Active Galactic Nuclei

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The Power Source

Accreting super-massive black hole: $\Delta E \sim mc^2$

Black hole is one billionth the size of the galaxy

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Cosmological Significance

Larger galaxies have larger black holes
Regulated growth of black hole and host galaxy?

\[ \frac{M_{\text{bh}}}{M_{\text{sph}}} \approx 10^{-3} \]

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Talk Overview

(1) How to Identify an AGN

(2) The Unified AGN model

(3) AGN activity and the Growth of Black Holes

(4) Cosmological Growth of Galaxies and Black Holes
How to Identify an AGN
What is an AGN?

An Active Galactic Nucleus (AGN)

- Non-stellar emission produced at the core of a galaxy (not always visible at optical wavelengths)
- AGNs are bright from X-rays (even gamma rays) to radio wavelengths, unlike stars

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What is an AGN?

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Evidence for an AGN: Jets

Jets sometimes seen (radio, optical, X-ray)

$\rightarrow$ ~10% of luminous AGNs have radio “jets” and lobes but depends on sensitivity

Optical and Radio Views of Radio Galaxy 3C219
Montage (c) NRAO 1994

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Evidence for an AGN: Variability

Rapid Variability

→ Luminous rapidly variable emission → small region that can produce powerful emission

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Evidence for an AGN: Spectra

AGNs ionising continuum “harder” than that from stars/star formation: produces high-excitation emission lines
Luminosities of AGNs

Broad-range of luminosities (from $\sim 10^{38} - 10^{47}$ erg/s): quasars are highest luminosity AGNs but comparatively rare.
## AGN taxonomy

3 dimensional classification: spectral type, radio properties, and AGN luminosity

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<th>Name</th>
<th>Spectral Types?</th>
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<th>Luminosity?</th>
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<td>Narrow-line Radio Galaxies (NLRGs)</td>
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<td>Blazars</td>
<td>0!!!</td>
<td>Yes</td>
<td>Low-High</td>
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The Unified AGN Model
Unification of Type 1 and 2 AGNs

Hidden Type 1 AGNs in Type 2 AGNs

→ Spectropolarimetry revealing Type 1 AGN in at least some Type 2 AGNs
→ Polarised emission is scattered light that is hidden from direct view

NGC1068: Type 1 in polarised light

NGC1068: Type 2 in direct light

NGC1068: imaging polarimetry

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The Unified AGN Model

Postulate: the orientation of an optically and geometrically thick structure ("torus") dictates observed properties

Scattered/polarised light (effectively a mirror) can reveal Type 1 even when obscured (Type 1 AGN)

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(Type 2 AGN)
Evidence for a Dusty “torus”

Due to small angular size (i.e., 1-100 pc or sub-arcsec scale even for nearest objects), mostly indirect evidence

- Type 2 AGN near-IR spectrum showing Type 1 features
- Infrared emission: hot dust
- Near-IR variability: dust sublimation radius
- Emission collimated by torus?
X-ray Evidence for Absorption

X-ray observations show Type 2 AGNs have larger column densities of gas than Type 1 AGNs (they are more absorbed).

About 3-10 times more obscured than unobscured AGN

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But Not the Whole Story...

Sometimes obscured by dust lanes and dusty star-forming regions in the host galaxy (>100 pc scale)...

Type 2 AGN with no X-ray or optical absorption (and vice versa)

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Revised Physical Picture?

Torus is the gas and dust inflowing towards the black hole.

X-ray absorption is from the broad-line region and doesn’t always need to be associated with the “torus”.

Torus can disappear in sources with low mass accretion rates.

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The AGN Zoo

AGN properties driven by orientation of a dusty torus and mass inflow (which may be linked)?

Radio loudness: spin of black hole, mass accretion rate?

Broad range of possible properties means it is challenging to find ALL AGNs... need multi-wavelength observations
AGN Activity and the Growth of Black Holes
Black-Hole Growth Events

Is AGN activity continuous or is it a transient event?

Mass accretion from a quasar:
\~1-100 solar masses/year

Over 13 Gyrs of cosmic time:
\~ 10^{11} solar masses of accretion

Quasar space density is \~0.001 that of massive galaxies

So…
(1) do a few galaxies host \~10^{11} solar mass black holes? OR
(2) does every massive galaxy host a \~10^8 solar mass black hole?
All Massive Galaxies harbour Black Holes

Since all massive galaxies host a massive black hole, all massive galaxies must have harboured quasars/AGNs at some time over the past ~13 Gyrs

Black-hole growth is transient: there is a “duty cycle” of black-hole growth

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Where do you see AGN activity?

Which galaxies host AGN activity in the local Universe?

- Detailed AGN census of d<15 Mpc galaxies by Andy Goulding

~30% of *all* galaxy types host significant AGN activity in the local Universe: black-hole duty cycle ~30%

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Our “AGN” in the Milky Way

But deeper searches find even more AGNs - very weak “AGN” in the Galaxy: ~10,000 times weaker than previous study

3 million solar mass black hole

Stars Orbiting the black hole

Our “AGN”: Sgr A*

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Black-hole Growth Limitations

The AGN fraction constrains the duty cycle of black-hole growth but it doesn’t indicate how quickly a black hole is growing.

Eddington-limited black-hole growth: when radiation pressure on electrons balances gravitational pressure on protons:

$$L_{Edd} = \frac{4\pi G m_p c}{\sigma_T} M_{BH}$$

e-doubling time for black hole growing at Eddington rate: ~45 Myrs

Would take ~500 Myrs for black hole to grow to $10^8$ solar masses from 1000 solar mass seed (fastest possible time)

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How Quickly are Black Holes Growing in Local Universe?

Although AGN activity roughly constant for all host-galaxy types, it is the smaller black holes that are growing most rapidly today.

Therefore the most massive black holes must have grown more rapidly in the past.

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"Weighing" Black Holes in Distant Optical Quasars

Indicates that quasars host rapidly growing massive black holes... but a quasar survey will the miss the obscured AGN population and only finds rare luminous objects.

\[
M_{\text{BH}} = G^{-1} R_{\text{BLR}} V_{\text{BLR}}^2
\]

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X-ray Selection of AGNs

5 ks Bootes (shallow)

2 Ms HDF-N (deepest)

Deepest X-ray surveys: potential to identify “optical” quasars out to z~20 and find obscured AGNs out to the edge of the Universe:

~1000x larger AGN space density than optical quasars
Black holes in X-ray AGNs

X-ray selected AGNs - broader variety of types:

- Type 1 AGN
- Type 2 AGN
- No optical AGN signatures

X-ray AGNs at z~1

The majority of the growth of the most massive black holes (>0.1 billion solar masses) was probably completed by z~1-2

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**Fuelling the Black Hole?**

- **Stochastic instabilities:** slower black-hole growth but over long durations.
- **Majority of lower-luminosity systems:** tidal capture of nearby star/molecular cloud or stray gas?
- **Gas-rich major mergers:** rapid and luminous black-hole growth.
- **AGN luminosity function**
- **Some sites of z~2 major mergers**
- **High-luminosity systems:** more dominant at high redshifts when systems were more gas rich?

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Cosmological Growth of Galaxies and Black Holes
Evidence for Joint Growth

Suggests that black holes and galaxies grew together despite one billonth difference in linear size scale (equivalent below):

But factor of one thousand difference in mass

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The Evolution of AGN Activity

Most luminous AGNs peaked at higher redshifts than typical AGNs: Cosmic Downsizing

Luminosity-dependent density evolution (LDDE). downsizing quite possibly due to smaller mass black holes growing later than larger black holes (mimicking galaxy downsizing)

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Cosmological AGN-Star Formation activity

Star formation (scaled by factor of 1000) and mass accretion histories: concordant growth on average?

But growth may sometimes be temporarily out of sync (e.g., objects with intense AGN or star-formation activity)...
Outflows: the Black-Hole Arm?

An arm for the black hole to "orchestrate" star formation: potential to get over the factor of a billion difference in size scale.

Hydrodynamical simulations
Summary

(1) An AGN produces non-stellar emission: accretion onto a massive black hole

(2) Broad variety of AGN signatures: need multi-wavelength data to find all AGNs

(3) Some observable differences due to dusty “torus” blocking nucleus in Type 2 AGNs: but other factors also dictate appearances (BH spin… host galaxy… mass accretion rates)

(4) About a third of local galaxies host AGN activity: volume-average BH growth fastest for small black holes (<10 million solar masses) - larger black holes (>0.1 billion solar masses) grew mostly at higher redshift (z>1-2)

(5) Evolution of AGNs mimicks galaxy “cosmic downsizing”: growth of black hole and galaxy mostly concordant (can be temporarily out of sync in individual objects)

(6) Joint growth may occur due to AGN outflows, which could provide an “arm” for the black hole to orchestrate star formation despite factor billion difference in size scale

AGN activity is transient but common… a component in growth of galaxies

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