

The Interstellar Medium, and Star Formation

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Star Fields



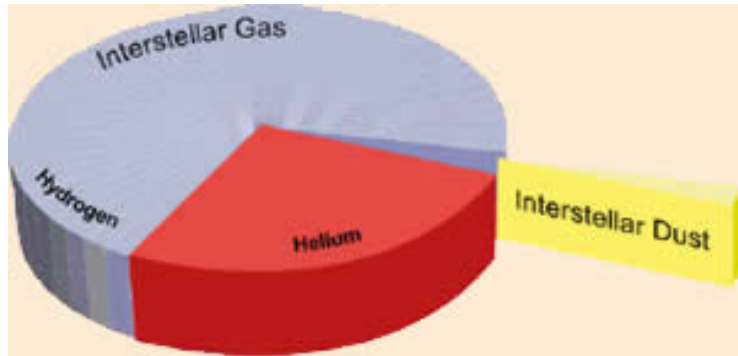
A typical star field, perhaps as seen from Vancouver.



A star field, as seen from a dark environment.

What do you see in these pictures? What don't you see?

Components of the interstellar medium



What we can't see optically, are the gas and dust—essential for the formation of new stars.

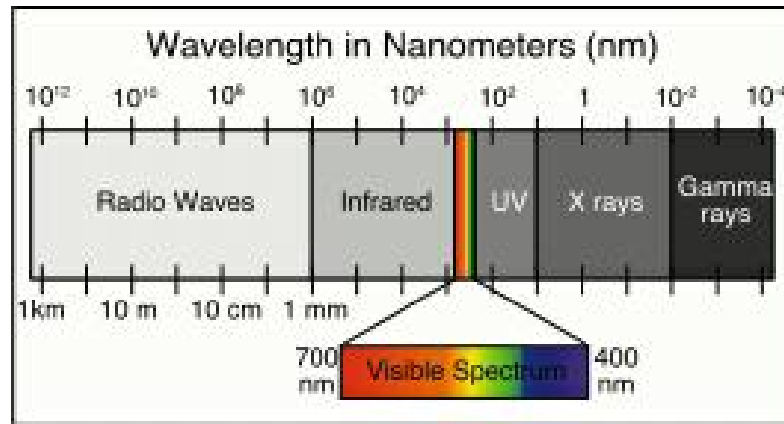
We can detect the electromagnetic radiation from the gas (hydrogen, or HI) and dust by using radio telescopes.



Jodrell Bank, University of Manchester, England

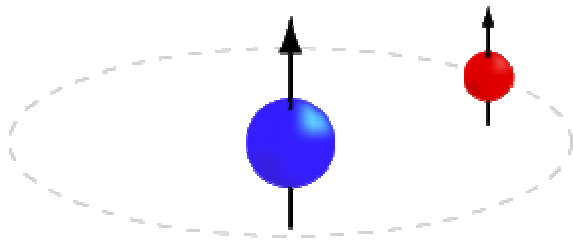


DRAO, Penticton, B.C.

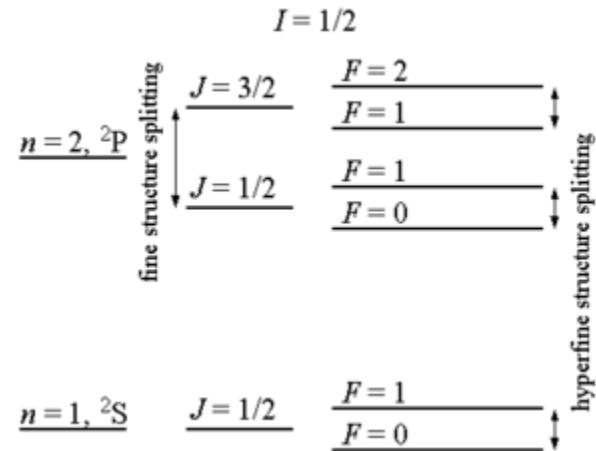


The electromagnetic spectrum.

The radio part of the spectrum is much broader in wavelength coverage than the optical part. The radio part of the spectrum that is most useful to the study of star formation, extends from 2.6 mm shortward to about 300 μm .



21 cm spin flip transition. When the spins are parallel as shown, the energy is higher than when they are anti-parallel.



When the spins flip to the lower energy level spontaneously, a photon of wavelength 21 cm is emitted. This spontaneous spin flip occurs once every 11×10^6 years. Radio telescopes can detect this 21 cm emission of electromagnetic radiation.

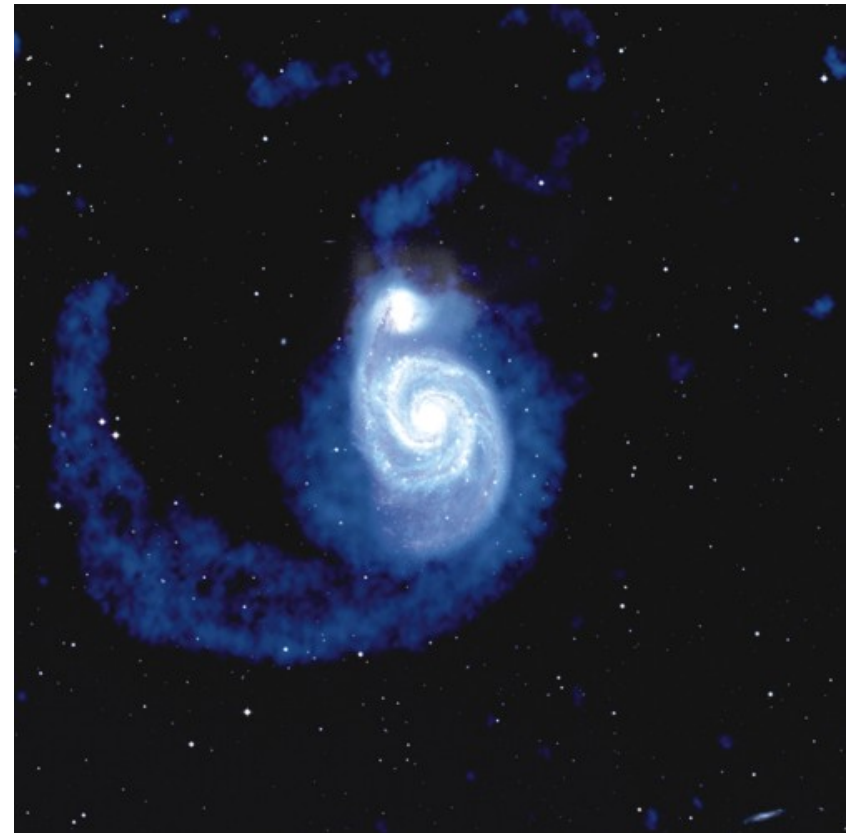
$$n_{\text{air}} = 5.4 \times 10^{19} \text{ cm}^{-3}$$

$$n_{\text{HI}} = 1-100 \text{ cm}^{-3}$$

$$\text{Gas/dust ratio} \approx 100$$



A model of what our galaxy looks like from 'above'.
The HI emission traces spiral arms.



The M51 (Whirlpool galaxy) and its companion
NGC 5195. HI emission is shown by the bluish
tinge.

Horsehead nebula



The outline of the horse head is caused by foreground dust obscuring background light.

Dust absorbs radiation from surrounding stars and comes to some equilibrium temperature. Dust then becomes a radiator of electromagnetic radiation at this temperature. The radiation wavelength is typically around 1 mm, or less. The warmer the dust, the shorter is the wavelength of the emitted radiation.

Hydrogen is the most abundant element in the universe. Next in order of decreasing abundance are:

Helium

Oxygen

Carbon

Neon

Iron

Nitrogen



Silicon

Magnesium

Sulfur

In regions of higher gas density, these atoms can form molecules.
It is in these regions of higher density that stars can form.

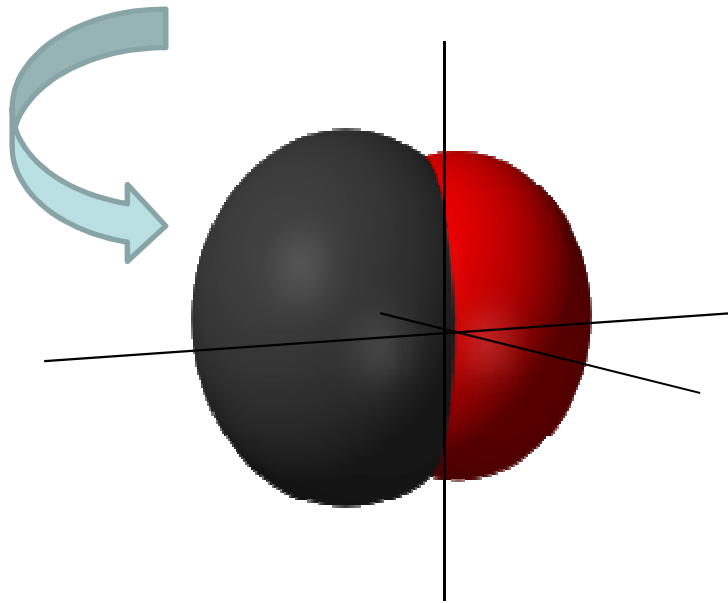
Molecules can be detected by their electromagnetic radiation using radio telescopes.

Diatomic	Triatomic	Four Atoms	Five Atoms	Six Atoms	Seven Atoms	Eight Atoms	Nine Atoms	Ten Atoms	Eleven Atoms	Thirteen Atoms
H ₂	O ₃	c-C ₃ H	C ₅	C ₅ H	C ₆ H	CH ₃ C ₃ N	CH ₃ C ₄ H	CH ₃ C ₅ N?	HC ₉ N	<u>HC₁₃N</u>
AlF	C ₃ H	l-C ₃ H	C ₄ H	l-H ₃ C ₄	C ₁₂ C ₁₀ CN	HC ₁₀ CH ₃	C ₃ H ₃ CH ₂ CN	(CH ₃) ₂ C ₃		
AlCl	C ₃ O	C ₃ N	C ₄ Si	C ₂ H ₄	CH ₃ C ₂ H	CH ₃ COOH?	(CH ₃) ₂ O	NH ₂ CH ₂ COOH?		
C ₂	C ₂ S	C ₃ O	l-C ₃ H ₂	CH ₃ CN	HCSN	<u>C₇H</u>	CH ₃ CH ₂ OH			
CH	CH ₂	C ₂ S	c-C ₃ H ₂	CH ₃ NC	HC ₆ CH ₃	<u>H₂C₆</u>	HC ₇ N			
CH ₂ ⁺	HCN	C ₂ H ₂	CH ₂ CN	CH ₃ OH	NH ₂ C ₂ H	<u>CH₂-OHCHO</u>	CRH			
CN	HCO	CH ₂ D ₁ ?	CH ₄	CH ₃ SH	 c-C ₂ H ₄ O					
CO	HCO [†]	HCCN	HC ₃ N	HC ₃ NH ⁺	 CH ₂ CHOH					
CO ⁺	HCS ⁺	HCNH ₂	HC ₂ NC	HC ₂ C ₂ O						
CP	HOC ⁺	HNC ₂	HCOOH	NH ₂ C ₂ O						
CSi	H ₂ O	HNC ₃	H ₂ C ₂ CN	C ₃ N						
HCl	H ₂ S	HOCO ⁺	H ₂ C ₂ O							
KCl	HNC	H ₂ CO	H ₂ NCN							
NH	HNO	l ₂ CN	HNC ₃							
NO	MgCN	H ₂ CS	SiH ₄							



Barnard 68, a dense molecular cloud

A list of many of the interstellar molecules. There are about 170 known molecules as of 2011.



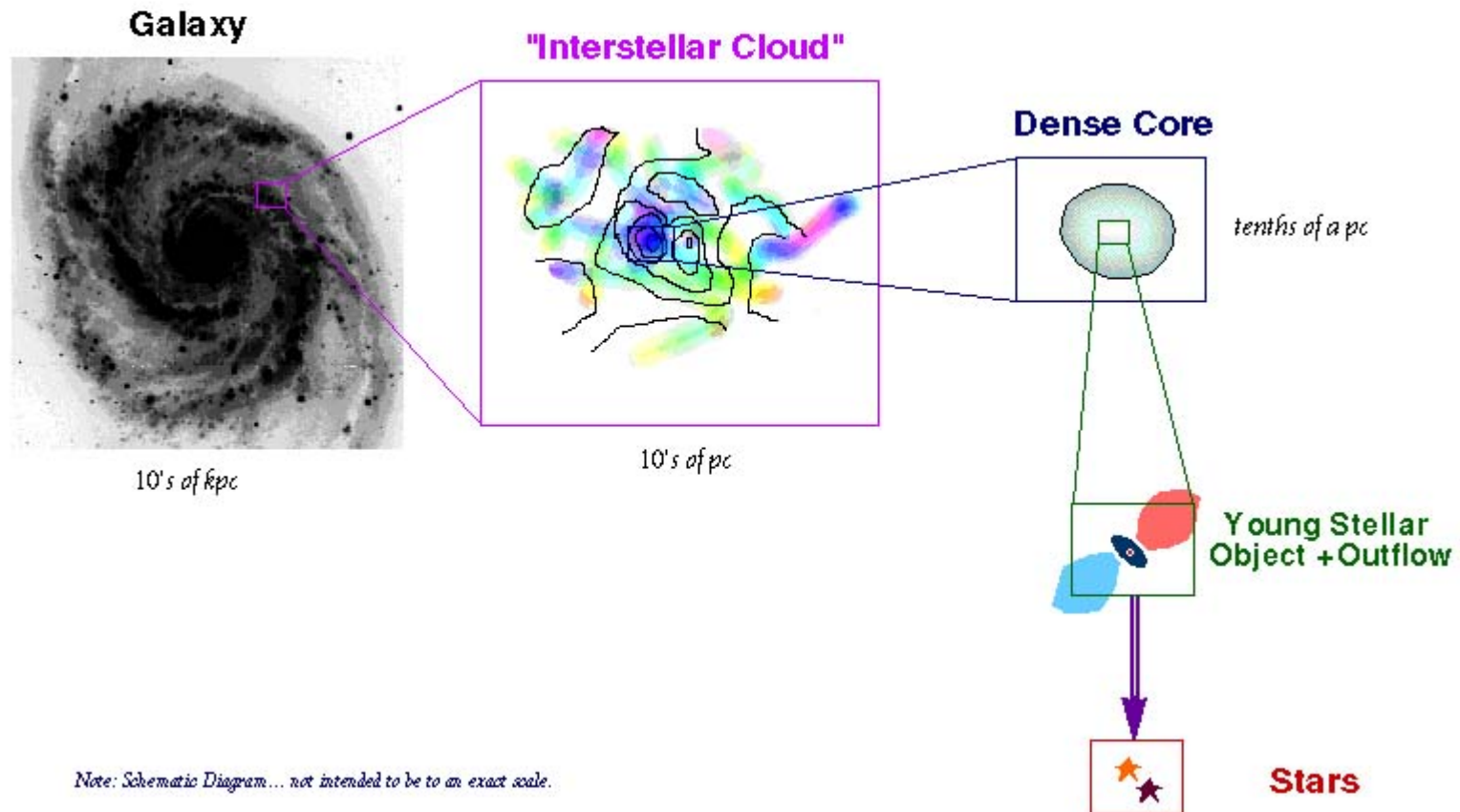
A carbon monoxide
diatomic molecule

When struck in a collision, the molecule can increase its rotational energy, but only in discrete steps.

When it decays to a lower energy spontaneously, it emits a photon of energy, i.e. a radio wave.

Component	Density (particles/cm ³)	Temperature (K)	State
HI diffuse medium	1-10 ²	50-100	neutral atoms
Molecular clouds	10 ³ - 10 ⁵	20-50	molecules

Star Formation in the Interstellar Medium



Note: Schematic Diagram... not intended to be to an exact scale.

Credit: Alyssa A. Goodman, Harvard University

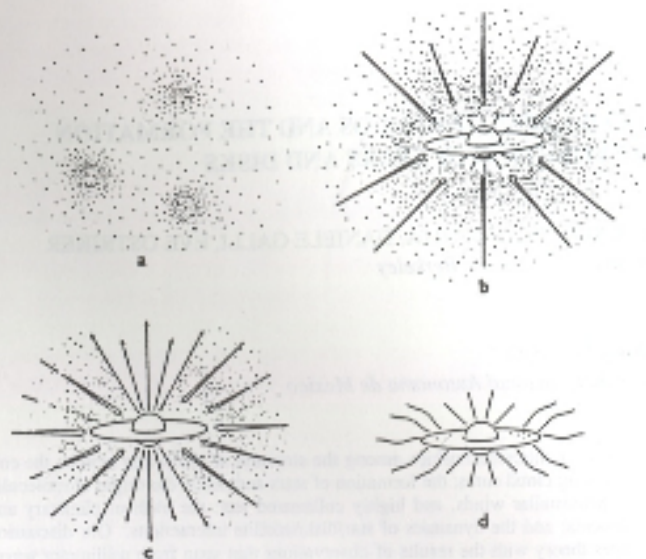


Figure 1. The four stages of star formation. (a) Cores form within molecular cloud envelopes as magnetic and turbulent support is lost through ambipolar diffusion. (b) Protostar with a surrounding nebular disk forms at the center of a cloud core collapsing from inside-out. (c) A stellar wind breaks out along the rotational axis of the system, creating a bipolar flow. (d) The infall terminates, revealing a newly formed star with a circumstellar disk (figure from Shu et al. 1987a).

Four stages of star formation. In stages b and c, there is a bipolar outflow of gas.

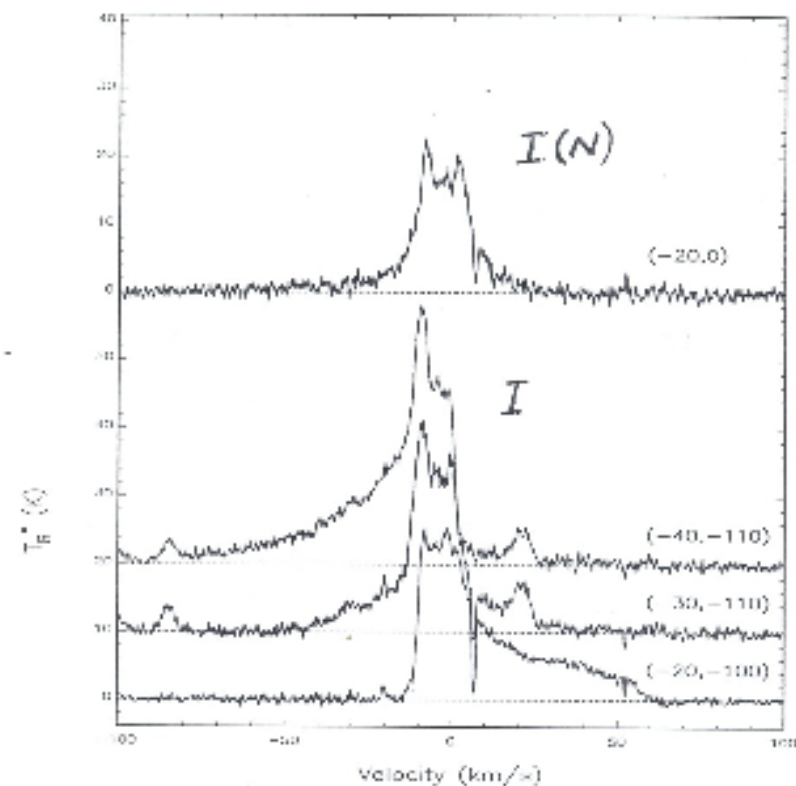


Figure 5.1: Sample CO $J = 3 \rightarrow 2$ spectra. CO line profiles from beam positions corresponding to peak I(North) $(-20, 0)$ and peak I $(-40, -110)$, $(-30, -110)$ and $(-20, -110)$. The coordinates are R.A. and declination offsets in arcseconds from the map reference position ($\alpha = 17^h 17^m 34.158^s$, $\delta = -35^\circ 42' 10''$). For I, spectra from three positions are shown to illustrate the bipolar wing structure.

CO ($J=3-2$) spectra obtained using the JCMT and observed toward the star forming region NGC 6334. Note the wide wings, indicating a bipolar outflow.

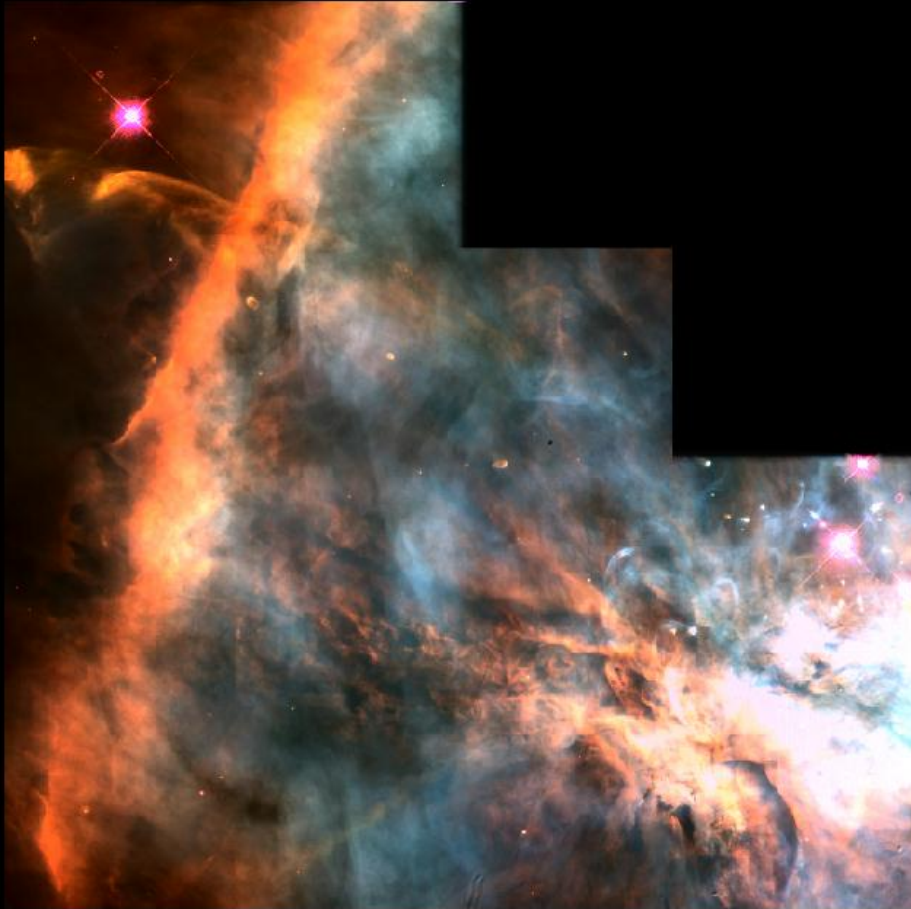


What are we looking at here?



The Constellation of Orion. In ancient mythology, the three bright stars in the middle form the belt of Orion, the hunter. The stars in a vertical line below are the sword of the hunter. The great nebula in Orion is the bright patch in this sword.

The Orion Nebula



Hubble Space Telescope
Wide Field Planetary Camera 2

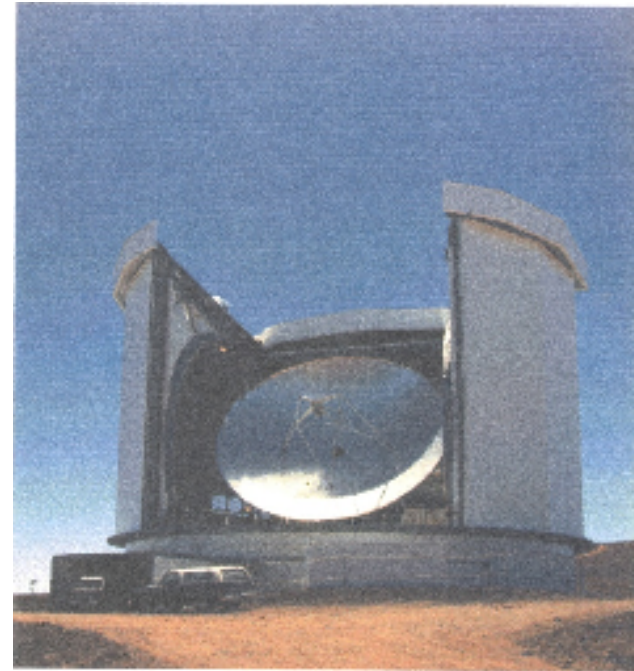


Giant molecular clouds, like this one in Orion, consist of dust and cool gas, mostly molecular hydrogen. When these gas clouds become massive enough, they form dense cores and begin to collapse.

Warmer than the surrounding regions, these cores, called protostars, become even more massive and hotter. The internal pressure in the cores mounts, igniting nuclear reactions. A star is born.



The James Clerk Maxwell Telescope (JCMT) on Maunua Kea in Hawaii. There is a protective membrane to protect the dish from sunlight.



The JCMT's 15 m diameter parabolic dish.

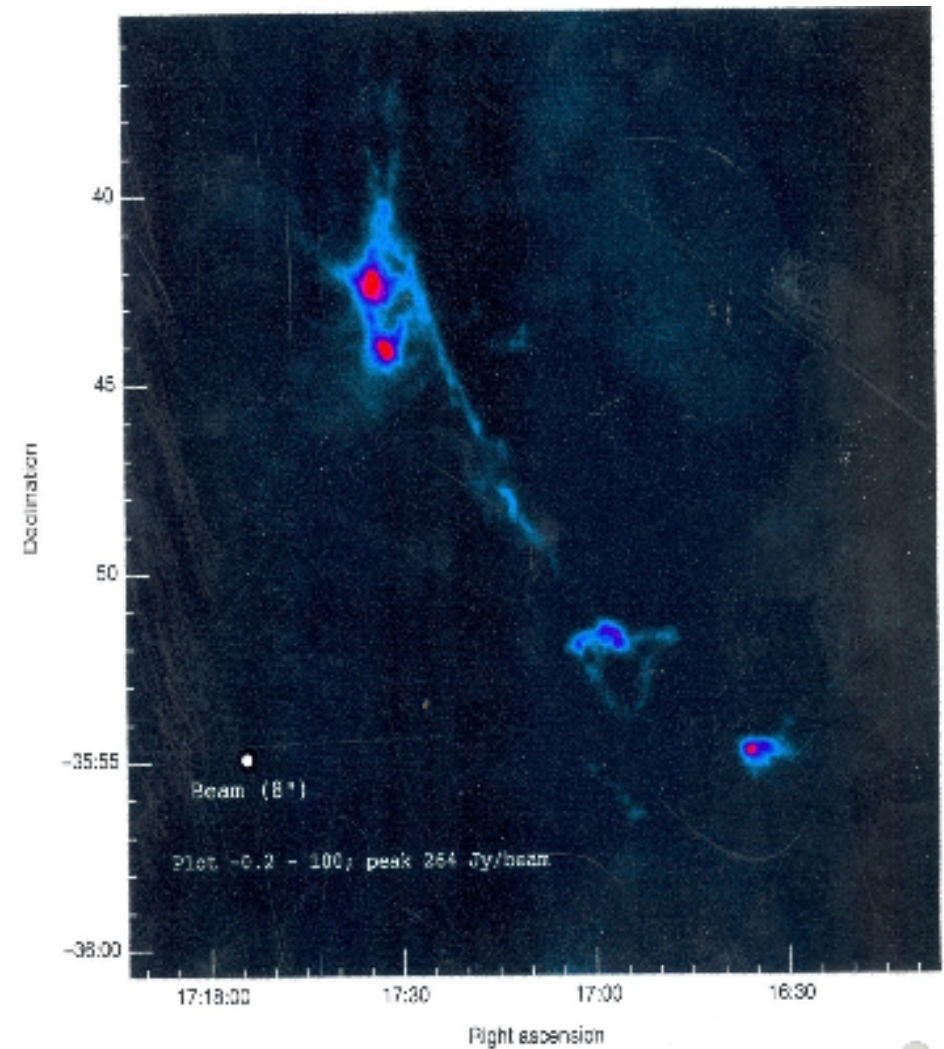
The JCMT, is the largest telescope single dish telescope in the world dedicated to detecting submillimetre radiation. In order to operate at these short wavelengths, it must be situated at a high elevation (4000 m).



Optical image of the nebula NGC 6334

Y-axis are, (blue, red, green and yellow are false). White is the area of the nebula, and yellow is the area of the GMC. The blue and yellow are, as a Giant Molecular Cloud (GMC) Complex.

The rectangle outlines the area of a Giant Molecular Cloud which lies behind the optical image. This GMC can be detected using radio telescopes.



The emission from dust in the GMC. The compact regions of intense emission (hot spots) are the cores where new stars are forming.

ATACAMA (Chile)



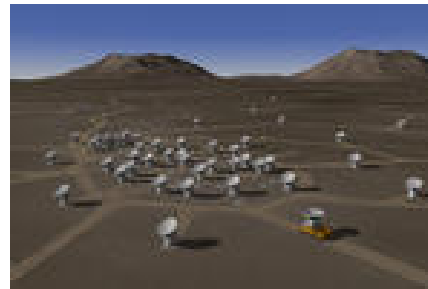
ALMA site (Atacama Large Millimetre Array)



Some of the telescopes in place



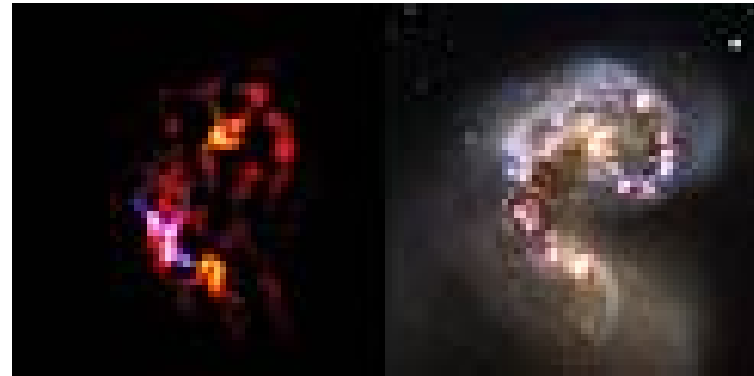
Atacama plain



Artists concept of full array



Antennae galaxies



ALMA observations
at mm and submm
wavelengths.

VLT (optical)
observations.