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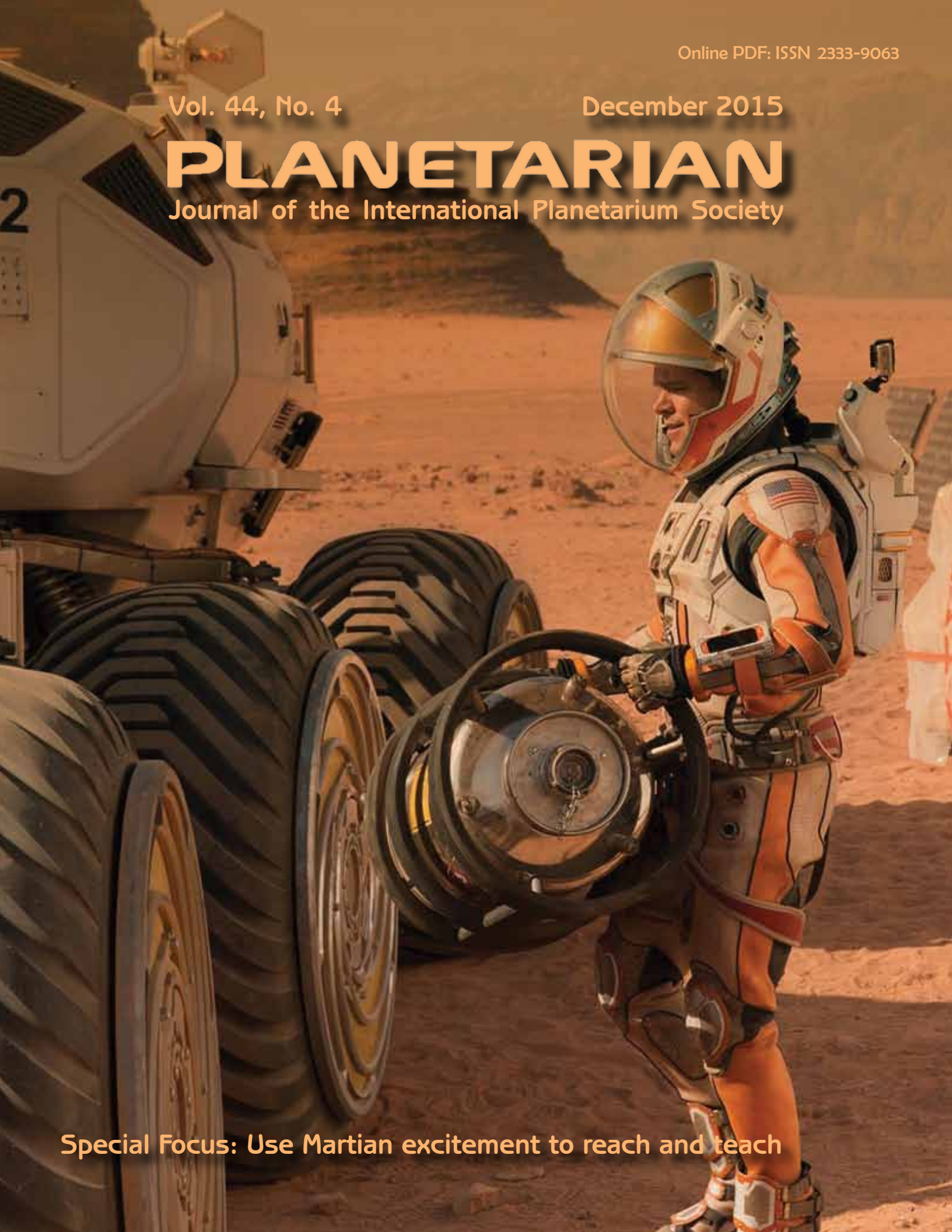

Special Focus: Use Martian excitement to reach and teach

National Museum of Natural Science, Taichung

Digital renovation of the Space Theater

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Abstract

The Space Theatre in the National Museum of Natural Science, Taichung was the first large planetarium in Taiwan. It was opened in 1986 with a GOTO opto-mechanical GSS-I star projector and an IMAX 15/70 film projector, along with some slide and special effect projectors.

Upon deciding to update the facility, the museum started its renovation with a single multi-purpose 8K Digistar 5 system in August 2014, with the renovation completed in June 2015. The new system provides us a more active and flexible way to present shows and brings visitors a dynamic and exciting experience of learning. In this article, I would like to share with all what we learned from the installation and operation of such a system.

Introduction

The Space Theatre was opened in 1986 as part of the first of five stages in the construction of National Museum of Natural Science (NMNS) in Taichung. It included an IMAX® 15/70 Omnimax film projector and a GOTO GSS-I opto-mechanical star projector. The diameter of the dome is 23 meters and there are 300 seats tilted 30 degrees.

The major function of the theater was to play 15/70 IMAX movies. The ticket box income of this theater provides more than 20%

Facing page, top: Thousands of people waiting in line at the first opening of Space Theater in 1986. (credit: Lee,Yuin-Long/NMNS).
Below: In 2015, the reopening of the theater attracted 25,268 visitors in the first 10 days. In July, the ticket box increased 12% more than the same period in 2014. Unless otherwise specified, all photos courtesy the National Museum of Natural Science.

of the budget of the whole museum. There are 7 regular IMAX shows through week and 9 on the weekends. Two films are on the show list by turns, and we usually change one of them every 6 months.

There is also a 40-minute planetarium show provided for free each week day. Additionally, there is always a short, 5- to 10-minute planetarium show given by the theater staff before each IMAX show. The IMAX shows are purposely selected to include educational and/or science promotional topics.

In the past 29 years, the theater has served over 13 million visitors, averaging 450,000 visitors per year. The number of annual attendances reached a peak of 659,364 in 1990 and has since fallen gradually to 253,358 in 2014. That trend is quite logical since the projectors, both the IMAX and GOTO, have gotten older as the years go by. Breakdowns have become more frequent in recent years.

Renovation planned for years.

During that period, the target of our new system changed from a hybrid of a new opto-mechanical starball plus a new Omnimax to a hybrid of a new opto-mechanical starball plus a digital film playing system, and finally to a multi-purpose, fully digital system, which can be used to play both planetarium shows and 4K movies.

In mid-2014, the museum was informed that we would receive a special budget for the renovation from the Ministry of Education, so we immediately started our purchasing process. The committees chose the 8K Digistar 5 system that uses six Sony SRX-T615 projectors provided by Evans and Sutherland along with their local partner, Dacoms, as our new system.

The new system was installed from 20 April to 9 June, 2015. As the installation was completed, a one-week test run and a two-week free opening to the public were performed to examine the new system. On 18 June, a press conference of the new system was held and received very positive responses from the visitors.

Finally, the theater was formally reopened on 1 July. In the summer vacation period that followed, the number of attendances increased about 12% than the same period in 2014.

In this article I will share with all the experiences we learned during the procedure of purchasing, installation and operation. Section 2 is devoted to how the specifications of new system was determined and why they were so decided. In section 3, I will describe the performance of the new system, some phenomena we observed and discussions on these phenomena will also be given there. In section 4, a brief conclusion will be given. We hope it is helpful to those who also have plans to renovate their planetariums with a digital system.

Determining the specifications

As described above, the museum has surveyed many years for a new system before the renovation. Since we planned to replace both the Omnimax projector and GSS-I starball at the same time, the target we considered at the beginning was a hybrid of a new opto-mechanical starball and a new Omnimax projector. However, IMAX stopped providing new Omnimax to their customers around early 2000s.

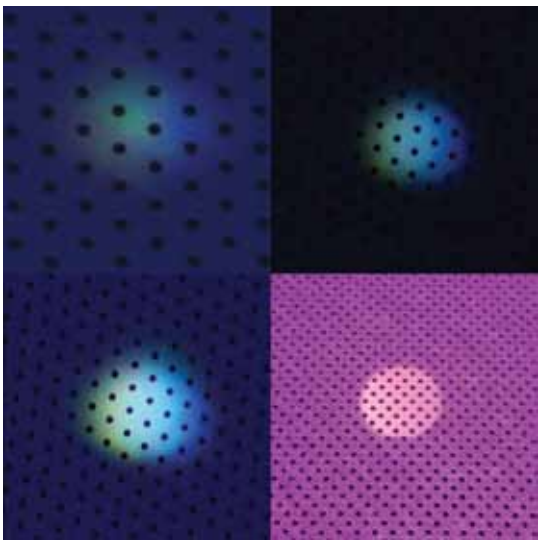
Thus we turned our target to the hybrid of a digital animation playing system plus a new opto-mechanical starball. However, we hesitated for several years since the performance of digital projectors was still much inferior to the Omnimax projector at that time. Besides, there were also some critical maintenance problems, like the blending and alignment among/between projectors for such multi-channel projection systems. These problems make the color and brightness of projected images not always uniform and homogeneous. Boundaries among/between areas projected by different projectors become obvious even in just few days after calibration.

Several years ago, technicians would have had to spend many hours to calibrate the system, since that work can only be done manually. Thus, it is very difficult to keep the theater always in a good condition. However, these problems have been solved in recent years with new auto-calibrating software provided by Digistar 5.

During the IPS 2014 conference held at Beijing Planetarium, two important new technologies were demonstrated. One was the new digital projector with a contrast ratio 12,000:1 and a brightness up to 18,000 lumen. The other was the Digistar 5 auto-calibrating software capability, including alignment and blending. These two technologies make a fully digital system become very attractive, with uniform and homogenized display on the dome.

Since the new projector provides high contrast ratio and high brightness at the same time. It is possible that the system could cover theoretically a 10.2-magnitudes range while the faintest stars can still be seen by human eyes. If one assumes the faintest stars can be seen by human eyes were magnitude +6.5, the brightest stars can be performed with one single pixel by the projector will be magnitude -3.7.

That means one can use one single pixel to demonstrate the brightness of almost all stars and planets in the sky. The only exception is Venus, which may reach the apparent magnitude −4.9 during crescent phase.

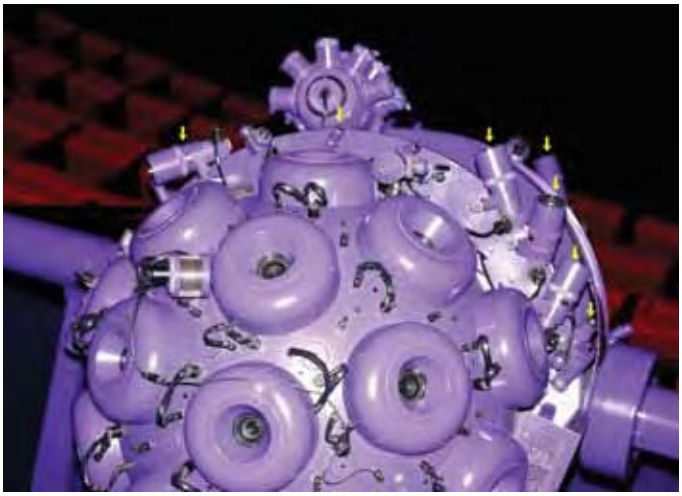


Upper left: The size of a magnitude +3 faint star which uses only one single pixel is less than 5mm when projected onto the screen. The size of the pinholes, the black dots, on the screen is 2mm. Upper right: The size of a magnitude +1 star. Lower left: The projected image of the brightest fixed star, Sirius. The size of its central bulge is about 18mm. Lower right: Star point of Betelgeuse projected onto the 25 meters dome in Taipei Astronomy Museum by their Zeiss Mark IV. Its diameter is about 15mm. But it is obviously much more compact and solid than the digitally projected ones.

Before the IPS 2014 conference, we had been informed that we probably would receive a special budget for the renovation from the Ministry of Education. One month after the conference, the budget was formally permitted and the theater was scheduled to reopen by 1 July, 2015.

Based on the experiences learned and discussions with experts in the IPS 2014 conference, the specification of the new system was soon determined as:

- A fully digital system that can be used for both playing 4Kx4K movies and planetarium shows.
- Resolution: ≥ 6.5Kx6.5K or 33 million effective pixels with 4K (≥3840x2160) projectors.



Bright stars were projected with extra "bright star projectors" rather than with the star plates so as to keep the stars compact and sharp.

- Contrast ratio: ≥ 10,000:1.
- Brightness: Totally, ≥ 70,000 lumens with multiple projectors or 3.0 ft-L measured on the screen.[1]

Time to decide on the new system

Committees, which included specialists from two other planetariums in Taiwan and staff of our museum, were assigned to make the decision on the new system. Three manufactures submitted their proposals in the final stage and, although it was not easy to determine which one is the best, the committees chose Evans & Sutherland and its local partner Dacoms as the winner. A major reason for this decision was their good after-installation service in several previous cases in Taiwan, in addition to their Digistar 5 software's auto-blending and auto-alignment capabilities.

The new system includes a Digistar 5, software, corresponding hardware, and six Sony SRX-T615 projectors with 108,000 lumens in brightness and 12,000:1 in the contrast ratio. There is no industry standard for defining 8K, and 8Kx8K resolution is just a theoretical value. The value measured in the theater will depend on the detailed allocation of the projectors. The real value we measured in the final test is about 7.2Kx7.2K. That's better than what we expected of the new system. The details of the performance test will be described in next section.

Performance measuring

The museum had sent staff to visit planetariums around the world to survey different systems in past years. However, brief visits for just several days are not enough for deep learning, as there are many things can only be learned at the scene of operation for a long period of time. During the first few months after reopening, we observed many interesting phenomena in the daily run of the new system and learned much from analyzing these phenomena.

During the test run of the new system we compared it with the old systems. We surprisingly found that its resolution looks better than our old 15/70 projector, which was usually claimed to be as good as 8K in resolution, especially at the edge of the screen.

However, we realized that this should not be strange at all. There are two major factors which make the digital system perform better than the 15/70 film projectors. One is the multi-channel composition,[2] which uses six wide-angle lenses instead of the single fisheye lens used by the 15/70 projector. The second is that digital projectors are free of mechanical vibrations which always occur when the film is running through the track.

The angle-of-view of lenses in a 6-projector system would be $1/\sqrt{6}$ or 40.8% of that of a fisheye lens. For example, if the AOV of a fisheye lens were 180 degrees, the AOV of lenses needed for a 6-channel system would be only 73.4 degrees. As it is well known to the optical engineers, the wider the AOV of a lens, the worse the resulting aberrations.

Regarding the problem caused by mechanical vibration of 15/70 film projectors: taking our theater as an example, any tiny vibration of the image was enlarged more than 500 times when projected onto the screen. Even though Kodak[3] says that the resolution of their 35mm negative (22 mm x 18.6 mm) is 6K horizontally, and IMAX claims the resolution of 15/70 format (70mm x 48.6mm) could potentially be as good as 18K,[4] these figures can be achieved only for still images. The mechanical vibration reduces the performance severely even for a new Omnimax, not to mention the 29-years old one in our theater.

While industry terminology refers to systems of our type as 8K, the value measured in our theater is about 7.2K, which is to be described in detail below. It is already better than our old Omnimax projector and even compatible to a new one. That is also one of the reasons we made the decision to renovate our theater in mid-2014.

Field examinations

Besides the theoretical discussions, we also made some field examinations in the theater to measure the real performance of the new system. Theoretically, one has a normal visual acuity, usually referred to as a 20/20 or 6/6 vision, if one can tell two points separated apart by an angle of one arc minute or 1/60 degrees. Thus, a perfect fulldome theater would have a resolution as good as 14.4Kx14.4K to cover a 180-degree hemisphere.

Taking our theater as an example, that means the size of each pixel should not exceed 2.5mm. In the ideal condition, the size of each single pixel projected by an 8Kx8K system should be as small as 4.8mm. The measured size of the central bulge of a faint star illuminated with one single pixel in our theater is about 5mm (see Fig.3). That means the real resolution of the system is about 7.2K. However, we saw faint halos around these points which would reduce the quality a little, but not too much.

For digital planetariums, a traditionally common cause of discontent is loose and puffy bright stars. In previous digital systems, one had to use many pixels to compose a bright star since the poor contrast ratio, say 2,500:1, of the projectors can cover only 8.7 magnitude. The brightest star can be projected with such a pixel is about magnitude -2.2 if one let its faintest level be at the magnitude +6.5. However, even large traditional opto-mechanical starballs do not project bright stars with the star plates. They usually use isolated "bright star projectors" (see Fig.4) to project these stars.

Theoretically, the 12,000:1 contrast ratio could cover a magnitude range of 10.2 or from magnitude +6.5 to -3.7. Aside from the sun and moon, which are not point stars to human eyes, Venus is the only body, including planets, which cannot be projected with one single pixel of this system. In our field test, the measured size of the brightest fixed star, Sirius, is about 18mm. That means DS-5 uses at least 9 pixels to compose the brightness of Sirius. Many of these pixels seem superfluous if one

1 The request of brightness was determined based on the standard of our old Omnimax projector.

2 The proto-type of Omnimax was a 9-projector film presented at EXPO '67 in Montreal. The syncing problem bothered the team very much and that's why they decided to invent the IMAX technologies. But, that would reduce the optical quality especially at the edge of the scene. More details of the story can be found at www.imax.com/about/history. However, since the syncing, alignment and blending among projectors are now no more problems, a multi-channel system becomes a better choice than the single fisheye lens projector nowaday.

3 motion.kodak.com/motion/Hub/nRodriguez.htm

4 www.slashfilm.com/film-interview-imax-executives-talk-the-hunger-games-catching-fire-and-imax-misconceptions

(Continues on page 54)

(Continued from page 48)

has such a high contrast ratio.

Additionally, our digital system now renders the starfield in real-time and we can save a preferred starfield look or adjust real-time parameters to provide a wide range of visual results not previously possible.

On the other hand, the diameter of Sirius projected onto our 25-m dome with the Zeiss Mark IV starball is estimated as about 15mm. It means that digital planetariums are now coming closer to the opto-mechanical planetariums.

Since the new system was supposed to replace both GSS-I starball and Omnimax projector, some items not very important for a planetarium become very critical for a film playing system.

At the beginning, we did not appreciate the real value of Digistar 5's auto-calibration functionality, though we saw it before, until the system was set up and tested in our own theater. During the first few days of the test run we noticed a problem of inhomogeneous blending which was caused by different decay rates between projectors, which is a common occurrence during the first 100 hours of using new lamps.

Providing the best

The museum expects to always provide visitors the best experience possible at our theater. So we decided to calibrate the system, mostly the blending work, every few days at the beginning, and about one month at a time since, as the lamps became stable. The auto-calibrating software enables us to finish such work within 15-30 minutes. Our staff can even run the calibration immediately at the end of daily shows if they see anything wrong during the shows. That is very helpful to keep our theater always in a good condition.

During the renovation, E&S and Dacoms helped us immensely. They demonstrated great efficiency in scheduling the installation. That enabled us to minimize the shut-down period for the renovation and allowed us to reopened much earlier than 1 July, the date we originally expected. As a result, we even had a week to test the system before the press conference on 18 June.

Two shows, *Flight of the Butterflies* and *Mysteries of the Unseen World,* converted from 15/70 format, are now playing in the theater. Besides them, two short planetarium shows were produced in-house, with E&S training staff's assistance. Both of these shows are about 5 minutes in length, one showing the summer constellations and the other taking the audiences to fly from the outer solar system through several planets, satellites, asteroids, and then to Earth, Asia, Taiwan, Taichung, and finally to our museum.

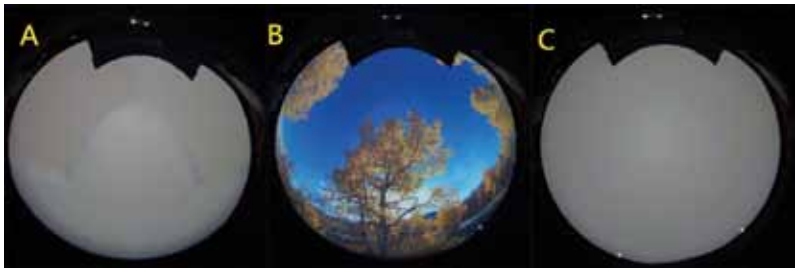
The audiences love these shows. Screaming and shouting can be heard always during the shows, especially from school kids coming in groups.

During the 10 days of free activity in late June, 25,268 visitors came to the theater to experience the new system. In July, the first month of formal reopening, the ticket box was 12% higher when compared to the same period in 2014.

Visitor response, conclusions

In the past 29 years, IMAX and GOTO tried every effort to keep our theater always in the best condition. GOTO even customized a main-control computer in 1998 and reproduced all 32 star plates in 2004 for our GSS-I. Those activities extended the lifetime of our GSS-I for at least 15 extra years. We deeply appreciate their efforts working with us during the past years.

However, renovation is an unavoidable issue. During the competitive bidding, three manufactures presented their products to us. It was not an easy process to determine which manufacturer and product would be best qualified to fit our immediate and future needs.



After 6 weeks playing without any calibration, the boundaries among different projection areas became significant like A. When playing animations, the visitors will see what like B. After calibration, the brightness became much more homogeneous, like C.

Two films are now on our show list by turns and short planetarium shows are given at the beginning of each show, just in the same way we operated under our old systems. However, owing to the good capability and flexibility of the new system, we plan to add more films onto the show list and to try to extend the existing planetarium shows to some 30-40 minutes shows in the future.

Below, some points are summarized from our experience learned in these months. I hope that could be helpful to those who are considering a digital system for their theaters/planetariums.

- Maintenance of the new system is much easier than the original systems. We expect that will save lots of money for us.
- Operation is also much easier and thus reduces the load on our staff. That is helpful since the government has been cutting the museum's prescribed number of personnel gradually in recent years.
- For playing movies, the 7.2K resolution is good enough to compete with the 15/70 projectors. The homogeneous problem is now solved with the Digistar 5 auto-calibrating technology.
- For replacing the opto-mechanical star projector, the new system is already very close to traditional starballs. Since the DS-5 software still uses 9 pixels to compose the brightness of Sirius and many of them seem superfluous, I guess there is still room for improvement even with the existing system since the DS-5 starfield is adjustable by setting several parameters.
- A digital system allows us to extend the show list with more films in the same day and provides the visitors more choices. This is what we are planning to do in 2016.
- The planetarium shows produced by ourselves are unique and customized. That will give the visitors motivation to come back to the theater again.
- The expected lifetime of a digital system is much shorter than the traditional mechanical systems. It seems not easy to do the mid-life upgrade like what we did in past years. The museum certainly will meet the issue of next renovation in 8-10 years from now.
- The performance of such a multi-channel projection system is now approaching the limit of human eyes. But, the quality of the image sources is getting far behind since movies are still shot with cameras having a fisheye lens or produced with computer-graphic (CG) technology. Several multi-camera systems are now under development. But they are now still far from mature. That will be a big challenge of the giant screen industry in the future. ☆

Chilong Lin, an associate curator of the Exhibition Department, has worked at the National Museum of Natural Science for 18 years. His favorite part of the renovations was acquiring the capability of producing programs by themselves.