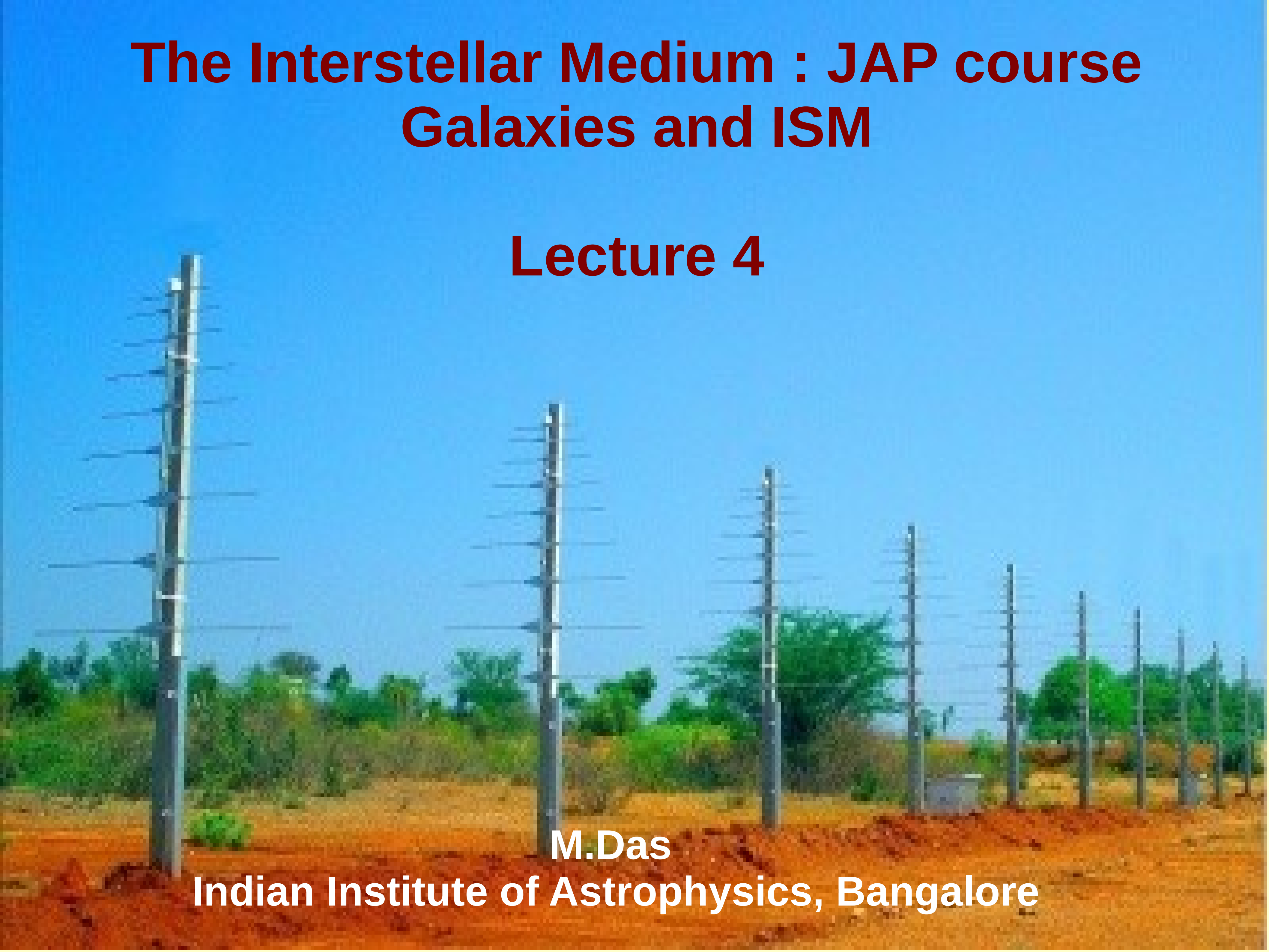
The Interstellar Medium : JAP course
Galaxies and ISM

Lecture 4



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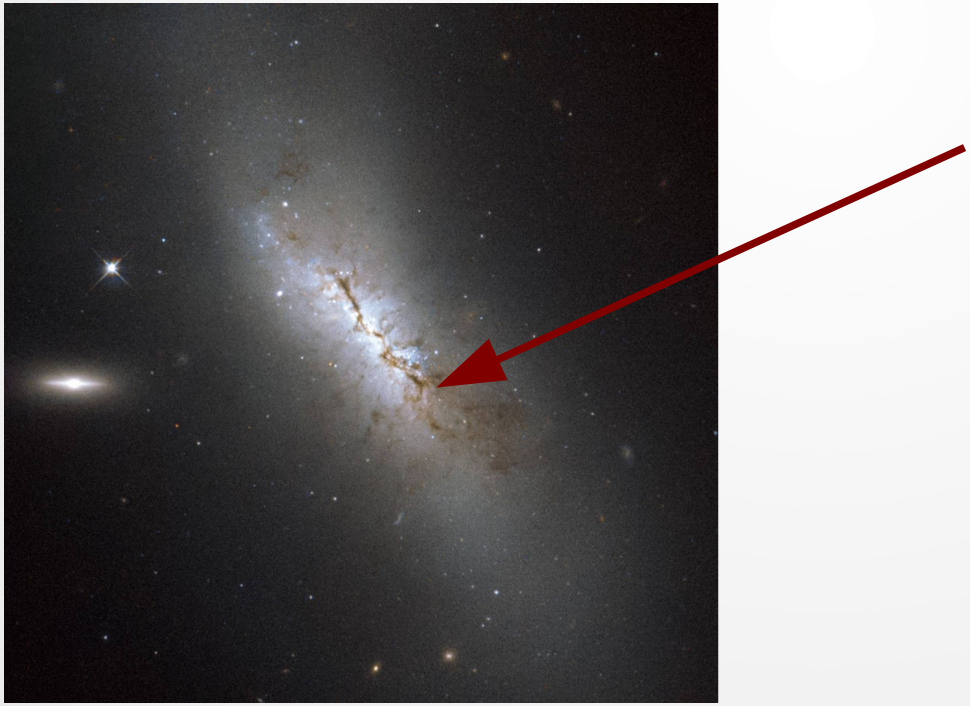
Interstellar Grains

- Interstellar (IS) grains are very small dust particles of size 10^{-9} to 10^{-7}m in size. The IS dust comprises typically only ~1% of the stellar mass of galaxies.
- But IS grains have a strong effect on the radiation emitted from stars because they scatter, absorb and polarize radiation.

Interstellar extinction : Images of galaxies in visible light show dark patches. This is because light is extinguished along these directions. The effect is called interstellar extinction and is due to interstellar dust.



The dark patches running through the center of the galaxy NGC4244 is due to dust lanes. They are made up of dust grains that absorb the light.

Image credit : HST-ESA image from nasa.gov

Extinction Processes due to Dust in ISM

- **1. Absorption :** Dust absorbs light from stars and galaxies. The majority of dust grains are of size similar to the wavelength of UV light, i.e. a(dust)>=100nm. Hence dust grains absorb UV light . This warms the dust grains to T>~10K.

  The grains then re-emit at infrared wavelengths ($\lambda\sim200\mu m$). The dust grains act like black bodies and the emission peaks in the FIR.

  Very few dust grains are ~10μm in size. So FIR is not absorbed but only re-emitted. Thus dust grains absorb UV (and other near-blue light) from stars and emit in the infrared range. **Thus starlight is reddened by dust.**

  Star Forming regions : Stars form deep within molecular gas clouds and such clouds are rich in dust. Hence, young star forming regions are bright at FIR wavelengths; as the light from the young stars is reprocessed by dust and emitted over IR wavelengths.

- Good examples are Ultraluminous galaxies that are extremely bright in IR and young protostellar regions.

Dust Extinction …. contd

- **2. Scattering :** Light is also scattered by dust grains. The process is the Rayleigh scattering of light and the intensity is proportional to λ^{-4}. This especially is seen in dense clouds that are rich in dust. They clouds often form **reflection nebulae** due to the scattering of light from an associated bright star near the cloud. The scattered light has a spectrum similar to the bright star.

  Scattered light also produces diffuse emission in our Galaxy. It can be shown using Rayleigh scattering formula that the diffuse emission is not due to atoms or molecules but instead is due to particles the size of interstellar dust.

- **Polarization :** The ISM dust grains also linearly polarize the stellar light by a few %. The amount is proportional to the extinction (will discuss later).

The image on the left is the reflection nebula NGC1435. The bright light is reflected light from a nearby star. Many small carbon grains in the nebula reflect the light. The blue light is because blue is more relected than red light by the dust.

Image credit : apod.nasa.gov

Measuring Extinction

Since extinction is the dimming of light by dust we will measure it in magnitudes.

- Let A_x be the **extinction coefficient** of a star in the waveband x. Then

  $A_x = (m-m_0)$ where m_0 = magnitude without extinction

- For no extinction we have the magnitude relation (m-M)=5logd – 5. Now the modified relation with extinction is ,

  $$(m-M)_x = 5\log d - 5 + A_x$$

  For example in the V band ($\lambda = 5450$ Angstrom) it becomes ==>

  $(m-M)_V = 5\log d - 5 + A_V$ ==> this is the most cited or used extinction coefficient

- The **reddening or color excess** is the difference in extinction between bands i.e.

  $$E(X - Y) = [m(X) - m(Y)] - [m_0(X) - m_0(Y)] \quad \text{or } E(X - Y) = A_x - A_Y$$

- The most common extinction is A_V and common color excess is E(B-V).

- Extinction is derived along different directions in the sky using known stars. It is a measure of the dust column in that direction. The most commonly used stars are O and B type stars as they are very bright and have distinct spectra.

Dependence of Extinction on Wavelength

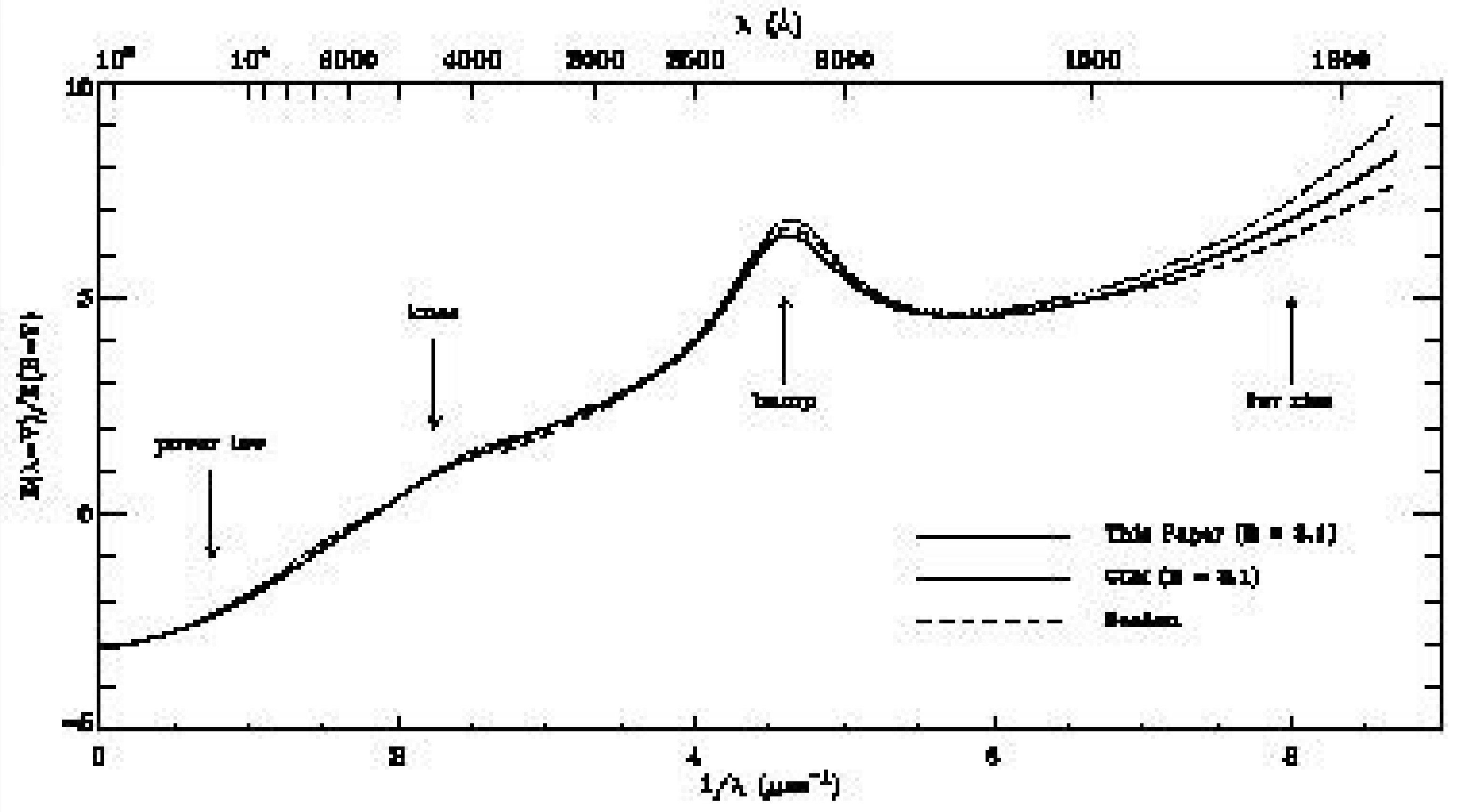
There are 5 major wavebands in the optical range:

- U band : 3500 A B band : 4400 A V band : 5500 A

  R band : 6400 A I band : 8000A
- Another commonly used set of wavebands are u,g,r,i,z and are used in SDSS images.
- The dependence of extinction on wavelength has the following form (please also see Dyson and Williams for another figure).

Extinction – Wavelength Plot

Image credit:
Fitzpatrick et al.
PASP 1999, 111, 63.
Obtained from
ned.ipac.caltech.edu
/level5/Fitzpatrick/



The above plot shows the normalized extinction variation with 1/ λ . The solid and dotted curves are for different A_V/E(B-V) ratios.

(i) The initial rising part lies in the visible range and the rise is nearly linear. The end rise is in the FUV range.
(ii) There is a peak at λ= 220 nm or 1/λ =4.6. This bump in the UV range is due to tiny pieces of graphite with 50 atoms each only.
(iii) There are 2 bumps in the IR region at 9.7 and 18 μm due to silicate grains.

Color Excess and the ratio Rv

The color excess, $E(B-V)=A_B - A_V$ can be used to study the properties of dust along different lines of sight, since extinction is different for the V and B bands.

- For line of sight not passing through dense clouds, ratio defined as R_V is approximately constant.

$$R_V = A_V/[A_B - A_V] = A_V/E(B-V) = 3.1$$

- The ratio R_V measures the selective extinction along a line of sight.
- The relation is important for estimating Av from E(B-V) which is a much easier quantity to measure. The extinction curve is approximately constant until the V band. After that it depends on line of sight.

Dust to Gas ratio and E(B-V)

The color excess, E(B-V) is approximately proportional to the column density of HI gas along the line of sight. This is because cold gas is always associated with dust. The column density N(H) is measured in number of atoms per unit cm^2. The relation with color is

$$E(B-V) = N(H) / 5.8 \times 10^{25}\ m^{-2}$$

- Where the ratio E(B-V)/N(H) is called the dust to gas ratio and N(H) is the column density in units of m^{-2}. The ratio is constant because a given mass of gas (either H_2 or HI) contains a characteristic mass of dust.
- Problem : Show that along a typical line of sight in our Galaxy,

$$E(B-V)=0.52(d/kpc) \quad \text{and} \quad A_V = 1.6(d/kpc)$$

where the number density of hydrogen n(HI)=1 cm^{-3} and $A_B/A_V = 1.324$

Polarization by Interstellar Dust Grains

- Interstellar light is usually polarized by a few % where the polarization fraction is measured by $P=\sqrt{(Q^2 + U^2)}/I$. The IS dust is thought to polarize it.
- There are 2 conditions that have to be met for grains to polarize light.
  (i) grains must be elongated. So if the electric vector E_0 is at an angle of θ to the major axis of the grain, then $E_0 \cos\theta$ is the component along the grain and the light along this direction will be reduced. E.g. Grains such as graphite and silica are elongated
  (ii) There must be some degree of alignment of these elongated grains. The direction will give the net polarization. The magnetic field B aligns the grains in the ISM because grains are made up of paramagnetic material. The B exerts a drag on the garisna and aligns them.
- The IS grains have a random motion. In a gas of temperature T there is equi-partition of the gas thermal energy and the rotation of grains about their major axis. $\frac{1}{2} I\omega^2 = 3/2\, kT$

End of Fourth Lecture