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Velocity-Resolved Line Response of the Emission Lines in the High-Luminosity ($M_V \approx -24$) Seyfert 1 Galaxy Fairall 9

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Abstract. A detailed emission-line decomposition has been made from 15 years of observations with the *IUE* satellite of the highly variable Seyfert 1 galaxy Fairall 9, allowing us to study the line variability as a function of velocity and continuum brightness. The variability over the different velocity domains of the broad lines has been related to the continuum variability over a large wavelength domain from the X-rays to the infrared. Clear delays were established between the redshifted and blueshifted parts of the lines in Lyα and C IV, with the red sides of the lines responding faster with no delay and the blue sides responding with a delay of some 230 days. The observed spectral variability behavior of the continuum has been used as input for photoionization model calculations and the combined constraints from the models and differences for gas at different velocities define the structure and motions in the BLR.

1. Introduction

The galaxy Fairall 9 (F9) was identified as a Seyfert 1 galaxy by Fairall (1977), who noted its high luminosity of $M_V \approx -24$ mag. It has displayed a very large amplitude variability, with a decrease in optical brightness from 1978 to 1984 of $\Delta m_V = 0.8$ mag and in the UV of $\Delta m(1350\,\text{Å}) = 3.6$ mag (Wamsteker et al. 1985). After that time the brightness increased again, but as of 1996 it had not recovered the extreme luminosity seen in 1978 (see also Rodríguez-Pascual, this volume). The variability at other wavelengths has been described by Clavel, Wamsteker, & Glass (1989) for the IR (and UV), Morini et al. (1986) for the X-rays, and Lub & De Ruiter (1992) for the optical. The combined results from the study of these quasi-simultaneous observations have been described in detail by Recondo-González et al. (1996). We will here only supply a summary of the main conclusions.

2. The Spectral Energy Distribution (SED) of F9

Although most of the observational material used in this study has not been obtained exactly simultaneously, sufficient observations have been made very close in time. The relatively high sampling density of the UV data (the mean interval between observations is 98 days) allows us to interpolate the UV light curve to determine the SED, even at times when the observations are not exactly simultaneous. Since the available simultaneous epochs cover most of the large brightness variation and other epochs used to characterize the SED are very close in time, the results can be considered to be valid for the general variability characteristics from the X-ray to the FIR. After correction for the contribution of the stars in the bulge of the galaxy, the thermal emission of dust, the Balmer continuum and the pseudo-continuum due to the blending of the many Fe II multiplets in the UV and optical, we found that we can describe the AGN continuum radiation as a power law of the form $F_\nu \propto \nu^\alpha$, with indices $\alpha_{\text{UV-OPT}} = 0.06 \pm 0.27$ and $\alpha_{\text{UV-NIR}} = 0.06 \pm 0.27$, and the X-ray index $\alpha_{2\text{-}10\,\text{keV}} = -0.96$. All these remained constant at all brightness levels. Only the UV–X-ray index showed a dependence on the UV brightness in such a way that two distinct values appear, $\alpha_{\text{UV-X}} = -1.38 \pm 0.04$ for $F_{1400} > 2.0 \times 10^{-13}\,\text{ergs s}^{-1}\,\text{cm}^{-2}\,\text{Å}^{-1}$ and $\alpha_{\text{UV-X}} = -1.15 \pm 0.03$ for $F_{1400} < 1.0 \times 10^{-13}\,\text{ergs s}^{-1}\,\text{cm}^{-2}\,\text{Å}^{-1}$. A single simultaneous observation with *GINGA*, *ROSAT*, *IUE*, and optical telescopes shows that the cutoff energy of this power-law spectrum must be located around 3.5 Ryd, contrary to the ~ 0.7 Ryd suggested by Clavel & Santos-Lleó (1990) and Binette et al. (1989).

3. Emission-Line Variations

For reference with previous data, we have also measured the total line intensity. We found, as is quite commonly seen in AGN that most high-excitation lines respond strongly to variations in the continuum emission, while the lower-ionization lines, such as Mg II and the Fe II blends, show only a weak correlation with the continuum at low brightness levels. The Balmer continuum, on the other hand shows a very tight correlation with the ionizing continuum level, but shows a flattening when the continuum level exceeds $F_{1400} \approx 1.6 \times 10^{-13}$ ergs $\text{s}^{-1}\,\text{cm}^{-2}\,\text{Å}^{-1}$, very similar to the Wamsteker–Colina effect shown by C IV in F9 (Shields, Ferland, & Peterson 1995).

3.1. Line Decomposition

After line decomposition into three Gaussian components, respectively representing the *blue*, *central* and *red* sides of the BLR (for relative velocities with respect to the narrow-line, see Table 1), all strong lines (Lyα, N V λ1240, Si IV λ1397, C IV, He II, and C III]) were measured in these three components. The response of the line components to the continuum variations was determined by cross-correlation (CC) analysis. The component line intensities were measured and their relative intensities evaluated at all brightness levels of the continuum of F9 as described in §2. CLOUDY (Ferland 1991) was used to derive the BLR model conditions which gave line ratios consistent with those observed under an input central ionizing radiation field with spectral characteristics at three distinct brightness levels given by the observed SED of F9. From these results, the relations between the BLR and the central source of continuum radiation were determined and are given in Table 1. The results in Table 1 give self-consistent solutions at all brightness levels.

Table 1. Velocity-Resolved Characteristics of the BLR

BLR Characteristic	$-3500\,\mathrm{km\,s^{-1}}$ *blue*	Velocity $0\,\mathrm{km\,s^{-1}}$ *central*	$+3500\,\mathrm{km\,s^{-1}}$ *red*
Mean line delay	230 ± 95 days	400 ± 100 days	-4 ± 70 days
Photoionization size (lt. days)	50–250	50–250	50–250
N_{column}	$10^{23-26}\,\mathrm{cm^{-2}}$	$10^{24-26}\,\mathrm{cm^{-2}}$	$10^{24-26}\,\mathrm{cm^{-2}}$
Density n	$10^{11-10}\,\mathrm{cm^{-3}}$	$10^{12-10}\,\mathrm{cm^{-3}}$	$10^{11-10}\,\mathrm{cm^{-3}}$
Covering factor	5–2%	12–3%	6–3%
Ionization Parameter U	0.089–0.014	0.003–0.039	0.009–0.039

4. Conclusion: Structure of the BLR

Keeping in mind that the smallest regions of the BLR at $R < 50$ light days have not been resolved at the time resolution of our data (98 days), we find that the BLR of F9 can be described as follows: in agreement with the results of Koratkar & Gaskell (1991), we find general infalling motion to be present at velocities of some $3000\,\mathrm{km\,s^{-1}}$. The innermost part of the BLR is at a distance of ~ 80 light days from the central source, and the blue and red components correspond respectively to the far and near side with respect to the observer. The central component is located at a distance of ~ 200 light days and is adjacent, or even coexistent, with the location where dust is also present, as indicated by the observed delay between the NIR and UV continuum. No evidence is present indicating that the BLR fills the region inside this radius; rather, a shell-like structure is indicated. The radiation field should be strongly anisotropic to allow the distinct separation of the clearly identifiable components in the lines, although an anisotropic matter distribution around the central black hole cannot be excluded at this stage. The black-hole mass was found to be $M \approx 2 \times 10^8\,M_\odot$, as indicated by the turbulent velocity suggested by the width of the central component. With this central mass and the turbulent velocity of the blue and red component of $\sim 6000\,\mathrm{km\,s^{-1}}$, we find that these two regions are at a distance of some 80 light days from the center. This is only consistent with the CC result in Table 1 when the material associated with the blue part of the line is at the far side of the AGN and that emitting on the red side of the line between

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the nucleus and the observer. The velocity field resulting from this geometry requires an infall velocity of order 3500 km s^{-1}.

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