

Variable spectral energy distribution of γ Cassiopeiae in the optical region

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Abstract. Spectrophotometrically measured continuum energy distribution of γ Cassiopeiae are presented during six nights in the wavelength range of $\lambda\lambda$ 3200–8000 Å. The observations are compared with the theoretical models and are used to derive the values of effective temperature, gravity and to explore the behaviour of the continuum.

It is found that γ Cassiopeiae exhibited moderate to strong near-ultraviolet and near-infrared excess radiation over the underlying photospheric emission, with variable intensity on a time-scale of months to years. The amount of extra emission has been measured in magnitude units. The discovery of two steps in Balmer jumps during one night is being reported for the first time in this star. The second step of Balmer jump is found strongly in emission and exhibited short time-scale variations. The measures of Balmer jumps and λ_1 (Å) parameters are also made for this star.

Keywords: Spectrophotometry stars : variability excess emission : individual - γ Cassiopeiae.

1. Introduction

The Be star γ Cassiopeiae (27 Cas, HR264, HD5394, B0.5 V_e, ADS 782A) is the very first early-type emission line star to be discovered by Secchi (1867). It is the brightest Be star of the northern hemisphere and is among those well known objects showing large-scale light variations (Baldwin 1942; Edwards 1956; Kitchin 1970; Doazan 1982). Of

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all other Be stars it has the most complete spectroscopic history. It is an outstanding example of early-type emission line stars whose study has led to major discoveries. It is the first among Be stars for which the existence of intrinsic reddening has been proven (Chalonge & Safir 1936) and which led to the discovery of intrinsic polarization (Behr 1959). Surprisingly enough it was the first Be star for which super-ionised, high temperature, high velocity regions (corona) were also discovered (Bohlin 1970).

During the last about 120 years, this star has displayed transient shell phases, prolonged periods of weak and strong Balmer, He I and Fe II emissions and even passed through the stage of normal B star without any trace of emission line (Merrill & Burwell 1933, 1943, 1949; Cowley & Marlborough 1968). Nevertheless, γ Cas is much better known for its spectacular variations in light, colour, line spectrum, colour temperature etc. which were observed in the visible region during 1932–1942 and which have long been considered as unique (Baldwin 1942; Edwards 1956). It exhibited spectral and light variations on different time-scales. The history of its prolonged long-term, spectral and light variations has been summarised by Edwards (1956), Cowley & Marlborough (1968), Kitchin (1970), Cowley et al. (1976), Howarth (1979), Doazan (1982), Doazan et al. (1983), and Telting & Kaper (1994).

The investigations from space, since 1976 have renewed our interest in γ Cas, first, for its identification with the X-ray source MX 0053+60 (Jernigan 1976; Mason et al. 1976; Bradt et al. 1977; Horaguchi et al. 1994) and, second, for the appreciable changes exhibited in the far-UV (FUV) spectrum (Hammerschlag - Hensberge 1979; Doazan et al. 1980; Henrichs et al. 1980; Henrichs 1982; Henrichs et al. 1983; Doazan et al. 1987). Parmar et al. (1993) and Horaguchi et al. (1994) have explored the X-ray variability over time-scales from tens of seconds to half an hour. Smith (1995) has reported the X-ray and FUV continuum rapid variability over time-scale of ~ 1 hour. It has been explored that γ Cas is a member of the visual multiple system (Gontcharov et al. 2000). Harmanec et al. (2000) have reported the first detection of the regular radial velocity (RV) variations of H α and HeI lines and attributed them to the orbital motion in a binary. These authors found a relatively high eccentricity of the orbit, which is usually observed in Be/X-ray binaries with a compact secondary (Okazaki & Negueruela 2001). Robinson et al. (2002) made X-ray studies of γ Cas and have proposed a magnetic dynamo located in the inner parts of the primary's disk.

Another important study was made by Miroshnichenko et al. (2002) in which they reported the emission line long-term changes in the peak intensities on a time-scale of a few years and found a continuous decrease of the line intensities in 1993-2001. They also proposed that this might manifest the beginning of a new phase in the evolution of γ Cas, and suggested that the star may enter a new normal B phase. One of the main results of their observations was the confirmation of the periodic RV variations in the spectrum of γ Cas.

The hydrogen envelope of γ Cas was angularly resolved by using the Grand Inter-

ferometre 2 Telescope (GI2T), in southern France, in 1986 (Thom 1986). Further high resolution details of the envelope were investigated by Mourard et al. (1989) by using this GI2T optical interferometer. The first spectrally resolved observations of the Be star γ Cas have been reported by Stee et al. (1998). They secured milliarcsecond angular resolution measurements during Oct. and Nov. 1993.

Berio et al. (1999) obtained high spectral resolution data across the $H\alpha$ lines of γ Cas with GI2T interferometer in 1988, 1991, 1993 and 1994. Their analysis revealed azimuthally asymmetric variations which are correlated with those of V/R of the $H\alpha$ profile. This type of correlation supports a prograde one-armed oscillation processing in the equatorial disk of γ Cas due to the confinement by a radiative effect. Recently, Saad et al. (2006) carried out a spectroscopic survey of many Be stars. They reported strong $H\alpha$ double emission line in the spectra of γ Cas. The high angular resolution interferometric observations rule out the spherical or spheroidal structure of the circumstellar envelope of Be stars, in general (Mourard et al. 1994a,b).

Several detailed models for γ Cas have been developed by Marlborough (1977), Poeckert & Marlborough (1977, 1978), Marlborough et al. (1978), and Scargle et al. (1978) to explain different properties. By applying a new approach for the structure of $H\alpha$ regions to large number of Be stars, Lyrtzi et al. (2005) have calculated rotational velocity, radial velocity and optical depth in the region where $H\alpha$ emission is created. For this purpose they made use of the models proposed by Danezis et al. (2003) and Lyrtzi & Danezis (2004). None of these models have taken into account all the observed features of this object. Since, the Be phenomenon is primarily defined in the visible part of the spectrum, thus any model for γ Cas must also take into account its visual characteristics. The model which neglects the visual behaviour would be considered as incomplete. The studies of line and continuum variations of the star are of importance in order to further explore the system's properties.

Spectrophotometry at moderate resolution provides better informations than do the broad-band data about the exact location of the ultraviolet and infrared excess emission, and hence about the emission mechanism. With this aim in mind we observed γ Cas, spectrophotometrically, in the optical region ($\lambda\lambda$ 3200-8000 Å) on various epochs.

2. Measurements and reduction

The spectrophotometric measurements of γ Cas, in the visible region $\lambda\lambda$ 3200-8000 Å, were made during six nights with the 104 cm reflector of Aryabhata Research Institute of Observational Sciences (ARIES), Nainital. The Hilger and Watts spectrum scanner mounted at the Cassegrain focus (f/13) of the telescope was used for obtaining continuous spectral scans. The scanner was used in the first order with an exit slit of 50 Å passband. A cooled (-20°C) EMI 9658B photomultiplier and standard d.c. techniques were employed for recording the signal.

Table 1. Basic parameters of γ Cassiopeiae.

| Parameter | Value ^(a) |
|--------------------------|------------------------------|
| Spectral type | B0.5Ve |
| Effective temperature | 25000 K |
| | 30000 K ^(b) |
| Mass | 16 M_{\odot} |
| Radius | 10 R_{\odot} |
| Stellar angular diameter | 0.45 mas |
| Luminosity | $3.51 \times 10^4 L_{\odot}$ |
| $v \sin i$ | 230 km sec ⁻¹ |
| Inclination angle (i) | 45° |

(a) Stee et al. (1995)

(b) Telting et al. (1993)

Alongwith γ Cas the standard star ξ^2 Cet was also observed many times during the night to be used for applying extinction corrections and to convert the observations of γ Cas to absolute values. Many reverse and forward scans of γ Cas were obtained during the night and were reduced separately to instrumental magnitudes at a step of 100 Å. The average of all these scans was finally worked out. The instrumental magnitudes of γ Cas thus obtained were transformed to the standard system by using the absolute calibration of ξ^2 Cet given by Taylor (1984). The standard deviation of the measurements does not exceed $\pm 0^m.03$ in the entire wavelength range.

The most important factor in the investigation of ultraviolet and infrared excess emission in Be stars from their observed energy curves, is to remove the effect of interstellar reddening from the observed continuum. As has been discussed by Goraya (1984), the direct measurement of interstellar reddening in Be stars is almost impossible due to the existence of ultraviolet and infrared excess emission. Several different methods (Bohlin 1970; Savage & Jenkins 1972; Woolf et al. 1970; Moffat et al. 1973; Sjögren 1964; Macaul-Hercot et al. 1978) yield the values of colour excess, $E(B-V)$, in the range 0.02-0.18, but most of them are subject to contamination of the colours due to extra emission or absorption by the circumstellar shell. To overcome this problem upto some extent we have used the distance moduli method described by Goraya (1985, 1986) for the determination of colour excess, which gives $E(B-V)=0.07 \pm 0.02$ for γ Cas.

The absolute monochromatic magnitudes of γ Cas were dereddened by using our determined $E(B-V)$ value and adopting the mean value of total-to-selective extinction, $R=3.25$ (Moffat & Schmidt-Kaler 1976). The reddening curve given by Lucke (1980) for the Cassiopeiae region was used for applying interstellar reddening corrections. The dereddened magnitudes normalised to wavelength $\lambda 5500$ Å are displayed in Figs 1, 2 and 3. The basic parameters of γ Cas are listed in Table 1.

3. Observed continua and excess emission

In Figs 1, 2 and 3, the observed continuum energy distributions of γ Cas, observed on different epochs are compared with the theoretical models calculated by Kurucz (1998). The observed energy curves are represented by dots and crosses and the theoretically developed models are shown by continuous curves. The normalisation points of observations at wavelength λ 5500 Å are highlighted by a circle centered with dot. Date of observations has been labelled to each observed curve followed by the value of T_{eff} and $\log g_{eff}$ of the compared theoretical models within the bracket.

In Figs 1, 2 and 3 we have displayed the comparison of the observations of the measured continuum (dots and crosses) and theoretical models (continuous curves) for three different values of the temperatures viz. 25000 K, 30000 K and 35000 K respectively. It is important to mention here that the main emphasis has been given to the wavelength range between λ 4000-6000 Å when comparing observations with theory. It is clear that theoretical models with the T_{eff} value of 25000K and 35000K does not match with the observations as is seen in Figs 1 and 3. The model with the T_{eff} value of 30000K gives a best fit with the observations as is obvious in Fig. 2. This represents the value of T_{eff} and $\log g_{eff}$ of the star. The derived value of the temperature and gravity of γ Cas obtained from the best fitted model (Fig. 2), are listed in Table 2 along with expected error. It is seen that the star exhibited the same value of T_{eff} and $\log g_{eff}$ during all the six nights from 1981 to 1985.

Fast rotation and circumstellar envelope in Be stars affect the derived parameters. Owing to rapid rotation of the star, the gravity darkening (von Zeipel 1924) will lead to a lower value of effective temperature and reduction of effective gravity (Snow & Marlborough 1976). The temperature of the photosphere in the equatorial region may become several thousand degree Kelvin lower than that at the poles (Slettebak et al. 1980; Collins & Smith 1985). Geometrical deformation and non-uniformity of temperature and gravity on the stellar surface produces a non-isotropic emergence of radiation (Zroec & Briot 1997). In addition to rotational and circumstellar reddening these effects introduce errors in the derived values of parameters.

It is well known that many Be stars exhibit flux excess and a few possessed deficiency in the near-ultraviolet and near-infrared regions. This flux excess or deficiency may disturb the continuum energy distribution of Be stars. As a result, the estimation of the parameters of Be stars gets further affected. To overcome this problem, upto some extent, the main emphasis was given to the wavelength region between λ 4000-6000 Å, while matching observed energy distribution curves with the theoretical models. This was done because the continua in this wavelength range is least affected by near-ultraviolet and near-infrared flux excess or deficiency.

Since we have covered the Balmer discontinuity region in the observed spectrum, so we have also made measurements of the Balmer jump (D) at λ 3700 Å (in mag) and λ_1

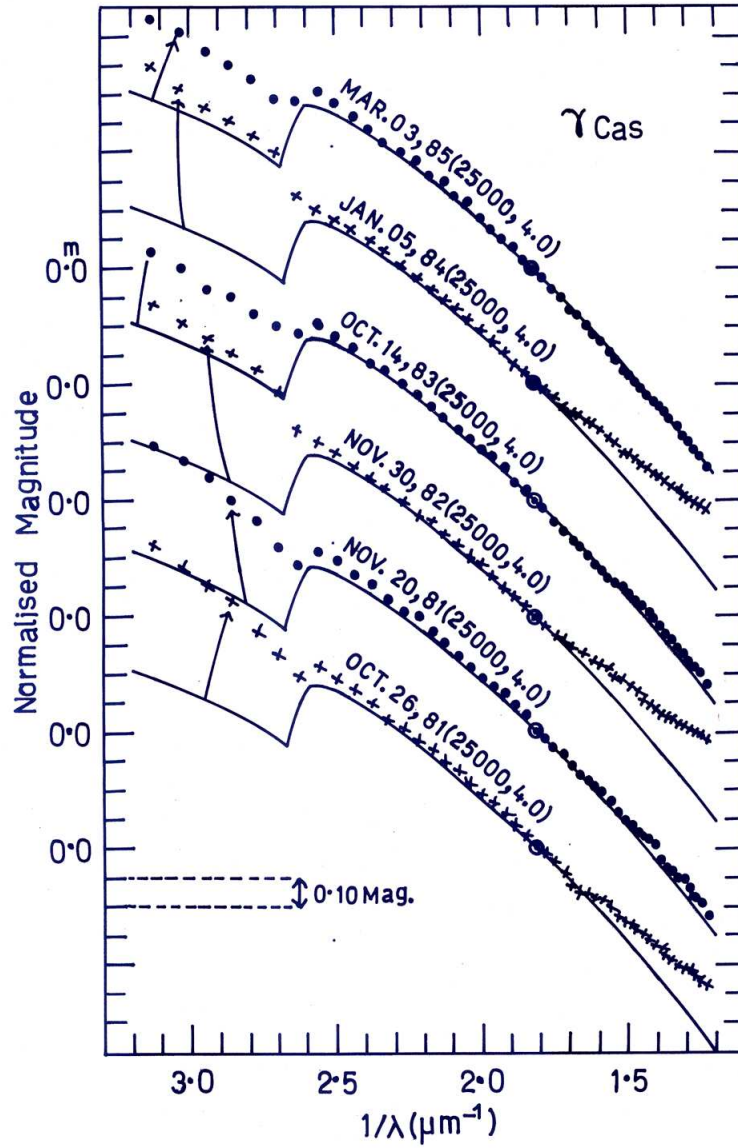


Figure 1. The observed continuum energy distribution curves (dots & crosses) of γ Cas compared with the theoretical models at T_{eff} value of 25000K (continuous curves). The normalisation point at $\lambda 5500 \text{ \AA}$ has been shown by a circle with dot for each curve. The theory does not match with observations in this figure.

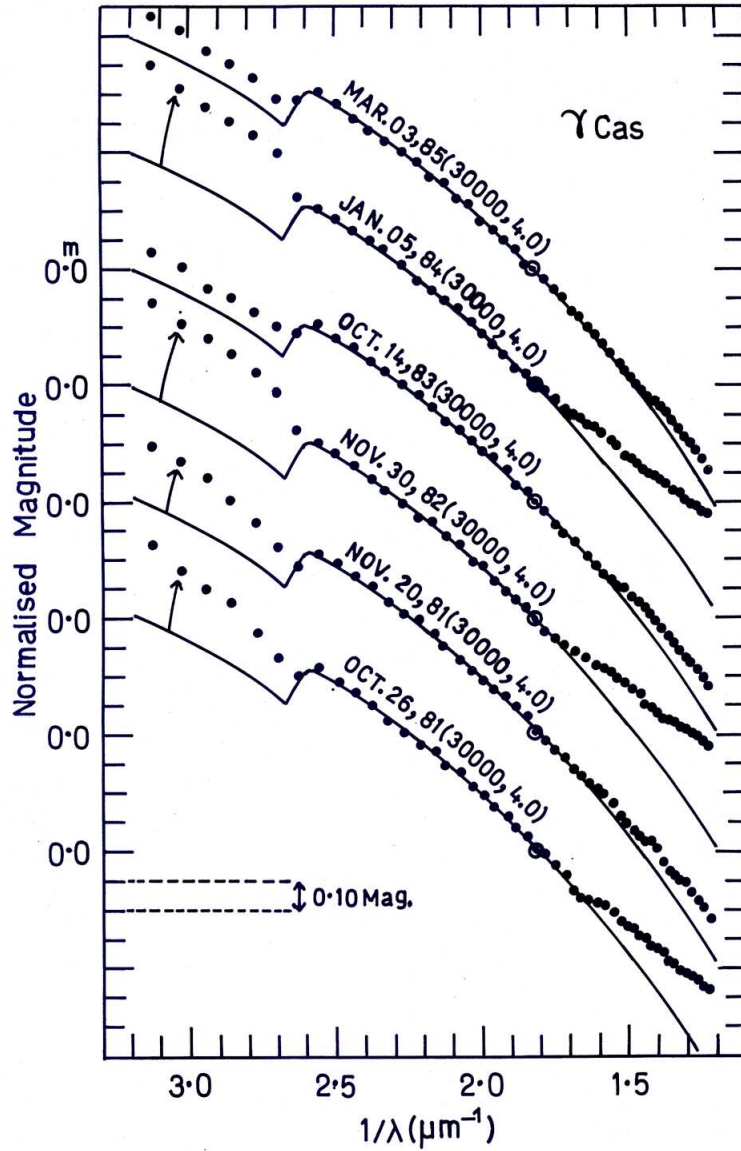


Figure 2. The observed continuum energy distribution curves (dots) of γ Cas compared with the theoretical models at T_{eff} value of 30000K (continuous curves). The normalisation point at $\lambda 5500 \text{ \AA}$ has been shown by a circle with dot for each curve. The best fit of theory with observations has been achieved in this figure.

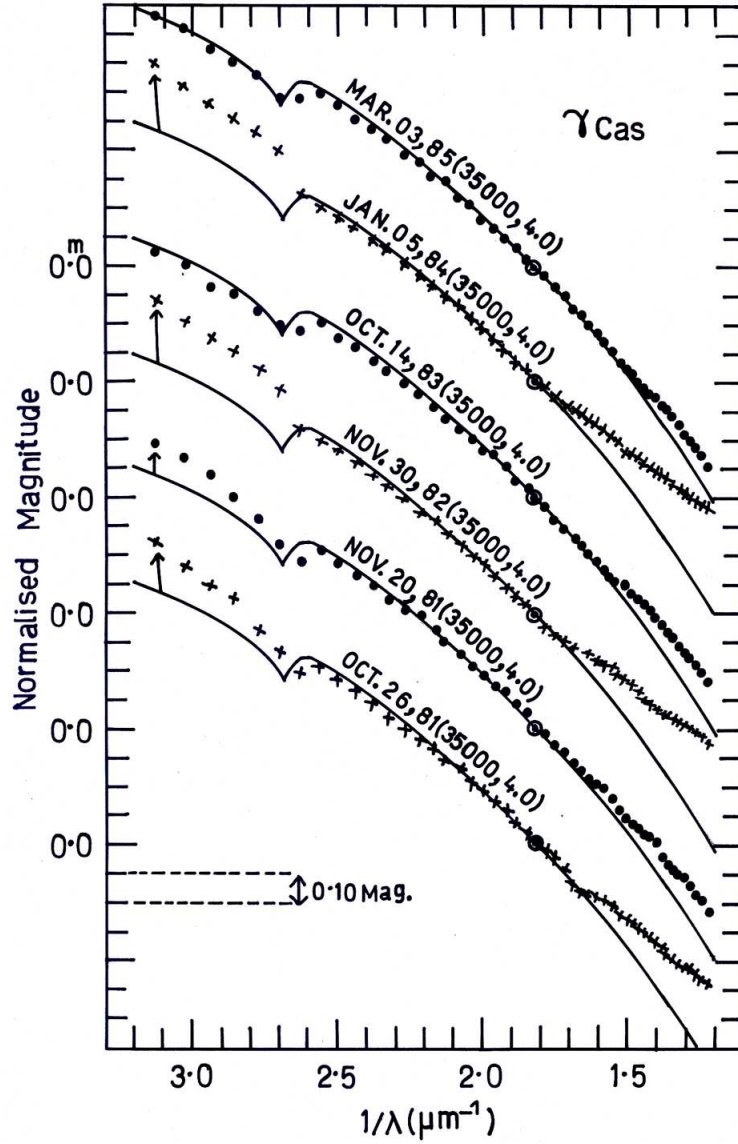


Figure 3. The observed continuum energy distribution curves (dots & crosses) of γ Cas compared with the theoretical models at T_{eff} value of 35000K (continuous curves). The normalisation point at $\lambda 5500 \text{ \AA}$ has been shown by a circle with dot for each curve. The theory does not match with observations in this figure.

(\AA) parameter. These values are listed in Table 2 along with Balmer jump (D^*), with errors, corresponding to the underlying photosphere.

The comparison of the measured and theoretical curves in Figure 2 display very interesting features of the physical state of the circumstellar envelope of γ Cas. The star is seen to show variable near-UV and near-IR excess radiation during all the six nights from 1981 to 1985. It exhibited strong continuum excess emissions during Oct. 26, 1981; Nov. 30, 1982 and Jan. 05, 1984 in both the near-UV and near-IR regions. The near-UV excess radiation was strong but of moderate strength in the near-IR region during Nov. 20, 1981. During the nights of Oct. 14, 1983 and Mar. 03, 1985 the star was passing through relatively quiet stage showing moderate value of near-UV and near-IR extra radiation.

It is seen from Figure 2 that the star exhibited moderate to strong near-UV and near-IR excess continuum emission. Near-UV emission was present throughout the observed Balmer continuum in the near-UV part and started gaining intensity longward of about $\lambda 5700 \text{ \AA}$ in the near-IR part of the observed spectrum during the nights of Nov. 30, 1982 and Jan. 05, 1984. During Oct. 26, 1981; Nov. 20, 1981; near-IR emission started originating longward of about $\lambda 6100 \text{ \AA}$. But during Oct. 14, 1983 and Mar. 03, 1985 emission began longward of $\lambda 6500 \text{ \AA}$ and was of moderate strength. The amounts of extra radiation (measured in magnitude unit) on various nights are listed in Table 2.

4. Two steps in Balmer discontinuity

In the present study, the inspection of original tracings surprisingly showed that γ Cas exhibited two steps of Balmer jump during Nov. 30, 1982. Such type of behaviour in γ Cas has been discovered for the first time.

In Fig. 4, we have displayed the original spectrophotometric scans of γ Cas as observed on Nov. 30, 1982, in the wavelength range $\lambda\lambda 3200\text{-}4300 \text{ \AA}$, to cover the Balmer jump spectral region of the star. In Fig. 5 we have shown the spectrophotometric scans of another Be star namely 14 Lac (B3IVe, HR8690, HD216200), which was also observed during the same night. This star exhibited normal behaviour and has been used as a comparison star.

In Fig. 4 the positions of both the jumps have been depicted by two vertical dotted lines, located at $\lambda 3647 \text{ \AA}$ and $\lambda 3700 \text{ \AA}$. It is obvious that the first Balmer jump appeared towards longer-wavelength side, at around $\lambda 3700 \text{ \AA}$ and its position is also indicated by the letter 'A'. The second jump occurred towards short-wavelength side very near to the theoretical limit of the Balmer series at around $\lambda 3647 \text{ \AA}$ and its position is indicated by the letter 'B'. The dotted curve drawn with each scan shows the approximate level of the normal Balmer continuum in case of single Balmer jump of the star. Further inspection of the spectral scans show that the second Balmer jump was strongly in emission and was a variable also. Although, many external factors may affect the observations, still, variability in the emission strength of second Balmer jump may not be ruled out, as is indicated from the original spectral scans displayed in Fig. 4.

Table 2. Observed and derived parameters of γ Cas.

| Date of observations | m_{5500} | T_{eff} (K) | ΔT_{eff} (K) | $\log g_{eff}$ | $\Delta \log g_{eff}$ | D^* (mag) | D (mag) | λ_1 (\AA) | ΔE (NUV) | ΔE (NIR) |
|----------------------|-----------------|---------------|----------------------|----------------|-----------------------|-----------------|------------------|------------------------------|------------------|------------------|
| Mar. 03, 1985 | 2.17 ± 0.06 | 30,000 | ± 1000 | 4.0 | ± 0.3 | 0.16 ± 0.03 | 0.09 ± 0.03 | 62 ± 5 | -0.095 | -0.062 |
| Jan. 05, 1984 | 2.14 ± 0.06 | 30,000 | ± 1000 | 4.0 | ± 0.3 | 0.16 ± 0.03 | -0.10 ± 0.03 | 65 ± 5 | -0.298 | -0.301 |
| Oct. 14, 1983 | 2.19 ± 0.06 | 30,000 | ± 1000 | 4.0 | $+0.3$ | 0.16 ± 0.03 | 0.09 ± 0.03 | 63 ± 5 | -0.081 | -0.093 |
| Nov. 30, 1982 | 2.21 ± 0.06 | 30,000 | ± 1000 | 4.0 | $+0.3$ | 0.16 ± 0.03 | 0.08 ± 0.03 | 65 ± 5 | -0.290 | -0.297 |
| Nov. 20, 1981 | 2.26 ± 0.06 | 30,000 | ± 1000 | 4.0 | $+0.3$ | 0.16 ± 0.03 | -0.04 ± 0.03 | 66 ± 5 | -0.205 | -0.103 |
| Oct. 26, 1981 | 2.24 ± 0.06 | 30,000 | ± 1000 | 4.0 | $+0.3$ | 0.16 ± 0.03 | 0.02 ± 0.03 | 67 ± 5 | -0.230 | -0.274 |

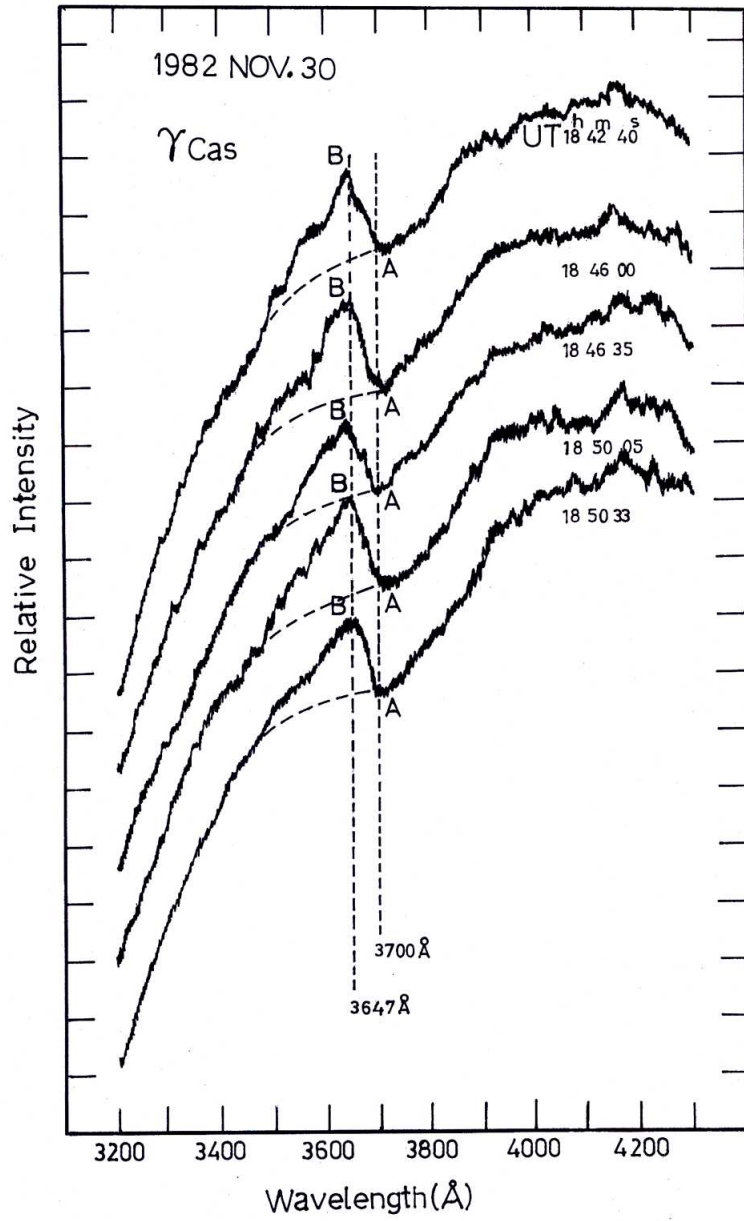


Figure 4. The original spectral tracings of γ Cas showing two separate Balmer jumps at 'A' and 'B' positions.

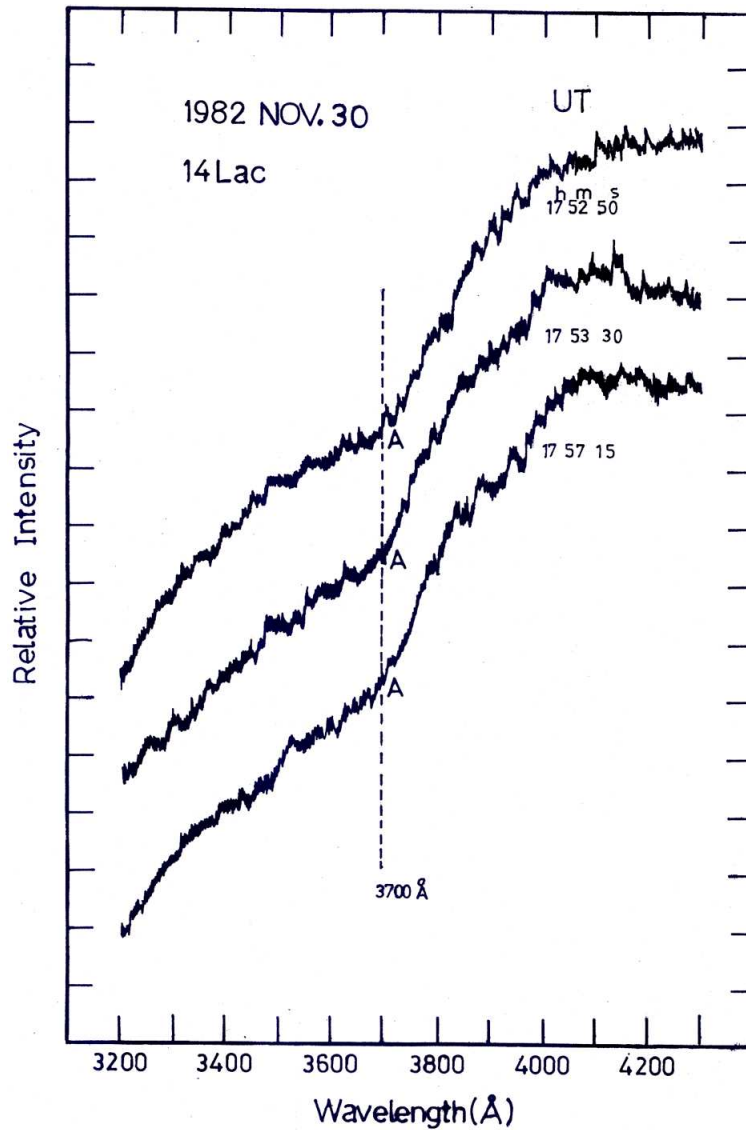


Figure 5. The original spectral tracings of comparison star 14 Lac showing only one Balmer jump at 'A' position.

The spectrophotometric scans of another Be star 14 Lac used as comparison star are displayed in Fig. 5. The position of the Balmer jump in this star has also been shown by a vertical dotted line at $\lambda 3700 \text{ \AA}$. Again letter 'A' is used to indicate the position of the first Balmer jump as in case of γ Cas. It is very clear from this Figure that this

star showed normal behaviour and possessed only one Balmer jump which appeared at its normal position at $\lambda 3700 \text{ \AA}$. There is no second Balmer jump at position 'B'. This normal jump is due to the underlying photosphere of the star.

The very first reporting about two steps in Balmer jumps was made by Barbier & Chalonge (1939) in the Be star ζ Tau which exhibited second Balmer jump in absorption. Following this Chalonge & Divan (1952) observed two separate Balmer jumps in four other Be stars. Two steps in Balmer jumps have been described in detail by Divan (1979) in some Be stars. They have reported that the Be star α Ara displayed second Balmer jump in emission whereas the other Be star 48 Lib exhibited second Balmer jump in absorption.

The first Balmer jump (D*) is attributed due to the central star and is always in absorption. This jump almost remains constant. The second Balmer jump can either be in emission or in absorption. This second Balmer jump can vary and can even disappear completely. This jump can even overlap the first Balmer jump when very strong. The second Balmer jump originates from the extended circumstellar envelope of hydrogen layers at low pressure.

5. Discussion

The study of γ Cas is of special importance because the visible region of this star almost displayed, in turn, all the characteristic features which are observed in the random sample of Be stars : a Be spectrum, a shell spectrum and a quasi-normal B spectrum. This type of behaviour confirms that these different spectra do not only represent different objects but also different phases in the life of a single object.

Since the discovery of γ Cas, its behaviour remained inactive till 1932, having the normal apparent magnitude $\sim 2^m.25$ (Baldwin 1942). After 1932 almost every physical parameter of this star was variable. This star really suffered maximum perturbation of various parameters during 1933-1942, when it was nearly twice as bright ($\sim 1^m.52$) as compared to normal ($\sim 2^m.25$) brightness. This period is known as the Great Outburst Period (GOP). During this outburst period the temperature of γ Cas fell down to minimum in early 1938. This is the lowest value of the temperature ($\sim 8000 \text{ K}$) ever found in the history of γ Cas. The star became brightest ($m_v \sim 1^m.52$) in 1937, followed by two short ($\sim 1 \text{ yr}$), but very strong shell phases.

During 1940-1941, the star displayed maximum value of temperature ($\sim 35000 \text{ K}$) and simultaneously achieved the faintest level of brightness ($m_v \sim 2^m.8$) during 1942. From 1940 to 1946 the star retained the minimum level of brightness, with short fluctuations, and behaved like a normal B star without envelope. The extreme variations of brightness in γ Cas took place from 1932 to 1942 with visual magnitude variations ranging from $1^m.50$ to $2^m.80$. The outstanding changes in the magnitude and spectrum which occurred

from 1933 to 1942 have been summarised by Baldwin (1942) and Cowley & Marlborough (1968).

Since 1943 onwards, γ Cas displayed slow and almost gradual increase in brightness interrupted by small outbursts. Another large outburst ($\sim 0^m.4$) occurred in 1949-1951 with maxima of intensity in 1950. No doubt, this outburst was much smaller than that occurred in 1932-1942 ($\sim 1^m.3$). After 1952, most possibly, the star continued slow and gradual increase in brightness touching the normal value ($\sim 2^m.25$) during around 1978. Our present measured values of the apparent visual monochromatic magnitude (m_{5500}) at $\lambda 5500 \text{ \AA}$ (Table 2) show that the brightness was at the normal value ($\sim 2^m.25$) during 1981 and the star started slow gain in brightness from 1982 through 1985, with small fluctuations.

Fig. 2 shows moderate to strong near-UV and near- IR variable excess continuum emission during all the six nights. The amount of extra radiation in magnitude measures are listed in Table 2 also. The amount of emission is strongly variable and can also be seen in Table 2. Long back Arnulf et al. (1938) found Balmer discontinuity strongly in emission during 1937 and significantly variable on time-scale of months.

On the basis of broad-band photometry Johnson et al. (1966), Allen (1973), and Ashok et al. (1984) found that γ Cas possessed infrared excess emission. Spectrophotometric energy distribution measurements by Schild (1976) show both ultraviolet and infrared excess radiation in this star with continuous energy distribution across the Balmer jump. However, the spectrophotometric observations made by Goraya (1980) show star's Balmer jump strongly in absorption displaying near-ultraviolet deficiency. Goraya's (1980) measurements also show that γ Cas exhibited variable Balmer jump during 1977-1978. Strong IR excess radiation has also been measured by Telting et al. (1993) and Hony et al. (2000). From the analysis of a large sample of Be stars, including γ Cas, Yudin (2001) also confirmed that most Be stars of early spectral type have a large value of IR excess in comparison with the late spectral type stars.

The description of the infrared continuum excess radiation was first made by Johnson (1967) in Be stars, in general. Schmidt Kaler (1967) suspected that its cause may be the same mechanism as for emission at Balmer lines. The continuum excess radiation may be attributed to free-free and free-bound emission from the ionized hot gas in the huge sized circumstellar envelope surrounding the central star. This proposal was later-on confirmed, quantitatively, by Woolf et al. (1970) and Gehrz et al. (1974).

Recently, by applying a new approach to IRAS observations of Be stars, Zhang et al. (2004) have found that many Be stars, including γ Cas, possess large infrared (IR) excess. They also investigated that far IR excess of Be stars increases with wavelength. They further concluded that not only free-free emission or free-bound emission from the circumstellar ionized gas can be made responsible for the large IR excesses of Be stars, as

suggested previously, but also, for some Be stars, thermal radiation from the circumstellar dust and/or nebula around the star can produce large IR excess as well.

The presence of the dense disk in the equatorial plane has already been well established in Be stars (Waters 1986; Quirrenback et al. 1994). These objects are also thought to possess fast radiatively-driven winds, which are well described by theories (Friend & Abbott 1986; Kudritzki et al. 1989). The sporadic mass ejection from the central star may be one of the reasons for variable excess emission in γ Cas. As a result of mass-loss the density, size and opacity of the envelope may vary, resulting in the variable emissions. Some of the changes like brightness, taking place over long time base-line might likely be originating from the central star itself.

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References

- Allen, D.A., 1973, MNRAS, 161, 145
Arnulf, A. et al., 1938, AnAp, 1, 293
Ashok, N.M. et al., 1984, MNRAS, 211, 471
Baldwin, R.B., 1942, Sky & Telescope, 1, 5
Barbier, D., & Chalonge, D., 1939, ApJ, 90, 627
Berio, P. et al., 1999, A&A, 345, 203
Bohlin, R.C., 1970, ApJ, 162, 571
Chalonge, D., & Divan, L., 1952, AnAp, 15, 201
Chalonge, D., & Safir, H., 1936, C.R. Acad. Sci. Paris, 230, 1329
Collins, G.W., & Smith, R.C., 1985, MNRAS, 213, 519
Cowley, A.P., & Marlborough, J.M., 1968, PASP, 80, 42
Cowley, A.P., Rogers, L., & Hutchings, J.B., 1976, PASP, 88, 911
Divan, L., 1979, IAU Coll. 47, Vatican Obs., Rome, 247
Doazan, V., 1982, Be Stars with and Without Emission Lines, NASA SP-456
Doazan, V. et al., 1984, A&AS, 55, 1
Doazan, V. et al., 1987, A&A, 182, L25
Doazan, V. et al., 1980, Second European IUE Conf. ESA SP-157, 151
Doazan, V., et al., 1983, A&A, 128, 171
Edwards, D.L., 1956, Vistas in Astr., 2, A. ed. Beer, Pergamon: New York, 1470
Friend, D.B., & Abbott, D.C., 1986, ApJ, 311, 701
Gehrz, R.D., Hackwell, J.A., & Jones, T.W., 1974, ApJ, 191, 675
Gontcharov, G.A., Andronova, A.A., & Titov, O.A., 2000, A&A, 355, 1164
Goraya, P.S., 1980, Ap&SS, 73, 319

- Goraya, P.S., 1984, *A&A*, 138, 19
Goraya, P.S., 1985, *MNRAS*, 215, 265
Goraya, P.S., 1986, *MNRAS*, 222, 121
Hammerschlag-Hensberge, G., 1979, IAUC No. 3391
Harmanec, P. et al., 2000, *A&A*, 364, L85
Henrichs, H.F., 1982, in IAU Symp. 98, eds M. Jaschek & H.G. Groth, p. 431
Henrichs, H.F. et al., 1983, *ApJ*, 168, 807
Henrichs, H.F., Hammerschlag-Hensberge, G., & Lamers, H.J.G.L.M., 1980, Second European IUE Conference ESA SP-157, p. 146
Hony, S. et al., 2000, *A&A*, 355, 187
Horaguchi, T. et al., 1994, *PASJ*, 46, 9
Howarth, I.D., 1979, *JBAA*, 89, 378
Jernigan, J.G., 1976, IAUC No. 2900
Johnson, H.L., 1967, *ApJ*, 150, L39
Johnson, H.L., Mitchell, R.I., Iriarte, B., & Wisniewski, W.Z., 1966, *Comm. Lunar Planet Lab.*, 4, 99
Kitchin, C.R., 1970, *Ap&SS*, 8, 3
Kudritzki, R.P. et al., 1989, *A&A*, 219, 205
Kurucz, R.L., 1998, <http://kurucz.harvard.edu/grids/gridm05ODFNEW/fm05k2odfknew.pck>
Lucke, P.B., 1980, *A&A*, 90, 350
Lyratzi, E. et al., 2005, *MmSAI*, 7, 114
Macau-Hercot, D. et al., 1978, *Suppl. Ultraviolet Bright Star Spectrophotometric Catalogue*, ESA SR-28
Marlborough, J.M., 1977, *PASP*, 89, 122
Marlborough, J.M., Snow, T.P., & Slettebak, A., 1978, *ApJ*, 224, 157
Mason, K.O., White, N.E., & Sanford, P.W., 1976, *Nature*, 260, 690
Merrill, P.W., & Burwell, C.G., 1933, *ApJ*, 78, 87
Merrill, P.W., & Burwell, C.G., 1943, *ApJ*, 98, 153
Merrill, P.W., & Burwell, C.G., 1949, *ApJ*, 110, 387
Miroshnichenko, A.S., & Bjorkman, K.S., 2002, *PASP*, 114, 1226
Moffat, A.F.J., & Schmidt-Kaler, Th., 1976, *A&A*, 48, 115
Moffat, A.F.J., Haupt, W., & Schmidt-Kaler, Th., 1973, *A&A*, 23, 433
Mourard, D. et al., 1989, *Nature*, 342, 520
Mourard, D. et al., 1994a, *A&A*, 283, 705
Mourard, D. et al., 1994b, *A&A*, 288, 675
Okazaki, A.T., & Negueruela, I., 2001, *A&A*, 377, 161
Parmar, A. et al., 1993, *A&A*, 275, 227
Poeckert, R., & Marlborough, J.M., 1977, *ApJ*, 218, 220
Poeckert, R., & Marlborough, J.M., 1978, *ApJ*, 220, 940
Qurrenback, A. et al., 1994, *A&A*, 283, L13
Robinson, R.D., Smith, M.A., & Henry, G.W., 2002, *ApJ*, 575, 435
Saad, S.M. et al., 2006, *A&A*, 450, 427
Savage, B.D., & Jenkins, E.B., 1972, *The Scientific Results from the Orbiting Astronomical Observatory (OAO-2) NASA SP-310*, 237
Scargle, J.D. et al., 1978, *ApJ*, 224, 527
Schild, R.E., 1976, in IAU Symp. 70 ed. A. Slettebak, 107
Schmidt-Kaler, 1967, IAU Symp. 31, ed. H. van Woerden, Academic Press, London, N.Y., 161
Secchi, A., 1867, *Astr. Nachr.*, 68, 63

- Sjogren, V., 1964, *Arkiv. Astr.*, 3, 339
Slettebak, A., Kuzma, T.J., Collins, G.W., 1980, *ApJ*, 242, 171
Smith, M.A., 1995, *ApJ*, 442, 812
Smith, M.A., Robinson, R.D., & Corbet, H.D., 1998, *ApJ*, 503, 877
Snow, T.P., & Marlborough, J.M., 1976, *ApJ*, 203, L87
Stee, Ph. et al., 1995, *A&A*, 300, 219
Stee, Ph., Vakili, F., Bonneau, D., & Mourard, D., 1998, *A&A*, 332, 268
Taylor, B.J., 1984, *ApJS*, 54, 259
Telting, J.H. et al., 1993, *A&A*, 270, 355
Telting, J.H., & Kaper, L., 1994, *A&A*, 284, 515
Thom, C., 1986, Thesis Univ. of Nice
von Zeipel, H., 1924, *MNRAS*, 84, 665
Waters, L.B.F.M., 1986, *A&A*, 162, 121
Woolf, N.J., Stein, W.A., & Strittmatter, P.A., 1970, *A&A*, 9, 252
Yudin, R.V., 2001, *A&A*, 368, 912
Zhang, P., Chen, P.S., & He, J.H., 2004, *NewA*, 9, 509
Zorec, J., & Briot, D., 1997, *A&A*, 318, 443