Calibrators

PLATO GOP Workshop

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Nikki Miller, Pierre Maxted

Keele University, UK

Executive summary

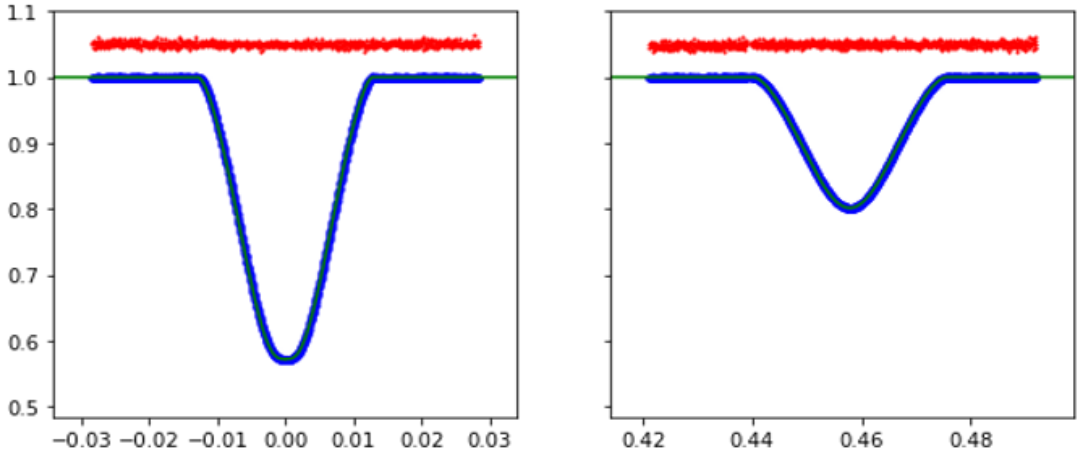
- **Detached eclipsing binaries (DEBS) are ideal calibrators for PLATO spectroscopy and asteroseismology pipelines**
  - *Accurate, model-independent masses and radii to ±1% or better*
  - *Direct measurements of T_{eff} to ±50K or better*
- **SPIRou, CRIRES+, etc. make it possible to study DEBS with optical flux ratio $L_2/L_1 \ll 1\%$**
  - *Demonstrated for EBLM J0113+31 using SPIRou*
- **New sample of ≈20 DEBS with $L_2/L_1 \approx 1\%$ in prep.**
  - *Echelle spectroscopy on 1 – 2-m class telescopes would be helpful*
  - *Multi-colour photometry of eclipses would be helpful*

Detached eclipsing binaries – state of the art

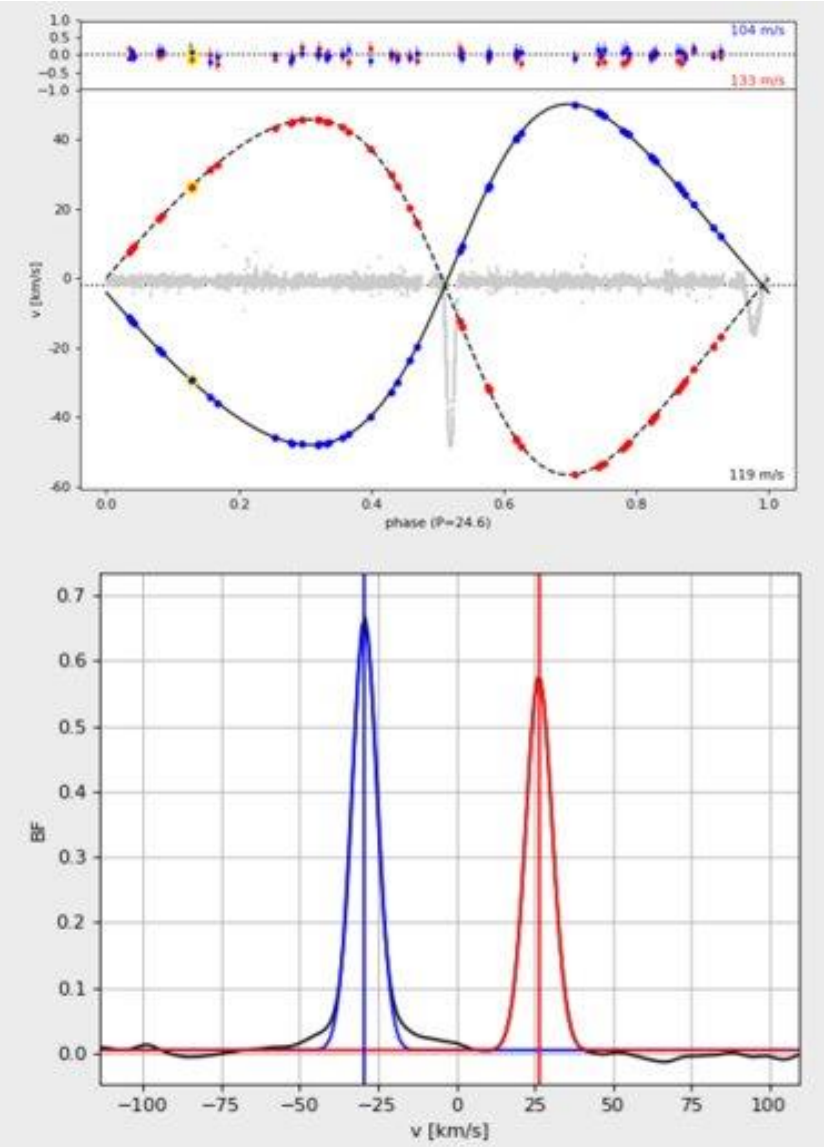
- **Significant differences between published mass/radius measurements remains an annoying problem for DEB studies**
  - *Sometimes happens for the first one or two studies on a new system*
  - *Not as bad as it seems – there is a bias to publish results that are significantly different and/or better than previous studies.*
- **Repeatable results are possible at 1% level or better**
  - *Can be demonstrated using independent analysis by experienced analysts*
- **Reliable mass/radius measurements accurate to 0.5% or better are possible for "well-studied" systems using good quality data**

Best case scenario – AI Phoenicis

K0_IV + F7_V
V = 8.6
P = 24.6 days

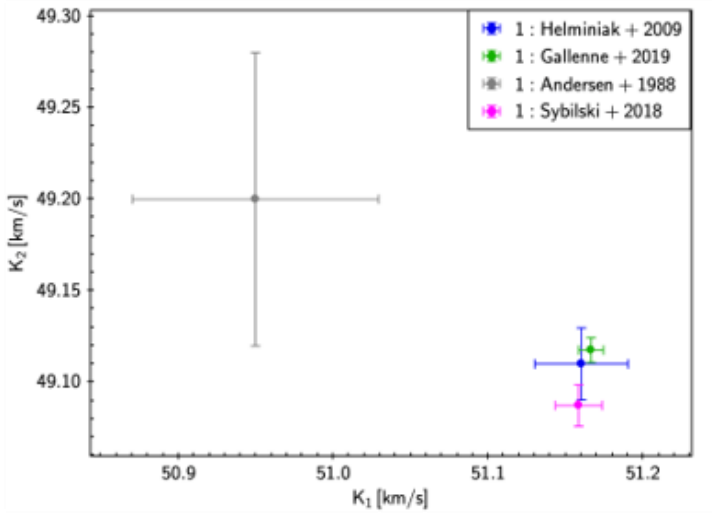


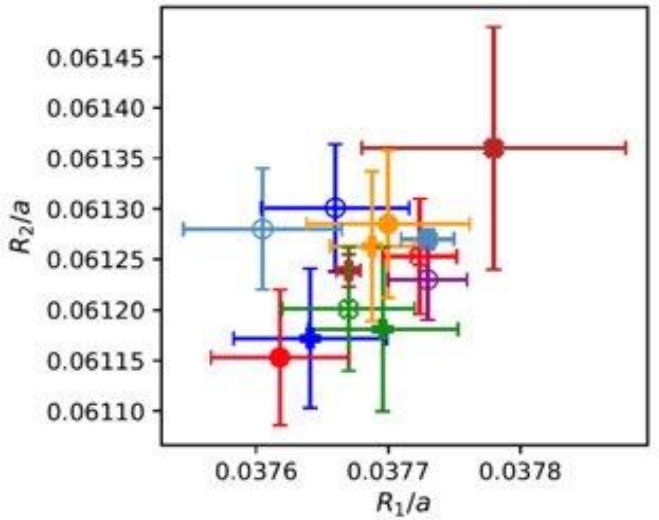
TESS light curve of AI Phe with fit and residuals



Best case scenario – Al Phoenicis

- Bright, long-period DEB with total eclipses.
- Excellent agreement in masses from three different echelle spectrographs
- Independent analyses of the TESS light curve agree well
- Mass and radius ±0.1%
  - (Maxted et al. 2020MNRAS.498..332M)



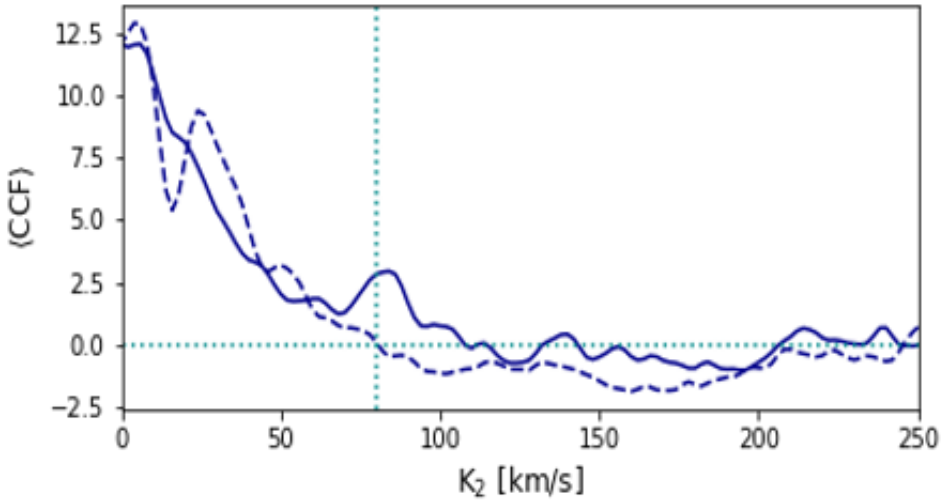


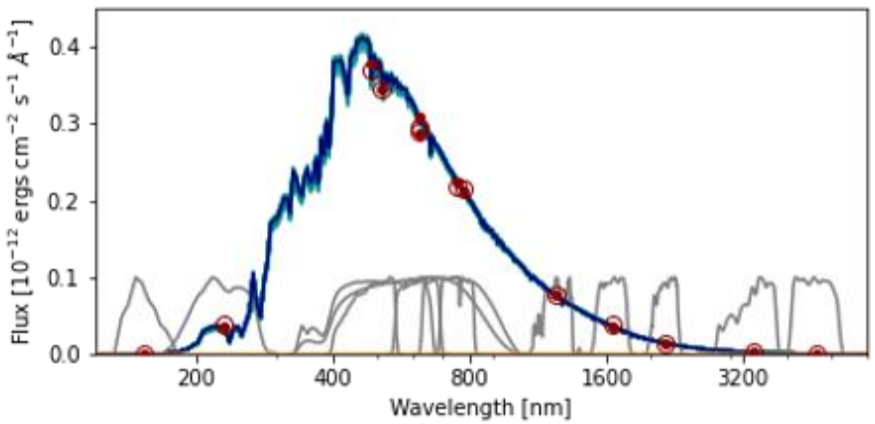
Fundamental T_{eff} measurements for DEBs

- **$T_{eff} = (4F_{bol}/\sigma_{SB}\,\theta)^{1/4}$, $\theta = 2R_{\star}/d$, by definition.**
- **Precise distances, *d*, to DEBs now available from Gaia**
- **Bolometric flux, F_{bol}, from GALEX + GAIA + 2MASS + …**
- **For DEBs, $F_{bol} = F_1 + F_2 = F_1\,(1 + F_2/F_1)$**
  - F_2/F_1 from light curve(s) + empirical colour-T_{eff} relations.
- **Full method described in Miller et al. 2020MNRAS.497.2899M**
- Results for AI Phe:
  - $T_{eff,1} = 6199 \pm 22$ K
  - $T_{eff,2} = 5094 \pm 16$ K

DEBs with extreme flux ratios

- EBLM J0113+31
  - G0V + late-M binary, P = 14.3 days
  - L_2/L_1 = 0.15% in TESS band
- M-dwarf spectrum detected at 4-σ
  - 22 SPIRou spectra, S/N~100
- $T_{eff,1}$ = 6124K ± 40K
- log g_1 = 4.148 ± 0.006

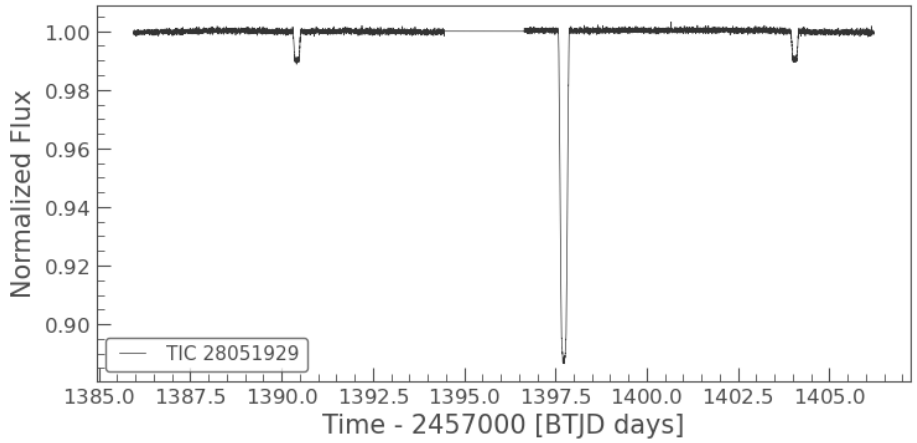


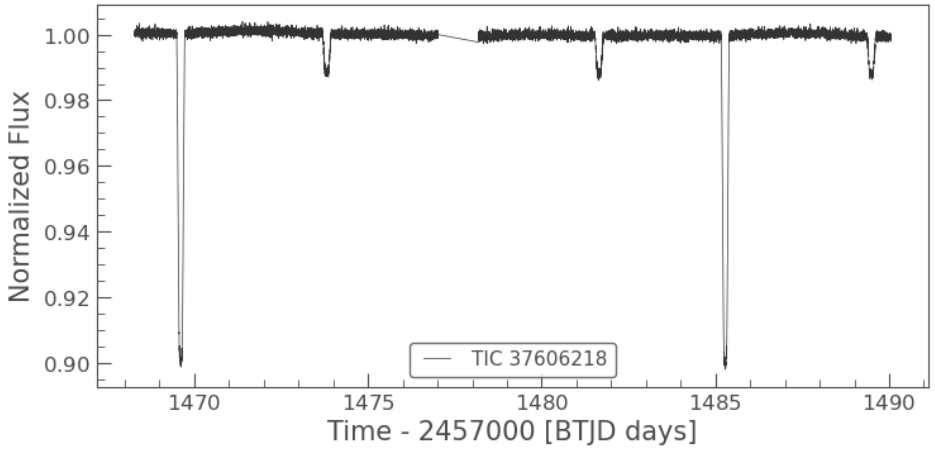


Maxted et al. 2022MNRAS.513.6042M

PLATO benchmark DEB sample – the sample

- All-sky sample of DEBs with …
  - FGK dwarf/subgiant primary star
  - $L_2/L_1 \approx 0.5\% - 2\%$ in TESS/K2
  - very little/no spot modulation
  - V ≈ 9– 13
  - P ≈ 6 – 60 days
  - narrow eclipse / no ellipsoidal effect
  - total eclipses
- Initial sample size ≈ 20
  - *A few may be rejected after follow-up*





PLATO benchmark DEB sample – follow-up

- **RV measurements over 2-3 years**
  - *To measure K_1 and to check for any 3rd body in the system.*
  - *Good project for an echelle spectrograph on a small telescope*
- **Multi-band photometry covering the eclipses**
  - *Useful to check for contamination by background stars / companions*
  - *Improves accuracy of T_{eff} measurements*
- **High-resolution (AO) imaging**
  - *Nice to have, but not essential?*
- **High-resolution, high-S/N NIR echelle spectroscopy**
  - *The last and most expensive step*
  - *Can be done with NIRPS, Carmenes, SPIRou, GIANO, etc.*

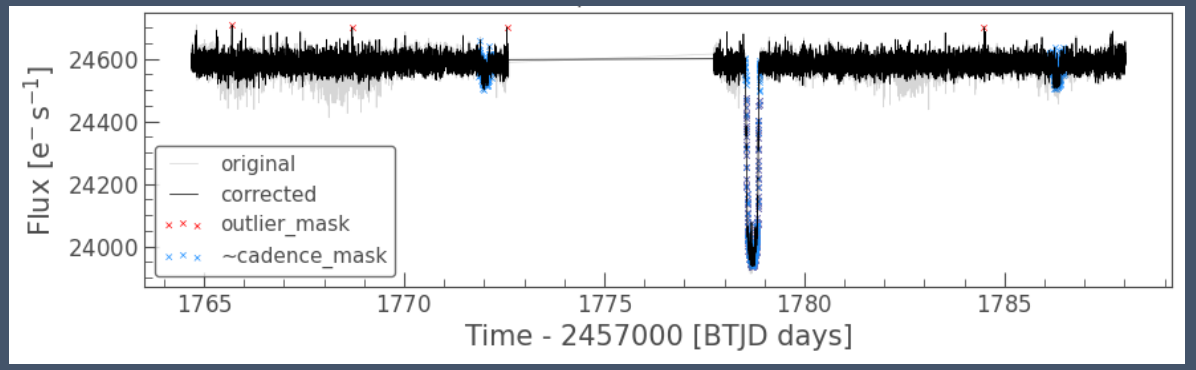
Thanks for your attention

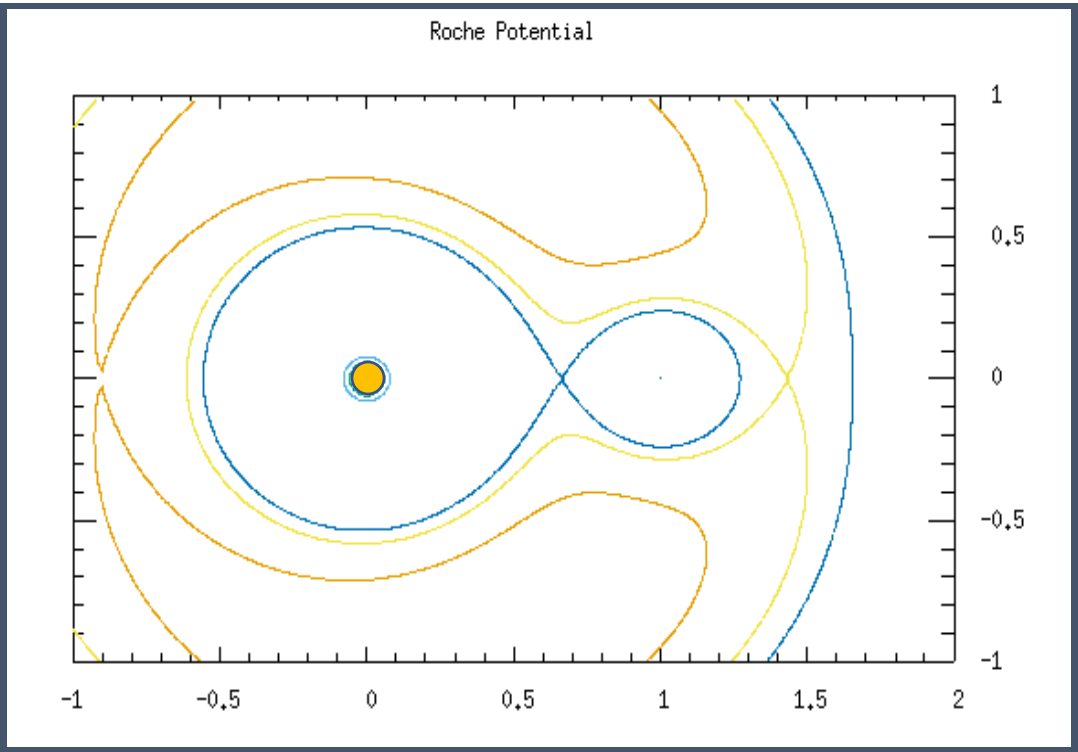
For further information contact:

- n.j.miller1@keele.ac.uk
- p.maxted@keele.ac.uk

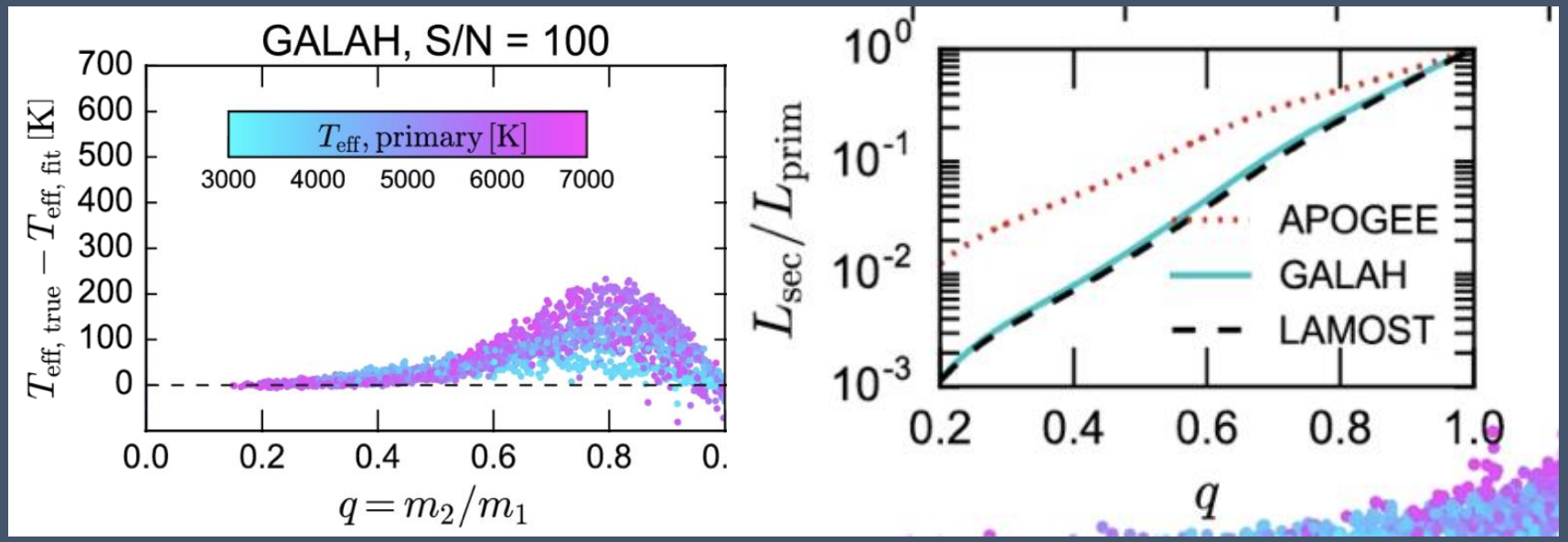
Is EBLM J0113+31 a "normal" G0 star?

- Oblateness ~0.0003
  - Mostly due to rotation
- Photometrically quiet
  - Variability ≲ 0.01% outside transit
- $V_{rot} \sin i = 6.6$ km s^{-1} ⇒ $P_{rot} \approx 11$ days
  - Slightly faster than solar-type stars at this age
- No mass transfer in the past 6 Gyr
- Negligible tidal torque from companion
- No weird abundances
  - A(Li) = 2.7, as expected for $T_{eff} = 6124$ K
  - [α/Fe] ≈ 0, as expected for thin-disk kinematics
- Apart from moderately low [Fe/H], *this is a boring, slightly evolved G0V star*





Is contamination from the M-dwarf a problem?



El Badry et al. 2018MNRAS.473.5043E

- For F-/G-dwarf stars using optical spectra – No
  - Optical flux ratio ≈ 1.5% ⇒ systematic error in Teff ≈ 5K before any correction