AGN & host galaxy scaling relations

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Work done in collaboration with:
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Malizia, Molina @ OAA
Marconi, Maiolino et al.

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Main scenario of Galaxy and AGN early assembly

- low density filaments feed high density regions
- merging events (@ z~10 )
- galaxies and SMBH form
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Hydro-simulation, Pallottini et al. 2017, courtesy A. Pallottini
ADLA at $z=5.939$ detected towards $z=6.0025$ QSO J2310+1855

Becker et al. (2012) 9 absorption systems at $4.7 < z < 6.3$

Very metal poor, nearly pristine gas

$[\text{Fe/H}] = -3.08 \pm 0.12$  
$[\text{Si/H}] = -2.86 \pm 0.14$
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**Serenity-18: the Rosetta Stone of galaxy formation**

D’Odorico, CF + 2018 ApJL, 863, 29

**Most sensitive ALMA observation of a QSO at cosmic dawn**

Detection of CO(6-5)-emitting galaxy at z=5.939

**QSO J2310+1855**

Redshift

2746 km/s

5.939

40 kpc

**DLA**

Serenity-18

**ALMA J231038.44+185521.95**

<table>
<thead>
<tr>
<th>RA (J2000)</th>
<th>DEC (J2000)</th>
<th>Redshift of CO(6-5) emission</th>
<th>Impact parameter [arcsec]</th>
<th>FWHM$_{CO(6-5)}$ [km/s]</th>
<th>$\int S_{CO(6-5)} d\nu$ [Jy km/s]</th>
<th>$L'CO(6-5)$ [K km/s pc$^2$]</th>
<th>M(H$<em>2$) [M$</em>\odot$]</th>
<th>$M_{dust, sin(i)}$ [M$_\odot$]</th>
<th>$L_{IR}$ [L$_\odot$]</th>
<th>SFR [M$_\odot$/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>23:10:38.44</td>
<td>18:55:21.95</td>
<td>5.939757</td>
<td>6.7</td>
<td>155 ± 30</td>
<td>0.06 ± 0.012</td>
<td>$(2 \pm 0.4) \times 10^9$</td>
<td>$5.4 \pm 0.5 \times 10^8$</td>
<td>&lt; $5.6 \times 10^9$</td>
<td>\approx 10$^{14}$</td>
<td>\approx 115</td>
</tr>
</tbody>
</table>
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Detection of CO(6-5)-emitting galaxy at z=5.939
Main questions

- Relation SF-AGN feedback, quenching vs enhancement
- Agent(s) of AGN feedback (winds vs jets)
- Physical scales affected
- Net effect on host galaxy
AGN & host galaxy co-evolution

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- **Cold molecular gas (H2) - site of star formation**
- Warm ionised gas
- Stars within outflows
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**Molecular emission lines** CO, HCN, … also [CII] …
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Methods
Scaling relations between
\[ \dot{M}, \dot{M}/SFR, M(H_2)/M^*, t_{\text{depl}} \]
and \[ M^*, L_{\text{AGN}}, M_{\text{BH}}, \lambda_{\text{Edd}} \]

- Need unbiased AGN samples • IbisCO : low z AGN
  • SUPER : z~2-3 AGN
Molecular gas fraction $F_{\text{gas}} = \frac{M(\text{H}_2)}{M^*}$ probes the richness of gas available for SF

Molecular Gas fraction $\frac{M(\text{H}_2)}{M^*}$ strong function of $z$

Genzel+2015, Tacconi+2018

Star Forming galaxies
Molecular gas fraction $F_{\text{gas}} = \frac{M(H_2)}{M^*}$ probes the richness of gas available for SF.

Molecular gas fraction $\frac{M(H_2)}{M^*}$ is a strong function of $z$.

After correcting offset from MS and $z$, mass quenching occurs.

$\frac{M(H_2)}{M^*}$ is reduced at high $M^*$, suggesting AGN feedback at play.

Star forming galaxies are depicted in the diagram.
Unbiased survey of H$_2$ reservoirs & outflows in AGN host galaxies

- 60 Hard X-ray 20-100 KeV AGN from the **IBIS Integral survey** unbiased against nuclear obscuration
  - L$_x$ > 10$^{43}$ erg/s
  - z < 0.05
  - Accurate BH masses
  - M*, SFR

Several Seyferts from Maiolino+1997 and other works

Reaches fainter flux limits than BASS survey - **Sample of NLSy1**
IbisCO survey: Observations

• **@IRAM 30m:** CO (1-0) & (2-1) - Gas reservoirs & outflows
  P.I. Feruglio - 70 hours survey completed 2017 - 80% detection rate

• **@ALMA band 6:** map CO with 50 pc resolution - P.I. Feruglio (cycle 5)

• **@INTEGRAL, NuSTAR, XMM:** X-ray spectra - P.I. Malizia
  ——> Lx, N_H, Ṁ_{ACC} + WA, UFO

• + ancillary data from CALIFA, Manga: SFR, M*, M_{BH}
  • Stellar Masses: Koss+2011, other literature, all corrected to match beam size
  • Beam 30m size (21") probes different galaxy fractions at different z
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IbisCO sample properties

IbisCO  \[ 43 < \log L_{\text{bol}} < 45.5 \]
\[ 9 < \log M^* < 11.4 \]

SUPER  \[ 44 < \log L_{\text{bol}} < 47 \]
\[ 9.5 < \log M^* < 11.4 \]

PG QSO  (Shangguan & Ho 2018)  
\[ 45 < \log L_{\text{bol}} < 47 \]
\[ 10 < \log M^* < 11.6 \]

Feruglio in prep.
IbisCO survey: gas fractions

Molecular gas fraction $F_{\text{gas}} = \frac{M(H_2)}{M^*}$ probes the richness of gas available for SF

- Molecular gas fraction of IbisCO host galaxies
- $L(\text{CO}) - M(\text{H}_2)$
  Conversion factor
  $= 3.2 \, M_\odot \, \text{K}^{-1} \, \text{km/s} \, \text{pc}^{-2}$
  for all
- Metallicity dependence not yet included (can be refined)
- Similar to COLDGASS
  Saintonge+2011/17

IRAM30m observations + Maiolino+1997 + others
Feruglio in prep.
IbisCO survey: $F_{\text{gas}}$ vs $M^*$

- Do AGN have smaller $F_{\text{gas}}$ than Main Sequence SF galaxies?

- Normalized Gas Fraction consistent with SF galaxies
  - Several have $F_{\text{gas}} \sim 3$-10 times smaller
  - Larger scatter at high $M^*$
  - NLSY1 in lower $M^*$ hosts
IbisCO survey: $F_{\text{gas}}$ vs $M^*$

- Do AGN have smaller $F_{\text{gas}}$ than Main Sequence SF galaxies?

- Normalized Gas Fraction consistent with SF galaxies

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AGN with massive outflows do have smaller $F_{\text{gas}}$

Why?
- FF17 biased sample
- FF17 $F_{\text{gas}}$ - outflow regions matched
- single dish $F_{\text{gas}}$ diluted by outer galaxy

Fiore+2017
Menci + 2018 blast model

Biased sample:
Possible to measure strong outflows only if OF projected velocity is $\geq$ disk velocity
Normalized Gas Fraction: no trend with $L_{bol}$ or $L_{bol}/L_{Edd}$

- NLSY1 gas fraction larger than CT AGN
- NLSY1 larger $L_{bol}/L_{Edd}$ than CT AGN

Samples: PG QSO Shangguan & Ho 2018 - IR selected Kirkpatrick+14 - Brusa+18, Kakkad+17, Vayner+17, …
IbisCO survey: \( F_{\text{gas}} \) vs \( L_{\text{bol}}/M^* \)

Normalized Gas Fraction vs AGN Specific Accretion Rate

- No trend
- Large scatter
- CT AGN on average lower specific accretion rates than NLSy1 and average IbisCO

Feruglio in prep.
Conclusions

- AGN gas fractions similar to those of MS galaxies with similar masses (e.g. COLDGASS)

- Large scatter. Many outliers! both in IbisCO and other samples, with factor 3-10 smaller gas fraction

- For IbisCO the outliers are found when sampling the inner part of the galaxy

- No strong dependencies between gas fraction and AGN properties ($L_{\text{bol}}$, $L_{\text{bol}}/L_{\text{Edd}}$, specific accretion rate)