# Part 9: The Interstellar Medium (ISM)

- nearly as much mass in the voids between stars as in stars themselves
- interstellar space is where stars are born
- region into which old stars expel their matter

It is very important to study the gas and dust (called the Inter-stellar medium, ISM) between the stars, because this is the matter from which new stars are formed!

# Interstellar Matter

This is an image looking towards the centre of our Galaxy, the Milky Way. You can see that there are brighter and darker patches in the image:

What do you think the dark patches are?
What is the pink colour due to?

# Interstellar Matter

- bright regions: unresolved stars
- dark areas: ***interstellar matter*** blocking the starlight

- distributed ***unevenly*** throughout the space between stars

$\boxed{\text{Interstellar Matter = Gas + Dust}}$

## Gas and Dust

- The interstellar medium consists of ***gas+dust*** intermixed throughout space

### Gas

- mainly individual atoms and small molecules
- very little blocking / obscuration of starlight

### Dust

- more complex clumps of atoms and molecules (like chalk dust, smoke, soot)
- causes obscuration of starlight from stars behind it

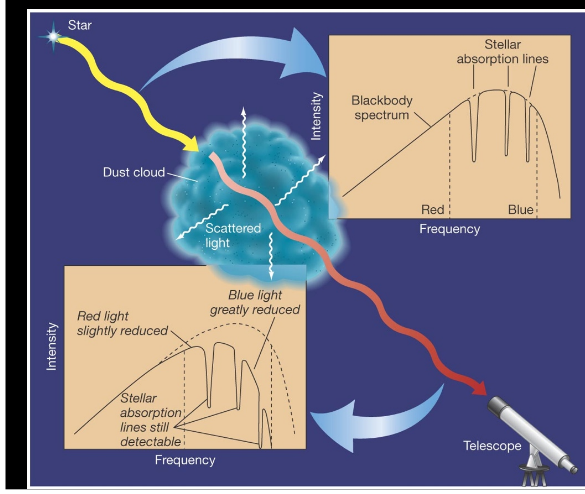
The two main components of the ISM are **gas** and **dust**.
The gas mainly consists of atoms and small molecules, while the dust is made up of more complex clumps of atoms and molecules and can be thought of like chalk dust, soot, smoke, etc.
The gas allows light to pass through it with little absorption or obscuration, while the dust blocks out the light from objects behind it. (look again at the previous slide and you can see that where the dark dust is located, you can’t see the starlight coming through).

## Extinction & Reddening

Dust affects starlight in 2 ways and we can use the information to learn more about the properties of the dust:

**Extinction:**
- overall ***dimming*** of starlight by ISM
- size of dust grains determine which wavelengths of light affected:
  - affects short wavelengths more

**Reddening:**
- stars ***appear redder*** since shorter wavelengths (blue light) are absorbed/scattered more easily



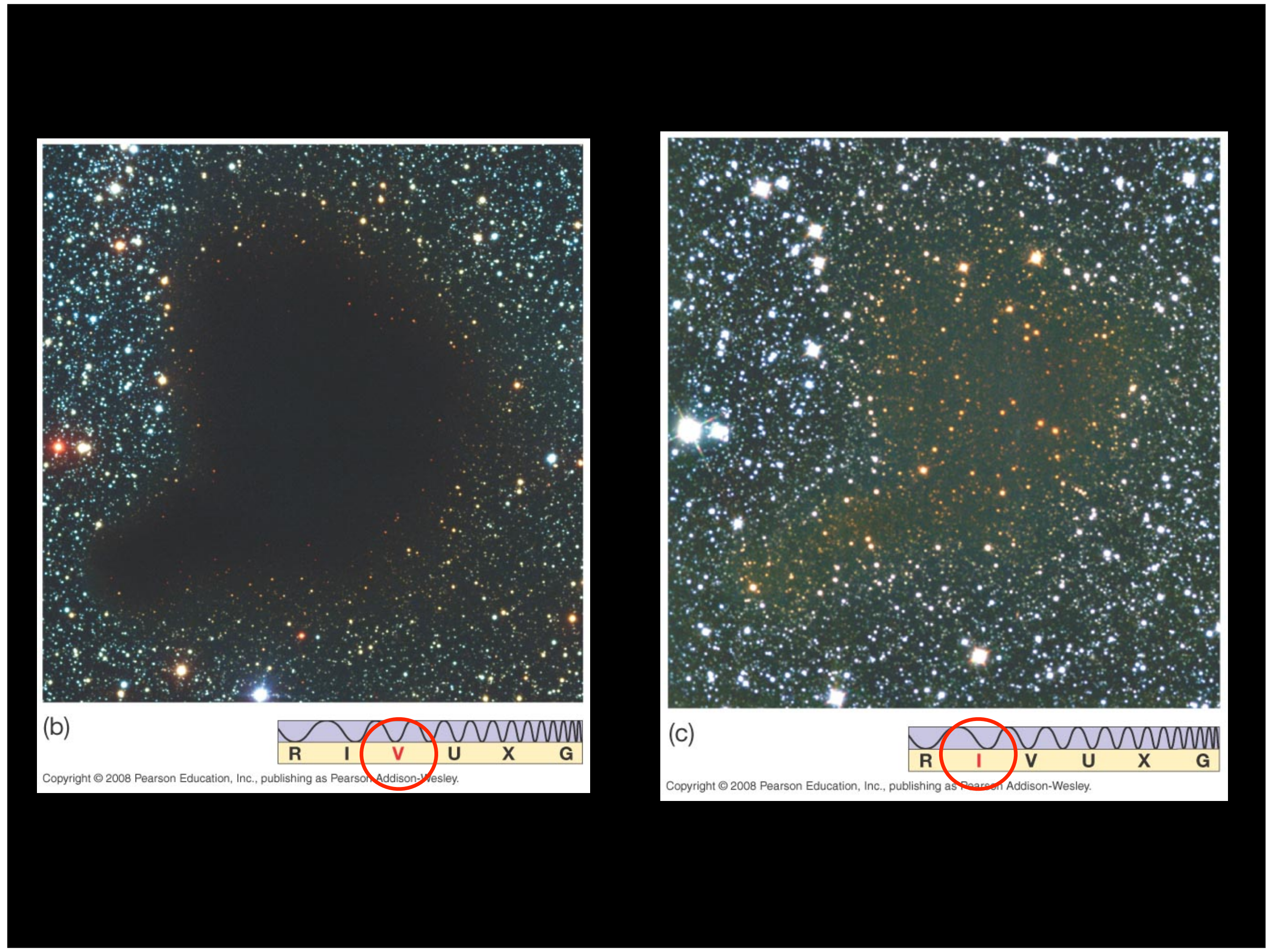

- absorption line pattern remains so can still find **spectral type** of star and get back real colour!
- compare to observed colour and intensity and derive how much dust in between it and earth

Absorption or scattering of light by particles with sizes comparable to or greater than the wavelength of the light (so shorter wavelengths are affected more).

Dust causes 2 main effects on starlight:

1) Extinction – affects shorter wavelengths of light more than longer wavelengths and causes dimming of starlight. (e.g. will absorb and scatter blue light while radio waves can pass through dust relatively unscathed.)

2) Reddening (or de-blue-ing!) – because shorter wavelength (blue) light is more affected by scattering and absorption by dust, these wavelengths are more affected and so objects can appear redder than they would if dust had not obscured them.




Look at the great example of visual extinction and infrared reddening above:

The left shows a picture of the dusty interstellar cloud Barnard 68 in visual wavelengths (i.e. taken with a normal optical telescope). You can see the dark region of the dusty cloud and it is obscuring the light from stars behind it -you can't see the stars behind it.

On the right is another picture of the same dusty cloud but in infrared. (using an infrared telescope). Because infrared light has longer wavelengths than visible light, it is less sensitive to absorption by the dust and it can travel through the dust cloud from the distant stars to the infrared detector on the telescope! We can therefore see the background stars via their infrared emission!
Notice also though, that the stars in the image which we are seeing through the dust cloud, appear redder than the other stars on the edges of the image. This is because the shorter wavelength infrared light is more affected by dust absorption/extinction than the longer wavelengths of infrared light.

## ISM Gas and Dust Properties

Density:

- Gas and dust found ***everywhere*** in interstellar space
- Average ***gas*** density = $10^6$ particles/m$^3$ ($10^4$ -$10^9$)
- ***Dust*** very rare: 1000 particles / km$^3$

Question: With such low densities of gas and dust, why do we still see extinction and reddening?

Look at the densities of gas and dust above. To put this in perspective, the best vacuum we can achieve in physics labs on Earth is about $10^{10}$particles/m$^3$!
(10^10 / m^3)
This is denser than the average gas density in interstellar space!

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Answer: We still observe extinction and reddening because the vast distances between stars mean that there is still a lot of matter to pass through, even if it's low density!

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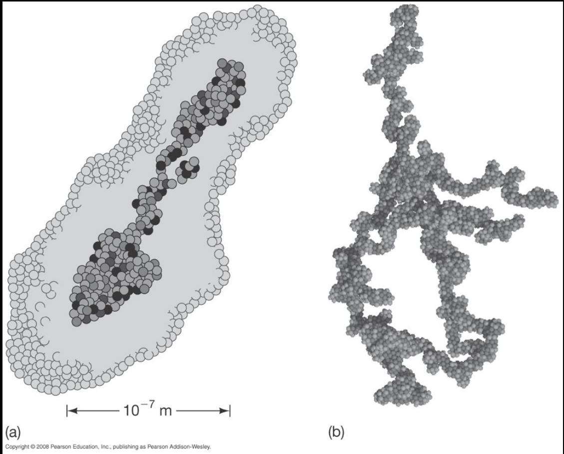
**Composition:**

- ***Gas:*** 90% H, 9% He, 1% heavier elements
- ***Dust:*** not well-known (silicates, graphite, iron, ‘dirty’ ice)

**Dust Shape:**

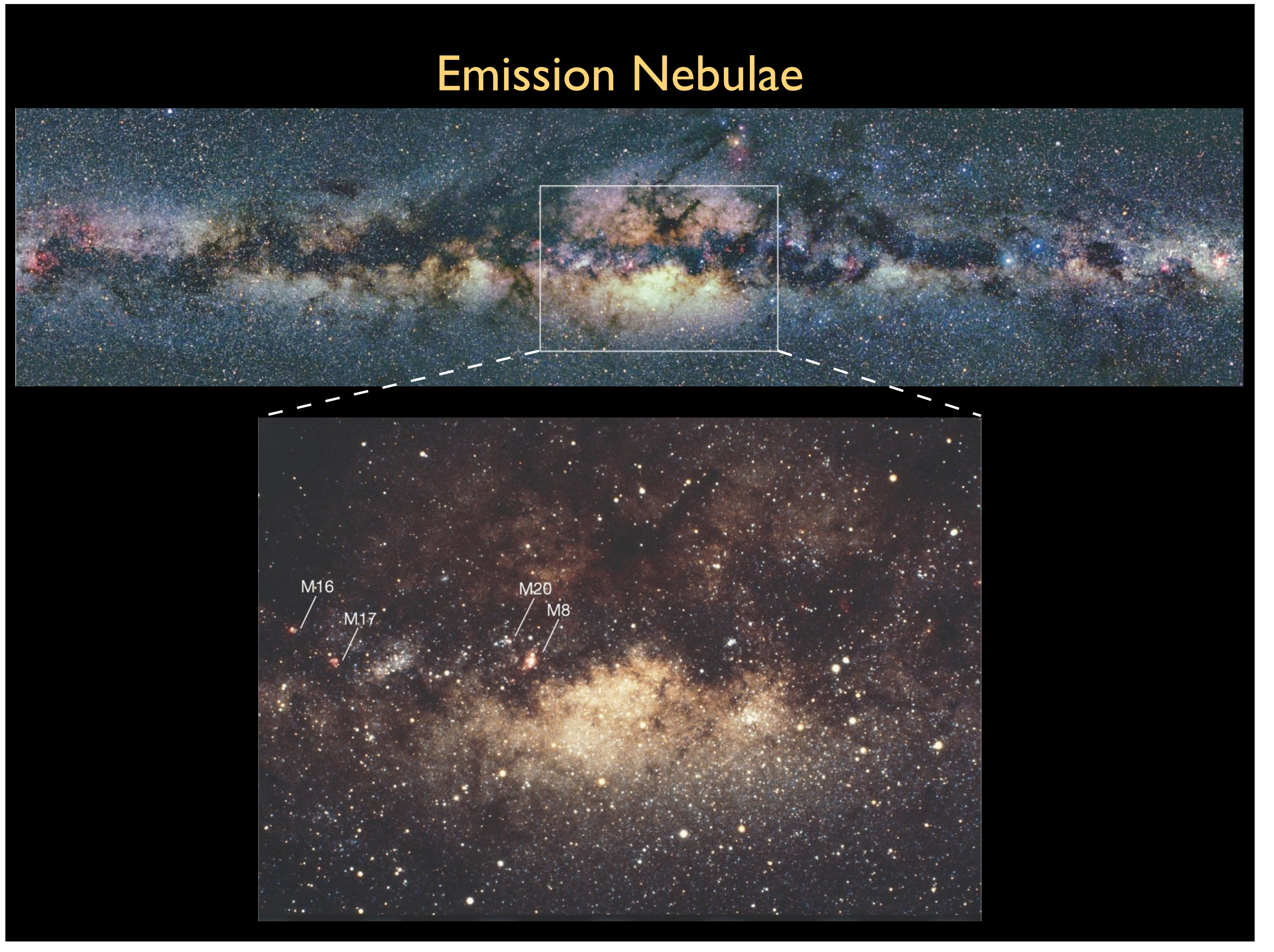
- elongated / rod-like (known from polarisation of starlight




The interstellar gas is composed overwhelmingly (90%) of hydrogen (most abundant element in the Universe!) with about 9% helium and then 1% other heavier elements.
Dust is much rarer and more difficult to identify its components, but we think it’s mostly silicates, graphite, iron, and dirty-ice.

‘dirty’ ice = water ice with trace amounts of ammonia, methane, etc.

We know that the dust must have an elongated shape to the molecules because starlight passing through dust clouds is observed to be polarised (like sunlight passing through your Polaroid sunglasses!)




As we've seen in the previous slides, the interstellar medium is not evenly or smoothly distributed throughout our galaxy. It is clumpy and found in large clouds called nebulae (singular = nebula). There are different kinds of these gas clouds that we will go through in the next few slides.

**Emission nebulae:**
Emission nebulae are glowing clouds of **hot** interstellar matter. Look at the zoom-in on the central region of the Milky Way above. The pink/red bright spots, M8, M16, M17, M20 are all emission nebulae. The 'M' stands for Messier after Charles Messier who made a catalog in the 1700s of fuzzy objects in the sky not be confused with comets (so that people could recognise new comets and didn't mix them up!).

# Nebulae

- Nebulae are clouds of interstellar gas and dust

## Emission nebulae

- glowing clouds of hot interstellar matter
- hot stars (O or B-type) inside the nebula ionise the gas with their UV radiation and when the atoms recombine, the gas glows (fluoresces)
- typically red due to H-alpha emission

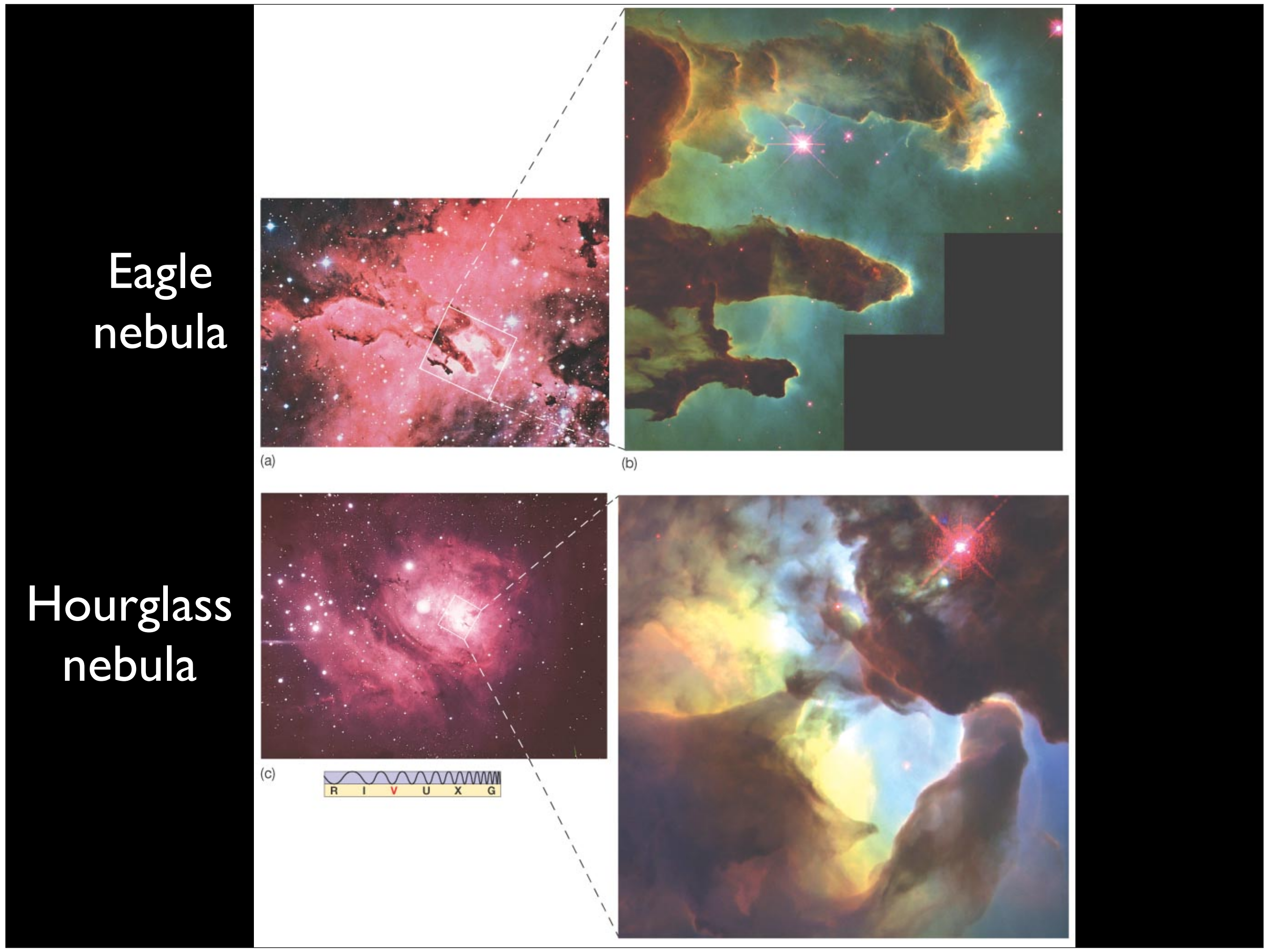
## Dark nebulae

- cloud lies in front of background stars and obscures them - forms dark patch on sky

A nice example of an emission nebula is the Heart Nebula: IC 1805. The red glow is from the Hydrogen line H-alpha (remember from Spectroscopy, the electron in the hydrogen atom is dropping down from n=3 to n=2 energy level and emitting a red photon)!

Another emission nebula example: the Seagull Nebula. The reddish glow from ionised Hydrogen (HII) recombining

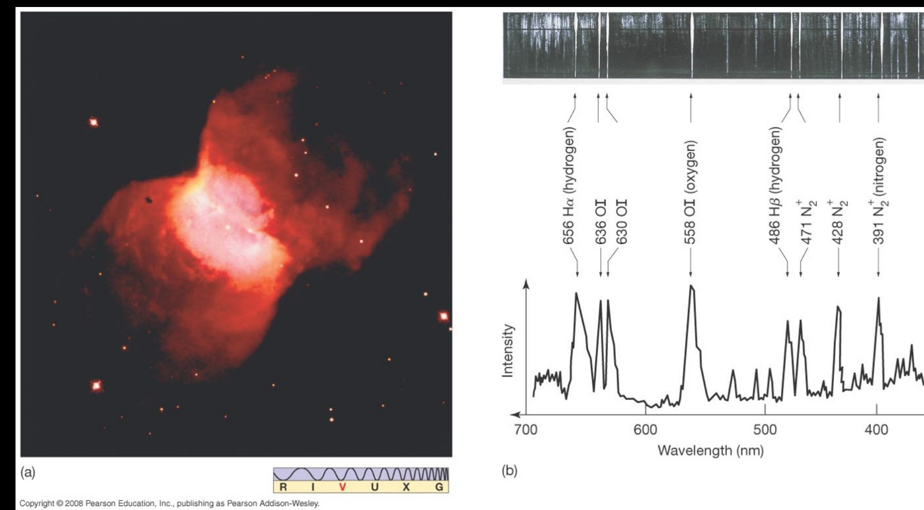
More emission nebula + dark nebulae clouds: Horsehead nebula (bottom left) is a dark nebula.  Orion nebula (top right) - red glow from H-alpha.




Note the bright hot stars located inside the nebulae which cause them to fluoresce.

# Nebula Spectra and Forbidden Lines

Emission nebulae spectra have <u>emission</u> lines:




What properties can astronomers deduce from the spectra of emission nebulae?

# Nebula Spectra and Forbidden Lines

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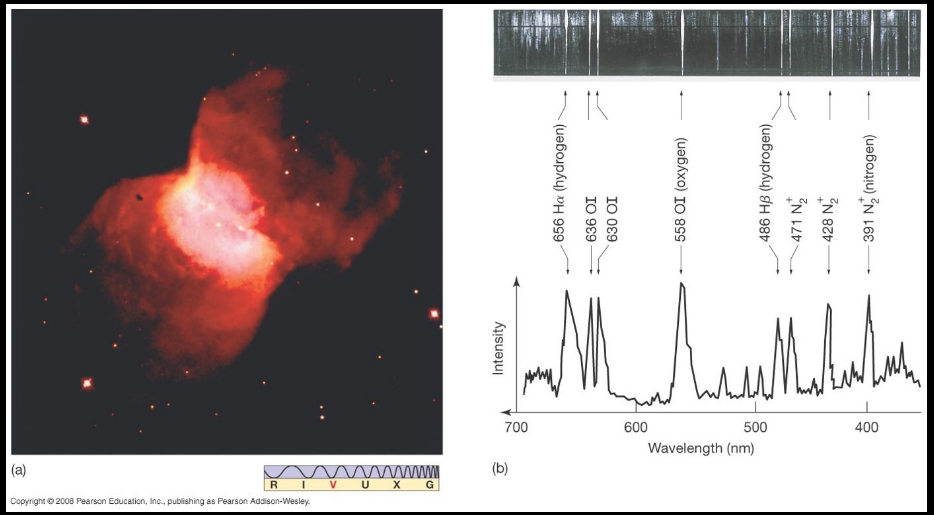
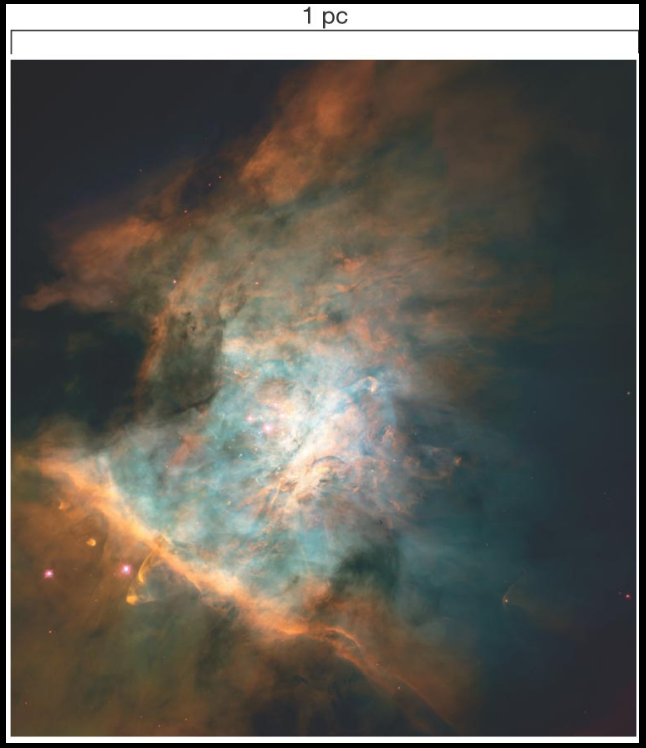



- Astronomers can identify chemical composition, temperature, density etc. from the spectral lines
- T ~ 8000 K

# Nebula Spectra and Forbidden Lines

- Green light - unidentified in lab: ***Nebulium***
- With understanding of the atom and transitions, identified as OIII transition (only happens if oxygen remains in excited state for long time)
- Called a “forbidden” line - because not observed in earth labs, only in low density interstellar environments!

Orion Nebula




Impossible in lab on Earth due to very low density needed – but possible in very low density regions in interstellar space!
– not really forbidden by physics, but instead very low probability to occur on Earth

# Dark Dust Clouds

Dark dust clouds are **cold** (10s of K) and very dense compared to surroundings

- very dense (!) (> $10^7$ -$10^{12}$ atoms / $m^3$)
- very large (larger than solar system, many parsecs across)
- mainly composed of gas and some dust

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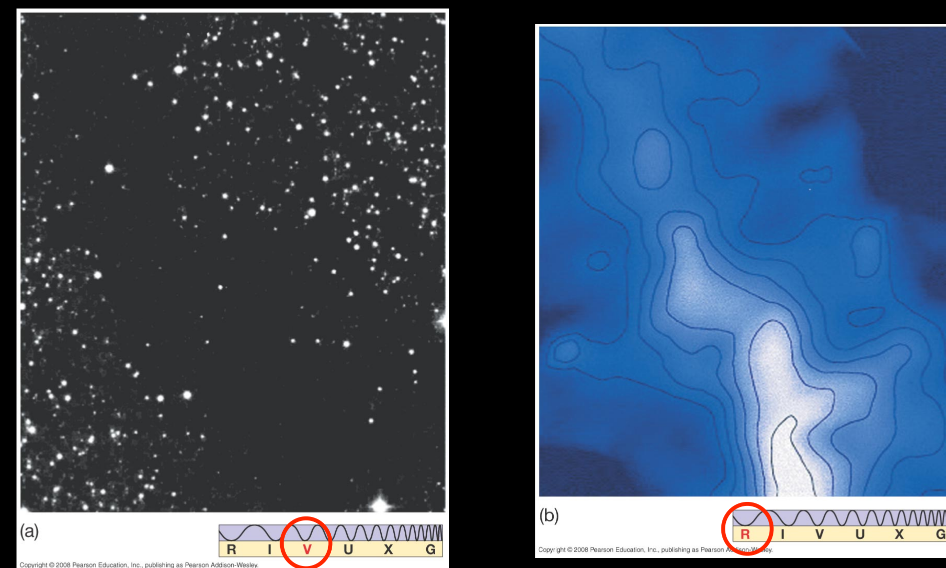
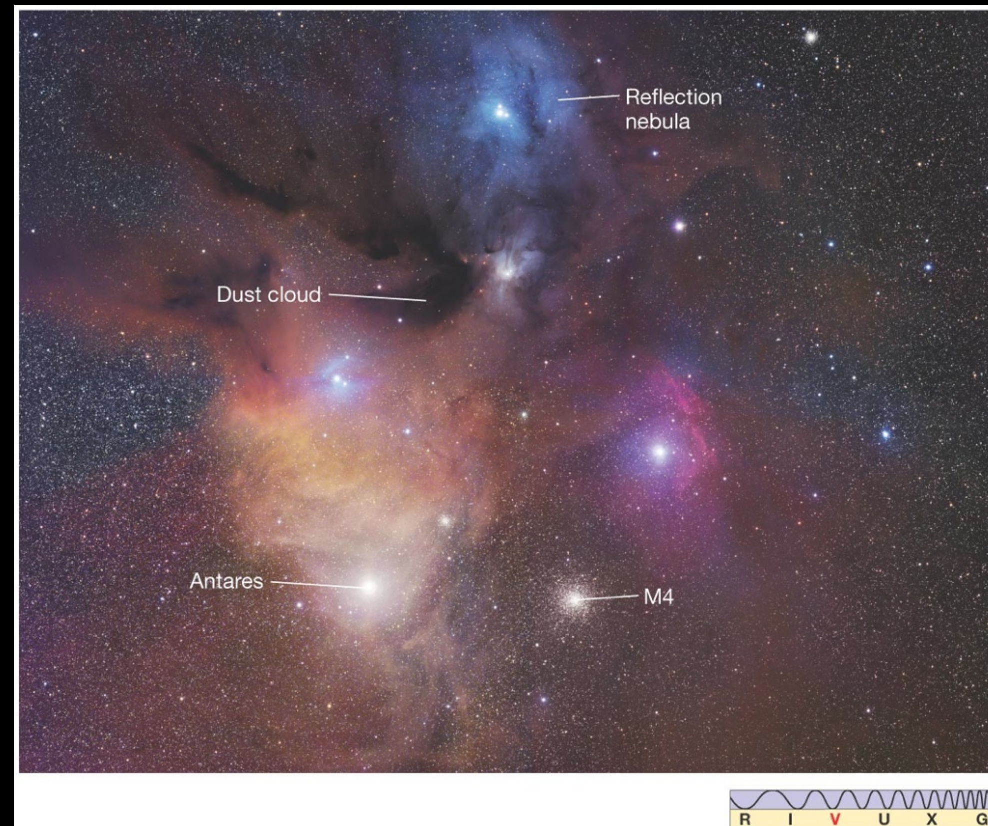



Look at the density above. While it's dense for space, it's still very low density!
- average density of interstellar space = $10^6$ particles/$m^3$ (10^6/m^3)
- radio wavelengths shed light on densities

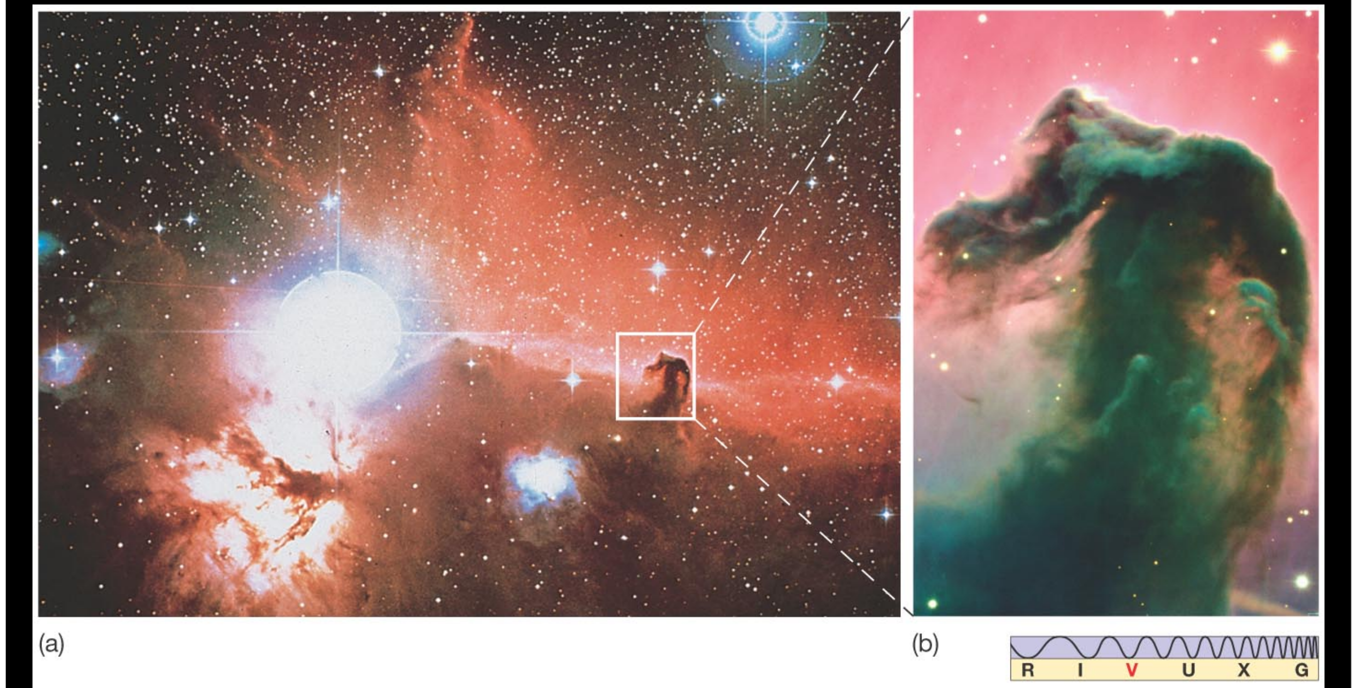
# Dark Dust Clouds





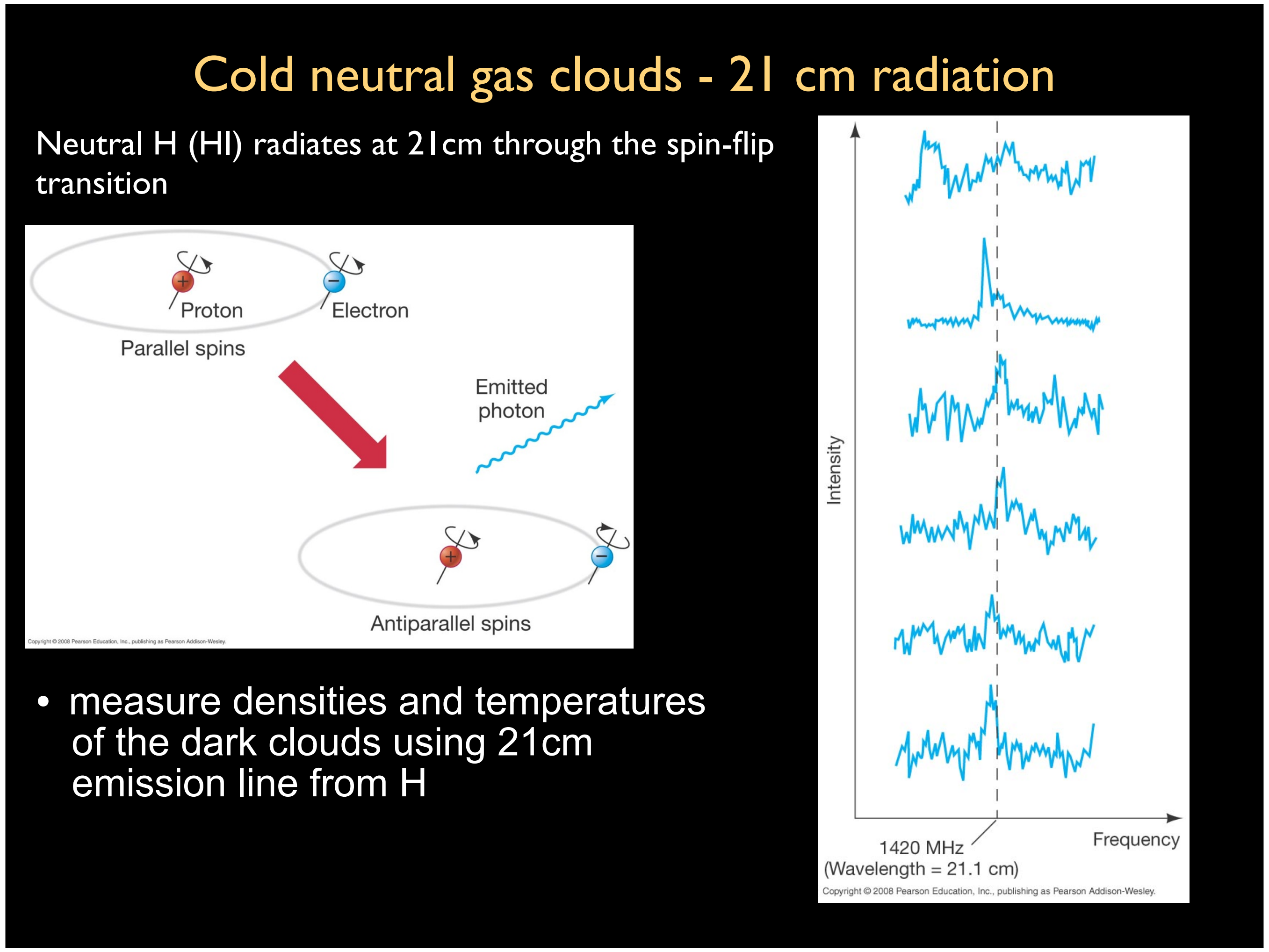

Rho Ophiuchus - 170 parsecs from Sun
irregular shape - not spherical

## Dark Dust Clouds






Here is a nice zoom-in of the Horsehead nebula in Orion - neck is 0.25 pc across (0.8 light years/ 5000 AU!) It is a very large structure!



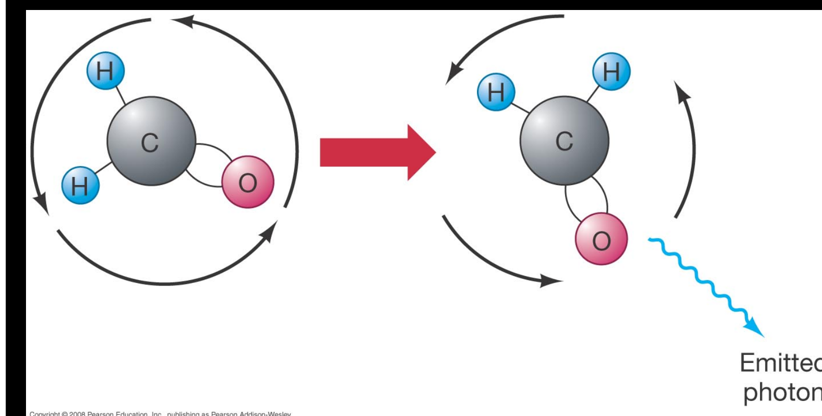

Cold neutral atomic hydrogen (called HI) has a spectral line transition at a wavelength of 21 cm. When the electron flips its spin to be anti-parallel to the proton, it goes down to a slightly lower energy level and emits a 21cm wavelength photon. We can observe this long wavelength emission with radio telescopes like MeerKAT. You can see HI spectral lines on the right hand side of the slide above.

Why are the lines not all centered at 1420 MHz?
 - gas is moving! Doppler shifted!

## Molecular Clouds

In very cold regions (~20K) densities can get as high as $10^{12}$ particles/$m^3$

- Very dense interstellar clouds of molecules: ***Molecular Clouds***
- Much bigger (~50 pc across) even than emission nebulae!
- Found in darkest, dustiest regions:
  - dust helps to shield molecules from energetic radiation
  - dust might be catalyst for molecule formation
- Molecular Hydrogen ($H_2$) is most abundant molecule in mol. clouds but does not emit radio radiation
- Other molecules e.g. CO, $NH_3$, $H_2CO$ (formaldehyde), etc., radiate in radio frequencies




- Emit radio wavelength EM radiation (rotational transitions)

The densest interstellar clouds are called **Molecular clouds**. They form at very low temperatures where atoms can form molecules. They are very large (50 pc across!) - even bigger than emission nebulae.

We can observe the different molecules in molecular clouds by looking for the radio and microwave emission from the molecules such as:
CO, hydrogen-cyanide, ammonia, water, methyl alcohol, formaldehyde