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Changes in the Unchangeable: Simulation of Transient Astronomical Phenomena with Stellarium

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Abstract. The open-source desktop planetarium Stellarium has become very popular in astronomical education and outreach. Our recent changes aim for its applicability in historical and archaeoastronomical simulation contexts. Apart from visualizing the seemingly perpetual regular motions of the celestial bodies, it can be used to visualize and demonstrate historical solar and lunar eclipses, historical and present comets, meteors, and also novae and supernovae.

Keywords. Simulation, phenomenology, desktop planetarium, outreach

1. Introduction

One of the most popular desktop planetarium programs is the open-source Stellarium project started by Fabien Chéreau in 2001 (Zotti & Wolf 2018). The original purpose of the project was to visualise the current skies as realistically as possible. Although it was mostly geared towards contemporary amateur astronomers and laypeople, some of its original features, such as its easily exchangeable "sky cultures" (constellation patterns), as well as its simple usability and free availability, also made the program very attractive to researchers in cultural astronomy (i.e., ethnoastronomy and archaeoastronomy).

A powerful aspect of Stellarium is the possibility to extend the program with plugins for special — educational or scientific — purposes without deep changes in the core code. Several of those, including a 3D mode to explore potentially astronomically oriented buildings in their surrounding landscape, have been developed for purposes of visualisation and research in historical astronomy and archaeoastronomy (Zotti 2016).

In this paper we want to highlight several features which can be used to simulate for research, but also and especially for outreach, several transient astronomical phenomena: Solar and Lunar eclipses, comets, meteors, and Supernovae and Novae.

2. Simulation of Eclipses

Total Solar eclipses may well be described as nature's visually most impressive, yet still harmless, spectacle (in contrast to "true" disasters like earthquakes). An unprepared witness will easily be deeply impressed or even terrorized by the visually stunning phenomenon, which in contrast nowadays draws thousands of travellers around the globe.

The geometry between Moon and observer location on the surface of Earth (modelled as ellipsoid) automatically should cause eclipse geometry to be correct in the simulation. When the Moon covers the Sun, the amount of light illuminating the atmosphere is reduced and the sky becomes much darker. During totality, the brightest planets and stars are shown. We have also added a view of the solar corona. However, a complete simulation of the "circular twilight" during totality, or even of the approaching or receding "wall of darkness", has not been achieved so far.

A critical parameter for all eclipse simulations is the computation of ΔT, the irregular deceleration of Earth's rotation. In Stellarium, the user can select from more than 30 different models of ΔT, including a custom parabolic formula.

Lunar eclipses are likewise simulated by projecting Earth's shadow onto the Lunar sphere. During the eclipse, the sky brightening by the Full Moon is diminished and more stars are visible in the sky. The penumbra is indicated by a small minimum darkening which gets gradually darker, then the umbra border is represented by a steep darkening.

Currently, Stellarium does not compute particular numerical data for eclipses like Bessel elements, nor does it have an "eclipse finder". Contact times for the total solar eclipse of 2017-08-21 were within seconds of reality, and solar eclipses from Espenak & Meeus (2006) and Mucke & Meeus (1983) are well reproduced.

3. Simulation of Comets and Meteors

Bright comets used to surprise people all over the world, and most cultures saw them as bad *omina*. Their sudden appearance did not fit into the antique world view of heavenly bodies perpetually orbiting Earth on circular orbits or crystalline spheres, and only Tycho Brahe finally could show that they must be farther from Earth than the Moon.

Comets have been available in Stellarium pretty early, but they were only displayed as core with Coma. In 2014 we added a simple tail model based on Zotti (2001). It consists of two parabolic shells, one narrow and long which points straight away from the sun and represents the gas tail, and the other, which represents the dust tail, is wider and curved. The gas tail length and coma diameter follow the models from *Project Pluto* (n.d.). The curvature of the dust tail takes the comet's speed and distance from the Sun into account, and its strength relative to the gas tail can be parameterized in the orbital elements data file. The final appearance was crucially influenced by our own observations of the two Great Comets of the 1990s, C/1996 B2 Hyakutake and C/1995 O1 Hale-Bopp.

As is usual for this kind of software, position is computed from osculating orbital elements which are valid for a limited time only. Stellarium includes a collection of over 1000 element sets for historical comets. Orbital elements can be updated using the element service provided by the Minor Planetary Center (MPC).

Related to comets, Stellarium can also provide simulation of sporadic meteors and information (radiant location, activity) on meteor showers.

4. Historical Supernovae and Bright Novae

Only few bright supernovae exist in the historical records, yet for observers in earlier times, deeply rooted in the belief of the unchanging stellar sphere, a bright additional "guest star" must have been a very uncommon and miraculous sight. The idea of creating a tool for visualization of supernovae outbursts was born in a discussion between users and developers of Stellarium on a Russian astronomical forum in October 2010. This idea was obvious and yet none of the planetarium programs at that time had the ability to visualize supernovae outbursts. A first public release of the "Historical Supernovae" plugin was available near the end of the year 2010, and this version contained 10 bright historical supernovae observed by unaided eyes or with telescopes since 1006 (Tsvetkov & Bartunov 1993). By today (version 0.18.2 of August 2018) the list contains 47 supernovae brighter than 12.00^m at maximum. The JSON based format of our supernovae catalog can be updated through the Internet or modified by the user. Light curves of the historical

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supernovae cannot be obtained for obvious reasons, therefore we model the typical light curves for type I and type II supernovae. Those models are very simple, fast and limited to V-band observations of magnitudes (Utrobin 1986). For visual validation of models we used data from Green & Stephenson (2003) and Polcaro & Martocchia (2005).

Similar to the "Historical Supernovae" plugin, also bright Novae have been made available to simulation in Stellarium in 2013. We use a simple model for calculation of light curves based on decay time by N magnitudes from the maximum brightness value, where $N \in [2, 3, 6, 9]$. If a nova has no recorded values for decay of magnitude then this plugin will use generalized values for it. The list of novae is limited to magnitude 9.00^m and brighter at peak of brightness and currently (2018) contains 54 stars (Strope *et al.* 2010).

5. Conclusion and Further Work

In this short review we presented and discussed the possibilities of simulating transient astronomical phenomena for research and outreach in the popular open-source desktop planetarium Stellarium. Many more details are given in the User Guide which was also significantly enlarged in recent years (Zotti & Wolf 2018).

The application of Stellarium for simulation of historical skies has required several improvements in the accuracy of astronomical computation like including the long-time precession model by Vondrák *et al.* (2011) and accessing the DE430/431 solutions from Folkner *et al.* (2014). A known shortcoming is the current handling of stellar proper motion mentioned by De Lorenzis & Orofino (2018). Future developments should clearly include GAIA data and 3D proper motion.

Stellarium as a community project lives from voluntary contributions and donations. We invite contributions in code, data or just pointers to better models.

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