Title: The potential of tomographic surveys to detect departures from GR growth

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Abstract: We study the possibility of detecting departures from GR using the tomographic surveys as Pan-starrs and LSST (Will be updated).

Searching for modified growth patterns with tomographic surveys

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Simon Fraser University

June 05,2008 PASCOS08

With collaborators
Levon Pogosian, Alessandra Silvestri, Joel Zylberberg

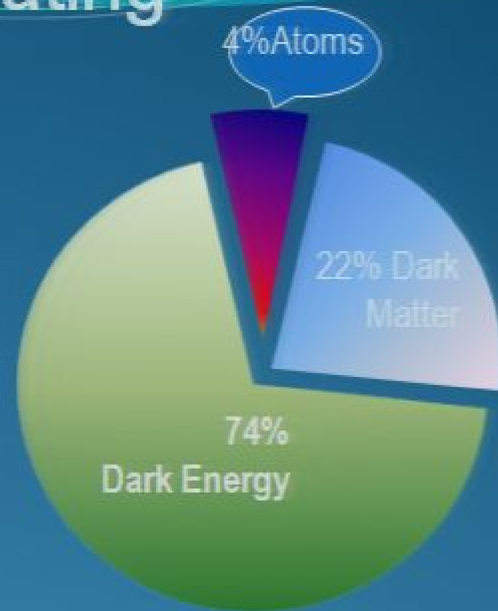
Outline

- Introduction of modified GR
- Current constraints of Non-GR parameters using CMB, WL, LSS, CMB/LSS cross-correlations…
- Error forecast from future tomographic surveys, such as Pan-starrs, LSST …
- Summary

Universe is currently accelerating

In GR: $\ddot{a}/a = -\frac{4\pi G}{3}(\rho + 3p)$

$\ddot{a} > 0 \rightarrow \rho + 3p < 0 \quad w = p/\rho < -1/3$



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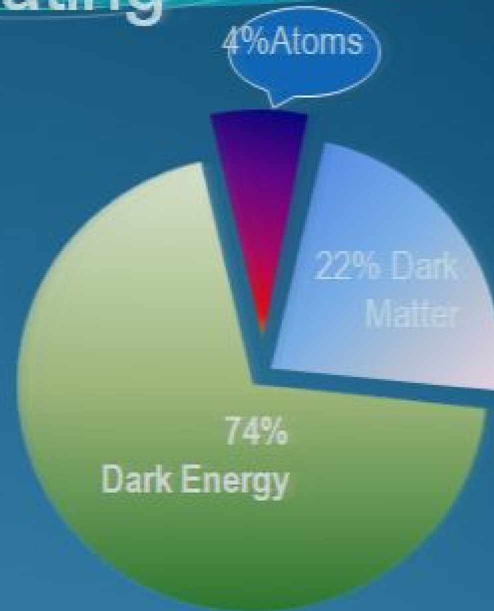
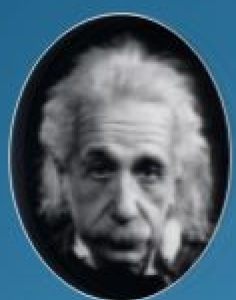


Cosmological constant (Vacuum Energy)



$$w = p/\rho = -1$$

$$\rho^{th}/\rho^{ob} \sim 10^{120}$$

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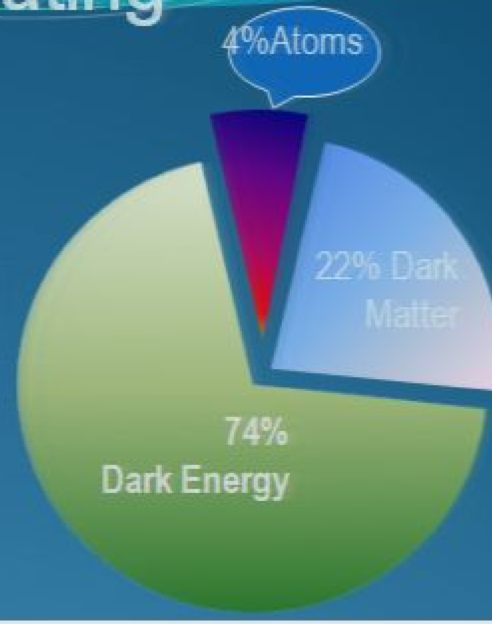

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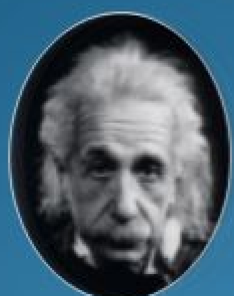

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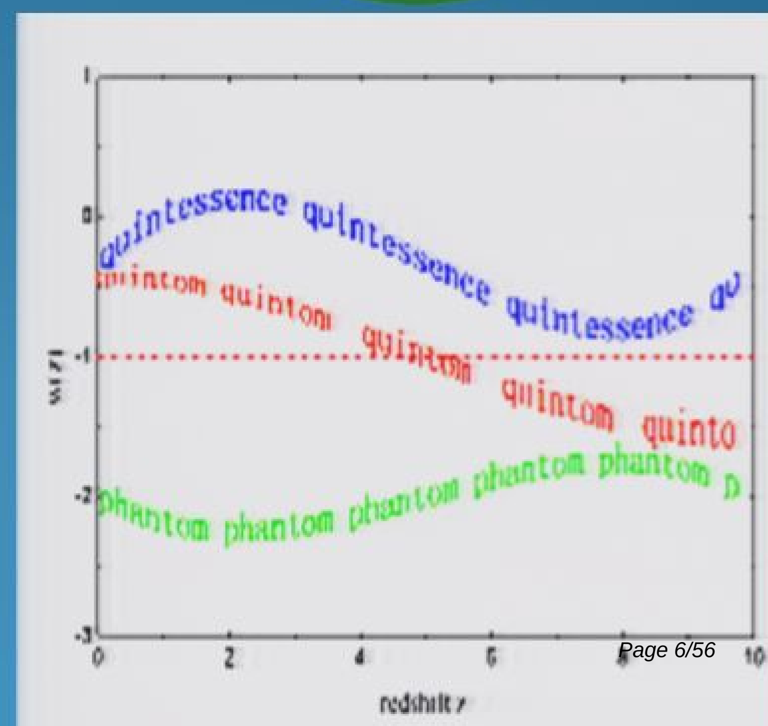

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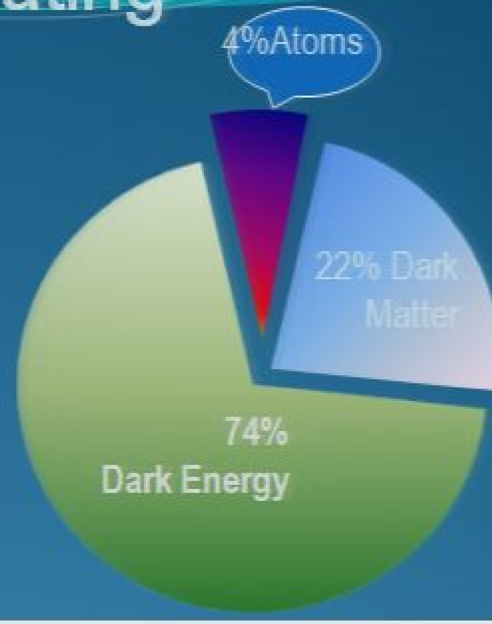

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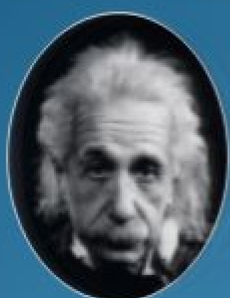

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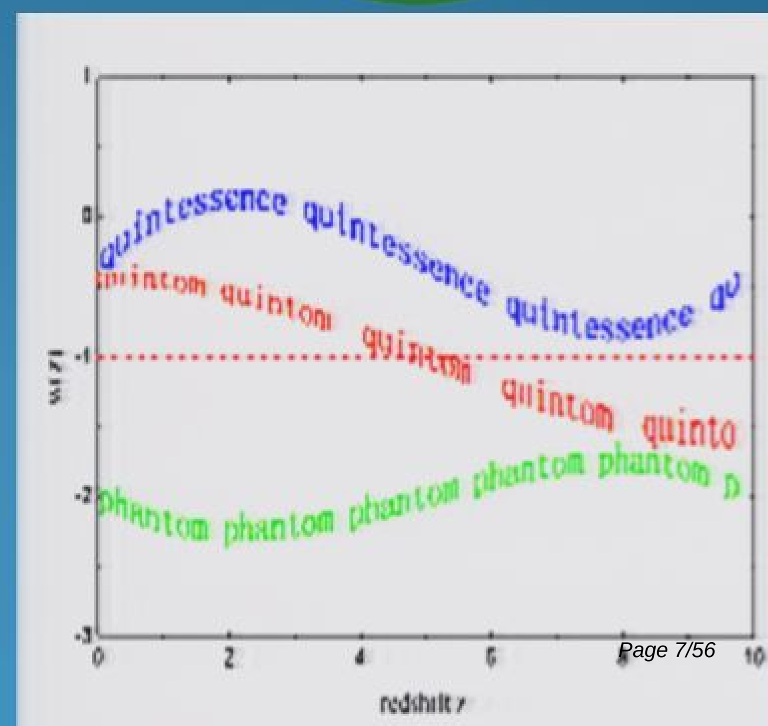
Alternatives: Modified GR
f(R),DGP, scalar-vector-tensor….



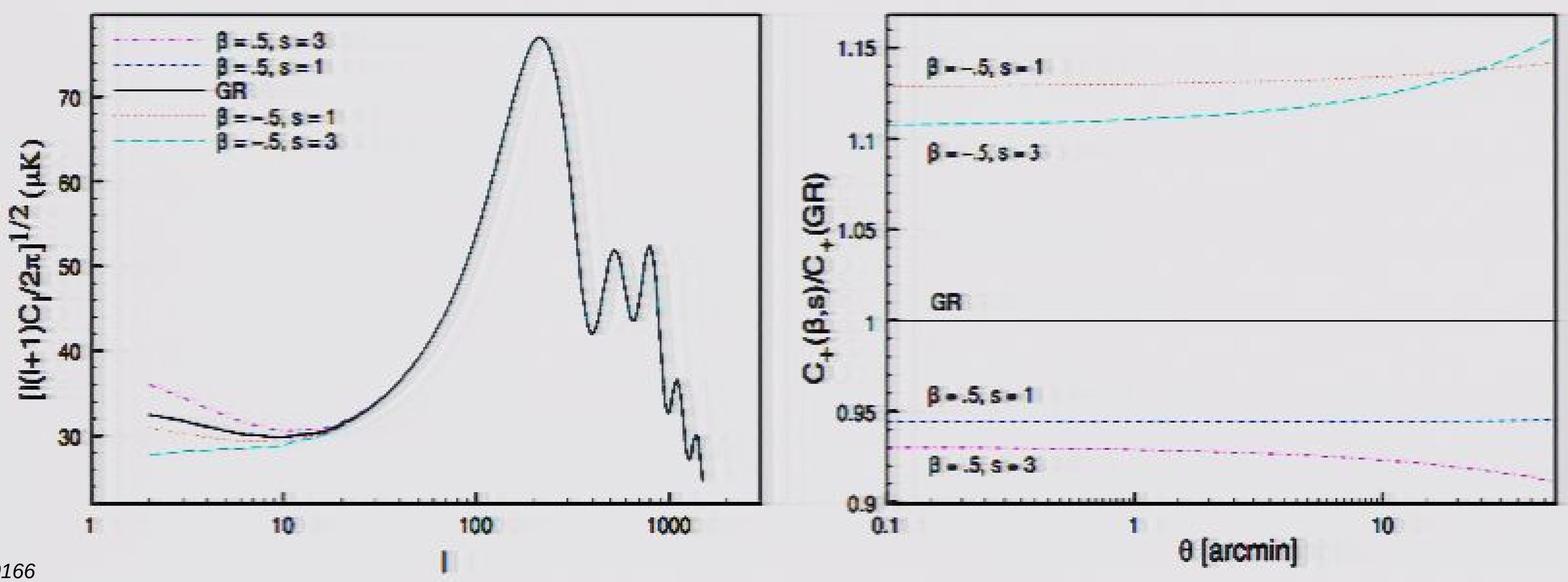
Post-Newtonian parameterizations

I. Scale-independent : A. Bertschinger & Zukin (2008) (BZ08)

$$\frac{1}{a^2}\frac{\partial}{\partial t}\left(\frac{a^2\Psi}{\mathcal{H}}\right)+\Phi-\Psi=\left[\frac{1}{a}\frac{\partial}{\partial t}\left(\frac{a}{\mathcal{H}}\right)+\frac{K}{\mathcal{H}^2}+O(k^2)\right]\zeta$$

$$\Phi(\mathbf{k},t)=F(a)\zeta(\mathbf{k})+O(k^2\zeta) \qquad \Psi(\mathbf{k},t)=\gamma(a)\Phi(\mathbf{k},t)+O(k^2\zeta)$$

$$\gamma(a)=1+\beta a^s \qquad \gamma=1 \text{ for GR}$$



B. Daniel,Caldwell,Cooray & Melchiorri (2008) (DCCM08)

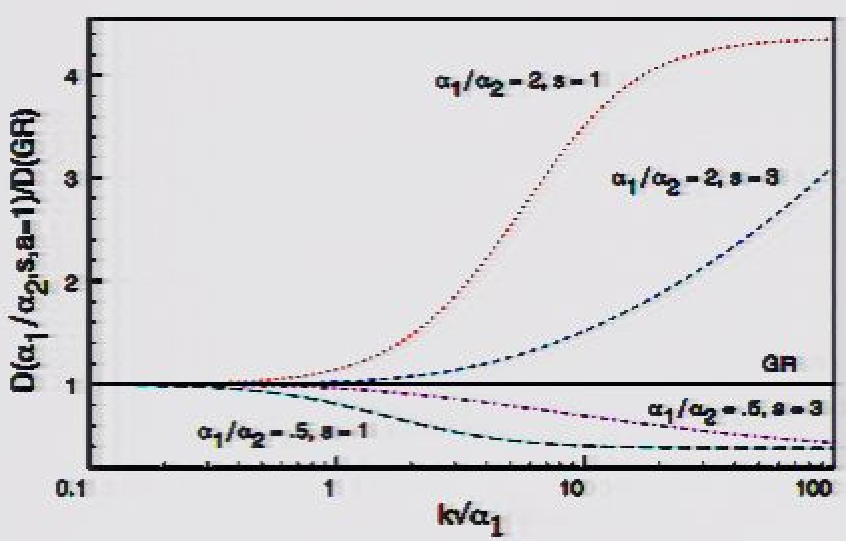
$$\psi(\tau,\vec{x}) = [1+\varpi(\tau,\vec{x})]\times\phi(\tau,\vec{x}) \qquad \varpi(\tau,\vec{x}) = \varpi_0\rho_{\rm DE}(\tau,\vec{x})/\rho_{\rm m}(\tau,\vec{x})$$

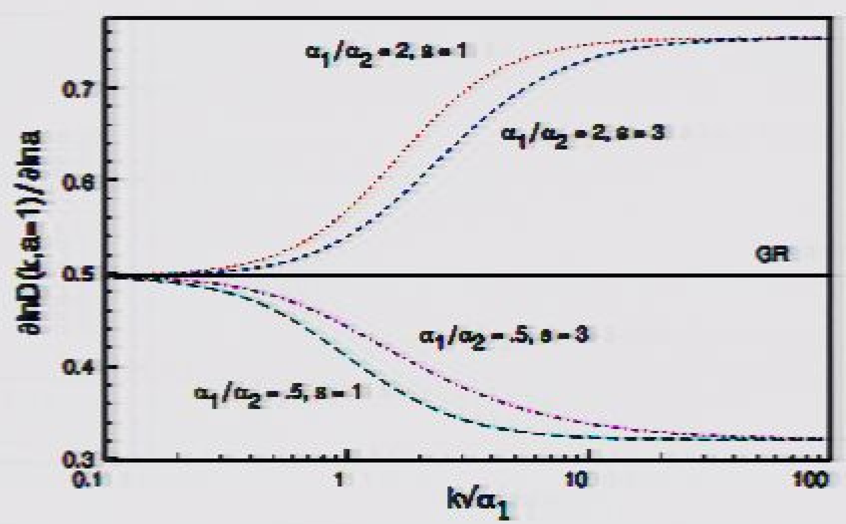
See Scott's talk

II. Scale-dependent : Bertschinger & Zukin (2008) (BZ08)

$$G_\Phi(x) = \frac{1+\alpha_1 x^2}{1+\alpha_2 x^2}, \gamma(x) = \frac{1+\beta_1 x^2}{1+\beta_2 x^2}, x \equiv ka^p, G_\Phi = \gamma = 1 \text{ for GR}$$

Feature: G_Φ, γ are basically tanh,transiting from 1 to constant





Constraints on PPN parameters using current data

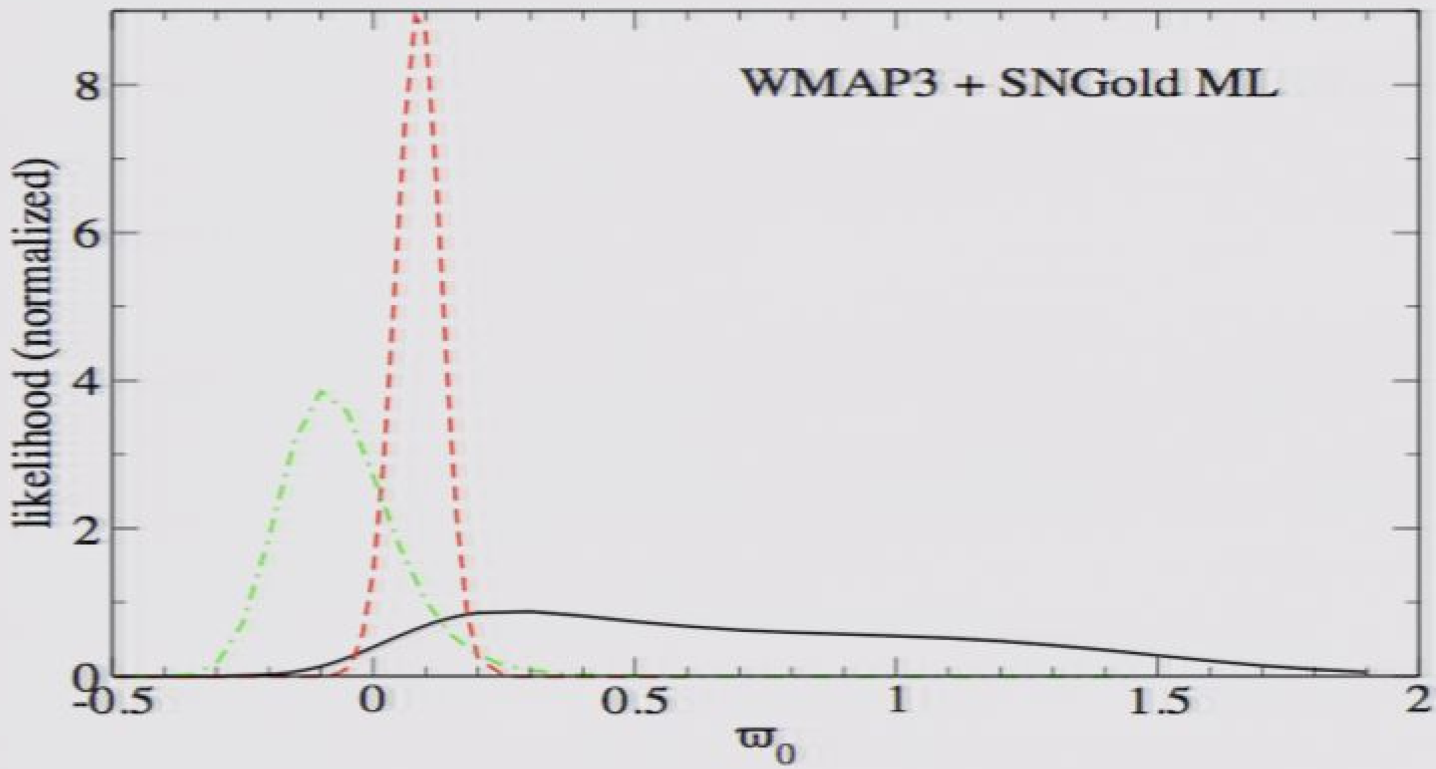


FIG. 16: The likelihood distributions for ϖ_0, based on the CMB (solid curve), weak lensing (dashed), and ISW-galaxy cross correlation (dot-dashed) using the WMAP3+SNGold ML model parameters is shown.

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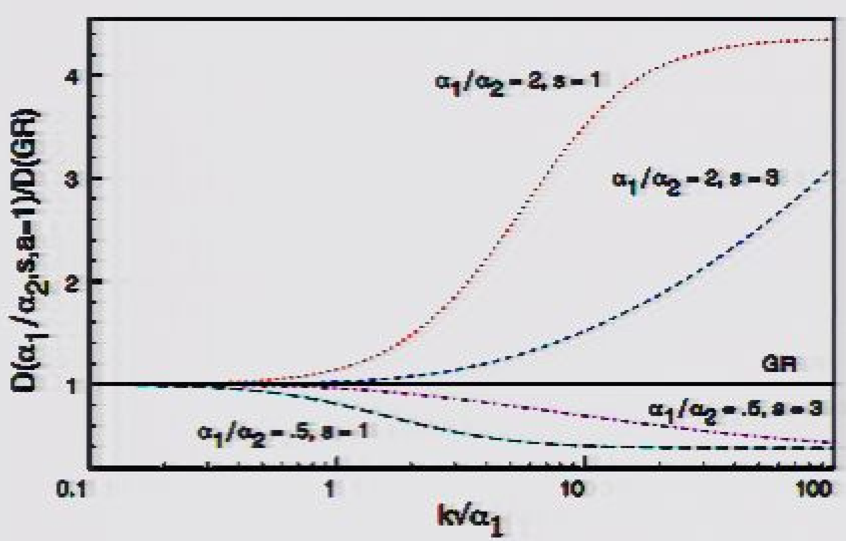

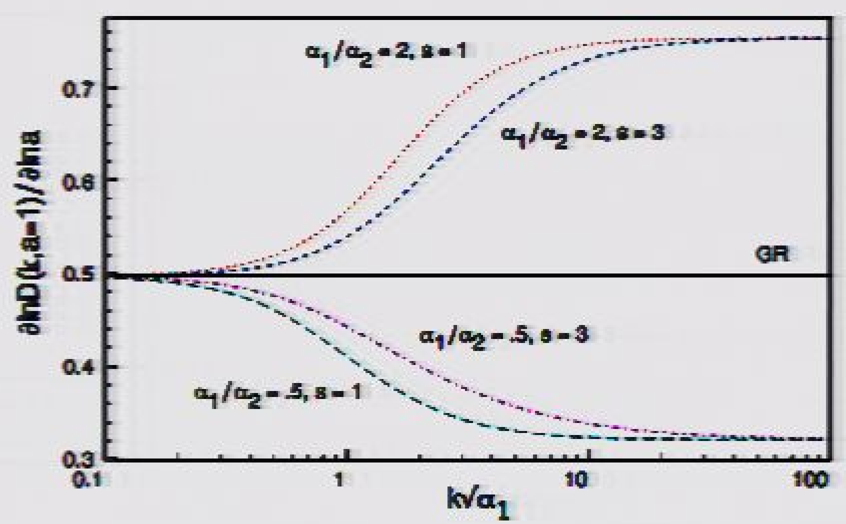

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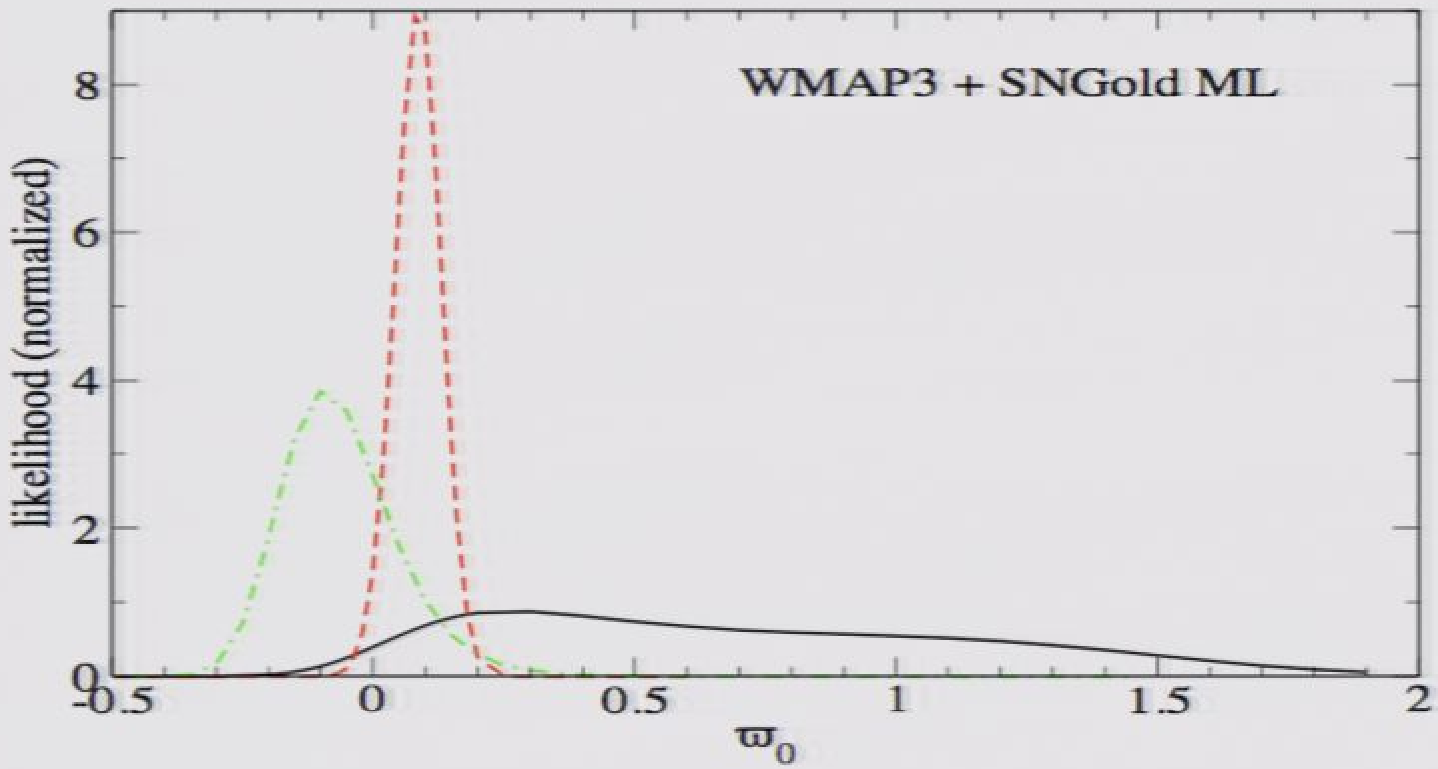

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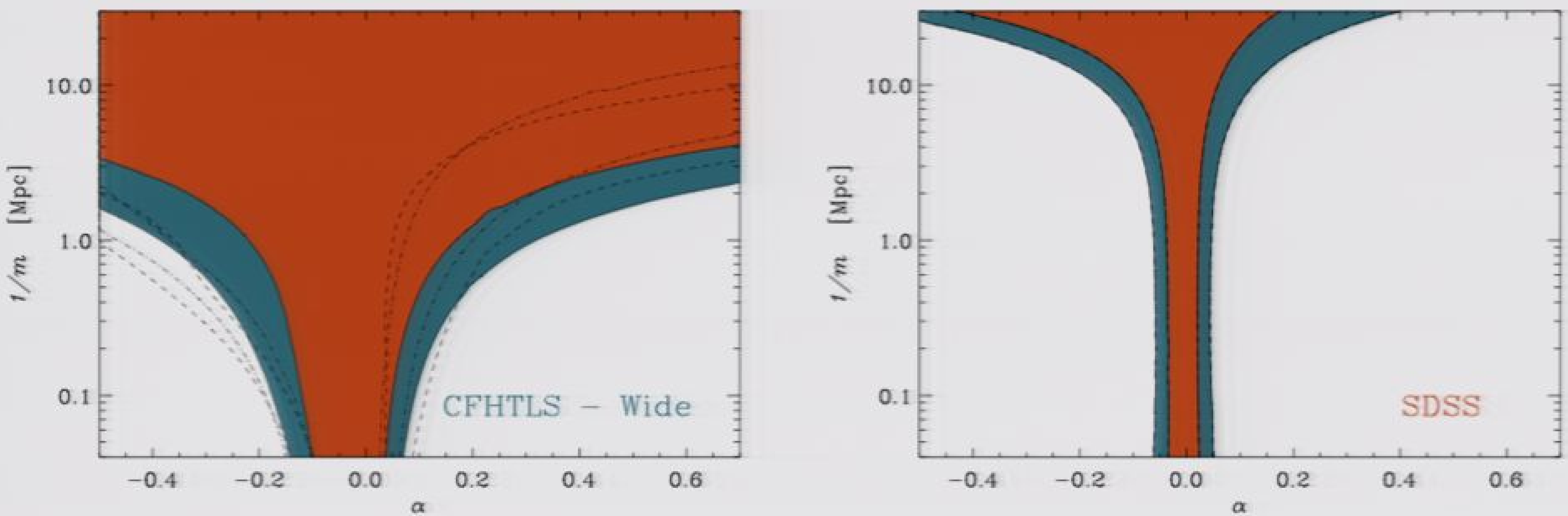
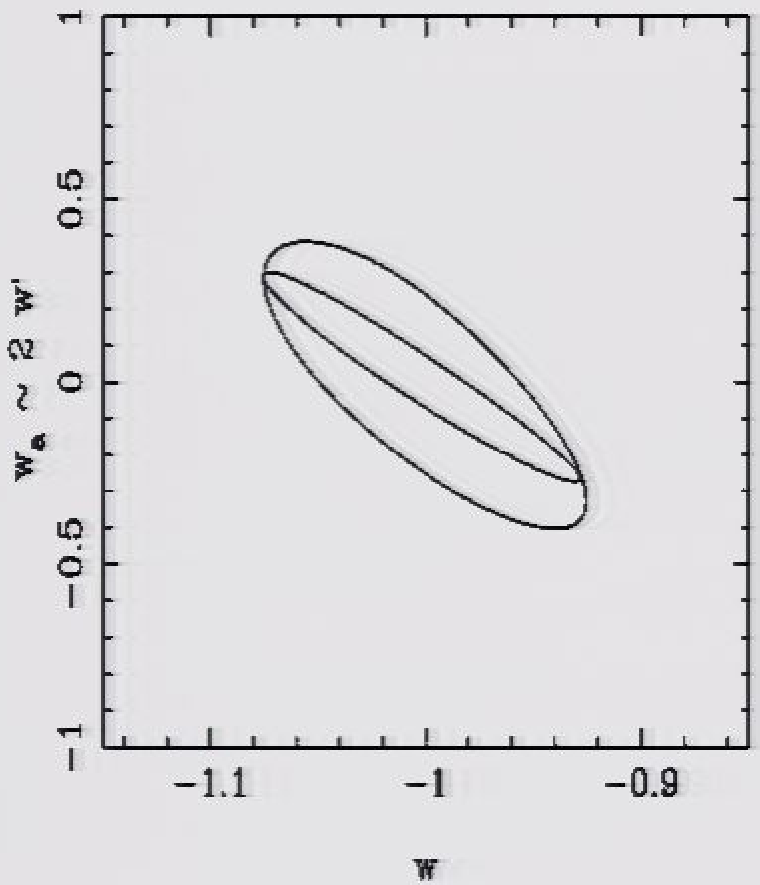


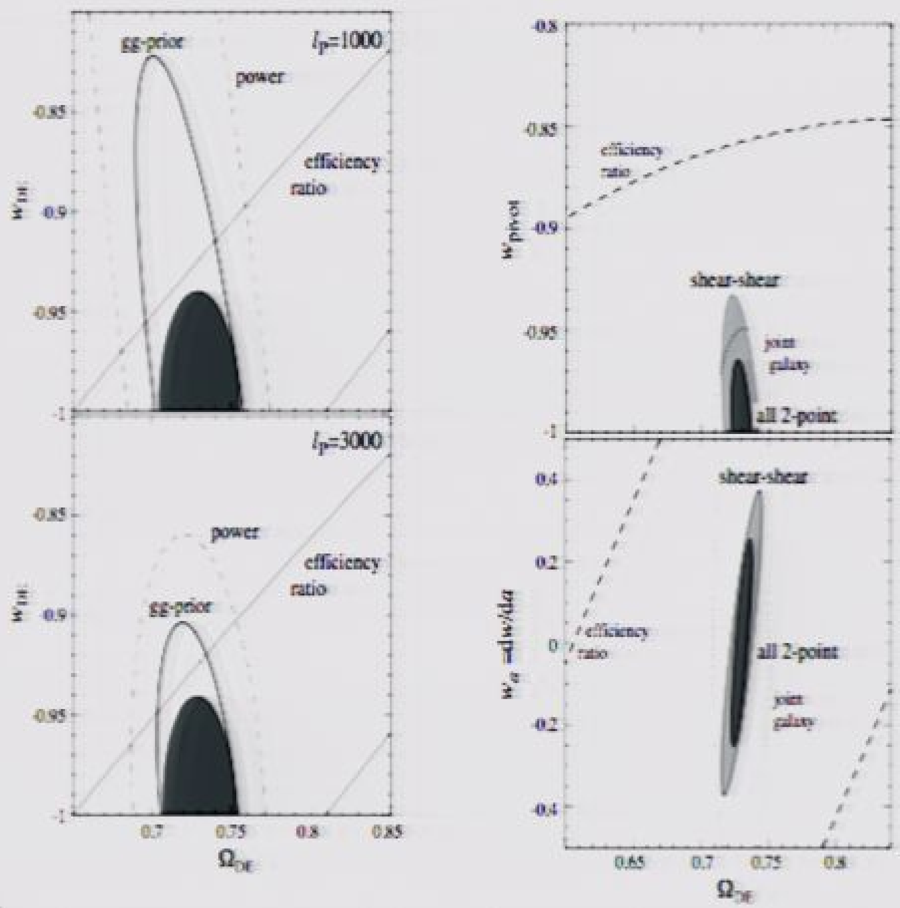
FIG. 2: Likelihood contours at 68% and 95% confidence levels for the $1/m$ and α parameters of the Yukawa type modification to gravity. The left panel corresponds to the CFHTLS-Wide constrains while the right panel corresponds to SDSS LRGs. Colored contours correspond for CFTHSL-Wide to the use of the M_{ap}^2 statistic with the halofit non-linear prescription. The dashed lines were obtained using the M_{ap}^2 statistic with the Peacock and Dodds [76] prescription whereas the dot-dashed lines were obtained with the halofit non-linear prescription but using the ξ_E statistic. The agreement between these various prescriptions and statistics is a satisfying of robustness of our measurement. As expected given the wider area covered by SDSS (42 times bigger than the current status of CFHTLS-Wide), the SDSS constraints are much narrower despite the bias uncertainty.

Dore et.al. (2007)

Powerful tool: Tomography



Jain & Taylor (2003)



Hu & Jain (2004)

Our Methodology

$$ds^2 = -a^2(\tau)\left[(1+2\Psi)d\tau^2 - (1-2\Phi)d\vec{x}^2\right]$$

$$k^2\Phi = -\frac{a^2}{2M_P^2}G_\Phi(k,a)\rho\Delta$$

$$\frac{\Phi}{\Psi} = \gamma(a,k)$$

$$\rho\Delta \equiv \rho\delta + 3\frac{aH}{k}(\rho+P)v$$ Comoving density perturbation

Our Non-GR parameterization

Scale-independent: $G_\Phi = 1 + \beta_1 a^s, \gamma = 1 + \beta_2 a^s$

Scale-dependent: $G_\Phi = \dfrac{1 + \lambda_1 \alpha k^2 a^s}{1 + \alpha k^2 a^s}, \gamma = \dfrac{1 + \lambda_2 \beta k^2 a^s}{1 + \beta k^2 a^s}$

Equivalent to the parameterization in BZ 08

Parameter space

$$P \equiv \{\Omega_b h^2, \Omega_c h^2, H_0, \tau, n_s, A_s, \text{non - GR para., bias para.}\}$$

Fiducial $\Omega_b h^2 = 0.022, \Omega_c h^2 = 0.12, H_0 = 72, \tau = 0.09, n_s = 0.95$

Observables for tomography

$$C_l^{XY} \propto \int \frac{dk}{k} \Delta^2_{\mathcal{R}} I_l^X(k) I_l^Y(k)$$

$$I_l^{X(Y)}(k) = \int \mathcal{S}^{X(Y)}(z) j_l[kr(z)] dz$$

We then calculate power spectra of TT, shear-shear, galaxy-galaxy, shear-CMB, galaxy-CMB and shear-galaxy by modifying CAMB code.

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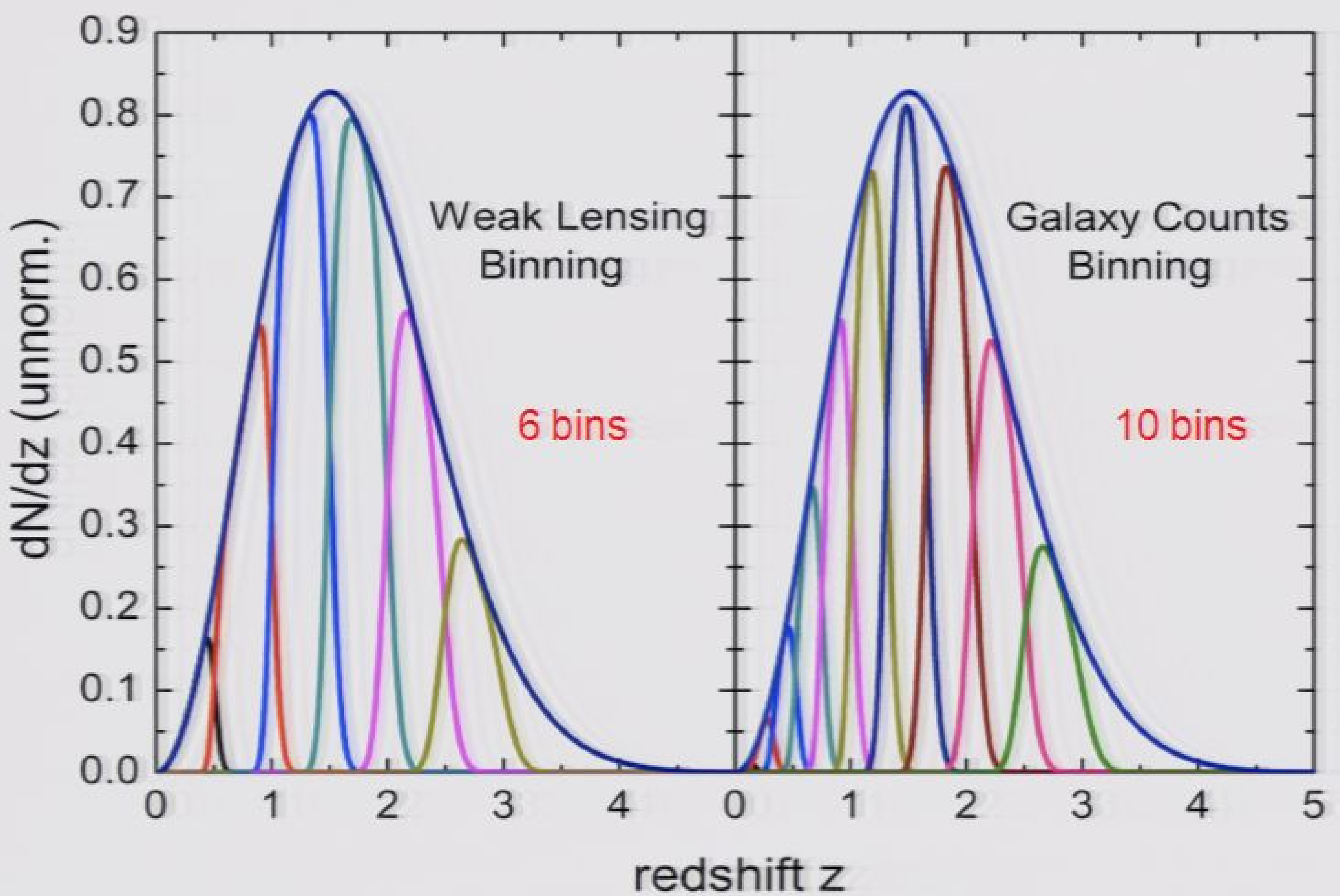
No Limber Approximation used!!

Surveys : LSST-like (see Anthony's talk)



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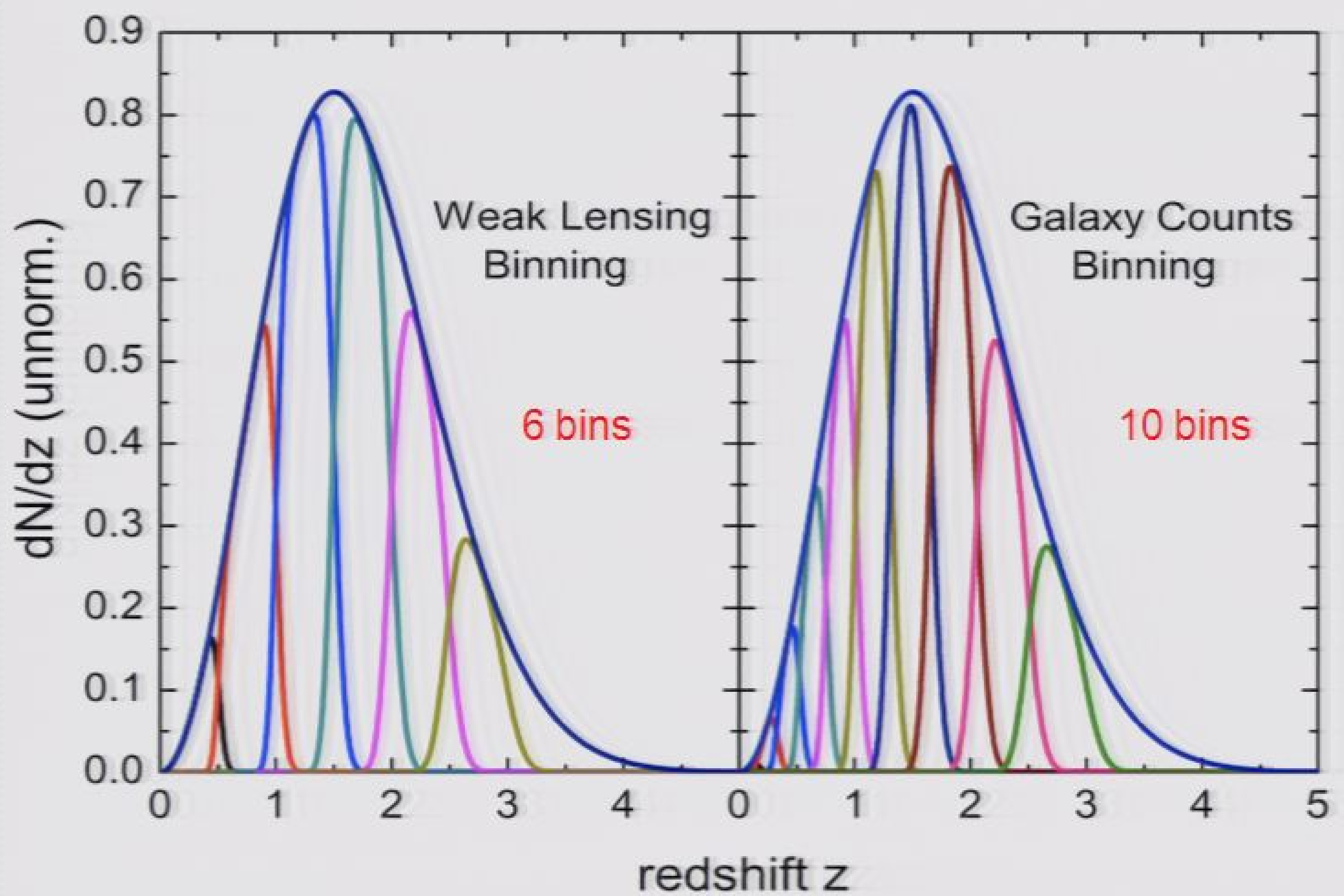

	E	T	G1 … … G10	WL1… … WL6
E				
T				
G1 . . . G10				
WL1 . . . WL6				

	E	T	G1 … … G10	WL1… … WL6
E	CMB			
T	(3)			
G1				
.				
.				
.				
G10				
WL1				
.				
.				
.				
WL6				

	E T	G_1 … … G_{10}	WL_1… … WL_6
E T	CMB (3)		
G_1 . . . G_{10}		Gal/Gal (55)	
WL_1 . . . WL_6			

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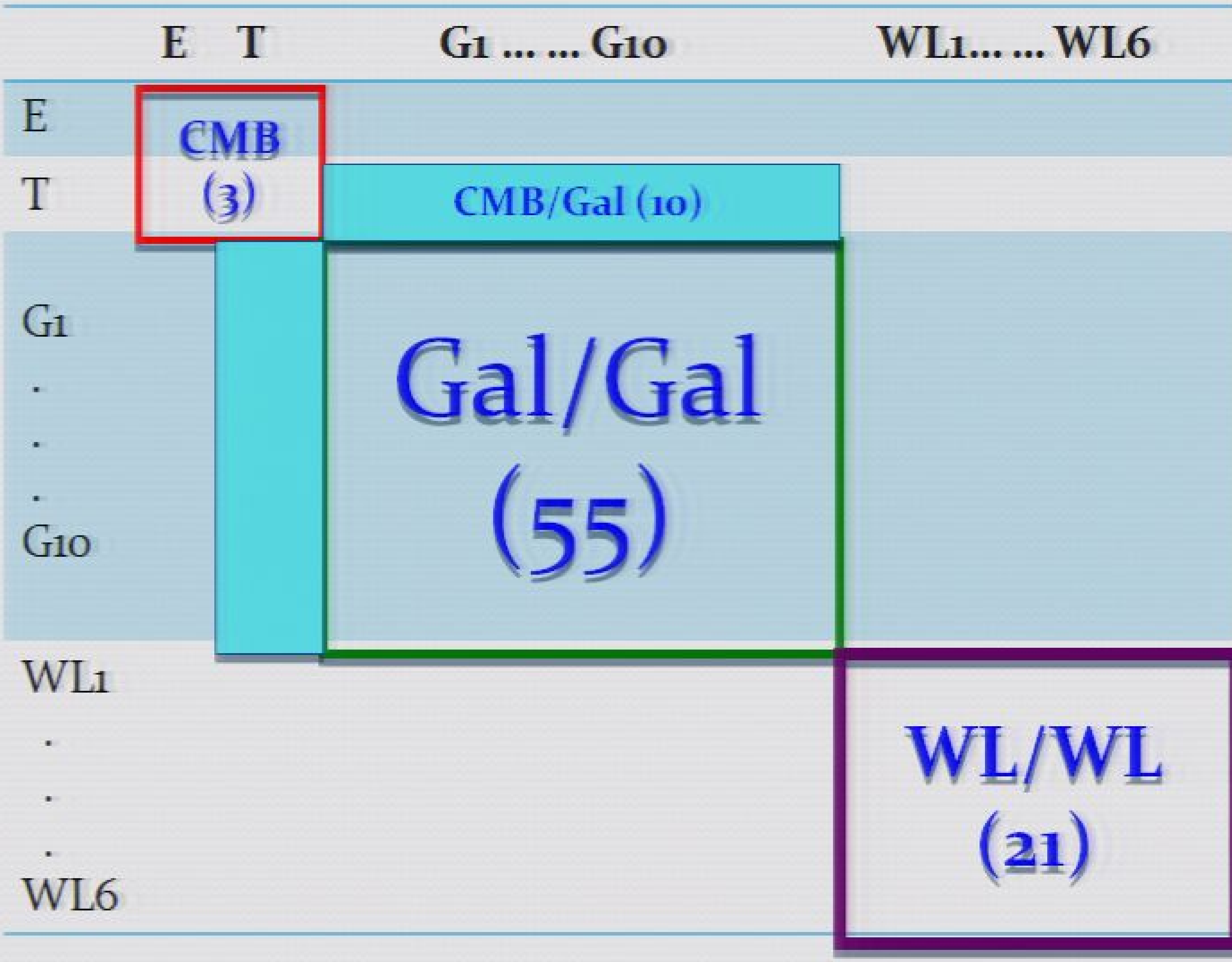
WL1 . . . WL6			WL/WL (21)


E T
G1 … … G10
WL1… … WL6
E
T
G1
.
.
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WL1
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WL6
CMB
(3)
CMB/Gal (10)
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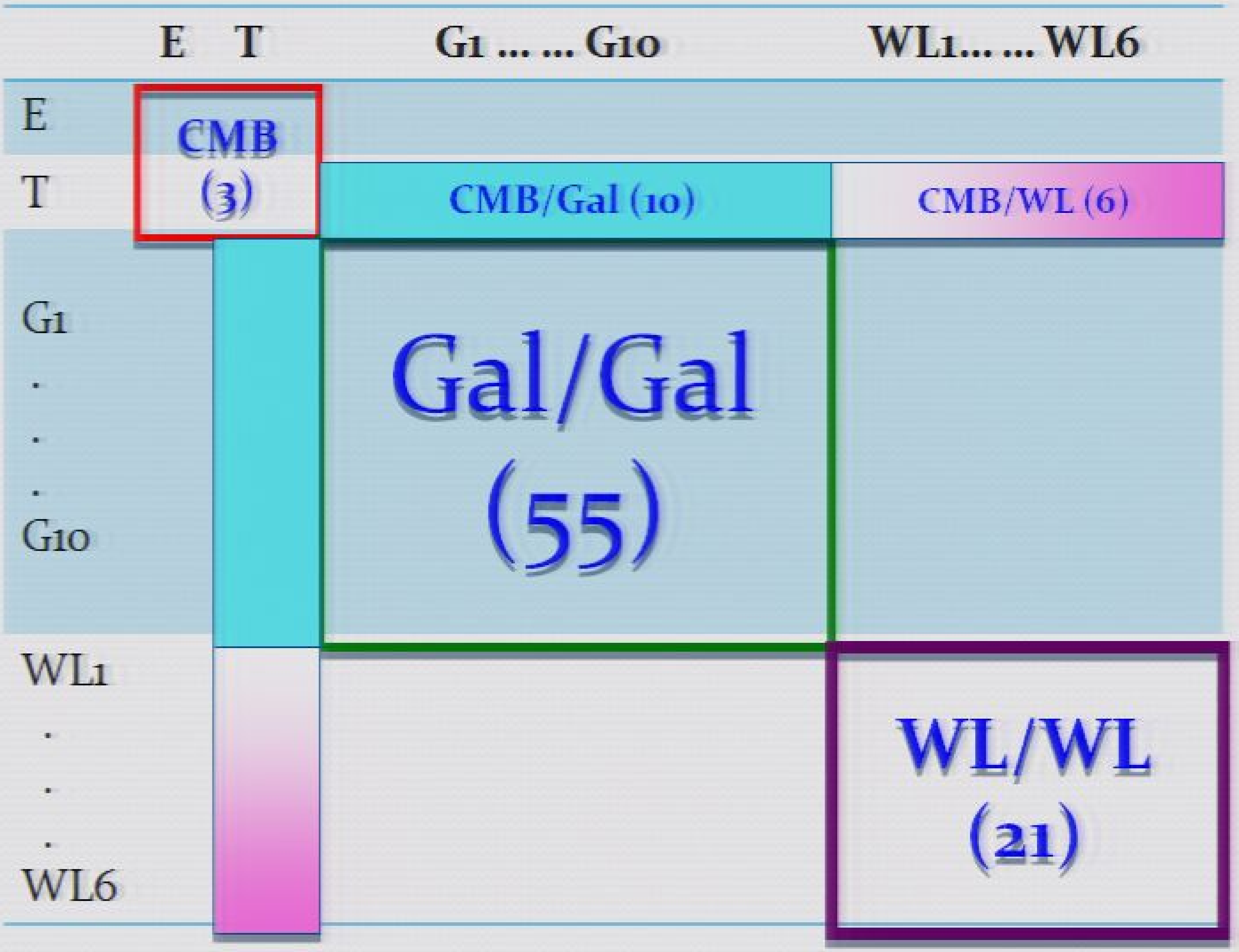
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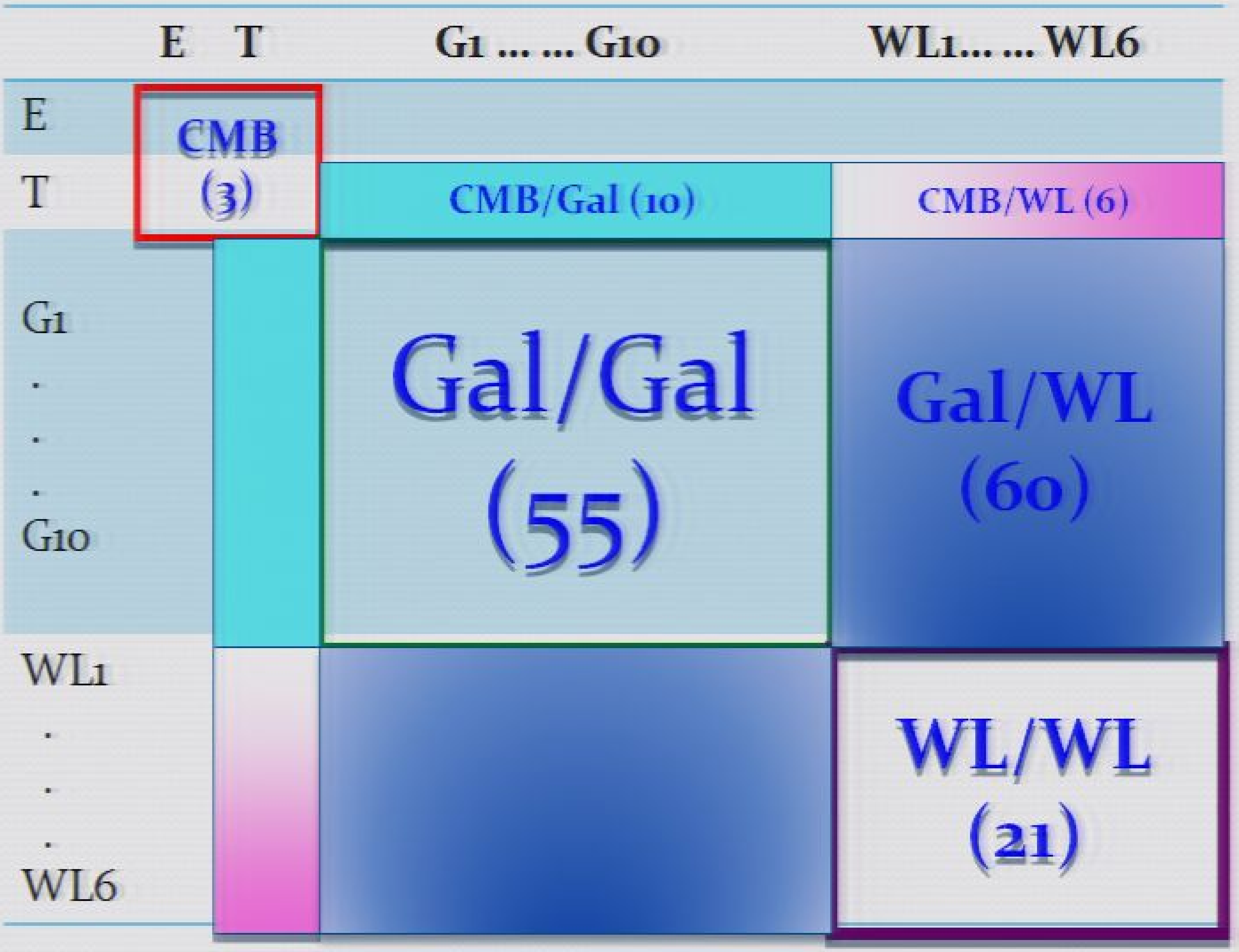
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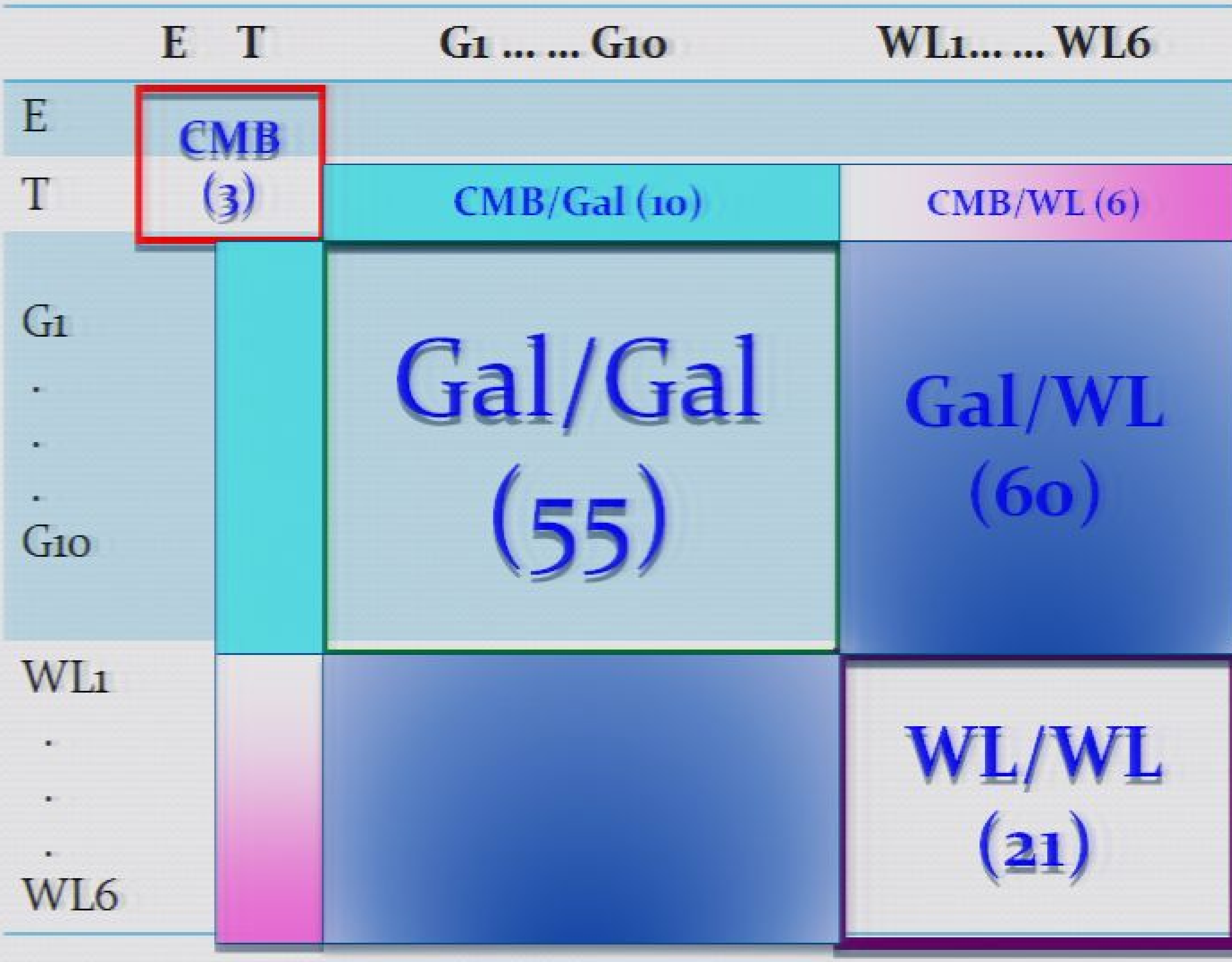
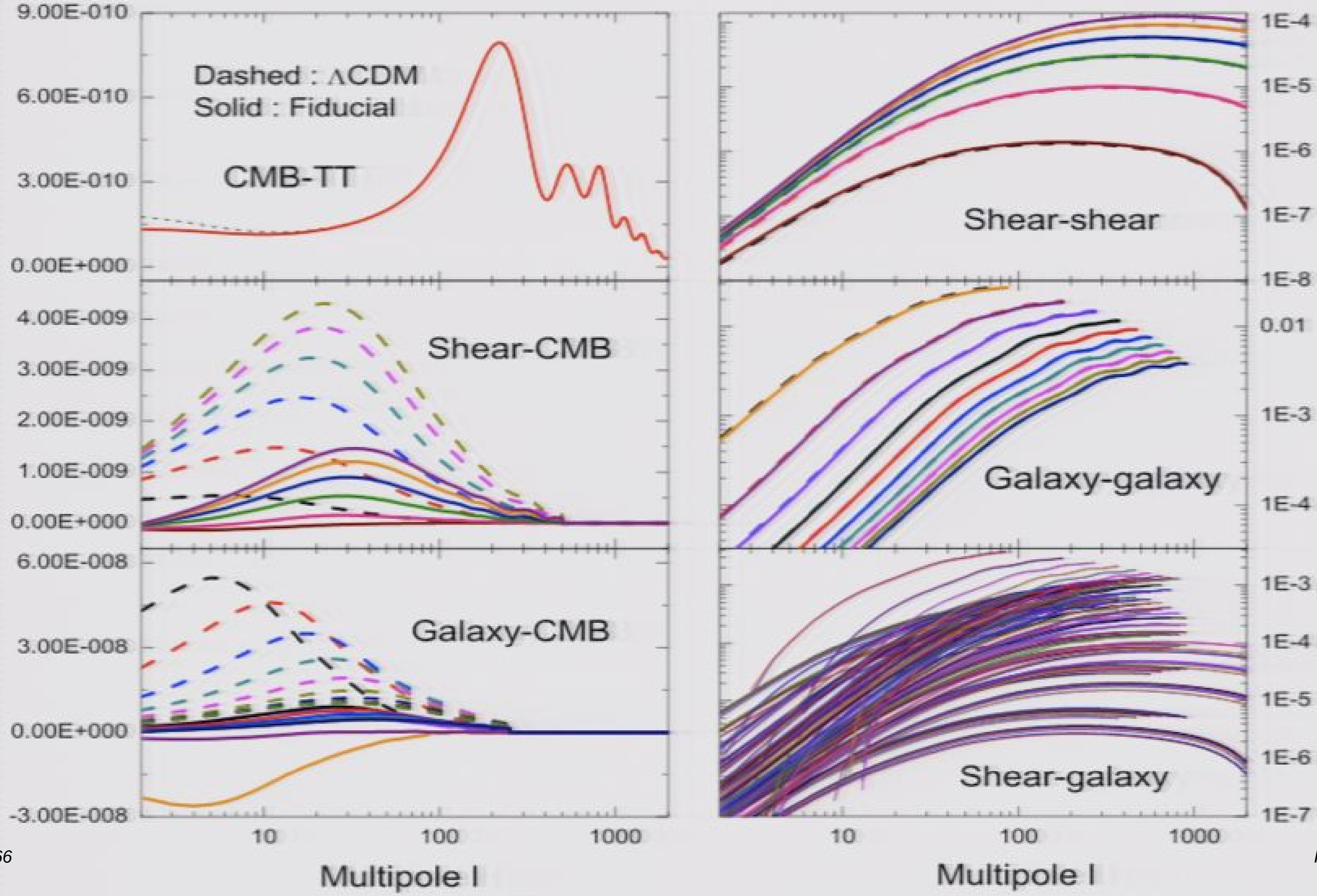
Gal/Gal
(55)
Gal/WL
(60)
WL/WL
(21)



We have 155 Cls for each model!!

Observables for scale-independent modification of GR

Fiducial : $G=1+\beta_1 a^s$, $\Phi/\Psi=1+\beta_2 a^s$, $\beta_1=\beta_2= -0.5$, $s=3$



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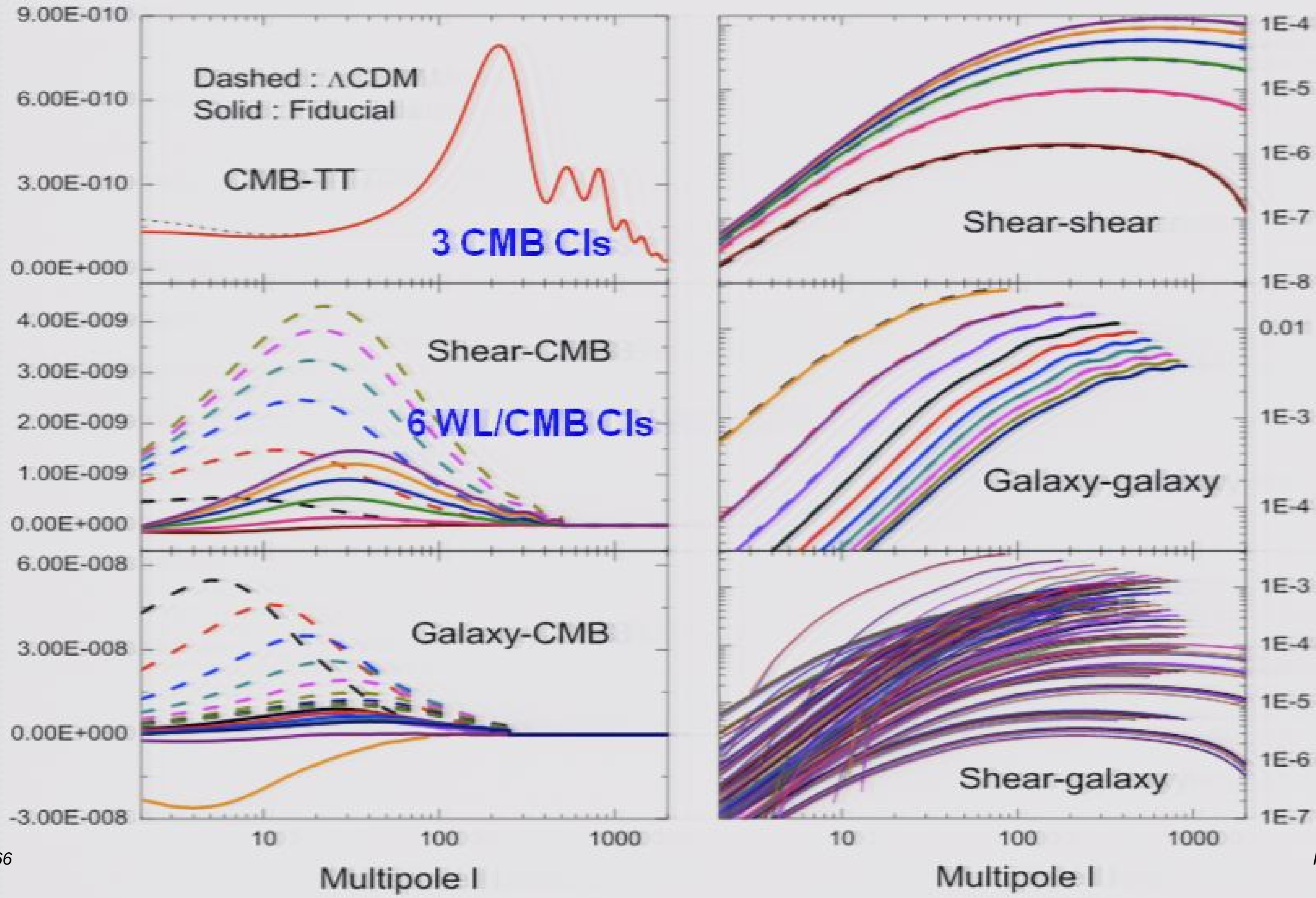

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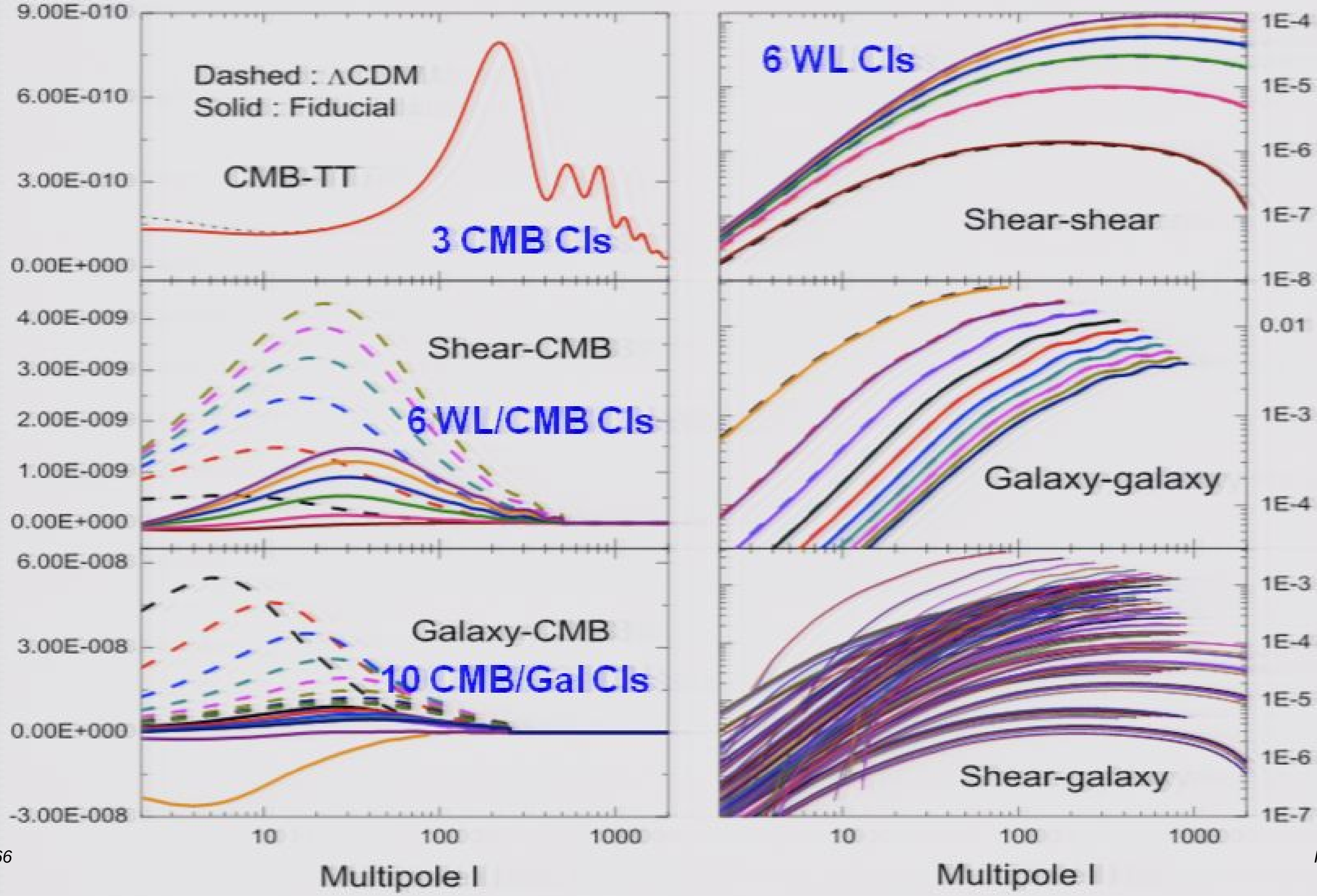

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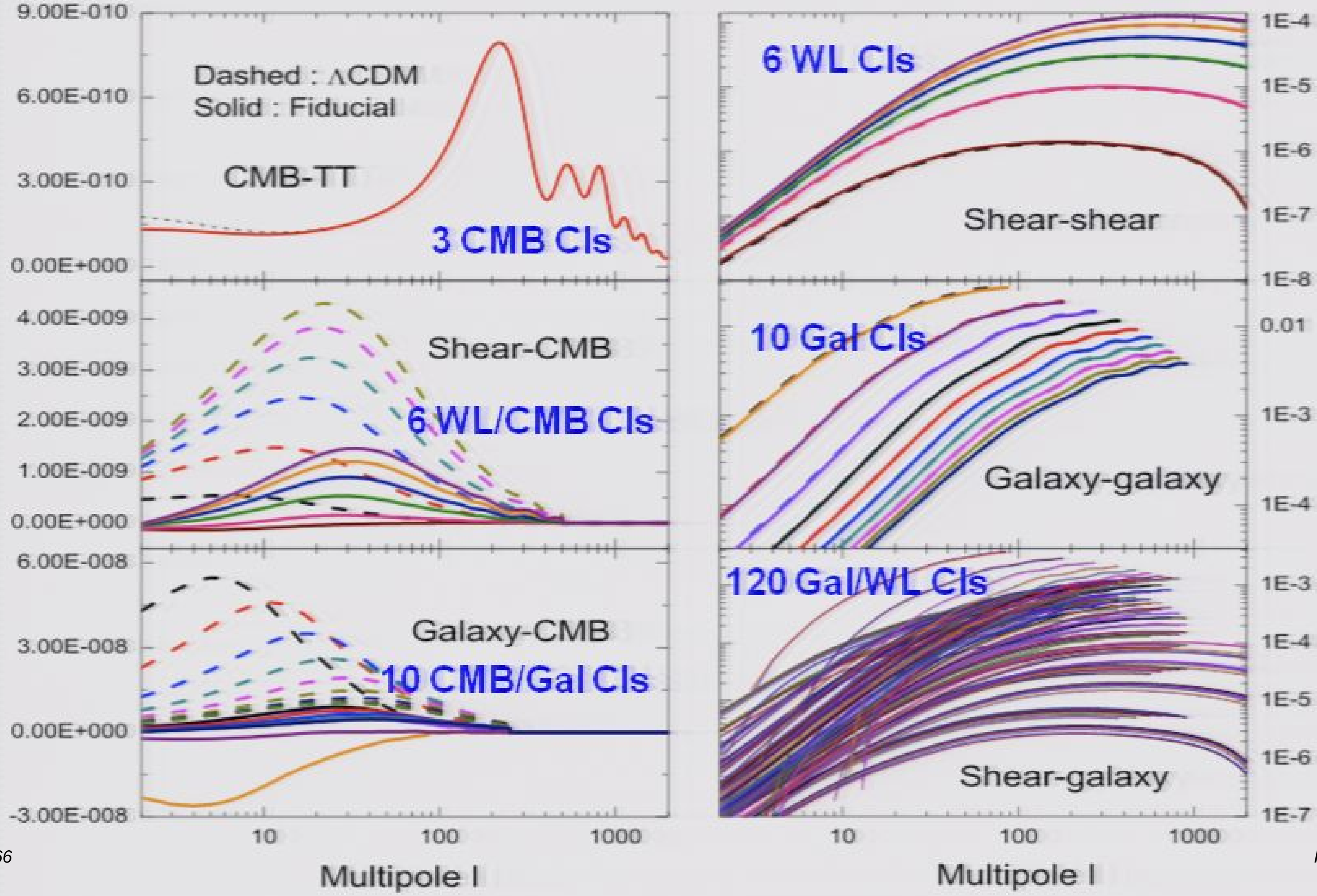

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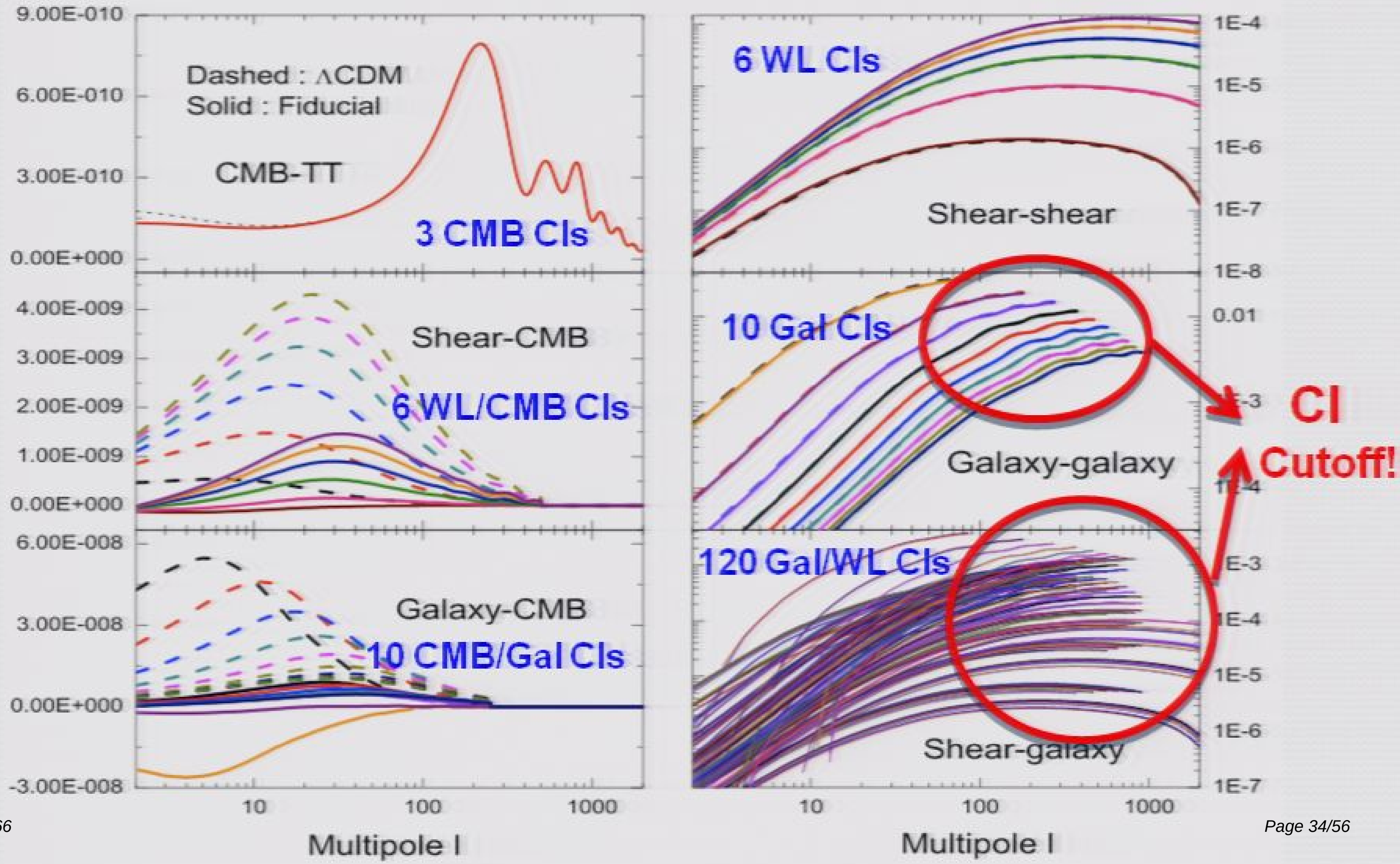

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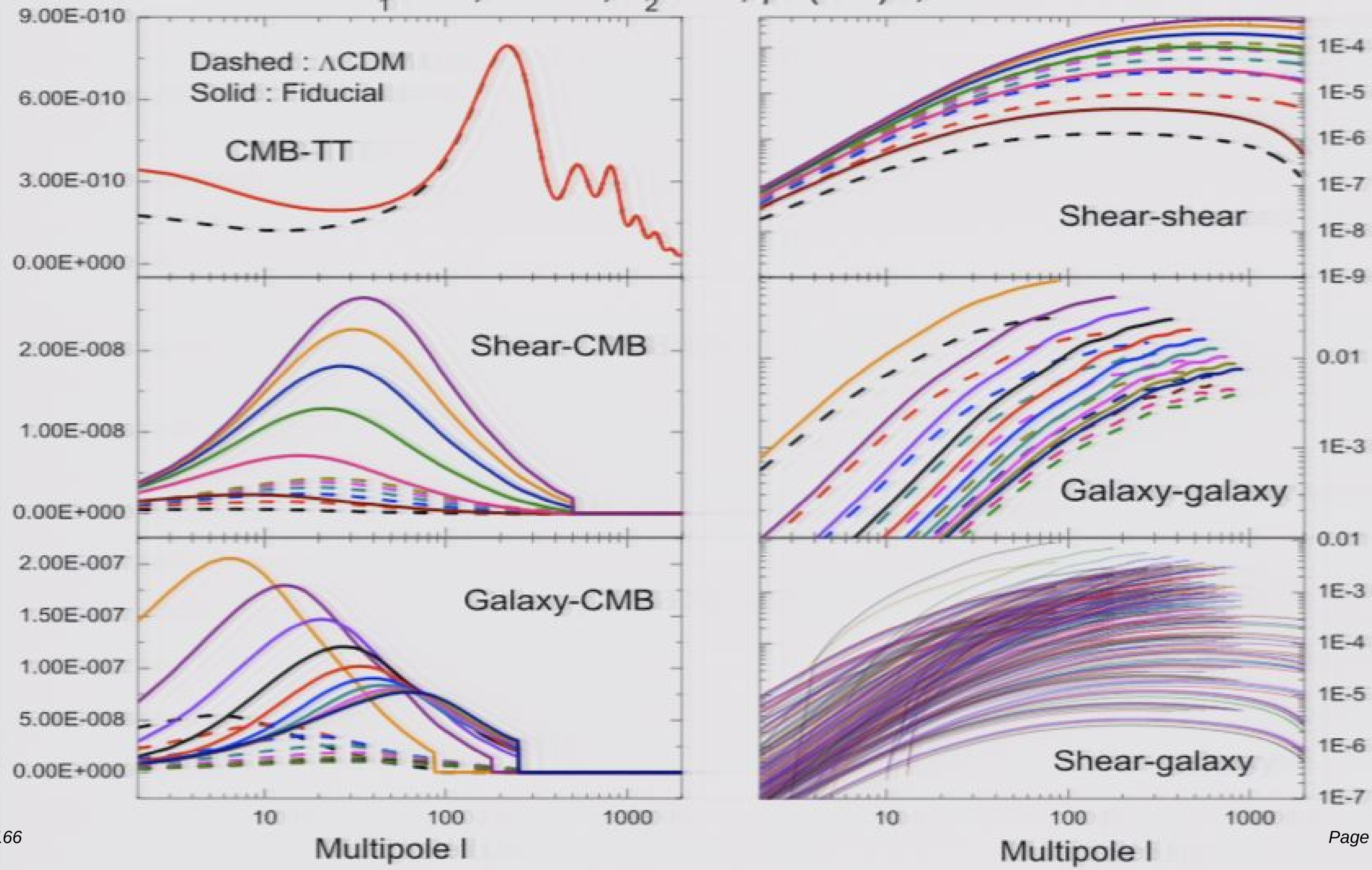

Fisher Analysis

For CMB, WL-WL, galaxy-galaxy:

$$F_{ij} = \sum_{l=l_{min}}^{l_{max}} f_{sky} \frac{2l+1}{2} Tr\left(A_i^l A_j^l\right) \qquad A_i = C_{lk}'^{-1} \frac{\partial C_{lk}'}{\partial P_i}$$

For CMB-WL, CMB-galaxy, WL-galaxy cross-correlations:

$$F_{\alpha\beta}^{\rm sub} = f_{\rm sky} \sum_l (2l+1)\Delta l \sum_{(ij)(mn)} D_{l\alpha}^{x_i x_j} [\tilde{\mathbf{C}}_l^{\rm sub}]^{-1} D_{l\beta}^{x_m x_n}$$

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Hu & Jain (2004)

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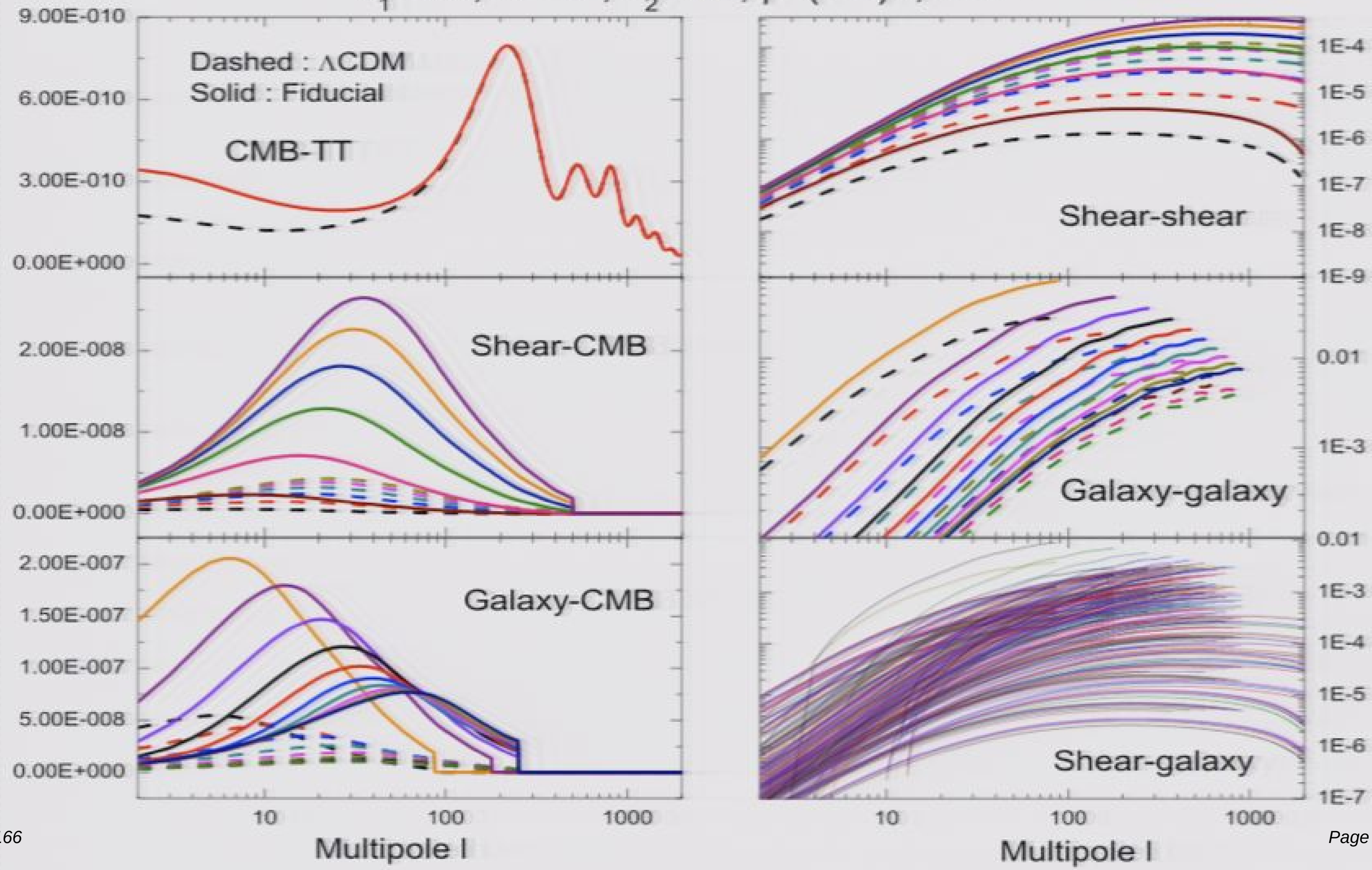

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Hu & Jain (2004)

Noises

$$C'^{l}_{jk} = \tilde{C}^{l}_{jk} + N^{l}_{jk}$$

$$N_l^{\epsilon_i \epsilon_j} = \delta_{ij} \frac{\gamma_{\rm rms}^2}{\bar{n}_{Ai}},$$

$$N_l^{g_a g_b} = \delta_{ab} \frac{1}{\bar{n}_{Aa}},$$

$$N_l^{\epsilon_i g_a} = 0,$$

$$N^l_{aa} = \left[\sum_c \left(N^{l,c}_{aa}\right)^{-1} \right]^{-1}$$

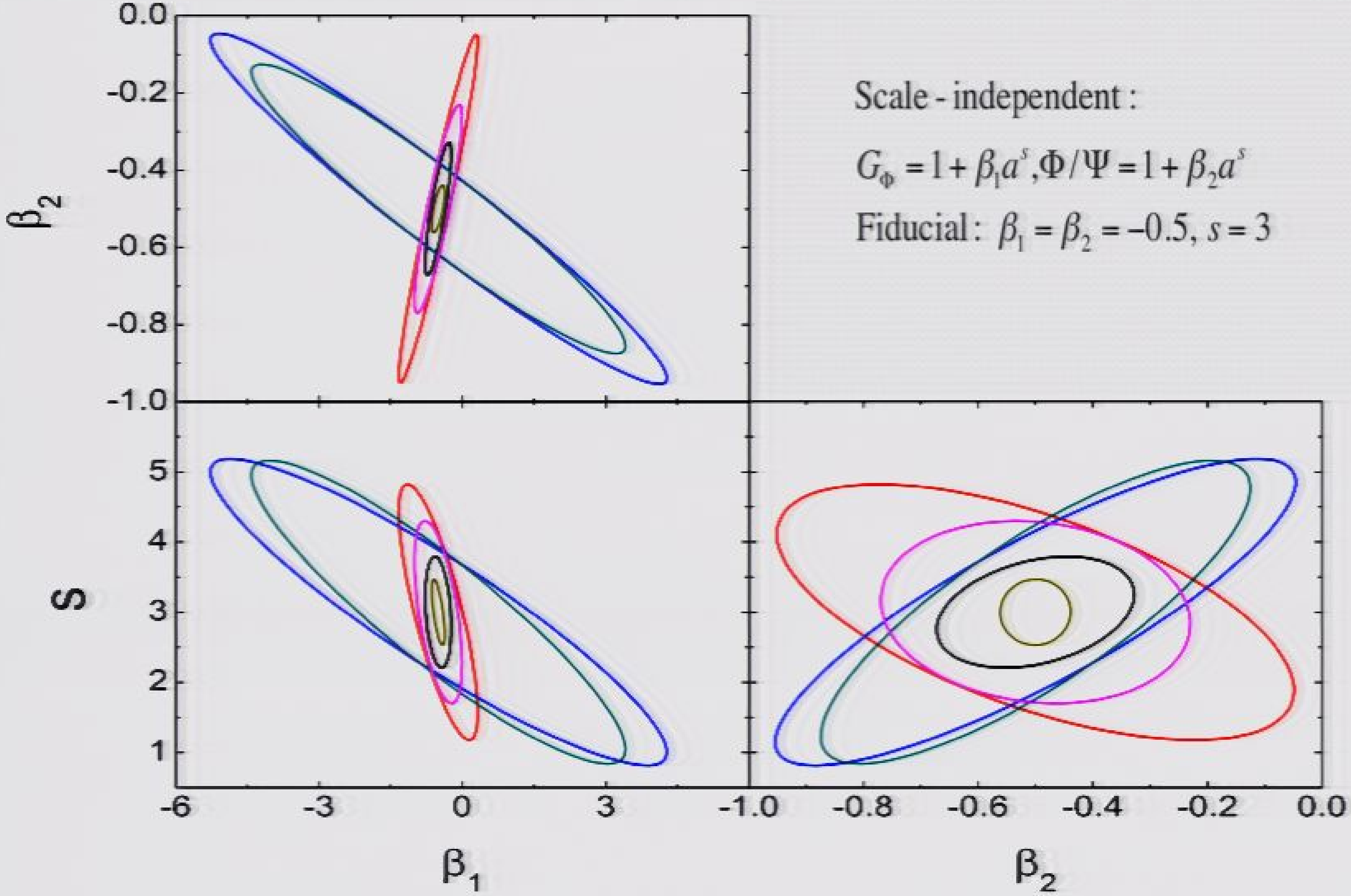
$$N^{l,c}_{aa} = \left(\frac{\sigma_{a,c}\theta_{FWHM,c}}{T_{CMB}} \right) e^{l(l+1)\theta^2_{FWHM,c}/8ln2}$$

Priors

$$\sigma(H_0) = 8(\mathrm{HST}),\ \sigma(\mathrm{bias}) = 0.1$$

Preliminary results:

Zhao, Pogosian, Silvestri & Zylberberg (2008), appear soon



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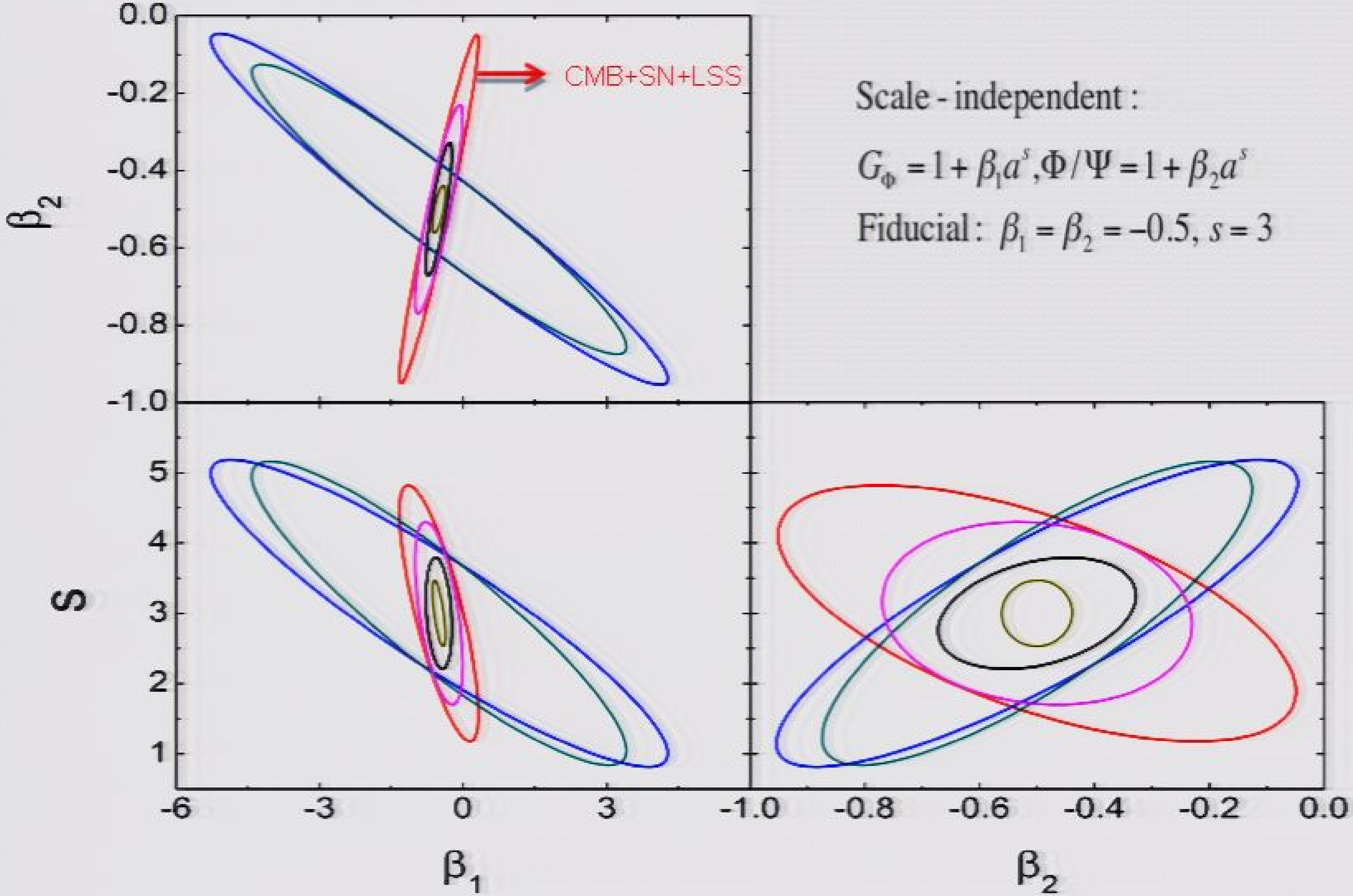

Scale - independent :

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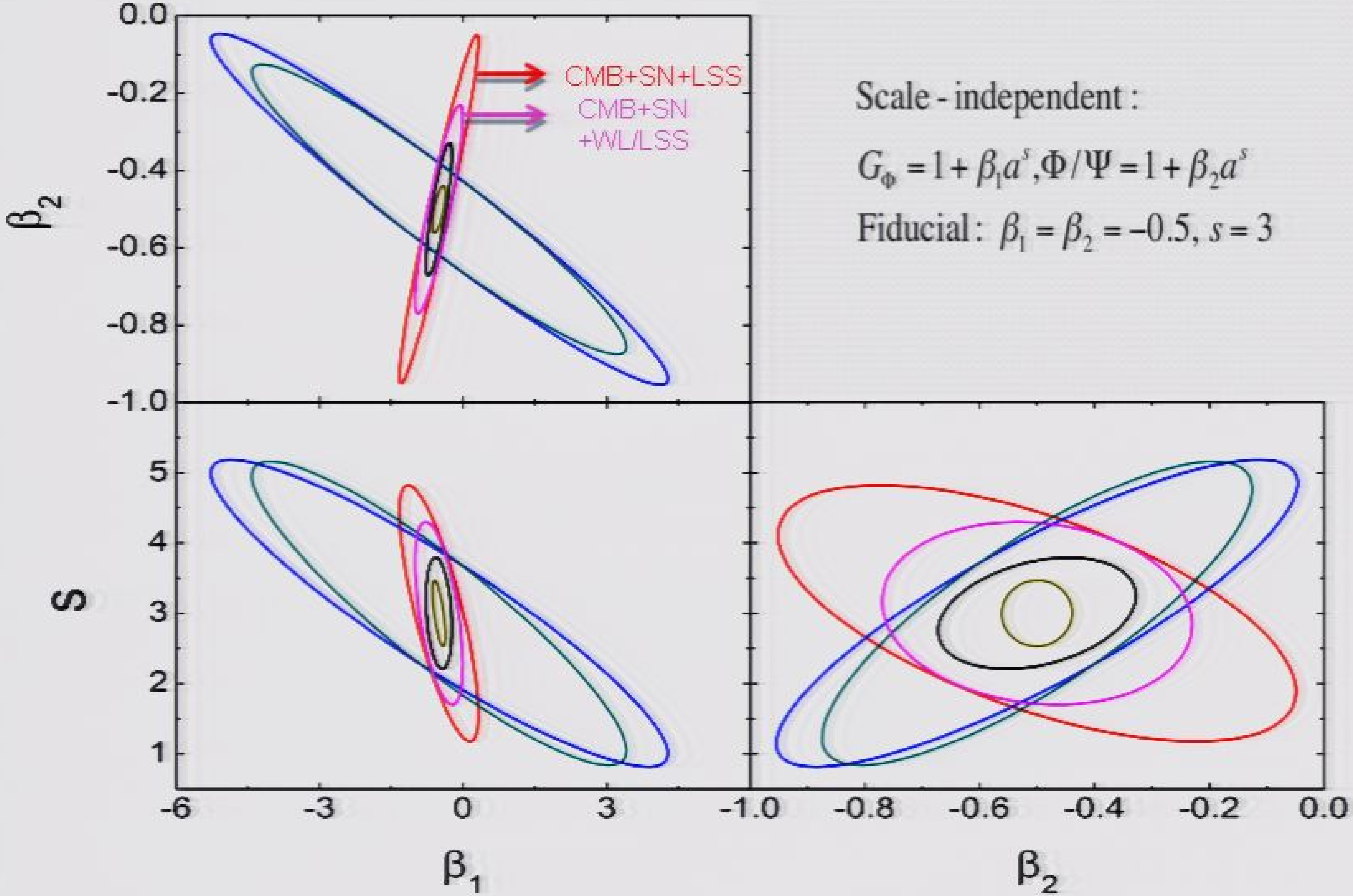

Scale - independent :

$G_\Phi = 1 + \beta_1 a^s, \Phi/\Psi = 1 + \beta_2 a^s$

Fiducial: $\beta_1 = \beta_2 = -0.5, s = 3$

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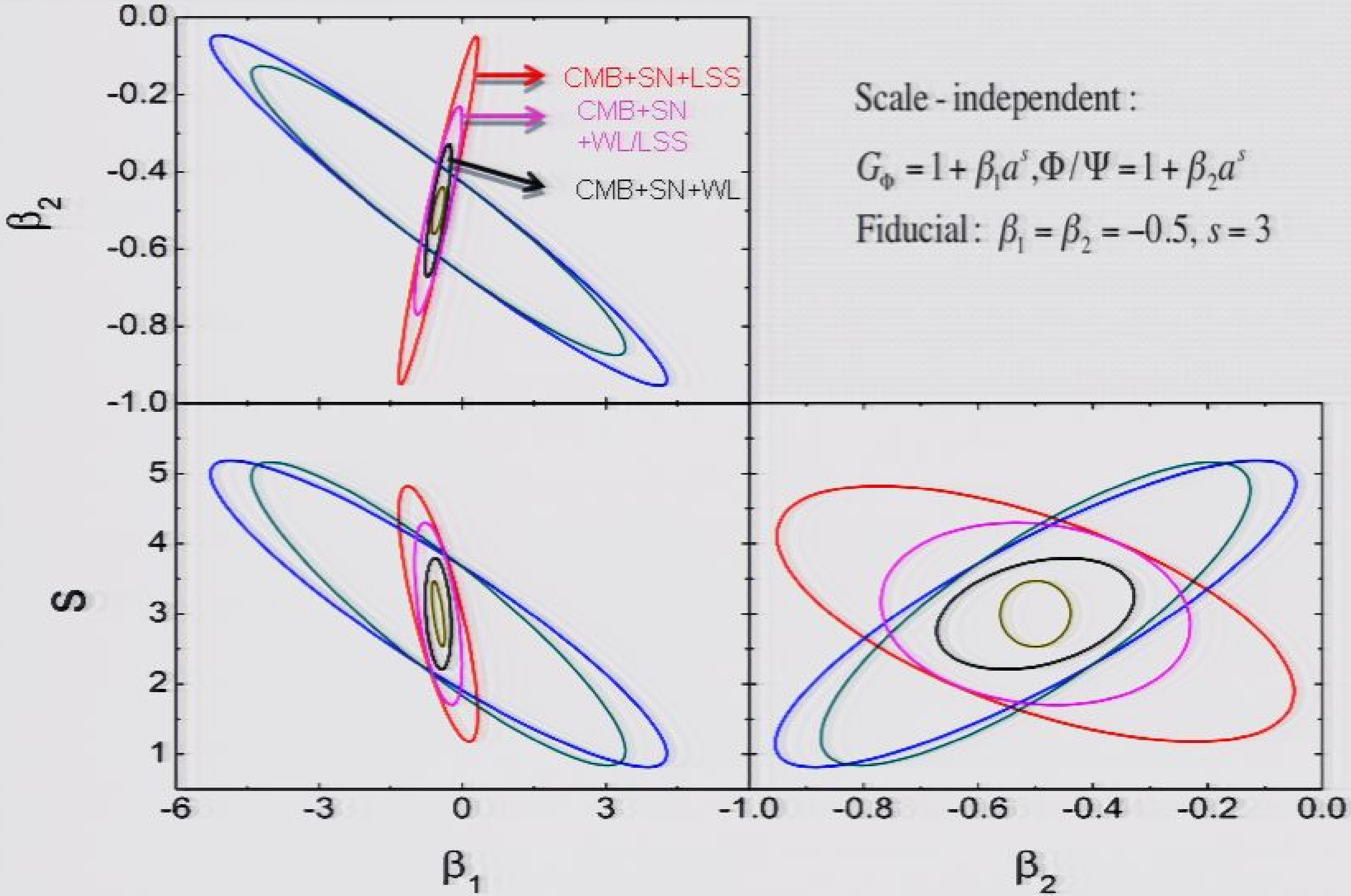

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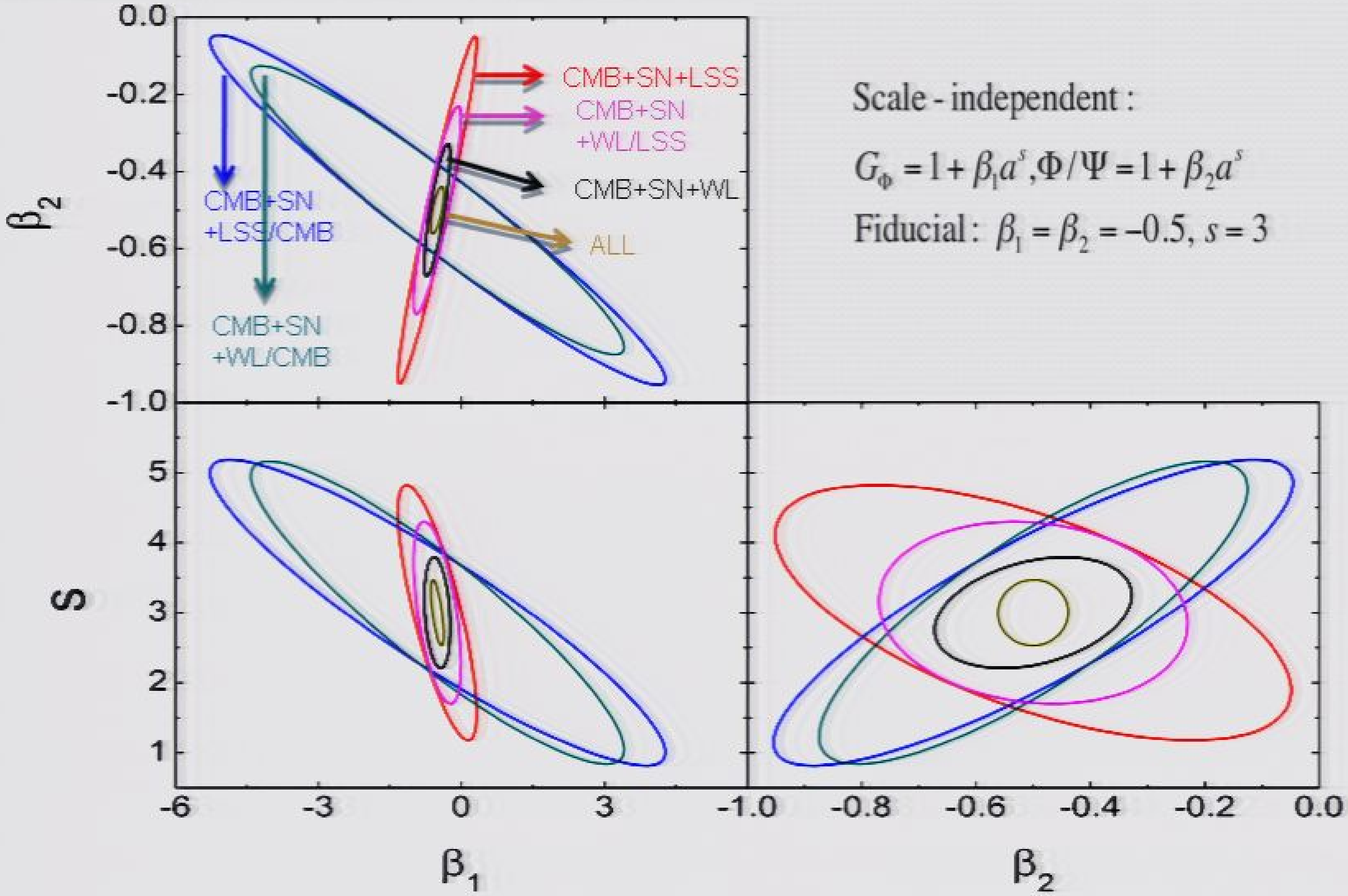

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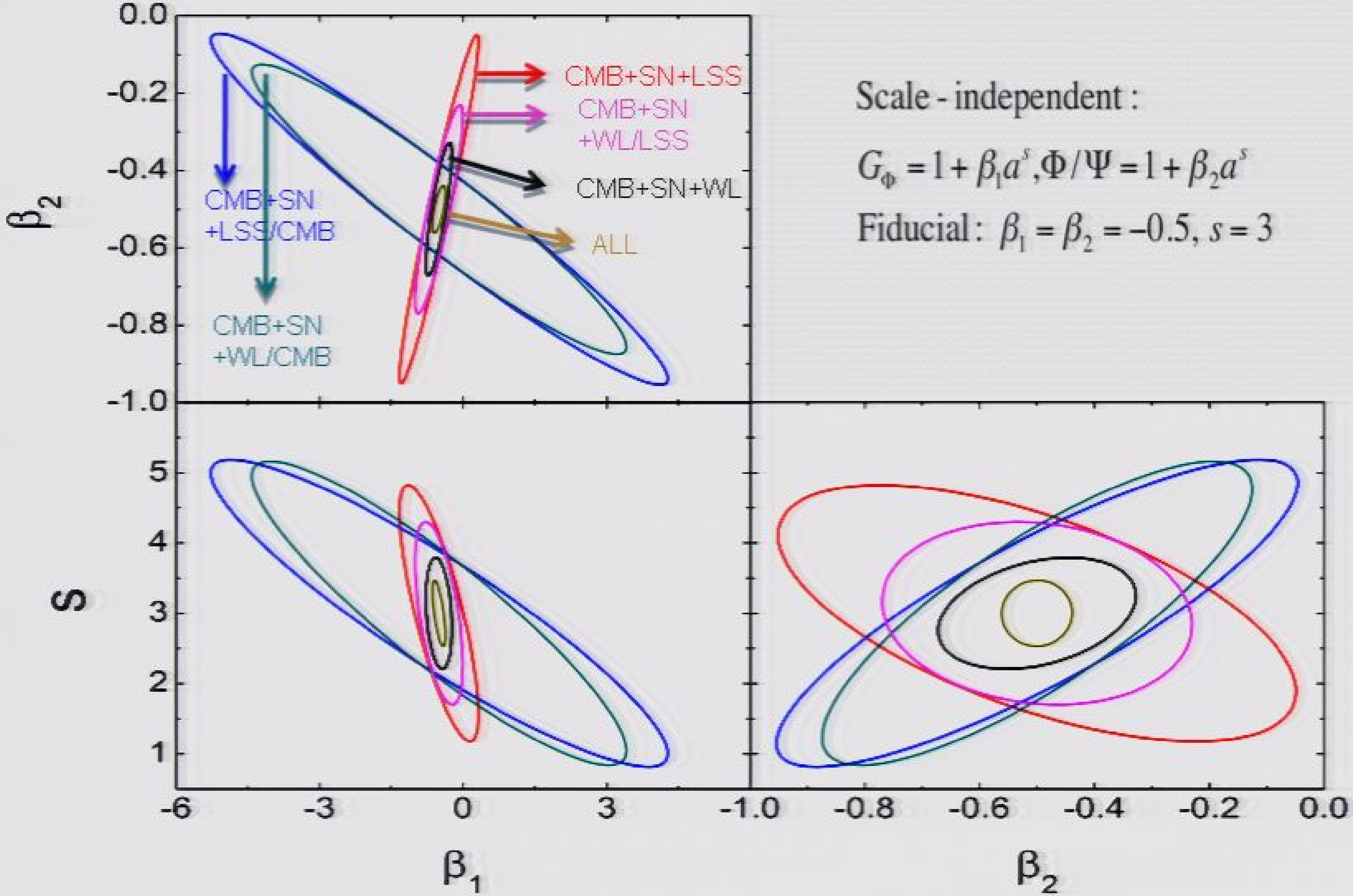

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All data: $\sigma(\beta_1) = 0.134, \sigma(\beta_2) = 0.061, \sigma(s) = 0.470$

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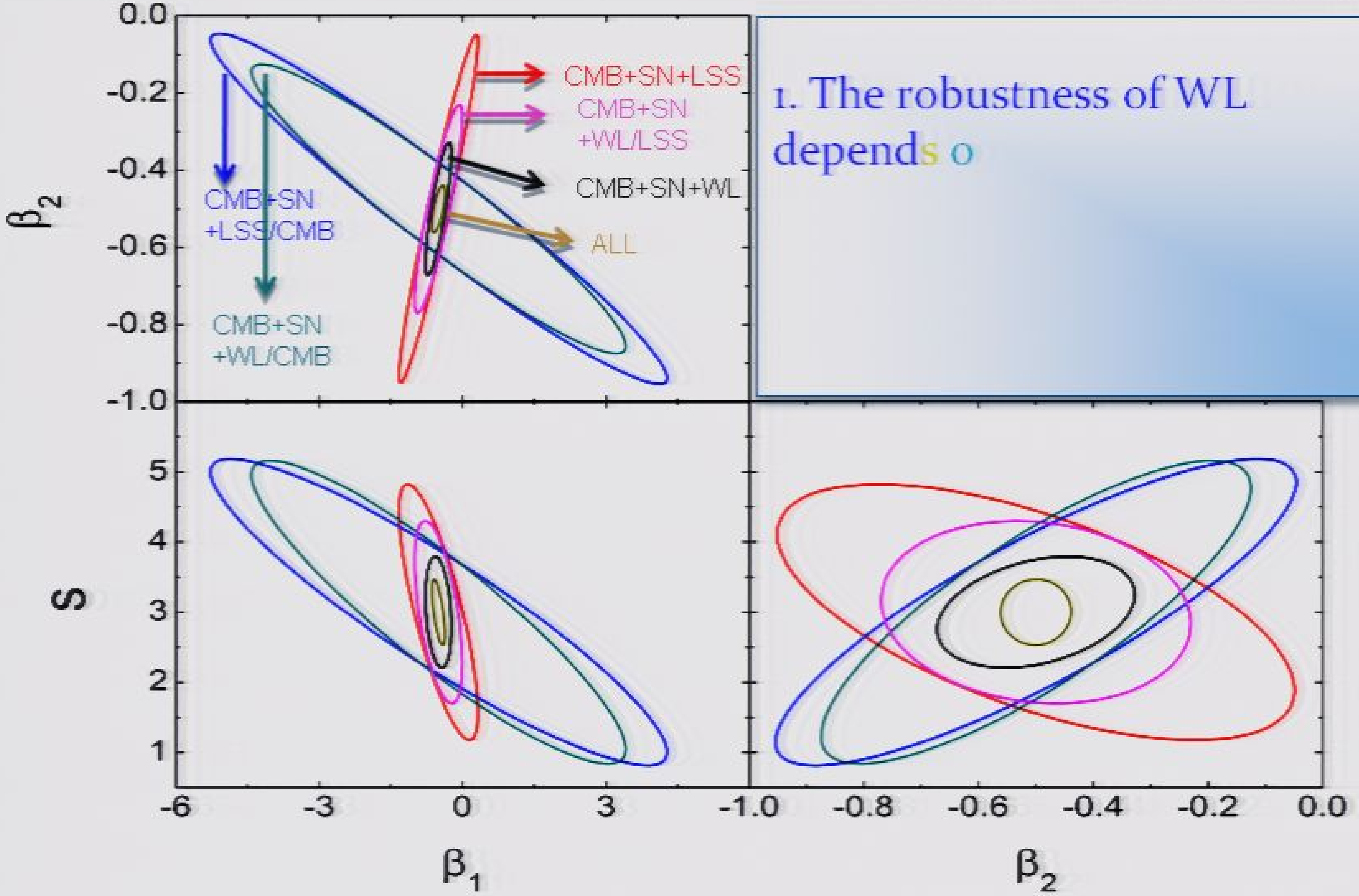

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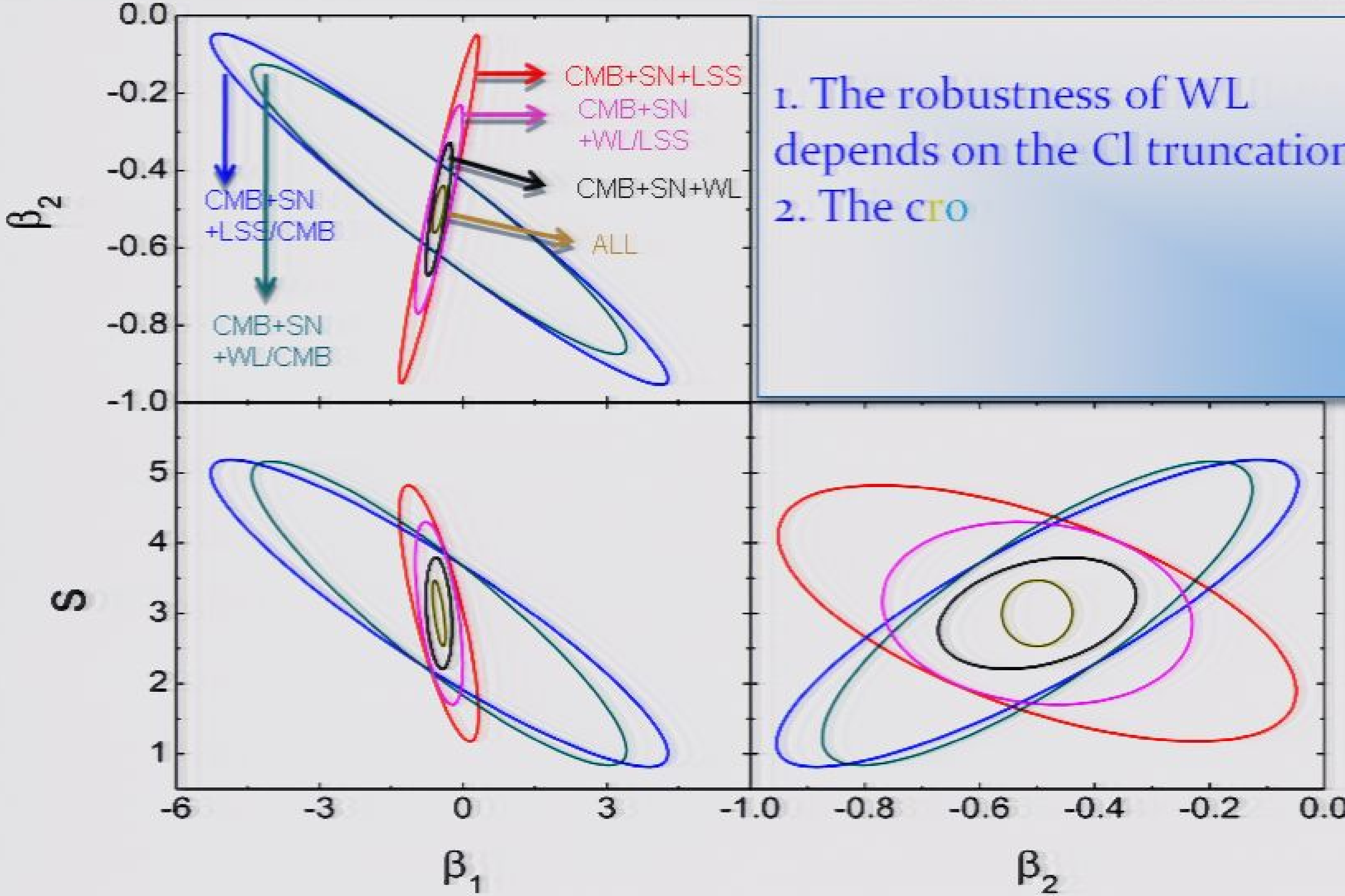

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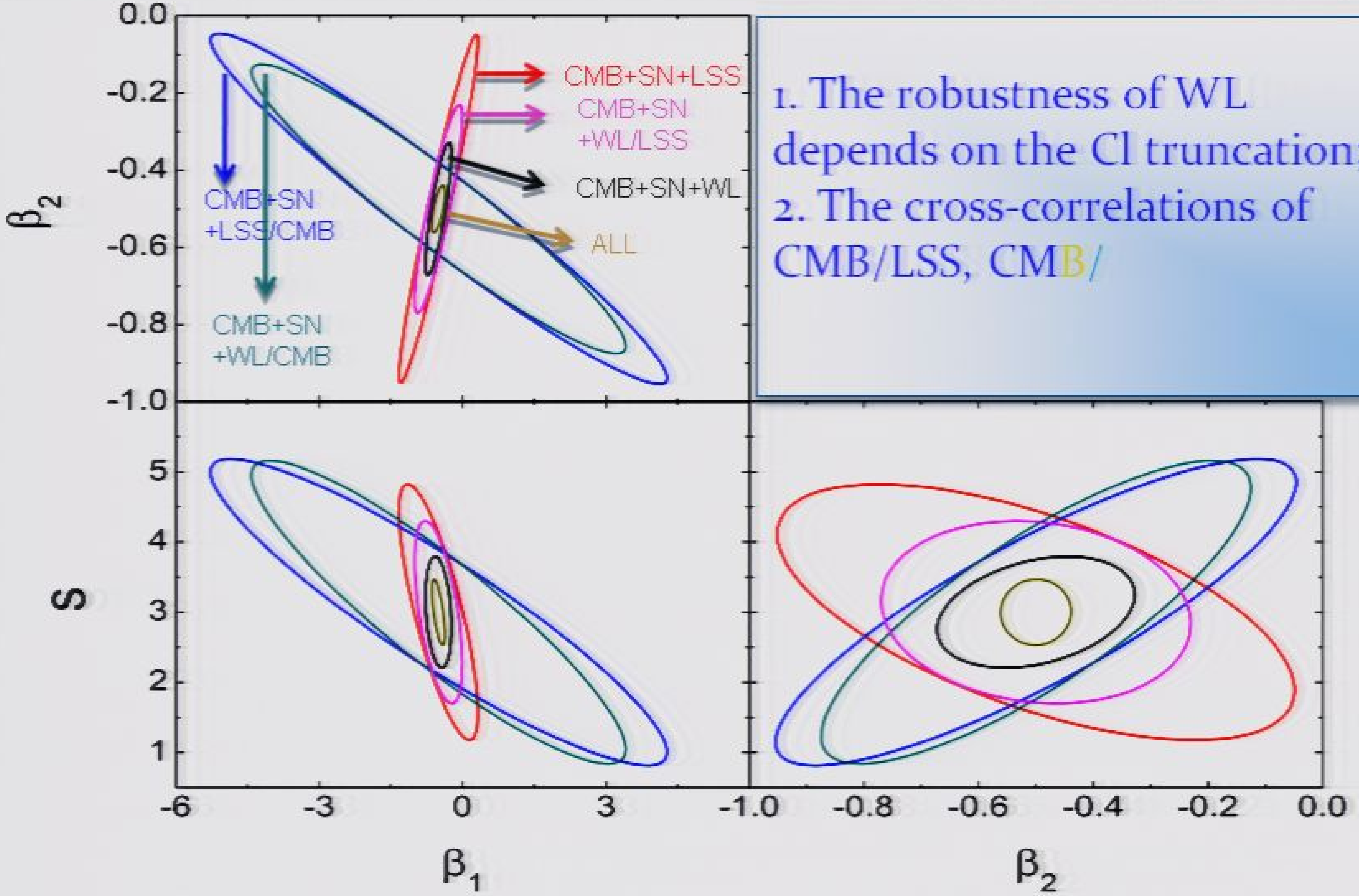

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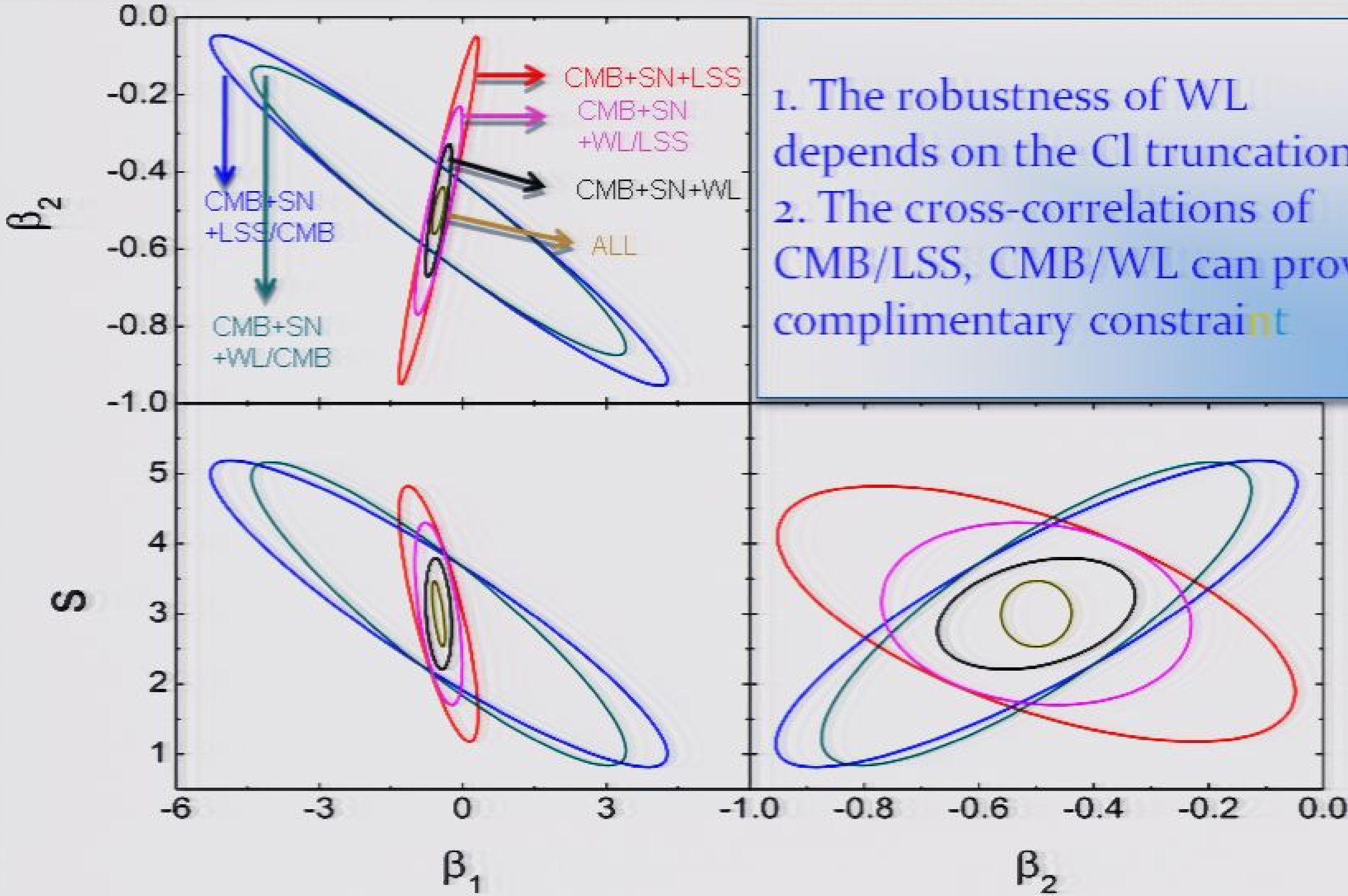

1. The robustness of WL depends on the Cl truncation;
2. The cross-correlations of CMB/LSS, CMB/WL can provide complimentary constraint

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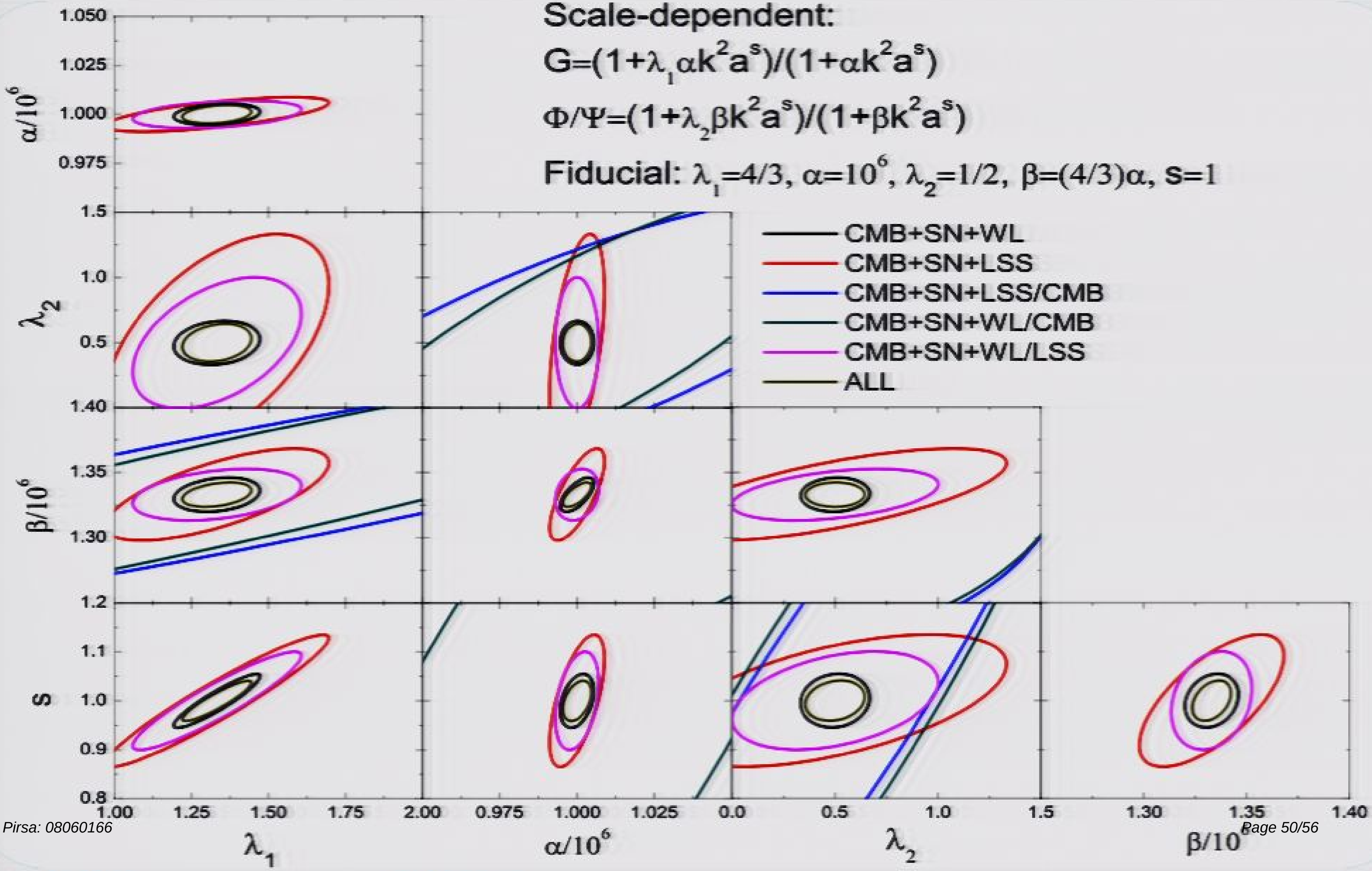
Scale-dependent:

$G=(1+\lambda_1\alpha k^2 a^s)/(1+\alpha k^2 a^s)$

$\Phi/\Psi=(1+\lambda_2\beta k^2 a^s)/(1+\beta k^2 a^s)$

Fiducial: $\lambda_1=4/3$, $\alpha=10^6$, $\lambda_2=1/2$, $\beta=(4/3)\alpha$, $s=1$



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$$\sigma(\lambda_1)=0.112, \sigma(\alpha/10^6)=0.005$$

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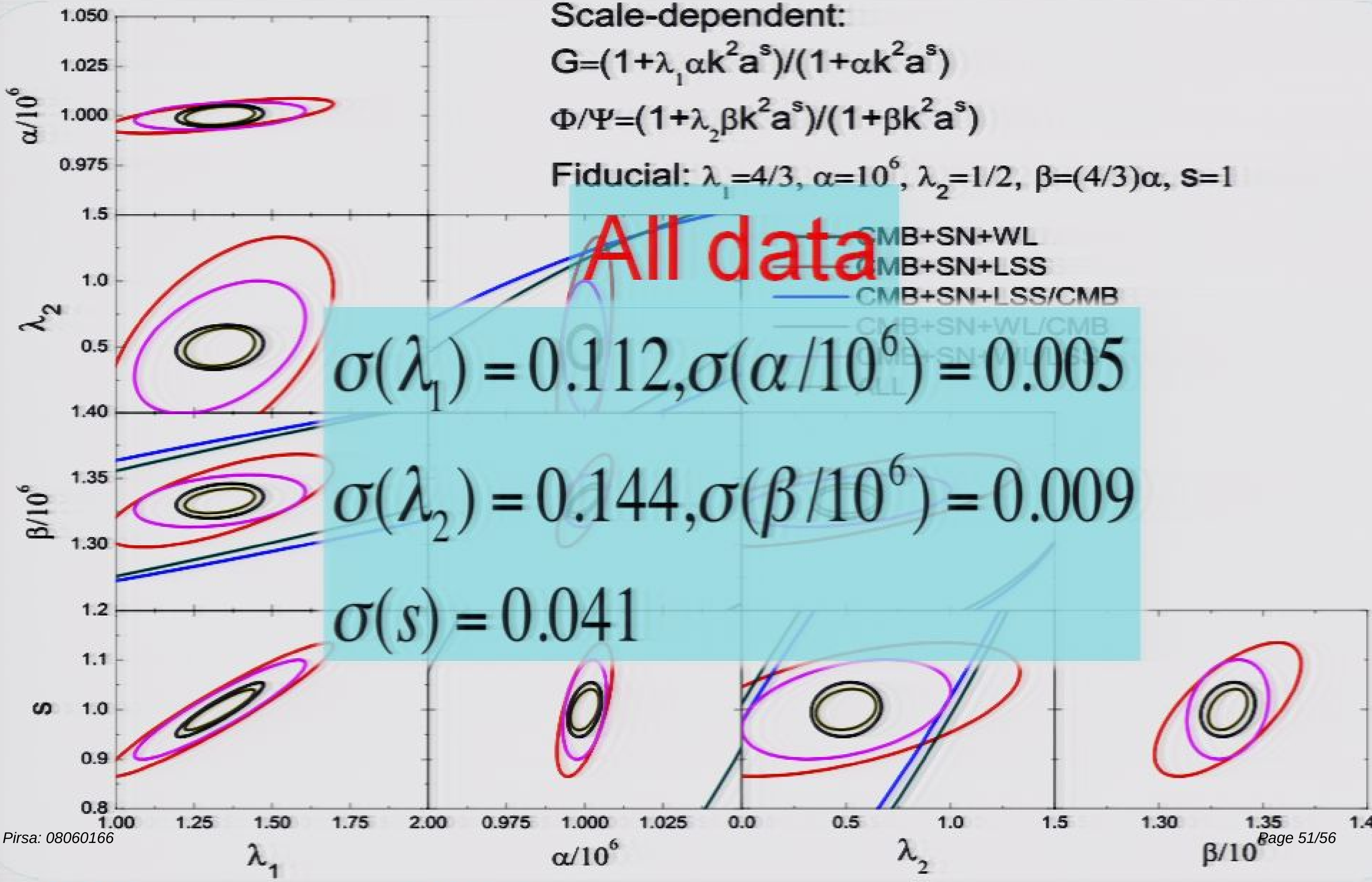
$$\sigma(s)=0.041$$



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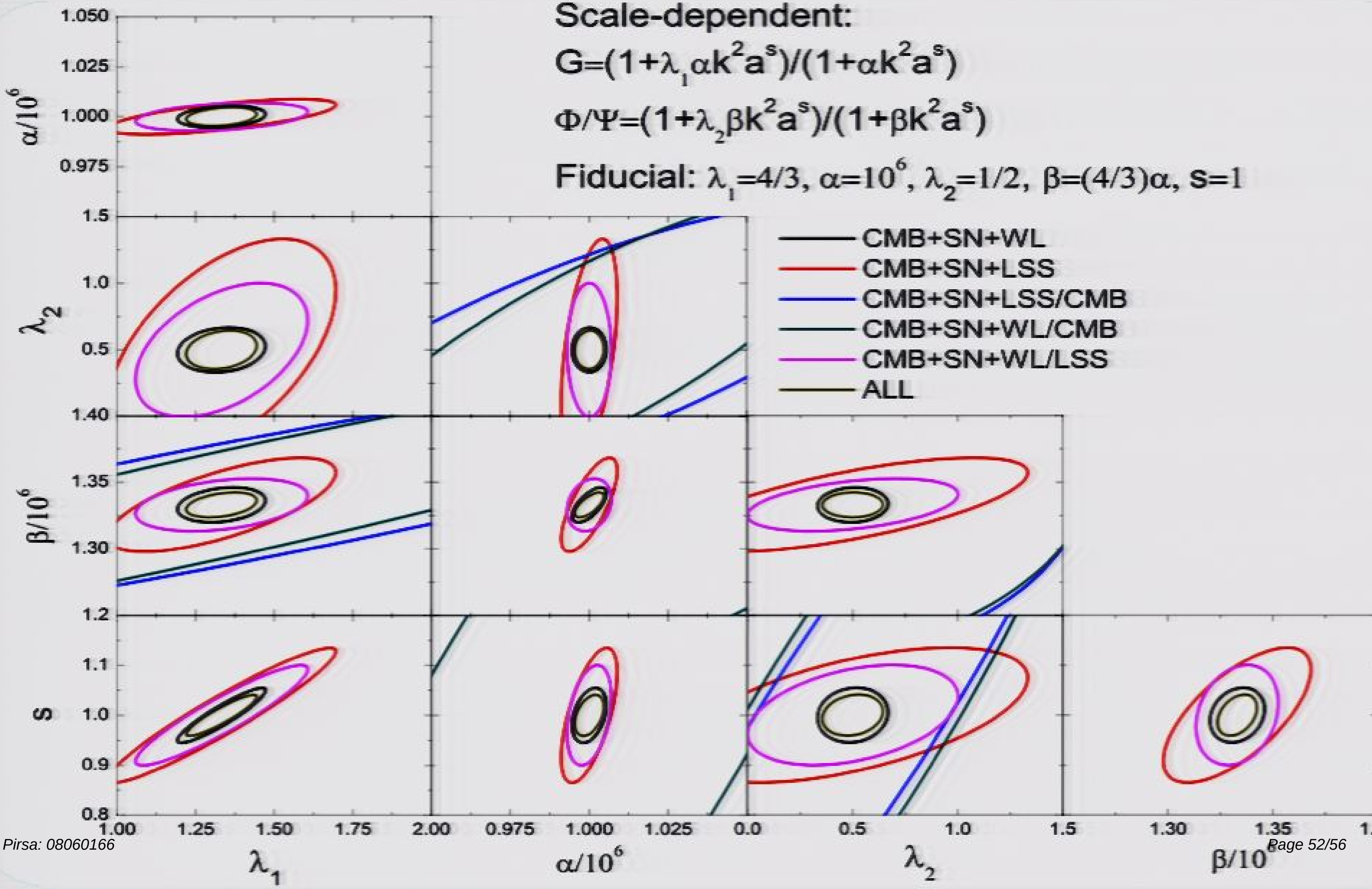

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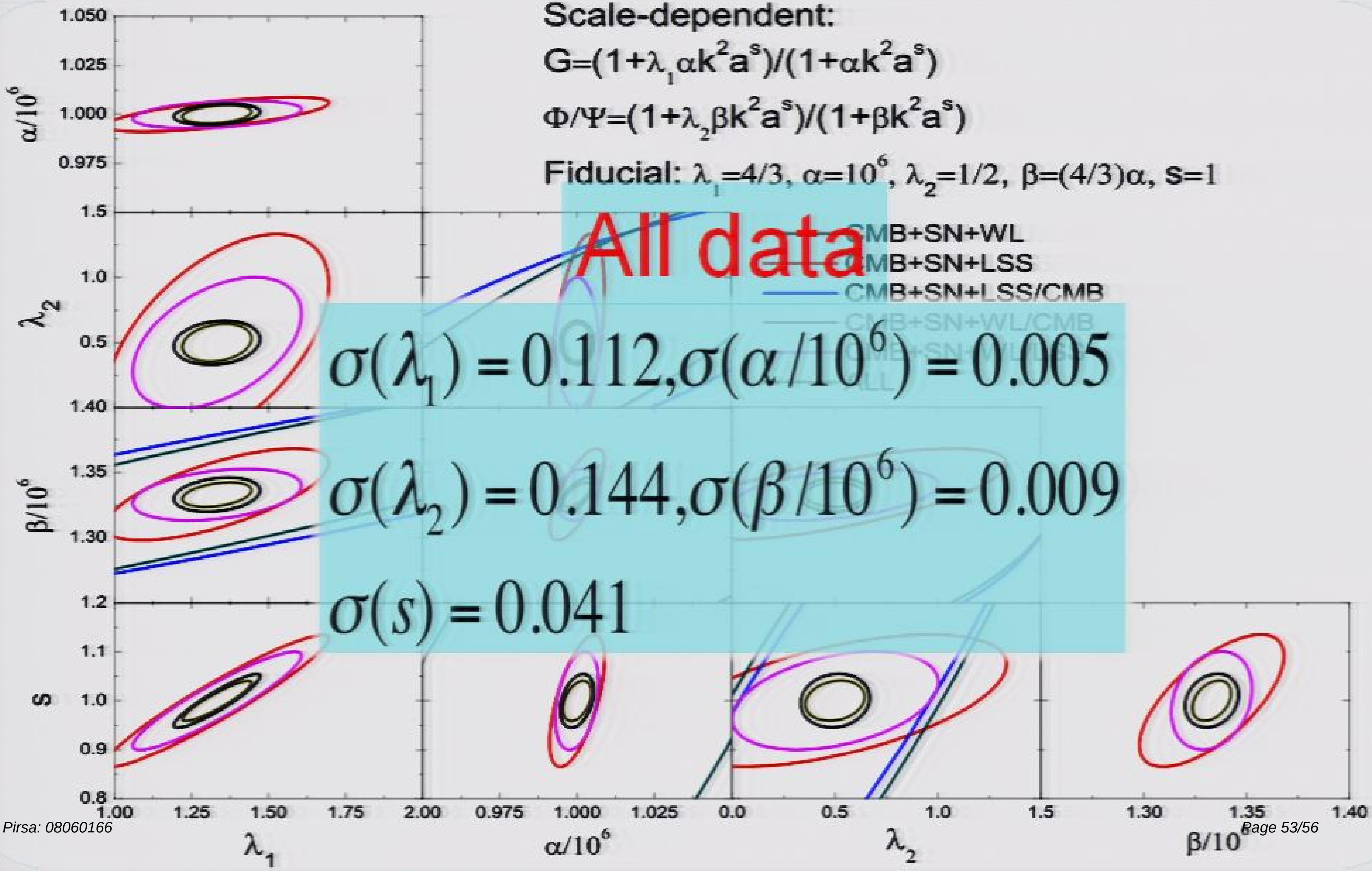

Summary

- Tomographic surveys can provide powerful constraints on possible deviation from GR;
- Results depends on the choice of fiducial model and parameterization;
- Need to further study using non-parametric methods, such as principle component analysis (PCA).

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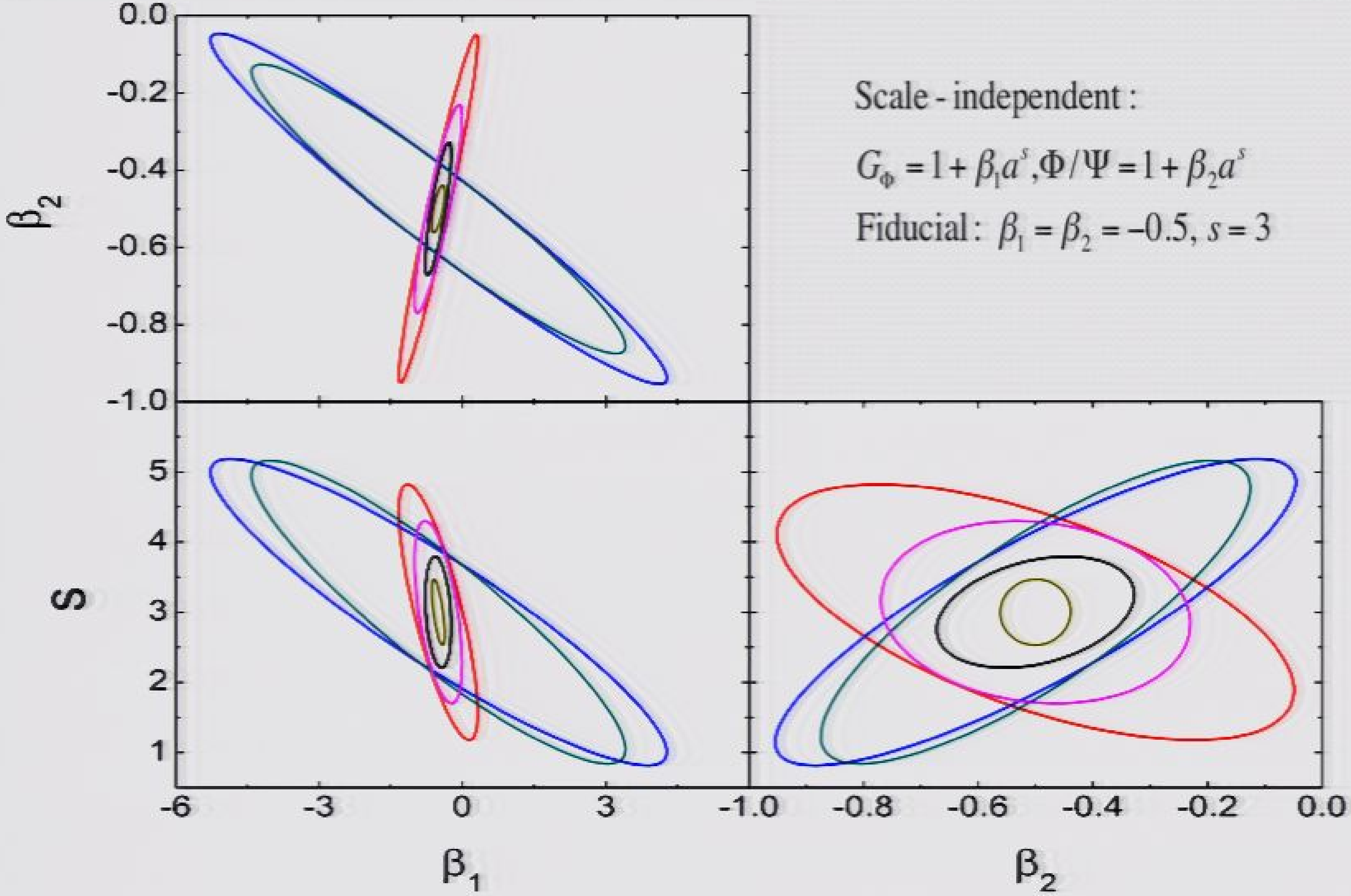

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Noises

$$C'^{l}_{jk} = \tilde{C}^{l}_{jk} + N^{l}_{jk}$$

$$N_l^{\epsilon_i \epsilon_j} = \delta_{ij} \frac{\gamma^2_{\rm rms}}{\bar{n}_{Ai}},$$

$$N_l^{g_a g_b} = \delta_{ab} \frac{1}{\bar{n}_{Aa}},$$

$$N_l^{\epsilon_i g_a} = 0,$$

$$N^l_{aa} = \left[\sum_c \left(N^{l,c}_{aa}\right)^{-1} \right]^{-1}$$

$$N^{l,c}_{aa} = \left(\frac{\sigma_{a,c} \theta_{FWHM,c}}{T_{CMB}} \right) e^{l(l+1)\theta^2_{FWHM,c}/8ln2}$$

Priors

$$\sigma(H_0) = 8(\mathrm{HST}),\ \sigma(\mathrm{bias}) = 0.1$$