Statistical Methods: Assignment 3

This is the final assignment, for which help and advice is available during the tutorials. Part A is worth 20% of the final course grade and Part B is worth 40% of the final course grade.

The deadline for Part A of this assignment is the end of Sunday 30 Jan (23:59h). The deadline for Part B of this assignment is the end of Sunday 6 Feb (23:59h). Late work which is submitted up to a day after the deadline will receive a penalty of -20% of the awarded grade, while work submitted 1-2 days after the deadline will receive a penalty of -40% of the awarded grade. Work submitted later than this will not be assessed. The rubric for the assessment of all the assignments, listing the categories assessed and the requirements for each of them, is provided separately on Canvas.

What you should submit
You should submit your work via Canvas. ***For this assignment there are two separate places to upload A and B, because of the different deadlines. Be sure to submit your assignment in the right place!*** Make sure that you upload the correct files, and check that all the cells run successfully (***and in the correct order***, from start to finish) before you submit them!

When answering each question, use a cell with markdown to briefly explain your approach (a few sentences is fine) along with any assumptions you made. Explanations of your code should be included as comments (or docstrings for functions) in the code cells. Following your code and results obtained should summarise your findings (and interpret them if needed) in a markdown cell following the code cells which produce your results.

Remember that the usual plagiarism rules apply to your work: if you cut-and-paste code from somewhere/someone else you must cite the source (simply replacing variable names is not sufficient to make it your own!). We make an exception to this rule for code from the course's own material, which we allow you to use without citation. We also expect you to help each other, at least early on, and/or be inspired by methods you see online, so programming ***your own version*** (i.e. not cut and pasted) of someone else's method is fine and does not require citation.

Part A (20% of final course grade)

Do the programming challenge at the end of each episode, 10, 11 and 12. Challenge 12 is more extensive than the others, so the split in weighting for the three will be 5%/5%/10%.

Part B (40% of final course grade)

For this final Part B, you have each been given a set of 4 simulated data files which represent data from a hypothetical future gamma-ray space observatory (a distant successor to the *Fermi* mission[1]). This powerful new mission is optimized to study the gamma-ray bursts (GRBs) associated with extreme cosmic events such as hypernovae and binary neutron star mergers, in order to search for new physics.

The 4 data files each correspond to observations immediately following a gravitational wave event trigger which corresponds to a binary neutron star merger. Each file corresponds to 40 seconds of data following the trigger and consists of the photon arrival times in the 1st column (in seconds since the trigger) and the energies of those photons (in GeV) in the 2nd column. Some important information about the instrument:

- The energy range in which the instrument can detect photons is 10-200 GeV.
- There is a background signal (not associated with the GRB) which has a flat spectrum with a constant (in energy and time) count-rate density of 0.01 photons s^{-1} GeV^{-1}.
- The limited energy resolution of the instrument means that any narrow emission features in the spectrum will appear as Gaussians with width $\sigma = 2$ GeV.

[1] https://fermi.gsfc.nasa.gov/

- You can assume that there is no instrument dead-time for this assignment!

You also have the following information:

- Of the four binary neutron star mergers, only the first one (file ending `grb1.txt`) has a confirmed redshift (via detection of a corresponding optical transient) which is $z = 0.70$. The remaining three events do not have definite redshifts but the GW signals can be used to locate them in the following ranges: Event 2: $1.8 < z < 2.2$; Event 3: $1.25 < z < 1.55$; Event 4: $0.89 < z < 1.11$
  You can assume the probability for the binary neutron star mergers to lie at a given redshift within each of these ranges is uniform across the range.

Now use what you have learned in the course to investigate these gamma-ray bursts, to look for interesting behaviour and possible spectral features. Some scientifically-interesting questions to guide your analysis are:

1. What shape does the gamma-ray (energy) spectrum have and does it contain any emission features which could be associated with the neutron star merger? (Note: such features are purely hypothetical so you cannot look this up!).
2. Can you determine more precise redshifts for bursts 2-4? Remember that the redshift shifts the energy of photons by multiplying the rest-frame photon energies by a factor $(1 + z)^{-1}$.
3. What about the burst profile (that is, the time-variation of the photon count rate from the burst), does it show any differences between the different bursts? Do they follow a pattern?
4. Does the gamma-ray spectral shape change significantly during the burst? In what way?

Note that the optimal analysis will involve model-fitting. You can assume that any priors on parameters are uniform so that standard maximum likelihood estimation methods will be adequate. However, you are otherwise free to use whatever methods you think are appropriate to study the data and try to answer these questions in an optimal way. Most important is that you do not just make qualitative and unsupported statements about the data: you should use what you have learned to demonstrate that your conclusions are consistent with the data and assign significances or confidence intervals/limits where appropriate. **And do not use any methods we did not cover in the course!**

Always be sure to explain and state any assumptions behind your approach **in your own words**, using markdown cells to do this and also to add your explanation/interpretation of your findings. And **do check the rubric on Canvas for how Assignment 3, part B will be graded** (it is different to the others).