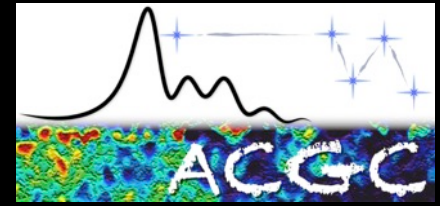




Galaxy flow fields and hidden structures in the Zone of Avoidance



Renée C. Kraan-Korteweg
University of Cape Town

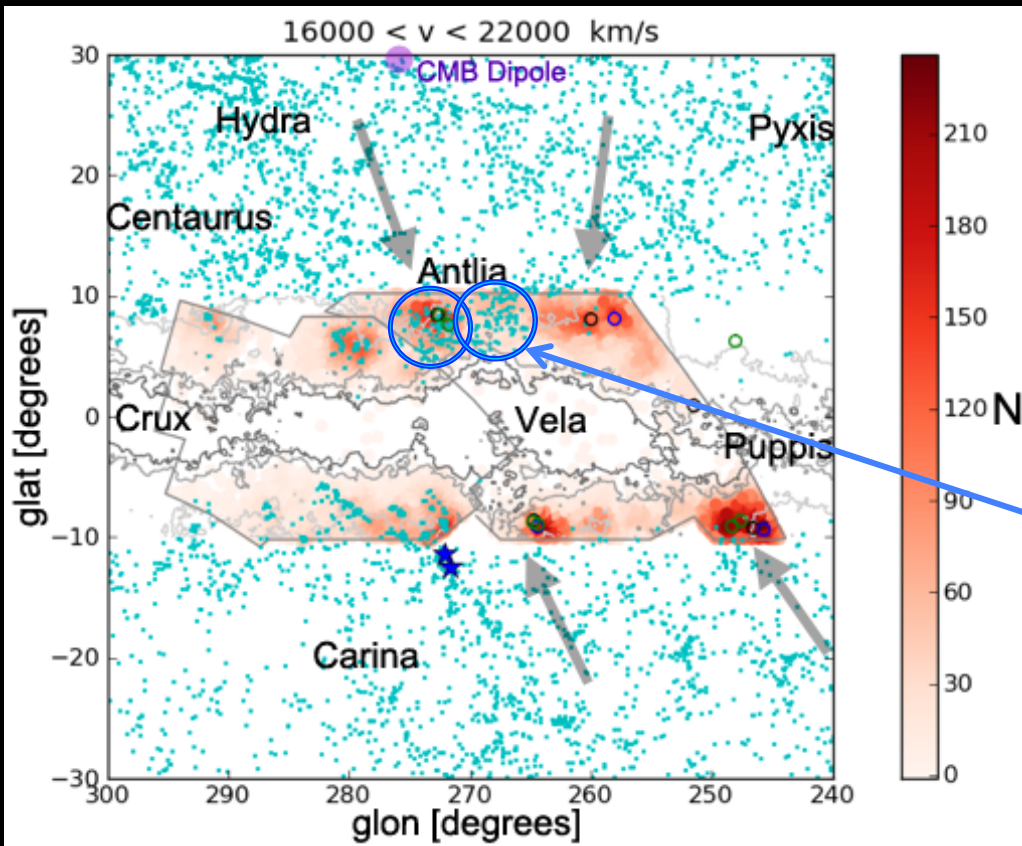
Michelle Cluver, Tom Jarrett, Maciej Bilicki, Matthew Colless, Hans Boehringer, Gayoung Chon

- **First hints of existence of massive overdensity**
- **SALT & AAOmega spectroscopic results**
 - **Discovery of Vela Supercluster hidden by ZOA**
- **First assessment and implications**
- **Future Plans**
 - **MeerKAT & Taipan**
 - **Other follow-up surveys**

Cosmology & Large Surveys
21-24 Nov 2106, Durban

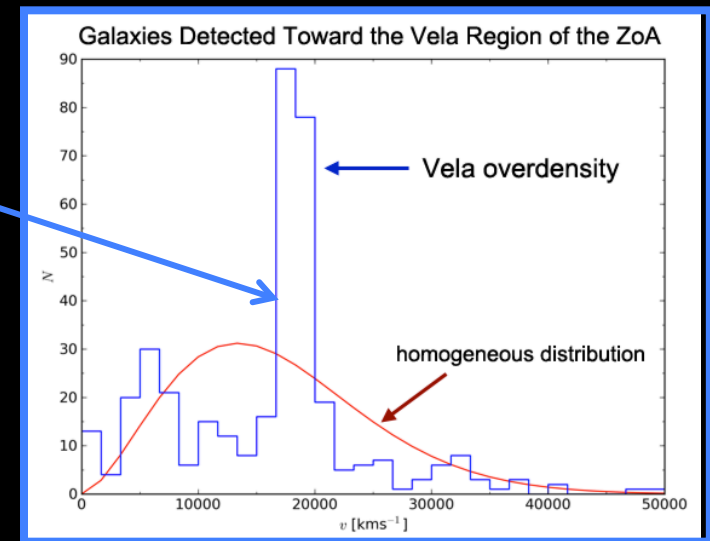
Suspicion of existence of massive overdensity in ZOA

just beyond boundaries of current surveys 16-22000km/s



Various follow-up redshift observations of optically detected galaxies in ZOA in Vela (KK et al):

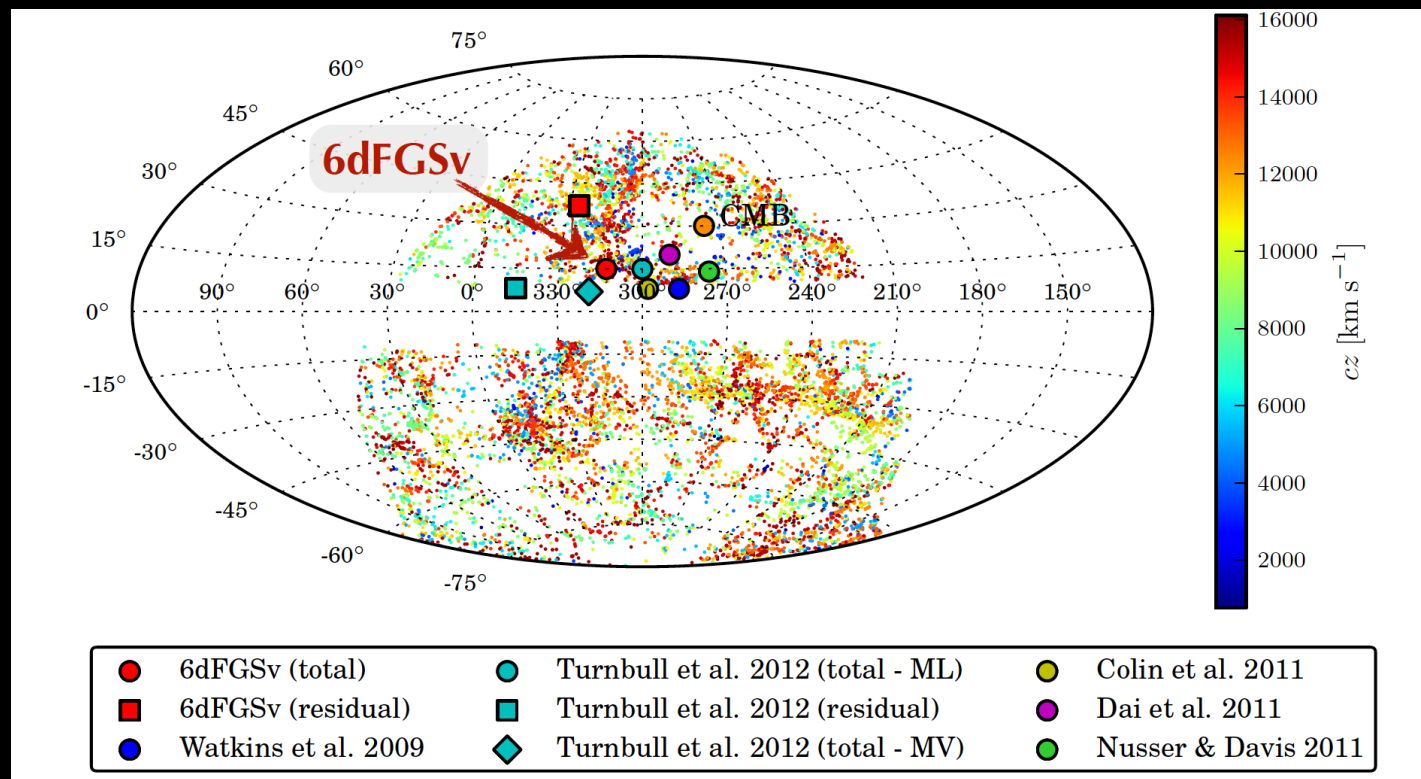
Two adjacent 6dF fields; $\sim 370z$



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

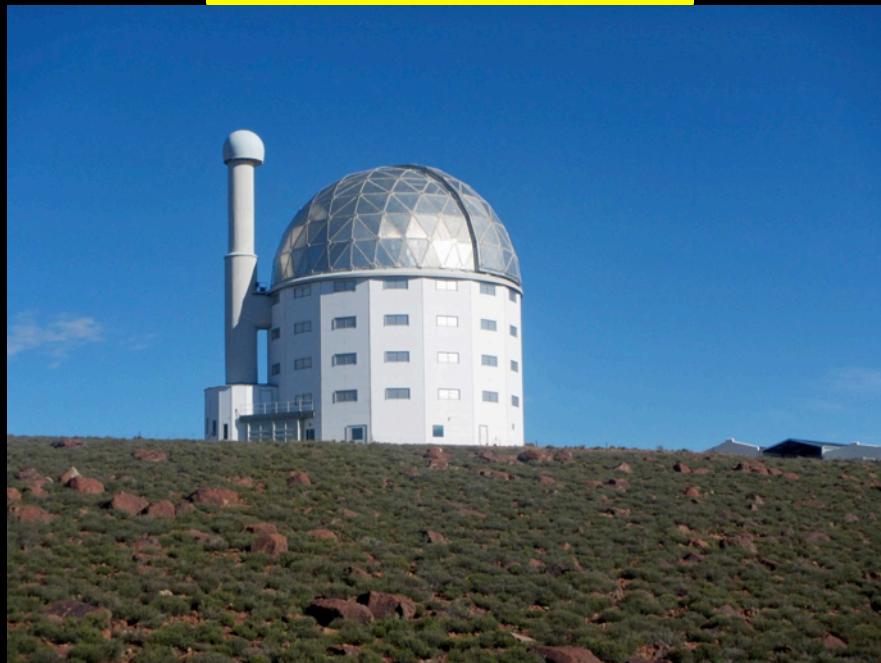
- Bulk-flow within 160 Mpc/h: $V = 365 \text{ km/s} \rightarrow (l,b) = 313^\circ, 15^\circ$
- Residual flow of: $V = 292 \text{ km/s} \rightarrow (l,b) = 313^\circ, 36^\circ$

→ Hints of structure influencing local dynamics outside of survey volume



→ SALT & AAOmega observations of *optically and 2M* galaxies to map extent of overdensity $(l,b) = 240^\circ - 290^\circ; \pm (4^\circ-10^\circ)$

**SALT 10m & RSS:
FoV = 8'; N~25**



2012-2014:

- About a dozen fields of prospective cluster cores
- **Most confirmed as clusters at Vela overdensity distance**

**AT 4m & AAOmega:
FoV 2°; N = 392**

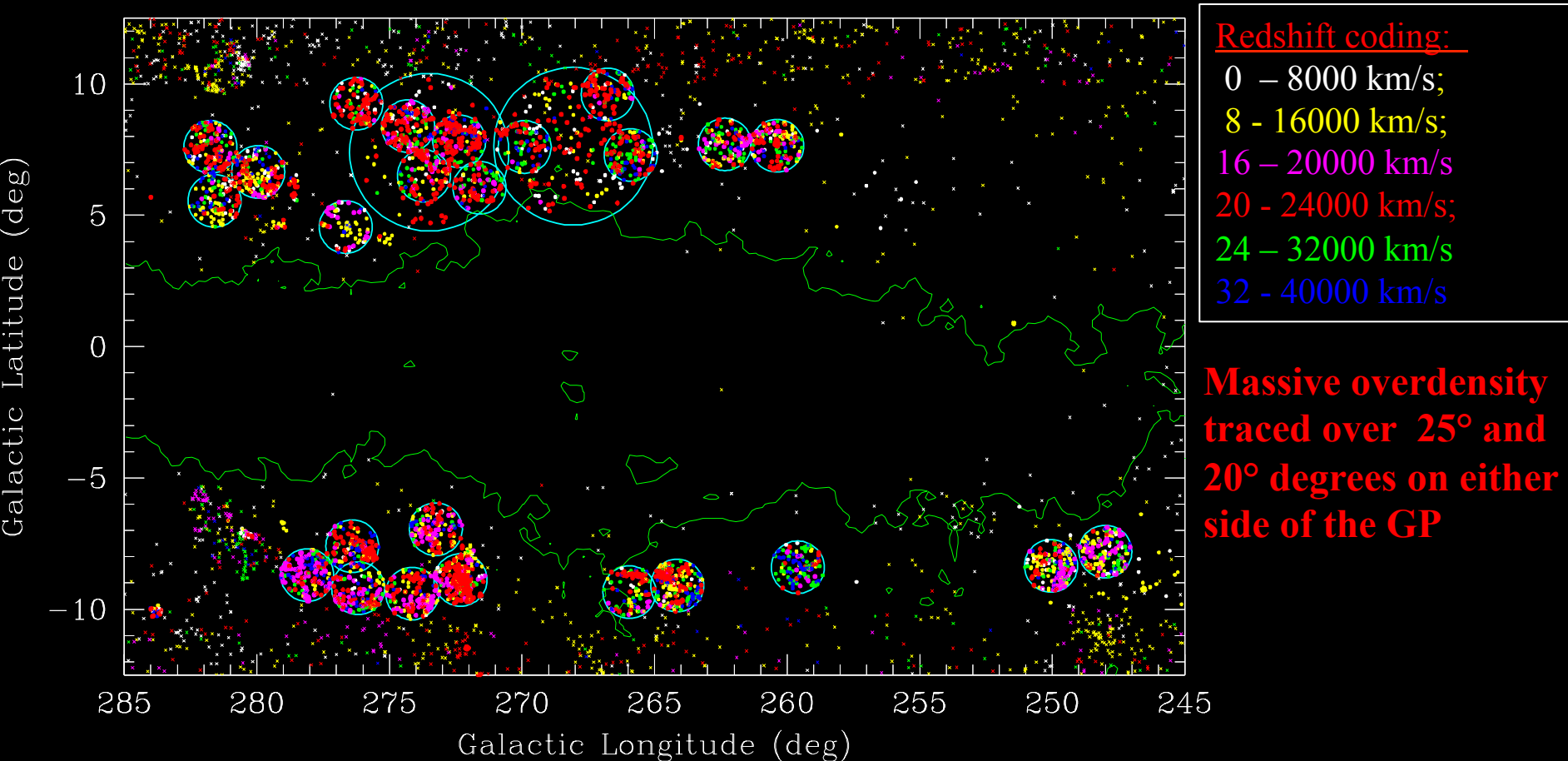


2014: 6 nights in February:

- **4300 redshifts in 25 AAOmega fields: overdensity extends over vast region**

On-sky redshift coverage along ZOA survey region

20 o/o 25 AAOmega fields show peak around $\sim 18'000$ km/s



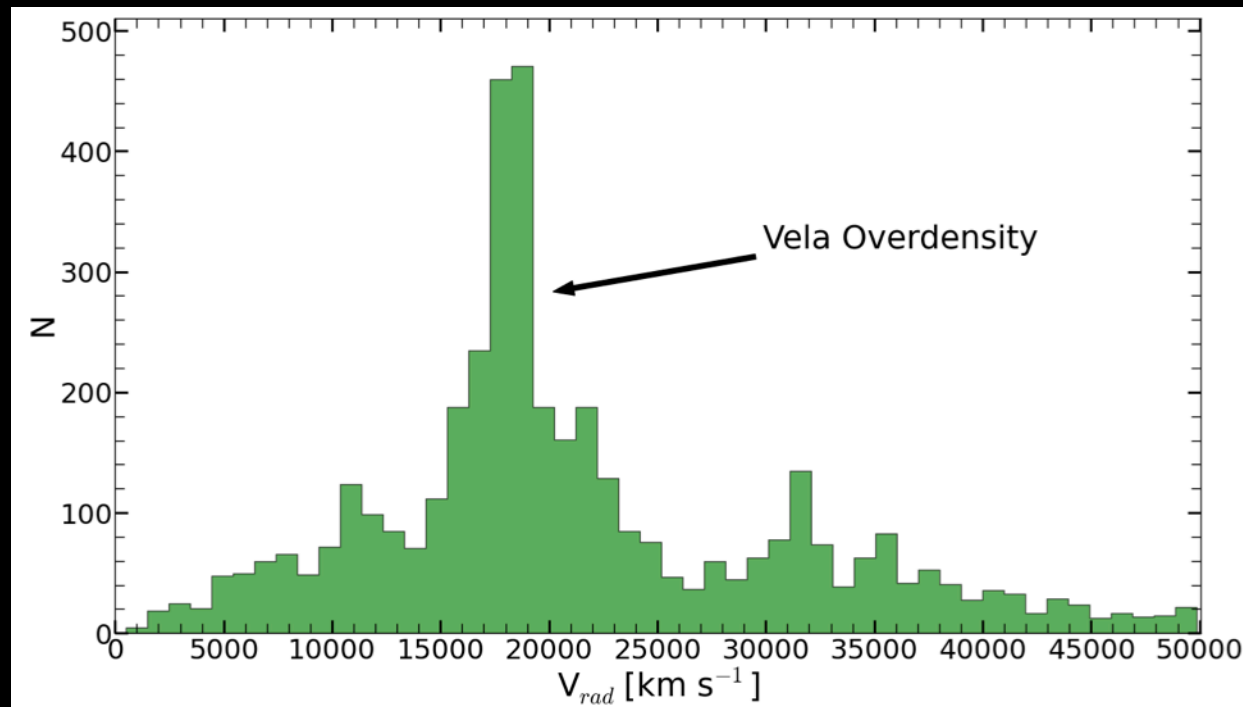
Still very sparsely sampled – and only at intermediate latitudes (between 5° - 10°)

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

Results from AAOmega, SALT, older 6dF & Optopus \pm literature Over ZOA region of $(l,b) = 245^\circ - 285^\circ; \pm 10^\circ (4^\circ-10^\circ)$

Results 4756 redshift *~ only 5% ZOA redshifts known before*

→ Velocity histogram shows highly significant peak centred at $\sim 18000\text{km/s}$
just beyond boundaries of current surveys 16-22000km/s

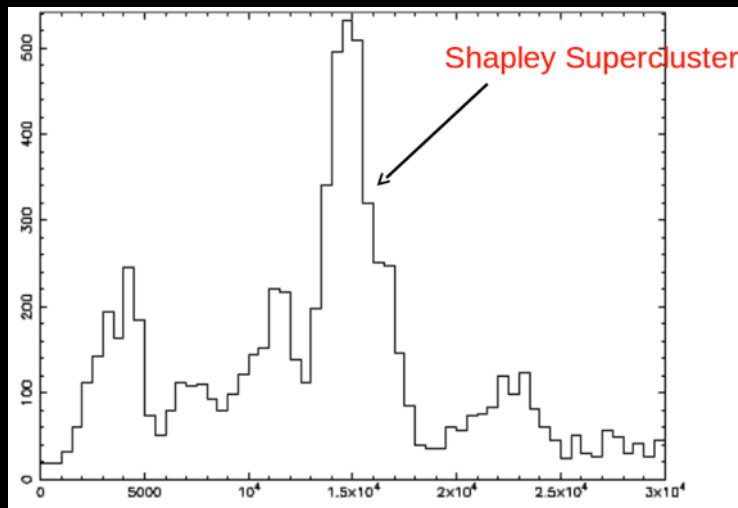
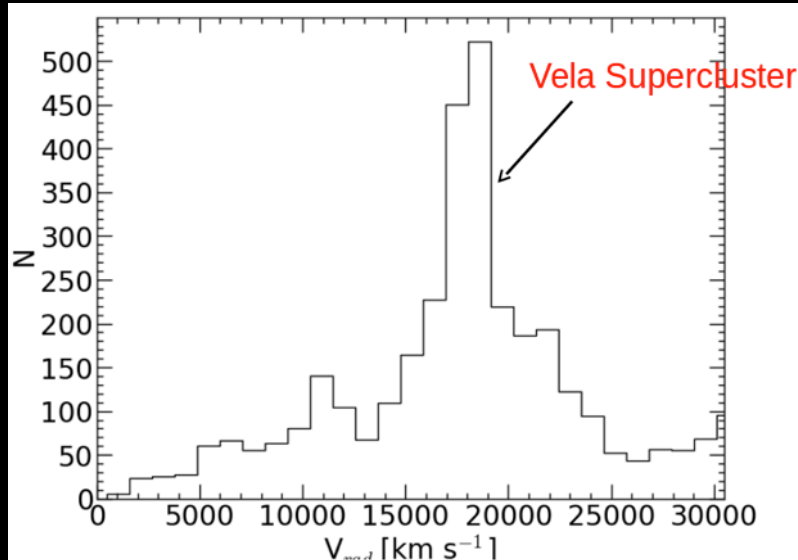


Despite sparse sampling, prominence bears remarkable similarity to Shapley SC survey (*Proust et al 2006*)

Comparison of Redshift histograms of Vela versus Shapley:

~ 4000 in $20^\circ \times 20^\circ$; sparsely sampled

~ 8600 in $12^\circ \times 30^\circ$; fully sampled



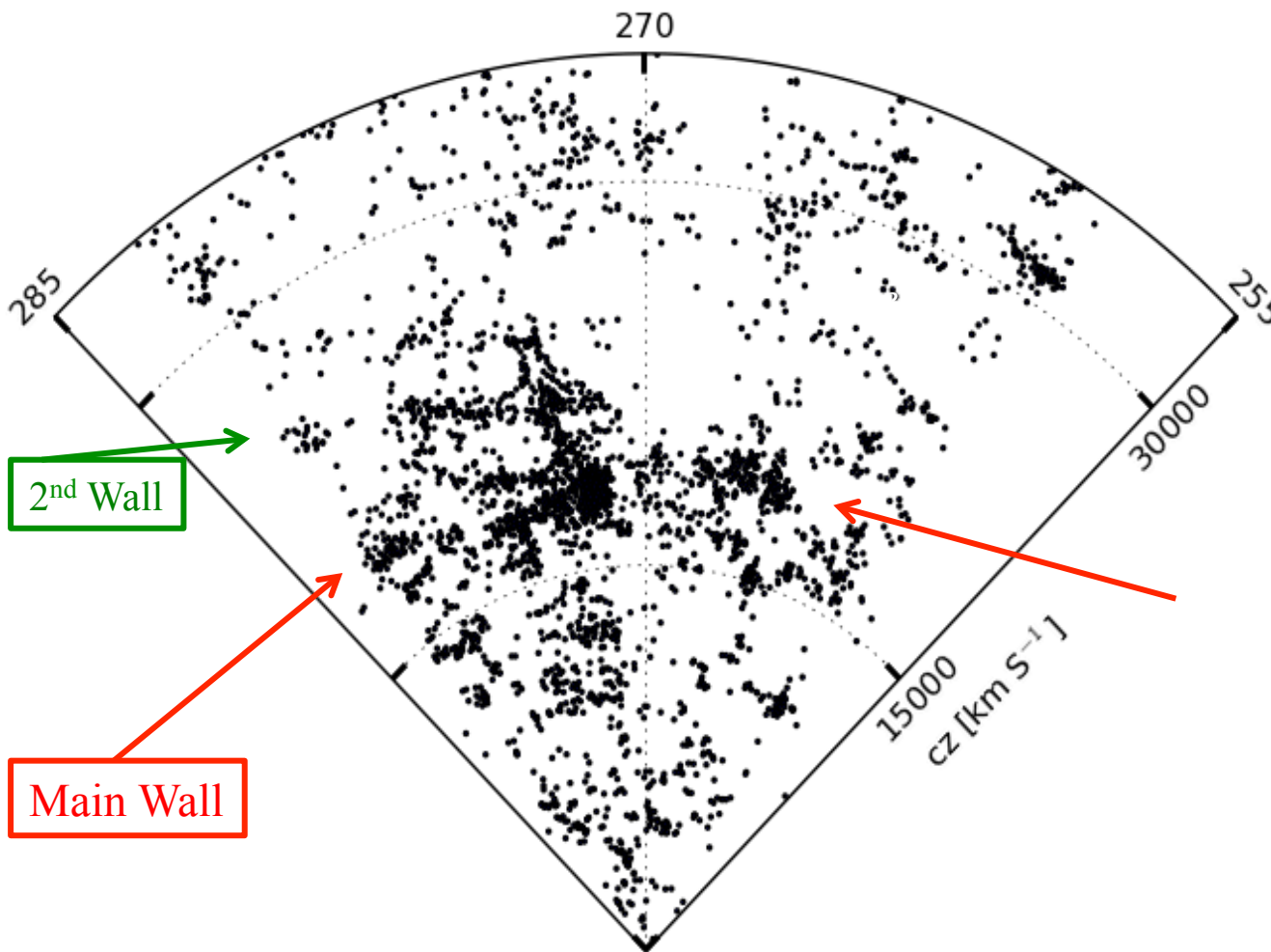
- Massive overdensity traced over $(\Delta l, \Delta b) > \sim 25^\circ \times 20^\circ$
- Redshift histogram similar to Shapley SSC (*Proust et al 2006, N ~ 8600*);
- Vela SCL is $f \sim 1.2$ more distant \rightarrow quite extended on the sky:

Vela	SSC
$\sim 25^\circ \times 20^\circ$	$19^\circ \times 16^\circ$
115 x 90 Mpc	70 x 60 Mpc

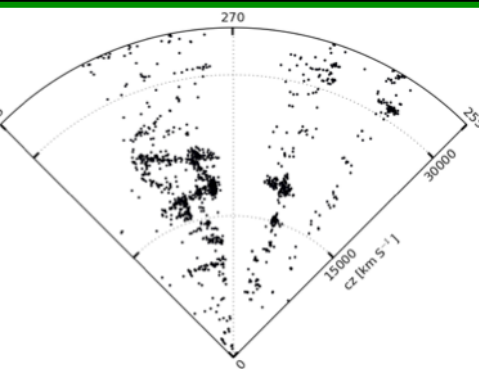
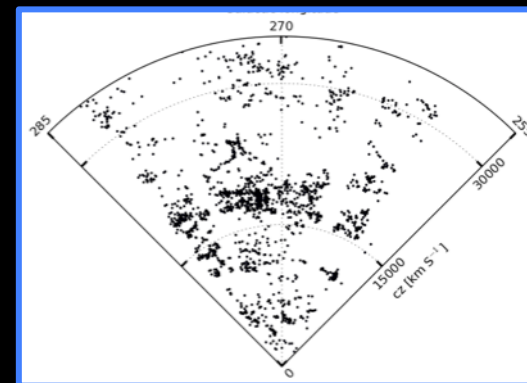
Redshift slices for ZOA Survey area

4756 redshifts from *AAOmega* + *SALT* + *6dF* + *Optopus* + *1.9m SAAO* & *Literature*
~ 95% unpublished data

within ZOA: $|b| < 10^\circ$



Above GP: $0^\circ < b < +10^\circ$

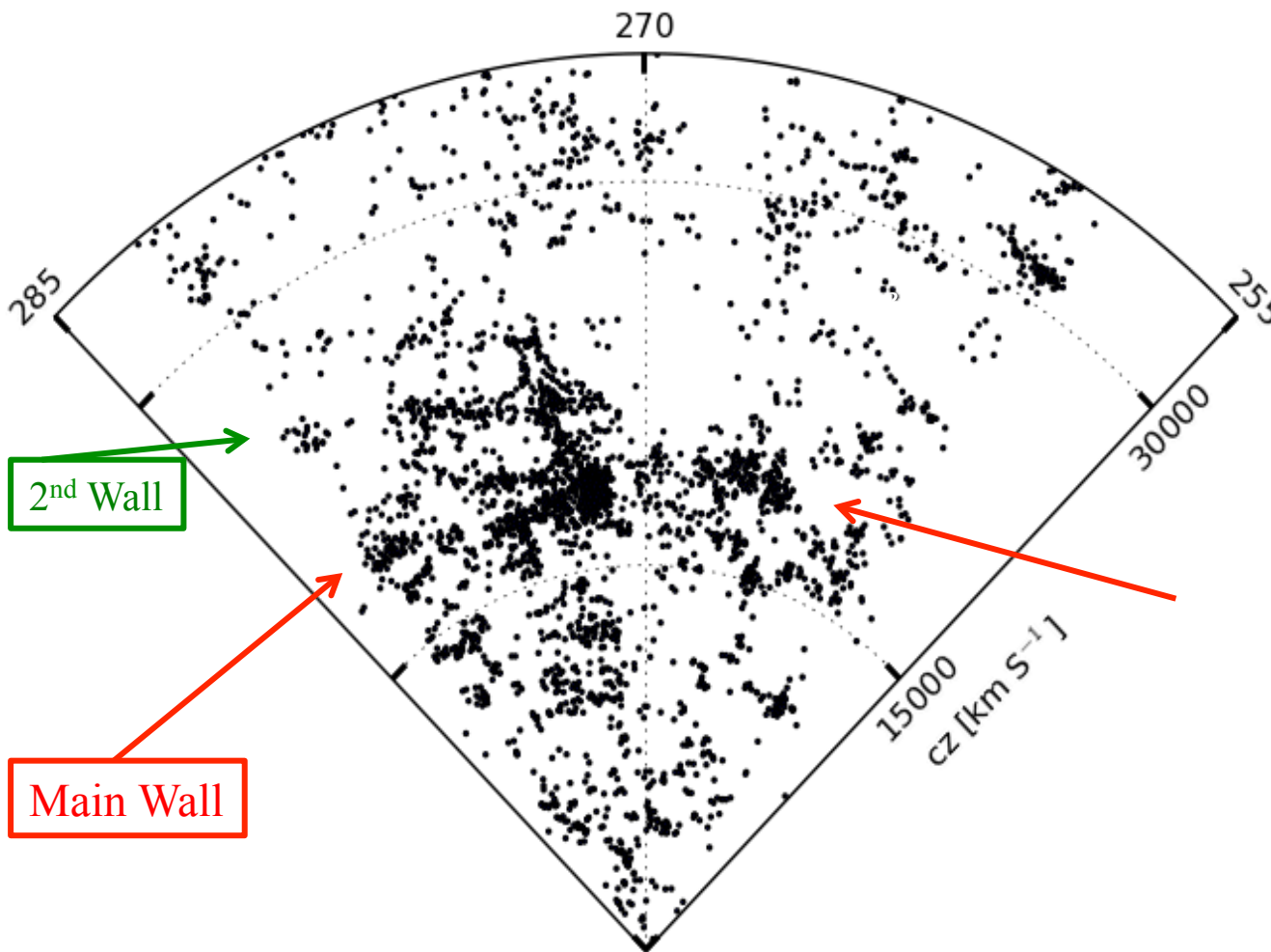


Below GP: $-10^\circ < b < 0^\circ$

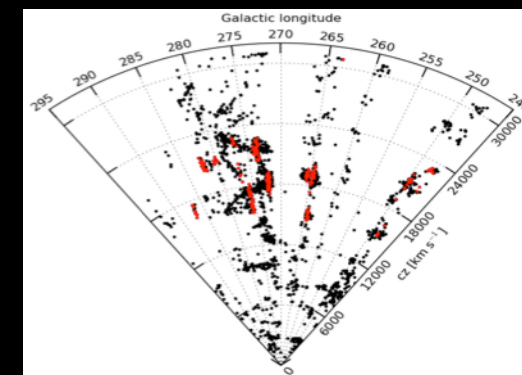
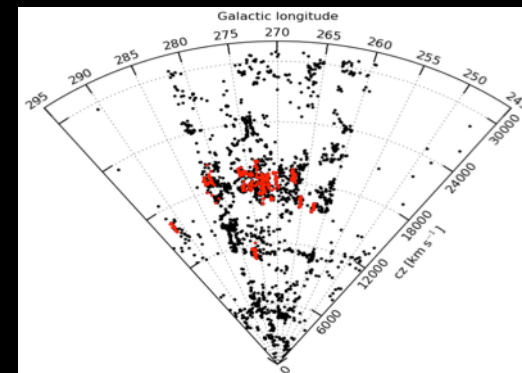
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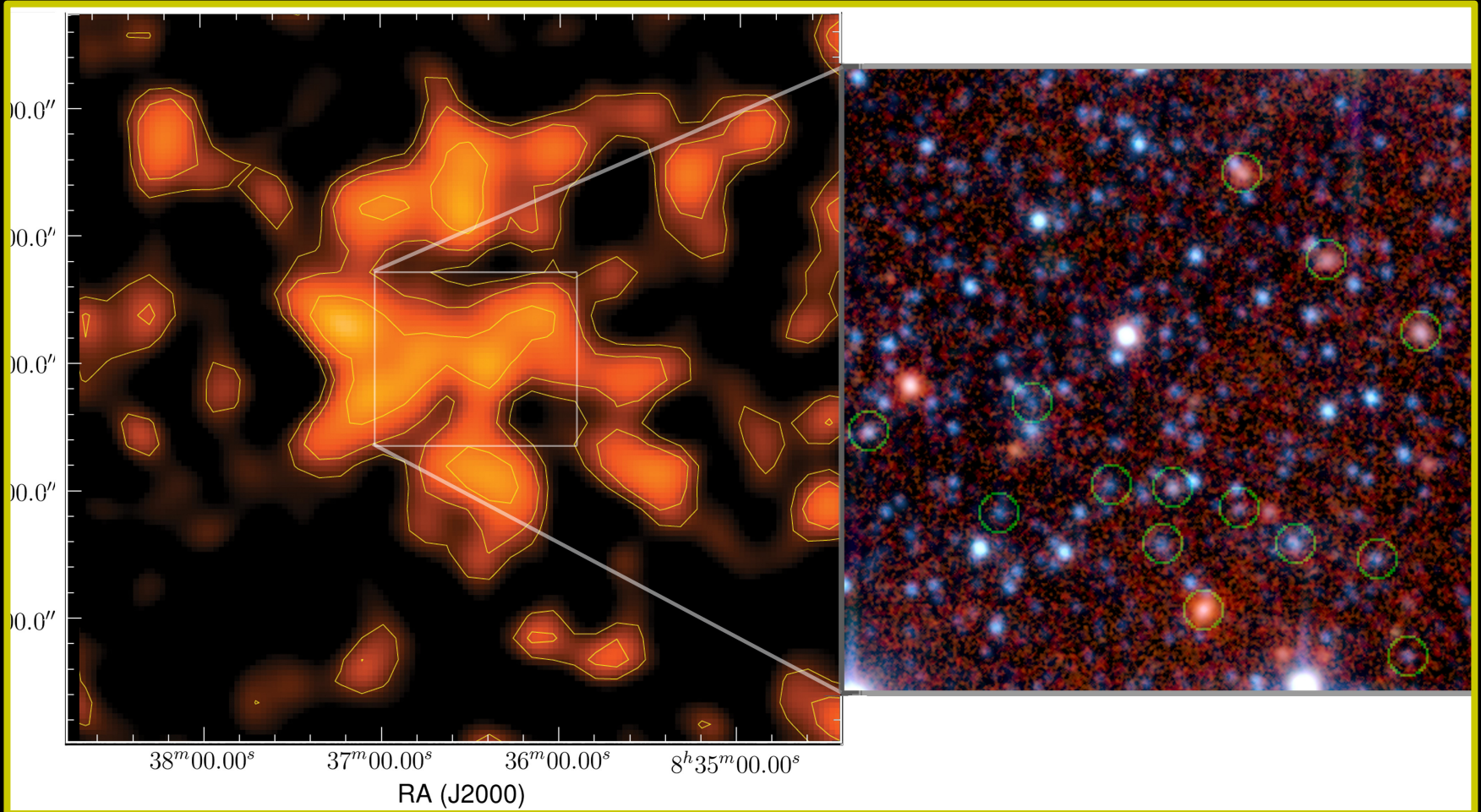


Above GP: $0^\circ < b < +10^\circ$



Below GP: $-10^\circ < b < 0^\circ$

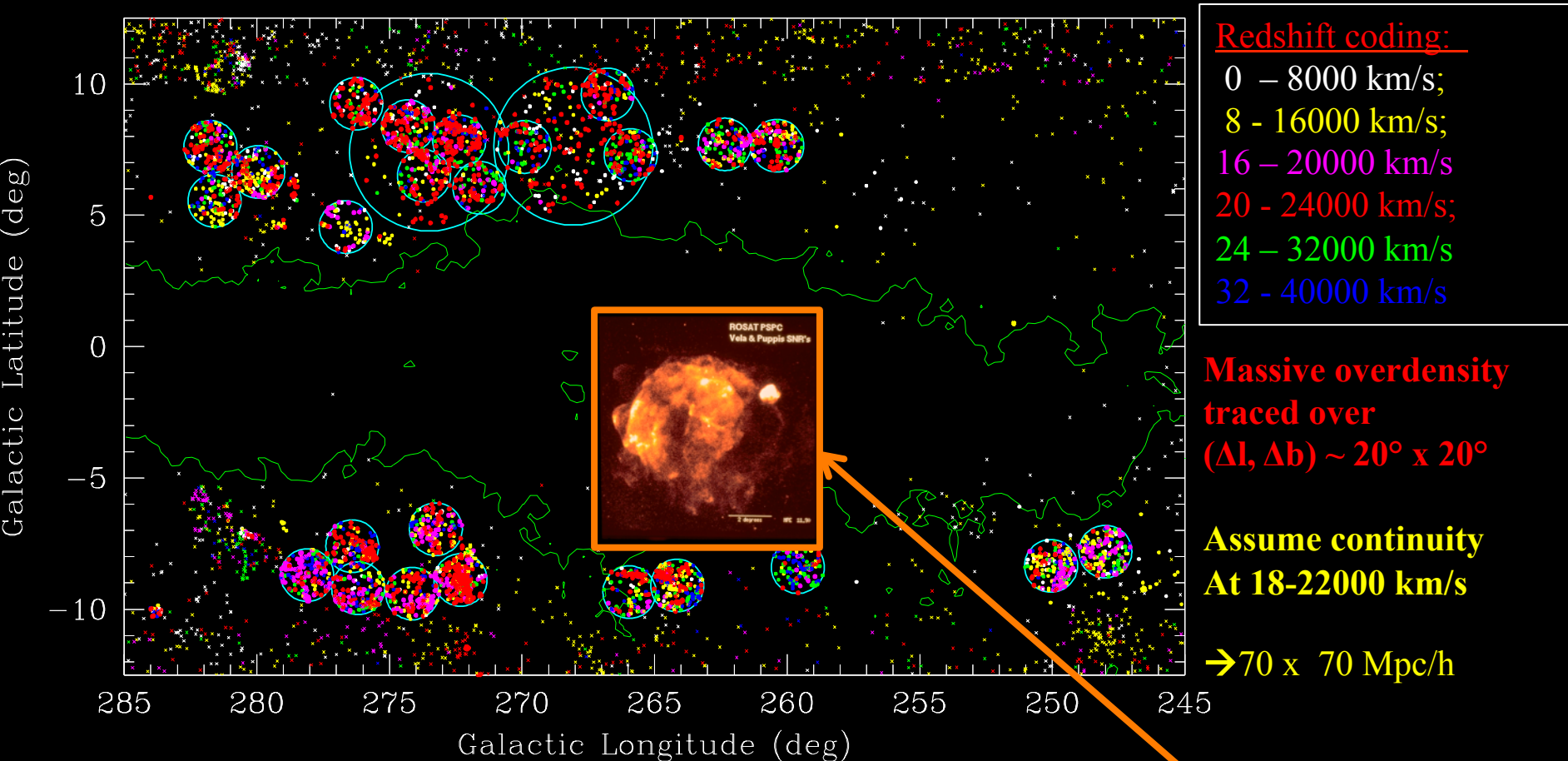
VC04 in X-ray (ROSAT) – WISE zoom-in



2_X-ray clusters found (not in CIZA);

→ Few, but still overdense given prediction for survey region ($f \sim 2.5$)

In addition to Vela SNR which covers about 8 x 8 degrees



Where extinction reaches $\sim A_B > 2\text{mag}$

- hard to get redshifts, even for 2MASX galaxies
- Area of $\sim |b| < \pm 5-7^\circ$ unsampled

Vela SNR

What have we found – what does it signify?

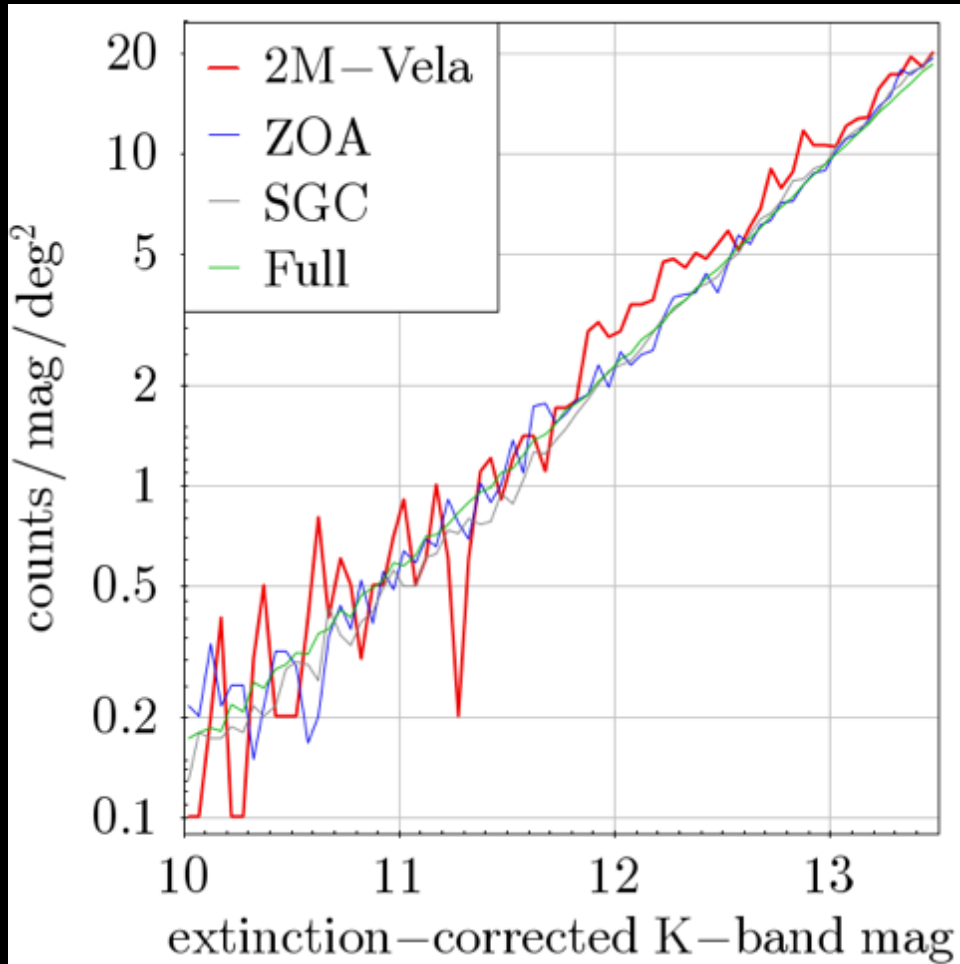
- Clear evidence for a galaxy supercluster in Vela
 - *possibly a supercluster in formation*
(two merging walls, many young clusters, many star-forming galaxies in clusters)

Despite sparse sampling we find

- The 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
 $6^\circ < b < 10^\circ; 260^\circ < l < 285^\circ$

99% complete for $A_K < 0.3\text{mag}$ and $K < 13.8 \rightarrow K^0 \sim 13.5\text{mag}$

3 comparison samples:

ZOA: $110^\circ < l < 260^\circ$

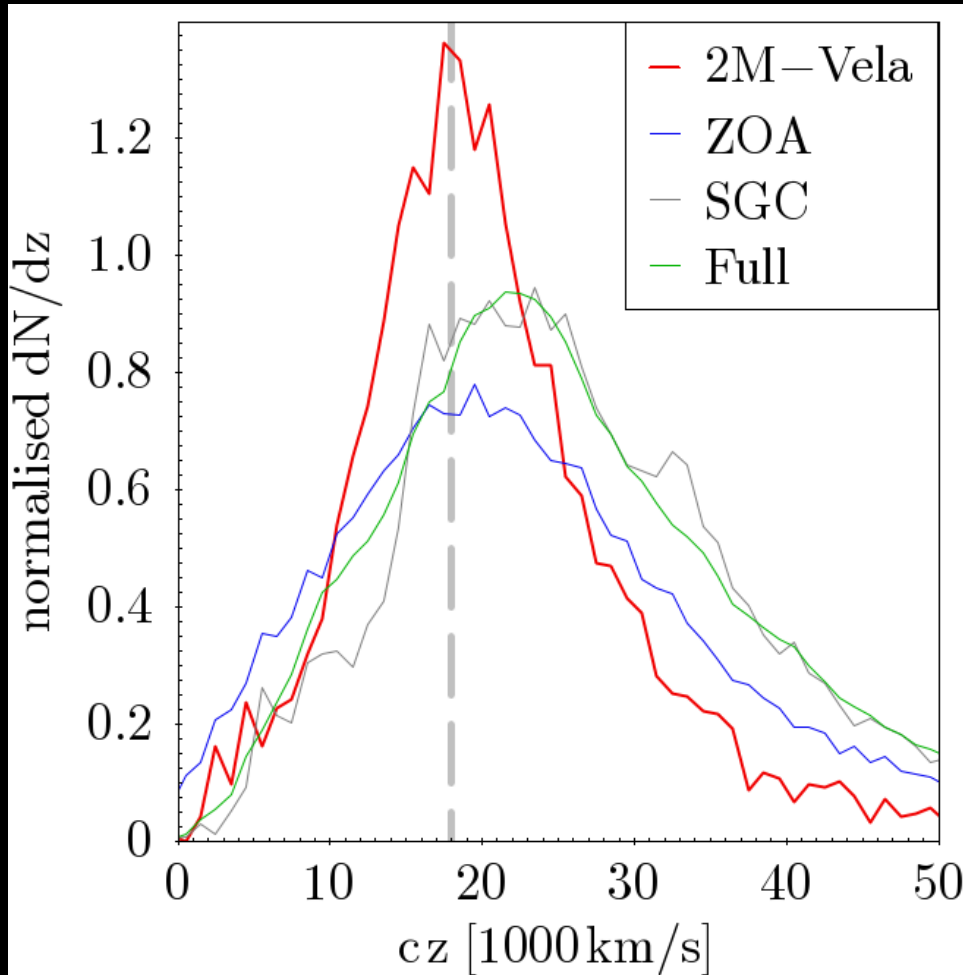
SGC: $b < -60^\circ$

Full: 2MASX for $|b| > 15^\circ$

→ 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 $\delta_{\text{Vela}} \sim 0.60$

What have we found – what does it signify?

- Clear evidence for a galaxy supercluster in Vela
 - *possibly a supercluster in formation*
(two merging walls, many young clusters, many star-forming galaxies in clusters)

Despite sparse sampling we find

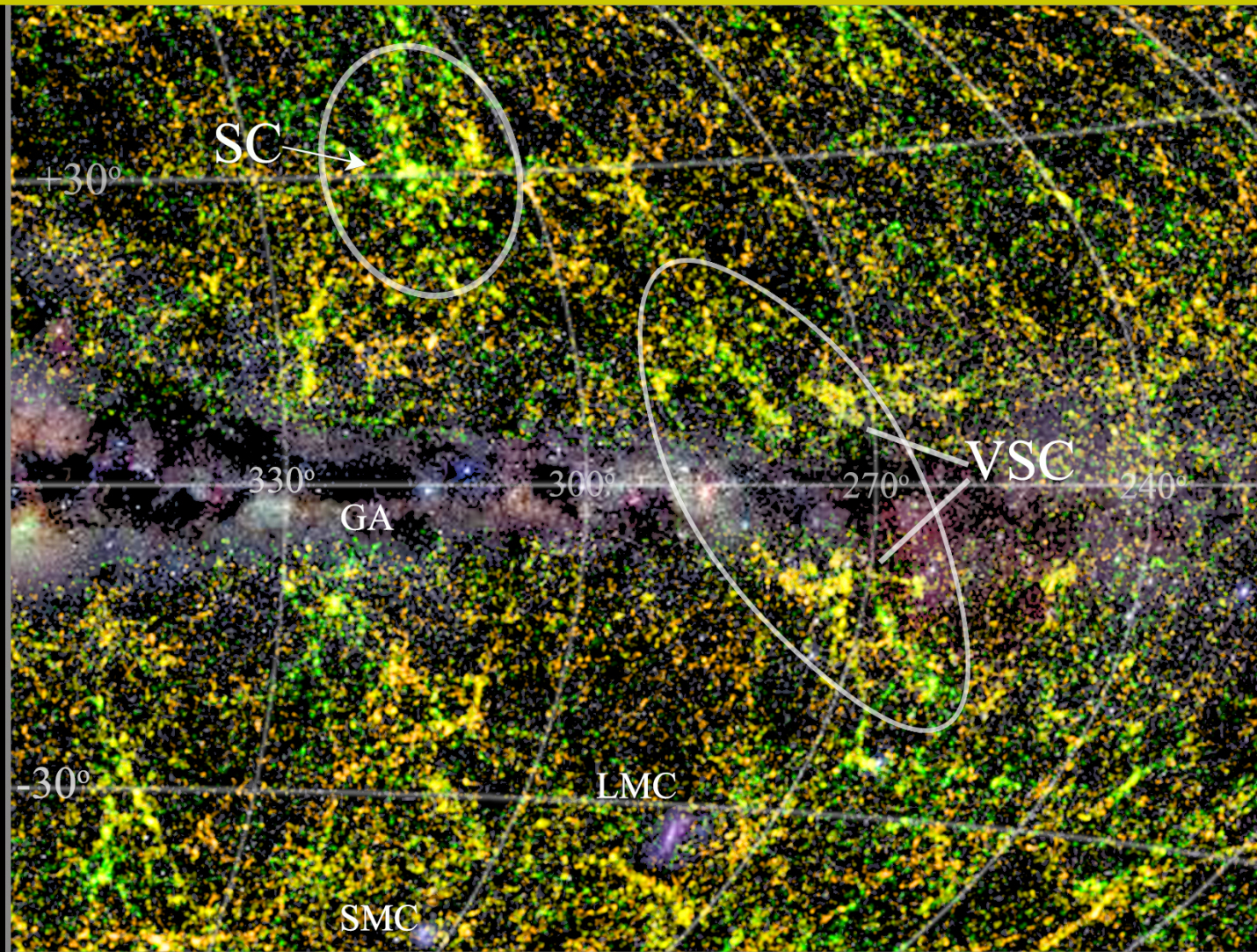
- The Vela SCL is significantly overdense in 2M galaxy counts and in volume defined by the overdensity
 - $\delta_{SSC} \sim 1.4$; however if subjected to same completeness limit and biases this would be reduced by $f \sim 2.3$
making overdensity similar to Shapley

It's impact on bulk flow may be significant

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

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

Discovery of a prospective supercluster in the ZOA in Vela



*Kraan-Korteweg, Cluver, Bilicki, Jarrett et al 2016, MNL in press;
arXiv:1611.04615*



Taipan observations

→ in Science Verification early 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.

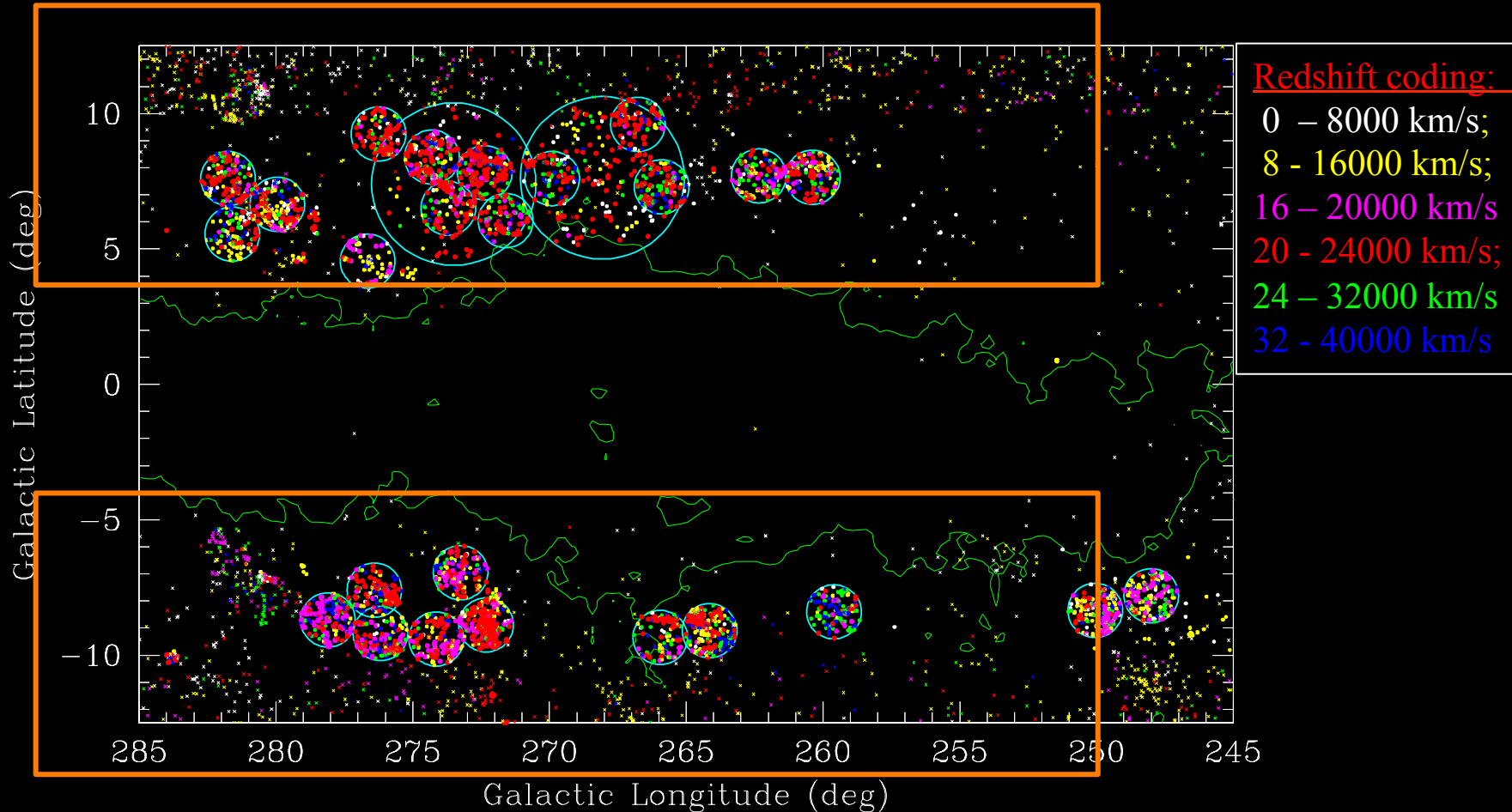
TAIPAN instrument:

- on 1.2m UK Schmidt Telescope (Siding Springs)
 - innovative starbugs optical fibre positioner
- 150 objects per 6-deg field
- reasonable complete redshifts, as faint as $r = 17.5$ mag in 15 min integration

ZOA ($|b| < 10^\circ$) 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



MeerKAT observations

→ in early or open science time



MeerKAT roll-out:

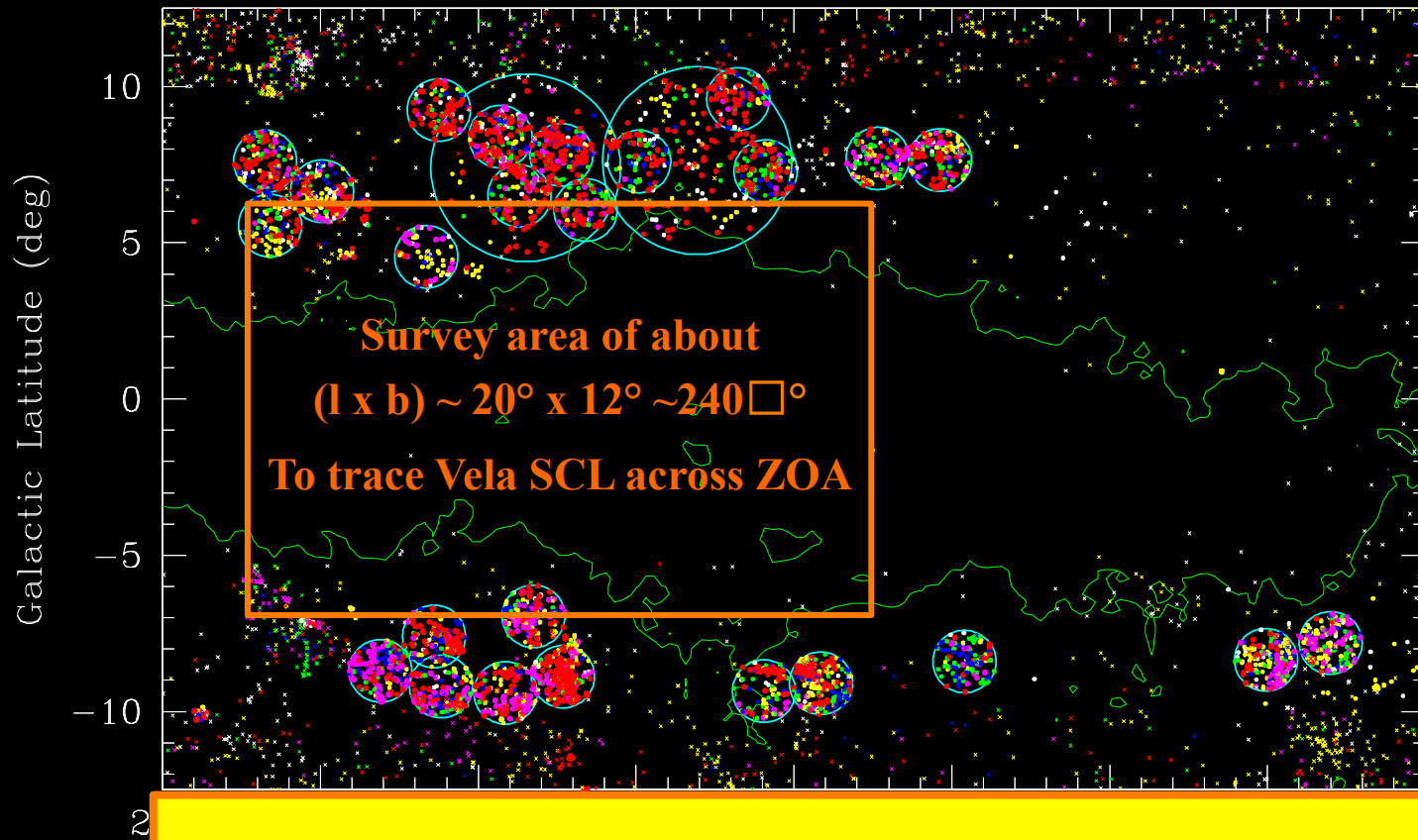
- AR1 (M16) : mid-July 2016 (*fully operational – verification concluded*)
- AR2 (M32) : end March 2017 (*early science operations starting*)
- AR3 (M64) : end 2017 (*science ready*)

Time allocation (goal): 70% for Large-Survey Projects; 30% open time

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
And future planned Taipan survey



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

MeerKAT M32 Early Science survey scenario

Goal: identify “all” galaxies complete to $\log M_{\text{HI}} > 9.5 M_{\odot}$
for VSC redshift range (18000km/s ~ 250 Mpc)

- $F(\text{HI}) = 0.2 \text{ Jy km/s}$
- For a 5σ detection limit over $\Delta v = 200 \text{ km/s}$
- **Requires: rms = 1mJy/beam in 10 km/s channel**

Updated MeerKAT Specifications for L-band:

$$T_{\text{sys}} = 22 \text{ K}; A_e/T_{\text{sys}} \sim 424 \text{ m}^2/\text{K};$$

$$\sigma_s = \frac{2kT_{\text{sys}}}{A_e \eta (\delta t \delta \nu)^{1/2}}$$

T_{int}

pointing

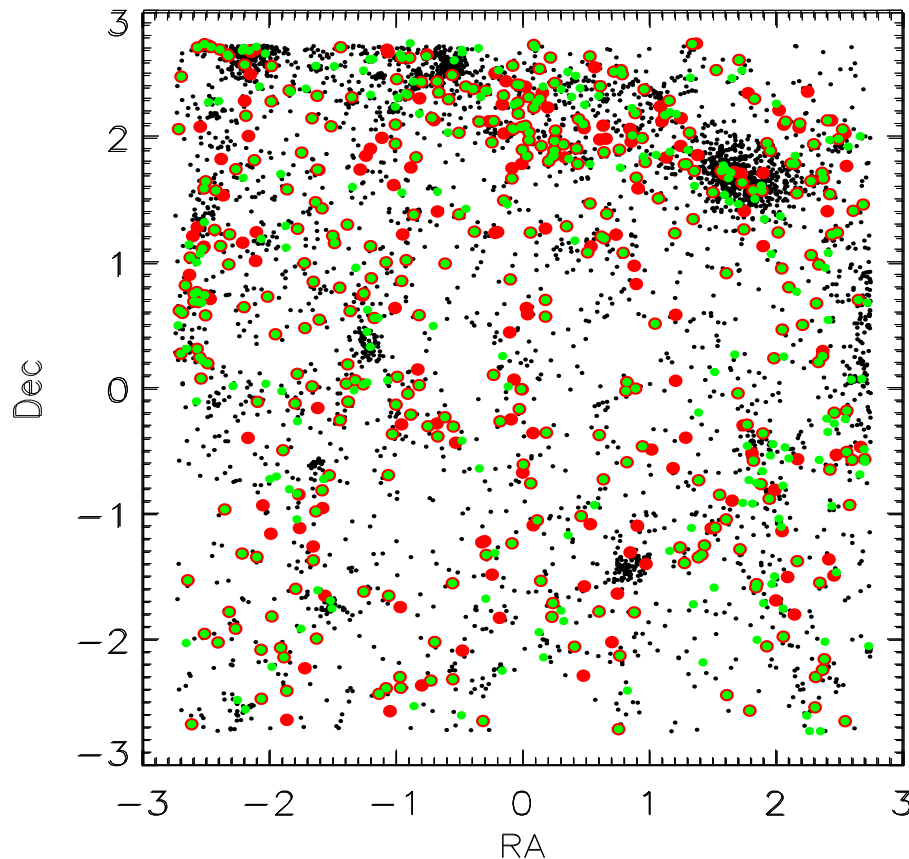
M32 : 30 min
M64 : 7.5min

Nyquist sampling: will require 960 pointings → but reduce $T_{\text{int}} \rightarrow 15 \text{ min}$

→ Full survey: 240 hours with M32

Galaxies at 16-24000km/s in simulated HI-data cube of 30Mpc^2

*Simulations by Ed Elson (UCT) based on semi-analytic models S^3 -SAX
(Obreschkow et al 2009, 2014)*



Will we recognise the
supercluster wall/filamentary
structure?

For 16-24000 km/s and 30Mpc^2

VSC $> 5\sigma$ $\lg M_{\text{HI}} > 9.5$

5072 465 118

For 240Mpc^2 survey area

40000 3720 950

Goal:
determine mass overdensity
based on HIMF

Steps towards a full census of the Vela SCL

... to determine its extent, richness and mass overdensity

→ and contribution to bulk flow

- Taipan survey in science verification mode
- Further SALT observations of potential clusters
- Follow-up VSCL cluster observations (**IRSF, WISE, SALT**)
 - *(K-band LF, mass - possibly peculiar velocities using WISE TF over the MeerKAT HI survey area)*
- Early Science Survey with MeerKAT (M32) to cover optically obscured part of Vela SCL ($|b| < 6^\circ$)
 - *First simulation show that this is feasible in about 240 hrs with M32*
 - *With M64: extend survey, and include 2nd hidden part of Big Circle towards TriAu clusters*