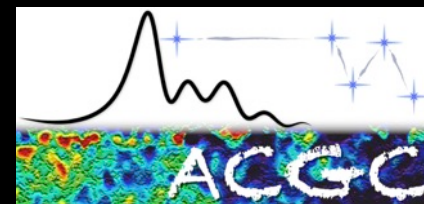




Discovery of a massive Supercluster in Vela



Renée C. Kraan-Korteweg

ACGC (Astrophysics, Cosmology and Gravity Centre), UCT

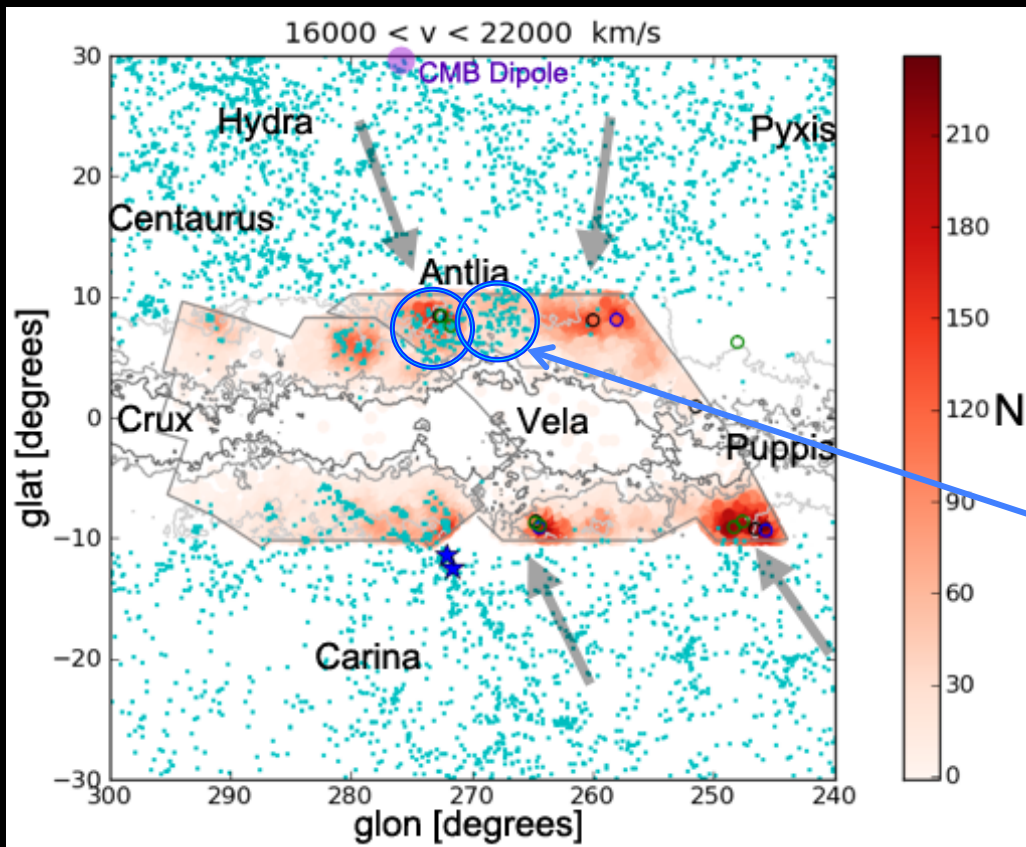
Michelle Cluver, Tom Jarrett, Maciej Bilicki, Matthew Colless & Ahmed Elagali

- **First hints of existence of massive overdensity**
- **SALT & AAOmega spectroscopic results**
 - **Discovery of Vela Supercluster hidden by ZOA**
- **First assessment**
- **Future Plans**
 - **MeerKAT & other proposed/ongoing follow-up surveys**

LSS & Galaxy Flows
3-9 July, Vietnam

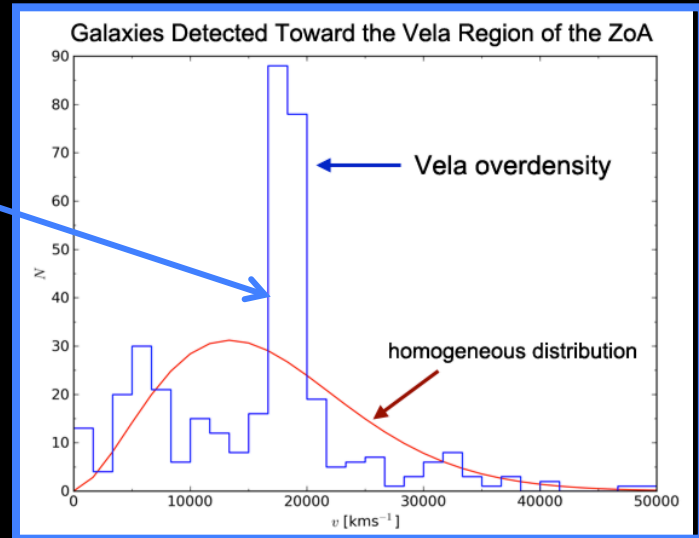
Suspicion of existence of massive overdensity in ZOA

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):

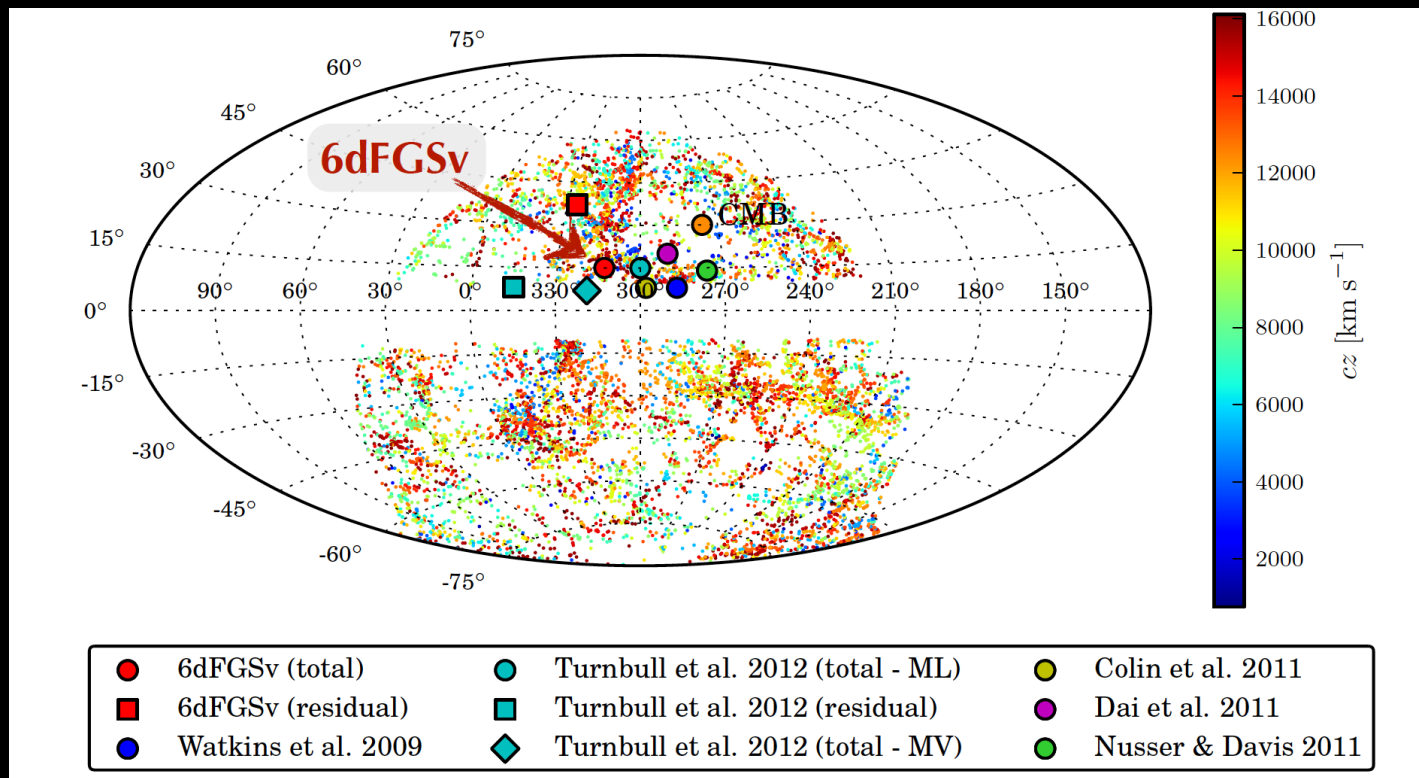
Two adjacent 6dF fields; $\sim 370z$



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

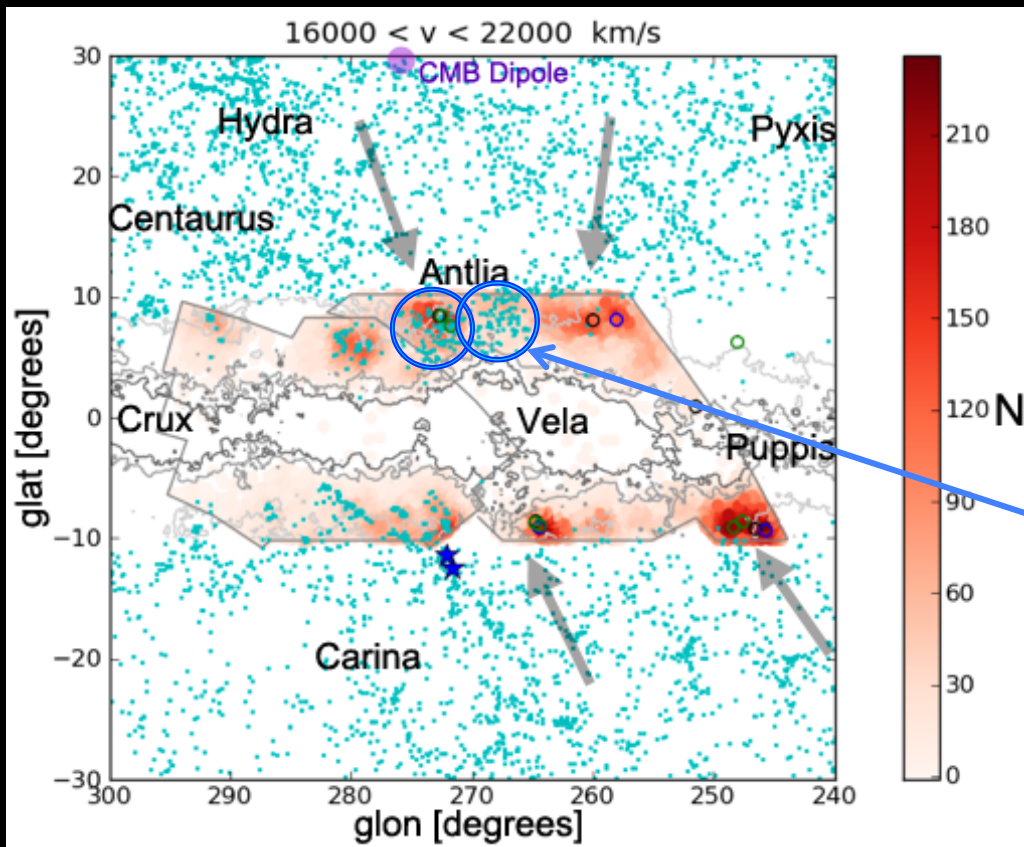
- Bulk-flow within 160 Mpc/h: $V = 365 \text{ km/s} \rightarrow (l, b) = 313^\circ, 15^\circ$
- Residual flow of: $V = 292 \text{ km/s} \rightarrow (l, b) = 313^\circ, 36^\circ$

→ Hints of structure influencing local dynamics outside of survey volume



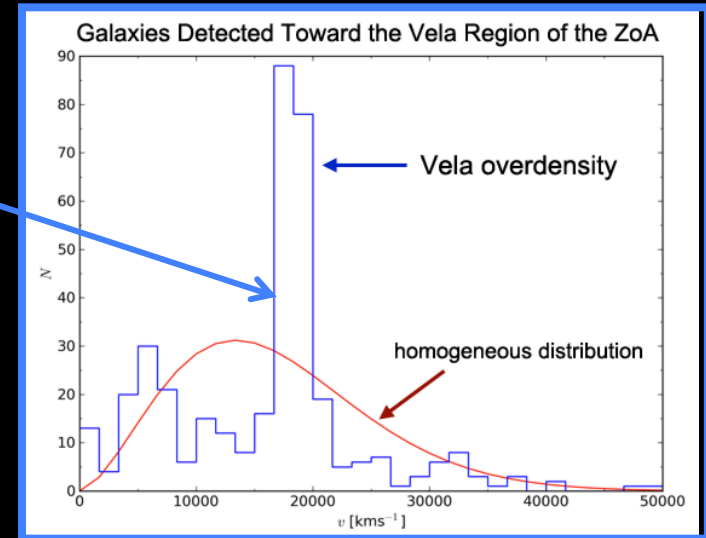
Suspicion of existence of massive overdensity in ZOA

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

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



→ First SALT then AAOmega proposals to consolidate & map extent of overdensity (with M Cluver, T Jarrett, M Bilicki, M Colless)

→ 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 = $8'$; $N \sim 25$



2012-2014:

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

AT 4m & AAOmega:
FoV 2° ; $N = 392$

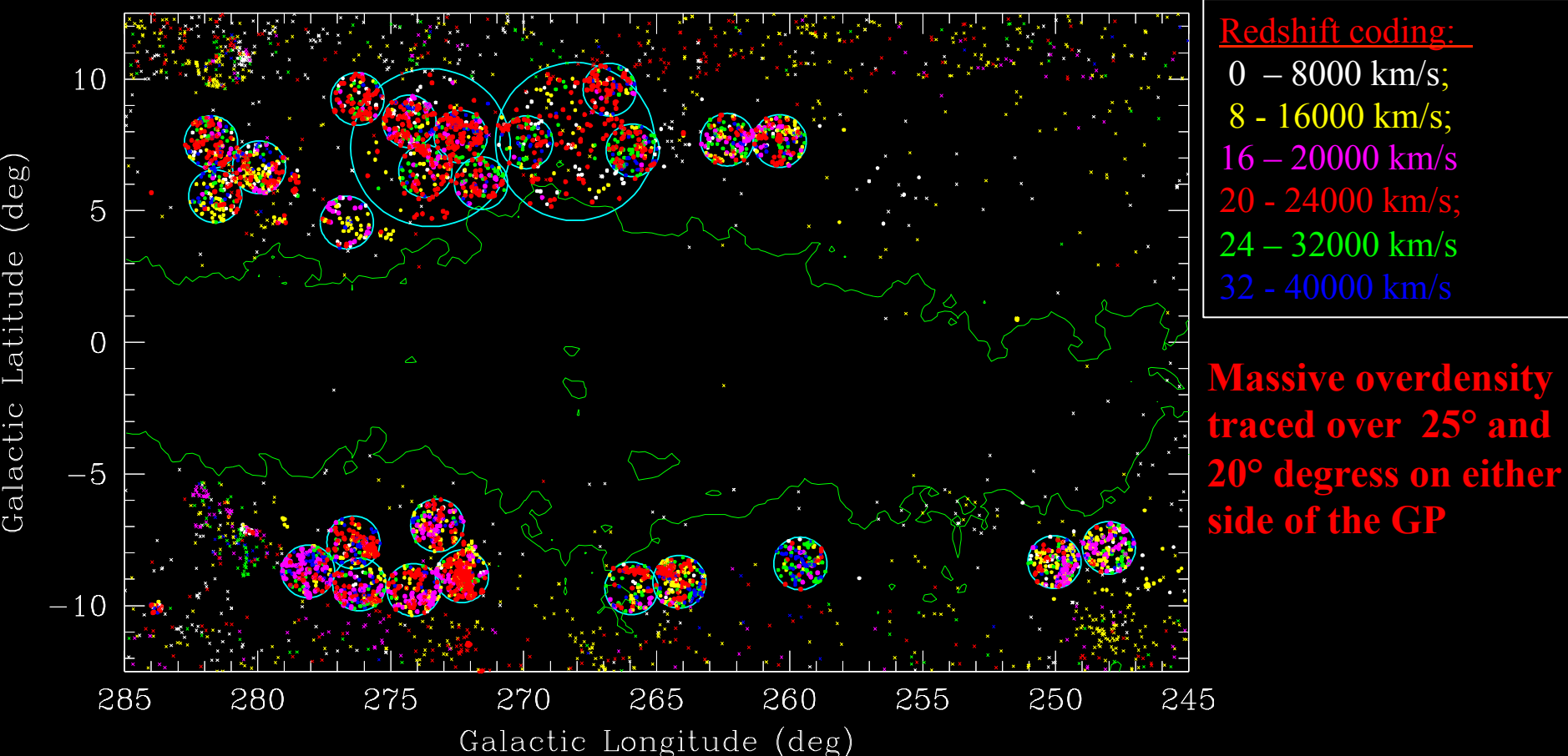


2014: 6 nights in February:

- **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



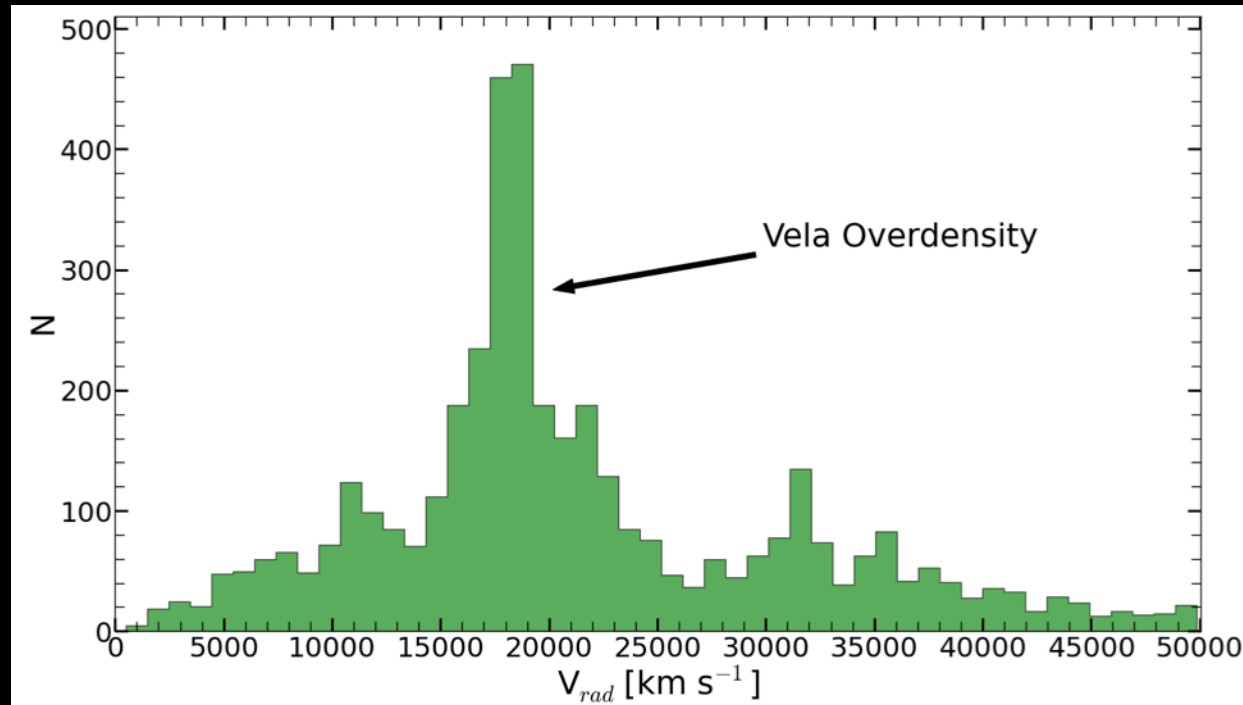
Still very sparsely sampled – and only at intermediate latitudes (between 5° - 10°)

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 16-22000 km/s

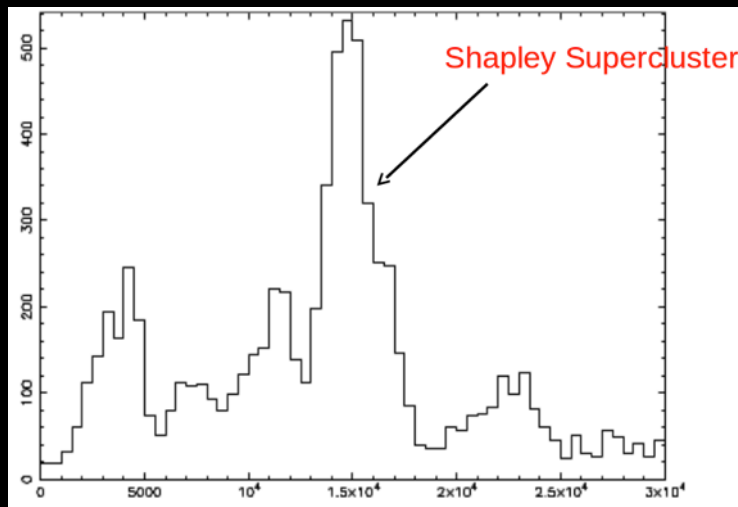
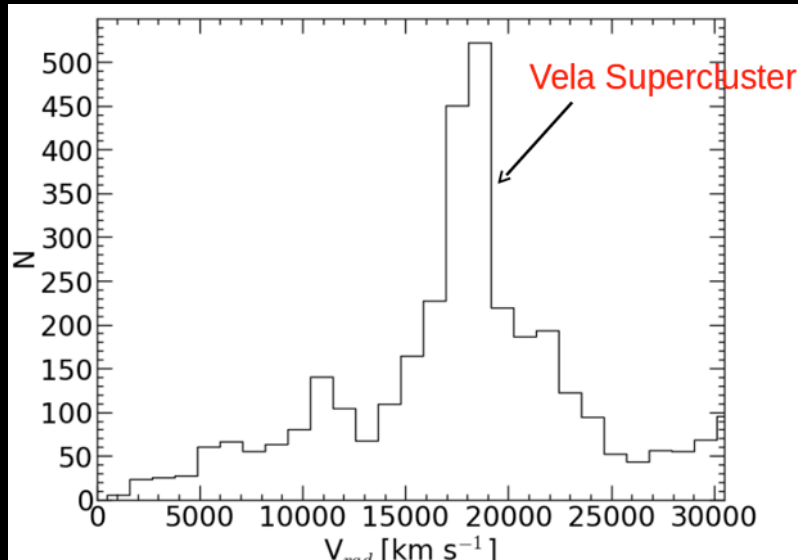


Despite sparse sampling, prominence bears remarkable similarity to Shapley SC survey (*Proust et al 2006*)

Comparison of Redshift histograms of Vela versus Shapley:

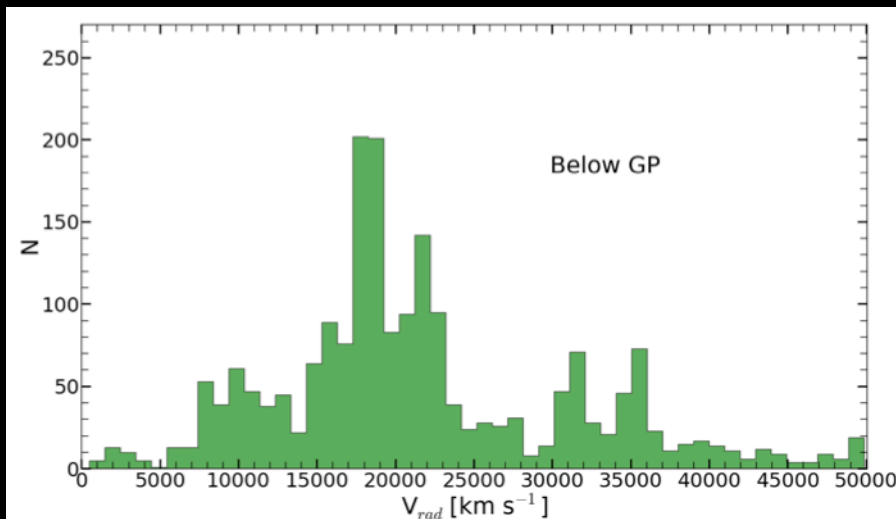
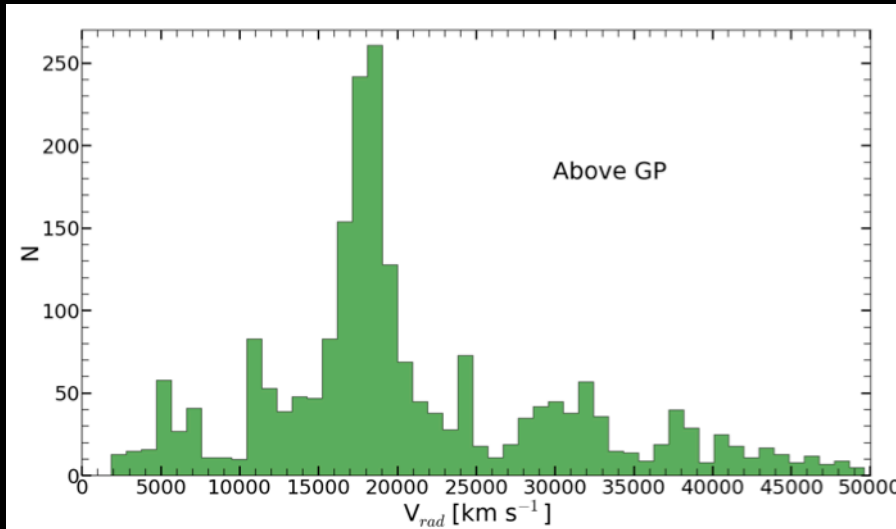
~ 4000 in $20^\circ \times 20^\circ$; sparsely sampled

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



- Massive overdensity traced over $(\Delta l, \Delta b) > \sim 20^\circ \times 20^\circ$
- Redshift histogram similar to Shapley SSC
(Proust et al 2006, $N \sim 8600$);
- Vela SCL is $f \sim 1.2$ more distant
→ quite extended on the sky:
 $12^\circ \times 30^\circ \leftrightarrow \sim 20^\circ \times 20^\circ$
 $30 \times 75 \leftrightarrow 65 \times 65 \text{ Mpc/h}$

Combined ZOA redshift survey divided above and below the Galactic Plane

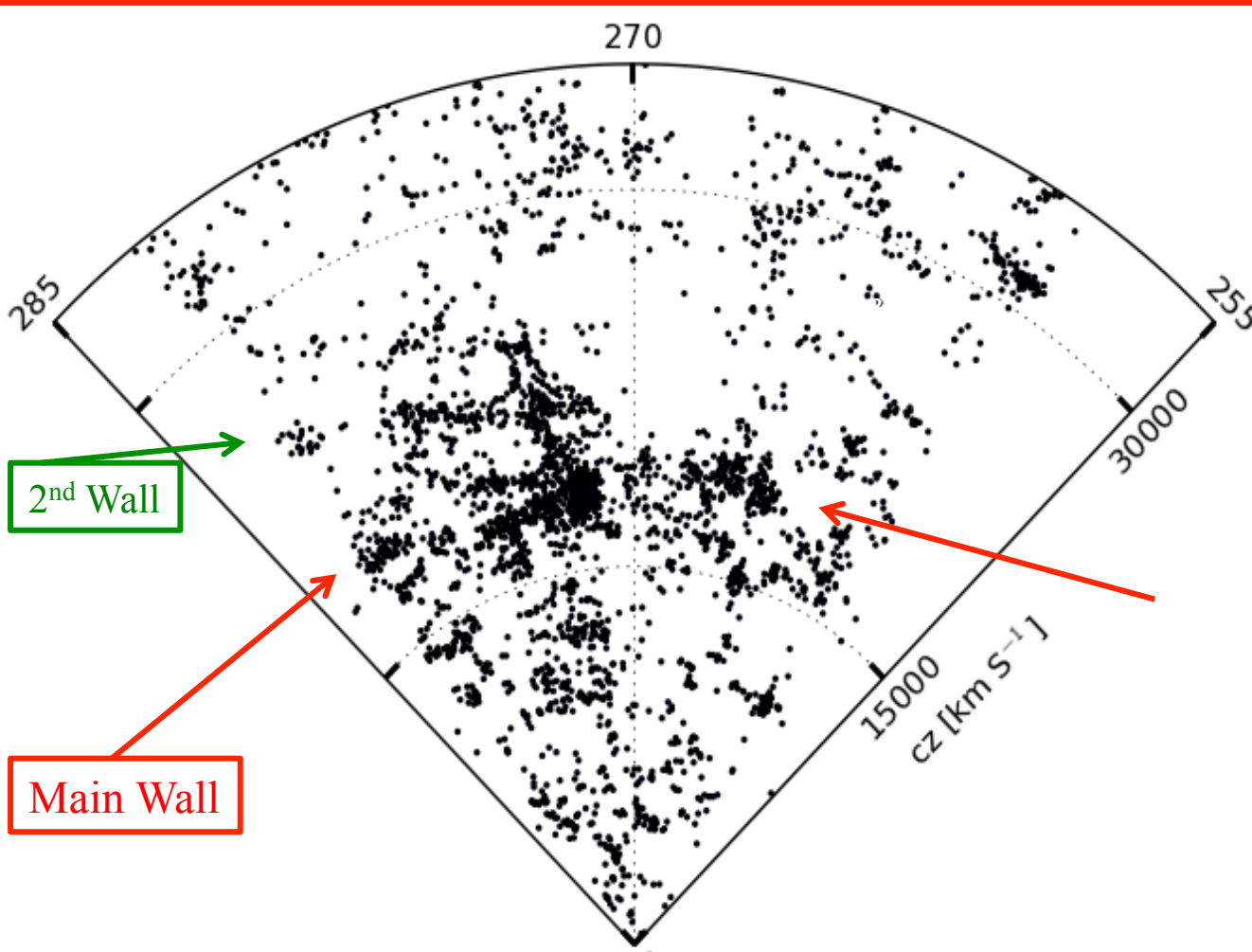


- Velocity histogram shows highly significant peak centred at $\sim 18000 \text{ km/s}$
- *just beyond boundaries of current surveys 16-22000 km/s*
- **Overdensity** equally prominent above and below optical ZOA
- Numerous clusters at 18-20000 km/s
- Embedded in broader wall-like structure (16-24000 km/s)

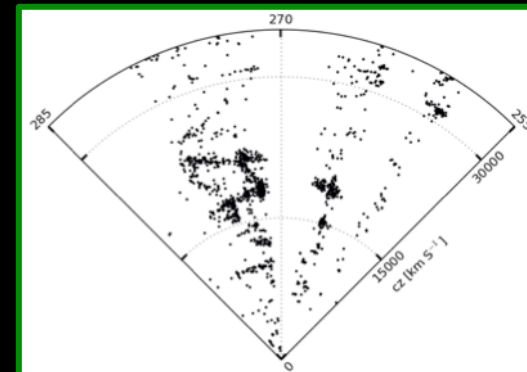
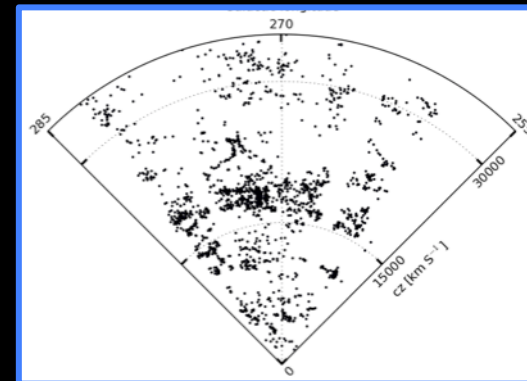
Redshift slices for ZOA Survey area

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

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



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

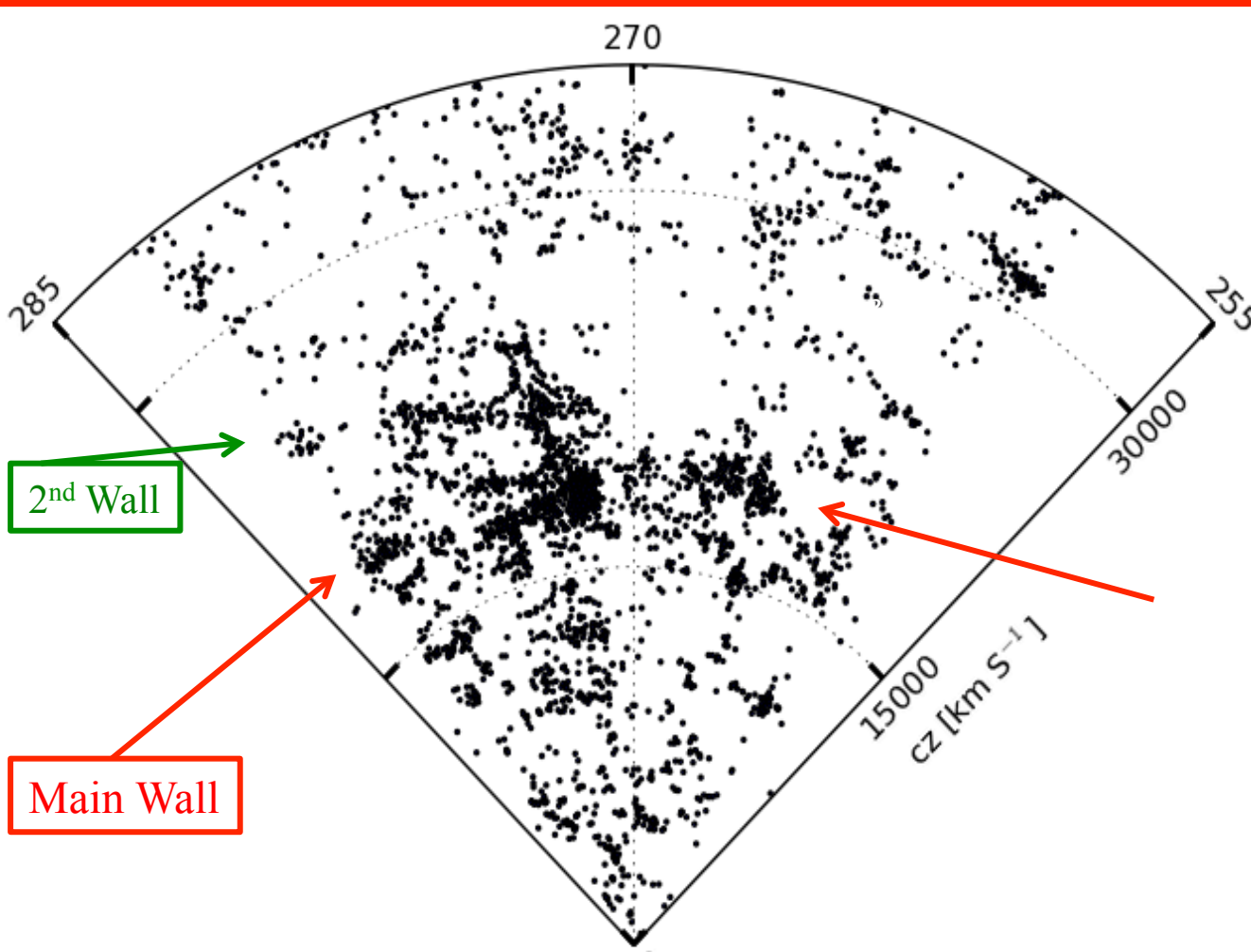


Below GP: $-10^\circ < b < 0^\circ$

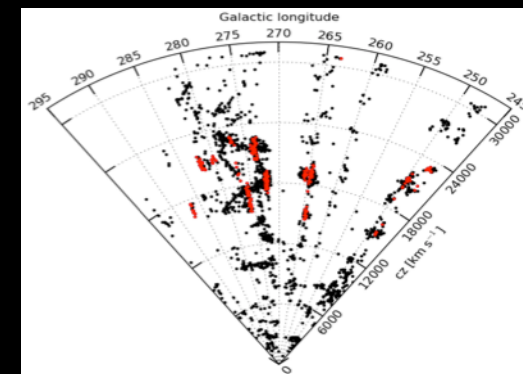
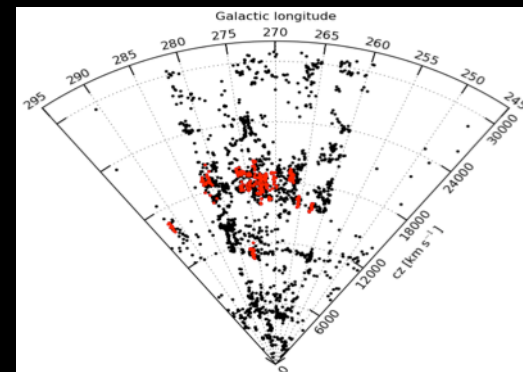
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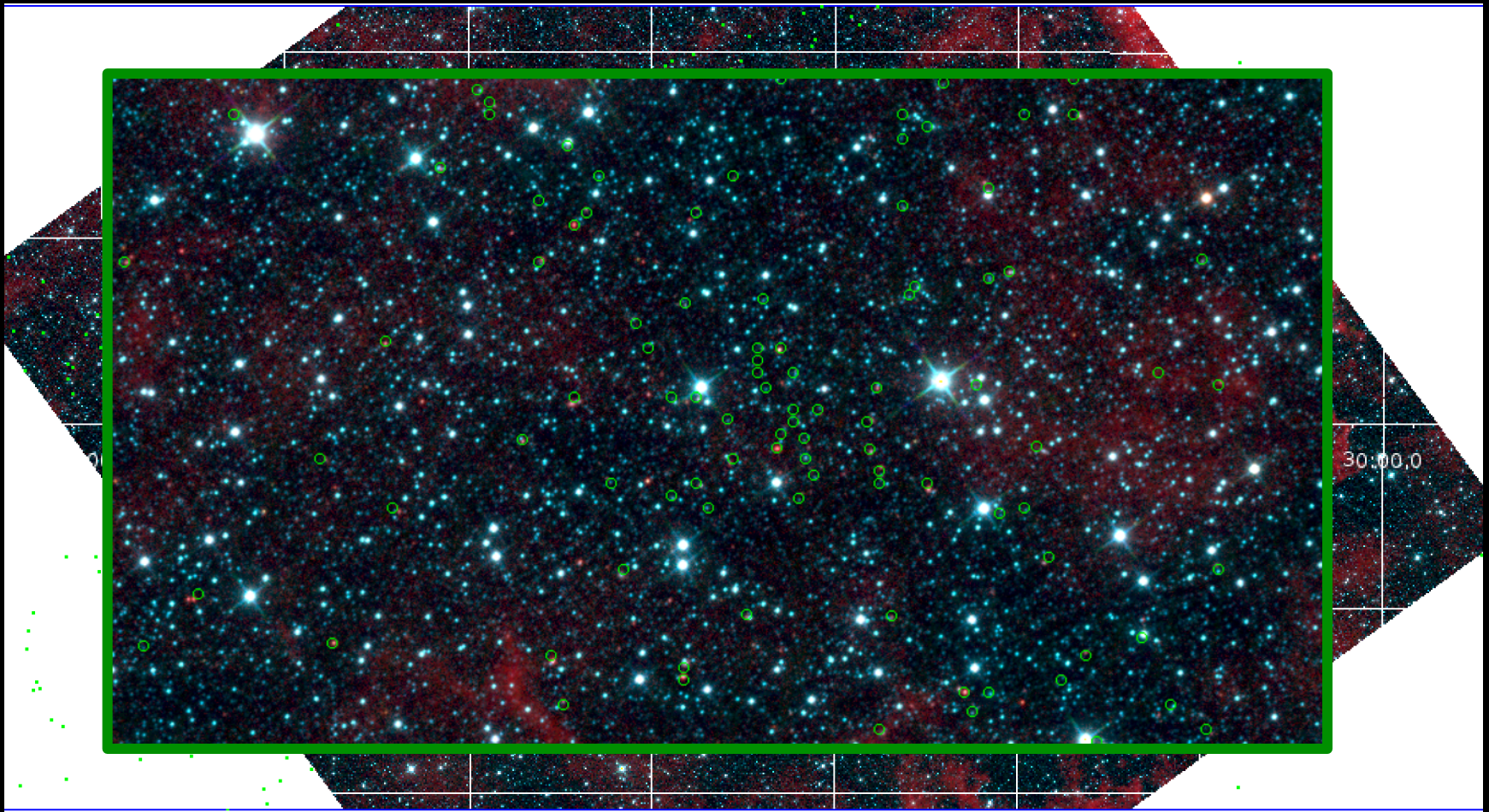
Above GP: $0^\circ < b < +10^\circ$



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

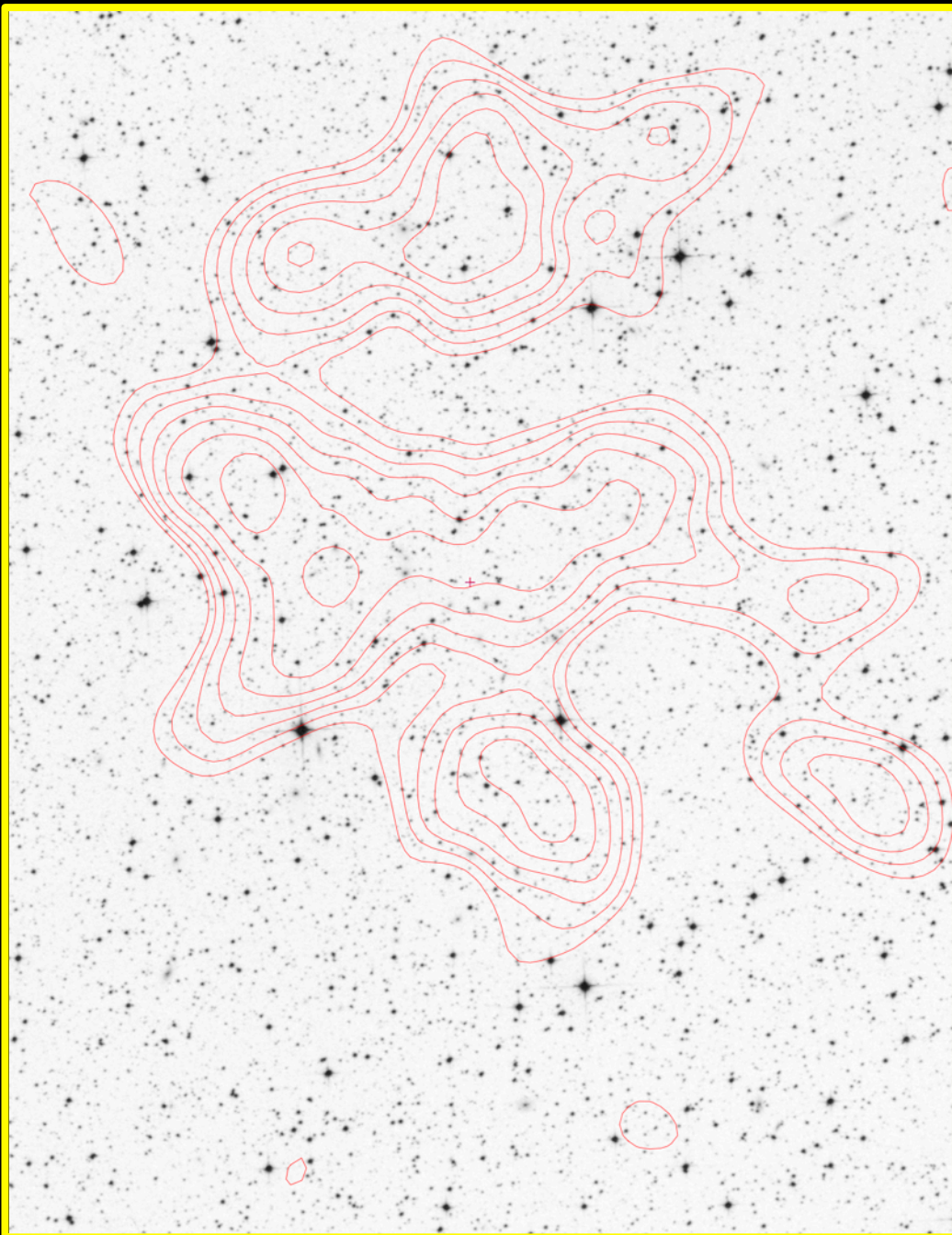
WISE image around one of our richer clusters (VC 04)

Heavily contaminated by Galactic foreground; but many star-forming galaxies



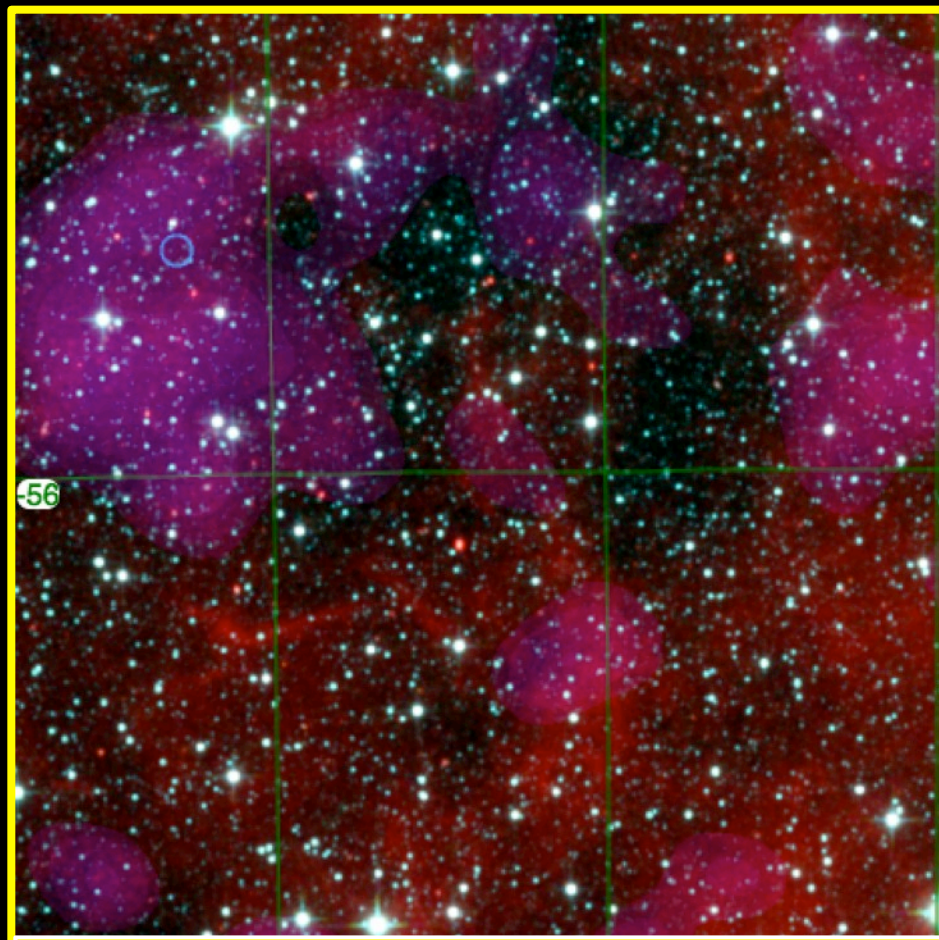
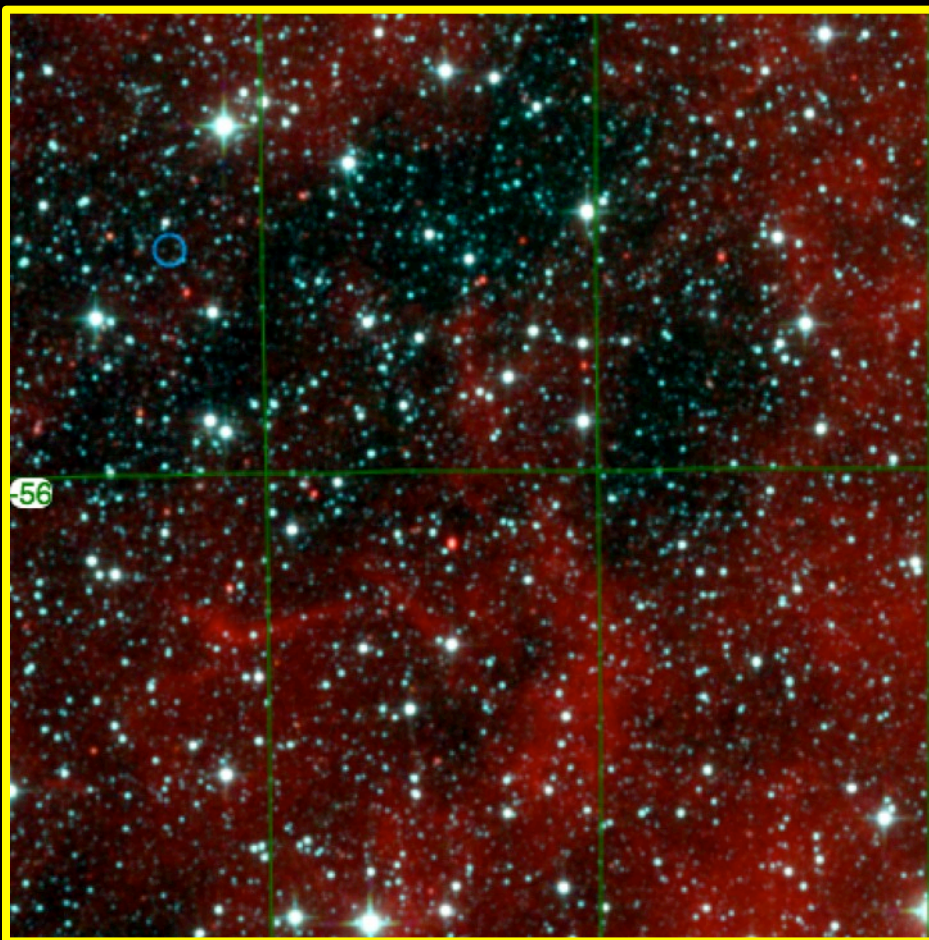
Courtesy Tom Jarrett

VC04 in X-ray (ROSAT)
overlaid on DSS2 R



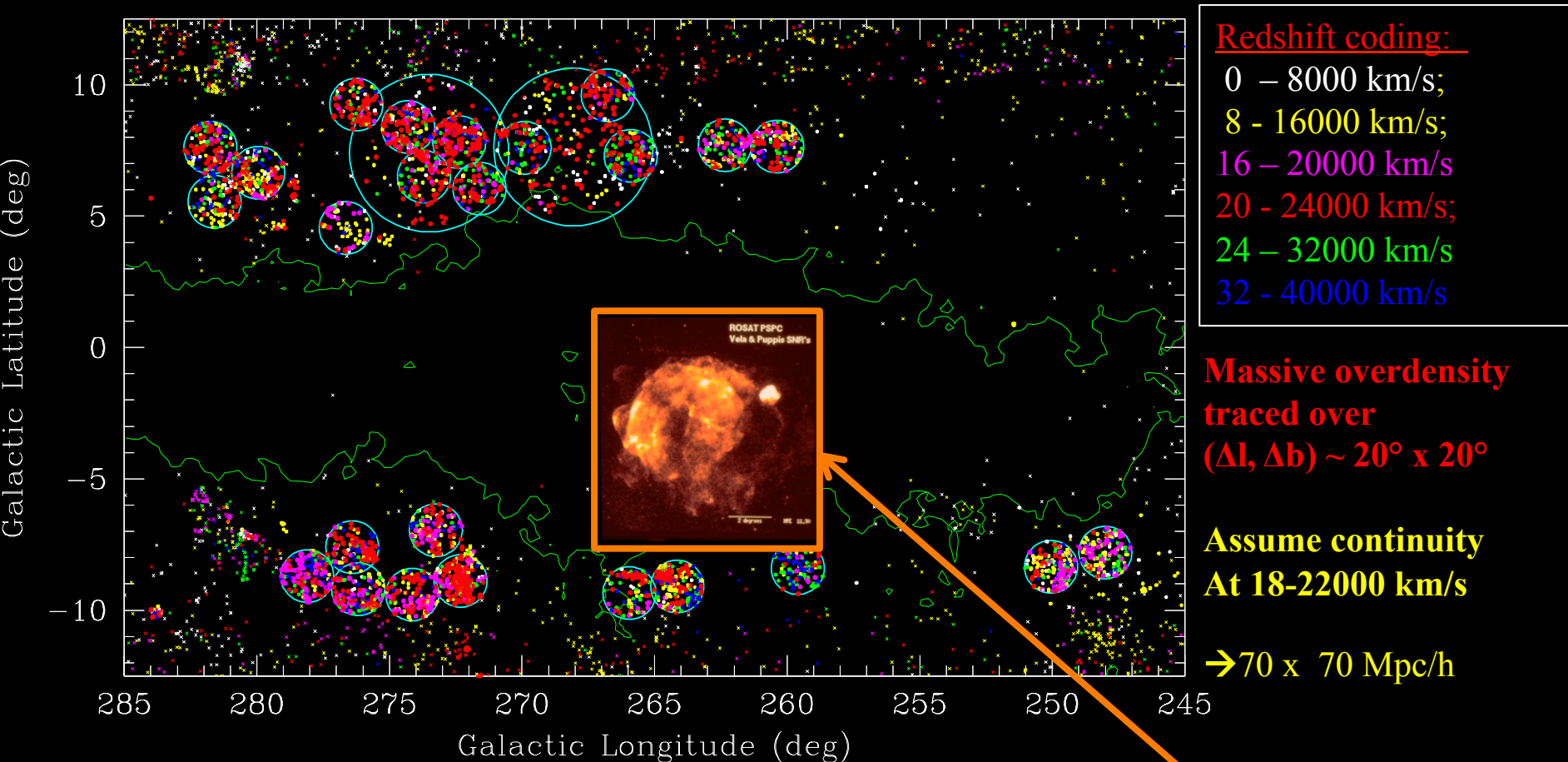
prepared by H Boehringer

WISE image plus X-ray (ROSAT) around clusters (VC 04)



*X-ray contours determined by H Boehringer
Composite prepared by T Jarrett*

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



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
traced over
($\Delta l, \Delta b$) $\sim 20^\circ \times 20^\circ$**

**Assume continuity
At 18-22000 km/s**

$\rightarrow 70 \times 70$ Mpc/h

Where extinction reaches $\sim A_B > 2\text{mag}$
 \rightarrow hard to get redshifts, even for 2MASX galaxies
 \rightarrow 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)

Vela SCL redshift histogram similar to the SSC

Forms Big Circle of SCL's across the sky:

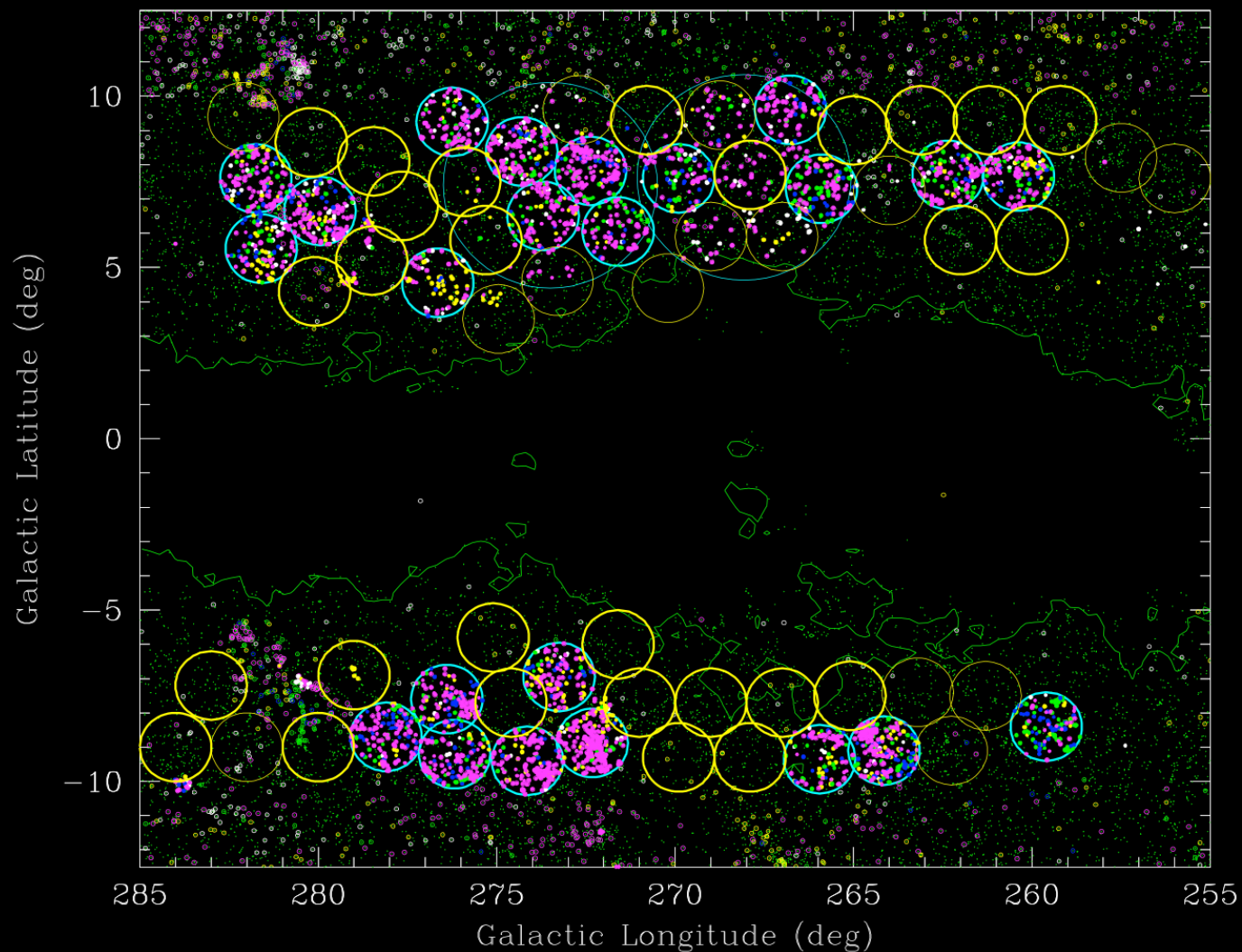
Vela SCL → Shapley SCL → Ara/Triangulum?

It's impact on bulk flow may be significant

– *But difficult to assess properly with sparse sampling*

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

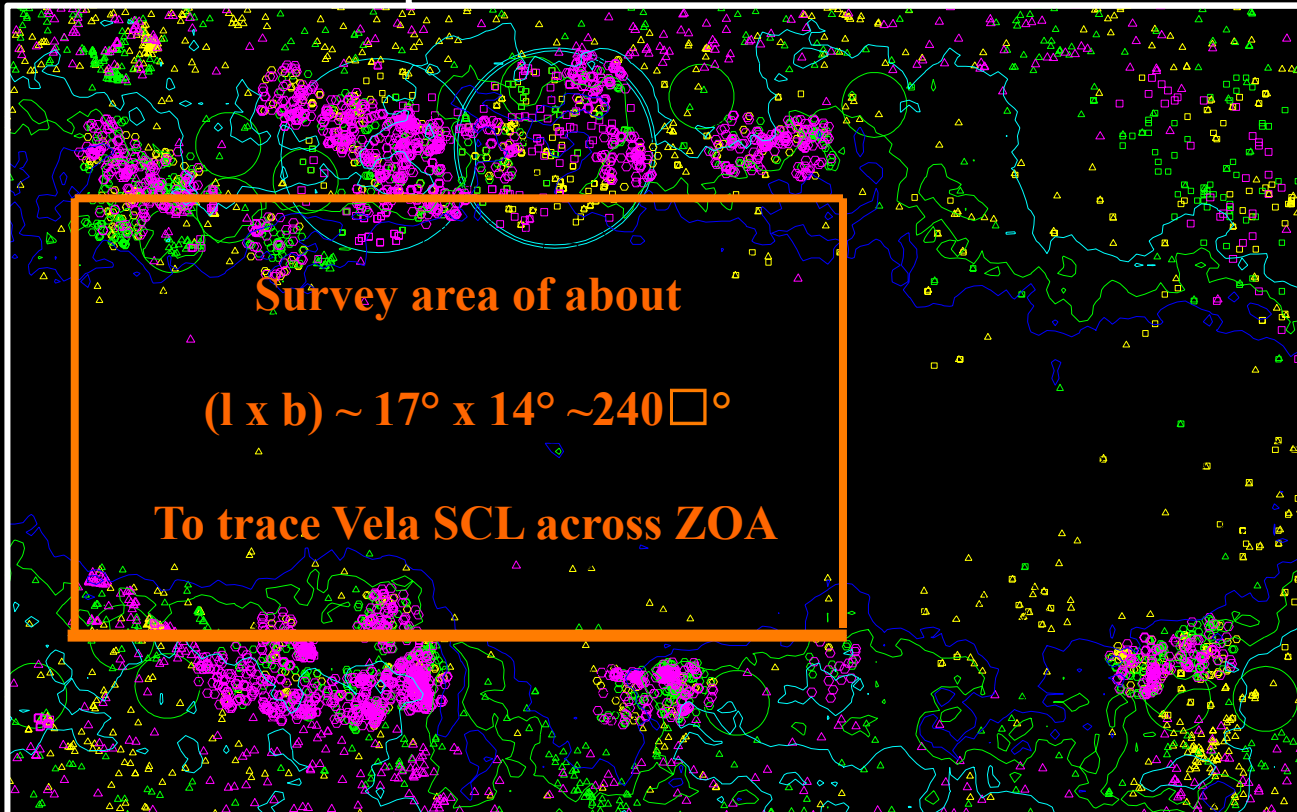
AAOmega proposal for further observations at intermediate latitudes



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

0 – 10000; 10-16000; 16-24000; black: 24-50000



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

Previous ZOA survey
experience with WSRT
of hidden cluster in
PP-SCL complex

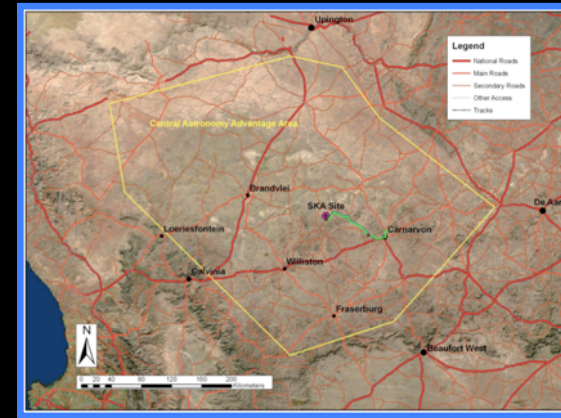
450 hrs
Mosaic of 35 pointings
→ 9.6 □°
2200 - 16500 km/s
rms ~ 0.4 mJy / beam

*Ramatsoku et al 2016,
arXiv:1605.02603*



MeerKAT

64 dishes over 8 km baseline
13.5-m with Gregorian offset
single pixel receiver (0.9-1.7 GHz)
Compact core, extended baseline



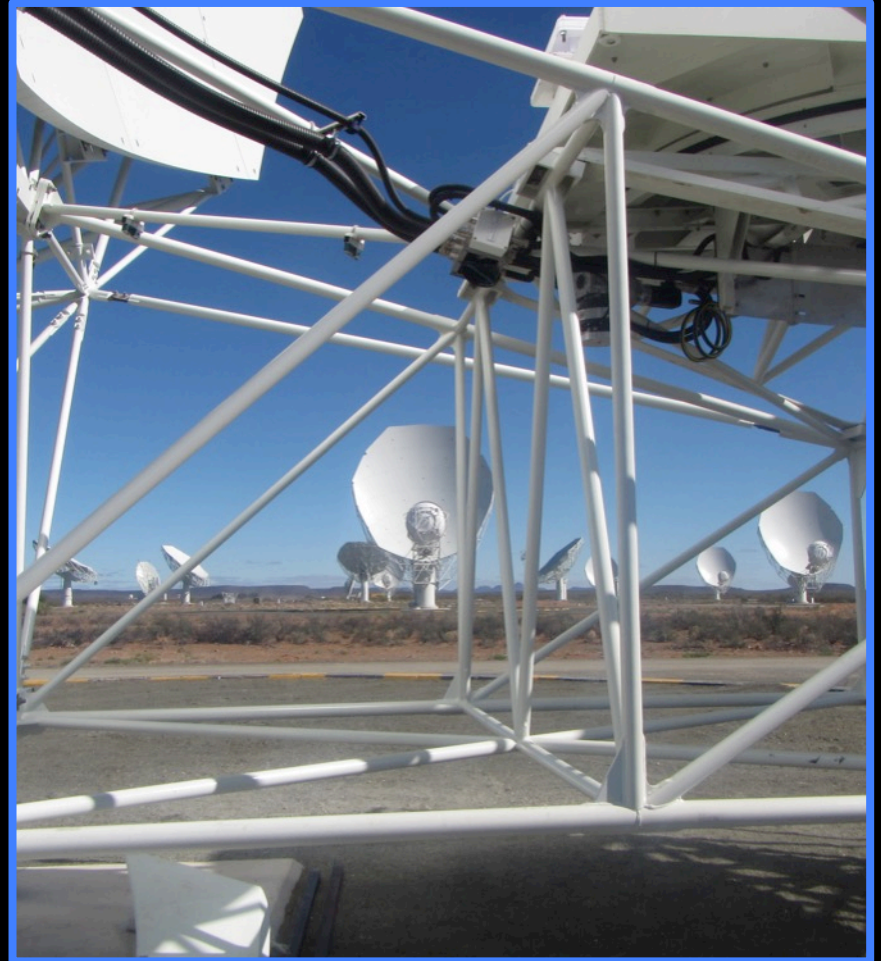
MeerKAT roll-out:

- 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



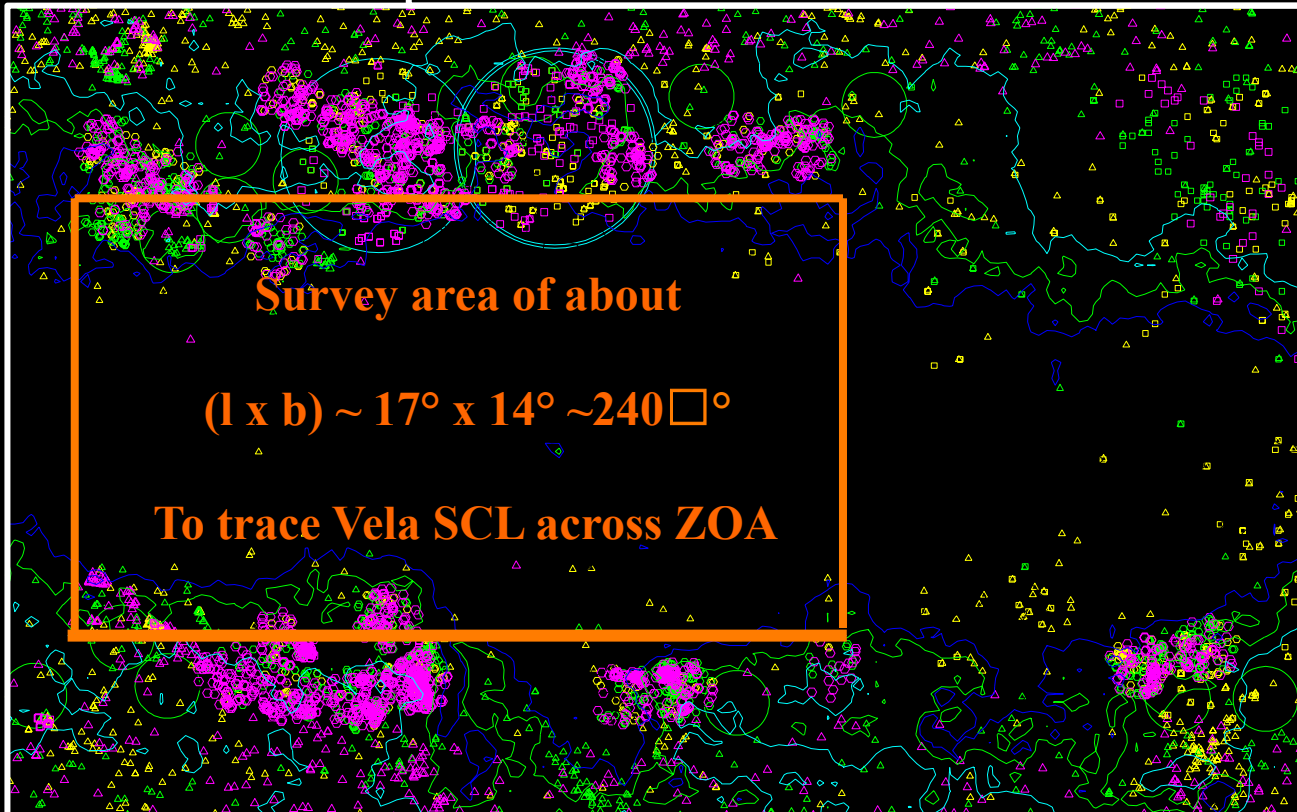
Recent MeerKAT pictures



MeerKAT M32 Early Science survey scenario

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rms ~ 0.4 mJy / beam

*Ramatsoku et al 2016,
arXiv:1605.02603*

MeerKAT M32 Early Science survey scenario

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

→ $F(\text{HI}) = 0.2 \text{ Jy km/s}$

→ For a 5σ detection limit over $\Delta v = 200 \text{ km/s}$

→ **Requires: rms = 1 mJy/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

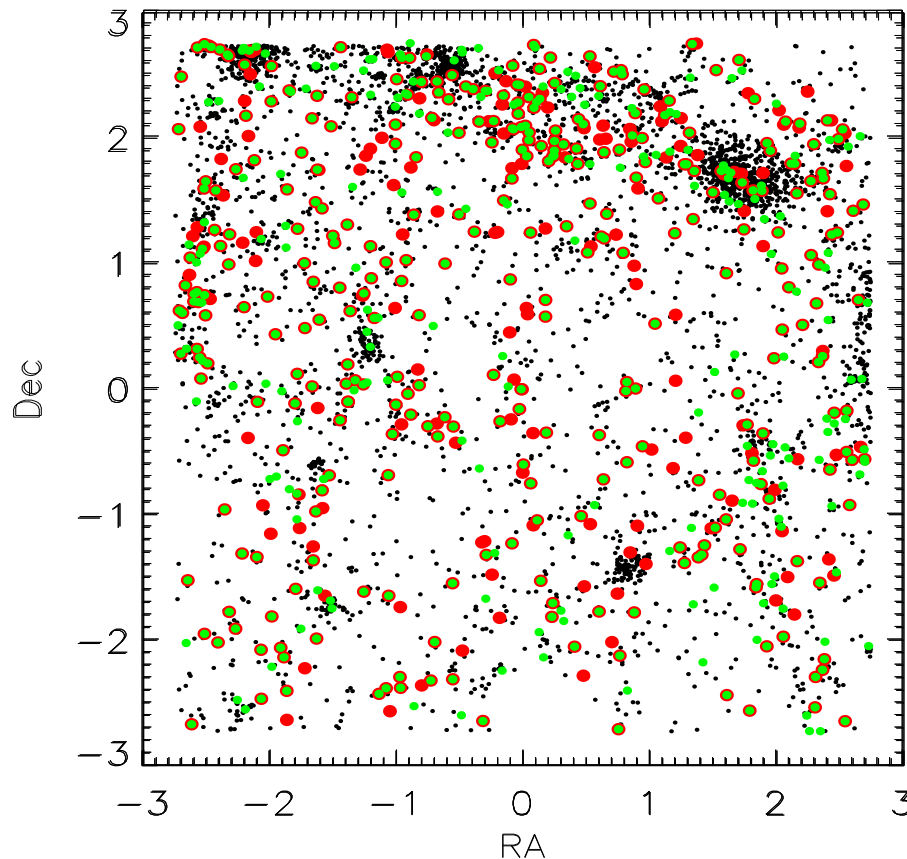
M32 : 30 min
M64 : 7.5 min

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 30°

*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 30°

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

5072 465 118

For 240° 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

- Further AAOmega & SALT observations
- Analysis of clusters in VSCL (*K-band LF, mass - possibly peculiar velocities using WISE TF over the MeerKAT HI survey area*)
 - *deep IRSF (JHK) imaging study of clusters with 1.4m telescope at Sutherland (12 done within $0.8 R_{\text{abell}}$)*
 - *WISE photometry on mosaics of cluster fields galaxies (4 surveyed)*
- 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*