X-ray Emission from Active Galactic Nuclei

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Active Galactic Nuclei

Nuclei of galaxies that are active - an energy source other than stars. Called AGN if the activity is substantial in some characteristic determined observationally e.g., Strong X-ray Variability, Jets from nuclei, Broad emission lines, etc.
Active Galactic Nuclei
(Phenomenological description)

- **Large luminosity:** $\sim 10^{42-48}$ erg/s
- **Compact:** $\text{size} \ll 1\text{pc}$
- **Broadband Continuum emission**
  - $dL/d\log \nu \approx \text{constant (IR to X-rays and $\gamma$-rays)}$
- **Strong emission lines** in the optical/UV
- **X-ray & gamma-ray Emission**
- **Strong variability** over the EM spectrum on a range of time scales: *minutes to days and months*
- **Jets & lobes in radio-loud AGN:** sizes $\sim \text{kpc}$ — Mpc
AGN – Physical picture

- High luminosities
- Highly variable
- Eddington limit $\Rightarrow$ Large mass
- Small size
- Accretion onto SMBH

Central SMBH

$\left( M_{BH} \sim 10^5 - 10^{10} M_{\odot} \right)$

Powered by accretion

$L = \eta \dot{M} c^2$

Size scale: Schwarzschild radius

$R_S = \frac{2GM_{BH}}{c^2}$

Luminosity: Eddington luminosity:

$F_{rad} = F_{gravity}$

$\Rightarrow L = 1.38 \times 10^{38} \left( \frac{M_{BH}}{M_{\odot}} \right) \text{erg s}^{-1}$
Observer's View of RQ AGN

Direct view of central engines in RQ type 1 AGN such as nearby bright Seyfert 1 galaxies
Why are X-rays important probes of RQ AGN?

Optical/UV: $\Delta t_{\text{obs}} \approx 1-10\text{d} \Rightarrow \ell \approx 0.001-0.01\text{pc}$

X-ray: $\Delta t_{\text{obs}} \approx 1\text{ hour} \Rightarrow \ell \approx 10^{-5}\text{pc}$

In comparison:

Schwarzschild radius $R_S = \frac{2GM}{c^2}$

<table>
<thead>
<tr>
<th>$M/M_\odot$</th>
<th>$R_S$</th>
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<td>$10^6$</td>
<td>$10^{-7}\text{pc}$</td>
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<td>$10^8$</td>
<td>$10^{-5}\text{pc}$</td>
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<td>$10^9$</td>
<td>$10^{-4}\text{pc}$</td>
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X-ray Variability in the vicinity of SMBH

X-rays probe immediate environment of SMBH

Akn 564 (Dewangan et al. 2007)
X-ray continuum of AGN

Powerlaw: \( N_E \) (photons cm\(^{-2}\) s\(^{-1}\) keV\(^{-1}\)) = \( AE^{-\Gamma} \)

Origin: Comptonization in a hot corona

Powerlaw continuum with a high energy cutoff at \(~100\) keV

Credit: Jorn Wilms
Compton up-scattering of soft photons from a cool accretion disk (<50eV) in an optically thin hot corona (100keV, \( \tau < 1 \))

A fraction \( \tau \) of seed photons get upscattered to energies by a factor

\[
1 + \frac{4kT_e}{m_e c^2}
\]

Repeated upscattering => powerlaw with a cutoff

\[
E_{\text{cut}} \sim kT_e
\]

Schematic X-ray SED of type 1 AGN

Credit: Neil Brandt
Soft X-ray Excess Emission

Soft X-ray excess emission (discovered by Singh et al. 1985, Arnaud et al. 1985)

Single or multiple BB kT~100-300eV

Optically thick emission from an accretion disk – NO

Origin not clearly understood - blurred reflection?
Broad iron line and reflection hump

MCG-5-23-16: Suzaku observations

Observed Flux

\[ f_{2-10\text{keV}} = 9 \times 10^{-11}\text{ergs cm}^{-2}\text{s}^{-1} \]
\[ f_{15-100\text{keV}} = 2 \times 10^{-10}\text{ergs cm}^{-2}\text{s}^{-1} \]

Absorbed powerlaw

\( N_H = 1.65 \times 10^{22}\text{cm}^{-2} \), \( \Gamma = 1.95 \)

Iron K line between 6-7 keV

Reflection hump above 12 keV

(Reeves, Awaki, Dewangan, et al. 2007)
MCG-5-23-16: Broad Iron K line
(XMM & Simultaneous XMM/Suzaku)
Iron K line shape – Data to 3-5 keV best-fit PL ratio

(Dewangan et al. 2002)

Narrow and broad iron K lines

Broad component: FWHM ~ 50000 km/s
X-ray Reflection

Hot corona – powerlaw spectrum
Some of the high energy photons from the hot corona re-enter the accretion disk

Two possible fates of the incident high energy photon

- Compton scattering by free electrons in the disk
- Photoelectric absorption by metals in the disk and fluorescent line emission
At soft X-ray energies, reflection is small due to photoelectric absorption by lighter elements.

At hard X-rays, incident photons are Compton back-scattered from the disk.

A spectrum of fluorescent emission lines arises from the photoionization of metals in the disk.

Iron Kα line at 6.40 keV is the most prominent due to high fluorescence yield and large cosmic abundance.

X-ray reflection: Xillver, reflionx table models.
Broadening of iron line – Strong gravity

Discovery of broad Iron line profile in MCG-6-30-15 (Tanaka et al. 1995, Nature)

Fabian et al. (2000)

diskline, laor, relline models in XSPEC/ISIS/Sherpa
Broad Iron Line – Measuring BH spin


Dimensionless BH spin parameter

$$a = \frac{cJ}{GM^2}$$
Reflection & Relativistic blurring

SE + broad line + hump

Reflected spectrum

Relativistic reflection: relxill model

Soft excess

Relativistically blurred reflection

Broad FeKα
BH Spin from broad iron line

Extreme red-wing requires emission from below $6R_g$

Inner disk radius at $\sim 2R_g$

Highly spinning BH
Broad Iron line and Reflection hump

MCG-6-30-15: \(~350\)ks Suzaku

(Miniutti et al. 2007)

Reflection hump

\[ R_{in} \leq 2.1R_g \]
Reflection & Absorption

Absorption, if present, can strongly affect the continuum and broad iron line.
X-ray Absorption

Kaspi et al. (2002)

Absorbing cloud

900ks Chandra/HETG observation

Blustin et al. 2002

RGS
Absorption in the X-ray band

K and L bands
Of abundant elements

Image credit: Frits Paerels
X-ray Warm Absorbers in Seyfert 1s (XMM RGS)

Laha, Guainazzi, GCD+2014

Cloudy-based Warm absorber models
Complex & Variable Absorption

(Risaliti et al. 2009; Mailino et al. 2010)

Variable neutral partial covering absorption on hours-days scale.

Both $N_H$ and CF vary on short time scales. Cometary-shaped BLR clouds crossing the line of sight.

NGC 1365
Reflection & Absorption

Simulated Spectra

Obscured from view

Miller & Turner 2009

Photoionized emission
X-ray narrow-line region
NGC1068: Compton-thick Seyfert 2

Photoionized Plasma
NGC1365: **Photoionized + Collisionsionally ionized Plasma**

Chandra

Guainazzi et al. 2009
Multi-wavelength SED of AGN

Simultaneous MW observations are important!
LAXPC
3-100 keV X-ray Timing, broadband spectroscopy

SXT
0.2-8 keV imaging & line spectroscopy

CZTI
10-250 keV hard X-ray imaging, timing, spectroscopy

UVIT
1.4” UV imaging

SSM
rotating 2-10 keV monitor

Phased Array Antenna

Star Sensors

PI: S. Seetha (ISRO)
PMs: S.N. Tandon (UVIT), J.S. Yadav (LAXPC), K.P. Singh (SXT), A.R. Rao (CZTI), M.C. Ramadevi (SSM)

LAXPC: TIFR, RRI
SXT: TIFR, ISRO, UoL
CZTI: TIFR, ISRO, IUCAA, RRI, PRL
SSM: ISRO, IUCAA, RRI
UVIT: IIA, ISRO, IUCAA, CSA

Spacecraft: ISRO
Operations: ISRO
Ground software: ISAC, SAC, TIFR, RRI, IIA, IUCAA, NCRA, PRL
Integrated AstroSat before launch
weight: 1.5 ton

PSLV XL Rocket
Launched: 28 Sept. 2015
AGN SED & Astrosat coverage

UVIT: FUV/NUV/VIS
15 optical/UV filters (1300 - 5500Å)

SXT (0.2-8 keV)
LAXPC (3-80 keV)
CZTI (10-100 keV)

AGN truly MW objects
Astrosat well suited for MW study of nearby bright AGN
Fairall 9: UVIT observations

NUV Grating exposure : 6000s

Sriram, 2017
Fairall 9 : SXT Data

Net exposure : 25.8ks, source : 0.46 counts/s

$\Gamma \sim 2.2$

Reduced $\chi^2 = 1.17$

Fe line ?
SXT Observations of AGN

BH mass : $6 \times 10^6$ solar mass
Flux (2-10keV) $\sim 1 \times 10^{-11}$ cgs

NGC4051 ($\sim 1.7$ days long)
Timing capability of LAXPC: GRS1915+105

Very large count rates

Rare High frequency QPOs detected with LAXPC

Courtesy: J. S. Yadav
NGC4151: AstroSat SXT/LAXPC broadband continuum

data and folded model

[Graph showing normalized counts vs energy]
Fairall 9: Spectral Energy Distribution

Excess NUV emission
Thank You