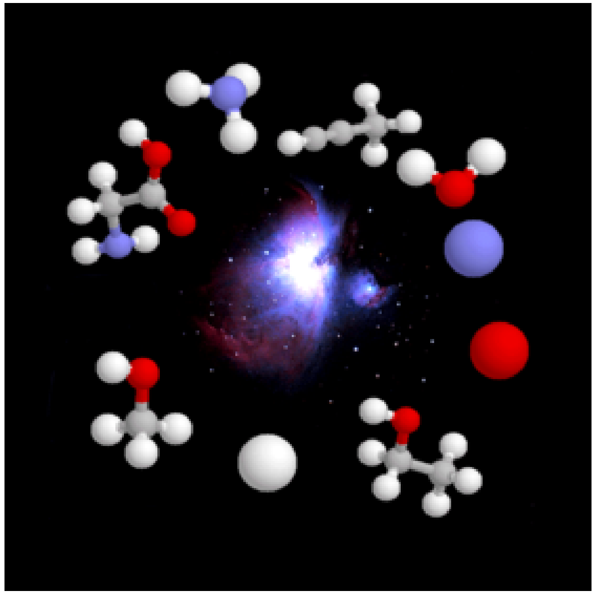
Synthesis of Complex Organic Molecules: Organic Molecules in Space



Based on a presentation by Jeremy Bailey, ACA

A joint venture by Swinburne Astronomy Online and the Australian Centre for Astrobiology

Summary

We have learned about the importance of biomolecules to life on Earth (and possibly life elsewhere). In this Activity, we will look at how the elements and compounds that make up biomolecules were formed in space and arrived on Earth. In particular, we will look at:

- the production of elements;
- extraterrestrial organic molecules – where we find them and how we detect them; and
- how organic material is delivered to the Earth.

Finally, we will look at chirality in molecules in space and compare this to chirality of biomolecules.

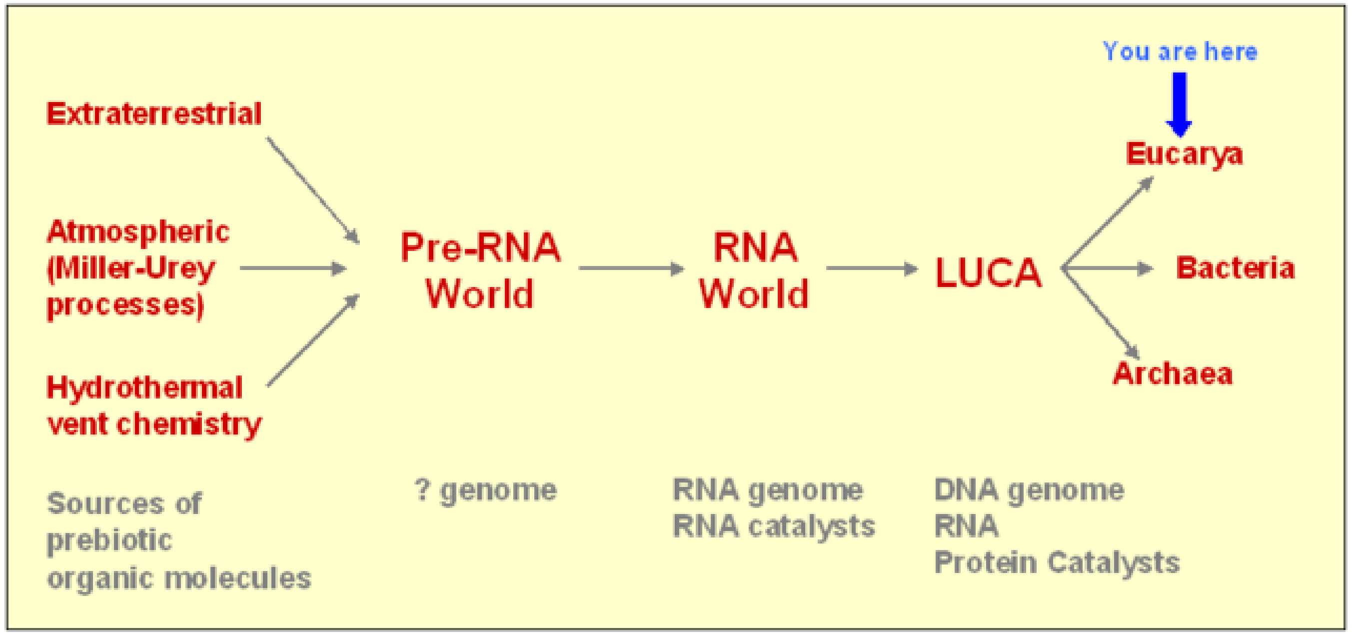
Introduction

There is a wide variety of sources of prebiotic organic molecules, including within the Earth's atmosphere, at hydrothermal vents within the Earth's oceans, plus a host of extraterrestrial sources. But before we look at these sources in detail, let's first ensure we understand what prebiotic organic molecules are.

Organic molecules are based on carbon, usually in combination with hydrogen, oxygen and nitrogen. Prebiotic organic molecules are just organic molecules that are not produced by living things, so they do not have a biological origin.

Organic molecules are fundamental to the chemistry of life.

While naturally occurring organic compounds on Earth are usually produced by living organisms, organic molecules can easily be produced by abiotic processes.



As we have seen in previous Activities, if life arose spontaneously on Earth, the prebiotic molecules required may have come from atmospheric chemistry or from hydrothermal vents. But where did the elements and organic material come from in the first place?

There is a lot of evidence for organic material in space. However, there is no evidence that any of this material is of biological origin (despite the claims of panspermia supporters).

In this Activity, we will give a brief overview of some of the extraterrestrial sources of prebiotic organic molecules. But we will first start with the creation of the elements themselves.

The production of elements

We know that the Earth has a core of iron and nickel, a mantle of magnesium-iron silicates, plus appreciable concentrations of oxides of aluminum, calcium and sodium, and a predominately silicate crust. Where did all these elements come from and how did they find themselves in the Earth?

Apart from hydrogen and helium (which were produced in the Big Bang about 13 Byr ago), all the other elements are produced in stars, with elements heavier than iron synthesised in supernova explosions at the end of the lives of massive stars.

The elements are then distributed back into space and are recycled, forming future generations of stars – and planets.

Big Bang nucleosynthesis

The universe began with a radiation-dominated phase which, after cooling, turned into a matter-dominated phase. Within a fraction of a second quarks coalesced to form protons, and protons could then fuse to form helium nuclei.

The Big Bang created both matter and anti-matter (and, luckily for us, there was a slight excess of matter over anti-matter!). There was a brief period of inflation which resulted in the formation of quarks once the strong force decoupled from the weak and electromagnetic forces. The **quarks** combined to form **hadrons** (massive particles). The universe continued to expand and cool until **electrons** were stable.

About 100 seconds after the Big Bang, protons, neutrons and electrons existed in photon radiation at a temperature of about of about 10^9 K. Hydrogen, deuterium and helium could then form.

Besides H and He, the only other element that could form via collisions during this nucleosynthesis epoch was lithium. However, lithium is destroyed by fusion reactions in stars, so it is difficult to determine its initial abundance. Some lithium is still present in the cool outer layers of low mass stars, suggesting an initial Li/H ratio of about 10^{-10}.

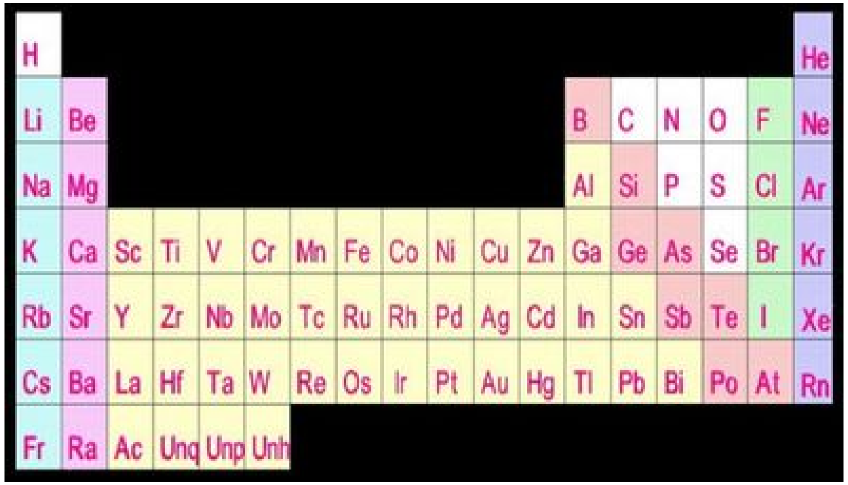
Beyond about 100 seconds after the Big Bang, the matter density declined and nucleosynthesis of such light elements halted.

For details of Big Bang nucleosynthesis, follow these links:
http://www.astro.ucla.edu/~wright/BBNS.html
http://astron.berkeley.edu/~mwhite/darkmatter/bbn.html

Elements of low mass stars

Carbon, oxygen, nitrogen and other ‘life elements’ are synthesised in stars. In the cores of stars, hydrogen atoms fuse to produce helium, and the ashes of subsequent fusion processes give us the elements of the periodic table – the material out of which living systems are made.

Einstein’s famous equation, $E = mc^2$, tells us that the excess mass of the fusion process is converted into energy. So as well as producing the elements of life, nuclear fusion also ensures a continuous energy supply, allowing life to develop on the star’s accompanying planet.



In the cores of stars, hydrogen nuclei (protons) are fused to form helium nuclei (2 protons and 2 neutrons). The reaction also emits 2 photons, 2 neutrinos and energy, and can be written as:

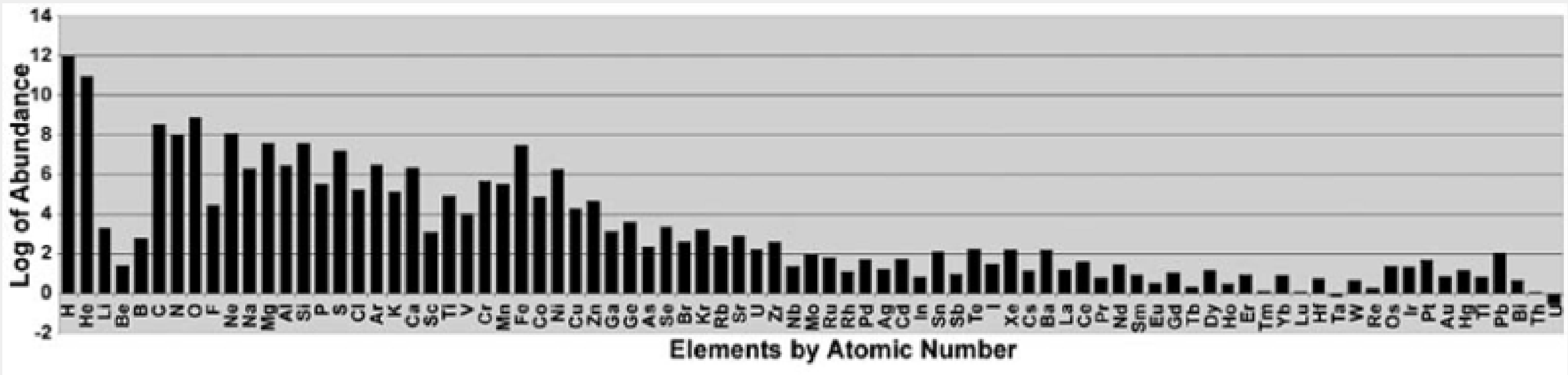
$$6\,^1H^+ \rightarrow \,^4He^{++} + 2\,^1H^+ + 2e^+ + 2\nu + 2\gamma$$

Once the hydrogen in the core has been exhausted, we're left with a helium core. The star starts to contract (since the hydrogen fusion ceases) and the temperature and density increase, maintaining the pressure balance. This results in the ignition of helium burning.

Helium fusion releases more energy than hydrogen fusion, so the star swells, forming a large and cool but luminous star called a **red giant**. When the Sun enters the red giant phase, it will engulf the inner terrestrial planets, including the Earth. . .

In the core of red giants and AGB[1] stars, the helium fuses to form carbon, and carbon and helium fuse to form oxygen. Carbon and oxygen are the most abundant elements produced in stars.

The table below shows the abundances of elements in the Universe, which are determined by the details of nuclear physics. Note that lithium, beryllium and boron are 10^6 times less abundant that carbon.

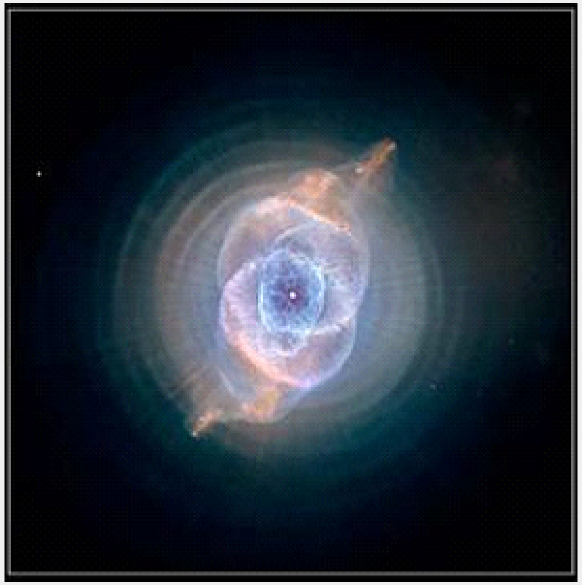


Credit: NASA/GSFC

[1] AGB stars: asymptotic giant branch stars

The red giant phase only lasts a few million years. The last stage of burning is unstable and the outer layers form shells of expanding gas around the star during the **planetary nebula** phase. Carbon rich material may be dredged up by convection and freshly synthesised material escapes, forming a sooty cocoon of graphite.

Once the central fuel supply is exhausted, the core of the red giant contracts, resulting in a cooling **white dwarf**. A single white dwarf will simply continue cooling and fade away. If the star is in a binary system, its companion may supply mass to the white dwarf, provoking a type Ia supernova event and the synthesis of new elements.



NGC 6543 Cat's Eye Planetary Nebula.

Credit: Hubble Heritage, NASA/STScI

Elements of high mass stars

“Normal” type II supernovae are the result of exploding massive stars. The higher central temperatures lead to a more diverse set of reactions. Carbon nuclei fuse to form neon and magnesium. Oxygen fusions yields silicon and sulfur. Silicon fuses to form iron.

Iron is the most tightly bound nucleus. Fusion reactions usually release energy, but fusion of elements past iron require energy. So once an iron core has formed in a massive star, there’s no way to generate energy by fusion. The core will collapse in just seconds, resulting in either a neutron star or black hole.

The core cannot contract any further and as the outer material rushes inwards it collides with the core and rebounds, sending out huge shock waves. The shock reaches the surface and the star explodes. The exploding star shines brighter than an entire galaxy and material expands outwards at over 1000 km/s. As much energy is released in a supernova explosion as our Sun outputs in its entire 10 billion year life.

Type II supernovae play a special role in the chemical enrichment of the Universe. The supernovae eject layers of unprocessed material from within the star, belching out He, C, O, Si, S...

New elements are also synthesised behind the shock wave – the intense heat allowing elements heavier than iron to fuse. Neutrons bombard iron nuclei, producing gold and, subsequently, lead then uranium. These heavy elements are very rare – for every 100 billion hydrogen atoms there is just one uranium atom.

SN 1987A was a 20 $M_{\odot}$ star in the Large Magellanic Cloud that went supernova on February 23, 1987. Neutrinos were detected in Ohio and Japan a few hours after the star began to brighten, while satellites and balloons detected gamma rays emitted by the newborn radioactive nuclei.

HST images taken in 1994 revealed a ring around the supernova. Its expanding rings of material are caused by successive cycles of star formation and destruction that enrich the interstellar medium (ISM) with heavy elements.

Extraterrestrial organic molecules

If we look at the abundance of elements in the **Sun**, we can see that our planet's host star contains all the main elements of life: H, O, C and N.

Element	**Symbol**	**Relative number of atoms**
Hydrogen	H	1,000,000
Helium	He	63,000
Oxygen	O	690
Carbon	C	420
Nitrogen	N	87
Silicon	Si	45
Magnesium	Mg	40

Note that these same elements are not as common on Earth, where O, Si, Fe, Al and Mg predominate.

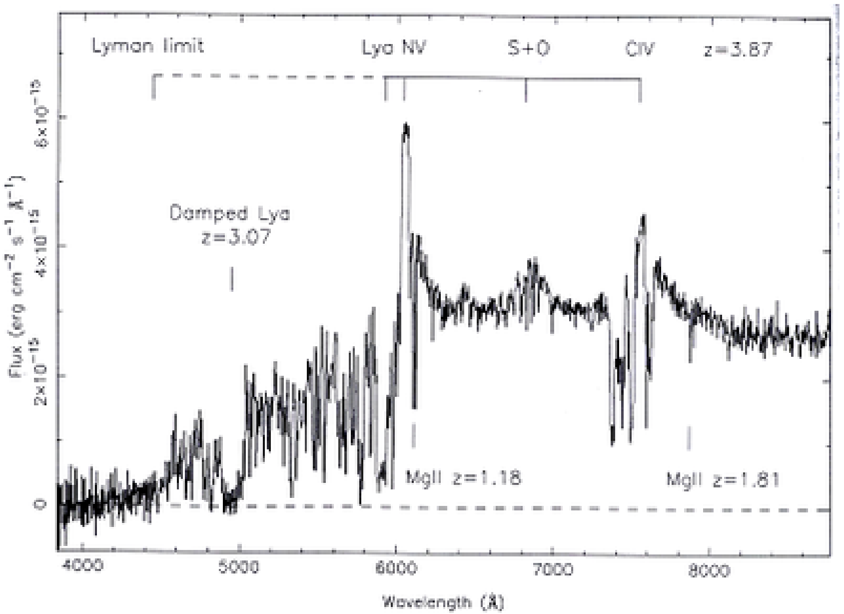
As well as in the Sun, we find organic material elsewhere in the Solar System, the Galaxy and the more distant Universe. Organic material has been found in comets and meteorites, in dense, cold interstellar clouds, in energetic young protostellar environments (which may be particularly important as planets are a natural by-product of the star formation process), in diffuse interstellar clouds, in the envelopes of evolved stars and planetary nebulae, and in the interstellar medium of external galaxies.

But let's first look at some of these sources and how we detect the organics in them.

Quasar spectra

Quasars, the most distant and presumably the oldest objects in the Universe, contain H, as we would expect, but their spectra also reveal S, O and C. This means that an ancient generation of stars must have produced the heavy elements seen in quasars.

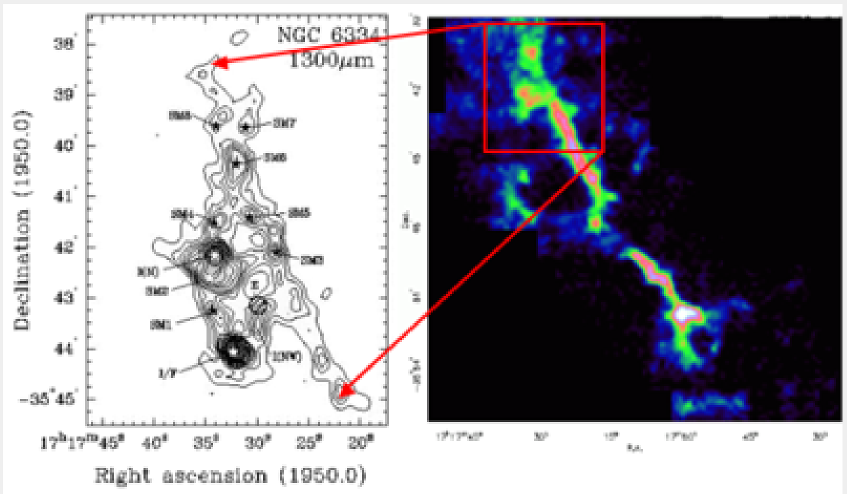
While no one suggests that quasars might host life, it is interesting that organic material existed so early in the history of the Universe.



Molecular clouds

Molecular clouds are cold clouds of gas and dust. Because these clouds are so cold (10–50 K), most of the gas is in the form of molecules. These molecules provide the raw material from which new stars form.

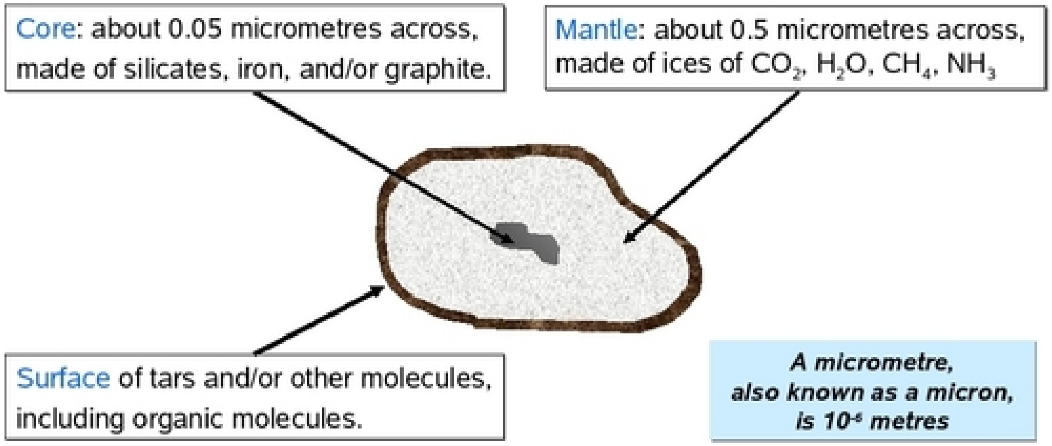
The most common molecule in these clouds is H_2 (which is also the most difficult to detect – it is not detected at radio wavelengths like most other molecules). The second most common molecule is CO (which is radio detectable). More than 100 different molecules have been detected in molecular clouds, hence their name!



NGC6334 seen in CO emission.

Credit: Left: Bill McCutcheon (University of British Columbia); Right: Glenn White, University of Kent

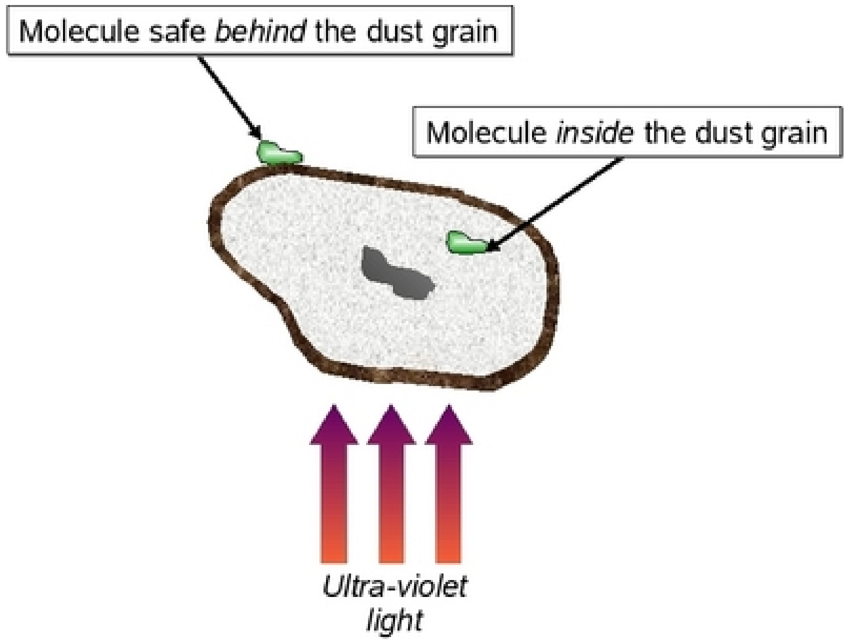
Dust also has an important role to play in molecular clouds. The dust grains have icy mantles made up of common molecules (CO_2, H_2O, CH_4, NH_3) and the surfaces of the grains can often contain organic molecules.



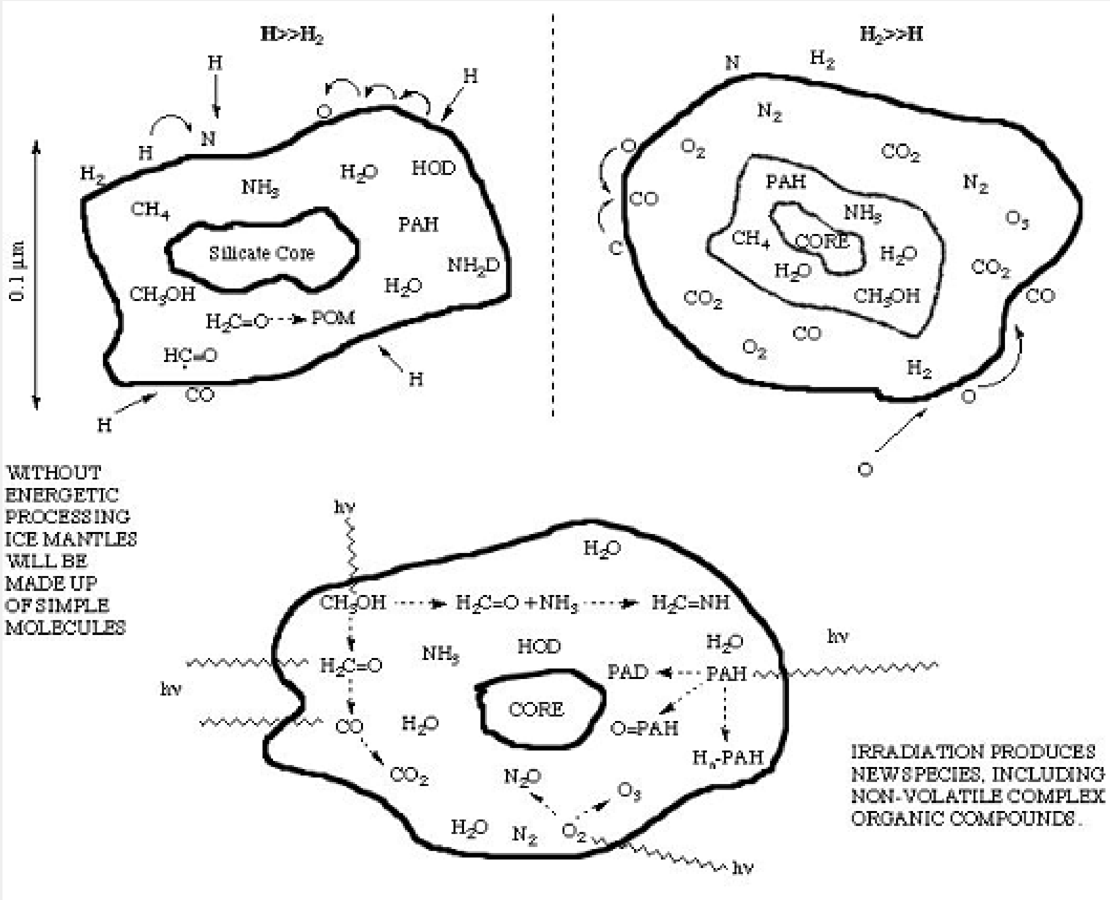
As discussed in the Activity *Star Formation*, the grains act as a catalyst, introducing atoms and molecules of gas to each other so that they can form larger molecules. The (gravitational or electrostatic) forces between atoms and small molecules may be too weak for them to attract each other, but a much larger, sticky, tarry object (like the surface of a dust grain) and some random motion can ensure that they merge.

Once new molecules are formed, the dust grain can then shield them from high-energy ultraviolet starlight that can break the molecular bonds.

So dust can increase the chance of still more complex molecules being formed in a molecular cloud.



However, UV irradiation can also *produce* more complex molecules. Some of these molecules can be returned to the gas phase (especially in "hot cores" of molecular clouds) and can be detected at millimetre wavelengths.



Credit: Courtesy A. Tielens

Molecular transitions and quantum mechanics

Just as for atoms, emission and absorption lines of molecules are due to transitions between allowed energy states. As well as having **electronic transitions** (which occur in atoms as well[2]), the nuclei of molecules can also move relative to one another, so molecules have many more potential quantum states that atoms do.

There are three main types of motion that molecules can undergo:

(1) The entire molecule can move through space in some particular direction with a specific velocity. This is called **translational motion**. We say that the molecule has 3 translational degrees of freedom (x, y and z directions in 3D space).

[2] For more information on electronic transitions, follow this link.

(2) The molecule can also **rotate** about some axis. Again there are three degrees of rotational freedom (for the x, y and z directions in 3D space)[3].

(3) And finally the molecule can **vibrate**. Each atom has three degrees of vibrational freedom to move relative to the other atoms (for the x, y and z directions in 3D space). Vibrational modes are often given descriptive names, like stretching, bending, scissoring, rocking and twisting. (To see animations of these various vibrational modes, follow this link).

So a molecule composed of N atoms has 3N degrees of freedom, six of which are **translations** and **rotations** of the molecule itself, and 3N - 6 degrees of **vibrational** freedom.

[3] Note that linear molecules only have two degrees of rotational freedom, since a rotation about the axis of symmetry doesn't do anything. This leaves 3N - 5 degrees of vibrational freedom.

Translational motions are not quantized, while the energies of rotational and vibrational transitions are. Transitions are also possible that change both the vibrational and rotational states (vibrational-rotational transitions) as well as the electrical and rotational states (electronic-rotational transitions).

The type of transition that occurs depends of the exact amount of energy the molecule receives. In general, molecular spectra can be divided into three spectral ranges:

- UV and visible – electronic spectra;
- infrared – vibrational and vibration-rotation spectra; and
- microwave – rotational spectra.

The types of transitions possible also depend on the state of the molecule. Gases, for example, can experience all three transitions (translations, vibrational and rotational), while solids can only vibrate.

To think about the vibrational modes of solids, think of people standing in a circle holding hands – they can't spin around individually (rotate) or cross to the other side of the circle (translate), but they can still turn their heads (vibrate).

Radio rotational lines

Molecules can be detected using millimetre-wave telescopes such as the Mopra telescope in New South Wales, Australia.

The **rotational state** of a molecule defines the energy and orientation of a molecule's tumbling motion though 3D space.

When a molecule spontaneously drops from one rotational energy state to another, it releases a photon at radio or millimetre-wave frequencies.

Mopra radiotelescope, Coonabarabran, NSW

Credit: © ATNF/ CSIRO

Table of molecules

The many narrow lines seen in molecular clouds allow unambiguous detection of specific molecules. To date, over 100 different molecules have been detected in molecular clouds.

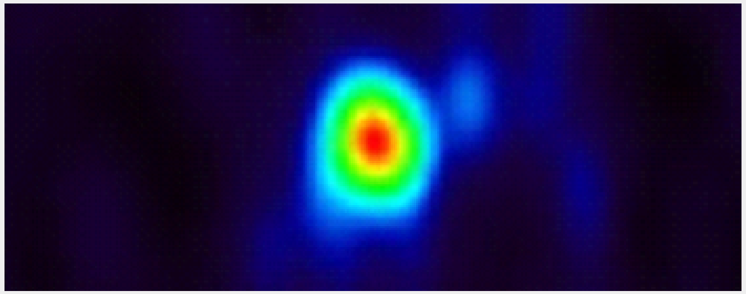
Number of Atoms										
2	3	4	5	6	7	8	9	10	11	13
H_2	C_3	c-C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N?	HC_9N	$HC_{11}N$
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH?	$(CH_3)_2O$	NH_2CH_2COOH?		
C_2	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH			
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$	H_2C_6	HC_7N			
CH^+	HCN	C_2H_2	CH_2CN	CH_3OH	NH_2CH_3		C_8H			
CN	HCO	CH_2D^+?	CH_4	CH_3SH	c-C_2H_4O					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+						
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO						
CP	HOC^+	HNCO	HCOOH	NH_2CHO						
CSi	H_2O	HNCS	H_2CHN	C_5N						
HCl	H_2S	$HOCO^+$	H_2C_2O							
KCl	HNC	H_2CO	H_2NCN							
NH	HNO	H_2CN	HNC_3							
NO	MgCN	H_2CS	SiH_4							
NS	MgNC	H_3O^+	H_2COH^+							
NaCl	N_2H^+	NH_3								
OH	N_2O	SiC_3								
PN	NaCN									
SO	OCS									
SO^+	SO_2									
SiN	c-SiC_2									
SiO	CO_2									
SiS	NH_2									
CS	H_3^+									
HF										

Note that observations suggest the presence of large PAHs and fullerenes in the interstellar gas (Tielens et al 1999, Foing & Ehrenfreund 1997).

Credit: Tielens et al. (1999), Foing & Ehrenfreund (1997)

In 1994, Miao and Kuan (of the University of Illinois at Urbana) and collaborators reported the detection of the amino acid glycine in the star-forming region Sagittarius B2 near the centre of the Milky Way.

The glycine was detected in a gaseous state and Miao suggested that it may have been coating grains within the cloud and evaporated when heated. This detection was not confirmed by F. Combes et al. (1995) using the 30m IRAM telescope. However, in 2003, Kuan and collaborators (again) reported the detection of glycine (NH_2CH_2COOH) in Sgr B2, Orion KL, and W51. Subsequently, Synder et al. (2005) have disputed the Kuan et al. (2003) detection. The observations and identification are extremely difficult and controversial.



Millimetre image of Sagittarius B2.

Credit: R. Plante, NCSA/Univ. of Illinois (© 1995: Board of Trustees, University of Illinois)

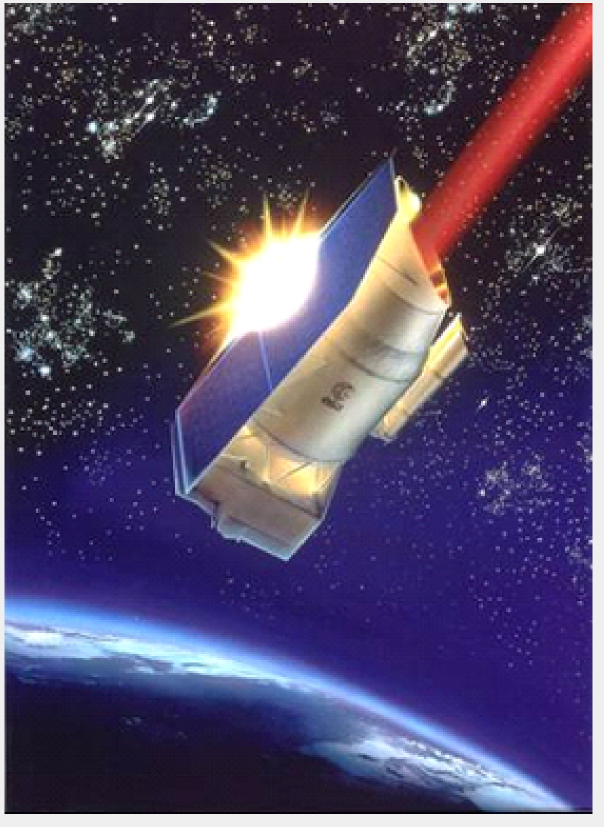
As glycine is an important amino acid in the formation of proteins for life on Earth, a detection may mean that the ingredients of life are freely available in space!

In 2002, Max Bernstein of NASA's Ames Research Center and colleagues *experimentally* replicated the conditions thought to be present in interstellar clouds, and produced three amino acids: glycine, alanine and serine.

Infrared absorption bands

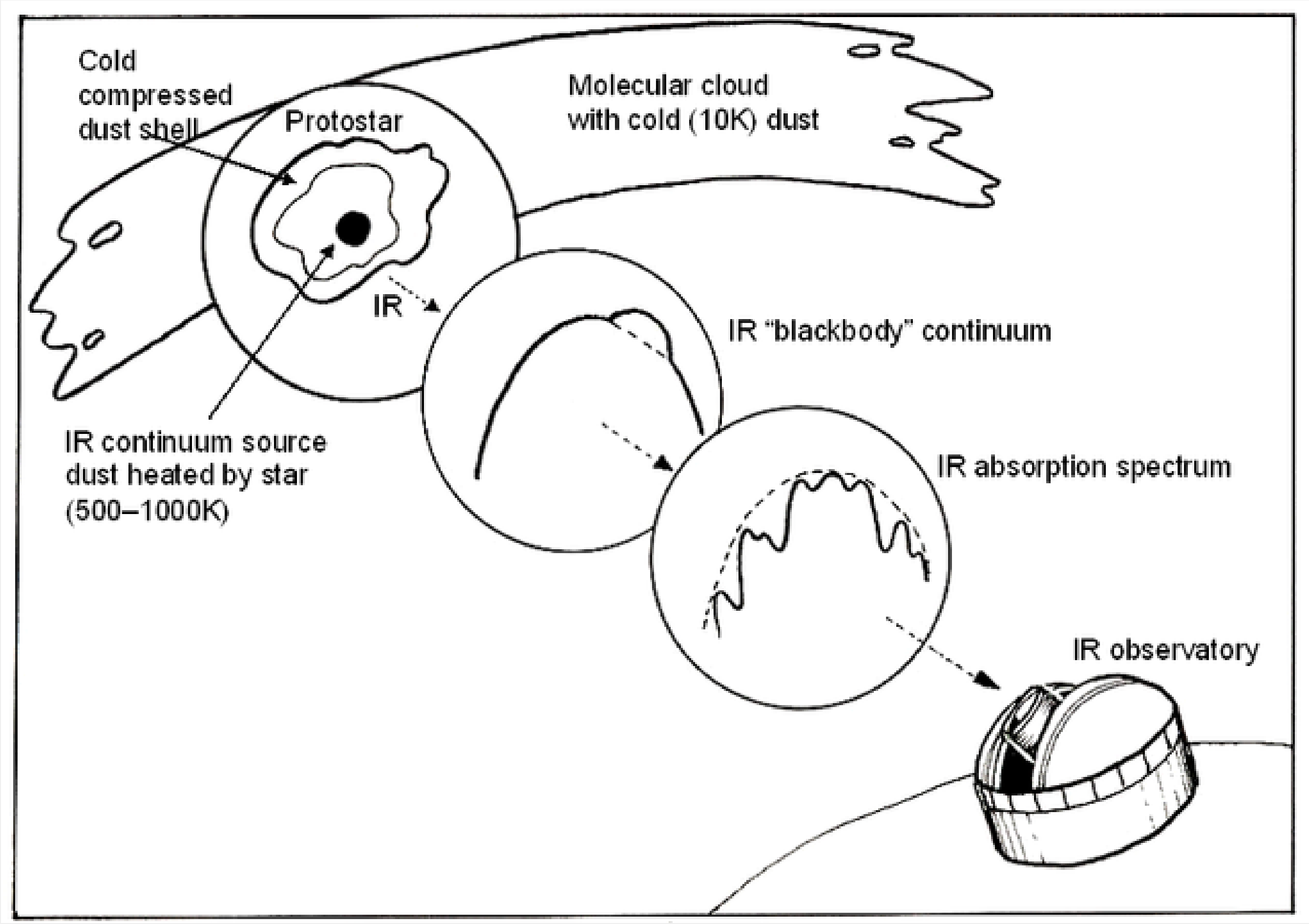
Infrared absorption bands are observed with ground-based telescopes or satellites such as ISO, the Infrared Space Observatory.

Mid-infrared radiation (2.5–50 μm) can excite molecular vibrations to higher energy levels. IR absorption bands result from vibrations of solid state molecules in the form of icy mantles on dust grains. Specifically, the bands are due to stretching of bonds such as C-H, C-C, etc. It is difficult to distinguish specific molecules, except for the simplest.



Infrared Space Observatory

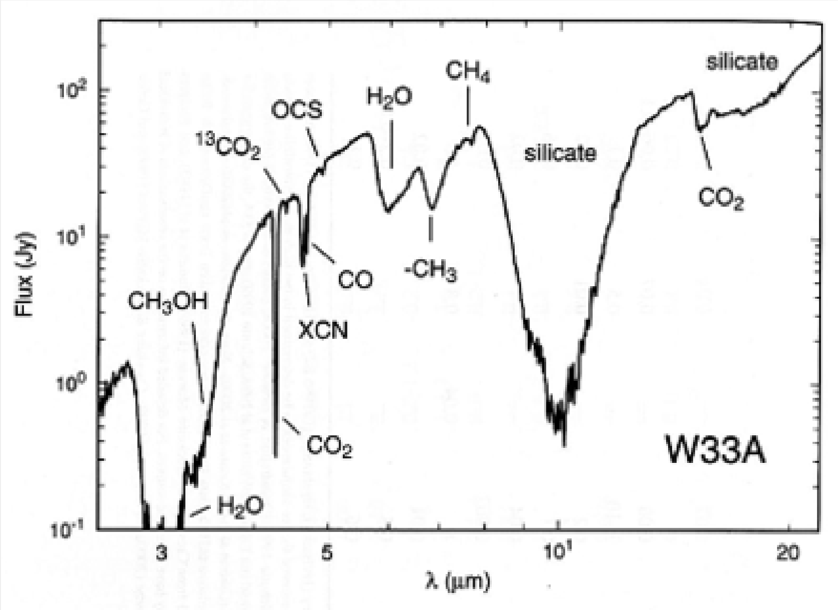
Credit: ESA



Credit: R. Daly, Eden, NSW

A variety of molecules can be detected in the IR absorption bands of molecular clouds surrounding young stars. In this example of the W33A cloud, the massive protostar W33A provides the IR energy which the molecules in the surrounding cloud absorb.

ISO observations were made of W33A from 2.4 - 25 μm (Gibb et al. 2000). The spectra showed absorptions bands at 3 μm (water ice features), 4.27 μm (CO_2 ice features), 4.67 μm (CO ice features), and 10μm (silicate features). A large number of organics are also seen in the 2 – 2.5 μm range.



2.4–25μm spectrum of W33A.

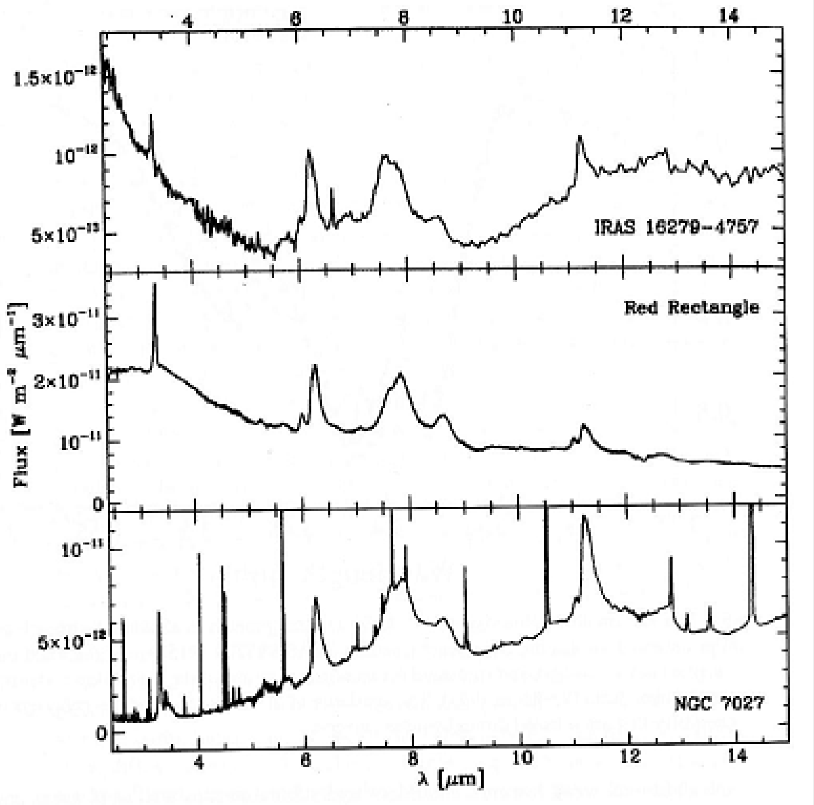
Credit: A. Tielens

Infrared emission from hot molecular cores

When dust is heated, it re-radiates like a blackbody and can be detected at IR wavelengths. We can detect the IR emission of dust in hot molecular cores that have been heated radiatively and by shocks.

There are three possible origins for organics in hot molecular cores:

1. cold phase chemistry and accretion onto grains during cloud collapse can result in CO, CHN and acetylene formation;
2. grain surface reactions (sputtering) can produce H_2O and NH_3; and
3. evaporation of simple mantle molecules can drive complex gas phase chemistry.



Examples of IR emission features.

Credit: Tielens et al. (1999)

Dust production

The dust and refractory grains are produced in the cool envelopes of late-type post-asymptotic giant branch (post-AGB), M giants, supergiants and carbon stars. The grains are formed in the cool outer atmospheres and power the outflowing circumstellar winds.

The grains, unlike the gas, are affected by the stellar radiation pressure which pushes them outwards, and the grains then drag the gas outwards with them.

Carbon that is not already in CO molecules is incorporated into organic molecules and carbonaceous grains such as PAHs.

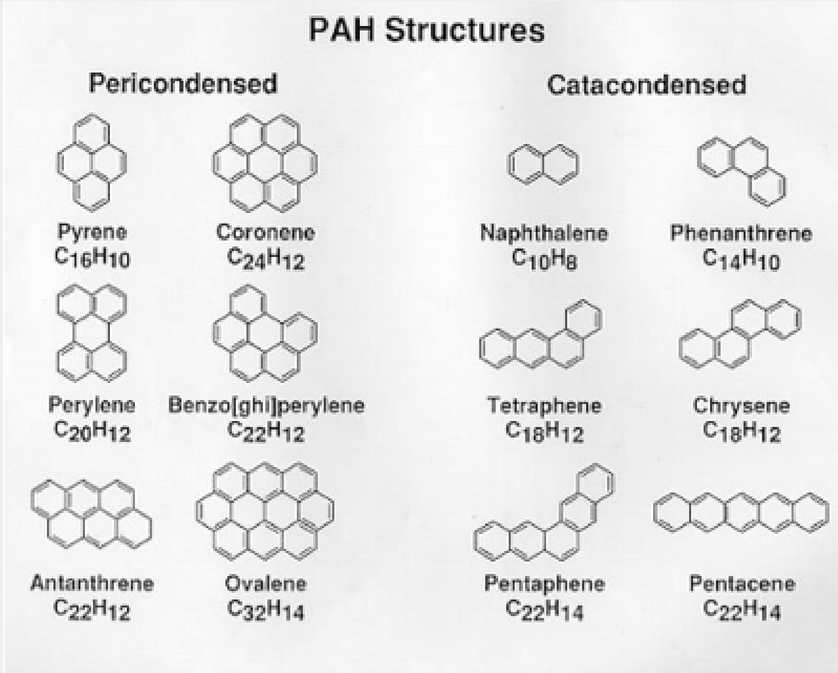
The "Rotten Egg" Nebula and the associated outflow from an AGB star.

Credit: NASA/STScI

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are found in diffuse clouds in the gas phase and attached to dust grains. They comprise a group of very stable aromatic hydrocarbons that contain multiple interconnected 6-carbon (benzene) rings.

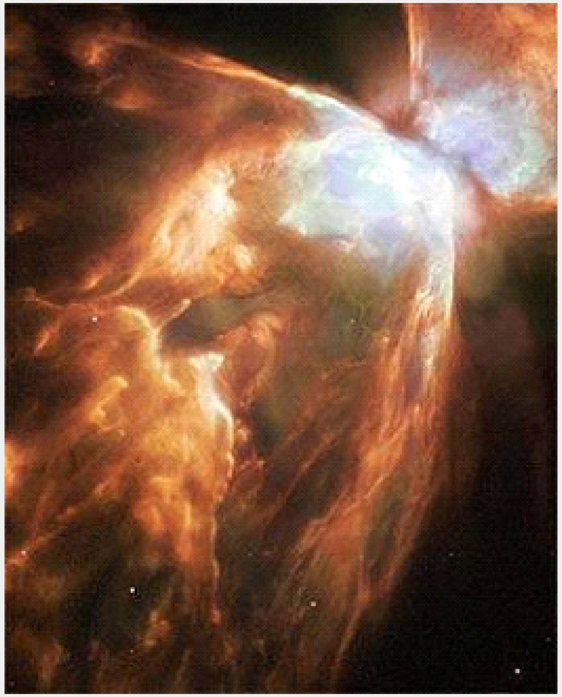
PAHs can be produced in the atmospheres of carbon stars and may also result from energetic processing of ice in dense clouds. They're probably the most abundant organic molecules in space.



Credit: Tielens et al. (1999)

In 2005, Matsuura and collaborators observed the “Bug Nebula”, NGC 6302, with HST, ESO’s VLT (at L- and M-bands), and the James Clerk Maxwell Telescope (at 450 μm). They detected strong PAH emission in an ionised shell of gas close to the central ionising hot star.

On Earth, PAHs are produced from biological processes but those found in space are produced chemically.

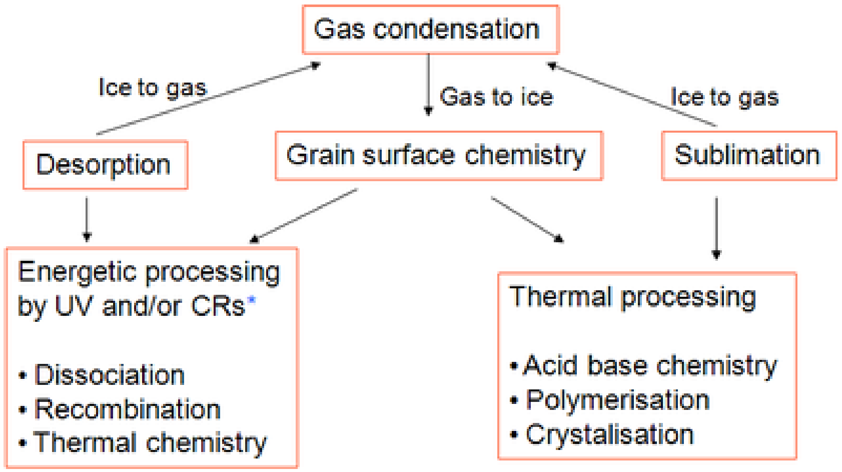


NGC 6302 - the Bug Nebula

Credit: NASA/STScI

Cycle of ice and gas in dense clouds

We can summarise the various pathways between gas and ice phases in dense clouds as follows:



(where CR in the diagram above stands for ‘cosmic rays’)

Delivery of organic material to Earth

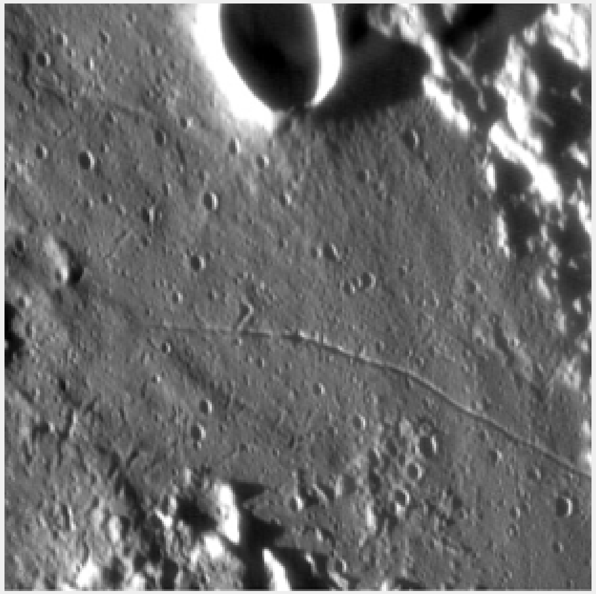
So far, we have discussed where to find organic molecules in space and how we detect them.

However, what are the possible mechanisms of delivery and how do the different methods affect the probability of subsequent existence on Earth?

We know already that the Earth underwent a period of heavy bombardment early in the life of the Solar System.

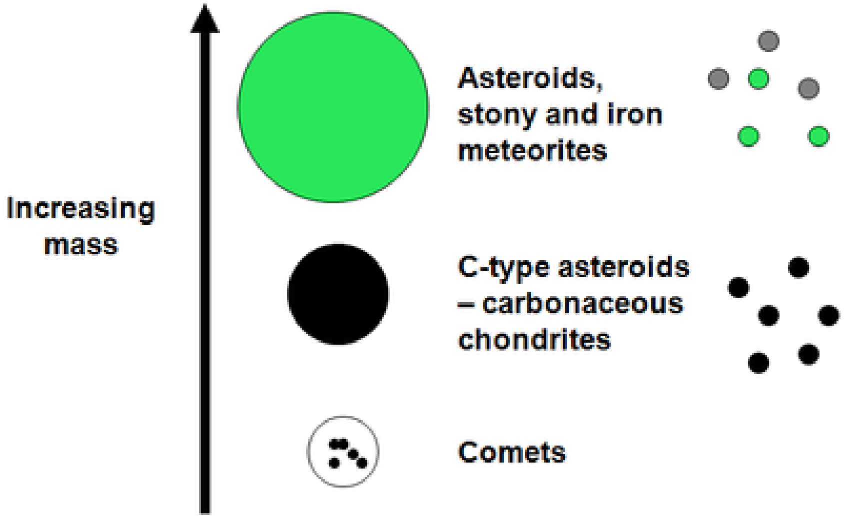
The heavy bombardment phase occurred in the first few hundred million years of the Solar System. The Earth and other planets were bombarded by left-over debris from the formation of the Solar System (asteroids and comets) and we know that most of the large craters on the Moon formed at this time. The end of the heavy bombardment period (3.8 Byr ago) coincides with the first evidence for life on Earth.

It is thought that cometary and meteorite impacts in the first 100 Myr may have delivered organics to the Earth (Chyba & Sagan 1992), which may have helped the development of life.



Credit: ESO

Interestingly the size of the potential delivery object tells you if the organics can survive! If objects are large enough to be differentiated, the heating process should have destroyed any organics. If the object is too small to differentiate, the organics will be retained. So comets and C-type asteroids contain organics while the differentiated asteroids (and hence stony and iron meteorites) do not.



Organics in comets

When comets orbit near to the Sun, sublimation of “parent” volatiles leads to the production of “daughter” molecules, radicals and ions.

In 1986, in situ observations of comet Halley by Giotto and Vega 1 and 2 found large amounts of dust and organics. More recent observations of comets Hayakutake and Hale-Bopp have identified over 25 parent species.

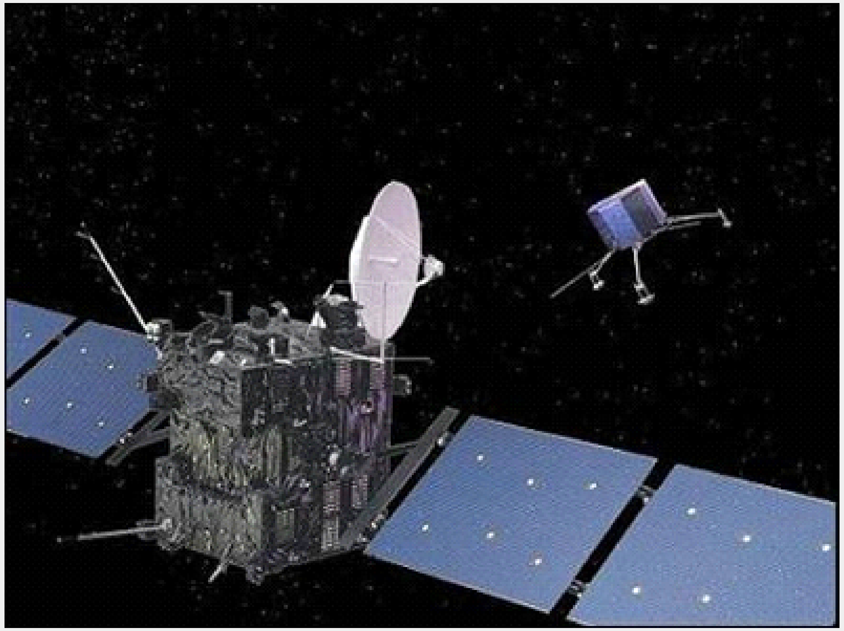
Molecules in comets detected by millimetre-wave, optical and IR spectra include H_2O, CO, CO_2, C_2H_2, CH_3OH, $HCOOCH_3$ and CH_3CN.

Comet Hyukatake (Comet C/1996 B2)

Credit: © AAO

ESA's Rosetta spacecraft will be the first to undertake the long-term exploration of a comet at close quarters. Rosetta was launched on 2 March 2004 from Kourou, French Guiana. After entering orbit around Comet 67P/Churyumov-Gerasimenko in 2014, the spacecraft will release a small lander onto the icy nucleus, then spend the next two years orbiting the comet as it journeys towards the Sun.

For details of the mission, follow this link.



Artist's impression of Rosetta orbiter and lander.

Credit: ESA

Organics in meteorites

Credit: F. Coffa, Museum Victoria

The Murchison meteorite fell in Murchison, Victoria, Australia, on 28 September 1969. A total of 100 kg of material was collected from the impact site. Analysis showed that the meteorite contained a wide variety of organic compounds including many amino acids (more than 100 have now been identified).

As well as the Murchison Meteorite, a few similar meteorites show a much wider variety of molecules than are detected in molecular clouds. Were these molecules (such as the amino acids) formed in the meteorite or its parent body, or do they come from molecular clouds? If they come from molecular clouds we may expect to find the same molecules in comets (which are the least processed examples of primordial material, although they are not totally pristine. . .).

The most widely-accepted interpretation of the existence of organics in meteorites is that carbon compounds are probably abiotic but have the potential to initiate life in the right conditions.

Most of the earlier explanations for the origin of organics in meteorites (apart from them being due to contamination or artifacts of the extraction process) involved processes occurring during the formation of the parent body of the meteorite.

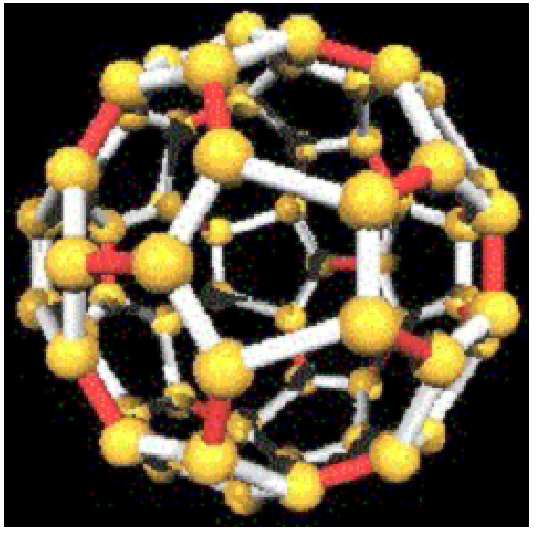
However, recent opinion has shifted somewhat; many astrobiologists now think that organic molecules formed, perhaps by ion-molecule reactions, in the pre-accretion gas cloud or even in the ISM, or that they resulted from reactions taking place on the parent body between liquid water (the presence of which seems increasingly certain) and anhydrous minerals.

Delivery of organics to Earth

Until recently, most studies assumed that only small bodies and dust particles can successfully transport organic material. It was thought that in major impact events of large comets and asteroids, the heat produced would destroy any organic compounds.

Several studies now suggest some organics can in fact survive major impacts. Zhao & Bada (1989) found extraterrestrial amino acids (AIB and isovaline) in K/T impact sediments, while Becker et al. (1994) found extraterrestrial fullerenes from K/T and Sudbury impacts. Blank et al. (University of California Berkeley) reported on laboratory experiments which simulated impact shocks with temperatures up to 800°C and pressures of 20 GPa and they found that some amino acid survives in all cases.

Fullerenes



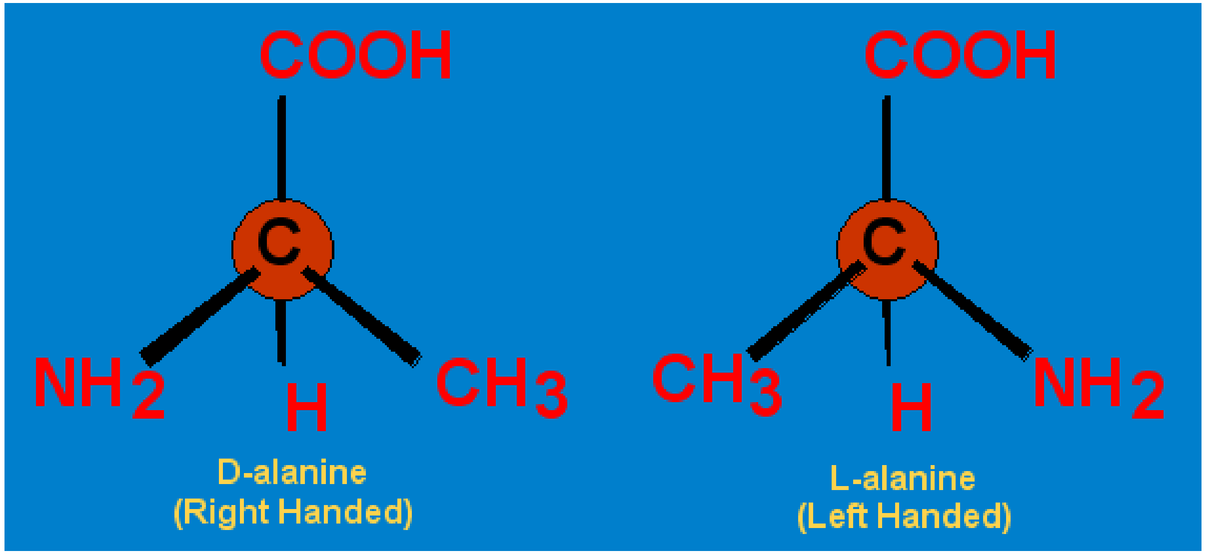
Fullerenes – as found by Becker et al. (1994) at the K/T and Sudbury impacts – are particularly interesting because they have a spherical structure that naturally traps
material. Analysis of isotope ratios of such trapped material can indicate terrestrial or extraterrestrial origins.

In particular, fullerenes can contain trapped He and the isotopic ratio ^{3}He/^{4}He can be used to distinguish between extraterrestrial and terrestrial origin.

Extraterrestrial isotope ratios have been found in fullerenes from the Sudbury impact (1.85 Byr), the K/T impact (65 Myr), the Permian/Triassic border (240 Myr) and in the Allende and Murchison meteorites. Therefore, these fullerenes are extra-terrestrial and some part of the impactor must remain below 1000°C.

Chiral molecules

We have briefly introduced chirality earlier in the Activity *How Life Began & Searching for LUCA*. Remember that a chiral molecule is one that cannot be superposed on its mirror image.



Chirality is most commonly due to a tetrahedral arrangement of bonds around a carbon atom. A molecule is chiral (mirror asymmetric) if four different groups attach to carbon, resulting in two mirror image forms called **enantiomers**. Chirality is common in organic molecules.

Laboratory synthesis of molecules from achiral precursors produces **racemic mixtures**, meaning equal amounts of left handed (L) and right handed (D) forms.

Living organisms, on the other hand, use one form exclusively (and exhibit **homochirality**): all amino acids in living organisms are L form while all sugars in living organisms are D form. Biological processes depend on and maintain this asymmetry.

As discussed before, amino acid precursors can be formed by UV irradiation of interstellar ices (Bernstein et al. 2002; Munoz Caro et al. 2002).

It had been thought that amino acids may be locked up in icy dust grains and not present with sufficient abundance in the gas phase to be detected, or that they may be present as precursors rather than as amino acids (the chiral centre may be already formed). As mentioned previously, the observational detection of glycine is controversial (Kuan et al. 2003; Synder et al. 2005).

Chirality of the Murchison meteorite

There is some controversy over whether the extraterrestrial amino acids found in the Murchison meteorite are chiral or not.

Engel et al. (1982, 1990, 1997) find large enantiomeric excesses (up to 50%) in common protein amino acids such as alanine, while Cronin and Pizzarello (1997) find enantiomeric excesses (of 2–15%) in several a-methyl amino acids. Other scientists, however, believe that the chiral animo acids could be due to contamination.

For more details, follow this link.

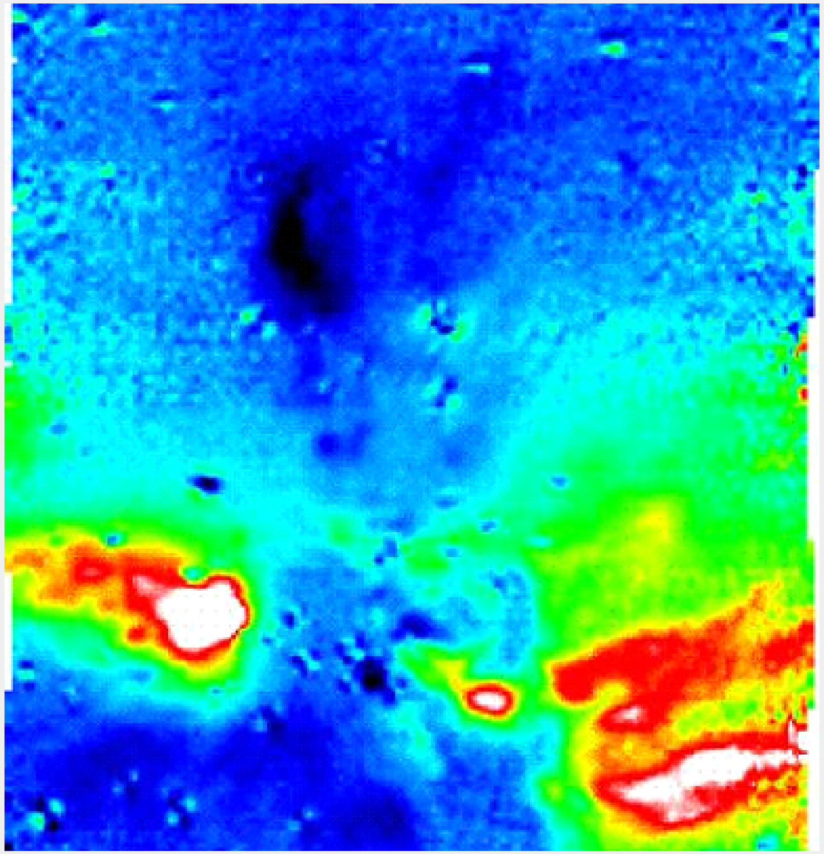
Circular polarised light for origin of homochirality

Rubenstein et al. (1983) first proposed the idea that the homochirality seen in living organisms on Earth may have an astrophysical origin. (See also Bonner, 1991, and Greenberg, 1994, 1997.)

The idea is that an astronomical source of circular polarized light could have imprinted chiral asymmetry in interstellar molecules before or during the formation of the Solar System. These molecules could then find their way onto Earth during the heavy bombardment phase and form part of the prebiotic organic material available for origin of life. This could have provided a trigger for the development of life with left-handed amino acids and right-handed sugars.

IR circular polarisation of up to 17% has been observed in the Orion nebula by Bailey et al. (1998), who suggest that the high circular polarisation is due to interstellar dust acting as a polarising grate.

If similar circular polarisation is present in the UV, it could cause asymmetric photolysis of amino acids in the cloud or in a protostellar disk.



High circular polarisations (red and white regions) in infrared light from reflection nebulae in the star forming regions Orion OMC1 (a region in the Orion nebula M42).

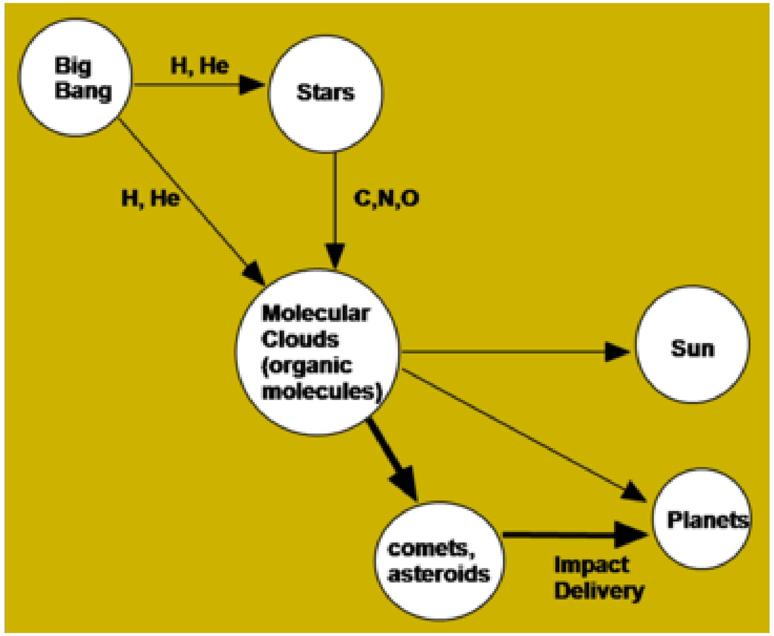
Credit: J. Bailey

Summary

In this Activity, we investigated biomolecules, in particular their formation in space and possible delivery to Earth. Observations now reveal over 100 extraterrestrial organic molecules in a variety of sources (e.g. dark clouds, molecular cores, stellar winds, etc.). However, the current detection of glycine, an amino acid, is controversial, whilst laboratory experiments that reproduce ISM conditions can produce several types of amino acids.

Numerous delivery methods are available to transport organic material to Earth. Such material may even survive the extreme physical conditions associated with the heavy bombardment phase and large impacts.

Homochirality seen in living organisms on Earth may have an astrophysical origin. Circular polarisation, as observed in IR (and if seen in UV), could have imprinted chiral asymmetry in interstellar molecules before or during the formation of the Solar System. Hence, if this material was delivered to Earth, it could have provided a trigger for the development of life.



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