

# A Survey of Large-Scale Immersive Displays

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## Abstract

Immersive displays generally fall within three categories: small-scale, single-user displays (head-mounted displays and desktop stereoscopic displays); medium-scale displays designed for small numbers of collaborative users (CAVEs, reality centres and power walls); and large-scale displays designed for group immersion experiences (IMAX, simulator rides, domes). Small- and medium-scale displays have received by far the most attention from researchers, perhaps due to their smaller size, lower cost and easy accessibility. Large-scale immersive displays present unique technical challenges largely met by niche manufacturers offering proprietary solutions. The rapidly growing number of large-scale displays in planetariums, science centers and universities worldwide (275 theaters to date), coupled with recent trends towards more open, extensible systems and mature software tools, offer greater accessibility to these environments for research, interactive science/art application development, and visualization of complex databases for both student and public audiences. An industry-wide survey of leading-edge large-scale immersive displays and manufacturers is provided with the goal of fostering industry/academic collaborations. Research needs include advancements in immersive display design, real-time spherical rendering, real-time group interactive technologies and applications, and methods for aggregating and navigating extremely large scientific databases with imbedded physical/astrophysical simulations.

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## 1 Introduction to Digital Domes

Immersive displays can be broken into three general categories. Small-scale, single-user displays include head-mounted displays, desktop stereo displays, and small personal projection domes. Medium-scale displays provide multi-user collaboration [Traill 1997], and include rectilinear immersive displays [Cruz-Neira et al. 1993], curved screen displays [Jo et al. 2006], and multi-channel “mega walls” [Li 2004], all accommodating a small number of collaborative users. Large-scale immersive displays employ wide field-of-view screens such as domes to provide a high sense of immersion for a dozen up to many hundreds of viewers – essentially, VR for a mass audience [Lantz 1997]. Wrap-around cylindrical or dome screens are preferred over rectilinear immersive screens in cinematic applications as they provide a more seamless

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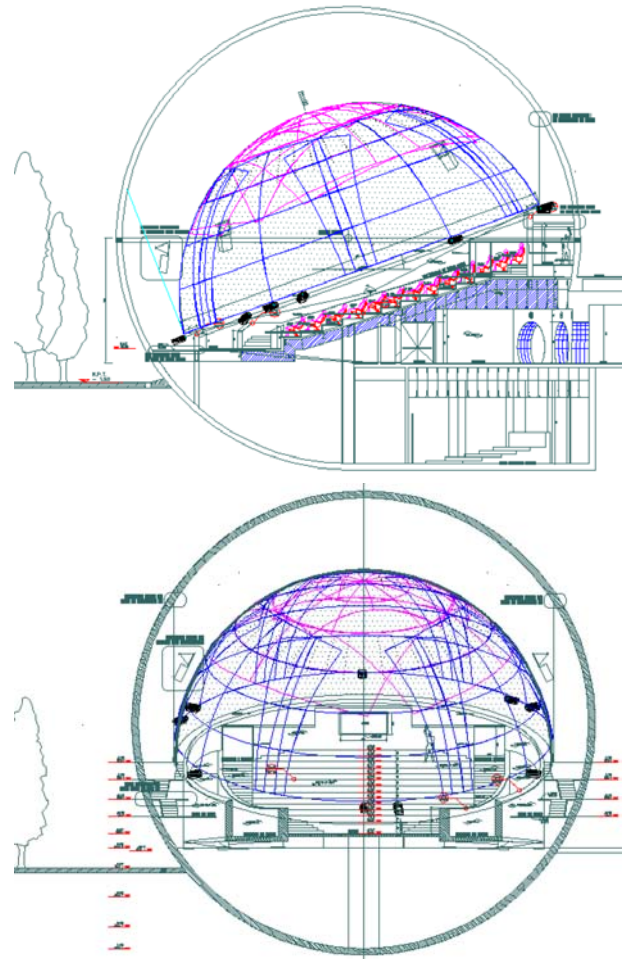


Figure 1: Papatote Museo del Nino’s 23 meter dome display with 9 edge-blended Barco Galaxy DLP projectors (Courtesy Barco and Spitz, Inc.).

appearance over a greater range of viewing angles and conditions [Lantz 1998].

While originally the domain of CINERAMA, IMAX, OMNIMAX (now IMAX Dome) and other large-format film variants, innovations in digital projection over the past decade have fueled an explosion of large-scale digital theaters, commonly referred to as “digital dome” or “fulldome” theaters. Large-scale raster video display technology originated in training simulator systems [Fisher 1987 and Reno 1989], later migrating into planetariums in the mid-1990’s [Lantz 1995; Lantz 2002; Scott and McColman 1999]. Digital domes are now found in venues including theme parks, planetariums and science centers [Lantz 1998; Ratcliffe 2001; Wyatt 2005; Yu 2005], universities [SEOS 2007a], corporate tradeshow and other special venues. The displays host a range of applications including linear playback of immersive cinema productions [Davis 2005], real-time simulation of

virtual environments [Emmart 2005], live art performance [Yu 2007b] and audience interactive applications [Chiwiy 2000].

A typical fulldome theater design with tilted dome and stadium seating deck is shown in Figure 1. Modern theaters utilize LED cove and dome lighting and (minimally) 5.1 surround sound. A greater number of audio channels are common – systems have been designed with up to 23.1 channels of surround sound.

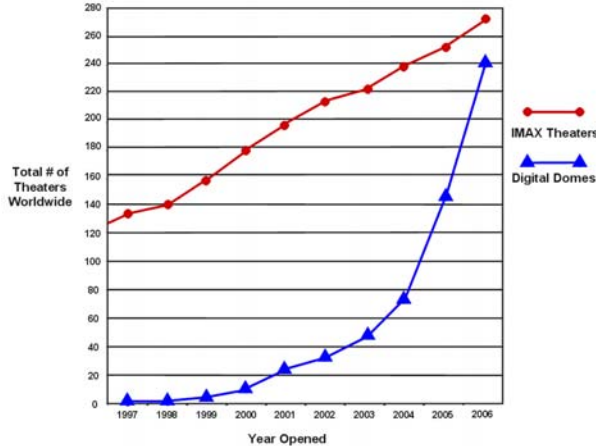


Table 1: Digital domes vs. IMAX theaters [Lantz 2007].

As shown in Table 1, the worldwide number of digital dome theaters is rapidly growing and will soon overcome the total number of IMAX branded theaters. Domes also far outnumber other competing formats such as wrap-around “Ridefilm” screens and cylindrical designs – many of which are film-based. Domes will therefore be the primary focus of this survey.

An NSF-sponsored website is dedicated to tracking the world’s fulldome theaters, ranging from small 3m diameter digital domes up to the largest 25-27m domes [Lochness 2007]. The rapid growth of fulldome theaters is in part due to the retrofitting of analog planetariums with digital projection systems. There are over 3,000 planetariums worldwide serving over 100 million visitors annually.

Fulldome facilities are generally either dedicated educational institutions including digital planetariums and visualization centers (i.e.classrooms), or are theaters open to the public that charge a fee for admission (public theaters). The distinction is an important one, as public theaters must offer a compelling cinematic experience that competes favorably with other leisure attractions, requiring a greater emphasis on image, sound fidelity, and viewer engagement. Researchers believe that these immersive environments provide greater spatial context than flat-screen displays, and may enhance learning in ways not possible via other pedagogical methods [Yu 2005].

Unlike small- and medium-scale displays, the development of large-scale immersive displays has been driven largely by commercial interests that are heavily invested in proprietary technologies. Non-proprietary “do it yourself” digital dome solutions are rare, perhaps because of the large system costs and the perceived need to minimize risks. One notable exception is the spherical mirror system developed by Paul Bourke while at Swinburne University [Bourke 2005]. Nearly

all other solutions utilize proprietary projection lenses, edge-blending hardware or software, or other custom solutions.

The proprietary nature of these displays, coupled with their high cost and large space requirements, have served to limit their accessibility by the research community. At the same time, large-scale immersive displays have presented unique challenges that could clearly benefit from collaborative research. Such challenges include optimization of image brightness and resolution, spherical multi-projector edge-blending techniques, real-time spherical mapping, spherical stereoscopic display, scalable database visualization, and standards development.

Interestingly, many of these challenges are increasingly met using standard commodity hardware and software solutions (Windows or Linux clusters, NVIDIA or ATI graphics cards, off-the-shelf video projectors) with proprietary components or “middleware” provided by value-added integrators (custom lenses and proprietary graphics software engines). This maturation of digital dome display platforms and greater reliance on commodity solutions has opened the door for greater 3<sup>rd</sup> party participation, particularly on the interactive application side.

## 2 Digital Dome Displays

Eye-limited resolution on a hemisphere requires over 100 million pixels. This currently lies beyond practical limits for all but the highest-end displays, typically single-user systems for tactical military aircraft training such as SEOS’s Griffin, a multi-projector edge-blended display with a rear-projected dome screen [Blackham and Berwick 2000]. In practice, hemispheric systems with less than million pixels can be used as an effective teaching tool in educational theaters. Cinematic quality imagery generally requires at least 6-8 million pixels and >1 ft-L, although systems with as few as 2 million active pixels and 0.2 ft-L are in use in public theaters.

A survey of fulldome systems currently in use is presented in Table 2. Display designs are listed in ascending resolution as measured in pixels-per-degree [Lantz 2004]. Systems include single-lens fisheye projectors (including LCD, LCoS and DLP versions), dual-projector fisheyes (with a single edge-blend), stereoscopic systems, and multi-projector edge-blended designs. Projectors are mounted either in the center of the dome or along the cove at the dome perimeter. Integrators for these systems are listed in Section 5.

Many existing large-scale immersive display systems still rely on CRT projection. CRT projectors have superior contrast, and many planetarium applications can survive the low brightness levels of CRT projectors. Planetariums utilizing optomechanical star projectors require full dark adaptation of the eye to fully resolve the starfield, and the addition of a low-contrast video system tends to wash out the starfield display. Ultra-high contrast projectors such as the Zeiss ADLIP [Zeiss 2007] with 30,000:1 sequential contrast (sequential contrast is the brightness ratio of full white to full black), the new SEOS Zorro with 500,000:1 seq. contrast [SEOS 2007b], JVC’s new LCoS projector with 15,000:1 seq. contrast [JVC 2007], or even several of the new high-contrast DLP projectors promise to replace CRT projectors entirely, even in the most demanding dark-theater applications.

Educational domes, portable planetariums and non-cinematic

Table 2: Survey of large-scale dome video displays [Survey 2007].

System	Image Resolution					Image Brightness		Contrast (seq.)	System Integrators/Manufacturers
	# of Projectors /Channels	Projector Resolution	Pixels per degree	# Pixels on Dome	Min. Dome Master Size	Lumens Per Projector	Est. Total Lumens on Dome		
Ultra-Portable Fisheye (hemispheric)	1/1	1024x768	4.3	0.46M	768x768	2500+	1950	>900:1	Digitalis, Elumenati, Sky-Skan
Ultra-Portable Fisheye (truncated hemisphere)	1/1	1024x768	5.7	0.66M	1024x1024 (truncated)	2500+	2100	>900:1	Elumenati, e-Planetarium, Sky-Skan
Small Format Mirror XGA, SXGA+	1/1	1024x768 1400x1050	≈5-6 ≈6-8	0.75M 1.4M	1024x768 1400x1050	2500 3300	≈1900 ≈2500	2100:1 2500:1	CosmoDome, e-Planetarium, [Bourke 2005]
Fisheye SXGA (hemispheric)	1/1	1280x1024	5.7	0.77M	1024x1024	2500+	1570+	>1000:1	E&S/Spitz, Learning Tech., Minolta, Sky-Skan., Elumenati
Fisheye SXGA+ (truncated hemisphere)	1/1	1400x1050	7.8	1.2M	1400x1400 (truncated)	6500+ (up to 20k)	5450 (up to 16.8k)	>1500:1	Elumenati, E&S/Spitz, Sky-Skan
Fisheye Stereoscopic SXGA+ (truncated)	1/2 (stereo)	1400x1050	7.8	1.2M	1400x1400 (truncated)	8000	1280 (active stereo)	>1500:1	Elumenati
Dual-Projector Fisheye (SXGA+)	2/2	1400x1050	7.8	1.5M	1400x1400	2000 6500+	2600 6800+	>1500:1	E&S/Spitz, GOTO, RSA Cosmos Sky-Skan,
Fisheye QXGA	1/1	2048x1536	8.5	1.9M	1536x1536	7000	4100	1000:1	E&S/Spitz, Minolta
Dual-Projector Fisheye (1080p)	2/2	1920x1080	10.3	2.7M	1860x1860	3,500	4600	>1500:1	E&S Spitz, GOTO
5-Projector DLP (XGA+)	5/5	1280x720	10.5	2.8M	1890x1890	400	1200	1500:1	Zeiss
Fisheye 1080p (truncated)	1/1	1920x1080	10.7	1.7M	1920x1920 (truncated)	12,000	9700	1000:1	Elumenati
5-Projector DLP (SXGA+)	5/5	1400x1050	12.4	3.9M	2240x2240	2500	6700	2500:1	RSA Cosmos
6-Projector DLP (SXGA+)	6/6	1280x1024 1400x1050	16	6.5M	2880x2880	6500+	29,250	>1800:1	Barco, E&S/Spitz, GOTO, RSA Cosmos, SEOS, Sky-Skan
6-Projector Stereoscopic DLP (SXGA+)	12/12	1400x1050	16	6.5M	2880x2880	6500+	12,600 (Infitek™)	>1800:1	SEOS
9-Projector DLP	9/9	1280x1024	17.1	7.4M	3070x3070	5000	27,000	1000:1	Barco & E&S/Spitz
8-Projector DLP (SXGA+)	6/6	1400x1050	18.7	8.9M	3360x3360	2500	15,000	2500:1	RSA Cosmos
6-Projector 9" CRT SXGA, UXGA	6/6	1280x1024 1600x1200	16 19	6.5M 9.2M	2880x2880 3420x3420	280	1260	10 <sup>6</sup> :1	Barco, E&S/Spitz, GOTO, RSA Cosmos, SEOS, Sky-Skan
Dual 6-Projector 9" CRT	12/12	1280x1024 1600x1200	16 19	6.5M 9.2M	2880x2880 3420x3420	280	2520	10 <sup>6</sup> :1	E&S/Spitz, Sky-Skan, RSA Cosmos
6-Projector Scanned Laser	6/6	1600x1200	19	9.2M	3420x3420	3000	13,500	30,000:1	RSA Cosmos, Zeiss
11-Projector DLP (SXGA)	11/11	1280x1024	19.9	10.1M	3580x3580	5000	38,500	1000:1	SEOS
Dual-Projector Fisheye (4K)	2/8	4096x2160	22.7	13M	4096x4096	10,000+	14,900+	1800:1	E&S/Spitz, GOTO, RSA Cosmos Sky-Skan, Zeiss
Dual-Projector Stereoscopic Fisheye (4K)	4/16	4096x2160	22.7	13M	4096x4096	10,000+	4500+ (Infitek™)	1800:1	Sky-Skan
Grating Light Valve Laser	1/8	5120x4096	25	16.5M	4096x4096	4000	4000	3300:1	E&S/Spitz, GOTO

applications gravitate towards less expensive and simpler single-lens fisheye projectors. Many of these systems are relatively portable and can be driven by a single laptop computer. A typical single-projector configuration is shown in Figure 2.

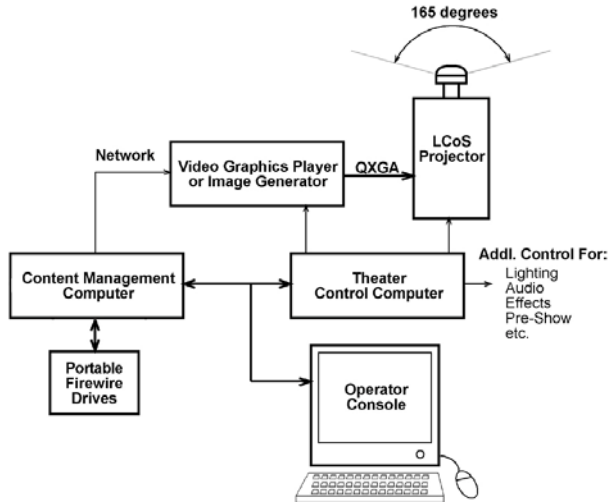


Figure 2: Typical single-projector fisheye configuration.

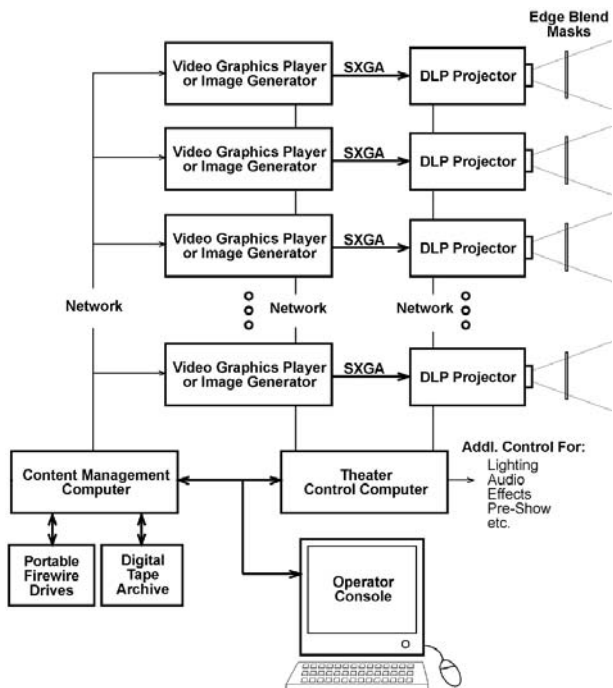
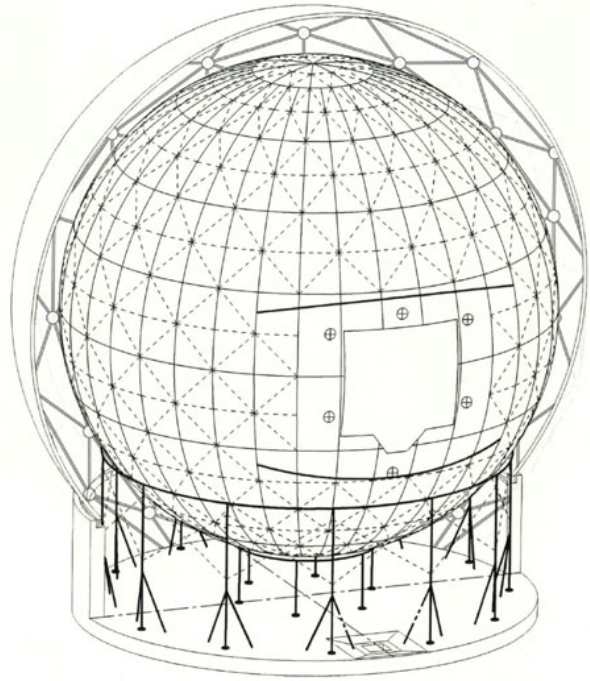


Figure 3: Typical multi-projector edge-blended configuration.

Multi-projector systems require more complex applications that run across PC clusters. Even relatively simple projection designs based around two Sony 4k SXRD projectors require 8 render pipelines to feed the 4096 x 4095 effective pixel display formed by edge-blending. Multi-projector systems must manage projector geometry for accurate overlay, color balancing between projector channels, and edge-blends for seamless blending between projectors. Display management may be handled entirely in the projectors, entirely in the image generator, or in dedicated outboard processors. Projector-based blending may be optical (using masks) or electrical

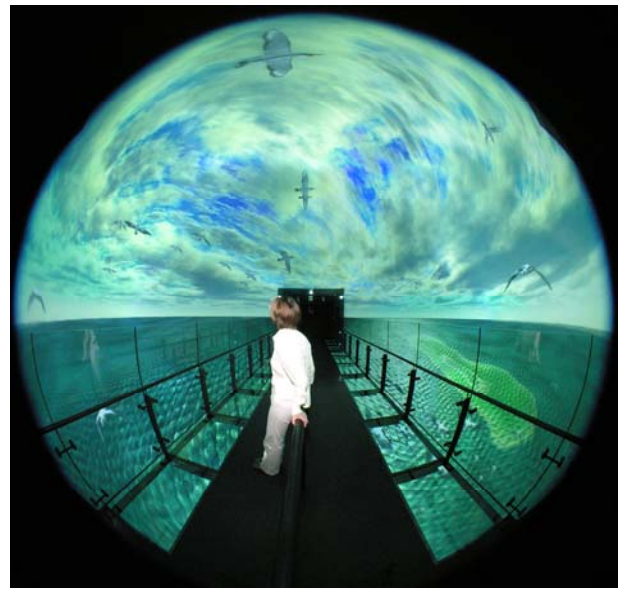


Figure 4: THEATER 360, a 12.8m, 360° spherical display at National Museum of Nature and Science, Japan (Courtesy GOTO, Inc.).

(applying blends to the video signal). A typical multi-projector configuration is shown in Figure 3.

While techniques for automated geometric mapping and edge-blending on a spherical surface have been demonstrated [van Baar 2003; Raskar 2004; Webb and Jaynes 2005], very few multi-channel displays utilizing automated calibration techniques have been demonstrated in large-scale domes.

In addition to the standard display configurations surveyed, several unique special-venue large-scale immersive displays have been demonstrated, including the full sphere walk-through display from GOTO, shown in Figure 4. The large-

format film industry also has a close eye on the emerging fulldome market [Lantz 2006; Harris 2006]. Imax Corporation recently announced a digital projection system based on two edge-blended 4k projectors for their flat-screen venues [Hyder 2007]. Obscura Digital, LM Productions and Absolute Hollywood all provide special-venue display designs

### 3 Immersive Programming

Developers of linear fulldome programming face challenges created by the immersive nature of the dome requiring a paradigm shift in narrative storytelling [Shedd 2003; Lantz 2003; Wyatt 2005]. Most fulldome programming is currently linear programming rendered in 3D. A small number of pioneering programs have utilized live-action cinematography [Yu 2007a]. However recent trends have been towards real-time applications, particularly for digital planetariums and live VJ art performances.

Integrators have developed real-time applications for managing astronomical, astrophysical, architectural and geospatial databases in real time. Dome-enabled versions of Starry Night [Spitz 2007] and the open source Stellarium [Stellarium 2007] are popular in educational planetariums. Multi-projector real-time graphics systems running on Windows or Linux PC clusters include DigitalSky 2 from Sky-Skan, Digistar 3 from E&S, and Uniview from SCISS AB. Interestingly, all three of these applications are compatible with Digital Universe Atlas, an astrophysical dataset collection curated by the American Museum of Natural History [Abbott 2007]. It has been suggested that a greater effort to create a “model of the known universe” be undertaken to provide an international database resource for all fulldome theaters.

Real-time 3D experiences in fulldome theaters are primarily navigated by experienced lecturers. Networked domes have been proposed for education and training purposes [Emmart 2005]. Group interactive paradigms are in use at a handful of facilities using audience responders [Ratcliffe 2001]. Loren and Rachel Carpenter’s CINEMATRIX photonic audience interaction system [Donoghue 1998] was successfully demonstrated in a dome theater, but has yet to gain traction at these institutions. Recent experiments with group gaming in domes have produced interesting results [Comley et al. 2004]. It is hoped that researchers will gain a greater understanding of how to create effective group interactive paradigms for large-scale immersive spaces so that the tremendous power of these real-time virtual environments can be fully realized.

### 4 Digital Dome Integrators

A listing of digital dome integrators and manufacturers appearing in Table 2 is provided below:

**Absolute Hollywood**, Tel: + 1.443.341.6424, Email: events@absolutehollywood.com

**Immersive Display Products:** Large inflatable dome screens, projection systems.

**Astro-Tec Manufacturing, Inc.** 550 Elm Ridge Avenue, P.O. Box 608, Canal Fulton, Ohio 44614-0608. Tel: (330)854-2209, Fax: (330)854-5376, Email: shopper@astro-tec.com, Web: www.astro-tec.com.

**Immersive Display Products:** Aluminum and fiberglass dome screens.

**CosmoDome**, 12 Larter Court, Hoppers Crossing, VIC 3029 Australia, Email: journeyman@labyrinth.net.au, Tel: (03) 9748 8326 Fax: (03) 9749 593.

**Immersive Display Products:** Portable and fixed fulldome displays, digital planetarium software and inflatable domes.

**Digitalis Education Solutions, Inc.**, P.O. Box 2976, Bremerton, WA 98310 USA, Tel: +1.360.616.8915, Fax: +1.360.616.8917

Email: info@digitaliseducation.com

Web: www.digitaliseducation.com

**Immersive Display Products:** Portable and fixed educational fulldome systems, inflatable domes, digital planetarium software.

**e-Planetarium**, P.O. Box 235, Methuen, MA 01844 USA

Tel: (978) 662-3099, Fax: (978) 662-3241

Email: contact@e-planetarium.com

**Immersive Display Products:** Portable and fixed fulldome displays, digital planetarium software and inflatable domes.

**E&S Computer Corporation**, 770 Komas Drive, Salt Lake City, UT 84108 USA, Tel: +1 801-588-1000, Fax: +1 801-588-4500 Web: www.es.com

**Immersive Display Products:** A variety of fulldome display systems, extensible multi-pipe real-time graphics generation and playback engine, spherical compositing plug-in for After Effects.

**Goto Inc.**, 4-16 Yazakicho, Fuchu-shi, Tokyo 183-8530, JAPAN

Tel: +81-42-362-5312, Fax: +81-42-362-9571

Email: info2@goto.co.jp, Web: www.goto.co.jp

Ken Miller, GOTO USA Inc., +1-888-847-5800,

Email: gotousa@earthlink.net

**Immersive Display Products:** Fulldome displays, real-time multi-pipe digital planetarium hardware

**Konica Minolta Photo Imaging USA, Inc.**, Planetarium Division,

725 Darlington Avenue, Mahwah NJ, 07430 USA

Tel: +1-201-574-4111, Fax: +1-201-574-4144, Email:

stanaka@ph.konicaminolta.us, Web: www.konicaminolta.us

**Immersive Display Products:** Fulldome displays, real-time digital planetarium software and hardware.

**LM Productions, LLP**, Unit 6H Southbourne Business Park, Courtlands Road, Eastbourne, East Sussex, BN22 8UY, UK Tel: +44 (0)1323 432170, Fax: +44 (0)1323 432171

**Immersive Display Products:** Portable fulldome displays and screens.

**Obscura Digital**, 460 Bryant St., San Francisco, CA 94107 USA

Tel: 415.227.9979, Fax: 415.227.9494

Web: www.obscuradigital.com

**Immersive Display Products:** Single and multi-projector dome displays and playback systems, portable domes.

**R. S. A. Cosmos**, Rue des Mineurs, ZI de la Vaure, B.P. 40, F-42290

Tel: +33 4 77 533 048, Fax: +33 4 77 533 861

Email: sales@rsacosmos.com, www.rsacosmos.com

**Immersive Display Products:** A variety of fulldome display systems, real-time and 3D Max digital planetarium software, spherical image slicing and stitching software, portable and fixed dome screens.

**Sciss AB**, 60186 Norrköping, Sweden, Tel: +46-8-55924619

Email: sales@sciss.se

**Immersive Display Products:** Real-time image generation software for single and multi-pipeline immersive displays.

**SEOS Ltd.**, Edward Way, Burgess Hill, West Sussex RH15 9UE, UK, Tel: +44 (0)1444 870888, Fax: +44 (0)1444 870777

Email: info@seos.com, www.seos.com/planetarium

**Immersive Display Products:** Custom engineered immersive displays, real-time edge-blending and geometry correction hardware, multipipe render clusters, show playback software, display management systems.

**Sky-Skan, Inc.**, 51 Lake Street, Nashua, New Hampshire 03060 USA  
Phone: +1 603 880 8500, Fax: +1 603 882 6522

Email: office@skyskan.com, Web: www.skyskan.com

**Immersive Display Products:** A variety of fulldome display systems, extensible multi-pipe real-time graphics generation and playback engine, spherical compositing plug-in for After Effects.

**Spitz, Inc. (division of E&S)**, 700 Brandywine Drive, Chadds Ford, PA 19317 USA, Tel: +1.610.459.5200, Fax: +1.610.459.3830, Email: sales@spitzinc.com, Web: www.spitzinc.com

**Immersive Display Products:** Fulldome display systems, digital planetarium software, standard and custom dome projection screens.

**Starlight Productions, LLC**, 5951 S. Wahlquist Ln., Salt Lake City, UT 84123, USA, Tel: 801-545-4367, Fax: 801-545-4394

**Immersive Display Products:** Lightspeed 3D rendering software components to facilitate fulldome rendering.

**The Elumenati, LLC**, 27 Maple Place, Minneapolis, MN 55401 USA  
Tel: 1-888-384-3826, Fax: 1-612-605-0826,

Email: info@elumenati.com, Web: www.elumenati.com

**Immersive Display Products:** Single-lens fisheye projectors and related show playback software, real-time spherical OpenGL library, real-time performance software, Fulldome Plugin for After Effects, and a variety of inflatable domes.

**Carl Zeiss Jena GmbH, Jena**, Unternehmensbereich Optisch-Elektronische Module, Tel: +49 3641 64 2283, Fax: +49 3641 643023

Email: planetarium@zeiss.de, Web: www.zeiss.de/planetarien

Laura Misajet, North American Sales Manager

Tel: +1-215-694-0023, Email: zeissstars@aol.com

**Immersive Display Products:** A variety of fulldome display systems, scanning laser projector, multipipe render clusters, digital planetarium software, and related hardware and software.

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