Tutorial 1 – Observational Cosmology

Acceleration and Dark Energy from Supernova Data

RECREATING THE 2011 NOBEL PRIZE

Complete this tutorial using the cloud.sagemath.com account supplied to you by email. Include text descriptions and answers as latex in the worksheet.

1. Download the Union2 SNIa data from http://supernova.lbl.gov/union/figures/SCPUnion2.1_mu_vs_z.txt.

   The data is described at http://supernova.lbl.gov/union/descriptions.html#Magvsz.

2. Add an intrinsic scatter of *0.12 mag* in quadrature to the photometric errors (column three of the data file) on each supernova. This is now the appropriate error to use for each supernova for the rest of the tutorial.

3. Analytically derive the luminosity-redshift relation for a flat, matter-dominated universe with $\Omega_m = 1$ (Einstein-de Sitter). Plot the corresponding distance modulus vs z for $z < 2$. Plot the Union 2 data, with error bars, on the same plot. What can you already deduce from the plot?

4. Make a plot of $\Delta\mu$ vs z with errorbars, where $\Delta\mu = \mu(z) - \mu_{empty}(z)$ is the distance modulus residual with respect to the Einstein-de Sitter universe you computed in 3.

5. On the same plot show:
   a. a standard ΛCDM model with $H_0 = 70$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.
   b. a flat model with no dark energy, $H_0 = 70$, $\Omega_m = 1$
   c. a standard ΛCDM model with $H_0 = 60$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.

6. Explain briefly what is going on in your plot. Why do the various theoretical plots look like they do in terms of the parameters?

7. Write an MCMC code to fit for H_0 and Ω_Λ (assuming flatness) using the SNIa data.

8. Produce a 2D scatter plot for H_0 and Ω_Λ with at least 50,000 steps and a marginalized histogram for Ω_Λ. Describe the MCMC input choices you make in running your code (step sizes, starting values, priors etc…).

9. Produce 68% and 95% confidence limits for Ω_Λ and discuss your results and what they imply for dark energy. What does marginalizing over H_0 do to your constraints on Ω_Λ?

10. Now extend your MCMC code to vary curvature as well (vary Ω_Λ and Ω_m separately). Show your chain in the Ω_Λ and Ω_m plane. Explain the degeneracy that you see.