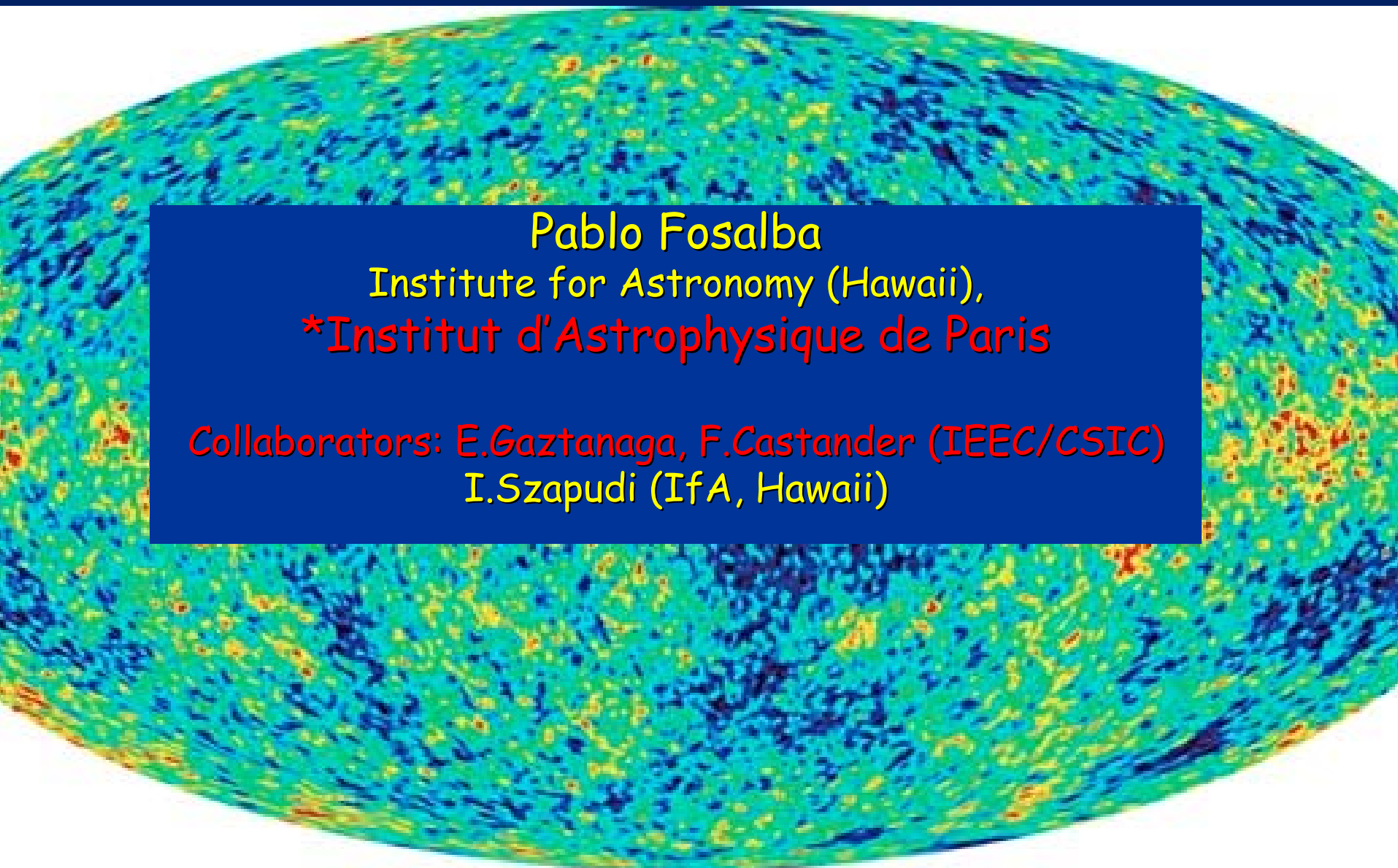
DETECTION OF THE ISW EFFECT



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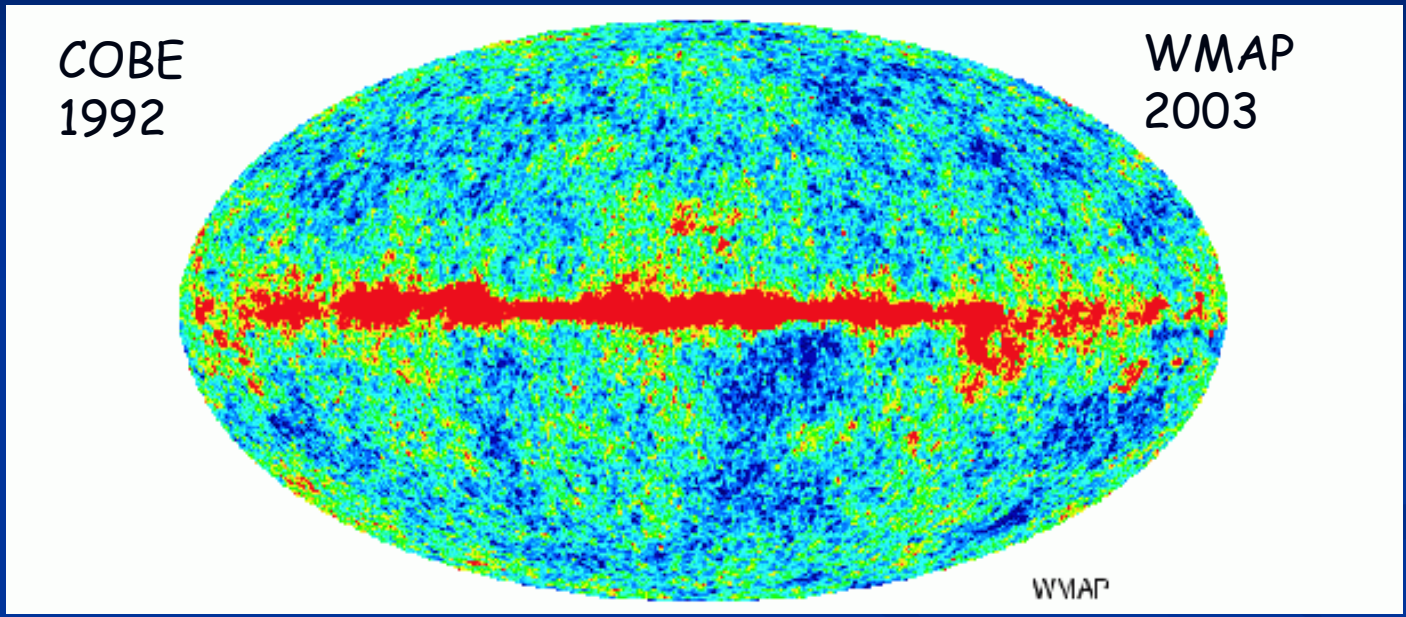
I.Szapudi (IfA, Hawaii)

OUTLINE

- First detections of the ISW effect
  -CMB-LSS cross-correlation measurements

- Future of the ISW analysis

Precision Cosmology from CMB: New Tests



- New estimators for CMB-LSS joint analysis
  - → Consistency of the model
  - → Breaking parameter degeneracy

BREAKING PARAMETER DEGENERACY

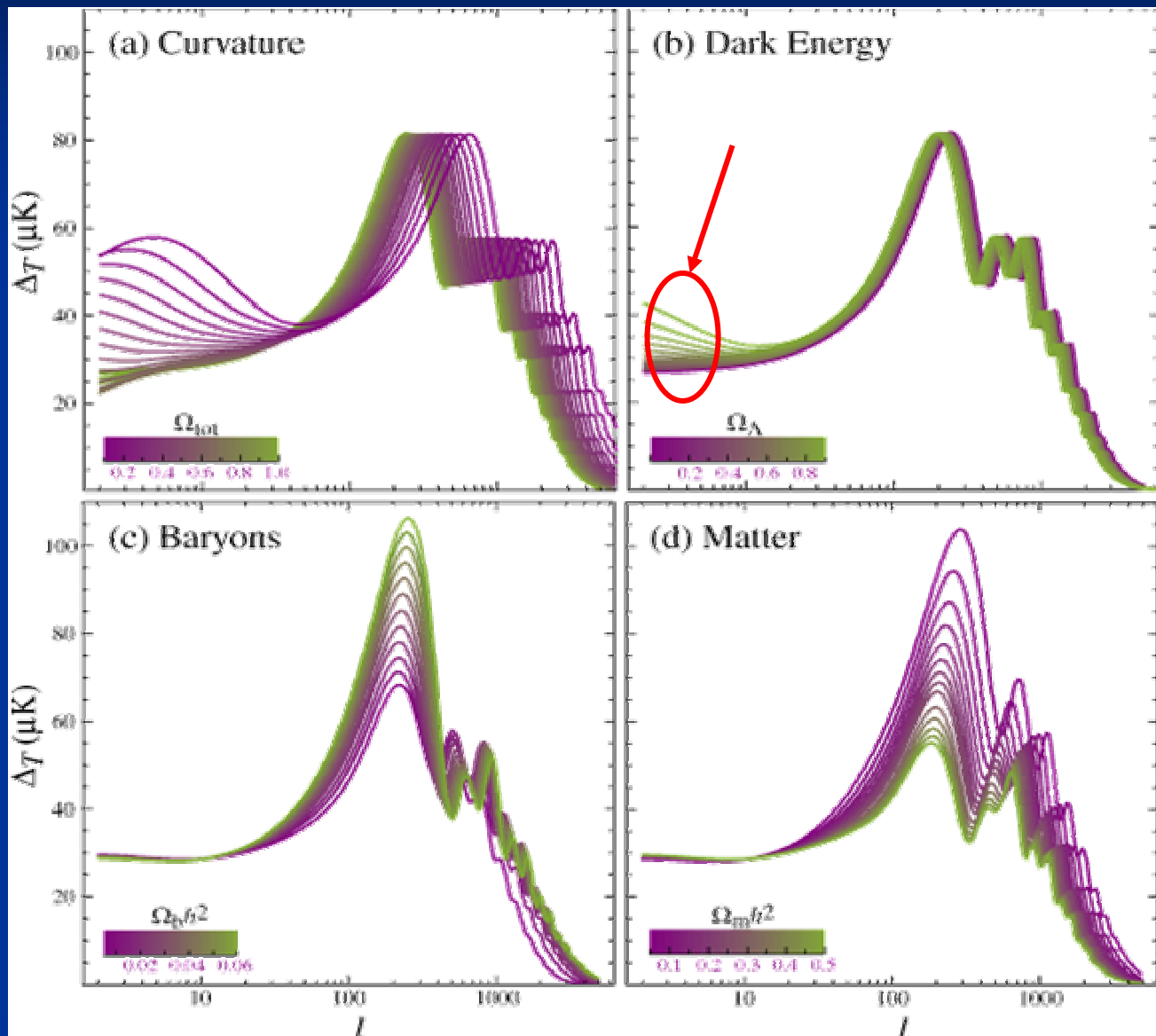
Primary temperature anisotropies ~ $\Omega_m h^2; \Omega_B h^2; \Omega_{tot}; n_s; :::$

Degeneracy wrt

$\Omega_E; h; T=S; \ddot{u}; :::$

External Priors (HST, SNe Ia)

Polarization



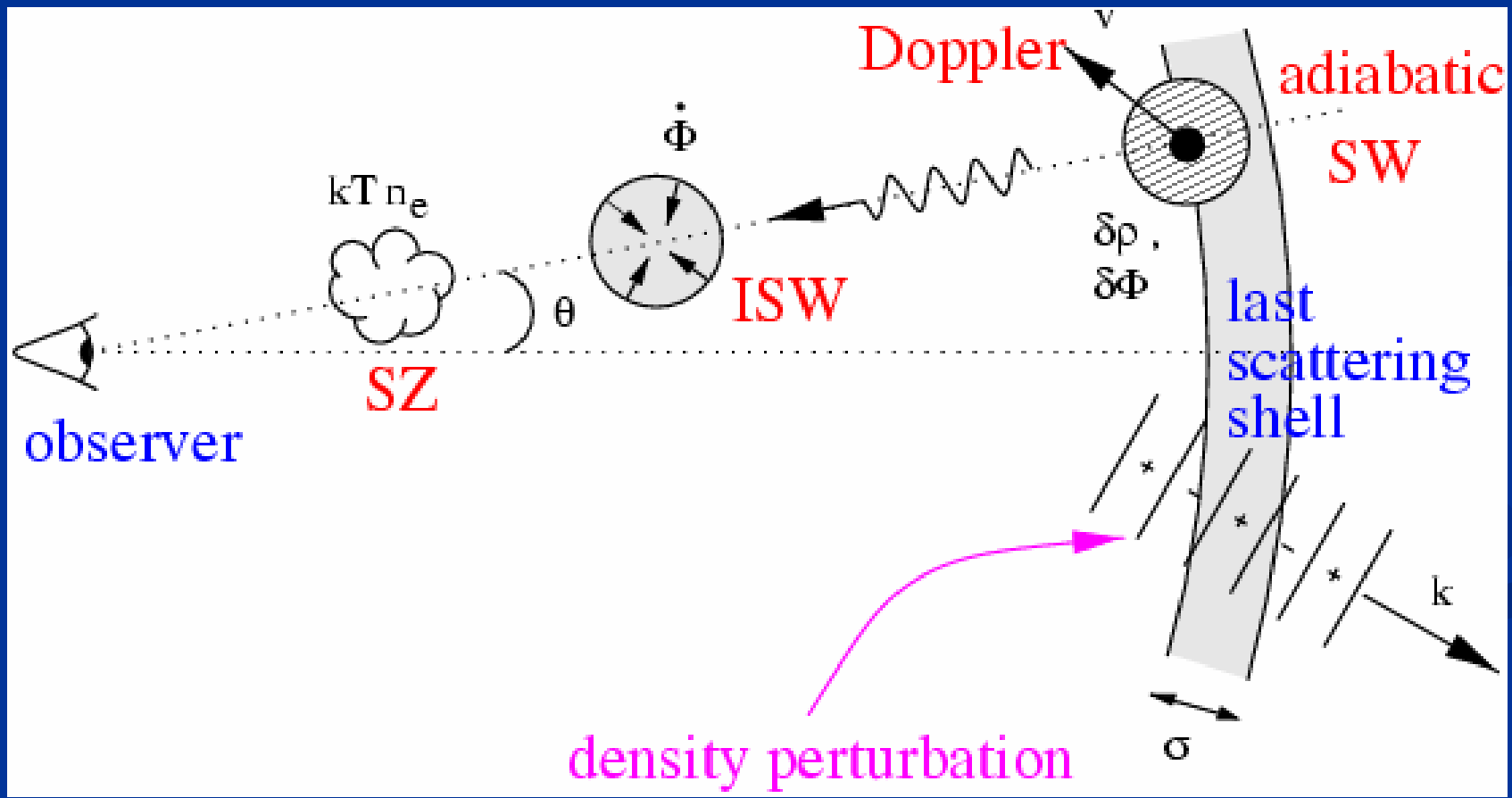
(W.Hu)

CONSISTENCY OF THE MODEL

Cross-correlating CMB maps with Low redshift tracers

Secondary Anisotropies *Primary Anisotropies*

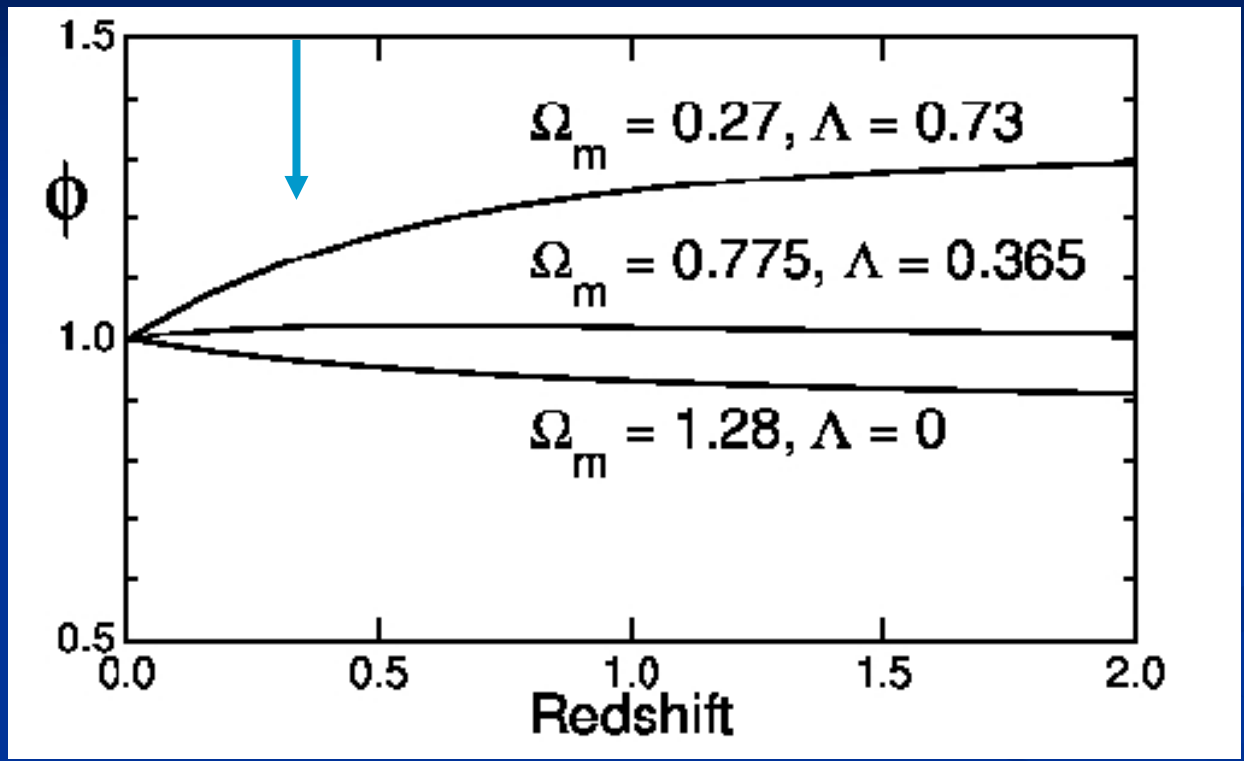
Z=0 Z=0.5 Z=2 Z=1100



ISW Effect in LCDM Models

$$\left(\frac{\Delta T}{T}\right)_{ISW} = 2 \int \dot{\phi}\, d\eta$$

Sachs & Wolfe (1967)
Kofman & Starobinsky (1985)



(Nolta et al.)

$\Omega_\Lambda = 0$ → $\left(\frac{\Delta T}{T}\right)_{ISW} = 0$

If we live in a flat universe

$\Omega_\Lambda + \Omega_m = 1$

Measures Dark-energy !

Requirements for a detection

- LSS Survey:
  Large area, medium-low redshift, densely populated,...
  currently: SDSS, NVSS, APM, 2MASS, HEAO,...

- CMB map:
  Large area, low-noise, "clean",...
  currently: WMAP, Archeops, ...

First ISW Effect Detections: CMB-LSS Correlations

Authors	LSS Survey	CMB Map
Boughn & Crittenden	HEAO (Xray)	WMAP
	NVSS (radio)	WMAP
Nolta et al. (WMAP team)	NVSS	WMAP
P.F & Gaztanaga	APM	WMAP
P.F, Gaztanaga, Castander	SDSS DR1	WMAP
Scranton et al. (SDSS Coll.)	SDSS	WMAP
Afshordi, Loh, Strauss	2MASS	WMAP

→ various LSS tracers, one CMB dataset: WMAP

Measurement of the CMB-Galaxy Correlation

CMB data:

-**WMAP** 1yr-data (V & W bands, kp0 mask)

Galaxy surveys:

-**APM**

1.2 million galaxies (20 > bj > 17)

z ~ 0.15

Survey Area: 4300 sq. deg (10% sky)

-**SDSS (First public Data Release)**

photometric catalog

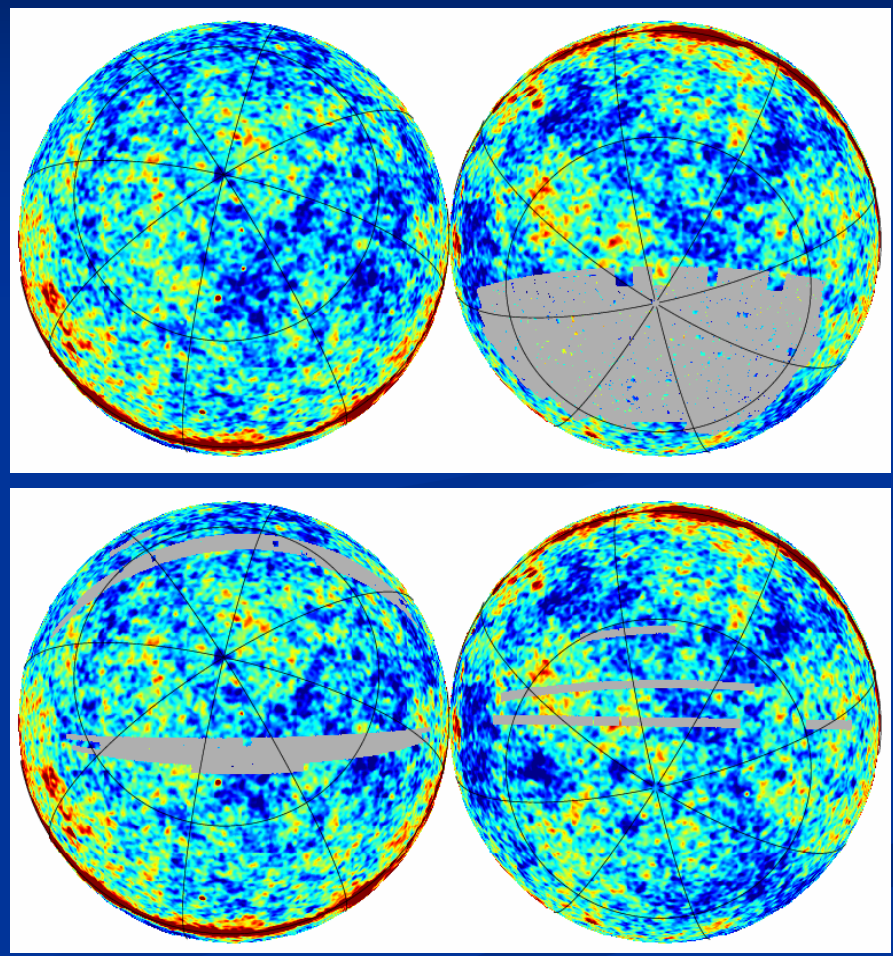
SDSS All: z~ 0.3

SDSS High-z : z ~ 0.5

7.5 million galaxies (21 > r > 17)

Survey Area: 2100 sq deg (5% sky)

(North: 1500 sq. deg)



P.F. & Gaztanaga 2004, MNRAS 350, L37 (WMAP-APM)

P.F., Gaztanaga, Castander 2003, ApJ, 597, L89 (WMAP-SDSS)

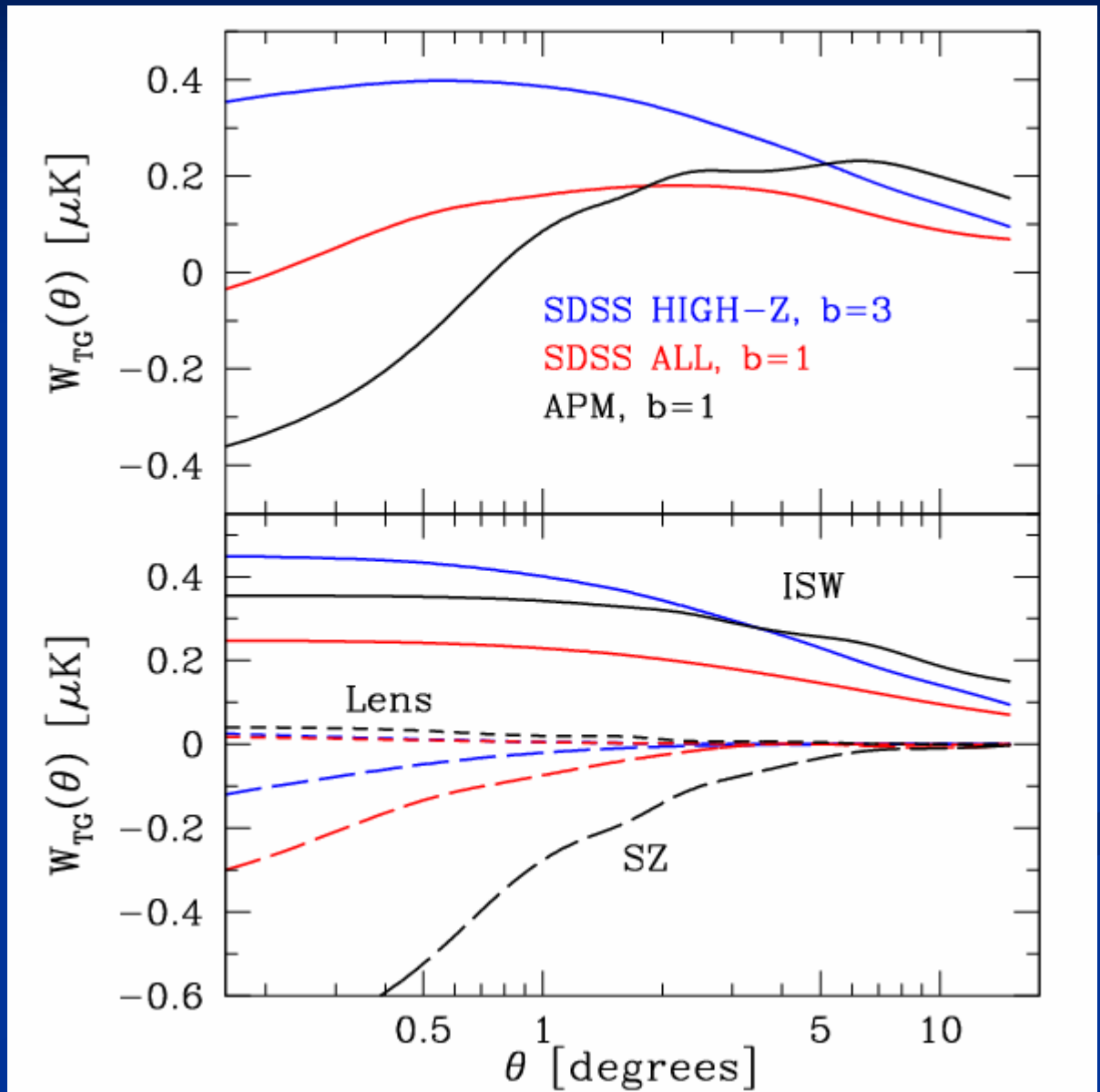
Theoretical Predictions for LCDM models: ISW+SZ+Lensing

SDSS High-z	z~0.5
SDSS All	z~0.3
APM	z~0.15

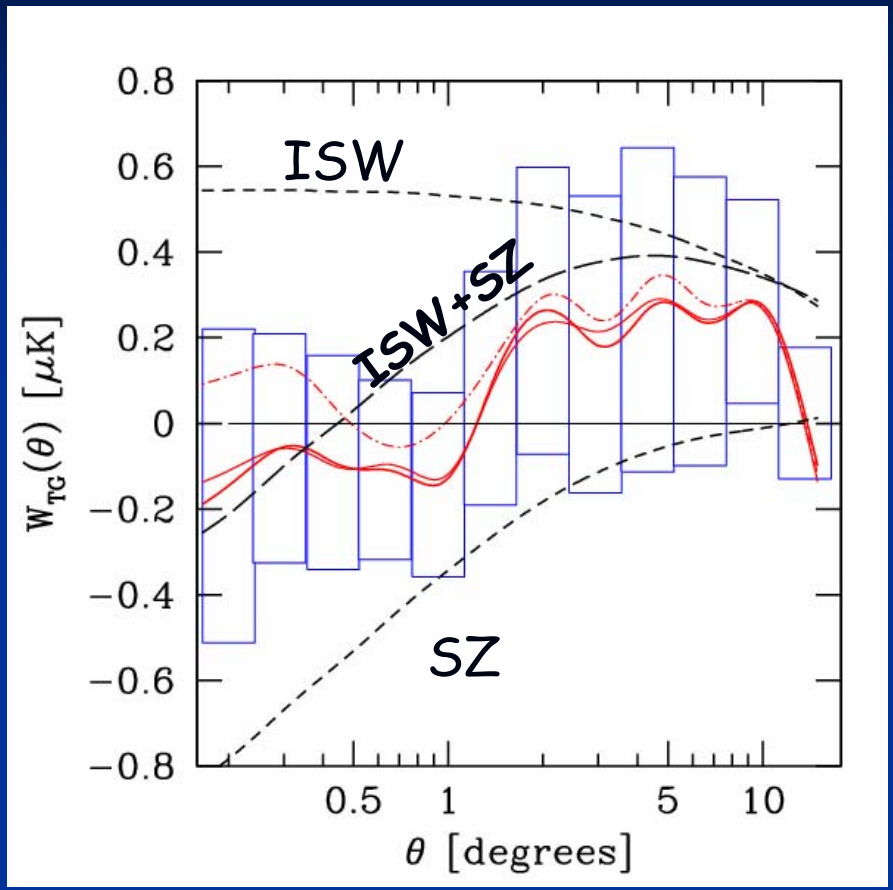
and WMAP

ISW parameters:
Dark energy, bias, selection function

SZ parameters:
gas bias, Yc, mean cluster size



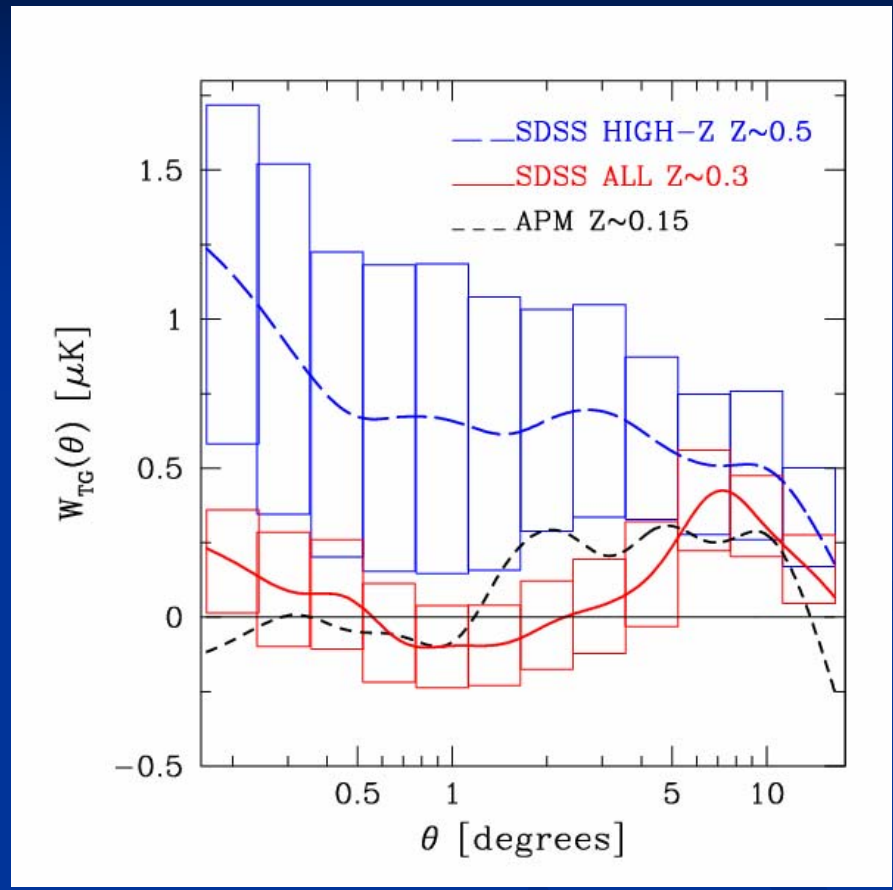
WMAP-APM



ISW detection @ 98.8 % C.L.

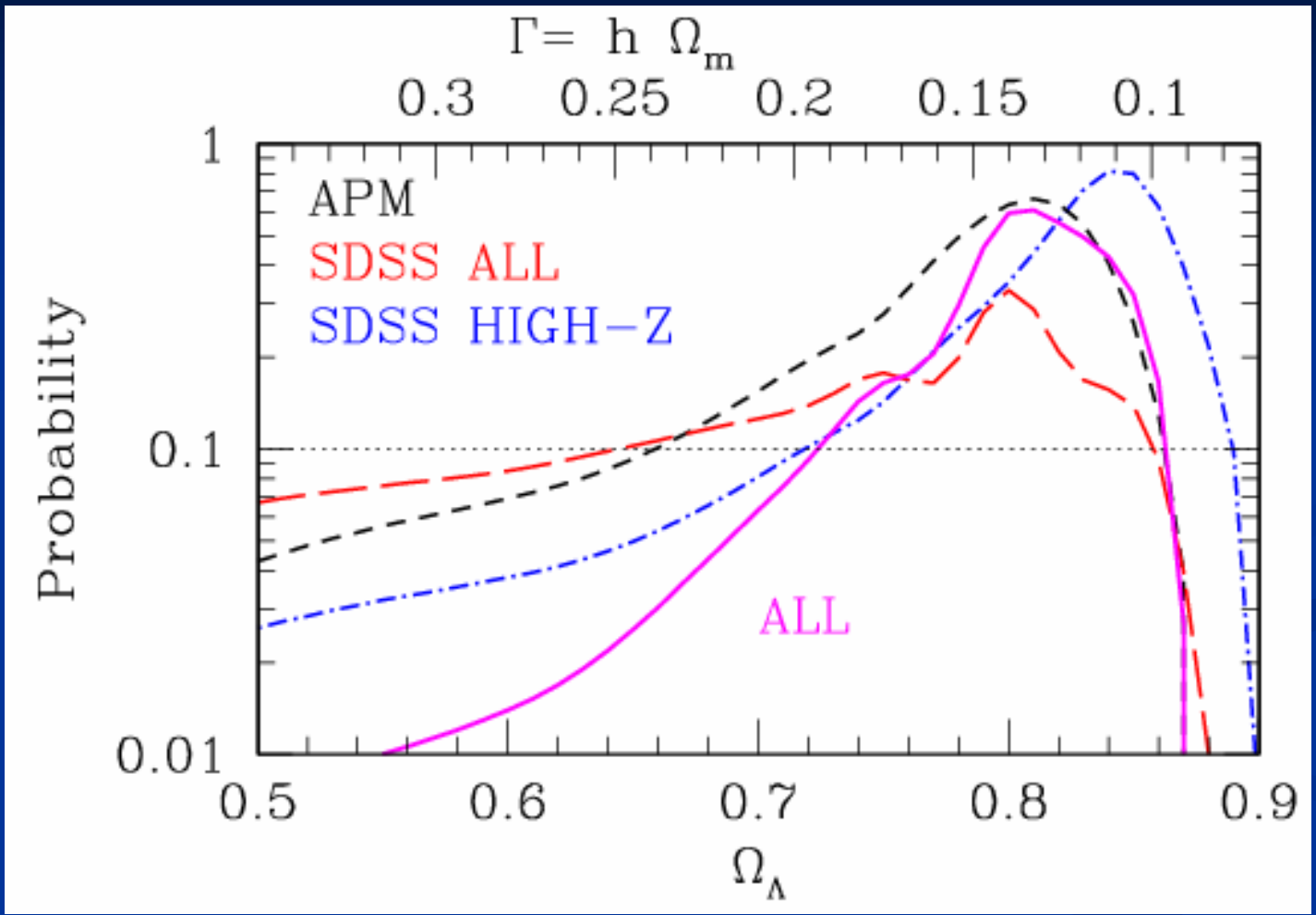
$\Omega_\Lambda = 1 - \Omega_m$, $\sigma_8 = 1$

WMAP-SDSS



Combining datasets:
detection @ 99.9 % C.L.
(> 3 σ)

WEIGHING DARK-ENERGY



ÒË = 0:69 à 0:87 (99.5 % C.L.)

(Independent of SN Ia estimates)

The Quest for the ISW effect…

- Wider, deeper (and higher quality) datasets :
  LSS : SDSS DR2, DR3,… PanSTARRS
  CMB : WMAP 2yr data, 4yr data, PLANCK

  best as of today: SDSS-WMAP
  best in the *near* future: PanSTARRS-PLANCK (?)

- New methods/tools:
  - optimal weighting of data using redshift tomography (LCDM vs. Q-essence ?)

-Fast & nearly-optimal estimators for surveys with complex geometries

New Cross-correlation Toolbox (I): SpICE

Spatially Inhomogeneous Correlation Estimator

[Szapudi et al 2001; Szapudi, Prunet & Colombi 2001]

- Calculate correlation function $C_{12}(\cos\theta) = \sum_{ij} f_{ij}\left(\Delta_i \Delta_j - N_{ij}\right)$

→ allows dealing with *complex masks* and using *heuristic noise weighting* of data

- Compute power spectrum, Cls $C_{12} = \sum_l \frac{l+1/2}{l(l+1)} C_l P_l(\cos\theta)$

→ Cls inverted by *Gauss-Legendre quadrature*

* Nearly optimal results
* Combines best of pixel and harmonic space

SpICE Analysis of Megapixel maps:
FAQ: How long does it take in my laptop?

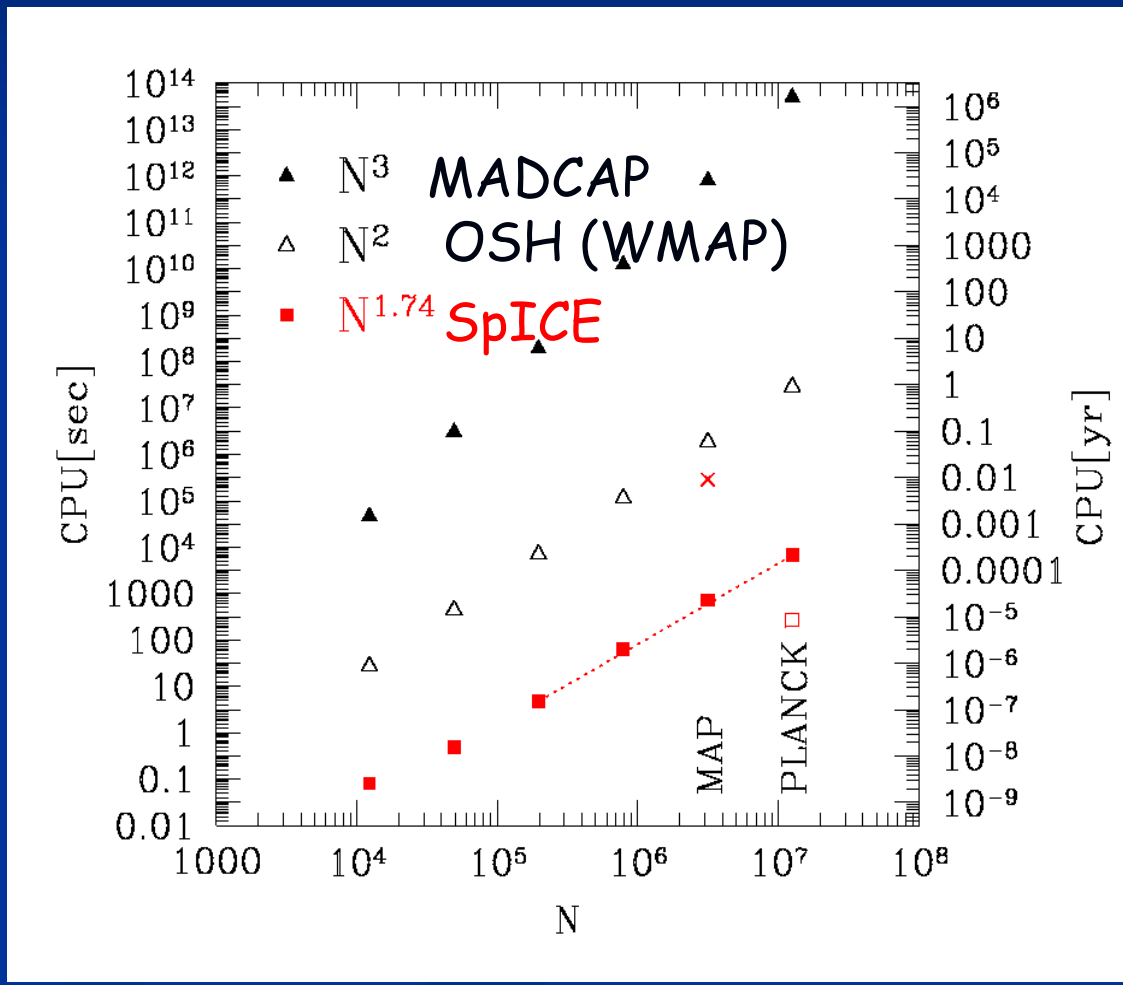
(let's assume a 2 GHz, Pentium 4)

Answer:

WMAP: 5 mins (3 Mpix)

PLANCK: 9 hours (50 Mpix)

(factor of 2 longer
for cross-correlation)

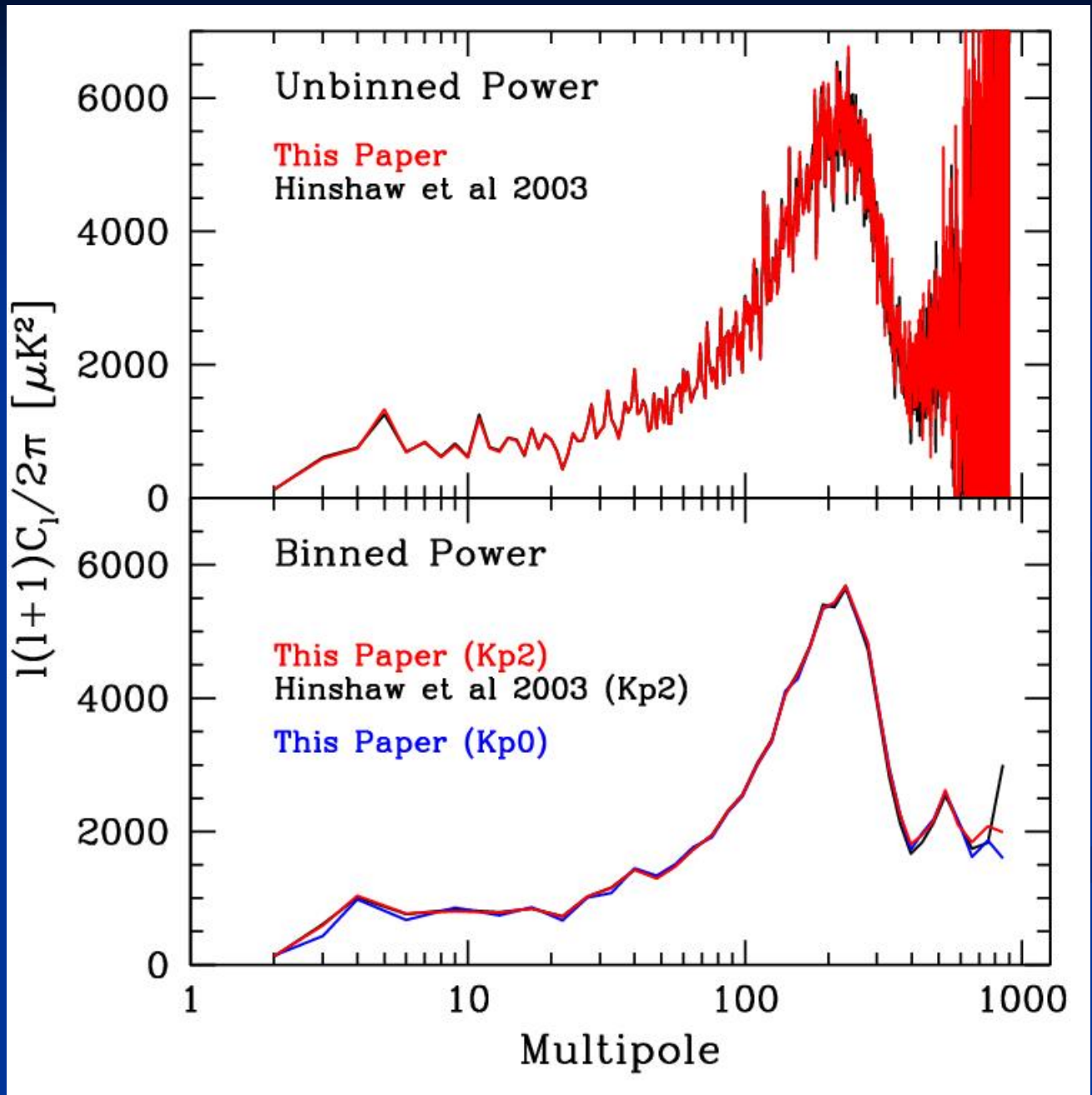


SpICE validation: WMAP angular power spectrum

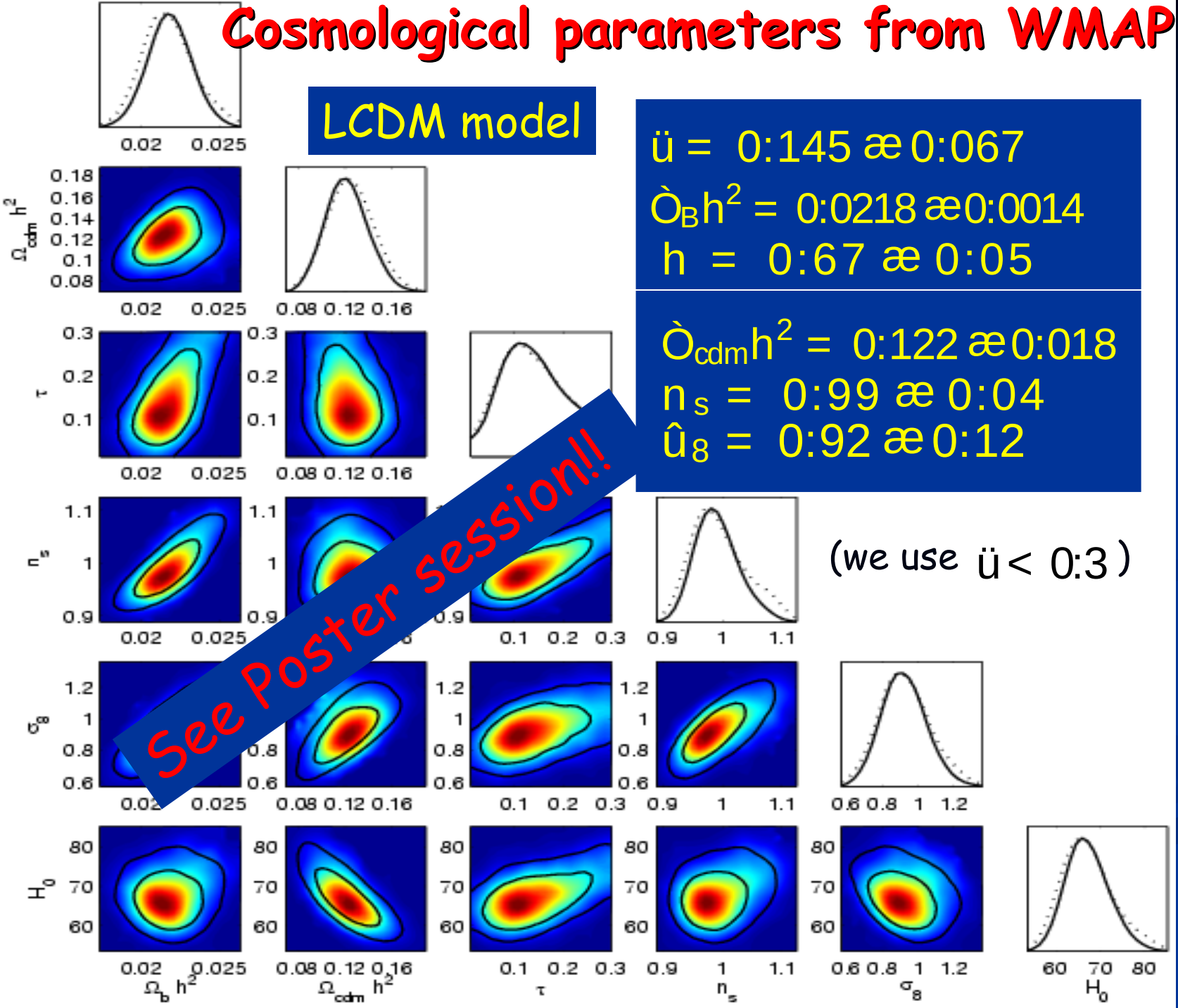
P.F & Szapudi (2004)
astro-ph/0405589

Data used:

Q,V,W bands
(28 xcorr channels)



Cosmological parameters from WMAP

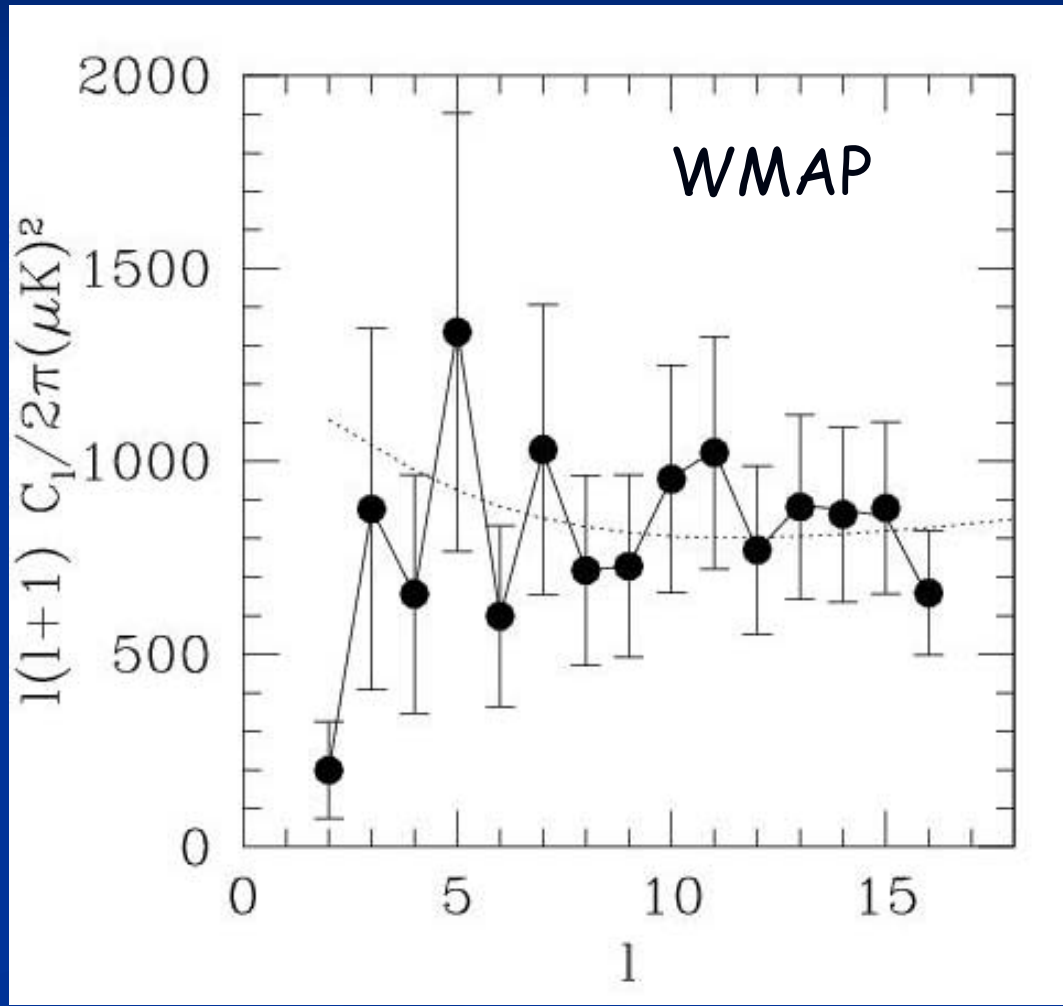


New Cross-correlation Toolbox (II): Maximum Likelihood

ML estimator has lower variance than Pseudo-Cl estimators (SpICE, MASTER) *@ low-l*

→ optimal estimator for ISW

(with I.Szapudi, in preparation)



CONCLUSIONS

- The ISW effect has been detected !
- Near future analysis should confirm it with higher S/N
- We might be able to detect SZ and Lensing as well