Discriminating Theoretical Models of Dark Energy

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Introduction

One of the most important discoveries in astronomical history is the Type Ia Supernovae (SNe Ia). SNe Ia are thermonuclear explosion that occur when a carbon, oxygen white dwarf exceeds its Chandrasekhar limit. By observing and calibrating the light curves of SNe Ia, we use the objects as standard candles. Using the available information, we receive and study the apparent magnitudes and redshifts.

How is this related to dark energy? Imagine a universe that is completely dominated by matter. The laws of physics would show that all objects would begin to attract each other, and the rate of expansion would decelerate. However, the observations of SNe Ia show that the rate of expansion is accelerating. In conclusion, there exists some form of energy of different nature from matter that is presently dominating the universe. We call this dominant energy dark energy.

Objectives

•Use both current and simulated data based on future projects

•Study the data using different parameters for dark energy using MATLAB

•Attempt to classify the different parameters for dark energy based on how efficient each parameter is in discriminating between theoretical models of dark energy.

Methods

1. Create a MATLAB code to receive SNe data
2. SNe data => χ^2 minimization
3. Find best fit parameter values $\{A_i\}$
4. Find the Likelihood in the $\{A_i\}$
5. Plot the confidence level contours on $\{A_i\}$
6. Find which $\{A_i\}$ parameter values fall within 2σ
7. Combine parameter values $\{A_i\}$ into w(z), ρ(z), or q(z)
8. Find the 2σ contours for parameters at each redshift (z)
9. Plot them against the redshift
10. Plot these over the theoretical models and rule out models

Abstract

The accelerated expansion of the universe poses one of the most challenging puzzles in cosmology today. Most theoretical models which attempt to explain the phenomenon introduce a new form of energy, which we call dark energy due to its peculiar properties. The origin of such a dark energy is completely unclear and in the absence of any single compelling theory many theoretical models of dark energy have been introduced. This poses a problem of which model best describes dark energy. Many different parameters exist to describe dark energy, such as the density (ρ), equation of state (w), and deceleration parameter (q). In order to discriminate between various theoretical models of dark energy, we attempt to understand which dark energy parameter acts as the most efficient discriminator using current and simulated Type Ia supernovae (SNe Ia) data. For this investigation I am using the "Union" compilation dataset of 307 observed SNe Ia and three simulated JDEM like datasets of 2098 observations. I have developed a MATLAB code to solve the dynamical equations for different dark energy models and to calculate the likelihood and parameters for a given model, plot confidence level contours on the parameters, and plot the relationship between parameter and the redshift . My results will allow me to gauge which parameter provides the most efficient and accurate distinction of dark energy models.

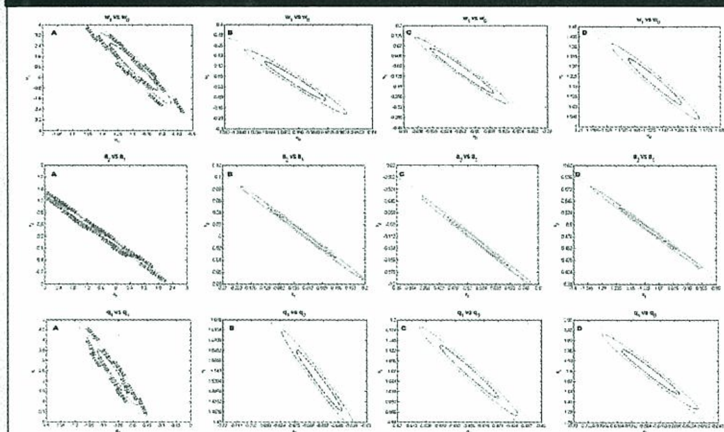

Fig. 1 — 68.3%, 95.4%, and 99.7% confidence level contours on ansatz parameters .

Top graphs are the Equation of state ansatz; Middle graphs are the dark energy density ansatz; Bottom graphs are the deceleration parameter ansatz.(A) Real data of SNe Ia observations (B) Simulated data #1 (C) Simulated data #2 (D) Simulated data #3

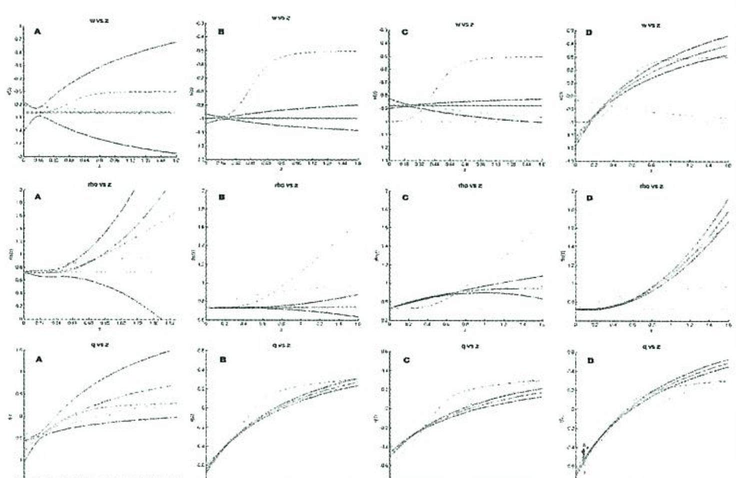

Fig. 2 — Final Results. Parameters versus the redshift; plotted against the theoretical models; blue = max error , red = best fit values, black = min error.

Dashed lines — Theoretical Models; green Cosmological Constant; orange and pink are two different Quintessence.

Top graphs are the Equation of state (w(z) vs. z); Middle graphs are the dark energy density(ρ(z) vs. z); Bottom graphs are the deceleration parameter (q(z) vs. z) (A) Real data of SNe Ia observations (B) Simulated data #1 (C) Simulated data #2 (D) Simulated data #3

Results

•By using three dark energy parameters: w (equation of state), ρ (dark energy density), and q (deceleration parameter), we tried to discriminate against three theoretical models of dark energy using current and simulated data.

•From the plots, current data cannot discriminate against any of the theoretical models.

•For simulated datasets, the parameters studied can discriminate against the theoretical models of dark energy.

•Parameter w and q do not reconstruct the true model very accurately, but ρ does reconstruct the true model more accurately.

Summary

•During this project, I investigated the "Union" compilation dataset of 307 observed SNe Ia and three simulated datasets as expected from future surveys such as JDEM.

•I studied the data using three parameters: w (equation of state), ρ (dark energy density), and q (deceleration parameter).

•By utilizing the mathematical software MATLAB, I was able to calculate the many dynamical and statistical equations of dark energy.

•I then found confidence level contours using the ansatz $\{A_i\}$ parameters.

•Finally, I combined the ansatz $\{A_i\}$ parameters into their respective parameters and plotted them against the theoretical models.

•As a result, I found that current data could not discriminate against any models.

•For simulated datasets, ρ can reconstruct the true models more accurately than w or q.

•For future work we need to marginalize over matter density

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Outline

- Introduction to Dark Energy
  - Type Ia Supernovae and the relation to DE
  - Project Background Information
- Objectives/Purpose
- Method
  - Procedure of coding, data analysis, plotting
- Results
- Summary

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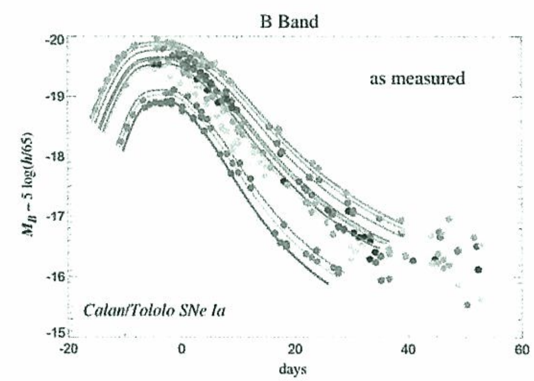
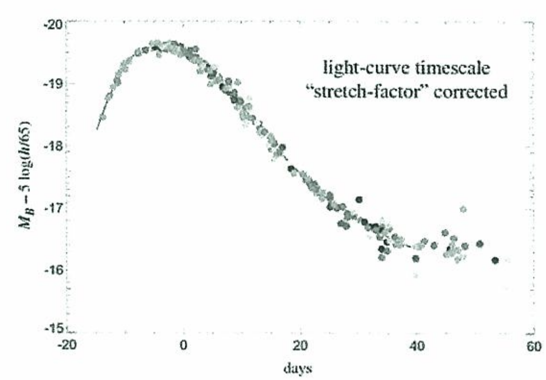
Type Ia Supernovae

- Type Ia supernovae => greatest discoveries
- SNe Ia is a thermonuclear explosion from C+O white dwarfs
- Observe multiple SNe Ia light curves => calibrate single light curve
- Obtain apparent magnitudes and redshifts





Relationship

- Imagine a universe dominated by matter
- Physics would show an attraction => rate of expansion of the universe to decelerate
- SNe Ia => rate of expansion to accelerate
- There exists some energy form of complete different nature to matter
- We call this dominant energy **Dark Energy**

Project Background

- Accelerated expansion = most challenging puzzle
- Origin of DE is unclear => Proposals of many theoretical models
- Many theoretical models attempt to explain this situation

Theoretical Models

- Cosmological constant– $w = -1$
- Quiessence – $-1 < w = \text{constant} < -1/3$
- Quintessence – scalar field
- Much more…
- Models => which model best describes DE?

Project Info

- Many parameters can describe DE
- Focusing on equation of state (w), density (ρ), and deceleration para. (q)
- Can the parameters be used to help discriminate the models?
- Investigate using 4 datasets

$\frac{d}{dz}$	Geometrical Parameter	Physical Parameter
1	$H(z) \equiv \frac{\dot{a}}{a}$; $\mathrm{Om}(z) = \frac{H^2(z)/H_0^2 - 1}{(1+z)^3 - 1}$	$\rho_{\mathrm{DE}} = \frac{3H^2}{8\pi G} - \rho_{0m}(1+z)^3$
	$\mathrm{Om}(z)_{\Lambda\mathrm{CDM}} = \Omega_{0\mathrm{m}}$	$\rho_{\Lambda\mathrm{CDM}} = \rho_{0c}(1 - \Omega_{0\mathrm{m}})$
2	$q(z) \equiv -\frac{\ddot{a}a}{\dot{a}^2} = -1 + \frac{d \log H}{d \log(1+z)}$	$w(z) = \frac{p_{\mathrm{DE}}}{\rho_{\mathrm{DE}}}$
	$q(z)_{\Lambda\mathrm{CDM}} = -1 + \frac{3}{2}\Omega_m(z)$	$w(z)_{\Lambda\mathrm{CDM}} = -1$
3	$r(z) \equiv \frac{\dddot{a}a^2}{\dot{a}^3}, s \equiv \frac{r-1}{3(q-\frac{1}{2})}; E(z) = \frac{d^2H^2(z)}{d((1+z)^3)^2}$	
	$\{r,s\}_{\Lambda\mathrm{CDM}} = \{1,0\}$; $E(z)_{\Lambda\mathrm{CDM}} = 0$	

Objectives

- Use current and simulated future data
- Study data using different parameters of DE using MATLAB
- Attempt to classify the different parameters for dark energy based on how efficient each parameter is in discriminating between theoretical models of dark energy.

Minimization

- Use MATLAB to calculate dynamical and statistical equations
- Pass datasets
- SNe data =>χ^2 minimization
- Finds the best fit ansatz $\{A_i\}$ parameter values: (w_0-w_1), (a_0-a_1), (q_0-q_1)

Contour Plots

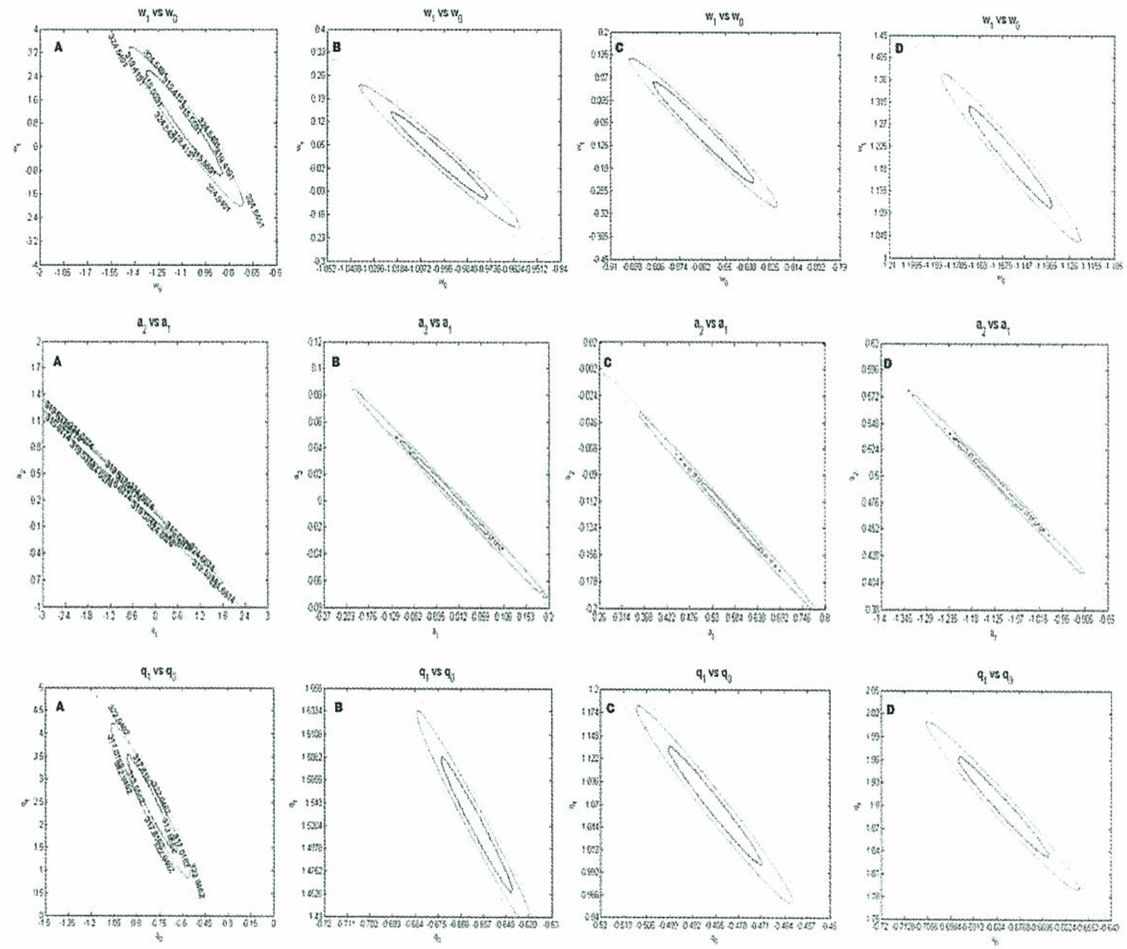
- Find a range for the ansatz $\{A_i\}$ parameters
- Calculate χ^2 value along the ranges
- Find the Likelihood in the $\{A_i\}$ parameters
- Plot the confidence level contours

Confidence Level Plots

68.3%, 95.4%, and 99.7% confidence level contours on ansatz parameters .

Top graphs are the Equation of state ansatz; Middle graphs are the dark energy density ansatz; Bottom graphs are the deceleration parameter ansatz.

(A) Real data of SNe Ia observations **(B)** Simulated data #1 **(C)** Simulated data #2 **(D)** Simulated data #3



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Combine parameters

- Find which $\{A_i\}$ parameter values fall within 2σ
- Combine the parameters: $(w_0-w_1),(a_0-a_1),(q_0-q_1)$ into $w(z)$, $\rho(z)$, and $q(z)$
- Find the 2σ contours for parameters at each redshift (z)
- Plot them against the redshift
- Compare them against the theoretical models

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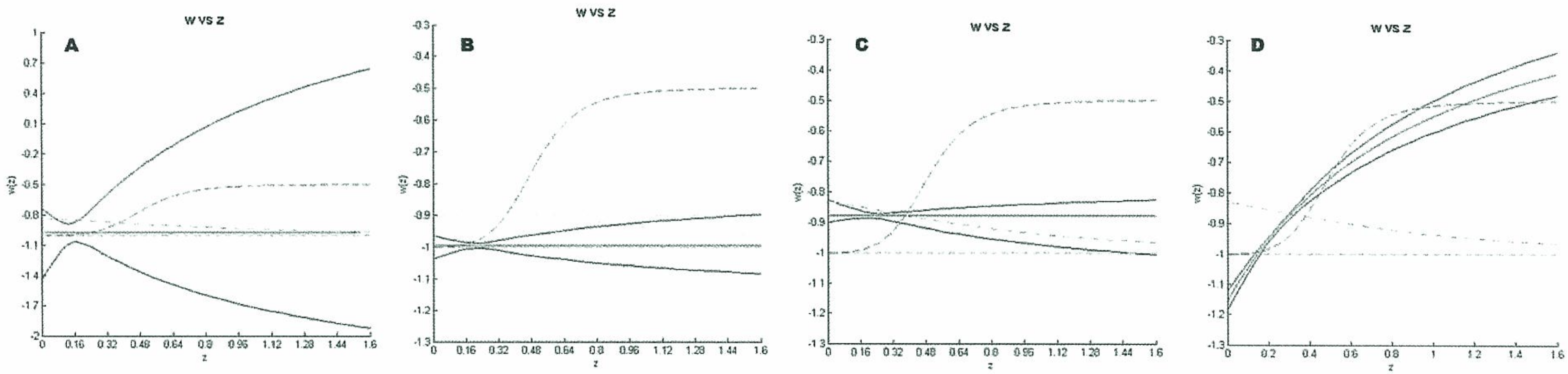
Equation of state



- Parameters versus the redshift; blue = max error , red = best fit values, black = min error.
- Dashed lines --- Theoretical Models; grey is Cosmological Constant; green is Quiescence; orange is Quintessence.
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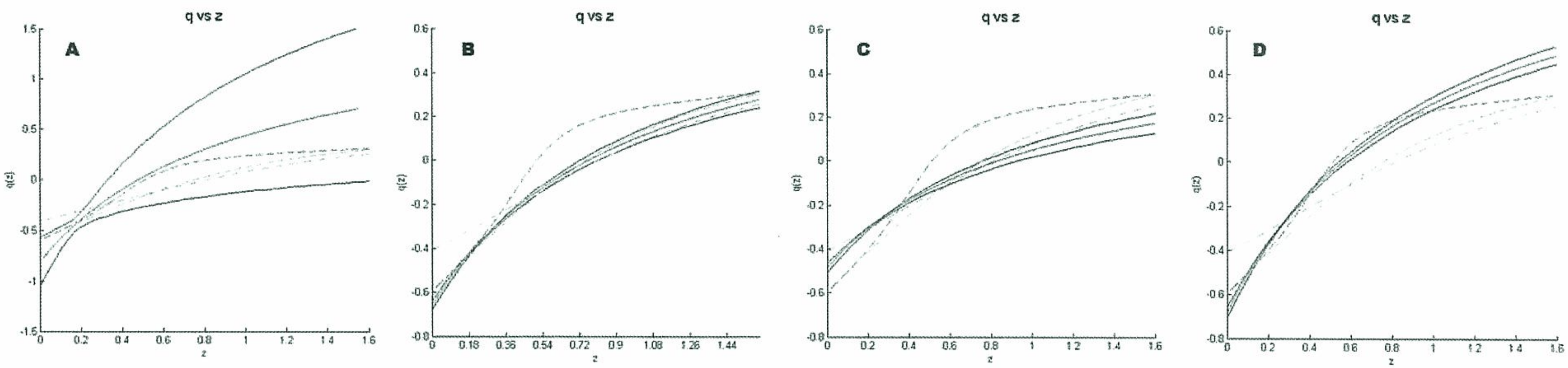
Deceleration parameter



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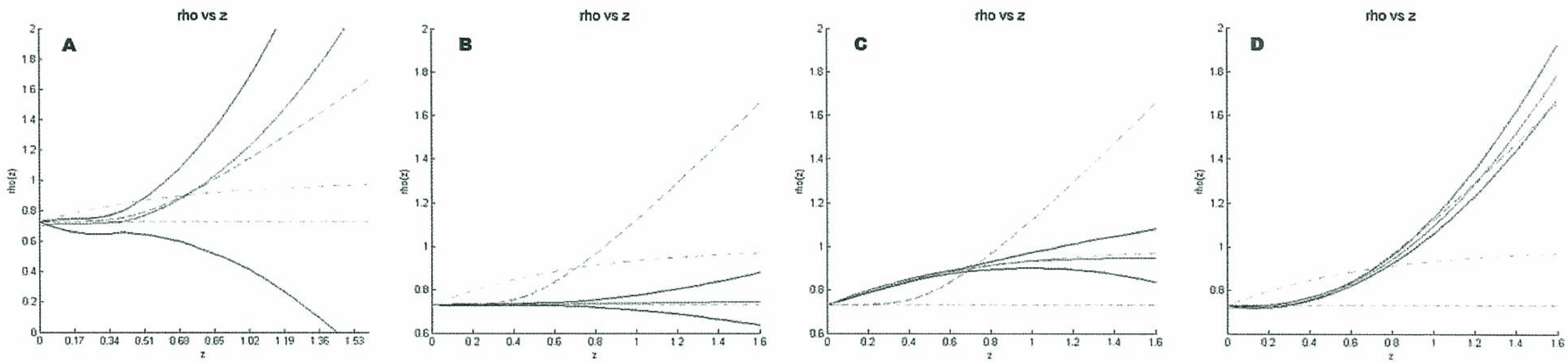
Dark energy density



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