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WOW! 625 Descend on Fermilab

Reflections from SPS Reporters who covered the 2008 Quadrennial Congress of Sigma Pi Sigma. For full reports and extensive photo collections, visit www.sigmapisigma.org/congress/2008/reports/

Photo by Philip Payette

Breakfast in one of the historic barns preserved and still used on Fermilab's campus. The Laboratory respects the histories of the family farms that were here beforehand.

Community

Abilene Christian University: The conference allowed all of us to look outside of our own personal experience as physicists — be it as students, researchers, or teachers — and view things from a more national and global perspective. It brought about reflection on what it means to live not just as a scientist, but as a citizen scientist, and imbued a sense of greater responsibility to the community that invests in us.

North Carolina State University-Raleigh: The first evening provided a quaint coffee and dessert social where we became fast friends with several interesting individuals.... Students and faculty from schools across the country poured into the hotel throughout the evening and into the next morning, eventually totaling more than 600. Representatives from education and industry were present from as far away as New Zealand and Australia.

Juniata College: What we found most compelling about the conference was the chance to see and interact with the scientific community....The chance to listen to some of the giants of physics and scientific citizenship and to meet fellow physics students was spectacular. Brad Dinardo, one of our students, said, "I loved the anecdote told about Galileo by Leon Letterman, and his comparison between the telescope and the LHC [Large Hadron Collider]–how a discovery by the LHC could have an impact on the state of the world that we cannot imagine."

Scientific Citizenship

Angelo State University: Congress Planning Committee members [and student organizers] Mike Gaither and Justin Stimatze made their way to the stage and spoke briefly about

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A Year and More as the SPS Associate Zone Councilor Representative

Ann Deml, University of Wisconsin-River Falls, and Colorado School of Mines

Ann Deml

Throughout the past year, I have been privileged to be serving as the elected SPS Associate Zone Councilor (AZC) Representative, the student representative on the SPS Executive Committee. It has been a wonderful experience in which I have been very truly involved with the Society and its decisions at the national level. My position began last fall as one of the eighteen student AZCs elected to represent our respective geographical regions throughout the U.S. We met along with faculty Zone Councilors from each region, the SPS Executive Committee, and the SPS National Office Staff for the 2007 National Council Meeting in Washington D.C.

Even having heard that the National Council meeting in September is the most anticipated event of the year, I had no idea what a great experience it would be. I met so many other students who were passionate about physics and about sharing that enthusiasm through outreach events in their communities. The National Council meeting was a fabulous opportunity for us to talk about the great things going on in our local chapters and to learn about our roles in representing a larger regional zone. I was chosen by the AZCs to serve as the student representative for the entire society, but I think we all quickly recognized what unique positions we were in and how much our contributions were valued by the National Office. We were very literally able to direct the goals and positions of SPS and made decisions such as selecting the Future Faces of Physics theme that was promoted throughout this last year.

We joined committees and worked together on projects determining the goals of SPS. I

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AIP Member Societies: American Physical Society • Optical Society of America • Acoustical Society of America • The Society of Rheology • American Association of Physics Teachers • American Crystallographic Association • American Astronomical Society • American Association of Physicists in Medicine • AVS, The Science and Technology Society • American Geophysical Union ***Other Member Organizations:*** Sigma Pi Sigma, Physics Honor Society • Society of Physics Students • Corporate Associates

Photo courtesy of Chicago State University

Fred Jerome (2nd from left) and Rodger Taylor (2nd from right) with students from Chicago State University.

Photo by Phillip Payette

SPS Zone Councilor Toni Sauncy facilitates a workshop discussion.

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their efforts in developing the theme of Scientific Citizenship....

North Carolina State University-Raleigh: With a theme of "Scientific Citizenship" for [the] Congress, the goal was simple: connect with others, learn how to become a better scientific citizen, and help decide what action Sigma Pi Sigma and the Society of Physics Students should take to promote good scientific citizenship...When science involves itself with politics, it needs to be tempered with humility...

"The chance to listen to some of the giants of physics and scientific citizenship, and to meet fellow physics students, was spectacular.

Angelo State University: Jill Tarter, Director of the Center for SETI Research at the SETI Institute, ...shared with Congress attendees some stimulating ideas about the Search for Extraterrestrial Intelligence.... Speaking with Dr. Tarter [afterwards],...we asked if she could offer advice to undergraduate students. She stressed the importance of finding something you love, and then making a career out of it....Dr. Tarter counseled us to always be humble about what we know... It's important to be humble and approachable as a scientist.

North Carolina State University-Raleigh: We were moved by the society's concern for the welfare of the community as a whole.... At the end of the Congress, we could not wait to get back to NC State and organize outreach events...

University of Southern Mississippi: The workshops [were] tailored to the theme of the Congress, "Scientific Citizenship: Connecting Physics and Society..." [For example,] Adrian Melott, founder of the Kansas Citizens for Science...fought for the Kansas School System to teach the Theory of Evolution in its science curricula....[his] talk provoked some passionate roundtable discussions...

Grove City College: Dr. Leon Lederman [gave] the last lecture of the conference, entitled "What Presidents and Physicists Need to Know About Science." Dr. Lederman is Director Emeritus at Fermilab and a Physics Nobel Laureate... [His] passion became immediately clear: education... Dr. Lederman says...we must convince the best college students to go into teaching. We need to restore the high social status that teachers enjoyed in the 1940's...Dr. Lederman is a leader and an educator, but, at heart, he is a scientist. He says the happiest moments of his life were spent in a lab. It is 3:00 a.m. after a long night of monitoring an experiment, and suddenly he sees something he does not expect....

Many Faces of Physics

St. Peter's College: It was great to see so many different scientists of all races and colors sitting with one another. It doesn't matter where we all come from, but the key thing is to work together to change the world... We are all different people, but we share one common goal...I truly want to be a part of this family of scientists....

Angelo State University: The number of women and other traditionally under-represented groups present served as a true inspiration....

Photo by Phillip Payette

Over 100 posters were presented at the Congress, the majority by undergraduate physics students.

This theme of diversity was the subject of the Friday night dinner presentation by Fred Jerome and Rodger Taylor when they discussed their book, *Einstein on Race and Racism*. Their presentation on the passion of Einstein for racial diversity and ending racism was inspiring, educational, and eye-opening....

"The conference… imbued a sense of greater responsibility to the community that invests in us."

Chicago State University: While physics is a universally challenging subject, [workshop speaker] Dr. Aziza Baccouche faces challenges that would seem daunting to anyone. Due to a tumor in her third ventricle, her optic nerve was damaged and caused her to become legally blind at the age of eight. This however, did nothing to impair her "vision." She makes a definitive distinction between "sight" and "vision." Sight is one of the five senses. Vision is your outlook on life; your ability to imagine and pursue your goals. For Dr. Aziza vision is something that her medical affliction cannot tarnish.

Fermilab Itself

North Carolina State University-Raleigh: On Friday, we were treated to "insider" tours of the Fermilab campus, including the accelerators, the Feynman Data Center, the Grid Computing Center, the Meson Detector Building, Lederman Science Education Center, and Wilson Hall...we were overcome by various works of art: sculptures, and paintings dotting our surroundings. The Congress even hosted an art competition on display all weekend long in the Wilson Hall Atrium... Fermilab is one of the most diverse ecological, scientific, and artistic landmarks we've ever visited.

Grove City College: It was exciting to see the scientists at their work.

Photo by Phillip Payette

Photo by Phillip Payette

The Congress featured a student-focused, lively 25-table exhibit hall.

It gave this feeling of awe sort of like watching the astronauts in space or exploring the moon.

Juniata College: On the architecture tour, we appreciated the attention to detail that was put into the design of the buildings of Fermilab. We liked the convolution of science and human ideals that came together to make Fermilab a center of both culture and science. It was inspiring to see the unique way in which architecture and nature coexist together.

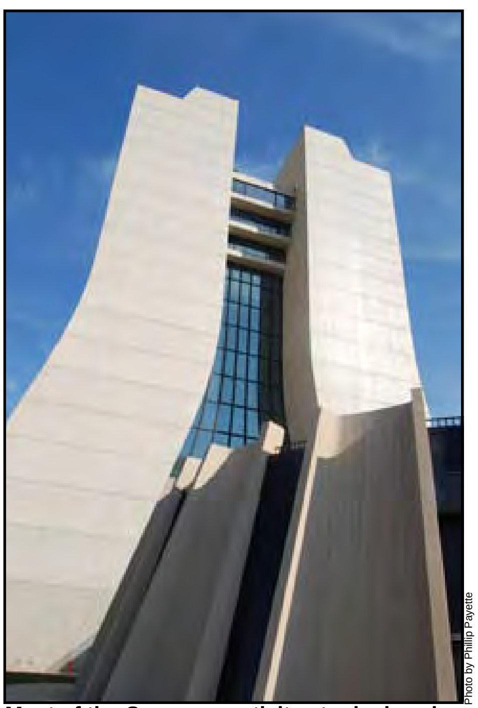

Photo by Phillip Payette

Most of the Congress activites took place in Fermilab's iconic Wison Hall

A Year and More continued from page 1

served on a committee that was presented with the challenge of working to increase the number of undergraduate degrees earned in physics. We discussed a variety of means to do so, ranging from providing students with more resources about the variety of careers available, to endorsing similarly focused initiatives by other groups. The committee continued to work together during the year, and its work has been continued by members of this year's National Council.

However, the excitement of being the AZC representative did not end there. The American Institute of Physics (AIP) Education Advisory Committee meeting was held in March, where I served as the student representative on the committee. The structure of this meeting was very interesting to me in that, as a committee, we were given the opportunity to provide feedback to AIP about the work it does in support of physics education. We were able to commend many of the Institute's efforts and also identify new tasks that we would like to see become areas of greater focus. Again, the committee was very eager to hear about my opinions, experiences, and perspectives as a student, and I felt that I was able to make valuable contributions to the group because of my participation in events such as the National Council meeting and the SPS internship program.

In June, I again returned to Washington D.C. for an SPS Executive Committee meeting. It was an opportunity to see many now familiar faces and also to meet this year's SPS Summer Interns at a Washington Nationals baseball game. Of course, between meetings we continued to interact with the SPS National Office and made decisions such as choosing the location for the Sigma Pi Sigma 2012 Congress. I would have never expected to have a significant part in something like that before becoming an AZC, but participation from students is strongly encouraged in SPS, even (or maybe especially) at the national level.

This year the 2008 National Council of faculty and student representatives from each of the regional zones met in November at the Fermi National Accelerator Laboratory near Chicago. That means that we were given the opportunity to participate in the Sigma Pi Sigma Congress 2008, the only national physics meeting specifically designed for undergraduates! It also meant that in September we were able to be a part of the first virtual meeting as a National Council. The entire Council met via a webinar which included an introduction to the Society and our roles for the upcoming year. This meeting, early in the fall semester, also allowed us to form a variety of committees to which we will contribute throughout the year. It was an exciting, new use of technology that I think we can continue to utilize.

I am continually surprised and impressed by the input that we as students are encouraged to have as members of SPS. Being involved with the Society at a national level has been very personally rewarding for me. It has also been a great opportunity to meet many other enthusiastic physicists of all ages and learn much more about the careers available in physics, as well as the network of support that is available. The work carried out by SPS as a whole really does impact our experiences as physics students, and many of us have been a nontrivial part of that process. I think we can all have pride as we look forward to the continued work of future students who will also represent us in the physics community.

SPS Program Deadlines

March 15. 2009

SPS Outstanding Student Award for Undergraduate Research applications must be postmarked:

www.spsnational.org/programs/awards/student.htm

April 15, 2009

Letters of Nomination for Outstanding SPS Chapter Advisor must be postmarked:

www.spsnational.org/programs/awards/advisor.htm

Blake Lilly Prize entries must be postmarked:

www.spsnational.org/programs/awards/lilly.htm

May 1, 2009

Chapter Ballots for national and zone offices must be submitted online or postmarked:

www.spsnational.org/governance/elections/

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 the cosmic background radiation. We are honored to have his son, Victor S. Alpher, tell us his story. This is Part 2.

There is little doubt that my father, Ralph A. Alpher, considered himself a theoretical physicist at a time when there was no discipline of astrophysics and no field of cosmology. Some of the current generation of astrophysicists consider him the "father" of modern astrophysics and cosmology (Neil deGrasse Tyson, personal communication, July 27, 2007). Theoretical physics was the only "niche" in which one could develop mathematical models of the early universe and the formation of the chemical elements, and make predictions about phenomena as-yet unobserved in the cosmos.

We will have more to see later when we consider the elaboration of the Big Bang model where his ground-breaking work was confirmed by very sophisticated observations of the expanding universe. Such observations became possible only with the financial support made possible by confirmation of his early theoretical hypotheses. These observations led to four Nobel Prizes, to the launch of the COBE (Cosmic Background Explorer) Satellite in 1989, and, finally, to a National Medal of Science awarded to Ralph A. Alpher himself shortly before his passing on August 12, 2007.

In my first paper in this series, we saw that in 1948 his original work on nucleosynthesis, suggesting in lay terms that the "Universe was created in five minutes", created a noticeable stir not only in the scientific community, but also in the mass media as well. Dr. Alpher was interviewed on early broadcast television. Through the 1950s he continued with several colleagues to produce major theoretical advances in Big Bang Cosmology. Erroneously, some believed that his "fifteen minutes of fame" had come and gone….

Don't Quit Your Day Job

People with cutting edge, or less-conventional interests, such as musicians, artists, and inventors, are often advised to find a conventional way of earning a living, and sticking to it–until or unless they become successful with their true passion. By 1948, Ralph Alpher already had nearly 10 years of full-time work in the scientific world of national defense physics as a"hired gun", so to speak. Cosmology was not a recognized subspecialty of physics.

Technically, from 1940 to 1945 he was a contract employee of the Naval Ordnance Laboratory (NOL) (as was Albert Einstein). In fact, he was also working with the scientist-technician teams under Merle Tuve at Section T of the Department of Terrestrial Magnetism of the Carnegie Institution. NOL remained his paymaster, but such shifting around of personnel depending on research needs was common. Lacking only one course in Botany, he had to wait until 1943 to receive his B.S. and appointment at the higher pay grade of Associate Physicist. He had applied for a commission in the U.S. Navy earlier in the war, but was turned town because of his nearsightedness.

When my father responded to a draft call in 1944 (see Fig. 1.), he was deferred because of the essential nature of his work for the Navy on protection of ships from magnetic mines, and projects necessary for personnel in the field (for example, adaptation of the Proximity Fuse to various ordnance—it was used in mortars and artillery in the Battle of the Bulge).[1] It is interesting to notice that the Naval Ordnance Laboratory listed his "essential" occupation as "Professional Engineer" on the application for deferment (see Fig. 2).

Solving the Mark 14 Problem

In his final year of war work for the Navy, Ralph Alpher oversaw aspects of the development of improved reliability of magnetically-influenced detonation, and improved guidance of Naval torpedoes (the Mark 14, a surface-launched torpedo, and the Mark 13, an air-to-surface launched torpedo). "Duds" were not the only major problem in the previous years of the war–these torpedoes also occasionally swung around to attack the launching vessel![2,3] With the success of other projects at the Johns Hopkins University Applied Physics Laboratory (JHUAPL), his time was freed up by mid-1944 to work on the torpedo problem (see Fig. 3.).

The Mark 9 Torpedo Exploder

Dr. J. E. Henderson, Director of the Applied Physics Laboratory of the University of Washington at Seattle, led the Section T work on what became known as the Mark 9 torpedo exploder in collaboration with JHUAPL, where this work was led by Wilbur Goss. My father was "Project Supervisor, Production Problems" during his year with the Mark 9 Torpedo Exploder Group (Fig. 6).

Henderson was no stranger to Section T, and since 1940 had worked on "influence" (magnetic and radio wave) detonation. Because

Figure 1. Organizational reply form to Ralph Alpher's Draft Induction Notice seeking deferment based on his work being essential to the war effort. Unless otherwise mentioned, figures come from the personal collection of Ralph A. Alpher, courtesy of Victor S. Alpher.

Figure 2. Page 2 of the reply form in Figure 1.

the Mark 9 TE was so advanced, correcting for problems with yaw, pitch, roll, and broaching, many of its characteristics are still classified.[4] During this time, my father traveled to Puget Sound to observe torpedoes in action from a small wooden boat, which often proved dangerous as errant torpedoes "broached" and deviated from their intended courses (Fig. 4). The life of a physicist in this kind of testing work appeared on the surface to have an equivalent value to that of a Marine or Ranger storming an occupied and heavily fortified beach. The Mark 9 TE was


NAVY DEPARTMENT
BUREAU OF ORDNANCE
9-JUL 1945
10 AUG 1945

Figure 3. Two commendations (top section dated 9 Jul 1945 and bottom section dated 10 Aug 1945, four days before V-J Day in North America) from G. F. Hussey, Jr., to Officer in Charge, Naval Ordnance Laboratory and then from the Officer in Charge, Capt. W.G. Schindler to Ralph A. Alpher for development of mines at the NOL which "have and are currently taking a heavy toll of enemy shipping and have disrupted Japanese industry by blockading large numbers of ships."

required to have a 99% reliability—the difference between even a 95% and 99% reliability being very significant. It took a year to achieve that goal. Ralph did not become an official employee of JHUAPL until the end of the war.

From that point onward, he worked on several projects, which will be described further (Fig. 5). However, like many of the scientists who were recruited for work on ordnance projects and other war-related research, my father faced a difficult problem. Having won its notoriety on military projects during the war, afterward JHUAPL devoted only five percent (5%) of its budget to scientific research involving rockets acquired from Germany's V-2 program.

Figure 4. Mercury lamp used by Ralph Alpher while testing torpedoes in Puget Sound during World War II. If it was necessary for the testing crew to abandon their wooden boat, this lamp would emit a faint blue signal at night that could be seen by rescue teams.

Onward to High Altitude Research and Guided Missiles

When World War II ended, Section T (rumored to be named for its director, Merle Tuve) became officially the Applied Physics Laboratory of Johns Hopkins University, the first freestanding laboratory-for-hire of its type in the United States. By this time, many scientists and their military liaisons were involved in chronicling as quickly as possible the scientific developments brought on by the need for advancement in ordnance capabilities during the war. [5,6]

Initially, after the war, all unused V-2 rockets were brought to the U.S. for testing at the White Sands Missile Range in New Mexico. During this time, many of the German scientists who had worked with Wernher von Braun, first at the Kummersdorf[7] artillery testing range, and then at Pennemünde, lived at Fort Bliss, Texas. (Removal of Germans who could be useful to the U.S. military and intelligence was called Operation Paperclip). Before the supply of V-2s was exhausted, other missile designs based on the V-2 followed. My father also worked on the Terrier and Talos guided missiles, which were developed and studied during part of the time that he worked in James van Allen's High Altitude work group at JHUAPL. The Talos surface-to-air missile first flew in 1951.

All such projects had a double purpose. In the case of James van Allen's rockets, they supplied information about their characteristics as rockets and guided missiles that would carry nuclear warheads. Equipment in the empty warhead also provided data on a variety of scientific projects approved by the people directing the "V-2 Panel." This often led scientists without the right "connections" out in the cold for conducting space research. The "five percenters", as they were called,[8] struggled under the leadership of James van Allen to piggy-back high altitude scientific research materials into the empty warheads of sixty-six V-2 German rockets, and on van Allen's own Aerobee between 1946 and 1951. The multi-institutional "V-2 Panel" directed scientific research aboard these rockets, first meeting officially on February 27, 1946 at Princeton, New Jersey. Van Allen was its second director, from late 1946 through 1957. On a shoestring budget, from 1946 through 1951, a number of purely scientific results emerged from what was renamed the Upper Atmosphere Rocket Research Panel.[9]

Merle Tuve saw the potential of space science not directed toward immediate practical or commercial findings. However, the atmosphere at JHUAPL was increasingly tilted in the direction of military ordnance and technology, so much so that Tuve returned to non-military science at the Department of Terrestrial Magnetism in 1950. As the Cold War and Korean conflicts loomed, a new director, Ralph Gibson, was keenly devoted to seeing JHUAPL return to

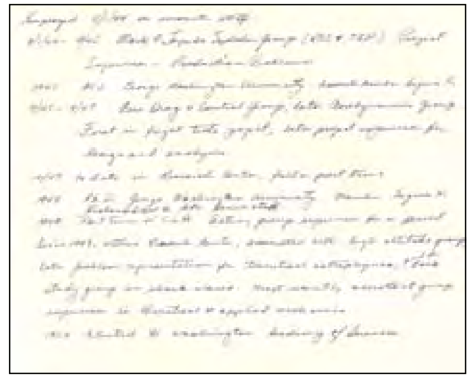

Figure 5. Handwritten notes by Ralph Alpher concerning his activities from August 1, 1944 through about 1950.

its glory days of the development of the Proximity Fuze. This was fortuitous for the laboratory, but not necessarily for scientists "at heart" who had diverted so much of their creativity in the direction of military ordnance. During the ensuing several years, a number of scientists left the lab, beginning with Merle Tuve in 1950, and also with van Allen, who returned to the University of Iowa as Chairman of the Department of Physics in 1951.

As Ralph Alpher worked with James van Allen's high altitude work group at JHUAPL in the late 1940s, the characteristics of cosmic rays were investigated miles above the earth's surface, before their breakup in the upper atmosphere. This also made necessary the further sophistication of telemetry that would become the hallmark of advanced rocket research. The ozone layer that protected the planet from ultraviolet rays was discovered, as well as nuclear reactions in solar flares. Space walks, which we take for granted now, were found to pose great danger to astronauts and cosmonauts during solar flare activity. Because of this early research, space walks are prohibited during such times.

Meanwhile, at night and on weekends my father also avocationally pursued astrophysics and cosmology, the subjects of many peer-reviewed publications, colloquia, and media attention. However, he also learned during his early career that scientific research at the laboratory would always be the stepchild of military deep pockets–particularly at free-standing laboratories beholden to the government for meaningful research support and to companies at the vanguard of space science, such as Lockheed and General Electric.

George Gamow Takes on a New Student

After receiving his bachelor's degree in 1943, Ralph Alpher successfully appealed to George Gamow to become his thesis advisor and dissertation director. This put him in a direct intellectual line of cosmological inquiry going back through George LeMaître and Gamow to Aleksander A. Friedmann in the early 20th

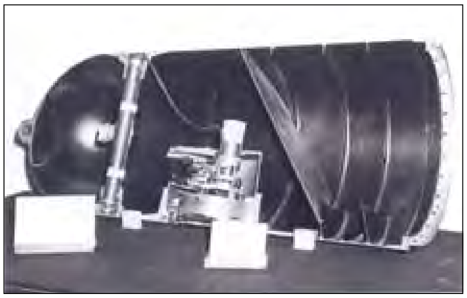

Figure 6. Photograph of the Mark 9 Torpedo Exploder Mechanism.

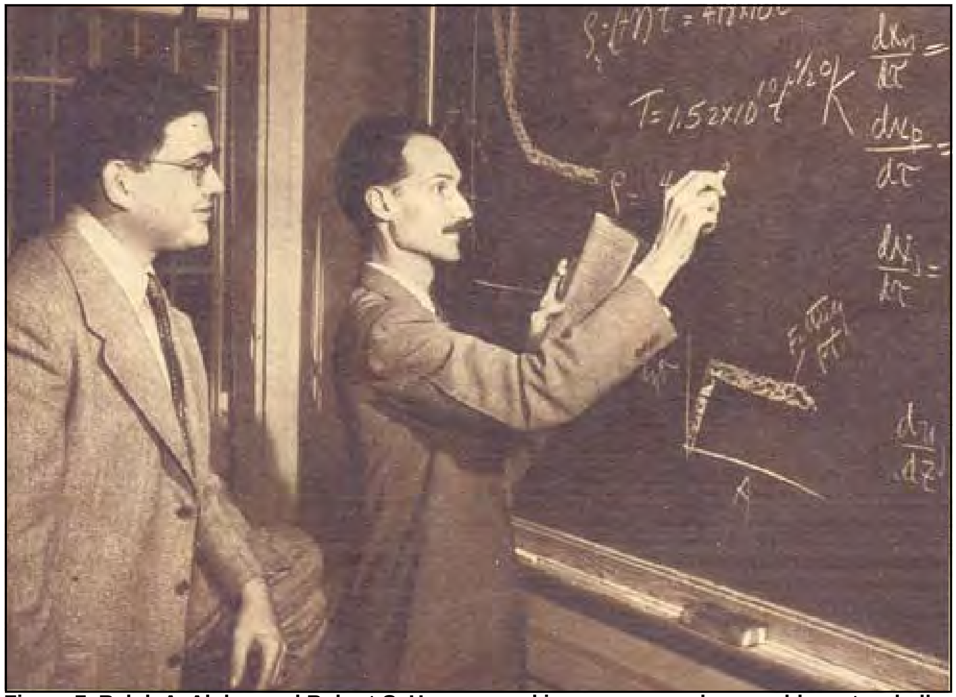

Figure 7. Ralph A. Alpher and Robert C. Herman working on a cosmology problem at a chalkboard sometime in the late 1940s or early 1950s.

century. Ralph brought to the enterprise a level of mathematical genius not yet applied to the questions at hand.

Fortunately for the fledgling cosmologist, the nascent military-industrial complex provided a solid income during a period of time when he earned his bachelor's, master's, and doctoral degrees at George Washington University at night, while working during the day at the National Bureau of Standards, the Carnegie Institution, the Naval Ordnance Laboratory, and finally, the Applied Physics Laboratory of Johns Hopkins University. From photos I have seen, I believe my father's favorite "office" was the space in front of a long blackboard. The location of that blackboard, whether in a converted used car garage (JHUAPL on Georgia Avenue) or a majestic U.S. Government structure, was of secondary significance! At times, a pub napkin would do–meetings with his advisor, George Gamow, a Soviet defector and a JHUAPL consultant, often occurred at lunchtime in Silver Spring, Maryland, at the converted Wolfe Garage, or in the evening at a pub or corner bar in the vicinity of G.W.U. (only one of the two men was reputed to be a hard drinker: it was not Ralph).

In the 1940s, Washington, D.C. was a good place to be studying physics, because of the creativity of the people he came in contact with early in his career, such as Merle Tuve, Robert and Vera Rubin, George Gamow, James van Allen, Freeman K. Hill, Robert Herman, Scott Forbush, and Wilbur Goss, just to name a few. His freshman physics course was taught by Edward Teller, who had emigrated to the U.S. from Hungary in 1935 and, like Ralph Alpher, was something of a prodigy in mathematics.

By 1945, Germany had advanced far beyond the U.S. in the development of rocketry and missile technology.[10,11,12] My father began immediately to work on the ram-jet after the war, one of several candidates for further development. Rockets and missiles, of course, are distinguished from bombs in that the former have their own propulsion and guidance systems. Earlier in the run-up to the war beginning with the formation of the OSRD in November, 1940 (at which time the U.S. Government professed caution and neutrality), my father had already done considerable work (as an undergraduate!) on detonation technology--most significantly on the Proximity or VT (variable time) Fuze, as well as on torpedo propulsion and detonation, and degaussing Navy and Merchant Marine vessels.

Just a Side Trip to New Mexico

Later in the war, my father was assigned briefly to the secret facility at Los Alamos, New Mexico, where he was involved in formulating and making calculations to determine the altitude for each atomic bomb (Little Boy and Fat Man) to detonate for maximum desired effect. He often said to me that "somewhere there is a photograph of me with Fat Man" (the second of the two bombs, dropped over Nagasaki, Japan). He also told me that he designated the trajectory, flight path, and speed of the B-29s after dropping the bombs.

This was necessary so that this stripped B-29 bomber would not be blown apart by the shock waves following the detonation of the two bombs above each city. This was the first of many studies of shock waves and blast effects that he would make in the ensuing fifteen to twenty years. Back in Maryland, he also conducted research on early warning of ballistic missile attack, and later worked at General Electric on problems of the protection of missiles during atmospheric reentry.

For the next ten years (1945-1955), my father continued working at JHUAPL, and quite productively, keeping a list of his major writings and collaborations over the years. During the war, with Freeman K. Hill, he had translated Robert Sauer's *Introduction to Theoretical Gas Dynamics*[13,14,15] which, though initially restricted, was eventually published in English in

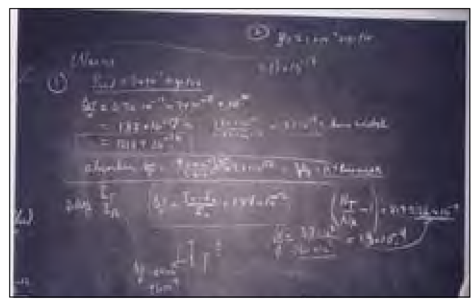

Figure 8. Polaroid Land Camera photograph of some blackboard calculations done in preparation for a paper on the Finlay-Freundlich Red Shift Hypothesis.

1947, as well as several other languages (French, Russian). Sauer's exposition was undoubtedly important for my dad's later work and that of Freeman Hill. Examination of a partial list of reports written by Ralph A. Alpher, solely or in collaboration with others, shows clearly that by 1955 he would have been considered an expert on guided missiles, interaction of shock waves with moving targets, air flow characteristics around missles, percussive blast effects, the use of radar in target acquisition, telemetry, and other applications of refined wartime technology.

By 1951 my father was already becoming familiar with the use of shock tubes in the study of damage from pressure blasts. He continued to work in later years with shock tubes in collaboration with Don White at the General Electric Corporate Research and Development Center (GECRD). So, although he had completed a great deal of theoretical work on the Big Bang by the mid-1950s (Figs. 7, 8, 9), he and one of his major collaborators, Dr. Robert C. Herman, seemed to go separate ways when Herman left JHUAPL for the General Motors Research Laboratories in Michigan, and Ralph Alpher left for GECRD in Schenectady, New York. Such an assumption would have been quite misleading.

My father had applied for positions at the University of Iowa in Iowa City (where James van Allen was chairman), Lawrence Livermore Laboratory (where Edward Teller was employed), California Institute of Technology, the Glenn L. Martin Company,[16,17,18] and other quasi-independent laboratories that had sprung up with government financing. These attractive institutions drained many scientists from academia during the 1950s with better pay and better research funding. My dad continued to be very productive, publishing and writing Big Bang and guided missile-related papers. Unfortunately, much of his written work for JHUAPL was classified and had limited distribution which continued to be a problem when he was with the General Electric company (including the constraints of limited distribution of work in which GE had a proprietary competitive interest). And to this day, much of the detailed work remains classified.

Series to be continued in the next issue.

Footnotes

1. Baldwin, Ralph. *The Deadly Fuse. Secret Weapon of World War II.* San Rafael, CA, Presidio Press, 1980.

2. Newpower, Anthony. *Iron Men and Tin Fish*. Westport, CT: Praeger Security International, 2006.

3. Gannon, Robert. *Hellions of the Deep*. State College, PA: Pennsylvania State University Press, 1996.

4. Boyce, Joseph C. *New Weapons for Air Warfare*. Part of a series of publications on science in World War II sponsored by the NDRC and OSRD, covering the work of Divisions 4, 5, and 7 of NDRC, and Section T, OSRD. Boston: Little, Brown & Co., 1947. By employing principles of the Proximity Fuze, stated J. A. Hynek, author of the Section T chapter, "prove-in tests of the Mark 9 provided a spectacular finish to a hectic development and production program" (p. 166). These were intended to explode under the keel, "breaking the back" of vessels attacked and sending them swiftly to the ocean bottom. A spectacular, dramatic version of such a keel attack (based on the real wartime reporting of Lothar Günther-Buchheim, Marinekriegsberichter (Naval War Reporter) for the Kriegsmarine on a wartime patrol aboard U-96) on the keel can be seen in the hugely successful German film about U-Boat warfare, *Das Boot* (1981), see www.imdb.com.

5. Davis, Leverett, Jr., Follin, James W., Jr., & Blitzer, Leon. *Exterior Ballistics of Rockets*. Princeton, NJ: D. Van Nostrand Co., Inc., 1958. The complexity of analyzing rocket ballistics is amply illustrated in Appendix A, which lists a staggering quantity of symbols for variables that may affect even a simple rocket's course. The authors note that classification difficulties would be inherent in any update of this text, the majority of which was actually written in 1946, when it was realized that much of the mass of scientific information produced under OSRD contracts needed to be assembled and written down in some systematic way.

6. See, for example, the many reports of the twenty-three administrative divisions, panels, and committees of the National Defense Research Committee, published following the war and classified originally as SECRET under the meaning of the Espionage Act, 50 U.S.C. 31 and 32, as amended, numbering eventually some seventy or so volumes. Of related interest see also Boyce, Joseph C. (Ed.), *New Weapons for Air Warfare: Fire-Control Equipment, Proximity Fuzes, and Guided Missiles*. Boston, MA: Little, Brown and Company, 1947; and, Baxter, James Phinney, III, *Scientists Against Time*. Boston, MA: Little, Brown, and Company, 1948. These works amply demonstrate how scientific research within industry and academia became intertwined with national defense for the first time, leading to what President Eisenhower termed the military-industrial complex in 1961 (see below).

7. Fleischer, Wolfgang. *The Wehrmacht Weapons Testing Ground at Kummersdorf*. Atglen, PA: Schiffer Military History, 1997. Translated from the German by David Johnson. Originally published as *Die Heerenversuchstelle Kummersdorf* by Podzun-Pallas Verlag.

8. Foerstner, Abigail. James van Allen. *The First Eight Billion Miles*. Iowa City: University of Iowa Press, 2007.

9. Ibid.

10. Locke, Arthur S. Guidance. In Merrill, G. (Ed.), *Principles of Guided Missile Design*. New York: D. Van Nostrand., 1955.

11. Department of the Army Technical Manual TM 9-1985-2 and Department of the Air Force Technical Order TO 11A-1-26. *German Explosive Ordnance (Bombs, Fuzes, Rockets, Land Mines, Grenades and Igniters)*. Washington, D.C.: Government Printing Office, 1953.

12. Department of the Army Technical Manual TM 9–1985-3 and Department of the Air Force Technical Order TO 39B-1A-10. *German Explosive Ordnance (Projectiles and Projectile Fuzes)*. Washington, D.C.: Government Printing Office, 1953.

13. Sauer, Robert. *Introduction to Theoretical Gas Dynamics*. Translated by Freeman K. Hill and Ralph A. Alpher. Ann Arbor, MI: J.W. Edwards, 1947. Originally published in 1943 by Springer-Verlag, Berlin.

14. Bauer, Friedrich L., & Schmidt, G. (eds.) (n.d.). *Erinnerungen an Robert Sauer*. Collection of papers in memory of Robert Sauer, a volume of papers presented following a conference in memory of Robert Sauer's life and work on 20 October, 1980. Berlin, Germany: Springer-Verlag.

15. Bauer, Friedrich L. (ed.). Robert Sauer and Klaus Samelson. Papers collected following a memorial colloquium on 5 October 1990. Club Informatik. E. V., Prof. Dr. Christoph Zenger, Director : 1999.

16. Letter dated 4 October, 1952 from Ralph A. Alpher to Dr. Henry Paul at the Radiation Laboratory, U.S. Geological Survey regarding a proposal for a book on "nuclear geology" in which Dr. Henry requested a chapter from Dr. Alpher. In this letter, Alpher mentions as the primary reason for declining that the "work in our Laboratory on *military and associated problems* (italics added; he had also referred to the great demands of his work at JHUAPL in his first response to Henry dated 31 July 1952) is occupying more and more of my time" noting that "what spare time I have is devoted to the furtherance of two research problems which I should like to complete while they are still of interest" (nucleosynthesis and the CMBR). My dad also noted that he was already commited to "one or two" articles for the *American Journal of Physics* and a "commitment of long standing for the preparation of a book" and therefore he had "no hope of fulfilling even these commitments in the foreseeable future." He also recommended a possible author for a chapter on nucleogenesis, referring to two review articles on which he was a coauthor with Dr. Robert Herman in the prior two years. A year later, on 25 October 1953, he nonetheless provided an extensive and thoughtful commentary on the chapters then assembled by Dr. Henry-which gives you an idea about how he treated projects to which he was not even committed.

17. Letter from J.J. Holley, Technical Employment Manager, The Glenn L. Martin Company, dated 20 August, 1955, regarding my father's decision to decline the company's offer of employment. Holley requested that he feel free in the future to reopen his application to the company, as "we should be more than pleased to have the opportunity to consider you."

18. Both the letter from Holley and his correspondence with Henry support the observation that cosmology, from graduate school forward, was an "after hours" endeavor which though groundbreaking, never threatened his primary vocational commitment. This meant days consumed with thinking about contemporary developing military problems, which, following the war through the mid-1960s, involved guided missiles and national defense.

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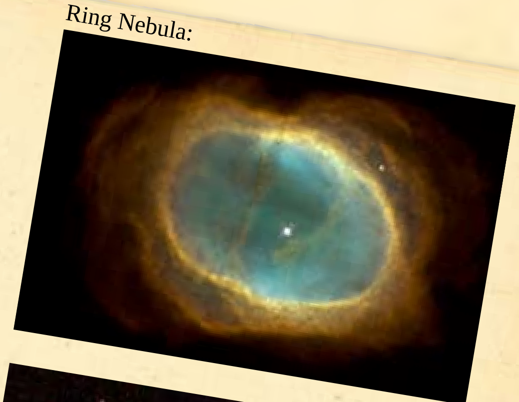


Over the course of their lifetime, stars change. For example, at a certain point in its lifetime, a red giant star puffs off its exterior gasses. The star's core collapses to form a white dwarf star. The result is called a "planetary nebula" (a misnomer, they have no connection to planet formation).

What to look for:

• Wispy cloud (called nebula). Some are spherical, but most have a double-lobe configuration, where matter has been ejected from the stellar poles. Sometimes the lobes are oriented head-on toward us and appear as a ring (for example, the Ring Nebula).

• Like snowflakes, no two of the same complex patterns in each nebula, indicative of multiple emissions by the dying star.

• Tiny white dwarf star in the center of the nebula. White dwarf star is the remnant of a once huge red giant star.

Stars are colorful: white, blue, red, yellow (our Sun appears yellow from within Earth's atmosphere). However, photos capture star color, as in this Hubble telescope image of a globular cluster.

Globular clusters are regions dense with stars -- located above and below the spiral arms of our galaxy. It is unknown why globular clusters formed.

What to look for:

• Globular clusters- star clusters with dense central regions.

• Red stars rule! Few blue stars!

Why more RED stars?

Red dwarf stars burn very slowly over time, while the bright blue stars burn fast and die young.

Comparing the relative abundance of long lived red dwarfs with the less prevalent stars of other colors in globular clusters allows astronomers to date our galaxy at about 13 billion years.[1]

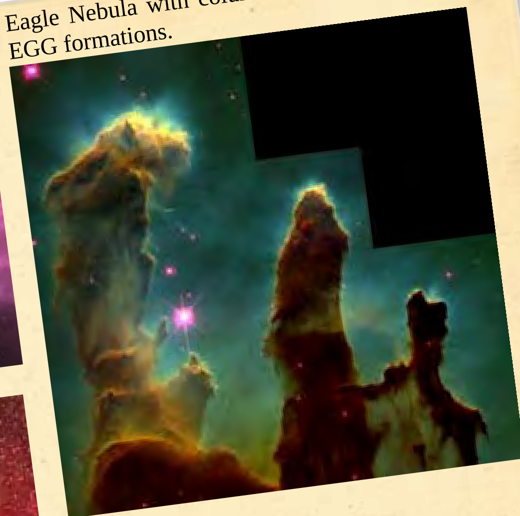
Also, aging yellow stars temporarily become red giants, adding to the population of red stars.

Photo of Globular cluster, Red stars rule!

[1]http://map.gsfc.nasa.gov/universe/uni_age.html

Photo of Horsehead Nebula

Eagle Nebula with columns and other smaller EGG formations.



Emission nebula:

Nebulae are clouds of gas and dust, remnants of previously exploded stars. Some nebulae form shapes appealing to the human eye, such as the Horsehead Nebula.

In dense nebulae, stellar material is recycled to form new stars, so that many nebulae act as baby star nurseries, where a new generation of stars is born.

What to look for:

Different types of nebulae including:

• Glowing nebulae ("emission nebula") composed of hot gases.

• Nebulae that are thermally cool just reflect light from nearby stars ("reflection nebula") but only if that light is available. Otherwise they appear dark. The Horsehead Nebula is illuminated from behind.

• Small dense regions called Evaporating Gaseous Globules, or EGGs, which are exposed via photo-evaporation by light from nearby stars. New stars are believed to form inside EGGs (no pun intended).

Photo of Gravitational lens

Einstein's General Theory of Relativity first predicted that light could be deflected by the gravitational well of a star or a galaxy.

Gravitational lenses have been used to observe other galaxies that are even more distant (and hence younger).

Micro-lensing has allowed astronomers to infer the presence of planets. Someday direct viewing of distant planets as small as earth may be possible.

What to look for:

• Central galaxy (or cluster of galaxies) that is creating the effect,

• Smeared/stretched repeating images of another object (such as a galaxy) around the periphery (blue in this photo).

Other great pictures can be obtained from NASA's Astronomy Picture of the Day website http://apod.nasa.gov/apod/archivepix.html

Another great website is: http://www.seds.org/MESSIER/

Elegant Connections in Physics

History of Big Bang Cosmology, Part 4: Alexander Friedmann and the Expanding Universe

Dwight E. Neuenschwander

This article continues a history of big bang cosmology with a summary of the work of Alexander Friedmann, "the man who made the universe expand."[1] In Part 1 we recalled how humanity became aware of spiral nebulae and, by 1924, began to appreciate the vast distances to them.[2] Part 2 addressed the "problem at infinity," the impossibility of an infinite array of stars in a static Newtonian universe to achieve long-term stability.[3] In Einstein's 1917 application of General Relativity (GR) to cosmology, he attempted to abolish the problem at infinity by abolishing infinity. He modeled the universe as a static population of stars in a spherical containing space closed back on itself (positive curvature). However, to make this solution work he had to introduce the cosmological constant Λ, that behaves as an anti-gravitational influence. Part 3 reviewed de Sitter's alternative to Einstein's solution for a closed static universe.[4]

Unlike Newtonian relativity, in Special Relativity the time interval dt and the space interval ds between two events are not separately invariant among all inertial reference frames. But the difference in their squares *is* invariant, and equals the square of the *proper* time $d\tau$ between the events, $d\tau^2 = dt^2 - ds^2$ (absorbing the speed of light into dt to measure time in meters).[5] GR allows transformations among *accelerated* frames. Thanks to the Principle of the Equivalence of gravitational and inertial mass, GR offers a theory of gravity. In terms of spacetime coordinates x^ν in an arbitrary coordinate system (Greek superscripts or subscripts denote one of the four spacetime dimensions), the spacetime interval between two nearby events generalizes to

$$d\tau^2 = g_{\mu\nu}\, dx^\mu\, dx^\nu \qquad (1)$$

(sum over repeated indices) where the coefficients $g_{\mu\nu}$ denote components of the metric tensor (or matrix) that convert coordinate displacements into distances.

To conceptualize his closed universe quantitatively,[6] Einstein imagined the three spatial dimensions to be the *surface* of a hypersphere of radius a embedded in a four-dimensional Euclidian space mapped with coordinates (x,y,z,u). Points on the surface of the hypersphere satisfy the equation

$$a^2 = x^2 + y^2 + z^2 + u^2 \equiv r^2 + u^2. \qquad (2)$$

As was shown in Parts 2 and 3 of this series, in such a geometry the metric of Eq. (1) is given by

$$d\tau^2 = dt^2 - (1 - r^2/a^2)^{-1}\, dr^2 - r^2 d\Omega^2\,. \qquad (3)$$

where (r,θ,ϕ) denote familiar spherical coordinates, with

$$d\Omega^2 \equiv d\theta^2 + \sin^2\theta\, d\phi^2. \qquad (4)$$

The value of the r-coordinate is defined as the circumference around the origin divided by 2π. Radial distance is not $\int dr$, but rather $\int (1 - r^2/a^2)^{-1/2}\, dr$. To calculate the volume of the closed universe, we calculate the surface area of the hypersphere. For this purpose, it's convenient to introduce another "latitude" χ defined by $r = a \sin\chi$. In terms of χ Eq. (3) may be written[7]

$$d\tau^2 = dt^2 - a^2(d\chi^2 + \sin^2\chi\, d\Omega^2). \qquad (5)$$

Integrating the surface area over the domains of $0 \le \chi \le \pi$, $0 \le \theta \le \pi$, and $0 \le \phi \le 2\pi$, we find the volume:

$$\int\int\int (a d\chi)\,(a \sin\chi\, d\theta)\,(a \sin\chi \sin\theta\, d\phi) = 2\pi^2 a^3. \qquad (6)$$

Einstein's task in 1917 was to determine if the metric of Eq. (3) was a solution to the GR field equations for cosmic sources of gravity. Those sources were expressed in the components $T_{\mu\nu}$ of the energy-momentum tensor, and in the cosmological constant Λ. The field equations, written schematically as

$$(g\partial g + \partial^2 g \text{ terms})_{\mu\nu} = -8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu} \qquad (7)$$

(G denotes Newton's gravitational constant) are a set of second-order partial differential equations that one solves for the metric tensor components, given the sources. Assuming an isotropic and homogeneous distribution of matter and radiation (justified by deep space surveys), and assuming a static universe, the spacetime interval could be parameterized as

$$d\tau^2 = e^{A(r)}\, dt^2 - e^{B(r)}\, dr^2 - r^2(d\theta^2 + \sin^2\theta d\phi^2). \qquad (8)$$

It remained to solve the field equations for $A(r)$ and $B(r)$. The nonzero components of $T_{\mu\nu}$ include the pressure P and energy density ρ. Einstein's field equations gave three differential equations relating A and B to the pressure and density. The simplest of these was

$$P' = -\tfrac{1}{2}(\rho + P)A' \qquad (9)$$

where the primes denote derivatives with respect to r. With uniform pressure, $P' = 0$. Because the masses of stars imply nonzero energy density, Einstein set $A' = 0$. The other field equations gave a spherical solution,

$$d\tau_E^2 = dt^2 - (1 - r^2/a_E^2)^{-1}\, dr^2 - r^2 d\Omega^2 \qquad (10)$$

with "Einstein radius" $a_E \equiv (\Lambda - 8\pi G P_o)^{-1/2}$.

De Sitter took another bizarre path offered by Eq. (9), allowing zero pressure and energy density, a model universe devoid of matter or radiation! But this led self-consistently to another closed static solution, that alters *both* the time and space dimensions:[8]

$$d\tau_S^2 = (1 - r^2/a_S^2)\, dt^2 - (1 - r^2/a_S^2)^{-1}\, dr^2 - r^2 d\Omega^2 \qquad (11)$$

with $a_S \equiv (\tfrac{1}{3}\Lambda)^{-1/2}$ the "de Sitter radius." In terms of the latitude variable χ the de Sitter metric becomes

$$d\tau_S^2 = \cos^2\chi\, dt^2 - a_S^2(d\chi^2 + \sin^2\chi\, d\Omega^2). \qquad (12)$$

Although de Sitter's model universe contains no matter or radiation, it was thought to be a first approximation to the real universe because the density of matter and the pressure of light are cosmically low.

Both models make predictions about redshifts, the fractional change in wavelength, $\Delta\lambda/\lambda$. As told in Part 3, Einstein's model had matter with curvature but no cosmic redshifts, and de Sitter's model had curvature and cosmic redshifts without matter! The real universe shows matter *and* redshifts! Although the Einstein and de Sitter models started modern cosmology, the subject stalled there for about five years. The sticking point was the assumption of a static universe. Its tenacity must be understood to appreciate how radical was the notion of a dynamic universe. Friedmann's biographers emphasize it:

"The long-established scientific and philosophical tradition, the accepted paradigm, described the Universe as static and invariable, which was seen as its most important property. It appeared to be an extremely stable element of the generally accepted vision of the world worked out through the efforts of many generations of thinkers. This view of the world was based on ideas about the uncreatedness of

the Universe; it was thought for many centuries that the scientific approach to the Universe requires recognition of its eternity and identity to itself at all times. Einstein, as we have seen, also proceeded from this assumption; his point of view was shared by de Sitter and, as far as we know, by all other physicists and astronomers who were concerned at the time with cosmological problems..."[9]

Tentative steps towards loosening the rigidities of a static universe were taken by Comes Lanzcos (1922), Georges Lemaître (1925), and H.P. Robertson (1928), who performed coordinate transformations on the de Sitter metric, putting some time-dependence into the coefficients of the spatial displacements. But new thinking came from Russia, in the person of Alexander A. Friedmann. In 1922 and 1924 he published two revolutionary papers that were unfortunately overlooked at the time. The 1922 paper showed a time-dependent radius $a = a(t)$ to be consistent with GR: a closed universe could be *dynamic*. The 1924 paper showed that Einstein's equations also allowed an "open" hyperbolic (negative curvature) universe.

Alexander A. Friedmann

Alexander Alexandrovich Friedmann (Fig. 1) was born into a musical family, in St. Petersburg, Russia, in 1888. As a secondary-school student he took an active role in the student movement of 1905-06. Through meetings and manifestos, lockouts and strikes, in which Alexander was a member of the student organization's Central Committee, the dissidents won some control over instructional processes and concessions for changing school rules. In 1906 our young revolutionary entered the department of Physics and Mathematics at St. Petersburg University, from where he graduated in 1910. Throughout his career he was interested in meteorology and aeronautics. In World War I he served in the aviation units of the southern and northern fronts, and became an instructor at a Kiev pilot training school. Following a stint as Director of the Moscow Aviapribor plant, he returned to academic life as the Chair of Mechanics at Perm University (1918-20), landing finally at Petrograd University.

Friedmann was blessed with broad interests and far-ranging abilities. The year of his first cosmology paper he also published a book called *The Hydromechanics of a Compressible Fluid*. When he published his second cosmology paper, he also happened to be editor of the journal *Geophysics and Meteorology*.

Because of the Great War and the blockade of Soviet Russia, it was not until 1921 that a review of GR was published in a Soviet journal by Friedmann's colleague, Vsevelod K. Frederiks. In the 1920's Friedmann and Frederiks organized seminars on GR at

Leningrad University

Fig. 1. Alexander A. Friedmann.

Petrograd University. In them Frederiks was noted for emphasizing qualitative physical understanding, and Friedmann for precise mathematical rigor. Indeed, it was the theory's mathematical challenges that attracted Friedmann to GR in the first place. By 1923 he had completed a 131-page book on relativity, written originally for the philosophical journal *Mysl* (Thought), which came out as a separate edition in 1923. This rare book was called *The World as Space and Time* ("the world" meant "the universe").[10] Friedmann and Frederiks co-authored a five-volume technical monograph, *Fundamentals of the Theory of Relativity*. Its publication began in 1924 with *Part 1: Tensor Calculus*. Unfortunately, the rest of the series was not completed. In July 1925 Friedmann and a colleague, P.F. Fedoseyenko, ascended in a meteorological research balloon to a record-breaking altitude of 7,400 meters. Sadly, a month later Alexander Alexandrovich fell ill, the doctors diagnosed typhoid fever, and he passed away on September 16, only 37 years old.[11]

The 1922 Paper on the Expanding Universe

Friedmann's radical cosmology paper bears the modest title "On the curvature of space," but the subject is dynamics.[12] Like Einstein and de Sitter, Friedmann concerned himself with a closed universe, and he also modeled the matter and radiation as an ideal dust of energy density ρ and pressure P. His point of departure was allowing the radius of curvature to vary with time. Writing again $r = a \sin\chi$, Friedmann parameterized the metric as

$$d\tau^2 = dt^2 - a^2(t)\,(d\chi^2 + \sin^2\chi\, d\Omega^2). \qquad (13)$$

Plugging these metric tensor components into Eq. (7) produces a pair of differential equations which allow the radius of curvature $a(t)$ to change *and* accelerate:

$$(da/dt)^2 + 1 = (8\pi G/3)\,\rho a^2 + \tfrac{1}{3}\Lambda a^2 \qquad (14)$$

and

$$d^2a/dt^2 = -(4\pi G/3)(\rho + 3P)a + \tfrac{1}{3}\Lambda a. \qquad (15)$$

Considering a universe of negligible pressure, Friedmann set $P = 0$. Eliminating the energy density ρ between Eqs. (14) and (15) gives

$$2a\, d^2a/dt^2 + (da/dt)^2 + 1 - \Lambda a^2 = 0. \qquad (16)$$

Writing out $d/dt\,[a\,(da/dt)^2]$, this may be integrated, to produce

$$a\,(da/dt)^2 = a_1 - a + \tfrac{1}{3}\Lambda a^3 \qquad (17)$$

with integration constant a_1. Substituting Eq. (17) into Eq. (14) yields

$$\rho = 3a_1/(8\pi G\, a^3). \qquad (18)$$

To fix a_1, for a closed universe, we may define a "mass parameter" M from the density and volume of the universe:

$$\rho \equiv M/(2\pi a^3). \qquad (19)$$

Strictly speaking this M is *not*, numerically or conceptually, the "mass of the universe." Rather, Eq. (19) merely *defines* M. To see what is at issue here, recall that to measure the Earth's mass we *infer* it using data from a satellite's orbit period and radius as input into Kepler's Third Law. But we cannot orbit the entire universe to measure its mass! Be that as it may, Eqs. (18) and (19) fix the integration constant in terms of M:

$$a_1 = 4GM/3. \qquad (20)$$

The Friedmann equations may now be simply written as an apparent "conservation of energy" or "velocity equation,"[13]

$$(da/dt)^2 + 1 = a_1/a + \tfrac{1}{3}\Lambda a^2. \qquad (21)$$

and an "acceleration equation,"

$$d^2a/dt^2 = -\tfrac{1}{2}\, a_1/a^2 + \tfrac{1}{3}\Lambda a. \qquad (22)$$

The study of the evolution of $a(t)$ now forms our primary task.

If a begins from zero, then in that first instant the radius of curvature of this model universe expands infinitely fast, from a state of infinite energy density. The subsequent expansion, however, is described by well-behaved functions. Friedmann's biographers wrote, "The discovery of the initial singularity is one of the most remarkable achievements of Friedmann's theory. Friedmann did not dwell

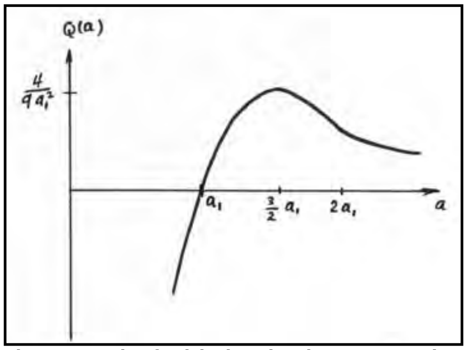


Fig. 2. Graph of Q(a) showing its asymptotic behavior as a_1 0 and as a →∞. A zero of Q occurs at a = a1, its maximum at a = $3a_1/2$, and an inflection point at a = $2a_1$.

too much on this question..., only stating the fact as such..."[14]

Consider the universe at small but finite values of a, when $a_1/a >> ⅓\Lambda a^2 - 1$. In this epoch the Friedmann velocity equation, Eq. (21), gives approximately

$$(da/dt)^2 \approx a_1/a \qquad (23)$$

which integrates to a power law, $a(t) \sim t^{2/3}$, which you can verify to be consistent with the acceleration equation. If the universe continues to expand and $a(t)$ encounters no turning points, eventually a grows so large that the universe approaches a state of vanishing energy density and $⅓\Lambda a^2 >> a_1/a - 1$. Then the Friedmann equations become

$$(dr/dt)^2 \approx ⅓\Lambda a^2 \qquad (24)$$

and

$$d^2a/dt^2 \approx ⅓\Lambda a. \qquad (25)$$

Both of these give an accelerating, exponential expansion that evolves asymptotically into a de Sitter state, $a \sim e^{⅓\Lambda t}$.

Having examined the extremes, now let's look at more nuanced behavior of $a(t)$, including possible turning points encountered during the expansion. Transpose Eq. (21) into

$$da/dt = \pm\, {}^2⅓a\, [\,\Lambda - Q(a)]^{½}. \qquad (26)$$

where

$$Q(a) \equiv (3/a^3)(a - a_1)\,. \qquad (27)$$

Eq. (26) predicts the universe may expand (positive sign) or contract (negative sign), provided the quantity inside the square root remains always non-negative to maintain da/dt as a real number. A root of $\Lambda = Q(a)$ determines a turning point, where $da/dt = 0$. To investigate possible turning points for a given value of Λ, let's collect the information needed to sketch $Q(a)$.

First, notice that $Q \to -\infty$ as $a \to 0$, $Q(a)$ crosses the a-axis at $a = a_1$, and $Q \to 0$ asymptotically as $a \to \infty$. Next, locate maxima and minima. The first and second derivatives of Q are

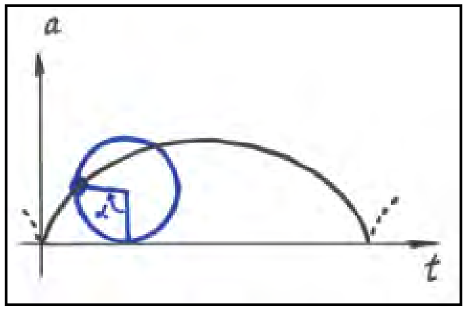


Fig. 3. The expansion and re-contraction of the Friedmann closed universe. The curve is the parametric solution of Eq. (35).

$$Q'' = (3/a^3)\,(3a_1/a - 2) \qquad (28)$$

and

$$Q'' = (18/a^4)\,(1 - 2a_1/a) \qquad (29)$$

(prime means d/da). The first derivative vanishes at the $a \to \infty$ asymptote, and more interestingly also at the finite critical point $a_c = 3a_1/2$. At that critical point $Q'' < 0$, so $Q(a)$ exhibits a *maximum* there, and in particular,

$$Q_{max} = Q(a_c) = 4/9a_1^2. \qquad (30)$$

The second derivative of Q indicates the existence of an inflection point at $a = 2a_1$, where $Q'' < 0$ for $a < 2a_1$, and $Q'' > 0$ for $a > 2a_1$. Now we have enough information to make a rough sketch a graph of $Q(a)$, as in Fig. 2.

Friedmann put some numbers into his model. He estimated a universe with "the mass of 5×10^{21} of our suns,"[15] for which $GM/c^2 = 7.5\times10^{25}$ m, so that, in conventional units,

$$a_1 = 4GM/3\pi c^2 \approx 3\times10^{25}\text{ m} \sim ⅓\times10^{10}\text{ ly}, \quad (31)$$

$$Q_{max} = 4/9a_1^{\,2} = \pi^2(c^2/GM)^2 \sim 10^{-50}\text{ m}^{-2}\,. \quad (32)$$

Now we can return to the equations for the velocity and the acceleration of the expansion, Eqs. (21) and (22), and draw some conclusions for various values of Λ. For da/dt to be real, the Eq. (26) demands

$$\Lambda \geq Q(a) \text{ where } Q_{max} = 4/9a_1^2. \qquad (33)$$

Consider three cases:

(a) $\Lambda > Q_{max}$. From Eq. (26) we find that da/dt remains a real number for all values of a from zero to infinity, and, if da/dt is positive (redshifts!), the universe *keeps* expanding monatonically while experiencing gravitational deceleration from $a = 0$ to $a = 2a_1$. For $a > 2a_1$ the expansion accelerates with a positive sign as the cosmological constant dominates over energy density, an exponential expansion to a dynamic de Sitter state.

(b) If $\Lambda = Q_{max}$ precisely, then as a evolves from zero it decelerates until reaching $a = 3a_1/2$, where the expansion halts. Looking back to our discussion of the Einstein universe

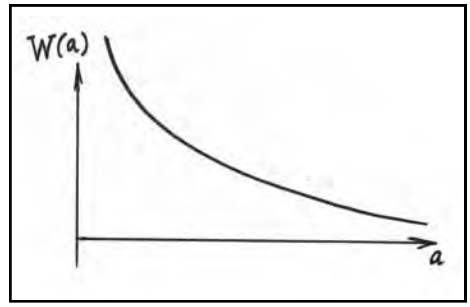


Fig. 4. W(a) for the open universe model. As a increases from 0, W begins from a singularity, decreasing asymptotically to 0 as a →∞.

with its radius $a_E = 3a_1/2$, we now appreciate how the Einstein universe is contained within the Friedmann model as a special case. In that context, the Einstein universe is now seen to be highly unstable, poised on a precarious peak at $a = 3a_1/2$. If through some fluctuation a decreases ever so slightly, then the universe collapses; or if a increases a tiny amount above $3a_1/2$ the universe irreversibly expands.

(c) Suppose $0 \leq \Lambda < Q_{max}$. Now a genuine turning point exists when $\Lambda = Q(a) < Q_{max}$. The cubic equation

$$a = a_1 + ⅓\Lambda a^3 \qquad (34)$$

holds a turning point a_T as its solution. But even without solving the cubic equation explicitly, we see that the turning point occurs in the range $a_1 \leq a_T < 3a_1/2$. If the universe begins with $a = 0$, it expands until $a = a_T$. Because $Q'' < 0$ here, the universe stops expanding and begins to contract, falling eventually back to $a = 0$. During the era of contraction, any observer watching the galaxies would see blueshifts prior to the inevitable "crunch." Could an "oscillating universe," an infinity of repeating cycles of expansion and contraction, be possible? That speculation would be difficult to reconcile with the Second Law of Thermodynamics!

A case of an expansion to maximum size that is followed by a contraction emerges in its simplest form in the special case $\Lambda = 0$. With the change of variable $d\alpha = dt/a(t)$,[16] you may show that the parametric solution of the cycloid emerges from Eqs. (21) and (22):

$$a = ½a_1\,(1 - \cos\alpha), \quad t = ½a_1\,(\alpha - \sin\alpha). \quad (35)$$

This solution describes a trajectory in of a point on the rim of a rolling wheel of radius $½a_1$, as in Fig. 3.

The expansion starts from $a = 0$ at $t = 0$, reaches maximum radius at time $t = ½\pi a_1$, then re-collapses back to zero radius. The period for one cycle is $T = a_1\pi = 4GM/3\pi c^3$ (restoring c for conventional units), for which Friedmann's numbers imply $T \sim 10^{10}$ y.

The 1924 Paper: A World with Negative Curvature

At the suggestion of his close friend and colleague Y.D. Tamarkin, in 1923 Friedmann turned his attention to the application in GR of Lobachevskian geometry, spaces of negative curvature. The result, a paper called "On the possibility of a world with constant negative curvature," was finished in November 1923, and published in the January-February 1924 issue of *Zietschrift für Physik*.[17]

One can try to imagine non-spherical hypersurfaces embedded in 4-D Euclidian space. Consider a hyperbolic surface. The equation of its surface replaces one plus sign in Eq. (2) with a minus sign,

$$a^2 = r^2 - u^2. \qquad (36)$$

In contrast to Eq. (3), the coefficient of dr^2 in the metric acquires an internal plus sign,

$$d\tau^2 = dt^2 - (1+ r^2/a^2)^{-1}\, dr^2 - r^2 d\Omega^2. \qquad (37)$$

The acceleration equation remains as before, but the velocity equation acquires a sign difference:

$$(da/dt)^2 - 1 = a_1/a + \tfrac{1}{3}\Lambda a^2. \qquad (38)$$

The $a \sim t^{2/3}$ power law for the early universe, and the $a \sim e^{\frac{1}{3}\Lambda t}$ accelerating expansion for the old universe appear as they did for the closed universe. At any value of a,

$$da/dt = \pm\, {}^2\!\tfrac{1}{3}a\, [\,\Lambda + W(a)]^{1/2}. \qquad (39)$$

where

$$W(a) \equiv (3/a^3)(a + a_1)\,. \qquad (40)$$

Again the velocity equation allows the universe to expand or contract, provided the quantity inside the square root remains non-negative. Proceeding as before, we find that, for nonzero but finite a, W exhibits no maximum or minimum. A sketch of $W(a)$ appears in Fig. 4.

The open universe *inevitably* expands forever, for any value of $\Lambda \geq 0$.

To sum up for now: In terms of the "latitude" variable χ we may paramaterize the closed and open geometries as

$$d\tau^2 = dt^2 - a^2(t)\,[d\chi^2 - S^2(\chi)\, d\Omega^2] \qquad (41)$$

with

$$S(\chi) = \sin\chi; \quad \text{closed, } 0 \leq \chi \leq \pi \qquad (42)$$

$$\text{or } S(\chi) = \sinh\chi; \quad \text{open, } \chi \in [0, \infty) \qquad (43)$$

The Velocity-Distance Relation

The Friedmann models predict the astonishing velocity-distance relation.[18] The expansion carries apart any two points A and B located at fixed *coordinates*. A and B do not move *through* space; they are carried apart, at a rate proportional to their separation, by the *stretching of space itself*. We can see this feature emerge from Eq. (41), in the expression for the distance s:

$$s = a \int d\eta \qquad (44)$$

where $\int d\eta \equiv \int\sqrt{[d\chi^2 + S^2(\chi)\, d\Omega^2]}$. Thanks to the growth of a, by virtue of Eqs. (21) and (44), the *distance* between two points located at fixed *coordinates* in space increases at the rate

$$ds/dt = (da/dt) \int d\eta$$

$$= [\tfrac{1}{3}\Lambda + (1/a^3)(a_1 \mp a)\,]^{1/2}\; s \qquad (45)$$

where the minus sign holds for the closed universe and the plus sign for the open universe. Notice that the velocity v of one of point relative to another (both at fixed coordinates) is ds/dt. Furthermore, if we define the "Hubble parameter"

$$H(t) \equiv (1/a)\,(da/dt), \qquad (46)$$

then Eq. (21) may be written in terms of it as

$$H(t) = [\tfrac{1}{3}\Lambda + (1/a^3)(a_1 \mp a)\,]^{1/2}. \qquad (47)$$

Importing $H(t)$ back into Eq. (48), we now see a linear "velocity-distance relation,"

$$v = Hs. \qquad (48)$$

If we let t_o denote the present age of the universe, with $a(t_o) \equiv a_o$, then $v = H_o s$, where H_o denotes the rate of cosmic expansion for the present epoch. This H_o is today called "Hubble's constant." Notice that a redshift is proportional to v, so the *linear* velocity-distance relation contrasts distinguishably from the *quadratic* de Sitter redshift. The interpretation of this linear result, which picked up the name "Hubble's Law" after it was demonstrated observationally in 1929,[19] goes as follows.

At the cosmic scale, *any* two points in the universe are carried apart by the expansion with a relative velocity proportional to the separation between them. The "expansion of the universe" means that *space itself* gets stretched. To use the venerable metaphor, picture space as a rubber sheet, and the galaxies as pennies sitting on it. As the sheet gets stretched the pennies are carried apart, but do not expand themselves, because they are held together by their own local internal forces.

A quantitative metaphor for visualizing the expansion can be seen with the enlargement feature of photocopy machines.[20] Draw three dots, A, B, and C on a sheet of paper. Place B 10 cm from A and put C 20 cm from A. Now enlarge the image by 5%. In the enlargement, all distances are stretched by a factor of 1.05. The new distances are AB = 10.5 cm, and AC = 21.0 cm. The original and enlarged images show two time slices for this "universe." During that time interval, B receded 0.5 cm from A, and C moved 1.0 cm from A. Therefore, relative to dot A, dot C moves twice as fast as dot B. Relative velocity and separation are proportional, the linear "velocity-distance relation," a "Hubble expansion!"

Even though observers on A see *all* points receding from them, their home A does *not* reside at the center of the expansion. No objective "center" exists! Observers on B or C see all other points receding from *them* with the *same* velocity-distance relationship.

Now run this movie backwards. The points A, B, and C get closer and closer together. If they are plotted on a grid, the grid *mesh* shrinks smaller and smaller, even though the *coordinates* of A, B, and C stay the same. Shrinking the scale all the way to zero, all points come together, the initial singularity.

Alas, the influence of Friedmann's paper had to await a renaissance in cosmology that began in 1929 when, on the observational side, Edwin Hubble published data showing that the velocity-distance relation had to be taken seriously. On the theoretical side, Friedmann's conclusions were re-discovered independently by Georges Lemaître in 1927. He was perhaps the first person to take seriously the physical inferences of the very early universe as a physical system. Thus was the stage set when, in 1948, Ralph Alpher and George Gamow made the first attempt at calculating the relative abundances of the nuclei that should precipitate out of an expanding universe.[21] We will visit their stories in the next installment of this series.

Acknowledgment

With deep gratitude I thank Charles Misner for his generous advice given at the beginning of this multi-article project.

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[10] A second edition was published in 1965, a third in 1966.
[11] Biographical notes gleaned from various passages of Ref. 1.
[12] A. Friedmann, "On the Curvature of Space," *Zeitschrift für Physik* **10**, 379 (1922).
[13] Because of the analogy between Eq. (21) and conservation of energy in a Newtonian gravitation problem, and the similarity between Eq. (25) and $F = ma$, one can develop some limited features in the dynamics of the cosmic expansion in a pseudo-Newtonian approach. This perspective was introduced by W.H. McCrea and E.A. Milne, Quarterly J. Math. (Oxford) **5**, 73 (1934); E.A. Milne, Quarterly J. Math. (Oxford) **5**, 64 (1934); explained by Misner, Thorne, Wheeler in Ref. 6, pp. 704-710; and utilized (with caveats mentioned) for a popular audience by S. Weinberg in *The First Three Minutes* (Basic Books, 1988), Appendix.
[14] Tropp *et. al.*, Ref. 1, p. 158.
[15] *ibid*., p. 158.
[16] E.g., see E.F. Taylor and J.A. Wheeler, *Black Holes: Introduction to General Relativity* (Freeman, 2000), p. G-7.
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[18] Hermann Weyl had developed a linear velocity-distance relation earlier with the de Sitter model. For an overview see J.E. Peebles, *Principles of Physical Cosmology* (Princeton Univ. Press, 1993), p. 81.
[19] Edwin Hubble, "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae," *Proc. Natl. Acad. of Sciences of the U.S.A.* **15,** 168-173 (1929). Like Ohm's Law, Hubble's Law is ultimately a linear approximation to more complex phenomena. *Departures* from Hubble's Law for deep space are of special interest, as we will discuss in later installments of this series.
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Physics News Update

The American Institute of Physics Bulletin of Research News

Top Ten Physics Stories of 2008

by Phil Schewe

Former presidential science advisor Vannevar Bush referred to science as an endless frontier of new discoveries. So what were the big physics findings for 2008? Editors and science writers at the American Institute of Physics and the American Physical Society have winnowed a wealth of stories and discoveries into ten topic areas, a sampling of which follows, in no particular order. For the complete top ten topic areas, as well as background information and photos on each topic, visit: www.aip.org/pnu/2008/split/879-1.html

SUPERCONDUCTORS

What's new–discovery of an unusual class of materials made from iron and arsenic. Superconductors don't lose any energy when electricity runs through them, providing they're chilled to very low temperatures. Superconductors are used in specialty applications where high electrical currents are needed, such as in MRI scanners at hospitals or in the magnets used to steer particles at atom smashers. There are two reasons that superconductors aren't used more widely, such as for carrying electrical power: superconductors need lots of cooling apparatus and it's hard to turn the material into miles-long strands of wire. The new iron-arsenic materials are the first relatively high-temperature materials that remain superconducting above a temperature of 50 K that don't contain copper; the copper materials are brittle. Researchers hope that the iron-arsenic version might lead to the more practical manufacture of superconducting wire. Furthermore, having a new class of materials to study should help theorists understand how high-temperature superconductors work in the first place.

LARGE HADRON COLLIDER

What's new–the LHC, the world's largest scientific instrument, started operations in September. At this huge particle accelerator, located underground near Geneva, Switzerland, two beams of protons, each traveling at unprecedented speeds will be smashed together. The goal is to create exotic new particles that can't be observed in any other way except in the tiny fireball created by such violent collisions. These collisions have not yet occurred, but physicists did succeed in sending proton beams in both directions around LHC's 27-km (16 mile) circular path. Problems with some of the apparatus forced a premature shutdown shortly thereafter. General operations should resume in summer 2009.

PLANETS

What's new–planets orbiting distant stars have been imaged directly, and a host of interesting results have come back from spacecraft hovering near the planets in our own solar system. Extrasolar planets, planets orbiting far-away stars, had been detected indirectly by watching what happens to the light coming from the star. But now the glare of the star has been blocked sufficiently so that the extrasolar planet itself could be imaged. The Gemini, Keck, and Hubble telescopes provided pictures.

In our own solar system, at Mercury, the Messenger spacecraft (which will be the first to orbit the planet) made first-ever maps of large portions of the surface. It also determined that Mercury's magnetic field is highly symmetric. At Saturn, the Cassini craft found geysers near the south end of the moon Enceladus. At Mars, measurements made by several craft strengthened evidence in favor of sub-surface glaciers outside the polar regions. Meanwhile, the Venus Express craft recorded pictures at several wavelengths, facilitating, among other things, a better knowledge of clouds on Venus.

NASA/JPL/Space Science Institute

Cassini imaging scientists used views like this one to help them identify the source locations for individual jets spurting ice particles, water vapor and trace organic compounds from the surface of Saturn's moon Enceladus.

Spotlight on SPS Outreach

Fun with physics: Union students inspire local youngsters

The Chronicle, November 13, 2008: Volume 74, Number 10. Reprinted with permission

Buckets, balls, bananas and balloons – these are some of the ordinary objects Union students used to take physics lessons out of the textbook and into the hands and minds of fourth-, fifth- and sixth-graders.

Tom Perry ('09), Daniel Otto ('11), Shivani Pathak ('10) and Hillary Bauer ('11), all members of the Society of Physics Students, Union College Chapter, joined Professor Samuel Amanuel at Schenectady's Katharine Burr Blodgett Elementary School last week. They performed experiments and did other "really cool, interesting stuff," as Perry told his young audience.

One of those cool things was overturning a bucket with liquid that immediately turned into a gas that permeated the air, surprising and delighting the children. Perry explained that it was liquid nitrogen, which is a liquid when cold but turns to gas at room temperature.

Shivani Pathak ('10) captivates her young audience.

The Chronicle, Union College, NY

The Union classmates also submerged a rubber ball, banana and balloons in the liquid nitrogen, then showed how the banana broke like glass when hit with a hammer. The children had one word for it: "Wow."

"We want to trigger the youngsters' interest in the field of science and encourage them to start looking ahead to college," Amanuel said.

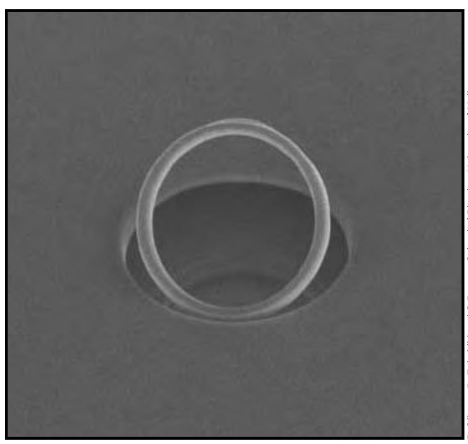
The physics visit was part of a program with Union's Kenney Community Center, which has a longstanding relationship with Blodgett Principal Nancy Fontaine, formerly a teacher leader for Kenney's SAIL (Studying Arithmetic in Literature) Program.

"We're constantly looking for ways to bring our students and the city students together," said Kenney Director Angela Tatem.

Not only does the physics outreach enrich the undergraduate experience, she said, but it lets local school children "know that this is where they can meet people who are interested in seeing them succeed."

DIAMOND DETECTORS

What's new–getting little imperfections in diamonds to tell us about how atoms behave like tiny magnets. Diamonds are much favored for their hardness and for their clarity, which makes them popular in jewelry. But they might also be useful in creating a new type of electronic circuit. Diamond is made of a cross-linking of carbon atoms. If one carbon atom is missing from this network, the empty hole, in combination with a stray nitrogen atom, acts as a sort of strange molecule in the middle of all those carbon atoms. This "molecule" can light up like a little LED when you shine laser light in. This in turn, can be used to measure extremely weak magnetism. Possible applications include data storage for computers or high-sensitivity detectors. Manipulating the spin of an electron caught in a vacancy within a diamond sample, scientists from Delft University of Technology and the University of California at Santa Barbara detected the spin of a single electron (*Science*, April 18); while a Harvard group (*Nature*, 2 Oct) located the position of a single carbon-11 impurity in diamond to within 1 nanometer through the carbon atom's nuclear spin interactions.



P. Olivero, B. Fairchild and S.Prawer, School of Physics, University of Melbourne.

Picture of the world's smallest diamond ring, measuring 300 nanometers (billionths of a meter) thick and 5 microns (millionths of a meter) across. A diamond is not mounted on a ring: the ring itself is made of diamond. It was made by carving out a circular structure in an artifically made diamond. The ring will be used to access single photons coming out of a tiny impurity region inside the diamond.

FARTHEST SEEABLE THING

What's new–seeing a flash of light from 7 billion light years away. One of the brightest of all celestial objects is gamma-ray bursters, objects that emit immense amounts of gamma radiation, the highest-energy form of light. The brightest-ever gamma ray burster was observed by the Swift satellite–specially designed to detect gamma rays–and other telescopes as well. They deduce that this burst event came from a place in space 7 billion light years away, and was bright enough to have been observable by the naked eye. Since looking out into space is equivalent to looking back in time, this flash would have been coming from a moment when the universe was only half its present age.

MACROSCOPIC FEEDBACK COOLING

What's new–Scientists at the AURIGA lab in Padova, Italy have cooled a one-ton aluminum bar to a temperature below 1 milli-kelvin using special electrical circuits. The bar is part of a detector designed to measure passing gravity waves from space. Using sensitive magnetic sensors and feedback coils, the ringing of the bar (which is essentially a large tuning fork) at one characteristic frequency was cooled from an equivalent temperature of 4 K (the temperature of the bath of liquid helium in which the bar sits) to a temperature of about 0.17 mK. Lower temperatures than this have been achieved with this feedback cooling technique but only with much smaller masses.

A Universe of Wonder

SPS Celebrates International Year of Astronomy 2009 (IYA2009)

The International Year of Astronomy 2009 is a global effort initiated by the International Astronomical Union (IAU) and UNESCO to help the citizens of the world re-discover their place in the Universe through the day- and night-time sky, and thereby engage a personal sense of wonder and discovery. See www.astronomy2009.org for details.

SPS Statement on the International Year of Astronomy 2009

-by the SPS National Council

The Society of Physics Students (SPS) is pleased to partner with and offer its unqualified support for the International Year of Astronomy in 2009. The SPS is proud to be a part of the effort in the IYA 2009 to raise awareness of astronomy. In keeping with the IYA theme "The Universe, Yours to Discover" the Society of Physics Students has chosen "A Universe of Wonder" for its theme in 2009. We believe this theme compliments that of the IYA and offers the SPS an opportunity to help advance not only astronomy and cosmology, but also such diverse areas of physics such as quantum gravity, particle physics and string theory. These areas – and others – are playing a vital role in contributing to our understanding of the universe. The Society of Physics Students is proud to lend its support to the efforts of all the individuals who are working to make the IYA 2009 a reality.

While physics and astronomy are related yet distinct, the fields share many of the same goals – none greater than educating the public about science and science policy issues. An informed electorate is a vital part of any democratic society, and it is the duty of all scientists to help advance the dialog between citizens and their government whenever possible. The IYA 2009 offers us all the opportunity to lend our voices to the discussions of issues which impact us all, and the SPS can help by lending its voice to the chorus of others.

The events and activities that are planned for the IYA are meant to showcase astronomy and related issues for the general public. The numerous national and local events planned for the IYA 2009 share many of the same attributes as SPS activities. By involving SPS chapters around the country during IYA 2009 activities, we draw on the strengths of various members of the SPS that can help make the IYA 2009 successful in reaching a larger audience.

All too often we pass up the opportunity to participate in events that enrich us in many ways. Bound by the constraints of our daily lives, we miss participating in events that can truly change our world. Let us not pass up the challenge to be involved in the IYA 2009 activities that will enrich us all.

In this spirit, SPS also recognizes the 2009 Year of Science (www.copusproject.org/yearofscience2009/), led by the Coalition on the Public Understanding of Science (COPUS), and the 2007-09 Year of Planet Earth (www.yearofplanetearth.org/), a joint initiative by UNESCO and the International Union of Geological Sciences (IUGS).

IYA2009 in the United States

Working with the IAU and other astronomy partners, the American Astronomical Society (AAS) will help organize and carry out a dynamic program of activities for the International Year of Astronomy. Students can join the AAS as Junior Members and get two years for the price of one. See details at: www.aas.org/membership/classes.php

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