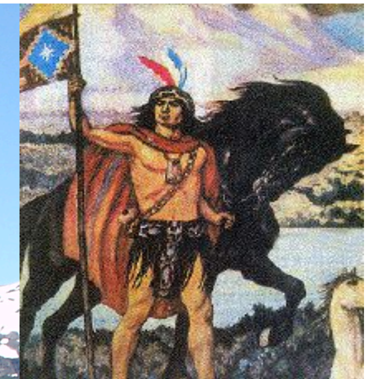
The metallicity effect on Cepheid absolute magnitudes – progress report on ESO Large Programme 190.D-0237

Wolfgang Gieren

Universidad de Concepción, MAS, CATA, Chile

8 October 2015, ESO workshop on Public Surveys and Large Programmes

Sub-project of Araucaria Project
Team members:



Jesper Storm	AIP Potsdam
Grzegorz Pietrzyński	Warsaw Univ. Obs.
Pascal Fouquè	Toulouse
Giuseppe Bono	INAF Rome
Dante Minniti	UNAB, MAS
Nicolas Nardetto	Nice
Ian Thompson	Carnegie
Marek Gorski	Concepciòn, MAS
Alexandre Gallenne	Concepcion, ESO
Piotrek Konorski	Warsaw Univ. Obs.

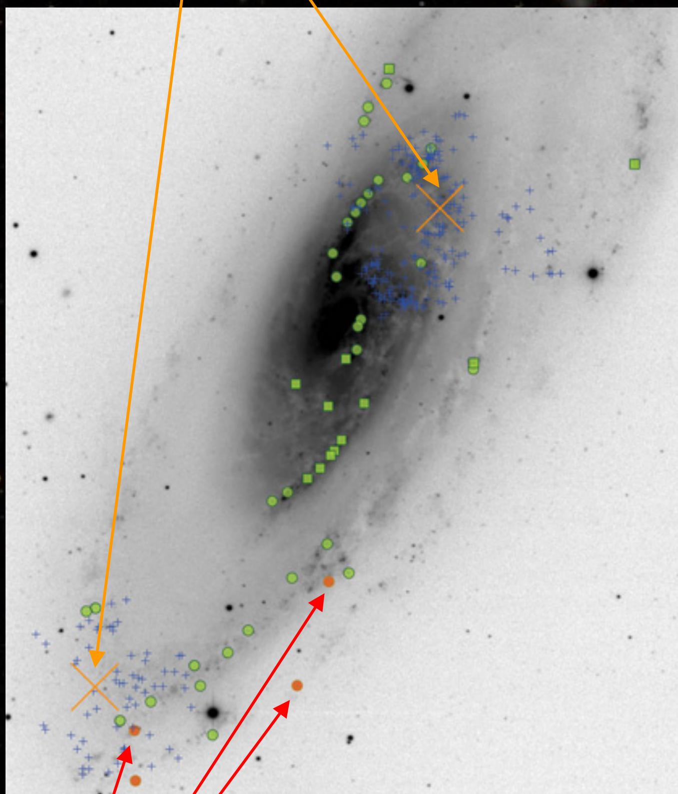
A determination of the Hubble constant accurate to 1% from the Cepheid – SN Ia method

- **Zero point of the Cepheid distance scale:** greatly improved by the work on LMC late-type eclipsing binaries (Pietrzynski et al. 2013, Nature, 495, 76)
- LMC distance determined to ±2.2% (8 systems)
- Improvement to ~1% soon to follow (Araucaria Project group, 2016)
- **Extinction:** through general shift of Cepheid PL relation work to the near- and mid-IR (Araucaria Project, Shoes Project, Carnegie Hubble Program) much less a problem than in the HST Key Project (2001), and generally previous work in optical bands, but still requires very careful treatment in the analyses if 1% distances are to be measured!
- **Effect of metallicity on the Cepheid PL relation:** main interest now is its effect on near- and mid-IR Cepheid absolute magnitudes
- **Size, and even sign of the effect are presently not well determined. Uncertainty on the metallicity effect is currently the largest obstacle towards a 1% determination of H_0 !**

Table 1. Overview of recent results for the metallicity sensitivity of Cepheid distances. In the first column is listed the variation of the distance modulus μ per dex of metallicity, the negative sign indicates that the true distance is longer than the one obtained neglecting the effect of the metallicity. In the second column is listed the elemental abundance used as reference for the metallicity. The third and fourth columns give the method and the reference of the different studies. See also Fig. 1.

$\delta\mu/\delta$[M/H] (mag/dex)		Method	Reference
-0.32 ± 0.21	[Fe/H]	Analysis of Cepheids in 3 fields of M 31 (*BVRI* bands)	Freedman & Madore (1990)
-0.88 ± 0.16	[Fe/H]	Comparison of Cepheids from 3 fields of M 31 and LMC (*BVRI* bands)	Gould (1994)
-0.40 ± 0.20	[O/H]	Simultaneous solution for distances to 17 galaxies (*UBVRIJHK* bands)	Kochanek (1997)
$-0.44^{+0.10}_{-0.20}$	[O/H]	Comparison of EROS observations of SMC and LMC Cepheids (*VR* bands)	Sasselov et al. (1997)
-0.24 ± 0.16	[O/H]	Comparison of HST observations of inner and outer fields of M 101	Kennicutt et al. (1998)
-0.12 ± 0.08	[O/H]	Comparison of 10 Cepheid galaxies with Tip of the Red Giant Branch distances	Kennicutt et al. (1998)
-0.20 ± 0.20	[O/H]	Value adopted for the HST Key Project final result	Freedman et al. (2001)
0	[Fe/H]	OGLE result comparing Cepheids in IC 1613 and MC (*VI* bands)	Udalski et al. (2001)
0	[O/H]	Comparison of Planetary Nebula luminosity function distance scale and Surface Brightness fluctuation distance scale	Ciardullo et al. (2002)
-0.24 ± 0.05	[O/H]	Comparison of 17 Cepheid galaxies with Tip of the Red Giant Branch distances	Sakai et al. (2004)
-0.21 ± 0.19	[Fe/H]	Baade-Wesselink analysis of Galactic and SMC Cepheids (*VK* bands)	Storm et al. (2004)
-0.23 ± 0.19	[Fe/H]	Baade-Wesselink analysis of Galactic and SMC Cepheids (*I* band)	Storm et al. (2004)
-0.29 ± 0.19	[Fe/H]	Baade-Wesselink analysis of Galactic and SMC Cepheids (*W* index)	Storm et al. (2004)
-0.27 ± 0.08	[Fe/H]	Compilation from the literature of distances and metallicities of 53 Galactic and MC Cepheids (*VIWK* bands)	Groenewegen et al. (2004)
-0.39 ± 0.03	[Fe/H]	Cepheid distances to SNe Ia host galaxies	Saha et al. (2006)
-0.29 ± 0.09	[O/H]	Cepheids in NGC 4258 and [O/H] gradient from Zaritsky et al. (1994)	Macri et al. (2006)
-0.10 ± 0.03	[Fe/H]	Weighted mean of Kennicutt, Macri and Groenewegen estimates	Benedict et al. (2007)
-0.017 ± 0.113	[O/H]	Comparison between Cepheid and TRGB distances for 18 galaxies	Tammann et al. (2007)
0	[Fe/H]	Comparison between the slopes of Galactic and LMC Cepheids	Fouqué et al. (2007)
$+0.05 \pm 0.03$	[Fe/H]	Predicted Period-Wesenheit (*V, I*) relation	Bono et al. (2008)

Example: Cepheids in NGC 4258



HII regions

Macri et al. 2006, Riess et al., 2009

using Zaritsky et al., 1994

$$\gamma = \frac{\delta(m-M)}{[Z]} = -0.29$$

Bresolin 2011, ApJ 729, 56

$$\gamma = \frac{\delta(m-M)}{[Z]} = -0.69!!!$$

Another problem: inner Cepheids are blended, and therefore brighter; not a metallicity effect!

Residuals from LMC PL relations from U to 8μ, plotted against spectroscopic metallicity determinations of Cepheids in the LMC of Romaniello et al. 2008 (Freedman & Madore 2011, ApJ, 734, 46)

Effect at V is opposite in sign to inner-outer field results!

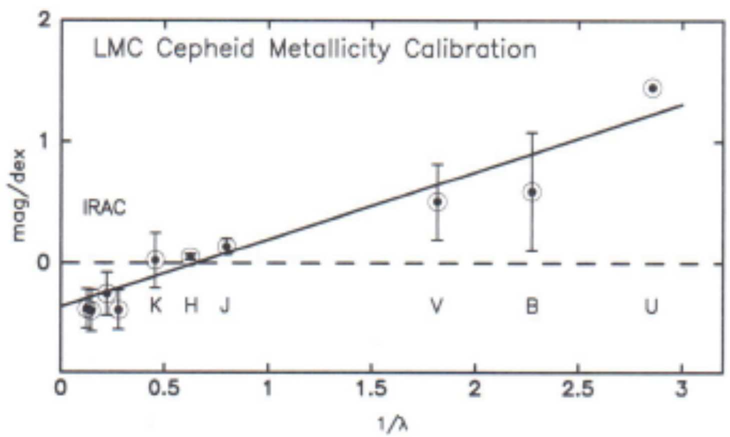
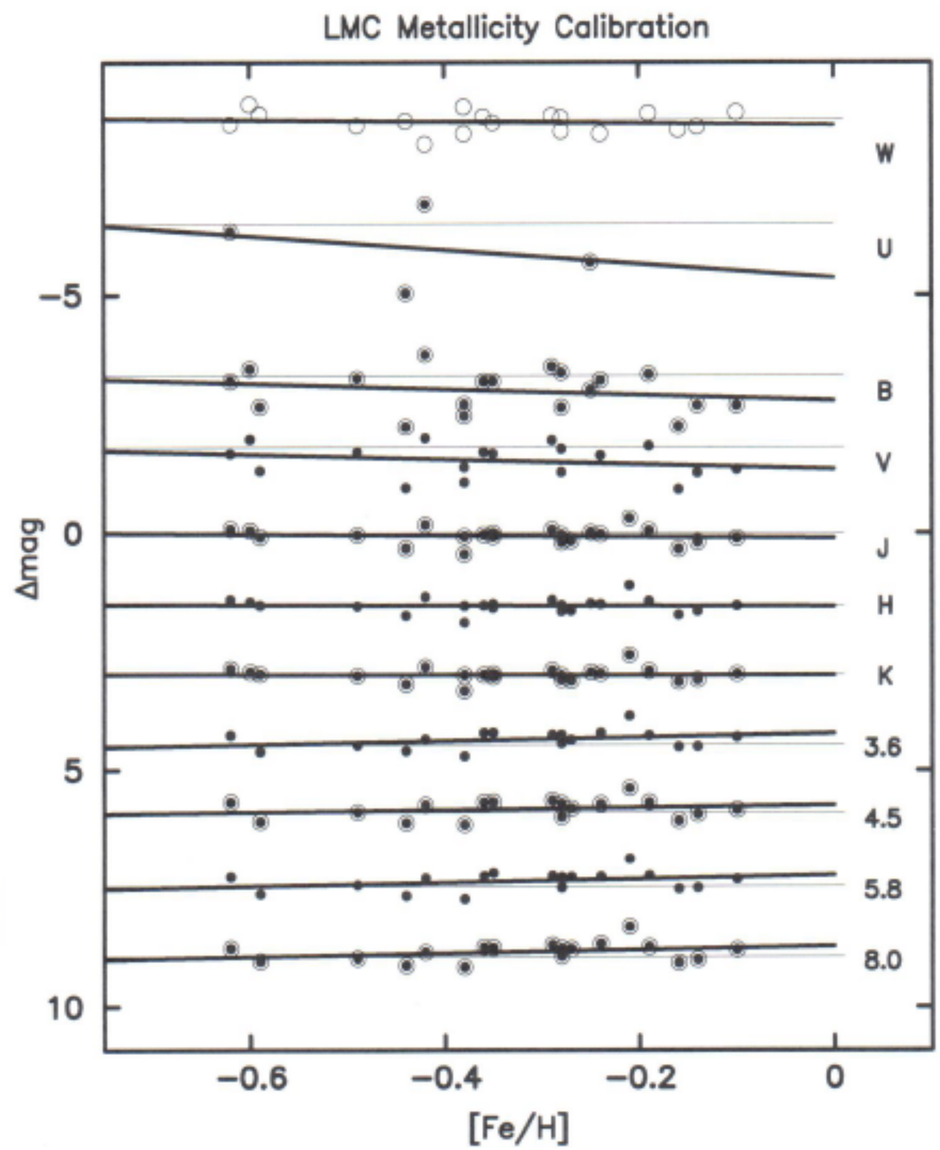


Figure 4. Sensitivity of Cepheid magnitudes to metallicity as a function of wavelength. The slopes derived from the plots in Figure 1 are shown as a function of bandpass (expressed as the inverse wavelength). The error bars are from the noise-decorrelated data. The line is a unweighted fit (excluding the low-significance *U*-band data point to the far right) designed simply to emphasize the trend.

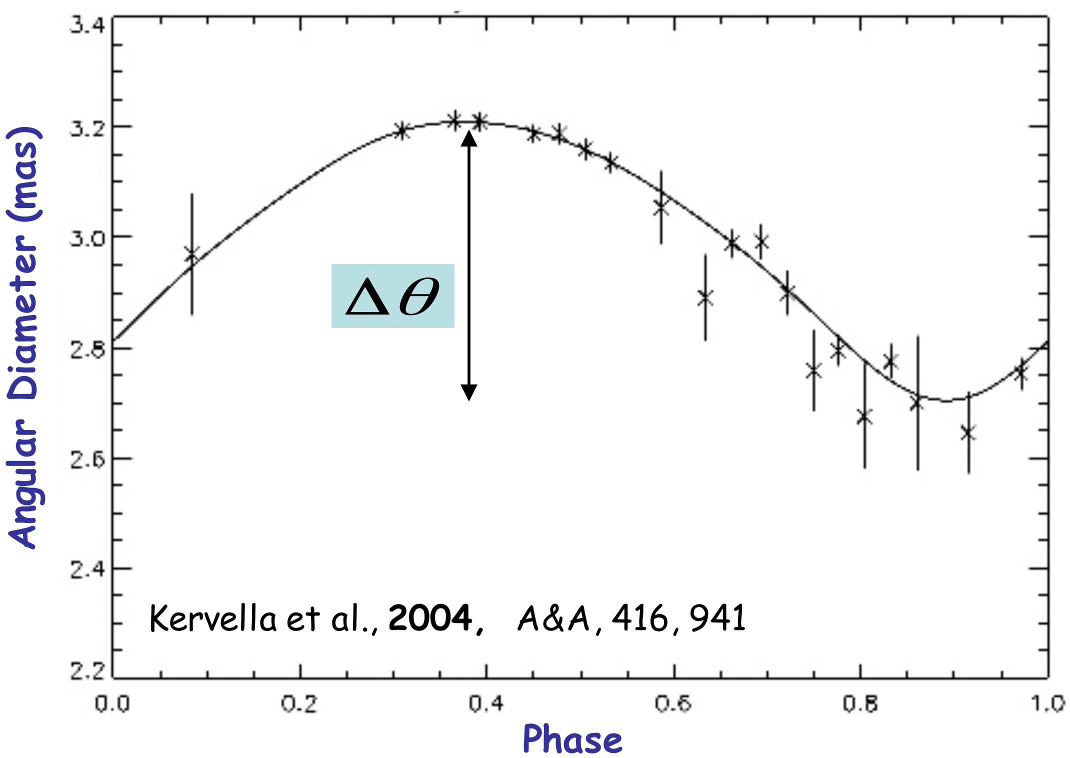


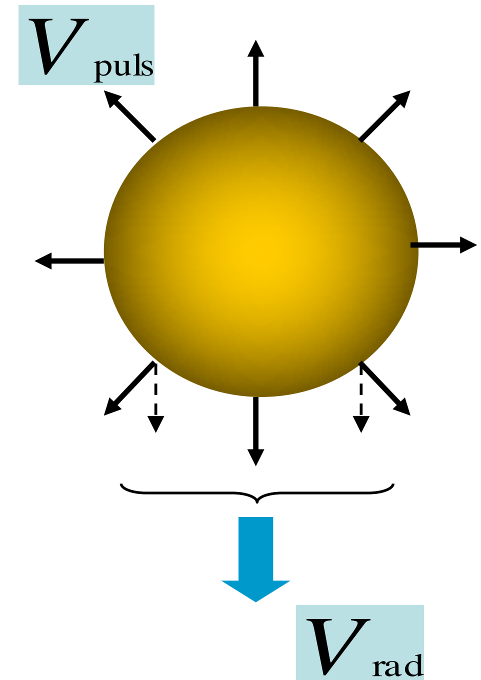
The Baade-Wesselink method

Interferometry

or

IRSB





$$p = \frac{V_{puls}}{V_{rad}}$$

$$d \propto \frac{\Delta R}{\Delta \theta} \text{ with } R(t) = \int p V_{rad} dt$$

$\Delta R \Leftrightarrow \Delta \theta$

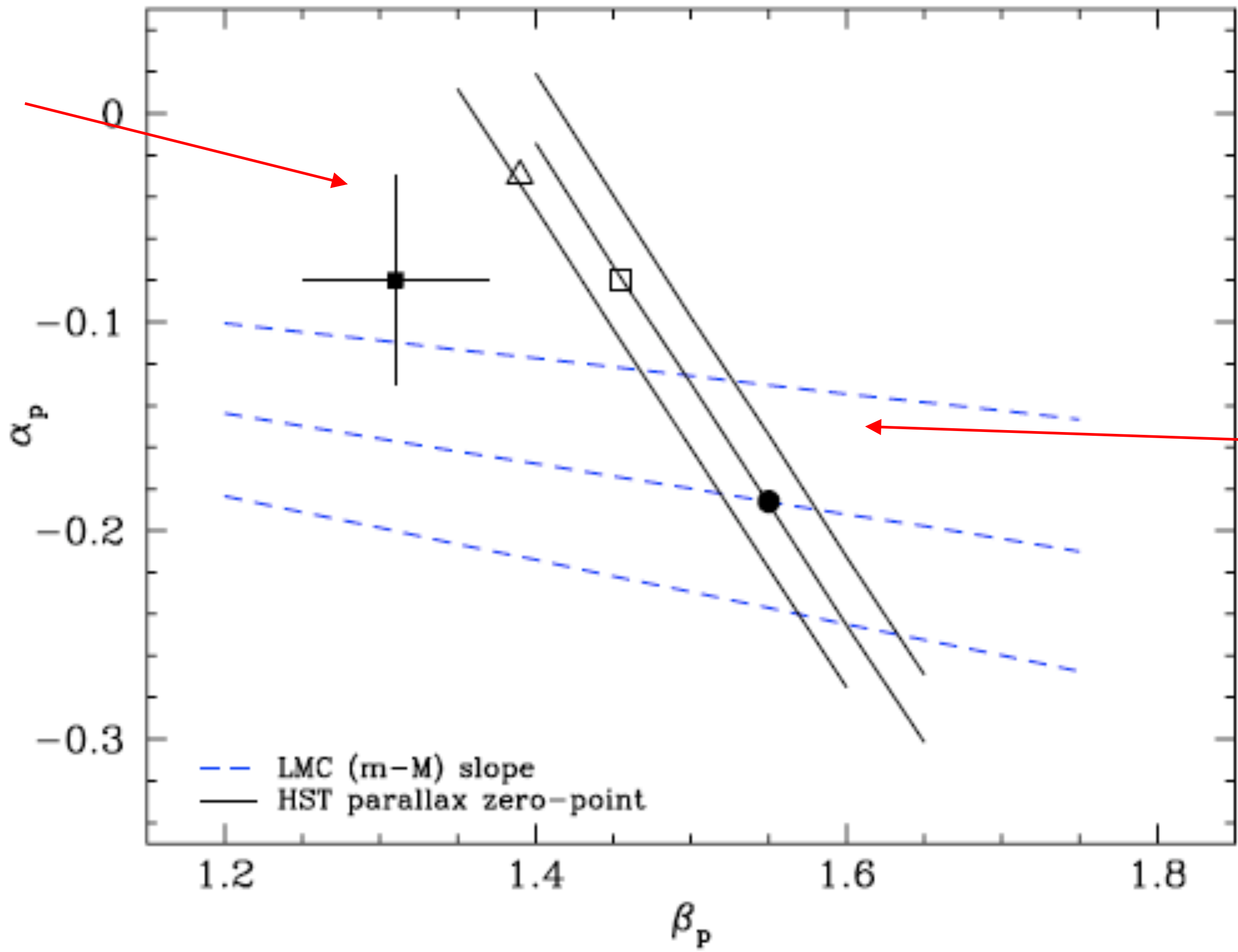
A direct linear relation; p is period-dependent

The Pp relation calibrated with HST and LMC:

$P_p = \beta_p + \alpha_p \log P$

Storm et al. 2011, A&A, 534, A94

Theory



Observation

Distances to classical Cepheids from the infrared surface brightness (IRSB) technique:

- **Surface brightness parameter:** $F_V = 4.2207 - 0.1\ V_0 - 0.5 \log \varphi$
- **Surface brightness-color relation:** $F_V = 3.9530 - 0.1336\ (V\text{-}K)_0$

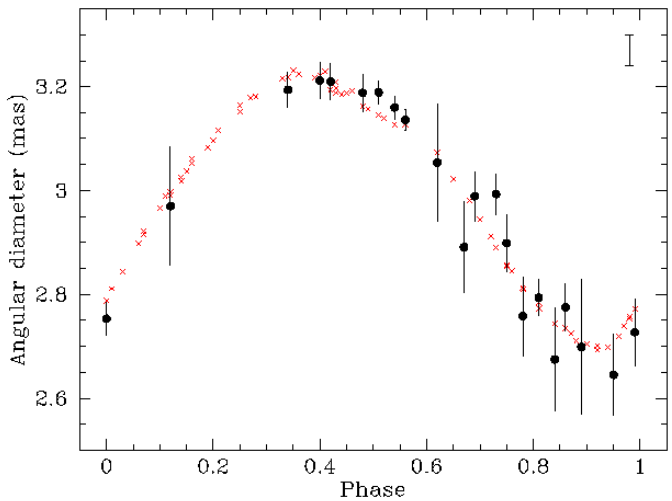
calibrated from phase-resolved angular diameters of nearby Cepheids measured with the ESO VLTI (Kervella et al. 2004, A&A, 428, 587); agrees within 2% with original Fouqué & Gieren (1997) calibration from stable giants

→ **V,K light curves yield the Cepheid angular diameter curve**

- **Technique very insensitive to reddening, metallicity, gravity**

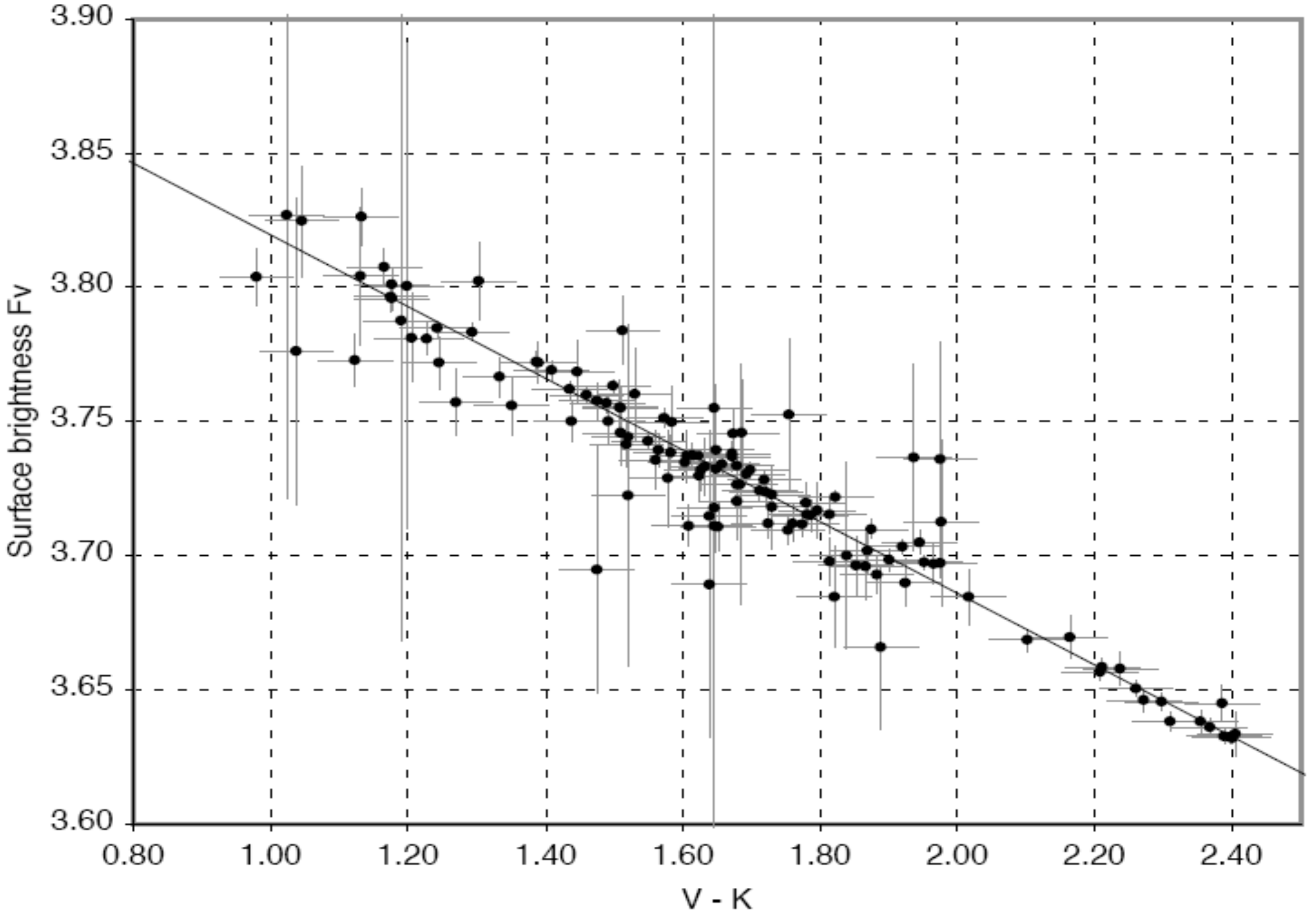
(Laney & Stobie 1995, Storm et al. 2004)

l Carinae: agreement between IRSB and interferometric angular diameter curves is ±1%
(Kervella et al. 2004, ApJ 604, L113)



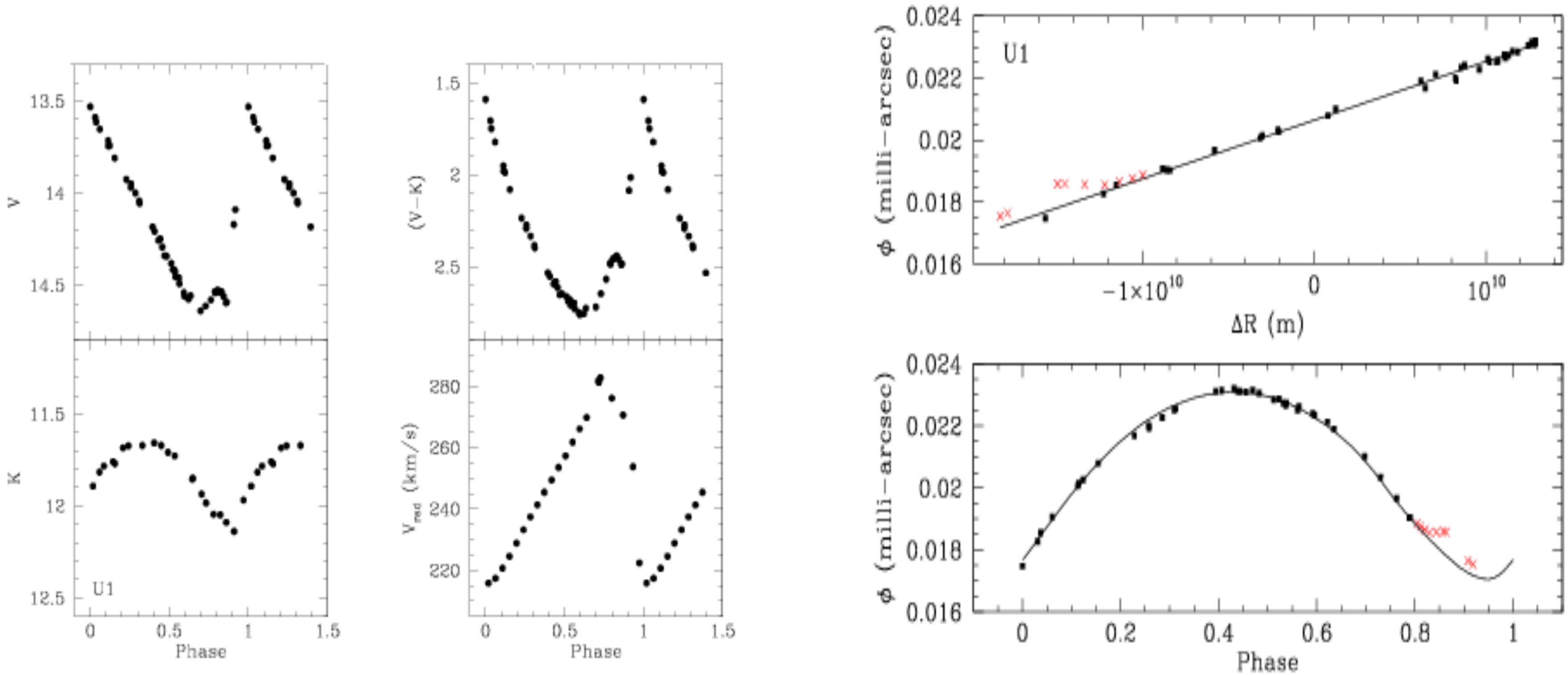
Surface brightness-color relation from ESO VLTI pulsation-resolved angular diameters of nearby Cepheids

→ Cepheid angular diameters to *better than 2%* from V,K photometry



An example of a IRSB solution on the LMC Cepheid U1 (P=22.5 days)

The slope on the upper right panel yields the distance to the Cepheid

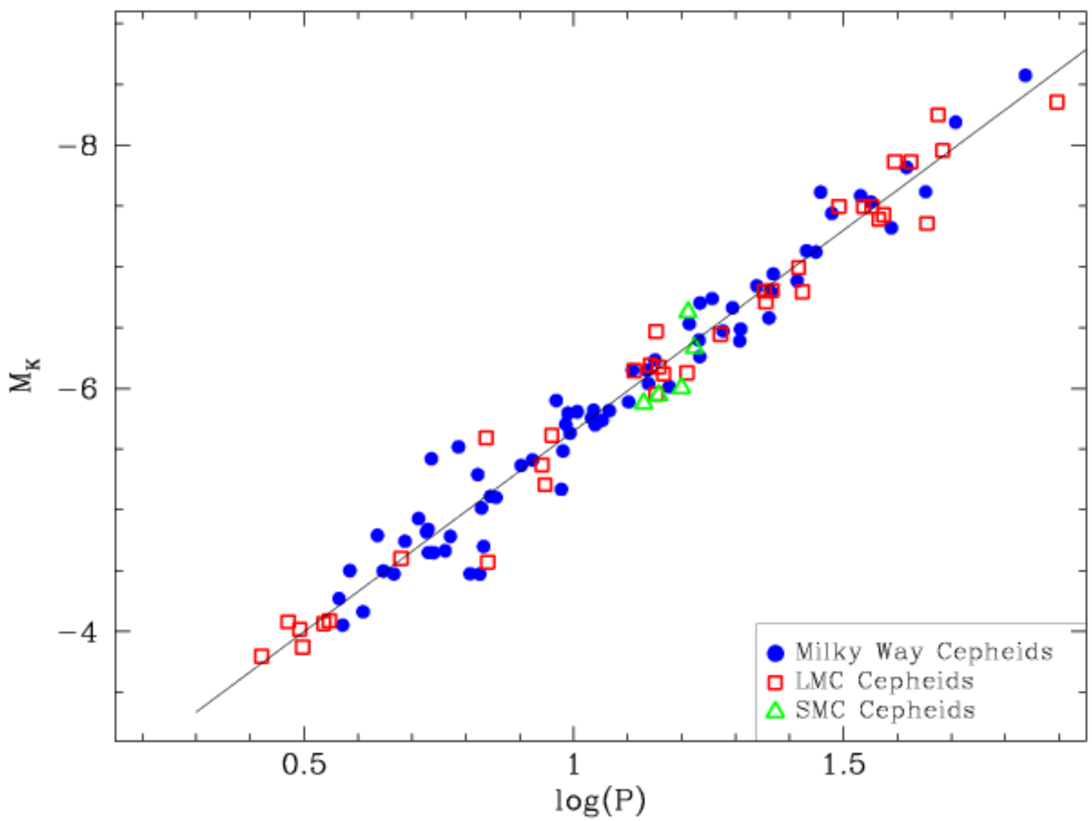


K-band Cepheid absolute PL relations for Milky Way (blue) and LMC (red) from the IRSB technique:

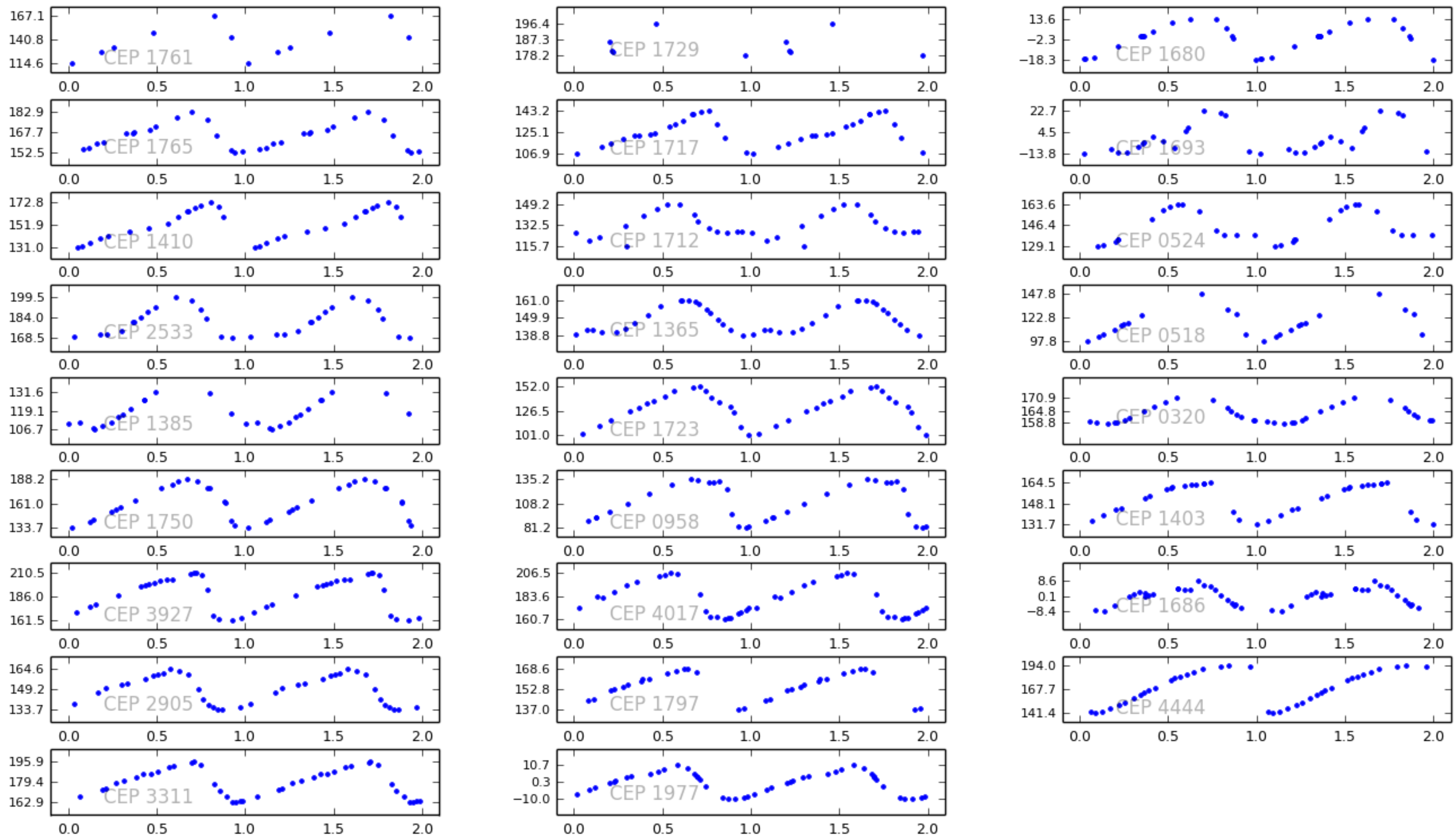
MW: M_K = -3.33±0.09 (logP – 1) -5.66 ±0.03

LMC: M_K = -3.28±0.09 (logP – 1) -5.64 ±0.04

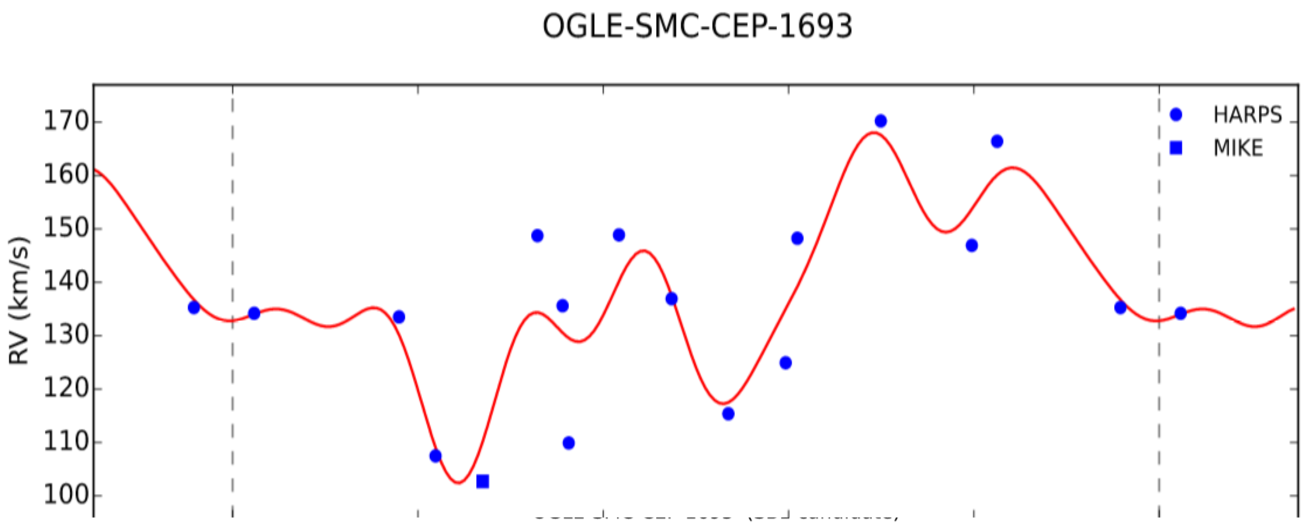
Identical slopes and zero points → *no metallicity effect* in range -0.35 dex < [Fe/H] < 0.0 dex (Storm + 2011, A&A, 534, A94 and A95)

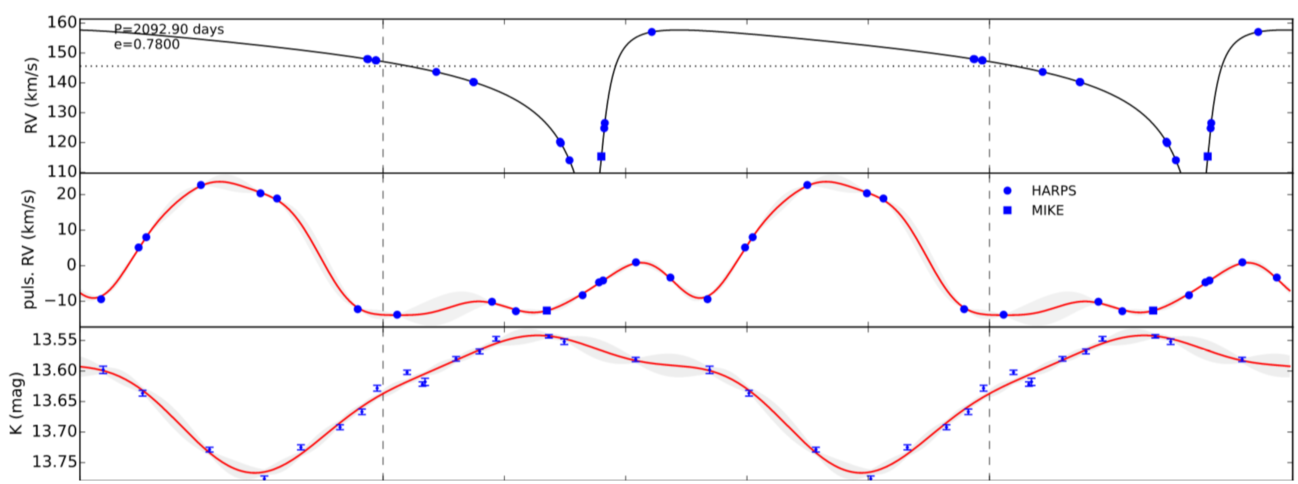


Current LP: **Radial velocity curves of 27 classical Cepheids in the SMC, mean metallicity -0.75 dex**, periods 4-68 days (HARPS)

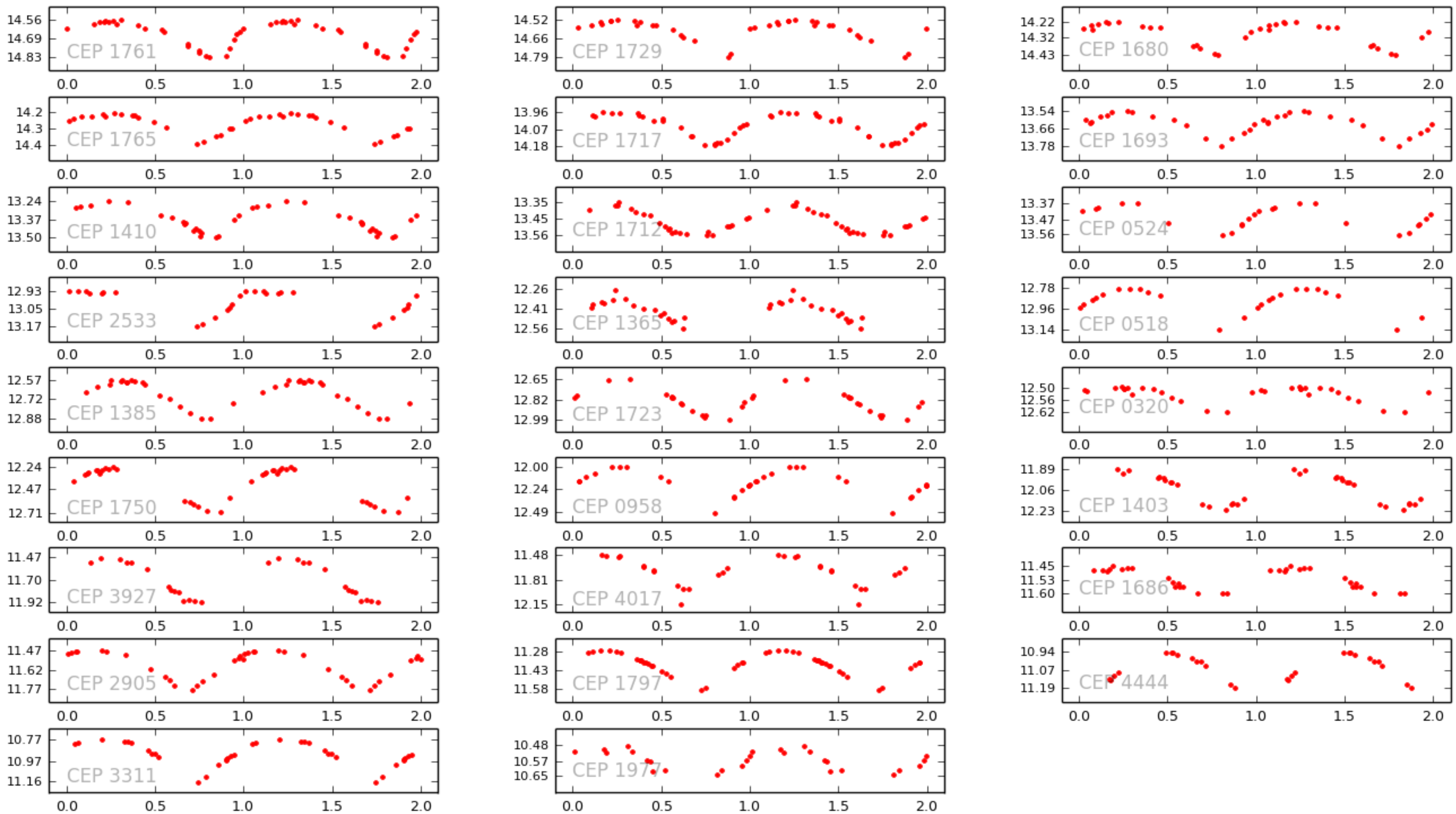


Several Cepheids in the sample are spectroscopic binary candidates (expected!)

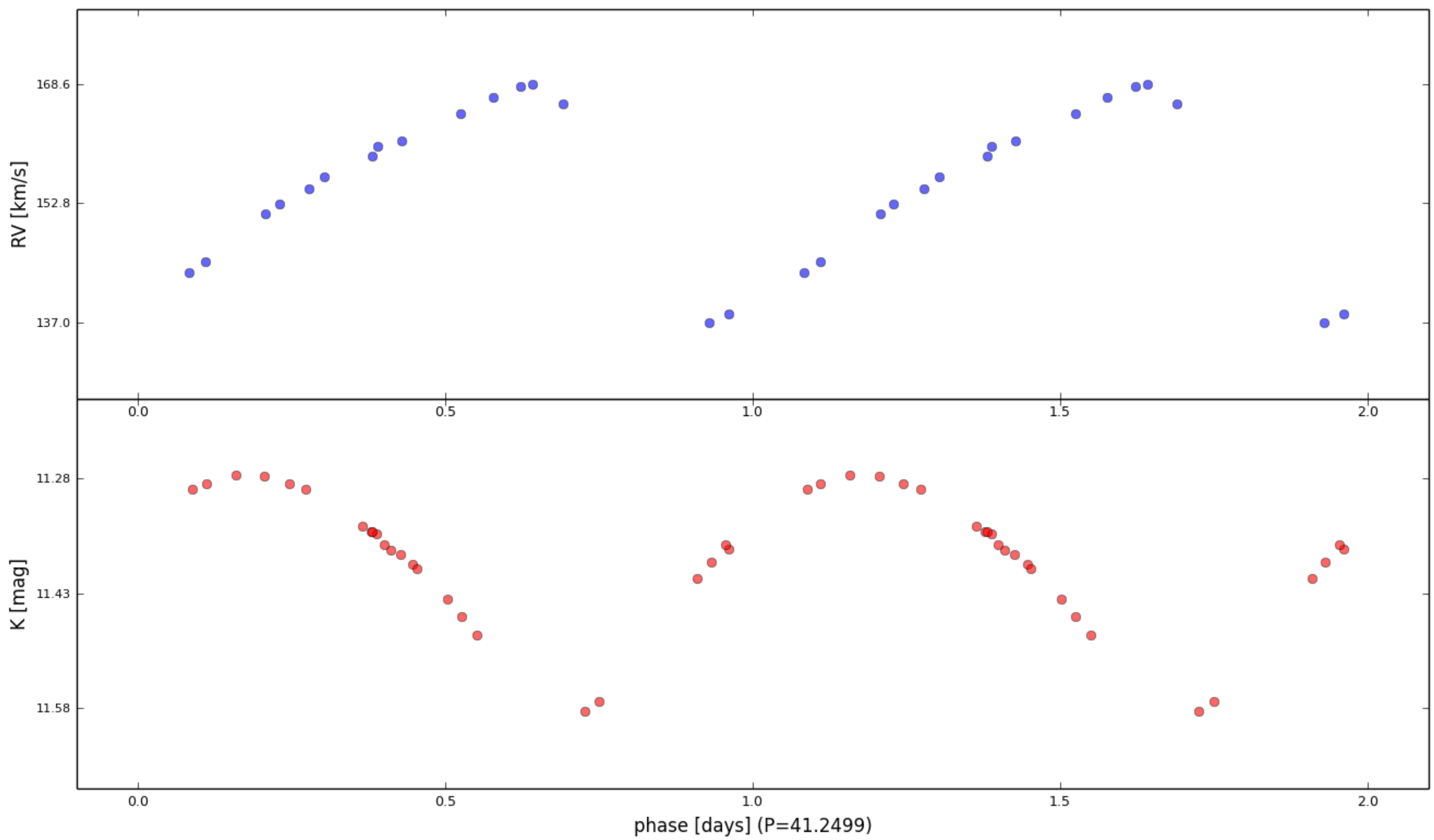




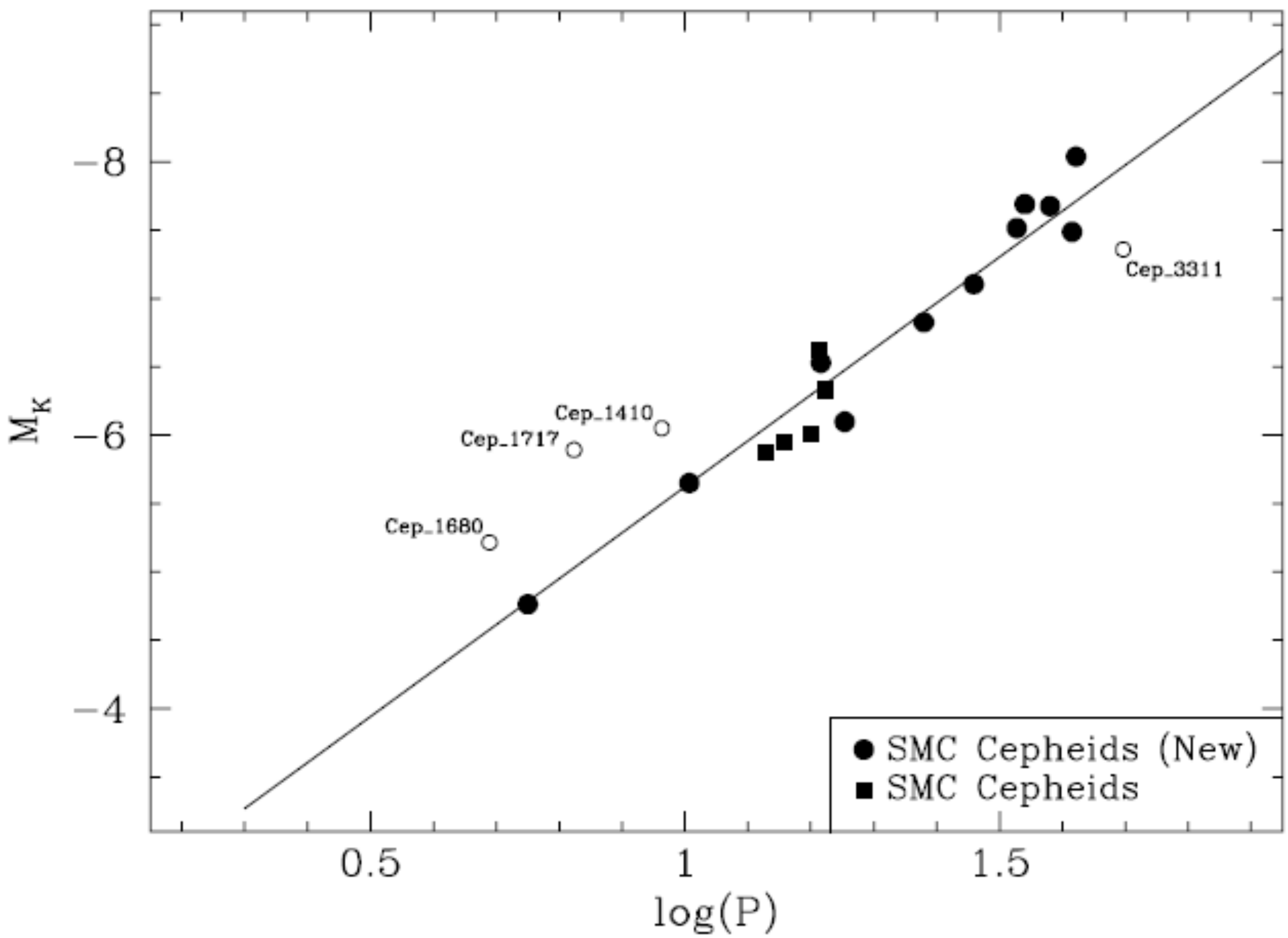
K-band light curves of the SMC Cepheids, obtained for the Gieren et al. LP with NTT/SOFI. As for HARPS, 30% of the time was lost due to bad weather. V light curves for all stars complete (LCO, Polish 1.3 m tel.)



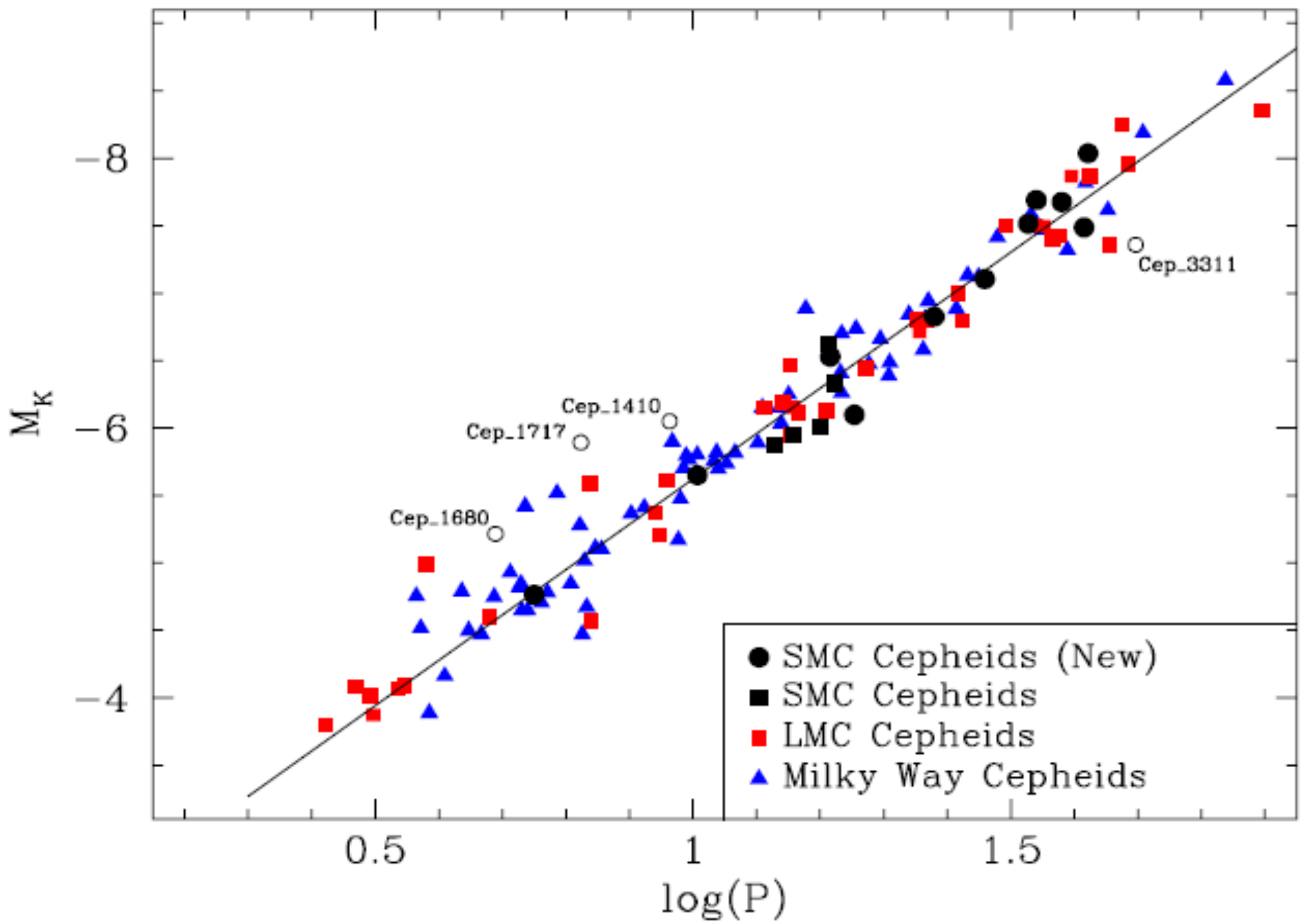
Typical data from the Large Programme (HARPS, SOFI): excellent quality, but significant phase gaps in RV and/or K curves left for ~half the sample which need to be closed for an accurate calculation of the star`s distance with the IRSB method



Preliminary SMC Cepheid PL relation in the K band using data from the present ESO LP (~half the sample). Outliers are due to incomplete radial velocity and/or K light curves



Preliminary SMC Cepheid K-band PL relation, together with MW and LMC relations (from Storm et al. 2011, A&A, 534, A94 and A95)



Preliminary (!!) metallicity effect on the K-band Cepheid PL relation from the IRSB technique, in metallicity range -0.75 < [Fe/H] < 0.0