NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electric & Electronic Engineering

THEORY OF IONOSPHERS AND MAGNETOSPHERE

Graduation Project
EE - 400

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Nicosia-2001

ACKNOWLEDGMENTS

Iam deeply indebted to my parents for their love and financial support they have always encouraged me to pursue my interests and ambitions throughout life.On this moment I would like to pay my regards to my teacher **Assoc.Prof.Dr. Sameer Ikhdair** from Near East University Nicosia,Cyprus. With out his help I was not able to get too much information about this topic. Really he is an appreciated teacher. He has a divine place in my heart. To all my friend especially Mohamed abu shaban, Imad kirt, Ahmed El- Taha, Raid Bader and my housemate who has helped me to write and print this project. To all of them, all my love.

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INTRODUCTION

As it is the 21^{st} century which is leading the human kind to the new era of magic and wonders of sciences. Man is seeing those all same things about which he was saying in previous centuries that it is ever possible. Today science has made every thing possible to whom we dream or wish for us.

The very last century was devoted to the measurement of speed of data processing. and locomotive speed with too many problems but today in this century we are sending a large number of data in every place thousands of miles away from us within few seconds and with low loss in the field of communication especially in satellite communication, the most famous subject we have to face and to whom I am going to describe is Ionosphere and Magnetosphere.

Ionosphere

Ionosphere or Thermosphere, name given to a layer or layers of ionized air in the atmosphere extending from almost 80 km (50 mi) above the surface of the Earth to altitudes of 640 km (400 mi) and more. At these altitudes the air is extremely thin, having about the density of the gas in a vacuum tube. When the atmospheric particles undergo ionization by ultraviolet radiation from the Sun or by other radiation, they tend to remain ionized, because few collisions occur between ions.

The ionosphere exerts a great influence on the propagation of radio signals. Energy that is radiated from a transmitter upwards towards the ionosphere is in part absorbed by the ionized air and in part refracted, or bent downwards again, towards the surface of the Earth. The bending effect makes possible the reception of radio signals at distances much greater than would be possible for waves that traveled along the surface of the Earth.

Such refracted waves, however, reach the Earth only at certain definite distances from the transmitter; the distance depends on the angle of refraction and the altitude. Hence, a radio signal may be inaudible at 100 km (60 mi) from the transmitter hut audible at 500 km (300 mi).

This Phenomenon is known as skip. In certain other areas the ground-wave the refracted signals from the ionosphere may reach the receiver and interfere with each other, producing the phenomenon known as fading.

The amount of refraction in the ionosphere decreases with an increase in frequency and for very high frequencies is almost non-existent. There fore long distance transmission of high-frequency radio waves is limited to the line of sight. Both television and frequency modulation (FM) radio use high-frequency waves. Long-distance transmission can be achieved only in a direct line, such as between the Earth and a communications satellite; the signal then may be relayed from the satellite to a distant point on the Earth.

The ionosphere is usually divided into two main layers: a lower layer, designated the E layer (sometimes called the Heaviside layer or Kennelly Heaviside layer), which is between about 80 and 113 km (50 and 70 mi) above the Earth's surface and which reflects radio waves of low frequency; and a higher layer, the F. or Appleton. layer, which reflects higher frequency radio waves. The tatter is further divided into an $F1$ layer, which begins at about 180 km (112 mi) above the Earth; and an F2 layer, which begins at about 300 km (186 ml) from the surface. The F layer rises during the night and therefore changes its reflecting characteristics.

Magnetosphere

Magnetosphere, the immediate space environment of the Earth, in which the planet's magnetic field dominates the magnetic field of the interplanetary medium. Despite its name, the magnetosphere is not spherical. On the side of the magnetosphere that faces the Sun the Faith's magnetic field lines are compressed by the solar wind, a stream of ionized atomic particles continually emitted from the Sun at 400 to 800 km/s (250 to 500 mils).

In this direction the magnetopause, or boundary of the magnetosphere, is about 60,000 km (37,000 mi) from the Earth, but in the opposite direction, away from the Sun, the magnetosphere has a very long tail, stretching to I million km (600,000 ml) or more.

If the space round the Earth. were empty, the Earth's magnetic field would resemble that of a vast bar magnet. As the solar wind strikes the Earth's magnetic field, its pressure is balanced by the pressure of the magnetic field over the magnetopause. If magnetic field lines are pressed together, as they are in this case by the solar wind, they exert a force resisting the pressure. This can he shown by trying to press two bar magnets together, side-by-side, with their poles in the same direction. In this case, it is the compression of the field lines of the two magnets that resists the force as they are pressed together.

The average position of the magnetopause, and therefore the size of the magnetosphere, can be calculated from the properties of the solar wind. Much of the solar wind is deflected round the magnetopause. Round the magnetosphere there is a shock wave, similar to the how wave of a ship, where the magnetic field lines abruptly change direction.

Some of the waves that can propagate in plasmas ionized gases such as the solar wind are similar to ordinary sound waves. The nature of' the interaction of an obstacle, such as the Earth's magnetic field, with the solar wind depends on the ratio of the velocity of the medium to the sound velocity, the Mach number. If the Mach number is greater than 1, a shock wave develops ahead of the obstacle. Depending on solar wind conditions.

The Mach number of the magnetosphere in the solar wind is between 5 and 10. When the properties of the solar wind are disturbed by conditions on the Sun, these disturbances are transmuted to the magnetosphere, causing storms in the Earth's magnetic field. This buffeting of the magnetosphere by the solar wind, is responsible for the aurora and many other phenomena, some of which affect Earth - orbiting spacecraft. Auroras are usually restricted to the Polar Regions and are caused by the energization and dumping? of' electrons into the upper atmosphere from the night side of the magnetosphere. When the magnetosphere is disturbed, auroras can be seen as distant as 400 from the poles. Geomagnetic storms (storms in the magnetosphere) can also disturb the Earth's radiation belts, dumping highly energetic particles into the Ionosphere and the upper atmosphere. Nevertheless, the magnetosphere acts as a shield to protect the Earth from the direct impact of cosmic rays and high energy radiation from the Sun, and is therefore a vital part of our environment.Other planets that have a magnetic field also have a magnetosphere round them: these are Mercury. Jupiter, Saturn, Uranus, arid Neptune.

CHAPTER ONE

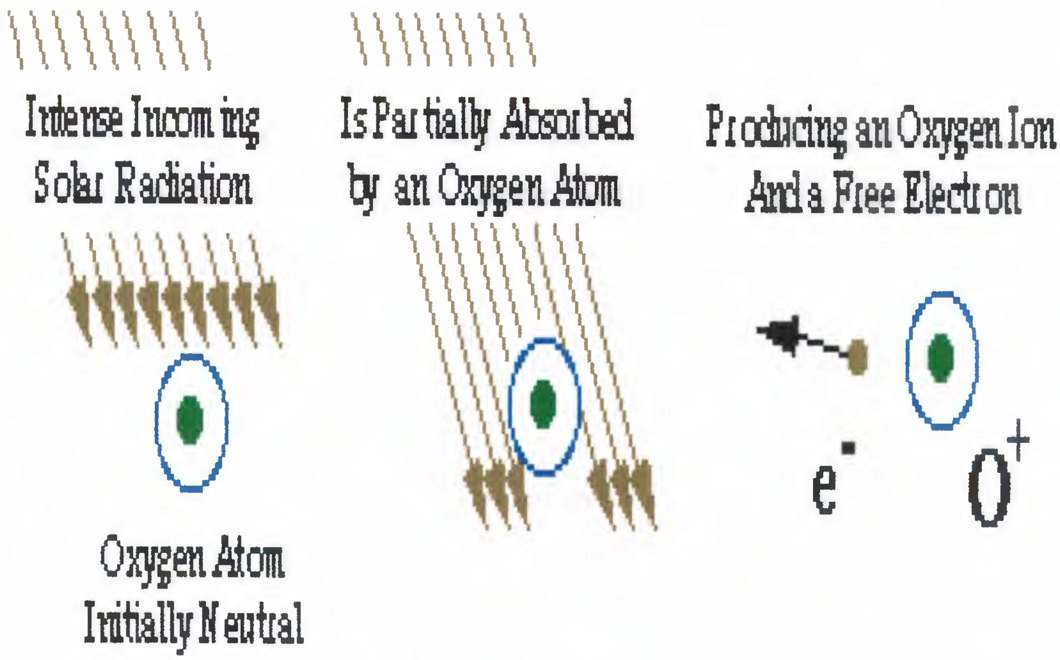
THEORY OF IONOSPHERS

1.1 Introduction to Ionosphere

Earth's atmosphere varies in density and composition as the altitude increases above the surface. The lowest part of the atmosphere is called the troposphere (the light blue shaded region in the figure to the left) and it extends from the surface up to about 10 km (6 miles). The gases in this region are predominantly molecular Oxygen (O_2) and molecular Nitrogen (N_2). All weather is confined to this lower region and it contains 90% of the Earth's atmosphere and 99% of the water vapor. The highest mountains are still within the troposphere and all of our normal day-to-day activities occur here. The high altitude jet stream is found near the tropopause at the the upper end of this region.

The atmosphere above 10 km is called the stratosphere. The gas is still dense enough that hot air balloons can ascend to altitudes of 15 - 20 km and Helium balloons to nearly 35 km, but the air thins rapidly and the gas composition changes slightly as the altitude increases. With in the stratosphere, incoming solar radiation at wavelengths below 240 nm. Is able to break up (or dissociate) molecular Oxygen (O_2) into individual Oxygen atoms, each of which, in turn, may combine with an Oxygen molecule (O_2), to form ozone, a molecule of Oxygen consisting of three Oxygen atoms (O_3). This gas reaches a peak density of a few parts per million at an altitude of about 25 km (16 miles).

The yellow shaded region in the (figure.1) shows the ozone layer. The gas becomes increasingly rarefied at higher altitudes. At heights of 80 km (50 miles), the gas is so thin that free electrons can exist for short periods of time before they are captured by a nearby positive ion. The existence of charged particles at this altitude and above, signals the beginning of the ionosphere a region having the properties of a gas and of a plasma. The ionosphere is indicated by the light green shading in the (figure 1).



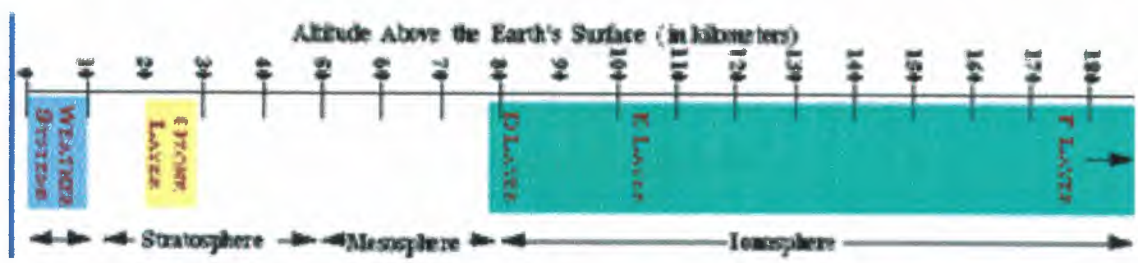


Fig.1.1 shows the altitude above the Earthm's surface (in Kilometers)

1.2 The Ionosphere Formed

At the outer reaches of the Earth's environment, solar radiation strikes the atmosphere with a power density of 1370 Watts per meter^2 or 0.137 Watts per cm^2, a value known as the "solar constant." This intense level of radiation is spread over a broad spectrum ranging from radio frequencies through infrared (IR) radiation and visible light to X-rays.

Solar radiation at ultraviolet (UV) and shorter wavelengths is considered to be "ionizing" since photons of energy at these frequencies are capable of dislodging an electron from a neutral gas atom or molecule during a collision. The conceptual drawing below is a simplified explanation of this process.

Incoming solar radiation is incident on a gas atom (or molecule). In the process, part of this radiation is absorbed by the atom and a free electron and a positively charged ion are produced. (Cosmic rays and solar wind particles also play a role in this process but their effect is minor compared with that due to the sun's electromagnetic radiation.) At the highest levels of the Earth's outer atmosphere, solar radiation is very strong but there are few atoms to interact with, so ionization is small. As the altitude decreases, more gas atoms are present so the ionization process increases.

At the same time, however, an opposing process called recombination begins to take place in which a free electron is "captured" by a positive ion if it moves close enough to it. As the gas density increases at lower altitudes, the recombination process accelerates since the gas molecules and ions are closer together. The point of balance between these two processes determines the degree of "ionization" present at any given time. At still lower altitudes, the number of gas atoms (and molecules) increases further and there is more opportunity for absorption of energy from a photon of UV solar radiation. However, the intensity of this radiation is smaller at these lower altitudes because some of it was absorbed at the higher levels.

A point is reached, therefore, where lower radiation, greater gas density and greater recombination rates balance out and the ionization rate begins to decrease with decreasing altitude. This leads to the formation of ionization peaks or layers (also called "Heaviside" layers after the scientist who first proposed their existence). Because the composition of the atmosphere changes with height, the ion production rate also changes and this leads to the formation of several distinct ionization peaks, the "D," "E," "F1," and "F2" layers.

1.3 Conduct Ionospheric Research

In 1864, a Scottish mathematician named James Clerk Maxwell published a remarkable paper describing the means by which a wave consisting of electric and magnetic fields could propagate (or travel) from one place to another. Maxwell's theory of electromagnetic (EM) radiation was eventually proven correct by the German physicist, Heinrich Hertz in the late 1880's in a series of careful laboratory experiments. It was not until the last decade of the 19th century that an Italian scientist named Guglielmo Marconi converted these theories and laboratory experiments into the first practical wireless telegraph system for which he was granted a British patent. In 1899, Marconi demonstrated his wireless communication technique across the English Channel.

In a landmark experiment on December 12, 1901, Marconi, who is often called the "Father of Wireless," demonstrated transatlantic communication by receiving a signal in St. John's Newfoundland that had been sent from Cornwall, England. Because of his pioneering work in the use of electromagnetic radiation for radio communications, Marconi was awarded the Nobel Prize in physics in 1909. Later, the Institute of Electrical and Electronics Engineers awarded Marconi its Medal of Honor for his "pioneering work in radio telegraphy."

Marconi's famous experiment showed the way toward world wide communication, but it also raised a serious scientific dilemma. Up to this point, it had been assumed that electromagnetic radiation traveled in straight lines in a manner similar to light waves. If this were true, the maximum possible communication distance would be determined by the geometry of the path as shown in Figure 1.1.

The radio signal would be heard up to the point where some intervening object blocked it. If there were no objects in the path, the maximum distance would be determined by the transmitter and receiver antenna heights and by the bulge (or curvature) of the earth. Drawing from light as an analogy, this distance is often called the "Line-of-Sight" (LOS) distance.

In Marconi's transatlantic demonstration, something different was happening to cause the radio waves to apparently bend around the Earth's curvature so that the communication signals from England could be heard over such an unprecedented distance.

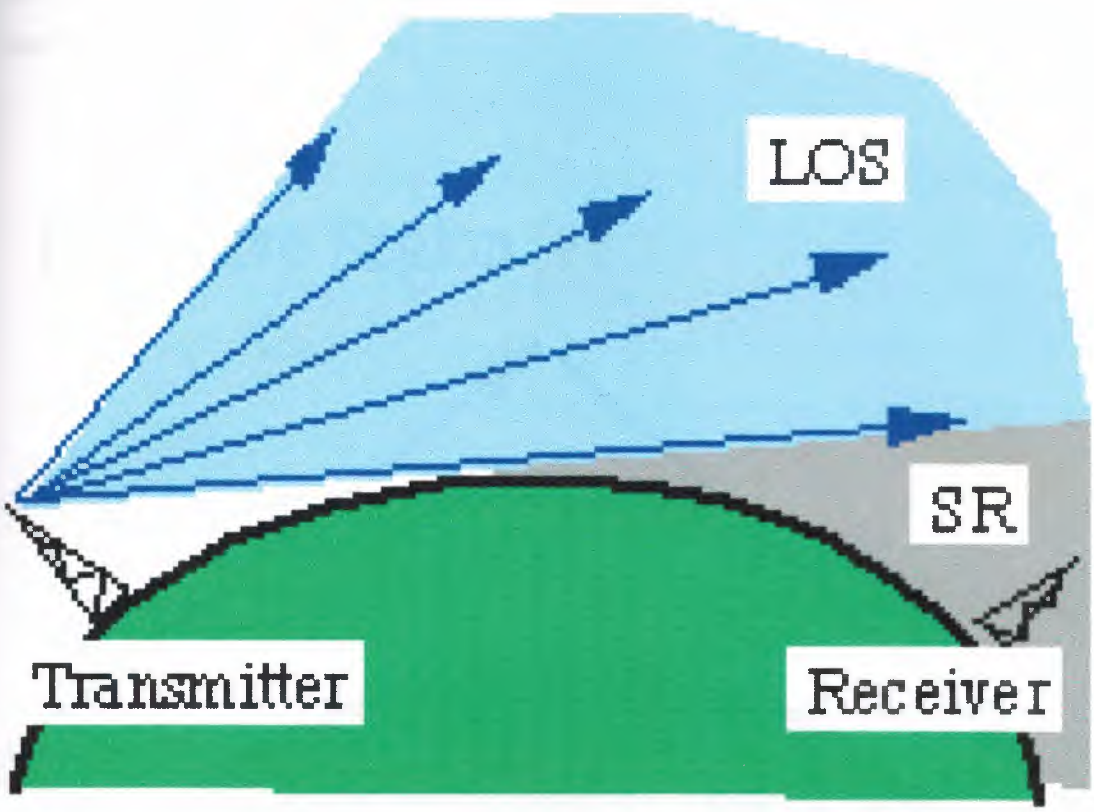


Fig1.2 shows a conductive region at high altitude

Figure 1.2 Areas in the light blue region are within the radio "Line of Sight" (LOS). The receiving antenna is in the shadow region (SR) and cannot receive a signal directly from the transmitter.

In 1902, Oliver Heaviside and Arthur Kennelly each independently proposed that a conducting layer existed in the upper atmosphere that would allow a transmitted EM signal to be reflected back toward the Earth. Up to this time, there was no direct evidence of such a region and little was known about the physical or electrical properties of the Earth's upper atmosphere. If such a conductive layer existed, it *would permit a dramatic extension of the "line-of-Sight" limitation to radio communication as shown in Figure 1.3.*

During the mid-1920's, the invention of the ionosonde (an instrument that is an important part of the HAARP observatory) allowed direct observation of the ionosphere and permitted the first scientific study of its characteristics and variability and its affect on radio waves.

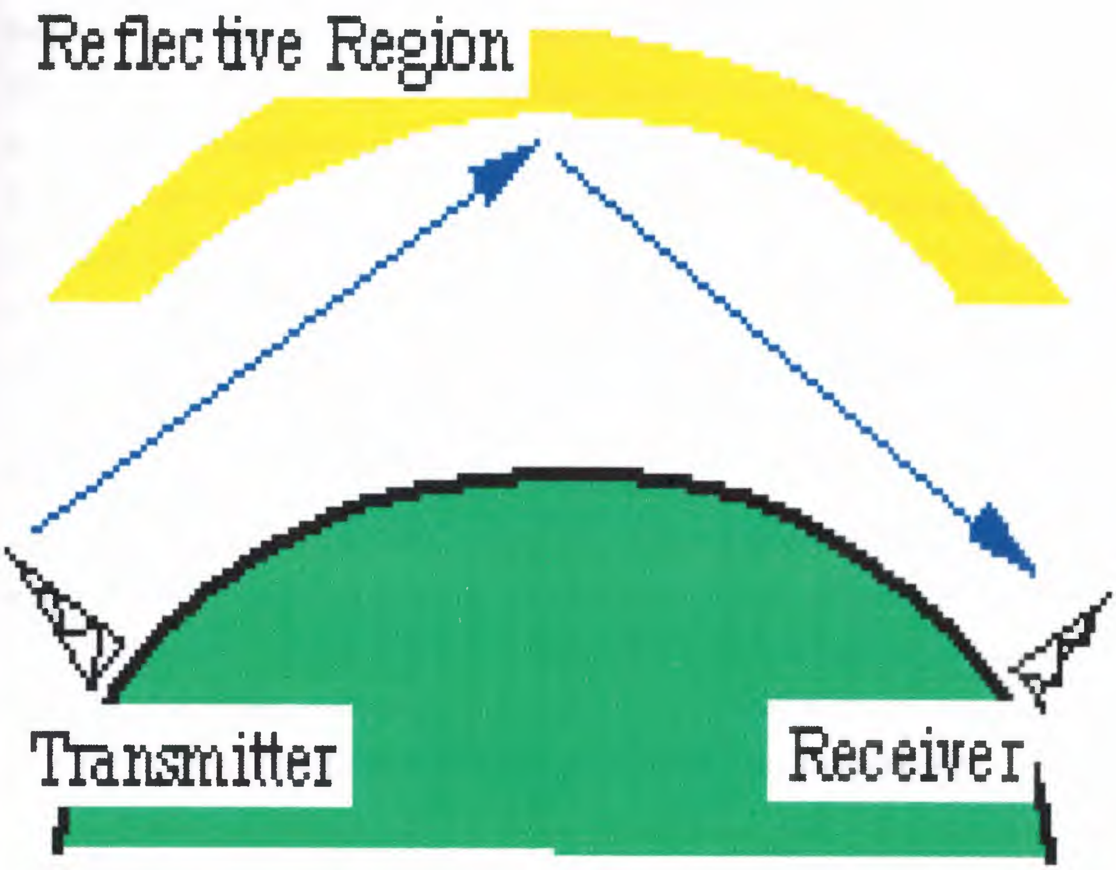


Fig1.3 shows a conductive region at high altitude

Figure 1.3 A conductive region at high altitude would "reflect" radio signals that reached it and return them to Earth.

The excitement of Marconi's transatlantic demonstration inspired numerous private and commercial experiments to determine the ultimate capabilities of this newly discovered resource, the ionosphere.

Among the most important early experiments were those conducted by radio amateurs who showed the value of the so called high frequencies above 2 MHz for long distance propagation using the ionosphere.

1.4 The Importance of Ionospheric Research

Although our society has learned to use the properties of the ionosphere in many beneficial ways over the last century, there is still a great deal to learn about its physics, its chemical makeup and its dynamic response to solar influence. The upper portions of the ionosphere can be studied to some extent with satellites but the lower levels are below orbital altitudes while still too high to be studied using instruments carried by balloons or high flying aircraft. Much of the current theory is inferred by observing the ionosphere's effect on communication systems. In addition, some very useful information has been obtained using rockets.

1.5 Active ionospheric research facilities

Like HAARP, have provided detailed information that could not be obtained in any other way, about the dynamics and responses of the plasma making up the ionosphere. Incoherent Scatter Radars (ISRs), such as the one that will be built at the HAARP observatory, can study from the ground, small scale structures in the ionosphere to nearly the degree that an instrument in the layer could provide.

The ionosphere affects our modern society in many ways. International broadcasters such as the Voice of America (VOA) and the British Broadcasting Corporation (BBC) still use the ionosphere to reflect radio signals back toward the Earth so that their entertainment and information programs can be heard around the world. The ionosphere provides long range capabilities for commercial ship-to-shore

Communications, for transoceanic aircraft links, and for military communication and surveillance systems.

The sun has a dominant effect on the ionosphere and solar events such as flares or coronal mass ejections can lead to worldwide communication "blackouts" on the short wave bands. We have created data from a communications blackout that occurred on August 3, 1997 showing how the instruments at the HAARP observatory can be used to study the underlying physics of these telecommunication disruptions.

Signals transmitted to and from satellites for communication and navigation purposes must pass through the ionosphere. Ionospheric irregularities, most common at equatorial latitudes (although they can occur anywhere), can have a major impact on system performance and reliability, and commercial satellite designers need to account for their effects.

In the Auroral latitudes, the ionosphere carries a current that may reach magnitudes up to or beyond a million amperes. This current, which is called the auroral electrojet, can change in dramatic ways under solar influence, and, when it does, currents can be induced in long terrestrial conductors like power lines and pipe lines. While such effects found in nature cannot be reproduced by active ionospheric research, the sensitive instruments at observatories like HAARP can follow the progress of natural magnetic storms and provide insight into the physical mechanisms at work in the ionosphere.

To varying degrees, the ionosphere is plasma, the most common form of matter in the universe, often called the fourth state of matter. Plasmas do not exist naturally on the Earth's surface, and they are difficult to contain for laboratory study. Many current active ionospheric research programs are efforts to improve our understanding of this type of matter by studying the ionosphere, the closest naturally occurring plasma.

Recently, it has become possible to produce computer simulations of ionospheric processes. A visualization (3.1 MB MPEG) produced by the University of Alaska demonstrates the enormous variability and turbulence that occurs in the ionosphere during a major solar geomagnetic storm. Active ionospheric research facilities like

HAARP attempt to produce small temporary changes in a limited region directly over the facility which, in no way, compare to the worldwide events frequently caused by the sun. But the extraordinary suite of sensitive observational instruments installed at observatories like HAARP permit a detailed and comprehensive correlation with the induced effects, resulting in new insights into the ways the ionosphere responds to a much wider variety of natural conditions.

1.6 protection is provided by the ionosphere

Earth's atmosphere is a mixture of gases, mostly Nitrogen and Oxygen. At the surface, nearly all of these gases are in molecular form (ie, two atoms of Oxygen, O_2 or two atoms of Nitrogen, N_2). As the altitude above the earth increases, the density of the gases decreases rapidly and the makeup of the gases also changes as some of the molecules are broken into individual atoms by incoming solar radiation. The following figure shows how the concentration of atomic and molecular gases changes as the altitude above the earth's surface increases.

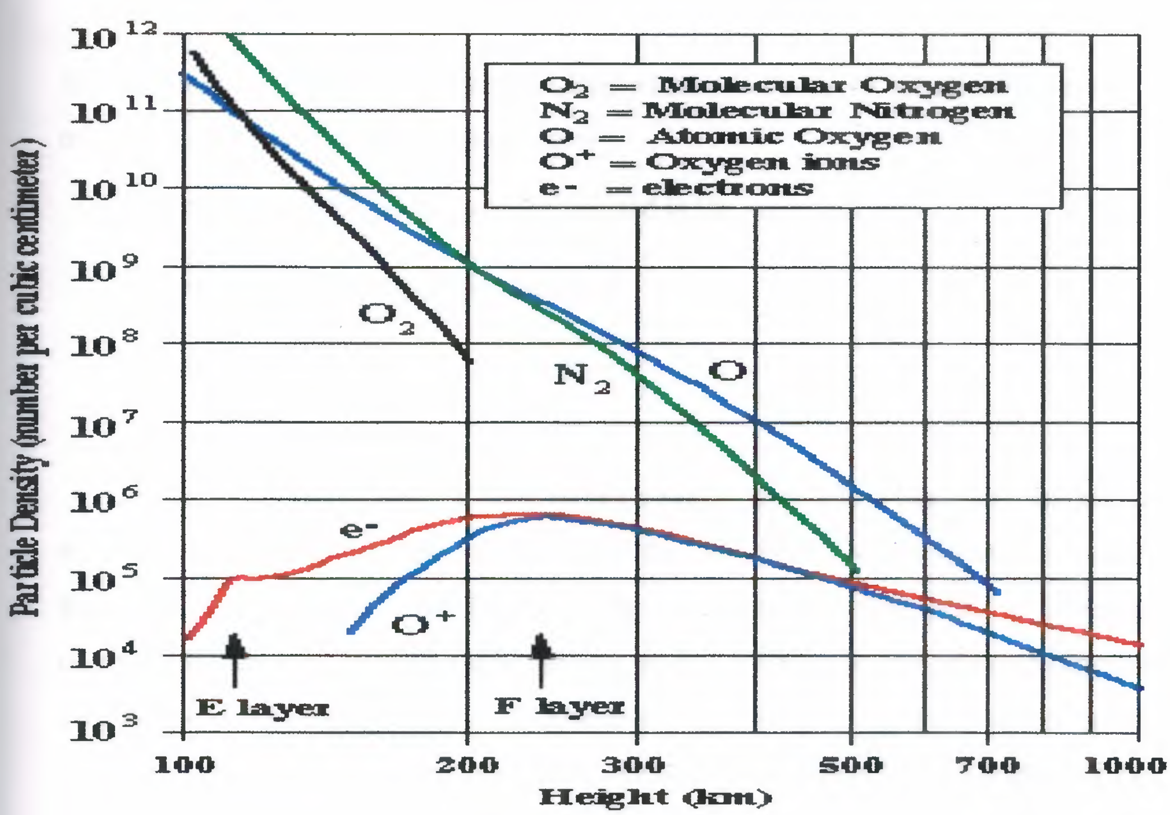


Fig 1.4 shows the particle density (number per cutie centimeter)

At ionospheric heights, the gases have thinned out considerably and atomic Oxygen, O, dominates molecular Oxygen, O_2. In ionospheric physics, these non-ionized gases are called "neutrals."

The gases at all heights provide protection from the sun's ultraviolet (UV) radiation. At the highest levels of the ionosphere where the F2 layer is found (250 km or 150 miles), the gases interact with Extreme Ultraviolet (EUV) radiation. At lower altitudes (less than 30 km or 20 miles), far below the height where HAARP has any effect, the gases interact with lower energy UV and create and are absorbed by the ozone layer. Again, HAARP has no affect on the gases at these lower altitudes.

In the ionosphere, protection is obtained when a neutral atom absorbs incoming radiation from the sun and becomes an ion when one of its electrons is freed.

Prior to the absorption of the incoming EUV radiation, we have:

1. One high energy (EUV) photon
2. One Oxygen atom (a "neutral")

The photon gives up its energy in the collision and causes one of the electrons of the oxygen atom to be dislodged. The result is:

1. No EUV photon (it has been consumed in the collision)
2. One Oxygen ion (positively charged)
3. One electron (negatively charged)

The result has been that a neutral (an oxygen atom) has been ionized and an incoming photon has been blocked. This is the process by which ionization occurs. Referring to the chart, at the height of the F2 layer where the peak of ionization occurs, the density of ionized atoms (almost entirely Oxygen at this altitude) is around 700,000 to 1,000,000 per cubic centimeter (cm^3). Electrons have the same density. The density of non-ionized, or neutral Oxygen atoms is around 500,000,000 per cm^3 or about 500 times as many in any given volume. The density of Nitrogen (molecular at this altitude) is equal to that of Oxygen (again 500 times as great as the ions).

We have used the heading image on this page to illustrate this point. The blue dots could represent the number of Oxygen neutrals in a given volume at 250 km (150 miles) the height of the peak ion density in the F2 layer. The green dots would then represent the number of Nitrogen neutrals present in the same volume. There are 1000 of each. The ions in this volume would then be represented by the two yellow dots, a ratio of 500 to one.

While it is certainly possible that an incoming EUV photon may collide with an already ionized Oxygen atom, it is clear that the neutral Oxygen atoms greatly outnumber (by 500:1) the ionized Oxygen atoms. Clearly, the neutrals are the primary protection not the ionized atoms. (Electrons, because of their very small cross section, do not afford any protection from UV radiation).

Another way of looking at this is that the ionization in this part of the earth's atmosphere is the manifestation of the protection being afforded by the neutrals. The ionization does not, in itself, provide any meaningful protection and the fact that it disappears at night is further evidence that the protecting action of the neutrals has ceased temporarily, until the sun rises.

HAARP creates an external electric field at the F2 layer height. Particles interact with an electric field only if they are charged (ionized). As a result, HAARP only affects the 0.2% of the ionospheric volume directly over the facility that has already been ionized by the sun (the yellow dots in the image). The remaining 99.8% of the gas in this limited volume is in the neutral state and remains unaffected by HAARP and ready to intercept incoming UV radiation. That portion of the ionosphere that is not directly over the facility is not affected in any way by HAARP. As a result, there will be no impact produced by HAARP on the protective qualities of the earth's atmosphere. This was the conclusion of the environmental impact process, and the question was thoroughly studied by experts in the field prior to granting permission to proceed with the project.

It is very important to realize that the bulk composition of the gas in the volume that is being studied changes imperceptibly. The protective qualities of the atmosphere over HAARP do not change. It takes some very highly sensitive instruments to observe the effects, and the HAARP facility will have some of the best instruments currently available for this purpose.

1.7 The Effects of HAARP on the Ionosphere Overview of Active Ionospheric Research

In the field of geophysics, the use of high power transmitters, such as the one located at the HAARP facility, to study the upper atmosphere is called "active ionospheric research." The HAARP facility will be used to introduce a small, known amount of energy into a specific ionospheric layer for the purpose of studying the complex physical processes that occur in these naturally occurring plasma regions that are created each day by the sun. The effects of this added energy are limited to a small region directly over the HAARP observatory ranging in size from 9 km in radius to as much as 40 km in radius.

It is important to realize that HAARP interacts only with charged (or ionized) particles in a limited region of the ionosphere directly over the facility. Interaction occurs because a charged particle (electron or positive ion) will react to an external electric field. HAARP does not interact with the neutral atoms and molecules that make up the bulk of the gas at all atmospheric heights.

When the HAARP HF transmitter is shut down at the end of an experiment, any ionospheric effects rapidly dissipate, becoming imperceptible over time frames ranging from fractions of a second to minutes. Extensive research conducted over many years at other active ionospheric research facilities around the world has shown that there are no permanent or long term effects resulting from this research method. The following sections discuss these points in greater detail.

1.8 Ionization Varies Naturally

The following chart [1] in fig (1.4) shows the degree of ionization measured in number of electrons per cm^3 as a function of height in kilometers for a typical case. The chart also shows the generally accepted positions for the most important ionospheric regions: the D, E, F_1 and F_2 layers. The red curve in this chart shows the level of ionization that is typical during the daytime and the blue curve, the ionization during the evening hours.

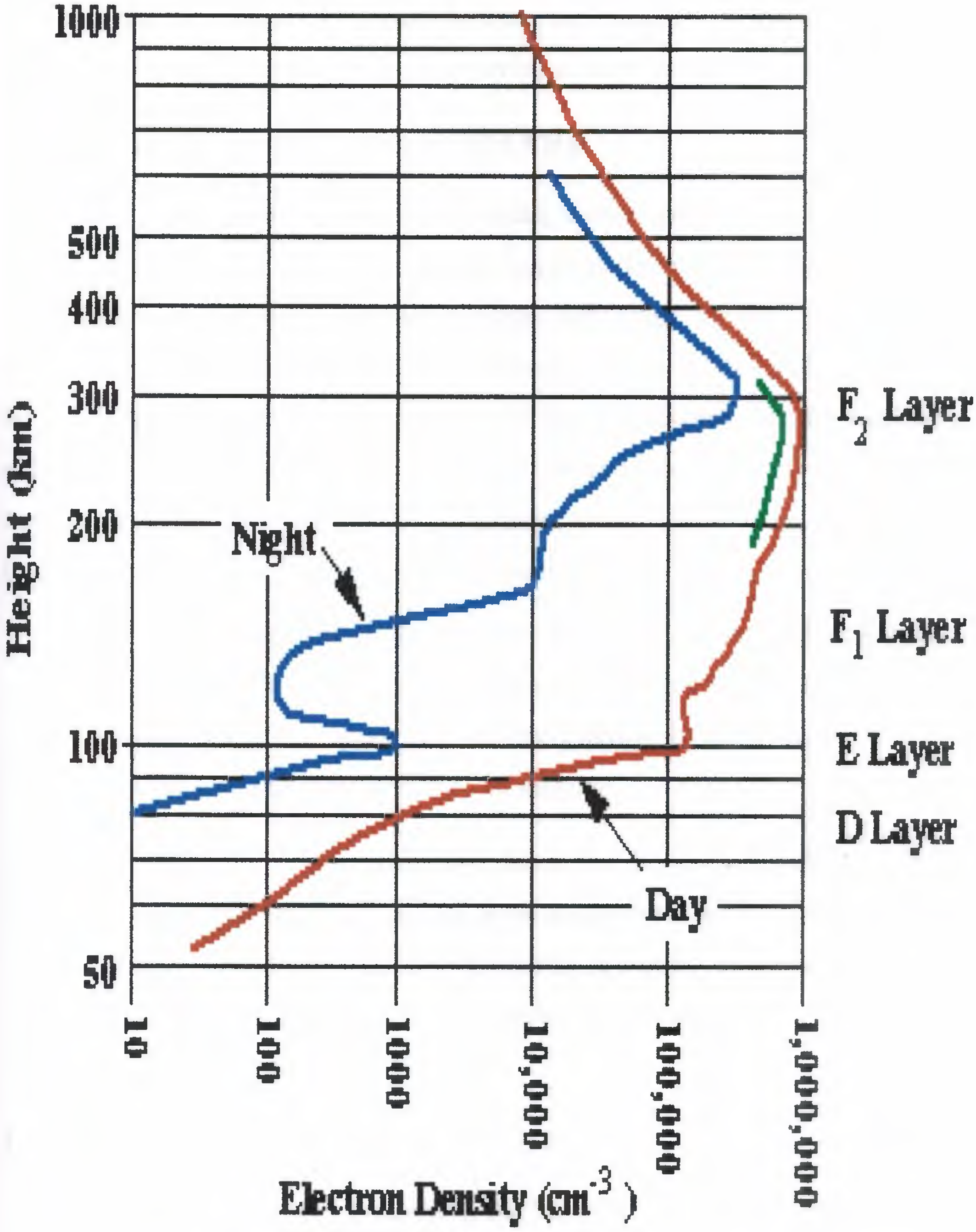


Fig 1.5 shows chart [1] shows the degree of ionization measured in number of electrons per cm^3

It is quite apparent from this chart that the ionosphere undergoes a dramatic change in ionization from day to night. The D layer, for example, disappears entirely as soon as the sun sets. The electron (and ion) density in the E layer decreases by a factor of 200 to 1 and the F_1 by nearly 100:1. For all practical purposes, the lower layers disappear during the evening hours as the sun's radiation is no longer creating new ions and the recombination process depletes the existing ion supply. The density of neutral (non-ionized) particles, on the other hand, does not vary from day to night.

1.9 The Ionosphere Affected by HAARP

During active ionospheric research, a small, known amount of energy is added to a specific region of one of the ionospheric layers as discussed previously. This limited interactive region directly over the facility, will range in size, depending on the frequency of operation and layer height, from as little as 9 km in radius to as much as 40 km in radius and may be as much as 10 km in thickness. The interactions occur only with ionized particles in the layer; neutral (non-ionized) particles, which outnumber ionized particles by 500:1 or greater, remain unaffected.

HAARP is not able to produce artificial ionization for the following two reasons.

1. The frequencies used by the HAARP facility are in the High Frequency (HF) portion of the spectrum. Electromagnetic radiation in the HF frequency range is *non-ionizing* - as opposed to the sun's ultraviolet and X-ray radiation whose photons have sufficient energy to be *ionizing*.

2. The intensity of the radiation from the completed HAARP facility at ionospheric heights will be too weak to produce artificial ionization through particle interactions. The power density produced by the completed facility will not exceed 2.8 microwatts per cm^2, about two orders of magnitude below the level required for that process.

1.10 Effects Are Produced By HAARP

A portion of the energy contained in the HF signal transmitted by HAARP can be transferred to existing electrons or ions making up the ionospheric plasma through a process called absorption, thus raising the local effective temperature. As an example, the electron temperature at a height of 275 km (the peak of the F_2 region) is over 1400°K. [2]. Work at other active ionospheric research facilities has shown that it is possible to raise this temperature by as much as 30% within a small, localized region during an experiment. The affected region would then temporarily display electrical characteristics different from neighboring regions of the layer. Sensitive scientific instruments on the ground can then be used to study the dynamic physical properties of this region in great detail.

As the electrons (and ions) acquire additional energy, their temperature increases, their kinetic energy increases and they begin to move more rapidly. In the F layer, this increased movement or expansion results in a decrease in the electron density. Experience at other active ionospheric research facilities [3] has shown that electron densities in the small, affected region can be reduced by 10% to 20%. This reduction in electon density is shown in the above chart by the dark green line.

Natural ionization in the F layer may produce an electron and ion density during the daytime of 1,000,000 cm^{-3}, about 0.2% of the total gas present. Active ionospheric research using the HAARP HF transmitter (interacting *only* with the ionized particles and not the neutral gas) could suppress this electron density in a localized region to 800,000 cm^{-3}.

Compare this with the decrease in electron density that occurs naturally through a large portion of the nighttime F region (shown in the blue curve) of 500,000 cm^{-3} or less and it is clear that active ionospheric heating cannot duplicate what happens naturally, even within the small affected region directly over the facility.

According to some studies, the electron density in the E region may actually increase as a result of active heating because of the suppression of recombination processes. Compare this with the natural depletion that occurs every evening when the electron density in the E layer falls as much as 200 times to levels of 1,000 cm^{-3} over almost the whole night hemisphere.

1.11 Effects In the Ionosphere as Stated in the Environmental Impact Statement

The HAARP transmissions would interact with the charged particles in the ionosphere. The interaction of the IRI transmissions with the ions would cause temporary increases in temperatures and decreases in electron densities within the ionosphere lasting from a few seconds to several hours and possibly continuing through a polar winter night [1].

The temporary changes in ionospheric properties, caused by the IRI transmitted radio waves, would be many orders of magnitude less than those changes caused by *variations in the sun's energy output.*

The IRI would transmit radio waves over the frequency range 2.8 to 10 MHz. The transmitted radio wave beam would occupy a conical volume roughly 30 miles in diameter at an altitude of 300 miles. The transmitted radio waves would have up to 3.3 MW of power, only slightly higher than waves transmitted by radio and television stations.

Even if the ionosphere absorbed all the transmitted power from the IRI it would take more than 33,000 HAARP-scale IRIs, transmitting simultaneously to account for just 1 percent of the aurora ionosphere's energy budget. Another way of showing the vast difference between the amount of energy that would be dissipated in the atmosphere by the HAARP transmissions and natural processes is through a comparison of the local dissipation power in terms of power densities. The maximum power density of the IRI transmitted waves would be about 30 mill watts per square meter (mW/m^2) at 50 miles altitude decreasing to 1 mW/m^2 at 186 miles altitude in the F region. In comparison, the densities of power dissipated by an aurora could exceed 2 W/m^2, or roughly 2000 times greater then the expected maximum dissipation due to the absorption of the HAARP high frequency transmissions in the F region. Even the daily absorption of solar radiation easily exceeds the most intense, low altitude HAARP inducted energy deposition rate by a factor often.

1.12 Temperature Effects

The ionosphere's temperature would be detectably affected within a few milliseconds of initiating IRI transmissions. Within seconds of initiating IRI transmissions the temperature of the affected conical volume of the ionosphere would begin to rise. The magnitude of the temperature rise would be a function of transmitted power and duration, transmission characteristics such as frequency, and perhaps most importantly, ionospheric conditions.

Existing facilities, such as the IRI in operation at Tromsoe, Norway, typically can enhance F region electron temperatures over a small range of altitudes by up to about 80° F, relative to natural ambient temperatures of 1340° F to 1727° F.

Elevated temperatures due to the IRI would rapidly return to ambient levels once transmissions are ended. The rapid return to ambient conditions would be the result of the dissipation of the extra heat energy by collisions of heated electrons with ambient ions and neutral particles. In the F region the temperatures would return to ambient levels in a few tens of seconds. The return time to ambient temperature levels decreases with decreasing altitude through the F and E layers and down into the D layer where the neutral gas density is about one million times greater than in the F layer. In the D layer the temperatures would return to background levels within less than a millisecond of terminating transmissions.

1.13 Electron Density

Changes in electron density would be associated with high frequency induced temperature increases. IRI transmission induced temperature increases would cause increases in electron densities in the D, E, and F layers below approximately 124 miles above the ground and decreases in electron density in the F layer above approximately 124 miles above ground.

Two primary temperature dependent processes would affect electron densities due to IRI transmissions. One process involves the recombination of ions and electrons into neutral molecules (two or more bonded atoms), which make up the troposphere and statosphere. Higher temperatures slow down the recombination rate resulting in higher electron densities. The second process involves the expansion of the ionospheric atmosphere due to heating. The expansion causes the ionosphere electron density to decrease.

Thermal expansion would be inhibited and electron recombination rates would decrease in the D, E, and F layers below approximately 124 miles above the ground. As a result, electron densities within the conical volume of the IRI beam could increase on the order of 20 percent. Above approximately 124 miles, above ground, in the F layer, thermal expansion would prevail over reduced recombination rate effects and the electron density within the affected conical volume of the F layer would decrease.

The magnitude of the decrease could range up to 10 - 15 percent over an altitude range of a few tens of miles.

CHAPTER TWO

A SPHERE OF INFLUENCE

2.1 Magnatosphere

Saturn, its moons and its awesome rings sit inside anonymous cavity in the solar win created by the planet's strong magnetic field. This "sphere of influence" of Saturn's magnetic field called a magnetosphere resembles a similar magnetic bubble surrounding Earth. The region is not at all spherical rather the supersonic solar wind, flowing at 300–1000 kilometers per second against Saturn's magnetic field, compresses the magnetosphere on the side facing the Sun and draws it out into along magnetotail in the direction away from the Sun.

2.2 Inside the Magnetosphere

Saturn's vast magnetosphere bubble is a mixture of particles, including electrons, various species of ions and neutral atoms and molecules, several populations of very energetic charged particles (like those in Earth's Van Allen Belts) and charged dust grains. The charged particles and dust grains all interact with both the steady and the fluctuating electric and magnetic fields present through out the magnetosphere. These ionized gases contain charged particles (electrons and ions) such as occur in the solar wind and planetary magnetospheres and are called plasmas.

The steady fields can cause organized motions of the charged particles, creating large currents in the plasma. Plasma behavior is more complex than that of neutral gases because, unlike neutral particles, the charged particles interact with each other Electro magnetically as well as with any electric and magnetic fields present. The plasma's fluctuating fields (including wave fields) can "scatter" the charged particles in a manner similar to collisions in a neutral gas and cause a mixing of all the magnetospheric components.

An artist's rendition of Saturn's immense magnetosphere. $\overrightarrow{\Omega_s}$ is the planet's rotation axis, closely aligned with the magnetic axis. [IM-age courtesy of Los Alamos National Laboratory]

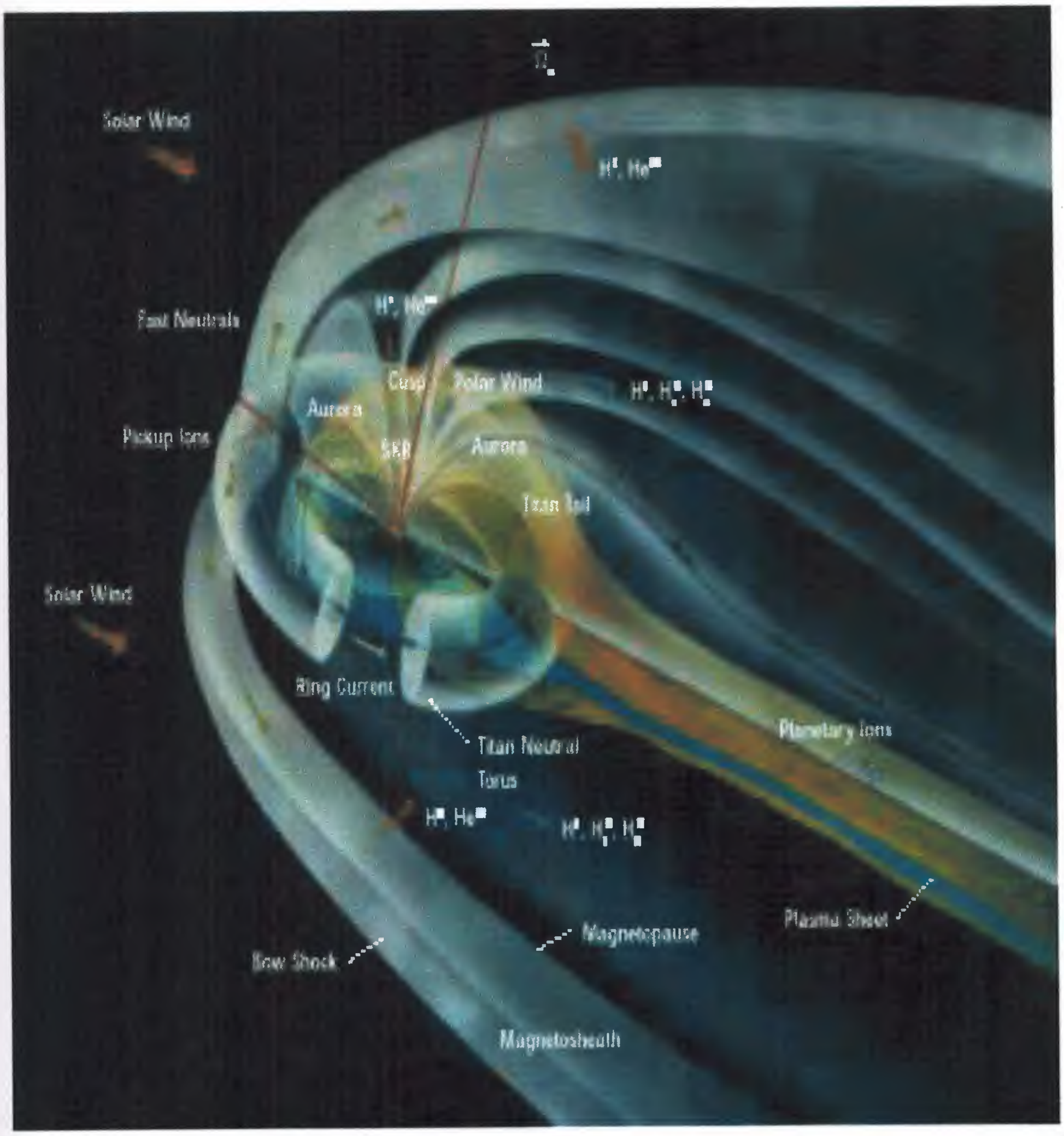


Fig.2.1 shows an artist's rendition of Saturn's immense magnetosphere.

Most of what we know about Saturn's magnetosphere comes from the brief visits by Pioneer 11 and Voyagers 1 and 2, but remote observations by the Hubble

Space Telescope and other spacecraft have also provided us with intriguing information.

Magnetospheric Particle Sources Saturn has a variety of sources for the particles in its magnetosphere. Particles can escape from any moon, ring or dust particle surface, or they can be "sputtered" off by energetic particles or even micrometeoroid impacts. The primary particle sources are thought to be the moons Dione and Tethys. But, the solar wind, ionosphere, rings, Saturn's atmosphere, Titan's atmosphere and the other icy moons are sources as well.

Recent Hubble Space Telescope results show large numbers of neutral hydrogen atoms (the neutral hydrogen cloud in the illustration above) throughout the magnetosphere that probably come from a number of these sources. It has even been proposed that water ions and molecules may form a dense "ionosphere" above Saturn's rings. Recent Hubble Space Telescope results show large numbers of neutral hydrogen atoms throughout the magnetosphere that probably come from a number of the sources mentioned.

Determining the relative importance of the varied sources in different parts of Saturn's space environment is a prime objective for the Magnetospheric and Plasma Science (MAPS) instruments aboard the Cassini spacecraft. Neutral particles can escape from any moon, ring or dust particle surcles can be created by processes within the magnetosphere or they can leak in from the solar wind. These and many other magnetospheric phenomena were seen by the three earlier spacecraft.

The mysterious "spokes" in the rings of Saturn, clearly seen in Voyager images, are probably caused by electrodynamic interactions between the tiny charged dust particles in the rings and the magnetosphere. Auroras, which exist on Saturn as well as Earth, are produced when trapped charged particles precipitating from the magnetosphere collide with atmospheric gases.

Sphere, rings, Saturn's atmosphere, Titan's atmosphere and the other icy moons are sources as well. Recent Hubble Space Telescope results show large numbers of neutral hydrogen atoms (the neutral hydrogen cloud in the illustration above) throughout the magnetosphere that probably come from a number of these sources. It has even been proposed that water ions face or they can be "sputtered" off by energetic particles or even micrometeoroid impacts.

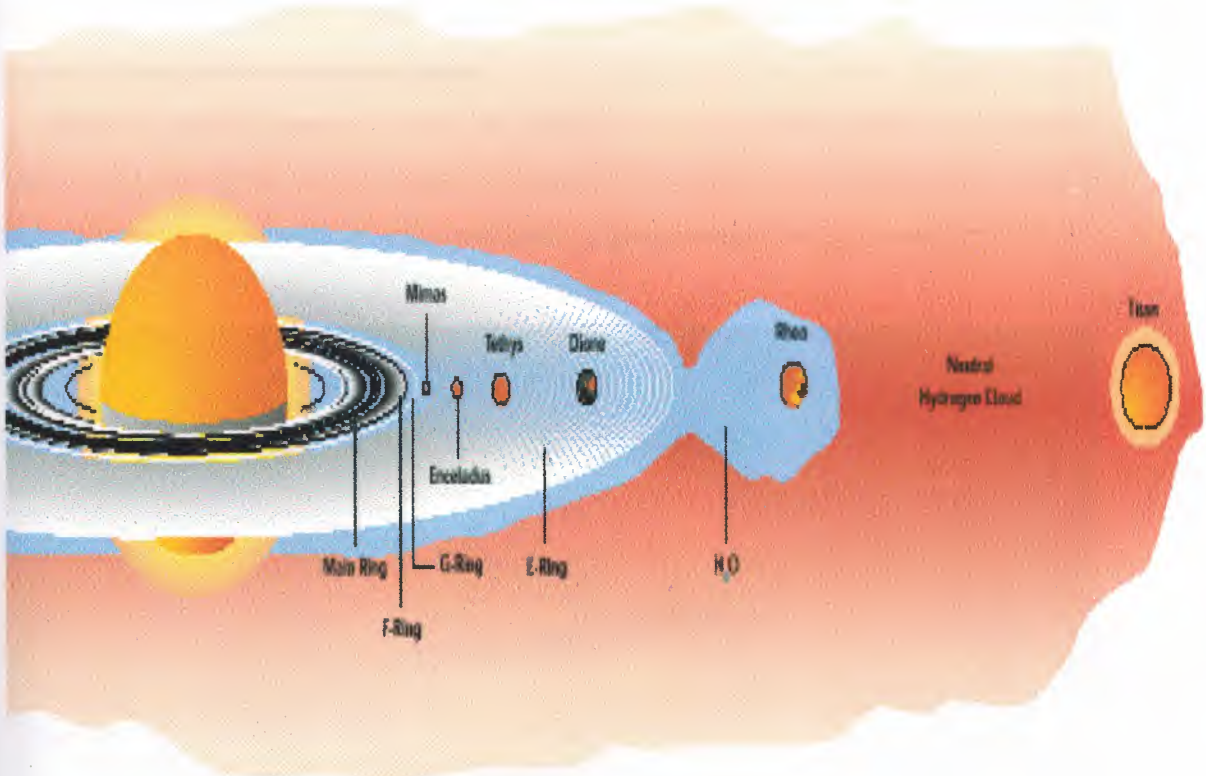


Fig.2.2 shows Sources of particles in Saturn's magnetosphere

2.3 Sources of particles in Saturn's magnetosphere

When these particles become ionized, they can excite electromagnetic waves with a frequency that can be used to determine their type. The icy rings absorb the energetic particles inward of the moon Mimas. Energetic partiespite many exciting discoveries, many more questions about the physical processes in Saturn's magnetosphere remain unanswered. This chapter examines the current state of knowledge about Saturn's magnetosphere and discusses the observations we expect to make with Cassini's instruments and the knowledge we expect to gain from forth-coming explorations. Sources of particles in Saturn's magnetosphere.

2.4 The MAPS Instruments

Coordinated observations are required from all the Magnetospheric and Plasma Science (MAPS) instruments aboard Cassini to fully understand Saturn's various dynamic magnetospheric processes. The Cassini Plasma Spectrometer will measure in situ Saturn's plasma populations including measurements of electron and ion species

(H + , H 2 He ++ , N + , OH + , H 2 O + , N2) and determine plasma flows and currents throughout the magnetosphere.

Saturn's aurora, imaged in the far ultraviolet by the Wide Field and Planetary Camera 2 aboard the Hubble Space Telescope. The aurora (the bright region near the pole) is caused by energetic charged particles exciting atoms in the upper atmosphere.

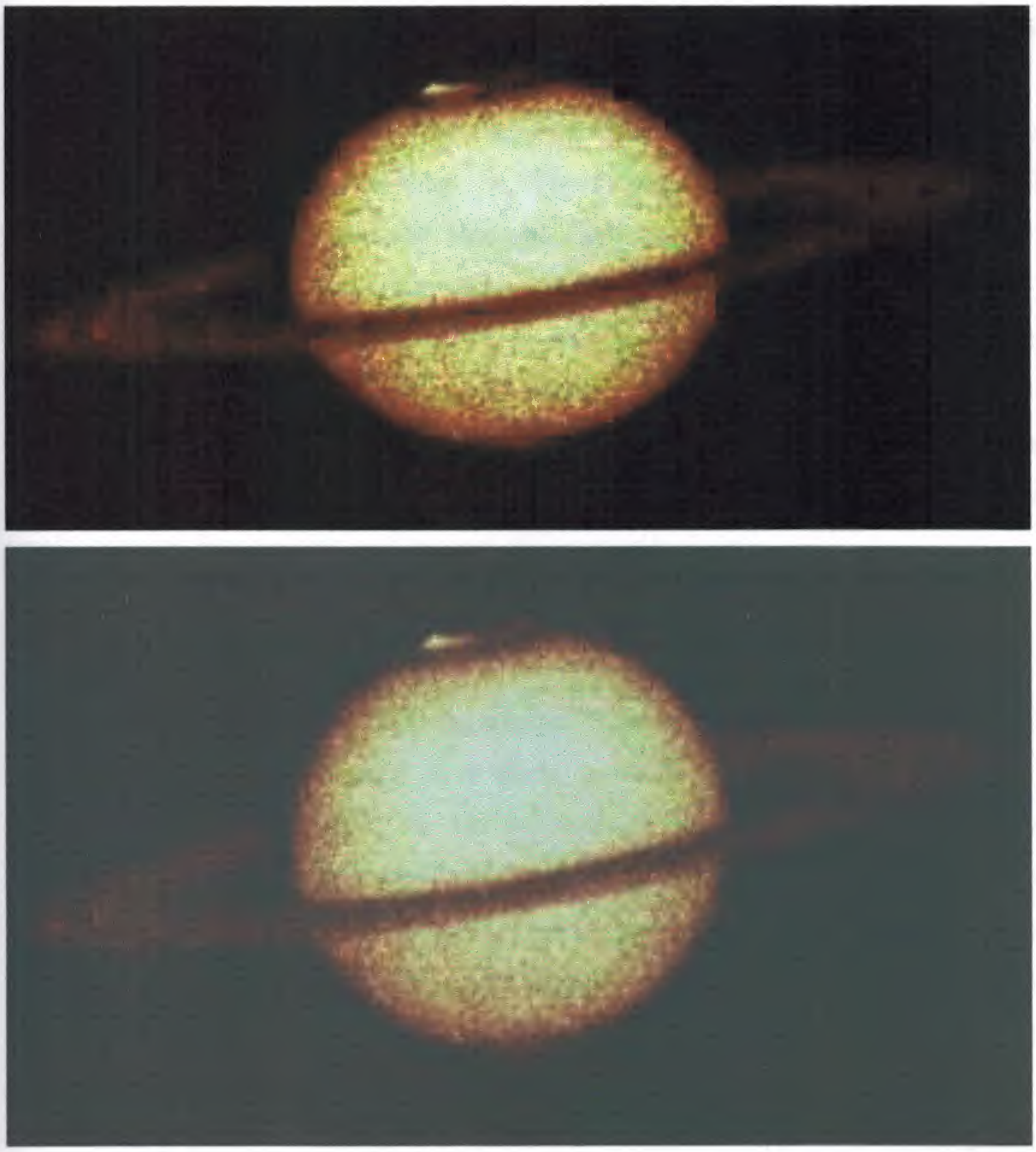


Fig.2.3 shows Saturn's aurora

The Cosmic Dust Analyzer will make measurements of dust particles with masses of 10^{-19} -10^{-9} kilograms, determining mass, composition, electric charge, velocity and direction of incoming dust particles. Perhaps this instrument's most important capability will be measuring the chemical composition of incoming dust particles, making it possible to relate individual particles to specific satellite sources.

The ion and Neutral Mass Spectrometer will measure neutral species and low energy ions throughout the magnetosphere and especially at Titan. The Dual Technique Magnetometer will measure the strength and direction of the magnetic field throughout the magnetosphere. The first ever global images of Saturn's hot plasma regions will be obtained by the Magnetospheric Imaging Instrument, which will also measure in situ energetic ions and electrons. The Radio and Plasma Wave Science instrument will detect the radio and plasma wave emissions from Saturn's magnetosphere, which will tell us about plasma sources and interactions in the magnetosphere. The Radio Science Instrument will measure the ionosphere of Saturn and search for ionospheres around Titan, the other moons and the rings. The Ultraviolet Imaging Spectrograph will map the populations of atomic hydrogen and weak emissions from neutrals and ions including auroral emissions.

2.5 The Magnetic Enigma

Saturn's magnetic field presents an enigma. Planetary fields such as those of Earth and Saturn can be approximated by a dipole, a simple magnetic field structure with north and south poles, similar to that produced by a bar magnet. Magnetic field measurements from the three previous flybys revealed a dipole like field at Saturn with no (less than one degree) measurable tilt between Saturn's rotation and magnetic dipole axes. This near perfect alignment of the two axes is unique among the planets. The Earth and Jupiter have dipole tilts of 11.4 and 9.6 degrees, respectively. The polarity of Saturn's magnetic dipole, like Jupiter's, is opposite to that of Earth.

There is a general consensus that the internal magnetic fields of the giant planets arise from dynamo action somewhere inside the planets' gaseous atmospheres.Of-course, we do not really know what is inside Saturn or where the field is generated, although we have a number of theories.

The inside of Saturn is probably quite exotic because of the great pressures caused by its large size. There may be a rocky (Earth-like) center with a molten core, but wrapped around this core we would expect to find layers of other uncommon materials (like liquid helium). The Saturn we see with telescopes and cameras is really only the cloud tops.

Although the measured field is symmetrical about the rotation axis, a number of observed phenomena can only be explained by an asymmetry the magnetic field. Two examples are the occurrence of major emissions of Saturn kilometric radiation (SKR), the principal radio emission from Saturn, at the presumed period of the planetary rotation and a similar variation in the formation of the spokes in the Bring.

The SKR observations can be explained by a magnetic anomaly in the otherwise symmetric field of less than five percent of the field at Saturn's surface (0.2 gauss), small enough to be imperceptible at the closest approach distances of the previous flybys of the Voyagers and Pioneer.

With magnetic field measurements made close to the planet over a wide range of latitudes and longitudes, the Dual Technique Magnetometer on Cassini will measure the details of the magnetic field and tell us more about Saturn's interior. The magnetometer will measure the strength and direction of the magnetic field throughout the magnetosphere, close to the planet where the field is dipolar and further from the planet where the field is nondipolar due to distortion by current systems.

The magnetometer will measure the field with sufficient accuracy to determine if it is indeed symmetrical. If so, the basic tenets of dynamo theory may need to be reexamined.

2.6 Solar Wind Interaction

A planetary magnetosphere forms when the magnetized solar wind (the supersonic, ionized gas that flows radically outward from the Sun) impinges upon a planet with a sufficiently large magnetic field. Like Earth and the other giant planets, Saturn has a strong magnetic field and an extensive magnetosphere. Although the morphology and dynamics of planetary magnetospheres vary according to the strength and orientation of their internal fields, magnetospheres share many common features. Because the solar wind flow is almost always supersonic, a "bow shock" forms Sun ward of the magnetosphere. The bow shock heats, deflects and slows the solar wind.

Pioneer 11 made the first in situ measurements of Saturn's bow shock in 1979 when discontinuous jumps in solar wind parameters (magnetic field strength, density, and temperature) were observed. Because of the variation in characteristics of the solar wind with distance from the Sun, by the time the orbit of Saturn is reached, the average Mach number, which determines the strength of the bow shock, is quite large.

The bow shock of Saturn is a high Mach number shock similar to that of Jupiter and differs from the low Mach number shocks of the terrestrial planets. Saturn's bow shock provides a unique opportunity to study the structure of strong astrophysical shocks.

The magnetopause marks the boundary of the magnetosphere, separating the solar wind plasma and magnetospheric plasma. Between the bow shock and the magnetopause is a layer of deflected and heated solar wind material forming the magnetosheath. The boundaries move in and out in response to changing solar wind conditions. The average distance to the nose of the magnetopause at Saturn is roughly 20 R_S (R_S = one Saturn radius or 60,330 kilometers). These boundaries, shown in the image on the first page of this chapter, are of interest in understanding how energy from the solar wind is transferred to the planet to fuel magnetospheric processes.

2.7 Extensive observations of Earth's

Magnetosphere have demonstrated that solar wind energy is coupled into the magnetosphere primarily through a process called magnetic reconnection, in which field lines break and reconnect to change the magnetic topology. Similar processes must indeed occur at Saturn. Given the proper relative orientation of inter planetary and planetary magnetic fields on the sun ward side of the magnetosphere, the field lines reconnect and a purely planetary magnetic field line (with both ends attached to the planet) becomes a field line with one end attached to the planet and the other end open to interplanetary space.

It is on these open field lines that format high Saturn latitudes that energetic particles of solar, interplanetary or cosmic origin can enter the magnetosphere. These regions of the magnetosphere over the northern and southern poles are referred to as the polar caps. The open field lines are then pulled back by the drag of the diverted solar wind flow to make the magnetotial.

Because charged particles and magnetic field lines are "frozen" together, this drives a tail ward flow within the magnetosphere.

In the magnetotail, reconnection again occurs. Here, the magnet field reverses direction across the tail's plasma sheet (a thin sheet of plasma located approximately in the planet's equatorial plane, where currents flow and particles are accelerated. The process of reconnection and opening of field lines on the sun ward side of the magnetosphere is thus balanced by reconnection that closes field lines in the magnetotail.

The newly closed field lines contract back to ward the planet, pulling the plasma along and driving a circulation pattern, as shown in the figure below. The process of reconnection on the Sun ward side of the magnetosphere is thus closely coupled to processes that occur in the magnetotail.

These processes are known to be strongly affected by the changing conditions in the solar wind. At Earth, reconnection processes can give rise to large, erratic changes in the global configuration of the magnetosphere referred to as geomagnetic storms. Cassini's MAPS instruments will investigate to see if similar magnetospheric storms occur at Saturn. Voyager 1 made the first direct measurement of Saturn's magnetotail, finding it to resemble its terrestrial and Jupiter counterparts.

The magnetotail was detected to be roughly 40 R S in diameter at a distance 25 R_S downstream; it may extend hundreds of Saturn radii in the downstream solar wind. Understanding the processes that occur in the magnetotail is fundamental to understanding overall magnetospheric dynamics; coordinated measurements by the MAPS instruments during the deep tail orbits planned for the Cassini tour will contribute to that understanding. In turn, by understanding overall magnetospheric dynamics, scientists will gain insight into how Saturn's magnetosphere harnesses energy from the solar wind.

2.8 SOLAR WIND CIRCULATION

Large-scale circulation driven by the solar wind as it occurs at Earth. An analogous process occurs at Saturn. The orientations of magnetic field lines and plasma flows are shown. When the interplanetary magnetic field is oriented south ward, as shown, field lines reconnect at the nose of the magnetopaue and then again in the magnetotail, driving the flows described inthe chapter text.

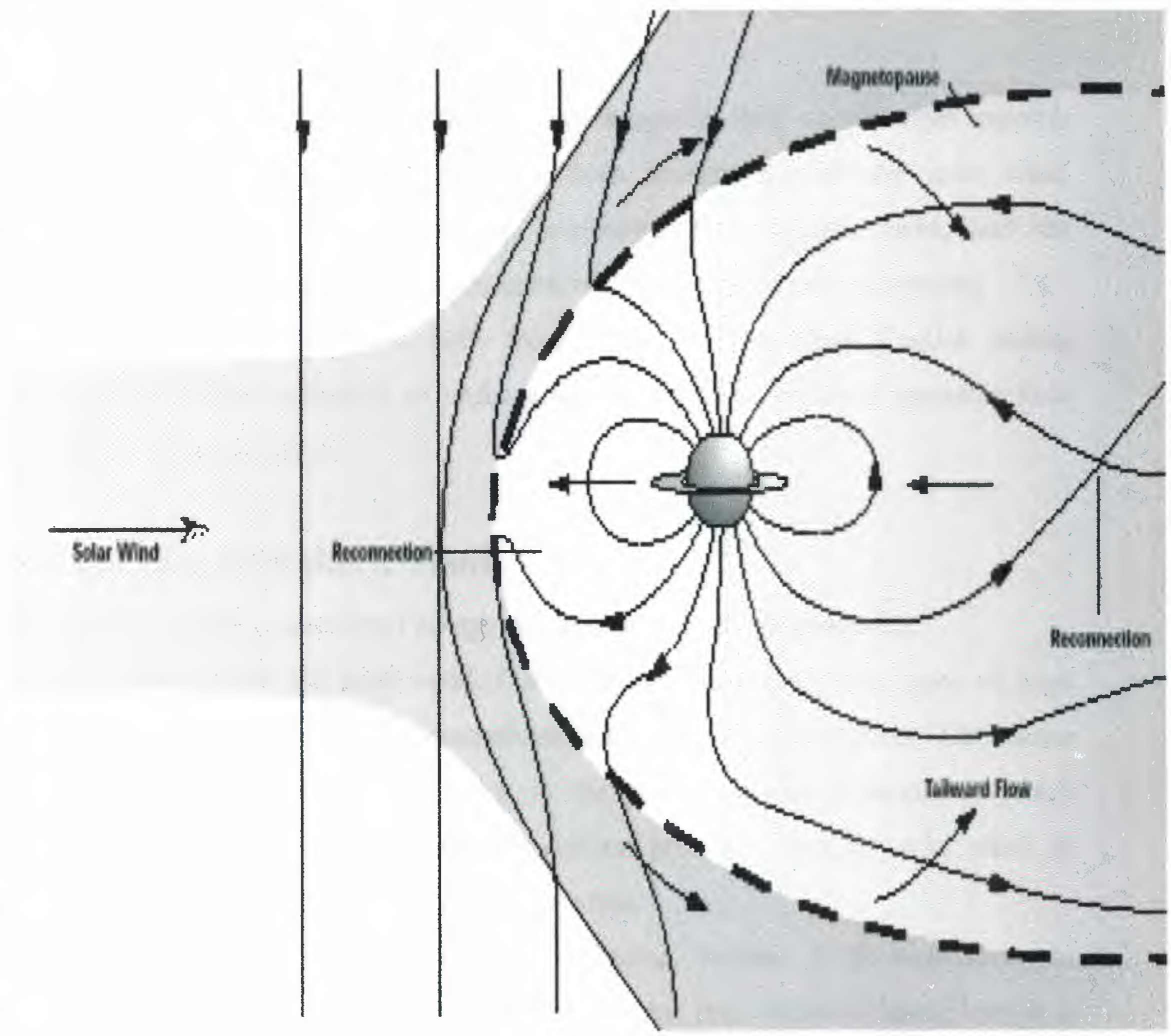


Fig.2.4 shows solar wind circulation

2.9 Current Magnetospheric Systems

Various large-scale current systems exist in Saturn's magnetosphere due to the collective motions of charged particles. Cross-tail currents flow from dusk to dawn in the plasma sheet located near the center of the magnetotail. An equatorial ring current distorts the magnetic field from its dipolar configuration, particularly in the outer magnetosphere where it stretches the magnetic field lines in the equatorial plane. This ring current, caused by electrons and ions drifting around the planet in opposite directions, is probably primarily due to the energetic particles discussed later in this chapter. The effect of this ring current s moderate when compared with Jupiter, however.

Another major contribution to Saturn's total magnetic field comes from currents flowing in the magnetopause, which result from interaction with the solar wind. Cassini's Dual Technique Magnetometer, measuring the magnetic field, and the Cassini Plasma Spectrometer, suing the warrants, will help map the current systems.

These measurements, together with those taken by the other Cassini plasma instruments, will allow scientists to make a global model of Saturn's magnetic field throughout the magnetosphere.

2.10 Major Magnetospheric Flows

There are two primary sources of energy driving magnetospheric processes:
the planet's rotation and the solar wind. Correspondingly, there are two types of large scale plasma flow with-in the magnetosphere coronation and convection. The nature of the large-scale circulation of particles in the magnetosphere depends on which source is dominant. At Earth, the energy is derived primarily from the solar wind; at Jupiter it is derived from the planet's rapid rotation rate.

Saturn's magnetosphere is especially interesting because it is somewhere in between: both energy sources should play an important role. Saturn's ionosphere is a thin layer of partially ionized gas at the top of the sunlit atmosphere. Collisions between particles in the atmosphere and the ionosphere create a frictional drag that causes the ionosphere to rotate together with Saturn and its atmosphere.

The ionosphere, which extends from 1500 kilometers above the surface (defined as the visible cloud layer) to about 5000 kilo meters, has a maximum density of about 10,000 electrons per cubic centimeter at about 2000–3000 kilometers.

The rotation of Saturn's magnetic field with the planet creates a large electric field that extends into the magnetosphere. The electromagnetic forces due to the combination of this electric field and Saturn's magnetic field cause the charged magnetospheric plasma particles to "corotate" (rotate together with Saturn and its internal magnetic field) as far out as Rhea's orbit (about nine R_S). Convection, the other large-scale flow, is caused by solar wind pulling the magnetic field lines toward the tail. This leads to a plasma flow from day side to night side on open field lines and to a return flow from night side to day side on closed field lines (particularly near the equatorial plane).

On the dawn side, the coronation and connective flows will be in the same direction, but on the dusk side, they are opposing flows. The interaction of these flows may be responsible for some of the large variability observed in the outer magnetosphere. While at present we can only speculate about the consequences of these plasma flow patterns, we may expect
some answers from investigations by Cassini's plasma instruments (especially the Cassini Plasma Spectrometer and the Magnetospheric Imaging Instrument).

2.11 Magnetospheric Plasma Regions

Saturn's magnetosphere can be broadly divided in two parts: a fairly quiet inner magnetosphere extending to about 12 R_S (beyond all moons except Titan), and an extremely variable hot outer magnetosphere. In both regions, the plasma particles are concentrated in a disk near the equatorial plane, where most plasma particle sources are located.

Saturn's inner and outer magnetospheres, Pioneer and both Voyagers passed through several different plasma regions. The spacecraft observed a systematic increase in electron temperature with distance from Saturn, ranging from one electron volt (equivalent to a temperature of 11,600 Kelvin's) at four R_S in the inner magnetosphere and increasing to over 500 electron volts in the outer magnetosphere.

The thickness of the plasma disk increases with distance from Saturn. Inside about four R_S a dense (about100 per cubic centimeter) population of low-energy ions and electrons is concentrated in a thin (less than 0.5 R_S) equatorial sheet.

Saturn's magnetic field. Field lines are shown for a dipole field model (solid line) and a model containing a dipole plus a ring current(dashed line). The stretching out of the field lines due to the ring current (shaded region) is moderate.

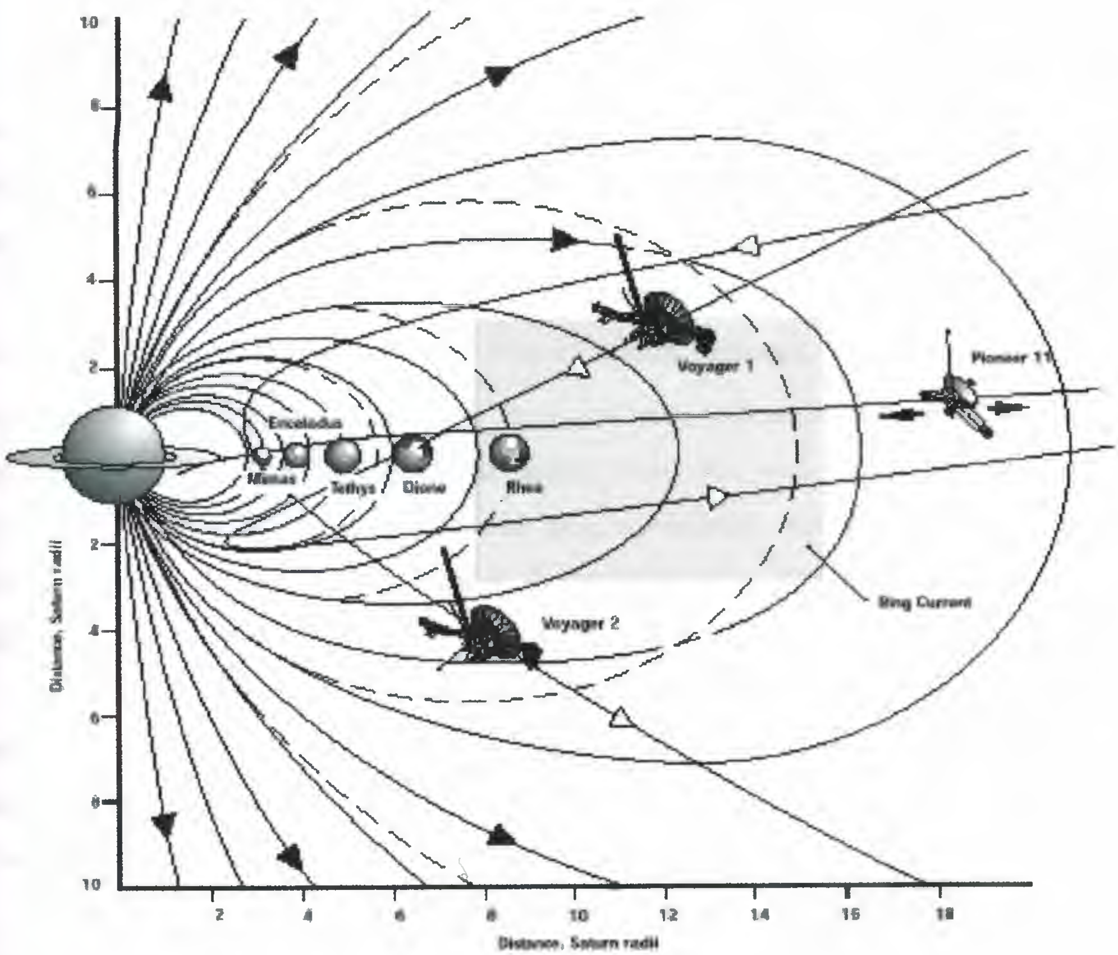


Fig.2.5 shows Saturn's magneticfield

The low temperature is probably due to interactions with ring material; it has even been proposed that water ions and molecules may form a dense "ionosphere" above

Saturn's rings. In the inner magnetosphere, there is an oxygen-rich Dione-Tethys torus extending from four to about eight R_S ,beyond Rhea's orbit.

The icy surfaces of Dione and Tethys and other moons and rings in the magnetosphere are continually bombarded by both particles and solar radiation. Water molecules released by the bombardment form a disk-shaped cloud of water molecules and fragments of these molecules.

The charged particle density in this region is a few particles per cubic centimeter and is composed of about 20 percent light ions (primarily hydrogen ions) and about80 percent heavy ions with masses between 14 and 18 (species such as O^+ and OH^+). In between Saturn's inner torus and outer magnetosphere is an extended equatorial plasma sheet of charged particles with densities between 0.1 and 2 particles per cubic centimeter.

The inner edge of the sheet has "hot" (temperatures in the thousands of electron volts) ions and coincides with a vast cloud of neutral hydrogen, extending to $25R_S$, which probably escaped from the moon Titan, and other sources as well. Possibly, the hot ions are newly born ions from the neutral cloud that were heated by Saturn's rotational energy. The Voyager spacecraft saw considerable variability in both the charged particle density and temperature in the outer magnetosphere on very short time scales.

This has been inter prated as "blobs" of hot plasma interpreted with outward moving cold plasma and may be pieces of the plasma sheet that have broken off. The variability may also be due to dense "plumes" of hydrogen or nitrogen escaping from Titan that wrap around Saturn.

Alternately, the variations may be caused by fluctuations in the solar wind, since both the outer magnetosphere and the magnetotail are thought to be the primary regions where solar wind energy enters the magnetosphere. The dynamics, composition and sources of the outer magnetospheric plasma particles are not well understood. Investigation of this region is one important Cassini objective, so the MAPS instruments will make coordinated observations in this region. Until Cassini determines the composition here, the extent of the role of Titan in Saturn's outer magnetosphere will remain unknown.

2.12 Major Magnetoshere Flows

Major flows in Saturn's magnetosphere. The solar wind flows in from the left; the magnetotail is to the right. Convection, a tail ward plasma flow, is caused by the solar wind dragging magnetic field lines past the planet.

Corotation, magnetosphericrotation at the rate of Saturn, is caused by the corotation of Saturn's ionosphere.

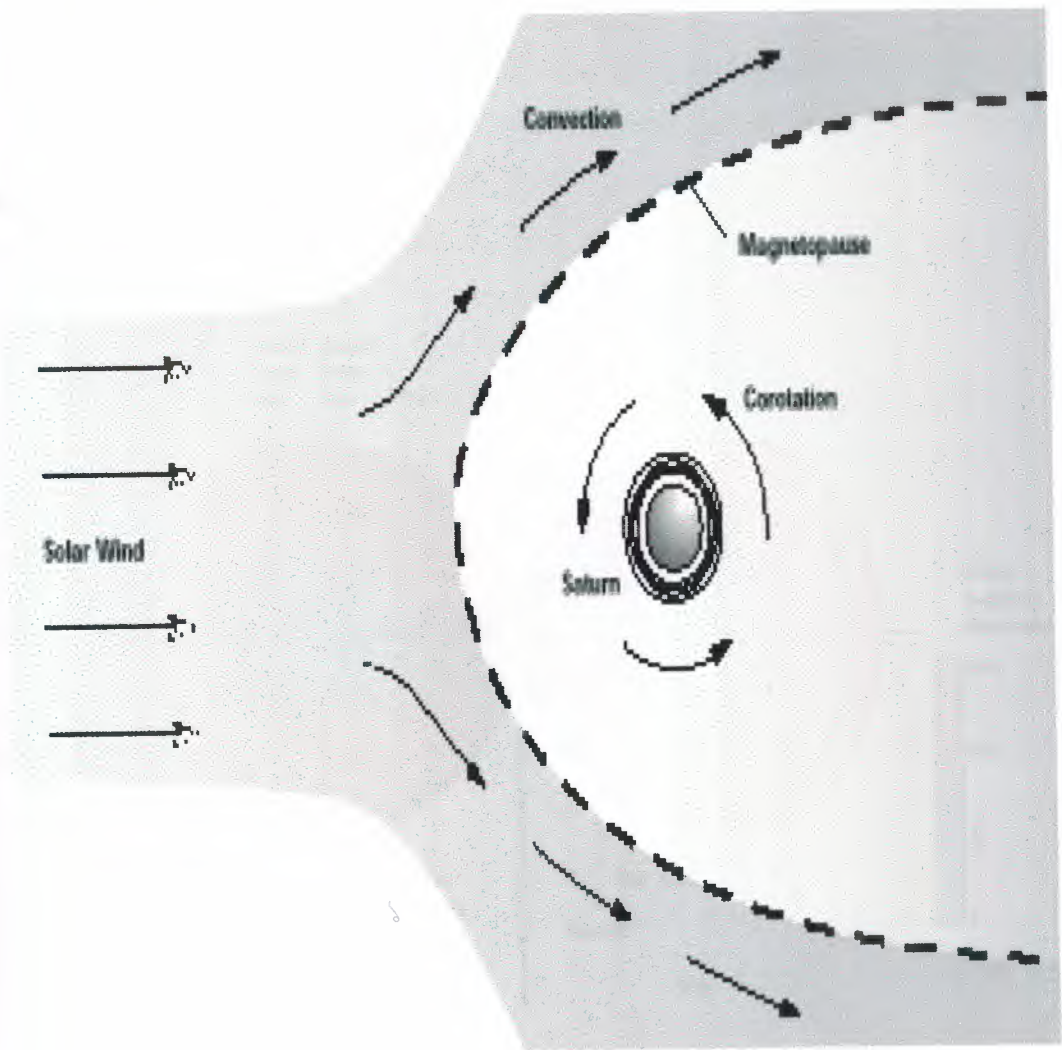


Fig.2.6 shows Major Magnetosphere Flows

2.13 Regions of Saturn's magnetosphere.

The various plasma regions inner tours, extended plasma sheet, variable outer magnetosphere, etc. Are shown in relationship to the location of the moons and the magnetosheath.

The temperature is indicated by the color scale, going from cold (blue) to hot (pink). Note the asymmetry: The left side shows the noon magnetosphere (that portion closest to the Sun). [Based on Sittler, et al., 1983]

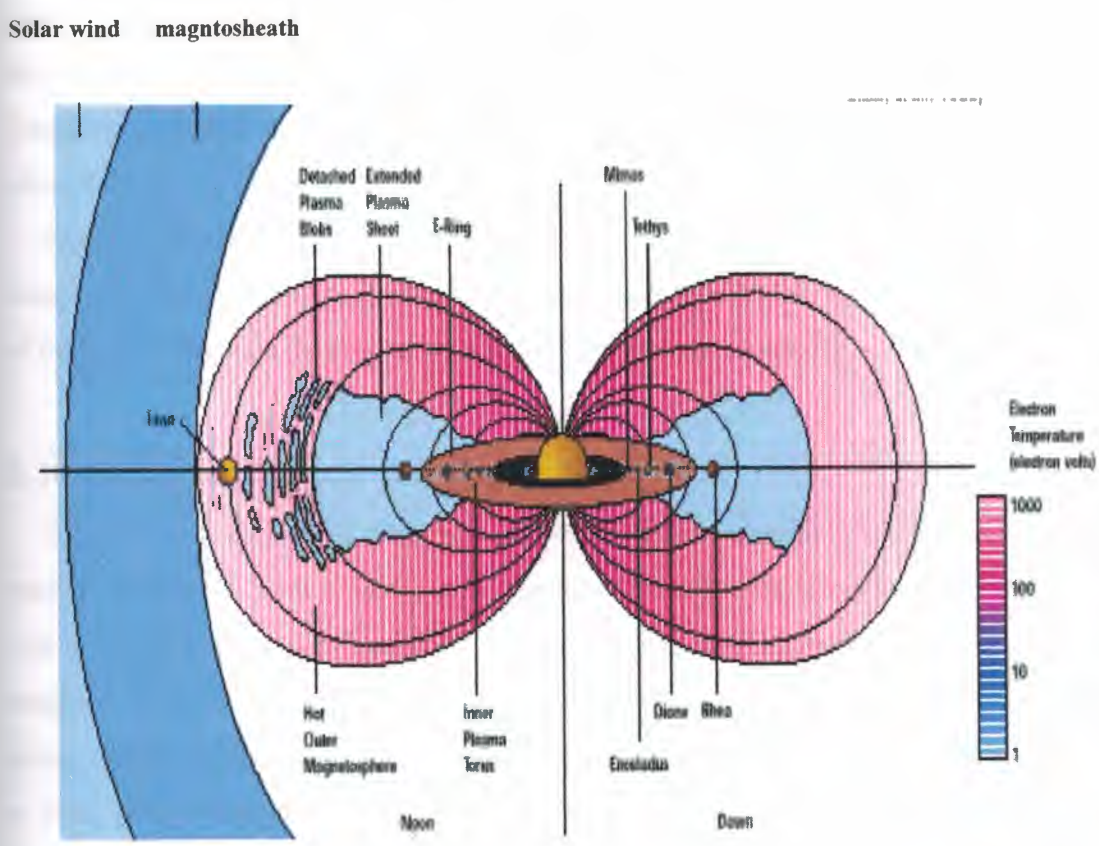


Fig.2.7 shows regions of Saturn's magnetosphere.

In the inner region of the magnetosphere, most of the particles "corotate" with the planet.

The coronation speed of charged particles differs from the speed of normal orbital motion (determined by gravity). Beyond approximately eight R_S, the charged particles lag behind the coronation speed by 10–30 percent. Here, the gravitational orbit velocity is much slower than the coronation speed; the lag is probably due to new ions born from the neutral hydrogen cloud or Titan's atmosphere that have not yet been brought up to Saturn's rotation rate (the coronation speed).

In the outer magnetosphere, the plasma rotation rate is about 30 percent lower than the coronation speed. When neutral particles from the moons or rings are ionized, they begin to move relative to the other neutral particles because of the difference in the orbital speed and the corotation speed. Since these new ions add to the mass of the corotating plasma population, they can slow it down, as suggested by the observations.

Outward motion of plasma from the inner magnetosphere may also contribute to slowing it down. Cassini's MAPS instruments will investigate the relative importance of these two effects on the coronation rate in the outer magnetosphere.

2.14 Energetic Particle Populations

Saturn's magnetosphere, like that of other planets, contains populations of highly energetic particles similar to those in Earth's Van Allen radiation belts (kilo electron volt to megaelectron volt energies). These particles are trapped by Saturn's strong magnetic field. In a uniform magnetic field, charged particles move in helical orbits along magnetic field lines. In Saturn's dipolar magnetic field, the field strength along a field line increases toward the planet. At some point determined by the particle speed and the magnetic field strength, the particle is "reflected" or "mirrored" and it reverses direction along the same field line.

A "trapped" charged particle moves in such an orbit in Saturn's field, bouncing back and forth along a single magnetic field line. The radiation belts are made up of energetic particles moving in such orbits.

Collisions with neutral particles or interactions with the fluctuating electric and magnetic fields in the plasma can change a charged particle's orbit. Voyager 2 data showed Saturn's magnetosphere to be populated largely by low

energy (tens of electron volts) electrons in the outer regions with more energetic electrons dominating further inward. Substantial fluxes of high-energy protons were observed inside the orbits of Enceladus and Mimas, forming the hard core of the radiation belts. Pioneer 11 investigators concluded that these protons probably originated from the interaction of cosmic rays with Saturn's rings.

The origin of these and other energetic particles is unclear and will be investigated by Cassini's MAPS instruments. In particular, the Magnetospheric Imaging Instrument will make in situ measurements of energetic ions and electrons.

Some energetic ions such as helium and carbon may originate in the solar wind, but others may come from lower energy particles that are energized in Saturn's magnetosphere.

The energetic particles drifting in the dipole like magnetic field create Saturn's magnetosphere.

Cassini's Magnetospheric Imaging Instrument will use these energetic neutral atoms as if they were photons of light to make global images and study the overall configuration and dynamics of Saturn's magnetosphere.

The instrument will obtain the first global images of Saturn's hot plasma regions with observations of features such as Saturn's ring current and Titan's hydrogen torus. Cassini will be the first spacecraft to carry an instrument to image the magnetosphere using energetic neutral atoms.

2.15 Polar Region Interactions

Aurora. Most energetic particles bounce back and forth along field lines in trapped particle orbits.

If, however, the mirror point is below the top of the atmosphere, the particle can deposit its energy in the upper atmosphere. Energetic particles reaching the atmosphere create the auroral emission by exciting gases in the upper atmosphere (molecular and atomic hydrogen lines in the case of Saturn; oxygen and nitrogen in Earth's atmosphere).

Saturn's aurora was first detected by the Voyager ultraviolet spectrometer.

While is it not clear which magnetospheric particles (electrons, protons or heavy ions) create the aurora, it is clear that planets with higher fluxes of energetic particles have stronger auroral emissions. Cassini's MAPS instruments will make coordinated studies of Saturn's aurora, with the Ultraviolet Imaging Spectrometer providing images.

2.16 Charged particle orbits

In a magnetic field. Left: in a uniform field, charged particles are tied to field lines and move along them in helical orbits. Right: in a dipole-like field, trapped charged particles move in helical orbits along field lines, but at some point "mirror" or "reflect," leading to a bounce motion along the field line. Charged particles in such trapped orbits also drift in circles around the planet due to the in homogenous magnetic field. Ions drift in one direction and electrons in the other, leading to a ring current that modifies the planetary magnetic field.

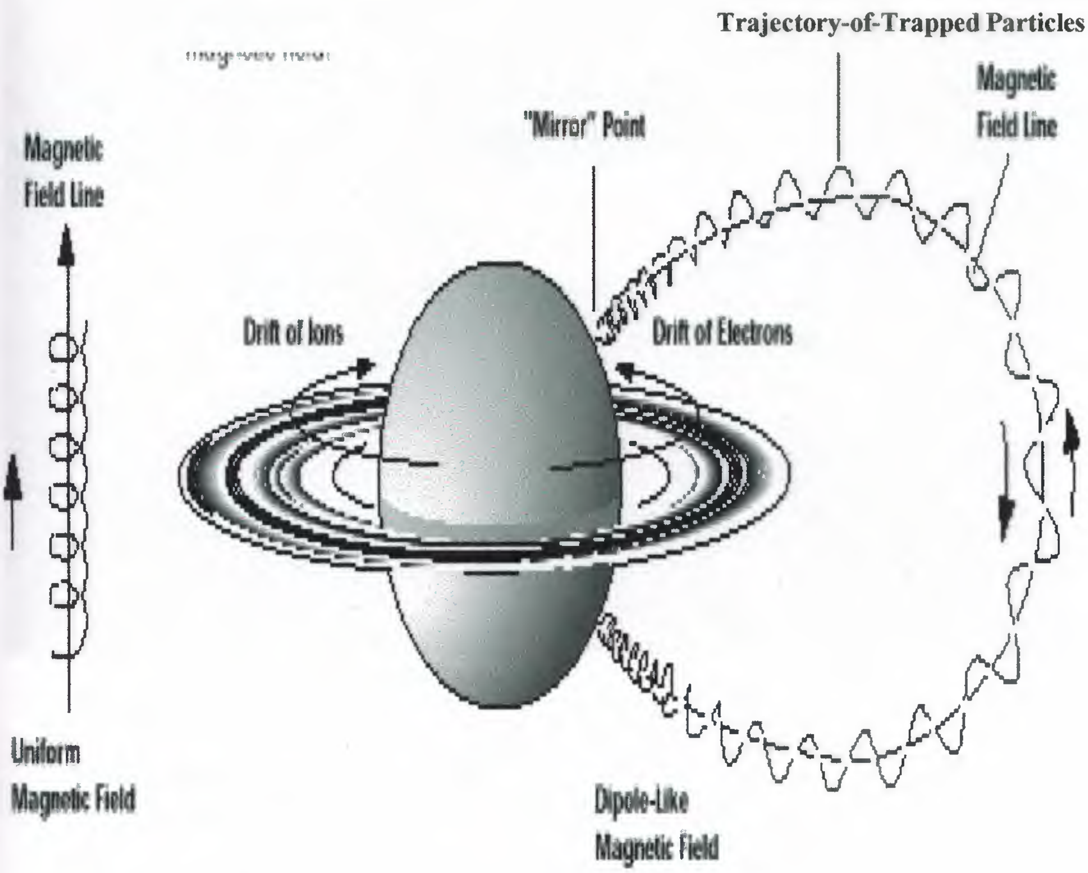


Fig.2.8 shows charged particle orbits

Energetic neutral imaging energetic neutral imaging Simulation of an Energetic neutral atoms(ENA) image of the type that will be obtained by Cassini's Magnetospheric Imaging Instrument. The Saturn magnetosphere appears close to the center of the image and Titan is on the left.

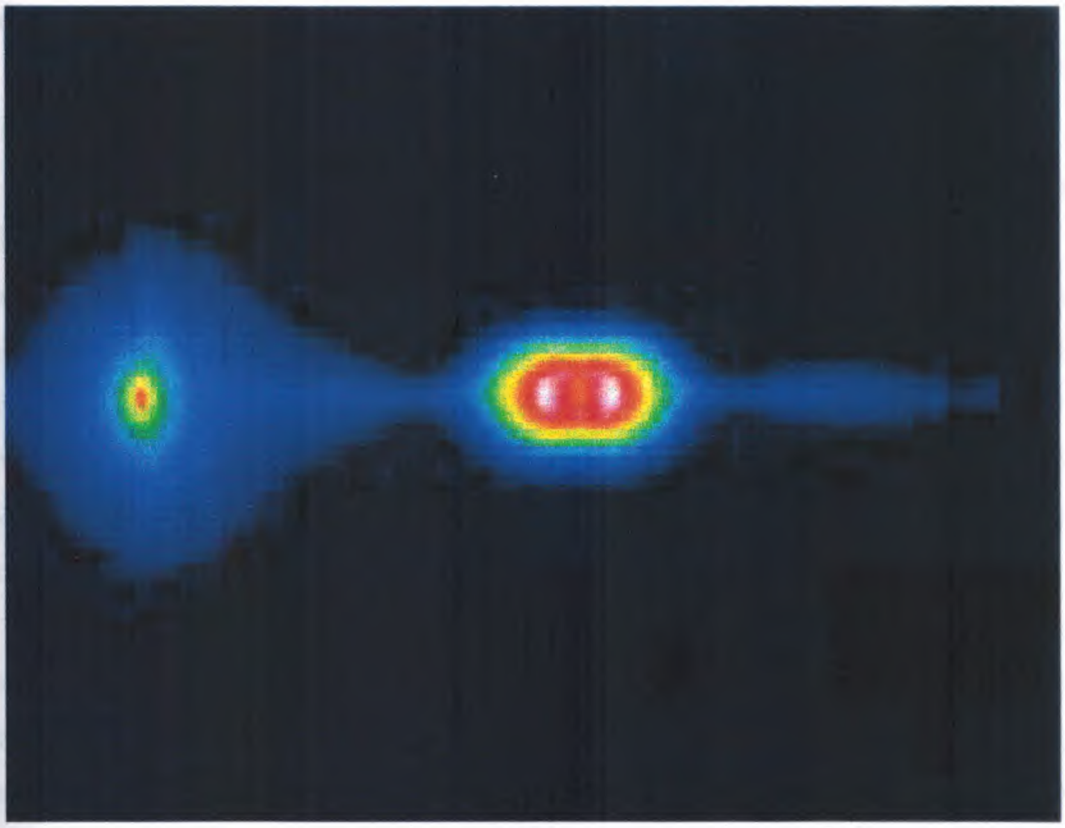


Fig.2.9 shows simulation of an energetic neutral atoms

Saturn Kilometric Radiation. For about 20 years prior to the Voyager visits to Saturn, radio astronomers had been searching for Saturn's radio emissions. We now know that Saturn is a much weaker radio source than Jupiter. Confirmation of radio emissions from Saturn came only when Voyager 1 approached within three astronomical units of the planet.

Saturn emits most strongly at kilometric wavelengths. Like the radio emission of other planets, Saturn kilometric radiation (SKR) comes from the auroral regions of both hemispheres and the radio beams are fixed in Saturn's local time. However, the emitting regions are on the night side for Earth and on the dayside for Saturn. The emission appears to come from localized sources near the poles one in the north and one in the south that "light up" only when they reach a certain range of local times near Saturn's noon.

The periodicity of these emissions is about 10 hours, 39 minutes, assumed to be the rotation rate of Saturn's conducting core.

This is somewhat longer than the atmospheric rotation rate of 10 hours, 10 minutes observed at the cloud tops near the equator. The periodicity in SKR emission is unexpected for planet with such a symmetrical magnetic field. Possibly, magnetic anomaly exists that allows energetic electrons to penetrate further down into the polar region (at some point) and the SKR radiation is generated at the electron's natural frequency f oscillation. Based on the local time of emission, the source energy for the SKR appears to be the supersonic solar wind and, in fact, changes in the solar wind strongly control the SKR power.

For example, a solar wind pressure increase by a factor of about 100 results in an increase by a factor of about 10 in the SKR power. For a period of about two to three days following the Voyager 2 encounter, no SKR emission was detected. It is thought that since Saturn was immersed in Jupiter's long magneto-tail at this time, the planet's magneto-sphere was shielded from the solar wind. One of the main objectives of the Radio and Plasma Wave Science instrument aboard Cassini is to make measurements of the SKR, study its variation with variations in the solar wind and map the source region.

2.17 The Fourth State Of Matter

Plasma is the fourth state of matter. A plasma is an ionized gas containing negatively charged electrons and positively charged ions of a single or many species; it may also contain neutral particles of various species. Examples are the Sun, the supersonic solar wind, Earth's ionosphere and the interstellar material. Plasmas behave differently from neutral gases; the charged particles interact with each other elector-magnetically and with any electric and magnetic fields present.

The charged particles also create and modify the electric and magnetic fields. In a highly conducting plasma, the magnetic field lines move with (are "frozen to") the plasmas. The X-ray image here shows a million-degree plasma, the solar corona, which is the source of the supersonic solar wind plasma that pervades the solar system. [Image from the Yohkoh satellite].

Fig.2.10 shows the fourth state of matter

2.18 Other Magnetospheric Emissions

We are all familiar with waves in a vacuum (electromagnetic waves) and waves in a gas and fluid (electromagnetic waves, sound waves, gravity waves). A magnetized plasma supports all these waves and more. Because of the electromagnetic interactions between charged plasma particles and the magnetic field, new types of waves can propagate that have no counterpart in a neutral gas or fluid. Waves in the magnetosphere can be produced via various Processes, for example by ionization of atmospheric neutral atoms in the magnetospheric plasma or by currents flowing between different plasma populations.

These waves, as well as other types of waves (Alfvén waves, magnetosonic waves and ion and electron cyclotron waves, to name a few) can propagate in a plasma and be detected by sensors such as the magnetic and electrical antennas of Cassini's Radio and Plasma Wave Science instrument.

These waves are trapped within the magnetosphere and thus can only be sampled inside it.

Saturn produces a variety of radio and plasma wave emissions from narrow (single frequency) and bursty to broadband (several frequencies) and continuous. The primary goal of the RPWS instrument is to study these wave emissions. As mentioned, neutral atoms from various sources supply Saturn with magnetospheric plasma. As they do, they leave a "signature" in the plasma waves that can be used to determine their species.

Emissions in magnetospheres are waves of the plasma driven to large amplitudes by magnetospheric processes that tap some reserve of free energy. There are many modes, interactions and energy reserves; the emissions are studied to help discover the interactions and energy sources driving them.

2.19 Free Energy Sources.

We have seen how energetic particles from the solar wind are one source of energy. Both non uniform and non thermal plasma distributions represent additional sources of free energy.

Generally, waves that grow at the expense of a non thermal or non uniform feature interact back on the plasma distribution to try to eliminate the non uniform or non thermal feature. For example, the Pioneer 11 magnetometer saw low frequency waves associated with Dione; these have been interpreted as ion cyclotron waves, apparently resonant with oxygen ions.

These waves were probably generated by newly born oxygen ions, created from Dione's ice as a sputtering product, interacting with the corotating magnetosphere plasma and tapping the energy in the plasma rotation. The waves generated by these new ions then act to thermalize their highly nonthermal distribution.

A modulation of the radio emission was also associated with the orbital phase of Dione, raising the possibility that Dione is venting gases. Plasma waves can also scatter particles into orbits, taking them down into the upper atmosphere, where they drive auroral processes. Although the RPWS instrument is the primary detector of plasma waves, the causes and effects of the plasma waves are seen in measurements by Cassini's other MAPS instruments and coordinated observations of wave phenomena will be important in understanding the sources and sinks of magnetospheric plasma and dynamic processes in general.

Atmospheric Lightning. Lightning in Saturn's atmosphere is thought to cause the unusual emissions designated Saturn electrostatic discharges (SED). These are short, broadband bursts of emission apparently coming from very localized regions (presumably atmospheric storms).

It was determined that the source acts like a searchlight and is not fixed relative to the Sun, as is the case for SKR emissions. A 10 hours, 10 minutes periodicity was seen in the emissions by Voyager 1, quite different from the10 hours, 39 minutes periodicity of the SKR emissions.

2.20 Those Surprising Spokes

The "spokes" in Saturn'srings were first seen from Earth, but Voyager observations allowed the first studyof how these surprising features evolve. The spokes are cloud like distributions of micrometer sized particles that occasionally appear in the region from approximately1.75 R_S to 1.9 R_S .

Voyager saw spokes form radially over thousands of kilometers in less than five minutes. Subsequent Keplerian motion (motion due to gravity) changes these spokes into "wedges." The images shown here form a time sequence from upper left to lower right. Most likely, these non radial features result from interactions of tiny charged ring dust particles with the electromagnetic fields and or charged particles in the magnetosphere.

Moreover, the spokes occur preferentially at the same longitude and the same periodicity as the Saturn kilometric radiation, albeit at different local times, suggesting a relationship to the magnetic anomaly. Cassini's MAPS and imaging instruments will make coordinated studies of the formation and evolution of the spokes.

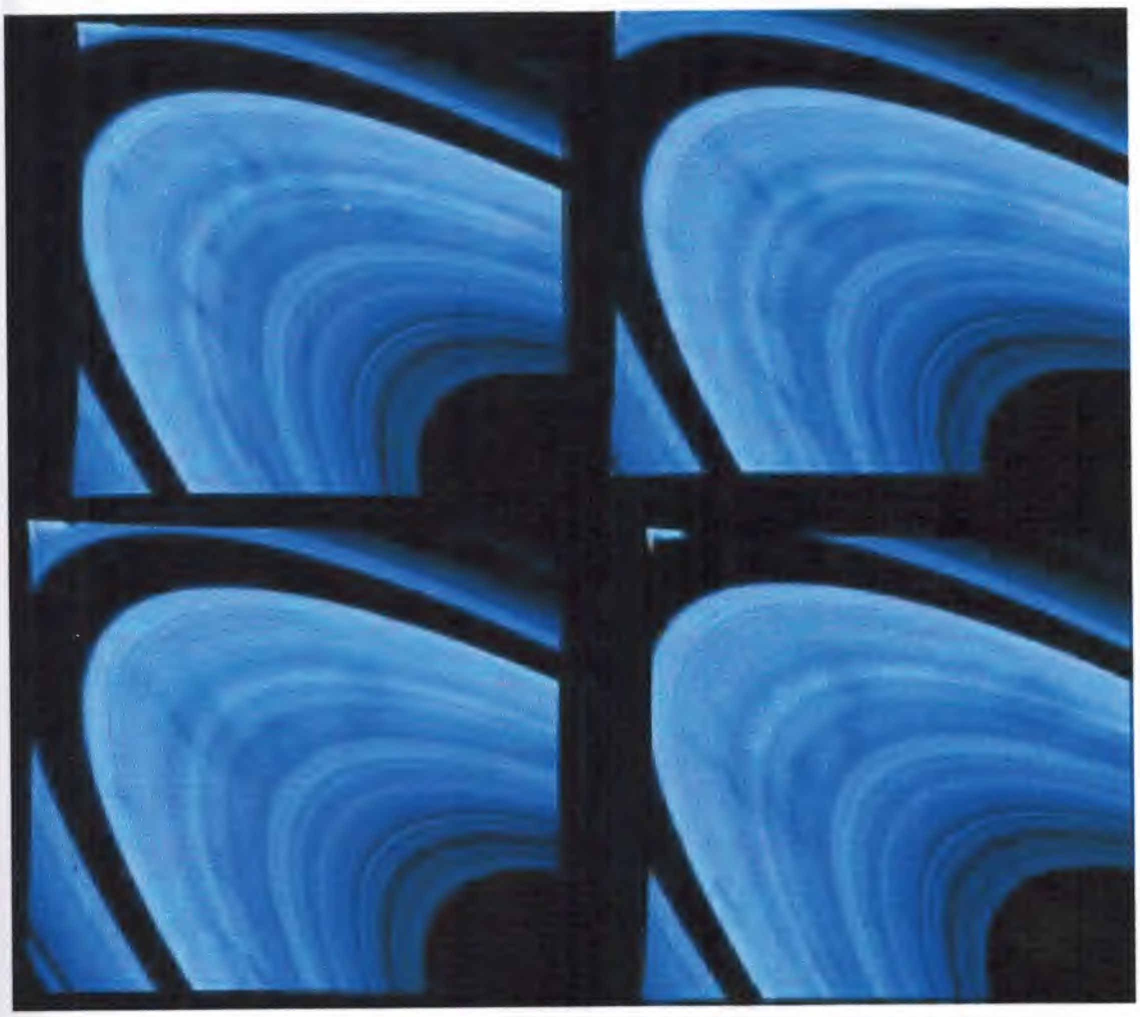


Fig.2.11 shows surprising spokes

2.21 CASSINI'S MAPS INSTRUMENTS

From Voyager imaging results, the rotational period of the equatorial cloud tops had also been measured at 10 hours, 10 minutes, consistent with the interpretation of the source as lightning. Cassini will further investigate the nature of these bursts, which give potential in-sight into Saturn's atmospheric processes, the planet's "weather." The Cassini RPWS instrument will make measurements of SKR emissions, electromagnetic emissions from lightning and SED as well. Measurements by the Cassini MAPS instruments will enhance an understanding of Saturn's complex and fascinating magnetosphere.

CASSINI'S MAPS INSTRUMENTS

Instrument	Objective
Cassini Plasma Spectrometer	Measures composition, density, velocity and temperature of ions and electrons
Cosmic Dust Analyzer	Measures flux, velocity, charge, mass and composition of dust and ice particles from 10^{-16}–10^{-6} grams
Dual Technique Magnetometer	Measures the direction and strength of the magnetic field
Ion and Neutral Mass Spectrometer	Measures neutral species and low-energy ions
Magnetospheric Imaging Instrument	Images Saturn's magnetosphere using energetic neutral atoms, and measures the composition, charge state and energy distribution of energetic ions and electrons
Radio and Plasma Wave Science	Measures wave emissions as well as electron density and temperature
Radio Science Instrument	Measures the density of Saturn's ionosphere
Ultraviolet Imaging Spectrograph	Measures ultraviolet emissions to determine sources of plasma in Saturn's magnetosphere

Fig.2.12 CASSINI'S MAPS INSTRUMENTS

CHAPTER THREE

THEORY OF ATMOSPHERE

3.1 Atmosphere

It is mixture of gases surrounding any celestial object (such as the Earth) that has a gravitational field strong enough to prevent the gases from escaping. The principal constituents of the atmosphere of the Earth are nitrogen (78 per cent) and oxygen (2 1 per cent). The atmospheric gases in the remaining1 per cent are argon (0.9 per cent), carbon dioxide (0.03 per cent), varying amounts of water vapors. and trace amounts of hydrogen, ozone, methane, Carbon monoxide, helium, neon, krypton, and xenon.

The mixture of gases in the air today has had 4.5 billion years in which to evolve. The earliest atmosphere must have consisted of volcanic emanations alone. Gases that erupt from volcanoes today, however, are mostly a mixture of water vapors, carbon dioxide, sulphur dioxide, and nitrogen, with almost no oxygen. If this were the same mixture that existed in the early atmosphere, then various processes would have had to operate to produce the mixture we have today. One of these processes was condensation. As it cooled, much of the volcanic water vapors condensed to fill the earliest oceans. Chemical reactions would also have occurred. Some carbon dioxide would have reacted with the rocks of the Earths crust to form carbonate minerals, and some would have become dissolved in the new oceans. Later, as primitive life capable of photosynthesis evolved in the oceans, new marine organisms began producing oxygen. Almost all the free oxygen in the air today is believed to have formed by photosynthetic combination of carbon dioxide with water. About 570 million years ago, the oxygen content of the atmosphere and oceans became high enough to permit marine life capable of respiration. Later, some 400 million years ago, the atmosphere contained enough oxygen for the evolution of air breathing land animals.

The water-vapors content of the air varies considerably, depending on the temperature and relative humidity. With 100 per cent relative humidity the water-vapors content of air varies from 190 parts per million (ppm) at -40° C (400 F) to 42,000 ppm at 30° C (86° F). Minute quantities of other gases, such as ammonia, hydrogen sulphide, and oxides of sulphur and nitrogen, are temporary constituents of the atmosphere in the vicinity of volcanoes and are washed out of the air by rain or snow. Oxides and other pollutants added to the atmosphere by factories and vehicles have become a major concern, however, because of their damaging effects in the form of acid rain, in addition the strong possibility exists that the steady increase in atmospheric carbon dioxide, mainly as the result of' fossil-fuel combustion over the past century, may affect the Earth's climate through the process known as the greenhouse effect.

Similar concerns are posed by the sharp increase in atmospheric methane. Methane levels have risen Ii per cent since 1978. About 80 per cent of the gas is produced by decomposition in rice paddies, swamps, and the intestines of grazing animals, and by tropical termites. Besides adding to the greenhouse effect, methane reduces the volume of atmospheric hydroxyl ions, thereby impairing the atmosphere's ability to cleanse itself of pollutants.

The study of air samples shows that up to at least 88 km *(55* mi) above sea level the composition of the atmosphere is substantially the same as at ground I eve I; the continuous stirring produced by atmospheric currents counteracts the tendency of the heavier gases to settle below the lighter ones. In the lower atmosphere, ozone, a form of oxygen with three atoms in each molecule, is normally present in extremely low concentrations.

The layer of atmosphere from 19 to 48 km (12 to 30 mi) up contains more ozone, produced by the action of ultraviolet radiation from the Sun. Even in this layer, however, the percentage of ozone is only 0.001 by volume, Atmospheric disturbances and down drafts carry varying amounts of this ozone to the surface of the Earth. Human activity adds to ozone in the lower atmosphere, where it becomes a pollutant that can cause extensive crop damage.

The ozone layer became a subject of concern in the early 1970s when it was found that chemicals known as chlorofluorocarbons (CFCs), or chlorofluoronicthanes, were rising into the atmosphere in large quantities because of their use as refrigerants and as propellants in aerosol dispensers. The concern centered on the possibility that these compounds, through the action of sunlight, could photochemical attack and destroys stratospheric ozone, which protects the Earth's surface from excessive ultraviolet radiation.

As a result, industries in industrialized countries have replaced chlorofluorocarbons in all but essential uses. Results of subsequent atmospheric studies are inconclusive about the actual threat to the ozone layer by human activities.

The atmosphere may be divided into several layers. in the lowest one, the troposphere, the temperature as a rule decreases upwards at the rate of $5.5^{O}C$ per 1,000 m ($30^{0}F$ per 1,000 ft) This is the layer in which most clouds occur. The troposphere extends up to about 16 km (10 mi) in tropical regions (to a temperature of about. -79^{0} C, or -110^{0} and to about 92 km (6 mi) in temperate latitudes (to a temperature of about -51° C, or $60^{0}F$). Above the troposphere is the stratosphere. In the lower stratosphere the temperature is practically constant or increases slightly with altitude, especially over tropical regions. Within the ozone layer the temperature rises more rapidly, and the kniperalure at the upper boundary of the stratosphere, almost 50 km (30 nil) above sea level is about the same as the lenIperature at the surface of the Earth. The layer from 50 to 80 km *(30* to 5Omi), called the mesosphere, is characterized by a marked crease in temperature as the altitude increases.

From investigations of the propagation and reflection of radio waves, it is known that beginning at an altitude of 80 km (50 mi)5 ultraviolet radiation, X-rays, and showers of electrons from the Sun ionize several layers of the atmosphere, causing them to conduct electricity; these layers reflect radio waves of certain frequencies hack to Earth. Because of the relatively high concentration of ions in the air above 80 km (50 mi), this layer, extending to an attitude of 640 kin (400 mi)5 is called the ionosphere. It is also termed the thermosphere, because of the high temperatures in this layer (rising to about 2,200^{0}F, or 1 ,200^{0}C at about 400 km/250 nil). The region beyond the ionosphere is called the exosphere, which extends to about 9,600 km (6,000 ml), the Outer limit of the atmosphere.

The density of dry air at sea level is about 1/800 the density of water; at higher altitudes it decreases rapidly, being proportional to the pressure and inversely proportional to the temperature. Pressure is measured by a barometer and is expressed in torrs, which are related to the height of a column of mercury that the air pressure will support; I torr equals 1 mm (0:03 9 in) of mercury. Normal atmospheric pressure at sea level is 760 tons, that is. 760 mm (29.92 in) of mercury. At about 5.6 km (3.5 mi) it is 380 torrs (14.96 in); half of all the air in the atmosphere lies below this level. The pressure is again approximately halved for each additional increase of 5.6 km in altitude. At 80 km (50 mi) die pressure is 0.007 torr (0.00027 in).

The troposphere and most of the stratosphere can be explored directly by means of sounding balloons equipped with instruments to measure the pressure and temperature of the air and with a radio transmitter to send the data to a receiving station at the ground. Rockets carrying radios that transmit meteorological instrument readings have explored the atmosphere to altitudes above 400 km (250 mi). Stud of the term and spectrum of the aurora gives information to a height possibly as great as 800 km *(500* mi).

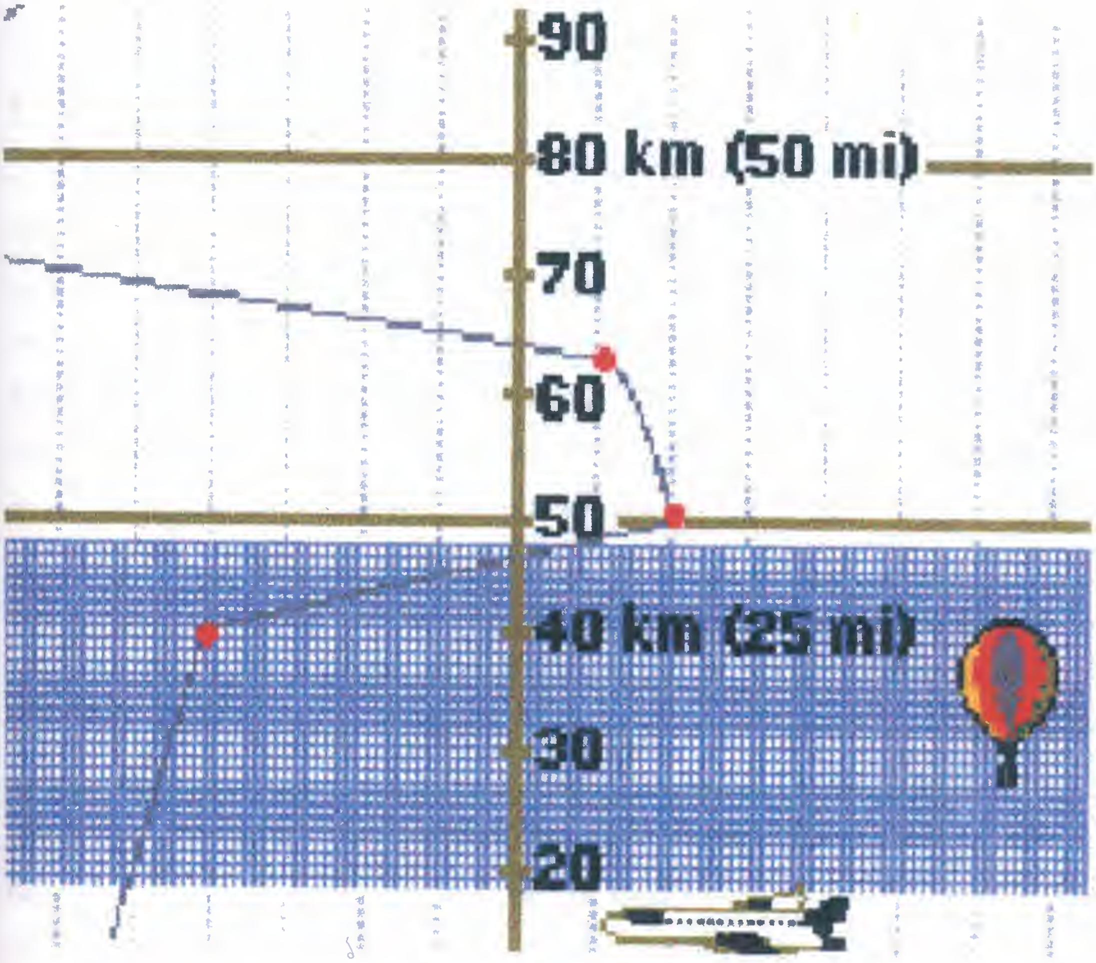


Fig.3.1 show investigations of the propagation and reflection of radio waves

3.1.1 Divisions of the Atmosphere

Without our atmosphere, there would be no life on earth. A relatively thin envelope, the atmosphere consists of layers of gases that support life and provide protection from harmful radiation.

3.1.2 Stratosphere

Upper layer of the atmosphere commencing at an altitude of 12.9 to 19,3 km (8 to 12 ml) and extending upwards to almost 50 km (30 ml). in the lower portion of the stratosphere, the temperature remains nearly constant with height, but in the upper portion it increases rapidly with height because of absorption of sunlight by ozone. The stratosphere is almost completely free of clouds or other forms of weather.

3.2 ionization

The formation of electrically charged atoms or molecules is called ionization. Atoms are electrically neutral; the electrons that bear the negative charge are equal in number to die protons in the nucleus bearing the positive charge. When sodium combines with chlorine, for example, to form sodium chloride, each sodium atom transfers an electron to a chlorine atom, thus forming a sodium ion with a positive charge and a chloride ion with a negative charge. In a crystal of sodium chloride the strong electrostatic attraction between ions of opposite charge holds the ions firmly in place and close together in an ionic bond. When sodium chloride is melted, the ions tend to dissociate because of their thermal motion and can move about freely. If two electrodes are placed in molten sodium chloride and an electrical potential is applied, the sodium ions migrate to the negative electrode and the chloride ions migrate to the positive electrode, causing a current of electricity to flow. When sodium chloride is dissolved in water, the ions are even freer to dissociate (because of the attraction between the ions and the solvent), and the solution is an excellent conductor of electricity. Solutions of most inorganic acids, bases, and salts conduct electricity and are called electrolytes; solutions of sugar, alcohol, glycerin, and most other organic substances are poor conductors of electricity and are called non electrolytes.

Electrolytes that give strongly conducting solutions are called strong electrolytes (for example, nitric acid, sodium chloride); electrolytes (hat give weakly conducting solutions are called weak electrolytes (for example, mercury (II) chloride, ethanoic acid).

3.2.1 Research

The Swedish chemist Svante August Arrhenius was the first to recognize that substances in solution are in the form of ions and not molecules, even when no electrical potential is applied. In the 1.880s he stated the hypothesis that when an electrolyte goes into solution it is only partly dissociated into separate ions5 and that the amount of dissociation depends on the nature of the electrolyte and the concentration of the solution.

Thus, according to the Arrhenius theory. when a given quantity of sodium chloride is dissolved in a large amount of water; the ions dissociate to a greater degree than when the same quantity is dissolved in less water. A different theory of tile dissociation of electrolytes, developed by the Dutch physicist Peter .Debve has been generally accepted since 1923. The so-called Debye-Huckel theory assumes that electrolytes are completely dissociated in solution.

The tendency of ions to migrate and thus conduct electricity is retarded by the electrostatic attraction between the oppositely charged ions and between the ions and the solvent. As the concentration of the solution is increased, this retarding effect is increased. Thus, according to this theory, a fixed amount of sodium chloride is a better conductor when dissolved in a large amount of water than when dissolved in a smaller amount, because the ions are farther apart and exert less attraction upon one another and upon. the solvent molecules.

The ions are not infinitely free to migrate, however. The dielectric constant of the solvent is also important in the conductance of a solution ionization is most marked in a solvent such as water, with a high dielectric constant.

3.2.2 ionization in Gases

When a rapidly moving particle, such as an electron, an alpha particle, or a photon, collides with a gas atom, an electron is ejected from the atom, leaving a charged ion. The ions render the gas conductive. The amount of energy necessary to remove an electron from an atom is called the ionization energy. The principle of ionization of gases by various types of radiation is used in the detection and measurement of radiation and in the separation and analysis of isotopes in the mass spectrometer. The atmosphere always contains ions dial are produced by ultraviolet light and cosmic radiation.

A gas that is composed of nearly equal numbers of negative and positive ions is called plasma. The atmospheres of most stars, the gas within the glass tubing of neon advcrtistn2 signs, and. the gases of the upper atmosphere of the Earth are examples of plasmas. A gas becomes plasma when the kinetic energy of time gas particles rises to equal the ionization energy of the gas. When this level is reached, collisions of the gas particles cause a rapid cascading ionization, resulting in plasma. If the necessary energy is provided by heat, the threshold temperature is from 50,000 to 100,000 K and the temperatures for maintaining a plasma range up to hundreds of millions of degrees. Another way of changing a gas into plasma is to pass high-energy electrons through the gas. Nuclear physicists believe that plasma contained within a. closed magnetic field will enable them to harness the vast energy of thermonuclear fusion for peaceful purposes. In the conceptual stage is a plasma-driven rocket motor for propelling vehicles in deep space.

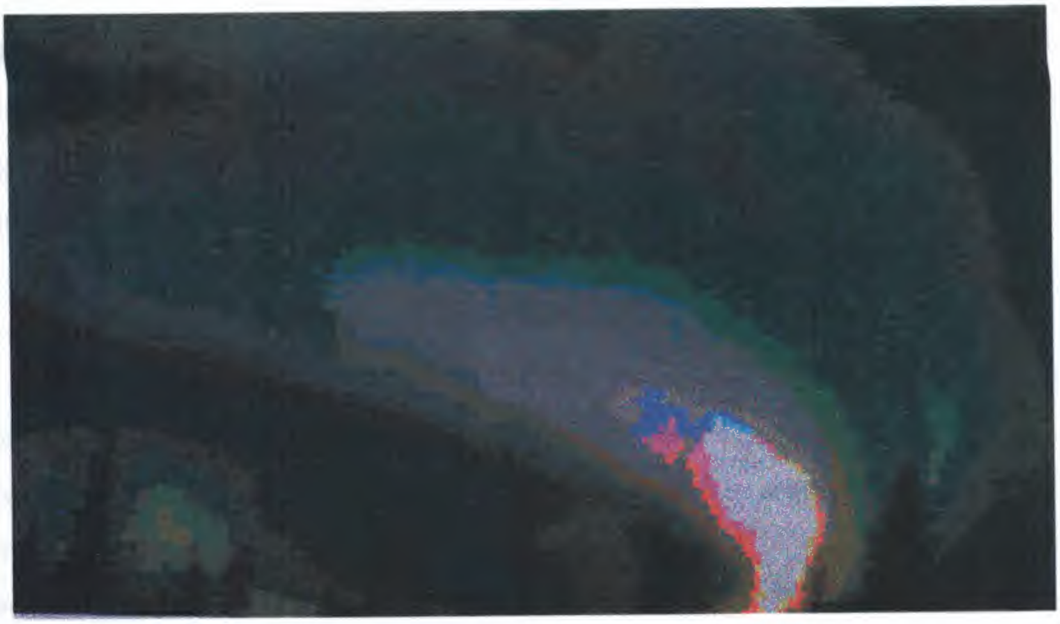
3.3 Aurora

It is high-altitude luminosity occurring most frequently above 60° north or south latitude, but also in other parts of the world. It is named specifically, according to its location, aurora borealis (northern lights) or aurora austral is (southern lights). The term aurora Polaris, polar lights, is a general name for both.

The aurora consists of rapidly shilling patches and dancing columns of light of various hues. Extensive auroral displays are accompanied by disturbances in terrestrial, magnetism and interference with radio, telephone, and telegraph transmission. The periods of maximum and minimum it intensity of the aurora coincide almost exactly with those of the sunspot cycle, which is an 11-year cycle Studies made during and after the 1 957-] *958* International Geophysical Year indicate that the aurora glow is triggered when the solar wind, which permeates the solar system, is enhanced by an influx of high-energy atomic particles emanating from sunspots.

The electrons and protons penetrate the magnetosphere of the Earth and enter the lower Van Allen radiation belt, overloading it. The excess electrons and protons are discharged into the atmosphere over an area centering on the north and south magnetic poles and extending about 200 from them. These particles then collide with gas molecules in the atmosphere, thereby exciting the molecules and causing luminescence, the emission of visible light.

The aurora assumes an endless variety of forms, including: the aurora arch, a luminous arc lying across the magnetic meridian; the aurora band, generally broader and much more irregular than the arch; filaments and streamers at right angles to the arch or band; the corona, a luminous circle near the zenith; aurora clouds, indistinct nebulous masses that may occur in any part of the heavens; the aurora glow, a luminous appearance high in the sky, the filaments converging towards the zenith; and curtains, fans, or streamers of various shapes. Auroras have also been observed in the atmospheres of other planets, notably Jupiter.



Figures.3.3 show aurora borealis, or Northern lights

3.3.1 Aurora Borealis, or Northern Lights

The effects of solar activity on the Earth's magnetosphere often become apparent as aurora, luminous displays in the upper atmosphere. Aurora often occurs in phase with the most active parts of sunspot cycles. They typically occur above the Earth's polar regions when the magnetosphere is temporarily deformed by the solar wind. Charged particles that originally came from the sun spill over from the Van Allen belts and interact with gases in the Earth's atmosphere. Excited gas molecules give off light, often in the red and green part of the spectrum. This display of multiple aurora hands was photographed in Fairbanks, Alaska.

3.4 Cosmic Rays

These are high-energy sub atomic particles arriving from outer space. They were discovered when the electrical conductivity of the Earth's atmosphere was traced to ionization caused by energetic radiation. The Austrian-American physicist Victor Franz Hess showed in 1911-1912 that atmospheric ionization increases with altitude, and he concluded that the radiation must have been coming from outer space. The discovery that the intensity of the radiation depends on latitude implied that the particles composing the radiation are electrically charged and are deflected by the Earth's magnetic field.

3.4.1 Properties

The three key properties of a cosmic-ray particle are its electric its rest mass, and its energy. The energy depends on the rest mass velocity. Each method of detecting cosmic rays yields information a specific combination of these properties. For example, the track left by a cosmic ray in a photographic emulsion depends on its charge and its velocity: an ionization spectrometer determines its energy. Detectors are used in appropriate combinations on high-altitude balloons or on spacecraft (to get outside the atmosphere) to determine, for each charge and mass of cosmic-ray particle, the numbers arriving at various energies. About 87 per cent of cosmic rays arc protons (hydrogen nuclei), and about 12 per cent are alpha particles. Heavier elements are also present, but in greatly reduced numbers.

For convenience, scientists divide the elements into light (lithium, beryllium, and boron), medium (carbon, nitrogen, oxygen, and fluorine), and heavy (The remainder of the elements). The light elements compose 0.25 per cent of cosmic rays. Because the light elements constitute only about I billionth of all matter in the universe, it is believed that light-element cosmic rays are termed by the fragmentation. of heavier cosmic rays that collide with protons, as they must do in traversing interstellar space.

From the abundance of light elements in cosmic. rays, it is inferred that cosmic rays have passed through material equivalent to a layer of water 4 cm (about 1.5 in) thick. The medium elements are increased by a factor of about 10 and the heavy elements by a factor of about 100 over normal matter, suggesting that at least the initial stages of acceleration to the observed energies occur in regions enriched in heavy elements.

Energies of cosmic-ray particles are measured in units of giga-electron volts (billion electron volts, Gev) per proton. or neutron in the nucleus. The distribution of proton energies of cosmic rays peaks at *0.3* GeV, corresponding to a velocity two-thirds that of light; it falls towards higher energies, although particles up to $10^{11} GeV$ have been detected indirectly, through the showers of secondary particles created when they collide with atmospheric nuclei. About I electron volt of energy' per cubic centimeter of space is invested in cosmic rays in our galaxy, on average.

Even an extremely weak magnetic field deflects cosmic rays from straight-line paths: a field of 3×10^{-10} tesla, such as is believed to be present throughout interstellar space. is sufficient to force a 1-GeV proton to revolve in a circular path with a radius of 10^{-6} light year (10 million km). A 10^{11} GeV particle moves in a path with a radius of 10 light years, about the size of the Galaxy. So the interstellar magnetic field prevents cosmic rays from reaching the Earth directly from their points of origin, and the directions of arrival are is otropically distributed at even the highest energies.

In the 1950s. radio emission from the Milky Way, the plane of the Galaxy, was discovered and interpreted as synchrotron radiation from energetic electrons gyrating in interstellar magnetic fields. The intensity of the electron component of cosmic rays, about 1 per cent of the intensity of the protons at the same energy, agrees with the value inferred for interstellar space in general from the radio emission.

3.4.2 Source

The source of cosmic rays is still not certain. The Sun emits cosmic of low energy at the time of large solar flares, but these events are far too infrequent to account for the bulk of cosmic rays. If other stars are like the they are not adequate sources either.

Supernova explosions are responsible for at least the initial acceleration of a significant fraction of cosmic ray's, as the remnants of such explosions are powerful radio sources, implying the presence of energetic electrons. Such observations and the known rate of occurrence of supernovas suggest that adequate energy is available from this source to balance the energy of cosmic rays lost from the Galaxy, which is about 10^{34} joules per second. Supernovas are believed to be the sites at which the nuclei of heavy elements are formed; so it is understandable that the cosmic rays should be enriched in heavy elements if supernovas are cosmic ray sources.

Further acceleration is believed to occur in interstellar space as a result of the shock waves propagating there. No direct evidence exists that supernovas contribute significantly to cosmic rays.

Theory does suggest, however, that X-ray binaries such as Cygnus X-3 may be cosmic ray sources. In these systems, a normal star loses mass to a companion neutron star or black hole. Radio-astronomical studies of other galaxies show that they also contain energetic electrons. The nuclei of some galaxies are far more luminous than the Milky Way in radio waves, indicating that sources of energetic particles are located there. The physical mechanism producing these particles is not known. Cosmic rays are extremely energetic subatomic particles that travel through outer space at nearly the speed of light Scientists learn about deep space by studying galactic cosmic rays, which originate many light-years away (a light-year represents the distance light travels in one year). This photograph, taken in the late I940s with a special photographic emulsion called the Kodak NT4, records a collision of a cosmic-ray particle with a particle in the film. The cosmic-ray particle produced the track that starts at the top left corner of the photograph; this particle collided with a nucleus in the center of the photograph to create a spray of subatomic particles.

3.5 Plasma (physics)

It is a fluid made up of electrically charged atomic particles (ions and electrons)it has specific properties that make its behavior markedly that of other states of matter, such as gases. Matter as we see it around us consists of atoms, which are the building I solids, liquids, and gases. Plasma, often called the fourth state of matter, is termed when atoms, instead of being combined into more complex structures, are broken up into their main constituent parts. This happens in natural environments such as the stars, where the temperature is very high, greater than tens of thousands. or even millions, of degrees. The plasma state of matter is also of great importance to controlled nuclear fusion, which is a potential future energy source. the physical laws that govern plasmas are important both for understanding astrophysical phenomena and for controlling die generation and release of nuclear energy by fusion processes.

All atoms are made up of a nucleus, which carries a positive electric charge, surrounded. by electrons, which carry a negative electric charge. in plasma, some or all of the electrons are stripped off the atoms, so that it consists of positively charged ions (atomic nuclei surrounded by fewer electrons than is needed to compensate for their positive charge), and the electrons that have broken free of the atoms. Heating a collection of atoms to high temperatures generates plasmas. This makes the atoms move at high speeds, so that when they collide, electrons are stripped off the colliding atoms. Once a plasma is created, it can be maintained either by keeping the temperature very high or, if the temperature drops, by reducing the density (the number of ions and electrons per unit volume) so that further collisions, in which electrons and ions could recombine to form atoms again, are avoided. Most of the universe is made up of either very hot and dense plasma (in the interiors of stars) or cooler, rarefied plasma in space.

On Earth, the heat generated by electrical discharges in gases can also generate plasmas: for example, lightning strokes turn the air into very hot plasma, though only 11w a very short time. Another important plasma is the Earth's ionosphere, a layer of ions and electrons mixed with the neutral gases of the atmosphere, about 100 km (60 mi) above the Earth's surface. In the ionosphere, electrons are stripped from the atoms by the ultraviolet tight and X-rays emit led by the Sun.

The plasma state is different from other slates of matter because its constituents, the ions and electrons. are electrically charged. This means that they interact through the electric (Coulomb) force, which acts at long range, unlike the mechanical forces involved when electrically neutral atoms collide. Colliding atoms can be viewed as billiard balls interacting only when in contact with each other. Ions and electrons in plasma "sense" each other at large distances, compared to their sizes, so that each particle ion or electron is subjected to forces from a very large number of particles surrounding it. This makes plasma behave very differently from other states of matter fields play a significant, role in plasmas. They influence the motion of electrically charged particles by forcing them to gyrate around the magnetic lines of force. As a result, most properties of plasmas depend on e direction of the magnetic, field. See Magnetism.

In plasma the basic laws of physics, such as Newton's laws of motion. Faradays low of induction, and Ampere's law of magnetic induction, need to be combined in new ways to describe the phenomena that in it. For some of the phenomena, plasma behaves in accordance with laws that resemble those of ordinary fluid mechanics, but the presence of the magnetic field makes these laws more complex. Magnetohydrodynamics (MHD) is the branch of science that deals with these laws of plasma behavior. This treatment is applicable when the plasma has very high (in theory, infinite) electrical conductivity'. Ohm's law, which describes the relationship between currents and electric fields in ordinary electrical conductors, takes a new form in plasmas. When the conductivity becomes very large, MHD equations show that magnetic fields are "frozen into" the plasma. 'this means that magnetic fields and plasmas are forced to move together; the electric field in these circumstances is generated by the magnetic field moving with the plasma.

MHD equations and their solutions are used to describe and explain the properties of plasmas found in the atmospheres of stars (such as the solar corona). The properties of the solar wind (a fast-flowing plasma from the Sun) and of the Earth's magnetosphere are also explained using he MI-ID description of plasmas.

The MHD description of the plasma is no longer valid when the detailed behavior of particles that make up the plasma becomes important.

This happens when there are large changes in the properties of the plasma over small distances. as at the boundaries separating plasmas of different origin. For example, the physical processes that control the interaction between the solar wind and the Earth's magnetosphere take place in a thin boundary, the magnetopause. A full description of the interaction at the magnetopause needs to take into account the motion of particles in the presence of the magnetic field.

Waves play a special rote in plasmas because they provide the means for particles to interact with each other. Many different kinds of waves exist only in plasmas. Sound waves are modified in plasma, and are described as magneto acoustic waves, which have different propagation characteristics according to the direction of the magnetic field. Other wave modes also exist in plasmas related to the motion of the electrically charged particles.

It is the rich variety of waves that control the interaction of particles making up the plasma. Roughly speaking, the motions of particles cause the different waves, and these waves in turn affect the motions of particles. Interactions between the different waves and particles from the heart of the physics of plasmas Nuclear fusion, in which mass is converted to energy, can take place only in a hot and dense plasma. This is how stars, including the Sun, generate energy in their cores.

Thermonuclear weapons work on the same principle. The engineering challenge is to create the right conditions in plasma to produce controlled nuclear fusion. This has so far proved difficult because the temperatures needed are about 100 million degrees C (about 180 million degrees F), while the high density of the plasma needs to be maintained. Promising results have been obtained by using an experimental apparatus called a tokamak, in which the hot plasma is confined by very powerful magnetic fields. Other ways to create and confine the plasma needed for generating fusion energy, using very powerful lasers, are also being explored.

3.6 Solar system

It is the system consisting of the Sun; the nine planets and their satellites; the asteroids, comets, and meteoroids; and interplanetary dust and gas the dimensions of this system are specified in terms of the mean Earth to the Sun, called the astronomical unit (AU). One is 150 million km (about 93 million ml).

The most distant known planet, has an orbit at 39.44 AU from the Sun. The boundary between the solar system and interstellar space called the heliopause is estimated to 100 AU. The comets, however, achieve the greatest distance from in; they have highly eccentric orbits ranging out to 50,000 AU or more.

System is the only planetary system known to exist, although in the a number of relatively nearby stars were found to he encircled by of orbiting material of indeterminate size or to be accompanied by objects suspected to he brown dwarfs. Many astronomers think it likely that systems of Some sort are numerous throughout the universe.

3.6.1 The Sun and the Solar Wind

The Sun is a typical star, of intermediate size and luminosity. Sunlight and other radiation are produced by the conversion of hydrogen into helium in the Sun's hot, dense interior (see Nuclear Energy). Although this nuclear fusion is converting 600 million tonnes of hydrogen each second, the Sun is so massive (2 $x10^{27}$ tonnes) that. it can continue to shine at its present brightness for 6 billion years. This stability has allowed life to develop and survive on the Earth.

For the Sun's entire steadiness, it is an ex4remely active star. On its surface dark sunspots bounded b intense magnetic fields come and go in 11-year cycles; sudden bursts of charged particles from solar flares can cause auroras and disturb radio signals on the Earth:, and a continuous stream of protons, electrons, and ions leaves the Sun and moves out through the solar system, spiraling with the Sun's rotation. This solar wind shapes the ion tails of comets and leaves its traces in the lunar soil, samples of which were brought back from the Moon's surface by Apollo spacecraft.

3.6.2 Density Map of Solar Corona

A map of the Sun's outer atmosphere, the corona, shows different densities in the layers of hot gas that surround the Sun. Blue regions indicate the highest density; yellow highlights areas of lower density. The magnetic field of the Sun interacts with gas layers to cause the strange curves, streamers, and bumps observed here. The corona consists primarily of electrons and ionized atoms heated to temperatures of approximately2.2million^{o} C(4million^{o} F).

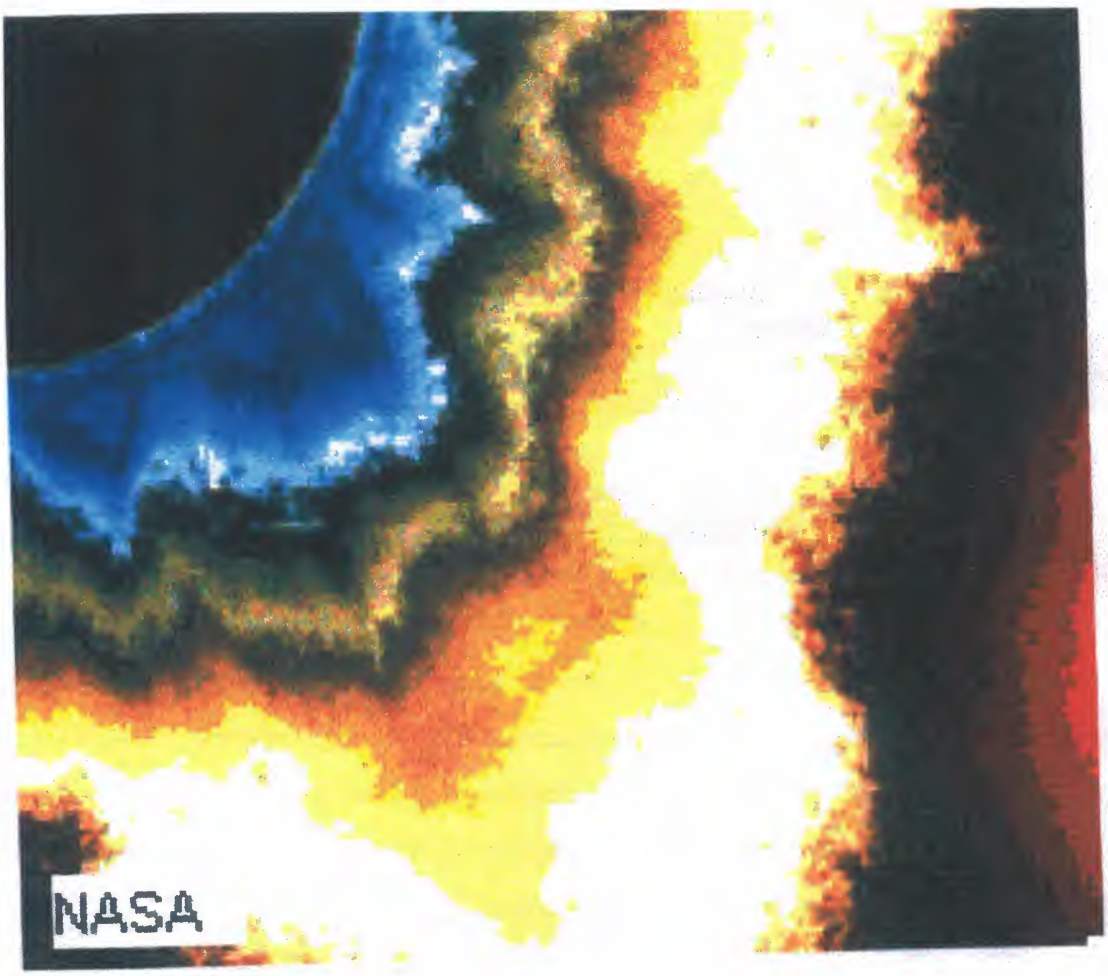


Fig.3.4 shown density map of solar corona

3.7 Magnetic Storm

Magnetic Storm, disturbance of the Earth's magnetic field that follows the arrival of energetic particles from the Sun, released during violent activity associated with coronal mass ejections or solar flares.

Such events are commonest in the years around sunspot maximum (the period of maximum activity in the 11-year sunspot cycle), and lead to stress on the Earth's magnetosphere. Release of this stress leads to acceleration of electrons into the tipper atmosphere, causing a. brightening and expansion of the aurorae. Major disturbances carry the aurora to much lower latitudes than normal. For example, the major auroral display of March 13-14, 1989.

was visible from the southern United States and the Mediterranean. During major magnetic storms, the horizontal component of the Earth's magnetic field at ground level shows rapid fluctuations, and a sensitive compass needle may wander markedly from its normal bearing. More precise measurements can be obtained with magnetometer equipment, which gauges horizontal and vertical field strength and direction. Ground-level electrical currents induced during magnetic storms have been cited as the cause of corrosion in oil and gas pipelines in Alaska and Siberia. Surges in the electrical grid system across the province of Quebec led to a nine hour blackout. affecting 6 million people, during the March 1989 event. Spacecraft such as the solar probe SOHO (launched in 1996) now make it possible to give earlier and more accurate warnings of impending magnetic storms.

However, currents flowing in the ionosphere between altitudes of 80 to 250 km (50 to 155 mi) pose a hazard to artificial satellites during magnetic storms, when build-up of charge on electrical components can cause damage. Two Canadian Anik communications satellites were damaged by magnetic storms activity in January 1994, for example. Ionospheric disturbances also disrupt short wave radio communication.

3.8 Materials of magnetic properties

The magnetic properties of materials are classified in a number of different ways. One classification of magnetic materials into diamagnetic, paramagnetic, and ferromagnetic is based on how the material reacts to a magnetic field.

3.8.1 Diamagnetic

Diamagnetic materials, when placed in a magnetic field, have a magnetic moment induced in them that opposes the direction of the magnetic field. This property is now understood to be a result of electric currents that are induced in individual atoms and molecules. These currents produce magnetic moments in opposition to the applied field. Many materials are diamagnetic; the strongest ones are metallic bismuth and organic molecules, such as benzene, that have a cyclic structure, enabling the easy establishment of electric currents.

3.8.1.1 Diamagnetism

It is a property of materials whereby they become weakly magnetized in the opposite direction to an applied magnetic field. A magnet weakly repels a diamagnetic material. The induced magnetism disappears when the applied held is removed. All materials show diamagnetism, but the term "diamagnetic" is applied only to those materials in which ills not masked by other types of magnetic effect.

3.8.2 Paramagnetic

Paramagnetic behavior results when the applied magnetic field lines up all the existing magnetic moments of the individual atoms or molecules that makes tip the material. This results in an overall magnetic moment that adds to the magnetic field. Paramagnetic materials usually contain transition metals or rare earth elements that possess unpaired electrons. Paramagnetism in non-metallic substances is usually characterized by temperature dependence; that is, the size of an induced magnetic moment vanes inversely with the temperature. This is a result of the increasing difficulty of ordering the magnetic moments of the individual atoms along the direction.

3.8.2.1 Paramagnetism

It is a property of materials whereby they become magnetized in the same direction as an applied magnetic field. A magnet attracts a paramagnetic material, The induced magnetism disappears when the applied field is removed.

3.8.3 Ferromagnetic

A ferromagnetic substance is one that like iron which retains a magnetic moment even when the external magnetic field is reduced to zero. This effect is a result of a strong interaction between the magnetic moments of the individual atoms or electrons in the magnetic substance that causes them to line up parallel to one another.

In ordinary circumstances ferromagnetic materials are divided into regions called domains; in each domain, the atomic moments are aligned parallel to one another. Separate domains have total moments that do not necessarily in the same direction. Thus, although an ordinary piece of iron might not have an overall magnetic moment, magnetization can be induced in it by placing the iron in a magnetic field, thereby aligning the moments of all the individual domains.

The energy expended in reorienting the domains from the magnetized back to the demagnetized state manifests itself in a lag in response, known as hysteresis. Ferromagnetic materials, when heated, eventually lose their magnetic properties. This loss becomes complete above the Curie temperature, named after the French physicist Pierre Curie, who discovered it in 1 895. The Curie temperature of metallic iron is about 770° C/1420° F.

3.8.3.1 Ferromagnetism

It is a property of certain materials whereby they become strongly magnetized in an external magnetic field, and retain some of their magnetization when that field is removed.

3.8.4 Example

Liquid oxygen becomes trapped in an electromagnet's magnetic field because oxygen (O_2) is paramagnetic. Oxygen has two unpaired electrons whose magnetic moments align with external magnetic field lines. When this occurs, the O_2 molecules them selves behave like tiny magnets, and become trapped between the poles of the electromagnet.

The induced magnetism disappears when the applied field is removed. AU materials show diamagnetism, but the term diamagnetic is applied only to those materials in which it is not masked by other types of magnetic effect.

3.8.5 Applications

Numerous applications of magnetism and of magnetic materials have arisen in the past 100 years. The electromagnet, for example, is the basis of the electric motor and the transformer in more recent times, the development of new magnetic materials has been important, in the computer revolution.

Computer memories can be fabricated using bubble domains, These domains are small regions of magnetization that are either parallel or antiparallel to the overall magnetization of the material.

Depending on this direction, the bubble indicates either a one or a zero, thus serving as a digit in the binary number system used in computers. Magnetic materials are also important constituents of tapes and disks on which data are stored. Large, powerful magnets are crucial to a variety of modem technologies. Magnetic levitation trains float above the tracks using strong magnets, so that there is no function with the tracks to slow the trains down. Powerful magnetic fields are used in nuclear magnetic resonance imaging, an important diagnostic tool used by doctors. Super conducting magnets are used in today's most powerful particle accelerators to keep the accelerated particles focused and moving in a curved path.

CHAPTER FOUR

USEFUL APPLICATIONS

4.1 Radio applications

4.1.1 Radio

It is a system of communication using electromagnetic waves propagated through space. Radio waves are used in wireless telegraphy, telephone transmission, television, radar, navigation systems, and space communication they are also used in radio broadcasting; the term "radio" is therefore most popularly applied to sound broadcasting in general.

4.1.2 Radio Frequencies

Because of their varying characteristics, radio waves of different lengths are employed for different purposes, and are usually identified by their frequency. The shortest waves have the highest frequency, or number of cycles per second; the longest waves have the lowest frequency, or fewest cycles per second. Heinrich Hertz's name has been given to the cycle per second (hertz, Hz), with 1 kilohertz (KHz) being 1,000 cycles per second, and 1 megahertz (MHz) being I million cycles per second. Low and medium frequencies (30 to 3,000 kHz are used by radio broadcasters transmitting on those parts of the spectrum traditionally described as long or medium wave, and most early transmissions in Europe and the United States were solely of this type.

Because electromagnetic waves in a uniform atmosphere travel in straight lines and because the Earth's surface is approximately spherical, long distance radio communication is made possible by the reflection of radio waves hurn the Earth's ionosphere. This allows programmers to be received both nationally and beyond national borders. However, these frequencies tend only to be able to use reflection from the ionosphere to bounce round the Earth's curvature under night time atmospheric conditions, thus creating the possibility of each radio station covering a much wider area, hut simultaneously contributing to increased interference between rival signals.

4.1.3 Short-Wave Radio

Short-wave radio uses higher frequencies (3 to 30 MHz) and shares the ability to (ravel long distances. in this case, however, transmitters can switch their precise frequency several times throughout the 24-hour period to take continuous advantage of die reflective properties of the ionosphere. The first short-wave transmitters of the 1930s opened up the prospect of much more controlled long-distance radio broadcasting, and the International Telecommunication Union has since allocated much of the short-wave spectrum for just such use.

Most remaining parts of the short-wave spectrum are used for amateur (ham) radio, and various marine, air, and mobile land services. The very shortest radio waves designated as very high, ultra-high, and super-high frequencies (VHF. UHF and SHF) are not reflected by the Earth's ionosphere, and their use is restricted to television, satellite transmissions by microwaves, or VHF radio stations, the last now more popularly described by the term "FM" radio.

4.2 Radar Applications

4.2.1 Radar

It is an electronic system, used to locate objects beyond the range of vision, and to determine their distance by projecting radio waves against them. The term radar is derived from the phrase "radio detection and ranging", and Allied forces used this name during world War 11 for a variety of devices concerned with radio detection and position finding. Such devices not only indicate the presence and range of a distant object, called the target, but also determine its position in space, its size and shape, and its velocity and direction of motion.

Although originally developed as an instrument of war, radar today is used extensively in many peacetime pursuits, such as navigation, controlling air traffic. Detecting weather patterns, and tracking spacecraft.

Fig. 4.1 show satellite radar image

4.2.2 Satellite Radar Image

Radar images obtained by satellites have a wide range of applications. Radar devices provide invaluable information to navigators and meteorologists on water currents and weather conditions. This satellite radar image shows Holland's Frisian isles surrounded by the North Sea.

4.2.3 Skywave Radar

Skywave (sw) radar makes use of scattering from the ionosphere to look down on a 'toot print' well beyond the horizon. The main application lie in detecting ballistic missile launches and tracking military and civilian air targets. Most skywave radars also have a significant capability for detecting surface targets and for sea sensing as shown in figures 4.2 below.

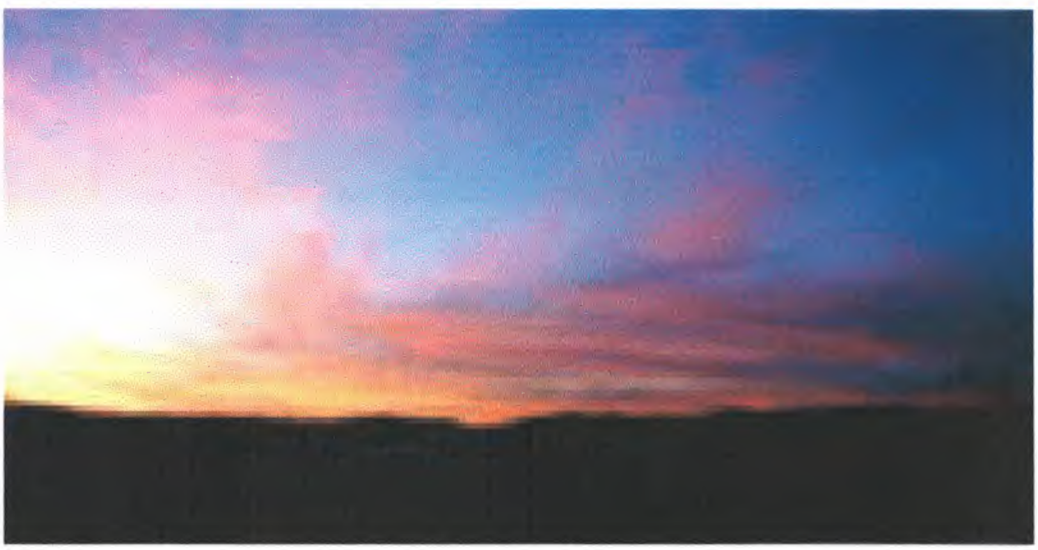
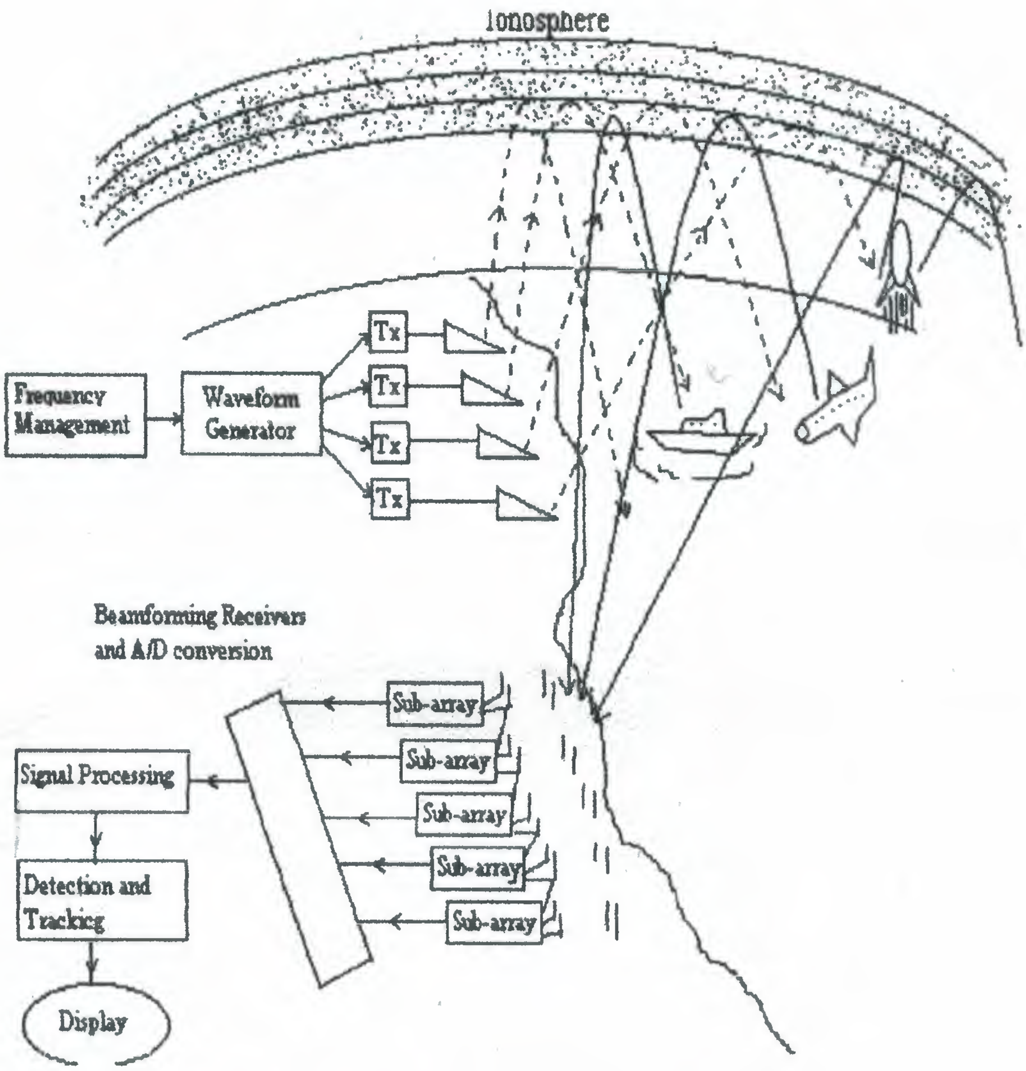


Fig 4.2 Show Skywave Radar

Fig 4.2 Show Skywave Radar



Typical skywave radar installation

Fig.4.2 show skywave radar

4.2.4 Propagation and Frequency management

The skywave radar engineer seeks to capitalize on these effects, particularly reflection, to look beyond the horizon. Of the three ionized regions in the ionosphere, D, E, and F only E and F regions turn out to be useful for sw radar, The flee electron content of the D region (70-90 Km altitude) is insufficient to scatter I IF radio waves and layer acts as an unwanted absorber of radio energy. This absorption occurs because the electrons, while trying to oscillate with the incident radio wave, Experiences many collisions with neutral air molecules.

The 13 region is a narrow layer of ionization at about 110 Km attitudes. The ionization is uneven, but can be very intense at times (owning to auroral effects and intense patches known as sporadic F), and it specially a daytime phenomena. The maximum Electro density of approximately 10^{11} [electrons m^{-3}] occurs near midday and corresponds to a critical frequency (called the f E) of 2.8 MHz, meaning that this is highest frequency that will be reflected at vertical incidence, Frequencies higher than f B pass straight through the E layer if traveling vertically hut can be scattered if they are transmitted at oblique incidence.

The answer to problems of using the ionosphere for OTH radar lies in the process known as frequency management. Extensive mathematical modeling and continuous observations of ionosphere are used to select the best frequency band and then wideband look ahead' or channel occupancy monitoring receivers are used to find, a channel free of interference.

Over the years, quite realistic mathematical models of the ionosphere have been constructed (as computer software) to include both local databases of observations over several solar cycles and maps of the mean ionosphere produced by the CCIR (International radio consultative committee), Statistically these models provide a good prediction of expected conditions. hut on any given day the vagaries of the ionosphere are such that the predictions can he substantially in error. These errors can be minimized by

Ionospheric. Sounding, which measures the current state of ionosphere as an aid to selecting the most appropriate model.. Occasionally, the part of the radar system it self is used for oblique sounding, hut it is more usual to use a vertical sounder or ionosonde, a small pulsed radar system that transmits upward and sweeps in frequency to locate the critical frequencies of B and F layers.

The most common form of display for sounding data is an ionogram, a plot of virtual height (not always equal to the real height because of the slowing of radio waves in ionosphere) against frequency as shown in fig 4.3. After some calculations fig 4.3 can be plotted as true height against, electron density to create a form suitable lbr ray tracing programs to predict where signal transmitted on any given frequency will end up. This is information needed by sw radars to choose best operating frequency.

There practical methods to ensuring that the frequency management program is working as predicted. The radar operator can ensure that easily recognized targets (cities. coastlines islands) are detected and appear in the correct locations. Also know targets and transponding devices can be placed within the coverage area to give the confidence in the terrain illumination and some feed hack on the ionospheric absorption.

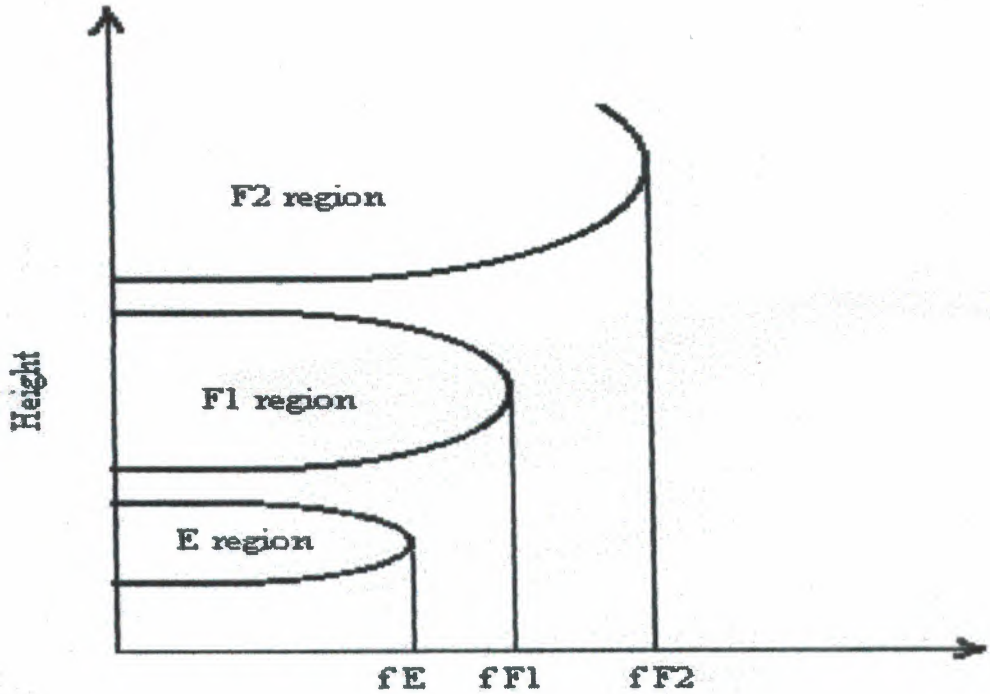


Fig.4.3 Show against frequency

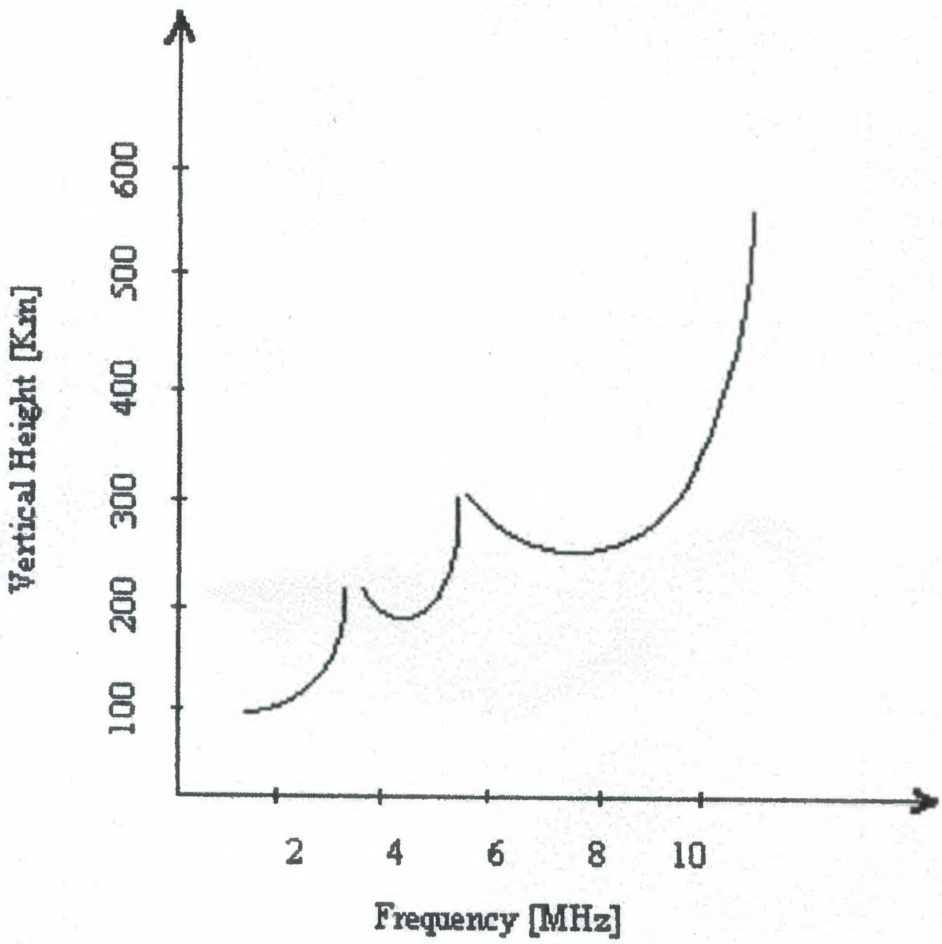


Fig.4.3 show against frequency

4.3 Comparison of Techniques for Derivation of Neutral Meridional Winds from Ionospheric Data

4.3.1 Determination of neutral meridional winds

The dates of the 34 Millstone Hill incoherent scatter radar experiments included in the present study are listed in table-1. The average daily magnetic index Ap and average 10.7 cm solar flux during the days of each experiment arc also givcn in the tablc. The data well represent the ionosphere above Millstone Hill (42.6° N, 288.5° E), as they include all levels of solar and geomagnetic. activity, season, and time of (lay. The experiments chosen for this study include profiles of electron density calibrated with a local Digisondc, and measurements of T_e,T_I and line of sight ion velocities in at least three directions so that the ion drift vector above the station can be determined.

These data are then used to calculate neutral winds from the field aligned component of the ion drift velocity (V) and a calculation of the O^+ diffusion velocity using the method described by Vasseur [1969], as implemented by Salah and Holt [1974], Buonsanto et al. [1989, 1990], Hagan [1993]. We refer to these winds as ISR winds. For most of the radar experiments horizontal gradients in the components of the ion drift vector are assumed to be zero.

This is called the no gradient method. However, for 4 experiments when data from 9 or 10 pointing positions were available, horizontal gradients could be determined using the constant gradient technique [Buonsanto and Holt, I 995]. When this technique gave a statistically better fit to the ion velocity data, the values of V derived from this method were used. While differences between the ISR winds and winds derived from hmF_2 on individual days occur due to our assumptions of uniform or zero gradients in the ion velocity field, these differences should average to near zero in a climatological study such as this.

We have recently found errors in the ISR line-of-sight velocities measured in experiments nm since March I992 using a new data acquisition system at Millstone Hill. These errors take the form of an offset typically 20 ms^{-1}, but varying from experiment to experiment. Work is continuing at Millstone H ill to correct this problem, hut in the meanwhile these data must he used with extreme caution in studies of winds and electric fields above the station. For the present study we have adjusted the line-of-sight velocity data for experiments run during this period by matching the derived JSR winds with winds from a coincident Fabry-Perot interferometer (FPI). Experiments without any coincident FPI data were excluded from the study. We also excluded two experiments where the velocity bias seemed to be varying during lb e experiment.

The ISR winds are calculated at different heights and interpolated to hmF_2, [or direct comparison with winds derived from the other techniques. Thus systematic offsets between ISR winds and winds calculated from hrnF2, associated with altitude variations of the meridional winds are avoided.

Servo model winds, as well as winds from the methods of Miller et al. [986], Richards [1991] and Titheridge [1995a] are calculated using Millstone Hill ISR hmF_2 and $V\perp_N$ measurements.

The MSIS-86 neutral atmosphere [Hedin, 1987] is used to obtain the atomic oxygen. molecular oxygen arid molecular nitrogen densities as well as the neutral temperature required by the FLIP model and the Titheridge [1995a] model, and needed to calculate the O^+ recombination rate, ion neutral diffusion coefficient and atomic oxygen scale height in the servo model. The servo model also requires T_e and T_i at hmF_2 as input;

these are obtained from ISR measurements. The O^+, O collision cross section recommended by Salah 11993] is used in the present study. This includes a multiplicative factor F= 1 .7 times the formula derived by Dalgarno [1964] and Banks [1966].

Some recent work supports a smaller value of F (=1.2-1.3 [Pesnell et al., I993 Reddy et al.,1994 Davis et al., 1995].

Use of the smaller cross section recommended by Pesnell et aI. results in significantly larger equatorward winds at night when diffusion is more important. However, it has similar effects on the ISR winds and winds derived from hinb, so the present results in which we compare winds lrom the different techniques are not affected sigriifican tly by the choice of *F.* For the same reason, uncertainties in the MSIS-86 atomic oxygen density do not affect our conclusions.

We illustrate this in figure 4.3 where we show *cfac*. The factor needed to multiply the servo model daytime and nighttime empirical constants c in order to bring the ISR and servo model winds into agreement, for the 10-day January 1993 campaign. The 10 days of data are binned in one-hour intervals and the niean values of the best *cfac* are shown vs. local solar lime. Local sunrise (solar zenith angle $\chi = 90^o$) is indicated with vertical dotted lines. Results are shown for the Salah cross section (labeled Salah *c/s*), and the Besnell et ai. cross section (labeled Pesnell *c/s*). The difference between the two curves is small and not deemed significant. The results do show a drop in *cfac* after sunrise, consistent with the results of Titheridge [1993, 1995 a,b]. as we discuss further below.

The fact that the differences between the ISP. Winds and winds derived from the servo model do not depend significantly on the O density or on the O^+,O collision cross section means that any systematic differences in the climatological means should be due to the need for a changing c/ac, which we determine by varying *cfac* untile ISR and servo model winds agree.

4.3.2 Determination of a time-varying *cfac*

For each of the 34 Millstone Hill iSP. experiments, the radar winds were first interpolated to hmF_2 and to the time of the Iunb measurements. The *cfac* value was then determined which brought the servo model winds into agreement with the ISR winds at that time. Results were binned in one hour intervals vs. local solar time, and in five-degree increments of solar zenith angle(ϕ), and average diurnal variations were determined for summer (May-August), equinox (March-April and September-October), and winter (November-February) at two solar activity levels (F10.7 less than or greater than 115). Derived values of *cfac* below 0.4 or in excess of 1.75 and winds in excess of 400 ms^{-1} were excluded from the analysis, as they represent erroneous data or some form of larg.e systematic error in either the servo model or ISR wind lcclmiqtte. or resul.t f'roni severe storm conditions. For the same reason, derived *cfac* values more than 2 standard deviations from the mean were also excluded from the final averages in each local time bin.

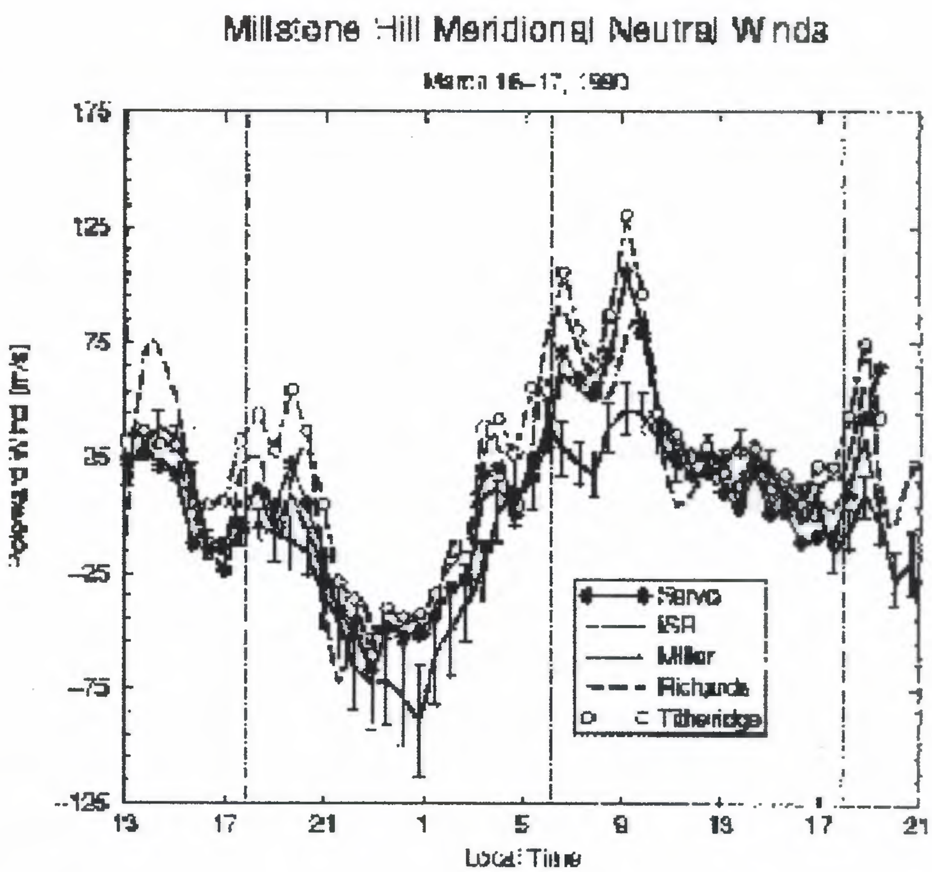


Fig.4.4 show Millstone Hill meridional neutral winds

Figure 4.4 The mean best *cfac* during the period January 20-29, 1993 calculated using different formulae for the O^+,O collision frequency .cfac is the factor needed to multiply the servo model daytime and nighttime empirical constants c to give best agreement between the ISR and servo model winds. Vertical dotted lines show sunset times ($\chi = 90^o$).

4.4 Ground based magnetometers

Ionospheric and magnetospheric current systems create disturbances in the geomagnetic field. Thus, by measuring these effects with ground-based magnetometers, one can monitor the magnetosphertc activity (e.g., the development ot geomagnetic storms and substorms) continuously. For example, several geomagnetic indices are calculated from these measurenients.

It is custoniary to arrange the instruments in meridional chains, like is the case with the image chain in Finland, and samnet chain in United Kingdom. Canopus is a big Canadian array of magnetometers, while intermagnet is a project to promote the exchange of magnetic observatory data around the world.

The magnetic field perturbations are usually resolved along a geomagnetically' north-south (positive north), east-west (positive east), and parallel to B directions (in the northern hemisphere) and are denoted by H,D, andZ. components, respectively. Sometimes a geographic coordinate system is used. in which case ihe symbols X, Y, and Z (lenote the magnetic perturbations in the north, east, and vertical (positive down) directions.

It is impossible to derive the true horizontal IonoSpheric current distribution uniquely from ground magnetic perturbations, since they are a superposition of contributions from the horizontal ionospheric currents, field-aligned currents, distant currents in the magnetosphere, and currents induced in the Earth's siirliice. [or this reasons the ground magnetic perturbations are usually expressed in terms of "equivalent' ionospheric currents.

The time resolution of magnetometers is typically about 10 seconds. Pulsation magnetometers, which are used to study geomagnetic pulsations at ULF range, have much better resolution, about 0. 1 seconds.

CONCLUSIONS

Ionosphere behaves like a sheet oI chaiged ions around our earth. It is impossible to transmit immediately both local and national signals using same signal with same frequency, So ionosphere behaves like a reflecting media and helps us to communicate all over the world.

It allows the programmers to receive both nationally and beyond national programs in case of radio frequency.

Ultra-high, and super-high frequencies are not reflected by the Earth's ionosphere. so these are used for television and satellite transmissions by microwaves or VHF radio stations. So it results as low loss for our data. it means that the noise error in our transmissions can be minimized including that when our signal to be sent is in microwaves or VHF radio wave.

Ray tracing programs using ionogrm in skywave radars is used to predict where signal transmitted on any given frequency will end up. This is infonnation necded by sw radars to choose best operating frequency.

Using Ground based magnetometers; one can monitor the inagnetospheric activity (e.g., the development of geomagnetic storms and substorms) continuously likewise several geomagnetic indices are calculated from these measurements.

We radio signals we have to nice a problem that when our signals are reflected from the layer of ionosphere, much of the data is disturbed during its reflection. For example we transmit a. signal with a certain frequency. We want to receive ii. at receiver we can see that it is not the same as it was transmitted. If our signal to he sent was $(1010)^2$, May be at receiver we collect $(10\ 01)^2$.

However there are some methods, we are using now a days for our communications, named as multiplexing and coupling. According to the situation and behavior of our signal we are using these techniques to save our data. In these way we have minimized the disturbance occurred by the layers of ionosphere.

Our results have shown that use of a constant *cfac* produces satisfactory results in routine servo model wind calculations, typically resulting in smaller errors than those due to measurement errors, spatial vanations in the wind field above the station, and the assumption that hmF_2 is the peak in the m altitude profile.

Results horn the Ti/iiericigc [1995a] model indicate that errors in the servo *cfac* model winds calculated using a constant might he larger at stations lower in latitude than Millstone Hill. This could be investigated using incoherent scatter rachir dala at a station such as Areeibo.

The four winds horn *hmF2* techniques give comparable results, though winds from the Titheridge [1995a] method showed a pole ward offset which is easily corrected by usint a smaller rate coefficient k_2 for the O^+ charge transkr reaction (5).

Our comparison of ISR and servo mode] winds from 34 experiments at Millstone Hill confirms the theoretical results of Titheridge [1993, 1995a,b], which require a decrease after sunrise in the servo model c parameter below the constant daytime values given in [RisIibeth. 1967. Rishbeth et al., 1978].

However, we find no evidence that use of a constant *cfac* introduces serious errors in the derived meridional winds, at least for the location of Millstone Hill.

Most differences between ISR winds and servo model winds at this location are due to other factors, which are difficult to quantify. These include measurement errors in hmF_2 and the ISR line-of-sight ion velocities, spatial variations in the wind field above the station, and the assumption that *hm* F_2 are the peaks in the O^+ altitude profile.

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