The Dark Side and the Bright Side of the Universe

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Summary:

- We learn about the dark side of the Universe (Ω_K, w) by cross correlating CMB with large scale structure datasets:

  ISW: 3.69 σ away from 0 ,

  WL of CMB: 2.5 σ away from 0

-> cosmological parameters (Ω_K, w)

->note: constraints on Ω_K is made without any priors on H_0

- We connects galaxies to clusters by

investigating the Halo Occupation Distribution for LRGs

->We also find the merging timescale of LRGs!

- We learn about the baryons via SZ imprint on the CMB

-> finding missing baryons,

-> understanding distribution of gas around different types of galaxies,

-> gas temperatures,

-> quasar energy inputs.

- A lot to gain by cross-correlating CMB with large scale structure using ISW, WL of CMB, kSZ and tSZ.

Outline

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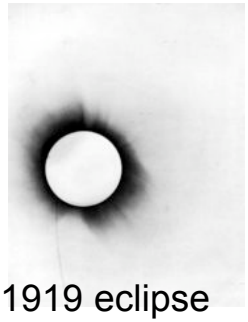
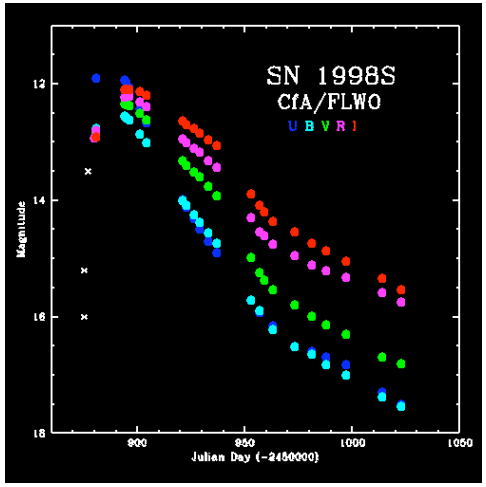
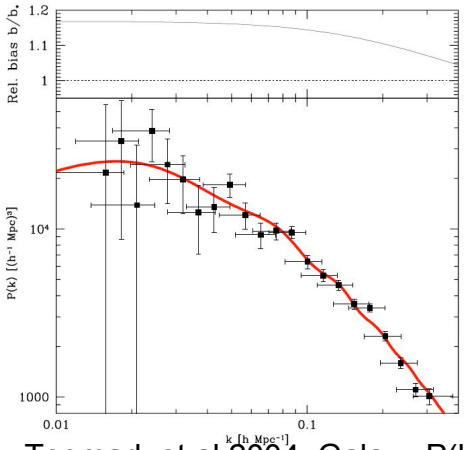
Motivations:



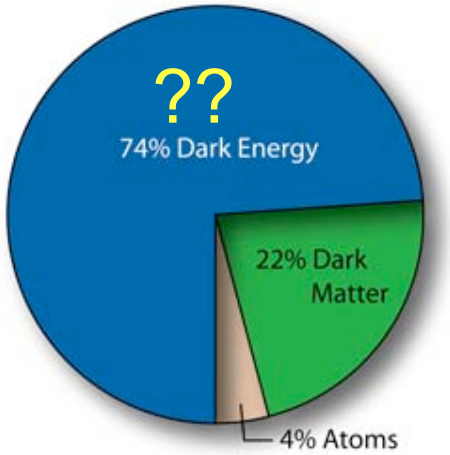
1919 eclipse



SN1998 lightcurve



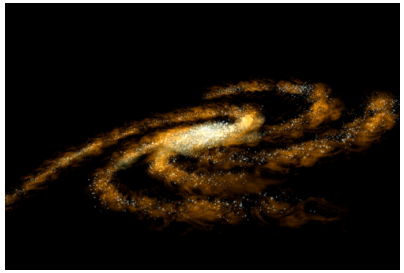
Tegmark et al 2004, Galaxy P(k)



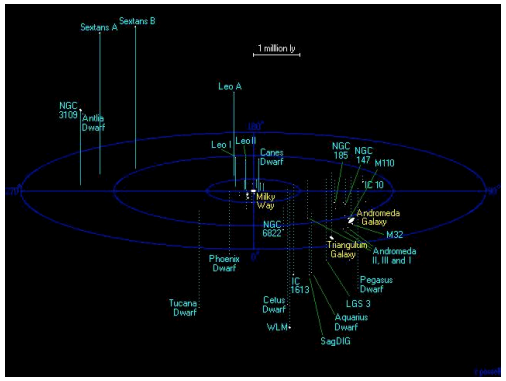
Cosmic Pie Chart (NASA)

Distance from Earth

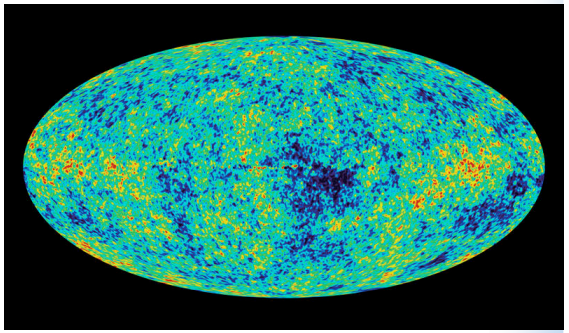
Home Earth (NASA)



Milky Way (NASA)



Local Group (NASA)



Cosmic Microwave Background, WMAP

Motivations:

redshift

- z~ 10^{10}: Baryongenesis
- z~1100: CMB
- z~6: Lyman alpha forest
- z~0: stars and galaxies
  -> MISSING BARYON Problem
  (Fukugita & Peebles 2004)

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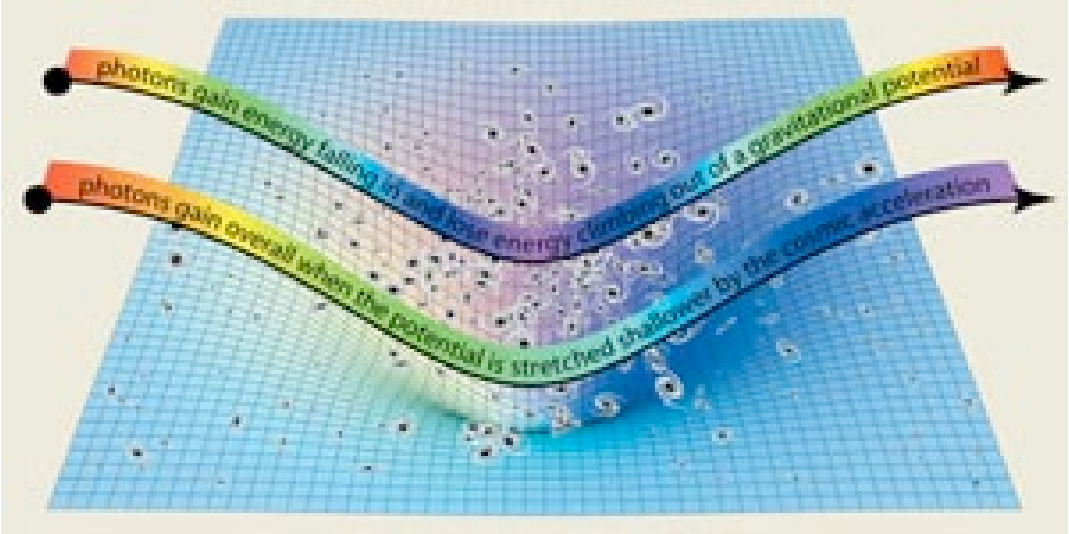
Physics of ISW:

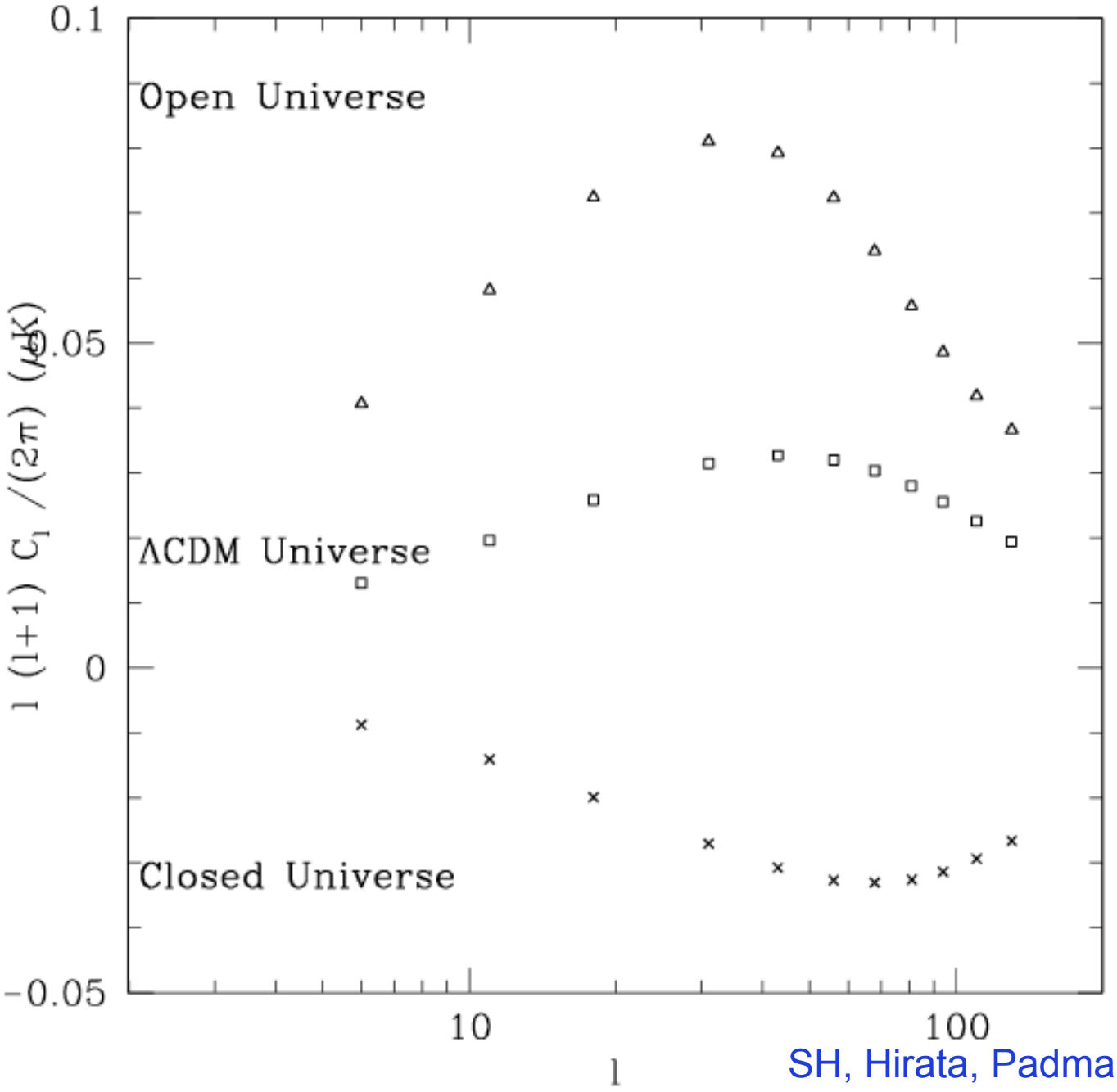


$$\frac{\delta T}{T} = -2\int_0^{y_0} dy\, \dot{\phi}(y, y\hat{n})$$

- As $\Phi \to 0$ and a blue-shift is observed in overdense ($\Phi<0$) regions.

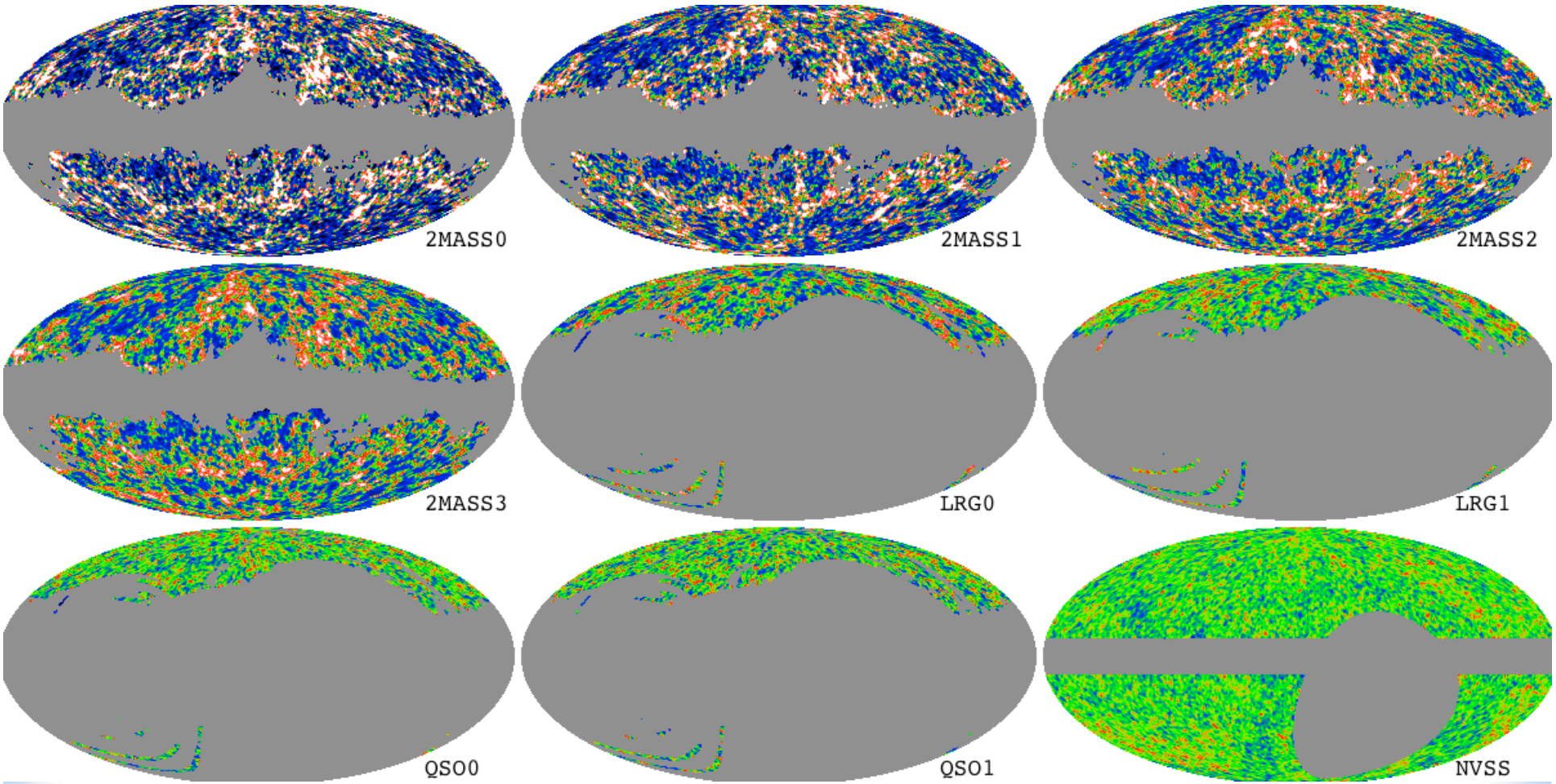
Thus we see a positive correlation between CMB temperature and density.

Cross power between galaxies and T_{ISW}



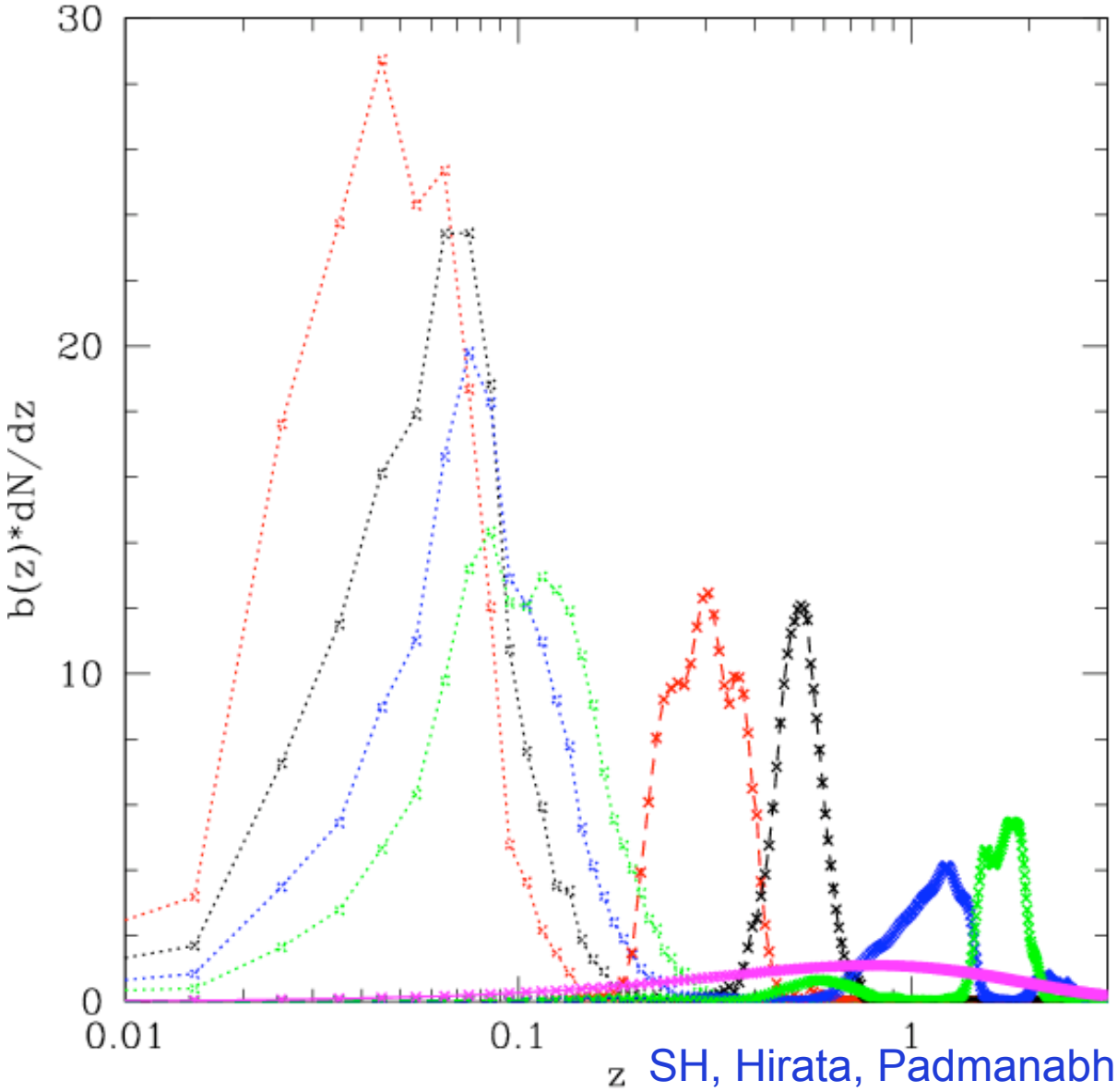
SH, Hirata, Padmanabhan & Seljak (2007)

Large scale structure samples



SH, Hirata, Padmanabhan & Seljak (2007)

Redshift distributions



SH, Hirata, Padmanabhan & Seljak (2007)

ISW Systematics

- Dust extinction
- Stellar density contamination
- Galactic foregrounds (add to CMB)
- Point Sources (add to CMB)
- Thermal SZ (add to CMB)

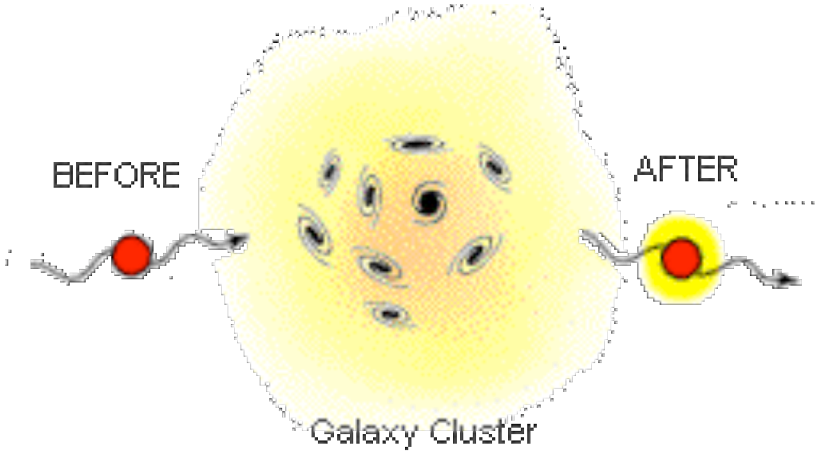
SH, Hirata, Padmanabhan & Seljak (2007)

Physics of tSZ:

-Thermal Sunyaev Zeldovich:

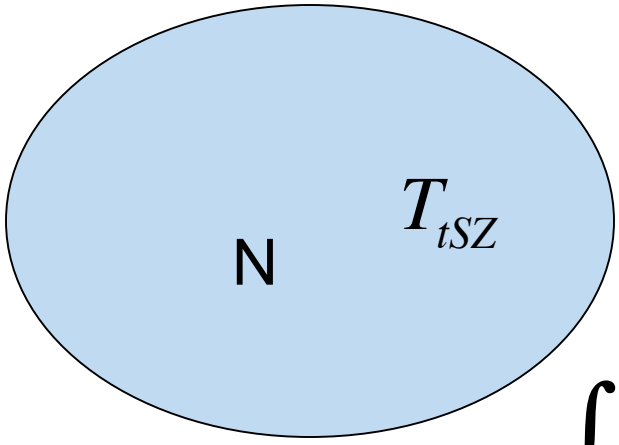
electrons interact with photons!

-> a incre/decrement of the photon energy depending on the temperature and density of electrons and the frequency of photons
-> correlations between the overdensity and the temperature of cmb



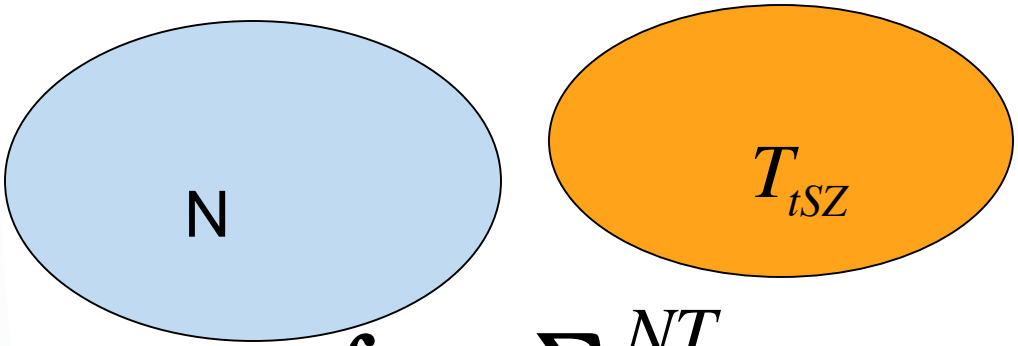
ISW Systematics (tSZ)

- 1-halo term



$$\int dT_{tSZ} \sum_N \frac{N T_{tSZ}}{\bar{n}_g} n_{2D}(N, T_{tSZ})$$

- 2-halo term



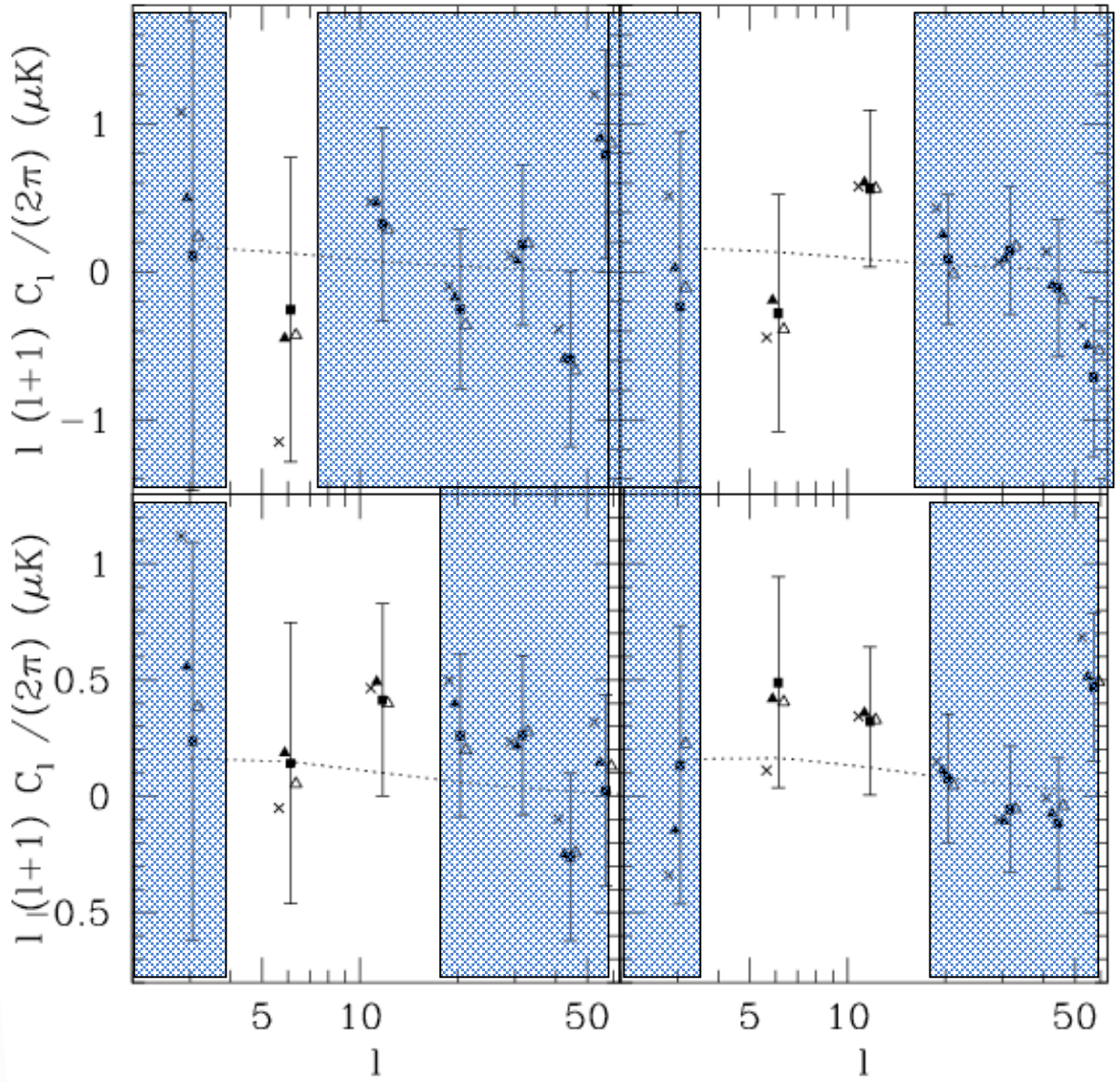
$$\int dT_{tSZ} \sum_N \frac{N T_{tSZ}}{\bar{n}_g} n_{2D}(N) n_{2D}(T_{tSZ}) C_l(N; T_{tSZ})$$

SH, Hirata, Padmanabhan & Seljak (2007)

Systematics' mini conclusion

- After a long list of systematics check, we identify the l-bins that are not contaminated by any of the above mentioned effects and take:
- 2nd l-bin to l (k=0.05)
- For all of the samples.

ISW Cross-correlations



Sample	sigmas
2MASS0:	0.19
2MASS1:	0.43
2MASS2:	1.17
2MASS3:	1.33

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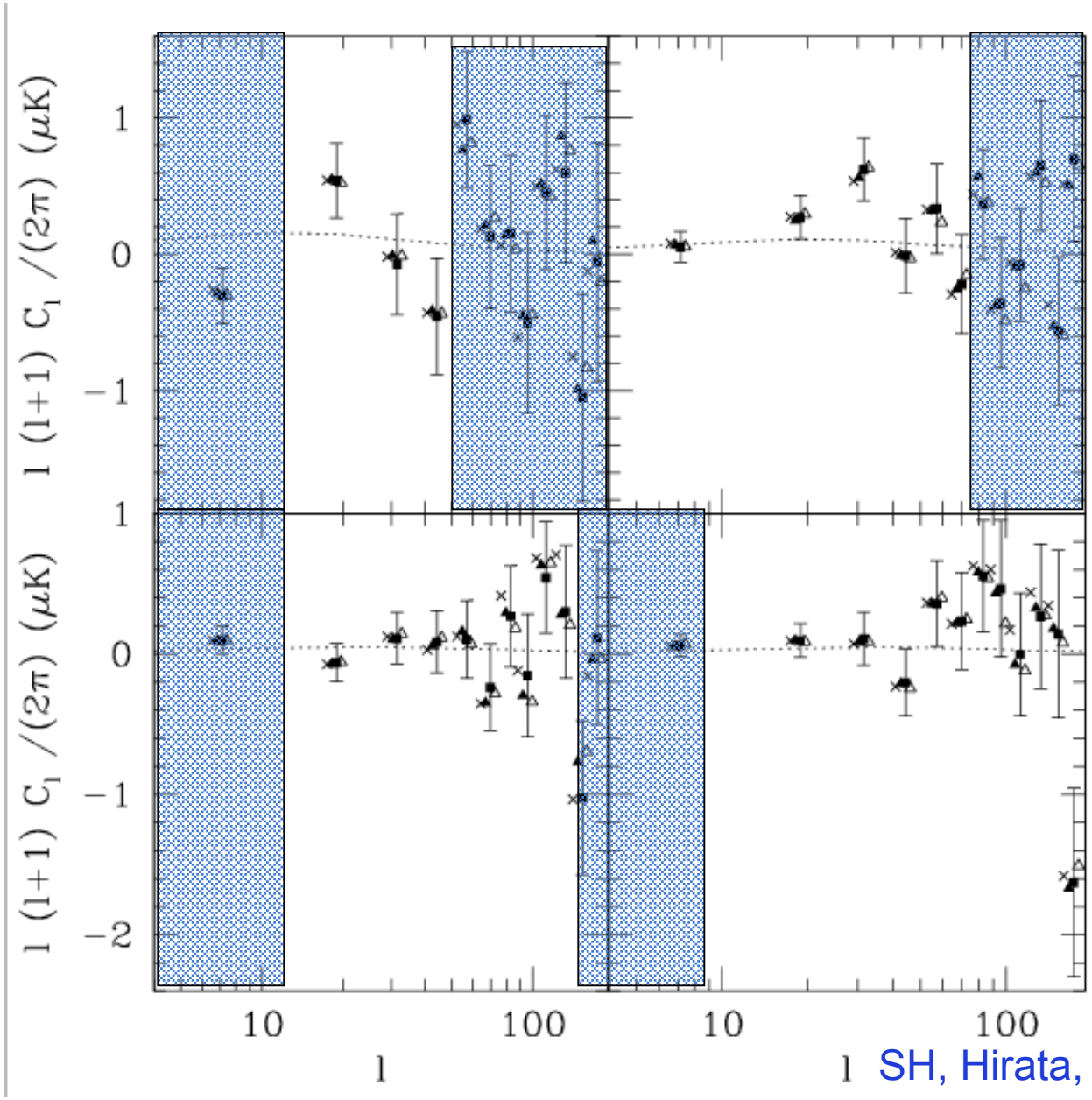
ISW Cross-correlations



Sample	sigmas
2MASS0:	0.19
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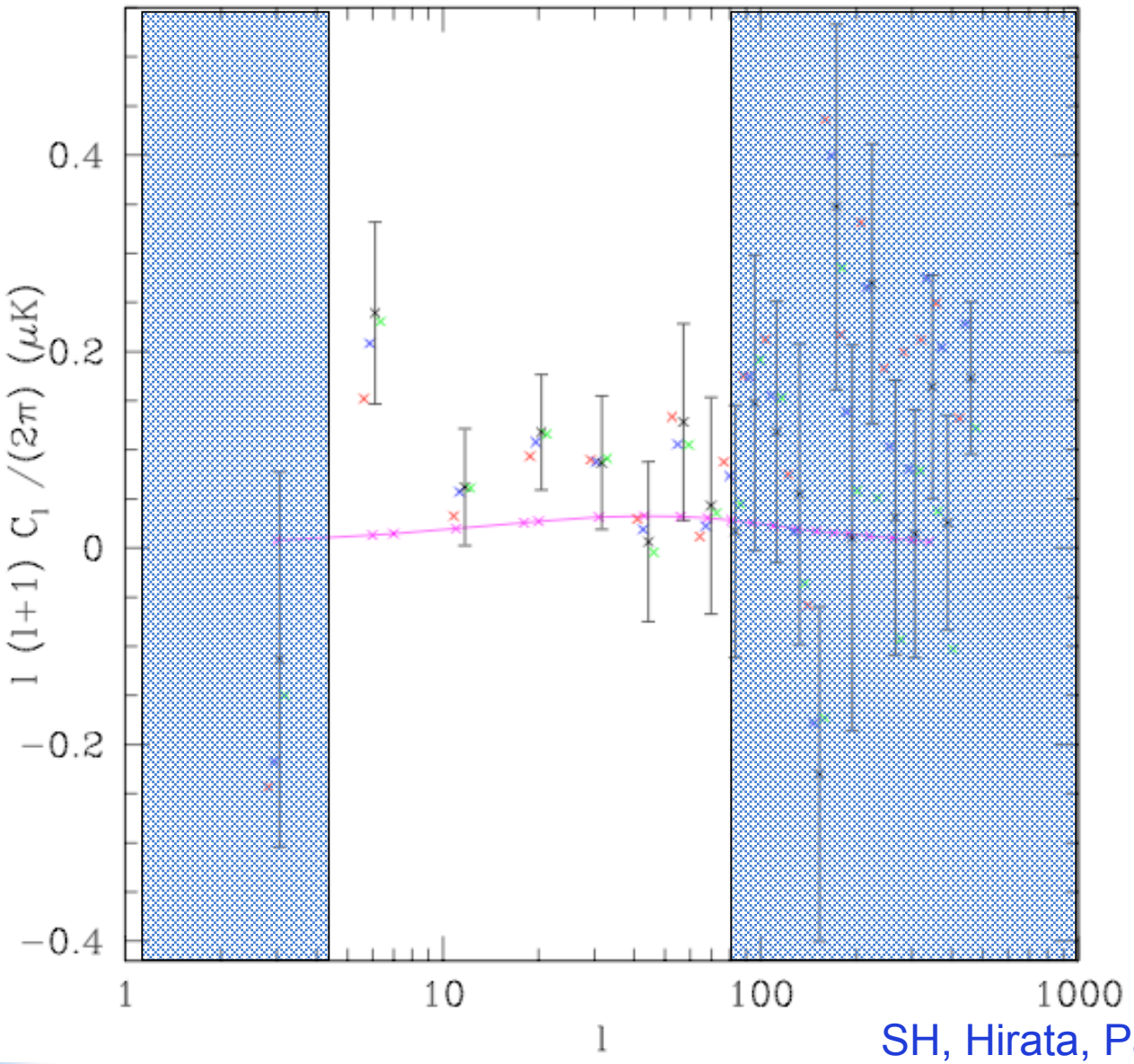
2MASS3:	1.33
LRG0 :	0.17
LRG1 :	2.59
QSO0 :	0.81
QSO1 :	1.35

SH, Hirata, Padmanabhan & Seljak (2007)

ISW Cross-correlations



Sample	sigmas
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2MASS3	1.33
LRG0	0.17
LRG1	2.59
QSO0	0.81
QSO1	1.35
NVSS	3.01
ALL	3.69

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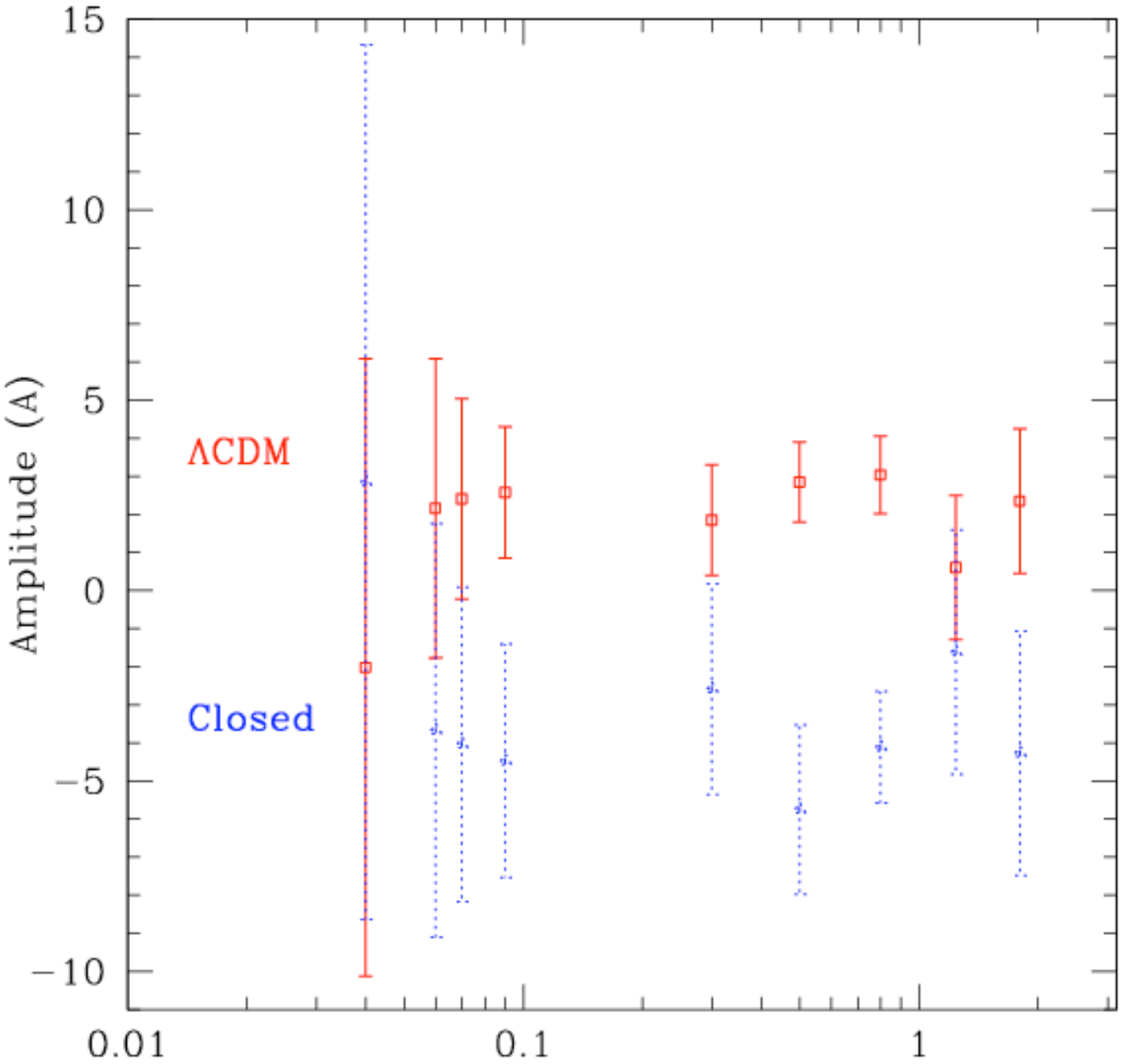

SH, Hirata, Padmanabhan & Seljak (2007)

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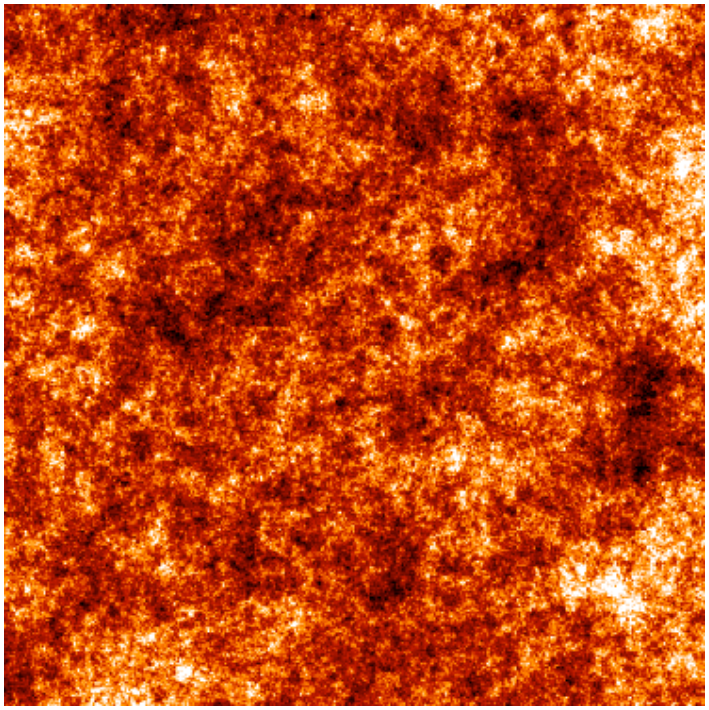
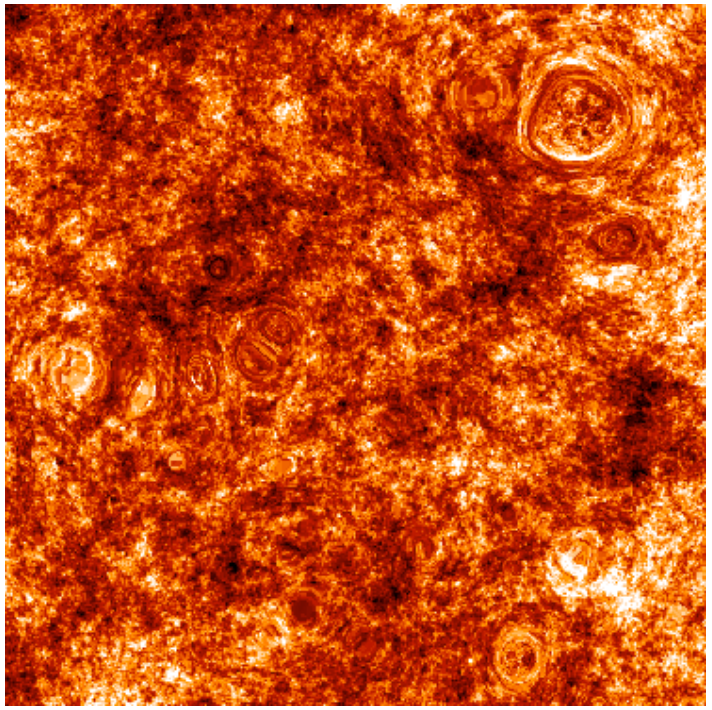
Physics of WL of CMB





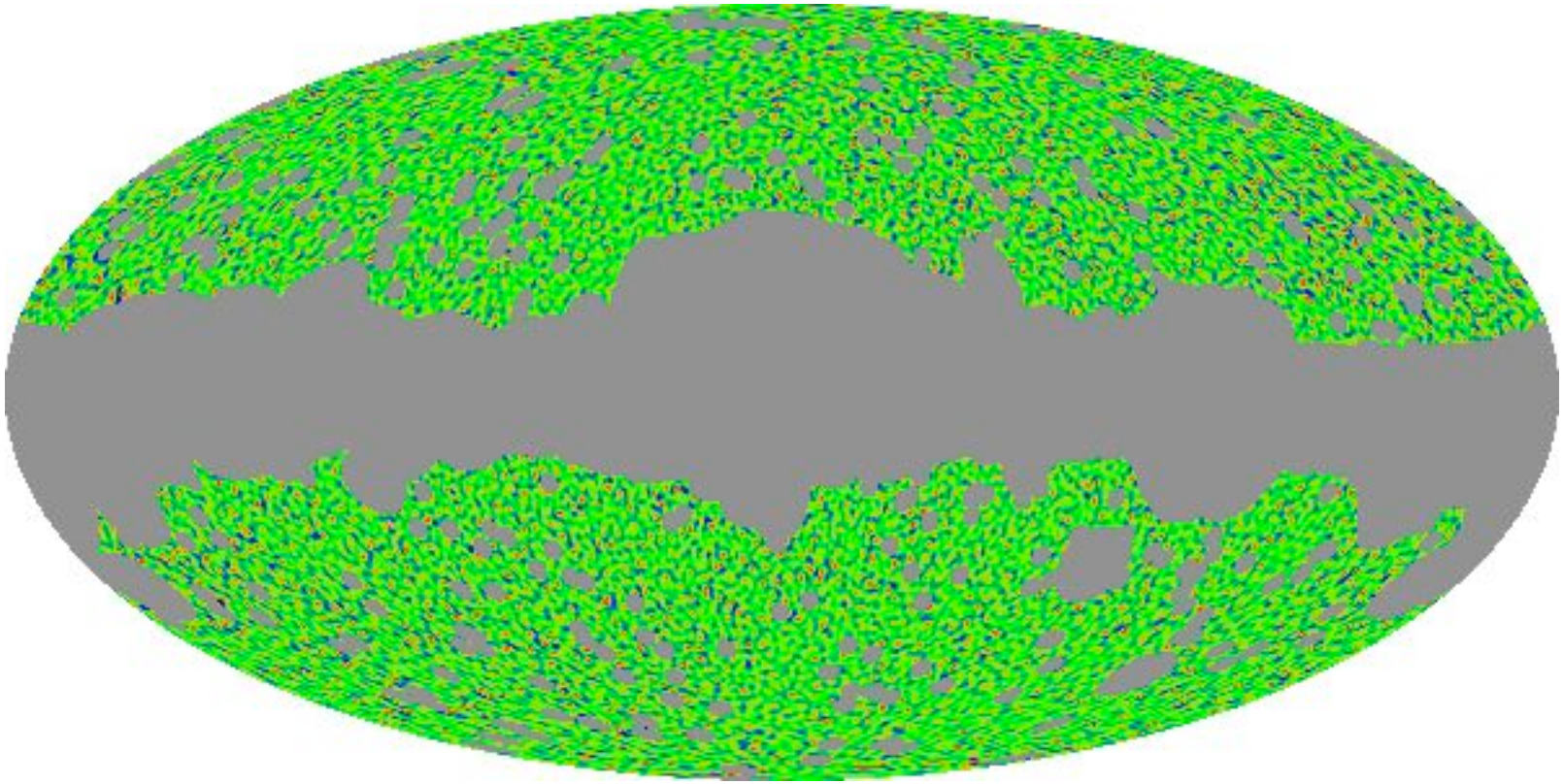
Courtesy images from Max-Planck Institute for astronomy of Heidelberg

$$T_{lensed}(\mathbf{n}) = T_{unlensed}(\mathbf{n} + \mathbf{d}) \qquad \mathbf{d} = -2\nabla\nabla^{-2}\kappa$$

Here d is the deflection field, κ is the convergence and is a projection of the matter density perturbation

WL of CMB

- CMB lensing map :



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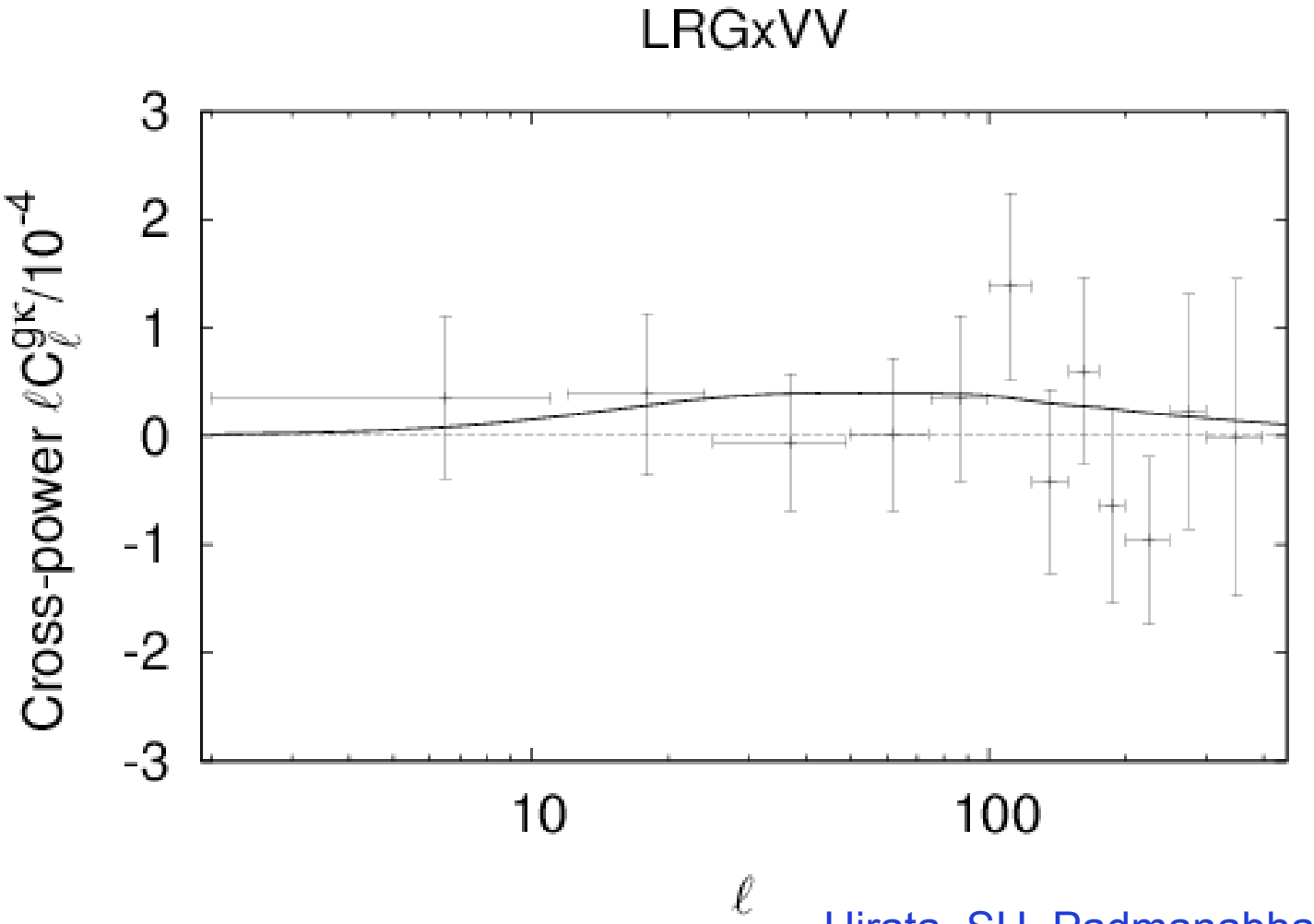
Weak Lensing of CMB

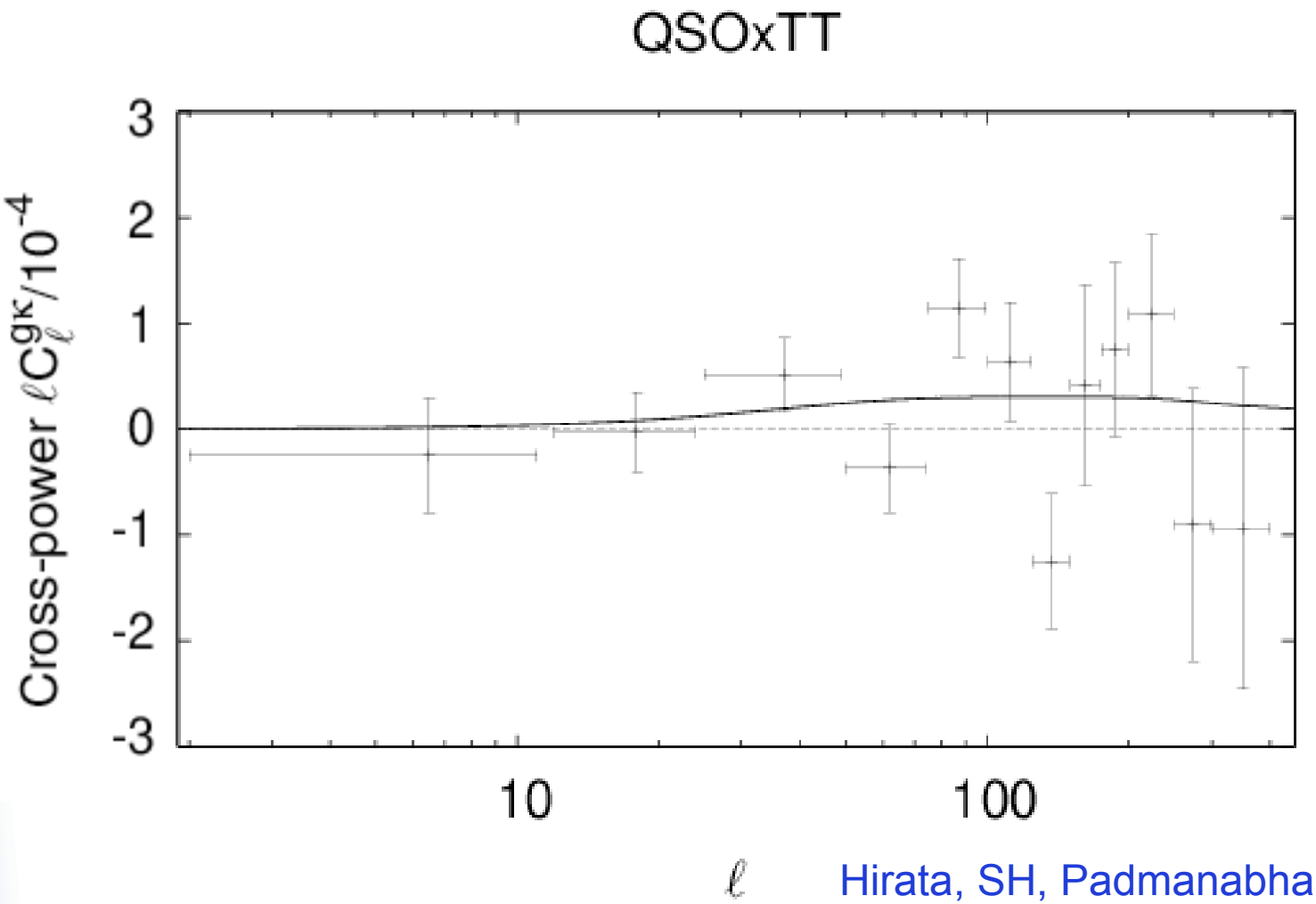
$A_{LRG} = 0.72 +/- 0.76$



Hirata, SH, Padmanabhan & Seljak (2007)

Weak Lensing of CMB

$A_{QSO} = 1.20 +/- 0.73$



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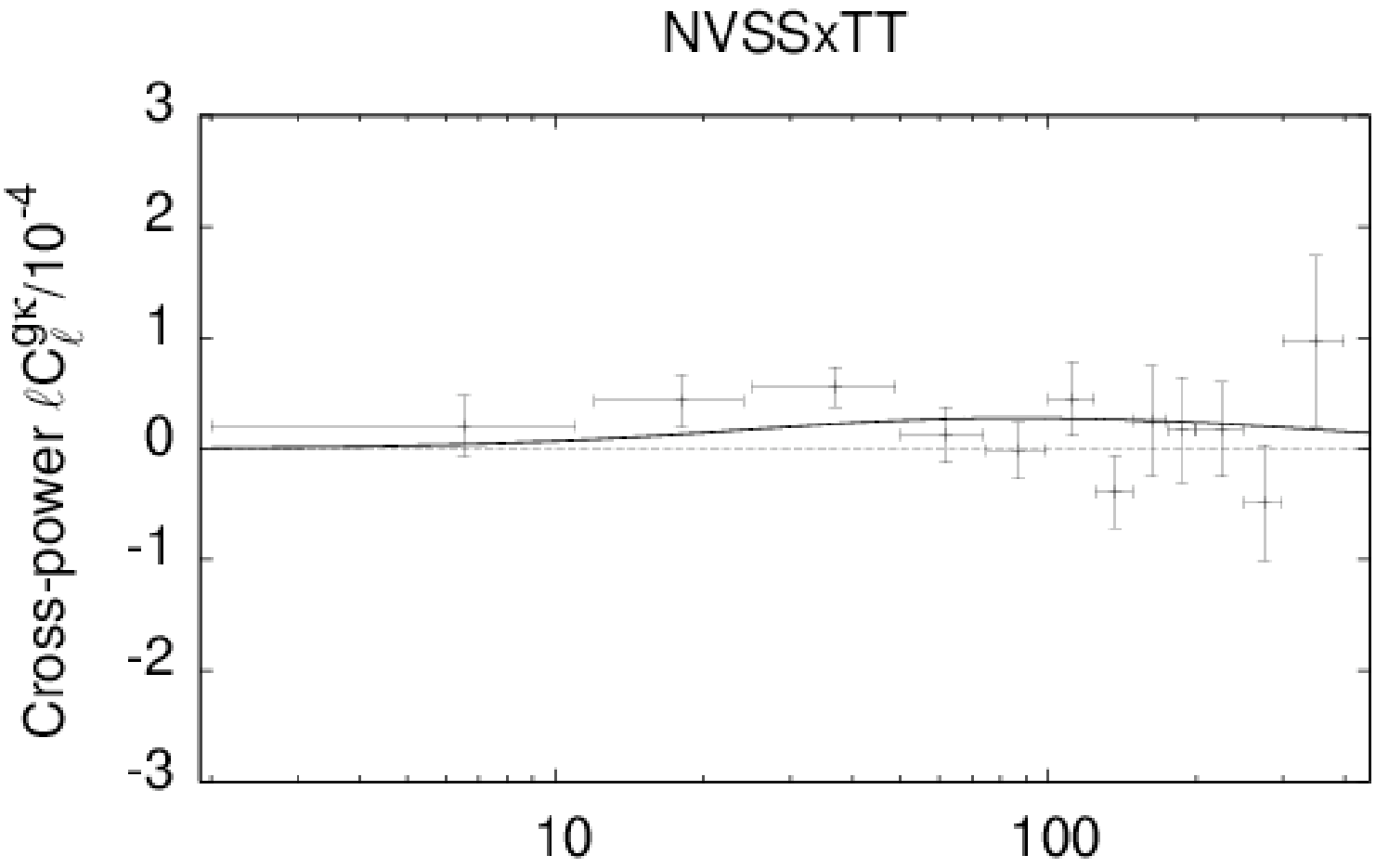
Weak Lensing of CMB

$A_{NVSS} = 1.11 +/- 0.52$



Hirata, SH, Padmanabhan & Seljak (2007)

WL of CMB: Systematics!

List of systematics:

- Beam ellipticity
- Galactic foregrounds
- Extragalactic foregrounds:

  a) point sources (radio, infrared)

  b) tSZ

  c) kSZ

  d) ISW

  e) correlations between different foregrounds (gal-radio-ir, gal-ps-tSZ)

Hirata, SH, Padmanabhan & Seljak (2007)

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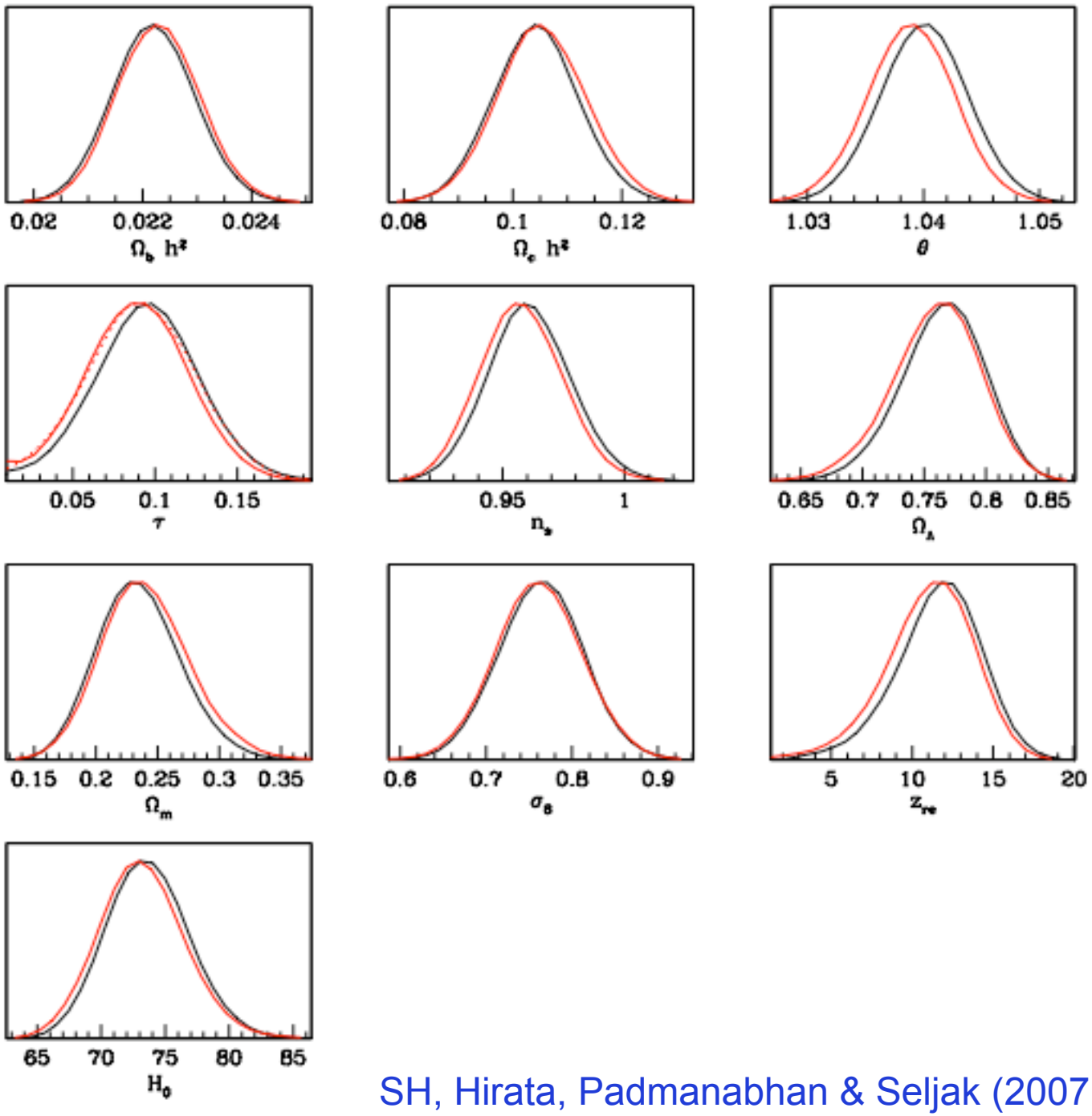
Cosmological parameters

- 3 models:
- a) LCDM
- b) CDM + Ω_K(allowing curvature)
- c) CDM + w
- More Constraints especially for cosmological models that have interesting behavior at high redshifts

- LCDM

~ WMAP parameters

~ smaller error than using only WMAP primary anisotropies

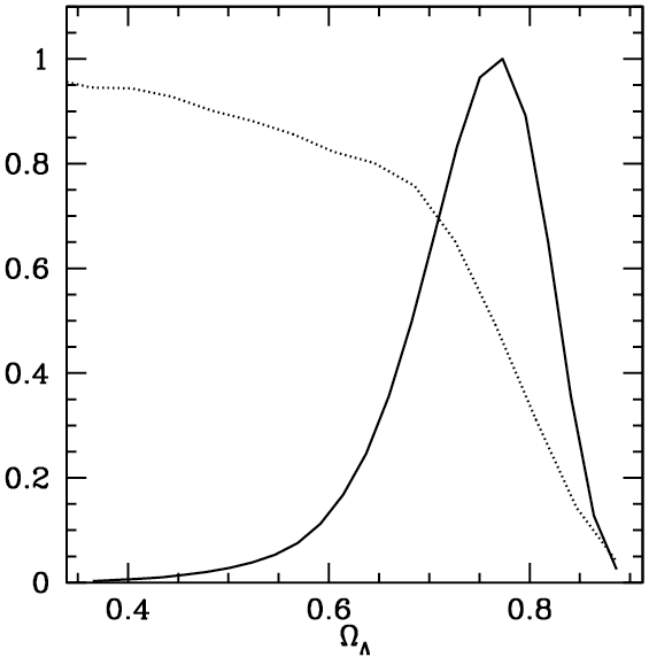


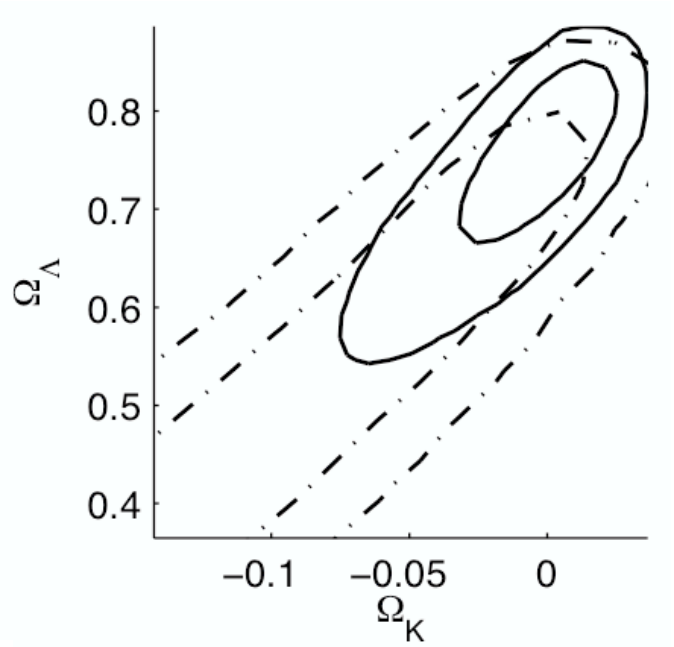
SH, Hirata, Padmanabhan & Seljak (2007)

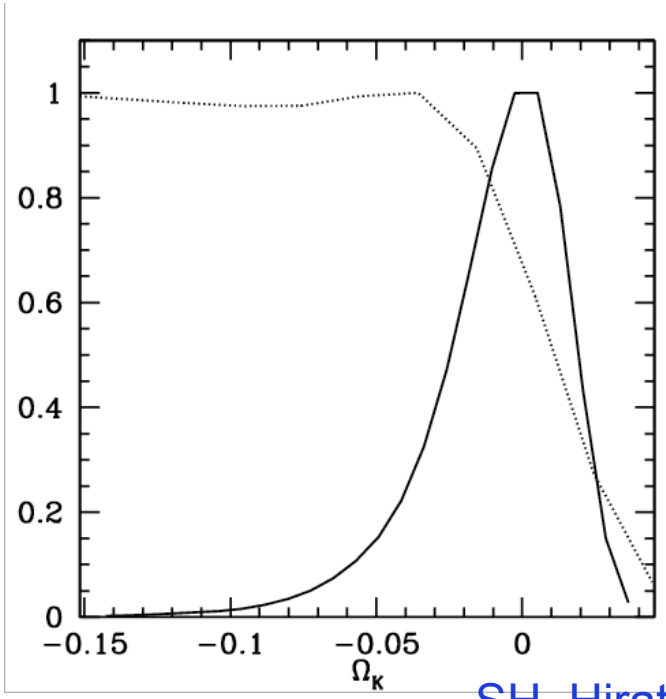
CDM+ Ω_K

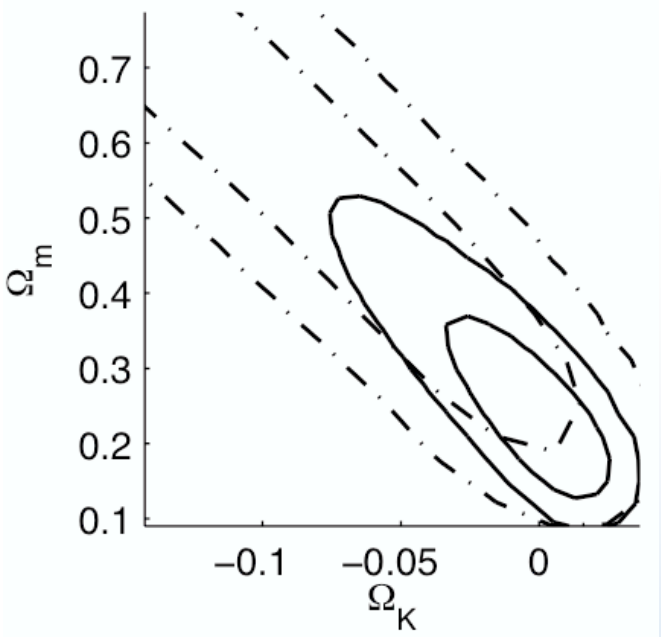
- Testing the flatness of universe!
- Using:

1) CMB (primary)
2) Galaxies (as mass tracer)
3)Weak Lensing (indep. mass tracer)









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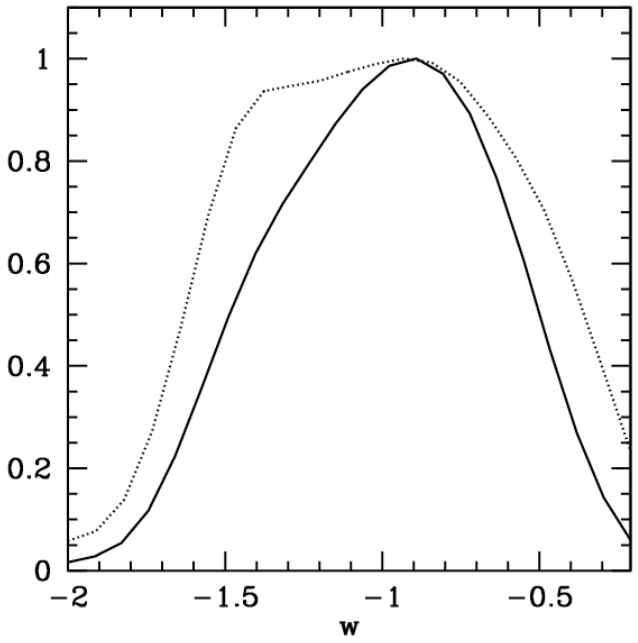
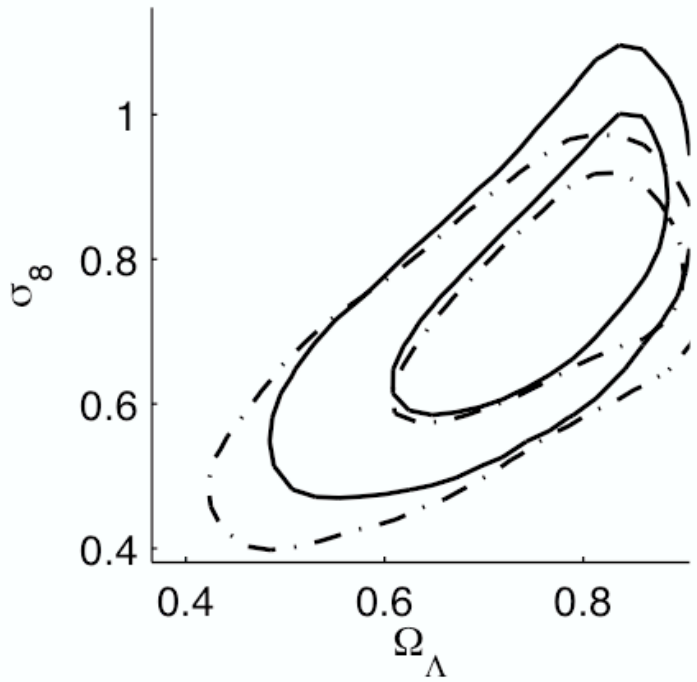
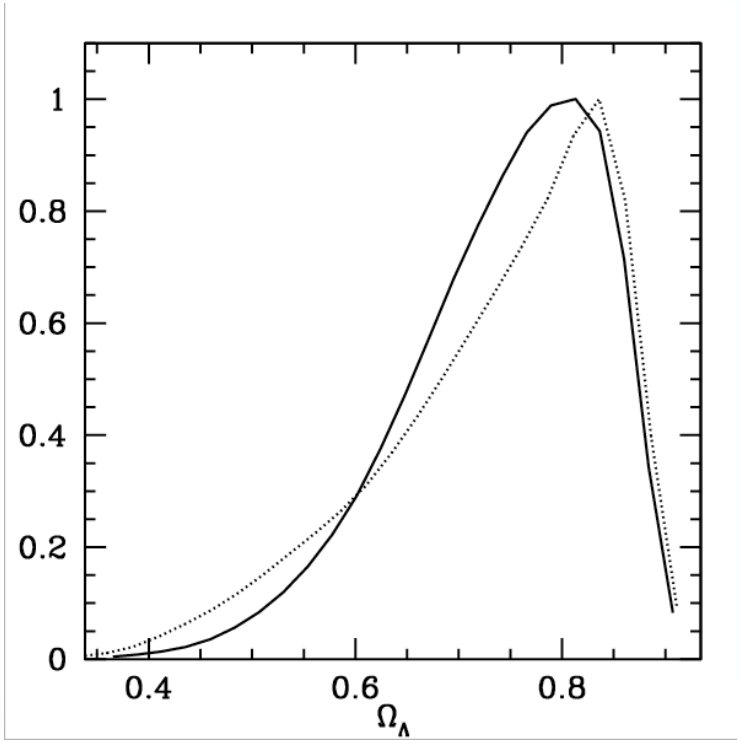
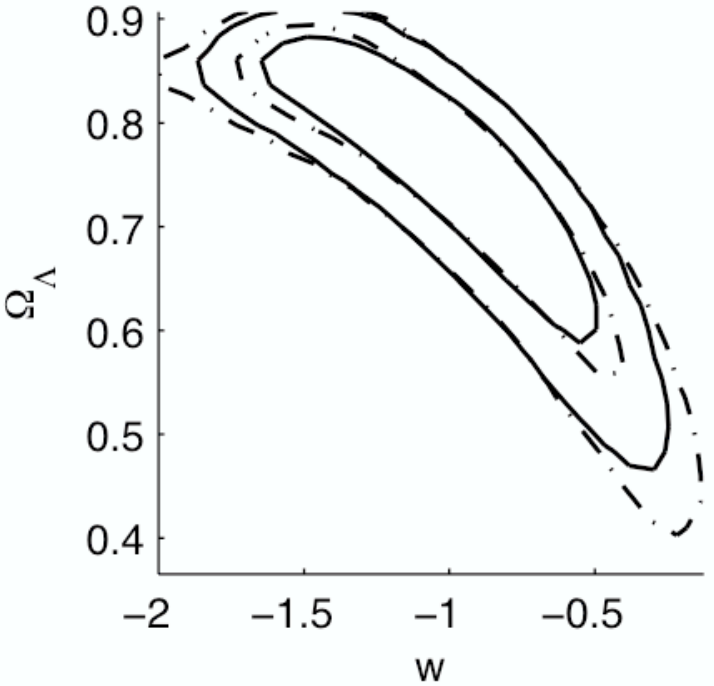




wCDM





SH, Hirata, Padmanabhan & Seljak (2007)

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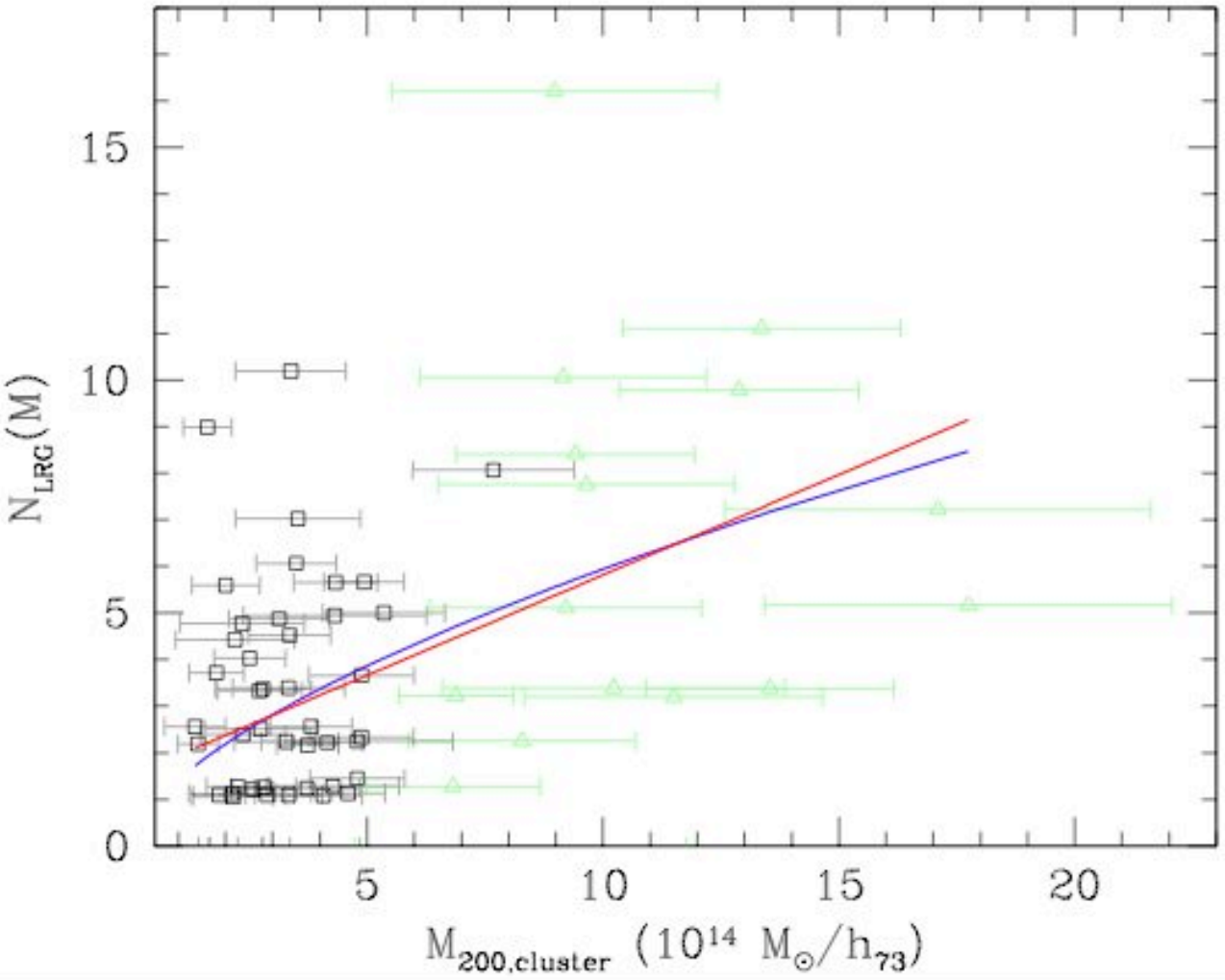
Luminous Red Galaxies and Clusters

Questions:

- Given a dark matter halo of mass M, how many luminous red galaxies are there?

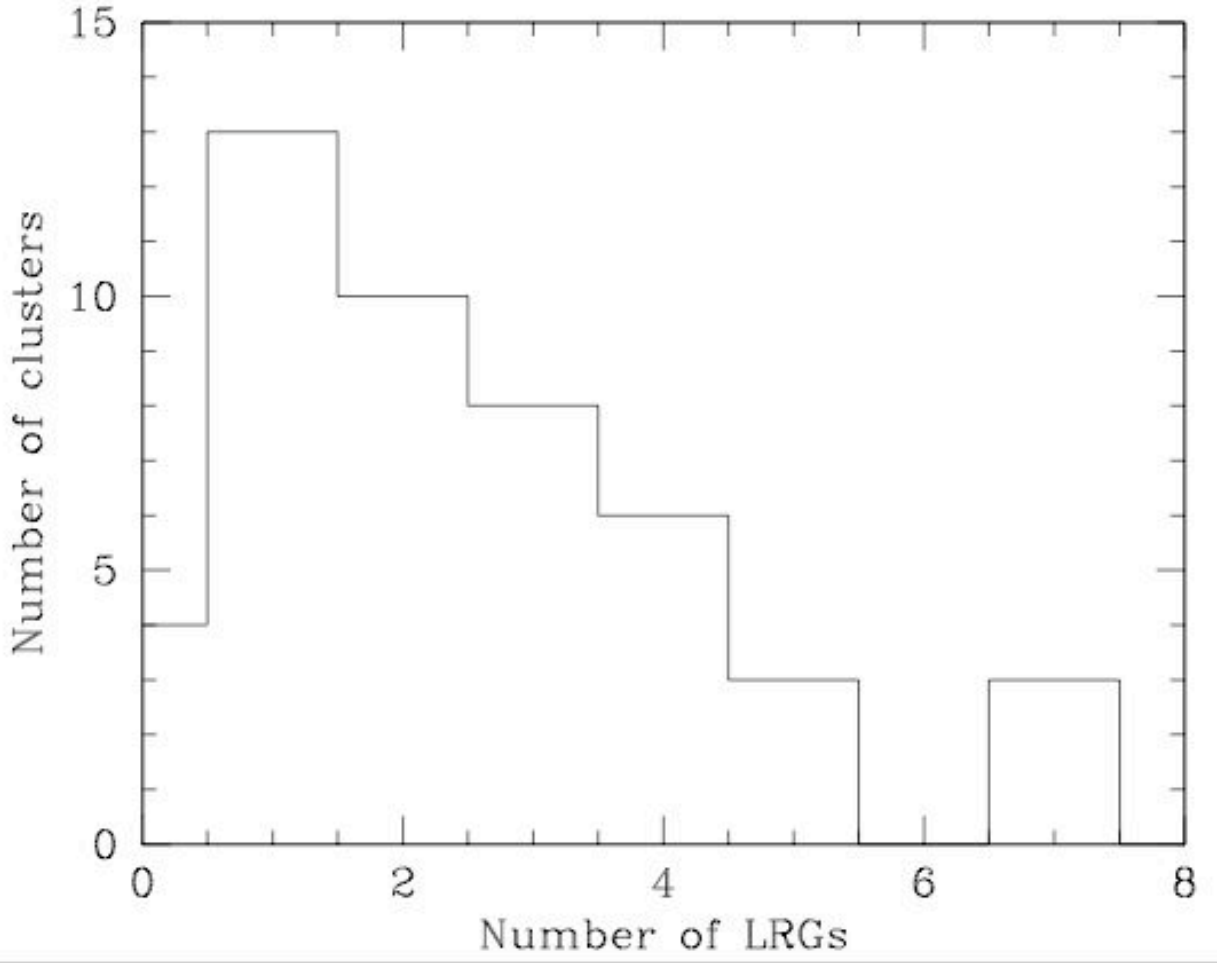
- How long does it take for the galaxies to merge/disrupt?

LRG N(m)



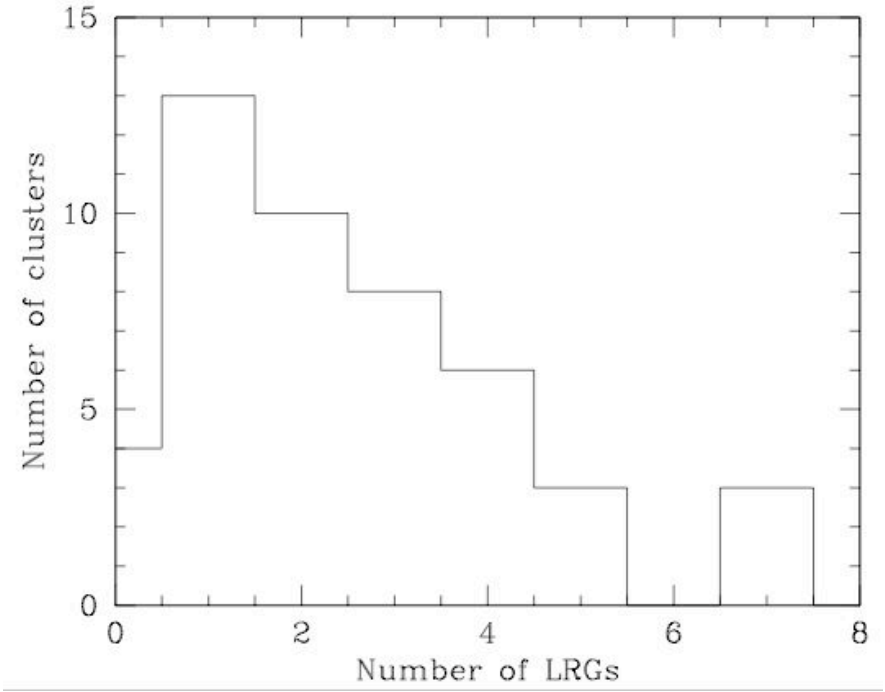
SH, Lin, Spergel & Hirata (2007)

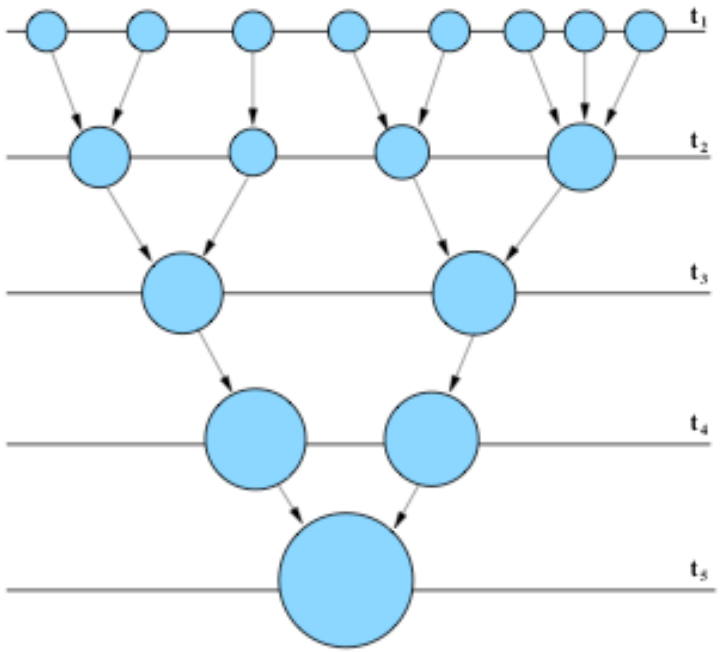
LRG multiplicity function



SH, Lin, Spergel & Hirata (2007)

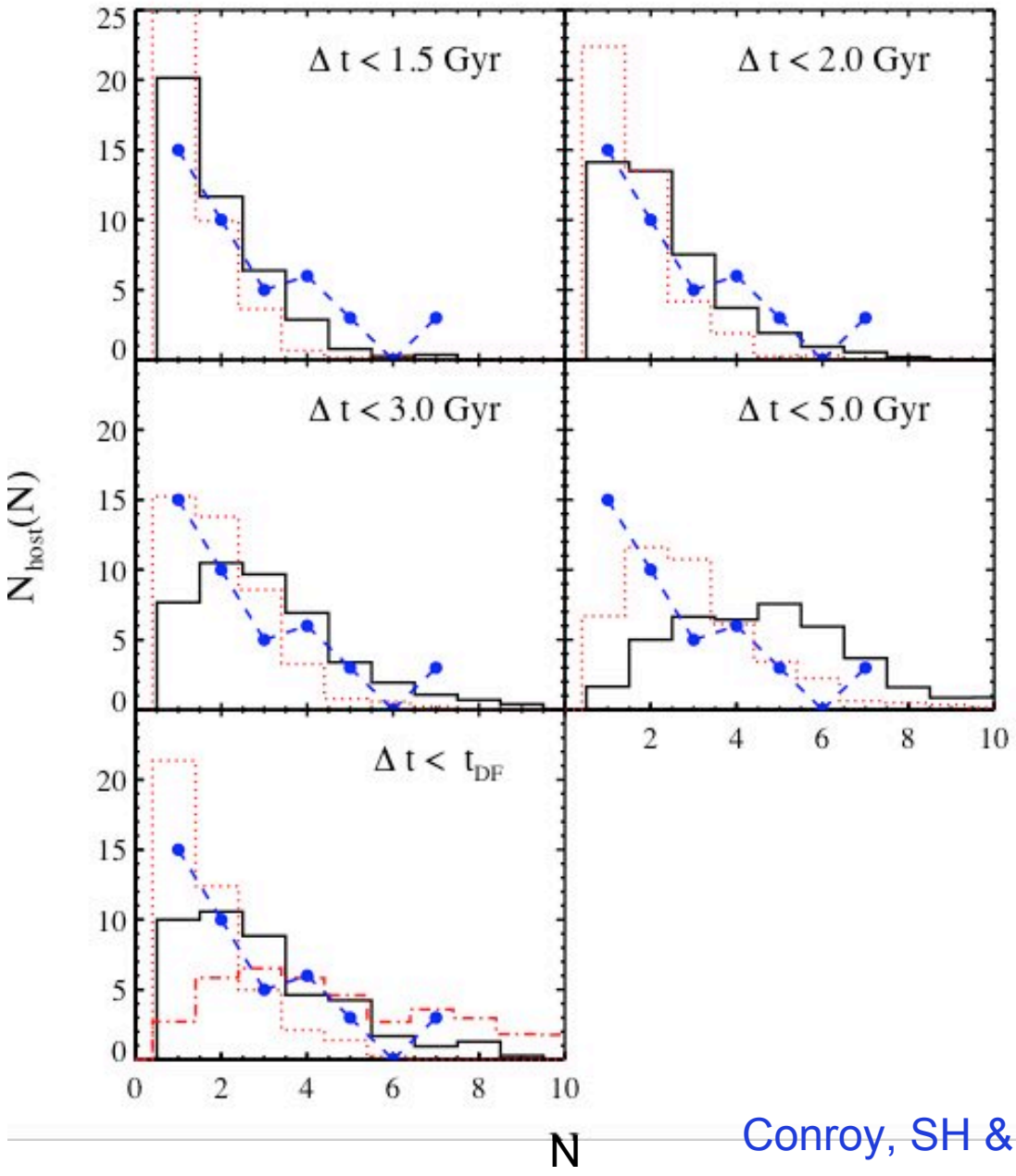
LRG multiplicity function + Merger trees





Conroy, SH & White (2007)

LRG merging timescales



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Physics of kinetic SZ:

-Kinetic Sunyaev Zeldovich:

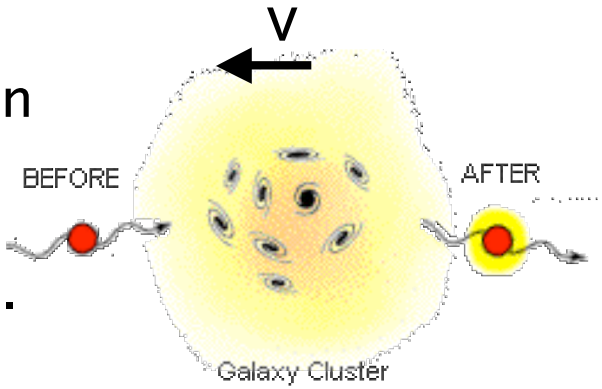
$$\frac{\delta T_{ksz}}{T_{cmb}} = -\int n_e \sigma_T \left(\frac{\dot{v}}{c} \cdot \hat{n}\right) dl$$

1)electrons interact with photons!

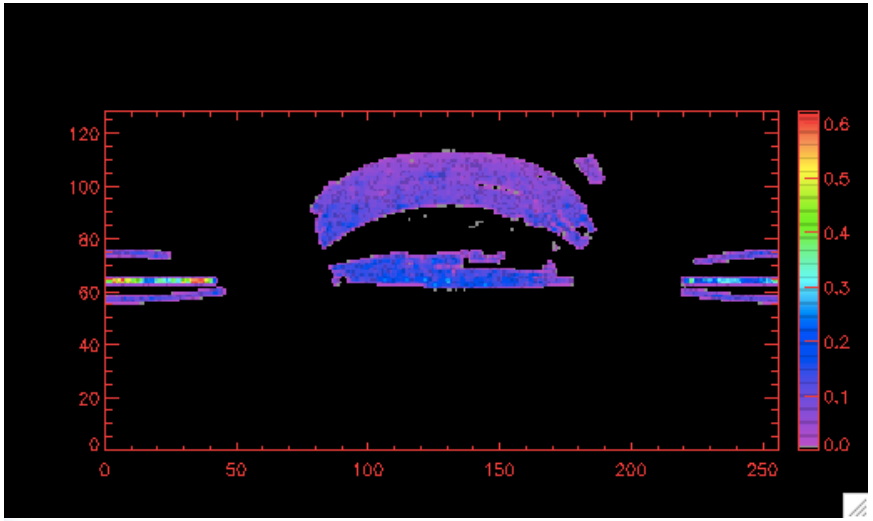
-> a i/decrement of the photon energy depending on the direction of the **velocities**.

-> amount of ionized electrons

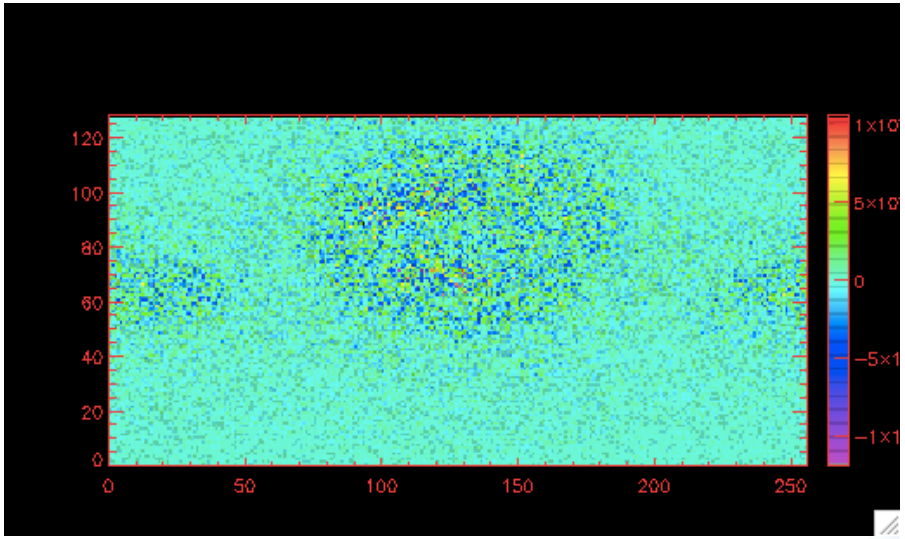
-> baryon fraction in the universe.



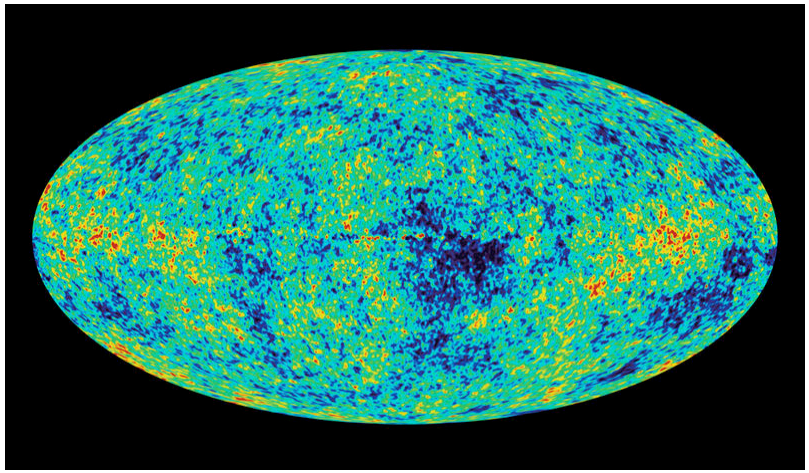
kSZ estimator



x



Cross correlate with



SH, Dedeo & Spergel (2007, in prep)

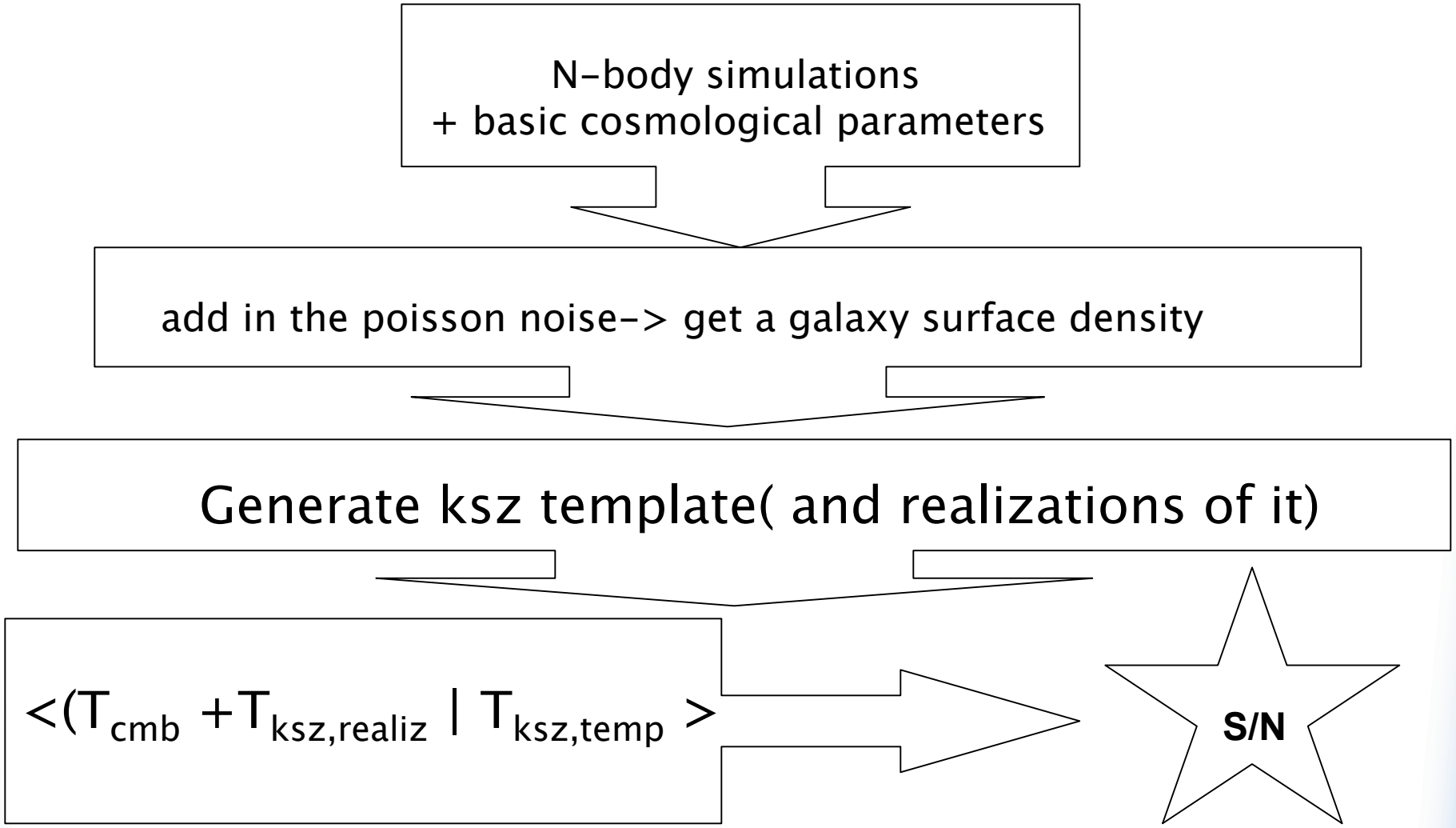
KSZ Applications!

- Applicable to CMB with LSS survey, such as:
  1) ACT(with SDSS),
  2) SPT (with BCS/DES) and
  3) PLANCK (with ADEPT, LSST)

- In particular: ACT and SDSS
  1) SDSS equatorial stripes
  2) ACT: (Atacama Cosmology Telescope)

  we used the ACT specifications for its noise and beam size, 100 square degrees for the S/N analysis.

KSZ
S/N Analysis



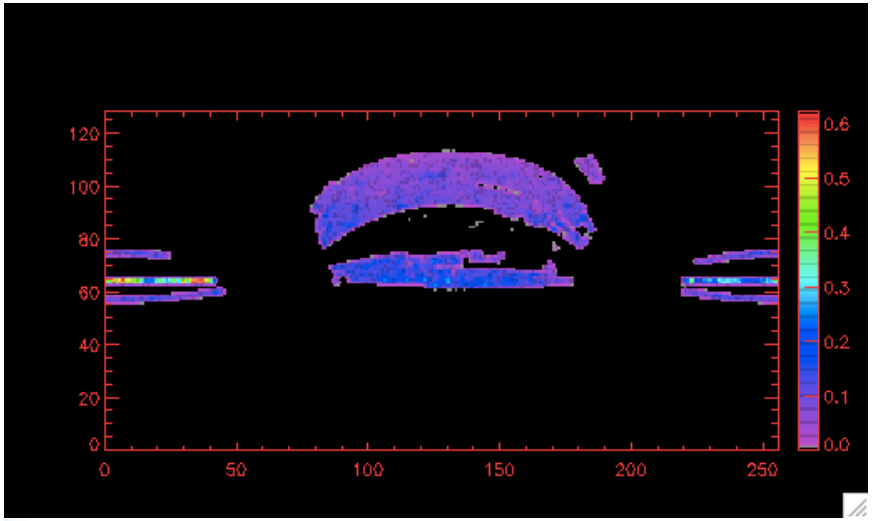
SH, Dedeo & Spergel (2007, in prep)

KSZ
predicted S/N

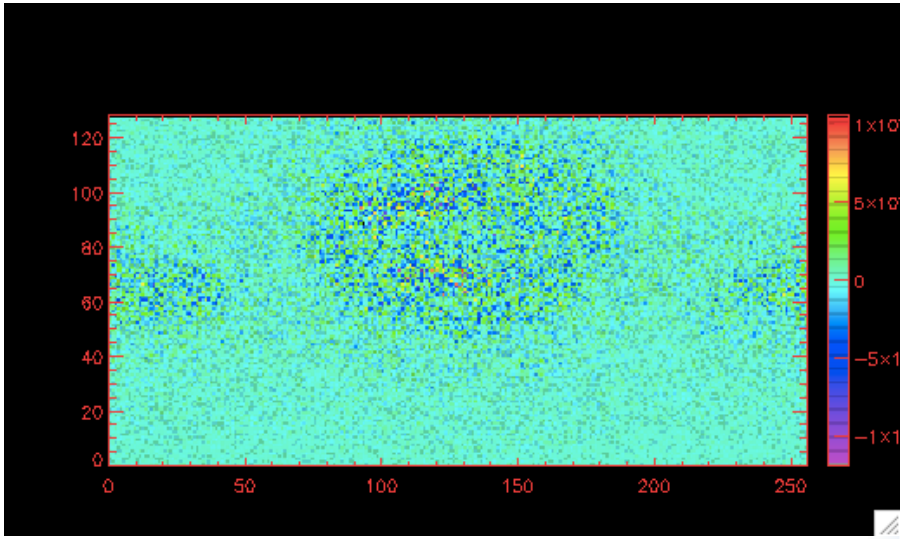
- 100 realizations of ksz
- 100 square degree of ACT only
- Overlap of galaxy survey in same region
- ->S/N of 30!
- Promising tool for finding the missing baryons!

There is more you can do with SZ!

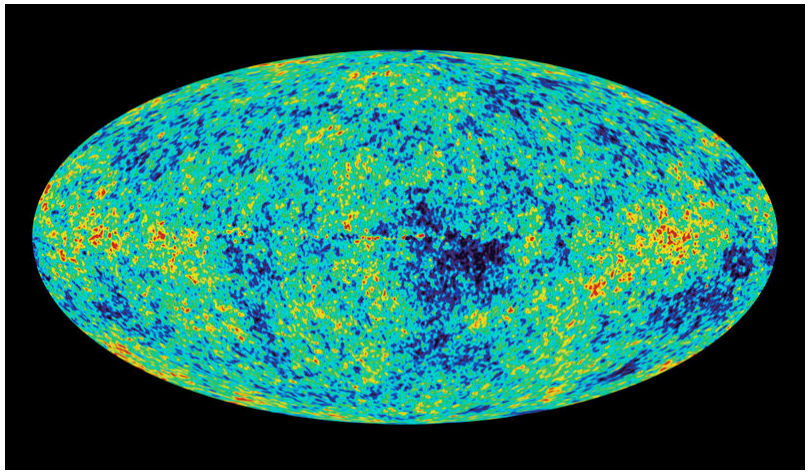
kSZ and gas profiles



x



Cross correlate with



SH, Dedeo & Spergel (2007, in prep)

tSZ and gas temperatures

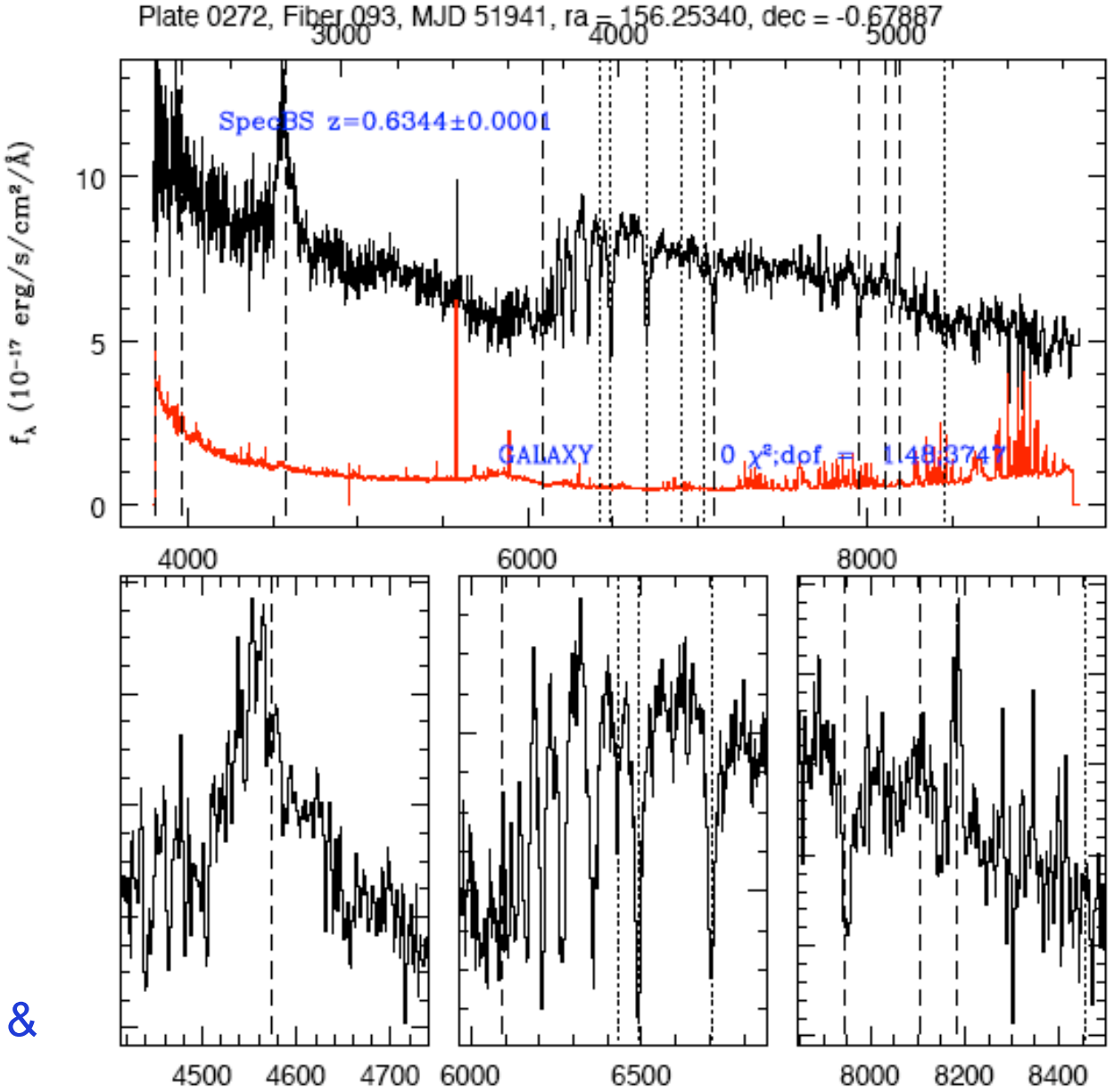
- Use kSZ to find out

  a) gas fraction b) gas distributions
- Predict the tSZ signals from (a) and (b)
- The only free parameter is T_{gas} in the galaxy
- Cross-correlate the predicted tSZ template with the CMB
- -> $<T_{gas}>$ of galaxies in question

SH & Spergel (in prep)

tSZ and Quasars

- Quasars are heating up the gas
- -> <E> input from Quasars to the gas



Chatterjee, SH, Spergel & Kosowsky (in prep)

Summary:

- We learn about the dark side of the Universe (Ω_K, w) by cross correlating CMB with large scale structure datasets:

  ISW: 3.69 σ away from 0 ,

  WL of CMB: 2.5 σ away from 0

-> cosmological parameters (Ω_K, w)

->note: constraints on Ω_K is made without any priors on H_0

- We connects galaxies to clusters by

investigating the Halo Occupation Distribution for LRGs

->We also find the merging timescale of LRGs!

- We learn about the baryons via SZ imprint on the CMB

-> finding missing baryons,

-> understanding distribution of gas around different types of galaxies,

-> gas temperatures,

-> quasar energy inputs.

- A lot to gain by cross-correlating CMB with large scale structure using ISW, WL of CMB, kSZ and tSZ.

Motivations:

ALL THESE COSMIC NOISE!!!

I just want it as a BACKLIGHT!!