AGNAGN Seminar Sec9-9.4

Misato Fujii

9.1 Introduction

- consider HII regions in the wider context
  - distributions of HII regions, both in MW Galaxy and in other known galaxies
  - HII regions' galactic kinematics
  - examine the stars in HII regions, their formation, and HII region formation
  - their use to determine the evolution of the elements in ISM

9.2 Distribution of HII Regions in Other Galaxies

・HII regions can be recognized on direct images of galaxies taken in the radiation of strong nebular emission lines

・best spectral region: **red** (around $\mathrm{H\alpha}\ \lambda 6563$, $[\mathrm{NII}]\lambda\lambda 6583, 6548$)

・quite **narrow-band interference filters**

→reject unwanted continuum radiation

・comparison with a narrow-band image in the nearby continuum

→nearly complete discrimination between HII regions and continuum sources

→many galaxies have been surveyed for HII regions in this way

→・almost all the nearby **spiral galaxies contain many HII regions**

↔**elliptical and S0 galaxies typically don’t contain HII regions**

・few S0s have some HII regions, but much less than typical later-type spirals

HII region in spiral galaxies and irregular galaxies

・HII regions in spiral galaxies

・general feature: **the concentration of HII regions along relatively narrow spiral arms** and spurs

・in fact, HII regions are the main objects defining the spiral arms

↔there are no HII regions in the inner parts of the spiral galaxies

・there are regions of interstellar extinction

⇨in the inner region, there is interstellar matter, but no O stars to ionize it and make it HII regions

・HII regions in irregular galaxies

・**the distribution of HII regions is less well organized**

・some areas may contain many HII regions, but other areas may contain no HII regions

・there are some galaxies with HII emission spread through their volume

・called “HII galaxies”, “extragalactic HII regions”, or “blue compact dwarf galaxies”

9.3 Distribution of HII Regions in Our Galaxy

・analogy with observed external galaxies

→suggest that **the HII regions in our Galaxy are also concentrated to spiral arms**

・HII regions are strongly concentrated to the galactic plane

↔it's difficult to survey much of the Galaxy optically for HII regions and to determine their distances accurately

・approach to locate the spiral arms in our Galaxy

(1)use the exciting O stars (the original method)

(2)find the distances of more numerous young galactic clusters

(3)use radio-frequency emission line

approach to locate the spiral arms

(1)use the exciting O stars

- not easy if extinction is heavy
- identify the O stars, classify their spectra, and find their distances from their absolute magnitudes, using a standard extinction ratio and the star's intrinsic color
- most of the nearby bright HII regions
  - the exciting O stars can easily be recognized from available spectral surveys
- more distant H II regions
  - the exciting star or stars cannot be identified among the many foreground and background stars

(2)find the distances of more numerous young galactic clusters

- available even if they don't contain O stars or don't have an observable HII region
- UBV photometry and fitting to a standard zero-age main sequence to eliminate extinction and obtain the distance
- more accurately determined than by the spectral types of a highly luminous O stars
- there are many more clusters than O stars

approach to locate the spiral arms

(3)the radio-frequency region

・there is essentially zero extinction

→**radial velocities can be measured with high accuracy for interstellar gas** with particular spectral line, such as HI λ21.1cm

・the variation of circular velocity with distance from the center of the Galaxy

・derived from measured stellar radial velocities near the sun, and from the λ21-cm radial velocities and geometrical considerations at greater distance

→measured radial velocities can be converted into distances

→early maps of the spiral arms by neutral H^0 were constructed

・more accurate measurements can be made by the sharper CO λ2.59 mm lines in molecular clouds, or radio-recombination lines such as H109α λ5.99 cm in HII regions

approach to locate the spiral arms

→using all the methods, Figure9.3

・the scatter is large

・the logarithmic spiral certainly guides

↔probably incorrect in detail due to oversimplification

・Galaxy is a spiral, and most likely to be an Sbc type in the Hubble classification scheme

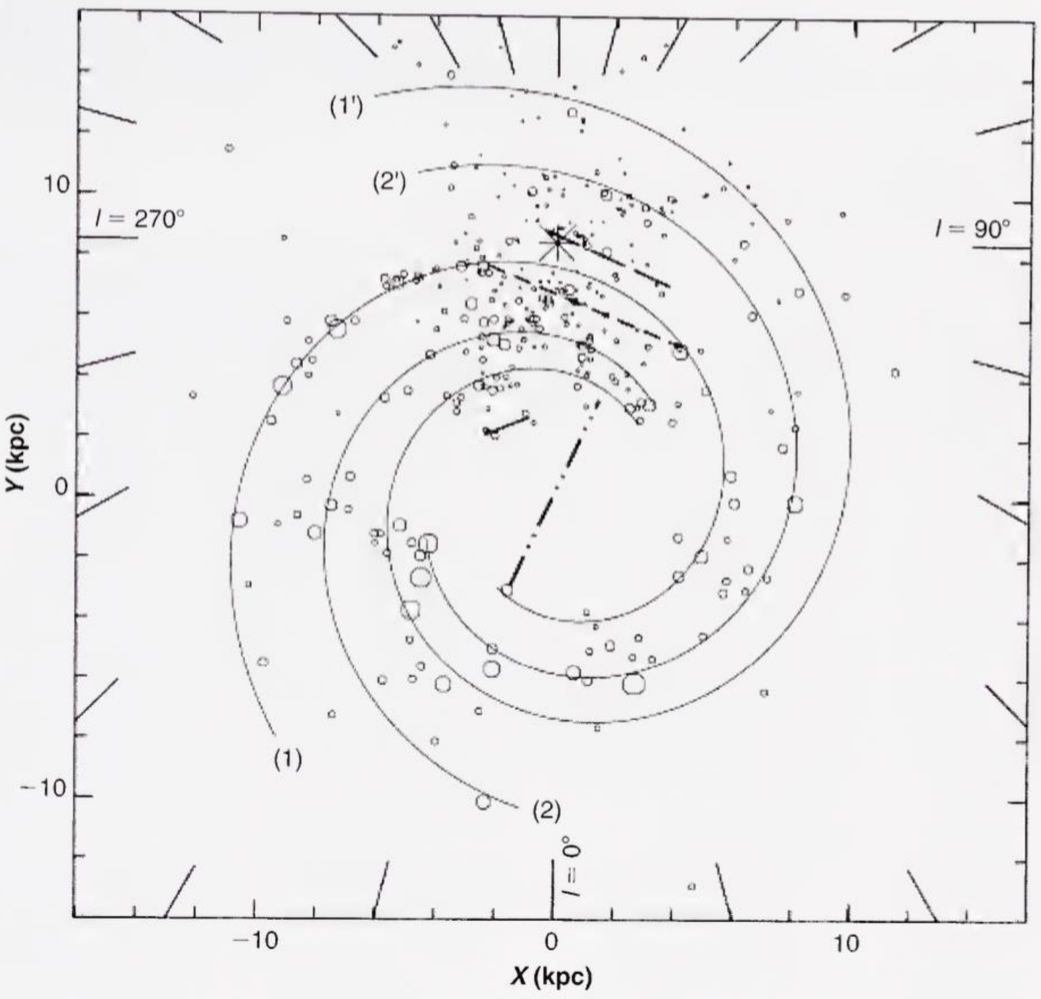

Figure 9.3

Distribution in the Galactic plane of H II regions. The deduced positions of the spiral arms are drawn as solid lines.

Problem to decide the distance

・the galactic rotation model **doesn't uniquely determine the distance of HII regions closer to the Galaxy center than the sun**

・the same measured radial velocity corresponds to two possible positions equally distant from the galactic center

→in Figure 9.3, some of these ambiguities are resolved

・by additional information from radio absorption lines if available

・by continuity arguments in the absence of other information

・this ambiguity doesn't exist for HII regions more distant from the galactic center than the sun

・for all HII regions, any errors in the kinematic model, and the dispersion of this relationship, lead to errors in the derived distance

9.4 Stars in HII Regions

・O stars: very high luminosities, and short lives,

　・O6 star: approximately 4×10^6 years

→**O stars are formed recently**

　　・there are also many less luminous stars in the Orion Nebula cluster

　　　・many of them have emission lines in their spectra

　　⇨indicate that they also formed recently

　　⇨stars over a wide range of luminosity, or mass, have formed recently there

　　⇨assume **star formation occurs with a range of masses given by an initial mass function (IMF)**

　　　　・a power law fit the observational data

Star formation with IMF and SFR

- star formation occurs when an interstellar cloud collapse gravitationally
  →fragments into a large number of smaller clumps
  →form stars with $10^{-1}M_{\odot} \leq M \leq 10^{2}M_{\odot}$
- IMF: the number of stars per unit mass interval
  - $\varphi(M) \propto \frac{dN}{dM}$
    - $\varphi(M)$ is in reasonable agreement with the Salpeter IMF
      - $M\varphi(M) = 0.17M^{-1.35}$ $(M > M_{\odot})$
        - the integral of $M\varphi(M)$ over the mass interval $10^{-1}M_{\odot} \leq M \leq 10^{2}M_{\odot}$ is unity
        - the newly-formed stellar population is weighted towards smaller masses
        - note that IMF may not apply equally well in other regions
- star formation rate (SFR) $\psi(t)$: total mass of stars formed per unit time
  - mass of stars of a particular mass bin that form per unit time
    - $r(M) = \psi(t)M\varphi(M)$ $(M_{\odot}\mathrm{yr}^{-1})$

Star formation in HII region

- limiting case of star formation
  - **instantaneous star formation**
    - the cluster is assumed to have formed in a short period of intense activity
    - shorter-lived high-mass stars leave MS first
      - as the cluster ages, the radiation field corresponds to progressively cooler stars
  - **continuous star formation**
    - the massive stars that leave the MS are replaced with newly formed stars
      →the hydrogen-ionizing radiation field doesn’t evolve
    - the number of long-lived low-mass stars increase
- HII regions are ionized by the integrated light of the central cluster
  - the ionizing radiation field is dominated by the hottest stars in the cluster
  - the spectrum of an HII region is strongly influenced by the ionizing stellar continuum
    ⇨possible to use the lines to estimate star-formation properties

SFR from H α

・H α emission-line luminosity can be used as an indicator of the current star formation rate

・H α luminosity

→the number of ionizing photons emitted by the O stars and absorbed locally

→the number of stars of each luminosity and spectral type for the assumed IMF

・the high-luminosity O stars exhaust their H and die so quickly (typically within 10^6 years)

⇨ (their present number / their calculated lifetimes) = present formation rate

⇨the total rate of star formation for solar abundances and the adopted IMF

$$\mathrm{SFR}(M_\odot \mathrm{yr}^{-1}) = 7.9 \times 10^{-42} L(\mathrm{H}\alpha); \qquad [L(\mathrm{H}\alpha) \text{ in erg s}^{-1}]$$

$$= 1.08 \times 10^{-53} Q(\mathrm{H}^0); \qquad [Q(\mathrm{H}^0) \text{ in photons s}^{-1}]$$

・same relation can be applied to any region of a galaxy

・note:

・transformation between mass and luminosity, the stellar evolution models and the IMF

・assuming that observational data apply in all galaxies, and give SFRs down to the faint or small mass galaxies

→many possible errors

・uncertain correction for dust absorption must be made