Vol. 34, No. 3 September 2005

PLANETARIAN

Journal of the International Planetarium Society

Special Focus: Digital Domes and the Future of Planetariums.

Digital Full-Domes: The Future of Virtual Astronomy Education

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Abstract

Even simple concepts in astronomy are notoriously difficult for the general public to understand, since many ideas involve three-dimensional spatial positional relationships and orientations between astronomical objects. However much of the teaching materials used in astronomy education are 2D in nature. Digital video full-dome planetariums have the potential to bridge the comprehension gap, using 3D virtual simulations in immersive environments that not only provide spatial context but may enhance learning in ways not possible via other techniques.

Although digital video full-dome theaters have the potential for showing a wide range of content, debate continues on how appropriate they are for astronomy education [1]. Such debate is not new. More than twenty years ago, Charles Hagar decried the fact that planetariums displaying video within their domes were trying to compete against first class Hollywood productions, and failing at it [2]. Given the expense involved in converting to full-dome theaters and the work necessary to create new visitor programming, operators and managers at traditional optical-mechanical planetariums may wonder whether the positives outweigh the negatives when taking the digital plunge. Since the main focus of planetariums has historically been that of astronomy education, what are the educational benefits of a digital system over its analog counterpart? Is the new technology actually worth it from an astronomy instructional point of view?

Before addressing how digital domes can be of use, it must be acknowledged that astronomy is a subject that has historically been difficult to teach. Although U.S. education standards identify astronomy topics as being important for K—12 science literacy [3, 4], most college students including many preservice teachers retain misconceptions that are not easily changed by standard classroom instruction (e.g., [5-8]).

The difficulty of understanding astronomy is due in part to concepts involving geometries and orientations of celestial bodies in three dimensions. Students have to build conceptual knowledge about a three-dimensional (3D) physical space while being taught using two-dimensional (2D) textbook materials. Many educational researchers have therefore advocated the use of 3D models as being crucial for astronomy learning [9, 10].

A suite of technologies especially appropriate for creating representational 3D models of physical phenomenon are the artificial realities or virtual environments. Virtual environments (VEs) are computer-generated, 3D environments that a user can interact with and navigate through. A carefully constructed VE allow users to gain direct experience about a place or phenomenon that would otherwise be difficult or impossible to observe in real life. When astronomy VE software[1] is run immersively in a full-dome theater, the illusion of the artificial reality is further enhanced by the wrap-around projection that surrounds the user with imagery on all sides.. As the following review will show, the combination of VE and full-dome technologies result in a unique opportunity for astronomy instruction that is not possible in any other milieu.

Misconceptions in Astronomy

Many involved in astronomy education are aware of the video *A Private Universe*, which shows the broad scope of misconceptions involving explanations of the seasons and the phases of the Moon among Harvard graduates [13]. For those familiar with basic astronomy, it is hard to imagine how phases of the Moon can be so extraordinarily difficult for people to understand. But more than five decades of research have shown how pervasive such errors are, with the same mistaken notions concerning lunar phases appearing from grade school children to undergraduate teachers in training, and in every country where this topic has been studied (e.g., [14-23]). As a further indicator of how perplexing this concept is, techniques for teaching lunar phases have had mixed success. Many studies have post-instruction understanding rates far below 50% [5, 24-27].

Phases of the Moon is not the only subject that is difficult to teach. Astronomical misconceptions by children and adults have been studied for a medley of topics, including the shapes and nature of orbits, the scale of the solar system, the Sun, distances to the stars, the Milky Way, the Big Bang, gravity, and the shape of the Earth [21, 28-33].

Studies of children's common perceptions of the shape of the Earth are particularly revealing. Their misconceptions can be startling to those not familiar with the educational research literature. Children at the K-3 level have been found to have a diverse

This is the first of four invited articles on the special topic **Digital Domes and the Future of Planetariums**. This topic will conclude in the next issue of the *Planetarian*. To become more involved in shaping the digital future of our profession, please see Steve Tidey's Forum on page 40, and visit my Digital Frontiers column on page 53 of this issue. – Ed Lantz

1. Such as UniView from SCISS-American Museum of Natural History [11] or the Denver Museum of Nature and Science's Cosmic Atlas [12}

set of mental models for the shape of the Earth [19, 21, 34]. These include (Fig. 2) [a] a flat rectangular surface that people reside on; [b] a flattened round disc; [c] a hollow sphere inside of which is a flat surface where people dwell; [d] a sphere flattened at the top and bottom where people can live; [e] a dual Earth consisting of a flat inhabited surface and a round Earth that is up in the sky; and [f] a spherical Earth with a population over the entire surface. Only in the last model is the concept of gravity correct. In most of the other models, gravity is seen as a force with a single universal up and down direction.

These mental models give a hint to the thinking processes of schoolchildren. Their models are the result of views that *make sense to them*. In the case of the Earth, their fundamental axioms include: the ground is flat, and objects including the Earth will fall down if not supported. When children learn from authority that "The Earth is round," they incorporate this new fact into their preexisting model. A child who initially starts with a flat, rectangular Earth in his mind will modify his model into a disc-shaped Earth. Stella Vosniadou [21, p. 230] points out that the "dual Earth" model – a round Earth floating above a flat ground plane – can be attributed to children being shown pictures of the round Earth floating in space. They synthesize this new element without actually discarding their old mental model of a flat Earth plane where people live.

Such results are consistent with *constructivist theory* in education [35, 36], which states that people are not merely blank slates who automatically take in the knowledge taught to them. Instead they actively construct knowledge: they build mental models based on past experiences and everyday observations, in addition to formal instruction. However once a model is constructed for a phenomenon, it is difficult to displace. Information from additional teaching can merge into the mental model, and further modify it, but the original framework is rarely thrown out entirely. Developing instruction to correct for tightly held misconceptions is therefore a difficult task. The teacher has to be aware of what alternative mental models students hold, and has to create a curriculum that directly addresses these misconceptions. In order for students to replace their old models with scientifically correct viewpoints, they must become dissatisfied with their original mental model. And for new concepts to take hold, scientifically valid concepts must be taught so that they appear intelligible, plausible, and fruitful enough to lead to new discoveries [35].

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Three-Dimensional Astronomy Teaching

Traditional astronomy teaching is made even more difficult by the fact that much classroom instruction involves 2D pictures, charts, slides, and written descriptions in textbooks. For instance, most of the past research on teaching phases of the Moon have used 2D drawings and diagrams (e.g., [19, 20, 24, 25, 37]). It is usually up to the student to conceptualize 3D abstractions using 2D descriptions. Using hand-held physical models of the Moon can help [38], but generally, it is a difficult task to translate and orient oneself to the perspective of another Solar System object, and look back at the Earth.

Computer 3D modeling and visualizations have therefore been suggested as critically important tools for learning new astronomical concepts and correcting naive but non-scientific notions [9, 39]. A prime strength of

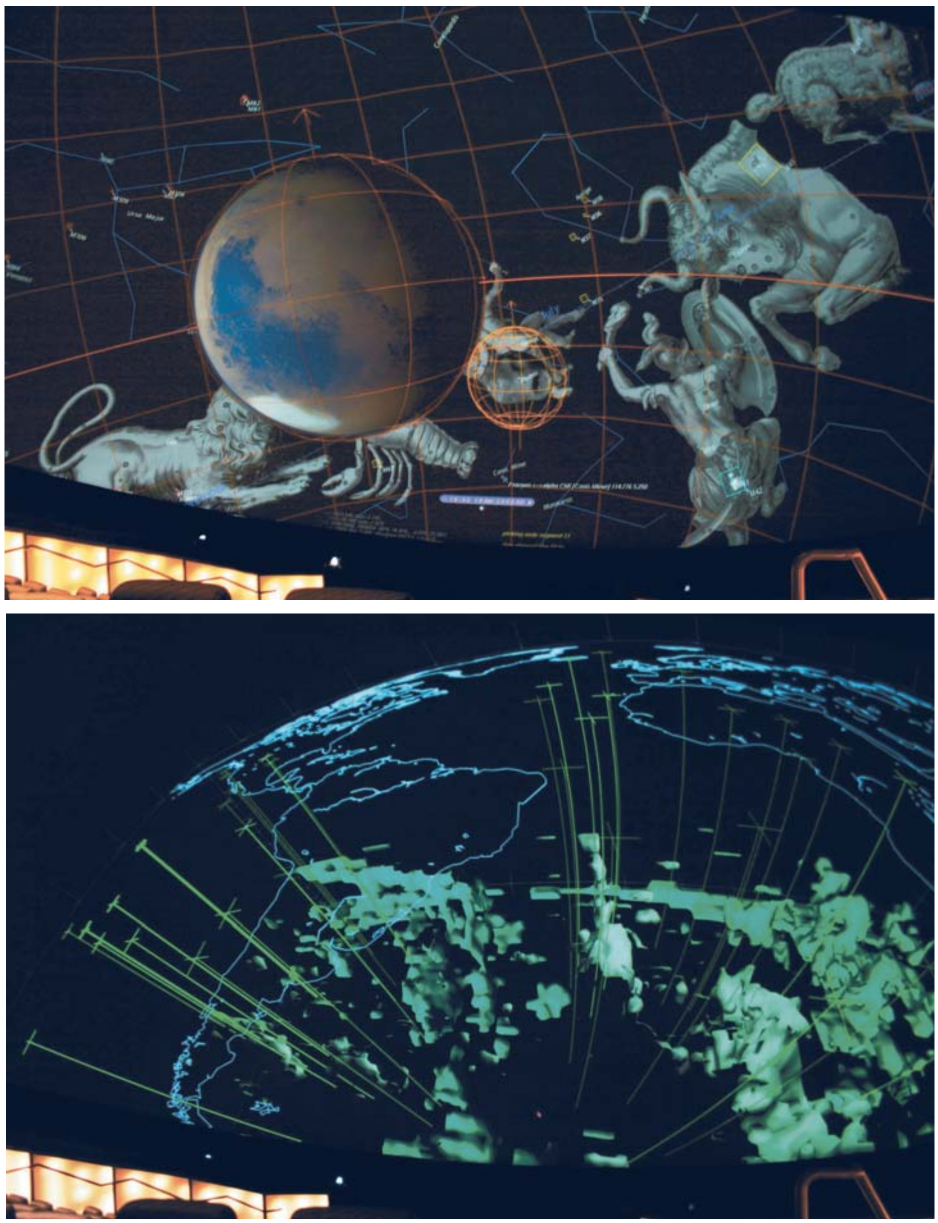

Figure 1: Virtual environment simulations running in the Gates Planetarium's real-time computer system at the Denver Museum of Nature & Science: (top) DMNS' Cosmic Atlas software showing the view above Phobos and Mars; (bottom) a 3D geological simulation of the Earth's mantle plumes displayed with an all-purpose model-loader.

computer-based simulation is the ability to change frames of reference. With immersive visualizations, users can have frames of reference that are external as well as internal to the simulated model. When a user is looking at the simulation from the outside, she has a global or *exocentric* perspective about its individual components. When a user is inside the model with its components all around her in an immersive display, this *egocentric* view reveals not just detail at the local level but makes the user feel as if she was actually in the space, as opposed to merely observing it. Having both perspectives can provide greater benefit than either alone [40]. The Virtual Solar System project at Indiana University and the University of Georgia allowed students to build their own solar system models in the computer, and gave them the ability to observe and change vantage points interactively. Those enrolled in classes using the software showed significant gains in learning of lunar phases and eclipses [10, 41, 42].

Another challenge in astronomy teaching concerns the distances to objects in space. Although the distance to objects in near Earth orbit (roughly 100 kilometers above ground) are well within most people's perceptual experience, most other measurements are vastly larger. The magnitude of distances to other planets, stars, or galaxies and their lack of any connection to personal experience is probably why the general public holds many misconceptions about astronomical sizes and distances [21, 31, 32].

Computer visualizations that encompass both small and large scales may be especially advantageous for understanding astronomical distances. For instance, the misconception that the space shuttle has visited the stars [31] or that the stars are located in the solar system [43], can be addressed by a virtual simulation that compares the scales of objects near the Earth to those elsewhere in the solar system and to distances to the stars. Side-by-side comparisons of human-scale spacecraft to large rocky planets and even larger gas giants would be difficult with physical models, but can be performed easily in a VE by "zooming out" to view increasingly larger objects. At least one study has taken advantage of the capability of VE software to switch frames of reference in such a way, and was able to correct students' notions about the shape and size of the Earth [44].

Finally most astronomical phenomena are also time-dependent. They require not just the understanding of spatial positions and orientations, but how those change over time. As a result, animated movies showing time-varying astronomical phenomena are now common in multimedia instructional materials that come with college astronomy textbooks [45]. Although such animations can show a physical phenomenon at different times, the perspective is usually fixed to a single vantage point. Only a VE simulation gives the user the freedom of moving to multiple perspectives in time as well as space.

The Psychology of Immersive VEs

The benefits of computer-generated reality systems in education have been studied by many researchers. For instance, Chris Dede and his collaborators have highlighted a number of advantages of VEs for learning complex spatial concepts, such as those often found in the physical sciences [46—48]. They include immersion which can increase student engagement; the ability to view 3D models from multiple frames of reference which can give additional insights into any phenomenon that occurs in a 3D physical space; and the increased student motivation from interactions with a well designed VE, even after the initial novelty has worn off.

Researchers have also discovered that visualizations of complicated data sets in immersive VEs can be more effective than the same visualizations in a non-immersive VE [49]. Test subjects using highly immersive VEs show better task performance and have higher satisfaction levels than those in non-immersive VEs [50].

Furthermore, large display systems (such as those found in digital domes) can increase the psychological sense of *presence* [51-54]. Presence (or "telepresence" as originally coined by Marvin Minsky twenty-five years ago [55]) is defined as the sense of "being there," where a user responds psychologically to a mediated environment as if that environment was local, not remote [56-58]. By using various psychological and physiological measures of presence, researchers have shown that increasing presence is correlated with an increase in attention [59], in the persuasiveness of the mediated message [60], improvements in memory and retention [61-63], and enhancements to task performance and navigation within a VE [54, 64]. Therefore any increase in presence can potentially increase the effectiveness of the content that is being taught [65].

Other parameters that increase the sense of presence happen to be suited perfectly for the new generation of full-dome theaters. These include improving image resolution [66, 67], widening the field-of-view (FOV) of the display [67-69], and enlarging the physical size of the display [70, 71]. Desney Tan and his collaborators have shown the importance of not just increasing the FOV, but increasing the dimensions of the display surface. In a series of papers, they showed that even when the same angular size of display is used, subjects using the physically larger display perform better in virtual navigation and spatial orientation [72-74].

The Future

Although traditional planetariums have been in wide use for many decades, studies of their effectiveness in astronomy teaching versus normal classroom instruction have had mixed results. Past research has shown improved performance in the planetarium [75-78], no difference between the two [79, 80], and better performance in the classroom [81, 82]. Because these studies involved traditional analog planetarium presentations

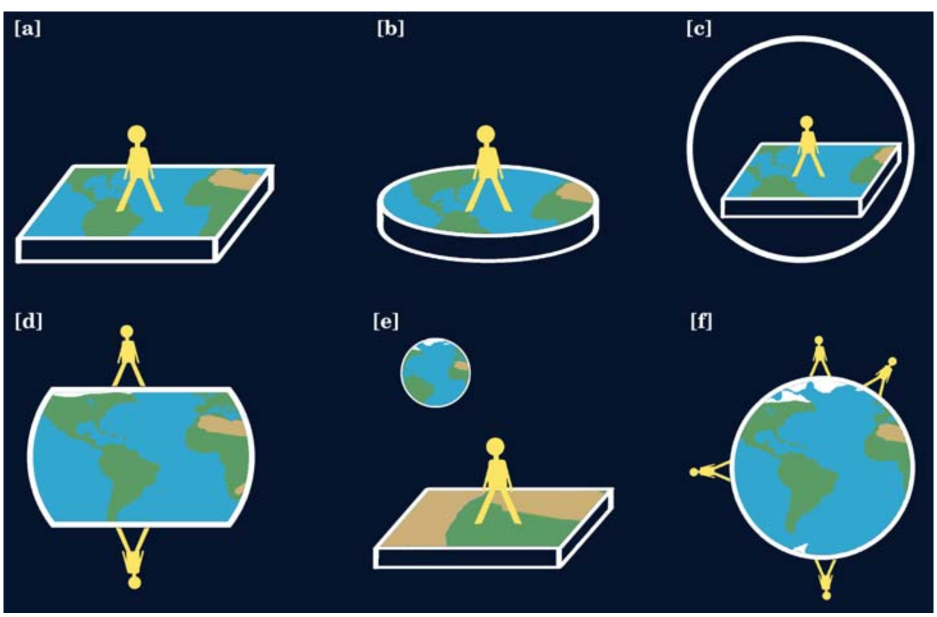

Figure 2: Examples of some of the most common notions of the shape of the Earth by schoolchildren. Only the last depiction is scientifically correct.

using mechanical star machines, their experimental subjects learned in an immersive dome, but did not benefit from any VE visualizations.

In recent years, advocates in the full-dome community have argued the qualitative advantages of the full-dome theaters, based on their large FOVs, and the educational potential of the technology. However only a handful of quantitative studies have looked at the effectiveness of domed displays (e.g., [68, 83]). A critical study at the Houston Museum of Natural Science showed significant improvement in comprehension from immersive full-dome 3D visualizations over 2D and non-immersive teaching methods [84]. But clearly more work needs to be done to quantify the advantages of immersive learning for astronomy education.

As suggested by the literature review above, immersive VEs combined with full-dome theaters may be a powerful tool for education. Not only astronomy but any other subject requiring complex spatial understanding may gain from visualization software running in such venues. If visual immersion also has quantifiable benefits, then full-dome theaters may offer instructional value that is not possible even if the same VE software were used in a "smart" classroom.

Digital full-domes are not usually regarded as true virtual reality (VR) systems[2]. However, they have far greater educational potential than traditional VR systems such as CAVEs and head-mounted displays. These mainstays of VR research are still expensive enough to be restricted to academic research settings and to industrial labs. They are also constrained by design the number of people they can accommodate at any one time. Although full-dome theaters are also expensive, they are built with large audiences in mind, and can be used for social and collaborative learning.

A growing number of full-dome theaters have been constructed at museums and science centers as part of planetarium renovations. Planetariums have built-in audiences numbering in the tens of millions [85], and as more institutions "go digital," the impact of full-domes on informal science education worldwide can be enormous. However the specific nature of this impact has to be properly quantified. (We at the Gates Planetarium have already started looking at research projects to study the best way to use immersive full-domes for teaching astronomy.) The techniques discovered must also be disseminated to planetarium educators, managers, and operators for them to be globally effective. Only by doing so can the successes from this new technology be leveraged for greater support and recognition for the entire full-dome community. Armand Spitz is oft quoted as calling the original Zeiss planetarium "the greatest teaching instrument ever invented" [86]. Digital video full-domes clearly have the promise to uphold that tradition.

2. Virtual reality is usually associated with — in addition to visual and aural immersion — stereoscopic displays, head-tracking sensors, and full user interactivity.

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Feeding the Beast

and other Responsibilities of Digital All-Dome Planetarium Owners

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Abstract

This paper outlines the realities involved in operating, maintaining, and producing for a digital, all-dome planetarium. These realities present challenges for planetarians significantly more demanding and costly than past productions using older technologies. Strategies are suggested to meet these challenges.

Introduction

Let's start with a thought experiment. Turn your mind back ten years. Try to remember the PC you were working with then. What was the brand? What were its capabilities? How much could it store? What was the operating system? What kind of Internet capabilities did it have? Though you might be able think back even further or it could be that you have not been one to upgrade very frequently, most of you have probably kept up pretty well with the changes in PCs and have at least bought new computers more than once in that span of time. Even the operating systems need to be upgraded almost every other year. Storage and graphic capabilities, so crucial to those who work with images, change geometrically with time. Processor speed improvement alone makes decade old computers seem like sputtering Model Ts compared to a turbocharged Ferrari.

The continual rising performance trajectory of solid-state technology, with accompanied declining price increases, has led to the revolution now facing the entire planetarium community. It used to be that only high-end planetariums could afford the computers and all-dome video projectors – but that situation is changing rapidly. Like it or not, many planetarians feel the pressure to bring this technology into their planetariums in the form of digital, full-dome video. Often the only way to generate buzz to upgrade or create a new theater is to stay at the cutting edge of technology. Furthermore, since planetariums have always been perceived as technical wonders dealing with futuristic science, we are expected to upgrade.

There are two primary arguments for using this technology. First, is the potential it offers to depict realms of the Universe far beyond the confines of what a star projector alone could do. It also allows us to display content that is real-time or near-real time. Yet our former planetarium projector technology has been one that changed as little as the world-view of the Egyptian pharaohs. The deterministic, mechanical star fields we all grew up on are no longer the primary experience we can deliver. Our potential is far greater, and so are the challenges.

Experience-based programming is sweeping the museum and exposition world – immersive virtual realms are part of this trend. But, the excitement of these virtual realms also brings with it a new set of realities for planetarians who must implement, manage, and operate such theaters. This article tries to frame and discuss the principal challenges implementers and operators face with digital all-dome systems. It does this by outlining the **four responsibilities** that come with digital theaters. These tasks parallel challenges that come if one had adopted a gorilla. They are: feeding the beast; health care; trained keepers; and learning new tricks. Finally, the paper gives several strategies to help planetarians become successful digital theater owners. And, like a gorilla, if one doesn't heed these responsibilities, one could have a planetarium that is equally difficult to handle.

The Four Responsibilities of Digital Theater Owners

• **Feeding the Beast** – Programs

Because an all-dome, digital video planetarium can depict almost anything and can display content generated in many ways, its *diet* is not only varied, but it can include expensive ingredients. These theaters are fed by their program offerings: (1) pre-recorded, (2) real-time and (3) hybrid programs. Each type presents a special challenge.

(1) *Pre-recorded* videos are the dominant program in digital theaters. Domes projecting these are essentially presenting a movie, the same way IMAX theaters present 70 mm films. The most sophisticated of these programs are not produced by any but the largest planetariums or other well-financed producers. Few planetariums will make their own elaborately rendered programs for the simple fact that they don't have the appropriate programmers or computing resources at their disposal. Elaborate scenes require tremendous amounts of rendering time. But, once rendered the job is essentially done and can be widely distributed. The challenge is in the original production.

Even large planetariums face a major hurdle in obtaining the production funding for pre-rendered shows. The hope for these programs is standardization and a sufficient number of outlets so that they will follow the road of IMAX – with all its successes and limitations. The rapid increase in numbers of digital dome theaters has finally made distributing production costs possible. But, like IMAX, stunning and attractive programs will be absolutely necessary for success. The downsides are that planetarium owners will need sufficient funding to lease such programs and may become more like movie theater operators than educators if these are the only programs they offer.

(2) *Real-time* programs, however, offer much more hope for those who wish to deliver educational programs or ones looking for more audience participation. Real-time programs rely on a computing system with models, simulations or imbedded videos that can be run in real-time. The visual quality of real-time graphics cannot be the same as for a scene that required a thousand processor hours per rendered minute. Nevertheless, even real-time visualizations can be dramatic and stunning. Most digital video systems for theaters now come with a night sky model. But, to achieve its fullest potential, these visualization theaters need to go well beyond the night sky.

Successful, real-time programming requires two essential ingredients: models and presenters. The first are the digital models themselves. If the models are not available, then someone must create them. One of the primary motives of the Hayden Planetarium's Digital Galaxy project, which was started late in 1996 with NASA funding, was to begin assembling the data sets and expertise to build a virtual galaxy. Another good example of a serviceable and robust model for real-time programming is that used by the Tokyo Science Museum in its **Universe Science Live Show** (http://universe.chimons.org/about-en.html). Riken Institute programmer Toshiyuki Takehai has created a digital orrery that is extremely useful for live demonstrations about the solar system. There will be more such models as these, but unlike electromechanical star projectors, the model isn't hard-wired into visualization theaters.

The second ingredient required for real-time programming is a trained and skilled presenter. It has always been this way even with older planetarium technology. 3D models used in real-time require a new level of expertise, however. Not only the degrees of freedom for motion are disorienting, but the scope for possible models is infinitely greater than basic night-sky motions. A good digital dome presenter might conceivably take an audience on a flight to Saturn in one show, tour the galaxy in another, and then explore the inner workings of a brain cell in yet another program. Presenters will have to be both great pilots and knowledgeable tour guides. Programs and training must be available to upgrade our profession.

As of the writing of this article and to the knowledge of its author, only a few institutions have succeeded in routinely doing full-dome, real-time digital programs. Developing the skills and talent to do so will be necessary, however, if we wish to fully exploit these new systems.

(3) *Hybrid* programs are ones in which the digital video projection system is used in conjunction with other technologies, such as star projectors. Or, hybrid programs might combine pre-recorded visualizations or videos in a larger digital framework. A full-dome PowerPoint presentation where one has other projection systems at their disposal is maybe a better way to think of these programs. Hybrid programs can be presented live or with pre-recorded audio. There is high potential for these programs, if the planetarium producers have both the right content and tools at their disposal.

Most planetarians have long preferred the components necessary to assemble their own productions over complete shows. Hubble imagery and JPL's Museum Visualization Alliance have been some of the best examples of great content for hybrid programs. Successful productions of hybrid programs will require well-stocked and easily accessed libraries of such visualizations.

Hybrid programs also require software designed to accept a variety of content and either render or present it in a serviceable show. Most digital systems are capable of this, but software vendors will face pressure to create software to produce hybrid shows as powerful and easy to use as possible. Because planetariums are a small market sector, this will be a special challenge, as will be the times when we might be compared to other digitally-based media.

These other media might be tempting for those who seek alternative examples of programs to *feed* digital planetariums. There is a tendency for new planetarium technologies to *ape* ascendant entertainment technologies. Examples of these latter technologies might be high-end motion pictures, video games, or certain Internet sites. In most cases, these technologies translate poorly over to the planetarium world. We do not have the budgets of Spielberg, or the opportunity for individual interactivity required by games or the Internet. The best strategy is to play to our strengths as an immersive venue and produce programs possible, whether they be pre-rendered, real-time or hybrid.

In summary, the most important responsibility of a digital all-dome owner is the programs – digital planetarium theater owners need to know what kinds of programs they will feed their *beast* and how they will finance and produce them. If they don't they will find themselves in an unhappy situation. The demands of these types of theaters have upped the stakes especially for ongoing revenue and financing. New ways of sharing resources will almost certainly be necessary or planetarians will lose control of their digital theaters.

• **Health Care** – Maintenance and Upgrade

Digital all-dome planetariums, with their computers and video projectors, require frequent maintenance and periodic upgrade. This process will be much more technically demanding and costly than the old days when maintenance simply meant gear lubrication and incandescent lamps replacement.

Multi-projector video systems require tuning and alignment to deliver seamless images. This task is a formidable challenge for blended CRT projectors. Most theater operators require outside experts to perform this task. Although newer technologies, including lasers could make this challenge easier for multi-projector venues, there is likely to be other new high-technology maintenance challenges placed upon the owners.

Upgrade costs associated with digital theaters are much higher than they were for traditional planetariums. The disk drives one is using today will probably not be useful or even supported by manufacturers in a matter of five to ten years. Lamps for video projectors are two orders of magnitude more expensive than the 12-volt lamps of old. There will always be a demand for faster processors and communications. And, as well all know too well with our PCs, the operating systems will continually upgrade whether we like it or not.

Large theme parks and expositions are often showcases for similar digital video technologies, but those owners have advantages most planetariums do not enjoy. The parks and expos have large budgets and often only play only one program continuously. Any institution considering a full-dome video system must understand the long-term financial commitments they are making before committing to maintaining this technology. If not, their system will, at best limp along in poor health. At worst, they will have a theater they cannot afford to operate.

• **Trained Keepers** – Staffing and Development

If a visualization theater needs proper feeding and maintenance, then it also needs skilled staff. The mere sophistication of the technology alone will require technicians capable of operating and maintaining systems different from those in the past. Furthermore, problems with digital systems can be more catastrophic than those of simpler systems. If key elements fail or cannot be serviced, then one may have no program to show if a backup does not exist.

Sophisticated skills are necessary beyond basic operations and maintenance. If one is to do any form of production for these new theaters, one must have staff capable of using the necessary programs. Since the technology evolves rapidly, continual training and staff development is required even for those who are hired with the high technical abilities.

Competition from other employers for staff with the skills described above will compound the problems. Digital graphics producers and video technicians are more in demand than were traditional planetarium technicians. As a result, a planetarium director could be faced with hiring workers from industries that typically pay well above what planetariums have paid in the past.

Staffing costs, plus the challenges of the previous two sections mean that operating and production costs associated with digital planetariums are significantly higher than their predecessors. To be financially successful, however, the new visualization theater operator will need to pay special attention to the next, and last, reality.

• **Learning New Tricks** – Innovation Imperative

When planetariums that have upgraded to digital systems promote themselves they often rely on the buzz created by the new technology. In the popular mind, outer space represents a future reliant on high technologies too. If a planetarium positions oneself, therefore, as a cutting edge theater, then it is committed to an innovation imperative. They will need to keep teaching their theater new *tricks* in order to be perceived as an innovative venue.

A recent paper by the author (Sweitzer 2004) demonstrated quantitatively how important the continual innovate with new programs to attract new and repeat audiences can be for the long term financial viability of a new or renovated planetarium. If one doesn't, then one will lose the ability to generate the additional funding necessary to feed, maintain, and care for a digital planetarium.

Two plots from that paper illustrate the point. Figure 1 shows how even a highly successful opening year attendance can retreat to the former steady state attendance if one does not have strong follow-up programming. Figure 2 shows a better case where the new venue repeatedly offers innovative programming and average attendance numbers remain significantly higher than those from before the new innovation.

Planetariums that are seen primarily as serving an educational function can perhaps side step this innovation imperative. But, they too will require secure additional streams of funding to operate. If one is hoping, however, to significantly support a planetarium with ticket sales, then seats will need to be filled with higher-paying customers. Only innovative and varied programming will attract repeat customers as well as new audiences.

Strategy Recommendations

The realities of owning this new type of *beast* should not overwhelm the new opportunities it offers. Planetarians must take on these four responsibilities because of all the new technology offers our audiences.

Recent experience supports the following five recommendations from which to build a strategy for success.

- **Think beyond the technology.** Those implementing planetarium renovations or creating new digital all-dome theaters should keep in mind that success requires much more than simply choosing the right technology for the theater.
- **Plan your programming carefully.** Know the types of programs you will be offering and make sure you have a plan to secure or create them within your budget.
- **Budget properly.** Know your maintenance and long-term upgrading costs before you buy any all-dome system.
- **Keep high theatrical values.** Although producing content for these theaters is technically different from the past, the values, techniques and skills that made good shows before still hold. No amount of new technology will cover for a poor script or ham-fisted visual choreography. This applies to both in-house productions, but also to commercially produced programs. Owners must demand the highest quality from content providers or team up to oversee joint productions with high values.
- **Plan to continually innovate.** Keeping the digital all-dome *beast* properly funded and attractive will require ongoing innovation and is not only an opening day concern.

Conclusion – Not Your Father's Planetarium

We'll end with one final thought experiment. How many planetarium projectors constructed in the 1960s can you think of that are still in operation? You can probably think of several Zeiss, Goto and Spitz instruments still going strong. Many systems from that era are no longer with us, but that older technology has had typically a thirty-year lifetime. Most owners of the older systems would probably like to upgrade, but nevertheless, they are still operating.

Alternatively, how many computers are still operating that were new in the 1980s or even the '90s? The time horizon for the digitally driven planetariums is easily one-third closer than any electro-mechanical planetarium technology. Keeping ahead of these changes is a tremendous challenge for digital planetariums both from a technical standpoint, but more significantly from a financial standpoint.

This paper is not advocating staying with older technology; in fact we must upgrade in order to properly visualize the rapidly changing contemporary model of the universe. But we must also understand the realities of digital all-dome systems to be successful – we must tend the beast.

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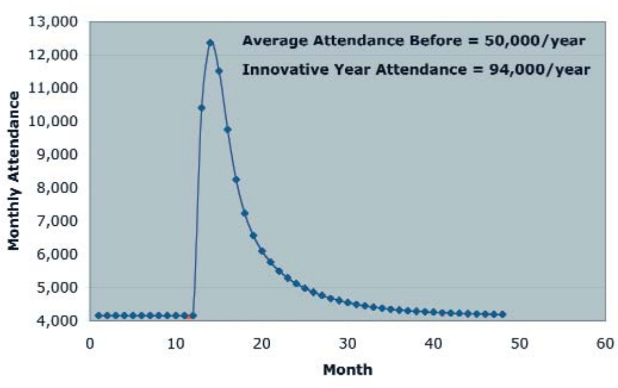

Figure 1 - The Danger of One-Time Innovation: Model for Newly Renovated Planetarium Without Subsequent Innovative Programs. This plot displays a simplified quantitative model due to the program Spectacle. It depicts attendance projections for a successful innovative new planetarium under ideal assumptions. The prior yearly attendance was 50,000 per year and jumped to 94,000 in the first year of the new innovation. Note that without routine innovations, the attendance dropped back close to the original numbers within two years. Plot is from Sweitzer (2004).

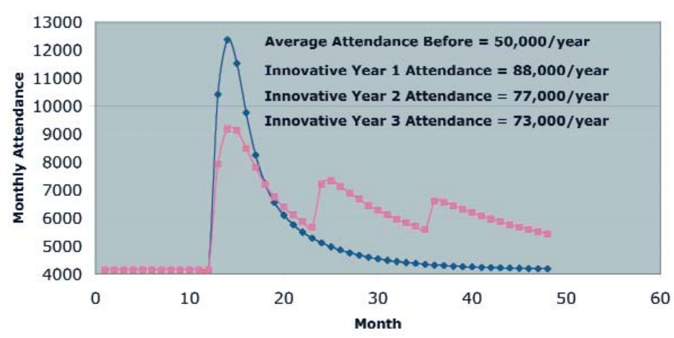

Figure 2 - The Power of Repeated Innovation: Model for Newly Renovated Planetarium With Subsequent, Ongoing Innovative Programs. This plot displays another simplified quantitative model due to the program Spectacle. It depicts attendance projections for a moderately successful innovative new planetarium under similar assumptions as the previous plot. In addition, it assumes that the planetarium owners focus on repeated innovative programming that appeal to new and repeat audiences on a yearly basis. Although it doesn't spike as high as the previous figure, the average yearly attendance now remains nearly 60% above the time before the innovation (=digital system) was introduced. Plot is from Sweitzer (2004).

Planetarium Paradigm Shift

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Abstract

Immersive video represents a paradigm shift in the planetarium field: new opportunities for teaching and presentation will necessitate new ways of thinking about the medium. We can now present the discoveries of 21st-century astronomy with great fidelity and within an accurate three-dimensional context, but such possibilities expand our content area significantly and require creativity in their implementation. Furthermore, fulldome video also demands a new approach to planetarium production, as taking visitors on a "narrative journey" that places greater focus on the audience experience. The planetarium community must grow with the technology we use, and the future holds both great potential and tremendous challenges.

It is tempting, when writing an article such as this, to stick to the third person: authoritative, distanced, and "objective," third-person prose seems to offer greater impact than first-person musings. But my partisan passion for the fulldome medium does not permit such a strategy. I believe that emerging technology offers planetarians remarkable new opportunities that will benefit our profession and the educational goals we all share. I feel so strongly, so optimistically, about the potential, that I cannot easily express my views with mere "its" and "theys." To top it off, the promise of fulldome technology cuts to the very core of what I love about astronomy. So I hope you will not begrudge me the first person.

When I was a teenager growing up in Arizona, I would drive into the foothills of the Rincon Mountains, park my car and lie on the hood staring at the night sky. I didn't know many constellations, and I rarely used the department-store telescope my well-intentioned parents had bought me, but the sky fired my imagination. I had read Carl Sagan's *Cosmos*, and I gobbled up books on a variety of astronomical topics. And I had attended shows at the Flandrau Planetarium, roaming the exhibits (the light table, polarizing filters, and solar spectrum made strong impressions, as I recall) for hours on end.

Lying under Sonoran skies two decades ago, I considered why people had traveled to the Moon and no farther, and I wondered how far humankind might travel in the future. I looked at the stars and tried to imagine how far away they were, even the closest billions of times more distant than the Moon! I marveled at the concept that we could know so much about the Universe just by studying light. In short, the sky simply awakened in me the questions that modern astronomy attempts to answer – and challenged me to see the extraordinary activity beyond the apparent serenity of the constellations.

Today, tools have become available to connect the realms of sky and science in unprecedented ways. We can teach contemporary astronomy as never before, illustrating concepts with self-consistent, data-driven moving images that put elements in their appropriate and accurate context. Furthermore, such didactic accomplishments can take place in an immersive and stimulating environment, namely our planetarium domes.

Two technological streams have converged. First and more familiarly (because it has been discussed with such frequency in our profession), video projection technology now allows us to cover domed surfaces with increasingly high-resolution, full-color, full-motion imagery that creates an immersive environment to engage our audiences. But on the other side of the video cable, we also have unprecedented (and increasingly affordable) capability to bring real-time, high-resolution 3-D graphics covering sufficient size scales to accommodate the incredible dimensions of our Universe. Together, these technological innovations offer the promise of a planetarium paradigm shift – from the tools and techniques developed over the last eighty years to a host of new possibilities.

I would like to tackle the astronomical side of the equation first: to address the fundamental reasons why I believe the "Digital Universe" promises a new way of viewing astronomy. Then I want to get into some of the reasons why the fulldome medium offers an

Earthrise over a planetarium audience in the Hayden Planetarium, during a showing of the Rose Center for Earth & Space's 2002 program, *The Search for Life: Are We Alone?* Courtesy American Museum of Natural History.

ideal format for astronomical content. Finally, I would like to comment on some of the production challenges associated with fulldome video and end with a few thoughts on the future.

The Digital Universe

Inside the Hayden Planetarium, we have spent many late nights touring friends and colleagues through our 3-D atlas of the Universe. We offer a course for the general public that introduces the dome and describes how we developed the database we use – as well as a monthly program that tours audiences through a selection of datasets, based primarily on our digital atlas. In 2004, a few of us had the opportunity to take a similar program "on the road," presenting at various institutions nationwide. Our collective experience constitutes, I believe, a new way of contextualizing astronomical discoveries, facilitated by new technology.

On a typical "grand tour," we begin with the orbits of the planets and the trajectories of the Voyager spacecraft (the farthest humans have sent physical objects) and travel out to the Oort cloud (the distant reaches of our Sun's influence), past the exoplanetary systems we have discovered to see the "radiosphere" bubble sixty-some light years in diameter (the farthest humans have made our presence known through radio signals sufficiently strong to be detected), and out to the scale of the Milky Way Galaxy. We then use our extragalactic atlas to highlight the large-scale structure of the Universe, give a sense of the extensive mapping done by surveys such as 2dF and Sloan, and introduce the Cosmic Microwave Background. From each transition to the next, each previous step remains visible long enough to provide a visual and conceptual link to the ever-increasing scales we describe. Traditional planetarium tools do not allow such seamless integration of size and distance.

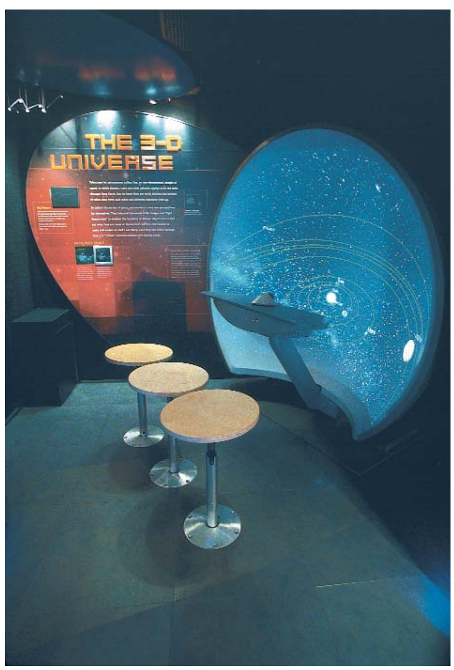
As we say in our advertising copy for the "Virtual Universe" program: "You'll tour through charted space – an experience that will redefine your sense of 'home.'" We wrote that sentence based in part on the reactions people have had to experiencing the atlas. People often leave an hour-long session under the dome expressing awe at the scale of the Universe and wondering at the magnitude of astronomical discoveries. My colleagues and I would love to attribute such impressions to impeccable presentation style, but we concede that it more likely reflects the power of showing people real data in a visceral, yet intellectually satisfying, context.

Indeed, context is the crux of the matter. What does it mean when a new planet is discovered around another star, if one lacks a sense of interstellar versus interplanetary distances? What is the Milky Way band that crosses through the night sky, and what connection does that have with the Milky Way "Galaxy"? How can we tell that we live inside a spiral galaxy, let alone estimate its size? Most contemporary discoveries require spatial and temporal context in order for our audiences to appreciate them.

Cinema has had more than a century to develop a visual language (of pans, zooms, cuts, etc.) that allows viewers to understand the narrative flow of a piece. … But large-format film has been around only a third of a century, and it demands a new approach.

Traditionally, one gains a sense of where things are in the Universe by poring over text, photos, and diagrams – in recent years, a video or interactive element may help one along – but placing this varied information in a coherent 3-D construct can prove dauntingly difficult.

Three-dimensional visualization of digital datasets provides a context for the vast quantity of information churned out by astronomers – not simply as piecemeal images or videos, but potentially within a coherent 3-D construct that conveys a significant level of understanding about our Universe. Thus, you not only visit the Orion Nebula, but you travel the 1,500 virtual light years to get there. You not only fly around inside a computer simulation of a globular cluster; you lift out of the plane of the galaxy to see the distribution of globular clusters around the galactic center, then choose one to fly into. Basically, you can explore a "Digital Universe" that approximates and incorporates what we know about the actual one. With such tools, audiences can experience the relationships between different datasets, establishing a visual and conceptual framework that supports the acquisition of more detailed information.



A small domed surface immerses pilots in a digital model of the solar system in the American Museum of Natural History's "moveable museum," a traveling collection of astronomy-oriented interactive exhibits. Courtesy American Museum of Natural History.

To be perfectly blunt, a traditional planetarium can teach 19th-century astronomy very well, but our 21st-century audiences want to glimpse the broader horizons that modern astronomy has revealed to us. Modern computer technology allows us to do this, and fulldome video is the conduit by which it can reach planetarium-goers.

The Digital Dome

At its best, a planetarium immerses an audience in science stories. Although such stories have typically revolved around the night sky, planetarium technology today can represent the discoveries of space science (and other sciences) better than ever before. With immersive video technology, domes can be filled with computer-generated visuals that depict current astronomical discoveries with unprecedented fidelity.

In the most recent Rose Center Space Show, *The Search for Life*, each image (out of more than 42,000) covers about four million square inches of dome surface. Audience members view a show that fills almost half their field of view, at a rate of 30 images per second, which visually approximates an alternate reality – corresponding not to an experience under a dome, but an experience inside an environment. At its best, immersive video allows audiences to connect with a virtual environment in an exceedingly visceral way. An "immersed" audience member becomes part of the action – and part of the science! New technology expands the natural planetarium environment from the night-sky diorama of traditional projectors to a universe of topics limited only by rendering resources.

Award-winning large-format-film director Ben Shedd's article, "Exploding the Frame," describes an approach to large-format cinema that seeks a new cinematic language to work in this medium. He writes, "The whole group of giant screen film formats have one thing in common: the gigantic images extend the edges of the projected film image to the edge of our peripheral vision or even beyond it. I believe we are not just talking about bigger films here, but a new cinematic world. It is a frameless view, an unframed moving image medium."

In many discussions of fulldome technology, people bring up "the story" and the need to tell good stories in the dome. I take issue with the term "story," in part because it has very specific connotations in films and in literature; furthermore, the term misses an essential element of the production challenges associated with immersive experiences. Because the medium shifts emphasis from story to environment, a fulldome planetarium show is more about taking a journey than watching a story.

Fundamentally, Shedd offers a way of thinking about what every large-format film-goer has experienced – the catch in the throat as the camera dives off a cliff, the sinking feeling in one's stomach as the motion on-screen seems disturbingly real. The "frameless" perspective gives audiences a very visceral experience, engaging a more physical, more primitive part of the mind than the intellectual or even affective responses other media might provoke.

With computer-generated, geometrically-correct imagery, fulldome video continues the trend established by large-format film over the last several decades. Unlike film, however, the use of digital imagery allows for relatively low-cost production and playback, with the ability to experiment relatively cheaply (e.g., previewing real-time or low-resolution experiments in-dome) and no need to print to film! However pricey fulldome productions seem to planetarians, the budgets come nowhere near the amount spent on an average large-format film, and digital technology has the potential to become increasingly affordable. More importantly, it has a democratizing aspect to it as well: digital tools already offer tremendous access to a large cross-section of the population (again, compared to film), and they get cheaper as time goes on.

For example, working with my laptop and low-cost or free software, I have had the opportunity to produce two short fulldome pieces that have appeared as part of the LodeStar Astronomy Center's annual fulldome festival, "DomeFest." Other shorts in the festival have included student projects, work by Native American artists, and visual musings on the nature of perception and memory – not the stuff of ordinary planetarium shows, but very much the work of individuals. The experimental nature of "DomeFest" underscores another important aspect of fulldome video: its production challenges as an emerging medium.

The Narrative Journey

I will consider fulldome video in the context of its filmic predecessors, rather than attempting to contrast fulldome presentations with traditional planetarium shows.

Central to my argument is the idea of a filmic language. Cinema has had more than a century to develop a visual language (of pans, zooms, cuts, etc.) that allows viewers to understand the narrative flow of a piece. A variety of styles have evolved over time, film schools have developed well-honed curricula, and scores of books describe how to construct films and television shows. But large-format film has been around only a third of a century, and it demands a new approach.

Shedd contrasts the "framed" experience of traditional cinema with the "frameless" experience of large-format film. In particular, he compares the third-person style of traditional filmic language with the first-person nature of an immersive experience: "The movement sensation of the theater must be accounted for throughout a frameless film, in shots and from shot to shot. Either the audience is having a first-person experience or it isn't. This idea represents a complete shift of approach in filmmaking, where the audience experience is the first order of focus, where all of the action occurs on the audience's side of the screen."

Harlem students interact with a digital model of the solar system in the American Museum of Natural History's "moveable museum," a traveling collection of astronomy-oriented interactive exhibits. Courtesy American Museum of Natural History.

I believe that an approach to the medium that follows Shedd's philosophy not only makes good use of fulldome's strengths, but also stands in refreshing contrast to the media most people experience on a day-to-day basis: more than a sales pitch or a plotline being pushed at a viewer, a "frameless" experience can involve people in a way that television or movie screens do not. Furthermore, producing from a "first-person," viewer-oriented perspective requires a respect for the audience that bodes well for content creation. If we create programs that focus on the audience experience, we effectively invite people to appreciate the scientific content in a new and deeper way.

One of the effects of the audience-oriented approach is the need to consider how a viewer moves from one scene to another: rapid cuts become jarring experiences because one's sense of place is disrupted. Also, too-swift motion can either nauseate viewers or distance them from the action: images moving too quickly onscreen lose their coherence as an environment and instead function merely as wallpaper. And maintaining the sense of dimensionality on the dome demands maintaining a sense of motion – of foreground relative to background – that yields a parallax effect. Continuity and carefully-orchestrated movement characterize the most effective fulldome productions. Again, this kind of pacing and editing stands in stark contrast to the rapid-fire, "MTV-style" video and film that people see elsewhere, and I think there is strength in that difference. In the same way that planetarium domes have long offered the solace of the night sky, fulldome presentations can offer an exhilarating and inspiring glimpse into new environments.

In many discussions of fulldome technology, people bring up "the story" and the need to tell good stories in the dome. I take issue with the term "story," in part because it has very specific connotations in films and in literature; furthermore, the term misses an essential element of the production challenges associated with immersive experiences. Because the medium shifts emphasis from story to environment, a fulldome planetarium show is more about taking a journey than watching a story. At the end of a trip, fellow travelers may compare notes and find they have gleaned very different experiences from the same itinerary. Likewise, at the end of a planetarium journey, every audience member takes home something unique to him or her.

In short, a successful fulldome presentation takes the audience on what I call a "narrative journey." In its simplest form, this takes the shape of a guided tour, traveling from place to place with a bit of wit and wisdom to make the trip pleasurable and more meaningful. In a more sophisticated sense, one can carefully structure a sequence of locations to incorporate and illustrate a sequence of elements in a storyline. In a narrative journey, a viewer is taken along on a tour of virtual sites that parallel an intellectual and affective excursion reinforcing the itinerary. I do not intend to suggest that it is the only means by which a fulldome presentation can succeed, but I will say that the best fulldome content I have seen fits the bill.

In short, a successful fulldome presentation takes the audience on what I call a "narrative journey." In its simplest form, this takes the shape of a guided tour, traveling from place to place with a bit of wit and wisdom to make the trip pleasurable and more meaningful. In a more sophisticated sense, one can carefully structure a sequence of locations to incorporate and illustrate a sequence of elements in a storyline. In a narrative journey, a viewer is taken along on a tour of virtual sites that parallel an intellectual and affective excursion reinforcing the itinerary.

Keep in mind that natural history museums developed as storehouses of objects returned from distant journeys – localizations of exotica that became stand-ins for traveling to the places whence they came. Long after 17th-century "curiosity cabinets" grew into museums that allowed visitors to experience realms to which they could not travel in person, 20th-century science centers initiated a completely visitor-oriented experience that allowed for exploration and inquisitiveness of a different sort. In the sense that museums allow for travel without leaving a building, or science centers offer opportunities for exploration, the planetarium "journey" mirrors other paradigms in informal education.

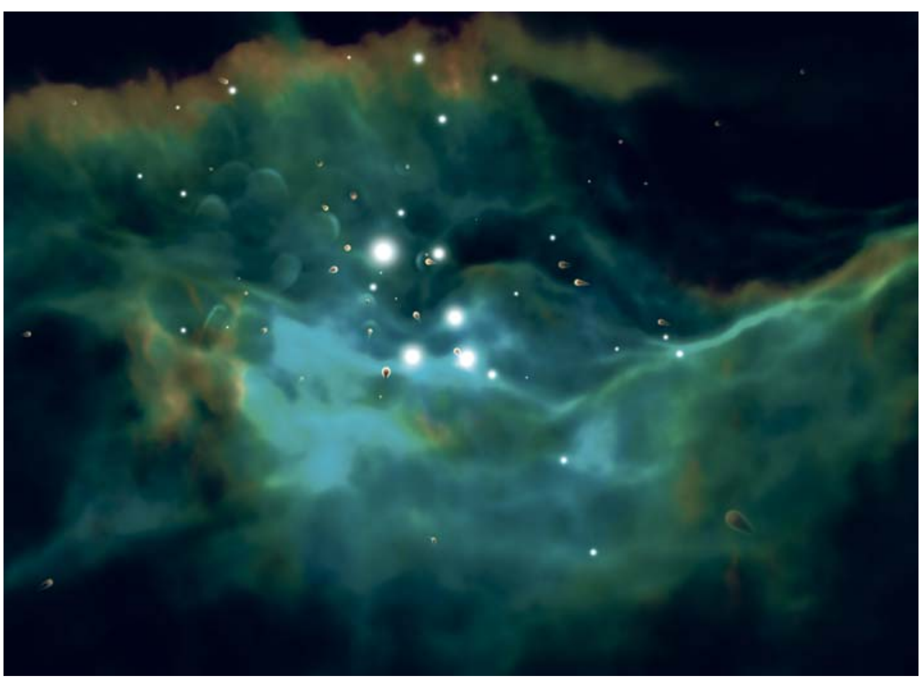
The Audience Experience

The individuality of the experience presents challenges to those of us who would like to evaluate the quality and effectiveness of planetarium programs – a challenge throughout the realm of informal education. Somehow, one would like to account for the matrix of reactions from the cognitive to the aesthetic to the visceral, while probing further than, "So, did you like it?"

To that end, the American Museum of Natural History conducted pre- and post-viewing surveys of audiences who attended the Rose Center's debut space show, *Passport to the Universe*. Those surveyed responded positively to the show and showed significant gains in comprehending many of the show's underlying concepts: an understanding of humanity's "cosmic address," the relative size and location of stars, the structure of the Milky Way Galaxy, and the origin of heavy elements through nucleosynthesis. Further surveys of audiences who saw *The Search for Life* indicated that the immersive feel of the show had broad appeal, from eight-year-olds to adults. As one teenager commented, "It was much better than seeing it in a movie theater. The special effects were like actually being there."

Every survey helps, but overall, greater attention needs to be paid to the learning process that occurs under the planetarium dome. Carolyn Sumners at the Houston Museum of Natural Science has shown that immersive video sequences show greater gains in student understanding than other media, but her research barely scratches the surface. Increased evaluation can help pinpoint what works and what does not – an especially important step as the technology driving the shift in planetariums reaches an increasing number of theaters and the audience for immersive video widens. Implementation of the technology in new theaters should take advantage of what their predecessors have taught.

Another challenge planetariums face is a variety of audience expectations that range from sitting under the stars with a lecturer to watching slide shows with pre-recorded narration, from listening to rock music accompanied by laser projections to (perhaps) an large-format-film-style immersive production. Audiences do not understand the diversity of experiences that take place under planetarium domes, let alone the changing nature of the medium, and most people's expectations are defined by the trips that they took to planetariums as elementary-school students. The typical planetarium-as-experience (as opposed to planetarium-as-venue, where a changing slate of programs might be more expected) places most visitors in a "oh, I've done that before" mode of thinking that curtails return visits to a facility. According to



A three-dimensional model of the Orion Nebula, based on the research of astronomers C. Robert O'Dell and Zheng Wen, formed the cornerstone of the Rose Center for Earth & Space's premiere program, *Passport to the Universe*. Courtesy American Museum of Natural History / San Diego Supercomputer Center.

a frequently-quoted planetarium adage, the typical person visits a planetarium three times in their life: as a child, with their children, and with their grandchildren.

Unfortunately, because most data about planetariums are approximately as anecdotal as the child-to-grandchildren adage, it is difficult to identify means by which planetariums can help define expectations and attract a wider audience. With any luck, immersive video will help attract more people into planetariums and perhaps increase the visibility of the field in general.

The Future

Our culture is immersed in science – science inextricably linked to people's everyday lives. Astronomy and space science have proven to be an appealing and effective inroad to science education, and planetariums are part of that success. As planetariums continue to immerse audiences in increasingly realistic scientific visualizations and narratives, they can help people contextualize complex science stories.

Immersive video productions began as the purvey of a small number of sizable venues associated with fairly large-scale institutions. But as the medium evolves, smaller theaters have gained access to similar technology, and the variety of presentations (from prerecorded to real-time, fairly passive to highly interactive) will increase dramatically.

For example, Small Digital Planetariums (affectionately called "SDPs") will soon offer unprecedented interactivity with the cosmos, in a format that permits each participant to control their own experience. In the spring of 2001, AMNH rolled out its astronomy-oriented Moveable Museum, featuring a 1.5-meter-diameter vertically-oriented dome running software that allows students to pilot around the solar system. The Adler Planetarium uses the same projection technology in one of their galleries. Although similar opportunities for one-on-one interaction may be rare, the same single-lens projectors work in small domes, and with the appropriate software, an experienced pilot can offer tours through space and time.

Particularly as the medium continues to evolve, the quality of tools and access to supporting media need to improve. With an increasingly large audience of planetarians (with varying technical expertise) interested in incorporating immersive video in their presentations, hardware and software tools need to support easy acquisition and inclusion of materials into fulldome programs.

Ideally, our community will begin to support the idea of an "open-source universe," in which contributors can add to an existing collection of 3-D data that would be shared by users of different systems. The idea has particular merits for the real-time systems that have come online in the past few years. Most fulldome systems include real-time displays – of traditional planetarium functions such as sidereal motion and orrery simulation as well as 3-D data and virtual spaces. Real-time solutions gain particular importance in light of the fact that pre-rendered, high-resolution fulldome video will remain relatively expensive to produce for the foreseeable future. But with user-friendly, real-time digital planetarium technologies, we open up a new realm of possibilities.

To choose one example, think of the revolution that can take place in school planetariums. First off, I have always seen (mostly real-time, interactive) fulldome video as an opportunity to revitalize the unused domes in schools across the country (some couple dozen in New York City alone): with the possibility of addressing more universal topics in a domed classroom, perhaps many school boards would invest in the equipment to reopen them. Plus, the generation of teachers being trained now probably feels more at home with a computer than with a knob-and-lever planetarium projector, so perhaps the transition to newer technology will come as a welcome step to them! But what is most key in my mind is the kind of science we can begin to teach with new technology: not just night-sky motions and slides or videos of isolated objects, but an integrated view of our 3-D Universe. The experience offers a paradigm shift in the way students think about the cosmos, even as it represents a shift in our own community.

During my nights up in the Rincon foothills, I asked questions that I like to convey to an audience now, if not under desert skies, then under a digital dome where I can try to answer some of the queries that kept me awake as a kid. Computer databases and software tools allow for the exploration of a Digital Universe that reveals relationships otherwise difficult to convey. And fulldome video allows me to immerse audiences in the exploration – perhaps not yet with the crisp clarity of a desert sky, but with sufficient impact to create a memorable experience. I am simply pleased that technology is finally catching up to my imagination!

References

Ben Shedd is currently working on a book, but in the meantime, his "Exploding the Frame" article is available online at http://members.aol.com/sheddprod2/ExplodingtheFrame.html

Carolyn Sumners presented her research at the NASA OSS Conference in 2002, and you can find her article in the published proceedings: Sumners, C., and Reiff, P., "Creating Full-Dome Experiences in the New Digital Planetarium," ASP Conference Series Volume 319, *NASA Office of Space Science Education and Public Outreach Conference*, p. 155.

Download the Hayden Planetarium's Digital Universe at www.haydenplanetarium.org/hp/vo/du.

Also, take a look at "Virtual Universe," which appeared in the April 2004 issue of *Natural History* magazine; also available online at www.nhmag.com/0404/0404_feature.html. ☆

Not all fulldome programming focuses on astronomy: entertainment programs such as the American Museum of Natural History's *SonicVision* allow for a more experimental approach to the medium. Courtesy American Museum of Natural History.

Some Thoughts From an Artist on Fulldome Theaters

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Abstract: The medium of fulldome projection is in its infancy, but the means are fairly easily available to produce original content. As more content appears, the astronomy community will be but one beneficiary of this effort. The skill sets required to provide content for a fulldome facility are production rather than academic in nature.

The planetarium as a simulation of the night sky will always fulfill an important role in astronomy education. The many smaller facilities doing this job are preserving awareness of the night sky as a window to the universe for millions of people who live under the lights of cities. There will always be small but tightly focused planetarium facilities that perform their tasks using minimal but effective means, with the aid of live lecturers who at their best can impress young minds, as well as the most expensive visual effects, but who do little if any original show production of their own.

There are other facilities with more than one staff member and a little work space with possibilities for some level of show production. Large domes in government and commercial facilities are at the top of this "spectrum" of capability, recently enriched by the explosion of fulldome moving image projection. Fulldome projection is inviting the conceptual transformation of the high end "planetarium" to the general purpose "domed theater." As time passes less will be written about the machinery involved and more about the innovative productions being shown.

Emergence of Fulldome

The first public showing of a wraparound projected panorama was at the Paris World's Fair of 1900, where audiences suspended in a balloon gondola were shown a simulated flight projected around them with overlapping motion picture projections made with similarly oriented flown cameras. The 1964 New York World's Fair included a dome projection film, made by Graphic Films in Los Angeles, *To The Moon and Beyond*. This film greatly impressed Stanley Kubrick during the conceptual stages of *2001-A Space Odyssey*.

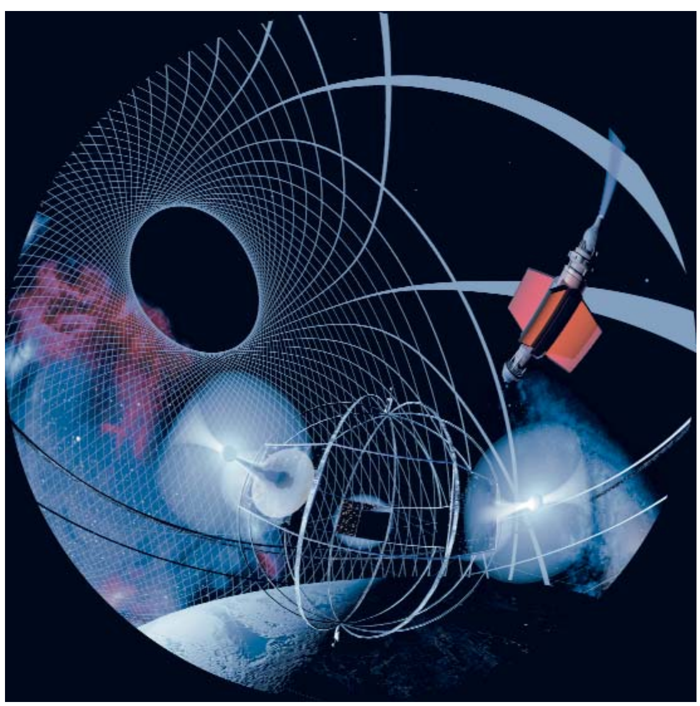
The planetarium and film were first combined in quantity by O. Richard Norton, who in the late 1960s carried 35mm film cameras with fisheye lenses on cars winding through city overpasses, perched on desert cliffs, and on white-water rafting trips. The resulting projections were enthralling, an intriguing Camera Obscura-like preview of the possibilities awaiting fulldome projection. Since then a very few 70mm Omnimax dome projection films were made (in true fisheye format); however the expense of large format film caused that medium to figuratively collapse of its own weight. Some 35mm fisheye productions for projection in planetarium domes continued, improved from earlier attempts but clearly pushing the capabilities of that medium to its limits (one intriguing 35mm fisheye film, *Space Shuttle, an American Adventure* has apparently suffered the fate of the original negatives being lost, although quality duplicate material apparently survives).

Film production, particularly in 70mm, is beyond the reach of all but the richest of institutions. Until the advances in affordable computer technology and video projection converged in the late 1990s, the ability to fill the dome with quality moving images was largely a dream. Production values in computer animation comparable to professional standards have now become affordable to most institutions and individuals.

Changing Skill Sets

This growing opportunity for larger facilities to present to audiences visualizations of ongoing research should be a powerful incentive to utilize fulldome media to its fullest. There should be, in any science-oriented academy or institution with a fulldome facility, people eager to share the enthusiasm of their chosen subject and willing to interact with people in a visualization team. In my PBS production experience there was a system of integrating the information to be presented with the activities of the production staff. The writer of a given episode of a show, usually with a science background, would bring still and video reference materials to the effects facility and make sure the ideas to be demonstrated were understood, periodically checking the progress and reviewing preliminary material. I see small visual effects houses as a good model of the production environment for fulldome animation, although because of the computer graphic nature of the imagery the work space no longer needs to be large enough for significant model photography.

I suggest that one potential



Megastructures near a planet within a Dyson sphere, from the Evans & Sutherland show *Cosmic Safari*, ©Evans & Sutherland.

As fulldome media progresses it should not be allowed to turn into another IMAX in its dominance of "grand but bland" content. ... Let that not be the fate of fulldome theaters.

area of attention concerning the growth of fulldome media is outdated concepts of the kind of professional backgrounds best suited to commanding such an unspecialized visual environment. Once you have a projection system that is not specific to astronomy it becomes more of a "blank canvas" for visual possibilities and inherently less of simply being a teaching device for any one field. If a given facility capable of ground-breaking production does no more than pretend to be a traditional planetarium, it seems wasteful of the possibilities. Surely among the necessary and inspirational roles of the traditional planetarium, other areas of exploration of this open ended visual environment warrant attention.

The director of a fulldome facility should be open-minded to running a theater as well as a classroom. I believe a director actually involved in production need not be hired solely on academic credentials such as are routinely listed in job descriptions. A planetarium director in larger facilities was traditionally at or near the helm of the show production process, and of course was well-educated in the relevant aspects of the phenomena to be simulated. In recent decades some facilities now divide the duties involved in running things, with an administrative director working with a creative director who actually creates the shows. Whoever actually determines what is shown in the dome can either act as a facilitator or a bottleneck for production-capable facilities, depending on how the potentials versus the possibilities are matched.

If paying audiences are sought, they must be shown things which will generate significant word-of-mouth publicity. A creative director is more likely to succeed in the role of creating such visualizations if they came from a production environment, acquiring relevant knowledge in the process of the job than when an academically-based individual attempts to learn the arts of visual effects and movie directing. Providing paying audiences with an experience they will recommend to others requires a very intensive effort to create visual experiences backed by all the expertise applicable to this medium.

Fulldome Production Issues

IMAX productions can be regarded as both a historical parallel with the visual environment provided by dome projection and as a warning. As fulldome media progresses it should not be allowed to turn into another IMAX in its dominance of "grand but bland" content. The sheer expense of shooting large format film made experimentation prohibitive. Many fine helicopter shots of terrain are shown, but most such films are generally dull narrated travelogues, as if the medium is simply too costly to take any chances with. Let that not be the fate of fulldome theaters. The fairly limited selection of IMAX films and the near impossibility of creating films on specific topics often resulted in large-format movies drawing audiences in science centers due to the unique visual experience they provide and not necessarily the quality of their storytelling or relevance to topics dear to facility directors. Fulldome digital media is changing the trend of "ready-made" content being antithetical to teaching and telling stories of ones choice. As more material becomes available and more facilities choose to pursue even limited content creation, the many shows in circulation will serve as a kind of "stock footage: pool for many of the more modest fulldome theaters with solely "playback" capability.

Fulldome is at present primarily a computer graphic medium. The technological challenge for designing a camera for this medium will be to capture a 4000 pixel diameter circular image format with near lossless compression at 30 frames per second. Such a camera must be able to image the Sun in the daytime sky all day without damage to the pickup device. I worry that the first fulldome cameras will be so dear that years may pass before sufficient experimentation allows the defining the new "film grammar" of immersive video. Live capture of real environments, with time lapse capability, will probably dominate the early use of such cameras. The horrors of managing in a fisheye environment scenic lighting, model setups, camera crane movements, and other considerations routinely managed in traditional cinematography promise some intriguing times ahead for future fisheye filmmakers.

Facilitating the bringing together of equipment and the filmmakers is of overriding importance for the development of this art form. As this new visual medium emerges, more and more content producers will be attracted as the growing number of theaters provides a distribution network for new works. There should be some kind of accommodation of independent animators agreed to by facilities who see the mutual benefit of attracting and providing varied fulldome content, such as percentages of the "box office" being paid to independent animation producers when their works are shown. Animated "shorts" could be a great asset to the available programming of a domed theater, reminiscent of the cartoons once routinely shown in movie theaters between features. Once experimentation has reached a certain level, the kinds of visual experiences available will overlap with and perhaps revive the audience appeal once generated by laser shows, which were quite crude compared to what can be done with immersive abstractions even now. The idea is to promote a variety of appropriate material to attract and bring back audiences treated to unique immersive experiences.

In considering the options for fulldome presentation, the visual impression made on the audience is greatly affected by the orientation of the "center of attention." Traditional horizontal dome planetaria were designed to simulate a night sky and little else, with scenery projected along the bottom of the already elevated "horizon line." This generally created a "view from an open pit" appearance to the overall view, although the quality of such projected environments could be otherwise quite high. Duplication of projected images was one way of allowing

Apollo 14 site region. © **Don Davis.**

the entire audience to see slides of specific subjects mentioned in the narration.

Immersive video in horizontal (non-tilted) domes is cursed by the need to "squeeze" the view to bring the surrounding horizon above the "cove line" to simulate the types of landscapes done in traditional planetaria with multiple slide projections. This results in objects of known shape such as planets being squashed on the vertical axis. Trying to compose scenes for a horizontal dome theater with concentric seating is an awkward task. In a show at the American Museum of Natural History, slowly spinning the entire view on the vertical axis was used to share scenes with different portions of the audience under their horizontal dome, but this cannot be comfortably relied upon for an entire show. Extra effort must also be made to provide comfortable neck rests on the seats if the zenith of the dome is to be made the center of the audience attention. The varieties of presentations possible are compromised when attempting to wed a fulldome theater with a traditional "flat" dome planetarium, especially one including a traditional electro-mechanical projector.

I believe tilted domes allow the best use of a hemispherical visual environment, with a tilt angle of 22.5 degrees being my preference. I create practically all of my animations, a significant portion of those now available, with this orientation, using 1/16 slice of the hemisphere to display the scenery below the horizon. Greater tilts can show more scenery below the viewer, but require more extreme theater design. Significantly lesser tilts tend to minimize the advantages of this design. Tilted domes allow a true eye-level horizon to be simulated and experienced by at least some of the audience, which does away with a level of "suspension of disbelief" traditionally imposed on audiences of horizontal domed presentations noted above. Seating which faces the lowest point of a tilted dome allows everyone to face a common center of attention for appropriate presentations, while allowing an immersive environment to be experienced without having to look up at the zenith. For cinematic approaches the usefulness of some type of "frame" within which to compose shots is an important device to have available, even as wide a frame as a tilted hemispheric view.

Pre-Rendered Versus Real-Time

Although fulldome content is and will likely continue to be primarily a medium for showing "pre-rendered" programming, the sophistication of real-time presentations will continue to grow. Real-time shows in fulldome theaters wave the banner of spontaneity; however they also shoulder the burden of operator and software-related idiosyncrasies absent from a refined pre-rendered production. Because of the need to simplify rendered scenes for real time use, their apparent visual quality tends to lag several years behind that of pre-rendered shows. In relatively simple graphics such as starfields, there is little difference between pre-rendered and real-time. In scenery and architecture-intensive shots, the complexity and detail of the simulated environments result in more apparent visual compromises. Pre-rendered material can use all the cinematic methods of carefully-crafted dramatic moves within detailed scenery, but with no excuses to offer for less-than-professional results.

The viewing experiences of participants and passive audiences tend to be divided in real-time shows. The person using the joystick acts as one using a flight simulator, while the rest of the audience sees a real-time quality animated experience with awkward camera moves. Finding a useful way for more than one audience member at a time to interact with a show is a challenging task.

Where real-time presentations truly excel is in presenting data such as models of the local universe which can be flown through and related to the skies as seen from Earth. Audience reactions and individual requests can be accommodated, and no two shows are quite alike. Here the abilities of the presenter become an important aspect of the show once again, a potential strength that small planetaria have enjoyed to this day. As datasets in the Earth sciences, biology, and other sciences suited to visual presentation are prepared, the opportunities to present the developing knowledge in these fields will multiply.

The Future

The range of subjects which will fill domes will soon transcend those traditionally emphasized in domed theaters run as astronomy classrooms. Astronomy will be but one floating scrap in a flood of visual instruction and entertainment to come. As fulldome media comes of age directors will arise, working out ways to tell stories suited to the possibilities of the medium. It is my hope that the development of domed theaters will be seen as a worthy medium for dramatic and esthetic presentation by the heads of such facilities as well as by "filmmakers" and, of course, paying audiences. ☆

Digital Frontiers

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The planetarium profession is changing forever. The shift to digital image generation and projection is sweeping the world's planetariums, both large and small. Some planetariums will make the digital conversion sooner, some later, but it is clear that in time optomechanical astronomical simulators will eventually go the way of the Model T Ford. The issue is no longer whether digital technologies are appropriate for planetariums, but rather how and when they should they be applied, what are the long-term implications, and how we can proactively work together to make the digital transition as seamless as possible.

In order to take proactive control of our future as planetarians, we need to assess where we are and where we are going with the new digital technologies. This special issue on Digital Domes and the Future of Planetariums is intended to spark dialog, debate, introspection – and hopefully, clarification of the issues for readers. It is time to examine some of the more subtle issues, such as changes in maintenance and funding paradigms, changes in required staff and skill sets, new educational and show production capabilities and workflow demands, new opportunities for collaboration, and the resulting impacts on our profession, both near-term and distant future.

No one person has all the answers, of course. It is through listening to many voices from diverse quarters that clarity emerges. With eyes wide open, we will be in the best position to take the future into our hands and move forward proactively with a clear vision for the future of the planetarium. I therefore invite the reader to listen to the voices in this issue, and consider with an open mind what positive directions we might set our sights on as a profession, and how you can individually contribute to shaping this future.

Our first article by Ka Chun Yu, Curator of Space Science at the Denver Museum of Nature and Science, draws parallels between digital domes and virtual environments. He also reviews how 3D astronomy teaching can help alleviate common misconceptions regarding fundamental astronomical concepts. Next Jim Sweitzer, principal of Science Communications Consultants and former Director of Special Projects for the new Rose Center for Earth and Space Science in New York City during the Hayden Planetarium digital upgrade, discusses his insights into the care and feeding of digital domes. Ryan Wyatt, Science Visualizer at the American Museum of Natural History's Rose Center, expresses his passion for the fulldome medium and offers his insights into immersive show production. Finally, astronomical artist Don Davis gives us a fulldome artist's view of the profession.

We will continue to explore the topic in the next issue of the *Planetarian* with another round of invited papers. If you are interested in submitting a paper for the next issue feel free to contact me with an abstract, or contact the editor John Mosley at any time. I also encourage you to respond to Steve Tidey's Forum topic in this issue.

There are many ways to get involved in the digital planetarium revolution. A good start is to join the online forum at http://fulldome.org and the yahoo fulldome email list at http://groups.yahoo.com/group/fulldome. If you are interested in becoming active professionally, we are continuing to accept members in the IPS Full-Dome Video Committee. Our first goal is to establish a standards document for the dome master format for show transfer. This is clearly the "low-lying fruit" of standards formation. From here we will move on to more challenging tasks, such as adopting a standard nomenclature (i.e. are next-generation planetariums digital all-domes, fulldome theaters, digital planetariums or immersive visualization environments?), developing standards for display measurement, and authoring guidelines for fulldome theater design and show production.

Many of us feel that fulldome standards development is important for IPS, as it firmly establishes digital dome theaters as a legitimate medium, provides common ground for communications and content exchange, and encourages third party providers of content and equipment to enter our field rather than "re-inventing" fulldome technology and independently branding it as something else. Standards and guidelines also provide the individual institution with the backing of the entire profession when seeking funding for upgrades or original programming, or when insisting on certain theater design features. In short, they provides IPS members with a measure of control in our digital future by establishing ourselves as an authority in fulldome technologies and by gently guiding the design and application of this emerging medium.

This summer the Fulldome Standards Subcommittee will be holding international meetings to recruit members and to begin development of standards. Stay tuned to fulldome.org for a meeting near you – or provide your inputs online when the draft documents are posted for public review.

Thanks again to our special issue authors for taking the time to share their vision and experience.

For more information on standardization procedures, check out the following two links: American National Standards Institute: http://www.ansi.org and Institute of Electrical and Electronics Engineers standards process: http://standards.ieee.org/guides. ☆

(**IPS 2006**, continued from page 26)

that we can make this a conference to remember. The IPS 2006 website at www.ips2006.com is filled with information relevant to the conference. You can download our Registration and Call for Papers brochure. Further information about the Planetarium Showcase and other Sponsorship and Exhibition opportunities can be found in our Sponsorship & Exhibitor Prospectus, which can also be downloaded from the website. The website includes information about our special events – the Night Sky Tour and the keynote speakers – as well as more general information about visiting Melbourne, including travel and visa arrangements, local weather, time zones, and currency information. Do not hesitate to contact us should you have any questions; we are here to support your participation in every way. We look forward to seeing you at IPS 2006! ☆