An empirical method to estimate distances using B-stars in eclipsing binary systems

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Eclipsing binaries: outline

Paczyński advocated the use EBs as distance indicator to external galaxies.

- Guinan et al. (1998) and other groups: ”Flux-fitting method”
- ”Alternative empirical method”

Flux-fitting & Alternative method

Step 1:

- Photometric monitoring
- Radial velocity monitoring

$\Longrightarrow$ Analysis with "Wilson-Devinney" type code gives masses and radii ($\log g$) for both components, individual colours and magnitudes, ratio of effective temperatures (one assumed, second derived)

Flux-fitting method II

Step 2:

- Guinan et al. 1998, Fitzpatrick et al. 2001, Ribas et al. 2002: high-resolution UV-optical spectra (HST FOS) + broadband photometry + model atmospheres + χ^2 fitting
- Bye the way: Harries et al. 2002 (MN in press): disentangle spectra, Spt. type by eye, $T_{\rm eff}-$Spt. type, reddening from adopted $(B-I)_0$

Flux-fitting method III

$$f_{\rm model}(\lambda) = \left(\frac{r_{\rm A}}{d}\right)^2 [F_\lambda^{\rm A} + (r_{\rm B}/r_{\rm A})^2 F_\lambda^{\rm B}]$$

$$\times 10^{-0.4\, E(B-V)\, [k(\lambda-V)+R]}$$

$$k(\lambda-V) = c_1 + c_2\, x + c_3/((\gamma^2 + (x - x_0^2/x)^2) + c_4 F(x)$$

degeneracies: $R - c_1$, and $c_1 - \left(\frac{r_{\rm A}}{d}\right)^2$
(Groenewegen & Salaris 2001, A&A 366, 752)
nine parameters: $T_{\rm eff,A}$, [Fe/H], $E(B-V)$, d
R, x_0, γ, c_3, c_4.

Flux-fitting method IV

- Observationally expensive
- Merging of FOS spectra (difficulty to get highly accurate flux-calibrated spectra over the entire wavelength region)
- Folding spectra with broadband transmission curve give magnitudes in disagreement with ground based photometry.
- Fitting procedure: relative weights of broadband data and spectral data
- Uncertainty in model atmospheres (Groenewegen & Salaris 2001)

Alternative method I

Purely empirical

surface brightness:

$S_\lambda = m_\lambda + 5 \log \phi$

or

$\phi_{(m_\lambda=0)} = \phi \ \ 10^{m_\lambda/5}$,

and

d(pc) = 1.337×10^{-5} R(km) / ϕ (mas)

Key step: calibrate $\phi_{(m_1=0)}$ versus colour $(m_2 - m_3)$

Choose m_1, m_2, m_3

Alternative method II

Wish list

-tight relationship for main-sequence B-stars

-local calibrators available

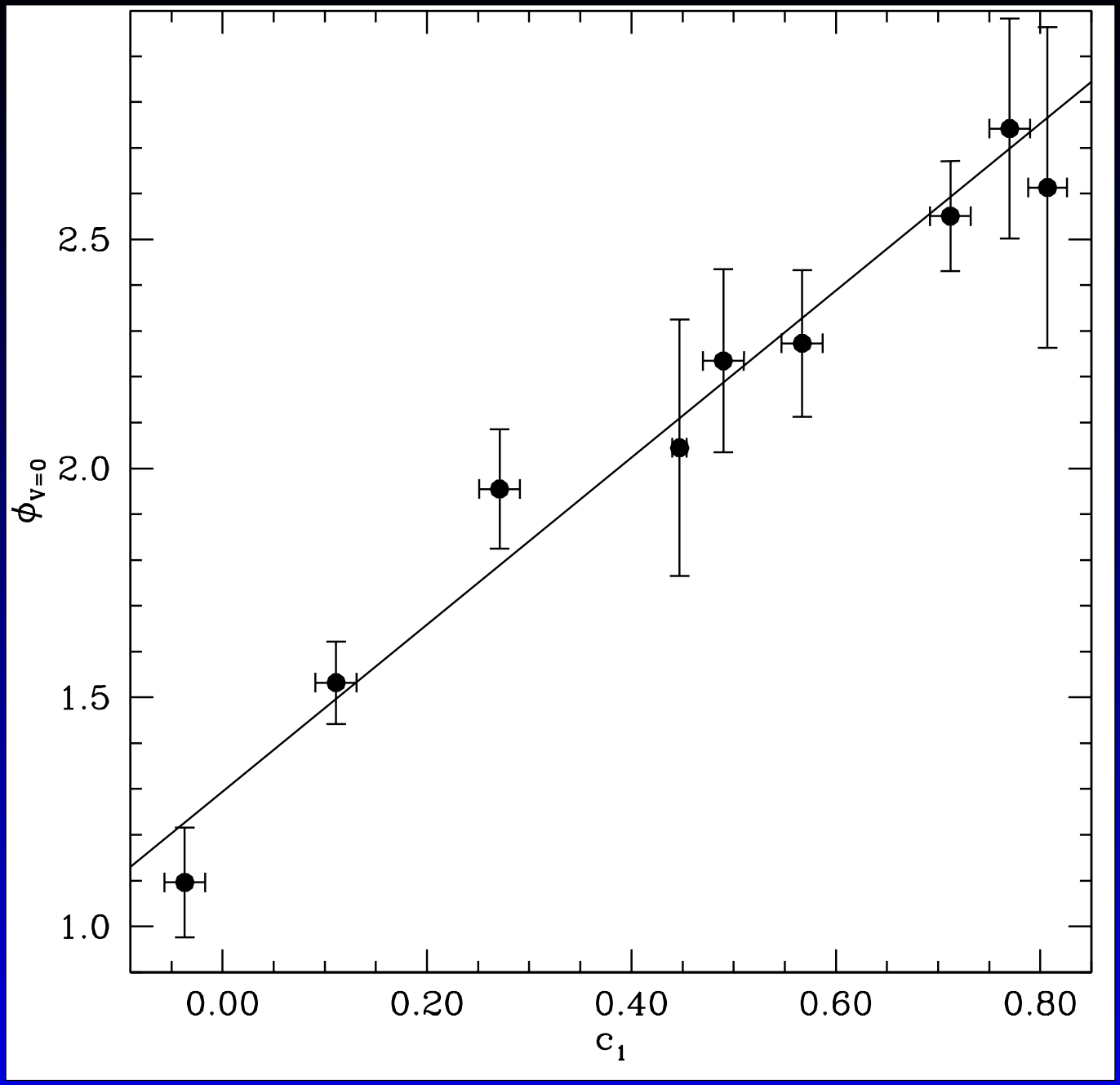
-depends as little as possible on reddening and metallicity

In the end.....: Strömgren photometry

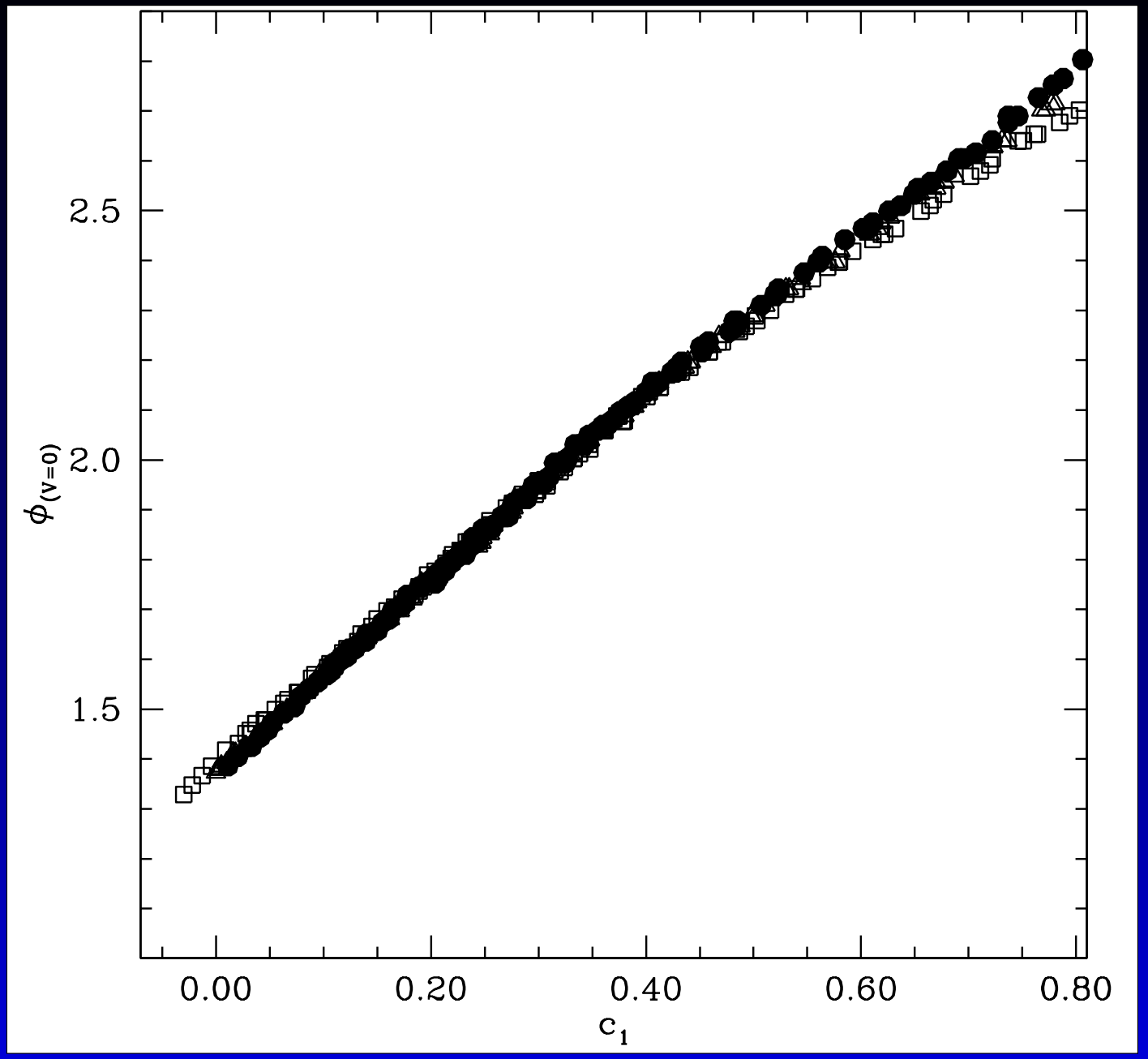
$\phi_{(V=0)}$ = 1.824($\pm$0.180) c_1 + 1.294($\pm$0.078)
(Salaris & Groenewegen 2002, A&A 381, 440)

Calibrators

9 B-stars: 2 EB with accurate Hipparcos parallaxes + 5 with direct angular diameter determinations



The calibration



[Fe/H]= −0.7(●), −0.4(△), 0.0 (□)

Alternative method III

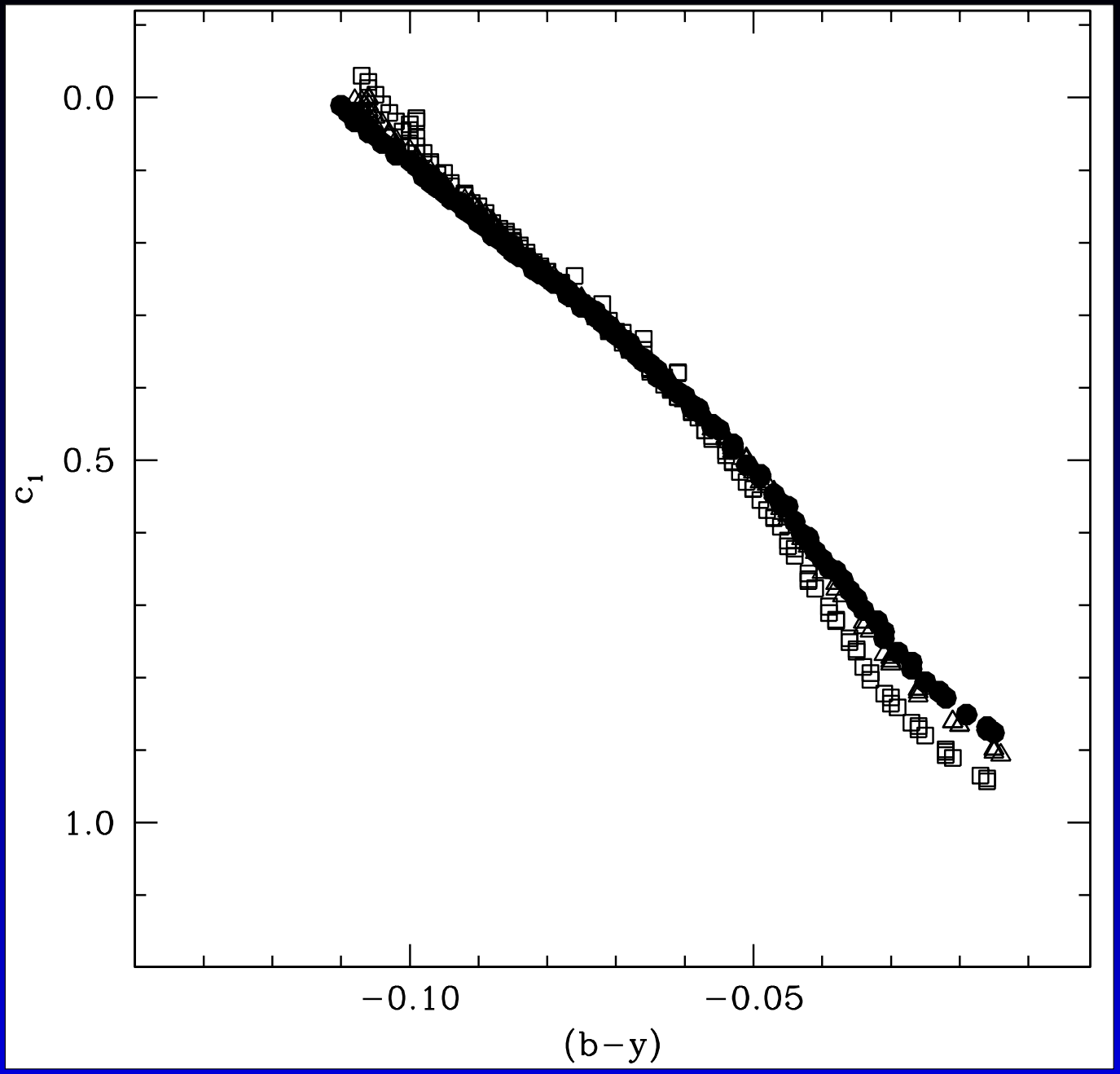
Advantage: reddening

Standard relationship $(c_1)_0$ versus $(b-y)_0$ for B-stars (Perry et al. 1987)

c_1 depends very weakly on reddening –
$(c_1)_0 = c_1 - 0.20E(b-y)$

$E(b-y) = E(B-V)/1.4 = (b-y) - (b-y)_0$

reddening determination is metallicity independent



[Fe/H]= −0.7(●), −0.4(△), 0.0 (□)

Applications I

3 Galactic EB systems with poor Hipparcos parallaxes

name	σ_V	$\sigma_{(b-y)}$	σ_{c_1}	$(m-M)_0$	$(m-M)_{0,Hip}$
HD24909A	$\pm$0.014	$\pm$0.004	$\pm$0.011	7.29$\pm$0.12	7.62$\pm$0.78
HD161783A	$\pm$0.010	$\pm$0.005	$\pm$0.010	7.83$\pm$0.12	7.01$\pm$0.52
HD218066A	$\pm$0.04	$\pm$0.010	$\pm$0.015	9.60$\pm$0.16	9.30$\pm$1.53
HD218066B	$\pm$0.04	$\pm$0.010	$\pm$0.015	9.62$\pm$0.16	9.30$\pm$1.53

Final accuracy in distance depends on accuracy in photometry

Applications II

LMC

name	σ_V	$\sigma_{(b-y)}$	σ_{c_1}	$(m-M)_0$
HV 982 A	$\pm$0.02	$\pm$0.041	$\pm$0.045	18.43$\pm$0.24
HV 982 B	$\pm$0.02	$\pm$0.041	$\pm$0.045	18.42$\pm$0.24

Summary

- Empirical surface-brightness method calibrated on main-sequence B-stars
- Calibrations almost independent of metallicity for [Fe/H] values spanning a range between the SMC and the Galactic bulge metallicity
- Reddening and distance can be derived simultaneously
- Single object accuracy of $\sim$0.15 mag in distance modulus for $\sim$0.02 mag photometric accuracy
- Observationally “cheap”
- Now extended to Geneva photometry

$$\phi_{(V_{\rm Geneva}=0)} = 0.446(\pm 0.084)\ \ d + 0.265(\pm 0.128)$$

THE END