Appendix A

On the absolute calibration of Sirius

Abstract: *In this appendix, we discuss the use of Sirius as absolutely calibrated standard star in the southern hemisphere. We find that, because of problematic colors of Vega in the near-IR, any absolute calibration of the Sirius spectrum by magnitude-differences with Vega should be done in the optical and not in the IR. This leads to a re-scaling of the Sirius spectrum with a factor of 1.037 w.r.t. the absolute calibration proposed by Cohen et al. (1992)*

A.1 The Northern Hemisphere

In the northern hemisphere, Vega is *the* absolute photometric reference. Its absolute monochromatic flux at 0.5396×10^{15} Hz was measured to be 3.45×10^{-23} W/m^2/Hz by Hayes & Latham (1975), hereafter HL. Subsequent revisions of this value range from 3.38×10^{-23} W/m^2/Hz to 3.49×10^{-23} W/m^2/Hz. Megessier (1995), hereafter M95, analysed all available measurements and derived a best estimate of 3.46×10^{-23} W/m^2/Hz, accurate to within 0.7%.

A dedicated atmosphere model and corresponding synthetic SED were computed by Kurucz and are readily available from his webpage. Its stellar parameters are listed in column 2 of Table A.1.

The angular diameter of Vega was determined through optical interferometry by Hanbury Brown et al. (1974) (hereafter HB) and conversion of their UD diameter to a limb-darkened diameter yields $\theta_{LD} = 3.245$ mas.

Combining the interferometric diameter with Kurucz' dedicated model does indeed yield the measured absolute flux (within 1% of the HL/M95 value). Since diameter, model and flux were determined independently, this consistency confirms their accuracy.

One can thus use the Kurucz model, scaled with the HB diameter (or the HL/M95 flux) as an absolute representation of the photospheric emission of Vega. Since the calibration of the Geneva photometric system (Rufener & Nicolet 1988, hereafter RN) is primarily based on Vega (absolutely calibrated with the HL flux), the match between the Geneva photometry of Vega and the HB scaled Vega Kurucz model is near perfect (see Figure 5a–e of Rufener & Nicolet 1988).

A.2 The Southern Hemisphere

However, for some of the most southern observatories, Vega is not observable. Hence the need for another bright, well-known and absolutely calibrated stellar candle in the southern hemisphere. Cohen et al. (1992) (hereafter CohenI) deem Sirius to be suitable for this purpose. From line analysis, Kurucz determined the atmospheric parameters (column 3 of Table A.1) and built the appropriate model. Since no absolute flux measurements are available for Sirius, CohenI chooses to absolutely calibrate the Sirius model with respect to Vega. By using observed magnitude difference between Vega and Sirius in K,L,L',M and 4 Mid-IR wavelengths (Deacon 1991), the Sirius model is scaled to -what is believed to be- its absolute flux level. The resulting diameter for Sirius is 6.04 mas.

Table A.1 — Atmospheric parameters for Vega and Sirius according to Kurucz

parameter	Vega	Sirius
T_{eff} (K)	9550	9850
$\log(g)$	3.95	4.3
[Fe/H]	-0.3	+0.4
θ_{LD} (Cohen*)	3.335	6.04
θ_{LD} (This work)	3.245	6.15

* These values are updates by Kurucz after CohenI

A.3 Vega versus Sirius

Quite surprisingly, CohenI did not notice that the magnitude differences (between Vega and Sirius) they used in the (near-)IR, are not compatible with those in the UV/optical, under the assumption that the models are correct.

Figure A.1 shows the observed magnitude differences in the Geneva system and at JHKL, together with the magnitude differences predicted by the models. For this figure, the Sirius model was scaled so as to match the observed Geneva magnitude differences, *which requires Sirius to be 6.15 mas large, instead of 6.04 mas.* Clearly, the match in the Geneva photometry is excellent, through all filters, and thus confirms the quality of both models. From hereon, we will refer to the 6.15 mas Sirius model as *our* Sirius model.

What are the possible origins of this problem? We checked the observed magnitude differences against another photometric system (JP11) and found them to be correct. The problem must thus be with the (synthetic) SEDs.

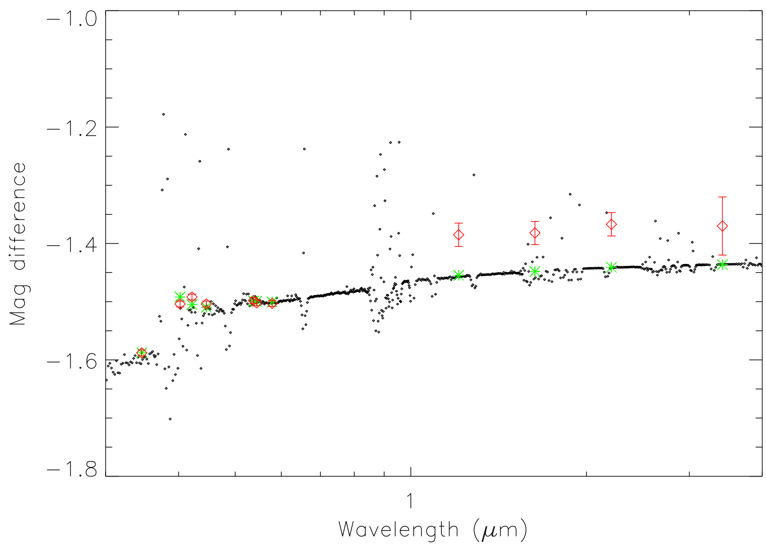

Figure A.1 — Observed (red) vs. synthetic (green) magnitude differences between Vega and Sirius ($\mathrm{Mag_{Vega}} - \mathrm{Mag_{Sirius}}$). The Sirius model is scaled in such a way as to match the observed difference in the Geneva system. The corresponding diameter for Sirius is 6.15 mas. Clearly, the (N)IR magnitude differences are not compatible: they differ by up to 10 %.

A.4 The near-IR excess of Vega

The far-IR excess of Vega due to its circumstellar debris disk is well studied and is one of the reasons why CohenI prefers the use of Sirius as primary calibrator in the IR. However, after quite some inconclusive evidence already in the 80s, more recent publications (last decade) present much stronger indications of the presence of a near-IR excess as well! Blackwell et al. (1983); Campins et al. (1985); Selby et al. (1983); Mountain et al. (1985); Rieke et al. (1985) present absolute (mountaintop) measures of IR Vega fluxes. CohenI actually compares these absolute IR measures with the Kurucz model for Vega, and notices the systematics: *"...the disposition of the mountaintop measurements is predominantly above the model"*. After inspection of the IRAS LRS spectrum, they find no significant departures from the model shortward of 16.5 μm. Furthermore, they refer to Bessell & Brett (1988), who find in their observations that the colours of Vega correspond to those of a normal A0 star, and thus that the apparent near-IR excess is not real.

If we return to Figure A.1 though, it is obvious that either the colours of Vega or Sirius are not those of an A0 star.

Recently, Ciardi et al. (2001) found through long baseline interferometry at 2.2 μm that $3-6\%$ of Vega's flux at that wavelength is probably coming from the debris disk.

Furthermore, M95 note that the near IR magnitudes of Vega differ from the mean colours for an A0V field star given in Johnson (1966), up to 0.1 mag. M95 also found that *"all the IR flux calibrations based on a comparison between Vega observations and atmosphere models lead to lower absolute monochromatic fluxes than those obtained by direct methods."* and are therefore not thrustworthy. M95 presents a new IR set of ZPs, based solely on direct measurements, which is presented in the next section.

A.5 A fully consistent set of Geneva/SAAO zeropoints

The South African JHKL system was calibrated with an ensemble of A0V stars, not including Vega (because not observable), with magnitude 0 for each wavelength determined by forcing the colours to be zero for the average A0V star, so that the IR magnitude scale should not be biased by the anomalies observed in Vega. New zeropoints for the SAAO system are published by Glass (1993). These were provided by CohenI and are *supposedly* calculated by integrating the Vega model over the combined filter/atmosphere/detector transmission profiles. With these zeropoints (column 2 of Table A.2) our observed Sirius magnitudes (column 3 of Table A.2) —which correspond to the values published by CohenI to within 1σ— agree with our absolutely calibrated Sirius model to within 1σ (except for K), to be compared to a more than 3σ deviation (in J) if we use a diameter of only 6.04 mas. With the same ZP, we computed the magnitudes of the Vega model in the same system (using the total transmission profiles we received from Cohen, private communication), and arrived at the values in the last column of Table A.2.

Table A.2 — SAAO zeropoints, observed Sirius magnitudes and differences with our own absolutely calibrated Sirius SED. The zeropoints are supposed to be those for a clean Vega photosphere (Glass 1993), but according to our own calculations, the Kurucz Vega model does not have 0 magnitude with these ZP.

Filter	ZP [log $Wm^{-2}Hz^{-1}$]	Sirius [mag]	Sirius model [mag]	offset [mag]	Vega model [mag]
J	-22.78	-1.393	-1.397	0.004	0.054
H	-22.98	-1.391	-1.391	0.000	0.054
K	-23.20	-1.378	-1.420	0.042	0.014
L	-23.54	-1.386	-1.418	0.014	0.032

It is not clear to us where exactly those published ZP come from: they are neither compatible with a 0 mag Vega model, nor with a 6.04 mas Sirius model. However, they are rather consistent with a 6.15 mas Sirius model, and thus also with a true 0 mag (hypothetical) Vega observation.

M95 derives a new set of ZPs for a 0 mag source in the ESO JHKL system. These agree quite well with the published ZP for SAAO (Glass 1993) in J and H, but differ more in K and L. They are repeated here in Table A.3. Under the assumption that a 0 mag A0V star in the ESO system has the same magnitude in the SAAO system, which we will discuss further on, these new ZPs can also be used to calibrate our SAAO observations of Sirius.

When doing so, we arrive at a highly satisfactory agreement between our absolutely calibrated

Table A.3 — ESO JHKL zeropoints, as determined by Megessier (1995), which we will also use to calibrate the SAAO observations.

Filter	λ (μm)	ZP (log $\mathrm{Wm^{-2}Hz^{-1}}$)
J	1.244	-22.79
H	1.634	-22.97
K	2.190	-23.18
L	3.770	-23.59

Sirius model and the SAAO observations: the residuals are all within 1 σ of the observations. The same Sirius model compared to the Geneva-data, yields an equally convincing fit. The ratio of the Sirius model with the observations in both the Geneva and SAAO systems is presented in Figure A.2.

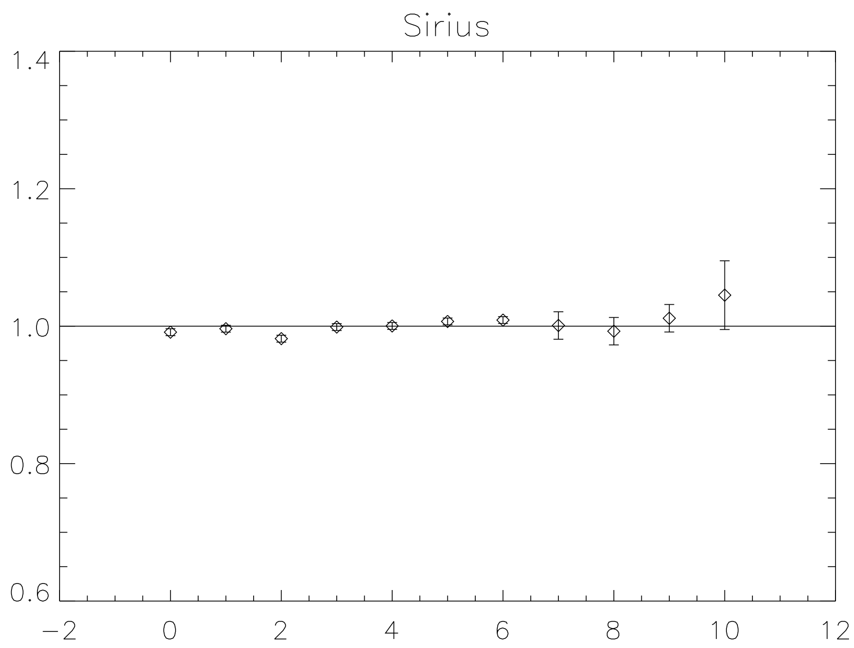

Figure A.2 — Ratio of our Sirius model and the observations (in photon counts), with the standard Geneva ZPs and those of M95 for JHKL. From left to right, we show U, B_1, B, B_2, V, V_1, G, J, H, K, and L. As discussed in Chapter 3, the B fi lter is problematic due to poorly-modelled Balmer lines.

A remark should be made on the assumption that a 0 mag A0V star in the ESO system has the same magnitude in SAAO. Carter (1990) presents conversion formula from one system to the other, which have rather large offsets (0.04 mag at J) and a high scatter, but those offsets are still within $2\,\sigma$ from 0. Furthermore, the ESO measurements used for this analysis were obtained in the ESO-Engels system, which is no longer in use. The M95 calibration refers to the latest ESO setup, which should be much more consistent with other near-IR systems (Bersanelli et al. 1991). Unfortunately, no recent ESO JHKL photometry of Vega and Sirius could be found.

A.6 Conclusions

We conclude that: (1) the absolute calibration of the Vega model presents no problems, (2) Vega shows a near-IR excess which renders it useless for IR calibration, (3) Sirius can be used as an alternative, if calibrated correctly with respect to Vega, i.e. with magnitude differences in the optical instead of the IR and (4) the resulting Sirius model is compatible with both Geneva and SAAO photometry. The agreement is best if the latter is calibrated as suggested by M95, i.e. with only direct measurements, but is acceptable also with the ZP published by Glass (1993). However, we were unable to trace the origin of the latter.