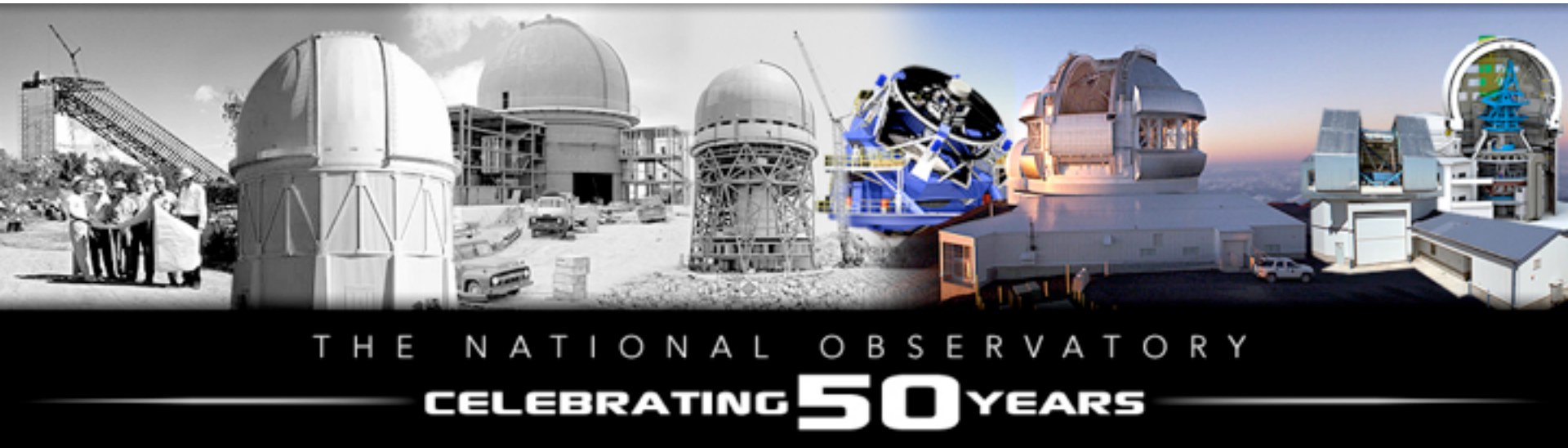
The Calán/Tololo Supernova Survey

Mark M. Phillips

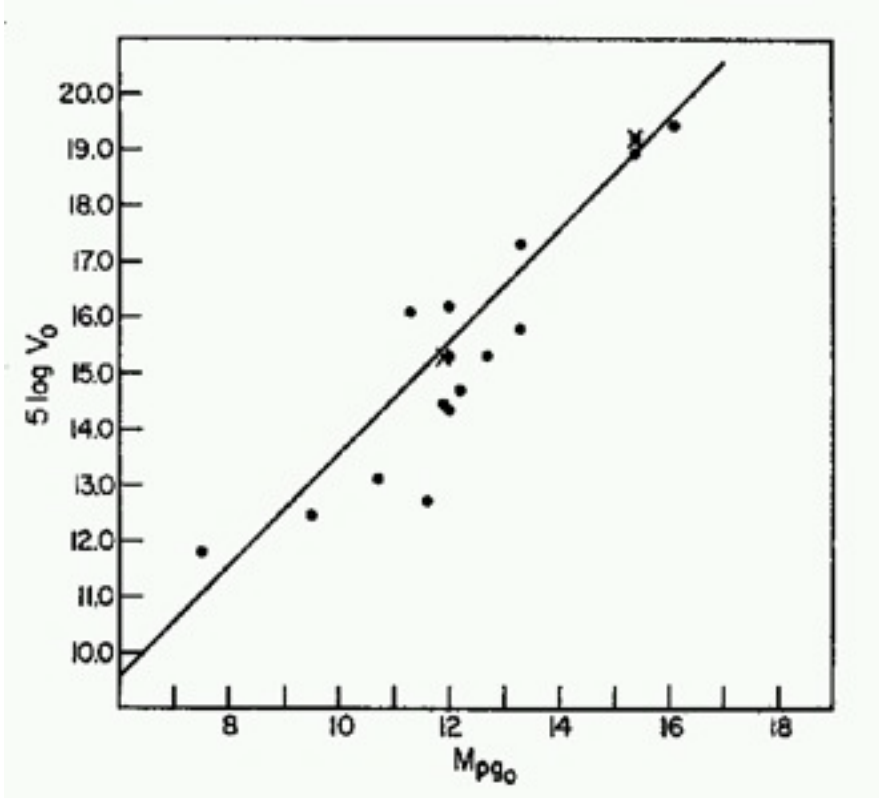
Carnegie Observatories



Type Ia Supernovae (SNe Ia) as Cosmological Standard Candles

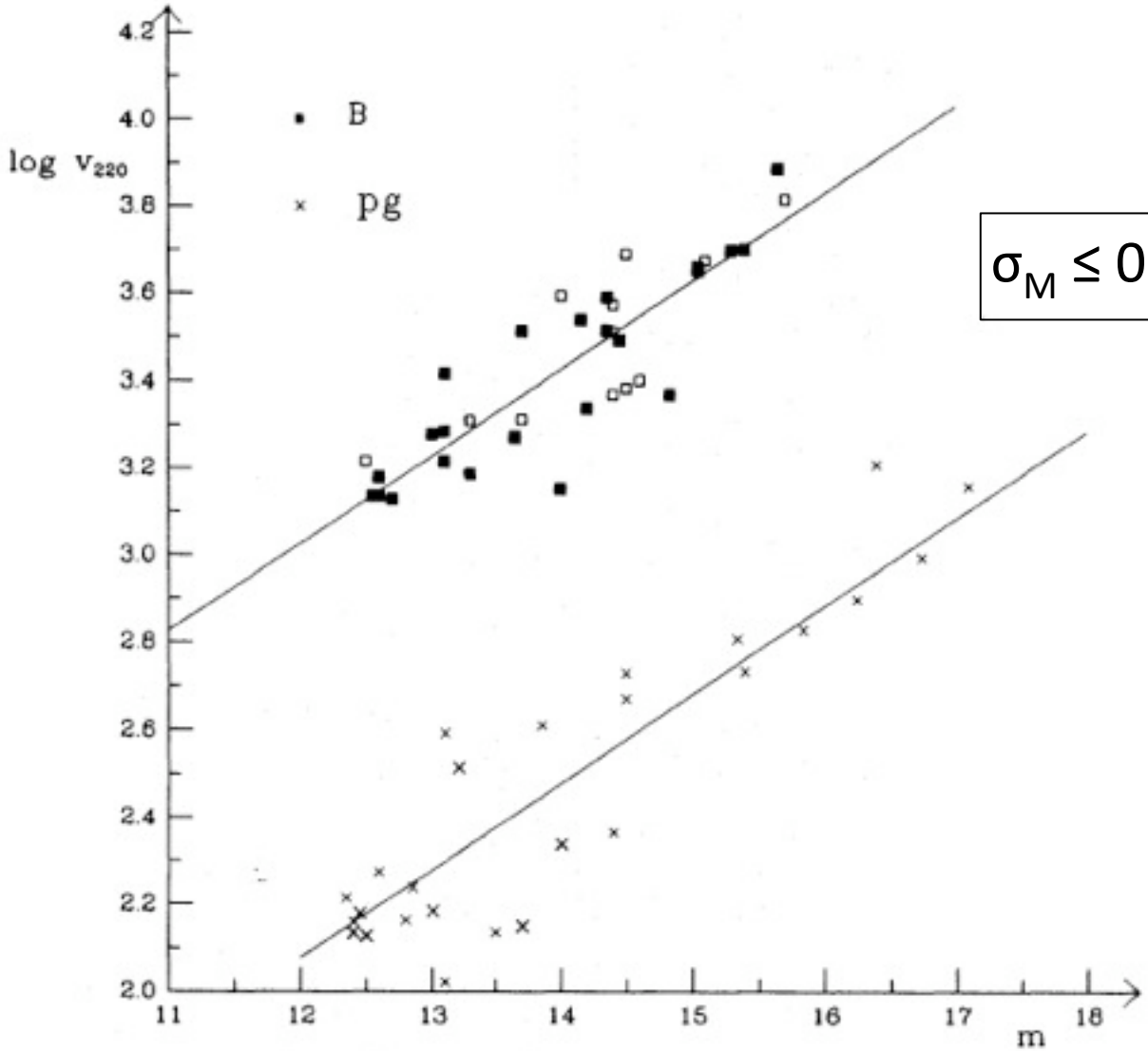
- Since the 1960s, the light curves of SNe were known to be remarkably homogenous

- In 1968, Kowal published a Hubble diagram for 22 SNe Ia with a dispersion of 0.6 mag, demonstrating the potential utility of these events as cosmological standard candles



Kowal (1968)

Hubble Diagram of SNe Ia Circa 1990



$\sigma_M \leq 0.25$ mag

Tammann & Leibundgut (1990)

Typical Light Curves

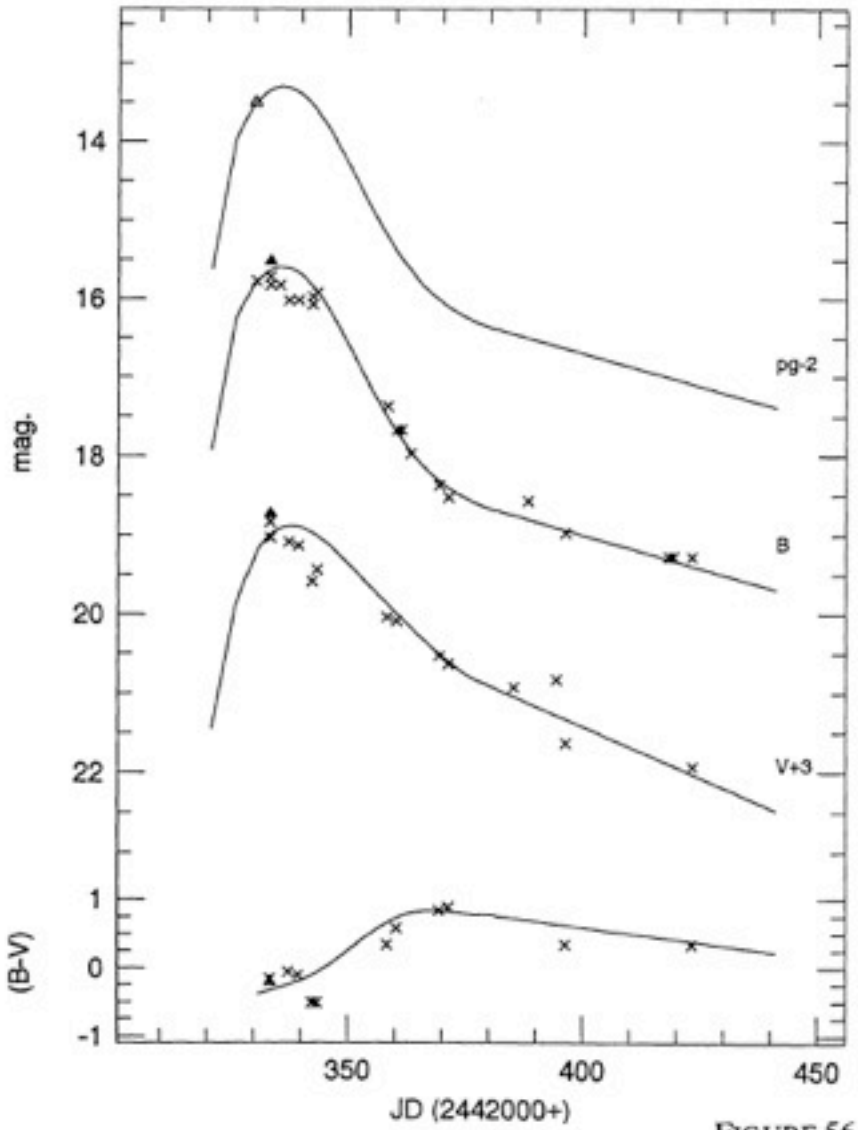


FIGURE 56.

SN 1974J

NGC 7343

b = -21.2

$A_{pg} = 0.23$, $A_B = 0.23$, $A_V = 0.17$

△ Rosino, L.: 1974, IAU Circ. No. 2707
pg

▲ Bianchini, A., Ciatti, F., Rosino, L.: IAU Circ. No. 2714
B, V, (B-V)

× Ciatti, F., Rosino, L.: 1977, Astron.Astrophys. 57, 73
B, V, (B-V)

Date of maximum (JD): 2442336

pg at maximum: 15.3

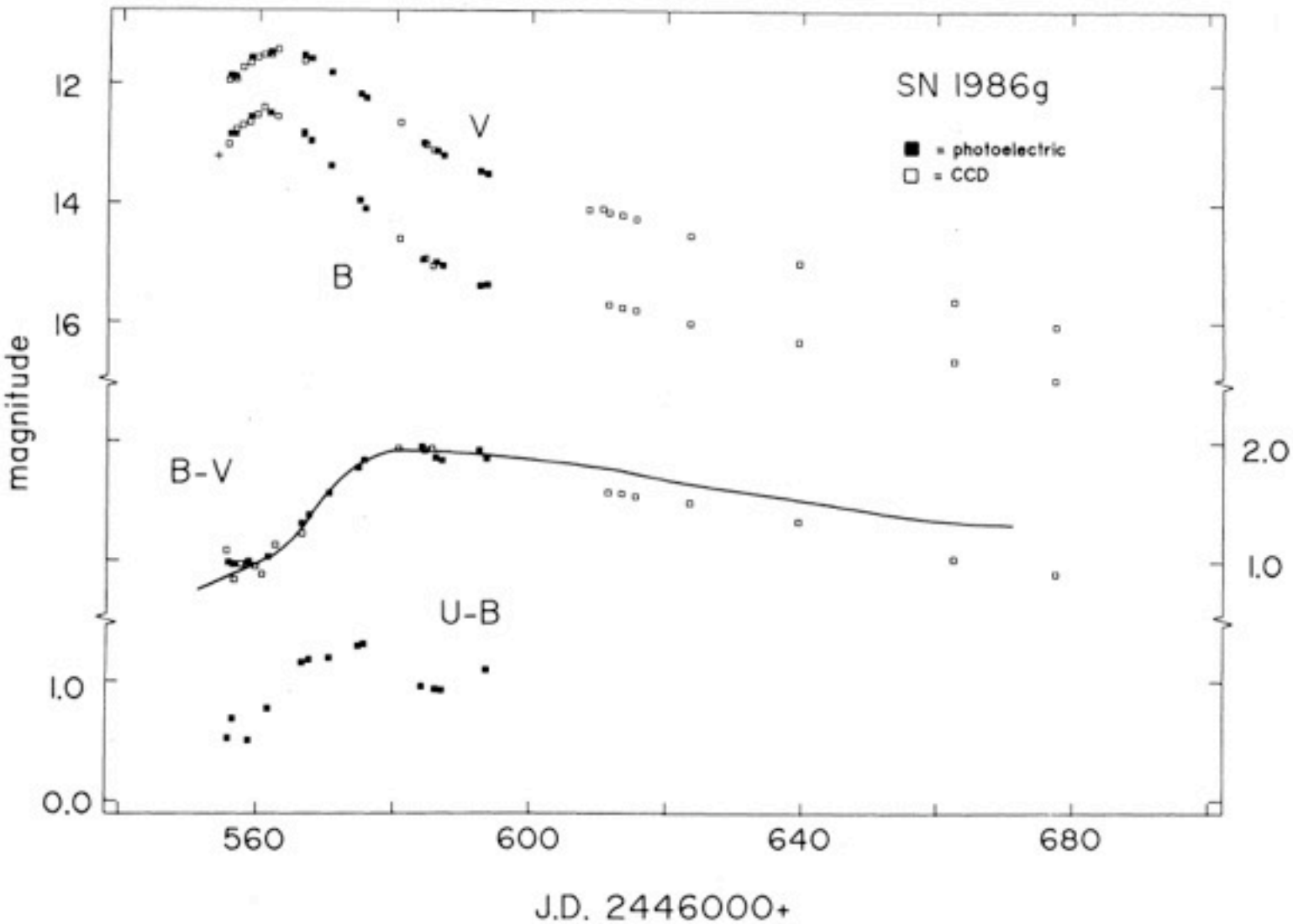
B at maximum: 15.6

V at maximum: 15.9

(B-V) at maximum: -0.28

Leibundgut et al. (1991)

The Impact of CCDs



Phillips et al. (1987)

The Calán/Tololo Supernova Survey

ABSTRACT

We have started a search for supernovae as a collaboration between the University of Chile and the Cerro Tololo Inter-American Observatory, with the aim of producing a moderately distant ($0.01 < z < 0.10$) sample of Type Ia and Type II supernovae suitable for cosmological studies. The project began in mid-1990 and continues to the present. This paper reports on the Calán/Tololo discoveries in the course of 1990, and on the spectroscopic and photometric observations gathered for these objects. All of these observations were obtained with CCDs, with the extensive collaboration of visiting astronomers. Great care was exercised in the reduction of the light curves in order to properly correct for the background light of the host galaxy of each supernova. Of the four supernovae found in 1990, one proved to be a SN II-n; the remaining three were members of the Type Ia class at redshifts that ranged between $z=0.04$–0.05. One of the Type Ia events, SN 1990af, was found in the elusive premaximum phase at a redshift of $z=0.0503$, and was observed through maximum light. Peak magnitudes for the other two SNe Ia, which were not observed at maximum light, were derived using a χ^2 minimization technique to fit the data with various template curves that represent a broad range of SNe Ia light curves. In future papers we will make use of these estimates in order to discuss the Hubble diagram of SNe Ia.

Hamuy et al. (1993)

The Calán/Tololo SN Survey Objectives

- Produce a sample of moderately distant ($0.01 < z < 0.1$) SNe suitable for cosmological study
- Determine the intrinsic dispersion of SN Ia absolute magnitudes at maximum light
- Produce a Hubble diagram based on SNe Ia observed entirely with CCDs

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José Maza

Nick Suntzeff

“El Diablo”

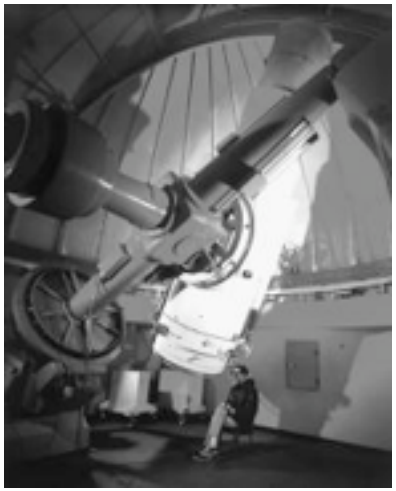
Bob Schommer

Luis Gonzalez

Chris Smith

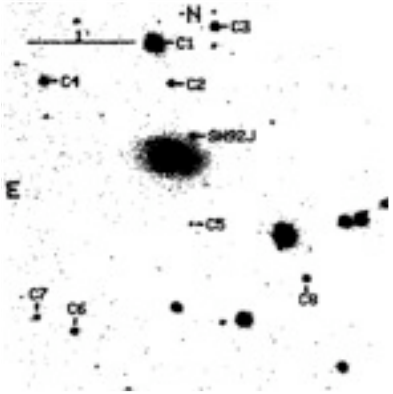
Roberto Antezana

The Calán/Tololo SN Survey: Methodology



• Observe ~25 fields (5°x5° each) photographically with the Curtis Schmidt telescope twice per month in order to improve the chances of catching SNe Ia on the rise.

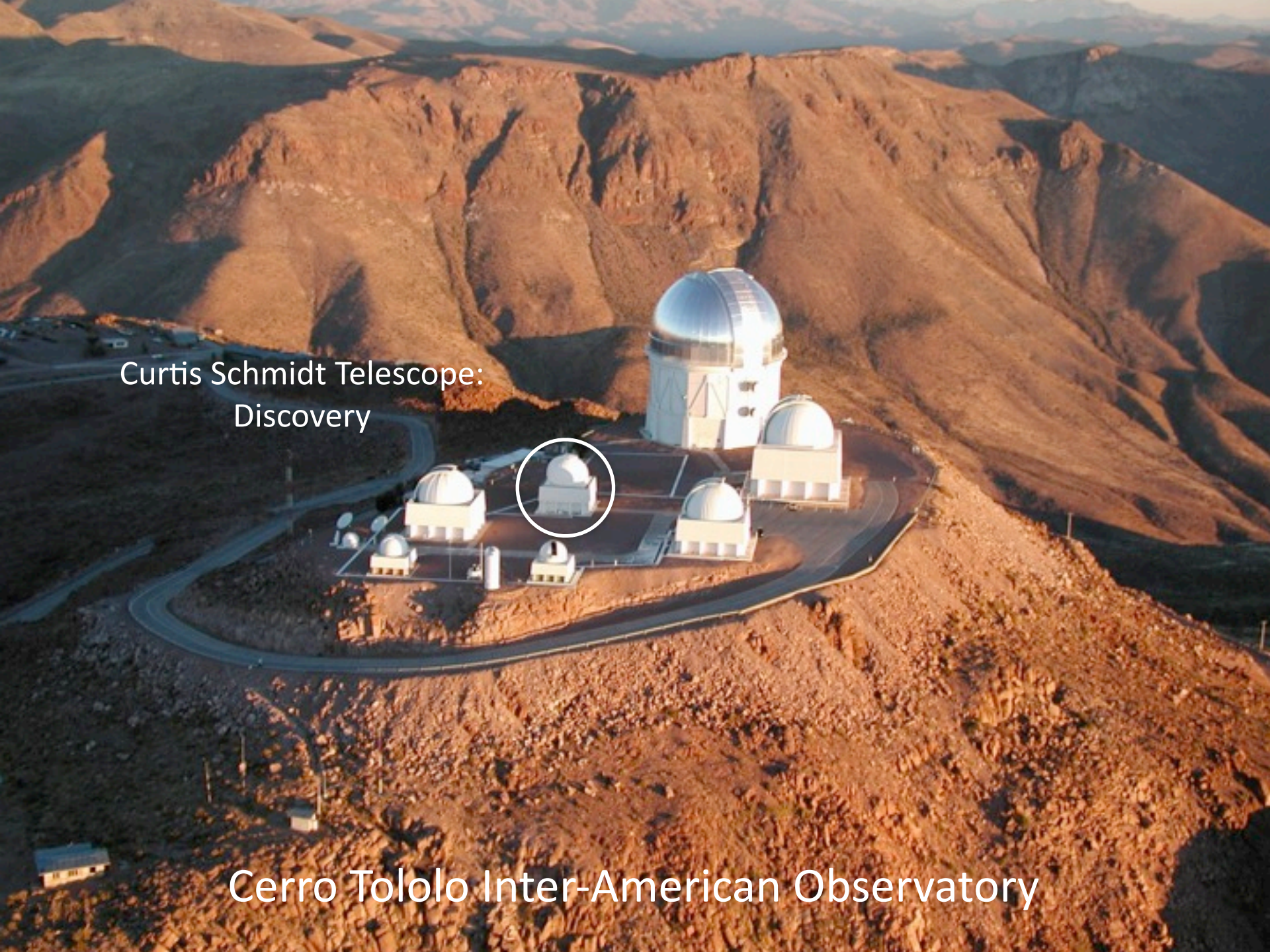
• Send the plates by bus to Cerro Calán in Santiago where they were blinked to find candidate SNe

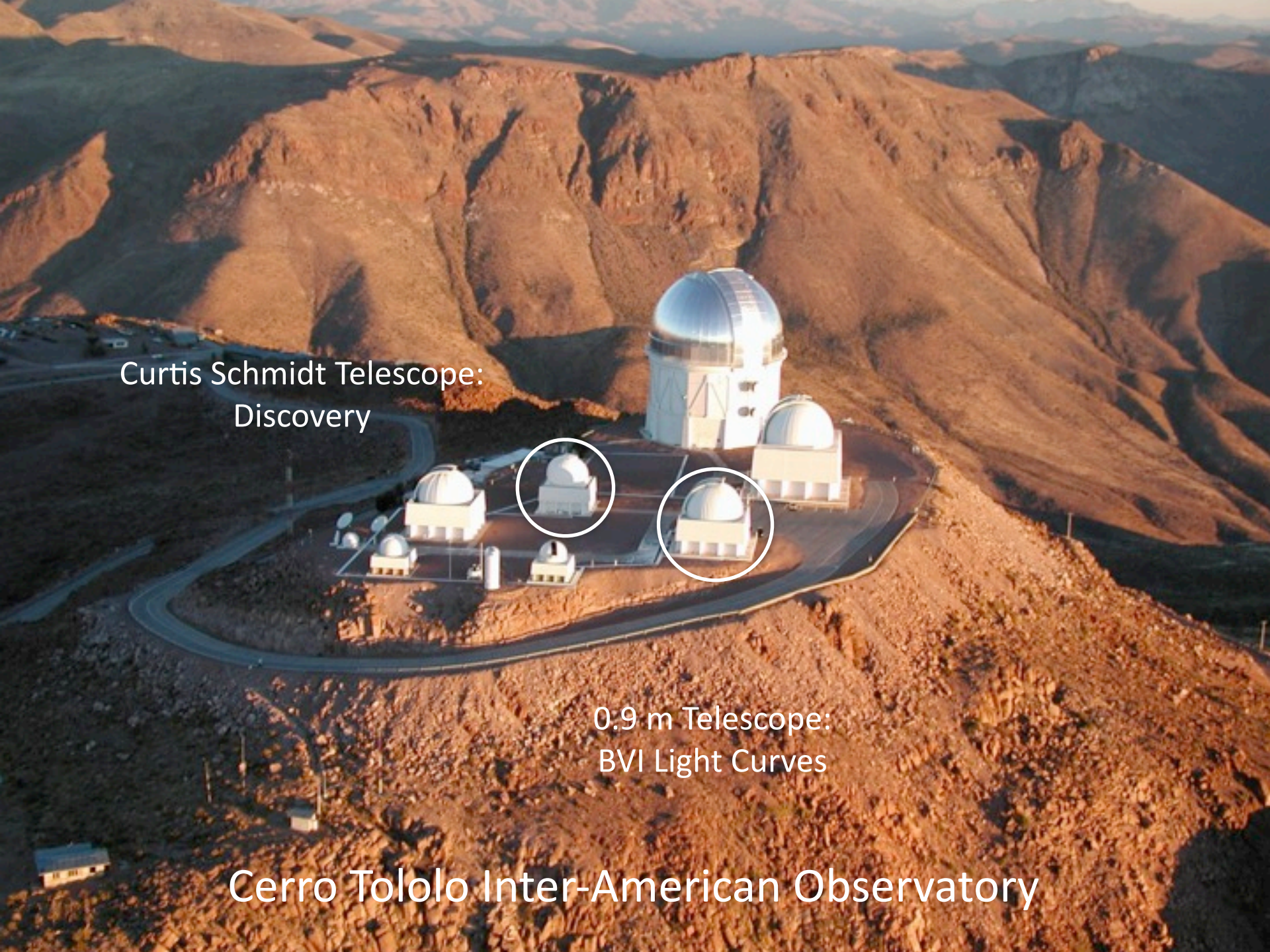


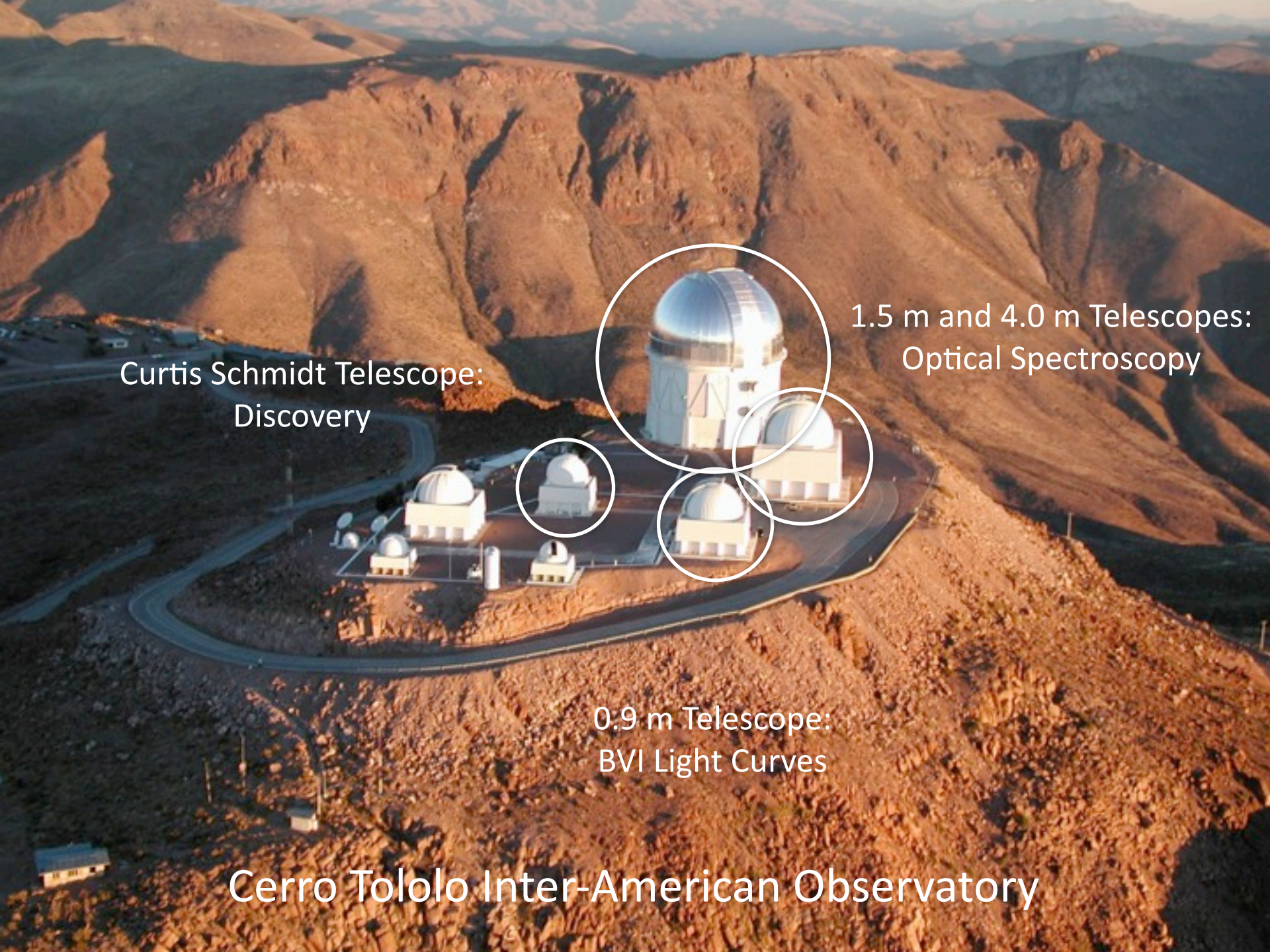
• Schedule nights on the 0.9 m for follow-up CCD imaging in BVI

• Use the 1.5 m and 4.0 m telescopes to obtain classification spectra

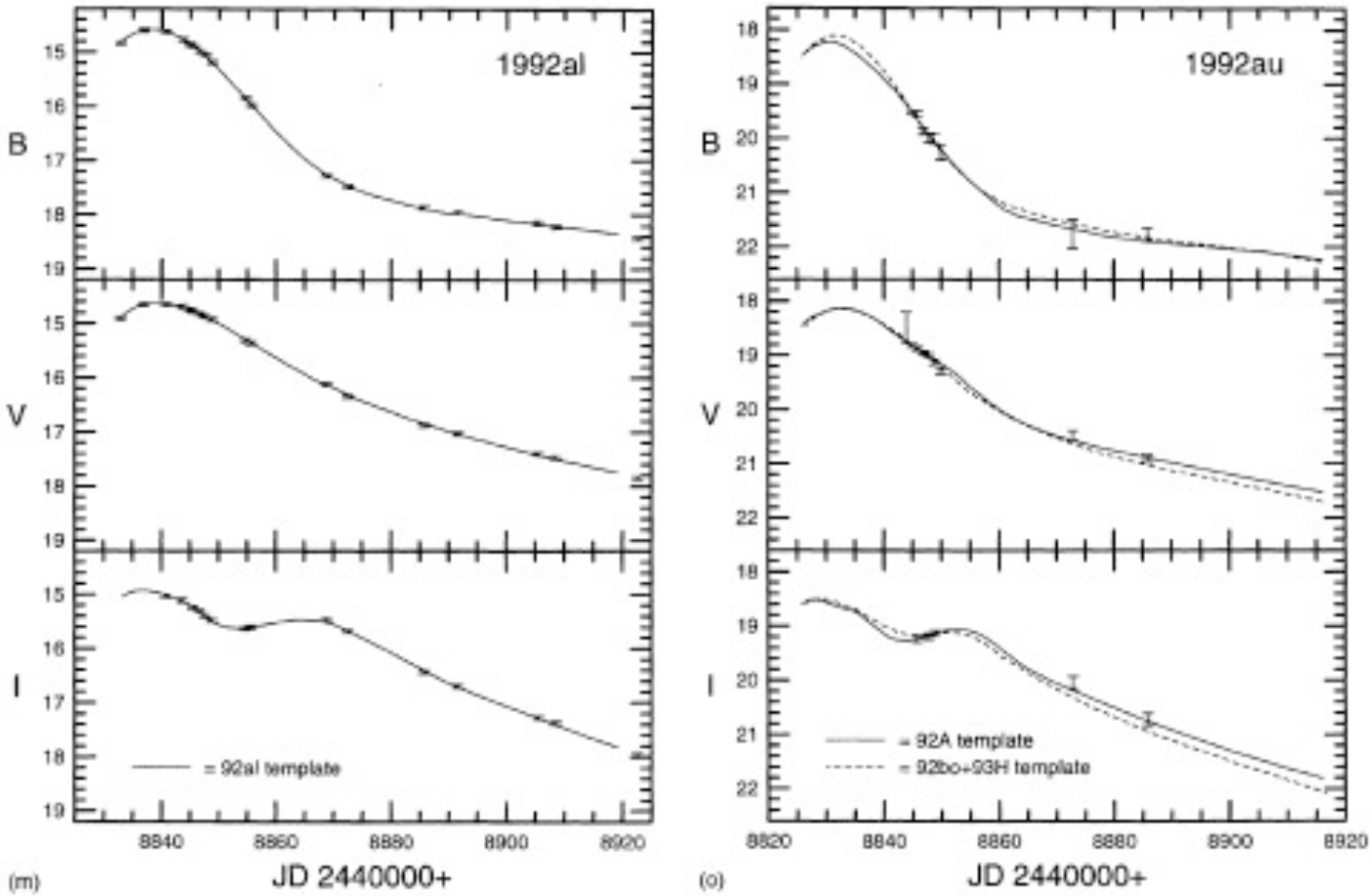

Cerro Tololo Inter-American Observatory


Curtis Schmidt Telescope:
Discovery
Cerro Tololo Inter-American Observatory


Curtis Schmidt Telescope:
Discovery
0.9 m Telescope:
BVI Light Curves
Cerro Tololo Inter-American Observatory


1.5 m and 4.0 m Telescopes:
Optical Spectroscopy
Curtis Schmidt Telescope:
Discovery
0.9 m Telescope:
BVI Light Curves
Cerro Tololo Inter-American Observatory

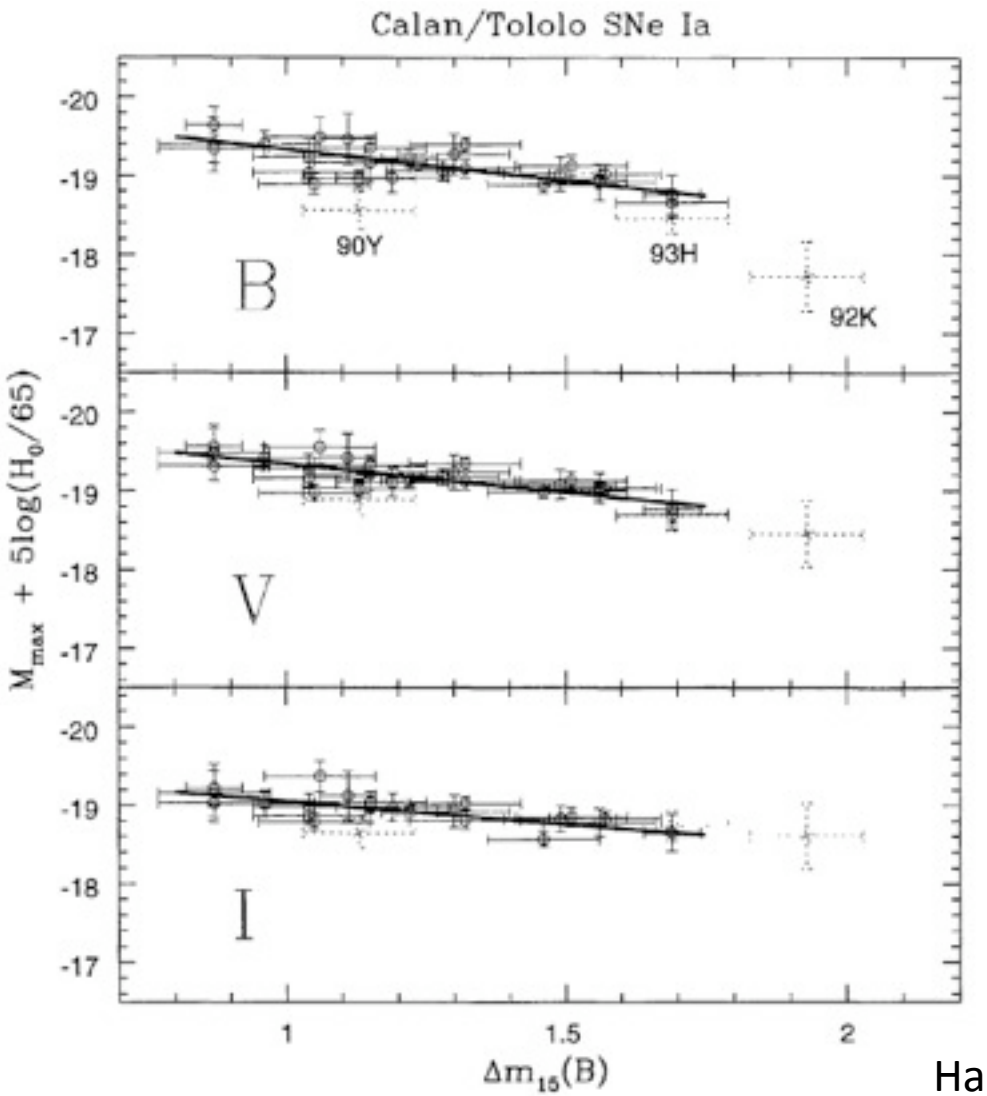
The Calán/Tololo Supernova Survey Sample Light Curves



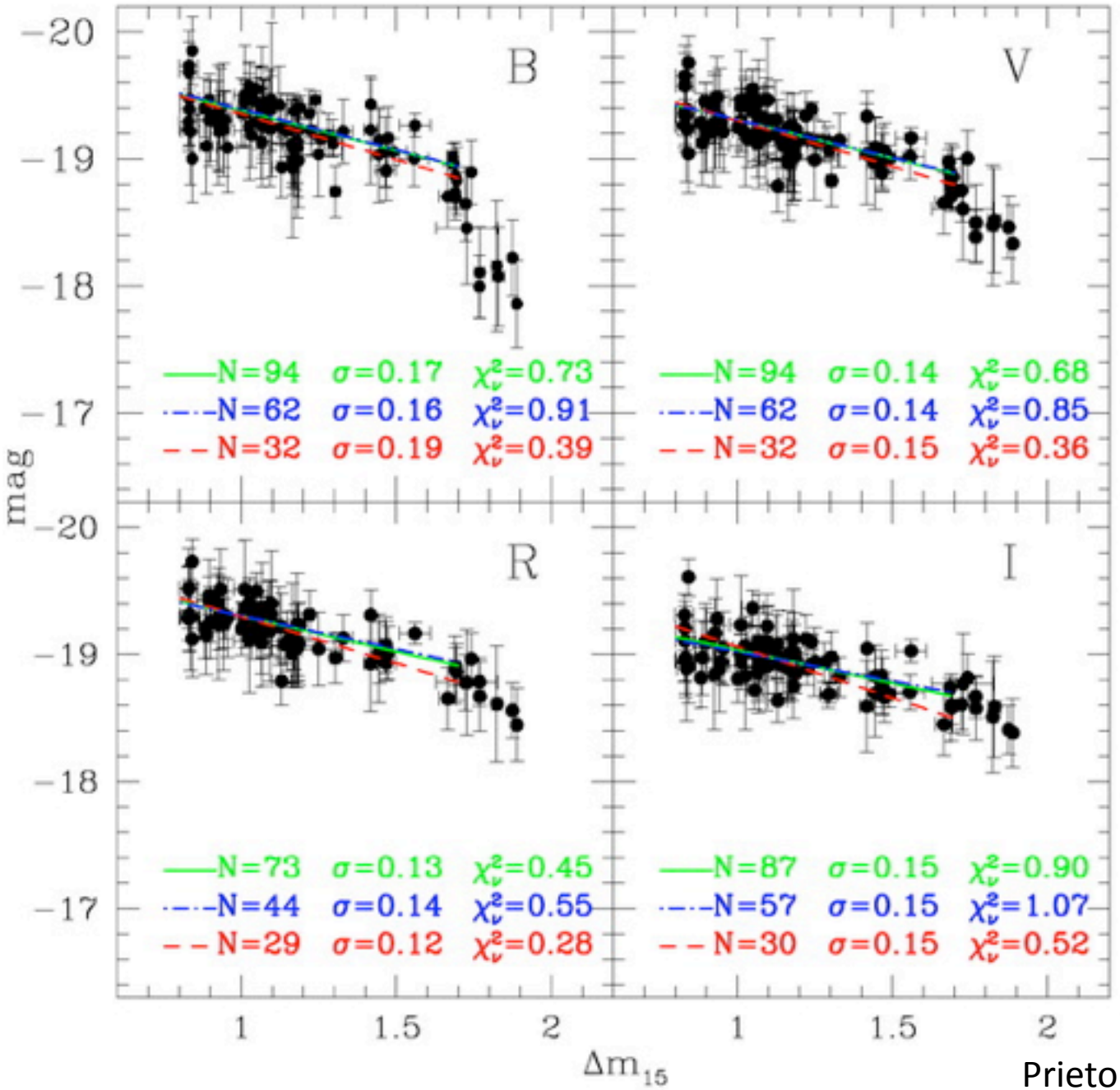
Hamuy et al. (1996c)

The Calán/Tololo SN Survey Results:

Confirmation of the Luminosity-Decline Rate Relation



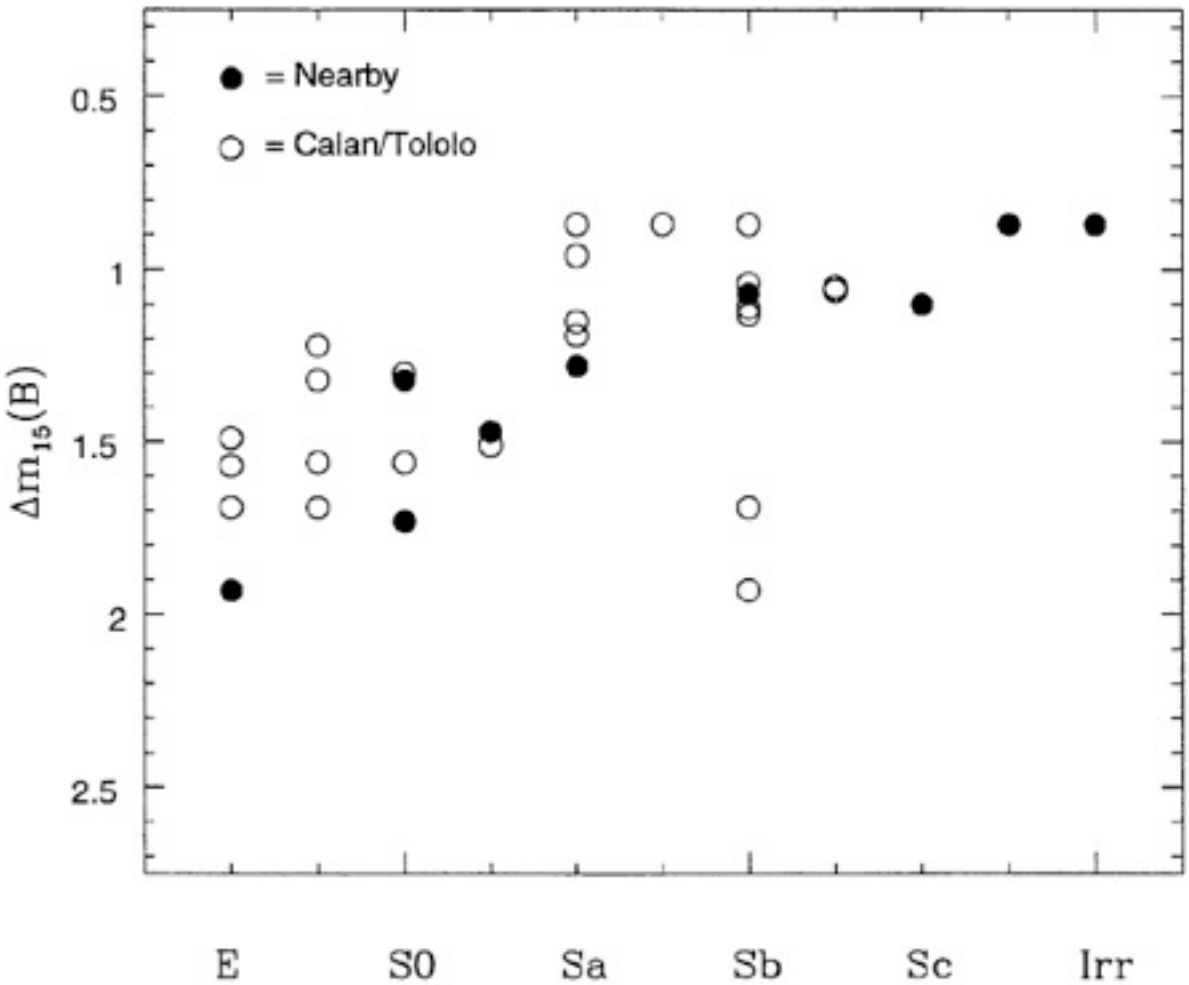
Hamuy et al. (1996a)



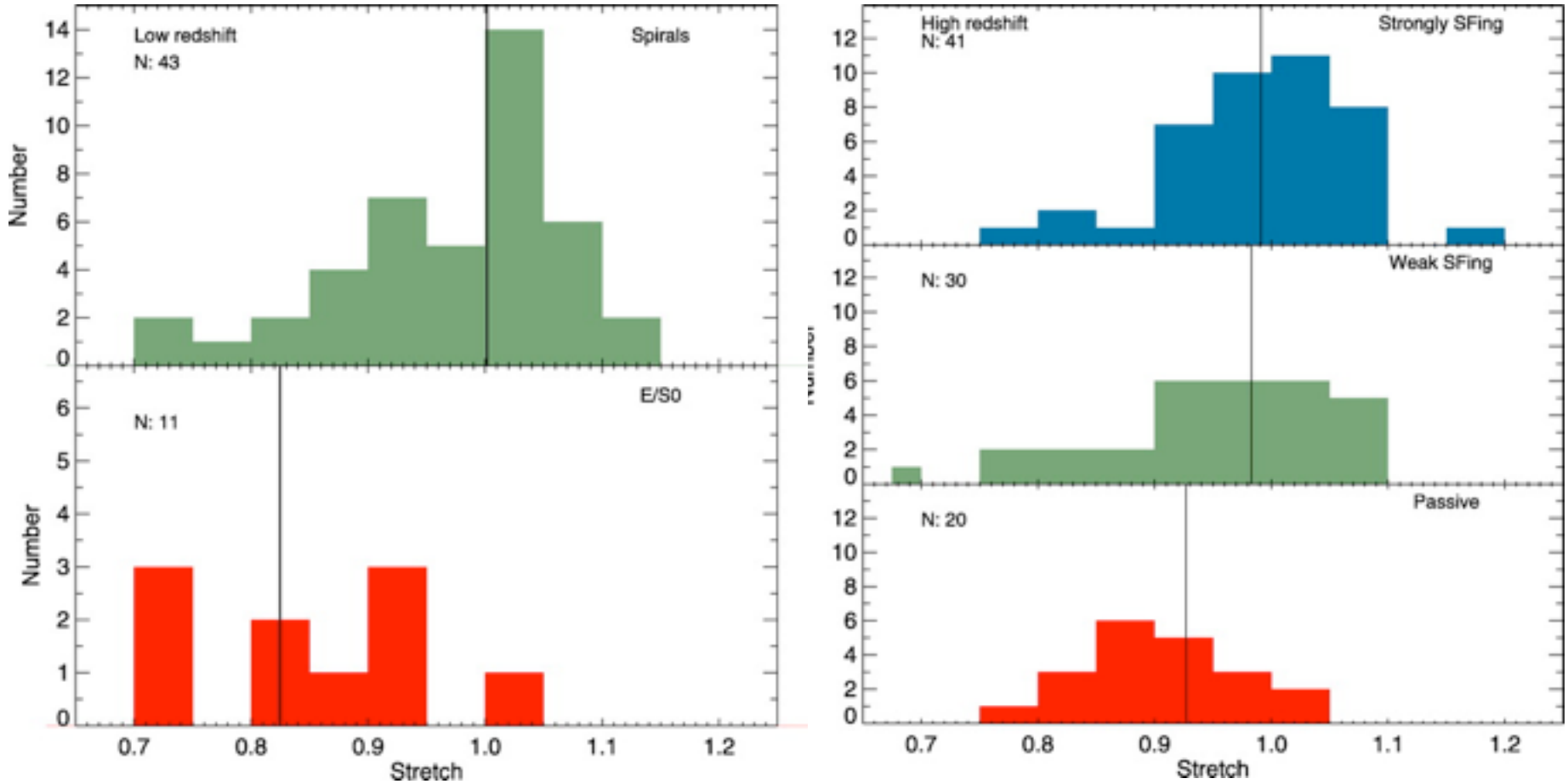
Prieto et al. (2006)

The Calán/Tololo SN Survey Results:

Discovery of the Galaxy Morphology-Decline Rate Dependence



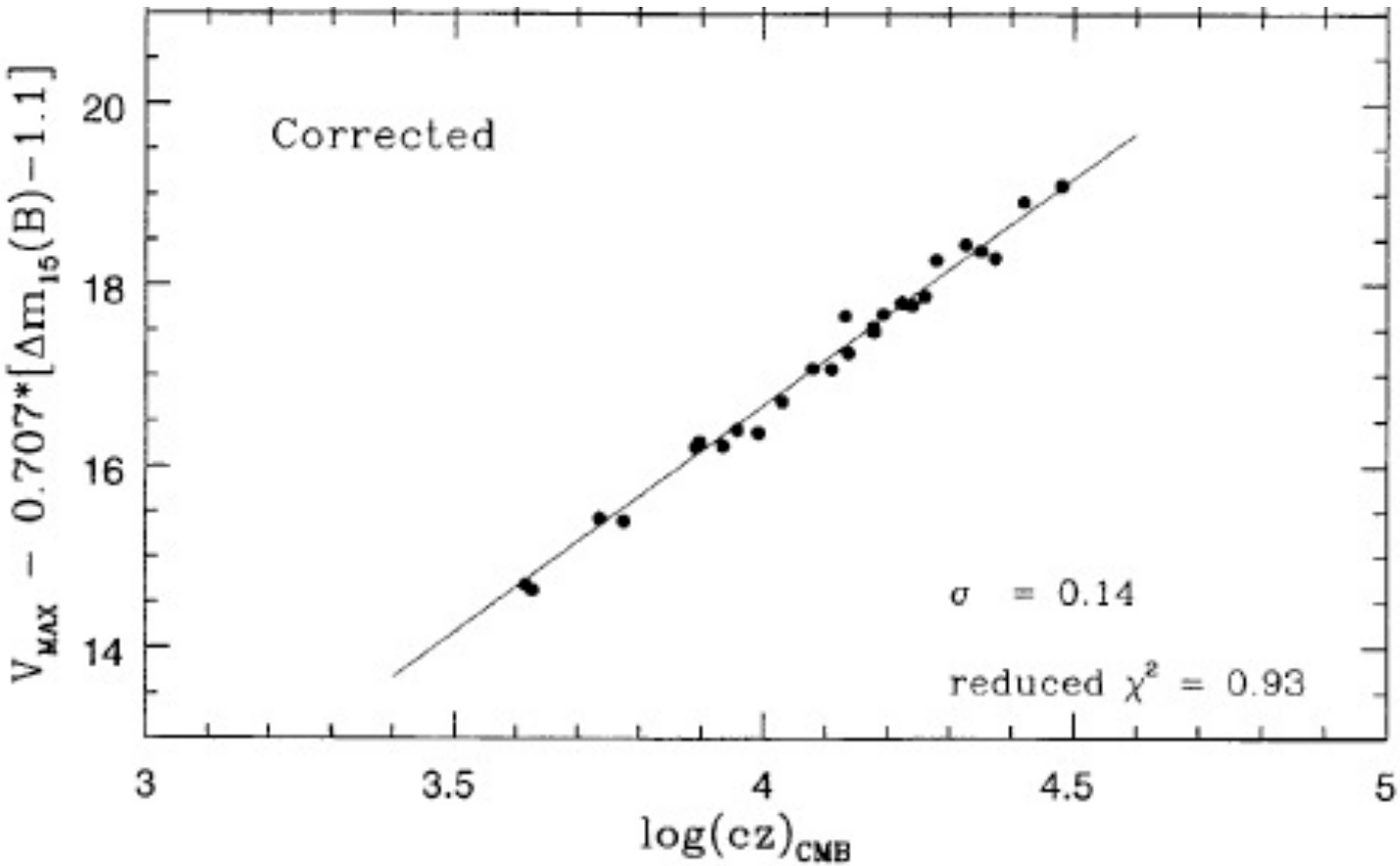
Hamuy et al. (1996a)



Sullivan et al. (2006)

The Calán/Tololo SN Survey Results:

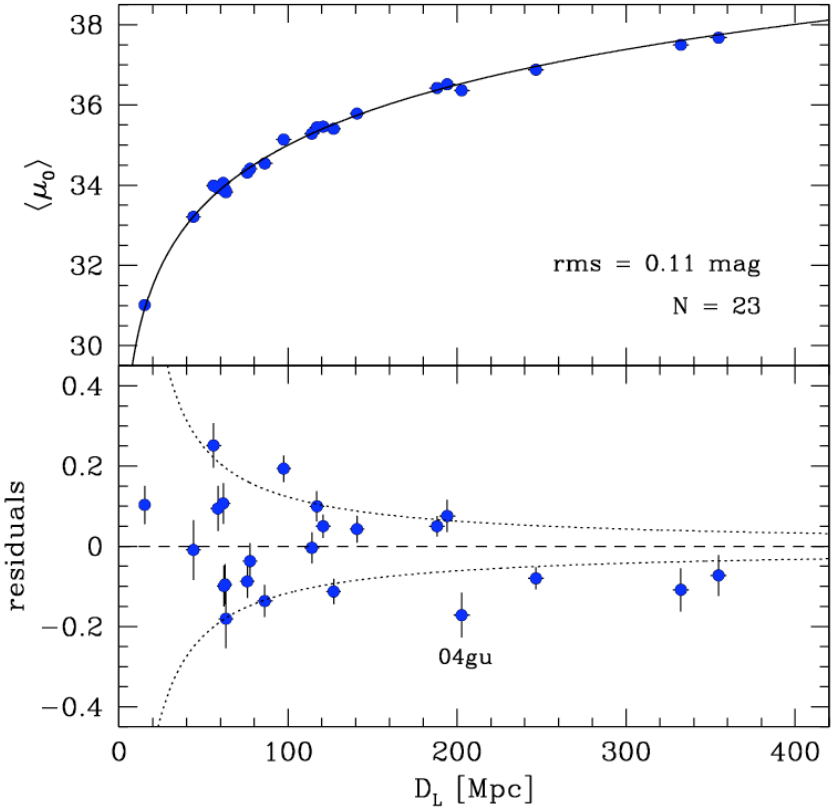
Hubble Diagram

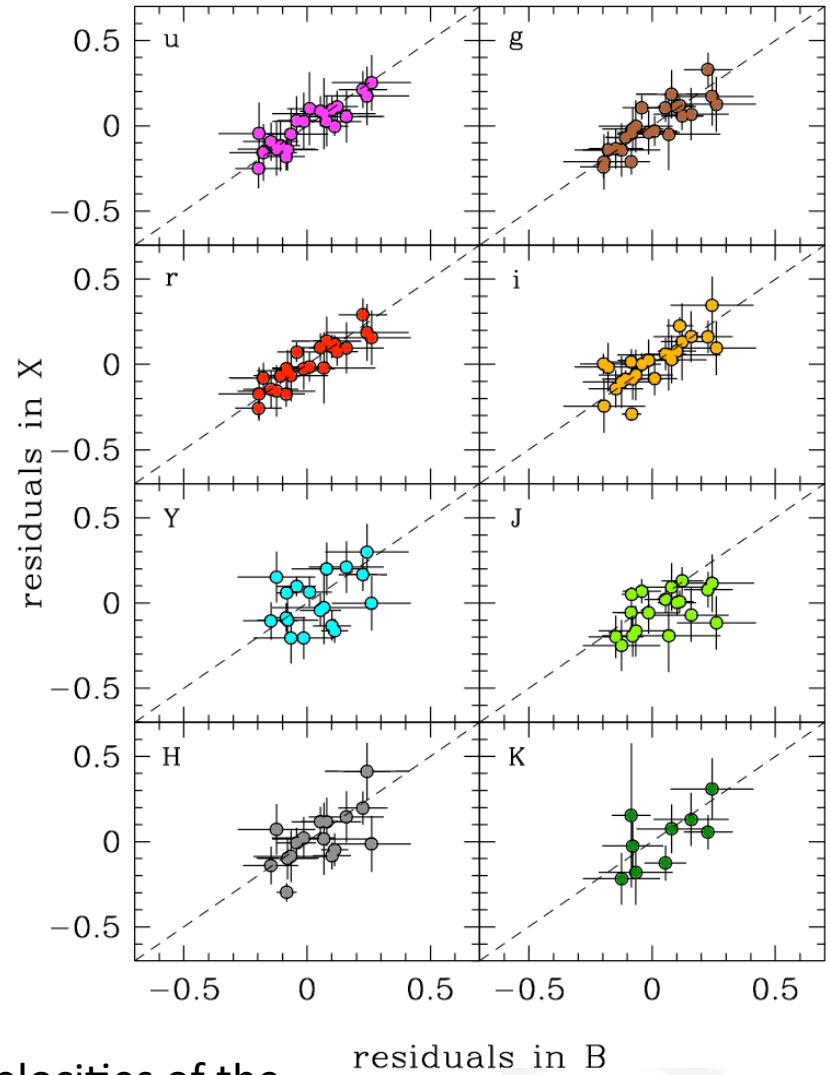


SNe Ia can be used to derive distances to 7-10% precision

Hamuy et al. (1996b)

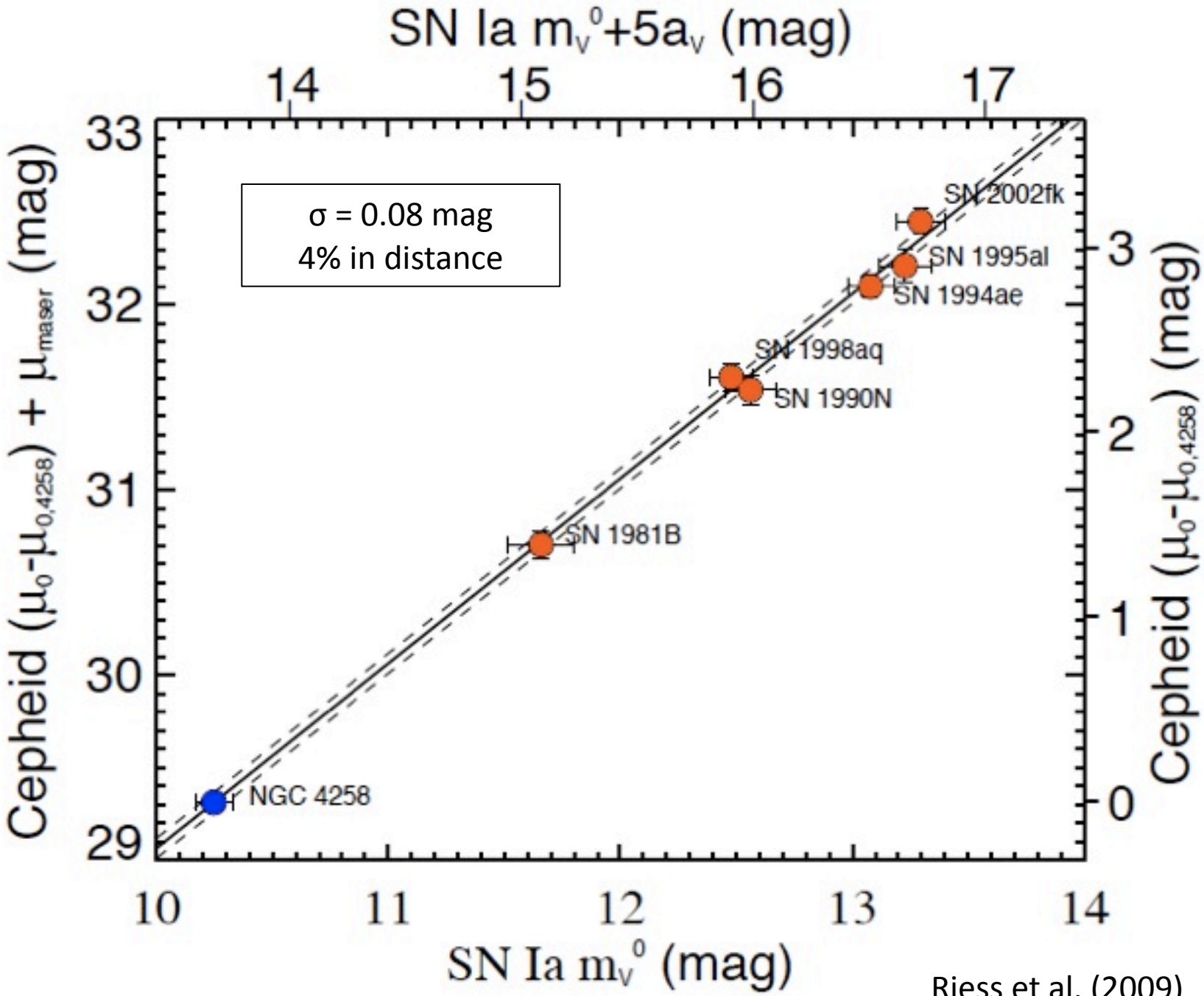
The Carnegie Supernova Project (CSP)





- Scatter of 0.11 mag is limited by the peculiar velocities of the host galaxies as evidenced by strong correlation between the distance modulus residuals observed in the individual filters.
- The implication is that the actual precision of Type Ia supernovae distances is 3–4%.

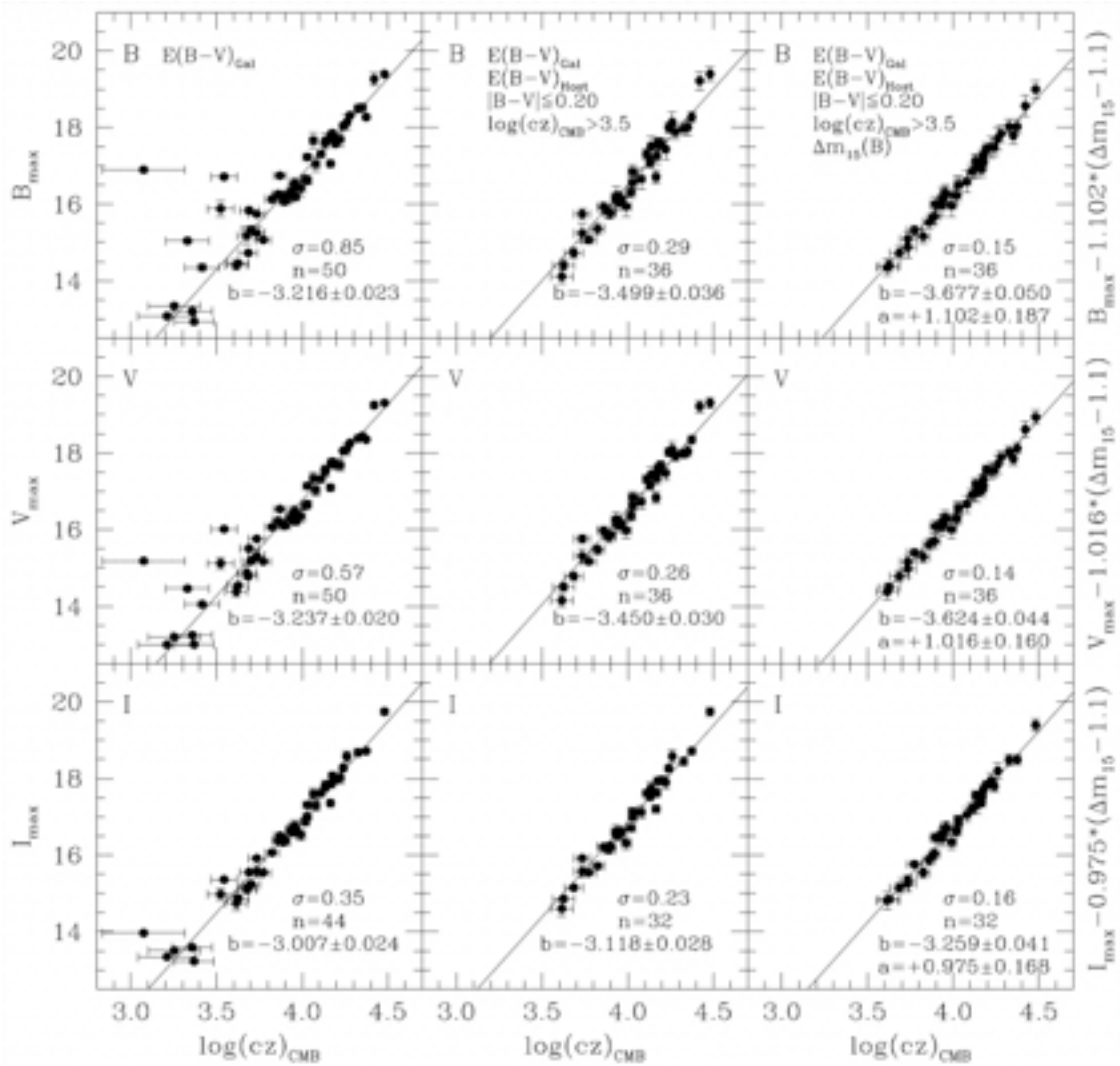
Folatelli et al. (2010)



Riess et al. (2009)

The Calán/Tololo SN Survey Impact:

The Hubble Constant

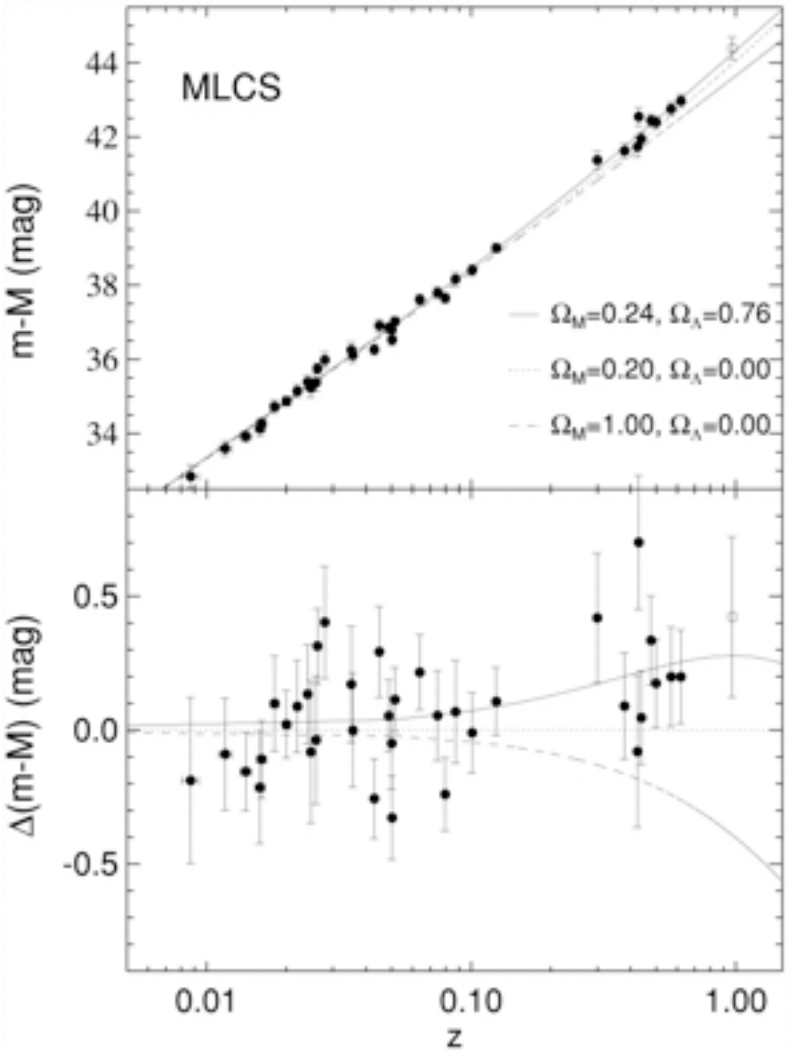


28 of the 36 SNe Ia used by the HST Key Project to measure the Hubble constant were drawn from the Calán/ Tololo survey

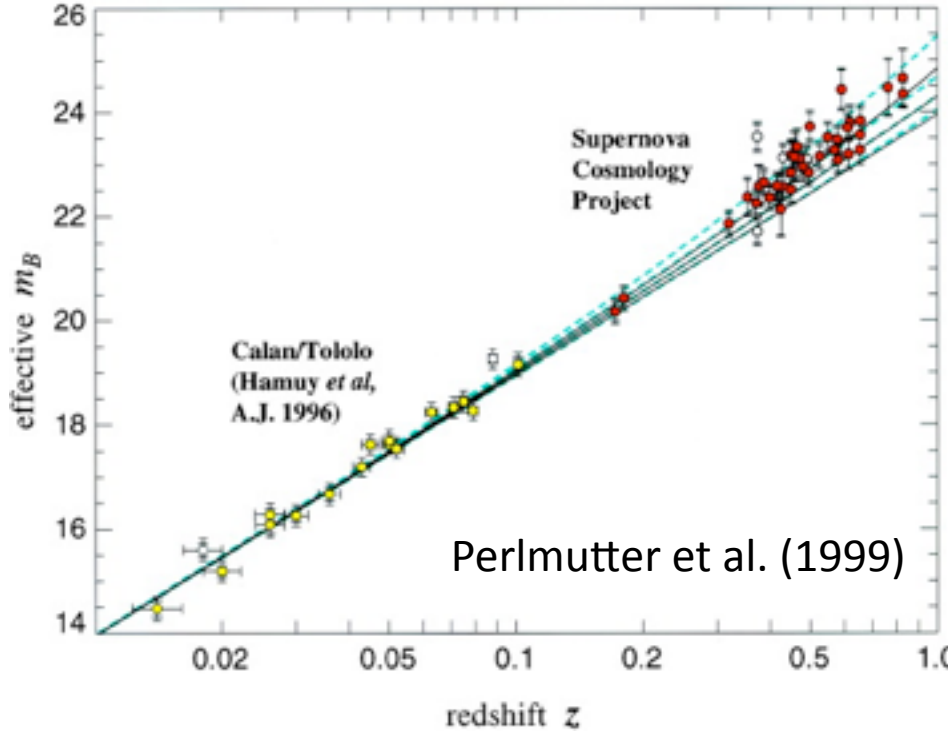
Freedman et al. (2001)

The Calán/Tololo SN Survey Impact:

The Accelerating Universe



Riess et al. (1998)



Perlmutter et al. (1999)

The Calán/Tololo data set served as the nearby reference sample for both the High-Z and SCP papers on the discovery of the accelerating universe

Conclusions

- The Calán/Tololo survey was the first modern search for supernovae and established several of the techniques now commonly used to discover SNe Ia

- This was one of the first time that telescope time was assigned by a TAC to observe objects not yet discovered!

- Finally, the Calán/Tololo SN survey provided a compelling demonstration of the ability of “small” telescopes to make fundamental contributions to astronomy