The concept of time has always held a special fascination for humans. Even before Einstein provided us with Special Relativity and its notions of space-time, people mused on the possibility of knowing the future. Those who purported to be able to foretell events were often confidants of the power brokers of the day. Even more intriguing was the notion that one could somehow move through time in the way we move through space, both forward and backward. Science fiction contains many tales anchored solidly in this notion.

The passing of time is of particular significance to people. We annually mark the time since our birth with a special day, and when a sufficient number of these celebrations have occurred we are allowed to participate in certain rituals of our culture. For example, after 16 celebrations, we are permitted to terrorize fellow citizens and cause considerable expense to our parents by driving a motor vehicle. After 35 celebrations we are deemed capable of holding the highest political office in the land!

Viewed quantitatively, the rate at which we move with the arrow of time is well determined and specific (currently clocks are available that are accurate to one part in 1,000,000,000,000,000!). However, our qualitative sense of this rate of passage is another matter. Thomas Mann in his classic work *Magic Mountain* explores the fact that humans perceive the passage of time in ways that are extremely subjective. As we age, our sense of the passage of time leads to an often alarming compression of the interval between events. We all recall that when in elementary school the few months of summer seemed to last an eternity. Yet most of us now are astonished to find that it is time to once again write our annual progress report. Didn’t we just submit the damn thing?!

It is the issue of age, and how we determine the passage of time, that is the subject of this article. I am here concerned not with the age of any old system or individual, but rather the age of the universe. The motivation for this brief contribution is the interest and confusion, both in the public and among scientists, generated by the announcement in the fall of 1994 that a team of astronomers had observed Cepheid variable stars in a distant galaxy using the refurbished Hubble Space Telescope. Based on those observations one could conclude that the universe was only about 8 billion years old. While that was not cause for concern for many people, others immediately recognized that this age was in conflict with the generally quoted age of the galaxy based on the oldest stars it contains: If the interpretation by the Hubble team was correct, the galaxy was older than the entire universe! Something was amiss.

A member of the Institute staff, during a chance encounter in the hall, asked me to explain this conflict. I faked it at the time. That experience and discussions with colleagues during the most recent Lunar and Planetary Science Conference led me to examine this issue more carefully to better understand the significance of the Hubble observations. What follows are the results of an admittedly brief effort that served as the foundation for a seminar that I gave recently at the Institute. The editor of the *Bulletin* then bullied me into summarizing the seminar for publication here.
A CONCEPTUAL FRAMEWORK

Any discussion requires a shared language or concept. It is in that spirit that I present a Readers Digest version of the history of the universe in order to define the context of this paper as well as some terminology.

The chronology of the universe is depicted schematically in Fig. 1. While some remarkable events occurred in the earliest phases of the evolution of the universe, the intervals of time that are relevant to our discussion are those indicated by the symbols $\Delta G$, $\delta_{ss}$, and $\tau_{ss}$. The first of these is the interval of time since the Big Bang until the epic of galaxy formation (we are actually interested only in the time when our galaxy was formed, but we will use a number that is representative of many galaxies). The second interval marks the passage of time from the formation of the galaxy until the solar system was formed. The third interval corresponds to the age of the solar system. A value of $1.0 \pm 0.4$ billion years will be taken here for the interval $\Delta G$.

These intervals are relevant to two approaches to establishing the age of the universe, both involving ways to estimate the age of the galaxy. One way is to estimate the age of the oldest star(s) in the galaxy and associate that with the age of the galaxy. The other way has to do with the age of the elements, the majority of which were created by stellar processes in the galaxy.

The intervals shown in Fig. 1 are not germane to the method for estimating the age of the universe using the recent Hubble observations. Ignoring for the moment subtle, but fundamental, nuances regarding the early history of the universe, its current

![Diagram of the Chronology of the Universe](image-url)
expansion is well described by what is known as the Friedmann equation:

$$H^2(t) = \frac{8\pi G}{3}\left(\rho + \rho_r\right) - \frac{k}{a^2}$$  \hspace{1cm} (1)

where $H(t)$ is the Hubble constant at time $t$, $T(t)$ is the Hubble time, $a(t)$ is an arbitrary distance metric of the universe, $k$ is Einstein's curvature parameter, and $\rho$ and $\rho_r$ are the mass-energy density of matter and radiation and the vacuum mass-energy density respectively. A universe that is flat and Euclidean in three dimensions is described by

$$H_0 = \frac{8\pi G}{3\Omega_0}$$  \hspace{1cm} (2)

This equation is often expressed in terms of the dimensionless quantities $\Omega$ and $\lambda$ where

$$\Omega = \left(\frac{8\pi G}{3H^2}\right) \rho$$
$$\lambda = \left(\frac{8\pi G}{3H^2}\right) \rho_r$$

and

$$\Omega_0 + \lambda_0 = 1$$  \hspace{1cm} (3)

The subscript denotes values at the current epoch. The age of the universe, $t_\odot$, is some multiple of the Hubble time, $T_\odot$, with the multiple depending on the exact values of $\lambda$, $\Omega$, and the so-called deceleration parameter, $q_0$, where

$$q_0 = \frac{1}{2} \Omega_0 - \lambda_0$$  \hspace{1cm} (4)

A standard Einstein-de Sitter model of the universe with $\Omega_0 = 1$ yields $t_\odot = (2/3)T_\odot$. The variation of $t_\odot$ with $H_0$ and $\Omega_0$ is shown in Fig. 2. We will return to Fig. 2 later in this article.

**COSMOCHRONOLOGY AND THE AGE OF THE UNIVERSE**

The past three decades have witnessed remarkable achievements in our ability to detect and accurately measure elemental isotopes that arise in part from radioactive decay. A great deal of effort has been spent in converting the data gathered from laboratory measurements of extraterrestrial materials to knowledge about the age of the elements, and thus, by assumption, the age of the galaxy.

Different workers approach the problem in different ways. Many researchers consider only the systematics of element creation in stars (nucleosynthesis) in their approach to estimating the age of the universe (e.g., papers by Fowler and coworkers).

Others argue that nucleosynthesis alone cannot give us a firm value for the age of the galaxy. These workers (e.g., papers by Clayton and coworkers) argue that one needs to consider the dynamical history of the galaxy, with emphasis on extragalactic material that falls into the galaxy over time ("infall"), as well as the record revealed by radioactive decay over the age of the galaxy.

Space does not permit a full review of this important area of research, so I will only give the basic results from the published literature. Interested readers can refer to the review by Cowan et al. (1991) and references therein for more details.

One thing that is agreed upon by all workers in the field is that the age of the solar system, $t_\odot$, is 4.6±0.1 billion years. The trick is to obtain a value for the parameter $\delta$, the time between the formation of the galaxy and the formation of the solar system.

One can obtain a simple lower limit for $\delta$, from the following argument. If we assume that all of the elements, but notably uranium, were created in a single event prior to formation of the solar system, then

$$\delta = \frac{\ln \left( P_{38}/A_{38} \right)}{\lambda_3 - \lambda_5}$$

where $P$ and $A$ are respectively the production and abundance ratios of a radioactive, $R$, and a "stable," $S$, isotope. Using $^{235}$U
and $^{238}$U as the radioactive and "stable" isotopes respectively, and values of $P = 1.34$ and $A = 0.283$ from Fowler, we find that\[
\delta_{ss} \geq 1.87 \text{ billion years}\]

Taken in conjunction with the age of the solar system, we find a lower limit to the age of the galaxy of 6.5 billion years and the age of the universe of 7.5 billion years.

Fowler, in a series of papers at the end of the last decade, argues that the available data suggest that the best value for the parameter $\delta_{ss}$ is 5.4±1.5 billion years. This value, taken with the other time interval values, yields an age of the universe $t_0 = (1.0 + 5.4 + 4.6) = 11.0±1.6$ billion years.

Clayton and coworkers employ a different approach to estimating the age of the elements through the development of a family of analytic models of the chemical evolution of the galaxy (Clayton, 1989). He finds that in the case of a closed galaxy, i.e., one that is not affected by addition of material over its history, the chronometer based on the isotopes $^{232}$Th and $^{238}$U gives\[
\delta_{ss} \approx 5.8 \text{ billion years}\]

A similar estimate, based on the isotope pair $^{187}$Re and $^{187}$Os, yields\[
\delta_{ss} \approx 9.4 \text{ billion years}\]

The former estimate by Clayton gives $t_0 = 11.4$ billion years, while the latter estimate gives $t_0 = 15$ billion years. Clayton (1989) suggests that when one considers all the factors that can influence isotopic ratios over the history of the galaxy the age of the galaxy is likely to be in the range $12 < (\delta_{ss} + \tau_{ss}) < 20$ billion years, or $13 < t_0 < 21$ billion years. A nearly identical range in ages is argued by Cowan et al. (1991).

GLOBULAR CLUSTERS AND THE AGE OF THE UNIVERSE

The Hertzsprung-Russell (HR) diagram has proved to be one of the more powerful constructs in all of science. It provides ground truth for virtually all of theoretical stellar astrophysics, which in turn serves as the foundation for much of modern extragalactic astronomy. The power of this simple diagram lies in the fact that the locations of separate stars at a given time trace the evolution of individual stars over stellar lifetimes.

The fact that stars tend to be formed in large family units, as opposed to birth in obvious isolation from other stars, has been a boon to our understanding of many aspects of star formation and evolution. Notable among these family units are galactic clusters, and in particular globular clusters. What makes globular clusters, especially the metal-poor ones, so important in this discussion is that the place on the HR diagram where the cluster "turns off" from the main sequence curve provides a measure of the age of that cluster (Fig. 3).

A recent study of globular clusters by Chaboyer (1995) indicates that the apparent age spread of clusters is more likely due to our general lack of observational knowledge about certain regions of the HR diagram, rather than flaws in our detailed models of stars. Chaboyer provides an informative and extensive assessment of this issue and concludes that the ages of the oldest galactic globular clusters is in the range 13–17 billion years, giving $14 < t_0 < 18$ billion years. A similar conclusion is reached by van den Bergh (preprint to a paper presented at the Dahlem Workshop in 1995) who concluded that globular clusters indicate an age for the galaxy of 18 billion years, or $t_0 = 19$ billion years.

THE HUBBLE CONSTANT AND THE AGE OF THE UNIVERSE

We return now to the observations that caused the furor. Shown in Fig. 4 is a Hubble Telescope image of the galaxy M100, located in the Virgo cluster of galaxies. It is in this galaxy that a team of astronomers detected Cepheid variable stars using the Hubble

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Fig. 3. A composite color versus magnitude diagram of 10 galactic clusters and 1 globular cluster. Ages corresponding to the various main-sequence termination points are given along the righthand ordinate. The zero-age main sequence is taken to be the blue envelope of the observed sets of main-sequence stars. Notice the rapidly evolved red giants in $h + x$ Persei, which are apparently no more than 2 million years old. Some white dwarfs are known in the Hyades, indicating that it is possible to form them in a few million years, either directly or as the end product of the evolution of upper-main-sequence stars. Curiously enough, the Hyades has no red giants. The oldest galactic cluster, M 67, is older than the Sun and has scores of white dwarfs. Many fascinating problems are uncovered in the attempts to interpret the star densities in these diagrams quantitatively. [After A. Sandage, Astrophys. J., 125:435 (1957). By permission of The University of Chicago Press. Copyright 1957 by The University of Chicago.]
Telescope. A no-less-spectacular, but less-well-publicized, set of observations by a team using the groundbased Canada-France-Hawaii Telescope (CFH) also detected Cepheid variables, but in the galaxy NGC 4571. This galaxy, like M100, is located in the Virgo cluster. The characteristic luminosity changes of a Cepheid variable in M100 are shown in Figs. 5 and 6.

Cepheid variables are giant stars that exhibit regular, periodic dimming and brightening. They are of great value in establishing distances because they provide a means of assessing their intrinsic brightness through the Cepheid period-luminosity relation. If one can determine the period of the variability, one can determine the intrinsic brightness of the star. Given the intrinsic brightness and the apparent brightness, the Cepheid's distance can then be determined. There are many subtle aspects of this logic chain, but suffice it to say that, when due care was taken, these two groups of observers obtained distances to the Virgo cluster that were in reasonable agreement with one another.

The Hubble team concluded that M100 lies some 17.1 megaparsecs (Mpc) away, while the CFH team concluded that NGC 4571 is at a distance of 14.9 megaparsecs. While a difference of just over 2 megaparsecs may seem like a lot to people who do precise isotopic analyses, it should be pointed out that the Virgo cluster contains some 2000 galaxies and a separation of 2 megaparsecs between members of the cluster would not be a surprise.

The Hubble constant given by the CFH observations is \( H_0 = 87\pm 7 \, \text{km s}^{-1}\text{Mpc}^{-1} \), whereas the corresponding value from the Hubble observations is \( H_0 = 80\pm 17 \, \text{km s}^{-1}\text{Mpc}^{-1} \).

While these new results are significant because they derive from measurements involving more distant galaxies than ever before, the inferred value of \( H_0 \) is in keeping with values obtained previously. According to van den Bergh (1994) the preferred indicators from all data prior to 1994 give a value of \( H_0 \geq 75 \, \text{km s}^{-1}\text{Mpc}^{-1} \). The key word here is "preferred," as there is a large body of evidence that is consistent with \( H_0 = 50 \, \text{km s}^{-1}\text{Mpc}^{-1} \). Typically, these latter data involve distance measures using supernovae as standard candles. An interesting variant on using supernova light curves that has been advanced recently by Reiss et al. (1995) yields a value of \( H_0 = 67\pm 7 \, \text{km s}^{-1}\text{Mpc}^{-1} \).

The wide variation in recently reported values of the Hubble constant must be a concern for any serious student of this subject. Until there is an adequate explanation of why this discrepancy exists, it will be difficult to take too seriously any inferences regarding the age of the universe based on Hubble Constant values alone.

The situation is complicated further by the fact that even if an agreed-to value for the Hubble constant were available, there remains uncertainty as to how that relates to the true age of the universe. Recall that the inverse of the Hubble constant gives the Hubble time, it does not give the age of the universe. In order to obtain the age of the universe from the Hubble time there must be additional information regarding the parameters discussed in connection with equation (3).

Figure 2 is a plot depicting how given values of \( H_0 \) and \( \Omega_0 \) combine to yield an age of the universe. The white area in the figure indicates the nominal value and uncertainty in the Hubble constant obtained by the Hubble team taken in conjunction with a possible range in the value of \( \Omega_0 \) from 0.1 to 1.0. As can be seen, this box intersects the line labeled "12 Gyr" as the age of the universe for low values of \( \Omega_0 \). Perhaps more significant is that the 2\( \sigma \) limits on the Hubble measurement are easily consistent with ages of the universe that are near or slightly in excess of 15 billion years.

**CONCLUDING REMARKS**

Was Emerson's observation correct? Is the universe really much younger than we had previously thought? Are results from the recent Hubble Telescope observations, coupled with the chain of reasoning implicit in the Hubble method of estimating age, still too uncertain to provide a meaningful constraint on this important measure of the universe in which we live?

My personal view is that the current data are not totally inconsistent with one another when all the uncertainties inherent in each of the three methods are considered. If pushed, I would bet on the galactic measures, viz., cosmochronology and the ages of the oldest galactic clusters, as giving the more accurate measures of the age of the universe. They are two independent methods and they give results that are broadly in agreement with one another. That there remains a significant issue in the value of the Hubble constant, along with uncertainties in relating that constant to the age of the universe, indicates that one should not be overly enthusiastic about determining the age of the universe through measures of the Hubble constant alone.
Figs. 5 and 6. Hubble Telescope images taken with the Wide Field Planetary Camera 2 of Cepheid variable stars in M100. The Cepheid (center of each image frame) exhibits the characteristic, periodic change in luminosity that allows astronomers to use them as “standard candles” in estimating distances in the universe.

The debate about the age of the universe will certainly continue, but let us hope that the quality of the debate is not characterized by the following quotation:

"BRICK: Well, they say nature hates a vacuum, Big Daddy. Big Daddy: That’s what they say, but sometimes I think that a vacuum is a hell of a lot better than some of the stuff that nature replaces it with."

(Tennessee Williams, Cat on a Hot Tin Roof, Act 2).


(David C. Black is the director of LPI)
REVIEW

THE GREAT COMET CRASH: THE COLLISION OF COMET SHOEMAKER-LEVY 9 AND JUPITER
edited by John R. Spencer and Jacqueline Mitton
Color photographs and illustrations.
Hardcover, 0-521-48274-7. $24.95

A WEEK THAT WAS

On the warm, swampy Saturday afternoon of July 16, 1994, a handful of scientists with nothing terribly interesting to do were trying to look busy or wandering the nearly empty hallways of the Lunar and Planetary Institute in suburban Houston. Some of our summer intern students were also loitering about trying to be busy. In fact, we were all waiting. Around 4 p.m., a message was received via electronic mail. We read this simple message several times. After months of second-guessing and speculation, the first of some 21 fragments of disrupted Comet Shoemaker-Levy 9 were in; they had struck Jupiter. The resulting impact was visible from Earth after all, and was brighter in the infrared than Jupiter’s large satellite Io. And the big fragments were yet to hit! Even without details or pictures, our initial realization that these events were producing major and obvious damage was electrifying. We returned late that evening from a futile attempt to witness light from the (fizzled) second comet fragment to see the amazing Hubble images of the first impact showing a domelike plume of hot gas rising over the limb of Jupiter.

There is a special exhilaration for many humans that comes from witnessing such a powerful natural event for the first time, whether in the trenches doing the observing or on the sidelines as we in Houston were that week. I remembered similar emotions when we first saw the surface of Triton nearly five years earlier. Reading The Great Comet Crash, edited by John Spencer and Jacqueline Mitton, brought back vivid memories of that special week last July. The Great Comet Crash is a delight to read and leaf through. The text, by some of the astronomers and planetary scientists who participated, covers nearly every possible aspect of this event. Indeed, observing the comet and its fate united many branches of astronomy, geology, chemistry, and physics as few human endeavors can.

If I permit myself a quibble, it would be that times are given in Universal Time (UT), which not everyone knows requires five hours subtraction to convert to Eastern Standard Time (and which took us geologists half an hour to figure out). Also, the book does not fully benefit from the remarkable synthesis achieved during the IAU Colloquium on the SL9 impacts, held in Baltimore in May 1995, just after the book...
The G impact produced the most dramatic impact scar yet seen, as shown in this HST image. It was taken between 09:19 and 09:25 UT, one and three-quarter hours after impact, when the site had rotated onto the visible disk. A dark ring, presumably some type of wave, spreads outward at 2000 kilometers per hour from the impact site, which is at one end of a dark streak that marks the approximate direction of the comet’s entry into the atmosphere. Beyond the circular wave is a huge (Earth-sized) asymmetric halo. The much smaller site of the D impact, now 28 hours old, can be seen to the left of the E site. (Heidi Hammel and the HST Comet Team; additional processing by Robin Evans of JPL; courtesy John Trauger.)

was completed. Several authors represented in the book come close to achieving this themselves, however. A reader may catch up with the colloquium results by reading articles in the October 1995 Sky and Telescope, which make nice companion pieces for this volume. This is by no means a flaw, because in the fast-paced world of astronomy (or most sciences), no book can be 100% up-to-date, and no doubt several more years will be required to fully reconstruct what occurred on Jupiter that fabulous week. Fortunately, little in this book will require revision on this basis.

The book itself is visually impressive. The black-and-white and especially the color illustrations are all reproduced with excellent detail and color balance, and it is obvious considerable care went into figure selection and preparation. Observational images are nicely supported by a number of useful diagrams or supplementary photographs.

But the real magic of this book is the story behind the pictures: Why comets are interesting, what was special about this comet, how observations were conducted, and some of the difficulties and adventures involved in obtaining these data are well described. The story of how the comet was discovered, including a foreword by Gene and Carolyn Shoemaker, as well as the process by which we determined its fate and set about planning to observe it, are all nicely told. Although not intended as a technical treatise (those will be published in the next few years), the scientific “impact” of this event is well explained in generally understandable terms.

The book concludes with two chapters discussing the comet crash and its aftermath as it affects our perceptions, both of the events themselves and what they might mean for our place in the solar system. (Two or three lines are missing from the final chapter and these are the only production flaws I encountered.) Even better, these stories are told by some of the major players and are all written in an easily accessible, occasionally humorous, but always meaty style. During the last 10 years we have begun to understand that the solar system is a vastly more dynamic place than the static, ordered family of regular planets visualized in many of the books I read growing up in the 1960s. The events of the week of July 16, 1994, demonstrate this in dramatic fashion, and this book nicely captures these and the events leading up to it with style.

—Paul M. Schenk

NEW FROM LPI

CLEMENTINE SLIDE SET

Clementine Explores the Moon, compiled by Paul D. Spudis, is a 20-slide set that features an overview of the Clementine Mission, also known as the Deep Space Program Science Experiment, as well as images and image products from the data collected during the spring of 1994. Clementine began the work of building the first truly global digital image model of the Moon. With its ultraviolet-visible and near-infrared camera, the spacecraft obtained 11-color multispectral data of virtually the entire Moon. Compiled by the Deputy Science Team Leader for the Clementine Mission, the set includes a south pole mosaic, nearside and farside albedo maps, global color data, global topography, global iron data, a full-Earth mosaic, and more. $15.00 from LPI; see Order Form in this Bulletin.
The 27th LPSC will be held March 18–22, 1996, in Houston, Texas. As usual, sessions will be held at the NASA Johnson Space Center and the Lunar and Planetary Institute.

The LPSC program committee will select the conference program from written abstracts, which researchers in appropriate scientific disciplines are invited to submit by January 10, 1996. Instructions for preparing abstracts are available from the Publications and Program Services department at LPI, 713-486-2166; e-mail: dotson@lpi.jsc.nasa.gov. Abstracts submitted by fax or e-mail will not be acknowledged as submissions or accepted for publication. Printed abstracts will be available at conference registration. Abstracts and conference program will be available on line around February 9.

ORAL PRESENTATIONS

Oral presentations will be scheduled during the four-and-a-half days of parallel sessions Monday through Friday noon. Talks will be scheduled to allow eight minutes for speaking and seven minutes for discussion and speaker transition.

POSTER PRESENTATIONS

Poster sessions will be scheduled for Tuesday and Thursday evenings from 6:30 to 9:30 p.m. at the LPI. Authors of papers scheduled for poster presentations will be asked to be on hand to display and discuss their results in the poster area during the assigned time period. Additionally, posters may be viewed at LPI each day of the conference. Shuttle transportation between the Gilruth Center and LPI will be available. Each poster will have a space 44" x 44" for display. Requests for tables, computers, video equipment, etc., cannot be honored due to the limited space available for poster displays.

STEPHEN E. DWORNIK STUDENT AWARDS

The Stephen E. Dwornik Planetary Geoscience Student Paper Awards are given for the best student research presentations at the Lunar and Planetary Science Conference. Two awards are given annually: one for an oral presentation and one for a poster presentation. These awards are open to U.S. citizens who are currently enrolled as students at any degree level in the field of planetary geosciences. Postdoctoral fellows are not eligible. Complete instructions for application are available from the Publications and Program Services department at LPI, 713-486-2166. The awards are administered through the Planetary Geology Division of the Geological Society of America.

The abstract deadline is January 10, 1996. Only one abstract per student will be considered for the award. The student must be the senior author of the abstract and the material should not have been previously presented at another meeting.

SPECIAL SESSIONS

Masursky Lecture

The Harold Masursky Lecture Series will continue this year at a special plenary session scheduled for Monday afternoon. More information on the Masursky Lecture will be included in the LPSC third announcement mailed to conference participants early in 1996.

Mars Deep Interior: Geochemical and Geophysical Constraints

Though rather detailed models have been constructed for the internal stratification of Mars, they are based on relatively few direct constraints. A number of recent developments suggest that now is a good time to reconsider some aspects of these models. Significant recent progress has been made on high-temperature and high-pressure equations of state and phase relations in candidate Mars mantle and core materials. Also, though current estimates of the moment of inertia of Mars are still model dependent, planetary orbiter and lander missions planned for the next few years will dramatically change that situation. Abstracts are invited that address new results relevant to the deep internal structure and composition of Mars based on laboratory experiments, spacecraft data, or modeling results. Authors submitting abstracts for this session should check topic #15, "Special session: Mars deep interior," on the 27th LPSC Abstract Information Form.

Galileo Mission to Jupiter—Results from Encounter

The Galileo probe entered the atmosphere of Jupiter on December 7, 1995. The orbiter will explore the jovian system during approach and for almost two years thereafter. This session is devoted to reporting the preliminary results from this historic encounter with Jupiter. The session will include invited abstracts only. Authors invited to give presentations at this session should check topic #16, "Special session: Galileo mission to Jupiter," on the 27th LPSC Abstract Information Form.
Poster and Display Sessions on Education

Two special poster/display sessions on education will be held at LPI on Tuesday and Thursday evenings during the regular technical poster sessions. This format provides much more interactivity, which is lacking in an oral session; it allows participants to demonstrate some of the projects "hands-on" rather than simply describing them orally. The education special sessions will be located in and around the LPI library. Participants will be expected to provide their own computer equipment.

Participants will be selected on the basis of the traditional informative abstracts by the program committee. (At the discretion of the program committee or its designates, some poster/display presentations may be invited.) Authors submitting abstracts for this session should check topic #17, "Special session: Education (posters/displays)," on the 27th LPSC Abstract Information Form.

Note to Special Session Authors

All abstracts for special sessions, whether invited or contributed, must be received by the January 10, 1996, deadline for consideration by the program committee. No abstracts received after this date will be published in the conference abstract volume, regardless of special session status.

SPECIAL EVENTS

Chili Cookoff and Barbecue Dinner

The chili cookoff and dinner will be held on Wednesday from 6:30 to 9:30 p.m. at the Landolt Pavilion. Out-of-town teams are encouraged to enter. Because the conference staff can no longer provide cooking equipment, the "preparation on site" rule common to most cookoffs will be waived to encourage more teams to compete. The goal of this event is fun, not serious cooking competition. Enter your favorite concoction and compete against other secret recipes! There will be awards for best presentation and first-, second-, and third-place winners for best chili.

CONFERENCE SHUTTLE SERVICES

Conference shuttle buses will provide service between selected hotels (Nassau Bay Hilton, Days Inn, Holiday Inn, Ramada Kings Inn, Quality Inn, Comfort Inn, Motel 6, and Best Western), the JSC Gilruth Center, and LPI. There will be rotational runs in the morning, during lunch, at the close of sessions, and to and from these hotels during special events. Computer displays, exhibits, poster sessions, and other conference-related events will be located at LPI; shuttle buses will make hourly stops there throughout conference week. Your conference badge will serve as your bus ticket.

CONFERENCE PROGRAM ON LINE

The program and first paragraph of abstracts for the 27th LPSC are scheduled to be placed on line on or about February 9, 1996.

World-Wide Web Access

If you are using an Internet information browser like NCSA Mosaic, the URL for CASS is:

http://cass.jsc.nasa.gov/lpi.html

Internet Access

At your system's prompt, type:

telnet cass.jsc.nasa.gov

or
telnet 192.101.147.17

The username prompt should be displayed. Only use lower-case characters for logging onto this account.

USERNAME: cass
PASSWORD: online

Modem Access

For modem access (at 28.8K), DEC VT series terminal emulation (100 and above) is required.

713-244-2089 or 713-244-2090

Press <ENTER> until you receive the username prompt. Use only lower-case characters for logging onto this account.

Questions about the online program and abstracts can be directed to:
LeBecca Simmons
phone: 713-486-2158
e-mail: simmons@lpi.jsc.nasa.gov

For help in accessing the LPI computer, contact:
Kin Leung
phone: 713-486-2165
e-mail: leung@lpi.jsc.nasa.gov

ADDITIONAL INFORMATION

Contact the LPI Publications and Program Services Department for further information about conference logistics (713-486-2166) or abstracts (713-486-2161).
GALILEO RECORDER SCARE CANCELS APPROACH IMAGING OF IO, EUROPA

After a nailbiting week when it appeared that Galileo’s tape recorder may have failed, spacecraft engineers were greatly relieved when test results over the weekend of October 21 showed that the device remains functional. On October 24, a revised command sequence ordered the spacecraft to resume readouts of data from several science instruments as well as normal housekeeping duties and engineering operations such as flushing of rocket thrusters.

The new command sequence replaced the one ground controllers stopped after the October 11 malfunction, when the data tape recorder failed to cease rewinding after recording an image of Jupiter. The tape recorder had remained in a standby mode until the October 20 test. Engineering data shows that the tape recorder can be unreliable under some operating conditions, project officials said. However, the problem appears to be manageable, and should not jeopardize return of the nearly 2000 images of the jovian system that are to be stored on the recorder for playback during Galileo’s two-year mission.

New precautions included commands for the tape recorder to wind 25 extra times around a section of tape possibly weakened when the recorder was stuck in rewind mode with the tape immobilized for about 15 hours. This portion near the end of the tape reel has been declared off-limits for future recording. The approach image of Jupiter that Galileo took on October 11 is stored on this portion of tape and hence will not be played back.

The tape recorder is a key link in techniques developed to send images and data to Earth without Galileo’s high-gain antenna, which is stuck, unusable, in a partially open position.

Since the tape recorder incident, Galileo project officials have decided to cancel imaging of Io and Europa on the day the spacecraft arrives at Jupiter in favor of devoting the tape recorder to gathering up to 75 minutes of data from Galileo’s atmospheric probe as it descends into the atmosphere—the first-ever direct measurements of its chemistry and weather. Scientists are especially disappointed to lose imaging from the closest planned flyby of Io. “Our priorities are clear,” said William O’Neil, Galileo Project Manager, “We have to get all the probe data.”

COMET SAMPLE RETURN MISSION PICKED AS NEXT DISCOVERY FLIGHT

A spacecraft designed to gather samples of the dust spewed from a comet and return it to Earth for analysis has been selected to become the fourth flight mission in NASA’s Discovery program. Known as Stardust, the mission also will gather and return samples of interstellar dust that the spacecraft encounters during its trip through the solar system to fly by Comet Wild-2 in January 2004. Stardust was selected from among three Discovery proposals funded for further study last February.

“Stardust was rated highest in terms of scientific content and, when combined with its low cost and high probability of success, this translates into the best return on investment for the nation,” said Wesley Huntress, NASA Associate Administrator for Space Science. “The Stardust team also did an excellent job of updating their plan to communicate the purpose and results of this exciting mission to educators and the public.”

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A 10-micron interplanetary dust particle collected in the stratosphere with U2 aircraft. This particle is similar in elemental composition to primitive meteorites but differs in having higher carbon and volatile element abundance. The particle is composed of glass, carbon, and many types of silicate mineral grains. It is a sample of either an asteroid or a comet. The porosity and unusual mineralogical composition suggests that it may be of cometary origin. In the first hour of examination of the returned Stardust samples it will be possible to determine whether this particle or any other type of meteoritic material is similar or related to comets.

NEWSPRINT FROM SPACE

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The Stardust mission team is led by Principal Investigator Donald Brownlee, University of Washington in Seattle, with Lockheed-Martin Astronautics, Denver, as the contractor building the spacecraft. Jet Propulsion Laboratory will provide project management.

Comet Wild-2 is known as a “fresh comet” because its orbit was deflected from much farther out in the solar system by the gravitational attraction of Jupiter in 1974. Stardust will approach as close as 100 kilometers (62 miles) to the comet’s nucleus. “Space scientists are intensely interested in comets because we believe that most of them are well-preserved remnants from the earliest days of star and planetary formation,” Huntsress said.

Stardust will be launched on an expendable launch vehicle in February 1999 for a total mission cost of $199.6 million. The return capsule carrying the dust samples will parachute to Earth to land on a dry Utah lakebed in January 2006. Stardust will use an unusual material called aerogel to capture the dust samples. This porous, extremely-low-density material is somewhat like glass in that it is made of silica and it has about the same melting point. Although aerogel does not absorb moisture, the fluorescent substance can absorb large amounts of gas or particle matter because of its large internal surface area.

The spacecraft will also carry an optical camera that will return cometary images with 10 times the clarity of those taken of Comet Halley by previous space missions, as well as a mass spectrometer provided by Germany to analyze basic composition of the samples in-flight.

ASTRONOMERS ANNOUNCE FIRST CLEAR EVIDENCE OF A BROWN DWARF

Astronomers have made the first unambiguous detection and image of a brown dwarf. The observations include an image from the 60-inch Mt. Palomar telescope, a spectrum from the 200-inch Hale telescope (also on Mt. Palomar), and a confirmatory image from the Hubble Space Telescope. The collaborative effort involved astronomers at the California Institute of Technology and the Johns Hopkins University.

The brown dwarf, Gliese 229B (GL229B), is a small companion to the cool red star Gliese 229, located 19 light-years from Earth in the constellation Lepus. At 20 to 50 times the mass of Jupiter, GL229B is too massive and hot to be classified as a planet, but is too small and cool to shine like a star. At least 100,000 times dimmer than the Sun, the brown dwarf is the faintest object ever seen orbiting another star.

“This is the first time we have ever observed an object beyond our solar system which possesses a spectrum that is astonishingly just like that of a gas giant planet,” said Shrinivas Kulkarni, a member of the team from Caltech. “It looks like Jupiter, but that’s what you’d expect for a brown dwarf.” The infrared spectroscopic observations of GL229B, made with the 200-inch Hale telescope, show that the dwarf has the spectral fingerprint of Jupiter—an abundance of methane. Methane is not seen in ordinary stars, but it is present in Jupiter and other giant gaseous planets in our solar system.

The Hubble data show that the object is far dimmer, cooler (no more than 1300 degrees Fahrenheit), and less massive than previously reported brown dwarf candidates, which are all near the theoretical limit (eight percent the mass of our Sun) at which a star has enough mass to sustain nuclear fusion.
Brown dwarfs form the same way stars do, by condensing from a cloud of hydrogen gas, but they do not accumulate enough mass to generate the high temperatures needed to sustain nuclear fusion at their core, which is what makes stars shine. Instead brown dwarfs radiate energy as Jupiter does, through gravitational contraction. In fact, the chemical composition of GL229B’s atmosphere looks remarkably like that of Jupiter.

The discovery is an important first step in the search for planetary systems beyond the solar system because it will help astronomers distinguish between massive Jupiter-like planets and brown dwarfs orbiting other stars. Advances in ground- and space-based astronomy are allowing astronomers to further probe the “twilight zone” between larger planets and small stars as they search for substellar objects, and eventually, other planetary systems.

Caltech astronomers Kulkarni, Tadashi Nakajima, Keith Matthews, and Ben Oppenheimer and Johns Hopkins scientists Sam Durrance and David Golimowski first discovered the object in October 1994. Follow-up observations a year later were needed to confirm that it is actually a companion to Gliese 229. The discovery was made with a 60-inch reflecting telescope at Palomar Observatory, using an image-sharpening device called the Adaptive Optics Coronagraph, designed and built at the Johns Hopkins University. The scientists teamed up with Chris Burrows of the Space Telescope Science Institute to use Hubble’s Wide Field Planetary Camera-2 for follow-up observations on November 17. Another Hubble observation six months from now will yield an exact distance to GL229B.

The astronomers suspect that the brown dwarf developed during the normal star-formation process as one of two members of a binary system. “All our observations are consistent with brown dwarf theory,” Durrance said. However, the astronomers say they cannot yet fully rule out the possibility that the object formed out of dust and gas in a circumsellar disk as a “super-planet.”

The difference between planets and brown dwarfs is how they formed. Planets in the solar system are believed to have formed out of a primeval disk of dust around the newborn Sun: Their orbits are nearly circular and lie almost in the same plane. Brown dwarfs, like full-fledged
DECEMBER

4–5
Eleventh Annual Conference of the Center for Environmental Information, Inc.—Sustainable Development and Global Climate Change: Conflicts and Connections, Arlington, Virginia. Contact: Center for Environmental Information, 50 Main Street West, Rochester NY 14614-1218. Phone: 716-262-2870.

4–6

4–8
Science with the Hubble Space Telescope II, Paris, France. Contact: E-mail: hst2@eso.org WWW: http://http.hq.eso.org/hst2.html

11–15

JANUARY (CONTINUED)

29–Feb 2

FEBRUARY

5–7
First ISU Symposium—Space of Service to Humanity: Preserving Earth and Improving Life, Strasbourg, France. Contact: Emma Moyen, International Space University, Parc d’Innovation, Boulevard Gonhier d’Andernach, 67400 Illkirch, France. Fax: 33-88-65-54-47. E-mail: moyen@isu.isunet.edu

8–13
American Association for the Advancement of Science Annual Meeting & Science Innovation Exposition, Baltimore, Maryland. Contact: AAAS Meetings Department, P.O. Box 630285, Baltimore MD 21263. Phone: 202-326-6417; fax: 202-289-4021.

12–14
Workshop on Evolution of Martian Volatiles, Houston, Texas. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. E-mail: simmons@lpi.jsc.nasa.gov

18–21
Second Annual Pre-College Education Workshop for Space Scientists, Boulder, Colorado. Contact: Carl Wuth, Space Science Institute, 1234 Innovation Drive, Suite 294, Boulder CO 80383-7814. Phone: 303-492-3774; fax: 303-492-3789. E-mail: wuth@colorado.edu

MARCH

11–14
Infrared Space Interferometry Workshop, Toledo, Spain. Contact: Margie Guitart, Secretary LOC, L.A.E.F.F., Apdo. 50727, 28080 Madrid, Spain. Phone: 34-1-813-1161; fax: 34-1-813-1160. E-mail: irinter@laeff.esa.es

18–22
27th Annual Lunar and Planetary Science Conference, Houston, Texas. Contact: Publications and Program Services Department, LPI,
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<td>ESO Workshop on The Early Universe with the VLT, Garching b. München, Germany. Contact: European Southern Observatory, VLT96, attn. Ch. Stoffer, Karl-Schwarzschild-Str.2, D-85748 Garching bei München, Germany. Phone: 49-89-320-060; fax: 49-89-320-06-480. E-mail: <a href="mailto:VLT96@eso.org">VLT96@eso.org</a></td>
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<td>19-25</td>
<td>20th International Symposium on Space Technology and Science and 8th International Astrodynamics Symposium, Gifu, Japan. Contact: Tomifumi Godai, 20th ISTS General Chairman, 1-29-6 Hamamatsu-cho, Minato-ku, Tokyo 105 Japan. Phone: 03-5473-7014; fax: 03-5473-7814.</td>
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<td>Space 96: The Fifth International Conference and Exposition on Engineering, Construction, and Operations in Space and RCE II: The Second Conference on Robotics for Challenging Environments, Albuquerque, New Mexico. Contact: Dr. Stewart W. Johnson, Chair, Space and Robotics Conferences, Johnson and Associates, 820 Rio Arriba, S.E., Albuquerque NM 87123-5103. Phone: 505-298-2124; fax (by arrangement): 505-298-2124. E-mail: <a href="mailto:StWJohnson@aol.com">StWJohnson@aol.com</a></td>
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<td>Statistical Challenges in Modern Astronomy II, University Park, Pennsylvania. Contact: Gutti Jogesh Babu, Department of Statistics, The Pennsylvania State University, 319 Classroom Building, University Park PA 16802-2111. Phone: 814-686-2837; fax: 814-863-7114; Internet: <a href="mailto:babu@stat.psu.edu">babu@stat.psu.edu</a>. Or: Eric Feigelson, Department of Astronomy and Astrophysics, The Pennsylvania State University, 525 Davey Labora-</td>
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<td>IAU Colloquium 159: Emission Lines in Active Galaxies: New Methods and Techniques, Shanghai, People’s Republic of China. Contact: IAU Colloquium 159, Department of Astronomy, Ohio State University, 174 West 18th Avenue, Columbus OH 43210. Fax: 614-292-2928. E-mail: <a href="mailto:iau159@payne.mps.ohio-state.edu">iau159@payne.mps.ohio-state.edu</a> ftp bessel.mps.ohio-state.edu or ftp 128.146.37.206 WWW: <a href="http://www-astronomy.mps.ohio-state.edu/iau159.html">http://www-astronomy.mps.ohio-state.edu/iau159.html</a></td>
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<td>International Conference on the SL9-Jupiter Collision, Meudon, France. Contact: Agnes Fave, Conference SL9-Jupiter, DESPA, Observatoire de Paris, F-92195 Meudon Cedex, France. Fax: 33-1-45-07-28-06. E-mail: <a href="mailto:sl9jupiter@megasx.obspm.fr">sl9jupiter@megasx.obspm.fr</a></td>
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<td>Asteroids, Comets, Meteors, Versailles, France. Contact: ACM, Aeronomie CNRS, BP3, 91371 Verrieres, France.</td>
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<td>59th Annual Meteoritical Society Meeting, Berlin, Germany. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. E-mail: <a href="mailto:simmons@lpi.jsc.nasa.gov">simmons@lpi.jsc.nasa.gov</a></td>
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<td>Space Microdynamics and Accurate Control Symposium (SMACS 2), Toulouse, France. Contact: Agnes Letraublon, CNES, 18, avenue</td>
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SEPTEMBER (CONTINUED)


OCTOBER

7-10

Hypervelocity Impact Symposium, Freiburg, Germany. Contact: Susanne Deschoux, 1996 HVIS, Ernst-Mach-Institut, Fraunhofer-Institut fur Kurszeitdynamik, Eckerstr. 4, D-79104 Freibur I. BR, Germany. Or: Mark Boslough, MS 0821, Sandia National Laboratories, P.O. Box 5800, Albuquerque NM 87185-0821. Phone/fax: 505-845-8851. E-mail: mbboslo@sandia.gov

16-18

Evolution of Igneous Asteroids, Houston, Texas. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. E-mail: enticknap@lpi.jsc.nasa.gov

22-25

28th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society, Tucson, Arizona. Contact: Steve Larson, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721. Phone: 520-621-4973; fax: 520-621-4933. E-mail: slarson@lpi.arizona.edu

OCTOBER (CONTINUED)

28-31


DECEMBER

2-5

Aerospace Technologies in Earth Sciences, Moscow, Russia. Contact: MIIGAIK, 103064, Gorochovskiy per., Moscow, Russia. Phone: 7-095-267-5436; fax: 7-095-267-4681. Or: Russian Aerosol Society, 103064, Vorontsovo pole str., 10, NIFHI, Moscow, Russia. Phone: 7-095-916-6389; fax: 7-095-147-4361. E-mail: kirill@cc.nifhi.ac.ru

1997

JULY

17-19

Workshop on Parent Body and Nebular Modification of Chondritic Materials, Maui, Hawaii. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. E-mail: simmons@lpi.jsc.nasa.gov

NEWS FROM SPACE

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...stars, would have fragmented and gravitationally collapsed out of a large cloud of hydrogen but were not massive enough to sustain fusion reactions at their cores.

The orbit of GL229B will provide clues to its origin. If the orbit is nearly circular then it may have formed out of a dust disk, where viscous forces in the dense disk would keep objects at about the same distance from the star they orbit. If the dwarf formed as a binary companion, its orbit probably would be far more elliptical, as seen with most binary stars. The Hubble observations will provide initial data for calculating the orbit. However, because the orbital motion is so slow, it will take many decades of telescopic observations before a true orbit can be calculated. GL229B is at least four billion miles from its companion star, roughly the distance between Pluto and the Sun...
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THE GREAT COMET CRASH

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