Void spin distribution as a powerful probe of cosmological parameters.

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arxiv 2501.09476

Cosmology 2025
@ Elba Island

서울대학교 물리·천문학부
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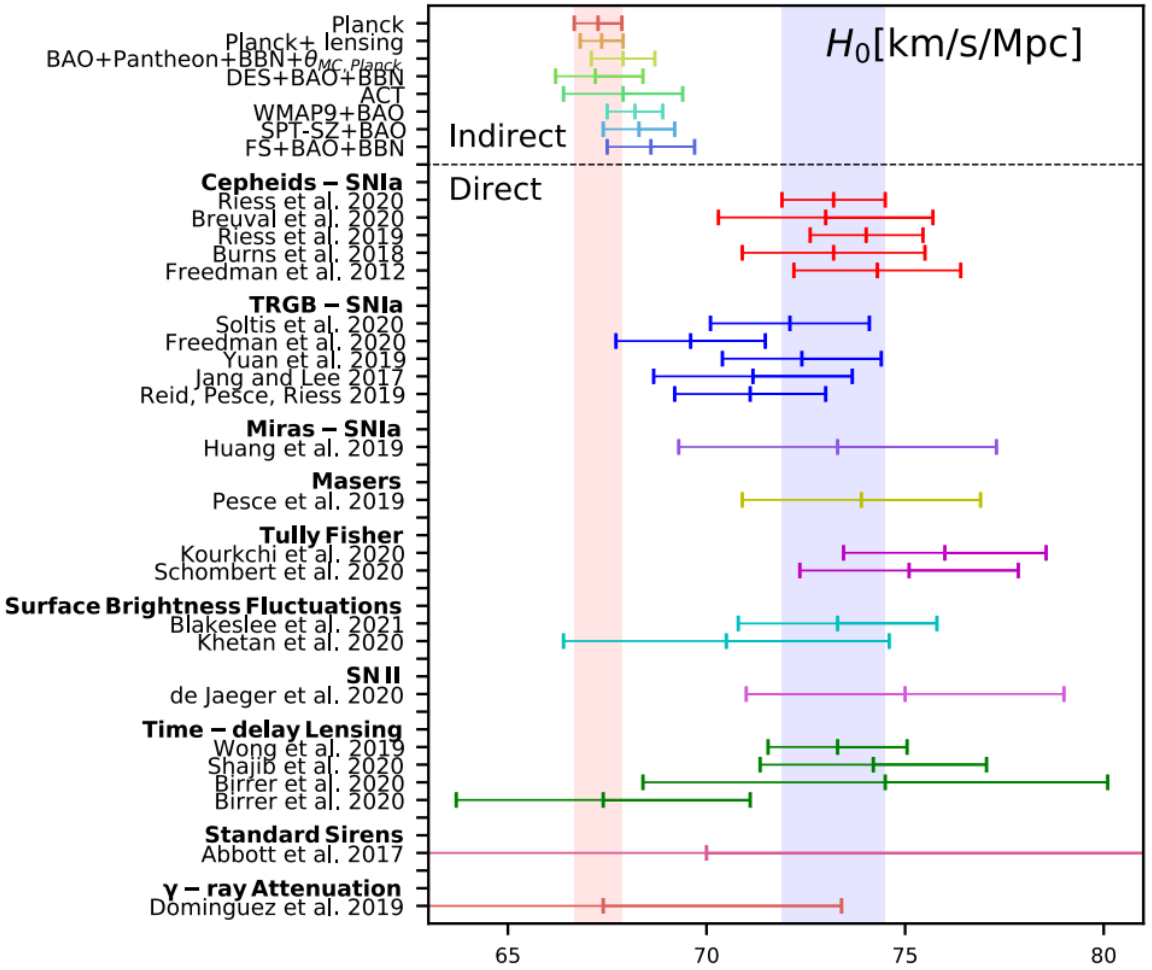
ΛCDM in crisis?

- $\boldsymbol{H_0}$ **tension**

Late Universe probes give
5 σ higher then Early type probe

- S_8 tension

- DESI result



Credit: Di Valentino (2021)

ΛCDM in crisis?

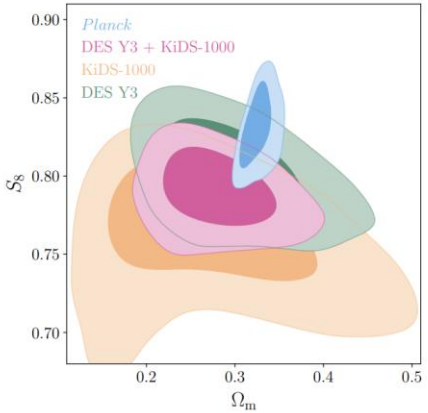
- H_0 tension

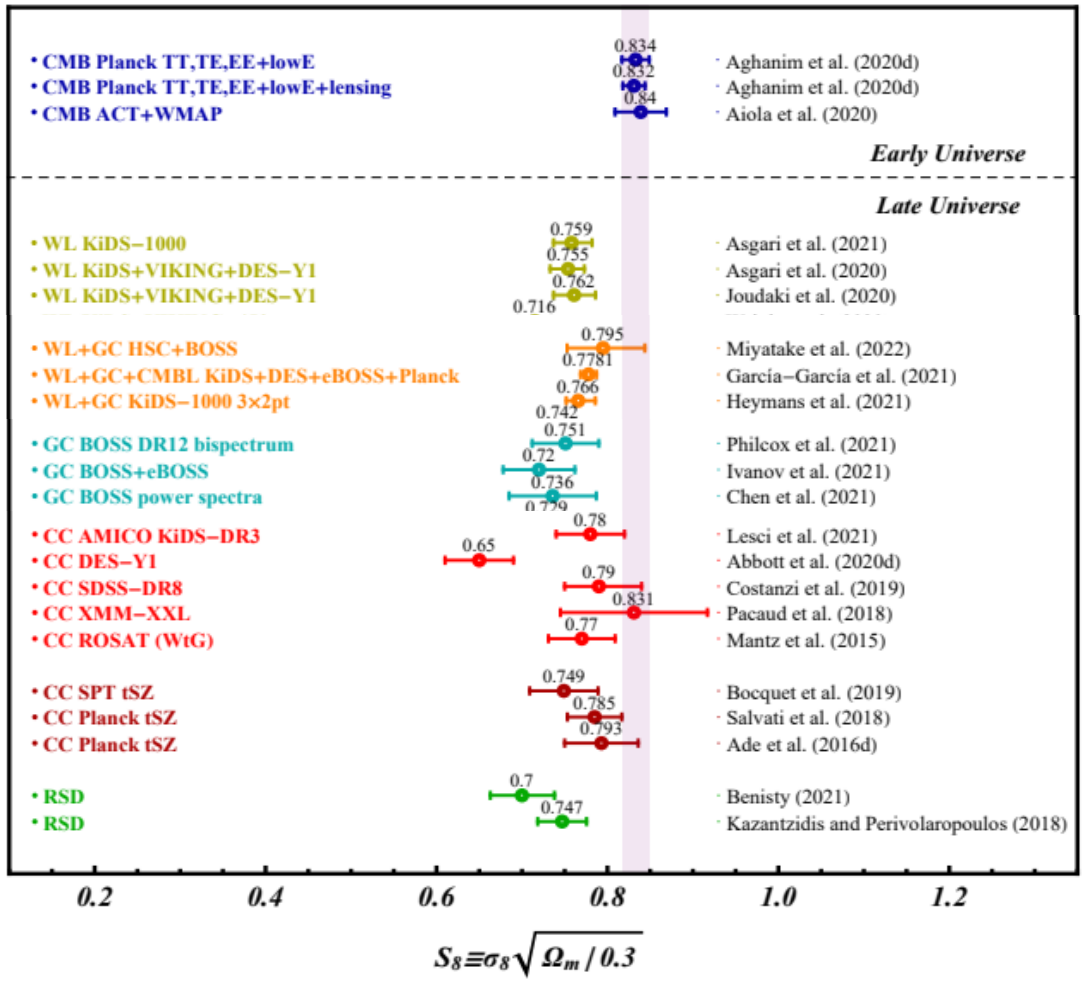
- **S_8 tension**

DESY3+KiDs gives

3 σ lower value then Planck

- DESI result





Credit: DES and KiDs Collaboration(2023), E. Abdalla et al. (2022)

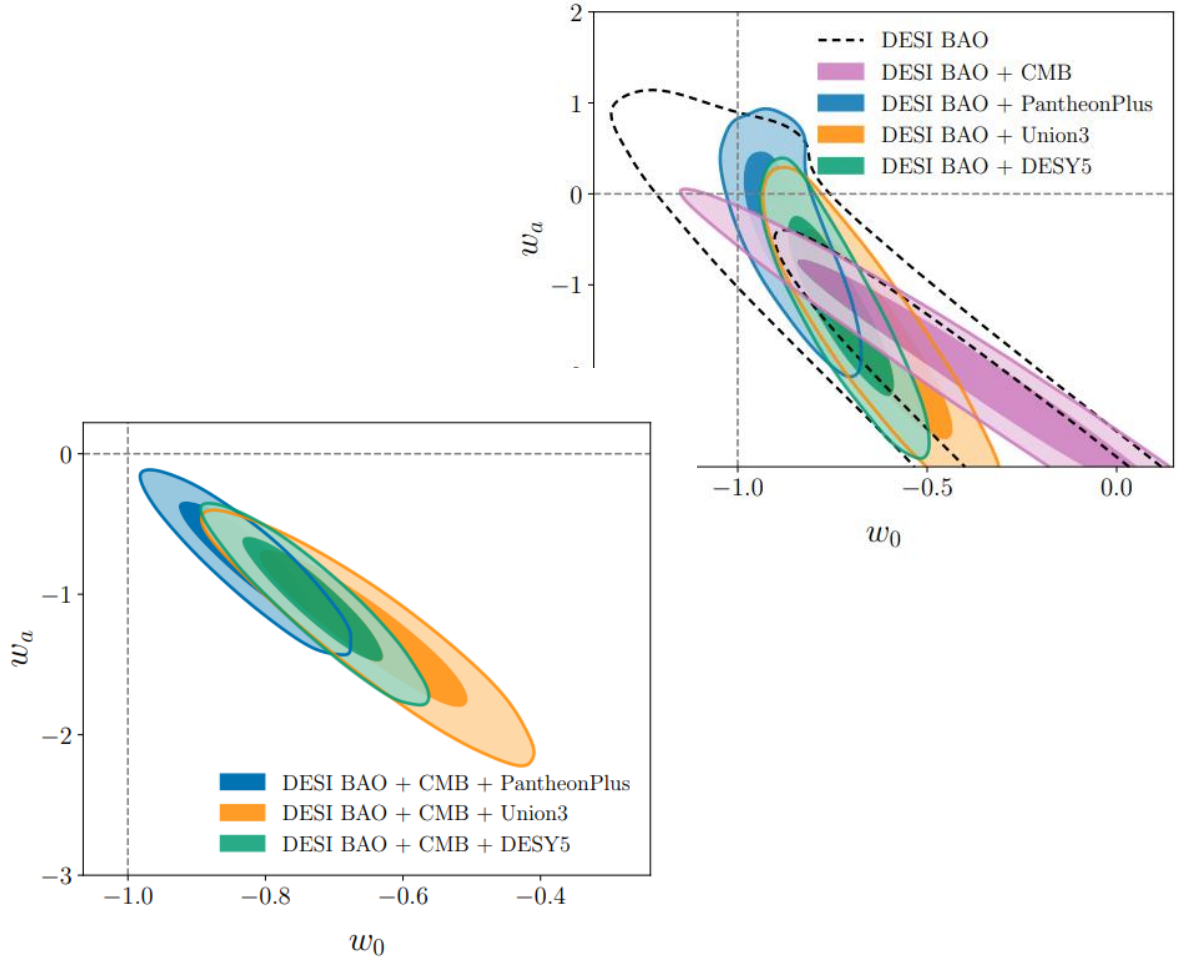
ΛCDM in crisis?

- H_0 tension
- S_8 tension
- **DESI result**

Dynamic dark energy $\boldsymbol{w(z)}$

+unresolved

Cosmological degeneracy



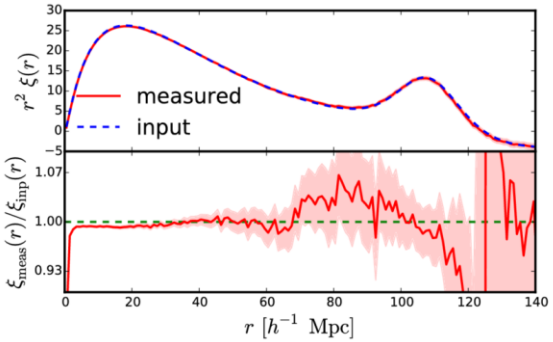
Credit: DESI collaboration. (2024)

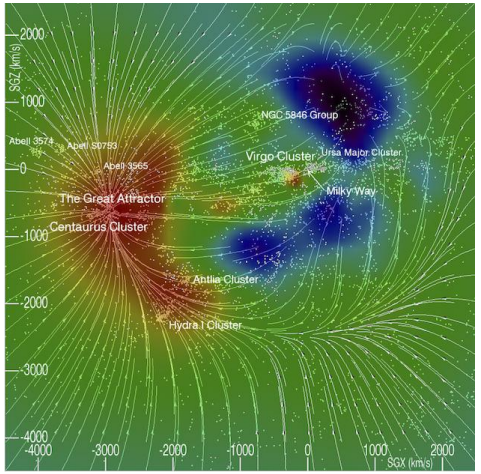
Need of new cosmological probe

Overdense region

With **position** and **velocity**

2pcf power spectrum

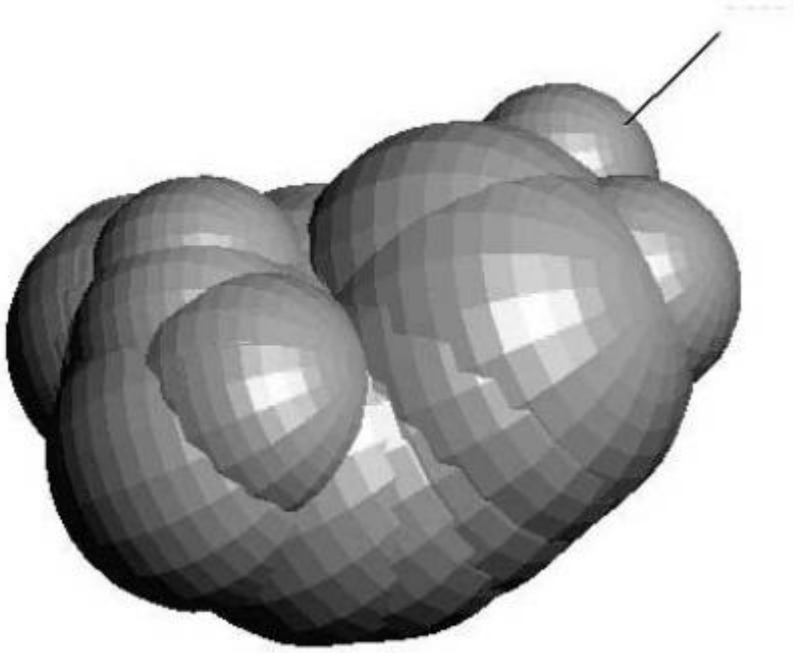




Velocity Field

Credit: Agrawal(2017), Courtois et al. (2013)

Credit: Lee & Park (2006)



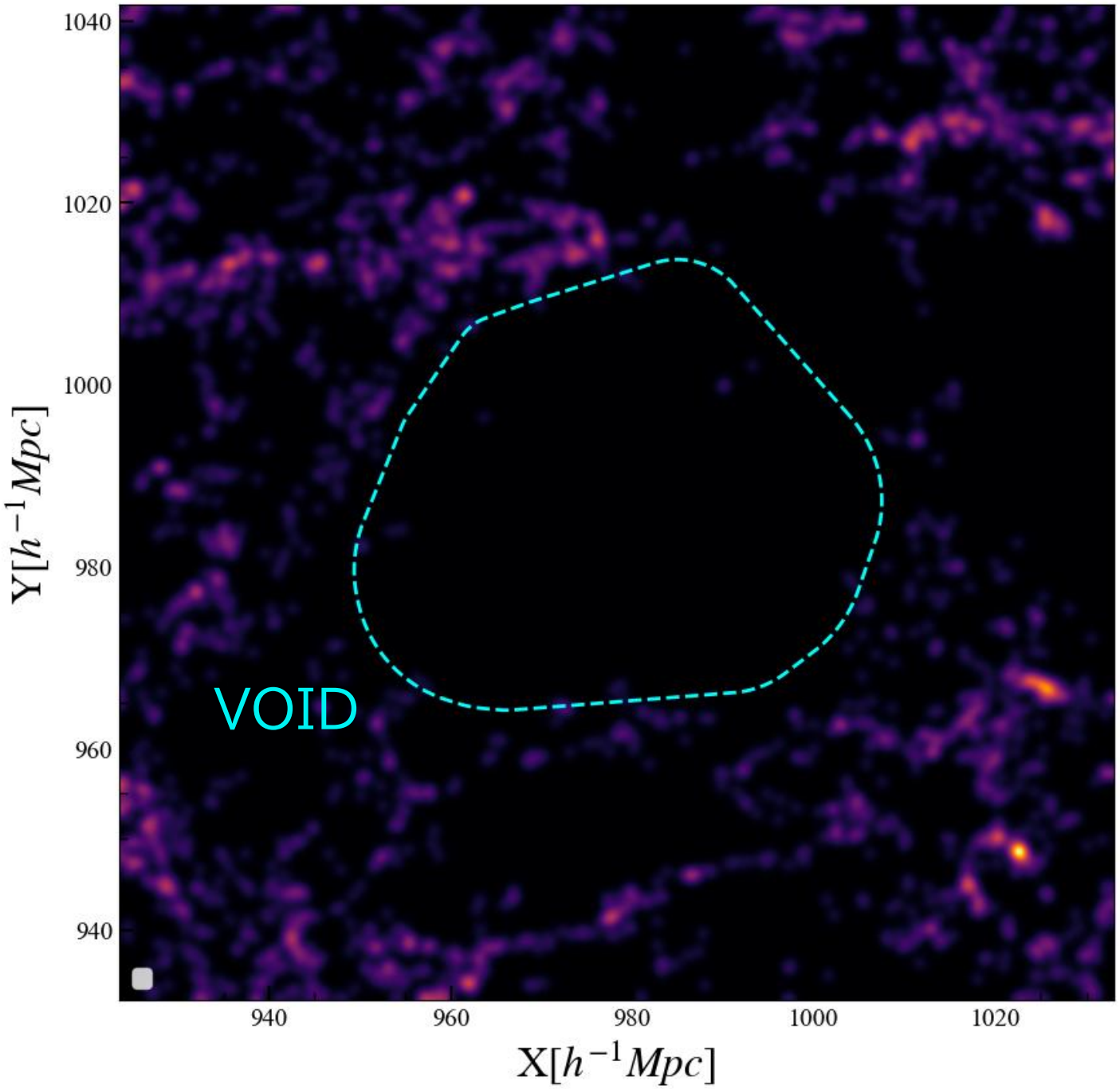
With **angular momentum**

Underdense region

Voids?

Largest, extremely underdense regions surrounded by filaments and sheets,

Ideal for probing initial conditions and cosmological parameters.



A Void from AbacusSummit c000 By Kang

Raw data - AbacusSummit

We choose 14 cosmologies + Planck
That have maximum of

$\Omega_{cdm}h^2$ 10%

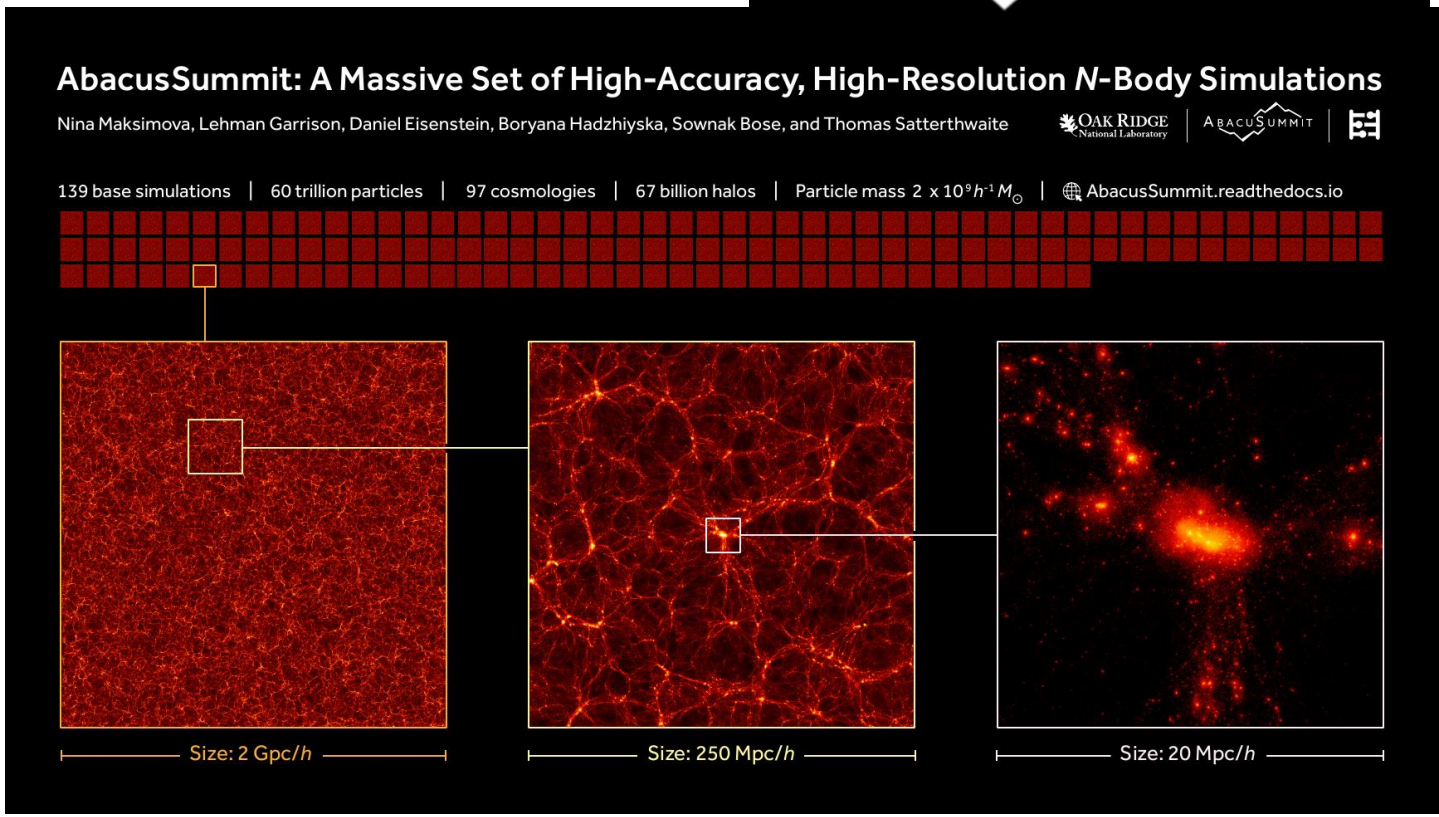
σ_8 12%

M_ν 100%

w 10%

Single parameter deviation
from Planck 2018 result

And used only $\log m_h > 11.5$ halos



Credit: The AbacusSummit Team

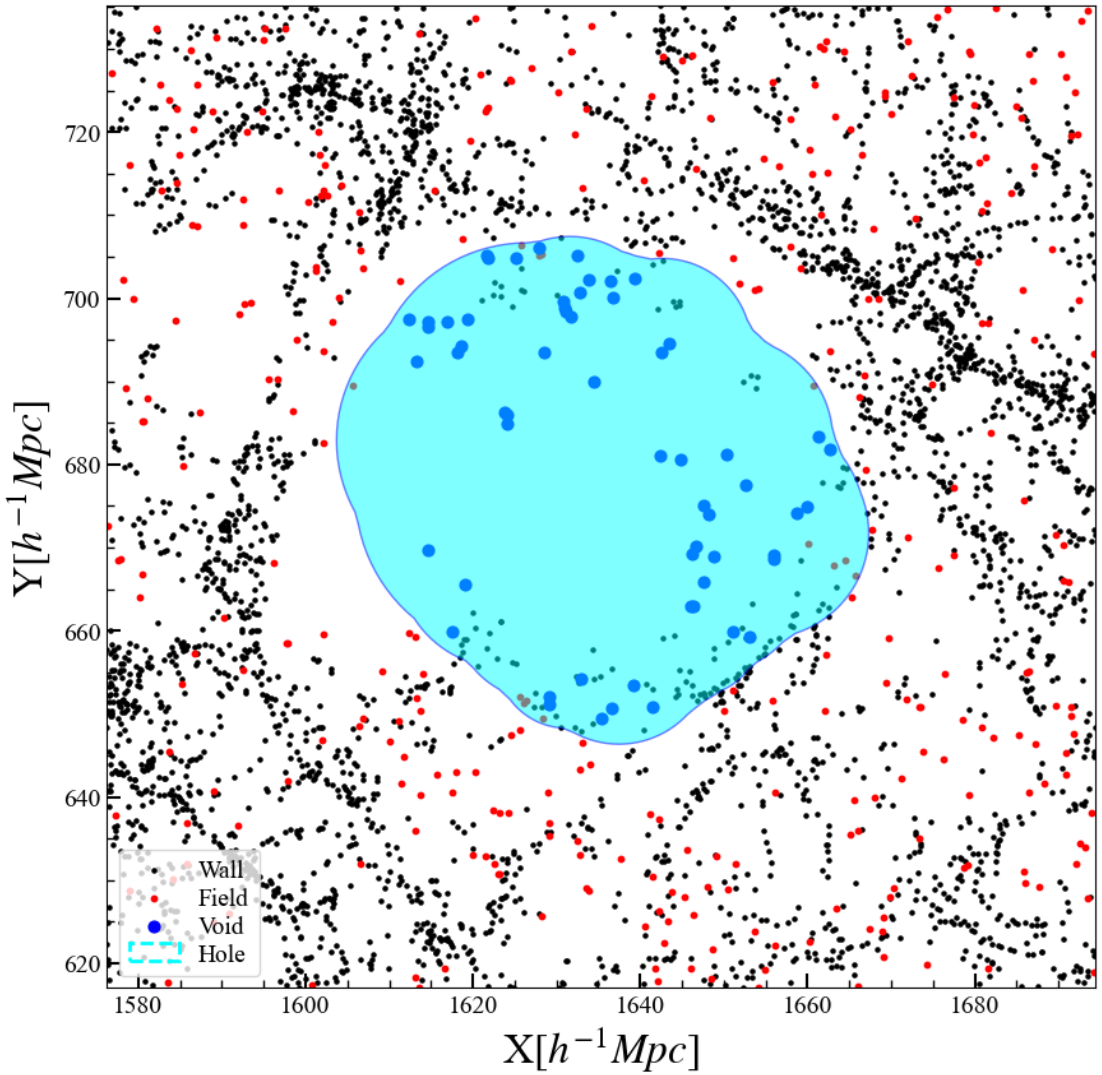
Void identification

Hoyle & Vogeley (2002)
Voidfinder algorithm

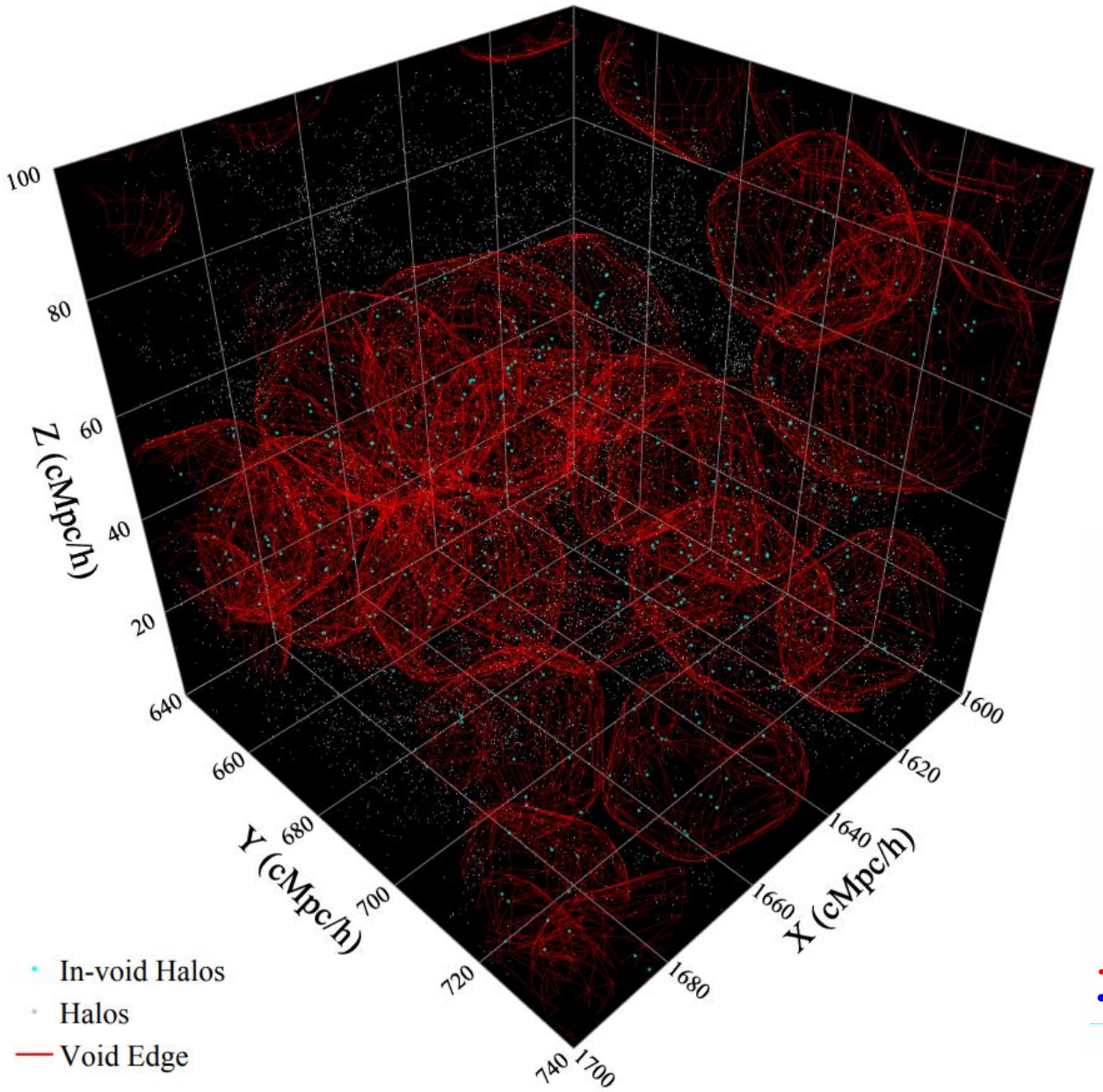
Precise underdense criteria

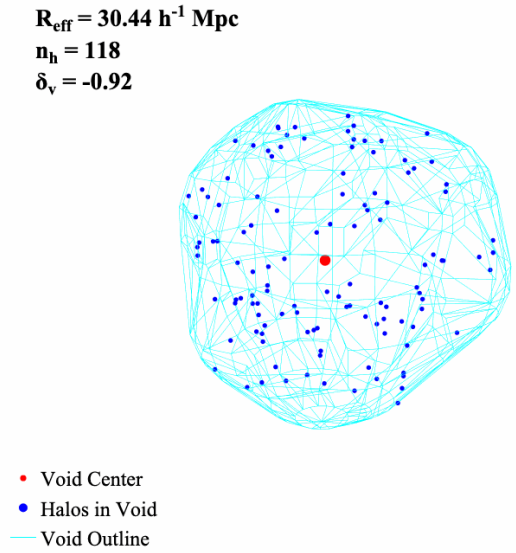
Works well on **observational data**

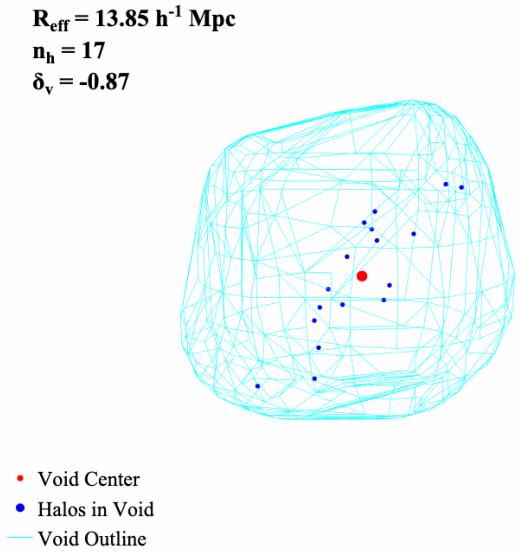
Reveals **complex void structures**

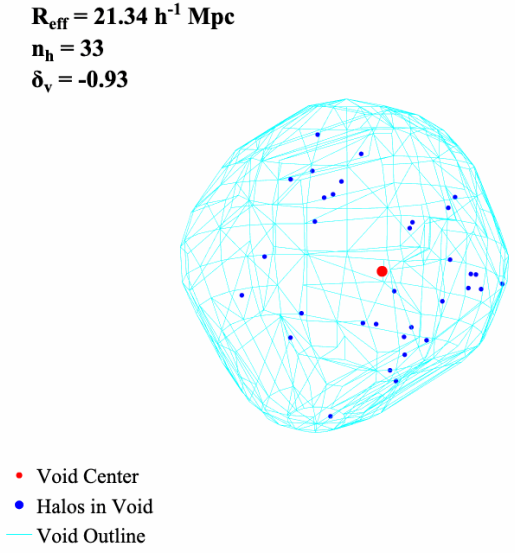


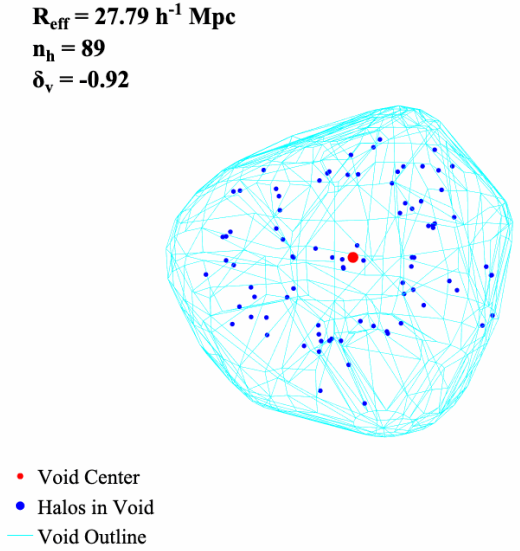
VoidFinder Algorithm, by Kang











Void distribution and shape from AbacusSummit c000, by Kang

Void properties

Kang&Lee(JCAP, 2025)

On $[2\,\mathrm{h}^{-1}Gpc]^3$ periodic box,

$N_v \sim 170{,}000$

$\overline{R_{eff}} \sim 15\ h^{-1}Mpc$

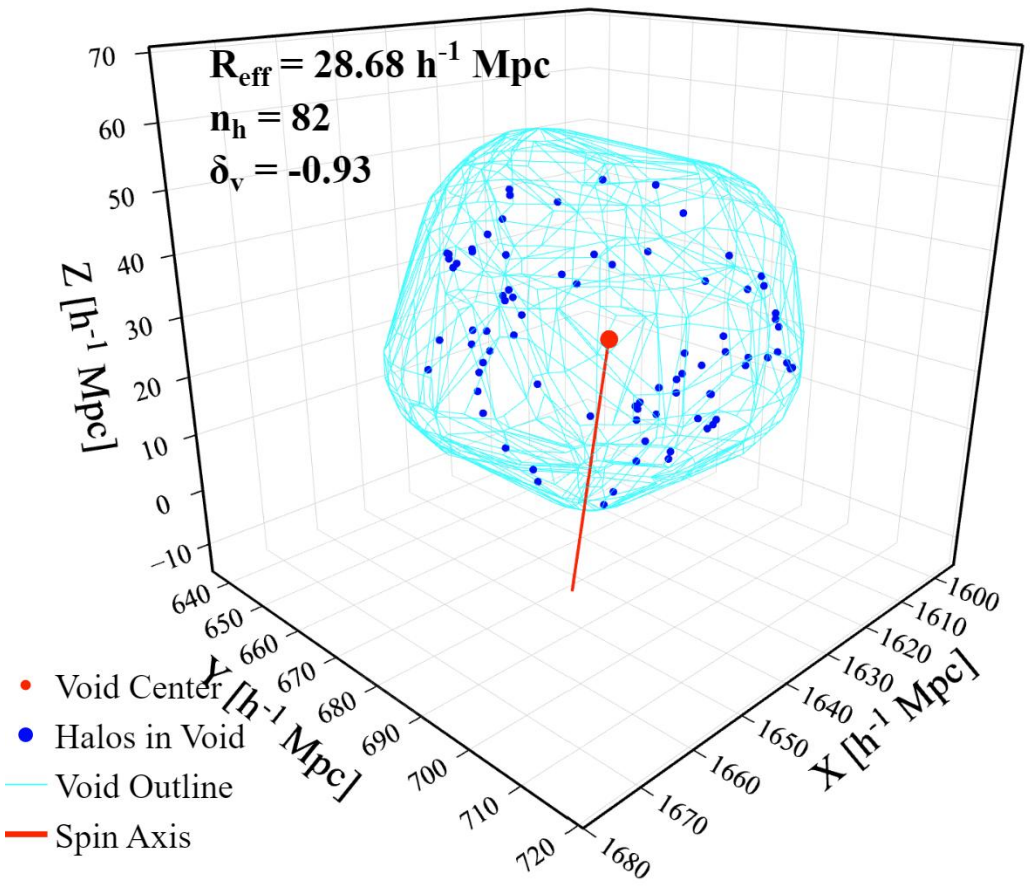
$\overline{\delta_v} = -0.87$

$$\delta_v = \frac{n_{halo}^{void} - n_{halo}^{volume}}{n_{halo}^{volume}}$$

	model	N_v	$N_v(n_h \geq 15)$	$\bar{R}_{\rm eff}$ $[h^{-1}\mathrm{Mpc}]$	$\bar{\delta_v}$	l_c $[h^{-1}\mathrm{Mpc}]$
Planck 2018	c000	633932	188804	15.20	-0.87	4.50
$\boldsymbol{\sigma_8}$ difference	c113	633800	188561	15.18	-0.87	4.50
	c116	636195	187907	15.28	-0.87	4.52
	c130	633349	188399	15.12	-0.87	4.49
	c133	637702	186933	15.34	-0.87	4.54
$\boldsymbol{\Omega_{cdm}h^2}$ difference	c102	616167	201465	14.80	-0.87	4.40
	c103	649396	176263	15.62	-0.87	4.62
	c131	671979	153260	16.51	-0.87	4.86
	c134	572507	228304	14.07	-0.87	4.19
$\boldsymbol{M_\nu}$ difference	c009	634499	188468	15.20	-0.87	4.51
	c019	630400	191454	15.11	-0.87	4.48
$\boldsymbol{w}$ difference	c108	612243	205815	14.73	-0.87	4.37
	c109	653567	171388	15.72	-0.87	4.66
	c121	628681	193031	15.07	-0.87	4.47
	c122	640020	183450	15.34	-0.87	4.55

Table 2. Total number of voids, number of giant voids having ≥ 15 halos, mean effective radii, mean density contrast and criterion distance for the classification of wall halos.

Dimensionless void spin vector



Kang&Lee(JCAP, 2025)

Pseudo angular momentum of void
without mass term
= No need to know single halo mass

Normalization term

$$\mathbf{j} \equiv \frac{1}{\sqrt{2}(V_v R_{eff})} \sum_{i=1}^{n_h} (\mathbf{x}_i - \mathbf{x}_c) \times (\mathbf{v}_i - \mathbf{v}_c) \ ,$$

$$v_c = \frac{1}{n_h} \sum_{i=1}^{n_h} v_i \quad x_c = \frac{1}{n_h} \sum_{i=1}^{n_h} x_i$$

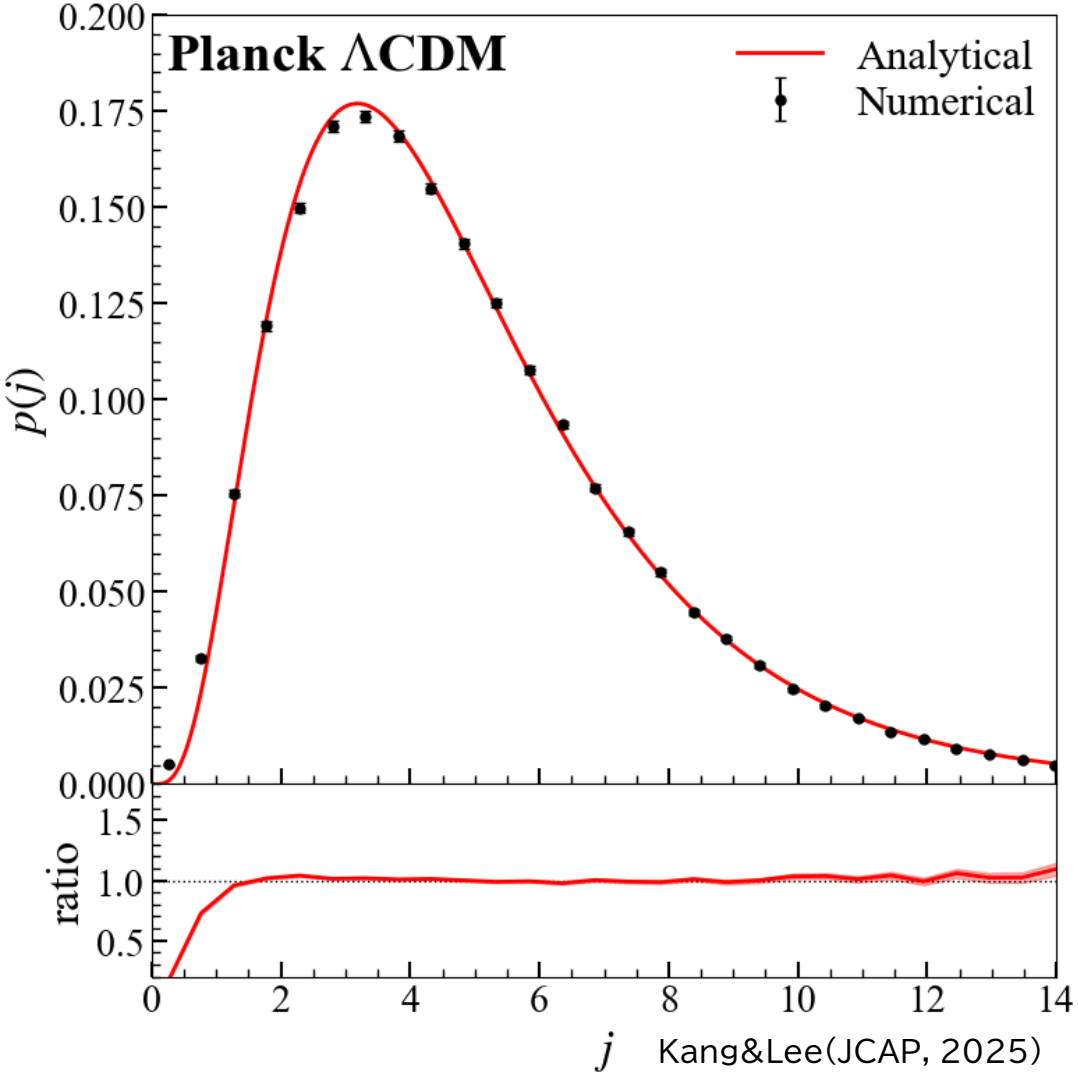
V_v : Mean Circular velocity at R_{eff}
R_{eff} : Effective radius

Void spin distributions

For the first time, we found that
The **distribution of Void Spin** in cosmology
can be fitted well with
Generalized gamma distribution
With two parameters {k, θ}

$$p(j) = \frac{j^{k-1}}{2\Gamma(2k)\,\theta^k} \exp\left[-\left(\frac{j}{\theta}\right)^{1/2}\right]$$

$$\Gamma(2k) \equiv \int_0^\infty dt\, t^{2k-1} e^{-t}$$



Kang&Lee(JCAP, 2025)

As cosmological probe

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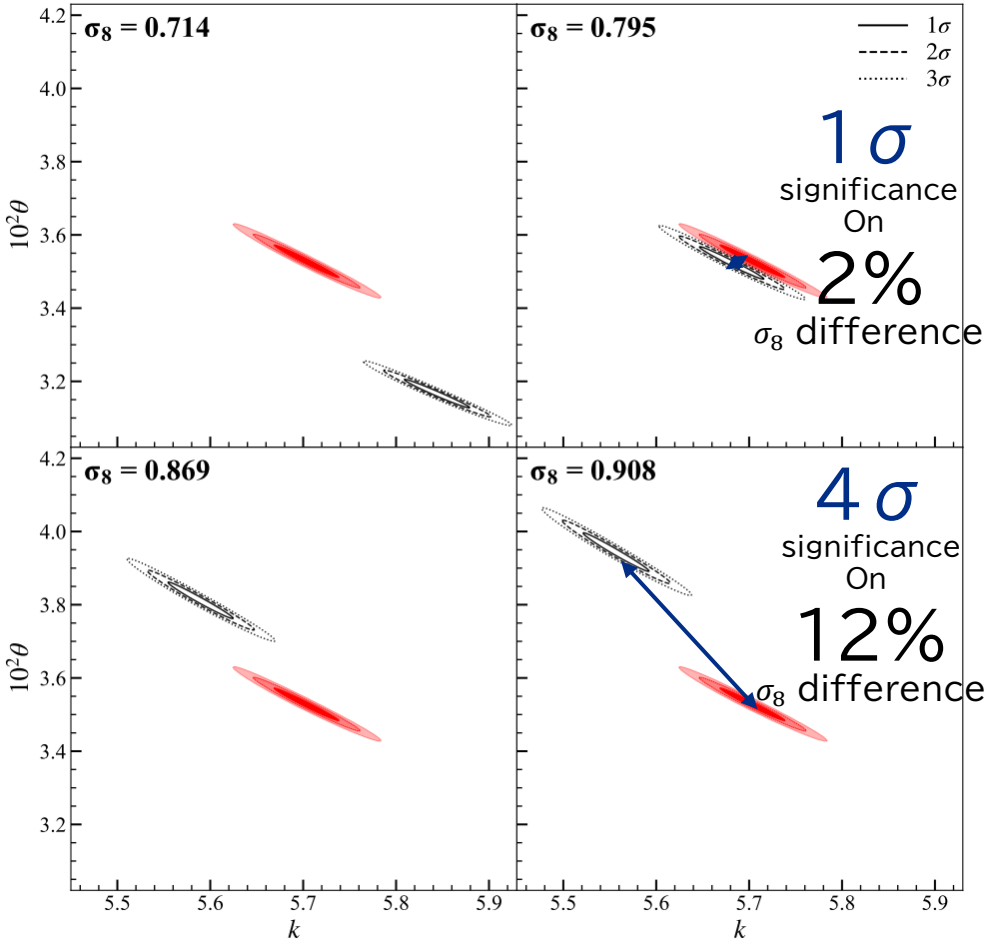
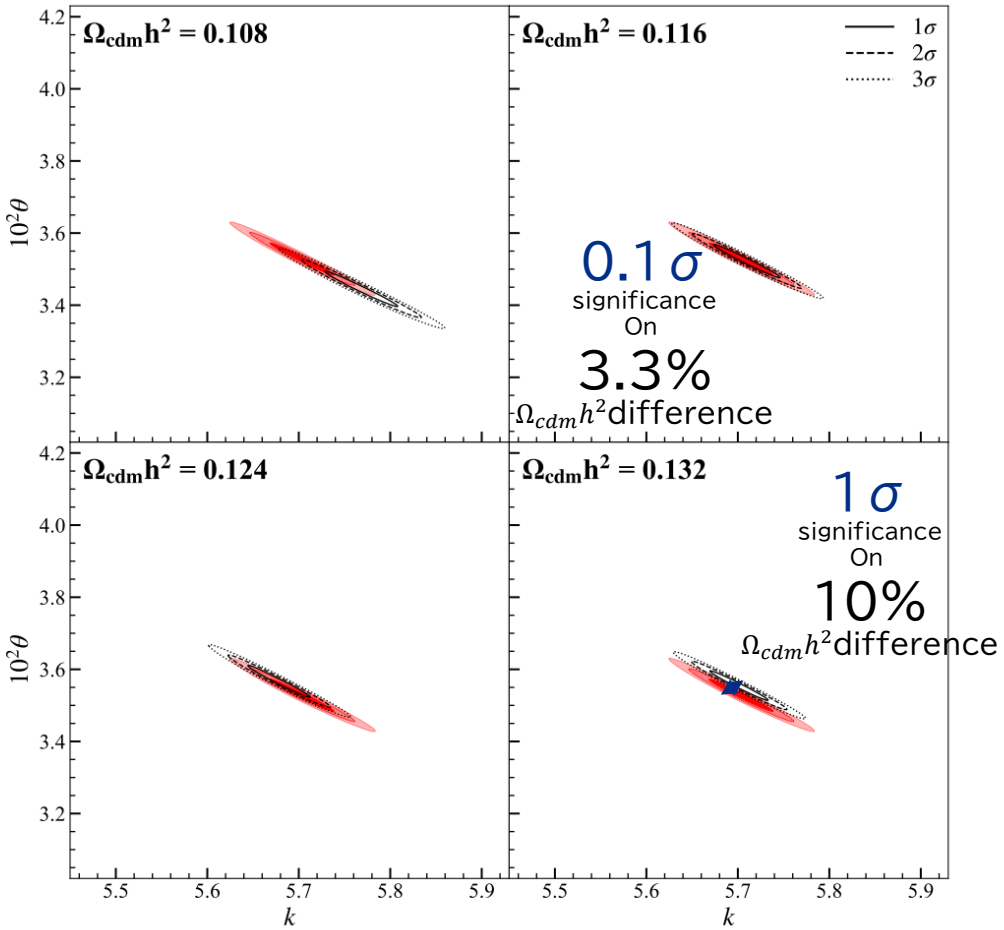
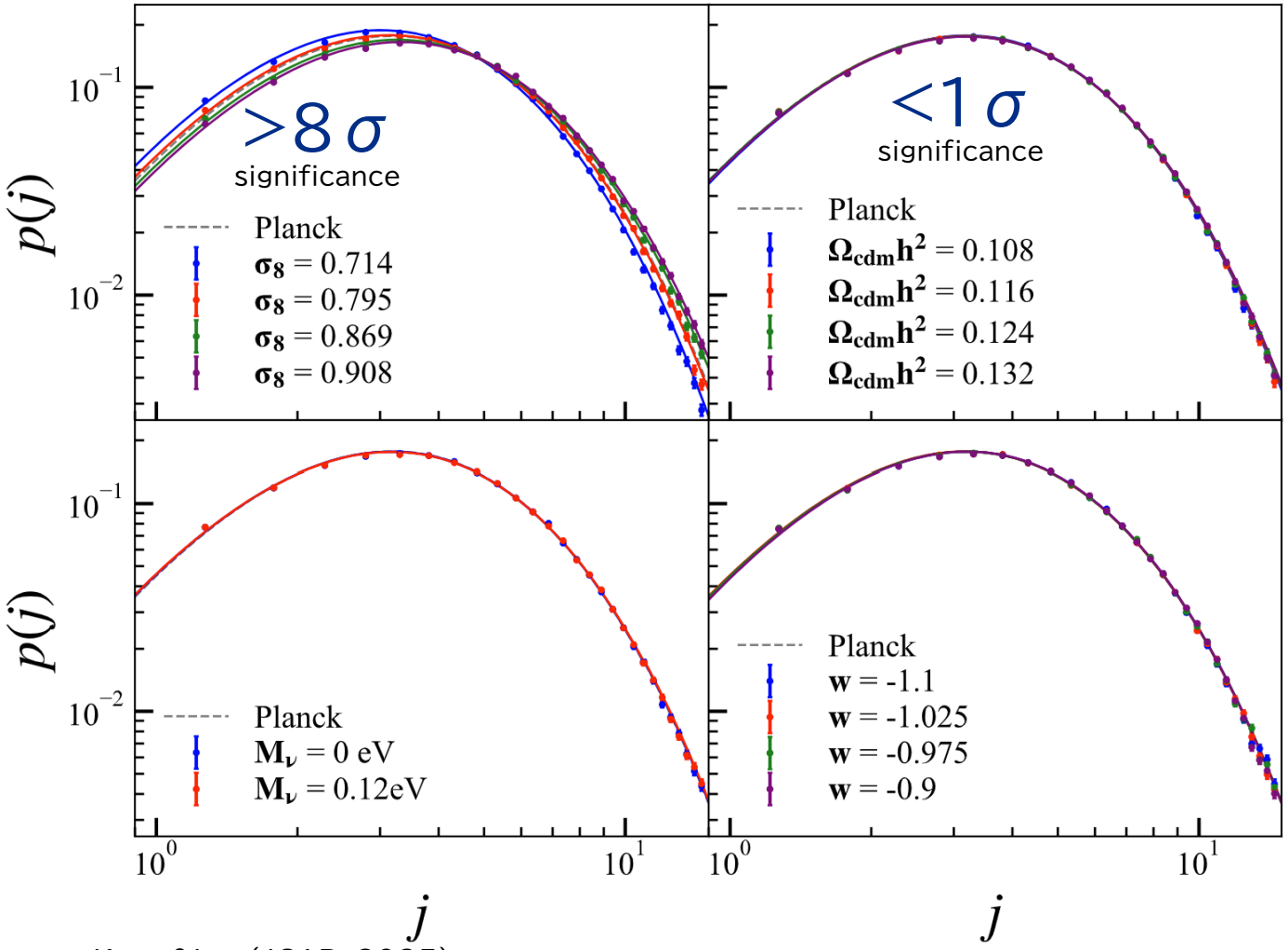




+ no statistically significant (<1σ) difference on
10% difference in w, 100% difference in M_ν

Why meaningful?



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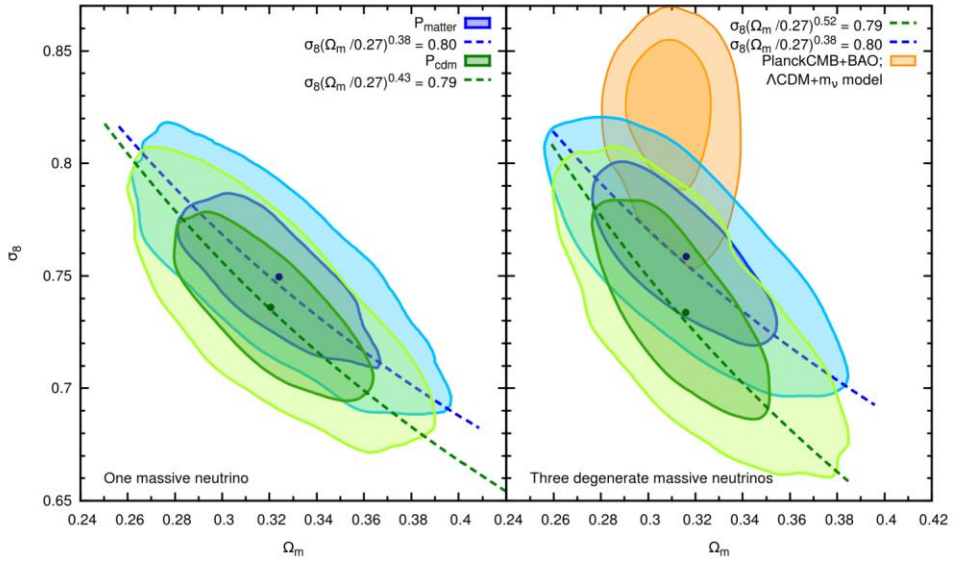
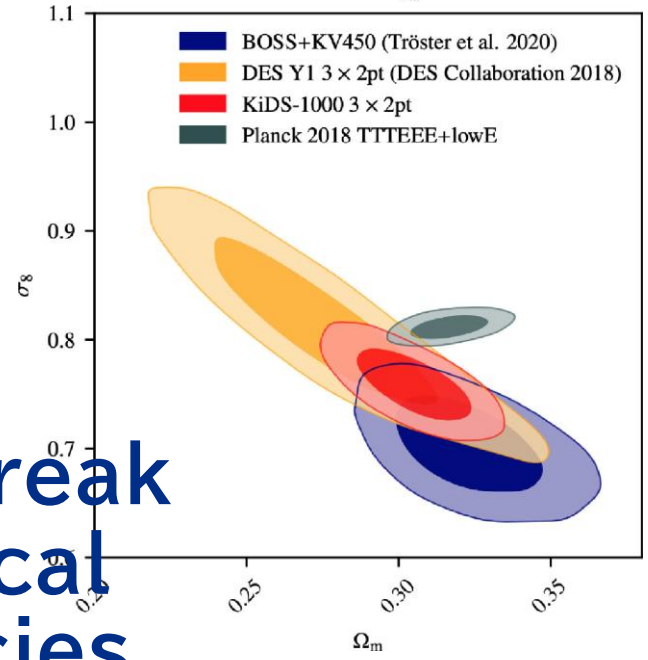


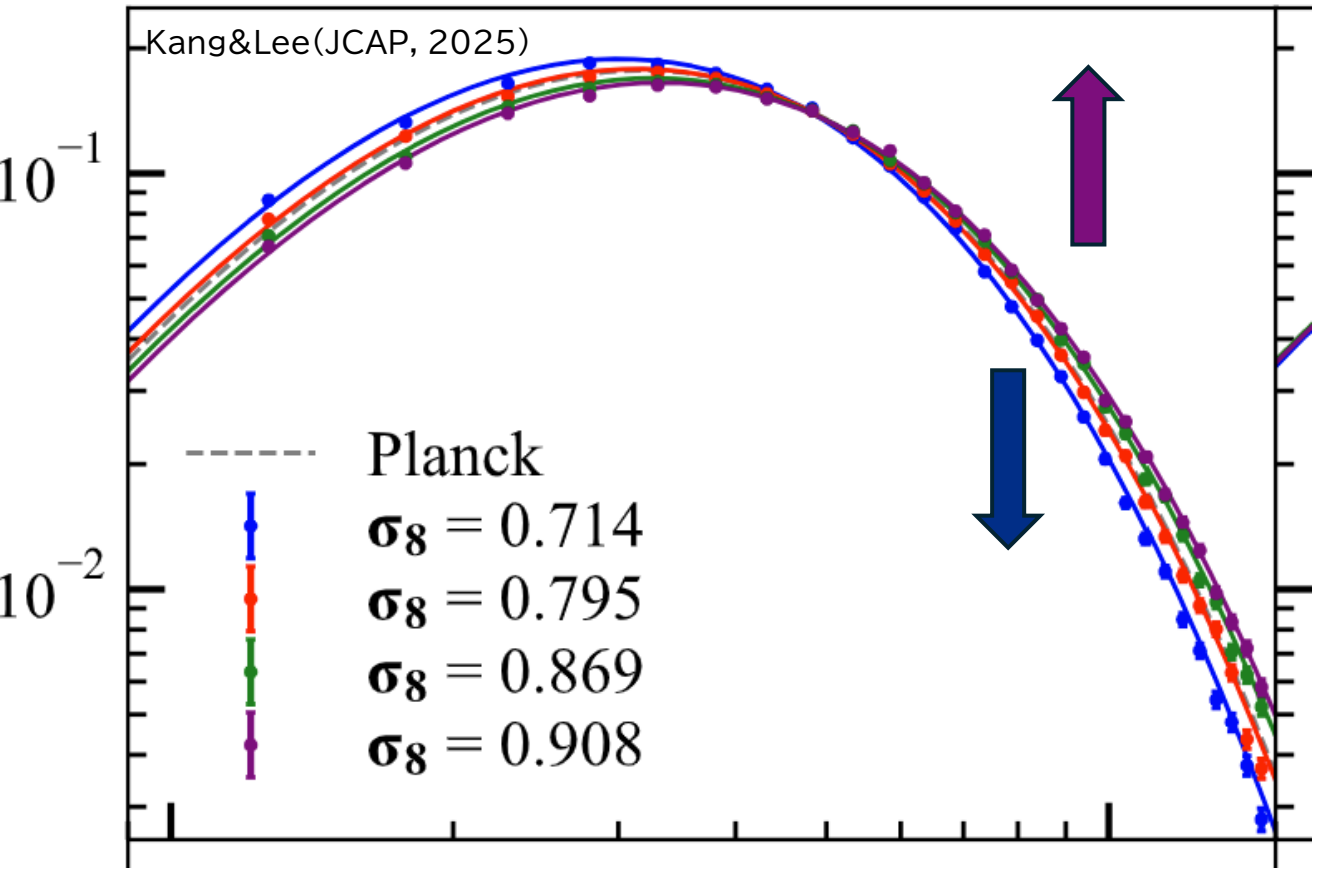


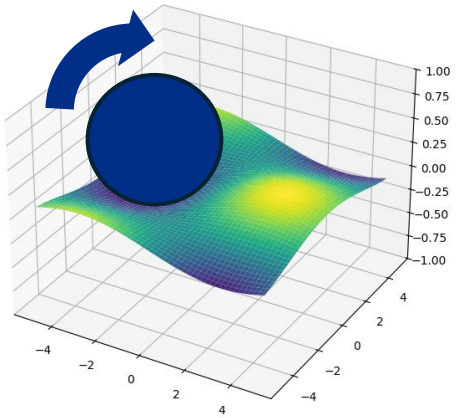
Potential to **break cosmological degeneracies.**

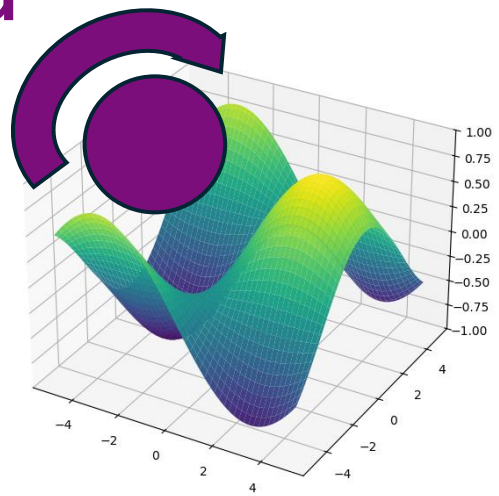
Credit: Costanzi et al. (2013) (up)
Valentino et al. (2021) (bottom)

σ_8 on void spin

High σ_8 > More Void with high j







Low σ_8 > Less Void with High j

Higher density fluctuation due to High σ_8

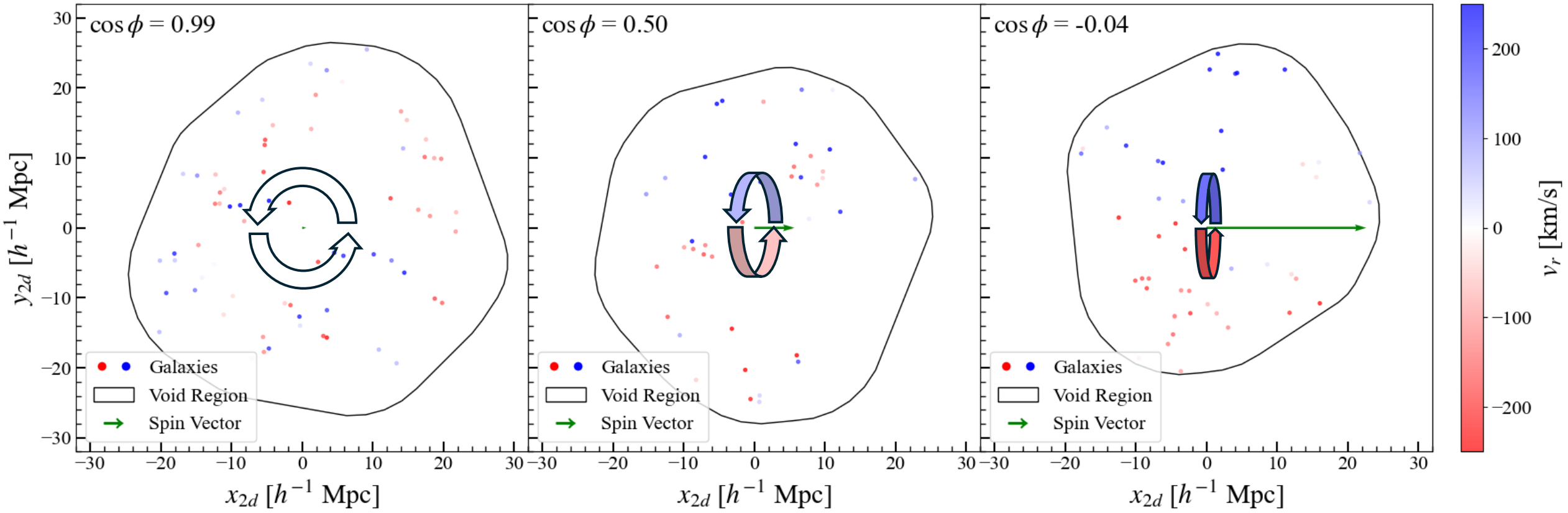
Change the **strength of large scale tidal field**

Resulting

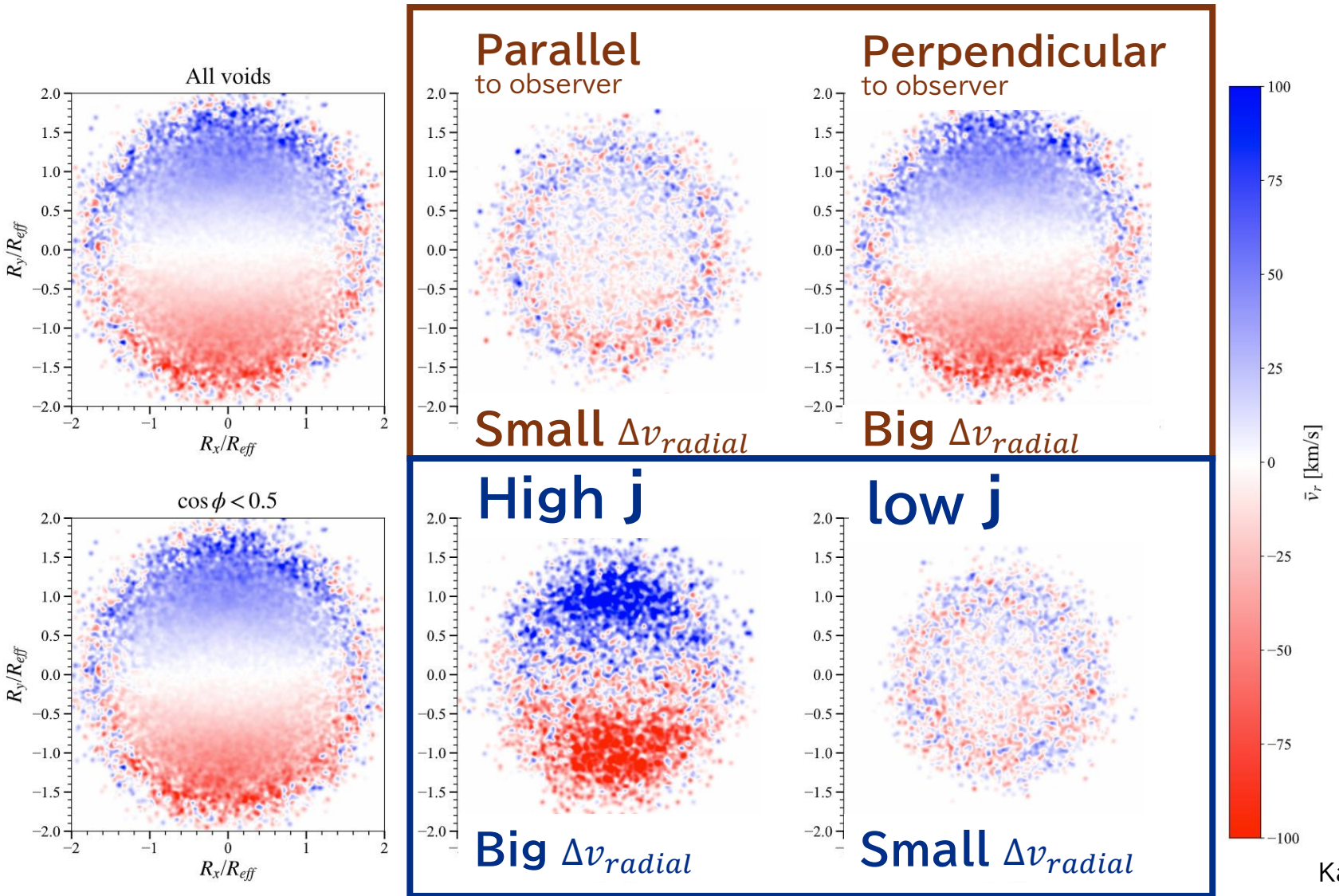
high void spin amplitude

Observational feasibility

Kang&Lee(JCAP, 2025)



Observational feasibility



Kang&Lee(JCAP, 2025)

Future works

Constraining cosmological parameters with observed void

Starting from lightcone simulation.

In DESI and SDSS catalog + LSST.

Develop physical model from first principles

Probing large scale parity violation

Future works

Constraining cosmological parameters with **observed void**

Develop physical model from first principles

Strengthen theoretical foundation

Probing large scale **parity violation**

Future works

Constraining cosmological parameters with **observed void**

Develop **physical model** from first principles

Probing large scale parity violation

Void spin distribution as probe of parity violation

Summary | Q&A

Effective σ_8 / Ω_{cdm} constraint without degeneracy.

We've numerically discovered that **void spin distribution** which very well described in **generalized gamma distribution** has potential to **work as effective constraints,** showing **separable dependence on σ_8 and $\Omega_{cdm}h^2$** while remaining **insensitive to, M_ν, w.**

Arxiv here:

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