The unexpected silicate emission features in a type 2 AGN

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The unified model of active galactic nuclei (AGN) predicts silicate emission features at 10 and 18 μm in type 1 AGN, and such features have now been observed in objects ranging from distant QSOs to nearby LINERs. More surprising, however, are recent *Spitzer* detections of silicate emission in a few *type 2* AGN. To explain the silicate emission in these objects, in which the nucleus is traditionally thought to be obscured by a large column of cool dust, it has been proposed that the silicate-emitting dust exists in an extended, dusty narrow-line region (NLR) rather than in the compact torus of AGN unified schemes.

By combining Gemini and *Spitzer* mid-infrared imaging and spectroscopy of NGC 2110, the closest known Seyfert 2 galaxy with silicate emission features, we can constrain the location of the silicate emitting region to within 32 pc of the nucleus. This is the strongest constraint yet on the size of the silicate emitting region in a Seyfert galaxy of any type. While this result is consistent with a NLR origin for the emission, we use clumpy torus models to demonstrate that emission from an *edge-on* torus can also explain the silicate emission features and 2--20 μm spectral energy distribution of this object. In many of the best-fitting models the torus has only a small number of clouds along the line of sight, and does not extend far above the equatorial plane. Extended silicate-emitting regions may well be present in AGN, but this work establishes that emission from the torus itself is also a viable option for the origin of silicate emission features in active galaxies of both type 1 and type 2 (Mason et al. 2009).

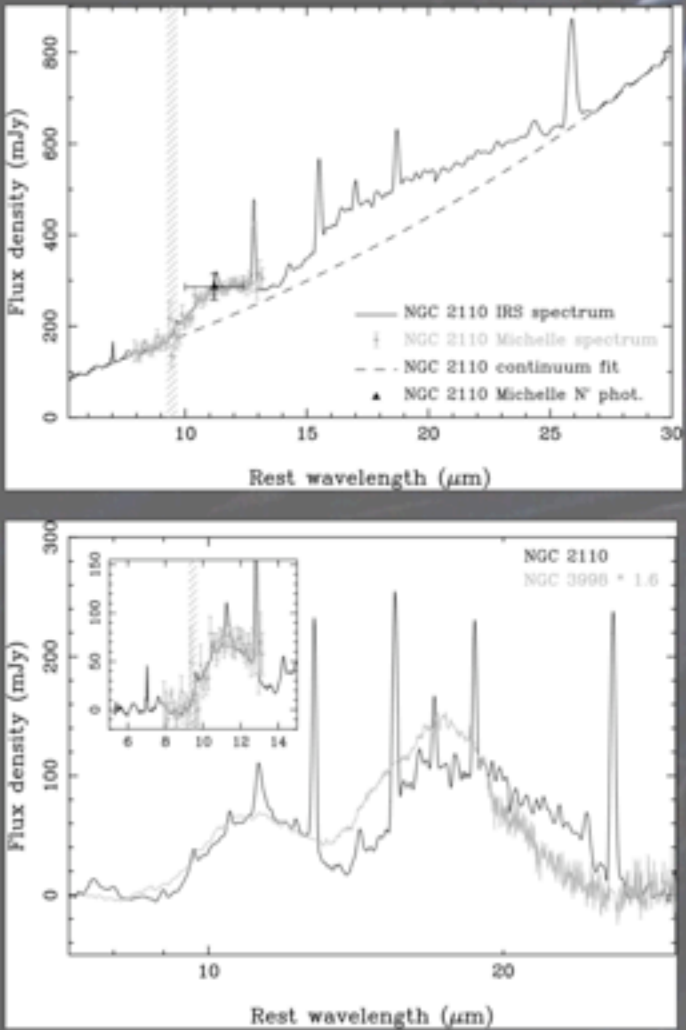


Fig. 1: Top - Spitzer/IRS and Gemini/Michelle spectra of NGC2110 (3.7-10.7" and 0.36" slits, respectively). The hatched area shows the telluric O_3 band, which is not well removed by division by the standard star. The Michelle spectrum was calibrated using the N' imaging but has been scaled slightly for ease of comparison with the IRS data. Bottom - Continuum-subtracted Michelle and IRS spectra of NGC 2110 (inset), and continuum-subtracted IRS spectra of NGC 2110 and NGC 3998 (Sturm et al. 2005, emission lines removed). The NGC 3998 spectrum has been multiplied by 1.6 and the data in the main figure displayed on a logarithmic wavelength scale to emphasize the feature profiles.

At a distance of 32 Mpc, NGC 2110 is the nearest known type 2 AGN with silicate emission (Shi et al. 2006). This object is unique in being both bright enough for ground-based mid-IR spectroscopy, and close enough for spatial resolution of a few x 10 parsecs to be attainable using an 8 m telescope in the mid-IR.

Fig. 1 compares Gemini/Michelle and Spitzer/IRS spectra of NGC 2110. Broad silicate emission features, the 11.3 μm PAH band and many fine structure lines are visible above a red continuum in the Spitzer data, and the 10 μm silicate feature is clearly detected in the Michelle spectrum. Aside from the 11.3 μm PAH band, the 8-13 μm spectral region changes very little between the Michelle and IRS spectra; the flux densities of the continuum and silicate emission in the Michelle and IRS spectra agree very well. The similarity of the strength and profile of the 10 μm silicate feature in both spectra implies that the silicate emission in NGC 2110 arises within the point source detected in our ground-based 11.2 μm imaging, whose FWHM < 63 pc (0.42"). At that distance the emission could arise in the torus itself, whose outer radius is thought to be only a few pc, or in the inner part of the narrow line region, which extends to ~230 pc in the optical. Using the dusty NLR models of Schweitzer et al. (2008), we estimate that for an AGN with the bolometric luminosity of NGC 2110, any silicate emitting dust in the NLR of NGC 2110 would be located within ~11 pc from the nucleus.

We also compare the Spitzer spectrum with spectra of a type 1 LINER (Sturm et al. 2005) and several type 1 QSOs (Hao et al. 2007). In terms of the peak wavelength, feature profiles and 10/20 μm feature ratios, NGC 2110 is within the range of properties seen in these other object classes.

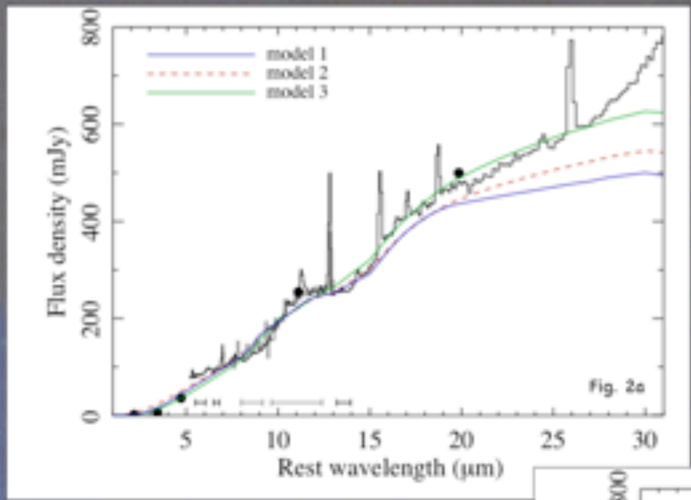
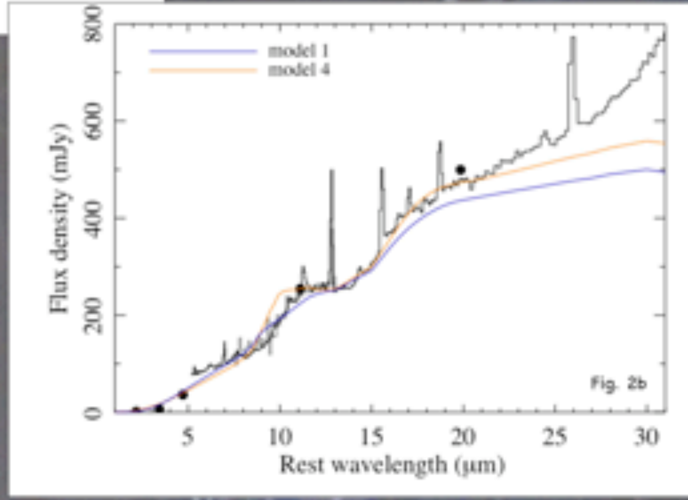


Fig. 2: We fit clumpy torus models to the MIR spectrum/SED of NGC 2110, to establish whether the silicate emission features can arise in the torus of this type 2 AGN. In these radiative transfer computations, the individual clouds have a fixed optical depth. The additional parameters detail the distribution of the clouds. They are radially distributed according to a power law, $\propto r^{-q}$, from the dust sublimation radius, R_d to an outer radius R_o, which we parameterize with $Y=R_o/R_d$. The torus has scale height σ with a Gaussian edge. The average number of clouds along an equatorial ray is N_0. The number along a given line of sight declines with altitude, with $N_{los}(\beta)=N_0 \exp(-\beta^2/\sigma^2)$ along angle β from the equator, and the emergent reprocessed emission is calculated for all viewing angles, i.

Fig. 2a shows the formally best-fitting model, which has $\tau_V=20$, Y=30, q=0, N_0= 5, σ=15°, and i=80°. A similar model changes N_0 to 10 and i to 70°. The opening angles are smaller than required by the unified model to explain the relative numbers of types 1/2 AGN. Slender tori are suggested by the disk-like BLR of NGC 2110, though, and the apparent scarcity of type 2 AGN with silicate emission may indicate that these objects are outliers in terms of torus properties. A different solution has fewer clouds along a line of sight and covers a larger angular extent (τ_V=40, Y=30, q=0, N_0=2, σ=45°, and i=90°. Fig. 2b: The clumpy torus can produce strong silicate emission even when the direct view of the AGN is blocked (i=80°). This model is formally a poor fit; the wavelength of the silicate features depends on the dust composition and grain size, which we do not vary.



To distinguish between NLR and torus origins for the silicate features, we fit the Nenkova et al. (2008) clumpy torus models to 2-20 μm spectroscopy and photometry of NGC 2110 (Fig. 2). In a clumpy torus (below), both hot and cold cloud faces are visible from any given line of sight, and classification as a type 1 or 2 AGN depends on the distribution of clouds along the line of sight, rather than being a strict function of viewing angle. The total cloud distribution determines the MIR emission, so various combinations of total number of clouds, outer extent, and radial profile produce similar spectra. ***The best-fitting models all have near-equatorial views through the torus,*** and imply column densities sufficient to obscure the BLR. The inclination of the torus is driven by the NIR/MIR ratio in the data; more face-on models predict too little MIR emission compared to the observed NIR flux. Fig. 2b shows an alternative model, again with an edge-on torus. Although formally a poorer fit, the 10 μm silicate feature does not show the "double-peaked," self-absorbed structure seen in the other models. It is well known that silicate emission features in AGN differ from those observed in the Galactic ISM (e.g. Li et al. 2008); incorporating different dust compositions in the clumpy models may allow the details of the fits to be improved.

We have shown that the silicate emission features in type 2 AGN can come from an *edge-on* clumpy torus, and need not necessarily arise in the NLR. SED modelling is a key tool in understanding AGN populations and their central engines, and the complexity of the torus contribution should not be underestimated.

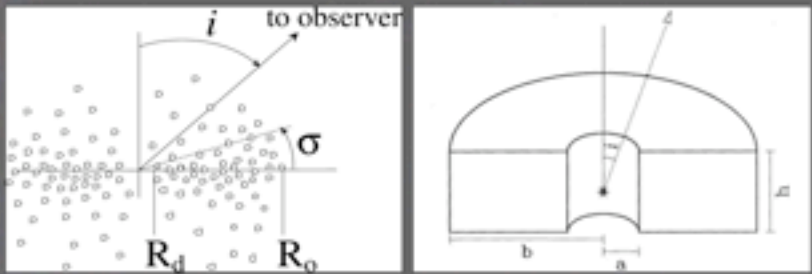


Fig. 3: Left - schematic of a clumpy torus (Nenkova et al. 2008). Right - example of a smooth torus (Pier & Krolik 1992)