Ionized Gas Outflows in Infrared-bright Dust-Obscured Galaxies at $0 < z < 1$


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Introduction

What are Dust-Obscured Galaxies (DOGs)?

We discovered IR-bright DOGs with strong ionized gas outflow.
We discovered IR-bright DOGs with strong ionized gas outflow

Dust-Obscured Galaxies

\[ i - [22] > 7.0 \text{ (AB mag)} \]

- An optically faint but infrared (IR) bright objects.

~ ULIRGs, HyLIRGs

- Most DOGs are ultra-luminous infrared galaxies (ULIRGs: \( L_{\text{IR}} \geq 10^{12} L_{\odot} \))
- Some DOGs are hyper-luminous infrared galaxies (HyLIRGs: \( L_{\text{IR}} \geq 10^{13} L_{\odot} \))

\[ F(\text{IR}) > 1000 \times F(\text{optical}) \]

Toba et al. 2015, PASJ, 67, 86

The importance of IR-bright DOGs

- In the context of major merger scenario, particularly IR-bright DOGs (F_{\text{MIR}} > 1 \text{ mJy}) may correspond to a maximum phase of AGN activity behind a large amount of dust.

- Some IR-bright DOGs are expected to be a “blowout” phase during the co-evolution.

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We discovered IR-bright DOGs with strong ionized gas outflow

Introduction

Dey+09
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The importance of IR-bright DOGs

In the context of major merger scenario, particularly IR-bright DOGs (FMIR > 1 mJy) may correspond to a maximum phase of AGN activity behind a large amount of dust.

Some IR-bright DOGs are expected to be a "blowout" phase during the co-evolution.

We discovered IR-bright DOGs with strong ionized gas outflow. IR-bright DOGs are key population to understanding the co-evolution.

They are a good laboratory to investigate the AGN feedback phenomenon.
We discovered IR-bright DOGs with strong ionized gas outflow

**IR-bright DOGs survey with SDSS and WISE**


**Introduction**

**SDSS spec** → **WISE** → **SDSS-WISE object**

\[ i - \text{[22]} > 7 \]

**SDSS-WISE DOGs**

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We discovered IR-bright DOGs with strong ionized gas outflow

**Introduction**

IR-bright DOGs survey with SDSS and WISE

We focus on 32 IR-bright DOGs (0 < z < 1) with [OIII]λ5007 line

SDSS spec → WISE → SDSS-WISE object

SDSS-WISE DOGs 67

We discovered IR-bright DOGs with strong ionized gas outflow
Some objects have broad and blueshifted [OIII] line that is mis-identified as Lyα based on the SDSS pipeline.
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Purpose of this work

To investigate the properties of outflowing gas based on a detailed spectral analysis.
We discovered IR-bright DOGs with strong ionized gas outflow

Data and Analysis

How do we evaluate a peculiar profile of [OIII] line?
Spectral analysis

We discovered IR-bright DOGs with strong ionized gas outflow.
Spectral analysis

We discovered IR-bright DOGs with strong ionized gas outflow.

Data and Analysis

collaborated with Dr. Hyun-Jin Bae
We discovered IR-bright DOGs with strong ionized gas outflow.
We discovered IR-bright DOGs with strong ionized gas outflow

Spectral analysis

![Spectral analysis graph](image)
We discovered IR-bright DOGs with strong ionized gas outflow.

**Spectral analysis**

**velocity offset**

\[ v_{\text{[OIII]}} (\lambda) = \frac{(\lambda_0 - \lambda_{\text{rest}}) c}{\lambda_{\text{rest}}} - v_{\text{sys}} (\lambda) \]

**velocity dispersion**

\[ \sigma_{\text{[OIII]}} (\lambda) = \sqrt{\frac{\int \lambda^2 f(\lambda) \, d\lambda}{\int f(\lambda) \, d\lambda}} - \frac{\lambda_0^2}{\int f(\lambda) \, d\lambda} \]

\[ \lambda_0 = \frac{\int \lambda f(\lambda) \, d\lambda}{\int f(\lambda) \, d\lambda} \]
Results and Discussions

Comparison of outflow strength between IR-bright DOGs and Sy2s

What determines the outflow strength?

How about other lines such as [OIII]λ3727?
**Results and Discussions**

**IR-bright DOGs with strong ionized gas outflow**

**Velocity offset — Velocity Dispersion diagram**
~75% IR-bright DOGs have $\sigma[\text{OIII}] > 300$ km/s
Results and Discussions

IR-bright DOGs show relatively strong outflows compared to Sy2s
**LIR (AGN) vs. outflow strength**

**Results and Discussions**

- **SDSS Sy2s (Woo et al. 2016)**
- **IR-bright DOGs (This work)**

**$v_{\text{[OIII]}}$ vs. $L_{\text{IR (AGN)}}$**

- SDSS Sy2s (Woo et al. 2016)
- IR-bright DOGs (This work)

**$\sigma_{\text{[OIII]}}$ vs. $L_{\text{IR (AGN)}}$**

- SDSS Sy2s (Woo et al. 2016)
- IR-bright DOGs (This work)
LIR (AGN) correlates with $V_{\text{[OIII]}}$ and $\sigma_{\text{[OIII]}}$
LIR (AGN) vs. outflow strength

IR-bright DOGs with strong ionized gas outflow

**Results and Discussions**

LIR (AGN) correlates with V[OIII] and $\sigma$[OIII]

SDSS Sy2s (Woo et al. 2016)
IR-bright DOGs (This work)

IR-bright DOGs
SDSS Sy2s (Woo+16)

The systematic offset on the VVD is due to the difference in LIR(AGN)
VVD diagram for other lines

Results and Discussions

IR-bright DOGs with strong ionized gas outflow

[OIII]  [OII]  [NeIII]
The highly ionized gas tends to show stronger outflows.
How about a molecular gas?

How about a molecular gas?

moment 0
CO(2-1)

moment 1
CO(2-1)

moment 0
CO(4-3)

moment 1
CO(4-3)
How about a molecular gas?

The molecular gas properties of this DOG are normal despite that its optical spectrum showing a powerful AGN outflow.
We investigated ionized gas properties of 32 IR-bright DOGs selected with SDSS and WISE

- 24/32 (75%) IR-bright DOGs have a strong [OIII] outflow
- IR-bright DOGs show relatively strong outflows compared to Sy2s due to the difference in LIR(AGN)
- The highly ionized gas tends to show stronger outflows
I ❤️ DOGS