Chapter 6

Sources of Radio Frequency Emissions

Objectives: Upon completion of this chapter, you will be able to define and give examples of a "point source," a "localized source," and an "extended source" of radio frequency emissions; distinguish between "foreground" and "background" radiation; describe the theoretical source of "cosmic background radiation"; describe a radio star, a flare star, and a pulsar; explain why pulsars are sometimes referred to as standard clocks; describe the relationship between pulsar spin down and age; describe "normal" galaxies and "radio" galaxies; describe the general characteristics of the emissions from Jupiter, Io, and the Io plasma torus; describe the impact of interference on radio astronomy observations; and describe a major source of natural interference and of human made interference.

Classifying the Source

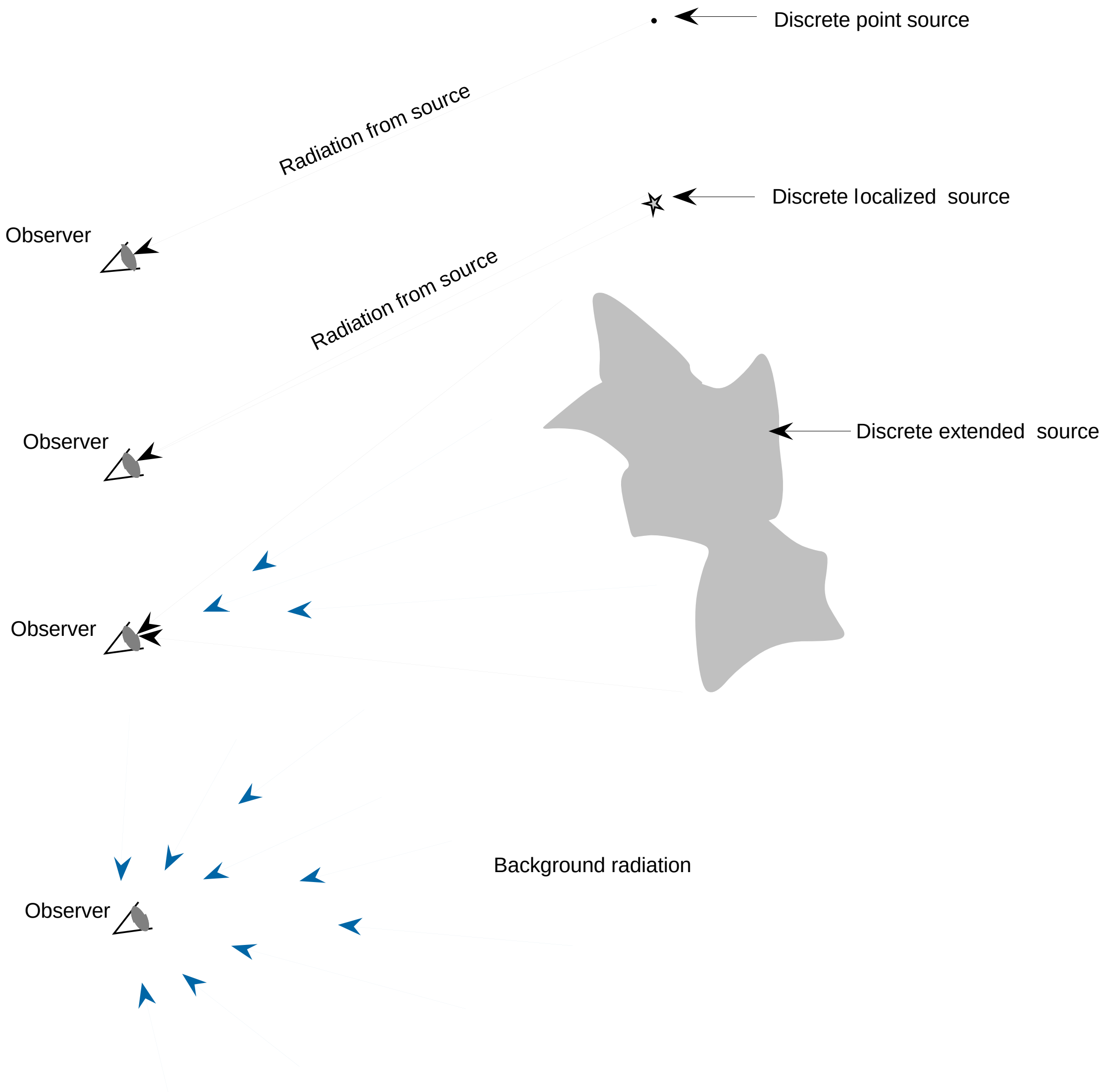
Radiation whose direction can be identified is said to originate from a *discrete source*. A discrete source often can be associated with a visible (whether by the naked eye or by optical telescope) object. For example, a single star or small group of stars viewed from Earth is a discrete source. Our sun is a discrete source. A quasar is a discrete source. However, the definition of "discrete," in addition to the other terms used to describe the extent of a source, often depends upon the beam size of the radio telescope antenna being used in the observation.

Discrete sources may be further classified as point sources, localized sources, and extended sources.

A *point source* is an idealization. It is defined as a source that subtends an infinitesimally small angle. All objects in reality subtend at least a very tiny angle, but often it is mathematically convenient for astronomers to regard sources of very small extent as point sources. Objects that appear smaller than the telescope's beam size are often called "unresolved" objects and can effectively be treated as point sources. A *localized source* is a discrete source of very small extent. A single star may be considered a localized source.

Emitters of radiation that covers a relatively large part of the sky are called *extended sources*. An example of an extended source of radiation is our Milky Way galaxy, or its galactic center (called Sagittarius A) from which radiation emissions are most intense.

Classifying the Extent of the Source



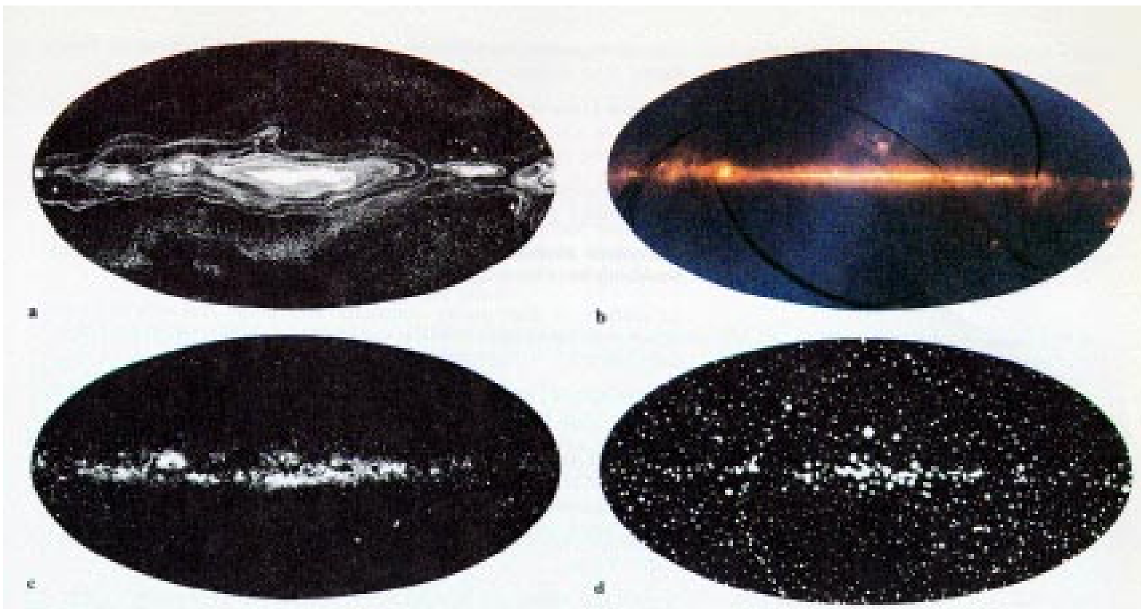
An optical analogy to the extended source would be the view of a large city at night from an airplane at about 10 km altitude. All the city lights would tend to blend together into an apparently single, extended source of light. On the other hand, a single searchlight viewed from the same altitude would stand out as a single object, analogous to a localized or point source.

The terms localized and extended are relative and depend on the precision with which the telescope observing them can determine the source.

Background radiation is radio frequency radiation that originates from farther away than the object being studied, whereas *foreground radiation* originates from closer than the object being studied. If an astronomer is studying a specific nearby star, the radiation from the Milky Way may be considered not merely an extended source, but background radiation. Or, if it is a distant galaxy being observed, the Milky Way may be considered a pesky source of foreground radiation. Background and foreground radiation may consist of the combined emissions from many discrete sources or may be a more or less continuous distribution of radiation from our galaxy.

Cosmic background radiation, on the other hand, is predicted to remain as the dying glow from the big bang. It was first observed by Arno Penzias and Robert Wilson in 1965. (They won a Nobel Prize for this discovery in 1978). As discussed in Chapter 3, much of background and foreground radiation tends to be of non-thermal origin. The cosmic background radiation, however, is thermal.

In the group of pictures below (from Griffith Observatory and JPL), the entire sky is shown at (a) radio, (b) infrared, (c) visible, and (d) X-ray wavelengths. Each illustration shows the Milky Way stretching horizontally across the picture. It is clear that radio wavelengths give us a very different picture of our sky.



Star Sources

Many thousands of visible stellar objects have been discovered to also be strong emitters of radio frequency radiation. All such stars may be called radio stars.

It is helpful in discussing star types and activities to review stellar evolution. For a discussion of star birth, maturation, old age, and death, please read Chapters 20-22 in *Universe*, by William J. Kaufmann III, or Chapters 28-30 in *Abell's Exploration of the Universe*, by David Morrison, Sidney Wolff, and Andrew Fraknoi.

Variable Stars

Stars do not shine uniformly brightly all the time. Stars that show significant changes in brightness over periods we short-lived humans can perceive are of great importance to astronomy because of what we can surmise from those changes. And fortunately for radio astronomy, it has been discovered that stars whose output of visible radiation varies over short periods, either regularly or irregularly, have corresponding variations in their output of radio frequency emissions.

Some *variable stars* , such as *Cepheids* (SEE-fee-ids), are absolutely regular in their cyclic changes, varying from a few days to a few weeks. It has been found that stars with longer regular periods are always more luminous (emitting more energy) than those with shorter regular periods. Variable stars with very short periods (1.25 to 30 hours) are called *RR Lyrae variables*. None of these shorter period variables is bright enough to see with the naked eye. Because the intrinsic luminosities of Cepheids and RR Lyraes with similar periods are comparable, variable stars such as these can be used to work out interstellar and even intergalactic distances.

Other variable stars have much longer periods, are less regular in their cycles, and vary by a much greater magnitude. These are called *semi-regular variables*. The red giant Betelgeuse in the Orion constellation is an example. No period-luminosity relationship has been found for semi-regular variables.

Irregular variables have no set periods at all. They usually are young stars and their luminosities may vary over a very large range.

Flare stars are faint red dwarf stars (older and feebler than white dwarfs) that exhibit sudden increases in brightness over a period of a few minutes due to intense flare activity, fading back to their usual brightness within an hour or so. Typical flare stars are UV Ceti and AD Leonis.

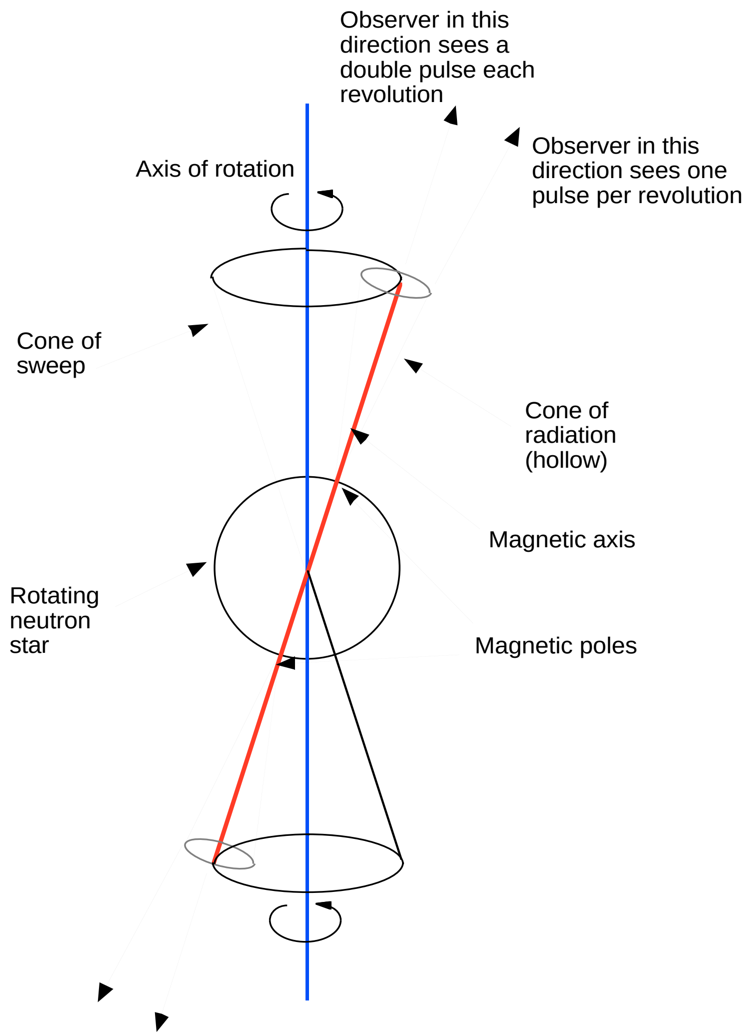
Binary (double) *stars* may produce apparently regularly varying radiation if the two stars eclipse one another in their orbits. Also, radio emissions from binaries are more common than for single stars. The interaction of stellar winds and magnetospheres, bow shocks, and tidal effects may contribute to the conditions producing radio frequency emissions.

Pulsars

Sometimes when a star goes supernova, all that is left after this most violent of processes is a cloud of expanding gas and the tiny remnant of extremely dense material only a few tens of kilometers in diameter. The supernova implosion is so intense that the protons and electrons in the atoms of the star are jammed together, thus canceling out their electrical charges and forming neutrons. This neutron star may be 1014 times as dense as water! It will have extremely powerful magnetic fields and may rotate very rapidly. Because the magnetic axis may not correspond to the spin axis, a beam of radiation emitted from the magnetic poles may seem to an observer to pulse like a rotating searchlight. Thus we call these rotating neutron stars *pulsars*. Although some pulsars are seen at visible and x-ray frequencies, many more are seen at radio frequencies.

Since 1967, when the first pulsar was detected by Jocelyn Bell, hundreds of pulsars have been discovered. The Crab pulsar spins at 30 times per second. The pulsar 1937+21 in Cygnus pulses 642 times per second. We receive this emission on Earth as if it were a signal produced by a cosmic clock. Over the brief period we have been observing them, however, they all them seem to be gradually slowing down. Their energy is dissipating with age. After correction for this effect, some millisecond pulsars are at least as accurate at timekeeping as the best atomic clocks. The rate at which pulsars slow down has been helpful in confirming aspects of Einstein's theory of general relativity. Also, the timing of pulsars can be useful in determining properties of the interstellar medium.

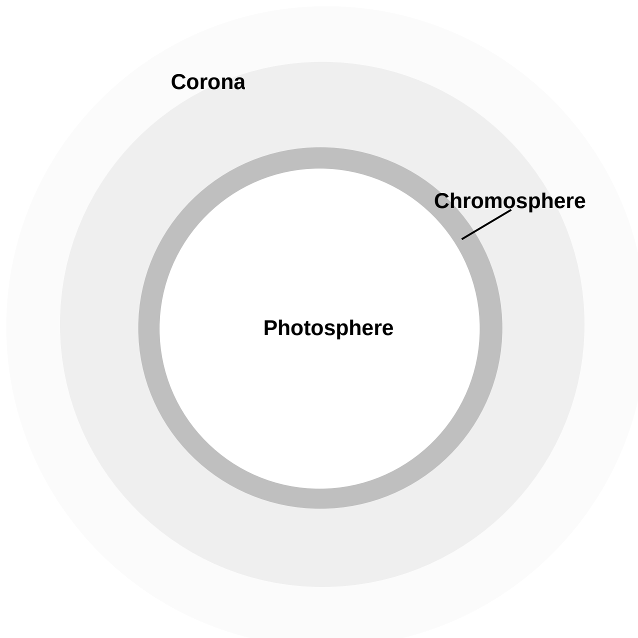
Pulsar


Observer in this direction sees a double pulse each revolution
Observer in this direction sees one pulse per revolution
Axis of rotation
Cone of sweep
Cone of radiation (hollow)
Magnetic axis
Rotating neutron star
Magnetic poles

Our Sun

The strongest extraterrestrial radio source we experience here on Earth is our own star. The Sun is a very ordinary star—not particularly massive or small, not particularly hot or cold, not particularly young or old. Perhaps we are fortunate it is so typical because from it we can learn much about stars in general.

Our Sun

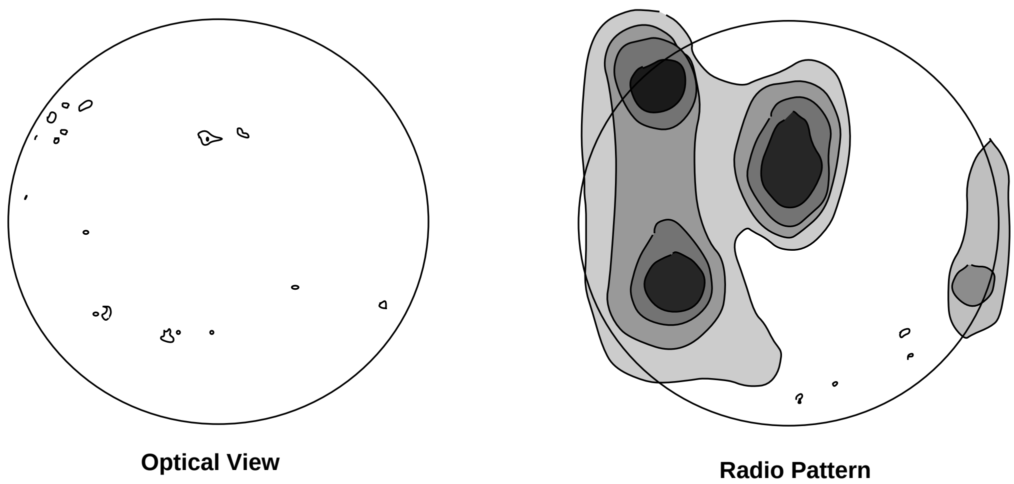


The photosphere is the part of the sun's atmosphere that emits most of the visible light, while the corona, the sun's outer atmosphere, is much less dense and emits only a very small amount of visible light. The chromosphere, cool and dim compared to the photosphere, forms the boundary between the photosphere and the corona.

The sun seems to have about an 11-year cycle of activity. When the sun is in a quiet phase, radio emissions from the photosphere (the part that also emits radiation in the visible wavelength) are in the wavelength range of 1 cm, while radio emissions from the corona approach a wavelength of one meter. The size of the radio solar disk appears only slightly larger than the optical solar disk as long as the telescope is tuned to only the 1-cm to 10-cm wavelength range. But at the longer wavelengths, the radio solar disk is much larger, including, as it does, the corona, which extends millions of kilometers above the photosphere.

Sunspots are darker appearing areas on the photosphere, and, as mentioned above, they seem to fluctuate in frequency over about an 11-year cycle. They appear darker because they are a "cool" 4,000°C relative to the surrounding 6,000°C surface. They are the centers of magnetic fields, apparently related to the sun's magnetic field. It is possible that the sun's magnetic lines of force periodically get "tangled" and destabilized since the sun's rate of rotation varies from the equator to the poles. Solar flares breaking out of the sun's upper atmosphere are usually associated with sunspot groups.

Comparison of Optical and Radio Solar Flares



Solar flares emit short bursts of radio energy, with wavelengths observable from the ground from about 1 to 60 m (300-5 MHz). Sometimes during intense flares, a stream of high-energy cosmic ray particles is emitted, travelling at over 500-1000 km per sec. When these charged particles reach Earth's magnetic field, we get magnetic storms and the aurora. The pattern of radio emissions from solar flares appears to originate from a larger area of the solar surface than does the pattern of visible-range radiation, but it is still apparent that they are the result of the same activity.

The radiation associated with solar flares is circularly polarized, rather than randomly polarized as is usual from extraterrestrial sources. This polarization may be caused by electrons gyrating in the localized, intense magnetic field of the flare.

The sun is studied by radio astronomers both directly, by observing the actual radio emissions from the sun, and indirectly, by observing the effect of the sun's radiation on Earth's ionosphere.

Recap

1. The Milky Way galaxy is an example of a(n) _______________ source of radio emissions.
2. A single star is a __________________ discrete source.
3. Stars that show significant changes in brightness over short periods are called _________________ stars.
4. Cepheids with longer periods are always _____________ luminous than those with shorter periods.
5. It is believed that pulsars are rapidly spinning ______________ stars.
6. The strongest source of radio emissions that we experience on Earth is the ___________.
7. Solar flares, associated with groups of sun spots, emit short bursts of ____________ _______________.

1. extended 2. localized 3. variable 4. more 5. neutron 6. sun 7. radio energy (or radio emissions)

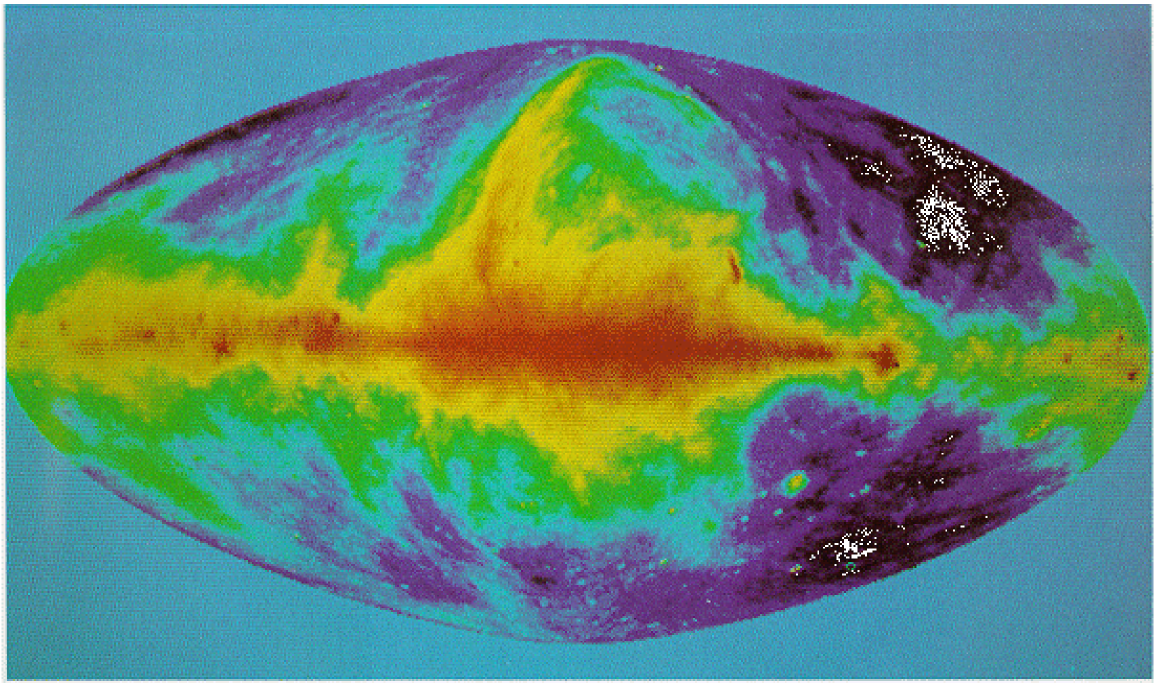
For Further Study

- *Cosmic background radiation:* Kaufmann, 532-535; Morrison et al., 616-619.
- *Star evolution:* Kaufmann, 364-420; Morrison et al., 467-520.
- *Our sun:* Kaufmann, 310-335; Morrison et al., 434-466.
- *Variable stars:* Kaufmann, 396-398, 477; Morrison et al., 488-492, 661.
- *Pulsars:* Kaufmann, 310-335; Morrison et al., 516-518, 529; Wynn-Williams, 119.

Galactic and Extragalactic Sources

We can think of extra-terrestrial radio emissions as originating either within our galaxy or outside our galaxy. Inside our galaxy, remnants of supernova explosions are strong sources of radio emissions.

Outside our galaxy, we find great variation in the radio emissions from different galaxies. So we have arbitrarily divided these other galaxies into "*normal*" and "*active*" galaxies.



Radio View of the Milky Way

Normal galaxies are not very strong sources. For example, the Great Andromeda Spiral, the largest galaxy in our so-called local group of galaxies, emits 10^{32} watts of power. In contrast, Cygnus A, over half a billion light years from Earth, is one of the most conspicuous radio sources in the sky, with a power output of 10^{38} watts. (See figures at end of Chapter 8 for a rough idea of the locations of these galaxies.)

Active galaxies include radio galaxies, quasars, blasars, and Seyfert Galaxies.

Radio galaxies emit a very large quantity of radio waves.

Quasars, coined from the phrase "quasi-stellar radio source," may be pouring out energy a million times more powerfully than a normal galaxy. Quasars are the most distant objects we have detected, some approaching 15 billion light years distant—their radiation requiring nearly the age of the universe to reach us. And some seem to be receding from us at a rate 90% the speed of light.

Blasars are galaxies with extremely bright centers, whose luminosity seems to vary markedly over a very short period.

Seyfert galaxies are also intense sources of radiation whose spectra include emission lines.

In all these, the predominant radiation-producing mechanism is synchrotron radiation. An active galaxy may radiate 1,000,000 times more powerfully in the radio frequencies than a normal galaxy. Much of the radiation often seems to come from the nucleus of the galaxy. Astronomers are now investigating the plausibility of a "unified theory of active galaxies," which would account for the varying behavior observed by all these types of active galaxies. It may be that these galaxies have a black hole or a supermassive black hole at their centers, and their appearance to us depends on the angle at which we are observing them.

Please read Chapter 27 of *Universe*, by Kaufmann, for more information, including many color photos, about these fascinating and mysterious objects.

Planetary Sources and Their Satellites

Unlike stars, the radio energy observed from planets and their satellites (except the Jupiter system and, to a small extent, Saturn) is mostly thermal blackbody radiation. The wavelengths of radiation observed from these bodies gives us fairly precise indications of their temperatures, both at their surfaces and at varying depths beneath their surfaces.

The Jupiter System

By far the most interesting planet for radio astronomy studies is Jupiter. As beautiful and fascinating as it is visually, it is even more fascinating and complex to observe in the radio frequency range. Most of the radiation from the Jupiter system is much stronger at longer wavelengths than would be expected for thermal radiation. In addition, much of it is circularly or elliptically polarized—not at all typical of thermal radiation. Thus, it must be concluded that non-thermal processes similar to those taking place in galaxies are at work. That is, ions and electrons accelerated by the planet's spinning magnetic field are generating synchrotron radiation.

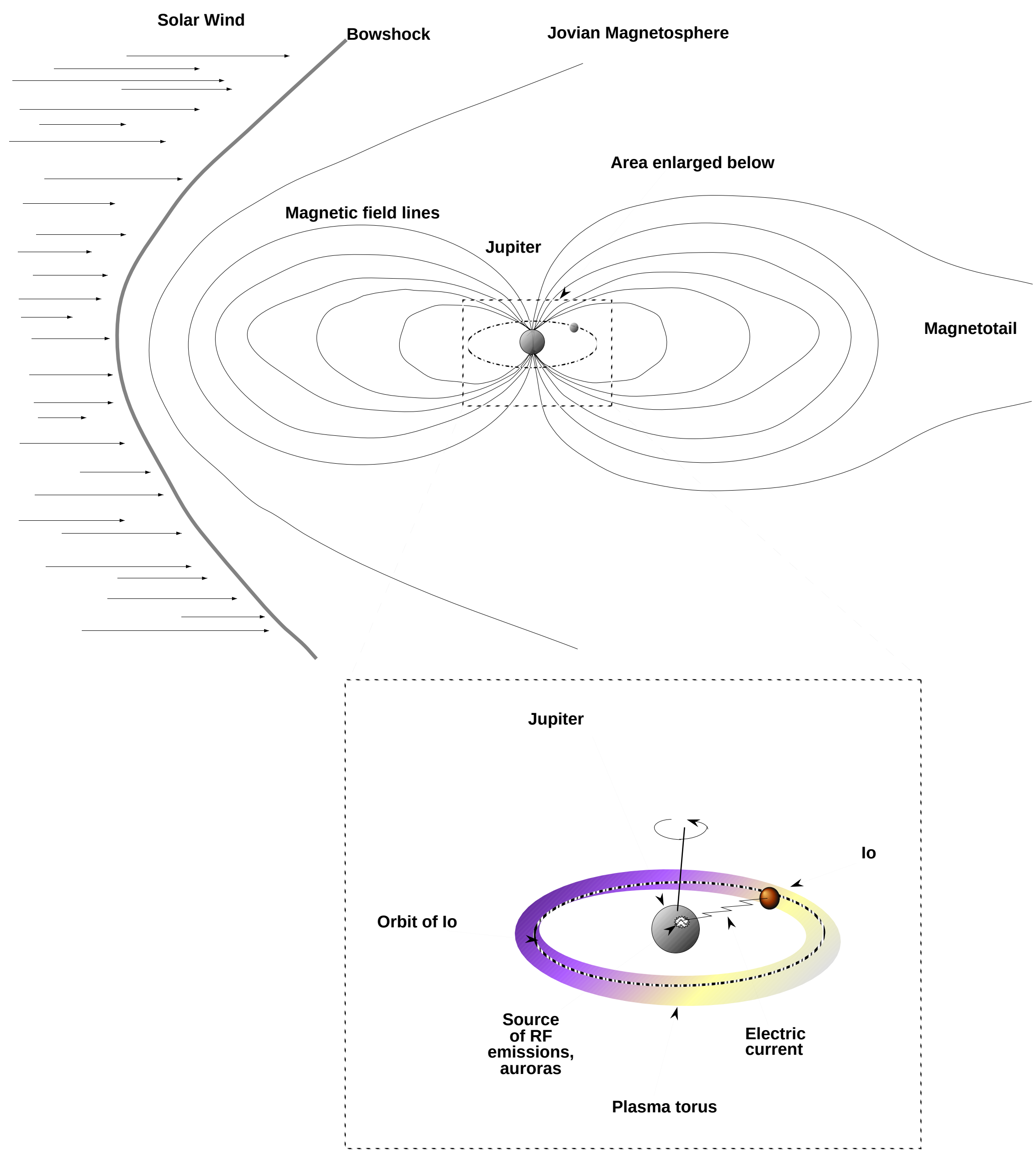
Jupiter is 318 times as massive as Earth. Its magnetic axis is tilted 15° from its rotational axis and offset from the planet's center by 18,000 km. Its polarity is opposite that of Earth (that is, a compass needle would point south).

Jupiter's surface magnetic field is 20 to 30 times as strong as that of Earth. The *magnetosphere* of a planet is the region around it in which the planet's magnetic field dominates the interplanetary field carried by the solar wind. If we could see Jupiter's magnetosphere from Earth, it would appear as large as our moon!

The farther a planet is from the sun, the weaker will be the pressure from the solar wind on the planet's magnetosphere. Thus, Jupiter's magnetic field, already quite intense, has considerably less pressure holding it close to the planet than does Earth's magnetic field. Jupiter's magnetosphere expands and contracts with variations in the solar wind. Its upstream (closest to the sun) boundary (called the *bowshock*) varies from 50 to 100 Jupiter radii and envelopes Jupiter's four large Galilean satellites. (Sixteen Jupiter satellites have been discovered; the Galilean satellites are by far the largest).

The magnetosphere of a planet traps plasma, as magnetic lines of force catch protons and electrons carried on the solar wind and atoms that escape upward from the planet's atmosphere. In the case of Jupiter, since the magnetosphere is so large, it also traps atoms from the surfaces of the satellites orbiting within it. Io, the innermost Galilean satellite, is an especially rich source of oxygen and sulfur ions from its many violently active volcanoes. Io is estimated to contribute 10 tons of material to the magnetosphere per second!

Magnetosphere of Jupiter



As a matter of fact, a predominant feature of Jupiter's magnetosphere is the plasma torus that surrounds the planet, corresponding closely with the orbit of Io, which is at about five Jupiter radii. It is an intensely radiating plasma within a slightly less active outer plasma. To add to the adventure, as Io orbits through the magnetic field lines, an electric current of up to 5 million Amps is generated between Io and the planet! Where this current reaches the atmosphere of Jupiter, it generates strong radio frequency emissions that can be associated with the orbital position of Io. The current also generates auroras in the upper atmosphere of Jupiter.

The Goldstone-Apple Valley radio telescope will be used to measure time variable radio frequency emissions from Jupiter's magnetic field. These observations can provide new information about the magnetosphere, the plasma torus, and the rotation of Jupiter's core and how it differs from the rotation of the visible atmosphere.

Sources of Interference

Radio frequency "noise" complicates the task of the radio astronomer, at times making it difficult to distinguish emissions from an object under study from extraneous emissions produced by other nearby sources. Interference comes from both natural and artificial sources, the latter ones becoming a bigger problem every day. By international agreement (the World Administrative Radio Conference), certain frequencies have been allocated strictly for radio astronomy (Kraus, p. A 24). However, there is disagreement about how far beyond the restricted limits is acceptable "spillover" (for example, radio broadcasters may think 10mm over their wavelength limit is acceptable, while radio astronomers may think .001 mm is too much). In some countries, the restrictions are not enforced, so may as well not exist.

Natural sources of interference include:

- Radio emissions from the Sun
- Lightning
- Emissions from charged particles (ions) in the upper atmosphere

Among the growing list of human-made sources of interference are:

- Power-generating and transforming facilities
- Airborne radar
- Ground-based radio and television transmitters (which are getting more powerful all the time)
- Earth-orbiting satellite transmitters and transponders, including Global Positioning Satellites (GPS)
- Cellular phones

Human-generated interference that originates on the ground (such as radio and television transmissions) travels along the ground and over the horizon. It used to be that such interference tended to be weak at ground level, increasing in strength with height above ground. For this reason, most radio telescopes have been situated in valleys or other low places, unlike optical telescopes which are often built on mountain tops. (The exceptions are radio telescopes built for studying sub-millimeter wavelengths, as mentioned in Chapter 4). However, more and more, interference at ground level is becoming a problem even for low-lying radio telescopes.

Recap

1. Galaxies that emit up to 106 times more radio frequency energy than is normally observed from galaxies are called _______________ _____________.
2. ________________ are the most distant objects astronomers have detected.
3. Quasars, blasars, and radio galaxies are examples of __________________ radio sources.
4. The planet in our solar system that emits the most intense radio waves is ______________.
5. An interesting feature of Io is the ____________ ___________, which surrounds Jupiter and corresponds closely with Io's orbit.
6. Lightning is an example of a source of natural RF __________________ for radio astronomy studies.

1. radio galaxies   2. Quasars   3. extra-galactic   4. Jupiter   5. plasma torus   6. interference

For Further Study

- *Our galaxy:* Kaufmann, 454-473; Morrison et al., 539-558.
- *Galaxies and galactic evolution:* Kaufmann, 474-503; Morrison et al., 559-586.
- *Active galaxies:* Kaufmann, 504-525; Morrison et al., 576-577.
- *Jupiter and its magnetosphere:* Kaufmann, 228-240; Morrison et al., 284-288.