AGNAGN Seminar Sec13.4-13.End

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13.4 Densities and Temperatures in the Narrow-Line Gas

- narrow emission lines observed in Seyfert 2 and narrow-line radio galaxies
  - like the emission lines observed in HII regions and planetary nebulae
    - ↔the range of ionization is considerably greater
    - [OII], [OIII], [NII], [NeIII], [OI], [NI], [NeV], [FeVII], and [FeX]
    - [SII] (relatively low stage of ionization) is generally much stronger in AGN
    - permitted lines (HI, HeI, and HeII) are moderately strong too

⇨narrow lines are emitted by a highly-ionized gas with normal abundances of the elements

Balmer decrement from narrow line

- measured Balmer-line relative strengths don't fit the recombination predictions (Table4.4)
  - observed Balmer decrement is steeper than the calculated recombination decrement
    - same as planetary nebulae and H II regions
    - result from the effects of extinction by interstellar dust
      - natural in the AGNs

- calculate the amount of extinction from the Balmer decrement

  →Hα/Hβ (corrected by standard redding law) = 3.08
    - larger than the calculated recombination (=2.85)
    - this increase is the result from an additional contribution due to collisional excitation of Hβ

  →correct for dust extinction on the measured line intensities
    - there isn't sufficient information to make more sophisticated correction for dust extinction in AGNs
    - automatically very nearly correct at Hα and Hβ
    - there can't be a large error because the extinction probably varies smoothly with wavelength

Physical condition of AGN

- estimate the relative abundances of the ions
  - the approximate elemental abundances (Cyg A, Table 13.4)

  ⇨approximately the same composition as Galaxy and galaxies with HII regions or starburst nuclei
    - H is the most abundant element
    - He is less abundant (1/10 of H)
    - O, Ne, N, and presumably C are the most abundant heavy elements
    - Fe is clearly under abundant
      - due to depletion onto grains

    ⇨dust is mixed with the ionized gas

- corrected intensities

  →diagnostic information on the physical conditions in the ionized gas

  →mean values of T and n_e from the [OIII], [NII], [OII], [SII], and [OI] line ratios

13.5 Photoionization
the main source of energy input

- temperatures in the ionized gas in NLRGs and Seyfert 2: $\sim 1-2\times 10^4\mathrm{K}$

  →strong observational evidence that the main source of energy input is photoionization
  - other plausible mechanism: shock-wave heating or collisional heating
    - results in collisional ionization and a direct relationship between temperature and ionization
    - under only shock-wave heating condition
      - [OIII] lines would be radiated at $T > 5\times 10^4\mathrm{K}$ and indicate a much higher than observed
  - under photoionization conditions
    - no direct relationship between gas temperature and ionization
    - effect of radiative cooling by collisionally excited line radiation increases with increasing temperature

      →keep $\mathrm{T}\sim 1-2\times 10^4\mathrm{K}$

  ⇨mechanism must be photoionization in all AGNs

The main source of the radiation

・the main source of the radiation can't be hot stars as in HII regions and planetary nebulae

・NLRG and Seyfert 2 has a wide range of ionization with strong emission lines

⇨main source must have much "harder" spectrum

→many high-energy photons $(h\nu = 100\text{eV})$

→・high ionization near the source

・long, partially-ionized "transition zone" in which H^0, H^+, e^-, O^0, and S^+ all coexist

→strong [OI] and [SII] lines can be collisionally excited

・physically, the width of the transition zone ≈ mean free path of an ionizing photon

・the higher the photon energy is, the longer the mean free path is, and the larger the transition zone is

Spectrum of AGN

・continuum in AGN: featureless and extend across a broad range of wavelengths

・Figure13.7: representative SEDs

・observed optical-UV approximately fits a power law:

$L_\nu = C\nu^{-\alpha}$ (typically, $\alpha \approx 1 - 2$)

・power law can both fit the observed continuum and produce reasonably strong [OI], [SII], [NeV], and [FeVII] emission lines

・comparison of the observed emission-line spectrum can be made

・instead of model AGNs' complicate structure

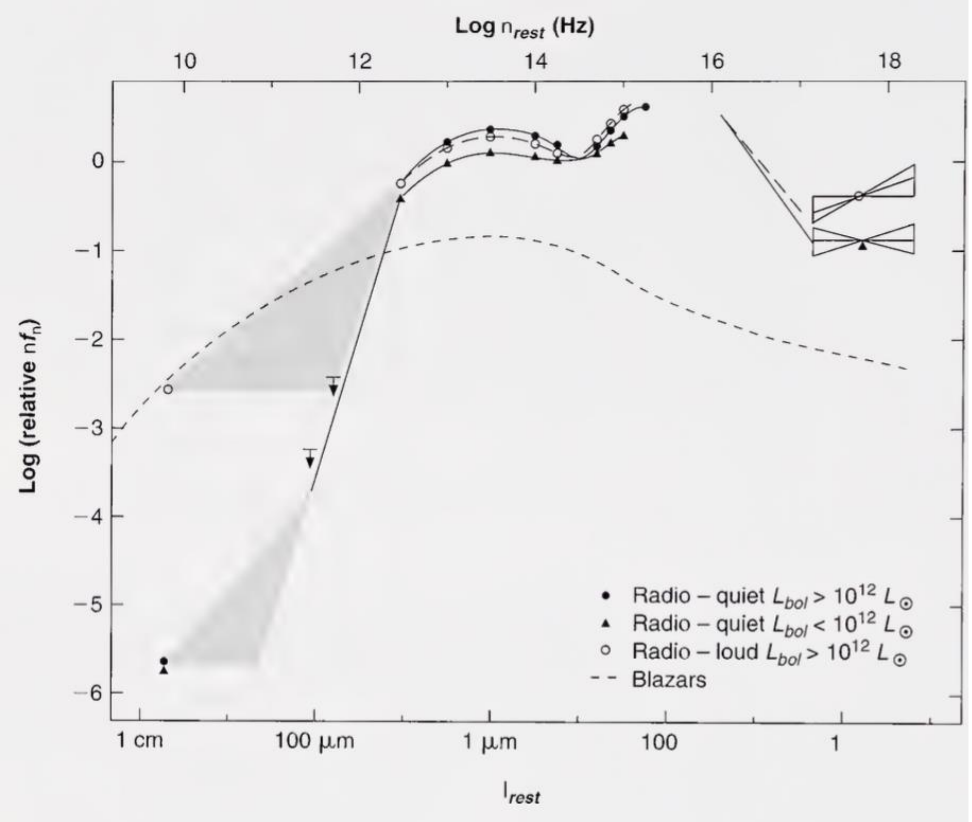

Figure 13.7

Spectral energy distributions for several sets of active nuclei. A horizontal line on this plot corresponds to $L_\nu \propto \nu^{-1}$, and roughly approximates the energy distribution from infrared wavelengths to X-ray energies.

Narrow-line regions

・narrow emission-line spectra of BLRGs, Seyfert 1, and Seyfert 1.5 are similar to NLRGs and Seyfert 2s

⇨the narrow-line regions (NLRs) in which the narrow lines arise in AGNs are photoionized by high-energy photons

・the high level of ionization in a greater proportion of the NLRs in Seyfert 1 than in Seyfert 2s

・indicate a difference in the shape of the ionizing spectrum at high energies, or in the fluxes of ionizing photons incident on NLR

・in terms of the ionization parameter

→ $$U = \frac{1}{4\pi r^2 c n_{\rm H}} \int_{\nu_0}^{\infty} \frac{L_\nu}{h\nu} d\nu$$

・L_ν: the luminosity of the source per unit frequency interval

・r: the distance from the source

・U: the dimensionless ratio of the ionizing photon density to the electron density

Mass and size of NLR

- estimate the mass and size of the NLRs by the same method as planetary nebulae
  - luminosity emitted in a recombination line (Hβ)

    → $L\,(\mathrm{H}\beta) = n_e n_p \alpha^{eff}_{\mathrm{H}\beta} h\nu_{\mathrm{H}\beta} V \varepsilon$ [erg s^{-1}]
      - V: the total volume of the NLR
      - ε: the filling factor (Section 5.9)
  - mass of ionized gas: $M = \left(n_p m_p + n_{\mathrm{He}} m_{\mathrm{He}}\right) V \varepsilon$[gm],
    - $n(\mathrm{He}) = 0.1 n_p$ (assume solar abundances)
    - $n_e = [n_p + 1.5n(\mathrm{He})]$ (assume that He is an equal mix of He^{+} and He^{++})
  - assume a spherical NLR→ $V = \frac{4\pi}{3} R^3$ [cm^3],
    - R: a specific numerical value of the dimension
  - the most luminous Seyfert 2s or NLRs of Seyfert 1→ $L(\mathrm{H\beta}) \approx 2 \times 10^8 L_\odot$

    ⇨ $M_{ion} \approx 7 \times 10^5 (10^4/n_e) M_\odot$, $R \approx 20\varepsilon^{-1/3}(10^4/n_e)^{2/3}\mathrm{pc}$
    - $n_e = 10^4 \mathrm{cm}^{-3}$, $\varepsilon \approx 10^{-2}$

    ⇨$M_{ion} \approx 10^6 M_\odot$, $R \approx 90\mathrm{pc}$
  - agree with the fact that the nearest Seyfert 2 NLRs apparently have diameters $\sim 10^2 - 10^3\mathrm{pc}$

13.6 Broad-Line Region

- spectral feature of Seyfert 1 and 1.5, and BLRGs:
  - broad permitted HI emission lines
  - weaker broad HeI λ 5876
  - broad HeII λ 4686
- most Seyfert 1s and 1.5s have broad FeII$\lambda\lambda$4570, 5250 with a wide range of strength
  - usually considerably fainter in BLRGs, but present
- broad HI, HeI, HeII, and FeII emission lines, and blue bump are seen in quasars and QSOs
  - "blue bump": feature in the continuum in $\lambda\lambda$2000-4000 region
    - composed of many unresolved FeII lines and HI Balmer continuum and higher-order Balmer lines
  - In UV region, recombination lines of HI and HeII, and collisionally excited lines of the heavy elements are present

Electron density in BLRs

- all the broad emission lines observed in AGNs are permitted or intercombination lines
  - forbidden lines don't have similar broad profiles
  - the broad lines arise in a so high density region ($n_e > n_c$)

    →all the levels of abundant ions which can emit forbidden-line are collisionally deexcited
    - broad component of [OIII] λ 5007 is at most 1% to H β with respect to the same line in narrow-line objects
      - $n_c(\mathrm{O\ III}) \approx 10^6 \mathrm{cm}^{-3}$

        →lower limit to the mean electron density in BLR: $n_e > \sim 10^8 \mathrm{cm}^{-3}$
  - in UV, [CIII] λ 1909 is observed with a broad profile
    - $n_e \leq n_c(\mathrm{C\ III}) \approx 10^{10} \mathrm{cm}^{-3}$

    →the mean electron density in observed BLRs: $n_e \sim 10^9 \mathrm{cm}^{-3}$

Physical conditions of BLRGs

- the observed FeII emission indicates that T < 35,000 K
  - at higher temperature, it would be nearly completely ionized to FeIII
    ⇨for approximate estimates, $T \sim 10^4 \mathrm{K}$
- estimate the amount of ionized gas in the BLR
  - the most luminous AGNs of Seyfert 1 and BLRGs have $L(H\beta) \approx 10^9 L_\odot$
    - $M_{ion} \approx 36 M_\odot (10^9/n_e)$ and $R = 0.015 \varepsilon^{-1/3} (10^9/n_e)^{2/3} \mathrm{pc}$
  - representative density $n_e \approx 10^9 \mathrm{cm}^{-3}$ and $M_{ion} > 40 M_\odot$, and assumed $\varepsilon \approx 10^{-3}$
    →$R \approx 0.07 \mathrm{pc} \approx 0.2\ \mathrm{light\ yr}$
      - too small to resolve even for the nearest BLR
- the broad emission line profiles, and the fluxes vary in a week or two in many BLRs

→several campaigns to measure the time lag between a continuum variation and the response of the emission lines

⇨the BLR is stratified with higher ionization species having shorter lags, and originating at smaller distances from the continuum source

↔the narrow-line spectra of AGNs occur on very long time scales

- the much longer light-travel times estimated

Mechanism of energy input in the BLR

・the nature of the energy input to BLR: most probably, photoionization by the high-energy extension of the observed featureless continuum

・evidence: correlation of the luminosities in recombination lines and featureless continuum

・different AGNs have essentially the same H α emission equivalent width

・not only for the Seyfert 2 and NLRGs, but also for the Seyfert 1.5s, BLRGs, Seyfert 1s, and quasars and QSOs

⇨all the ionization (NLR and BLR) is due to photoionization

・other evidence: the variations in the continuum and emission lines are correlated

・observed results are consistent with photoionization being the energy input to BLR

Facts about AGN

・optical spectrum shows forbidden lines ($n_c \approx 10^4 \mathrm{cm}^{-3}$), and permitted lines ($n_c \approx 10^{14} \mathrm{cm}^{-3}$)

・the NLR is more distant from the continuum source, and has lower density than the BLR

⇨gas present on a variety of distance scales

・lower density gas is more distant from the nucleus, and have narrower linewidths than denser gas

・X-ray lines (Fe Kα) have $n_c \approx 10^{20} \mathrm{cm}^{-3}$, even higher than the optical and UV permitted lines (Figure13.9)

・permitted lines in the optical and UV have $n_c \approx 10^{14-15} \mathrm{cm}^{-3}$ but don't show broad wing

⇨gas emitting the Fe Kα must have $10^{14} \mathrm{cm}^{-3} < n_c < 10^{20} \mathrm{cm}^{-3}$

・equivalent width is proportional to the gas column density (must be large)

⇨Fe Kα line is from the densest gas close to massive black hole

・is broadened and shifted by a combination of Doppler motions and gravitational redshifts

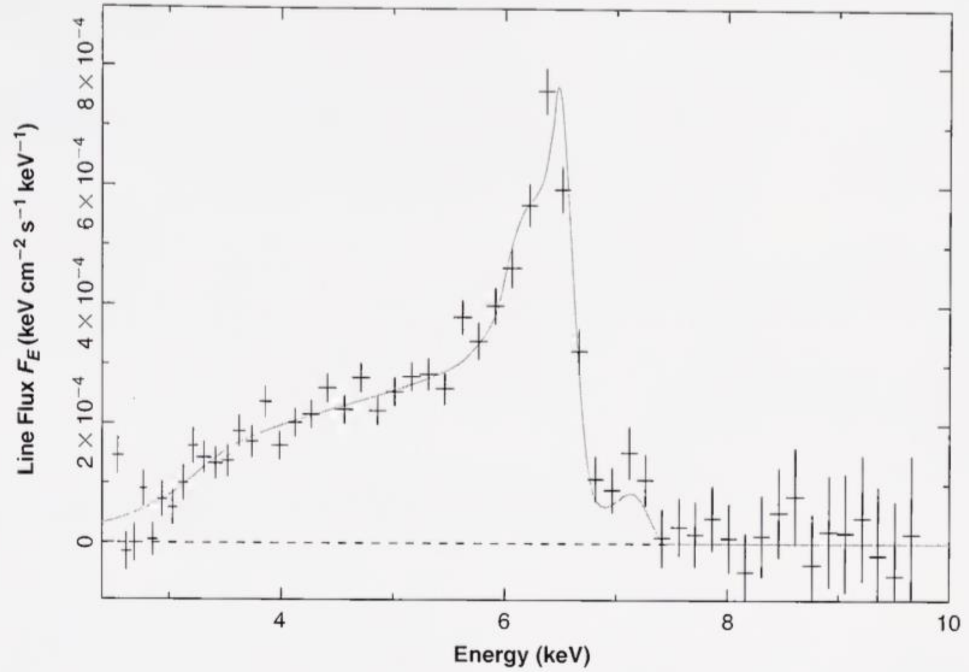

Figure 13.9
The Fe Kα line in the Seyfert 1 galaxy MCG–6–30–15. The rest-frame line center is at 6.4 keV.