WISE Hot DOGs and AGN

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NASA’s WISE mission (3.4, 4.6, 12, 22 um all-sky survey) have made major contribution to the AGN study

• Reveal a huge amount of hidden (obscured) AGNs
• Locating the most luminous obscured AGNs
Spitzer/WISE can efficiently select AGNs:

- **Spitzer**
  - Stern et al. 2005

- **WISE**
  - Stern et al. 2012
  - Assef et al. 2013
WISE reveals a hidden AGN world: There are more obscured than unobscured AGNs

Green circle: SDSS AGNs
Yellow circle: WISE AGNs

Obscured: Un-obscured

COSMOS: 3:1
Bootes: 6:1

(Stern et al. 2012)
(Assef et al. 2013)
We discovered **Hot DOGs**, the reddest, dustiest WISE galaxies; The most luminous obscured galaxies in the universe (WISE mission goal)

**W12drop-out selection** (Eisenhardt et al. 2012)

Plot Credit: C.W.Tsai
intensive follow-up campaigns

- > 200 Spectra & redshifts from Keck/GMOS-S/Palomar
- > 900 *Spitzer* IRAC1+IRAC2
- > 200 *Herschel* PACS+SPIRE
- > 200 Opt/IR photometry with NOAO facilities
- > 40 CSO SHARCII+Bolocam
- > 10 JCMT SCUBA2
- > 30 with EVLA
- > 25 with *HST*
- >25 *Chandra, XMM, NuSTAR*
- > 10 ALMA follow-ups

Publications of Hot DOGs by our group:
Eisenhardt et al. 2012; Wu et al. 2012, 2014, 2018,
Stern et al. 2014; Assef et al. 2015; 2016, Tsai et al. 2015; 2018,
Ricci et al. 2016, Díaz-Santos et al. 2016, 2018
Hot DOGs Highlight

- **High redshift:**
  \[1 < z < 4.6, \text{ mostly at } z \sim 2-3\]

- **Hyper-luminous:**
  \[L_{\text{bol}} \sim 10^{13} L_\odot \sim 10^{14} L_\odot,\]
  \(~10\% > 10^{14} L_\odot\text{(ELIRGs)}\)
  No sign of lensed

- **Hot**
  \[T_{\text{dust}} \sim 60-100K\]

- **Rare**
  \[1 \text{ per } 30 \text{ dg}^2\]

- **Highly Obscured, AGN**
  \[A_v \sim 20-60;\]
  \[\log N_{\text{H}_2} \sim 24, \text{ Compton thick}.\]

(Tsai et al. 2015)
Characteristic AGN emission lines, most are type II (Obscured).

AGN dominates luminosity

Blue: Starburst
Green: Sbc spiral
Red: Type 1 AGN with Av extinction
Hot DOG SEDs:

- Consistent SED shapes, but quite different from known galaxy templates
- Unusually high mid-IR to submm ratios, dominated by hot dust emission.

Plot Credit: Chao-Wei Tsai
• They qualify DOG selection criterion ([24]>0.3mJy, R-[24]>14, Dey et al. 2008)

• They are much hotter
• 10 times more luminous
• 10,000 times rarer

So we call them
Hot DOGs
(Wu et al. 2012)
Given the similar z distribution with SMGs and DOGs; all are AGN+starburst systems
An evolutionary connection to SMGs and DOGs?
An evolution driven by the growth of the central SMBHs?

(Wu et al. 2012)
A popular model of galaxy evolution via merging

SMGs, DOGs

SFR

Lum

Hot DOGs?

(Hopkins et al. 2008)
Is Hot DOG the “blow-out” phase?

Other Evidence:
A large fraction show
Lyman A Blobs > 20 kpc

The high luminosity and hot dust

An evolutionary sequence?

SMG -> DOGs -> Hot DOGs -> QSOs
Evidence: CII lines in the most luminous obscured galaxy: Hot DOG W2246-05 (z=4.6)

Isotropic outflow or Explosive event

An ALMA CII observation reveals a surprisingly large (>2.5 kpc), uniform, extended turbulence (FWHM~600 km/s) albeit much smaller velocity gradient (~100km/s).

(Díaz-Santos et al. 2016)
The unusually high-luminosity of Hot DOGs can either come from a very massive SMBH well above BH-host relation, or from a normal SMBH with very high accretion rate, even super Eddington accretion.

Directly measure their BH masses.

BH masses of $5 \, z \sim 2$ Hot DOGs from Keck/Gemini (Wu et al. 2018)
$z \sim 2$ Hot DOGs have BH masses greater than SMGs and DOGs, comparable to QSOs, but with a much higher accretion rates that are close to Eddington limit.
Compare Hot DOGs to all SDSS QSOs:
Maximum level luminosity for given BH masses
Hot DOGs and SDSS QSOs at similar redshifts
An evolutionary trace of quasars at $z \sim 2$

(Wu et al. 2018)
They may overlap in $M_{BH} - M_{host}$ relation plot
Z=2-3 galaxies accretion history

From Hot DOGs to the most luminous SDSS QSOs: ELIRGs

Staying at high luminosity, when BH accretion rates reach and cross a peak.

(Tsai et al. 2015)
Hot DOGs may not only the peak phase of accretion, but also the heaviest obscuration phase.

X-ray observations towards 20 top luminous Hot DOGs
⇒ They are Compton thick
Vito et al. (2018.)
An evolutionary trace + accretion history, extends to other redshifts.
Such a phase during galaxy evolution should be seen in other redshifts.
HST/WFC3 images for 12 z~2 Hot DOGs (Farrah et al. 2017)
Summary

• Hot DOGs are a linking population to connect obscured and un-obscured quasars.

• Hot DOGs may accrete at the highest possible rates for their BHs. This is also true to known z~6 quasars, which make them the most luminous objects in their own epoch.

• Suggested evolutionary sequence: SMG--DOG—Hot DOG—red QSO— SDSS QSO. Hot DOGs may be the peak phase of both the accretion and the obscuration.

• Hot DOGs may exist in different cosmic epochs.