TRANSIT

The April 2013 Newsletter of

Cleveland & Darlington Astronomical Society

<u>NEXT TWO MEETINGS at Wynyard Planetarium</u>

Friday 12 April 2013

Presidential address:
David Sinden – a life in optics

Jack Youdale, FRAS

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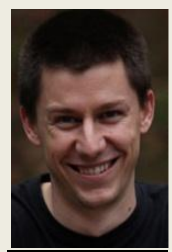
Friday 10 May 2013

The ALMA telescope – a new window on the Universe

Dr Mark Swinbank, *Durham University*



Content

Editorial

Rod Cuff

This is a rather different kind of *Transit* from those we've had in recent years. Apart from the now-abbreviated Skylights, the regular quiz and the transcript of one of Andy Fleming's excellent Andromeda Child podcasts on Radio Hartlepool, the issue is given up to a single long article, offered up by Ray Brown and gratefully accepted by your editor.

It's not a casual read. It tackles the topic of how elements (especially the lower-mass ones) are created in stars – more formally known as nucleosynthesis. Some readers will shy away at the terminology and use of chemical equations (which you can skip, actually!), but stick with it if you can – it's a fascinating story, and one that is much more many-sided than I'd previously realised.

I'm happy to include an article like Ray's from time to time, but of course I welcome any observation reports, short articles on any aspect of astronomy, opinion pieces, letters …. whatever. Just send them in, please!

A warm welcome to new members who have joined us in the last month or two: hi to Craig, Julie & Olivia Todd; John Cuthbert; Steve Bansey; and Philip Lovett.

Best wishes -- Rod

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(01287 638154, mobile 07775 527530)

OBSERVATION REPORTS AND PLANNING

Skylights – April 2013

Here are some suggestions for websites that will highlight some of the best of what you can see (clouds permitting!) in the night sky in the coming month.

- EarthSky April 2013 guide to **the five visible planets**:

  http://tinyurl.com/CaDAS2013Apr-1

- HubbleSite: a **6-minute video** of things to see in April, with particular mention of a **partial lunar eclipse** on the 25th:

  http://hubblesite.org/explore_astronomy/tonights_sky

- **Night Sky Info's comprehensive coverage of the night sky this month**:

  www.nightskyinfo.com

- **Jodrell Bank Centre for Astrophysics – The night sky, April 2013**. Includes focuses on Saturn; Comet C/2011 L4 PANSTARRS; transit times for Jupiter's Great

Red Spot; how to find out when you can see the International Space Station; some Moon craters; and objects in Gemini, Leo, Virgo and Ursa Major;

www.jb.man.ac.uk/astronomy/nightsky

- **Astronomy.co.uk** – sky map for April 2013:

  www.astronomy.co.uk/skymap

GENERAL ARTICLES

Uranus

Andy Fleming

[*Here's another fine show transcript from one of Andy's recent broadcasts on Radio Hartlepool. — Ed.]*

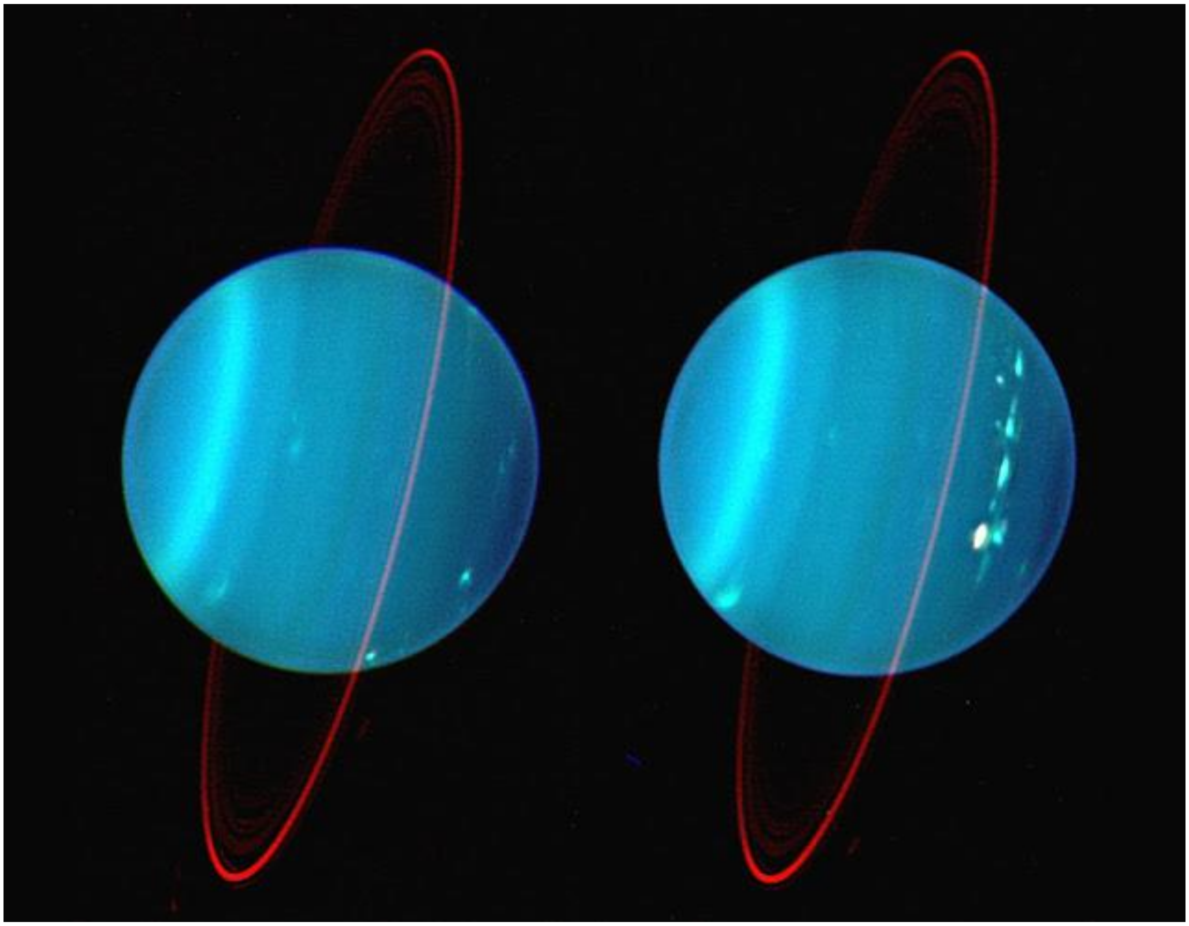
Uranus was discovered by William Herschel in 1781, and is visible with the naked eye from a very dark site. It's nearly two and a half billion kilometres away, so it isn't very bright, but it can be seen as a bluish-green disk through binoculars, or better still, a telescope.

It's the seventh planet from the Sun and has the third-largest planetary radius and fourth-largest planetary mass in the Solar System. It is similar in composition to Neptune, and both are of different chemical composition from the larger gas giants Jupiter and Saturn. For this reason, astronomers sometimes place them in a separate category called 'ice giants'.

Uranus's atmosphere, while similar to Jupiter's and Saturn's in its primary composition of hydrogen and helium, contains more 'ices' such as water, ammonia and methane, along with traces of hydrocarbons. It is the coldest planetary atmosphere in the Solar System, with a minimum temperature of −224 °C. It has a complex, layered cloud structure, with water thought to make up the lowest clouds, and methane thought to make up the uppermost layer of clouds. In contrast, the interior of Uranus is mainly composed of ices and rock.

Like the other gas giants, Uranus has a ring system, a magnetosphere and numerous moons. Uranus' moons are named after Shakespearean characters. Oberon and Titania are the largest, but others have wonderful-sounding names such as Ariel, Miranda and Umbriel.

The Uranian system has a unique configuration among the planets because its axis of rotation is tilted sideways, nearly into the plane of its revolution about the Sun. Its north and south poles therefore lie where most other planets have their equators. In 1986, images from Voyager 2 showed Uranus as a virtually featureless planet in visible light, without the cloud bands or storms associated with the other giants. Terrestrial observers have seen signs of seasonal change and increased weather activity in recent years as Uranus approached its equinox. The wind speeds on Uranus can reach 560 mph.



These sharp views of Uranus show dramatic details of the planet's atmosphere and ring system. The remarkable ground-based images were made using a near-infrared camera and the Keck Adaptive Optics system to reduce the blurring effects of Earth's atmosphere. Recorded in July 2004, the pictures show two sides of Uranus. In both, high, white cloud features are seen mostly in the northern (right-hand) hemisphere, with medium-level cloud bands in green and lower-level clouds in blue. The artificial colour scheme lends a deep reddish tint to the otherwise faint rings. Because of the severe tilt of its rotational axis, seasons on Uranus are extreme and last nearly 21 Earth years.

(Credit: Lawrence Sromovsky, (Univ. Wisconsin-Madison), Keck Observatory)

Uranus will be visible by mid-April, and for timings of this and details of astronomy in general, visit my astronomy blog at www.andromedachild.com.

The strange case of elements 3, 4 and 5

Ray Brown

A bit of background

Each chemical element is characterised by the number of positively charged protons within the nucleus of each of its atoms or ions. This number is the element's *atomic number*. The nucleus also contains a number of uncharged neutrons, which, in the cases of most elements, is equal to or slightly greater than the atomic number. Not all atoms of any given element have the same number of neutrons in the nucleus – i.e., elements can have various *isotopes*. Neutrons and protons have almost identical masses and are generally called nucleons. The number of nucleons in a nucleus is the *mass number* of that isotope.

Electrically neutral atoms have negatively charged extra-nuclear electrons equal in number to the atomic number. Some isotopes are unstable and spontaneously decay by various mechanisms, so forming other isotopes of either the same or a different element. The time taken for half of the original amount of an unstable isotope to decay is its *half-life* $t_{½}$. The *binding energy* of a nucleus is the energy required to split it into its component nucleons.

We will describe isotopes by specifying their atomic number as a subscript and their mass number as a superscript. The least massive isotope known is protium, the most abundant isotope of the element hydrogen, which has the chemical symbol H. Protium (more commonly simply called 'hydrogen') is $_1H^1$, from which you can deduce that it consists of a single proton, and, uniquely amongst all isotopes, no neutrons at all.

Free electrons are referred to as *β-particles* and the $_2He^4$ helium nuclei as *α-particles*. The *positron* β^+ is the positively charged antimatter equivalent of the electron. Nuclear reactions commonly produce high-energy γ-rays (*gamma radiation*).

Big Bang nucleosynthesis (BBN)

Whether you are a believer or a sceptic concerning the claims that are made for detailed knowledge of the sequence of events immediately following the birth of the universe, few would deny that within a short time – the experts tell us a matter of a few minutes – the universe consisted of a lot of extremely hot protons, neutrons and electrons and many more photons and neutrinos. Whilst its energy was still largely in the form of radiation and its temperature at about a billion degrees, the universe was expanding and cooling rapidly. There were present about 7 protons for every neutron at this 'freeze-out' temperature. Free neutrons are unstable with a half-life $t_{½}$ = 881 seconds, yielding a proton by β-decay:

$$_0n^1 \rightarrow {}_1H^1 + \beta$$

The formation of deuterium, a second stable isotope of hydrogen $_1H^2$ (alternatively denoted by D), could proceed:

$$_0n^1 + {}_1H^1 \rightarrow {}_1H^2$$

as could that of the unstable third hydrogen isotope, tritium $_1H^3$ or T, which spontaneously loses an electron (β-decay) to form an isotope of helium with the release of 18.6 keV of energy and a half-life $t_{½}$ = 12.32 years:

$$_1H^3 \rightarrow {}_2He^3 + e^-$$

So began the process of building heavier isotopes by combining particles of lower mass.

Almost as soon as they form, deuterium nuclei react further, fusing together to form the particularly stable α-particle, either directly by the process

$$ {}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 $$

or in two stages by the processes

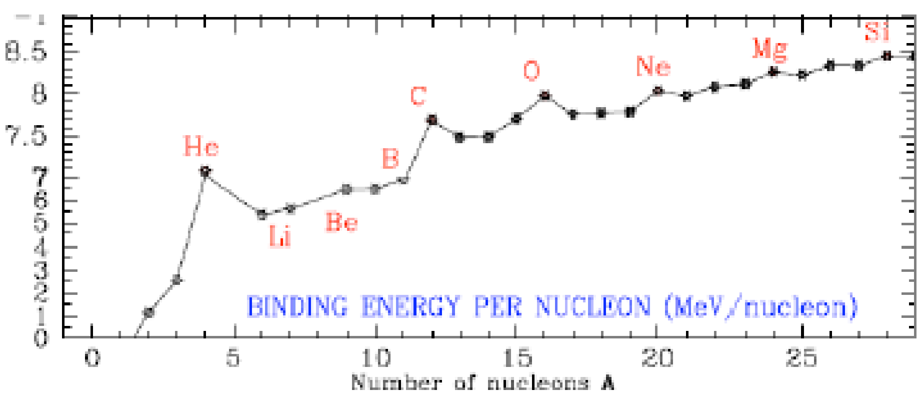
$$ {}_1H^2 + {}_1H^1 \rightarrow {}_2He^3 $$

$$ {}_2He^3 + {}_0n^1 \rightarrow {}_2He^4 $$

$$ {}_2He^3 + {}_2He^3 \rightarrow {}_2He^4 + {}_1H^1 + {}_1H^1 $$

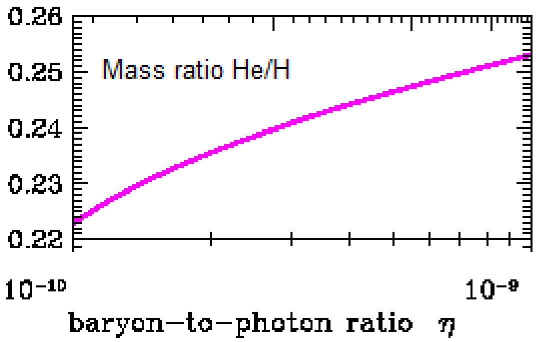
Here, a new element, helium, had been built up in stages, starting with two protons and two neutrons. Within a short while, all the neutrons had been consumed and there was then approximately one α-particle for every remaining 12 protons.

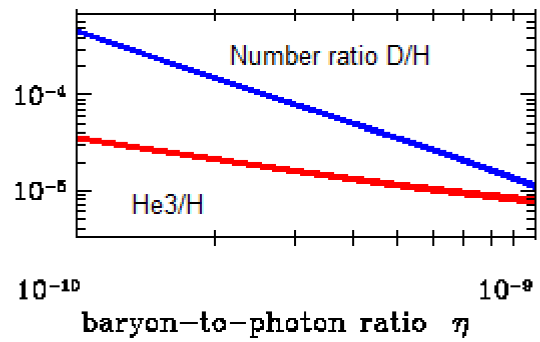
For several reasons the building of isotopes heavier than helium was seriously inhibited. True, miniscule traces of the next more massive elements lithium, beryllium and perhaps boron had been formed. However, the processes by which they form are so slow that they had scarcely started in the short time-interval of less than an hour that had passed before the temperature fell so low that the energies of reacting particles were no longer sufficient to permit contact. All nuclear fusion reactions require contact to be made between two positively charged nuclei. As every schoolboy (and girl) knows (or should know), opposite charges attract one another but like charges are mutually repellent. Getting one nucleus to approach another is analogous to firing a ping-pong ball into an electric fan; it needs to be projected with a huge velocity if it is to strike the fan. Likewise, reacting nuclei need huge energies and therefore high temperatures for fusion to occur. Furthermore the fusion of α-particles to build a more massive stable nucleus is unusually difficult because lithium, beryllium and boron, the elements with atomic numbers 3, 4 and 5, all have particularly low binding energies.

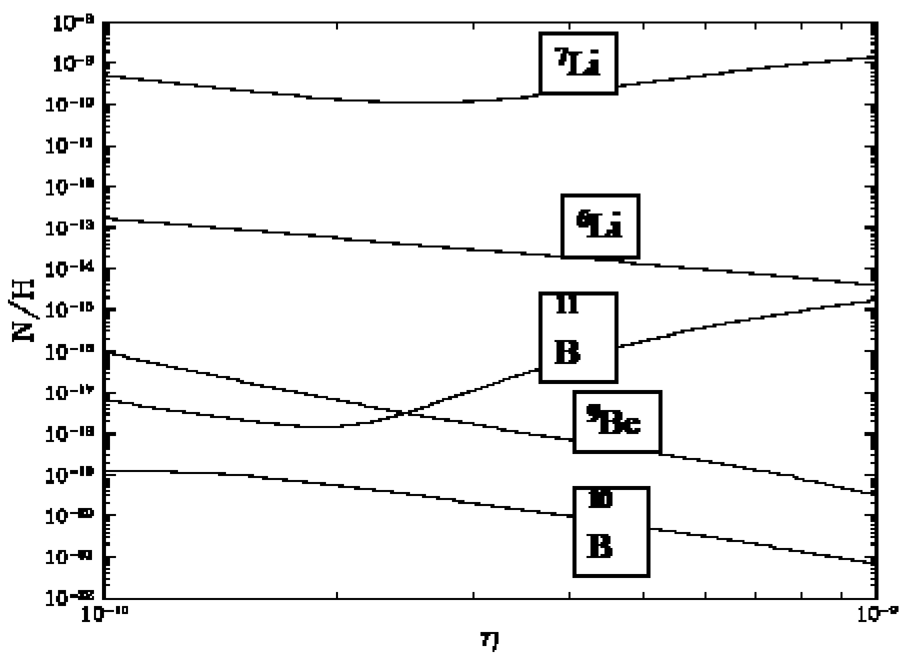


That is not to say that these elements have no stable isotopes; indeed ${}_3Li^6$, ${}_3Li^7$, ${}_4Be^9$, ${}_5B^{10}$ and ${}_5B^{11}$ all exist in nature and none of them decays spontaneously. The problem is that it is not possible to envisage any exothermic (energetically favourable) fusion reactions involving ${}_2He^4$ that will yield any of them. ${}_3Li^5$ and ${}_2He^5$ are highly unstable, as are all isotopes with five nucleons, so it is impossible to fuse an α-particle with either a proton or a neutron. Likewise ${}_4Be^8$, the product of fusion of a pair of α-particles, has a half-life $t_{½} = 10^{-16}$ seconds, decaying as the reverse of its formation. A deuterium fusion with an α-particle could conceivably afford ${}_3Li^6$, and it is believed that this isotope as well as ${}_3Li^7$ and ${}_4Be^9$ are produced in small amounts in BBN. The α-particle is a particularly stable unit, so the process of building heavier elements cannot easily move on further. An analogy is to attempt to cross a river by means of regular stepping stones where one stone ($_4Be^8$) is far below water level. This is the beryllium bottleneck.

The numbers of various isotopes relative to hydrogen resulting from BBN are calculated theoretically as a function of the so-called baryon-to-photon density ratio η (i.e. the ratio of nucleon particles to radiation), which increased with time during BBN.







This suggests that lithium made up only about one atom in a billion in the early universe and that the amounts of beryllium (Be) and boron (B) were insignificantly small. The order-of-magnitude value for lithium is in correspondence with its abundance in the Solar System, but the abundances of Be and B, although low, are now much greater than the amounts believed to have been formed in BBN.

Nucleosynthesis in first-generation stars

It became possible for the heavy elements to form only millions of years later, when the first stars had formed by condensation under gravity, which produced rising temperatures so that eventually fusion reactions became feasible. The extents of compaction and temperature rise were stabilised for long periods by the negative feedback effect of the internal pressure rise supplemented by radiation pressure from the nuclear reactions.

Of course, the problem encountered in BBN of the beryllium bottleneck was still there, but in stars time is on the side of making the metallic elements; instead of a few minutes, millions and billions of years are available. The big leap from the ${}_2He^4$ 'stepping stone' to the next isotope with a high binding energy, ${}_6C^{12}$, is possible by virtue of the 'Hoyle resonance', a phenomenon first recognised by Fred Hoyle, an achievement that more than compensated for his mistaken devotion to the 'steady-state universe'. The sequence of fusion reactions is

$$ {}_2He^4 \quad + \quad {}_2He^4 \quad \rightarrow \quad {}_4Be^8 \quad - 93.7 \text{ keV} $$

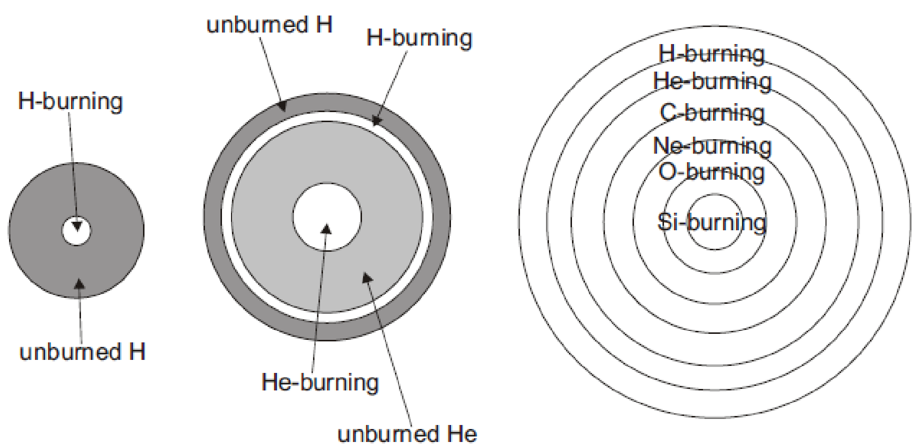
$$ {}_4Be^8 \quad + \quad {}_2He^4 \quad \rightarrow \quad {}_6C^{12} \quad +7.367 \text{ MeV} $$

Although the former process is energetically unfavourable, the second affords the correct amount of energy (the Hoyle resonance) to produce an excited state of carbon, so allowing that fusion. Some carbon then fuses with a further α-particle, forming oxygen:

$$ {}_6C^{12} \quad + \quad {}_2He^4 \quad \rightarrow \quad {}_8O^{16} \quad + \quad \gamma \quad (7.162 \text{ MeV}) $$

For completeness it should be mentioned that carbon and oxygen nuclei can only be synthesised in stars of at least half the mass of our Sun, and even then only when they have reached the stage of maturity in which their core temperature rises above 2×10^8K. Smaller first-generation stars could not form elements heavier than helium and even could do that only if they could reach 6×10^7K. Very small stars, 'brown dwarfs', are unable to kindle any form of nuclear 'fire' and are described as sub-stellar objects rather than as stars.

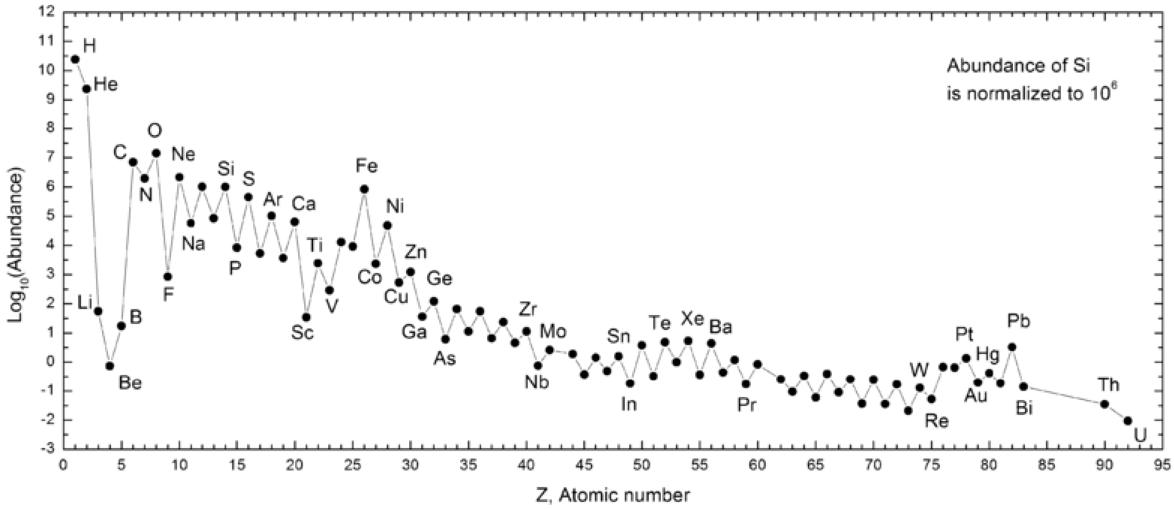
A sufficiently massive star can, as its lifetime progresses and its core temperature rises, proceed to synthesise heavier and heavier elements up to ${}_{28}Fe^{56}$ by fusing lighter isotopes with α-particles.



process	fuel	products	temperature (K)
H-burning	H	He	6E7
He-burning	He	C, O	2E8
C-burning	C	O, Ne, Na, Mg	8E8
Ne-burning	Ne	O, Mg	15E8
O-burning	O	Mg to S	2E9
Si-burning	Mg to S	elements near Fe	3E9

N.B. Here 6E7 is an alternative way of writing 6×10^7

Estimated relative abundances of atoms of elements in the Solar System



We see that isotopes with nuclei that are multiples of α-particles are particularly abundant; relative abundances of ${}_6C^{12}$, ${}_8O^{16}$, ${}_{10}Ne^{20}$, ${}_{12}Mg^{24}$, ${}_{14}Si^{28}$, ${}_{16}S^{32}$, ${}_{18}Ar$ and ${}_{20}Ca^{40}$ are essentially as expected. Intermediate elements (the dips in the abundance distribution) are formed by subsequent nuclear reactions. Elements heavier than ${}_{28}Fe^{56}$ are produced by neutron absorption, possibly with follow-up nuclear reactions. Iron itself is particularly plentiful through having the highest binding energy. Especially noticeable are the anomalously low abundances of lithium, beryllium and boron – the consequence of their low binding energies.

Later generation stars

Carbon, nitrogen and oxygen inherited from earlier-generation stars provide alternative pathways that avoid the beryllium bottleneck. In the CNO cycle, protons are added to carbon to produce nitrogen and then oxygen. The result is that an α-particle is produced from four protons and ${}_6C^{12}$ is recycled. This cycle does nothing to redress the paucity of lithium, beryllium and boron.

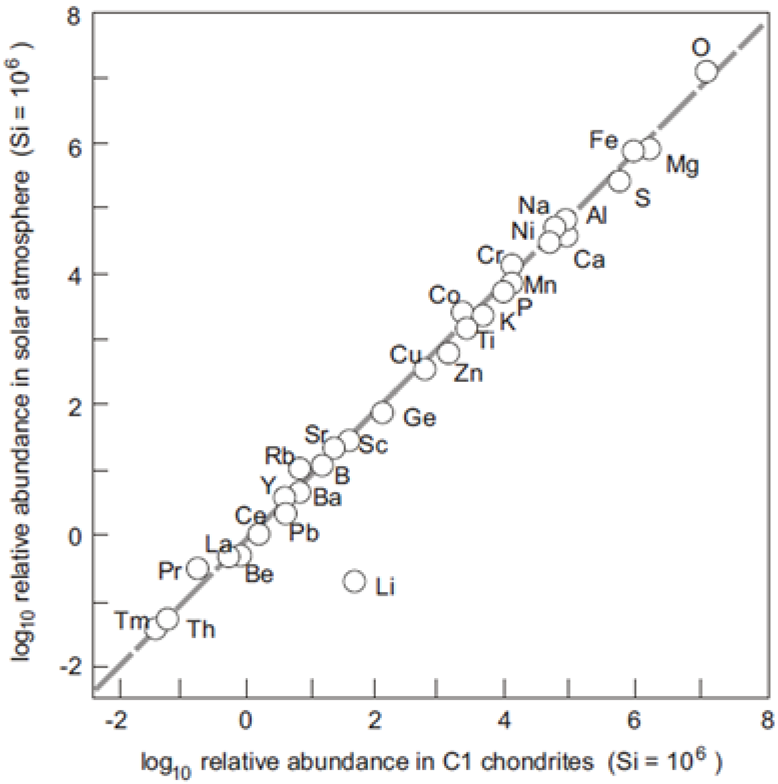
$${}_6C^{12} + {}_1H^1 \rightarrow {}_7N^{13}$$
$${}_7N^{13} \rightarrow {}_6C^{13} + \beta^+$$
$${}_6C^{13} + {}_1H^1 \rightarrow {}_7N^{14}$$
$${}_7N^{14} + {}_1H^1 \rightarrow {}_8O^{15}$$
$${}_8O^{15} \rightarrow {}_7N^{15} + \beta^+ + \gamma$$
$${}_7N^{15} + {}_1H^1 \rightarrow {}_6C^{12} + {}_2He^4$$

Nucleosynthesis elsewhere

The stable isotopes ${}_3Li^6$, ${}_3Li^7$, ${}_4Be^9$, ${}_5B^{10}$ and ${}_5B^{11}$ all exist in nature, yet evidence suggests that, of these, only some of the ${}_3Li^7$ might be explained as having arisen during BBN and possibly also through stellar syntheses, although it is likely that ${}_3Li^7$ would actually be destroyed in stars by the process

$${}_3Li^7 + {}_1H^1 \rightarrow {}_2He^4 + {}_2He^4$$

More lithium is found in meteorites and brown dwarfs than in burning stars; further evidence that Li is destroyed in stars. However, many low-mass, metal-poor, Li-rich red giants are known with ${}_3Li^7$ abundances larger than the universe's primordial value, so the Li in these stars must have been created rather than saved from destruction. $_3Li^7$ can also be generated in carbon stars.



Certain orange stars that appear to have a higher than usual concentration of lithium (such as Centaurus X-4) orbit massive objects – neutron stars or black holes – whose gravity evidently pulls heavier lithium to the surface of a hydrogen–helium star, causing more lithium to be observed.

See www.iap.fr/lithiuminthecosmos2012/scripts/affiche_abstract.asp for some developments.

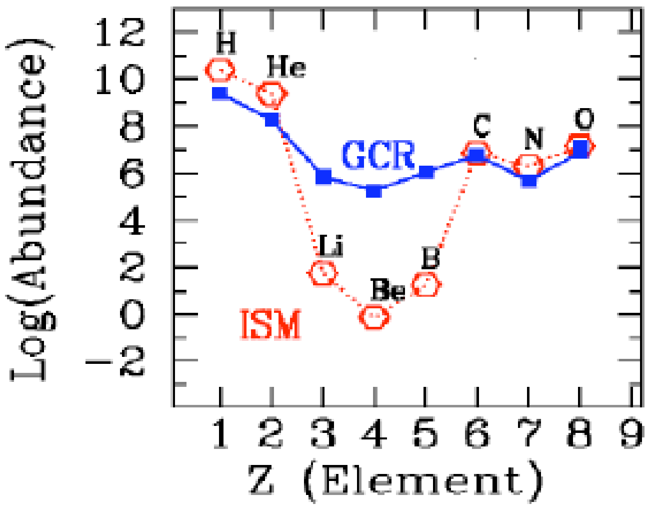
Spectroscopic studies of all three elements in the Sun show that none was much above the parts-per-trillion level. The levels of Be and B are comparable with their levels found in meteorites, but those of lithium isotopes are only one-thousandth of the lithium in meteorites, confirming the view that lithium is destroyed in stars. If Be and B are formed in stars, they must also be destroyed there. So where does the nucleosynthesis of these three elements occur?

As nuclei of these three elements have low binding energies and are therefore vulnerable to destruction, it is most likely that they have been formed under conditions where they are unlikely to be exposed to further nuclear reactions.

Cosmic ray spallation

A long-standing and the most persuasive explanation for the nucleosynthesis of Li, Be and B involves the interaction of cosmic rays with the interstellar medium (ISM). The rays, principally high-energy protons, can collide with a nucleus of carbon, oxygen or nitrogen, causing it to undergo fission. Alternatively, any cosmic rays that are themselves C, O or N nuclei can collide with interstellar hydrogen.

Compare the abundances of the lighter elements in the interstellar medium with those in galactic cosmic rays (GCR) (note the logarithmic scale in the diagram below). It is estimated that 46% of all boron has formed in this way.



The number of lithium, beryllium, and boron (LiBeB) nuclei in the cosmic rays is only 4 or 5 orders of magnitude smaller than the number of cosmic-ray protons. Since the LiBeB abundance fraction is only 10^{-9} in stars, it is believed that LiBeB cosmic rays are produced almost entirely as a result of fragmentation reactions of heavier cosmic-ray nuclei (e.g., carbon and oxygen) with interstellar material.

Most stable nucleides of lithium, beryllium, and boron are thought to have been produced by cosmic ray spallation in the period of time *between* the Big Bang and the solar system's formation. However, radioactive isotopes such as ${}_4Be^7$ and ${}_4Be^{10}$ must have more recent origins. In the case of GCRs containing carbon, nitrogen or oxygen that have been fragmented during collisions with the thin interstellar gas composed mostly of hydrogen, the GCRs would need to have been travelling for about 10 million years to produce enough interstellar collisions to yield the observed number of light nuclei.

The timescale for this travel is based in part on the observation of such radioactive fragments as ${}_4Be^{10}$. This radionuclide has a half-life of 1.5 million years, and the number of such particles that can survive to be detected on Earth depends on their total travel time. But ${}_4Be^{10}$ is also produced in the Earth's atmosphere by the cosmic ray spallation of oxygen. It accumulates at the soil surface, where its relatively long $t_{½}$ permits a long residence time before decaying to ${}_5B^{10}$. The production of ${}_4Be^{10}$ is inversely proportional to solar activity, because increased solar wind during periods of high solar activity decreases the flux of galactic cosmic rays that reach the Earth.

Nucleosynthesis during supernovae

It has been suggested that light elements can be synthesised by the interactions of C and O nuclei ejected from supernovae with the H and He in the surrounding gas. There are indications from theory that significant amounts of ${}_3Li^7$ and ${}_5B^{11}$ can be formed by α-capture in type II supernovae as the shock traverses the base of the hydrogen envelope:

$$_{2}He^{3} + {}_{2}He^{4} \rightarrow {}_{4}Be^{7} \qquad {}_{4}Be^{7} + \beta \rightarrow {}_{3}Li^{7}$$

$$_{4}Be^{7} + {}_{2}He^{4} \rightarrow {}_{6}C^{11} \qquad {}_{6}C^{11} \rightarrow {}_{5}B^{11} + \beta^{+}$$

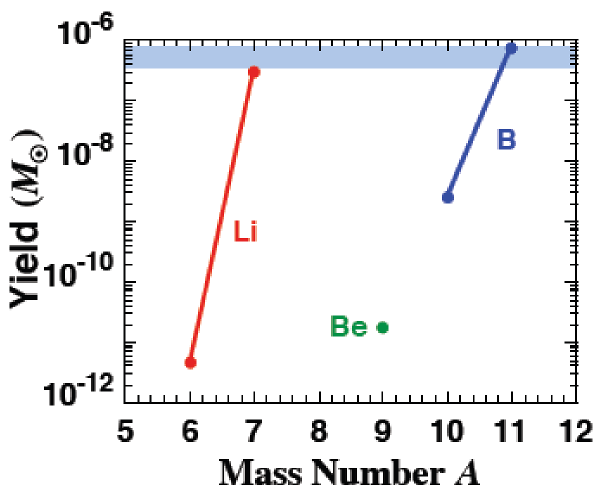
Here the $_{2}He^{3}$ isotope is supposed to have been formed by a so-called v-process of neutrino interaction:

$$_{2}He^{4} + v \rightarrow {}_{0}n^{1} + {}_{2}He^{3}$$

Other examples of proposed v-processes include

$$_{6}C^{12} + v \rightarrow {}_{1}H^{1} + {}_{5}B^{11}$$

Some published work even claims that isotopes of all three low-abundance light elements can be formed in certain envelopes within the exploding star under appropriate conditions involving certain supernovae. Calculated yields in units of the Sun's mass are shown below for a supernova in a star of 16.2 × the Sun's mass.

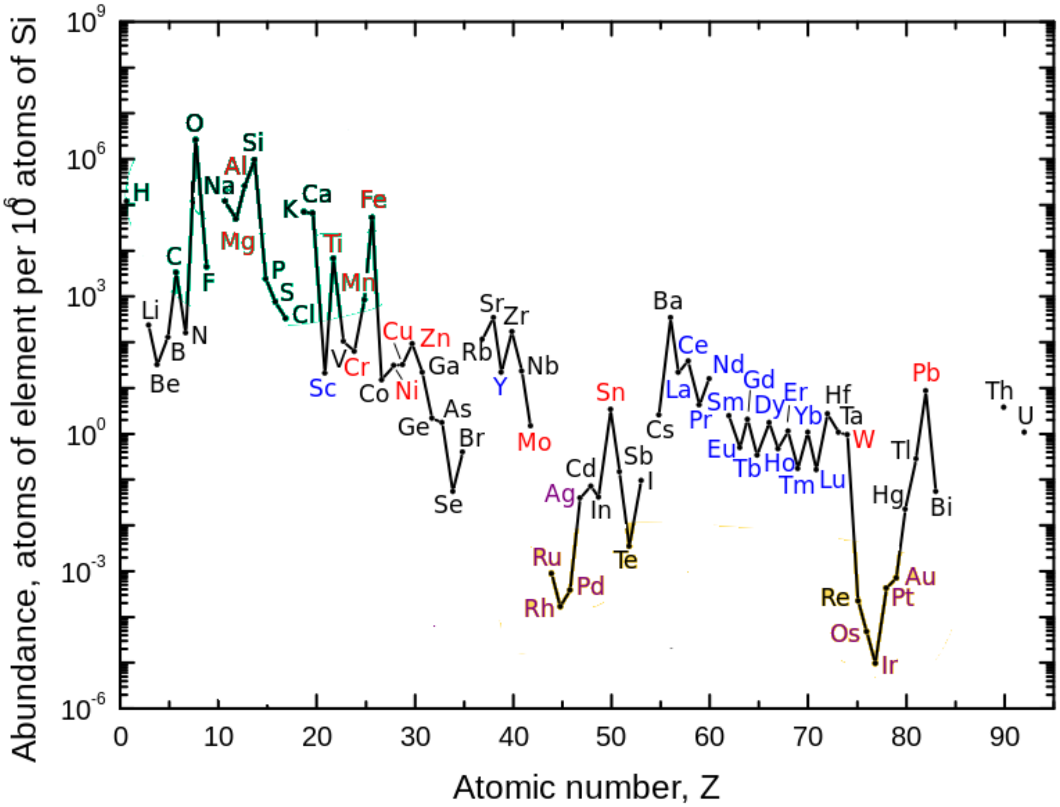


Many of these studies sought to explain the abundance ratios amongst $_{3}Li^{7}$, $_{3}Li^{6}$, $_{5}B^{11}$ and $_{5}B^{10}$ observed in meteorites. The results of such calculations depend greatly on the assumed values of input parameters. Theoretical physics seems to be a vocation high in speculation and low in certainty.

Down to Earth

Symbol	Earth abundance/ppm	Crustal abundance/ppm mass	2011 production/tonne	Element
Li	1.1	18	34,000	Lithium
Be	0.05	2.4	240	Beryllium
B	0.2	9.3	4,300,000	Boron
Cu	60	64	16,100,000	Copper
Sn	0.25	2.2	253,000	Tin
Pb	0.23	12	4,500,000	Lead
Au	0.16	0.0035	2,700	Gold

Abundances of elements in the Earth's crust



In comparison with, say, carbon, we see that the relative abundances of Li, Be and B in the Earth's crust are significantly higher than in the solar system – e.g., the Sun has a concentration of 0.1 parts per billion (ppb) of beryllium.

This concentration in the crust arises because B and Be are two of the most magmaphilic elements that have been brought towards the surface by volcanic action; about 20% of the total abundances of B and Be are in the crust. About 7% of the Earth's lithium is in that layer.

Each of the elements 3, 4 and 5 has widespread applications: beryllium in alloys, semiconductors, heat-sinks, mirrors, radiation windows and nuclear industries; lithium and its compounds in batteries, medicine, alloys, greases, specialised optics, and in the ceramics and nuclear industries. Boron and its compounds have a plethora of uses, too numerous to detail in this article. Today's world relies upon these rare elements, which the beryllium bottleneck would have denied us, so don't thank your lucky stars. Thank cosmic rays!

THE TRANSIT QUIZ

Answers to March's quiz

Every answer starts with the letter C.

1. An optical arrangement in a reflecting telescope in which light is reflected by a secondary mirror to a focus behind the primary mirror. **Cassegrain focus**

2. The layer in the Sun's atmosphere between the photosphere and the corona. **Chromosphere**

3. The 'giraffe' constellation. **Camelopardalis**

4. The brightest cosmic radio source in the sky. **Cassiopeia A (a supernova remnant)**

5. The maximum mass of a white dwarf (about 1.44 solar masses). **Chandrasekhar limit**

6. A glassy, roughly spherical blob found within some meteorites. **Chondrule**

7. A large nebula illuminated by the star Xi Persei whose shape resembles a certain area on Earth. **California Nebula (NGC1499)**

8. A planetary nebula in the constellation Draco, named for its oval shape and greenish colour. **Cat's Eye Nebula (NGC 6543)**

9. The originator of the O, B, A, F ... etc spectral classification of stars. **Annie Jump Cannon (1863–1941)**

10. The first person to observe a solar flare. **Richard Christopher Carrington (1826–75)**

<u>April's quiz</u>

Every answer starts with the letter D (I imagine you're getting the hang of this by now …). The questions are in very rough order of increasing difficulty.

1. The angular distance of a celestial body north or south of the celestial equator.
2. Another name for the planetary nebula M27.
3. The NASA mission that sent a 500kg instrument package hurtling into Comet 9P/Tempel 1 in July 2005
4. A useful empirical measure of the resolving power of a telescope.
5. The numerical difference between the apparent and absolute magnitudes of a star.
6. The most distant and most luminous of all first-magnitude stars.
7. The phase of a body in the Solar System when exactly half of its sunlit side is visible.
8. Epsilon Lyrae.
9. Another name for the diffuse nebula M43.
10. The Danish compiler of the *New General Catalogue* [NGC] *of Nebulae and Clusters of Stars.* He worked at Birr Castle and became Director of the Armagh Observatory.