Characterizing obscured AGN in powerful outflow hosts using mid-IR spectral diagnostics

Avani Gowardhan
Cornell University

In collaboration with:
Henrik Spoon (Cornell)
Dominik Riechers (Cornell)
Duncan Farrah (Virginia Tech.)
AGN feedback is important!

AGN-driven feedback in massive galaxies is invoked to explain observations like the:

- Black-hole bulge co-evolution
  
  see Kormendy & Ho, 2013

- Downturn of the galaxy mass function

Feedback

Houck et al, 2004

Dust-rich, IR-luminous ULIRGs

Optically luminous, unobscured quasar

Dead elliptical
AGN feedback via outflows

Neutral, ionized and molecular gas outflows known

Galaxy-wide, molecular gas outflows — long-term impact on SF by quenching

Redshifted emission

Blueshifted absorption

OH 119 μm doublet P-cygni profiles are an outflow signature!

Credits: ESA/AOES Medialab

e.g Rupke et al. 2005, Fischer et al 2010
AGN drive faster molecular outflows

$v_{\text{max}}$ increases with $L_{\text{AGN}}$

maximal outflow velocity

Increasing AGN luminosity

*starburst AGN composite*

e.g. Sturm et al., 2011, Spoon et al. 2013
And more massive outflows

$M_{\text{out}}$ increases with $L_{\text{AGN}}$ and $L_{\text{AGN}}/L_{\text{bol}}$
The most extreme outflows in the local universe

Follow up in CO(1-0)!

- Bulk of molecular gas
- Not line-of-sight
- Spatial Resolution

Atacama Large (sub)millimeter Array (ALMA)

Plateau de Bure Interferometer (PdBI)

Spoon et al. 2013
High-velocity outflow wings seen in CO(1-0)

IRAS 20100-4156
Maximal outflow velocity $\sim 1600$ km/s

IRAS 03158+4227
Maximal outflow velocities $\sim 1700$ km/s

Gowardhan et al 2017 in prep
High-velocity outflow wings seen in CO(1-0)

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High-velocity outflow wings seen in CO(1-0)

Maximal outflow velocity ~ 1600 km/s

Mass outflow rate: 2310 (M_⊙/yr)
SFR : < 215 (M_⊙/yr)

Maximal outflow velocities ~ 1700 km/s

Mass outflow rate: 1110 (M_⊙/yr)
SFR : < 125 (M_⊙/yr)
High-velocity outflow wings seen in CO(1-0)

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Are these powered by AGN or nuclear starburst?

Gowardhan et al 2017 in prep
Mid-IR spectroscopy offers numerous ways to get the AGN fraction in dust-obscured nuclei.
Mid-IR diagnostics for AGN fraction

- AGN-heated dust $\rightarrow$ flatter mid-IR slope $\rightarrow f_{15}/f_{30}$

- Decomposition of 5-8 $\mu$m mid-IR spectra into starburst and AGN templates

Veilleux et al. 2009

Nardini+09, 10; pvt comm.
Comparing different AGN estimators

\( f_{15}/f_{30} \) method systematically overestimates \( f_{\text{AGN}} \)

Mid-IR decomposition works better

Our two sources are NOT AGN-dominated

Gowardhan et al 2017 in prep
Outflow energetics

\( \mathcal{L}_{\text{AGN}} \) insufficient to power outflows, need \( \mathcal{L}_{\text{SFR}} \)

\[
\dot{E}_{\text{tot}} \sim 0.05 \mathcal{L}_{\text{AGN}}
\]

\[
\dot{E}_{\text{tot}} \sim 0.05 \mathcal{L}_{\text{IR}}
\]

Increasing AGN luminosity   Increasing IR luminosity

Gowardhan et al 2017 in prep
Conclusions and future work

- We have spatially resolved the 2 most massive galaxy wide (~kpc) scale outflows (~x 1000 $M_\odot$/yr) in the local universe.

- No dominant AGN contribution; powered by powerful nuclear starbursts, based on mid-IR diagnostics.

Next steps:

- JWST (MIRI and NIRSPEC) for $H_2$ ro-vibrational lines, Ne[V], Ne[VI] lines, and spatially resolved outflow mapping on ~pc scales.
Outflow energetics

$L_{\text{AGN}}$ insufficient to power outflows, need $L_{\text{SFR}}$

SDSS J0905157, $z \sim 0.7$

Compact nuclear starburst driving an outflow, $v \sim 1000$ km/s, mass outflow $\sim 250 \, M_\odot/yr$

Gowardhan et al. 2017 in prep

Geach et al. 2014
Comparing different AGN estimators

\(f_{15}/f_{30}\) method systematically overestimates \(f_{\text{AGN}}\)

Mid-IR decomposition works better

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Gowardhan et al 2017 in prep
P-cygni profiles

OH 119 μm profiles show deeper absorption/higher $v_{\text{max}}$ than Mrk 231 (red)
The energetics become more consistent with the modification of alpha to more reasonable numbers, as suggested by Richlings et al 2017.
Mid-IR diagnostics for AGN fraction

Veilleux et al. 2013, Nardini+09, 10; pvt comm.
Spectral Energy Distribution (SED) fitting