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THE Hβ EMISSION LINE PROFILE OF ARAKELIAN 120

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ABSTRACT

A high-quality (30 < S/N < 100), high-resolution (~1.8 Å) spectrum of the photometrically and spectroscopically variable Seyfert 1 galaxy Arakelian 120 has been obtained in the wavelength region including Hβ. The observed Hβ line profile can be considered as a benchmark for future line profile studies of this interesting object. The origin of the extended red wing of Hβ is discussed.

I. INTRODUCTION

The recent theoretical studies of Capriotti, Foltz, and Peterson (1982) and Blandford and McKee (1982) emphasize the importance of the study of the temporal behavior of the broadline profiles in Seyfert 1 galaxies as a diagnostic of the structure and dynamics of the broad-line emitting gas. Arakelian 120 is an excellent candidate for such a study. Long known to be both spectroscopically and photometrically variable, Akn 120 is bright enough to be accessible to telescopes of modest aperture. It has been shown that the Hβ emission line responds rapidly to changes in the luminosity of the continuum source (Peterson et al. 1983, and references cited therein).

Most of the previous work on the nature of the spectroscopic variations of Akn 120 have been based on the variations of the equivalent widths of Hβ and [O III] λλ 4959, 5007, and though Hβ profile variations have been clearly observed, the signal-to-noise ratios (S/N) and resolution of these observations are, in general, not superior.

In order to test the suggestions of Capriotti, Foltz, and Peterson (1982) that variations in the continuum source will be manifest as structure in the emission line profiles, it is essential that any irregularities in the profiles are readily identifiable and that the temporal behavior of these individual small-scale features be closely monitored. In this contribution a high S/N, high-resolution profile of Hβ in Akn 120 is presented. Our intent is to provide a benchmark line profile against which future profiles can be compared.

II. OBSERVATIONS

Akn 120 was observed for a total of 14,400 s on the night of 1983 January 9 (U.T.) with the Boller and Chivens spectrograph equipped with a dual beam photon-counting Reticon detector mounted on the Steward Observatory 2.3-m telescope. The spectrograph entrance apertures were circular holes with a projected diameter of 2.5 arcsec. All observations were made during conditions of good transparency and fair seeing.

Though the data were reduced following fairly standard procedures, the desired very high S/N of the spectrum dictates some additional discussion.

Wavelength calibration. A fourth-order polynomial was fitted to the positions of 35 He-Ar comparison lines with a standard deviation of 0.12 Å. Observations of comparison spectra were liberally interspersed with the observations of Akn 120. These were carefully checked for systematic shifts due to physical and/or magnetic flexure. Since no shifts greater than 0.1 Å were found; the data were coadded on a pixel-to-pixel basis.

Removal of pixel-to-pixel sensitivity variations. Coadded spectra were divided by spectra of a quartz incandescent lamp in order to remove pixel-to-pixel sensitivity variations which have an amplitude of 2%-3% in the raw data. The lamp spectra were broken into several short integrations enabling quotients of independent lamp observations to be formed. Their deviations from unity were consistent with photon-counting statistics to within ~1%.

Extinction corrections and flux calibration. The effects of atmospheric extinction were removed using a mean extinction curve appropriate for Kitt Peak. Reduction of the data to relative flux units (energy/cm²/s/Hz) was facilitated by referencing the data to observations of the white dwarf EG20 whose spectrometric properties are known (Oke 1974). Flux calibration points fully covered the observed spectral range, running from 4420 to 5620 Å at 40-Å intervals. Due to the combination of fair seeing and small entrance apertures, no attempt was made to determine the absolute flux scale of the final spectrum.

Since the Reticon scanner is a dual-beam instrument, data from each aperture were reduced separately, binned into a common wavelength scale, averaged and

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smoothed via convolution with a 3-pixel-wide boxcar. The resolution of the raw data as determined by the FWHM of an unresolved comparison line was 1.5 Å. After rebinning and smoothing, this was degraded to ~1.8 Å as determined by performing the same operations on the comparison lamp spectrum as were performed in the reduction of Akn 120.

The analysis of the quartz lamp spectra indicates that the data are photon noise limited. Assuming that this was the only source of noise, the variance of the data was propagated through the reduction procedure. Sources of noise considered were photon noise in observations of the object, sky, and quartz lamp.

In Fig. 1 our spectrum of Akn 120 is presented along with the spectrum of the 2σ level of the noise. The actual value of S/N varies from > 30 at the ends of the spectrum to > 100 at the peak of the Hβ profile.

III. DISCUSSION

The spectrum in Fig. 1 was examined for weak emission features. It is found that, in general, most of the irregularities in the spectrum can be identified with individual transitions or blends of transitions mostly due to permitted multiplets of Fe II. Also identified are [Ca v] λ 5308, [N i] λ 5199, [Fe vi] λ 5177, and possibly [A iv] 4711, 4740. The only identifiable irregularity within the Hβ profiles is Fe II λ 4924. Due to the severe intrinsic blending of the weak features, no attempt was made to measure their line strengths.

The Hβ equivalent width was measured in the manner described by Peterson et al. (1983) to be 110 ± 5 Å in the rest frame of the [O iii] lines (z = 0.032 48). This measurement includes the extended red wing of Hβ after the [O iii] lines have been excised via interpolation of the red wing of Hβ. The relative strength of [O iii] λ 5007 was measured to be 0.083 ± 0.002 (Hβ = 1.000). Both λ 5007 and λ 4959 were measured to arrive at this value, assuming F(λ 5007):F(λ 4959):=3:1.

Comparison of these line measurements with those of Peterson et al. (1983) reveals that the optical continuum level has increased significantly (by ~0.5 mag which is greater than ~3σ) since the period between 1982 October–December. The Hβ flux, however, appears to be comparable to that observed late in 1982, which implies that the effect of the recent outburst has not yet been communicated to the entire broad-line emitting region.

The Hβ profile itself is remarkably free of small scale irregularities. A strong bump is observed at ~4890 (rest), approximately 1800 km/s redward of line center as defined in the rest frame of the [O iii] lines. It is of interest to note that a feature was reported at this displacement by Foltz et al. (1981). A similar feature is seen in the spectrum observed by Osterbrock and Phillips (1977) in 1976 November and in most of the Hβ profiles presented by Capriotti, Foltz, and Peterson (1982). Foltz et al. (1981) point out a second feature at ~ −1300 km/s. Though this feature is not resolved as a separate peak in our profile, the additional inflection in the blue wing giving rise to a shoulder on the line suggests its presence at roughly the same wavelength.

We now turn our attention to the extended red wing of Hβ which is clearly apparent in Fig. 1 beneath the [O iii] λλ 4959, 5007 profiles. Osterbrock and Shuder (1982) attribute the excess emission to Fe II multiplet 42 emission at λλ 4924, 5018 arising in the broad-line clouds. Both Oke and Lauer (1979) and Phillips (1978) show that the shape of the Fe II blends at λ 4570 and λλ 5190, 5320 are consistent with the Fe II emission having the same profiles as Hβ. Thus, the breadth of the
Fig. 2. A summary of the procedure used to isolate the extended red wing of Hβ. Top: Observed Hβ profile; middle: profile corrected for [O m] λ 4959, 5007; bottom: result of subtracting scaled Hγ profile from the middle profile.

wing can ostensibly be explained. It has also been suggested (e.g., Shields 1978; Mathews 1982) that for models of the broad-line region in which all of the emitting clouds do not have the same electron density, some of the clouds may be of sufficiently low density such that [O m] emission is not effectively quenched. In the case of Mathews radiatively accelerated “pancake” clouds, broad, flat-topped emission with widths roughly equal to that of the broad lines are expected.

In order to investigate the nature of the red wing, it was isolated from the surrounding emission lines in the following manner: the [O m] λ 5959, 5007 profiles were isolated and subtracted by interpolating the Hβ profile under them. This process is fairly unambiguous at the S/N of these data. It was then assumed that the λ 5007 profile is characteristic of the forbidden line emission and it was used to subtract the narrow component of the Hβ emission from the Hβ profile and the narrow component of Hγ and [O m] λ 4363 emission from the broad Hγ profile. The flux ratios adopted in this subtraction are F(Hβ narrow): F(λ 5007):1:12, F(Hγ narrow):F(λ 4363):F(λ 5007):1:1:20. This results in Hβ and Hγ profiles, which are approximately corrected for narrow-line emission. Two independent methods were used in the subtraction of the broad Hβ profile. First, the Hγ profile was shifted into the velocity space of Hβ and used as a template broad-line profile. Due to its proximity to the end of the spectrum, the continuum level in and beyond the blue wing of Hγ is uncertain and therefore, the blue wings of the two profiles could not be compared satisfactorily. Therefore, Hγ was scaled by a constant until the central portions and near-red wings of the two profiles agreed reasonably well. The scaled and shifted Hγ profile was then subtracted from Hβ, isolating the spectrum of the red wing of Hβ. The results of each stage of this process are displayed in Fig. 2.

It must be noted that this procedure suffers from several possible sources of error. Clearly the placement of the continuum affects the wings of the profile much more on a percentage basis than they do the parts of the profile near line center. The continuum level is particularly difficult to establish in the case of Hγ due to its proximity to the end of the scan. Although the flux calibration should be accurate over the entire spectral range, the limited number of pixels observed shortward of Hγ make the placement of the continuum extremely difficult. Furthermore, emissions from multiplets 37 and 38 of Fe II between Hγ and Hβ also make the location of the continuum longward of Hγ uncertain. Finally, the Hγ profile itself is contaminated by an unknown amount of Fe II multiplet 27 emission. None of these problems is easily addressed.

As a consequence of the difficulties discussed above, a second attempt to isolate the red wing of Hβ was made. In this case it was assumed that the wings of the broad Hβ emission are symmetric. The blue wing of the Hβ profile was reflected about a point such that this reflected wing was in agreement with the “near-red” wing (i.e., between ~ 4890 and 4915 Å rest). The position of the print of reflection was ~ 380 km/s longward of line center in the rest frame of the [O m] lines. The resultant profile is remarkably free of the problems discussed above. A similar procedure has been used in the study of the line profiles of QSOs and active galaxies by Wilkes (1983) and Meyers and Peterson (1983). The synthetic profile was then subtracted from the observed Hβ profile. The results of this subtraction are discussed below.

In order to investigate the veracity of the proposed sources of the emission, synthetic blends were generated and compared with the observed feature following the method discussed by Wilkes and Carswell (1982). In the first case, the Hγ profile, and in the second case, the symmetric Hβ, was used as a template for both Fe II and broad [O m] emission. Clearly this is not appropriate for the [O m] emission but this avoids the problem of selecting a theoretical shape for the lines. Both profiles are roughly rectangular in shape and so the comparison made below using it as a template profile is probably a reasonable approximation to the radiative acceleration model of Mathews (1982) in which any broad [O m] emission would be roughly rectangular. The template profile was shifted, in turn, into the velocity space of the Fe II and [O m] lines and scaled by their expected strengths in the optically thick case (Fe II λ 5018:λ 4024::1:1, [O m] λ 5007:λ 4959::3:1). The re-
IV. SUMMARY AND CONCLUSIONS

(1) A high-quality Hβ line profile for Akn 120 is presented for use as a benchmark for future line profile studies.

(2) The extended red wing of Hβ is probably not due solely to Fe II multiplet 42 emission where the individual transitions are emitted with the same profile as the Balmer lines. Some broad [O III] emission may be present.

(3) There are apparently two features in the Hβ profile at -1300 and +1800 km/s with respect to line center in the rest frame of the forbidden lines. The redward feature, and probably the blueward feature as well, have been stable in velocity for more than six years, though their relative strengths have varied.

It is interesting to speculate on the origin of the latter features. As noted by Peterson et al. (1983), they are probably not due to irregularities of excitation of the broad-line region caused by temporal variation of the continuum source as has been suggested by Capriotti, Foltz, and Peterson (1982). Possibly they indicate the presence of a kinematic component to the BLR distinct from that giving rise to the roughly logarithmic core and wings of the profile—e.g., a rotating disk or counterposed ejection of material. From symmetry consideration it is difficult to understand how the apparent V/R
asymmetry could be produced by a rotating structure alone. Since A kn 120 appears nearly face-on on the POSS, it is tempting to speculate that the material giving rise to this emission is being ejected parallel to the rotation axis of the galaxy. Perhaps some information as to whether such an additional component exists could be obtained by comparison of Hβ with C iv λ 1550 and Mg II λ 2798 profiles obtained with the space telescope or possibly IUE.

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