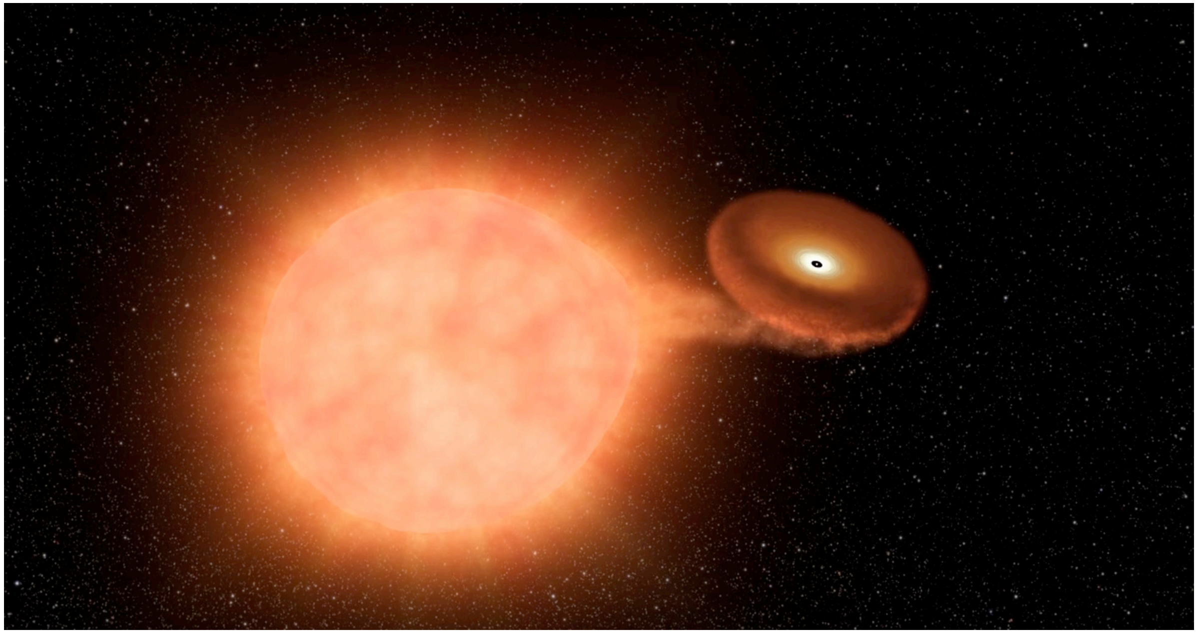
Distant Standard Candles: Type Ia Supernovae

Review:

- *White dwarf held up by electron degeneracy pressure. In degeneracy, pressure depends only on density, not temperature.*
- *In a binary system, mass transfer from companion slowly adds mass to the WD, increasing central density and temperature.*
- *When mass reaches 1.3 Msun, temps get high enough that C/O can begin fusing. This releases energy and raises core temp, which in turn drives faster C/O fusion.*
- *Runaway effect. When half the C/O converts to Fe, enough energy is released that the star blows up.*

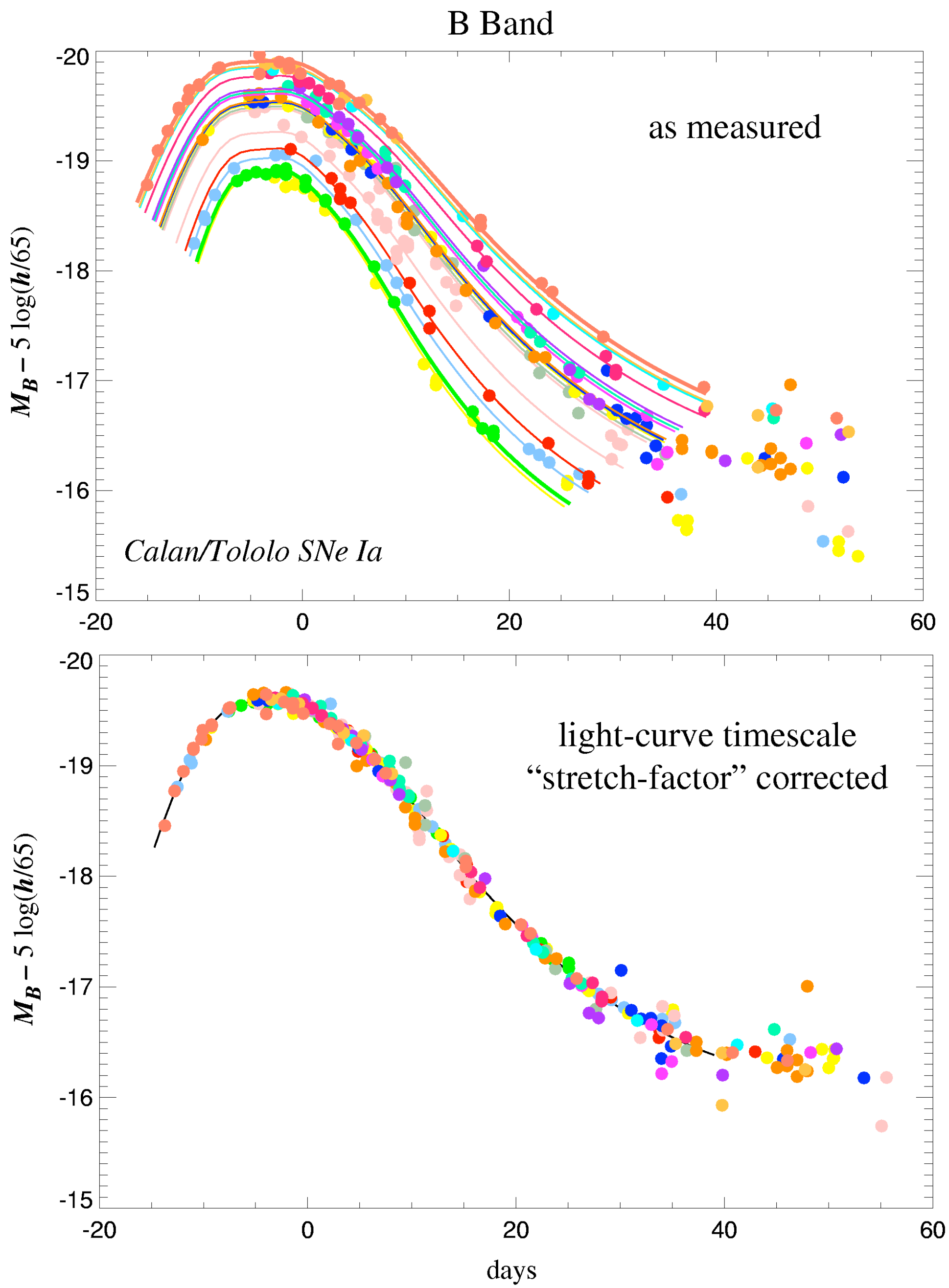
But they are rare. Typically not feasible for distances to a *particular* galaxy, but good for statistical/cosmological studies of expansion rate.



Type Ia SNe are standard candles once we apply the decline rate correction (more luminous SNe fade more slowly).

Δm_{15} = magnitude change 15 days after peak, correlates with peak absolute magnitude

Note, though, that the absolute magnitudes shown here are derived from Hubble Law distances, and thus *depend* on the adopted Hubble Constant. They are not *independently* calibrated.



Kim, *et al.* (1997)

Calibrating Type Ia SNe

To calibrate the peak luminosity, we want Cepheid distances to galaxies that have hosted observed Type Ia supernovae.

The situation in 1997:

A. Saha: H_0 *from type Ia supernovae*

SN Ia	Galaxy	$M_B(max)$	$M_V(max)$	$\Delta m_{15}(B)$
1937C	IC 4182	-19.65 ± 0.18	-19.64 ± 0.13	1.07
1895B	NGC 5253	-19.80 ± 0.28	—	—
1972E	NGC 5253	-19.55 ± 0.23	-19.50 ± 0.21	0.94
1981B	NGC 4536	-19.29 ± 0.13	-19.32 ± 0.12	1.10
1960F	NGC 4496	-19.43 ± 0.14	-19.52 ± 0.20	1.06
1990N	NGC 4639	-19.33 ± 0.23	-19.42 ± 0.23	1.01
1989B	NGC 3627	-19.51 ± 0.26	-19.49 ± 0.25	1.31

$$\langle M_B(max) \rangle = -19.51 \pm 0.06$$

scatter = 0.17 mag

Much progress since then! (from Riess+16)

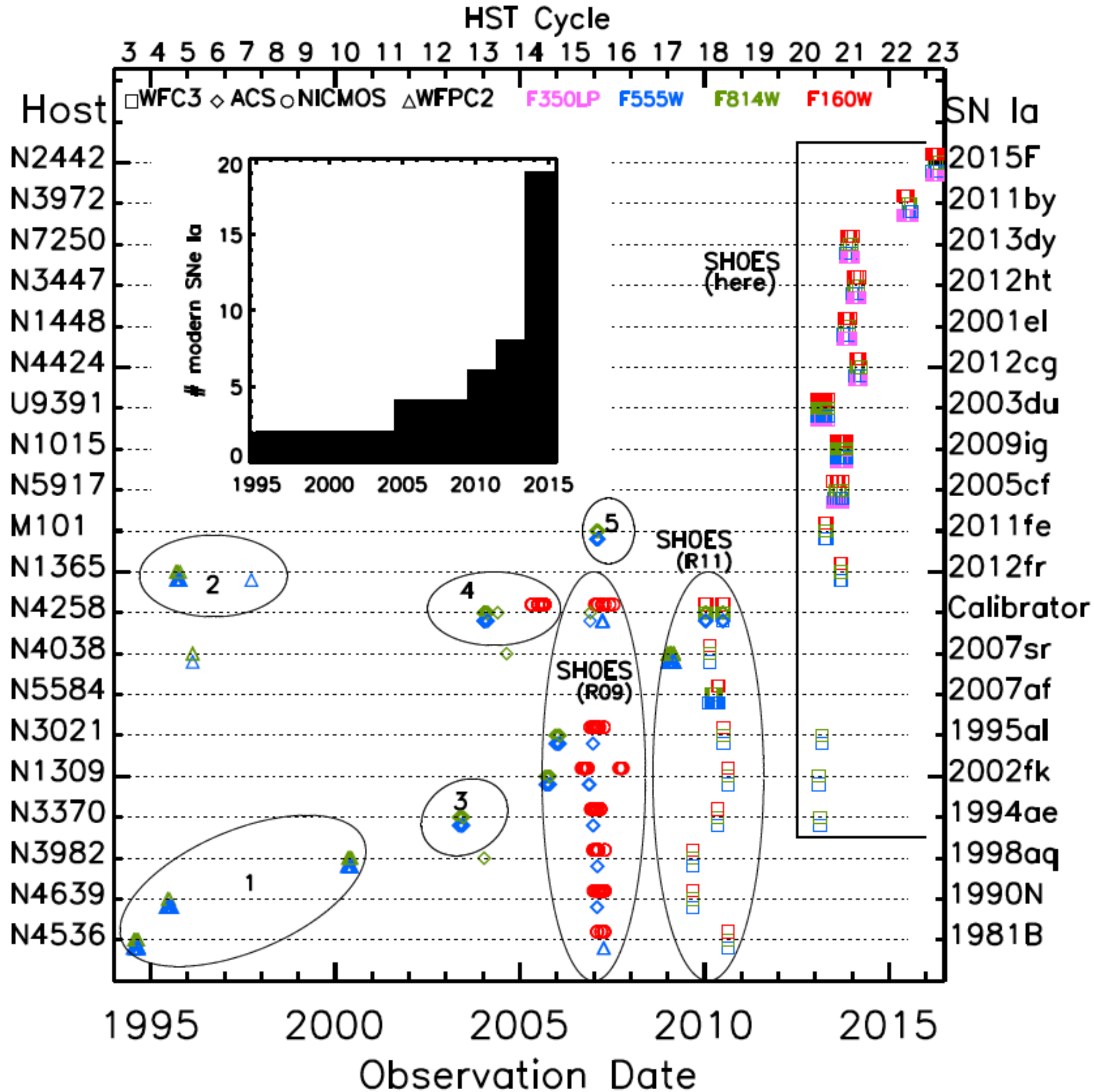


Figure 2. *HST* observations of the host galaxies of ideal SNe Ia. The data used to observe Cepheids in 19 SN Ia hosts and NGC 4258 were collected over 20 years with four cameras and over 600 orbits of *HST* time. 60–90 day campaigns in *F555W* and *F814W* or in *F350LP* were used to identify Cepheids from their light curves with occasional reobservations years later to identify Cepheids with $P > 60$ days. Near-IR follow-up observations in *F160W* are used to reduce the effects of host-galaxy extinction, sensitivity to metallicity, and breaks in the *P–L* relation. Data sources: (1) *HST* SN Ia Calibration Project, Sandage et al. (2006); (2) *HST* Key Project, Freedman et al. (2001); (3) Riess et al. (2005); (4) Macri et al. (2006); and (5) Mager et al. (2013).

Cepheid Period-Luminosity plots for each galaxy

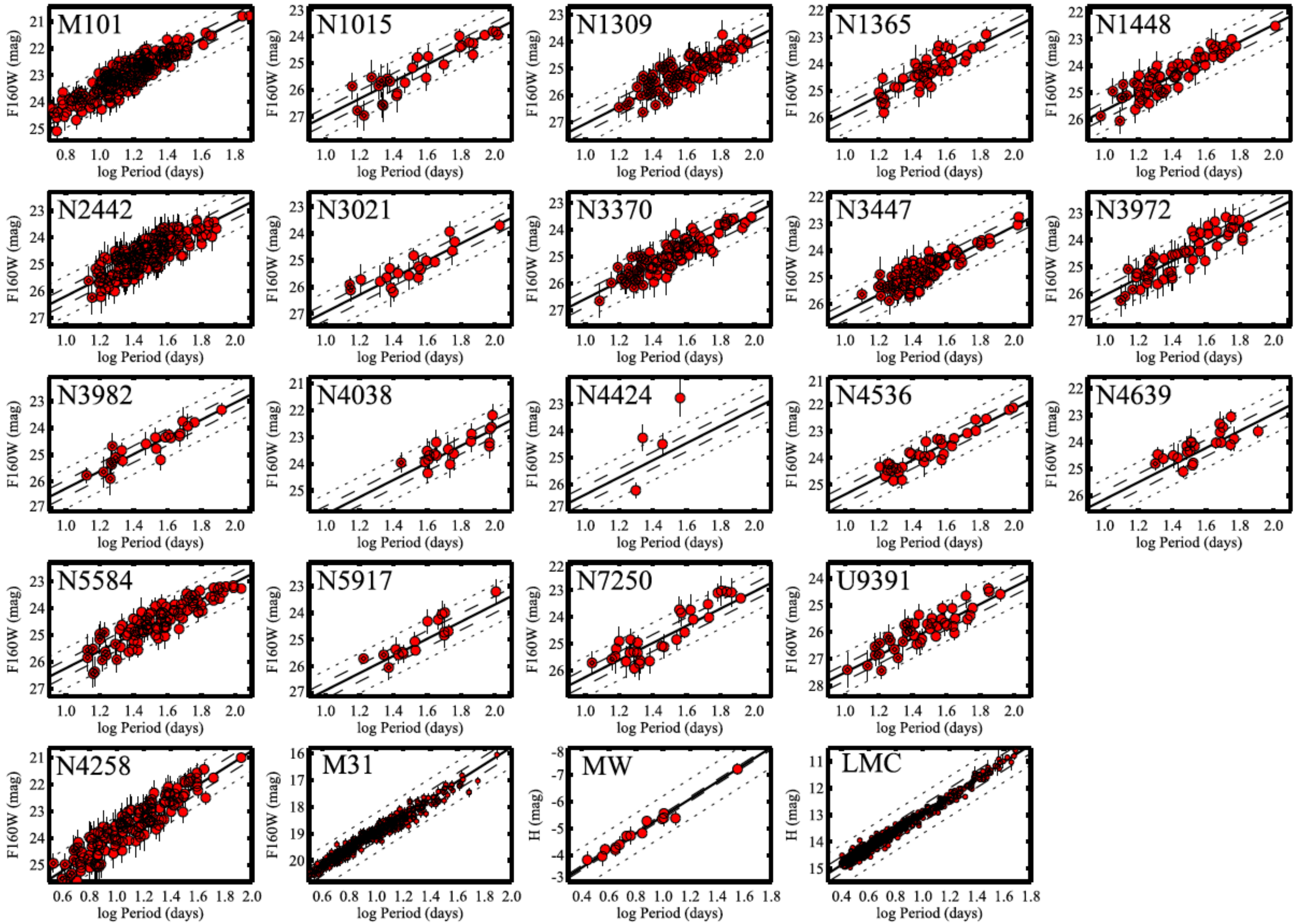
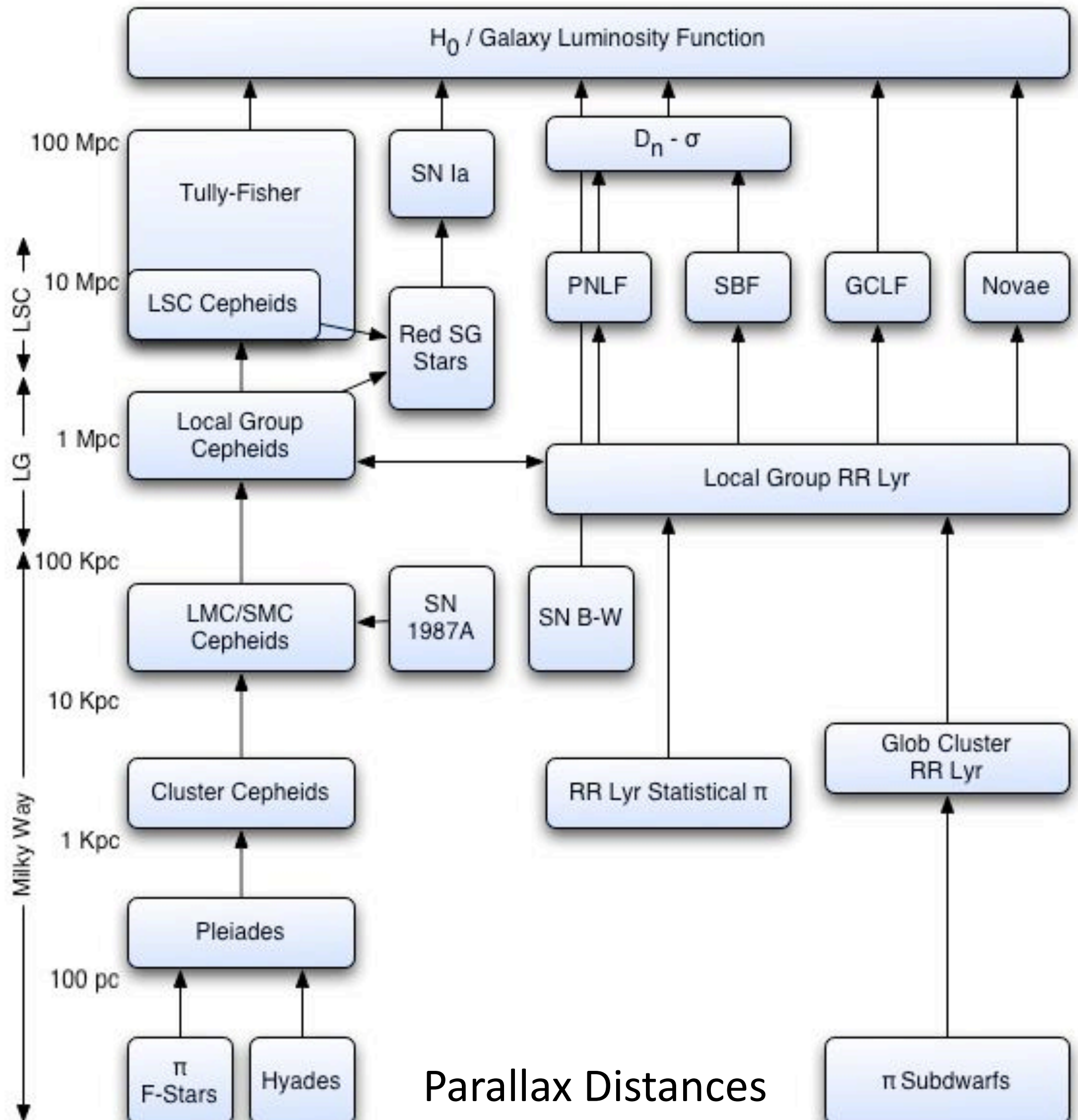


Figure 6. Near-infrared Cepheid *P–L* relations. The Cepheid magnitudes are shown for the 19 SN hosts and the four distance-scale anchors. Magnitudes labeled as *F160W* are all from the same instrument and camera, WFC3 *F160W*. The uniformity of the photometry and metallicity reduces systematic errors along the distance ladder. A single slope is shown to illustrate the relations, but we also allow for a break (two slopes) as well as limited period ranges.

Rethinking the Cepheids: How well do we know the calibrated period-luminosity relation?

Remember, to get the calibrated Cepheid P-L relationships, we had to have distances to Cepheids, which have uncertainties of their own.



Adapted by Stuart Robbins from: Jacoby et al. *A Critical Review of Selected Techniques for Measuring Extragalactic Distances.* PASP, **104** (1992).

Riess+18

Direct Trigonometric Parallaxes for Milky Way Cepheids from Hubble

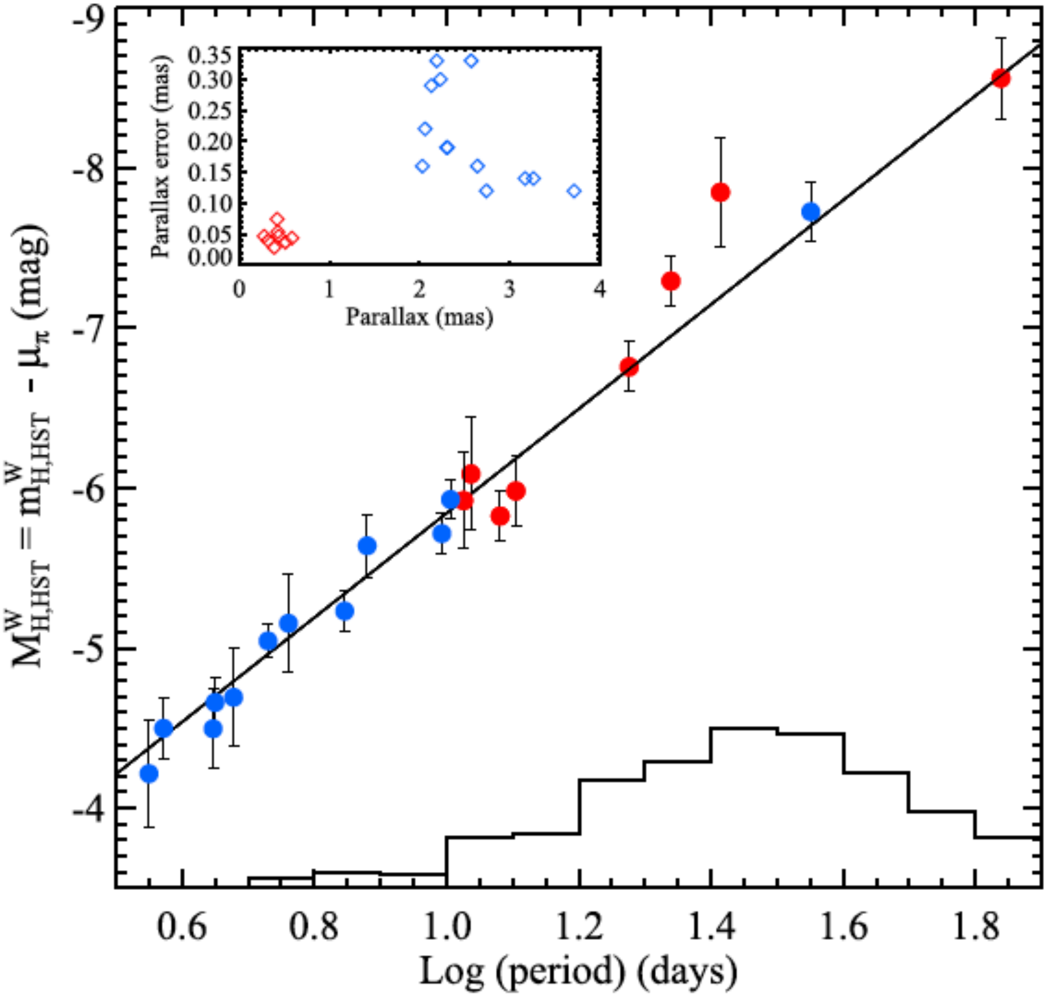


Figure 12. *P–L* relation of Milky Way Cepheids based on trigonometric parallax measurements. The points in blue were measured with the *HST* FGS (Benedict et al. 2007) and *Hipparcos* (van Leeuwen et al. 2007) and are all within 0.5 kpc, and the points in red are presented here from spatial scanning of WFC3 and are in the range of $1.7 < D < 3.6$ kpc. The inset shows the uncertainties in the measured parallaxes.

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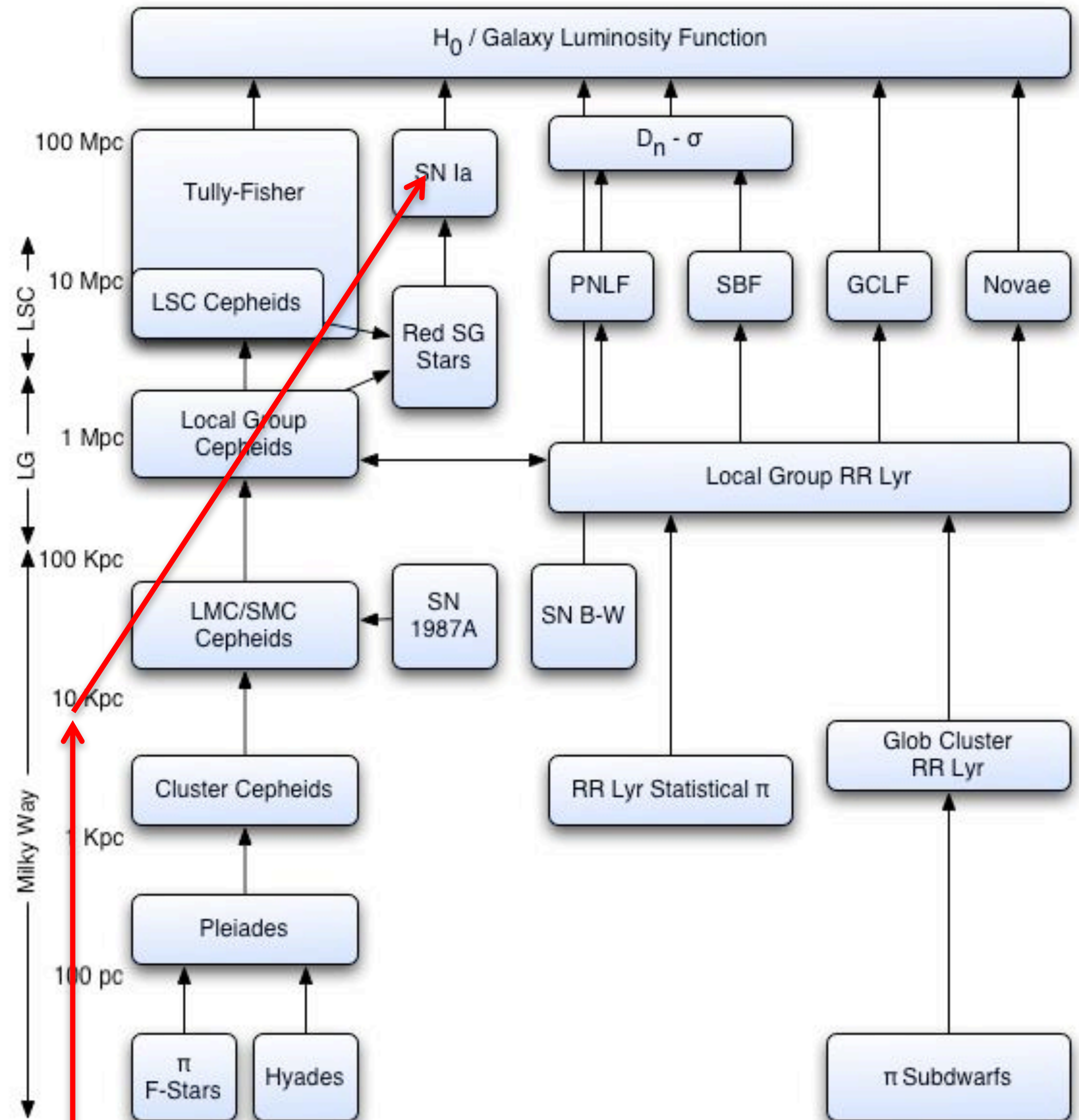
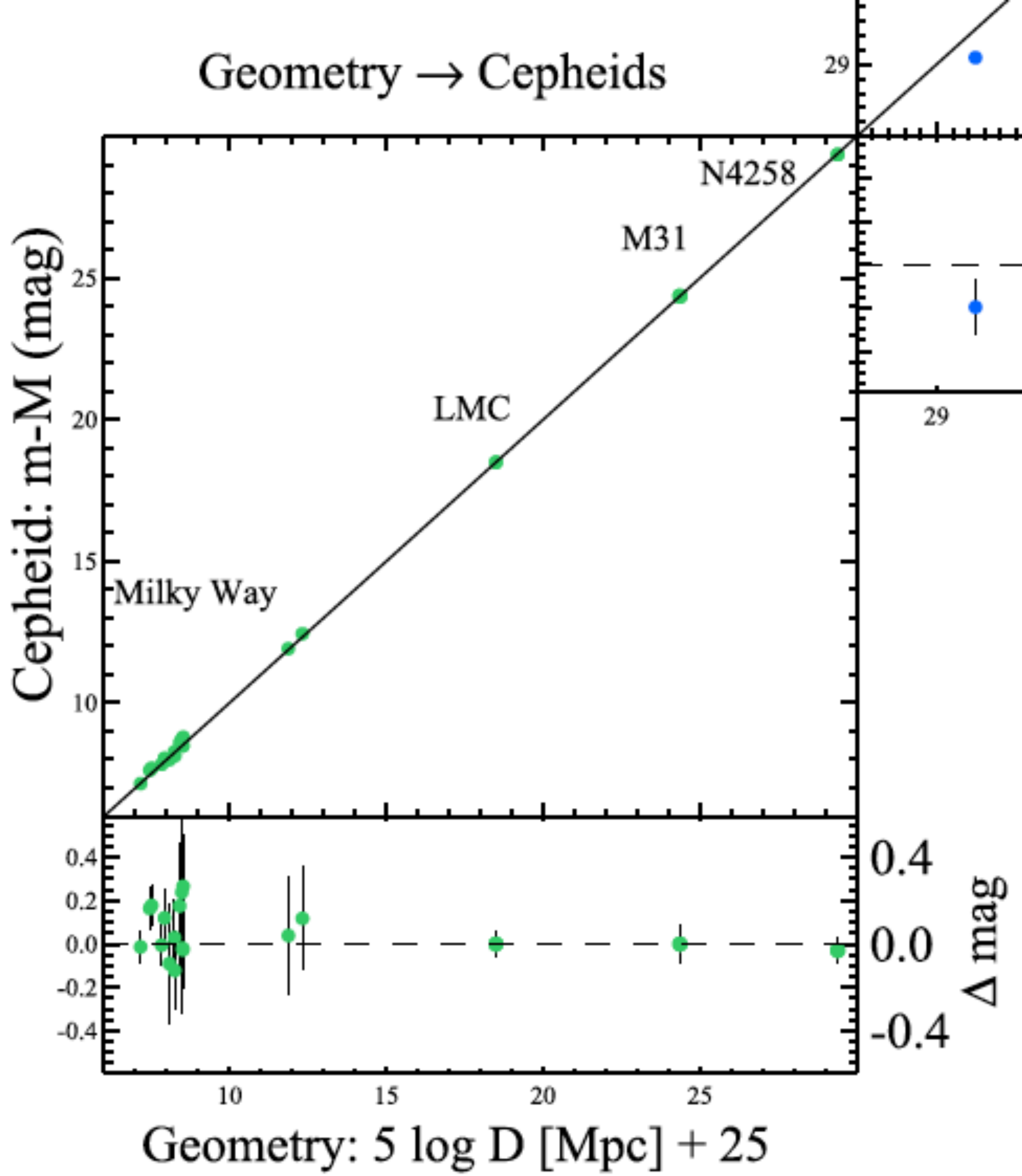


Adapted by Stuart Robbins from: Jacoby et al. *A Critical Review of Selected Techniques for Measuring Extragalactic Distances.* PASP, **104** (1992).

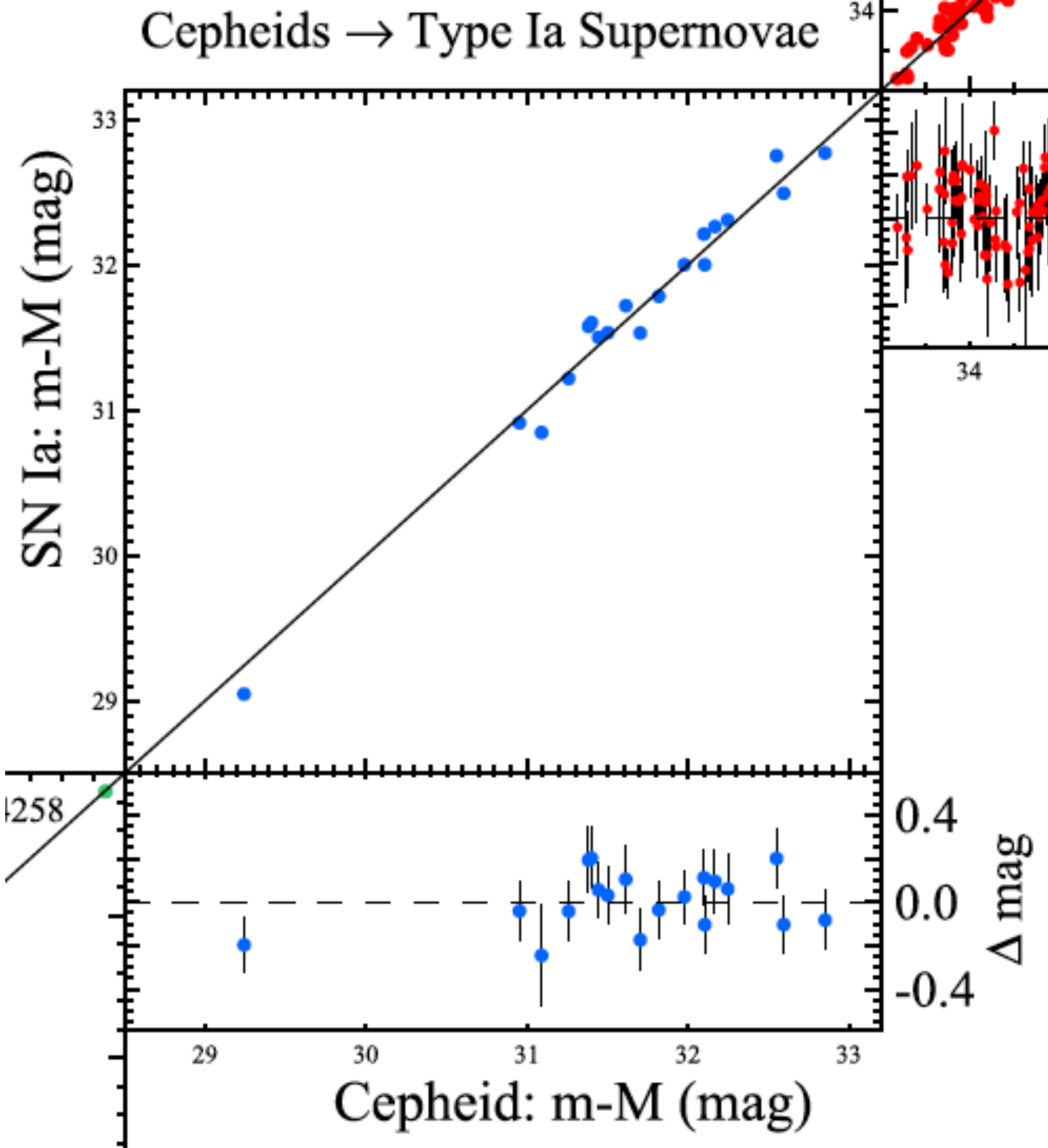
Given a direct geometric distance from parallax (or other methods), you can calibrate the Cepheid P-L relationship.

(If your Cepheid P-L relation is calibrated wrong, geometric distances and Cepheid distances will disagree.)



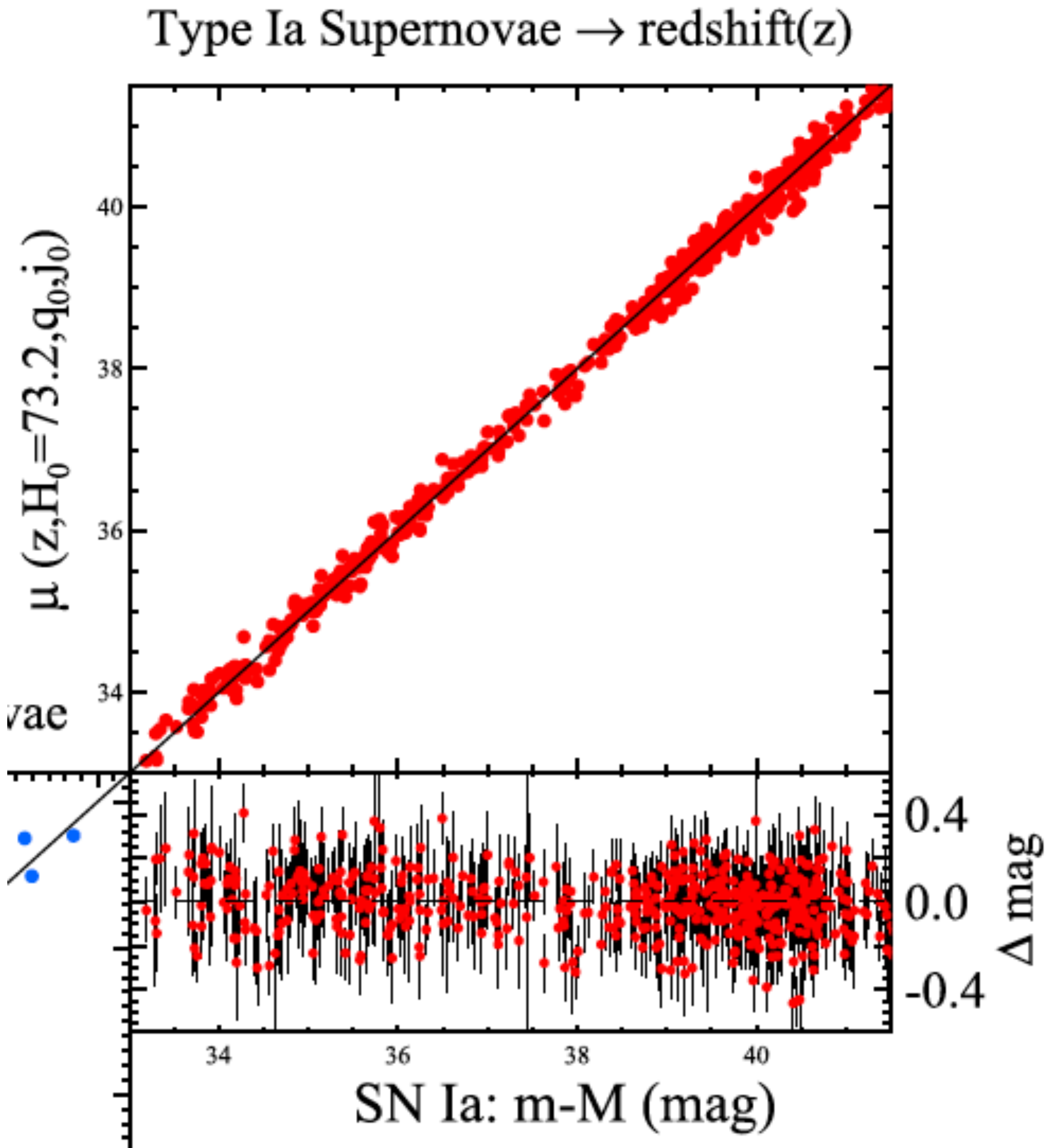
Given distances from Cepheids, you can calibrate the Type Ia SNe peak magnitudes.

(If your SNe mags are calibrated wrong, Cepheid distances and SNe distances will disagree.)



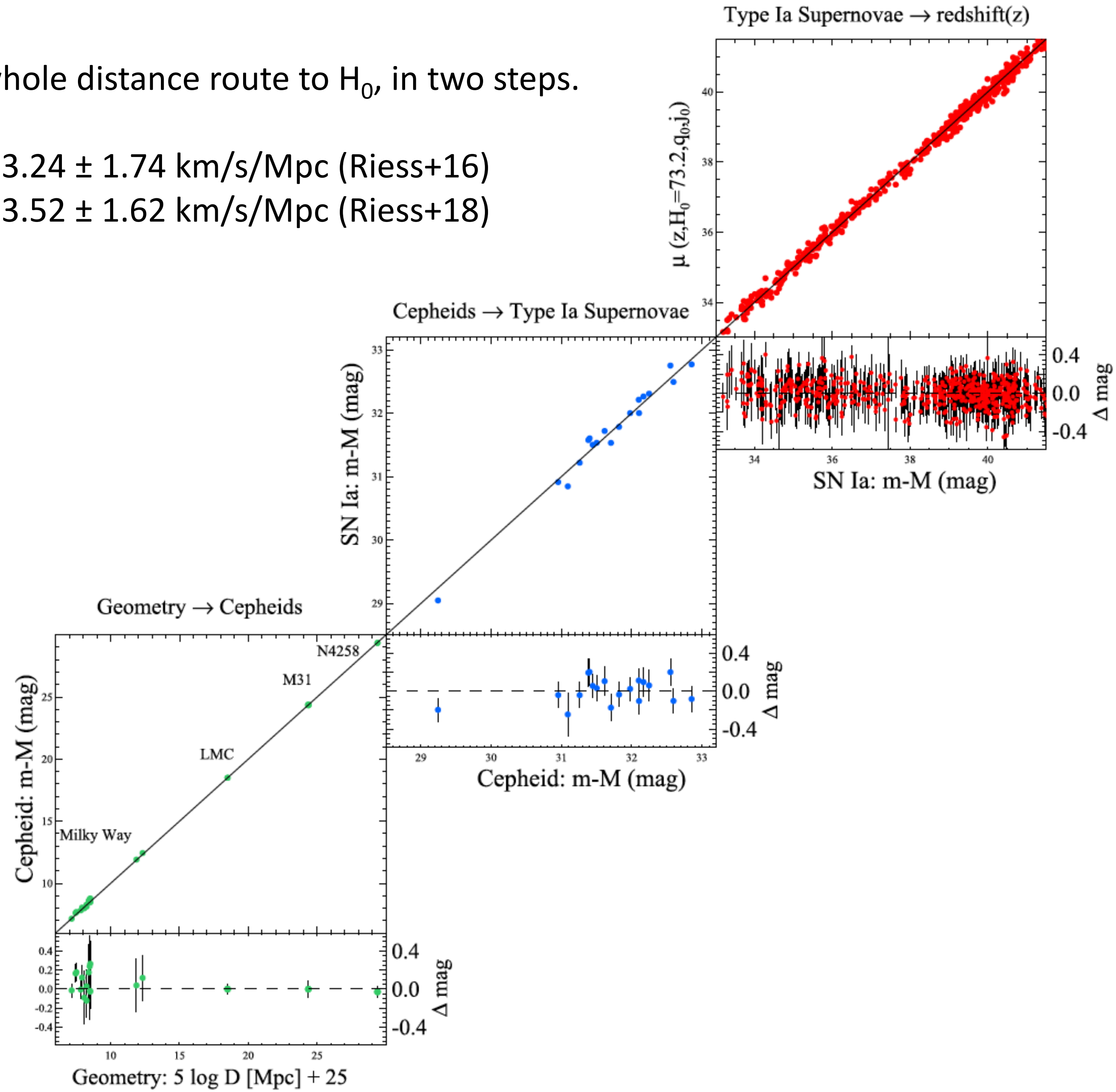
Given distances from SNe, you can solve for the Hubble constant by making luminosity distance match for more distant SNe.

(If your Hubble constant is wrong, SNe distances and luminosity distances will disagree.)



The whole distance route to H_0, in two steps.

H_0 = 73.24 ± 1.74 km/s/Mpc (Riess+16)
H_0 = 73.52 ± 1.62 km/s/Mpc (Riess+18)



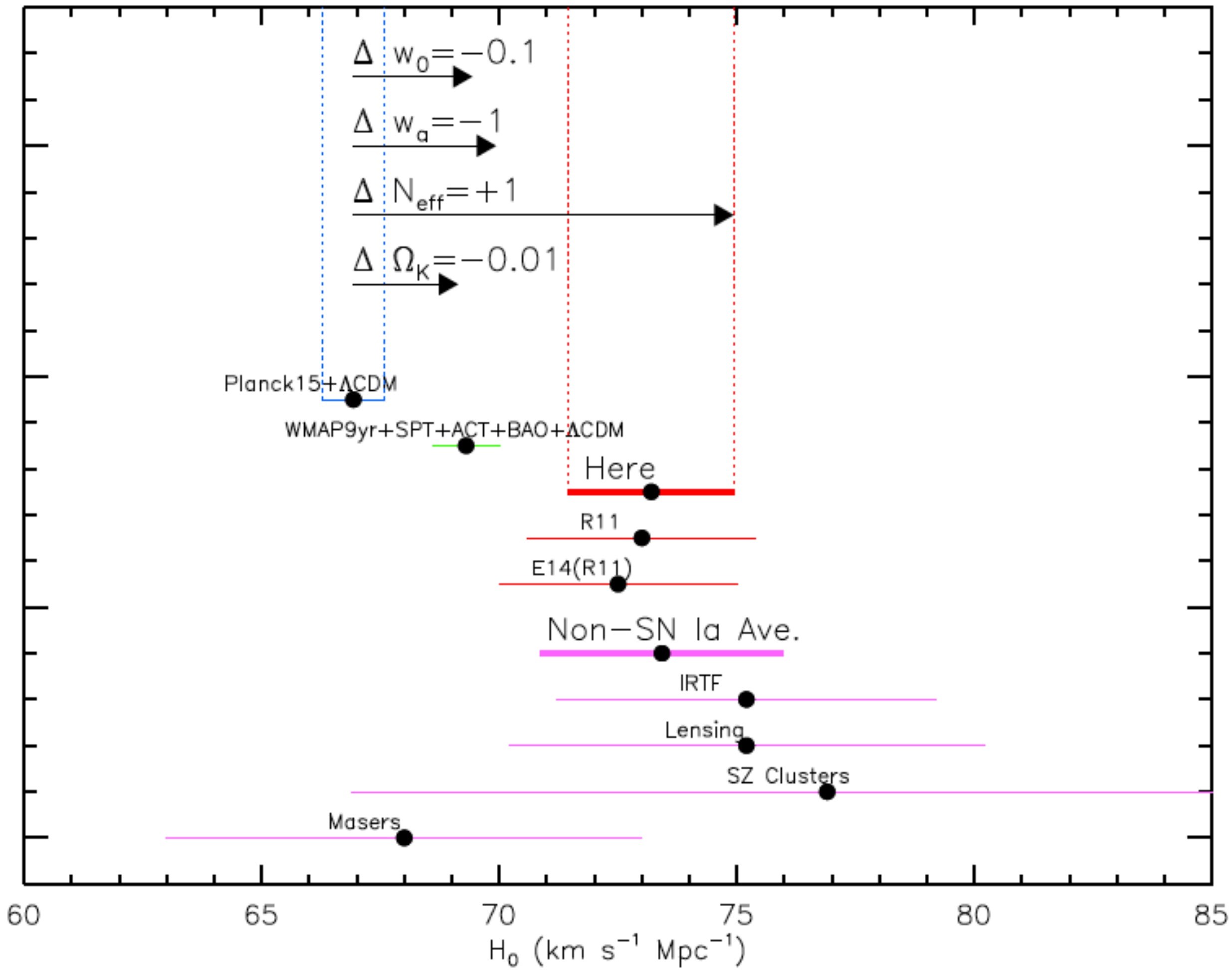


Figure 13. Local measurements of H_0 compared to values predicted by CMB data in conjunction with ΛCDM. We show 4 SN Ia-independent values selected for comparison by Planck Collaboration et al. (2014) and their average, the primary fit from R11, its reanalysis by Efstathiou (2014) and the results presented here. The 3.4σ difference between *Planck*+ΛCDM (Planck Collaboration et al. 2016) and our result motivates the exploration of extensions to ΛCDM.