The H0 Tension

And repercussions on opposite datasets

Outline

1. Motivation for precise H0

2. How is it measured locally?
   a. Parallaxes
   b. Cepheids/TRGB
   c. SNe Ia

3. If Planck H0 right, what happens locally?

4. Future local H0 measurements

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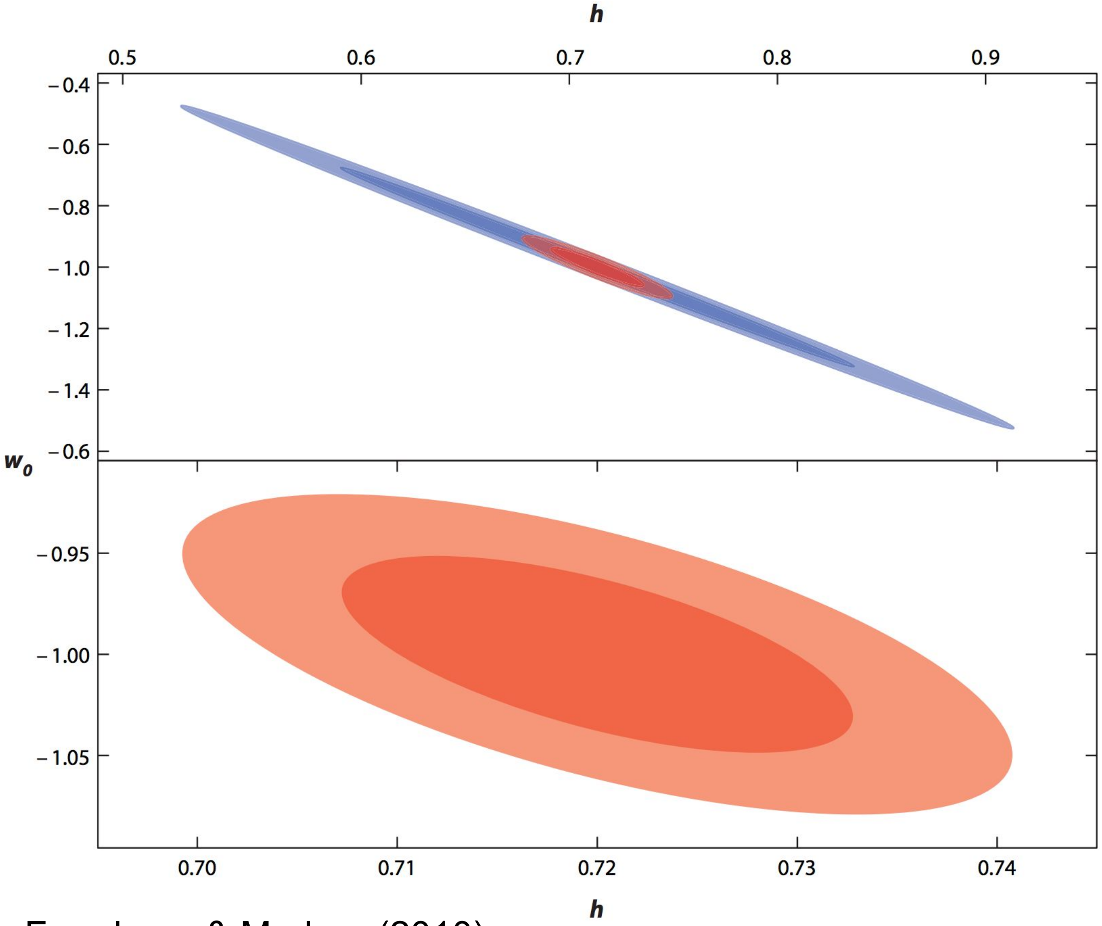
Why such a fuss?

H0 + w degenerate in CMB

H0 informs very-late-time deviations from smooth w(a) = w0+(1-a)wa

Additional constraints on intermediate z probes



Freedman & Madore (2010)

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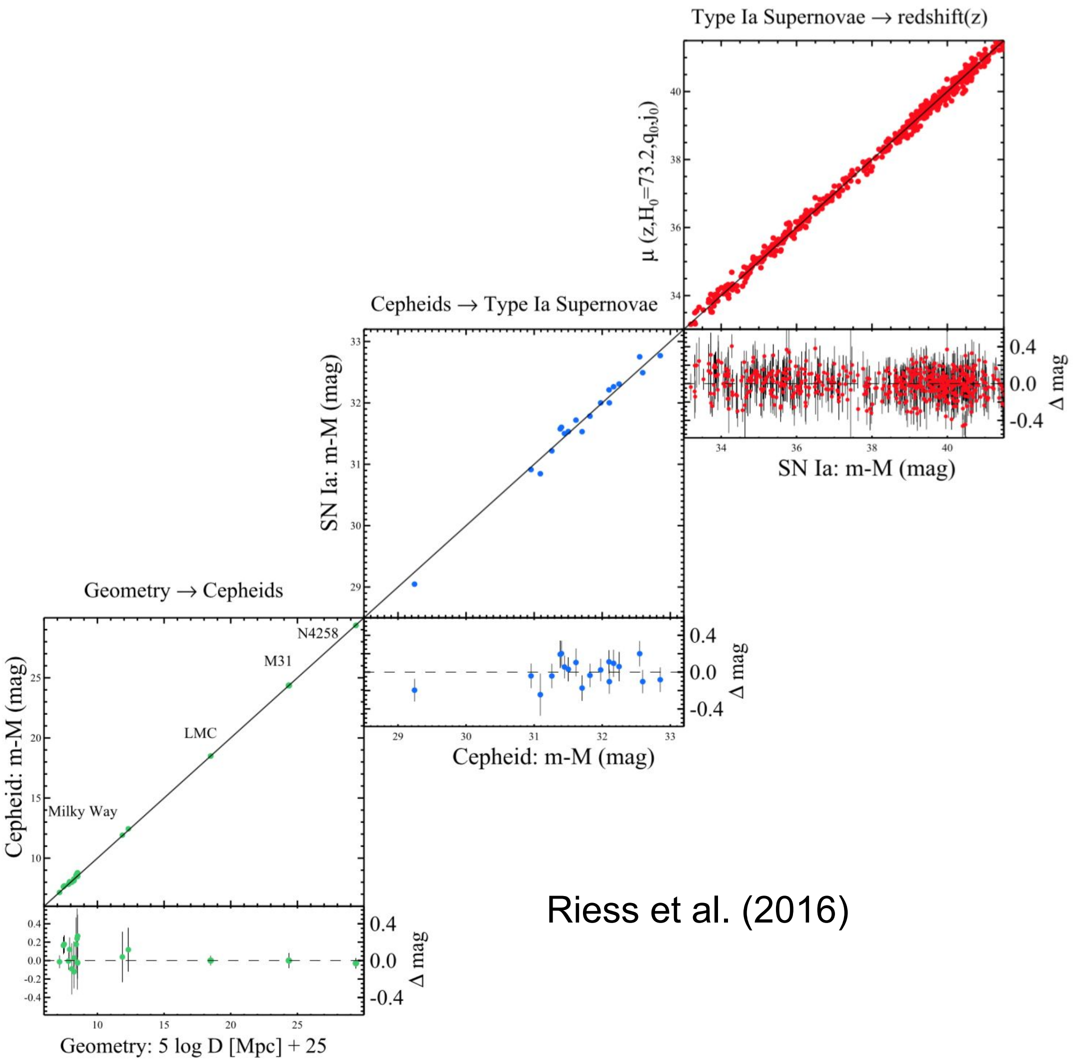
How to measure?

Split Hubble diagram into pieces

Calibrate each rung's absolute magnitude

SN calibration low N; dominates error



Riess et al. (2016)

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Parallaxes

Current HST (~8%) parallaxes for only 10 Cepheids in Benedict+07

GAIA will have 100s of Cepheids and 1000s of Red giants with parallax errors <1%

~2% error budget decrease to <~0.5%

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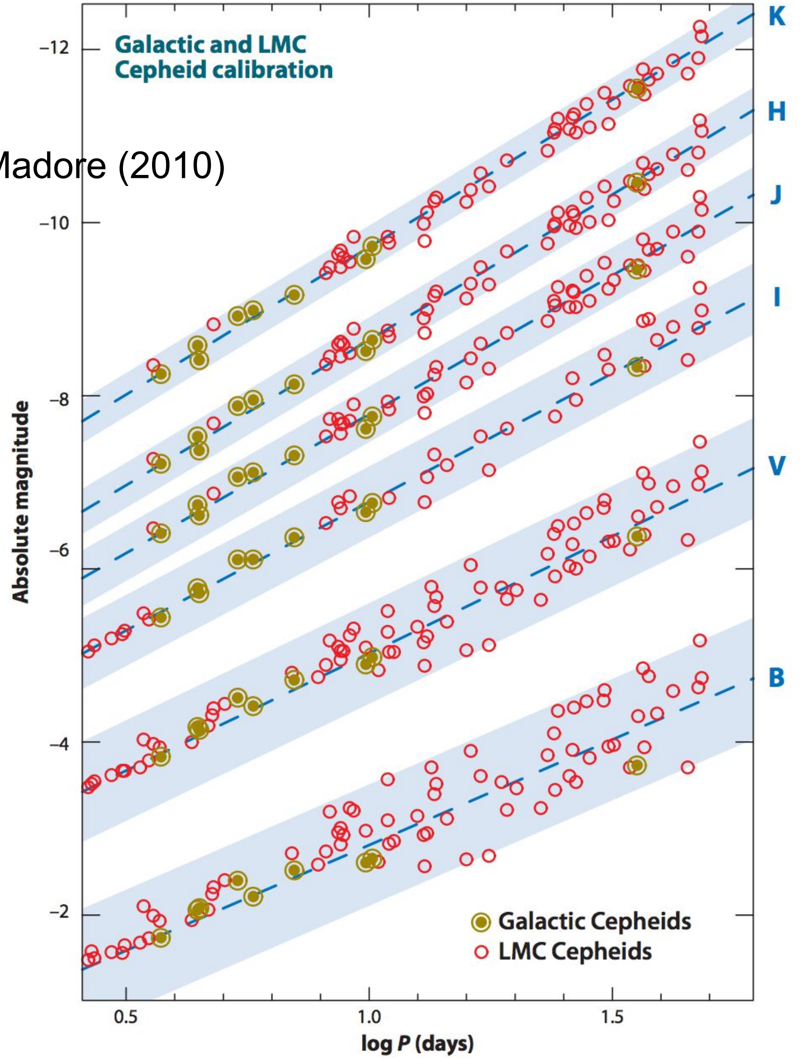
Cepheids

Freedman & Madore (2010)



IR to avoid reddening and metallicity effects

NIR Scatter ~0.10 mag

$$L = 4\pi R^2 \sigma T_{eff}^4$$

Period -- mean density relation

$$M_V = \alpha \log P + \beta (B - V)_0 + \gamma$$

Freedman & Madore (2010)

Known	**Key Project**	**Revisions**	**Anticipated**	**Basis**
Systematics	(2001)	(2007/2009)	*Spitzer*/JWST	
(1) Cepheid Zero Point	±0.12 mag	±0.06 mag	±0.03 mag	Galactic Parallaxes
(2) Metallicity	± 0.10 mag	±0.05 mag	±0.02 mag	IR + Models
(3) Reddening	±0.05 mag	±0.03 mag	±0.01 mag	IR 20–30 × Reduced
(4) Transformations	±0.05 mag	±0.03 mag	±0.02 mag	Flight Magnitudes
Final Uncertainty	±0.20 mag	±0.09 mag	±0.04 mag	Added in Quadrature
Percentage Error on H_0	±10%	±5%	±2%	Distances

Revisions (Column 2) incorporating the recent work of Benedict et al. (2007) and Riess et al. (2009b).

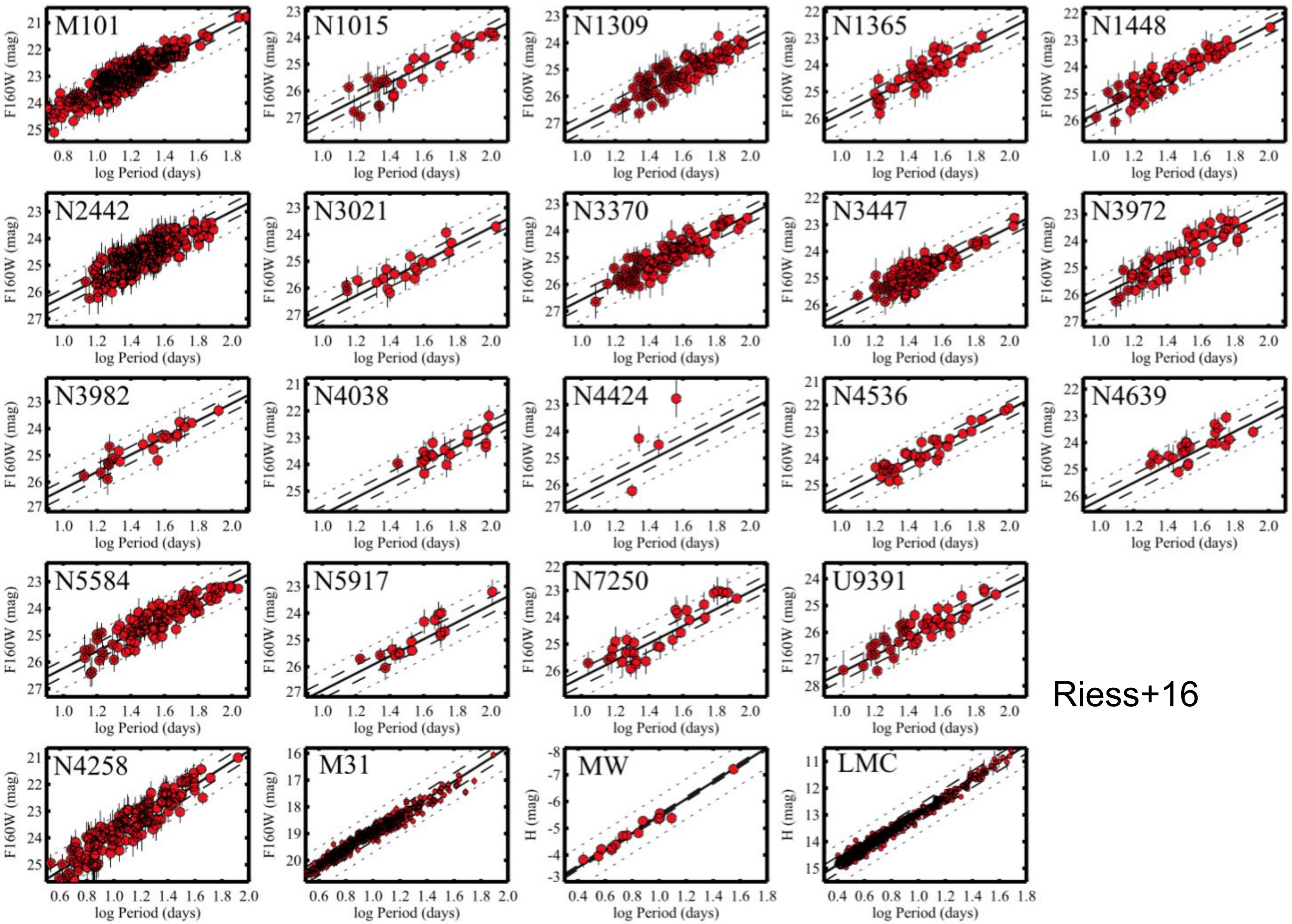
Freedman & Madore (2010)

Future of Cepheids

Reached their limit

Crowding is killer

Need to avoid crowded arms



Riess+16

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.

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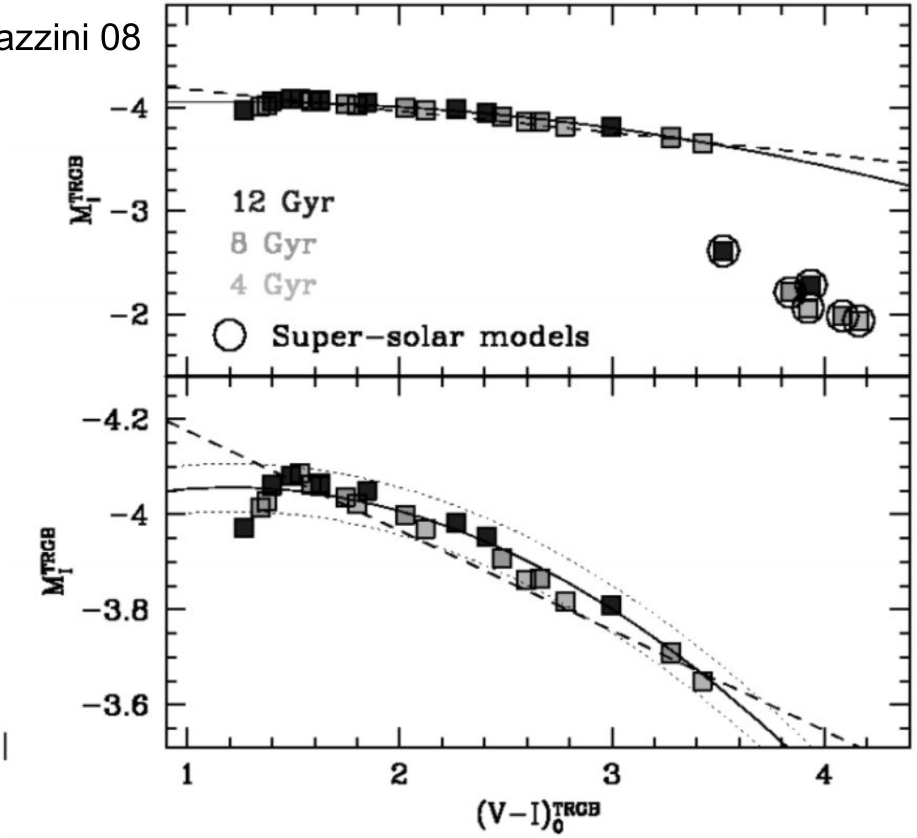
The Tip of the Red Giant Branch (TRGB)

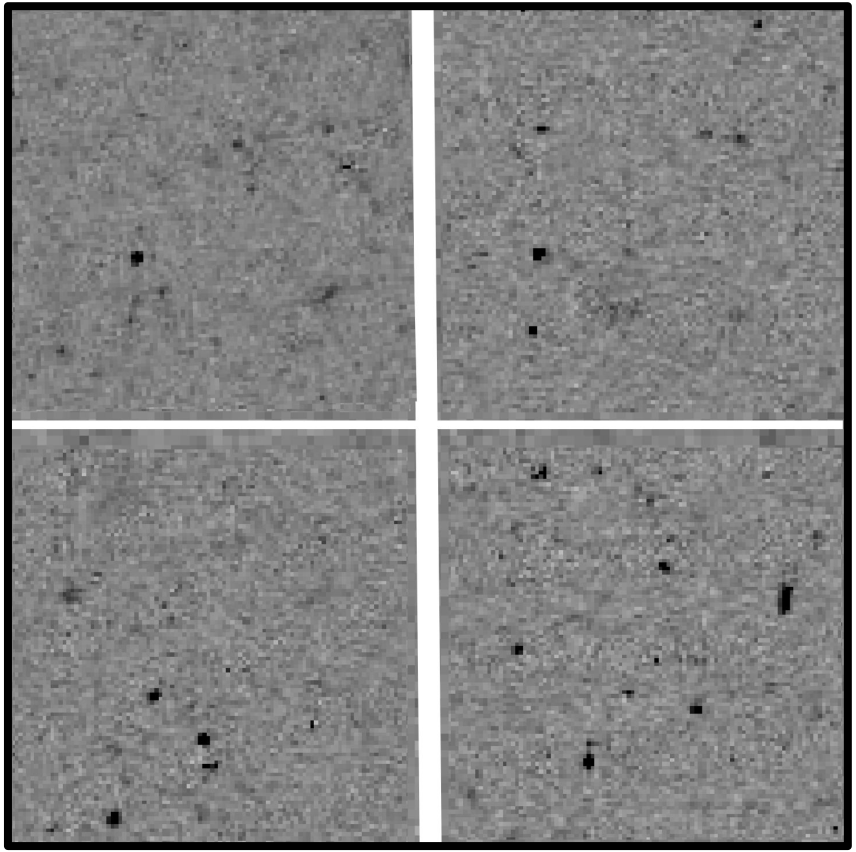
Compared to Cepheids

1. Metallicity dependence theory+empirical consistent
2. Reddening minimized by NIR *and* halo pointing
3. Inverted crowding “problem”; futu with JWST

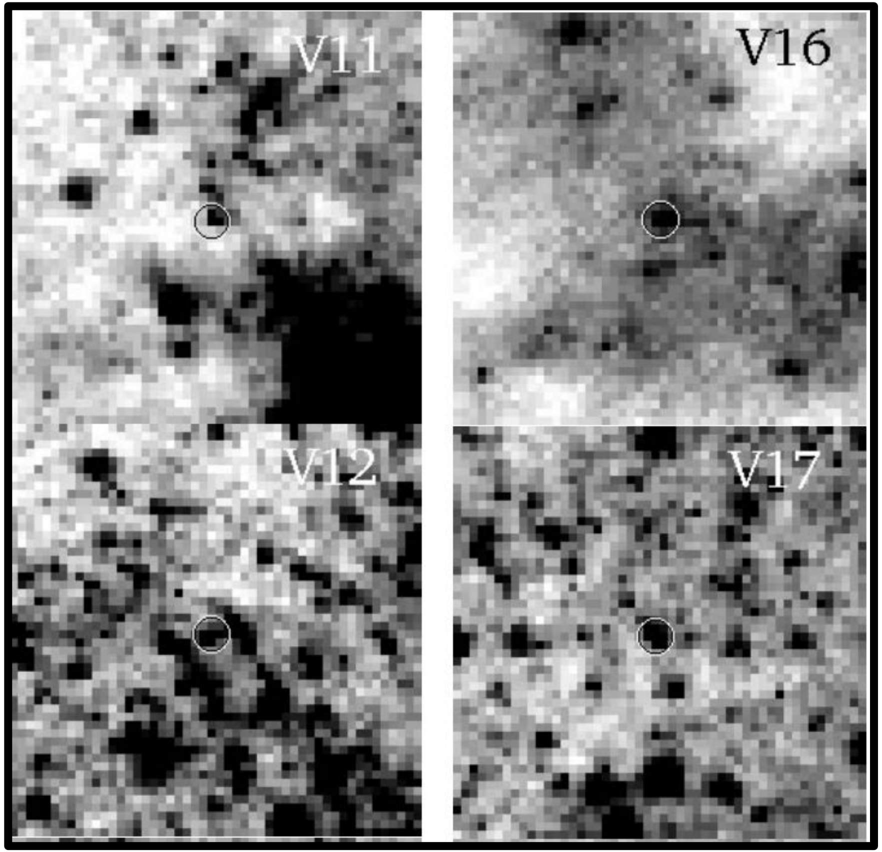
Bellazzini 08

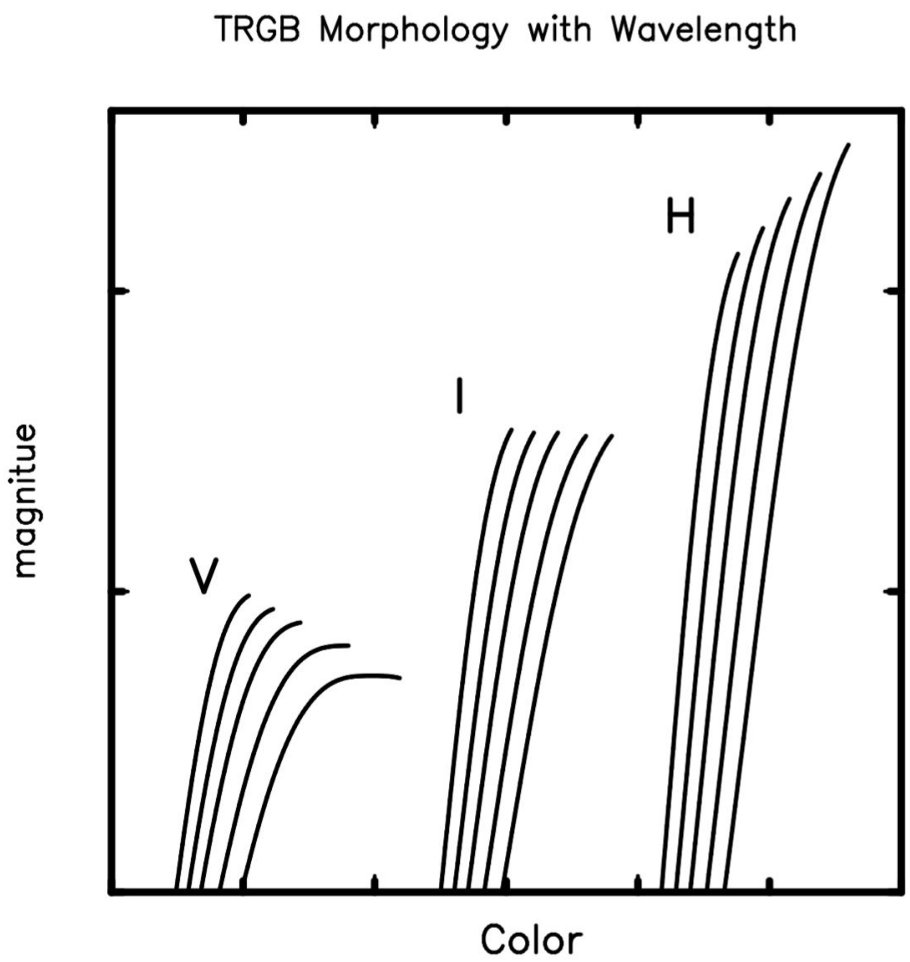


(lack of) crowding



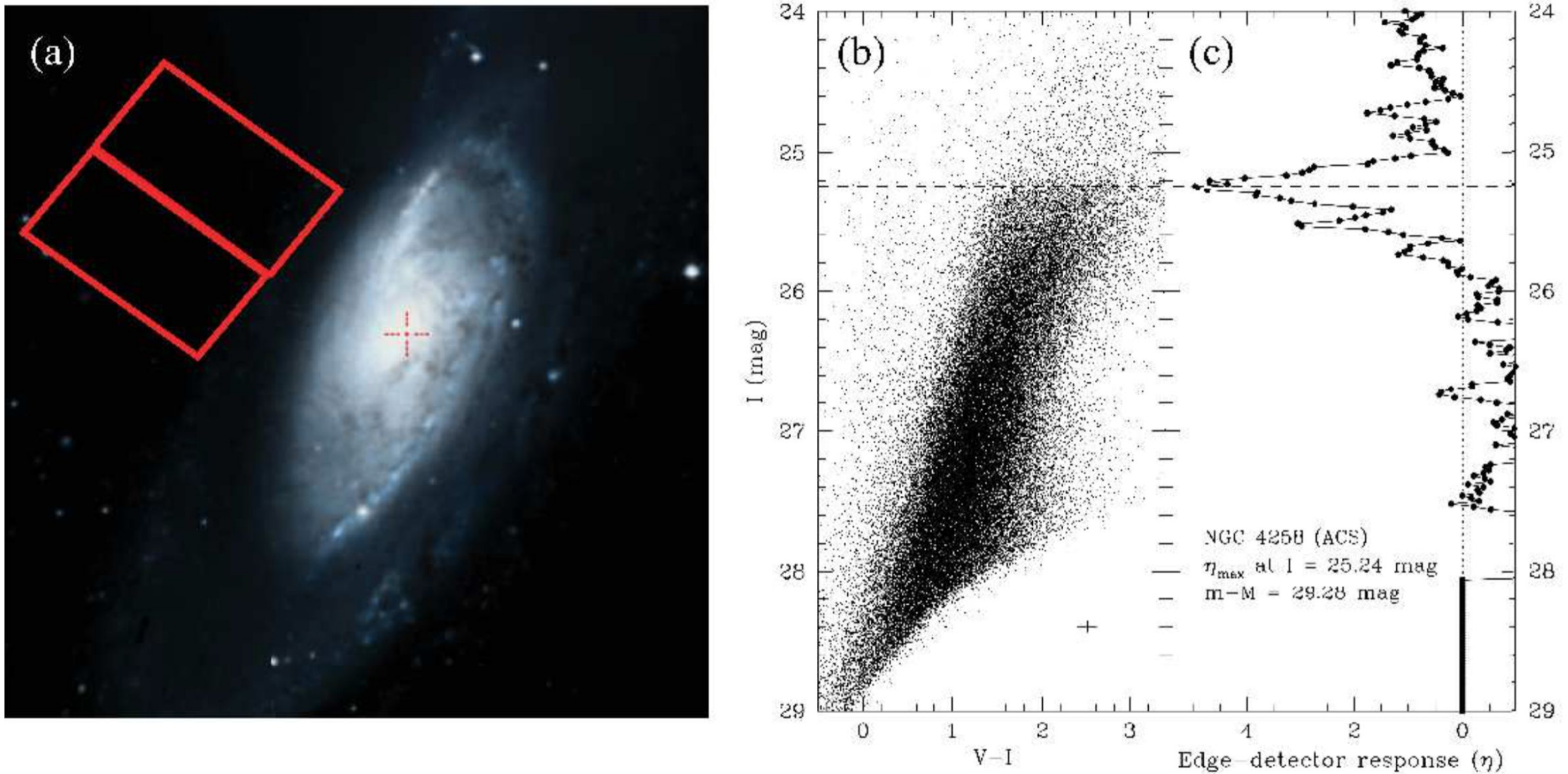
Silbermann+98





Potential systematics

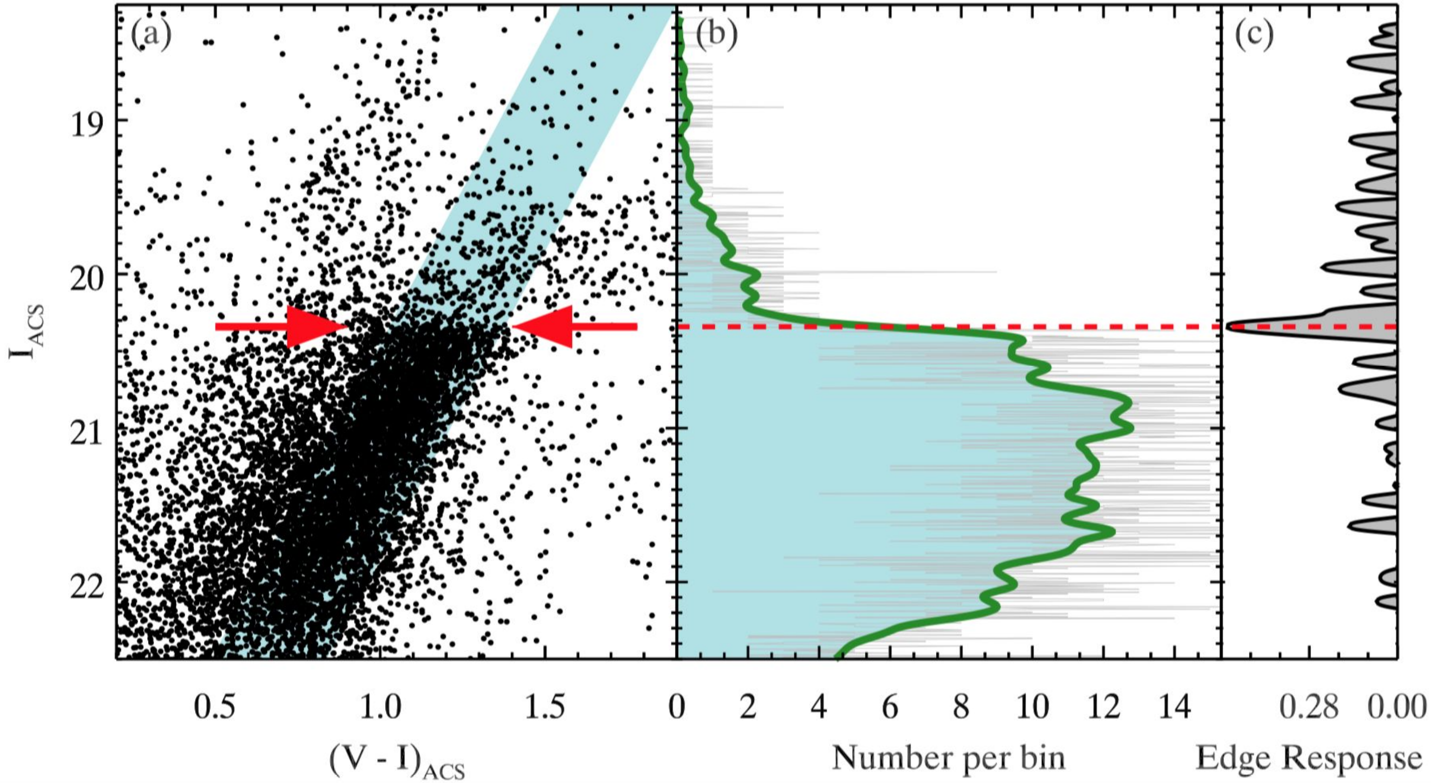
1. Mass dependency of TRGB luminosity (mass indep. for M <~ 1.6 M_sun)
2. Underpopulation of Tip
3. Detection of maximal slope in luminosity function (~few 0.01 mag)



(a)
(b)
(c)
I (mag)
V−I
Edge−detector response (η)
NGC 4258 (ACS)
η_{max} at I = 25.24 mag
m−M = 29.28 mag

Beaton+16

Near Infrared TRGB



Hatt+17 (in press)

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Type Ia Supernovae

Kim et al. (1997)

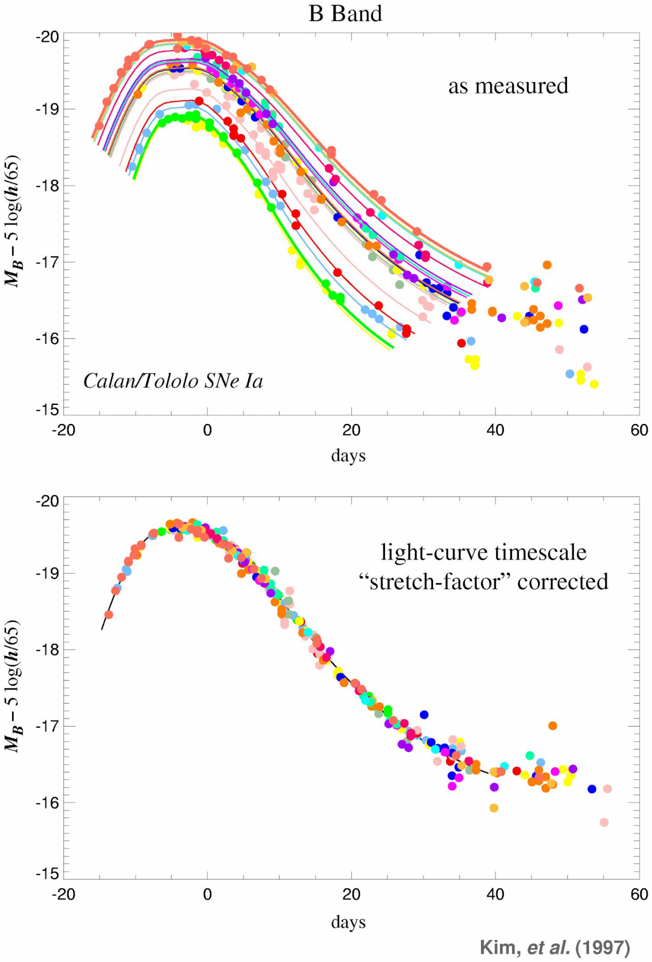
$M = M_{ch}$ gives almost standard candle

Assuming m_{peak} vs. Δm_{15} linear relation, scatter in Hubble diagram is <10%

Recent triumphs

Multi-wavelength lc fitting (Guy+07, SALT2; Burns+11, SNooPy)

Common photometric system (Scolnic+15)



SNe Ia Problems

Not theoretically well understood

Light-curve fitting an “art”

Entangled Intrinsic color + host galaxy reddening

Dependence on galaxy environment

Small numbers between $0.05 < z < 0.1$

Evolution with redshift

Carnegie Supernova Project

WFIRST(?)

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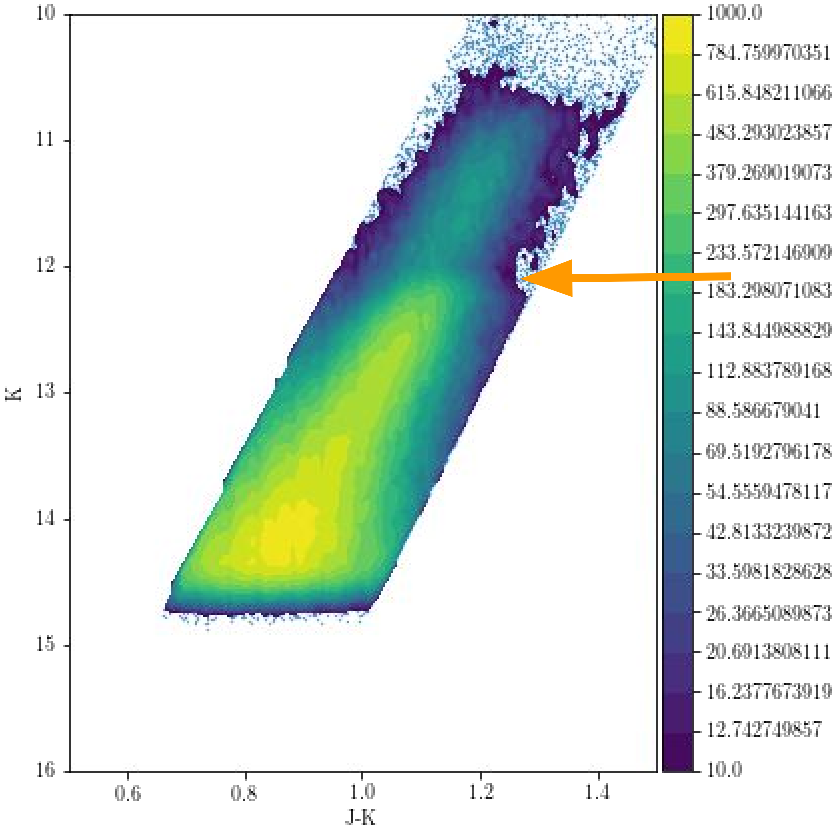
The LMC

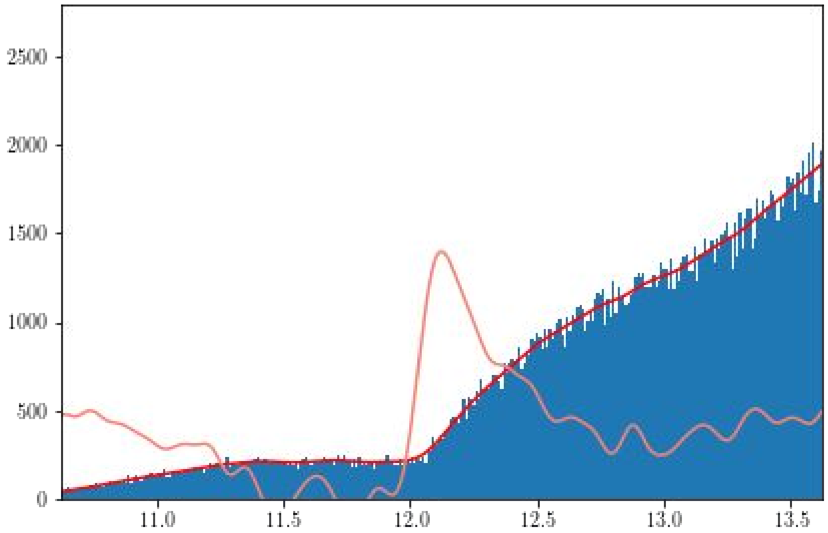
Eclipsing binaries, Cepheids, RR Lyrae, TRGB, all agree within a few %

CMB H0 shifts *everything* by **0.05 mag**

Eclipsing Binaries	18.493 ± 0.008(statistical) ± 0.047 (systematic) mag	Pietrzyński+13
Optical RR Lyrae	18.45 ± 0.09 mag	Clementini+02
MIR Cepheids	18.477 ± 0.033 mag	Scowcroft+12
NIR TRGB	**In progress!**	**Freedman+ in prep.**

Preliminary LMC NIR-TRGB





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Future measurements

Gaia + Webb => $\sigma(H0) < 1\%$

Direct into Hubble flow (50-60 Mpc < d < 100 Mpc)

First precise check on SNe Ia

Lots of work still to do in the NIR -- stay tuned