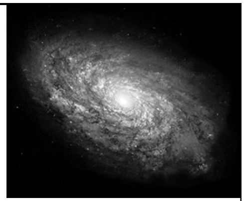
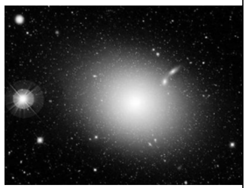
FORMATION AND EVOLUTION OF GALAXIES

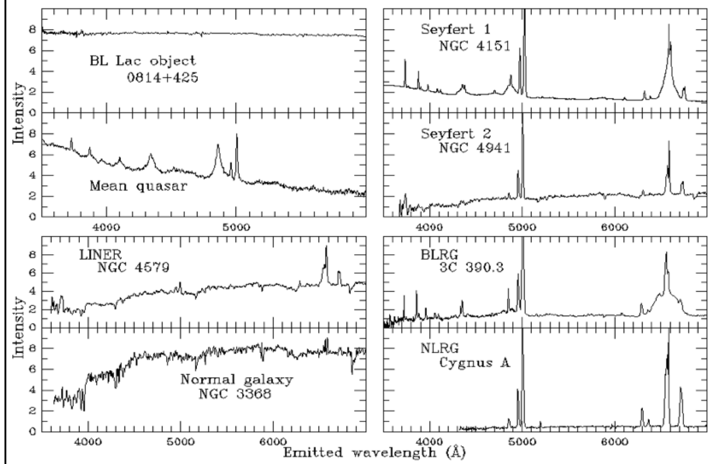
Lecture 15



- **Active Galactic nuclei**
  - The unified model
  - Emission lines: allowed and forbidden



Somak Raychaudhury



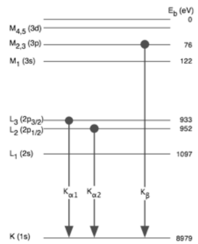
Why study quasar emission lines?

- Probe inner few parsecs of the AGN
- Learn about the unobservable UV continuum
- UV originates in the inner region of the accretion disk
- UV photons from quasars an important contributor to the metagalactic UV background
  (all the galaxies in the Universe as a system)
- Interesting line-formation phenomena because conditions are extreme
- Want to understand the source of the gas which fuels the central engine
- Unique probe of abundances at z=5-6
- Possible uses as cosmological probes (e.g. Baldwin effect)
- Use to measure central black hole masses in AGN

The Fe Kα emission line

K-alpha emission lines result when an electron transitions to the innermost "K" shell (principal quantum number 1) from a 2p orbital of the "L" shell (with principal quantum number 2)

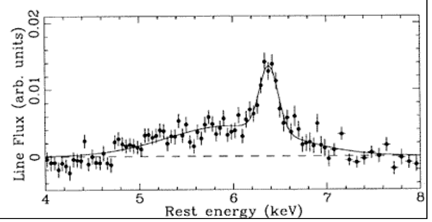
Same as Lyα in Hydrogen



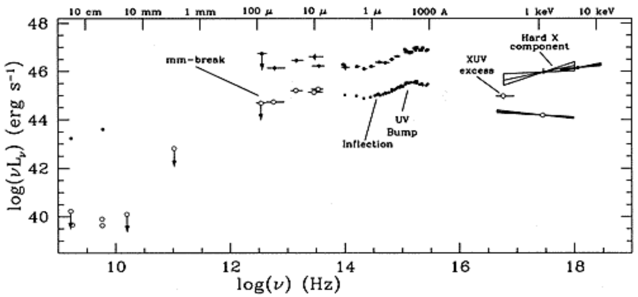
Moseley's Law:

Energy of K-alpha for $_{26}$Fe

$=10.2\,(Z-1)^2$ eV
$=10.2\,(26-1)^2$ eV
$= 6.38$ keV.



Continuum Spectral energy distributions



Radio: Synchrotron (relativistic electrons in B-field)
Mm-1 micron: Dust emission
1 micron - .2 keV: Thermal emission from optically thick accretion disk
X-rays: Synchrotron, Inverse Compton, Hot corona + reflection

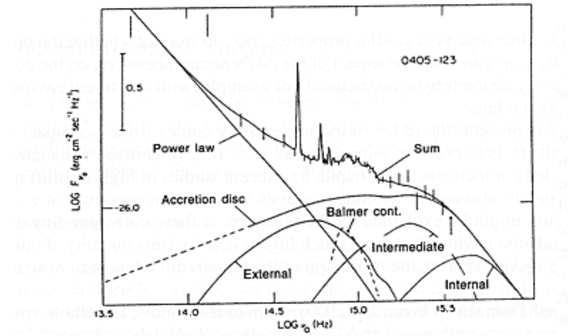
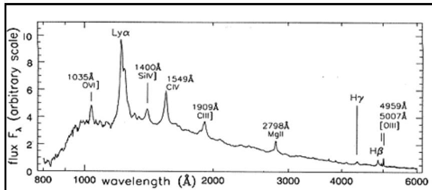
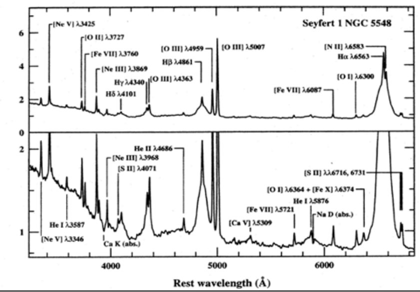


Figure 9.2 The spectrum of the QSO 0405−123 ($z = 0.57$) in the near infrared, the visible, and the ultraviolet. The fit involves three components (corresponding to three regions at various temperatures) and the Balmer continuum. (From Malkan 1983.)





Quasar and Seyfert 1 Spectra

Broad permitted lines (widths > 10,000 km/s)

Narrow forbidden lines (widths only few hundred km/sec),
e.g. [OIII] 4959, 5007

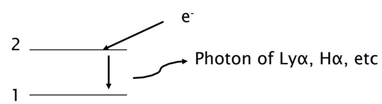
CIII] 1909 is broad

Forbidden Lines:
[O III]

Semi-Forbidden:
C III]

Recombination:
Ly alpha, Hα

Aside: forbidden v. permitted lines, recombination lines:



In photoionized gas, the lines of hydrogen and helium are **"recombination" lines**, and to first order do not depend on physical conditions like density or temperature.

Most **metals** are collisionally excited (the first excited level is low enough that for nebular temperatures, collisions can populate the upper levels)

Whether or not the electron is de-excited via emitting a photon or by a collision with a free electron depends on
(1) density of particles,
and (2) the Einstein A for the radiative de-excitation transition.

Permitted lines: Radiative de-excitation is fast (Einstein A is high) , so atom radiatively de-excites before a collision

Forbidden lines: Radiative de-excitation is not likely. If the density is low enough, a collision will not happen, and the atom will de-excite radiatively → we see the line.

If the density is greater than the "**Critical density**" then the atom collisionally de-excites before it emits a photon
→ no line

Emission Lines arise in 2 separate "regions"

1. Narrow Line Region (NLR)
   - Extended spatially (~kpc) in nearby Seyferts
   - Low density
     $n \sim 10^{3-6}$ cm^{-3} since you see forbidden lines like [OIII]
   - FWHM < 1000 km/s
   - Line diagnostics → photoionized gas

2. Broad Line Region (BLR)
   - Permitted Lines only
   - T~10,000 K from CIII 977 / CIII]1909 ratios
   - Line widths up to ~40,000 km/sec
     Recall thermal gas at $T=10^4$ K has width of ~10 km/sec
     → Must have Doppler broadening due to bulk motion of emitting gas
   * Densities $n \sim 10^{9-10}$ cm^{-3}
     Since you don't see forbidden lines, n>n(critical)
     they must be collisionally de-excited,
     although you do see broad CIII] so n<n(critical) for CIII]

NLRG, Seyfert 2's: NLR only, BLR obscured or absent
Seyfert 1's, Quasars, BLRG: NLR and BLR visible

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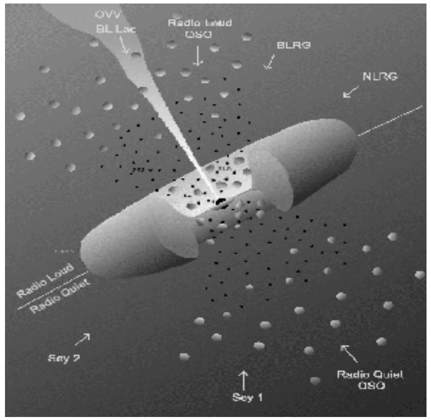
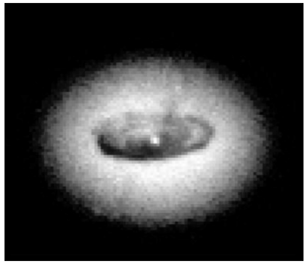
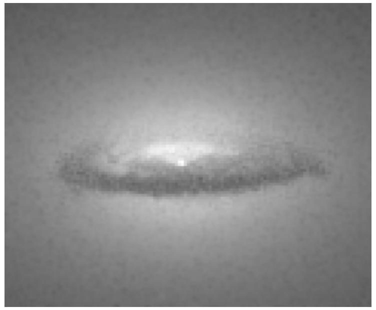


Although local Seyferts, imaged with HST, often show disk-like, dusty structures in their cores on relatively large scales, direct evidence for an obscuring torus, required by the Unified Models, doesn't really exist.

Theoretically, it's not clear how you'd "make" a torus and why it would be where it is





WFPC images of Seyfert Nuclei

Another part of the puzzle

Broad Absorption Line Quasars (BAL QSOs)
Warm (i.e. ionized) UV and X-ray absorbers
Associated Absorbers

All these objects have outflowing, radiatively driven winds
In a few cases, the absorption varies with time → must be very close to the central engine
Typically see very high ionization states, not typical of ISM clouds, e.g. NV, OVI, OVII etc

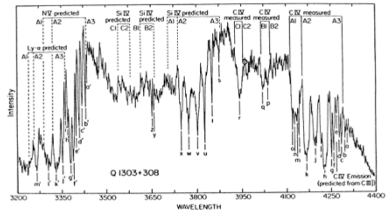


Fig. 3.—2 Å resolution blue photographic spectrum of Q1303+308 taken at the 2.3 m

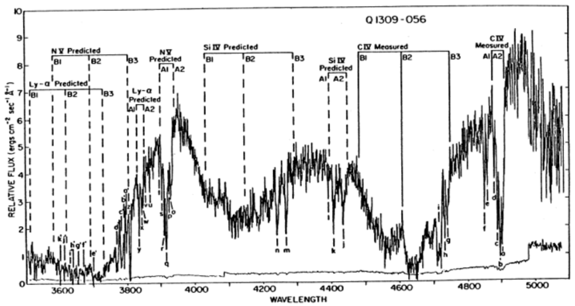


Fig. 6.—2 Å resolution IPCS spectrum of Q1309−056 taken at the AAT

Although BAL winds are thought to be radiatively driven, it's hard to have enough radiation force without totally ionizing the material and making it Impossible to radiatively drive out