Accretion and Ejection Power in the Universe (and prospects for Athena)

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Outline

1. Framework
   Brief recall on context: AGN feedback/winds
   Key to several TPs of SWG2: from studies of SMBH formation/evolution to studies of accretion/ejection physics

2. From the “classic” X-ray view of winds/outflows to a “new” X-ray view
   “Static” Warm Absorbers → ”Variable” Ultra-Fast Outflows (UFOs)
   Impact of UFOs

3. Open issues, analogies and differences?
   comparison/link with WAs?
   comparison/link with molecular outflows?
   comparison with binaries/microquasars?

4. Future studies?
   now, next years, and in 2028?


Kaastra et al., ’14, Mehdipour et al. +15
Chartas et al. ‘14, ‘15
~20 years ago, a somewhat unexpected “revolution” in extragalactic astrophysics: not only most (all?) galaxies have SMBHs in their centers, these also correlate with host bulge properties.

Framework: Co-evolution of AGN and galaxies

INWARD BOUND—THE SEARCH FOR SUPERMASSIVE BLACK HOLES IN GALACTIC NUCLEI

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Kormendy & Richstone, 1995, ARA&A

A statistical survey finds BHs in ~20% of nearby E–Sbc galaxies, consistent with predictions based on quasar energetics. BH masses are proportional to the mass of the bulge component. Most candidates are inactive; in some cases, the abundance of fuel is not easily reconciled with BH starvation. Flashes caused by the
Evidence for feedback mechanism between SMBH(AGN) and its host galaxy.

Framework: Feedback in the co-evolution of galaxies

\[ M_{bh} \sim L_{\text{bulge}}^{0.4} \]

- Magorrian et al. '98
- Tremaine '02; Gebhardt '02; Ho & Kim '14... etc
(see e.g. King and Pounds '03, Crenshaw, Kraemer & George '03, ARA&A)
Framework: MBH vs SFR, most (important) "action" is at $z \sim 2-3$

e.g. Madau et al. '96; Wall et al. '05; Hopkins et al. '08

$M_{bh}$-$\sigma$ relation, AGN-gal coevolution, L-Tx relations, Heating cooling flow

AGN Feedback!
Framework: Three major feedback mechanisms between the SMBH and its environment

1. radiative feedback:
   \[ L_{\text{acc}} = \eta (M_{\text{acc}}) c^2 \]
   Able to quench the star formation and the cooling flow at the center of elliptical galaxies
   e.g. Ciotti & Ostriker 2001, Sazonov et al. 2005
   But it is not enough to reproduce the \( M_{\text{BH}} - \sigma \) relation
   e.g., Ciotti et al. 2009
   How much radiation on dust is relevant in high-luminosity sources/quasars?

2. mechanical/kinetic feedback:
   i. mass outflows from collimated, radiatively bright, relativistic radio JETS:
      Heat the IGM and the ICM, quench the cooling flow in rich Clusters of Galaxies
      e.g., Fabian et al. 2009, Sanders et al. 2009
   ii. mass outflows from wide angle, radiatively dark, massive WINDS/outflows
      e.g., Silk & Rees 1998
      e.g., Begelman 2003

See reviews by Crenshaw, Kraemer & George, 2003 and more recently by Fabian '12, ARAA
Absorbers variability on timescales 1000-10000s

NGC1365

The “new” X-ray view: Not (only) a static WA but also variable Ultra Fast Outflows (UFOs)

X-ray spectral variability of PDS 456

Absorbers variability on timescales 1000-10000s

N.B: Variability allows to place robust limits on location, mass, etc.

(See also Krongold et al. 2007 on NGC4051; Behar et al. 2010 on PDS456, Braito et al. 2007 on MCG5-23-16; MC et al. 2009 on Mrk509 etc.)

Risaliti et al. 2005

Reeves et al. ’10, ’13, ‘15
The “new” X-ray view: (Not only WAs but) UFOs in ~30-40% of AGN & QSOs

**XMM-Newton sample of nearby AGNs (Seyferts)**

- Column density
- Ionization
- Outflow velocity

**Suzaku sample of AGNs (Sey+RGs+RQQs)**

- Blue-shift velocity distribution
- Average outflow velocity 0.110±0.004 c

**Table 5. Outflow velocity comparison**

<table>
<thead>
<tr>
<th>Velocity (km s⁻¹)</th>
<th>Suzaku</th>
<th>XMM-Newton</th>
</tr>
</thead>
<tbody>
<tr>
<td>No outflow</td>
<td>3/20</td>
<td>2/19</td>
</tr>
<tr>
<td>0 &lt; v_{out} ≤ 10,000</td>
<td>5/20</td>
<td>2/19</td>
</tr>
<tr>
<td>v_{out} &gt; 10,000</td>
<td>11/20</td>
<td>15/19</td>
</tr>
<tr>
<td>v_{out} ≥ 30,000</td>
<td>8/20</td>
<td>9/19</td>
</tr>
</tbody>
</table>

**References**

- Gofford et al. 2012

**Not only WAs in AGN and QSOs, but UFOs (Ultra-Fast Outflows) have been found and are quite common**

- 11/44 objects with outflow velocity >0.1c (≈25%)
- Blue-shift velocity distribution ~0-0.3c, peak ~0.1c
- Average outflow velocity 0.110±0.004 c
The “new” (unifying) X-ray view of UFOs and non-UFOs (WAs)

Several Press releases in ‘10, ‘12 and ‘13 (also NASA and ESA in 2012)

UFOs kinetic energy $>$ 1% of $L_{bol}$

Feedback (potentially) effective!

Tombesi, MC et al., ‘12b, ‘13

$\log N_h$ (cm$^{-2}$)

$\log N_h$ (cm$^{-2}$)

$\log V_{out}$ (km/s)

$\log V_{out}$ (km/s)

$\log \xi$ (erg s$^{-1}$cm)

$\log \xi$ (erg s$^{-1}$cm)

$\log \xi$ (erg s$^{-1}$cm)

Log $D$ (pc)

Log $E_{out}$

Log $L_{bol}$

→ UFOs kinetic energy $>$ 1% of $L_{bol}$

→ Feedback (potentially) effective!
**The "new" X-ray view:** Absorber variability measured simultaneously in X-rays and UV!

Kaastra, Kriss, MC, et al., 2014, Science

**XMM-Newton Large Program (+ Nustar + Chandra)**

**Simultaneous HST/COS**

→ Best detailed measurements possible only with multi-ni campaigns
The “new” X-ray view: Variability in (nearby) PG QSOs

Sample: 15 UV *AL QSOs with 32 XMM exposures

UFOs and/or FeK structured lines seen also (no, always!) in lensed high-z QSOs

**Figure 3.** Left: final best-fit solar abundance self-consistent relativistic reflection model (pha(zpha(zpo+zgauss+relconv*reflionx))) to the summed Chandra observation.

**Table 1.** Log of Observations of APM 08279+5255

<table>
<thead>
<tr>
<th>ID (ks)</th>
<th>net counts (erg s(^{-1}) cm(^{-2}) sr(^{-1}))</th>
<th>Ebounds (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0092800201 83.46 12,820</td>
<td>7684 88.06 6,938</td>
<td>5</td>
</tr>
<tr>
<td>2979 88.82 5,627</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1.** The spectrum of combined images A+B of HS 0810+2554 fit to the data shown in panel (a) overplotted with the unfolded best-fit model comprising photoionization model (pha(zpha(zpo+zgauss+relconv*reflionx))).

**Figure 2.** The illuminating power law is indicated in green, the reflected emission in blue, and the narrow Fe K line in cyan.

**Table 2.** Summary of the results from the fits to the pn data alone more robust with respect to our ability to constrain the Fe parameter for both models. It is clear that our ability to constrain the spin is robust with respect to our ability to constrain the Fe parameter for both models.
UFOs seen also (no, always!) in high-z QSOs

(z=2.73) high-z RQ (NAL) QSO HS1700+6416

(z=2) PG1247+268

Another high-z UFO candidate?

Lanzuisi et al., ’12

HS1700: The 4° high-z QSO to show variable, high-v, high-Xi absorbers, but the 1° non-lensed

N.B.: Would be very important also to confirm on other non-lensed, high-z QSOs

→ Desperately need more and longer XMM observations
UFOs/outflows/winds in AGNs & QSOs: Possible models

**Radiatively driven accretion disc winds**

- Sim et al., '08, '10ab
- Murray et al. '95, Proga et al. '00

**...and/or...**

**Magnetically driven winds from accretion disk**

- Emmering, Blandford & Shlosman, '92; Kato et al. '03
- Fukumura, et al. 2010
- Kazanas et al. 2012
Most important open issues: need a complete census on:

- $N_w$ (cm$^{-2}$)
- Location (R, DeltaR)
- Ionization state ($\xi$)
- Velocity
- Covering factor
- Frequency in AGNs
- Density

**Fundamental to:**

i) PHYSICS of accelerated and accreted flows (winds?, blobs?, acceleration mechanism? etc.)

ii) COSMOLOGY: i.e. estimate the mass outflow rate, thus the impact of AGN outflows on ISM and IGM enrichment and heating!

**WA Location and feedback budget:**

- NGC3783: ~25pc (Gabel+05); NGC4151: ~0.1 pc (Crenshaw & Kraemer 09); NGC5548 < 7pc (Kraemer+09); Mrk279 < 29 pc (Ebrero, EC+10); NGC3516: 0.2 pc (Netzer+02); NGC 4051 0.5-3 l.d. 1-3pc (Krongold+07, Steenbrugge+09); Mrk 509: >0.04 pc (Ebrero +11; Detmers+11; Kaastra,+11)

**UFOs:**

Sample of AGN and QSOs: few 100s to 1000s Rs (Tombesi+11, Reeves+, Chartas+, Gofford+)

**Outflow rate:**

$$M_{out} = 4\pi r N_H m_H C_g v_r$$

$$M_{\text{sun}} \text{yr}^{-1}$$

**Kinetic energy:**

$$L_{\text{kin}} = 1/2 M_{out} v^2$$

WAs seem to be energetically unimportant, unlike UFOs

Current estimates go from: $\dot{d}M/\dot{d}t$ ($\propto L_{\text{kin}}$) few % to several % $\dot{d}M_{\text{acc}}/\dot{d}t$ ($\propto L_{\text{edd}} \propto L_{\text{bol}}$)

This is a fundamental (and still open) issue

Elvis et al. '00, Crenshaw et al. '03, King et al. '03, Chartas et al. '03, Yaqoob et al. '05, Blustin et al. '05, Risaliti et al. '05, Krongold et al. '07
How WAs/UFOs compare/relate to (low-z) colder molecular/gas outflows?

NGC6240

+ see talks by Andy Ptak and Francoise Combes

Feruglio et al. 2013

Wang et al. 2012a,b,c
How WAs/UFOs compare/relate to (high-z) colder molecular & ionized gas outflows?

**[CII] 158 µm broad wings (FWHM~2000 km/s) + extension →**

\[ \dot{M}_{\text{out}} > 3500 \, M_{\odot} \, \text{yr}^{-1}; \text{and Quasar driven outflow (not SB)} \]

ULIRG SDSSJ1 14816.64+525150.3 (z=6.42) – IRAM PdBI

ULIRG Mrk231 - CO (resolved) map
FWHM~700 km/s, \( \dot{M}_{\text{out}} \sim 250-2200 \, M_{\odot} \, \text{yr}^{-1} \)

Z=6.42 quasar CO (resolved) map
V~250 km/s

Bertoldi et al. 2003
Walter et al. 2004

Feruglio et al. 2010
ULIRG F1119+3257 (z=0.19): Molecular outflow could have been energized by UFO

- **OH doublet at 1000 km/s**  
  Veilleux et al. 2013

- **UFO detection (v~0.3c) consistent with energy-conserving outflow from Inner X-rays to outer molecular outflow**  
  Tombesi et al. 2015, Nature
How WAs/UFOs compare/relate to binaries winds and jets?

Ubiquitous equatorial accretion disc winds

H1743-322 disk-wind detected in soft, disc-dominated state

FeXXV and FeXXVI are variable, and have $V_{\text{out}} \sim 300-670$ km/s

Ionization, $N_h$, variability similar to UFOs

Large velocities (wrt mass) too

Miller et al., 2006, 2012

See talk by Ponti
Future: i) Longer exposures with existing instruments

Chandra (+XMM) AO15 approved proposal on lensed QSO/Sey HS0810 (z=1.5)

HETG 270 ks obs. of Mrk 509

Chartas et al., 2013

XMM approved proposal on HS1700 (z=2.89)

Kastra et al, 2013

Lanzuisi et al. 2012
Swift observations (this proposal) allowing daily samples of very small variations in the outflow. This shows that both RGS and pn can be used to trace even longer time scales. Finally, we developed methods (paper II & VIII) to monitor flux on timescales available (Swift), giving excellent spectra in 50 ks exposures. NLS1s, like Mkn 509, will fully characterise the absorber components. Our observations are timely for time-resolved high-resolution spectroscopy. Long-term spectral variability for time-resolved high-resolution spectroscopy is about 1–2% max/min that the resulting spectral changes can be measured by XMM-Newton/pn (see Fig. 4). Luminosity variations derived from RGS, we predict the expected spectral changes responding ionising luminosities and the AMD shape dependence on continuum variability time scale from Mrk 509: ii) Longer exposures and multiwavelength campaigns with existing instruments.

Kaastra, Kriss, MC, et al., 2014, Science
Future: ii) Longer exposures and multiwavelength campaigns with existing instruments

XMM-Newton Large Program (+ Nustar + Chandra)

Simultaneous HST/COS

→ Best detailed measurements possible only with multi-ni campaigns
Fig. 4. Cartoon of the central region of NGC 5548 (not to scale). The disk around the black hole (BH) emits X-ray, UV, optical and IR continuum and is surrounded by a dusty torus. The curved lines indicate the outflow of gas along the magnetic field lines of an accretion disk wind. The obscurer consists of a mixture of ionized gas with embedded colder, denser parts and is close to the inner UV broad emission line region (BLR). The narrow line region (NLR) and the persistent warm absorber (WA) are farther out.

Future: ii) Longer exposures and multiwavelength campaigns with existing instruments.

Location
(n sensitive lines + Trec prop. 1/n)

+ velocity
(up to 5000 km/s)

+ partial covering
(30-80%)

+ variability
(within 2 days)

+ long-lasting event
(>2.5 years)

→ Best consistent with origin in accretion disc wind
(w.r.t distant clumpy torus or small BLR clouds)

→ Our new “vision”: 
**Future: iii) ASTRO-H**

Measure amount/characterisation of absorption in winds/outflows

- **SXS → Detect absorption features/lines**
- **SXS → Direct measure of partial covering, and line profiles?**

First probes of absorption line profiles (P-Cygni?)

Probe of flow dynamics on short time-scales

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**N.B.:**

- **Cf=100%**
- **Cf=50%**

Simulations by F. Tombesi
Quasar PDS456 (z=0.18)
Warm and hot fast outflow ($v_{\text{out}} \sim 0.2c$)
$\Delta T < 50$ ks

Only X-rays probe the highest energy outflows, need X-IFU with high effective area to probe fast outflows on the wind launching regions (few tens ks)

Future: iv) Athena: 1. accretion disc wind characterization/formation

Based on simulations by V. Braito and J. Reeves

MC et al., ‘13, Athena+ SP, ArXiv

See talk by Ponti
Future: iv) Athena: 2. Impact of winds, radiation and SF into host galaxy

ULIRG NGC6240 (merging AGN+SB)

See talk by A. Ptak
Future: iv) Athena: 3. Will detect WAs and UFOs up to \( z \sim 2-3 \)

where the cosmic peak of AGN/SF is

**See talks by Carrera+Aird**

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**Georgakakis et al., ‘13, Athena+ SP, ArXiv**
Summary

- **General framework/importance**
  - Recognized importance of UFOs (to AGN feedback AND wind/outflows/jets physics)

- **Critical/remaining open Issues for UFOs/winds**
  - Acceleration mechanism?
  - Covering & filling factor in high-z QSOs?
  - How/where energy released in ISM?

- **How they relate/compare to**
  - WAs?
  - Cold molecular outflows in QSOs, ULIRGs, high-z QSOs?
  - Accretion/state/jet formation/wind quenching?

- **Future?**
  - Multi-freq. massive campaigns, Astro-H, Athena
Thank you very much for your attention