SDSS III

SLOAN DIGITAL SKY SURVEY III

APOGEE

TECHNICAL NOTE

Conversion from vacuum to standard air wavelengths

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Abstract

We explore possible expressions for the conversion between vacuum wavelengths and wavelengths in standard air. We find that the equation proposed in the SDSS website is not appropriate for APOGEE. The differences between the available approximations in the H band are at the level of a fraction of a milliAngstroms, or several meters per second, and a significant contribution is related to the change in the definition of *standard* air. The most recent revision seems a sensible choice, and a second-order polynomial can be used in the H-band without any loss of accuracy. It is recommended that vacuum wavelengths be used for APOGEE.

1 Introduction

Since the APOGEE spectrograph is operating in vacuum, and given the tradition in SDSS of using vacuum wavelengths, it is proposed that vacuum wavelengths be used for APOGEE.

Further support for embracing a vacuum scale is motivated by the fact that, historically, the definition of standard air includes tight constrains on temperature (15 C), pressure (1 atmosphere), and humidity (dry), but not so clearly the CO_2 concentration, which is time and spatially dependent, and the standard temperature scale has also seen multiple changes in the past century, and these drag the air-to-vacuum corrections. In addition, the reference wavelengths for the Th and Ar lines usually employed for calibration come from vacuum-housed spectrographs, and are therefore more naturally used in vacuum (Norlén 1973, Palmer & Engleman 1983, Hinkle et al. 2001, Lovis & Pepe 2007, Kerber et al. 2008).

This note describes the differences on the vacuum-to-air conversions and proposes adopting a specific one for dealing with such corrections in the APOGEE project.

2 Available formulae

The IAU standard for the vacuum to standard air corrections (see resolution No. C15, Commission 44, XXI General Assembly in 1991) refers to Oosterhoff (1957), which adopts the results by Edlén (1953)

$$\frac{\lambda_0 - \lambda}{\lambda} = n - 1 = a + \frac{b1}{c1 - 1/\lambda_0^2} + \frac{b2}{c2 - 1/\lambda_0^2} \tag{1}$$

where λ_0 is given in μm, and the constants are given in the first row of Table 1.

Later work widely adopted in the Physics literature by Edlén (1966) rederived the constants from optical and near UV data, and later Peck & Reeder (1972 and references therein) added additional measurements extending into the IR, up to 1.7 μm,

Table 1: Parameters for Eq. 1

Reference	a	b_1	b_2	c_1	c_2
Edlén 1953	6.4328×10^{-5}	2.94981×10^{-2}	2.5540×10^{-4}	146.0	41.0
Edlén 1966	8.34213×10^{-5}	2.406030×10^{-2}	1.5997×10^{-4}	130.0	38.9
Peck & Reeder 1972	0.0	5.791817×10^{-2}	1.67909×10^{-3}	238.0185	57.362
Ciddor 1996	0.0	5.792105×10^{-2}	1.67917×10^{-3}	238.0185	57.362

which showed a systematic deviation from Edlén's equation at the level of several 10^{-9}, or a few m/s.

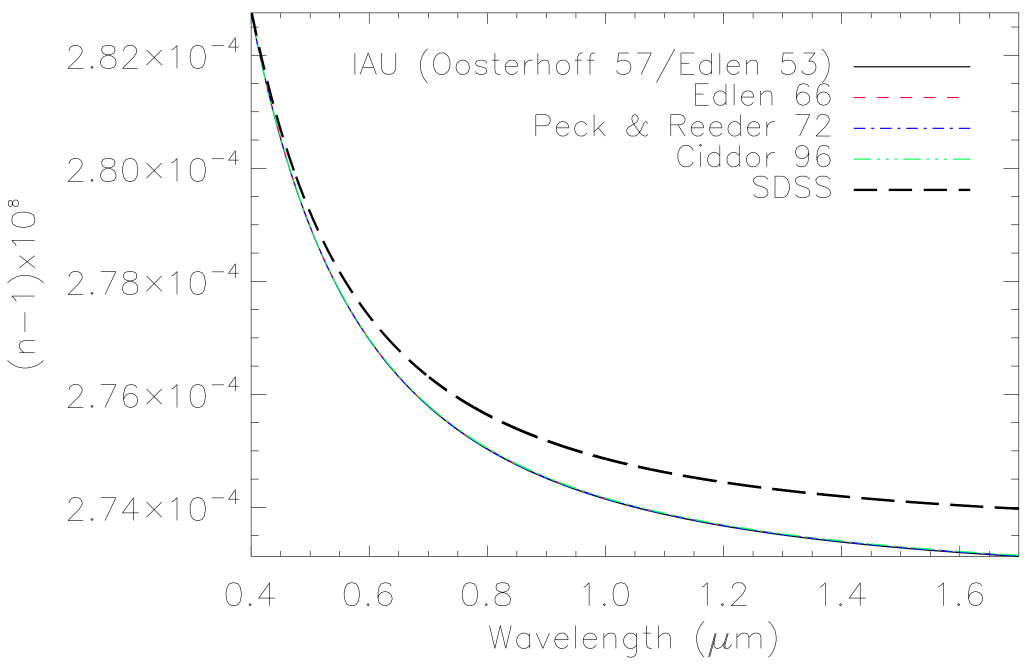

Figure 1: Difference between the refractive index of standard air (n) and unity in the optical and near-IR for five different sources.

Table 1 compares the parameters proposed by Edlén (1953, 1966), Peck & Reeder (1972), and Ciddor (1996), the latter reference largely based on Peck & Reeder (1972), but updated to account for the changes taken place in the international temperature scale since their work, and adjusting the results for the CO_2 concentration.

Fig. 1 compares these four references with the approximate formulae adopted in the SDSS documentation[1]. The differences between the first four sources are relatively small, but the expression proposed in the SDSS website is off by 2 parts

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[1] http:www.sdss3.orgdr8spectrospectra.php#vacuum

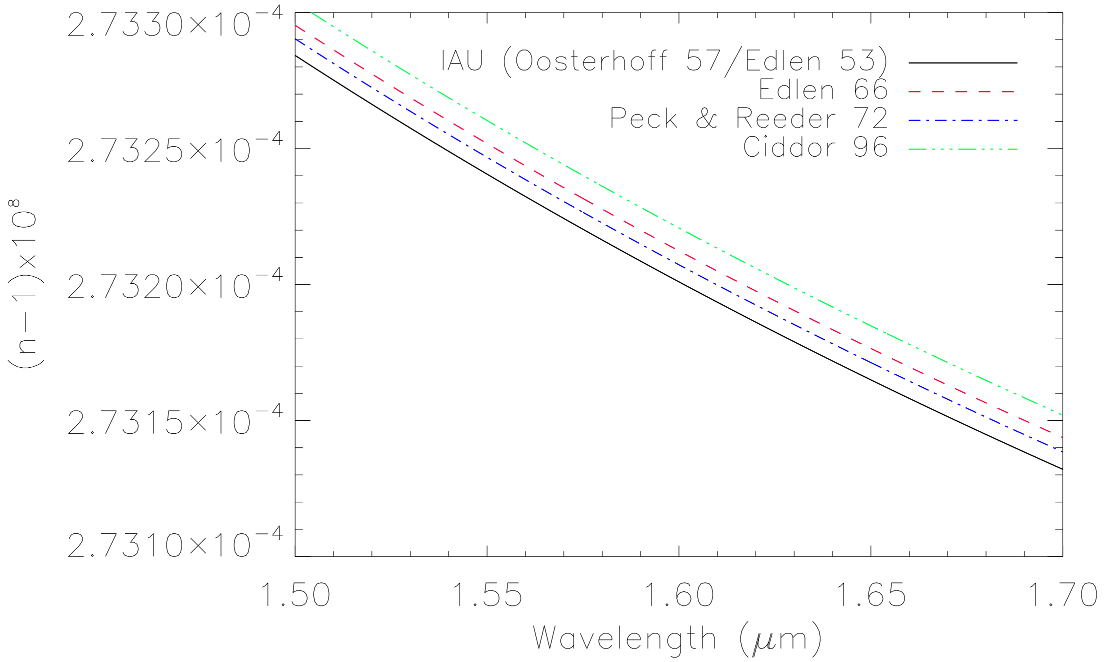

Figure 2: Difference between the refractive index of standard air (n) and unity in the H band for four different sources considered.

in a million in the infrared, equivalent to 250 m/s at 1.6 μm[2].

Fig. 2 zooms into the H band and shows maximum discrepancies at the level of 3×10^{-8}, or 10 m/s at 1.6 μm. The equations proposed by Edlén (1966) and Peck & Reeder differ only by about one fourth of that. About half of the difference between Peck & Reeder and Ciddor (2×10^{-8} or 6.5 m/s at 1.6 μm) is related to the temperature scale. The paper by Peck & Reeder is not specific regarding the scale used, and Ciddor assumes they used the IPTS-48 standard[3], which is warmer than the one currently in use (ITS-90) by 9.2 mK at 15 C. If Peck & Reeder used the IPTS-68 standard instead, the difference would be reduced to 5.6 mK. Changes of 9.2 mK and 5.6 mK amount to an increase in $(n-1) \times c$ of about 2.6 and 1.6 m/s, respectively, at 1.6 μm. The rest of the correction between Peck & Reeder and Ciddor's review (3.9 m/s at 1.6 μm) is related to the CO_2 concentration in standard air. Because of secular variations in the typical laboratory air, Birch & Downs proposed to use 450 ppm[4] in the definition of standard air, while Ciddor

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[2] As of this writing a bug report has been filed by David Schlegel and the appropriate IDL routines (VACTOAIR.pro and AIRTOVAC.pro) have been modified by Wayne Landsman to remove this discrepancy, caused by approximating Eq. 1 by a truncated expansion.

[3] International Practical Temperature Scale; $t_{68} = 1.00024 \times t_{90}$ (Saunders 1990); $t_{68} = t_{48} - 4.4 \times 10^{-6} t_{48} \times (100 - t_{48})$ (Fofonoff & Bryden 1975)

[4] parts per million

estimates that a value closer to 300 ppm is adequate for the measurements used by Peck & Reeder. In summary, the variation between between Pecker & Reeder and Ciddor (1996) is connected to a change between the actual conditions of standard air now and at the time of the measurements.

3 Conclusions

In view of the preceding discussion, we underline the advantages of using vacuum wavelengths for the APOGEE spectra. In some cases, corrections between air and vacuum will be needed, and for those it is proposed that the formulation proposed by Ciddor (1996) be used. This corresponds to Eq. 1 with the Ciddor constants given in Table 1. This is valid for the wavelength range between 0.23 and 1.7 μm, and the estimated accuracy in the predicted refraction index of standard air is about 10^{-8} or roughly 3 m/s at 1.6 μm. Note that it is straightforward to go from vacuum to standard air wavelengths with Eq. 1, but the inverse process requires iteration since n is given as a function of vacuum wavelength.

4 References

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