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Introduction

The Adler Planetarium brings together a unique mix of a world-class collection of historic celestial cartography, world-leading citizen science initiatives, and an established public audience for programs on astronomy and its history. This combination facilitates a wide-reaching, comprehensive integration of historic maps and present astronomical knowledge by both including the public in its creation and in making the results publically available in compelling ways.

Dating from the fifteenth through twentieth centuries, the Adler's celestial cartography focuses on European astronomy but also includes significant examples from China and the Islamic world. From antiquity to the present day, maps of the heavens reflect terrestrial culture. The intellectual content of this celestial cartography reaches well beyond the history of astronomy. On the most fundamental level, these maps show relationships between objects in space; just as a terrestrial political map defines arbitrary national borders, a celestial map creates imaginary groupings of stars physically very far apart. In selecting groupings of stars and other information for their maps, celestial cartographers reveal contemporary awareness of the universe around them, as well as prior beliefs assimilated into that awareness. With a perspective embedded in time and place, the artist or astronomer understands and portrays the universe based on the surrounding society and culture. Available technologies, dominant religious sensibilities, prevailing philosophical thoughts, and popular artistic styles all influence celestial maps.

Digital Historic Skies uses citizen science methods to expand our knowledge of historical star mapping, organizing data in order to give insight into what was important about the night sky to both individuals and cultures. *Digital Historic Skies* was part of Adler's Collections Access Initiative, a five-year (2013-2018) plan to bring Adler collections to the broadest possible audience.

The project had three major goals: 1) to develop an alpha prototype citizen science project to catalog celestial objects in Adler's historic maps; 2) to develop a proof-of-concept prototype mobile phone application that teaches about cultures through historic celestial cartography; and 3) to draft implementation plans.

Goal 1: Citizen science prototype

Citizen science, Zooniverse, and DHS

Adler's citizen science department develops projects for Zooniverse, the world's largest and most successful platform for citizen science online. Zooniverse crowd-sources aspects of data processing by engaging the general public in the cleaning, annotating, and processing of scientific data. Zooniverse currently supports more than forty active projects, producing data which has been used in more than one hundred peer-reviewed papers. Its volunteer workforce of 1.5 million volunteers is shared across these projects.

Digital Historic Skies was the first Zooniverse project aiming at exploring the research potential of the Adler's historical collections. The objective of the prototype was to allow museum visitors and volunteers to catalog astronomical objects in fifty samples of historic celestial cartography from Adler's collections.

In an initial phase, the team evaluated technologies available for rendering tiled map images, including Leaflet and Tile Mill, and for displaying the background celestial scene, namely WorldWide Telescope. The team then started to design the prototype that would allow citizen scientists to standardize object names and positions, allowing historic celestial maps to digitally align to match the current, accurately mapped sky.

Designing and testing a first citizen science prototype

The first challenge in designing the prototype was how citizen scientists would classify objects that have been mapped, sometimes inaccurately, using varying projections. Moreover, the names of astronomical objects have varied over centuries and across cultures. It must be noted, though, that these variations and inconsistencies are both essential to understanding the mapmaker's perspective, and the barriers to making meaningful comparisons.

Experience with Zooniverse projects has shown that citizen science volunteers are motivated by more game-like experiences and that the most successful projects provide opportunities for volunteers to complete simple tasks. Taking this into account, the DHS team adjusted the goals of the science data collection aspect of the project.

The initial proposal planned to have citizen scientists catalog individual stars on the celestial charts. However, this project would require a high level of knowledge and would be a slow-moving task. Thus it was decided that the goal remained the same - to catalog all stars on the historic charts using astronomical standards - but the process would now involve two steps.

First, the citizen scientists would tag stars on the maps, without providing any astronomical names. Second, the project team would submit the tagged images to astronometry.net, a project partially supported by the National Science Foundation, the National Aeronautics and Space Administration, and the Canadian National Science and Engineering Council. At astrometry.net, users upload images of the sky with unknown coordinates, and the site returns astrometric calibration metadata and lists of known celestial objects in the image.

The team selected fifty samples of celestial cartography from the Adler's collections previously digitized in the context of the NEH funded Celestial Cartography Digitization project (NEH Award #PW-51687-14). These samples covered Western and non-Western charts, pictorial and non-pictorial, dating from the 16th century to the 20th century. Web developer Chris Snyder prepared a first prototype for the citizen science data collection tool (fig. 1), which was tested with museum visitors. The general reaction was that tagging the stars was a simple and appealing task.

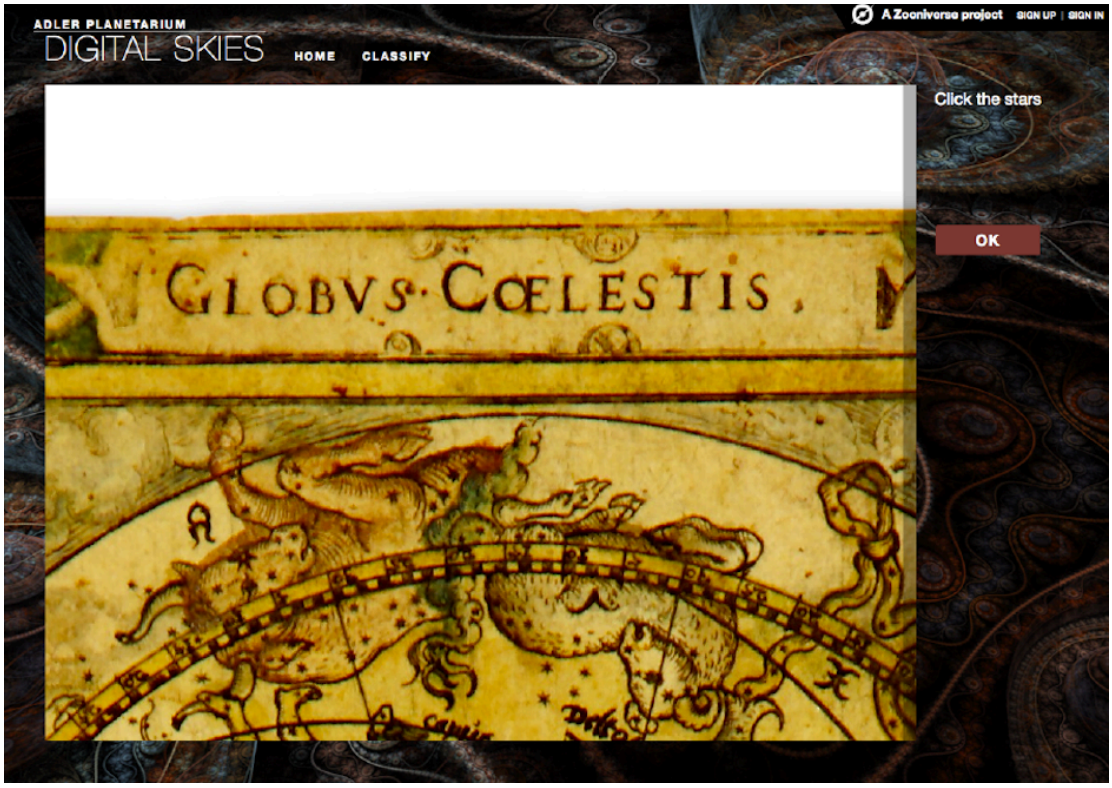


Fig.1 - Screen shot from the first citizen science prototype.

However, several issues emerged when the team tried to use the resulting data in astrometry.net. The team was well aware that the site cannot read most historic maps, but hoped that a combination of digitized maps and citizen-scientist-tagged stars would ease the process. It soon became clear however that the data obtained with the prototype did not render satisfactory results. These results were likely due to the varying levels of precision of historic charts as well as the different types of projections involved. While engaged in development and deployment of this initial citizen science prototype, work was also being done to develop the mobile app.

Goal 2: Outline of a mobile app

Some stargazing apps have proven incredibly popular with smartphone and tablet users. Although some of these apps offer a historical-looking overlay, for those wanting to evoke the celestial realm of centuries past, none of the current apps actually plot the stars in the antiquarian source material - rather they merely use them for an aesthetic gimmick that offers not much more than decoration.

The project team intended the mobile application to incorporate citizen science data, a smartphone's GPS, historic celestial cartography from different cultures, and current astronomical data. The mobile app was also intended to be developed through crowdsourcing to catalog celestial objects in historic maps,

standardize names and positions, and allow the maps to digitally align to match the current sky.

Dr. Anna Friedman was hired as a curatorial consultant to assist the team in designing a proof-of-concept prototype mobile application able to overlay historic celestial cartography with the current night sky for a user's exact location found via GPS.

The curatorial consultant researched and developed an outline for content of a mobile application. Dr. Friedman proposed to create content for an existing star-mapping app that would offer users the chance to travel through space and time by navigating the contemporary sky using updated star positions from maps from different time periods and cultures. In addition to allowing users this tour, the team intended to incorporate educational functions into the experience. Points of interest would be highlighted with eye-catching graphic "beacons" that would give viewers a chance to "pop-up" a deeper level of didactic information that relates a blend of art, humanities, and science knowledge.

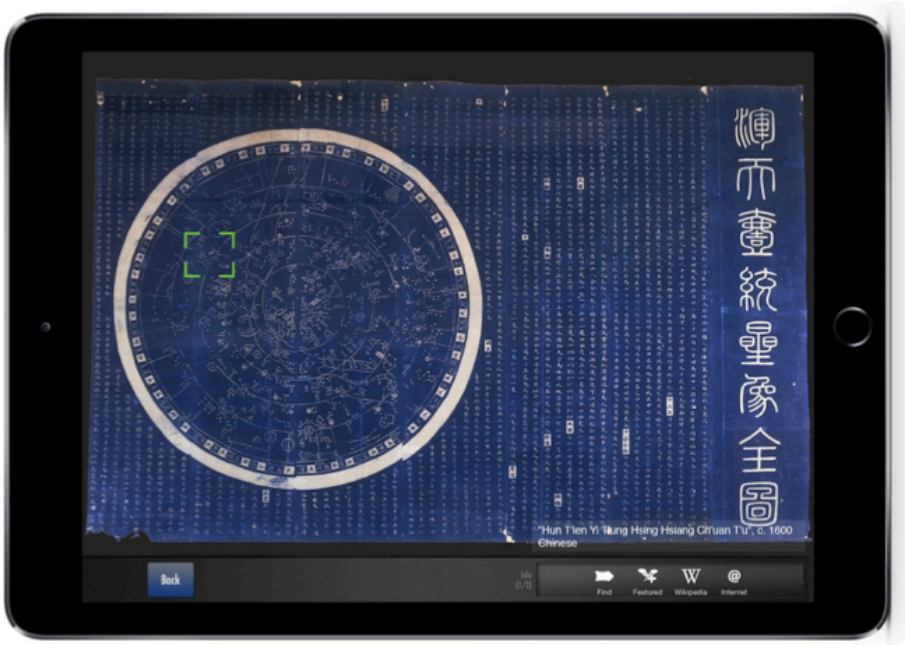
The mobile application Star Map was used as a reference in this part of the project. Dr. Friedman's proposal included a prototype with four whole-sky maps, two from the European tradition (two centuries apart to offer strikingly different aesthetics and contexts), one from the Chinese tradition, and one from the Islamic tradition. These three cultures provide the fewest challenges with correlating historically plotted stars with their present-day counterparts in the night sky as the maps either feature careful projections or correlate to star catalogs from which coordinates can be determined. The four maps were:

- The 1603 *Uranometria* of German astronomer Johann Bayer, in its day a revolutionarily accurate and comprehensive pre-telescopic scholarly project.
- Ezra Otis Kendall's *Atlas of the Heavens…* (Philadelphia, 1846) designed for use by a general-public audience similar to today's app users.
- Adler's P-69, an enormous Chinese wall map from 1828 based on the Suchow chart believed to date to 1193.
- One of the medieval manuscript Sufi-latinus corpus map sets, to offer a deeper date range and another mapping medium (the Adler does not own one of these, so we would have to partner with an institution who has one).

Additional "pop up" educational content would be included to:

- Explain why some stars are misplaced, assigned the wrong magnitude, or otherwise different from how we locate or categorize them today.
- Tell the story behind certain constellations or asterisms.
- Point out details about design history, artistic style, and other aesthetic components.

The proposal was presented to the Advisory Board together with a PowerPoint mock-up combining images from Star Map, digitized images of the abovementioned items, and a structure for menus and additional information "pop-ups" (figs. 2 and 3).



Figs. 2 and 3 - Images from the mobile app mock-up

Reassessment of goals and priorities

The DHS advisory board met at the Adler Planetarium on March 16 and 17, 2015. The team presented the citizen science prototype and curatorial content for the mobile app. During the two-day meeting, the project team,

advisory board, and curatorial consultant discussed project goals and the challenges in implementing them. The advisory board felt strongly that detailed naming of constellations would be beneficial to researchers.

The original grant proposal described the citizen science-based, crowdsourced tagging of stars as essential to the precise placement of historically mapped stars in a contemporary mobile application such as Star Map. During project team meetings where potential implementation was discussed, it became clear that this is not the case. Users view mobile applications on small screens, making the precise match unnecessary for that aspect of the project. As a result, the mobile app aspect of the project started to be regarded separately from the citizen science component.

Based on these considerations and on the feedback from the advisory board, it was decided that:

- From this point forward, the team would focus on the development of the citizen science prototype, while the proposal and mock-up for the mobile app provided by the curatorial consultant could serve as a sufficient basis for a prospective implementation.
- The citizen science prototype would be redesigned to add the ability to crowd-source both the tagging of stars and the cataloging of constellation names.
- The tagging of stars would now be aimed at gathering information about the number of stars on a certain chart, segment of a chart, or particular rendition of a constellation, not for astrometric purposes.

Second version of the citizen science prototype

Following the Advisory Board's recommendation the second citizen science prototype was developed with two levels of interaction for users: one where users were able to tag the stars as previously planned and a second where users identified constellations. This second level was originally considered to be suitable only to users with a previous knowledge of constellations. However, the team became increasingly interested in exploring the possibility of including this function in such a way that no previous knowledge of astronomy, constellations, or celestial cartography was necessary. Furthermore, the team would use a new tool called Zooniverse Project Builder to develop the new prototype.

The Zooniverse Project Builder was launched in July 2015, and is the product of eight years of crowdsourcing application development experience. It is a free DIY tool of a transformative nature. Prior to its development, a typical Zooniverse project required professional web development, and even rapid projects took months to develop. With the Project Builder, anyone can now build and deploy a project in an hour, using a set of browser-based tools. The Project Builder supports the most common types of crowdsourcing interaction including classification, multiple-choice questions, comparison tasks, marking and drawing tools, or any combination thereof.

The use of Project Builder to develop the second DHS Citizen Science

prototype not only made it easier for the team to design and reconfigure menus and workflows, it also provided relevant feedback for the improvement of the Project Builder itself.

The new prototype (figs. 4 and 5) included two major tasks, giving the citizen scientist the possibility to chose which one to perform:

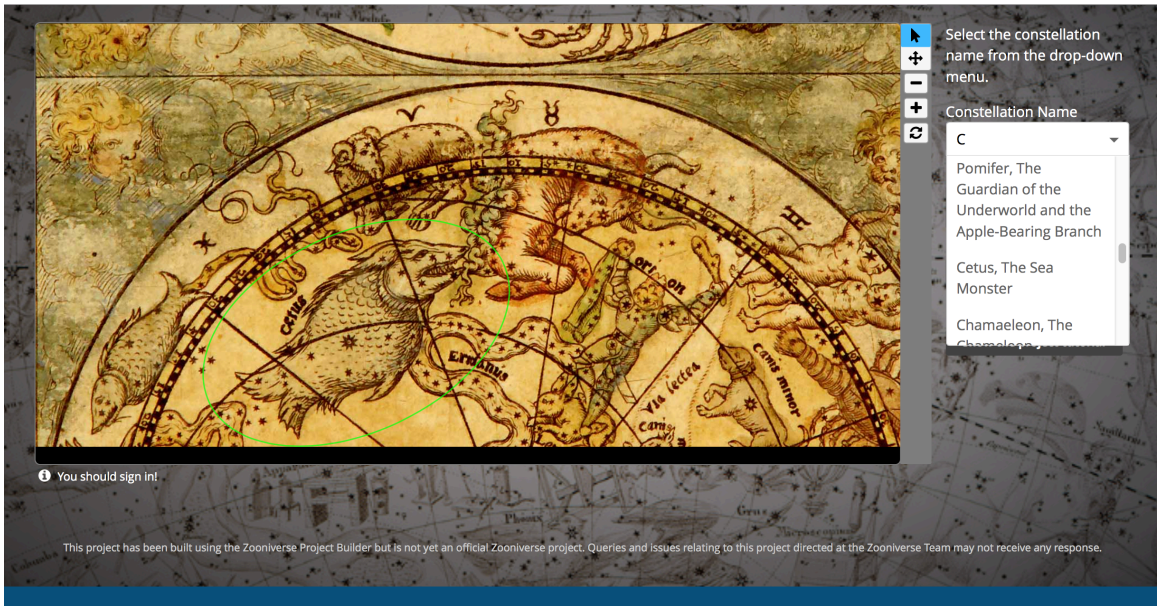
1) Tagging stars for the sole purpose of quantifying the number of stars associated with a certain constellation on a given chart or illustration, as mentioned above.
2) Tagging constellations by encircling/cropping the respective area in a given image, and identifying them by using textual information in the image, and/or by following a well-defined set of criteria.

The set of tools to tag stars was similar to the one used in the first prototype. A new set of tools and menus was developed for the second task. There were four basic options for each image:

1) “There is at least one constellation that I can identify by name”. If this option is chosen, the citizen scientist is then expected to circle the constellation with an encircling tool, and to choose its name from a menu of constellation names.
2) “There is at least one constellation with artwork, but I don't know its name”. The constellation is similarly circled, and then the user chooses the most adequate option from a menu under the header “Does the constellation you’ve chosen show…”. The options are: “An animal?”; “A man or a woman?” “A shape?”; etc.. After choosing the most suitable option, the user compares the circled constellation with a menu of historic renditions of constellations that fit the previously chosen criterion.
3) “There are stars and/or constellations, but I can’t identify any constellations by name and there is no artwork”. This option leads to the next classification.
4) “There are no stars or constellations”. The same as 3).

Testing the second citizen science prototype

The second prototype was tested remotely by volunteers both remotely and on the museum floor by visitors. The first group of volunteers was engaged in the testing through Adler social media and mailing lists related to the history of astronomy and historical scientific collections. Thus they constituted a group that presumably had a previous knowledge of astronomy and its history. They were asked to fill in a questionnaire (prepared with Google Docs) after testing the prototype.



Figs. 4 and 5 - Screen shots from the second citizen science prototype.

From the pool of fourteen volunteers who tested the prototype remotely, only two considered it hard to tag the stars. The number was the same for those who found it difficult to identify the constellations. The majority considered both tasks to be either moderately easy or very easy. Although most volunteers seemed to have understood the goal of the prototype, the team realized that it could have been stated more explicitly. Several observations concerning particular aspects of the prototype's tools and menus were also made in the

answers to the questionnaire. Two recurring remarks were that additional information about the cartographic items in the prototype would be useful, and that the prototype should include translation tools to facilitate easier understanding of charts in languages such as Chinese and Arabic.

Twenty museum visitors were randomly invited to test the prototype in the Adler's galleries, during regular museum hours. They were assisted by museum facilitators, who collected anecdotal evidence about the testing. Again, it was often remarked that more information about each image would be useful, and that maps in languages such as Chinese were difficult to tag. A significant number of visitors considered it difficult to identify the constellations and found it necessary to go back and reexamine certain functions. Some also found it hard to get through the decision tree after making a choice they came to recognize as flawed. Testers also mentioned that sometimes it was difficult to associate unlabeled and unknown figurative constellations with the categories provided in the identification menu. The facilitators who assisted the visitors further remarked that having more accessible samples of constellations images or a planisphere for comparison would make constellation tagging easier.

Despite these concerns, the general reaction was very positive. Participants engaged actively with the tasks in the prototype; some couples even engaged in debates about specific tasks and images. Although a previous knowledge of history of astronomy and familiarity with star charts certainly predisposed them to engage actively with the prototype, the volunteers who tested it remotely generally expressed a great interest in the project and on its further development.

The team examined all feedback carefully, agreed that the points highlighted above should be taken into account in a prospective implementation, and further noted the following:

- The prototype was designed to be seen on a large screen, not in mobile devices such as those used in the testing on the museum floor, which might have made it more difficult for visitors to test it.
- The way the original images were cropped to be included in the prototype was not always effective, often resulting in cumbersome images with truncated constellations. The process of cropping images needs to be improved.
- As far as constellations are concerned, non-pictorial charts, especially those lacking lines connecting stars to highlight a pattern and/or labels for stars and constellations, are generally difficult to tag. The project should focus on pictorial material.
- This project should be designed not only to engage citizen scientists in the tagging of stars and constellations, but also to provide opportunities to learn about the charts used in the project and about celestial cartography in general.
- The citizen science interface should allow participants to see the progress of the project, namely a growing database of identified constellations. This could actually provide additional reference material and comparison for further identification of constellations.

Prospects for further development and implementation

The development of the project led the team to realize that the original plans to combine a mobile app, crowd-sourced tagging of stars and constellations, and astrometric tools, would be too complex to implement, without any guarantee that sound results could be produced. However, the project showed that historic celestial cartography, especially in its visually and aesthetically more elaborate forms, has a great potential to engage different audiences with astronomy and its cultural heritage at large. It also showed that this is a very appropriate field to explore through Zooniverse tools.

As to the first goal of developing a citizen science prototype, the team considers it to have been completely fulfilled. The team feels that the resulting prototype could be successfully implemented after some adjustments based on the feedback gathered through testing, together with the assessment made by the team. However, the team also believes there is potential for further development of the prototype, namely to make it suitable to include images related to non-Western traditions of celestial cartography.

The second goal of producing a proof-of-concept mobile app was partially fulfilled. Even though a proper beta-version app was not produced - to a great extent, because the development of the project led to focus on the citizen science prototype - the outline developed with the consultant suffices as a basis to further pursue this part of the project. The realization that precise astrometric calibration is not relevant for this purpose is important, showing that time and resources should preferably be invested in the production of engaging educational content and an appropriate set of tools and functions to display it on the app.

This leads to the third goal of the project: drafting implementation plans. The team had reservations about developing detailed implementation plans, especially due to the high number of staff changes in the Adler Planetarium during the grant period, which resulted in frequent changes in the project team itself, including a change of Project Director. Since staff changes continued to be significant around the time of the conclusion of the project, the team preferred to simply consider some possibilities, leaving detailed implementation decisions and plans to be made when staff expected to be involved in a prospective implementation are stabilized.

The mobile app idea has not been excluded, but in a first stage of implementation the focus would be on a Zooniverse project to identify constellations on historic charts and globes, with the aim of producing a comprehensive database of historic representations of constellations. This database would be very useful to planetaria and science museum staff, historians of science and art, cultural historians, astronomers interested in the development of celestial cartography, science writers, and educators.

There are two major possibilities to consider, as far as implementation is concerned. One is to implement the citizen science prototype with a focus on Western celestial cartography, after some basic improvements on the basis of the feedback and assessment presented above.

The other possibility, which would require applying for an implementation grant, is to further develop the citizen science prototype so that it includes appropriate tools to allow examination of celestial cartography items from both Western and non-Western cultures. The team would also like to include here the development of an interface suitable to be used on the museum floor, so that Adler visitors could engage with the project while visiting the Planetarium. A decision about applying for future funding will be made when the relevant staff is stabilized.