LUCIFERS, A PHOTOELECTRIC RADIAL-VELOCITY
SPECTROMETER

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(Received 22 March, 1994)

Abstract. A spectrometer dedicated to the measurement of stellar radial velocities has been developed at the University of Canterbury and the Mt John University Observatory. The spectrometer scans a spectrum from the Observatory's 1-metre McLellan reflecting telescope and fibre-fed échelle with an oscillating mask having 2447 rectangular slots representing absorption lines in the spectrum of the star α Centauri A covered by the wavelength range 397 to 570 nm in orders 40 to 58 of the spectrograph and measures the light passing through the mask as a function of mask position. A dedicated computer constructs a cross-correlation function to which a Gaussian distribution function is fitted. The difference between the radial velocities of a star and a zero-velocity reference spectrum provided by a hollow-cathode iron emission lamp is calculated from the Gaussian parameters. The sources of random error in the system are discussed and its magnitude for stars of spectral types F0 to M3.5 is estimated. Systematic errors in the system are also discussed.

1. Introduction

The use of a photoelectric spectrometer to obtain radial velocities by the cross-correlation of a spectrum and a mask was proposed by Felgett (1953), and the construction and use of several spectrometers of this type have been described, notably by Griffin (1967), Griffin and Gunn (1974), Beavers and Eitter (1977 and 1986), Fletcher et al. (1982), McClure et al. (1984), Fletcher and McClure (1986), Mayor (1977), Baranne et al. (1979), and Mayor and Maurice (1984).

It follows trivially from the formula for the Doppler shift \( \delta \lambda \) of a spectral feature of laboratory wavelength \( \lambda \) subject to a radial velocity \( v \)

\[
\delta \lambda = \frac{v}{c} \lambda,
\]

that there will be a wavelength-dependent mismatch between any Doppler-shifted spectrum and a rigid physical mask which will increase in severity with the radial velocity \( v \). The mismatch can be minimized by restricting the spectral range which is observed, or by altering the plate scale of the spectrum or the mask to compensate for it. In the instrument at Palomar described by Griffin and Gunn (1974), the plate scale of the spectrum was carefully adjusted for each observation to reduce the observable mismatch to an acceptable level. In the instrument at Victoria described by Fletcher et al. (1982), McClure et al. (1984), and Fletcher and McClure (1986), the arrangement of the slots in the mask in combination with the mounting and direction of oscillation of the mask effectively altered the plate scale of the mask in a velocity-dependent manner to compensate for the mismatch. The designers of
the other spectrometers have, however, chosen to reduce mismatch by restricting
the observed spectral range.

The first photoelectric radial-velocity spectrometer was constructed by Griffin
(1967) and used with the existing coude spectrograph at the Cambridge 90-cm
telescope, and mismatch was minimized by restricting the spectrum which was
used to the narrow region between 463.9 and 482.7 nm. Griffin (1967) estimated
the greatest possible mismatch between a spectral line and its representation in
the mask of his instrument to be 5 km s\(^{-1}\) at the extremes of the instrument's
velocity range. The Fick Observatory instrument described by Beavers and Eitters
(1977, 1986) appears to have used a 40-nm spectral range centered on 460 nm.
Alternatively, the observed spectral range may be narrowed by using an echelle
grating to provide many short segments of spectrum in different diffraction orders.
Because the spectral range in each order is small, the mismatch over that range
is also small, and since the reciprocal dispersion in different orders is inversely
proportional to the order number, the lines in all orders of an echelle spectrum
suffer the same displacements as a result of their Doppler shift (Hearnshaw, 1977a).
An echelle radial-velocity spectrometer would, in principle, reduce the mismatch
problem while still allowing a relatively large total spectral range and number of
lines to be included in the mask.

The advantages of using an echelle grating were first realized in the Coravel
cassegrain echelle radial-velocity spectrometer which was constructed in 1977 by
the Geneva and Marseilles observatories. Being mounted at the cassegrain foci of
their telescopes, the Coravel spectrometers are subject to the classical problem of
all cassegrain radial-velocity spectrometers and spectrographs, namely mechanical
flexure, thermal effects and the need for a good autoguider to reduce guiding
errors on the slit. Mechanical flexure has been minimized in the Coravel design
by incorporating both the echelle grating and the mask as non-moving parts of a
very rigid structure, the spectrum produced by the grating being oscillated across
the mask at about 4 Hz by passing the light through a thick rocker plate. The
mask contains about 3000 slots in 20 echelle orders between 360 and 520 nm,
and the cross-correlation function is recorded from the signal of a photomultiplier
tube behind the mask, to which the light is sent by means of a large Fabry lens.
The designers report (Mayor and Maurice, 1984) that the radial velocities obtained
using the Coravel spectrometer mounted on the 1.54-m Danish telescope at the
European Southern Observatory in Chile are reproducible to between 0.20 and
0.25 km s\(^{-1}\).

Recently, Murdoch and Hearnshaw (1991a) have discussed the unavoidable
random error bars in radial-velocity determinations due to photon noise in the raw
data, based on an analysis of cross-correlation functions between two spectra or a