Highlights of Astronomy, Volume 15
XXVIIth IAU General Assembly, August 2009
Ian F. Corbett, ed.

doi:10.1017/S1743921310010082

Mid-IR Spectroscopy of Submm Galaxies: Extended Star Formation in High-z Galaxies

K. Menéndez-Delmestre[1], A. W. Blain[2], I. Smail[3], D. M. Alexander[4], S. C. Chapman[5], L. Armus[6], D. Frayer[6], R. J. Ivison[7,8] and H. Teplitz[6]

[1]NSF Astronomy & Astrophysics Postdoctoral Fellow; Carnegie Observatories, Pasadena, CA email: kmd@obs.carnegiescience.edu [2]Caltech, Pasadena, CA
[3]Computational Cosmology, Durham, UK [4]Physics, Durham, UK
[5]Inst. of Astronomy, Cambridge, UK [6]SSC, Pasadena, CA [7]Astronomy Technology Centre, Edinburgh, UK [8]Inst. for Astronomy, Edinburgh, UK

Abstract. Ultra-luminous infrared galaxies (ULIRGs; L $> 10^{12}$ L$_\odot$) are quite rare in the local universe, but seem to dominate the co-moving energy density at $z > 2$. Many are optically-faint, dust-obscured galaxies that have been identified only relatively recently by the detection of their thermal dust emission redshifted into the sub-mm wavelengths. These submm galaxies (SMGs) have been shown to be a massive objects (M$_\star \sim 10^{11}$ M$_\odot$) undergoing intense star-formation(SFRs $\sim 10^2 - 10^3$ M$_\odot$ yr^{-1}) and the likely progenitors of massive ellipticals today. However, the AGN contribution to the far-IR luminosity had for years remained a caveat to these results. We used the *Spitzer* Infrared Spectrograph (IRS) to investigate the energetics of 24 radio-identified and spectroscopically-confirmed SMGs in the redshift range of $0.6 < z < 3.2$. We find emission from Polycyclic Aromatic Hydrocarbons (PAHs) – which are associated with intense star-formation activity – in $> 80\%$ of our sample and find that the median mid-IR spectrum is well described by a starburst component with an additional power-law continuum representing $< 32\%$ AGN contribution to the far-IR luminosity. We also find evidence for a more extended distribution of warm dust in SMGs compared to the more compact nuclear bursts in local ULIRGs and starbursts, suggesting that SMGs are not simple high-redshift analogs of local ULIRGs or nuclear starbursts, but have star formation which resembles that seen in less-extreme star-forming environments at $z \sim 0$.

Keywords. infrared: galaxies — galaxies: starburst — galaxies: AGN — galaxies: submillimeter

---

Deep X-ray studies suggest that $> 28 - 50\%$ of SMGs host an obscured AGN (Alexander *et al.* 2005). Although X-rays provide one of the most direct routes to estimate the luminosities of AGN, under high column densities such as found in SMGs, hard X-ray photons may be completely absorbed. The mid-IR provides an indirect insight to the dust-enshrouded nature of SMGs. We present the largest sample of SMGs observed in the mid-IR with *Spitzer* IRS (see Menéndez-Delmestre *et al.* 2009, hereafter MD09, for full discussion). Our main results are:

1. We find that $> 80\%$ of the SMGs in our sample display luminous PAH features and only four SMGs have continuum-dominated spectra (weak or absent PAH features). This indicates that, although some diversity exists within the population, SMGs are in general a population dominated by intense star-forming activity.

2. The composite SMG spectrum is best fit by the combination of a starburst template and an additional power-law continuum representing a maximum AGN contribution of $< 32\%$ to the far-IR luminosity in SMGs (see Fig. 1).

3. We quantify the strength of the silicate absorption feature and find that the distribution in $\tau_{9.7\mu m}$ for SMGs falls below that of local ULIRGs and the most obscured low-redshift nuclear starburst-dominated galaxies. This suggests that SMGs have lower dust obscuration to their mid-IR continuum emitting regions than these local samples.

4. Comparison of 7.7/11.3 PAH flux ratios suggests that SMGs host similar radiation envi-

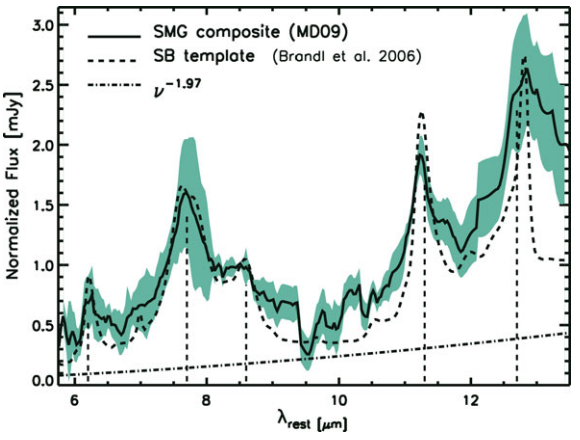

Figure 1. The SMG composite spectrum (solid line) is dominated by strong PAH emission features (vertical dashed lines). We fit this composite with a local starburst template (dashed spectrum) and derive an upper limit to the contribution from an AGN by making the conservative assumption that the additional continuum emission (dot-dashed line) arises solely from an obscured AGN. As described in MD09, we estimate that AGN activity contributes $< 32\%$ to the far-IR luminosity in typical SMGs. We emphasize that this is a strong upper limit for the SMG population, since a fraction of the red continuum in this composite spectrum likely arises from dust emission heated by optically-thick HII regions.

ronments to local starbursts. However, the 7.7/6.2 PAH ratio is lower in SMGs than in local nuclear starbursts. A stronger 6.2-μm PAH emission relative to the 7.7μm PAH feature may be attributed to lower extinction by ice (at 6μm) along the line of sight to SMGs

We conclude that the detailed mid-IR spectral properties of SMGs show several differences to local ULIRGs and nuclear starbursts. The differences in Si-absorption strengths and 7.7/6.2 PAH ratios can be most easily explained by a difference in the extinction to the mid-IR continuum and line emitting regions of these galaxies, with the SMGs showing systematically lower extinction. Considering that SMGs are very dusty objects, a lower extinction suggests that the warm dust is distributed over spatial scales significantly more extended in SMGs than found in local ULIRGs and nuclear starbursts.

References

Alexander, D. M., Bauer, F. E., Chapman, S., Smail, I., Blain, A., Brandt, W. N., & Ivison, R. 2005, *ApJ*, 632, 736

Brandl, B. R. *et al.* 2006, *ApJ*, 653, 1129

Chapman, S., Blain, A., Smail, I., & Ivison, R. 2005, *ApJ*, 622, 772

Krabbe, A., Böker, T., & Maiolino, R. 2001, *ApJ*, 557, 626

Menéndez-Delmestre, K. *et al.* 2009, *ApJ*, 699, 667 (MD09)

https://doi.org/10.1017/S1743921310010082 Published online by Cambridge University Press