Exploring the evidence for Large Local Inhomogeneity with supernovae Ia data

Vladimir V. Luković[1]

[1]University of Rome Tor Vergata

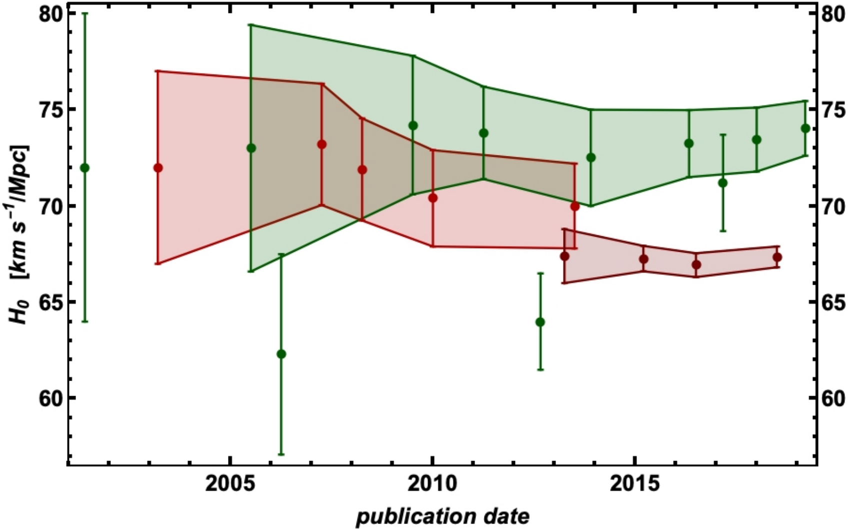
B. S. Haridasu, N. Vittorio

29th May 2019

UNIVERSITA' degli STUDI di ROMA TOR VERGATA

Outline

H_0 tension



- **CMB** vs. **distance ladder** – 9% discrepancy, 4.4σ tension
- 67.36 ± 0.54 vs. 74.03 ± 1.42 km/s/Mpc

Reports on Large Local Void

EVIDENCE FOR A ~ 300 MEGAPARSEC SCALE UNDER-DENSITY IN THE LOCAL GALAXY DISTRIBUTION

R. C. KEENAN[1], A. J. BARGER[2,3,4], L. L.COWIE[4]

Draft version August 7, 2013

ABSTRACT

Galaxy counts and recent measurements of the luminosity density in the near-infrared have indicated the possibility that the local universe may be under-dense on scales of several hundred megaparsecs. The presence of a large-scale under-density in the local universe could introduce significant biases into the interpretation of cosmological observables, and, in particular, into the inferred effects of dark energy on the expansion rate. Here we measure the $K-$band luminosity density as a function of redshift to test for such a local under-density. For our primary sample in this study, we select galaxies from the UKIDSS Large Area Survey and use spectroscopy from the SDSS, 2DFGRS, GAMA, and other redshift surveys to generate a $K-$selected catalog of $\sim 35,000$ galaxies that is $\sim 95\%$ spectroscopically complete at $K_{\mathrm{AB}} < 16.3$ ($K_{\mathrm{AB}} < 17$ in the GAMA fields). To complement this sample at low redshifts, we also analyze a $K-$selected sample from the 2M++ catalog, which combines 2MASS photometry with redshifts from the 2MASS redshift survey, the 6DFGRS, and the SDSS. The combination of these samples allows for a detailed measurement of the $K-$band luminosity density as a function of distance over the redshift range $0.01 < z < 0.2$ (radial distances $D \sim 50 - 800\ h_{70}^{-1}$ Mpc). We find that the overall shape of the $z = 0$ rest-frame $K-$band luminosity function ($M^* = -22.15 \pm 0.04$ and $\alpha = -1.02 \pm 0.03$) appears to be relatively constant as a function of environment and distance from us. We find a local ($z < 0.07, D < 300\ h_{70}^{-1}$ Mpc) luminosity density that is in good agreement with previous studies. Beyond $z \sim 0.07$, we detect a rising luminosity density that reaches a value of roughly ~ 1.5 times higher than that measured locally at $z > 0.1$. This suggests that the stellar mass density as a function of distance follows a similar trend. Assuming that luminous matter traces the underlying dark matter distribution, this implies that the local mass density of the universe may be lower than the global mass density on a scale and amplitude sufficient to introduce significant biases into the determination of basic cosmological observables. An under-density of roughly this scale and amplitude could resolve the apparent tension between direct measurements of the Hubble constant and those inferred by Planck.

Reports on Large Local Void

THE KBC VOID: CONSISTENCY WITH SUPERNOVAE TYPE IA AND THE KINEMATIC SZ EFFECT IN A ΛLTB MODEL

Benjamin L. Hoscheit[1,2] and Amy J. Barger[2,3,4]

[1]Department of Physics, University of Wisconsin-Madison, 1150 University Avenue, Madison, WI 53706, USA
[2]Department of Astronomy, University of Wisconsin-Madison, 475 N. Charter St., Madison, WI 53706, USA
[3]Department of Physics and Astronomy, University of Hawaii, 2505 Correa Road, Honolulu, HI 96822, USA
[4]Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA

ABSTRACT

There is substantial and growing observational evidence from the normalized luminosity density in the near-infrared that the local universe is underdense on scales of several hundred megaparsecs. We test whether our parameterization of the observational data of such a "void" is compatible with the latest supernovae type Ia data and with constraints from line-of-sight peculiar-velocity motions of galaxy clusters with respect to the cosmic microwave background rest-frame, known as the linear kinematic Sunyaev-Zel'dovich (kSZ) effect. Our study is based on the large local void (LLV) radial profile observed by Keenan, Barger, and Cowie (KBC) and a theoretical void description based on the Lemaître-Tolman-Bondi model with a nonzero cosmological constant (ΛLTB). We find consistency with the measured luminosity distance-redshift relation on radial scales relevant to the KBC LLV through a comparison with 217 low-redshift supernovae type Ia over the redshift range $0.0233 < z < 0.15$. We assess the implications of the KBC LLV in light of the tension between "local" and "cosmic" measurements of the Hubble constant, H_0. We find that when the existence of the KBC LLV is fully accounted for, this tension is reduced from 3.4σ to 2.75σ. We find that previous linear kSZ constraints, as well as new ones from the South Pole Telescope and the Atacama Cosmology Telescope, are fully compatible with the existence of the KBC LLV.

Reports on Large Local Void

The Local Hole revealed by galaxy counts and redshift

J.R. Whitbourn[1⋆] and T. Shanks[1]†
[1] *Extragalactic & Cosmology Group, Department of Physics, Durham University, South Road DH1 3LE*

Accepted 2013 October 18; Received 2013 October 7; in original form 2013 July 16

ABSTRACT

The redshifts of ≈ 250000 galaxies are used to study the Local Hole and its associated peculiar velocities. The sample, compiled from 6dF Galaxy Redshift Survey (6dFGS) and Sloan Digital Sky Survey (SDSS), provides wide sky coverage to a depth of ≈ $300h^{-1}$Mpc. We have therefore examined K and r limited galaxy redshift distributions and number counts to map the local density field. Comparing observed galaxy $n(z)$ distributions to homogeneous models in three large regions of the high latitude sky, we find evidence for under-densities ranging from ≈4-40% in these regions to depths of ≈$150h^{-1}$Mpc with the deepest under-density being over the Southern Galactic cap. Using the Galaxy and Mass Assembly (GAMA) survey we then establish the normalisation of galaxy counts at fainter magnitudes and thus confirm that the underdensity over all three fields at $K < 12.5$ is $\approx 15 \pm 3\%$. Finally, we further use redshift catalogues to map sky-averaged peculiar velocities over the same areas using the average redshift - magnitude, $\bar{z}(m)$, technique of Soneira (1979). After accounting for the direct effect of large-scale structure on $\bar{z}(m)$ we can then search for peculiar velocities. Taking all three regions into consideration the data reject at the $\approx 4\sigma$ level the idea that we have recovered the CMB rest frame in the volume probed. We therefore conclude that there is some consistent evidence from both counts and Hubble diagrams for a 'Local Hole' with a ≈ $150h^{-1}$Mpc under-density that deeper counts and redshifts in the Northern Galactic cap suggest may extend to ≈ $300h^{-1}$Mpc.

Reports on Large Local Void

Gaia Cepheid parallaxes and 'Local Hole' relieve H_0 tension

T. Shanks,★ L.M. Hogarth, N. Metcalfe.
Physics Department, Durham University, South Road, Durham, DH1 3LE, England

ABSTRACT

There is an $\approx 9 \pm 2.5\%$ tension between the value of Hubble's Constant, $H_0 = 67.4 \pm 0.5 \mathrm{km\,s^{-1}Mpc^{-1}}$, implied by the *Planck* microwave background power spectrum and that given by the distance scale of $H_0 = 73.4 \pm 1.7 \mathrm{km\,s^{-1}Mpc^{-1}}$. But with a plausible assumption about a *Gaia* DR2 parallax systematic offset, we find that *Gaia* parallax distances of Milky Way Cepheid calibrators are $\approx 12-15\%$ longer than previously estimated. Similarly, *Gaia* also implies $\approx 4.7 \pm 1.7\%$ longer distances for 46 Cepheids than previous distances on the scale of Riess et al. Then we show that the existence of an $\approx 150 h^{-1}$Mpc 'Local Hole' in the galaxy distribution implies an outflow of $\approx 500 \mathrm{km\,s^{-1}}$. Accounting for this in the recession velocities of SNIa standard candles out to $z \approx 0.15$ reduces H_0 by a further $\approx 1.8\%$. Combining the above two results would reduce the distance scale H_0 estimate by $\approx 7\%$ from $H_0 \approx 73.4 \pm 1.7$ to $\approx 68.9 \pm 1.6$ $\mathrm{km\,s^{-1}Mpc^{-1}}$, in reasonable agreement with the *Planck* value. We conclude that the discrepancy between distance scale and *Planck* H_0 measurements remains unconfirmed due to uncertainties caused by *Gaia* systematics and an unexpectedly inhomogeneous local galaxy distribution.

Reports on Large Local Void

The Local Perspective on the Hubble Tension: Local Structure Does Not Impact Measurement of the Hubble Constant

W. D'Arcy Kenworthy,[1] Dan Scolnic,[2] and Adam Riess[1,3]

(Received 1/24/19; Revised 3/8/19; Accepted 3/10/19)

Submitted to ApJ

ABSTRACT

We use the largest sample to date of spectroscopic SN Ia distances and redshifts to look for evidence in the Hubble diagram of large scale outflows caused by local voids suggested to exist at $z < 0.15$. Our sample combines data from the Pantheon sample with the Foundation survey and the most recent release of lightcurves from the Carnegie Supernova Project to create a sample of 1295 SNe over a redshift range of $0.01 < z < 2.26$. We make use of an inhomogeneous and isotropic Lemaitre-Tolman-Bondi metric to model a void in the SN Ia distance-redshift relation. We conclude that the SN luminosity distance-redshift relation is inconsistent at the $4-5\sigma$ confidence level with large local underdensities ($|\delta| > 20\%$, where the density contrast $\delta = \Delta\rho/\rho$) proposed in some galaxy count studies, and find no evidence of a change in the Hubble constant corresponding to a void with a sharp edge in the redshift range $0.023 < z < 0.15$. With empirical precision of $\sigma_{H_0} = 0.60\%$, we conclude that the distance ladder measurement is not affected by local density contrasts, in agreement with cosmic variance of $\sigma_{H_0} = 0.42\%$ predicted from simulations of large-scale structure. Given that uncertainty in the distance ladder value is $\sigma_{H_0} = 2.2\%$, this does not affect the Hubble tension. We derive a 5σ constraint on local density contrasts on scales larger than 69 Mpc h^{-1} of $|\delta| < 27\%$. The presence of local structure does not appear to impede the possibility of measuring the Hubble constant to 1% precision.

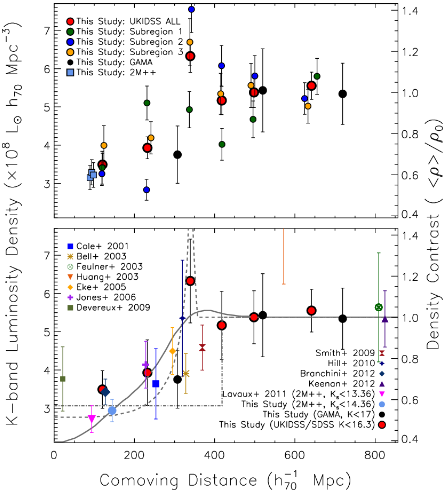
Indications of a void in luminosity density data

35,000 galaxies over $0.01 < z < 0.2$

- 2dFGS
- UKIDSS Large Area Survey
- GAMA Survey
- 2M++ catalogue

Suggested conservative void (KBC13):

- $z_{size} \sim 0.08(\sim 300\mathrm{h}^{-1}\mathrm{Mpc})$
- $\delta\rho_m \sim -30\%$

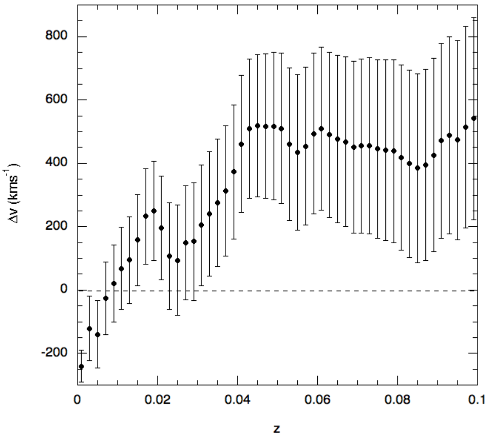


Indications of a void in peculiar velocity field

250,000 galaxies
- 6dFGS
- SDSS
- GAMA Survey

Suggested void (WS14):

- *size* $\sim \{150, 300\}\mathrm{h}^{-1}\mathrm{Mpc}$
- $\delta\rho_m \sim \{-4, -40\}\%$



Lemaître-Tolman-Bondi (LTB) metric

$$ds^2 = c^2 dt^2 - \frac{R_r(t,r)^2}{1 - k(r)r^2} dr^2 - R(t,r)^2 d\Omega^2$$

Friedmann-Lemaître equation:

$$\left(\frac{R_t}{R}\right)^2 = \frac{2GM}{R^3} - \frac{c^2 k\, r^2}{R^2} + \frac{c^2 \Lambda}{3}$$

Lemaître-Tolman-Bondi (LTB) metric

$$ds^2 = c^2 dt^2 - \frac{R_r(t,r)^2}{1-k(r)r^2} dr^2 - R(t,r)^2 d\Omega^2$$

Friedmann-Lemaître equation:

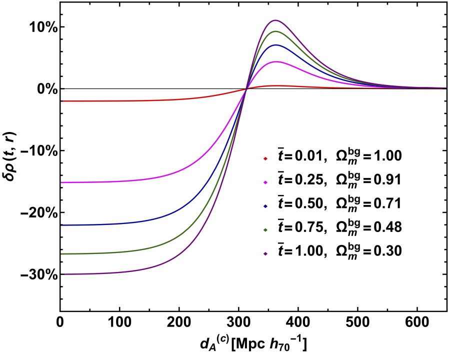
$$\left(\frac{R_t}{R}\right)^2 = \frac{2GM}{R^3} - \frac{c^2 k\, r^2}{R^2} + \frac{c^2 \Lambda}{3}$$

$$\delta\rho_0 = \frac{\rho_m^{\rm loc}(t_0)}{\rho_m^{\rm bg}(t_0)} - 1 = \left(\frac{1}{a_0^{\rm loc}}\right)^3 - 1$$

$$\delta\Omega_0 = \frac{\Omega_m^{\rm loc}}{\Omega_m^{\rm bg}} - 1 = \left(\frac{H_0^{\rm bg}}{H_0^{\rm loc}}\right)^2 \left(\frac{1}{a_0^{\rm loc}}\right)^3 - 1$$

Two contrast are different due to spatial inhomogeneity of the expansion rate:

$$\delta H_0 = \frac{H_0^{\rm loc} - H_0^{\rm bg}}{H_0^{\rm bg}}$$

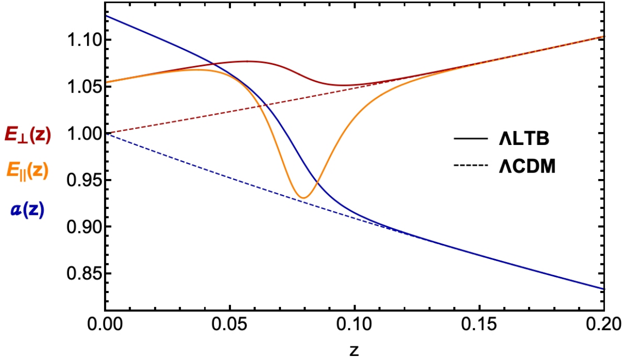


Inhomogeneous cosmic expansion

$$ds^2 = c^2 dt^2 - \frac{R_r(t,r)^2}{1-k(r)r^2} dr^2 - R(t,r)^2 d\Omega^2$$

Friedmann-Lemaître equation:

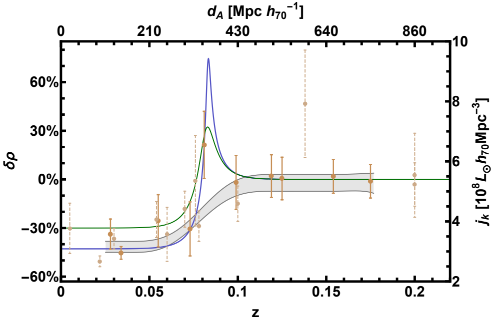
$$\left(\frac{R_t}{R}\right)^2 = \frac{2GM}{R^3} - \frac{c^2 k\, r^2}{R^2} + \frac{c^2 \Lambda}{3}$$



Evidence for the void?

Fitting KBC13 data

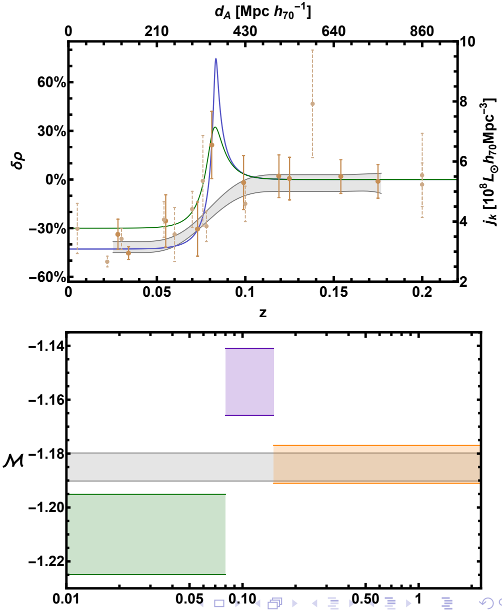
- 3 parameters of $k(r)$ and a normalization factor.
- Much stronger under-density



Evidence for the void?

Fitting KBC13 data

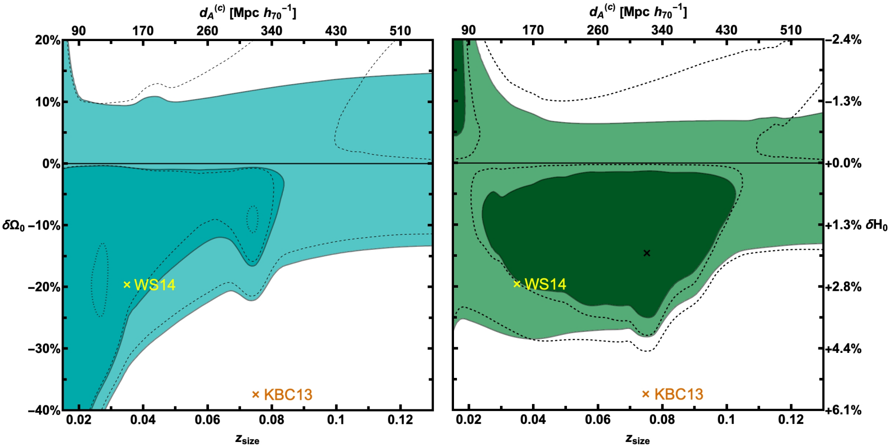
- 3 parameters of $k(r)$ and a normalization factor.
- Much stronger under-density



Binned SN Ia analysis:

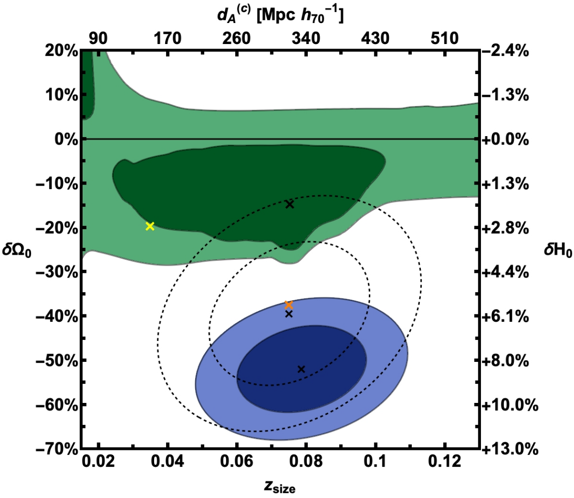
- Homogeneous cosmology
- $\mathcal{M} = M_b + \mathrm{Log}_{10}(\mathrm{c}/\mathrm{H}_0)$

Analysis on SN Ia datasets



- Dashed contours are for JLA (left) or Pantheon (right) SN samples
- Coloured contours are for SN using Planck constraint $\Omega_m^{\mathrm{bg}} = 0.315 \pm 0.007$

Analysis on SN Ia datasets



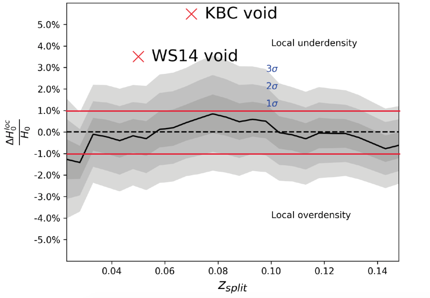
- Pantheon SN Ia vs. KBC13 are in $\sim 4\sigma$ tension
- Dashed contours are for modified KBC*

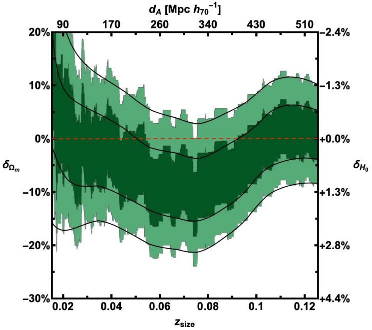
Constraints comparison

data	$z_{\rm size}^{b.f.}$	$z_{\rm size}^{1\sigma}$	$\delta\Omega_0^{b.f.}$ [%]	$\delta\Omega_0^{1\sigma}$ [%]	$\delta\rho_0^{b.f.}$ [%]	$\delta\rho_0^{1\sigma}$ [%]	χ^2	ΔAIC
KBC	0.082	$0.079^{+0.012}_{-0.012}$	−51.1	$-51.9^{+6.3}_{-6.3}$	−42.9	$-43.8^{+6.0}_{-6.1}$	2.62	
KBC*	0.082	$0.075^{+0.015}_{-0.015}$	−39.7	$-39.4^{+10.3}_{-10.3}$	−32.4	$-32.1^{+9.0}_{-9.5}$	0.29	
JLA	0.025	$0.025^{+0.046}_{-0.015}$	−19.5	$-14.6^{+19.7}_{-11.2}$	−15.1	$-11.2^{+14.9}_{-9.0}$	678.30	1.35
JLA+P	0.025	$0.025^{+0.033}_{-0.015}$	−19.6	$-14.3^{+14.5}_{-11.6}$	−15.1	$-10.9^{+11.0}_{-9.4}$	678.34	1.07
Pan	0.075	$0.075^{+0.018}_{-0.032}$	−16.2	$-12.6^{+11.7}_{-9.5}$	−12.4	$-9.6^{+9.0}_{-7.6}$	1020.72	0.67
Pan+P	0.074	$0.075^{+0.017}_{-0.030}$	−14.4	$-11.6^{+8.4}_{-7.8}$	−11.0	$-8.8^{+6.4}_{-6.2}$	1021.01	0.40

Top hat analysis for H_0 comparison

Revisiting Kenworthy et al. (2019)

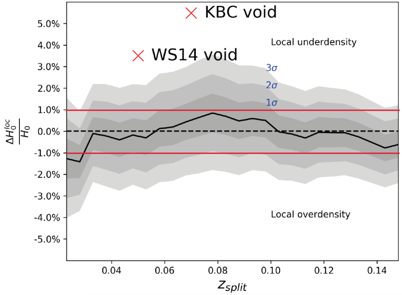


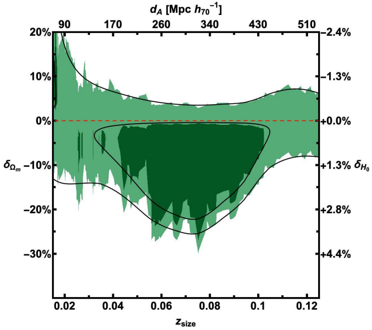


$> 4\sigma$ inference for $|\delta\rho_0| < 20\%$

Top hat analysis for H_0 comparison

Revisiting Kenworthy et al. (2019)

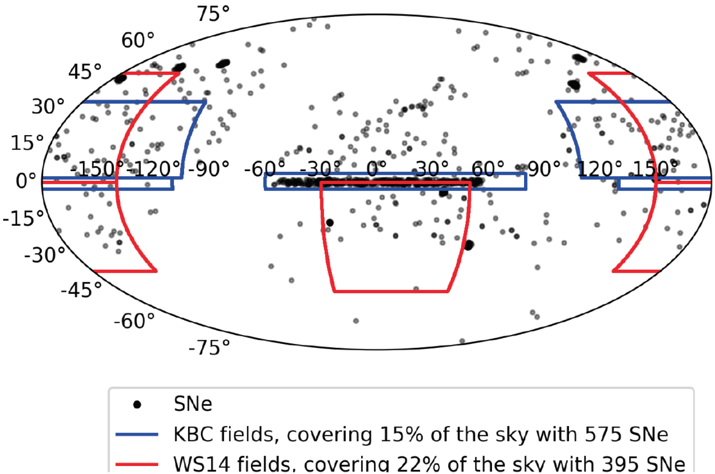




$> 4\sigma$ inference for $|\delta\rho_0| < 20\%$

Sky coverage

Kenworthy et al. (2019)



Concluding remarks

- Implementing a well formulated ΛLTB model with luminosity data from KBC13, we find a density contrast of $\delta\rho_0^{1\sigma} = -43.8 \pm 6.0\%$, a much higher value than originally proposed $\delta\rho_0 = -30\%$.
- Using the most recent Pantheon SNe Ia compilation we do not find a strong evidence for a void or otherwise, with $\delta\rho_0^{1\sigma} = -9.6^{+9.0}_{-7.6}\%$, corresponding to $\delta\Omega_0^{1\sigma} = -12.6^{+11.7}_{-9.5}\%$ and a wide range for the redshift size $z_{\rm size}^{1\sigma} = 0.075^{+0.018}_{-0.032}$.
- JLA likelihood is in a good overall agreement with Pantheon, except in the range $z \leq 0.04$.
- The constraints from Pantheon dataset are at $\sim 4\sigma$ tension with our result obtained from KBC13 data, but in excellent agreement with parameters of the isotropic void proposed by WS14.

Concluding remarks

- Leave One Out analysis of KBC13 data reveals that the estimated contrast is dominantly constrained by one stringent point. Removing this only data point from 2MASS survey and using the remaining 9 points from UKIDSS and GAMA surveys, relaxes the tension with SNe.
- Our analysis of SN datasets does not find any evidence for a large isotropic void that could resolve the 9% discrepancy between the two H_0 estimates in tension, leaving this local effect to be highly unlikely explanation alone.
- Contrary to the findings of KSR19, our Pantheon constraints have no tension and, therefore, allow for a void of e.g. $z_{\rm size} \lesssim 0.08$ and $\delta\Omega_0 \approx -25\%$, which would induce the expansion rate inside the void to be higher by $\delta H_0 \sim 3\%$ than on the background. Hence, SN Ia data alone do not exclude the possibility for a local matter density profile that can significantly contribute to the systematic error budget in H_0 measurement.


Thank You