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PSI SAGITTARII, A SYSTEM WITH THREE EVOLVED COMPONENTS*

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RESUMEN

La binaria visual Psi Sagittarii (ADS 12214, HR7292) es en realidad un sistema triple espectroscópico con períodos orbitales de 10.78 días y 20.0 años. El paso por el periastro en la órbita de largo período ocurrió el JD 2442410 ± 30 días. Las masas obtenidas de los parámetros orbitales espectroscópicos y visuales son: 2.7 $m_\odot$ para la primaria visual y 2.1 $m_\odot$ para la primaria del par de período corto y 1.7 $m_\odot$ para la secundaria del par con período corto. La distancia al sistema es de 100 parsecs. La inclinación orbital del par cerrado es casi la misma numéricamente que la de la órbita visual. Las clasificaciones espectrales que se han sugerido indican que las tres componentes han evolucionado fuera de la secuencia principal. Aún no ha ocurrido intercambio de masa en el par cerrado.

ABSTRACT

The visual binary Psi Sagittarii (ADS 12214, HR 7292) is a spectroscopic triple system with orbital periods of 10.78 days and 20.0 years. Periastron passage in the long period orbit occurred on JD 2442410 ± 30 days. Masses derived from the parameters of the spectroscopic and visual orbits are 2.7 $m_\odot$ for the visual primary, 2.1 $m_\odot$ for the short period pair primary, and 1.7 $m_\odot$ for the short period pair secondary. The distance to the system is 100 parsecs. The orbital inclination of the close pair is nearly the same numerically as that of the visual orbit. Suggested spectral classifications indicate that all three components have evolved off the main sequence. Mass exchange in the close pair has not yet occurred.

The star ψ Sagittarii (ADS 12214, HR 7292) is a visual binary, one component of which is a spectroscopic binary. Components of the visual pair are of nearly equal magnitude and have a maximum separation of less than 0$''$.3. A visual orbit called reliable by Finsen and Worley (1970) was computed by van den Bos (1957) who found a period of 18.55 yr, an eccentricity of 0.45, a visual inclination of 78°.4, and a semimajor axis of 0$''$.138. At certain orbital phases lines of all three stars are visible in a single spectrum.

* Figures 1, 2, 3 and 5 have been reproduced from *Astronomical Journal,* Vol. **80**, p. 844 ff, published by the American Institute of Physics for the American Astronomical Society.

A few stars of this type have previously been discovered and include HD 100018 (Petrie and Laidler 1952; Petrie and Batten 1970), p Vel (Evans 1956, 1969) and Innes 365 (Evans 1968). This type of system is of particular interest because masses of the individual stars may be determined from a combination of visual and spectroscopic parameters.

Because of the enormous number of lines in the specturm of ψ Sgr at certain orbital phases, high dispersion coudé spectra are required. The large number of lines also makes component identification difficult. Because of this the measurement technique of Evans (1968) was used. In the discussions that follow, the single star which is the visual primary

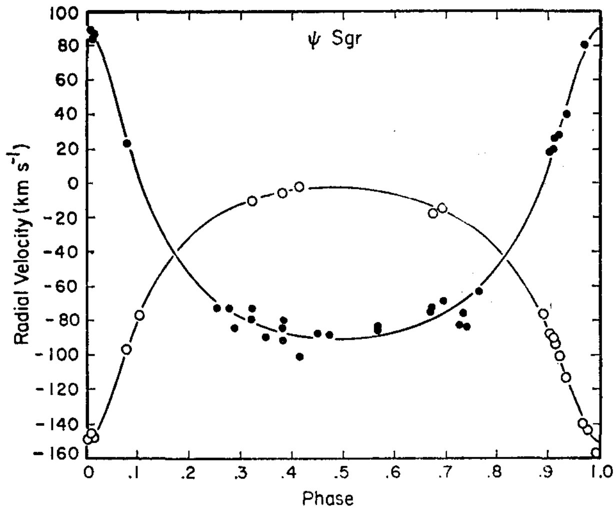

FIG. 1. Orbital element solution of the short period pair, components 2 and 3, of ψ Sgr. Curves represent computed radial velocities. Open circles represent observations of the primary, component 2; filled circles represent observations of the secondary, component 3. The radial velocities have been adjusted to the γ velocity for 1974.4. Phase is computed from periastron passage.

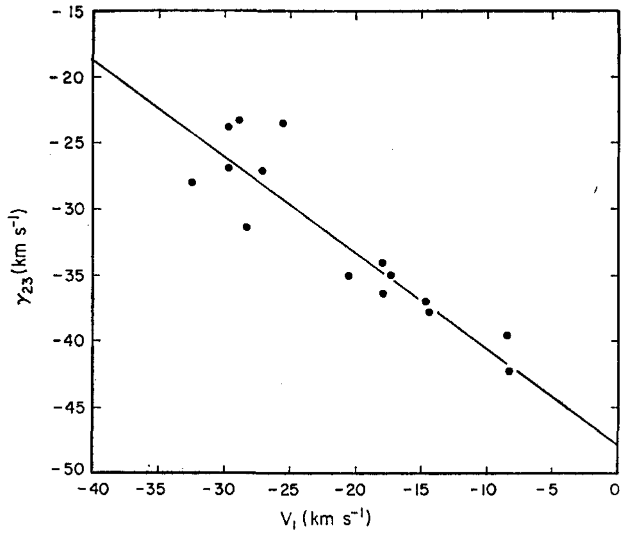

FIG. 2. Velocity plot of the visual primary velocity, V_1 versus center of mass velocity for the short period pair, γ_{23}. The slope of the line gives the mass ratio $m_1/(m_2 + m_3)$.

of van den Bos will be called star 1; the short period primary, star 2; and the short period secondary, star 3.

The orbital motion of the short period spectroscopic binary about the third star will cause the γ velocity of the former to change with time. The final orbital element solution for the short period pair, after the application of γ velocity corrections in shown in Figure 1 and Table 1. Figure 2 plots v_1 versus γ_{23} and the slope gives the mass ratio $m_1/(m_2 + m_3) = 0.73$. There is now enough information to determine the individual masses if a trigonometrical parallax is available. Unfortunately the parallax is negative and of no help.

Figure 3 shows the relative radial velocity curve of the visual pair computed by Dommanget and Nys (1967) using a parallax of 0″011. The observed annual mean radial velocity differences indicate an error in the period or epoch of the orbit or both.

TABLE 1

ORBITAL ELEMENTS OF THE SHORT PERIOD PAIR (STARS 2 AND 3)

$P = 10.77862 \pm 0.00004$ days (m.e.)
γ_{23} (1974.4) $= -43.3 \pm 0.7$ km s^{-1}
$e = .470 \pm 0.008$
$T_0 = 2442226.01 \pm 0.03$
$K_2 = 72.5 \pm 0.6$ km s^{-1}
$K_3 = 90.6 \pm 1.9$ km s^{-1}
$\omega_2 = 179^\circ.3 \pm 1^\circ.8$
$\omega_3 = 359^\circ.3 \pm 1^\circ.8$
$a_2 \sin i_s = 9.48 \pm 0.09 \times 10^6$ km
$a_3 \sin i_s = 11.85 \pm 0.26 \times 10^6$ km
$m_2 \sin^3 i_s = 1.86 \pm 0.06$ $m_\odot$
$m_3 \sin^3 i_s = 1.48 \pm 0.04$ $m_\odot$

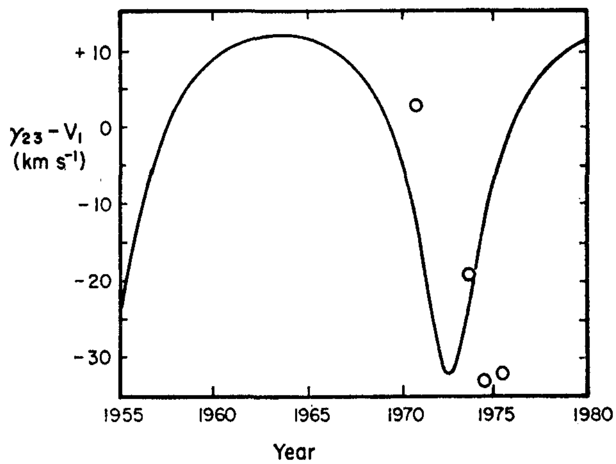

FIG. 3. The smooth curve is the radial velocity difference, $\gamma_{23} - V_1$, of the visual components calculated by Dommanget and Nys (1967) with $\pi = 0''11$. Open circles are the observed annual mean radial velocity differences.

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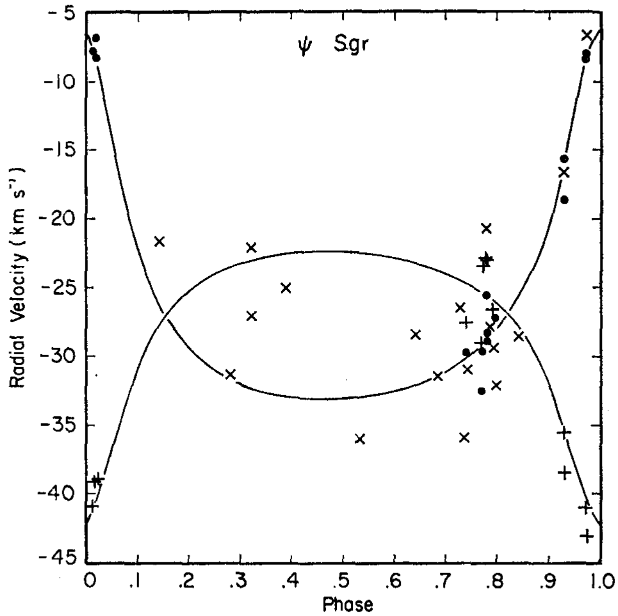

FIG. 4. Spectroscopic orbital element solution of the visual binary. Curves represent computed radial velocities. Dots represent coudé observations; X's represent old Cassegrain observations of component 1, the visual primary. The γ velocity of components 2 and 3, the short period pair, is represented by +'s. Phase is computed from periastron passage.

Old Cassegrain observations from the literature combined with the coudé observations indicate a lengthening of the period to 20.0 years. The spectroscopic orbit of the visual pair is shown in Figure 4. Observations in 1975 show that periastron passage occurred on JD 2442410 ± 30 days. Spectroscopic orbital elements for the visual primary are listed with the corresponding visual elements in Table 2 and show good agreement. The visual inclination, the mass ratio $m_1/(m_2 + m_3)$, the mass function of the visual system, and $(m_2 + m_3)\sin^3 i_s$ were combined to give a distance of 100 pc, the short period system inclination, i_s, of 74°.5 or 125°.5, and individual masses, $m_1 = 2.7 \pm^{0.7}_{0.5}\, m_\odot$, $m_2 = 2.1 \pm 0.25\, m_\odot$ and $m_3 = 1.7 \pm 0.15\, m_\odot$.

Initial spectral classifications for the three stars were obtained from a visual estimate by Dr. David S.

TABLE 2

ORBITAL ELEMENTS OF THE VISUAL PRIMARY

Spectroscopic (this paper)	Visual (van den Bos 1957)
$P = 7320.0 \pm 34.0$ days (m.e.)	
$= 20.04 \pm 0.1$ years	18.55 years
$\gamma_{123} = -27.0 \pm 0.5$ km s^{-1}	
$e = 0.50 \pm 0.06$	0.45
$T = 2442410.0 \pm 30.0$ days	
$K_1 = 13.4 \pm 1.8$ km s^{-1}	
$\omega_1 = 4°.0 \pm 5°.0$	359°.1
$a_1 \sin i_v = 1.2 \pm 0.2 \times 10^9$ km	
$f(m) = 1.19 \pm 0.3 m_\odot$*	

* Estimated uncertainty.

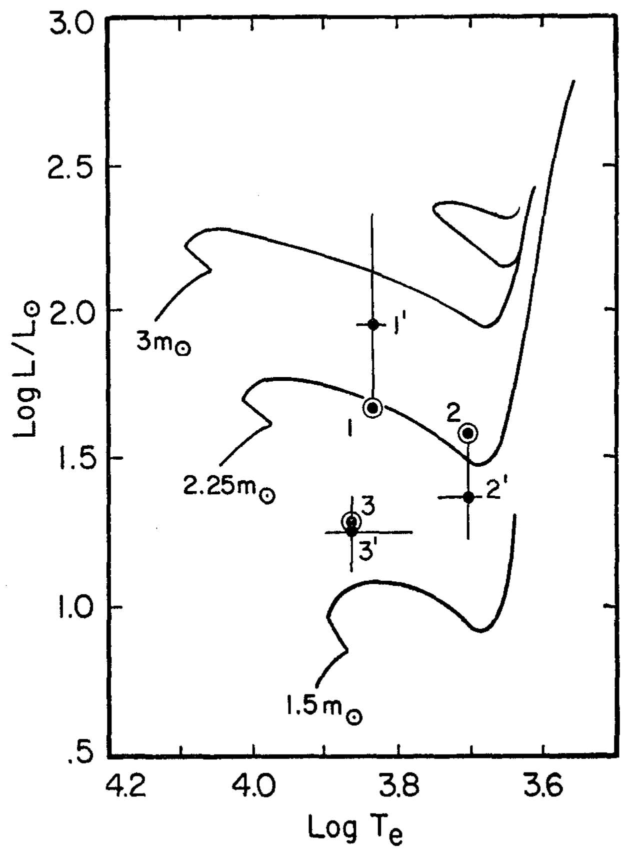

FIG. 5. Components of ψ Sgr plotted on a theoretical HR diagram containing the population I evolutionary tracks of Iben (1967*a*, *b*). Each star is plotted twice with the dots plotted using the observed masses, the circled dots plotted on the absolute luminosity scale and the effective temperature the same in each case. Points 1 and 1′ are the visual primary; points 2 and 2′, the short period primary; and points 3 and 3′, the short period secondary. Estimated errors in mass and effective temperature are represented by the horizontal and vertical lines.

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Evans. These were modified until reasonable agreement was obtained with the parallax, magnitude requirements and integrated colors of the system. The final classifications are F2II-III for star 1, the visual primary; G5 III-IV for star 2, the short period primary; and F0 III-IV for star 3, the short period secondary.

The assumption that all three stars are coeval places ular importance because of the lack of well determined masses for giant stars. The combined lists of Harris, Strand, and Worley (1963) and Heintze (1973) list only five giants whose masses are well determined. Of these only components A and B of α Aur, G5 III and G0 III respectively are similar in spectral type to any of the stars in the ψ Sgr system. In Figure 5 the stars are plotted on the population I evolutionary tracks of Iben (1967*a*, *b*). Each star is plotted twice with the primed points plotted using effective temperatures and the observed masses and the unprimed points plotted using effective temperatures and luminosity. In each case all three stars have evolved from the main sequence.

The asumption that all three stars are coeval places an additional constraint on the system. The luminosities of stars 1 and 2, the visual primary and short period primary respectively, place them very close to Iben's 2.25 $m_\odot$ track with an age of about 5.5×10^8 years for both. However, star 3, the short period secondary, lying between the 1.5 $m_\odot$ and 2.25 $m_\odot$ tracks is two to three times as old as stars 1 and 2. For the age of star 3 to agree with the other two its luminosity must be increased or its spectral type made much earlier, or both. When the stars are plotted according to their observed masses, the ages of stars 2 and 3 are in somewhat better agreement. If star 1 has already been up the giant branch at least once its age may agree with that of star 2.

The spectra show no evidence of mass transfer in the short period system. The high eccentricity, 0.47, of the short period orbit supports this view since it is thought that mass transfer leads to a nearly circular orbit. However as the short period primary ascends the red giant branch its radius increase will cause case B mass loss to begin within 1-2 $\times 10^7$ years.

Occultations of ψ Sgr are possible and high speed two color photometric observations would determine colors and magnitude differences of the visual components. Unfortunately, the next lunar occultation series will not begin until 1983.3 in the northern hemisphere (van Flandern 1975).

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DISCUSSION

Scarfe: How serious is the effect of blending in the measurement of radial velocities and hence in the elements?

Fekel: The plate dispersion is high, 8.6 Å mm^{-1}, and the lines of the short-period primary are strong and sharp, so for this component I do not think blending is a problem. The lines of the short-period secondary are much weaker and difficult to find and may be subject to blending problems. Lines of the visual primary are also strong and probably not affected too much by blending. The most probable cause of any blending would be from lines of other wavelengths because of the complicated nature of the spectrum.

Beardsley: Since I reported the triple nature of this system at the previous IAU Double Star Colloquium, I am pleased to see these results presented at this meeting.