The Nature of \( z \approx 2 \) Dust-Obscured Galaxies

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Summary: We examine the nature of \( z \approx 2 \) Dust-Obscured Galaxies (DOGs) in the Boötes Field of the NOAO Deep Wide-Field Survey using high spatial resolution HST imaging, CSO 350\(\mu\)m and CARMA 1mm imaging, and stellar population synthesis SED modeling. Our main results are:

1. The subset of DOGs with mid-IR spectral features typical of AGN are spatially extended and not dominated by an unresolved component at rest-frame optical wavelengths, yet they show more regular morphologies than those objects selected to show a bump in their mid-IR SEDs.
2. The most luminous DOGs have SEDs similar to Mrk231 (an AGN-dominated ULIRG at \( z \approx 0 \)), with dust temperature lower limits of 35-45 K.
3. DOGs have \( M_{\text{star}} \approx 10^{10} - 10^{11} \) \( M_{\odot} \), with star-formation histories favoring young (~100 Myr) stellar populations.

These results suggest that DOGs may represent an important stage in massive galaxy evolution that can be used to test AGN feedback models.

The most luminous systems in the local universe (ULIRGs) are thought to be produced by major mergers of gas-rich spirals (Sanders et al. 1988).

A critical transition phase in this process is characterized by emission from warm dust heated by the growth of an AGN.

High-\( z \) analogs of local universe transition objects?

1. Sub-mm galaxies (SMGs) are starburst systems at \( z \approx 2 \). These objects tend to have morphologies and kinematics suggestive of on-going or recent major mergers (Conselice et al. 2003, Tacconi et al. 2008).
2. Surveys combining deep mid-IR and optical imaging have identified sources with extremely red optical – IR colors that are located at \( z \approx 2 \) (e.g., Yan et al. 2007, Fiore et al. 2008, Dey et al. 2008, Farrah et al. 2008, Lonsdale et al. 2009, Younger et al. 2009).
3. The clustering properties of SMGs and 24\(\mu\)m-selected sources are similar, implying they inhabit similar mass dark matter halos (Blain et al. 2004, Brodwin et al. 2008)

DOGs are Spitzer-selected galaxies satisfying a single flux density ratio criterion: \( F_{24}/F_{R} > 1000 \)

DOG mid-IR SEDs range from power-laws to showing a prominent bump at \( \lambda_{\text{rest}} = 1.6\mu m \)

HST Imaging of DOGs

Cutouts of 31 DOGs observed by HST with NIC2/F160W, shown with a linear stretch. Each cutout is 2” on a side and is oriented north up and east left.

Star-formation Histories of DOGs

Sample

- 39 bump DOGs w/ spec-z > 1.4
- 51 power-law DOGs w/ spec-z > 1.4
- 58 SMGs at z > 1.4 (Chapman et al. 2005)

Photometry

- DOGs: Bw, R, I, J, H, Ks, 3.6, 4.5
- SMGs: B, R, I, J, Ks, 3.6, 4.5

Assumptions

- CBOT BC03 simple stellar populations
- Calzetti et al. 2000 extinction
- Chabrier, Salpeter IMFs
- Uncertainties
  - \( M_{\text{star}} \approx 0.3 - 0.5 \) dex
  - \( A_{\text{B}} \approx 0.2 - 0.5 \)
  - \( \text{Age} \approx 0.5 - 1 \) dex
  - \( A_{\text{N}} \) and Age degenerate

Future Work: High-res SMA imaging of gas and dust in lensed ULIRGs identified by WISE and Herschel — Lensing models, gas kinematics

HST Imaging of DOGs

Cutouts of 19 “bump” DOGs observed by HST with NIC2/F160W, shown with a linear stretch. Each cutout is 2” on a side and is oriented north up and east left.

Visual classification experiment: Power-law DOGs have regular morphologies more frequently than bump DOGs.

Quantitative measures (e.g., Gini, M20, C) consistent with models showing bump DOGs evolve into power-law DOGs


Stellar Population Synthesis Modeling

Sample

- 5/12 DOGs detected at 350\(\mu\)m with CSO/SHARC-II
- 0/2 detected at 1.3\(\mu\)m with CARMA
- Compare with 1.2mm observations of similar objects (e.g., Sajina et al. 2008, Lonsdale et al. 2009, Younger et al. 2009, Fiolet et al. 2009)

Dust Properties of DOGs

Representative sample of brightest power-law DOGs in 9 deg\(^2\) Boötes field.

- Optical through sub-mm SEDs of DOGs in the SHARC-II sample. Flux densities have been normalized by the rest-frame 8\(\mu\)m flux density, computed from the observed 24\(\mu\)m flux density.
- Mrk231 provides the best fit over the rest-frame UV through sub-mm range because it has a warm dust SED (unlike Arp220) and because it lacks a strong stellar component (unlike both Arp220 and M82).