Interstellar Medium-Hot Ionized Medium

Introduction

Interstellar medium (ISM) is the matter that exists in the space between the star systems in galaxies which comprises of relatively low density gas(95% by mass) and microscopic dust particles(5% by mass).The following table gives some insight into the different gas phases of the ISM.

Phase	Temperature K	Density cm^{-3}	Fraction of Volume	Mass in 10^9 $M_\odot$
Hot ionised medium	$3–20 \times 10^5$	3×10^{-3}	0.4–0.7	0.003
Warm ionised medium	10,000	3×10^{-1}	0.15–0.4	0.05
Warm neutral medium	8000	4×10^{-1}	0.2–0.6	0.2
Cold neutral medium	40–100	6×10^{1}	0.01–0.04	3
Molecular Clouds	3–20	3×10^{2}	0.01	3

From the above table it can be inferred that much of the interstellar volume in our Galaxy (and possibly in other similar galaxies) is filled by the hot ionized medium, though the mass in this phase is only a small fraction of the total ISM mass. Whereas, the giant molecular clouds occupy only a tiny fraction of the Galaxy's volume, but a lot of mass is locked up in them. According to Jean's criteria,

$$M_{cloud} > M_J \tag{1}$$

$$M_J = \left(\frac{5kT}{G\mu m_h}\right)^{\frac{3}{2}} \left(\frac{3}{4\pi\rho}\right)^{\frac{1}{2}} \tag{2}$$

Hence, cold molecular clouds act as sites for star formation because of their low temperature.

Hot Ionized Medium(HIM)

It is hot($\geq 10^{5-6}$K),low density (<0.01 cm^{-3})gas, heated and ionized mainly by Supernovae explosions and occupies about 70% of the ISM. The puffed up gas or bubble ejected in the Galactic disc, hot ionized gas at the halo of the galaxy also known as 'Galactic Corona' are regions of HIM. Its presence can be inferred through:

- Intervening absorption of lines of highly ionized atoms seen in the spectrum of high Galactic latitude stars. In the coronal gas,much of the hydrogen is collisionally ionized. Hence hydrogen absorption lines are not seen.

- Detection of soft X-ray emission from this hot gas (this is very faint because of the diffuse nature of the gas). Soft X-ray diffuse emission from the Galactic halo indicates the presence of coronal gas.

Heating of ISM: The velocities of the supernovae remnants are supersonic in nature, which produces shock and in turn heat up the ambient ISM thereby causing irreversible changes to the entropy of the medium.

Astrophysical Shock: It is generally pressure driven disturbance propagating through a medium with supersonic velocities.

Where does astrophysical shocks occur?

- Cloud-cloud collisions
- HII regions expanding into neutral medium
- Stellar wind encountering medium
- Supernova or GRB blast wave (internal and external shocks)
- Accretion onto compact objects: spherical or disk
- Accretion onto hydrostatic intracluster medium

The following table shows the properties of supernova:

	Type I	Type II
Ejected mass ($M_\odot$)	0.5	5
Mean velocity (km sec^{-1})	10 000	5000
Kinetic energy (erg)	5×10^{50}	1×10^{51}
Visual radiated energy (erg)	4×10^{49}	1×10^{49}
Ionizing radiated energy (erg)	10^{44} or 10^{48}–10^{49}	10^{48}–10^{49}
Frequency (yr^{-1})	1/60	1/40
Stellar population	old disc	young disc

Type II supernova contribute more towards the heating up of the ISM because they are contemporaneous. Most of the energy emerges as the kinetic energy of the ejecta. The high velocity ejecta predominantly alters the phase of the ISM than the visible radiated energy as is evident from the above table.

POST SHOCK TEMPERATURE:

The region through which the shock wave moved, the temperature varies as,

$$T_s = \frac{3}{16}\mu V_s^2 \tag{3}$$

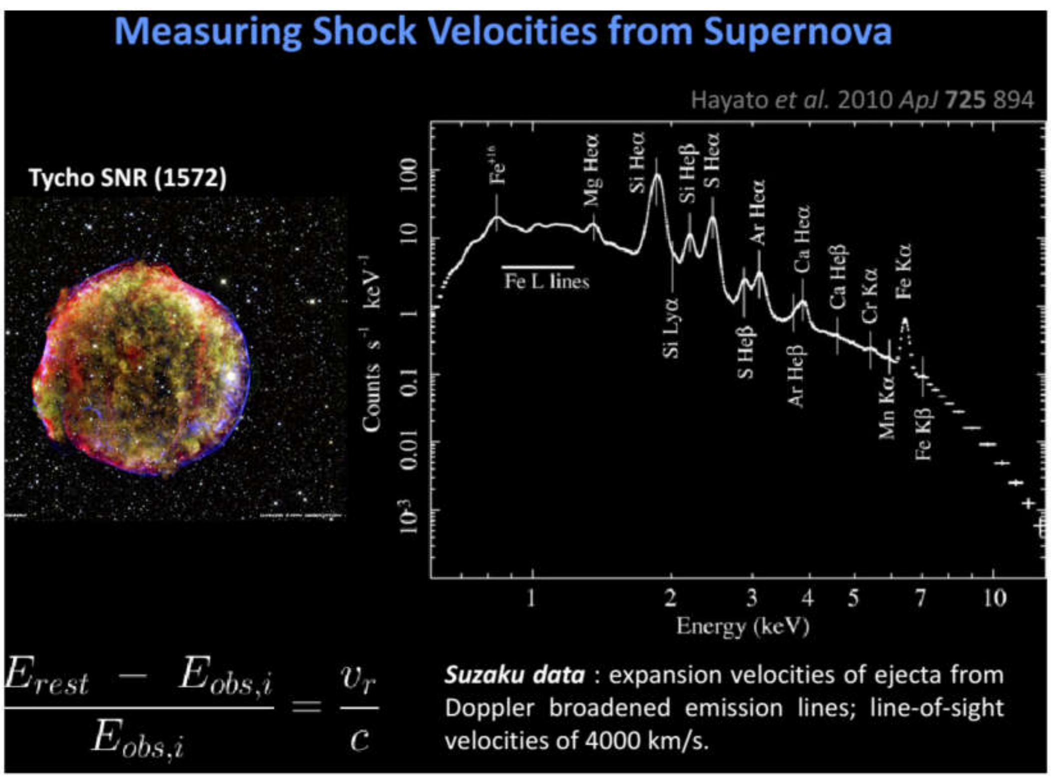
where T_s is the shock temperature, V_s is the shock velocity, μ is mean molecular weight of the medium. The above equation is rewritten with V_s in km/s and μ in terms of m_H as,

$$T_s \approx 2890K \left(\frac{\mu}{1.273 m_H}\right) \left(\frac{V_s}{10 km/s}\right)^2 \Rightarrow \because \frac{n_{He}}{n_H} \approx 0.1 \tag{4}$$

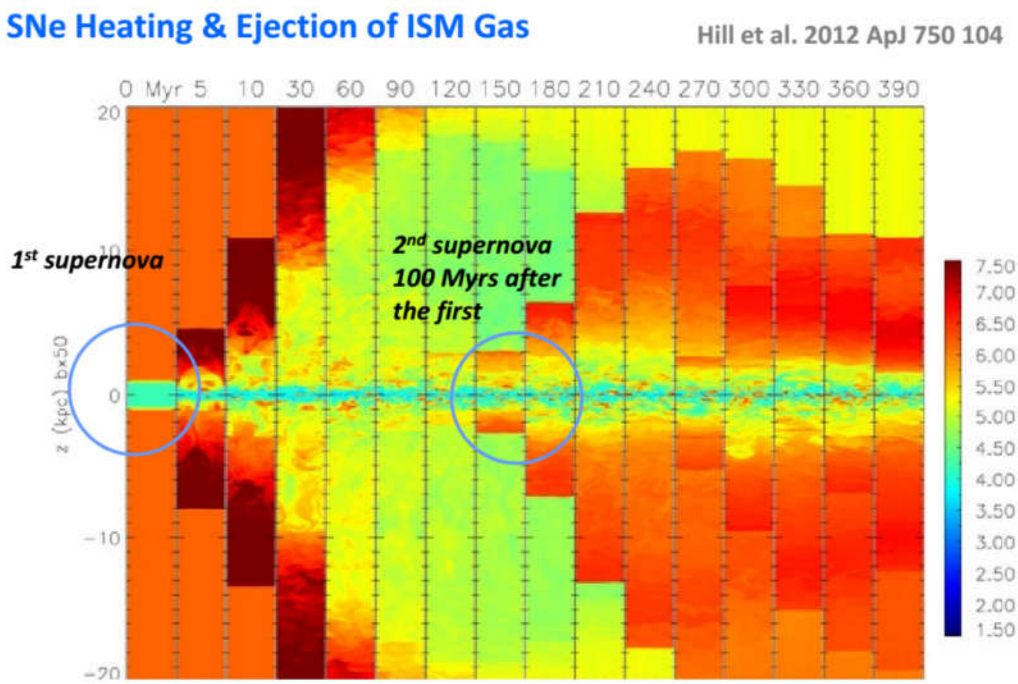
The post shock temperature depends on the composition of the gas and the velocity of the shock.

SHOCK VELOCITY:

- One approach to measure the velocities of the supernova ejecta is through long time line observations. The growth in angular size of the SNR can be translated into a velocity perpendicular to the line of sight (provided the distance to the SNR is known).
- The broadening of spectral lines (emission and absorption lines) yield a measure of the line-of-sight velocity with which the supernova ejecta is expanding.



Computer simulations involving the hydrodynamics of plasmas are used to develop a theoretical understanding of the energetics of supernova explosions in a galaxy, how it affects the ambient interstellar gas etc.



A snapshot from a MHD simulation showing the evolution along vertical direction of a region of the ISM affected by supernova driven turbulence.

Each vertical strip represents the snapshot from a simulation taken at equal time steps of roughly 5 million years. z = 0kpc is the mid-plane of the Galaxy. At time t=0, the first supernova explosion occurs which is later followed by two simultaneous explosions after 100 MYrs. This simulation shows the changes in the ambient gas because of the injection of energy and momentum from the supernova explosion.