Optical Emission Line Spectra

1. Basics & Nomenclature

Optical (and near ultraviolet and near infrared) emission lines of galaxies are predominantly associated with ionized gas. The emission lines are the result typically of *recombination radiation* or *collisionally excitation*. The physical conditions of ionized gas in galaxies varies by large orders of magnitude in density, from 0.3 to 10^4 cm^{-3} but typically has temperatures around 10^4 K.

In astronomical spectroscopy, the ionization state is indicated by Roman numerals. XI indicates neutral "X," XII indicates singly-ionized "X," XIII indicates doubly ionized "X," etc.

The ionization state of gas is determined by the balance among effects such as photoionization, collisional ionization, and recombination. In the interstellar medium, the radiation field is generally far from blackbody and statistical mechanical rules like the law of mass action that would otherwise govern the ionization state do not hold.

1.1. Photoionization

[photoionization]

[other sources of ionization: collisional, etc]

1.2. Recombination radiation

[cross section]

In ionized gas, hydrogen and other elements have electrons recombining at some rate that balances the ionization rate. Typically the recombination is to a high energy bound state. The electron will thereafter decay into successively lower states. For hydrogen, two limiting cases exist:

- Case A: optically thin to ionizing photons. The recombination rate is the sum of the recombination rates to each energy level indexed by quantum states n and l:

$$\alpha_A(T) = \sum_{n=1}^{\infty} \sum_{l=0}^{n-1} \alpha_{nl}(T) \tag{1}$$

- Case B: optically thick to photons at energies just above the H ionization limit (13.6 eV). The recombinations to $n = 1$ do not count, because they just result in an ionizing photon that is immediately recaptured:

$$\alpha_B(T) = \alpha_A(T) - \alpha_{1s}(T) \tag{2}$$

For most cases within the interstellar medium, Case B is appropriate because enough neutral H is available, even in HII regions. In such cases, the system is optically thick to all Lyman-series photons.

The Case A recombination spectrum can be calculated by assuming the levels are populated by recombination as above, and then using the decay probabilities from each state. The Case B recombination spectrum is calculated the same way, but just taking all transitions to $n = 1$ out of the picture. The temperature enters the calculation weakly due to its effect on the recombination coefficients α. The density enters the calculation even more weakly (until $n > 10^6$ cm^{-3}), because collisions affect the high n levels.

In HII regions, where Case B holds, Lyman lines have a special fate. They undergo *resonant scattering*; every Lyman line emitted is very quickly reabsorbed. Since they undergo many scatterings, and also can decay to lower levels between scatterings, eventually they result in a Lyman-α photon. In HII regions, they can escape only through a rare two-photon decay to a continuum (when the state is 2s) or by being Doppler scattered into a wing of the line.

Helium also contributes recombination radiation. For very hard photoionization sources, He III will predominate. This is a hydrogen-like system with an ionization energy four times as large. The emission lines are shifted in energy by that much, and the overall pattern of transitions in gas at temperature T is the same as hydrogen for a gas with temperature $T/4$.

[Other elements]

1.3.   Collisional excitation

1.4.   Measurements of emission lines

2.   Key References

- *Physics of the Interstellar and Intergalactic Medium, Draine et al. (2007)*

3.   Order-of-magnitude Exercises

1. Dependence on temperature and resulting metallicity dependence of Halpha

4.   Analytic Exercises

- alpha calculation

- Ly-alpha scattering

5.   Numerics and Data Exercises

1. Use of Balmer decrement for dust

2. Running MAPPINGS or other

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REFERENCES

Draine, B. T., Dale, D. A., Bendo, G., et al. 2007, ApJ, 663, 866