Quasars are rapidly accreting supermassive black holes at the centres of massive galaxies. They display a broad range of properties across all wavelengths, reflecting the diversity in the physical conditions of the regions close to the central engine. These properties, however, are not random, but form well-defined trends. The dominant trend is known as 'Eigenvector 1', in which many properties correlate with the strength of optical iron and [O III] emission\(^1\).\(^2\)\(^3\). The main physical driver of Eigenvector 1 has long been suspected\(^4\) to be the quasar luminosity normalized by the mass of the hole (the 'Eddington ratio'), which is an important parameter of the black hole accretion process. But a definitive proof has been missing. Here we report an analysis of archival data that reveals that the Eddington ratio indeed drives Eigenvector 1. We also find that orientation plays a significant role in determining the observed kinematics of the gas in the broad-line region, implying a flattened, disk-like geometry for the fast-moving clouds close to the black hole. Our results show that most of the diversity of quasar phenomenology can be unified using two simple quantities: Eddington ratio and orientation.

The optical and ultraviolet spectra of quasars show emission lines with a wide variety of strengths (equivalent widths) and velocity widths. However, despite their great diversity in outward appearance, quasars possess surprising regularity in their physical properties. A seminal principal-component analysis\(^1\) of 87 low-redshift broad-line quasars discovered that the main variance (Eigenvector 1, or EV1) in their optical properties arises from an anti-correlation between the strength of the narrow [O III] at 5,007 Å and broad Fe II emission. Along with other properties that also correlate with Fe II strength\(^2\)\(^3\)\(^5\), these observations establish EV1 as a physical sequence of broad-line quasar properties. In the two-dimensional plane of Fe II strength (measured by the ratio of Fe II equivalent width within 4,434–4,684 Å to broad Hβ equivalent width, \(R_{\text{Fe II}} = \frac{\text{EW}_{\text{Fe II}}}{\text{FWHM}_{H\beta}}\)) and the full-width at half-maximum of broad Hβ (FWHM\(_{H\beta}\)), EV1 is defined as the horizontal trend with \(R_{\text{Fe II}}\) where the average [O III] strength and FWHM\(_{H\beta}\) decrease\(^1\)\(^2\). Figure 1 shows the EV1 sequence for about 20,000 broad-line quasars drawn from the Sloan Digital Sky Survey (SDSS)\(^6\)\(^7\) (see Supplementary Information for details of the sample).

The statistics of the SDSS quasar sample allows us to divide the sample into bins of \(R_{\text{Fe II}}\) and FWHM\(_{H\beta}\) (the grey grid in Fig. 1) and study the average [O III] properties in each bin. Figure 2 shows the average [O III] line profiles in each bin, as a function of the quasar continuum luminosity \(L\) measured at 5,100 Å. In addition to the EV1 sequence, the [O III] strength also decreases with \(L_{5,100}\), following the Baldwin effect\(^8\)\(^9\) initially discovered for the broad C IV line\(^8\). The [O III] profile can be decomposed into a core component, centred consistently at the systemic redshift, and a blueshifted wing component. The core component strongly follows the EV1 and Baldwin trends, while the wing component only shows a mild decrement with \(L\) and \(R_{\text{Fe II}}\) (Supplementary Information and Extended Data Figs 1–2). This may suggest that the core component is mostly powered by photoionization from the quasar, while the wing component is excited by other mechanisms, such as shocks associated with outflows\(^4\).

In addition to the strongest narrow [O III] lines, all other optical narrow forbidden lines (such as [Ne v], [Ne iii], [O ii] and [S ii]) show similar EV1 trends and the Baldwin effect. Hot dust emission detected using WISE\(^3\), presumably coming from a dusty torus\(^2\)\(^3\)\(^9\), also increases with \(R_{\text{Fe II}}\). In the Supplementary Information (and Extended Data Figs 3–7) we summarize all updated and new observations that firmly establish the EV1 sequence.

The [O III]-emitting region is photoionized by the ionizing continuum from the accreting black hole. But the EV1 correlation of [O III] strength with \(R_{\text{Fe II}}\) holds even when optical luminosity is fixed, as demonstrated in Fig. 2. This suggests that another physical property of black hole accretion changes with \(R_{\text{Fe II}}\), one that, in turn, affects the relative contribution in the ionizing part of the quasar continuum as seen by the narrow-line region. The most likely possibility is the black hole mass \(M_{\text{BH}}\), or equivalently, the Eddington ratio \(L/M_{\text{BH}}\), given that \(L\) is fixed. The much less likely alternative would be that the [O III] narrow-line region changes as a function of \(R_{\text{Fe II}}\). Reverberation mapping studies of nearby active galactic nuclei (AGN)\(^3\)\(^5\) have suggested that a virial estimate of \(M_{\text{BH}}\) may be derived by combining the broad-line region size \(R_{BLR}\) (measured from...
The average FWHM$_{\text{H}\beta}$ does decrease by about 0.2 dex when $R_{\text{Fe} \text{II}}$ increases from 0 to 2, and this fact underlies the earlier suggestion that EV1 is driven by the Eddington ratio$^{4,16}$. A remarkable feature in Figs 1 and 2 is that the sequence is predominantly horizontal: there is little trend with FWHM$_{\text{H}\beta}$ at fixed $R_{\text{Fe} \text{II}}$. The standard virial mass estimators$^{15,17}$ would suggest that there is a strong vertical segregation in $M_{\text{BH},\text{virial}}$, by a factor of a few in the vertical bins in Fig. 1. If lower $M_{\text{BH},\text{virial}}$ (or higher Eddington ratio) leads to weaker [O III], as in the EV1 relation (that is, the horizontal trend), we should also see a vertical trend in Fig. 1. The absence of such a trend suggests that there is substantial scatter between FWHM$_{\text{H}\beta}$ and the actual virial velocity, and the vertical spread in FWHM$_{\text{H}\beta}$ in the EV1 plane largely does not track the spread in true black hole masses.

We propose, instead, that the sequence in $R_{\text{Fe} \text{II}}$ is driven by $M_{\text{BH},\text{virial}}$ but the dispersion in FWHM$_{\text{H}\beta}$ at fixed $R_{\text{Fe} \text{II}}$ is largely due to an orientation effect, as expected in a flattened broad-line region geometry. We first demonstrate that the average $M_{\text{BH},\text{virial}}$ indeed decreases with $R_{\text{Fe} \text{II}}$ for our quasar sample. We achieve this by measuring the clustering of SDSS quasars with low and high $R_{\text{Fe} \text{II}}$ values. In the hierarchical clustering Universe, more massive galaxies (which contain more massive black holes) form in rarer density peaks and are more strongly clustered$^{18}$. We therefore expect quasars with larger $R_{\text{Fe} \text{II}}$ to be less strongly clustered. This exercise, however, requires a very large sample size to achieve statistically significant results and has not been possible until now. Here we take advantage of the largest spectroscopic sample of galaxies from SDSS-III$^{19}$, and use the much larger (by a factor of about 40) galaxy sample to cross-correlate$^{20}$ with our quasar sample at redshift $z \sim 0.3$ to substantially improve the clustering measurements. The resulting cross-correlation functions are shown in Fig. 3a for the two quasar subsamples divided at the median $R_{\text{Fe} \text{II}}$. A significant clustering difference is detected at 3.48$\sigma$: quasars with larger $R_{\text{Fe} \text{II}}$ are indeed less strongly clustered, confirming that they have on average lower $M_{\text{BH},\text{virial}}$

In the EV1 plane (Fig. 1), the distribution in FWHM$_{\text{H}\beta}$ at fixed $R_{\text{Fe} \text{II}}$ is roughly log-normal, with mean value decreasing with $R_{\text{Fe} \text{II}}$ and a dispersion of about 0.2 dex (Extended Data Fig. 8). We argued above that this dispersion is largely due to orientation-induced FWHM variations in the case of a flattened broad-line region geometry. For a small subset of quasars that are radio-loud (around 10% of the population), it is possible to infer the orientation of the accretion disk, and by extension, the broad-line region, using resolved radio morphology to deduce the orientation of the jet. Such studies$^{21,22}$ show that high-inclination (more edge-on)
broad-line radio quasars have on average larger FWHM\textsubscript{BHp} in accordance with the orientation hypothesis. Below, we perform a different test for the more general radio-quiet quasar population, and we provide further evidence to support this argument in the Supplementary Information and Extended Data Figs 9 and 10.

We compile a sample of 29 low-redshift AGNs with literature broad-line region size measurements from reverberation mapping\textsuperscript{21}, host stellar velocity dispersion (\(\sigma\)) measurements\textsuperscript{23}, and optical spectroscopy\textsuperscript{24}. We use the well-established local \(M_{\mathrm{BH}}\)–\(\sigma\) relation\textsuperscript{25} to independently estimate black hole masses for the 29 AGNs. We supplement the 29 local AGNs with a sample of about 600 SDSS AGNs\textsuperscript{26}, where the host stellar velocity dispersion was estimated from the spectral decomposition of the SDSS spectrum into AGN and host galaxy components, and the broad-line region size \(R_{\mathrm{BLR}}\) was estimated using the tight correlation between \(R_{\mathrm{BLR}}\) and the AGN luminosity found in reverberation mapping studies\textsuperscript{27}. We can then define a virial coefficient, \(f \equiv GM_{\mathrm{BH}} / (R_{\mathrm{BLR}} \cdot \text{FWHM}_{\text{BHp}})\).

At a given \(M_{\mathrm{BH}}, f\) should not depend on FWHM\textsubscript{BHp}; if the latter is a faithful indicator of the broad-line region virial velocity. However, if FWHM\textsubscript{BHp} is orientation-dependent, as suggested above, \(f\) will be anti-correlated with FWHM\textsubscript{BHp}.

Indeed, there is a strong dependence of \(f\) on FWHM\textsubscript{BHp} at fixed \(M_{\mathrm{BH}}\), shown in Fig. 4, consistent with the orientation hypothesis. A direct consequence is that the standard virial black hole mass estimates using FWHM\textsubscript{BHp} are subject to a significant uncertainty (about 0.4 dex), owing to this orientation dependence. To test this, we perform the same cross-correlation analysis as above, but for quasar subsamples divided by their virial black hole mass estimates based on FWHM\textsubscript{BHp}. The results are shown in Fig. 3b: there is no significant detection (1.64\(\sigma\)) in the clustering difference between the two quasar subsamples. This is in accordance with there being substantial overlap in the true black hole masses between the two subsamples, owing to the uncertainty in virial black hole mass estimates induced by using FWHM\textsubscript{BHp}. The division by \(R_{\mathrm{BLR}}\) provides a cleaner separation of high-mass black holes from low-mass black holes in our sample.

The collective evidence from this work leads to a simple interpretation of the observed main sequence of quasars (Fig. 1): the average Eddington ratio increases from left to right, and the dispersion in FWHM\textsubscript{BHp} at fixed \(R_{\mathrm{BLR}}\) is largely an orientation effect. The many physical quasar properties correlated with EV1 are thus unified as being driven by changes in the average Eddington ratio of the black hole accretion. Although we do not discuss any physical model here, we suggest that the trends with the Eddington ratio are most probably caused by the systematic change in the shape of the accretion disk continuum and its interplay with the ambient emitting regions, which may in turn change the ionizing continuum (as seen by the emission-line regions) by modifying the structure of the accretion flow.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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**Supplementary Information** is available in the online version of the paper.

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**Author Information** Reprints and permissions information is available at www.nature.com/reprints. The authors declare no competing financial interests. Readers are welcome to comment on the online version of the paper. Correspondence and requests for materials should be addressed to Y.S. (yshen@obs.carnegiescience.edu).
Extended Data Figure 1 | Decomposed [O III] λ = 5,007 Å luminosity. The core component (a) and the wing component (b) are shown for each composite spectrum shown in Fig. 2. Error bars are 1σ measurement errors estimated using Monte Carlo trials of mock spectra generated using the estimated flux error arrays of the co-added spectra. Both luminosities are normalized to the quasar continuum luminosity $L_{5100}$, hence reflecting the strength of [O III]. The [O III] shows a prominent anti-correlation with both $L_{5100}$ and $R_{Fe}$. For both [O III] components there is no correlation with FWHM $H_{beta}$, as shown in Figs 1 and 2. The Baldwin effect and EV1 correlation for [O III] shown in Fig. 1 and Fig. 2 are then primarily associated with the core [O III] component. The difference between the core and wing [O III] components may suggest different excitation mechanisms for both components.
Extended Data Figure 2 | Kinematic properties of the decomposed core and wing [O III] components. a, FWHM against luminosity for core [O III]. b, FWHM against luminosity for wing [O III]. c, Velocity offset against luminosity for core [O III]. d, Velocity offset against luminosity for wing [O III]. Error bars are 1σ measurement errors estimated using Monte Carlo trials of mock spectra generated using the estimated flux error arrays of the co-added spectra. The most significant correlations are the correlation between luminosity and the core [O III] FWHM, and the correlations between the wing [O III] blueshift and L/R_{Fe II}. The former correlation is consistent with the scenario that more luminous quasars are on average hosted by more massive galaxies with deeper potential wells, hence having larger core [O III] widths. The latter correlations are consistent with the scenario that the wing [O III] component is associated with outflows.
Extended Data Figure 3 | Composite SDSS quasar spectra for several other lines in the same R_{core}-FWHM_{H_{\beta}} bins as defined in Fig. 1. a, H_{\beta} and [O iii]. b, Mg ii. c, [O ii] 3,727 Å. d, [Ne v] 3,426 Å. As in Fig. 2, each composite spectrum has been normalized by the continuum such that the integrated line intensity reflects the strength of the line. The composite spectra for the H_{\beta} region are generated using the pseudo-continuum-subtracted spectra, while for each of the other three lines (Mg ii, [O ii] and [Ne v]) the composite spectrum is the median spectrum created using the full SDSS spectra and normalized at a nearby continuum window.
Extended Data Figure 4 | Distribution in the EV1 plane in terms of C iv properties. A sample of low-redshift quasars with both H β and C iv measurements is shown, colour-coded by the C iv strength. A clear trend of decreasing C iv strength with $R_{\text{FeII}}$ is seen, consistent with that seen for the other forbidden lines. The typical 1σ measurement uncertainty in C iv equivalent width is about 7% (relative to the measurement), and hence is negligible compared to the strong EV1 trend observed.
Extended Data Figure 5 | Distributions of SDSS quasars in the EV1 plane in terms of the optical–infrared ($r - W1$) colour. $r$ is the SDSS $r$ band (6,166 Å) and $W1$ is the WISE $W1$ band (3.4 μm). a, $r - W1$ for quasars with $0.4 < z < 0.8$, for which the band-shifting effect is small. We see a trend of increasing mid-infrared emission relative to optical emission with increasing $R_{FeII}$. b, A similar result, using the excess colour, $\Delta(r - W1)$, which is the deviation of $r - W1$ colour from the mean colour at each redshift. Using $\Delta(r - W1)$ removes the redshift dependence of colours, and we can apply this to all quasars in our sample. This test suggests that the torus emission is enhanced in quasars with larger $R_{FeII}$. Given that we have argued that $R_{FeII}$ is a good indicator for the Eddington ratio, this result suggests that quasars with higher Eddington ratios have stronger torus emission, which may have implications for the formation mechanism of the dusty torus.
Extended Data Figure 6 | A detailed look at the median excess optical-WISE colour Δ(r−W1) in the EV1 plane. The same bins as defined in Fig. 1 are used. Error bars are the 1σ uncertainty in the median, estimated by the standard deviation divided by the square root of the number of objects in the bin. At fixed \( R_{FeII} \), we see increasing relative torus emission when FWHM_{3.4μm} increases. This is consistent with the orientation scenario: larger FWHMs indicate more edge-on systems, which suffer more from geometric reduction (the \( \cos I \) factor) and/or dust extinction in the optical than in the infrared parts of the spectrum.
Extended Data Figure 7 | Distribution in the EV1 plane in terms of X-ray properties. The subset of our SDSS quasars with available measurements of their soft X-ray photon index $\Gamma_X$ are shown. $\Gamma_X$ increases (becomes softer) with increasing $R_{Fe II}$, consistent with earlier findings\(^3\,^5\). CSC refers to objects from the Chandra Source Catalog and XMM refers to objects from the XMM-Newton Serendipitous Catalog. The contours are the distribution of all SDSS quasars in our sample, as in Fig. 1.
Extended Data Figure 8 | The same EV1 plane as in Fig. 1 in logarithmic FWHM Hβ. The dashed lines show the running median value as a function of \( R_{\text{FeII}} \) and the dotted lines show the 16% and 84% percentiles, for objects in different luminosity bins. The distribution of FWHM Hβ at fixed \( R_{\text{FeII}} \) roughly follows a log-normal distribution, with a dispersion of about 0.15–0.25 dex, which we argued comes mostly from orientation-induced variations.

Lower-luminosity objects tend to have slightly larger dispersion in FWHM Hβ, possibly caused by a broader Eddington ratio distribution at lower luminosities, which introduces additional dispersion in FWHM Hβ. 

\[ L_{\text{Ed}} = 1.3 \times 10^{38} (M_{\text{BH}}/1 M_\odot) \text{ erg s}^{-1} \] is the Eddington luminosity of the black hole.
Extended Data Figure 9 | Distributions of radio-loud and radio-quiet quasars in EV1 plane. The radio-loud population shifts to lower $R_{\text{Fe II}}$ and larger FWHM $H_p$, compared with the radio-quiet population. We further divide the radio-loud quasars into core-dominant and lobe-dominant subsets, but we caution that our morphological classification is very crude, and there is potentially a large mixture of true morphological types between the two subsamples. The core-dominant (more pole-on) radio quasars have systematically smaller FWHM $H_p$, compared with the lobe-dominant radio quasars, consistent with the hypothesis that orientation leads to variations in FWHM $H_p$. The points with error bars are the median and 1σ uncertainty for the median in each $R_{\text{Fe II}}$ bin.
Extended Data Figure 10 | Distribution in the EV1 plane colour-coded by the FWHM/σ ratio. The distribution has been smoothed over a box of ΔR_{FeII} = 0.2 and ΔlogFWHM_{Hβ} = 0.2. We show only points for which there are more than 50 objects in the smoothing box to average. The black open circles show the median FWHM_{Hβ} at fixed R_{FeII} (using all objects in that bin), with the error bars indicating the 1σ uncertainty for the median. The transition in FWHM/σ reflects the change in orientation of the broad-line region disk relative to the line of sight.