AST 309L Tues Sept 9

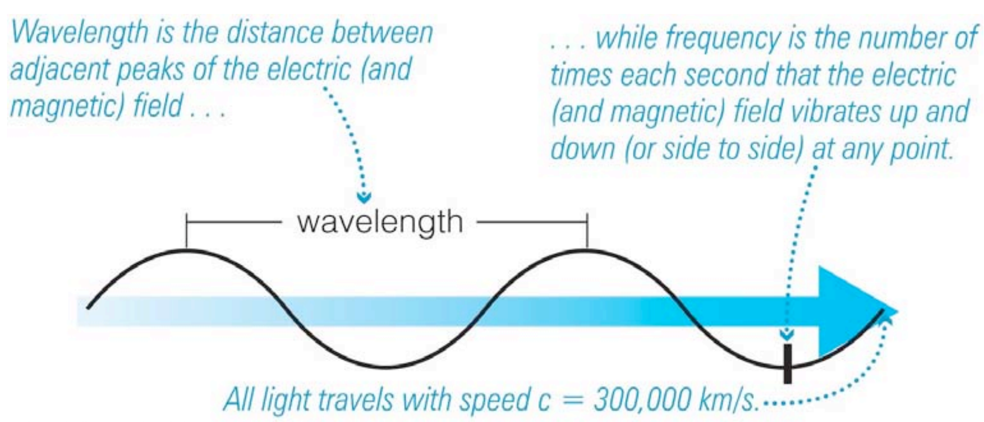
- Review of the electromagnetic spectrum: how the continuous spectrum of an object tells you its temperature

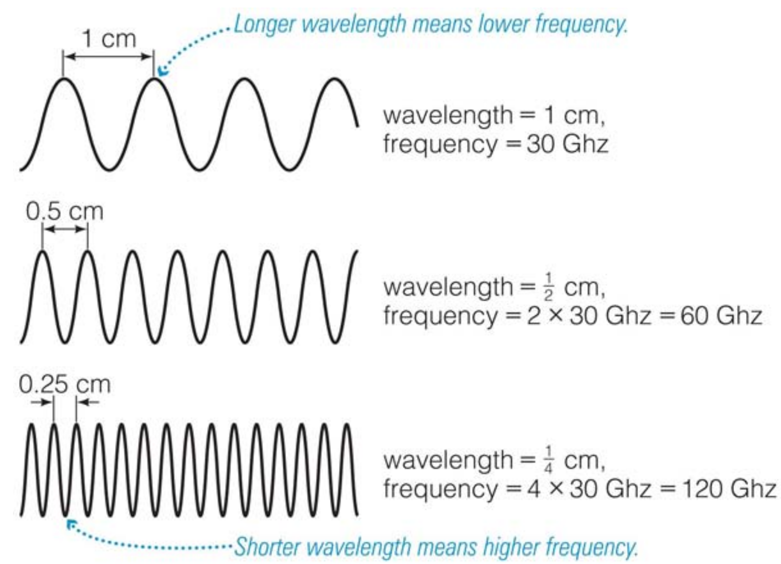
- And important lesson thanks to spectral lines:
  Ubiquity of complex organic molecules: interstellar star-forming regions, comets, elsewhere. (Assignment included)

- Planet formation (on next set of slides)
  1. Inferences from our own solar system
  2. Observational evidence for disks
  3. Theory of planet formation

Wavelength, frequency, energy

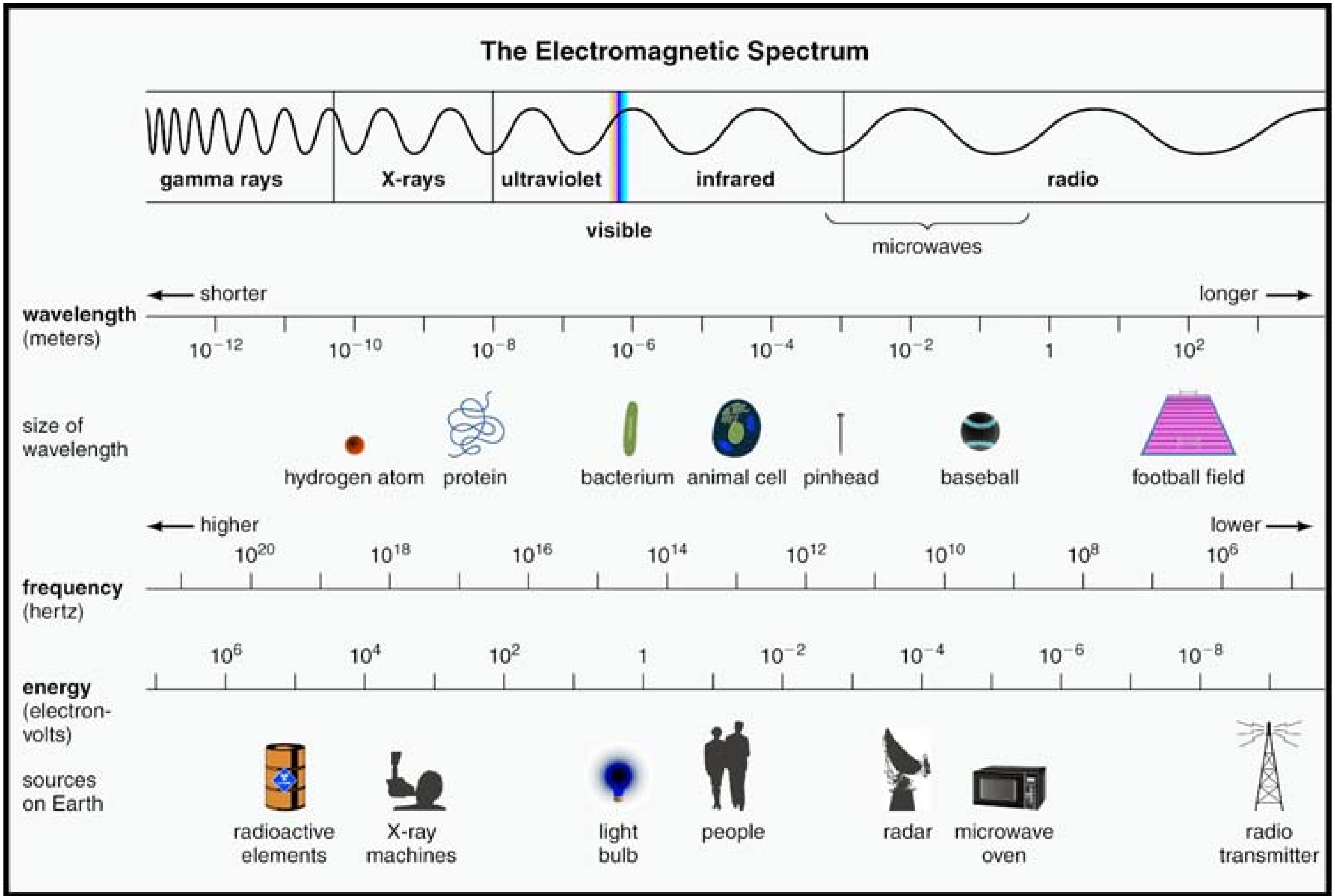
You don't have to remember specific wavelengths or be able to convert between units, but you *should* recognize the names of the basic regions of the spectrum, which is best for (say) observing a star to detect planets from the star's radial velocity variations, or to detect a planet directly, or the wavelength region where you can best observe emission from a disk in which planets are forming, and so on. Also, specifically what the barriers to detecting Earth-like planets are, from the ground, and from space. Which wavelengths are most harmful to complex molecules that might become organisms? ….



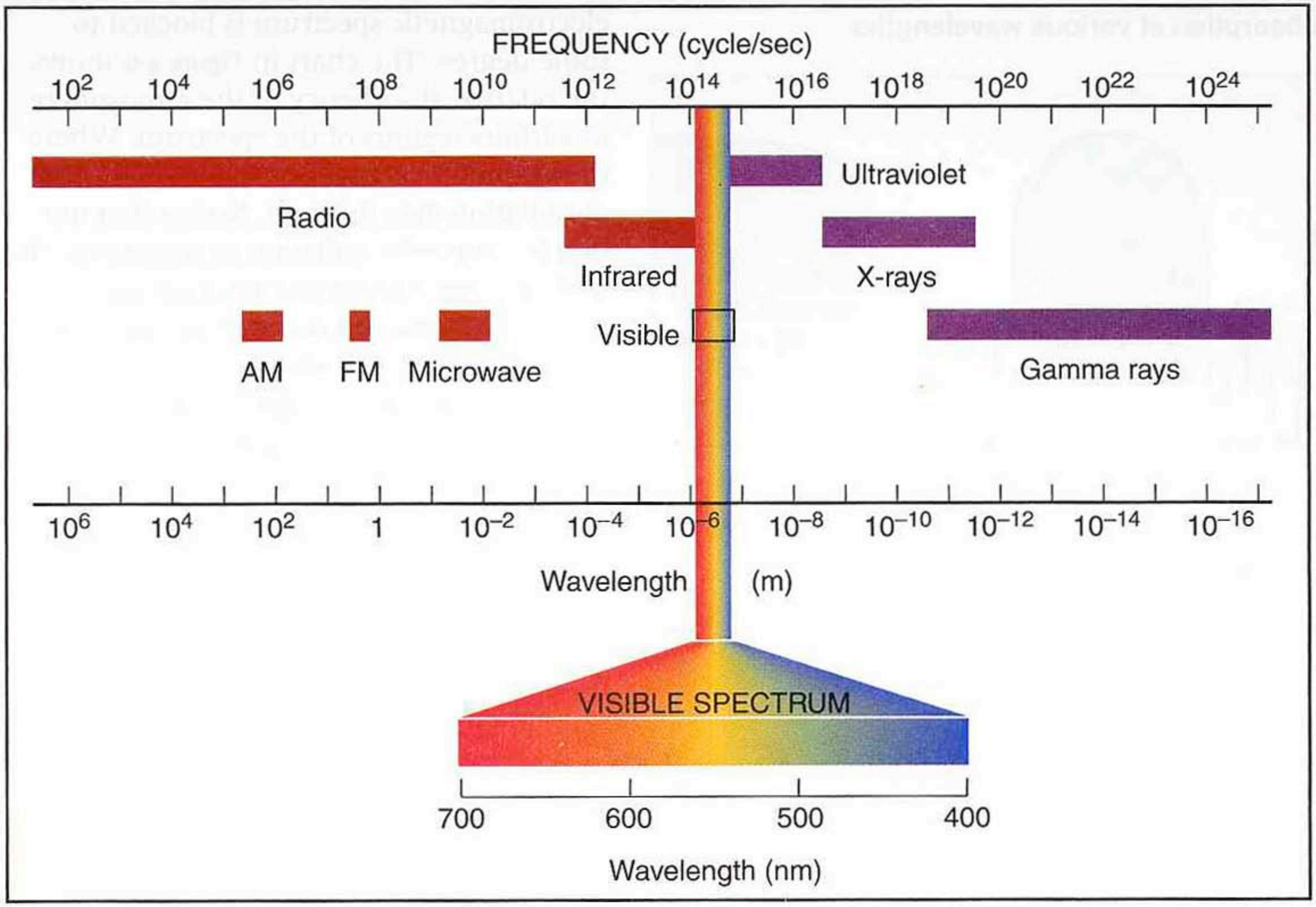


Which of the waves on the right has the most ***energy***? Try to associate each wavelength range with a commonplace energy, or temperature, range. For example, gamma rays should remind you of nuclear explosions. Radio waves correspond to extremely *cold* temperatures. Why? See (overly) complex diagram on next slide.

Know the regions of the spectrum - why is infrared light so important in this course?



Wavelength Regions in the Electromagnetic Spectrum



Continuous spectrum of an object: "Color" tells you temperature

Example where this is not true: reflected light

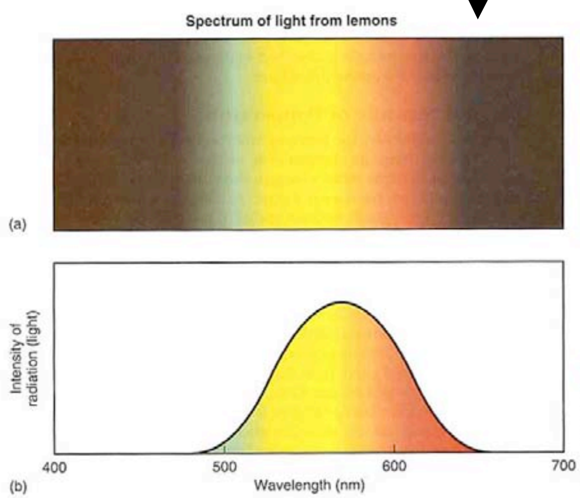


Figure 4-7
(a) If light reflected from the lemons were sent through a prism to reveal its spectrum, we would see that the lemons reflect mostly yellow light.
(b) This graph indicates the relative intensity of the various wavelengths of light from the lemons.

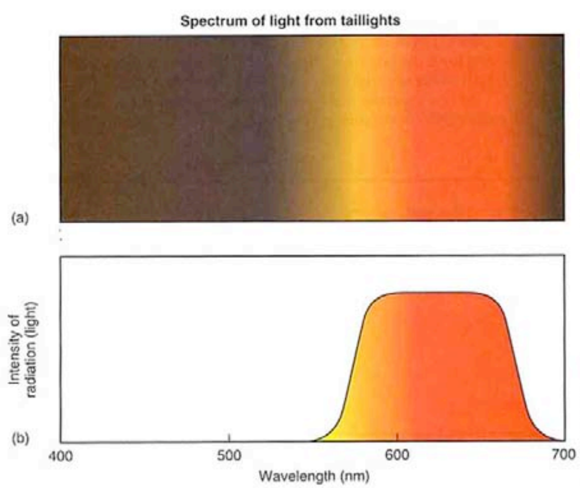
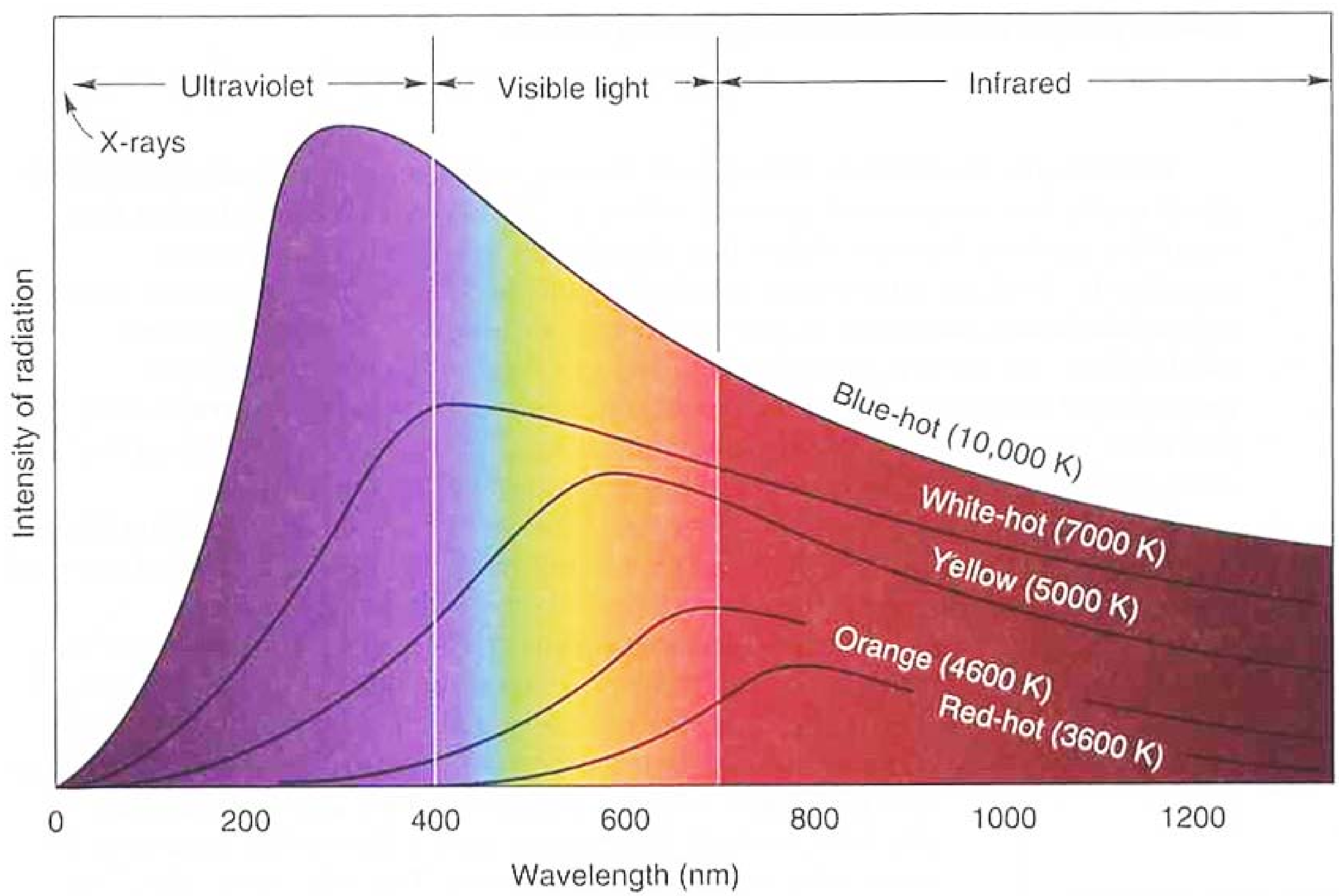


Figure 4-8
The spectrum of light from the taillight of this particular car. The light bulb emits white light, but the plastic cover over the bulb absorbs much of the light, letting pass some wavelengths in the red, orange, and yellow regions of the spectrum.

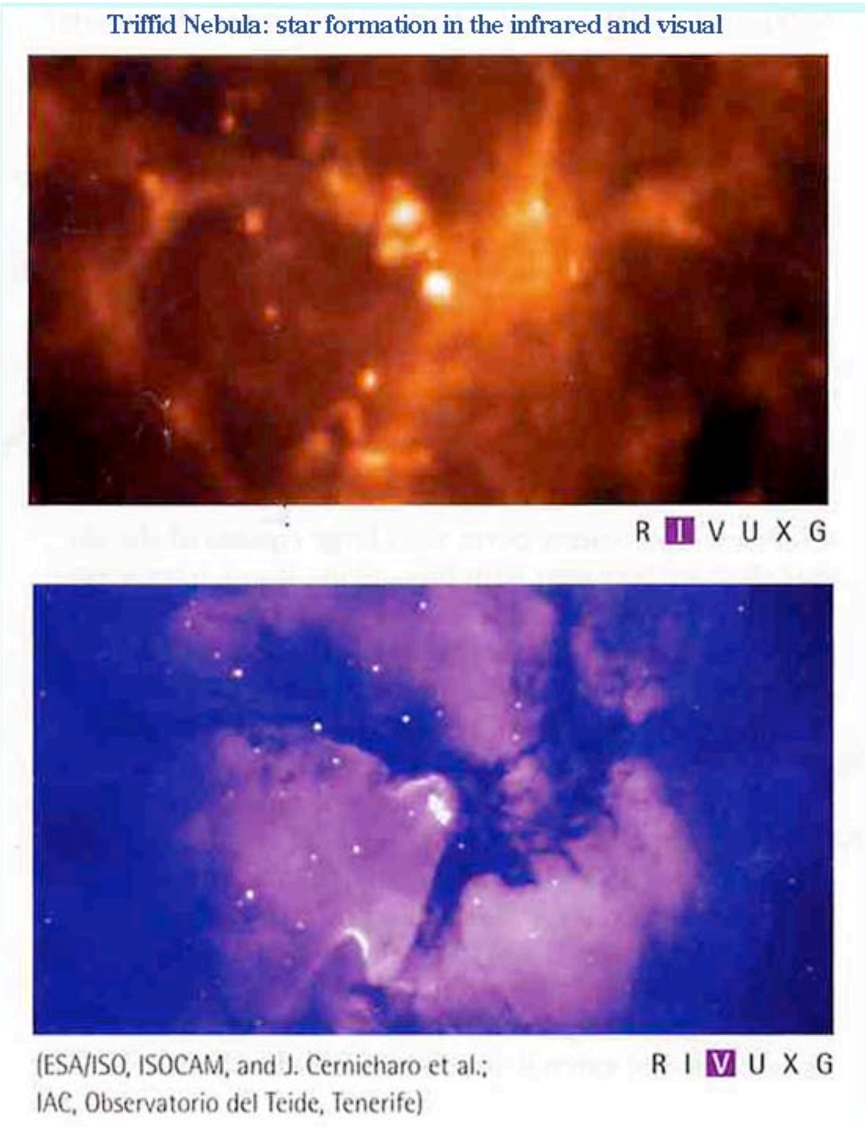
All objects emit at all wavelengths, but usually have a dominant wavelength region, where most of their energy is emitted or reflected. This is "Wein's Law." But in the cases shown to the left, the color you perceive is *not* related to the temperature; if you could see all wavelengths, ***you would see both cases as having a peak in the infrared*** (we will see why).

At what wavelength could we best obtain an image of an extrasolar planet? Of a planetary system in the process of formation? Of its parent star? *The key is the temperature*.

Many objects emit light in a continuous spectrum that is similar to a "blackbody". The peaks in the continuous spectra below depend on the ***temperature*** of the object. Solids around stars (dust in protoplanetary disks, planets themselves) are at temperatures around 100 to 500 K (just think of your planet if you think you won't remember this), so they will emit mostly in the **infrared,** just as objects around you do. *That* is where we would observe if we wanted to detect planets *directly*.



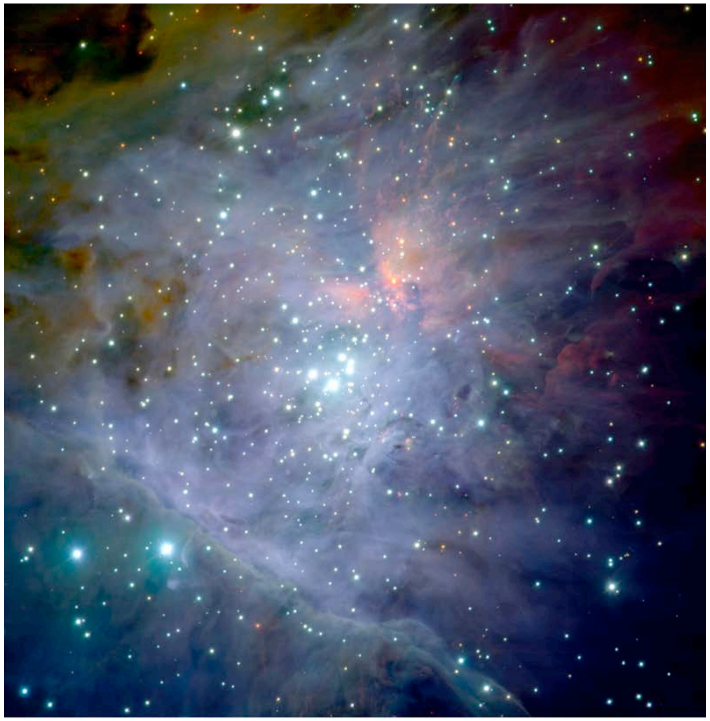
Star formation regions: Good place to search for protoplanetary disks, planets in the process of formation.



Star formation regions (and the entire interstellar medium) contain about 1% dust grains, which are believed to play an essential role in the formation of planets. The dust glows in the infrared (top; ***why IR***?) and appears dark in the visual part of the spectrum (bottom, why?).

Key words: Thermal radiation (top); extinction by dust grains (right)

Planets, if they form at all, must form as part of the star formation process: Planets are literally what formed out of the “debris” that didn’t find its way into a star



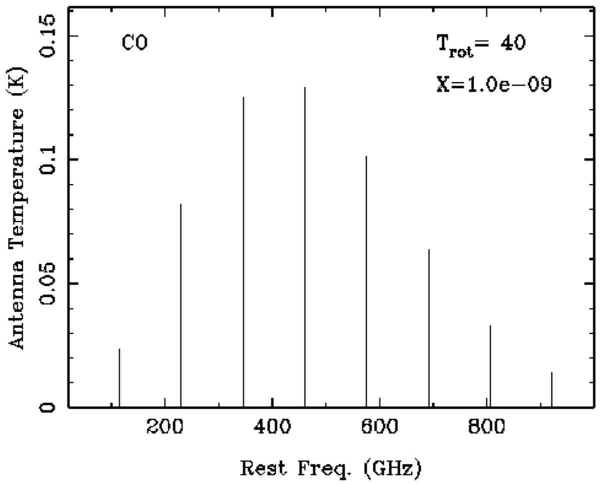
The Orion Nebula and Trapezium Cluster
(VLT ANTU + ISAAC)

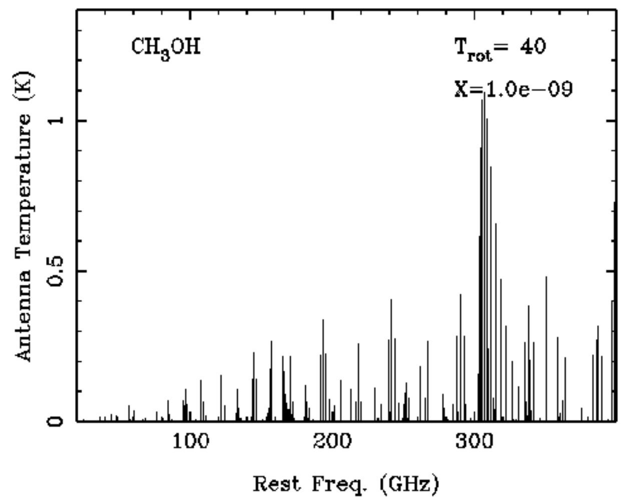
These images are the Orion and Omega Nebulae: star-forming regions as observed in the visual part of the spectrum. These regions are typical, containing hundreds to thousands of newly-formed (and forming) stars from ~ 0.1 to 100 solar masses. The gas is glowing because of the radiation from the massive young stars. The “dark lanes” are dense regions in front of the glowing gas; they are dark because of the dust they contain. Planets will have to form amidst this energetic activity due to the massive stars (winds, jets, explosions), so it is not obvious whether the formation of planets is likely.

Spectral lines in interstellar clouds:

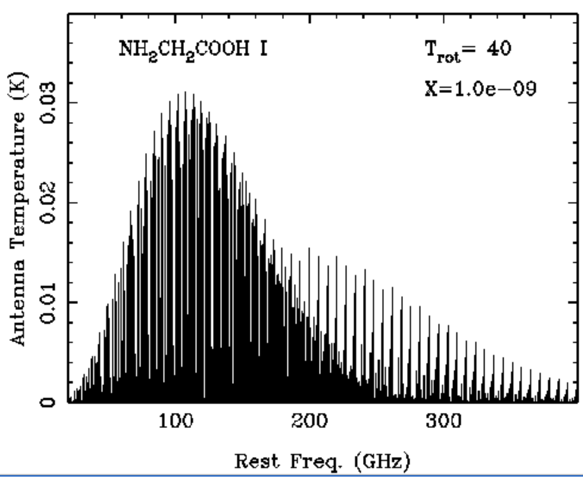
Evidence that organic molecules form easily, even in extremely harsh environments

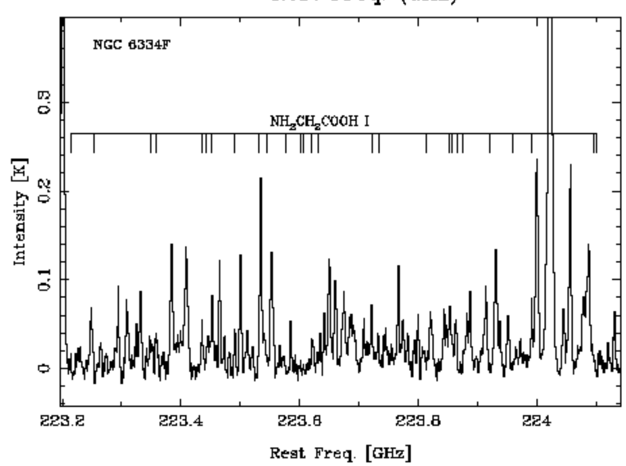
One promising result is that many molecules, some complex, are observed, mostly through their spectral lines due to rotational transitions in the radio part of the spectrum. Some examples of molecular rotational spectra, from simple to more complex, are shown below.





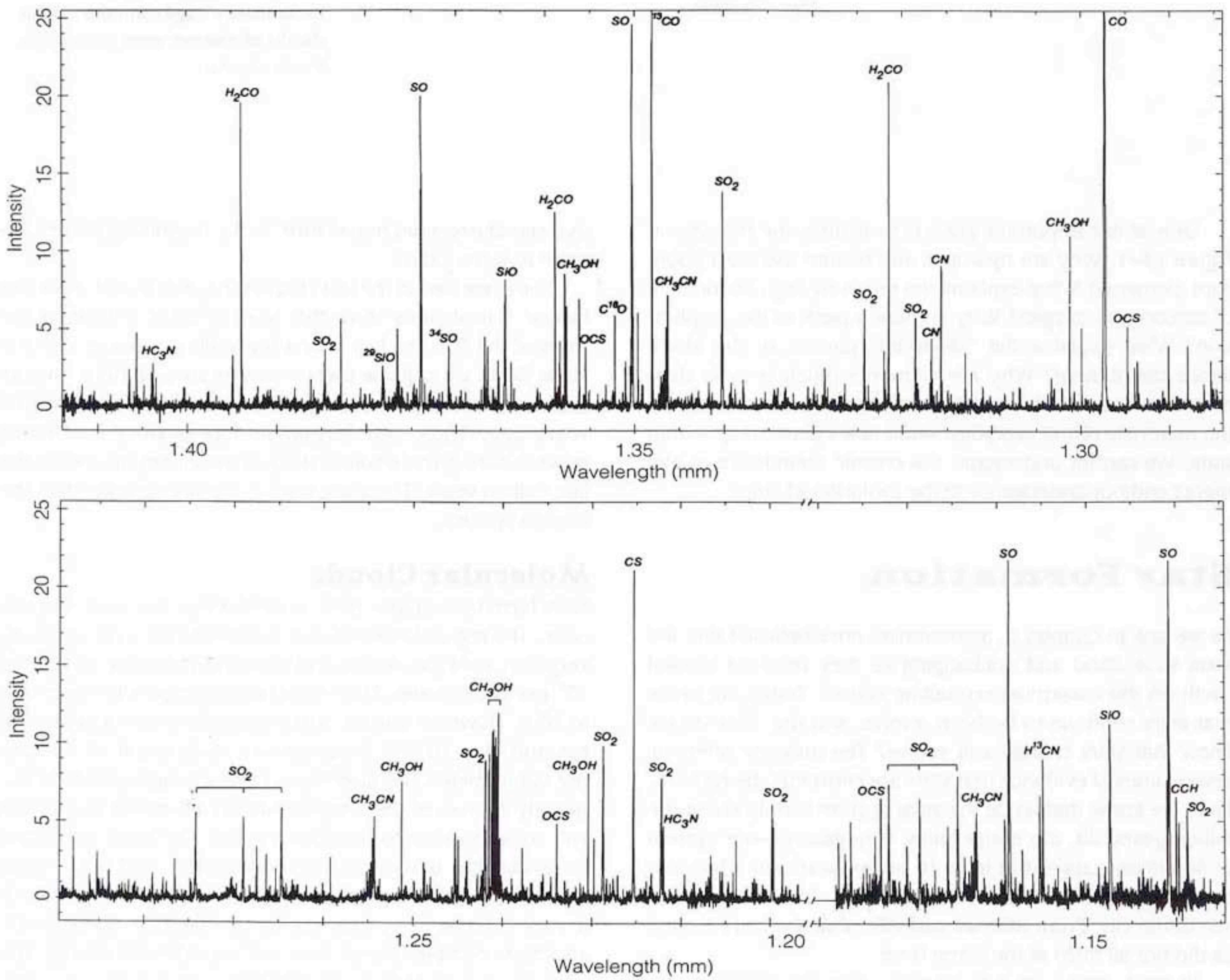
Glycine





Methanol

Radio molecular emission lines observed in the Orion Nebula



Molecules identified in dense interstellar clouds (where stars and planets form!)

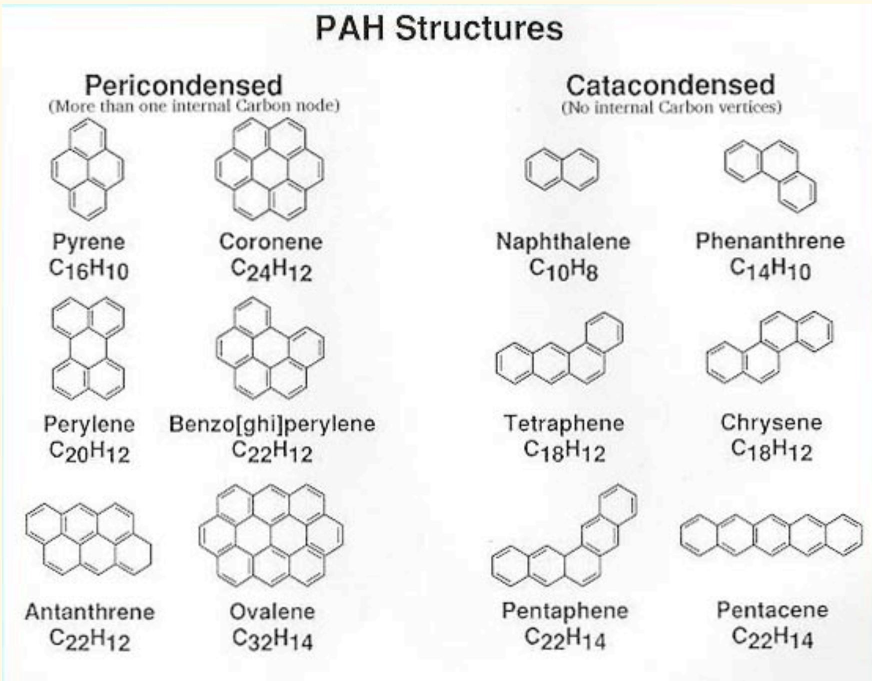
Identified Interstellar Molecules Classified by Number of Atoms per Molecule

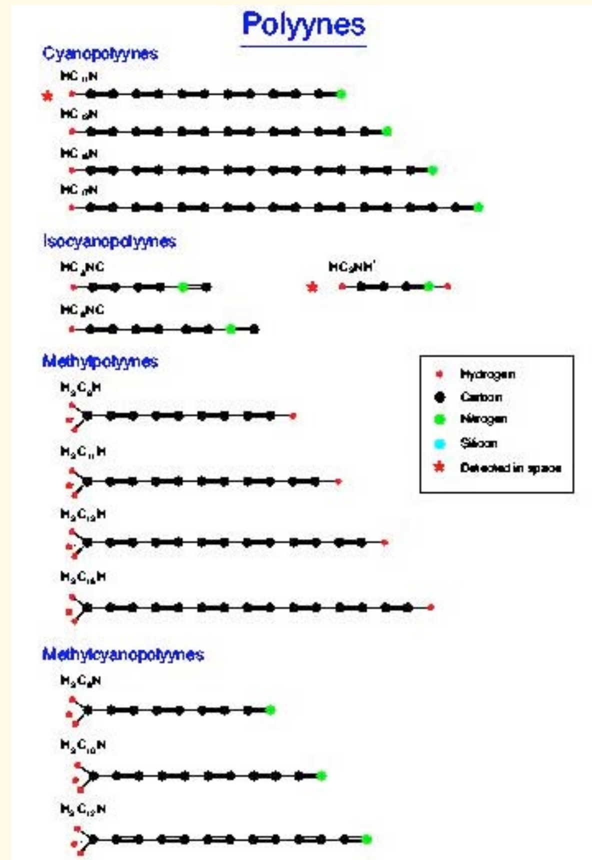
2 Atoms	*3 Atoms*	*4 Atoms*	*5 Atoms*	*6 Atoms*	*7 Atoms*	*8 Atoms*	*9 Atoms*	*10 Atoms*	*11 Atoms*	*13 Atoms*
H_2	H_2O	NH_3	SiH_4	CH_3OH	CH_3CHO	$HCOOCH_3$	CH_3CH_2OH	CH_3C_5N?	$H(C\equiv C)_4CN$	$H(C\equiv C)_5CN$
OH	H_2S	H_3O^+	CH_4	CH_3CN	CH_3NH_2	C_7H	$(CH_3)_2O$	$(CH_3)_2CO$		
SO	SO_2	H_2CO	HCOOH	CH_3NC	CH_3CCH	H_2C_6	CH_3CH_2CN			
SO^+	N_2H^+	H_2CS	$H(C\equiv C)CN$	CH_3SH	CH_2CHCN	CH_3C_3N	$H(C\equiv C)_3CN$			
SiO	HNO	HNCO	CH_2NH	C_5H	$H(C\equiv C)_2CN$	CH_3COOH	$H(C\equiv C)_2CH_3$			
SiS	C_2O	HNCS	NH_2CN	HC_2CHO	C_6H	CH_2OHCHO	C_8H			
NO	HCN	C_3N	H_2CCO	C_2H_4	$HCOCH_3$					
NS	HNC	HCO_2^+	C_4H	H_2CCCC						
HCl	HCO	SiC_3	C_3H_2	HC_3NH^+						
NaCl	HCO^+	c-CCCH	CH_2CN	l-H_2C_4						
KCl	N_2O	$HCNH^+$	C_5	$HCONH_2$						
AlCl	OCS	C_2H_2	SiC_4	C_5O						
AlF	NaCN	HCCN	H_2CCC	C_5N						
PN	HCS^+	H_2CN	HC_2NC							
CH	C_2H	C_3O	HNC_3							
CH^+	C_2S	C_3S	H_2COH^+							
CN	C_3	C_3H								
CO	c-SiC_2									
CO^+	NH_2									
CS	CH_2									
C_2	H_3^+									
HF	MgCN									
SiN	CO_2									
CP	HOC^+									
LiH	MgNC									
CSi										
NH										
SH										

(Don't memorize any of these--just inspect the list to realize that some are pretty complex organic molecules.)

Assignment: Have any amino acids been detected in space? Begin by trying Wiki with "glycine". Is this up to date? Has glycine been discovered in space yet? Have any other amino acids been found? Where?

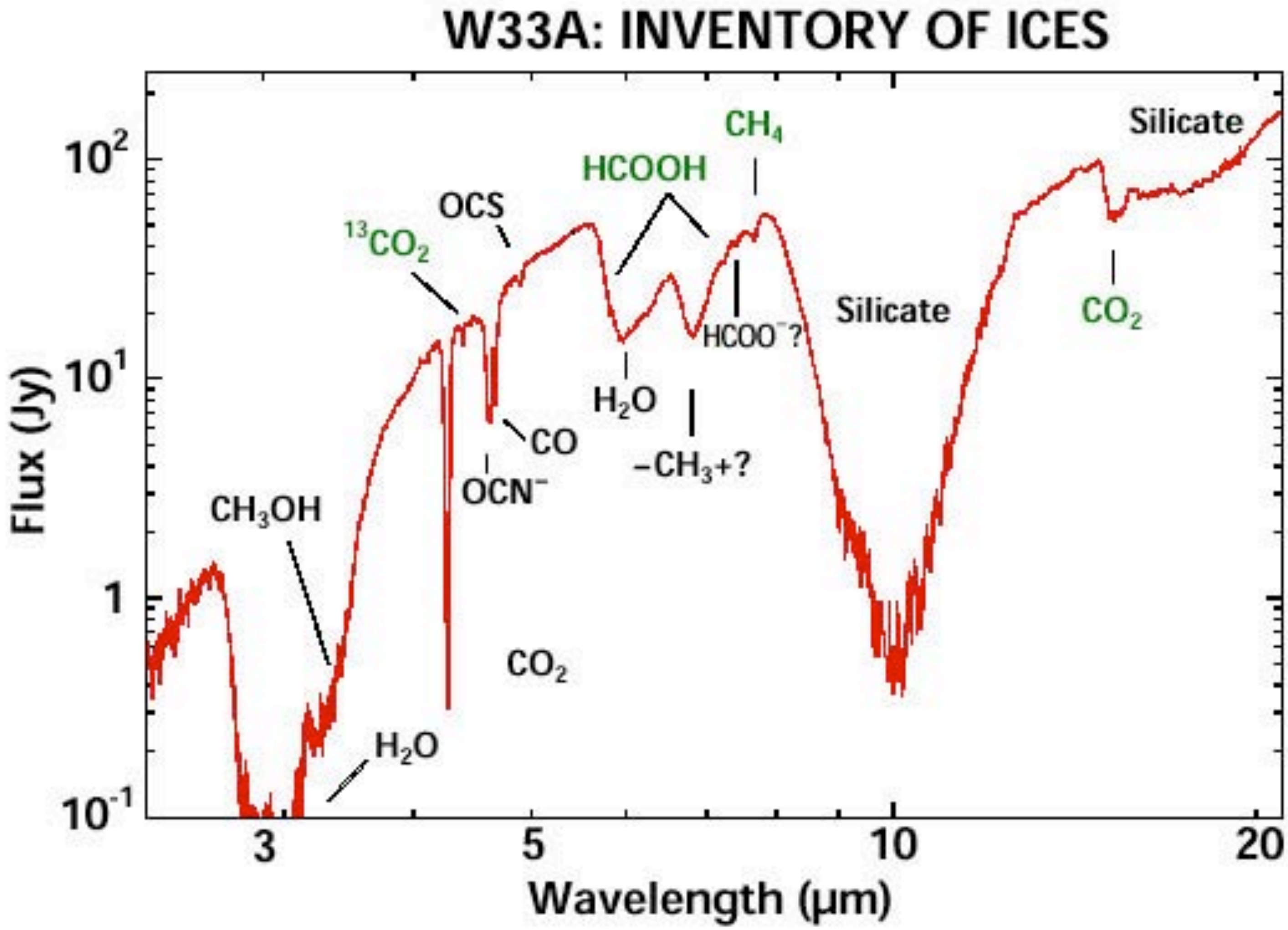
Complex organic molecules can form in dense interstellar clouds, where they are protected from UV radiation. Some of the most interesting are PAH's (polycyclic aromatic hydrocarbons) and long linear polyynes.





All of this evidence suggests that forming complex organic molecules is probably not very difficult. Getting to the much more complex *bio*molecules is a much more difficult problem, but Interstellar (and comet) molecules show that the basic building blocks should be available.

Many types of molecules in the *solid* form have been identified in the spectra of interstellar dust grains in the near-infrared part of the spectrum. This spectrum of the very young star-forming region W33A shows many **mineral** (silicate), **ice** (water, carbon dioxide,…), and gas phase features. *Notice that these are some of the most important solids for terrestrial-like planets.*



Molecules Detected in Comet Hale-Bopp

Molecule	*Abundance as a Percentage of the Amount of Water (Ice) in the Comet*
H_2O	100
CO	20
CO_2	6
CH_3OH	2
H_2S	1.6
H_2CO	1
CH_4	1
NH_3	0.6
SO	0.6
OCS	0.5
C_2H_2	0.5
C_2H_6	0.5
HCN	0.2
CS_2	0.2
SO_2	0.15
HNCO	0.1
HCOOH	0.05
$HCOOCH_3$	0.05
HNC	0.03
H_2CS	0.02
CH_3CN	0.02
HC_3N	0.02
NH_2CHO	0.01
S_2	0.005

Molecules identified in a comet

Bottom line: *simple* organic molecules form easily even in relatively harsh conditions, in the interstellar medium, meteorites, in comets, and are found in atmospheres of other planets.

(Ask yourself: How did these results depend on the analysis of light?)

So, the *elements* for life as we know it are common everywhere, and so are the molecules that form from them (some of them important precursors to more complex molecules associated with biochemistry). However, the next step in complexity will prove to be extremely difficult. We come back to that in detail in Part II of the course. *Next*: Theories and observations of extrasolar planets.