THE ASTROPHYSICAL JOURNAL, 295:L33–L37, 1985 August 15

BALMER PROFILE VARIATIONS DURING THE FADING OF THE SEYFERT 1 GALAXY FAIRALL 9[1]

WILLEM WAMSTEKER[2]
IUE, Vilspa

DANIELLE ALLOIN AND DIDIER PELAT
Observatoire de Meudon

AND

ROBERTO GILMOZZI[2]
IUE, Vilspa

Received 1985 February 4; accepted 1985 May 28

ABSTRACT

We present variations of the Hβ profile during the fading of the Seyfert 1 nucleus of Fairall 9, between 1981 and 1984. Decays with time scales from 250 days to 1000 days are found for the ultraviolet and optical continua, as well as for the Hβ line emission. These cannot be easily interpreted in terms of a change in the accretion rate in a steady state thick disk, while disk instabilities provide time scales of the right order of magnitude.

Subject headings: galaxies:individual — galaxies:nuclei — galaxies:Seyfert

I. INTRODUCTION

Spectral variations from the broad line emitting region (BLR) appear to be a characteristic feature in active galactic nuclei (e.g., Alloin *et al.* 1985 and references therein). However, the details of these variations are still a matter of debate. Previous studies show a complex relationship between the ultraviolet and optical line intensity changes as well as *individual line shape variations* (Ulrich *et al.* 1984; Menzies and Feast 1983; Osterbrock and Shuder 1982; Foltz *et al.* 1981).

Previous attempts to analyze line profiles in detail have been limited by the existence of many free parameters (Pelat, Alloin, and Fosbury 1981; Van Groningen 1984). The number of these could be reduced by isolating individual components within the profile from *their specific time variation*. With this intention we started a long-term program to monitor simultaneously the optical and ultraviolet spectra of a few Seyfert 1 galaxies. In the optical we obtain spectra at 3 Å and 10 Å (FWHM) resolution to study the Hβ and Hα line profiles, while continuum variations are followed primarily from ultraviolet spectra.

We present here an analysis of Hβ profile variations observed in the extreme Seyfert 1 galaxy Fairall 9 (≡ ESO 113−G45) over the period 1981–1984. At the time of its discovery (Fairall 1977), F9 was one of the brightest Seyfert 1 galaxies and showed an Hβ luminosity larger than 10^{43} ergs s^{-1}, in the range of QSOs (Hawley and Phillips 1978; Danks *et al.* 1979). A preliminary report on the continuum variations of this object was given by Wamsteker *et al.* (1984) who showed that the period from 1978 to 1984 was marked by a general slow decline in the ultraviolet continuum amounting to Δm (1350 Å) = 3.6 mag. Such a decrease is also seen in the optical (U, B, V) although its amplitude is considerably less (de Ruiter and Lub 1985; Gilmozzi and Wamsteker 1985).

II. OBSERVATIONS AND RESULTS

The spectra were obtained at the European Southern Observatory (La Silla), using the Image Dissector Scanner at the 3.6 m and 1.5 m telescopes. A 4″ × 4″ entrance aperture was employed in seeing conditions which ranged between 1″ and 2″ (FWHM). Standard procedures were applied to derive absolute fluxes (photometric accuracy ≈ 10%, except for 1984 August where it is slightly larger due to instrumental problems). As expected the measured absolute fluxes for the [O III] lines at 4959 and 5007 Å (Table 1) agree within 10%, in support of the idea that the narrow line emission does not vary on such a short time scale. Thus we used the [O III] measurements to derive a gray correction given in Table 1, to take into account minor departures from photometric sky conditions. This has been applied to both the line and continuum measurements shown in Table 1.

The spectrum of F9 shows strong Fe II emission. Although we shall base most of the analysis below on results derived from *differential spectra*, it is imperative for the final line profile fitting that the strong Fe II multiplets which fall under the broad Hβ wings be removed. From our data the Fe II 5100, 5470 Å blend is constant to within the measuring accuracy (Table 1); we therefore adopt the continuum modeling proposed for Seyfert 1 galaxies by Wamsteker *et al.* (1984). Specifically, we assume for F9, that the continuum between 4000 and 5500 Å is dominated by the constant contribution of Fe II and a variable power-law spectrum (with constant $\alpha \approx 0$).

[1]Based on observations collected at the European Southern Observatory (La Silla).

[2]Affiliated with the Astrophysics Division, Space Science Department, ESA.

TABLE 1

LINE AND CONTINUUM VARIATIONS

COMPONENT	DATE 1981 Aug 28	1981 Dec 26	1982 Nov 20	1983 Nov 23	1984 Aug 26	FWHM	V_{rel}[a]
	Measured Intensity (10^{-14} ergs s^{-1} cm^{-2})						
[O III] λ5007	16.3	17.8	20.8	20.9	20.0	670	...
[O III] λ4959	5.6	5.9	6.4	6.2	5.7	670	...
g[b]	1.23	1.14	1.00	1.01	1.05:	...	...
	Intensity (10^{-14} ergs s^{-1} cm^{-2})						
Hβ(n)	3.8	5.6	6.0	6.1[c]	2.4	670	0
Hβ(rs)	8.7	8.9	2.4	3.4	0.9	1650	+2280
Hβ(i)	66.7	66.6	56.2	29.1	16.3	3730	+130
Hβ(b)	22.1	21.7	20.2	11.9	14.1	9220	−1710[d]
Fe II λ5100, 5470[e]......	...	32.1	32.8	32.0	32.4	...	...
	Continuum Flux (10^{-14} ergs s^{-1} cm^{-2} $Å^{-1}$)						
λ5076	1.18	1.03	0.70	0.48	0.37	...	...
λ4737[f]	1.23	1.17	0.87	0.48	0.43	...	...
λ1350[g]	13.8	12.7	9.7	2.9	0.85	...	...
	Equivalent Width (Å)						
$H\beta_{tot}$	85 ± 15	100 ± 15	120 ± 20	105 ± 15	90 ± 15	...	...

[a] $Z = 0.04601$ for Hβ narrow. The fits were performed using least-squares fitting techniques from the IHAP image processing system (ESO) as installed in Vilspa.

[b] The gray correction factor has been derived using a weighted mean of the two [O III] line fluxes. The most accurate data of 1982 Nov were chosen as the normalization level.

[c] The actual value has been corrected for a weak absorption to the blue of Hβ(n).

[d] The central emission velocity of Hβ(b) is uncertain owing to its large width and low intensity. The Hα profiles we have obtained show symmetric wings.

[e] From multiplets 35, 41, 42, 48, and 49.

[f] The λ4737 window may be slightly contaminated by the wings of Hβ and some possibly variable He II λ4686 emission.

[g] In the case where a simultaneous ultraviolet observation was not available, the 1350 Å flux at our observing epoch was interpolated from Fig. 2 in Wamsteker *et al.* 1984.

As may be seen, this model matches the continuum quite well, independently of the nucleus brightness (Fig. 1). After subtraction, we obtain clean Hβ and [O III] profiles which can be subjected to a multiple Gaussian fit.

In Figure 2 we give the continuum-subtracted Hβ profiles, which show that the line underwent dramatic changes over this time interval. As a first step we used the variability as a tool to identify individual components, subtracting the profiles at consecutive epochs one from the other. We could recognize the following four components: (1) Hβ(n), a *narrow* component common to many Seyfert 1 line profiles; (2) Hβ(rs), a *red shoulder* covering a well-defined velocity interval, responsible for the variation between 1981 December and 1982 November (Fig. 3); (3) Hβ(i), an *intermediate* velocity width (3700 km s^{-1}) component which contains the bulk of the Hβ line emission; and (4) Hβ(b), a *broad* feature with a velocity dispersion around 9000 km s^{-1}, thought to represent the inner part of the BLR. These four components were then used to make a detailed Gaussian fit to the Hβ profile at each epoch, allowing only the peak intensities to vary. The single modification to this procedure was the need for a faint absorption on top of Hβ(n) in 1983 November. The quantified results are given in Table 1 and the resulting fits in Figure 2. Our method reduces the degrees of freedom in each profile fit from about 17 down to 4; then nonuniqueness problems become minor.

The question arises whether Hβ(rs) may include substantial Fe II emission. The only likely candidate would be Fe II 4886 Å. However, no consistent fitting of the profiles could be achieved by forcing this component to the appropriate wavelength. In addition the observed constancy of the Fe II emission (Table 1) provides strong evidence against the assignment of Hβ(rs) to any Fe II multiplet since it should go away in the subtraction procedure. We conclude that Hβ(rs) is a genuine part of the Hβ complex.

III. DISCUSSION AND CONCLUDING REMARKS

From our study the main asymmetry in the Hβ profile is due to one component, Hβ(rs). Such a component could be responsible for the commonly asymmetric profiles observed in other Seyfert nuclei.

We show the light curves for the Hβ components and Fe II blend in Figure 4*a*, for the continuum points in Figure 4*b*. The whole Hβ complex fades away with the ultraviolet and optical fluxes, thus suggesting that the BLR is radiation

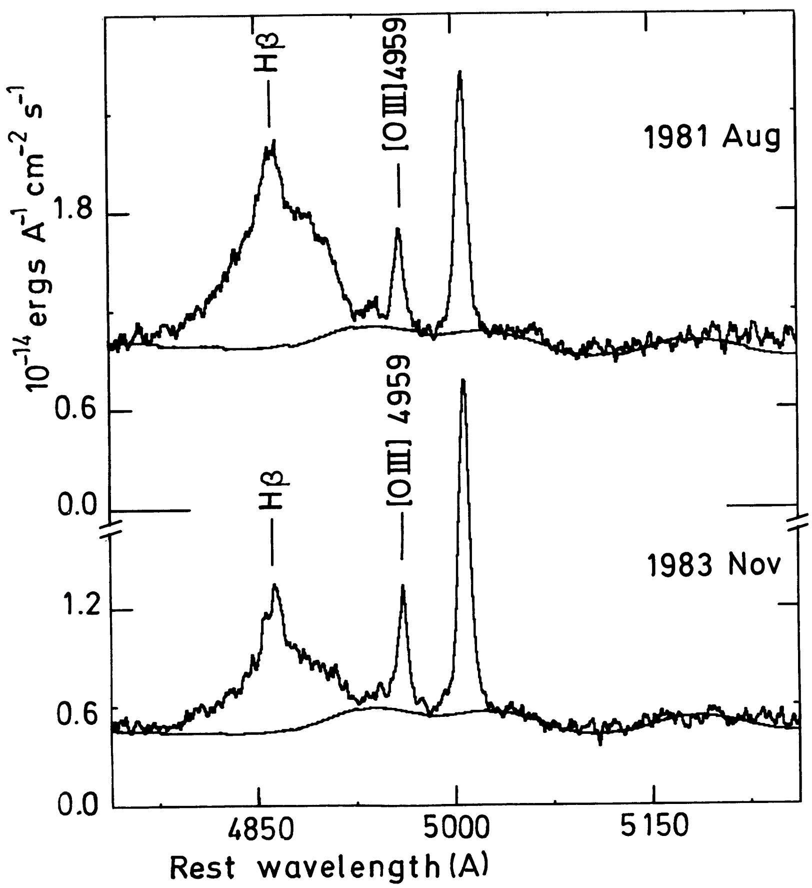

FIG. 1.—Comparison between the data set and the modeled continuum, power-law plus Fe II emission (Wills, Netzer, and Wills 1985). The data at that stage were not yet corrected for gray absorption.

bounded. In contrast to Hβ and the continuum, the Fe II 5100, 5470 Å and the Fe II ultraviolet (Gilmozzi *et al.* 1985) emission does not vary significantly. This suggests that, in F9, photoionization is not the dominant process in the Fe II zone or that this region is somewhat farther away and responds later.

As one can see in Figure 4*b*, over the period 1981 August to 1982 November, the ultraviolet and optical continua follow an exponential decay with a characteristic time $\tau_1 = 1000$ days. After this date, the 1350 Å light curve drops more steeply with $\tau_2 \approx 250$ days, while the optical one decreases steadily with the same time scale τ_1. Correspondingly, the derived power-law index changes slightly from 0 to 0.3.

Prior to 1983 February, the Hβ(i) decrease is similar to that of the continuum, whereas, later on, its decay time shortens to $\tau_3 \approx 600$ days. The differences in the characteristic times for the Hβ(i) and 1350 Å flux decays after 1983 February can be tentatively interpreted in a simple way. Let us assume that the Hβ(i) emission originates in a shell responding linearly to variations of the central source at a distance R, and that the 1350 Å flux follows the variations of the ionizing source for the Hβ(i) BLR clouds. The Hβ(i) light curve is then the integration of the source variations over the different time delays involved in the BLR geometry. If this source started a τ_2 exponential decay at $t = 0$ (~ 1983 February), then the Hβ line also starts a slow decrease at $t = 0$ and reaches the τ_2 exponential decay after a time $t = 2R/c$; in between, its decay time is larger than τ_2. Indeed the Hβ(i) line does not drop as fast as the 1350 Å flux ($\tau_3 > \tau_2$) and 18 months later has not yet reached the same decay τ_2. We therefore obtain a lower limit for the intermediate BLR size, $R \geq 9$ lt-months. Interpreting the Hβ(i) FWHM in terms of Keplerian broadening ($v = [R/2M]^{-1/2}$), one gets a lower mass limit within this radius, $M \geq 4 \times 10^8\ M_\odot$.

The intensities of Hβ(b) and Hβ(n) are constant within the measurement errors. The red shoulder Hβ(rs) drops by a factor of 3, prior to the break in the 1350 Å flux. It may indicate that this component responds first to a shortage of energetic photons that we did not observe, possibly in the keV range, and occurring before 1981 December. The absolute luminosity of this component at the date of 1981 December, $L[\text{H}\beta(\text{rs})] = 3.2 \times 10^{41}$ ergs s^{-1}, corresponds to a mass of 0.08 $M_\odot$ to 8 $M_\odot$, assuming the matter is fully ionized, $T_e = 10^4$ K, and N_e of 10^{10}–10^8 cm^{-3}, respectively.

Models have been proposed in which the variations come from changes in the parameters governing a steady state accretion disk around a massive object. Following the discussion in Alloin *et al.* (1985), one finds in the case of F9 characteristic times $T_a \approx 10^5$ yr for the accretion rate changes and $T_s \approx 5$ yr for disk instabilities (assuming $T = 3 \times 10^4$ K,

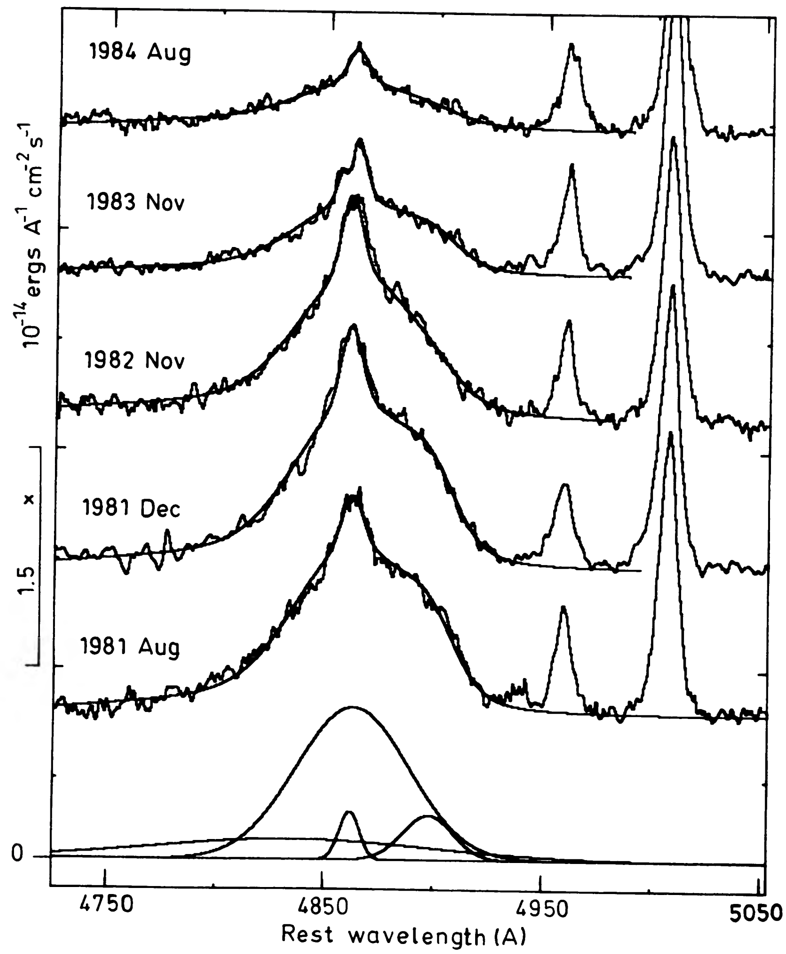

FIG. 2.—Continuum-subtracted, gray-corrected, Hβ profiles for all five epochs. The full line drawn on top is the resulting fit. The four individual components used in the fit are displayed at the bottom.

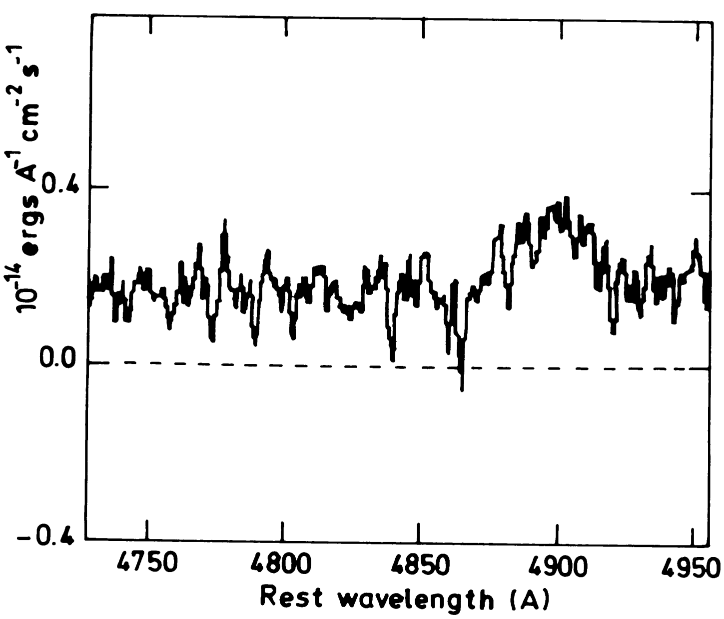

FIG. 3.—Difference between the spectra obtained on 1981 December and 1982 November showing the enhanced red shoulder

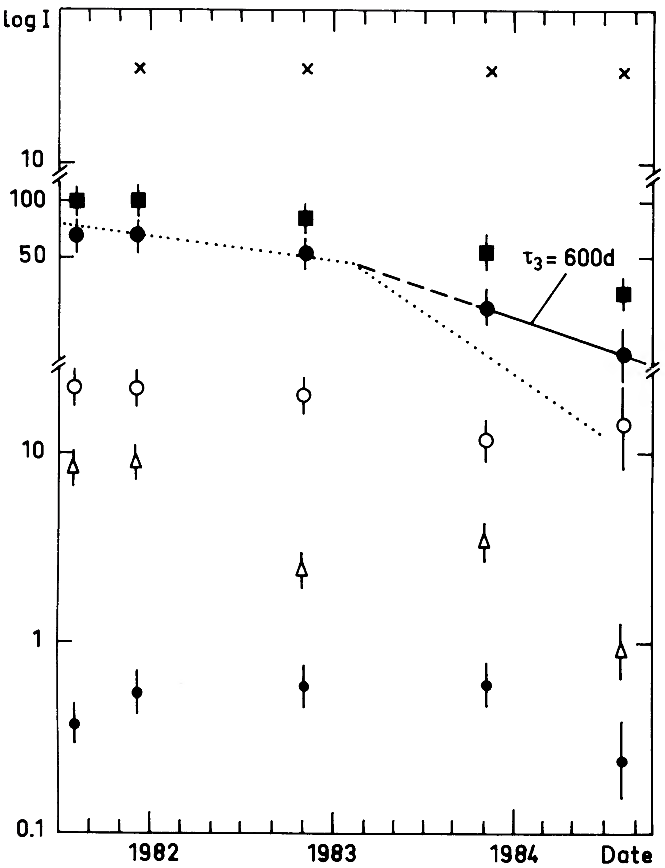

FIG. 4*a*

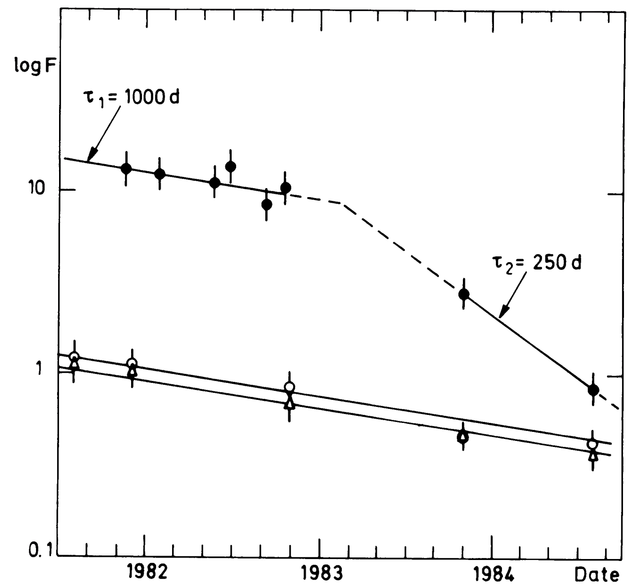

FIG. 4*b*

FIG. 4.—(*a*) Light curves for the Fe II and Hβ line emission. Crosses correspond to Fe II 5100, 5470 Å; filled squares to Hβ total; filled circles to Hβ(i); open circles to Hβ(b); open triangles to Hβ(rs); and black dots to Hβ(n). The dotted line represents the 1350 Å flux variations from Fig. 4*b*, while the solid line shows the Hβ(i) exponential decay after 1983 February. (*b*) Light curves for the continuum. Filled circles correspond to the 1350 Å flux; open circles and triangles, respectively, to the 4737 and 5076 Å fluxes. Lines drawn on the ultraviolet light curve have been fitted to the data. Those for the optical light curve have been drawn at the location imposed by $\alpha = 0$ and $\tau = 1000$ days; they match the data points quite well.

$r/2M \approx 5$). One can eliminate changes in the accretion rate since T_a is much larger than τ_1 and τ_2, whereas disk instabilities give time scales of the right order of magnitude.

The interest of F9 is that its luminosity, BLR size, and mass of the central object resemble those of QSOs, while its characteristic times for variations are surprisingly short. On the grounds of classical criteria, F9 would have changed from a QSO to a Seyfert 1.5. This result suggests that a classification closer to the physical processes involved in such objects is still to be done.

We are indebted to A. Danks who obtained one of the spectra; R. Poulain for *U, B, V, R, I* measurements in 1984 August; and M. Phillips for helpful comments.

REFERENCES

Alloin, D., Pelat, D., Phillips, M. M., and Whittle, M. 1985, *Ap. J.*, **288**, 205.
Danks, A. C., Wamsteker, W., Vogt, N., Salinari, P., Tarenghi, M., and Duerbeck, H. W. 1979, *Ap. J.* (*Letters*), **227**, L59.
de Ruiter, H. R., and Lub, J. 1985, *Astr. Ap. Suppl.*, in press.
Fairall, P. 1977, *M.N.R.A.S.*, **180**, 391.
Foltz, C. B., Peterson, B. M., Capriotti, E. R., Byard, P. L., Bertram, R., and Lawrie, D. G. 1981, *Ap. J.*, **250**, 508.
Gilmozzi, R., and Wamsteker, W. 1985, preprint.
Gilmozzi, R., *et al.* 1985, preprint.
Hawley, S. A., and Phillips, M. M. 1978, *Ap. J.*, **225**, 780.
Menzies, J. W., and Feast, M. W. 1983, *M.N.R.A.S.*, **203**, 1P.
Osterbrock, D. E., and Shuder, J. M. 1982, *Ap. J. Suppl.*, **49**, 149.
Pelat, D., Alloin, D., and Fosbury, R. A. E. 1981, *M.N.R.A.S.*, **195**, 787.
Ulrich, M. H., *et al.* 1984, *M.N.R.A.S.*, **206**, 221.
Van Groningen, E. 1984, Ph.D. thesis, Sterrewacht, Leiden.
Wamsteker, W., *et al.* 1984, in *Proc. Third IUE Conference*, Rome (ESA SP-218).
Wills, B., Netzer, H., and Wills, D. 1985, *Ap. J.*, **288**, 94.

DANIELLE ALLOIN and DIDIER PELAT: Observatoire de Meudon, F-92195 Meudon Principal Cedex, France

ROBERTO GILMOZZI and WILLEM WAMSTEKER: *IUE Observatory*, ESA, Apartado 54065, 28080 Madrid, Spain