Constraints on Principal Components of the Dark Energy Equation of State

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Phys. Rev. D86 (2012) 103004
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Santa Fe Cosmology Workshop
July 5, 2013

Outline

- Overview of Principal Components of $w(z)$
  - What are they?
  - Why use them?
  - How to apply them
- Datasets
- Parameters and Associated Priors
- Resulting Constraints
- Figures of Merit

Principal Components (PCs)

- A More General Basis
  - Model independent form for $w(z)$
  - Lets the data dictate the form
- Bin $w(z)$ into equal size bins in a
- Compute Fisher Matrix and Diagonalize
- Resulting eigenvectors $e_i(z)$ are the PCs

Huterer and Starkman (2003)

Principal Components (PCs)

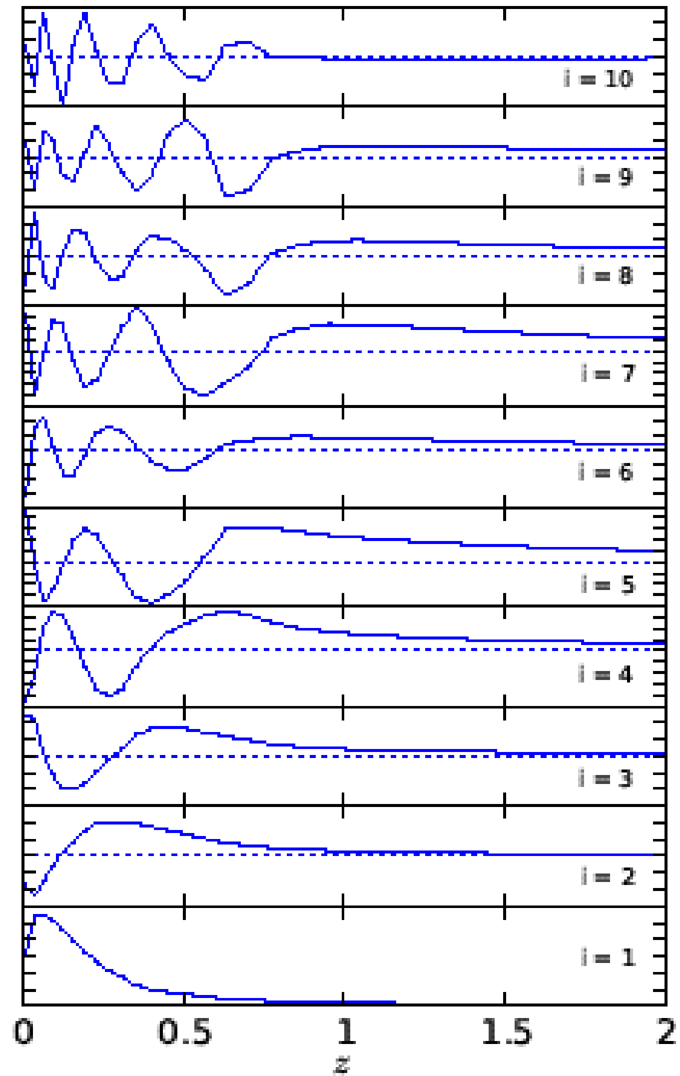
- Use a linear combination of the eigenvectors
  - $w_j = w(z_j) = -1 + \sum_{i=1}^{N} \alpha_i e_i(z_j)$
- For w_j in the bin j, $z_j - \Delta z_j/2 < z < z_j + \Delta z_j/2$, the energy density of dark energy is
  - $\rho_X(z) =$
    $\rho_X(z=0)\left(\frac{1+z}{1+z_j-\Delta z_j/2}\right)^{3(1+w_j)} \times \prod_{i=1}^{j-1}\left(\frac{1+z_i+\Delta z_i/2}{1+z_i-\Delta z_i/2}\right)^{3(1+w_i)}$
- $H^2(z) = H_0^2[(1-\Omega_M)\,\rho_X(z)/\rho_x(0) + \Omega_M(1+z)^3]$

Huterer and Starkman (2003)

Principal Components (PCs)

- For this project, $w(z)$ is piecewise constant divided into 36 bins of $\Delta a = 0.025$ starting at $a = 0.1$
  - Fiducial value: $w_i = -1$
  - Used first 10 PCs for analysis

Albrecht et. al. (2009) (FoMSWG)



Data – Supernova and more

- 472 data points
  - Magnitudes, color, stretch, redshift, etc., as well as associated statistical errors
- Associated off-diagonal systematics covariance matrix
  - Calibration, Milky Way Dust, Malmquist bias, Non-Ia contamination, etc.
- Also include constraints from BAO and CMB
- Compared constraints between diagonal statistical errors only and statistical + off-diagonal systematics

Conley et. al. (2011)

Parameters and Priors

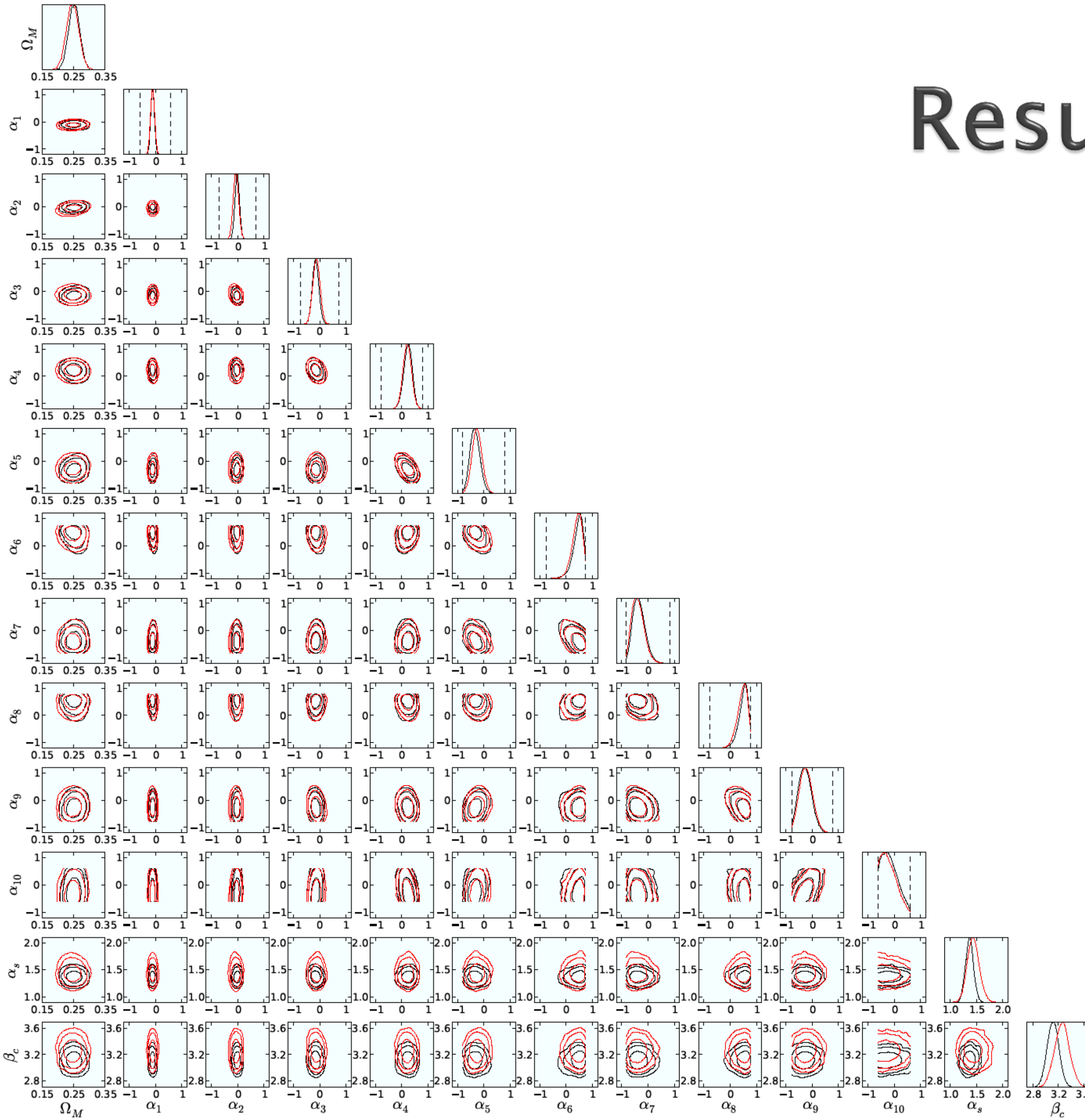
- $\{\Omega_M, \alpha_1, \alpha_2, \dots, \alpha_{10}, \mathcal{M}, \alpha_s, \beta_C\}$
  - Marginalize over $\mathcal{M}$ analytically
- Find constraints on remaining 13 parameters using Markov Chain Monte Carlo (MCMC)
- Limit MCMC to reasonable region
  - Helps with convergence
- Take prior $-2 \leq w \leq 0$
  - Based on predictions of some scalar field quintessence models
- $\Delta\alpha_i = \frac{2}{N_{z,PC}} \sum_{j=1}^{N_{z,PC}} \left|e_i(z_j)\right|$

Mortonson, Huterer, and Hu (2010)

Results

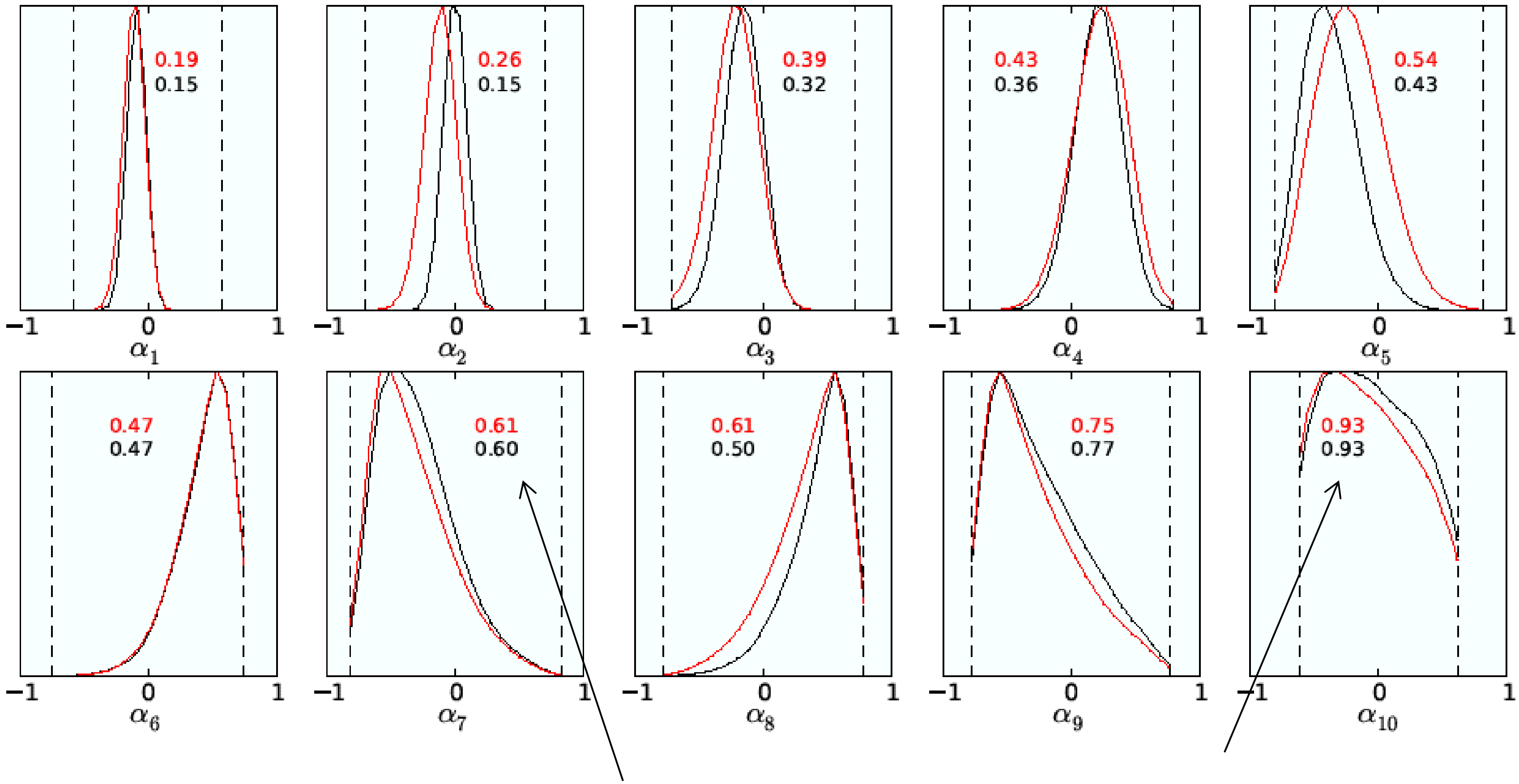
- Black contours: Constraints using statistical (diagonal) covariance between supernovae
- Red contours: Constraints using full covariance, which includes systematic (off-diagonal) covariance

Results



Ω_M
α_1
α_2
α_3
α_4
α_5
α_6
α_7
α_8
α_9
α_{10}
α_s
β_c

Results



Ratio between contour st. dev. and prior rms

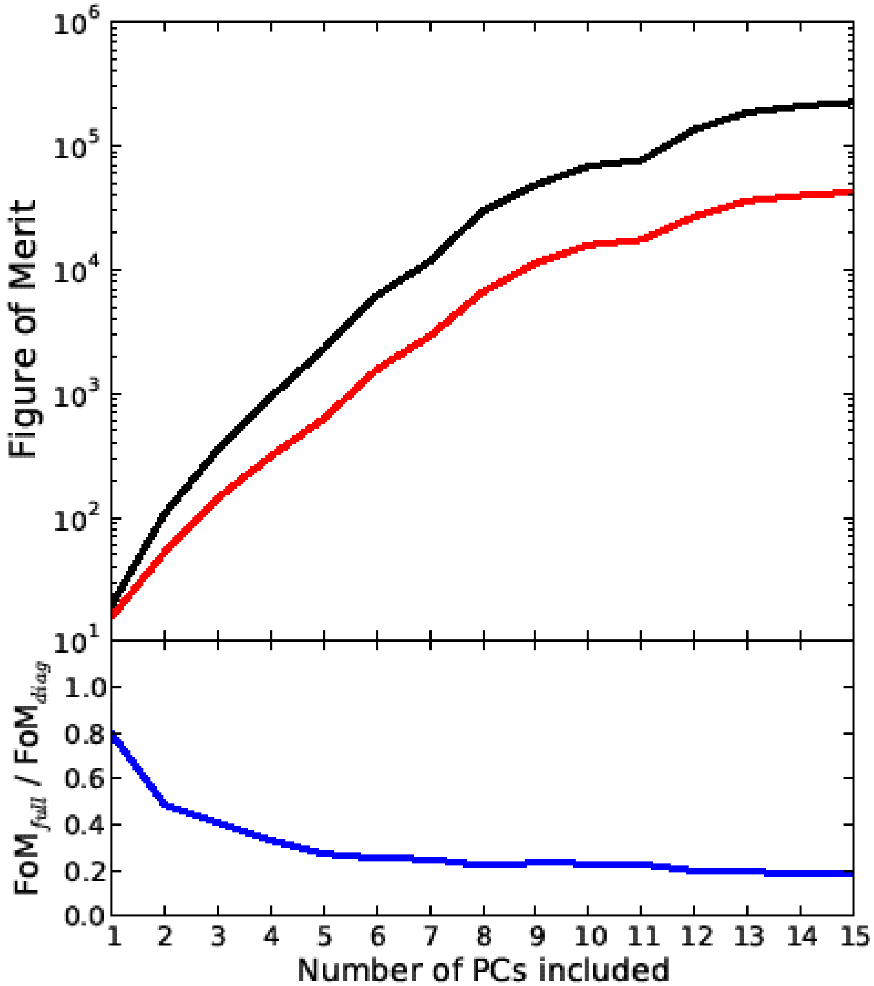
Figure of Merit

- Encapsulates the constraining power of cosmological data
- $FoM_n^{(PC)} \equiv \left(\frac{\det C_n}{\det C_n^{prior}}\right)^{-\frac{1}{2}} \sim \frac{1}{V_{95,n}}$
  - C_n is the $n \times n$ covariance submatrix of n PCs
  - $\det C_n^{prior} = \prod_{i=1}^{n} \left(\frac{\Delta\alpha_i}{\sqrt{12}}\right)^2$

Mortonson, Huterer, and Hu (2010)

Figure of Merit

- Increase with number of PCs
- Levels off with more PCs added
- Ratio levels off even faster



Conclusion

- Studied Effects of Systematics on Dark Energy Equation of State PCs
- Found that the first few PCs are constrained well within the prior
- Systematics weaken constraints, reduce FoM by a significant amount