7 Our Place in the Universe

Dr Charles H. Lineweaver

Fig. 5b Earth from Moon with astronaut in foreground. Courtesy NASA (68-H-1401 and AS11-40-5903)

←

Dr Charles Lineweaver is an Australian Research Fellow in the School of Physics at the University of New South Wales. He studied undergraduate physics at Ludwig Maximillian Universität, Germany and at Kyoto University, Japan. He obtained his PhD from the University of California at Berkeley for research on COBE satellite observations of the cosmic microwave background. After a postdoctoral fellowship in Strasbourg, France, he came to UNSW in 1997. He speaks four languages and has played semi-professional soccer. He teaches a popular new course at UNSW entitled: 'Are We Alone?: The Search for Extraterrestrial Life'.

I. Where Are We?

In a canoe called the Earth, we are drifting down an unknown river. We have no maps. What lies around the next bend? Some of us hear an ominous roar ahead – a waterfall? Some of us see the stream broadening and an immense unknown ocean on the horizon. We are on a journey through time. We may encounter other life forms or there may be billions of lifeless shores. We paddle and stab at the water trying to avoid jutting boulders and eddies. Many of us are bailing. We bail for about 80 years, then we give our scoops and paddles to our children. If our canoe holds – if we can see far enough ahead to avoid waterfalls and whirlpools, then surely our children's children's children… will live to see this river empty into a placid infinite ocean. In the dark of the night, we gaze at the heavens and wonder who we are. How did we get on this canoe? Where did we come from?

Suppose that somewhere in the Universe a cosmic postman wants to deliver a letter

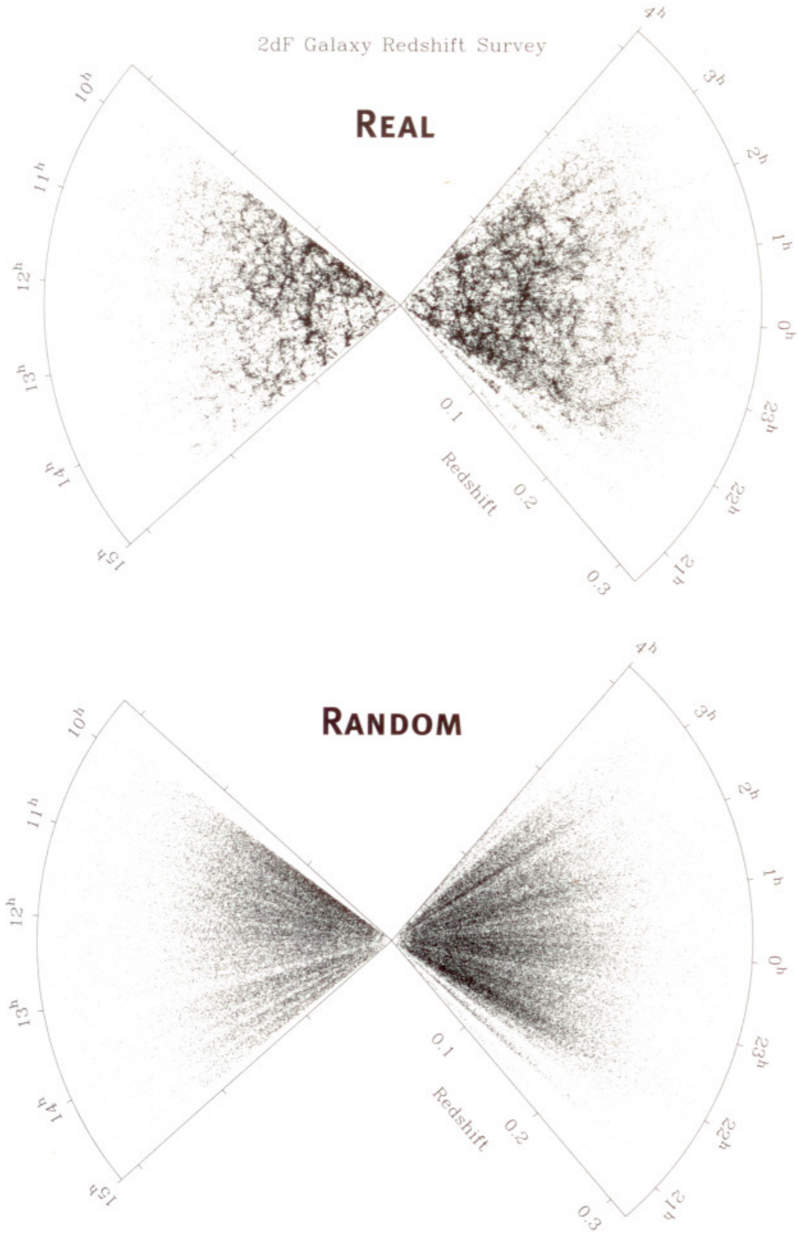


Fig. 1a **A letter addressed to us.**
Courtesy Dr Charles Lineweaver

Fig. 1b **Our local Universe (REAL) and simulated random galaxies (RANDOM). The top panel (REAL) is a map of the Local Universe. Each dot is a galaxy with a few hundred billion stars. The scale is: 1 millimetre = 100 million light years. The bottom is a simulation. If the galaxies in the Universe were laid out at random like raindrops on a footpath, this is what they would look like (RANDOM). The real patterns (REAL) are very different. This map extends far enough to encompass a fair sample of the Universe. Notice that there are many frothy voids and walls in this image, but there is no structure that seems to be as large as the map itself – the structures nearby resemble the structures far away. Where did this large scale structure come from? What determined this distribution of galaxies in the Universe? The answer seems to be quantum fluctuations on the smallest scales imaginable. This map was made with the 2dF instrument on the Anglo-Australian Telescope in Coonabarabran, NSW.**
Image courtesy of the 2dF galaxy redshift survey team. Simulation map courtesy of Roberto de Propris and Carole Jackson, UNSW School of Physics.

Fig. 1c **Our Virgo cluster.**
© Anglo-Australian Observatory/Royal Observatory, Edinburgh. Photograph from UK Schmidt plates by David Malin

addressed to us. How could he find the 'Local Universe'? The top part of Figure 1b is a map that will help. It is the largest and most detailed map of the local Universe that we have been able to make. It was made in Australia. Each black dot represents a galaxy. There are bubble-like voids where fewer galaxies live. There are also clumps of dots. These are clusters of galaxies. In a few dozen places, the clumps line up to make great irregular walls that look like flattened swarms of bees. The 'Supergalactic Plane' in our address is such a flattened swarm but does not show up well in this map. If you think there is no pattern in this map – that the galaxies look like they've been thrown down at random – have a look at the lower part of Fig 1b. It is a simulation of what the local Universe would look like if galaxies were distributed at random like raindrops on a footpath.

The patterns of great walls and voids in the real map help the postman identify our Local Universe and zero in on the particular wall we call the Supergalactic Plane – a motley irregular wall, but it is the largest identifiable structure in which we live. Embedded in this wall, like a spherical brick, is our cluster, the Virgo Cluster of galaxies, with its several

Fig.1c thousand galaxies. At the centre of the Virgo Cluster is the giant elliptical galaxy M87, and at the heart of M87 is the largest black hole we know of – 3 billion times the mass of our Sun.

After finding Virgo, the postman will need a more detailed map. Sixty million light years away on the very outskirts of Virgo, we live in a little village of galaxies called the Local Group – the astronomical analogue of back of Bourke. The montage of Fig. 1d is a roster of our galactic neighbors. Fig.1d

In the Local Group our Milky Way Galaxy is the second most massive galaxy. The Andromeda Galaxy (only two million light years away) is the gravitational boss since it is twice as big. There are also about two dozen small galaxies. The Large and Small Magellanic clouds are the two closest. They are being tidally ripped apart and gravitationally swallowed by our galaxy.

In the disk of the Milky Way, two thirds of the way out from the centre, our Sun shines on the edge of the Orion-Cygnus spiral arm. Just as the Earth goes around the Sun, the Sun goes around the centre of our galaxy, taking 200 million years for each orbit. Therefore, since its formation 4.5 billion years ago, the Sun has made 22 orbits of the Galaxy. With the other few hundred billion stars, it bobs up and down in the disc as it goes around. The Sun has a cloud of comets around it called the Oort cloud that extends out for two light years; half way to the nearest star Alpha Centauri. Closer to the Sun than the Oort cloud is a flaring disc of dirty snowballs and asteroid-like objects known as the Kuiper Belt.

If the postman can avoid Jupiter's pull on the way by, he will find in the inner Solar System, the third planet from the Sun. Humanity with all its joys and wars, and all life on Earth, live in a thin 10-kilometre thick skin of water, air and dirt, clinging to a ball of rock and iron. This thin membrane of life, this diaphanous biosphere, is us. Our letter has arrived. Fig.1e

II. When Are We? Fig.2a

The Earth, Moon, Sun and stars seem permanent and unchanging. But none of these objects, nor even the Universe itself, is infinitely old. The Universe does not come with a birth certificate, but there are dozens of ways to measure its age. Current estimates for the age of the Universe and some things in it are given in the table following.

WHEN DID WE BECOME WHO WE ARE?

(age estimates in millions of years)

Universe (Time, Space)	13,400
Milky Way Halo	12,200
Milky Way Disc	8700
Sun	4566
Earth	4550
Moon	4540
Life	possibly before 3850
Recognisable fossils	3500
Eucaryotes	before 2700
Sex	before 1000
Animals, Heads	before 600
Backbones	500
Mammals	220
Primates	60
Independent Australian Continent	30
Great Apes	20
Homo sapiens	0.1
Agricultural Revolution	0.01
Industrial Revolution	0.0002
Independent Australian Nation	0.0001
Computer Revolution	now

The main plot of the big bang story is that as the Universe expanded, it cooled. When things cool down they change. For example, as steam cools it condenses into water and water freezes into ice. Many structures of the current Universe that we take for granted – molecules, atoms, protons and even the existence of matter – are the frozen relics of a hotter past.

The changes that occurred as the Universe cooled may be easier to understand if we run time backwards and see how increasing the temperature affects things. Heat our bodies and our molecules begin to separate as we change from a liquid into a gas. Heat our molecules further and they break up into their parts, atoms. Heat atoms and they break up; the electrons fly off leaving only the nuclei. Heat these nuclei and they break into their parts, protons and neutrons. Heat these and they break into fundamental particles called quarks. The Universe becomes a hot dense quark soup. Heat this soup further and you have so much energy that antiparticles and particles form in equal numbers from the photons. Heat the Universe further and, like water absorbing heat to become steam, the vacuum absorbs all the matter and energy in the Universe as it changes phase from the true vacuum into a higher energy state vacuum called a false vacuum. This

Fig. 1d **Our Galactic Neighborhood. A roster of the galaxies in our Local Group. Andromeda (lower left) is twice as massive as our Milky Way galaxy (lower right). A close-up of the boxed object in M33 (upper left) is shown in Fig. 3b. The Galaxies of the Local Group drawn to scale.**
Courtesy of Bruno Binggeli, University of Basel, Switzerland

←

Fig. 1e **Our current understanding of quantum cosmology and the beginning of the Universe is far from complete, but what we do know strongly suggests that our Universe may be part of an eternal budding network of universes called the multiverse. Our cosmic address keeps getting longer. From *Sky and Telescope: The Self-Reproducing Universe* by Eugene F. Mallove**
Copyright © September 1988 by Sky Publishing Corporation

→

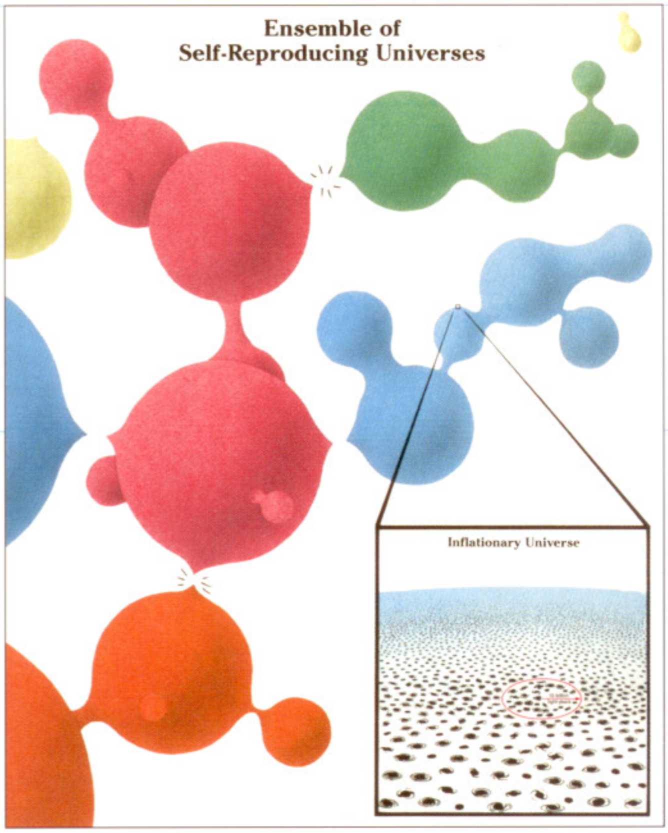
transition makes the Universe collapse by at least a factor of 10^{26} = 100,000,000,000,000,000,000,000,000. Heat this collapsed false vacuum and space-time itself begins to froth and boil. Time, as an entity separates from space, loses its meaning and there your heating stops. Play this scene in the opposite direction and you have the history of the Universe. Thus, the answer to the question, 'Where did the stuff of the Universe come from?' is: 'from the energy of the false vacuum'.

One billion years after the big bang there was a period of intense star formation that lasted for a few billion years. Our Sun was not part of it. The Earth and Sun formed eight billion years after the big bang, 4.5 billion years ago. The Sun is about one-third the age of the Universe and younger than 90 per cent of the stars in the Universe. The Earth formed about 10 million years after the Sun turned on.

Why Do We Think the Universe Had a Beginning?

In the 1920s and 1930s, Edwin Hubble and others discovered that light from distant galaxies was shifted towards longer wavelengths. The more distant the galaxy, the more the light was shifted. This is similar to the Doppler shift that lowers the pitch of receding train whistles and enables policemen with radars to give you speeding tickets. Distant galaxies are all receding from us and the more distant they are, the faster they are receding. When we trace the motion of all the galaxies in the Universe back into the past, we find that they used to be closer together. At a point in time, about 13 billion years ago, all galaxies were on top of each other in a cosmic traffic jam. We call this hot, dense traffic jam of galaxies the big bang. Thus, we think there was a beginning to the Universe because, today, we see all the galaxies in the Universe moving away from each other. The discovery that the Universe had a beginning is one of our greatest achievements.

When we say the Universe is 13 billion years old, we don't mean that just the objects in it are 13 billion years old. We mean that the objects and space itself and even time itself are 13 billion years old. Before then, we don't think time or space (or 'before') existed.



Zen master: 'There was never a time in which time did not exist'. *Physicist:* 'Time and space emerged from quantum space-time foam about which we know very little'.

III. What are We?

When we eat, cook, burn, break and recycle things, we destroy molecules by rearranging the atoms, but we do not make new atoms. There are only two places in the Universe hot enough to make atoms. These two atom factories are the big bang and inside stars. The big bang made the hydrogen and helium while all the other atoms (and a bit of the helium) are made in stars.

When massive stars reach the end of their short lives, they explode. The new atoms they have created are dispersed into interstellar space. Over billions of years such supernovae have strewn the main elements needed for life (carbon, hydrogen, oxygen and nitrogen) throughout the Universe. The molecules needed for life (H_20, CO_2 , N_2) are also strewn throughout the Universe, having formed when the supernovae debris condensed into molecular clouds. Water, the elixir of life, is probably the most abundant tri-atomic molecule in the Universe. Amino acids, the building blocks of proteins and life, are found in some meteorites and, they too, are strewn throughout the Universe. Thus the ingredients for life are abundant; the basic chemical requirements for the emergence of life are present wherever stars and their planets form.

The Universe is made of strange stuff. Only in the last g.3a few years has our inventory become complete – we think. Observations of the glow from the big bang and distant supernovae are only consistent with each other if about 70 per cent of the stuff in the Universe is unusual anti-gravitating stuff called 'vacuum energy'. Even worse, most of the rest is some kind of strange cold dark matter. We have never detected it directly and we only know of its existence from its gravitational influence on normal galaxies. Perhaps we should congratulate ourselves on being able to classify the remaining five per cent of the Universe into Mendeleyev's periodic table of the elements.

IV. Who Are We?

Imagine a chain of your ancestors. You hold the hand of your mother. She holds the hand of her mother, your grandmother, who holds the hand of her mother and so on for generation after generation into the past. As we follow this living chain into the past, about six million years ago, the 300,000th mother is your ancestor. She is also an ancestor of all chimpanzees alive today. Follow the chain 200 million years into the past and your ancient mothers are nocturnal shrews whose successful avoidance of death enabled this chain to lead to you. Four hundred million years into the past and your mothers lose their hands, feet and lungs. They are fish; the fins of the mothers touching the fins of the daughters. About 800 million years into the past, your mothers are tiny worms writhing against each other. Two billion years ago they are microscopic single-celled amoebas of dubious gender. Between 2.5 and 3.5 billion years ago the unbroken chain becomes a series of microbes. Somewhere around four billion years ago the chain of your biological mothers diffuses into a chain of your physical mothers – a chain made of the molecules from which our ancestors arose. Here there is a ig.4a transition from living to non-living. We no longer follow the flow of DNA information in the chain, we follow the molecules that came together to make us. This pre-biological, physical chain winds its way back to the early heavy bombardment of the Earth, leaves the Earth and spreads out into the pre-solar ig.3b molecular cloud where our water formed. Then it diffuses further into the centres of myriad stars where our atoms formed and ultimately back in time to inflation where matter formed out of the false vacuum and then back to the big bang where time and space formed out of quantum space-time foam.

The scientific discovery and continuing exploration of this great chain of cosmic evolution – this flow of information and material – is documented by fossils, DNA sequencing, geological records, chemical analyses, Moon rocks and the spectra of the most distant stars and galaxies. Our biological, chemical and physical roots run deep into the fabric of the Universe. And because they run so deep we don't really Fig.4b know what life is. Are viruses alive? Are the mitochondria with their own DNA, inside every cell of your body, alive? Are the chloroplasts in plant cells alive? Is an ecosystem alive? Is a hurricane alive? The wonderful problem with biology is we do not know where its limits are. Fig.4c

The Origin of Life

The Earth is 4.5 billion years old. We have found suggestive isotopic evidence that life is at least 3.85 billion years old. We have found recognisable fossils 3.5 billion years old. If life had been on Earth earlier than four billion years ago we would not expect to find it because rocks of that age are extremely rare and have been almost unrecognisably altered by compression, heat and erosion. As soon as the Earth cooled down enough for life to form, we find evidence for life. Life seems to have formed as soon as it could have.

Our best guess about life on other planets is that if it exists, it might have emerged like life on Earth – it would have started simple and then diverged in ways we are ill-equipped to predict. In the Solar System where water exists (or existed) we are looking for the simplest life forms; for fossil bacteria on Mars, not dinosaur bones.

In the Solar System, the best candidates for extra-terrestrial life seem to be Mars, Europa, Titan and Io (one planet and three moons). About 3.8 billion years ago, when life was probably already established on Earth, Mars was much like the Earth. Water flowed over its surface. It had a thicker atmosphere. There doesn't seem to be any reason why life couldn't have emerged there. Mars probably still has sub-

Fig. 2a One of the oldest objects in the Universe. The oldest stars in the Universe are found in globular clusters like this one. Globular clusters are beautifully spherical clumps of thousands of stars which form in spherical halos at the initial stages of galaxy formation.

←

Fig. 3a Composition of the Universe, the Sun and Life.
Courtesy Dr Charles Lineweaver
→

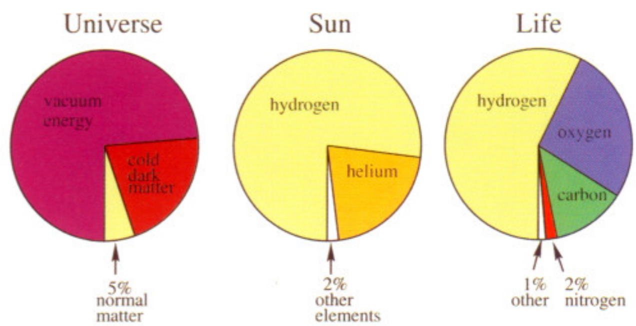


Fig. 4b **Cosmic evolution and the terrestrial tree of life. Our biological, chemical and physical roots run deep into the fabric of the Universe. The identification of DNA as the molecular blueprint of all life has led to the construction of this terrestrial tree of life and our position on it ('animals', upper right). Our tree of life has been seeded and fertilised by stars, watered by comets and energised by the Sun. The seeds for stars were planted by the irreducible quantum fluctuations of the big bang.**
Courtesy Dr Charles Lineweaver

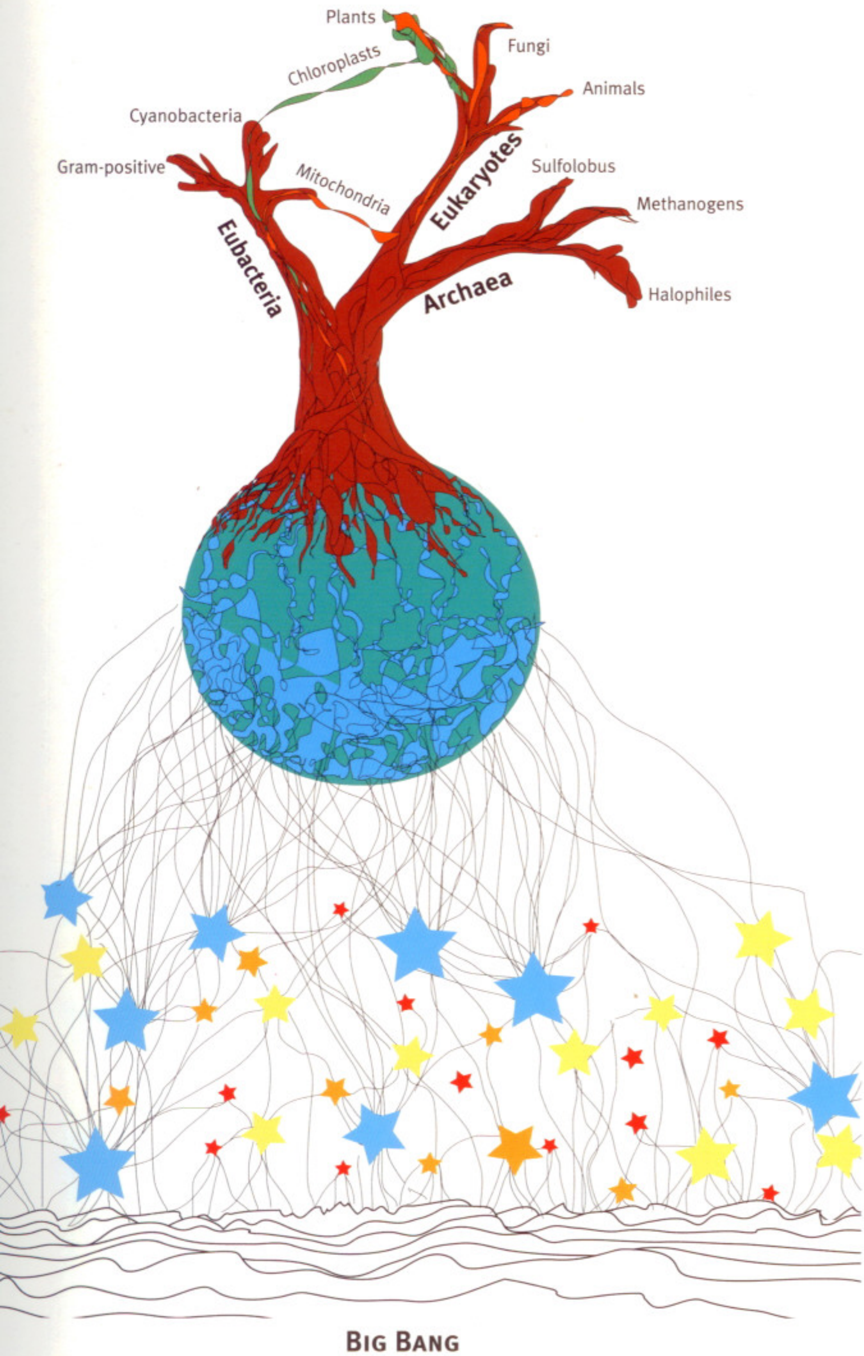
↓

Fig. 4a **Four billion years ago we woke up out of chemistry and we became biology.**
M. C. Escher, *Liberation*, lithograph, 1955.

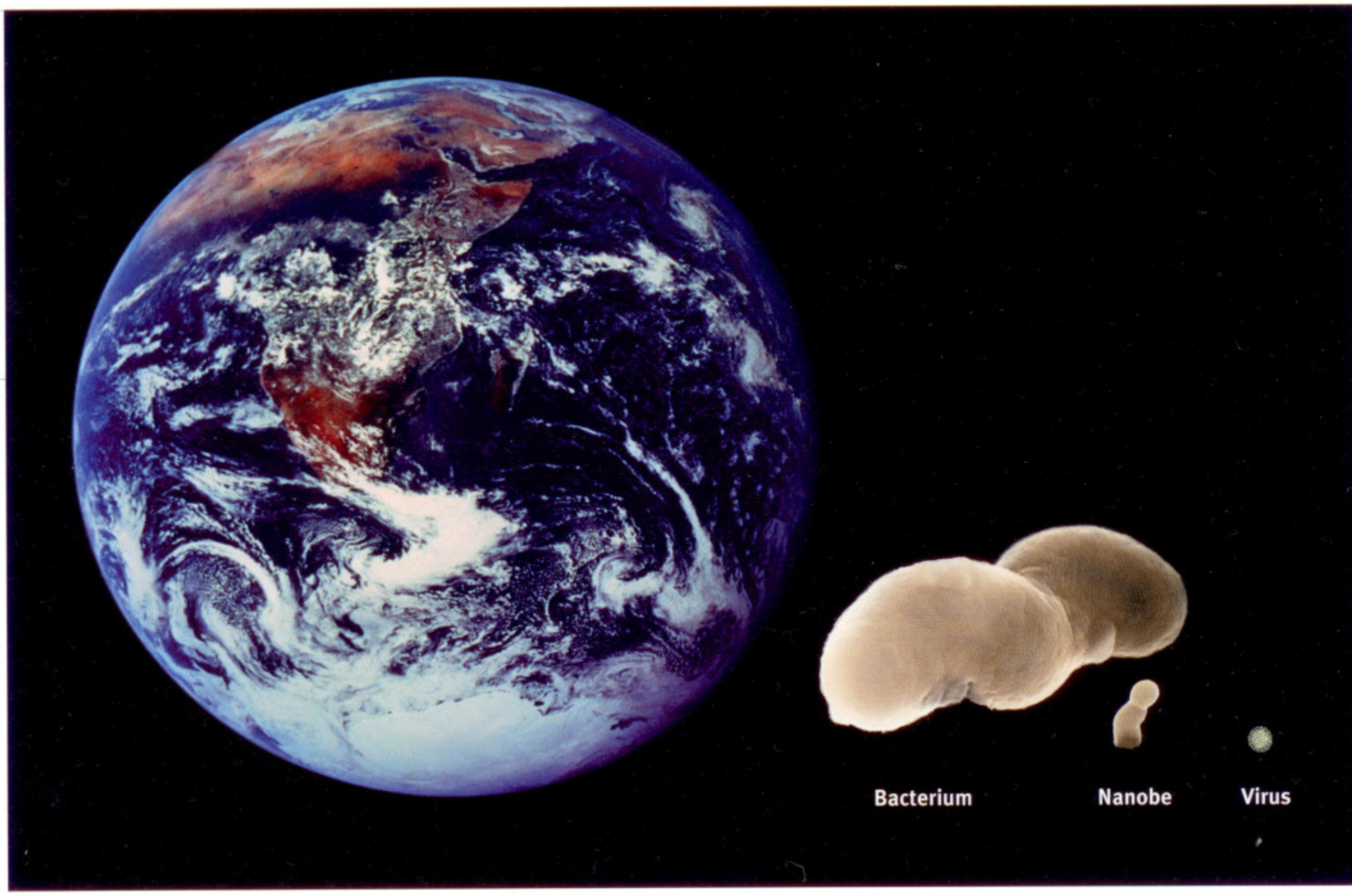
↓

Fig. 3b **Fertile Fumes of Supernovae. Our Sun, 4.57 billion years ago, was a small clump in a cloud of gas and dust like this one, NGC 604 — a dense molecular cloud formed from the remains of supernovae. Dense clumps have collapsed into stars and the brightest stars light up the cloud like fireworks lighting up the smoke from previous fireworks. This giant molecular cloud is 1500 light years across and about 3 million light years away in the third largest member of the Local Group (see red box in Fig. 1d).**
Courtesy Hui Yang (University of Illinois) and NASA

→



OUR SUN, 4.57 BILLION YEARS AGO, WAS A SMALL CLUMP IN A CLOUD OF GAS AND DUST LIKE THIS ONE…A DENSE MOLECULAR CLOUD FORMED FROM THE REMAINS OF SUPERNOVAE.



surface water oozing around. Europa (a moon of Jupiter) is covered with a cracked and creviced icy crust but we think there is a deep ocean of liquid water underneath that crust. Perhaps it has deep ocean sea-dwellers like the albino tube worms and blind crabs we have deep in our oceans. Titan, the largest moon of Saturn, has a thick atmosphere of photochemical smog (nitrogen, methane and a rich mixture of hydrocarbons). Some type of frigid hydrocarbon-based life may have arisen. In 2004 the Cassini-Huygens orbiter and lander will arrive at Titan and have a look. Io, another moon of Jupiter, has sulphur volcanoes that might provide the energy or food for life.

Extra-solar Planets

Most of the stars in the Universe probably have planets orbiting them. This expectation is based on many observations. Here are a few:

1. Our Solar System has many planets, not just Earth.
2. We have multiple examples of mini Solar Systems in the systems of moons around seven of the nine planets in our Solar System.
3. The formation of a flattened proto-planetary disk of dust and debris is a natural consequence of the formation of normal stars and all new stars seem to have them.

In contrast to the observable but short-lived discs of dust, planets are hard to detect. They do not give off light but shine dimly by reflecting the light of their parent stars. Although no one has ever seen an extra-solar planet by its reflected light, more than 70 extra-solar planets have been detected.

How have they been detected? If you attach a basketball to a tennis ball with a stick, and spin it, the lighter tennis ball will go around in a big circle while the heavier basketball will go around in a small circle. This is how planets (tennis balls) make their host stars (basketballs) wobble a bit. It is the detection of this wobble via the periodic Doppler shift of the star's light that has enabled us to detect planets around nearby Sun-like stars.

The 70 or so planets that have been detected have been called 'hot Jupiters'. They are 'hot' because they are in orbits close to their host stars (most of them are closer to their host stars than Mercury is to the Sun). They are 'Jupiters' because they are so big. No one expected such planets to exist so close to stars. However, these results have little to say about Earth-like planets because 1) hot Jupiters are only found around 5 per cent of the stars surveyed, and 2) hot Jupiters are the only types of planets that our technology has been capable of seeing, i.e., these 70 are not a random sample. Thus there is plenty of room in the remaining 95 per cent of the stars to have Solar-System-like planetary systems with broadly Earth-like planets.

Fig. 4c **'Every component of the organism is as much of an organism as every other part.' (Barbara McClintock Nobel Prize in physiology or medicine 1983)**

The largest and the smallest known life forms.
A: View of Earth as seen by the Apollo 17 crew travelling towards the Moon 12 July 1972.
Courtesy NASA (EL-1996-00155)
B: A bacterium, a nanobe and a virus.
Courtesy Phillipa Uwins

←

Fig. 5a **We have a built-in inability to understand that we are part of the Universe.**
Drawing courtesy Victor Juhasz
'The rock doesn't want anything, the volcano pursues no purpose, rivers quest not the sea, wind seeks no destination.' (Hofstadter and Dennett, *The Minds I*, p. 120)

→

Are We Alone?

'We might be alone in the Universe, or there might be innumerable inhabited planets in innumerable galaxies. Scientists argue both ways. One day we will know.' (Steven J. Dick)

I'm not so sure. If you don't know what a duck is, you will never know if you're the only one on the pond. We don't really know what life or intelligence is. Life could be staring us in the face and we may not be able to recognise it. The question 'Are we alone?' is also ambiguous. Who is 'we'? It can mean 'Are we (the life forms on Earth) the only life in the Universe?' or 'Are we (*Homo sapiens*) the only intelligent life in the Universe?'. Without a universal definition of life or intelligence both questions are unanswerable.

We and trees share an ancestor that lived about two billion years ago. We will share no biological ancestor with ETs. That suggests to me that it will be easier to talk to a tree than to an extra-terrestrial.

There are about a dozen projects on Earth listening for ET. The Parkes Telescope has been outfitted with an ET detector. So far we have found no artificial signals from extra-terrestrials.

'I see nobody on the road,' Alice said.

'I only wish I had such eyes,' the King remarked in a fretful tone. 'To be able to see nobody! And at that distance too!'

'The probability of success is difficult to estimate, but if we never search the chance of success is zero.'
G. Cocconi and P. Morrison, Sept. 1959, *Nature*, 184.

V. Why Are We Here?

We would like to think of ourselves as rational investigators
5a but of course we are not. Even scientifically constructed
worldviews don't come without emotions. We want to know
5b why we are here. Is there a point to all this – a purpose? Is
there any meaning in all this information about our place in
the Universe?

In one of the most cited passages in popular science at the end of his book on the big bang model, Nobel Prize winner Steven Weinberg muses:

'Below, the Earth looks very soft and comfortable – fluffy clouds here and there, snow turning pink as the Sun sets, roads stretching straight across the country from one town to another. It is very hard to realise that this all is just a tiny part of an overwhelmingly hostile Universe. It is even harder to realise that this present Universe has evolved from an unspeakably unfamiliar early condition, and faces a future extinction of endless cold or intolerable heat. The more the Universe seems comprehensible, the more it also seems pointless.'

Cheer up Steven! The Atlantic Ocean was overwhelmingly hostile until Columbus found some beautiful Caribbean islands on the other side of it. And remember the tombstone of two amateur astronomers: 'We have loved the stars too fondly to be afraid of the night'. As to the Universe being pointless, I think our expectations are to blame. The Universe is only pointless to the degree that we insist it have a point.

'If there is no meaning in it,' said the King, 'that saves a world of trouble, you know, as we needn't try to find any. ' (*Alice in Wonderland*, page 59 of *Annotated Alice*)

Further Reading

Astronomy

Lineweaver, C. H., 'The Origin of the Universe', Newton Graphic Science, September/October 2000, Australian Geographic Publication
Barrow, J., *Origin of the Universe*, Basic Books, 1994
Harrison, E. R., *Cosmology: the Science of the Universe*, 2nd edition, 2000, Cambridge University Press
Weinberg, S., *The First Three Minutes*, Bantam Books, 1977
Hogan, C., *The Little Book of the Big Bang*, Copernicus, 1998

Extra-terrestrials

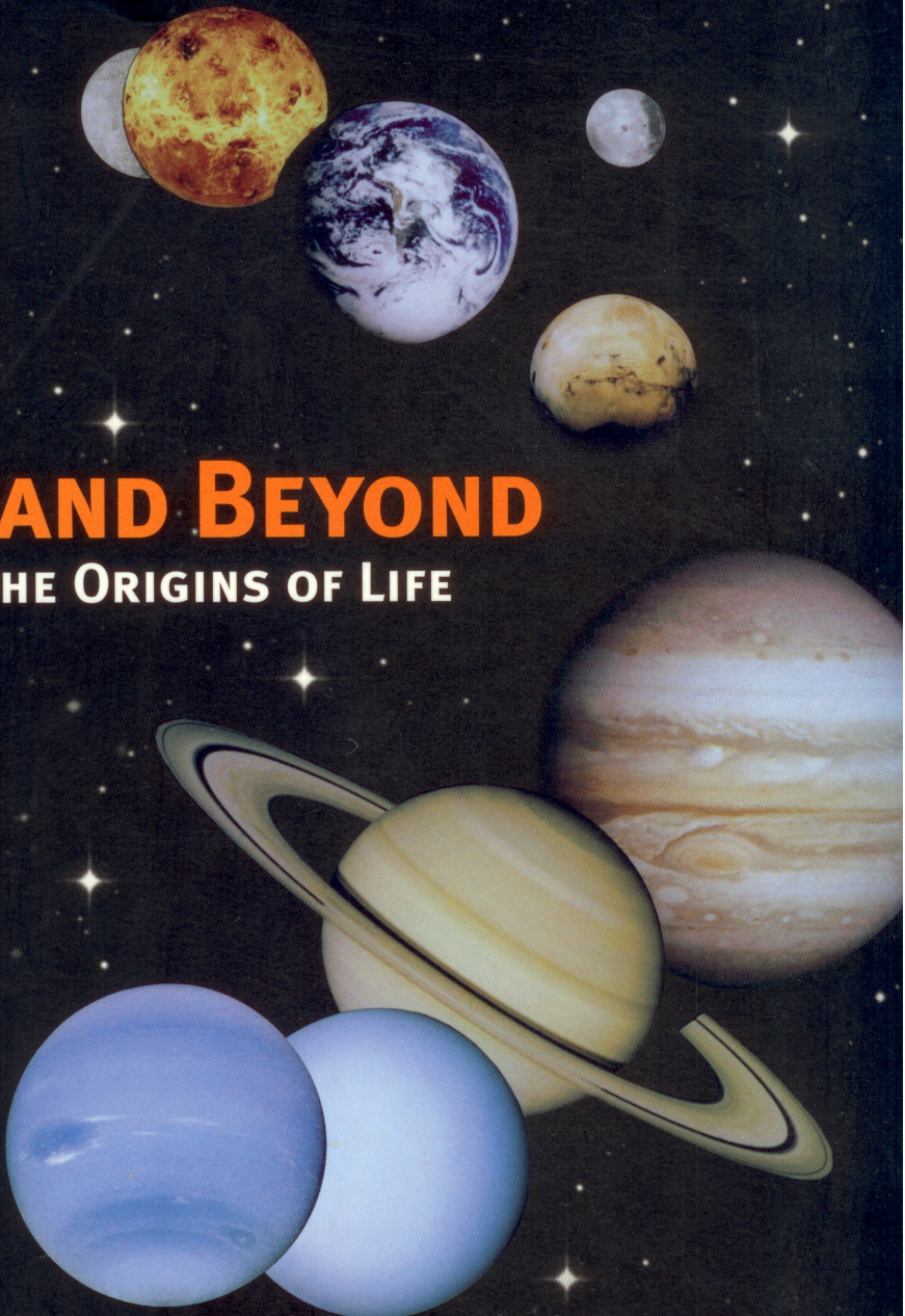
Koerner, D. and LeVay S., *Here be Dragons: The Scientific Quest for Extraterrestrial Life*, Oxford University Press, 2000
Goldsmith, D., *The Quest for Extraterrestrial Life: A Book of Readings*, University Science Books, 1980

Life on Earth

Dyson, F., *Origins of Life*, 2nd edition, Cambridge University Press, 1999
Dennett, D., *Darwin's Dangerous Idea*, Penguin, NY, 1995
Margulis, L. and Sagan, D., *Microcosmos*, Summit Books, NY, 1986
Margulis, Lynn, *Symbiotic Planet*, Basic Books, 1998
Lovelock, J., *Healing Gaia*, Harmony Books, NY, 1994

To Mars and Beyond

Search for the Origins of Life



National Museum of Australia, Canbe

Contents