THE SCIENCE REVISION WEEKEND

Sponsored by the Chemistry and Physics Societies of the Open University

S381
The Energetic Universe

Block 4
Active Galactic Nuclei

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Adapted from notes by
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Overview of Active Galactic Nuclei (AGN)

- Thousands of astrophysicists work on AGN, and there are many puzzles concerning them. S381 aims to familiarize you with what is known & how we know it, and the reasons why much remains to be discovered.
- The taxonomy of AGN (B4 Fig 108) is more complicated than that of interacting binaries.

Do you need to memorise this figure?
No. Being familiar with it would help though.

Key points:

- The division between high-luminosity quasars vs low luminosity Seyfert galaxies.
- The effect of changing orientation on visibility of central engine: Seyfert 1 vs Seyfert 2.
- The effect of changing orientation on observed radio emission: FR I & II radio galaxies vs radio loud quasars vs blazers.
- The division between strong and weak jets: radio-loud vs radio quiet.

- Try to understand the underlying physics which is invoked. S381 is about understanding and applying principles, not about rote learning.
- Note that in AGN, the underlying physics is not always clear, even to experts.
- Understand what has been and can be measured, and the logic and assumptions underlying interpretation.

Exam hint: one long question may be an *inter-block question*. Accretion physics spans B3 & B4; stellar densities play a role in the Roche tidal limit, spans B2 & B4. So look out for topics like this.

EXTRAGALACTIC DISTANCES

There is no direct way to measure further than the nearest few thousand stars!

Q: What direct way is there of measuring distances?

- Cepheid variables have P-L relationship and are visible in cosmologically nearby galaxies.
- Can use *standard* candles:
  - HII region
  - Globular cluster
  - Entire galaxy

  to make distance determination from $F = L/(4\pi d^2)$.
- Cosmological expansion of Universe:

  As distance increases, redshift z increases.

  Hubble law: $z = \frac{H_0 d}{c}$ where $z = \frac{\Delta\lambda}{\lambda_0}$

  H_0 is the Hubble constant. In local Universe this linear relationship between d and z is found.
- In more distant Universe can only measure z:

  Don't actually know d !

  Deceleration parameter q describes how acceleration of Universe has changed over time (i.e. how H_0 varies !)
- Measure z, assume q, deduce look-back time:

  For $z \sim 6$

  Look-back time $\sim$ 0.8-0.9 $\times$ age of Universe!

STRUCTURE OF AGN

- Central engine: accreting supermassive black hole:
  - *Coherence arguments*
    luminosity, variability timescale.
  - Nearby galaxies harbour supermassive black holes – stars' orbits reveal mass enclosed.
  - Hard to get direct *proof*.
- Accretion disc inferred:
  - No double-peaked disk lines seen ☹
  - No unambiguous evidence in spectrum ☹
  - Expect that accreting gas will have angular momentum.
  - Discs ubiquitous in astrophysics.
  - Collimated jets seen.
- Broad line region:
  - Seen in Type 1 Seyferts (Type 1 AGN).
  - Broad photo-ionized emission lines.
  - B4 table 7 summarises properties.
  - Know how these properties are estimated.
  - Nature of broad line clouds unclear.
  - Virial arguments imply close to central engine.
- Narrow line region:
  - Seen in Type 1 & 2 Seyferts (Types 1 & 2 AGN).
  - Can spatially resolve, ionisation cones (P fig 6.7), further from the central engine.
  - B4 table 7 summarises properties.
  - Know how these properties are estimated.

- Obscuring torus:
  - Inferred in unified models.
  - Blocks view of BLR in type 2 AGN;
    - See scattered light from BLR in polarised light.
    - See IR Broad lines (Paschen & Brackett lines).
    - Sy 2s on average less luminous than Sy 1s.
    - More Sy 2s than Sy 1s: torus blocks 3/4 of sky!
    - Ionization cones: light from central source not seen by whole galaxy.
  - Composed of dust and gas.
- 10% of quasars are radio loud.
- Radio jets:
  - Relativistic jets, assumed perpendicular to disc.
  - Appearance affected by Doppler favouritism.
  - Approaching jet much brighter ($\gamma^{3+\alpha}$)

    Q: What are γ and α ?

  - Blazars have jets directed towards us.

    Doppler-boosted emission from the jets dominates all else.

  - In less extreme cases, often see only approaching jet.
- Radio galaxies:
  - ~Jets in plane of sky: classic double-lobed sources.
  - Core, jet, lobe, hotspot B4 fig 22

  Fanaroff-Riley classification

  FR1: core-dominated, fainter toward edges, weaker.

  FR2: limb-brightened, more luminous.

AGN SEDS (Spectral Energy Distributions)

Features: Pe,§4

Big blue bump	Thermal source at 10^4-10^6 K. Accretion disc?
IR bump	Thermal source at <2000 K. Dust? (sublimation temp ≤ 2000 K) Pe,§4.3
EUV gap	ISM opaque due to H ionisation.
mm gap	Few mm detectors.
Sub-mm break	Radio-quiet AGN fade at λ > 100μm.
Radio flux	Non-thermal: Radio loud and Radio quiet.
Soft X-ray excess > 0.1 keV	Uncertain origin: Pe,§4.2,F4.3 Inverse-Compton-scattered UV or optical photons? Electrons in corona over disc? Thermal?

BLAZARS

BL Lacs (weak lines) **and OVVs** (broad lines) Pe,§4.5

- No big blue bump or IR 1 μm minimum or sub-mm break; continuum is non-thermal. Pe,Fig4.9
- Smooth, featureless continuum; unresolved.
- Large amplitude variability of flux and polarization over days.
- Highly variable optical polarization.
- Strong, variable radio flux; core dominated.

SELECTION EFFECTS

- Most important selection effect is Malmquist bias:
  - Intrinsically luminous objects rare.
  - Intrinsically dim objects undetectable as distance increases.
  - In flux-limited sample, only luminous objects detected at high *z.*
- Extragalactic astronomers work hard to understand and correct for biases when interpreting observations.
- Ideally want volume-limited samples.
  Detect all objects down to a particular luminosity threshold within a given volume of space.
  - This means must throw away some data.
- Even with a volume-limited sample there are dangers:
  - Do U band photometry.
  - Count how many objects have M_U > threshold, as a function of *z* (indicating look-back time).
  - Conclude history of space density of AGN.

Q: What implicit assumption/approximation has been made?

Q: Can you correct for this? What would you need to do?

- Once selection effects understood they can be used to detect AGN, e.g. B4 figs 27 and 88 illustrate very efficient photometric detection of high *z* quasars.
- Carefully designed samples overcome selection effects:
  - Combine surveys with a variety of flux limits; sample a range of luminosity over a range of redshifts, e.g. Blundell et al, B4 §8.
  - Study objects chosen to have same narrow range of *L* over a wide range of *z,*
    e.g. Kukula et al, 2002TMA04.

UNIFICATION OF AGN

- Unification is driven by urge to simplify.
  This urge underlies much good science.
- Strong unification:
  One intrinsic property + Orientation.
- Weak unification:
  More than one intrinsic property + Orientation
- Strong unification: L varies; all else is orientation
  Probably not true: radio-loud and radio-quiet.
- Weak unification: L_{opt} & L_{radio} vary independently.
- Unification must be consistent with number densities difficult to test:
  Orientation introduces selection effects.

ACCRETION PHYSICS FOR AGN

- Much of the accretion disc physics you learned in B3 is applicable. B4§2
- Some things change appreciably with scale:

Q: $$T(r) = \left(\frac{3GM_{BH}\dot{M}}{8\pi\sigma R_S^3} \right)^{1/4} \left(\frac{r}{R_S} \right)^{-3/4}$$

is the temperature profile of an optically thick geometrically thin accretion disc around a black hole. Substitute for R_S in the first bracket. Hence say how the temperature at $r = 10\ R_S$ depends on the black hole mass.

Q: Block 1 page 10 says the conditions in AGN are *even more extreme* than in interacting binary stars. Do you agree?

- Accretion of whole stars (or fridges) may not liberate light. The Roche limit describes when tidal disruption will occur.
- Advection may occur: the flow may pass thru the event horizon carrying heat energy with it.

EVOLUTION OF AGN

- For z = 5 quasar,
  lookback time is 80-90% of age of Universe.
- Universe has evolved in this time.
    - Stars formed, gas depleted.
    - SNe exploded, gas enriched.
    - Density decreased.
    - Galaxy formation (?)
- AGN have evolved in this time.
    - Black holes' mass increased.
    - Gas swallowed.
    - Jets interacted with surroundings.
    - Radiation affected surroundings.
- Difficult to disentangle the two effects.
- Not enough energy in Universe for all AGN to have been active at currently observed L since Big Bang.
    - Universe's population of AGN must have evolved.
- Maybe all galaxies have been AGN at some stage?
    - Milky way harbours supermassive black hole.
    - *Density evolution*: fraction of galaxies in active state changes with time.
    - *Luminosity evolution*: fraction of galaxies harbouring AGN constant, L changes.
- Luminosity-dependent density evolution likely .

Q: What are γ and α?

Q: What implicit assumption/approximation made?

Q: Can you correct for this? What would you need to do?

Q: What are γ and α?

A: The Lorentz factor and spectral index.

Q: What implicit assumption/approximation made?

A: Assumes observed U-band measures same part of SED for all objects. In fact the rest wavelength varies with *z*. (By definition of *z*!). The flux in the rest-wavelength interval sampled is different for each value of *z*. This is very important if a strong emission line is red-shifted into the observed pass-band. In the specific case given, Lyman alpha is shifted into the observed U band for $z \sim 2$. This is known as the Lyman alpha selection effect.

Q: Can you correct for this? What would you need to do?

A: Yes, this can be corrected for, but only by measuring the matching intervals of rest-wavelength for all the objects in the sample!