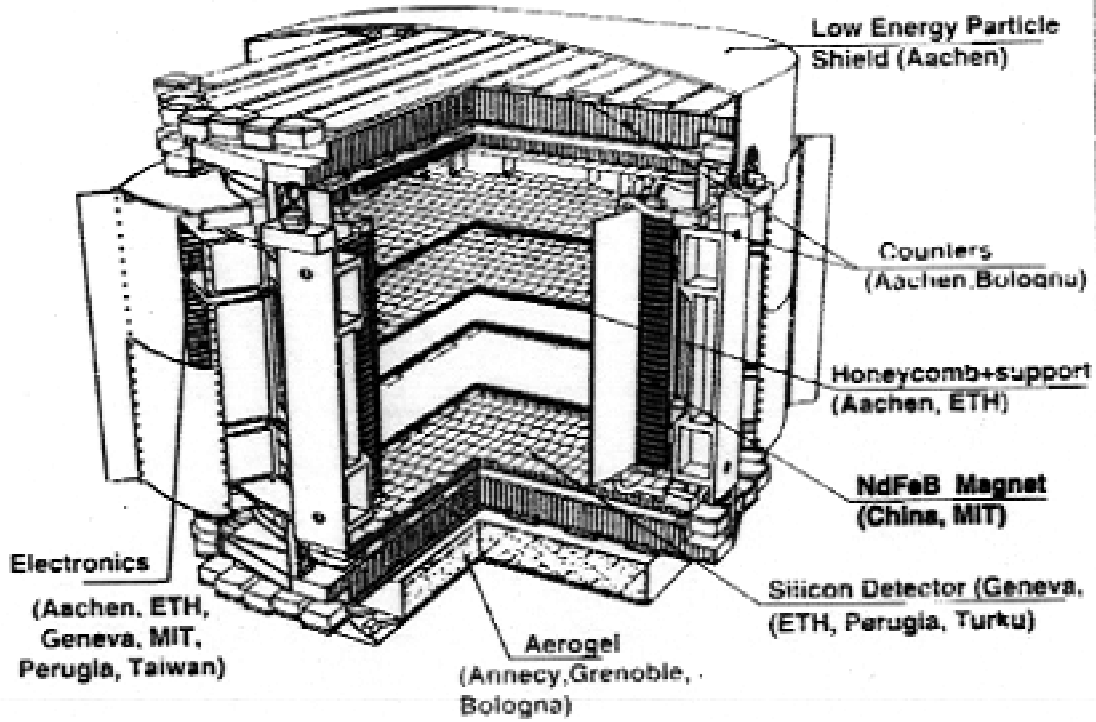
Satellite Astrophysics Experiments

Peter Michelson
Stanford University

ICFA Seminar
October 7, 1999
FermiLab

AMS ALPHA MAGNETIC SPECTROMETER



Detector Configuration for STS-91 Mission

- joint project of NASA, DOE and foreign agencies
  37 institutes in 10 countries

Project Chronology

- May 9, 1994 meeting with NASA Administrator
- DOE panel review of project and approval
- Experiment delivered to Kennedy Space Center in December 1997
- AMS flight on STS-91, June 2-12, 1998

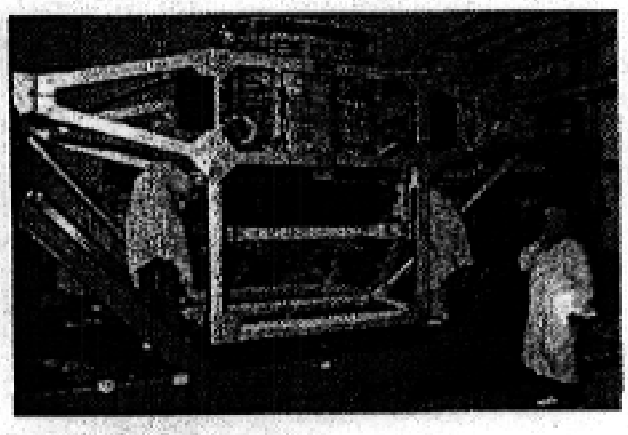
Science Objectives:

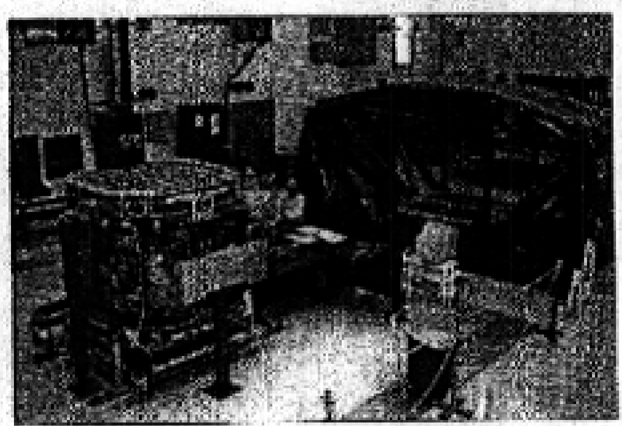
- study the origin and structure of "dark matter"
- determine the presence or absence of antimatter in distant galaxies and to understand why there is a conspicuous preponderance of matter over antimatter in the visible universe. Through the detection of anti-Helium or anti-Carbon, learn whether stars and galaxies composed of antimatter do indeed exist
- study the origin and composition of cosmic rays

AMS Physics Goals

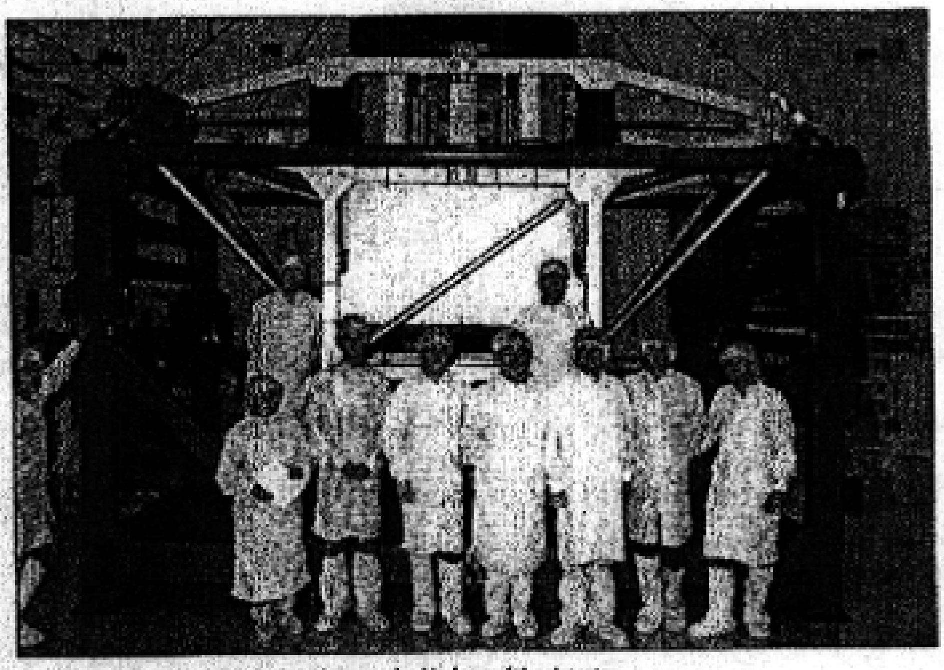
AMS

Elements	Yield (or sensitivity)	(Now)	Energy Range (GV)	Physics
e^+	$\sim 10^6$	$(\sim 1.5 \times 10^3)$	0.5 - 100	↑ Dark Matter (SUSY) ↓
$\bar{p}$	5×10^5	(~ 75)	0.5 - 100	
γ			~ 1 - 300	
$\bar{H}_e/H_e$	$\frac{1}{10^9}$	$(\sim \frac{1}{10^5})$	0.5 - 20	↑ Anti Matter Grand Unified Thoery Electroweak Theory (CP Violation) ↓
$\bar{C}/C$	$\frac{1}{10^8}$	$(\sim \frac{1}{10^4})$	0.5 - 20	
D, H_2	10^9		1 - 3.0	↑ Astrophysics (By Product) ↓
${}^3H_e, {}^4H_e$	10^9		1 - 3.0	
B_e^9/B_e^{10}	2%		1 - 3.0	





Testing of AMS payload at Kennedy Space Center before integration into *Discovery* orbiter



Members of the AMS Collaboration photographed in front of the detector.

CERN Courier, Vol 39, 6 July 1999

Magnetic detector sees cosmic-ray anomalies

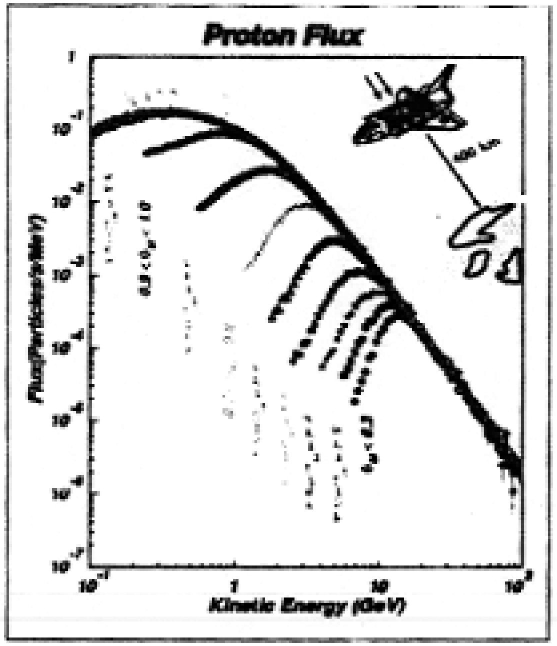


Fig. 1: Expected cosmic-ray proton distribution with latitude at an altitude of 400 km.

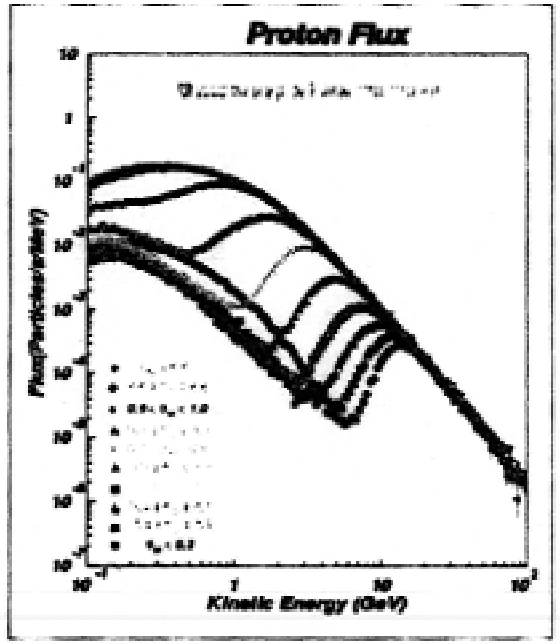


Fig. 2: Cosmic-ray proton distribution measured by the AMS experiment aboard the Space Shuttle at various latitudes.

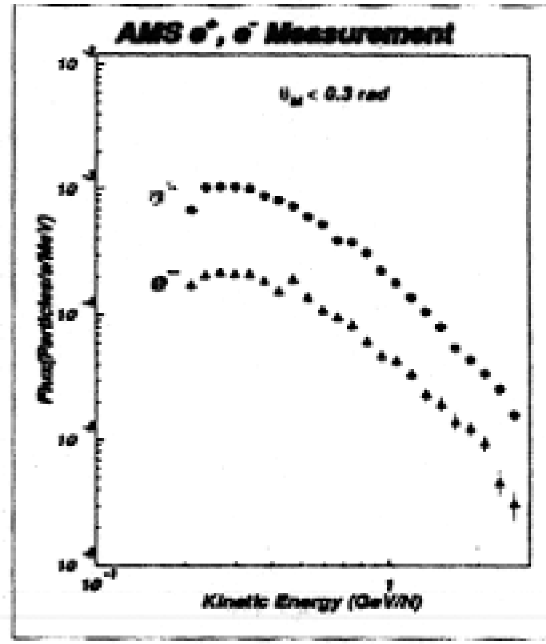


Fig. 3: Antiparticle puzzle. In the equatorial region, AMS sees about four times as many low-energy positrons as it does electrons.

Expected distributions of protons showing cutoff due to terrestrial magnetic field

Protons below the magnetic rigidity cutoff are trapped on field lines and reenter the atmosphere

predicted by Trieman (1953, PR 91, 957)

first observed by Verma (1967, JGR 72 915)

need to know orientation of detector in geomagnetic field

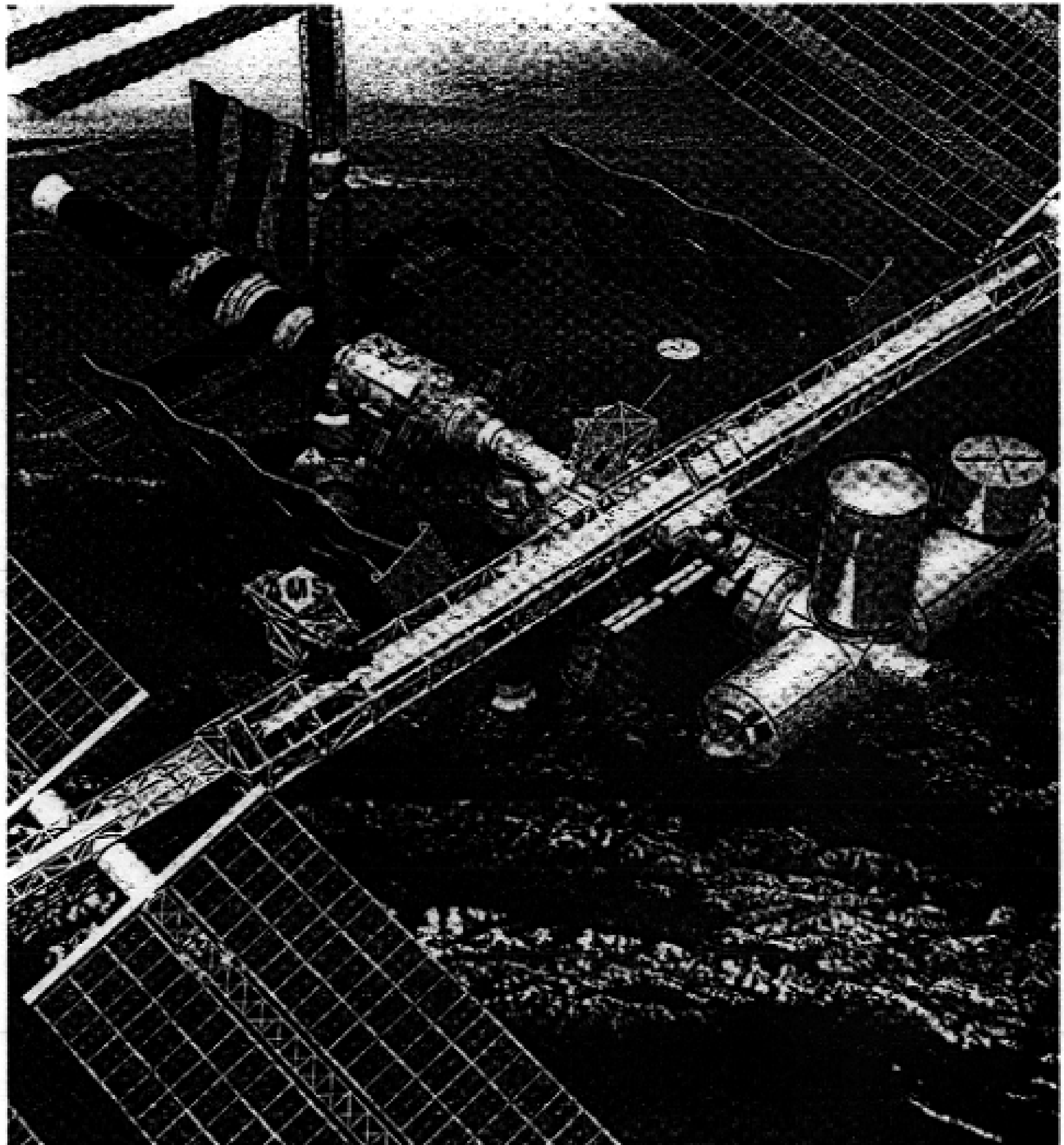
probably related to East-West effect

see also measurments by Voronov et al. (1986, Fizika 9, 19)

AMS - The Next Step

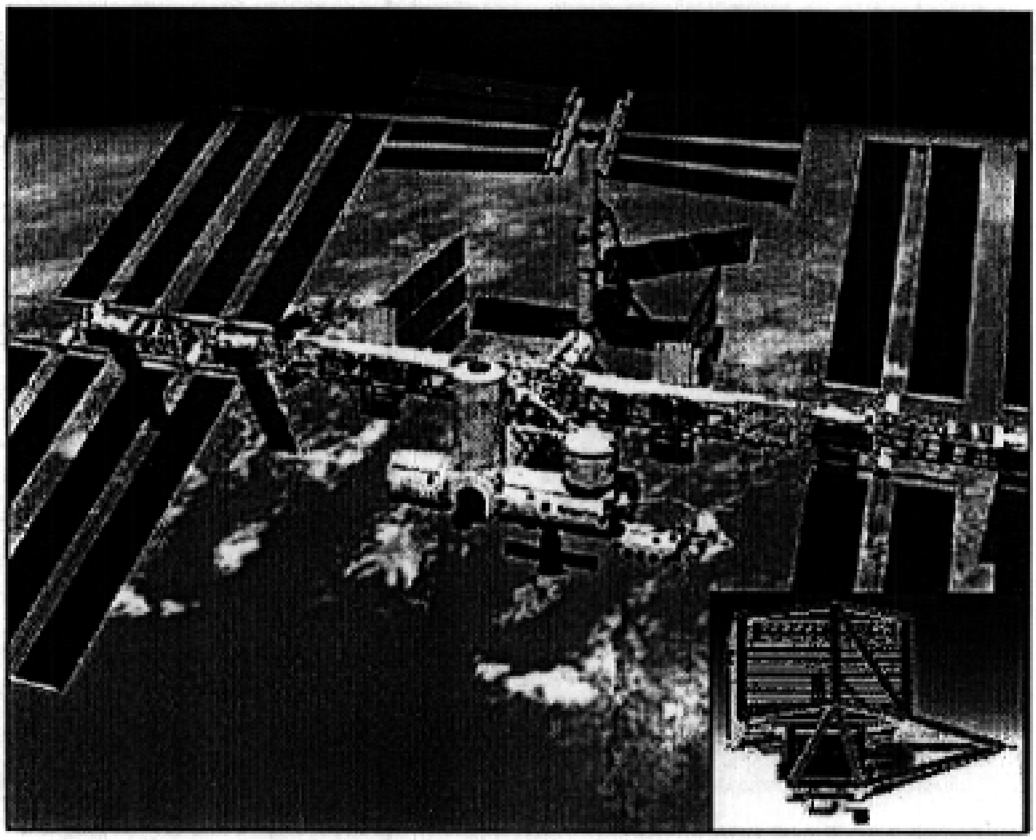
International Space Station
Deployment in 2002

Experiment configuration changes, including
- superconducting magnet



ACCESS - Advanced Cosmic Ray Composition Experiment for the Space Station

large area transition radiation detector + hadronic calorimeter - measure elements $1 < Z < 28$ up to 10^15 eV.

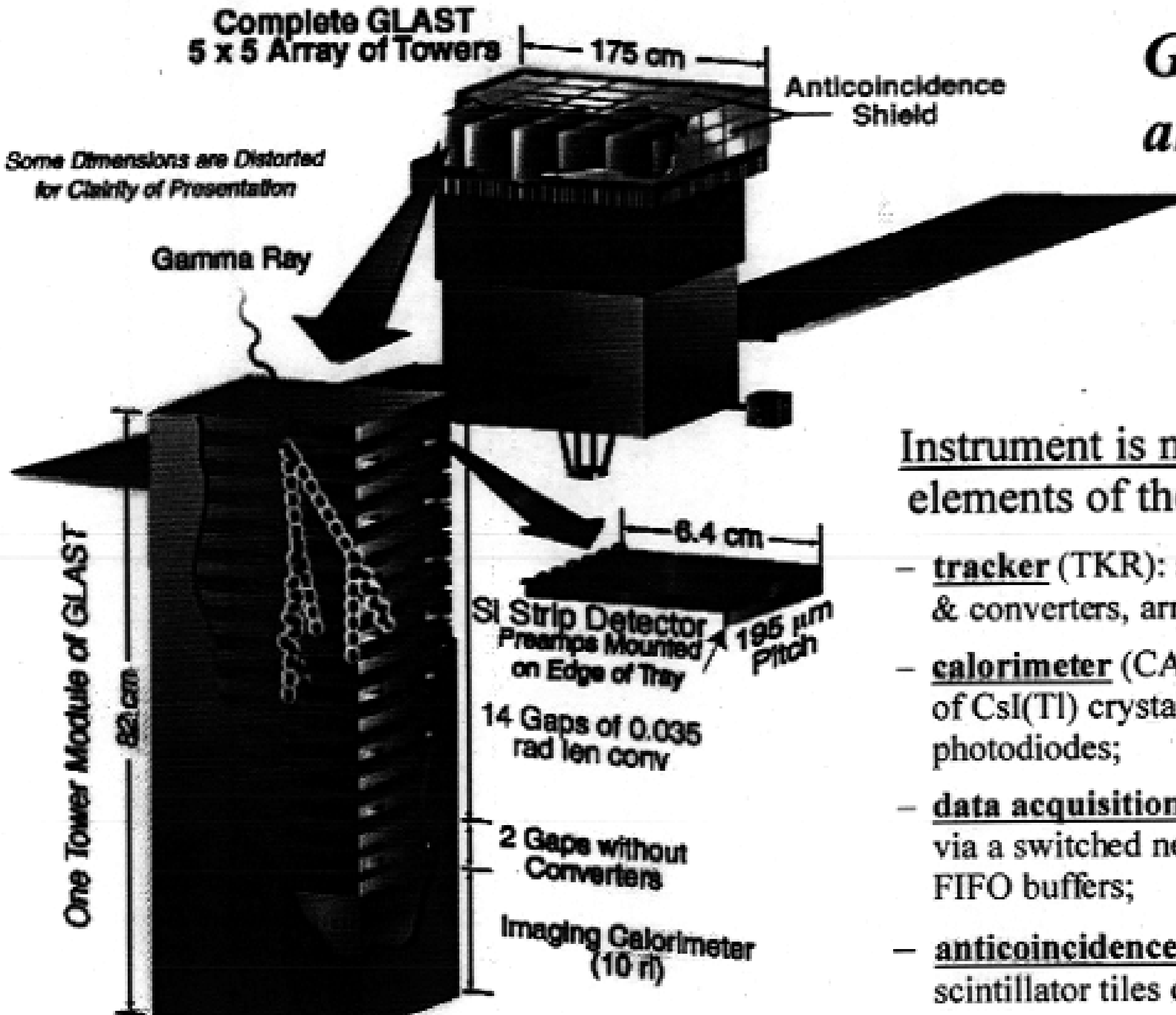


ACCESS designed to directly explore the connection of cosmic rays with supernovae

- small steepening, or "knee", in the power law energy spectrum of cosmic-rays near 10^15 eV is thought to be associated with maximum possible energies achievable by direct shock acceleration.

- ACCESS has large enough collecting power to measure directly the particles near these energies. Direct measurements can provide important information on how fluxes of each type of cosmic-ray nucleus acts at high energy

Instrument Overview



Instrument Module

GLAST Spacecraft and Instrument

Instrument is modular. Each module contains elements of the complete telescope:

- **tracker** (TKR): single-sided silicon-strip detectors & converters, arranged in 16 x,y tracking planes;
- **calorimeter** (CAL): segmented, hodoscopic array of CsI(Tl) crystals, 10. r.l. thick; readout with PIN photodiodes;
- **data acquisition system** (DAQ): 36 boards connected via a switched network. Parallel serial readouts with FIFO buffers;
- **anticoincidence shield** (ACD): mosaic of plastic scintillator tiles covering front and sides of array.

GLAST Project History

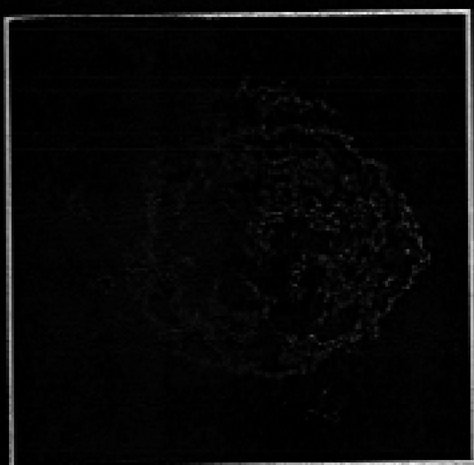
Development effort began in 1992 as a collaboration involving members of the high-energy physics (HEP) community and members of the high-energy astrophysics community:

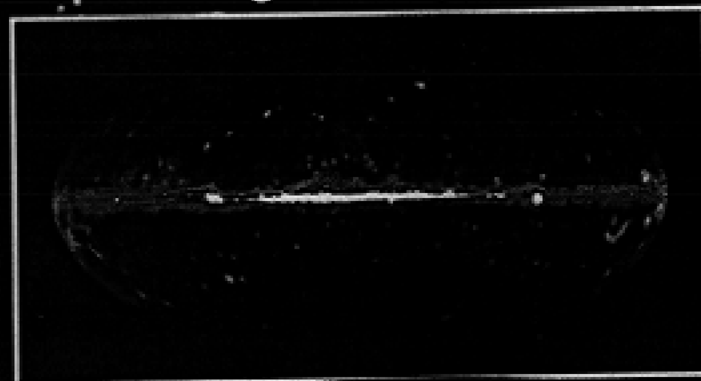
- initial R&D effort to develop Si-strip based pair telescope funded by DOE(SLAC) and NASA, 1993;
- GLAST selected by NASA for mission concept study in response to proposal by collaboration, 1994;
- completion of beam test at SLAC that successfully demonstrates performance of technologies proposed by collaboration, Nov 1997;
- proposal to NASA for GLAST Technology Development of silicon-strip based telescope funded, July 1998;
- collaboration proposal to DOE endorsed by SAGENAP and DOE, 1998;
- collaboration currently involves about 100 scientists from U.S., France, Japan, Italy, Germany, U.K., and Sweden

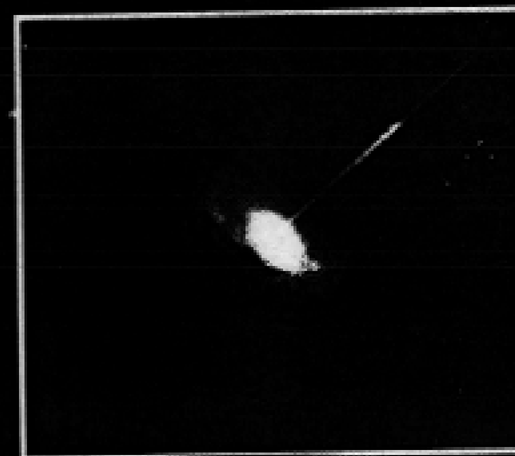
GLAST Science

0.01 GeV | 0.1 GeV | 1 GeV | 10 GeV | 100 GeV | 1 TeV

Map the High-Energy Universe







- GLAST pulsar survey: provide a new window on the galactic neutron star population
- "Map" pulsar magnetospheres and understand the physics of pulsar emission
- Origin of cosmic-rays: characterize extended supernova sources
- Determine the origin of the isotropic diffuse gamma-ray background

- Study physics in regions of strong gravity, and large electric & magnetic fields, e.g. particle production & acceleration near the event horizon of a black hole
- Study physics of gamma-ray bursts at cosmological distances
- Use gamma-rays from AGNs and bursts to study the evolution of the early universe
- Probe for particle dark matter
- Discovery Potential: relics from the Big Bang such as primordial black holes and cosmic strings

GLAST Observations of Active Galactic Nuclei

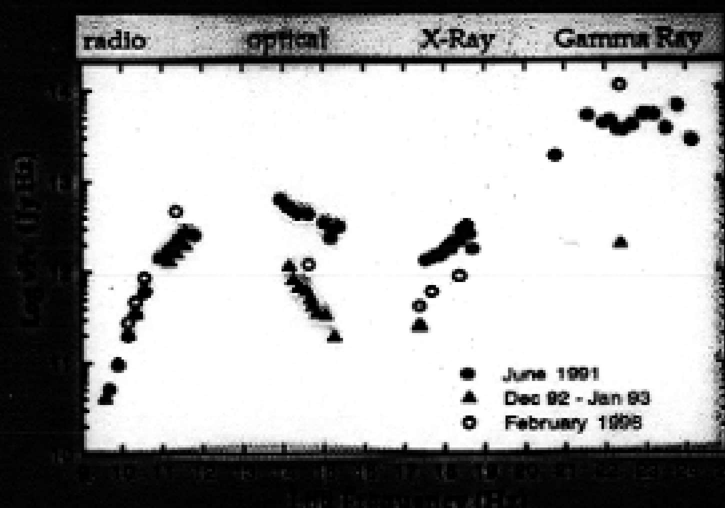
Highly-collimated particle jets (e^+, e^-, p, p^+, p^-, p^o, ..?) that emit powerful beams of γ-rays form near the central massive black hole in some Active Galactic Nuclei (AGN) and quasars

γ-rays

radio

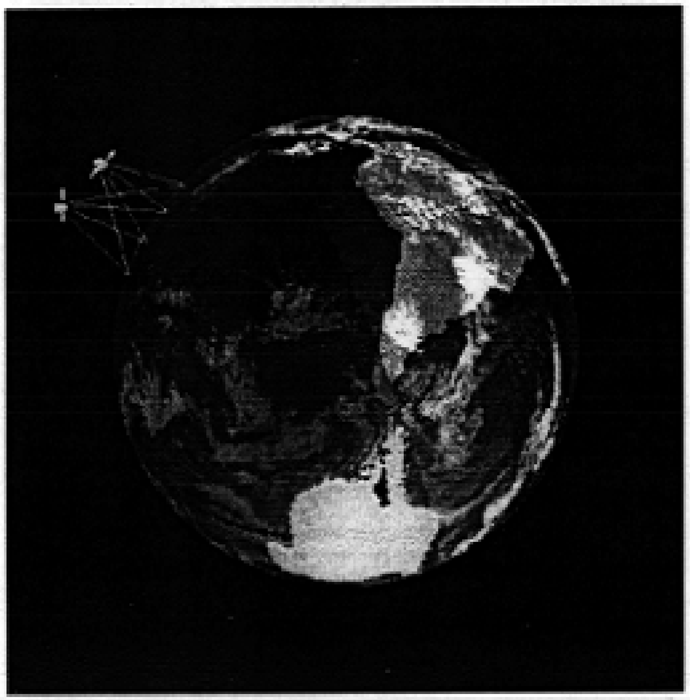
Observations of ejecta in 3C 279 in radio and γ-rays show apparent motions greater than the speed of light

- GLAST will observe a large sample of AGNs over a broad range of redshifts, allowing evolutionary studies
- γ-ray measurements with GLAST provide a direct probe of particle production, acceleration and emission mechanisms operating near the black hole's event horizon



Multiwavelength Spectrum of the Quasar 3C 279

OWL - Orbiting Wide-Angle Light Collectors

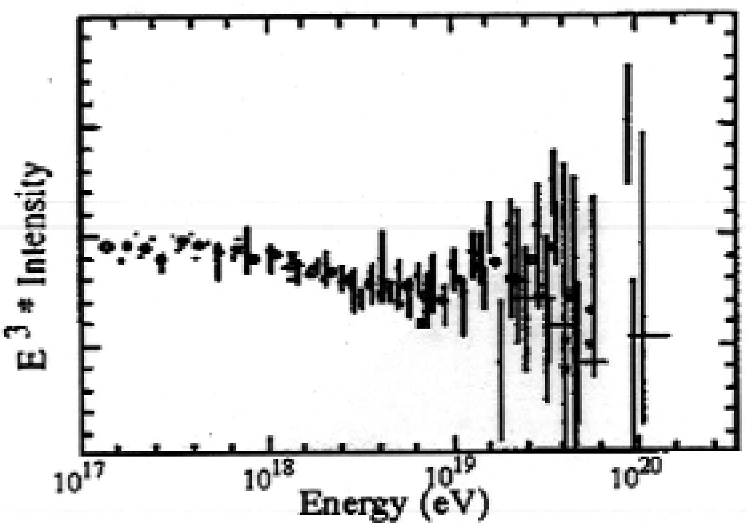


Owl will measure the highest energy cosmic ray air showers by observing atmospheric scintillation light.

Effective Area x solid angle efficiency - 10^5 km2 sr

expect to observe more than 100 events per year above 2 x 10^20 eV
(assuming flux of 1 per km2 per sr per millennium inferred from 2 events to date)

geometry factor about a factor of 10 larger than any proposed Earth-based cosmic-ray detector

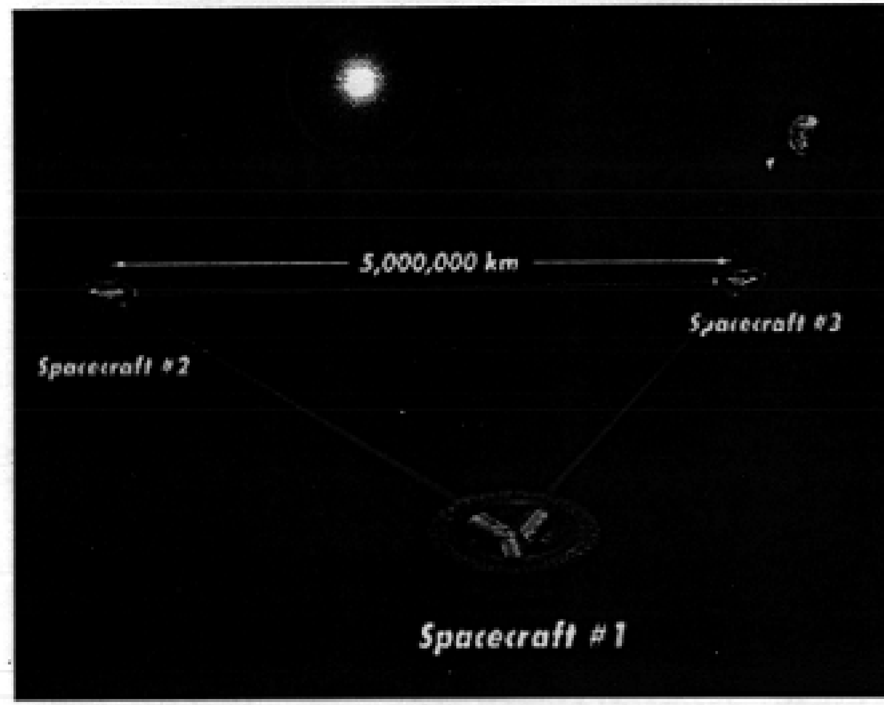


High energy end of cosmic ray energy spectrum. Spectrum has been flattened by multiplying the flux by E^3. Yellow triangle shows the signature of a new source of ultra high energy cosmic rays.

Highest energy cosmic rays, beyond 10^20 eV, presents us with the challenge of understanding their origin. They are unlikely to be galactic and, in light of the serious energy loss processes (p, gamma) of the Greisen-Zatsepin-Kuzmin (GZK) effect, protons and nuclei cannot reach us from far-distant extra-galactic sources. Identifying acceleration mechanisms to such extremely high energies is a longstanding unsolved mystery in astrophysics.

OWL observations will explore the frontiers of cosmic ray and gamma ray astrophysics, fundamental particle physics, and early universe cosmology, and depending on the results could have important impact on them all. The decades of data obtained with imaginative pioneering experiments, have raised puzzling fundamental questions which can only be answered by instruments capable of detecting hundreds of events per year.

formation flying of 3 spacecraft

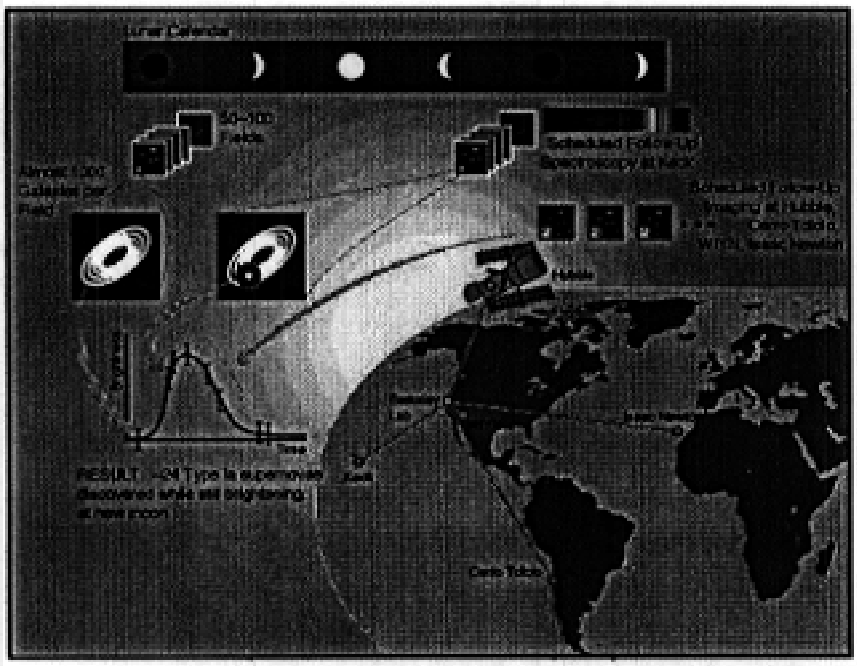


LISA Science: Observe Gravitational Radiation

Coalescence of massive black holes during collisions between galaxies, perhaps in formation of massive black holes, probing the central engines powering quasars.	Black holes orbiting massive black holes, providing precision tests of gravitational theory in the high-field limit.	Hundreds of galactic binary star systems, many containing neutron stars or black holes, including several known binary systems.

Cosmology from

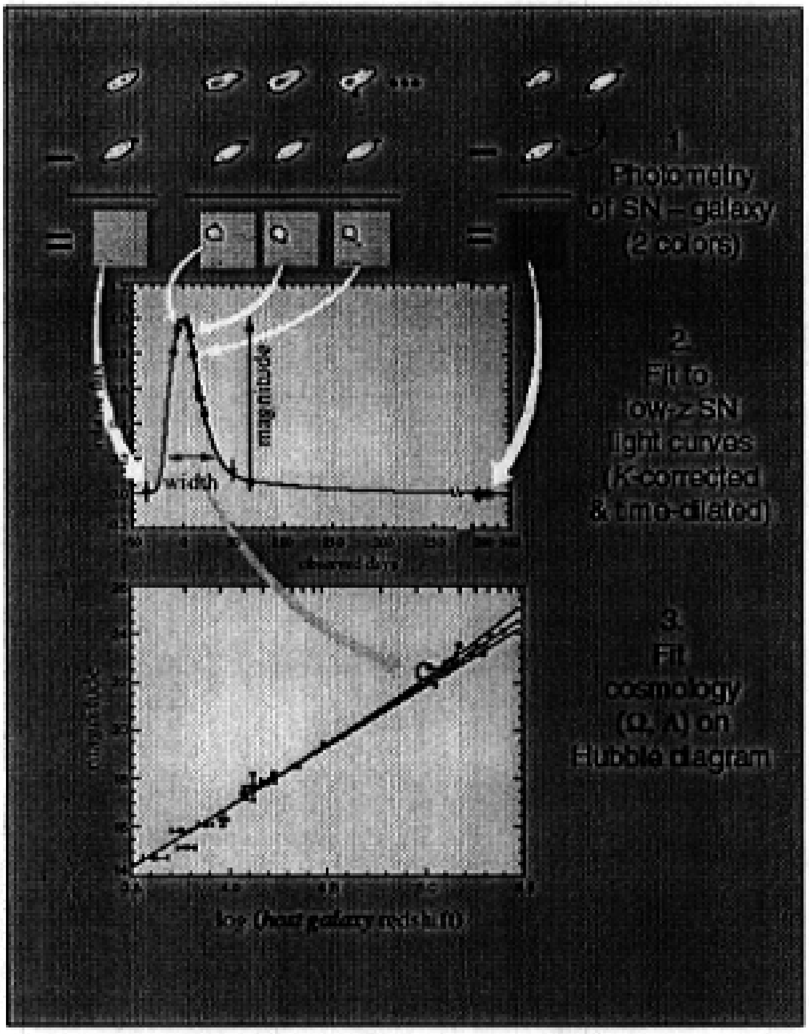
Strategy



Perlmutter, et al., in Thermonuclear Supernovae, NATO ASI, v. 486 (1997)

We developed a strategy to guarantee a group of supernova discoveries on a certain date. Just after a new moon, we observe some 50 to 100 high-galactic latitude fields—each containing almost a thousand high-redshift galaxies—in two nights on the Cerro Tololo 4-meter telescope with Tyson & Bernstein's wide-field camera. We return three weeks later to observe the same fields, and then examine the images of all of the tens of thousands of galaxies. On average, some two dozen Type Ia supernovae will thus be discovered just before new moon—and while still brightening, since the three week time baseline is less than the rise time of a Type Ia supernova. We follow the supernovae, with spectroscopy at maximum light at the Keck telescope, and with photometry over the following two months at the CTIO, WIYN, INT, and (particularly for the highest redshifts) the Hubble Space Telescope.

Analysis Steps



The supernovae are analyzed in the following three steps: First, the final image of the host galaxy alone is subtracted from the many images of each supernova spanning its lightcurve. The resulting *R*- and *I*-band photometry points are then fit to *K*-corrected (see Kim, Goobar, & Perlmutter, *P.A.S.P.* 1996) and (1+z)-time-dilated *B*- and *V*-band template SN Ia lightcurves. This fit yields the apparent magnitude at peak and the best fit "stretch factor" that indicates the timescale (and hence the intrinsic luminosity) of each supernova. Finally, all of the supernova magnitudes—corrected for the stretch-luminosity relation—are plotted on the Hubble diagram as a function of their host galaxy redshift (when available, or supernova redshift, when not). The magnitudes vs. redshifts can then be fit to various alternative cosmologies. We fit the two "favorite" one-dimensional cases, the flat ($\Omega_M + \Omega_\Lambda = 1$) universe, and the $\Lambda = 0$ universe, as well as solving for a confidence region in the Ω_M-vs-Ω_Λ plane.

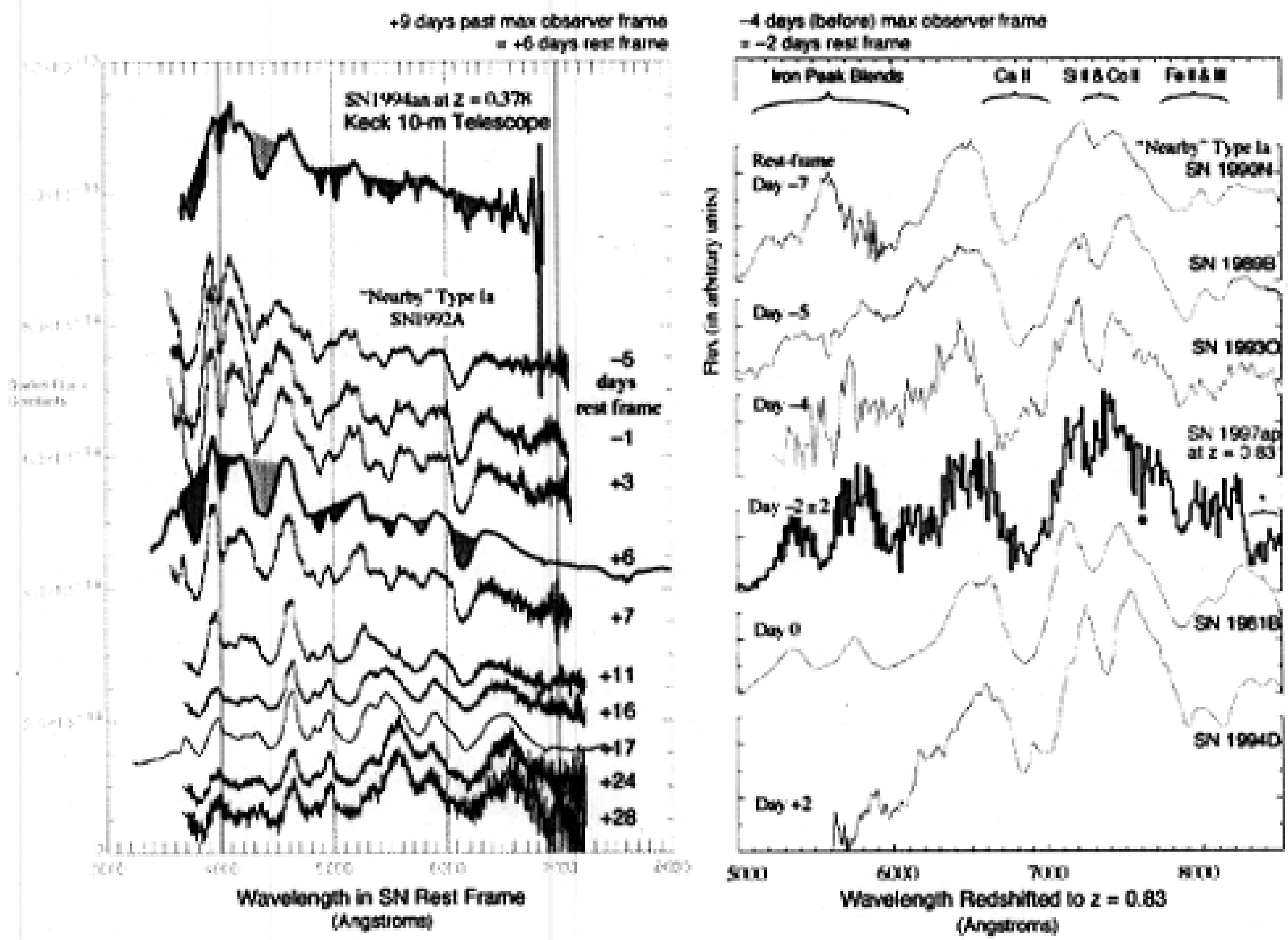
SUPERNOVA COSMOLOGY PROJECT

S. Perlmutter, G. Aldering, S. Deustua, S. Fabbro, G. Goldhaber, D. Groom, A Kim, M. Kim, R. Knop, P. Nug
Lawrence Berkeley National Laboratory & Center for Particle Astrophysics, U.C. Berkeley

N. Walton — Isaac Newton Group
A. Fruchter, N. Panagia — Space Telescope Sci. Inst.
A. Goobar — Univ. of Stockholm
R. Pain — IN2P3, Paris
I. Hook, C. Lid — European Southern

Spectra

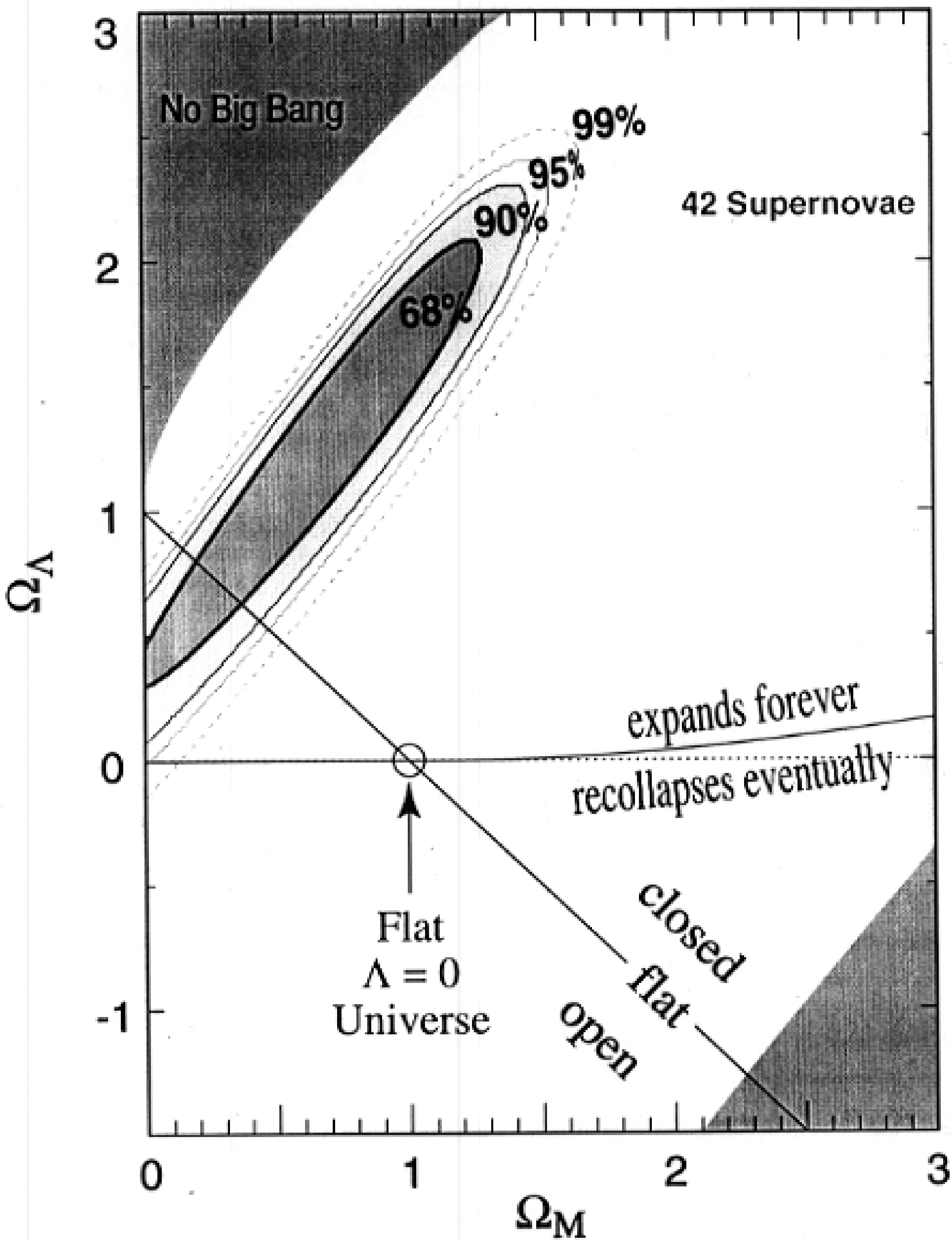
at z = 0.38 . . .   . . . at z = 0.83



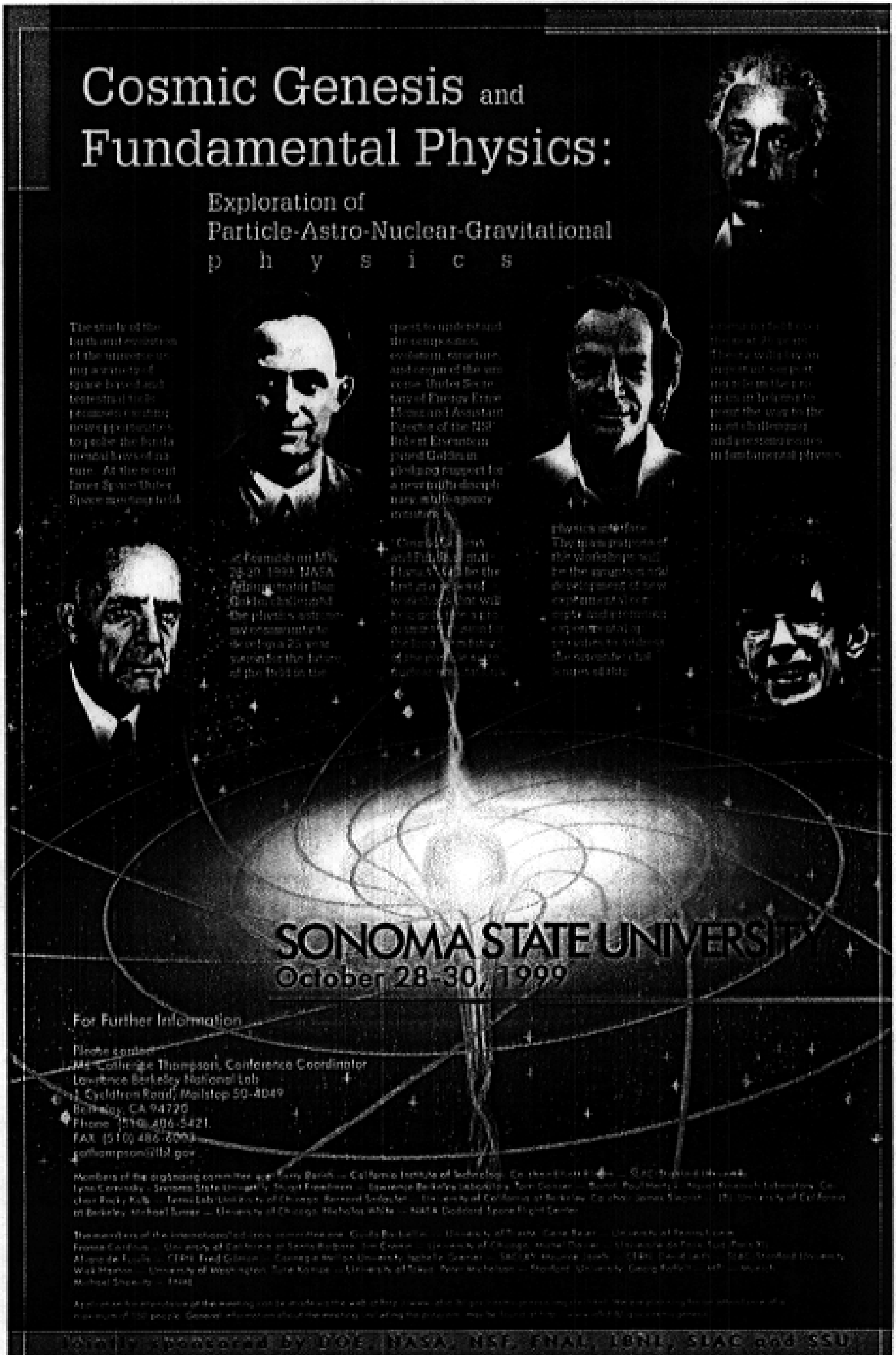
Perlmutter, et al. Nature (1998)

As a Type Ia supernova brightens and fades, its spectrum changes, showing on each day which elements in the expanding atmosphere are passing through the photosphere. This provides a rather tight constraint on the high-redshift supernova spectra: they must show all of the same features on the same day of the explosion as nearby Type Ia supernovae, or else we have evidence that the Type Ia supernovae have evolved over the 4-to-7 billion years that we are studying. So far, we have seen no indications of evolution, even as far back in time as the highest redshift Type Ia supernova spectrum, shown on the right plot above in its place in the time sequence of "nearby" Type Ia supernova spectra. Note that the spectra are almost all observed with the Keck 10 m Telescope, a necessity for these very faintest supernovae.

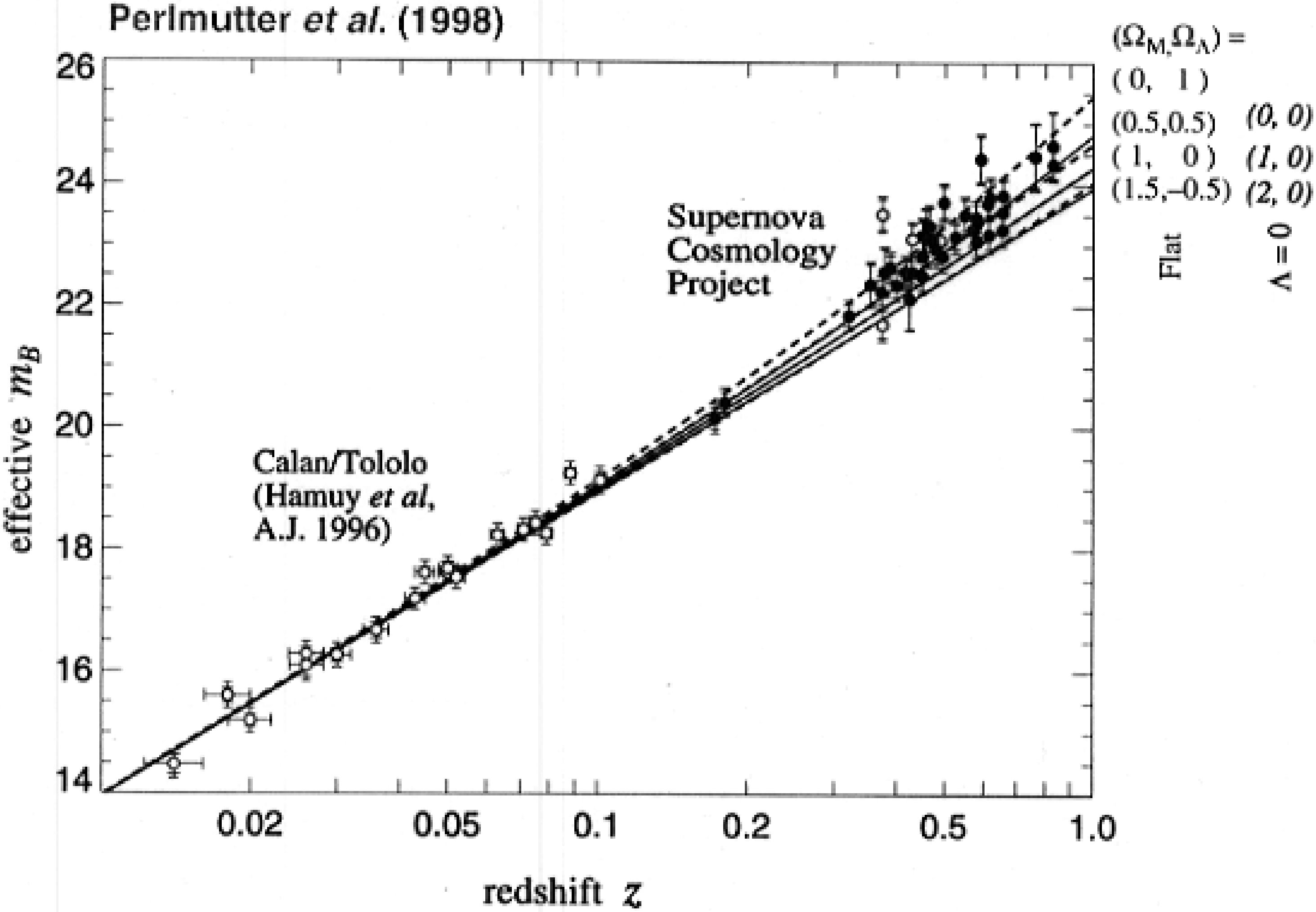
Supernova Cosmology Project
Perlmutter *et al.* (1998)



Ap.J.
astro-ph/9812133


Cosmic Genesis and
Fundamental Physics:
Exploration of
Particle-Astro-Nuclear-Gravitational
p h y s i c s
SONOMA STATE UNIVERSITY
October 28-30, 1999
For Further Information
Ms. Catherine Thompson, Conference Coordinator
Lawrence Berkeley National Lab
Berkeley, CA 94720
Jointly sponsored by DOE, NASA, NSF, FNAL, LBNL, SLAC and SSU

Supernova Cosmology Project
Perlmutter *et al.* (1998)



In flat universe: $\Omega_M = 0.28$ [± 0.085 statistical] [± 0.05 systematic]

Prob. of fit to $\Lambda = 0$ universe: 1%

astro-ph/9812133