Cosmic Calibration - Statistical Modeling for Dark Energy

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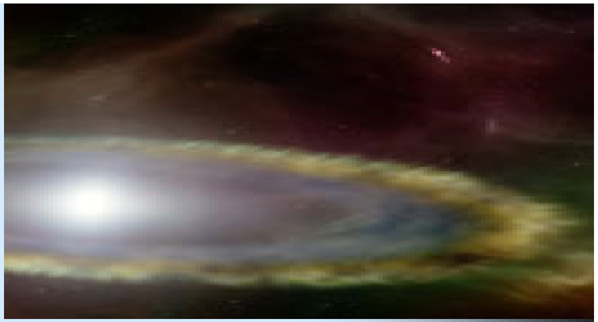
LA-UR-08-06357

Overview



-The Universe is expanding (1920s)

-Observations have been made that the Universe is expanding at an accelerating pace (1998)

-Ordinary matter would mean the Universe is decelerating

-Dark energy is the unknown driver of this acceleration

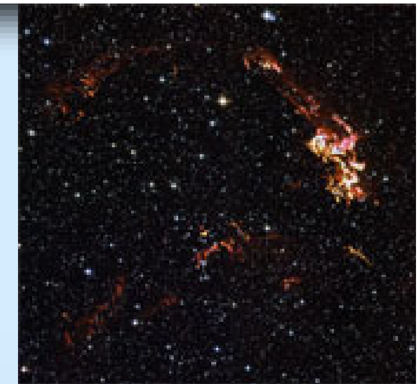
-Dark energy has an equation of state relating its pressure to density; this equation is our focus to understand more about the nature of dark energy

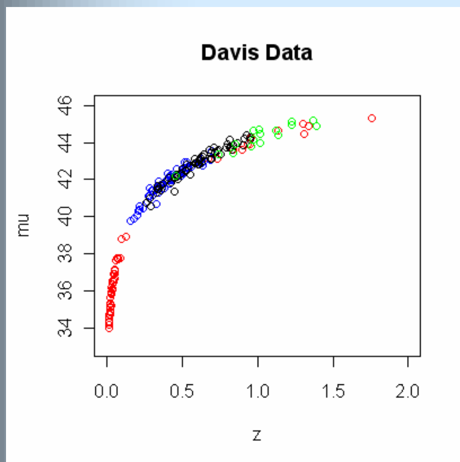
-This equation of state can be measured by studying the luminosity distance-redshift relation for supernovae

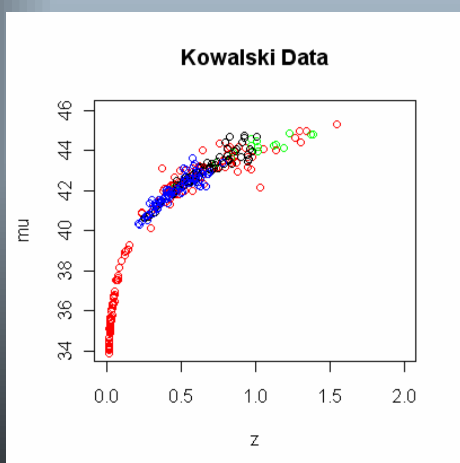
-In this study, we employ supernovae data, including measurement errors, to determine whether the equation of state is constant or not

-Our current method is based on Bayesian analysis of a differential equation and modeling w(z) directly, where w(z) is the equation of state parameter.

Datasets of Interest







The data we receive has a redshift (z) value for each supernova and a value for μ (observed distance modulus) and a standard deviation for the observational error of μ. These are summary statistics for each supernovae that have come from complex fitting algorithms of weeks worth of observational data.

The Davis data -192 supernovae (SNe Ia)
The Kowalski data – 307 supernovae (SNe Ia)

The four colors mark different observers of the supernovae. Certain astronomers focus on particular values of z to collect supernova data.

Likelihood Equation

-The main parameter of interest is w(z)

-Three other unknown parameters also have to be estimated H_0, Ω_m, and σ

-The main equation of interest is a transformation:

$$T(z,H_0,\Omega_m)=25+5\log_{10}\left(\frac{c(1+z)}{H_0}\int_0^z\left(\Omega_m(1+s)^3+(1-\Omega_m)(1+s)^3e^{3\int_0^s\frac{w(u)}{1+u}du}\right)^{-0.5}ds\right)$$

-To be able to use this equation we will need to specify a form for w(u).

-This leads to the following likelihood equation:

$$L(\sigma,w_0,H_0,\Omega_m)\propto\left(\frac{1}{\tau_i\sigma}\right)^n e^{\frac{-1}{2}\sum_{i=1}^{n}\left(\frac{\mu_i-T(z_i,H_0,\Omega_m)}{\tau_i\sigma}\right)^2}$$

Model 1: $w(u) = w_0$

Priors:

Prior sensitivity was examined and thus far it seems that the prior does not change the outcome of the estimations; we are also using rather non-informative priors with large spread:

$$\pi(w_0) \sim U(-25,2)$$
$$\pi(H_0) \sim N(73, 3.2)$$
$$\pi(\Omega_m) \sim N(0.266, 0.04)$$
$$\pi(\sigma) \sim IG(2.01, 1)$$

Posteriors: (these are obtained through MCMC Metropolis-Hastings steps)

Dataset	w_0	H_0	Ω_m	σ
Davis	(-1.43,-0.93)	(65.09,67.79)	(0.227,0.346)	(0.94,1.10)
Kowalski	(-1.37,-0.89)	(69.50,71.56)	(0.238,0.357)	(0.95,1.08)

Model 2: $w(u) = \alpha+\beta u$

Priors:

$\pi(\alpha) \sim U(-25,2)$

$\pi(\beta) \sim U(-10,10)$

$\pi(H_0) \sim N(73, 3.2)$

$\pi(\Omega_m) \sim N(0.266, 0.04)$

$\pi(\sigma) \sim IG(2.01, 1)$

Posteriors:

Dataset	α	β	H_0	Ω_m	σ
Davis	(-1.54,-0.77)	(-2.26,1.59)	(64.9,67.8)	(0.22,0.35)	(0.93,1.11)
Kowalski	(-1.53,-0.97)	(-0.52,1.98)	(69.9,72.1)	(0.21,0.35)	(0.95,1.08)

Conclusions

Is w(u) = -1 ?

- We cannot conclusively say that w(u)=-1
- But currently both Model 1 and Model 2 support this hypothesis
- The fitters being used to compile the two datasets are producing different results for H_0
- Also all methods presented here have been tested with simulated datasets and correct results have been obtained

Future Work

- More work needs to be done in explaining the role of H_0 and the differences in the two datasets
- We are in the process of fitting a Gaussian Process to w(u) instead of explicitly specifying its parametric form
- We also have found trends in the standard deviations for the measurements of μ from different observers that will be examined
- The cosmologists would like to know where more observations (on the z axis) are needed to shrink uncertainty