INTERSTELLAR MATTER

The enormous volume of space between the stars in the Milky Way Galaxy is filled with interstellar matter (ISM). The ISM plays a central role in the processes of star formation and the evolution of the Galaxy. Stars form from the ISM in dense molecular clouds. The radiant and mechanical energy produced by stars heats, ionizes, and produces structures in the ISM. Gradual or catastrophic mass loss from stars enriches the ISM in heavy elements and causes the composition, distribution, and physical state of the ISM to change as the galaxy evolves. Current studies of the ISM are aimed toward characterizing its basic properties, determining the physical processes that control these properties, and establishing the role the ISM plays in the evolution of the Galaxy.

The existence of matter between the stars was first proposed by Wilhelm Struve in 1847 based on an analysis of star counts which suggested that the number of stars per unit volume decreases with distance from the sun. Struve proposed that the star light was experiencing absorption proportional to distance. It was not until 1909 that Kapteyn realized the full significance of this interstellar extinction. Shortly later Barnard documented through direct imagery the irregular variations in the distribution of the absorbing matter. The identification of the source of the extinction with small particles of interstellar dust was finally accepted in the 1930s through the work of Trümpler, Stebbins, Huffer and Whitford.

Diffuse emission nebulae powered by O stars with T > 30,000 K were the component of the ISM first observed spectroscopically by astronomers The spectrum of the brightest example, the Orion nebula, was recorded in 1863 by Huggins. In the late 1920's Eddington, Zanstra, and Bowen were able to show that such emission nebulae were clouds of ionized interstellar hydrogen containing He and trace amounts of heavier elements.

Absorption by interstellar Ca^+ in the interstellar gas was first spectroscopically recorded by Hartmann in 1904. However, it was not until the early 1930s that Plaskett and Pearce obtained extensive surveys of Ca^+ absorption in a large number of stars and convincingly associated the absorption with gas between the stars. They showed that the strength of the Ca^+ absorption increased with distance and that the absorption line radial velocity varied with distance and direction according to that expected from a simple model of gas rotating in a disk galaxy.

In more recent times the full diagnostic power of observations across the entire electromagnetic spectrum have been used to study emission and absorption produced by interstellar gas and dust in order to determine its composition, distribution, and physical state.

Components and Composition

The ISM (gas+ dust) in the solar vicinity has Population I element abundances. This has been established through abundance studies of the gas in diffuse emission nebulae, optical and ultraviolet absorption line studies of gas in neutral hydrogen regions, and by inference from studies of the composition of matter in the atmospheres of young O and B stars that have recently formed from the ISM. The ISM gas phase composition by relative number of atoms is 91% H, 9% He, and a trace abundance of the heavier elements.

Given the great abundance of H and He in the gas, much of the physics of the ISM involves interactions among these atoms, electrons, and photons. The H can exist as H^o, H_2, or H^+ while the He can exist as He^o, He^+, or He^{++}. Absorption of radiation by H and He plays a dominant role in determining the nature of the average radiation field in interstellar space. In a neutral hydrogen region the strong H I absorption at the 13.6 eV Lyman edge results in an average radiation field resembling that of A and B type stars for $3 < E < 13.6$ eV with a greatly reduced intensity for $E > 13.6$ eV from H I absorption. At energies between ~3 and 1 eV the interstellar radiation field is dominated by the light from G and K stars.

The ionization state of the heavier elements in an H I region is determined by the ionization potential of the element compared to 13.6 eV. As a result, the abundant heavy elements listed in order of decreasing abundance O, C, Ne, N, Mg, Si, Fe, and S exist in the ionic states O^o, C^+, Ne^o, N^o, Mg^+, Si^+, Fe^+, and S^+. In H II regions where the H I is photoionized by radiation from stars with T > 30,000 K, the heavier elements are in higher states of ionization, eg. O^+, O^{+2}, C^{+2}, C^{+3}, etc. with the actual ionic ratios controlled by the ionizing radiation field of the star. In the hot ISM where the gas is heated to T > 10^6 K by shock processes, the heavy elements exist in high states of ionization created by electron collisions. Therefore, elements such as O and C will exist as O^{+6}, O^{+7}, C^{+6}, and C^{+7}, with the actual ionic ratios determined by the kinetic temperature of the electrons. A study of these very different gas phases requires observations in the radio, infrared, optical, ultraviolet, extreme ultraviolet and X-ray regions of the spectrum.

The gas phase abundances of heavy elements in HI regions are reliably measured by ultraviolet absorption line spectroscopy toward hot stars. The line of sight column densities of HI and H_2 can be measured via the HI Lyman series absorption lines and the H_2 Lyman band absorption in the far-ultraviolet. The metal line column densities can be determined from the many resonance line absorption transitions found in the ultraviolet. The results of these studies with the Copernicus Satellite (1972-1980) and more recently the Goddard High Resolution Spectrograph (1990-1997) aboard the Hubble Space Telescope (1990-) reveal that many of the heavy elements have gas phase abundances substantially less than Population I abundances because of the incorporation of the heavy elements into solid particulate matter. This effect is referred to as element depletion. For sight lines through moderately dense clouds in the Galactic disk, the highly refractory elements such as Fe, Cr, and Ni have gas phase abundances reduced by factors of 100 to 200 while for other elements such as S, P, and Zn, the gas phase abundances are only reduced by factors of several. Si, Mg, and Mn exhibit intermediate reduction factors ranging from 10 to 30.

A detailed study of elements both missing and present in the gas phase of the ISM provides important indirect information about the presence or absence of those elements in interstellar dust. It is found that there is a general progression toward increasing gas-phase abundances of the depleted elements from cool neutral clouds found in the Galactic disk to warm neutral clouds in the disk to warm neutral clouds in the Galactic halo at distances away from the mid-plane of up to 1 kpc. This progression provides information about the destruction of dust grains in those processes that transport matter between these different Galactic regions.

The interstellar dust grains can also be studied via their emission, scattering, and absorption properties. Approximately 1% of the mass of the ISM is in the form of interstellar dust. The most abundant particles consist of solid silicate grains and a separate carbon component which may be in the form of graphite grains. The silicates have been spectroscopically identified through infrared emission and absorption features at 9.7 and 18 μm while the graphite grains may be responsible for the 217.5 nm interstellar extinction bump. The grains likely have a distribution of sizes ranging from very small up to several μm in diameter. In the denser interstellar regions the grains can accrete atoms which form mantles on the grain cores. In the densest regions, mantles of H_2O ice are detected through an infrared absorption feature near 3.1 μm. The grains can affect the intensity of the interstellar radiation field though the extinction they produce especially in dense interstellar regions. By locking up heavy elements from the gas the grains remove important coolants from the ISM. The grains also have significant roles in several interstellar processes including molecule formation and the heating of the gas through both molecule formation and photoelectric heating. The most abundant molecule observed in interstellar space, H_2, forms on the surfaces of grains. The dust also likely includes a population of very small grains, the PAHs or polycyclic aromatic hydrocarbons, which consist of planar molecules of combined benzene rings with attached H atoms. These particles have nm sizes and may represent the dividing line between large molecules and small particles. The PAHs are the leading candidates for a number of infrared emission bands.

High energy (10^6 to 10^{20} eV) cosmic rays exist in the space between the stars. Cosmic ray protons are most abundant with $n(p) \sim 10^{-10}$ cm^{-3} and $n(e) / n(p) = 10^{-2}$. The cosmic ray electrons have lower abundances than protons because they lose their energy more rapidly than the protons through the production of Galactic non-thermal synchrotron. Cosmic rays are $\sim 10^6$ times over abundant in various light elements because of cosmic ray spallation collisions of protons with heavier nuclei. Although the cosmic rays have a very low particle density, they can have substantial effects on the physical state of the thermal gas in the ISM through the processes of cosmic ray ionization and heating. Cosmic ray collisions with the gas also produce Galactic γ rays. Cosmic rays interacting with the Galactic magnetic field may have important dynamical consequences. For example, the pressure of cosmic rays may play a role in the support of the gas found in the Galactic halo.

The Galactic general magnetic field in the solar region of the Galaxy has an average absolute strength of $\sim 5 \times 10^{-6}$ Gauss. It contains an ordered component and an irregular component of roughly comparable strength. High energy cosmic ray electrons spiraling in the Galactic magnetic field produce non-thermal synchrotron radiation. Spinning dust grains are aligned by the magnetic field which leads to the observed interstellar polarization of starlight. The magnetic field has considerable dynamical effects since its pressure ($B^2 / 8\pi$) is comparable to the interstellar gas pressure. In dense interstellar regions the magnetic field strength is greatly amplified. Theories of the processes causing the collapse of an interstellar cloud into a protostar must involve a consideration of the dynamical consequences of the interstellar magnetic field. On the larger scales, loop like Galactic interstellar structures may be dynamically controlled by magnetic fields.

The different interacting components of the ISM discussed above have comparable energy densities (and pressures). For example, the energy density of the ISM radiation field from 91.2 nm to 8 μm is ~ 0.5 eV cm^{-3}, the cosmic rays have ~ 1.5 eV cm^{-3}, and $B^2 / 8\pi$ for a magnetic field with $B = 5 \times 10^{-6}$ Gauss is 0.6 eV cm^{-3}. Gas motions associated with turbulence and waves in the ISM are estimated to have an energy density of ~ 1 eV cm^{-3}. The different thermal phases of the gas discussed in the next section have $P/k = nT \sim 3 \times 10^3$ cm^{-3} K which implies an energy density of 0.3 eV cm^{-3}. The similarity of these energy densities (and pressures) is probably not a coincidence but is suggestive of a strong interaction and resulting energy and pressure equipartition among these different components of the ISM.

Phases and Physical Conditions of the ISM

The conditions in the ISM deviate very significantly from those found in a gas in thermal equilibrium. The mean energy density of the ISM radiation field is ~ 0.5 eV cm^{-3} which corresponds to the energy density of a Planck black body distribution at $T \sim 3$ K. However, the spectrum of the interstellar radiation field is produced by the integrated but diluted radiation from stars with temperatures ranging from ~3000 to ~30,000 K. The extremely dilute nature and spectral hardness of this radiation field causes huge deviations from conditions found in thermal equilibrium. In the ISM, the populations of atomic and molecular energy levels and of different states of ionization will not be determined by the temperature of the gas but from the actual dominating processes for populating and de-populating the given state. The temperature assigned to gas in the ISM only refers to the fact the gas particles have a distribution of velocity reliably described by a Maxwell-Boltzmann distribution at a particular temperature. The existence of such a velocity distribution is caused by the overwhelming number of elastic compared to inelastic particle collisions in a gas consisting of mostly H and He. Thus, the temperatures given for various interstellar regions only refers to the kinetic temperature of the gas.

The ISM of the Milky Way contains separate gas phases with kinetic temperatures that are cold ($T \sim 10$ K), cool (100 K), warm (10^4 K) and hot (10^6 K). The different phases of the ISM are listed in Table 1 with approximate properties given for each phase including the kinetic temperature, T(K), the representative physical density, n(cm^{-3}), the volume averaged density, $\langle n(\mathrm{cm}^{-3}) \rangle$, the exponential scale height above the Galactic plane, h(Kpc), and the very uncertain volume filling factor, f. Most of the mass of the ISM(~80%) is contained in the confined and extended components of the neutral gas. The extended component of the warm ionized gas contains ~15% of the mass and the very extended hot gas contributes ~3% to the mass.

In molecular clouds the hydrogen is mostly molecular and cold ($T \sim 10$ K). The molecular clouds are traced by emission from CO and other molecules. Although the molecular clouds comprise a small fraction of the volume of the ISM, they are estimated to contain ~50% of the mass of the ISM. Molecular clouds are not normally considered a 'phase' of the ISM since they are not in pressure equilibrium with the more widely distributed gas.

The cold neutral medium (CNM) contains HI and H_2 and is studied via 21 cm HI emission and absorption, and ultraviolet absorption by HI, H_2, and various heavy elements. With a temperature of ~80 K and a physical density of ~ 40 atoms cm^{-3} the CNM occupies only ~3 % of the volume of the ISM in the Galactic disk.

The warm neutral medium (WNM) produces HI 21 cm emission but weak absorption. It can also be studied via ultraviolet absorption line spectroscopy. With $T \sim 8000$ K and $n \sim 0.4$ cm^{-3} the WNM occupies a substantial fraction (~35 %) of the volume of the ISM in the Galactic disk.

The warm ionized medium (WIM) has been studied through the optical emission lines of Hα, [N II], and [S II] it produces. Observations of radio wave dispersion in the direction of pulsars yields a direct measure of the line of sight value of the electron column density in the WIM. With T ~ 8000 K and n ~ 0.2 cm^{-3}, the WIM occupies ~ 25% of the volume of the gas in the disk of the Milky Way. The power (~10^{41} ergs s^{-1}) required to maintain the ionization of the WIM is comparable to the total power input of all Galactic supernovae or ~15 % of the ionizing radiation emitted by Galactic O stars.

The hot ionized medium (HIM) contains gas with T ~ 10^6 K and n ~ $3x10^{-3}$ cm^{-3}. It is detected through its soft X-ray emission. Somewhat cooler hot gas associated with the HIM has been detected through highly ionized atomic absorption produced by O VI, N V, and C IV and by emission from C IV. The HIM has a very uncertain volume filling factor of 40±25 %.

The different gas phases probably exist in rough pressure equilibrium. Various techniques have been used to estimate the thermal pressure in the neutral phase of ISM. The pressures are most often reported as P/k = nT [cm^{-3} K]. In neutral interstellar regions containing C^o a typical value of P/k is ~$3x10^3$ cm^{-3} K. However, there are large deviations from this typical value particularly in regions overpressurized by shock waves from exploding stars or from the winds of hot stars. Pressures are substantially elevated in H II regions where relatively dense gas is rapidly heated to T ~ 8000 K by the O stars that have recently formed. Such overpressurized H II regions expand outward as the gas in them tries to achieve pressure equilibrium with the general ISM. In dense molecular regions pressures are found to be much larger as a result of the self-gravity of the gas. The pressure in the ionized gas at distances of ~ 1 kpc from the Galactic plane has been estimated to be ~ 3000 cm^{-3} K. The rate of drop off of gas pressure at larger distances away from the Galactic plane is not well determined.

Table 1 Phases of the Gaseous ISM[a]

phase	state of H	~T(K)	~ n(cm^{-3})	<n(cm^{-3})>	h (kpc)	$N_\perp$(cm^{-2})	f
cold neutral medium (CNM)	H^o, H_2	80	40	1.1	0.1	$2.1x10^{20}$	3%
warm neutral medium (WNM)	H^o	8000	0.4	0.16	0.4	$1.8x10^{20}$	35%
warm ionized medium (WIM)	H^+	8000	0.2	0.024	1	$6.7x10^{19}$	25%
hot ionized medium (HIM)	H^+	10^6	0.003	0.001	5	10^{19}	40±25%

[a] Molecular clouds are not listed as a phase of the ISM since they are not in pressure equilibrium with the more diffuse gas. In molecular clouds the hydrogen is mostly molecular, T ~ 10 K, and n > 300 cm^{-3}.

The total pressure produced by all the components of the ISM must be capable of supporting the Galactic gas layer. At the Galactic mid-plane that weight per unit area requires a total pressure, P/k , of approximately 30,000 cm^{-3} K. The combined pressure contributions from the various components of the ISM (e.g. gas thermal pressure, magnetic pressure, cosmic ray pressure, gas turbulent pressure) must add up to this number. In regions of greatly elevated pressure such as in OB associations with frequent supernova explosions, the higher pressure may drive gas into the halo in a flow pattern sometimes referred to as a "Galactic fountain." In such a flow, high temperature (T>10^6 K) gas bursts out of the Galactic plane into the halo , cools by adiabatic expansion, and eventually rains back onto the Galactic disk as warm and cool infalling fountain clouds.

General Distribution

The stirring of matter in the Galactic disk by supernova explosions, stellar winds, cloud-cloud collisions and other processes causes the various phases of the ISM to extend different distances away from the plane of the Galaxy. The stratification of this "Galactic atmosphere" is roughly described by layers with exponential density distributions away from the Galactic plane with scale heights h ~0.1 kpc for the cool clouds, ~0.4 kpc for the warm neutral gas, ~1 kpc for the warm ionized gas, and ~5 kpc for the hot ionized gas. These scale heights have been determined by studying the fall off of N(X)sin|b| versus |z| where N(X) represents the column density of species X toward stars at galactic latitude b having different distances, z, away from the Galactic plane. For cold neutral gas and warm neutral gas, ultraviolet observations of HI Lyman alpha and H_2 Lyman band absorption are used to obtain N(X). For the warm ionized medium, the observations are of pulsar dispersion measure which is proportional to the line of sight electron column density. The ~5 kpc extent of the hot phase has been traced by observations of highly ionized atoms such as C^{+3} and N^{+4} toward stars in the Galactic disk and halo. The thick warm neutral gas layer is often called the Lockman Layer while the warm ionized gas layer is called the Reynolds Layer.

The ISM gas density distribution in the Galaxy exhibits a radial dependence. The mid-plane densities of H_2 in the ISM as traced by the CO molecule are greater for regions interior to the Solar circle and appear to peak at a Galactocentric distance R of approximately 5 kpc. In the outer Galaxy, the HI is observed to warp and flare. The warp is to positive values of b over the region l = 70 to 140° and to negative values of b over the region l = 240 to 300°. The warping and flaring in the outer Galaxy has been observed to extend over a region ~10 kpc thick. The radial extent of the neutral HI in the Galaxy is roughly 30 kpc or more.

Structures

The various kinds of structures found in the interstellar gas provide important information about the many physical processes affecting the ISM. In the disk of the Galaxy the cool interstellar matter has a highly irregular cloud like structure. Information about the extents and sizes of these clouds can be inferred from observations of dust extinction toward large numbers of stars and from observations of interstellar atomic absorption lines toward stars. While clouds of many shapes and sizes probably exist, the extinction data yield information about the average properties of clouds containing dust. A summary of those properties is given in Table 2. Interstellar atomic absorption line studies confirm the existence of ~ 7 cool diffuse clouds kpc^{-1} along the lines of sight to stars within several kpc of the Sun. Extreme examples of the large clouds are the molecular clouds which often trace regions of active star formation. Molecular clouds have masses in the range from 10^5 to 10^6 $M_\odot$.

Table 2. Average Properties of Neutral Interstellar Clouds Traced by Dust

	Diffuse Clouds	Large Clouds
<E(B-V)>	0.061 mag	0.29 mag
Number kpc^{-1}	6.2	0.8
Contribution to <n(H)>	0.7 cm^{-3}	0.4 cm^{-3}
Diameter	4 pc	70 pc
n(H) in cloud	40 cm^{-3}	10 cm^{-3}
mass for spherical cloud	50 M_O	$6x10^4$ M_O

In addition to these clouds found in the mostly neutral gas, the ISM contains numerous structures which illustrate the direct interaction between stars and the ISM. These include the photoionized H II or diffuse nebulae which are found in star forming OB associations and the associated reflection nebulae which are evident when the stars illuminating the gas and dust are cooler than B2 and therefore do not have adequate amounts of Lyman continuum radiation to ionize the gas. Other examples, are the supernova remnants and planetary nebulae which trace the processes of violent and peaceful stellar death, respectively. The shock heating of the gas in the supernova remnants can create large volumes of hot gas that expands outward and eventually joins with the general ISM. The processes of both violent and peaceful stellar death provide a means to enrich the ISM in elements created at some stage in the interiors of the dying stars.

Energetic events occurring in the disk can create HI shells and HI supershells. The extensions of these structures into the halo may produce structures called worms and Galactic chimneys. Some of these structures mark the sites of OB associations where the combination of multiple stellar winds and multiple supernovae create over-pressurized regions which can in some cases feed hot gas into the halo and leave behind HI shells and supershells.

The HI observed at intermediate velocity ($|v| = 30$ to 100 km s^{-1}) at high latitudes in the northern Galactic hemisphere traces substantial amounts of gas in arch-like features. The high velocity HI clouds ($|v| > 100$ km s^{-1}) which cover ~ 20% of the sky trace gas with a number of different origins including gas stripped out of the Magellanic Clouds through tidal interactions with the Milky Way, Galactic fountain gas, and perhaps infalling intergalactic gas. The recent discovery that the extensive high velocity cloud Complex C has a metallicity of 0.09±0.02 Solar implies that the Galaxy may still be accreting low-metallicity material which could be a remnant of the formation of the Local Group of galaxies.

In the Galactic disk the ISM has a greater density in the Galactic sprial arms which are waves of enhanced density that move through the gas and the stars of the disk. Local examples of these spiral arms in the Milky Way are clearly traced by the young stars of OB associations and the molecular clouds from which the stars have recently formed. The three most prominent sprial arms near the Sun are the Perseus Arm, the Local Arm and the Sagittarius Arm. These three sprial arms have widths of ~ 1 kpc and are separated by ~1.5 kpc. In between the spiral arms, the interarm gas has a lower density and is more smoothly distributed.

Near the Galactic center there is a ~10^9 solar mass concentration of the ISM mostly in the molecular form in an expanding ring of ~200 pc radius. This expanding structure may have its origins in the explosive release of energy from the Galactic center or from the dynamical effects of a stellar bar. The ISM in this highly disturbed molecular ring has much more extreme properties than found elsewhere in the Galaxy.

Controlling Physical processes

The physical state and distribution of the different components of the ISM are controlled by a number of physical processes. Identifying the dominant (controlling) processes is an important goal of studies of the ISM. In many interstellar situations it is assumed that the populations of ionic states or atomic and molecular energy levels are not changing with time. Under such "steady state" assumptions an identification of the dominating processes allows for a determination of the basic properties of the gas. However, in situations where the time evolution is rapid the steady state assumption may be invalid in which case it is necessary to follow the full time dependent evolution of the gas.

The ionization state of the interstellar gas in HI and HII regions is controlled by starlight photoionization balanced by radiative and dielectronic recombination. In HI regions the radiation is produced by the integrated radiation from stars which is strongly attenuated for $E > 13.6$ eV by HI absorption. In an H II region one or more O stars are usually the dominant sources of the ionizing radiation. In the hot ISM the ionization is controlled by electron collisions followed by radiative and dielectronic recombination.

The equilibrium abundances of molecules in the ISM are controlled by the dominating molecule production and destruction processes. The most abundant molecule, H_2, forms on the surfaces of grains and in diffuse clouds is destroyed by the absorption of far-UV radiation between 91.2 and 111 nm in the Lyman and Werner absorption bands. Following the absorption into an excited molecular electronic state, the excited H_2 molecule undergoes radiative emission into a bound state of the ground electronic state or into the unbound vibrational continuum of the ground electronic state which results in dissociation. The dissociation process occurs ~10% of the time. Once the H_2 has formed, it can react with heavy atoms in various molecular reaction chains to form many of the ~100 different molecules found in dense interstellar clouds. The atom-molecule reaction process is greatly accelerated by the atomic ionization occuring in dense interstellar clouds penetrated by ionizing cosmic rays. The ion-molecule chemistry occurring in diffuse and dense clouds seems capable of explaining the existence of many of the molecules found in these clouds. In very dense interstellar molecular clouds the dissociating UV radiation is absent. This allows the molecular chemistry to proceed to the creation of very complex polyatomic molecules containing as many as 10 to 13 atoms. Interstellar grains also likely participate in the production of molecules other than H_2. For example, in addition to molecule production processes similar to the formation of H_2 on grain surfaces, the exposure of a grain with a complex icy mantle to a harsh environment may lead to the ejection of various complex molecules from the matter in the surface layers.

The equilibrium kinetic temperature of the gas is controlled by the important cooling and heating processes. In most interstellar regions the cooling is produced by collisional excitation of atomic fine structure levels followed by radiative deexcitation with the loss of the photon from the region. In HI regions electron or hydrogen collisional excitation of low lying states in C^+ and O^o can lead to the production of the cooling transitions of C II at 157 μm and OI at 204 and 76 μm. In hotter H II regions where the colliding particles have more energy , the important cooling transitons occur as forbidden optical emission lines from O^+, O^{+2}, and N^+. In the H II regions surrounding hot stars, the dominant heating process is the difference in the relatively large kinetic energy liberated to the gas by ejected photoelectrons (mainly from HI) as compared with the energy of the recombining electrons. The heating processes are not as well understood for HI regions. Several possibilities include heating caused by the photoelectric ejection of rapidly moving electrons from grains, or the heating occurring as high speed H_2 molecules are ejected from grain surfaces during the molecule formation process. In this ejection process a modest fraction of the H_2 energy of formation is available to eject the molecule from the grain with a substantial energy of motion.

Theories of the Physical State of the ISM

Theories of the interstellar gas and dust in the Galaxy must be able to explain the co-existence of the different observed phases of the ISM. Over certain ranges of conditions in the ISM, multiple gas phases can co-exist in rough pressure equilibrium. Multi-phase models of the ISM consider the various interactions occurring between the general ISM and the stars which form from the intersellar gas and subsequently heat and ionize the gas. Before the discovery of the hot ISM in the early 1970s, a two phase model was developed by Field, Goldsmith, and Habing to explain the co-existence of a cool neutral phase with $T \sim 10^2$ K and a warm neutral phase with $T \sim 10^4$ K. This two phase model of the ISM demonstrated that two thermally stable gas phases could exist at the same pressure provided a thermally unstable phase occurred at an intermediate temperatures. With the discovery of the hot ISM with $T \sim 10^6$ K, the two phase model of the ISM was extended into a three phase model by McKee and Ostriker. In the three phase model the dynamic third hot phase is created by the collective action of stellar winds and supernova explosions that shock heat large volumes of gas to high temperatures. This shock heated high temperature gas tries to achieve pressure equilibrium with the other gas phases and begins to cool by evaporating the matter contained in the warm and cool clouds. The hot gas can also cool by radiative emission and by adiabatic expansion into the halo provided it can break out of the Galactic plane.

In the three phase model of the ISM the warm ionized gas can be explained as a ionized transition region between the warm neutral phases and the hot phases. The importance of this component of the gas was not fully recognized when the three phase models of the ISM were first introduced. Although the warm ionized medium produces quite faint Hα emission over most of the sky, it radiates a very large total power of $\sim 10^{41}$ ergs s^{-1} which is equivalent to the total power of all supernovae or ~15% the ionizing radiation produced by O stars.

The three phase model of the interstellar gas has been developed into a detailed theory involving the interactions among the different gas phases, luminous hot stars, and various types of supernova explosions. The self gravitating molecular clouds are not considered a phase in the three phase model of the ISM since the gas they contain is not in pressure equilibrium with the other gas phases. One of the most uncertain aspects of the three phase model of the ISM involves our knowledge of relative filling factors and the overall importance of the different phases. Estimates of the average filling factor of the hot gas in the disk of the Milky Way unfortunately currently range from ~15% to ~ 65%. It is disturbing to conclude this overview of the ISM by saying that even in 1999 we do not know which phase of the ISM fills most of the space between the stars in the disk of the Milky Way.

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