RevMexAA (Serie de Conferencias), **23**, 77–80 (2005)

DUST AND THE ULTRAVIOLET ENERGY DISTRIBUTION OF QUASARS

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RESUMEN

La distribución de energía de los cuasáres presenta en el ultravioleta un quiebre abrupto a 1000 Å. Se describe como llegamos a considerar que el quiebre se debía a la absorción por granos de polvo constituidos de carbono cristalino.

ABSTRACT

The ultraviolet energy distribution of quasars shows a sharp steepening of the continuum shortward of 1000 Å (rest-frame). We describe how we came to consider the possibility that this continuum break might be the result of absorption by carbon crystallite dust grains.

Key Words: **GALAXIES: ACTIVE — GALAXIES: INTERGALACTIC MEDIUM — RADIATIVE TRANSFER — ULTRAVIOLET: GENERAL**

1. INTRODUCTION

The ultraviolet energy distribution of quasars is characterized by the so-called "big blue bump", which peaks in νF_ν at approximately 1000 Å. The quasar 'composite' spectral energy distribution (SED) of Telfer et al. (2002, hereafter TZ02) obtained by co-adding 332 HST-FOS archived spectra of 184 quasars between redshifts 0.33 and 3.6, exhibits a steepening of the continuum at $\sim$ 1100 Å. A fit of this composite SED using a broken powerlaw reveals that the powerlaw index changes from approximately -0.69 in the near-UV to -1.76 in the far-UV. We label this observed sharp steepening the 'far-UV break'. In these proceedings, we describe how we came to propose that absorption by crystalline carbon dust is the possible cause of the UV break observed in high redshift quasars. The argumentation behind this interpretation of the UV break has been presented in detail in Binette et al. (2005a, hereafter BM05). Further information can be found in recent proceedings such as in Binette et al. (2005b, c).

2. THE NEARBY AGN WITH FUSE

In an earlier paper, Binette et al. (2003) showed that H I scattering by a tenuous intergalactic component could *not* be the cause of the 1000 Å break. This negative result supported the prevailing view that the break is an intrinsic feature of quasar SED. More recently, Scott et al. (2004) derived a composite SED similar to TZ02 but for 'nearby' ($z_q < 0.7$) active galactic nuclei (AGN), using archived data from FUSE. The authors reported the lack of evidence of a steepening in nearby AGN! This new piece of information intrigued us. Although this absence of a continuum break could be explained away by supposing that the nearby AGN are less luminous and hence possess a lower mass blackhole and as a result a hotter accretion disk, we were not initially satisfied by this explanation. An additional reason for being skeptical is that some individual spectra from the TZ02 sample are extremely far-UV deficient, showing a much steeper break than that seen in the composite. Two examples are given in Fig. 1. Yet their emission-line spectrum is no different than that of other quasars. Photoionization is generally believed to be the excitation mechanism of the emission lines. Therefore, the above-mentioned UV deficiency poses a serious challenge to our understanding of what mechanism powers the emission lines.

The original suggestion of investigating dust absorption as a possible cause of the break came from one of us, C. Morisset (CM), who had experimented with photoionization models of planetary nebulae that included dust mixed with the ionized gas. CM's suggestion arose after looking at an interesting figure prepared by S. Haro-Corzo (SHC), in which three spectra appeared, showing a steep far-UV break. LB argued that ISM dust could not reproduce the sharpness of the 1000 Å break, as had already been shown by Shang et al. (2004). This initial suggestion nevertheless lead to a bibliographical search by LB of a new grain composition, which would have the property of producing a sharp break at 1000 Å.

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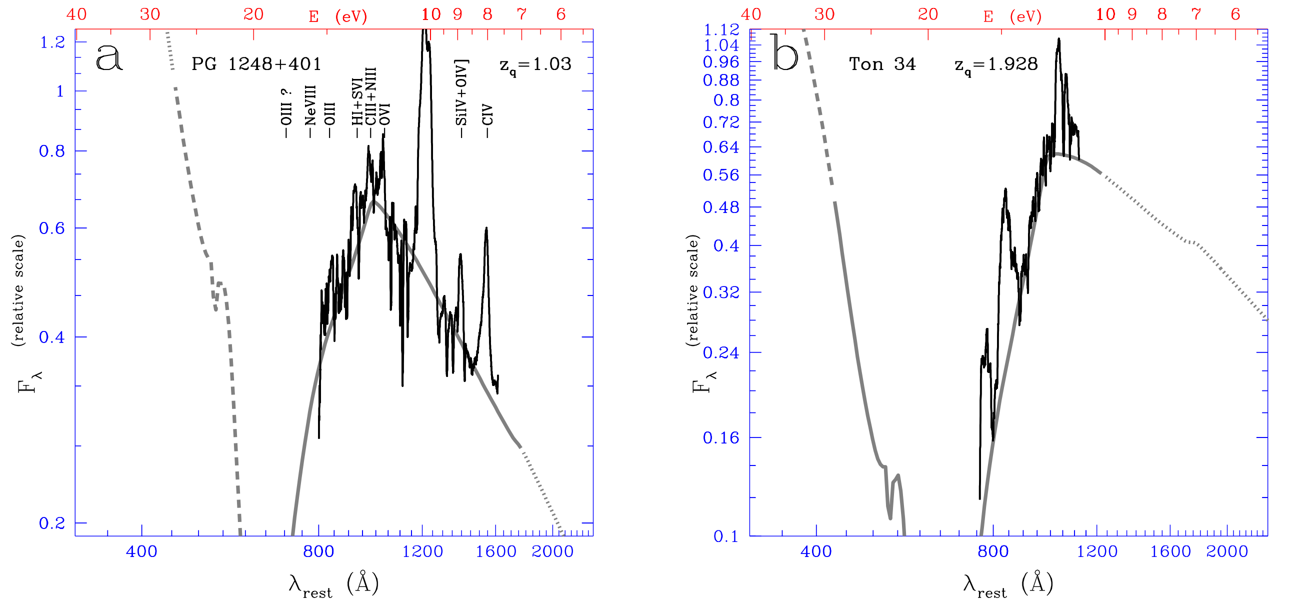

Fig. 1. Panel a: rest-frame spectrum of PG 1248+401 in black. The gray line represents a dust absorption model with $N_H = 3.2 \times 10^{20}\,\mathrm{cm}^{-2}$ using cubic diamond grains. Panel b: rest-frame spectrum of Ton 34 in black. The gray line represents a dust absorption model with $N_H = 5.0 \times 10^{20}\,\mathrm{cm}^{-2}$ using cubic diamond grains.

3. COMPARING RADIO-LOUD AND RADIO QUIET QUASARS

The first step has been to explore whether there might be evidence of reddening within the quasar sample that Telfer kindly lent to us in 2002. If dust was responsible for the break, we might for instance expect that the degree of steepening would scale with the amount of dust present. TZ02 had previously showed that the far-UV continuum was steeper in radio-loud (RL) than in radio-quiet (RQ) quasars. Within the paradigm of the dust being the cause of the break, this difference must be the result of differences in the amount of dust present. In other words, radio-loud quasars are possibly more absorbed[2] than radio-quiet quasars.

To verify this proposition, we over-plot in Fig. 2 the separate radio-quiet and radio-loud composite SEDs derived by TZ02. Each composite in this figure, however, has been multiplied by the appropriate normalization constant that made their flux equal to unity at 1350 Å. The radio-loud and radio-quiet composites in Fig. 2 are painted in black and gray, respectively. The black dot represents the renormalization wavelength. Within the narrow spectral segments that appear to be line-free between 2500 and 1200 Å, both continua overlap remarkably well. This suggests that the intrinsic SED longward of Lyα are very similar in both quasar subsets. The dotted line in panel *a* is a powerlaw fit to line-free segments, using the mean spectral index value of $\alpha_\nu = -0.69$ determined by TZ02 for the combined RL+QR sample.

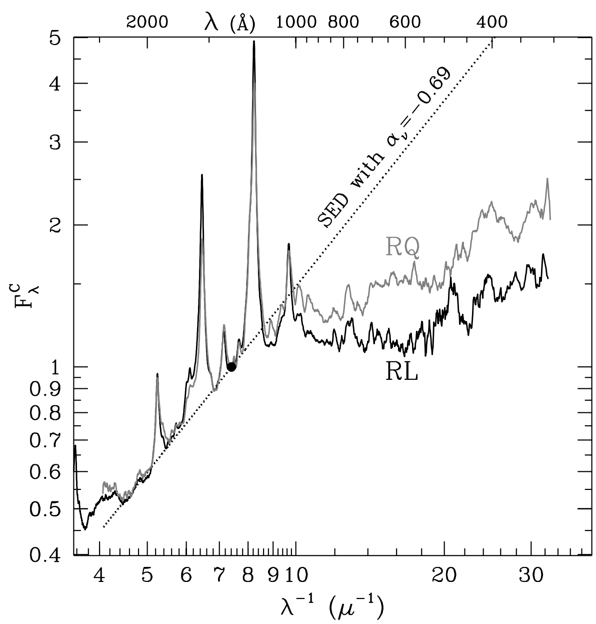

Fig. 2. The composite spectral energy distributions of Telfer et al. (2002) for radio-quiet (gray: RQ) and radio-loud (black: RL) quasars, respectively.

[2]This difference in absorption might be statistical in nature and arise from the particular RL and RQ subsamples at hand.

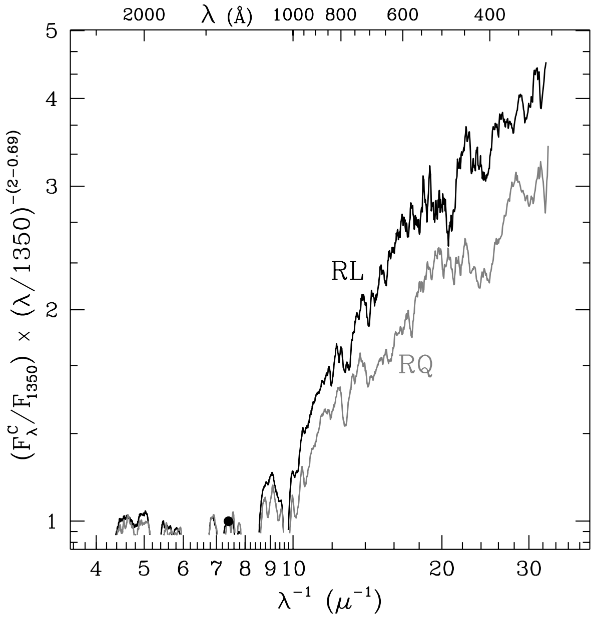

Fig. 3. The ratio of the fitted powerlaw with each composite SED: radio-quiet quasars (gray) and radio-loud quasars (black).

If we make the simplification that dust absorption is negligible below 1000 Å, we can take the ratio of the fitted powerlaw with either composite SED as a means of showing how the UV deficit increases with shorter wavelength. Such ratio-curves are plotted in Fig. 3. We can see that the UV deficit increases smoothly, starting at the break, near 1000 Å, down to about 550Å. The UV deficit increases faster in the case of radio-loud quasars than in radio-quiet quasars. Such a difference in the behavior of the ratio-curves is expected, if RL quasars are more absorbed than RQ quasars, and dust absorption is responsible for the UV deficit. The absorption would be characterized by an absorption cross-section that increases toward shorter wavelengths. At wavelengths shorter than 550 Å, some spectral features appear to be unique to each composite. The absorption test becomes therefore inconclusive in that region. This could be the result of having too few very high redshift quasars among the TZ02 sample, which result in a loss of reliability of the composite SEDs in that wavelength domain (see TZ02).

4. CARBON CRYSTALLITES

The UV deficit in RL and RQ quasars has been shown to behave qualitatively as expected, if dust absorption was responsible for the break. The next step consisted in searching the kind of material that might possess the optical properties required to produce a sharp absorption feature at the same position as the 1000 Å break. We looked for a dust constituent, whose absorption cross section peaked in the far-UV and yet causes negligible absorption at wavelengths longer than 1200 Å. Ideally, as it is the case with the interstellar medium (ISM) dust, the grain particles should be composed of the most abundant elements. Using ADS and Google, the most promising candidate appeared to be carbon in its crystal form, but with surface impurities. The so-called meteoritic nanodiamonds. The finding of the recently published work on nanodiamonds by Mutschke, Andersen and coworkers[3] (Mutschke et al. 2004) lead to a real breakthrough in the project, since Mutschke et al. (2004) had just measured the optical properties of nanodiamonds down to very short wavelengths. The grain size distribution could in principle be varied as needed, using the Mie theory to compute the extinction curve (Binette et al. 2005a, b). It turns out that it is unnecessary to assume a different grain size distribution than that which is found to characterize nanodiamonds embedded in primitive meteorites [Lewis et al. 1989] (provided the dust is intrinsic to quasars and not extragalactic, see BM05).

5. DUST GRAINS WITH AND WITHOUT SURFACE IMPURITIES

As matters stand, the crystalline form of carbon can exist either in the form of the well known terrestrial type of cubic diamonds or as the type found in primitive meteorites as in the Allende[4] meteorite, which was incidentally used by Mutschke et al. (2004) in their study of non-terrestrial nanodiamonds.

6. RESULTS

Using the complex refraction indices $n + ik$ from Mutschke et al (2004) for the Allende nanodiamonds, and Edwards & Philipp (1985) for the cubic diamonds, respectively, we proceeded to calculate the extinction curve corresponding to each of the two nanodiamond types. Assuming a simple intrinsic SED consisting of a powerlaw with the spectral index inferred from the observed near-UV region in each quasar, we proceeded to calculate the absorbed

[3]Both Harald Mutschke and Anja Andersen have since become collaborators of this project.

[4]This meteorite belongs to the category of carbonaceous chondrite meteorites. It is a relatively rare meteorite type, at a frequency of only $\sim 3.5\%$. The particular Allende meteorite which fell on Earth near the town of Allende in the state of Chihuahua, México, on February 8th, 1969, is one of the most studied meteorites of its kind.

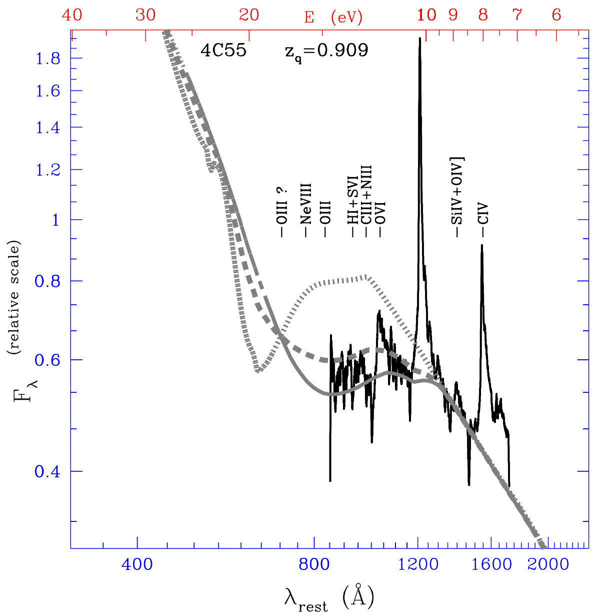

Fig. 4. The spectral energy distributions of 4C55. Gray continuous line: absorption model with $N_H = 1.1 \times 10^{20}$ cm^{-2} using nanodiamond grains from the Allende meteorite. Dashed line: absorption model (same column) using a grain mixture of 30% cubic diamonds and 70% Allende nanodiamonds. Dotted line: absorption model (same column) using cubic diamonds only.

powerlaw and compare it with the observed SED. We found that an acceptable fit could be obtained of the 1000 Å break in 80% of quasars. However, the dust absorbed powerlaw model requires in most cases that dust grains of the above two types be combined (the terrestrial cubic diamonds and the nanodiamonds of the type found in primitive meteorites). This result, as well as the computed extinction curves are shown in the proceedings of another meeting (Binette et al. 2005b). We will present here only a few spectra that can be fitted, using a *single* type of nanodiamonds.

As shown in Fig. 1, the cubic diamond extinction curve fits the abrupt breaks found in the quasars PG 1248+401 and Ton 34 very well. The Allende nanodiamonds, on the other hand fit better the break observed in 4C55 (continuous line), as shown in Fig. 4, where a comparison is also made with pure cubic diamonds (dotted line) or a combination of the two nanodiamond types (dashed line). The hydrogen columns quoted in the figure captions assume that all carbon is locked unto the dust, and that its abundance is solar. It corresponds to a dust-to-mass ratio of 0.003. The real dust-to-gas ratio cannot be constrained at this stage.

Instead of using optically known materials, one could have treated the absorption hypothesis as an inverse problem, working out the extinction curve that best succeeds. We consider, however, that it confers a higher degree of plausibility to have used an extinction curve based on a known material such as that of the Allende meteorite, rather than an invented cross-section. Finally, the vector that we propose to be responsible for the absorption consists of grains made of carbon atoms, a major constituent of the interstellar medium dust, albeit here in a less common form, that of crystals (nanodiamonds).

The authors acknowledge support from CONACyT grant 40096-F. We thank Randal Telfer for sharing the reduced HST FOS spectra. Diethild Starkmeth helped us with proof reading.

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