ALMA Observation of an IR-bright Dust Obscured Galaxy with Strong Ionized Gas Outflow

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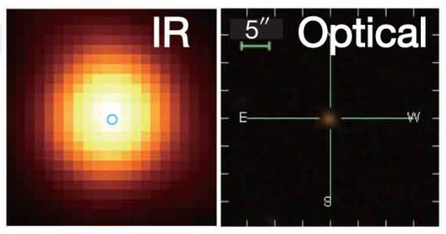
1. Introduction

What are Dust Obscured Galaxies?

i - [22] > 7.0 (AB mag) Toba et al. (2015)

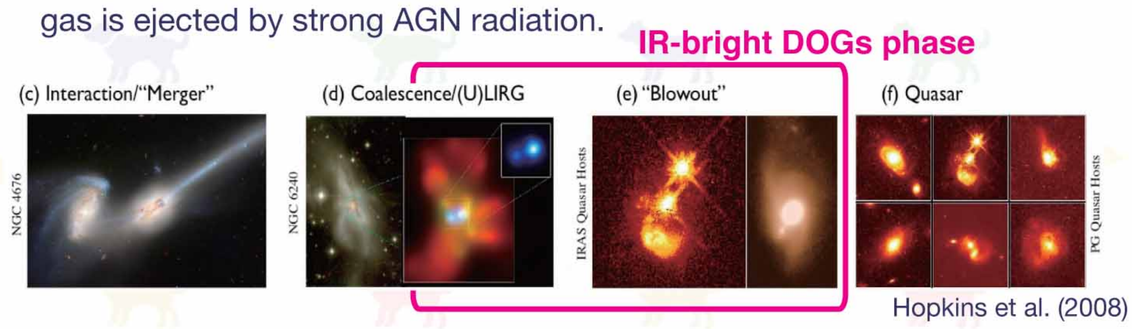
- DOGs are optically faint but IR bright objects.
- Most DOGs are ULIRGs ($L_{IR} > 10^{12}\ L_\odot$) or even HyLIRGs ($L_{IR} > 10^{13}\ L_\odot$).



Flux (IR) > 1000 Flux (optical)

Why do we care about DOGs?

- In the context of gas-rich galaxy merger scenario, particularly IR brighter DOGs correspond to the maximum phase of AGN activity.
- Some IR-bright DOGs may be a blowout phase where the surrounding gas is ejected by strong AGN radiation.

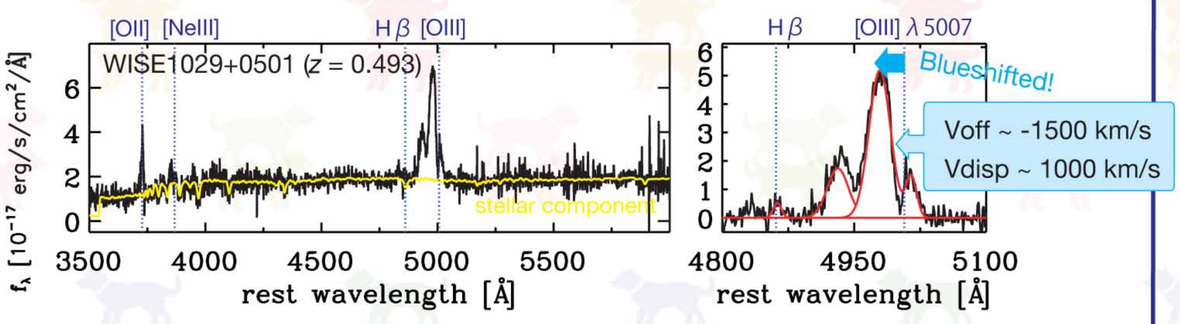


Hopkins et al. (2008)

- **IR-bright DOGs constitute a key population for understanding the co-evolution of galaxies and supermassive black holes (SMBHs).**
- **IR-bright DOGs are expected to be a good laboratory to investigate the AGN feedback phenomenon.**

A peculiar IR-bright DOG with a strong ionized-gas outflow

- Combining the SDSS (optical) and WISE (mid-IR) catalogs, we selected 67 IR-bright DOGs with spec-z (Toba & Nagao 2016).
- Among them, we discovered a peculiar DOG (WISE1029) with unusual [OIII] λ 5007 Å line profile in its SDSS spectrum (Toba et al. 2017c).



Motivation of this work

- The blueshifted and broad [OIII] line indicate that an ionized gas is strongly outflowing from this DOG.
- However, although the AGN-driven outflow of ionized-gas has been confirmed, whether or not there is molecular gas associated with outflows is still unclear.
- ***The purpose of this work is to investigate the molecular gas properties of this DOG (WISE1029) with strong ionized-gas outflow.***

2. ALMA observations

Cycle 3 (PI: Y.Toba)

#2015.1.00199.S

- The ^{12}CO(2–1) line was observed in band 4 on 2016 July 14 with the C40-4 configuration, and ^{12}CO(4–3) in band 7 on 2016 June 22 with the C40-5 configuration.
- For both runs, one of the four spectral windows were centered on the molecular line, with 1875 MHz bandwidth (corresponding to 3640 km/s in band 4 and 1809 km/s in band 7), and 1953 kHz resolution.

WISE J102905.90+050132.4	
R.A. (SDSS) [J2000.0]	10:29:05.90
Decl. (SDSS) [J2000.0]	+05:01:32.42
Redshift (Toba et al. 2017c)	0.4930
Band 4 continuum (146.6 GHz) [mJy]	0.18 ± 0.02
Band 7 continuum (303.9 GHz) [mJy]	0.85 ± 0.09
$S_{CO(2-1)}\ \Delta v$ [Jy km s^{-1}]	1.90 ± 0.13
$S_{CO(4-3)}\ \Delta v$ [Jy km s^{-1}]	4.66 ± 0.47
FWHM$_{CO(2-1)}$ [km s^{-1}]	336.3 ± 32.4
FWHM$_{CO\ (4-3)}$ [km s^{-1}]	373.1 ± 15.1
log L_{FIR} (40–120 μm) [$L_\odot$]	$11.83^{+1.63}_{-0.36}$
log L_{IR} (8–1000 μm) [$L_\odot$]	$12.40^{+0.70}_{-0.17}$
log $L'_{CO(2-1)}$ [K km s^{-1} pc^2]	10.25 ± 0.03
log $L'_{CO(4-3)}$ [K km s^{-1} pc^2]	10.04 ± 0.04
r_{42}	0.61 ± 0.07
log M_* [$M_\odot$]	$10.8^{+0.02}_{-0.06}$
log SFR [$M_\odot$ yr^{-1}]	$2.11^{+0.64}_{-0.28}$
log M_{dust} [$M_\odot$]	8.5
log M_{gas} [$M_\odot$]	10.2
M_{gas}/M_{dust}	53

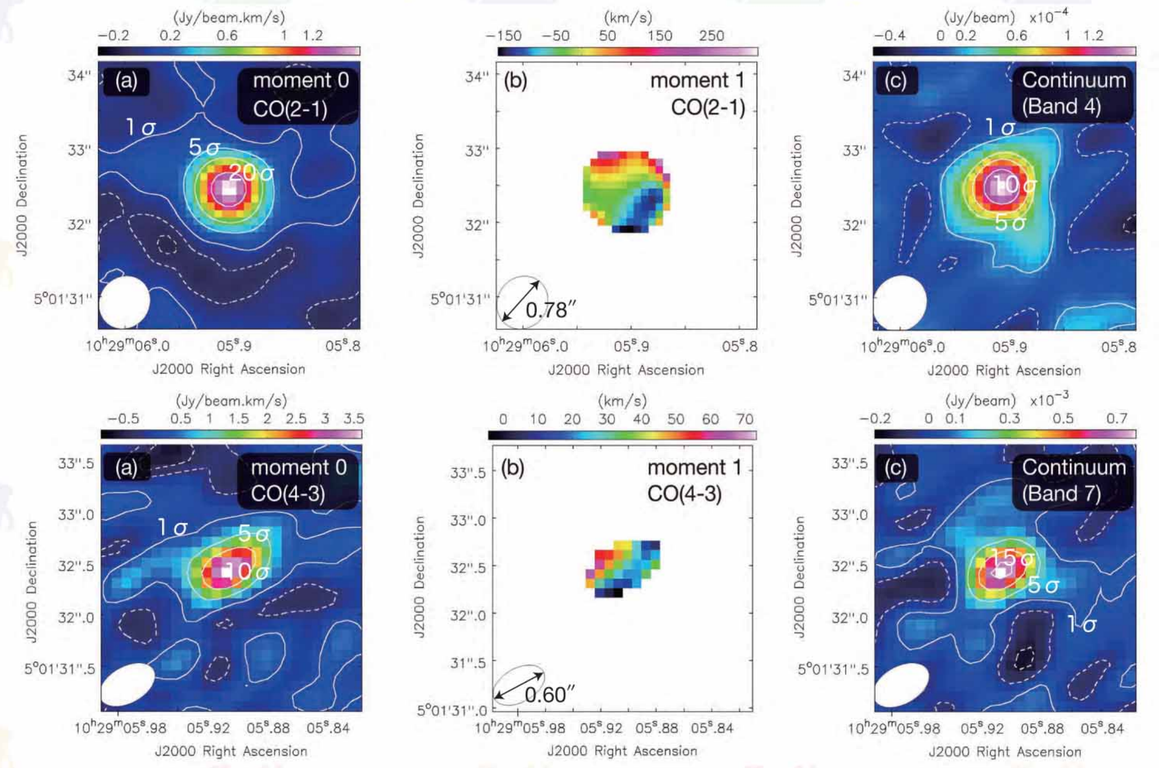
Take-home message

Thanks to an excellent capability of ALMA, we discovered an IR-bright DOG (WISE1029) that shows a strong ionized-gas outflow but no significant molecular gas outflow.

A powerful ionized-gas outflow caused by the AGN does not necessarily affect the cold ISM in the host galaxy, at least for this DOG.

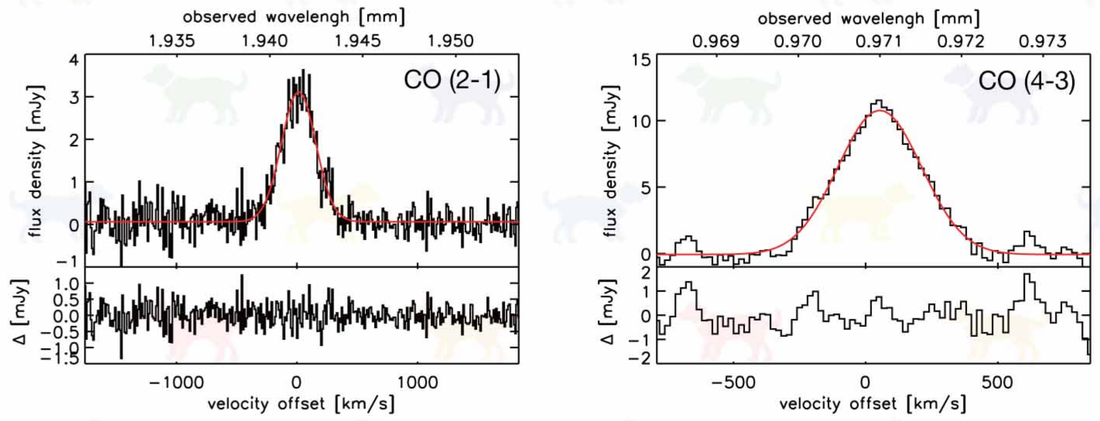
3. Results and Discussions

Moment 0 and 1 maps and continuum images



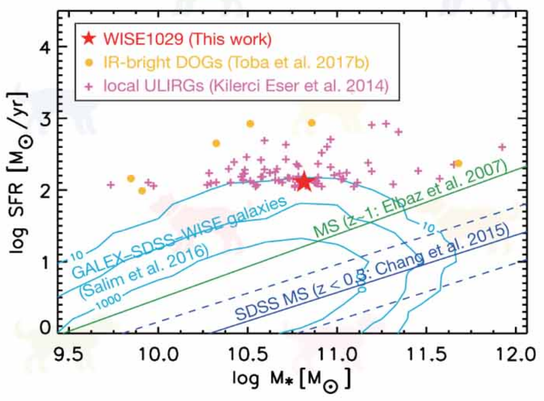
The velocity gradients for both lines can be seen, indicating that CO molecular gas in the DOG is unlikely to be strongly disturbed.

CO line profile

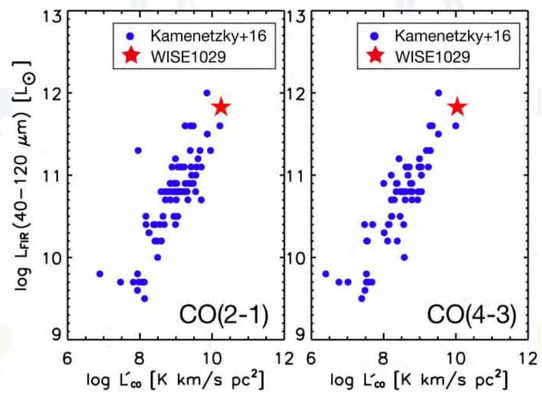


Both CO lines are well-fitted by a single Gaussian with a FWHM of ~350 km/s, which is close to a typical value of local (U)LIRGs.

Stellar mass - SFR relation



L_{FIR} - L_{CO} relation



These relations are consistent with those of typical ULIRGs at similar redshifts.

An interpretation of the above results

- **The ionized-gas outflow does not significantly affect the kinematics of molecular gas.**
- **The above situation could occur if the ionized-gas is outflowing in a different direction from distribution of molecular gas, for example, along the path of least resistance perpendicular to the disk plane (like M82).**