Using Virtual Reconstructions in a Planetarium for Demonstrations in Archaeo-Astronomy

Georg Zotti, Alexander Wilkie and Werner Purgathofer

Institute of Computer Graphics & Algorithms, TU Wien, Austria

Abstract

In the last decades, archaeologists in central Europe have found traces of enigmatic neolithic circular building structures buried in the soil. Recent studies indicate that the orientation of many of their doorways may have been chosen with an astronomical background in mind.

This paper explains the use of virtual reconstructions of these buildings from archaeological data, in combination with a simulation of the sky of that time in a Planetarium, to present the astronomical findings to the public.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Three-Dimensional Graphics and Realism]: Virtual Reality; I.3.8 [Applications]:

1. Introduction

Archaeological evidence shows the connection of ancient cultures to annually repeating celestial events. In many old cultures, temple axes were typically aligned along cardinal directions, with the Pyramids in Egypt as most popular and best studied example. Another kind of alignment is that towards solstitial risings and settings of the sun; Stonehenge (England), Newgrange (Ireland), and many other megalithic sites are the most prominent exponents [Kru94] of this type. Stonehenge in particular gave rise to an unfortunately large collection of speculative and esoteric literature, which is however also indicative of the popularity of this topic. Medieval churches were also frequently oriented towards the rising point of the Sun on the day of the church's patron [Fir84].

But apparently the orientation of buildings has a much older tradition. Since the 1960s, using systematic aerial photography, archeologists have discovered a certain class of neolithic circular *enclosures: Kreisgrabenanlagen* (KGA). They typically consisted of 1–3 nearly circular wooden palisade walls, surrounded by 1–3 V-shaped ditches of up to 6m depth and 12m width. The circular ditches were broken by "earth bridges", which allowed people to enter the enclosure through gaps ("doors") in the palisades. The overall diameter of these structures is approximately 40–180m. The best archaeological survey results, short of the slow and very costly direct excavation, come from geomagnetic surveys which

measure the minute deviations of the Earth's natural magnetic field caused by the different qualities of soil which today fill the ditches: a set of very sensitive magnetometers is mounted on a hand-moved cart, and the cart is moved over the soil in parallel lines, providing a "subsurface scan" of the terrain. According to Radio-Carbon (¹⁴C) dating of excavated bone material, all KGAs have been erected in the short time span between 4800 and 4500 B.C. These structures have been found over a large part of central Europe, from Hungary to northern Germany, with a concentration of over 40 such structures known in Lower Austria (*e.g.*, Figure 1). In contrast to the megalithic buildings on the British islands and in Brittany there usually are no visible traces of the ditches or palisades left.

Since the 1980s, as the number of known KGAs steadily increased, a large number of theories about their use – ranging from cattle paddocks to battle fortifications – were discussed, and most of them were eventually rejected as inconsistent with archaeological evidence. The best current interpretation is that they were used as a place for special gatherings, councils, cultic worship, or initiations. As with the much younger megalithic constructions of Great Britain and Brittany [TT78], some astronomical alignments have been proposed by the scientific community, most notably by Becker [Bec96], who found that *Kreisgrabenanlagen* of Bavaria had doors and access bridges aligned to rising or setting points of the Sun at the solstices.



Figure 1: Archaeological map of the Kreisgrabenanlage (KGA) Steinabrunn in Lower Austria [EHNM99]. The wide brown rings indicate the circular ditches which are connected by narrower radial ditches along 4 access bridges. In the central area, traces of 3 concentric palisade walls are marked in a lighter shade of brown. Small brown dots indicate singular postholes, the green area marks a central pit. A multitude of similar KGA traces has been found all over central Europe in the last decades. Among the many theories which have been put forward concerning their use, the idea that the orientation of the doorways has an astronomical significance has gained importance in the past years.



Figure 2: Virtual reconstruction of the Steinabrunn site.

During the preparation of the first large public exhibition on *Kreisgrabenanlagen*, the theory of astronomical connections was also investigated by using a diagram that combines the archaeological map (Figure 1) with a celestial map, and which allows the immediate identification of possible alignments [Zot06]. The most conclusive results were presented in the exhibition catalog [Zot05]. However, while diagrams like the ones developed for the exhibition are useful for communicating such findings to scientists and lay-persons with prior astronomical knowledge, we also searched for a medium which is more suitable to deliver a compelling experience to members of the general public.

For an impressive, immersive presentation of these results we propose a combination of the high-quality sky simulation as projected by the current generation of Planetarium projectors with a horizon panorama created from virtual reconstructions of these ancient sites.

The rest of the paper is structured as follows: first, some related work in virtual reconstruction is mentioned. Then, to better understand the phenomena and ideas we want to demonstrate, basic astronomical terminology is explained. After a short summary of the astronomical alignments which appear likely to have been built into the KGAs on purpose, a novel way to present these results to the public inside a Planetarium will be presented. More alternatives will be discussed in the section on future work.

2. Related Work

Virtual reconstructions have become a standard practice for public demonstration of buildings and whole cities long lost in the course of history. Frequently the main interest lies in the proper reconstruction of the buildings and cities, without much consideration being given to the surrounding landscape. At best, such models may show a piece of landscape modeled after digital elevation data from a Geographical Information System (GIS), with either a simple blue or more realistic daylight sky (*e.g.*, [PSS99]) as background. Alternatively, photographically captured HDR images of the daylight sky can be used for illumination of the scene [SJW^{*}04].

Rarely, the different illumination effects of the sun on an ancient temple dependent on time of day and year are studied [SCM04]. In a larger, immersive VR system dedicated to virtual reconstructions of archaeological sites, the orientation of a south american temple with respect to certain rising and setting directions of the sun on the local horizon has been investigated [Fri03]. An accurate depiction of the visual appearance of an ancient site during night-time appears to currently be of little interest to the archaeological community, however; no such system is known to the authors.

For public demonstration and explanation of the night sky, the last century has seen the development of Planetarium systems [Mei92], which consist of a closed hemispherical dome (auditorium) with a special projector in its centre. This device is capable of projecting the stars, planets, Milky Way, and sometimes explanatory graphs, coordinate grids and mythological figures onto the dome, and thereby simulates the night sky in a highly immersive fashion. The projector can be rotated around several axes to simulate the sky for any time and location on Earth. Demonstrations and lectures can be enriched with additional slide and specialeffect projectors. It is likely the best tool for astronomical demonstrations, and can be seen, in a certain sense, as a predecessor of computer-driven immersive Virtual Reality systems.

In the first generations of Planetarium projectors, large patches of the sky were projected with a technology similar to a slide projector, using a huge central light bulb and several projection optics outlets mounted on a sphere that use metal masks with star holes of different diameter. (Actually, two part-spheres were used for the northern and southern hemispheres, connected by a lattice structure where moving planet projectors were mounted.) One of the problems of this type of device was the simulation of stars with different brightness.

Given that the brightest stars are more than 100 times brighter than the dimmest naked-eye stars, the brightest stars had rather unrealistically large projected star blobs. Later projector generations used a dedicated projector with a brighter lamp for the projection of the brighest stars with a smaller dot size. The latest generation of projectors no longer have star field projectors, but project each star individually through a glass fiber of different diameter, which gives much smaller and (where needed) brighter star images and provides a simulation of the sky with much more realism, also allowing to show the slight color tint visible in a few bright stars. This latest generation of projectors even allows to simulate the scintillation, or twinkling, of the stars induced by turbulent air in the Earth's atmosphere, which adds to the overall impression of being under the "real" sky.

To simulate the horizon of the current observer location, a system of carefully aligned overlapping slide projections along the horizon is frequently used. By using different slide sets, different observing locations on Earth, or even on the surface of the Moon or Mars, can be simulated during a show.

Digital Planetarium systems [Sky03, Eva06] replace the classical Planetarium projector with a digital projection system also capable of full-dome projection, thus even allowing "interstellar travel experience", i.e., the three-dimensional view of the sky from anywhere in a large area around the Sun's position in our galaxy, for a large auditorium [Hay]. However, until recently, overlapping CRT projections were used, and stars were again drawn with diameters showing their relative brightness, which also limited the achievable realism by the need to draw oversized stars to compensate for the limited dynamic range of projectors. The recent development of Laser systems promise a wider dynamic range and a large increase in realism, however, being scanning systems, there will likely always be the impression of a "big flickering monitor". Therefore, also the most modern Planetaria are usually equipped with a "conventional" Planetarium projector.

For private use, in the last years "desktop planetarium" computer programs have become not only popular but gain ever more realism with each new release [Sta]. For example, the Milky Way is no longer shown as a flat gray area like on a printed atlas, but shows bright filaments and dark knots, stars vanish during twilight, and the daylight sun may cause a "lens flare" artifact to indicate its brightness. The latest versions do not plot stars from a catalog, but make use of an all-sky photographic atlas. It is even possible to use a self-made panorama photograph as "local horizon", so a better estimate on object visibility or rise and setting times of objects can be given, especially if there are mountains on the horizon. Like in a Planetarium, these foreground panoramas are obviously valid for one viewpoint only.

What is still missing is the combination of a desktop VR system, which allows a virtual walkthrough of a reconstructed archaeological structure, with an astronomically and physically correct sky model.

3. Important Celestial Phenomena in Archaeo-Astronomy

On any day of the year, stars rise and set approximately 4 minutes earlier than on the day before. Stars which surround the celestial pole of the observer's hemisphere do not set, are visible in every clear night and are called circumpolar. Others are only visible during certain parts of the year, the Sun being too close to them to be observable at other times. The last time such a star is visible at dusk is called its heliacal setting, where the star becomes visible slightly above the horizon in the darkening twilight, only to set moments later. After typically a few weeks of invisibility due to its close distance to the Sun, it emerges in the morning on the day of its heliacal rising: in the morning twilight, the star appears shortly over the horizon haze, only to become too washed out a few moments later by the increasing brightness of the emerging daylight. On each successive day, the star will be visible about four minutes earlier. It has long been known that heliacal risings of selected stars have been used by various peoples all over the world to mark specific days of the year [Kru94], the best known example being the Egyptian use of the heliacal rising of the sky's brightest star, Sirius, as "herald" of the Nile flood. While the exact day in each year also depends on atmospheric conditions, the average day can be computed at least approximately, and Schoch's empirical method [Muc93] is still widely used. An observation run in 1993 confirmed object visibility at least very close to the computed dates, although some corrections seem necessary [Pac94].

The rising and setting azimuths A_{\uparrow} , A_{\downarrow} on a location's horizon depend on its geographical latitude φ , the star's declination δ and the local horizon's altitude, and can be given for the mathematical horizon [Mee98], using the *hour an*-

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gles $H_{\uparrow}, H_{\downarrow}$ at the time of rising and setting as

$$\cos H_{\uparrow,\downarrow} = -\tan \varphi \tan \delta$$

$$H_{\uparrow} < 0, \quad H_{\downarrow} > 0$$

$$A_{\uparrow} = \arctan \frac{\sin H_{\uparrow}}{\cos H_{\uparrow} \sin \varphi - \tan \delta \cos \varphi}$$

$$A_{\downarrow} = \arctan \frac{\sin H_{\downarrow}}{\cos H_{\downarrow} \sin \varphi - \tan \delta \cos \varphi}$$

The arctan has to be evaluated in the correct quadrant, so e.g. atan2() should be used where available. These values are angles counted from the south point on the horizon. Frequently, azimuths are also given from the north point. On the northern hemisphere, any elevation on the horizon will shift both rising and setting points southward.

For precise investigation of rising and setting alignments along the horizon, two phenomena caused by the Earth's atmosphere have to be taken into consideration:

refraction, causing a slight increase of apparent altitude for all celestial objects, most pronounced close to the horizon. Refraction also causes the Sun and Moon to appear vertically compressed when they are near the horizon, because their respective lower limbs will be raised more than their upper limbs, and raises both these objects by more than 1/2 degree on the horizon, thus causing also (on the northern hemisphere) a slight northward shift in both rising and setting points. The shift is more pronounced in high latitudes and for objects far from the celestial equator, because here the diurnal paths intersect the horizon in a more oblique angle.

This shift also applies to stars, but only the very brightest stars are visible in so low altitudes because of the

extinction, which reduces the objects' luminosities, usually making dimmer stars invisible near the horizon.

Unfortunately, neither effect can be properly simulated in a classical Planetarium. Stars are mechanically masked off at the mathematical horizon. Modern special effect projectors can at least simulate a flattened and reddened sun close to the horizon. But also solutions found in popular desktop planetarium programs seem questionable, so that room for improvement is still there.

3.1. Sun and Moon

Mirroring Earth's motion around it, the Sun annually describes a great circle on the celestial sphere, which due to Earth's tilted axis intersects the celestial equator. The moments when the Sun is at these points define the beginnings of astronomical spring and autumn, respectively, in the northern hemisphere. The Sun can reach northern and southern declinations equal to the Earth's axis tilt from orbit normal, which is currently about $\varepsilon = 23.5^{\circ}$, but slowly and slightly varies over millennia. Reflecting this, over the year, the daily points of sunrise and sunset span wide arcs along



Figure 3: Like a Planetarium dome, the sky dome spans over a virtual model of the KGA Steinabrunn, with lines showing the Sun's annual sky coverage on the sky dome, viewed from south-west. [Zot06]

the eastern and western horizons. Near the solstices ("standstills"), the Sun rises or sets on almost the same positions for several days. The full range of positions the Sun can reach on the sky dome during a year can be seen in Figure 3.

It is known from older cultures [Kru94] that some peoples defined the seasons not as beginning and ending at solstices and equinoxes, but centered the seasons around these dates; this practice leads to terms like "midsummer", which is still used for summer solstice. Traces of this tradition survive in today's All Saints' Day/Halloween and Candlemas as start and end of Winter, and May Day as alternative start of Summer. In total, the Sun provides eight calendarical *key dates* with five characteristic declinations, which lead to ten characteristic azimuths (rising/setting at equinoxes, solstices and the intermediate dates).

Similar to the Sun, the Moon can reach a wide range of declinations. Thom [TT78] found interesting alignments in the orientation of stone circles in Great Britain and Brittany with Moon-related azimuths, and Pavúk and Karlovský [PK04] investigated lunar orientations in KGAs of Slovakia. However, our results from the Austrian KGAs currently do not show significant correlation with lunar risings or settings, so the discussion will be omitted here.

3.2. Stars

Although called *fixed stars*, over the course of centuries and millennia, stars do change their position on the celestial sphere mostly due to

precession, a motion of the Earth's axis counteracting the tug of the Moon and the Sun on the Earth's equatorial bulge, which both attempt to erect Earth's rotational axis. The Earth – acting like a spinning top – evades this erection by moving its axis sideways, resulting in a motion

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Figure 5: Horizon Panorama for a location near the south-east gate of the Steinabrunn site.

where the Earth's axis over about 25800 years traces a double cone with the tip in the Earth's center. Reflecting this motion, the stars seem to move parallel to the ecliptic (the apparent annual path of the sun), slowly changing their coordinates on the celestial sphere. For this reason, *e.g.*, the star we now know as Pole Star will be far from the pole in just a few centuries, rendering it unusable for navigational purposes.

On the other hand, the stars'

proper motion in space is hardly noticeable even after several thousand years, due to their enormous distance from the Solar system, with only a handful of bright exceptions.

Meeus [Mee98] describes algorithms to correct stellar catalog positions given for one epoch to another.

The neolithic sky was shifted by precession by about 90° from today's sky, so that even with real reconstructions of archaeological structures *in-situ*, as done at KGA Goseck, Germany, it is no longer possible to verify or photograph any intended stellar orientation using today's sky. (However, KGA Goseck appears to be only solar-oriented.)

In a classical Planetarium, precession can usually be simulated (by a rotation of the main projector), but not the proper motion of the stars, with the possible exception of a special-purpose projector showing just this effect for a handful of stars. In a Digital Planetarium, both effects are easily shown if the computational model is correct.

Sight lines inside the KGAs cannot currently be given to sub-degree accuracy, because the exact positions of, *e.g.*, post tops above the surface is lost and can only be inferred from post hole positions, admittedly leaving some room for speculation about the practical use of one or another stellar alignment. Also, some sight lines are difficult to set down, *e.g.*, where the ditch or palisades are not really circular and some door axes do not meet on one spot, so that defining a single point of observation is hardly possible. It would be fortunate to be able to interactively look for the best spot, *i.e.*, take a walk through a virtual model in combination with the sky, explore the most impressive sight lines on the ground and look whether they can be seen in combination with some celestial view which originally could have motivated the respective construction.

4. Our Work

Our astronomical investigation of 28 KGAs in lower Austria [Zot, Zot05, Zot06] indicated that several doorways and gates are not oriented randomly, but appear to be oriented so that for an observer in or close to the center of the KGA the sun will appear to rise or set there on one of the 8 *key dates* (see section 3.1), with the winter solstice as most prominent solar direction.

In addition, three groups of door and ditch alignments have been identified which appear to point towards the rising point of the star Deneb (α Cygni) and that of the most prominent of all star clusters, the Pleiades, and the setting direction of Antares (α Scorpii) as they have been around 4700 B.C. About 1/3 of the KGAs show the alignment towards the Pleiades rising direction, and almost as many show the setting direction of Antares. Moreover, the events of rising Pleiades and setting Antares took place almost simultaneously, while at that same time also Deneb will be at its highest close to the zenith. Further investigation led to the conclusion that the Pleiades' heliacal rising (see section 3) took place just after spring equinox, and it appears very likely that the neolithic farmers used this celestial event to start their agricultural year. Note that the Pleiades have been observed by many cultures worldwide in connection with the seasons [Kru94], although a star cluster like the Pleiades, which consists of dim stars, cannot be observed below an altitude of about 4° , which is however a typical horizon elevation in Lower Austria.

For a rapid presentation in time for the abovementioned exhibition, horizon panoramas (Figures 4, 5) for different observing locations inside several KGAs had been created from the virtual reconstructions which could be loaded into the desktop planetarium software Starry Night [Sta]. With

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Figure 6: Sunrise over a hill on a date which is early November or February in our modern calendar. These dates are right between equinoxes and the Winter solstice, thus marking a calendarical key date. The Sun rises in a direction pointed to by the doorway. -(a) Simulation from Starry Night Pro 4.5, from [Zot05]. -(b) The same scene, captured in the Planetarium, where only the part of the panorama above the mathematical horizon can be shown. The sun rises as reddened ball over the hill (appearing rather yellowish due to overexposure - quite natural for the sun!). The Planetarium dome is tiled, so any twilight simulation in the Planetarium is unfortunately rather poor. The sky gradient has therefore been added during image postprocessing.

this combination, some interesting snapshots of sky vistas have been taken, e.g., Figure 6 (a).

In the wake of the successful exhibition and rising public awareness of these remarkable structures, a television documentation on Kreisgrabenanlagen is currently under production. A part of the film will contain the topic of astronomical alignments. Now, in the course of a year, rising and setting alignments of the Sun with horizon features on the solar key dates (see section 3.1) are being filmed in situ, even if there are no building remains visible. Due to the Earth's slightly different axis tilt $(23.5^{\circ} \text{ today } vs. 24.15^{\circ} \text{ then})$, the solstitial extremes of previous times can no longer be reached and are missed by 1.2° , which is more than two apparent solar diameters. This means that any special phenomena that could have been visible from some locations at that time, like the solar disk "scratching" along a distant mountain slope, or diving slightly below the slope during the days of solstice can no longer be observed today. Still, such recordings give a good impression about why KGAs may have been built at their respective locations, and equinoctial events indeed have the same horizon point, so they can (and should!) be proven by documented observation, *i.e.*, film. On the other hand, trying to record stellar risings and settings in situ is completely pointless: Precession has shifted the stellar sky so that the rising and setting points today are totally different from those in the neolithic period. To create video content for this part of the TV documentation, we had to resort to simulation.

The first idea was to simply use the program mentioned above, which also allows the creation of video clips (Quicktime format). However, the resolution of the animations is rather low and not very well suited for presentation on television.

Therefore, we proposed to use the currently best artificial sky as available with a Zeiss Mark IX Universarium "star ball" projector installed at the Zeiss Planetarium Vienna, Austria. This Planetarium is also equipped with overlapping slide projectors to create a horizon panorama display, and a Zeiss Universal Laser Image Projector (ZULIP), which is used for special effects and as video projector which can be rotated, tilted and zoomed.

To create a horizon panorama for the Planetarium dome, the horizon image is exposed with proper pre-distortion on a set of several slides to be used with carefully aligned slide projectors. Typical panoramas in a Planetarium presentation show a city skyline (combined with a sky view of just the brightest stars and lots of background light to simulate the urban light pollution), a mountain panorama (combined with a dark rural sky), maybe some exotic destination to show the sky of a tropical location on Earth, or a Lunar panorama created from Apollo image data. Of course, being projected in the same way as the starry sky, bright stars sometimes appear to sit in front of the skyscrapers or mountain tops, which is one of the shortcomings of this approach. To cut off the stars, a mask of similar shape like the horizon line would have to be set up around the star projector, which is however impractical because the stars are not projected from the true center, but from an extended sphere, so that a border of parallactic mismatch remains. Also, changing the horizon panorama would also mean having to change the mask, so this is not done in practice.

When the Planetarium sky was set for the epoch of the Kreisgrabenanlagen (4700 B.C.), the vistas previously found



Figure 7: "Archaeo-Astrophotography". A fish-eye photograph taken in the Planetarium, showing the Milky Way spanning the whole sky through the zenith when Antares was setting (bottom edge) and the Pleiades were about to rise, with Deneb close to the zenith. This photograph can no longer be produced in nature in the same orientation, because the sky has shifted due to precession.

only on a custom-made planisphere and visualized in Starry Night could be replayed in unprecedented realism, and the added impression of the fully immersive Planetarium sky dome with the Milky Way spanning a high arc through the zenith and the bright Milky Way center setting on the Western horizon together with Antares was almost an eye-opener as to the (possible) "magical moment" the people of that time may have felt (Figure 7).

Test shots with the HDTV camera used for the documentary showed that the camera is unfortunately not sensitive enough to capture the Planetarium sky with a wide-angle lens, so that the capturing of the immersive look of the sky in the Planetarium with a full KGA panorama is not possible. However, with a mild telephoto setting, stars and even the Milky Way can be recorded. Therefore, it was decided to record only important views, *i.e.*, views through doors or along ditches, with the applicable part of the foreground panorama projected by the ZULIP, to save the cost of producing the slides for the full panoramas.

Because the "star ball" projector is centered in the Planetarium dome, the ZULIP is placed off-center, and the projection area least influenced by projection distortions is obviously on the same side of the star ball as the ZULIP. Fortunately, unlike older Planetarium projectors, the star ball can be rotated in azimuth, so that the cardinal points in the dome can be set arbitrarily. So, for the TV shots, the ZULIP projection direction was frozen towards this region of least distortion, showing one of the interesting doors of the KGA panorama, and the azimuth match was made with the central projector, so that the sky geometrically matched the view from Starry Night.

To counteract the abovementioned problem of stars projected onto the foreground panorama, we tried to mask off the stars from the star ball where they would project on the palisade walls with cardboard masks mounted on tripods. Unfortunately, the star fields of the star ball projector apparently overlap, so while stars of one star field could be masked off on the correct line, other star fields still cast stars on the foreground, so the idea had to be finally abandoned, and for the TV production, post-processing the shots using video overlays of shots taken with only the KGA doors are necessary to have a star-free foreground.

The simulation of twilight in the Planetarium is unfortunately a problem: around the horizon, several groups of coloured light bulbs can be activated, but of course their light mixes with the horizon projection, deteriorating the otherwise splendid view. Also, the inside of the dome of this Planetarium is not smooth but covered with painted sheet metal tiles from the 1960s which show their age by warping. While this is still not too problematic for the audience in a live show, twilight-type illumination of the background will not look very good in a video closeup, and again, therefore, twilight effects should rather be added in a post-processing step or right into the horizon panorama. Figures 6 (b) and 8 were created from combining photographs of the doorway projected with the ZULIP with and without the sky, and a layer showing a gradient for the twilight or sky colours as could be optimally simulated in a Planetarium.

5. Discussion and Future Work

Compared to the simulation in Starry Night, the main differences with simulating the celestial vistas in a Planetarium are

- + fully immersive feeling of being right under the stars
- + much smaller star points of much more intense brightness
- only the part of the panorama above the mathematical horizon can be shown on the dome.

While the ZULIP has a technical barrier built in that prevents casting Laser radiation downwards and possibly into the audience, a slide projection system could be designed that would add more of the horizon on the cylindrical gallery just below the sky dome.

For use outside of a Planetarium, an astronomically correct twilight and night sky model has to be developed and integrated in a system allowing virtual walk-throughs, allowing the demonstration of astronomical alignments in a desktop VR or CAVE setting.

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Figure 8: From the same location as Figure 6, shortly after spring begin, the Pleiades appear above the hill in the morning twilight for the first time after having been invisible for several weeks. Photograph taken from the Planetarium dome (causing the curved horizon line), combining the small star dots from the "star ball" with the foreground from the ZULIP. The twilight effect has been added during image postprocessing, where also stars overlaid on the foreground were removed.

The digital age has also entered the Planetarium world. While the star projection quality of a modern fiber glass projector is still unsurpassed, all-dome projection systems at least for special effects are becoming more common. Using such projectors, it should soon be possible to allow for continuously changing horizons, so that a complete walk through a virtual reconstruction, together with a sky with twilight effects, could be projected by digital image projectors and combined with the superb quality of the star projector, or the whole scene could be generated on the computer and projected on the dome with an all-sky laser projector system. This would allow interactive exploration of possible stellar alignments in a properly reconstructed virtual scene, and promises to become an exciting way to demonstrate the astronomical knowledge and the role of celestial events for people of the distant past.

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