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Composite Spectra

Paper 3: *π* Aquilae

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Abstract. *π* Aquilae is a visual double star whose angular separation of 1”.4 is so small that the system has been regarded as a composite-spectrum binary. However, by taking advantage of the excellence of the site and optics of the Mount Wilson 100-inch telescope, we have been able to obtain spectra of each component separately; the spectral types are about G8 III and A2 V.

Key words: composite spectra—visual binaries—stars, individual— *π* Aql

1. Introduction: existing knowledge concerning *π* Aquilae

π Aquilae (HR 7544) is visible to the naked eye as a faint star in the Milky Way about 3° north of Altair. It was discovered to be a double star on 1783 August 27 by Sir William Herschel (1785), who designated it ♅ 1.92, and is also listed in the catalogues of Herschel & South (1825, as Sh 306) and F. G. W. Struve (1827, as Σ 2583). It appears in Burnham (1906) as BDS 9634 and in Aitken (1932) as ADS 12962. Reliable measures of its position angle and separation were first made by Struve (1837) in 1825–1832, when the separation was 1″.5 and the position angle 121°. The system is clearly a physical binary of very long period: the separation is currently about 1″.4 and the position angle of the secondary has decreased to about 106°.

We are not aware of any photoelectric *UBV* photometry for *π* Aql; the *Bright Star Catalogue* (Hoffleit 1982) gives a visual magnitude of 5.72, whose origin is probably traceable to Geneva photometry (Rufener 1980), but no colours. The difference in visual magnitudes of the components has been widely agreed by double-star observers to be $0^{m}.5$ or $0^{m}.6$, and similar values have been derived semi-objectively by van Herk (1966) and Worley (1969), who used double-image micrometers operating on the principle developed by Muller (1949).

There is an obvious difference in colour between the components, the primary being a yellow star and the secondary white. Not surprisingly, the spectrum of the system appears composite, and was recognized as such in the compilation of the *Henry Draper Catalogue* (Cannon & Pickering 1923), in which *π* Aql appears as HD 187259 (spectral type F2) and 187260 (A2). However, Hynek (1938), in whose catalogue the system appears as no. 87, revised the spectral type simply to F2, although he noted the combined colour to be equivalent to G0. He also asserted that the components are main-sequence stars; and the *Bright Star Catalogue* follows Petrie (1942) in giving the types as dF2 and A2, a combination which would require the A star to have a curiously low luminosity. More plausible are the classifications given by Stephenson & Sanwal (1969) of G2 III: + Al V:.

The only radial velocities published for π Aql appear to be those from three plates taken in 1924/5 with a small Cassegrain spectrograph at Mount Wilson (Adams *et al.* 1929, Abt 1973). It is not clear what lines were measured, so there can be no telling which component's velocity was mainly being determined, but the mean velocity was quoted as +12.6 km s^{-1}, a value which is also listed in the *Radial Velocity Catalogue* (Wilson 1953) with quality *b*, implying that it should have an rms accuracy of about ± 2 km s^{-1}.

In view of the fact that we know for π Aql only one source (Adams *et al.* 1929) of radial velocities and one (Rufener 1980) of any sort of photometry, it is rather surprising that the *Bright Star Catalogue* notes suspected variability in both radial velocity and brightness.

2. Radial velocities

We have measured the radial velocity of π Aql A (the later-type, primary component), either at Cambridge or at Haute-Provence with 'Coravel', each year since 1982, with the results shown in Table 1.

In normal seeing conditions at Cambridge the system appears resolved at the 36-inch coude focus, and the stars can be imaged more or less separately upon the entrance slit of the radia-velocity spectrometer (Griffin 1967). In that way it was discovered, at the first observation, that the components gave approximately equal counting rates, showing that they had closely similar *B* magnitudes. The primary alone gave a radial-velocity dip, which was far deeper than would be expected for a star of type F2. The 'Coravel' spectrometer (Baranne, Mayor & Poncet 1979) at the 1-m Geneva telescope at Haute-Provence has an autoguider which presumably keeps the photocentre of the system (which in blue light must be approximately the mid-point between the two star images) centred on the slit.

There are obvious dangers with regard to radial-velocity accuracy in both the Cambridge and Coravel schemes of guiding. In the Cambridge scheme, the trace may be distorted by incursions of the image of the secondary star, which has no dip feature in its radial-velocity trace, onto the slit during the relatively slow scan (Griffin 1967) of the dip of the primary; alternatively (or even additionally), the concern of the observer

Table 1. Photoelectric radial velocities of π Aquilae A.

Date			Velocity km s^{-1}	Source
1982	Sept	23.89	+20.0	Cambridge
1983	July	3.01	+19.4	Cambridge
1984	Dec	7.69	+18.8	Cambridge
1985	Oct	22.78	+18.4	Cambridge
1986	Aug	28.93	+18.6	Coravel
1987	Oct	13.75	+17.7	Coravel
1988	Nov	6.72	+19.2	Coravel

to keep the secondary off the slit may result in asymmetrical guiding of the primary. The Coravel method of guiding on the photocentre places the primary asymmetrically on the slit unless the spectrometer is turned to align the stars along the length of the slit, which is possible but was not done in the observations listed above. (The freedom to rotate the instrument is provided to allow atmospheric dispersion to be aligned with the slit, and the position angle of *π* Aql is such that the components never appear vertically above one another; in retrospect it seems likely that it would be better to align the slit with the double star than with atmospheric dispersion.)

In view of all the possible sources of error, the agreement of the velocities shown in Table 1 must be considered surprisingly good. There is no evidence of any real variation in the velocity of the primary star; we can, of course, say nothing about that of the secondary. The mean velocity is + 19.0 ± 0.3 km s^{-1}. We do not regard the difference from the published velocity of + 12.6 km s^{-1} as significant.

3. Spectroscopy

Hynek (1938) considered *π* Aql to belong either to his Class III (Very close physical pair, observable as a binary, but whose component spectra cannot be obtained separately) or to Class IV (Wide physical pair, separate spectra obtainable but which, in the past, because of insufficient instrumental power, [has] been classed by other observers as a single composite spectrum).

The Mount Wilson 100-inch reflector used to offer star images which (even when viewed at third hand, as it were, at the coude focus) were often better, and sometimes much better, than one second of arc in subjectively perceived angular diameter. We felt, therefore, .encouraged, during the time when we were privileged to use the Mount Wilson telescope, to see if we could push *π* Aql definitively into Hynek's Class IV by actually obtaining separate spectra of the components. For uniformity with our spectra of other composite systems and single 'standard' stars, the spectra needed to be at a reciprocal dispersion of 10Å mm^{-1}.

The position angle of the secondary presented an immediate impediment to our plan. In order to widen spectra taken at the 100-inch coude focus, the star image had to be repeatedly trailed along the entrance slit of the spectrograph. That was ordinarily accomplished by deliberately setting the tracking rate of the telescope off the sidereal rate, and using an image rotator to align the consequent drift of the image with the direction along the slit. Thus the normal coördinate frame at the slit, regardless of the position in the sky of the object observed, was with right ascension along the slit and declination across it. Because the position angle of *π* Aql was rather close to 90°, the projected angular separation of the components in the all-important coördinate perpendicular to the slit was only about 0".4—not enough!—so we adopted the unusual stratagem of turning the image rotator to align the declination coördinate with the slit, leaving the projected right-ascension separation of some 1".3 across it. The only means available for trailing the image was then the declination slow motion which, though too fast for comfort, proved practicable. Acute anxiety was created by olfactory evidence that the venerable declination guiding motor was not rated for continuous operation, but fortunately no lasting harm was done to it.

Since the star exposures were broken up into a very large number of short instalments by the rapid trailing of the image, they were considered to be effectively continuous. Therefore the photometric calibrations (*cf.* Griffin 1986 (Paper 1)) were also made continuously for durations comparable with those of the star exposures.

The primary star was observed on 1985 April 14.4 U.T., and the secondary on 1985 June 19.4, only a week before the regretted closure of the 100-inch telescope. Both spectra have a trailed width of 1 mm; small parts of them are illustrated in Fig. 1. Plate transmissions were recorded digitally in steps of 5 μm; they were then converted into linear tracings of intensity versus wavelength, in the region $\lambda\lambda$ 3850–4650 Å, by our Standard procedure (Griffin, 1986). Tracings of the pure spectra of π Aql A and B are illustrated in Figs 2 and 3, respectively.

It is apparent from Fig. 1 that we were largely successful in getting separate, very different, spectra of the components of π Aql. It is, however, hardly surprising that close inspection (and, more particularly, quantitative study of intensity tracings) reveals that each is slightly contaminated by the other. Since both spectra were at our disposal, they were easily 'cleaned' of contamination by subtracting from each the appropriate small, wavelength-dependent, proportion of the other. We were then able to look critically for matching spectra amongst those of more readily observable single stars. The best match that we could find for the primary was β Crv and for the secondary was ψ Sco. Spectra of those stars have been added to Fig. 1.

The spectrum of β Crv has always been considered to be G5 II by the best authorities (Morgan, Keenan & Kellman 1943; Keenan 1983; Keenan & Yorka 1985, 1988), though in the last of those references the luminosity class has declined slightly to IIb. However, in the 1964 edition of the *Bright Star Catalogue* it appears as G5 III, as indeed it still does in the *Almanac* (Astronomical Almanac 1989). It is a fact—a rather troublesome fact—that the star whose spectrum gives, on the whole, the best match with that of π Aql A is also an MK standard for a type that we do not think it has, so we have been obliged to look rather closely into the classification of β Crv and to consider its relationship to the types of other stars with comparable spectra.

We have found—though we are not the first (Keenan & Wilson 1977) to notice it—that a group of absorption lines near λ 4536 Å is particularly useful for classification purposes at the dispersion (10 Å mm^{-1}) of our spectrograms. At about λ 4535.9 Å there is an obviously broadened line whose intensity varies particularly rapidly with spectral type, while at λ 4534.0 Å there is a line that is sensitive to luminosity. Reference to the *Arcturus Atlas* (Griffin 1968) and to the *Revised Rowland* table of solar lines (St. John *et al.* 1928) shows that λ 4536 Å is a massive blend dominated by three low-excitation lines of Ti I which are much more intense in sunspots than in the solar photospheric spectrum, whereas λ 4534 Å is a line of Ti II.

Spectra of five stars comparable in type with π Aql A were separately plotted, each with the spectrum of π Aql superimposed in a contrasting colour. The resulting tracings permitted sensitive discrimination of small differences between the plotted spectra. For each comparison star we assessed the differences in temperature and luminosity with respect to π Aql, using mainly the criteria mentioned above. In making our assessment we were guided only by the material in front of us; we disregarded the accepted spectral types, which we know from experience do not always accord exactly with spectra as we see them, and we were unaware at the time of the colours and published luminosity estimates of the comparison stars. We found that, according to our criteria, in comparison with π Aql A, 31 Vul is hotter; δ Boo is slightly hotter and less luminous, and has weak CN; β Crv is very slightly cooler and slightly more

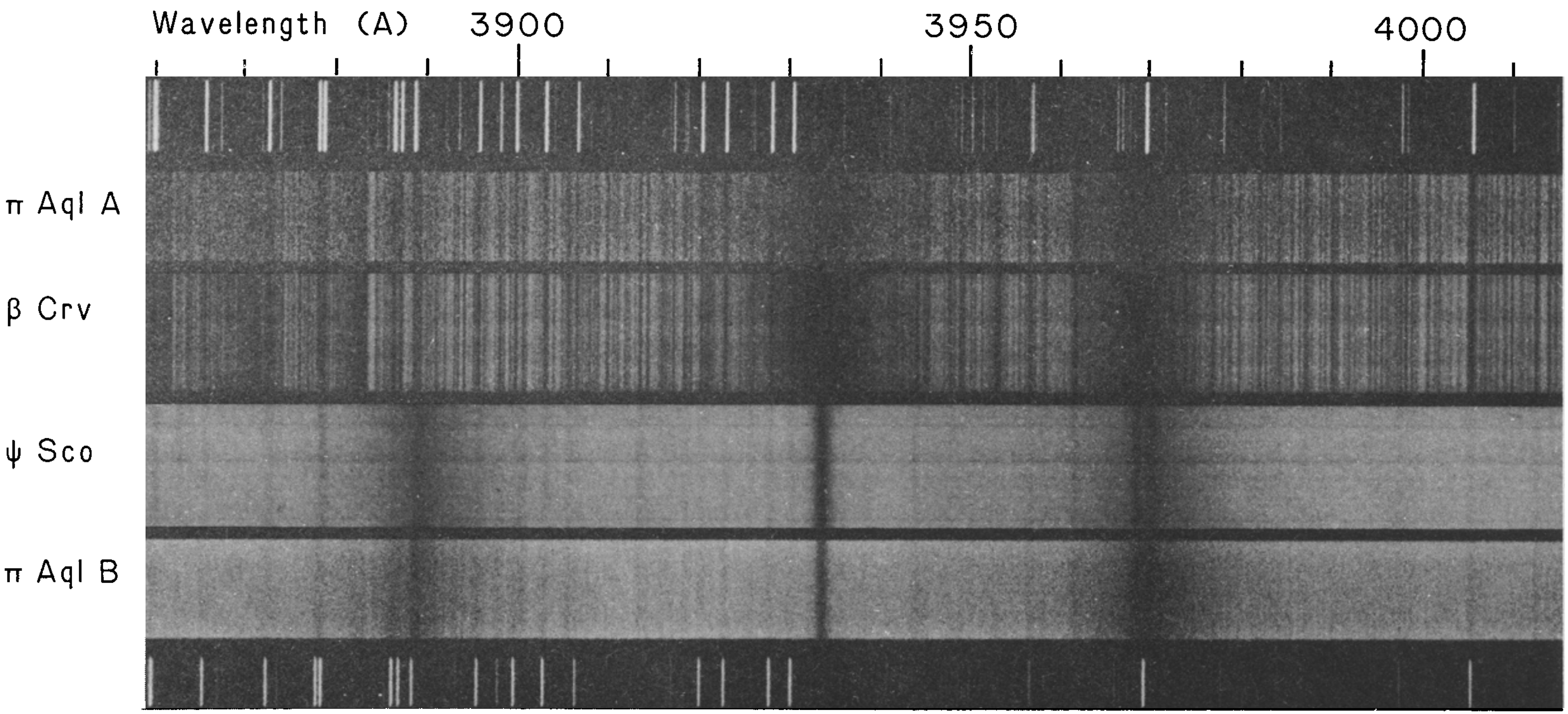

Figure 1. Small parts of the spectrograms of π Aquilae A and B, with spectra of other stars which are the best match we have found for the components of π Aquilae. The angular separation of the π Aquilae pair is only 1.4 seconds of arc, so it is not surprising that slight contamination of the spectrum of the B component is seen near the core of $H\zeta$ (λ3888 Å), where the light of that component is weak. These spectra were taken at 10 Å mm^{-1} with the coudé spectrograph of the 100-inch Hooker reflector on Mount Wilson. R. & R. GRIFFIN

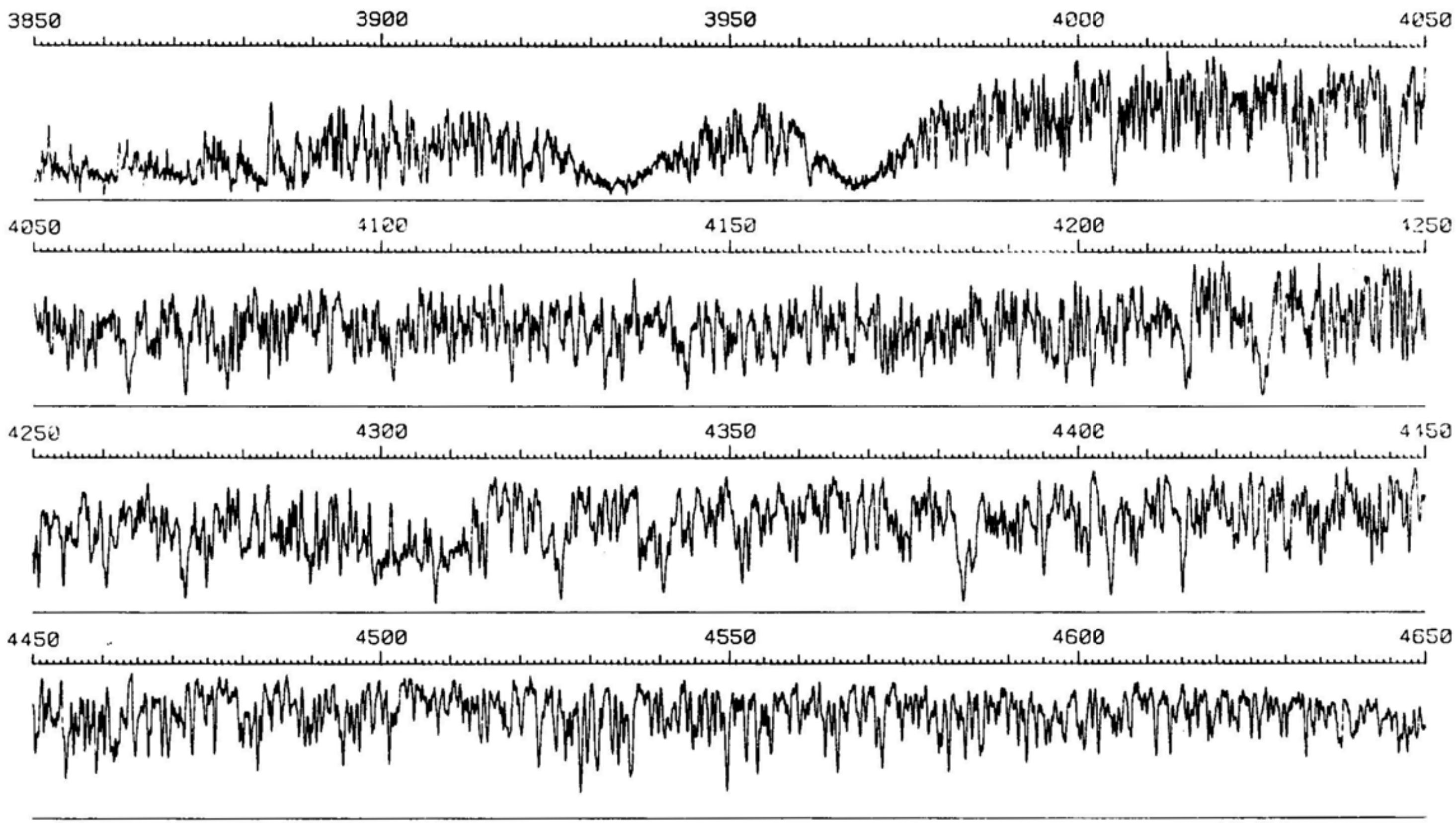

Figure 2. The spectrum of π Aquilae A, a star that is only 1.4 seconds of arc from the one whose spectrum is shown in Fig. 3. The horizontal line below each tracing is the zero-intensity level. Slight contamination by the secondary spectrum has been subtracted in the cases of the top two tracings. The spectrogram is very weak at the cores of the H and K lines of Ca II ($\lambda\lambda$3933 and 3968 Å), whose profiles may not be as accurate as the rest of the tracing. R. & R. GRIFFIN

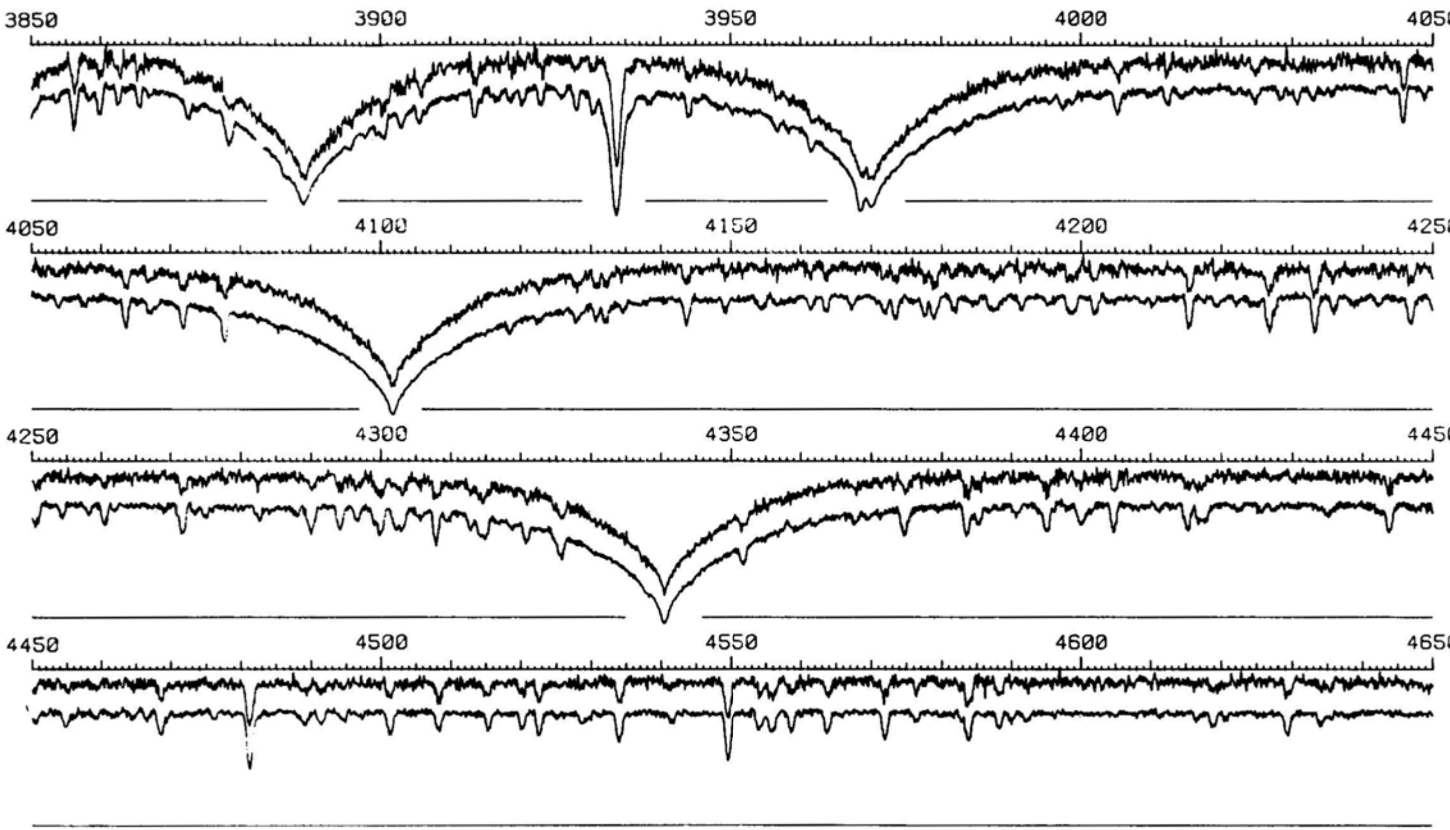

Figure 3. The spectrum of π Aquilae B, after 'cleaning' of the slight contamination, visible in Fig. 1, arising from the nearby primary component. The upper tracing in each panel is the one of principal interest, the lower tracing (which is displaced by -20 per cent of the continuum height) being of the spectrum of the A2 V star ψ Scorpii for comparison. R. & R. GRIFFIN

Table 2. Characteristics of stars compared spectroscopically with π Aql A, in apparent order of descending temperature.

	Star	Luminosity	$(B-V)$	Sp. Type	M_V(K)
	31 Vul	same	0.83	G8 III	+1.3
	δ Boo	lower	0.95	G8 III	+1.5
π Aql A ⟶	β Crv	greater	0.89	G5 II (?)	−0.2
	ε Vir	same	0.94	G8 III	+0.9
	15 Cyg	same	0.95	G8 III	+0.7

luminous; ε Vir is somewhat cooler; and 15 Cyg is much cooler. Those results, and some characteristics of the stars concerned, are set out in Table 2.

In the above table, the last column shows the absolute magnitude determined by Wilson (1976) from the width of the Ca II K line, which is probably the most reliable objective spectroscopic measure of the luminosities of late-type stars at present. In a preliminary paper (Wilson & Bappu 1957) the K-line absolute magnitude of β Crv was given as $-0^{m}.1$, and values of $0^{m}.0$ were quoted from both the trigonometrical parallax and from antecedent Mount Wilson spectroscopy. In our opinion, the weight of evidence is that β Crv, while somewhat more luminous than the average class III star, has not got a luminosity warranting its classification as class II. A downward revision of its luminosity would probably also involve its re-classification in type as well, perhaps to G6 or G7II–III. However, our principal concern in this paper is with π Aql and not with β Crv, and we have only discussed the latter star because of the similarity of its spectrum to that of π Aql.

Looking at Table 2, we see that our methods have successfully identified the stars of highest and lowest luminosity; π Aql falls somewhere in between, probably lightly brighter than $M_V = +1$, right at the level of luminosity class III. The temperature situation is more confused. Stars classified as G8 III occupy quite a large band of $(B-V)$ colour—larger than is represented in the Table—and π Aql falls towards the middle of it. It also falls in the middle of the G8 III stars according to our entirely independent temperature criterion, so there can be little doubt that G8 III is an altogether appropriate classification for it. Of course it would be nice if the spectral types and/or our own spectroscopy were to rank the five stars in Table 2 in an order that reflects their appreciable spread in $(B-V)$, but evidently they do not do that. The spectroscopic anomaly that we noticed in δ Boo, which is corroborated by objective measurements (Griffin & Redman 1960) but not shown by them to be extreme, ought at first sight to decrease the blanketing in the violet and result in an anomalously low value of $(B-V)$—the reverse of what is observed.

We cannot discuss in such detail the exact type of π Aql B because the classification of A-type stars is inherently complex and inexact, with axial rotation and metallicity playing important roles as well as temperature and surface gravity (luminosity). Moreover, we have not found among the bright A-type stars that we have so far observed a complete coverage of the multi-dimensional volume encompassed by even the principal variable characteristics. The best match that we have found for the spectrum of π Aql B is that of ψ Sco, whose type is given (Hoffleit 1982) as A2 V. We notice that the general strength of the metallic lines in ψ Sco is somewhat greater than in π Aql B (see Fig. 3), but the possibility that ψ Sco is an Am star has been explicitly considered and refuted (Bertaud & Floquet 1967).

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