Some remarks on new numerical estimations of the Rees-Sciama effect

FFP14

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Abstract

In previous editions of Frontiers of Fundamental Physics Symposia, we have presented our numerical computations of Cosmic Microwave Background (CMB) anisotropies at high ℓ's. We have adapted our algorithm to calculate such anisotropies through different N-body codes: Particle-Mesh (PM), linear and parallel Adaptative-Particle-Particle-Particle-Mesh (AP3M) Hydra codes. This way we have been able to compute weak lensing, Rees-Sciama (RS) and Sunyaev-Zel'dovich contributions to the CMB anisotropy. The use of parallel AP3M makes more accurate computations. In 2006, we computed RS effect using a PM N-body code. In this work, we present the improvements on the computation of RS contribution using parallel Hydra code. We also make some remarks on the coupling of contributions at high ℓ's.

Previous work

- ***AN APPROPRIATE RAY-TRACING PROCEDURE THROUGH N-BODY SIMULATIONS WAS PROPOSED IN THE FOLLOWING BASIC REFERENCES:***

1. Non Gaussian Signatures in the Lens Deformations of the CMB Sky: A New Ray-Tracing Procedure, P. Cerdá-Durán, V. Quilis, and D. Sáez, Phys. Rev. 69D, 2004, 043002. arXiv:astro-ph/0311431v1

2. Ray-Tracing through N-body simulations and CMB anisotropy estimations. Proceedings of Science: *CMB and Physics of the Early Universe* (PoS CMB2006 pp.058), Ischia, 2006, by D. Sáez, N. Puchades, M.J. Fullana and J.V. Arnau.

Previous work

- ***APPLICATIONS BASED ON RAY-TRACING THROUGH PM SIMULATIONS ARE IN:***

  1. Cosmic Microwave Background Maps Lensed by Cosmological Structures: Simulations and Statistical Analysis, L. Antón, P. Cerdá-Durán, V. Quilis and D. Sáez, ApJ, 628, 2005, 1. arXiv:astro-ph/0504448v1

  2. On the Rees-Sciama Effect: Maps and Statistics, N. Puchades, M.J. Fullana, J.V. Arnau and D. Sáez, MNRAS, 370, 2006, 1849. arXiv:astro-ph/0605704v1

Previous work

- ***APPLICATIONS BASED ON RAY-TRACING THROUGH*** **AP3M** ***SIMULATIONS ARE IN:***

- Estimating small angular scale CMB anisotropy with high resolution N-body simulations: weak lensing, M.J. Fullana, J.V. Arnau, R.J. Thacker, H.M.P. Couchman, and D. Sáez, ApJ, 712, 2010, 367. arXiv:1001.4991v1

Previous work

- ***ADVANCE OF OUR WORK PRESENTED IN FFP EDITIONS***

1. Making Maps of the Rees-Sciama Effect. Proceedings of *FFP6*, Udine, 2004, by M.J. Fullana and D. Sáez.

2. Status of CMB Radiation. Proceedings of *FFP8*, Madrid, 2006, by M.J. Fullana and D. Sáez.

3. Weak Lensing on the CMB: Estimations Based on AP3M Simulations. Proceedings of *FFP9*, Udine, 2008, by M.J. Fullana, J.V. Arnau and D. Sáez.

Previous work

- ***ADVANCE OF OUR WORK PRESENTED IN FFP EDITIONS***

1. Recent Observservations on CMB at high multipoles and AP3M computations at such scales. Proceedings of *FFP11,* Paris, 2010, by M.J. Fullana, J.V. Arnau, R.J. Thacker, H.M.P. Couchman and D. Sáez.

2. CMBR anisotropies computations using Hydra Gas Code. Proceedings of *FFP12*, Udine, 2011, by M.J. Fullana, J.V. Arnau, R.J. Thacker, H.M.P. Couchman and D. Sáez.

3. A new numerical approach to estimate the Sunyaev-Zel'dovich effect. Proceedings of ERE12, Guimarães, 2012, M.J. Fullana, J.V. Arnau, R.J. Thacker, H.M.P. Couchman and D. Sáez.

PM SEQUENTIAL CODE

- *OUR WORK* **STARTED** *USING A* **PM SEQUENTIAL** *CODE. WE MODIFIED THE CODE TO MOVE THE CMB PHOTONS THROUGH PM N-BODY SIMULATIONS. ONLY DARK MATTER WAS TAKEN INTO ACCOUNT IN THE EVOLUTION OF STRUCTURE. WE COMPUTED* **REES-SCIAMA (RS) AND WEAK LENSING (WL)** *CONTRIBUTIONS ON CMB ANISOTROPIES.*

AP3M SEQUENTIAL CODE

- **THEN**, ***WE CONTINUED WITH AN AP3M SEQUENTIAL CODE. WE MODIFIED THE*** **HYDRA AP3M SEQUENTIAL** ***VERSION OF CODE. WE MODIFIED THE CODE TO MOVE THE CMB PHOTONS THROUGH AP3M N-BODY SIMULATIONS. ONLY DARK MATTER WAS TAKEN INTO ACCOUNT IN THE EVOLUTION OF STRUCTURE. WE COMPUTED*** **REES-SCIAMA (RS) AND WEAK LENSING (WL)** ***CONTRIBUTIONS ON CMB ANISOTROPIES.***

AP3M PARALLEL CODE

- **WE FOLLOWED** ***BY MODIFYING THE HYDRA AP3M*** **PARALLEL** ***VERSION OF CODE TO MOVE THE CMB PHOTONS THROUGH HIGH RESOLUTION N-BODY SIMULATIONS. AGAIN ONLY DARK MATTER WAS TAKEN INTO ACCOUNT IN THE EVOLUTION OF STRUCTURE. WE COMPUTED*** **WL** ***CONTRIBUTIONS ON CMB ANISOTROPIES.***

- **IN THIS WORK WE PRESENT THE COMPUTATION OF RS ANISOTROPIES USING THIS AP3M PARALLEL HYDRA VERSION OF CODE WITH ONLY DARK MATTER.**

AP3M PARALLEL CODE WITH BARYONS

- ***NOW, WE ARE MODIFYING THE HYDRA AP3M*** **PARALLEL** ***VERSION OF CODE*** **WITH BARYONS*****. THE CMB PHOTONS MOVE THROUGH EVEN HIGHER RESOLUTION N-BODY SIMULATIONS. WE ARE CURRENTLY APPLYING THE CODE TO COMPUTE THE*** **SUNYAEV-ZEL'DOVICH (SZ)** ***CONTRIBUTION.***

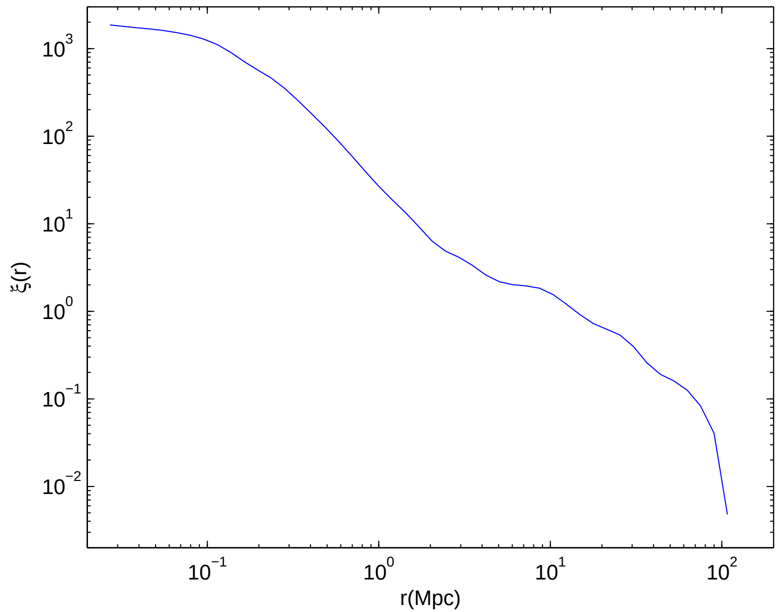
- WE WILL THEN COMPUTE RS AND WL CONTRIBUTIONS ON CMB ANISOTROPIES IN ORDER TO COUPLE THE THREE EFECTS.

AP3M PARALLEL CODE

- Calculations are carried out with the AP3M parallel Hydra code without baryons designed by members of the Hydra Consortium, which has been modified to move the CMB photons **while the AP3M N-body simulation is performed**.

- In this way, **the potential**, its gradient, the baryon density, temperature and peculiar velocity are known and used **at every time step** of the N-body simulation.

HYDRA SIMULATIONS: DESCRIPTION AND ANALYSIS

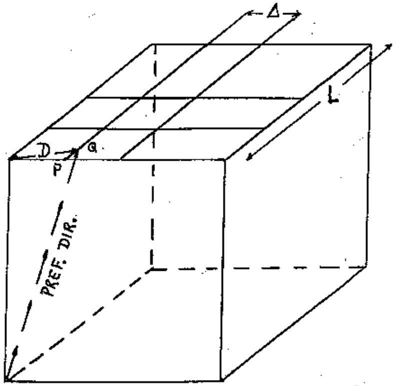


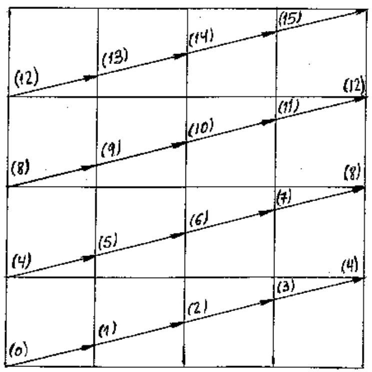
Simulations have been performed in the framework of the concordance model with the following parameters: $h = 0.7$, $\Omega_b = 0.046$, $\Omega_d = 0.233$, $\Omega_\Lambda = 0.721$, optical depth $\tau = 0.084$ and $\sigma_8 = 0.817$.

The power spectrum of the scalar (adiabatic) energy density perturbations has been obtained with the CMBFAST code. No tensor modes are considered at all.

The figure shows the correlation function $\xi(r)$ extracted from one simulation. Its form is that expected on account of the softening length and the box size. The code works properly in spite of the modifications required by our CMB calculations.

RAY-TRACING TECHNIQUE





- TOP FIGURE: Sketch of the photon motion along the preferred direction (P.D.) in the first box.

- BOTTOM FIGURE: Representation of the point (i) where the P.D. crosses the upper face of the (i)-th box. This direction has been chosen to reach the initial position after passing through 16 boxes. This procedure allows neglecting periodicity effects.

CHOOSING FREE PARAMETERS, REFERENCE RS SIMULATION (RRSS)

- Initial redshift: ———————————— $z_{in} = 6$
- Box size: ———————————————— $L_{box} = 512h^{-1}Mpc$
- Map size: ———————————————— $\sim 5^\circ \times 5^\circ$
- Number of photons: ————————— 256×256
- Number of particles: ————————— 256^3
- Softening length: ——————————- $S_p \sim 50h^{-1}kpc$
- Effective resolution: ————————— $E_{res} \sim 5S_p$
- Photon step: ——————————————- $\Delta_{ps} = 125h^{-1}kpc$

RS INTEGRAL

For Rees-Sciama contribution one has to compute the integral:

$$\frac{\Delta T}{T_B}(\vec{n}) = 2\int_{\lambda_e}^{\lambda_0} W(\lambda)\,\frac{\partial\phi}{\partial\lambda}\,d\lambda\,, \tag{1}$$

where ϕ is the peculiar gravitational potential ϕ,

$W(\lambda) = (\lambda_e - \lambda)/\lambda_e$ and the variable λ is

$$\lambda(a) = H_0^{-1}\int_a^1 \frac{db}{(\Omega_{m0}b + \Omega_\Lambda b^4)^{1/2}}\,. \tag{2}$$

Algorithm to compute the potential

1. Decide upon the direction of the normal rays representing the geodesics

2. Assuming the Born approximation and using the photon step distance Δ_{ps}, determine all the evaluation positions and times on the geodesics within the simulation volume from the initial redshift down to the final redshift

3. Associate test particles with each of these positions and times

4. At each time-step of the N-body simulation (while it is running) determine which test particles require potential evaluations as in the HYDRA algorithm

Algorithm to compute the potential

5. At each test particle position evaluate the potential on the test particle using the long-range FFT component and short-range PP correction as in the HYDRA algorithm

6. During the FFT convolution for the test particles eliminate contributions from scales larger than $42h^{-1}$ Mpc by removing the signal from wavenumbers satisfying $k \leq 0.15h$ Mpc^{-1}

7. If the evaluation time for a point on the geodesic lies between two time-steps calculate a linear interpolation of the two potentials from the time-steps that straddle the correct time

PREVIOUS RESULTS, WL

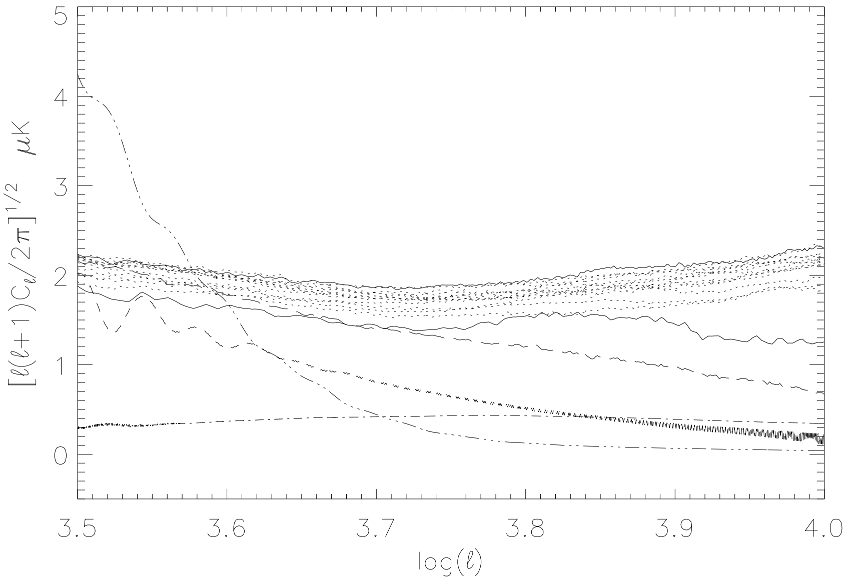


Fig 1. Angular power spectra, in μK, as functions of $\log(\ell)$. Solid and dotted lines represent spectra varying different parameters. The signal in the range $4000 < \ell < 7000$ is 2.0 ± 0.4 μK. The dash-three-dot line is the CMB spectrum in the absence of lensing, and the dash-dot (dashes) line is the AWL (BWL) effect obtained with the CMBFAST code in the case of nonlinear lensing including structures with sizes $L > 30h^{-1}$ Kpc.

Spatial Resolution

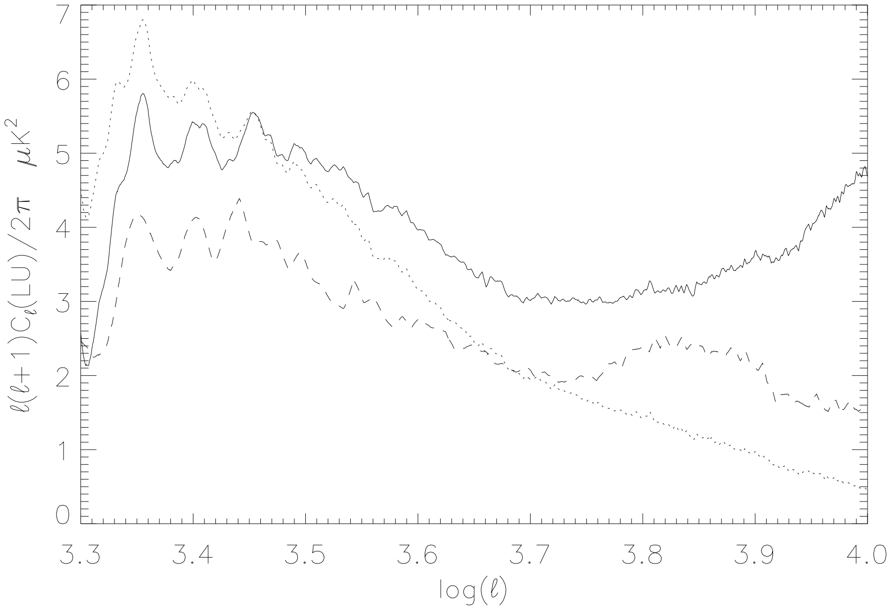
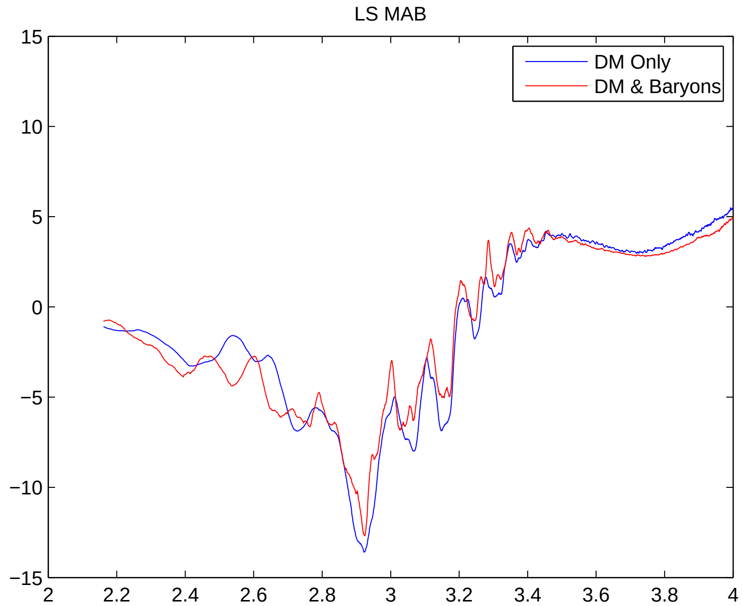


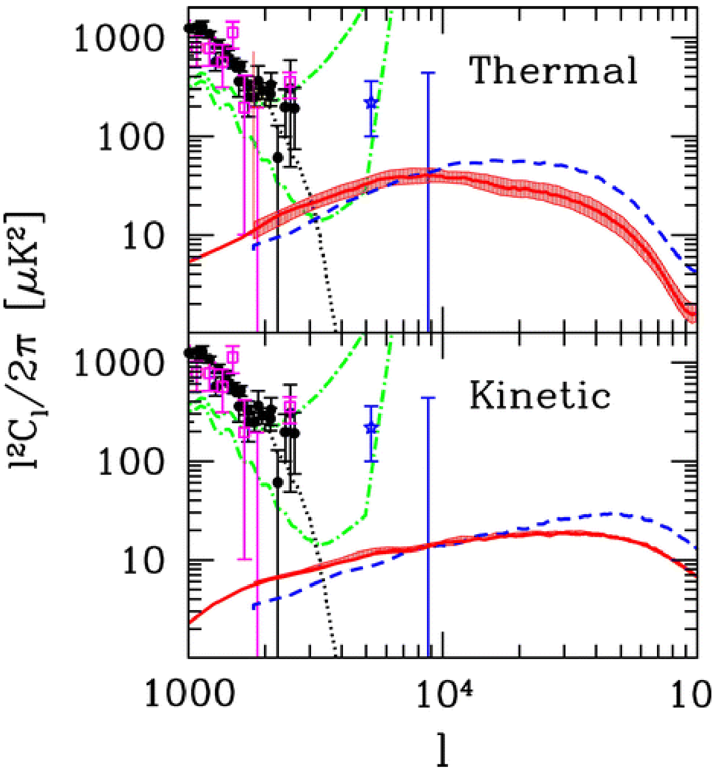
Fig 2. LU angular power spectra for one simulation (solid line) as compared to the same simulation but where deflections are calculated by including an average over the 8 nearest geodesics (dashed line). This reduces the resolution of geodesic method, but maintains the same resolution in the gravitational solver. We recover previous results (e.g. Das and Bode 2008, arXiv:0711.3793v3).

WL with baryons



Comparison of WL $Cl's$ computed from CDM Only version of Hydra Code and from CDM+baryons version. This test allows the progress of work.

FIRST RESULTS FOR SZ



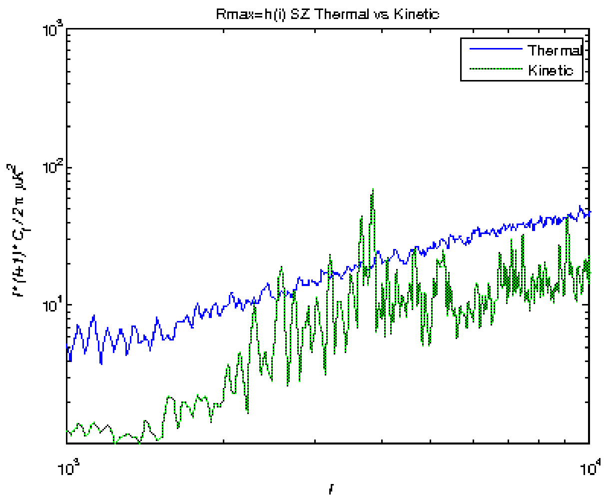
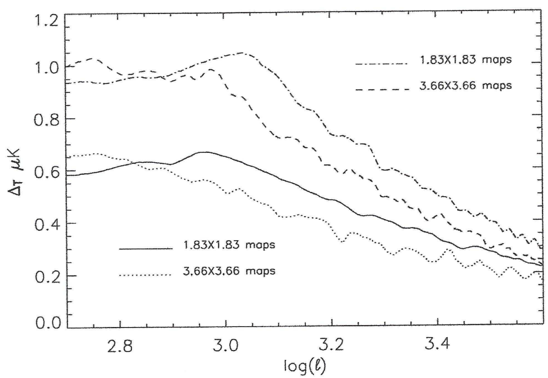


Fig 3. Left panel. Measuring AGN Feedback with SZ Effect, Scannapieco, E., Thacker, R. J., & Couchman, H. M. P. 2008, ApJ, 678, 674. arXiv:0709.0952v1

Different ray tracing method, taking slices. Right panel: our results.

Results on RS effect

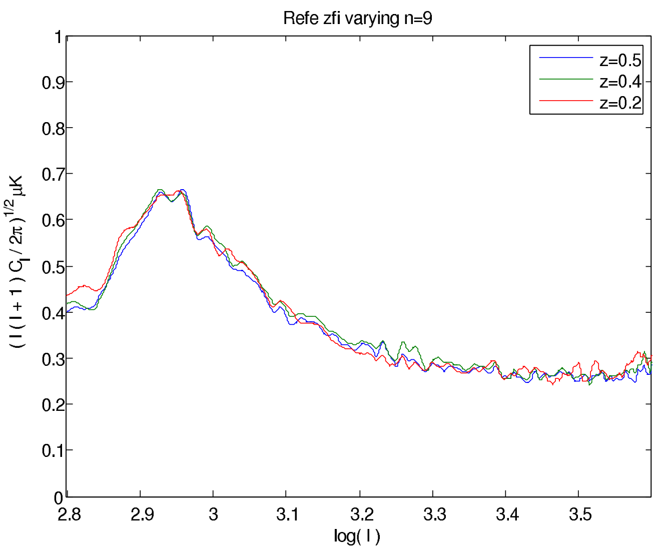
Comparison with our PM computations



RS computations with PM

(see MNRAS, 370, 2006, 1849.

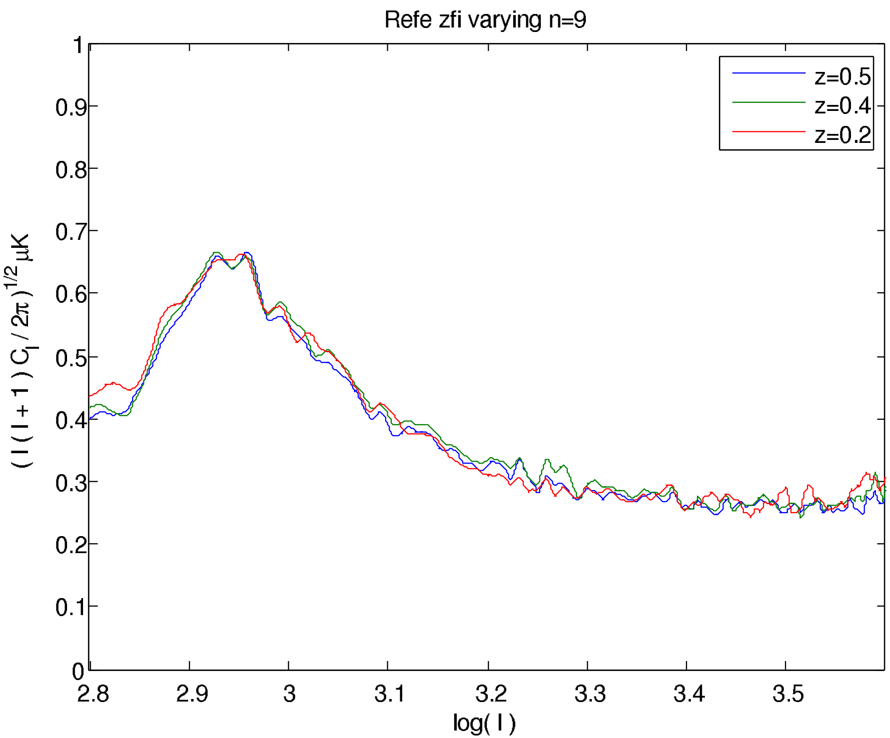
arXiv:astro-ph/0605704v1)



RS computations with Hydra Parallel AP3M code

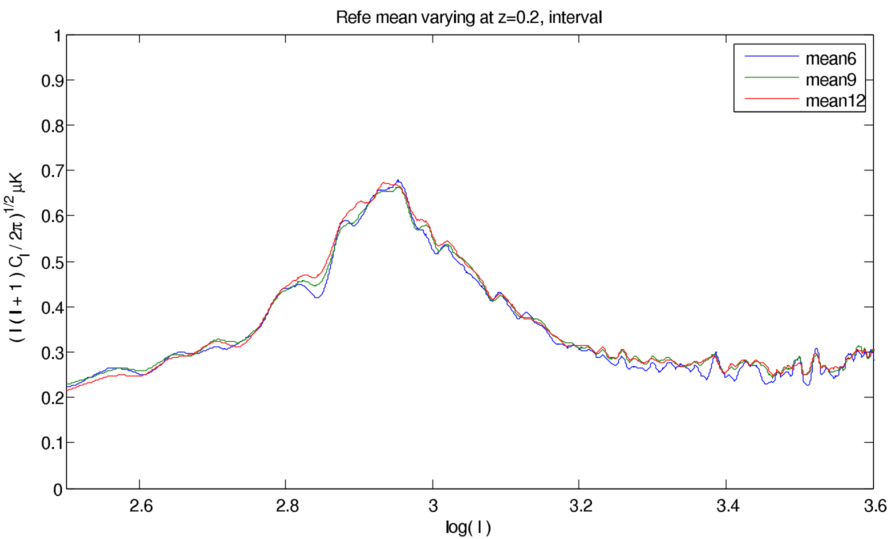
Results on RS effect

Effect of changing the final ray-tracing redshift



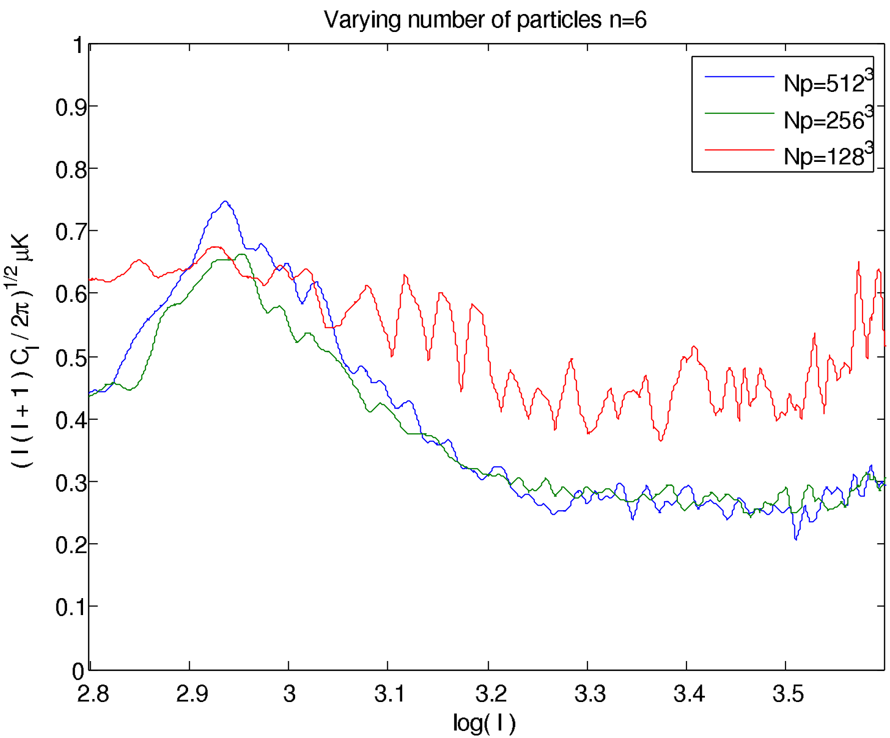
Results on RS effect

Increasing the number of simulations



Results on RS effect

Impact of mass resolution on convergence



Some recent observations

We focus our attention on the ℓ interval $(5000, 6000)$

- ***ACT*** arXiv:1001.2934v1
  ACT power is between $\sim 40\mu K^2$ and $\sim 50\mu K^2$

- ***SPT*** arXiv:0912.4317v1
  SPT power is only $\sim 20\mu K^2$

Effects explaining observations

- ***Sunyaev-Zeldovic', SZ*** ——————— n_e, T_e, v_r
- ***Weak Lensing, WL*** ——————— $\nabla\Phi$
- ***Rees-Sciama, RS*** ——————— Φ
- ***Dusty Star Forming Galaxies, DSFG***

CONCLUSIONS

- Our AP3M code adapted to CMB RS calculations can be run for different values of the parameters defining the RRSSs; hence, this code allows us to see how the resulting angular power spectra depend on the parameters defining both the N-body simulation and the ray-tracing procedure. We have studied these variations and conclude that they do not influence very much on the signal computed

- We have compared the results obtained with our new numerical algorithm using Hydra parallel AP3M code with our previous computations using a PM code and observed that there are not much changes. All those computations are in agreement with computations made by other authors.

- The signal in the range $4000 < \ell < 7000$ is 0.7 ± 0.1 μK, which is in agreement with that found elsewhere.

CONCLUSIONS

- One of the advantages of our new numerical algrithm is that due to the use of PP correction it achieves better resoltion by using a less number of particles and therefore it has much less CPU time cost.

- Before we needed 30 simulations to obtain acceptable results. Now only 6 simulations are enough to give quite acceptable results.

- Before simulations with 512^3 particles were needed to obtain acceptable results. Now, simulations with only 256^3 particles supply quite acceptable results.

- On the other hand, due to the small signal predicted, detection of this signal seems very far in time from the present moment.

PRESENT WORK

- Computation of WL and RS with baryons.
- Comparison of WL and RS with and without baryons. Interest in itself. See, for instance, Jing et al. arXiv:astro-ph/0512426v2
- IN PROGRESS:
- Computation of SZ with our methodology. Gas particles needed.
- Coupling of WL and RS and SZ. Crossing terms.
- Explanation of observational data.