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SALT and VLT spectroscopy of the VHE flat-spectrum radio quasar PKS 0903–57

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The γ-ray blazar PKS 0903-57 had strong flaring episodes in high energy (HE; 100 MeV $\leq$ E $\leq$ 100 GeV) and very high-energy (VHE; 100 GeV $\leq$ E $\leq$ 10 TeV) gamma rays in 2020 through 2022. The presence of a nearby star has posed a challenge over the years to efforts aimed at characterizing the nature of the blazar. The star is located at a distance of 0.67" from PKS 0903-57, essentially resulting in somewhat an obscuration of the blazar from observers. During the flaring period, the optical counterpart of PKS 0903-57 underwent spectroscopic observations by the Southern African Large Telescope (SALT) and the Very Large Telescope (VLT). Photometric monitoring was also performed with the Rapid Eye Mount (REM) telescope. Using recent (2024) VLT observations taken with a narrower slit (0.5" wide) under subarcsecond seeing (~0.5") conditions enabled the isolation of the signatures of the blazar from those of the star. This resulted in a firm measurement of the blazar's redshift z = 0.2621 ± 0.0006, using five narrow emission lines detected in the spectra. Additionally, a symmetric broad Hα line with full width at half maximum of 4020 ± 30 km/s was also detected. The spectrum revealed a jet-dominated continuum, which led to classifying PKS 0903-57 as a flat-spectrum radio quasar. Moreover, a redshift offset (~1500 km/s) between the broad Hα line and its narrow line counterpart, was detected with high significance. When compared to findings in the literature of similar systems, the detection implies several possibilities, including an unusual accretion mechanism, a merging of two supermassive black holes, or an ejection of a merged black hole from the system.

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1. Introduction

Blazars are the most energetic objects in the Universe in High Energy (HE) and Very High Energy (VHE) regimes of the electromagnetic spectrum. They are a subclass of radio-loud AGNs, in which the plasma jet is pointed near the line-of-sight of an observer. Blazars are divided into BL Lac objects and flat spectrum radio quasars (FSRQs). The optical spectra of the former mostly show weak to no spectral features, whereas those of the latter are characterised by strong emission lines. The gamma-ray blazar PKS 0903-57 was discovered in a Parkes survey of radio sources between the declinations of -20° and 60° in the 1960s [1]. It was detected by the Large Area Telescope (LAT) onboard the *Fermi Gamma-ray Space Telescope (Fermi)* early on in its mission and was already part of the sources that appeared in the first catalogue 1FGL [2]. PKS 0903-57 was classified as a blazar candidate of uncertain type in the Roma-Bzcat catalogue by [3]. It has been detected by *Fermi*-LAT multiple times since then and appears in all subsequent catalogues. The presence of a nearby star, separated from PKS 0903-57 by 0.67", has made its spectral investigations somewhat difficult over the years, as the optical spectra have been dominated by the stellar features. Recently, [4] conducted observations of PKS 0903-57 using the VLT under subarcsecond seeing conditions in an attempt to characterise its optical spectral properties, including redshift determination. A summary of the published results of such observations, their implications, and prior work, are what we present in this PoS paper. The paper also includes a figure from [5], describing the 2022 VLT observations.

2. Observations and results

Spectroscopic observations of PKS0903-57 were conducted in 2020 using the Robert Stobie Spectrograph (RSS, [6]) on SALT, following the detection of a γ-ray bright flare [7]. In 2022 and 2024, the observations were repeated using the Focal Reducer and Imager (FORS2, [8]) spectrograph on the VLT. Figure 1 shows the slit positions for the SALT/RSS (blue) and VLT/FORS (green) observations, superimposed on an R-band image of the field. Upon analyses of the SALT observations, it was clear that the stellar flux was dominant over that of the blazar. The features observed in the spectra from both slit orientations were those consistent with an F or G type star, as Figure 2 shows. Taking lessons from the SALT results, the configuration for the 2022 VLT/FORS observations were altered by employing a 0.7" slit, including a request for subarcsecond seeing conditions. The observations were divided into three blocks for each position angle (PA), with an exposure time of 890 seconds for each block. The resultant spectra still revealed flux dominance of the star over that of the blazar. However, a weak emission feature at ~6318 Å was detected in the spectra taken with PA = 108°, as Figure 3 shows. The emission feature could be interpreted as that of [OII] or [III] lines, which would correspond to $z \sim 0.675$ (the value by [9]) or $z \sim 0.262$, respectively. Further, the emission feature was the weakest in the red spectrum of Figure 3, which had the worst seeing value of the three spectra. This hinted that a clear detection of this emission feature could be achievable with improved seeing conditions. This prompted us to ask for more VLT/FORS observations with PA = 108° but using a narrower slit (0.5") and under exceptional seeing conditions. An increase in wavelength coverage up to 9000 Å was also proposed to search for other features. The proposal was accepted and FORS2 observations of PKS 0903-57 with the above

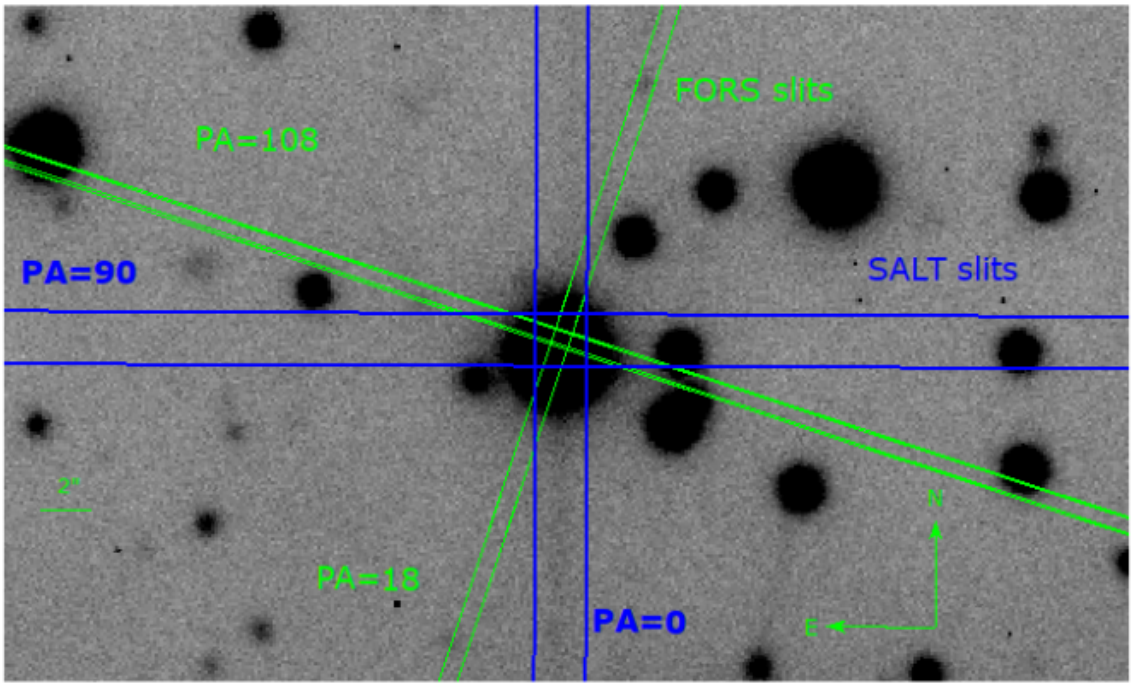

Figure 1: Positions of the slits on PKS 0903-57 and the star (centre) with PAs, for the 2020 SALT/RSS (blue) and 2022, 2024 VLT/FORS (green) observations. Figure from [4].

configuration were conducted during January of 2024. The resultant spectra are shown in Figures 4 and 5. The spectra in Figure 4 clearly show absorption (dashed magenta lines) and emission (solid black lines) features due to the star and the blazar, respectively. The weak narrow emission feature in the 2022 observations has higher signal-to-noise in these spectra and was identified as [OIII]b, placing the redshift at $z \sim 0.262$. The rest of the narrow emission features due to the blazar were identified as the [NII] doublet and Hα, all consistent with $z \sim 0.262$. Also detected was the broad Hα line (see Figure 5). The systemic redshift was then estimated using positions of the narrow lines. After taking the wavelength solution uncertainties into account, a redshift $z = 0.2621 \pm 0.0006$ was derived for PKS 0903-57. This value is different from that determined by [9], which, prior to the work of [4], was taken to be the redshift of PKS 0903-57 in the literature.

3. Discussion, conclusions and future work

The large equivalent width value of the broad Hα line EW = 7.94 ± 0.17 Å, coupled with its measured luminosity $L_{5100} \sim 4.7 \times 10^{45}$ ergs/s points to PKS 0903-57 being an FSRQ instead of a BL Lac [4]. The centroid of the broad Hα line has an offset of 1460 ± 30 km/s towards the red, which, as far as we know, is the first time it is seen in a blazar in the optical regime. And given the symmetric nature of the broad feature, a comparison of similar scenarios in the literature implies an accretion configuration for PKS 0903-57 possibly defined by three options: (i) tidal-disruption of infalling clumps of gas clouds from the dusty torus, (ii) merging of two supermassive black holes, or (iii) a recoiling black hole merger (see [4] for an indepth discussion). The VLT/FORS observations of 2024 enabled, for the first time, a detailed spectral study of PKS 0903-57, which culminated in a

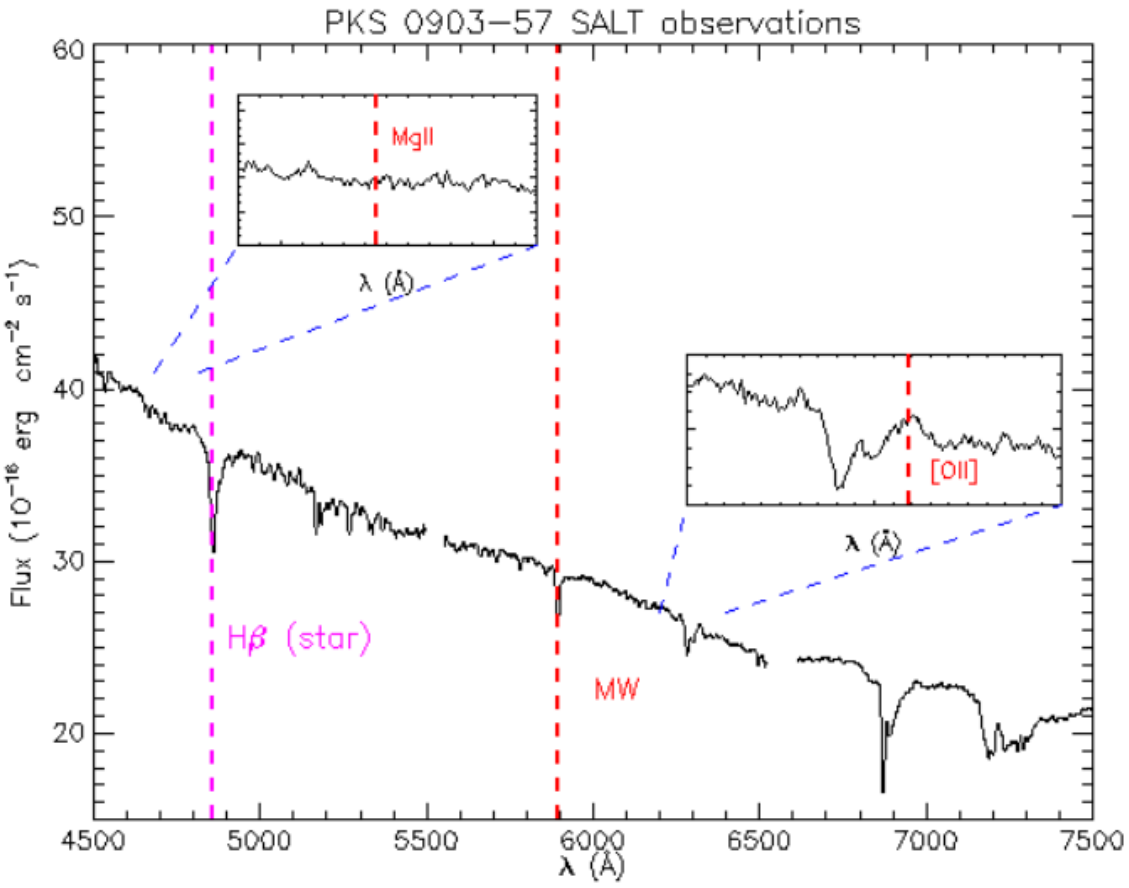

Figure 2: A spectrum of the 2020 SALT/RSS observations of PKS 0903-57, showing strong absorption features of the star and a prominent NaID Galactic absoprtion feature, labelled "MW". There is no detection of any features that could be linked to AGN activity. In addition, two insets showing a zoom in on the positions where spectral features detected by [9] should be reveal no definite features. Figure from [4].

firm spectroscopic redshift measurement and revealing exotic features such as the symmetric broad Hα line. This ended the long-time challenge posed by a 16th magnitude (G-band) star close to its location, which dominated the blazar flux contribution in the observed spectra. To further improve our understanding of this system, we require more spectroscopic observations to be conducted in very good seeing conditions. We wish to investigate the presence and properties of other emission lines, if present. All such investigations have the potential to provide useful constraints on the possibilities inferred by the detected symmetric broad Hα line.

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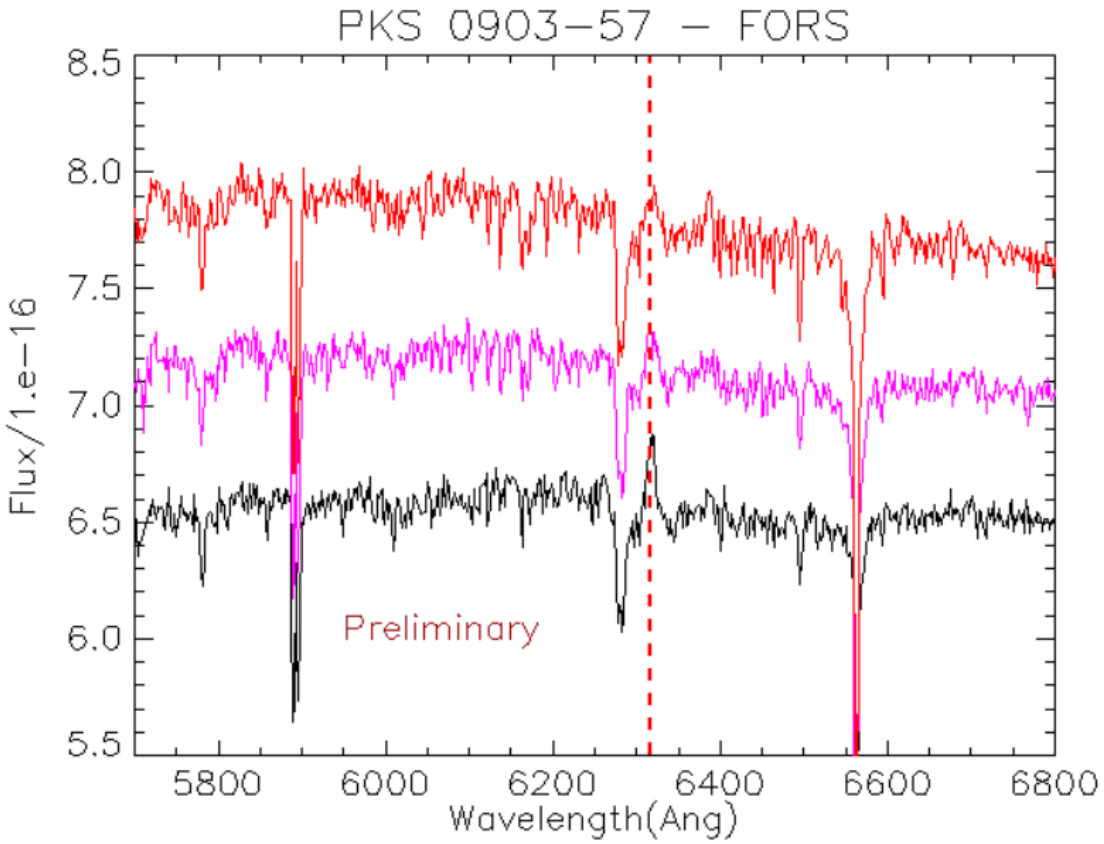

Figure 3: Three spectra of the 2022 VLT/FORS observations of PKS 0903-57, taken with PA = 108° with exposure time of 890 seconds apiece. The spectra still show dominance of the stellar flux, except for a weak emission feature at about 6318 Å, highlighted with the red dashed line. Figure from [5].

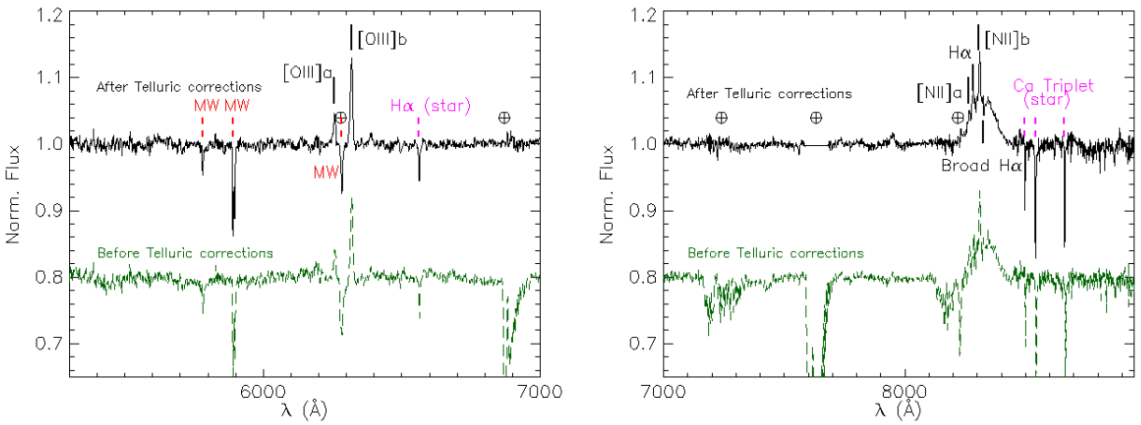

Figure 4: VLT/FORS spectra of PKS 0903-57 observed in 2024. *Left*: Normalized spectra in the range 5300-7000 Å before (green) and after (black) telluric corrections. *Right*: Same as *Left* but for the range 7000-8950 Å. In both panels, the stellar, Galactic, and telluric absorption features are marked with magenta dashed lines, red dashed lines and ⊕ symbols, respectively; whereas the AGN emission features are highlighted with solid black lines. Figure from [4].

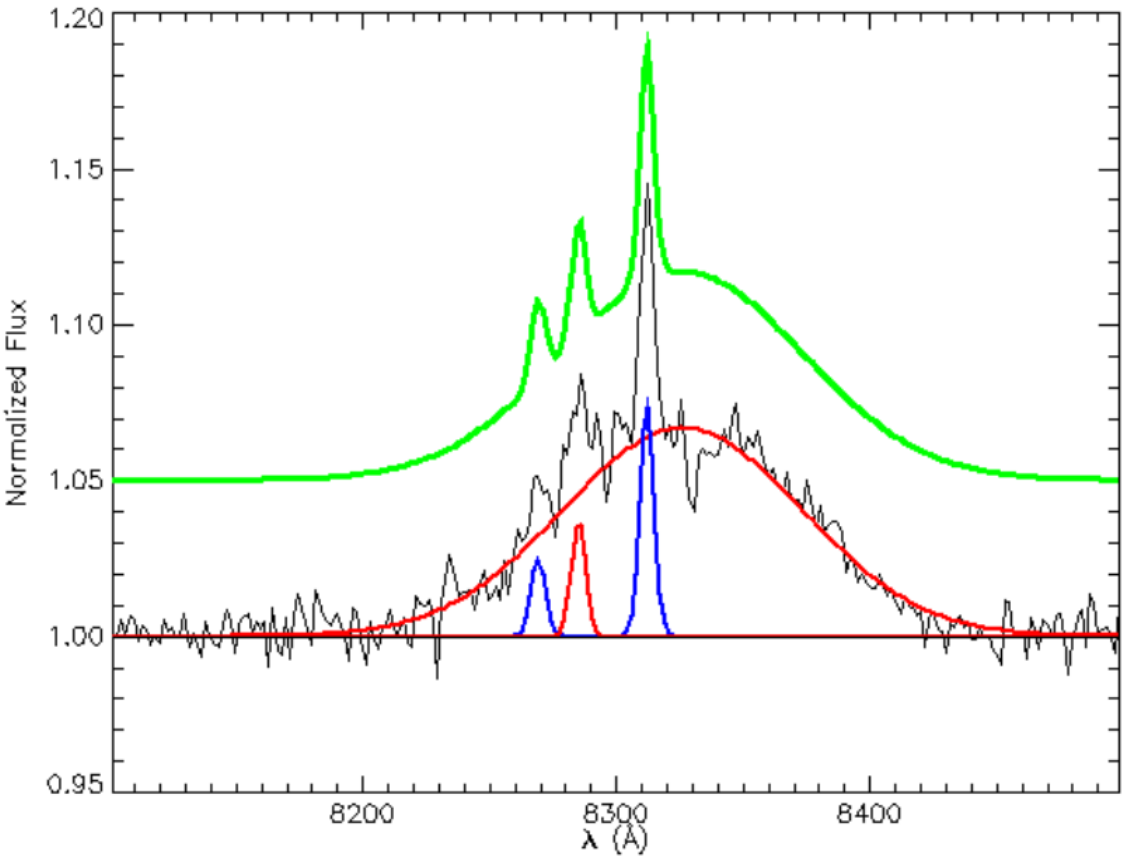

Figure 5: A zoom-in on the spectrum (7900-8700 Å) in the top of the right panel of Figure 4, showing the narrow [NII]a, [NII]b (blue) and Hα (red) lines, and broad Hα line (red). In green is the global fit to all four lines, rescaled upwards for illustration. Figure adapted from [4].

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