Precise standard candles – calibrators of SNIa brightness

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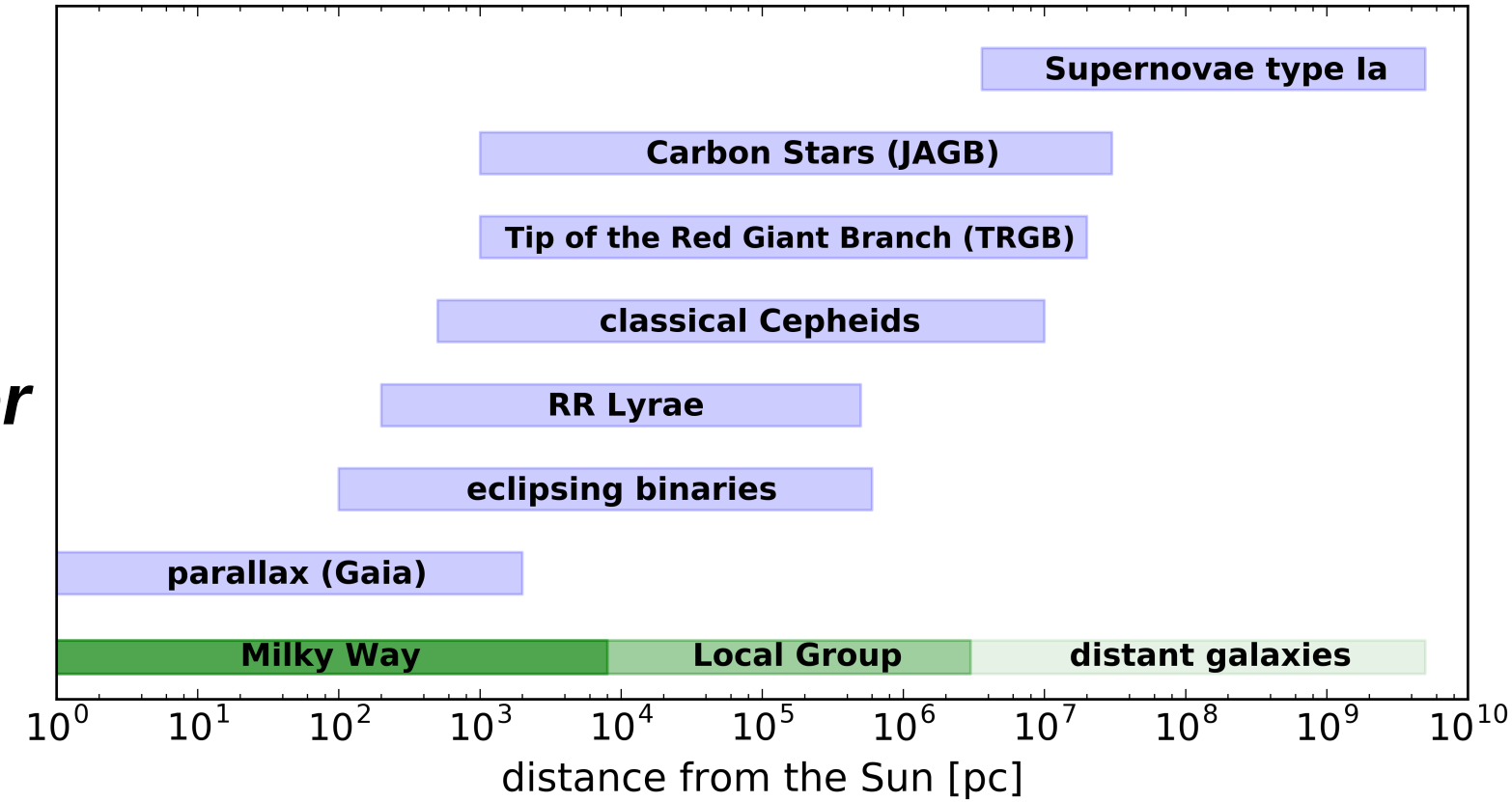
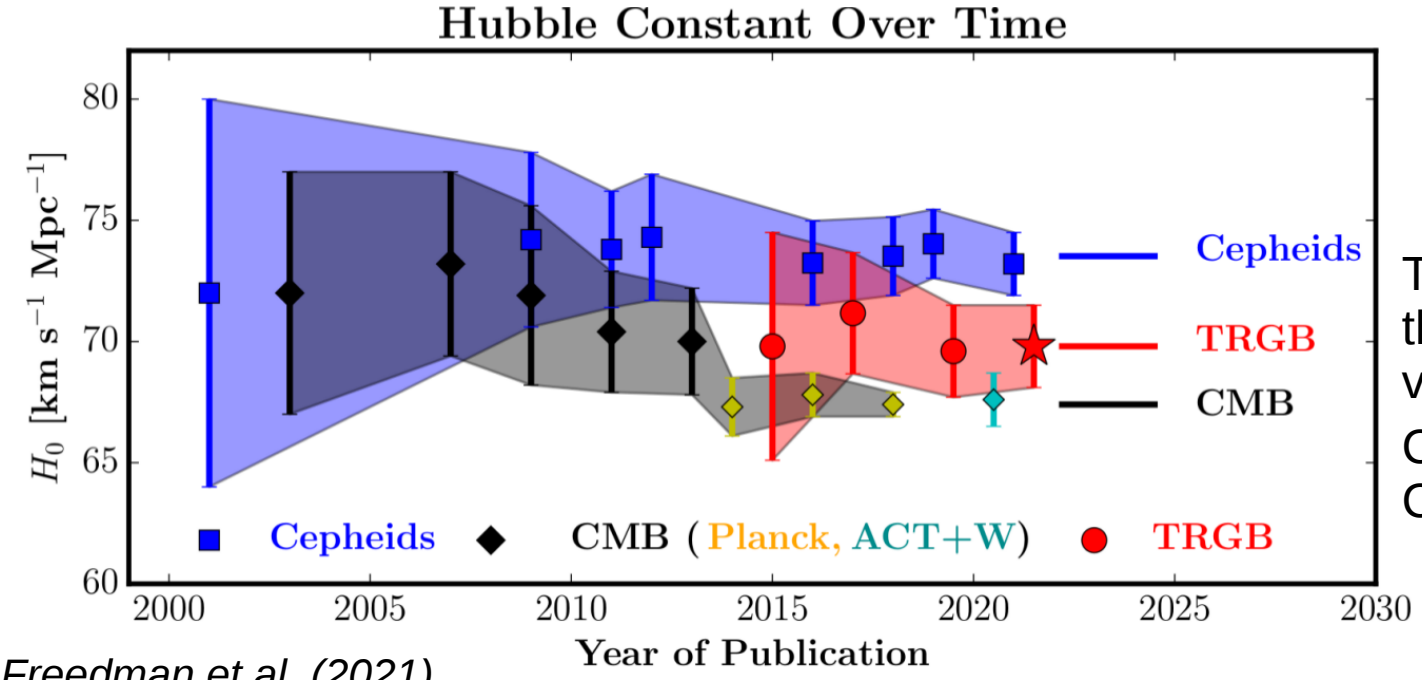
Nicolaus Copernicus World Congress
Toruń, 20 February 2022

The cosmic distance ladder





Freedman et al. (2021)

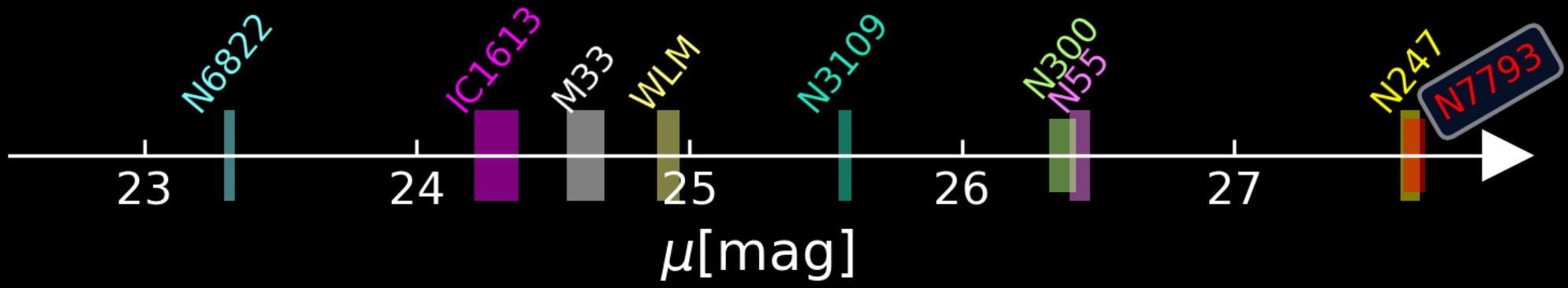
The *Hubble tension* –
the discrepancy of ~5σ between values of H_0 inferred based on CMB and SN calibrated using Cepheids (Riess et al. 2021)

Distance and reddening determinations based on multi-band P-L relations for Cepheids

- Identification of Cepheids using optical photometry (V, I) – 1.3 m Warsaw telescope

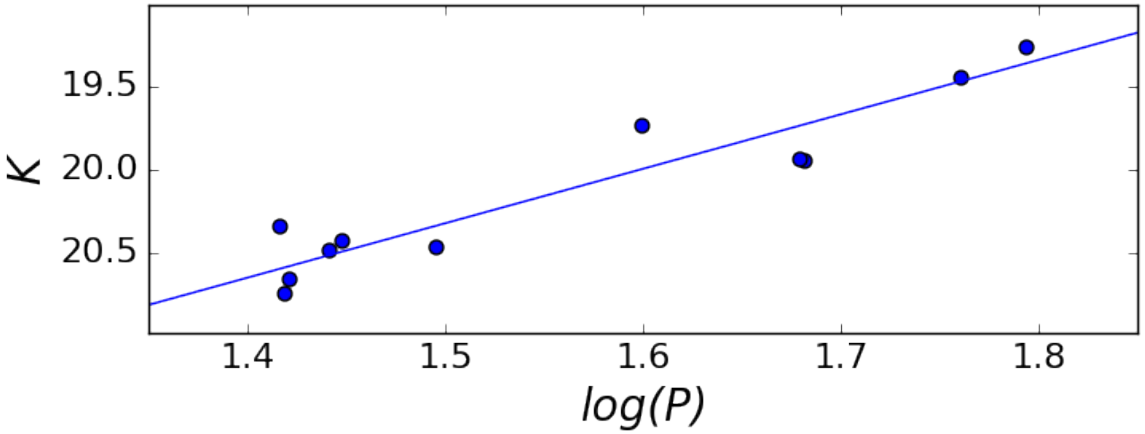
- Near-infrared photometry (J, K) using NTT, Magellan-Baade, VLT

- Distances fixed to the LMC (benchmark distance from eclipsing binaries, fiducial P-L relations for Cepheids)



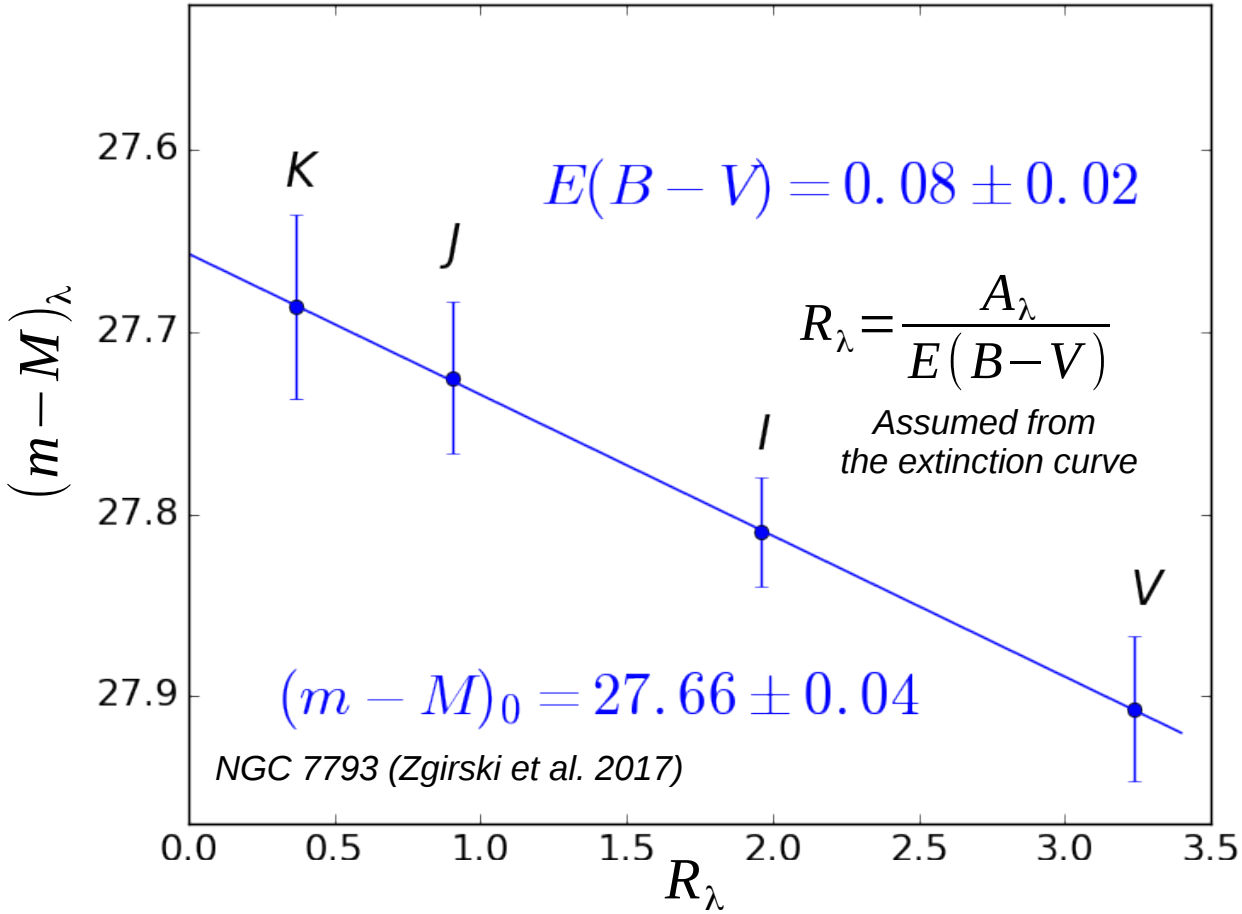
Araucaria Project's distance determinations using
multi-band Cepheid period-luminosity relations *(stat. errors)*
Typical precision of 3%

The multi-band method for Cepheids



intercept slope

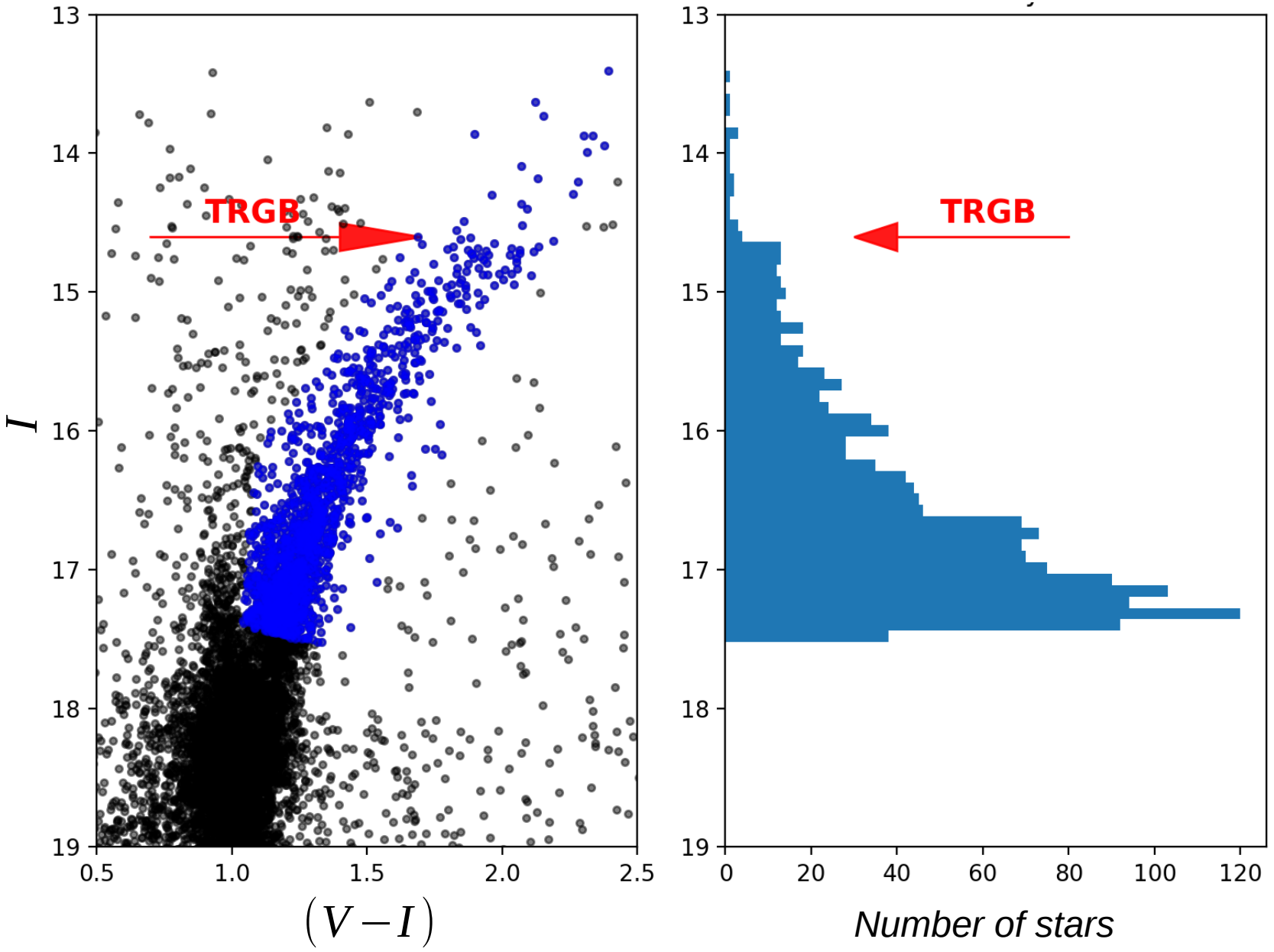
$$(m-M)_\lambda = (m-M)_0 + E(B-V)R_\lambda$$

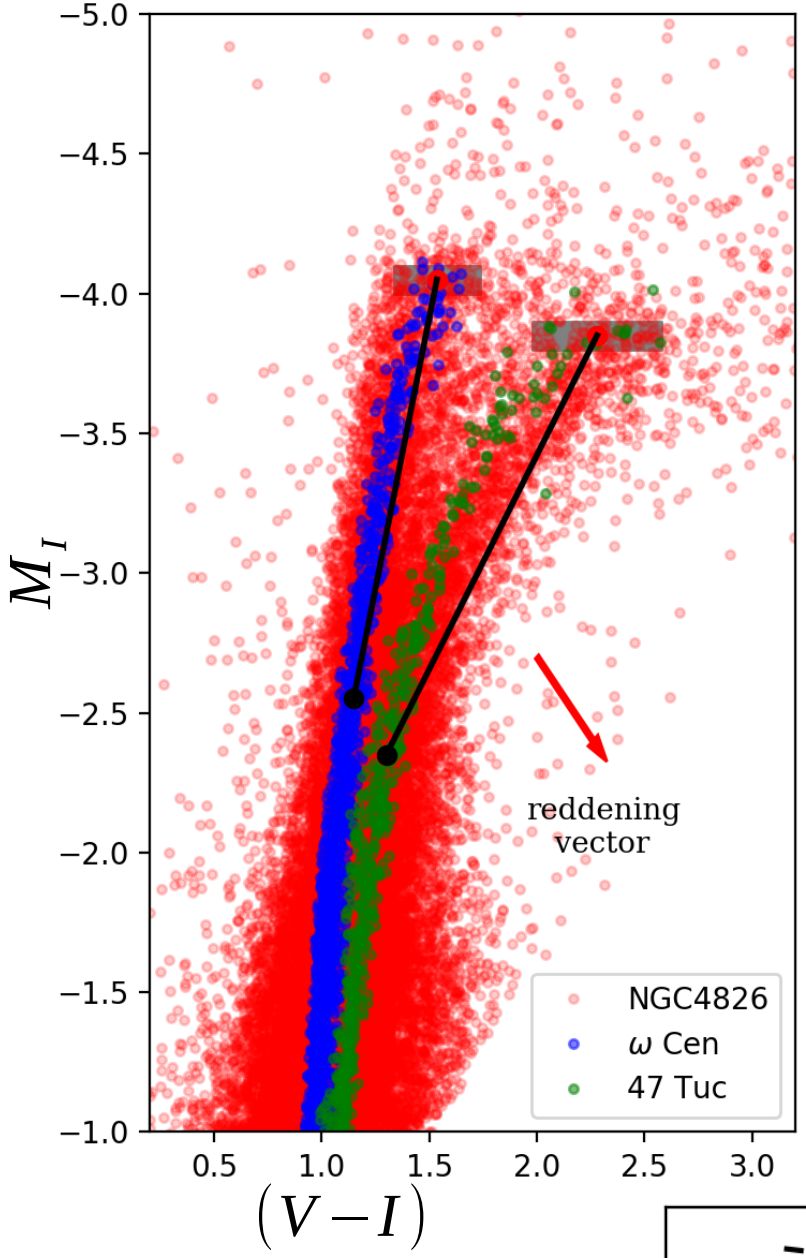


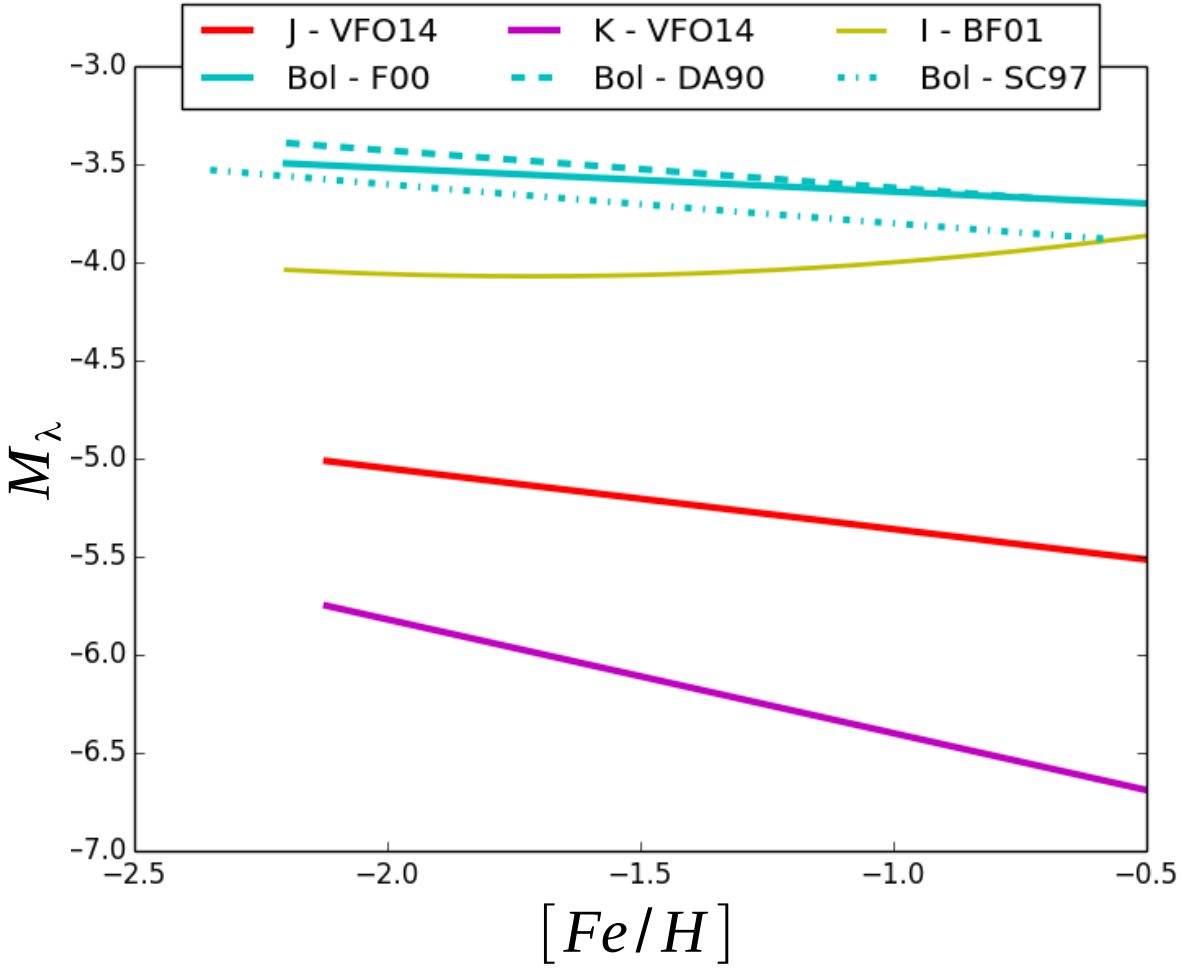
- *Example: NGC 247,* ***$E(B-V)_{tot}$=0.18±0.02 mag*** **(multi-band, Gieren et al. 2009)** v.s. ***$E(B-V)_{MW}$=0.0155+/-0.0001 mag*** **(foreground, Schlafly & Finkbeiner 2011)**

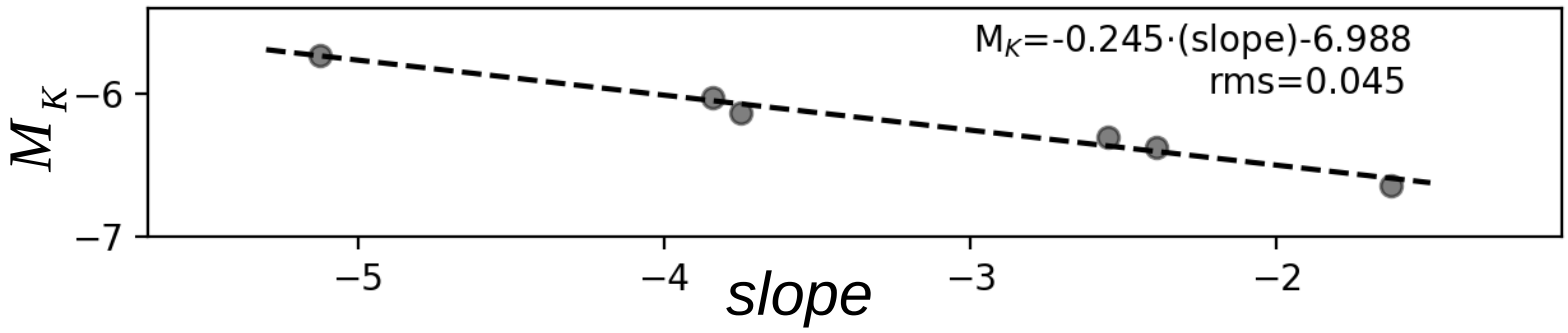
- The influence of **blending and crowding** studied using HST photometry of Cepheids in NGC 300, estimated at **up to 0.04 mag** ~ 2% (optical bands, Bresolin et al. 2005)

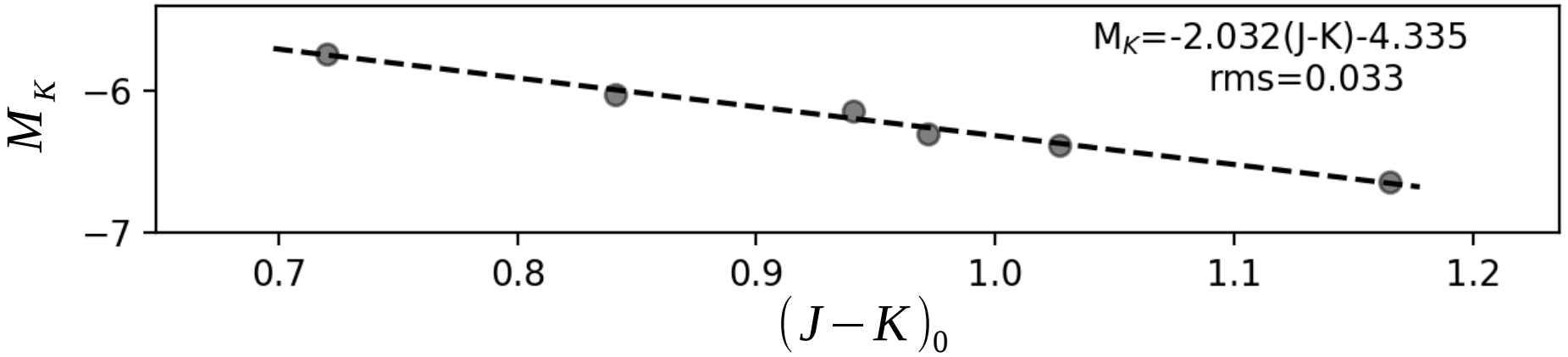
Tip of the Red Giant Branch




M_I
$(V-I)$
reddening vector
NGC4826
ω Cen
47 Tuc

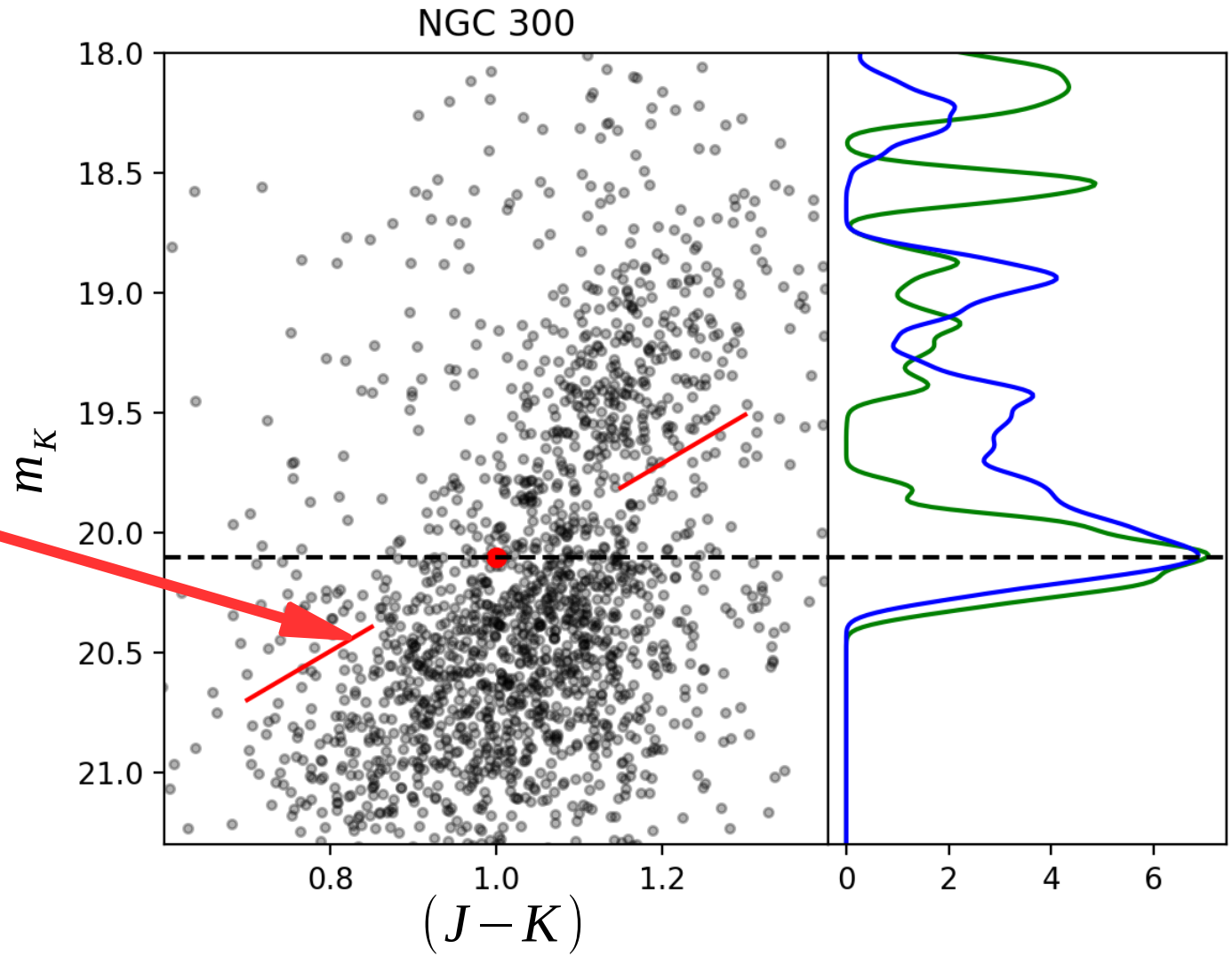

J - VFO14
K - VFO14
I - BF01
Bol - F00
Bol - DA90
Bol - SC97
M_λ
$[Fe/H]$


M_K=-0.245·(slope)-6.988
rms=0.045
M_K
slope



NIR TRGB

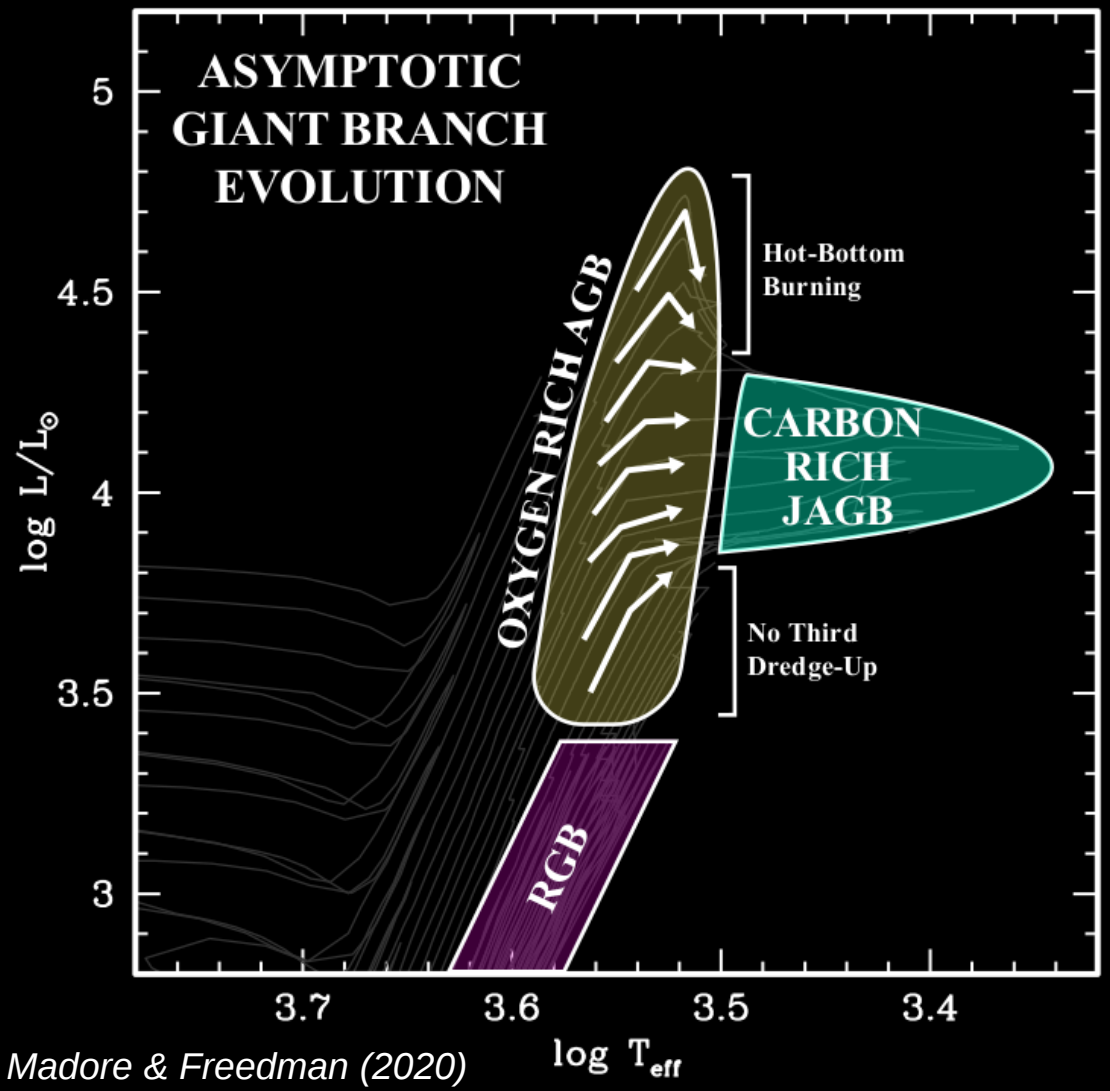
Rectification?
Intrinsic reddening
may alter
the slope here



Carbon stars

(the JAGB method)

mean NIR J- band magnitude as a standard candle



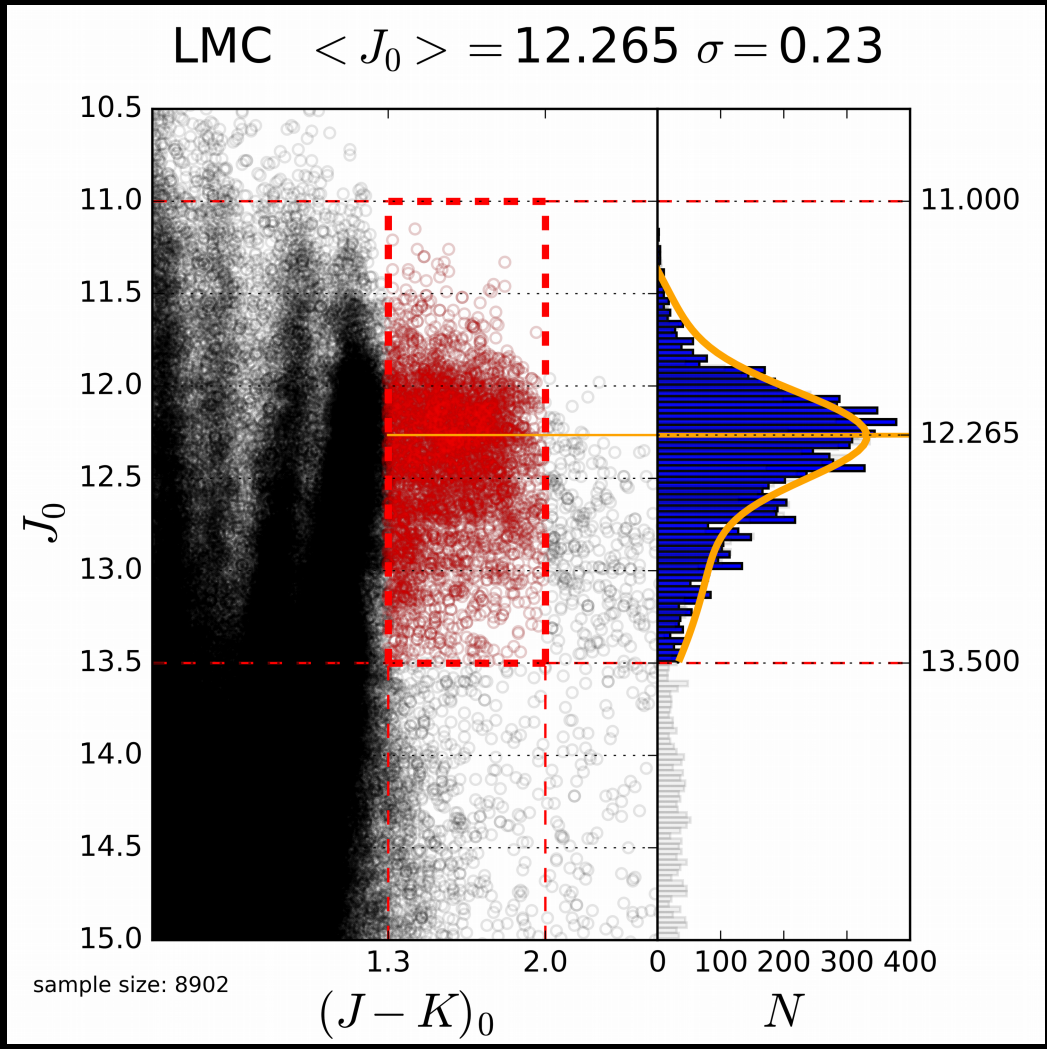
Madore & Freedman (2020)

- Well-confined luminosities, **constant mean J- band magnitude** for the whole range of colors $(J-K) \in (\sim 1.3, 2.0)$ mag
- Very luminous stars M_J=-6.2 mag – could provide an alternative to the calibration of SN

Calibration in the LMC

- NIR photometry of Kato et al. (2007) – IRSF telescope@SAAO
- Anchoring distance of Pietrzyński et al. (2019) accurate to 1%
- Extinction - Górski et al. (2020) reddening maps of the Magellanic Clouds

$$M_{JAGB} = -6.212 \pm 0.01 \pm 0.03 \; mag$$

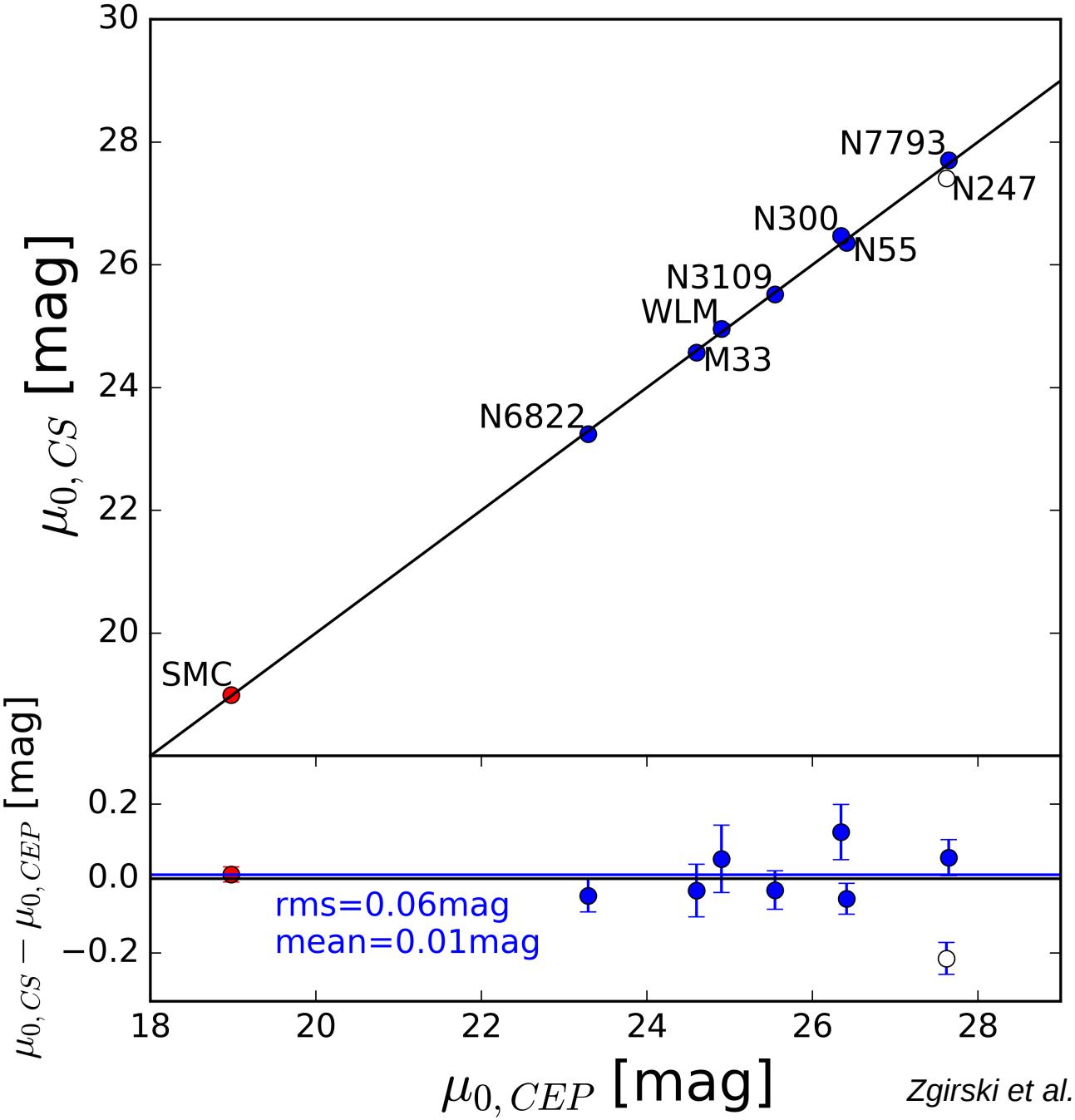


Zgirski et al. (2021)

$$\frac{dn}{dJ} = \frac{N}{\sigma\sqrt{2\pi}} \exp\left[\frac{-\left(J-\langle J\rangle\right)^2}{2\sigma^2}\right] + a\left(J-\langle J\rangle\right)^2 + b\left(J-\langle J\rangle\right) + c$$

Originally: *Paczyński & Stanek (1998)* for modeling of luminosity functions of Red Clump stars contaminated with Red Giant Branch stars

JAGB - the comparison with Cepheid distances



Zgirski et al. (2021)

Precise calibrators of SNIa
summary

- Cepheids (young pop.) – the multi-band method allows for accurate determination of $(m\text{-}M)_0$ and estimation of the average total reddening affecting Cepheids in a given system. Vague metallicity effect. Blending in the case of distant galaxies?
- TRGB (old pop.) – Population effects make the task harder for some systems. Metallicity effect should be included in order to obtain precision distance determinations. Development of the multi-band technique could further improve the treatment of reddening.
- Carbon stars (intermediate pop.) – the least developed method of the three but it gives promising prospects.