Constraining Dark Energy Models

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Collaborators

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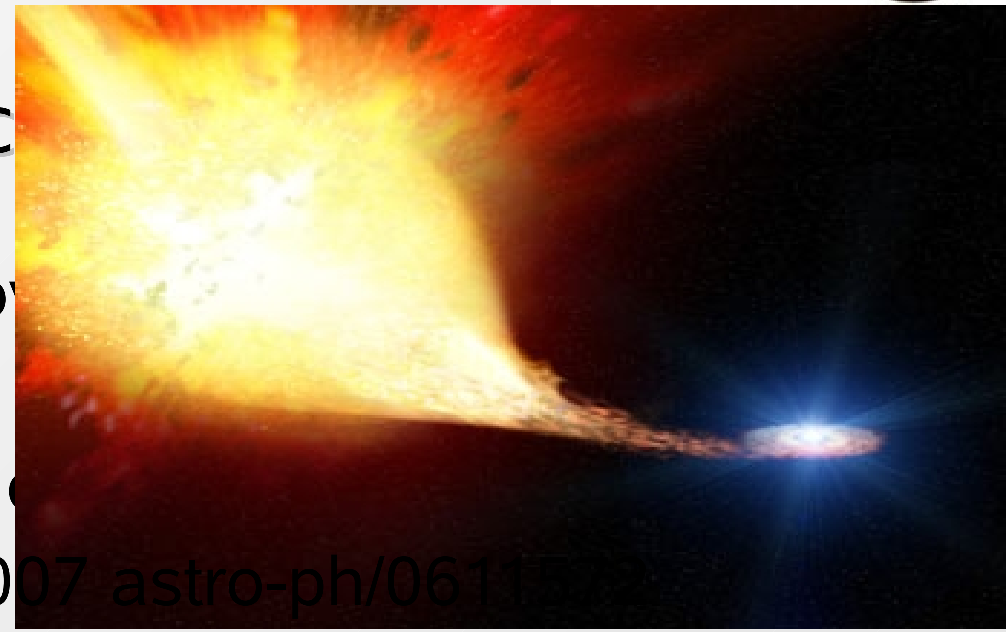
Parker, Komp & Vanzella ApJ **588** 663

Komp & Parker in preparation

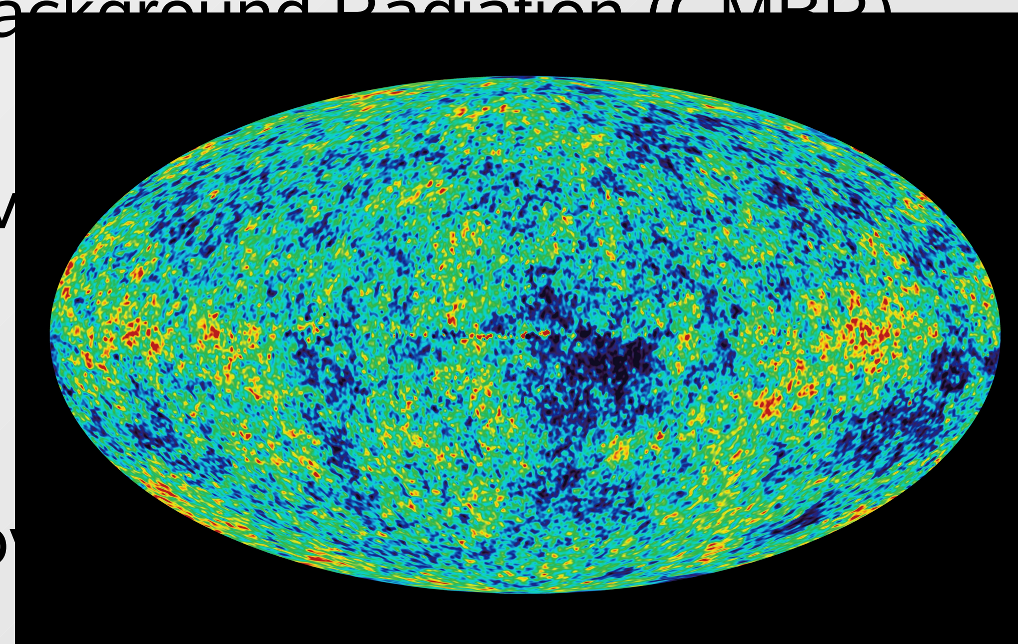
Outline

- Introduction
- Cosmology
- New Results
- Model Comparisons
- Conclusion

Introduc



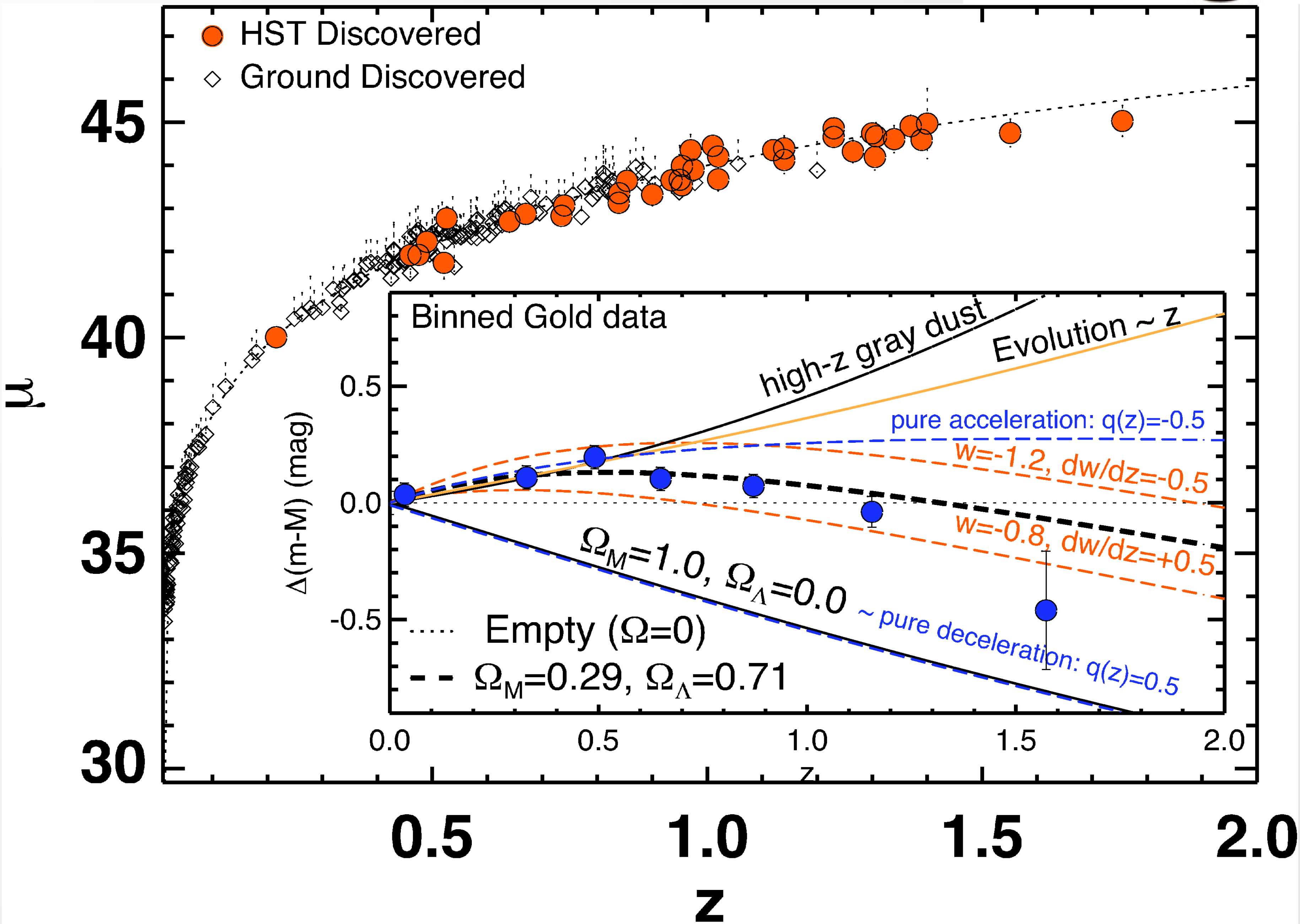
- 1998 Type-Ia supernov
- GOODS spacebased .8)
  Riess, et al. 2007 astro-ph/061
- Cosmic Microwave Background Radiation (CMBR)



Wilkinson Microwav

DASI, ACBAR, CBI

wmap.gsfc.nasa.gov



Riess, et al. astro-ph/0611572

- Models of Dark Energy:

  - Cosmological Constant:

$$\Lambda \approx 10^{-66} eV^2 \qquad w \equiv \frac{P_\Lambda}{\rho_\Lambda} = -1$$

Padmanabhan Phys. Rev. D.

  - Dark Fluid Models:

Arbey PRD **74** 043516

  - Parameterized Models

Gong Int. J. Mod. Phys. D **14** 599   Komp astro-ph/0511763

Linder PRL **90** 0913101

- Modified Gravity Models

Olmo PRD **72** 083505 Hu PRD **76** 064004

Odintsov PRL B **652** 343 Carroll et al. PRD

- Vacuum Metamorphosis Models

Super Acceleration Model (λ, ϕ)

Onemli & Woodard PRD **70** 107301

Vacuum Cold Dark Matter Model

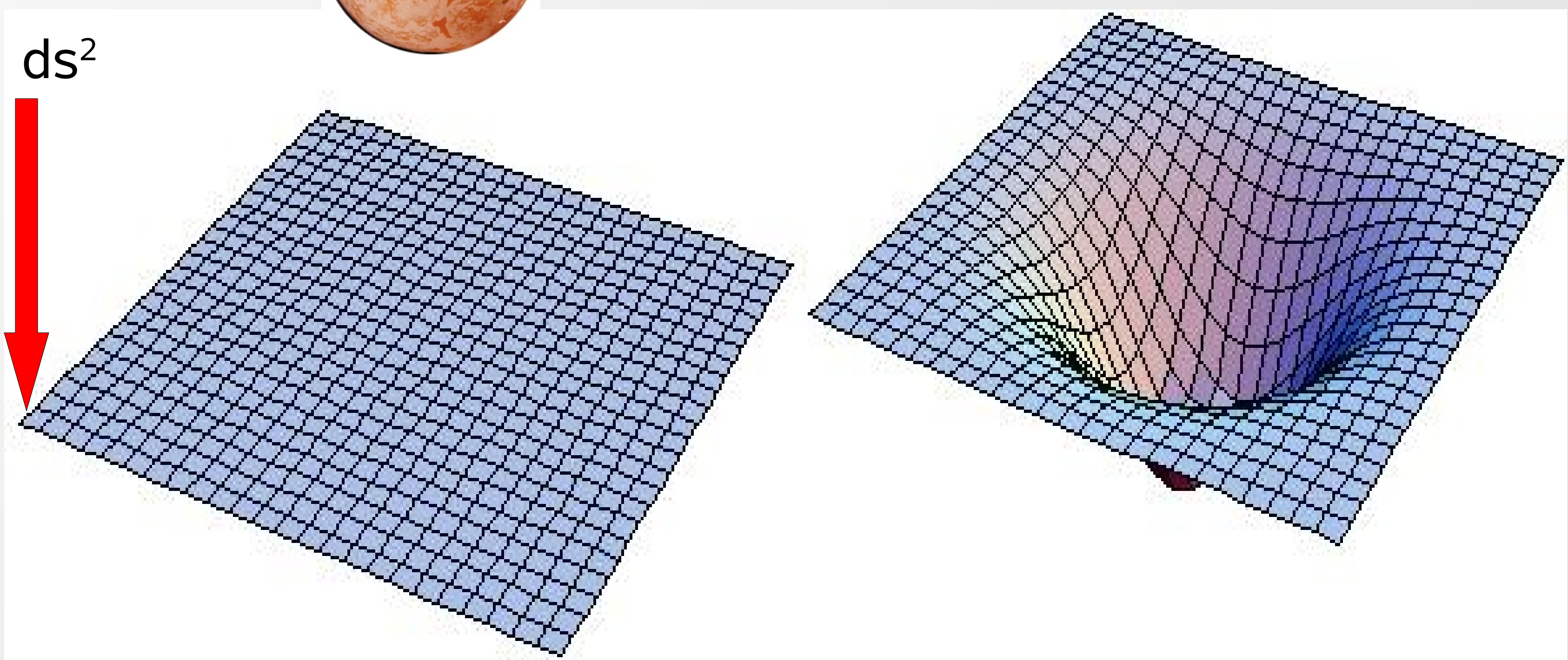
Parker & Vanzella PRD **69** 104009

Parker & Raval PRL **86** 749

Cosmology

- In GR: Gravity is Geometry (Space and time)

nuous, smooth spacetime



sources of energy and pressure distort the grid

GR: Sources of energy and stresses ∝ Geometry

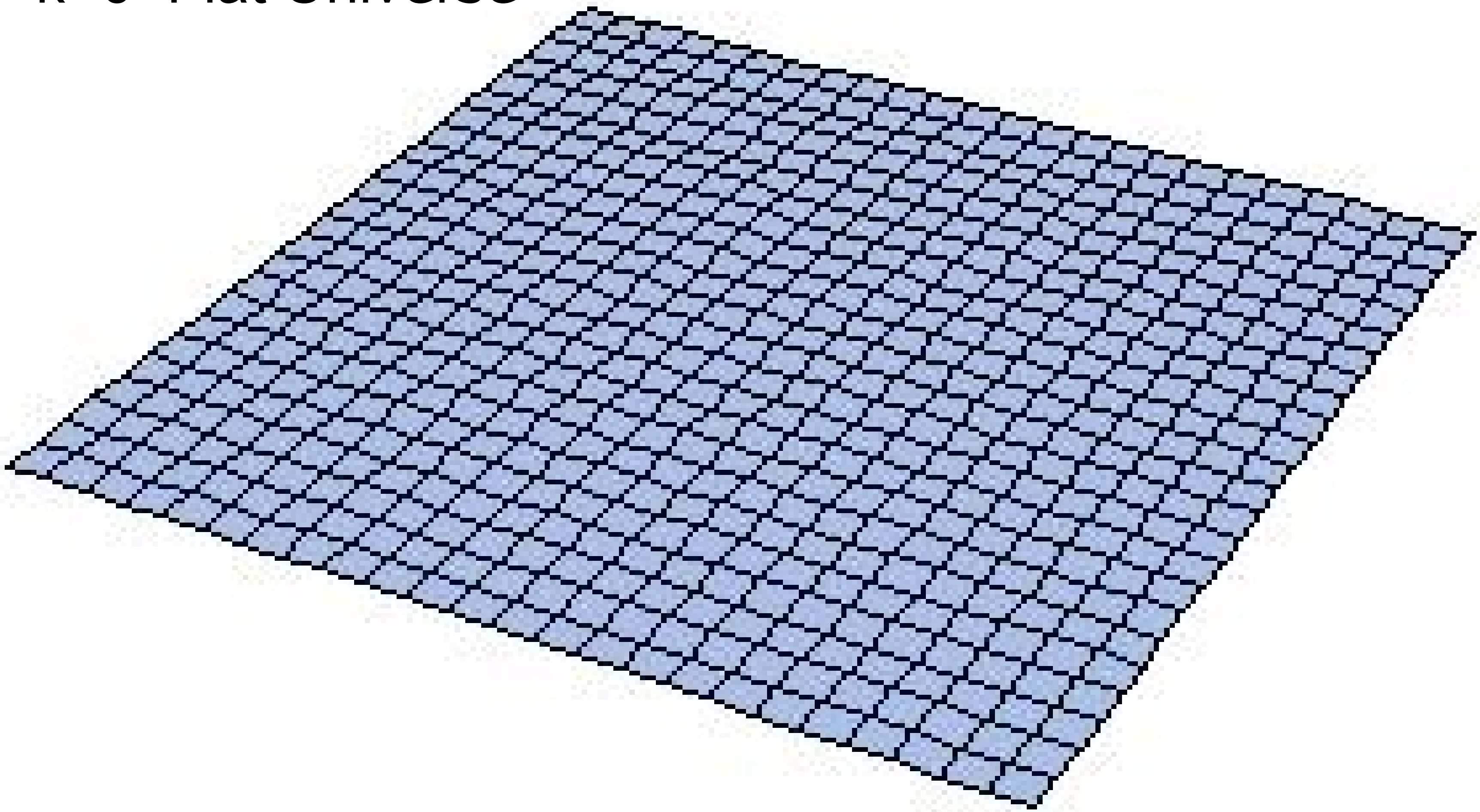
$$ds^2 \equiv g_{\mu\nu} dx^\mu dx^\nu \quad \Rightarrow \quad G_{\mu\nu}(g) = 8\pi G T_{\mu\nu}(\psi)$$

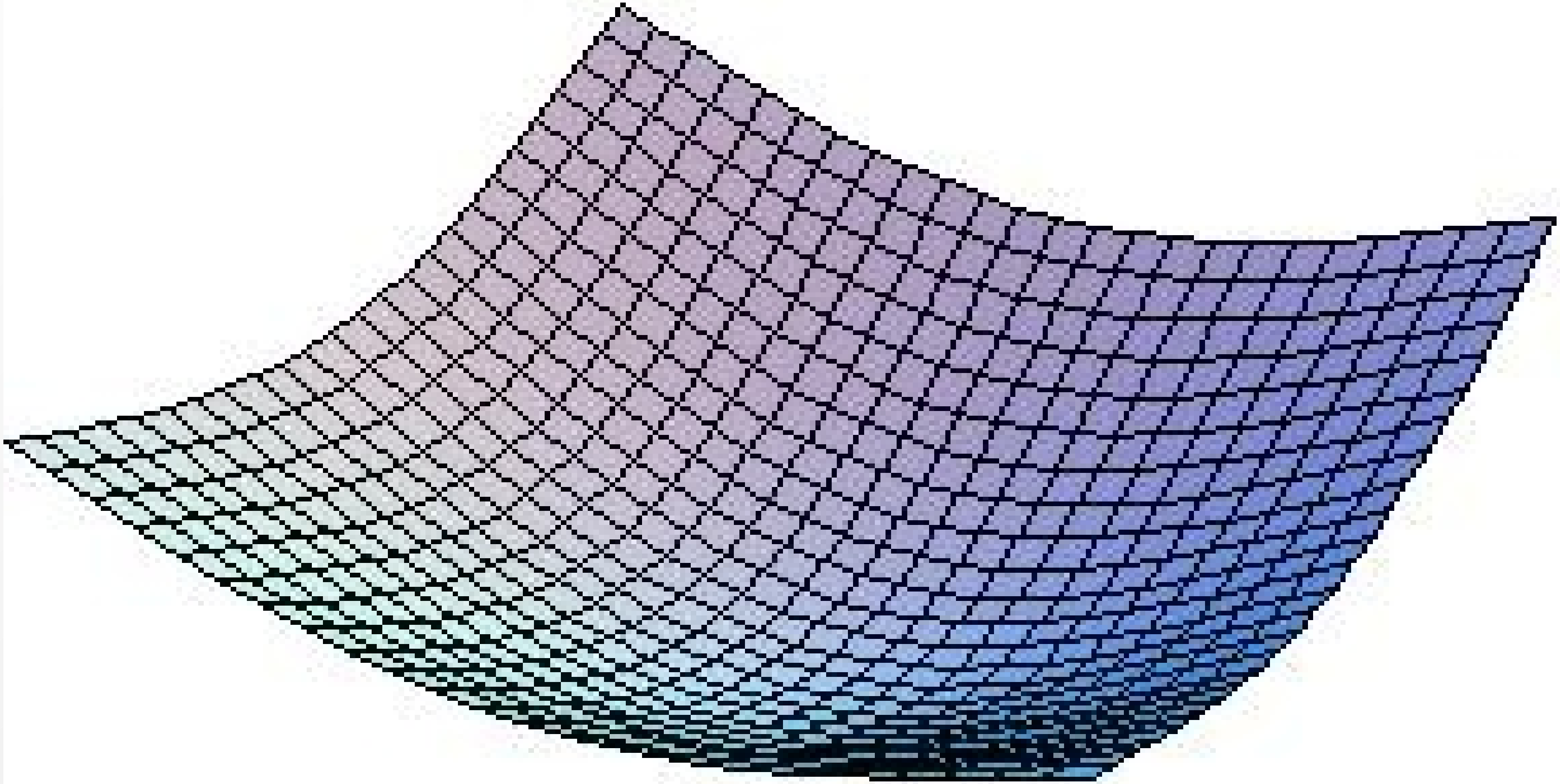
Comology:

Isotropic and Homogeneous

$$ds^2 = -dt^2 + a^2(t)\left(\frac{dr^2}{1+kr^2} + r^2 d\theta^2 + r^2 \sin^2\phi \, d\phi^2\right)$$

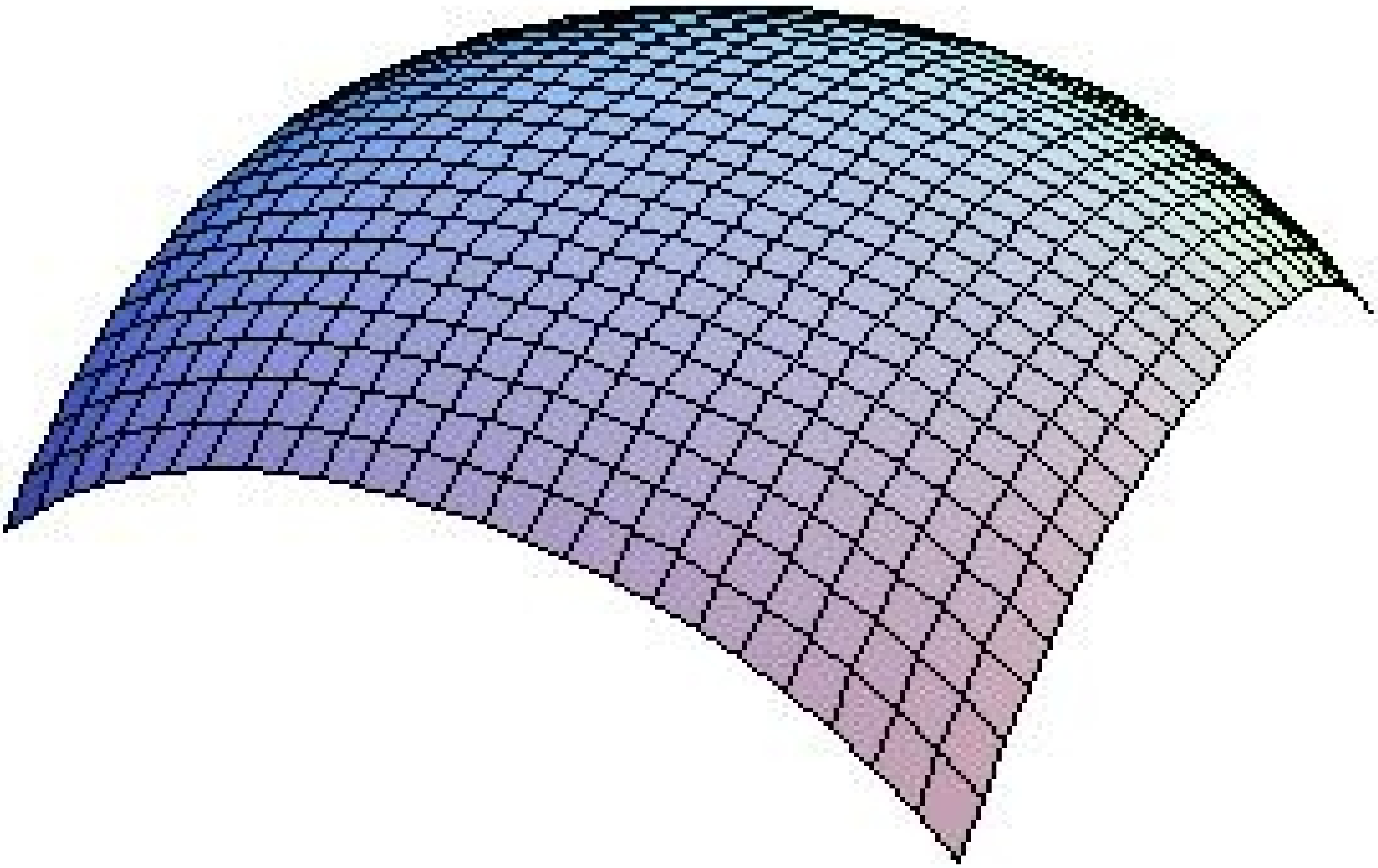
determines the geometry of the spatial hypersurfaces k=0 Flat Universe





k=+1 Closed Universe

k=-1 Open Universe



Friedman-Robertson-Walker Invariant Line Element

$$ds^2 = -dt^2 + a^2(t)(dx^2 + dy^2 + dz^2)$$

Stress-Energy: $T_{\mu\nu} = (\rho, P, P, P)$

Dynamical Equations

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 = 8\pi G\left(\rho_m(t) + \rho_{DE}(t)\right)$$

$$\frac{\partial(\rho_X a^3(t))}{\partial t} = P_X \frac{\partial a^3}{\partial t}$$

$$\rho_{DE} = \frac{\Lambda}{3H_0^2} \qquad \rho_{DE} \equiv \rho_{DE}(R) \qquad \rho_{DE} \equiv \rho_{DE}(\lambda, \phi)$$

•Parker-Raval Vacuum Metamorphosis Model

A low mass quantized scalar field

$$S = \int d^4 x \sqrt{-g}\, R + W_{eff}[R, R^2_{\mu\nu}, R^2_{\mu\nu\sigma\tau}] + S_m[g_{\mu\nu}, \phi_m]$$

Einstein Equations:

$$G_{\mu\nu}(g) + F_{\mu\nu}(R(g), R_{\sigma\tau}(g), R^{\sigma}_{\tau\rho\eta}(g)) = 8\pi G\, T(\psi)$$

Usual Friedman Equations $R = \bar{m}^2$ for $z < z_j$

VCDM of Parker-Raval:

$$\rho_{DE} = \frac{\bar{m}^2}{32\pi G}\left(1 - 4\left(\frac{1+z}{1+z_j}\right)^3 + 3\left(\frac{1+z}{1+z_j}\right)^4\right)$$

VCDM model assumes $\Lambda = 0$

Can relax this condition: LVCDM model

First cut at a non-zero Vacuum Expectation Value

New Results

Monte Carlo Makov Chains

random step through parameter space guided by the likelihood function L.

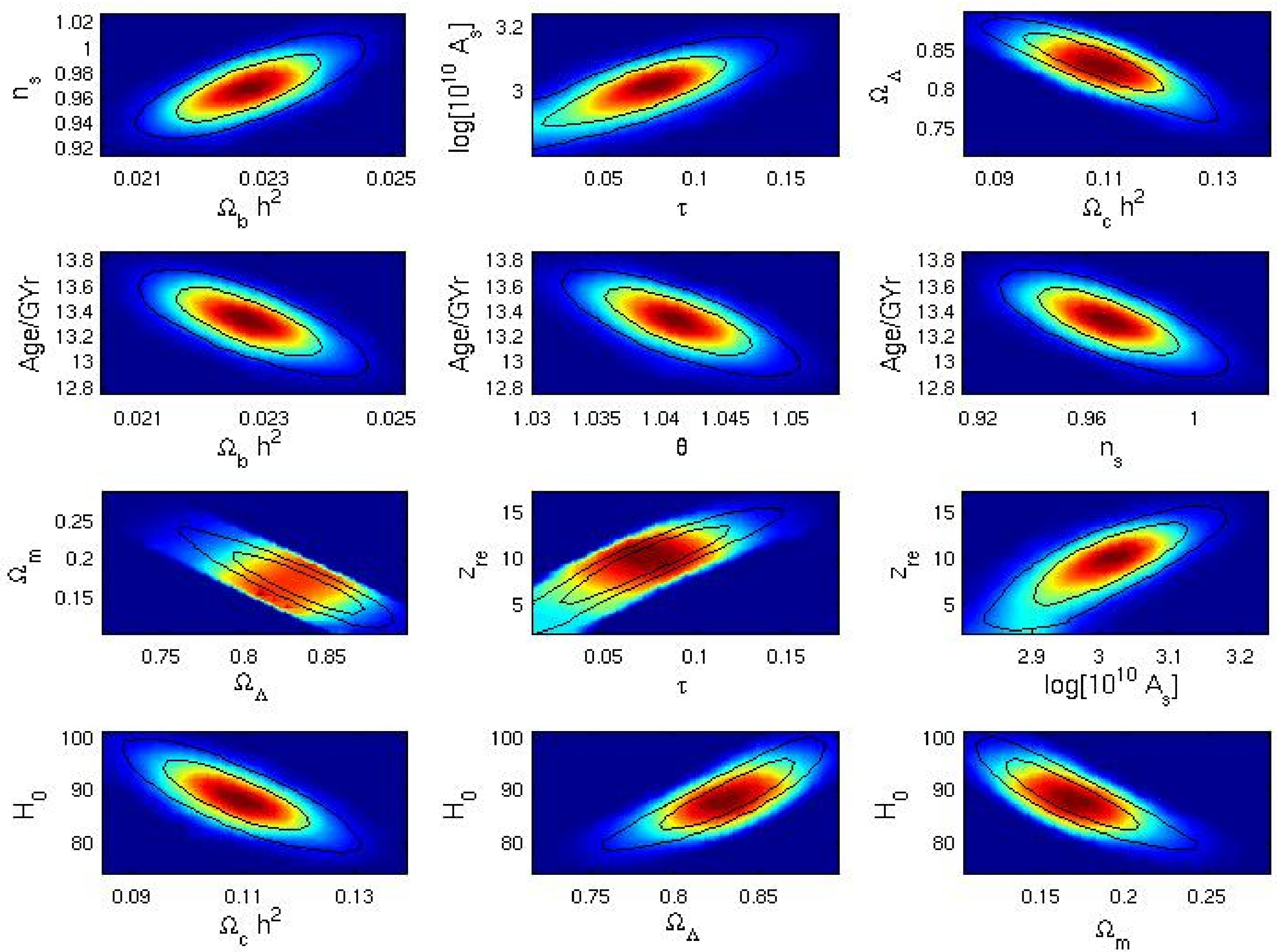
COSMOMC routine

VCDM Parameter Constraints (WMAP)

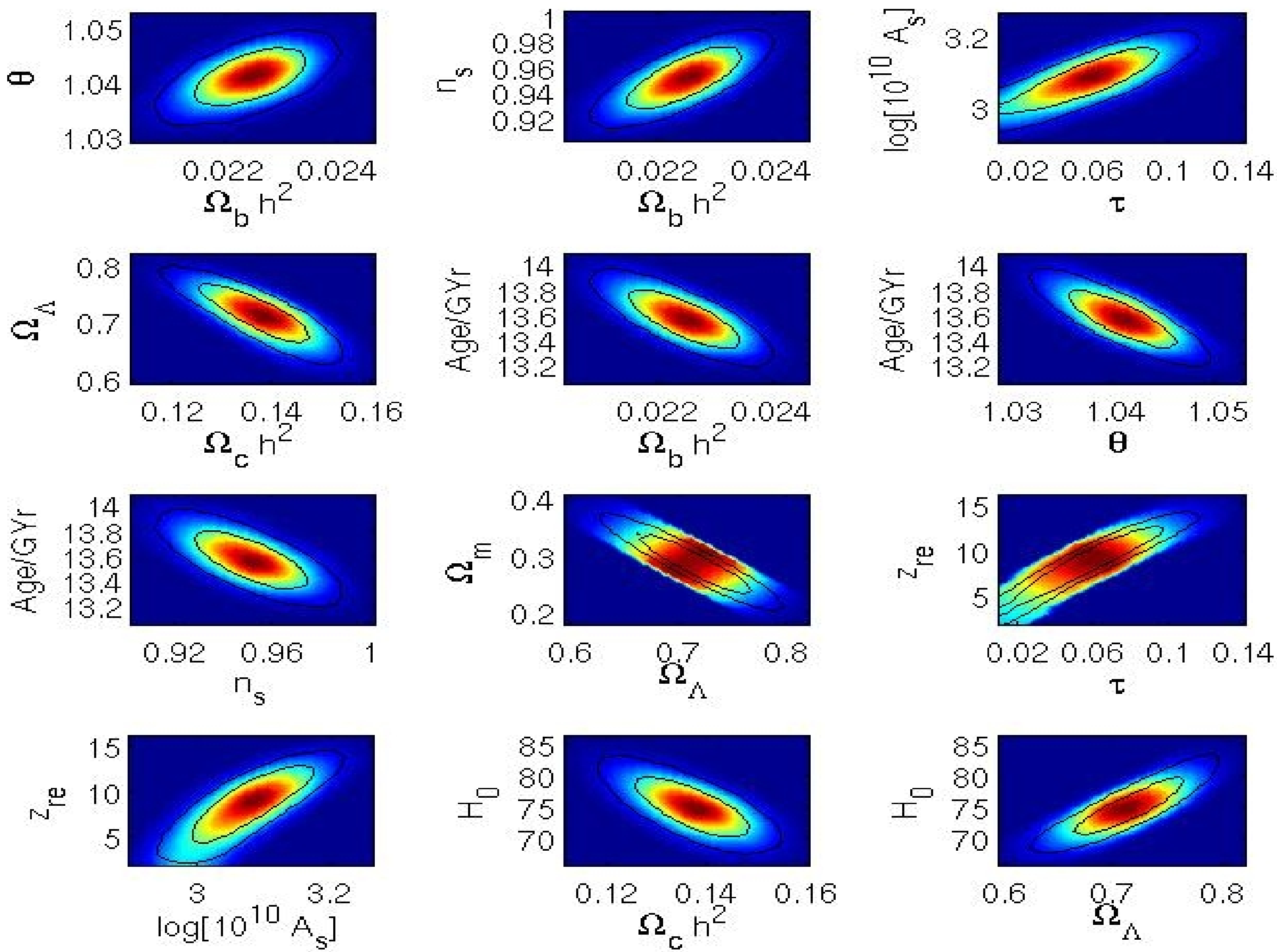
$$H_0 = 87 \pm 7\, km\, Mpc\, s^{-1},\ \Omega_{m0} = 0.2 \pm 0.07,\ \Omega_V = 0.80 \pm 0.07$$

VCDM Parameter Constraints non-zero Λ (WMAP)

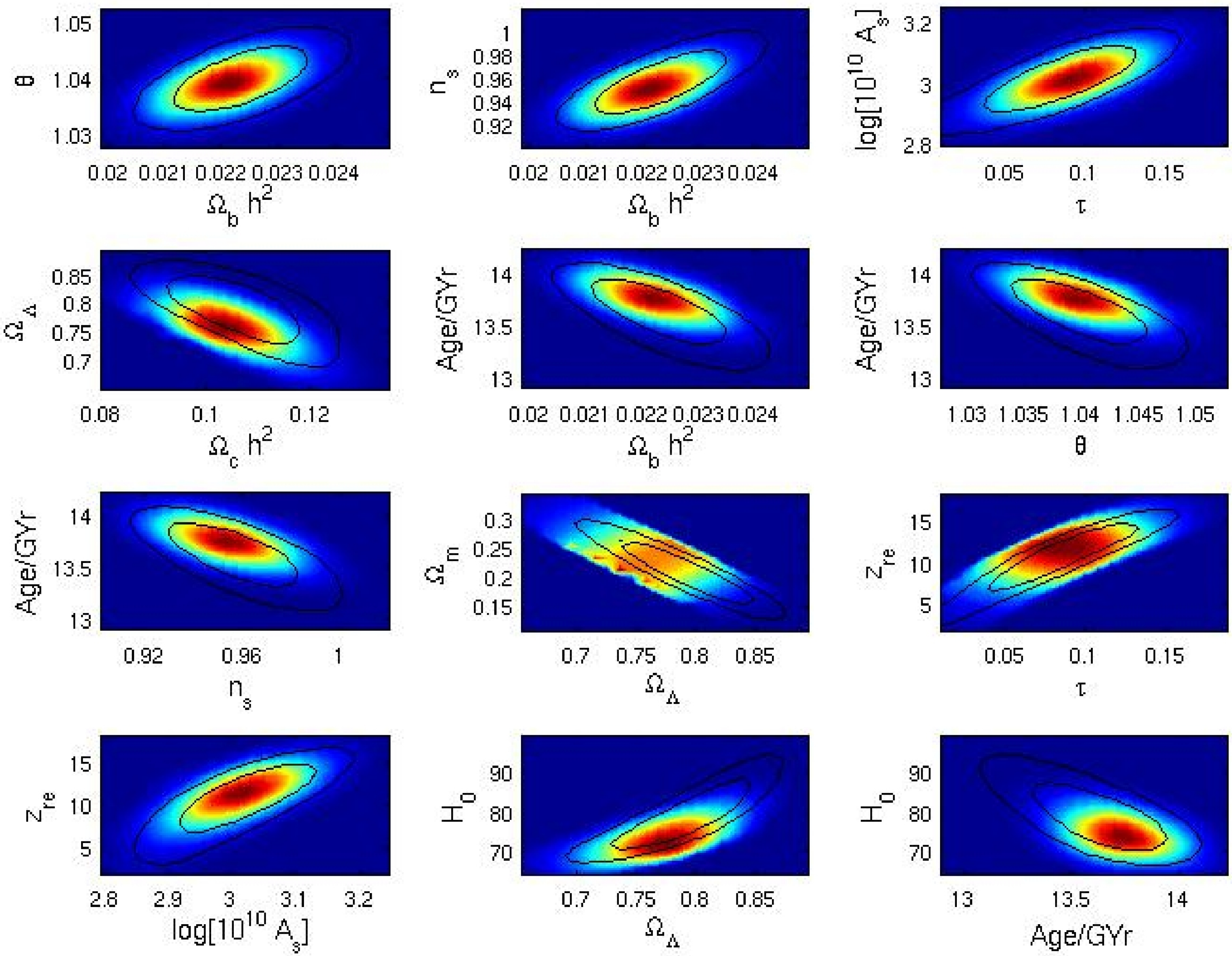
$$H_0 = 75 \pm 7\, km\, Mpc\, s^{-1},\ \Omega_{m0} = 0.24 \pm 0.07,\ \Omega_V = 0.76 \pm 0.07$$



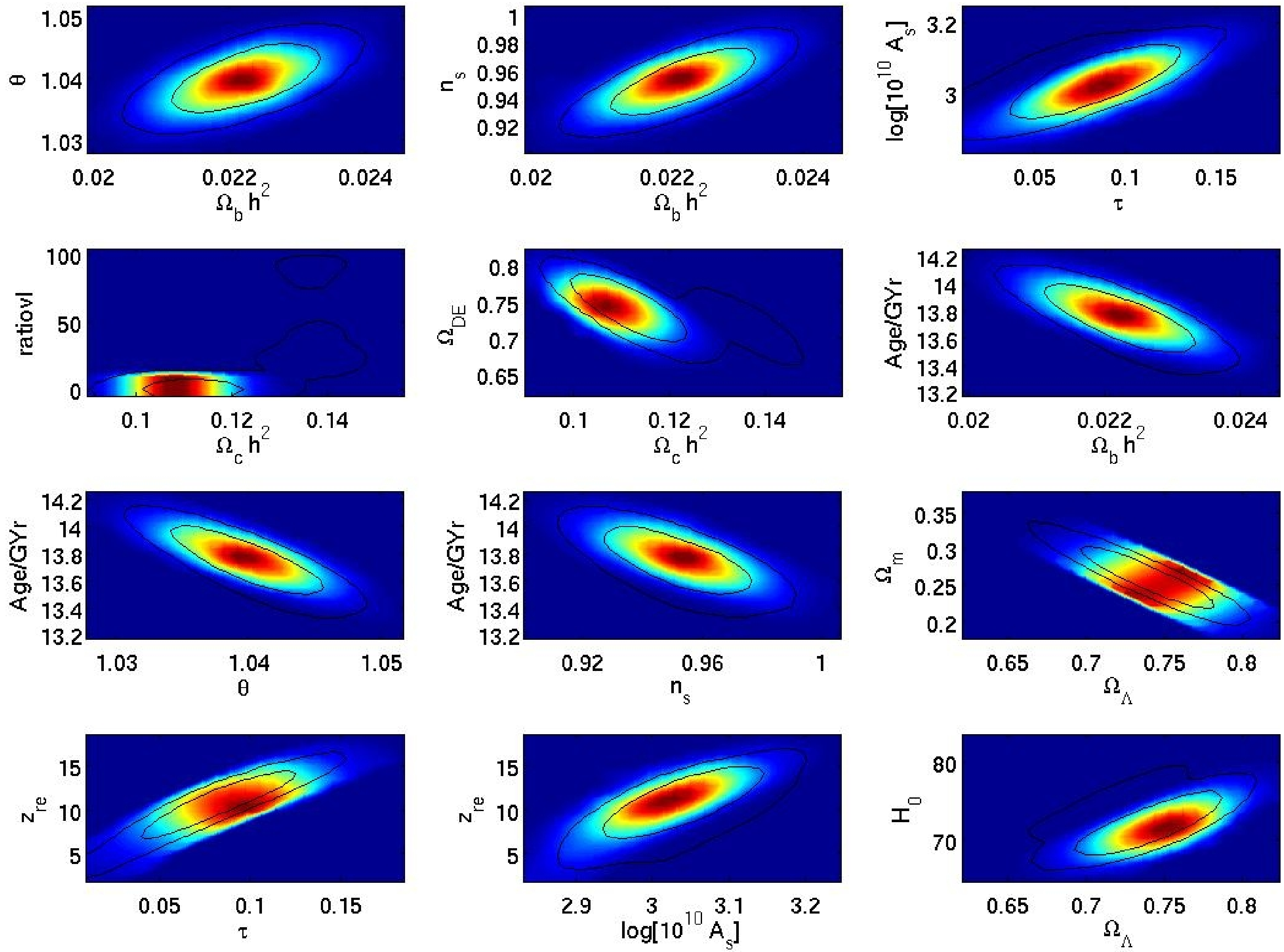
VCDM Model: WMAP



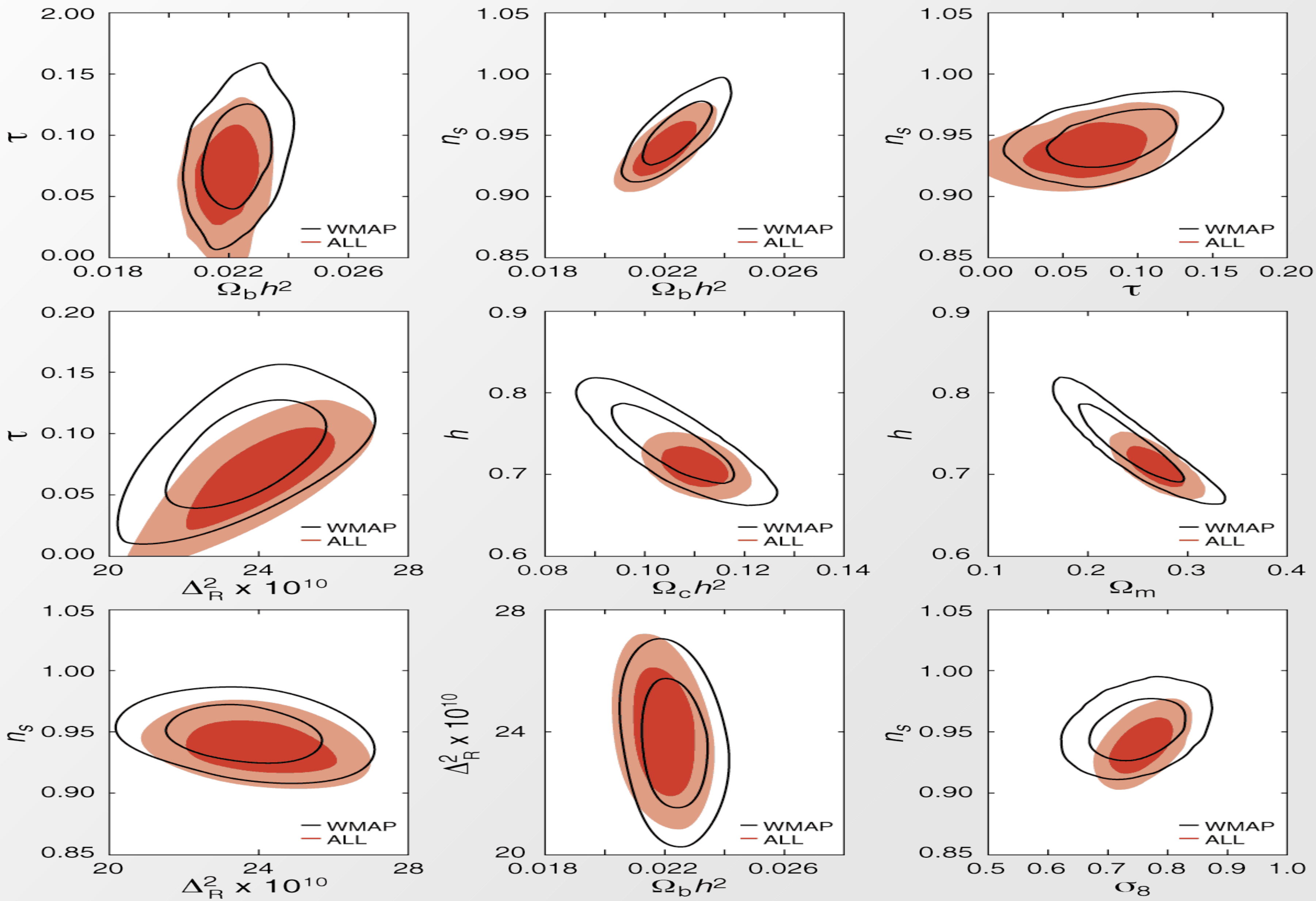
VCDM Model: WMAP+SN



LVCDM Model: WMAP



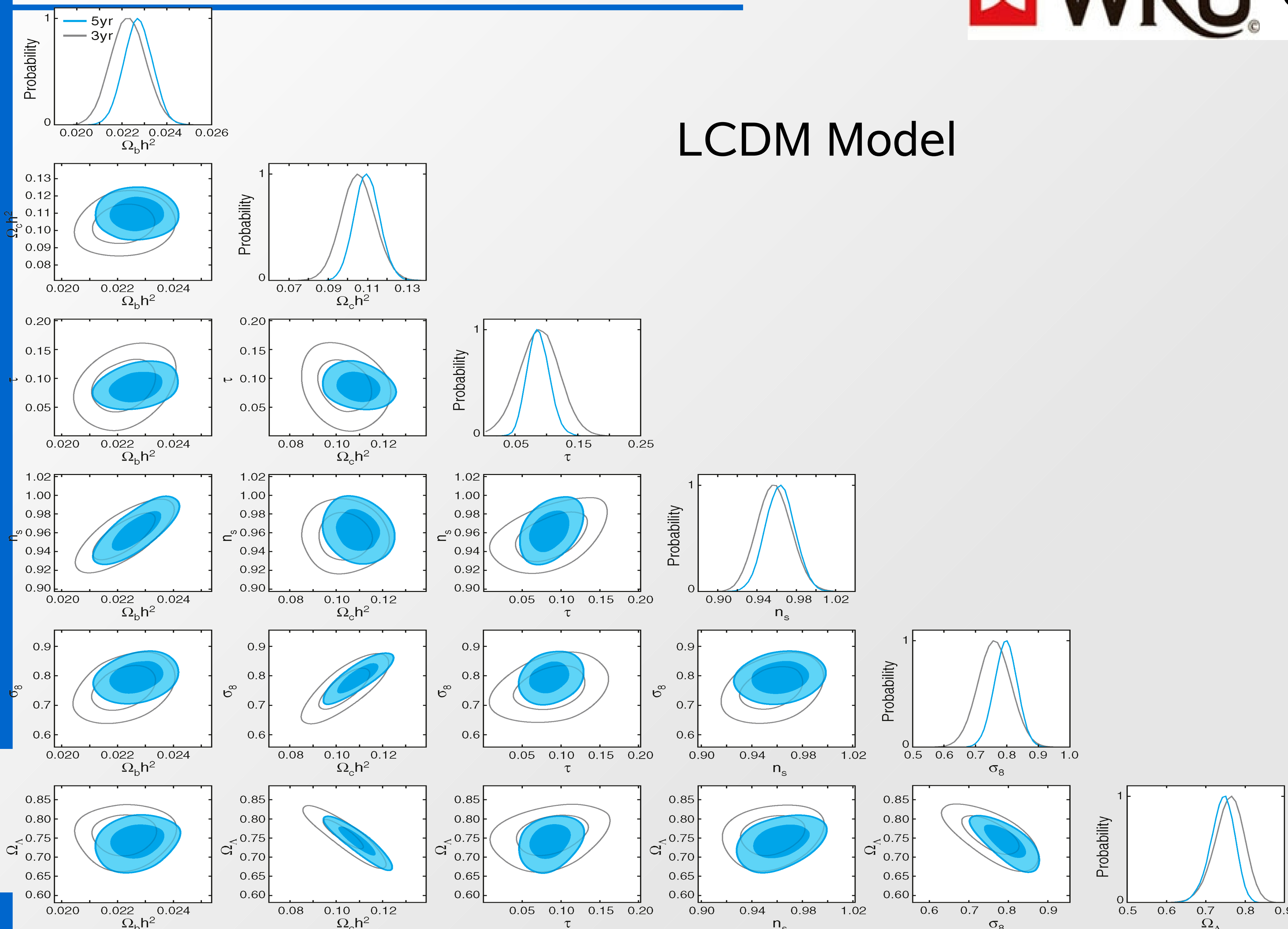
LVCDM Model: WMAP+SN



LCDM Model

wmap.gsfc.nasa.gov

LCDM Model



wmap.gsfc.nasa.gov

Direct Model Comparisons

Different Models → Different assumptions, dynamics and underlying physics

- VCDM model

  quantized low mass scalar field arising from field creation in the early expanding universe

- LCDM model

  potentially arising from string theory-Marco

- Goal of Observations

$$P(\,Dark\ Energy\ Model \mid Data\,,\,I\,)$$

- Propose

Bayesian Model Comparison Analysis

Bayes' Theorem:

$$P(M|D,I)=\frac{P(M|I)}{P(D|I)}P(D|M,I)$$

Compute

$$\frac{P(M_1|D,I)}{P(M_2|D,I)}=\frac{P(M_1|I)}{P(M_2|I)}\frac{P(D|M_{1,}I)}{P(D|M_{2,}I)}$$

Data Sets:

Type-Ia SN GOODS, SNLS, ESSENCE

CMB WMAP

Large Scale Structure   SDSS

Gravitational Lensing

Preliminary Analysis:

Assumed a cubic spline model of dark energy and Cosmological Constant Model

Simplifying assumptions about any fundamental physics priors for the models to be equally likely.

Occam Factor (OF): ratios of the prior probability function and parameter space volumes

$$R = \frac{P(M_1|SN, I)}{P(M_2|SN, I)} = OF\,\frac{P(SN|M_{1,}I)}{P(SN|M_{2,}I)}$$

Likelihood Function: $P(SN|M_{1,}I) \propto \exp[-\chi^2/2]$

2004: R=1 (both models equally likely)

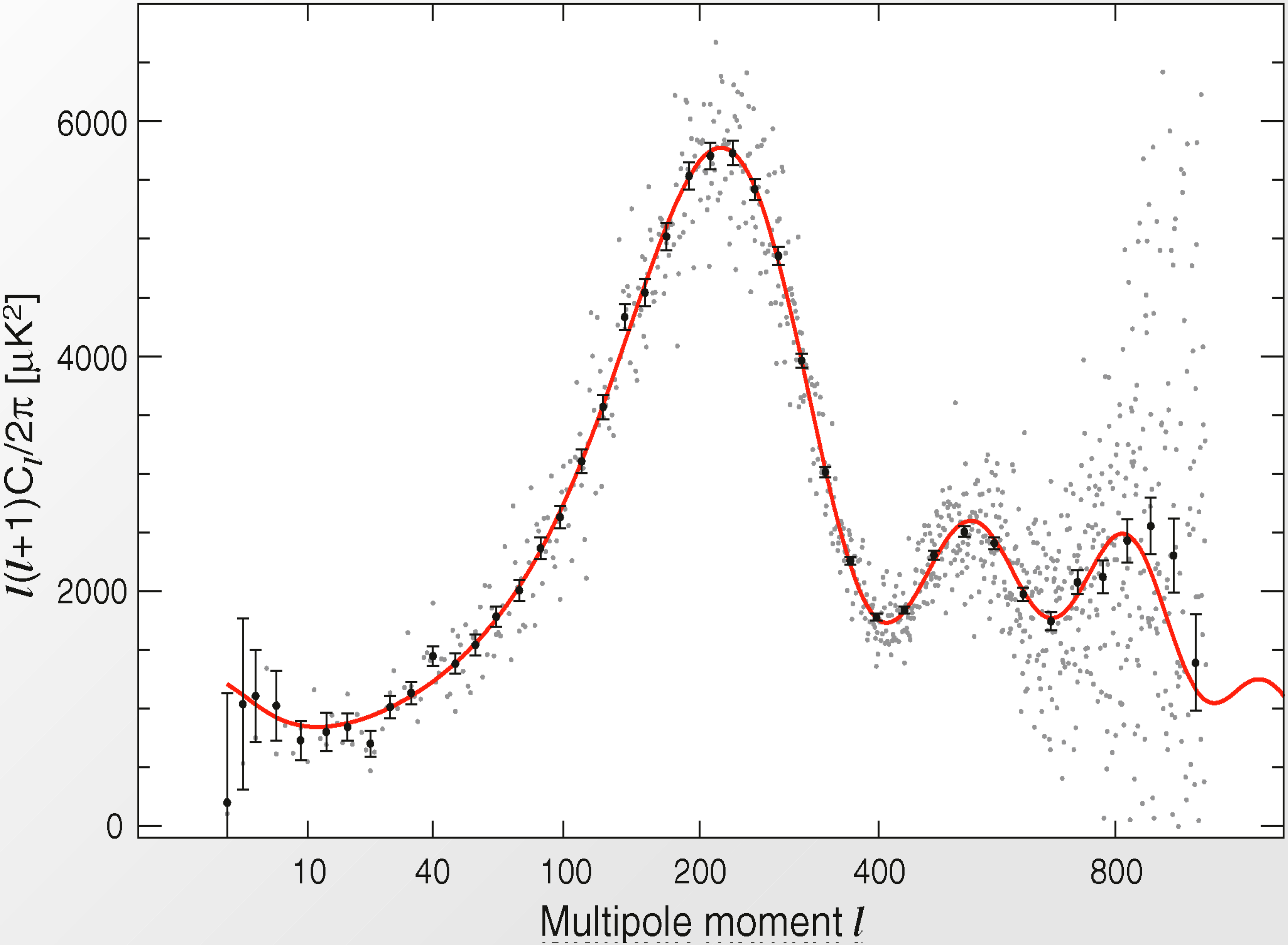
2006: R=1/4 (Spline model 4 times more likely!!!)

Conclusions

- Dark Energy is present but precise nature is still unknown
- There is general agreement amongst many models
- Trends in the data can potentially distinguish between models
- Future Work:

Direct Model Comparisons using results from data fitting

An archival search for more distant supernovae (out to redshifts of 1.8 or so) (Strolger)


6000
4000
2000
0
$l(l+1)C_l/2\pi$ [μK²]
10
40
100
200
400
800
Multipole moment l