby, bright supernovae. Finally, we request telescope time on the Schmidt telescope to investigate the next stage in the Calan/Tololo SN survey: a deeper CCD-based survey to $z \sim 0.25$.

2) Observing runs requested for this project:

Run	Telescope	Instruments, detectors, gratings, filters, camera optics, photographic plates, etc.	Leave Blank
1	0.9-m	CCD direct, TEK 1024 CCD, UBVRI filt.	
2	Schmidt	CCD direct, STIS TEK 2048 CCD, BVRI filt.	
3			
4			

Run	No. nights requested	Max days from new moon	Range of Optimum Dates	Range of Acceptable Dates
1	2 per month	-5 to +5		every month

Observing Proposal
Cerro Tololo Inter-American Observatory

Date: September 29, 1994 *Proposal number:*

TITLE: A Pilot Project to Search for Distant Type Ia Supernovae

PI: N. Suntzeff — Grad student? N — nsuntzeff@ctio.noao.edu
CTIO, Casilla 603, La Serena Chile — 56-51-225415

CoI: B. Schmidt — Grad student? N — brian@cfanewton.harvard.edu
CfA/MSSSO, 60 Garden St., Cambridge, MA 02138 — 617 495 7390

Other CoIs: C. Smith, R. Schommer, M. Phillips, M. Hamuy, R. Aviles (CTIO); J. Maza (UChile); A. Riess, R. Kirshner (Harvard); J. Spyromilio, B. Leibundgut (ESO)

Abstract of Scientific Justification:

We propose to initiate a search for Type Ia supernovae at redshifts to $z \sim 0.8$ – 0.9 in equatorial fields using the CTIO 4m telescope. This program is the next step in the Calán/Tololo SN survey, where we have found ~ 30 Type Ia supernovae out to $z \sim 0.1$. The proposed program is a pilot project to discover fainter SN Ia's using multiple epoch CCD images from the 4m telescope. We will follow up these discoveries with CCD photometry and spectroscopy both at CTIO and at several observatories in both hemispheres. With the spectral classification and light curve shapes, we can use our calibrations of the absolute magnitudes of SN Ia's from the Calán/Tololo survey to place stringent limits (Figure 2) on q_0 in a reasonable time-frame. Based on the statistics of discovery from the Calán/Tololo SN survey, we can expect to find about 3 SNe Ia per month.

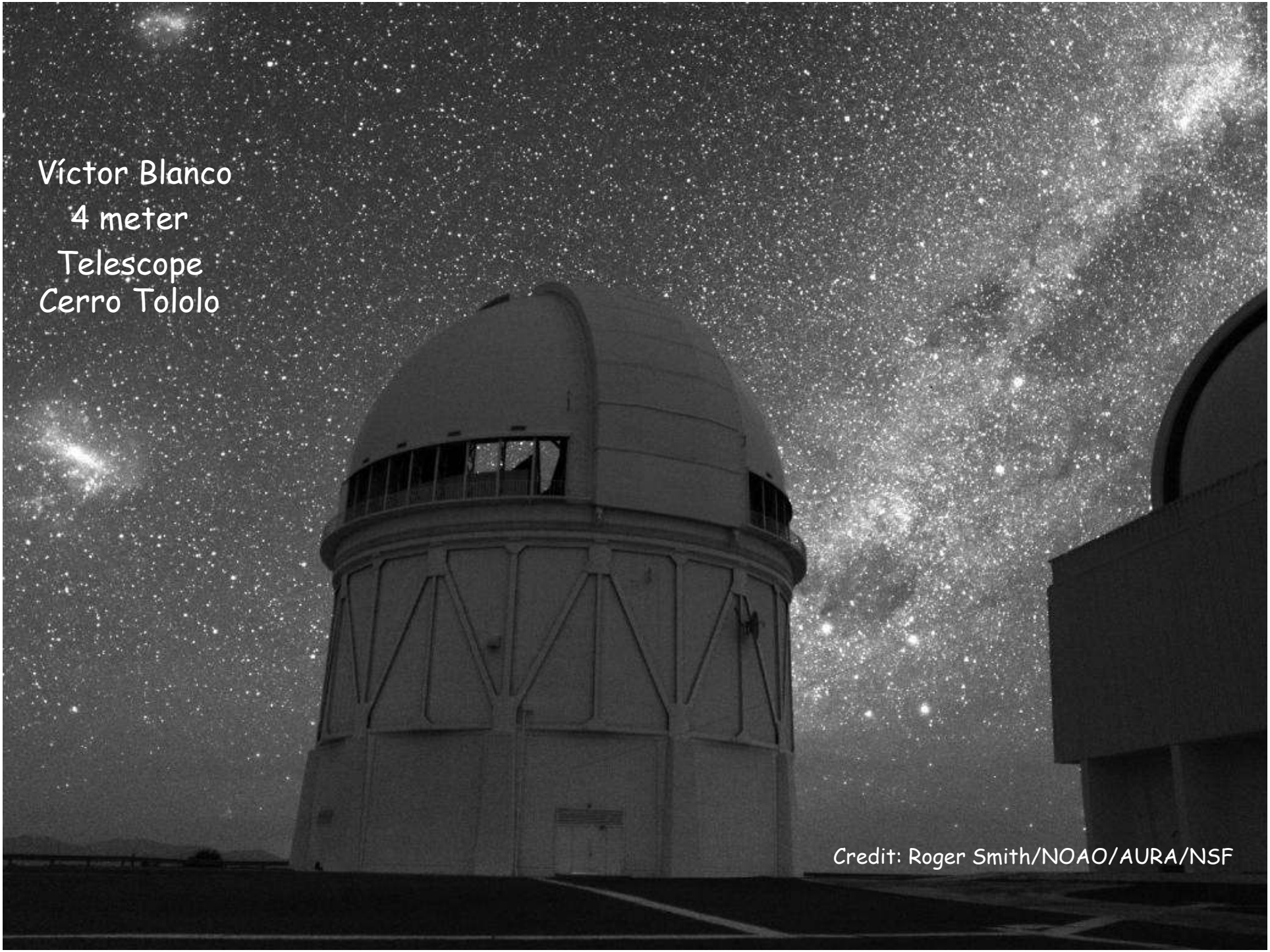
The goal of this pilot project is to obtain enough imaging data to allow us to verify that we can discover faint supernovae at the expected rates. The success rate of discovery for this program and the related (but independent) program proposed for the 0.9m rests primarily in the software used to search for the supernovae in digital images. The data set from this pilot project will allow us to tune the software to provide the most efficient discovery techniques.

- *Is this proposal part of a PhD thesis? If 'Y', you must send a letter; see instructions.* N
- *Are you requesting long-term status? If 'Y', please give details on the line below.* N

Summary of observing runs requested for this project

Run	Telescope	Instrument, detectors, gratings, filters, camera optics, etc.
1	4m	PFCCD Tek2048K, our set of reshifted *BV* filters
2		
3		

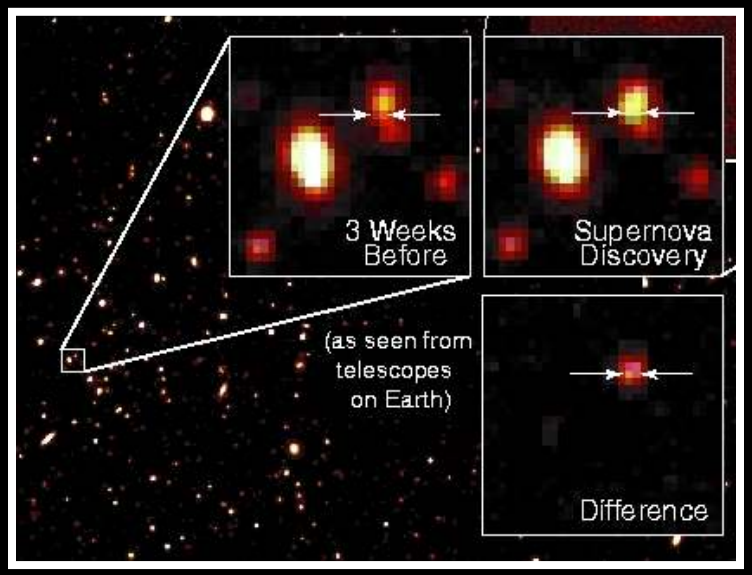
Run	No. nights	Moon age (d)	Optimal dates	Acceptable dates

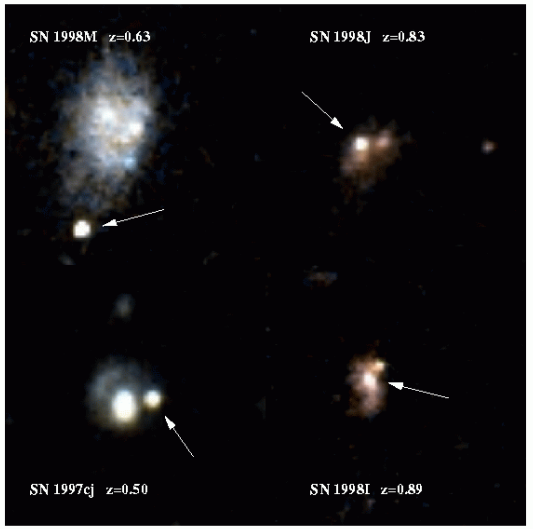

Víctor Blanco
4 meter
Telescope
Cerro Tololo
Credit: Roger Smith/NOAO/AURA/NSF


El Premio Nobel de Física del año 2011, fue logrado con observaciones hechas, en su primera etapa, con este instrumento de 4 CCD con el cual se descubrió la "Expansión Acelerada del Universo". Esta "Cámara de Alto Rendimiento" se usó en el telescopio Víctor Blanco, cuyo espejo principal (lente) mide 4 metros de diámetro y se encuentra ubicado en la cima de Cerro Tololo, frente a la ciudad de Vicuña.
17) Big Throughput Camera (BTC): "Cámara de Alto Rendimiento". Es el primer sistema de detectores que utiliza 4 CCDs simultáneos para fotografiar el cielo. Fue instalado en el Telescopio 4m Blanco en el año 1996 y es el precursor de otro de 8 CCDs. En la actualidad, en el telescopio 4-m Blanco, está la cámara de Energía Oscura con 62 CCDs simultáneos. Estos instrumentos de 8 CCDs pasaron a llamarse "Mosaicos".

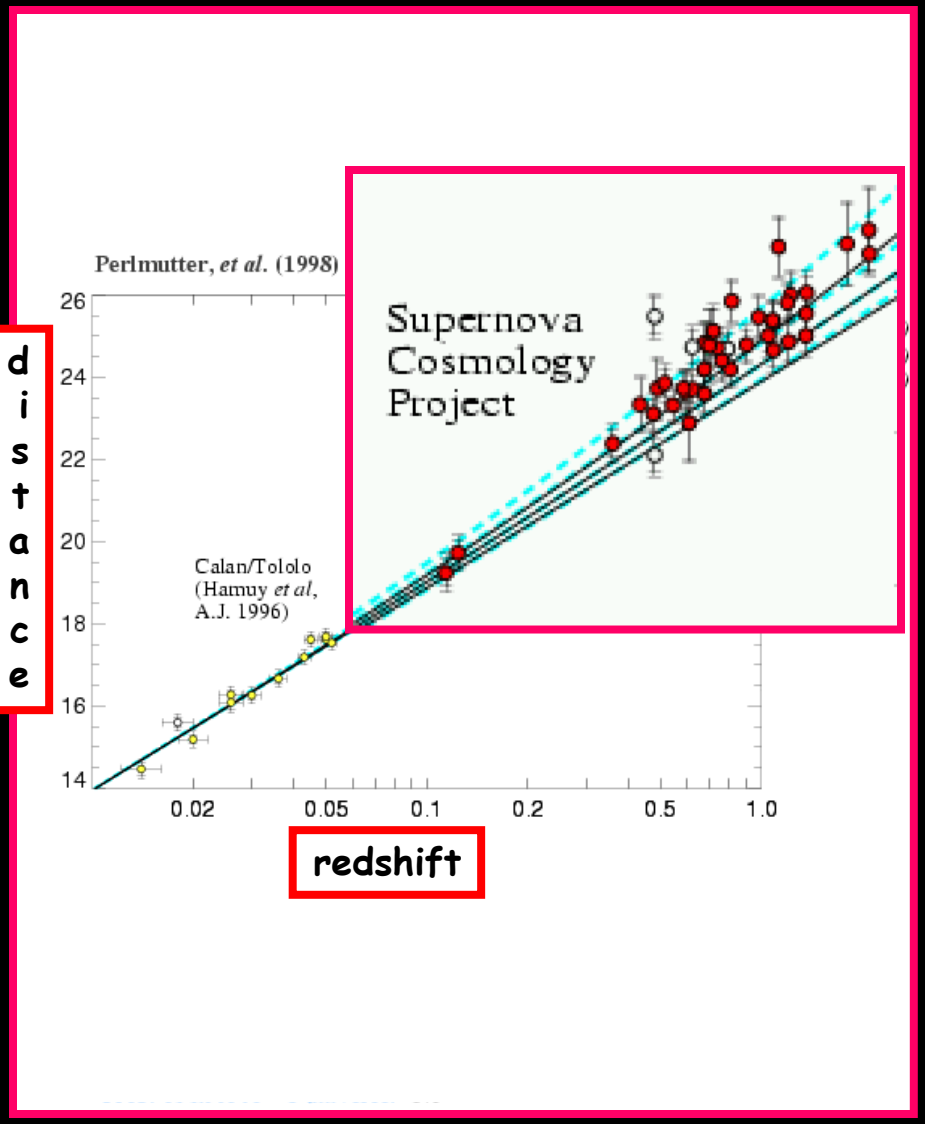
Search for distant supernovae

Supernova Cosmology Project (1988)
High-Z Supernova Team (1994)



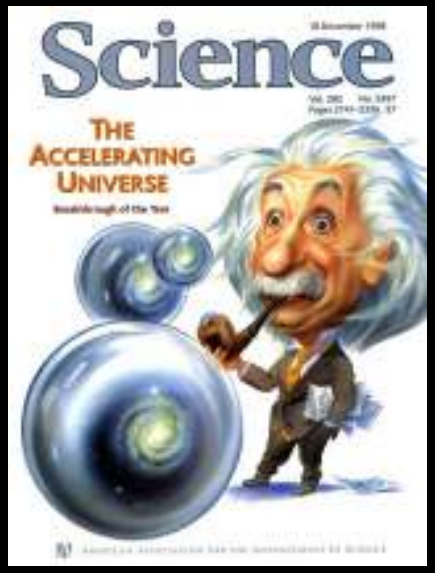


Precision Cosmology from Type Ia supernovae

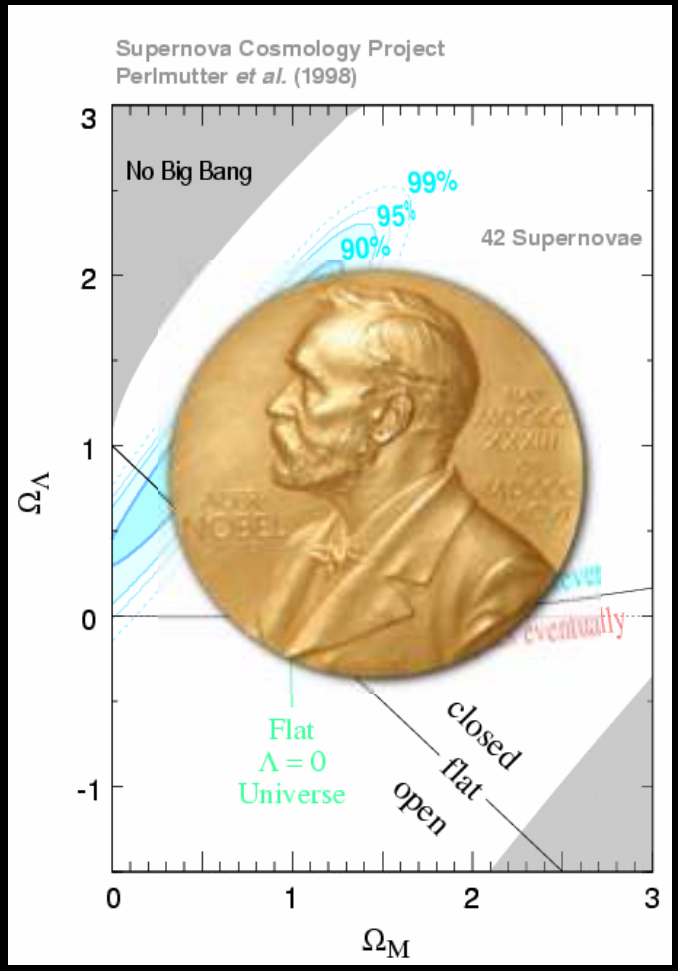


The Universe is accelerating!

Independently confirmed by two groups:
Riess, Schmidt, Clocchiatti, Leibundgut et al. 1998
Perlmutter et al. 1999

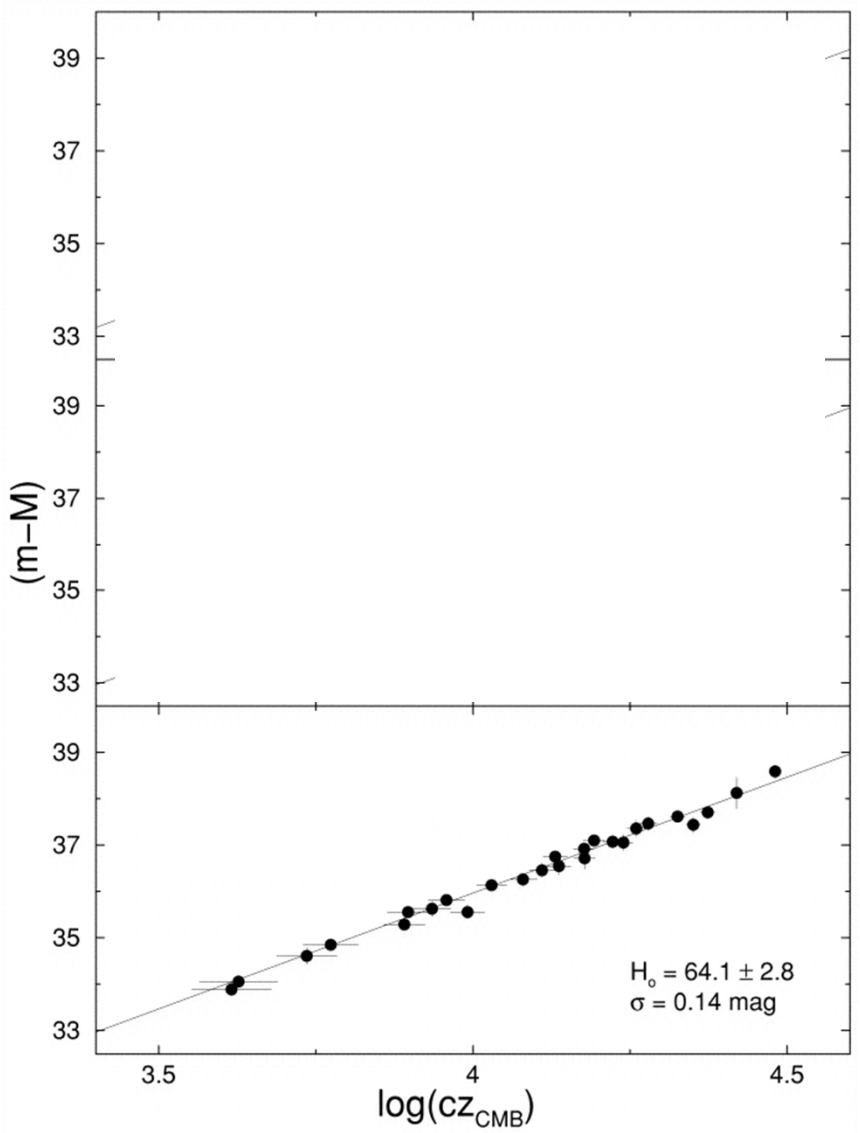


Cosmological Parameters (1998-1999)



Initially: acceleration modeled with Einstein´s cosmological constant

Two key results in cosmology from Calán/Tololo: (1) the Hubble constant



$m = 5 \log (cz) + (M - 5 \log H_0 + 25)$

$ZP = M - 5 \log H_0 + 25$

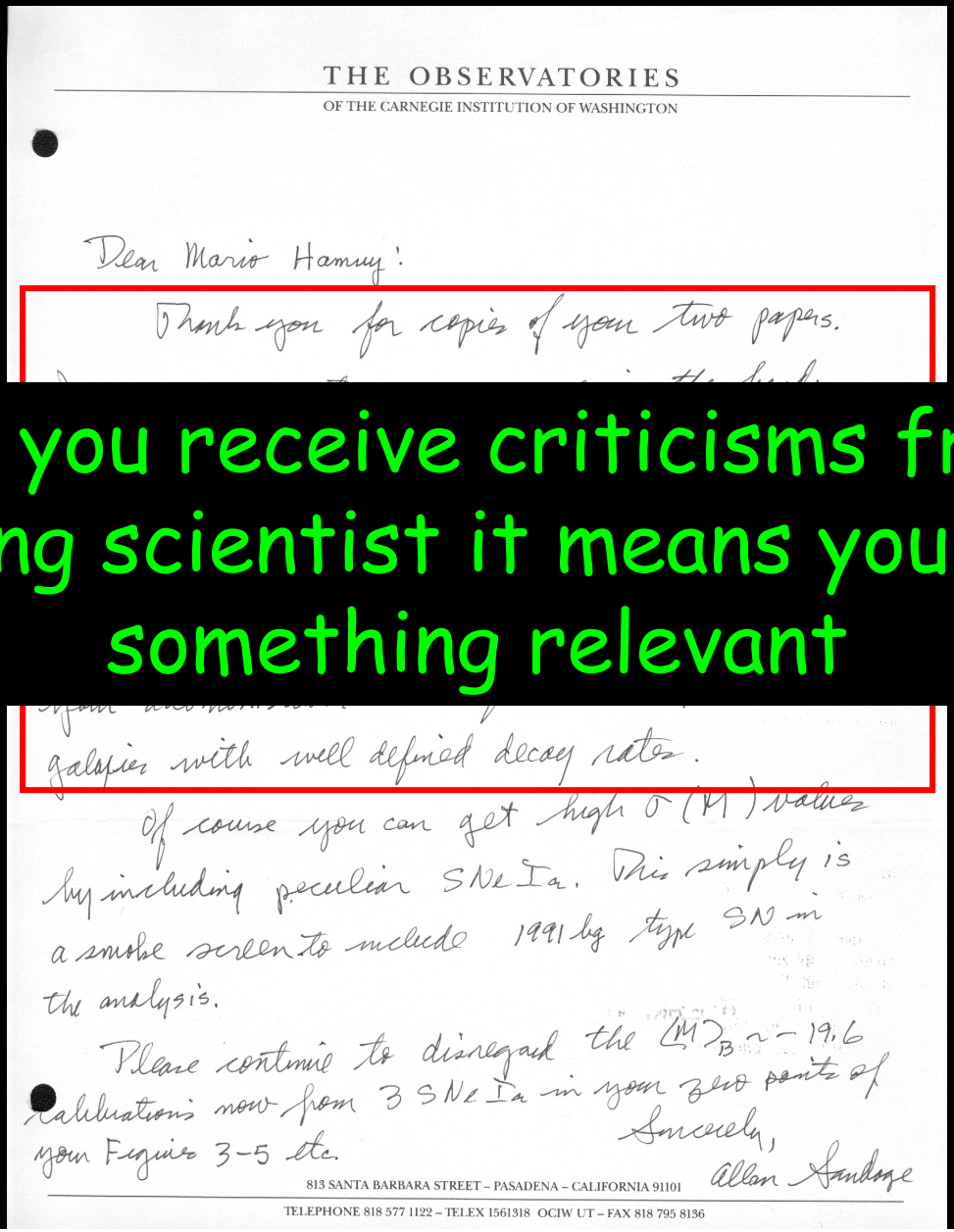
$\log H_0 = 0.2 \times (M + 25 - ZP)$

H_0 = 63-72 km/s/Mpc
(Sandage et al., Freedman et al)

Half of the data from HST data

Half of the data from supernovae in the Hubble flow

The Intrigue on the Hubble Constant



THE OBSERVATORIES
OF THE CARNEGIE INSTITUTION OF WASHINGTON

Dear Mario Hamuy:

Thank you for copies of your two papers.

galaxies with well defined decay rates.

Of course you can get high $\sigma(M)$ values by including peculiar SNe Ia. This simply is a smoke screen to include 1991bg type SN in the analysis.

Please continue to disregard the $\langle M \rangle_B \sim -19.6$ calculations now from 3 SNe Ia in your zero points of your Figures 3-5 etc.

Sincerely,
Allan Sandage

813 SANTA BARBARA STREET – PASADENA – CALIFORNIA 91101
TELEPHONE 818 577 1122 – TELEX 1561318 OCIW UT – FAX 818 795 8136

M3:If you receive criticisms from an outstanding scientist it means you are doing something relevant

Two key results in cosmology from Calán/Tololo: (2) the deceleration parameter

The discovery of the accelerating Universe was a differential measurement comparing low-z and high-z supernovae

The Calán/Tololo data represent half of the measurements

The key role of CTIO in supernova science

The Tololo Nearby Supernova Program (Phillips, Suntzeff, et al) :	1986-2000?
The Calán/Tololo Program (Hamuy et al) :	1989-1993
The Supernova Cosmology Project (Perlmutter et al): Blanco 4m, BTC	1992-1999
The High_Z Team (Schmidt, Suntzeff et al): Blanco 4m, BTC	1994-1998
ESSENCE (Suntzeff et al): Blanco 4m, MOSAIC II	2002-2005
Dark Energy Survey (DES, Friemann et al): Blanco, 4m, DECam	2012-2016
LSST	2022-2032


VLT
ALMA

FEDERICO RUTLLANT
Logro gran cosecha tras viaje a USA.


Courtesy of Kathy

Cerro Tololo Inter-American Observatory (est. 1962)

Association of Universities for Research in Astronomy