# THE NEW ASTRONOMY: OPENING THE ELECTROMAGNETIC WINDOW AND EXPANDING OUR VIEW OF PLANET EARTH

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# THE NEW ASTRONOMY: OPENING THE ELECTROMAGNETIC WINDOW AND EXPANDING OUR VIEW OF PLANET EARTH

A Meeting to Honor Woody Sullivan on his 60th Birthday

*Edited by*

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Cover credit:
Cosmic evolution is depicted in this image from the exobiology program at NASA Ames. Upper left: the formation of the stars, the production of heavy elements, and the formation of planetary systems, including our own. At left: prebiotic molecules, RNA and DNA are formed within the first billion years on the primitive Earth. At center: the origin and evolution of life leads to increasing complexity, culminating in intelligence, technology, and astronomers. Upper right: contemplating the Universe. The image was created by David DesMarias, Thomas Scattergood and Linda Jahnke at NASA Ames in 1986, and reissued in 1997.

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# FOREWORD

This is an unusual book, combining as it does papers on astrobiology, history of astronomy and sundials, but—after all—Woody Sullivan is an unusual man. In late 2003 I spent two fruitful and enjoyable months in the Astronomy Department at the University of Washington (UW) working on archival material accumulated over the decades by Woody, for a book we will co-author with Jessica Chapman on the early development of Australian astronomy. The only serious intellectual distraction I faced during this period was planning for an IAU colloquium on transits of Venus scheduled for June 2004 in England, where I was down to present the 'Cook' paper. I knew Woody was also interested in transits (and, indeed, anything remotely connected with shadows—see his paper on page 3), and in discussing the Preston meeting with him it transpired that his 60th birthday was timed to occur just one week later. This was where the seed of 'Woodfest' began to germinate. Why not invite friends and colleagues to join Woody in Seattle and celebrate this proud event? I put the idea to Woody and others at UW, they liked it, and 'Woodfest' was born.

The hard work involved in organising the logistics of the meeting fell into the capable hands of the Local Organising Committee, Bruce Balick, Jim Evans, Bruce Hevly (co-Chair) and Karl Hufbauer (co-Chair), while the program was addressed by a Scientific Organising Committee comprising John Baross, Ron Bracewell, David DeVorkin, Steven Dick, Ken Kellermann, Wayne Orchiston (Chair), Robert Smith, Richard Strom and Virginia Trimble. For his part, Woody became a *de facto* member of both Committees, and an excellent sounding board for our various ideas and the innumerable problems associated with organising a meeting.

Woody was also invaluable when it came to attracting speakers, particularly those in the astrobiology fold who lay well outside my own sphere of contacts. The final product was a meeting that had an almost equal mix of history of astronomy and astrobiology papers interwoven through the program, and three papers which we referred to as 'Woody indulgences', on sundials, art and the history of science. The full program is shown on pages xi-xiii. In addition, Frank Drake kindly agreed to present a public lecture, which was organised by the LOC and Linda Khandro, in conjunction with the University's Center for Astrobiology and Early Evolution.

The SOC also arranged a reception and the Conference Banquet. This unforgettable latter event was on the night of Woody's birthday, down on

the waterfront, and in addition to singing “Happy Birthday” to Woody we all joined him in a rather forgettable rendition of a number of rather forgettable Tom Lehrer songs, including “The Elements”! All in all it was a memorable night.

At the end of the Conference, some participants took part in a one-day outing to Mount Rainier. This enjoyable scenic field trip (see page xvi) was organised by the SOC.

From the start, we hoped to publish the papers from Woodfest, so it was very pleasing when Harry Blom from Kluwer (now Springer) heard about the Conference and approached us with a proposal that we could not refuse. My only regret is that most of those who presented astrobiology papers at Woodfest had already published much of their material elsewhere and so decided not to contribute to this volume. Those papers that are included are marked by asterisks on pages xi and xii.

Finally, it remains for me to thank the UW Kammeyer Fund and members of the LOC and SOC for making Woodfest happen; all those who presented papers at the conference; Harry Blom, Sonja Japenga and Kirsten Theunissen from Springer for seeing this volume safely through the press; Wolfgang Dick, Hilmar Duerbeck and Sandra Ricketts for helping me chase down those all-too-elusive references; Bruce Balick, David DeVorkin and Joe Tenn for kindly supplying photographs; and last but not least, our dear friend and colleague, the inimitable Woodruff T. Sullivan, III, for making the very concept of ‘Woodfest’ a reality. Happy Birthday Woody; these proceedings are our final—if somewhat belated—present to you. Enjoy …

**Wayne Orchiston**
*Chair, SOC*

# PARTICIPANTS

Peter Abrahams (USA)
Bruce Balick (USA)
John Baross (USA)
William Baum (USA)
Keith Benson (USA)
Ron Bracewell (USA)
Ron Brashear (USA)
Christopher Chyba (USA)
Carol Cleland (USA)
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Jim Evans (USA)
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Miller Goss (USA)
Mott Greene (USA)
Alastair Gunn (UK)
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Geoff Marcy (USA)
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Robert Smith (Canada)
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Paula Szkody (USA)
Joe Tenn (USA)
Daniel Tomandl (USA)
Virginia Trimble (USA)
Ed Turner (USA)
George Wallerstein (USA)
Peter Ward (USA)
Dan Werthimer (USA)

# ‘WOODFEST’ PROGRAM

Papers published in these Proceedings are followed by an asterisk.

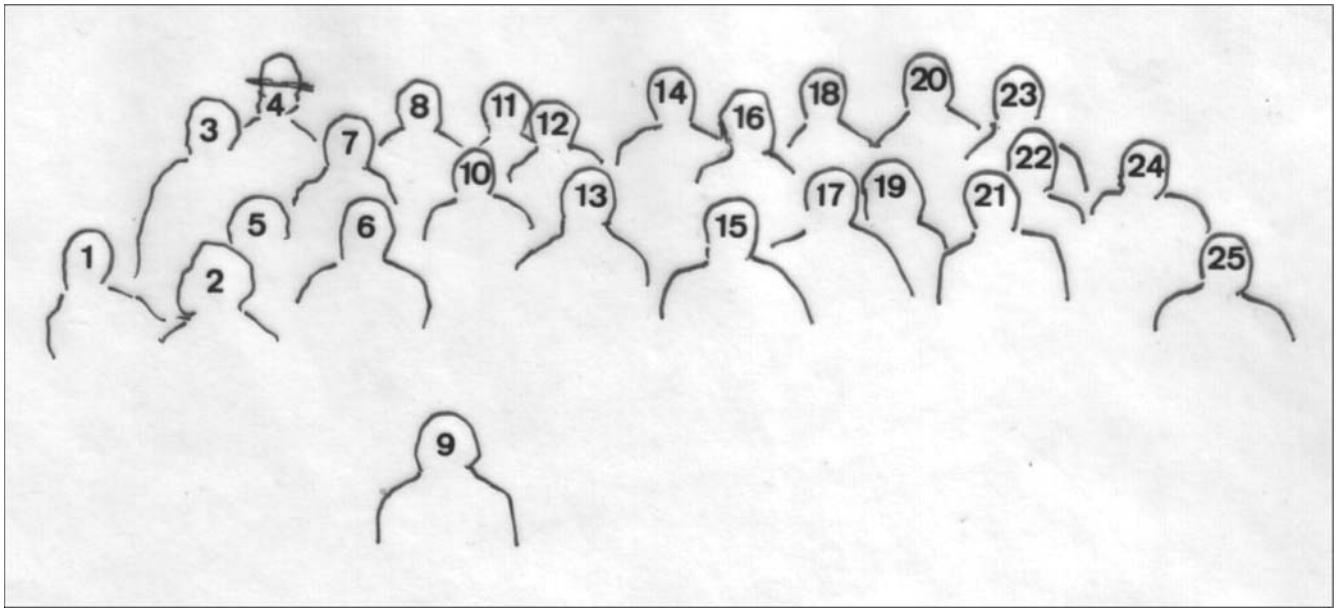
| Day | Time | Program |
|---|---|---|
| Wednesday<br>16 June | <br>9.00<br><br>9.10<br>9.15<br>9.30<br>10.00 | *Chair: Bruce Hevly & Karl Hufbauer*<br>Bruce Hevly & Karl Hufbauer: General house-keeping<br>Woody Sullivan: Welcome<br>Bruce Balick: Introduction<br>Steven Dick: “The Biological Universe revisited”*<br>Chris Chyba: “Contingency and the cosmic perspective”* |
| | 10.30 | *Morning Tea* |
| | <br>11.00<br><br>11.30<br><br>12.00 | *Chair: Robert Smith*<br>Ken Kellermann: “Grote Reber: founding father of radio astronomy and professional amateur”*<br>Alastair Gunn: “Rays, radiants and radishes: early radio astronomy at Jodrell Bank”*<br>Richard Strom: “Radio astronomy in Holland before 1960: just a bit more than HI”* |
| | 12.30 | *Lunch* |
| | <br>2.00<br><br>2.30<br><br><br>3.00 | *Chair: Steven Dick*<br>John Baross: “Parallel habitats on Earth, planets and moons”<br>Peter Ward: “A taxonomy of habitable planets: assessing the odds of life in variable planetary systems”<br>Carol Cleland: “The advent of historical science” |
| | 3.30 | *Afternoon Tea* |
| | <br>4.00<br><br>4.30<br>5.00 | *Chair: Bruce Balick*<br>Robert Smith: “The history of space astronomy: an attempt to see the big picture”*<br>Peter Abrahams: “Telescopes lofted to space”*<br>David DeVorkin: “SAO during the Whipple years: Project Celescope”* |
| | 5.30 | Reception |
| | 8.00 | Public Lecture<br>*Chair: Woody Sullivan*<br>Frank Drake: “New approaches in the search for SETI” |

| | | |
|---|---|---|
| Thursday<br>17 June | | *Chair: Ken Kellermann* |
| | 9.00 | Wayne Orchiston & Bruce Slee: "The Radiophysics field stations and the early development of radio astronomy"* |
| | 9.30 | Marshall Cohen: "Owens Valley Radio Observatory and dark matter"* |
| | 10.00 | Wayne Orchiston: "Dr Elizabeth Alexander: first female radio astronomer"* |
| | 10.30 | *Morning Tea* |
| | | *Chair: Virginia Trimble* |
| | 11.00 | Geoff Marcy: "Extra-solar planetary systems" |
| | 11.30 | Ed Turner: "Detection and characterization of extra-solar planets and plants" |
| | 12.00 | Rebecca Cummins: "Light work: contemporary artists consider the Sun"* |
| | 12.30 | *Lunch* |
| | | *Chair: David DeVorkin* |
| | 2.00 | Ron Brashear: "The transits of Venus and new astronomies: a time to reflect"* |
| | 2.30 | Bruce Hevly: "X-rays, extreme ultraviolet and the life of instruments" |
| | 3.00 | Virginia Trimble: "The origin of gamma ray astronomy: when one photon was a discovery, two was a spectrum, and three was the Rossi Prize"* |
| | 3.30 | *Afternoon Tea* |
| | | *Chair: Richard Strom* |
| | 4.00 | Jim Evans: "Gnōmonikē Technē: the dialer's art and its meaning in the Ancient World"* |
| | 4.30 | Karl Hufbauer: "Radio studies of solar phenomena, 1946-1958: their significance?" |
| | 5.00 | Richard Jarrell: "'Radio astronomy … whatever *that* is': the marginalization of early radio astronomy in astronomy"* |
| | 5.30 | *End of Session* |
| | 7.00 | Conference Banquet |
| Friday<br>18 June | | *Chair: Jim Evans* |
| | 9.00 | Mott Greene: "Astrobiology and anthropomorph-ism: are we still looking for ourselves?" |
| | 9.30 | Frank Drake: "Lessons from the history of SETI" |
| | 10.00 | Dan Werthimer: "Do we know how to search for ET?" |

| | | |
|---|---|---|
| | 10.30 | *Morning Tea* |
| | | *Chair: Wayne Orchiston* |
| | 11.00 | Bruce Balick: "Discovery of Sgr A*: an exposé"* |
| | 11.30 | Miller Goss & Ron Ekers: "The discovery of Sgr A and the almost discovery of Sgr A* in Big Pine – The impact of Galactic Center research since 1951" |
| | 12.00 | Woody Sullivan: "Points of view: shadows, planets and life"* |
| | 12.30 | *End of Conference* |

# CONFERENCE PHOTOGRAPH

Some of the Woodfest Conference participants (for identifications see the following page).




Key: 1 = Alastair Gunn, 2 = Carol Cleland, 3 = Steve Dick, 4 = Karl Hufbauer, 5 = Virginia Trimble, 6 = Joe Tenn, 7 = Bruce Balick, 8 = William Baum, 9 = Peter Abrahams, 10 = Wayne Orchiston, 11 = Marshall Cohen, 12 = Richard Strom, 13 = Ken Kellermann, 14 = Ron Brashear, 15 = Woody Sullivan, 16 = Ed Turner 17 = Bruce Hevly, 18 = Dan Tomandl, 19 = Rebecca Cummins, 20 = Richard Jarrell, 21 = Geoff Marcy, 22 = Dan Werthimer, 23 = Miller Goss, 24 = Frank Drake, 25 = David DeVorkin.

*Top:* Woody discusses the basics of sundial design. *Bottom:* The Mount Rainier excursion.

# INTRODUCTION

# POINTS OF VIEW: SHADOWS, PHOTONS, PLANETS, AND LIFE

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Abstract: I combine here a potpourri of topics that have been of keen interest over my career. The first is gnomonics, the art and science of sundials: at its heart are the *shadows* that elegantly chart the motions of the Sun on a defined surface. More broadly, shadows have been amazingly productive in astronomy through the centuries. Examples range from the ancient Greeks (the distances of Moon and Sun) to the Scientific Revolution (Roemer's determination of the speed of light). They also include twentieth century science (solar eclipse observations relative to general relativity) and current twenty-first century research (transits of extrasolar planets).

The ability to observe a shadow depends on one's *point of view*, and I have been fascinated with how our astronomical points of view have been reconstructed over time. For instance, our previous views of the Universe have been continually challenged as we have accessed new types of *photons*, i.e., the opening of the electromagnetic spectrum that began with radio astronomy seventy years ago.

Notions of what a *planet* is and how it works have been revolutionized by our capability to relocate to other planets and to look at planet Earth from the outside, as well as, over the past decade, to chart new worlds in orbit about other stars. This change is part of a long historical sequence in which we have gone from the seven planets of the ancient Greeks, to the six planets of Copernicus, to the nine planets of the mid-twentieth century to the ~150 of today.

Finally, we are in the midst of attaining an entirely new vantage point from which to surveil the phenomenon of *life*. Although still confined to one example, this astrobiologist believes that the signs augur well that life too, will eventually lose its uniqueness, just as has already happened to our Sun, our Earth, and our Galaxy.

Key words: History of astronomy, radio astronomy, shadows, sundials, extrasolar planets, astrobiology



*W. Orchiston, (ed.), The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth,* 3-12.

*For age is opportunity no less*
*Than youth itself, though in another dress,*
*And as the evening twilight fades away*
*The sky is filled with stars, invisible by day.*

Henry Wadsworth Longfellow (1874)

# 1. WHY THESE TOPICS?

The meeting from which this volume emerged was a marvelous gift to a fledgling sexagenarian. I was able to invite colleagues and friends who share my interests in history of astronomy, astrobiology, and sundials. But then how to tie together these disparate topics—were there any common intellectual threads? I (mostly) gave up on integrating sundials,[1] but the other two are central to understanding the remarkable new views of the Cosmos that have come to the fore since the middle of the twentieth century (just before I began graduate school in 1966). Are these as a whole enough to define a *New Astronomy*? Kepler wrote about a 'New Astronomy' four hundred years ago, and the rise of astrophysics in the late nineteenth century was termed a 'New Astronomy'. Have we also experienced one?

The opening of the electromagnetic spectrum has been a hallmark of astronomy's past fifty years. Trained as a radio astronomer under Frank Kerr and Gart Westerhout, I began research in the early history of radio astronomy as a sideline as I was obtaining my Ph.D. in 1971. Radio astronomy was of course only the first of many non-optical photon regimes that revealed novel phenomena and objects. Most of these windows only became possible because of the launch of the Space Age (men first walked on the Moon during my graduate school years) and the concomitant capability of sending telescopes and detectors above the Earth's atmosphere.

Simultaneously, the quest for extraterrestrial life entered a new phase with the invention of SETI in 1959-1960 and NASA's support for an exobiology initiative that culminated with the Viking mission to Mars in 1976. I became involved in SETI in 1977, which in turn opened up for me questions of the origin and evolution of life and intelligence. Eventually this all led to another NASA-led field in the mid-1990s, *astrobiology*, which has grown spectacularly, fueled by discoveries of extrasolar planets, a water ocean under the ice of Europa, putative evidence for life in a Martian meteorite, solid evidence for liquid water in the past on Mars, extremophile microorganisms that survive in an amazing range of conditions here on Earth, and new insights into the origin and early history of life on Earth. It is fun to think that the excitement that I experienced in the emerging years of

astrobiology must be akin to that felt by the early radio astronomers of half a century ago.

Carl Sagan, a man whom I very much admired, used to say we needed a "cosmic connection", that we should take on a "cosmic view".[2] I try to instill this in students. I believe that astronomers and other physical scientists indeed today have very different cosmic views than they did a half century ago. Steve Dick is right (see his paper in this volume)—a new Biological Universe has been spawned, one in which the phenomenon of life is integrated into the evolution of the Universe from the Big Bang onwards. And this is not only affecting astronomers, but also causing a profound change in many biological scientists; they now look at life as a phenomenon whose characteristics (as studied on Earth) are potentially only a starting point for how life might develop elsewhere. Our *point of view* toward our planet and ourselves has been radically altered. Note that this shift is independent of (and before) any discovery of actual extraterrestrial life. Sagan would have been delighted with how the past decade has played out.

## 2. SHADOWS IN ASTRONOMY

I have been fascinated with shadows ever since I fell into the world of sundials and gnomonics in 1992.[3] Shadows generally have a negative connotation (dangerous shadows, plotting in shadows, chasing shadows, being in someone's shadow), but I love them. Philosophers debate their ontological status ("Is the absence of light something in itself?"), but they are real. There is no doubt that one's perception and experience of a shadow depends on point of view.

A well-designed sundial can have a profound aesthetic and contemplative effect on viewers, even in this high-tech new millennium. Although stationary (no moving parts!), it records fleeting time in a timeless manner. Its surface is a marvelous projection of the celestial sphere, written by a 'shadow-pen'. Although passive in character, it speaks strongly: of the Sun, of the Cosmos and our place in it, of time and its passing, of history and mortality.

Although sundials have been obsolete as timekeepers for two centuries and of no importance in astronomy for twice as long, shadows more generally have continued to be vital in assembling our present picture of the Universe (see Casati, 2003). An incomplete list of major astronomical episodes in which shadows have been central includes:

- Aristotle: Earth's shadow on the Moon during a lunar eclipse → Earth is a sphere
- Ancient China, Egypt, Mesopotamia, Greece: shadows of vertical rods (gnomons) establish accurate measurement of seasons, latitude, and time (most famous is Eratosthenes' third century BC measurement of the Earth's circumference)
- Aristarchus (third century BC): lunar phases and lunar/solar eclipses → shape and distance of the Moon, distance to the Sun
- Galileo (AD 1610): Venus' phases; height of lunar mountains
- Rømer (1676): eclipses of Jovian satellites → speed of light
- 1761 through 1882: solar transits of Venus[4] → length of the astronomical unit
- total solar eclipses over centuries → secular slowdown of Earth's rotation, geophysics of tides, and chronology/provenance of historical documents
- early twentieth century: eclipsing binary stars → masses and sizes of stars
- 1919 onwards: total solar eclipses → evidence for general relativity
- 1963: lunar occultation of radio source 3C273 → optical identification with highly red-shifted object (the first quasar)
- 1999 onwards: transits of extrasolar planets in front of host stars → sizes and densities of the planets

# 3. NEW ASTRONOMIES

## 3.1 New Photons

New kinds of photons have been detected only because of new tools—collectors and detectors, and rockets to lift them above our opaque atmosphere. The interdependence between technology and scientific discovery is an old story. For instance, Galileo (1610) says in the opening words of his *Sidereus Nuncius*: "I propose great things for inspection and contemplation ... great, I say, because of the excellence of the things themselves, because of their newness … and also because of the instrument [his 20× telescope]."

Although the Sun, Moon, and bright stars had been observed in the infrared before World War II, the results were limited and did not lead to wholly new classes of astronomical objects. There was no field of infrared astronomy *per se*. The study of extraterrestrial *radio* waves over the decade 1945-1955, however, led to a revolution in how we viewed the Cosmos. The practitioners were not astronomers, yet they remade astronomy, reporting

new photons distributed over the sky in a manner corresponding not at all like optical photons. By the late 1940s they called themselves radio astronomers and said they were doing *radio astronomy* (which by the way soon necessitated the new term *optical astronomy*). This was indeed a New Astronomy, but succeeding decades showed that it was just the first of many to follow as rockets and satellites opened up unexplored ranges of photon energy: X-ray,[5] infrared, ultraviolet, and γ-rays.

These New Astronomies have profoundly changed our cosmic outlook. Because we have explored the limits of photons, we may think that no further New Astronomies remain. But this is short-sighted, for why should new 'windows' be confined to the electromagnetic spectrum? I imagine that over the *next* fifty years we may well see a comparable revolution as we sensitively map the sky in neutrinos, gravitational waves, dark matter, dark energy, 'quintessence' (how Aristotelian!), etc.

## 3.2 New Planets

A seminal event in the emerging field of astrobiology was the first detection of a 'normal' planet orbiting a 'normal' star (Mayor and Queloz, 1995). Most astronomers certainly already believed at that time that planetary systems occurred around other Main Sequence stars, but there is nothing like the *reality* of an actual detection to solidify one's thinking, in this case, that we may not be unique.

Similarly, in the remarkable, small volume *The Nature of the Universe* Fred Hoyle (1950) argued that the reality of the first photograph of the Earth from outside would transform how we think of ourselves—people would gain a visceral appreciation, not just intellectual knowledge, that the Earth is a planet. And he was proved right when in 1968 humans (Apollo 8 astronauts) for the first time saw the entire Earth as a small ball, and indeed could cover it with a thumb at arm's length. Spaceship Earth and the iconic image of a blue/white/brown planet became a reality. And this was not just abstruse knowledge—it also had *practical* consequences: the Full Earth image importantly contributed to the young environmental movement (e.g., the first Earth Day was in 1970).

Stepping back farther, we gain a better point of view on the magnitude of today's dawning era. The ancients had *seven* wandering planets (Moon, Sun, Mercury, Venus, Mars, Jupiter, and Saturn). Copernicus changed the number to *six*, tossing out the Sun and Moon, but adding in the Earth. Over the next four hundred years the number of planets slowly grew to *nine*,

although only with the Apollo missions did we for the first time truly appreciate the Earth as the ninth. Now we have about *one hundred and fifty* extrasolar planets, exhibiting a remarkable range of properties. Future prospects seem limitless.

## 3.3 New Life

Astrobiology is sometimes derided as a science without a subject to study. But this misses the point. Completely independently of actually finding extraterrestrial life, astrobiologists are looking in entirely new ways at terrestrial life, life as we know it. Motivated by wanting to know where and how to look for *extraterrestrial* life, we gain novel insights into the origin and evolution of *Earth's* life, the extremes under which that life can thrive, and the biochemistry of that life.

Whether focused on microorganisms or intelligent life, astrobiologists are not willing to accept the assertion that life has happened only once and in only one place. Since we do not know how rare 'Good Planets' are, we take the empirical approach: it's a fundamental question, we have a powerful set of tools to attack the problem, today's best evidence points to exciting possibilities, and so let's look! Astronomers who used to have little interest in biology and biologists who had been even less concerned with the Cosmos, are now talking to each other in ways that were rare a decade ago. And the same goes for all the other specialties that contribute to astrobiology: geology and geophysics, paleontology, evolutionary biology, biochemistry, atmospheric sciences, genomics, oceanography, etc. Ever since its founding in 1998, the University of Washington graduate program in Astrobiology has endeavoured to foster these conversations by breaching disciplinary walls to overcome academia's typical balkanization of knowledge. This in itself I find tremendously exciting and stimulating—for me it's like being a graduate student all over again!

Of course I do not know whether evidence of extant life or fossil life will be discovered soon … or ever. But I am convinced that it is unlikely and that the pursuit of such a discovery is fundamentally valuable.

# 4. IS THIS REALLY A SPECIAL TIME?

There is a tendency for every generation (at least over the past century or two of rapid change) to look upon its own time as unprecedented in its accomplishments and challenges. And yet a long historical view does reveal

certain epochs when the term 'New Astronomy' is apt, and sometimes is even used by the participants themselves. Ron Brashear discusses several of these in his paper in this volume, beginning with Kepler's fundamentally new *physical* Universe, as enunciated for example in his 1609 book *Astronomia Nova*. Much later we find a counterexample when in 1761 C.F. Cassini (III) exclaimed about his era: "Happy our century! to which is reserved the glory of witnessing the one event which will render it noteworthy forever in the annals of the sciences!" (cited in Sheehan and Westfall, 2004: 141). Cassini was excited about prospects that the upcoming transits of Venus would accurately determine the scale of the Solar System. But today we consider his assessment exaggerated, just as future historians may disagree with my feeling that the past fifty years have fundamentally altered astronomy.

Continuing onwards, John Herschel in 1852 wrote to Faraday regarding the newly discovered correlation between solar activity and changes in the Earth's magnetic field: "If all this be not premature we stand on the verge of a vast cosmical discovery such as nothing hitherto imagined can compare with" (Meadows, 1984: 8). This coincided with the start of an era when another New Astronomy, fueled by photography and spectroscopy and eventually called *astrophysics*, overtook visual and positional astronomy.

Trying to be objective, I nonetheless conclude that my generation has experienced a special epoch that ranks well with previous ones. A nexus of politics and technology made the post-World War II decades the trigger—Otto Struve (1960) talked about "astronomers in turmoil". And the era was defined not just by a single area, but the confluence of several: the ability to do science and exploration in space and on other planets, the opening of the electromagnetic spectrum, new cosmological understanding of the Universe (not discussed in this paper), and finally, and perhaps most profoundly, the incorporation of life into the central arguments of the previously 'dead' world of astronomy and space science.

## 5. A FINAL REFLECTION

Despite my involvement in SETI for over twenty-five years, I think it highly *un*likely that we'll detect an ETI signal in my lifetime. But we have the tools and should do the searches—one has to start somewhere. The real value of the SETI enterprise to me, regardless of any direct success, is that contemplation of *Them* ineluctably leads to thinking about *Us* in wholly different ways. This is equally true for astrobiology, although the discovery

of microbial extraterrestrial life would likely have less impact on society as a whole. Astrobiology makes us see ourselves as a particular carbon/water/DNA-based form of life that has given rise to one technological species and a vast array of other species on a small, rocky, ocean-covered, thinly-veiled planet near a middle-mass star. Politically speaking, I think that this enhanced appreciation of commonality can only be helpful as we struggle towards a world society at peace (see Chris Chyba's paper in this volume).

This reflexive mode has been nicely expressed by Adrienne Rich (1975):

> Is any light so proudly thrust
> From darkness on our lifted faces
> A sign of something we can trust,
> Or is it that in starry places
> We see the things we long to see
> In fiery iconography?

In a similar vein, at the meeting upon which this volume is based, Mott Greene made arguments at once compelling and provocative that modern SETI and astrobiology are engaged in a scientific search for a twenty-first century version of God, with characteristics largely a reflection of our own. He aptly ended with Edward Young's famous line: "An undevout astronomer is mad" (from *Night Thoughts*, 1741). I agree that astrobiology is both a scientific and a spiritual quest.

Notwithstanding today's astonishing scientific progress, we must also not forget how little we know. I close by returning to shadows and recalling Plato's allegory of the cave in *Republic.* The denizens of the cave could study the shadows on the cave wall and come to many logical, empirical conclusions, but the 'true' phenomena forever remained beyond their ken. I sometimes think that we too are at such a primitive stage in our understanding of the Universe (not to mention how humans behave). Hence the motto I chose for the University of Washington sundial:

*What you seek is but a shadow.*

## 6. SPECIAL THANKS

I too thank all of the people that Wayne Orchiston mentions in the Foreword, especially the SOC and LOC and of course, Wayne himself, who put in a tremendous amount of skillful work for the meeting itself, as well as

in editing this volume. I will never forget Woodfest, for which my colleagues and friends travelled from afar and gave of their valuable time to honor me with a first-rate intellectual feast. There was also a great *physical* experience for about ten of us who hiked up to the Carbon Glacier at Mount Rainier the day after the meeting.

Thanks also to Linda Khandro, Vickie Graybeal and Pat Taylor for logistical help, and to Ester Baum and Linda for music at the banquet and reception. Finally, my wife Barbara helped out with many arrangements for the social side of the meeting, only the latest instance of forty years of love and support in my life

## 7. NOTES

1. There is a saying, however, that deals with local solar time and is relevant to the unusual mixture of topics. The French say: *Il voit midi à sa porte*, which literally means "he sees noon from his door", implying that each observer can define his own local noon when the Sun transits his own particular longitude. The meaning of the aphorism is that "he has his own vision, his own unconventional ways", which may apply to the author.
2. Benjamin (2003: 174-203) has a nice discussion of SETI, Sagan (and others), and related religious ideas.
3. My gnomonics phase began with the design of a large wall sundial on the University of Washington Physics/Astronomy Building. Further details can be found in Rebecca Cummins' paper in this volume, and on the following web site: www.astro.washington.edu/woody/sundial_tour.html
4. The next transit of Venus occurred 122 years later, on 8 June 2004, just one week before the meeting upon which this volume is based; I was thrilled to see it from Marseille, France. In another coincidence, the first day of the meeting was the centennial of Bloomsday, the day in Joyce's *Ulysses* of Leopold Bloom's peregrinations around Dublin.
5. *Solar* X-ray astronomy began just after World War II, but the field did not expand until Galactic sources were first detected in the early 1960s. Ultraviolet astronomy had a similar story.

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# ASTROBIOLOGY

# THE BIOLOGICAL UNIVERSE REVISITED

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Abstract: Cosmic Evolution has been seen as leading to two possible world views: a physical universe in which life is rare or unique to Earth, and a biological universe, in which the processes of cosmic evolution commonly end in life. These two worldviews now hang in the balance, in the same way that the heliocentric and geocentric worldviews were in the balance four hundred years ago when Galileo wrote his *Dialogue on the Two Chief World Systems* (1632). Astrobiology is the science that will decide which of the two modern astronomical worldviews is true. A third world view, the postbiological universe, is also possible and deserves more discussion. The confirmation of one of these worldviews will have profound implications for human destiny.

Key words: artificial intelligence, biological universe, cosmic evolution, cultural evolution, Drake Equation, postbiological universe, Shapley

## 1. INTRODUCTION

Almost ten years ago I documented the twentieth century history of what I described as a major cosmological worldview, the biological universe—the idea that the universe is full of life (Dick, 1996). In this paper I want to revisit that claim, and suggest there is another possibility beyond the biological universe. To put it another way, I want to claim that cosmic evolution harbors at least three vastly different possibilities for the universe. The ultimate product of cosmic evolution may be only planets, stars and galaxies—a *physical universe* in which we are unique or extremely rare. By contrast cosmic evolution, through biological evolution, may commonly result in life, mind and intelligence, an outcome that I term the *biological*



*W. Orchiston, (ed.), The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth,* 15-26.

*universe*. Finally, there is another possibility not often discussed, but that I wish to argue needs to be taken seriously. Taking a long-term view, cultural evolution on other planets may have already produced artificial intelligence, constituting a *postbiological universe*.

Seen within this framework, these possible outcomes are not just speculation—they are the result of taking cosmic evolution seriously in all three components of the Drake Equation: astronomical, biological and cultural. Just as the outcome of astronomical evolution was once speculative, and just as the outcome of biological evolution in the universe still is speculative, so the outcome of cultural evolution is also speculative—even on Earth. But given the existence of extraterrestrial intelligence, the fact of cultural evolution beyond Earth is not speculative, and must be taken into account.

## 2. COSMIC EVOLUTION: THREE POSSIBLE OUTCOMES

Because cosmic evolution is the basis of my claims, I want to elaborate briefly how we came to the idea of cosmic evolution. A century ago, it is safe to say, cosmic evolution was not the accepted worldview. The worldview of that time was graphically captured in A.R. Wallace's volume on the plurality of worlds (Wallace, 1903). Wallace, co-founder with Darwin of the theory of natural selection, argued that the universe was only 3,600 light years in extent, a common view at the time. He noted how all the conditions for life on Earth had to be just right—the same kind of arguments recently used to claim that Earth-like planets are rare (Ward and Brownlee, 2000). Wallace concluded that humans were alone in the universe, that the Solar System was nearly at its center, and that humans were its ultimate purpose. Despite all the contributions he made to the study of biological evolution on Earth, Wallace believed in the physical universe, not a biological universe. And it was devoid of cosmic evolution in any significant sense.

A century later our view of the universe has immensely enlarged. We now know that the universe is about 13.7 billion light years in extent, and full of galaxies, as graphically captured by the Hubble Space Telescope. And size has not been the most important change in our ideas about the universe over the last century. We now detect not only the expanding universe, but also the accelerating universe; we also know about space-time, inflationary cosmology, and dark energy. But arguably no concept has been

so radical as cosmic evolution, which encompasses all these new concepts, and in fact embraces all we know about the universe. Despite his belief in biological evolution, Wallace's universe was static. Ours today is evolving, and cosmic evolution is the guiding principle for all of astronomy. Thus, in contrast to a century ago, we can speculate on the destiny of life—on Earth and in the universe—based on what we now know about cosmic evolution.

The intellectual basis for this guiding principle of cosmic evolution had its roots in the nineteenth century when a combination of Laplace's nebular hypothesis and Darwinian evolution gave rise to the first tentative expressions of parts of this worldview (Dick and Strick, 2004). But cosmic biological evolution first had the potential to become a research program in the 1950s and 1960s, when its cognitive elements had developed enough to become experimental and observational sciences, and when the researchers in these disciplines first realized they held the key to a larger problem that could not be resolved by any one part, but only by all of them working together. Harvard College Observatory Director, Harlow Shapley, was an early modern proponent of this concept, which he spoke of in the 1950s in now familiar terms. The Earth and its life, he asserted, are "… on the outer fringe of one galaxy in a universe of millions of galaxies. Man becomes peripheral among the billions of stars in his own Milky Way; and according to the revelations of paleontology and geochemistry he is also exposed as a recent, and perhaps an ephemeral manifestation in the unrolling of cosmic time" (Shapley, 1958). Shapley (ibid.) went on to elaborate his belief in billions of planetary systems, where "… life will emerge, persist and evolve." Shapley's belief in life was unproven then, and remains to be proven today. The transition from belief to proof is tantamount to discovering whether cosmic evolution commonly ends with planets, stars and galaxies, or with life, mind and intelligence. Put another way, does cosmic evolution produce not only a physical universe, but also a 'biological universe'? In recent years, Joann Palmieri has even found that Shapley in his correspondence used the term 'biological universe', unbeknownst to me when I titled my book *The Biological Universe* (see Palmieri, 2001).

Already as the Space Age began, then, the concept of cosmic evolution—the connected evolution of planets, stars, galaxies *and* life—provided the grand context within which the enterprise of exobiology was undertaken. The idea of cosmic evolution spread rapidly over the next forty years, both as a guiding principle within the scientific community and as an image familiar to the general public (Chaisson, 1981; Reeves, 1981; Sagan, 1980). NASA enthusiastically embraced, elaborated and spread the concept of cosmic evolution from the Big Bang to intelligence as part of its SETI and