AGN feedback

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AGN feedback

- Mechanism of AGN feedback
- Ionized gas
- Extreme ionized gas outflows at high z
- Sunyaev-Zeldovich effect
- Quasar winds and radio emission
1. Mechanism of AGN feedback

- On small scales: radiation pressure winds, jets
- Slams into surrounding gas
- Drive shocks, outflows into interstellar medium
- Morphology of wind critically depends on ISM structure, not on input morphology!
- Produces outflows $\sim 1000$ km/sec
- Quasar needs to be luminous enough to push gas out of galaxy ($>3\times10^{45}$ erg/sec, Veilleux et al. 2013, Zakamska & Greene 2014, King)

Murray et al. 1995, Proga et al. 2000
Equatorial disk winds

Gaibler et al., Begelman & Cioffi
growth of jet cocoon
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Wagner et al. 2013
Spherically symmetric models: King, Faucher-Giguere & Quataert:
typical velocities at large scales of 1000 km/sec.
2. Observations: ionized gas

Gas at several kpc from the nucleus, ionized by the quasar should be observable.

Focusing on radio-quiet type 2 quasars (no jets)

Liu, Zakamska, et al. 2013ab, 2014 based on Gemini IFU data, $L_{\text{bol}}>10^{46}$ erg/sec

Large widths, large asymmetries, on galaxy-wide scales

If quasi-spherical outflow, then $v \sim 800$ km/sec

Type 1 = unobscured
Type 2 = obscured

"Geometric unification model"
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FWHM=1800 km/sec
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  - Liu, Zakamska, et al. 2013ab, 2014 based on Gemini IFU data, $L_{\text{bol}}>10^{46}$ erg/sec
  - Large widths, large asymmetries, on galaxy-wide scales
  - If quasi-spherical outflow, then $v \sim 800$ km/sec
Now seen by several groups in type 1 and type 2 quasars (e.g., Harrison et al., Rupke & Veilleux, Husemann et al., Villar-Martin et al., Hainline et al., Alexander et al., Cano-Diaz et al., Carniani et al., Perna et al., etc.)
3. Extreme outflows at high z

z>2: the peak galaxy formation epoch, perhaps key point in evolution of massive galaxies

Population of red quasars at z=2.5 with unusual optical properties (Ross et al. 2015)

NIR / rest-frame optical spectra

Extreme broadening of emission lines

Physical velocities of >3000 km/sec.

Nothing like this seen at low z, perhaps a luminosity effect?
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Probing geometry of these outflows with spectropolarimetry observations

Poster by Rachael Alexandroff

4. Sunyaev-Zeldovich effect from quasar feedback

Models predict invisible, low-density, extremely hot component

Overpressured bubble

Use ACT and Herschel data to construct stacked SEDs of 20,000 quasars

Look for Sunyaev-Zeldovich effect

We have a detection!

\[ \int PdV = fL_{bol}\tau \]

\( f=15\% \) (\( \tau=10^8 \) years).

Crichton et al. 2016
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5. The nature of the radio emission in RQ quasars

Distribution of radio power is very broad

many (>5) orders of magnitude (faint end hard to probe)

Is it a smooth or a bi-modal function?

Is the mechanism of production of radio emission the same (just scaled up and down) or different?

Why do we care? – Is every black hole capable of producing a jet? Or are jet-producing BH special?

Ivezic et al. 2002
distribution of radio-to-optical ratios

Kimball et al. 2011

Galaxies
z<0.05

Star forming
AGN
Total

Quasars
0.2< z <0.3
5. The nature of the radio emission in RQ quasars

What is the origin of the radio emission in RQ quasars?

Star formation insufficient by a factor of 10.

Zakamska et al. 2016
5. The nature of the radio emission in RQ quasars

New evidence: Correlation between line width (=outflow velocity) and radio luminosity

These are “the 90%”: faint point sources

Quasar-driven shocks accelerate particles, produce radio emission

Zubovas & King, Faucher-Giguere & Quataert, Jiang et al, also Stocke et al. 1992

Different from jets accelerating gas

Zakamska & Greene 2014
5. The nature of the radio emission in RQ quasars

- Correlation between line width (=outflow velocity) and radio luminosity
- These are “the 90%”: faint point sources
- Quasar-driven shocks accelerate particles, produce radio emission
- Zubovas & King, Faucher-Giguere & Quataert, Jiang et al, also Stocke et al. 1992
- Different from jets accelerating gas
Distinguish between compact jets and quasar winds?

Combination of radio luminosity, morphology and spectral index can help

Steep spectrum, unresolved radio core and radio lobes imply

- compact jets with episodes on scales of $\sim 10^7$ years
- synchrotron emission from quasar winds

“Teacup AGN”
Harrison et al. 2015
$z = 0.085$

Alexandroff et al. 2016
$z = 0.3$

$\alpha = -0.65$
5. The nature of the radio emission in RQ quasars

Hints of extension in the correlation between outflow velocity and radio luminosity to high redshift (z~2.5)

If you want to learn more come by poster 14!
Conclusions

- Growing observational evidence for powerful, galaxy-wide quasar-driven winds
- Radio-quiet objects (no powerful jets)
- Ionized gas (including extreme kinematics, many x 1000 km/sec), molecular gas, bubbles, evidence for the volume-filling component!
- We propose that radio emission in RQ quasars = bi-product of shocked winds
- Effect of quasar feedback on star formation: talk by Dominika Wylezalek this afternoon
2. Observations: ionized gas bubbles

- Winds look for the path of least resistance
- In disk galaxies, expect them to “break out” perpendicular to galaxy plane
- Have several candidates

Energy estimates using completely different methods: a few per cent (large uncertainty) of $L_{\text{bol}}$
2. Observations: ionized gas bubbles

Multi-phase winds:
- hot, volume filling, invisible component
- cooler denser clumps (ionized, neutral, molecular)
- Ionized – emission lines
- Molecular – ALMA!
- 350 Msun/year, will deplete in $10^6$ years

Sun, Greene, Zakamska, Nesvadba 2014