

The Observer

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Jill Tarter asks "Are we alone?" ... stay tuned

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Early Career (Page 4)

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Science as a "Contact" Sport: Experiences of a SETI Researcher

Jill Tarter

Director, Center for SETI Research,
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Adapted from a plenary talk given at the 2008
Sigma Pi Sigma Congress,
Fermi National Laboratory, November 6, 2008

The Cosmos is vast and significant. Questions it raises for us today include:
How and when did our universe start?
How will it end?
Are there other universes?
How did galaxies, stars, and planets form?
Where did we come from?
Are we alone?

The numbers argue against our being alone. There are about 100 billion galaxies in the observable universe, with hundreds of billions of stars in each. Thus there are at least 10^{22} stars in the universe—more stars than grains of sand on the beaches of Earth!

Life as we know it is a *planetary* phenomenon. How much habitable real estate exists within our solar system? Candidate bodies, besides Earth, include Mars, our Moon, and the Jovian Galilean moons Europa, Ganymede, Callisto, and Enceladus. Europa, for instance, evidently has an ocean of water many miles deep. Mars may have water permafrost. How many planets and moons exist beyond our solar system?

We know that other stars have planets. So far we have found over 315 extrasolar planets. 272 stars—and 3 pulsars—have known planets. Most of the detections are indirect, by Doppler-



SPS Associate Zone Councilor Danielle Wedde, University of Rochester, (right) presented Plenary Speaker Jill Tarter (left) with Honorary Membership in the physics honor society Sigma Pi Sigma following Tarter's talk at the Society's 2008 Quadrennial Congress.

detected radial velocity measurements, astrometry, or gravitational lensing of the host star's light by the planet's gravity. The star HD40307 has three "super-Earths" with masses of 4.2, 6.9, and 9.2 Earth masses. Detecting Earth-size planets around other stars is the task of the Kepler and Corot satellites. Good planets are hard to find. How close a twin of Earth is needed to find life similar to what we know? Astrobiology tries to answer this question.

Microbes deserve our respect because they are the simplest forms of life. They form the foothold of life in a given environment. Microbes on our planet can thrive in boiling battery acid, within ice, at temperatures as high as 130° C, and



This is the Very Large Array in its tightest configuration
Photo by DEN.

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About the Cover

Dr. Jill Tarter, Director of the Center for SETI Research at the SETI Institute, is pictured at the Allen Telescope Array in northern California. Many people are now familiar with her work as portrayed by Jodie Foster in the movie *Contact*.

Photo courtesy of The SETI Institute



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without any light. They can survive ultraviolet light, radioactivity, high salinity, and high pressures. Such a wide range of microbial environmental tolerance presents many possible habitats for the origins of life.

The Search for Extra-Terrestrial Intelligence (SETI) seeks habitable worlds revealed through the deliberate actions of their inhabitants. However, microbes do not send signals that make their remote detection feasible, so “SETI” is a misnomer. The search for extraterrestrial intelligence is really the search for extra-terrestrial *Technology*. For us to detect extraterrestrial *intelligence*, we must detect the electromagnetic signals emitted by intelligent beings with their technology. For this purpose we can take a “left brain/right brain” approach. The left brain approach searches other planets for analogs of terrestrial technology, such as television broadcasts, perhaps from a “21st Century Earth on steroids.” The right brain outlook tries to imagine *all* possible artifacts of advanced technologies and what signals might reveal them, akin to “Terra-Incognita” in science fiction. The left brain outlook offers the possibility of yielding significant null results, ruling out specific hypotheses. The right brain approach suggests that we should keep our collective astronomical eyes and minds open!

How does one search for “ET,” the “Extra-Terrestrial”? Movies allow us to encounter other civilizations in imagination. The movie *Contact* (with Jodi Foster) holds some features in the search that are about the closest to reality that we can expect from movies so far. However, as good as *Contact* was, it wasn’t perfect. For instance, headphones are not used to search for signals; no walkie-talkies are allowed at radio observatories; script writers can’t do math: $10^{11} \times 10^{-18} \neq 10^6$; Kent’s last name is Cullers; the writers forgot the champagne... But let all that pass. More important, *Contact* treated with respect the search for extra-terrestrial technology and intelligence, as well as the scientists who perform the search.

We must try to imagine and discover ways that ET’s technologies reveal themselves in the observable universe. We might look for ET’s spacecraft, or signals from ET’s communication and power generation. We can’t go to ET’s home any time soon, and the detection of alien spacecraft, or other artifacts requires improbable astronomical serendipity. If somebody tells you they are already here, demand proof and examine it skeptically! When I’ve done that, I’ve been underwhelmed by the lack of evidence. This leaves the detection of signals. If ET resides beyond our solar system, for the foreseeable future we can only make remote observations. Given the vast interstellar distances, electromagnetic signal detection offers the most promise. Whether they are sent deliberately or come to us as incidental leakage, such signals must be easy to transmit and receive. They would travel over vast interstellar distances through “empty” space, so we must understand the effects of galactic magnetic fields and fluxes of charged particles on such signals.

Martin Harwit’s *Cosmic Discoveries* documents the grand astronomical tradition of building a new instrument to open a new cell of ob-

About Jill Tarter

Astronomer Jill Tarter is Director of the SETI (Search for Extraterrestrial Intelligence) Institute’s Center for SETI Research and also holder of the Bernard M. Oliver Chair for SETI. She has devoted her career to hunting for signs of sentient beings elsewhere, and almost all aspects of this field have been affected by her work.

Jill led Project Phoenix, a decade-long SETI scrutiny of about 750 nearby star systems, using telescopes in Australia, West Virginia, and Puerto Rico. While no clearly extraterrestrial signal was found, this project was the most comprehensive targeted search for artificially generated cosmic signals ever undertaken. Jill currently serves on the management board for the Allen Telescope Array, a massive new instrument that will eventually comprise 350 antennas, each 6 meters in diameter. This telescope will be able to greatly increase the speed, and the spectral range of the hunt for signals from other distant technologies by orders of magnitude.

Jill is committed to the education of future citizens and scientists. Beyond her scientific leadership at NASA and the SETI Institute, Jill has been actively involved in developing curriculum for children. She was Principal Investigator for two curriculum development projects funded by NSF, NASA, and others. In recognition of her valuable contributions to physics and astronomy, Dr. Tarter was presented with honorary membership in Sigma Pi Sigma, the physics honor society, following her plenary talk at the Society’s Quadrennial Congress.

TED Prize

Imagine being granted one wish in support of your greatest passion. That is what the TED (Technology, Entertainment, Design) Prize makes possible. The TED Prize is designed to leverage the TED community’s exceptional array of talent and resources. It is awarded annually to three exceptional individuals who each receive \$100,000 and, much more important, the granting of “One Wish to Change the World.” After several months of preparation, they unveil their wish at an award ceremony held during the TED Conference. These wishes have led to collaborative initiatives with far-reaching impact.

Jill Tarter’s “One Wish to Change the World”

“I wish that you would empower Earthlings everywhere to become active participants in the ultimate search for cosmic company.”

Jill’s TED Prize Plan

To assemble a group of engineers to advise on and create a system to facilitate mass collaboration over the web and incorporate innovative data processing methods, including the ability to input alternative search algorithms. The aim would be to tap into the power of open-source initiatives, to globalize the search for extraterrestrial intelligence, and empower a new generation of SETI enthusiasts. We would back the launch of this new system with a major storytelling and awareness campaign whose goal is to inspire millions to participate.

Learn more about Jill’s wish, follow her TED Prize blog, and offer help at www.tedprize.org/jill-tarter/

TED Prize information courtesy of www.tedprize.org

servational phase space and remarkably often discovering something totally unexpected. For example, the development of radio telescopes led to the discovery of pulsars (first whimsically called “LGMs” for “little green men”). [See the article in *Radiations* (Fall 2004 issue) by the discoverer of “LGM,” Jocelyn Bell-Ed.] In searching for advanced ET technology, we should remember Clark’s Third Law: “Any sufficiently advanced technology is indistinguishable from magic.” Thus, we should not try to predict magic—we just perform all the astronomical observations we possibly can!

Naturally occurring objects in the universe emit radiation at wavelengths across the electromagnetic spectrum, the distribution depending on the source’s temperature. For example, the radiation emitted by stars include the optical wavelengths, but clouds of hydrogen gas emit only long-wavelength radio. The problem for SETI searchers is to distinguish artificial radio signals from natural astrophysical ones. Encouragingly, we are getting pretty good at teaching our computers to find the certain types of artificial signals in noise. The bad news is that we might not be

asking the computers to find the right kind of signal.

Deliberately sent signals might appear clearly engineered [imagine a star fifty light years from us receiving right now a 1959 broadcast of “I Love Lucy”-Ed.], but other types of artificial signals might appear almost natural. These artificial beacons would have to be distinguished from natural pulsars, blinking stars, or natural transients in some subtle way.

We have some practice at detecting remotely engineered signals. We are still receiving signals from the Voyager 1 space probe as it makes its way out of the solar system. We have received its 8.4 GHz carrier signal even though it’s about 106 AU from Earth, near the heliopause that separates our local “solar weather” due to the Sun’s magnetic field from the interstellar medium.

SETI searches to date include “SETI@home” where your computer can analyze downloaded radio signal data when it goes into screen-save mode. A few other search programs are on optical and radio telescopes that provide data such as the Harvard OSETI Sky Survey,

Continued on page 7

Ralph A. Alpher's Early Career: What Kind of Physicists Were They?

by Victor S. Alpher, PhD

Ralph A. Alpher was a co-founder of Big Bang cosmology, for pioneering calculations linking the expansion of the universe to primordial nucleosynthesis, and predicting the existence of cosmic background radiation. We are honored to have his son, Victor S. Alpher, tell us his story. This is the first part of Part 2. For Part 1 see the Fall 2008 issue.

Eisenhower Follows the Lead of Vannevar Bush and FDR

Fully informed and impressed by the contributions of basic science to the fairly rapid conclusion of World War II, President Dwight D. Eisenhower was not ambivalent about the need to fund scientists as part of an overall national defense plan. In fact, he gave virtually *carte blanche* to such contracts and funding, particularly with Lockheed and the General Electric Company.[19] Much guided missile work was done under the veil of preparing for the International Geophysical Year in 1958.[20] Although the Eisenhower administration is sometimes thought of as a quiet and restrained period of little government activity and a burgeoning domestic economy, funding of defense work in the private sector grew tremendously.

The advent of the Cold War gave further opportunity for scientific research to come under the wing of military projects. The General Electric Company and Lockheed were major beneficiaries. Nonetheless, my father was concerned about the small amount of time he had available to devote to his strong interest in cosmology (he had successfully petitioned for short period of leave to study for his doctoral comprehensive examinations in 1946). He turned down the opportunity to contribute a major chapter on "nuclear geology" for a book being assembled (despite being offered essentially "no deadline" after declining), citing the extensive demands made on his time by the military work at the John Hopkins University Applied Physics Laboratory (JHUAPL).

Military-industrial work (the "military-industrial complex" was a term of caution advanced by Eisenhower in his farewell speech to the country three days before leaving office in 1961) occupied the bulk of my father's work commitment.[21] My Dad's drafts for letters inquiring about employment opportunities also stressed the exodus of major scientists from the climate at JHUAPL, about which he offered to be more specific, off the record. The departures of Tuve and van Allen were, of course, well-known, but job-seeking efforts by others were still confidential and developing.

The importance of having an established



Figure 9. While working at Johns Hopkins University Applied Physics Laboratory, Ralph A. Alpher continued to spread the word of advancements he had made in his work on cosmology as time permitted. This spritely flyer announces an evening talk at the Philadelphia Electric Co. on March 12, 1951. Photo courtesy of Victor Alpher

scientific community prepared to work in liaison with the military-industrial complex was well accepted at the highest levels of government, a legacy we owe as much to Vannevar Bush, Director of the Office of Scientific Research and Development (OSRD) as to anyone.[22,23] My Dad benefited from this *Zeitgeist*, and had been at the center of this environment for more than fifteen years in Washington, D.C.

As a brief aside, we should consider in context the history of missile and rocket research. As one area not prohibited for development by the Treaty of Versailles at the end of World War I, Germany embraced the development of rocketry long before other countries. Its potential for weapons technology was recognized long before World War II, and the German government supported and funded its early pioneers, such as Wernher von Braun and Walter Dornberger. One of our own experts familiar with the developments in Germany concluded: "If the guided missile had not been developed as a weapon, it would have been necessary to develop it as a stepping stone to space flight"[24] (italics in original, p. 59).

There can be little doubt that the Cold War accelerated the transition to space flight, and the United States was propelled into this area once the level of German advancement was known. A good deal of the technology we take for granted

today has its origins in research funded for military and national security purposes. From my own experience, I believe that most scientists working in this arena accepted this as a necessary aspect of their research progress. However, advances also occurred at a time when these multiple uses of research were broadly and generally understood and accepted, including the employment of former enemies when it was necessary to gain an edge.[25,26]

When Dad applied for a position at the University of Iowa, his JHUAPL colleague James van Allen was working hard to be productive with limited funds, using weather balloons as launch pads for rockets, even though he had designed the successful but relatively expensive Aerobee. Two of his early hires as chairman left Iowa for the well-funded Argonne Research Laboratory west of Chicago. My dad also applied for positions at other institutions that were doing much defense work, and his *curriculum vitae* was replete with related experience. He requested a reference from Edward Teller, while also inquiring about job opportunities at Berkeley, which ran Lawrence Livermore Laboratory.

On to General Electric under Dr. Guy Suits

Dr. Guy Suits, Vice President and Director of Research and Development at G.E., was a significant person in the direction of my father's continuing career (Figs. 10, 11). Dr. Suits was very positively disposed to people like my father whose primary identity was in the basic sciences.[27] This was more consistent with Merle Tuve's attitude and contrasted diametrically with one of Tuve's significant successors at JHUAPL in the 1940s, Ralph Gibson.

During the war, Dr. Suits had also been Director of Division 15 (Radio Coordination) of the National Defense Research Committee, which was involved with promulgating for the Allies a wide range of electronic countermeasures to enemy communications. Therefore, he had seen the effects of "scientists against time" in winning World War II. Dr. Suits was on leave from G.E. from 1942 to 1945; therefore he had more than a passing familiarity with the kind of research environment my father worked in during and immediately after the war.

Perhaps more significant was Dr. Suits' deep knowledge and appreciation of the difficulty of determining the "value" of output from scientific research and the absolute necessity of giving scientists a free reign to determine their major activities, to follow their passions and hunches—even if practical, bottom-line results were not immediately obvious. Business models



Figure 10. Photograph at the General Electric Research and Development Center around 1958. Left to right: Dr. Bob Johnson, unidentified G.E. staffer, Ralph A. Alpher, and Irving Langmuir (Nobel Prize-winner and inventor of ASDIC).

Photo courtesy of Victor Alpher

developed in the leading business schools later on would not permit such philosophically driven activity of publicly owned companies. At any rate, the climate at General Electric Company Research and Development (GECRD) was quite different from that at JHUAPL.

Regarding this climate in support of research, Dr. White commented that a degree of “G.E. relevance was always shown at Program Reviews, but it could be tenuous and was not questioned.” I believe, from my own observations of my father at work during my childhood and adolescence, that he concluded during his job search of 1954-1955 that General Electric Company would provide him the most professional and intellectual freedom. This included support of community activities, which were substantial and will be addressed in my next paper. The General Electric Company had a long history of supporting a breadth of activities by its scientists.

Despite other job offers (including the Glenn L. Martin Co., from which he received an invitation to re-apply at any time), and the Knolls Atomic Power Laboratory (funded by the Atomic Energy Commission and administered by G.E.), my dad was eventually hired into a small group of specialists directed by Dr. Anthony



Figure 11. Photograph of Ralph A. Alpher in the 1970s, in his office at the General Electric Research and Development Center. Note the CRT on his desk, which was an early desktop PC.

Photo courtesy of Victor Alpher

Nerad at the GECRD, working under an Air Force Ballistic Missile Division contract. The main purpose of the contract was to study the characteristics of missiles re-entering the atmosphere after a space flight. It was hoped that they could provide support for acquisition of a ballistic missile development contract by the Philadelphia division of G.E. (Dr. Donald White, personal communication, June 7, 2008).

My dad’s long period of collaboration in cosmology with Robert Herman, then with General Motors, continued, supported by almost-daily telephone calls on WATS lines (fairly inexpensive long-distance telephone lines used primarily in industry in the 1950s through 1980s). Together, they continued to publish major theoretical papers on the early Universe, and talked almost daily until Herman’s passing in 1997. I will pick up on the parallel thread of work in cosmology and astrophysics in the next paper.

So, for the first 20 to 25 years of his career, Ralph A. Alpher worked within the burgeoning military-industrial complex, while also keeping up with developments in cosmology and astrophysics. He managed to retain his primary identity as a theoretical physicist and cosmologist. Very shortly, an observation of the Cosmic Microwave Background Radiation (CMBR) in 1964 would have a major impact on his life and career. Ironically, this probably was not the first observation of the CMBR, a subject I will take up in the third of this series of papers.

After joining Dr. Nerad’s group, a considerable amount of his written work for several years at G.E. involved magnetohydrodynamics. Magnetohydrodynamics and hypersonic aerodynamics expertise were needed to develop a protective nose cone on a ballistic missile re-entering the earth’s atmosphere. Don White had been devoted to work on shock waves using a shock tube as an experimental model, to which my father also began to contribute. Although he considers the work in retrospect highly speculative, Dr. White asserts that at the time any possible method to enhance re-entry was being considered (personal communication, June 20, 2008).

By the early 1970s, my father began to become involved in other aspects of the GECRD’s mission, including technology forecasting. He also devoted more time to professional activities, such as the funding of science education in New York State, and employment of new PhDs in physics with the American Physical Society, to which he had been elected a councillor.

My father’s long years of

work in a variety of technical areas did lead to one prominent commercial application. He and a group at GECRD received an award for the development of the first large-screen television, long before “instant replays” at sports events were expected by large crowds at professional and collegiate games (he was co-recipient of the I-R 100 Award in 1968 for G.E.’s model PD400 large screen color television projector). However, one can easily see that his major professional activities, sometimes taking a second seat to his recognition for predicting the CMBR, were probably as significant in their own way as those of any Marine who stepped on the volcanic soil of Iwo Jima. At times it seems as though I have observed the career of two physicists. Perhaps, considering Robert Herman’s own eclectic career, I have witnessed up close the work of four or five very talented men. No doubt I have had a privileged vantage point.

The scientists of Dad’s generation gladly gave a substantial portion of the time of their early careers, when the majority of scientists are most productive and original, to the service of a country during its times of greatest need for “brain power.” In retrospect, my dad had the unique opportunity to work on countermeasures to the greatest perceived threats from Germany—magnetic mines and torpedoes—and Japan—airplanes dropping air-to-surface missiles, and kamikaze airplane raids.[28] Degaussing and the proximity fuze accomplished these enormous tasks. He also worked on the development of a missile defense system that became second to none. My maternal grandfather was a Marine during World War I, and his son a naval officer during World War II. Although my father at times seemed disappointed at not having been able to obtain a Navy commission, he clearly gave service where he could possibly do it best, over at least a 25 year period. By the 1970s, he also started to receive significant recognition, belatedly, for his work in cosmology and astrophysics. Finally, by January 1, 1987, when he became Distinguished Research Professor of Physics at Union College, he could devote all of his time to these fascinating and important fields.

Acknowledgments

Without many hours of patient discussions with my father about his work and issues raised throughout his career, this paper would have suffered greatly. I can only hope it conveys the spirit of scientific inquiry and curiosity that characterized him. I would like to thank Dr. Dwight Neuenschwander for his shepherding of this project, Prof. Dr. Robert Bauer for information on the career of Dr. Robert Sauer, and my wife Tatyana for her kind support of this research and many kindnesses to my father in his later life. Also, I have profited immensely from conversations with military veterans of World War II.

Dr. Don White, who worked closely with my father at GECRD, also provided important consultation and information about their work together in Dr. Tony Nerad’s group.

Footnotes and References

[19]. Taubman, Philip. *Secret Empire. Eisenhower,*

Continued on page 15

A Student Perspective: Joint Meeting of the American Association of Physics Teachers (AAPT) and the American Association for the Advancement of Science (AAAS), Chicago, IL, February 12–16, 2009

By Jenna Smith, Rhodes College
To read Jenna's entire report, visit
www.spsnational.org/meetings/reports/2009/aapt_winter.htm.

Thousands of attendees, hundreds of presenters, tens of speakers, two hotels, one city. I was able to attend two days of the joint meeting, along with another student from Rhodes College, Lulu Li, and a Rhodes faculty member, Dr. Deseree Meyer.

After workshops and field trips to Fermilab or the Museum of Science and Industry on Friday, meeting attendees gathered to see former U.S. Vice President and Nobel Peace Prize recipient Al Gore give a special invited address. We were thrilled that we actually got seats and waited for the presentation with barely contained enthusiasm. It was only when Mr. Gore appeared on the projection screen at the front of the room that we realized we were in the overflow room! It was a little disappointing, but Mr. Gore's address was just as poignant on the screen. He presented a shortened and updated version of his *An Inconvenient Truth* presentation, which I had never seen or read before. ...

After Mr. Gore's address, the Rhodes College crew trooped over to another hotel for the AAPT/AAAS Demo Show, with demonstrations ranging from a giant Newton's Cradle to an impressive bed of nails display. Just outside the Demo Show was the SPS Undergraduate Research and Outreach Poster Session. Approximately 10 posters were presented, with topics ranging from two different experiments conducted in microgravity to an impressive display of chapter outreach by Millikin University in Peru. There was so much interest in the posters that many presenters stayed much longer than the scheduled time!

Saturday morning began with an AAPT/



View of Al Gore's address from the "overflow" room.
Photo by Jenna Smith



Vera Rubin gives her Richtmyer Address on rotating galaxies and dark matter.

Photo by Warren Hein, AAPT



Lulu Li presents her poster at the SPS Undergraduate Research and Outreach Poster Session.

Photo by Jenna Smith

AAAS Richtmyer Address by Dr. Vera Rubin on rotating galaxies and dark matter. Dr. Rubin's analysis of orbital velocity and our distance from the center of the galaxy was one of the key observations that led to the conclusion that a great amount of "dark matter" exists in the universe. She presented not only the arguments for dark matter (rotation curves of galaxies, galaxy motions in clusters of galaxies, and gravitational lensing), but also the main alternative explanation of the data (modified Newtonian dynamics). ...

Saturday afternoon included a meet-and-greet with other young physicists, a plenary about exciting research at Fermilab National Accelerator Laboratory, and the SPS Undergraduate Research and Outreach presentation session. The meet-and-greet was a great experience; I highly recommend it to other SPS members who attend national meetings. We learned quite a lot about particle physics and the goings-on at Fermilab from their scientists. I enjoyed the SPS session also. I spoke about my experience as a summer intern for SPS (something else I highly recommend to other SPS members!) and also learned from presentations on subjects ranging from pseudo-science and how to fight wrong beliefs to theoretical calculations about Berry's phase.

Even if it was the middle of February in the Windy City, I thoroughly enjoyed my time at the 2009 AAPT/AAAS Winter Meeting. I was sorry to make the trip back to O'Hare airport and back to Memphis. I learned a lot, met many great peo-

ple who share my passion for physics, and experienced the national physics community, which is part of the reason I love this field.

Reaching out to Women in Physics

Women earn less than 25% of the physics bachelor's degrees awarded in the United States each year, and less than 20% of the physics PhDs awarded each year. As of 2006, 15% of all physics PhD-granting departments had no women faculty members, and nearly 25% had only one. The representation of women in physics is lower than any other scientific field (all data from the American Institute of Physics (AIP) Statistical Research Center, www.aip.org/statistics).

In response to these disparities, the University of Southern California (USC) organized the first Conference for Undergraduate Women in Physics in 2006 to give young women the confidence, motivation and resources to apply to graduate school and successfully complete a PhD. Twenty-nine undergraduate women attended that first conference. Now fast-forward to January of 2009. This year simultaneous conferences took place at USC, Yale University, and the University of Illinois at Urbana-Champaign, with over 200 undergraduate women participating. Some highlights from the Yale conference are presented here.

Reflections on the 2009 Conference for Undergraduate Women in Physics, Yale University, January 16-18, 2009

By Eteri Svanidze, SUNY Fredonia, an SPS reporter at the meeting. To read Eteri's entire report, visit www.spsnational.org/meetings/reports/2009/cuw_yale.htm.

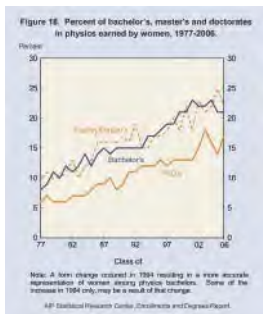
While browsing different websites in search of graduate school programs, I accidentally stumbled upon a conference for women in physics. Being the only female in my physics program, I did not have any other perspectives on the situation besides my own. It seemed to be a particularly resource-filled event, so I registered. I have seen a few women at other conferences I have attended, but I did not anticipate such a huge crowd. It was incredibly nice to meet so many women who were able to share their personal experiences.

One highlight of the conference was a panel that discussed possible careers in physics for women with doctoral degrees. Many people do not know there is such a variety of possible careers besides following the traditional academic path. It is very important for undergraduate women in science to know who may be their future employer, what to look for in a potential job, and what to expect from it. No matter what the choice, all can be equally fulfilling and rewarding.

A graduate school panel talked about how graduate school works. It was interesting to hear



Eteri Svanidze (left) and Mildred Dresselhaus (right), following Dresselhaus's lecture on nanotechnology. Photo by Filis Coba



To view data on the education and employment of women in physics in the U.S. and data on working women physicists across the world, visit the AIP Statistical Research Center, www.aip.org/statistics/trends/gendertrends.html.

of nanoscience. Current research on nanostructures is primarily concerned with possible applications, since a lot of studies have been done on their properties and characteristics. Nanostructures such as nanotubes, fullerenes and carbon strips have the potential of being useful in fields other than physics – chemistry, medicine, engineering, and many others. Talking to Dr. Dresselhaus assured me that I made the right decision regarding my future research area.

Events such as this conference actively and effectively promote physics among young women and are able to convince them not to give up their dreams. It is very uplifting to see women leading creative research and actively participating in modern scientific life. It is necessary for each female scientist to have inspiration and support from fellow scientists. It is also very important for them to know that they are not alone, that others experience similar troubles, and have the same everyday questions and concerns. After meeting so many people whom we can relate to, each one of us came back with the motivation and inspiration to do as much as possible to promote diversity in science.

from current graduate students with different backgrounds and physics experiences. One of the goals for this conference was to encourage undergraduate female physics majors to pursue doctoral study despite all of the difficulties and uncertainties.

My personal favorite was a lecture by Mildred Dresselhaus about nanotechnology. As a student, I am deeply interested in the future

As Seen Around SPS

Physicist

Because wearing pink shouldn't be a big deal

Because you can solve Schrödinger's equation in high heels

Because you played with Barbies and with trucks

Because you dreamed about what dress you'd be wearing when you won the Nobel Prize and when you got married

Because you are just as comfortable adjusting a vacuum pump or a vacuum cleaner

Because you are who you are in a field that you love

Join us for tea to celebrate women in physics!

This invitation was created for a Rhodes College Women in Physics Tea.

"Contact" Continued from page 3

the Southern SERENDIP in Argentina, the Lick Observatory, the Leuschner Observatory, and Arecibo in Puerto Rico. Additionally, of course there is the SETI Institute's Project Phoenix that observed ~1000 stars over 1 to 3 GHz using large radio telescopes around the world for more than a decade. So far we have not found anything, but the cosmic haystack is still mostly unexplored. We need a better pitchfork!

One important new "pitchfork" is the Allen Telescope Array, originally known as the One Hectare Telescope, a joint project of the SETI Institute and the University of California at Berkeley. Partially funded by Microsoft co-founder Paul Allen and former Microsoft Chief Technology Officer Nathan Myhrvold, this new instrument will give SETI observing capabilities 24/7, and it will be used for ordinary astrophysical research as well. This instrument of novel construction is being built at the existing Hat Creek Observatory operated by Berkeley's Radio Astronomy Lab in the Cascade Mountains. It features an array of inexpensive mass-produced dishes linked together. When fully operational, the array will consist of 350 antennas each 6.1m diameter, configured to be equivalent to a single 114 m dish. Each antenna features an unusual off-center feed horn that decreases the system noise and increases sensitivity (see cover). This array will speed up SETI targeted searching by a factor of 1000 compared to present reliance on the intermittent telescope time SETI receives from radio telescopes devoted mostly to other purposes. Unlike radio telescopes such as Arecibo, the Allen Array allows several stars to be examined simultaneously, at frequencies from 1 to 10 GHz, more than five times the range of the former projects. Several million stars can thereby be searched in a reasonable time, a significant advance for SETI.

The initial phase of the Allen Telescope Array has 42 dishes, is called the ATA-42, and is located in rural Shasta County in California. The Shasta County region enjoys low levels of

ground-based radio interference. Each telescope in the array features panchromatic feed and filter.

The ATA strategy is the "Commensal Targeted Search." The field of view from a 6 m dish is very large, 3.5 degrees across, at a frequency of 1 GHz. In that field we pay special attention to solar-type stars from astronomical catalogs. Other prime places to look include near the galactic center, where stars are much closer together than they are in the spiral arms.

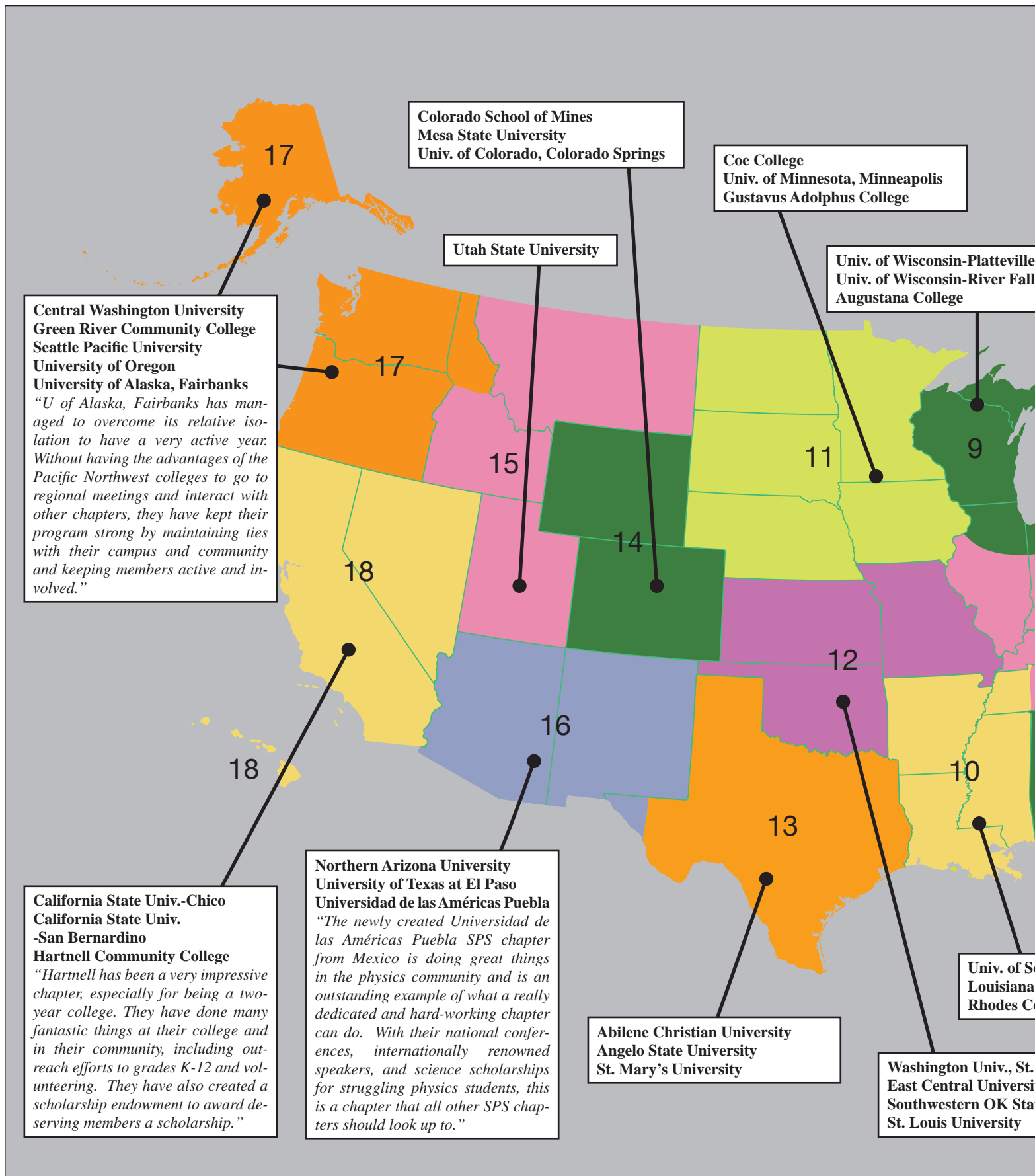
As Phillip Morrison has observed, "SETI is the archeology of the future"; a detected signal will tell us something about *their* past, but *our* future! Detection implies that it is possible for a technological society to *have* a long-term future. We are a very young technology in a very old galaxy. Another technology is more likely to be older than we are, and younger technologies wouldn't be detectable yet. If most technologies survive for only a brief time, SETI won't succeed. However, if a technological society can exist for the remaining lifetime of its host star, and broadcasts for millions to billions of years, then we may have a chance to detect their broadcasts. Such a development would suggest they have existed for timescales far longer than our own civilization, offering encouragement that our own technological society may be able to endure as long also.

When we think about *exchanging* signals with another intelligent civilization in the galaxy, assuming we are close enough together to make such exchanges meaningful, what would we talk about? What about ourselves would we want them to know? What do we want to know about them? What kinds of questions would be relevant to both transmitters and receivers, which may live in different epochs? And what kind of mirror would such contact, or such exchanges, hold up to us? One thought seems certain: The SETI mirror trivializes the differences among all humans.

In the meantime, let's stay tuned...

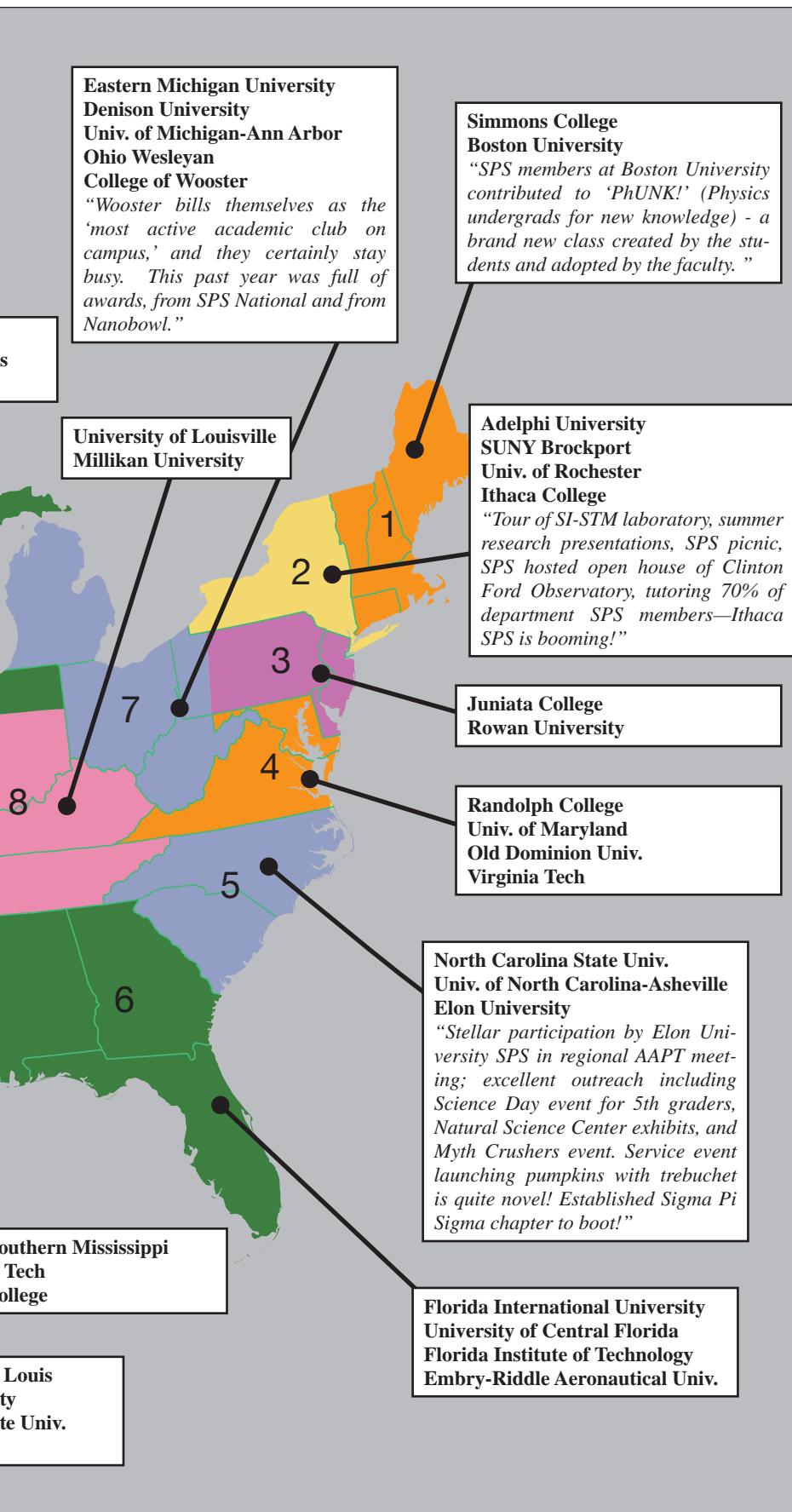
Congratulations 2008 Outsta

Award recipients are listed below by zone with selected commen



anding Chapters

tary from reviewers.



Students at Estabrook Elementary in Ypsilanti, Michigan, build balloon-powered cars to race and learn lessons about speed and collisions, with help from Eastern Michigan University SPS members.



Eastern Michigan University SPS members display "Crash Test Dummies" from the SOCK kits.



It's as easy as walking on water! The Rhodes College SPS chapter helped students explore the wonders of Oobleck and non-Newtonian fluids, in addition to their many other outreach and research events.



In addition to mentoring a robotics team, University of Rochester SPS members revel in optics related events such as a guest lecture from Emil Wolf and this laser lab tour.

Spotlight on SPS Outreach

Hosting SPS Movie Nights: From *The Trials of J.R. Oppenheimer* to *Real Genius*

By Stephen Crouch, Stevens Institute of Technology

Movie nights are a great tool for any SPS chapter to bring members together. At Stevens Institute of Technology we hold several movie nights each semester to view a physics related movie and discuss the selection afterward.



We begin our movie night with pizza and refreshments as we catch up with friends and have a chance to connect with new students. This congregation allows a great chance to relax amid the hectic schedule of a physics major. Professors and graduate students usually attend the event, and the informal atmosphere is an excellent way to build a stronger relationship with them.

Our choice of movies is far-ranging. Since starting the tradition we have watched everything from sci-fi classics like *Star Trek*, to cheesy flicks like *Chain Reaction* or *Real Genius*, to serious documentaries such as *Who Killed the Electric Car?* or *The Trials of J.R. Oppenheimer*. Our only criteria is that the movie be interesting and spark debate on the storied past, heated present, or exciting future of the world of physics. We like to start the semester with something on a sci-fi note to get everyone excited about the days ahead. Toward the middle of the semester we usually host a documentary. During finals we make a “ridiculous movie selection” full of comical disregard for physics. This helps get everyone through the dying days of the long semester.

Lecture halls are ideal locations as they have stadium seating and high-quality projectors (happy to take a break from beaming PowerPoints!) Another important consideration is when to have the movie. We find that Wednesday nights bring

out the most people. The best night for your chapter can be easily decided at a meeting. Movie nights also provide a great means of reaching out to other clubs. We found common ground with the Robotics Club in the cybernetics of *Star Trek: First Contact*, and the Philosophy Club will be joining us in April to see the mind-bending film *Waking Life*.

While we do plan field trips and other events, our SPS chapter has found that movie nights are the cheapest and easiest way to have fun as a group of physics students. All that is required is a movie, a bit of food, a movie projector, and students who like to have a good time. With a little planning your chapter is sure to have a blast. Best of luck.

SPS in the News

Science Day Brings Local Children to McMichael (Elon University)

By Margeaux Corby

Courtesy of *The Pendulum*, December 10, 2008. Reprinted with permission.

On Saturday, the serious and erudite silence of McMichael Science Building was shattered with peals of children’s laughter and the crunching sound of eggs smashing on the marble floor.

The Society of Physics Students sponsored Science Day for Kids last weekend, and nearly 20 children from local elementary schools ran around the floors of McMichael to watch various science exhibits and demonstrations.

“Part of what we want to do as a physics club is to have an educational outreach event,” said Martin Kamela, associate professor of physics. “We want to encourage children to ask questions and make sure they have a gung-ho approach to exploring science.”

Children from Elon Elementary, Hillcrest Elementary, and Marvin B. Smith schools watched and participated in the egg drop, where guests were charged with creating a casing that



A magnifying glass connected to a computer shows close-up shots of anything that is put under it. Here, children study the blown-up image of money.
Photo by Laura Bradford



Kids watch from a distance as sophomore Pierre Cieniewicz presses a button with a yardstick to complete the magnetic circuit, causing a small ring to launch into the air.
Photo by Laura Bradford

would protect an egg dropped from the third floor of McMichael’s atrium.

“That tarp was a good idea,” Kamela said. “We ended up doing crowd control and paper towel duty.”

The exhibits displayed were designed for the study abroad class GST 236: Science and Education Development that Kamela will be co-teaching in India this winter term. On the trip, students will present a traveling science center to middle school students in Kerala, India, and some exhibits from the trip were shown to the children last weekend.

Displays include a demonstration on inertia using soccer balls and bowling balls. A plastic human skeleton was hooked to a doorknob so when children turned the handle they could see how the joints in the hand, wrist, and arm moved to make simple motions.

“We wanted to show that science is cool,” said Evan Dempster, president of the society. “It may be boring in a class but there are ways to make it awesome when kids are able to explore and learn on their own.”

This is the second time the society has sponsored the science day. Kamela said they would like to make it an annual event.

“You need to encourage students to ask questions,” he said. “We need to have children be open to the field of science.”

Spotlight on SPS Outreach

Learning About Magnets, Electricity, and Acceleration at the Amusement Park

By Sarah Zielinski

Courtesy of Smithsonian Magazine-Surprising Science Blog, April 27, 2009

After mentioning the Six Flags America Roller Coaster Design Contest earlier this month, I received an invitation to Physics Day at the amusement park. I had to convince my boss I didn't intend to ride roller coasters all day (unlikely, since I get queasy riding backwards on the Metro), but then I was off to the park on a sunny, warm Friday morning last week.

A couple thousand high school (and a few middle school) students were at the park that day. Their teachers had been provided with an extensive workbook of activities for the kids—such as calculating the acceleration of the bus on their way to the park, determining angles of flight on the Flying Carousel, and calculating the power used to take students to the top of the Tower of Doom. Of course, there were plenty of roller-coaster related activities as well and there were even instructions on how to make a force meter (and, importantly, how to understand it).

In the park, college students from the Society of Physics Students and employees of the American Physical Society were on hand for demonstrations of physics concepts such as wave motion, conservation of energy, and gravity. I learned how to make a simple motor with a battery, nail, neodymium magnet, and wire.

However the seven roller coasters and other rides were the real fun. Students could wear a vest with an accelerometer that would track how fast they were moving in three axes (x, y, and z; side-to-side, up and down, and forward and backward). Once they got off the ride, the data would be downloaded onto laptops and a program called Data Studio would graph their ride. I had seen similar graphs before (they're a staple when designing rides in Roller Coaster Tycoon, once one of my favorite computer games), but I was a little surprised that the graphs were messier than the



Twenty-five SPS members from the Mid-Atlantic area joined staff from the national office to conduct outreach activities at Six Flags America's Physics Day. Photo by Matthew Payne

ones from the computer game. I shouldn't have been, though; reality is always more complicated than a simulation.

My favorite geeky moment of the morning repetitive "though" was the explanation I received of the Joker's Jinx roller coaster, the only induction coaster at Six Flags America. I was enjoying the coaster from a purely aesthetic viewpoint—the green and purple coloring was striking, and the cars made a lovely wooshing sound unlike any of the others. Becky Thompson-Flagg, of the American Physical Society, explained to me that the other roller coasters slowly take the cars to the top of a large hill and then rely on gravity for the acceleration that will move the cars through the remaining hills and loops. An induction coaster, however, uses magnets and electricity for acceleration. Gravity obviously still plays a role, but the main advantage, as I see it, is that there is no long waiting period at the beginning of the ride. Shortly after you move away from the entrance, you're propelled upward at high speed by the linear motor.

Six Flags America will host a Math and Science Day in May. And while some students will get nothing more out of these days than a bit of fun on the rides, I hope that at least a few will take advantage of the fun to be had in the acts of doing science and maybe get inspired to continue this as they grow up.

Toy Box Physics Video Contest

Like tossing yo-yos? Ever wanted to unravel the mystery of the drinking bird? Then the American Physical Society (APS) Toy Box Physics video contest is for you. Bounce, spin, jump, and splash your way into physics history—take any toy you want and use it to somehow express a physics concept. The winner will receive a trophy lovingly made by APS staff from some of our favorite physics toys as well as \$1,000 cash. All entries must be received by May 26th at midnight. For details, visit www.physicscentral.com/experiment/contests/toy-box/index.cfm



Becky Thompson-Flagg, Public Outreach Coordinator at the American Physical Society, with some of her favorite physics toys.

Photo by James Riordon, American Physical Society

SPS Outreach Awards

From an EcoPhysics program to a Superhero Training Academy, 14 SPS chapters received Marsh W. White Outreach Awards from SPS to help fund their outreach projects during the 2009 academic year. Marsh W. White Awards are made to SPS chapters "to support projects designed to promote interest in physics among students and the general public." To learn more about the award and see the recent winners, visit www.sps-national.org/programs/awards/2009/mw_recipients.htm



The Rhodes College SPS chapter (pictured here) is using their Marsh White Award to coordinate an event in conjunction with the International Year of Astronomy. This event, "From Earth to the Universe," is a display of astronomical images and interactive demonstrations that will be on display at the Memphis Public Library in order to coincide with the Shelby County Science Fair, reaching a city-wide audience.



SPS engaged students with accelerometers enclosed in vests that students could take on rides such as this roller coaster, science demonstrations, a presentation by Galileo himself, and rolling experiments that involved ramps, salt, canned corn, a car tire, and more. To learn more about amusement park physics, visit www.learner.org/interactives/parkphysics

Photo by Matthew Payne

History of Big Bang Cosmology, Part 5: Ylem and the CMBR

Dwight E. Neuenschwander

I. Introduction

This article continues our brief history of big bang cosmology[1-4] with an overview of the early attempts of theorists to match the observed abundances of the elements and the first prediction of the cosmic microwave background radiation (CMBR). The agreement of theory and observation on the element abundances and the CMBR provide crucial evidence that the “big bang” model of cosmology corresponds very closely to reality.

In this series we have seen how Albert Einstein started modern cosmology with his 1917 paper that applied general relativity (GR) to the entire universe.[5] To resolve the problem at infinity that long plagued Newtonian cosmology, Einstein abolished infinity by modeling the universe as a uniform distribution of stars in a spherical space closing back on itself. To obtain a static solution, he also had to introduce the cosmological constant $\Lambda > 0$, which, in effect, canceled at the cosmic scale the gravitation of matter. That same year Wilhelm de Sitter found an alternative closed static solution that required the cosmological constant but contained no matter![6] The “de Sitter effect” gave a fractional change in the wavelength of radiation that was not a Doppler effect, although it was often interpreted as one; rather, the meterstick to measure wavelength gets altered. de Sitter’s model had curvature and cosmic redshifts without matter; Einstein’s model had curvature and matter without cosmic redshifts. The real universe has matter *and* redshifts. Between 1917 and about 1930, the argument was over which of these two models best fit the real universe. Even Edwin Hubble, who in 1929 published an early installment of data that showed the universe to be expanding,[7] first interpreted his results as evidence for de Sitter redshifts.[8]

In 1922 Alexander A. Friedmann predicted that the closed universe could expand (or contract, or oscillate).[9] His subsequent paper in 1924 showed that Einstein’s equations also allowed an “open” hyperbolic (negative curvature) universe that could expand.[10] Unfortunately, Friedmann’s work went unnoticed at that time. Even more sadly, he never lived to see his ideas vindicated, as he passed away from typhoid in 1925.[11]

In 1924 the young Abbé Georges Lemaître from Belgium was visiting MIT after studying physics at Cambridge under Sir Arthur Eddington. While in America, Lemaître attended a meeting of the National Academy of Sciences in Washington, DC. There he heard Hubble present his results on measuring the distance to the Andromeda galaxy. Lemaître returned to Belgium inspired and in 1927 independently re-discovered Friedmann’s dynamic universe.[12]

At a meeting of the Royal Astronomical So-

ciety in 1930, “de Sitter propounded the dilemma that the actual universe apparently contained enough matter to make it an Einstein world and enough motion to make it a de Sitter world.”[13] About this Arthur Eddington insightfully reflected, “One puzzling question is why there should be only two solutions. I suppose the trouble is that people look for static solutions.”[14] Lemaître read these remarks and sent Eddington a copy of his 1927 paper on an expanding universe. Upon seeing it, Eddington wrote to de Sitter: “... *It was the report of your remarks and mine at the [Royal Astronomical Society] which caused Lemaître to write me about it... A research student [G.C.] McVittie and I had been worrying at the problem and made considerable progress; so it was a blow to us to find it done much more completely by Lemaître (a blow softened, as far as I am concerned, by the fact that Lemaître was a student of mine).*”[15]

In 1932 the Friedman-Lemaître metric was derived with enhanced rigor by H.P. Robertson and A.G. Walker. Today the “FLRW metric” forms the working tool of modern cosmological discussion.[16] Its implications formed the topic of the fourth part of our series.

After the neutron was discovered by James Chadwick in 1932, a large piece of the nuclear puzzle fell into place, which released the brake on attempts to understand the origin of the elements. The synthesis of nuclei in stars began making sense, but it was realized that some prestellar nucleosynthesis must have occurred.[17] Thus the very early expanding universe was seen as an environment of sufficiently high temperature and density to drive prestellar nucleosynthesis. In Section II of this article we consider the thoughts of those such as Subrahmanyan Chandrasekhar, George Gamow, Ralph Alpher, and Robert Herman, who were among the first who tried to understand this environment and its processes. As told in Section III, Alpher and Herman also predicted the existence and present temperature of the CMBR, the definitive signature of a universe that began with a “hot big bang.”

As discussed in Part 4 of this series, the cosmology features a cosmic scale factor $a(t)$ that allows space to be rescaled as time t elapses, and a curvature parameter $k = +1$ (-1) for the closed (open) universe, with $k = 0$ for no-curvature “flat” geometry. With the mass-energy distribution of matter and radiation modeled as a smoothed-out energy density $\rho = \rho_{\text{mat}} + \rho_{\text{rad}}$ and an equation of state relating pressure P to ρ , the field equations of GR may be written as a pair equations for the evolution of $a(t)$:

$$(da/dt)^2 = \kappa\rho a^2 + \frac{1}{3}\Lambda a^2 - k \quad (1)$$

and

$$d^2a/dt^2 = -\frac{1}{2}\kappa(\rho + 3P)a + \frac{1}{3}\Lambda a, \quad (2)$$

where $\kappa \equiv 8\pi G/3$. The study of $a(t)$ formed our task in Part 4. Here we examine the implications of having all the matter and radiation of the universe stuffed into a diminutive region.

When the data on the velocity–distance relation became robust enough to convince everyone that the universe *really expands*, Lemaître took seriously the inferences, spurring cosmology toward the next step, from dynamic geometry to early-universe thermodynamics and nuclear physics.

II. The Ylem

Because the universe expands now, it must have existed at smaller scales in the past. When $a(t)$ was very small, the matter and radiation in the universe would have been astonishingly dense. Since the largest known density was that of nuclear matter, Lemaître suggested the state of matter in the early universe may have been a giant nucleus, a “primaeval atom” or a “cosmic egg.” As the expansion began, the cosmic forces were local, stretching the primordial nucleus apart, eventually into “our poor little atoms.”[18] Lemaître sought in this scenario a possible explanation for high-energy cosmic rays.

By the 1930s the relative abundances of the various nuclear species and their isotopes was well known (see Fig. 1), and that distribution was apparently universal across the cosmos.

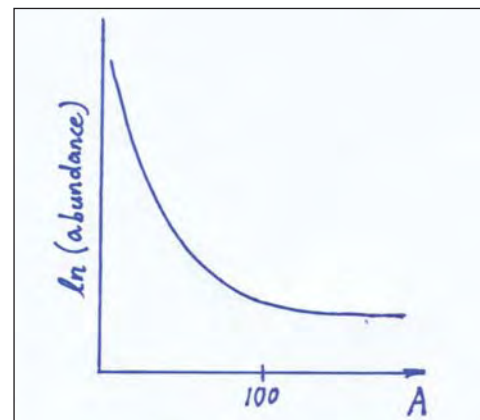


Fig. 1. Schematic smoothed-out plot of the logarithm of relative abundance vs. mass number $A =$ number of protons plus neutrons. The curve is approximately exponential out to about $A \approx 100$ and constant thereafter.

It was also realized that these abundances could not be accounted for entirely by nuclear reactions in stars, suggesting a prestellar episode of element production in cosmic history. This discussion requires a small digression into early-universe thermodynamics. Let’s do some back-of-the-envelope calculations here.

By differentiating Eq. (1) with respect to

time and using Eq. (2) we derive

$$d(\rho a^3) = -3Pa^2 da. \quad (3)$$

Because ρ denotes energy density and because the volume V of the universe is proportional to a^3 , the term ρa^3 represents the “internal energy” U of the universe. Thus Eq. (3) may be written $dU = -P dV$, which resembles the combined 1st and 2nd laws of thermodynamics, $dU = TdS - PdV$, but without the entropy S . So in the early universe, entropy is conserved, $dS/dt = 0$. One may calculate S from its usual definition,

$$S = \int (dU + PdV) / T \sim (\rho + P) a^3 / T \quad (4)$$

where we take the state variables to be spatially uniform, by our assumption of homogeneity and isotropy. In the very early universe, all the particles move at practically the speed of light. Therefore, like the photon, their energy densities and pressures are proportional to T^4 (Stefan’s law). Then from Eq. (4), it follows that $S \sim T^3 a^3$. But $S = \text{const.}$, so the universe expands and cools adiabatically according to

$$T = b/a \quad (5)$$

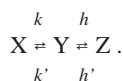
where b is some constant. To eliminate b we find the temperature T as a function of time t . From Stefan’s law we have $P \sim \rho = \sigma T^4 = \sigma b^4/a^4$ (σ denotes the Stefan’s law constant, weighted by spin multiplicities). When placed into Eq. (1), and neglecting Λ for the early universe, this yields

$$(da/dt)^2 + k = (\mu/a)^2 \quad (6)$$

where $\mu^2 = \kappa\sigma b^4$. At early times when a is small the $1/a^2$ term dominates over k , so that $da/dt \approx \mu/a$, and Eq. (6) integrates to $a^2 = 2\mu t$. Since $a = b/T$, the b cancels, and we find[19]

$$T^2 t \approx 2 \times 10^{20} \text{ K}^2 \text{ s}. \quad (7)$$

If one imagines the prestellar universe to be a gas of neutrons and protons, with an increasing contamination of nuclei made by collisions, and if during those high-temperature collisions the nuclear species are in “chemical” equilibrium with one another, then when the temperature drops to the point where fusion no longer occurs, those reactions cease and the abundance ratios of that moment would be “frozen” in. This idea was developed by several authors in the 1930s and 40s, and with particular thoroughness by Chandrasekhar and Louis R. Henrich in 1942.[20] They carried out a complex problem whose strategy may be illustrated here with a toy model. Consider elements X, Y, and Z that can change into one another as follows:



The rate at which the concentration [X] of species X decays to Y is proportional to the concentration of X, with some rate coefficient k , and

the rate at which X gets made from Y depends on the concentration [Y], with some rate coefficient k' . Therefore we may write

$$d[X]/dt = -k[X] + k'[Y]. \quad (8)$$

Including the other transformations between Y and Z with rate coefficients h and h' , we write

$$d[Y]/dt = -(k' + h)[Y] + k[X] + h'[Z] \quad (9)$$

$$d[Z]/dt = -h'[Z] + h[Y]. \quad (10)$$

In equilibrium, $d[X]/dt = d[Y]/dt = d[Z]/dt = 0$, and we find $[Y]/[X] = k/k'$ and $[Z]/[X] = kh/k'h'$. If the rate coefficients are known functions of temperature, and the temperature is a known function of time, and if the present abundances are the “frozen-in” values they had when the reactions were suddenly quenched, then from the observed abundances we can find the time and temperature of that quenching. Invariably the Boltzmann factor makes an appearance, so that $[Y]/[X]$ or $[Z]/[X] \sim \exp(-\Delta mc^2/k_B T)$ where Δm is the mass defect (or binding energy) and k_B Boltzmann’s constant. If the time and temperature of the quenching can be found by fitting to one known abundance, the rest can be predicted.

This program agreed well with the exponential decline for about the first half of the periodic table, but for the second half, where the actual abundance levels off, the predictions catastrophically continued their exponential decline. By 1946 George Gamow was suggesting in a series of talks and papers that “it appears that the only way of explaining the observed abundance-curve lies in the assumption of some kind of unequilibrium process taking place during a limited interval of time.”[21]

Gamow had tremendous intuition and physical insight, but mathematical patience for complex calculations was not his primary strength. Therefore when his graduate student Ralph A. Alpher was in need of a second PhD dissertation topic,[22] he took on the task of predicting the abundances of the elements in the complicated, out-of-equilibrium dynamics of the high-temperature environment in the early universe.

This good work resulted in a series of papers by Alpher and his colleagues over the next several years. The first to emerge from the dissertation was published in *Physical Review* in April 1948, bearing the title “The Origin of Chemical Elements.”[23]

Gamow, an irredeemable prankster, could not resist the temptation to put the name of Hans Bethe on the paper, a publication called to this day the “ $\alpha\beta\gamma$ paper.” Our Greek-letter authors wrote, “According to this picture, we must imagine the early state of matter as a highly compressed neutron gas (overheated nuclear fluid) which started decaying into protons and electrons when the gas pressure fell down as the result of universal expansion. The radiative capture of the still remaining neutrons by the newly formed protons must have led first to the formation of deuterium nuclei, and the subsequent neutron captures resulted in the building up of heavier and heavier nuclei.”

For nuclear species out to uranium (the various isotopes for common nucleon number A emerging later from beta decays), the rate equations for this building-up process (neglecting fissions) are of the form

$$dn_i/dt = f(t) [\sigma_{i-1} n_{i-1} - \sigma_i n_i] \quad (11)$$

where $f(t)$ carries time-dependent factors, n_i denotes the particle density of species i , and σ_i denotes its cross-section for neutron absorption (recall the cross-section is the area, centered on the target nucleus, within which the neutron must hit to make the reaction go). Given the rapidity of the reactions compared to the neutron half-life, it was assumed the nuclear reactions went to completion in a time short enough that the expansion was negligible during those moments. Upon integrating the coupled rate equations, it was found that the curve of relative abundances could be fit, for essentially all the elements, with a common value of $\rho_n \Delta t = 5 \times 10^4 \text{ g s/cm}^3$, the product of neutron density and time interval during which the element buildup occurred. Alpher’s calculations showed the process of element-building by neutron capture to be essentially finished when $t \approx 5 \text{ min}$.

These calculations were explained in more detail in a longer paper written by Alpher alone later that year, “A Neutron-Capture Theory of the Formation and Relative Abundance of the Elements.”[24] Into this discussion Alpher introduced the antique word *ylem*, pronounced $\text{i}'\text{-l}\text{e}\text{m}$ (see Fig. 2). Alpher explained, “According to *Webster’s New International Dictionary*, 2nd Ed., the word ‘ylem’ is an obsolete noun meaning ‘The primordial substance from which the elements were formed.’ It seems highly desirable that a word of so appropriate a meaning be resurrected.” Yes it should—and perhaps it has. My *American Heritage College Dictionary* defines *ylem* as “A form of matter hypothesized by proponents of the



Fig. 2. Robert Herman (left) and Ralph Alpher (right) witness George Gamow emerge from a bottle of *ylem*. This slide was sneaked into a stack for a talk that Gamow presented, and he first saw it when it flashed boldly on the screen. Alpher noted the bottle’s “contents were partially consumed by those in the photo to celebrate the mailing of the Alpher–Bethe–Gamow paper to *Physical Review* in 1948.” Photo courtesy of Victor Alpher.

big bang theory to have existed before the formation of the chemical elements.” In Alpher’s models of 1948, the ylem was a liqueur of very hot neutrons that became enriched with electrons, protons, neutrinos, and heavier elements during the first five minutes of the expansion.

Similar to Eq. (8), Alpher wrote for the rate of change of the number density n_A of nuclei of mass number A ,

$$dn_A/dt = k_{A-1} n_{n_{A-1}} - k_A n_n n_A, \quad (12)$$

where n_n denotes the number density of neutrons and the k ’s are rate coefficients. From kinetic theory of ideal gases, Alpher derived

$$k_A \propto (k_B T)^{-3/2} [(A+1)/A]^{1/2} \int_0^\infty \sigma_{nA} E \exp(-E/k_B T) dE \quad (13)$$

where k_B denotes Boltzmann’s constant and σ_{nA} the neutron-capture cross section for element A . The cross-sections as functions of A were fit to data according to $\ln(\sigma_{nA} E^{3/2}) = \alpha A - \beta$ for $A < 100$, and $\ln(\sigma_{nA} E^{3/2}) = \gamma$ where α , β , and γ are known measured constants. Alpher integrated the first four rate equations by hand; after that (working out to $A = 238$ for uranium) he grouped the elements into blocks of 5 or 20, with averaged rate coefficients and number densities. The product $n_n \Delta t$, where Δt denotes the time for the neutron-capture process to be completed, served as the independent variable. The grouped rate equations

were integrated numerically, and the resulting number densities vs. $n_n \Delta t$ were plotted logarithmically as shown schematically in Fig. 3a. The best fit to data occurred for $\ln(n_n \Delta t) = 17.91$, or $n_n \Delta t = 0.8 \times 10^{18}$ s/cm³. The abundances themselves, compared to data, as obtained by Alpher, are sketched schematically in Fig. 3b.

Further refinements to this program formed the subject of another 1948 paper which was written by Alpher and his colleague from the Johns Hopkins Applied Physics Lab, Robert Herman, who had studied relativity at Princeton under H.P. Robertson. (Herman disappointed Gamow by not changing his name to “Delter.” It should be noted that Alpher and Herman did cosmology *after* their day jobs of mostly classified defense-related work on topics like the hydrodynamics of missile re-entry into Earth’s atmosphere.) Their first joint cosmology paper, “On the Relative Abundance of the Elements,” discussed the effects of the expansion during nucleosynthesis and included beta decay in the calculations.[25] It was one of their first joint papers in what would prove to be a half-century of collaboration and lifetime friendship. [26]

III. The CMBR

In the summer of 1948 while he was at Los Alamos, George Gamow wrote a hasty paper called “The Evolution of the Universe” that attempted to connect nucleosynthesis criteria to galaxy formation by gravitational condensation. [27] He mailed the paper to *Nature* and sent a copy to Alpher and Herman. They scrutinized his work, noticed some minor errors, and informed him of them. Gamow replied that it was too late to change his paper, which was already in *Nature*’s publication pipeline, but he asked the journal’s editors to watch for Alpher and Herman’s corrections and publish their note as soon as possible.

Gamow’s paper appeared in the October 30 issue, and the Alpher- Herman corrections appeared on November 13, the latter also called “Evolution of the Universe.” At issue in Gamow’s paper, and corrected by Alpher and Herman, was the “cross-over time,” when the energy densities of matter and radiation became equal, a necessary condition for galaxies to form. After noting these corrections, Alpher and Herman remarked that, according to their thermodynamic calculations, “The temperature of the gas at the time of condensation was 600°K. and the temperature of the universe at the present time is found to be about 5°K. We hope to publish the details of these calculations in the near future.”[28]

Those details appeared in the *Physical Review* the following April as another article by Alpher and Herman, “Remarks on the Evolution of the Expanding Universe.”[29] Our authors considered “an expanding universe of non-interconverting matter and radiation,” after matter-radiation decoupling which occurred when their energy densities became *separately* conserved. The conservation of matter gives $\rho_m a^3 = const.$ If the radiation energy density is given by a Planck blackbody spectrum, $\rho_r \sim T^4$, and an adiabatic ex-

pansion where the $T \sim 1/a$, one has $\rho_r a^4 = const.$ Putting these together, it follows that

$$\rho_r \rho_m^{-4/3} = const. \quad (14)$$

Using primes to denote “then” as the time of element formation in the early universe and double primes to denote “now,” Alpher and Herman calculated that “the specification of $\rho_{m'}$, $\rho_{m''}$, and ρ_r fixes the present density of radiation, ρ_r'' . In fact, we find that

$$\rho_r \approx 10^{-32} \text{ g/cm}^3,$$

which corresponds to a temperature now of the order of 5°K. This mean temperature for the universe is to be interpreted as the background temperature which would result from the universal expansion alone.”

Radiation at a temperature of a few Kelvins means that the cosmic afterglow of the big bang would exhibit a Planck spectrum peaked in the microwave part of the spectrum. Thus was the existence and temperature of the cosmic microwave background radiation (CMBR) predicted by Alpher and Herman in 1948 and 1949.

Throughout the 1950s they attempted to convince radio astronomers to search for this relic radiation, to no avail. However, it seems to have been detected (but not recognized as the CMBR) in the early 1940s and discovered (and recognized) in the USSR in 1957.

In 1941 Walter Adams[30] and the Canadian Andrew McKellar were conducting spectral analysis of elements and simple molecules in stars and interstellar nebulae. McKellar’s paper[31] interpreted Adams’ observations of spectral lines of the CN molecule as being caused by its rotational states. McKellar calculated “that the ‘rotational’ temperature of interstellar space is about 2 K.” The thinking of the time held that the temperature of interstellar empty space should be absolute zero, so 2 K was thought to be the temperature of a nebula. Today many cosmologists attribute the first detection of the CMBR, if unrecognized as such, to Adams and McKellar.

In late 1964 A. Penzias and R.W. Wilson serendipitously detected an unaccounted-for 3 K temperature excess of their microwave antenna. [32] The Princeton group of R.H. Dicke, P.J.E. Peeble, P.G. Roll, and D.T. Wilkinson interpreted the excess temperature as the CMBR.[33] Neither one of these papers cited the CMBR prediction of Alpher and Herman, and until recent years few seemed to recall the Alpher-Herman prediction of the CMBR at all. Over the years, the error has been routinely propagated of citing Gamow or “Gamow and his students” as the author of the CMBR prediction.

This unfortunate circumstance put Ralph Alpher and Robert Herman in the distinguished cosmological company of Alexander Friedmann and Georges Lemaître. As in their cases, the overdue record of priority is slowly being set straight.[34-37] The detection of the CMBR, whose existence was predicted by Alpher and Herman, was the cinching link between theory and evidence, which compelled the astrophysics community to take the

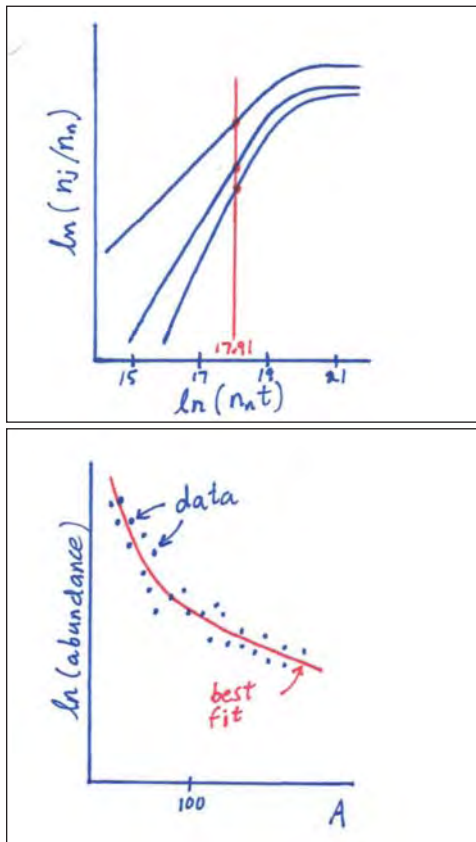


Fig. 3. (a) Sketch of Alpher’s logarithmic plot of relative abundance vs. $n_n \Delta t$, with best fit at $\ln(n_n \Delta t) = 17.91$. (b) Sketch of Alpher’s best fit calculation against actual abundance data.

hot big bang seriously. If Friedmann and Lemaitre “made the universe expand,”[11] then Alpher and Herman made it glow.

Acknowledgments

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SPS Takes a Stand on Undergraduate Research

The governing Council of SPS approved the following statement for general dissemination, with the final approval process being completed on December 1, 2008

“We advocate that every student majoring in physics and/or astronomy engage in a meaningful undergraduate research experience.”

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A Universe of Wonder: International Year of Astronomy 2009

Hubble Celebrates the IYA2009 with the Galaxy Triplet Arp 274

Space Telescope Science Institute, Baltimore, Md – On April 1-2, the Hubble Space Telescope photographed the winning target in the Space Telescope Science Institute's "You Decide" competition in celebration of the International Year of Astronomy 2009 (IYA2009). The winner is a group of galaxies called Arp 274. The striking object received 67,021 votes out of the nearly 140,000 votes cast for the six candidate targets.

Arp 274, also known as NGC 5679, is a system of three galaxies that appear to be partially overlapping in the image, although they may be at somewhat different distances. The spiral shapes of two of these galaxies appear mostly intact. The third galaxy (to the far left) is more compact but shows evidence of star formation.

Two of the three galaxies are forming new stars at a high rate. This is evident in the bright blue knots of star formation that are strung along the arms of the galaxy on the right and along the small galaxy on the left.

The largest component is located in the middle of the three. It appears as a spiral galaxy, which may be barred. The entire system resides at about 400 million light-years away from Earth in the constellation Virgo.

Hubble's Wide Field Planetary Camera 2 was used to image Arp 274. Blue, visible, and infrared filters were combined with a filter that isolates hydrogen emission. The colors in this image reflect the intrinsic color of the different stellar populations that make up the galaxies. Yellowish older stars can be seen in the central bulge of each galaxy. A bright central cluster of stars pinpoint each nucleus. Younger blue stars trace the spiral arms, along with pinkish nebulae that are illuminated by new star formation. Interstellar dust is silhouetted against the starry population. A pair of foreground stars inside our own Milky Way are at the far right.

The International Year of Astronomy is the celebration of the 400th anniversary of Galileo's first observations with a telescope. This global astronomy event is intended to stimulate worldwide interest, especially among young people, in astronomy and science.

Image credit: NASA, ESA, M. Livio, and the Hubble Heritage Team (STScI/AURA)

