AGNAGN seminar Sec.11.4-11.5

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11.4 Physical Conditions from X-ray Spectroscopy

X-ray spectrum

Classification of X-ray(based on detector technology)**:**

- **Soft X-ray(<2keV)**
  Emission lines from various element
- Hard X-ray(>2keV)
  No emission line from abundant element, except Fe

Soft X-ray spectrum of NGC1068
(Emission lines and recombination continua are formed by the same physical process with IR and optical)

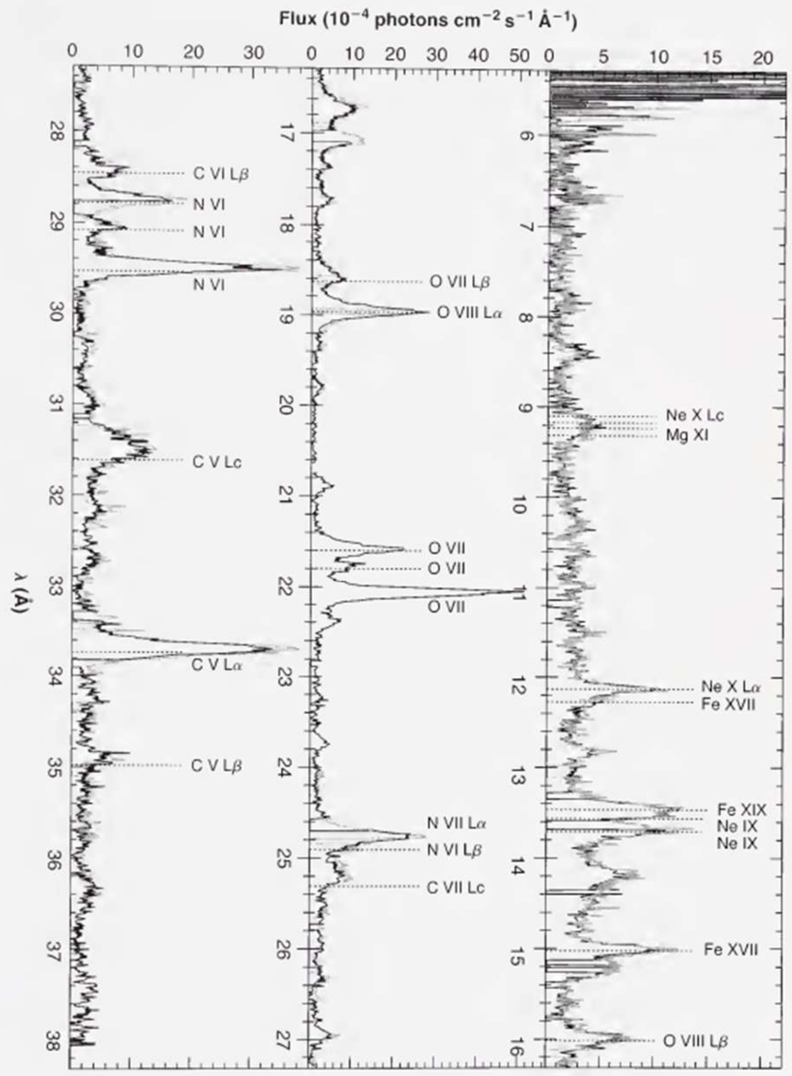


Figure 11.6
The soft X-ray spectrum of the Seyfert galaxy NGC 1068.

Representative emission lines:H-like ions

(Discuss in terms of **isoelectronic Sequences**)

- Ions with **1** electron: discuss the same as **H**
- Ions with **2** electrons: discuss the same as **He**
- **Transition probability: Z^4 Energy:Z^2**
  (Z: atomic number)

Table 11.2

H-like 1s–2p wavelength and two-photon critical density

Ion	λ (Å)	$h\nu$ (keV)	Transition probability $A(2\nu)$ (s^{-1})	Critical density $n_{crit}(2s)$ (cm^{-3})
C VI	33.74	0.366	3.8×10^5	5.1×10^{14}
N VII	24.78	0.499	9.7×10^5	1.7×10^{15}
O VIII	18.97	0.652	2.2×10^6	5.0×10^{15}
Si XIV	6.19	2.00	6.2×10^7	4.2×10^{17}
Fe XXVI	1.78	6.94	2.5×10^9	5.8×10^{19}

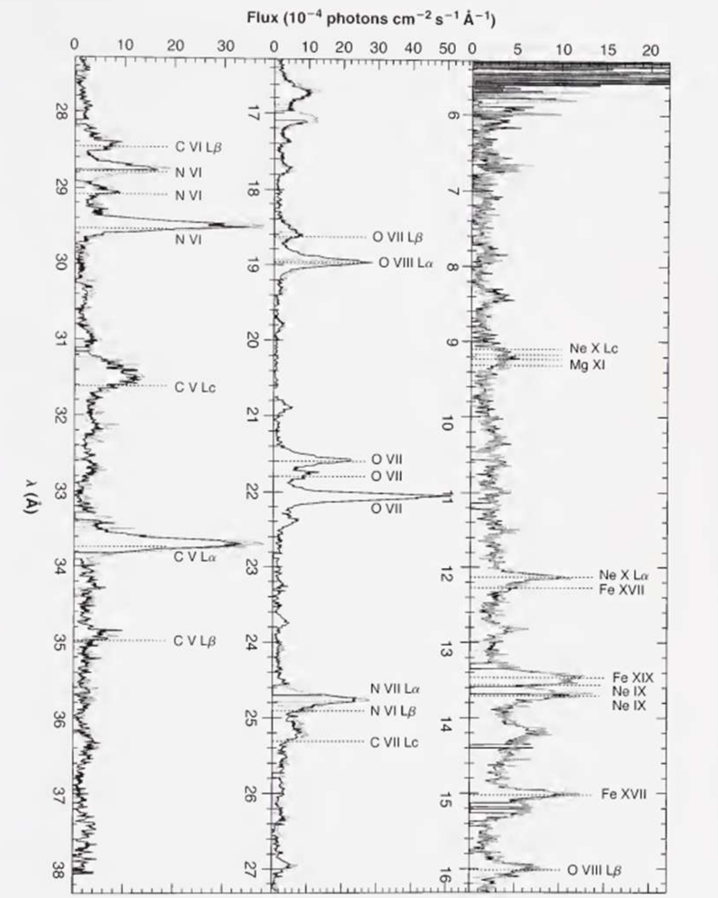


Figure 11.6

The soft X-ray spectrum of the Seyfert galaxy NGC 1068.

Gas temperature < excitation energies

⇒**Emission lines are produced by recombination**

⇒①(2/3) Populate 2p, and produce Lyα transition

②**(1/3) Populate 2s, and produce two-photon transition or Lyα**

⇑Gas density << critical electron density n_{crit}

⇒low density limit, two-photon transition is dominant

Higher Lyman recombination lines & Environment

① **Case A**

- **Optically thin**
- **continuum striking the clouds contains no radiation within the higher-n Lyman lines**
  (appropriate for a cloud ionized by a hot star with strong Lyman absorption features)

② **Case B**

- **Optically thick**
- **Higher Ly photon ⇒ Br photon +(Ly α or two-photon cont.)**

③ **Case C**

- **appropriate when the continuum is bright in the Lyman lines** (Similar environment with Case A, but contribution of continuum is strong)

Representative emission lines:
He-like ions

Table 11.3

He-like $n = 2$ lines and transition probabilities

	$1s^2\ ^1S_0 - 1s\ 2s\ ^3S_1$		$1s^2\ ^1S_0 - 1s\ 2p\ ^3P^o_1$		$1s^2\ ^1S_0 - 1s\ 2p\ ^1P^o_1$	
Ion	λ (Å)	A (s^{-1})	λ (Å)	A (s^{-1})	λ (Å)	A (s^{-1})
C V	41.46	6.9×10^3	40.74	2.6×10^7	40.27	8.9×10^{11}
N VI	29.53	249	29.09	1.4×10^8	28.79	1.8×10^{12}
O VII	22.10	1000	21.81	5.5×10^8	21.60	3.3×10^{12}
Si XIII	6.743	3.4×10^5	6.687	1.5×10^{11}	6.645	3.8×10^{13}
Fe XXV	1.867	3.9×10^9	1.856	5.8×10^{13}	1.848	4.6×10^{14}

Two photon transition ⟷ **Transition from n=2**

Transition probability is different
⇒relative intensities is sensitive to density

- Used for density diagnostics(range: $10^{8-12} cm^{-3}$)
- Situation: Case B or C

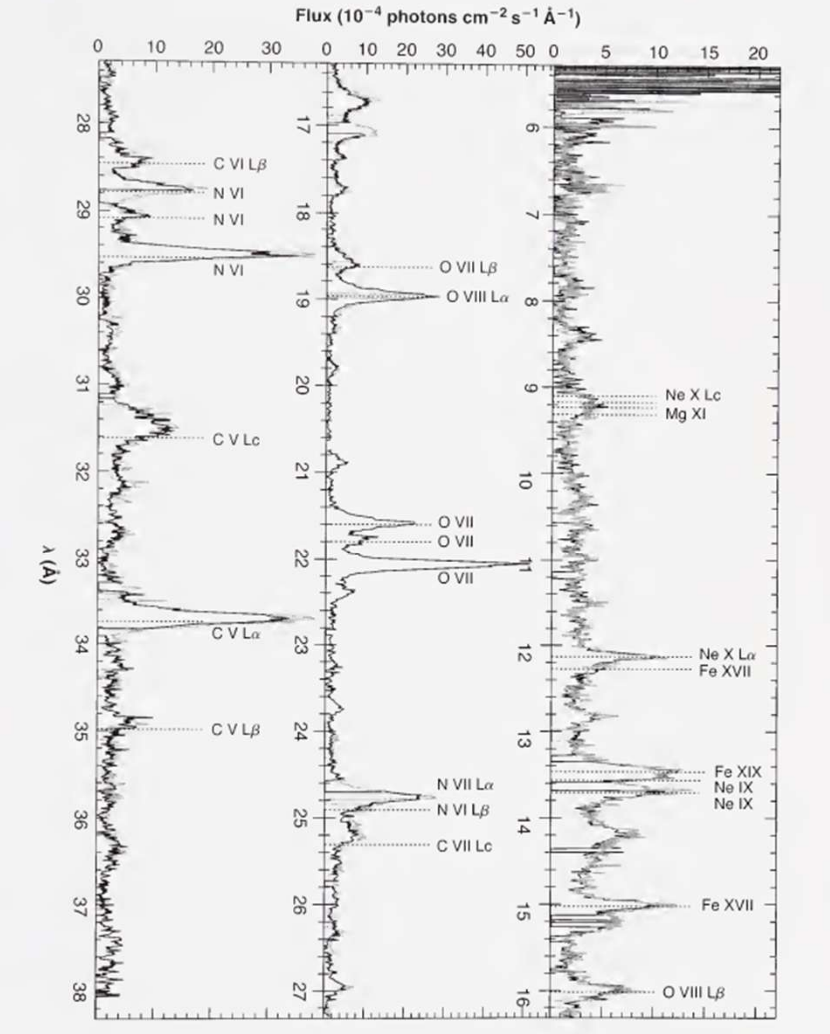


Figure 11.6

The soft X-ray spectrum of the Seyfert galaxy NGC 1068.

Characteristics of gas radiating X-ray

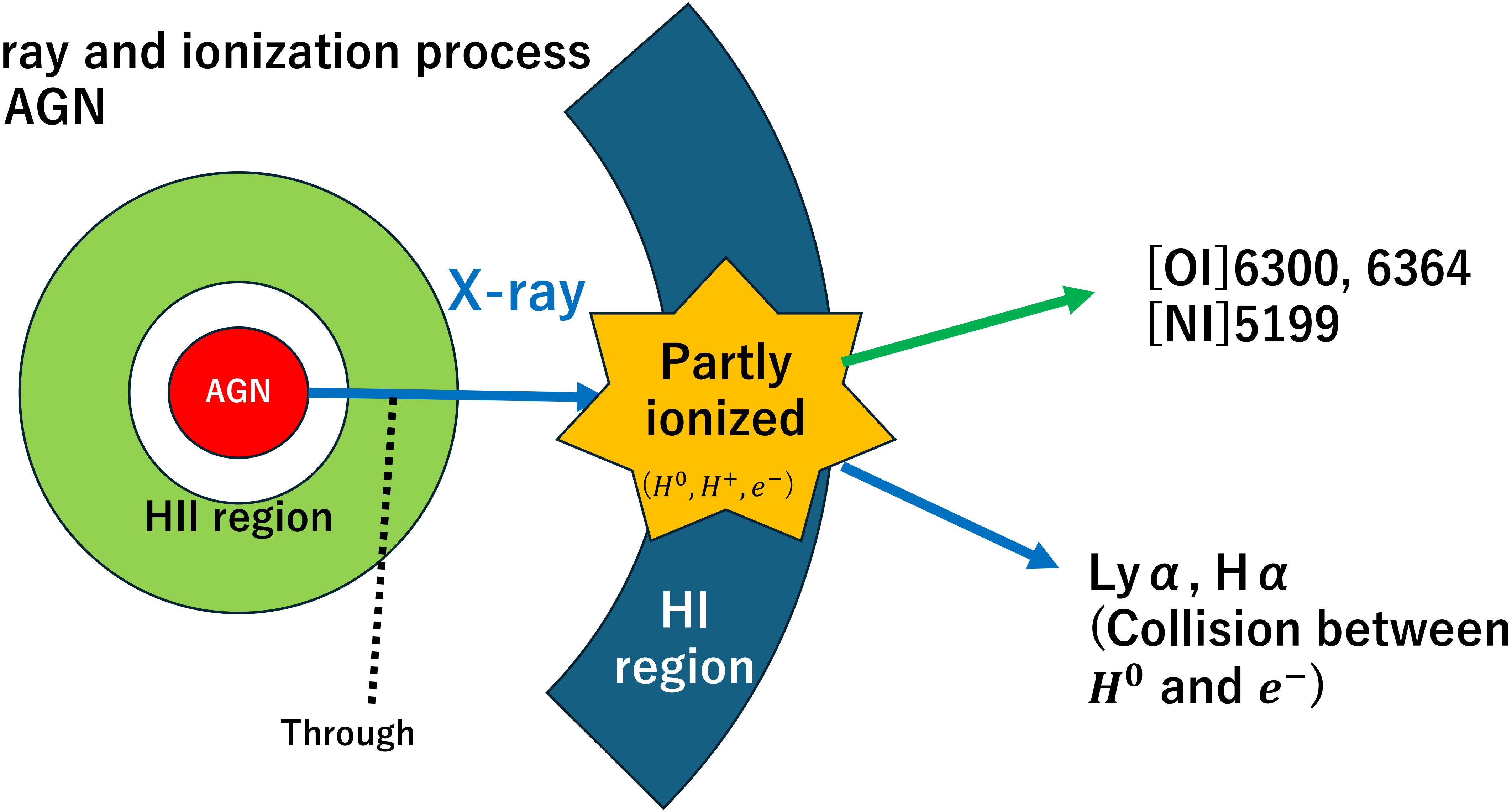
1. **Highly ionized**
   - **Many element have only 0~2 bound electrons**
   - **Emit very little optical/IR, because of ①high energy transitions and ②low emissivity of optical/IR lines due to high temperature**

2. **(Moderate ionized)**
   - **Strong sources of optical/UV emission**
   - **Produce fluorescent lines, but it needs large column densities(only see examples in AGN)** (Sec.11.3)

Emission line in hard X-ray: Fe K α line (Sec. 11.2)

11.5 Collisional Excitation of H°

X-ray and ionization process in AGN



Ly α collisional excitation(low density)

Reaction(direct excitation of the 2^2P^0):

$$H^0(1s\ ^2S) + e \rightarrow H^0(2p\ ^2P^o) + e, \quad (11.7)$$

Threshold: 10.2eV
Excitation cross section arises rapidly when (energy > threshold)

Emission coefficient(n=1 only, low density):

$$4\pi j_{L\alpha} = n_e n(H^0) q_{1\,^2S,2\,^2P^o}\, h\nu_{L\alpha}, \quad (11.8)$$

Table 3.16
Effective collision strengths for H I

T(K)	$1\,^2S, 2\,^2S$	$1\,^2S, 2\,^2P^o$	$1\,^2S, 3\,^2S$	$1\,^2S, 3\,^2P^o$	$1\,^2S, 3\,^2D$
10,000	0.29	0.51	0.066	0.12	0.063
15,000	0.32	0.60	0.071	0.13	0.068
20,000	0.35	0.69	0.077	0.14	0.073

Threshold and required collisional strength increase with n
⇒**Contribution of collisional excitation to higher level will increase**
(about 3~10%)

⇒consider higher n to derive (11.9)

Emission coefficient(n=1~3):

Contribution of higher n

$$4\pi j_{L\alpha} = n_e n(H^0)(q_{1\,^2S,2\,^2P} + q_{1\,^2S,3\,^3S} + q_{1\,^2S,3\,^2S} + q_{1\,^2S,3\,^2D} + \cdots) h\nu_{L\alpha}. \quad (11.9)$$

Lyα emission coefficient(low density)

Equation for Recombination:

$$4\pi j_{L\alpha} = n_e n_p \alpha^{eff}_{2\,^2P^o} h\nu_{L\alpha}$$
$$= n_e n_p (\alpha_B - \alpha^{eff}_{2\,^2S}) h\nu_{L\alpha} \quad (11.10)$$

Contribution of collisional excitation vs recombination:

Table 11.4

Lα emission coefficients in partially ionized regions (all in erg cm^3 s^{-1})

	Low density $n_e \ll 1.5 \times 10^4$ cm^{-3}		High density $n_e \gg 1.5 \times 10^4$ cm^{-3}	
T (K)	Collisional $\frac{4\pi j_{L\alpha}}{n_e n(H^0)}$	Recombination $\frac{4\pi j_{L\alpha}}{n_e n_p}$	Collisional $\frac{4\pi j_{L\alpha}}{n_e n(H^0)}$	Recombination $\frac{4\pi j_{L\alpha}}{n_e n_p}$
10,000	2.56×10^{-24}	2.87×10^{-24}	4.46×10^{-24}	4.25×10^{-24}
12,500	2.62×10^{-23}	2.39×10^{-24}	4.51×10^{-23}	3.53×10^{-24}
15,000	2.23×10^{-22}	2.01×10^{-24}	2.10×10^{-22}	3.06×10^{-24}
20,000	8.89×10^{-22}	1.51×10^{-24}	1.46×10^{-21}	2.34×10^{-24}

High temperature/(High density)

⇒**Collisional excitation is dominant**

Excitation of neutral H and contribution to Lyα (high density)

Critical density:

$$n_c = \frac{A_{2\,^2S,1\,^2S}}{q^p_{2\,^2S,2\,^2P} + q^e_{2\,^2S,2\,^2P}} \approx 1.5 \times 10^4\ [\mathrm{cm}^{-3}] \tag{11.11}$$

Collisionally Emission coefficient (high density, n=1)

$$4\pi j_{\mathrm{L}\alpha} = n_e n(\mathrm{H}^0)\left(q_{1\,^2S,2\,^2S} + q_{1\,^2S,2\,^2P}\right) h\nu_{\mathrm{L}\alpha} \tag{11.12}$$ ←(11.8)

Collisionally Emission coefficient (high density, n=1~3)

$$4\pi j_{\mathrm{L}\alpha} = n_e n(\mathrm{H}^0)\sum_{n=2}^{3}\sum_{L=0}^{n-1} q_{1\,^2S,n\,^2S,n\,^2L} h\nu_{\mathrm{L}\alpha}. \tag{11.13}$$ ←(11.9)

Recombination coefficient (high density)

$$4\pi j_{\mathrm{L}\alpha} = n_e n_p \alpha_{\mathrm{B}} h\nu_{\mathrm{L}\alpha} \tag{11.14}$$ ←(11.10)

Behavior are similar to “low density” case, but emission coefficient are larger by factors of approximately 1.5

Hα & collisional/recombination

Under standard Case B condition, Collisional excitation to any of the levels $3\,^2S$, $3\,^2P$, or $3\,^2D$ leads to Hα emission

Emission coefficient:

$$4\pi j_{\mathrm{H}\alpha} = n_e n_p \sum_{L=0}^{2} q_{1\,^2S,3\,^2L} h\nu_{\mathrm{H}\alpha}. \quad (11.15)$$

- Strongly depends on temperature
- Not so important, comparison to Lyα (small contribution)

Table 11.5

Hα emission coefficients in partly ionized regions (all in erg cm^3 s^{-1})

T (K)	Collisional $\frac{4\pi j_{\mathrm{H}\alpha}}{n_e n(\mathrm{H}^0)}$	Recombination $\frac{4\pi j_{\mathrm{H}\alpha}}{n_e n_p}$
10,000	2.12×10^{-26}	3.54×10^{-25}
12,500	3.47×10^{-25}	2.89×10^{-25}
15,000	2.28×10^{-24}	2.46×10^{-25}
20,000	2.25×10^{-23}	1.81×10^{-25}