Outline

Title: Bayesian Inference and MCMC Methods in Astrophysics

1. Introduction

    - Explain how Quantitative analysis is the backbone of research in modern Astrophysics.
    - Paragraph about the history of QA in physics (perferably astro), and the trend of problems coming into modern day.
    - Explain why this review will be focusing spcifically on Bayesian and MCMC: Their popularity in the field, flexibility, and compatibility with many types of problems.
    - Explain the structure of the rest of the paper.
        - Methodology section will cover the mathematical theory behind BI and MCMC. It will also explain how to implement them using Python using simple problems as examples.
        - For each case study, include a paragraph or so sumary about the general background, the problem, and how QA is helping solve it or advance research in the field.

2. Methodology (citing vonToussant, Brewer)

    (a) Bayesian Statistics

    - Review of Bayesian statistics and BI.
    - Include some example problems.

    (b) Markov Chain Monte Carlo

    - Explain the math and methodology of Monte Carlo methods.
    - Show how Markov Chain Monte Carlo builds off it.
    - Provide examples and the implementation of simple MCMC algoritms (like the Metropolis Algorithm)

3. Case Studies

    (a) Bayesian Frameworks for Exoplanet detection
    (citing Ruffio, Jones, Li)

- The major challenge in exoplanet detection is distinguishing planetary signals from stellar activity. (cite Li)
- MCMC methods are being used to create joint models of stellar and planetary signals (cite Jones)
- Bayesian models are being used to destinguish between stars and planets too (cite Ruffio)

(b) Cosmological Parameter Estimation with MCMC Methods
(citing Akeret, Christensen, Efstathiou)

- CMB parameter estimation faces a problem where different combinations of cosmological parameters can produce nearly identical CMB power spectra. (geometric degeneracies) (cite Efstathiou)
- MCMC methods are being used for more efficient parameter estimation when such degeneracies are present (cite Akeret and Christensen)

(c) Bayesian approach to Gravity wave detection
(citing Wong,Christensen)

- G-Wave data needs to be fitted to a waveform across a high-dimensional parameter space. This requires extreme computation costs. (cite Christensen)
- Gradient-based MCMC is being used to reduce computation time (cite Wong)

4. Conclusion

- MCMC methods are evolving to address increasing computational demands, as seen in the three case studies.
- Talk about areas of further work.

References

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4. Christensen, Nelson, and Renate Meyer. “Parameter Estimation with Gravitational Waves.” Reviews of Modern Physics, vol. 94, no. 2, 2022, 025001.

5. Efstathiou, George. “Challenges to the ΛCDM Cosmology.” Philosophical Transactions of the Royal Society A, 2024, arXiv:2406.12106.

6. Jones, D. E., D. Stenning, E. B. Ford, R. L. Wolpert, T. J. Loredo, C. Gilbertson, and X. Dumusque. “Improving Exoplanet Detection Power: Multivariate Gaussian Process Models for Stellar Activity.” The Annals of Applied Statistics, 2022.

7. Li, J., et al. “Direct Imaging Challenges: Disentangling Embedded Protoplanets from Disk Structures with MagAO-X Hα.” Proceedings of SPIE: Adaptive Optics Systems IX, 2024.

8. Ruffio, Jean-Baptiste, et al. “A Bayesian Framework for Exoplanet Direct Detection and Non-detection.” The Astronomical Journal, vol. 156, no. 196, Nov. 2018, pp. 1-16.

9. von Toussaint, Udo. “Bayesian Inference in Physics.” Reviews of Modern Physics, vol. 83, no. 3, 2011, pp. 943-999.

10. Wong, Kaze W. K., Maximiliano Isi, and Thomas D. P. Edwards. “Fast Gravitational Wave Parameter Estimation without Compromises.” arXiv:2302.05333, 13 Feb. 2023.