On the dust and gas content of high-redshift galaxies hosting obscured AGN in the CDF–S

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Obscured AGN

- **Unabsorbed**: log $N_H < 21$
- **Compton thin**: $21 < \log N_H < 24$
- **Mildly Compton thick**: log $N_H \sim 24 - 25$
- **Heavily Compton thick**: log $N_H > 25$

AGN fraction increases at high redshift
Sub–Millimetre Galaxies

SFR density and BH accretion density peak at $z \approx 2$

**SMGs**

- Peak at $z \approx 2$
- $M_* \sim 10^{10-11} M_\odot$
- $M_d \sim 10^8 M_\odot$
- $M_{H_2} \sim 10^{10} M_\odot$
- $\text{SFR} \sim 10^{2-3} M_\odot/yr$
- $\tau_d \sim 10^8 \text{ yr}$
- AGN fraction:
  - $\sim 0.5 \ (L_{IR} < 10^{12} L_\odot)$
  - $\sim 0.9 \ (L_{IR} > 10^{12} L_\odot)$
- Size $\sim$ few kpc

Contribution of the host galaxy to the AGN obscuration?
Objectives and targets

- Measure masses and sizes of both dust and molecular gas components of a sample of SMGs at $z > 2.5$, observing continuum emission at $\sim 2.1$ mm and one high–CO transition per source in ALMA band 4.

- Derive the column densities of the host ISM and compare them with those measured from the X–ray spectral fitting, assuming different geometries for the objects.

- Study the morphology and kinematics of the sources.
Objectives and targets

Parent samples
- 34 AGN at $z > 3$, selected in the 4–Ms CDF–S (Vito+13)
- 8 AGN at $z = 1.1–3.7$, selected in the 1–Ms CDF–S (Rigopoulou+09)

Selection criteria
- Secure spectroscopic $z > 2.5$
- Column density $\log N_{H} > 23$
- Detection at $\lambda_{obs} > 100\mu m$

Derived sample: 6 sources
- $2.5 < z < 4.7$
- 260–2000 counts in the 7–Ms CDF–S, $(2< L_{2–10keV} < 6) \times 10^{44} \text{ erg s}^{-1}$
- $SFR \sim 10^{2–3} M_{\odot}/yr$
- $M_{\ast} \sim 10^{11} M_{\odot}$
Three sources have been detected

### Gaussian fitting of the lines

<table>
<thead>
<tr>
<th>XID</th>
<th>$v_0$ (km/s)</th>
<th>FWHM (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>$498 \pm 14$</td>
<td>$368 \pm 32$</td>
</tr>
<tr>
<td>403</td>
<td>$-56 \pm 33$</td>
<td>$308 \pm 77$</td>
</tr>
<tr>
<td>490 (Blue c.)</td>
<td>$-194 \pm 26$</td>
<td>$474 \pm 67$</td>
</tr>
<tr>
<td>490 (Red c.)</td>
<td>$187 \pm 12$</td>
<td>$162 \pm 27$</td>
</tr>
</tbody>
</table>

**XID 34:** The velocity peak is $\sim 500$ km/s shifted wrt the rest-frame velocity at the spectroscopic redshift.

**XID 490:** Double-peaked line, likely Doppler effect.
Moments of the line

Considered channels: $\nu_0 \pm \text{FWHM}$

Image pixels $> 3\sigma$
Image sizes $\sim 2.7''$
Continuum images

XID 34

XID 403

XID 490
XID 34: Merger?

Displacement by $\sim 0.2''$ in the North direction between the center of the dust emission and the stellar bulk in UV band.

The shift of CO rest–frequency wrt optical spectrum rest–frequency can be explained as an intrinsic different motion velocity between the two regions.

V–band ($\sim 600$ nm) HST image

Green contours: ALMA continuum @3$\sigma$
Image size: $0.6 \times 0.9$ arcsec
Data fitting – Procedure

Fitting model: 2–D Gaussian

Dust: Continuum

Image fitting

Emission and size input parameters

Visibility fitting

CO: Moment 0

Dust
Flux density
Major axis
Axial ratio

CO
Flux density
Major axis
Axial ratio
Size of the sources

Assumptions

- **Undetected sources**: Size = mean of the detected sources, Error on $a = 30\%$, Error on $b = 50\%$
- **XID 490 dust $b$**: XID 490 dust $b$: Unconstrained by the fitting, assuming $R = 0.8$ (from the non–deconvolved image fitting), Error on $R = 50\%$

Size gas > Size dust
Gas mass - Different approaches

\[ \text{CO} \quad S_{(A-B)} \quad F_{(A-B)} \quad L'_{(A-B)} \quad \text{CO-SLED} \]

SMG
QSO
(Carilli&Walter+13)

\[ L'_{(1-0)} = 3.02 \times 10^{-21} L_{850 \mu m} \]
(Scoville+16)

\[ 0.8 \, M_\odot \, (\text{K km/s pc}^2)^{-1} \]

\[ L'_{(1-0)} \quad \alpha_{CO} \quad M_{H2} \]

Gray-body in optically thin regime
\[ S_v \propto B_v (T_d) \tau_v \]
\[ \tau_v \propto \nu^\beta, \beta = 2 \]

Dust
\[ S_{obs} \quad \text{Emission Model} \quad L_{850 \mu m} \quad L_{850 \mu m} \propto L'_{(1-0)} \]
Gas mass

Undetected sources

Upper limits at the 3σ level measured on the images for both the line and continuum emissions.

\[ M_{\text{DUST}}^{H_2} > M_{\text{CO-SLED}}^{H_2} \]

\[ M_{\text{SMG}}^{H_2} > M_{\text{QSO}}^{H_2} \]
Geometrical models – Sphere

Goal: comparison with the rotating disk model

\[ d = \frac{a_G + b_G}{2} \]
Geometrical models – Rotating disk

\[ b_D = a_D \cos(i) + h_D \sin(i) \]
\[ b_G = a_G \cos(i) + h_G \sin(i) \]

\[ i_\pm = \pm \cos^{-1} \left( \frac{b_G - b_D}{a_G - a_D} \right), \quad h_\pm = \frac{b_G - a_G \cos(i_\pm)}{\sin(i_\pm)} \]

XID 403: \( i = -41^{+84}_{-60}^{\circ}, \ h < 1.68 \text{ kpc}, \ h/a < 0.8 \ @1\sigma \)

XID 490: \( i = -81^{+52}_{-53}^{\circ}, \ h = 0.8^{+0.6}_{-0.6} \text{ kpc}, \ h/a < 0.38^{+0.29}_{-0.28} \)
Column density

Notes

- $N_{HX}$ from X–ray spectral fitting
- Upper limits at the 3σ level

$N_{HX}$ and $N_{H_{ISM}}$: same order of magnitude

host ISM can significantly contribute to the obscuration of the central AGN
**Dust mass and temperature**

<table>
<thead>
<tr>
<th>XID</th>
<th>T (K)</th>
<th>$M_d$ (10$^8$ $M_\odot$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>262</td>
<td>71</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>412</td>
<td>80</td>
<td>&lt; 0.9</td>
</tr>
<tr>
<td>34</td>
<td>55</td>
<td>4.9 ± 0.7</td>
</tr>
<tr>
<td>403</td>
<td>65</td>
<td>4.8 ± 0.5</td>
</tr>
<tr>
<td>546</td>
<td>65</td>
<td>&lt; 1.5</td>
</tr>
<tr>
<td>490</td>
<td>69</td>
<td>4.2 ± 0.5</td>
</tr>
</tbody>
</table>

**Temperature**

Single temperature (error $\approx \pm 5$ K), gray body IR–SED fitting:

$$S_\nu \propto B_\nu(T_d)\tau$$

$$\tau \propto \nu^\beta, \; \beta = 2$$

**Mass**

$$M_d = \frac{D_L^2 S_{obs}}{k_\nu B_\nu(T_d)(1 + z)}$$

$$k_\nu \propto \nu^\beta, \; \beta = 2$$
Dynamical mass

\[ M_{\text{dyn}} \sin^2 i = 6.5 \cdot 10^4 \left( \frac{\text{FWHM}}{\text{km s}^{-1}} \right)^2 \left( \frac{a}{\text{kpc}} \right) M_\odot \] (Wang+13, Calura+14)

Assuming \( v_{c,\text{max}} = 0.75 \text{FWHM} \)

XID 403: \( M_{\text{dyn}} \sin^2 i = 1.8^{+1.7}_{-0.9} \times 10^{10} M_\odot \) (Coppin+10, De Breuk+14)

XID 490: \( M_{\text{dyn}} \sin^2 i = 1.4^{+0.3}_{-0.3} \times 10^{10} M_\odot \)

\[ M_{\text{bar}} = M_* + M_{H_2} + M_{HI} \approx 10^{11} M_\odot, \sim 10 M_{\text{dyn}} \sin^2 i \]
\( M_* \) from SED fitting, \( M_{HI} \sim M_{H_2}/5 \) (Calura+14)

For \( M_{\text{dyn}} \approx M_{\text{bar}} \rightarrow |i| \lesssim 10^\circ, h \gtrsim 6 \text{ kpc} \) UNREALISTIC

Possible causes

- Underestimate \( M_{\text{dyn}} \sin^2 i \) conversion factor
- Different CANDELS/HST emitting region size wrt ALMA
- Uncertainty on position of \( v_{c,\text{max}} \), underestimate \( a \) due to low sensitivity
Conclusions and future perspectives

- Sources have $M_{H_2} \sim 10^{10} \, M_\odot$ and $M_d \sim 10^8 \, M_\odot$ confined in few kpc scale.
- The host galaxy ISM can significantly contribute to the obscuration of the central AGN for both spherical and disk model. $N_{ISM}^{SMG}$ is more consistent with $N_{Hx}$ than $N_{ISM}^{QSO}$.
- Rotating systems and one possible merger.

- Future observations at better resolution ($< 0.1''$) and higher sensitivity ($\sim 6$ h exposure to halve the current sensitivity) would drastically reduce the uncertainties on the physical quantities derived in this work.
- XID 403: CO–SLED coupling measured CO(7–6) with CO(2–1) by Coppin+2010 and CO(12–11) by Nagao+12 (upper limit).
San Giovanni in Monte complex
Registration (opening soon)

THANKS FOR YOUR ATTENTION