Origins

Volume V Number 6

International
Big History
Association

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Origins. ISSN 2377-7729

Please submit articles and other material to Origins, Editor, ibhanet@gmail.com

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International Big History Association

Introducing Big History to the general public by popular lecture series:
The Little Big History of the Nalón River (Asturias, Spain)

INTERDISCIPLINARY WORK HAS MARKED MY SCIENTIFIC CAREER since the end of my PhD investigation in geology. For about 6 years I was doing research in material science for my postdoc, working together in the lab with chemists, chemical engineers, physicists, and biologists in the fascinating field of nanostructured materials with many different applications. I specialized in thermally ultra-stable ceramic materials to be used as mirrors in telescopes and satellites. This was my first jump from the Earth, as a geologist, into the sky. Coming back to a geology position as a lecturer in Petrology and Geochemistry for geologists and Environmental Science for teachers, I have found it essential to keep this interdisciplinary approach in my career. A grant from the University of Oviedo (UO) to visit UC Berkeley under the coordination of Prof. Walter Álvarez was my introduction to Big History and the way I found to integrate this approach into my research and teaching.

After that stay in Berkeley, I was sure that the Big History approach would be of interest in my own university, and I have made what I consider a quite successful attempt of forming a Big History Group in Oviedo. I have introduced

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Big History in different departments of UO, and now we are a group of about 20 people interested in working together under this initiative, integrating our research activities and lecturer experience in different fields like biology, genetics, pedagogy, medicine, geography, cosmology, mathematics, archaeology, anthropology and, of course, geology. The first activity that we decided to undertake in order to start working together, and that would allow us at the same time to know each other and our investigation lines better, was a popular series of lectures using the Little Big History approach of E. Quaedackers.

In this article I summarize the experience of introducing Big History to the general public by this activity, which thankfully had the support of the Spanish Foundation of Science and Technology. The organization of the events was developed by the Transfer of Research Results Office of UO.

We chose a topic for the popular lecture series that was close to the society of our region and that could be easily followed through the whole Big History, dealing with the 8 thresholds proposed by the Big History Project. We divided the lecture series in 4 sessions with several presentations within each (Table 1). We all worked together to maintain the BH approach and to have the same historical thread based on the element Carbon, so that we can follow the story from threshold 1 to 8.

Table 1. Lectures in the different sessions of the LBH of the Nalón River.

Session 1: Cosmos	Session 2: Earth and Life	Session 3: Humanity	Session 4: Current Times
Intro to BH	Geological evolution and formation of the Nalón Valley	Environmental evolution in the Quaternary	Human Ecology
C formation and its evolution on Earth	C in living organisms	Human settlements	The different space-temporal scales
		Mining Activity	

The topic was the Little Big History (LBH) of the Nalón River. This river is very emblematic in Asturias and is situated in a coal basin with abundant coal mining activity since the XIX century. Its history at the beginning can be quite similar to other coal basins in Spain or England, but the characteristic geological history of each basin, as well as the geographic and human history imprint, will define their different future evolution and history.

In the first session people get the idea of the BH initiative, and those interested in interdisciplinary evolution, natural history, and global history get naturally involved in the rest of the session. We used the online tool ChronoZoom, firstly to present the time-line build up to handle the different time scales that we needed to use to tell our LBG of the Nalón, and secondly to explain the 8 thresholds of the BHP, which had helped us to organize all that we had learned about the Nalón and that we wanted to impart with this lecture series.

As a mere exercise of spreading science in society, our first presentation gives people the chance to understand how Carbon (C) is formed in the core of the stars and how it is dispersed during their evolution to dying stars, enriching the interstellar media. We go on to explain how we need stars and galaxies to build planetary systems and, following the C thread, how we can have this element concentrated in rocky planets like our Earth. The most important scope for this first session is to understand why the history and evolution of the Cosmos is important to us and why we have to understand the history from the very beginning. And I think we were successful with this. We live on our planet, Earth. Why here and not elsewhere? Why is it so important? Why are living organisms based on C and O and not on Sn or Se? The answer is in the stars.

Once we reach our planet Earth our task is to explain that we are inhabitants of a "living" planet that has been changing since its beginning and is changing today. We explain that the change is ruled by the internal heat that has been preserved in the Earth's interior since its formation after the violent and chaotic events that occurred in the young Earth. And this is how we have introduced geological history in the second session.

La Gran Historia es una iniciativa internacional que ofrece una nueva aproximación al conocimiento global del Cosmos, la Tierra, la Vida y la Humanidad. Nos ofrece una visión global e integradora de la historia desde el Big Bang a la actualidad, a través de los grandes acontecimientos que han condicionado la evolución y la historia de los seres humanos, para intentar explicar cómo hemos llegado hasta aquí.

En España, la Universidad de Oviedo ha elegido la cuenca minera del río Nalón como punto de partida para contar "La Pequeña Gran Historia del Nalón". Con una visión interdisciplinar e integradora, abordará la historia del río con un **Ciclo de conferencias** de divulgación científica. Tomando como hilo conductor el Carbono, investigadores de varios departamentos de la UO llegarán a interpretar de forma global la Gran Historia del Nalón.

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Edificio de Servicios Universitarios.
C/ La Ferrería, 7-9

OVIEDO
Aula Magna. Centro Cultural LAUDEO-Edificio Histórico.
C/ San Francisco, 3

EL ENTREGO
Edificio Valnalón.
Avda. de la Vega, 4 - 6

Día: 3 marzo
Día: 4 marzo
Día: 5 marzo

19:00h

"El COSMOS"

(Olga García Moreno y Luigi Toffolatti, Universidad de Oviedo).

Conferencia:
Introducción a la Gran Historia

Conferencia:
La formación del Carbono y su evolución en la Tierra

Día: 10 marzo
Día: 11 marzo
Día: 12 marzo

19:00h

"La TIERRA y la VIDA"

(Joaquín García Sansegundo, Miguel Arbizu Senosián, Olga García Moreno y Montserrat Jiménez Sánchez, Universidad de Oviedo).

Conferencia:
Evolución geológica y formación del valle del Nalón

Conferencia:
El Carbono en los seres vivos

Día: 17 marzo
Día: 18 marzo
Día: 19 marzo

19:00h

"La HUMANIDAD"

(Diego Álvarez Laó, Luis Vicente Sánchez Fernández y Luis Rodríguez Terente, Universidad de Oviedo).

Conferencia:
Evolución del medio en el Cuaternario

Conferencia:
Asentamientos humanos

Conferencia:
Actividad minera

Día: 24 marzo
Día: 25 marzo
Día: 26 marzo

19:00h

"EL MOMENTO ACTUAL"

(Eduardo Dopico Rodríguez e Ícaro Obeso Muñiz, Universidad de Oviedo).

Conferencia:
Ecología humana

Conferencia:
Las distintas escalas espacio-temporales

CLAUSURA DEL CICLO

Lugar: Aula Magna. Centro Cultural LAUDEO-Edificio Histórico, Oviedo. **Hora:** 19:00h

13 Mayo Conferencia: "El antropoceno y la globalización: etapas históricas del cambio climático"
(Arturo Giráldez. Catedrático de la Escuela de Estudios Internacionales, University of the Pacific Stockton California).

Entrada libre
hasta completar aforo.

In the case of the geology of our region, Asturias, there have been two very important cycles of mountain formation (orogenic cycles). It is difficult to explain that the beautiful mountains that we see today are the result of the deformation of the rocks in the last orogenic event that took place only 30-40 Ma ago, although the rocks that we see in those mountains were previously formed and deformed in an ancient orogenic event that took place between 325 and 300 Ma. We have found that telling this LBH was a good chance for us, as geologists, to highlight the importance of understanding what all these rocks that surround us and that for many years gave us the resources to grow economically and as a society, really mean and why this regions is different from other coal basins not so far away. We think this importance deserves to be highlighted. The audience was very grateful when they began to understand these points, and at the same time they were willing to discover what else BH could bring to the general understanding of their own stories.

In the lecture related to living organisms we highlighted the role of the element C in the development of life as we know it on our planet. But the main focus was placed on the evolution of life on Earth and its relation with the evolution of Earth altogether. Our planet is like it is because of the living organisms it has, in the same way that the living organisms are like they are because they live on Planet Earth. This was another reflection that was acknowledged by the audience. Of course, we focused on the formation of the coal deposits from dead plants being accumulated during thousands of years during the Carboniferous Period. We also related the formation of these deposits to the geological processes that were occurring at the same time and followed the geo-biological evolution to the Quaternary Period. We culminate at this point at the end of session 2, when humans are about to start acting in this show. Many people in the audience probably thought at the beginning of the series that from this point on they were going to feel

University of Oviedo

more comfortable, but the fact is that they responded to this milestone even more comfortably after understanding how we got to this point, as living organisms on a living planet.

The part on the environment in the Quaternary and the first human settlements in session 3 was interesting since, although our region is rich in archeological sites of Neolithic and older age, we are used to thinking about the first humans in Africa, and we forget our ancestors closer to home. This regional link was perfect to introduce the concept of collective learning and how those first humans had to adapt to the climate and orography of this peculiar region. In Asturias, two main areas are rich in archeological sites, one close to the coast (to the East), where there is a lot of karstic modeling with nice caves and shelters, and the other zone precisely the Nalón Valley, which has plenty of caves close to the river, perfect places for our ancestors to live, hunt and gather.

In the lecture on the mining history of the region there were very interesting discussions in the different towns where we presented it. People from the Nalón area were completely in favor of protecting the mines and continuing with the mining activity, which has been in decline since the last quarter of the XX century. The reason for this decline is only economic, as there is still as much coal underground as the volume that has been extracted during the last 250 years. We also discussed the idea of maintaining the closed wells in some way (like they do in Portugal with other kind of mines) because if a well is abandoned, it will never be useful again. Local people need the mines; they need to keep in touch with this part of their culture. This is so because, unfortunately, they have seen too many failed attempts to reconvert the mining and industrial framework of the region with abundant European Programs for reconversion, Yet still today the rising unemployment and low economic activity don't predict a bright future for the region. After the lecture members of the audience proposed new alternatives and new ways of ordering and using the landscape and the mining infrastructures that would cost many million euros. These ideas were taken up again in the last lecture.

From the last session about current times I would like to describe the

Geology Building at the University of Oviedo emotional effect on the audience of the lecture about Human Ecology. Marta was a kid in the 60's of the XX century, living in a small town in the Nalón coal basin, and she knew very well the Nalón River. The water was black, and nobody would like to go close to the smelly river. When her parents brought her, during the summer days, upstream only few kilometers from her place, she asked what the name of that river was. She couldn't recognize the Nalón River because it was so clear and couldn't believe that it was the same water coming from the melting of the snow up in the mountains. Many in the audience told stories like this one after the lectures in session 4. The last lecture about the different space-temporal scales was also very attention-grabbing for the audience as we showed photographs of different places in the Nalón area, interpreting the changes in the land's uses and landscapes during the last hundred years. All these changes were very well understood after studying in the previous sessions the changes in the societies and the uses by the different kinds of societies of the resources, relating the uses to the impacts in the landscapes and ecosystems.

We presented this series in three towns: Oviedo, Avilés and El Entrego, the last one actually located in the Nalón basin. Over a period of four weeks this was our experience introducing Big History from our different disciplines through the LBH of the Nalón River. We think it was very attractive to the audience (more than 300 people), which mainly consisted of secondary school teachers and retired people. At the end we realized that we had left out many parts of the history of the region, but nevertheless the BH perspective and the thread followed by the element C allowed us to travel through all of cosmic evolution to the present day. Sometimes we failed to repeat certain concepts in different lectures in an attempt to highlight some important processes, and this was criticized by the audience. But in general the activity was a great success, and members of the audience described it as a new way to look at the past to better understand the future.

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Did Columbus falsify his latitude measurements during his first voyage to the Americas?

Fred Spier, University of Amsterdam, NL

IN CLASS OBSERVATIONS

A few years ago, as part of teaching big history for small groups I started developing a series of observations that can be done by students in class. To my surprise, some of these observations turned out not only to be very helpful for teaching big history, but they also led to a few intriguing discoveries. This report is the second of a series of such observations with unexpected, exciting, results.

Did Columbus falsify his latitude measurements during his first voyage to the Americas?

To improve students' understanding of navigation in the period of early globalization, most notably the scientific and technological knowledge underpinning it, they measure in class the altitude of the sun using both a homemade quadrant and a replica of a mariner's astrolabe that I bought in a nautical antique shop in Rotterdam.

These instruments were formerly used to determine one's latitude, which is a measure of one's distance between the equator (which is defined as zero degrees), and one of the poles (located at ninety degrees either north or south). One degree along a line connecting the north and south pole equals 60 nautical miles, 69 (statute) miles, or 111 km. The city of Amsterdam, for instance, is situated at 52 degrees north of the equator. The concepts of latitude (and also longitude, the distance along the equator measured from a certain point) had already been used by Claudius Ptolemy of Alexandria (c.100-170 CE), whose geography was firmly based on the idea that the world was a globe. And Ptolemy had also been familiar with the quadrant for determining celestial and geographic altitudes.

The quadrant and the astrolabe are both used by holding them and lining up two holes on the instrument while aiming at a celestial object, the sun or a star, and then read the resulting angle on the scale. Doing so provides the celestial object's altitude in degrees with respect to the local horizon.

For observing the sun's altitude, this lining up of the holes is done by letting the sun shine through one hole and projecting its resulting small but bright image right onto the next hole, and then read the scale.

In contrast to what is stated on many web sites, there is no need at all to look at the sun through the holes, which would damage one's eyes. At night, however, one would directly observe Polaris, the pole star, by looking through these holes.

Because the sun's altitude changes throughout the year between +23.5 degrees north and -23.5 degrees south, accurate data about its daily positions are required to calculate one's latitude.

Measuring Polaris's rather stable altitude above the North Pole, by contrast, will immediately yield one's latitude with a precision of about one degree. No greater direct precision is possible because the pole star wobbles a little with respect to the true north. In practice, both sun and star observations were used whenever possible, sometimes as a check on each other.

The technology of using quadrants and astrolabes for measuring latitudes was further developed by the Portuguese after they started sailing southwards on the Atlantic Ocean to reach the African gold coast and later also Asia, both famous for their wealth.

Navigating the Mediterranean had not necessitated using such instruments because of its largely east-west orientation. Sailing it meant moving through changing longitudes, but never experiencing a significant change in latitude.

By sailing southward, however, the Portuguese did encounter a significant change in latitude. They also found that Polaris, situated almost exactly above the North Pole, disappeared below the horizon as soon as they crossed the equator. And in the southern hemisphere there proved to be no suitable stars situated above the South Pole that could be used for determining latitude.

The Portuguese solved this problem by developing more accurate methods to measure the sun's altitude, preferably at noon when the sun appears the highest in the sky. But because the altitude of the sun changes during the year from +23.5 degrees north to -23.5 degrees south and back, the Portuguese needed to construct tables based on accurate measurements that would provide those data from day to day.

Such documents are known as sun declination tables. The oldest extant Portuguese sun declination table, called **Regimento do estrolabio e do quadrante**, probably dates from 1509 CE, and was likely a printed version of earlier editions. A copy of the Regimento can be downloaded here as a pdf.

Such tables may have been constructed with careful observations made at the peninsula of Sagres, where the first Portuguese navigational school was founded in 1420 CE by Prince Henry the Navigator (1394-1460 CE).

Although old documents that could have shed a light on what happened at Sagres were lost, it is remarkable that this peninsula is oriented to the south, and thus very suitable for observing the noon sun and stars.

Furthermore, Sagres Point still offers the widest unobstructed view of the horizon over the ocean available in Portugal, and, in consequence, the largest possible reference line for determining celestial altitudes during both day and night over the broadest possible range.

In sum, Sagres was perfectly located for making sun declination tables. This would have allowed the Portuguese to take the remarkably accurate measurements that appeared in the Regimento.

Such measurements could not possibly have been taken with the small hand-held quadrants and astrolabes used by mariners. Much larger instruments were needed to achieve such a high precision. Traces of such possible instruments can still be seen at Sagres Point.

The rule for determining latitude, explained here, is: 90 degrees, minus the measured noon sun altitude, plus the noon sun declination of that particular day.

This way of determining latitude at sea remained in use until the 1990s CE while using sextants, which are much more precise than quadrants and astrolabes. And even after NavSat and GPS replaced sextants for everyday use, these instruments still remain in use as an emergency back-up option in case GPS fails.

For sextants, a fix on the horizon or an artificial horizon are required to determine celestial altitudes. This is not needed while using quadrants and astrolabes, because gravity's action on the instrument provides the required frame of reference.

In Columbus' time, the sun's altitude was preferably measured using a quadrant, because it was deemed more precise than the mariner's astrolabe, mostly because the plumb line can be very thin, and can therefore be read more precisely than the astrolabe's pointer (usually called alidade), which is a little more complicated to make, and therefore more likely to have a systematic error.

It can be very hard, however, to keep the quadrant's plumb line sufficiently steady on a rolling ship. The mariner's astrolabe is more stable, and therefore provides more accurate measurements at sea, which explains why that instrument became the preferred choice on board.

The mariner's astrolabe was a simplified version of the much more complicated medieval astrolabe, which has been called the world's first portable computer. Based on earlier Sumerian and Babylonian designs, astrolabes were already known in antiquity, and had reached Western Europe through the Arabs, who had developed them further.

The simplification of the mariner's astrolabe consisted of retaining only the alidade and the scale in grades, while making it so heavy so that it would be sufficiently stable on board of a rolling ship. Holes in the instrument provided as much room as possible for wind to blow through it to prevent it from swaying. In short, the mariner's astrolabe was a very rationally-designed and convenient solution based on the best available technology.

In class, students are asked to measure the sun's altitude with both instruments. They must also estimate the margin of error of their results, most notably by answering the following questions: what is the estimated average error of their measurements? And how large is the estimated systematic error due to the instrument's lack of perfection? And how would you deal with that to improve your measurements? In doing so, students become familiar with these concepts, which are most important aspects of all systematic observations.

The students' results tend to coincide with my measurements and estimates: 0.5 to 1 degree of maximum average error of measurement, and 1 to 2 degrees of maximum systematic error. Much like the mariners of old, also the students consider the quadrant more precise than the mariner's astrolabe, and for the same reason.

If students were able to measure the noon sun altitude –the sun does not always shine in Amsterdam– , they are requested to determine their latitude using sun declination data from the **Regimento do estrolabia e do quadrante** for that particular day, while comparing these data with modern data obtained from the Internet.

This introduces another problem, namely that the sun declination data provided by the Regimento are off by ten days. The reason for that is that in the meantime there has been a calendar change, from the Julian to the Gregorian calendar.

In 1582 CE, the Catholic church led by pope Gregory XIII struck ten days off the calendar, because it was no longer in phase with the observed solar positions, while a different arrangement with the leap years was made to ensure that this would not happen again for a long time to come.

Going back ten days in the Regimento, students will find data for the solar declination that rather closely conform to the modern predictions. So the Portuguese had done an excellent job!

This small remaining difference can mostly be explained by the fact that the noon sun declination for a certain date changes from year to year, because the solar calendar, which is determined by Earth's orbit around the sun, does not exactly fit day length, which is determined by Earth's rotation around its axis.

The resulting difference is mostly, but not entirely, corrected every four years by adding an extra day to the calendar. As a result, these tables had to be adjusted from year to year. If not, over a period of four years these tables would go out of whack to a maximum of about 20 minutes, which would add an error of about 35 km (21 miles) distance.

Furthermore, as a result of the decreasing tilt of Earth's axis over the past centuries, about 1 minute needs to be subtracted from these data. Most, if not all of this must have been known to the scientists who constructed the Regimento tables.

This does not yet take into account that around the equinox, so in March-April and September-October, the sun declination changes about 20 minutes in 24 hours. This means that these data also depend on the place where they were measured, or for which they were calculated to happen. In fact, the precision in stating the daily noon sun declination in degrees and minutes would allow us, in principle, to calculate that.

Such an assumption seems reasonable, because the differences per day mentioned in the Regimento very much agree with modern observations and predictions. Checking these old tables and interpreting them in such ways could become a fascinating research project.

While using these data, most students will usually arrive at a latitude of about 52 degrees for Amsterdam. They have, on average, at most an error of 40 miles, about 50 km, with respect to their real position. Not a bad result at all with this ancient technology.

Thanks to the fact that my long-standing research interest into the history of Peru had included its initial conquest, and that I had defended my Ph.D. thesis about Peru on October 12, 1992 CE, in name exactly 500 years after Columbus had stepped ashore for the first time on the other side of the Atlantic Ocean, I had begun studying the accounts of some of these early explorers.

Because the commemoration in 1992 CE had led to a wave of publications about Columbus and his exploits, I had become aware of some very smart recent Spanish scholarship, mentioned below. As a result, I was familiar, among other things, with Columbus' diaries as well as with some of the scholarly discussions about them.

All of that explains how I got onto the track of trying to find out which specific instruments Columbus had used on his first voyage and what measurements he had reported. This turned out to be a fascinating trail.

After students have determined their latitude using this ancient maritime technology, they are confronted with Columbus' measurements that he made during his first voyage in 1492-93 CE to what later would become known as the Americas.

According to Columbus' diary, of which only a partial transcription of a transcription survives, he measured his latitude several times: first on the island of Hispaniola on October 30, 1492 CE, with a quadrant; his result was 42 degrees, while in reality it was only about 20 degrees (p.85).

(All the pages mentioned in this context are from: Consuelo Varela, editor, **Cristóbal Colón: Los cuatro viajes; Testamento**. Madrid, Alianza Editorial, 1986.)

On November 2, 1492 CE, Columbus used the quadrant at night in the same place (apparently to get a fix on Polaris) and obtained the same result (p.88). On November 21, 1492 CE, along the coast of Cuba, Columbus found the same latitude of 42 degrees with his quadrant (p.102), while reporting very high temperatures.

At this point in the diary, the person who transcribed and edited it, Fray Bartolomé de las Casas (1484-1566 CE), expressed his doubt, because he thought that at 42 degrees north (about the latitude of modern Boston, MA) it had to be a lot colder in November, even though no Europeans were known to have gone there yet.

On December 13, 1492 CE, Columbus measured his latitude on the island of Hispaniola with the quadrant and obtained 34 degrees, while his correct latitude was closer to 19 degrees (p.128). And on February 3, 1493 CE, on the Atlantic Ocean on his way back to Spain, he used both the quadrant and the mariner's astrolabe to determine latitude, but was unsuccessful because of the high waves.

How could the so very experienced sailor Columbus get this so very wrong, one wonders, while his instruments would have caused an error of at most 1-2 degrees? What would students think about that? Was Columbus incompetent, or was something else going on?

Spanish scholar Consuelo Varela (1945 CE -), mentioned above, thought that Columbus probably falsified his data, because Cipangu, Japan, was also at 42 degrees on his map, and Columbus thought that he had reached that island (note 31, p.85). This may be a partial explanation for this situation.

But there may be more to this than that. The Spanish nautical expert and sea captain Luis Miguel Coín Cuenca (1953 CE -) has argued for decades that Columbus systematically falsified the diary of his first voyage for one single specific reason: namely to make sure that it appeared that he had stayed out of territory that the Portuguese could claim.

Dr. Coín Cuenca's thesis is best documented in his brilliant but virtually unknown book **Una travesía de 20 dias a dos rumbos que cambió el mundo**, Universidad de Cádiz, 2003. Dr. Coín Cuenca is also contributing such information to a most informative web site.

Dutch Ship, Rijksmuseum Amsterdam

When Columbus started his first voyage, Coín Cuenca argues, there was a treaty between Spain and Portugal known as the Alcaçovas Treaty, signed in 1479 CE, and confirmed in 1481 CE by the papal bull Æterni regis. This treaty granted all lands south of the Canary Islands to Portugal, and thus allowed the Spanish to go only as far south as the Canary Islands (about 25 degrees north).

According to Coín Cuenca, this is why Columbus reported in his diary that he sailed straight west from the Canary Islands, even though his descriptions of what he witnessed actually fit a more southerly course, while they do not agree with his stated course.

This also explains why, on all his subsequent voyages, Columbus did sail further south. He could do so legitimately, because the earlier treaty had been replaced by papal bulls issued in 1493 CE, and by the Treaties of Tordesillas of 1494 CE, which had redefined this situation in legal terms.

In his book, Coín Cuenca provides ample, very carefully assembled, evidence for his thesis, including his first-hand experience of having sailed this more southernly trajectory in 1990 CE as captain on a carefully-constructed replica of one of Columbus' ships.

But because Coín Cuenca's analysis ends when Columbus first reached land in the Americas, he did not discuss Columbus' later quadrant and astrolabe measurements, which very much support his thesis.

As a result of the Alcaçovas Treaty, Columbus had every reason to make sure that his measurements showed latitudes well north of 25 degrees, so that not only those lands could not be claimed by the Portuguese, but that also a considerable stretch of possible land situated to the south of where he had gone could be claimed by the Spanish. That is why, I think, all his measurements show these large systematic errors.

This may also explain why, in the fragments of his diary that survive, Columbus never reported latitude measurements on his way to the Americas, simply because he knew he was sailing in Portuguese territory.

Even if Columbus indeed sailed west after leaving the Canary Islands, as he reported in his diary, he would have been right on the borderline between Spanish and Portuguese territories, which could easily have led to Portuguese suspicions and claims. So from a political point of view it was a smart move not to report any latitude measurements on his outbound voyage.

This lack of celestial measurements on his way to the Americas has led to the impression that Columbus almost exclusively relied on dead reckoning: determining his position with the aid of measuring his direction by compass and his velocity by other means, which were rather unreliable.

Columbus surely did use dead reckoning all the time, as all mariners before and after him have done until the advent of GPS. Yet on his way home, Columbus did try to measure his latitude, as we saw above. So he was not averse to doing so if he felt the need.

What students learn from these observations, apart from doing the measurements themselves, is that one may only be able to judge historical documents well if one tries to place oneself into the other persons' positions, and that this may be surprisingly easy to do. They also learn that very interesting questions can be raised as a result of very simple and basic observations.

Finally, the change into the Gregorian calendar in 1582 CE may have led to new commercial opportunities. During the sixteenth century, the Dutch overtook the Portuguese and the Spanish by producing mariner's handbooks that were printed and sold in different languages. The Dutch first copied these manuals and subsequently improved them. This turned out to be an excellent business.

Remarkably, the seafaring Dutch provinces of Holland and Zeeland accepted the Catholic Gregorian calender almost immediately, even though the Dutch were rejecting papal authority by turning Protestant while fighting the Catholic Spanish.

The British, by contrast, only adopted the Gregorian calendar as late as 1752 CE, apparently because of their dislike of papal power. Could this coincide with the fact that in the 17th century and beyond, British mariner's handbooks appear to have sold not nearly as well as those of their more pragmatic Dutch competitors? And were these different attitudes perhaps connected to the Dutch running a republic in which mercantile interests dominated, while Britain was a mix between royalty and parliament?

All these intriguing questions, to which I do not have clear answers yet, as well as Columbus likely having falsified his latitude measurements, came as a result of the decision to ask students to observe the sun's altitude with ancient instruments and determine their latitude, while comparing those data with information from old documents.

New and Returning IBHA Members

One of the key purposes of the IBHA is for those of us who are interested in Big History to have a place to associate. It is a place to learn of other members' Big History activities and thoughts. So we are delighted to welcome new members to the IBHA – and by the vote of confidence and recognition of the value of our association by those who have renewed their membership. It is a pleasure to have each of you with us.

Todd Duncan
David Freeman
William Grassie
Philip J Hughes
Betty-Ann Kissilove
Vuk Milosevic
Christian Oddy
Frederick Paxton
Mark Saekow
Roland Saekow
Dana Visalli
Barbara Winkler

Nominations for IBHA Board of Directors

The members of the IBHA Board of Directors hold staggered three year terms. Each year, a few seats become open. Since the IBHA was founded, there have been a number of Board members who have cycled off the Board, a number of new people who have joined it, and a number who have stayed on. In the interest of fulfilling the mission of the IBHA through continuity, change, stability, and inclusivity, the IBHA selects Board candidates in two ways:

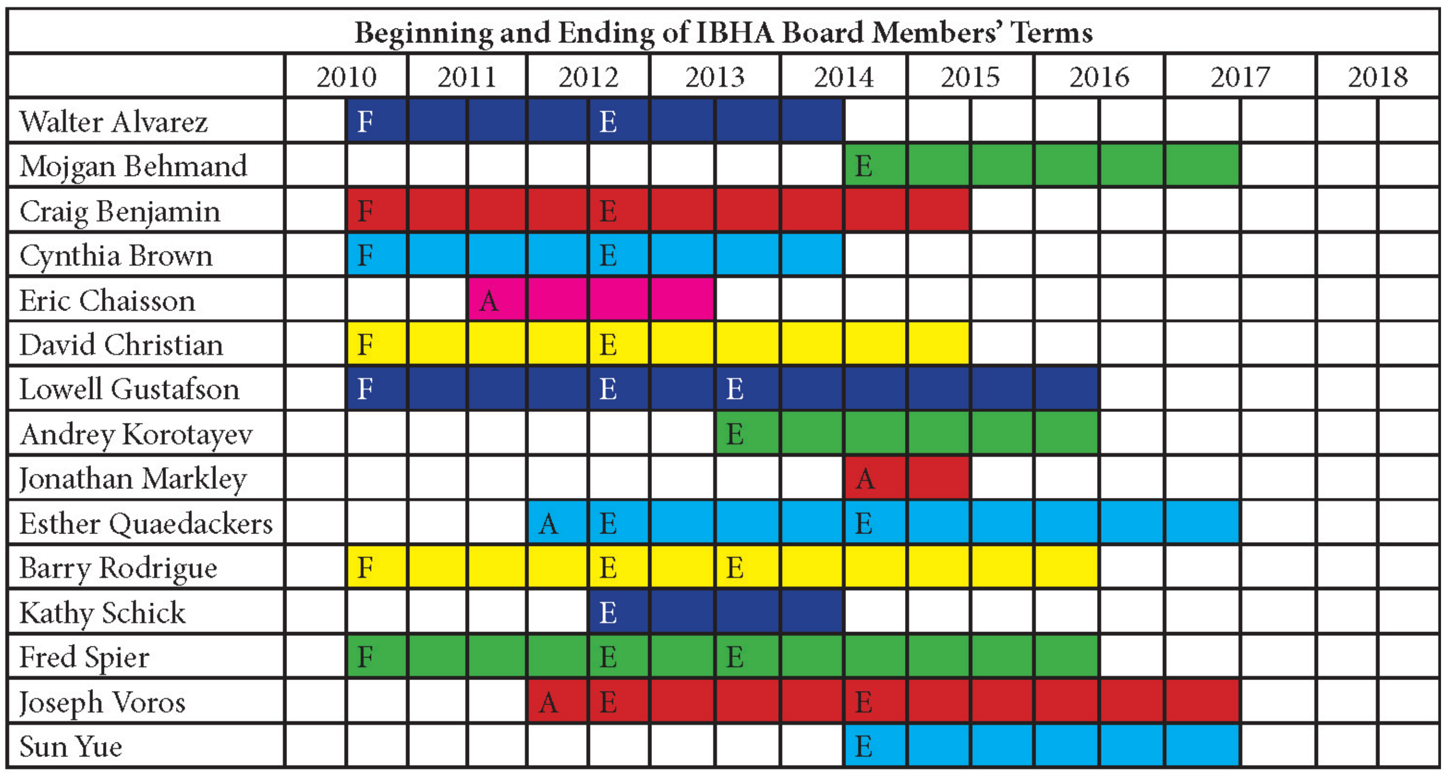
(1) IBHA members identify names
(2) and the existing Board proposes a list of names.

Between November 2014 and April 15, 2015, IBHA members could log on to the IBHA website at http://ibhanet.org/, click on "Forum," "IBHA Discussions," and "IBHA Board of Directors Nominations," and post the names of any members they recommended for Board membership. Nominees who were endorsed by at least 10% of IBHA membership before May 15, 2015 would become candidates. In April and May, the IBHA Board discussed and decided on its list of candidates.

As a result of this process, the candidates for the IBHA Board of Directors for three seats whose terms will run from August 1, 2015 through July 31, 2018 are:

Craig Benjamin
David Christian
Jonathan Markley

An electronic election for new Board members will begin on July 1, 2015, and end on July 31, 2015. The new Board will be announced in August.



F = Founding Member E = Elected A = Appointed

From IBHA By Laws

ARTICLE III. DIRECTORS

3.1 Board of Directors.

The business and affairs of the Corporation shall be managed exclusively by a Board of Directors. The Board of Directors shall consist of not less than three (3) nor more than twelve (12) persons, all but one of whom shall be elected by the members. The twelfth director shall be the immediate past president of the Corporation, who, subject to earlier resignation or removal, shall serve as director for one (1) year following the election of his or her successor as president of the Corporation. The initial directors shall consist of those individuals selected by mutual consent of the founders of the Corporation, all of whom are scholars involved in Big History, and specified by the incorporator as constituting the first Board of Directors. Thereafter, and until the first annual meeting of members, the Board may appoint additional directors. At the first annual meeting of members and thereafter, the number of directors shall be determined from time to time by action of the members. Commencing with the first annual meeting of the members in 2012, directors shall be elected for three-year terms at each annual members meeting; provided, however, that some directors may be elected to one or two year terms as the members may deem necessary in order to provide for a relatively balanced staggering of the terms of office, such that approximately one-third of directors' terms shall expire in any given year. Nominations for director shall be made by the then existing Board of Directors. Nominations may also be made by a written nomination signed by ten percent (10%) or more of the members and submitted to the Secretary of the Corporation at least sixty (60) days prior to the annual meeting of the members. All nominations shall be presented by the Board to the membership for consideration at least thirty (30) days prior to the annual meeting of members. Directors shall serve until their respective terms expire and until their successors are appointed or until their earlier resignation or removal. Directors may serve for any number of successive terms.

3.2 Director Qualifications.

To be eligible for election to the Board of Directors, an individual must not be an "Interested Person." For purposes of this section, an "Interested Person" is defined as either (a) a person currently being compensated by the Corporation for services rendered to it within the previous twelve (12) months, whether as a full time or part time employee, independent contractor or otherwise; or (b) any brother, sister, ancestor, descendant, spouse, brother-in-law, sister-in-law, son-in-law, daughter-in-law, father-in-law, or mother-in-law on any person described in subpart (a).

International Big History Association

3.3

Resignation and Removal. A director may resign by written notice to the Secretary of the Corporation, which resignation shall be effective upon receipt by the Corporation or at a subsequent time as set forth in the notice. Any director(s) or the entire Board of Directors may be removed, at any time with or without cause, by action of two-thirds of the members present in person or by proxy at a duly called meeting of the members.

3.4

Vacancies and Increase in Number. Vacancies on the Board of Directors occurring for any reason, including an increase in the number of directors, may but need not necessarily be filled by majority vote of the Board of Directors. A director elected to fill a vacancy occurring for any reason, including an increase in the number of directors, shall hold office until the next election of directors or until his or her earlier resignation or removal.


Third IBHA Conference
July 15 - 17, 2016
Amsterdam

IBHA Conference July 15 - 17, 2016
University of Amsterdam

The Board of the IBHA is delighted to announce that our third conference will be held in the beautiful and historic European city of Amsterdam from July 15 - 17, 2016. This will be the first IBHA conference held outside of the United States, and we are looking forward to working with our colleagues at the University of Amsterdam to stage another unforgettable event. We are benefitting from the on-site expertise of Esther Quaedackers in planning for the conference, with her familiarity of Amsterdam.

This building is called the Oudemanhuispoort (Old Man's Home Gate). Part of it was built, as the name implies, as a home for poor old people in the early 17th century. In the late 19th century the University of Amsterdam started to use the building. Around that the same time book traders also moved into the little shops that line the main hallway of the building. The book traders are still there.

We have retained two hotels – IBIS Amsterdam Centre Stopera (http://www.ibis.com/en/hotel-3044-ibis-amsterdam-centre-stopera/index.shtml) within a 15 minute walk to the University of Amsterdam, and the Volkshotel (https://www.volkshotel.nl/) within a 15 minute metro ride to the University. The two hotels are totally different types of hotels; check the great reviews of these hotels on tripadvisor (http://www.tripadvisor.com/) . A walking tour and other pre-conference tours of the city are underway, and a post-conference tour that will visit many of the leading scientific facilities in Europe (Central Paris Louvre, CERN, Swiss Alps, European Southern Observatory, and cities along the Rhine River). We will keep all members fully informed as plans for the third IBHA conference evolve, but for now please mark the dates of July 15 - 17 on your calendars, and start planning to join us in Amsterdam in July of 2016!

If you have any questions – just email Donna Tew, IBHA Office Coordinator @ tewd@gvsu.edu

The second edition of Fred Spier's *Big History and the Future of Humanity* was released on May 4.

A new web site provides a wide range of information about the book, in particular for using it as a textbook for teaching big istory at college level. Also e-book versions are available on Wiley.com and elsewhere, including Kindle and Apple iBook versions.

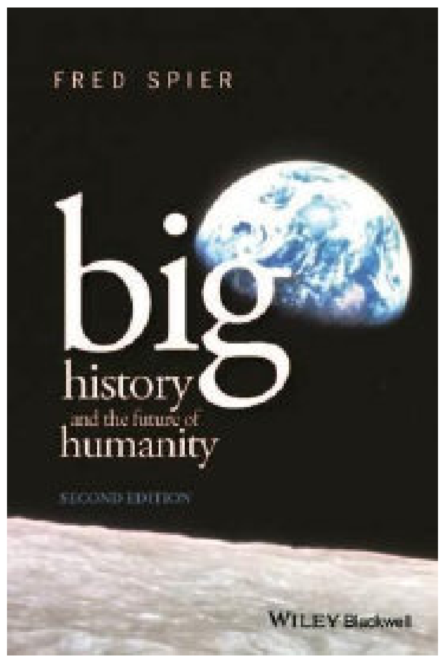
The web site provides important general information about big history, including links to other major web sites, that may be helpful to become familiar with big history.

Featuring updates and new discussions about salient topics in big history, the Second Edition presents an accessible and original overview of the entire sweep of history from the origins of the universe up to the present day.

While providing this overview, the book offers a simple original model that explains major underlying principles of big history, including every aspect of human history. This model has not been challenged so far, and is increasingly adopted by other scholars, most notably in the Big History Project sponsored by Microsoft cofounder Bill Gates.

The widely-acclaimed first edition is already being used for teaching big history at universities in the United States, Europe, Africa, and Australia. The book has also proven to be very popular in unusual settings, including teaching big history to adventurous cyclists biking all the way from Istanbul to Beijing along the ancient Silk Road as well as to inmates in a US high security prison. So the possibilities seem limitless.

The Second Edition has been adapted to be even more suitable for teaching big history. But because most teaching features will appear on the web site and not in the book, it can also be read very well separately without any teaching purposes.



For information about the book not provided on the web site, or to request an examination copy, please visit Wiley.com.

New Discoveries from Fred Spier's Twitter

May 7: A research team led from Uppsala University in Sweden has discovered a new kind of microbe that helps explain how complex (eukaryotic) cells evolved. The researchers found an entirely new group of Archaea in a hydrothermal vent in the Mid-Ocean Ridge, between Greenland and Norway. They named this new microbe "Lokiarchaeota," or "Loki" for short. Loki represents an intermediate stage between simple cells (prokarotes) and eukaryotes. Extreme environments like hydrothermal vents (volcanic systems located on ocean floors) contain lots of unknown microorganisms. Researchers believe that they are just getting started making discoveries that will force revisions of the textbooks. See Fred's link to *Science Daily* for more on this.

May 10: NASA's Hubble Space Telescope has discovered that the halo of gas surrounding the Andromeda galaxy is six times larger and a thousand times more massive than previously measured. Scientists cannot tell whether our Milky Way galaxy, a sort of twin of Andromeda, also has such a massive and extended halo of gas. If it does, then the two halos may be nearly touching. Hubble observations indicate that Andromeda and the Milky Way galaxies will merge to form one elliptical galaxy beginning about four billion years from now. See Fred's link to *Science Daily* for more on this.

Reprinting an Historical Article on Cosmic Evolution

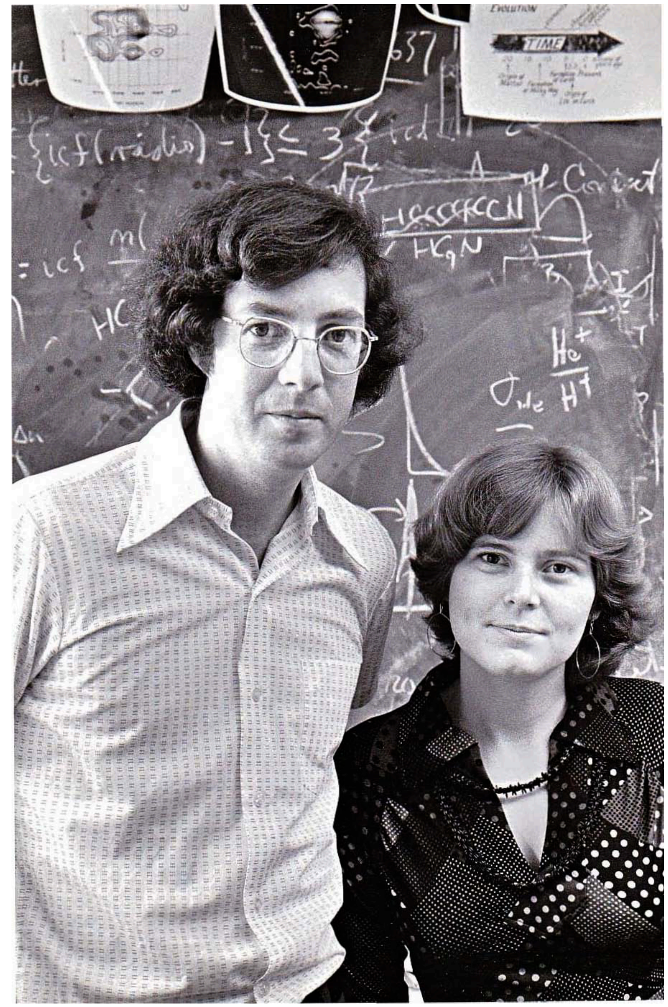
I was surprised when an IBHA board member recently requested permission to reprint my earliest article on cosmic evolution in *Origins*, but no more surprised than when a Harvard official asked me to write it in the first place nearly 40 years ago. That erstwhile objective aimed to capture in narrative form, not least aided by my wife's art, the uncommon success I was then having teaching natural science broadly in a highly specialized research university, as undergrads voted with their feet while trekking along their right of passage—much as they still do now in my cosmic evolution class each spring: https://www.cfa.harvard.edu/~ejchaisson/cosmic_evolution

I never expected then that anyone would read what I wrote. Nor do I now, some four decades later. Frankly, I write for myself, finding writing mentally therapeutic after hours, while on planes, trains, and holidays. My personal pedagogy has always maintained that we learn in three stages: first as students yet we often don't achieve real understanding, second as teachers but we still surprisingly often wave our hands, and third as writers when we are forced to express our subject matter in carefully chosen English words—and finally perhaps realize what we're talking about.

Some people ask me if this is the first published paper on the grand sweep of cosmic evolution, from big bang to humankind. My answer is that I don't care if it is or not. My aim is not to have the first—or the last—say. My goal was then, as it remains now, to share with others what I've discovered about this awesome, evidence-based, scientific philosophy, partly known to some as big history. This was the big-picture worldview that my persistently curious students were then seeking—and so was I. Indeed we all still are.

Herewith, in 1977 at the Harvard College Observatory, are the early explicators of cosmic evolution, Eric and Lola Chaisson. Amidst symbolic scribbles on the blackboard and pioneering radio maps of our galaxy's central black hole at the top, note at upper right the arrow-of-time sketch that has become an enduring graphic for most who seek to know who we are and whence we came.

- Eric Chaisson, May 2015,
Cambridge, Massachusetts



Editor's note: The following article, "The Scenario of Cosmic Evolution" was originally published in the November-December 1977 issue of *Harvard Magazine* (80:2; 20-33). The article won the Smith-Weld Literary Prize for the best general article by a Harvard faculty member that year. It also garnered 6 unsolicited book contracts, one of which with Atlantic Monthly, Little-Brown, led to Eric Chaisson's first book, *Cosmic Dawn*, which won several more literary awards—and much grief from his colleagues who thought he was misallocating his time and effort. We are pleased to reprint below with permission his 1977 *Harvard Magazine* article that remains a foundation of Big History.

To make new discoveries about the origins of matter and of life, modern science is synthesizing research from many disciplines.

THE SCENARIO OF COSMIC EVOLUTION

by Eric J. Chaisson

Since the dawn of civilization, men and women have wondered about, and even feared, the mysteries of the skies. At first, they approached their world subjectively, believing Earth to be the stable hub of the universe, with sun, moon, and stars revolving about it. Stability led to a feeling of security, or at least contentment—a belief that the origin and destiny of the cosmos were governed by the supernatural.

With the advent of recorded history, however, human beings became aware of another mystery—themselves. Indeed, the origin and destiny of man are as enigmatic as anything in the depths of space.

Later, but only as recently as a few hundred years ago, man began to adopt a more critical stance toward himself and his universe, seeking to view the world objectively. With it, modern science was born, the first product of which was the Copernican crisis. The idea of the centrality of the earth was demolished forever. Human beings came to feel that they were marooned on a tiny particle of dust drifting aimlessly through a hostile universe. This loss was nevertheless coupled with the emergence of the scientific method, in which observations generate a hypothesis to be followed by experimental testing, providing a new way of probing the most fundamental questions of our origin, our nature, and our future.

Recent scientific developments, particularly within the past two decades, have demonstrated that, as living creatures, we inhabit no very special place in the universe at all. We live on what appears to be no more than an ordinary rock called the earth, circulating about an ordinary star called the sun, at the edge of one galaxy called the Milky Way, one galaxy among countless billions of others distributed throughout the observable abyss called the universe.

It's perhaps a sobering thought to recognize that we play no special role in the universe, either astrophysically or biochemically. It is even more humbling at first—but then wonderfully enlightening—to recognize that it is gradual cosmic-evolutionary processes, operating over almost incomprehensible time and incomprehensible space, that have given birth to life on our planet. And should the scenario of cosmic evolution be valid, even in its broadest perspective, we can rightfully speculate about the

The author is assistant professor of astronomy at Harvard (see page 4).

associated implication for the plurality of extraterrestrial life throughout an almost inconceivably vast universe.

As we enter the last quarter of the twentieth century, experimental science is beginning to unravel the subtleties of cosmic evolution whereby we have come first to exist, and then to contemplate our existence, within the material universe. With a large degree of assurance, we now better understand the astrophysical sequences whereby countless billions of suns were born and died to create the matter that now composes our world. And, though substantial gaps remain, modern experimental science currently strives to demonstrate a clear understanding of the biochemical pathways that led to life as a natural consequence of the evolution of matter.

Contemporary cosmology holds that the universe began in a cataclysmic explosion some 15 to 20 billion years ago.

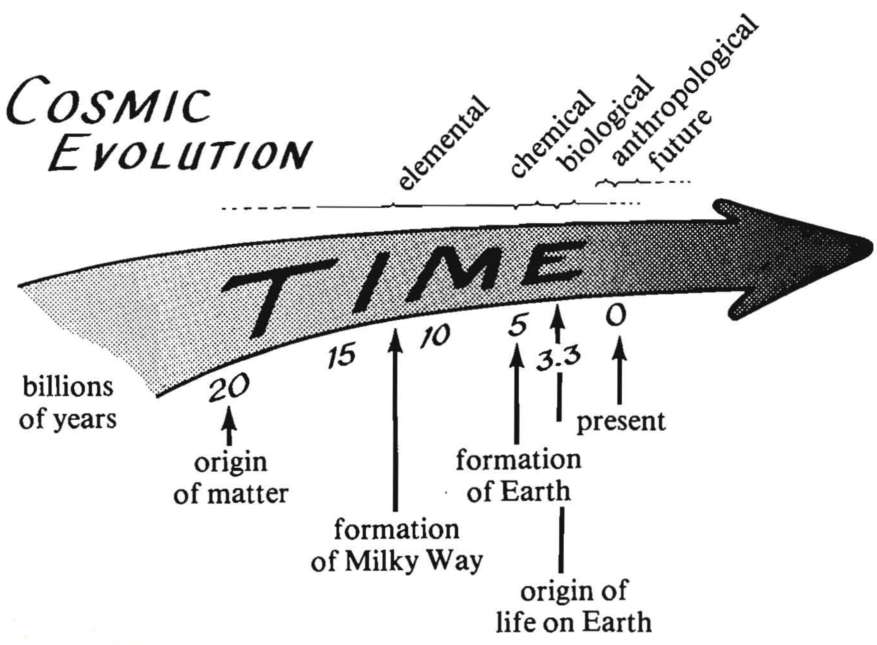
To answer the fundamental questions Who are we? and How did we come to be?, it is necessary to look far into the past, beyond the commencement of the scientific method centuries ago, beyond the onset of language and civilization as we know it tens of thousands of years ago, beyond the ancestral *Australopithecus* man-ape that roamed the savanna in search of meat several millions of years ago, even beyond the multicellular organisms that began to flourish on our planet some billion years ago. Back and back your thoughts spin through the biological record—facts of evolution documented by the fossils, a record that clearly shows complexity arising from simplicity.

Go back further into the past. There was a time about 4,000 million (or 4 billion) years ago when, according to the fossil record, there apparently was no life on planet Earth. A combination of astronomical and geological considerations furthermore suggest that the sun and planets did not even exist some 5 billion years ago. They were only forming out of a giant, swirling interstellar gas cloud at one edge of an enormous complex of older stars that had already been around in one form or another for about 5 billion years.

Here, in this so-called Milky Way Galaxy, massive stars ejected, through supernova explosions, their synthesized elements into the surrounding galactic or interstellar medium. Out of this debris other later-generation stars condensed, at least one, our sun, with rocky planets. And it was in this billion-year-old ocean and atmosphere of primordial Earth that some critical elements combined, according to the laws of physics and chemistry, to form the biochemical precursors of life as we know it. Rudimentary life eventually arose as a self-assembly of macromolecules, and it is from such simple unicellular organisms that all more advanced multicellular, even intelligent forms of life have since arisen.

Who are we? Where did we come from? In essence, we are a combination of chemical elements, produced eons ago inside the fiery cores of massive stars, elements that contribute to the earth's rocky continents, to the atmosphere and ocean, and to the myriad forms of life around us. The proper answers to these questions are evolutionary ones that enable us to relate ourselves to all forms of matter, indeed, to the whole material universe.

To trace the specific steps that led to our origin, modern science attempts to synthesize a wide variety of university offerings—physics, chemistry, astronomy, biology, geology, and anthropology, among others—in an attempt to unravel the two most outstanding problems of our time: the origin of matter and the origin of life. If we can understand better the scenario of cosmic evolution, then perhaps we can determine precisely who we are, specifically how it is that life originated on this planet, or, incredibly enough, how it is that living organisms have evolved large enough neural processes to invade land, to generate language, to create culture, to devise science, to explore space, or even to be able to speculate about ourselves, as you



The cosmic-evolutionary scenario in schematic-diagram form.

Giant radio telescopes, hundreds of feet in diameter, can eavesdrop on the physical processes deep within dense, dark, and dusty interstellar regions that cannot be observed optically. These antennas also pick up the relic hiss of the "big bang," echoing the extreme physical conditions existing at the very start of the universe.

and I are doing by reading and writing this article.

Yet there was a time when none of these capabilities existed on this planet. Long ago, there was no life on Earth. There was no Earth, no sun. Somehow the heavy elements synthesized, the solar system formed, and thereafter life originated, all apparently as a general development of universal matter.

There is, among many smaller ones, at least one great evolutionary link in our ancestral past: a link that connects coagulations of matter that clearly are living with those that clearly are not.

The central theme of cosmic evolution is that, given sufficient amounts of time, life arises as a natural consequence of the evolution of matter. One can then reasonably ask: Whence did matter arise? To address this fundamental inquiry, we must consider events at the earliest epochs of the universe.

Contemporary cosmology holds that the universe began in a cataclysmic explosion some 15 to 20 billion years ago. Evidence for the initial fireball, or "big bang," comes primarily from observations of external galaxies out beyond our Milky Way. Kinematic studies of such objects show them to be receding from us at a rate proportional to their distance. That is, those galaxies most distant from us have larger recessional velocities, some with a fair fraction of the speed of light. Now, because of the finite speed with which light (or any type of radiation) travels, the most distant objects are also the oldest, having emitted their light towards us eons ago at the earliest epochs of the universe. This is why the cosmologist often notes that looking out into space is equivalent to looking back in time. The most distant galaxies have the greatest velocities of expansion, since they were formed when the universe was young and energetic, and hence provide for us information about the early universe.

The big-bang model for the origin of the universe has received supporting evidence within the past decade with the discovery of a weak hiss of radio radiation. This low-level static, observed coming from every direction in space, is regarded as a cool relic of the initial fireball. Extrapolated back in time, it also provides information about universal physical conditions eons ago.

At the very beginning, the temperature of the fireball was unimaginably hot. But as the universe expanded to fill a larger volume, it began to cool, just as any gas will cool upon placement in a larger container. It can be shown mathematically that after about 15 to 20 billion years of expansion, the remnant of the initial fireball should have cooled substantially to the value now measured isotropically (in all directions) by large radio telescopes.

An important consideration for our cosmic-evolutionary scenario is the observed fact that the universe is not static: it's changing with time; it's evolving. But what is our position in this expanding universe? If all galaxies appear to be receding from us, are we at the center of the universe? No. Relativity theory specifies how the gravitational fields of massive bodies alter the nature of space and time, and, along with the Cosmological Principle, ensures that all observers in space see the universe in essentially the same way. The observational fact that virtually all galaxies retreat from us is not an indication of any special place in the cosmos; the four dimensions of space and time are warped so that all observers, everywhere, would note the galaxies receding.

Present knowledge of physics does not allow us to appreciate fully the extreme conditions that must have existed in the first few moments of the initial fireball. Surely there were elementary particles out of which present matter is composed. But the extreme heat of the early universe ensured that radiation completely overwhelmed matter, breaking it apart as soon as it formed, preventing even the simplest elementary particles from coägulating into matter that we now call atoms. Eventually, however—probably after only the first few minutes and certainly not longer than a million years after the initial fireball—the radiation had dispersed sufficiently into a larger volume, cooling as the universe expanded. Elementary particles of electrons and protons then united to form the simplest and most abundant ele-

Evidently, the disposition of the universe is no longer conducive to the formation of galaxies...

ment, hydrogen. And yet, before the first few seconds had elapsed and the universe had had a chance to cool below 10 million degrees Celsius, some of the hydrogen atoms would have had time to fuse, via thermonuclear processes, into the next heaviest element, helium. But the few seconds of intense heat available after the explosion was not time enough to permit the formation of elements heavier than helium. The elements composing the page you are now reading or the air you are now breathing were not synthesized in the big bang. There simply wasn't enough time; events at the start of the universe happened very rapidly.

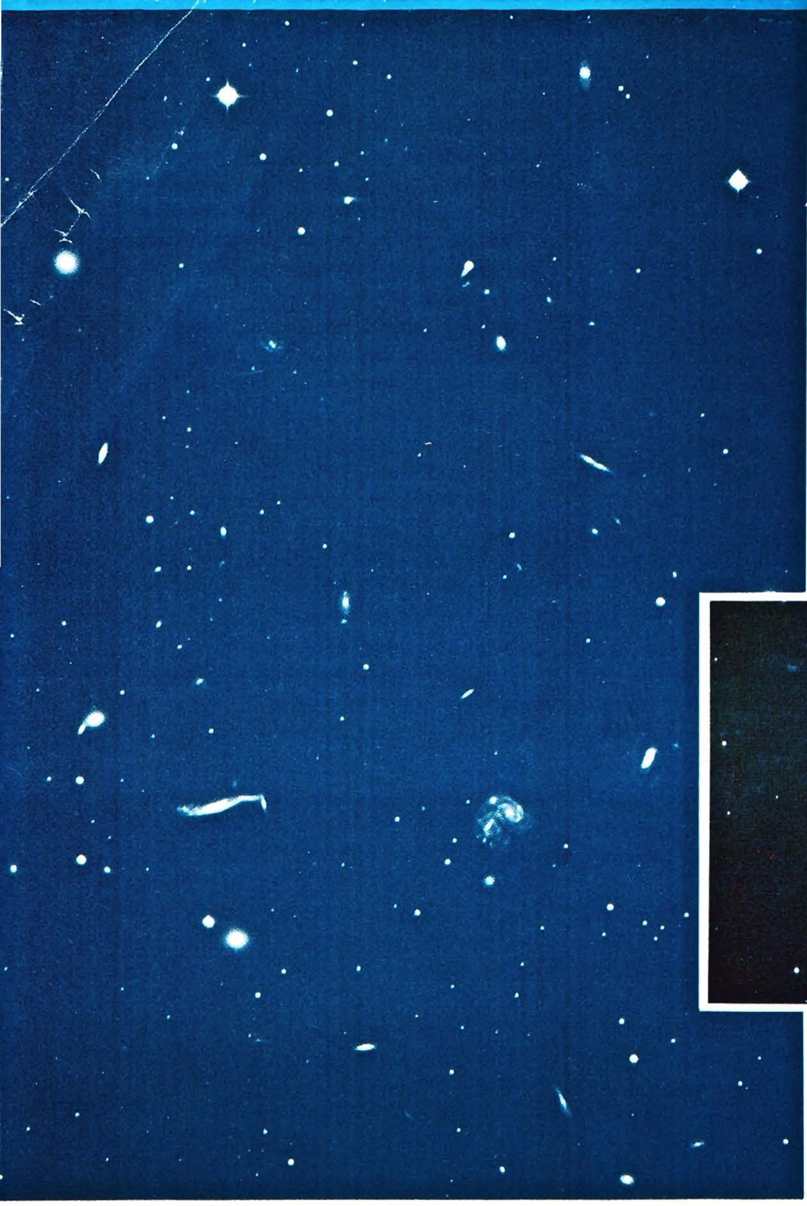
A million years or so after the bang, the universe had cooled sufficiently for matter to dominate radiation. Though probably distributed uniformly at first, matter, if left alone, tends to coagulate inhomogeneously. This is because a uniform, unbounded, self-gravitating medium is basically unstable, and will eventually fragment into individual pockets of matter. Some of these statistical fluctuations will disperse, but others will grow, especially in the presence of turbulence that was surely present in the early universe. Those material fluctuations (or eddies) that continue to grow by gravitationally attracting additional matter ultimately fabricate the galaxies. Provided there is enough mass—at least 100 billion times the mass of our sun—a reasonably warm condensation will contract gravitationally, rotate a little, heat up, radiate energy, contract some more, rotate a little faster, and so on in this cyclical fashion until an equilibrium is achieved between the inward pull of gravity and the outward force of rotation.

In this way, it is thought that all galaxies were formed in the first few billion years after the bang. Observationally, there indeed appear to be no young galaxies; there's no evidence for galaxies forming at the present epoch. Of course, stars are still forming within galaxies, but galaxies themselves are not. Evidently, the present disposition of the universe is not very conducive to the formation of galaxies. Perhaps the large-scale turbulence, the hotter gas, and the intense radiation field of the early fireball—physical conditions that have diminished substantially in the present quiescent universe—played efficient roles in sweeping up all the available matter into primordial coagulations that eventually became the galaxies now observable in deep space.

Fragmentation of matter continues even at the present epoch, producing stars within galaxies. Pockets of gas form, almost by accident, via statistical fluctuation, much as for galaxies noted above. But galactic or interstellar gas is very cold, generally only a few degrees above absolute zero, resulting in considerably less mass per pocket than for galaxies. You might ask then: How many hydrogen atoms are necessary for the collective pull of gravity to prohibit a pocket of gas, once formed, from dispersing back into the interstellar medium? A hundred? A thousand? A million? No, a much larger number. In fact, nearly a billion trillion trillion trillion trillion atoms are necessary to bind gravitationally a gaseous condensation. In scientific notation, this is 10^{57} atoms of hydrogen, which, not coincidentally, is the equivalent mass of our sun. It's a large number, larger than the 10^{25} grains of sand in all the beaches of the world, even larger than the 10^{51} protons and neutrons in all the earth's nuclei. It's large compared with anything with which we're familiar because there's simply nothing on Earth comparable to a star.

Most stars in our galaxy (and, as best we can tell, in other galaxies as well) have between 10^{56} and 10^{60} hydrogen atoms, or, equivalently, a mass between 0.1 and 1,000 times the mass of our sun. The most massive stars probably form either in particularly rich locations of the interstellar medium or in regions where heat, rotation, and/or magnetism competed with gravity, requiring the protostellar condensation to attract more than the canonical 10^{57} hydrogen atoms for the onset of gravitational contraction.

As an interstellar cloud undergoes collapse, the microscopic spaces among the individual gas particles diminish, increasing the frequency of atomic collisions. Collisions imply friction and, of course, friction is heat. Consequently, the interstellar cloud heats up, until such time that the cloud, or a small, dense portion of it, reaches 10 million degrees Celsius, at which point nuclear burning is initiated. This is a fusion process whereby individual hydrogen nuclei, namely protons, have so much energy and are therefore moving so fast that their mutual collisions can interpenetrate the domain of the nuclear forces, fusing the protons into a helium nucleus. This so-called proton-proton cycle is the relatively simple mechanism that provides the uniform rate of stellar energy to sustain life on our planet. It, or some process like it requiring equally high



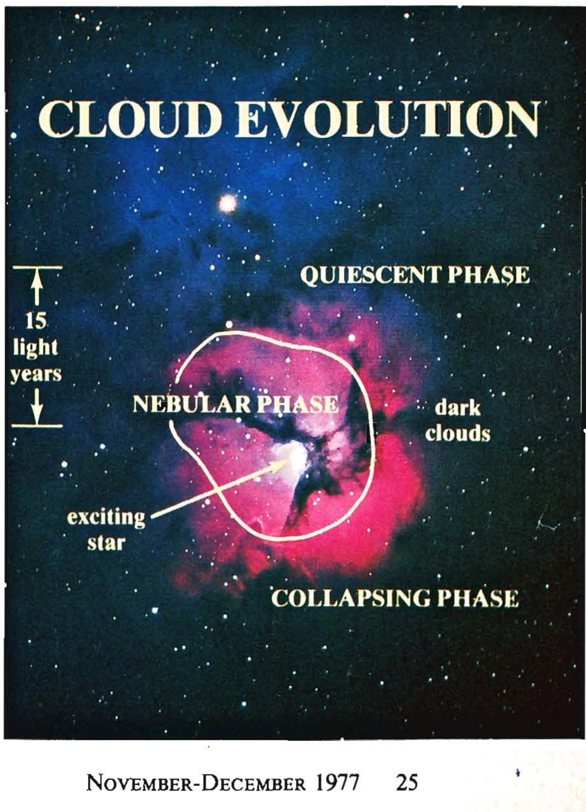
Clusters of galaxies top the hierarchy of material coagulations in the universe. Almost every speck of light at left is emitted from a full-fledged galaxy—members of the Hercules Cluster, formed eons ago in the early universe.

A typical, relatively nearby galaxy—such as the Spiral Galaxy in Pegasus, above—contains hundreds of billions of individual stars distributed over some million trillion miles. Our own Milky Way, too large and complex for us to observe accurately from within, may look like this one. If so, our sun would be seen as a rather undistinguished star near the galactic periphery.

temperatures, is understood to give rise to nuclear fires in the cores of all other stars, including all those seen above you on a clear night.

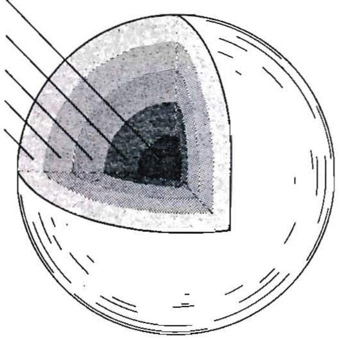
Until recently, this cloud-collapse scenario was little more than that—a good theory, but one for which there was very little observational evidence. Technological advances in the last few years, however, have enabled radio astronomers to probe deep within the dense, cool regions thought to be conducive to star formation. Such protostellar regions are often dark and dusty, effectively prohibiting useful work by conventional optical techniques. Light radiation, with a wavelength comparable to the typical size of an interstellar dust particle, is scattered and attenuated badly in relatively dense and dusty regions. Radio waves have a longer wavelength and are completely unaffected by interstellar debris, allowing the radio astronomer to listen to the physical processes deep within protostellar regions. Recent radio studies of candidate regions have produced some observational evidence that individual interstellar clouds are indeed collapsing under the force of gravity, presumably on their way toward formation of an individual star or cluster of stars.

The lifetime of a star, once formed, depends on its mass. Our sun is considered an intermediate-mass star and has been fusing hydrogen into helium for almost 5 billion years. And, according to our knowledge of stellar



Patches of gas aglow in deep space, called gaseous nebulae, are regarded as sites of recent star formation. At right, schematically superimposed on a photograph of one such region (the Trifid Nebula), are the results of the author's recent radio-observational study depicting the three principal phases of an interstellar-cloud evolutionary scenario: quiescent→collapsing→nebular. The nebula is approximately 200 trillion miles across.

The interstellar medium is regularly enriched by exploding stars, which eject heavy elements for later-generation stars...



Interior layers of a massive star, in which heavy elements are synthesized.

evolution, the sun should continue to do so for another 5 billion years, continuing to provide that constant source of heat and light necessary for the maintenance of future generations of Earth life. As the sun grows old, however, its helium content will undoubtedly increase, especially in the core. Though the sun's interior is amply hot to continue to fuse hydrogen into helium, it is not quite hot enough to fuse helium into the heavier elements. Lacking a nuclear fire, the sun's core will subsequently cool and, without outward radiation pressure to support gravity, shrink. The core shrinkage continues for about a billion years until the density at the core is sufficiently large for collisions to increase the temperature and hence the outward pressure, which eventually matches the inward pull of gravity and thereby stabilizes the core once again. The core temperature is now high enough (about 100 million degrees Celsius) for helium nuclei to penetrate the range of nuclear forces upon collision, and, in doing so, to produce the heavier element carbon.

Simultaneous to these core events, the solar periphery is heated by the underlying helium core to temperatures well in excess of the 10 million degrees Celsius needed to fuse hydrogen into helium. The proton-proton cycle consequently speeds up, producing greater amounts of nuclear energy, and overwhelming the inward pull of gravity in the sun's outer layers. So, despite the helium-core shrinkage to a size not much bigger than the earth, the outer solar layers expand enormously, engulfing the interior planets Mercury, Venus, and perhaps Earth. In this way, our sun will someday become a red giant star. Fortunately, it won't happen for 5 billion years.

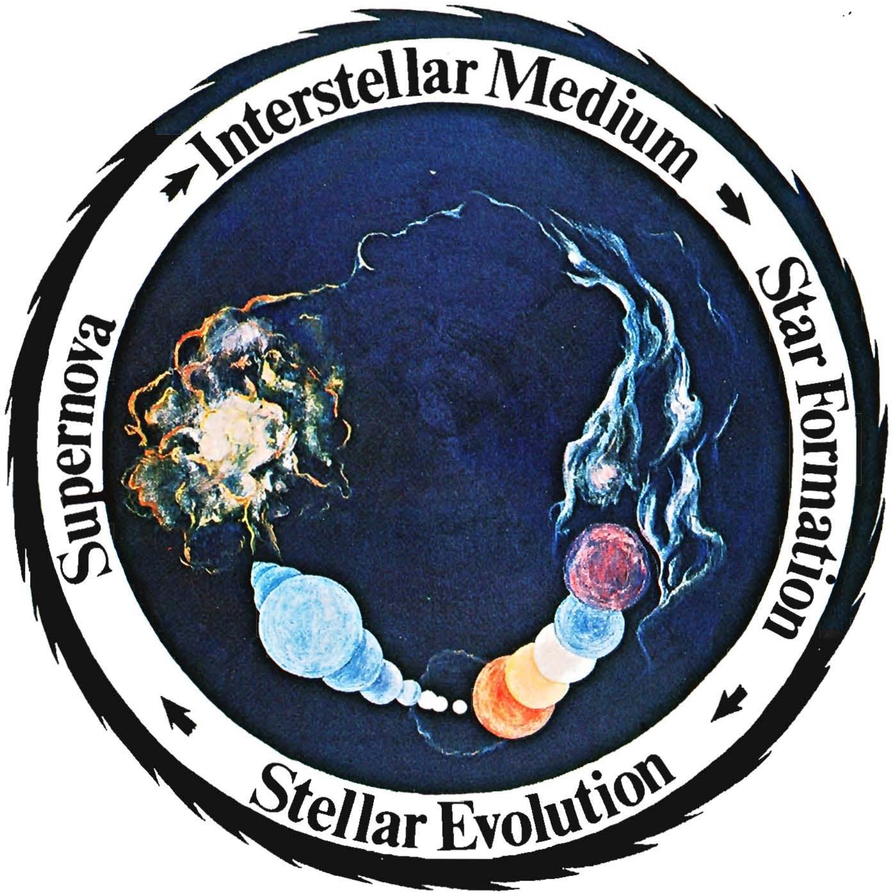
All stars are thought to obey the above evolutionary scenario, but their future depends critically upon the amount of mass they contain. A star having the mass of our sun or a little less will never achieve a large enough pull of gravity to squash the carbon core of a red giant to the 600 million degrees Celsius required to fuse two carbon nuclei together. Without a carbon nuclear fire in a red giant, gravity will rapidly overwhelm the gas pressure, shrinking the entire star to one of Earth dimensions—a white dwarf. Such a star, which is white-hot simply because of stored heat, will eventually fade into death as a black dwarf. Astronomers are unsure how many of these dark clinkers exist in space, for they can't be seen.

Stars more massive than the sun, on the other hand, can achieve enormously high temperatures in their cores, temperatures capable of producing many of the heavier elements familiar to us. A series of successive core shrinkings, followed by heating and renewed nuclear burning, routinely produces many heavy elements, such as oxygen, magnesium, silicon, and sulfur, up to and including iron. But iron acts as a fire extinguisher, absorbing energy upon fusion and robbing the nuclear fire of the higher temperatures necessary to balance the relentless pull of gravity. The star consequently collapses until nuclei touch one another, halts momentarily, and then suddenly rebounds in a supernova explosion, ejecting its heavy elements and about half of its original mass into the surrounding interstellar medium.

Provided the unexpelled stellar core exceeds several solar masses, it may proceed toward any one of several bizarre states, possibly even collapsing catastrophically to form a black hole. Such remnants of supernova explosions, recently observed indirectly by instrumented spacecrafts orbiting the earth, are regarded as sites of extraordinarily large density, where the nature of space and time becomes radically altered, and where perhaps even the laws of physics, as we know them, break down.

The temperature achieved at the moment of explosion is sufficiently high to synthesize many elements heavier than iron. Elements such as nickel, tin, bismuth, gold, uranium, and many others are produced by a series of complex nuclear reactions, precise knowledge of which has been acquired only in the past two decades during controlled experiments in sophisticated nuclear plants.

The theoretically computed abundance of all the elements processed in stars agrees well with the observed relative abundances of all the 105 natural and radioactive elements currently known. However, it's impossible to prove conclusively that we understand precisely all the steps of elemental nucleosynthesis—it is, quite simply, impossible to probe the chemical constitution of a star's interior. But observational studies of stellar age, surface composition, and physical disposition, coupled with a solid experimental knowledge of nuclear physics, have confirmed our belief in the general scheme of stellar nucleosynthesis. In fact, we know that at least one such nuclear process actually does occur within stars because of the observation of the rather special heavy element technetium. Since this element has a radioactive half-life of only 200,000 years, the widespread observa-



In a continuous process, stars formed from cool, dense regions of the interstellar medium explode much of their material back into the galaxy—thereby enriching the interstellar gas with heavy elements to form later generations of stars, planets, and people.

Above: A supernova explosion expelling heavy elements into the interstellar medium. The titanic death rattle of this expiring star, now known as the Crab Nebula, was observed and recorded by Chinese astronomers in the eleventh century.

Below: A collapsing, swirling interstellar cloud forming (left to right) a central star and planetary system. Thought to be a natural by-product of star formation, such planetary condensations argue for a plurality of planetary systems elsewhere.

tion of this element in numerous stars demonstrates the validity of the stellar nucleosynthetic process sketched above.

The upshot is that the interstellar medium is regularly enriched by exploding stars, which eject heavy elements for later-generation stars, planets, and other things, including living organisms, that consist of heavy elements. Because observations show that our sun already contains minute amounts of heavy elements, despite its relative youth and cool interior, we regard our sun as a second- or later-generation star. It, along with the planets, presumably condensed about 5 billion years ago from a cool cloud of interstellar matter already enriched with heavy elements.

Astrophysicists can agree on this broad outline for the origin of our solar system, but they can come to no consensus concerning specific details. The real problem is that the earth's geological record for the first half-billion years or so is missing, eroded away by violent internal (volcanic) and external (meteoritic) events that completely altered the make-up of the early surface.

The genesis of a planetary system is understood to be the outgrowth of a frequent natural phenomenon that develops as a by-product of star formation from the gravitational contraction of an interstellar cloud. A huge disk of interstellar gas and dust, flattened by rotation, breaks up into eddies—or protoplanets—of irregular size and shape, moving at various distances from the protosun's center. Given the remarkably ordered architecture of the entire solar system, including Earth, it does not seem reasonable that the planets could have materialized by some collisional encounter or another chance arrangement.

The so-called nebular hypothesis of planetary-system formation, then, clearly implies the plurality of planets in circulation about other stars. Thus far, however, astronomers are unaware of the unambiguous existence of any other planetary system. To be sure, there are a few nearby stars that are observed to wobble back and forth slightly on the plane of the sky—as might be expected if reasonably massive but unseen companions were orbiting about them. But no Earthlike planets around other stars have ever been observed with telescopes.

A central feature of cosmic evolution is the developing realization that life is a logical consequence of known physical and chemical principles operating within the atomic and molecular realm...

What was it like on the surface of primordial Earth? With the exception of helium (which is inert and hence plays no role chemically), the most abundant elements must have been hydrogen, carbon, nitrogen, and oxygen. Many of these light gases that composed Earth's primordial atmosphere probably soon escaped into space, because of a combination of astronomical and geological events that produced a surface considerably hotter than at present. But continued volcanic outgassing from the interior of the active planet surely produced a secondary atmosphere rich in hydrogen, though probably depleted in free oxygen. Many elements are known to unite spontaneously under such nonoxydizing conditions, and, especially as the earth cooled, to have produced chemical molecules such as ammonia (a mixture of hydrogen and nitrogen), methane (a blend of hydrogen and carbon), and water (a hydrogen-oxygen coalescence). Observations of these very substances in the atmospheres of the larger planets Jupiter and Saturn, as well as in the dark, dense clouds of the interstellar medium, provide strong evidence that such compounds must indeed have existed at an earlier epoch in Earth's history.

In the absence of free oxygen there would, of course, have been no appreciable ozone layer, allowing solar ultraviolet radiation to interact unabated with these imperceptibly small but relatively abundant chemical compounds. Remarkably enough, laboratory experiments have now shown conclusively that the application of radiant energy causes such simple chemicals to synthesize moderately complex products. After about a week of energetic irradiation of ammonia, methane, and water, a variety of amino acids and nucleotides are formed. These prebiological materials constitute many of the necessary molecular ingredients for life as we know it, the very building blocks of proteins and nucleic acids common to all life, from the amoeba to *Homo sapiens.*

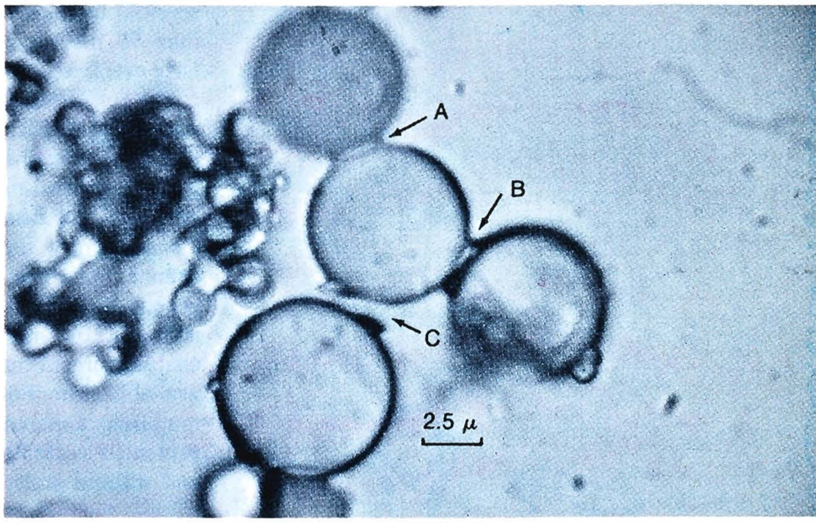
Recent biochemical experiments have furthermore shown that any one of a wide variety of energy sources can suffice for the production of these precursors of life: not only solar ultraviolet radiation, but also lightning discharges, volcanic heat, natural radioactivity, and atmospheric shock waves produced by incoming meteorites are all individually capable of synthesizing copious amounts of amino acids and other antecedents of the even more complex ingredients necessary for life.

Admittedly, there is a large gap between amino acids—even complex proteins—and life itself. But in recent years, laboratory simulations of the primordial ocean and atmosphere have demonstrated the existence of chemical compounds of substantial complexity. Polymerization experiments, in which numerous amino acids are united under the sole influence of slight amounts of constant energy, have fashioned proteinoid sequences that behave to some degree like the contemporary biological cell. Such protein or near-protein material resists dissolution in water and tends to coagulate into small droplets, sometimes called microspheres, much like oil globules floating on the surface of water. These laboratory-synthesized droplets are reasonably stable, and possess a semipermeable membrane capable of directing inward the passage of small molecules used in the catalytic activation of more complex molecules too large to pass back out through the membrane. In this way, proteinoid droplets, synthesized from the initial conditions that must have existed on primordial Earth, can be considered to possess a mechanism of food gathering—a primitive metabolism: they consequently grow, taking in nourishment from the surrounding primordial soup where organic matter is still produced via interaction with a source of external energy. Ultimately, the normal operation of the laws of fluid physics governing weight, size, and surface tension tends to break up the larger droplets into smaller ones, some of which dissipate, others of which survive.

Can these proteinoid substances be considered alive? It's hard to say. It's difficult to define life. Some biochemists regard such curious little bags of chemicals as possessing many of the characteristics of a living unicellular organism—they eat, eject wastes, exhibit metabolic processes, grow, reproduce, and die. They possess, however, neither the hereditary molecule DNA nor a well-defined nucleus. To be sure, laboratory biochemists have not yet succeeded in synthesizing from primitive Earth conditions the DNA molecule or many of the exceedingly complex enzymatic proteins

Chemical apparatus capable of synthesizing complex biochemical precursors by means of an energetic irradiation of a mixture of ammonia, methane, and water vapor. In the procedure diagramed above, the gases are placed in the bulb at upper left to simulate the primordial-Earth atmosphere, and then energized by spark-discharge electrodes. After about a week of recycled cooking, the gases have formed prebiological ingredients in the trap at the bottom, simulating the primordial oceans into which heavy molecules would have fallen.

Below: Proteinoid droplets displaying the result of coagulation of as many as a billion polyamino-acid molecules in a fluid medium. A semipermeable membrane can be noted in other experiments, as can the evidence for primitive replication of offspring proteinoid microsystems that grow after separation from parent microsystems. The scale of 2.5 μ is equivalent to one ten-thousandth of an inch.



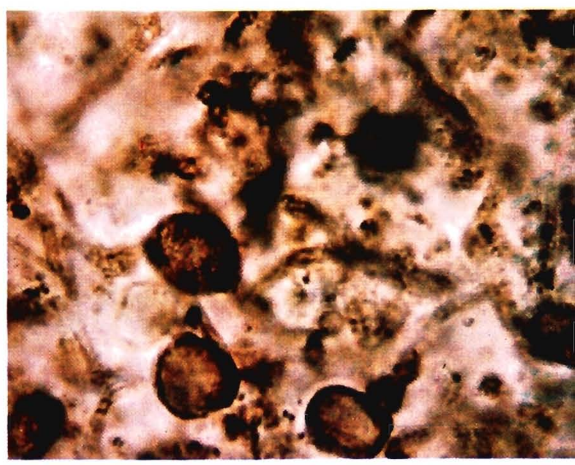
common to contemporary life. Neither can they justify how the first protein arose from a medium containing no nucleic acids, especially when the passage of information from nucleic acid to protein is considered by many to be the central dogma of contemporary molecular biology. But if the aforementioned synthesized droplets are not at least progenitors of living organisms, then nature would appear to have played an unusually malicious joke on modern science.

The basic problem here is that there is no clear-cut distinction between living and nonliving. Most scientists would argue that the amoeba is alive but that the dilute organic soup in the laboratory simulations or on the primordial earth is not. The proteinoid droplets appear to be somewhere in between. They do, however, bear a certain resemblance to the fossilized remains of the oldest living organisms found several years ago in the sedimentary rocks of South Africa. These fossils, radioactively dated as 3.3 billion years old, appear to have a microbiological morphology not unlike that of modern blue-green algae.

A central feature of cosmic evolution, then, is the developing realization that life is a logical consequence of known physical and chemical principles operating within the atomic and molecular realm, and, furthermore and more fundamentally, that the origin of life is a natural consequence of the evolution of that matter.

With the passage of almost inconceivably long durations, Earth's geophysical environment changed sporadically, granting some biological species a natural advantage over others, thereby giving rise to a myriad of living organisms. Biological evolution by natural selection is now considered to be a paleontologically documented fact. The key is the fossil record.

Briefly, the study of fossil remains shows the widespread appearance about 2.5 billion years ago of simple unicellu-



Photomicrograph of a fossilized organism from sediments of the Canadian Shield, radioactively dated as 2 billion years old. Not unlike the oldest organic fossils—the 3.3-billion-year-old specimens of South Africa—these procaryotic systems possess concentric spheres or walls connected by smaller spheroids. The scale of this photograph is about ten times larger than that of the photograph above it.

The human brain is the most complex clump of universal matter known to exist—the perfect example of the exquisite extent to which matter in the universe has evolved...

lar organisms such as blue-green algae—procaryotic systems, which are organisms that lack a well-defined nucleus. These were followed about 2 billion years ago by more complex unicellular creatures—eucaryotes (those that have a well-defined nucleus), such as the euglena. Multicellular organisms such as sponges did not actually appear until about 1 billion years ago, after which there rapidly flourished a wide variety of increasingly complex organisms—insects, reptiles, mammals, man.

But the fossil record also contains abundant evidence that some organic species did not adapt successfully to the changing environment, and subsequently perished. In fact, despite the present existence of some 2 million living species, biologists estimate that more than 99 percent of all organisms that have ever lived on earth are now extinct.

The fossil record no longer leaves any reasonable doubt that biological evolution has occurred and is continuing. The precise mechanisms of evolution, however, are still debated in some circles. Contemporary thought stipulates that chance mutations sporadically produce genetic variability in the DNA structure, acting as the motor of evolution and enabling organisms to strive for the best available niche. For example, some early mutations apparently allowed primitive protocells to use light energy, exclusively and without molecular nourishment, to sustain themselves via the process we now call photosynthesis. The 3.3-billion-year-old fossils show some evidence of chlorophyll products, implying a widespread occurrence at that time of photosynthesis, a process whereby carbon dioxide is converted to oxygen that we now breathe and carbohydrates that the cell assimilates.

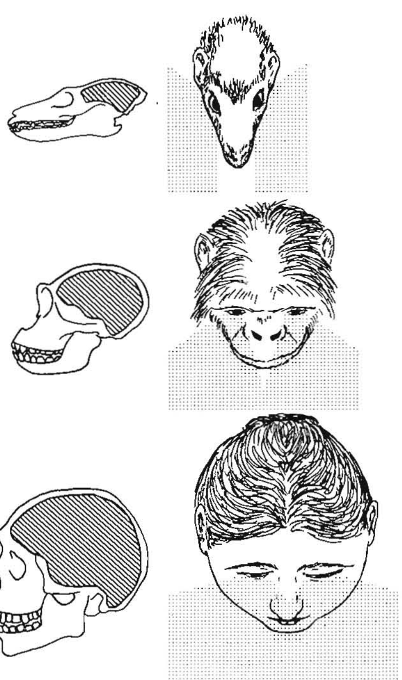
At any rate, it is fair to say that twentieth-century evolutionary theory is quite capable of accounting for the wide variety of life on earth, of explaining variations of species from ideal types, and of recognizing that universal change occurs everywhere in nature as a rule and not as an exception.

Life thus began on our planet at least 3.3 billion years ago. For about 2.5 billion years, evolution did not take matter beyond the single-cell way of life. Macroscopic evolutionary developments occurred only within the past 500 million years or less, with animals themselves mastering the land only about 300 million years ago, and birds, mammals, and flowers flourishing less than 100 million years ago. Interestingly, man has been around for only the last few million years, an exceedingly short time when placed into perspective within the entire cosmic-evolutionary scenario. In fact, if all events from the origin of life to the present could be compressed into a 24-hour day, we would have existed for less than a minute. A short time indeed in the cosmic scheme of things, but apparently not short enough for us to avoid ransacking our planet of fossil fuels and natural resources.

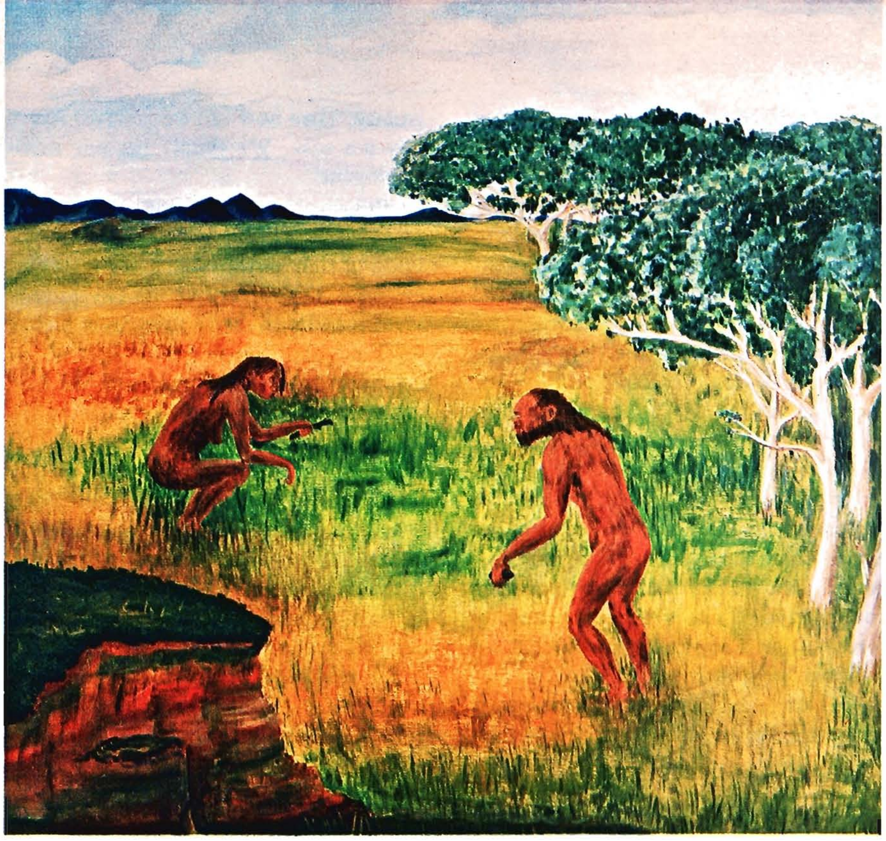
The precise lines of descent whereby the ape-man evolved from the man-ape remain debatable. The general picture is in place, however. Paleoanthropologists seek to trace our recent origin by unearthing fossil remnants of our ancestors in rich river beds, principally along the East African Rift Valley. Here, in recent years, substantial skull, jaw, and tooth fragments have been discovered, providing a wealth of information regarding our immediate predecessors. But molecular biologists argue that you can't tell a damn from a bone, despite an apparent agreement among all researchers that, in principle, fossils will someday be numerous enough to delineate unambiguously the true course of recent evolution. These behavioral scientists argue that the underlying reasons for evolution can be revealed only through the study of our closest living primate relative—the ape, particularly the chimpanzee.

At any rate, the consensus has it that genetic variability within a changing environment caused a rapid evolution of ratlike, insect-eating, tree-dwelling creatures of about 75 million years ago to transform paws into hands for gripping and leaping, smaller bodies into larger ones for greater protection, and to bring about the ascendancy of sight over smell for perception. The fossil record of about 40 million years ago shows that the prosimians with longer arms, dexterous hands, and binocular vision simply had a natural advantage in gathering food at the end of a branch and thereby had an increased opportunity for survival.

Even today, studies of the behavioral patterns of chimps demonstrate clearly their uncanny ability to strip leaves from a small twig, insert the twig into a termite mound, and systematically lick off the termites. Conduct of this type clearly requires not only adept manipulation, but also substantial intelligence. An increased dependence on the hands clearly has an evolutionary effect on the brain:



Helped by genetic mutations, some prosimians with frontal eyes and larger paws gained a natural advantage in reaching food at the end of a branch, thereby surviving. Binocular vision and dexterous hands undoubtedly contributed to an increase in cranial capacity—culminating in Homo sapiens*'s brain, currently used to unlock secrets of the universe.*



Australopithecus, *our immediate ancestor a few million years removed, emerging from forest into the African savanna.*

it gets bigger. Does this conceivably lead to the evolution, via continued genetic alteration, of an erect, large-brained, sophisticated, culture-oriented chimp? Theoretically, yes, if we wish to call erect descendants of the prechimp a chimp. But we don't; instead, we call the erect one that came down to the ground *Australopithecus,* and the one that stayed up in the trees eating figs a chimp. Why did one species come down to the ground? We don't know for sure. Perhaps one type of chimp hogged the figs, unwittingly encouraging the development of a ground-dwelling survivor that has eventually come, as man, to dominate the chimp and all other life on the planet.

Actually, recent fossil findings supported by radioactive studies suggest that there co-existed two distinct species of *Australopithecus* a few million years ago, a genus thought by many to represent the missing link between man and ape. Bone fragments attributed to *Australopithecus,* displaying a mixture of apelike and manlike characteristics, come in two sizes: a gracile, slender-jawed species with small molars, and a robust, heavy-jawed species with extremely large molars conducive to the eating of coarse vegetation. But the fossil record shows dramatically that there are no *robustus* findings more recent than a million years old, clearly implying that *gracile*, our immediate ancestor, expanded his brain, his capabilities, his niche, and hence crowded *robustus* right off the face of the earth.

H*omo* had emerged as a new genus of the animal kingdom. The dominant genus. But what makes man unique? The brain? No, not really. Even such primitive creatures as the paramecium and the half-inch-long flatworm possess something at one end of the body crudely approximating a brain.

In man, however, the elaboration of the brain took a decisive turn. Out of its maze of incredibly complex matter arose the gift of language, enabling us to communicate, to share ideas as well as food and shelter. Experience, stored in the brain as memory, could now be passed down from generation to generation—a new kind of evolution commenced, controlled by the brain. With it, we have created, within only the past 10,000 years or so, the great edifice of civilization, vastly extending our cerebral gifts: machines to supplement our sensory and motor capabilities; housing to augment our built-in temperature mechanisms; taboos and laws to control instinctive emotions and drives; books and computers to aid memory.

The human brain is the most complex clump of universal matter known to exist. It is the perfect example of the exquisite extent to which matter in the universe has evolved—as far as we know. Yet is it the pinnacle of cosmic evolution? Is it not possible to philosophize about coagulates of matter more intricate than the brain, more complex than a clump of matter capable of contemplating itself? But just think of it: the brain can contemplate the brain, just as we are doing here now! In short, the brain provides for us a tool, a living apparatus to reflect back upon the material universe from which that life arose. You can then ask, Where will evolution lead us? What is our future? In particular, what is the probable longevity of our civilization?

Our future, the future of the planet, is cloudy, shrouded in numerous crises, many of which threaten the continued existence of Earth civilization and perhaps Earth life itself. The steeper-than-exponential growth of population, the rapid depletion of natural resources, the apparent hell-bent desire to harm ourselves via nuclear warfare, and the genetic degeneration of our medically oriented society, among other things, will irreversibly lead either to self-destruction, if we fail to solve any one of these problems, or to a state of mental stagnation resulting from the increasing degree of regimentation and restriction of freedom necessary to solve them. Of course, stagnation implies a lack of curiosity, and one can then naturally ask: If curiosity dies, does intelligence die also?

It's important to realize that the problems we face today are not similar, even in principle, to those of previous generations. The recent exponential rise in technological achievements and the inability of society to cope with them have

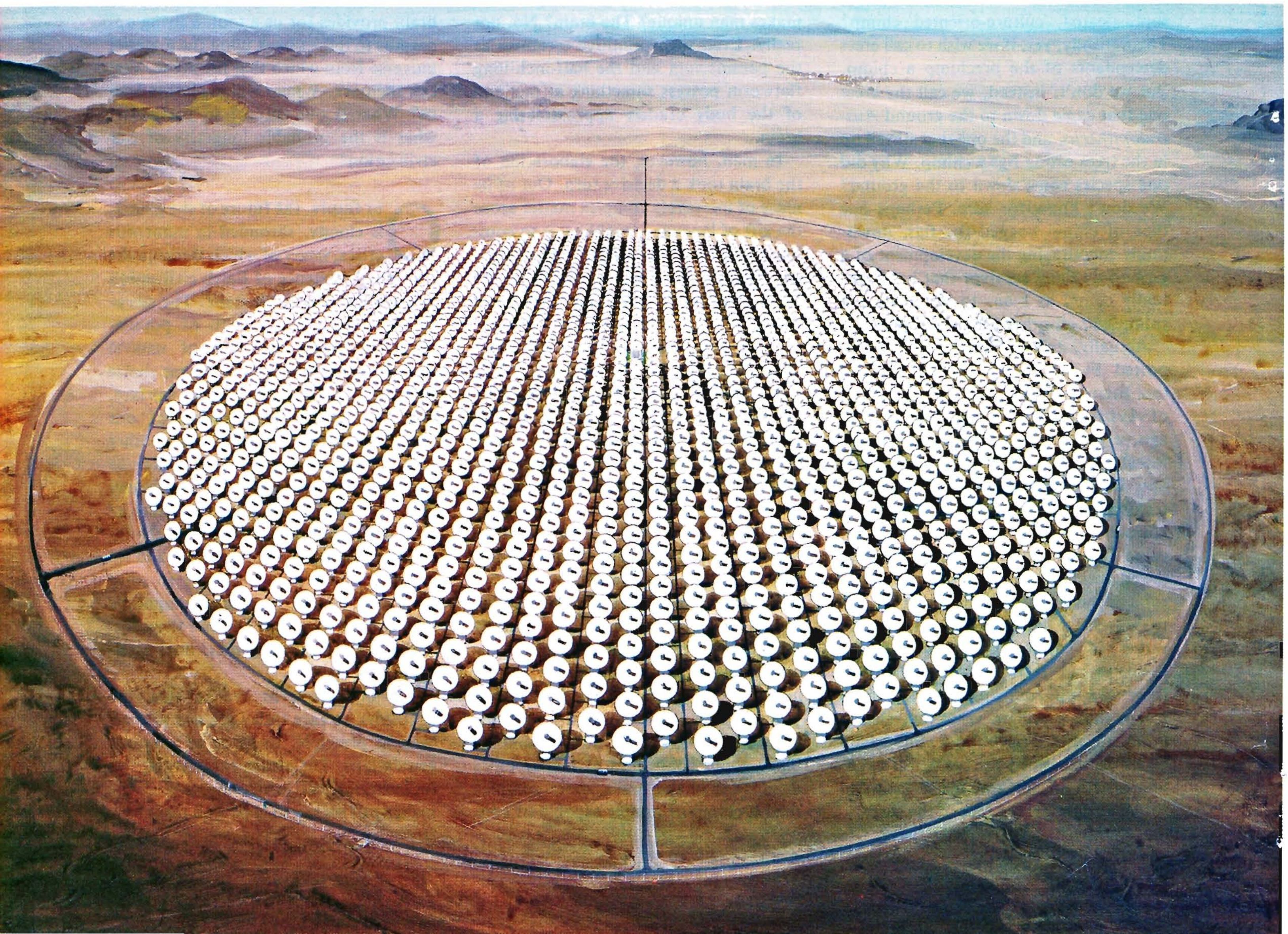
We are not independent entities, alien to Earth. The earth in turn is not adrift in a vacuum unrelated to the cosmos...

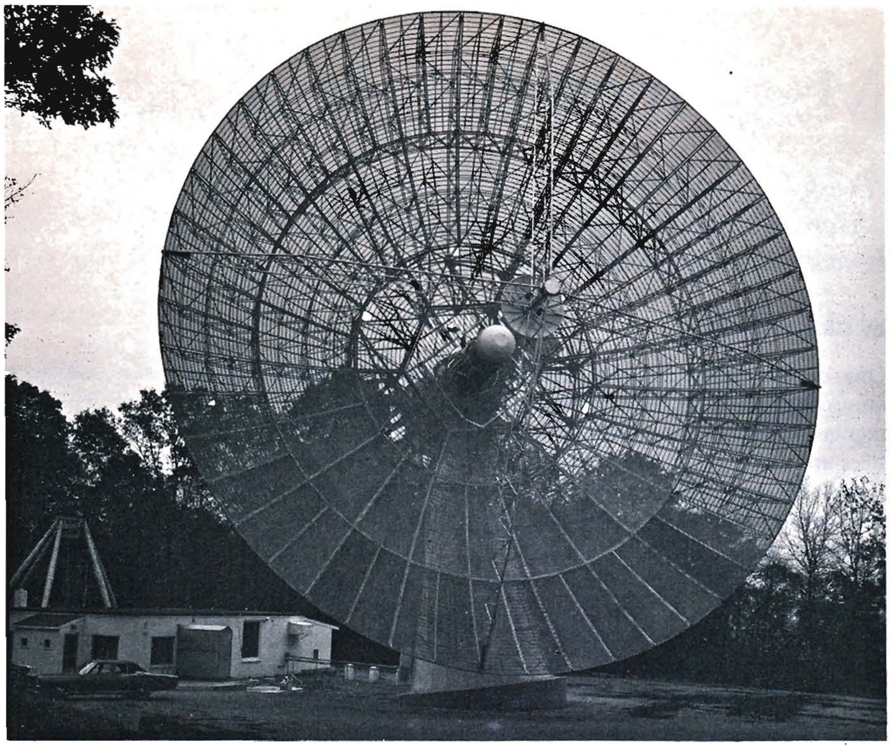
led to problems basically different from those confronting earlier civilizations. Unlike years past, we are now approaching definite natural limits that even technology of the future will not be able to overcome: we cannot communicate faster than light; we cannot travel about the earth faster than orbital velocity; we cannot solve the population problem by emigration into space; we cannot consume fuel at the rate capable of increasing the average Earth temperature by one degree and thereby melting the polar ice caps; and, with respect to weapons capabilities, we cannot be deader than dead. We are in a transition period that no Earth society has ever encountered. This is not a doomsday forecast, but a statement that social and political organizations appear unprepared to deal with the widespread changes necessary for our continued existence. Then how can we survive? Actually it's easy. We simply become more intelligent!

But can we do so rapidly enough to resolve future crises, several of which are upon us right now? Well, some researchers have suggested that the key to survival may be to strive towards a higher level of consciousness, to attempt to achieve what will probably be the last great evolutionary leap forward—making contact with extraterrestrial intelligent life and thereby entering into the community of galactic civilizations. This is not to suggest that contact itself will provide for us instantaneous intelligence (though it might), but that the very program of searching will stretch our curiosity, widen our horizons.

Remember, if the processes of cosmic evolution outlined here are valid, then they apply to every nook and cranny of

"Orchard" of a thousand radio antennas, hunting extraterrestrial intelligence in some distant star system, might look like this. Labeled "Project Cyclops," the apparatus was conceived in a design study sponsored by the National Aeronautics and Space Administration. It would be spread over a hundred-square-mile area, at a projected construction cost upwards of $10 billion.





Left: Harvard University's 25-meter (84-foot) Agassiz Radio Telescope at Harvard, Massachusetts. The author of this article is seeking federal and private funds to convert this machine—constructed in 1956, but remodeled in the Sixties—into a sensitive experimental apparatus capable of searching for extraterrestrial intelligence. The antenna could detect narrow-band transmissions from civilizations, no more advanced than the major Earth powers, near any of the 350 sunlike stars within 100 light-years of Earth.

the universe. And, although there is at present no concrete evidence for the existence of intelligent life elsewhere, straightforward and reasonable arguments can be made to justify the plurality of habitable planets within our Milky Way and other galaxies beyond. But are they inhabited? We don't know, of course.

A multinational surveillance program dedicated to the search and discovery of extraterrestrial intelligence may well be the proper program to pursue, giving us the advantage of competition and averting the danger of ultimate stagnation. Interstellar dialogue would surely enable our civilization to evolve toward heretofore unimagined heights. And, it's not inconceivable that life could evolve sufficiently to overwhelm matter, just as matter eventually overwhelmed radiation in the early universe. The destiny of matter in the universe may well be controlled ultimately by the life that arose from it. Together with our galactic neighbors, we may be in a position someday to gain control of the resources of the entire universe, restructuring the universe to suit our purposes and, in a very real sense, ensuring for our civilization a sense of immortality.

The critical consideration for us in the years ahead is this: when a civilization tries repeatedly to solve numerous crises that inevitably face an evolving society, and by solving them plunges straight towards mental stagnation—the crisis that ends all crises—will there be enough time to establish interstellar contact? Such a project obviously requires a good deal of financial enthusiasm and social commitment to sustain a search for tens, perhaps thousands of years. We may have evolved from universal matter, but our future is to a larger and larger degree in our own hands. Are we smart enough to recognize it and to act on it? Our future will truly be a measure of our current intelligence.

The philosophy that we are the product of cosmic evolution is not a new one. It may be as old as that first *Homo sapiens* who contemplated existence. But as we enter into the last quarter of the twentieth century, for the first time we can begin to identify conceptually and test experimentally some of the subtle astrophysical and biochemical processes that enable us to recognize the cosmos as the ground and origin of our existence. It's very much an interdisciplinary approach, interweaving knowledge from virtually every subject a university can offer. It's a warmer and friendlier scenario now, many parts of which have recently become substantiated by experimental science. We are not independent entities, alien to Earth. The earth in turn is not adrift in a vacuum unrelated to the cosmos. The cosmos itself is no longer cold and hostile—because it is *our* universe. It brought us forth and it maintains our being. We are, in the very literal sense of the words, children of the universe. □

For further reading

Robert Jastrow. *Until the Sun Dies*, Norton, 1977. An elementary, up-to-date examination of two great mysteries—the riddles of life and of creation.

Ronald Bracewell. *The Galactic Club*, Freeman, 1975. An entertaining consideration of Earth's chances of gaining membership in the community of galactic civilizations.

Carl Sagan. *The Cosmic Connection*, Doubleday, 1973. A qualitative survey of the prospects for detecting extraterrestrial life.

Cyril Ponnamperuma. *The Origins of Life*, Dutton, London, 1972. A beautifully illustrated examination of the scientific theory of Genesis.

Victor Weisskopf. *Knowledge and Wonder*, Doubleday, 1966. A superb but somewhat dated survey of man and his environment.

Related articles to be published in Harvard Magazine:

Steven Weinberg: "The first three minutes in the birth of our universe."

Dale F. Dickinson: "Galaxies, quasars, and the edge of time."