Studies of the high luminosity quasar, PDS 456

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Abstract

X-ray and multi-wavelength observations of the most luminous known local (z < 0.3) AGN, the recently discovered radio-quiet quasar PDS 456, are presented. The spectral energy distribution shows that PDS 456 has a bolometric luminosity of \(10^{47}\) erg/s, peaking in the UV. The X-ray spectrum obtained by ASCA and RXTE shows considerable complexity. The most striking feature observed is a deep, highly-ionised, iron K edge (8.7 keV, rest-frame), originating via reprocessing from highly ionised material, possibly the inner accretion disk. PDS 456 was found to be remarkably variable for its luminosity; in one flare the X-ray flux doubled in just \(\sim 15\) ksec. If confirmed this would be an unprecedented event in a high-luminosity source, with a light-crossing time corresponding to \(\sim 2R_s\). The implications are that either flaring occurs within the very central regions, or else that PDS 456 is a ‘super-Eddington’ or relativistically beamed system.

Key words: galaxies: active – quasars: individual: PDS 456 – X-rays: quasars

1 Introduction

PDS 456 is a bright, radio-quiet QSO (V=14) recently discovered by Torres et al. (1997), in a search for young stellar objects. It lies fairly close to the Galactic plane (\(\beta = 12\)) and is seen through an extinction of \(A_V = 1.5\). PDS 456 is at a similar redshift (\(z=0.184\)) to 3C 273, but has a higher bolometric luminosity (by a factor of \(\times 1.7\), Simpson et al. 1999). Overall, PDS 456 is
Fig. 1. (a) The radio to X-ray SED of PDS 456; the emission peaks in the blue/UV part of the spectrum. It is seen that the bolometric luminosity of PDS 456 approaches $10^{47}$ erg s$^{-1}$. (b) The optical spectrum of PDS 456.

the most luminous object in the local ($z < 0.3$) Universe (with $M_V = -27$, $L_{BOL} \sim 10^{47}$ erg s$^{-1}$).

2 Multi-Wavelength Properties of PDS 456

We have conducted an extensive campaign to observe PDS 456 from the radio through to the hard X-ray band. The spectral energy distribution (SED) is shown in Figure 1a and the optical spectrum in Figure 1b. PDS 456 shows strong H I emission lines, and like many NLS1s has strong optical Fe II emission but weak O III. Although by definition a broad-line quasar, PDS 456 has only a moderate width in H$\beta$ (FWHM = 3000 km s$^{-1}$). VLA observations confirm that, unlike 3C 273, PDS 456 is radio-quiet ($R_L = 0.7$) and has little extended radio emission. Overall the SED is dominated by the optical/UV ‘big blue bump’. The bolometric luminosity of PDS 456 is of the order $10^{47}$ erg s$^{-1}$ (assuming $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.5$).

3 X-ray Observations of PDS 456

3.1 The X-ray Spectrum

As part of our campaign, we observed PDS 456 with ASCA on 7-8 March 1998 and with RXTE on 7-10 March 1998. The hard X-ray spectrum of PDS 456 obtained by both ASCA and RXTE shows complex features (see Reeves et al. 2000 for details). The data/model residuals from a power-law fit ($\Gamma = 2.4$) to the RXTE data are shown in Figure 2a. Unsurprisingly a power-law gave an inadequate fit to the data in this band. We find that an unusually deep and ionised Fe K edge is observed, with best-fit parameters of $E = 8.7 \pm 0.2$ keV and
Fig. 2. (a) The data/model ratio residuals from a simple \((\Gamma = 2.4)\) power-law fit to the RXTE data of PDS 456. The effect of the deep, ionised iron K edge is clearly seen in the residuals. (b) The 2-10 keV RXTE lightcurve of PDS 456. The source appears to flare by a factor of 2.1 in 17 ksec, corresponding to a light-crossing size of \(\sim 2R_S\) under the assumptions of isotropy inherent in the Eddington equation.

\[ \tau = 0.75 \pm 0.15. \] The edge is detected in both the ASCA and RXTE data to \(>99.99\%\) confidence. There is also some evidence in the X-ray spectrum for a broadened \((\sigma \sim 1\text{ keV})\) line at \(6\text{ keV};\) this line may originate from the inner disk, as hypothesised in Seyfert 1s (Tanaka \textit{et al.} 1995). A ‘warm’ absorber of lower ionisation may also be present at soft X-ray energies, whose properties are also similar to those observed in Seyfert 1s (e.g. Reynolds 1997).

A model consisting of reflection off a highly ionised accretion disk provides the best-fit to the hard X-ray spectrum; with disk solid angle, \(R = \Omega/2\pi = 1.0\), ionisation parameter, \(\xi = 6000\text{ erg cm s}^{-1}\) and \(T_{\text{disk}} = 10^6\text{ K}.\) The high-ionisation of the disk reflection component can reproduce both the depth of the edge and its energy at \(8.7\text{ keV}.\) Such high-ionisation reflection features are predicted in disk photoionisation models (e.g. Ross, Fabian & Young 1999, Nayakshin \textit{et al.} 1999), particularly at high accretion rates when the primary X-ray emission is steep. Therefore the high ionisation of the reflector could imply a high accretion rate in PDS 456 (relative to the Eddington limit), particularly as \(\xi \propto \dot{m}^3\) for a photoionised accretion disk. This interpretation is consistent with the other X-ray properties of PDS 456, namely a steep underlying X-ray continuum and rapid X-ray variability, both of which are commonplace in NLS1s (Boller \textit{et al.} 1996). NLS1s are also thought to be accreting near the Eddington limit (e.g. Pounds \textit{et al.} 1995); indeed recent evidence has been found in one NLS1 (Ark 564) for a spectrum consistent with ionised disk reflection (Vaughan \textit{et al.} 1999).
3.2 X-ray Variability

Both the ASCA and RXTE data were examined to search for X-ray variability. A strong hard X-ray flare is observed in the RXTE observation (figure 2b), well above any residual fluctuations in the detector background; the doubling time for the flare was \( \sim 15 \) ksec. (Note that, unfortunately, the shorter ASCA observation had ended by the time of the flare.) We also calculated that the probability of finding another contaminating source of comparable brightness in the RXTE beam was low (< 2\%), although not totally excluded. Additionally there is no other X-ray source detected in the RASS (ROSAT All Sky Survey) to within a degree of PDS 456.

Therefore, if confirmed, this would be unprecedented behaviour in such a high-luminosity source. This suggests, from simple light-crossing arguments, a maximum size of \( l = 4.5 \times 10^{12} \) m for the varying region. For a black hole of mass \( 10^9 M_\odot \) (corresponding to PDS 456, with \( L_{\text{BOL}} = 10^{47} \text{ erg s}^{-1} \), at the Eddington limit), this implies that the X-ray flare occurs within a region of less than 2 Schwarzschild radii (2\( R_S \)). A smaller mass black hole would loosen this requirement somewhat, but would then imply a super-Eddington accretion rate. Therefore one possible implication of the rapid variability is accretion near to or greater than \( L_{\text{Edd}} \). The variability also implies a (non-beamed) efficiency of converting matter to energy of \( \sim 5\% \), close to the limit for a Schwarzschild black hole (see Fabian 1979).

4 Conclusions

In conclusion, PDS 456 is a remarkable object, showing clear features of a high ionisation reprocessor, one possible interpretation of which is through reflection off a highly ionised accretion disk. Overall the high ionisation spectral features, steep X-ray emission and the extreme rapid variability suggest that the super-massive black hole in PDS 456 could be running at an unusually high accretion rate.

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