Measurement of the absolute flux from Vega in the K band (2.2 μm)

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Summary. A method is described for determining absolute stellar flux in the infrared, based on a direct comparison between a star and a furnace at a known temperature. Observations have been made of Vega in the K band (2.2 μm) using the Tenerife flux collector. The absolute flux from this star at the Earth, reduced to the wavelength 2.20 μm, is found to be $0.375 \times 10^{-9}$ W m$^{-2}$ μm$^{-1}$ with an uncertainty of 8 per cent.

1 The need for an absolute calibration

Although there have been great advances in the application of infrared techniques to astrophysics, a direct calibration of infrared stellar flux, i.e. one in which the flux from a star is compared with that from a standard source, does not exist. Instead, there are several indirect calibrations. One of these, devised by Johnson (1964, 1966), is based on observations of stars having a spectral type similar to that of the Sun, and on knowledge of the solar constant. Another, that of Gehrz, Hackwell & Jones (1974), is based on an extrapolation of the UBVRIJK photometric system using fluxes predicted for a blackbody. More recently, Strecker, Erikson & Whitteborn (1979) obtained infrared spectra for 13 bright stars and placed them on an absolute scale using a model atmosphere for the star α Lyr. For many purposes an accurate calibration is not needed, but one is required for the application of the ‘infrared flux method’ for determining stellar angular diameters and effective temperatures (Blackwell & Shallis 1977; Blackwell et al. 1978, 1979, 1980; Shallis & Blackwell 1979, 1980). An accuracy of 2 per cent in infrared flux is desirable in order to realize the potential accuracy of the method, whereas present determinations of absolute flux are not of this accuracy. Furthermore, Blackwell et al. (1979) have suggested that there may be a wavelength dependent error in the Johnson calibration of about 11 per cent between 3 and 5 μm. The present paper describes a method for obtaining a direct measurement of infrared stellar flux and gives a preliminary measurement of the absolute flux from Vega in the K band (2.2 μm) obtained by its use with the Tenerife flux collector.
2 The method

A direct comparison in the infrared region between a star and a standard source, such as is done at shorter wavelengths (e.g. the calibration of Vega at wavelengths up to 1.08 \( \mu \)m; Hayes, Latham & Hayes 1975), is not easy. It is not practicable to observe a standard source on the ground at a large distance from the telescope because of the difficulty in determining the extinction to the source. An alternative is to use a collimated beam from the furnace at a shorter distance, but neither method is feasible with the Tenerife flux collector because this telescope cannot be used at large zenith distances. In our method, we have attached the furnace, used as a standard source, to the telescope in the arrangement shown in Fig. 1. Either the star may be observed through a 15 arcsec diaphragm at the Cassegrain focus or a signal may be obtained from the furnace via a MgO diffusing screen placed above a star diaphragm (whose diameter is selected to match the seeing angle) and irradiated by the furnace. Using this optical arrangement ensures that the illumination on the detector is the same for both star and furnace. The purpose of the limiting field stop on which an image of the primary is overfilled is to ensure that the geometry of radiation collection is identical for the star and furnace so that it does not enter into the reduction of the observations. The detector is used in a dc mode. The measurement that has to be made is the ratio \( R \) of these two signals. If the flux of radiation falling on the diffuser is \( F_\lambda \), and a fraction \( f/2\pi \) per steradian of this is scattered towards the star diaphragm, it may be shown that the flux of radiation from the star at the Earth, \( F_{s, \lambda} \), is given in terms of \( R \) by

\[
F_{s, \lambda} = \frac{RAf}{2\pi F^2 T_1 T_2} F_\lambda
\]

in which \( A \) is the area of the star diaphragm, \( F \) is the focal length of the telescope, and \( T_1 \) and \( T_2 \) the reflectivities of the primary and secondary mirrors.

3 Observations and results

Observations were made at Tenerife on several nights, but the nights of 1979 July 9/10 and July 14/15 were selected for reduction as the best for photometry, conditions on the former

Figure 1. Optical arrangement at Cassegrain focus of Tenerife flux collector.
Measurements of the flux from Vega

Table 1. Determinations of the absolute flux from Vega at \( \lambda = 2.2 \text{ \textmu m} \).

<table>
<thead>
<tr>
<th>Source</th>
<th>( F_\lambda ) ( (W \text{ m}^{-2} \text{\textmu m}^{-1} \times 10^9) )</th>
<th>( F_\nu ) ( (W \text{ m}^{-2} \text{Hz}^{-1} \times 10^{24}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Selby et al. (present work)</td>
<td>0.375</td>
<td>6.05</td>
</tr>
<tr>
<td>† Johnson (1966)</td>
<td>0.383</td>
<td>6.18</td>
</tr>
<tr>
<td>‡ Gehrz et al. (1974)</td>
<td>0.406</td>
<td>6.55</td>
</tr>
<tr>
<td>Strecker et al. (1979)</td>
<td>0.393</td>
<td>6.36</td>
</tr>
</tbody>
</table>

* The estimated accuracy is 8 per cent.
† Assuming \( K = +0.02 \text{ mag} \) on the Johnson system.
‡ Assuming \( K = -0.02 \text{ mag} \) on the Gehrz et al. system. The flux quoted by Gehrz et al. at \( \lambda = 2.3 \text{ \textmu m} \) has been converted to an equivalent flux at \( \lambda = 2.2 \text{ \textmu m} \) assuming a blackbody distribution. Gehrz et al. estimate their accuracy as \( \pm 5 \) per cent.

night being especially good. Observations were made primarily of Vega, the adopted standard star, but other stars were included in order to determine the atmospheric extinction. On July 9/10 this was 0.114 mag air mass\(^{-1}\). As observations of Vega were made to a minimum air mass of 1.01, the correction to zero air mass was 11.1 per cent. The furnace was used at a temperature of 1253.6 K measured to an accuracy of 1 K by means of a photoelectric pyrometer against a standard lamp calibrated at the National Physical Laboratory (Andrews et al. 1979). This uncertainty in temperature corresponds to an uncertainty of 0.4 per cent in the flux from the furnace, which is small in comparison with other uncertainties in the experiment. The reflectivity of the primary mirror was measured in the \( K \) band at 48 places on it using a specially constructed reflectometer, and an average used; that of the secondary mirror was measured at a smaller number of places. Finally, the scattering factor \( f \) of the MgO diffuser was measured using the furnace as a source in a separate experiment. A standard UKIRT \( K \) filter was used; with Vega, this has an effective wavelength of 2.162 \( \text{\textmu m} \).

In reducing our observations of the flux from Vega through the \( K \) filter, we have taken account of the variation over the filter bandwidth of the flux from the furnace and from Vega. The latter is taken to be that of a blackbody at the appropriate temperature. Our result for the absolute flux from Vega is \( 0.375 \times 10^{-9} \pm 0.03 \times 10^{-9} \text{W m}^{-2} \text{\textmu m}^{-1} \) reduced to the wavelength \( \lambda = 2.20 \text{\textmu m} \) in this manner. We consider that the principal uncertainty comes from the use of the MgO diffuser and the limitations resulting from sky conditions. This result is compared with those of Johnson (1966), Gehrz et al. (1974) and Strecker et al. (1979) in Table 1. The difference between our result and that of Johnson is not significant, but we suggest that the result of Gehrz et al. is high.

A magnesium oxide diffuser is suitable for use in the \( K \) band because this material is virtually opaque in small thicknesses at \( \lambda = 2.2 \text{\textmu m} \). However, such a diffuser is not suitable at longer wavelengths (e.g. the \( L \) band) because magnesium oxide is almost transparent there. We plan to repeat the \( K \) band measurement in future experiments in an optical arrangement without the diffuser, and to extend our measurements to the \( L \) band at least.

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References