



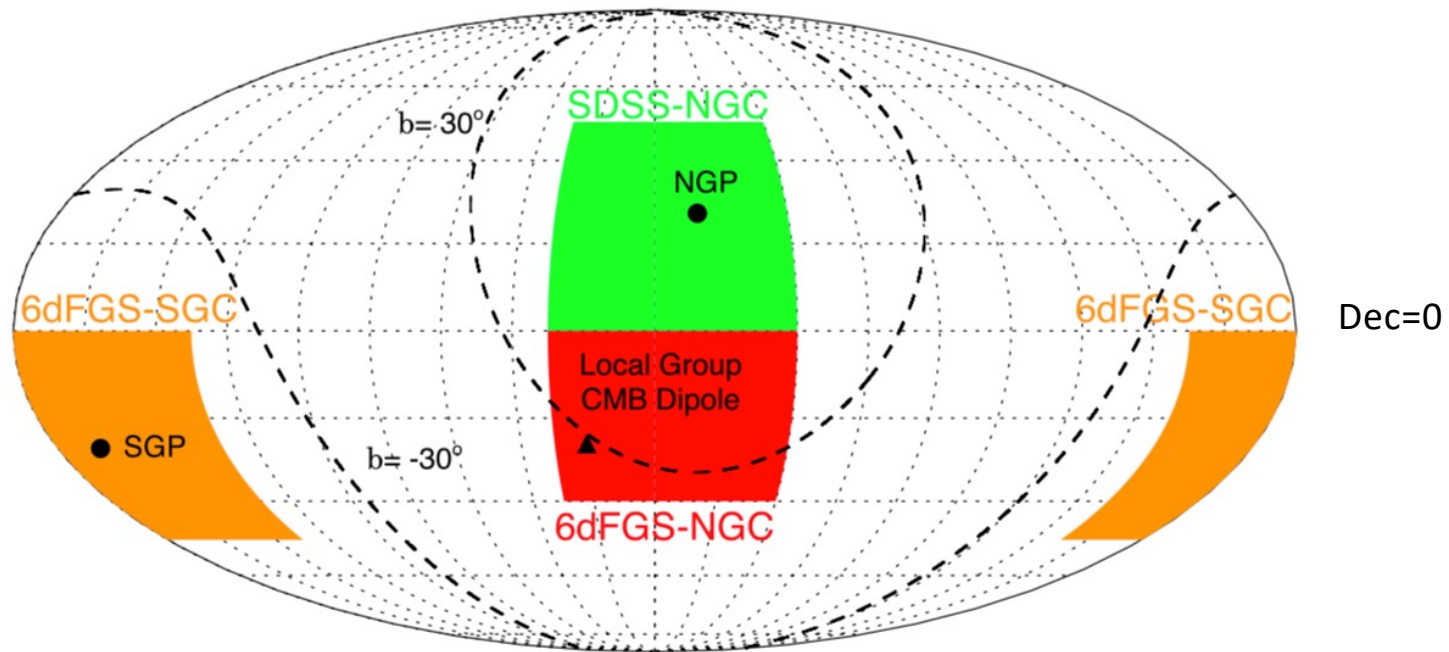
The Local Hole, Gaia + HST Cepheid Scales, Galactic Reddening and the H_0 Tension

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Summary

- Evidence for underdensity out to ~ 200 Mpc – “Local Hole”
- Other potentially neglected SH0ES distance scale errors:-
 - Gaia vs HST Parallaxes
 - Variable Reddening Law?
 - Cepheid PL incompleteness bias
- Effect on SH0ES - Planck H_0 Tension
- Explaining Local Hole- Λ CDM Tension and other LSS anomalies

H_0 tension – “Local Hole”



Whitbourn & Shanks (2014) \rightarrow $N(K)$, $N(z)$ to $K < 12.5$ in
3x $\sim 3000 \text{deg}^2$ areas – 6dFGS-SGC, 6dFGS-NGC and SDSS-NGC

“Local Hole” galaxy $n(K)$

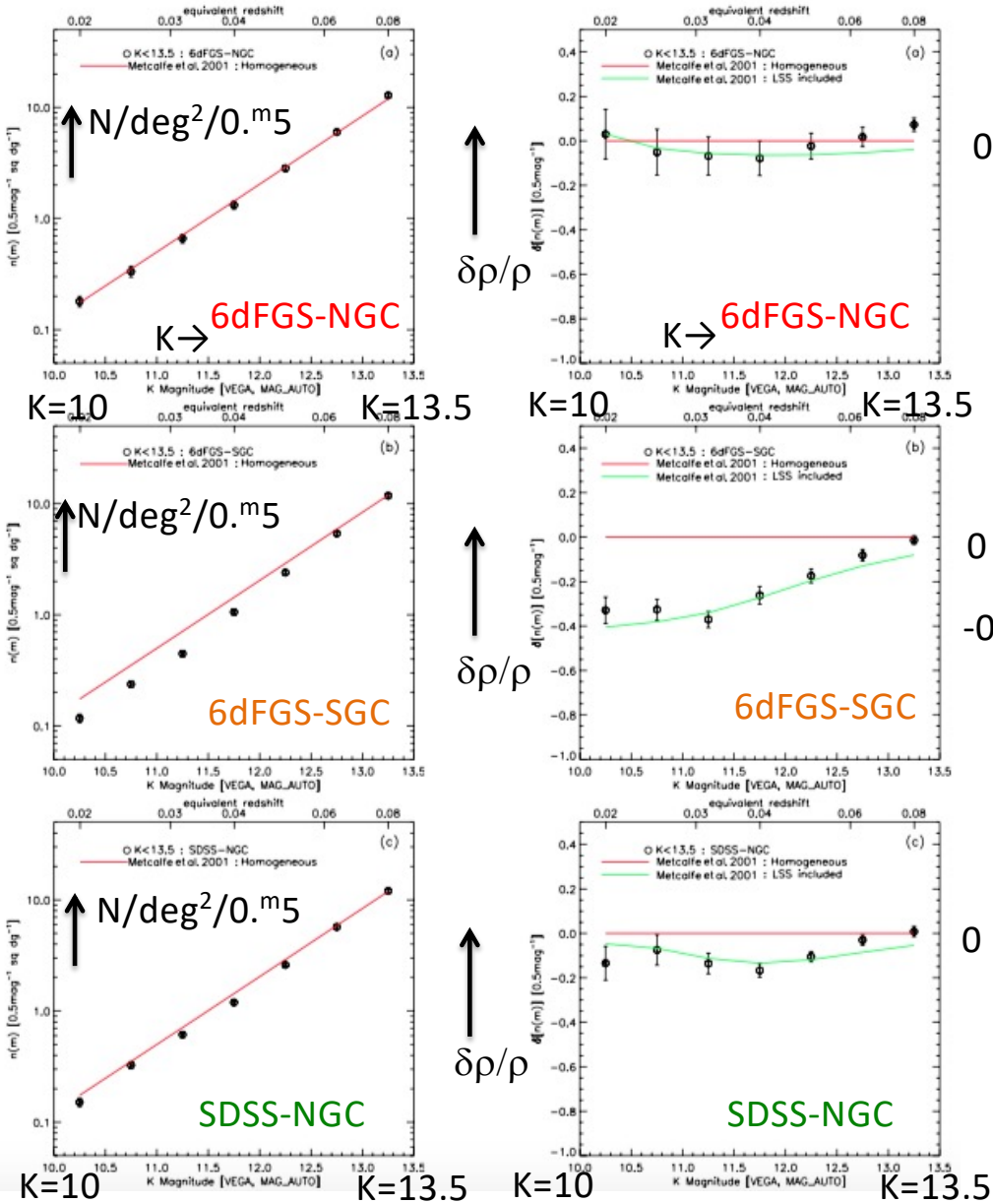
Left: $N(K)$, Right: $\delta\rho/\rho$

2MASS K calibrated to total via Loveday et al (2000)

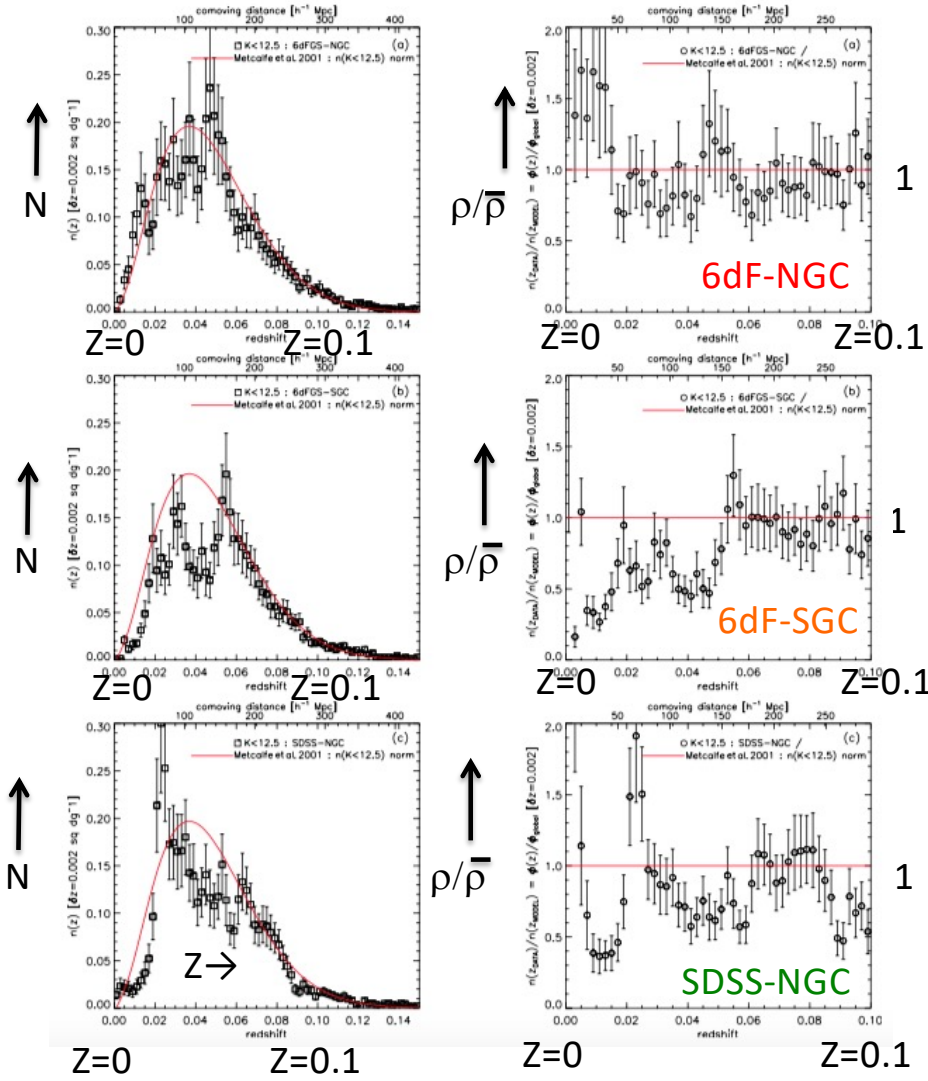
Red line: $N(K)$ PLE model (Metcalf et al 2005)

Green line: $N(z)$ consistency check

Underdensities seen in all 3 areas, particularly in 6dFGS-SGC (Whitbourn+Shanks 2014)



“Local Hole” – Galaxy N(z) K<12.5



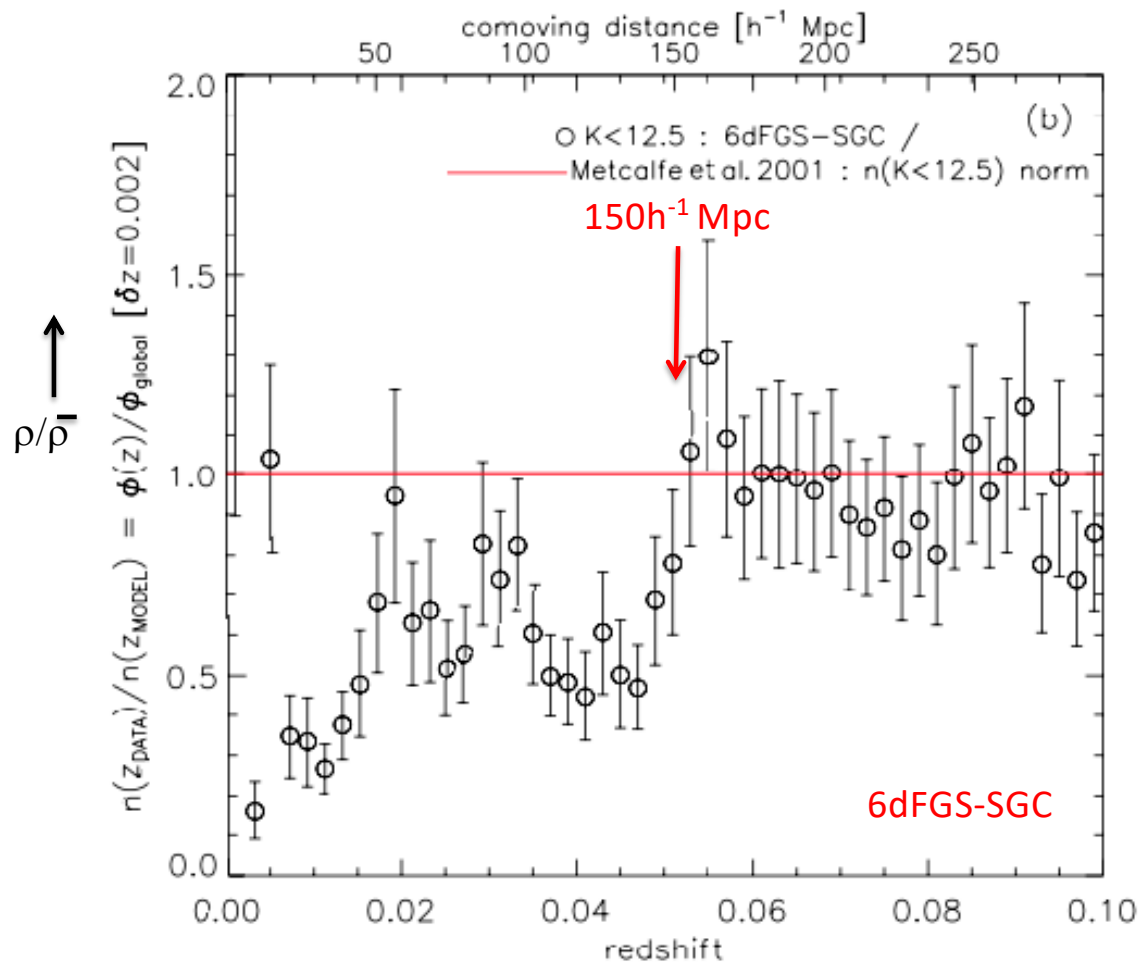
Left: $N(z)$, Right: $\rho/\bar{\rho}$

Red line: $N(z)$ PLE model (Metcalfe et al 2005)

Underdensities again seen in all 3 areas out to $z \sim 0.05$ or $\sim 150 h^{-1} \text{ Mpc}$, particularly in SGC.

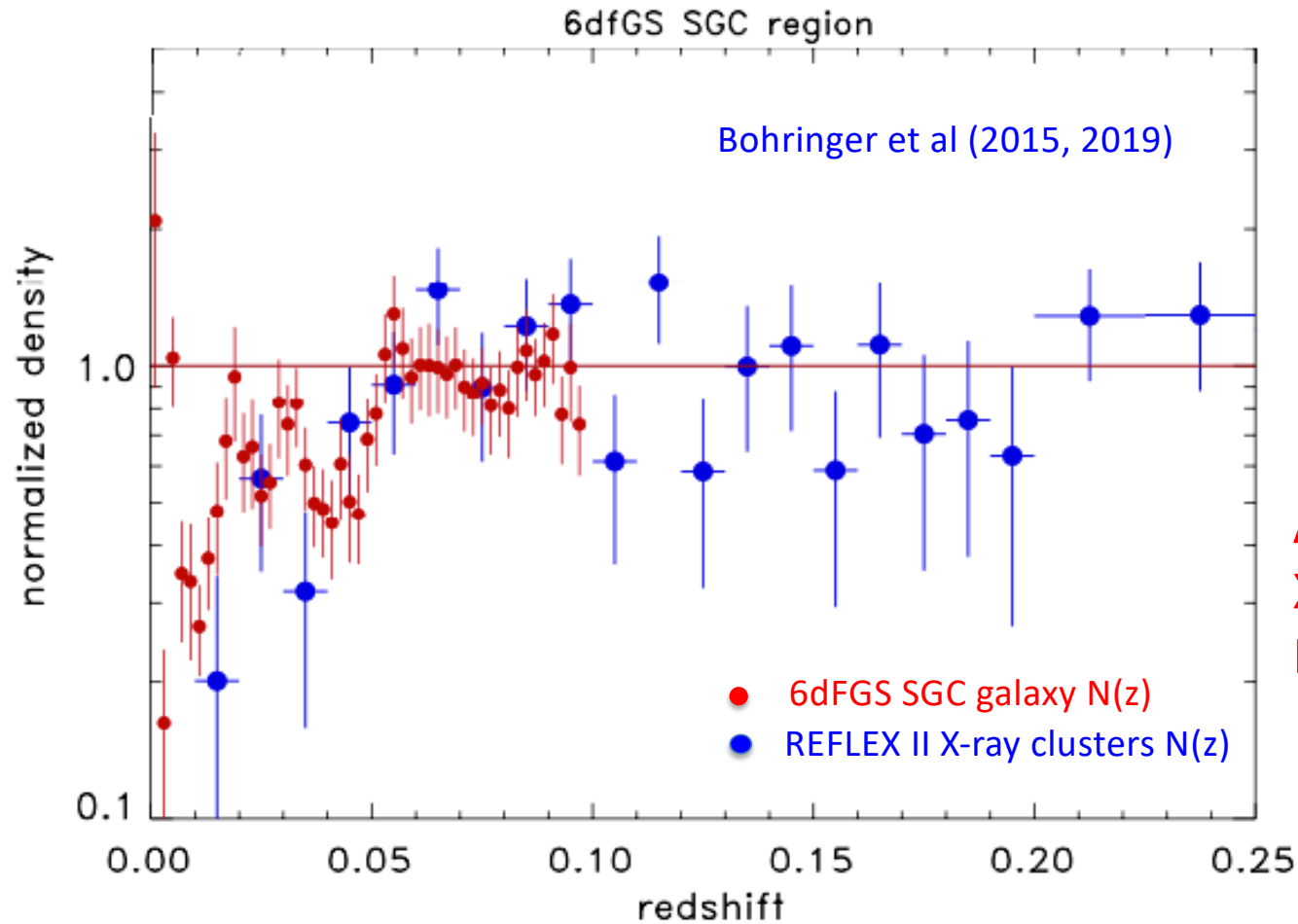
Overall median underdensity over $\sim 9000 \text{ deg}^2$ is $\sim 23\%$.

“Local Hole” - SGC $N(z)$ - $\sim 3000 \text{ deg}^2$



Whitbourn +
Shanks (2014)

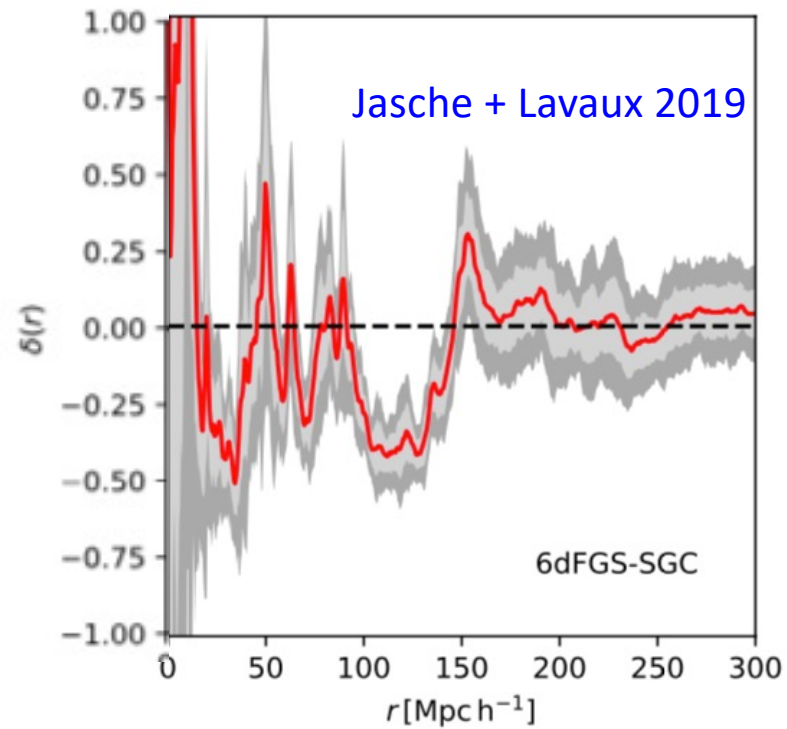
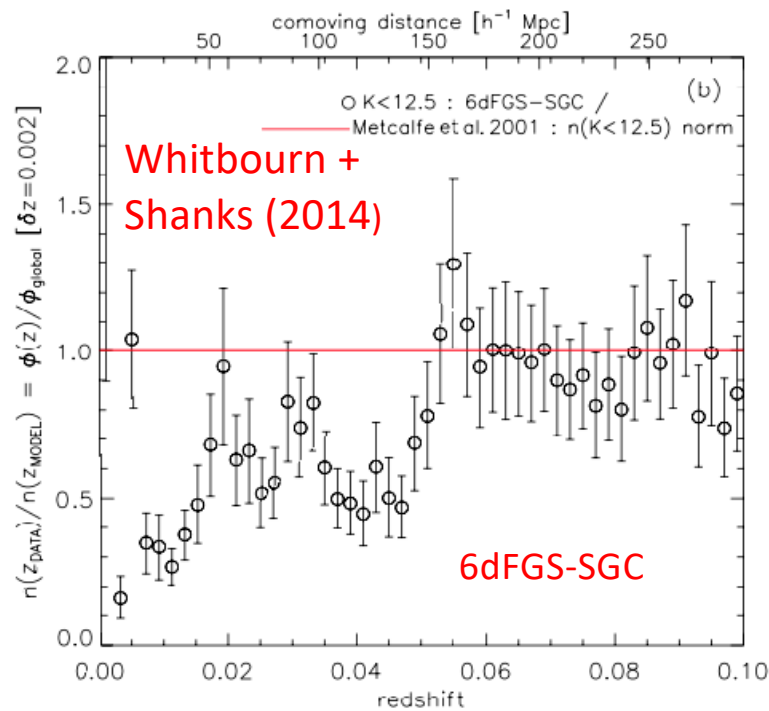
X-ray cluster vs. galaxy $n(z)$ comparison



WS14 found ~23%
underdensity in
 $r < 150h^{-1}$ Mpc

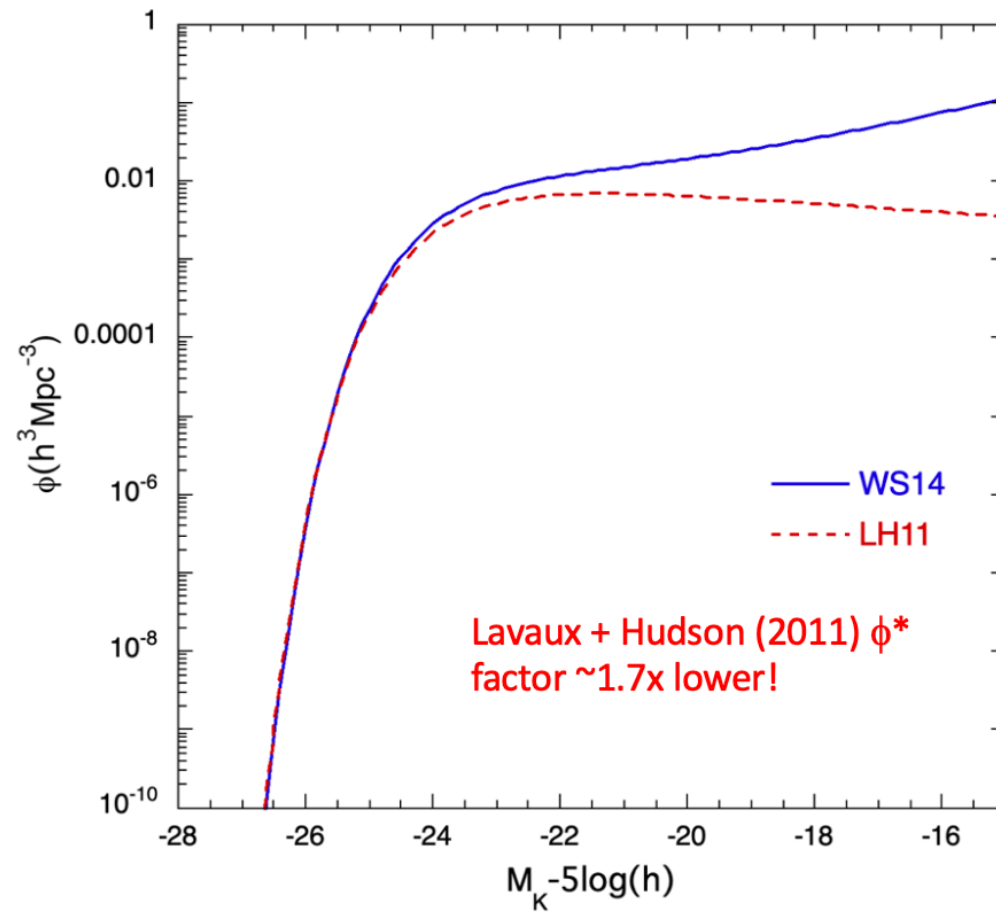
Agrees with
X-ray cluster
 $N(z)$!

WS14 vs Jasche & Lavaux (2019)

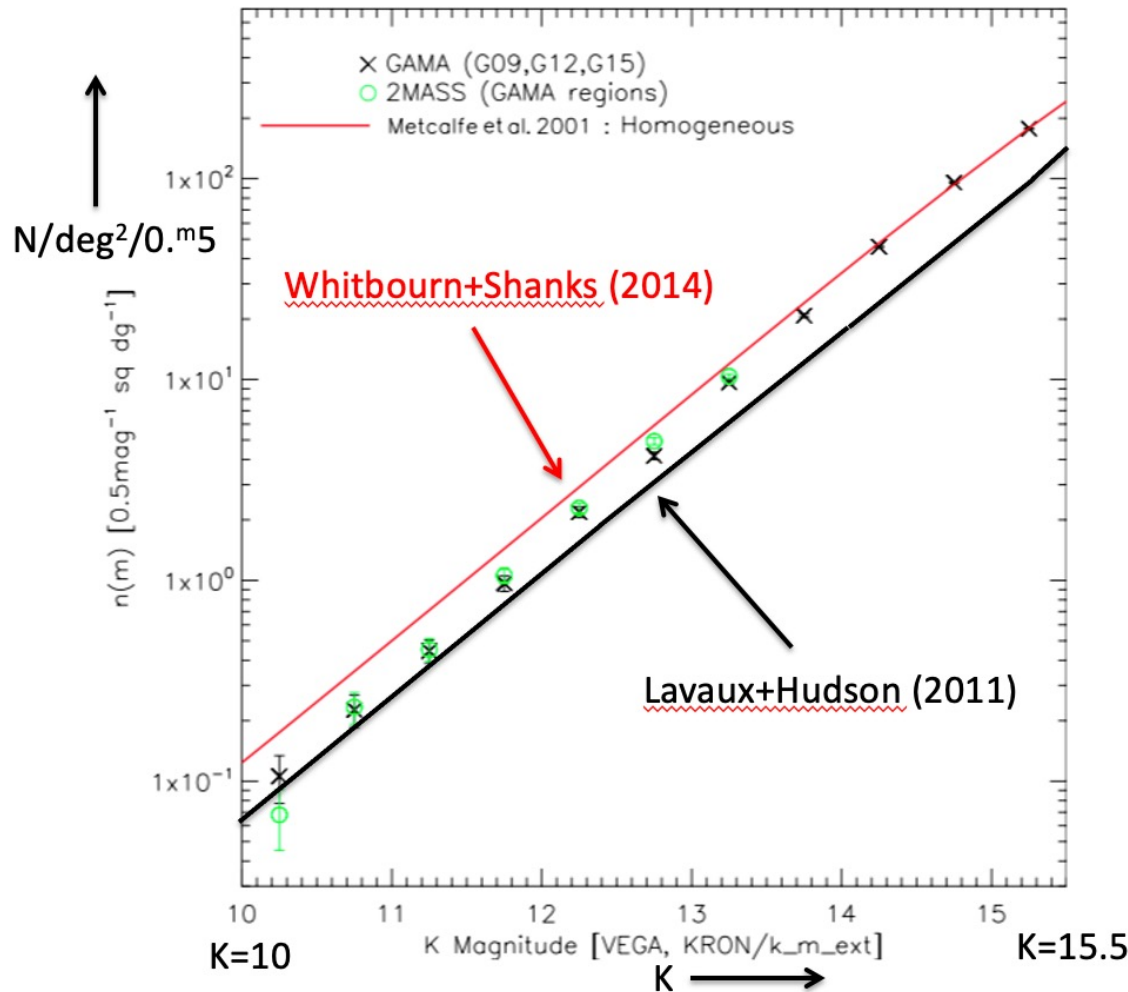


Jasche + Lavaux (2019) claim no “Local Hole” but depends on LF parameters...

WS14 vs LH11 Luminosity Functions



Local Hole – importance of LF ϕ^*



Vital to check LF ϕ^* normalisation from fainter K counts – WS14 used K counts in $3 \times 70\text{deg}^2$ GAMA fields.

Compare our model (red line) to Lavaux+Hudson (2011) LF model (black line).

LH11 model count $\sim 1.7\text{x}$ too low at $K \sim 15$ – their low LF ϕ^* normalises out Local Hole?

Riess rebuttal (2018)

SEVEN PROBLEMS WITH THE CLAIMS RELATED TO THE HUBBLE TENSION IN
ARXIV:1810.02595

ADAM G. RIESS,^{1,2} STEFANO CASERTANO,^{3,4} D'ARCY KENWORTHY,² DAN SCOLNIC,^{5,6} AND
LUCAS MACRI⁷

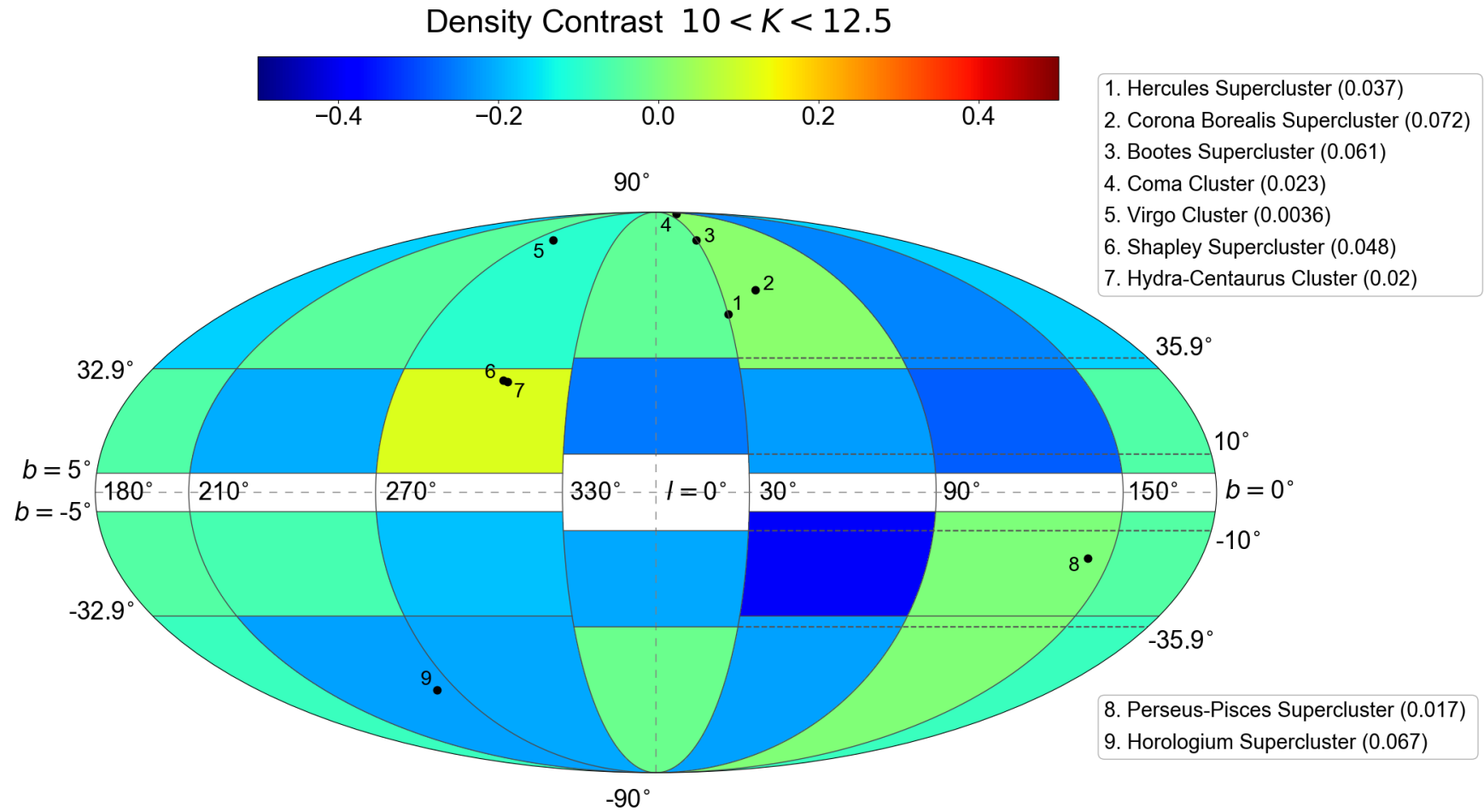
3. CLAIM B: THE LOCAL HOLE

Shanks et al. (2018) cites galaxy studies from Whitbourn & Shanks (2014) that show that over the $\sim 20\%$ of the sky they studied space is denser at $z > 0.05$ than at $z < 0.05$. They then assume that this feature persists over the 80% of the sky not similarly studied, i.e, they *assume a spherical structure* with the Milky Way located in a “local hole”. Its is important to stress that this model is dominated by an assumption, that 80% of the local Universe can be inferred from seeing 20% and guessing at a pattern, i.e., spherical symmetry centered on or near the Milky Way.

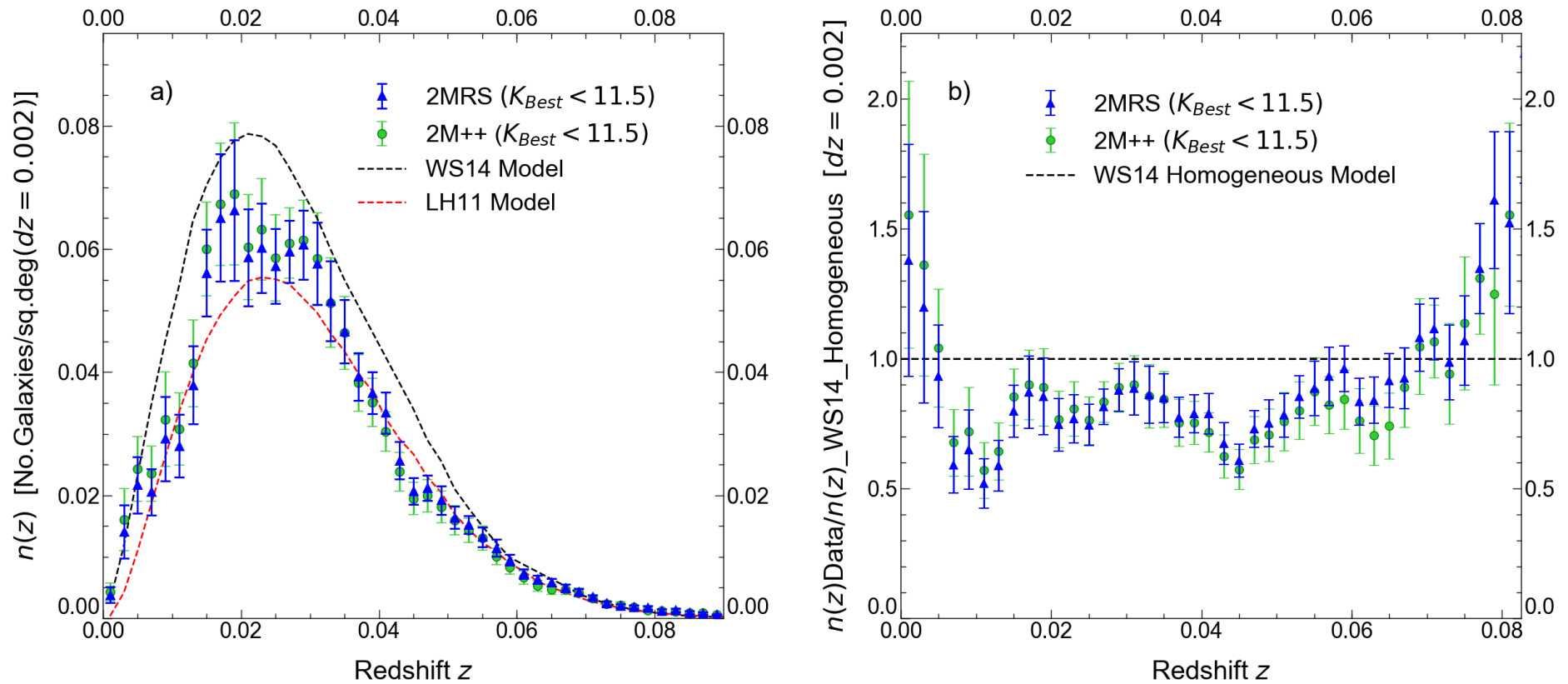
Riess complains that Local Hole of Whitbourn & Shanks (2014) at 9000deg^2 only covers $\sim 20\%$ of sky

So Wong et al (2022) exploit completeness of 2MASS Redshift Survey (2MRS) to $K=11.5$ to $|b|>5\text{deg}$ to explore 35000deg^2 covering 90% of sky.

2MASS counts to $K=12.5$

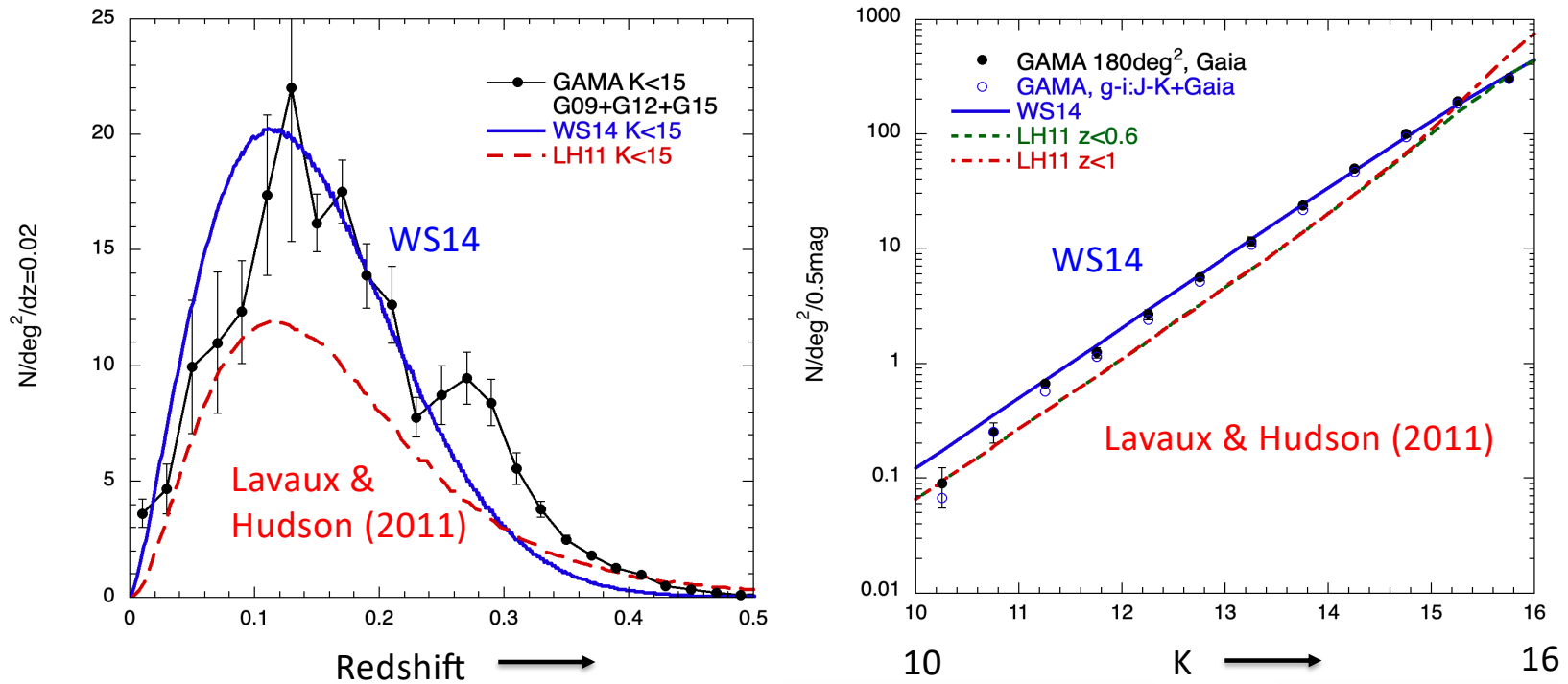


2MRS $K < 11.5$ “all-sky” $n(z)$



LH11 model suggests over density out to $z < 0.06$ rather than under density and fits better than WS14 model but....

GAMA Galaxy $n(z)$ and $n(K)$



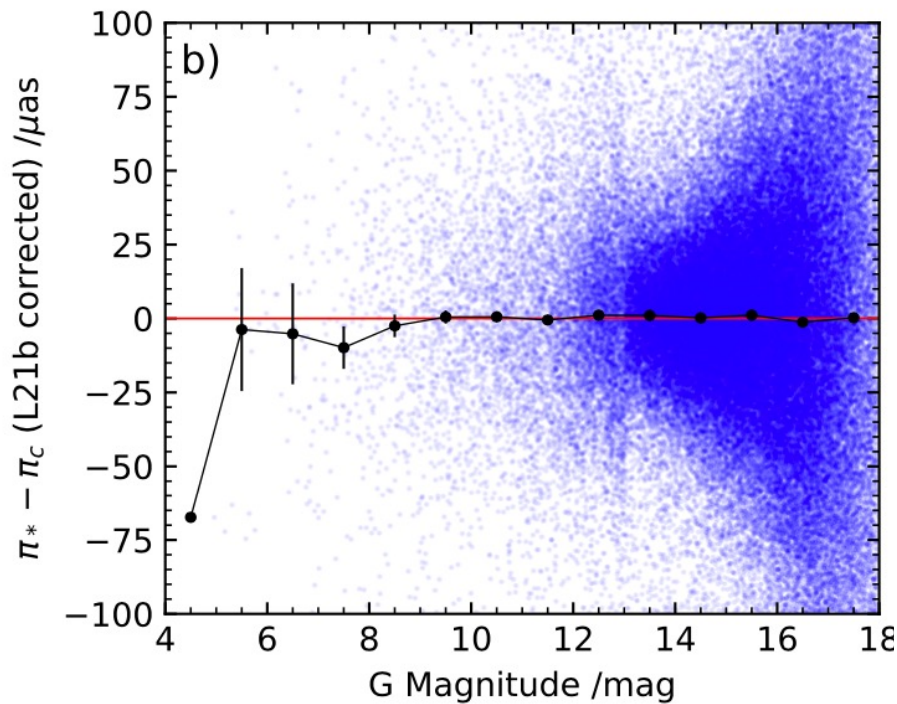
But Lavaux & Hudson (2011) model fails at $K > 11.5$, just outside range where it was fitted, underestimating observed GAMA G09+G12+G15 average $n(z)$ and $n(K)$ by $\sim 70\%$!

Whereas WS14 model fits GAMA $n(z)$ and $n(K)$ much better in this higher z , fainter range

Local Hole Summary

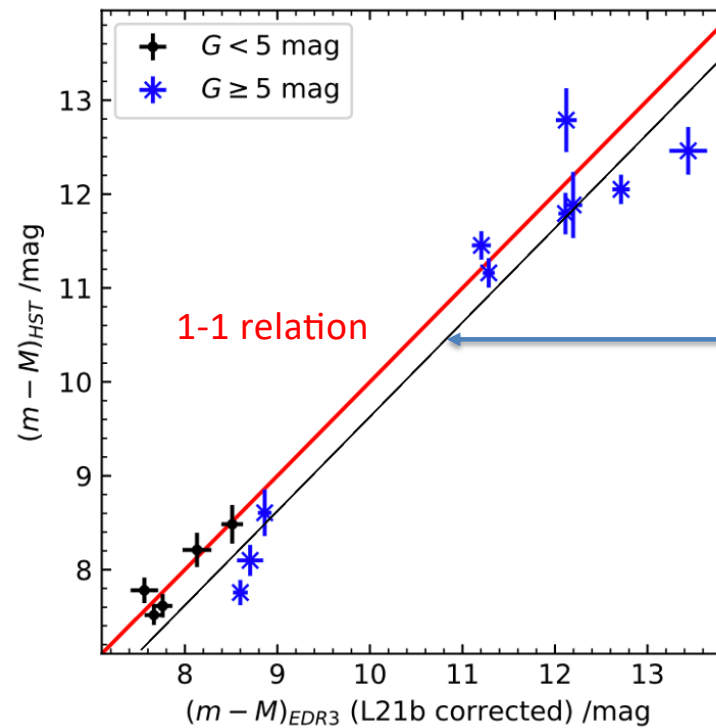
- So conclude LH11 model normalisation only works at $K < 11.5$ – they may have “normalized out” the Local Hole!
- Local Hole reduces SH0ES H_0 by 2.6%
- Other evidence of potential SH0ES error budget issues:-
 - Gaia vs HST Parallaxes
 - Variable Reddening Law?
 - Cepheid PL incompleteness bias

Open cluster Gaia parallax test



Conclusion: Gaia parallaxes OK even as bright as $G \sim 5$ mag (Kirkham et al 2023)

Gaia EDR3 v HST FGS/WFC Parallax distances



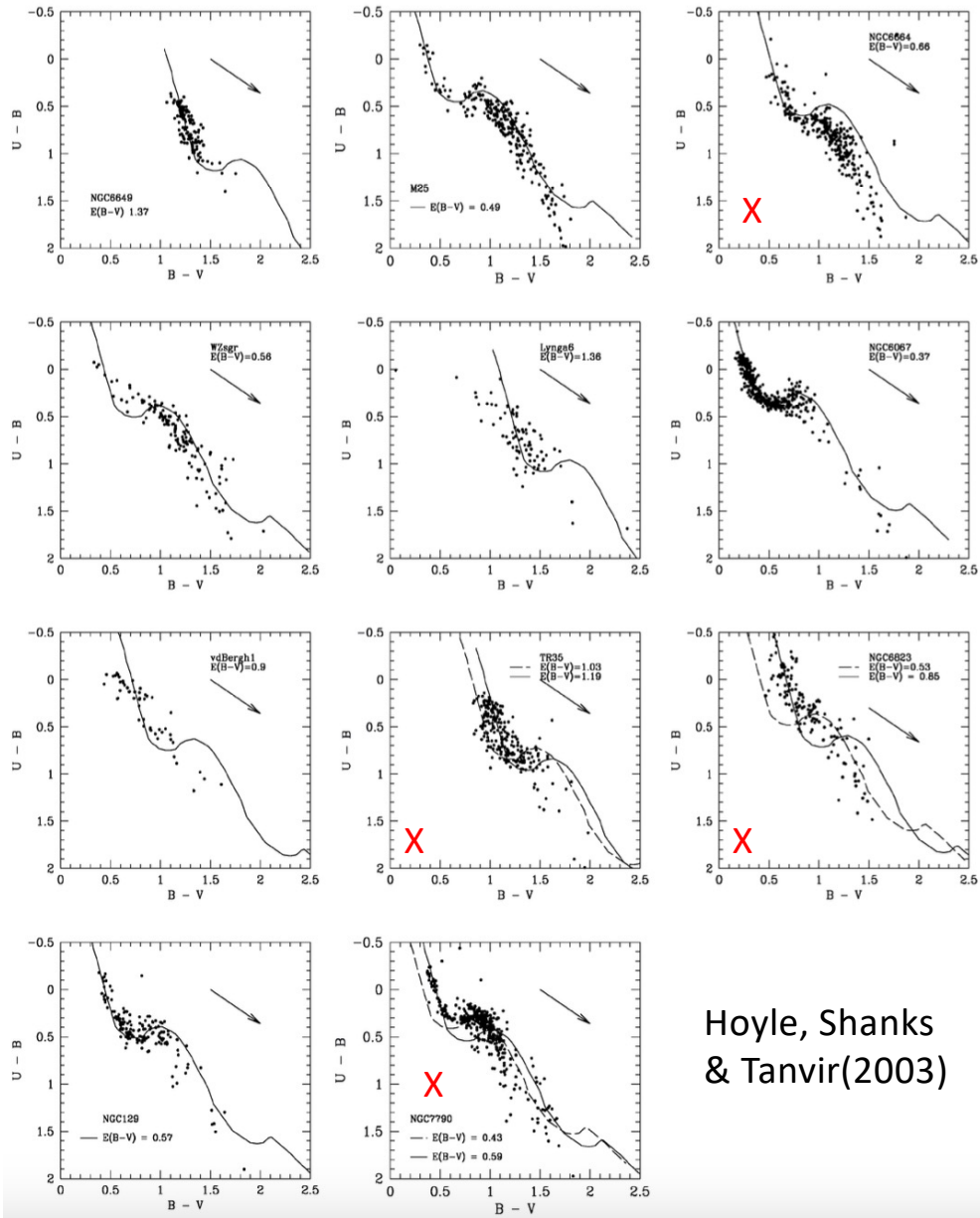
All 15 stars:
 $\Delta\mu = 0.181 \pm 0.003$ mag

10 stars with $G > 5$ mag
 $\Delta\mu = 0.285 \pm 0.005$ mag)

Contradicts claim that Gaia confirmed HST MW Cepheid distance scale of Riess et al

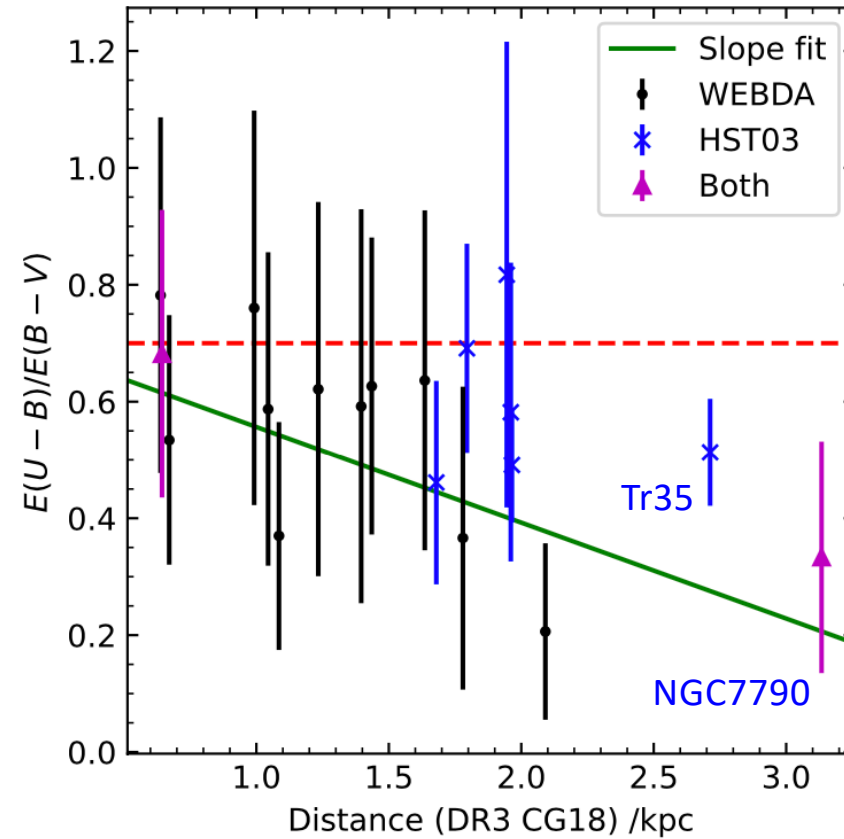
But this ~ 9 -14% reduction in H_0 offset by NGC4258 maser and DEB changes!

Shanks et al (2018)



Hoyle, Shanks & Tanvir(2003)

Variable Reddening Law?



Ratio of selective to total extinction may vary from $R \sim 3.3$ locally to $R \sim 4$ at 3kpc

Kirkham et al (2023) - see also Fitzpatrick (1999), Follin & Knox (2018), Mortsell et al (2022a,b)

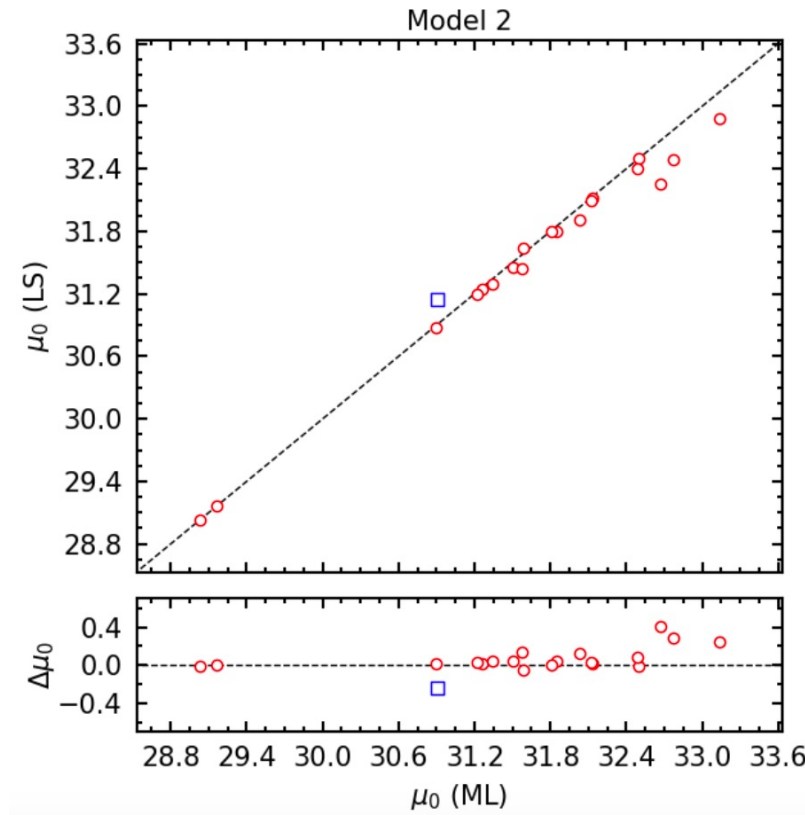
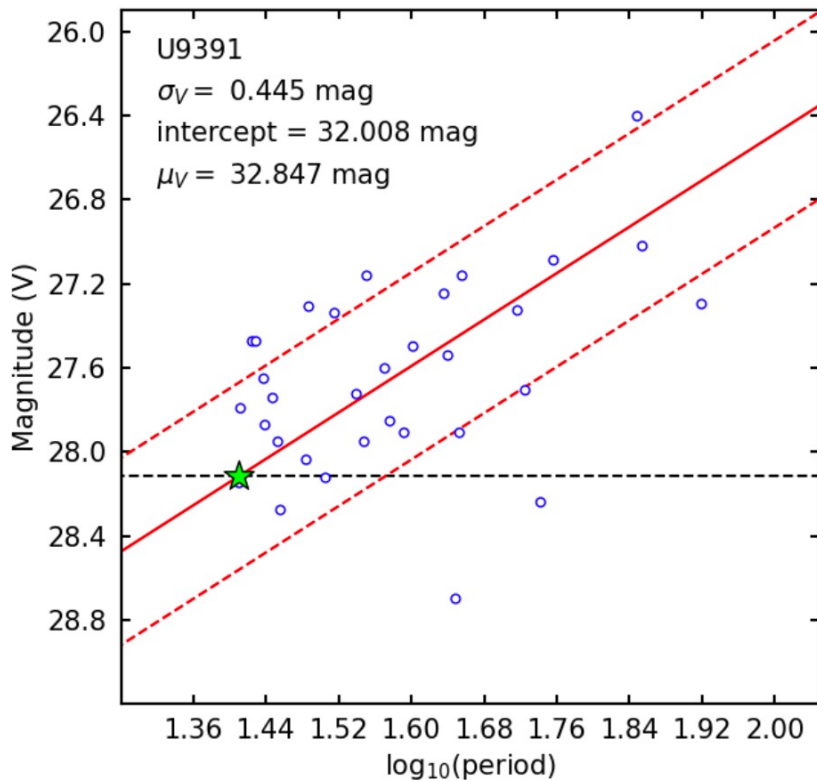
When Walter Baade was asked:-

“If you had your life to live over, would you be an astronomer again?”

He answered:

“Only if the ratio of total to selective absorption is everywhere the same.”

Cepheid incompleteness bias



PL relations can become sparse at large distances

Cepheid detection limit

- 1) Suppresses PL scatter
- 2) Distances underestimated




ML distances show bias of 3% overall

And suppressed scatter allows even larger bias (Allen+Shanks 2004, Guerrero et al 2021)

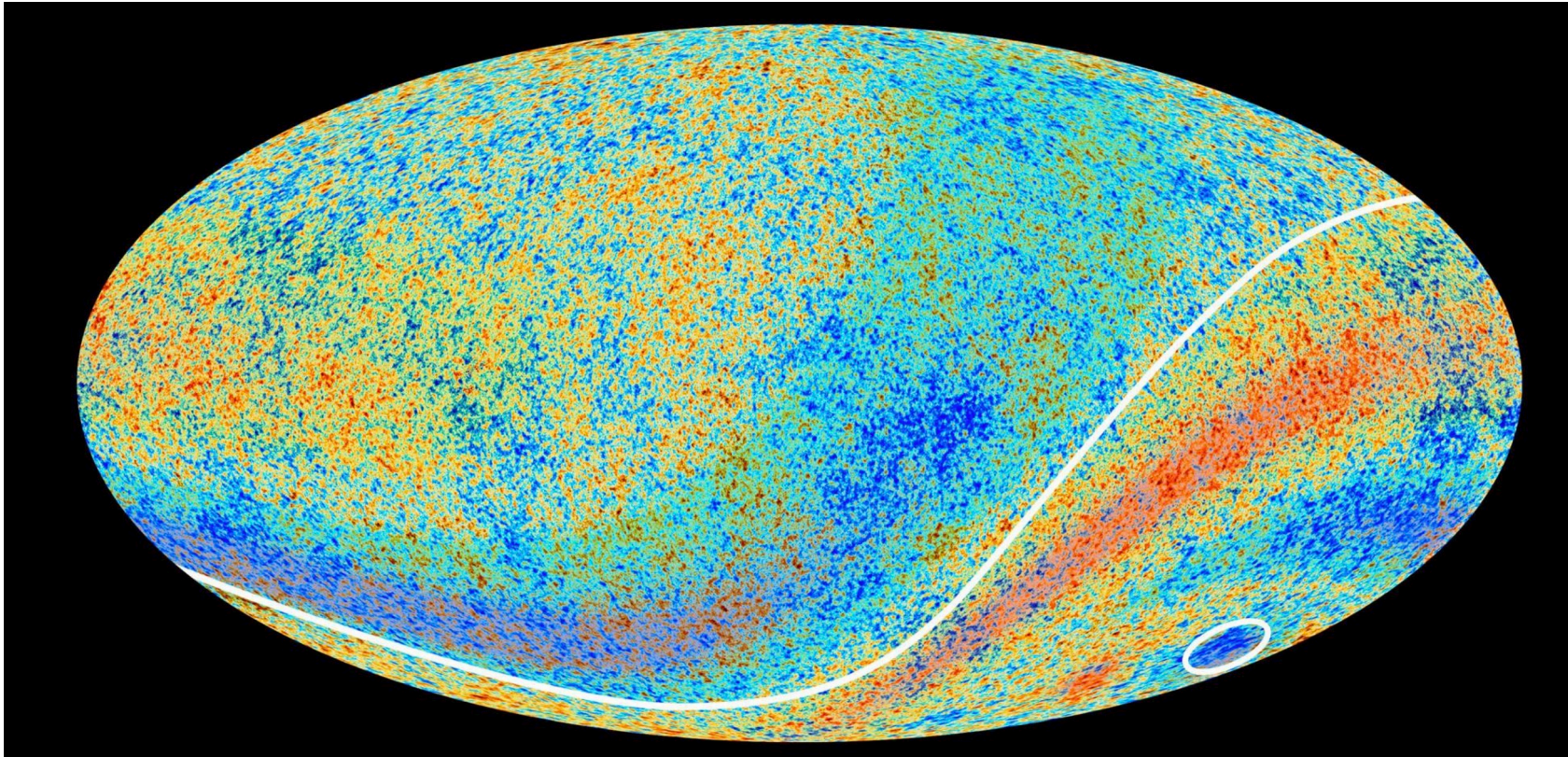
H₀ Tension Summary

- Local Hole reduces SH0ES H₀ by 2.6%
- Other evidence of potential SH0ES error budget issues
 - HST KP Cepheid parallax distances ~9-14% too small compared to Gaia
 - Variable Reddening Law? R~3.3 locally to R~4 at 3kpc
 - Cepheid PL incompleteness bias – lowers H₀ via MW Cepheids by ~3%
- Applying Local Hole correction gives H₀=71.1±1.04 v 67.74±0.46 -> tension reduced from 4.7 to 3.0σ
- (Then applying eg PL incompleteness bias gives H₀=69.0±1.0 v 67.74±0.46 - tension reduced from 4.7 to 1.1σ)
- But leaves new Local Hole in 4σ tension with ΛCDM!
- So no advance.....??

Local Hole links to other LSS Anomalies?

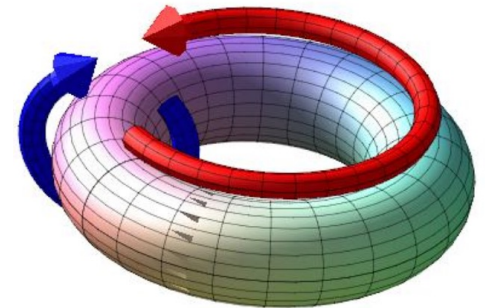
- Local Supercluster – sheet structure (Peebles 2023)
- The CMB “Axis of Evil” (de Oliveira-Costa et al 2004) 
- The CMB Cold Spot (Vielva et al 2004) 
- Coherence of LSS in SGC – Mackenzie et al (2017 MNRAS, 470, 2328) c.f. Broadhurst, Ellis, Koo & Szalay (1990, Nature 343, 726) 
- Anisotropic $z \sim 1.5$ QSO distribution – Secrest et al (2022)

CMB “Axis of Evil” => non simple universal topology?



“What if, perhaps we see the same things on both sides of the *axis of evil* because *they are literally the same things* and the universe has wrapped around on itself? ”

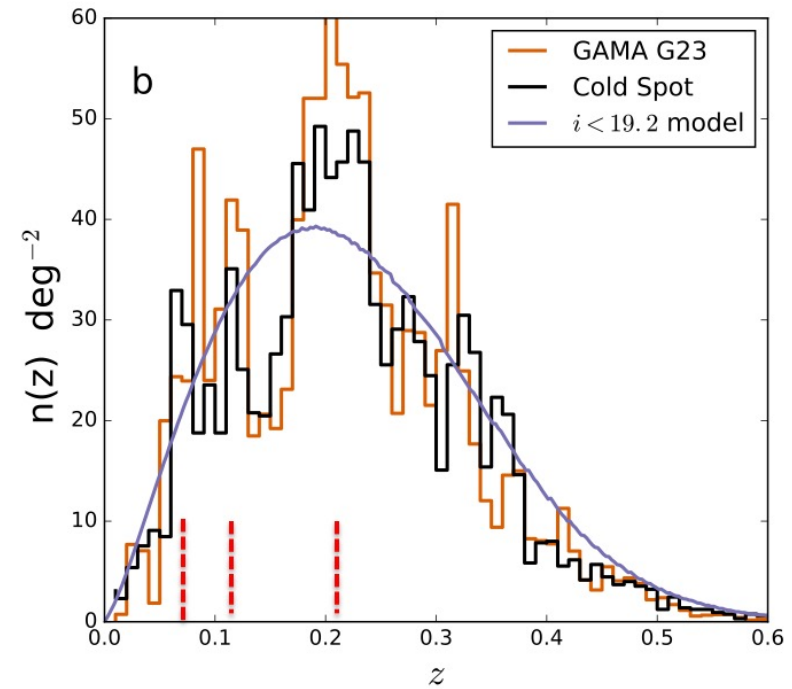
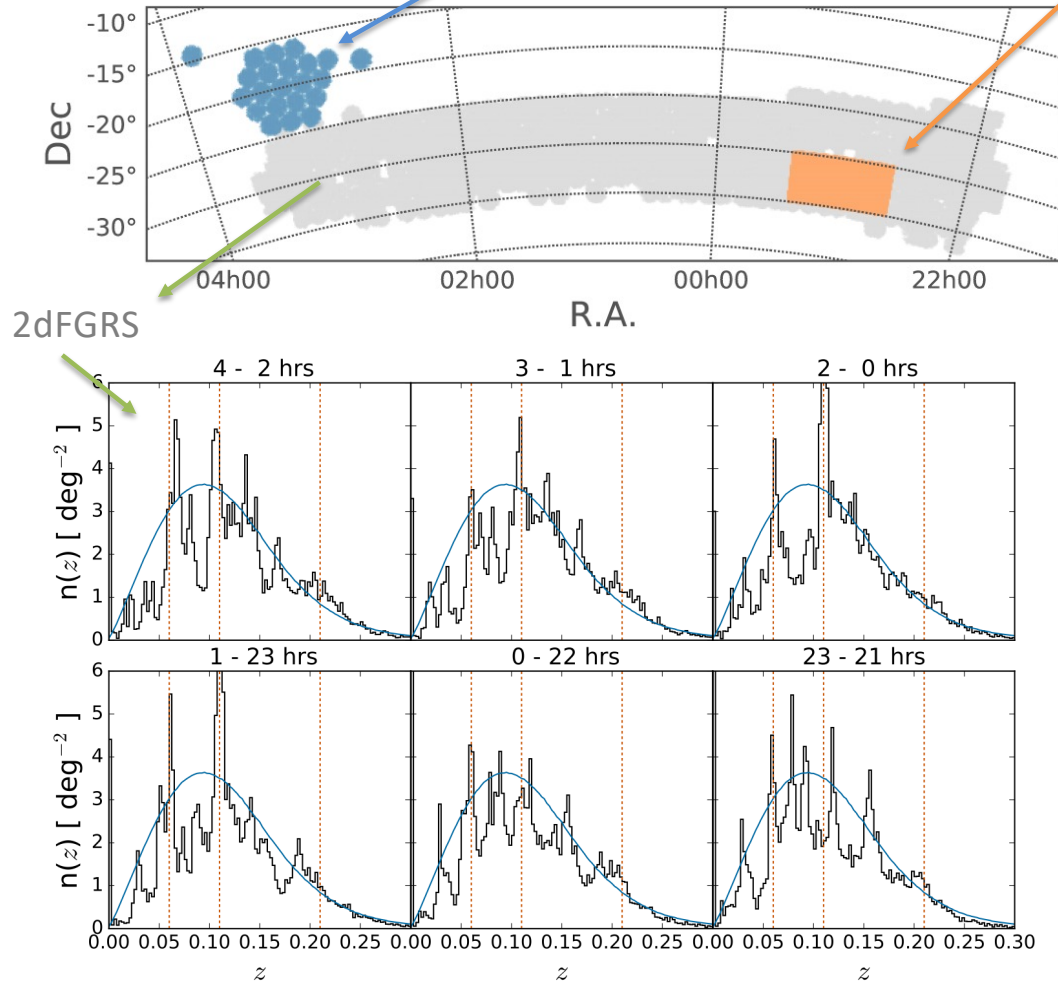
de Oliveira-Costa et al
(2004 Phys. Rev. D **69**,
063516)



Like ‘ant on doughnut’

But see Stevens et al
(1993) - restricts any
wraparound to 1 spatial
dimension?






Cold Spot v GAMA G23 $n(z)$



Striking similarity of galaxy $n(z)$ in Cold Spot and G23 “control” field even though separated by ~ 70 degrees on sky. Or $\sim 700h^{-1}\text{Mpc}$ at $z \sim 0.2$!

(Mackenzie et al 2017 c.f. Broadhurst et al 1990)

Local Hole links to other LSS Anomalies?

- Local Supercluster – sheet structure (Peebles 2023)
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- Anisotropic $z \sim 1.5$ QSO distribution – Secrest et al (2022)
- Evidence for non-simply connected topology? 
- Could “small universe” make Local Hole statistically more compatible with Λ CDM?? 

Summary

- Local Hole reduces SH0ES H_0 by 2.6%
- Other evidence of potential SH0ES error budget issues
 - HST KP Cepheid parallaxes 9-14% larger compared to Gaia
 - Variable Reddening Law? $R \sim 3.3$ locally to $R \sim 4$ at ~ 3 kpc?
 - Cepheid PL incompleteness bias – lowers H_0 via MW Cepheids by $\sim 3\%$
- Applying Local Hole correction gives $H_0 = 71.1 \pm 1.04$ v 67.74 ± 0.46
-> tension reduced from 4.7 to 3.0σ
- But need “new physics” to solve “Local Hole- Λ CDM tension” e.g. does Universe have non-simply connected “slab” topology?

Outflow model vs $\bar{z}:m$ vs SNIa

