Supernova Surveys in Chile

Massive Stars & Supernovae, Bariloche, Nov 5-9, 2018

Mark Phillips

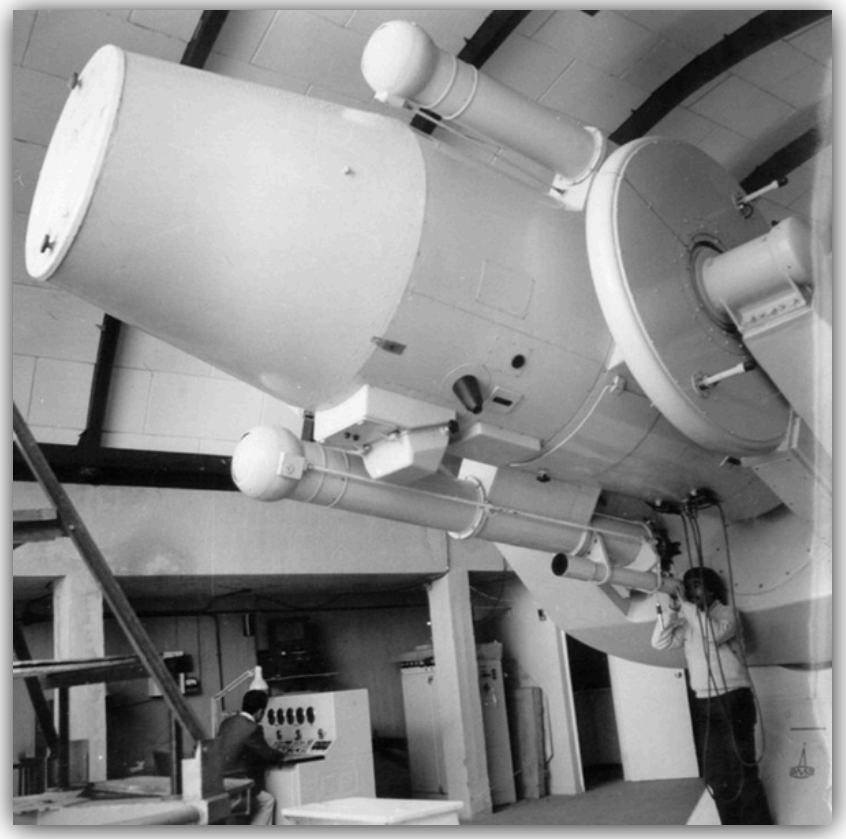
Las Campanas Observatory

Carnegie Institution of Science

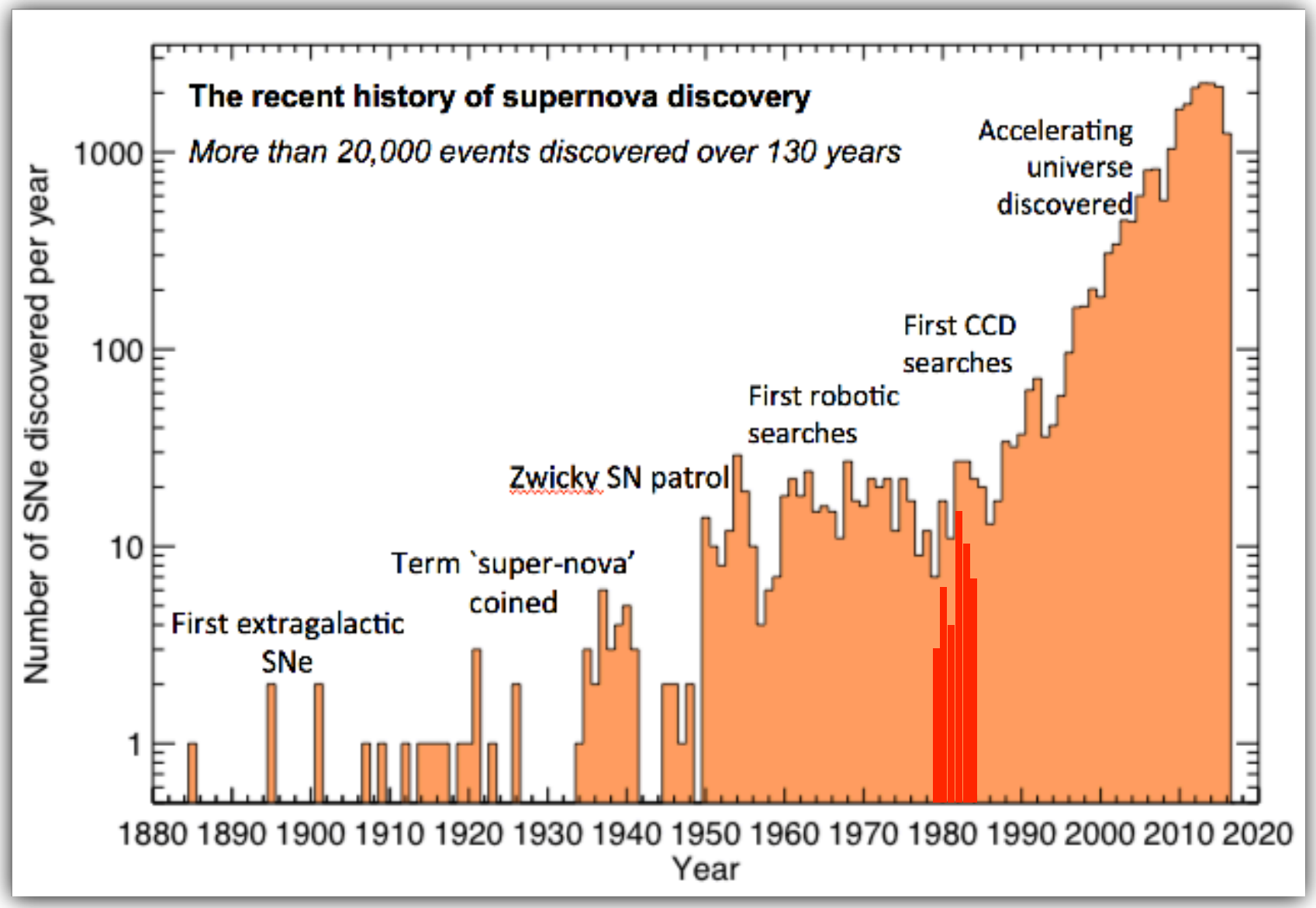
The Cerro El Roble Supernova Search

Between 1979 and 1984, José Maza and his colleagues, Marina Wischnjewsky y Luis González, discovered ~50 SNe with the 70 cm Maksutov telescope at the Cerro El Roble Observatory

Unfiltered, blue plates of a total of 39 fields were taken once a month at a limiting magnitude of about 20



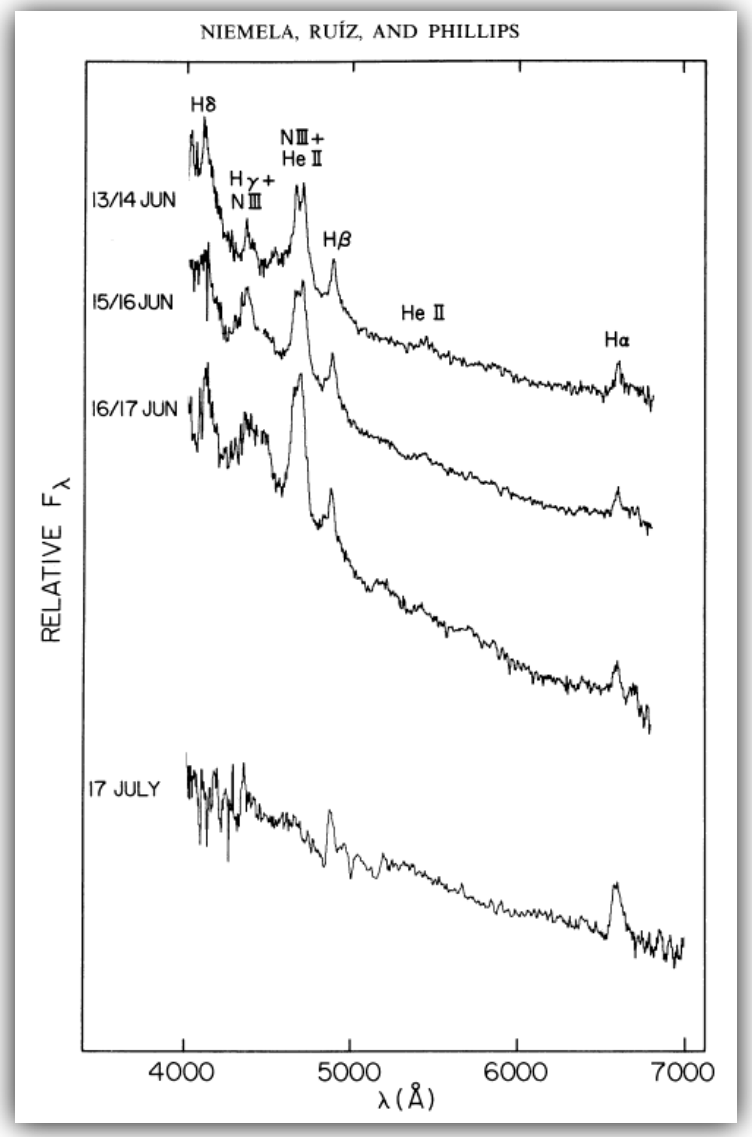
The Cerro El Roble Supernova Search

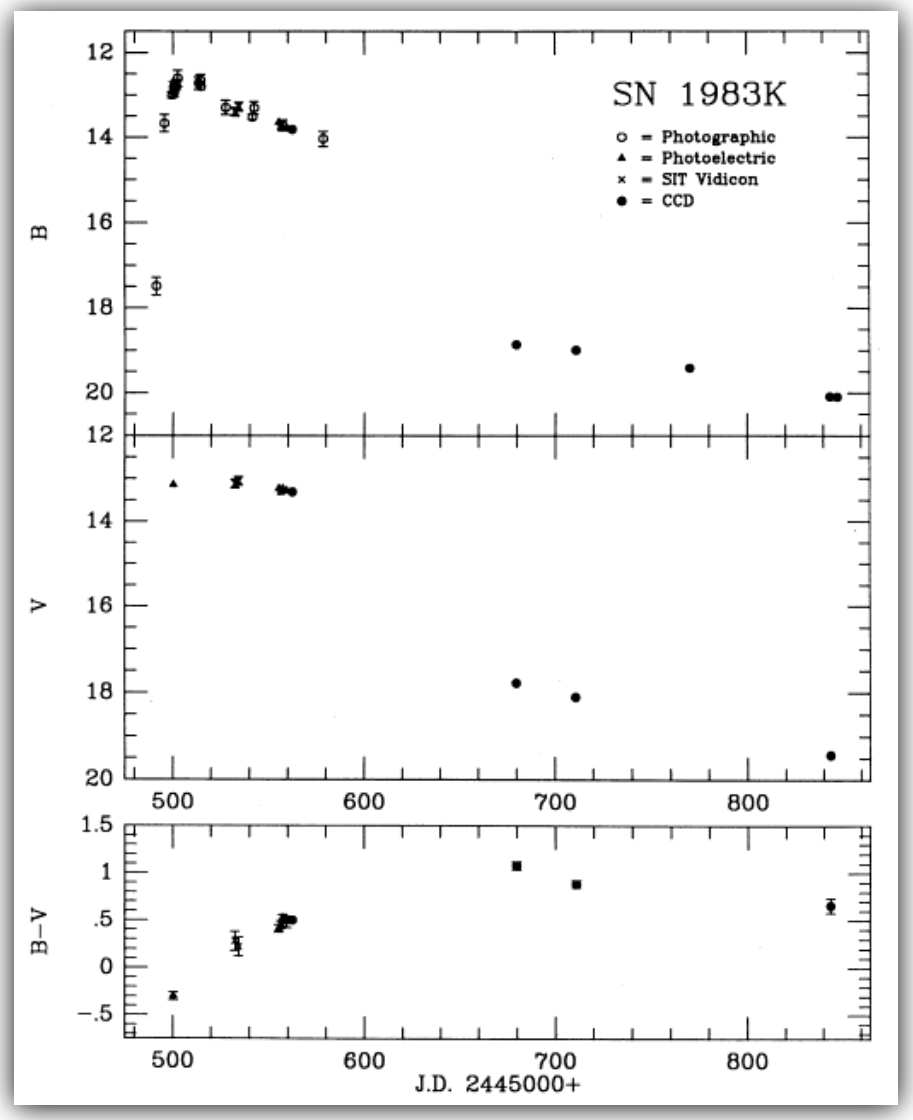


Credit: M. Sullivan

SN 1983K in NGC 4699

"Flash Ionized" CSM signature





Niemela, Ruiz, & Phillips (1985)

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)

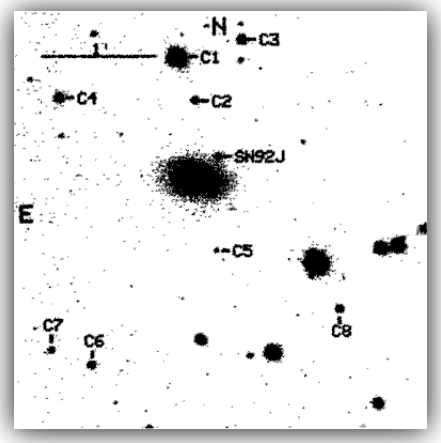
The Calán/Tololo SN Survey Objectives

- 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

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

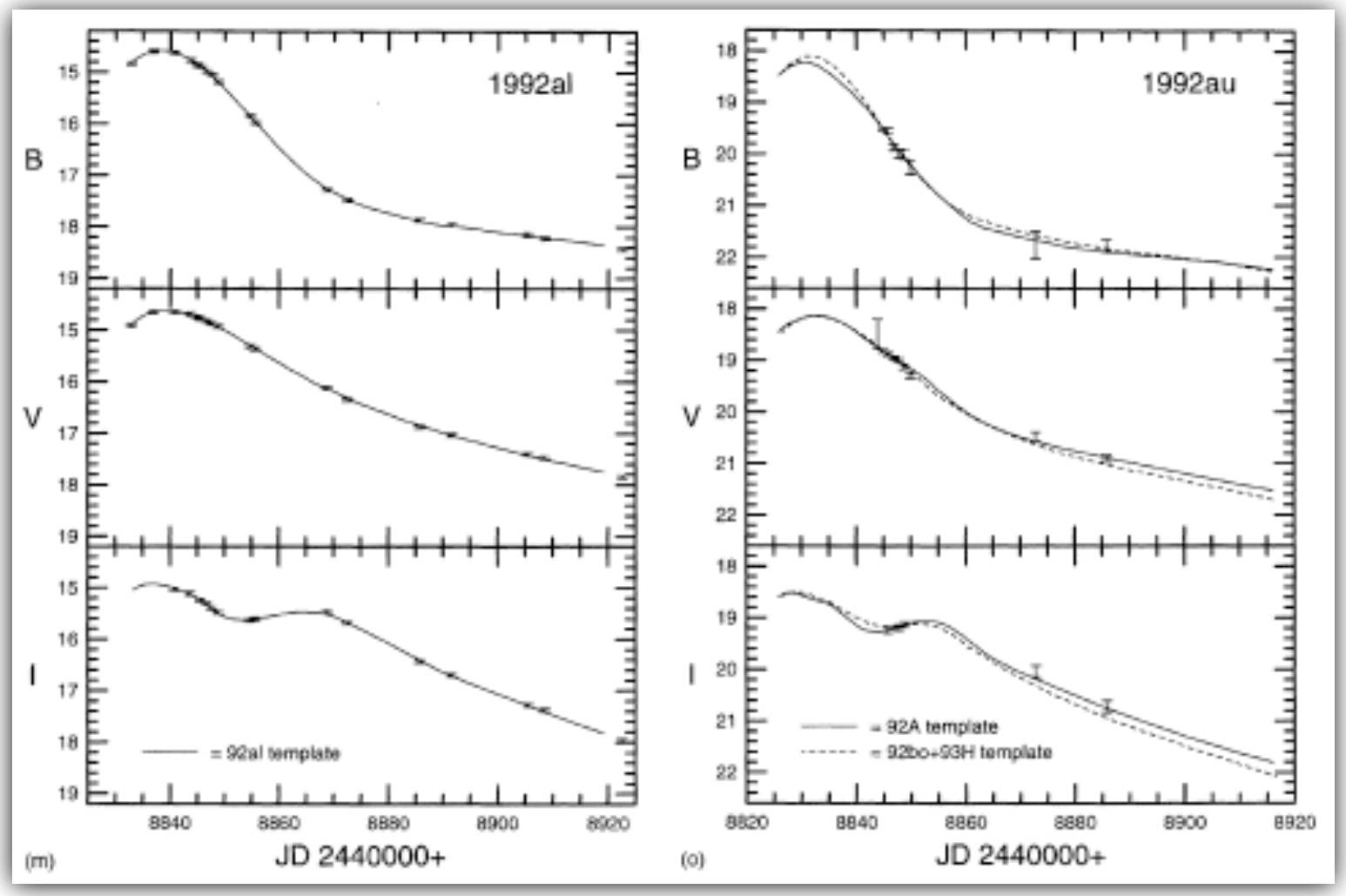
The Calán/Tololo Survey Milestones

- 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 times 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

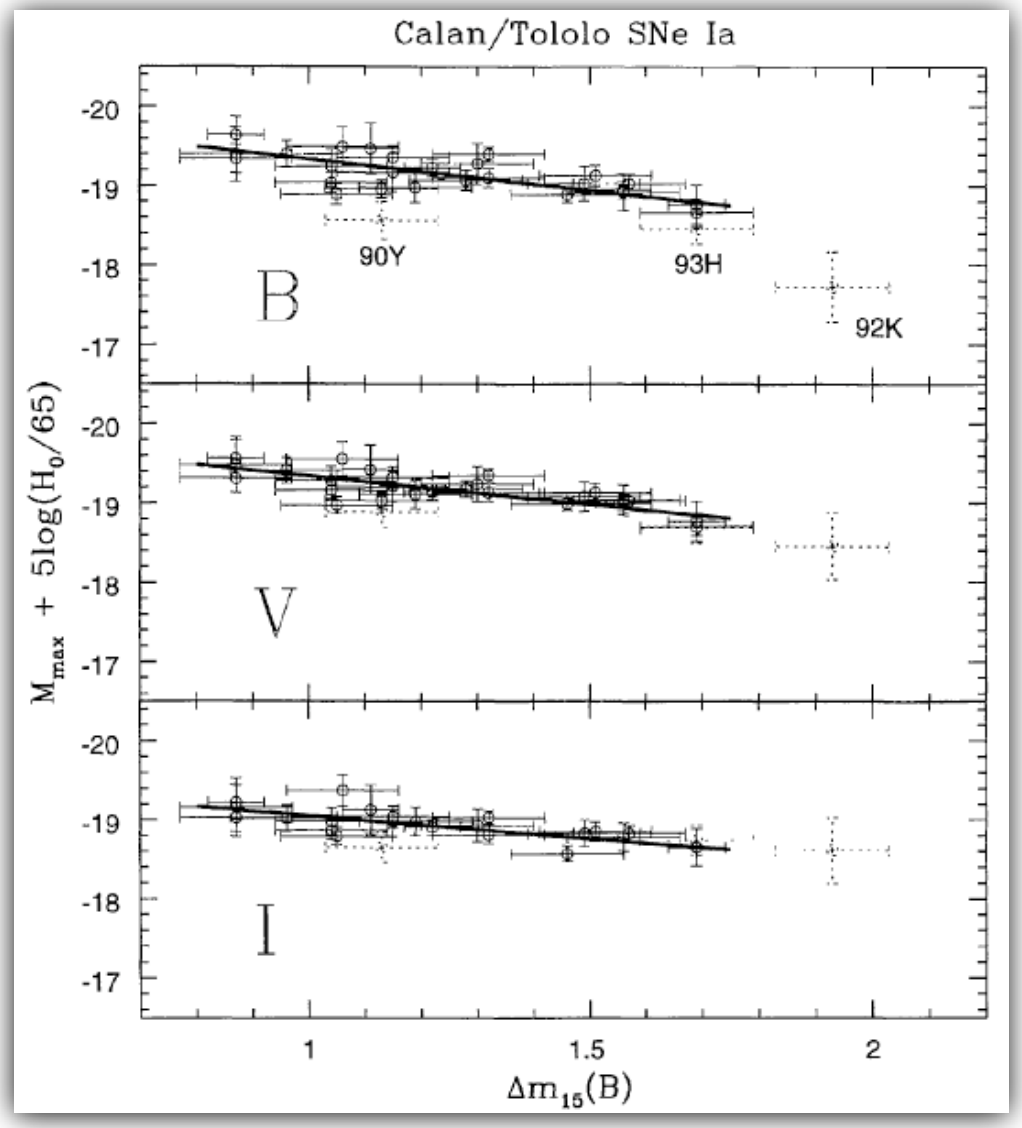
The Calán/Tololo Supernova Survey: Sample Light Curves



Hamuy et al. (1996c)

The Calán/Tololo SN Survey Results:

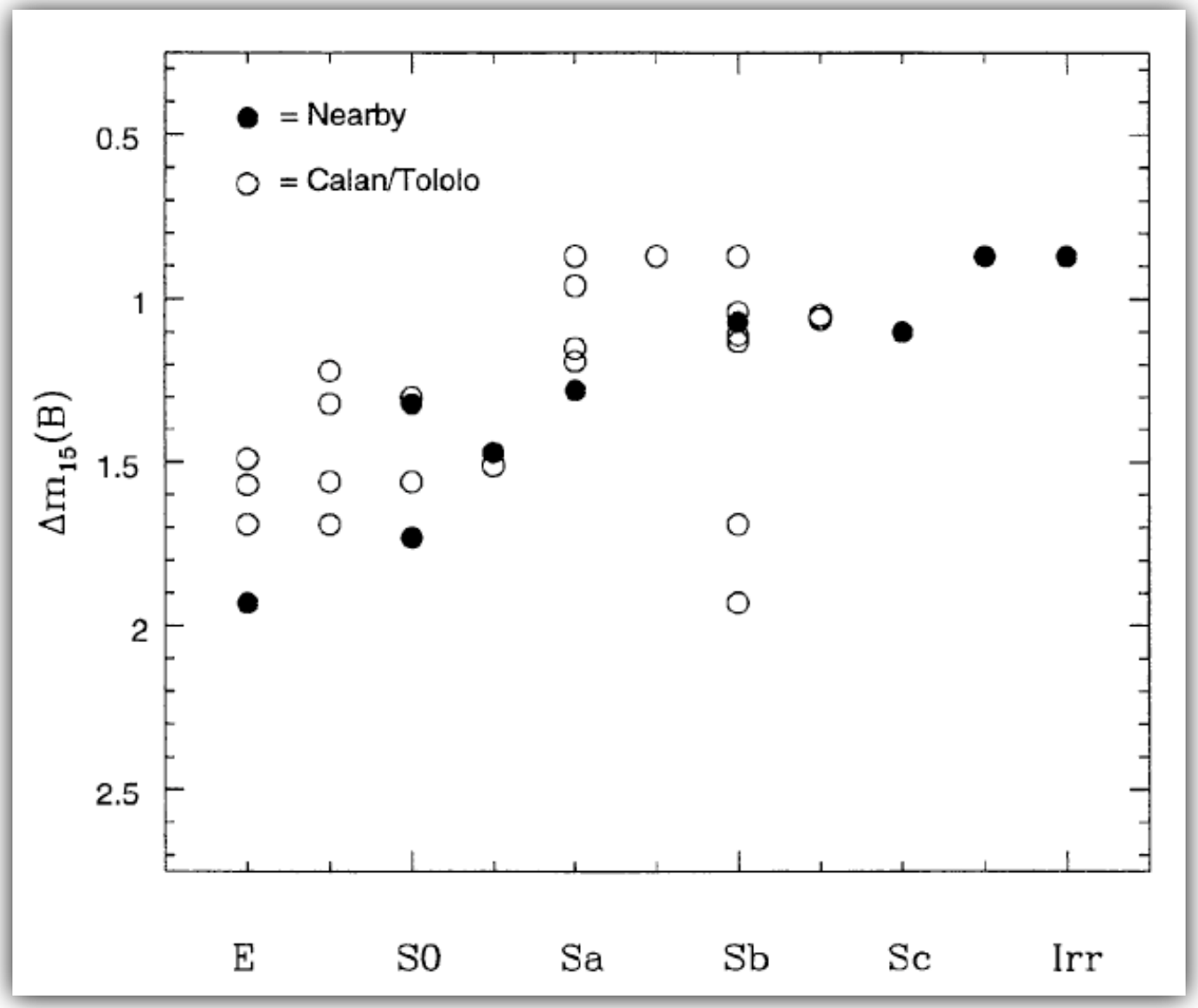
Confirmation of the Luminosity-Decline Rate Relation



Hamuy et al. (1996a)

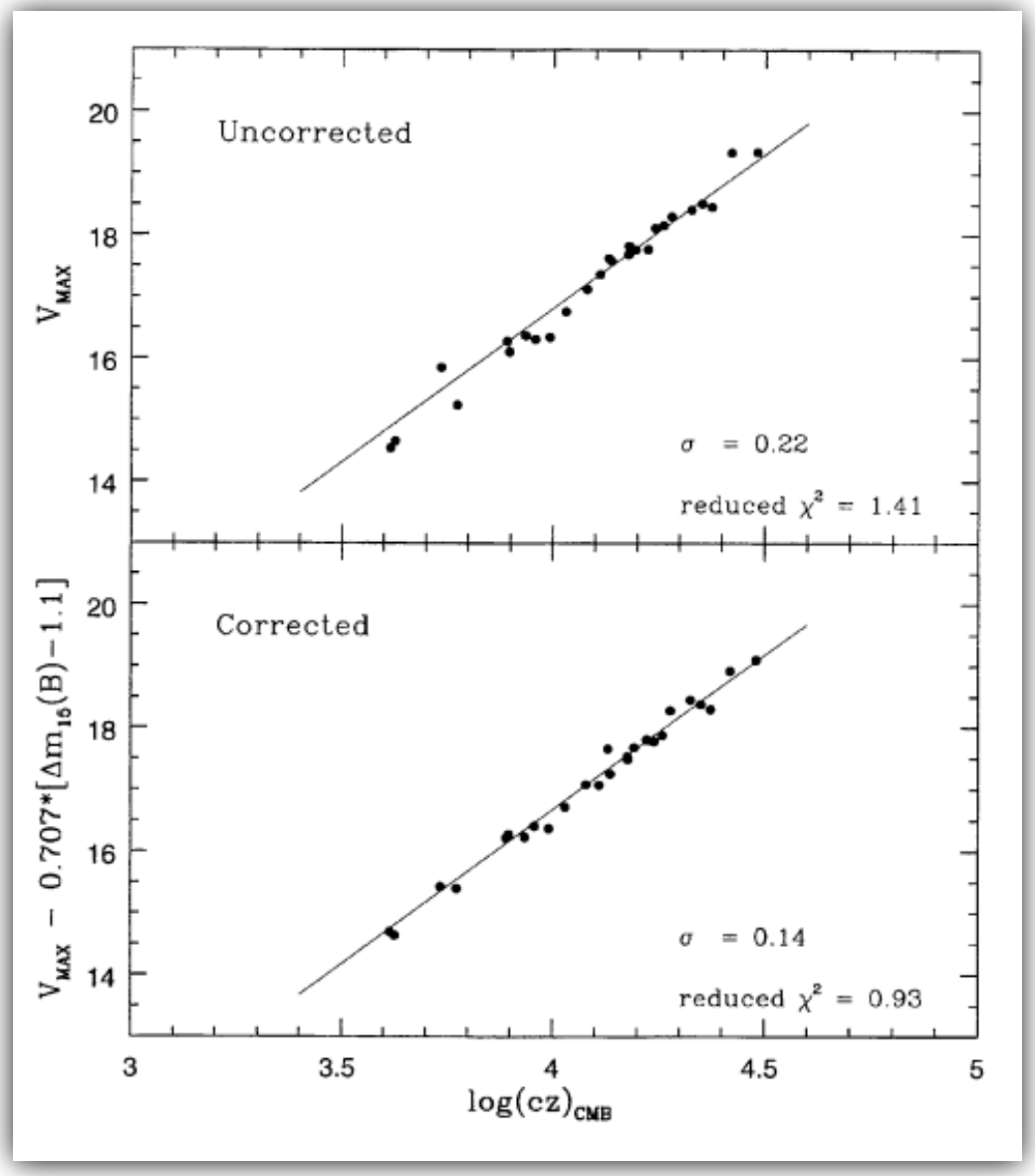
The Calán/Tololo SN Survey Results:

Discovery of the Galaxy Morphology-Decline Rate Dependence



Hamuy et al. (1996a)

The Calán/Tololo SN Survey Results:
Hubble Diagram

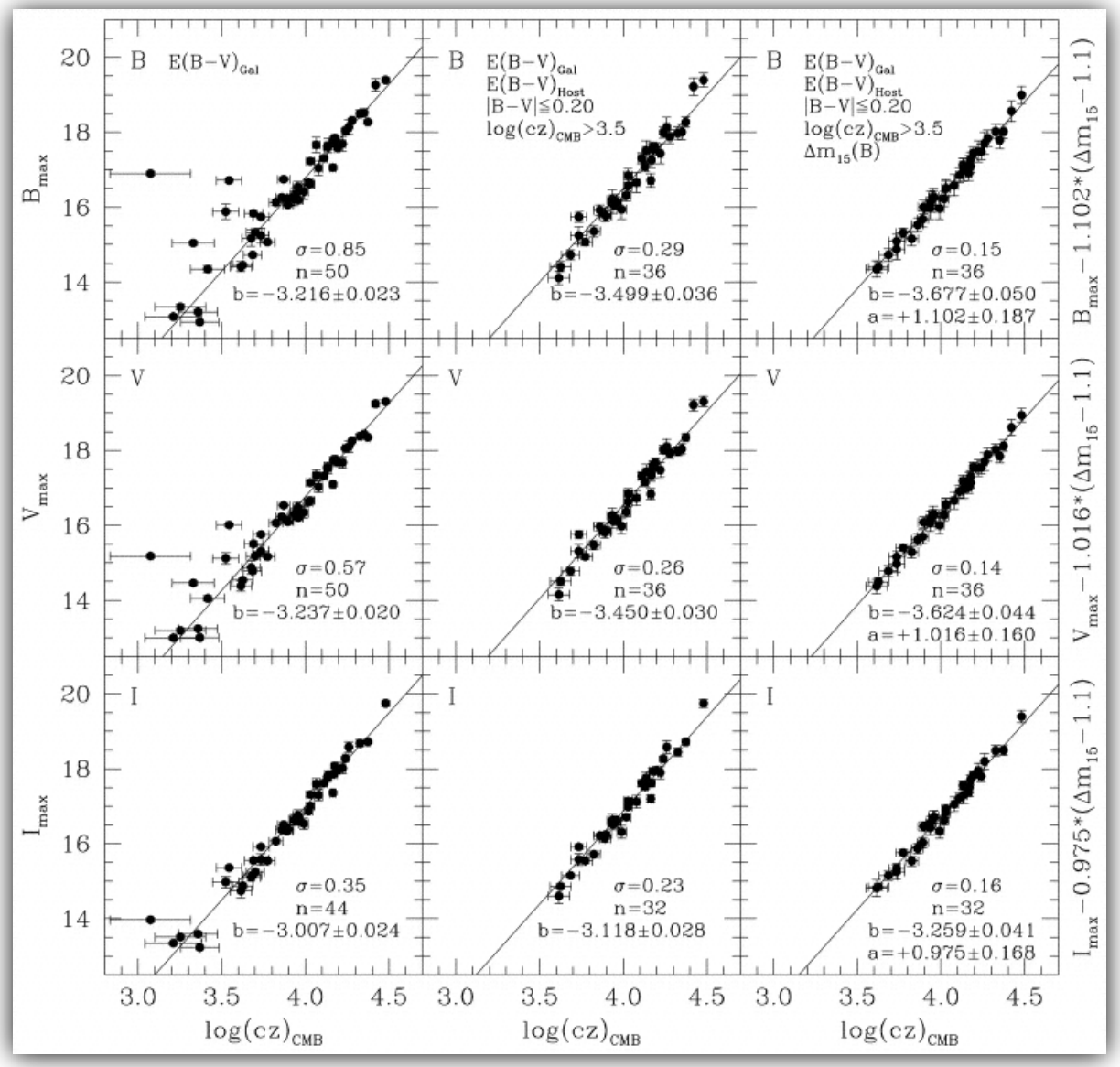


SNe Ia can be used to derive distances to 7-10% precision

Hamuy et al. (1996b)

The 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

$H_0 = 71 \pm 2$ (random)
± 6 (systematic)

Freedman et al. (2001)

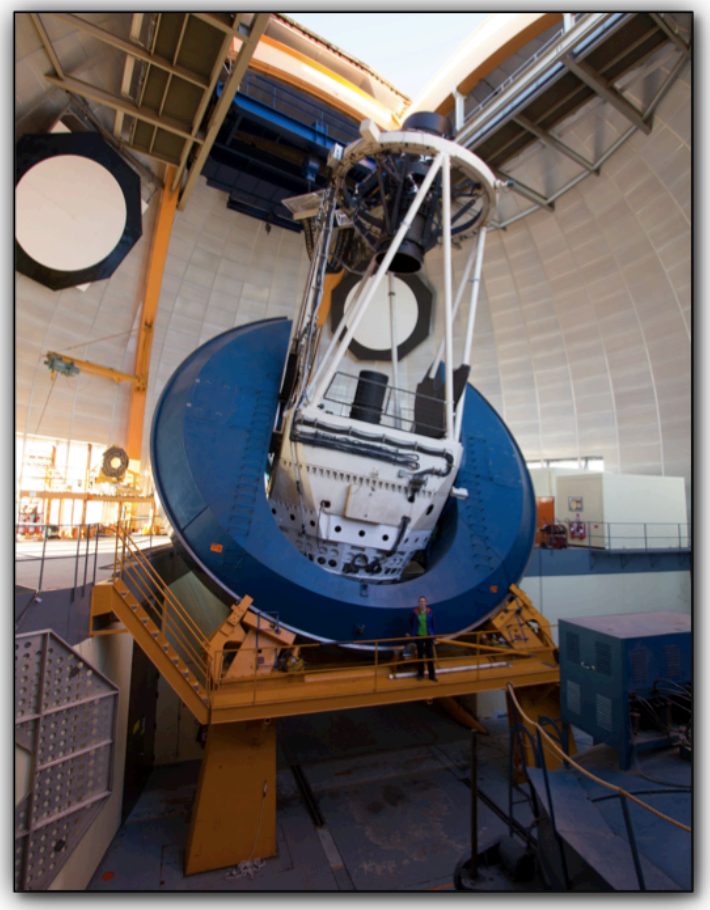
The High-z SN and SCP Surveys

- Based largely on the success of the Calán/Tololo project, the High-z SN and Supernova Cosmology Project (SCP) teams entered into a race to measure the decleration parameter, q_0

- Both teams used the CTIO Blanco 4 m telescope and BTC imager to discover the SNe

- En 1998-1999, both teams independently published their results that the expansion of the universe was actually accelerating

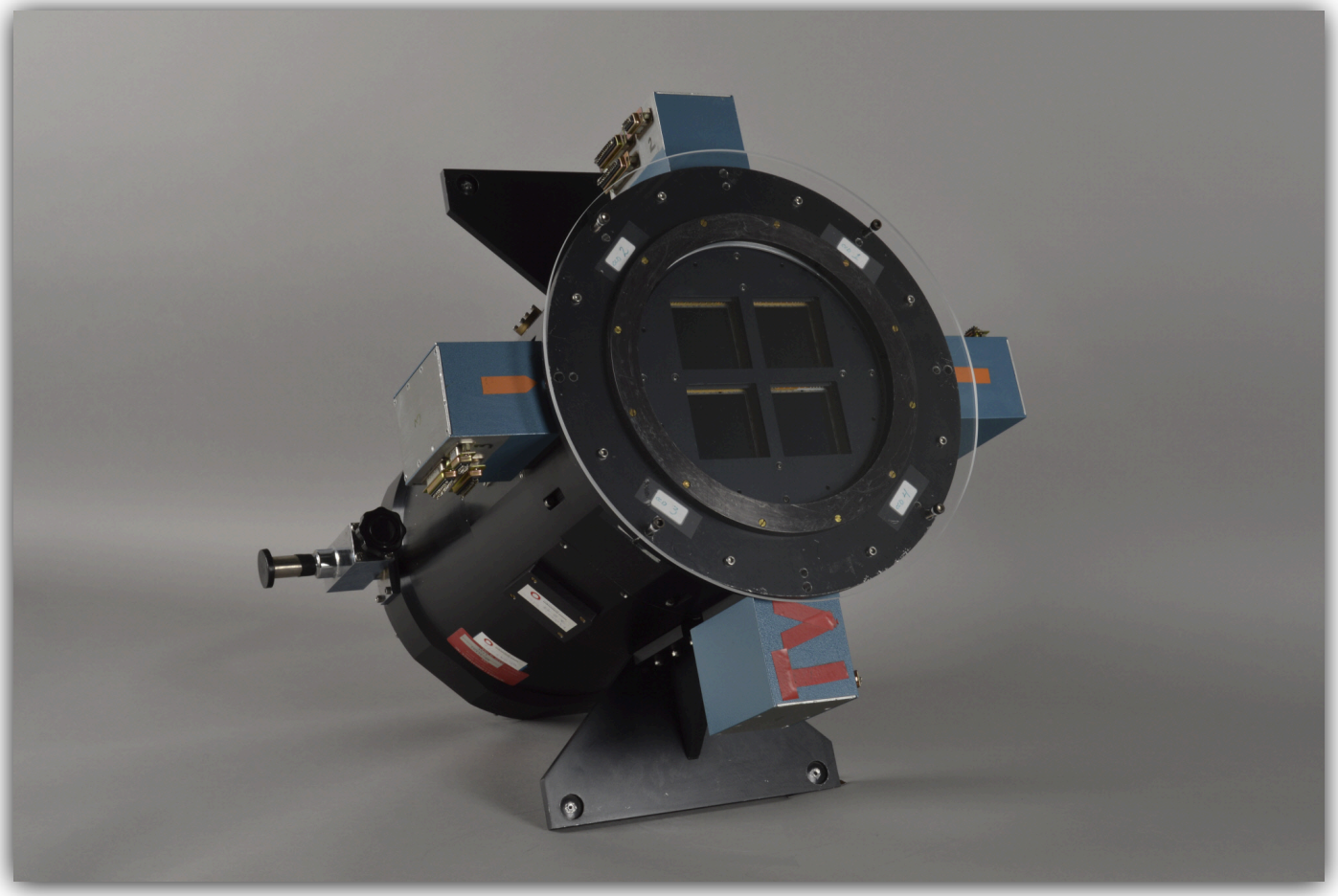
Type Ia SN at z ~ 0.9



Blanco 4 m telescope

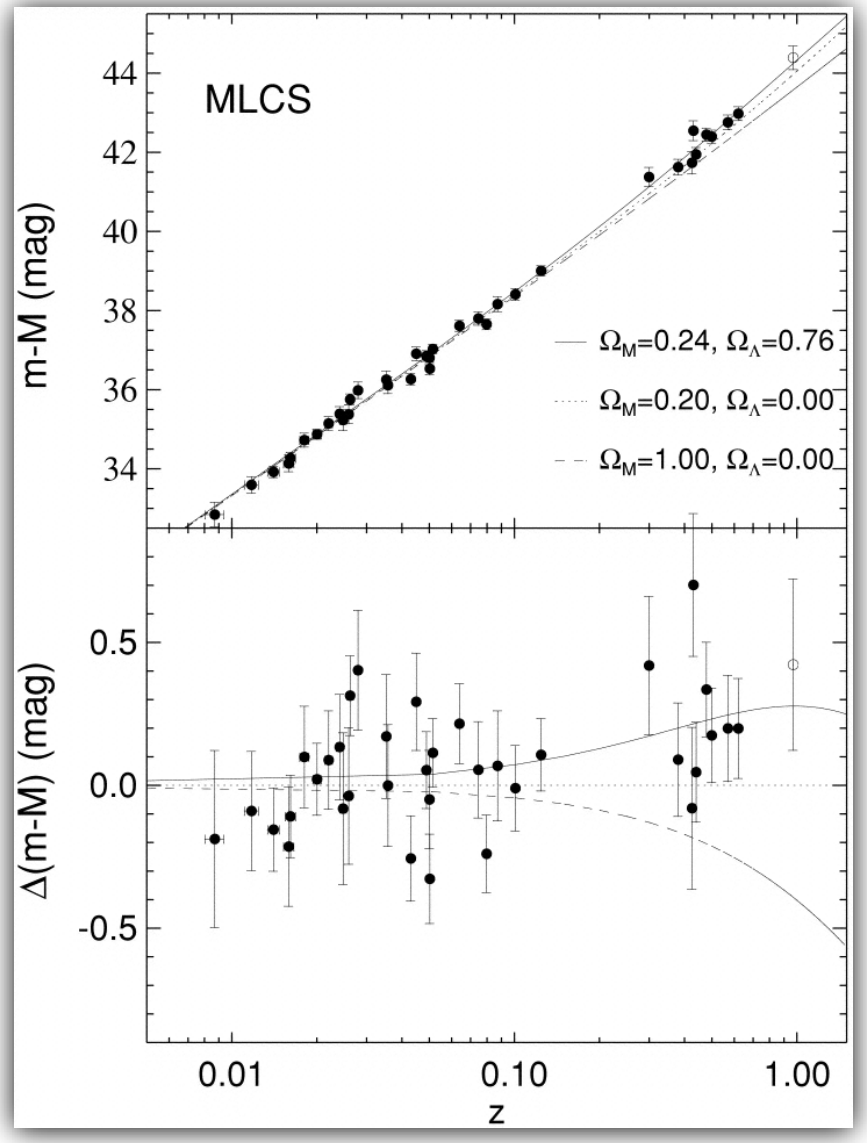
The Big Throughput Camera (BTC):

Built by Gary Bernstein and Tony Tyson

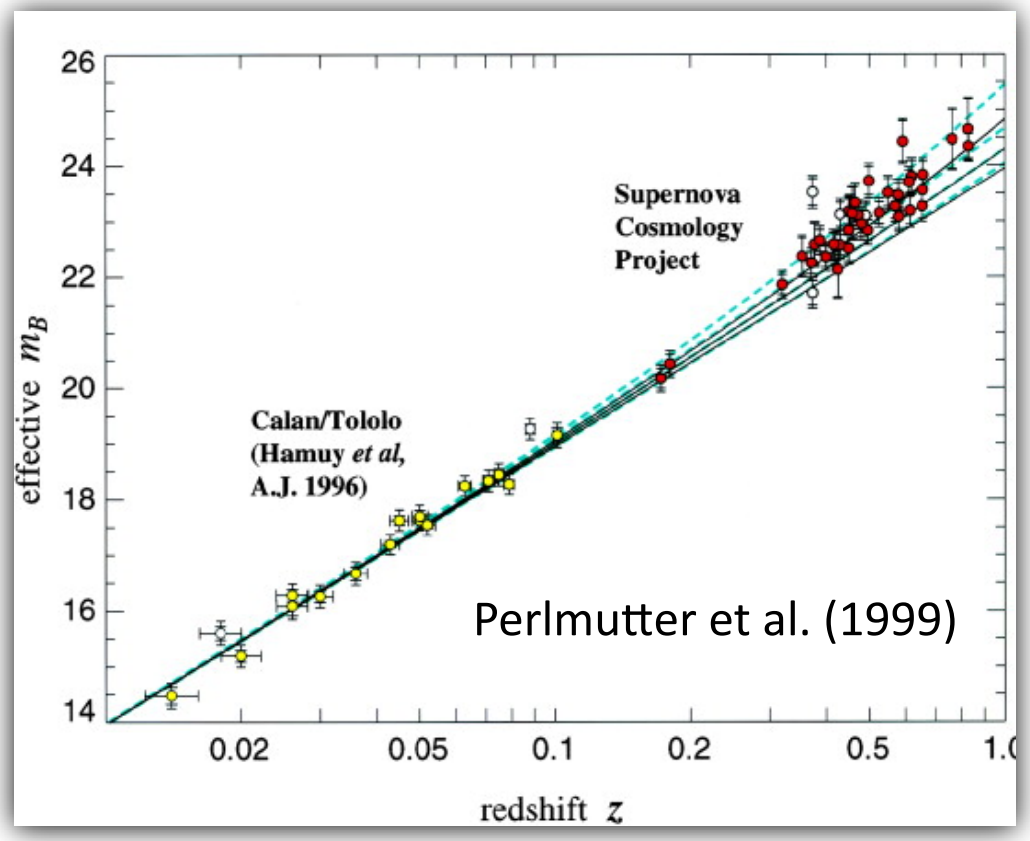


- In service at the prime focus of the CTIO Blanco telescope from 1997-1999
- Consisted of four thinned SITe 2048 x 2048 CCDs
- Now on exhibit at the Smithsonian Air & Space Museum

Discovery of the Accelerating Expansion of the 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

CHASE
(CHilean Automatic Supernovas sEarch)

- Since March 2007, the CHASE project has been discovering SNe using the PROMPT 0.4 m telescopes at Cerro Tololo
- More than 170 SNe have been discovered to date

Giuliano Pignata (UNAB)

José Maza y Mario Hamuy (U Chile)

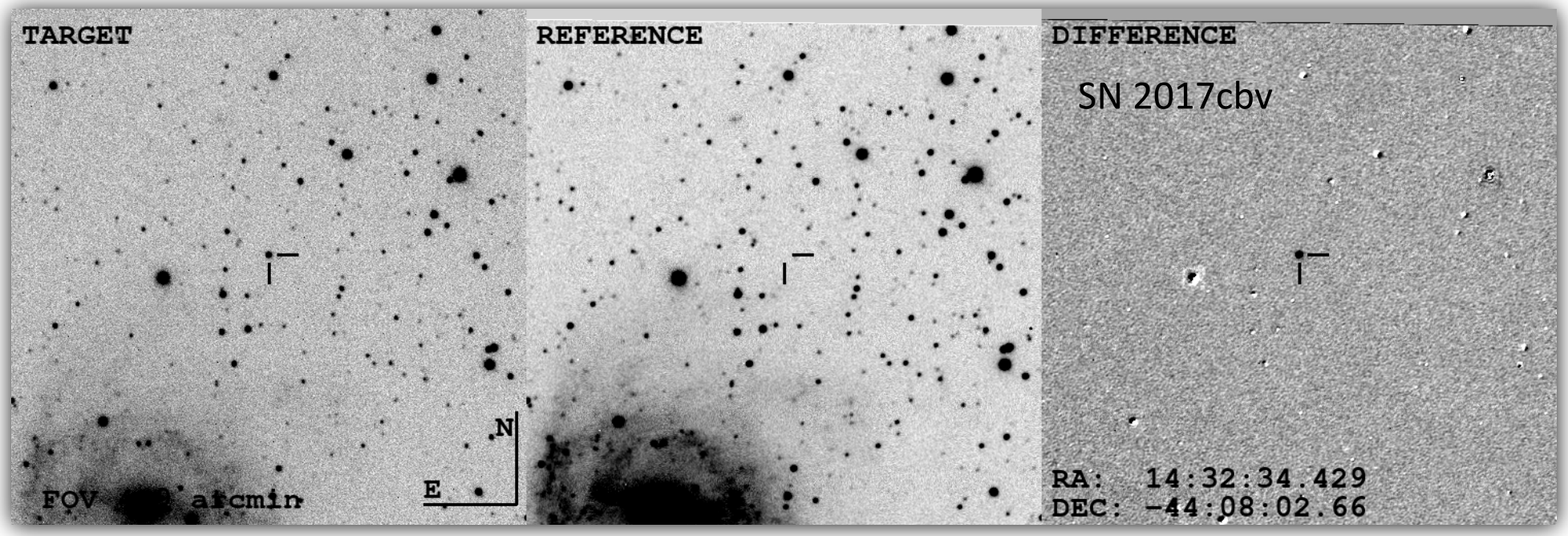
MCSS
Núcleo Milenio de Estudios de Supernovas

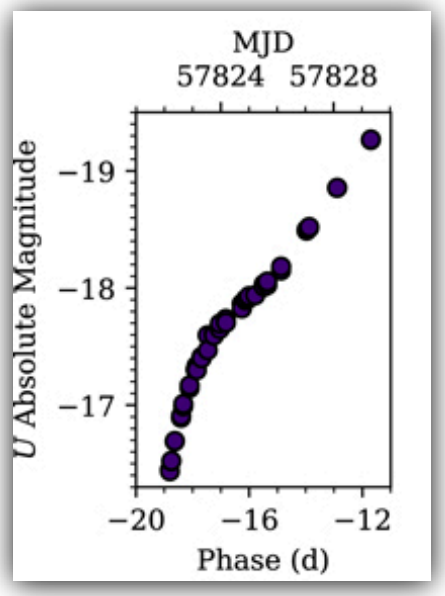
INSTITUTO MILENIO DE ASTROFÍSICA

DLT40
(Distance < 40 Mpc)

David Sand (U Arizona), et al.

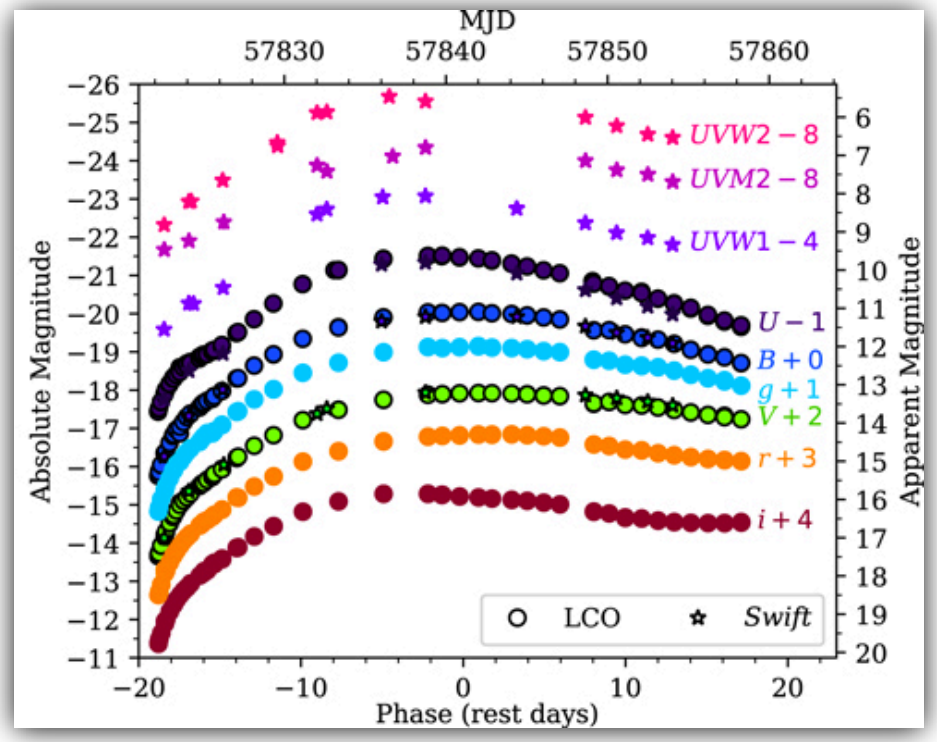
- The object of the DLT40 survey is *not* to discover lots of SNe, but rather to catch ~10 SNe nearby events per year within1 day of explosión
- The DLT40 survey uses one of the PROMPT 0.4 m telescopes at CTIO

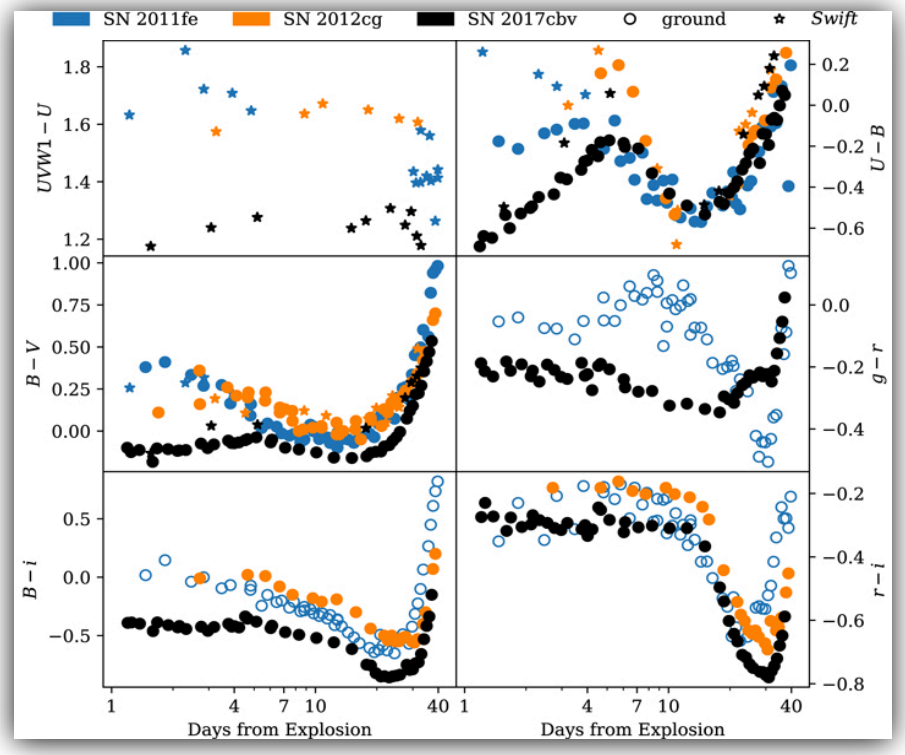




DLT40: SN 2017cbv

- Discovered ~1 day after explosion
- *U*, *B*, and *g* bands displayed a prominent "blue bump" during the first 5 days of observations





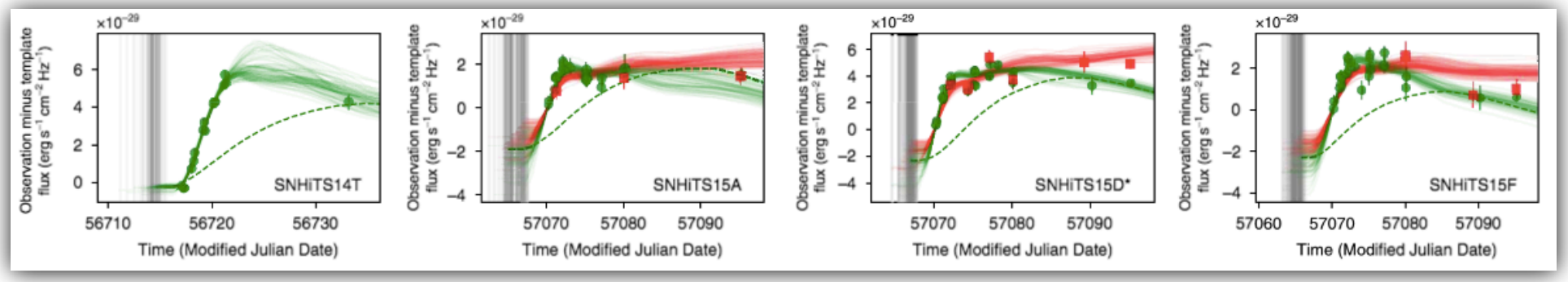
Hosseinzadeh et al. (2017)

HiTS
(High Cadence Transit Survey)

Francisco Förster (U Chile), et al.

The object of HiTS is to detect and follow astrophysical transients with timescales of hours to days, and especially the first hours of SNe

HiTS makes use of the “Dark Energy Camera” (DECam) on the Blanco 4 m telescope at CTIO



Förster et al. (2018)

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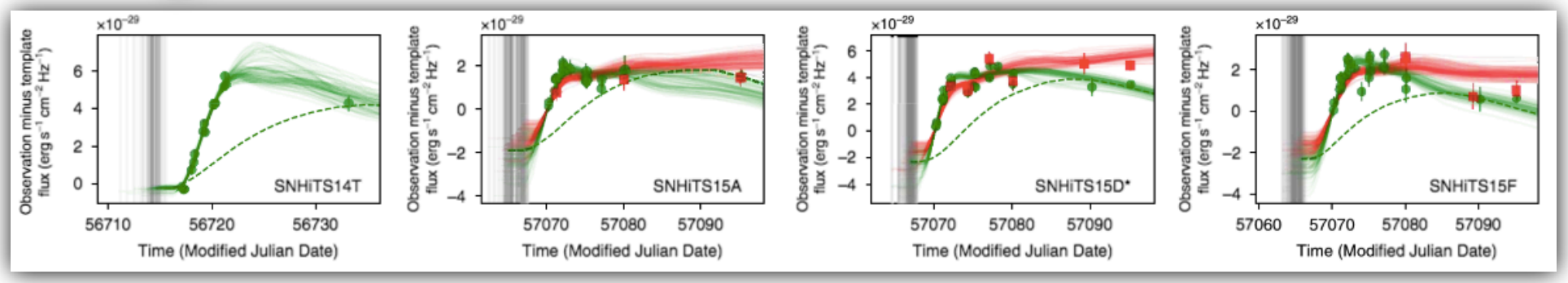
HiTS makes use of [illegible]ergy Camera" (D[illegible] Blanco 4 m tele[illegible]

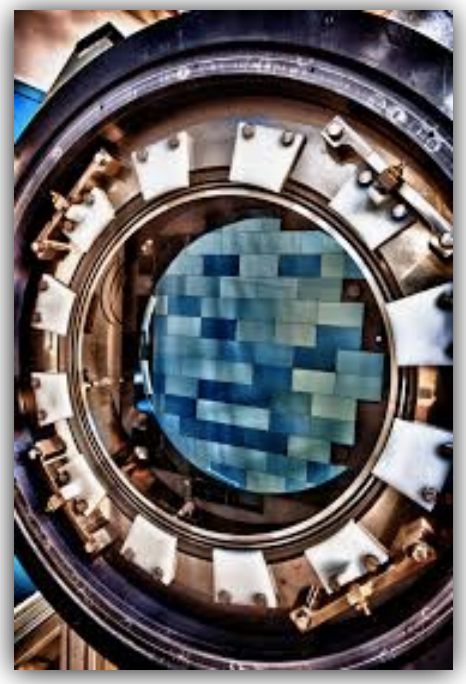
See Pancho's talk later today



Förster et al. (2018)

DES
(Dark Energy Survey)

Josh Frieman (Fermi Lab), et al.



DES is a 5-year project to study the nature of dark energy using four techniques:

- SNe Ia
- Baryon acoustic oscillations
- Galaxy cluster counts
- Weak gravitational lensing

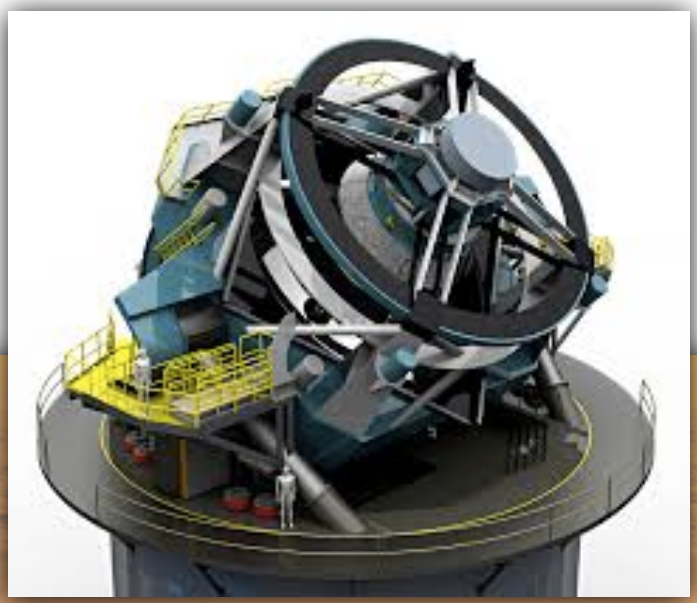
DES uses DECam, a 570 million pixel mosaic CCD camera, and has discovered thousands of SNe

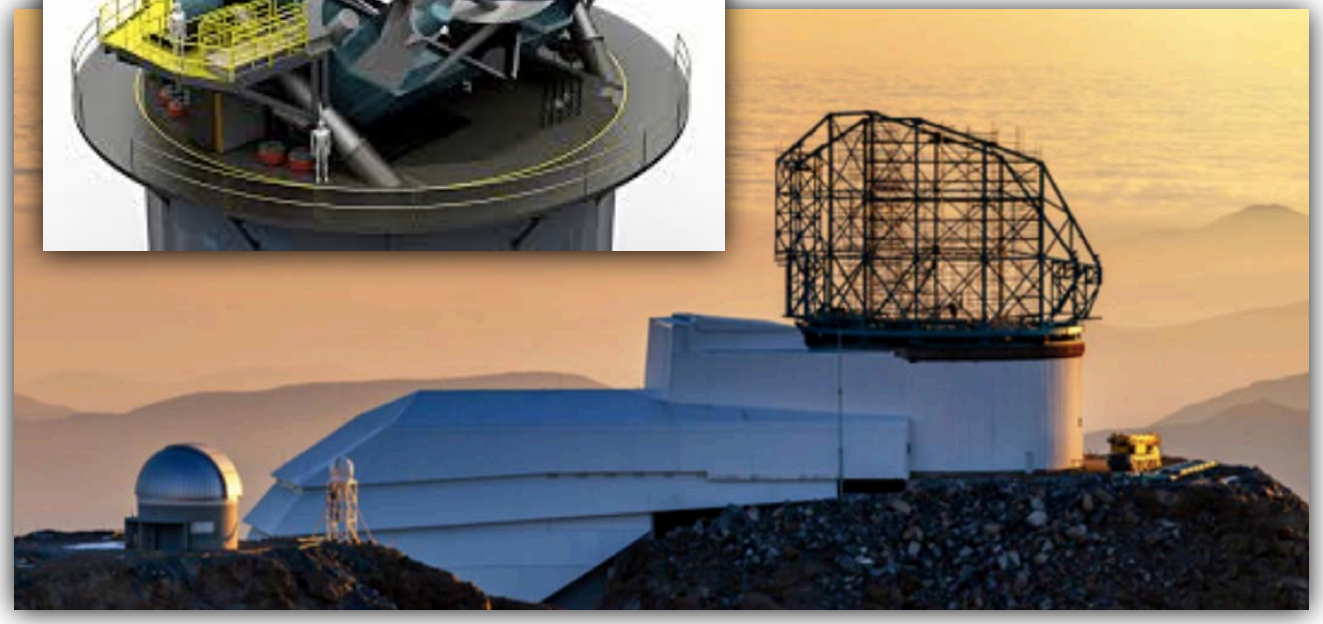
Blanco 4 m telescope

LSST (Large Synoptic Survey Telescope)

LSST will continually image the sky, identify changes in near real time, and over a decade of operations collect tens of petabytes of data building up the deepest, widest, image of the Universe:

- 8.4 m diameter primary mirror
- Mosaic camera with 3,300 million pixels
- Will discover up to 4 million SNe in 10 years of operation





LSST is scheduled to begin operations in 2022

The Carnegie Supernova Project I (CSP-I)

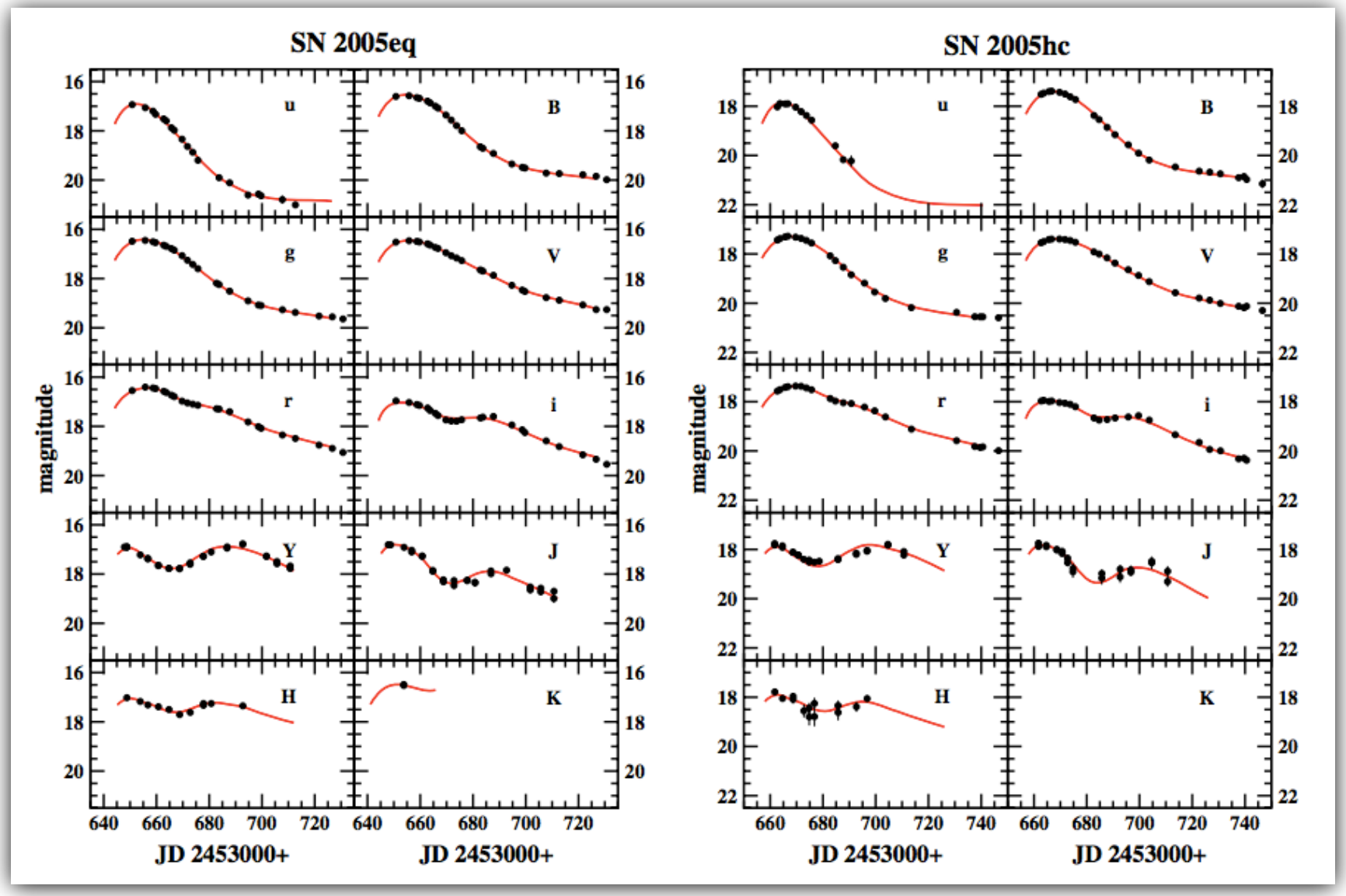
- Five campaigns between 2004-2009
- Follow-up optical (ugriBV) light curves obtained of
  - 123 SNe Ia (z_{median} = 0.025)
  - 5 SNe Iax, 2 Ia-csm, 2 06bt-like, 2 “super-Chandra”
  - 34 Stripped Core-Collapse SNe
  - 83 SNe II
- NIR (YJH) photometry obtained for the majority
- Extensive optical spectroscopy also obtained

Swope 1-m

Du Pont 2.5-m

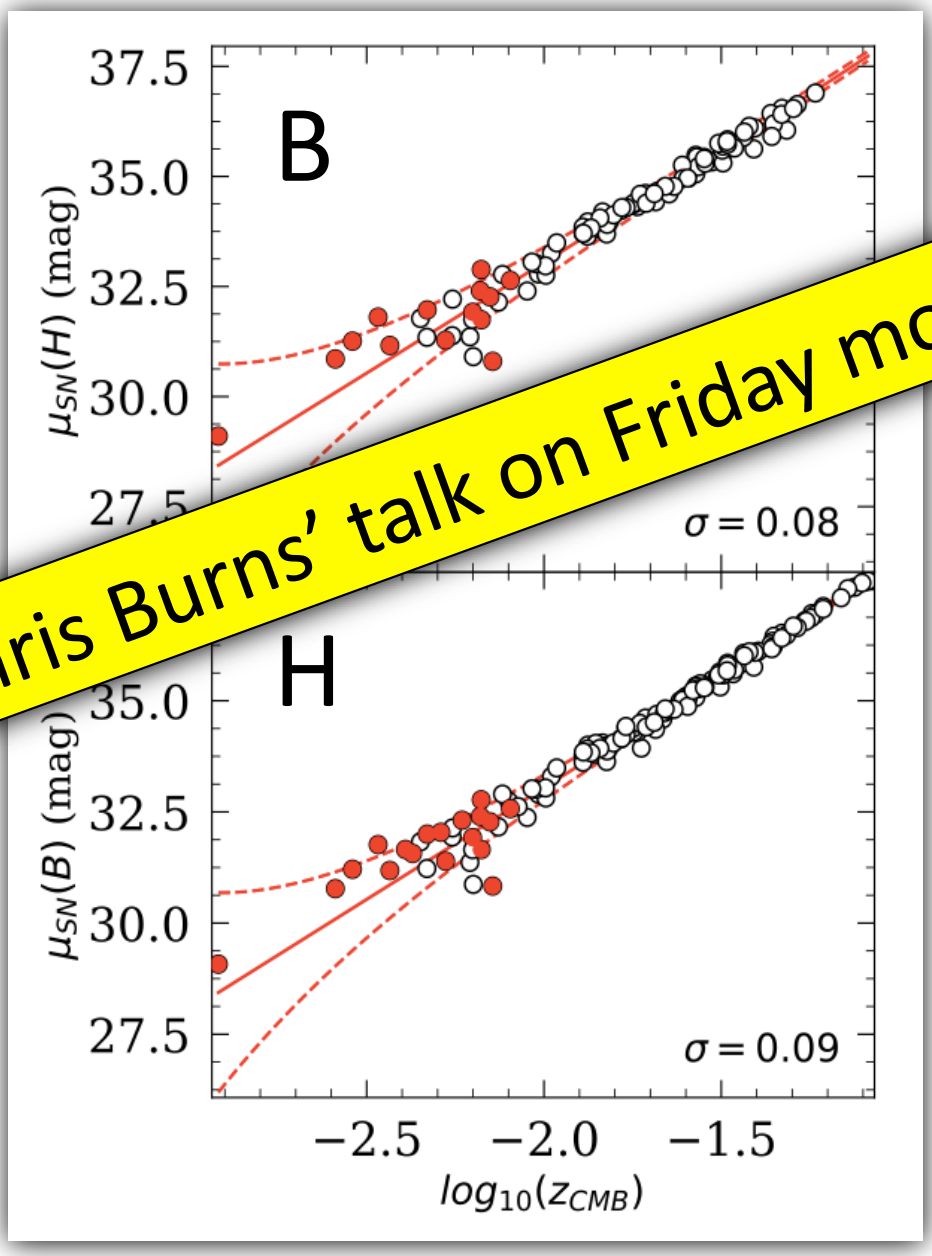
Magellan 6.5-m

Optical and NIR Light Curves of SNe Ia from the CSP-I



Contreras et al. 2010

CSP-I Hubble Diagrams



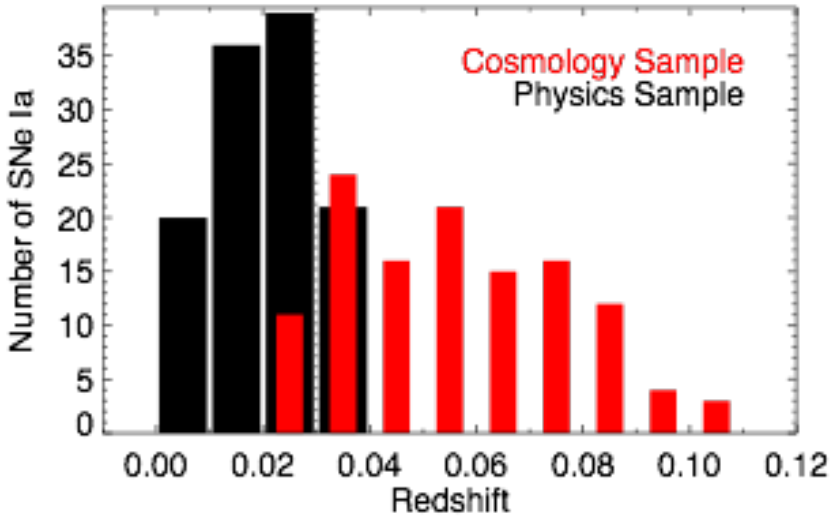
See Chris Burns' talk on Friday morning

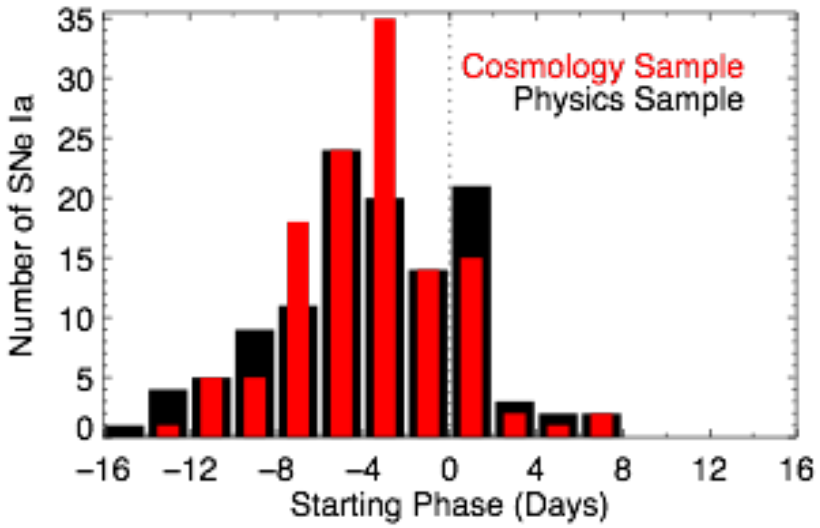
The Carnegie Supernova Project II (CSP-II)

- Four 9-month campaigns between 2011-2015
- Follow-up optical (ugriBV) light curves obtained of
  - 125 SNe Ia (z_{median} = 0.056) — "Cosmology Sample"
  - 90 SNe Ia ($z \lesssim 0.04$) — "Physics Sample"

} 21 in common

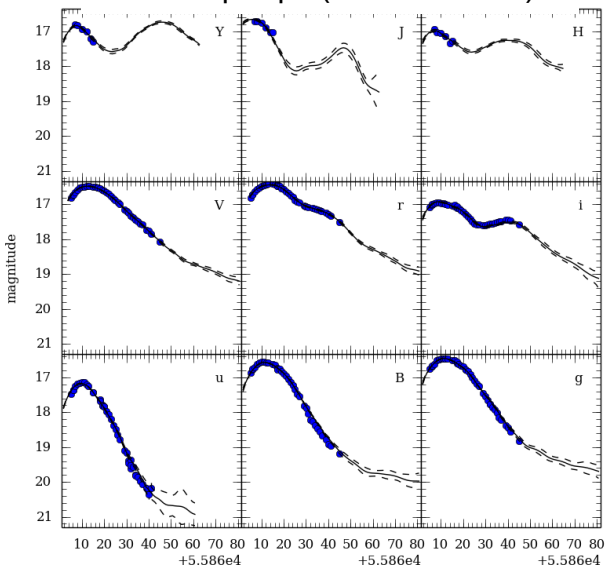
- NIR (YJH) photometry obtained of SNe Ia near maximum
- Extensive NIR spectroscopy obtained for SNe Ia in Physics Sample



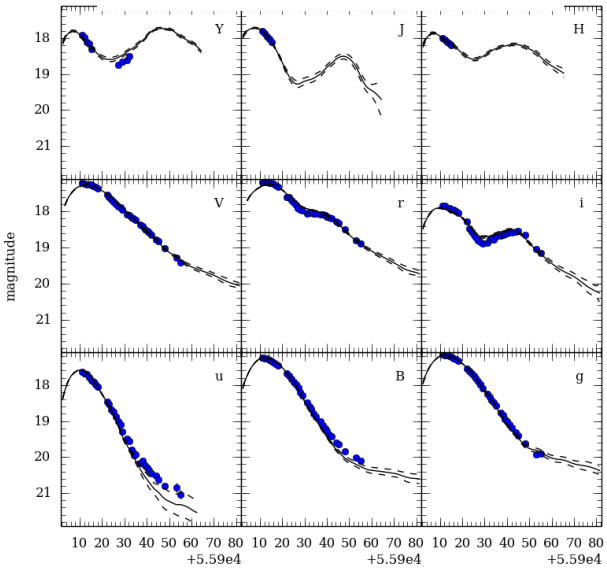


CSP-II: Sample Light Curves

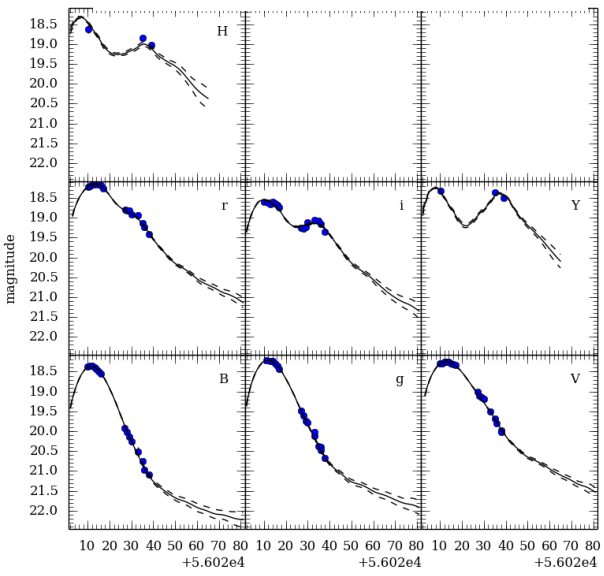
PTF11pbp (z = 0.028)



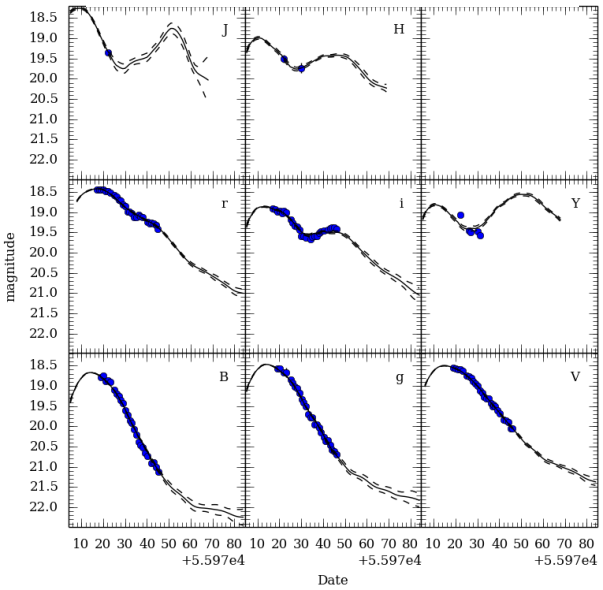
LSQ11bk (z = 0.040)



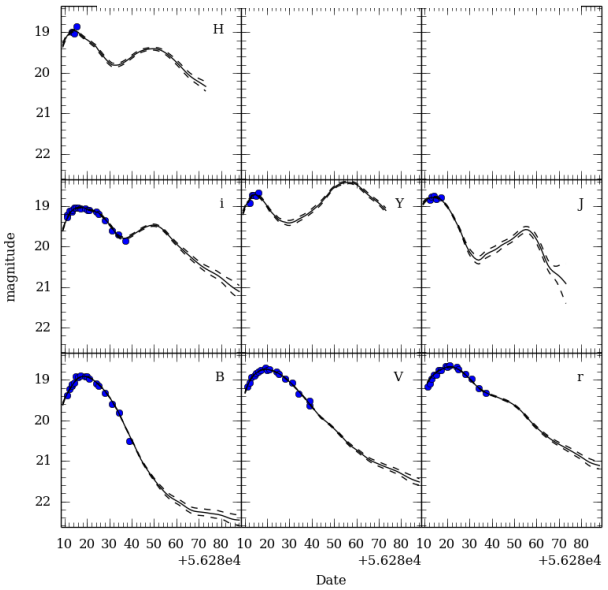
LSQ12btn (z = 0.055)



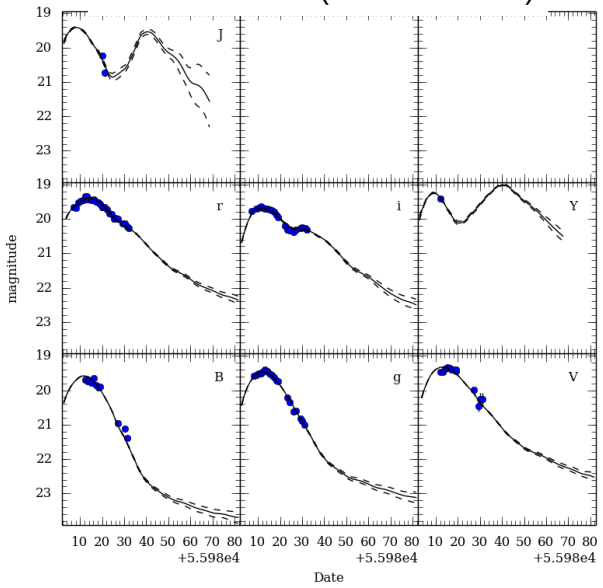
LSQ12agq (z = 0.065)



LSQ12hzs (z = 0.072)

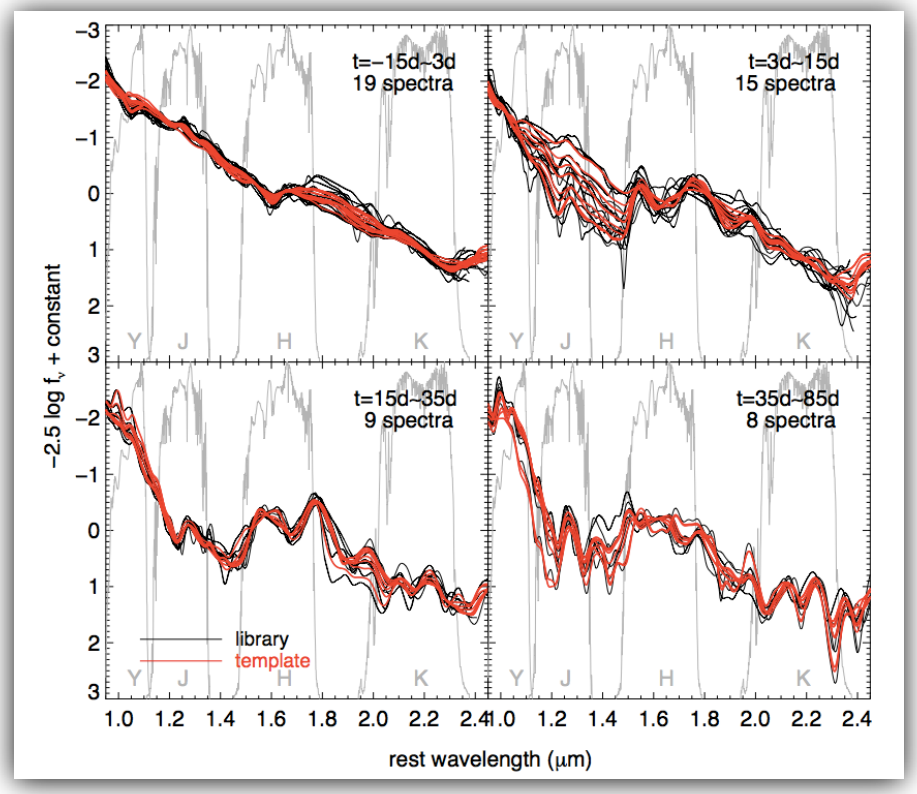


LSQ12aor (z = 0.095)

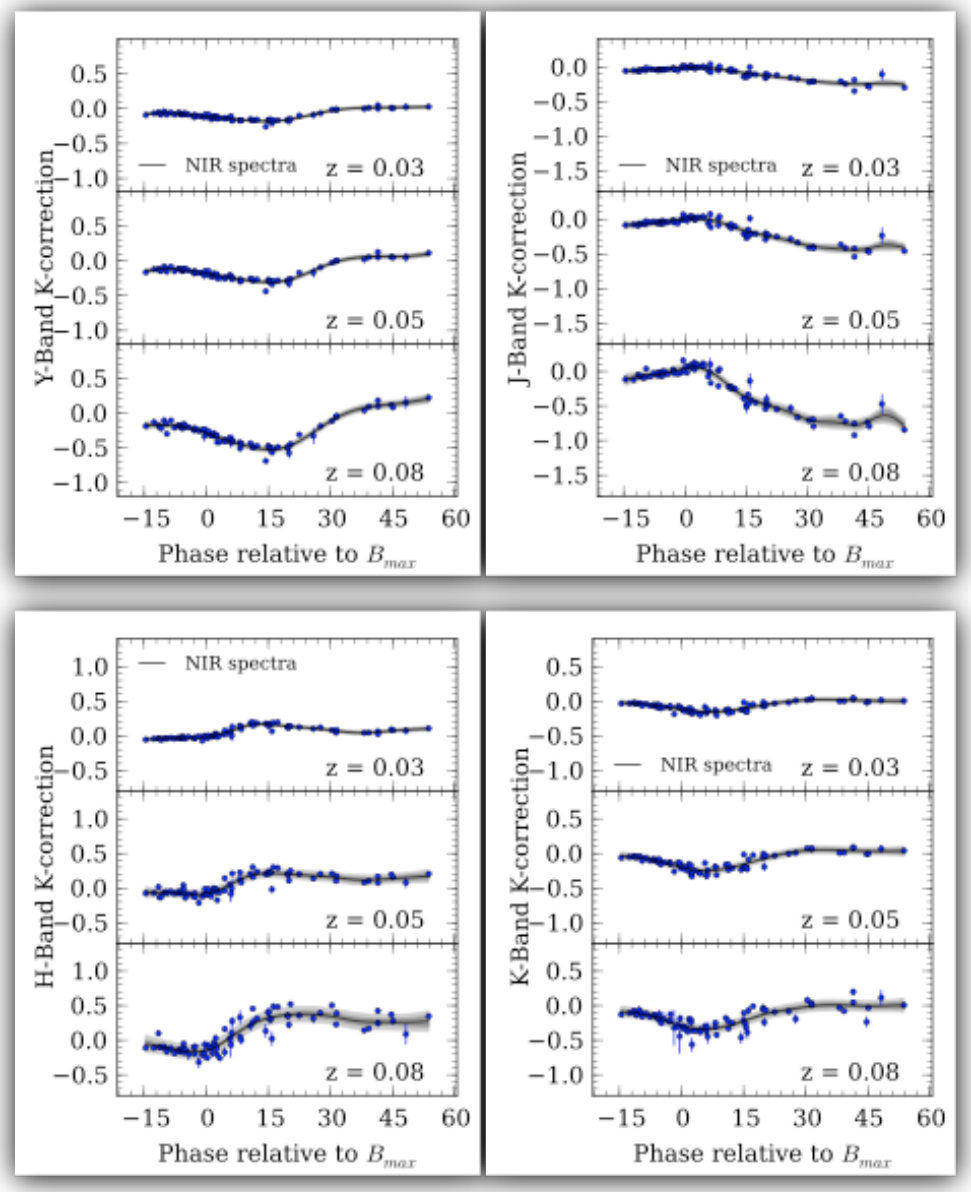


NIR Spectroscopy: K Corrections

- Near-IR spectral characteristics of SNe Ia are still relatively unexplored
- K corrections can be large!

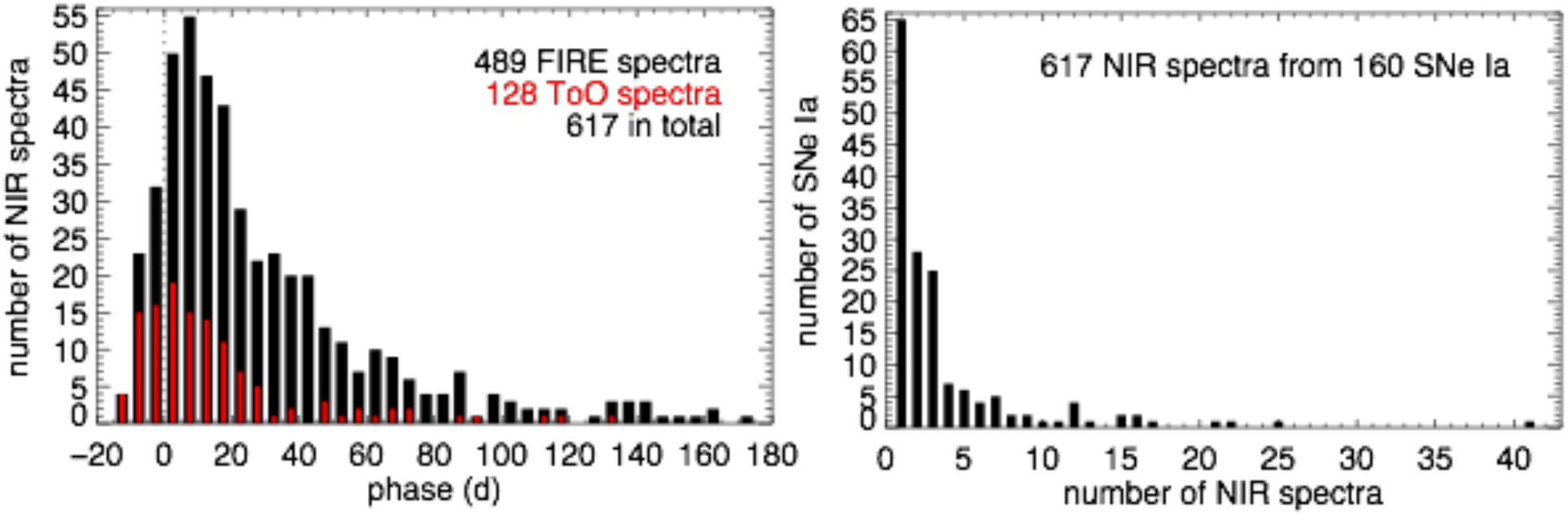


Hsiao (thesis, 2009)



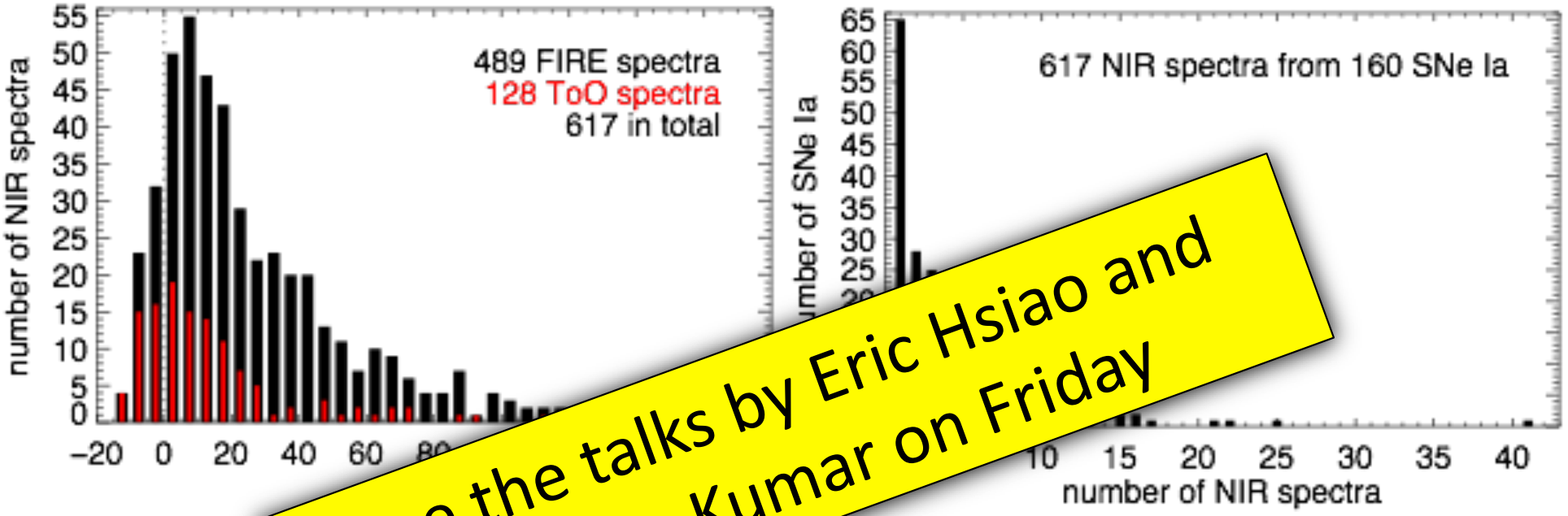
Boldt et al. (2014)

CSP-II: NIR Spectroscopy



- In collaboration with CfA group (Marion, Kirshner) and Dave Sand
- FIRE is the workhorse instrument, but ToO spectra obtained with IRTF and Gemini-N helped to improve the statistics at maximum and pre-maximum
- Sample is 15 times larger than the previous largest sample from Marion et al. (2009)

CSP-II: NIR Spectroscopy



See the talks by Eric Hsiao and Sahana Kumar on Friday

- In co[illegible]CfA group (Marion, Kirshner) and Dave Sand
- FIRE is the workhorse instrument, but ToO spectra obtained with IRTF and Gemini-N helped to improve the statistics at maximum and pre-maximum
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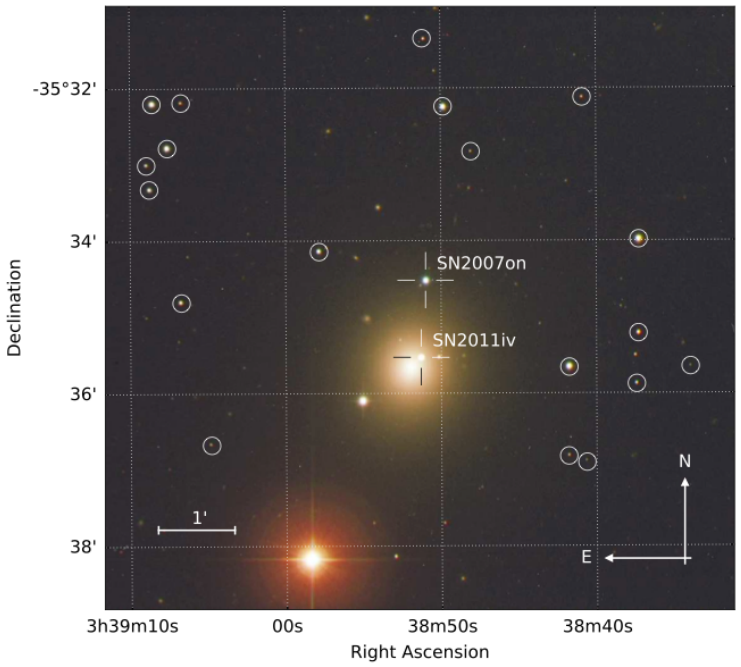
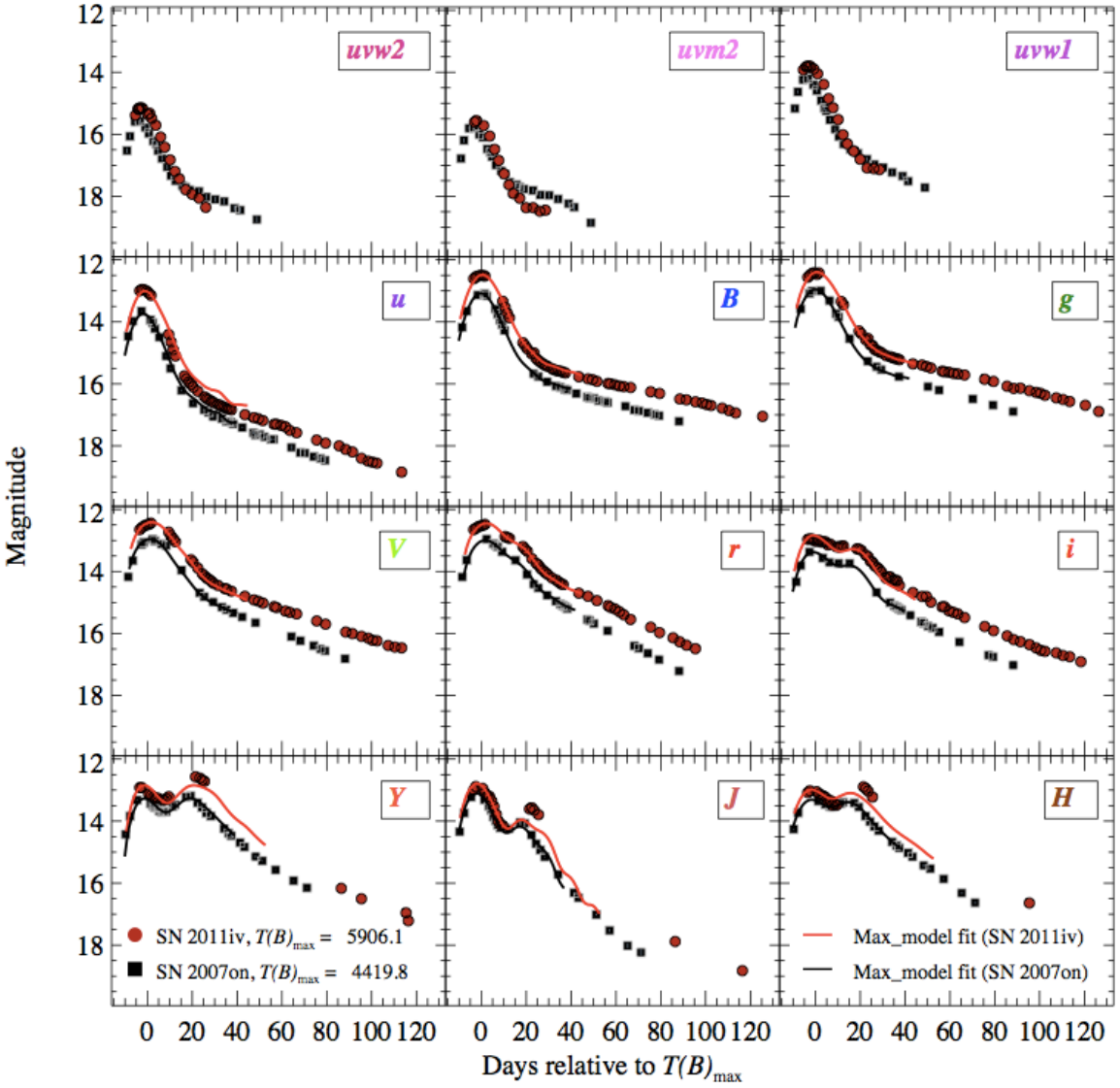
SNe 2007on & 2011iv in NGC 1404

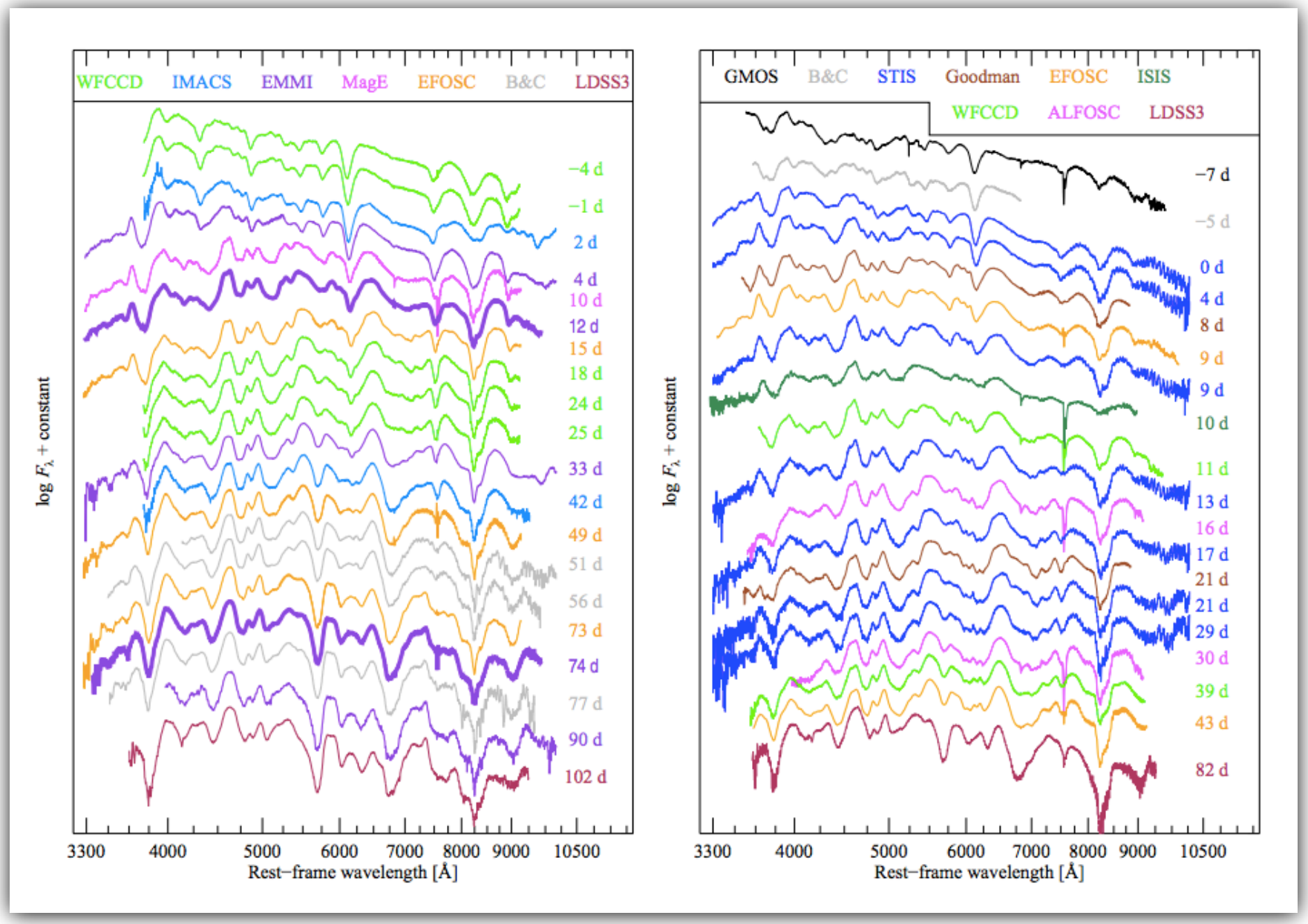


Two “transitional” SNe Ia hosted by the Fornax cluster member and elliptical galaxy, NGC 1404, and observed by the CSP-I and II.



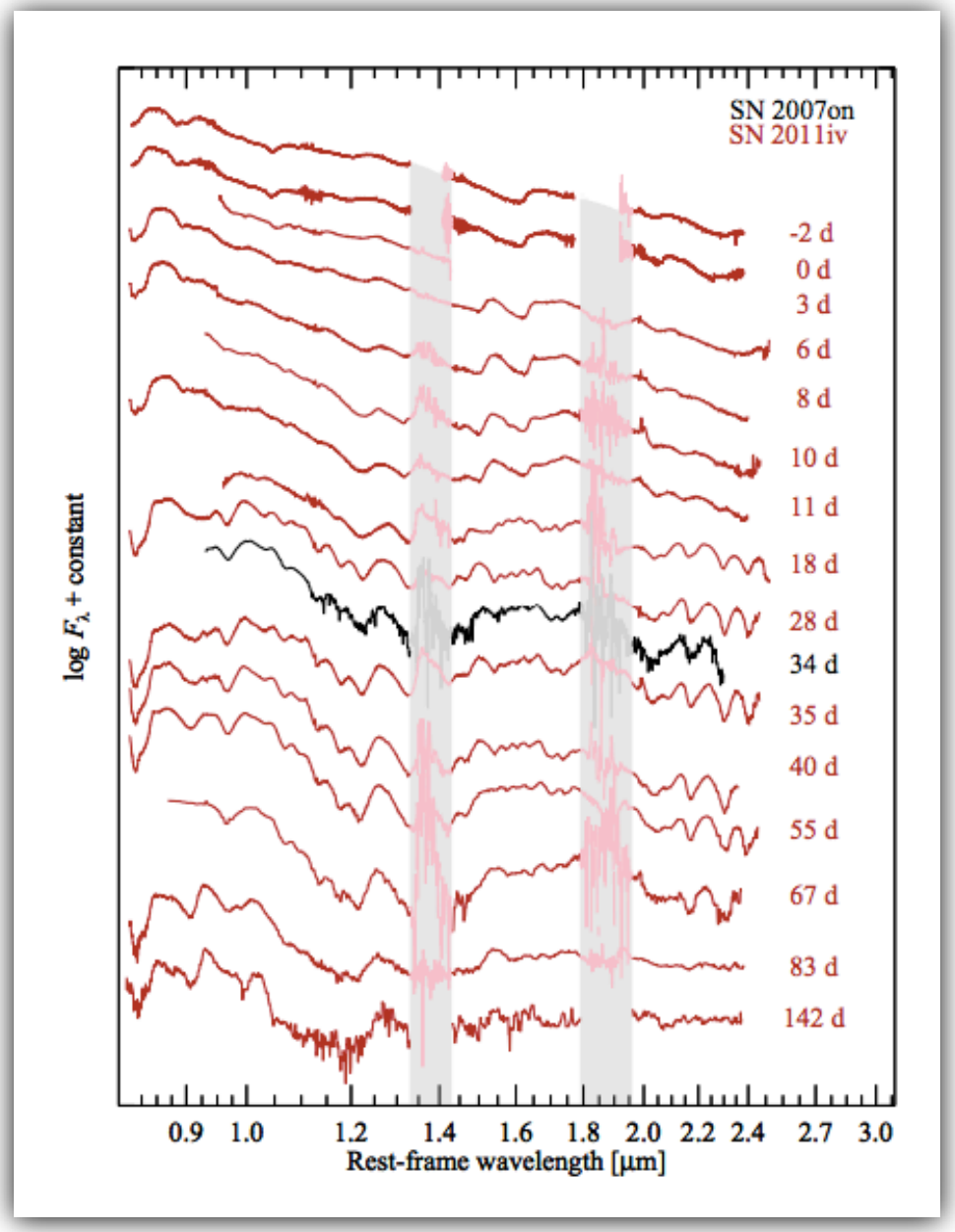
Gall et al. (2018)

SNe 2007on & 2011iv in NGC 1404



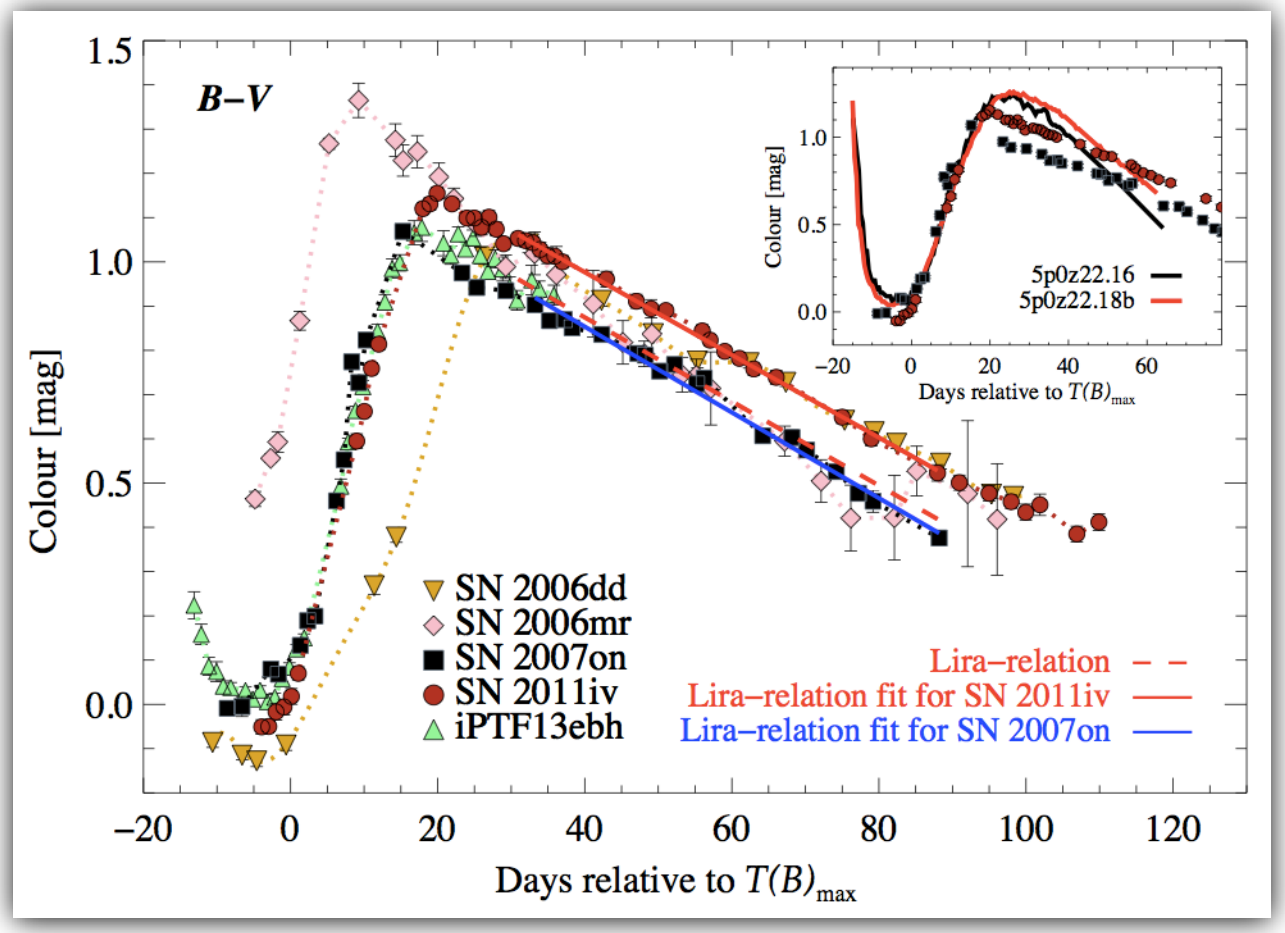
Gall et al. (2018)

SNe 2007on & 2011iv in NGC 1404



Gall et al. (2018)

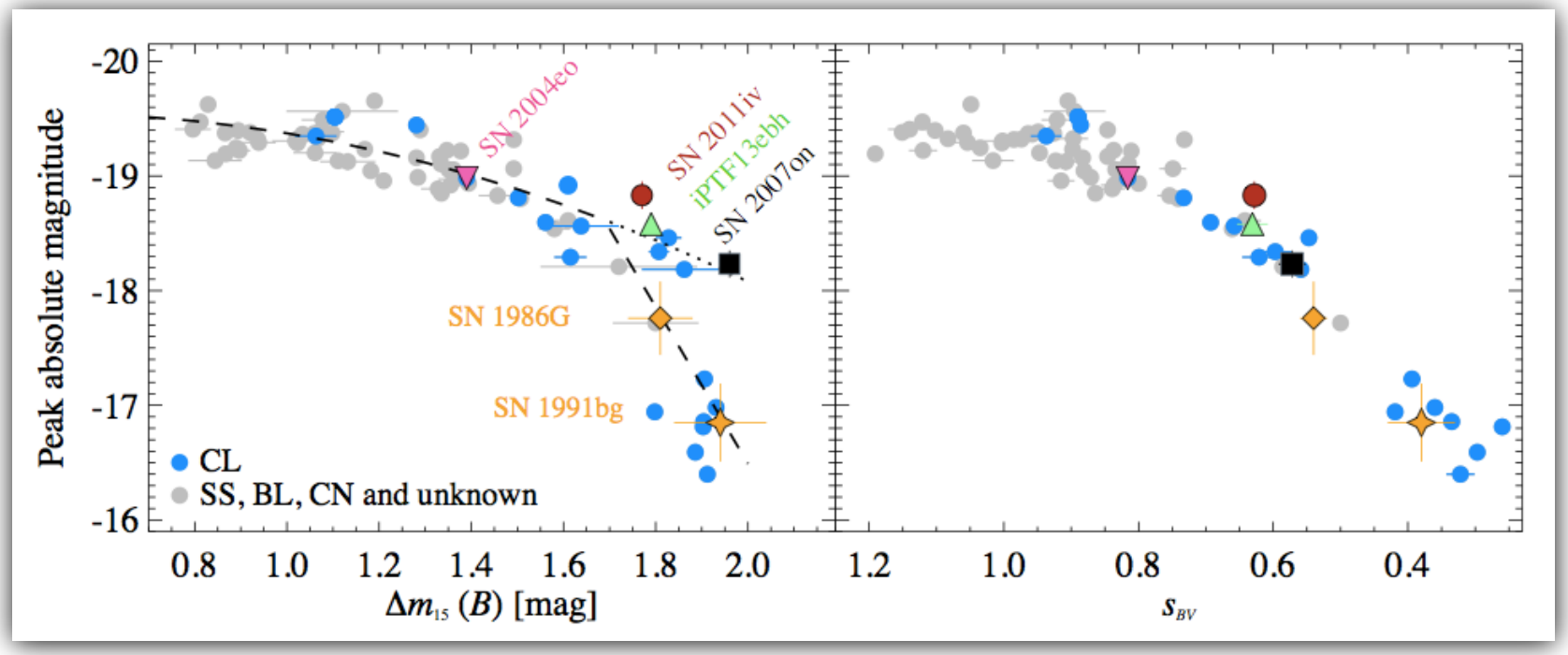
SNe 2007on & 2011iv in NGC 1404

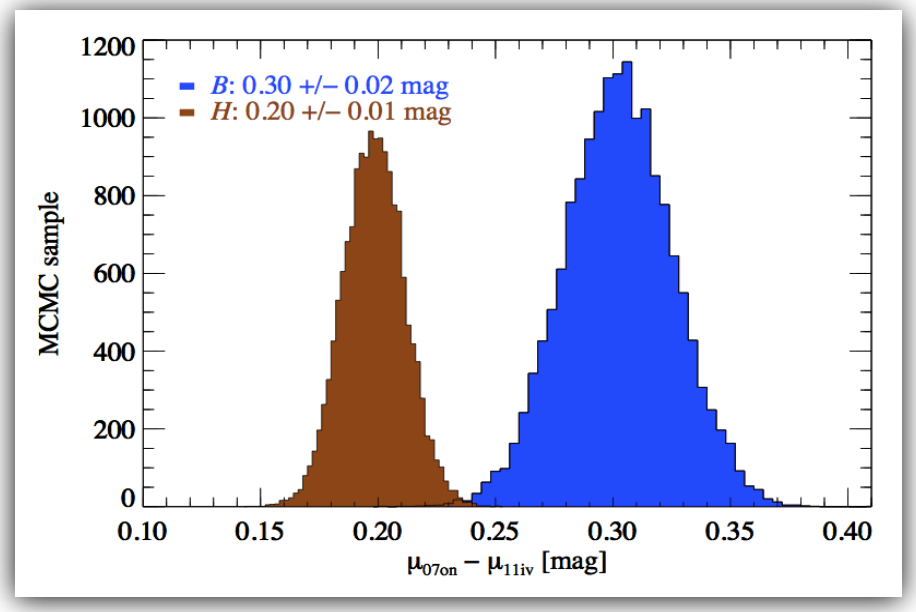


Gall et al. (2018)

In delay-detonation models, to first order, the transition density drives the luminosity–width relation, while the central density is an important second-order parameter. Within this context, the differences in the (B –V) color evolution along the Lira regime suggests the progenitor of SN 2011iv had a higher central density than SN 2007on.

SNe 2007on & 2011iv in NGC 1404

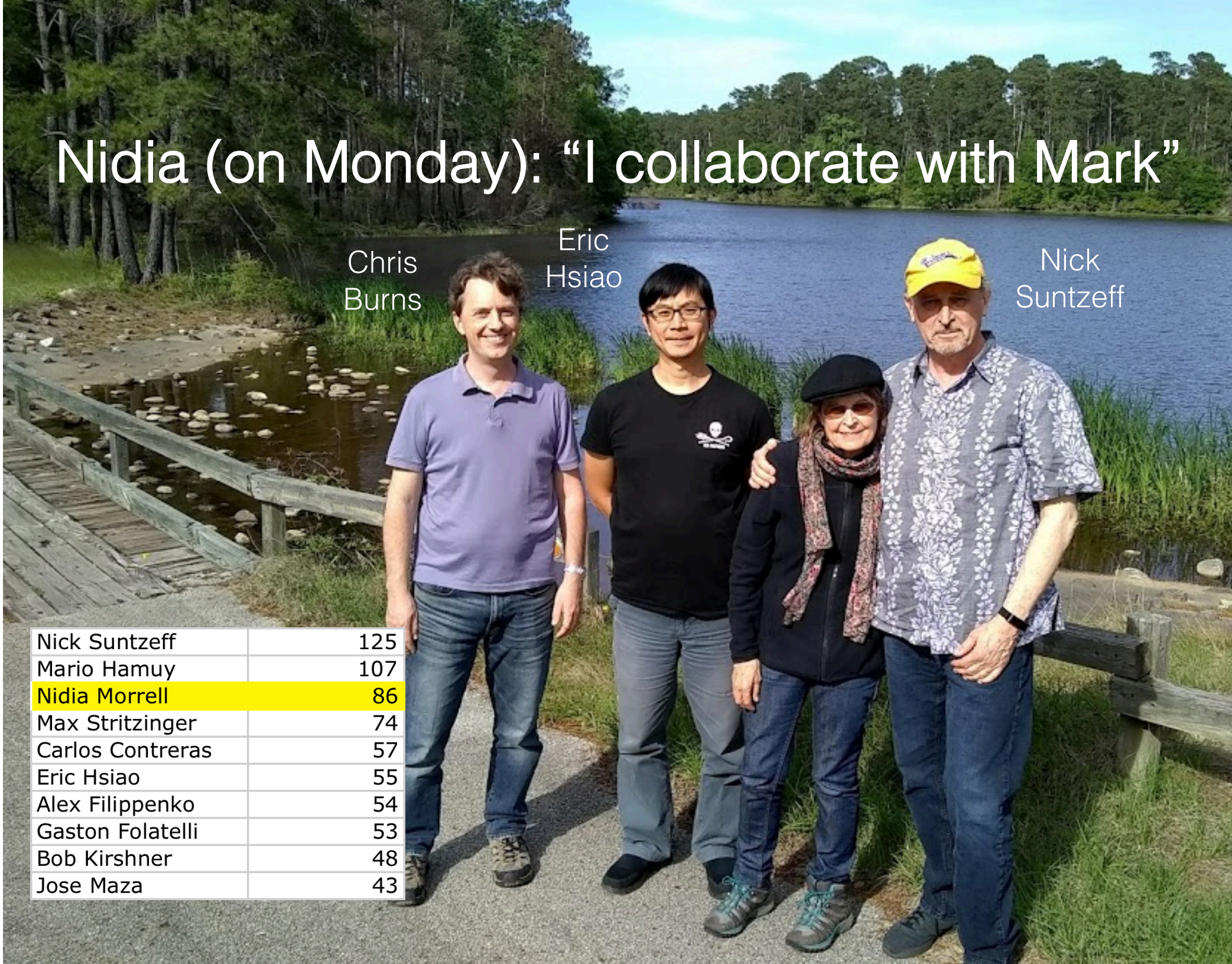




These findings serve as a cautionary tale for the use of transitional SNe Ia located in early-type hosts in the quest to measure cosmological parameters.

Gall et al. (2018)

Nidia (on Monday): “I collaborate with Mark”



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Summary

- Chile has a rich history of SN surveys
- Thanks to the work of the Calan-Tololo, High-z, and SCP surveys, the discovery of dark energy was made possible
- This legacy continues today with the Dark Energy Survey and, soon, LSST


Thank You!