The Milky Way Galaxy  Chapter 15

Topics to be covered:

1. Contents of our Galaxy: Interstellar Medium(ISM) and Stars . Nebulae

2. Distribution of galactic clusters and center of our Galaxy.

3. Structure of our Galaxy: Central bulge, Disk and Spiral arms

4. Methods of observations through dust: Ir, Radio, X-rays, gamma-rays

5. General description of Galactic Center, Spiral arms – birthplace of stars

6. The HI and HII regions of hot and cold hydrogen !

7. The 21-cm radio spectral line and mapping the galactic Hydrogen

8. Cradle of new stars: Giant Molecular Clouds (GMC)
Our galaxy contains different objects which show their presence by different observational techniques. I note some important points:

1. Type of radiation emitted depends on the temperature of the emitter.

   What is qualitatively the relation between T and peak wavelength?

   Higher the temp, smaller the peak wavelength
   Hot stars – violet, UV, X-rays as temp increases.
   Cooler stars – visible, IR, microwaves
   Still cooler environs – Radio waves – 21 cm line for neutral cold H

2. Transit from source to earth modifies the signal – obscuration, reddening..

   Visible light obscured by dust particles
   IR, radio and X-rays generally unobscured by dust.
Satellite observatories, WMAP (microwave), IRAS (IR), COBE, DIRBE (uv,ir)
Avoid atmospheric absorption.

Ground based observatories: Adaptive optics (corrects for atmospheric fluctuations), large multi-mirror Telescopes, Rapidly Orienting telescopes, Interferometry, and VLA and VLBA radio telescopes.

These have made us learn a great deal about our milkyway galaxy.

The galaxy contains, stars, gas, dust, magnetic fields, black holes and Dark Matter. We will survey this knowledge.
Our galaxy in 23 Giga Hz micro-waves as seen by WMAP satellite

Galactic disk is clearly seen. Map is in coordinate system whose x axis is longitude away from the galactic center (from -180 to 180 deg) and y axis is the latitude away from the plane of the galactic disk. Microwave radiation from the galactic disk is in red.
Composite of galaxy in visible light. Obscuration by Dust is clearly seen.

A view of a region of the galaxy not visible to the eye is shown below! Perseus spiral arm of the galaxy: In radio and IR light – false image.
Notice the distribution of globular clusters in a spherical region around the disk and distribution of gravitating matter extending in surrounding Halo.
A planar view:
The Whirlpool galaxy.

Where would the sun be?
An artist's drawing of our Milky Way galaxy

Plan view. Spiral arms shown.

Position of sun indicated.

~ 100,000 light years across
It was Harlow Shapley who first discovered that distribution of globular clusters of stars was not centered on the solar system but around a point some 28,000 light years distant from the sun, surrounding what we now know as the central bulge of the galaxy.

There are regions observed in the galaxy which are called nebula. They are large diffuse regions. They are of three types

Bright nebulae: Gas heated by radiation from hot young stars and the gas in turn emits radiation which we observe.

Dark nebulae: Regions populated by dust which absorbs visible light and which remits in the Infra-Red(IR) wavelength region

Reflection nebulae: Region which contain material which reflects the light from nearby stars.
Bright and Dark Nebulae. Shows the dark absorbing region of horsehead shape. Lot of glowing gas! Provide evidence for presence of gas and dust in the galaxy.

reflection

dark

bright
A collection of young OB stars are seen in this image. **Pleiadis Open cluster**: Star forming region

Viewing the galaxy in different wavelength bands is one of the ways in which we explore the structure of the galaxy. This is shown in the next figure.
Reveals distribution of stars, gas, dust and high energy sources.
Hot stars, shock waves from SN explosions heat up interstellar gas. Hydrogen gas and dust grains

**HII** (spherical and large)

**HISM**

- \( n = 3 \times 10^{-3} \text{/cc} \)
- \( T \approx 10^5 \text{K} \)
- \( B \sim 1-3 \mu G \)
- \( V > 80\% \)
- \( \text{Mass} \sim 4 \times 10^7 \text{M}_\odot \)
- \( \text{NO DUST} \)

**HI clouds**

- \( n \sim 1-100 \text{/cc} \)
- \( T \leq 10^4 \text{K} \)
- \( B \sim 3 \mu G \)
- \( V \leq 20\% \)
- \( \text{Mass} \sim 4 \times 10^9 \text{M}_\odot \)
- \( \text{DUSTY} \)

**SN rate**

- \( \frac{1}{10} - \frac{1}{30} \text{ /year} \)

**SN Power**

- \( 10^{42} \sim 3 \times 10^{42} \text{ erg/s} \)

**SN Mass Ejection**

- \( \sim 1 \text{ M}_\odot / \text{yr} \)
Observing the galactic center region:

Dust makes the galactic center region obscured in visible light. It can however be observed in IR, X-rays and Radio wavelengths. It reveals a very active and exciting features. The center is at a location close to that of Saggitarius A*.

Maps of the galactic center region by different techniques is shown next:
Why is the dust transparent to IR waves?

Short wavelength waves, less than or equal to dust grain size, are scattered or absorbed by the dust grains!

They usually re-emit in longer wavelengths.

Long wavelength waves are unaffected by the presence of dust grains which are much smaller in size than the wavelength and are transmitted through!

Consider deep sea waves passing by a small boat: The boat is lifted and then lowered by crests and troughs respectively but the deep sea waves keep on going.

Ripples on a pond will get scattered in all directions by the presence of the boat in the pond.
Wide field VLA map at 90 cm wavelength

Hubble Telescope IR of center

Galactic plane
A detailed look at the Arc in the previous figure at right angles to the disk.

We believe there are high energy electrons in the filaments and they produce X-rays by collisions with a million solar mass cloud of cold gas!!

Galactic plane
Stars Revolve around the galactic center:

Other stars orbiting the gc are shown in Fig 15-15 b in the text. **An analysis of these star orbits show that there must be a giant black hole at the location of Sag A_star with a mass about 4 Million solar masses.**
There is an extended source of X-rays as observed by Integral mission at the galactic center. See Figure 15-16 in text.
Spiral Arms

As we are located in the galactic plane, it is difficult to trace out the spiral arms.

By analyzing distances and directions to objects of various types we can infer the spiral structure.

We examine other spiral galaxies – some of which we see in their plan view – and find that young stars (O and B type) and gas and dust are preferentially distributed in spiral arms which are the cradles of star formation. By plotting out directions and distances to open clusters and HII regions we can trace out bits of three spiral arms.

We can map HI regions and dust regions by techniques of radio astronomy. In particular using the 21 cm line of neutral hydrogen.
Spiral Arms continued:

We can determine that our sun revolves around the center of the galaxy with an enormous speed: 200 km/sec!
It completes one revolution around the galactic center in 240 million years. As the sun is about 4.6 billion years in age, it would have completed some 18 revolutions.

These spiral arms are caused by spiral density waves – A matter compression and rarefaction wave similar to sound wave (along the direction of such waves) – probably originating in or near the galactic center and spiraling out. Where matter is compressed conditions are appropriate for star formation and a cluster of stars are formed. These open cluster stars tend to migrate. So at different epochs one has different stars along the spiral arms.
Interstellar medium: ISM:

The most predominant element in our galaxy is Hydrogen. If Hydrogen is cold it can either exit in atomic or molecular state.

Cold hydrogen regions are called H I regions and they have higher density than hot hydrogen regions which are called H II.

H II regions are formed by energetic radiation from hot stars which disassociate neutral hydrogen atoms into a P+ and an e-. When such a dissociated atom recombines to form neutral hydrogen again it emits characteristic H emission lines. Thus can be identified.

This is shown schematically in the next slide:
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A special quantum property of neutral hydrogen makes it detectable by radio astronomy. This property has to do with intrinsic spin of protons and electrons and leads to the emission of fixed wavelength radio wave – of wavelength 21 cm!
Model of molecular cloud structure of Orion Nebula: Cradle of star formation.