Filaments of Galaxies: An Observational Viewpoint.

Kevin A. Pimbblet (Univ. Queensland)

Collaborators:

Michael Drinkwater (UQ)

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Mary Hawkrigg

Overview

I. Intro: Why bother studying galaxy filaments?

II. Filament detection (X-ray, overdensity, lensing… etc)

III. Spectroscopic studies (focus on 2dFGRS)

IV. Multiscale analysis (brief)

V. Summary / Prospects / Proposal(s)

Cosmology:

Cosmology: Millenium Edition

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Know with some certainty values such as:

H0 = 72 (+/- few)

Lambda …

Omega (various flavors) …

Cosmology: Millenium Edition

Arguably more interesting / entertaining:

How do galaxies (+ clusters of, and LSS) form and evolve?

How do these particular environments affect galaxy evolution (c.f. super-clusters; clusters; filaments; voids)?

Hierarchical structure formation:

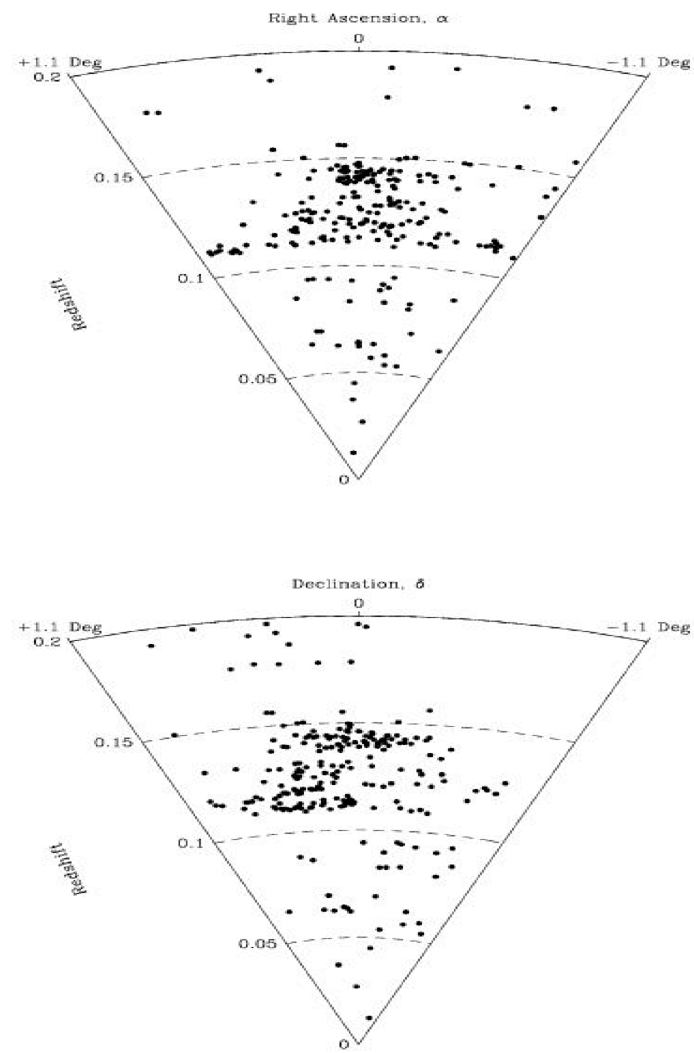
Clusters grow through repeated mergers and continuous accretion of surrounding matter

The accretion process is highly non-isotropic.

Can detect the filamentary directions in many modern datasets (2dFGRS, SDSS, LCRS etc.).

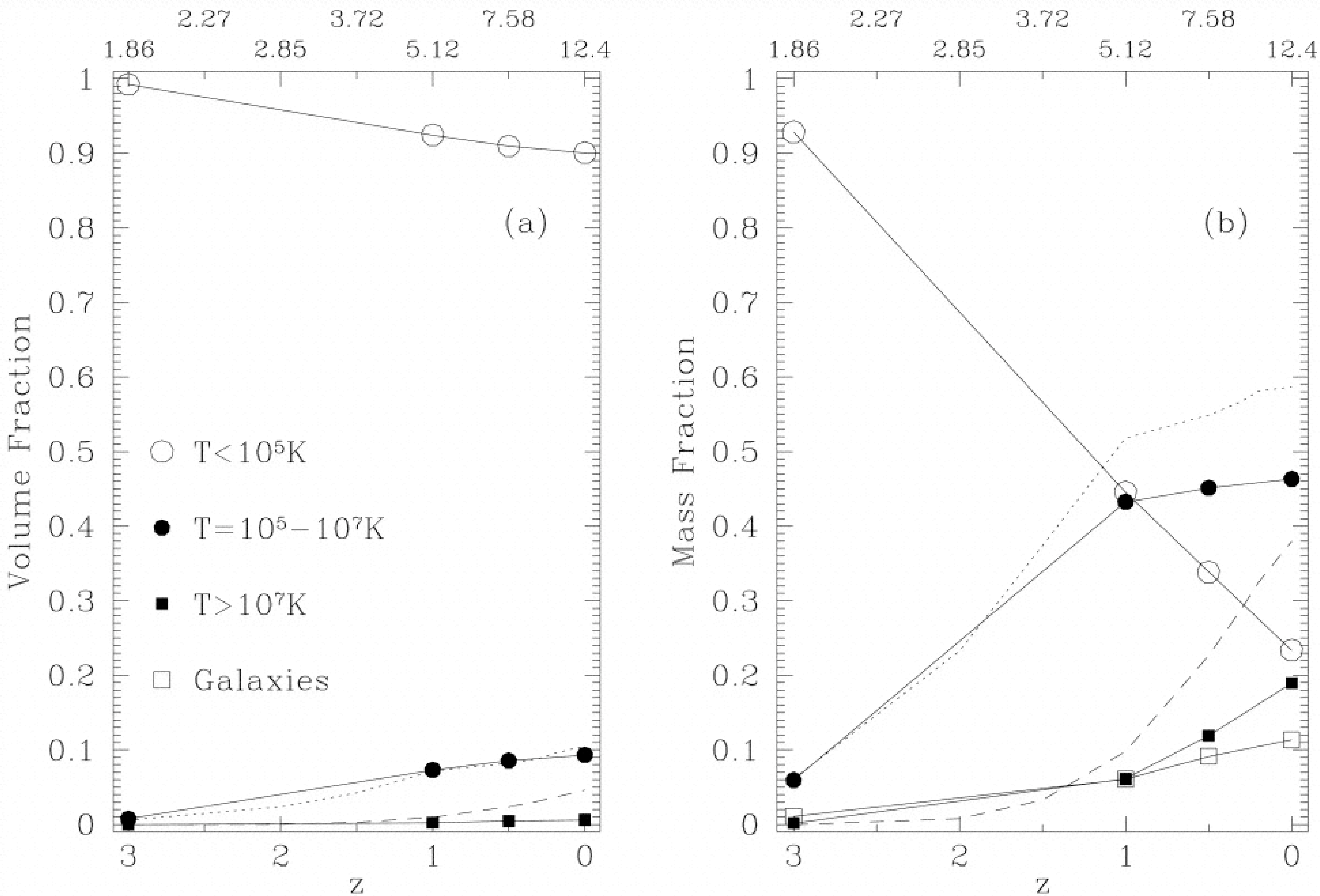
Abell 22

(Pimbblet et al. submitted)



Why study filaments?

Mass budget: they may have up to _ of all baryonic material in the Univserse. (Cen & Ostriker 1999; Fukugita et al. 1998)

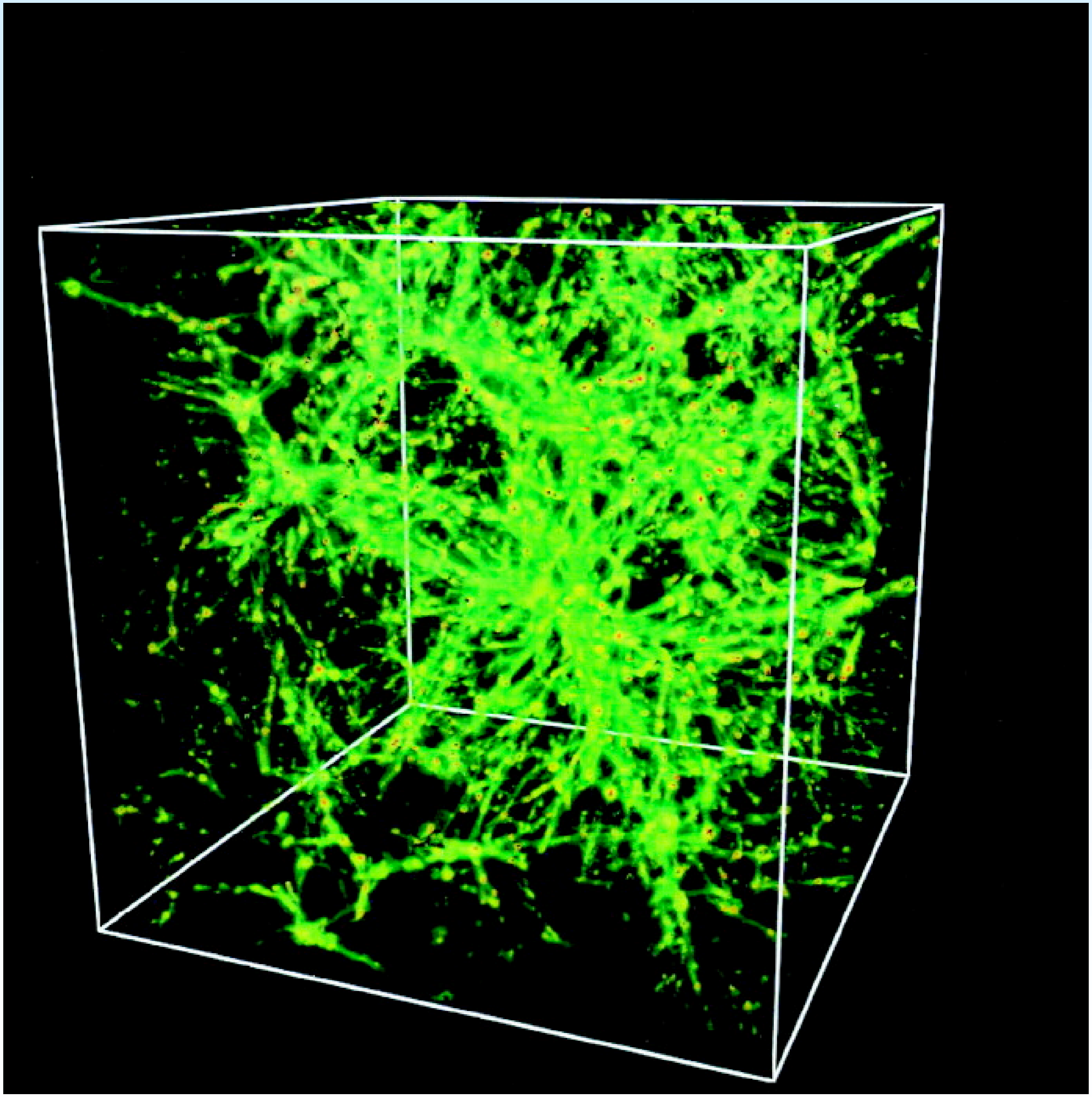


Cen & Ostriker (1999)

Cen &

Ostriker

(1999)



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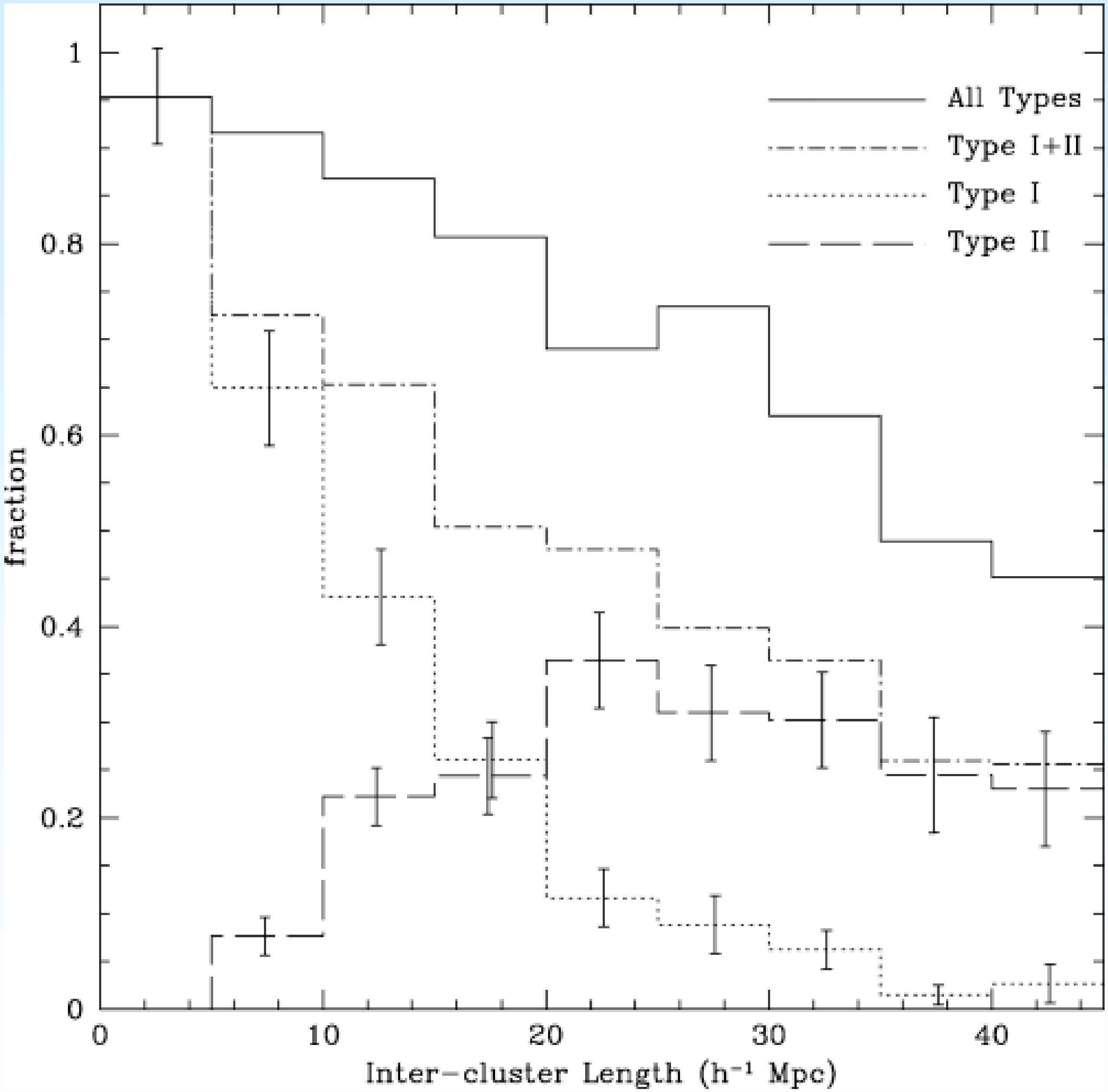
Test structure formation (c.f. Colberg et al. 2004 and Pimbblet et al. 2004).

Pimbblet,

Drinkwater

Hawkrigg

(2004)



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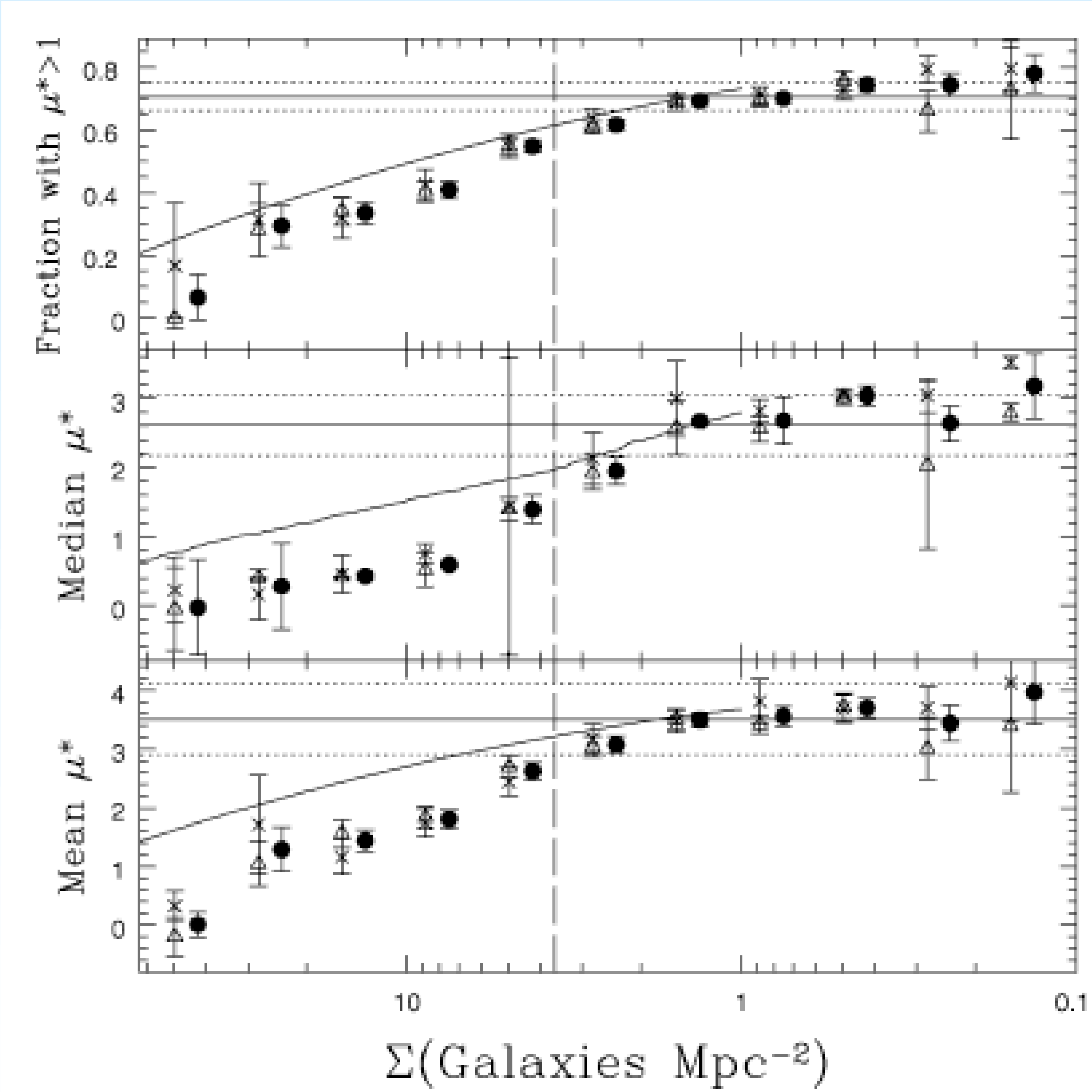
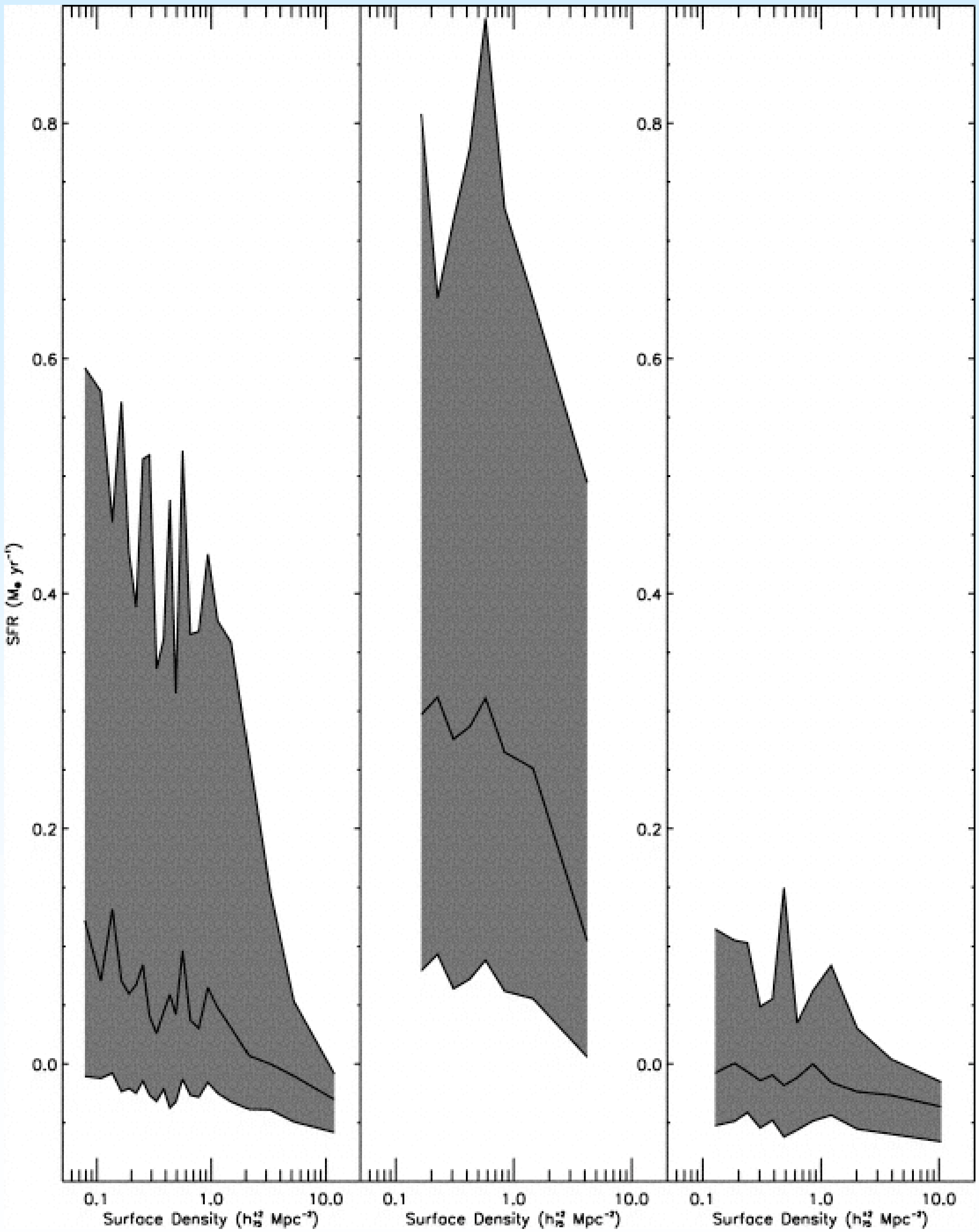
Star formation suppression (Balogh et al. 2004; Gomez et al. 2003; Lewis et al. 2002).

Lewis et al. (2002)



Gomez et al.

(2003)



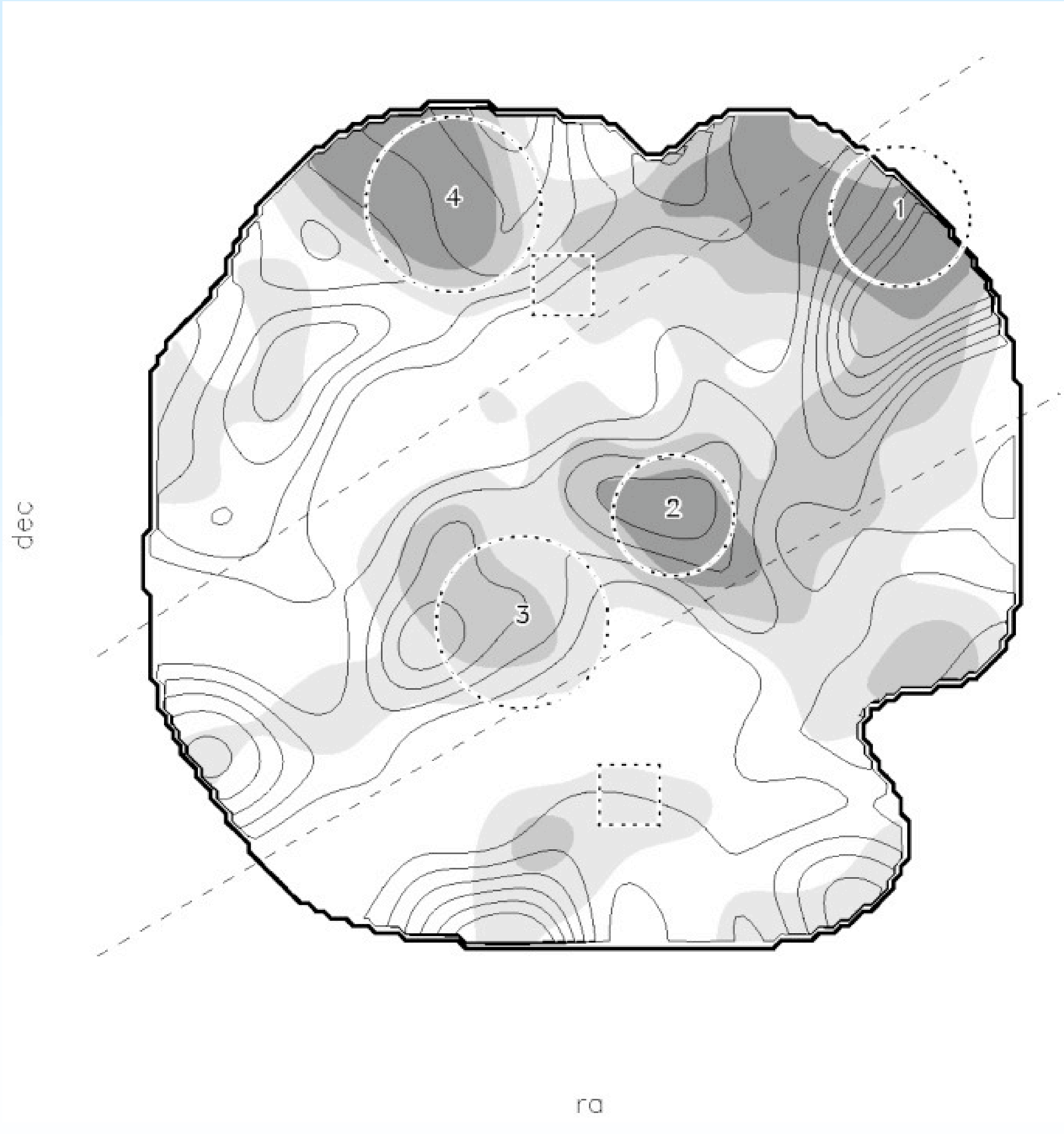
Filament detection.

X-ray gas (Briel & Henry 1995).

Unsuccessful direct detection, but place limit on flux from any filament present.

Scharf et al. (2000), find a 5 sigma joint X-ray and optical detection, however.

Scharf et al. (2000)



<u>Overdensity</u>.

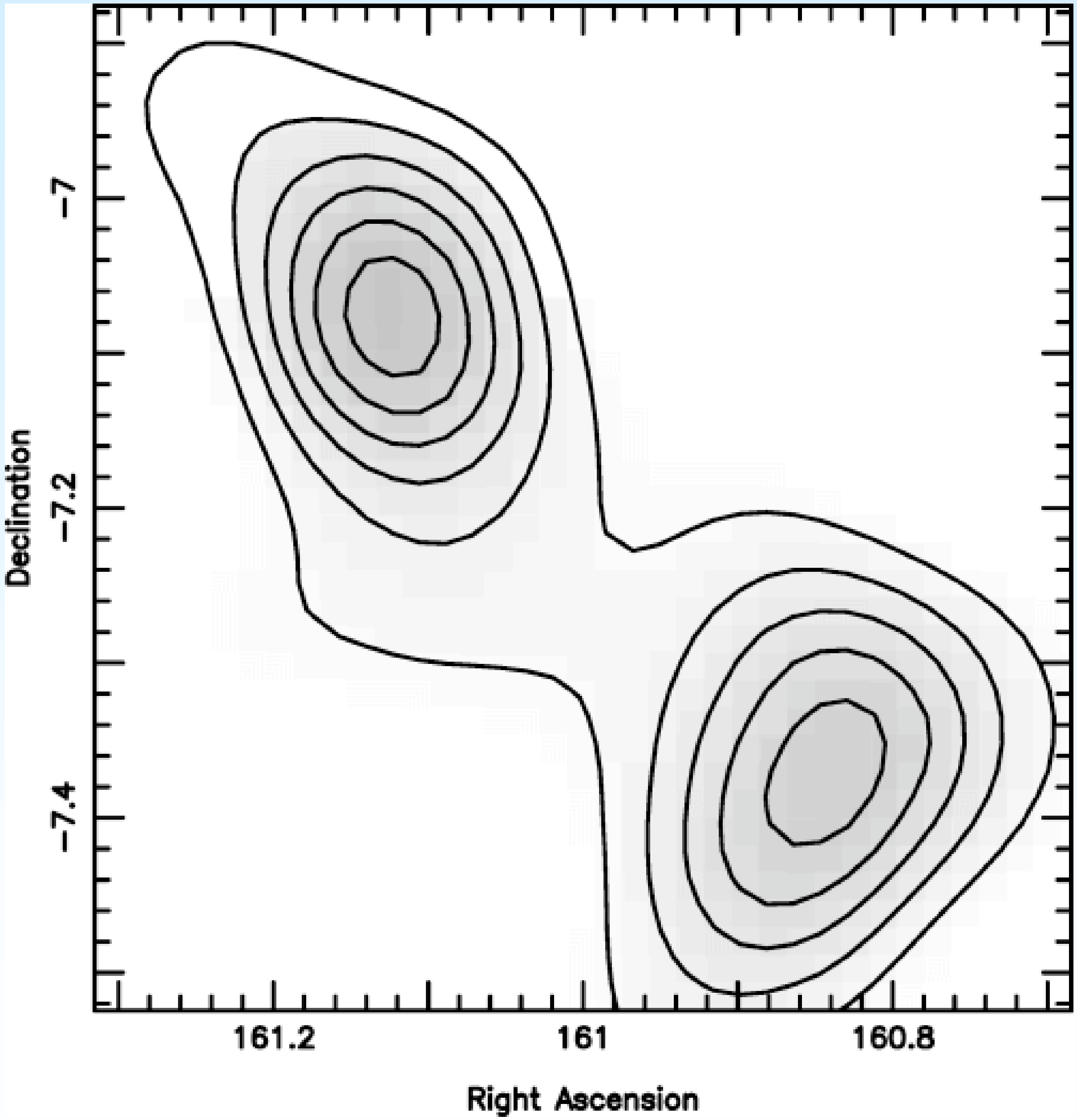
Filaments should have an overdensity of galaxies compared to the field.

These galaxies also appear to exhibit a color-magnitude relation (Visvanathan & Sandage 1977).

Typical fraction of early-type galaxies in filaments is in the range 0.2—0.4 (needs more work to better constrain this figure – offers of help most welcome!)

CMR is also a method to trace filaments (Ebeling et al. 2004)

Pimbblet & Drinkwater (2004) – Overdensity analysis at large radii



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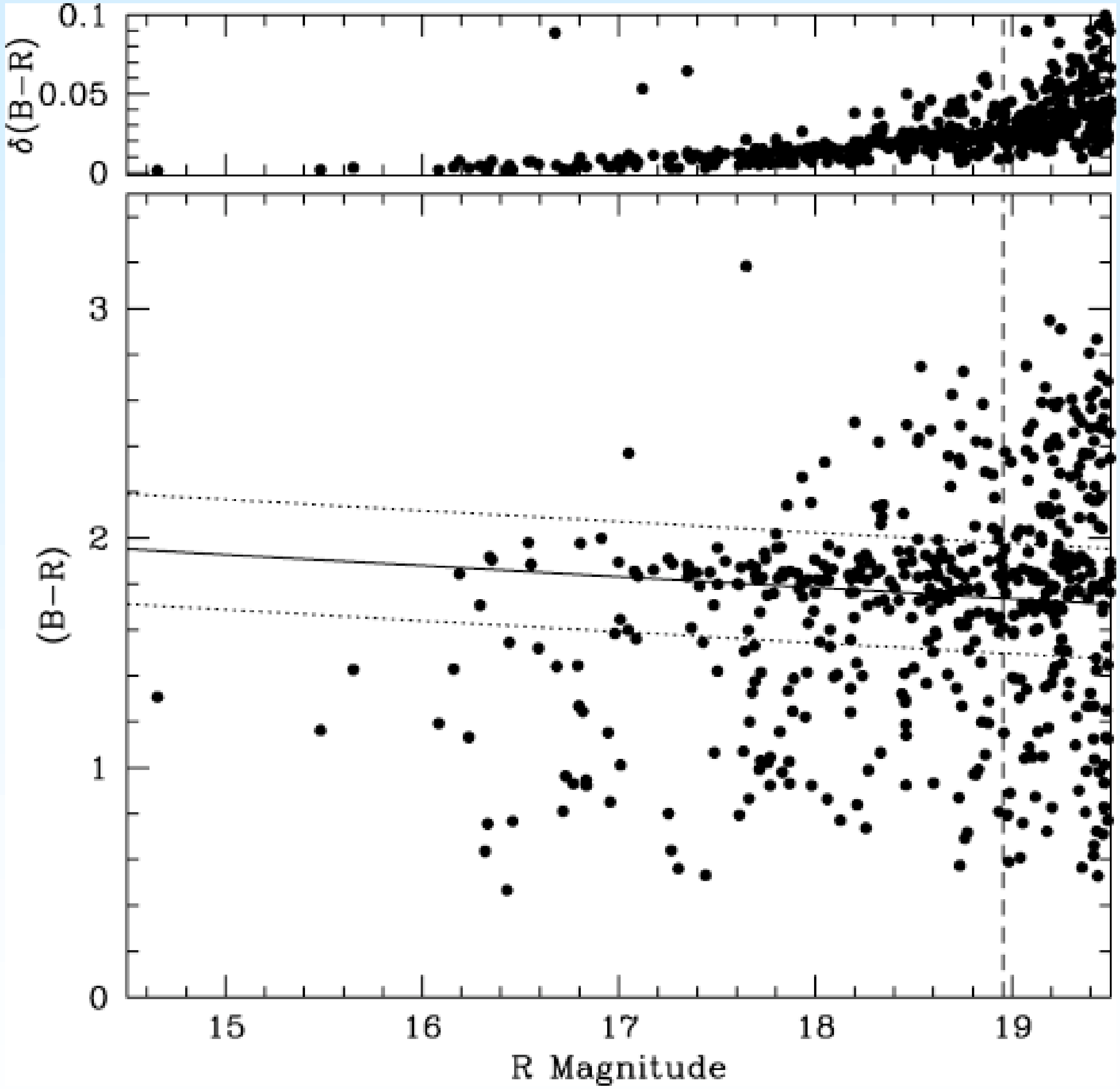

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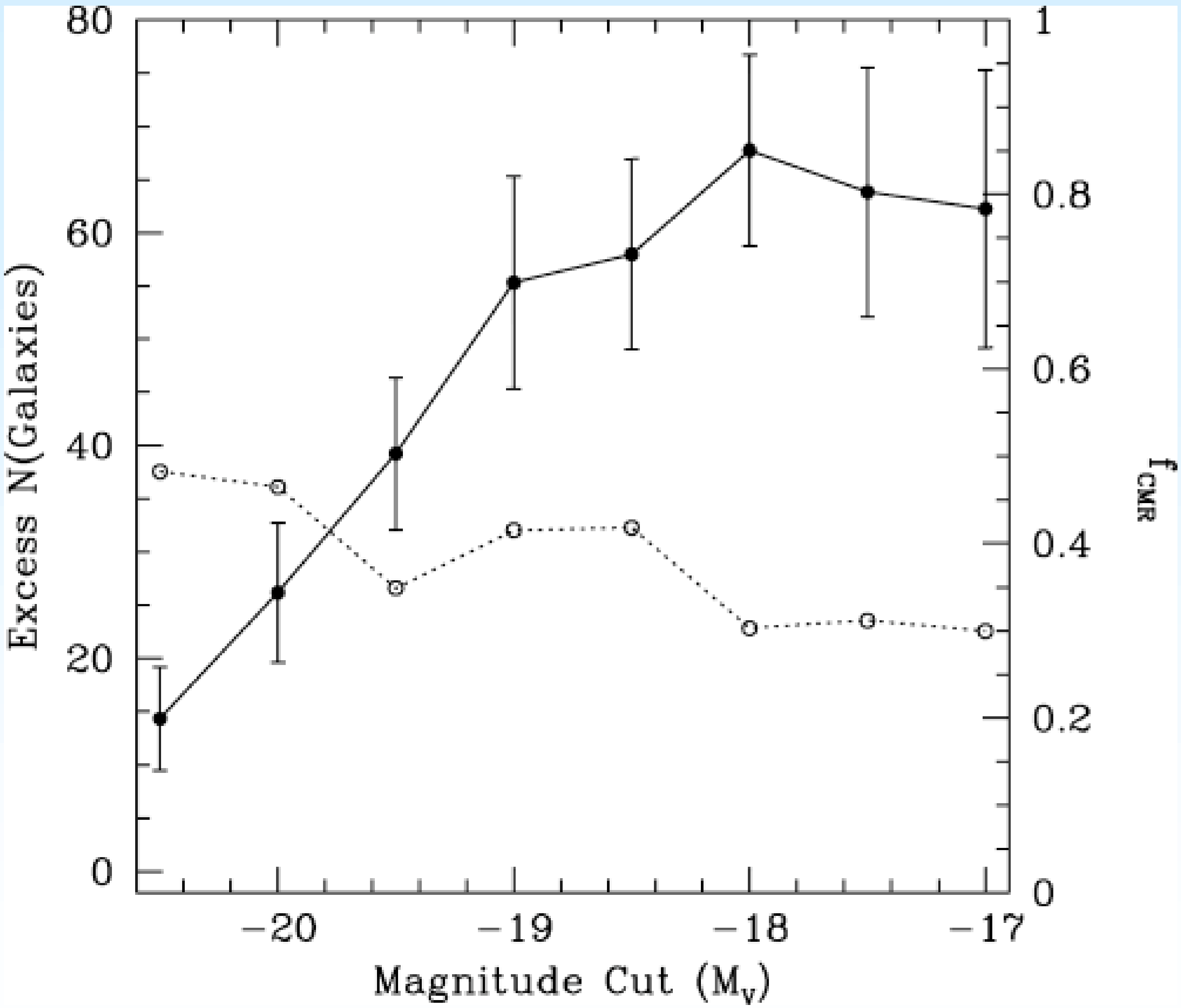
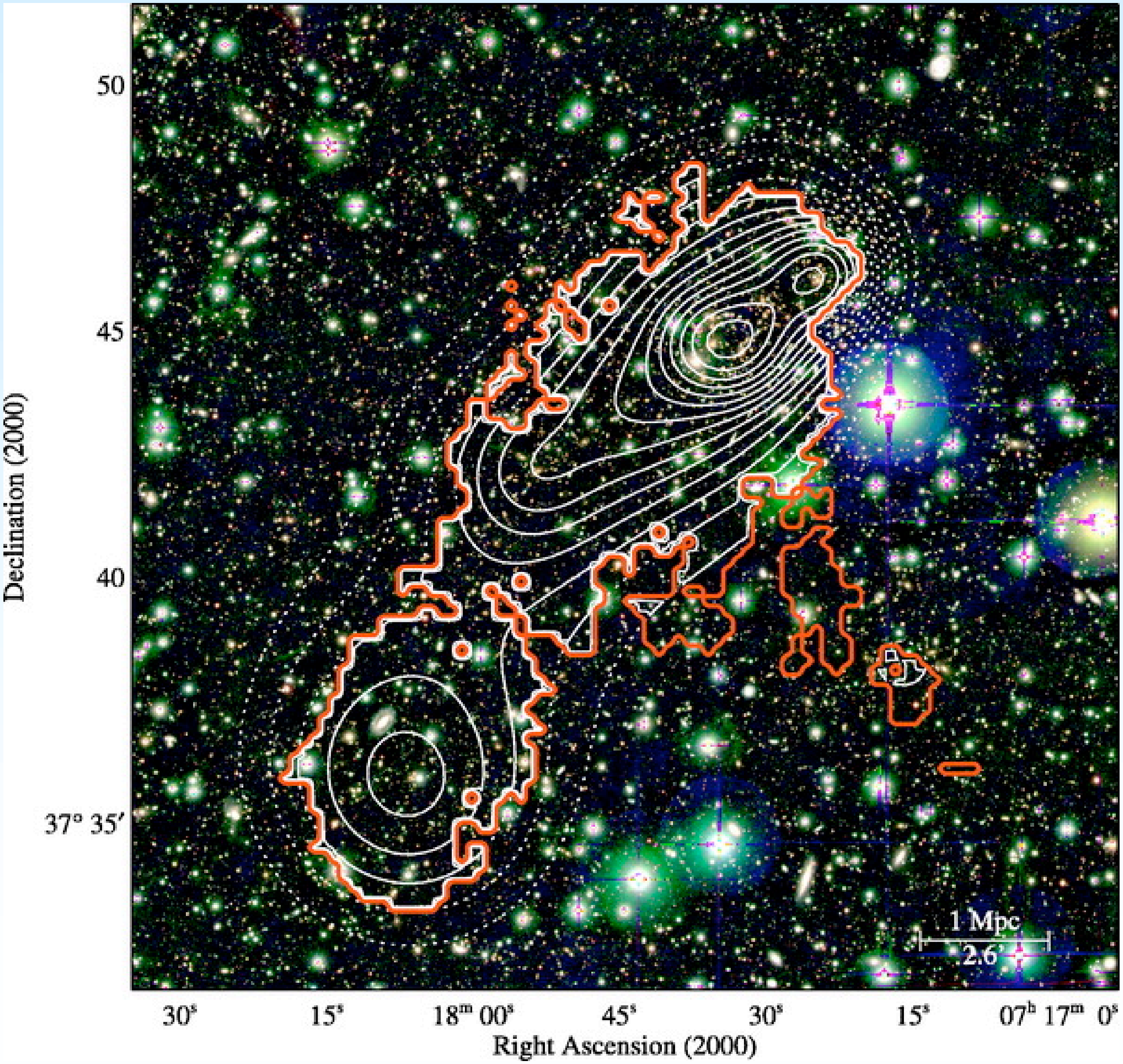
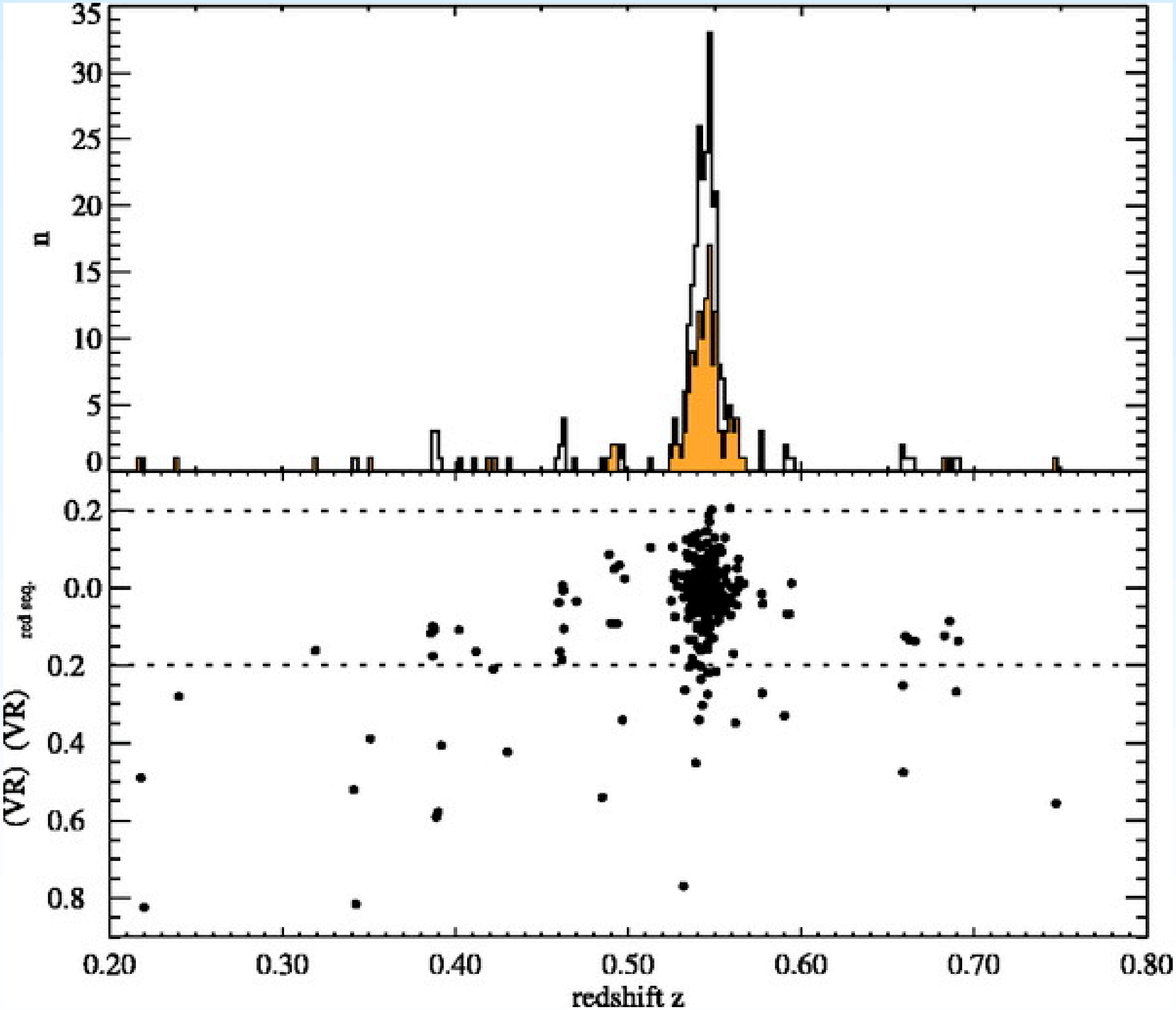


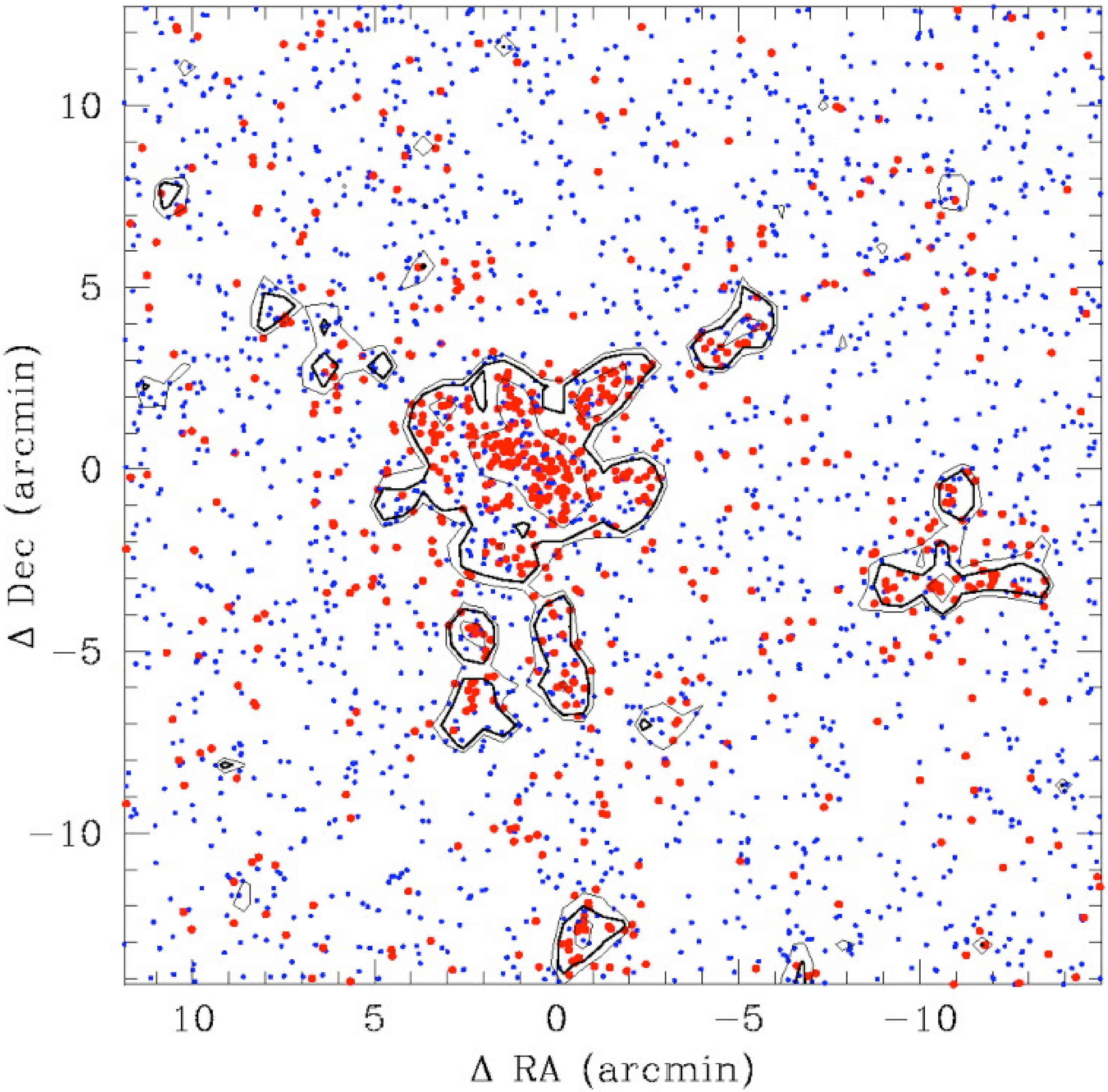
Ebeling, Barrett & Donovan (2004)



Ebeling, Barrett & Donovan (2004)



Kodama et al. (2001).

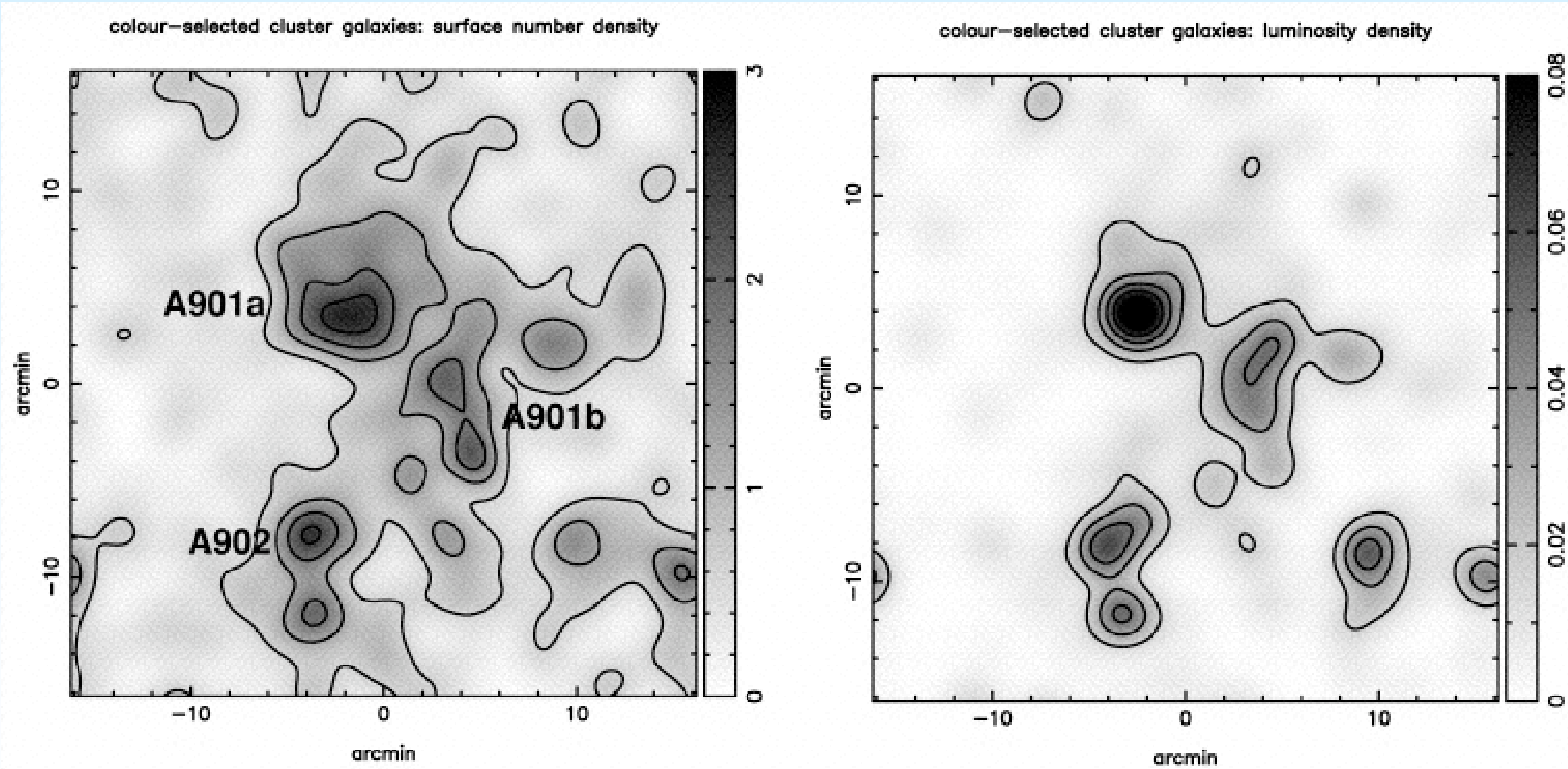


Weak Lensing.

Can directly map the dark matter, and therefore, can determine the relationship between the observed distribution of light against the underlying mass distribution.

Should be an efficient way of unambiguously detecting galaxy filaments. (see Gray et al. 2002; Dietrich et al. 2004).

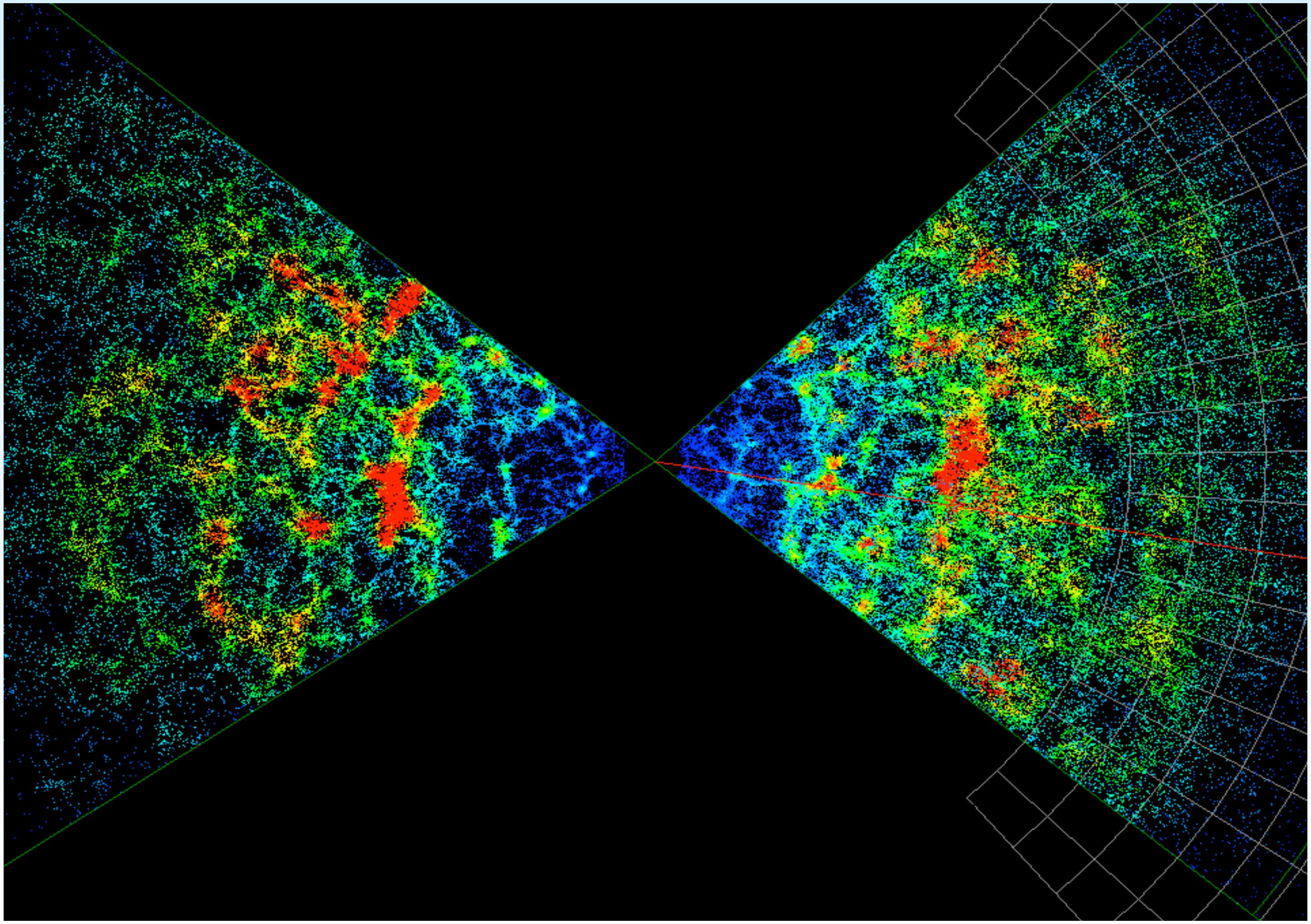
Gray et al. (2002) – A weak lensing detection

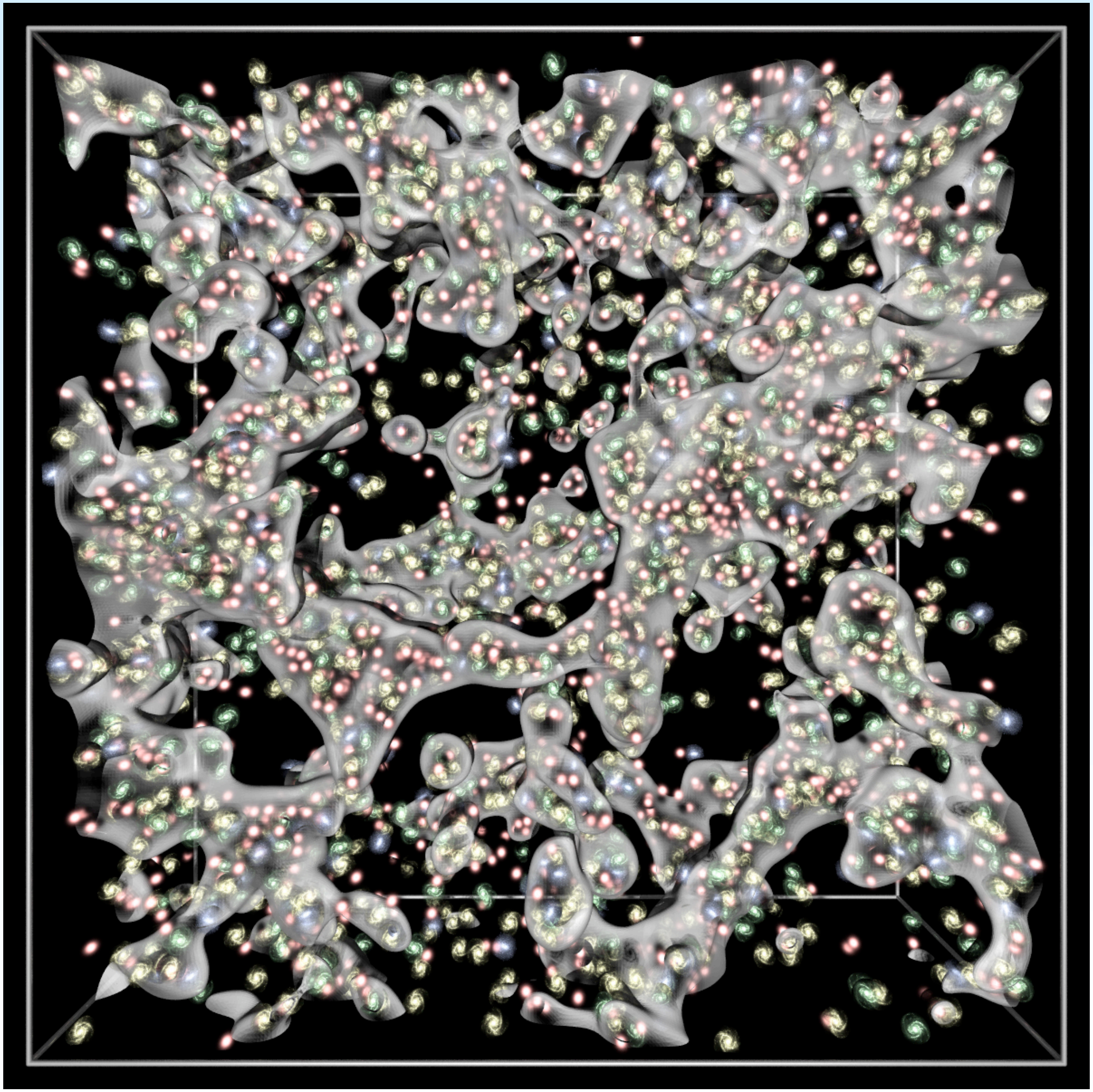


Spectroscopic studies.

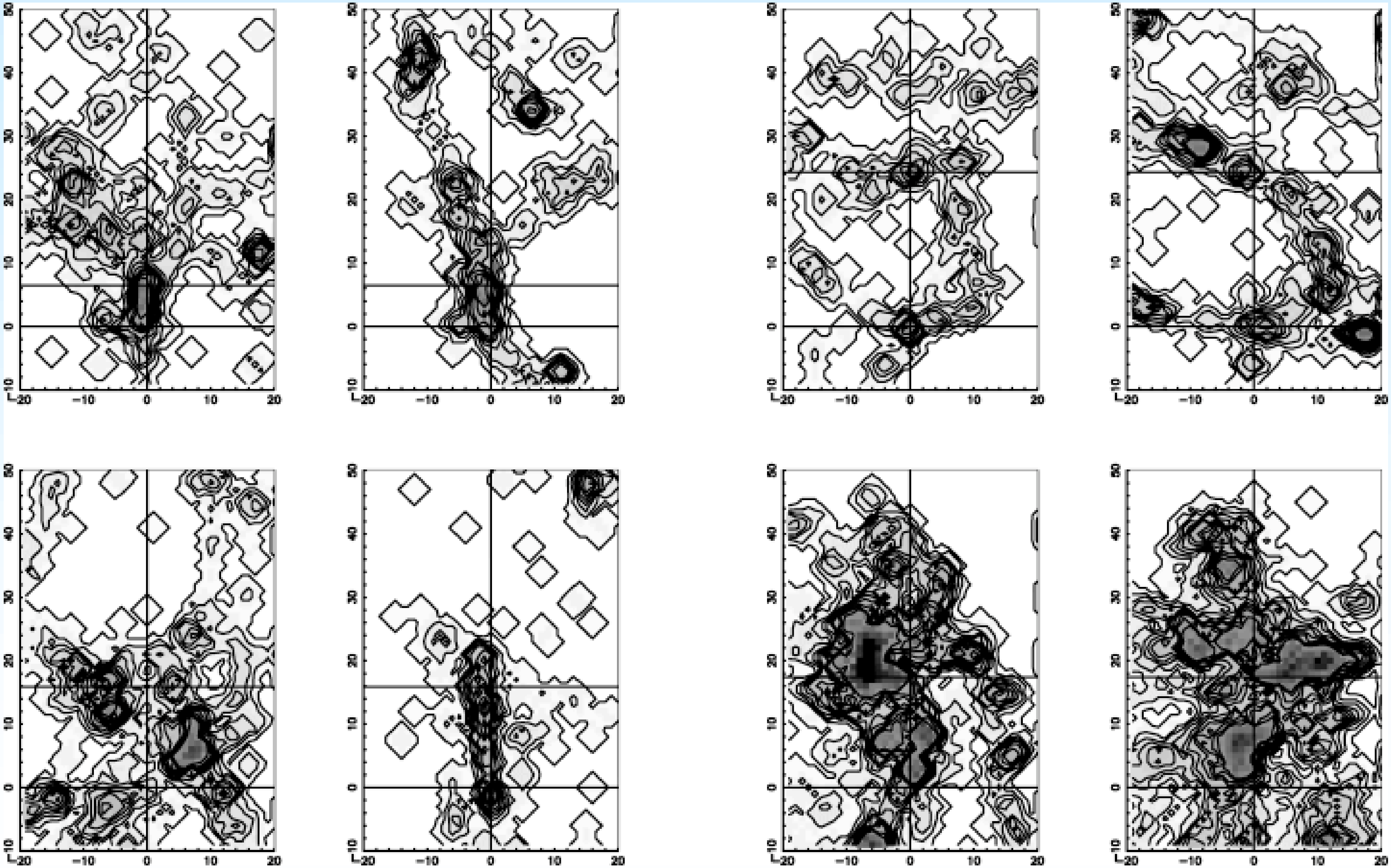
More promise to detect (inter-cluster) galaxy filaments – likely hear more about this later in the conference, so therefore I'll only briefly review some of the relevant work.

Advent of 2dFGRS, LCRS, SDSS provide us with a great opportunity to detect and study galaxy filaments in large numbers.



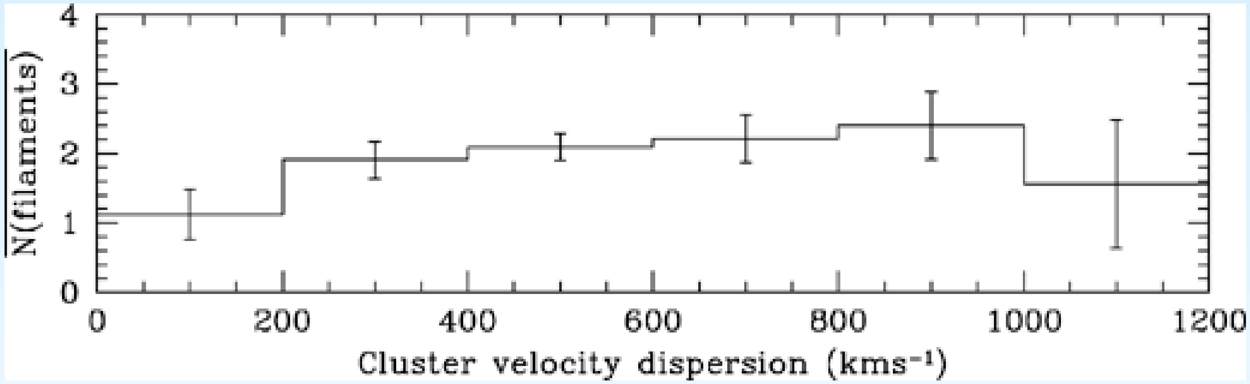


	Filament description
0	Near-coincident clusters. The cluster pair overlaps to such a degree that any filament present cannot be isolated.
I	Straight. The filament of galaxies runs along the axis from one cluster centre to the other.
	At small separations, the infall regions of the clusters likely overlap.
II	Warped (Curved). The galaxies lie off the axis and continuously curve (in a 'C' or 'S'-shape for example) from one cluster centre to the other.
III	Sheet (Planar; Wall). The filament appears as Type I or II viewed from one direction but the galaxies are approximately evenly spread out in the orthogonal view.
IV	Uniform (Cloud). Galaxies fill the space between the clusters in an approximately uniform manner viewed from any direction.
V	Irregular (Complex). There are one or more connections between both cluster centres, but the connections are irregular in shape and often have large density fluctuations.


-20 -10 0 10 20
-10 0 10 20 30 40 50

Sample	Percentage by type						
	0	I	II	III	IV	V	nil
Whole Sample	6.2 (0)	20.8 (16.5)	22.0 (32.7)	3.9 (56.0)	1.9 (75.0)	14.7 (22.7)	30.2 (0)
Connected	8.9 (0)	28.4 (16.5)	32.1 (32.7)	5.8 (56.0)	2.7 (75.0)	21.5 (22.7)	n / a
Filaments	n / a	31.3 (16.5)	35.2 (32.7)	6.3 (56.0)	2.9 (75.0)	23.7 (22.7)	n / a
Certain Filaments	n / a	36.9	33.5	3.6	0.8	25.9	n / a

Type	Sample	CKC 2004 (per cent)	PDH 2004 (per cent)
I	certain	38 ± 4	37 ± 3
II+V		62 ± 5	63 ± 3
III	whole	2 ± 1	3 ± 1
IV		3 ± 1	2 ± 1



Filaments per cluster scales with velocity dispersion and hence cluster mass.

<u>2dFGRS</u>:

Lots of straight filaments at short inter-cluster separations.

Plenty of curved ones at slightly larger separations (and generally curved toward a tertiary mass).

Walls (sheets) and clouds are relatively rare (<4%).

Lots of irregular connections (multiple & lumpy connections).

N(filaments) / cluster scales with cluster mass.

…. (similar with SDSS data….)

=> Consistent with Lambda CDM.

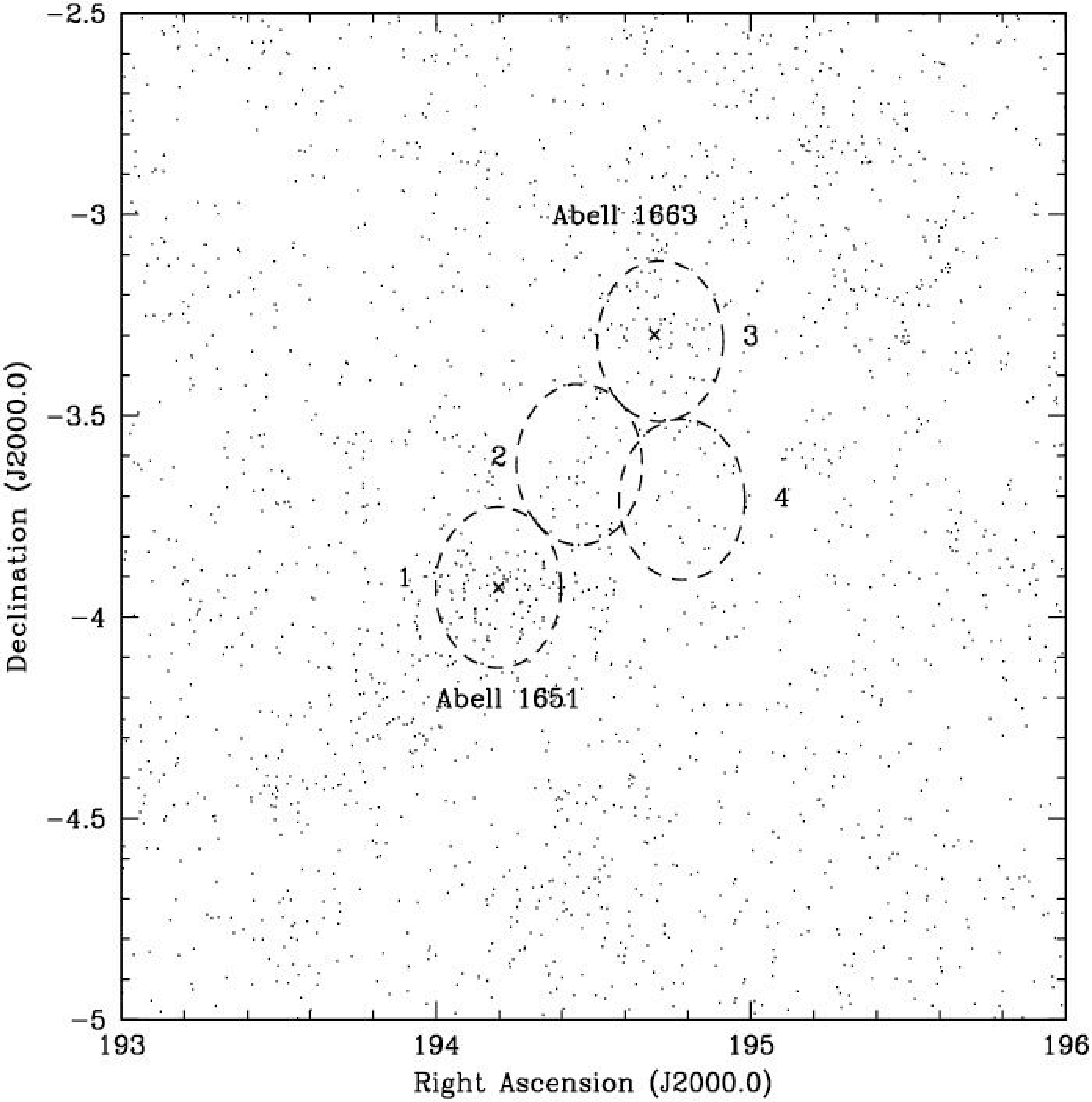
New detection method: use galaxy angles

Find: phi(I,F) = | theta(I) – theta(F) |

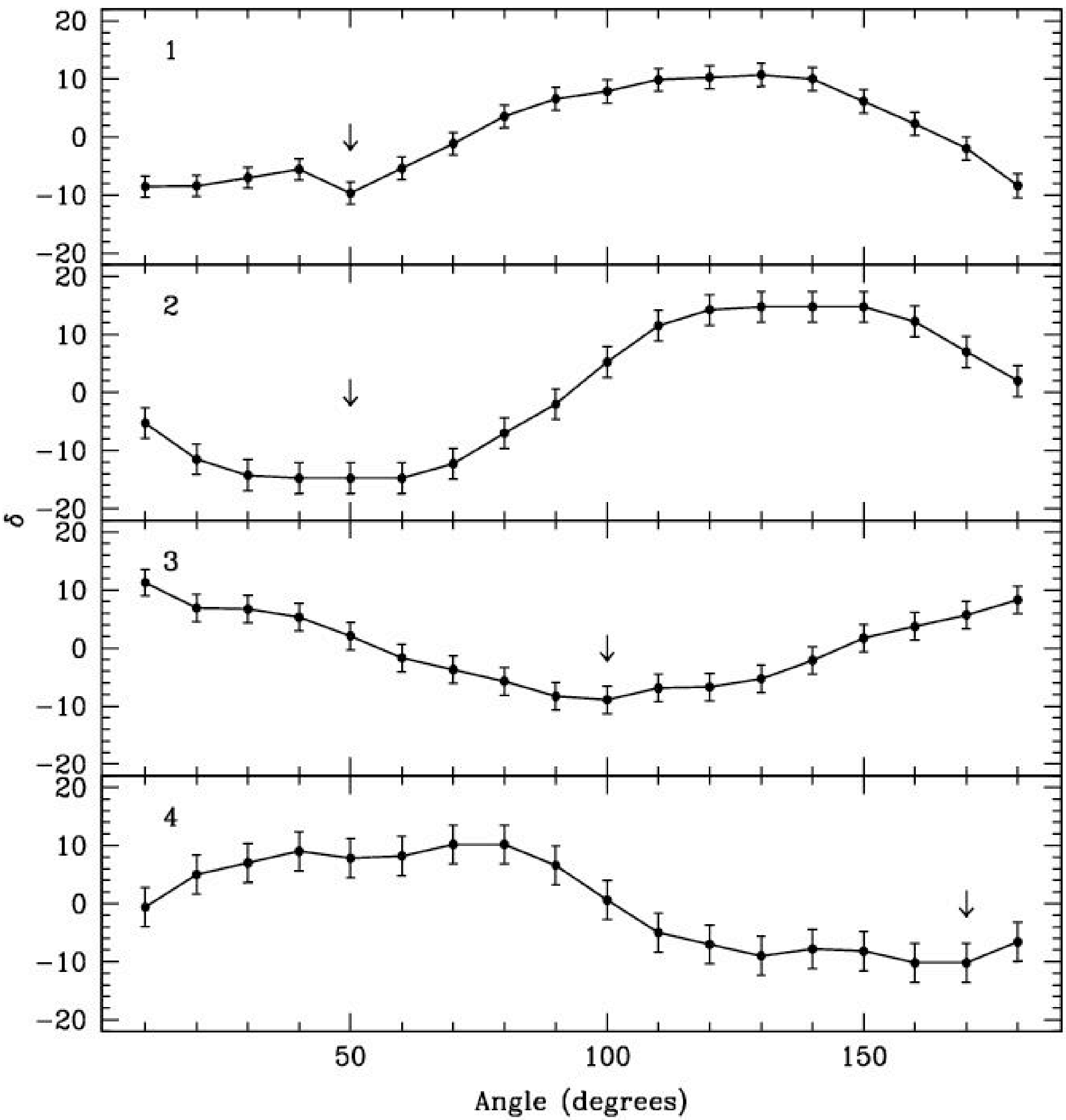
Compute: delta = SUM (phi(I,F)) / (N) - 45 deg

sigma = (90) / (12 sqrt(N))

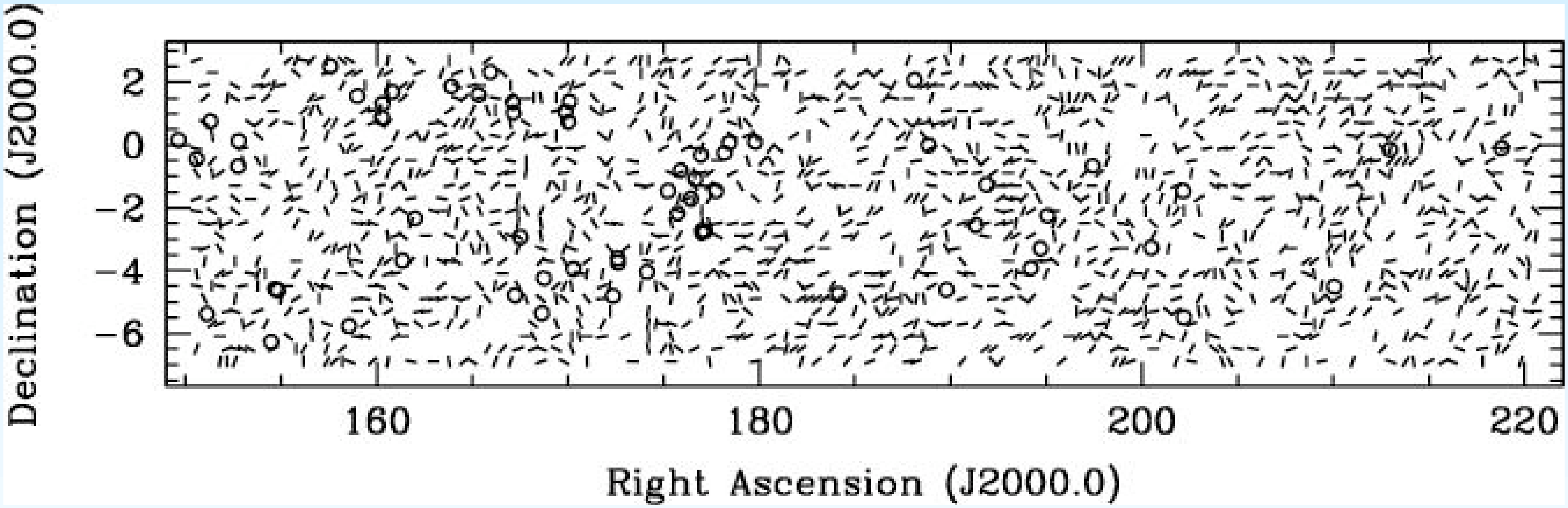
Find the angle theta(F) that minimizes delta.



Abell 1663
Abell 1651
1
2
3
4
−2.5
−3
−3.5
−4
−4.5
−5
193
194
195
196
Declination (J2000.0)
Right Ascension (J2000.0)



1
2
3
4
20
10
0
−10
−20
δ
50
100
150
Angle (degrees)



2dFGRS – NGP: galaxy filaments from position angles.

Multiscale analysis:

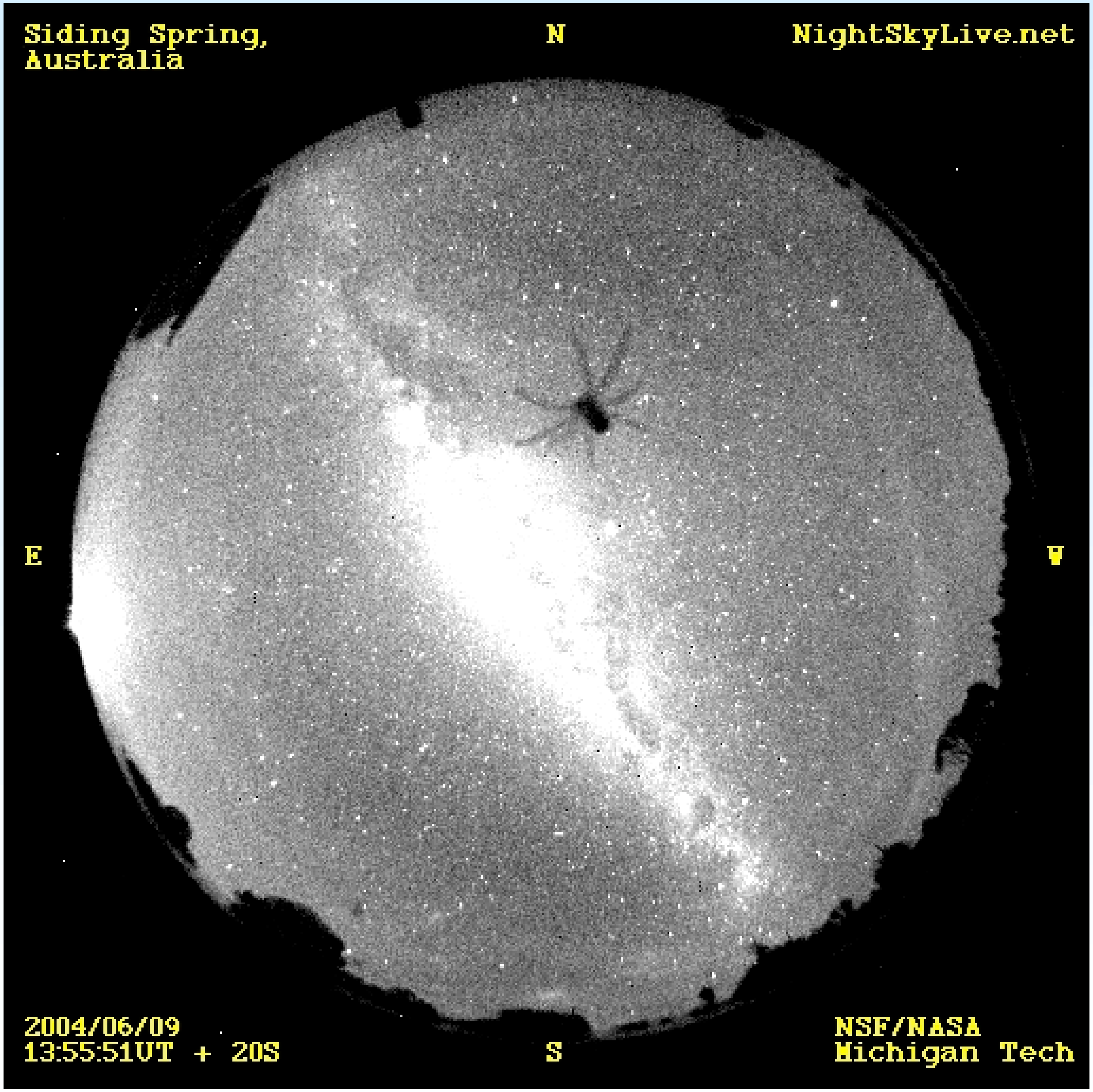
How do multiscale analyses square up to the other methods?

Do they produce similar results? (yes…)

Filament types: Walls, Straight Filaments, Galaxy Clouds (etc) and their (relative) abundances?

Length scales? (60 to 100 Mpc / h) i.e. At what length is the Univserse homogeneous?.

Mean free path length between filaments? (3 to 20 Mpc / h)


Siding Spring,
Australia
N
NightSkyLive.net
E
W
2004/06/09
13:55:51UT + 20S
S
NSF/NASA
Michigan Tech

Shapefinders. (e.g. Bharadwaj et al. 2004)

Geometric minkowski functionals:

(1) Volume, V

(2) the surface area, S

(3) the integrated mean curvature, C

(4) topological invariant: the genus, G

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Shani et al. (1988): Thickness, T = 3V/S

Breadth, B = S/C

Length, L = C / 4 pi (G+1)

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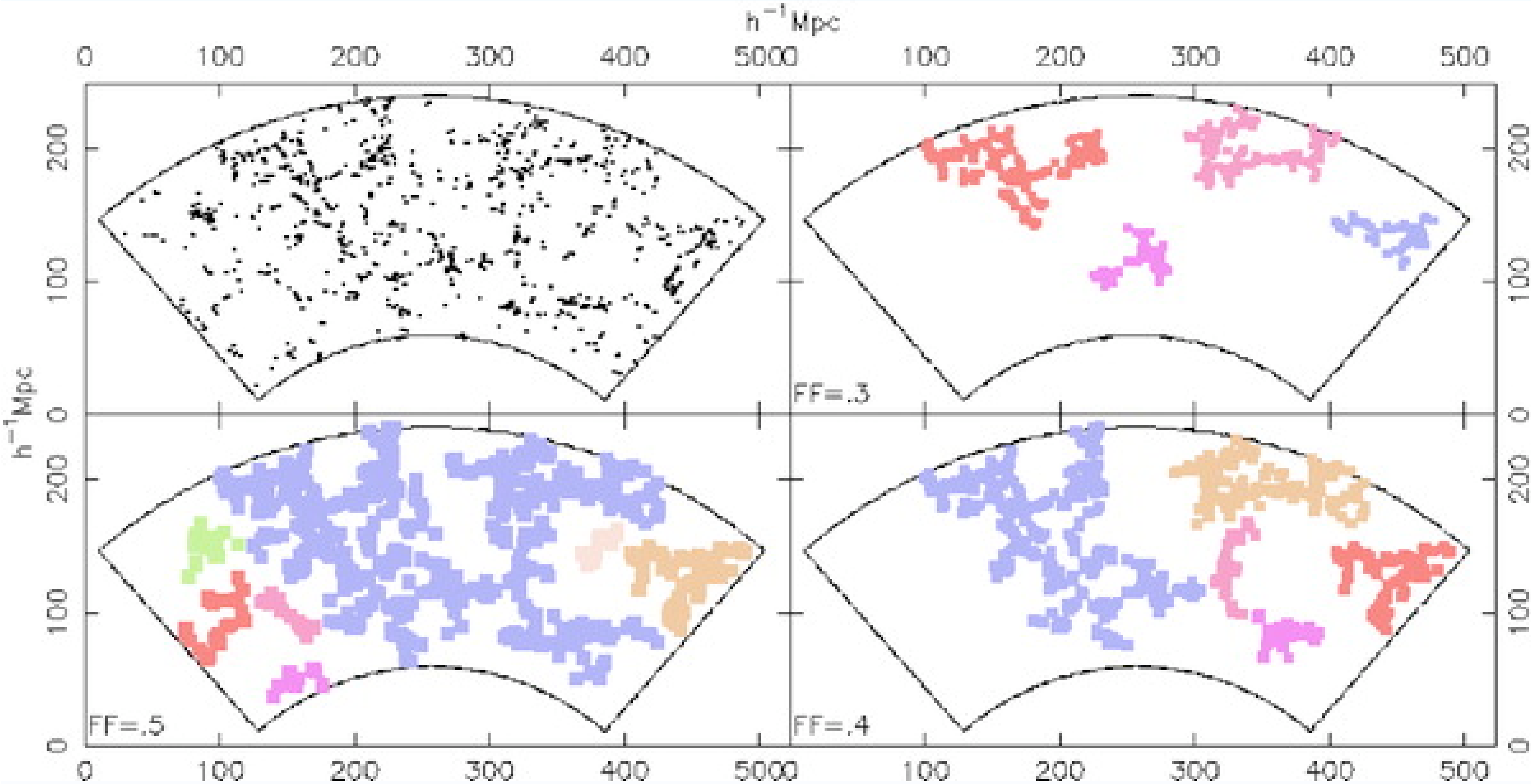
Breadth, B = S/C

Length, L = C / 4 pi (G+1)

Planarity = (B-T) / (B+T)

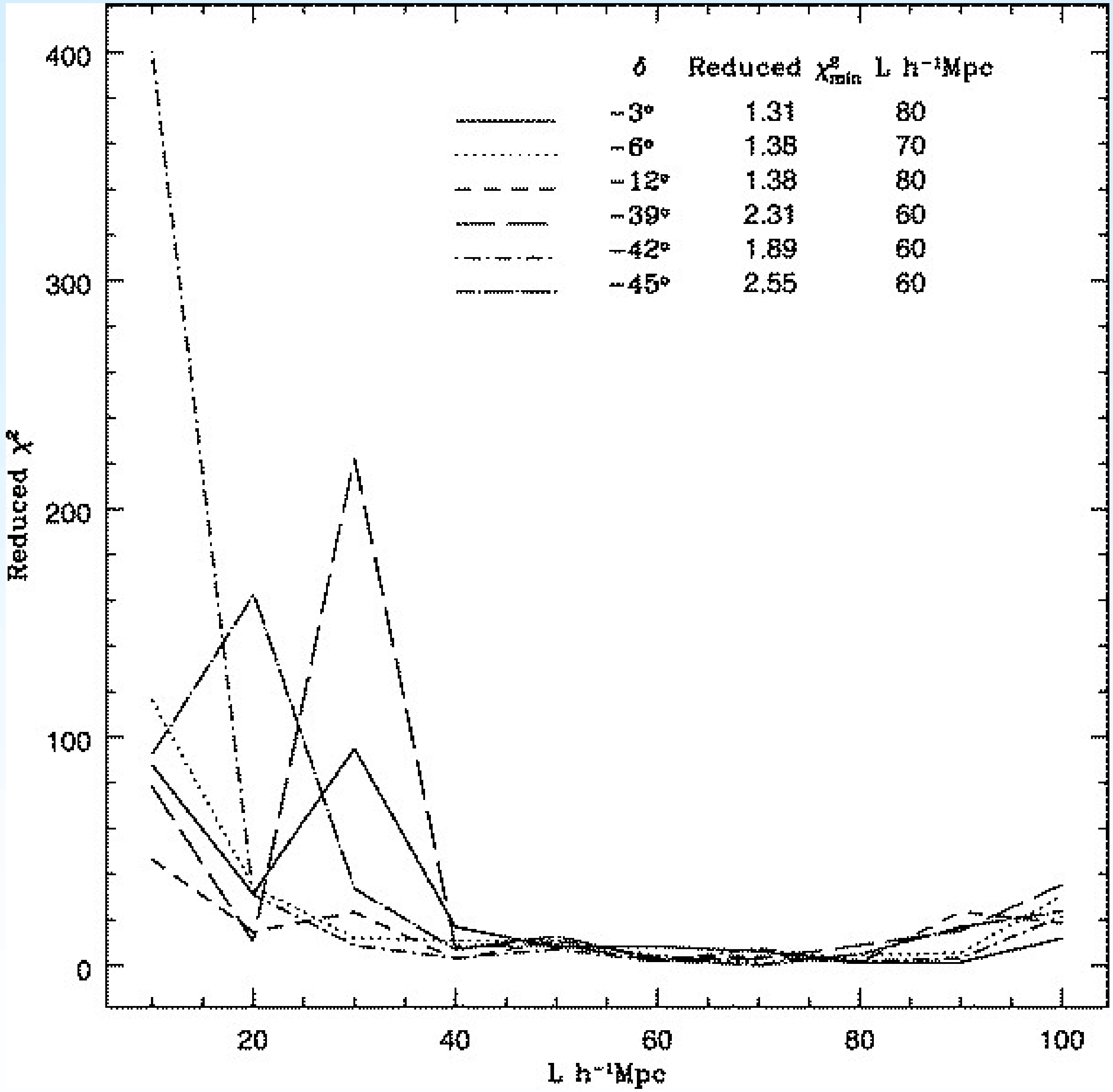
Filamentarity = (L-B) / (L+B)



Bharadwaj et al. (2004); F>0.8

Bharadwaj et al. (2004)

Scale length of Universe using *shapefinders* on LCRS.



Proposal(s).

What is the difference between various filament detection methods?

Do non-multiscale methods produce the same detections as (say) shapefinders / minimal spanning trees (etc.)?

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Why is there a (relatively) large range for homogeneity between different methods (ranging from 60 – 130+ Mpc)?

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Why is there a (relatively) large range for homogeneity between different methods (ranging from 60 – 130+ Mpc)?

What effect does catalogue incompleteness play (consider for example compact galaxies, LSBGs, etc.)?

What about other biases?