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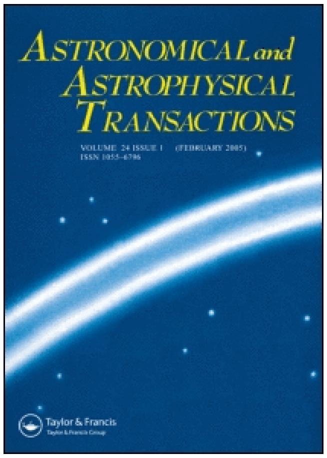

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Variability of the Seyfert 1 galaxy Ark 120 in 1992–2002

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We present the results of our spectral observations of the Seyfert 1 galaxy Ark 120 in 1992–2002.

Keywords: Active galaxies; Active galaxy nuclei; Seyfert galaxies; Ark 120; Photometry; Spectrophotometry

1. Introduction

The high variability of fluxes in the continuum and in broad emission lines, and strong Fe II multiplets characterize the first-type Seyfert galaxy Ark 120. More than 30 articles have been devoted to researching the relationship between the flux changes in the continuum and broad emission lines in Ark 120. In particular, a lag of 34–54 days between the continuum and Hβ light curves was found from our image-tube spectral observations of Ark 120 in 1989–1996 at the 2.6 m Shajn telescope of the Crimean Astrophysical Observatory [1]. From charge-coupled device (CCD) spectral observations of Ark 120 at the Lowell Observatory in 1989–1996 a lag of 60^{+31}_{-13} days was computed and it was shown that the lag changes with time [2]. The goal of this work is further study of the Ark 120 variability in the continuum and emission lines on the basis of our new observations.

2. Observations

We used the CCD spectral observations in the λ 4200–5400 Å spectral region at the 2.6 m Shajn telescope of the Crimean Astrophysical Observatory in 1992–2005 (89 spectra), the photometric observations in the V band with the 60 cm telescope of the South Laboratory of the Sternberg Astronomical Institute for the same time interval, and the CCD V-band

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observations with the 70 cm telescope of the Crimean Astrophysical Observatory in 2002–2005. Our spectra typically have a resolution of 8 Å and the signal-to-noise ratio is about 55. Typical uncertainties in the stellar magnitudes of the photometric data are about 0.02 with the photoelectric photometer, and 0.008 with the CCD.

3. Results

Ark 120 shows a variability that is typical for Seyfert galaxies (figure 1) with a standard deviation equal to 20.4%. There are flare-like events with a duration of some years and an amplitude magnitude of about 0.9, together with shorter variations on the timescale of weeks and days with a mean amplitude magnitude of about 0.2.

The analysis of our data via the structure function (SF) shows that flux variations in the Hβ line and continuum, which exceed the observational errors, are present on timescales of more than 1 day, in contrast with earlier results obtained by Peterson *et al.* [3], who did not find reliable evidence for real variations on timescales shorter than about 20 days. The amplitude of variations increases with increasing time interval of observations as SF $\propto \tau^b$, where $b > 0$ (figure 2).

On a log–log scale the slope of the SF for the continuum is $b = 0.86^{+0.18}_{-0.09}$ for a time interval from 1 to 1300 days. If the continuum changes are related to the disc instability, then the

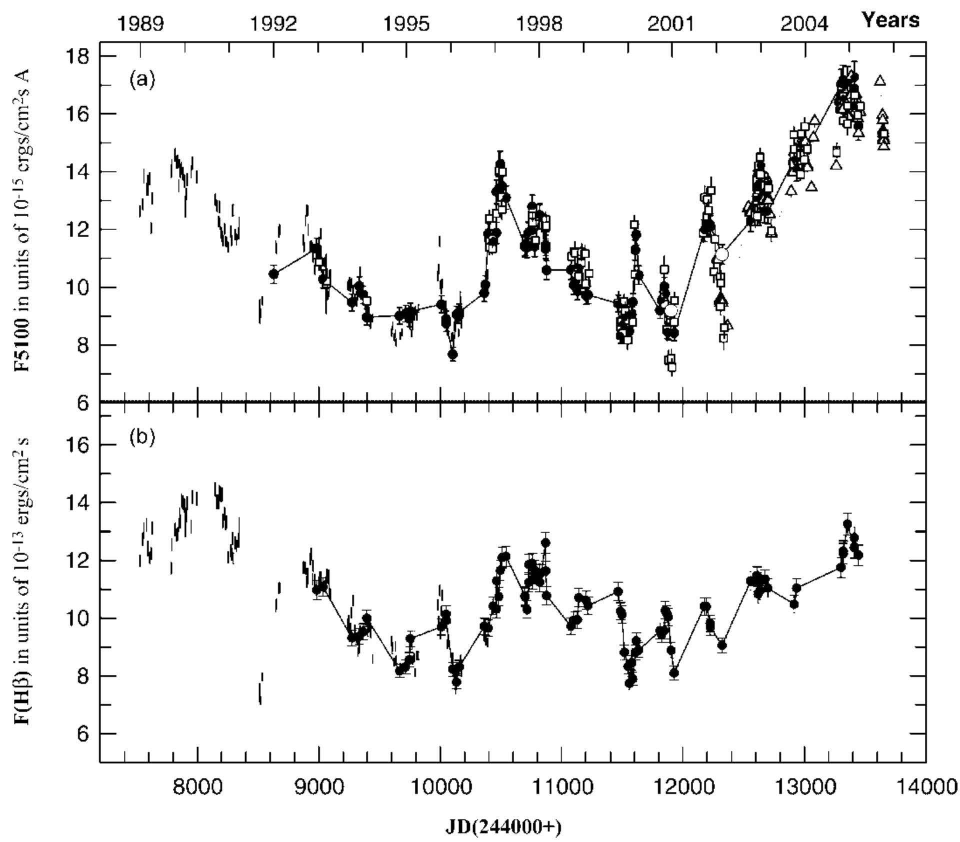

Figure 1. Ark 120 light curves: (a) the 5100 Å continuum data in units of 10^{-15} erg cm^{-2} s^{-1} Å^{-1}; (b) the Hβ data in units of 10^{-13} erg cm^{-2} s^{-1}.

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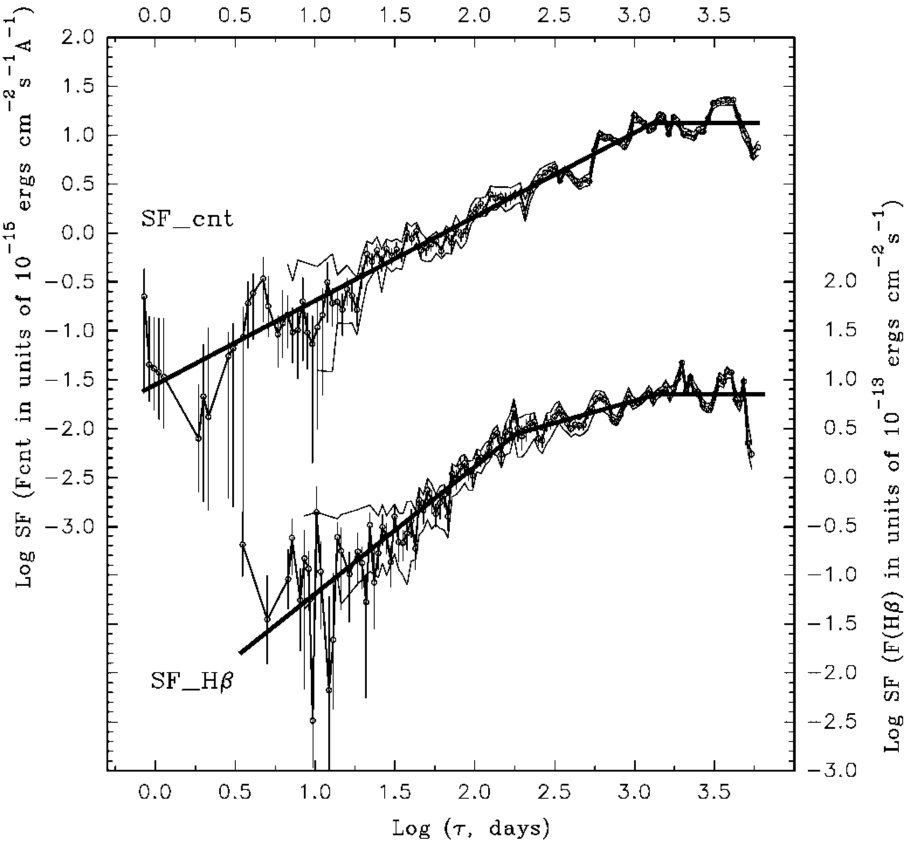

Figure 2. The SFs for the continuum (upper curve) and for the Hβ (lower curve) data of Ark 120. The thin vertical bars show the uncertainty calculated from Monte Carlo simulations. The thick lines show the best fit by the function $f(t) = at^b$. The upper plateau is also shown by thick lines.

power index b must be 0.8–1.0. So, our estimate $b = 0.86$ is in accordance with an accretion disc instability. The SF for Hβ emission line is best fitted by the power law function with two different values of the power index b: $b = 1.02^{+0.40}_{-0.11}$ for the time interval 5–170 days and $b = 0.46^{+0.19}_{-0.11}$ for the time interval 170–1320 days. Possibly, this is connected to the different natures of the fast and slow flux variations in the broad emission lines.

The time when the upper plateau of the SF is reached equals about 1000–1300 days (figure 2). This means that the events in the light curve are no longer correlated with previous events for such timescales; so this timescale can be treated as the maximum duration of flares in the continuum. For the light curve of the emission line it also corresponds to the upper limit for the outer boundary of the broad-line region (BLR) for this line.

It is widely known that photoionization of gas in the BLR by the continuum emission from the central source leads to the reverberation or echo effect in line with the continuum changes. However, our observations show that the response of the Hβ emission line to the continuum changes is ambiguous; the correlation between the line and continuum fluxes substantively changed in 2002–2005 with respect to those of earlier years (figure 3).

The Hβ line shows strong changes not only in the flux but also in the profile shape. It is seen from figure 4(c) that there is a zone of a poor correlation between the Hβ and continuum fluxes for the Hβ fluxes in the wavelength interval 4800–4830 Å (or for the radial velocity interval (−3800, −1900) km s^{-1}). This type of situation was not observed in 1974–1990 [1].

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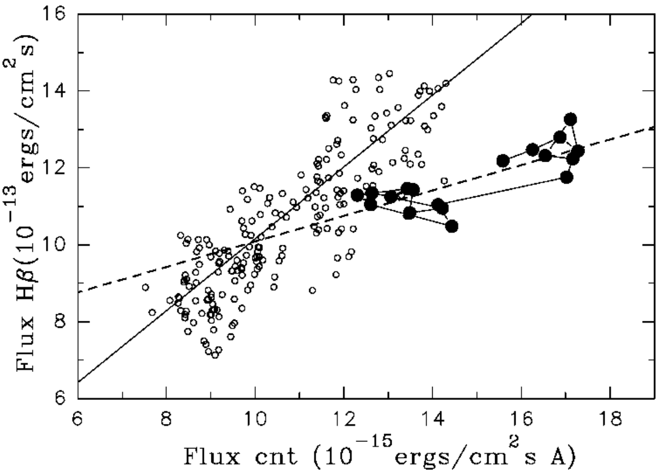

Figure 3. The 'flux–flux' diagram for Ark 120. The full circles are the data observed for 2001–2005.

Analysis of the Hβ and Hγ variable components has shown that both of these have two peaks in the line profiles with separation between the peaks of 24.6 and 26 Å, respectively (or 1500–1800 km s^{-1}). Moreover, the Hβ and Hγ variable components are shifted to long wavelengths relative to the line centre, which we take to be $z = 0.03269$. The Hβ shift equals 11.6 Å (or 720 km s^{-1}) and the Hγ shift is 18 Å (or 1200 km s^{-1}). If this is a gravitational red

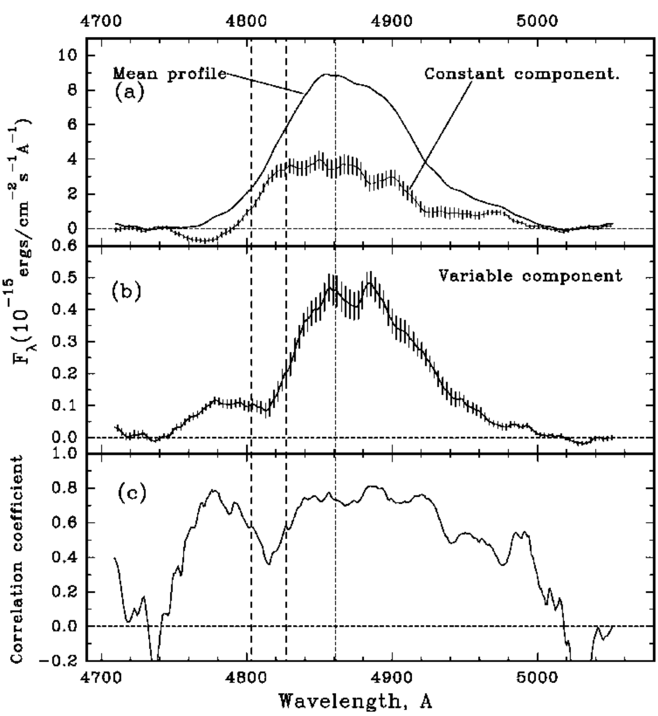

Figure 4. (a) The mean Hβ broad profile and the constant component of Hβ if we suppose that there are two components in the Hβ line profile: constant and variable. (b) The variable component. (c) The coefficient of correlation between the line flux and the optical continuum flux at $\lambda = 5100$ Å at different wavelengths along the line profile.

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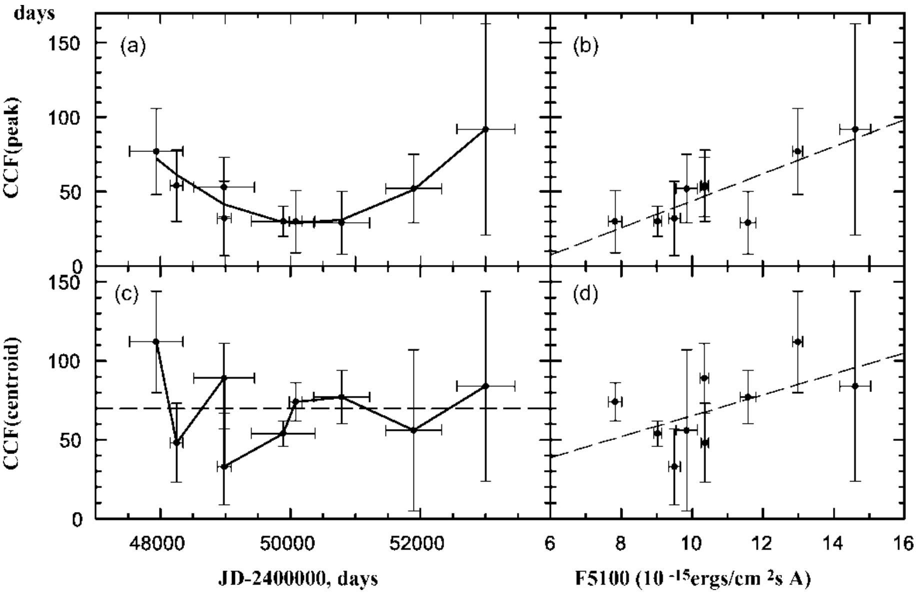

Figure 5. Changes in the time of the lag computed (a) from the peak of the CCF and (c) from the centroid of the CCF at the level $r \geq 0.5r_{\max}$, where $r_{\max}$ is the maximum value of the correlation coefficient. (b), (d) The lag computed from the peak and centroid of the CCF as a function of the continuum flux (F5100).

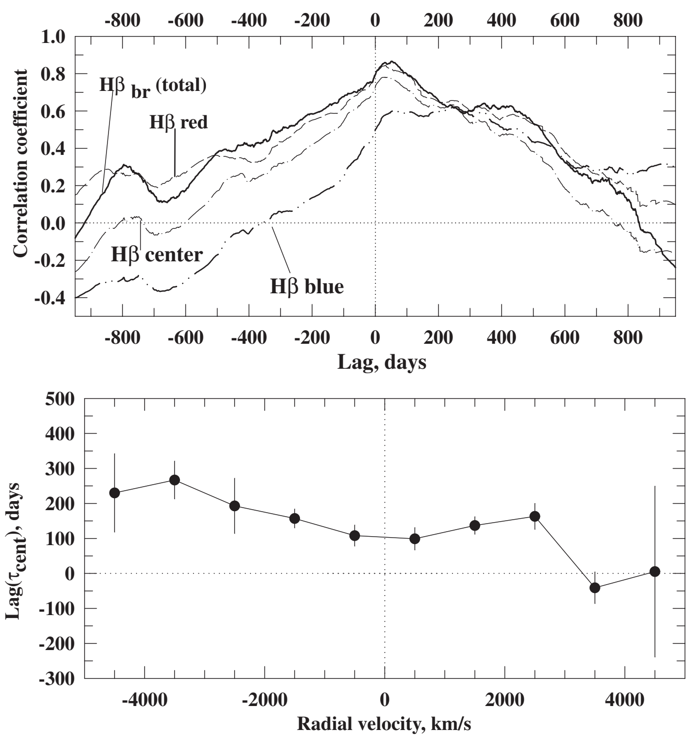

Figure 6. (a) The CCFs between the continuum obtained from spectral and photometric V data and the Hβ total broad-line flux (thick curve), between the continuum and the blue (–4000, –1500 km s^{-1}) wing flux (dash-dot-dotted curve), between the continuum and the red (1500, 4000 km s^{-1}) wing flux (dashed curve) and between the continuum and the central part of the Hβ profile (–1500, +1500 km s^{-1}) flux (dash-dotted curve). (b) The lag computed from the centroid of the CCF as a function of the radial velocity.

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shift, then the mass of the central source is an order of magnitude greater than the reverberation mass ($2.8 \times 10^9 M_\odot$ as against $3.6 \times 10^8 M_\varepsilon$).

The lag determined from the centroid of the cross-correlation function (CCF) approximately corresponds to the luminosity-weighted radius. It almost does not change within observational uncertainties during the observation time in 1989–2005 (figure 5) and equals 70 ± 8 days. On the other hand, the lag determined from the CCF peak, which corresponds more to the inner radius of the BLR, is possibly changed. We also can see from figures 5(b) and (d) that there is rather a good correlation between the continuum flux and the lag; when the continuum flux becomes weaker, the lag decreases. This means that, when the continuum flux decreases, the region of the line emission drifts inwards, nearer to the central source, and then the lag becomes smaller. The upper limit for the outer size of the BLR in the Hβ line, determined by the full width of the autocorrelation function of the Hβ light curve at zero correlation level, equals approximately 1300 light days. Then the ratio $r_{\rm out}/r_{\rm in} \leq 40$; so the BLR can be very thick geometrically.

The CCF analysis of the Hβ wings shows that the flux in the blue wing follows the continuum flux with more time delay than the flux in the red wing does (figure 6). This confirms the result obtained from the archive spectra in 1972–1993 [1]. More detailed analysis of the lag as a function of wavelength (figure 6(b)) shows that the kinematics of the BLR gas look chaotic or rotationally moving, but accretion can also be present for some of the gas.

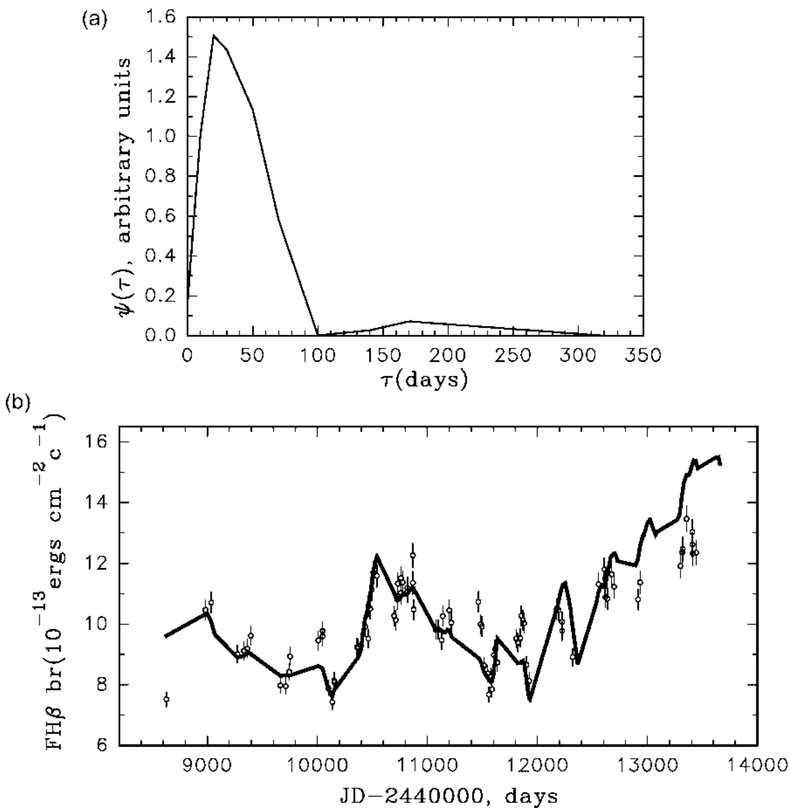

Figure 7. (a) The recovered transfer function for the Hβ line. (b) The observed line light curve (open circles with vertical bars) and the fitted light curve from the convolution of the transfer function and the continuum light curve (solid curve).

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We computed the transfer function between the continuum and the Hβ light curves. The envelope illuminated by the biconical continuum source produces the double-peaked line profiles. We observe double-peaked variable components for the Hβ and Hγ emission lines in Ark 120. It is possible that the non-correlated variations are results of a combination of changes in the anisotropy of the continuum emission and gas distribution in the BLR.

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