LOCALIZATION OF EM COUNTERPARTS AND GW SIGNALS: A NEW PYTHON PLUG-IN FOR ALADIN

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About 3D Volume Reconstruction

All sky images produced by LIGO-Virgo pipelines are HEALPix files, in which each pixel is related to a specific value ρ of the 2D posterior probability of having a GW source in the portion of the sky within the pixel. Therefore, since we have a complete description of 2D probability distributions for a GW event, L. P. Singer's idea [2, 3] was to introduce three more ansatz parameters: μ, *location*; σ, *scale* and N, *normalization,* from which one can compute the *conditional distribution of distance*, namely the probability of having a GW source along a line of sight.

Furthermore, combining the conditional distribution with the 2D posterior probability given by the HEALPix format, one can derive the probability that a source is within a pixel and at a distance between r and $r + dr$.

Finally, this result leads to the mathematical definition of the *probability density per unit volume for a GW source*.

Abstract

Here, a basic approach to get closer to 3D sky maps of gravitational-wave source is presented. Aladin [1] is the most used VO software for digitized astronomical images and gravitational-wave sky maps visualizer. Extending its functionality is challenging and helps in developing astronomical technical standards, as IVOA promotes. Thus, a Python algorithm has been developed to allow any Aladin user, from the expert researcher to random people just keen on astrophysics, to immediately receive information about the probability distributions of having a GW source along a line of sight in any given position of the sky map, just by clicking on it.

Figure 3: Final output: *Sky localization map of a GW event, visualized in Aladin sky atlas.*
The light-blue circle highlights the position that has been clicked.
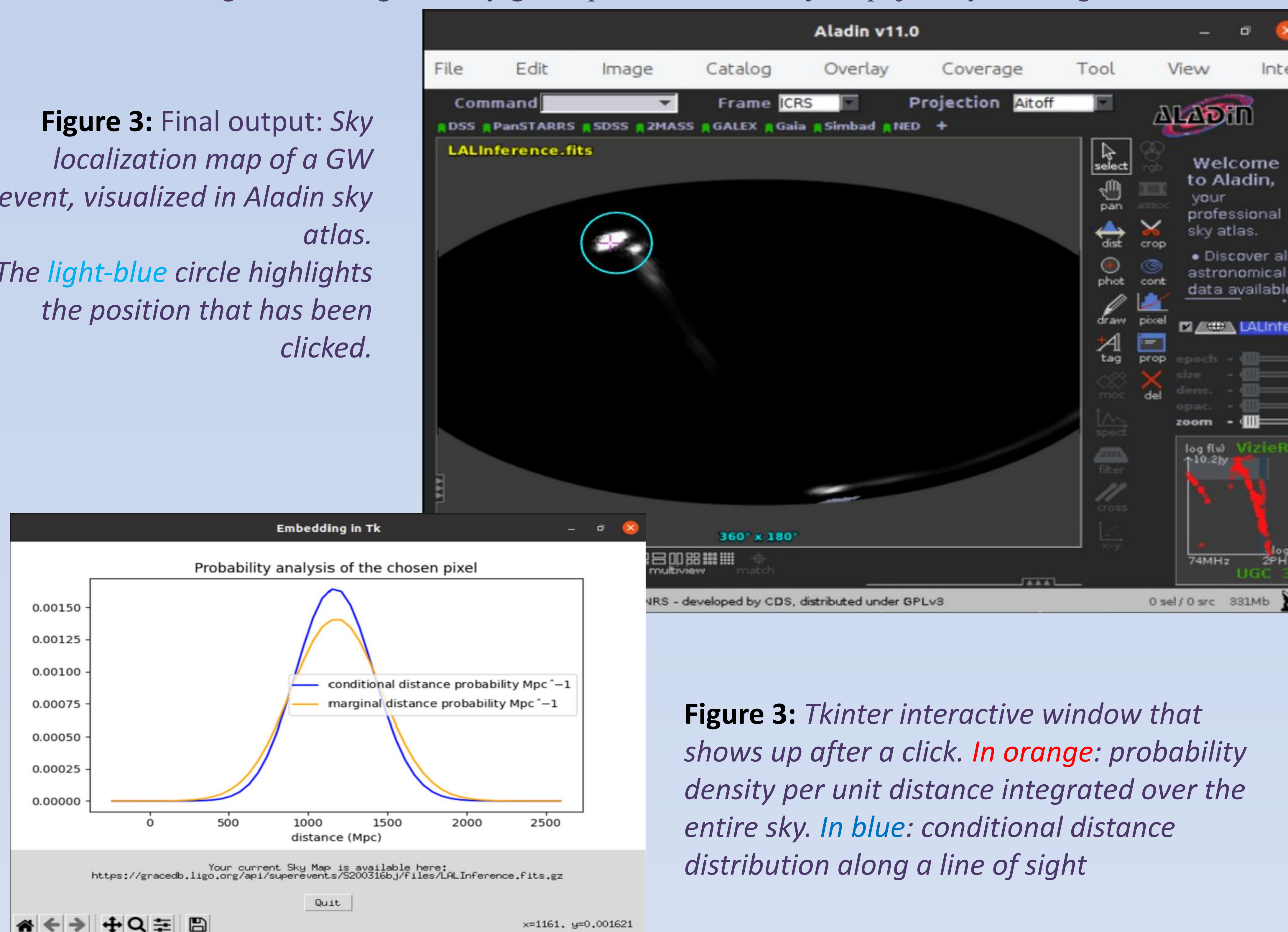

Figure 3: *Tkinter interactive window that shows up after a click. In orange: probability density per unit distance integrated over the entire sky. In blue: conditional distance distribution along a line of sight*

The Plug-in

Our proposal of 3D volume-reconstructed sky map consists in the implementation of a Python algorithm, which provides graphs of the conditional and the marginal distance probability for any position in the sky of any GW sky map.

Just by clicking on whichever spot of a GW sky map on Aladin, a Tkinter [4] interactive widget pops up and the probability analysis of the chosen pixel is available on a window. Moreover, a reference to the GW sky map in the background is provided.

The entire algorithm relies on SAMP [5] messaging connections to enable Pyhton environment and Aladin to interoperate and exchange data, such as the coordinates of the clicked position.

The complete algorithm is available at a public GitHub repository: https://github.com/ariannabartolomei/ariannabartolomei.

References

[1] Centre de Donn´ees astrominiques de Strasbourg, *Aladin Sky Atlas – Overview,* https://aladin.u-strasbg.fr.
[2] Leo P. Singer et al., *Going the Distance: Mapping Host Galaxies of LIGO and Virgo Sources in Three Dimensions Using Local Cosmography and Targeted Follow-up,* 2016, *http://dx.doi.org/10.3847/2041-8205/829/1/L15*
[3] Leo P. Singer et al., *Supplement: Going the Distance: Mapping Host Galaxies of LIGO and Virgo Sources in Three Dimensions Using Local Cosmography and Targeted Follow-up,* 2016, *arXiv:1605.04242*
[4] Python Software Foundation, *Tkinter - Python interface to Tcl/Tk,* 2001-2021, https://docs.python.org/3/library/tkinter.html.
[5] Taylor, M. et al., *Simple Application Messaging Protocol version 1.3,* 2011-2021, https://docs.astropy.org/en/stable/samp/index.html
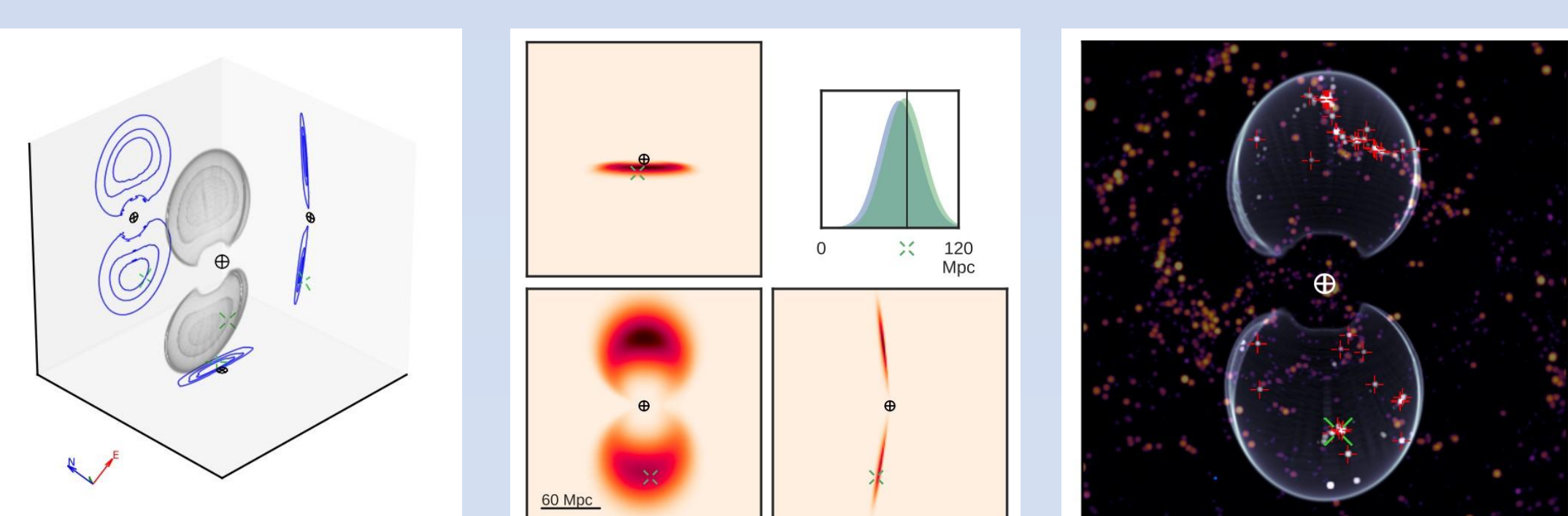
Figure 1: a. *Volume rendering of the 20%, 50% and 90% credible regions of a typical early ALIGO event;* **b.** *Marginal posterior distribution, namely, the conditional distance distribution integrated all over the sky, with respect to the planes showed in* **a**; **c.** *Volume rendering of the 90% credible region, superimposed over the correspondent galaxy map.*

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