DAVID SCHRAMM
1945-1997

His Life and Legacy
“He who has done his best for his own time has lived for all times”

Friedrich von Schiller
Inner Space - Outer Space
NUCLEOCHRONOLOGIES AND THE MEAN AGE OF THE ELEMENTS

DAVID N. SCHRAMM AND G. J. WASSENBURG
The Charles Arms Laboratory of Geological Sciences and The Kellogg
Radiation Laboratory, California Institute of Technology, Pasadena
Received 1969 December 18; revised 1970 March 16

ABSTRACT

The equations for a nucleosynthetic chronology are shown to be separable with the equations for extremely long-lived and stable nuclei yielding the mean age of the elements. This result is independent of the time-dependent production model used. This mean age is a lower bound on the age of the elements. The age of the elements is critically model-dependent. The short-lived isotopes are shown to yield the formation interval for the solar system which also is essentially model-independent. The short-lived and intermediate-lived isotopes taken relative to stable isotopes are shown to yield information on the rate of r-process nucleosynthesis with time and thus may provide the distribution of supernovae in time within the Galaxy.
The Age of the Galaxy

Nucleocosmochronology:

If a particular model is assumed, then the intermediate-lived nuclei also may yield a duration $T$, and this duration must agree with that obtained for the long-lived nuclei. If there is no agreement, the model must be wrong. In order for the model to agree, it must have the appropriate derivatives of $\rho(\tau)$ evaluated at $T$. Once a model-dependent duration $T$ is determined, then, if it is assumed that no $r$-process nucleosynthesis took place prior to galactic formation, an age for the Galaxy can be calculated:

$$\text{age} = T + \Delta + t,$$

where $t = 4.6 \times 10^9$ years is the age of solid bodies in the solar system.

Since $T$ is model-dependent, the age is model-dependent. A lower limit to the age of the Galaxy comes from the mean age of the elements which is a model-independent number. Age of Galaxy > mean age of stable $r$-process elements = $(T - \langle \tau \rangle) + \Delta + t$, which for a long-lived isotope is just $\Delta_{\text{max}} + t$.

Th/U ratio (see Appendix). The range of $\Delta_{232, 238}^{\text{max}}$ corresponding to the range shown in Table 1 for $R(232, 238)$ is $1.1 \times 10^9$ years < $\Delta_{232, 238}^{\text{max}}$ < $5.7 \times 10^9$ years.

Meyer and Truran (2000): $\frac{232}{238} : T + t = 12.8 \pm 3$ Gyr
“He went through life as if every door was open to him”

Gerald Wasserberg
Theorem: Age of the Universe $\geq$ Age of the Galaxy

Stellar Ages:

- 1800: $t_{\text{stars}} \approx 10,000$ yrs
- 1900: $t_{\text{stars}} \approx 100$ Myr
- 1945: $t_{\text{stars}} \approx 10$ Gyr
- 1980’s: $t_{\text{oldest stars}} \approx 16-20$ Gyr

To be compared with Hubble age:

for a flat matter dominated universe:

$t \approx \frac{2}{3}H^{-1} \approx 6.7 \ (h^{-1}) \ \text{Gyr}$
NGC 6652 [Fe/H] = -0.85

\[(m-M)_V = 15.15\]
\[E(V-I) = 0.15\]
11, 13, 15 Gyr isochrones
Theoretical Distribution of 1000 Isochrones

14 Gyr, [Fe/H] = -2.0
MS Turnoff

M_v vs. B-V
Median = 12.5 Gyr
95% CL lower limit: 10.2 Gyr
95% CL upper limit: 15.9 Gyr
Fraction of closure density in matter

Equation of state parameter \(( w = \text{pressure/density})\) for dark energy

- 95%
- 90%
- 68%
Making the Big Bang Worthy of A License Plate or an Airline Company
ON THE ORIGIN OF LIGHT ELEMENTS*

HUBERT REEVES
SEP, CEN Saclay, France, and Institut d'Astrophysique, Paris

AND

JEAN AUDOUZE†, WILLIAM A. FOWLER, AND DAVID N. SCHRAMM‡
California Institute of Technology, Pasadena, California

Received 1972 August 21

ABSTRACT

A summary is given of the current beliefs regarding the origin and history of the light elements $^2$D, $^3$He, $^4$He, $^6$Li, $^7$Li, $^7$Be, $^{10}$B, and $^{11}$B in the universe. A description of the various sites of nucleosynthesis for these elements is given, and the results compared with observations. It is found that the galactic cosmic rays (GCR) can spallogenically produce $^6$Li, $^7$Be, and $^{10}$B as well as the bulk of the $^{11}$B (perhaps all) and $\sim 10$ percent of the $^7$Li. The deuterium can only be produced pregalactically either in the big bang or in some pregalactic event. The big bang or pregalactic events will also produce $^3$He and $^4$He and some $^7$Li. Additional $^7$Li (and possibly even some $^{11}$B) can be synthesized during the helium-flash stage in red giants. Stellar synthesis might also add $^3$He to the galactic gas.

Subject headings: abundances — cosmic rays — cosmology — interiors, stellar — nuclear reactions
### TABLE 1
**Summary of the Observations**

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Interstellar Medium</th>
<th>Stars</th>
<th>Sun</th>
<th>Planetary System</th>
</tr>
</thead>
<tbody>
<tr>
<td>D/H</td>
<td>$&lt; 7 \times 10^{-5}$</td>
<td>$&lt; 6 \times 10^{-4}$</td>
<td>$&lt; 5 \times 10^{-6}$</td>
<td>$1.5 \times 10^{-4}$*</td>
</tr>
<tr>
<td>$^3$He/$^4$He</td>
<td>$&lt; 5 \times 10^{-4}$</td>
<td>...</td>
<td>$= 4 \pm 2 \times 10^{-4}$</td>
<td>$2.9 \rightarrow 7.5 \times 10^{-5}$†</td>
</tr>
<tr>
<td>$^4$He/H</td>
<td>$0.11 \pm 0.03$</td>
<td>$\sim 0.10$</td>
<td>$\sim 0.08$ to $0.10$</td>
<td>$(1 \pm 0.5) \times 10^{-4}$</td>
</tr>
<tr>
<td>Li/H</td>
<td>$\sim 10^{-9}$</td>
<td>$&lt; 10^{-12} \rightarrow 4 \times 10^{-9}$†</td>
<td>$\simeq 10^{-11}$</td>
<td>$1.2 \times 10^{-9}$</td>
</tr>
<tr>
<td>$^7$Li/$^8$Li</td>
<td>...</td>
<td>$&gt; 10$</td>
<td>...</td>
<td>$12.5 \pm 0.2$</td>
</tr>
<tr>
<td>Be/H</td>
<td>$&lt; 10^{-10}$</td>
<td>$&lt; 10^{-12} \rightarrow 5 \times 10^{-11}$†</td>
<td>$\simeq 10^{-11}$</td>
<td>$2 \times 10^{-11}$</td>
</tr>
<tr>
<td>B/H</td>
<td>...</td>
<td>...</td>
<td>$&lt; 3 \times 10^{-10}$</td>
<td>$3 \times 10^{-10} \rightarrow 3 \times 10^{-9}$</td>
</tr>
<tr>
<td>$^{11}$B/$^{10}$B</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>$4 \pm 0.5$</td>
</tr>
</tbody>
</table>

*Note: The units for the Planetary System refer to the abundances normalized to solar values.
†Note: The values are given as ranges or approximations.
§Note: The uncertainties are indicated.
## Nucleosynthesis


### A Chart of the Possible Origin of the Light Elements According to the Present Discussion

<table>
<thead>
<tr>
<th></th>
<th>Big Bang</th>
<th>Pregalactic Exploding</th>
<th>Pulsating Stars</th>
<th>Stellar Galactic</th>
<th>GCR Galactic</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Yes</td>
<td>?</td>
<td>?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>$^3$He</td>
<td>Yes</td>
<td>No</td>
<td>?</td>
<td>Possible</td>
<td>No</td>
</tr>
<tr>
<td>$^4$He</td>
<td>Yes</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>No</td>
</tr>
<tr>
<td>$^6$Li</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>$^7$Li</td>
<td>Possible</td>
<td>Possible</td>
<td>?</td>
<td>Possible</td>
<td>~20%</td>
</tr>
<tr>
<td>$^9$Be</td>
<td>No</td>
<td>Possible</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>$^{10}$B</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>$^{11}$B</td>
<td>No</td>
<td>?</td>
<td>?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Fig. 1.—Nucleosynthesis in the big bang as a function of the present universal density for the case $T = 2.7^\circ K$ and $L_e = 0$. This is a revised version of WFH (Wagoner 1972).
CAN SUPERNOVAE PRODUCE DEUTERIUM?

RICHARD I. EPSTEIN, W. DAVID ARNETT, AND DAVID N. SCHRAMM

Department of Astronomy, University of Texas, Austin, Texas 78712

Received 1974 February 28

ABSTRACT

An investigation has been made of the nucleosynthesis of the light elements in the shock waves of Type II supernova. The preliminary results basically confirm Colgate's estimates of the energy that is required to produce deuterium. It has also been found that there may be a very large production of $^7$Li, $^9$Be, and $^{11}$B, in which case Colgate's model is more likely to be a source of these isotopes than of deuterium. Some possible consequences of supernova shock waves on the heavy-element abundances, the cosmic-ray composition, and the diffuse $\gamma$-ray background are briefly discussed.

Subject headings: abundances — cosmology — nucleosynthesis — supernovae
AN UNBOUND UNIVERSE?*

J. Richard Gott III
California Institute of Technology

James E. Gunn†
Hale Observatories, California Institute of Technology, Carnegie Institution of Washington

David N. Schramm
The University of Texas at Austin

And

Beatrice M. Tinsley
The University of Texas at Austin and at Dallas

Received 1974 June 28

Abstract

A variety of arguments strongly suggest that the density of the universe is no more than a tenth of the value required for closure. Loopholes in this reasoning may exist, but if so, they are primordial and invisible, or perhaps just black.

Subject heading: cosmology
Nucleosynthesis
The origin of deuterium

RICHARD I. EPSTEIN*, JAMES M. LATTIMER† & DAVID N. SCHRAMM‡

*Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory
†Department of Astronomy, University of Texas at Austin and Enrico Fermi Institute, University of Chicago
‡Enrico Fermi Institute, University of Chicago

General nuclear constraints are used to show that deuterium is most likely of pregalactic origin.
Result:

\[ f_D = 3.3 \pm 0.08 \times 10^{-5} \]

\[ \Omega_B h^2 = 0.02 \pm 0.002 \]
$\Omega_B h^2 = 0.021$
Nucleosynthesis
The Emergence of Particle Astrophysics
Particle Physics Determines Astrophysics
Neutral Currents and Supernovas

David N. Schramm
Fermi Institute, University of Chicago, Chicago, Illinois 60637

and

W. David Arnett
Department of Astronomy, University of Illinois, Urbana, Illinois 61801
(Received 1 October 1974)

It is shown that if more accurate neutrino opacities (including effects of electron degeneracy) are used in a gravitational collapse calculation, then the effects of neutral currents and coherent scattering may be considerably greater than was previously thought. It is also shown that a careful inclusion of the electron-capture neutrinos should increase the importance of the region near densities of $\sim 2 \times 10^{11} \text{ g/cm}^3$. 
THE WEAK INTERACTION AND GRAVITATIONAL COLLAPSE

DAVID N. SCHRAMM
University of Chicago, Department of Astronomy and Astrophysics, and The Enrico Fermi Institute

AND

W. DAVID ARNETT
Department of Astronomy, University of Illinois

Received 1974 November 8; revised 1974 December 16

ABSTRACT

Recent developments in weak interaction physics as well as a more careful examination of previously known phenomena should yield a much clearer picture of the gravitational collapse of an evolved stellar core than has previously been possible. It is shown that the dominant neutrino-emitting process throughout much of the collapse is ordinary electron capture. The effects of neutral currents and the coherent scattering of neutrinos is discussed. A modified neutrino transport supernova model, whereby momentum transfer from neutrino scattering blows off the outer part of a star while leaving a dense remnant, may be quite reasonable. The boundary between collapse and ejection is near $\rho \sim 2 \times 10^{11} \text{ g cm}^{-3}$. Possible implications for origin of the cosmic rays and the heavy elements in the interstellar medium are discussed.

Subject headings: collapsed stars — interiors, stellar — neutrinos — supernovae
NEUTRINO OPACITIES AT HIGH TEMPERATURES AND DENSITIES

DAVID L. TUBBS AND DAVID N. SCHRAMM
University of Chicago, Enrico Fermi Institute
Received 1975 February 28; revised 1975 April 18

ABSTRACT

A detailed calculation is made of the major cross sections contributing to neutrino opacities at high temperatures and densities such as those encountered in gravitational collapse. These calculations include the effects of neutral currents, where applicable, and electron degeneracy. The processes considered are electron-neutrino scattering (including both electron and muon neutrinos and antineutrinos), neutrino-nucleon absorption and scattering, and coherent neutrino scattering. Results for these interactions are also given for the average energy transferred by the neutrino as well as the mean scattering angle (thus yielding momentum transfer).

Subject headings: dense matter — neutrinos — opacities

I. INTRODUCTION

With the prediction by Weinberg (1967) and Salam (1969) and the subsequent experimental discovery that weak interaction involves neutral currents (Hasert et al. 1973; Benvenuti et al. 1974; Barish et al. 1974; et al. 1974), there has been a flurry of interest in the possible effects this might have on astrophysics. Alth
NEUTRINOS FROM GRAVITATIONAL COLLAPSE

RON MAYLE AND JAMES R. WILSON
Lawrence Livermore National Laboratory

AND

DAVID N. SCHRAMM
University of Chicago

Received 1986 February 25; accepted 1986 December 10

ABSTRACT

Detailed calculations are made of the neutrino spectra emitted during gravitational collapse events (Type II supernova?). Those aspects of the neutrino signal which are relatively independent of the collapse model and those aspects which are sensitive to model details are discussed. The easier to detect high-energy tail of the emitted neutrinos has been calculated using the Boltzmann equation. This is compared with the result of the traditional multigroup flux-limited diffusion calculations. The harder to detect electron antineutrino background from historical supernova might be enhanced by matter oscillation of higher energy mu and tau neutrinos to electron antineutrinos.

Subject headings: neutrinos — stars: collapsed — stars: supernovae
Supernova 1987a
Prospects for measuring coherent neutrino-nucleus elastic scattering at a stopped-pion neutrino source

Authors: Kate Scholberg
Comments: 20 pages, 14 figures

Rates of coherent neutrino-nucleus elastic scattering at a high-intensity stopped-pion neutrino source in various detector materials (relevant for novel low-threshold detectors) are calculated. Sensitivity of a coherent $\nu N$ elastic scattering experiment to new physics is also explored.
Cosmological limits to the number of massive leptons

Gary Steigman
David N. Schramm
James E. Gunn

National Radio Astronomy Observatory\(^1\) and Yale University\(^2\), USA
University of Chicago, Enrico Fermi Institute (LASR), 933 E 56th, Chicago, Ill. 60637, USA
University of Chicago and California Institute of Technology\(^2\), USA

Received 29 November 1976. Available online 10 October 2002.

Abstract

If massive leptons exist, their associated neutrinos would have been copiously produced in the early stages of the hot, big bang cosmology. These neutrinos would have contributed to the total energy density and would have had the effect of speeding up the expansion of the universe. The effect of the speed-up on primordial nucleosynthesis is to produce a higher abundance of \(^4\)He. It is shown that observational limits to the primordial abundance of \(^4\)He lead to the constraint that the total number of types of heavy lepton must be less than or equal to 5.
Precision Electroweak Measurements on the Z Resonance

The number of light neutrino species is determined to be $2.9840 \pm 0.0082$, in agreement with the three observed generations of fundamental fermions.
Particle Physics Determines Cosmology!
SOME ASTROPHYSICAL CONSEQUENCES OF THE EXISTENCE OF A HEAVY STABLE NEUTRAL LEPTON

J. E. Gunn*
California Institute of Technology; and Institute of Astronomy, Cambridge, England
B. W. Lee†
Fermi National Accelerator Laboratory; ‡ and Enrico Fermi Institute, University of Chicago
I. Lerche
Enrico Fermi Institute and Department of Physics, University of Chicago
D. N. Schramm
Enrico Fermi Institute and Departments of Astronomy and Astrophysics and Physics, University of Chicago
AND
G. Steigman
Astronomy Department, Yale University
Received 1977 December 1; accepted 1978 February 14

ABSTRACT

Recently, high-energy particle theorists have constructed new extended gauge theories which may fit experiment somewhat better than previous already very successful theories. One of the predictions which is often discussed is the possible existence of a stable neutral lepton, probably with a mass of a few GeV/c². Following this motivation we here investigate some cosmological consequences of the existence of any stable, massive, neutral lepton, and show that it could well dominate the present mass density in the universe. The contribution to the mass density depends on the mass of the lepton, which should eventually be determined with high-energy accelerators. It is interesting that the more massive the lepton, the smaller its contribution to the present mass density. It is unlikely that these leptons affect big bang nucleosynthesis or condense into stellar size objects. However, such a lepton is an excellent candidate for the material in galactic halos and for the mass required to bind the great clusters of galaxies. Annihilation radiation from these structures should be detectable. At the end of the paper a brief mention is made of the astrophysical constraints on the mass-lifetime relationship if the neutral lepton is unstable.

Subject headings: cosmology — elementary particles
RELIC NEUTRINOS AND THE DENSITY OF THE UNIVERSE

DAVID N. SCHRAMM
Enrico Fermi Institute and Depts. of Astronomy and Physics, University of Chicago

AND

GARY STEIGMAN
Bartol Research Foundation of The Franklin Institute
Received 1980 June 2; accepted 1980 July 25

ABSTRACT

Relic neutrinos will be abundant today ($n_\nu \approx n_s$) and could, if they have a small mass ($m_\nu \gtrsim 1.4 \text{ eV}$), dominate the universal mass density. Ordinary matter (nucleons) appears to be incapable of accounting for the dynamically inferred mass on scales of clusters of galaxies; recent indications suggest that this problem may persist down to the scale of binary galaxies and small groups of galaxies. The difficulty is that, were the mass on these scales in nucleons, too much helium and too little deuterium would have been produced during primordial nucleosynthesis. Light neutrinos with $m_\nu \lesssim 4 \text{ eV}$ will remain unclustered but could supply a nonnegligible contribution to the total mass density if $m_\nu \gtrsim 1 \text{ eV}$. Heavy neutrinos with $m_\nu \gtrsim 20 \text{ eV}$ could have collapsed along with galaxies and, unless there were a subsequent segregation of nucleonic matter from neutrinos, would contribute too much invisible mass on such scales. Relic neutrinos with $4 \lesssim m_\nu \lesssim 20 \text{ eV}$ could supply most of the unseen mass on scales ranging from binaries through small groups to large clusters. Such neutrinos will dominate the mass of the universe and, along with ordinary nucleons, could come close to closing the universe without violating the nucleosynthesis constraints.
Galaxy and Structure Formation with Hot Dark Matter and Cosmic Strings

R. Brandenberger, (1) N. Kaiser, (2) D. Schramm, (3) and N. Turok (4)

(1) Department of Physics, Brown University, Providence, Rhode Island 02912, and Department of Applied Mathematics and Theoretical Physics, University of Cambridge CB39E W, United Kingdom

(2) Institute of Astronomy, University of Cambridge, Cambridge CB30HA, United Kingdom

(3) Astronomy and Astrophysics Center, University of Chicago, Chicago, Illinois 60637

(4) Blackett Laboratory, Imperial College, London SW7 2BZ, United Kingdom

(Received 24 July 1987)

Galaxy and structure formation in a neutrino-dominated universe with cosmic strings is investigated. Strings survive neutrino free streaming to seed galaxies and clusters. The effective maximum Jeans mass is about $1.5 \times 10^{14} h^{-2}_0 M_\odot$, lower than in the adiabatic scenario. Hence cluster formation is only marginally different from that in the cold-dark-matter and strings model, but galaxy masses are lower. The mass spectrum of galaxies is flatter than with cold dark matter, and the density profile about an individual loop is less steep, in better agreement with observations.
ULTRAHIGH-ENERGY NEUTRINO ASTRONOMY

STEVEN H. MARGOLIS AND DAVID N. SCHRAMM
Department of Astronomy and Astrophysics and The Enrico Fermi Institute, University of Chicago

AND

REIN SILBERBERG
Naval Research Laboratory, Washington
Received 1977 May 9: accepted 1977 November 14

ABSTRACT

High-energy cosmic ray interactions can produce neutrinos. We calculate the neutrino fluxes over a range of energies. The sources considered (and their ranges of importance) are cosmic-ray interactions in the Earth's atmosphere ($E_r < 10^4$ GeV), cosmic ray interactions with ambient hydrogen in galaxies ($10^4$ GeV $< E_r < 10^6$ GeV), regions of cosmic ray acceleration—e.g., pulsars—and cosmic ray interactions with the microwave background radiation ($10^6$ GeV $< E_r$). In addition, estimates of the flux from compact sources, such as active galaxies, are made. These flux levels, calculated conservatively, may be high enough for practical detection with a 1 km$^3$ seawater detector, i.e., count rates greater than 1 per day. Such observations would provide information mainly about high-energy physics, but also (over long times) about cosmic ray spectra, composition, and acceleration, and supernova and galactic nucleus explosions.

Subject headings: cosmic background radiation — cosmic rays: general — neutrinos — pulsars — stars: supernovae
AMANDA-II map(ps) of Northern Hemisphere neutrino sky using data from 2000-2002 (paper)

The AMANDA-II team has produced the most detailed map of the high energy neutrino sky so far. No sources of continuous emission have yet been observed, but data is streaming in.
Ultrahigh-energy cosmic-ray spectrum

Christopher T. Hill
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510

David N. Schramm
The University of Chicago, Chicago, Illinois 60637
and Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510
(Received 24 February 1984)

We analyze the evolution of the ultrahigh-energy cosmic-ray spectrum upon traversing the 2.7°K microwave background with respect to pion photoproduction, pair-production reactions, and cosmological effects. Our approach employs exact transport equations which manifestly conserve nucleon number and embody the laboratory details of these reactions. A spectrum enhancement appears around $6 \times 10^{19}$ eV due to the “pile-up” of energy-degraded nucleons, and a “dip” occurs around $10^{19}$ eV due to combined effects. Both of these features appear in the observational spectrum. We analyze the resulting neutrino spectrum and the effects of cosmological source distributions. We present a complete model of the ultrahigh-energy spectrum and anisotropy in reasonable agreement with observation and which predicts an observable electron-neutrino spectrum.
Fly’s Eye Anomalies

$3 \times 10^{20}$ eV!
Pierre Auger
The legacy continues....

Physics News Update
The AIP Bulletin of Physics News

Number 739 #3, July 29, 2005 by Phil Schewe and Ben Stein

Geoneutrinos Detected

Neutrinos have very little mass and interact but rarely, but are made in large numbers inside the sun as a byproduct of fusion reactions. They are also routinely made in nuclear reactors and in cosmic ray showers. Terrestrial detectors (usually located underground to reduce the confusing presence of cosmic rays) have previously recorded these various kinds of nu’s.

Now, a new era in neutrino physics has opened up with the detection of electron antineutrinos coming from radioactive decays inside the Earth. The Kamioka liquid scintillator antineutrino detector (KamLAND) in Japan has registered the presence of candidate events of the right energy; uncertainty in the model of the Earth’s interior makes the exact number vague, but it might be dozens of geo-nu’s.

The neutrinos presumably come from the decays of U-238 or Th-232. They are sensed when they enter the experimental apparatus, where they cause a 1000-ton bath of fluid to sparkle. Scientists believe the Earth is kept warm, and tectonic plates in motion, by a reservoir of energy deriving from two principal sources: residual energy from the Earth’s formation and additional energy from subsequent radioactive decays. The rudimentary inventory of geoneutrinos observed so far is consistent with the theory. (Araki et al., Nature, 28 July 2005.)
Antineutrino astronomy and geophysics

Lawrence M. Krauss*, Sheldon L. Glashow† & David N. Schramm‡

* Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
† Department of Physics, Boston University, Boston, Massachusetts 02215, USA
‡ Department of Physics and Astrophysics, Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, USA

Radioactive decays inside the Earth produce antineutrinos that may be detectable at the surface. Their flux and spectrum contain important geophysical information. New detectors need to be developed, discriminating between sources of antineutrinos, including the cosmic-background. The latter can be related to the frequency of supernovas.
Play to win, Dr. Schramm said.
always play to win.

Dennis Overbye
The Other Legacy
Founded in 1983, the Fermilab Theoretical Astrophysics Group consists of approximately 15 theoretical astrophysicists who perform research at the confluence of astrophysics, cosmology, and particle physics. The group is partially funded by a NASA Astrophysics Theory grant. Since its inception, the group has prepared over 1000 papers for publication.

We expect to have openings for postdocs starting in Fall 2006.

Particle Astrophysics Seminar, Monday, December 5: Andrew Zentner (Chicago) on Dark Halo Substructure: Constraining Fundamental Physics In The Non-Linear Regime

SNAP collaboration meeting at Fermilab November 30-December 2
Amy
Brett
Eric
Laura
Tegan
David was larger than life....

Stephen Hawking
“He went through life as if every door was open to him”

Gerald Wasserberg
“He who has done his best for his own time has lived for all times”

Friedrich von Schiller