The Art of Physics

Tuesday, February 8, 2011
Rackham Amphitheater
4:10 PM

Carl W. Akerlof
Professor of Physics

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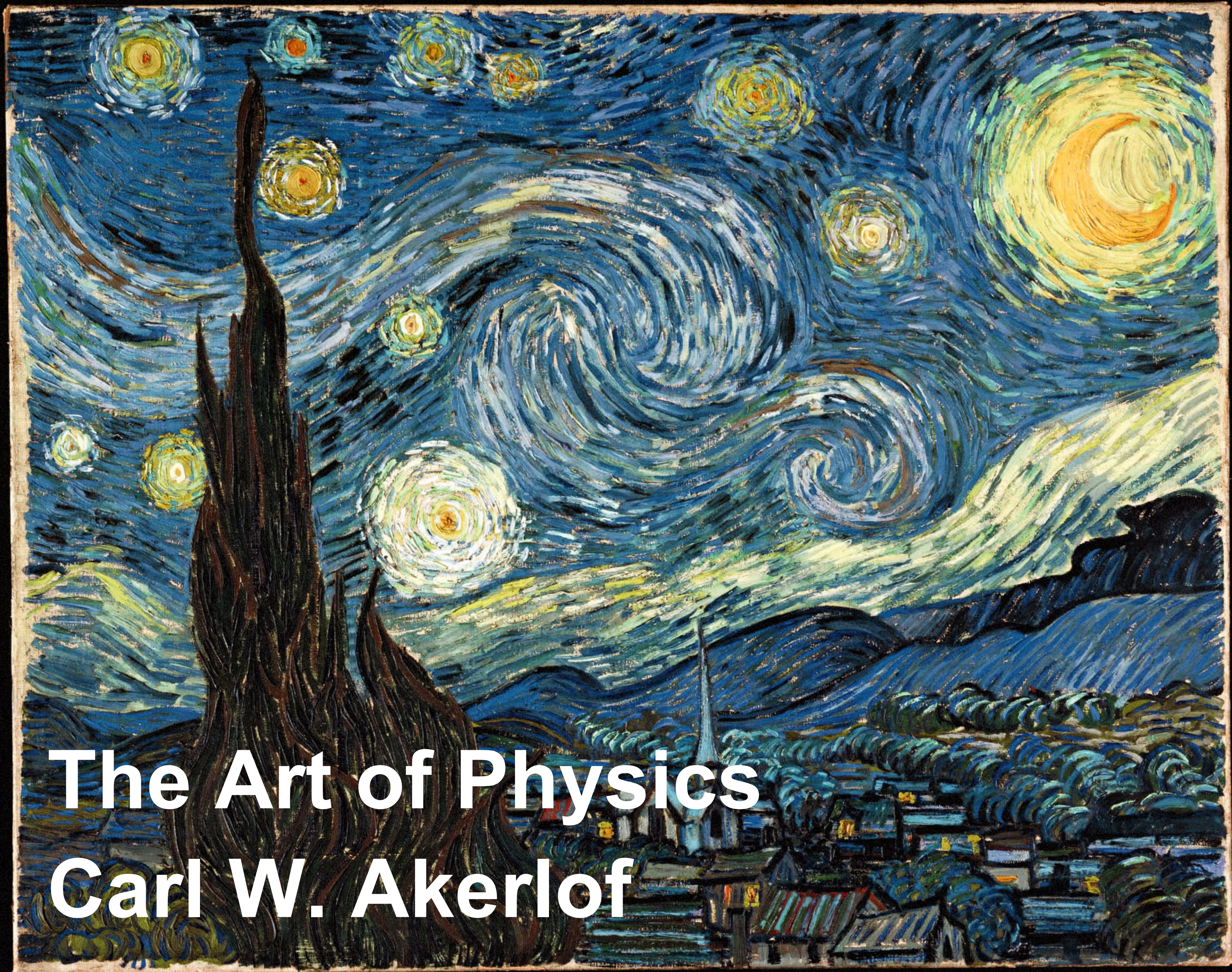
First of all, I would like to thank you all for this opportunity to discuss the enterprise of investigating our natural world. I must confess that as I was beginning to put together the material for this talk, I happened upon a rather distressing article in the New York Times. Apparently the 92nd Street Y in Manhattan has a Distinguished Lectureship series for which they had invited Steve Martin for an on-stage interview conducted by Deborah Solomon from the Times. The subject matter dwelt very heavily on art, the focus of a recent book by Martin. This was not a topic the audience was interested in; they had shelled out $50 a piece to hear more about Mr. Martin's personal life. The 92nd Street Y folks apparently agreed that "Art" was not a proper subject for discussion and promised to provide full refunds. I certainly do not want to inflict Dean McDonald with similar complaints so I will try to keep mention of this abhorrent word as infrequent as possible.


The Art of Physics
Carl W. Akerlof

The word “Art” has two common meanings which form the theme of this talk. The first is “a tangible object deliberately created to produce an emotional response”. The second refers to the “skill required to perform a complex or delicate task”. The wonderful thing about language is that we can maintain a sense of both meanings simultaneously. I will try to keep both ideas current throughout this lecture. This has an interesting parallel with quantum physics which often deals with the concept of a photon represented as a coherent superposition of two quite different states. As to the tangible forms of art, I have had the good fortune to meet two physicists during my career who have taken the creation of art as an important personal enterprise. The first is our own Jens Zorn who has created a number of sculptures that grace our campus as well as elsewhere.

Art:

1. Tangible object(s) specifically created to provoke human emotional response.

2. The skill required to accomplish a complex or delicate task.

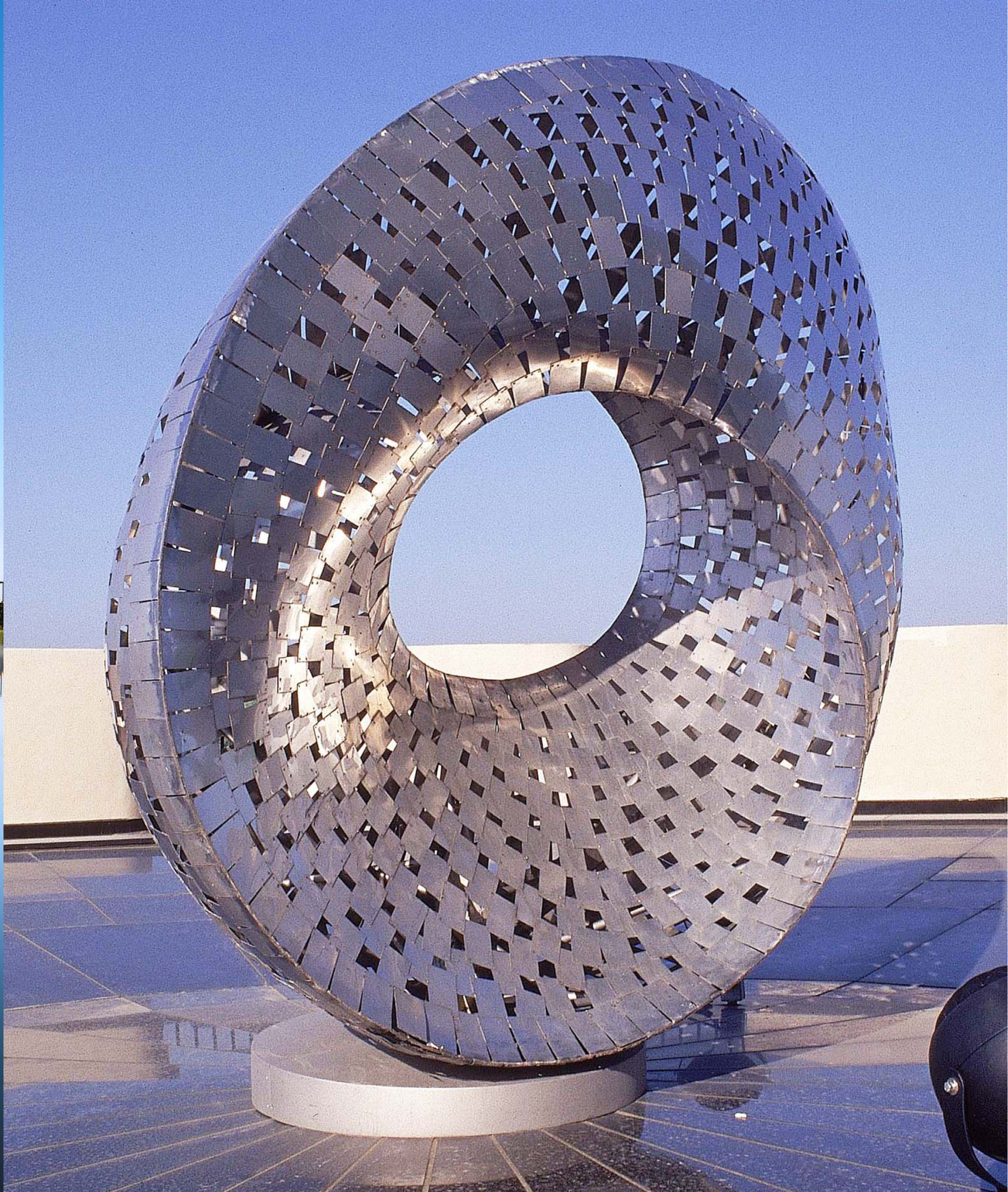
Here we see two of Jens's works that enhance the courtyard between West Hall and Randall. The first, "Positronium", depicts the atomic system that was extensively studied by Arthur Rich. For a physicist, the swirling curved planes represent an inspiraling electron and positron pair that annihilate to two gamma-rays escaping back-to-back along straight lines from the center. For those unfamiliar with the physics of positronium, it is an elegant geometric form which suggests the beauty of this field. The second piece, "g minus 2", is an abstract representation of the magnetic bottle that Dick Crane used to confine electrons to accurately determine their magnetic strength and thus provide one of the most stringent tests of quantum electrodynamics, one of the most successful theoretical structures of physics.


"Positronium"
Jens Zorn

"g minus 2"
Jens Zorn

Robert Wilson was the director of the Laboratory of Nuclear Studies when I was a graduate student at Cornell. He was responsible for developing a series of particle accelerators culminating ultimately in the Tevatron at Fermilab near Chicago. You will not be surprised that he was fond of mentioning that “accelerators are the cathedrals of the 20th century”. This idea is definitely encapsulated in the Fermilab central laboratory building inspired by a cathedral in Beauvais, France. The second example, “Mobius Strip” shows the fascination that most of us in science have for the richness of mathematical ideas.

Wilson Hall (Fermilab)



“Mobius Strip” Robert R. Wilson

However, as you have probably guessed, the focus of this talk will be more concerned with the art embedded directly in physics. We first need to ask what the origin of physics really is. The simplest and oldest idea is “divine inspiration”. The archetype is Moses who ascended Mount Sinai when he had an opportunity for direct communication with the Lord. Moses took careful notes on stone tablets, apparently the publication medium of the day. Some of these concepts did not meet with instant appreciation but, in time, his citation numbers were just fantastic.

For most of us, there are really two rival concepts for the basis of physics. Most of the time, the difference is of little practical consequence. In the first case, nature is considered to be a mathematically-driven engine obeying fundamental equations that we, as humans, are obliged to discover. My own take is somewhat different. I believe that physics is the order imposed by our own minds to codify as much experience as accurately and succinctly as possible. Whether or not nature is itself a mathematical structure is intrinsically unresolvable.

This later point of view is at odds with a recent piece in the New York Times by Steven Strogatz who suggested that computers could autonomously discover mathematical truths on their own. Without a self-awareness way beyond the capabilities of this Dell laptop and its Windows operating system, I think that’s pretty unlikely.

Where does physics come from?

1. Revelation (see Exodus 19-20)?
2. Discovery (physical laws pre-exist)?
3. Created by conscious intelligence?

Alternative view: “We may have to program computers to explain their (mathematical) discoveries to us. Otherwise they will become more like oracles than scientists, handing down mysterious utterances to us mere mortals.”

Steven Strogatz – NYT 11/09/2010

This leads to the entanglement of physics and emotion. An early example is the apocryphal story of Archimedes who overfilled his bathtub with water and realized that the same principles could be applied to measuring the volume of an irregular object. According to legend, he was so excited by this revelation, that he ran naked through the streets shouting “Eureka”. Many of us have been fortunate to have an occasional Eureka moment but manage to express our joy without shedding clothes.

Subrahmanyan Chandrasekhar was a theoretical astrophysicist perhaps most famous for his elegant derivation of the mass limit for white dwarf stars. He has written extensively about the importance of art in physics – the quote shown here is from a talk given in honor of Robert Wilson at Fermilab. “The measure in which science falls short of art is the measure in which it is incomplete as science…”

In 1974, Sam Ting discovered an elementary particle now called the J/ψ. This event revolutionized particle physics because it elevated the idea of quarks from a useful mathematical representation to something almost as tangible as electrons. His experiment at Brookhaven was based on a strong intuition that a particular reaction would reveal important results even though the experimental technique was extremely challenging and similar work by a previous group had been uneventful.

In a more playful vein, the 2010 Physics Nobel Prize winners, Geim and Novoselov, regularly set aside time on “fun Fridays” to try out ideas that were not always in the mainstream of their work. In 2004, this led to the discovery of how one could make graphene, monatomic layers of carbon, from solid graphite, Scotch tape and patience. Although interesting in its own right, this material may have revolutionary consequences for electronic devices in the future.

Finally, the neurophysiologist, Antonio Damasio, has written extensively about studies of patients with various brain lesions. The bottom line is that the capability of performing rational thought is inseparably linked to the ability to process emotional data.

The emotional content of science is not something that one mentions in proposals to the NSF, DoE or elsewhere. Nevertheless, it is the driving reason why people choose to enter fields like physics and obtain considerable satisfaction in the process. I have concerns that ignoring this issue may damage the abilities of universities like ours to maintain a vibrant research program in the future. Such effects are already being strongly felt in US K-12 science education with unpleasant implications for our national economic strength. The rest of this talk is devoted to my own experiences and how my choices have been influenced by non-technical considerations.

The emotional aspects of physics

A few examples:

Archimedes – bathtub hydrostatics (~240 BC)

Subrahmanyan Chandrasekhar – “The measure in which science falls short of art is the measure in which it is incomplete as science…” (April 27, 1979, FermiLab)

Sam Ting – discovery of J/Ψ in p-N collisions (1974)

Geim & Novoselov – graphene on a “fun Friday” (2004)

Antonio Damasio – neurophysiology of rational thought

Implications for two areas of concern:

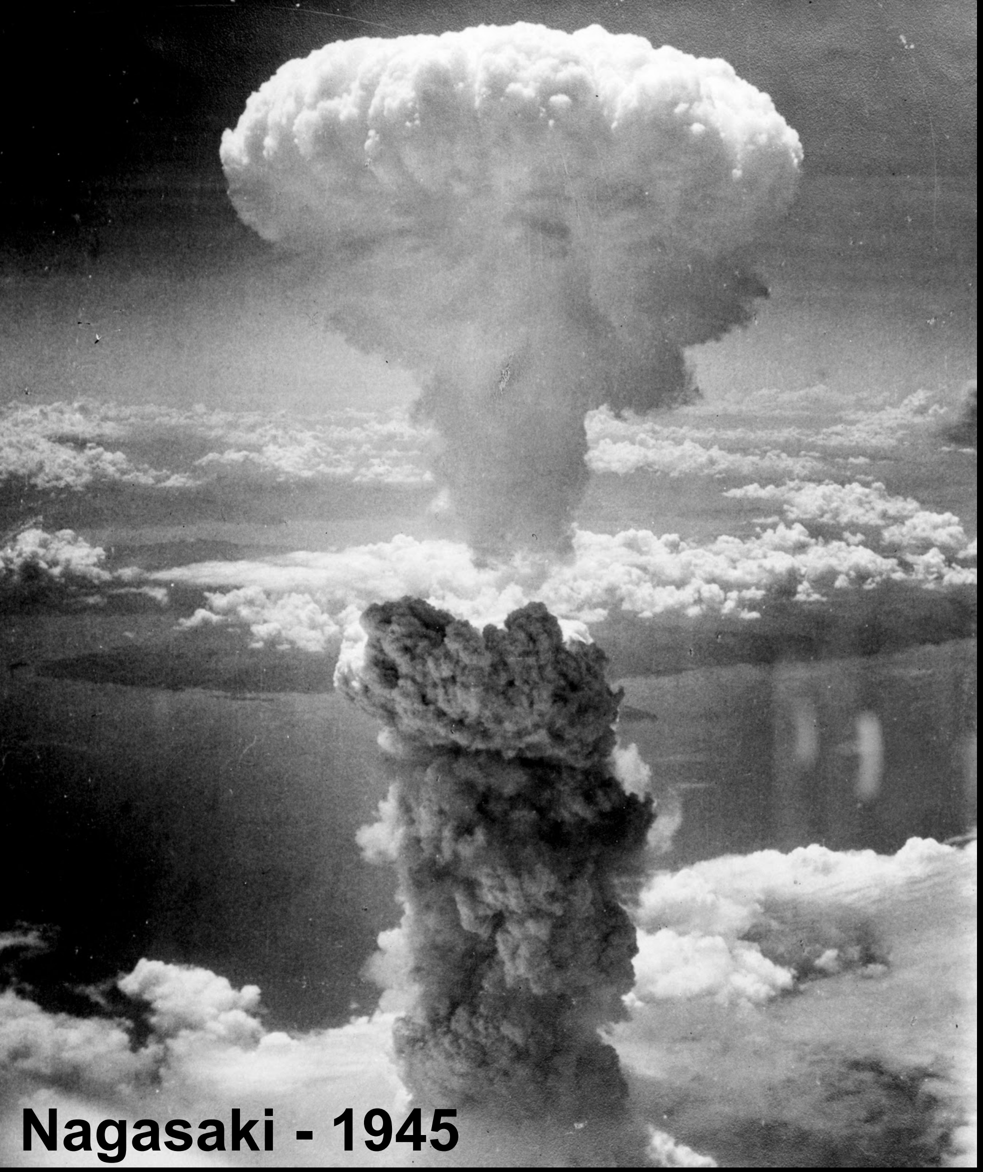
1. The evolution of physics research at universities
2. The apparent decline of US science education

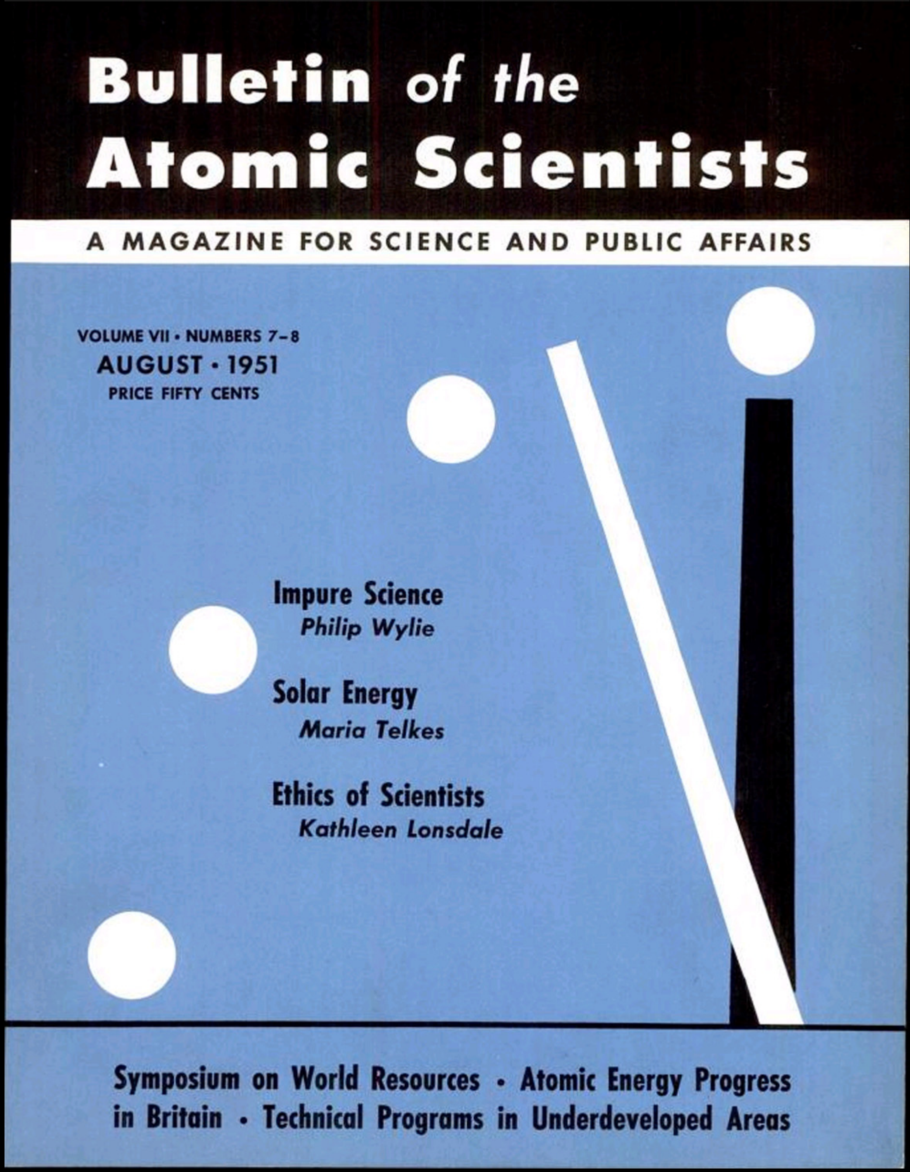
I plan to briefly describe four episodes in my career, listed in this slide. (1) A six-month sabbatical leave to the Soviet Union in 1974; (2) A discovery of astrophysical sources of TeV gamma-rays; (3) The detection of optical counterparts of gamma-ray bursts and other astrophysical transients and (4) the initiation of the Ann Arbor Hands-On Museum. Before I go much further, I need to provide a little information about my childhood background:

Some stories from my own journeys…

1. Spending six months at a Soviet high energy physics lab in 1974
2. Searching for astrophysical sources of TeV gamma-rays (1986 - 1997)
3. Searching for the optical counterparts of gamma-ray bursts and other astrophysical transients (1993 -)
4. Helping start the Ann Arbor Hands-On Museum (~1976 – 1982)

Both my father and uncle were chemists that worked on the Manhattan Project during World War II. In particular, my uncle, Joseph Hirschfelder, participated in the Alamogordo test and subsequently edited the “Effects of Atomic Weapons” published in 1950. Especially for a somewhat geeky teenager, it was impossible to be oblivious to the imminent threat of nuclear Armageddon. This is well typified by the ominous cover of the Bulletin of the Atomic Scientists which indicated “Three Minutes to Midnight” at the time that I turned 13 in 1951.





The prospects for humanity circa 1951

"Three minutes to midnight"

In 1951, my family moved to Princeton, New Jersey. The residents at the time included Einstein, John von Neumann, J. Robert Oppenheimer, Eugene Wigner and George Kennan, author of our USSR containment policy that defined the Cold War. At this moment, Princeton was in some sense the academic center of the American conflict with the USSR. Local citizens were sure that if Russia chose to attack the US, Princeton would be a primary target, perhaps higher on the list than Washington or New York City. Thus, silhouettes of Bison bombers were printed in the weekly newspaper, Town Topics, and faculty wives maintained an aircraft observation tower at the corner of the golf course overlooking the Princeton Inn. Clearly Fine Hall, Palmer Labs and Fuld Hall would be the prime targets.

As somehow the world managed to avoid incineration, I entered graduate school at Cornell, eventually choosing to get my degree in elementary particle physics. Gradually I came to learn of the very effective efforts by Hans Bethe to provide the kind of information to our government that led to a significant de-escalation of the nuclear saber-rattling that had characterized the ‘50s. I also met a post-doc at that time, Frank von Hippel, who became a national security advisor to Bill Clinton. I think the world owes an enormous debt to such people both in our country and in the USSR that obtained the ear of responsible national leaders and defused a very dangerous situation. Sadly, I do not see any members of a younger generation willing and able to assume a similar role.

In any case, I made a firm decision that the world did not need bigger nuclear weapons and so I had no interest in employment at Los Alamos or Livermore. I did however take away the message that scientists with a common faith in rationality could communicate successfully with one another even though they lived under different political philosophies.

Early influences on my career

Both my father and uncle (J. O. Hirschfelder) worked on the Manhattan Project. JOH edited "The Effects of Atomic Weapons" (1950) and participated in the Trinity test at Alamogordo, New Mexico.

My family moved to Princeton in 1951. Among the residents were Albert Einstein, John von Neumann, J. Robert Oppenheimer, Eugene Wigner & George F. Kennan ← author of USSR containment policy.

At Cornell, the faculty members included Hans Bethe and Robert R. Wilson. Frank von Hippel was a post-doc. Much later while working at SLAC, I met Pief Panofsky and Sid Drell.

I hope this gives some background for my interest in working in the Soviet Union in 1974. The reasons for doing so are listed on the slide:

1. In the ’70s, the fraction of the USSR GNP devoted to elementary particle physics probably exceeded the US.
2. The 70 GeV proton synchrotron at Serpukhov was the most powerful accelerator in the world until 1972.
3. The scientific productivity of this facility had been remarkably low.
4. The infrequent scientific collaborations between the US and the USSR had been almost completely uni-directional. (to Fermilab).

I must also confess that I was intrigued by the secrecy and mystery that surrounded all things Soviet. At the time my family and I made this expedition, only about three other Americans had spent significant time at the Russian laboratory.

By the end of our six-month stay, I had not participated in any interesting research whatsoever. On the other hand, it was an enormous learning experience for all of us which we would not easily forget. What I came to appreciate was the almost complete dysfunctionality of the Soviet system which I described in a “trip report” to the agency that is now the Department of Energy. If anyone is curious about this period of Soviet history, I recently submitted this document to the Michigan Library Deep Blue archive. I personally believe that if the US State Department had a somewhat more realistic assessment of the capabilities and problems of the USSR, the history of that period would have been less traumatic.

Why spend 6 months in the USSR?

1. In the '70s, the fraction of the USSR GNP devoted to elementary particle physics probably exceeded the US.
2. The 70 GeV proton synchrotron at Serpukhov was the most powerful accelerator in the world until 1972.
3. The scientific productivity of this facility had been remarkably low.
4. The infrequent scientific collaborations between the US and the USSR had been remarkably uni-directional. (to Fermilab)

Was there a missing opportunity here?

Report: Scientific visit in 1974 to the Institute of High Energy Physics at Serpukhov, USSR

http://hdl.handle.net/2027.42/78365 (Deep Blue)

It is impossible to distill impressions of the USSR into a few words or images but I hope the following will provide useful vignettes. Dubna was the second largest particle accelerator in Russia and had required 36,000 TONS of steel equivalent to 10,000 Cadillac Escalades. This is probably more iron than in all the rest of the world's particle accelerators put together. The accelerator didn't work very well because process control in Russian industry was too poor to maintain consistent magnetic properties from batch to batch.

The detection electronics at Dubna was relatively modern compared to what we had available at Serpukhov. This was in large part due to the participation of Eastern Bloc countries such as East Germany and Czechoslovakia.

Joseph Stalin was no longer an icon in the USSR but Lenin was treated as a god. These two images show the region of Moscow near Red Square on the occasion of the celebration of the October Revolution. The major point of this exercise was to show off the cool hardware.


Dubna
10 GeV
protons


Moscow, November 1974

Our children were just completely adorable and Russians like children very much. Karen and Will were excellent ambassadors. We lived in a model town that was often used for backdrops for Soviet films. (Shades of Ann Arbor!) However, a mile away or so, the infrastructure could be somewhat intimidating. Our town of Protvino marked the farthest eastern penetration of the German army. The mill here was the center of a ferocious artillery battle.


Мебель

After returning from the Soviet Union, the emphasis in elementary particle physics shifted very strongly towards understanding the quark and lepton structure of matter. I participated in three challenging experiments at Fermilab and SLAC. Although the experiments were well executed and many papers were written and published, the number of noteworthy results was minimal. Thus, I began to cast my eyes elsewhere.

About the same time, a number of predictions became quite popular. These included:

1. Magnetic monopoles
2. Proton decay
3. Dark matter in the form of massive sub-atomic particles
4. Ultra-high energy neutrinos and photons

Despite impeccable logic, none of these phenomena have ever been detected (but efforts continue).

Transition from particle physics to astrophysics...

After 1974, 3 experiments in HEP:

1. search for charmed mesons (Fermilab)
2. μ^+- μ^- pair production in $\bar{p}$ - p collisions (Fermilab)
3. e^+- e^- collisions at 30 GeV (SLAC)

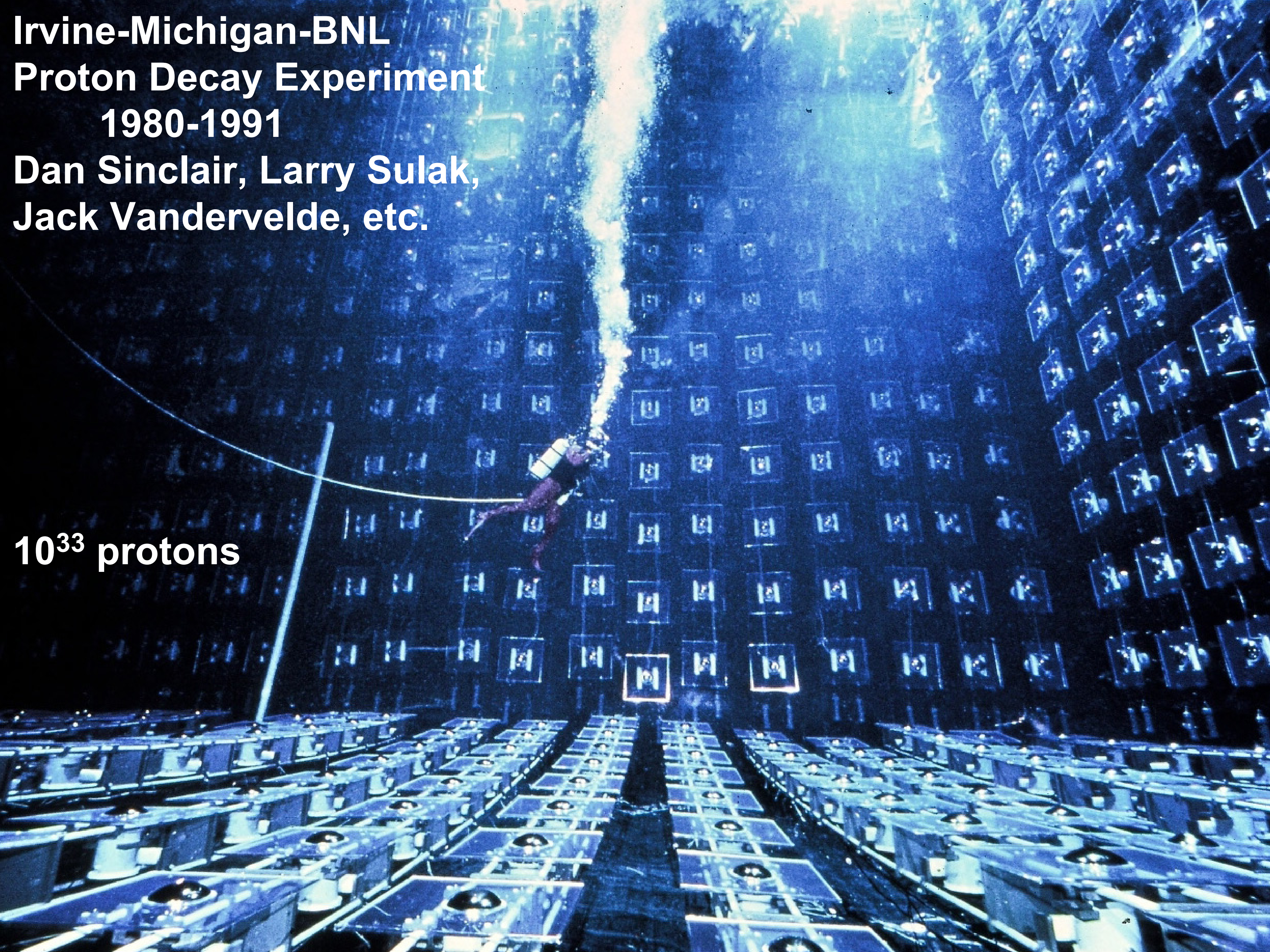
→ Good experiments – no noteworthy results

In the 1980’s, predictions of new phenomena:

1. Magnetic monopoles
2. Proton decay
3. Dark matter in the form of massive sub-atomic particles
4. Ultra-high energy neutrinos and photons

→ But to this date, none have ever been detected…

The most compelling idea was the expectation that protons would spontaneously decay to lighter particles, particularly a π^0 meson and a positron. This led to one of the most elegant experiments, designed and performed by Michigan faculty in collaboration with two other institutions. Once you realize that a standard 1.8 meter long human is in the center of a large tank of water, you can estimate that 10^{33} protons are being scrutinized by light sensitive detectors that surround all six walls. It is worth noting that a very large fraction of this detector was constructed in the Michigan physics instrument shop.


Irvine-Michigan-BNL
Proton Decay Experiment
1980-1991
Dan Sinclair, Larry Sulak,
Jack Vandervelde, etc.
10^{33} protons

One aspect of a large experiment is that when the expected results don't materialize, some folks get itchy. In this case, a member of the proton decay collaboration began to find some statistical evidence for particles in their detector correlated in direction with a notorious astrophysical object called Cygnus X-3. At a seminar presenting these results, Robert Kirshner, then astro department chair, mentioned to me that the evidence that Cyg X-3 was particularly unusual was extremely flimsy.

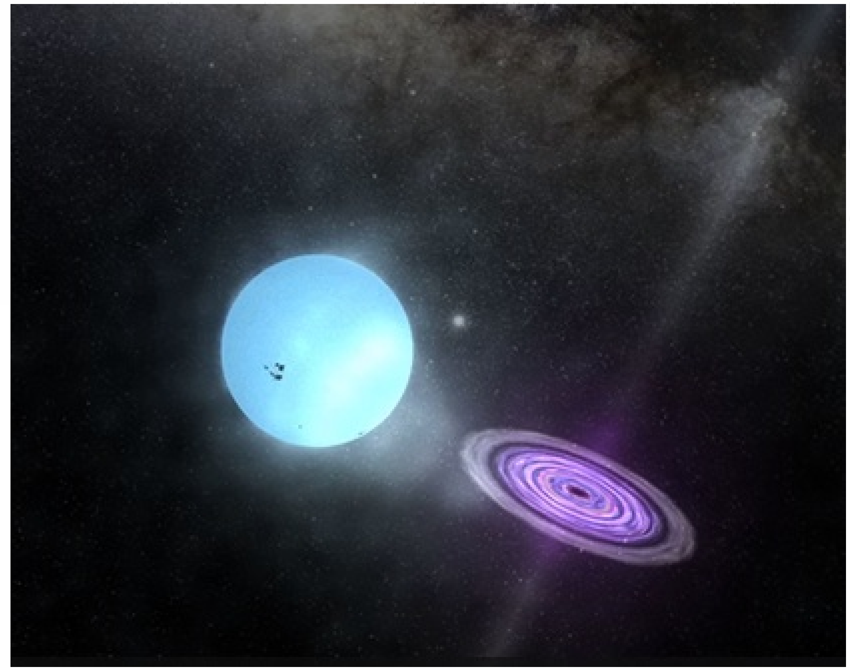
Although the proton decay group could not confirm this astrophysical result, Nature rewarded them extremely well for their diligence. On February 23, 1987, neutrinos from a supernova in the Large Magellanic Cloud reached the IMB detector in Cleveland and the Kamiokande detector in Japan and 19 interactions were recorded within a 13-second window. This confirmed a significant aspect of the theory that describes such explosions which are responsible for the chemical elements essential to life.

M. Mitchell Waldrop, Science **228**, 1298 (Jun. 14, 1985)

Something Strange from Cygnus X-3

At least two proton decay experiments have now detected particle showers that seem to be triggered by emissions from the galactic x-ray source Cygnus X-3. However, the emissions are baffling: known elementary particles, such as photons or neutrinos, can be ruled out. Nor is there an obvious candidate among the supersymmetric and grand unified particles concocted by the theorists. If real, the Cygnus X-3 particle would have to be something new.

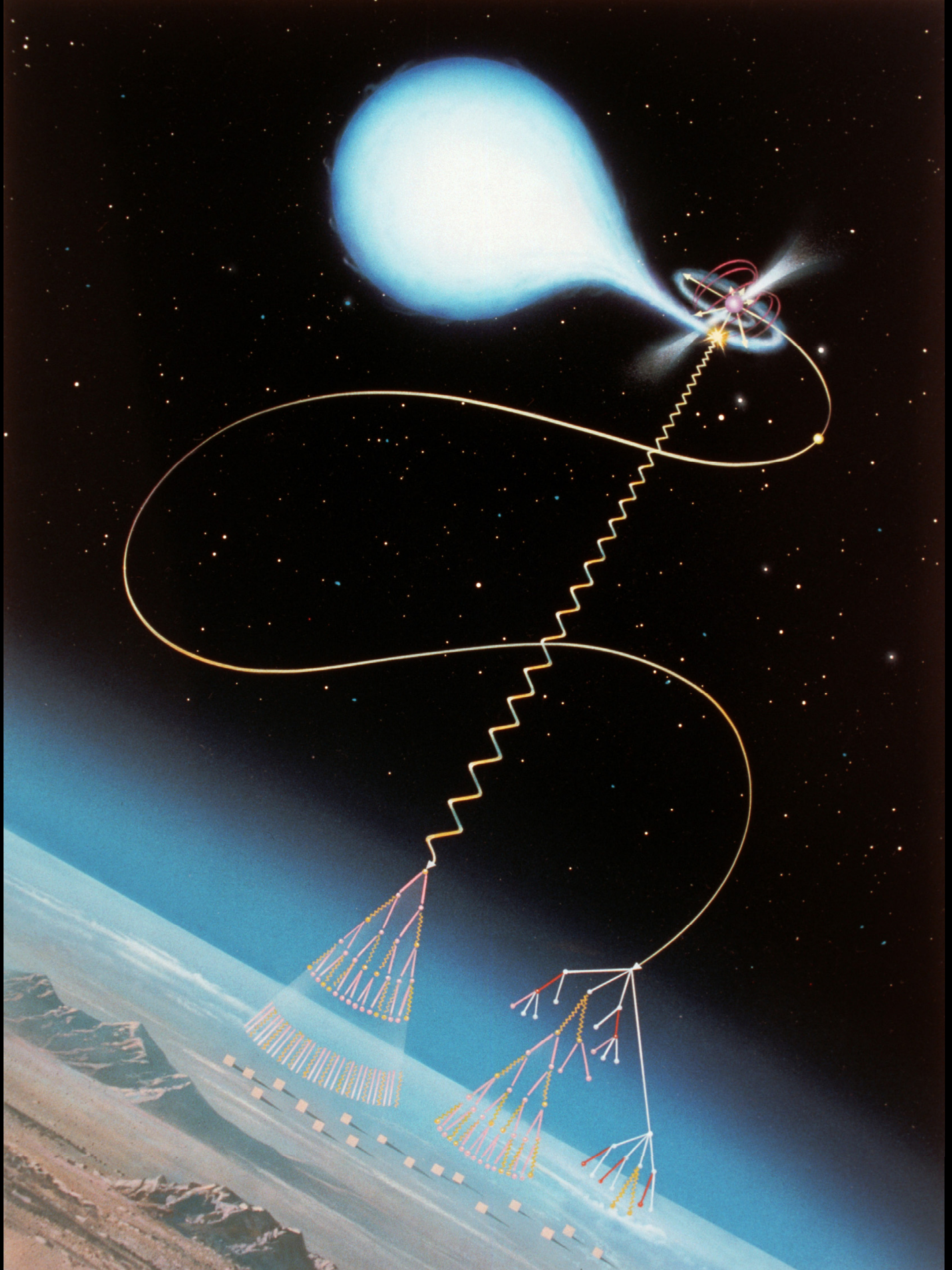
As it happens, when the Soudan group submitted their results for publication, one of the reviewers was John Learned of the University of Hawaii, a member of the team that operates the giant Irvine-Michigan-Brookhaven (IMB) detector in the Morton Thiokol salt mine near Cleveland. Following Soudan's lead, Learned started analyzing the IMB muon events with particular attention to Cygnus X-3; by Christmastime 1984, he and his students had found suggestions of a signal that matched both the 4.79-hour periodicity of Cygnus X-3 and its proper phase.



Cygnus X-3 is a high mass X-ray binary in our galaxy.
In the '80s, many reports of high energy γ-rays <u>but flimsy statistics</u>.

So the basic idea of this very schematic diagram is that a binary star system far, far away produces high energy photons and charged particles that can travel long distances before entering the Earth's atmosphere. The source of energy that drives this process is the accretion of matter from the extended envelope of a large normal star to a compact object such as a white dwarf or neutron star. The gravitational energy released in this process can be transformed to a small fraction of particles that escape this environment. This model was thought to apply to Cygnus X-3 and seemed to be an interesting question worth exploring as Bob Kirshner suggested.

photons and particles from accreting binary systems



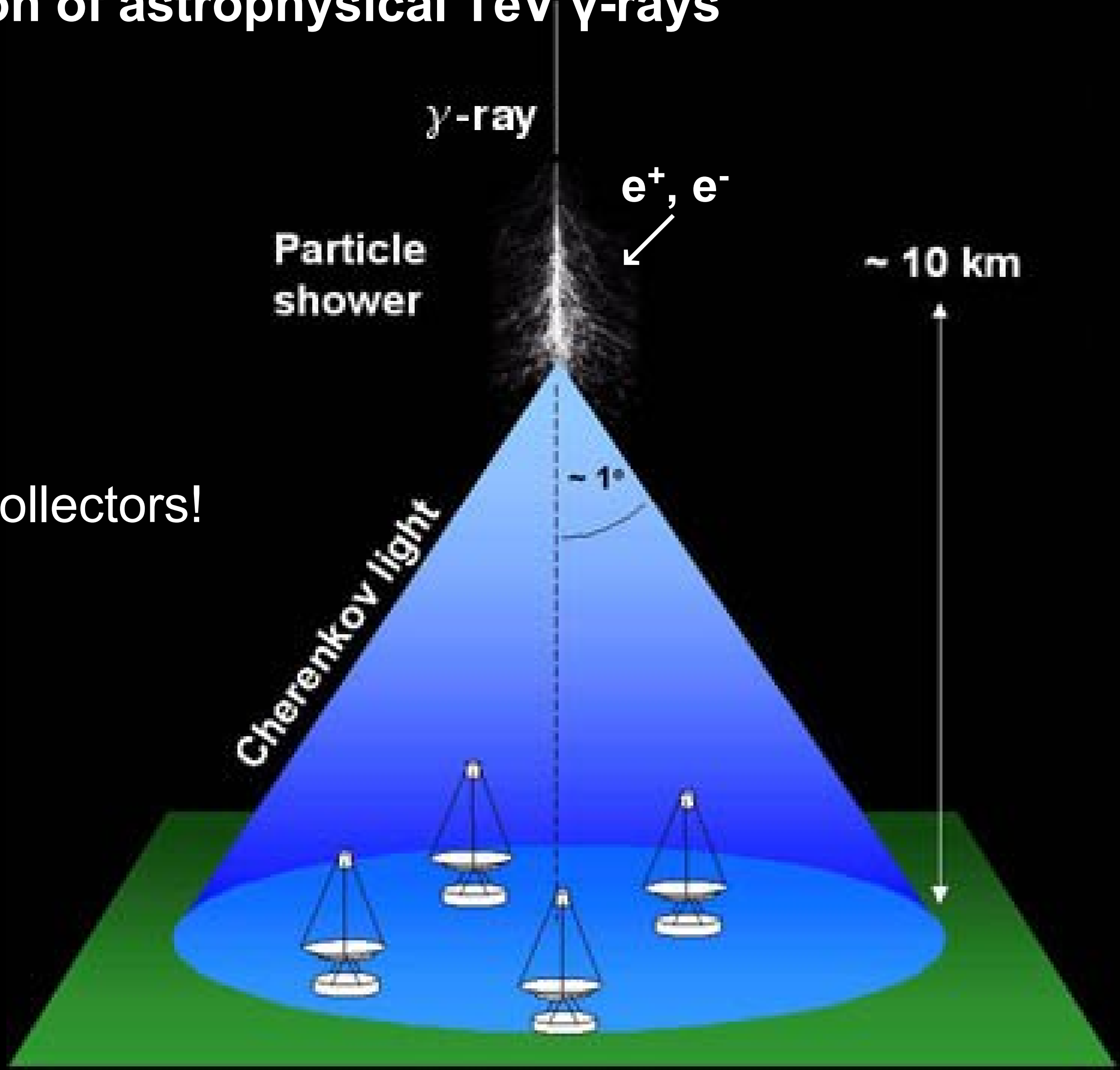
The problem of detecting very high energy gamma-rays is dictated by the low flux of quanta, much less than one per square meter per second. This makes detection by Earth-orbiting satellites next to impossible. One way to circumvent this problem is to look for interactions of the high energy photons in the upper atmosphere that produce showers of hundreds of electrons and positrons within a time span of the order of 10 nanoseconds. These in turn radiate a very faint glow of visible light called Čerenkov radiation which could be detected on the ground. The expected number of Čerenkov photons is about one per square meter so large light collectors are essential. More than one collector would be even better.

Indirect detection of astrophysical TeV γ-rays

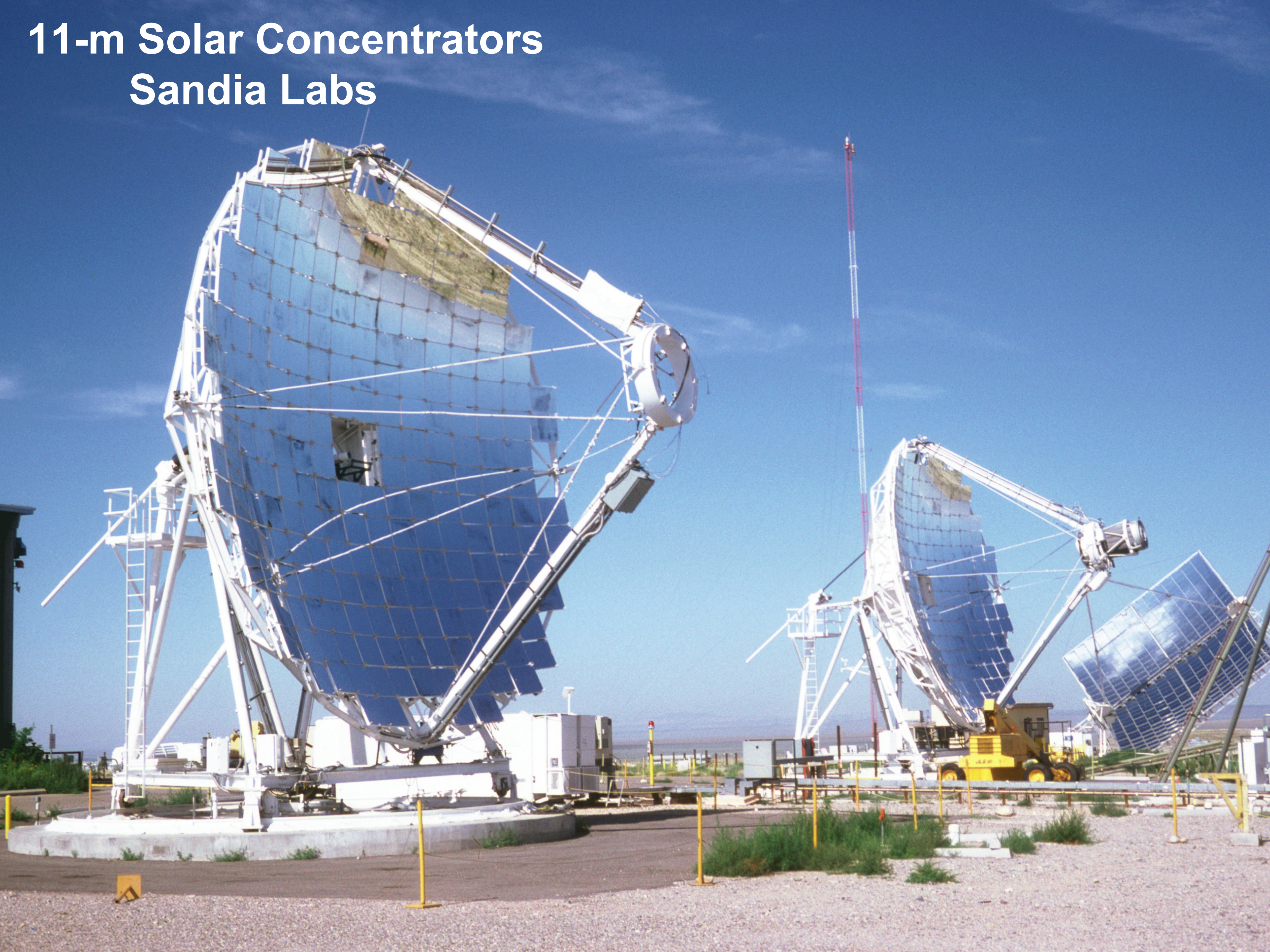
~ 1 photon/m²

Δt ~ 10 ns

Need big light collectors!



So the first step on this journey was to find some large parabolic reflectors that were not heavily used. I realized early on that the place to find such things was within the solar energy program that had been initiated under Jimmy Carter's presidency. In 1986, this led me to the Sandia National Labs in Albuquerque, New Mexico. Fortunately one of my roommates from grad school days introduced me to the appropriate leaders of the lab and they were quite intrigued by the possibility of doing astrophysics with devices that had been designed for quite different purposes. What you see in this photograph is two fully steerable dishes about 11 meters in diameter. The focal plane is at the ring at the center to the right.


11-m Solar Concentrators
Sandia Labs

This is what these dishes were designed to do: focus about 100 KW of sunlight to a circle with a diameter of a few inches. That is not a place you want to be on a bright, sunny day. Unfortunately, no one could find out anything very useful to do with this very high power density, especially considering the capital cost of the reflectors.

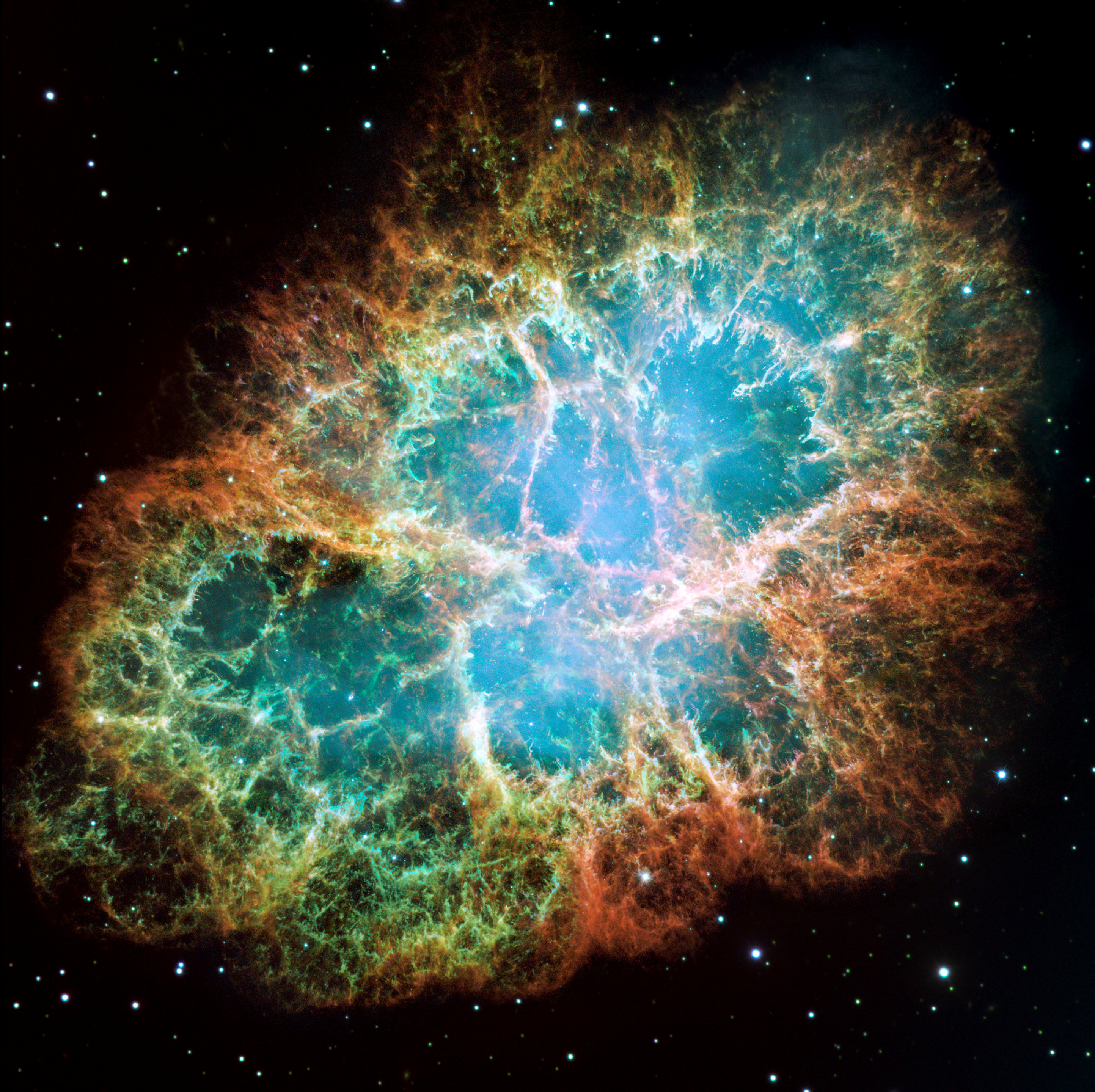

"On Sun"
~100 Kw

By this time, we knew that chasing after Cygnus X-3 was a waste of time. However a group in Arizona, led by Trevor Weekes, had been pursuing the same goal of detecting astrophysical gamma-rays for a number of years and now had achieved considerable success in finding high energy gamma-rays from a well-known supernova remnant, the Crab Nebula. This object was the consequence of an explosion in 1054 that was noted by the Chinese and Native Americans but not Europeans. At this point, our aim was to show that two telescopes in coincidence were better than one. The object was to find ways of significantly improving detection sensitivity.

Crab Nebula

SN 1054a

Luminosity:
75,000 × Sun



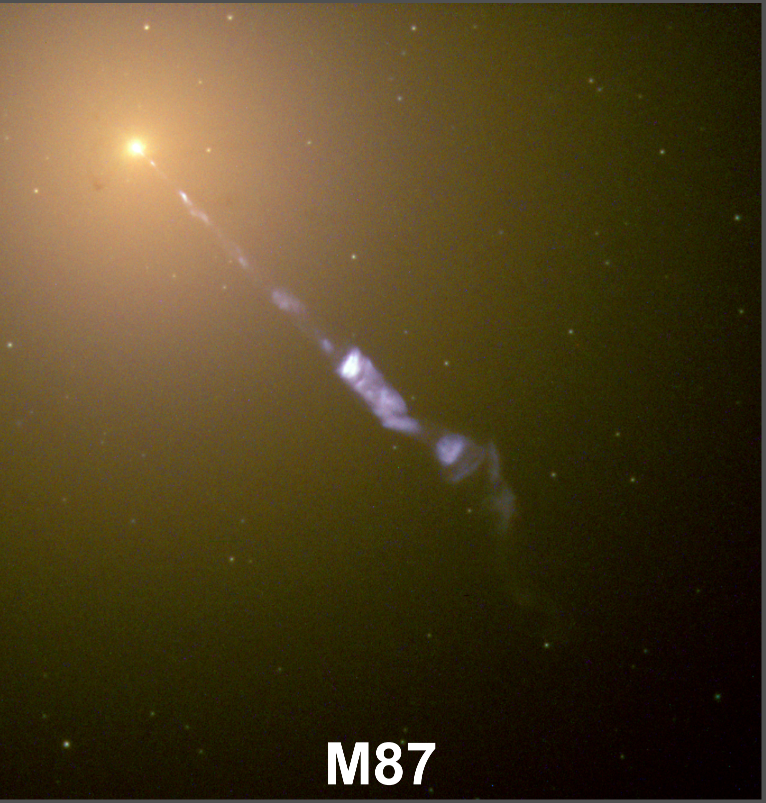
At this point, as a result of my prior affiliation with the brotherhood of particle physicists, I was still being funded by the US Department of Energy. DoE was also supporting the Arizona group and thought that competition was an expense they could live without. Thus, in 1989, we joined the Whipple collaboration which had constructed a much better designed optical reflector shown in this photograph. In 1991, the NASA Compton Gamma-Ray Observatory was launched into orbit. It could detect GeV gamma-rays with a sensitivity never before achievable. Within short order, it began to identify Active Galactic Nuclei, the centers of some extreme galaxies that emitted significant fluxes of high energy photons. With a variety of improved techniques, we quickly began aiming the Whipple Čerenkov telescope in those directions and were rewarded by unambiguous detections of TeV photons from many of these objects. This success transformed this sub-field from a highly suspect branch of cosmic ray physics to real astronomy.

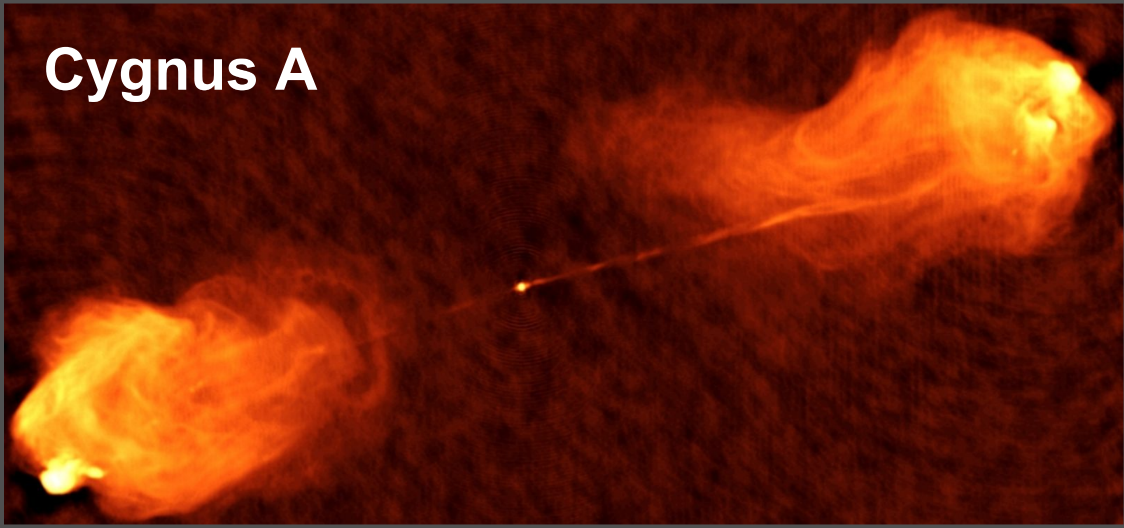
Whipple 10-m γ-ray telescope, Mt. Hopkins, AZ

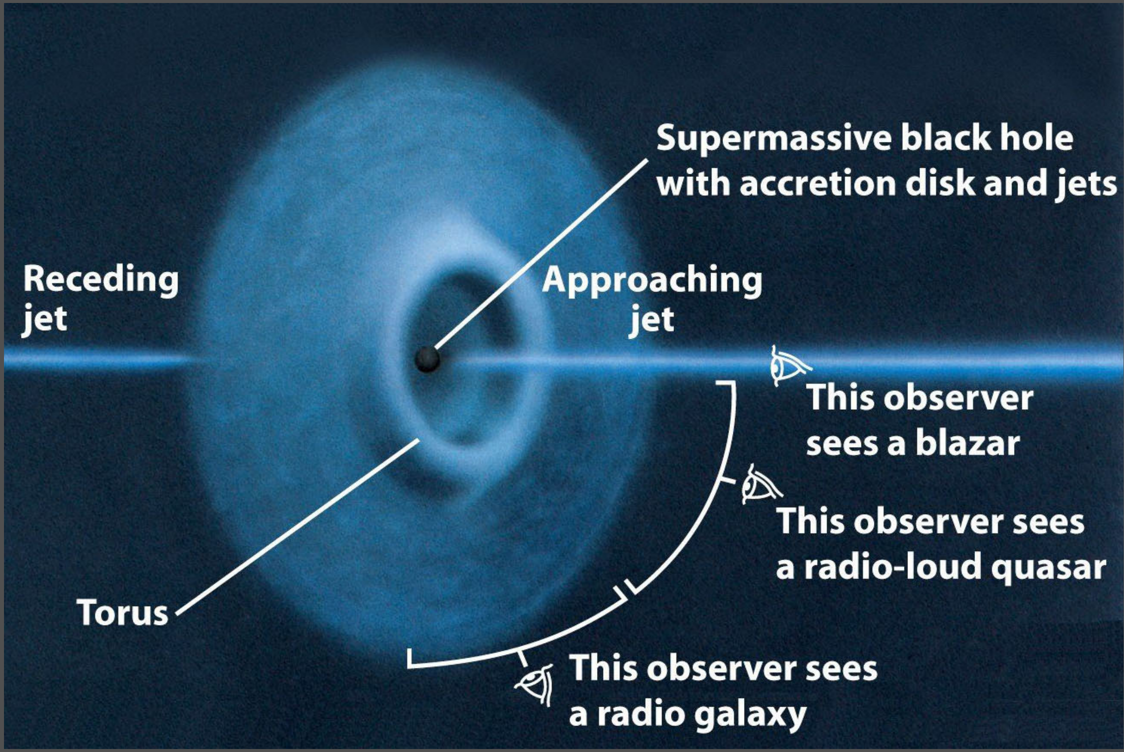
(built 1968)

Here are two radio images of what an AGN or quasar can look like. Narrow back-to-back jets of relativistic particles are seen streaming for distances of the order of the diameter of our galaxy from massive central cores. The objects we detected are believed to be those with high energy particle jets aimed within a few degrees of the Earth. Again, the mechanism for generating high energy photons resides with the gravitational energy released by material spiraling into a heavy but compact black hole.

VLA radio images







Active Galactic Nuclei (Quasars)

From our work at Sandia Labs, as well as common sense, we realized that greater instrumental sensitivity could only be achieved by using two or more telescopes looking at the same photon-electron cascade in coincidence. We proposed such a plan to DoE who, after much deliberation, told us they were only willing to finance the low cost option of refurbishing a surplus solar concentrator designed by the aircraft company, McDonnell-Douglas. Without much choice, we accepted the offer and proceeded to instrument this substitute with an appropriate electronic camera.

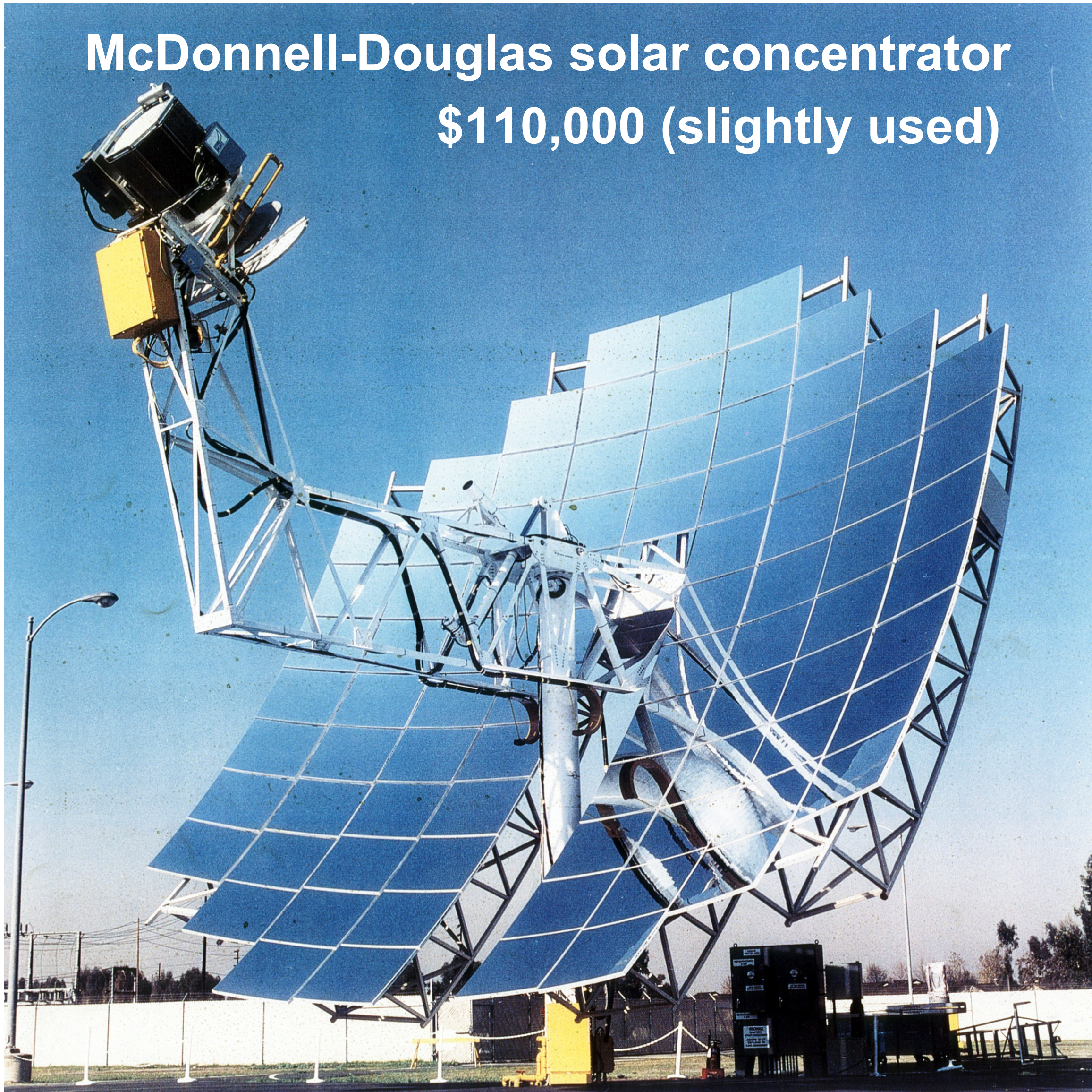
Clear need for greater sensitivity…

(background from charged particles ~1000 larger than signal)

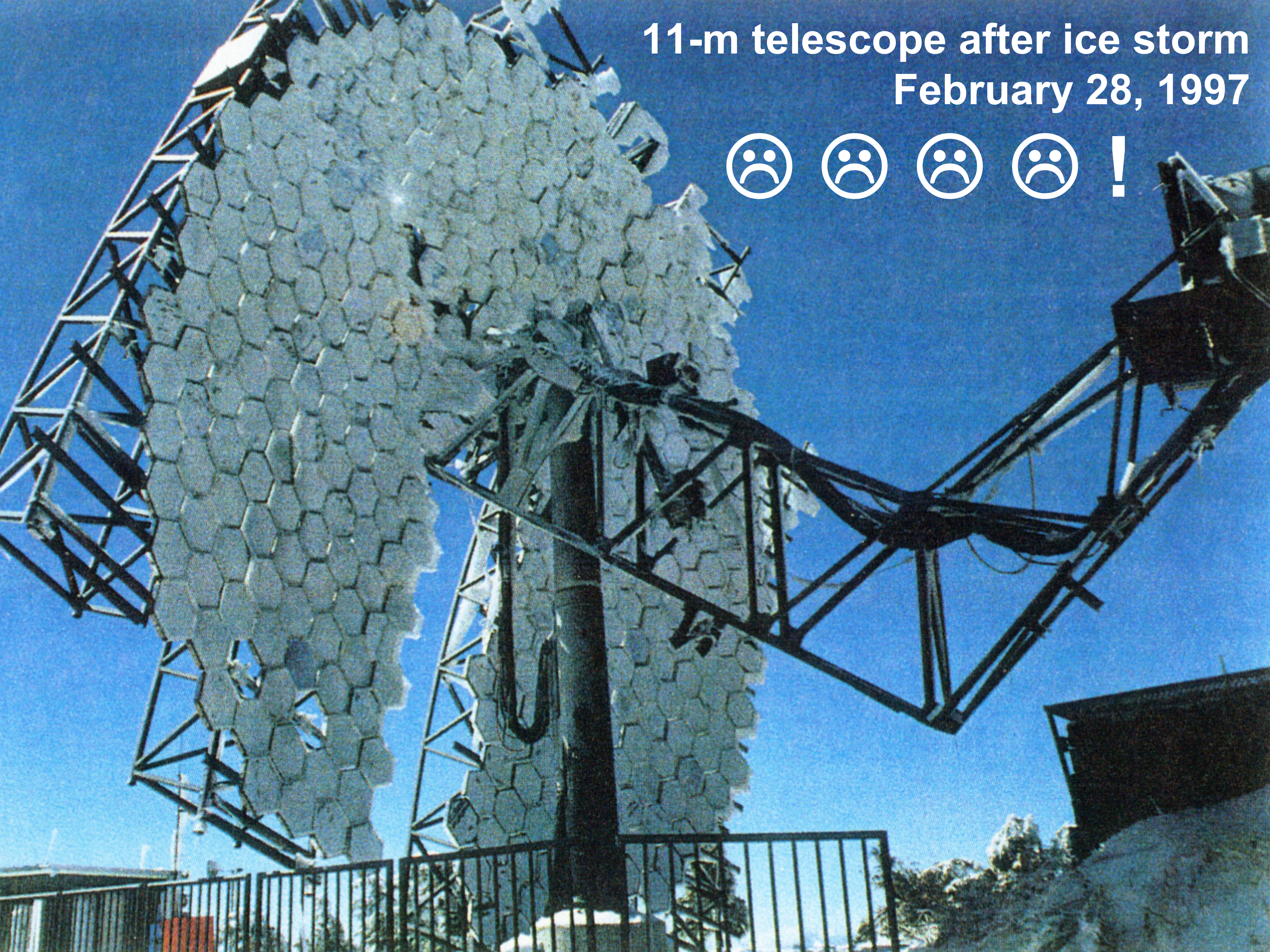
Our Sandia work helped demonstrate importance of multiple telescopes.

DoE would not support a 2nd high quality telescope at Mt. Hopkins.

No option except to go for cheap!



The result was an expensive waste of time and effort. On February 28, 1997, the structure collapsed under the weight of accumulated ice. After spending way more money than a well-designed mount would have cost, this effort came to a roadblock that still hampers the US effort to pursue this research. I also developed a strong aversion to flying in DC-10s.


11-m telescope after ice storm
February 28, 1997
☹ ☹ ☹ ☹ !

The principal result of this work was, first and foremost, that the technique provided reliable detections of distant astrophysical objects. During my participation with the Whipple group, four AGNs at modest redshifts were discovered to emit TeV radiation. Most of these showed erratic variation in intensity, often correlated with X-ray fluxes measured by satellites. The dynamics of these processes is far from completely understood. Although this field was completely developed in the United States, the lack of vision of the Federal funding agencies allowed the leadership to pass to Europe. Approximately 100 AGNs are now identified with high energy photons.

Principal results from TeV γ-ray astronomy

It actually can be done!!!

Crab Nebula

Active Galactic Nuclei:

1. Markarian 421 (z = 0.031)
2. Markarian 501 (z = 0.034)
3. BL Lacertae (z = 0.070)
4. ES 2344+514 (z = 0.044)

Probably now number ~ 100 objects

US funding agencies, DoE and NSF, have provided anemic support. Leadership has moved to Europe (HESS).

The German-French collaboration called HESS now plays a dominant role in this field. This photograph of their observatory taken a few years ago shows four 12-meter diameter Čerenkov telescopes that look in time coincidence at gamma-induced electron showers. Near the small white enclosure in the center of this image is now a 28-meter diameter dish that will allow detection of much lower energy photons. The site is in the Khomas Highlands of Namibia, far from any light pollution, and blessed with excellent clear dry weather most of the year. The American equivalent sits in a parking lot south of Tucson within a few miles of various gated retirement communities.

H.E.S.S. Imaging Atmospheric Čerenkov Telescopes

Khomas Highlands, Namibia

While attending an astrophysics conference in Taos in 1986, I first learned about mysterious objects called gamma-ray bursts (GRBs). Briefly these objects can be characterized by:

1. The objects were discovered in 1967 while looking for clandestine nuclear tests
2. This was a totally unexpected phenomenon
3. The typical signature is the emission of 200 KeV γ-rays for ~20 secs
4. The origin was completely unknown: either Galactic or Extra-Galactic
5. The apparent event rate is ~1/day/Universe
6. No counterparts were seen at other wavelengths (until 1997).

I paid very little attention to this at the time since I was concentrating on looking for those TeV gamma-rays at Sandia. However, five years later, Jack Vandervelde suggested that I should attend a meeting in Huntsville, Alabama where new results were being reported by the NASA Compton Gamma-Ray Observatory. The new data strongly indicated that GRBs were isotropically distributed on the sky in contradiction with what one would expect from sources localized to our galaxy. They could either be very near or very far. If these events could be correlated with an optical transient, the mystery would be easily resolved. An expert in this field, Brad Schaefer, took some time to tell me that no one had ever tried very hard to find GRB counterparts in real time and it was a wide open opportunity. That seemed like a fascinating idea to pursue. I realized from the beginning that I would be looking for a fairly dim star. For the next several months, I researched every possible source for a wide field, large aperture camera. Among the various possibilities was an outfit that rented wide aperture lenses by the month to private detectives engaged in divorce cases.

In any case, I was planning to take a sabbatical leave at Berkeley from 1992 to 1993 to work on an unrelated experiment associated with dark matter. This activity would be in collaboration with the Lawrence Livermore National Laboratory, one of the two leading US nuclear weapons development organizations. Somewhere along the way, I heard rumors that a group at Livermore had developed a wide field camera for the Star Wars program but I figured that it would be shrouded in secrecy.

The nature of gamma-ray bursts circa 1990

1. Discovered in 1967 while looking for nuclear tests
2. A totally unexpected phenomenon
3. Typical signature: 200 KeV γ-rays for ~20 secs
4. Origin: Galactic or Extra-Galactic?
5. Rate: ~1/day/Universe
6. No counterparts at other wavelengths until 1997

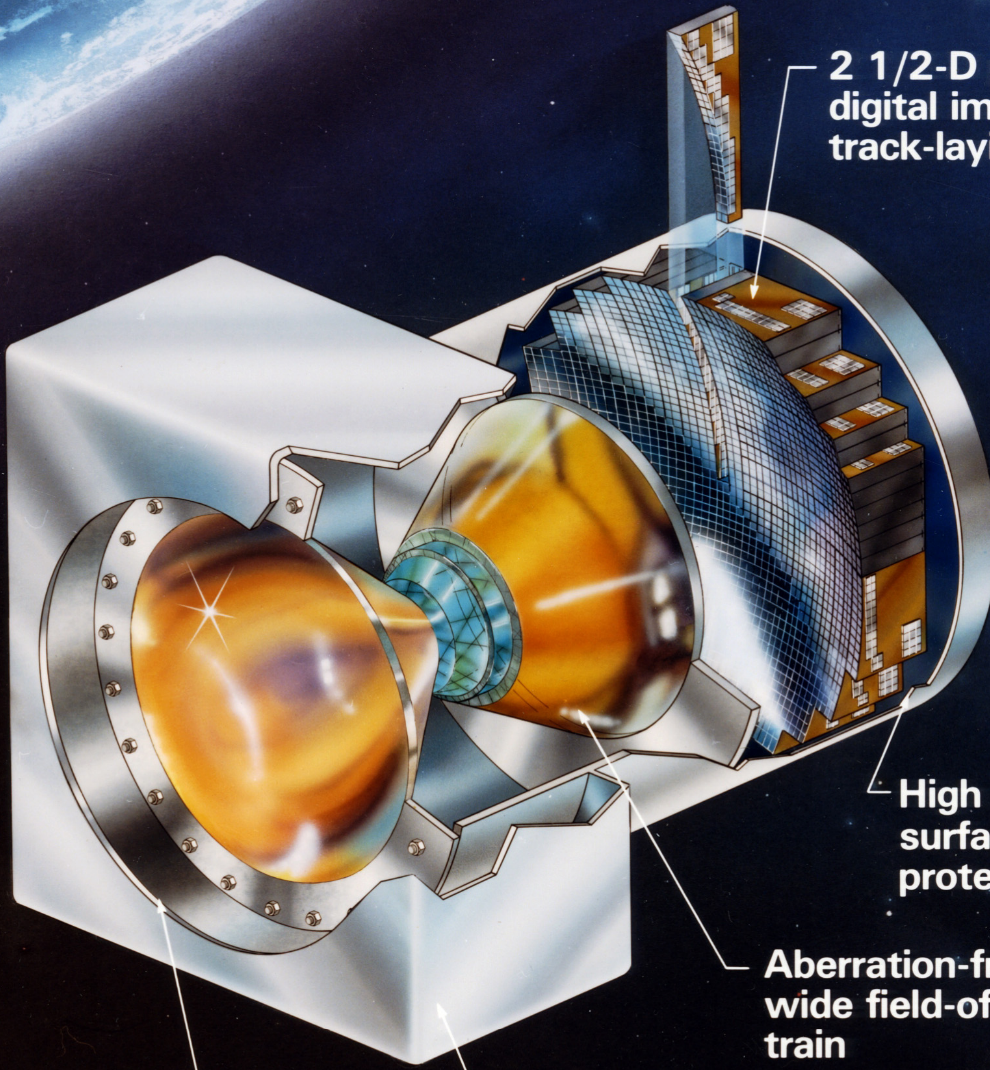
Optical identification would permit distance measurements, leading to total energy estimates. This would also provide insight to physical origins.

Brad Schaefer remarks that no one has really looked for GRBs in real time. (Huntsville, 1991)

On to Lawrence Livermore National Laboratory!

By 1992, the Star Wars program was on the junk heap of history. As it turned out, one of the members of the dark matter collaboration had assisted with the Star Wars camera development. The envisioned use of this instrument is depicted in this image. It was designed to detect incoming enemy missiles quickly enough to notify our own nuclear assets which would then use X-ray laser beams to vaporize the foreign intruder. The full scale version of this camera would require 2000 pounds of high quality optical glass but the Star Warriors would not shrink from ambitious projects. Their vision was that dozens of these cameras would be constantly orbiting the sky above us, ready to unleash nuclear-powered rays of prodigious energy.

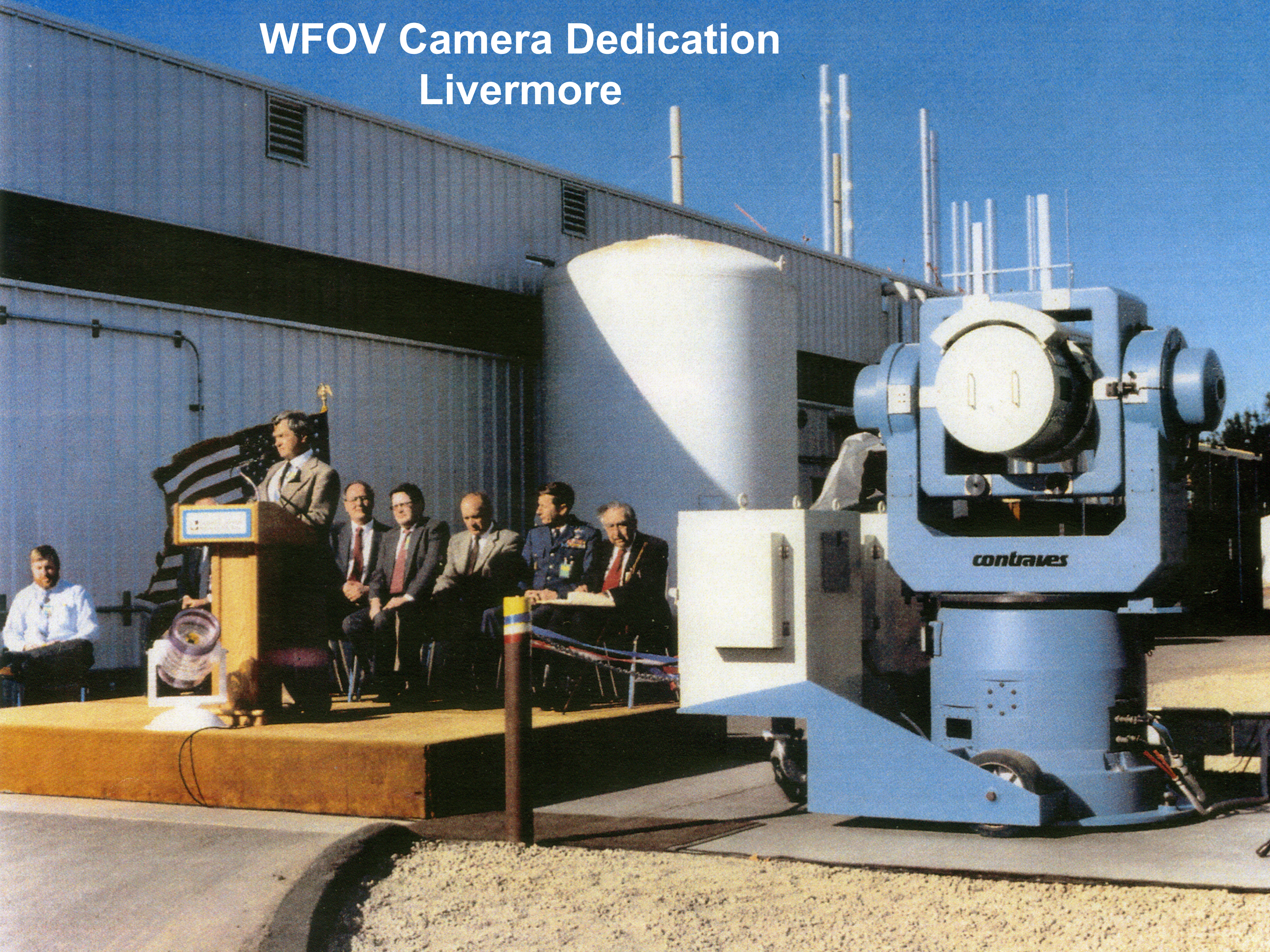
Advanced Strategic Defense Passive Optical Targeting System



In fact, a quarter-scale model of the camera lens was fabricated and attached to the blue two-axis mount shown on the right. This slide shows the “First Light” celebration of its completion. On the right, Edward Teller is glaring at the photographer; next to him is General James Abrahamson. Teller’s protégé, Lowell Wood, is sitting on the far left and the speaker is Carl Haussmann, a leader of the Livermore SDI program. A model of the actual lens is on the dais in front of the lectern.

In 1993, this ten million dollar device was accumulating cobwebs in a corner of a Livermore parking lot. The idea of using this gadget to look for gamma-ray bursts won enthusiastic approval from Bruce Tarter, then Director of the Livermore Physics Division. Bruce provided a budget of the order of $50,000 to get the gadget working again. I called a graduate student in our group to come out to Livermore for the summer and we set to work to make this Star Wars hardware respond to prompt GRB alerts from the NASA Compton Gamma-Ray Observatory.

WFOV Camera Dedication
Livermore



This Michigan/Livermore collaboration used the wide field camera between January, 1994 and June, 1996. The experiment, labeled GROCSE, recorded sky images for 28 GRB triggers with a limiting magnitude of 8.5, ~10× more sensitive than the human eye. As expected, there were no GRB optical detections but we learned an enormous amount about how to execute this kind of science. More importantly, we found out how to achieve 100 times better sensitivity for 1/100th of the WFOV cost.

In the course of this venture, a nasty personal kerfuffle broke out between Michigan and Livermore. This unseemly emotional behavior was duly reported by two books for the lay reader, published almost simultaneously by the Cambridge and Oxford Presses. News of this dissension travelled quickly and thus we were soon invited to move our project to Los Alamos. Once you understand that the two major US nuclear weapons labs are sworn enemies, such an enthusiastic offer was indeed quite natural.

Michigan/Livermore collaboration used WFOV camera between January, 1994 and June, 1996.

GROCSE recorded sky images for 28 GRB triggers.

Limiting magnitude 8.5, ~10× more sensitive than eye.

No GRB optical detections (as expected).

We learned how to achieve 100× better sensitivity for 1/100 of WFOV cost.

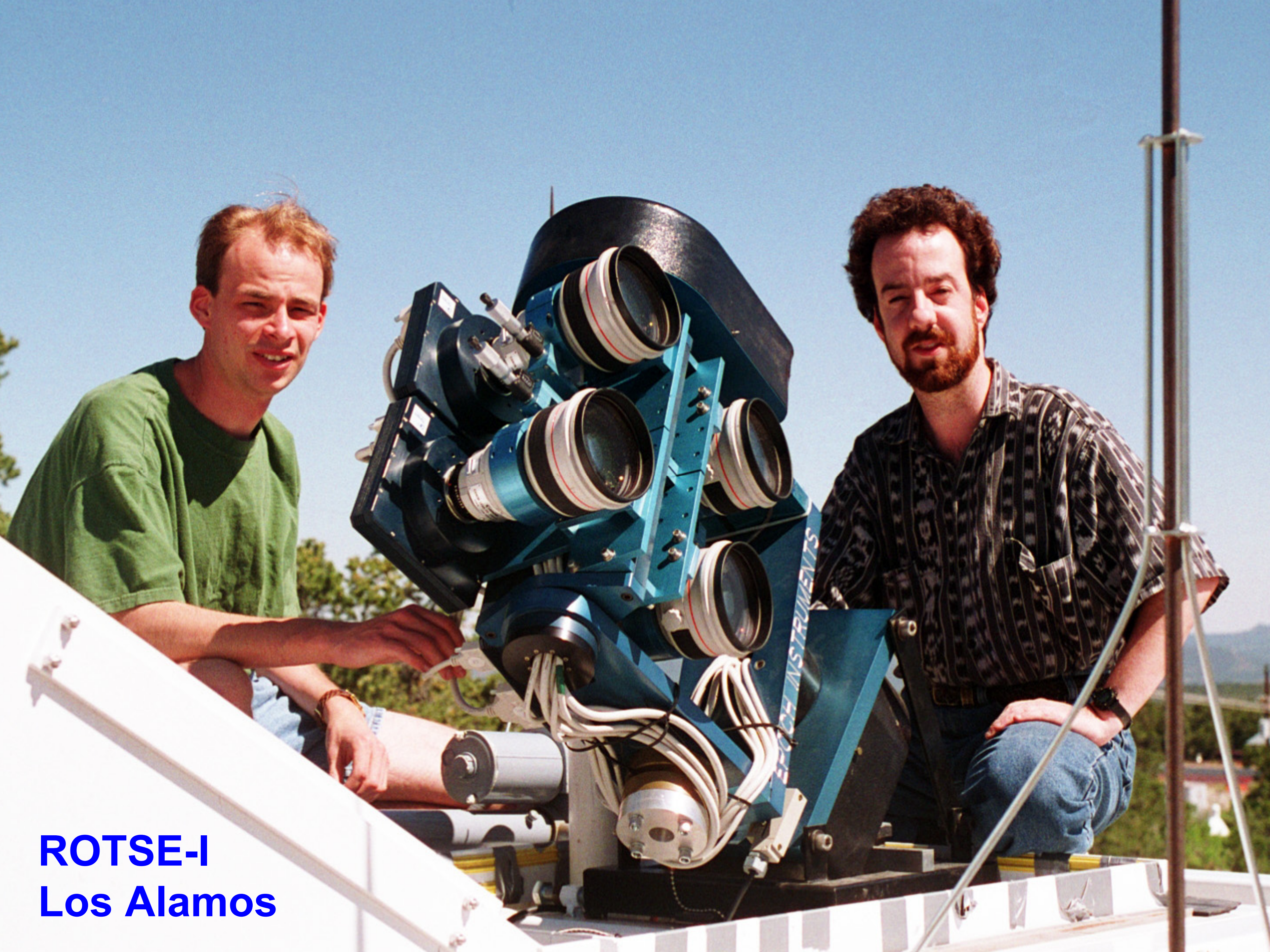
Nasty kerfuffle between Michigan and LLNL*

Thus, we were promptly invited to move our project to Los Alamos!

**Flash!: The Hunt for the Biggest Explosions in the Universe*, Govert Schilling, Cambridge Press (2002)

**The Biggest Bangs: The Mystery of Gamma-Ray Bursts, the Most Violent Explosions in the Universe*, Jonathan I. Katz, Oxford Press (2002)

Upon moving the project to Los Alamos, it was renamed ROTSE for Robotic Optical Transient Search Experiment. The key to its success was the revelation that Canon makes really impressive lenses. The market for this optics is mostly paparazzi who would like to take photos of recalcitrant celebrities under challenging light conditions. We had similar requirements but the kind of stars was different. Four cameras were mounted on a single rotating platform to image a total of 16 degrees by 16 degrees of sky. This photo taken in 1998 shows a Los Alamos staff member Jim Wren and Michigan post-doc Robert Kehoe perched on top of the camera control house.



ROTSE-I
Los Alamos

We knew that even with the improved sensitivity of the new ROTSE camera array, we would be extremely lucky to find a gamma-ray burst bright enough to detect. We were still waiting for such an event in November 1998 when I visited Los Alamos for a few days. Realizing that the Leonid meteor shower was about to occur, I suggested we aim the cameras at the Leonid meteor radiant. We watched in awe that night as the meteors streamed overhead. About a half-hour after I left for the evening, we recorded a sequence of 30 images of the meteor breakup shown in this image. This picture is the second frame. Some of our weapons oriented Los Alamos collaborators were ecstatic – they had not been able to study an atmospheric explosion since the Nuclear Test Ban Treaty was signed in 1963. The energy release here is equivalent to about $1/12^{th}$ of a ton of TNT. This is surprising considering that the meteor size is only about a quarter of a pound.

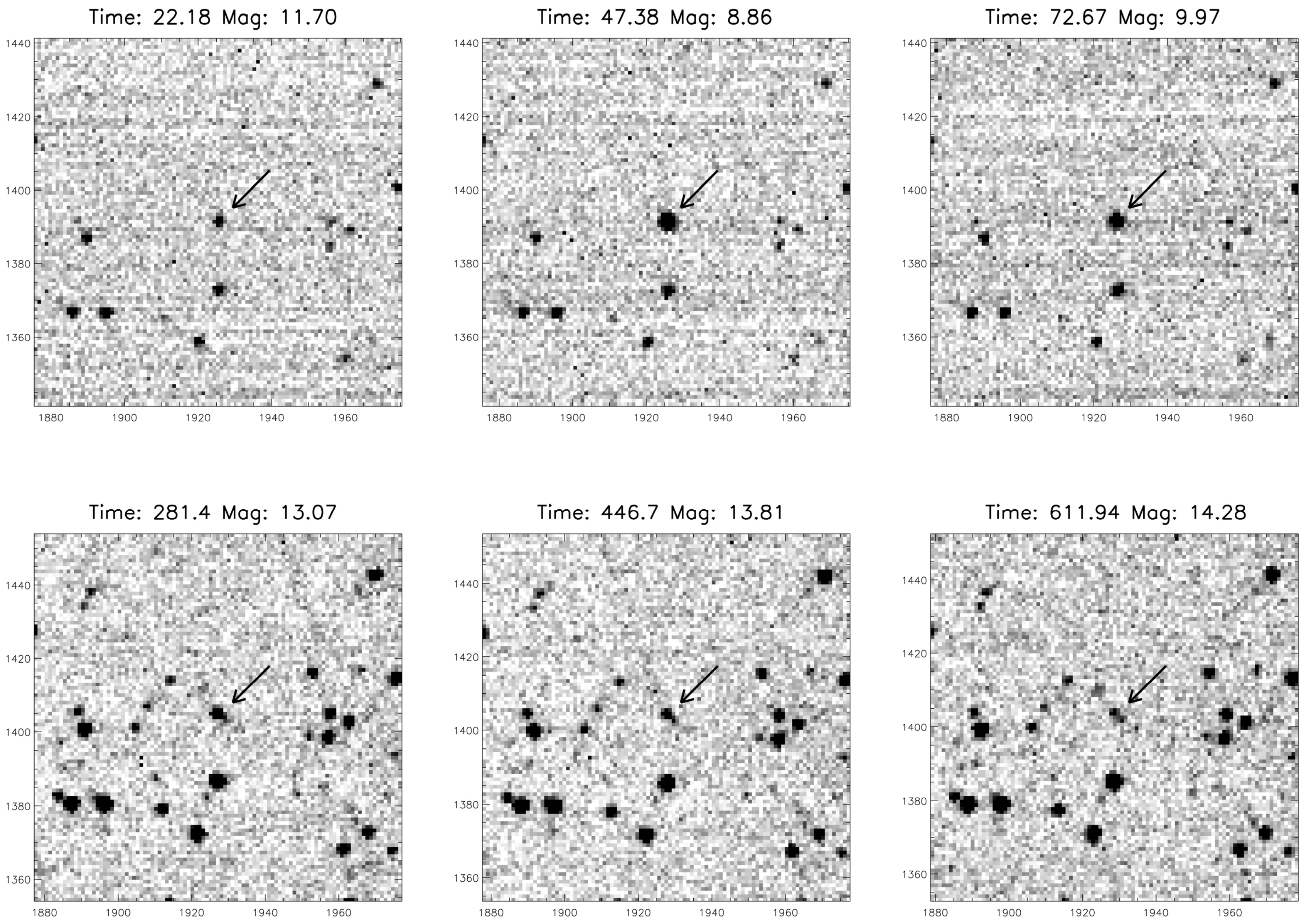
The next day, these images were posted on the NASA Astronomy Picture of the Day Web site. The ROTSE project gained some instant respect and the morale of our ROTSE troops lifted considerably.

E~⅓ GigaJoule

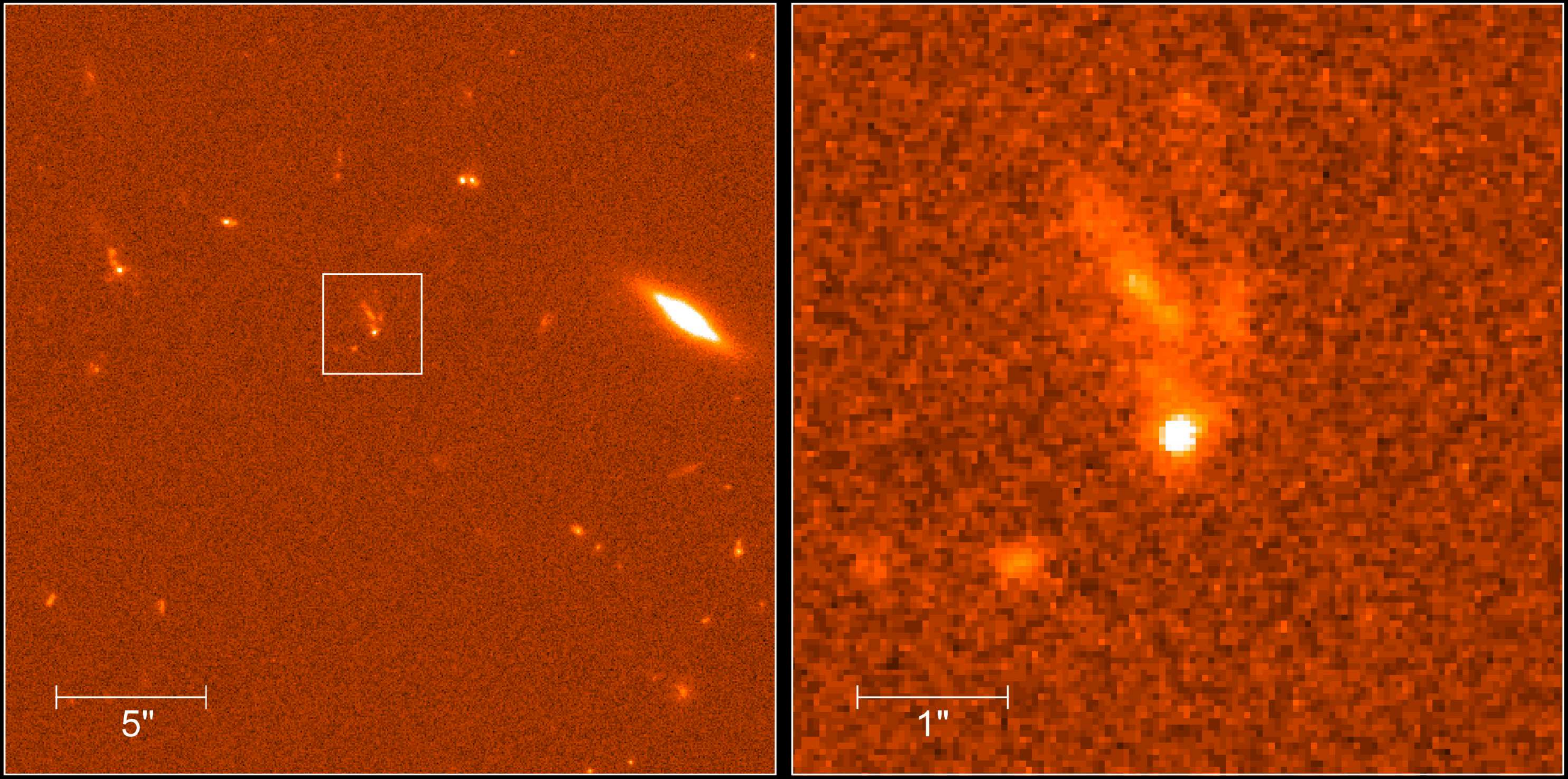
Leonid meteor breakup above Las Vegas, NM, November 17, 1998
http://www.rotse.net/science/meteor.html

The major breakthrough in this effort occurred on January 23, 1999. That morning I awoke to find an E-mail message signaling the NASA Compton Gamma-Ray Observatory detection of a bright GRB. Further investigation showed that our ROTSE cameras had responded. By this time, I also learned that a precise localization had been obtained from an Italian satellite, Beppo-SAX. Armed with this information, I began to comb through the ROTSE images, suspecting all along that some malign problem would soon be discovered. Instead, a clear example of a fast rising optical transient appeared without any ambiguity. This marked the first time that gamma-ray bursts had been imaged simultaneously in both gamma-ray and optical bands.

ROTSE-I prompt optical detection of GRB 990123



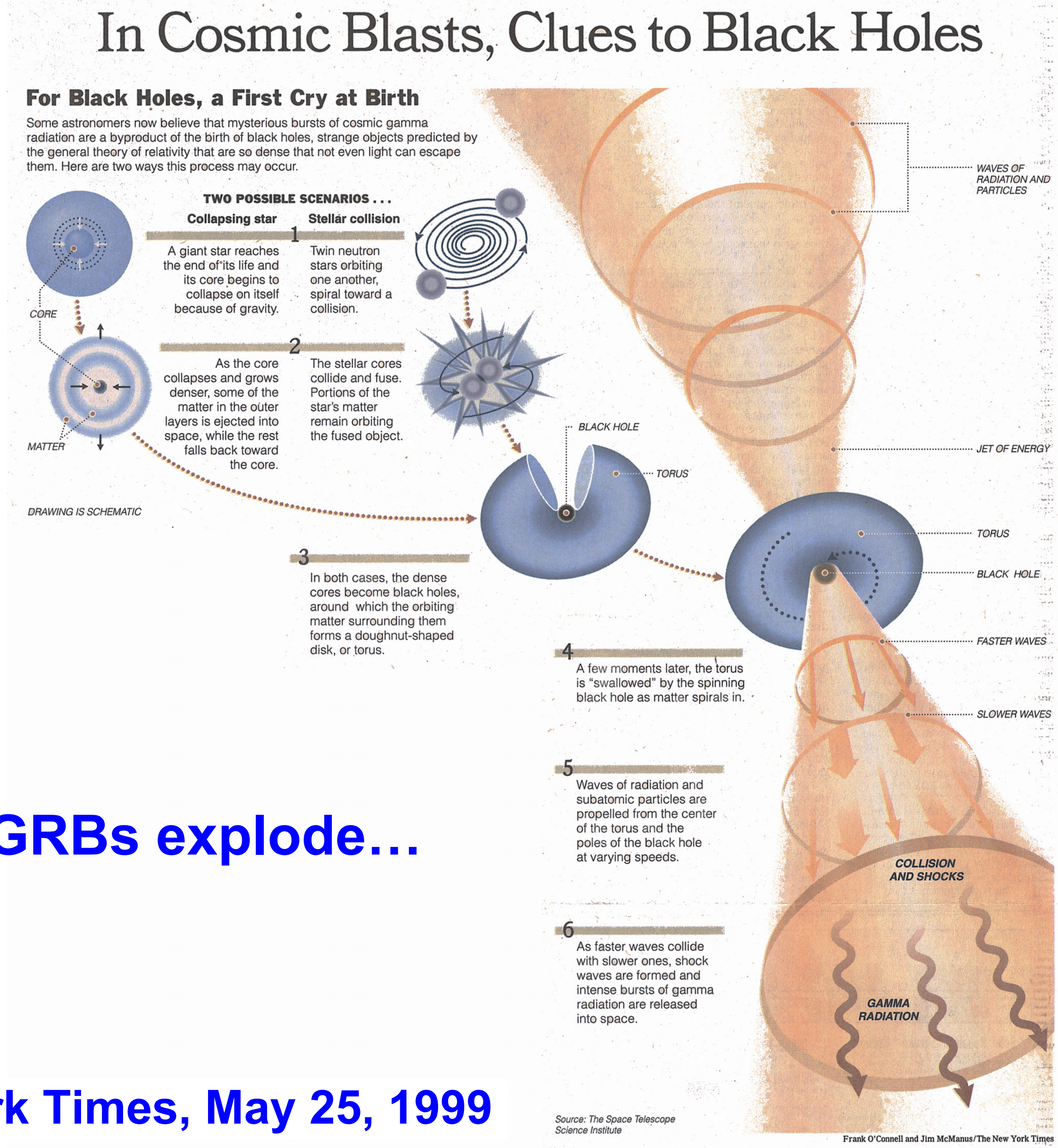
This was an event of major interest and was followed up by images from the Hubble Space Telescope. The faint smudges appear to be two galaxies in collision, a favorable environment for the kinds of stars expected to produce GRBs. The redshift was determined by spectroscopic measurements. The value of 1.61 corresponds to a distance of about 9 billion light-years. Even though one of the brightest bursts ever seen, it occurred when the Universe was a fraction of its present age.



Hubble image of GRB 990123

(redshift = 1.61)

This is a schematic drawing of the processes which are believed to drive a gamma-ray burst. In this case, a collapsing star with high angular momentum evolves to a black hole surrounded by a disk of material that accretes toward the center. This powers jets of highly relativistic particles that stream out along the spin axis of the progenitor. The gamma-rays are emitted by collisions between these particles while the optical photons come primarily from synchrotron radiation at the shock fronts developed as the high energy particles ram into the interstellar medium surrounding the star.



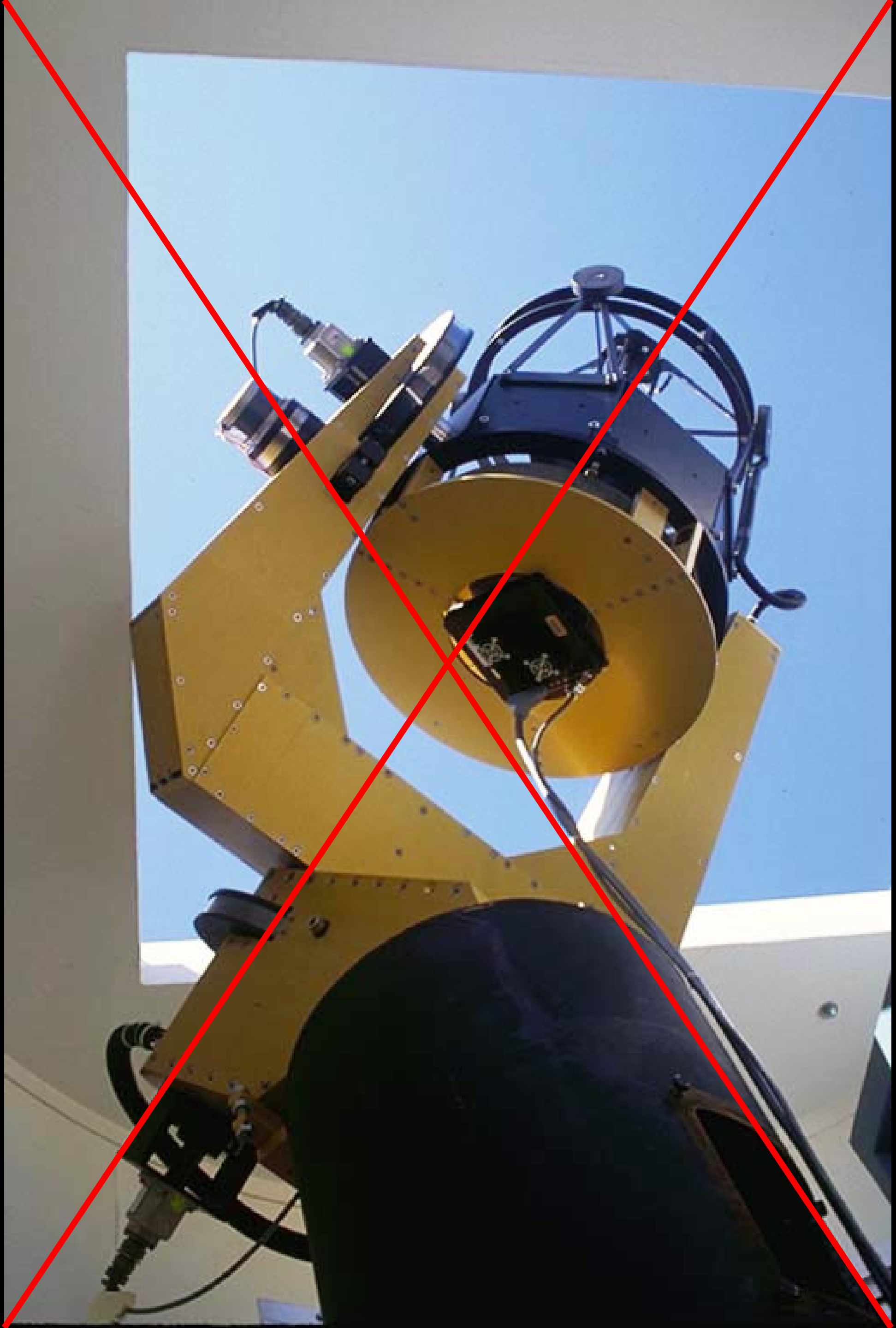
How GRBs explode…

New York Times, May 25, 1999

Although our success with GRB990123 was unequivocal, it was clear that very few bursts would be nearly as bright. Banking on our new-found fame, we applied successfully to NASA for funds to build custom telescopes that would give us considerably better sensitivity. With no previous experience in the technology of small telescopes, I followed advice from others and wrote a contract for $150,000 for two 0.45-meter telescopes to a small Iowa optics company that catered to the astronomical community. Unfortunately, they turned out to be totally incompetent in all respects. The mechanical design was simply inadequate but the optical quality of the mirror and lenses was a complete disaster. One of our Livermore collaborators had carefully evaluated the primary mirror surface shape and noted that it exhibited the symmetry of a Pringle. One of the best decisions I have made in my scientific career was to realize that these instruments should be written off as a total loss. That was the short, sad life of ROTSE-II. We eventually sold the pair for $150.

ROTSE-II

(a total disaster)



With some newly gained sophistication in optical design, we sought more professional assistance to develop telescopes satisfying our original requirements. The new design was called ROTSE-III and, although not perfect in all respects, has substantially answered all our demands. The optical design was considerably simplified by Harland Epps, a faculty member in the astronomy department at UC-Santa Cruz. The mechanical design was carried out by a small engineering firm in Pasadena with much greater professional experience. The glass came from Japan, the image sensors from England and the shutters from Germany. Separate contracts were written for optical fabrication, the cameras and the telescope enclosures. The first unit was installed in Australia in 2002. This whole design and fabrication process was administered mostly by Tina Wells, then our group secretary.

ROTSE-III

(Success!!!)

The total instrument package was designed to be completely self-sufficient and easily transportable to the four corners of the globe. The latter constrained the entire package to fit inside a standard sea-going shipping container. At sunset every day, the weather is automatically assessed and if there is no evidence of rain and the wind velocity is below certain limits, the telescope hatch opens and the telescope follows a computer script to image the night sky, interrupted as required by alerts from NASA satellites. Several of our four sites have constraints on the data bandwidth to Ann Arbor and thus a large fraction of the data analysis must be performed by computers inside the telescope enclosure.

ROTSE-IIIb near Ft. Davis, Texas

A major feature of the ROTSE-III project has been the installation of four identical systems, two in the northern hemisphere and two in the southern hemisphere at the locations shown on the map. This allowed us to claim with tongue in cheek that “The sun never rises on the ROTSE empire”, ie. one of the four telescopes is always under a night sky. The purpose, of course, was to substantially increase the number of gamma-ray bursts that could be promptly observed.

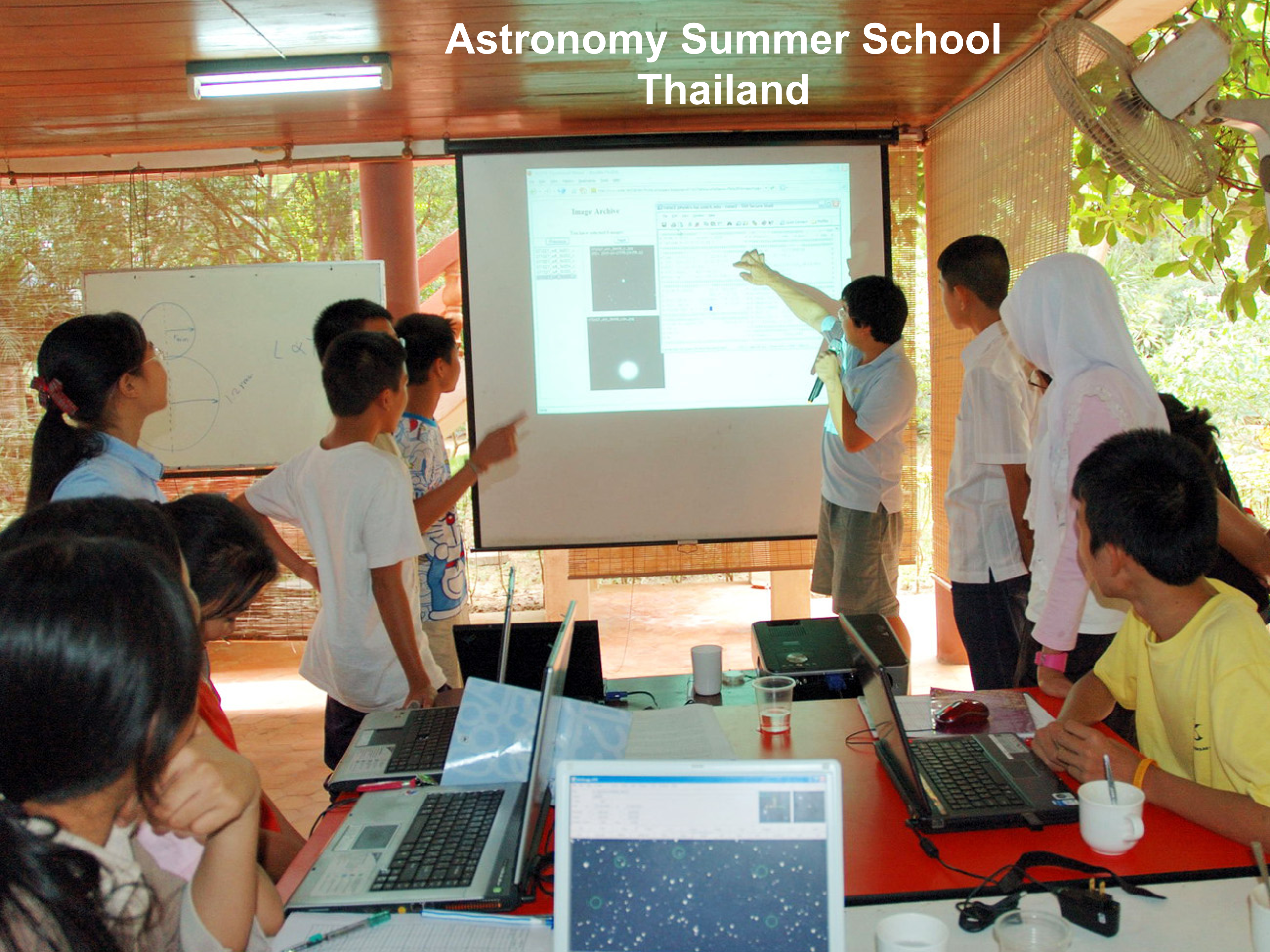
"The sun never rises on the ROTSE empire"

A project like this requires the concerted effort of a number of humans. This slide shows the participants at a collaboration meeting in Ann Arbor in 2004. Although the largest contingent is connected to the University of Michigan as students and post-docs, there are also folks from Texas and Germany. Most of our communications are through the Internet, enabling a program that would have been impossible a few years ago.


ROTSE Collaboration meeting
August 12-14, 2004

The data from ROTSE has been made available to anyone with a legitimate interest. A remarkable Michigan undergraduate working on ROTSE, Wiphu Rujopakarn, had developed a program with a friend for bringing astronomy to middle and high school students in Thailand. Thus in 2006, I signed an agreement with the Thailand Research Fund to provide near-realtime ROTSE images to students in a country frequently blessed by almost continuous rainfall. When I visited their astronomy summer camp near the River Kwai, they were very proud of the fact that among the participants were Islamic students from the south as well as those representing the Buddhist majority. These two ethnic groups are not always friendly. Although only a small positive step, it shows the universal appeal of science that had attracted me to this field as a teenager.

Astronomy Summer School Thailand



I have listed here what I consider the major ROTSE accomplishments:

- It was the first major ground-based robotic telescope project
- Its success is partly due to the high reliability of its components
- This project obtained the first measurement of prompt GRB optical radiation
- We currently make optical detections of ~8 GRBs per year
- We have gained much information (but not always scientific understanding)
- We also find ~15 supernovae per year
- Among these are the unexpected appearance of over-luminous supernovae whose dynamics are under investigation
- We also find and report a large variety of variable stars
- These observational facilities are made available to groups in Turkey & Thailand

However, science marches on and ROTSE is being superseded by a number of larger projects such as the Palomar Transient Factory, GROND, Pan-Starrs, LSST, etc.

ROTSE accomplishments:

- First major ground-based robotic telescope project
- Success due to high reliability
- First measurement of prompt GRB optical radiation
- Optical detections of ~8 GRBs per year
- Much information gained (but not understanding)
- Discovery ~15 supernovae per year
- Detections of over-luminous supernovae
- Discovery of numerous variable stars
- Observational facilities available to Turkey & Thailand

ROTSE is being superseded by a number of larger projects: PTF, GROND, Pan-Starrs, LSST, etc.

Some common themes

- Random conversations often initiate new research. Casual chats initiated both our TeV gamma-ray and GRB optical counterpart searches.
- Get advice from everywhere you can.
- Federal funding agencies can be very timid. Both DoE and NSF let us down at critical points.
- We were fortunate to get support from Sandia, LLNL & LANL.
- Both projects were developed over 3 generations (or more). Especially in a developing field, it takes experience to find the best techniques.
- If you make a mistake, acknowledge it as soon as possible.
- One is often rewarded by the unexpected.
- Try to push the envelope in unusual directions. This makes the unexpected easier.
- Make sure it’s fun for everyone, not just you.
- Make your research accessible to the public.
- Probably these are very bad projects for an untenured faculty member.

Some common themes

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As I look over the changes in my field during the 50 years since I graduated from college in 1960, one major development is the size of scientific collaborations. My thesis experiment performed at Cornell involved a total of four people and was executed after about one year of prior planning and construction. The dimensions of the entire detector were comparable to the height of my fellow graduate student, Bill Ash.

1965

PION PRODUCTION BY POLARIZED VIRTUAL PHOTONS*

C. W. Akerlof, W. W. Ash, K. Berkelman, and M. Tigner

Laboratory of Nuclear Studies, Cornell University, Ithaca, New York

(Received 10 May 1965)

In this paper we propose a new method for determining the spin and parity and the electromagnetic transformation form factors of nucleon isobars. We report on an experimental test of this technique using the well-known $N_{3/2}^*(1238)$ isobar.

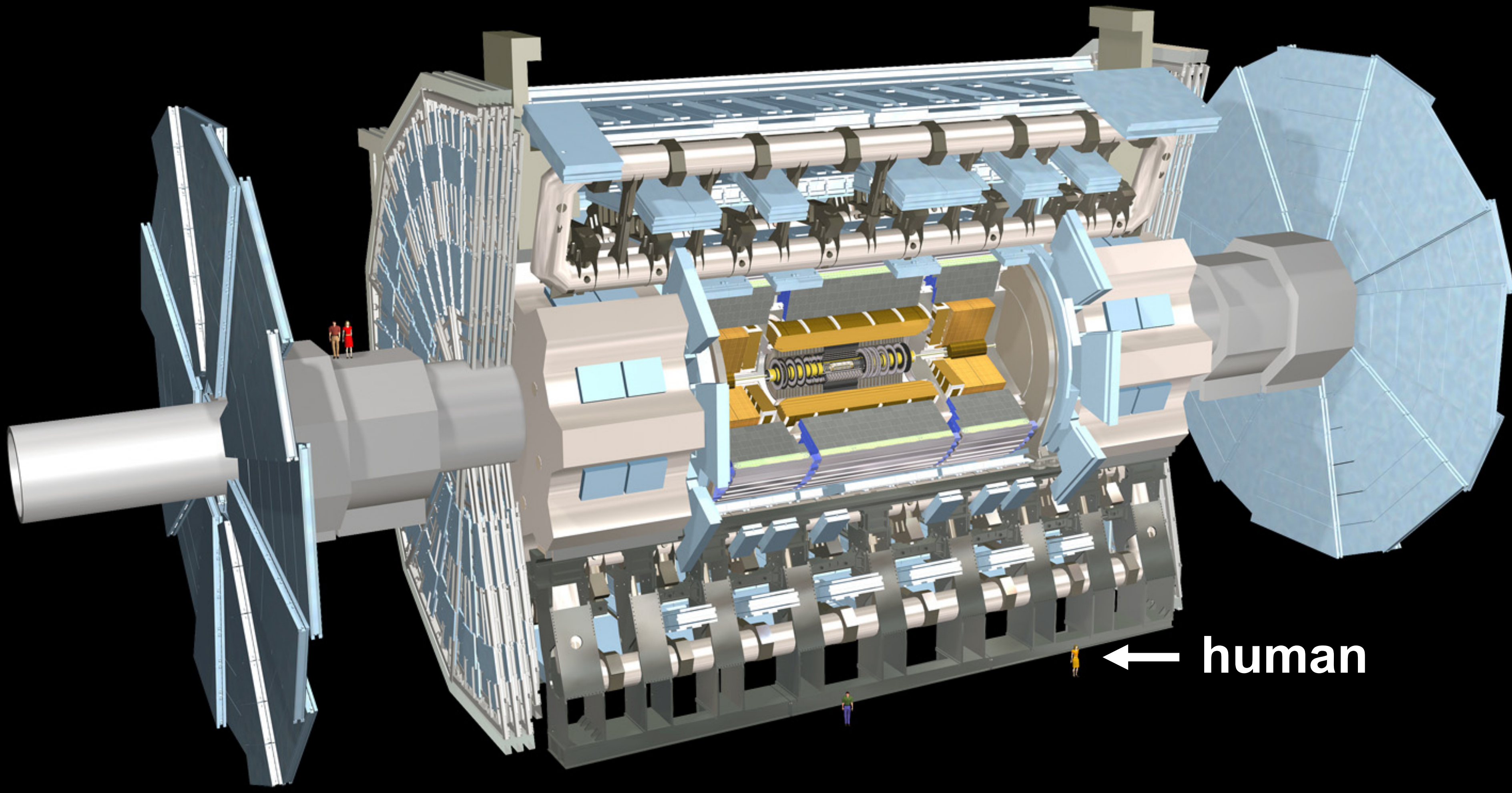
Consider the pion electroproduction reaction $e+N\rightarrow e+N+\pi$, and assume that the exchange of a single photon dominates [see Fig. 1(a)]. To concentrate our attention on the more interesting strong-interaction physics, we express the electroproduction differential cross section in terms of known quantities derived from the electron-photon vertex and photon propagator, and the differential cross section for pion photoproduction by virtual photons[1]:

$$\frac{d^3\sigma}{dr_0'd\omega d\Omega}=\frac{\alpha}{2\pi^2}\frac{r_0'}{r_0}\frac{|\vec{k}|}{(-k^2)}\frac{d\sigma}{d\Omega}. \quad (1)$$

All quantities in (1) are defined in the labora-

Akerlof PhD experiment

This is what an elementary particle physics experiment looks like today, in this case the ATLAS detector at the LHC at CERN. Note the relative size of the standard human near the bottom.



CERN ATLAS Detector (2008)

And here is the first page of the author list for a recent ATLAS paper, also published in Physical Review Letters. Rudi Thun used to joke that to succeed in particle physics, you needed a name like Aaron Aardvark. As you can see, Aardvark would now be relegated to second place. The total author list encompasses approximately 3000 names.

Search for New Particles in Two-Jet Final States in 7 TeV Proton-Proton Collisions with the ATLAS Detector at the LHC

G. Aad *et al.**
(ATLAS Collaboration)
(Received 13 August 2010; published 11 October 2010)

A search for new heavy particles manifested as resonances in two-jet final states is presented. The data were produced in 7 TeV proton-proton collisions by the LHC and correspond to an integrated luminosity of 315 nb^{-1} collected by the ATLAS detector. No resonances were observed. Upper limits were set on the product of cross section and signal acceptance for excited-quark (q^*) production as a function of q^* mass. These exclude at the 95% C.L. the q^* mass interval $0.30 < m_{q^*} < 1.26$ TeV, extending the reach of previous experiments.

DOI: 10.1103/PhysRevLett.105.161801 PACS numbers: 13.85.Rm, 12.60.Rc, 13.87.Ce, 14.80.−j

~ 3000 authors ↓↓↓↓

G. Aad,[48] B. Abbott,[111] J. Abdallah,[11] A. A. Abdelalim,[49] A. Abdesselam,[118] O. Abdinov,[10] B. Abi,[112] M. Abolins,[88] H. Abramowicz,[153] H. Abreu,[115] E. Acerbi,[89a,89b] B. S. Acharya,[164a,164b] M. Ackers,[20] D. L. Adams,[24] T. N. Addy,[56] J. Adelman,[175] M. Aderholz,[99] S. Adomeit,[98] C. Adorisio,[36a,36b] P. Adragna,[75] T. Adye,[129] S. Aefsky,[22] J. A. Aguilar-Saavedra,[124b,b] M. Aharrouche,[81] S. P. Ahlen,[21] F. Ahles,[48] A. Ahmad,[148] H. Ahmed,[2] M. Ahsan,[40] G. Aielli,[133a,133b] T. Akdogan,[18a] T. P. A. Åkesson,[79] G. Akimoto,[155] A. V. Akimov,[94] A. Aktas,[48] M. S. Alam,[1] M. A. Alam,[76] S. Albrand,[55] M. Aleksa,[29] I. N. Aleksandrov,[65] M. Aleppo,[89a,89b] F. Alessandria,[89a] C. Alexa,[25a] G. Alexander,[153] G. Alexandre,[49] T. Alexopoulos,[9] M. Alhroob,[20] M. Aliev,[15] G. Alimonti,[89a] J. Alison,[120] M. Aliyev,[10] P. P. Allport,[73] S. E. Allwood-Spiers,[53] J. Almond,[82] A. Aloisio,[102a,102b] R. Alon,[171] A. Alonso,[79] J. Alonso,[14] M. G. Alviggi,[102a,102b] K. Amako,[66] P. Amaral,[29] G. Ambrosio,[89a,c] C. Amelung,[22] V. V. Ammosov,[128] A. Amorim,[124a,d] G. Amorós,[167] N. Amram,[153] C. Anastopoulos,[139] T. Andeen,[34] C. F. Anders,[20] K. J. Anderson,[30] A. Andreazza,[89a,89b] V. Andrei,[58a] M-L. Andrieux,[55] X. S. Anduaga,[70] A. Angerami,[34] F. Anghinolfi,[29] N. Anjos,[124a] A. Annovi,[47] A. Antonaki,[8] M. Antonelli,[47] S. Antonelli,[19a,19b] J. Antos,[144b] B. Antunovic,[41] F. Anulli,[132a] S. Aoun,[83]

Here are the second and third pages of the author list. The University of Michigan is a relatively large contributor to this effort. I have indicated the Michigan members by the blue boxes around their names and in the list at the bottom.

G. Arabidze,[8] I. Aracena,[143] Y. Arai,[66] A. T. H. Arce,[44] J. P. Archambault,[28] S. Arfaoui,[29,e] J-F. Arguin,[14] T. Argyropoulos,[9] E. Arik,[18a,a] M. Arik,[18a] A. J. Armbruster,[87] K. E. Arms,[109] S. R. Armstrong,[24] O. Arnaez,[4] C. Arnault,[115] A. Artamonov,[95] D. Arutinov,[20] M. Asai,[143] S. Asai,[155] R. Asfandiyarov,[172] S. Ask,[27] B. Åsman,[146a,146b] D. Asner,[28] L. Asquith,[77] K. Assamagan,[24] A. Astbury,[169] A. Astvatsatourov,[52] G. Atoian,[175] B. Aubert,[4] B. Auerbach,[175] E. Auge,[115] K. Augsten,[127] M. Aurousseau,[4] N. Austin,[73] G. Avolio,[163] R. Avramidou,[9] D. Axen,[168] C. Ay,[54] G. Azuelos,[93,f] Y. Azuma,[155] M. A. Baak,[29] G. Baccaglioni,[89a] C. Bacci,[134a,134b] A. M. Bach,[14] H. Bachacou,[136] K. Bachas,[29] G. Bachy,[29] M. Backes,[49] E. Badescu,[25a] P. Bagnaia,[132a,132b] Y. Bai,[32a] D. C. Bailey,[158] T. Bain,[158] J. T. Baines,[129] O. K. Baker,[175] M. D. Baker,[24] S Baker,[77] F. 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Bindi,[19a,19b] S. Binet,[115] A. Bingul,[18c] C. Bini,[132a,132b] C. Biscarat,[177] R. Bischof,[62] U. Bitenc,[48] K. M. Black,[57] R. E. Blair,[5] J-B Blanchard,[115] G. Blanchot,[29] C. Blocker,[22] J. Blocki,[38] A. Blondel,[49] W. Blum,[81] U. Blumenschein,[54] C. Boaretto,[132a,132b] G. J. Bobbink,[105] A. Bocci,[44] D. Bocian,[38] R. Bock,[29] C. R. Boddy,[118] M. Boehler,[41] J. Boek,[174] N. Boelaert,[79] S. Böser,[77] J. A. Bogaerts,[29] A. Bogouch,[90,a] C. Bohm,[146a] J. Bohm,[125] V. Boisvert,[76] T. Bold,[163,g] V. Boldea,[25a] V. G. Bondarenko,[96] M. Bondioli,[163] M. Boonekamp,[136] G. Boorman,[76] C. N. Booth,[139] P. Booth,[139] J. R. A. Booth,[17] S. Bordoni,[78] C. Borer,[16] A. Borisov,[128] G. Borissov,[71] I. Borjanovic,[12a] S. Borroni,[132a,132b] K. Bos,[105] D. Boscherini,[19a] M. Bosman,[11] H. Boterenbrood,[105] D. Botterill,[129] J. Bouchami,[93] J. Boudreau,[123] E. V. Bouhova-Thacker,[71] C. Boulahouache,[123] C. Bourdarios,[115] A. Boveia,[30] J. 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U of M: A. J. Armbruster, J. W. Chapman, M. Cirilli, T. Dai, E. De La Cruz-Burelo, E. B. Diehl, A. Eppig

I believe the escalating size of collaborations in some subfields will require a reexamination of university research priorities. What kinds of projects are appropriate within our finite resources of both money and manpower?

- Experiments are increasing in duration at a faster rate than human lifetimes.
- Spontaneity of ideas is at risk as projects exponentiate in size.
- Funding agencies prefer BIG to small.
- Only a few universities have adequate resources to manage large projects.
- Even small projects like ROTSE are increasingly difficult.
- The research role of universities may atrophy in areas such as elementary particles and astrophysics as leadership inevitably devolves to the largest laboratories.
- History is not always a reliable guide to the future. Funding agencies such as NASA are being sorely stretched by commitments that have nothing to do with primary research or education.

Managing university research priorities…

- Experiments are increasing in duration at a faster rate than human lifetimes.
- Spontaneity of ideas is at risk.
- Funding agencies prefer **BIG** to small.
- Only a few universities have adequate resources to manage large projects.
- Even small projects like ROTSE are increasingly difficult.
- Research role of universities will atrophy in areas such as elementary particles and astrophysics.
- History is not always a reliable guide to the future.

I would now like to briefly discuss my concerns about K-12 science education as it exists currently. As a metaphor, I would like to describe my involvement in the early history of the Ann Arbor Hands-On Museum and the institution that it has become. The idea for the Ann Arbor Hands-On Museum originated with Cynthia Yao in the mid-70s. With her vast energy and enthusiasm, she soon persuaded a large number of people associated with the University that this was a community project well worth pursuing. The inspiration for this enterprise was the Exploratorium in San Francisco, the creation of Frank Oppenheimer, Robert's brother.

Ann Arbor Hands-On Museum

Founded in 1978 by Cynthia Yao
+
Jean Bollinger
Lucy Kirshner
Lorraine Nadelman
Marc & Joan Ross
Jean Williams
Maris & Judy Fravel
C^2 Akerlof
+
many others

ANN ARBOR HANDS-ON MUSEUM
PROPOSED RENOVATED EXTERIOR

MENEGHINI OVERHISER ASSOCIATES
ARCHITECTS

Inspired by the Exploratorium,
San Francisco

In this and the following two slides, I would like to show some contrasts between the Exploratorium which we tried to emulate and the Hands-On Museum as it exists currently. In my opinion, at some point there has been a tragic loss of focus and vision. Although a somewhat Spartan environment, the Exploratorium did not dumb itself down to a pre-school culture. Unfortunately, much of the Hands-On Museum now looks like a spacious child care facility.

The Exploratorium

Ann Arbor Hands-On Museum

I have an especial fondness for the bicycle wheel gyro since it was that demonstration that Cynthia Yao asked me to duplicate for an early set of travelling exhibits that caught the imagination of Ann Arbor school children and parents. The photograph on the left shows the Exploratorium original; on the right our local museum's version after being made totally safe and stripped of any useful educational significance. After this talk is over, we can offer you an opportunity to play with something closer to the Exploratorium model. Needless to say, you will be requested to sign a comprehensive liability release form in advance.


bicycle wheel gyro
HOSE

Again, on the left is shown the Exploratorium version of the Bernoulli Ball exhibit that demonstrates the lift forces that enable airplanes to fly. The Hands-On Museum version is on the right. Personally, I think this pair of photographs could be used in a class on industrial design to illustrate that the lamest exhibit is perfectly acceptable in the world of science education. For the curious, a hair dryer and a ping-pong ball makes a far more effective demonstration that you can try at home.


Bernoulli Blast

Clearly US science education has lost its way. A typical statistic indicates that in a comparison of the scientific literacy of 15-year olds, the US is 21st out of 30 advanced nations. I have attempted some personal efforts with mixed results. These include:

- Advising the Ann Arbor Hands-On Museum
- Mentoring students from local high schools
- Organizing a project for two students from Macomb County MSTC
- Participation in the "National Lab Day" program

The downhill race to the bottom that seems to be our current path has many roots. These include:

1. Secondary school science is not a rewarding career.
2. *No Child Left Behind* and *Race to the Top* willfully ignore the aspects of science and math that make them exciting.
3. Previous introductions to physics such as cars, ham radio, tree houses, shop classes are no longer available.

US science education has lost its way…

Typical statistic: 2006 survey of scientific literacy of 15-year olds: US is 21st out of 30 advanced nations.

Some personal efforts:

- Ann Arbor Hands-On Museum
- Mentored students from local high schools
- Project for two students from Macomb County MSTC
- "National Lab Day" program

Secondary school science is not a rewarding career.

No Child Left Behind and *Race to the Top* willfully ignore the aspects of science and math that make them exciting.

Previous introductions to physics such as cars, ham radio, tree houses, shop classes are no longer available.

The lack of adequate science and math education has severe consequences for our economy. In this slide, I have compared the top ten of the Fortune 500 in 1960 and 2010. The corporations that actually manufacture real things are marked in light green. Over the past 50 years, the relative value of manufactures in these lists has shifted from 64% to 22%. You will also note that the shift also is very strongly in the direction of imports, either in the form of petroleum or consumer goods from abroad.

Fortune 500 – then and now

	1960 (GDP = 0.526 T$)	
Rank	Company	Revenues ($ millions)
1	General Motors	11,233.1
2	Exxon Mobil	7,910.7
3	Ford Motor	5,356.9
4	General Electric	4,349.5
5	U. S. Steel	3,643.0
6	Mobil	3,092.9
7	Gulf Oil	2,713.0
8	Texaco	2,678.0
9	Chrysler	2,643.0
10	Esmark	2,475.5
	manufacturing fraction = 64.4 %	

2010 (GDP = 14.624 T$)	
Company	Revenues ($ millions)
Wal-Mart Stores	408,214.0
Exxon Mobil	284,650.0
Chevron	163,527.0
General Electric	156,779.0
Bank of America	150,450.0
Conoco Phillips	139,515.0
AT&T	123,018.0
Ford Motor	118,308.0
J. P. Morgan	115,632.0
Hewlett-Packard	114,552.0
manufacturing fraction = 22.0 %	

(green) = manufacturing

Manufacturing rows (shaded green): 1960 — General Motors, Ford Motor, General Electric, U. S. Steel, Chrysler, Esmark; 2010 — General Electric, Ford Motor, Hewlett-Packard.

As a teenager, I could not have possibly believed that General Motors would disappear from the Fortune 500 Top Ten within 60 years. I realize these images are totally unfair but I think it sharply captures the collapse of our automobile industry. The left image shows a 1955 Ford Thunderbird, the secret desires of every teenage male I knew. The image on the right is a 2010 Chevy HHR. Having had the unfortunate opportunity to drive this vehicle about a year ago, it is hard to believe that it was designed by people who actually had ever been behind the wheel of a car. It’s fun to imagine an alternate Universe in which Steve Jobs had decided to design cars instead of cell phones. However, Apple car owners would be insufferable friends and neighbors.

The decline of the US automobile industry…

1955 Ford Thunderbird

2010 Chevrolet HHR

This talk is now close to the end. During the past few years, I have been tasked with the job of improving the Physics Department undergraduate lab courses. Along the way, I have tried to combine science and art that would engage the imagination and enthusiasm of our students. Some of these will be available in the reception hall immediately following this talk. All of these are intended for hands-on interaction.

Some gadgets built for various physics classes…

- Ball bearing accelerator
- Optical rotation
- Gyroscope (and chair!)
- Interference from a CD
- Faraday rotation
- Mechanical refraction
- Magnetic induction
- Diamagnetic flotation
- Moments of inertia
- Rotational energy
- Michelson inteferometer
- Quadrupole rotor

Please go play with them!!!

In conclusion:

- Physics is more than solutions of differential equations or Terabytes of data.
- Including a respect for the emotional components of science should be an important function of what we teach at universities.
- We need to be aware that the styles of doing physics during the past 60 years may become obsolete in the decades ahead.
- High school science & mathematics education has become roadkill. Adult supervision is required!

Throughout my career, my efforts have been greatly amplified by University staff members. Their names are not often included in journal articles, etc. I am very grateful to Tina Wells and Beth Demkowski for their role in making our ROTSE project possible and to Dave Carter and Jim Tice for their skills in building the experimental gadgets for our various lab courses.

Conclusions

Physics is more than solutions of differential equations or Terabytes of data.

Including a respect for the emotional components of science should be an important function of what we teach at universities.

We need to be aware that the styles of doing physics during the past 60 years may become obsolete in the decades ahead.

High school science & mathematics education has become roadkill. Adult supervision required!

Thanks to Tina Wells, Beth Demkowski, Jim Tice, and Dave Carter for all their help!!!

I would like to end this talk with an image, not text. This photograph was taken by Fang Yuan who obtained a PhD with our group last year. This is the work of someone who appreciates the importance of the integration of art and science in the course of their career.


ROTSE-IIIb site at McDonald Observatory


Jens Zorn