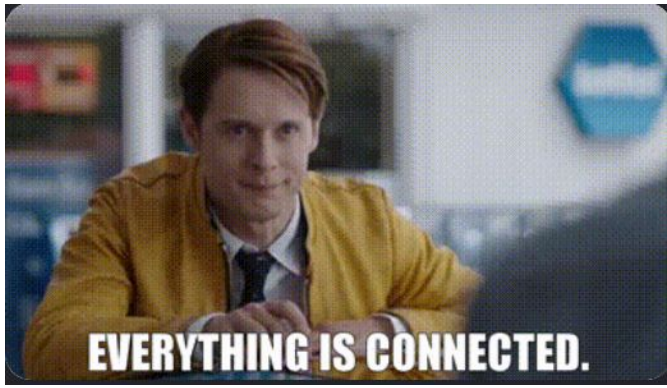
Observational astrophysics & Astrostatistics



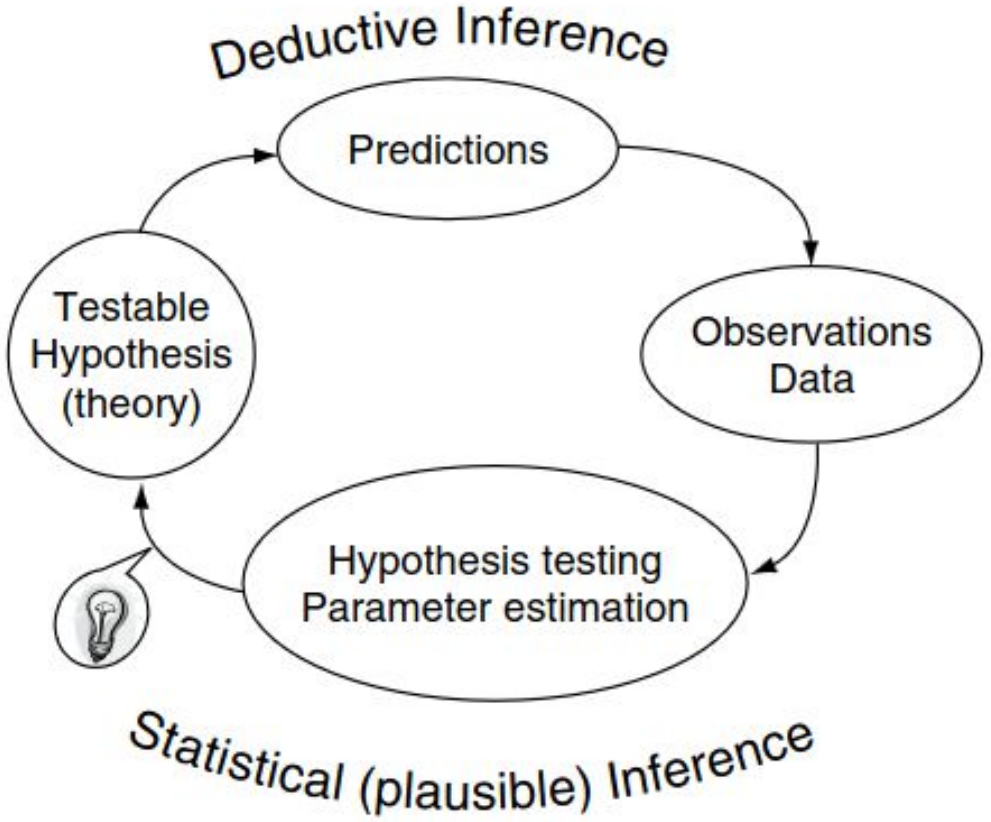


Figure 1.1 The scientific method.

Bayesian Probability Theory (BPT)

BPT = a theory of extended logic

Deductive logic is based on Axiomatic knowledge.

In science we never know any theory of nature is true because our reasoning is based on incomplete information.

Our conclusions are at best probabilities.

Any extension of logic to deal with situations of incomplete information (realm of inductive logic) requires a theory of probability.

Credit: Phil Gregory Lectures

What this course is about

- Turning photons, counts and catalogues into defensible physical statements
- The statistics behind every error bar, detection claim and model comparison you will read or write
- Modern tools: Python, Bayesian inference, MCMC, public archives
- Hands-on: real X-ray and multi-wavelength data from the first weeks

By the end you should be able to

- Choose the right likelihood for your data
- Quote an error bar and say what it means
- Decide whether a signal is real — and how sure you are
- Spot mistakes on other peoples work :)

Course map

Part I — Foundations	Weeks 1–3	Probability & Bayes · likelihood & goodness of fit · Bayesian inference & model comparison
Timing	[weeks]	Light curves, periodicity searches, noise
Correlations & lags	[weeks]	Cross-correlation, time lags between bands
Spectral analysis	[weeks]	Fitting counts spectra, response files, model selection
Catalogues & VO	[weeks]	Archive and catalogue access, cross-matching
Dimensionality reduction	[weeks]	Structure in large samples
Proposals & simulations	[weeks]	Statistical considerations when designing an astrophysical experiment

How you are assessed

Weekly

exercises — simulation-based, submitted as code + short report

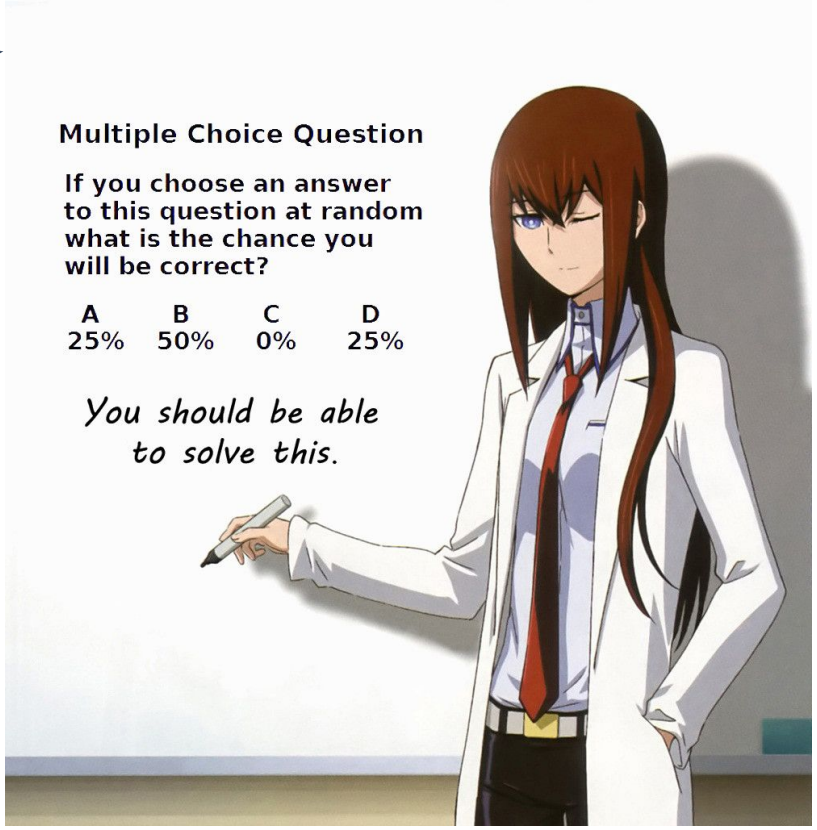
Week 4

short theory exam on the foundations (AI-free)

Final

written or oral exam (AI-free)

- Weights:
  20% Written exam, Nov 20
  50% Weekly assignments,
  30% Final oral exam/discussion (Sometime in January)
- Deadlines and submission: [TBD]
- Oral checks may be used: you must be able to explain everything you submit



Tools, reading and AI use

Tools

- Python (numpy, scipy, matplotlib, astropy)
- Jupyter notebooks
- Public archives: HEASARC, XMM, Chandra, GAIA

Reading

- Kashyap (2020), Basics of Astrostatistics — Part I backbone /quick cheat sheet
- Modern Statistical Methods for astronomy - with R applications
- Phil Gregory, Bayesian Logical Data Analysis for the Physical Sciences (recommended, but not freely available)

—

- Schmidt & Völschow (2021), Python refresher
- Further papers/books per week:

AI tools

- Allowed for syntax, debugging, documentation
- Statistical and physical reasoning stays with you
- Disclose use in every submission
- Full policy: Week 1

Reading

- Bambi, C. (ed.), Tutorial Guide to X-ray and Gamma-ray Astronomy: Data Reduction and Analysis, Springer, Singapore, 2020. https://doi.org/10.1007/978-981-15-6337-9 — including Kashyap, V. L., "Basics of Astrostatistics" (Ch. 6), https://doi.org/10.1007/978-981-15-6337-9_6 https://link.springer.com/chapter/10.1007/978-981-15-6337-9_6

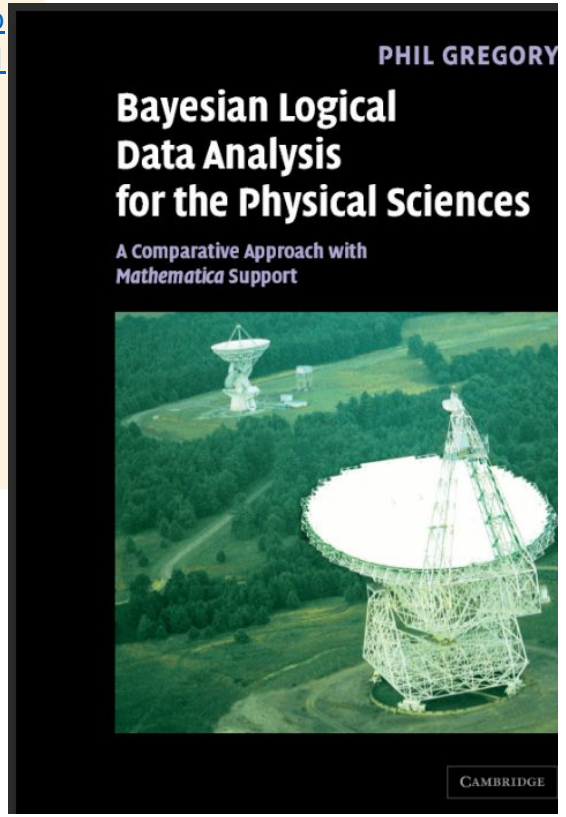
- Chattopadhyay, A. K. & Chattopadhyay, T., Statistical Methods for Astronomical Data Analysis, Springer Series in Astrostatistics 3, Springer, New York, 2014. https://doi.org/10.1007/978-1-4939-1507-1 https://link.springer.com/book/10.1007/978-1-4939-1507-1

- Meher, S. K. & Panda, G., "Deep learning in astronomy: a tutorial perspective," Eur. Phys. J. Spec. Top. 230, 2285–2317 (2021). https://doi.org/10.1140/epjs/s11734-021-00207-9 https://link.springer.com/article/10.1140/epjs/s11734-021-00207-9

- Schmidt, W. & Völschow, M., Numerical Python in Astronomy and Astrophysics: A Practical Guide to Astrophysical Problem Solving, Undergraduate Lecture Notes in Physics, Springer, Cham, 2021. https://doi.org/10.1007/978-3-030-70347-9 https://link.springer.com/book/10.1007/978-3-030-70347-9

- Eric D. Feigelson, G. Jogesh Babu - Modern Statistical Methods for astronomy - with R applications https://www.cambridge.org/core/books/modern-statistical-methods-for-astronomy/941AE392A553D68DD7B02491BB66DDEC
  (see also: https://arxiv.org/abs/1205.2064)
- Phil Gregory, **Bayesian Logical Data Analysis for the Physical Sciences**
  https://www.cambridge.org/gr/universitypress/subjects/statistics-probability/statistics-physical-sciences-and-engineering/bayesian-logical-data-analysis-physical-sciences-comparative-approach-mathematica-support?format=PB&isbn=9780521150125#resources

- Further papers/books per week:
  https://arxiv.org/abs/1012.3754
  https://arxiv.org/abs/1703.09824



About this Course

"Computing"

Statistics and data analysis are naturally computationally intensive.
The class of problems you can solve by hand is very, very small!
You will need to write your own programs or adapt existing tools (ex. python) to complete the HW assignments.

I will assume that you know some high-level programming language (e.g. C, C++, python, FORTRAN, Java), or that you are willing and ready to learn one as you go.
I am joking Python is fine, and I don't care which you use.

I will try my best to answer general questions about what approach you might take, but I will not debug your code for you. Your best resources for computing help are your fellow students (not AI please).

"Discussion Days"

The beauty of this course is that it almost certainly is relevant to your own research interests.

Accordingly I've introduced two "discussion days". For these classes I will ask you to submit questions for discussion, and we'll pick some and brainstorm together about them.

For example, if you have a relevant problem in your research you want advice about, you can share it with the class and we can discuss it together.

We can also discuss HW problems.

This will work only if people come prepared to discuss things.

Practical information

- Lectures: [Monday/Friday , 12:00-14:00 , Room 12]
- Office hours: [anytime, prior email is good]
- Course page: [https://eclass.uoa.gr/courses/PHYS388/]
- Contact: [gevas@phys.uoa.gr]
- Prerequisites: undergraduate probability; basic Python (refresher in Schmidt & Völschow Ch. 1–2)

