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GWSky - An Augmented Reality Mobile App for Gravitational Waves Sky Localization

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Abstract. As more and more gravitational wave events are detected each year via interferometry, the need for a clear, informative, handy representation and visualization of their characteristics is growing to be ever-more important, especially in the context of Multi-Messenger Astronomy. On one hand, such a tool can be a commodity for researchers, allowing for an effortless overlay of gravitational data on top of the electromagnetic view of the sky; on the other, it can be an effective instrument for educative purposes, especially in the context of mobile devices. In this paper, an Android/iOS application capable of performing these features is presented.

1. Introduction

The first observation of a gravitational wave signal was a milestone in Astronomy, dated the 14th of September 2015. (Abbott et al. 2016) Since then, considerable technical improvements for their detection have been made: reduction of ambient noise, dampening and software for online and offline analysis. These, coupled with the recent addition of *KAGRA* to the *LIGO-Virgo Collaboration*, will allow for even more events to be found in the near future. (Abbott et al. 2018) The importance of these gravitational signals lies in the fact that their shape carry information about their emitter, and this also applies to sources which may be obscured to the electromagnetic spectrum. And for visible astronomical bodies, nevertheless the contemporary and combined observation of both wave types yields an even greater amount of information than if considered separately. Indeed, the so-called **Multi-Messenger Astronomy** shows to be a promising field of research, albeit still in its infancy, with the first observation `GW170817` in both the optical and gamma-ray, as well as gravitational ranges. (Abbott et al. 2017)

1.1. Software Scope

The purpose of our application, given the context in Section 1, is to ease the retrieval of all recorded gravitational events data and their look-up relative to an accurate astronomical sky. In particular, our app, which is available for all smartphones running *Android* or *iOS*, displays data as a virtual sky on top of which gravitational data is layered; the user may freely look around in this environment by orienting their device in space, and the view shown by the application will reflect the one which the user could see in the real world, hypothetically or effectively, from their position in their local time at that same orientation. Thanks to this "stargazing" feature, as well as several educative components, the app is made accessible to the layman and may find a place in astronomy divulgation. *Flexibility* and *Ease of Use* are key qualities of this piece of software, and in particular the *Graphical User Interface* (GUI) has been designed to be minimal and large, preferring lighter colors for its text and elements for a better contrast against the darkly-colored pictures typical of astro-photography.

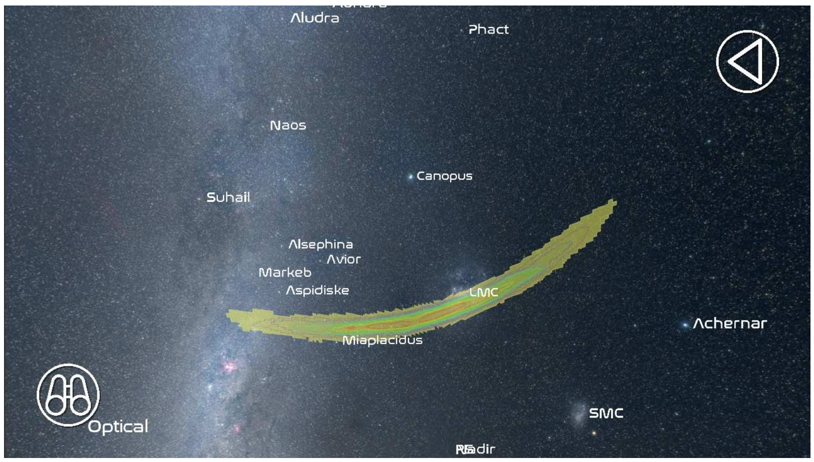

Figure 1. A screenshot of the running application.

2. Algorithms in Use

Our application uses sky maps fetched from the **Virtual Observatory** (VO), formatted appropriately and overlaid with gravitational data taken from the **LIGO-Virgo Database** of gravitational events. These are then aligned with the local sky of the user as detailed in Subsection 2.2. It is important to note that while the sky is aligned in real time (in UTC), gravitational sources are shown from a database of past events, as their display in real time would be infeasible, clearly.

2.1. Photosphere Preparation

The *Centre de Données astronomiques de Strasbourg (CDS)* provides a large number of **HiPS**. (Fernique et al. 2017) From this format, cutouts at any Level of Detail (LoD) can be computed via the online tool `hips2fits`, which generates an equirectangular projection in a standard image format such as JPG. The CDS also maintains the *Aladin* tool (Bonnarel et al. 2000), which is able to view both the HiPS and JPG formats. As for the gravitational data, probability maps associated with an event are given by the LIGO-Virgo database as all-sky images stored in the **HEALPix** projection format (Górski et al. 2005). Since the gravitational wave sky localizations are usually irregular in shape, the **Multi-Order Coverage map** (Fernique et al. 2014) is used for their efficient visualization and processing, (Greco et al. 2019) a standard of the VO which provides a multi-scale mapping based on the HEALPix sky tessellation. Thankfully, Aladin also implements an algorithm which is able to layer gravitational wave localization data (in MOC format) on top of any HiPS/JPG. This ultimately provides a visualization of the sky region in which the gravitational event has come from, and the resulting layered image, our *photosphere*, constitutes the main input to our program.

2.2. Alignment Algorithm

The photosphere obtained in Subsection 2.1 is fed into the application and used as a texture for the internal geometry of a sphere created in *Blender*. In particular, the sphere has been modeled starting from a simple plane, warping it in such a way as to reproduce the mapping from equirectangular projection onto a spherical surface. A camera is then placed at the center of this sphere and let free to rotate based on the gyroscope reading of the user smartphone. As for the alignment itself of the sphere, it is just a rotation around its origin, albeit not a trivial one. It is performed via a two-steps procedure:

1. The sphere is first aligned from the application world to the real world: the accelerometer reading of the smartphone is used to find pitch and roll, while the magnetometer provides the *magnetic North*, much like an **e-Compass**. The latter value is then compensated by the correct deviation to get the *true North*;

2. Since the photosphere image is in **ICRF**, the sphere is then rotated in such a way that it is moved to the local astronomical system of the user, also known as the **Horizontal system**. This is done by first finding the horizontal coordinates for two arbitrary, non-opposite points of the sphere expressed in equatorial coordinates, and then rotating the sphere such that these two points are aligned correctly with respect to the real world references we have found in the previous point.

3. Technical Notes

The algorithms in Subsection 2.2 have all been written in C#, since that is the programming language of the engine in use by this application, **Unity** (Goldstone 2009). This choice stems from the possibility provided by the engine to develop cross-platform, allowing for both Android and iOS releases with little changes in the code. It should also be noted that maintenance and versioning of the entire project has been done via *GitHub*. In fact, the entire project is open to consult, access, download and branch.[1]

4. Results

The final application satisfies all the requirements of Subsection 1.1. However, it is still in beta version, mostly because there are key features that we believe should be added before a proper release, as expressed in Subsection 4.2. For practical testing, the application has been executed on a pair of physical smartphones running Android, as well as a much larger number of emulated devices during pre-launch through the *Google Play Console*. It shows to be working correctly, without crashes and with good performances.

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[1] `https://github.com/ggreco77/GWsky-app`

4.1. Alignment Precision

The sensor deviations for the device running the application cause a measurement error in the alignment of Subsection 2.2. The magnetometer, in particular, may swing wildly, with at least ~7° of standard deviation on multiple runs for some devices (Ma et al. 2013). We reduce this error by repeated sampling in intervals of 0.1 seconds. To test the accuracy of the alignment in practice, we have performed a comparison using two popular augmented reality apps: *Google Sky Map* and *Stellarium*. The tests, conducted by taking independent screenshots at random positions in the sky, show a sky-alignment accuracy within a circle of radius $\sim 1^\circ$. Thus, GWSky alignment is approximately consistent with the augmented reality apps considered here.

4.2. Future Releases

The main feature planned for a future version is **Network Connectivity** against an external server to download more gravitational events, as well as **Push Service** so that, in correspondence of new events, every user of the app will receive a notification. Other minor improvements include support for *Virtual Reality*, a red light filter for a better nighttime experience and the possibility to show a greater amount of gravitational waves data via some type of HTML formatting and layout.

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