RULES FOR THE TERM PROJECT
Astr 513; Spring 2016

1. In the following pages, you can find a discussion of the accelerated expansion of the Universe and its inference using Type Ia SN data. You will also find a number of ideas on how to apply your statistics skills in order to understand some interesting properties of this very important problem in physics. You only need to pick one of these applications. You are welcome to find and explore different applications, but make sure that you first get approval from your instructor.

2. You are allowed to collaborate in groups of **at most three people**. Every person can be a member of at most one group. Every group must **submit only one paper**, signed with the names of all the collaborators. Each member of the group will get the same grade on the term project. It is to your advantage to collaborate with people that complement your abilities.

3. The papers can be submitted: (a) electronically (in Adobe Acrobat [PDF] format) with all the figures included, or (b) printed and delivered **in person** to the instructor. Papers left to the mailbox of the instructor will not be accepted. **Due date is Tuesday May 10, at 5pm**

4. Papers should be printed in single-spaced format, must be 10-15 pages long, written in clear English, and complete. An incomplete paper (e.g., without graphs, without results, or without references) will not be accepted.

5. All papers must include **at least**: (i) an introduction, where the problem is stated and motivated; (ii) a section on the assumptions, the statistical question that will be addressed , and the method chosen; (iii) a section on the data used; (iv) a section on results; (v) a section with conclusions.

6. All submitted papers will be reviewed quickly by the instructor. If they are acceptable they will be posted immediately on the web page of the class. If not, they will be returned to the authors with suggestions and comments and they will not be graded.

7. **Very Important:** It is your responsibility to know of all the papers that have appeared on the web page of the class before you submit your own. It is not acceptable to submit a paper on a subject for which a paper already exists on the web page, unless (i) you submit your paper within one business day of the earlier paper, in which case both papers will be considered contemporaneous, (ii) there are mistakes in the earlier paper which you discuss and correct or (iii) you approach the same subject from a very different viewpoint. It is always easier to write the first paper on a subject, but you have to be extremely careful not to make any mistakes, because there are very few other papers to compare your results with.

8. **No kind of plagiarism will be tolerated.** If you have any questions about what constitutes plagiarism, have a look at the University of Arizona Student Code of Contact.[1]

9. You are welcome and encouraged to submit draft papers for comments.

10. The group with the best paper will receive the highest grade for the term project and a present from the instructor.

[1] You can also have a look at http://www.library.arizona.edu/help/tutorials/plagiarism/index.html for a good reference on plagiarism with examples.

Type Ia Supernovae represent some of the most useful standard candles at high redshifts. Even though their maximum luminosities are not precisely constant, empirical relations exist between different properties of their lightcurves[2]. Applying these relationships to observations of Type Ia Supernovae observed at redshifts $z \sim 1$ has given the first direct evidence for an accelerated expansion of our Universe[3].

Today, large datasets of Type Ia Supernovae exist[4] as well as independent measurements of the Hubble expansion at low redshifts[5]. Even though the inference of accelerated expansion is not controversial and has been confirmed independently using other cosmological probes (e.g., the CMB, Baryon acoustic oscillations, etc), there is still some significant statistical tension in the Supernova data.

In your projects you can explore different statistical aspects of this subject. Here are some examples (from the simplest to the most complicated):

- **Degeneracy in inference of cosmological parameters.** What is this degeneracy? What is our confidence, using these data, that a non-zero cosmological constant (or a non-zero energy density for the dark energy) is present?
- **Compare (and combine) the Type Ia SN inference to other cosmological probes.** How does the degeneracy between the inferred parameters gets reduced when additional information from other cosmological probes is incorporated in the form of Bayesian priors?
- **Compare the low- and high-redshift universe.** Is the Hubble constant one infers from the low-redshift observations statistically consistent with the one inferred from the high-redshift supernovae?
- **Outlier detection.** Are there outliers in the sample of Type Ia Supernovae? How do the cosmological parameters depend on whether one includes or excludes the outliers?

[2]Phillips 1993, ApJ, 413, L105
[3]Perlmutter et al. 1999, ApJ, 517,565; Riess et al. 1998, AJ, 116, 1009
[4]see, e.g., Betoule, M. et al. 2014, A&A, 568, A22; Rest et al. 2014, ApJ, 795, 44 and references therein.
[5]see, e.g., Riess et al. 2011, ApJ, 730, 119