Analysis framework for Multi-messenger Astronomy with IceCube

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Abstract

We introduce a python-based unbinned-likelihood analysis package called i3mla (IceCube Maximum Likelihood Analysis). i3mla is designed to be compatible with the Multi-Mission Maximum Likelihood (3ML) framework, which enables multi-messenger astronomy analyses by combining the likelihood across different instruments. By making it possible to use IceCube data in the 3ML framework, we aim to facilitate the use of neutrino data in multi-messenger astronomy

Features of i3mla

- Using Python 3.7+ features
- Highly Modularized
- Flexible Instrument Response Functions modeling
- Compatible with 3ML framework

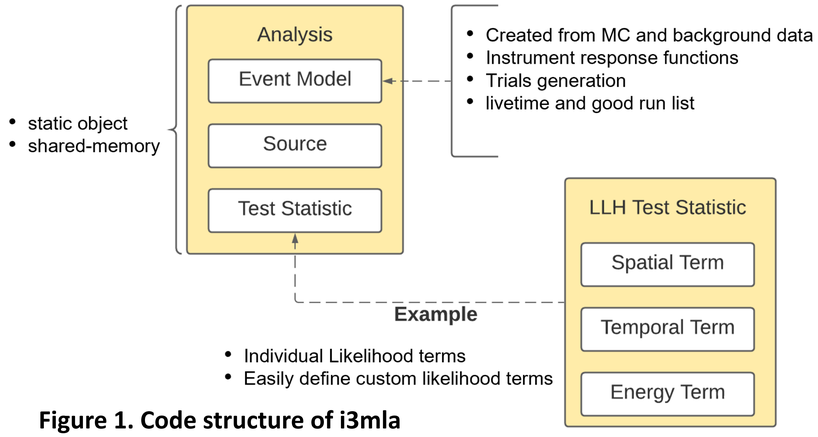

Figure 1. Code structure of i3mla

References

[1] A. Abeysekara, A. Albert, R. Alfaro, C. Alvarez, J. Álvarez, R. Arceo, J. Arteaga-Velázquez, H. A. Solares, A. Barber, N. Bautista-Elivar, et al. The Astrophysical Journal 843 no. 1, (2017) 39

[2] A. Abeysekara, A. Albert, R. Alfaro, C. Alvarez, J. Álvarez, J. A. Camacho, R. Arceo, J. Arteaga-Velázquez, K. Arunbabu, D. A. Rojas, et al. The Astrophysical Journal 881 no. 2, (2019) 134.

Testing signal bias and spectral bias

We inject a power law spectrum with a range of spectral indices at the location of TXS 0506+056 using a 3 year time window and fit it with a power law at the exact location to test for a potential bias in the normalisation and spectral index of the best-fit parameters. For E^-2.5 and E^-3 spectrum, we found no bias in best-fit spectral index but an underestimation of number of signal injected. For E^-2 specturm, we found underestimation of the spectral index but no bias in number of signal injected.

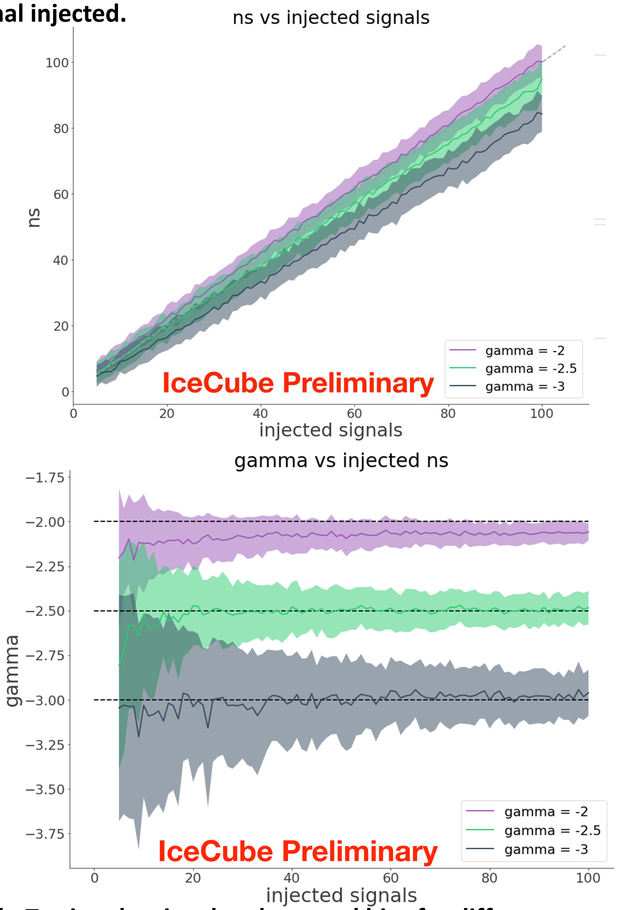

Figure 2a,2b. Testing the signal and spectral bias for different spectral indices

Example joint-fit with HAWC Crab data

We inject a neutrino source with the same Log-parabola spectral shape as observed in the gamma rays [1]. We use the HAWC public dataset of the Crab Nebula [2] and fit the flux normalisation and spectral parameters using 3ML and i3mla. We constraint the neutrino spectral shape to be the same as the gamma rays. A neutrino flux reaching a value comparable with the 90% (50%) of the gamma-ray flux from Crab Nebula would match the IceCube 3 sigma discovery potential (sensitivity) assuming a livetime of 545 days.

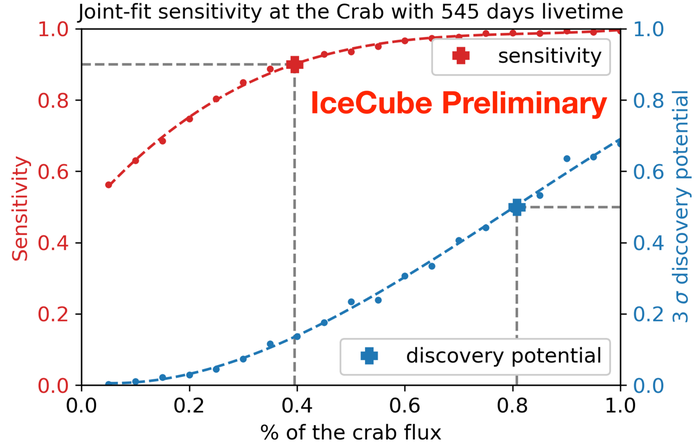

Figure 3. Sensitivity and 3σ discovery potential of IceCube when Joint-fit

Conclusion

We presented a new IceCube analysis software i3mla that is fully compatible with 3ML framework. i3mla aims to make multi-messenger analysis with neutrinos more accessible. We tested the potential signal bias and spectral bias of the software. We show an example joint-fit with HAWC public dataset to validate the joint-fit capability of the software framwork.