Mapping of the largest structures in the Universe

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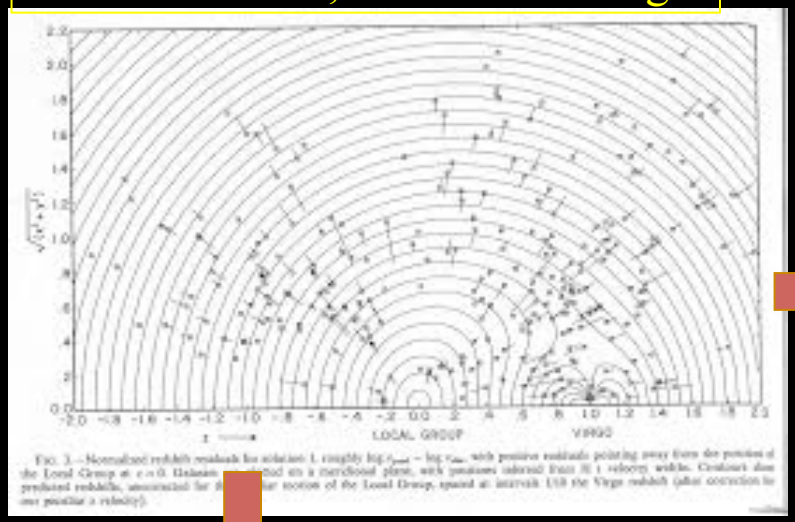
- From the smallest to the largest structures
- Large Superclusters versus standard cosmology
- What about the 'nearby' Vela SCL
  - Overview
  - Comparisons with reconstructions (CF2 & CF3)
  - Future Plans: MeerKAT & Taipan

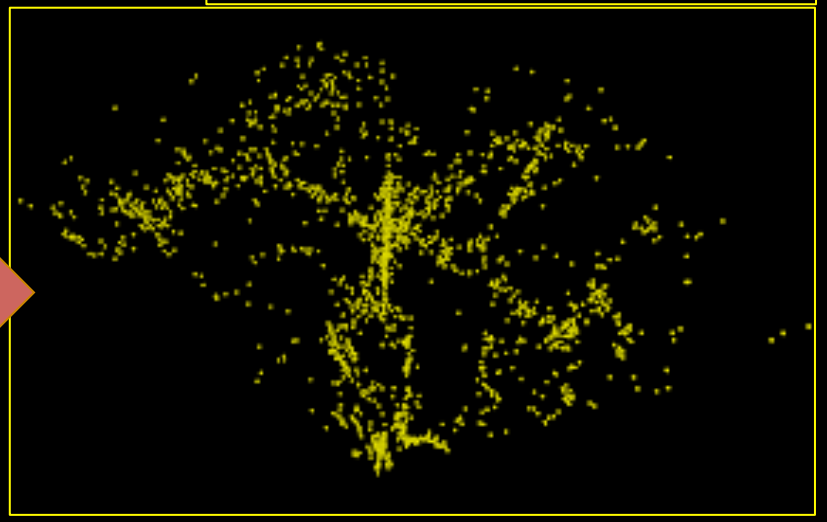
Feast Fest: Trends in Astronomy
SAAO, 31 July 2017

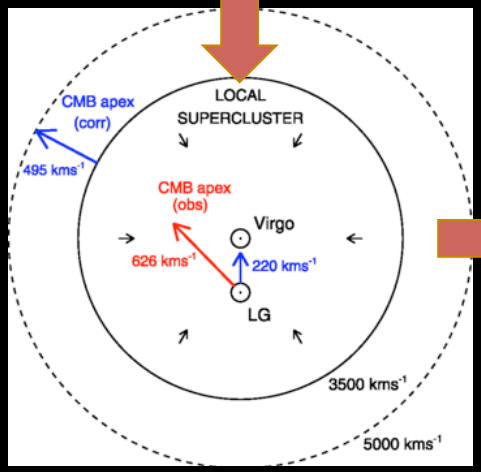
The uncovered structures got larger and larger ….

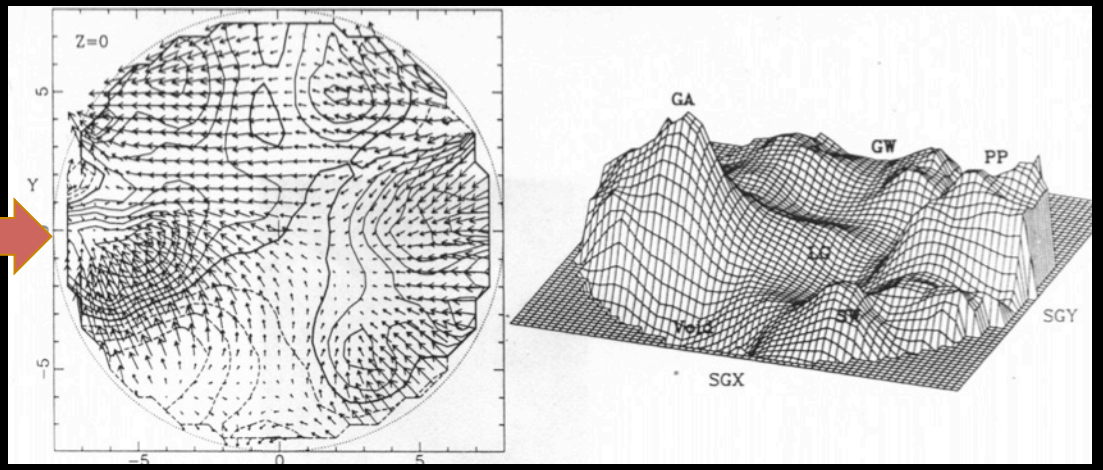
Our Local SCL; centered on Virgo



Coma in the Great Wall, CFA







→ And now we are all living the Laniakea Supercluster
(diameter ~ 160 Mpc; ~ 10^{17} $M_\odot$ *Tully+ 2014*)

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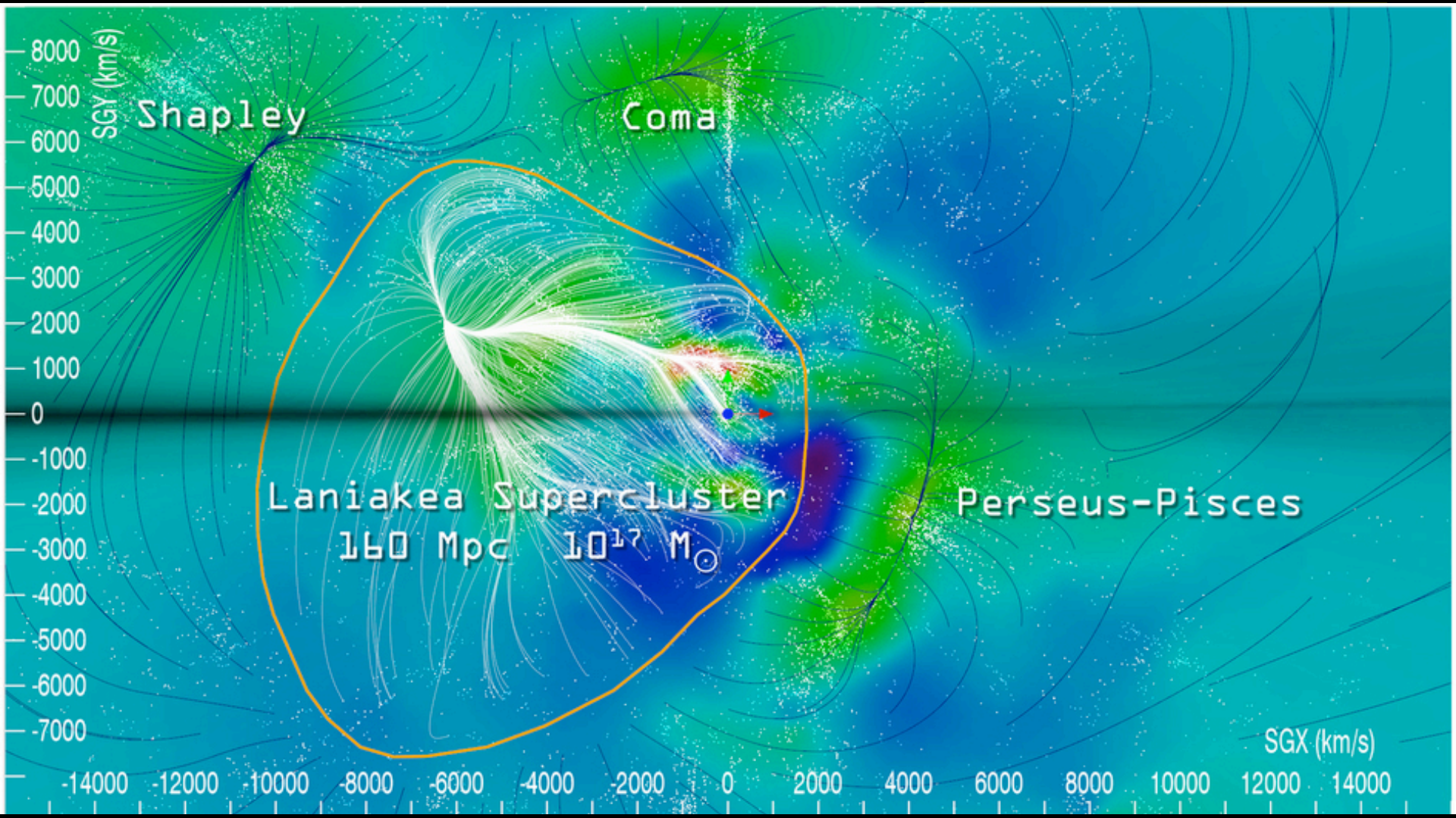


→ And now we are all living the Laniakea Supercluster (diameter ~ 160 Mpc; ~ 10^{17} $M_\odot$ *Tully+ 2014*)

Superclusters

- The largest (up to ~ 100Mpc) coherent structures in the Universe

  → Universe homogenous on scales of ~100Mpc

- SCL's have large masses: from a few times 10^{15} − a few 10^{16} $M_{\odot}$ (e.g. Shapley)

- Full superclusters are not bound - still in formation in today *(e.g. Einasto+ 2016)*

  → complex morphology, can be multi-branching of filaments and walls

  → high density cores are mostly still collapsing; or will in future evolution

- High-density cores are older & dynamically more evolved than outskirts

However, quite a few extreme superclusters have been discovered recently

  → larger than expected (> ~ 200 Mpc)

  → at higher redshift (z~0.3-0.4), partly with collapsed cores

  → too many in local Volume

Against common wisdom of SCL's − and possibly ΛCDM

Shapley Supercluster Wall (SSC)

-Announced as a dense cloud of galaxies by *Shapley 1932*

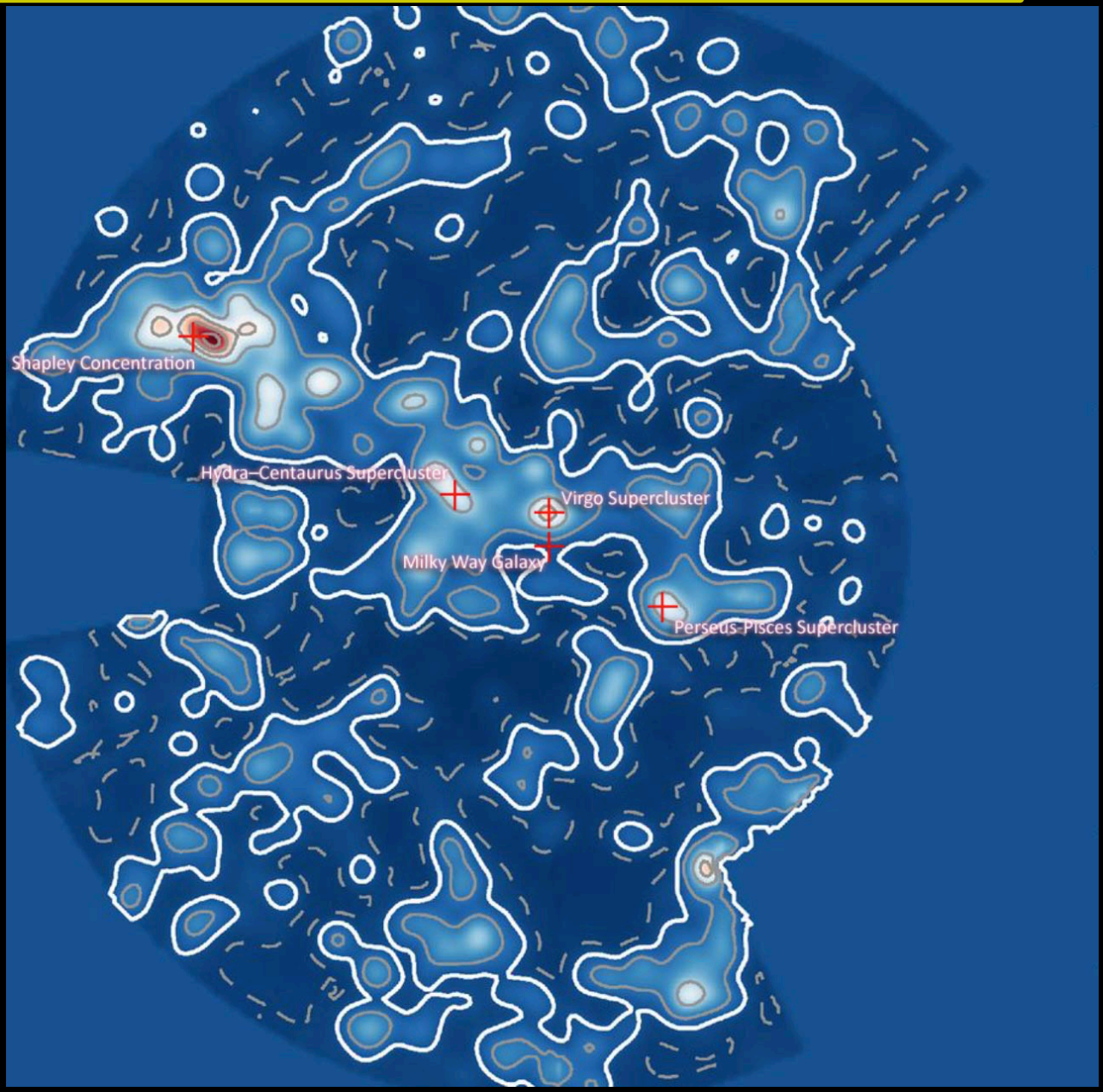
-Fully mapped (APM), while hunting for GA overdensity *Raychaudhury 1989*

Centrally condensed, full of high mass clusters *Raychaudhury+1991, Proust+2006*

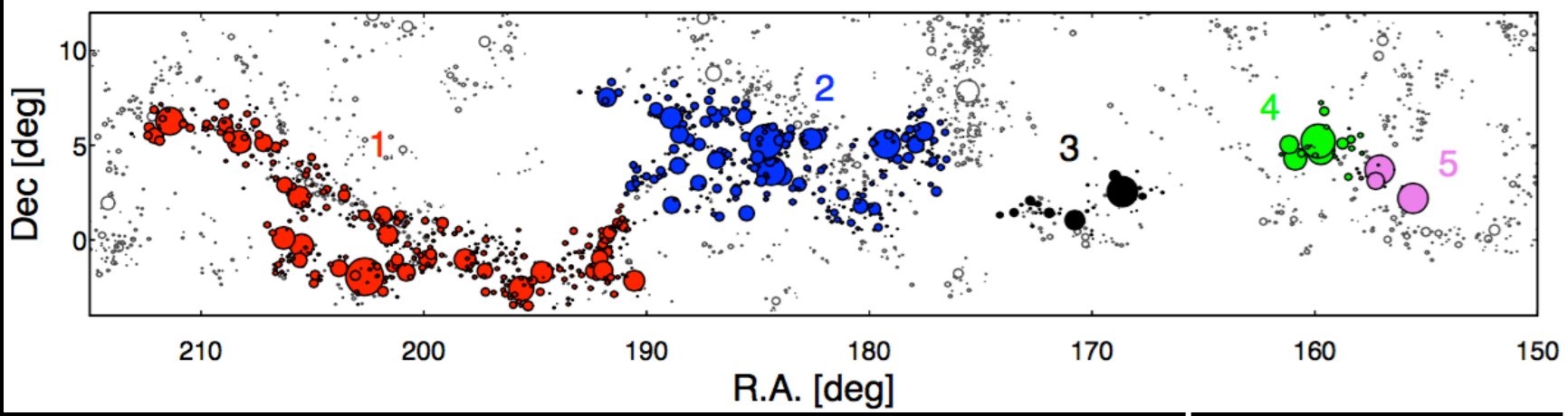
Controversy about its contribution to bulk flow since early 90's

V_{LG}: 50 - 150 km/s

Raychaudhury+ 1991, Munoz & Loeb 2011, versus Kocevski & Ebeling 2005



Sloan Great Wall (SGW)



Einasto+ 2016, A&A

Complex of 5 superclusters at ~ 200 – 260 h^{-1} Mpc (surveyed volume 120 -360Mpc)

- contains about 6000 massive galaxies
- two large SLC's, massive and elongated (about diameter ~ 100 and 50 Mpc each)
- but have multiple collapsed cores (3 and 2 each)

The 2 main clusters each have a mass between 1.2 – 6 x 10^{15} $M_\odot$

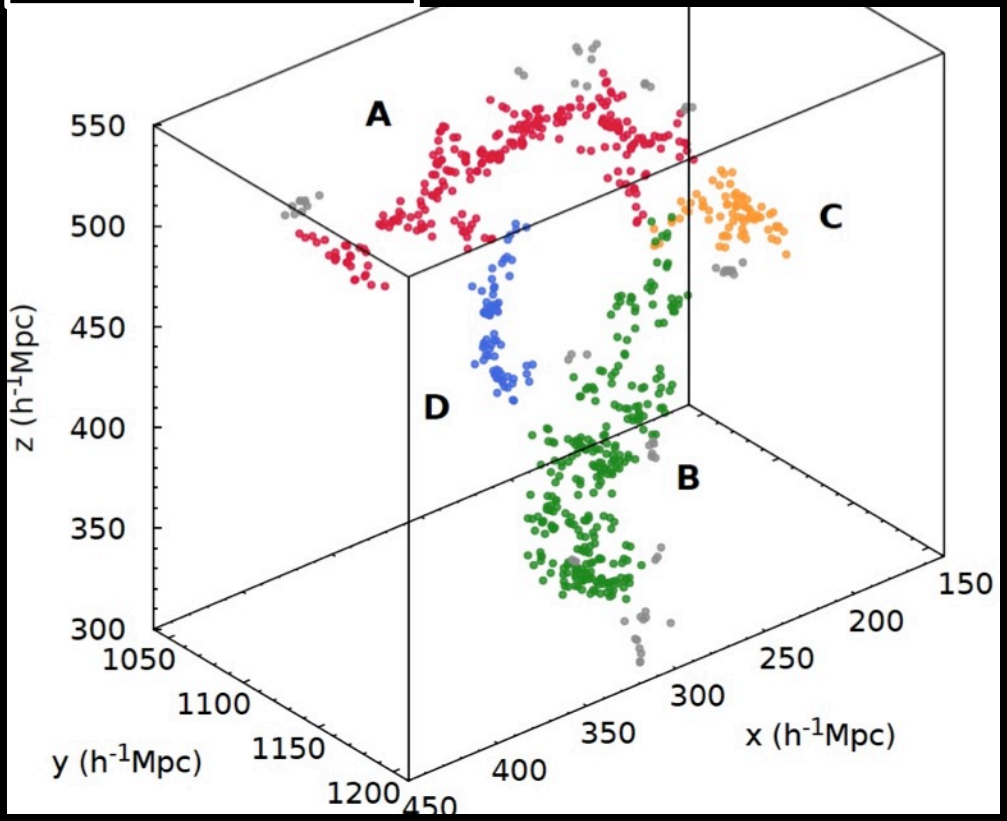
Estimated mass of whole complex: 2.5 x 10^{16} $M_\odot$

→ Shapley and Sloan: 2 major SCL's in nearby Universe - A conundrum for ΛCDM?
apparently not. According to *Sheth & Diaferio 2011* for the case of SSC

"as long as no other similar objects are within 200h^{-1} Mpc centred around Galaxy"

BOSS Great Wall (BGW)

Lietzen+ 2016, A&A



Supercluster at z ~ 0.47 (~ 1200 h^{-1}Mpc)

Complex of 4 superclusters:

2 massive walls (A & B) of

A: 186 h^{-1}Mpc; 6 x 10^{16} h^{-1} $M_\odot$
B: 173 h^{-1}Mpc; 4 x 10^{16} h^{-} $M_\odot$

plus 2 smaller walls (B & C)

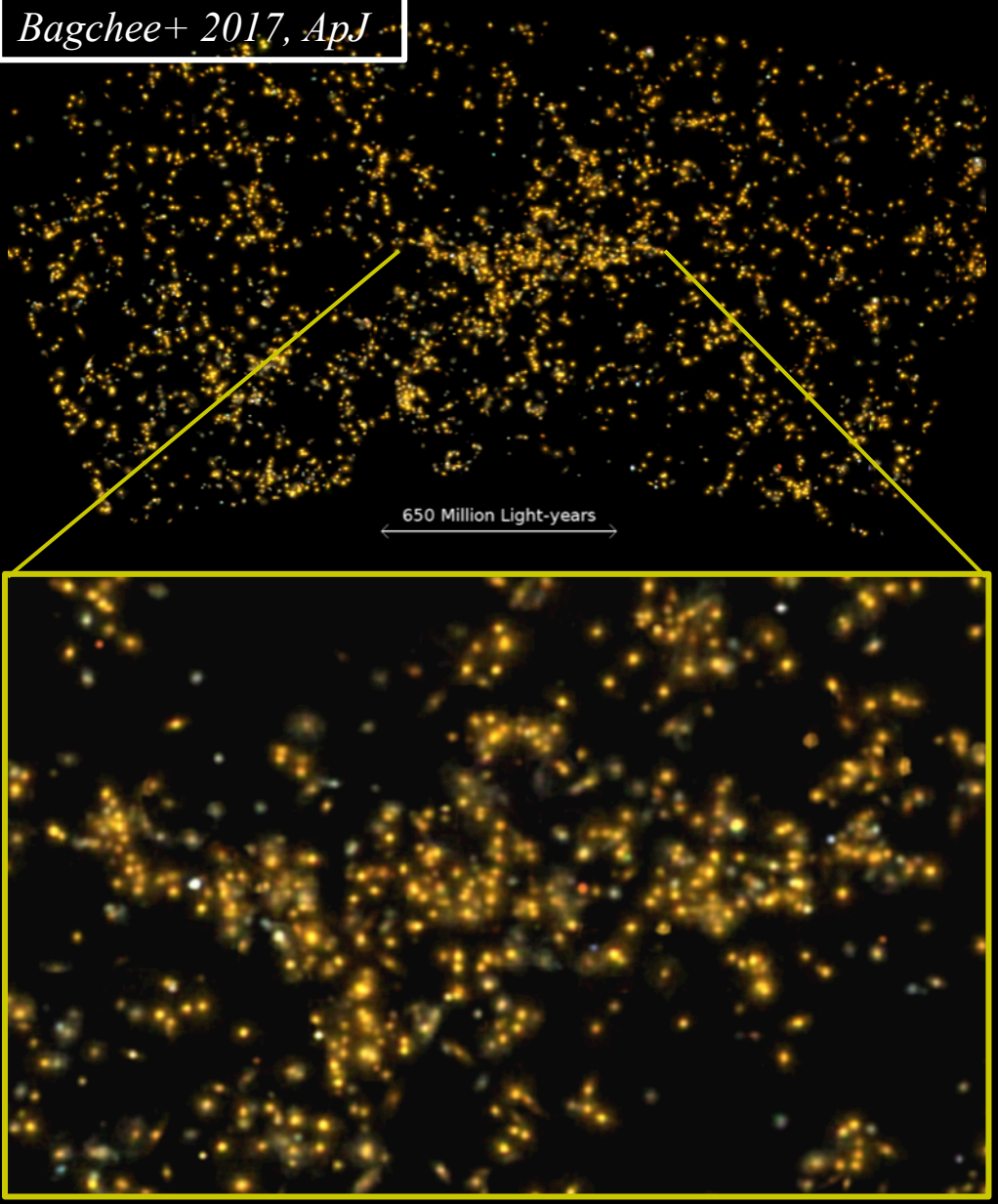
→ total: 270 h^{-1}Mpc; 2 x 10^{17} h^{-1} $M_\odot$

- Morphology similar to Sloan GW
- but larger
- Previously only smaller SCL at high z
- Very rare in simulations
  (e.g. Horizon Run 2; Parker 2012)

- Is it the most massive SCL in the Universe (known so far)?
- Does its extent & mass fit current structure formation models?
- Does it comply with standard ΛCDM?

Saraswati Great Wall

Bagchee+ 2017, ApJ



Identified in SDSS, examined with LBS
(LEGACY-BOSS-SOUTHERN)

at z ~ 0.3 (distance ~ 800 Mpc)
Also elongated (diameter ~270Mpc)
containing 43 massive clusters

→ total: 270 h^{-1}Mpc; 3 x 10^{16} $M_\odot$

→ Density contrast comparable to Shapley (1.62)

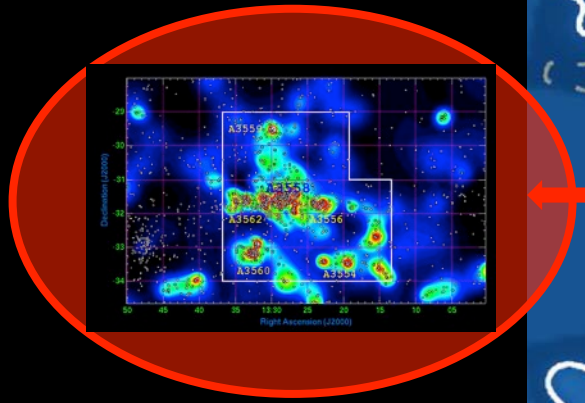
- Saraswati not yet fully collapsed
- but is SCL *(according to Chon+15)*

→ *„How can Sarasawti have formed already (4b yrs ago)?*
→ *DE had just started to dominate structure formation:*“

At z~0.37: $\Omega_\Lambda \cong \Omega_m$
→ *did major growth of LSS start much earlier?*

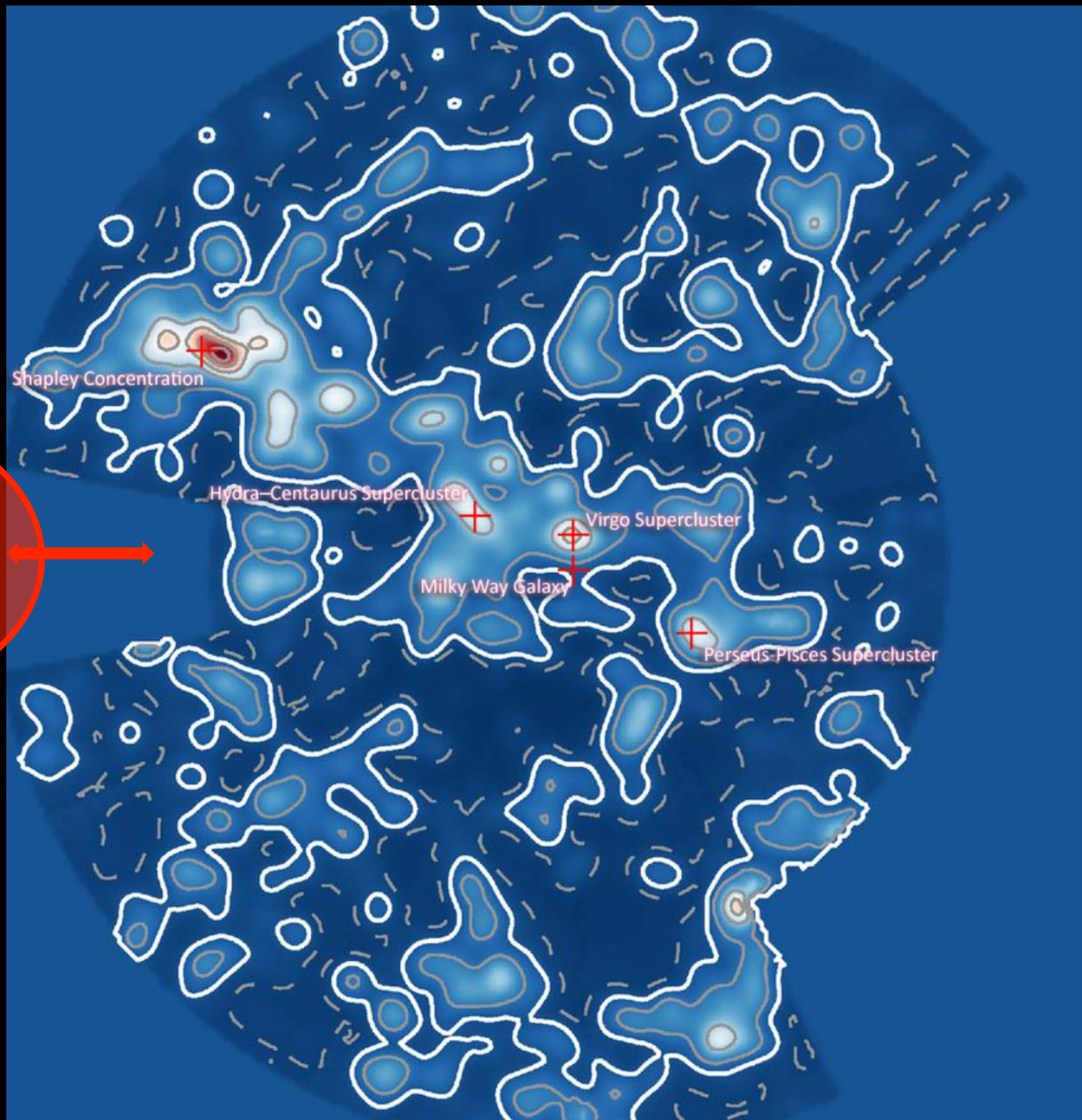
Discovery of another nearby supercluster:

In the ZOA



The Vela Supercluster

- A near clone to Shapley
- And in close proximity

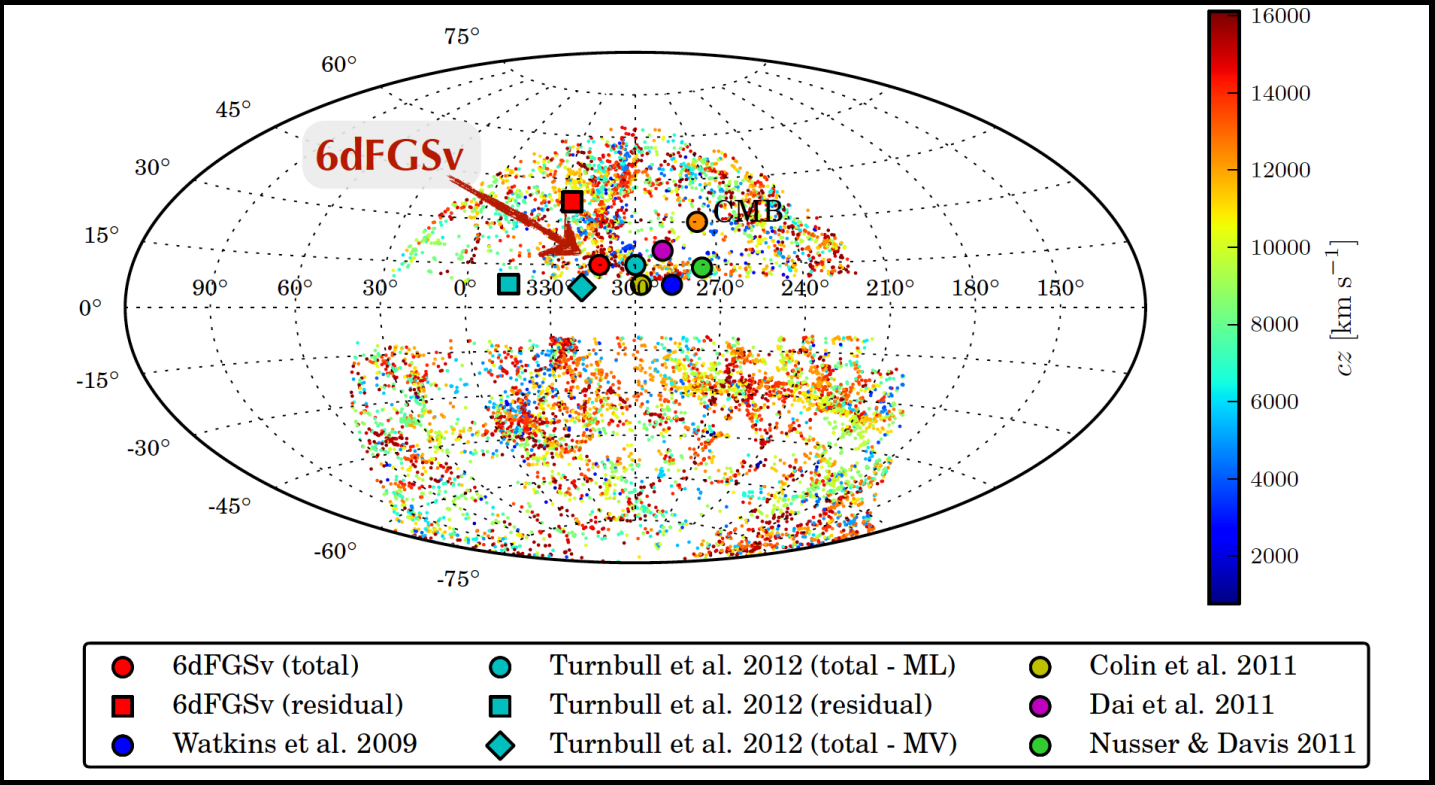


6dFGSv results: pec velocities from FP (N=9000)

- Bulk-flow within 160 Mpc/h: V = 365 km/s → (l,b) = 313º, 15º

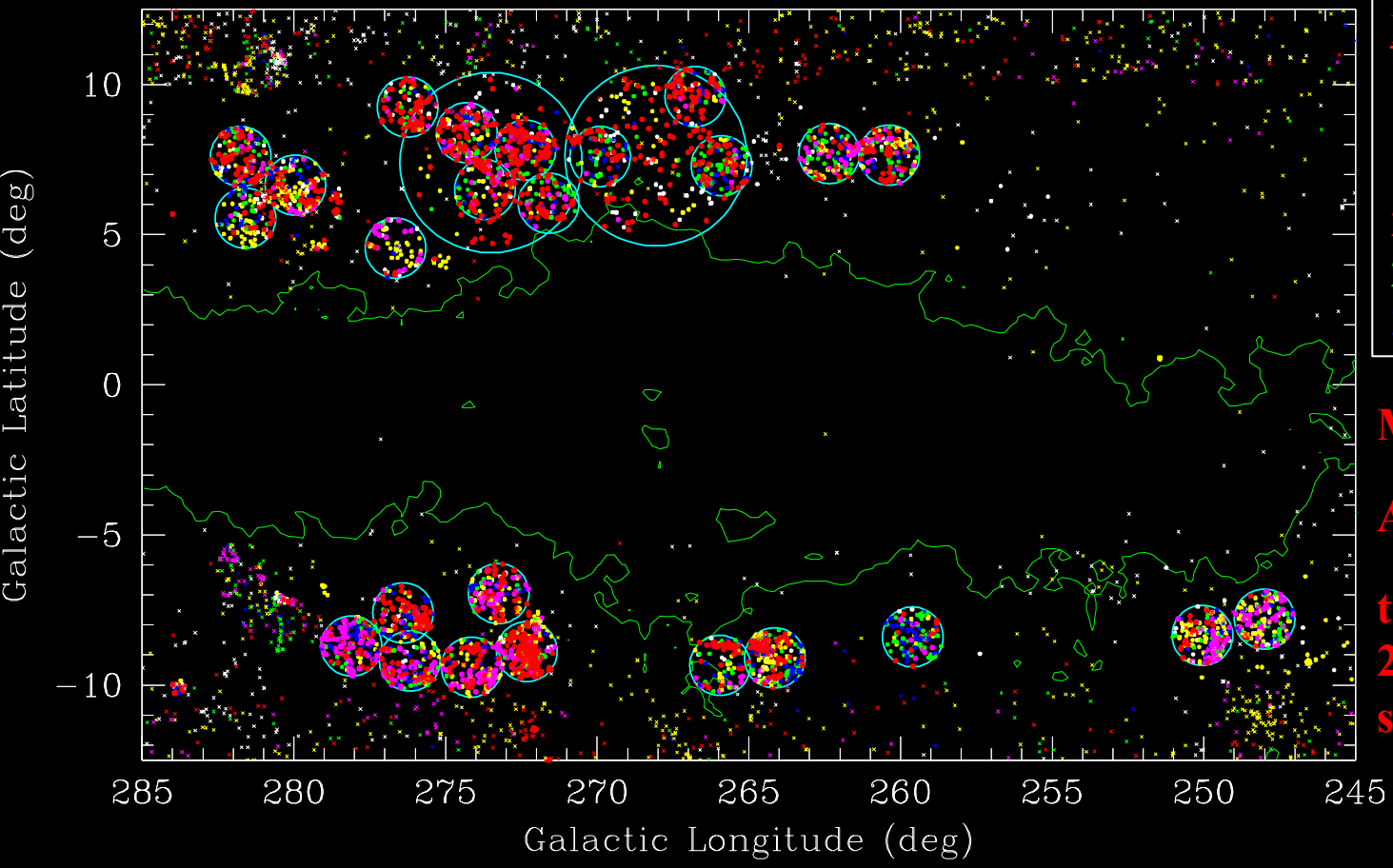
-_> Residual flow of: V = 292 km/s → (l,b) = 313º, 36º

→ Hints of structure influencing local dynamics outside of survey volume



Springob et al (soon on arXiv); Figure from Magoulas, Cosmic Flow meeting, 2013, Marseille

Sparsely sampled along Galactic Equator: Over ZOA region of (l,b) = 245° – 285°; ± 10° (4°-10°)



Redshift coding:
0 – 8000 km/s;
8 - 16000 km/s;
16 – 20000 km/s
20 - 24000 km/s;
24 – 32000 km/s
32 - 40000 km/s

Massive overdensity

At 18000 km/s

traced over 25° and 20° degrees on either side of the GP

4756 redshifts from AAOmega + SALT +6dF + Optopus + 1.9m SAAO & Literature

~ 95% unpublished data

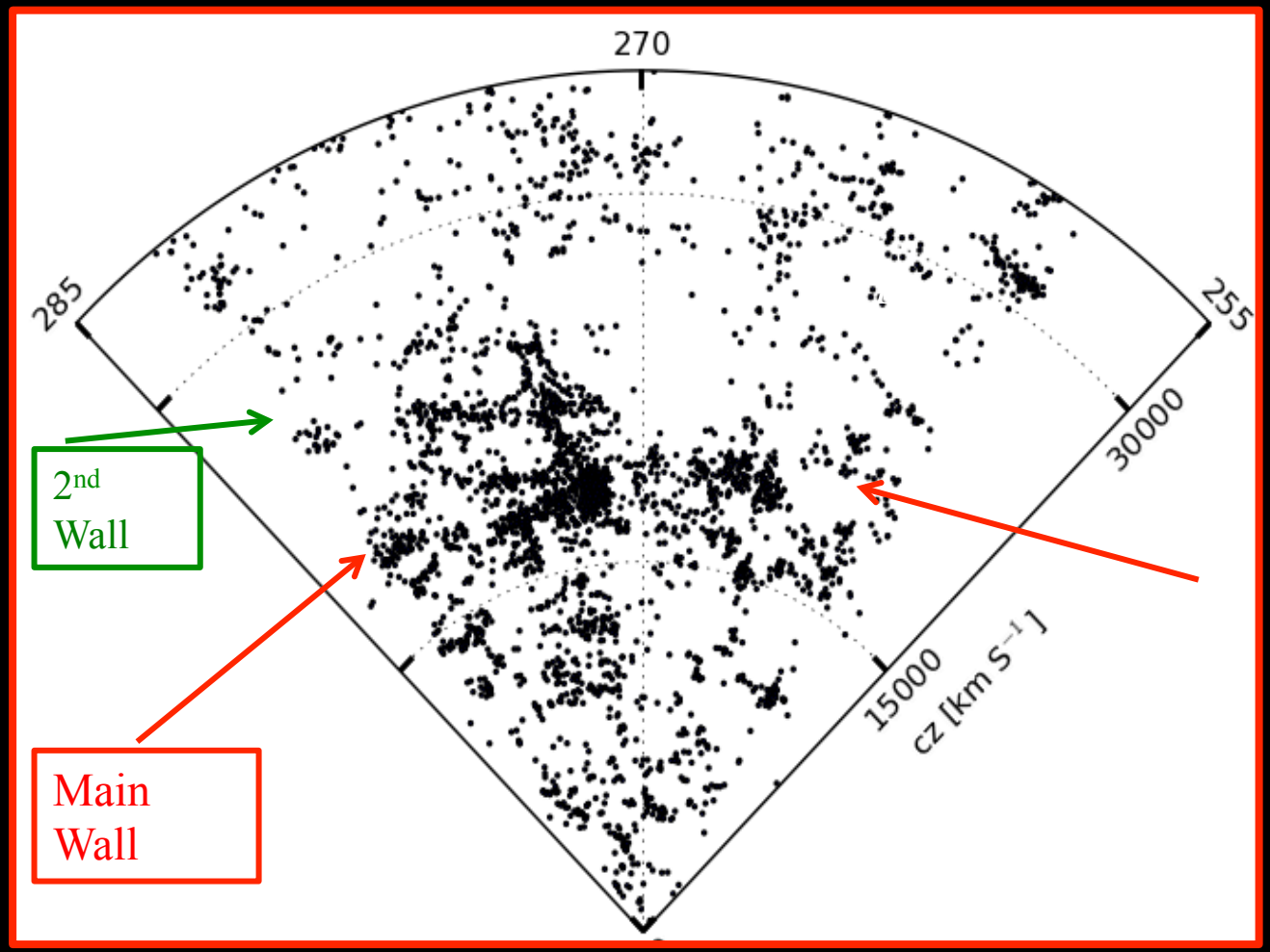
Where A_B > 2-3mag → hard to get redshifts, even for 2MASX galaxies

Vela Supercluster (VSCL)

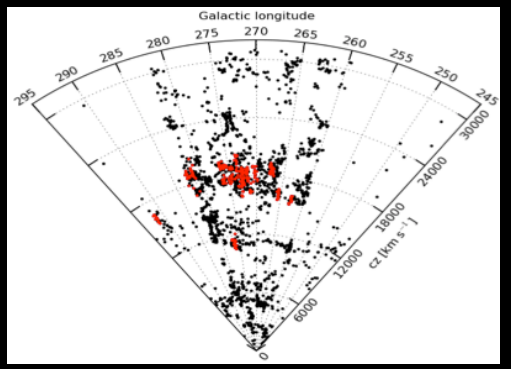
in ZOA: |b| < 10° Kraan-Korteweg+ 2017, MNL

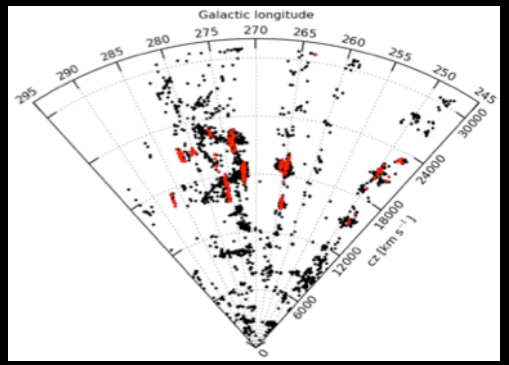
4756 redshifts from AAOmega + SALT +6dF + Optopus + 1.9m SAAO & Literature

~ 95% unpublished data



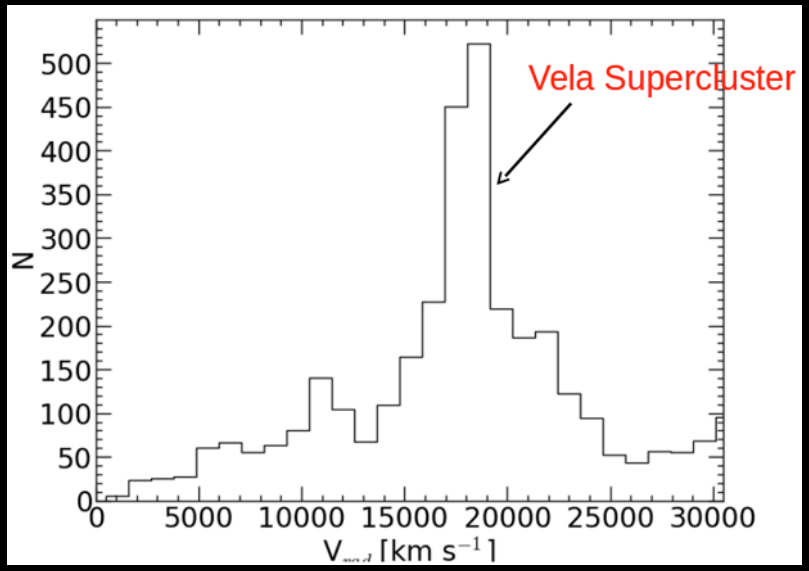
Above GP: 0° < b < +10°

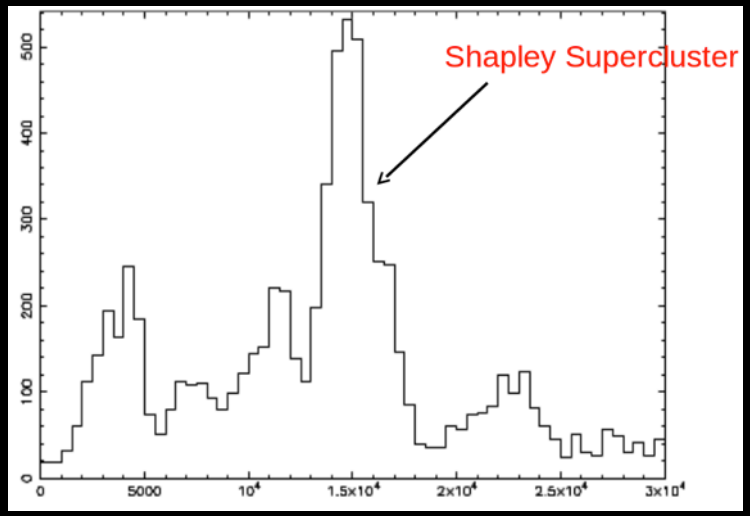




Below GP: -10° < b < 0°

Comparison of Redshift histograms of Vela versus Shapley:
~ 4000 in 20° x 20°; sparsely sampled
~ 8600 in 12° x 30°; fully sampled





- Massive overdensity traced over (Δl, Δb) >~ 25° x 20°

- Redshift histogram similar to Shapley SSC *(Proust et al 2006, N ~ 8600)*;

- Vela SCL is f ~ 1.2 more distant → more extended on the sky:

Vela	SSC
~ 25° x 20°	19° x 16°
115 x 90Mpc	70 x 60 Mpc

What have we found – what does it signify?

Clear evidence for a galaxy supercluster in Vela:

→ **possibly a supercluster in formation**

- not many X-ray clusters (but overdense in X-ray clusters)

- clusters are young, have many star forming galaxies

- two merging wall of extent of 80 x 65 h^{-1} Mpc

Despite sparse sampling

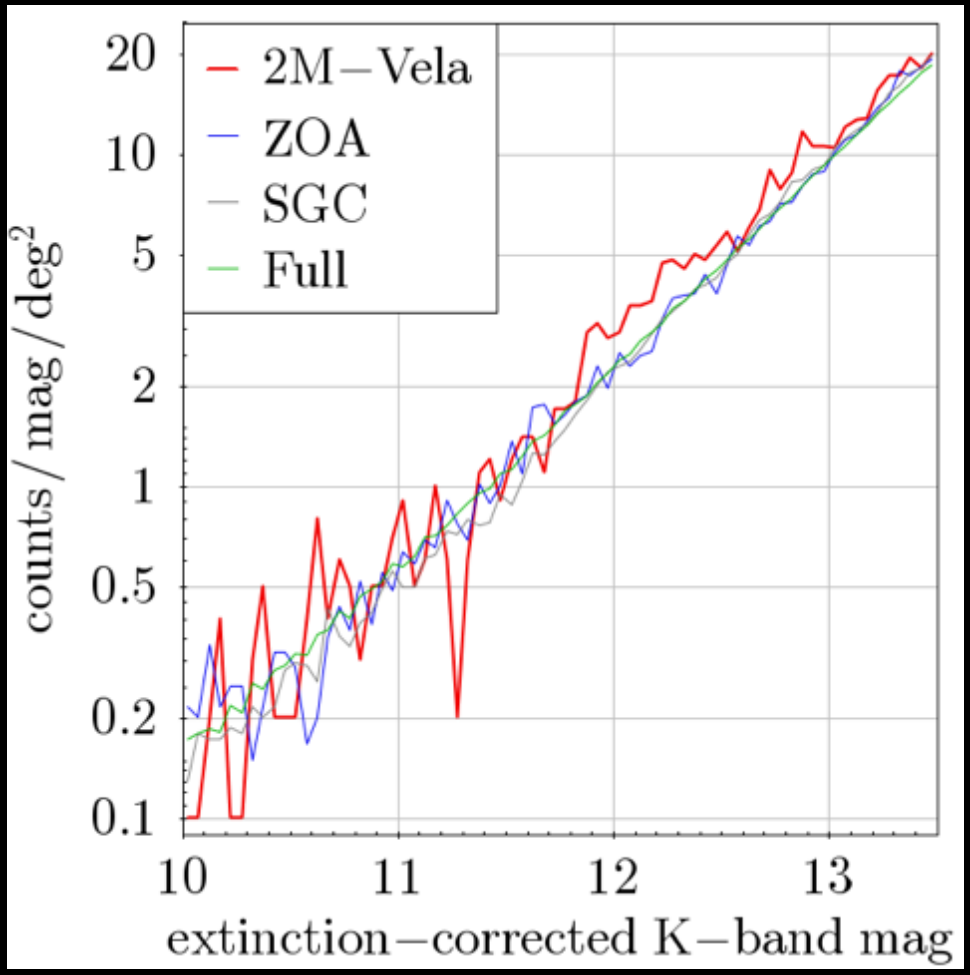
→ Vela SCL is significantly overdense

- in 2M galaxy counts and

- in volume defined by the overdensity

What have we found – what does it signify?

2M galaxy counts:



Vela survey area limited to
$6° < b < 10°$; $260° < l < 285°$

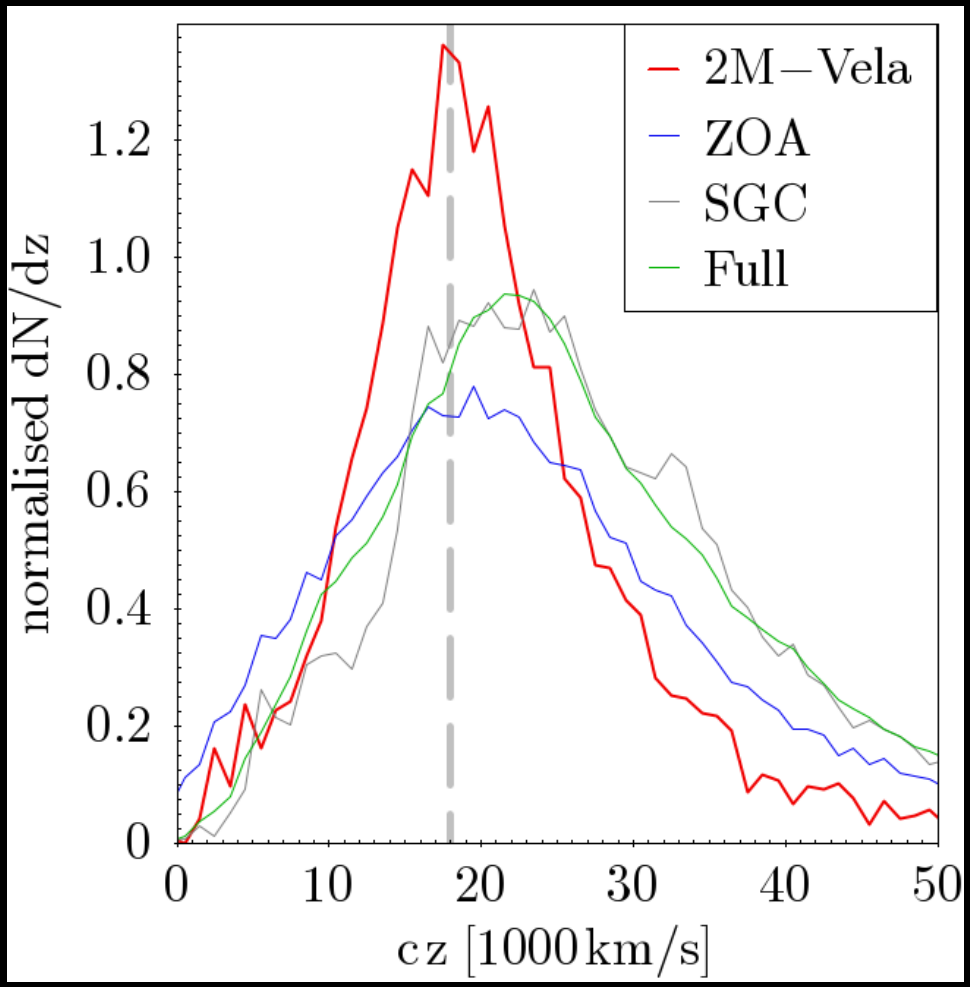
99% complete for $A_K < 0.3$mag and $K < 13.8$ → $K^0 \sim 13.5$mag

3 comparison samples:
ZOA: $110° < l < 260°$
SGC: $b < -60°$
Full: 2MASX for $|b| > 15°$

→ Enhancement in counts f = 1.2

What have we found – what does it signify?

Volume overdensity in shells:



Based on photometric redshifts
(2MPZ; Bilicki et al 2014)

Caution: large errors in phot-z
→ dilution of overdensity

Overdensity in shells
$0.055 < z < 0.065$

→ Overdensity $\delta_{Vela} \sim 0.60$

What have we found – what does it signify?

Clear evidence for a galaxy supercluster in Vela

The Vela SCL is significantly overdense

- in 2M galaxy counts
- in volume defined by the overdensity

→ $\delta_{SSC} \sim 1.4$; *however if subjected to same completeness limit and biases this would be reduced by* $f \sim 2.3$

→ *making overdensity similar to Shapley*

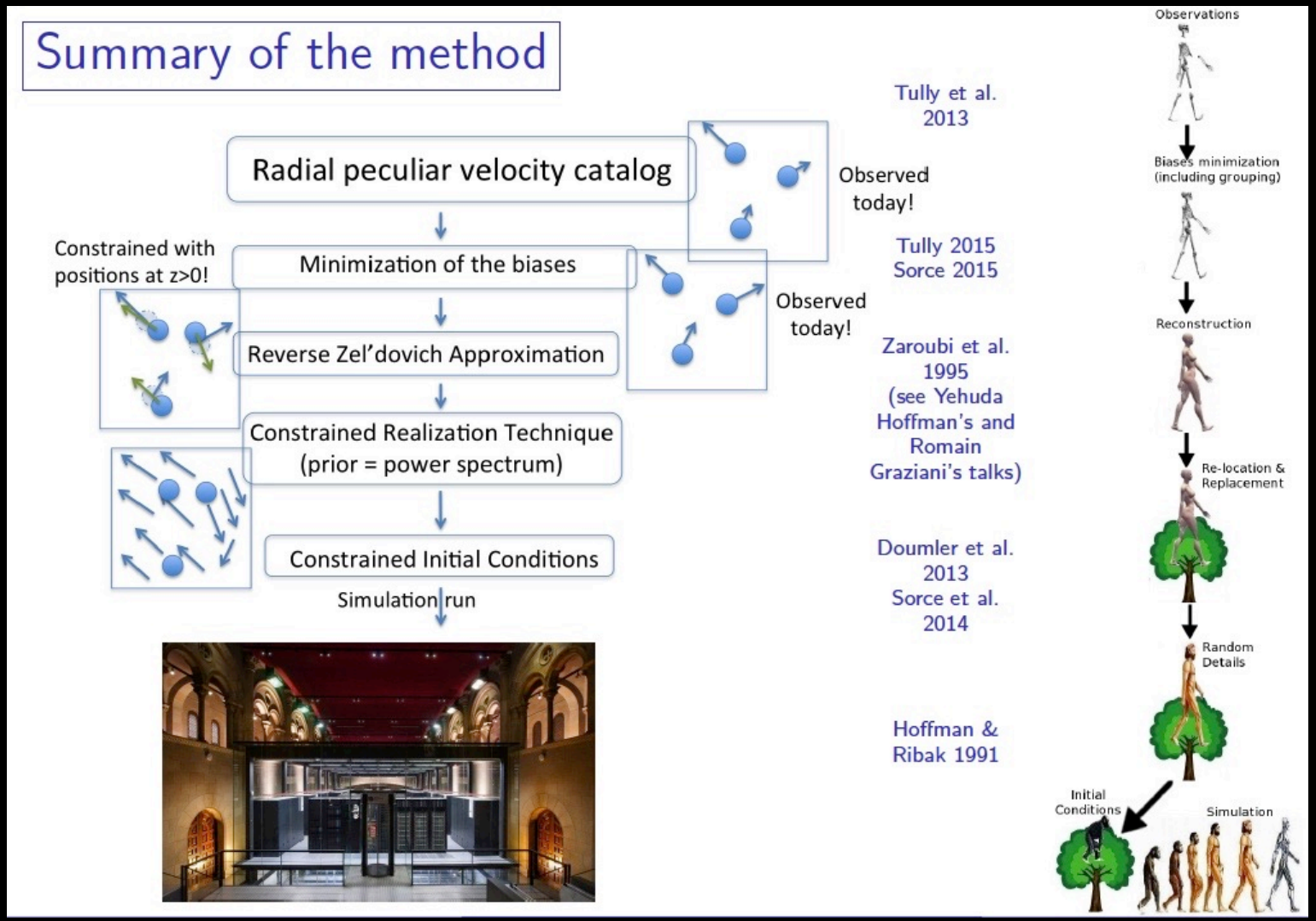
→ Simple linear perturbation theory → $V_{LG} \sim 50$ km/s

Independent evidence for Vela SCL?

→ Comparison to reconstructions based on

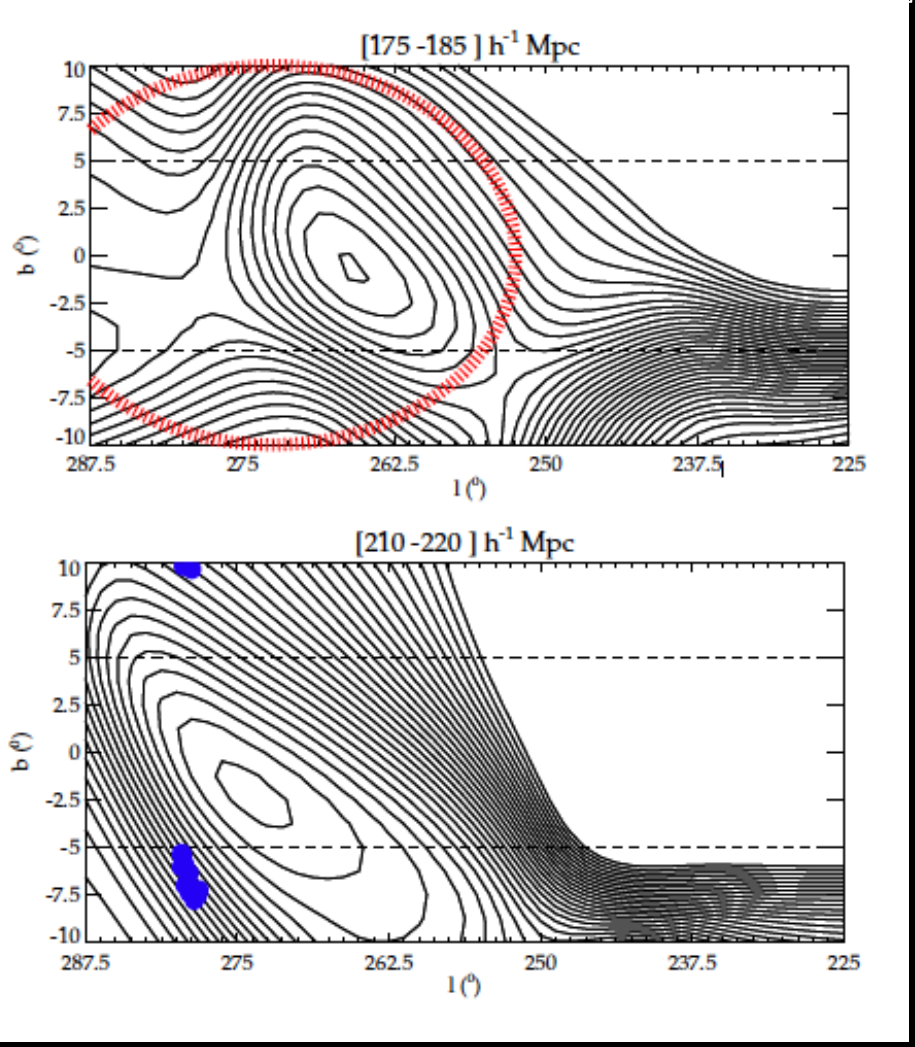
- CF2 (CLUES)
- CF3 (watershed ⋯)

CLUES: Constrained Local UniversE Simulations *(e.g. Sorce et al 2016, MN)*



Use CLUES method to predict hidden ZOA structures

Sorce, Colless, Kraan-Korteweg, Gottloeber 2017 MN (arXiv:1707:04267)



Data set: Cosmic Flows 2 (CF-2)

(Tully et al 2013)

→ 8315 pec vel out to ~30000km/s

200 constrained realisations

- interpreting the sums - not average

- various test about robustness of recovery of structures

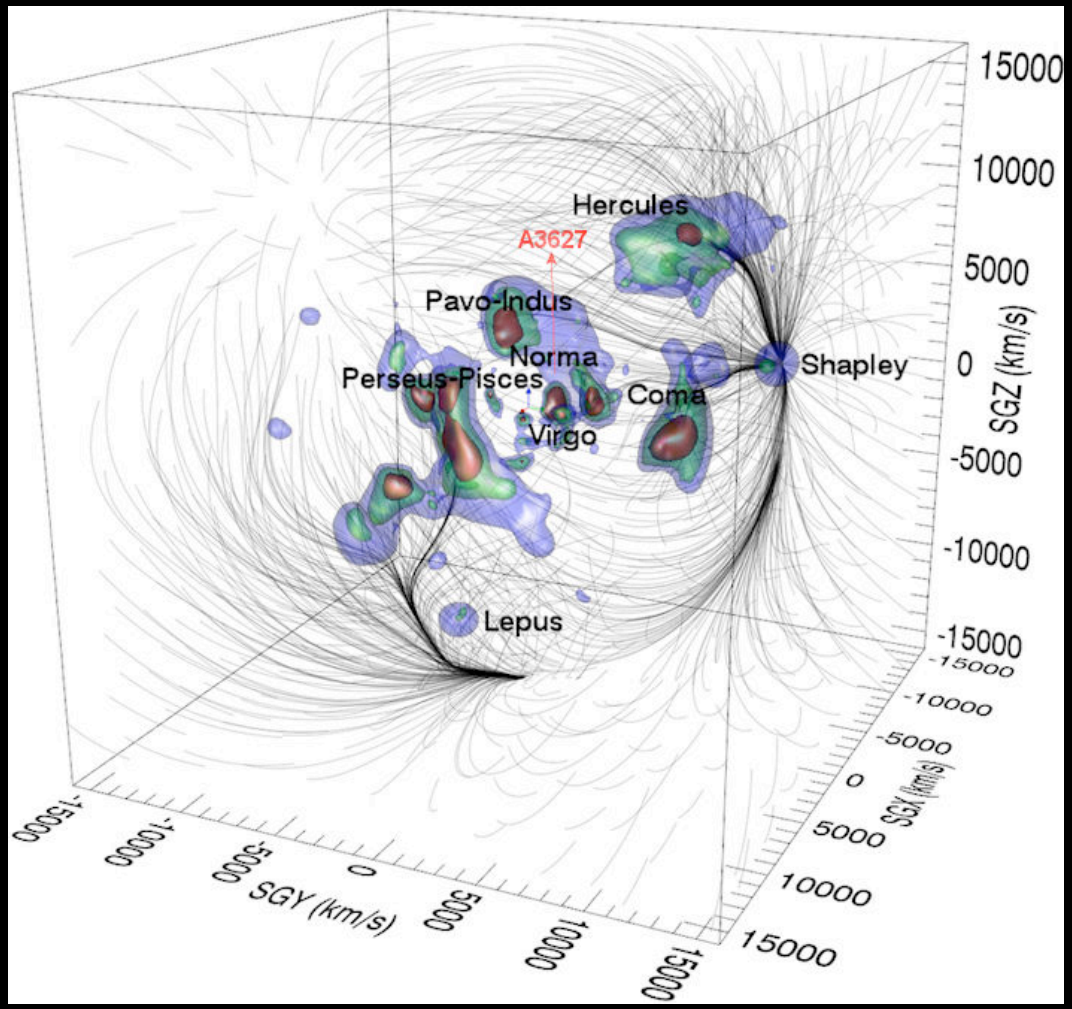
→ remarkable agreement for known nearer ZOA structures (GA,PuP)

→ *good agreement with 2MRS 2006 reconstructions (Erdogdu+ 2016)*

→ both Walls of Vela SCL recovered (18000 & 21000 km/s) in the Constrained Realisation

Using the Watershed Analysis on CF3

in collaboration with Hoffman, Courtois et al



Stepping back

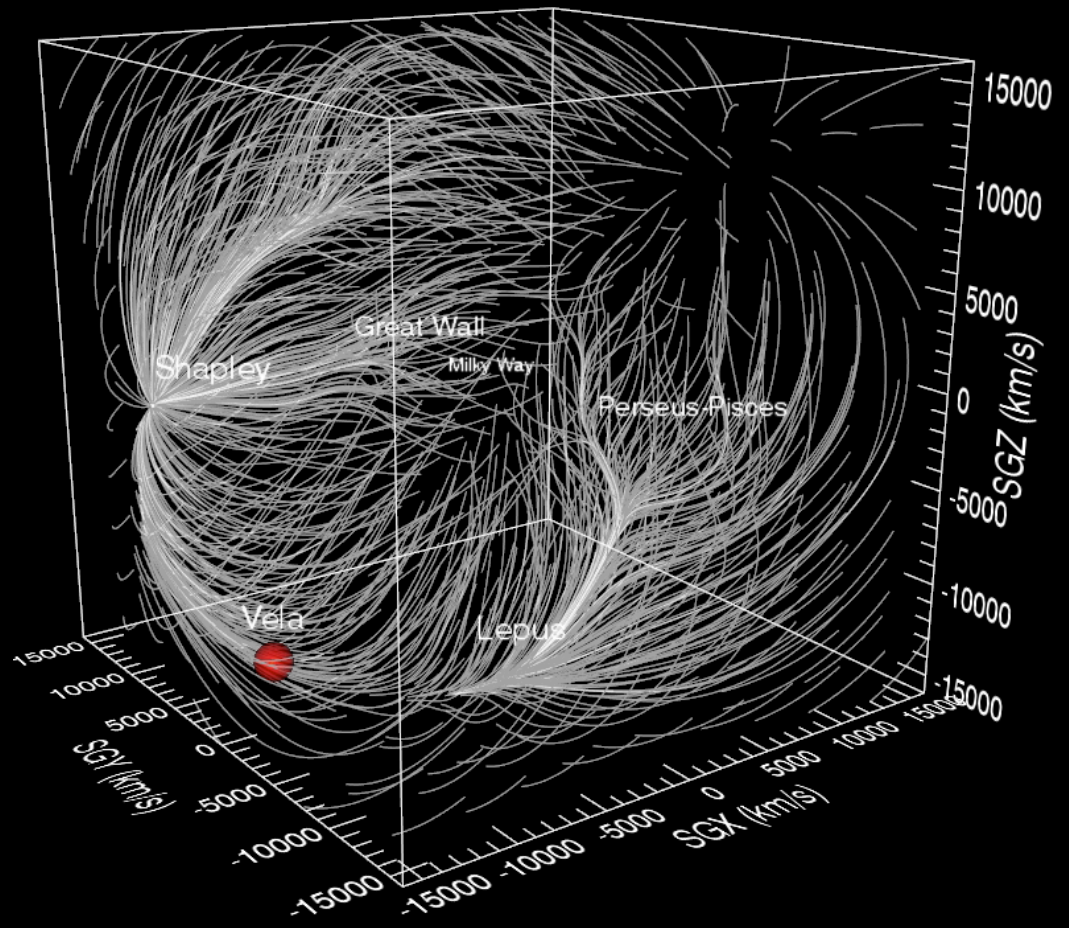
Results from Lanikea paper *Tully+ 2014*

Based on CF2

Although very sparse data at higher redshifts,
→ strong flow lines downwards from Shapley,
→ then bending to left

Using the Watershed Analysis on CF3

→ The Vela Antlia Basin



Hoffman, Courtois, Kraan-Korteweg, Pomarède, in prep

Preliminary Results
Based on CF3

CF3:
N= 18000 v_{pec}

Mostly:
- Spitzer TF: 2257
- 6dF: 8885

Some further
- TRGB
- SNIa

What have we found – what does it signify?

Clear evidence for a galaxy supercluster in Vela

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- in 2M galaxy counts
- in volume defined by the overdensity

→ $\delta_{SSC} \sim 1.4$; *however if subjected to same completeness limit and biases this would be reduced by* $f \sim 2.3$

→ *making overdensity similar to Shapley*

→ Simple linear perturbation theory → $V_{LG} \sim 50$ km/s

→ Independent evidence from reconstructions

- Conundrum persists: 2 SCL's in close proximity

How much remains hidden behind ZOA?
Does the Milky Way hide further surprises?

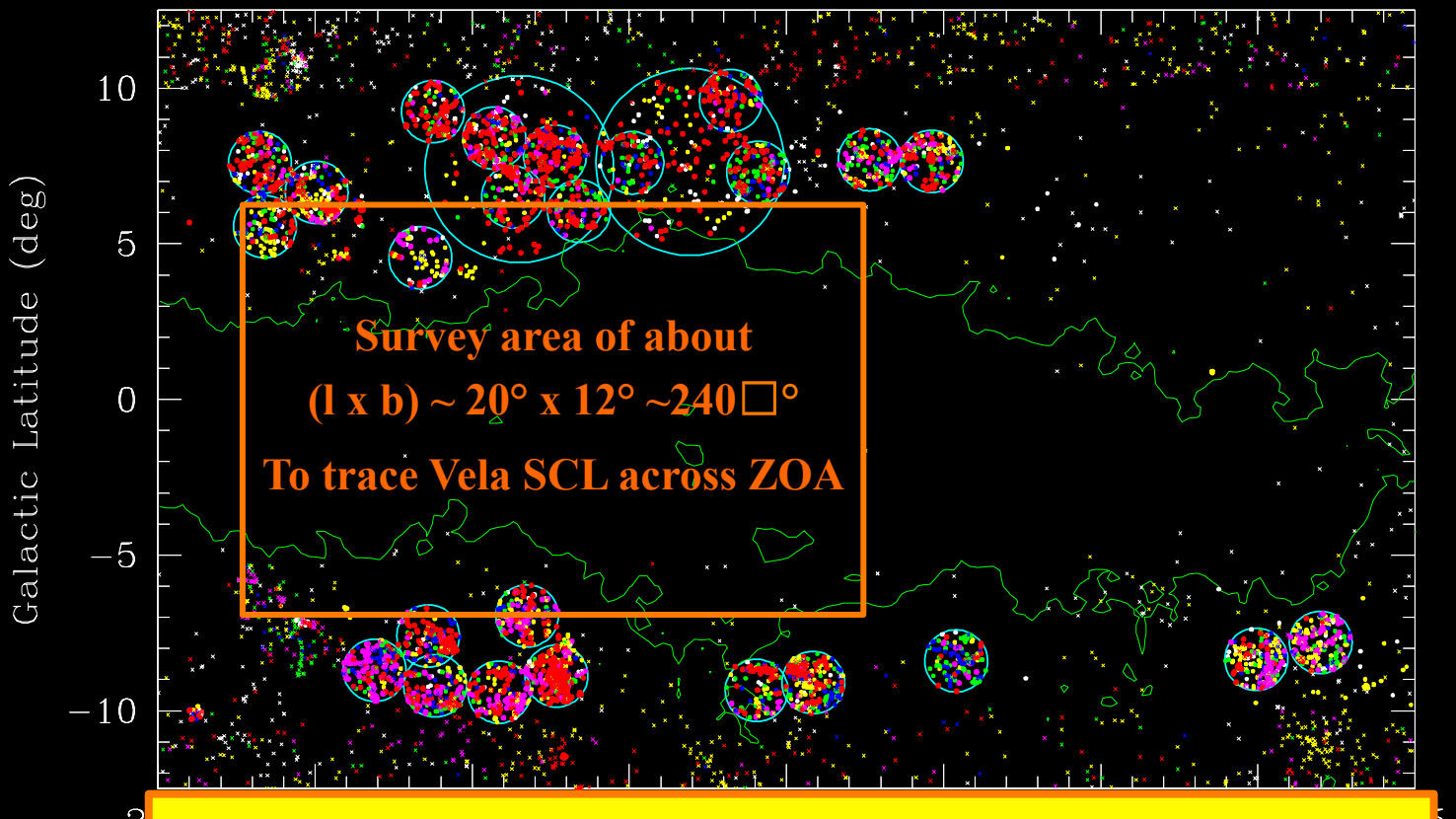
Steps towards a full census of the Vela SCL

... to determine its extent, richness and mass overdensity
→ and contribution to bulk flow

- Early Science Survey with MeerKAT (M32 and/or M64) to cover optically obscured part of Vela SCL (|b| < 6°)
  - *First simulation show that this is feasible (240 hrs with M32, 60hrs M64)*
  - With M64: extend survey, and include 2nd hidden part of Big Circle towards TriAu clusters
- Taipan survey in science verification mode (end of 2017)
- Follow-up VSCL cluster observations **(IRSF, WISE, SALT)**
  - *(K-band LF, mass - possibly peculiar velocities using WISE TF over the MeerKAT HI survey area)*
- Further/SALT observations of new potential clusters and deeper surveyed IRSF cluster
- Full-sky HI mapping (SKA Pathfinders)
- Optical spectroscpy (e.g. ne CSSOS

MeerKAT M32 Early Science survey scenario

- **Survey of fully opaque part of Vela SCL ZOA crossing**
  - With some overlap of high density Vela cluster regions on either side of GP



Goal: Map all galaxies log M_{HI} > 9.5 $M_{\odot}$ with 16-24000km/s

Taipan observations

→ in Science Verification; starting end of 2017

Taipan survey

- multi-object spectroscopic galaxy
- will cover the whole southern sky
- spectra for over 1 million galaxies in the local Universe ($z<0.3$) over 4 years.

TAIPAN instrument:

- on 1.2m UK Schmidt Telescope (Siding Springs)
- innovative starbugs optical fibre positioner

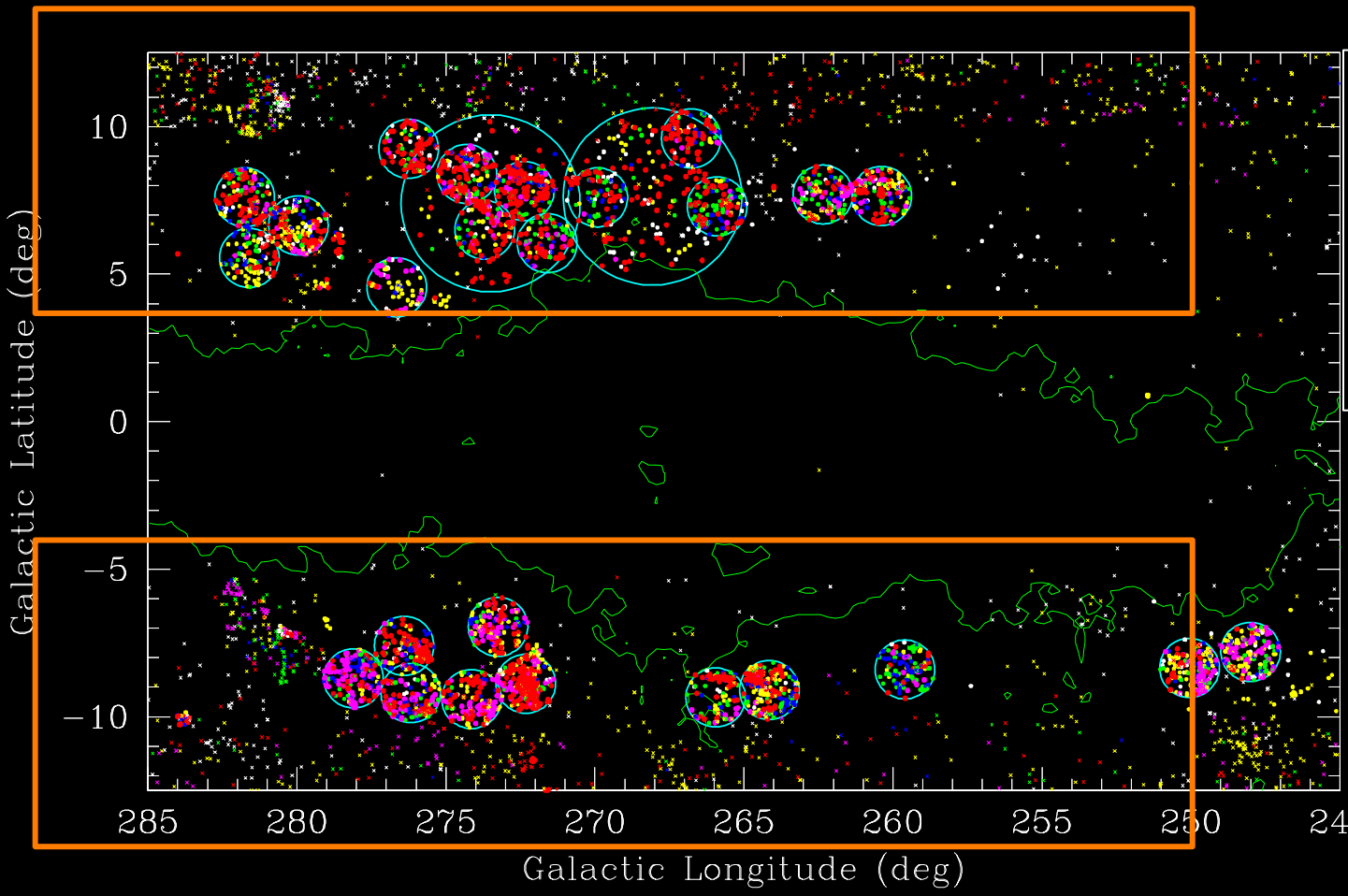
→ 150 objects per 6-deg field

→ reasonabl complete redshifts, as faint as r =17.5 mag in 15 min integration

ZOA ($|b| < 10°$) not part of the Taipan survey
But selected for the Taipan Science Verification

Taipan Vela Survey

- Minimal Survey Area
  over Vela area with intermediate extinction



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