AGNAGN Seminar
Sec.6.6-7.2

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6.6 Magnetic Fields

Interaction

Magnetic Fields ⇔ Gas dynamics

Energy density

$E_B = B^2/8\pi$ $E_{th} = nkT$

Limit of interaction:

Case A: $E_{th} \gg E_B$

- Gas is in control, and magnetic field lines will follow the matter

Case B: $E_B \gg E_{th}$

- Magnetic field is in control, and matter will follow along magnetic field lines

Magnetic field & Shocks

Shock = discontinuous transitions between two phases(Sec.6.1 & 6.2, J-type shocks)

Shocks created by the magnetohydrodynamical(MHD) wave (C-type shock)

Interaction between magnetic field & gas
⇒**Create MHD wave**(Wave transfers in Plasma)
⇒**Compress and accelerate gas**
(MHD wave can move faster than the speed of sound)
⇒**Create shocks**

Behavior of shocks

- **Non-magnetized gas**
  Supersonic turbulence is dissipated quickly into heat
- **Magnetized, ionized gas**
  MHD wave creates coherent gas motion
  ⇒**Do not produce heat**
  (Produce spectral lines with supersonic broadening)

6.7 Stellar Winds

Stellar winds: the outflow driven by the force of radiation

Momentum of each photon: $\frac{h\nu}{c}$

⇒Total momentum: $\boldsymbol{p = \frac{L}{4\pi r^2 c}}$ (r: distance from the star, L: luminosity of the star)

If $\boldsymbol{h\nu}$(photon energy) $\ll \boldsymbol{m_e c^2}$(rest energy of the electron)

⇒**Electron scattering happens**

Cross section(independent of frequency):

$$\sigma_T = \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2 = 0.67 \times 10^{-24} \ [\mathrm{cm}^2] \qquad (6.43)$$

Total momentum an electron by scattering (per unit time):

$$\dot{p} = \sigma_T p = \frac{\sigma_T L}{4\pi r^2 c}$$

This (radiation pressure) will work as **outward force**

Static equilibrium: **outward force=inward pull(gravity)**:

$$\dot{p} = GMm_H/r^2$$

Eddington limit

$$L_{Edd} = \frac{4\pi c G M m_H}{\sigma_T} \approx 3 \times 10^4 L_\odot \frac{M}{M_\odot}. \qquad (6.44)$$

※Stars more luminous than L_{Edd} will lose their outer layers

Simulations of stellar wind

Phenomena caused by stellar wind

1. **Shocks**

   Speed of stellar wind ≫ Speed of nebular material:
   ⇒**Creates a shock**

   Pressure equilibrium(stellar wind = nebular):

- **Density of the wind (shock interface):**

$$\rho_s = \frac{\dot{m}}{4\pi r^2 u} \quad [\mathrm{gm\ cm^{-3}}]. \tag{6.45}$$

- **Shock temperature:**

$$T_s = \frac{\rho}{n}\frac{u^2}{9k} \approx 0.6 m_{\mathrm{H}} \frac{u^2}{9k} = 8 \times 10^6 \left(\frac{u}{1000\ \mathrm{km/s}}\right)^2 \quad [\mathrm{K}] \tag{6.46}$$

2. Hot gas bubble

Shock heats the gas near the star

⇒**Hot inner region(radiates X-ray)**

& Cold outer region

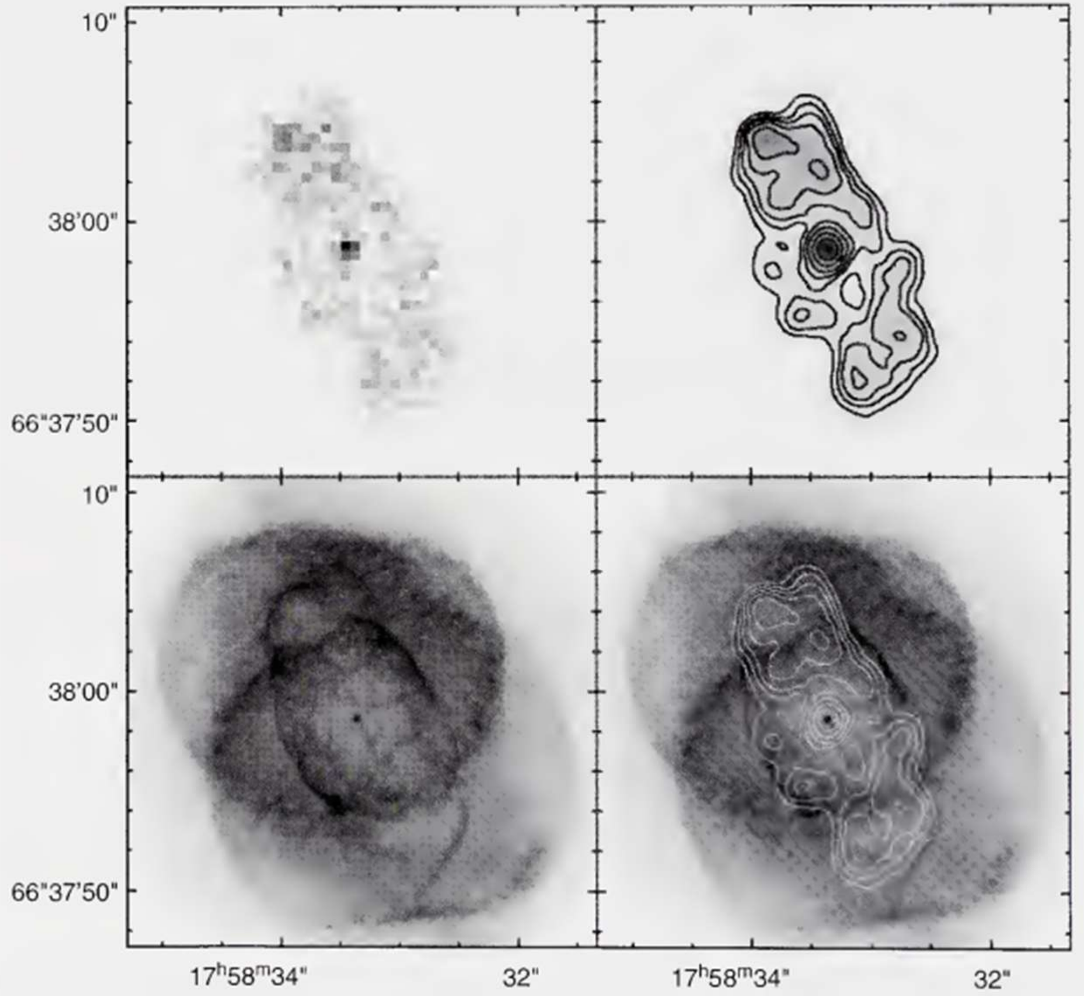

Figure 6.2

A comparison of X-ray and optical images of the planetary nebula NGC 6543. The upper Chandra images are in X-ray light and the lower HST images are in the light of Hα. The hot gas detected in the X-rays fills the central regions of the nebula.

3. Interaction with ionized dense gas flow

Proplyds in Orion nebular

- **Disk of molecular gas surrounding lower-mass stars**

1. Θ1 Ori C heats and dissociates gas in the disk
2. Forms a neutral gas flow
3. Ionize the gas flow
4. **Ionized gas flow collide with stellar wind**
   ⇒form the faint arcs of emission

7. Interstellar Dust

7.1 Introduction

Interstellar Dust:

- Gas within HII regions and planetary nebulae contain dust particles
- Affect on the properties of the nebulae

Contents of Sec.7

- Evidence for the existence of dust in nebulae
- Effect on observational data and how to correct
- Measurement of the radiation of HII region & planetary nebulae
- Dynamical effects results from dust

7.2 Interstellar Extinction

Extinction:

- **Most obvious effect of interstellar dust**
- **Happens due to scattering(main source), absorption(partly)**

Reduction in the amount of light:

$$I_\lambda = I_{\lambda 0} \exp\left(-\tau_\lambda\right) , \quad (7.1)$$

I_λ: observed intensity
$I_{\lambda 0}$: intrinsic intensity
τ_λ: optical depth

When applies to stars: $\boldsymbol{I \Rightarrow \pi F_\lambda}$
(※if the dust is mixed with the gas, this approximation is not so good)

Number of magnitudes of extinction:

$$A_{\lambda 1} = 2.5\log(I_{\lambda 1}/I_{\lambda 1}\ \ )$$

Measurement of extinction (optical depth)

1. Principle approach

Derived by spectrophotometric measurement of pairs of same spectral type stars

$$\frac{\pi F_\lambda(1)}{\pi F_\lambda(2)} = \frac{\pi F_{0\lambda}(1)\exp[-\tau_\lambda(1)]}{\pi F_{0\lambda}(2)\exp[-\tau_\lambda(2)]} = \frac{D_2^2}{D_1^2}\exp\{-[\tau_\lambda(1) - \tau_\lambda(2)]\} \quad (7.2)$$

$\Leftarrow$ (7.1)

D_1, D_2: distance

- In (7.2), optical depth depends on the ratio of distance
- Deriving distance independently is impossible
  ⇒**Measure the distance with observation in long wavelength (extinction is negligible)**

2. Empirical approach

Empirical law for optical depth:

$$\boldsymbol{\tau_\lambda = C f(\lambda)}$$

C: Constant factor, depends on the object

$\boldsymbol{f(\lambda)}$: Approximately the same for most stars in the Galaxy

2-1 Color approach(normalized to V band)

1. **Measure A_B and A_V based on observed color and intrinsic color**
2. **Take the difference between A_B and A_V (E(B-V)= $A_B - A_V$) and derive R= $A_V/E(B-V)$**
3. **Derive A_λ/A_V=f(λ)/f(V) with Fig.7.1 (standard reddening curve)**

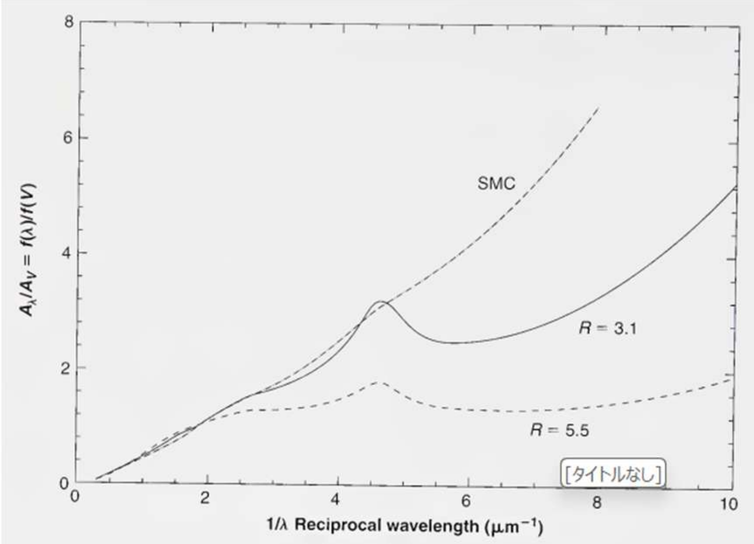

Figure 7.1

2-2 Emission line approach

Extinction on emission lines:

$$\frac{I_{\lambda_1}}{I_{\lambda_2}} = \frac{I_{\lambda_1 0}}{I_{\lambda_2 0}} \exp\left\{ -C\left[f(\lambda_1) - f(\lambda_2) \right] \right\}. \quad (7.6)$$

(extinction can be assumed to have the average form)

C is possible to be derived with the pairs of emission line whose intrinsic intensity ratio is known

Conditions:

- **Independent of physical conditions**
- **Easy to measure in all nebukae**

Line pairs for measurement of extinction

1. [SII]4069, 4076/[SII]10287, 10320, 10336, 10370
   - Same upper level(4S-2P, 2D-2P transition)
     ⇒transition probabilities≒intensity ratio
   - Detection is hard(weak intensities, contamination by OH atmospheric lines)

2. Ratio of Paschen lines and Balmer lines(like Paδ/Hε)
   - These lines arise from the excited terms with same principal quantum number
   - Weak lines

3. Ratios of two Balmer lines
   - Line ratio is almost independent from temperature

3. Radio continuum approach

Measure extinction with HI recombination line & radio continuum

$$j_\nu = \frac{1}{4\pi} n_+ n_e \frac{32 Z^2 e^4 h}{3 m^2 c^3} \left(\frac{\pi h \nu_0}{3kT} \right)^{1/2} \exp(-h\nu/kT)\, g_{ff}(T, Z, \nu), \quad (4.22)$$

(Optical)

$$g_{ff}(T, Z, \nu) = \frac{\sqrt{3}}{\pi} \left[\ln \left(\frac{8k^3T^3}{\pi^2 Z^2 e^4 m \nu^2} \right)^{1/2} - \frac{5\gamma}{2} \right], \quad (4.30)$$

(Radio)

$$\frac{n_+ \langle Z^2 \rangle}{n_p} \approx 1 + \frac{n(\mathrm{He}^+)}{n_p} + 4 \frac{n(\mathrm{He}^{++})}{n_p}, \quad (7.7)$$

Table 4.4
H I recombination lines (Case B)

	T								
	5,000 K			10,000 K			20,000 K		
n_e (cm^{-3})	10^2	10^4	10^6	10^2	10^4	10^6	10^2	10^4	10^6
$4\pi j_{H\beta}/n_e n_p$ (10^{-25} erg cm^3 s^{-1})	2.20	2.22	2.29	1.23	1.24	1.25	0.658	0.659	0.661
$\alpha^{eff}_{H\beta}$ (10^{-14} cm^3 s^{-1})	5.37	5.43	5.59	3.02	3.03	3.07	1.61	1.61	1.62
Balmer-line intensities relative to Hβ									
$j_{H\alpha}/j_{H\beta}$	3.041	3.001	2.918	2.863	2.847	2.806	2.747	2.739	2.725
$j_{H\gamma}/j_{H\beta}$	0.458	0.460	0.465	0.468	0.469	0.471	0.475	0.476	0.476
$j_{H\delta}/j_{H\beta}$	0.251	0.253	0.258	0.259	0.260	0.262	0.264	0.264	0.266
$j_{H10}/j_{H\beta}$	0.0515	0.0520	0.0616	0.0530	0.0533	0.0591	0.0540	0.0541	0.0575
$j_{H15}/j_{H\beta}$	0.01534	0.01628	0.02602	0.01561	0.01620	0.02147	0.01576	0.01612	0.01834
$j_{H20}/j_{H\beta}$	0.00657	0.00819	0.01394	0.00662	0.00755	0.01058	0.00664	0.00717	0.00832

1. **Estimate intrinsic intensity ratio with (4.22), (4.30), Tab4.4 and (7.7)**
2. **Derive C with observed intensity ratio and intrinsic intensity ratio**