Hasasia: A Python package for Pulsar Timing Array Sensitivity Curves

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DOI: 10.21105/joss.01775

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Submitted: 20 September 2019
Published: 23 October 2019

In partnership with

AMERICAN ASTRONOMICAL SOCIETY

This article and software are linked with research article DOI 10.3847/1538-4357/abdc29, published in the Astrophysical Journal.

Summary

Gravitational waves are quickly changing the way that we view the wider universe, enabling observations of compact objects in highly relativistic scenarios. Gravitational-wave detectors measure the minuscule, time-dependent perturbations to the spacetime metric. These detectors have long been characterized by a sensitivity curve, a plot in the frequency domain, which summarizes their ability to *detect* a given signal. Pulsar timing arrays (PTAs) are collections of highly precise millisecond pulsars regularly monitored for shifts in the spin period of pulsars indicative of gravitational waves in the nanohertz regime. See Hobbs & Dai (2017) and Burke-Spolaor & others (2019) for a review of pulsar timing arrays and the astrophysics of nanohertz gravitational waves. The sensitivity curves for PTAs are often overly simplified in the literature, lacking detailed information about the fit to a pulsar's timing parameters and assuming identical pulsar noise characteristics.

`Hasasia` is a Python package for calculating and building accurate PTA sensitivity curves, largely based on the formalism presented in (Hazboun et al., 2019). This software is designed for use by astronomers interested in sources of nanohertz gravitational waves and PTA data analysts alike. It uses standard Python packages, such as `Numpy` (Oliphant, 2006–) and `Astropy` (Astropy Collaboration et al., 2018) to build sensitivity curves from generic PTAs of individually constructed pulsars. `Hasasia` includes the ability to add time-correlated (red) noise into the noise power spectral density of individual pulsars. The strongest expected signal in the PTA band is the stochastic gravitational wave background from supermassive binary black holes, which is also modeled as a red noise process. Therefore, it is important to take low-frequency noise into account when assessing the sensitivity of a PTA.

The API is designed with a general astrophysics audience in mind. A number of "standard" PTA configurations are included as part of the package, including the NANOGrav 11-year data, with more coming soon. It has already been made a requirement of another Python package (Kaiser et al., 2019–). The various sensitivity curve objects in `hasasia` allow the calculation of signal-to-noise ratios for a generic user-defined gravitational-wave signal. Though the user interface is designed with the non-expert in mind, a PTA data analyst can use real pulsar timing data to assess the sensitivity of a given PTA.

Acknowledgements

JSH and JDR acknowledge subawards from the University of Wisconsin-Milwaukee for the NSF NANOGrav Physics Frontier Center (NSF PFC-1430284). JDR also acknowledges support from start-up funds from Texas Tech University. TLS acknowledges support from NASA 80NSSC18K0728 and the Hungerford Fund at Swarthmore College. Finally, we thank Robert Caldwell, Rutger van Haasteren and Xavi Siemens for useful discussions and Justin Ellis for sharing some preliminary code.

References

Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., Günther, H. M., Lim, P. L., Crawford, S. M., Conseil, S., Shupe, D. L., Craig, M. W., Dencheva, N., Ginsburg, A., VanderPlas, J. T., Bradley, L. D., Pérez-Suárez, D., de Val-Borro, M., Aldcroft, T. L., Cruz, K. L., Robitaille, T. P., Tollerud, E. J., … Astropy Contributors. (2018). The Astropy Project: Building an Open-science Project and Status of the v2.0 Core Package. *156*, 123. https://doi.org/10.3847/1538-3881/aabc4f

Burke-Spolaor, S., & others. (2019). The Astrophysics of Nanohertz Gravitational Waves. *Astron. Astrophys. Rev.*, *27*(1), 5. https://doi.org/10.1007/s00159-019-0115-7

Hazboun, J. S., Romano, J. D., & Smith, T. L. (2019). *Realistic sensitivity curves for pulsar timing arrays*. http://arxiv.org/abs/1907.04341

Hobbs, G., & Dai, S. (2017). Gravitational wave research using pulsar timing arrays. *Natl. Sci. Rev.*, *4*(5), 707–717. https://doi.org/10.1093/nsr/nwx126

Kaiser, A., McWilliams, S., & Hazboun, J. (2019–). *Gwent: Gravitational wave dEtector desigN toolkit*. https://gwent.readthedocs.io/

Oliphant, T. (2006–). *NumPy: A guide to NumPy*. USA: Trelgol Publishing. http://www.numpy.org/