Large-scale cosmic flows and moving dark energy

J. Beltrán Jiménez and Antonio L. Maroto

Dpto. Física Teórica I, Universidad Complutense de Madrid

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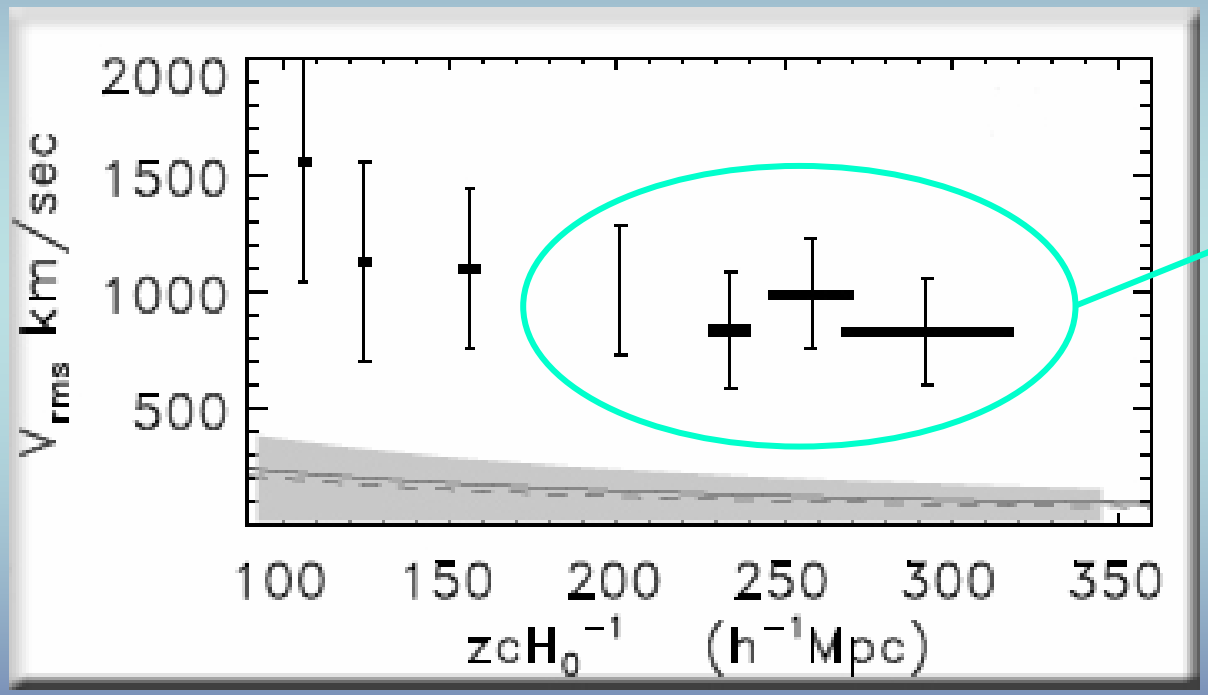
J. Beltrán and A.L. Maroto, JCAP 0903: 015 (2009)

Outline

- The dark flow
- Moving dark energy
- Effects on the CMB
  - The dipole
  - The quadrupole
- A model example: scaling dark energy
- Conclusions

The dark flow

Kinematic Sunyaev-Zeldovich effect



Peculiar velocities on large scales towards

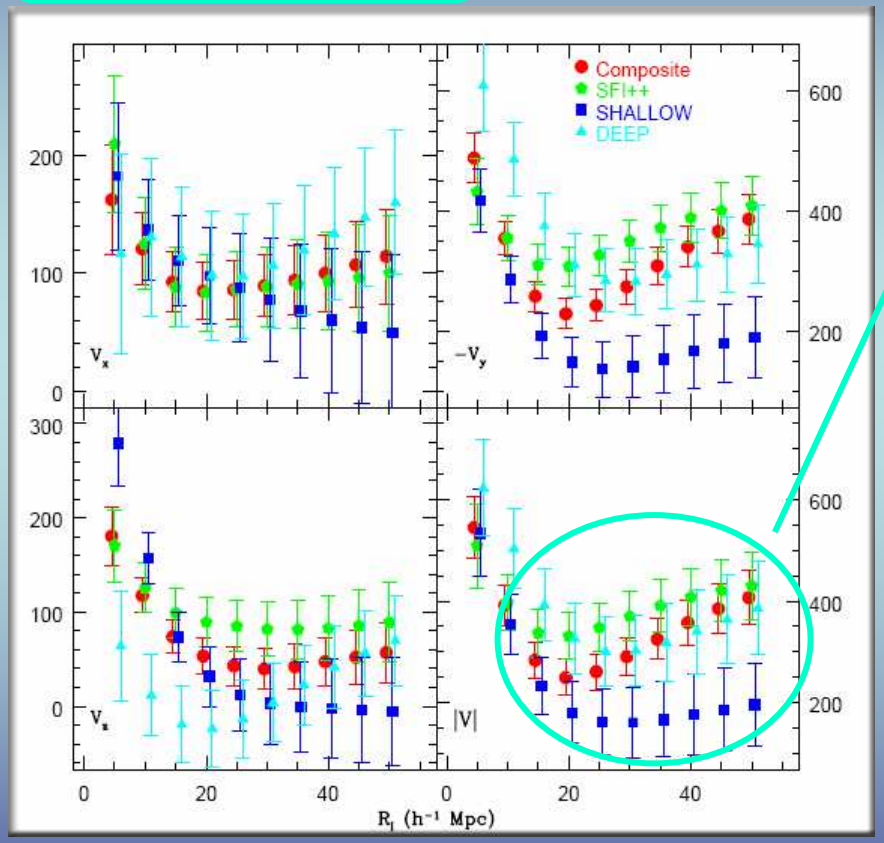
l= 283° ± 14°

b = 11° ± 14 °

A. Kashlinsky, F. Atrio Barandela, D. Kocevski and H. Ebeling
arXiv:0809.3734 [astro-ph]

The dark flow

Other tracers



Dark flow on large scales towards

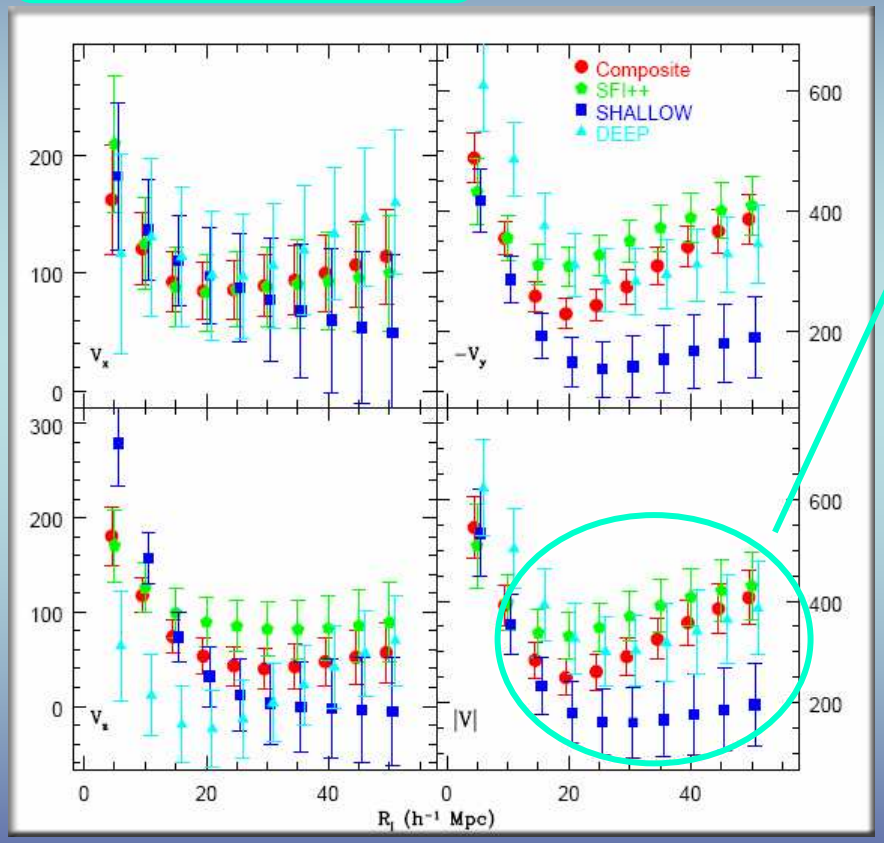
l= 287° ± 9°

b = 8° ± 6 °

R. Watkings, H.A. Feldman
And M.J. Hudson,
arXiv: 0809.4041 [astro-ph]

The dark flow

Other tracers



R. Watkings, H.A. Feldman and M.J. Hudson, arXiv: 0809.4041 [astro-ph]

Dark flow on large scales towards

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These results suggest the existence of a coherent flow of matter wit respect to CMB on very large scales:

$$\vec{V}_{R,bulk} = \vec{V}_{R,sta} + \vec{V}_{cosmic}$$

But, how is this possible?

Moving dark energy

$$T^{\mu\nu} = \sum_{\alpha} [(\rho_\alpha + p_\alpha) u^\mu_\alpha u^\nu_\alpha - p_\alpha g^{\mu\nu}]$$

$\alpha =$ B, R, DM, DE.

$$p_\alpha = w_\alpha \rho_\alpha$$

$$u^\mu_\alpha = \gamma_\alpha (1, \vec{v}_\alpha)$$

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Cosmic Center of Mass velocity:

$$\vec{S} = \frac{\sum_\alpha (\rho_\alpha + p_\alpha)\vec{v}_\alpha}{\sum_\alpha (\rho_\alpha + p_\alpha)}$$

$\vec{S} = 0$

$$\sum_\alpha (\rho_\alpha + p_\alpha)\vec{v}_\alpha = 0$$

Momentum conservation

$$\vec{S} - \vec{v}_\alpha = \vec{v}^0_\alpha a^{3w_\alpha - 1}$$

Effects on the CMB: the dipole

Sachs-Wolfe effect to first order

$$\frac{\delta T_{dipole}}{T} \simeq \vec{n} \cdot (\vec{S} - \vec{V})|_{dec}^{0}$$

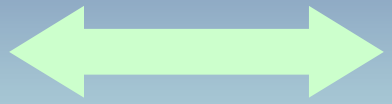
A. L. Maroto, *JCAP*0605:015 (2006)

Velocity of the observer with respect to the cosmic center of mass

Effects on the CMB: the dipole

$$\frac{\delta T_{dipole}}{T} \simeq \vec{n} \cdot (\vec{v}_R^0 - \vec{v}_M^0)$$

Relative motion of matter with respect to CMB



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Motion of CMB with respect to the CCM .

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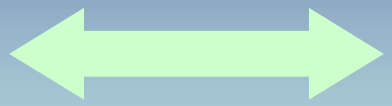


$$\frac{\delta T_{dipole}}{T} \simeq \vec{n} \cdot \vec{v}_R^0$$

Motion of CMB with respect to the CCM .

This would be the kind of motion recently detected!

Effects on the CMB: the dipole

$$\frac{\delta T_{dipole}}{T} \simeq \vec{n} \cdot (\vec{v}_R^0 - \vec{v}_M^0) \quad \Longleftrightarrow \quad \frac{\delta T_{dipole}}{T} \simeq \vec{n} \cdot \vec{v}_R^0$$

Relative motion of matter with respect to CMB

Motion of CMB with respect to the CCM .

This would be the kind of motion recently detected!

In the CCM rest frame we can obtain:

$$v_{DE}^0 = \frac{v_R^0}{(1+w_{DE}^0)\Omega_{DE}} \left(\frac{2}{3}\Omega_R + \frac{\Omega_B}{1+z_{dec}} + \frac{\Omega_{DM}}{1+z_*} \right) \Rightarrow v_{DE}^0 \sim 1 \text{ km/s}$$

$v_R^0 \sim 500$ km/s

$w_{DE}^0 \simeq -0.97$

Effects on the CMB: the quadrupole

The contribution to the quadrupole is

$$\frac{\delta T_Q}{T_0} = -\frac{1}{2} h \left(\hat{v}_i \hat{v}_j - \frac{1}{3} \delta_{ij} \right) n^i n^j$$

Dependency on the DE model

The total quadrupole is:

$$(\delta T)^2_T = (\delta T)^2_A + (\delta T)^2_I - 2 f(\hat{v}, \alpha_i) \delta T_A \delta T_I$$

Anisotropic constribution

Inflation contribution

Inflationary random phases

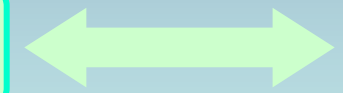
Measurements of the CMB quadrupole lead to constraints on h:

$$\begin{aligned} 0 \leq h \leq 6.92 \times 10^{-5} \quad & 68\% \text{ C.L.} \\ 0 \leq h \leq 1.23 \times 10^{-4} \quad & 95\% \text{ C.L.} \end{aligned}$$

Effects on the CMB: the quadrupole

Can we explain the low quadrupole?

$(\delta T)^2_I \simeq 1252\ \mu K^2$



$(\delta T)^2_{obs} = 236^{+560}_{-137}\ \mu K^2$ 68% C.L.

$(\delta T)^2_{obs} = 236^{+3591}_{-182}\ \mu K^2$ 95% C.L.

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$$(\delta T)^2_{obs} = 236^{+3591}_{-182}\ \mu K^2 \qquad 95\%\ \text{C.L.}$$

$$1.18 \times 10^{-5} \leq h \leq 9.96 \times 10^{-5} \qquad 68\%\ \text{C.L.}$$

$$0 \leq h \leq 1.54 \times 10^{-4} \qquad 95\%\ \text{C.L.}$$

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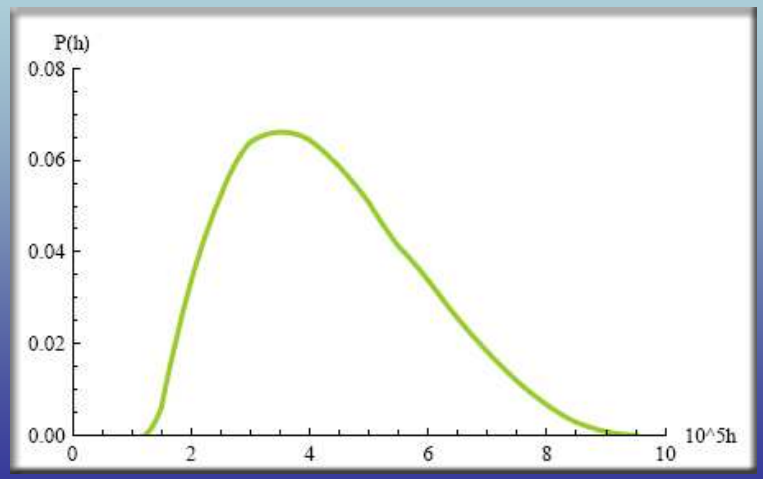
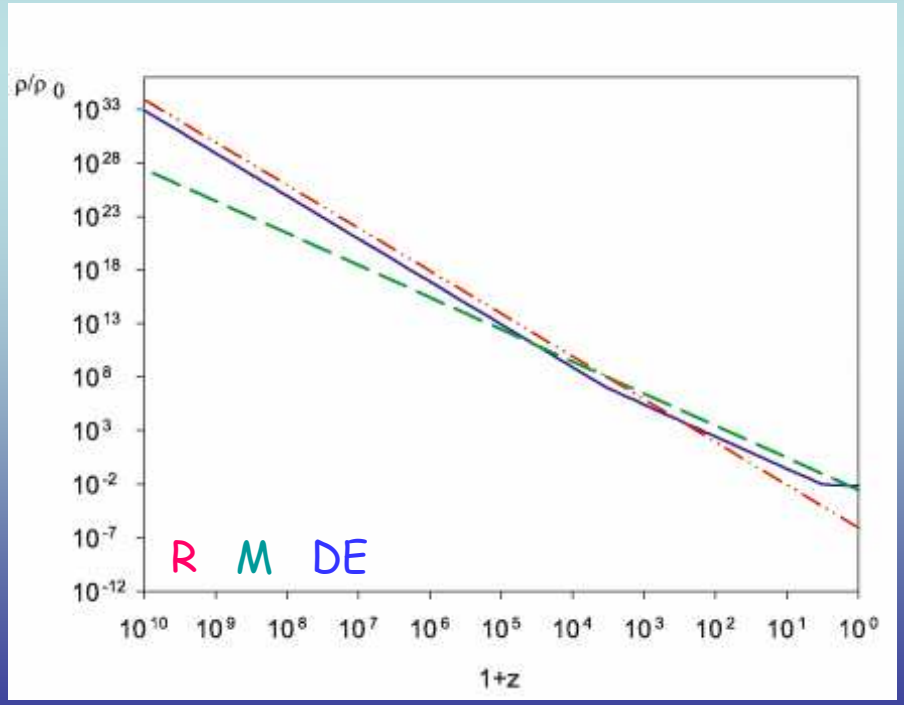
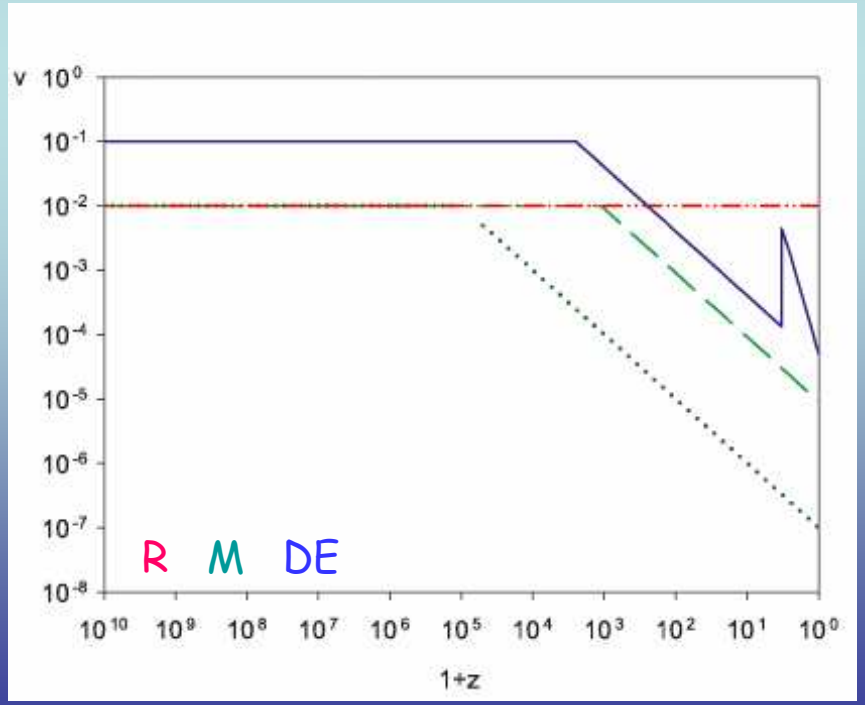
Although...



Model example: scaling dark energy

$$w_{DE} = \begin{cases} \frac{1}{3} & z > z_{eq} \\ 0 & z_{eq} > z > z_T \\ w^0_{DE} & z_T > z \end{cases} \qquad w^0_{DE} \simeq -0.97$$



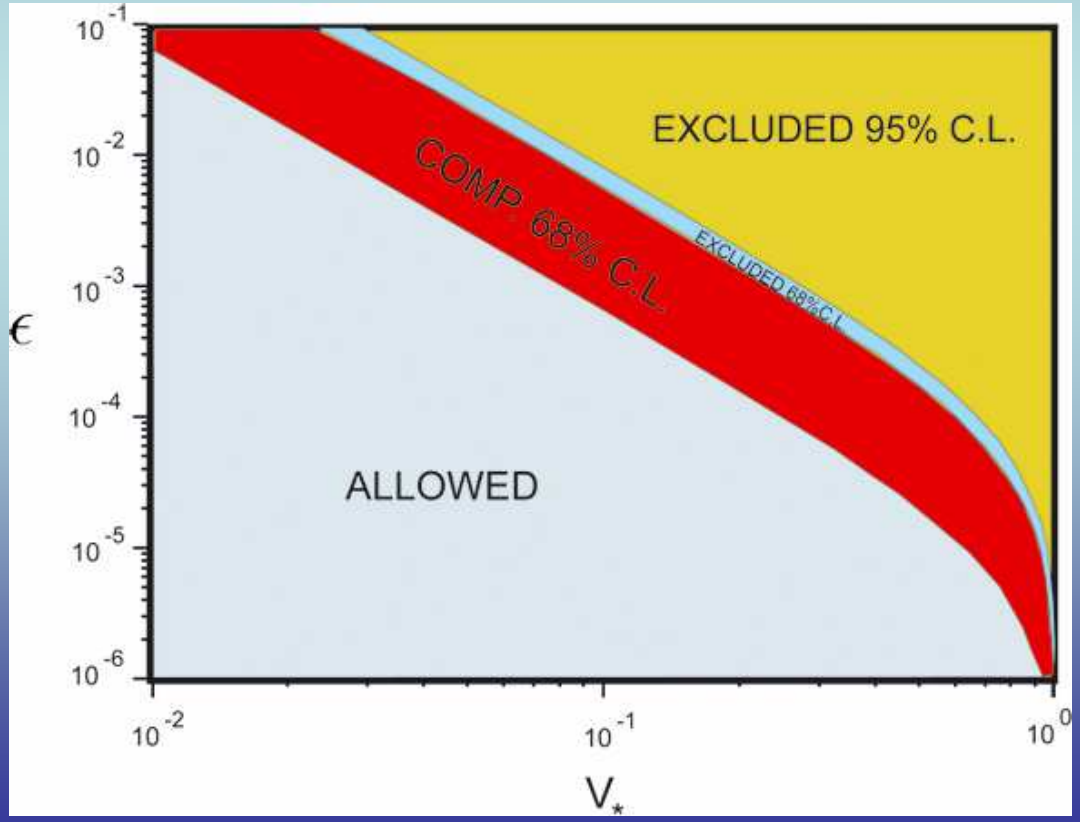


Model example: scaling dark energy

$$Q_A \simeq 0.44 v_R^2 \epsilon^{-1}$$

$v_R \simeq 500$ km/s

$$7.69 \times 10^{-2} \leq \epsilon \leq 0.2 \quad 68\%\ \text{C.L.}$$
$$4.32 \times 10^{-2} \leq \epsilon \leq 0.2 \quad 95\%\ \text{C.L.}$$



Conclusions

- A moving dark energy component could explain the observed large-scale dark flow.
- This motion would affect mainly the dipole and the quadrupole of the CMB.
- A scaling dark energy model could account for the large scale flow without conflicts with the quadrupole measurements.
- Common origin for the dipole and quadrupole. Axis of evil?