The Mid-Infrared Spectral Characteristics of Blazars

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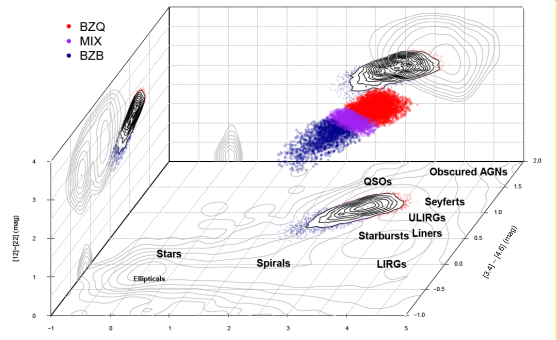


Figure 1: The WISE Color-Color Space of Blazars

BACKGROUND

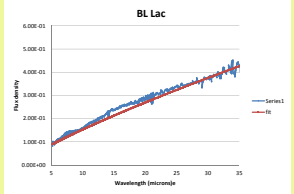
The Infrared Colors of Blazars: The Wide-Field Infrared Survey Explorer (WISE) was a NASA Medium Explorer mission launched in December 2009. Its all-sky survey had four broad-wavelength bands centered near 3.4, 4.6, 12, and 22 microns with an angular resolution of 6.1", 6.4", 6.5", & 12.0" respectively, and 5σ point source sensitivities better than 0.08, 0.11, 1 and 6 mJy in unconfused regions, respectively. In our initial paper on the first WISE release (Massaro *et al* 2011) , and then in our followup paper on the full sky release (Massaro *et al.* 2013) we report discovering that blazars have distinctive WISE colors. **Figure 1** shows the locus of points for blazars subdivided into categories of BZB, BZQ and mixed (from D'Abrusco *et al.* 2015).

Of particular note are **γ-ray blazars**, the locus of whose colors roughly overlaps with the QSO contours (see Fig. 1) but which is more tightly delimited and which extends beyond the edge opposite from (i.e., bluer than) ULIRGs and Seyferts. Since a large fraction of γ−ray sources are unassociated with any point source, but are expected to be blazars, identifying a WISE candidate blazar in the γ−ray source field enables efficient followup studies (see D'Abrusco *et al. 2012; Massaro et al. 2013a; Massaro et al. 2013b; Paggi et al. 2014; Massaro et al. 2014*). This method has proven to be fantastically successful. Our ground-based spectroscopic followups of WISE candidate blazars has so far confirmed in all cases the identification (e.g., Paggi *et al.* 2013; Landoni *et al.* 2014).

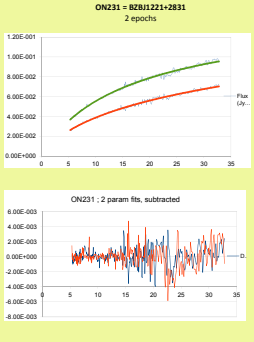
In an important further development, D'Abrusco *et al.* (2015) has published a catalog of all strongly detected WISE blazar candidates **with radio loud counterpart** sources ("WIBRaLS") with 7855 entries (1682 BZB, 3973 BZQ, and 2194 mixed). Since radio emission is one of the defining characteristics of blazars, combining it with distinctive infrared blazar colors enables this new catalog to more than double (potentially) the number of well-identified and located blazars.

In an effort to better understand why blazars have these colors, and indeed to make progress in understanding the mechanisms at work producing the infrared emission between 3 and 22 μm, we reduced and analyzed Spitzer Infrared Spectrometer (IRS) measurements on 73 blazars of varying types, some at several epochs. These spectra can be used to study the continuum emission (non-thermal), and search for atomic or other spectral features.

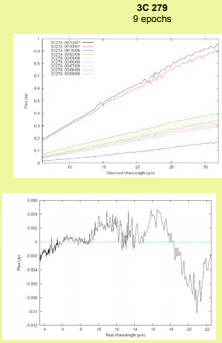
Since 2013, we have undertaken an optical spectroscopic campaign to observe blazars of uncertain classification as well as those selected from the WISE criteria above, to confirm and clarify the nature of the low-energy counterparts. Seventy-nine spectra have been published to date. All class "AGU" sources are confirmed to be blazars; their spectral indicies vary widely.



BL Lac : (Top) It was observed with the full IRS in one epoch, shown here with both the data points and the best fit to the 2-parameter curve. (Bottom) The difference spectrum for the two curves. The subtraction makes clear the silicate absorption feature which is commonly seen in luminous star-forming galaxies. Overplotted in blue is the IRS spectrum of the galaxy NGC4418, in which this feature is clear seen.



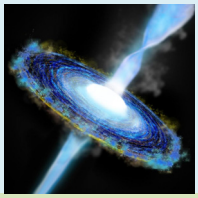
ON231 : (Top) It was observed in 2 different epochs, shown here with both the data points and the best fit to the 2-parameter curve. (Bottom) The difference spectrum for the two curves. No obvious features appear.

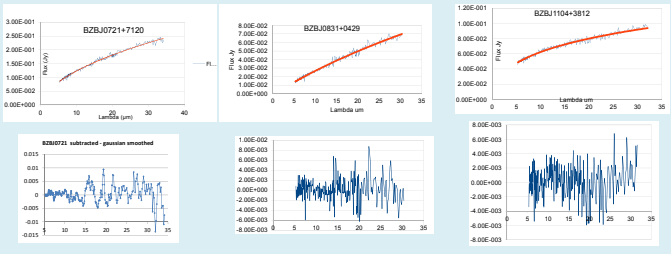


3C279: (Top) It was observed in 9 different epochs, shown here. (Bottom) The difference spectrum for 3C279 when all nine observations are normalized and averaged. The double-peaked silicate dust emission features are clearly visible; they are characteristic of PG quasars. The residuals at the tails are due to the choice of model.

Fitting some other blazars:

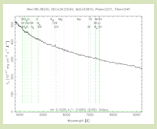
The three blazars to the right had high signal-to-noise ratios, and so we fit their continuum and subtracted to look for signs of any features.



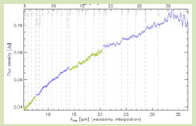


Spectral Groups:

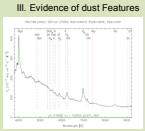
I. Featureless

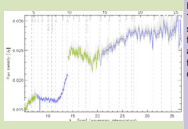


BZB ON231



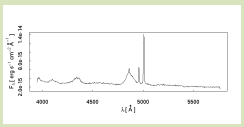
III. Evidence of dust Features

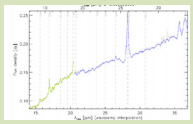




BZQ PG1222+216

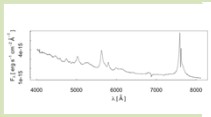
II. Evidence of Fine Structure Lines

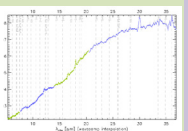




convex
BZQ PG007+106

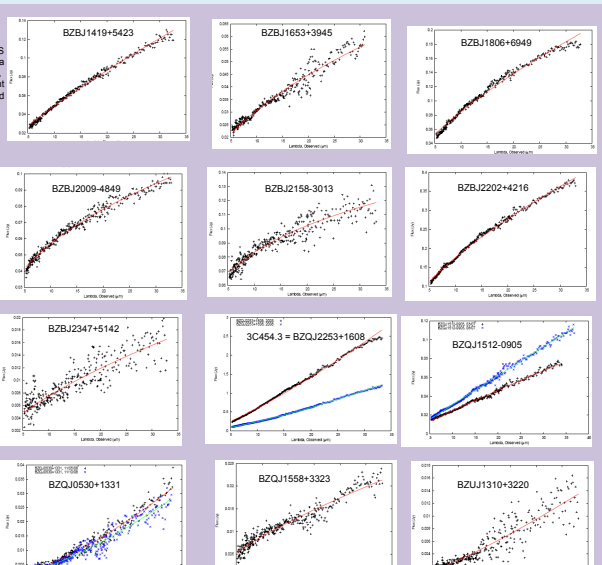
IV. Mixed/ Blend





BZQ 3C273

FEATURELESS (BZB) Blazars: To the right we show the IRS spectra of 12 other BZBs, and a few BZQ and BZU sources also, along with the two-component fits to the continuum data (red curve).



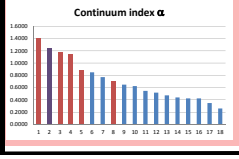
FITTING the MID-INFRARED CONTINUUM

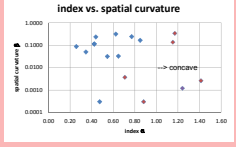
Not surprisingly, a simple power-law fit to the continuum shape from the IRS spectra does not work well. Instead, we adopted a two-component model:

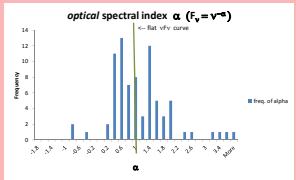
$$F_\nu = F_0 \left(\frac{\nu}{\nu_0}\right)^{-\left[\alpha+\beta\log\left(\frac{\nu}{\nu_0}\right)\right]}$$

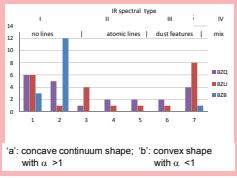
The index is α and the curvature parameter is β.
The results for this procedure are shown in all of the following spectra to the right – the red curve being the best fit.

The plots below show the distribution of α and β for the eighteen blazars; blue=BZB, purple=BZQ, red=BZU).









'a': concave continuum shape; 'b': convex shape
with α >1 with α <1

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