The motion of emptiness

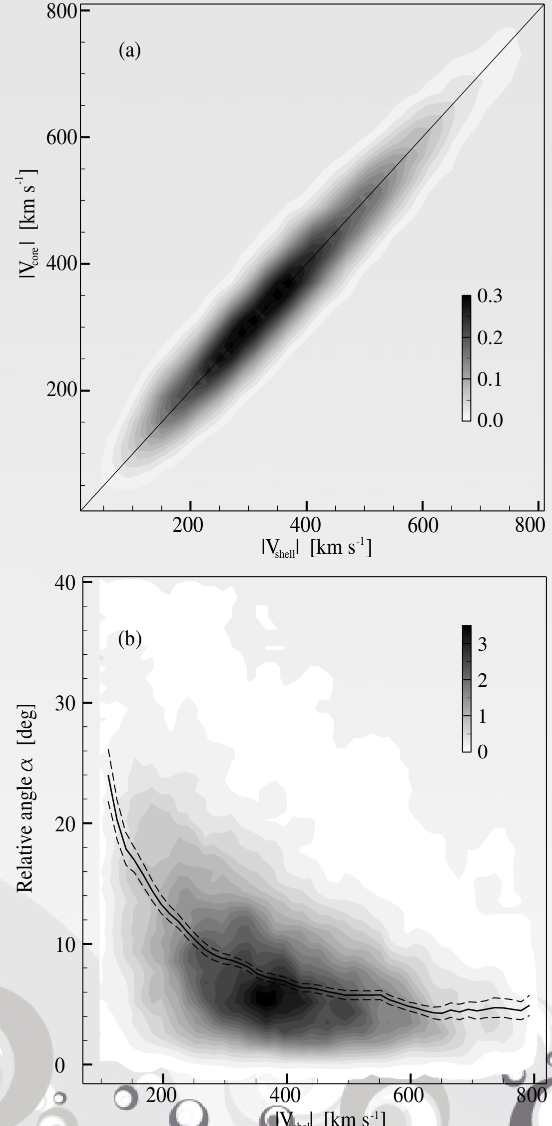
Dynamics and evolution of cosmic voids

Laura Ceccarelli
IATE, Observatorio Astronómico de Córdoba

The LSS team:
Diego G Lambas Marcelo Lares Heliana Luparello
Victoria Maldonado Dante Paz Andrés Ruiz

Void motions

Bulk velocities of void shells and cores



Bulk velocities of void shells and cores in the simulation.

V_{shell}: dark matter haloes mean velocity within 0.8<r/R_void<1.2.
V_{core}: mean velocity of dark matter particles within 0.8 R_void.

Upper: Distribution function of void counts in V_{shell}, V_{core} bins. Solid line shows the one-to-one relation.
Lower: Distribution function of void counts in bins of V_shell and the relative angle α between shell and core velocities. Solid and dashed lines correspond to the median and its standard error.

Lambas, Lares, Ceccarelli, Ruiz, Paz, Maldonado, Luparello. 2016, MNRAS Letters, 455, 99

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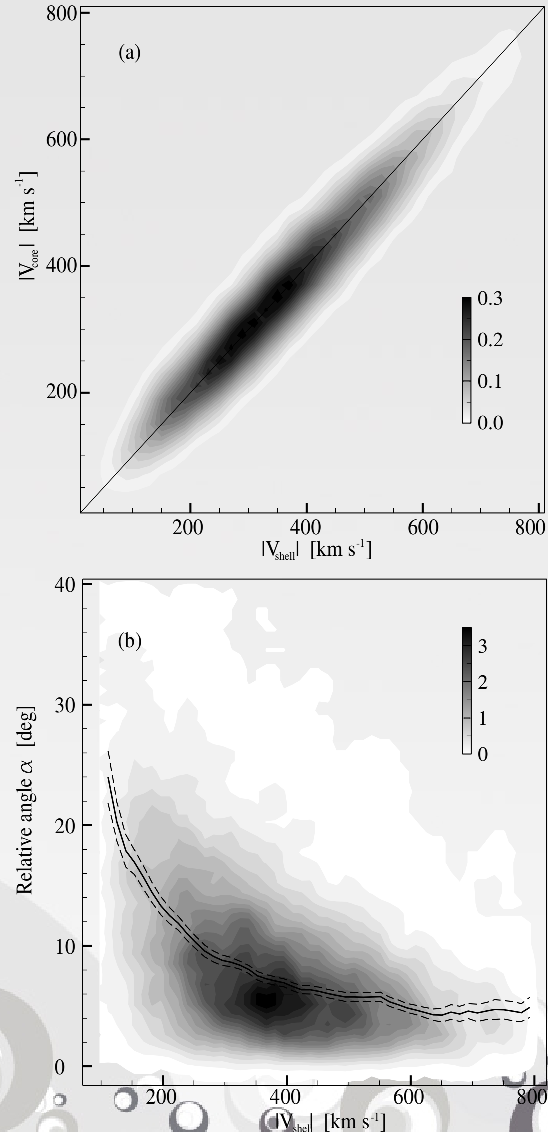
The dark matter in the void inner region and the haloes in the surrounding shell exhibit remarkably similar velocities (in magnitude and direction).



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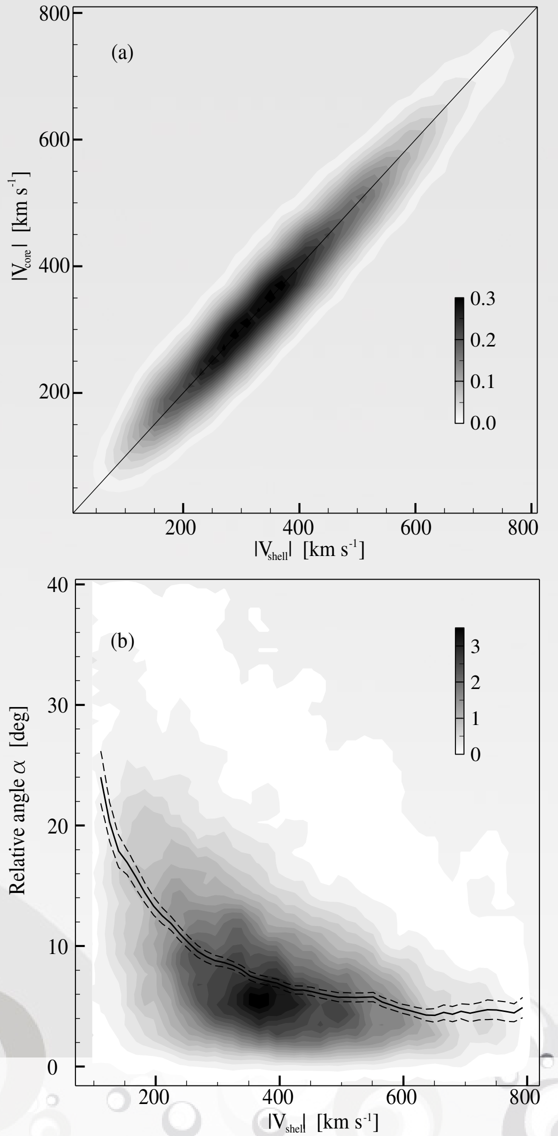

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Void inner material and the surrounding haloes have a global common motion.

Lambas, Lares, Ceccarelli, Ruiz, Paz, Maldonado, Luparello. 2016, MNRAS Letters, 455, 99

Void motions

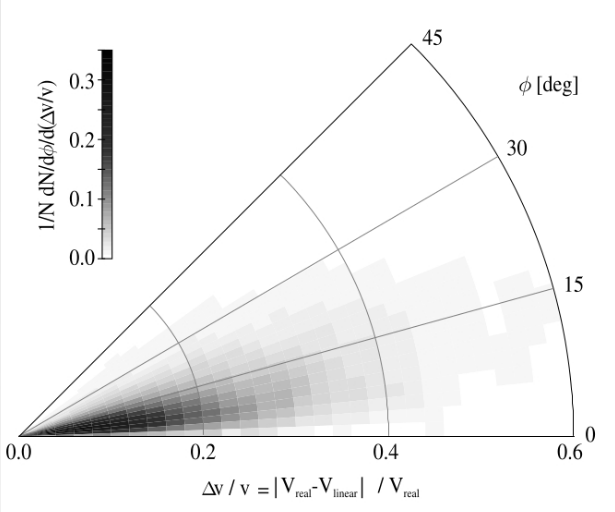
Bulk velocities of void shells and cores

Velocities in observational data

We have adopted the peculiar velocity field derived from linear theory by Wang et al. 2012. They use groups of galaxies as tracers of dark matter halos and its cross correlation function with mass, in order to estimate the matter density field over the survey domain. The linear relation between mass overdensity and peculiar velocity is used to reconstruct the 3D velocity field.

$$v(r) \approx -\mathrm{H}r\Delta(r)\frac{\Omega_m^{0.6}}{3}$$

Comparison between real and linearized velocities of voids in the simulation.



Polar diagram of the probability density as a function of the angle and the relative difference between the full and linearized velocities of voids.

Ceccarelli, Ruiz, Lares, Paz, Maldonado, Luparello, Lambas. 2016, MNRAS, 461,4013.

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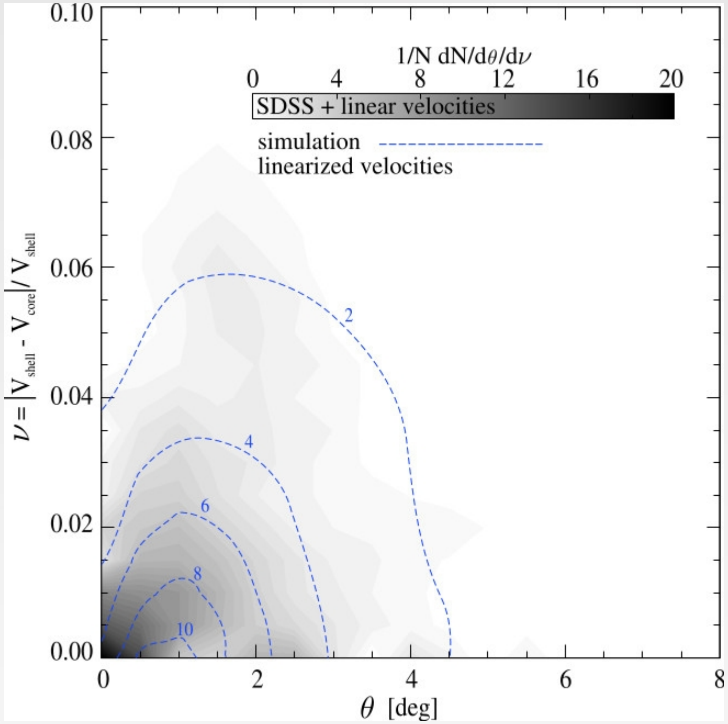
Bulk velocities of void shells and cores in SDSS



Probability density as a function of the angle between the core and shell velocities and the relative difference between both velocities obtained from the SDSS+linearized velocity field. The dashed lines corresponds to the same quantities computed through the linearized velocities of the simulation.

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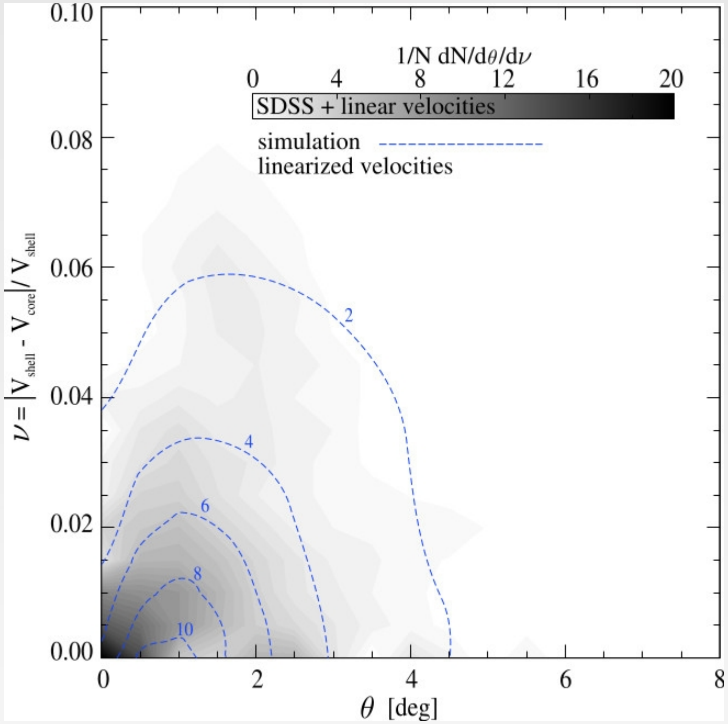


Probability density as a function of the angle between the core and shell velocities and the relative difference between both velocities obtained from the SDSS+linearized velocity field. The dashed lines corresponds to the same quantities computed through the linearized velocities of the simulation.

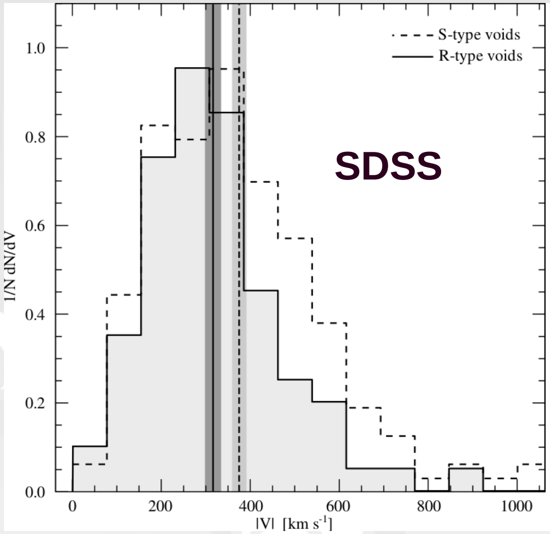
shell bulk velocities trace well the void core motions

void velocities: mean bulk velocity of haloes/glxs located at void-centric distances between 0.8 and 1.2 void radius (denser shell surrounding voids).

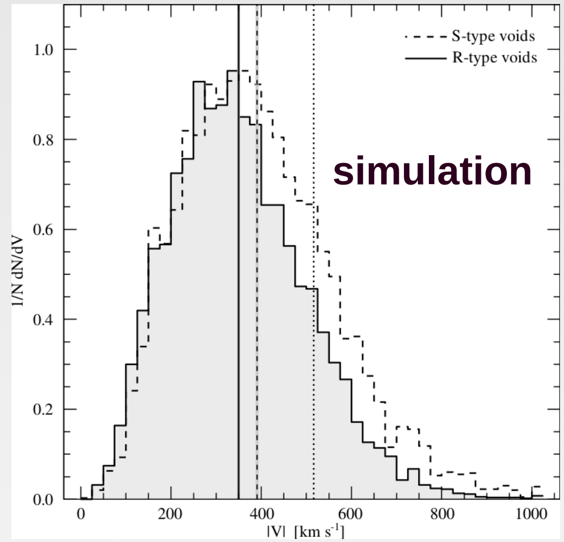
Ceccarelli, Ruiz, Lares, Paz, Maldonado, Luparello, Lambas. 2016, MNRAS, 461,4013.

Void Bulk Motions

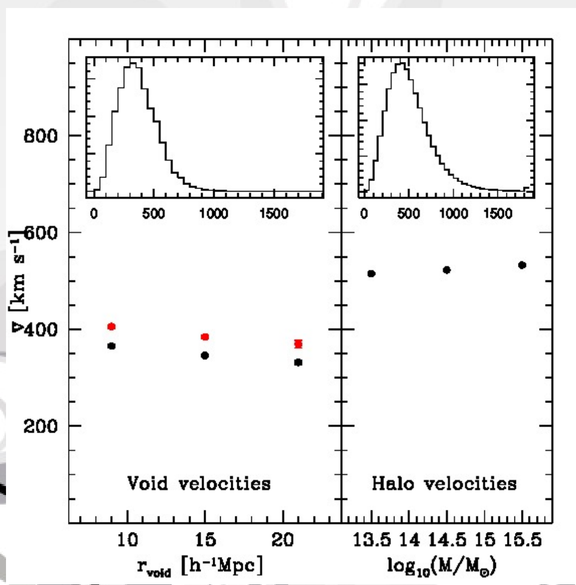
Void velocity normalized distributions in SDSS and simulations.



Solid (dashed) line represents voids in under (over) dense regions. Vertical lines and bands show the corresponding mean velocities and standard errors (~300-400 km/s).



Dotted line → mean velocity of haloes having M>10^{12} M_{sun}/h (~515 km/s).

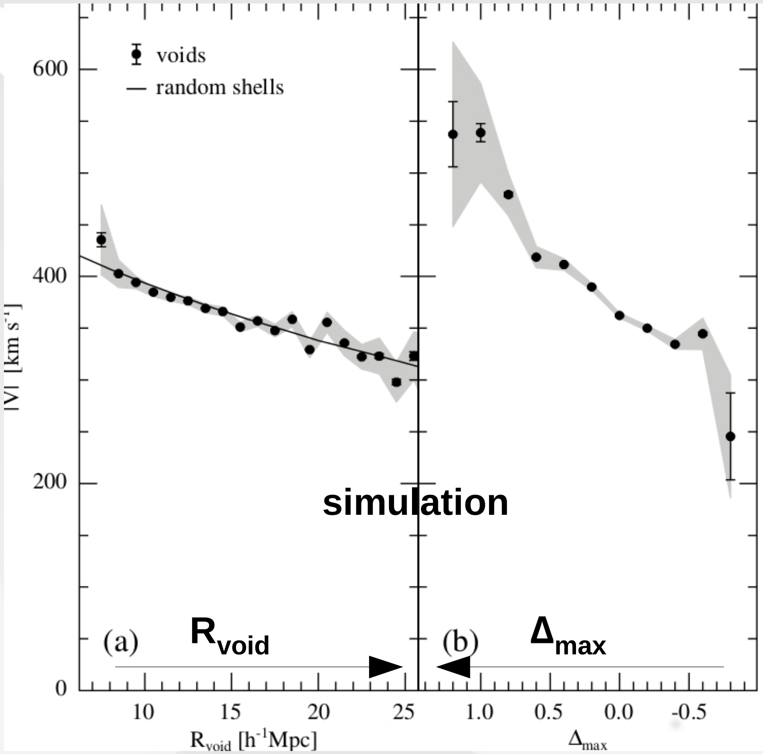


It is remarkable that mean void and halo velocities are of the same order despite their very different nature, haloes being the most compact, extremely dense objects, and voids the largest empty regions in the Universe

Ceccarelli, Ruiz, Lares, Paz, Maldonado, Luparello, Lambas. 2016, MNRAS, 461,4013.

Void Motion

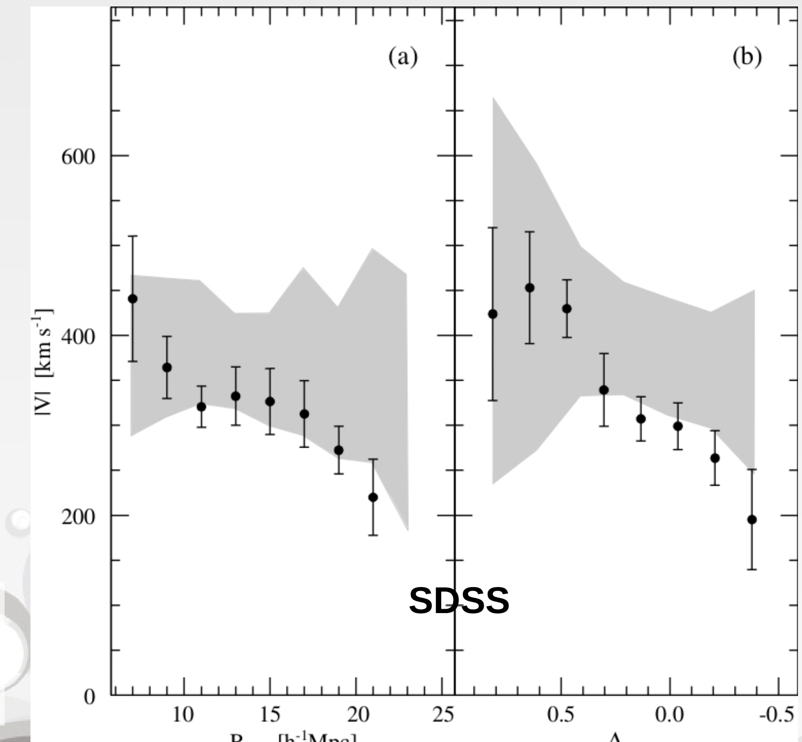
Dependence of mean velocity with size and surrounding density



Mean velocity for voids as a function of void radii (left) and Δ_max (right)

Void velocities tend to be smaller as void size increases.

Smaller voids (r_void<8 Mpc/h) exhibit velocities as larger as 400 km/s and this velocities decreases to 300 km/s for the largest voids (r_void>17 Mpc/h).



There is clear trend of void velocities to be larger as surrounding density increases.

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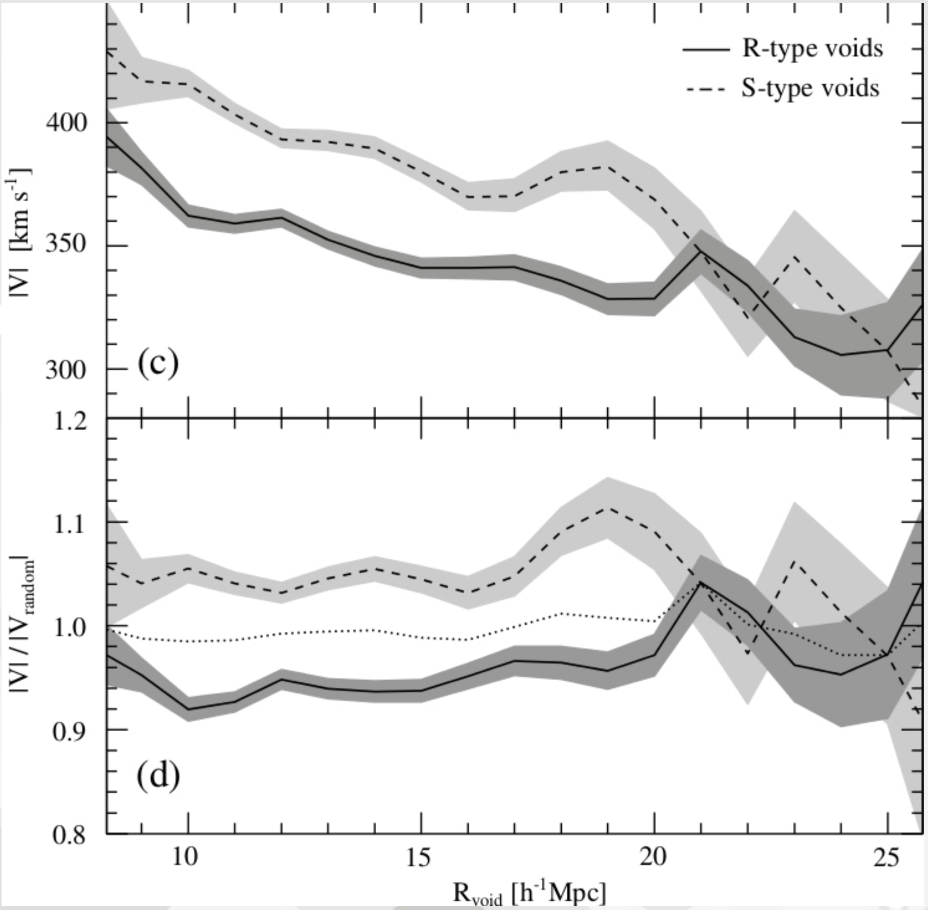


Results in simulation

Upper: Mean velocity as a function of the void radius for voids en over (dashed line) and under (solid line) dense regions in the simulation.
Lower: Ratio between the velocities of void and random spheres.

Besides the dependence of void size with the density of the region surrounding the void the magnitude of mean void velocity is related with both, void size and environment.

Ceccarelli, Ruiz, Lares, Paz, Maldonado, Luparello, Lambas. 2016, MNRAS, 461,4013.

Void Bulk Motions

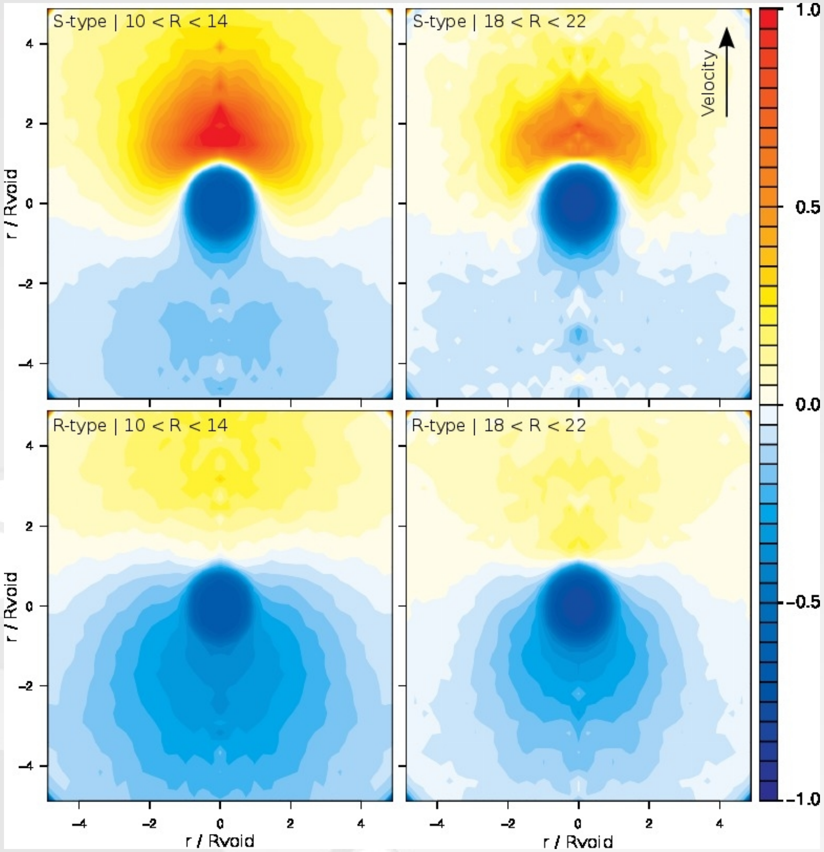
Pull & push mechanism

Voids in overdense environments

S-type voids

Voids in underdense environments

R-type voids



Density maps of stacked voids, the y-axis direction correspond to the void velocity vector. Overdensity increases from blue to red and white color correspond to the mean density.

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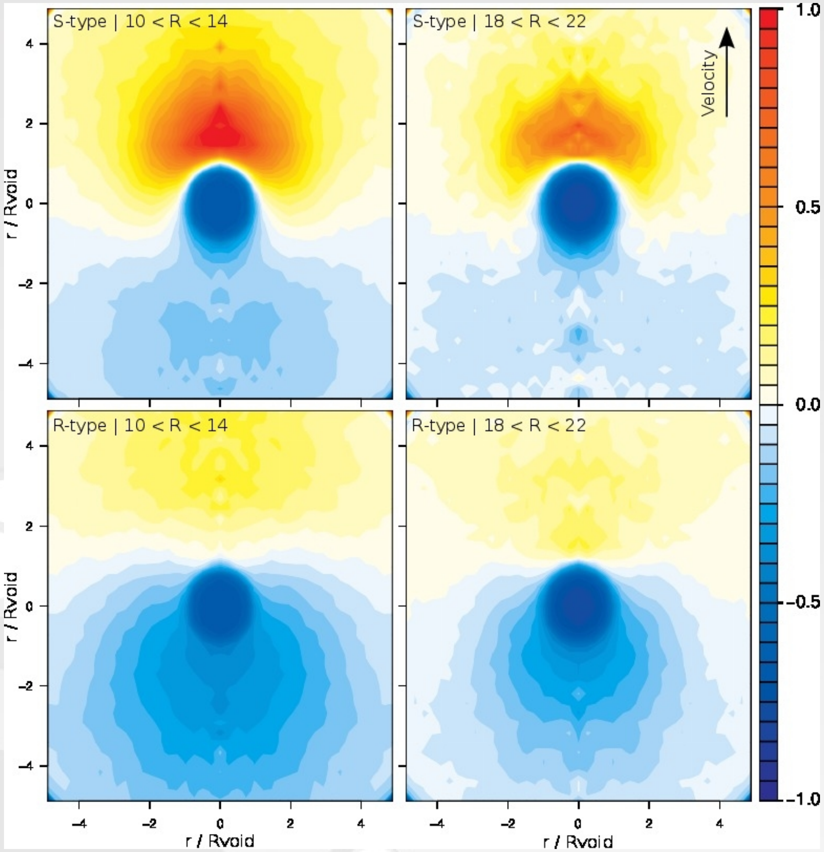

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There is a remarkable overdensity in the direction of velocity whereas in the opposite it is observed an underdensity

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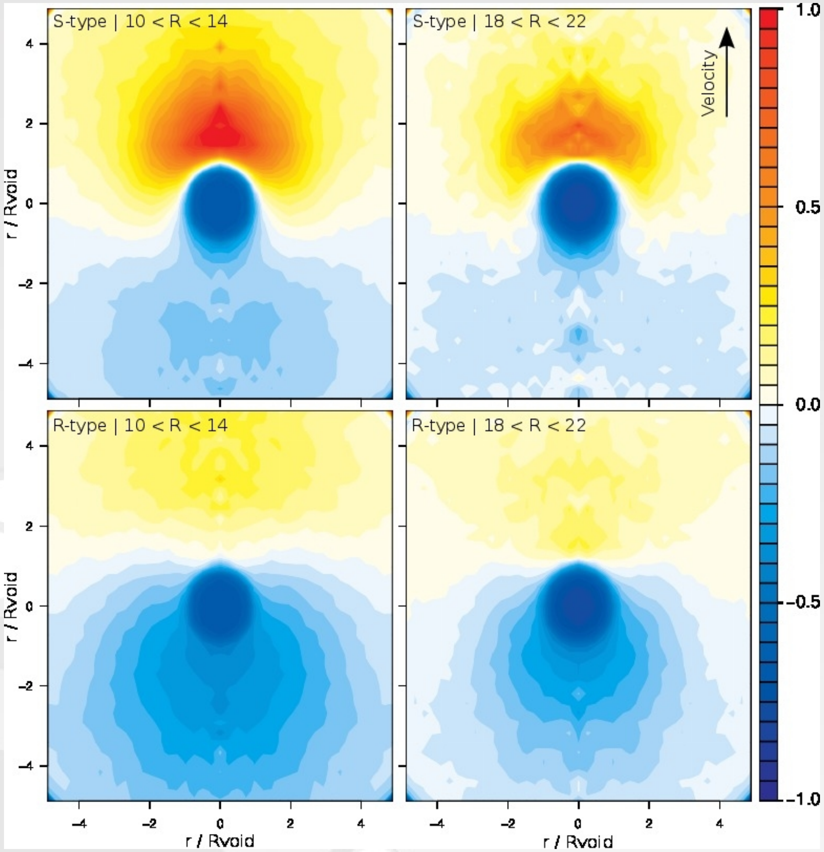

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Voids seem to be abandoning low dense regions and moving to overdensities

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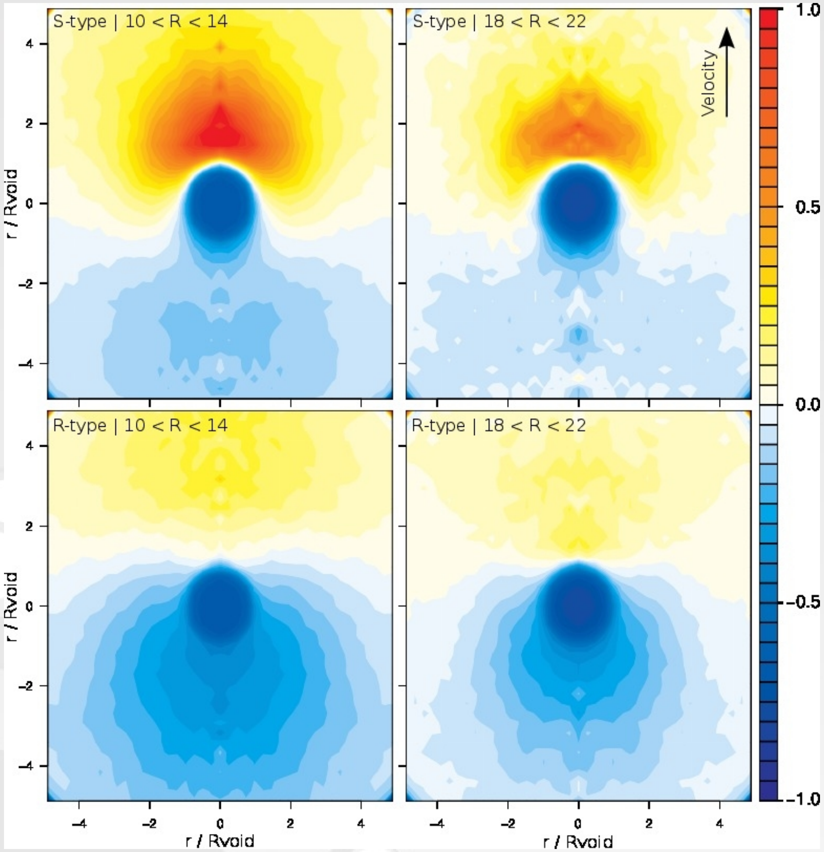

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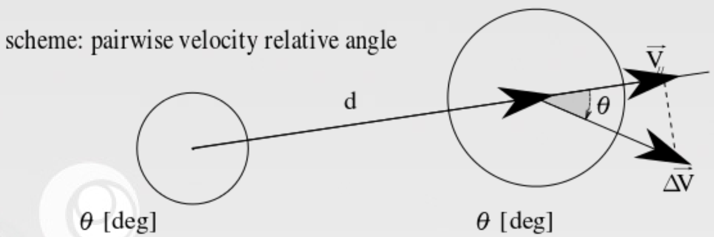
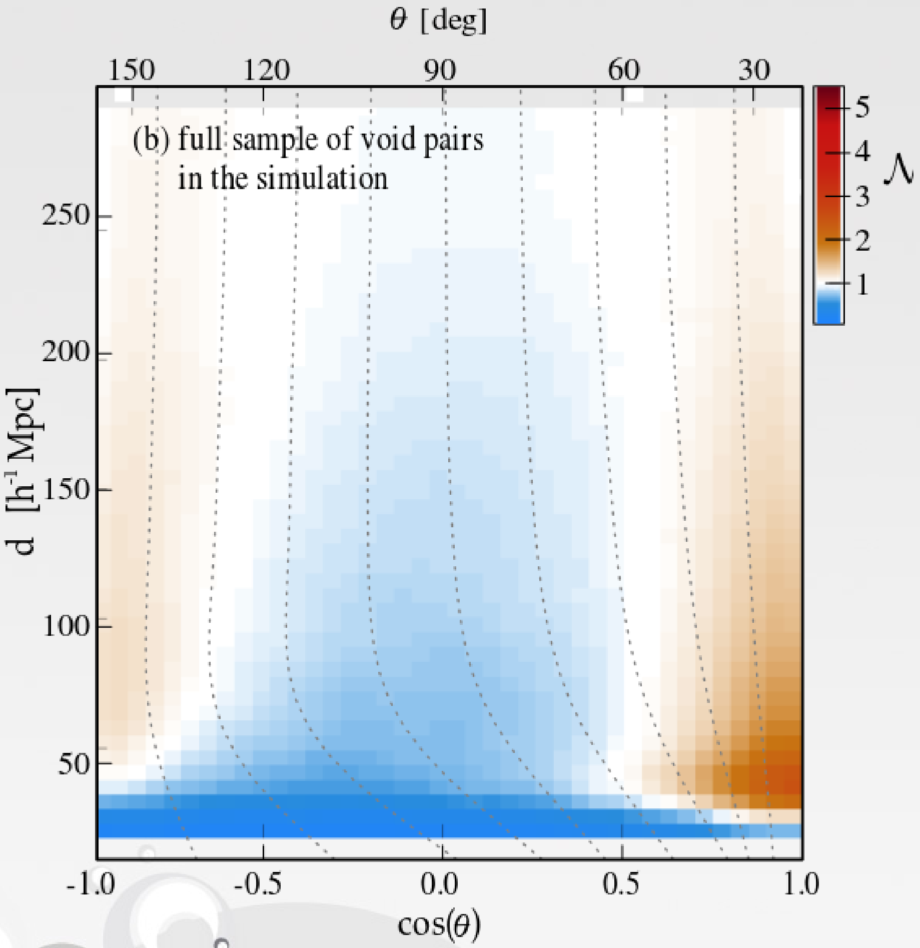
Large-scale flows can be understood as the result of the process of gravitational instability with overdense (underdense) regions attracting (repelling) material.

Ceccarelli, Ruiz, Lares, Paz, Maldonado, Luparello, Lambas. 2016, MNRAS, 461,4013.

The coherent motions of cosmic voids



θ : angle between the void relative velocity and the void relative separation vectors



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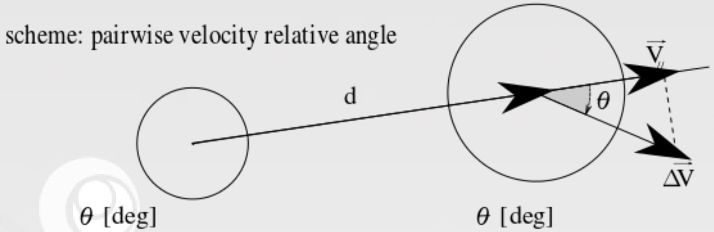
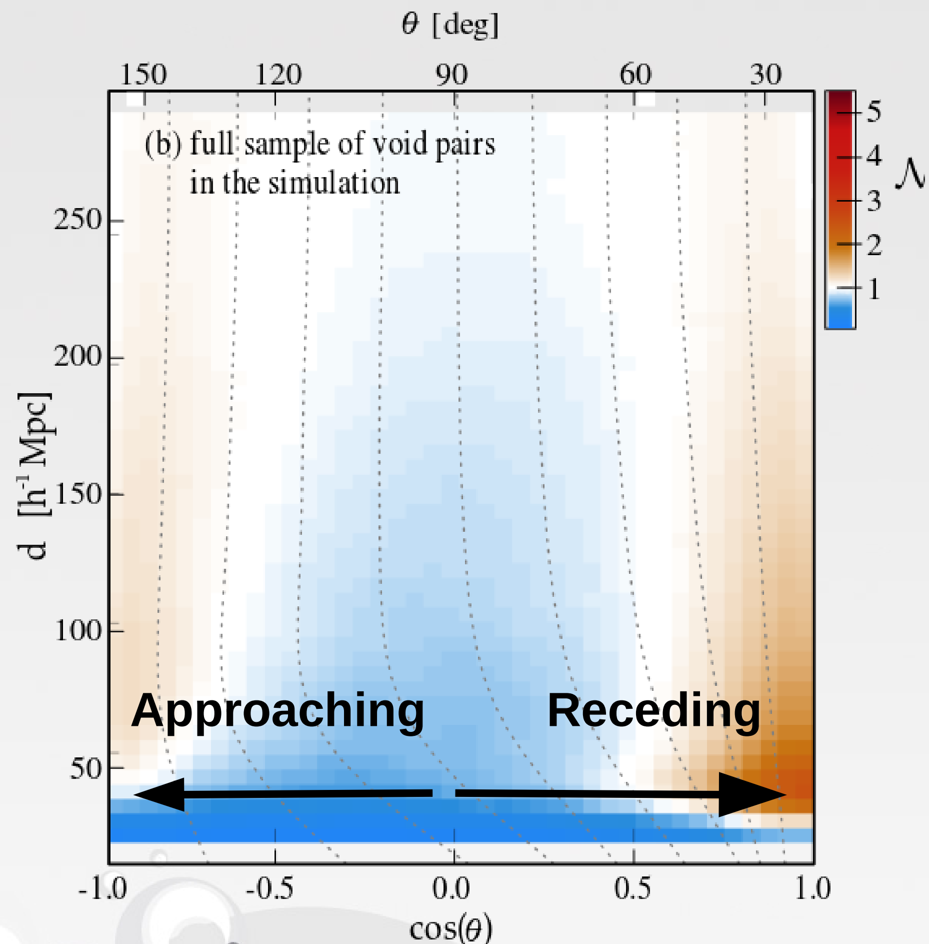


the angle between the void relative velocity and the void relative separation vectors exhibits two peaks,

showing the presence of two populations with voids mutually receding and approaching



Given the strong dichotomy of void dynamics, link to local environment?

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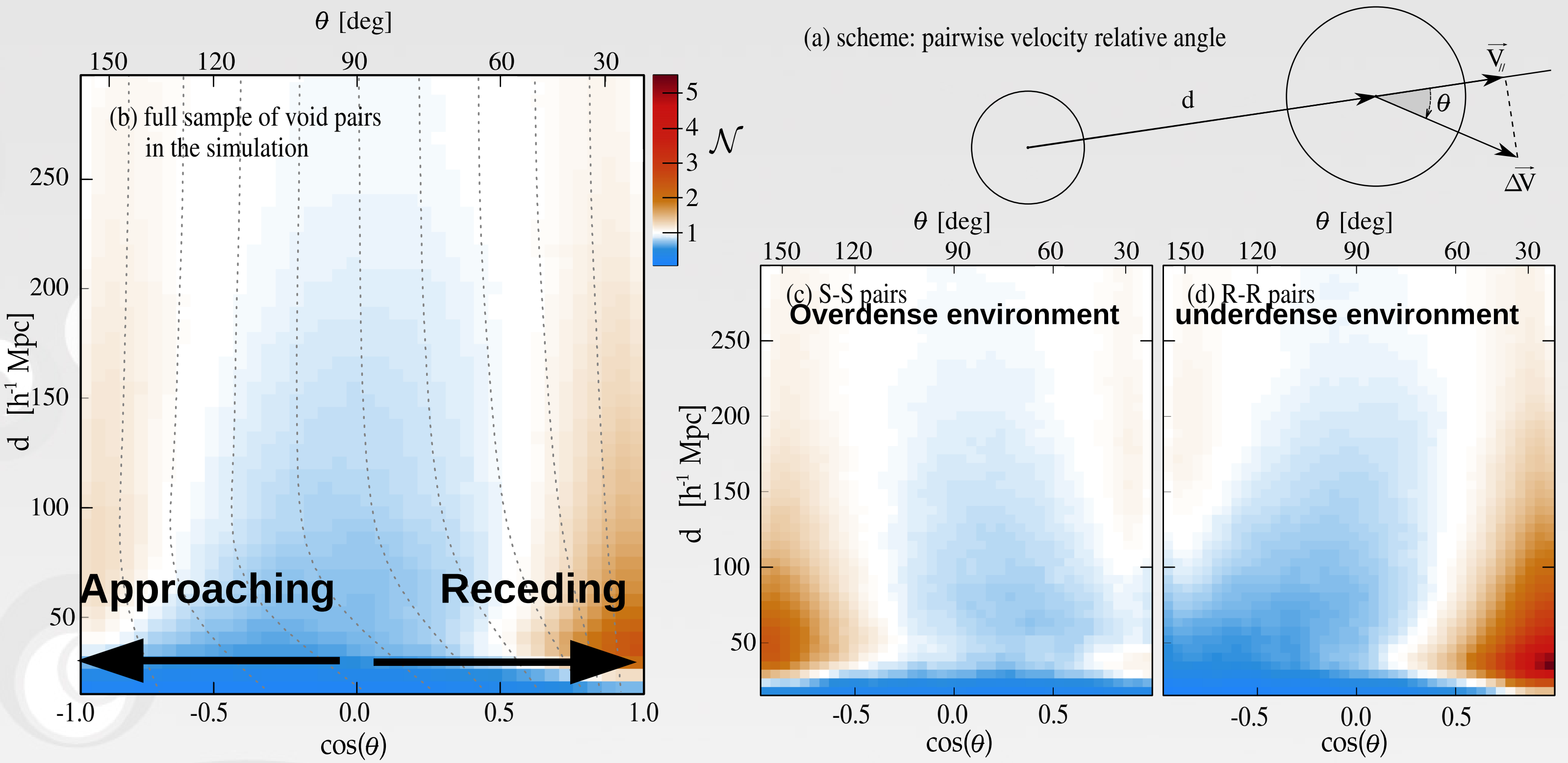
The coherent motions of cosmic voids



angle between the void relative velocity and the void relative separation for voids in under/over dense environments

populations of mutually receding/approaching voids

S-type void pairs are systematically approaching each other while R-type voids are mutually receding

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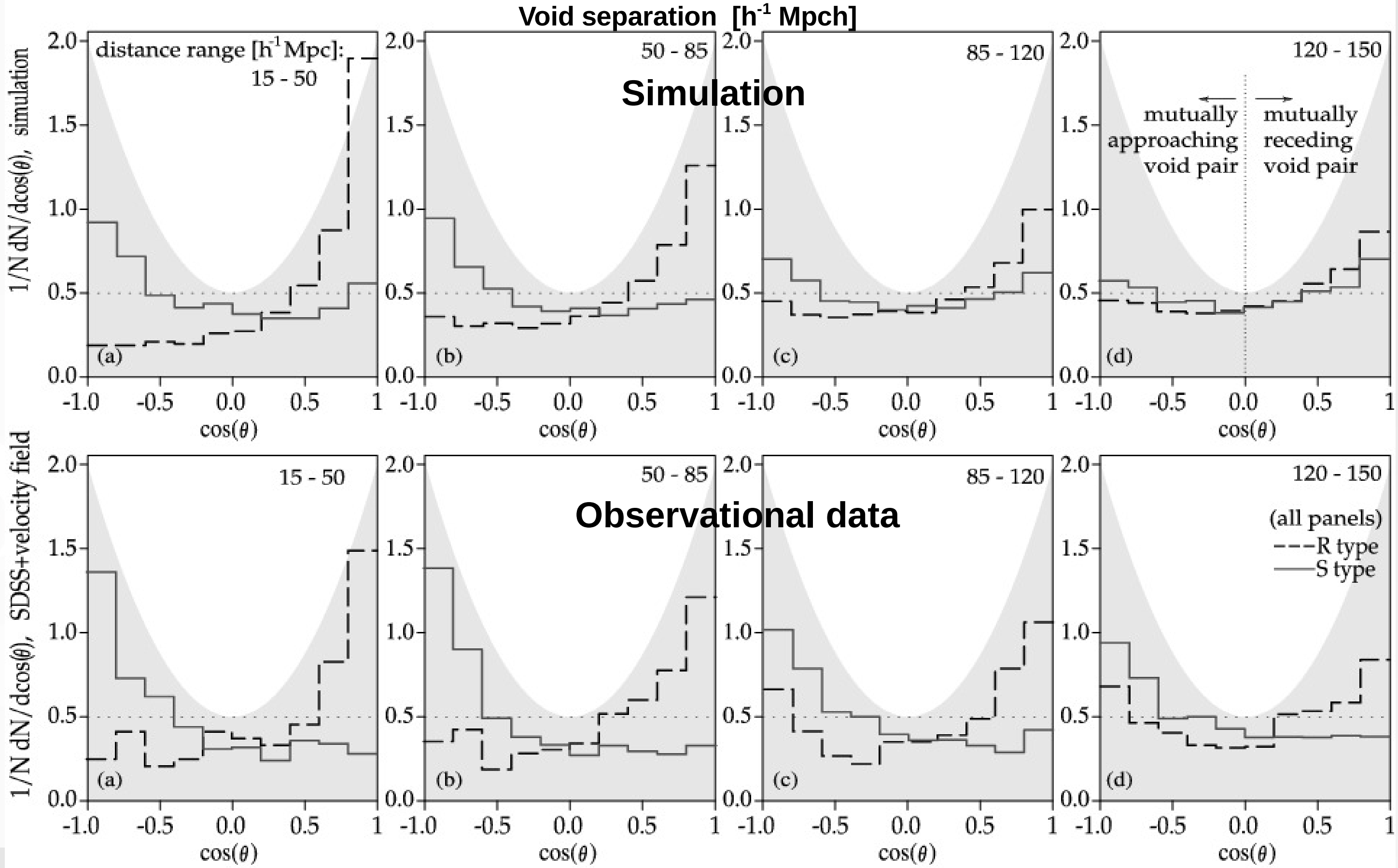
The coherent motions of cosmic voids

Bimodality of relative motions in observational data.

Histograms of cos(θ) for different void pair separations ranges in underdense (dashed) and overdense (solid) environments (R and S-types, respectively). We show for reference a quadrupolar distribution with arbitrary normalization. Histograms are normalized to show the excess of void pairs with respect to the expectation from a random distribution.

Figure 3 | Histograms of cosines of relative angles between separation vectors and pairwise relative velocities



The bimodality in observational data is consistent with the prediction of the ΛCDM model.

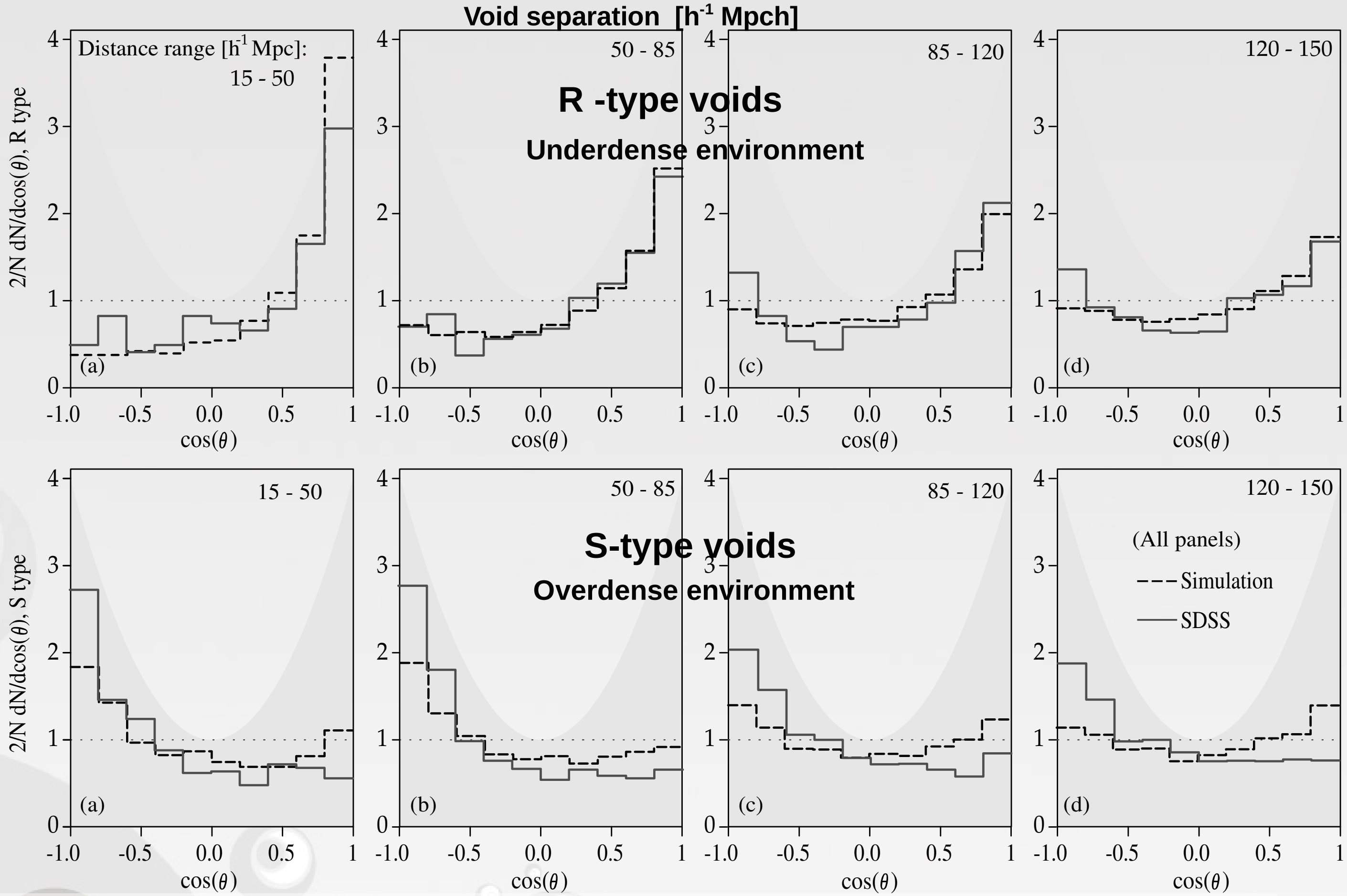
Two populations with voids mutually receding and approaching in observational data

Lambas et al. 2016

The coherent motions of cosmic voids

Bimodality of relative motions in observational data.

Histograms of cos(θ) for different void pair separations ranges in simulation box (dashed) and observational data (solid). Histograms are normalized to show the excess of void pairs with respect to the expectation from a random distribution.



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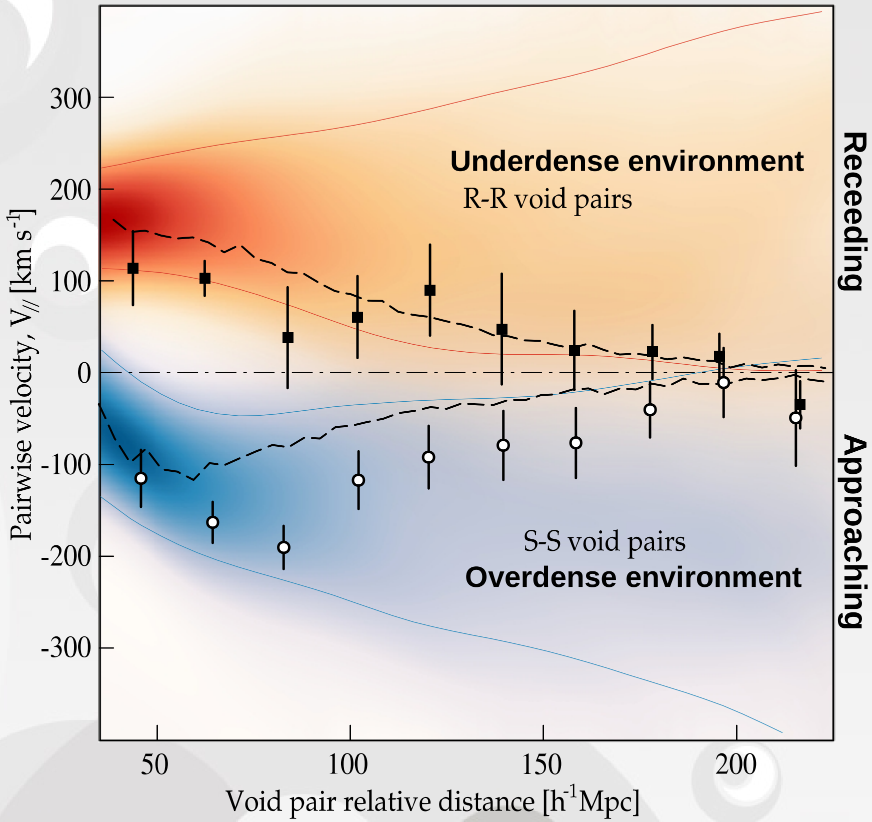

Mean pairwise velocity values of the observational and simulated voids as a function of void relative separation.

The colour density maps correspond to the results of R-R (red) and S-S (blue) void pairs in subboxes taken at simulation constrained to account cosmic variance in SDSS.

The thin blue and red lines correspond to the 0.16 and 0.84 quantiles of the distribution of V // , for S-S and R-R void pairs, respectively.

The thick dashed lines correspond to the full simulation box results for R-R and S-S pairs. Points represent SDSS results.

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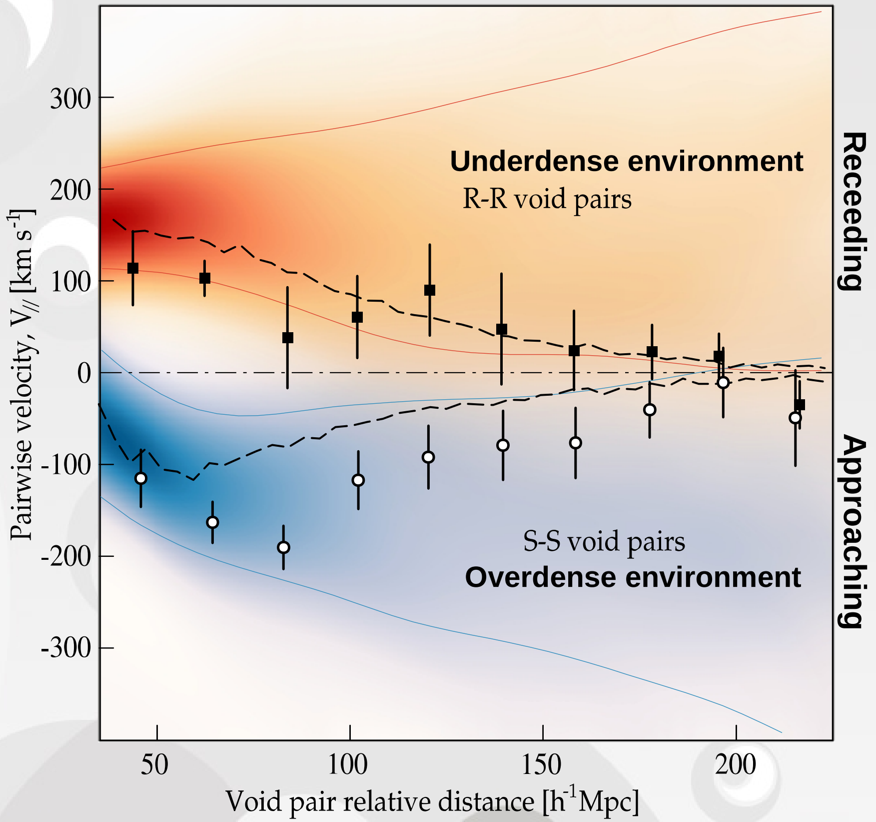
The coherent motions of cosmic voids



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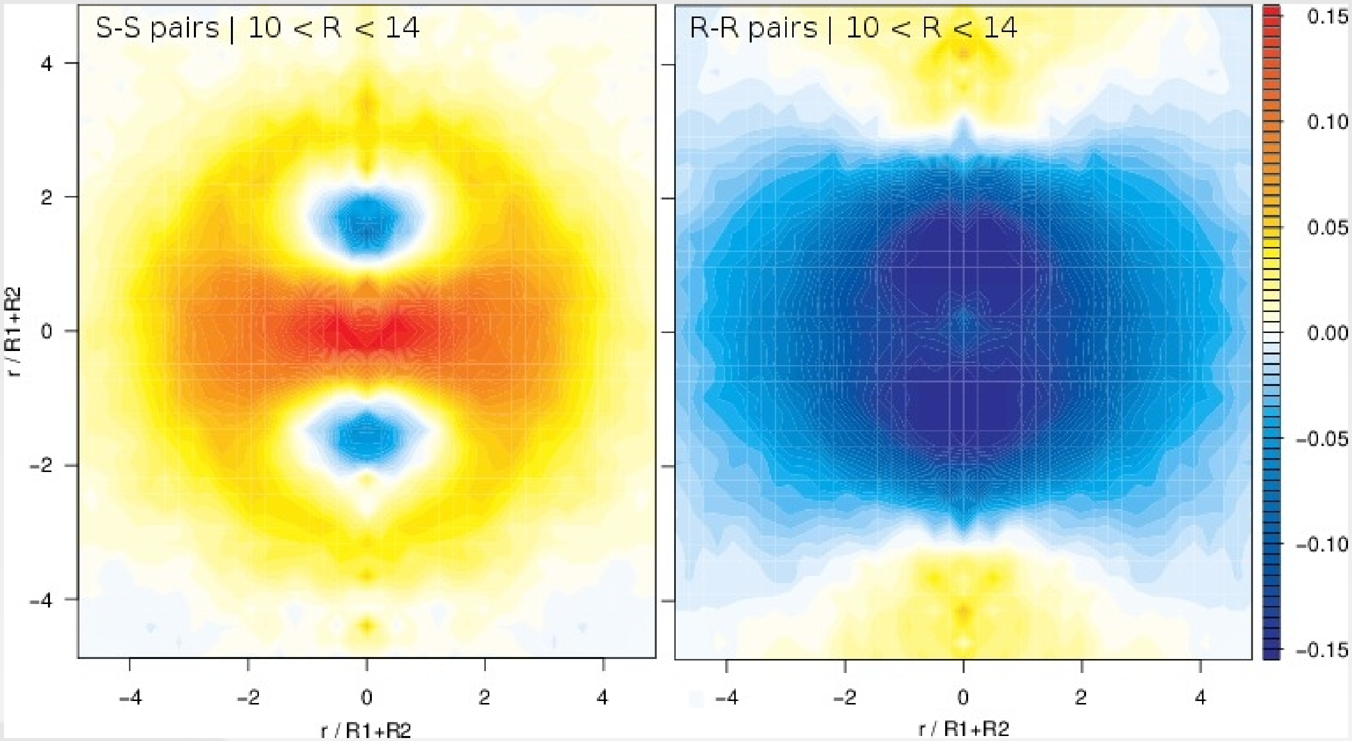
The observational results are entirely consistent with the prediction of the ΛCDM model.

Voids behave either receding or approaching each other according to their R/S-type classification with velocities of the order of 100–150 km/s up to 200 Mpc/h separation.

Lambas et al. 2016

The coherent motions of cosmic voids

Overdense Env | Underdense Env



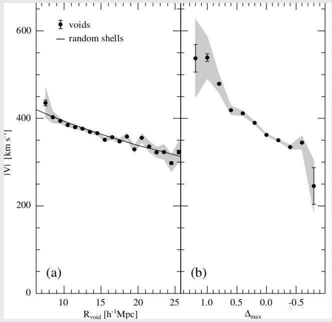
Staked mass density for S-S and R-R void pairs. The y-axis is oriented to the velocity difference direction.

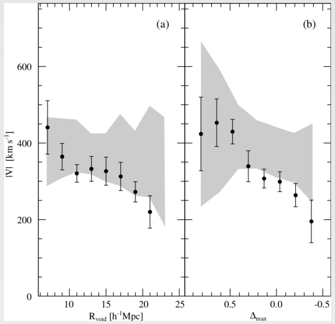
As this direction is aligned with the relative separation direction, the coherent pattern emerges

Ceccarelli, Ruiz, Lares, Paz, Maldonado, Luparello, Lambas. 2016, MNRAS, 461,4013.

Summary: results on void dynamics

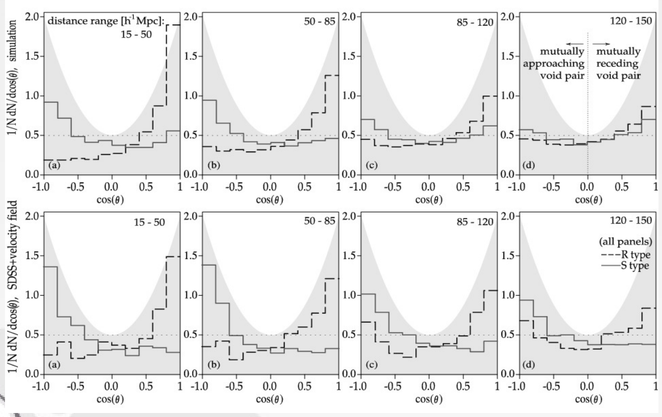
➔**We reported by first time on the significant motions of cosmic voids as a whole and studied the coherence pattern associated to the void velocity field up to large cosmological scales, both in simulations and observations** (Lambas et al. 2016, Ceccarelli et al. 2016).





➔**We reported the bimodality on void pairwise velocities in simulations and observations, with approching and receding voids according to their local environment** (Lambas et al. 2016).

Figure 3 | Histograms of cosines of relative angles between separation vectors and pairwise relative velocities



Summary: Final remarks

Voids have an active interplay with large--scale flows affecting the formation and evolution of structures in the Universe.

These large-scale underdensities exhibit local expansion which, depending on the large-scale environment, can be reverted to collapse at larger scales, generating global convergent or divergent flows.

Void coherent bulk velocities, with a bimodal dynamical population of mutually attracting or receding systems, contribute to imprint large scale cosmic flows, shaping the formation of future structures in the Universe.

The non-negligible void velocity suggest a scenario of galaxies flowing away from voids with the aditional contribution of void bulk motion to the total galaxy velocity