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Absolute energy distribution studies in stars and comets

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Abstract. Through the visible window of the earth's atmosphere, we measured portions of stellar continuum of six classical cepheids and a few Be stars, using a Hilger and Watts spectrum scanner at the Cassegrain focus of the one metre telescope. These observations after calibration give monochromatic magnitudes at various wavelengths. Based on these observations, effective temperatures of classical cepheids at their various phases of light cycle were estimated by comparing the observed absolute energy distribution in visible region with the stellar model atmospheres. These temperatures were used to established an effective temperature and colour relation. Similar technique was used to estimate effective temperatures of a few bright Be stars. Spectrophotometry of many bright comets was done using the same instrument to estimate the production rates and column densities of the molecular species giving emission bands.

1. Introduction

The visible stellar spectrum comes from a relatively thin part of the stellar atmosphere called the photosphere. It is the only region we can study extensively for most stars. The behaviour of the atmosphere is controlled by the density of the gases in it and the energy escaping through it. Stellar atmospheres are the connecting links between the observations and the rest of stellar astrophysics. Through the visible window of the earth's atmosphere, we measure portions of a stellar continuum. The primary aim is to obtain the photospheric temperature scale. In the hotter stars the shape of the continuum is modelled by the bound-free absorption of neutral hydrogen. In cooler stars where the negative hydrogen ion dominates, we are interested in the continuum from about 4000Å and longer.

2. Instrument and observations

The equipment used to study stellar continua must be capable of measuring radiation over a wide wavelength range either simultaneously or sequentially. Spectrophotometers having low, but precisely defined, resolution are suitable for measuring continuum. Compared to spectroscopic methods, they have the advantage of speed, linear response, high quantum efficiency etc. After calibration, using standard stars, absolute flux at a number of points in the continuum can be estimated.

We used a Hilger and Watts monochromator giving a dispersion of 70Å/mm at the exit slit. An exit slit 0.7mm wide admitting 50Å of the spectrum was used. To record the spectra, thermoelectrically cooled EMI 6558B or 9658B photomultipliers and standard d.c. recording techniques were employed. Several scans of programme and standard stars were taken on each night. The observations of each star after being corrected for atmospheric extinction correction, were converted to absolute fluxes with the help of standard stars. Oke and Schild (1970), Hayes and Lathams (1975) and Tug et al. (1977) calibration of a α Lyr were used for this purpose.

3. Classical Cepheids

We observed six classical cepheids viz. SU Cas, DT Cyg, SZ Tau, RT AUR, T Vul, and ζ Gem, with periods ranging from 1.95 to 10 days. Classical cepheids are Population I supergiants having spectral type at maximum of their light cycle between F8 to G8 and between F7 to K2 at minimum of the light cycle. Period lies in the range 2 to 50 days and M_υ lies in the range –2.6 to –7.0 mag. The (B–V) colour varies from 0.4 to 1.2 mag. We observed classical cepheids in order to find out, if improved model atmospheres, revised reddening corrections and recalibration of α Lyr leads to a better temperature scale for these stars. We also tried to look into the evolutionary and pulsation mass discrepancy by determining the luminosity of these stars through temperature and Wesselink radii. These stars were observed in the wavelength range 3390 to 7100Å at many phases of their pulsation cycle. The energy distribution curves were corrected for interstellar reddening using colour excesses from Dean et al. (1978) and reddening curve given by Schild (1977). Line blanketting corrections were applied using the data from Ardeberg and Virdefors (1975). Parsons (1969) and Kurucz (1979) model atmospheres were used for effective temperature estimations. Errors in temperature determination on account of least square fitting do not exceed ± 60 K. We have taken log g value constant over the light cycle, while actually log g varies during pulsation cycle. The error on account of this can reach a maximum of ± 100 K. The colour - effective temperature relation as obtained by Rautela and Joshi (1983) is of the form,

$$\Theta_\in = 0.274(B-V)_\circ + 0.637$$

$(B-V)_\circ$ values were taken from Mitchell et al. (1964). This temperature scale gives higher temperature by about 300 K with respect to the previous temperature scales.

Radius of these stars was estimated using the Wesselink (1946) method. Using the effective temperature and radius thus estimated, bolometric magnitude and then luminosity was determined.

4. Mass

Cox et al. (1972) method was used for the calculations of pulsation mass and Becker et al. (1977) method was used for the evolutionary mass estimates. The ratio of the evolutionary mass and pulsation mass was found to be greater than unity, ranging from 1.05 to 1.20, except for SZ Tau. This indicates that pulsation masses are lower than those given by evolutionary theory. But the error in determination of pulsation mass is nearly equal to the mass discrepancy obtained by us. Therefore, the mass discrepancy may not be real. For SZ Tau we suspect that this star may be metal rich cepheid. The mean values of the effective temperature, radius and mass are listed in Table 1.

Table 1.

Name of star	Te K° (mean)	R / R⊙ (mean)	M / M⊙ (pulsation)	M / M⊙ (evolution)
SU Cas	6650	21.8	3.65	4.66
DT Cyg	6294	29.0	5.31	5.04
SZ Tau	6178	37.8	7.50	5.72
RT Aur	6235	35.2	4.61	5.66
T Vul	6240	41.1	5.27	6.14
Zeta Gem	5935	70.7	6.07	7.83

5. Be stars

Be stars lie within the upper left region of the HR diagram. These stars are characterised by the presence of emission lines, which are attributed to the extended atmospheres of these stars. The continuum of these stars display many peculiarities. Majority of these stars show ultraviolet and infrared excess and also Balmer jump is smaller than normal B stars.

The continuum energy distribution studies are important to understand origin and nature of the ultraviolet and infrared excess emissions in Be stars.

We observed a few Be stars (Goraya, 1985) in the wavelength range 3300 to 7500Å, in steps of 50 or 100Å. The energy distribution curves were corrected for interstellar reddening. Due to the presence of circumstellar envelope in Be stars the determination of interstellar reddening is a complicated problem. For this E(B–V) values of normal B stars lying in the direction of programme stars were plotted against their distance moduli. From this figure E(B–V) value for programme star was read corresponding its distance moduli.

Effective temperatures for these stars were estimated using Kurucz (1979) model atmospheres. The slopes of energy distribution curves and models were compared in the wavelength range 4000-5500Å, as this region is least affected by envelope emissions. Log g=4 was assumed for luminosity class IV and V and log g = 3.5 for luminosity class III.

H_α observations of a selected sample of bright Be stars were taken using an exit slit admitting 28Å of spectrum, in order to get luminosity at H_α line. The available infrared observations at K band (2.2 micron) of these stars were used to find the infrared excess emission. The main conclusions derived from the study of the Be stars are :-

1. Infrared continuum luminosity is well correlated to Balmer H_α emission line luminosity.
2. Infrared excess radiation and the Balmer line H_α emission have the common origin.

3. The effective volume emitting infrared continuum emission and Balmer H_α emission are different.
4. Infrared excess emission is originated all through the circumstellar envelope.

6. Comets

The following comets were observed spectrophotometrically using the 104 cm telescope and scanner.

Crommelin (1818i) Goraya et al. (1984a), Austin (1982g) Goraya et al. (1984b), Enke (1984) Goraya et al. (1987), Halley (1982i) Goraya et al. (1988), Wilson (1986i) Sanwal and Rautela (1988), Bradfield (1987s) Sanwal and Rautela (1990), Hartley Good (1985) Rautela et al. (1988), Okazaki-Levy-Rudenko (1989r) Sanwal and Rautela (1991), Levy (1990) Rautela and Sanwal (1992), Swift-Tuttle (1992t) Sanwal et al. (1993), Hyakutake (1996B2) and Hale-Bopp.

The comets were observed to estimate production rates and number of molecules of each observed species contained in a cylinder of radius determined by the diaphragm used and extending entirely through the coma. The diaphragm used at the entrance slit was of diameter 3mm corresponding to 45 arc sec in the sky. The procedure described by Millis et al. (1982), A 'Hearn and Cowan (1975) and A'Hearn et al. (1979) was adopted for this analysis.

In all the comets it was found that gas production rate remains almost constant with heliocentric distance while, C_2 and CN production rates show variation with the heliocentric distance. A'Hearn and Millis (1977) found that the ratio of CN to C_2 production rate is remarkably constant between 0.3 and 0.5. In case of comet Bradfield a higher value of said ratio indicates that CN is overabundant with respect to other comets. A'Hearn also found overabundant CN in the comet Grigg-Skjellerup.

In comet Wilson an outburst of C_2 and C_3 production rates was found on May 25 1987. This outburst subsided on May 26, 1987 and did not occur in CN. The solar X-ray and optical flux increased on May 24 and 25 as reported in Solar Geophysical Data. This evidence makes the possibility of solar triggering more plausible for outburst in C_2 and C_3 production rates.

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