THE ORBITAL PERIOD OF G61-29

R. E. Nather, E. L. Robinson and R. J. Stover

McDonald Observatory and Department of Astronomy
University of Texas at Austin

Introduction

The proper-motion star G61-29 (Giclas et al 1971) was discovered to have an emission-line spectrum consisting entirely of helium by Burbidge and Strittmatter (1971), who noted that the very broad lines (ca. 32 Å at λ4471) seemed to have variable profiles. Warner (1972) suggested that the star might be a close binary system, with the emission lines arising from an accretion disk surrounding a white dwarf, and searched for evidence of binary motion using high speed photometry. He suggested a tentative orbital period of $6^h\ 16^m$, which subsequent observations were unable to confirm. Smak (1975) studied the star spectroscopically and agreed with Warner's accretion disk hypothesis based on his analysis of the emission line profiles, but was also unable to derive evidence of orbital motion from his spectra, which were exposed for about 40 minutes each. Greenstein et al.(1977) also observed profile variations in spectra with shorter exposures, but evidently did not search for periodicities.

Observations

We obtained a series of 112 digital spectra of G61-29 exposed for 4 minutes each, using the 82-in Struve reflector of the McDonald Observatory and the Cassegrain Digicon Spectrograph (Tull et al. 1979), on three successive nights in May, 1978. We used a narrow slit to permit the detection of radial velocity variations, should they be present, so the continuum slope is subject to the usual systematic errors caused by guiding, atmospheric refraction and so on.

While a single, unsmoothed exposure showed only the gross features of the spectrum (lower curve, Figure 1) the co-addition of the complete set, placed on a linear wavelength scale by our reduction procedures and corrected for extinction and instrumental response, show the features in considerable detail (upper curve, Figure 1). Each line which is sufficiently separate from its neighbors to be individually identified shows the broad, double-hump emission profile described by Smak (1975), with a narrow central emission "spike" slightly displaced to the red. (Subsequent analysis shows that this apparent displacement (about 1 Å) is an artifact of the summation around binary orbit, arising from the variable intensity of the "S-wave" modulation. When this effect is removed, the narrow emission features are centered in the profiles.) Hydrogen is conspicuous by its absence; based on the

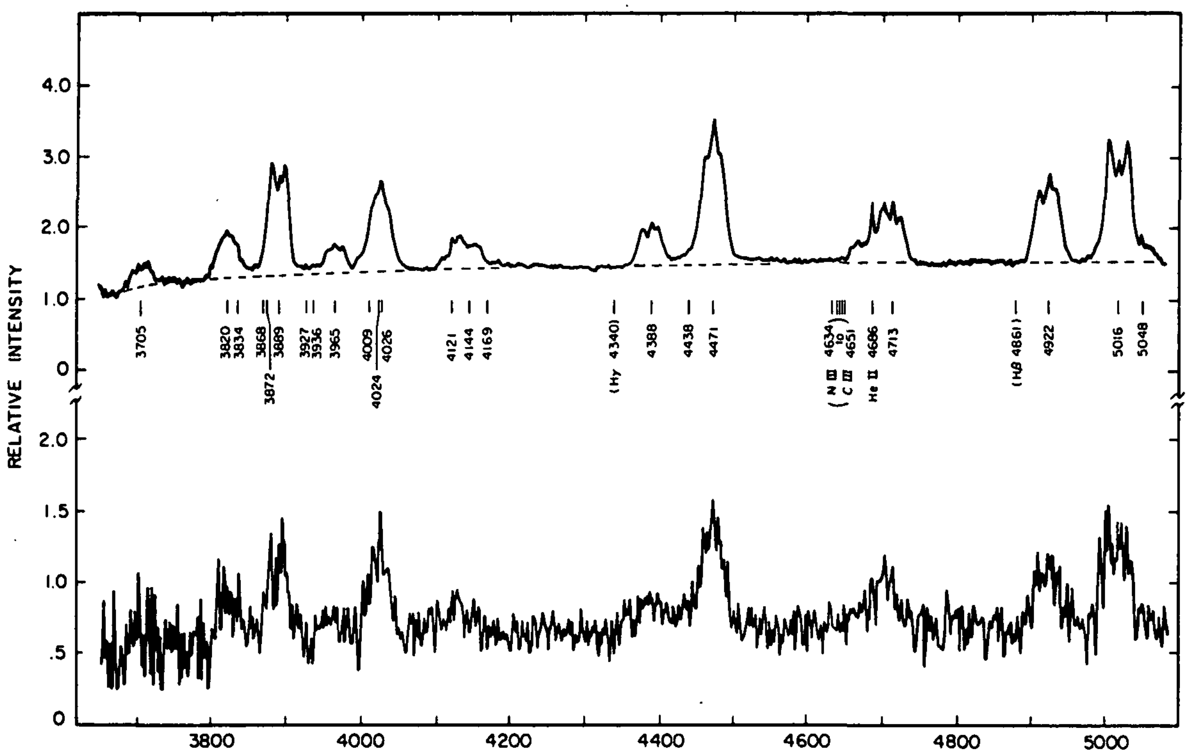

Fig. 1. A single 4 min. spectrum of G61-29 (lower) and the co-added sum of 112 such exposures (upper). All wavelengths indicated are He I unless otherwise identified; wavelengths in parentheses are not detectably present.

noise level of the continuum at the location of Hβ, the H/He ratio is reduced below that found in the sun by a factor of more than 5000. Our observations are consistent with its total absence.

In order to search for the suspected periodicity we devised a digital "masking" technique by which we could compare either the position or the intensity of one side of a spectral line with the other. Three separate masks are chosen: one of them (C) includes only continuum; the second, a "red mask" (R) is selected so that only the red-shifted portion of a line is included; and the third, a "blue mask" (B) encompasses the blue-shifted portion of the line. The R and B masks can thus include portions of any chosen group of lines in the spectrum. The masked portions of each spectrum are summed, normalized to the continuum value, and then compared:

$$I(t) = \frac{\Sigma R}{\Sigma C} - \frac{\Sigma B}{\Sigma C}$$

The red and blue masks were chosen so that a displacement in line position would yield a reduced intensity in one mask and a corresponding increase in the other; changes in line profile should have a similar effect. We applied this procedure to each of the digital spectra in succession. The resulting time series I(t) was then analyzed by conventional methods for the presence of periodic modulation. The first test of the method proved successful in detecting the periodicity; subsequent iterations, with masks selected to increase the signal-to-noise

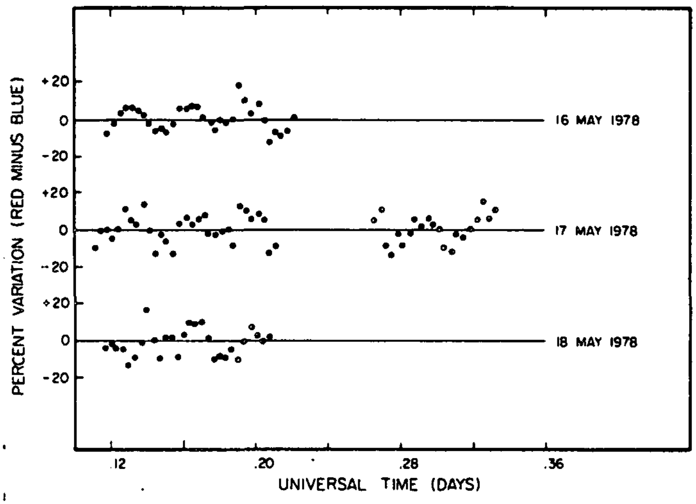

Fig. 2. The time series obtained by applying the masking procedure (see text) to successive spectra.

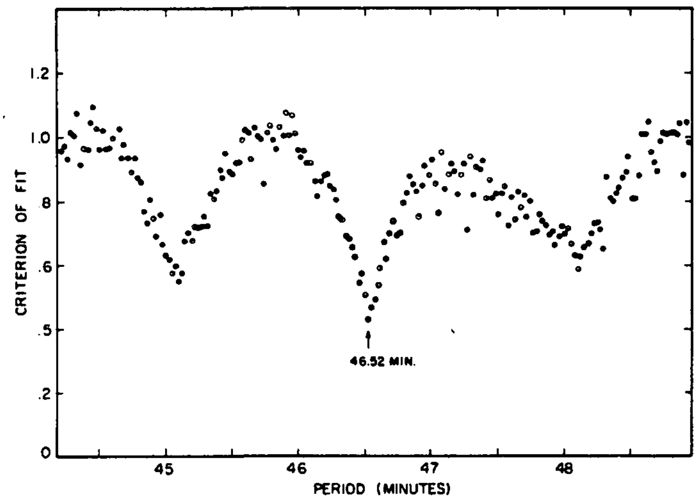

Fig. 3. The periodigram of the time-series data. Secondary minima are due to 24-hr aliasing.

ratio, yielded the time series shown in Fig. 2. Only a moderate amount of faith is needed to believe a period is actually present.

The classical 24-hr aliasing problem arises when the time series is analyzed, as shown in the periodigram representation (Figure 3). We used the period-finding technique devised by Deeming (Bopp et al. 1970), which yields a minimum value of the fitting function to signify the preferred fit. The period 46.52 minutes is clearly preferred (to a confidence level exceeding 90%), corresponding to about 31 cycles/day, but the other possible periods shown, corresponding to 30 or 32 cycles/day, cannot be completely excluded by the data in hand.

Once the period was determined, it became possible to co-add the individual spectra into phase bins at different parts of the cycle, to see just where the modulation was coming from. The data were summed into 12 equally-spaced phase bins with each bin covering 1/6 of the orbit so that there was a 50% overlap with the previous and succeeding bin. Some "phase smoothing" is achieved in this way, with every other profile formed from independent data. A further 3-point smoothing (weights of 0.25, 0.5, 0.25) was applied to each resulting spectrum.

Figure 4 shows the variations in the profile of the λ5016 line around the cycle, showing clearly that most, if not all, of the detected modulation arises from a fairly small, narrow emission feature wandering in wavelength between the limits set by the outer "humps" in the line profile. This corresponds directly to the "S-wave" modulation seen in several cataclysmic variables (Kraft 1963), and is identified as the characteristic signature of the "hot spot" in an orbiting accretion disk.

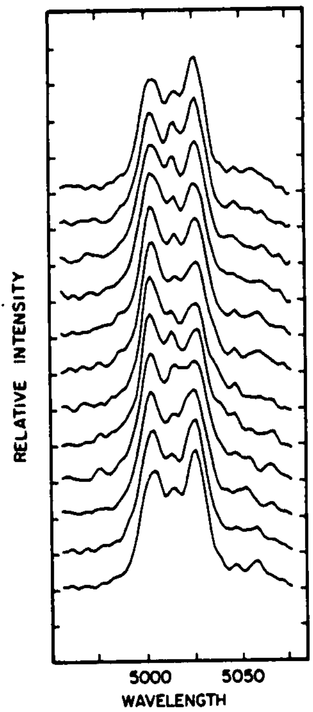

Fig. 4. Systematic profile variations around the orbit.

This amplitude enhancement of the line profile, varying in wavelength with orbital phase, is seen in all of the spectral lines. In most of the lines its intensity seems greatest following its maximum redward excursion, when the hot spot is located on the far side of the disk, and seems weakest 180° later, when the spot is nearest the observer. It is this asymmetry which distorts the "mean" profile of a spectral line when several orbital cycles are summed.

The character of the detected orbital modulation makes it very difficult to search the spectra for purely radial velocity variations. The "S-wave" effect extends well into the wings of the lines and must be removed before accurate radial-velocity motion of the accreting star can be measured. The lack of obvious line motions demonstrates that the mass ratio is large, but we are so far unable to set useful limits.

Discussion

If we accept the identification of the periodic modulation discovered in G61-29 as the "S-wave" process, then the orbital period for the system is 46.52 minutes, and the orbiting accretion disk consists of material which has been torn from the exposed, degenerate core of an evolved star. Faulkner et al. (1972) have considered the processes which can give rise to such a circumstance, in their study of the remarkably similar object AM CVn (=HZ-29). They propose that gravitational radiation, acting for sufficient time on a pair of white dwarfs in close orbit, can bring the larger (less massive) of the pair into contact with its shrinking Roche lobe, and permit mass transfer to begin. Because mass is being transferred from the less massive star to the more massive, their separation will slowly become larger and, if gravitational radiation is the only mechanism operating to keep them in contact, their orbital period will increase at a rate of 1 to 2 parts in 10^8 per year.

The period of HZ-29 is, in fact, increasing at 1000 times this rate (Patterson et al. 1979), suggesting that more efficient mechanisms are at work. The spectrum of HZ-29 also lacks hydrogen, showing only He in absorption, but with the high probability of an underlying emission component (Robinson and Faulkner 1975). G61-29 would thus appear to be a similar object in a somewhat later stage of the process.

The unmodulated "spike" in each of the spectral lines clearly does not arise in the rotating disk, and may be of circumstellar origin. (It may also be gravitationally attached to the accreting object, which shows little or no velocity modulation.) Should it prove to be circumstellar, it would suggest that secular mass loss from the system is playing a role in the process, one which could remove angular momentum much more rapidly than gravitational radiation and force a more rapid evolution, similar to that seen in HZ-29.

Faulkner et al. (1972) derive a useful relationship between the mass of the smaller component and the orbital period of the system, based on the known mass/radius relationships for different types of objects. They apply this relationship to the 18 min period of HZ-29 to obtain $0.04\mathcal{M}_{\odot}$ for the mass-losing secondary, and argue that only the mass/radius relationship for degenerate matter can apply. Similar reasoning yields a mass for the secondary of G61-29 of $0.02\mathcal{M}_{\odot}$, and distance arguments (Burbidge and Strittmatter 1971) can be used to verify that only the degenerate sequence can apply in this case as well.

Conclusions

G61-29 presents us with a superb way of studying the end-products of nuclear burning. This process of stellar involution provides an ideal way to examine, by direct observation, the layer-by-layer composition of an evolved stellar core. A cosmic autopsy is being performed for our benefit.

The end product of this bizarre process is directly predictable: it will consist of a single degenerate object with pure helium on the outside. It should be completely indistinguishable from a "garden variety" DB white dwarf star. While we cannot claim that this is the only process by which DB stars can be manufactured, we have found at least one mechanism which is doing the job, and we know roughly how long it takes to do it. If the mass transfer in HZ-29 retains its current rate, the secondary will be completely devoured in 10^5 years (Patterson et al.1979). A DB white dwarf has an observable lifetime of about 10^9 years (Shaviv and Kovetz 1976), roughly 10^4 times longer. Even allowing for the greater luminosity of the accreting objects, permitting them to be seen at greater distances, we are led to the conclusion that a significant fraction, perhaps all, of the known DB white dwarf stars have been formed in this manner.

References

Bopp, B.W., Evans, D.S., Laing, J.D. and Deeming, T.J. 1970, M.N.R.A.S. 147, 355.
Burbidge, E.M. and Strittmatter, P.A. 1971, Ap.J. 170, L39.
Faulkner, J., Flannery, B.P. and Warner, B. 1972, Ap.J. 175, L79.
Giclas, H.L., Burnham, R. and Thomas, N.G. 1971, Lowell Proper Motion Survey (Lowell Observatory, Flagstaff, AZ).
Greenstein, J.L., Arp, H.C. and Shectman, S. 1977, P.A.S.P. 89, 741.
Shaviv, G. and Kovetz, A. 1976, A. and A. 51, 383.
Kraft, R.P. 1963, Adv. Astron. Astrophys. 2, 43.
Patterson, J., Nather, R.E., Robinson, E.L. and Handler, F. 1979, Ap.J. 232, (in press).
Robinson, E.L. and Faulkner, J. 1975, Ap.J. 200, L23.
Smak, J.I. 1975, Acta Astronomica 25, 227.
Tull, R.G., Vogt, S.S. and Kelton, P.W. 1979, Proc. S.P.I.E. 172.
Warner, B. 1972, M.N.R.A.S. 159, 315.