Section II

Multiwavelength Properties of AGNs and Their Hosts

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The Quasar Continuum

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Abstract. The powerful compact continuum emission from quasars is understood only in outline. New surveys allow investigation of the quasar continuum over a wide range of parameters (z, L, $L/L_{\rm Edd}$) and wavelengths (radio to X-ray). I review the spectral energy distributions of quasars and how new scaling relations with physical parameters promise to take us to a deeper understanding of the quasar continuum.

Keywords. accreion disks, galaxies: active, galaxies: jets, galaxies: nuclei, galaxies: quasars: general, infrared: galaxies, radio continuum: galaxies, ultraviolet: galaxies, X-ray: galaxies

1. Introduction

Quasars and galaxies are the two strong, persistent, sources of radiation in the distant Universe. While galaxies emit primarily starlight with a well-defined temperature, quasars emit a strongly non-stellar continuum spanning the radio to X-ray bands, with almost equal power per decade over the five decades from $100\,\mu$m to 10 keV (Figure 1, Elvis *et al.* 1994), a distinctly "non-thermal" (i.e. non-Planckian) shape.

This quasar continuum poses one of the basic problems of AGNs: "How can so much luminosity, $\sim 10^{12}\,L_\odot$ ($\sim 3 \times 10^{45}$ erg s^{-1}), as much as a good-size galaxy, emerge from such a small region, ~2 AU, comparable with the Solar System?" We have had the broad-brush answer for 40 years: accretion of matter onto a supermassive black hole (SMBH) can release ~10% of its rest mass in radiation (Lynden-Bell 1969), if that mass forms a thin accretion disk around the SMBH (Shakura & Sunyaev 1973). This theory is now well supported by the little-disputed detection of SMBH in AGNs (Peterson 2008) and in nearby quiescent galaxies (Ferrarese & Ford 2005). The simplest theory predicts a "sum of black bodies" disk spectrum which matches quite well the observed spectral energy distribution (SED) of quasars in the ultraviolet (UV) and optical decade (0.1–$1\,\mu$m) (Shields 1978; Malkan & Sargent 1982; Kishimoto *et al.* 2008). However, accretion disk theory has no power to predict the other four decades of the quasar SED.

Quasars seem to have similar SEDs over six decades of luminosity and 13 Gyr of cosmic time, during which the population evolves strongly. Why do the apparently fundamental variables of SMBH mass and accretion relative to the Eddington rate ($\lambda_{\rm E} = L/L_{\rm Edd}$), not to mention the cosmic epoch and the evolution and merger state of their host galaxies, seem to have so little effect on the quasar SED shape? Or are we wrong to believe that quasar SEDs are so uniform? Here I review the state of the art of quasar SED measurements† and the newly found scaling relations between the radio, optical/UV and hard and soft X-ray bands that show the quasar continuum is not invariant, and point toward an as yet unrealized, theory for the quasar SED shape.

† I omit all discussion of blazar continua which, over 20 decades of the spectrum, are totally dominated by two broad peaks due to the synchrotron and Compton emission of a relativistic jet (e.g., Ghisellini *et al.* 1998).

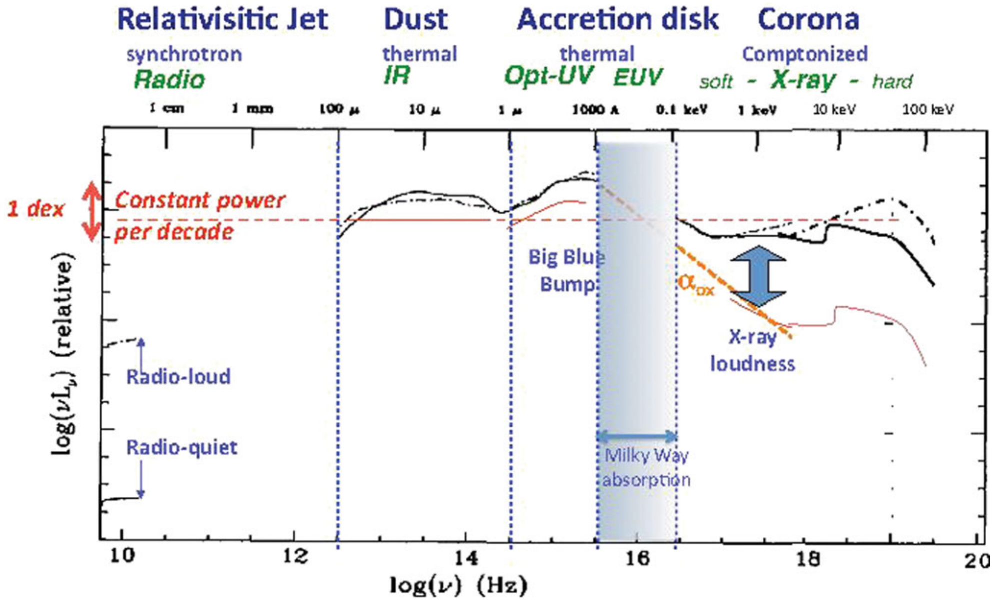

Figure 1. The mean radio to X-ray quasar spectral energy distribution (SED) from Elvis *et al.* 1994. Several features referred to in the text are noted. Units are erg s^{-1}Hz on the y-axis, Hz on the x-axis. Wavelengths in traditional units for each band are given along the top axis. The radio-quiet SED is the solid black line; the radio-loud SED is the dashed line. The title text is as follows: *top line* indicates the likely source of the radiation in each band; *middle line* gives the probable emission mechanism (light blue); the *bottom line* gives the name of each band.

2. How the Quasar Continuum Matters

The study of quasars has been *"All Changed, changed utterly"* (Yeats 1916) from a decade ago. Then we studied quasars for the physics puzzles they posed alone, with little contact with galaxy evolution or cosmology. Now quasars lie in the thick of galaxy evolution, and are seen less as objects in their own right, and more as one phase in the evolution of SMBH – the key phase during which they gain most of their mass and have most influence on their surroundings. The study of quasars has become the study of the growth and feeding of SMBH.

Two discoveries have caused this change of perspective: (1) *the* $M_{\rm BH}$–$M_{\rm host}$ *relation:* the mass of the SMBH is always ∼1/1000 of the mass of the bulge of the host galaxy in which it lies (Häring & Rix 2004); (2) *the Soltan argument:* (Sołtan 1982): the integrated emission of all quasars over all time requires the accretion of a total mass density (per Gpc^3) for a given efficiency. If this efficiency is ∼10%, as often assumed, then this SMBH mass density is consistent with the measured value from stellar dynamics in the cores of nearby galaxies (Yu & Tremaine 2002). So most SMBH growth happens while they are visible as luminous quasars.

The quasar continuum also powers, or is an indicator of the power available for, "AGN feedback;" i.e., the effect of the AGN on its host galaxy. AGN feedback is invoked to explain several features of galaxy evolution: the upper mass limit to galaxies and the existence of "red and dead" galaxies (Di Matteo *et al.* 2005; Somerville *et al.* 2008). Energetically this feedback poses no challenge: scaled to $10^8\,M_\odot$, a black hole releases $\sim 2\times10^{60}\eta_{0.1}(M_{\rm BH}/10^8\,M_\odot)$ ergs in its formation, while a 1000 times more massive galaxy has a binding energy of $\sim 10^{59}(v/300\,{\rm km\,s^{-1}})(M_{\rm BH}/10^{11}\,M_\odot)$ ergs, and its ISM

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much less. The physics that couples the available energy to the host galaxy ISM remains undetermined, however, and so may not be strong enough.

Superficially, there are physical mechanisms available to carry out this feedback. The quasar continuum supplies radiation pressure which directly drives winds in many, perhaps most (and possibly all) AGN by the three available mechanisms†: (1) Compton scattering, for quasars close to the Eddington limit (Reeves *et al.* 2009); (2) UV line driving (Murray *et al.* 1995; Elvis 2000); (3) dust opacity (Binette 1998). Indirectly, the quasar radio continuum indicates relativistic jet strength, which is clearly important to feedback in rich clusters of galaxies (McNamara & Nulsen 2007).

2.1. *Why There Should Be a Range of Quasar SEDs*

Current ideas of galaxy evolution and SMBH growth (e.g. Hopkins *et al.* 2008) stress the role of mergers in stimulating rapid star formation in "starburst" galaxies, rapidly followed by almost Eddington limited SMBH growth, which we see as quasars. Later SMBH growth is at lower $\lambda_{\rm E}$ and is, perhaps, fed by normal stellar mass loss (Norman & Scoville 1988), and is called the "radio" (Croton *et al.* 2006) or "Seyfert" phase or "mode." These two phases need not present the same SED, as accretion disks should behave differently both near (e.g. Abramowicz *et al.* 1988), and well below (Blandford & Begelman 1999; Esin *et al.* 1997) the Eddington limit. If so we would expect that the SED depends both on luminosity and on cosmic epoch, as mergers, starbursts and quasars were all far more common at $z \sim 1$–2 than in the present day Universe.

A two phase, or two accretion mode, picture of SMBH accretion would give meaning back to the, otherwise merely historical, distinction between "quasars" at high luminosity, and "Seyferts" or "AGNs" at lower luminosity. So it becomes important to ask "Is there a truly universal quasar SED, modified only by obscuration and host contamination?" (Ward *et al.* 1987) "Are there exceptions?" A new generation of quasar surveys is allowing us to find out.

3. The Canonical Quasar SED

Elvis *et al.* (1994; hereafter E94) presented a mean SED for radio-quiet and radio-loud quasars (Figure 1). These SEDs have been much used as a standard SED for all quasars‡. Are they correct?

The overall shape is well-supported: an optical/UV "Big Blue Bump" (BBB), very likely due to an accretion disk, dominates somewhat over the multi-temperature dust emission ($\sim$100 K – 1500 K) in the infrared (1–100 μm), and the X-rays ($\sim$0.5–10 keV), but overall the entire 10^{12}–10^{19} Hz continuum lies within a small range of power per decade. Instead the radio power is down by a factor 10^5, though in the $\sim$10% of objects that are "radio-loud" the drop is only a factor of $\sim$100. A well-defined inflection point occurs near 1 μm and is likely due to the Wien side of a Planck function at the hottest temperature attainable by dust without being destroyed (Barvainis 1987; Glikman *et al.* 2006).

However, this E94 SED was built on a rather limited data set: only 29 radio-quiet and 18 radio-loud quasars were included; all lay at $z < 0.3$, most at $z < 0.1$; all were chosen to have X-ray spectra from the first, small, true X-ray telescope, the *Einstein Observatory*, which biased the sample toward the most X-ray loud quasars, and to have UV spectra from the first, small, UV telescope, the *International Ultraviolet Explorer*, so that strong

† Here I have conveniently and unfairly neglected magnetically driven winds (Blandford & Payne 1982; Kartje & Königl 1996).

‡ E94 has over 900 citations as of August 2009.

BBBs were favored; lastly, most of the data had quite poor signal-to-noise ratio, and were highly non-simultaneous, so that variability is an issue. All of this should motivate us to go back to re-examine this canonical quasar SED.

3.1. *Next Generation Quasar SED Surveys*

Since E94 there have been some major updates to the quasar SED. Richards *et al.* 2006 used SDSS, *GALEX* and *ROSAT* data in *Spitzer* survey areas to obtain a less pro-X-ray, pro-UV biased quasar sample. Allowing for the scatter in the SED means that bolometric corrections, even when based on 5000 Å photometry, can be off by 50%. Vasudevan & Fabian (2008) eliminated variability from $\alpha_{\rm OX}$ measurements by using the simultaneous imaging of the XMM X-ray (EPIC) and UV (OM) instruments for 29 AGNs with reverberation mapping values for $M_{\rm BH}$. They found an $\lambda_{\rm E}$ dependence in $\alpha_{\rm OX}$, so that bolometric corrections depend on $\lambda_{\rm E}$. This result strengthens earlier claims by Kelly *et al.* (2008) and Shemmer *et al.* (2006). A different approach is taken by Assef *et al.* (2009). They use $\sim 10^4$ galaxies and AGNs from the Böotes field to derive both galaxy and quasar template shapes using a Bayesian approach. This produces a much stronger UV bump and deeper $1\,\mu$m inflection than Richards *et al.* (2006) or E94, which they attribute to having a self-consistent AGN-host-reddening fit.

The COSMOS survey (Scoville *et al.* 2007) contains several hundred spectoscopically confirmed AGNs from redshifts of 0.1 to over 3 (Trump *et al.* 2007; Brusa *et al.* 2010; Civano *et al.* 2010). Each of these quasars has some 40 high S/N photometry points populating the UV to mid-IR SED, plus radio and X-ray data. The optical/near-IR SEDs of a sample of 324 type 1 (broad emission line) AGNs (Elvis *et al.*, 2010) has been analyzed by Hao *et al.* (2010a). Host galaxy subtraction is difficult, even with *HST* imaging, at $z > 0.8$ (Jahnke *et al.* 2009), so a galaxy-quasar mixing curve approach (Grewing *et al.* 1968; Sandage 1971) was used. This method constructs lines on a color-color plane connecting a host galaxy template and a quasar SED template so that the degree of host "contamination" of the quasar SED can be estimated. The reddening vector lies in a different direction and so can be separately estimated. For the COSMOS type 1 AGNs, Hao *et al.* (2010a) defined rest-frame slopes either side of $1\,\mu$m inflection point, $\alpha(1\text{–}3\,\mu\text{m})$, $\alpha(0.3\text{–}1\,\mu\text{m})$, shown in Figure 2.

At low luminosities and Eddington ratios the COSMOS AGNs spread mainly along the line connecting the host templates with the E94 template, while at high luminosities and Eddington ratios they cluster tightly around the E94 point, with almost no UV spectra steeper than E94 (Figure 2, Hao *et al.* 2010a). As expected for these optically little-obscured AGNs, only a few show significant reddening away from the host–AGN mixing curve. Remarkably, a simple mix of host plus E94 SED works well over the entire range of redshift and luminosity sampled by COSMOS.

These color-color plots are also good at finding outliers (Hao *et al.*, 2010b). An interesting sub-group show a weak or no $1\,\mu$m inflection, and so presumably have little hot dust or "torus," and allow us to investigate the disk spectrum out to large radii (Hao *et al.* 2010b). Only a handful of AGNs reach the $\alpha(0.3\text{–}1\,\mu\text{m}) = 1.3$ slope expected from a simple Shakura & Sunyaev (1973) α-disk model. In polarized flux, which in some objects isolates the pure disk emission, Kishimoto *et al.* (2008) showed that an $\alpha(0.3\text{–}1\,\mu\text{m}) = 1.3$ slope is seen from ~ 0.6 to $\sim 2\,\mu$m, while the total light spectrum is flatter. Does this hint that another optical emission component is needed as in early BBB models (Malkan & Sargent 1982; see also Puchnarewicz *et al.* 1995).

Overall, the E94 SED seems to hold surprisingly well in this decade of the spectrum. Any BBB changes must lie in the UV, which is harder to study due to greater variability and contamination from strong emission lines (Hao *et al.* 2010c).

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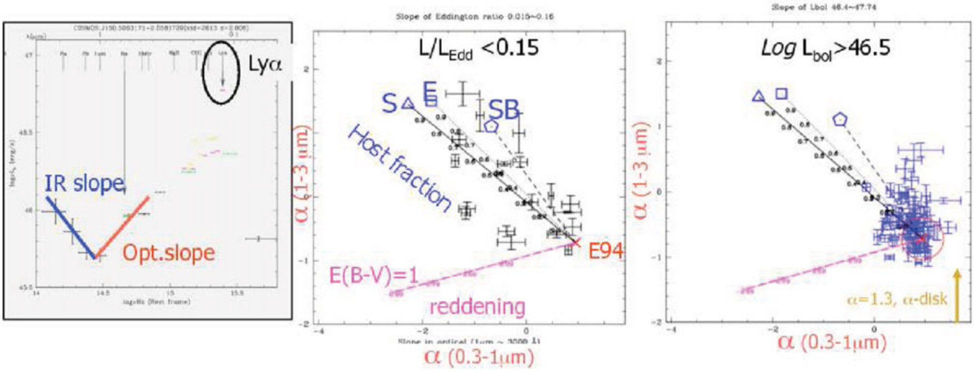

Figure 2. *Left:* The $\alpha(1\text{–}3\,\mu\text{m})$, $\alpha(0.3\text{–}1\,\mu\text{m})$ slopes define a galaxy–AGN mixing curve. *Center:* At low $\lambda_{\rm E}$ and low L COSMOS AGNs spread along this line. *Right:* At high L and $\lambda_{\rm E}$ the AGNs cluster around the E94 template location.

4. Highly Sub-Eddington SEDs

Below $\lambda_{\rm E} \sim 0.01$, accretion disks are expected have too low a density to support viscous transport, creating a geometrically thick, optically thin disk that is radiatively inefficient, although some accretion continues. The general case of accretion in this form is called "radiatively inefficient accretion flows" (RIAFs, Blandford & Begelman 1999).

Searches for RIAFs concentrate on low-luminosty AGNs (LLAGNs), in particular those in the Palomar sample (Ho 2009), and on nearby galaxies that have SMBH masses measured from stellar dynamics and show no obvious sign of nuclear activity (Pellegrini *et al.* 2003, Soria *et al.* 2006).

Ho (2008) has argued that LLAGNs with $L_{\rm X} < 10^{41}$ erg s^{-1} have weak or absent BBBs. However, Panessa *et al.* (2006) find that $L_{\rm X}$ and $L({\rm H}\alpha)$ are well correlated down to $L_{\rm X} \sim 10^{39}$ erg s^{-1}, and $\lambda_{\rm E} \sim 10^{-7}$. As H$\alpha$ is photoionized by the BBB, this correlation suggests that the AGN SED is unchanged down to these low values. This apparent contradiction is explained by the work of Maoz (2007), who used repeated UV imaging with *HST* and found quite strong nuclear variability. Maoz shows that host starlight contamination at 4000 Å is too strong to allow for reliable nuclear fluxes, i.e. the difference signal between the observations and the template is too small. Going to shorter wavelengths, even 3000 Å (below the 4000 Å break) but preferably deeper into the UV, increases the contrast sufficiently for the BBB to appear. With these new UV fluxes, the UV/X-ray ratio for the LLAGNs is comparable to that for normal AGNs. There is no clear sign of the onset of RIAFs down to remarkably low $\lambda_{\rm E}$.

The quiescent nuclei that have SMBH mass measurements and high resolution *Hubble* and *Chandra* imaging with implied $\lambda_{\rm E} \sim 10^{-6}$ also typically allow normal UV/X-ray ratios (Pellegrini *et al.* 2003; Fabbiano *et al.* 2004; Soria *et al.* 2006). They raise a new problem: fuelling from normal stellar mass loss within the Bondi capture radius should fuel them at higher $\lambda_{\rm E}$ than observed. The energy released must go into outflows of some sort. IC 1459, with $\lambda_{\rm E} \sim 3\times10^{-7}$, is an unusual "quiescent" nucleus, as it does show activity, but only in the radio band (Fabbiano *et al.* 2003). This suggests a jet model and a Falcke–Markoff model (Markoff *et al.* 2001) fits the radio and *Chandra* spectra well. The jet luminosity is ~10% of the Bondi luminosity. Perhaps there are also "dark jets," i.e., less efficient radio radiators, in the other quiescent nuclei (Soria *et al.* 2003b)? RIAFs inevitably imply outflows (Blandford & Begelman 1999). Perhaps IC 1459 is an example of this outflow in action.

5. Scaling Relations Among the Radio, Optical, and X-Ray Bands

The three bands in which we see the direct emission from the quasar nucleus, unmediated by the absorption and re-emission that power the emission lines or the IR dust emission, are (1) the optical/UV accretion disk emission, (2) the radio relativistic jet emission, and (3) the X-rays, which are likely Compton-scattered disk emission. The X-rays are re-processed in this model, but at a location so close to the accretion disk (often at a few Schwartzschild radii) that they should inform us about the basic structure of the emission region.

It is now clear that each of these three bands is connected to the others via *non-linear* scaling relations with luminosity and $\lambda_{\rm E}$. A number of these relations are new. Solving why these relations exist is likely to solve much of the physics of the quasar continuum.

5.1. *Optical–X-Ray*

For many years it has been known that optically more luminous quasars are relatively less luminous in X-rays (Tananbaum *et al.* 1979). This has been the only non-linear scaling known in the quasar continuum and current models of quasar X-ray emission in terms of a hot corona do not predict the $\alpha_{\rm OX}$ relation (Sobolewska *et al.* 2004, and references therein). Hence the $\alpha_{\rm OX}$ relation has rare potential diagnostic power, and has been expanded upon and tested in many papers (see, e.g., the 15 references in Young *et al.* 2009b).

This relation is usually defined in terms of $\alpha_{\rm OX}$, the notional slope between 2500 Å and 2 keV†. The relation has a shallow slope, $\alpha = -0.17$, and large scatter ($\sigma = 0.16\%$), which makes it hard to pin down. The primary goal of many papers on the $\alpha_{\rm OX}$ relation has been to distinguish a luminosity dependence from a redshift dependence, which are always hard to separate in surveys with a limited range of flux. Although there is some evidence for a redshift dependence (Bechtold *et al.* 2003; Kelly *et al.* 2007) most of the $\alpha_{\rm OX}$ variation seems to be due to a luminosity effect. $\lambda_{\rm E}$, which would seem to be a more fundamental physical variable, correlates weakly with $\alpha_{\rm OX}$ (Shemmer *et al.* 2008). As the relationship is continuous, a simple division into different black hole accretion states, as in X-ray binaries, is not plausible.

A drawback to all these studies is that they do not have X-ray spectra for large samples, and so rely on simple flux estimates. While X-ray spectra had been thought to be remarkably uniform, there is now a clear dependence of the X-ray slope Γ on X-ray luminosity, $L_{\rm X}$ (Page *et al.* 2005; Young *et al.* 2009a) – steeper at low $L_{\rm X}$. This dependence could well affect the $\alpha_{\rm OX}$–$L_{\rm opt}$ relation. The SDSS-XMM Quasar Survey (SXQS, Young *et al.* (2009a) with nearly 500 X-ray spectra, shows that the Γ–$L_{\rm X}$ relation is steeper at 10 keV than at the traditional 2 keV. There is also an apparently secondary trend for Γ to steepen as $\lambda_{\rm E}$ rises (Shemmer *et al.* 2008; Risaliti *et al.*, 2009). The cause of these relations is unknown at present. Are they a sign of a change within a single emission mechanism? Or do they indicate a changing ratio of components, as in X-ray binaries (Done *et al.* 2007)? Could Γ even be a useful measure of $\lambda_{\rm E}$ (Shemmer *et al.* 2008)? They may even affect X-ray background models.

In a new approach, the $\alpha_{\rm OX}$–$L_{\rm opt}$ relation has been investigated as a function of both optical wavelength and X-ray energy by Young *et al.* (2009b). They find that a factor 2 change within the BBB, from 2500 Å to 5000 Å, has little effect on the relation. In contrast, a factor 2 change in X-rays, from 2 keV to 4 keV, produces a significantly flatter slope, becoming almost linear, while changing a factor 2 the other way, to 1 keV, gives a clearly steeper slope. Moreover, the deviations from the $\alpha_{\rm OX}$(4 keV)–$L_{\rm opt}$ relation

† This power-law slope is defined as $\alpha_{\rm OX} = \log[f(2500\,\text{Å})/f(2\text{keV})]/\log[\nu(2500\,\text{Å})/\nu(2\,\text{keV})]$. Note that $\log[\nu(2500\,\text{Å})/\nu(2\,\text{keV})] = 2.604$ (Tananbaum *et al.* 1979).

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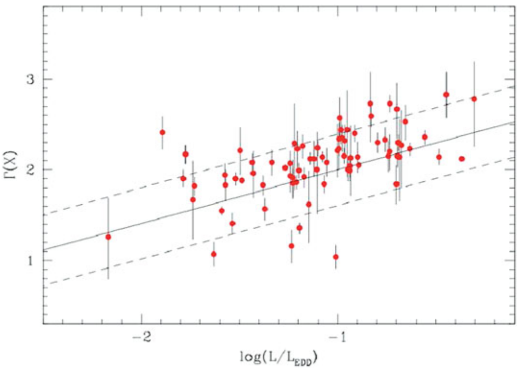

Figure 3. X-ray spectral slope Γ vs. Eddington ratio $\lambda_{\rm E}$ (Risaliti *et al.* 2009).

correlate with $\lambda_{\rm E}$. So while high energy X-rays seem to vary with the UV, albeit with large scatter, the soft X-rays scale up less with the UV luminosity. Are there two X-ray mechanisms at work? Or do these differences merely reflect a pivoting of the X-ray spectrum at a few keV? We do not yet know, but we now have much more to work with.

5.2. *X-Ray–Radio*

Radio-loud quasars have strongly correlated X-ray and core radio fluxes (Owen *et al.* 1981; Fabbiano *et al.* 1984), have flatter X-ray spectra ($\Gamma \sim 1.4$ vs. 2.0 for radio-quiet quasars, Wilkes & Elvis 1987) and are a factor ~ 3 more X-ray loud (i.e., have smaller $\alpha_{\rm OX}$) than radio-quiet quasars (Zamorani *et al.* 1981). These effects are generally explained as being due to a jet component overwhelming the normal quasar X-ray emission.

Radio-quiet AGNs and quasars, despite the name, still have radio emission, albeit weak (Ulvestad & Wilson 1984; Kellermann *et al.* 1989). Laor & Behar (2008) showed that for radio-quiet quasars radio and X-ray luminosities are linearly correlated with $L_{\rm radio}/L_{\rm X} \sim 10^{-5}$. The natural assumption might be that a residual jet component still dominates the X-ray emission, but Laor & Behar also point out that this $L_{\rm radio}/L_{\rm X}$ ratio is the same as ultra-luminous X-ray sources (ULXs) and, more surprisingly, M stars. Less coronally active stars, such as the Sun, have smaller $L_{\rm radio}/L_{\rm X}$ ratios. Does this point to a quasar accretion disk resembling the surface of an M star, covered in coronal loops?

A different conclusion was found by Panessa *et al.* (2005), who noted that though the $L_{\rm radio}/L_{\rm X}$) ratio of radio-loud and radio-quiet quasars differ by a factor ~ 1000, they are both constant with $L_{\rm X}$ over a wide range. Having the same linear correlation for both types of quasar suggests a common mechanism. If so, then this must be jet emission, as this clearly dominates radio-loud objects. But also, black hole spin cannot be essential to making jets, only strong jets.

5.3. *Radio–Optical*

The radio-to-optical flux ratio ("radio-loudness") is the original, striking, SED discriminator among quasars (Sandage 1965). The flux ratio $R_{\rm L} = \log(f_{\rm opt}/f_{\rm radio})$ is the usual definition of radio-loudness (Kellermann *et al.* 1989)† Radio-loudness measures the radiated jet power relative to the accretion disk power. A factor of $\sim$1000 separates the

† Here $f_{\rm opt}$ is usually defined at the B-band (4400 Å), and $f_{\rm radio}$ is usually defined as the 5 GHz core flux at VLA A-array resolution ($0.''4$ half-power diameter). Alternative definitions are needed for heavily obscured AGNs, where the optical flux is heavily suppressed. Appleton *et al.* (2004) introduced $q_{24} = \log(f_{24\mu{\rm m}}/f_{1.4\,{\rm GHz}})$ as an radio-loudness indicator for these type 2 AGNs (1.4 GHz is useful because wide area surveys, e.g., FIRST, COSMOS, typically use this frequency, and because this is $\sim$5 GHz in the rest frame at $z \sim 2$.)

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two types, and the distribution seems to be bi-modal (Kellermann *et al.* 1989), but only weakly (Ivezić *et al.* 2002). Strong jet emission might then be "switched on" in the ~10% of radio-loud quasars, by a merger spinning up a black hole, whose spin energy is then extracted by the Blandford–Znajek process to power a jet (Blandford & Znajek 1977; Wilson & Colbert 1995; Best *et al.* 2005).

LLAGNs are relatively radio-loud compared with higher luminosity radio-quiet AGNs (Ho & Peng 2001). This might be because at $\lambda_{\rm E}$ a RIAF outflow can be created that is more likely to form a relativistic jet (see §4).

This picture was refined by the claim by Sikora, Stawarz & Lasota (2007) that $R_{\rm L}$ forms two parallel families, both of which increase towards low $\lambda_{\rm E}$, such that by $\lambda_{\rm E} \sim 10^{-6}$ the "radio-quiet" family has the $R_{\rm L}$ of the "radio-loud" family at $\lambda_{\rm E} \sim 10^{-1}$. Maoz (2007) noted that the same two-family trend is present as a function of $L_{\rm opt}$, and that the LLAGNs fall on the extrapolation of the "radio-quiet" family, even though their $R_{\rm L}$ values are those of radio-loud, high-luminosity quasars. In this sense "radio mode" may be a good name for low $\lambda_{\rm E}$ accretion. As Sikora *et al.* point out, two families requires two mechanisms: one to give the continuous trend, and another to create the factor ~1000 separation of the families. Investigations with larger samples having a larger dynamic range of radio and optical fluxes would help sort out any potential selection effects. Meanwhile, these families provide food for thought.

6. Summary and Conclusions

We began by being surprised that quasar SEDs were so uniform. Now we have a large number of results showing that the quasar SED is not a simple linear luminosity scaling from the E94 template. That template still works remarkably well in the optical-near-IR decade (0.1–1 μm) over a wide range of luminosity, redshift, and Eddington ratio $\lambda_{\rm E}$, once host galaxy contamination is removed. So the accretion disk SED shape is largely invariant, even to values as low as $\lambda_{\rm E} \sim 10^{-6}$. Only in a few "quiescent" supermassive black holes does a switch to radiatively inefficient accrtion (RIAFs) sometimes occur.

However, the jet and "corona" parts of the continuum (radio and X-rays, respectively) vary considerably with luminosity and Eddington ratio, though there is little evidence of a redshift dependence. The hard X-ray continuum (~10 keV) scales almost linearly with the accretion disk, albeit with much scatter, but the soft X-ray continuum (~1 keV) scales up more slowly. An additional scaling with $\lambda_{\rm E}$, over and above the luminosity one, decreases the hard X-ray (4 keV) compared to the optical/UV (Young *et al.* 2009b). These changes are also reflected in the X-ray slope, Γ, which becomes steeper (or "softer") at high $\lambda_{\rm E}$. The radio/optical ratio $R_{\rm L}$ or "radio-loudness" of AGNs seems to vary continuously with both $\lambda_{\rm E}$ and $L_{\rm opt}$. Through all this, the X-ray (2 keV) to radio ratio is remarkably constant, and the same as that for ULXs and M stars.

This set of relationships can be used to refine the Sołtan argument and for X-ray background calculations. However, they do not yet have any physics behind them. Coronal models for quasars can now be usefully revisited (e.g., Haardt & Maraschi 1991). Out of these now confusing relations a consistent physical structure must emerge for these cosmic monsters that we call quasars. Perhaps then we can echo W.B. Yeats and say that "A terrible beauty is born."

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