Chapter 23

The Milky Way Galaxy

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- Early Computers

Galactic Structure

The Formation of the Milky Way

Galactic Spiral Arms

- Density Waves

Units of Chapter 23

The Mass of the Milky Way Galaxy

The Galactic Center

Cosmic Rays

23.1 Our Parent Galaxy

From Earth, see few stars when looking **out** of galaxy (red arrows), many when looking **in** (blue arrows). **Milky Way** is how our Galaxy appears in the night sky (b).

23.1 Our Parent Galaxy

Our Galaxy is a spiral galaxy. Here are two other spiral galaxies, one viewed from the side and the other from the top, which are thought to resemble the Milky Way:

23.2 Measuring the Milky Way

One of the first attempts to **measure** the Milky Way was done by Herschel using visible stars.

Unfortunately, he was not aware that most of the Galaxy, particularly the center, is blocked from view by vast clouds of **gas** and **dust**.

23.2 Measuring the Milky Way

We have already encountered **variable stars** –novae, supernovae, and related phenomena – these are called **cataclysmic variables**.

There are other stars whose luminosity varies in a regular way, but much more subtly. These are called **intrinsic variables**.

Two types of intrinsic variables have been found: **RR Lyrae** stars, and **Cepheids**.

23.2 Measuring the Milky Way

The upper plot is an RR Lyrae star. All such stars have essentially the same luminosity curve, with periods from 0.5 to 1 day.

The lower plot is a Cepheid variable; Cepheid periods range from about 1 to 100 days.

23.2 Measuring the Milky Way

The variability of these stars comes from a dynamic balance between gravity and pressure – they have large oscillations around stability.

23.2 Measuring the Milky Way

The usefulness of these stars comes from their period–luminosity relation:

23.2 Measuring the Milky Way

This allows us to measure the distances to these stars.

- RR Lyrae stars all have about the same luminosity; knowing their apparent magnitude allows us to calculate the distance.

- Cepheids have a luminosity that is strongly correlated with the period of their oscillations; once the period is measured, the luminosity is known and we can proceed as above.

23.2 Measuring the Milky Way

Many RR Lyrae stars are found in globular clusters. These clusters are not all in the plane of the Galaxy, so they are not obscured by dust and can be measured.

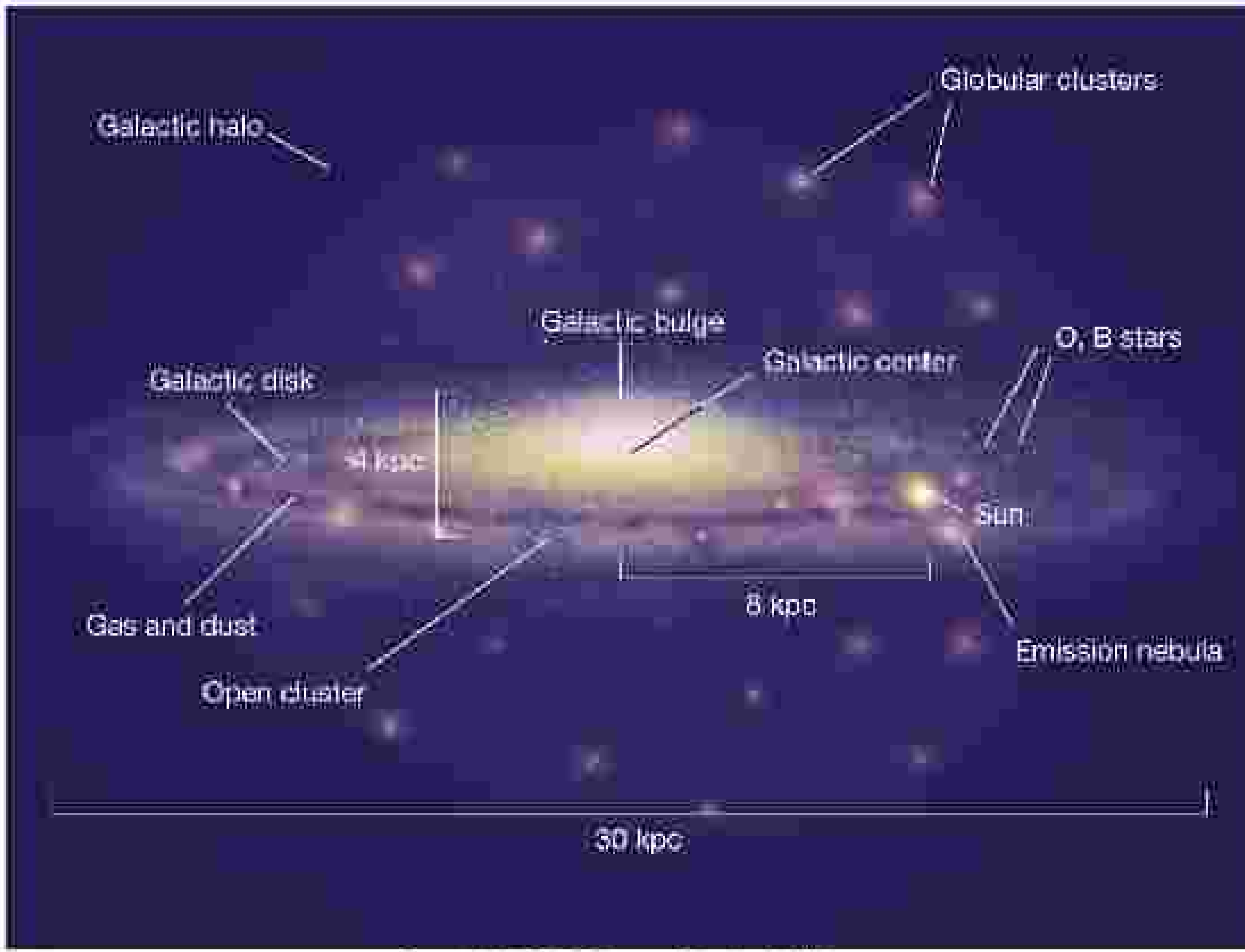
This yields a much more accurate picture of the extent of our Galaxy and our place within it.

23.2 Measuring the Milky Way

We have now **expanded** our cosmic distance ladder one more step:

23.3 Galactic Structure

This artist's conception shows the various parts of our Galaxy, and the position of our Sun:



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23.3 Galactic Structure

The **Galactic halo** and **globular clusters** formed very early; the halo is essentially spherical. All the stars in the halo are very **old**, and there is no gas and dust.

The **Galactic disk** is where the **youngest** stars are, as well as **star formation** regions – emission nebulae, large clouds of gas and dust.

Surrounding the Galactic center is the **Galactic bulge**, which contains a mix of older and younger stars.

23.3 Galactic Structure

This **infrared** view of our Galaxy shows much more detail of the Galactic center than the visible-light view does, as infrared is not as much absorbed by gas and dust.

23.3 Galactic Structure

Stellar orbits in the **disk** are in a plane and in the same direction; orbits in the **halo** and **bulge** are much more random.

23.4 The Formation of the Milky Way

Any theory of galaxy formation should be able to account for all the properties below:

23.4 The Formation of the Milky Way

The **formation** of the Galaxy is believed to be similar to the formation of the solar system, but on a much larger scale:

23.5 Galactic Spiral Arms

Measurement of the position and motion of gas clouds shows that the Milky Way has a spiral form:

23.5 Galactic Spiral Arms

The **spiral arms** cannot rotate along with the Galaxy; they would "curl up":

The "winding problem".

23.5 Galactic Spiral Arms

Rather, they appear to be **density waves**, with stars moving in and out of them much as cars move in and out of a traffic jam:

23.5 Galactic Spiral Arms

As clouds of gas and dust move through the spiral arms, the increased density triggers star formation. This may contribute to propagation of the arms. The origin of the spiral density waves is not yet understood.

23.6 The Mass of the Milky Way Galaxy

The **orbital speed** of an object depends only on the amount of **mass** between it and the Galactic center:

23.6 The Mass of the Milky Way Galaxy

Once all the Galaxy is within an orbit, the velocity should **diminish** with distance, as the dashed curve shows.

It doesn’t; more than **twice** the mass of the Galaxy would have to be outside the visible part to reproduce the observed curve.

23.6 The Mass of the Milky Way Galaxy

What could this "dark matter" be? It is dark at all wavelengths, not just the visible.

- Stellar-mass black holes?

    Probably no way enough could have been created

- Brown dwarfs, faint white dwarfs, and red dwarfs?

    Currently the best star-like option

- Weird subatomic particles?

    Could be, although no evidence so far

23.6 The Mass of the Milky Way Galaxy

A *Hubble* search for red dwarfs turned up very few; any that existed should have been detected:

23.6 The Mass of the Milky Way Galaxy

The **bending** of spacetime can allow a large mass to act as a **gravitational lens**:

Observation of such events suggests that **low-mass white dwarfs** could only account for about half of the mass needed.

See animation.

23.6 The Mass of the Milky Way Galaxy

Summary

Rotation curve gives total mass $2x10^{11}$ M_sun.

Rotation curve predicts dark matter.

Candidates: MACHO's, mini BH, brown dwarfs, Jupiters, fundamental particles (e.g., neutrinos).

Searches have not solved the mystery of the composition of dark matter.

23.7 The Galactic Center

This is a view towards the **Galactic center**, in visible light. The two arrows in the inset indicate the location of the center; it is entirely **obscured** by dust.

23.7 The Galactic Center

These images, in **infrared**, **radio**, and **X-ray**, offer a different view of the Galactic center.

23.7 The Galactic Center

The Galactic center appears to have a stellar density a million times higher than near Earth;

a ring of molecular gas 400 pc across;

strong magnetic fields;

a rotating ring or disk of matter a few parsecs across; and

a strong X-ray source at the center

23.7 The Galactic Center

Apparently, there is an enormous **black hole** at the center of the Galaxy, which is the source of these phenomena.

An **accretion disk** surrounding the black hole emits enormous amounts of radiation.

23.7 The Galactic Center

Stars from IR imaging with adaptive optics. The orbit on the right is the best fit; it assumes a central black hole of 3.7 million solar masses.

Summary of Chapter 23

• Galaxy is stellar and interstellar matter bound by its own gravity

• Our Galaxy is spiral

• Variable stars can be used for distance measurement, through period–luminosity relationship

• True extent of our Galaxy can be mapped out using globular clusters

• Star formation occurs in disk, but not in halo or bulge

Summary of Chapter 23, cont.

- Spiral arms may be density waves
- Galactic rotation curve shows large amounts of undetectable mass at large radii; called dark matter
- Activity near Galactic center suggests presence of a 2–3 million solar-mass black hole