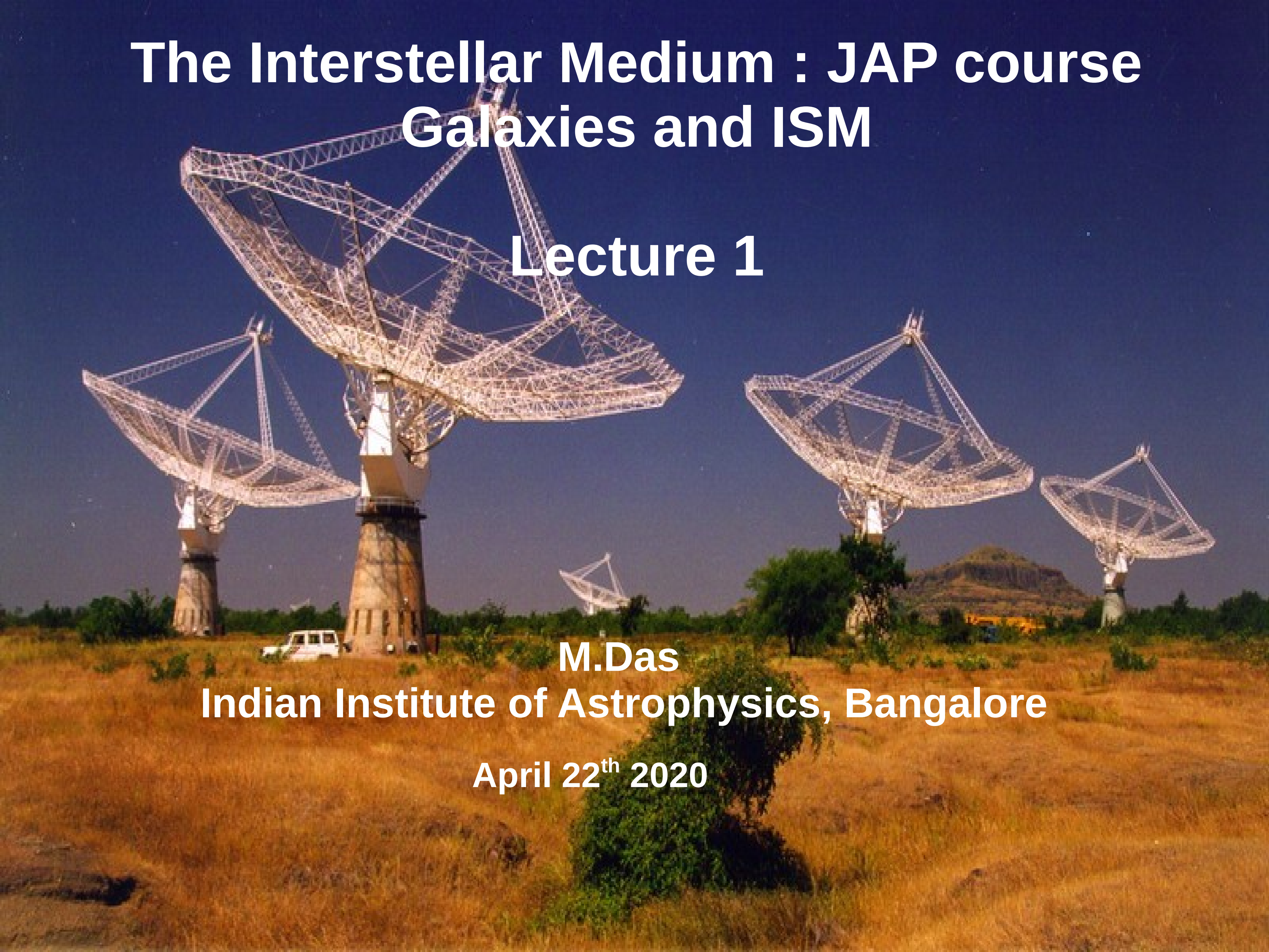
The Interstellar Medium : JAP course
Galaxies and ISM

Lecture 1



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Reference Books

The Two books that I will be mainly following :

- “Physics of the Interstellar and Intergalactic Medium”, Bruce T. Draine, Princeton Series in Astrophysics.
- “The Physics of the Interstellar Medium”, J.E.Dyson and D.A.Williams

Both should have pdf copies available online.

The Interstellar medium (ISM)

The ISM is the matter, radiation and fields lying between stars in galaxies. The corresponding component lying between galaxies is called the intergalactic medium (IGM). In this course we will focus only on the gas and dust in the ISM.

- At early epochs a large fraction of the baryonic mass was in the ISM. As galaxies evolved and merged, more and more of the ISM gas was converted into stars. Elliptical galaxies for example have very little ISM gas but disk galaxies still have significant reservoirs of gas.
- The ISM is depleted by star formation. Some of this mass is returned to the ISM by supernova explosions and stellar winds/outflows. But some of it never returns and is locked up in stellar remnants such as white dwarfs and black holes.
- The ISM mass is enhanced by gas infall from neighbouring galaxies and accretion from the IGM.

See figure 1.1 in Draine for the diagram and numbers.

Components of the ISM

1. Interstellar gas : this has the largest baryonic mass and is made up of ions, atoms and molecules all in the gas phase. The velocity distribution is approximately thermal. It includes the neutral hydrogen (HI), molecular hydrogen (H_2), ionized hydrogen, other elements such as He, Li, Mg etc that are in the gas.

2. Interstellar Dust : composed of small solid particles of size<~1μm.

3. Cosmic rays : ions, electrons that have kinetic energies much greater than thermal energies.

4. Electromagnetic radiation : this is made up of photons from the cosmic microwave background radiation, from stars as well as emission from ions, atoms and molecules in the ISM gas. The emission includes thermal emission from grains that act like small black bodies and synchroton emission from relativistic electrons.

5. Magnetic Field : associated with the galaxy.

6. Gravitational field

7. Dark Matter

8. Inter-galactic medium (IGM) : which includes the warm hot intergalactic medium (WHIM).

Gas Mass components of the ISM

The dust and gas in the disk of our Galaxy near the sun lies within a total thickness of 500pc about the z=0 mid-plane. The numbers for the gas masses in our Galaxy are the following and % of total gas mass is given:

1) Total HII (ionized hydrogen not including He) = $1.12 \times 10^9 \ M_{sun}$ **23%**

2) Total HI (neutral hydrogen not including He) = $2.9 \times 10^9 \ M_{sun}$ **60%**

3) Total H_2 (molecular hydrogen not including He) = $0.84 \times 10^9 \ M_{sun}$ **17%**

- These masses are typical of most large spiral galaxies.
- Typically M(HI) ~ few % of M(*). In some extreme late type galaxies and dwarfs M(HI) ~ M(*) ==> true for gas rich, low luminosity galaxies that have large dark matter content.

Thickness of the gas layer : let z(1/2) be the height above disk mid-plane where the gas density is half that of midplane. Then,

- Z(1/2) = 250pc ===> called a thin disk and supports star formation. The H_2 gas layer is associated with it.
- Z(1/2) = 500pc ===> layer made of HI and ionized gas.

Phases of the ISM

These are the phases of the ISM that are defined according to temperatures. Mainly applies to spirals but some components are present in ellipticals as well.

1) **Coronal Gas** (**HIM** or hot ionized medium) : The gas is hot, ionized gas with temperature $T>10^{5.5}$ K. Its origin is SNEs that give rise to shock fronts that collisionally ionize gas. The gas is associated with star formation in the disk. It is detected in O^{5+} emission lines. Cools on Myr timescales. It is often found in bubbles of 20pc size, but in general occupies nearly half the disk volume. Found at higher disk heights and hence called coronal gas.

2) **HII Gas** : Composed of hydrogen gas photoionized by UV emission from hot OB stars. It can be (I) associated with a star forming region in a molecular cloud, in which case it is called **HII region**. Forms bubbles of ionized gas of a few pc size around O-type stars. They last 3 to 10 Myr. (ii)Some it is part of the intercloud medium and called **diffuse HII** gas. It forms the warm ionized medium (**WIM**) and is lower in density than HII regions. Origin can be stellar winds, outflows. (iii) planetary nebula also give out ionized gas, like HII regions. But the gas cools within 10^4yrs..

3) **Warm HI gas** : This is neutral hydrogen (HI) gas at $T\sim10^{3.7}$ K and density $n(HI)\sim0.6cm^{-3}$. Also called warm neutral medium (**WNM**) and fills 40% of disk volume.

Phases of the ISM......Continued

4) **Cool HI gas** : Cold HI gas at $T \sim 10^2$ K and density $n(HI) \sim 30\ cm^{-3}$. Also called cold neutral medium (**CNM**) and fills only 1% of disk volume.

5) **Diffuse H_2 Gas** : The cold molecular hydrogen gas should have densities large enough to shield the H_2 molecules from being dissociated by UV radiation. It is the diffuse H_2 found between the dense clumps of H_2 in a moleular cloud.

6) **Dense H_2 gas** : Composed of gravitationally bound clouds that have $n(H_2) \sim 10^3\ cm^{-3}$. These gas clouds are usually associated with dark clouds that are made of dust and H_2 gas. These regions are the sites of star formation in galaxies as the gas densities are high enough (although these densities are vacuum densities on earth).

7) **Stellar Outflows** : This is the stellar ejecta that comes from winds from evolved stars. For cool stars the mass loss rate is $10^{-4}\ M_{sun} yr^{-1}$ and ejecta velocities <30 kms^{-1}. For hot stars the mass loss rate is much higher and ejecta velocities much faster.

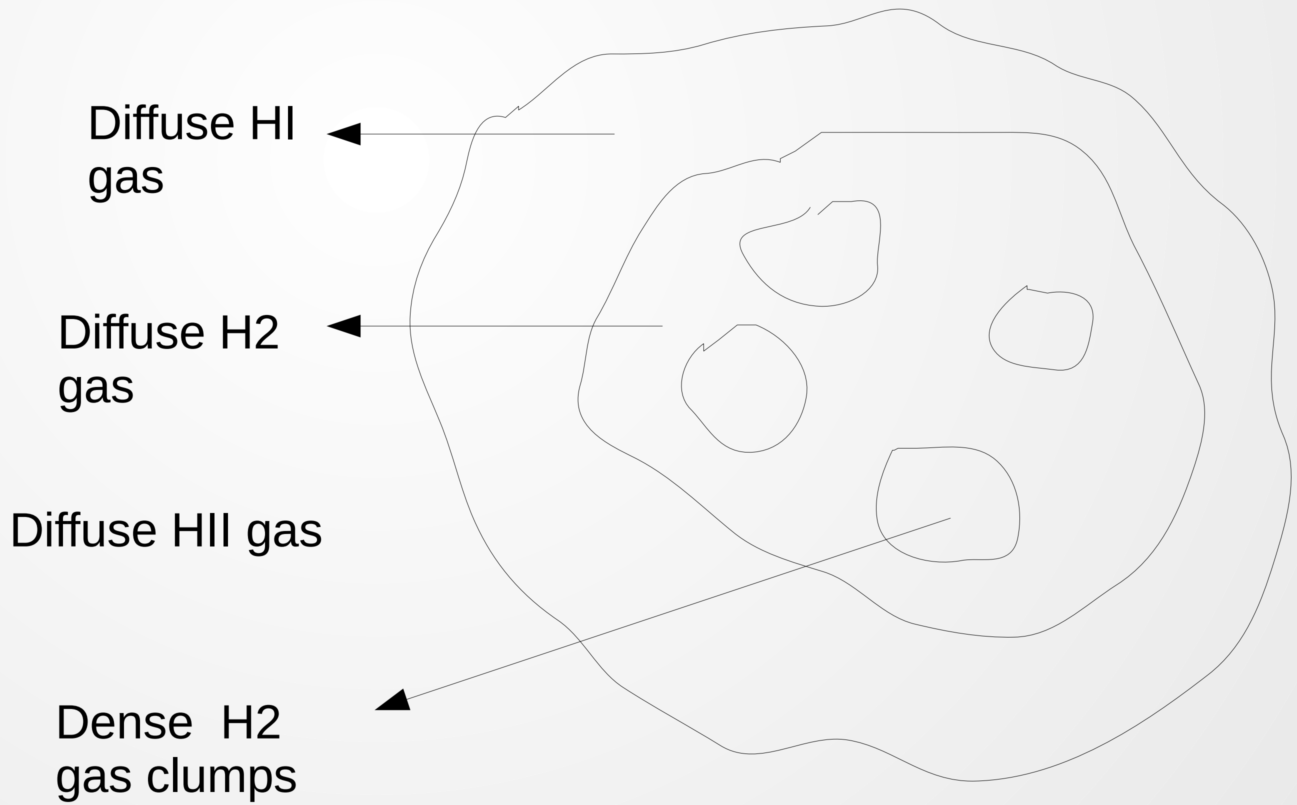
The diffuse and dense phases of the ISM

The dense phases of the ISM are the molecular gas clouds and the cold HI (CNM). They make up most of the mass and associated with the thin disk and star formation.

The diffuse phases ==> HIM, HII, WNM occupy most of the disk volume.

The diffuse and dense phases, hot and cool phases all remain in equilibrium in the ISM.

Model of a Molecular cloud with dense clumps of molecular hydrogen embedded in a diffuse molecular hydrogen medium.
The outer layer is diffuse HI and then finally the diffuse HII medium in the disk.



The Elemental composition and Energy composition of the ISM

- The composition of the ISM is mainly H and He.
- The other elements such as C, O, Mg, Ca, Si, Fe make up only ~1% of the stellar mass in a galaxy.
- In general any element other than H and He (n>3) is called a metal. The fraction of metals in a galaxy increases with the SFR in the galaxy.
- The metals in the ISM gas help cool the gas. Hence higher metal content means cooler gas and more SF.
- The energy densities are thermal (3/2nkT), bulk kinetic ($1/2\rho v^2$), magnetic ($B^2/8\pi$) and energy in photons (CMB + star light + dust emission).
- Apart from the CMB emission (which arises at early epochs) all the other energy densities are coupled as they arise from processes associated with SF in galaxies. The SF energies all have similar values 0.2 to 2 $eVcm^{-3}$.

See figure 1.3 in Draine for the energy flow diagram.

The Energy Flow and Correlation of Energy Densities of the ISM

- It is not coincidence that the 6 different energy components of the ISM are similar.
- The magnetic energy density is coupled to turbulent fluid motion in ISM.
- Also the B field helps to confine the cosmic ray particles in the ISM. The cosmic rays are important for maintaining the B in the molecular clouds and the turbulent pressure support.
- The starlight energy density is coupled to the grains because if it were higher than the radiation pressure on the dust grains would make them rise from the galactic midplane. This would suppress star formation. **Hence all the energies in the ISM are coupled.**
- The energy ISM is not in thermodynamic equilibrium. The energy input is from UV photons from stars and high velocity ejecta from SNEs. Also, a small fraction from stellar outflows and stellar ejecta. The energy is lost from the galaxy and ISM as photons from starlight.

See figure 1.3 in Draine for the energy flow diagram.

Why Study The ISM ?

- The ISM is usually not an important mass component of galaxies. The ISM mass is usually << M(stars) in a galaxy.
- But it is the medium via which stars form. We know that SF can only happen due to the collapse of cold molecular gas clouds. These clouds are dissociated by starlight (UV) and so have to be shielded by warmer HI gas.
- The localized H_2 clouds in the galactic plane affect the motion of stars because they are usually massive. The gravitational scattering of disk stars (mass~1 Msun) by molecular clouds of mass 100 to 10^5 Msun is a well studied phenomenon (L. Spitzer, 1958). So ISM gas does affect disk dynamics.
- The ISM of galaxies are important probes for understanding the mass distribution and energetics of disks and halos. The spectral emission lines from SF, X-ray halos of galaxies and the ISM gas components can help us trace the mass, elemental abundances, energetics and other details.

End of First Lecture