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Long–term Variability of π Aqr

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Abstract. We present our recent photometric and spectroscopic observations of the bright classical Be star π Aquarii and analyse those available in literature. This star currently shows only weak signs of circumstellar emission and a low optical brightness. Physical parameters of the underlying star are determined from data obtained during quiescence, while those of its circumstellar disk are estimated during the active period.

1. Introduction

π Aquarii (HR 8539) is a bright, rapidly rotating ($v \sin i \sim 300$ km s^{-1}) classical Be star whose variable characteristics have been the focus of observers' attention since the beginning of the century. However, its behavior until the 1960's is well-documented only spectroscopically. McLaughlin (1962) reported strong V/R variations (0.5–4.0) of the Balmer line profiles in 1911–1961 and a few periods of absence of emission (1936–1937, 1944–1945, 1950). This study showed that π Aqr was active, but provided only a qualitative view of its behavior.

Since the late 1950's the star has been observed periodically with different techniques that provide a more quantitative view. Several attempts have been made to determine the fundamental parameters of the star; however, these resulted in different values (Table 1), mainly due to the influence of the circumstellar envelope, whose parameters are still poorly known. The recent transition of π Aqr from a Be- to a normal-B star phase, in connection with our long-term monitoring of the star, provides a unique opportunity to refine our knowledge of this remarkable object.

2. Observations and data analysis

Our monitoring of π Aqr includes the following observations:

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1. *UBV* photometry at a robotic 10-inch telescope (1987–1997) operated by the Automatic Photoelectric Telescope Service on Mt. Hopkins in Arizona;
2. Spectroscopy from 5280–6600Å (resolving power $R \sim 26000$) with an échelle-spectrograph at the 1-m telescope of Ritter Observatory (1996–1998);
3. Johnson *UBVRIJHK* photometry with a two-channel photometer-polarimeter (Bergner et al. 1988) at a 1-m telescope of the Tien-Shan Observatory in Kazakhstan (1998).

Optical spectropolarimetric data were also obtained during the period 1989-1999 (see Bjorkman 1992), as well as broadband optical polarimetry during 1985-1999 (see McDavid 1992); details of these results will be reported elsewhere. During the period covered by the photoelectric data (since 1957, including data from the literature), π Aqr displayed slow variations of brightness and emission line profiles, with a maximum phase in 1975–1985 (Fig. 1a). Its near-IR brightness was almost constant from 1970–1985. We have identified π Aqr with the IRAS Faint Source Catalog (FSC) object F22227+0107, a connection not noted previously. The IRAS fluxes are in good agreement with earlier IR photometry by Gehrz, Hackwell, & Jones (1974). The IR brightness dropped significantly after 1989, while the optical flux had begun to fade several years earlier (Fig. 1a). By now almost all signs of circumstellar emission have disappeared in the Hα line (Fig. 1c) and in the spectral energy distribution (SED) (Fig. 1b).

Table 1. Observed and fundamental parameters of π Aqr

V	A_V	$T_{\rm eff}$ 10^4 K	log g	M_V	D pc	Ref.
4.57	0.47	2.25	4.0	−3.6		Nordh & Olofsson (1974)
		2.71				Underhill et al. (1979)
4.68		2.46		−3.7		Snow (1981)
4.70	0.25	3.00	4.0			Goraya (1985)
4.64	0.69	2.70				Theodossiou (1985)
4.60	0.34	2.80	3.3			Kaiser (1989)
4.93	0.57			−3.83	435	Fabregat & Reglero (1990)
4.53	0.37	2.93		−3.00	331	Zorec & Briot (1991)
4.85	0.14	2.40	3.9	−2.95	338	This work

3. Physical parameters

To construct the quiescent SED of π Aqr, we used our *UBVRIJHK* data, obtained in August 1998, and IUE fluxes, in intervals free of spectral lines from 0.13 to 0.32 μm, obtained on 1995 May 25. The resulting SED was fitted to Collins & Sonneborn (1977) rotating star model atmospheres, with the effective temperature ($T_{\rm eff}$) and interstellar extinction (A_V) as free parameters. Best fit values are shown in Table 1; they correspond to the parameters log $L_{\rm bol}/L_\odot = 4.1$ and

$R_* = 6$ R$_\odot$. These values are based on the HIPPARCOS distance, 340^{+105}_{-70} pc (ESA 1997), and have an accuracy of $\sim$ 30 %. Comparison with theoretical evolutionary tracks (Shaerer et al. 1993) gives the star's mass, $M_* = 11\pm1.5$ M$_\odot$, and hence log $g = 3.9\pm0.1$. Fitting our observed Hα and He I 5876 Å line profiles to theoretical ones (Kurucz 1994) broadened by rotation (Fig. 1cd) resulted independently in the following values: $T_{\rm eff} = 24000 \pm 1000$ K, log $g = 4.0$, $v_{\rm rot} = 300$ km s^{-1}.

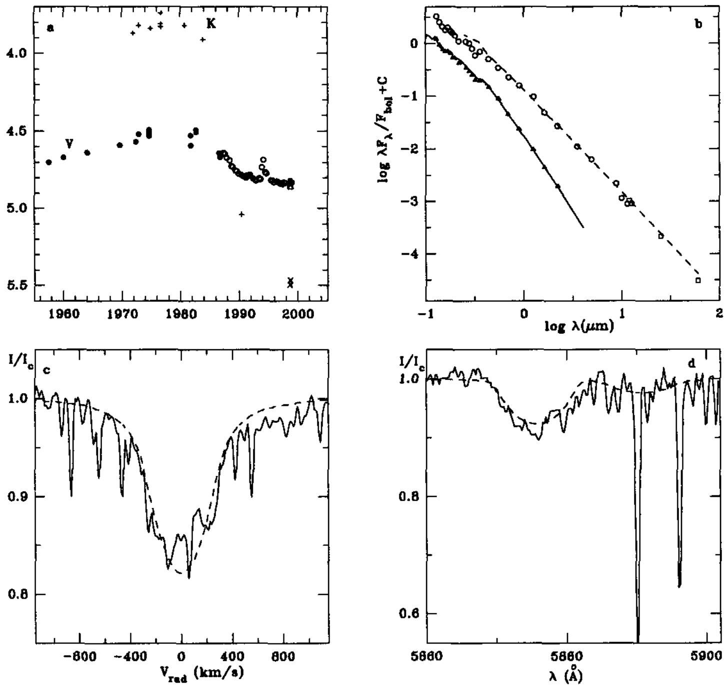

Figure 1. a. The V- and K-band light curves of π Aqr. The V-band data from literature (filled circles), Mt. Hopkins (open circles), and Tien-Shan (open squares) and the K-band data from literature (pluses) and Tien-Shan (crosses) are shown. The y-axis is in magnitudes. b. SEDs of π Aqr corrected for the interstellar extinction for 1995–98 (triangles) and 1973–83 (circles). The IRAS data are shown by open squares. The theoretical fits to the data are shown by a solid and dashed line. c,d. Parts of the π Aqr spectrum obtained at Ritter Observatory on 1998 November 11 (solid lines): the Hα line (c) and He I 5876 Å + Na I D$_{1,2}$ lines (d). The theoretical fits to the data are shown by dashed lines.

To estimate the parameters of the equatorial disk we constructed an SED during the active phase, using the averaged data of IUE, published optical and IR photometry, and IRAS fluxes, and compared it with theoretical predictions

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of a simple model consisting of a star surrounded by a gaseous disk with a 15° opening angle, similar to that proposed by Waters, Coté, & Lamers (1987). Density distribution in the disk was set by a power-law, $\rho \propto r^{-n}$, where r is the distance from the star. Our calculations showed that the IR excess of π Aqr can be reproduced with a mass loss rate of 2×10^{-8} $M_{\odot}\,yr^{-1}$ and $n \sim 2.75$ (Fig. 1b), which is 1 order of magnitude larger than that determined from the UV line profiles (Snow 1981).

4. Conclusions

We have analyzed available photometric and spectroscopic data for the classical Be star π Aqr obtained over the last 40 years. The star showed a brightening between the late 1950's and early 1970's, a maximum phase through 1989, and a decline to the present time. This study allowed us to derive more reliable physical parameters of the star, since previously the circumstellar contribution could not be taken properly into account. We found that π Aqr is less luminous than previously thought, identified it with the IRAS FSC source F22227+0107, and estimated its mass loss rate during the active phase.

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