Detecting cosmic voids via maps of geometric-optics parameters

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Overview

1. aim: detect cosmic voids via spacetime curvature instead of by stellar luminosity

   – galaxy image distortion maps = effect of curvature ⇒ blind detection of voids

   – Rubin–LSST: excellent photometric survey

2. method – heuristic algorithm proposed

3. results

   – Peper, Roukema & Bolejko 2023 (MNRAS, ArXiv:2304.00591)

1.1 Physics: GR

SDSS J1138+2754

1.2 Sky plane

- weak lensing formalism – simplified model of curvature effect on distant galaxies

  surface overdensity Σ

  mean tangential shear $\overline{\gamma_\perp}$

- geometric optics – model – closer to first principles

  Sachs expansion θ

  Sachs shear modulus $|\sigma|$

2.1 Reproducibility

- in principle, full simulation + results + final pdf reproducible from 740 kB source package `lensing-ddbb4ac-snapshot.tar.gz` (md5sum `66e4a9bbb0320393ee35f4a69cb84a15`)
- `https://zenodo.org/record/8103985`

2.2 Ab initio simulation pipeline

- 1993/1997 hybrid method (updated)
- initial conditions – MPGRAFIC
- DM N-body simulation – RAMSES
- DM halo detection + merger history trees – ROCKSTAR + CONSISTENT-TREES

|| semi-analytical gal formation recipes – SAGE

|| void detection – REVOLVER

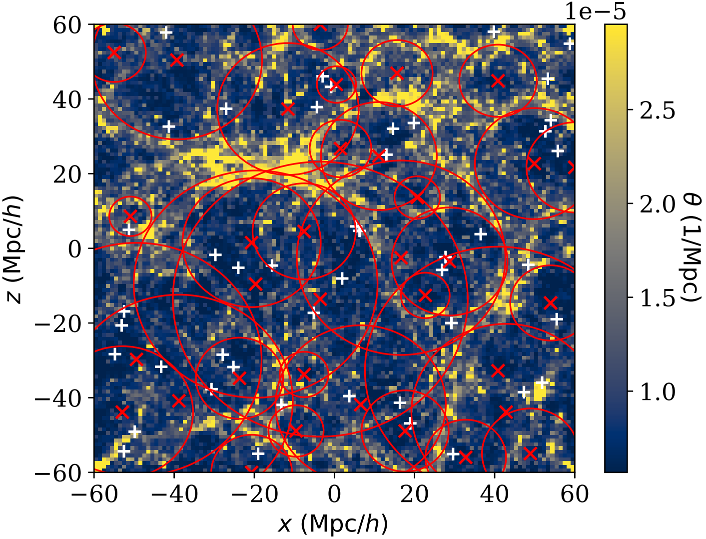
2.3 3D gal voids vs 2D curvature voids

- REVOLVER – watershed algorithm in comoving 3D space
- 2D – how?

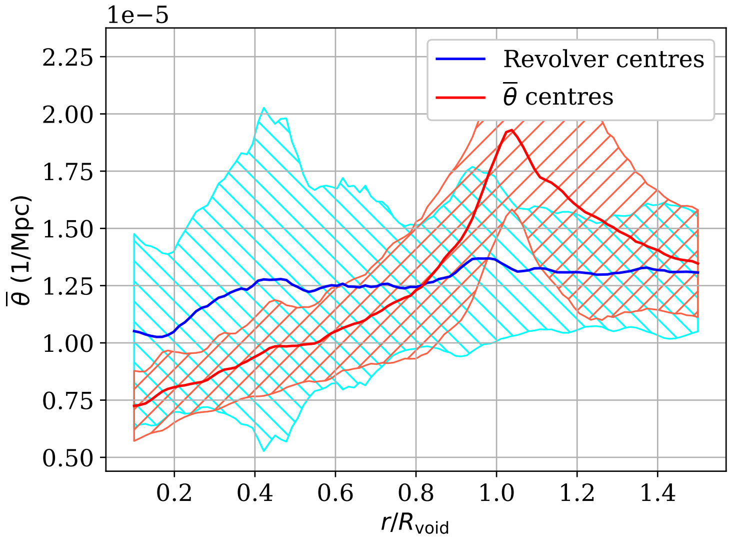
2.4 Heuristic for 2D void detection

- Σ – void-like profile
- $\overline{\gamma_\perp}$ – 0 at centre, negative (dip) at void wall and then rise
- Sachs parameters: $\theta, |\sigma|$ – qualitatively Σ-like profile
- algorithms derived by bio-neural semantic iteration

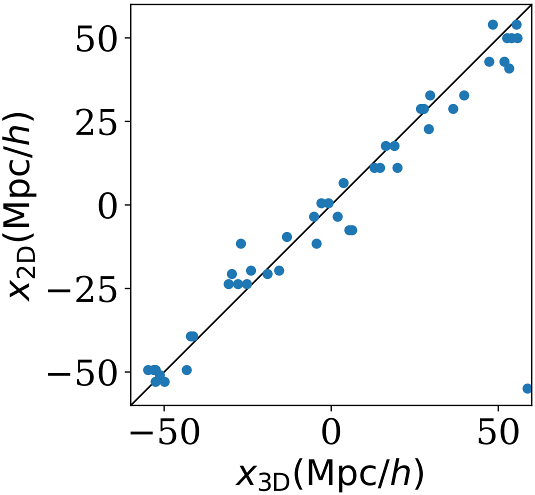
3.1 Sachs expansion θ: image



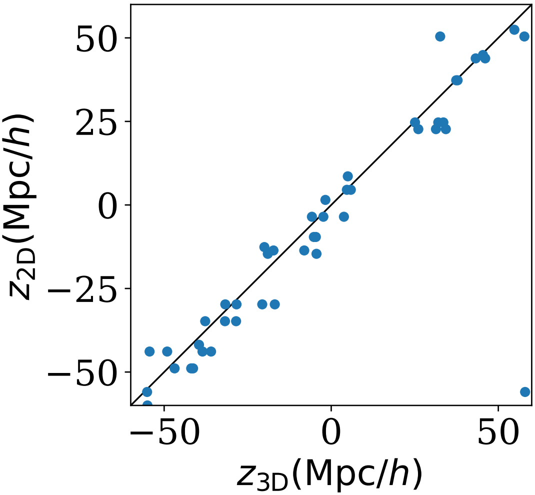
3.1 Sachs expansion θ: profiles



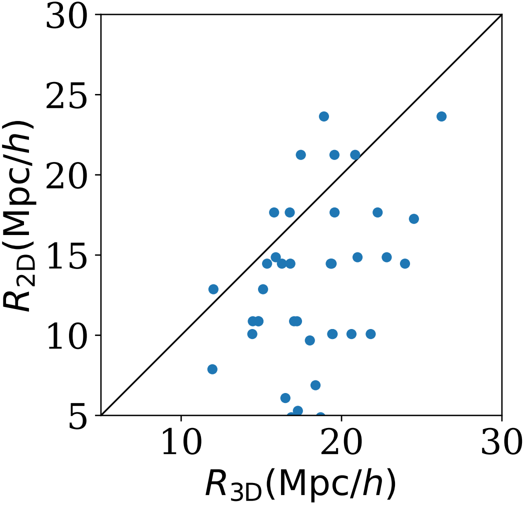
3.1 Sachs expansion θ: matches X



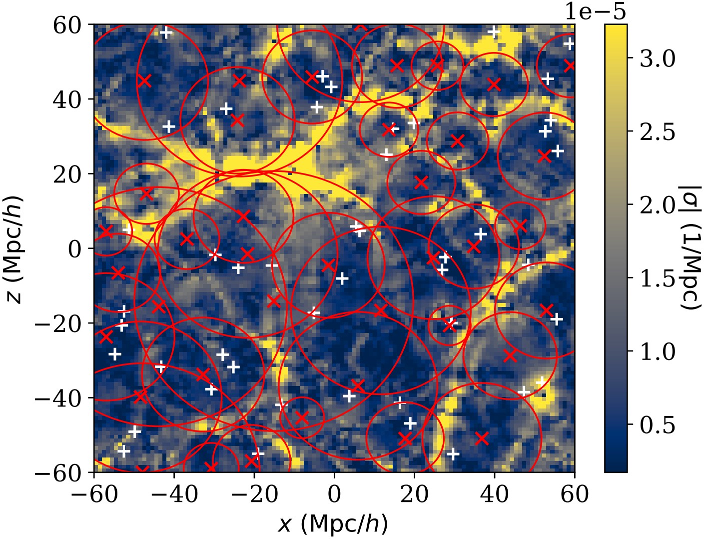
3.1 Sachs expansion θ: matches Z



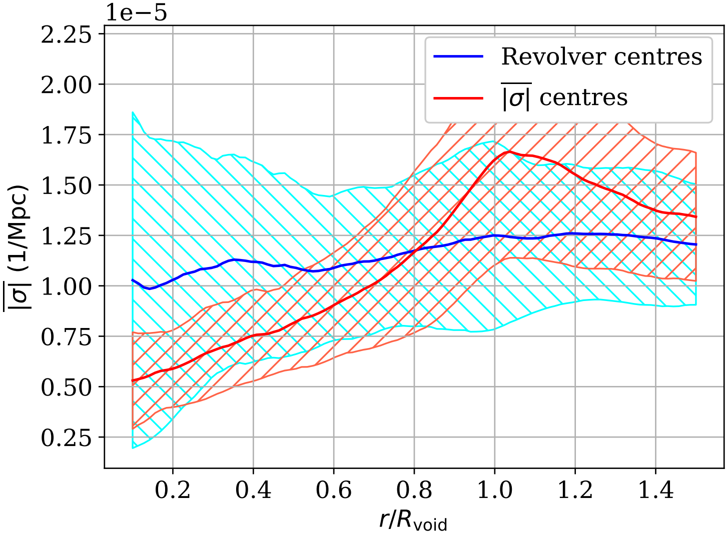
3.1 Sachs expansion θ: matches R



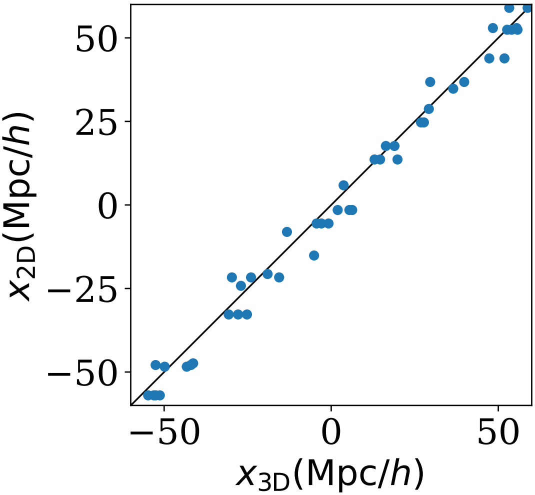
3.2 Sachs shear modulus $|\sigma|$: image



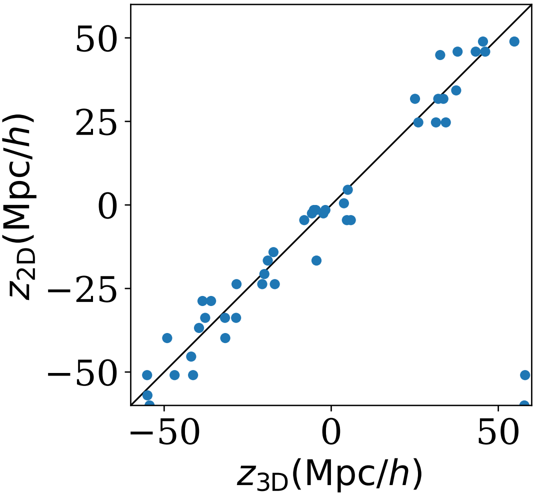
3.2 Sachs shear modulus $|\sigma|$: profiles



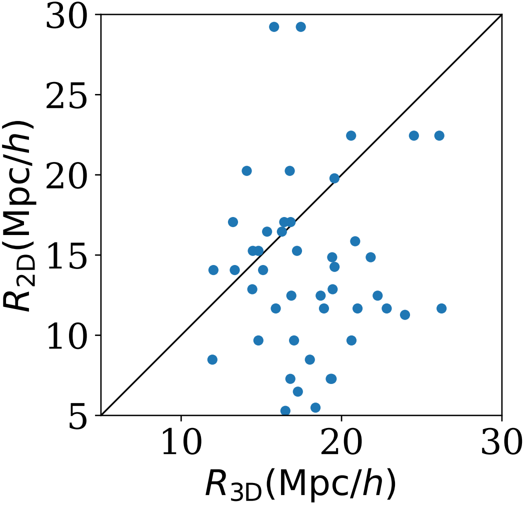
3.2 Sachs shear modulus $|\sigma|$: matches X



3.2 Sachs shear modulus $|\sigma|$: matches Z



3.2 Sachs shear modulus $|\sigma|$: matches R



3.3 Numbers of detections

Table: Numbers of intrinsic 3D voids detected with REVOLVER, N_{3D}, and in the 2D grid, N_{2D}^{Σ}, N_{2D}^{γ}, N_{2D}^{θ}, and N_{2D}^{σ}, using the surface overdensity Σ, the weak-lensing shear $\overline{\gamma_{\perp}}$, the Sachs expansion θ, and the modulus of the Sachs shear $|\sigma|$, respectively.

N_{3D}	N_{2D}^{Σ}	N_{2D}^{γ}	N_{2D}^{θ}	N_{2D}^{σ}
46	28	29	34	39

3.4 Significant detections?

Table: Probability that the matches between 3D and 2D voids are no better than for random 2D voids, $P^X_{xz}(3D|2D)$ when given 2D voids; or $P^X_{xz}(2D|3D)$ when given 3D voids; and probability that the Spearman rank correlation coefficient for the radii of matched 3D and 2D voids could be that for randomly paired values, $P^X_R(3D|2D)$ when given a 2D void; and $P^X_R(2D|3D)$ when given a 3D void.

X	$P_{x,z}(3D\|2D)$	$P_{x,z}(2D\|3D)$	$P_R(3D\|2D)$	$P_R(2D\|3D)$
Σ	0.027	0.0038	0.89	0.94
$\overline{\gamma_\perp}$	0.010	3.0×10^{-5}	0.85	1.0
θ	0.00050	3.0×10^{-5}	0.25	0.16
$\|\sigma\|$	0.00014	1.0×10^{-5}	0.27	0.61

Conclusion

- voids in principle detectable by lensing distortion maps
- best by Sachs θ and $|\sigma|$
- confusion: near-concentric-in-sky-plane voids
- photometric survey should give falsifiable predictions of 3D voids

– Peper, Roukema & Bolejko 2023 (MNRAS, ArXiv:2304.00591)