Eddington limit accretion in WISE Hot Dust-obscured Galaxies: Indication of evolutionary status

Jingwen Wu, Edward Wright (UCLA), Peter Eisenhardt, Daniel Stern, Chao-Wei Tsai (JPL)
Roberto Assef (Universidad Diego Portales), Andrew Blain (Univ. of Leicester)

Abstract

WISE has discovered a hyper-luminous, z~2-3 galaxy population, the hot, dust-obscured galaxies or Hot DOGs. Our submillimeter to millimeter follow-up observations using CSO, CARMA, SMA and IRAM reveal that they have substantially hotter dust than other infrared luminous galaxies at similar redshifts (e.g. submillimeter galaxies (SMGs), dust obscured galaxies (DOGs), and quasars); although their cold dust masses are comparable, the CO gas content is lower for Hot DOGs. Our results also suggest a scenario that Hot DOGs fall in an evolutionary sequence after the SMG and the DOG phases, but before the emerging of a visible quasar, either experiencing a short transitional phase with super high accretion rate, or hosting extraordinary massive black holes, or both. To clarify this degeneracy, we have started a project to measure the masses of their SMBH (via broad Balmer lines) using MOSFIRE on Keck and Flamingos-2 on Gemini. The preliminary results show that Hot DOGs host SMBHs with masses of ~10^9 $M_\odot$, which are greater than typical SMGs or DOGs, but comparable to optical quasars. The derived Eddington ratios are around unity, which are much higher than typical SMG, DOGs or quasars at z~2, but rather closer to quasars found at very high redshifts (z~6).

Introduction:

A rare, new population of hyperluminous dusty galaxies has been discovered (Eisenhardt et al. 2012, Wu et al. 2012,2014, Bridge et al. 2013, Jones et al. 2014, Stern et al. 2014, Assef et al. 2015, Tsai et al. 2015) by WISE survey (Wright et al. 2010), fulfilling one of WISE's primary science goals: finding the most luminous galaxies in the universe.

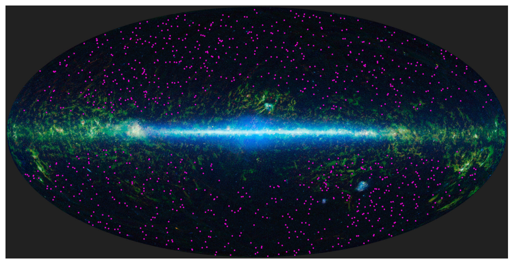

Figure 1. The IR sky as mapped by WISE, with hot DOG positions shown in magenta.

Intensive follow-up programs using Herschel, Spitzer, Keck, CSO, and other ground-based telescopes for more than 200 such galaxies have revealed following properties: 1) **High redshift**. Spectroscopic follow-up confirms most of them have redshifts between 1.5 to 4.6, peaking at z~2-3. 2) **Hyper-luminous**. Submillimeter follow-up reveals that their bolometric luminosities are well above 10^{13} $L_\odot$, with >10% exceeding 10^{14} $L_\odot$, comparable to the most luminous optical QSOs. 3) **Hot**. They have a consistent SED shape with unusually high mid-IR to submm ratio, suggesting a new population with a high dust temperature, likely due to the heating from a powerful SMBH. They meet the selection criterion for DOGs (Dey et al. 2008), but are 10,000 times rarer, more luminous, and significantly hotter, so we refer to them as Hot Dust Obscured Galaxies or Hot DOGs.

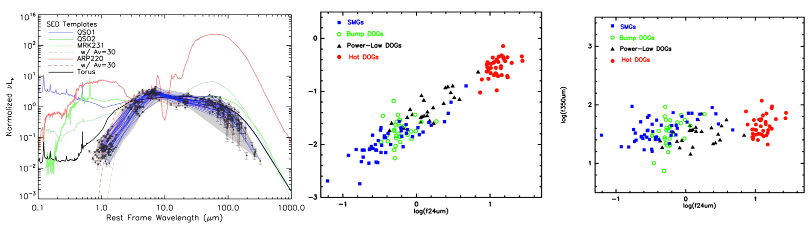

Figure 2: (Left) SEDs of Hot DOGs with warm Spitzer, WISE and available *Herschel* and CSO data, plotted in νL_ν units vs. rest wavelength. SEDs are normalized by total luminosities, and shifted to the rest frequency frame, normalized at their flux density at rest-frame 5 μm. A wide range of templates is overlaid for comparison but they fail to match the steepness of the SED on either side.
Hot DOGs have a higher ratio of 24 μm (from MIPS or W4) to 350 μm, than DOGs (Melbourne et al. 2012, AJ, 143, 125) and SMGs (Megnelli et al. 2012, AA, 539, 155) **(middle)**, while the 350 μm emission (a tracer of cold dust associated with starbursts) is similar for all these populations **(right)**. This suggests Hot DOGs are a new population with an unusually strong contribution from AGN; SMGs, bump DOGs, power-law DOGs and Hot DOGs may follow an evolutionary sequence tracing the growth of the central SMBHs. Hot DOGs either having more massive SMBHs, or are experiencing a short evolutionary stage with a very high accretion rate.

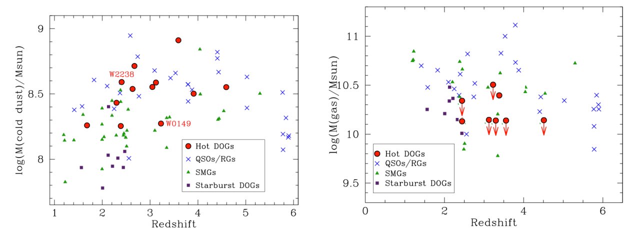

Figure 3. **(Left)** Based on longer wavelength (>0.85 mm) observations from CSO/Bolocam and JCMT/SCUBA2, we estimate the cold dust mass of Hot DOGs is comparable to that in SMGs, DOGs, and optical selected quasars (see references in Wu et al. 2014).
(Right) However, CO observations for Hot DOGs using CARMA (Wu et al. 2014) and IRAM (Blain et al. in prep) yield a moderate detection rate, suggesting their gas content may not be as rich as in SMGs and some quasars.

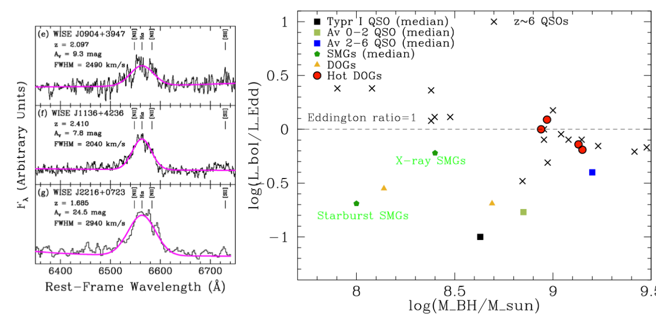

Figure 4. We have started a project to measure black masses of hot DOGs using broad Balmer lines. In a pilot survey (Wu, Assef, et al. in prep) we have successfully detected broad Hα lines in 4 Hot DOGs using Keck/MOSFIRE and Gemini/Flamingos-2 **(Left),** finding these Hot DOGs have SMBH masses of ~10^9 $M_\odot$, which is higher than typical SMGs and DOGs, but comparable to quasars **(Right),** supporting the scenario that Hot DOGs could be at an evolutionary phase between SMGs/DOGs and quasars.
The derived Eddington ratios for these Hot DOGs are around unity, which is much higher than other z~2 populations (e.g. SMGs, DOGs and quasars), but closer to another highly interesting population: the z~6 galaxies. By comparing Hot DOGs and existing z~6 galaxies, we find they share some important properties, and propose that Hot DOGs could be the analogous population of z~6 quasars at z~2.

References:
Assef et al. 2015, ApJ, submitted (arXiv:1408.1092). Bridge et al. 2013, ApJ, 769, 91. Dey et al. 2008, ApJ, 677, 943. Eisenhardt et al. 2012, ApJ, 755, 173. Jones et al. 2014, MNRAS, 443, 146. Stern et al. 2014, 794, 102. . Tsai et al. 2015, ApJ, submitted (arXiv: 1410. 1751). Wright et al. 2010, AJ, 140, 1868. Wu et al. 2012, ApJ, 756, 96; 2014, ApJ, 793, 8.