AGN feedback from accretion disk winds

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Summary

- Super-massive Black Holes
- Active Galactic Nuclei
- X-ray observations of AGNs
- Warm Absorbers (WAs)
- Ultrafast Outflows (UFOs)
- X-ray winds in local Seyferts, radio galaxies and high-z quasars
- AGN feedback from winds
- Future large X-ray observatories: ASTRO-H and Athena
Super-Massive Black Holes (SMBHs)

• The most “obscure” objects in Universe
• Nothing can escape event horizon
• Observed through gravitational effects
• The most efficient energy production mechanism in nature

\[ E = \eta M c^2 \]

\( \eta \approx 0.7\% \) for nuclear fusion H in the Sun
\( \eta \approx 30\% \) for black hole accretion disks

Astrophysical black holes:

• Stellar, \( M_{\text{BH}} = 3 - 10 \, M_\odot \)
• Intermediate, \( M_{\text{BH}} = 10^2 - 10^4 \, M_\odot \)
• Supermassive, \( M_{\text{BH}} = 10^6 - 10^9 \, M_\odot \)

(Radius of order Earth-Sun distance!)
Active Galactic Nuclei (AGNs)

- SMBHs are located at the very center of galaxies
- Accreting SMBH in AGNs, extreme luminosities ($>10^{11} L_\odot$)
X-rays produced few $r_g$'s from the central SMBH.

Centaurus A galaxy
Current X-ray satellites

- XMM-Newton
- Chandra
- Suzaku
- NuSTAR
Typical X-ray Spectrum of Seyfert 1 Galaxies

Total (observed) Spectrum

Comptonized spectrum
(≈PL+high-E cutoff)

Reflection continuum

FeKα (diskline)

Absorption edges
(≈C,N,O, etc.)

Energy (keV)

Disk Black-body

Hot (10⁶K) Corona

Cold (10⁵K) Accretion disk

BH
First detection of a “warm absorber” in the quasar MR 2251-178

Einstein data show absorption variability in MR 2251-178

First indication of an ionized “warm absorber” in an AGN

(Halpern 1984)
X-ray warm absorbers (WAs)

Detmers, Kaastra et al. 2011

Mrk 509 $v \sim 300-800$ km/s

(Detmers, Kaastra et al. 2011)

MR 2251-178 $v \sim 500$ km/s

(Reeves et al. 2013)
Ultrafast outflows ("UFOs") in AGNs

NGC 4051
\(v \sim 0.1c\)

(Tombesi et al. 2010a)

PG1211+143 (\(z=0.08\)) \(v \sim 0.1c\)

(Pounds et al. 2003)

PDS 456
\(v \sim 0.25c\)

(Reeves et al. 2009)
What is a “UFO”?

A rock band?

...a beer?

..or an alien invasion?
Ultrafast outflows

Active galaxy
Jet
UFO
Accretion disk
Super-massive black hole

From F. Tombesi’s European Space Agency press releases in 2012
Spectral analysis of local Seyfert galaxies

Ultrafast outflows (UFOs): $v \geq 10,000$ km/s

- Spectral analysis of 42 Seyferts for 101 XMM-Newton observations
- Uniform $E=4$-10keV EPIC-pn spectral analysis
- Fe K absorption line search with energy-intensity contour plots
- No EPIC-pn background or calibration problems
- Consistency between EPIC-pn/MOS

(Tombesi et al. 2010a)
Spectral analysis of local Seyfert galaxies

- Extensive Monte Carlo simulations, random generated lines $E=7-10$keV
- Extensive curve of growth analysis Fe XXV-XXVI absorption lines
- Photo-ionization modeling with XSTAR code

Monte Carlo simulations

Simulation number

(Tombesi et al. 2010a)

Absorber redshift

XSTAR absorption

(Tombesi et al. 2011a)
Global parameters of UFOs in local Seyferts

- UFO detected in 40% of the sources, wide angle outflows
- Spectral variability on time-scales of ~days, compact absorbers
- Plasmas with mildly relativistic velocities, high ionization/columns

(Tombesi et al. 2011a; see also Gofford et al. 2013)
\[ N_H \propto \xi^{0.72} \]

\[ v_{\text{out}} \propto N_H^{0.69} \]

\[ \log(N_H) \]

\[ \log(v_{\text{out}}) \]

\[ \log(\xi) \]

Comparison of UFOs and WAs in sample of 35 Seyfert 1 galaxies

- WAs found in >60% sources
- UFOs in >40%, >70% also WAs
- Significant correlations (>6σ)

(Tombesi et al. 2013a)
Unification as a large-scale, multi-phase AGN outflow

Density $n \sim r^{-1.4}$, conical/bipolar geometry; velocity $v_{\text{out}} \sim r^{-1/2}$, escaping wind

High ionization and velocity. Acceleration through radiation pressure? and/or MHD? (e.g., King & Pounds 2003; Proga & Kallman 2004; King 2010; Ohsuga et al. 2009; Fukumura et al. 2010; Reynolds 2012)

Outflow momentum rate 1:1 radiation momentum: interaction radiation/matter?
X-ray disk winds in radio galaxies
Ultra-fast outflows in radio-loud AGNs

The sample:
- 26 local RL-AGNs from Swift BAT catalog
- Majority FR II, no blazars
- 61 XMM-Newton and Suzaku obs

Analysis method:
- Search for Fe K absorption lines
- Confirmation with broad-band analysis
- XSTAR photo-ionization modeling
Fe K absorption lines in Centaurus A

EW~10eV, Fe XXV-XXVI, >5σ

Observed velocity <1500 km/s, projected ~vertical wind?

High jet inclination 50°<i<80°

3 Suzaku obs in 2009
Fe K absorbers in radio-loud AGNs

- Combining results with literature, UFOs in 7/26 (~30%) sources
- But only ~56% spectra have enough S/N, frequency of UFOs is f=(50±20)%
- Similar to RQ AGNs: jet related RQ/RL dichotomy does not apply to disk winds? (Tombesi et al. 2014)
Comparison between the disk, winds and jet in 3C 111

2-10keV RXTE monitoring

- Correlation X-ray dips & VLBA radio jet ejections (Marscher et al. 2002; Chatterjee et al. 2009, 2011)

- Disk winds with v~0.1c stronger during disk-jet ejection cycles (Tombesi et al. 2012b)
Ultrafast outflows in high-z quasars

- Gravitationally lensed BAL quasar APM 08279+5255 ($z = 3.9$), XMM-Newton and Chandra observations, $v_{\text{out}} \sim 0.2-0.7c$ (Chartas et al. 2009)

- Mini-BAL QSO PG1126-041, XMM-Newton observations; $v_{\text{out}} \sim 16,500$ km/s (Giustini et al. 2011)

- NAL QSO HS 1700+6416 ($z = 2.7$), Chandra observations, $v_{\text{out}} \sim 0.1-0.6c$ (Lanzuisi et al. 2012)
KEEP CALM AND BLAH BLAH BLAH
Scale relations between SMBHs and host galaxies

(e.g., Magorrian et al. 1998; Ferrarese & Merritt 2000; review by Kormendy & Ho 2013)

- SMBH size $\sim 10^{10}$ smaller typical galaxy ($\sim$atom $10^5$ nucleus)
- SMBH mass is $\sim 1\%$ stellar bulge mass
- SMBH gravitational energy $\sim$ binding energy galaxy bulge!
AGN feedback from accretion disk winds

(e.g., Silk & Rees 1998; King 2003; Di Matteo et al. 2005; Hopkins & Evlis 2010; Gaspari et al. 2011; Zubovas & King 2012/2014; Faucher-Giguere & Quataert 2012; Zubovas & Nayakshin 2014; Costa et al. 2014/2015; ...)

(Ohsuga et al. 2009)

(Zubovas & King 2014)

(Wagner et al. 2013)
Accretion disk wind detected with Suzaku

- IRAS F11119+3257, ULIRG z=.189, AGN dominated, QSO luminosity $10^{46}\text{erg/s}$
- Detection (6.5sigma) broad absorption line at $E=9.82\text{keV}$
- Excluded slower absorber (edge) and disk reflection (variability, luminosity)
- XSTAR fit UFO: $v=0.255c$, $\log xi=4.11$, $NH=6\times10^{24}$, covering fraction $>0.85$

(Tombesi et al. 2015, Nature accepted)
Large-scale molecular outflow with Herschel

- Herschel spectrum of the OH 119µm P-Cygni line profile
- Massive (800 Msun/yr) large-scale (300 pc) molecular outflow
- Average outflow velocity 1000 km/s, covering fraction 0.2

(Tombesi et al. 2015, Nature accepted)
AGN feedback from energy-conserving winds

- UFO momentum rate $1.3 \, L_{\text{AGN}}/c$, power $15\% \, L_{\text{AGN}}$
- Molecular outflow momentum rate $11 \, L_{\text{AGN}}/c$ (boosting), power $2\% \, L_{\text{AGN}}$
- Consistent energy-conserving flow (bubble): $P_{\text{out}}=f(v_{\text{in}}/v_{\text{out}})(L_{\text{AGN}}/c)$
- Efficiency energy conservation $f=C_{F,\text{OH}}/C_{F,X}=0.2$ (Tombesi et al. 2015, Nature accepted)
To be launched in early 2016... stay tuned!
“UFO” sightings with ASTRO-H

- SXS micro-calorimeter unprecedented energy resolution (6eV) and sensitivity
- Simultaneous broad-band coverage 0.5-200 keV (SXS+SXI+HXI+SGD)
ATHENA
THE ASTROPHYSICS OF THE HOT AND ENERGETIC UNIVERSE

Europe’s next generation X-RAY OBSERVATORY

How does ordinary matter assemble into the large scale structures that we see today?

How do black holes grow and shape the Universe?

100ks, PDS 456, UFO v~0.2-0.3c
Thank you for your attention!