Dissecting AGN feedback: the extraordinary multi-phase outflow in the NLSy1 IRAS17020+4544

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AGN feedback via AGN winds?

Outflows may provide the connection between BH and host galaxies required to reconcile theory & observations

Hydrodynamical simulations of galaxy mergers require SF to be regulated by BH feedback  

\textit{Di Matteo et al. 2005}

If the power of AGN feedback is equivalent to a tiny fraction of the AGN luminosity (0.5–5%), this process can regulate the growth of the galaxy by altering its star formation  

\textit{Hopkins & Elvis 2010}

\[ M_{\text{BH}} - \text{Stellar vel dispersion} \]

\[ \log(\phi/L) M_\odot \text{ Mpc}^{-3} \text{ mag}^{-1} \]

Bower et al. 2006

Luminosity function of galaxies

Without AGN feedback

With AGN feedback

(Cole et al. 2001)  

(Huang et al. 2003)

\[ M_k - 5\log h \]

\[ \sigma \text{ (km/s)} \]

(Kormendy & Ho 2013)
Wind Output Rate: Ultra Fast Outflows (UFO) vs Warm Absorbers

Outflow velocity makes the difference (not only in the name!):

\[ \dot{M}_{out} \sim \Omega \, N_H \, m_p \, v_{out} \, R_{in} \]

<table>
<thead>
<tr>
<th>Mass outflow rate</th>
<th>Solid angle</th>
<th>Column density</th>
<th>Outflow velocity</th>
<th>Launching radius</th>
</tr>
</thead>
</table>

Mechanical power of the wind depends strongly on wind velocity: if this kinetic energy rate amounts to 0.5-5% of the AGN radiative luminosity, the outflow is able to blow out the galaxy gas at large scale and quench its star formation.
2015: Golden year for AGN fast winds

Several new discoveries, most of all supported by evidence for multi-phase AGN outflows

Nardini+2015

P-Cygni-like profile
Wide-angle wind, feedback on host galaxy

PDS456

Molecular winds at Kpc-scale

Tombesi et al. 2015

Connection of X-ray fast wind and massive molecular outflows follows the prescription of an energy driven outflows (momentum not constant)

see also Cicone et al. 2014

Mrk 231

Nuclear Disk Winds

Feruglio et al. 2015

The relation of the momentum flux for the two wind phases suggests that the nuclear wind is driving the giant molecular outflow

Longinotti+2015

Warm absorber features (slower winds)

Multi-component UFO in NLSY IRAS17020
First view of an UFO at X-ray high-resolution reveals a stratified, multi-component wind.
Fast + Slow winds with complex velocity pattern in IRAS17

5 UFO distinct components wide range of ionization and N$_H$ outflowing at same velocity $\sim$30,000 km/s (Longinotti et al. 2015)

4 components of warm absorber with “standard” velocities $10^2$-$10^3$ km/s variable inflow/outflow between XMM 2004-2014 (Sanfrutos et al. 2018)

Unusual feedback properties in the X-ray multi-component fast wind later observed in other NLSy1:
- IRAS13224-3809 Parker et al 2017
- PG1211+143 Reeves et al 2018
- Mrk 1044 Krongold et al submitted

- IRAS17020+4544 host galaxy is a barred Spiral
- $L_{\text{bol}} \sim 5 \times 10^{44}$ erg s$^{-1}$ (not as QSO, ULIRG)
- No evidence of merger/disturbed morphology/dust obscuration
- Small black hole $\sim 6 \times 10^6$ M$_\odot$ and High M
Chandra LETG look at IRAS17020+4544 (250 ks)

RGS UFO+WA best fit model (2014) overlapped on 2017 Chandra data: confirms absorption structure

Longinotti+ in prep.
Evolution of the slow wind in IRAS17020+4544

-Slow Wind components 3 and 4 decreased their velocity
-Fast wind seems persistent (confirmed by Chandra’s look in 2017)
-Source luminosity stays constant

How can we explain co-existence of a stable UFO with a variable warm absorber without continuum flux variations?

### XMM 2014

<table>
<thead>
<tr>
<th>Component</th>
<th>$\log U$</th>
<th>$\log N_H^a$</th>
<th>$\nu_{\text{turb}}^b$</th>
<th>$\nu^c$</th>
<th>$\Delta C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA 1 (rest)</td>
<td>$-1.88^{+0.03}_{-0.02}$</td>
<td>$21.09^{+0.01}_{-0.01}$</td>
<td>$160 \pm 30$</td>
<td>$-320 \pm 70$</td>
<td>530</td>
</tr>
<tr>
<td>WA 2 (rest)</td>
<td>$-0.57^{+0.05}_{-0.04}$</td>
<td>$21.12^{+0.03}_{-0.04}$</td>
<td>$&lt;40$</td>
<td>$-430 \pm 90$</td>
<td>120</td>
</tr>
<tr>
<td>WA 3 (outflow)</td>
<td>$-2.47 \pm 0.02$</td>
<td>$20.93 \pm 0.01$</td>
<td>$&lt;40$</td>
<td>$2300 \pm 200$</td>
<td>90</td>
</tr>
<tr>
<td>WA 4 (inflow)</td>
<td>$0.35^{+0.11}_{-0.16}$</td>
<td>$20.84^{+0.16}_{-0.14}$</td>
<td>$100 \pm 60$</td>
<td>$-1750 \pm 250$</td>
<td>24</td>
</tr>
<tr>
<td>UFO 1</td>
<td>$-2.47^{+0.15}_{-0.19}$</td>
<td>$20.10^{+0.06}_{-0.09}$</td>
<td>$50^f$</td>
<td>$26900 \pm 200$</td>
<td>27</td>
</tr>
<tr>
<td>UFO 2</td>
<td>$2.63^{+0.11}_{-0.13}$</td>
<td>$23.70 \pm 0.15$</td>
<td>$50^f$</td>
<td>&quot;</td>
<td>7</td>
</tr>
<tr>
<td>UFO 3</td>
<td>$-0.35^{+0.12}_{-0.19}$</td>
<td>$20.4^{+0.2}_{-0.4}$</td>
<td>$50^f$</td>
<td>$24100 \pm 100$</td>
<td>5</td>
</tr>
<tr>
<td>UFO 4</td>
<td>$-1.22^{+0.05}_{-0.03}$</td>
<td>$20.85^{+0.03}_{-0.06}$</td>
<td>$50^f$</td>
<td>&quot;</td>
<td>4</td>
</tr>
</tbody>
</table>

### XMM 2004

<table>
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<tr>
<th>Component</th>
<th>$\log U$</th>
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<th>$\nu^c$</th>
<th>$\Delta C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA 1 (rest)</td>
<td>$-2.10^{+0.07}_{-0.06}$</td>
<td>$21.01^{+0.03}_{-0.11}$</td>
<td>$170 \pm 60$</td>
<td>$-380 \pm 160$</td>
<td>100</td>
</tr>
<tr>
<td>WA 2 (rest)</td>
<td>$-0.57^{+0.08}_{-0.11}$</td>
<td>$21.25^{+0.11}_{-0.20}$</td>
<td>$&lt;50$</td>
<td>$-490 \pm 110$</td>
<td>61</td>
</tr>
<tr>
<td>WA 3 (outflow)</td>
<td>$-2.81^{+0.07}_{-0.19}$</td>
<td>$20.88^{+0.03}_{-0.03}$</td>
<td>$&lt;60$</td>
<td>$4000 \pm 200$</td>
<td>34</td>
</tr>
<tr>
<td>WA 4 (inflow)</td>
<td>$-1.3^{+0.3}_{-0.4}$</td>
<td>$20.6^{+0.2}_{-0.4}$</td>
<td>$110 \pm 70$</td>
<td>$-2900 \pm 200$</td>
<td>14</td>
</tr>
<tr>
<td>UFO 1</td>
<td>$-2.2^{+0.3}_{-0.2}$</td>
<td>$20.4 \pm 0.2$</td>
<td>$50^f$</td>
<td>$28500 \pm 1000$</td>
<td>9</td>
</tr>
<tr>
<td>UFO 2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>UFO 3</td>
<td>$-0.30^{+0.05}_{-0.07}$</td>
<td>$21.27^{+0.15}_{-0.19}$</td>
<td>$50^f$</td>
<td>$23900 \pm 100$</td>
<td>36</td>
</tr>
<tr>
<td>UFO 4</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

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Can shocked outflow model explain IRAS17?

Fast outflow radiatively launched at accretion disk scale at $v_{\text{out}} \geq 10^4$ km/s

The wind shocks with the ambient medium producing two shock fronts separated by a contact discontinuity

The shocked ambient gas could decelerate to velocity of the order of 100 km/s, the wind shock (reverse) maintains its high velocity while entraining the ambient gas and pushing it further out

The density of the impacting wind and of the impacted medium are different

King 2010
Faucher-Giguere & Quataert 2012
Zubovas & King 2012
King & Pounds 2015
Simulated shocked outflow with instabilities

3-D numerical hydrodynamical simulation

Mean density of outer medium: 1/cm$^3$

BH mass: $10^6$ M$\odot$ (IRAS17 M$_{BH}$)

Density gradient (in and out of the shock) induce Rayleigh-Taylor instability that keeps slowing down shocked gas (similar to SN remnants)

Expanding shock pushed within a turbulent medium by an inner wind with $V_{out}=20,000$ km/s

Expansion time: 20 yr

Sim by P. Velazquez, based on GUACHO code


(Instituto de Ciencias Nucleares, UNAM)
Shocked outflow with instabilities may explain multi-velocity wind components

Our line-of-sight crosses several “fingers” of gas with different $V_{out}$

Work in progress on column density and temperature (ionization) distribution

Longinotti 2018 1808.01043
Let’s leave the nuclear region and see what’s happening in the host galaxy…

**multi-phase winds!**

suggesting that an AGN-driven wind may be affecting the galaxy at large scales
Connection

X-ray disk wind with Molecular Outflow

The LMT detects unexpected and powerful outflow of molecular gas in a distant active galaxy similar to the Milky Way.
Connection X-ray-Molecular Outflows in IRAS17

Longinotti et al. 2018 ApJL

<table>
<thead>
<tr>
<th>Component</th>
<th>FWHM [km s(^{-1})]</th>
<th>Centroid [km s(^{-1})]</th>
<th>Integrated Intensity [mK km s(^{-1})]</th>
<th>(L_{\text{CO}}) ((\times 10^8))</th>
<th>(M_{\text{CO}}) ([10^8 \text{ M}_\odot])</th>
<th>(\alpha) (CO-to-H(_2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad wing</td>
<td>1112</td>
<td>-660</td>
<td>798(\pm)252</td>
<td>3.08(\pm)0.97</td>
<td>1.54(\pm)0.49</td>
<td>0.5</td>
</tr>
<tr>
<td>Line A</td>
<td>213</td>
<td>-51</td>
<td>1390(\pm)114</td>
<td>5.37(\pm)0.44</td>
<td>4.62(\pm)0.38</td>
<td>0.86</td>
</tr>
<tr>
<td>Line B</td>
<td>210</td>
<td>233</td>
<td>1171(\pm)110</td>
<td>4.53(\pm)0.42</td>
<td>3.89(\pm)0.36</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Rotational transition of the carbon monoxide molecule (CO J = 1-0)
~108GHz

LMT -RSR Spectrum

Broad wing
-660 to -1600 km/s
Connection X-ray-Molecular Outflows in IRAS17

\[ \dot{M}_{\text{of}} = 3 \times \frac{v_{\text{max,of}} \times M(\text{H}_2)_{\text{of}}}{R_{\text{of}}} \]

The momentum flux of the wind is related to the velocity with which the gas is pushed outward.

The relative proportion of the wind momentum and of the radiation force at nuclear scale (X-ray) and at galaxy scale (CO gas) determines if the wind is momentum-conserving or energy-conserving.

\[ \frac{\dot{P}_{\text{[CO]}}}{\dot{P}_{\text{[X]}}} = \frac{v_{\text{out-X}}}{v_{\text{out-CO}}} \]
NOEMA confirms Energy Driven outflow in IRAS17


How many source of uncertainties? Many!

- Mass outflow rates (outflow velocity, M[CO], CO-to-H2 conversion factor)
- Wind spatial extent and geometry
- Bolometric luminosity

….mitigated in our new interferometry data
IRAS17: NOEMA interferometry view of molecular gas from the galaxy

- Velocity integrated CO 1-0 emission map
- Line integrated on vel range of 760 km/s (no outflow, CO distribution consistent with rotation in the galaxy)
- Spectrum extracted from the region with signal above 2σ

Q. Salomé in prep.
IRAS17: NOEMA interferometry view of the molecular outflow

- Line integrated on a velocity range of ~1600 km/s
- Outflow in the velocity integrated CO map detected at 6.5σ, spatial scale ~3kpc
- Possibly two velocity components

Preliminary Courtesy of Chiara Feruglio

Credit: A. Olguin-Iglesias, Longinotti+ in prep.
Radio Properties of IRAS17: consistent with shocks?

*Giroletti et. al 2017 A&A*

**VLBA Observations in 2000 and 2014**
- Compact bright core, secondary fainter component
- Steep spectral index possibly synchrotron (shocks?)
- Elongated jetted structure /outflow at ~10 pc scale
- Possible connection with X-ray outflow?

\[ P_{1.4 \, \text{GHz}} = 10^{24} \, \text{W Hz}^{-1} \quad T_b = 10^8 \, \text{K} \]

**Ongoing work…**

*VLBA Observations in 2017*
- Source resolved in 3 components
- No clear core detected
- No expansion detected
- Radio source on RQ—RL threshold
- Origin of radio emission still unclear
Voigt profile fits (1σ error bars)

Absorption near the inflow velocity of $\sim 300$ km s$^{-1}$ was detected clearly in the Ly$\alpha$ and NV transitions. Agreement with X-ray slow winds in shocked outflow?

Other weaker lines are possibly present at -1000 and 1700 km/s

No detection of UFO UV counterpart: possibly too shallow (low ionization X-ray winds have low NH), or non-simultaneity

Conclusions and outlook

The Narrow Line Seyfert Galaxy IRAS17020+4544 has proved so far to be an excellent laboratory to dissect, track and possibly understand the effect of a powerful nuclear X-ray wind during its encounter and journey through the interstellar medium.

This extensive multi-wavelength campaign was addressed to follow the evolution of the shocked outflow initiated by this wind in its propagation at larger scale.

We will seek other observations to corroborate the outflow properties (IFU for the ionized gas, additional radio and X-rays data, and future X-rays High-res instruments).

…but other sources?

“SUBWAYS” Poster #405 by Marcella Brusa
Thanks for your attention!

Pico de Orizaba
5740 m; 18832 ft

LMT
Volcán Sierra Negra
4600m; 15091 ft

Credit: R.J. Terlevich