Cosmic Flows

Lecture course
University Groningen
Feb. 2007-April 2007

Gravitational Instability

$$\frac{\partial \delta}{\partial t} + \frac{1}{a}\nabla \cdot (1+\delta)\mathbf{v} = 0$$

$$\frac{\partial \mathbf{v}}{\partial t} + \frac{\dot{a}}{a}\mathbf{v} + \frac{1}{a}(\mathbf{v}\cdot\nabla)\mathbf{v} = -\frac{1}{a}\nabla\phi$$

$$\nabla^2\phi = 4\pi G\,\bar{\rho}\,a^2\,\delta(\mathbf{x},t)$$

Gravitational Instability

$$\frac{\partial \delta}{\partial t} + \frac{1}{a}\,\nabla \cdot \mathbf{v} = 0$$

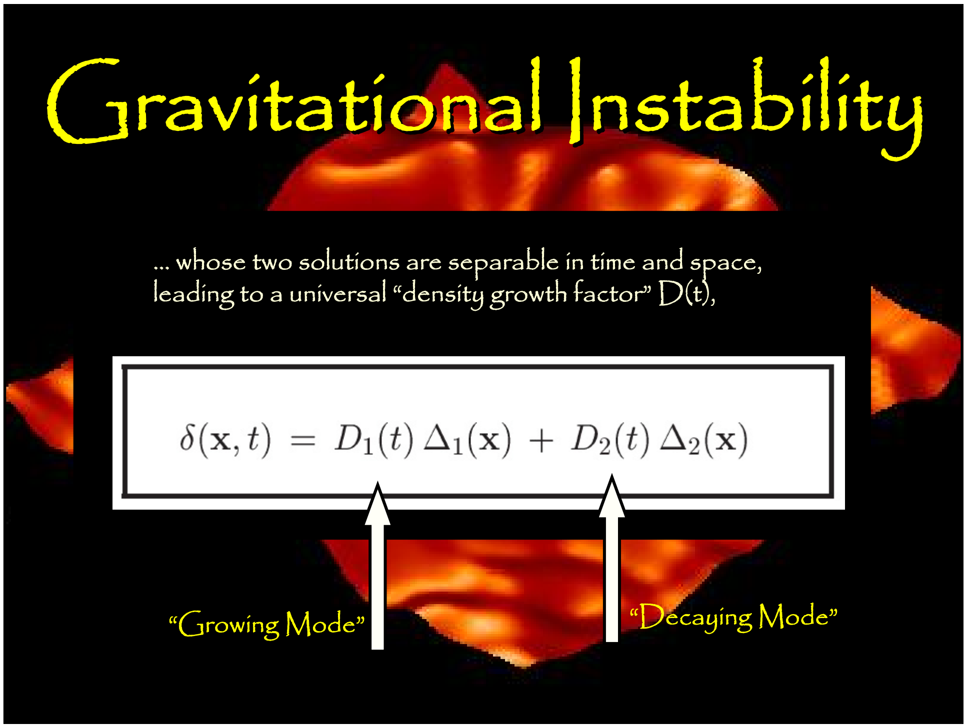
$$\frac{\partial \mathbf{v}}{\partial t} + \frac{\dot{a}}{a}\mathbf{v} = -\frac{1}{a}\,\nabla \phi$$

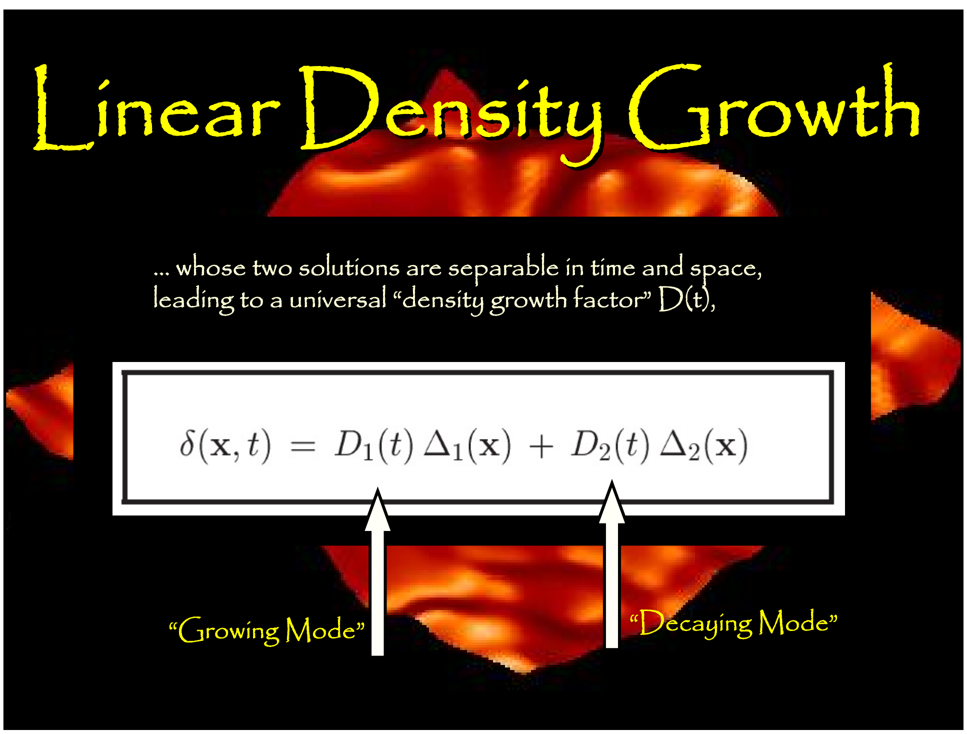
$$\nabla^2 \phi = \frac{3}{2}\Omega H^2 a^2\, \delta(\mathbf{x}, t)$$

Gravitational Instability

The linear system of structure growth equations can be written in terms of a second order differential equation,

$$\boxed{\frac{\partial^2 \delta}{\partial t^2} + 2\frac{\dot{a}}{a}\frac{\partial \delta}{\partial t} = \frac{3}{2}\Omega_0 H_0^2\,\frac{1}{a^3}\,\delta}$$


Gravitational Instability
... whose two solutions are separable in time and space,
leading to a universal "density growth factor" D(t),
$\delta(\mathbf{x},t) \;=\; D_1(t)\,\Delta_1(\mathbf{x}) \;+\; D_2(t)\,\Delta_2(\mathbf{x})$
"Growing Mode"
"Decaying Mode"


Linear Density Growth
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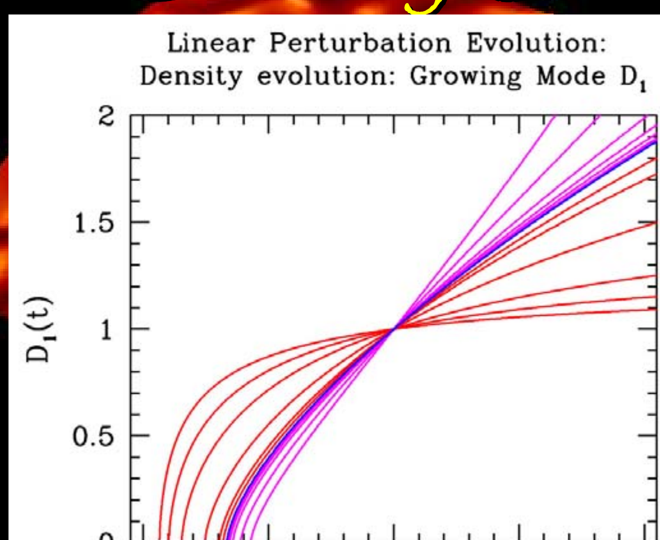
$\delta(\mathbf{x},t) \;=\; D_1(t)\,\Delta_1(\mathbf{x}) \;+\; D_2(t)\,\Delta_2(\mathbf{x})$
"Growing Mode"
"Decaying Mode"

Linear Density Growth

… The universal "density growth factor" D(t) can be computed for any cosmology through the integral

$$D(t) \approx H(t) \int \frac{dt}{a^2 H^2(t)}$$

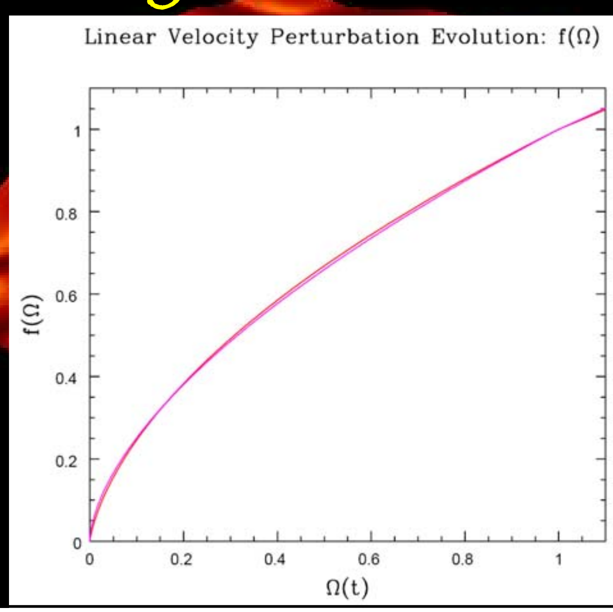
Linear Density Growth



Gravitational Instability

$$\mathbf{g}(\mathbf{r},t) = -\frac{1}{a}\nabla\phi = \frac{3\Omega H^2}{8\pi}\int \mathrm{d}\mathbf{x}'\,\delta(\mathbf{x}',t)\,\frac{(\mathbf{x}'-\mathbf{x})}{|\mathbf{x}'-\mathbf{x}|^3}$$

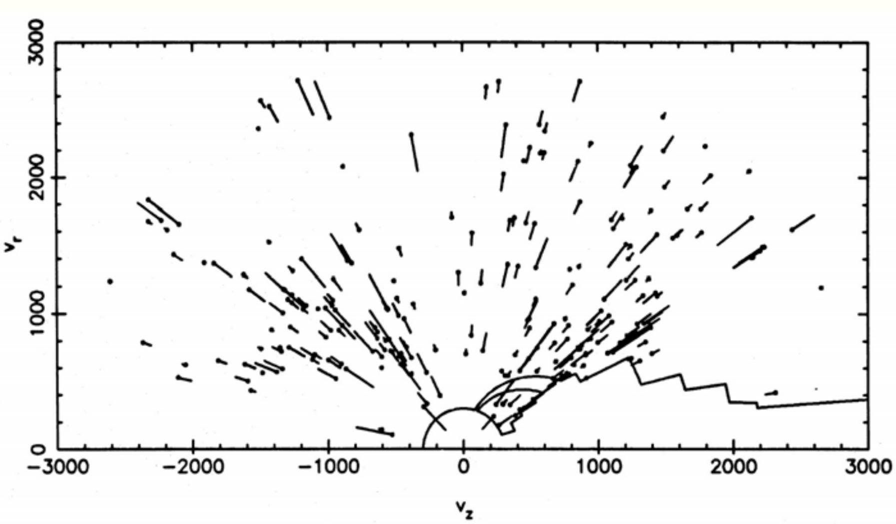
Velocity Perturbations



Local Universe Peculiar Velocities

Local Supercluster flow

Lilje, Yahil & Jones 1986

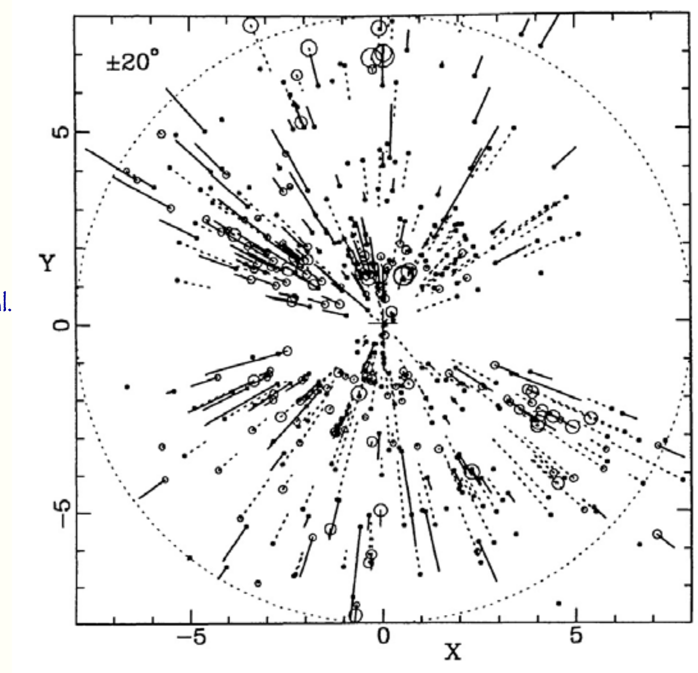


Mark III

Peculiar velocities
Local Universe

Willick, Strauss et al.

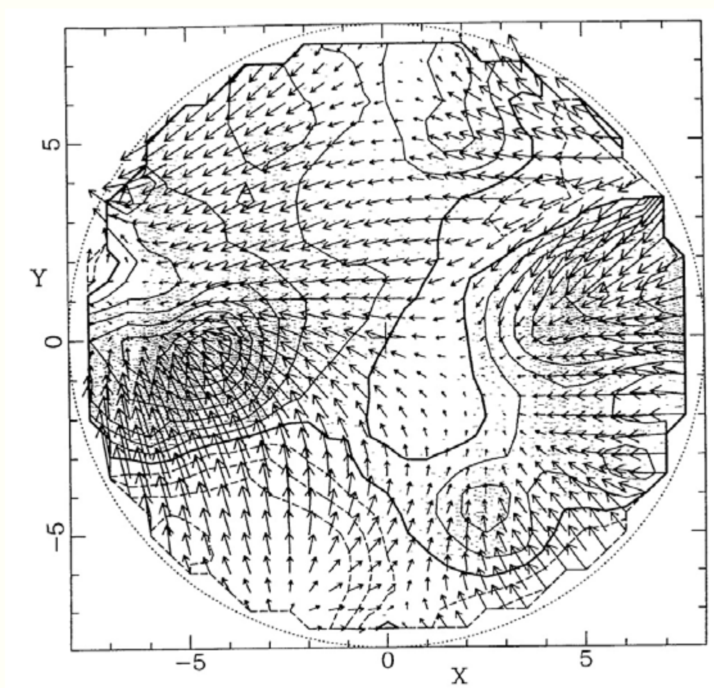
First flow maps:
7 Samurai

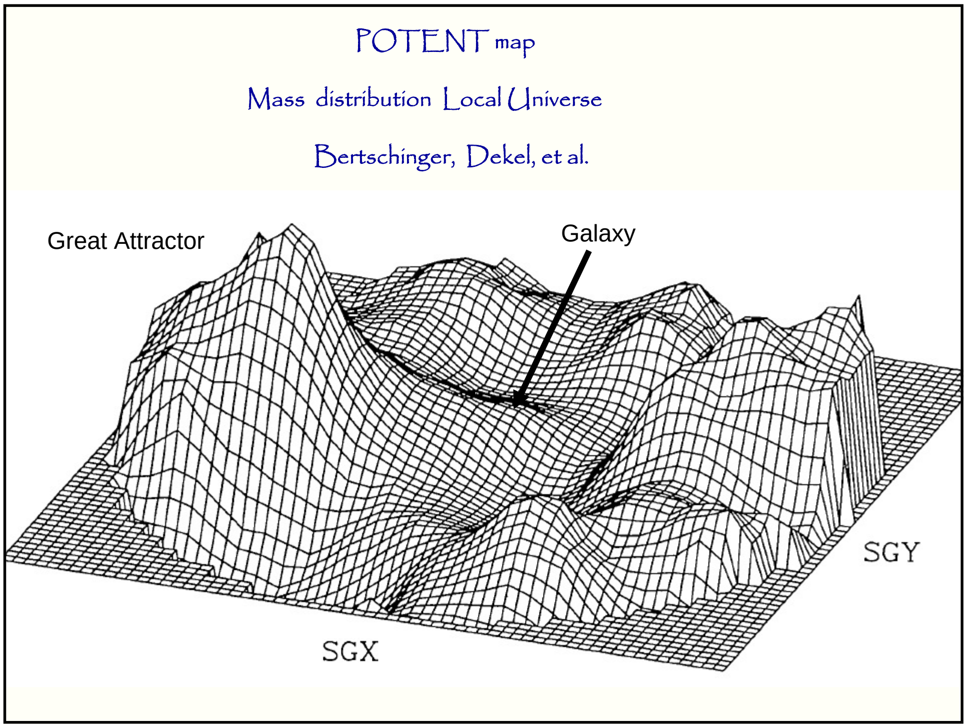


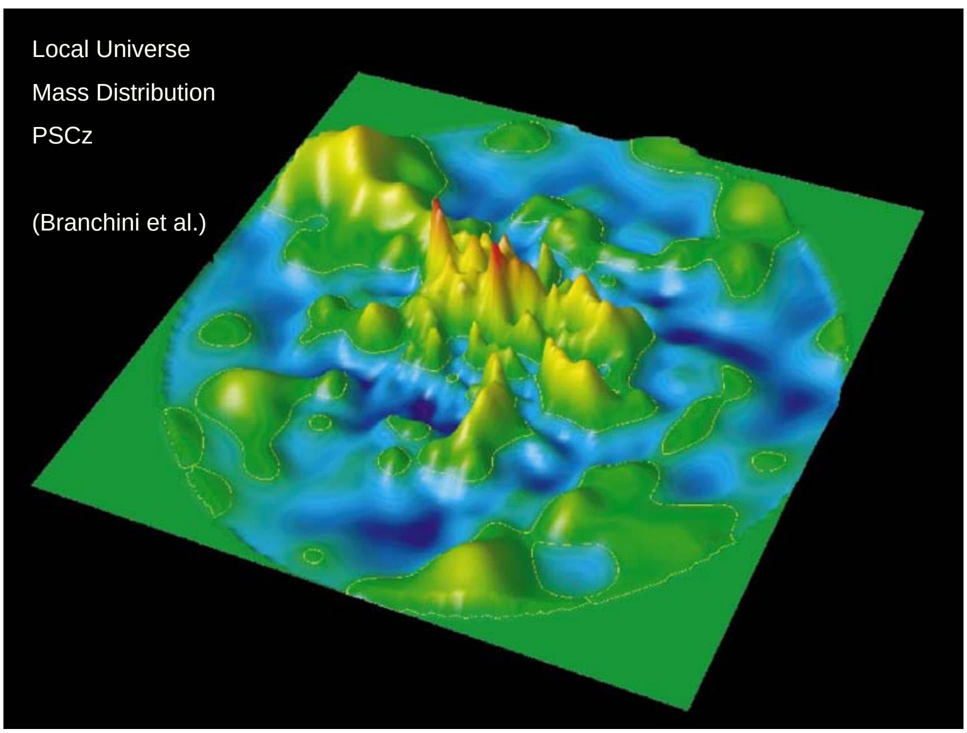
POTENT map

Mass distribution
Local Universe

Bertschinger,
Dekel, et al.




POTENT map
Mass distribution Local Universe
Bertschinger, Dekel, et al.
Great Attractor
Galaxy
SGY
SGX


Local Universe
Mass Distribution
PSCz
(Branchini et al.)

Great Attractor

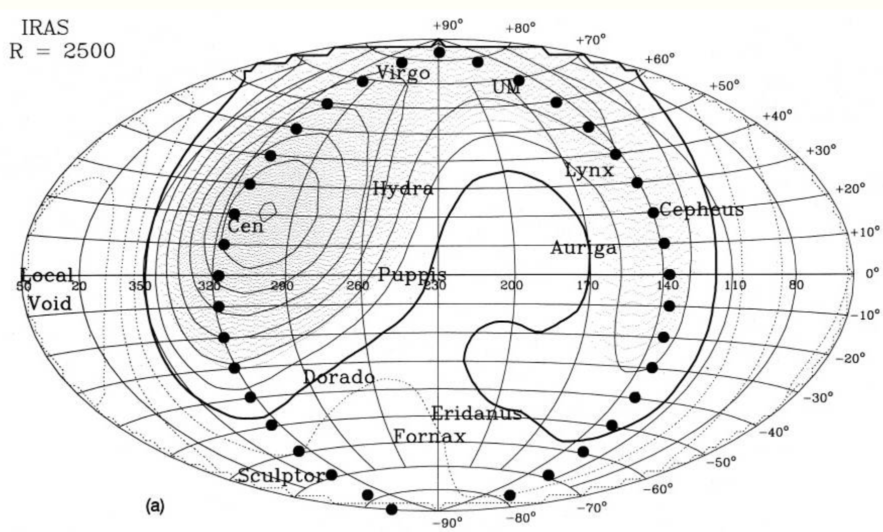


Figure 4. The galaxy density fluctuation field from the *IRAS* 1.9-Jy survey (by Yahil et al. 1991). Coordinates, smoothing, contours and shell distances are as in Fig. 3.

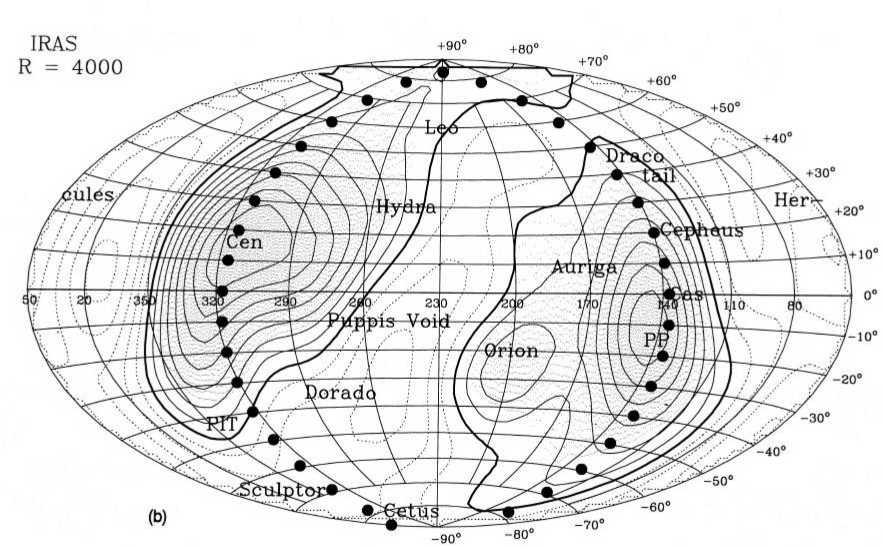
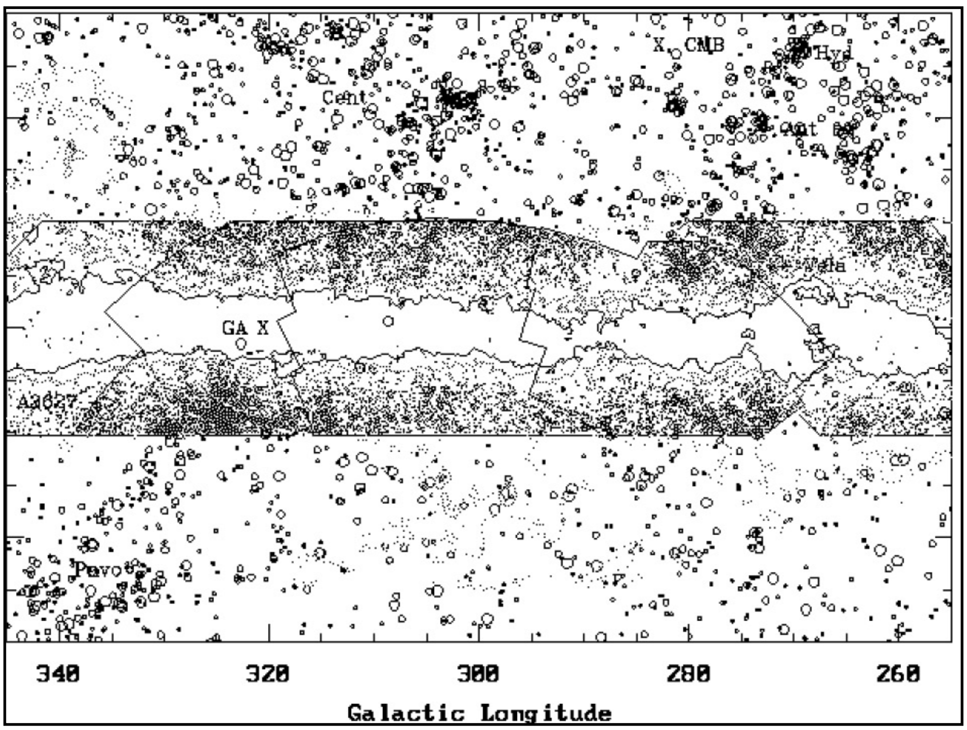


Figure 4 – *continued*

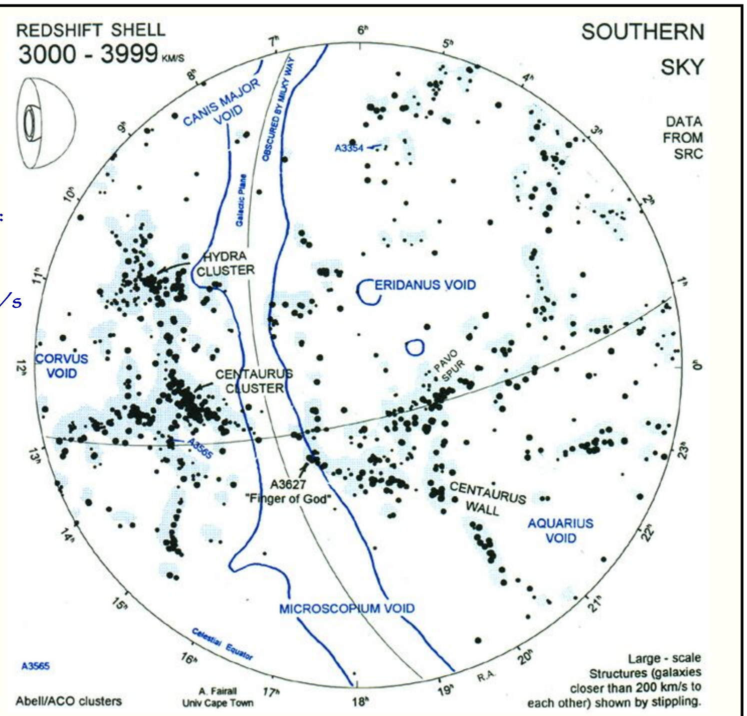


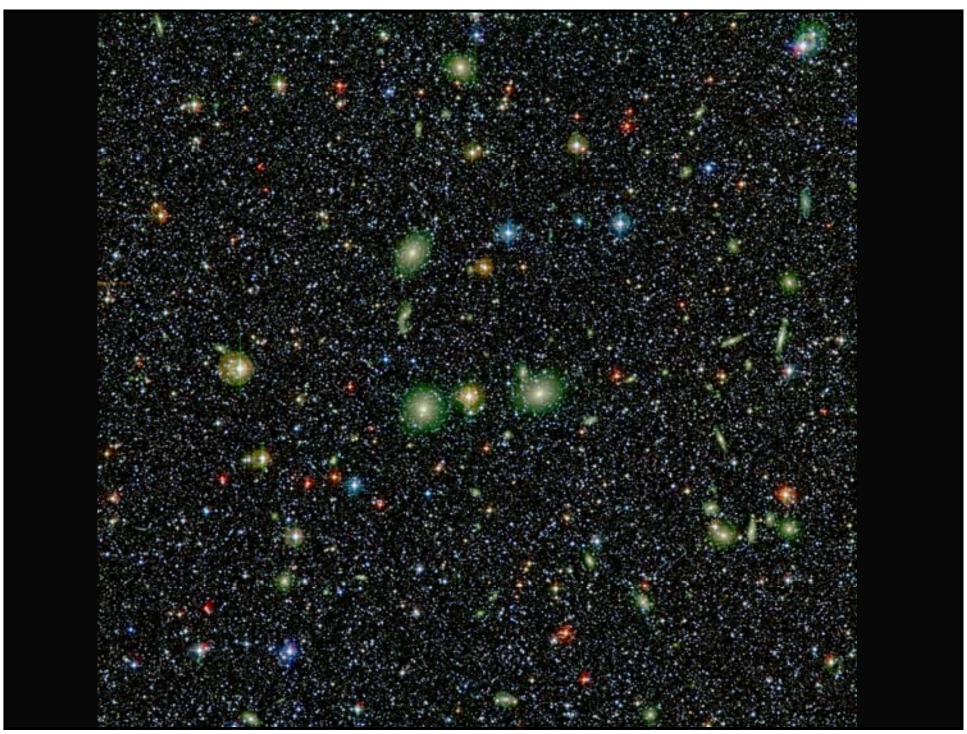
Tony Fairall's
nearby LSS map:

cz=3000-3999 km/s

clear views of
Great Attractor:

Norma Cluster/
A3627





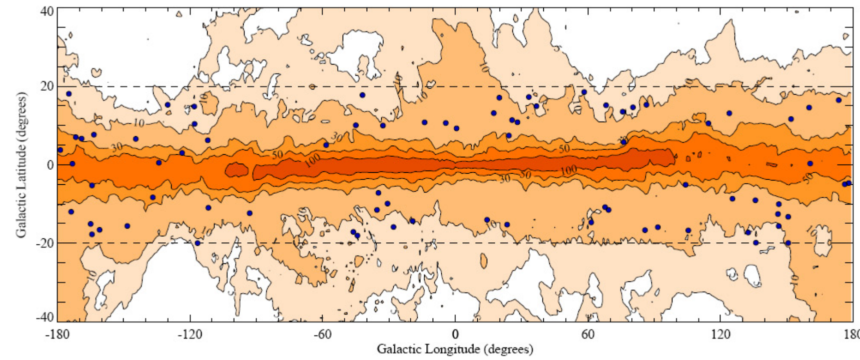
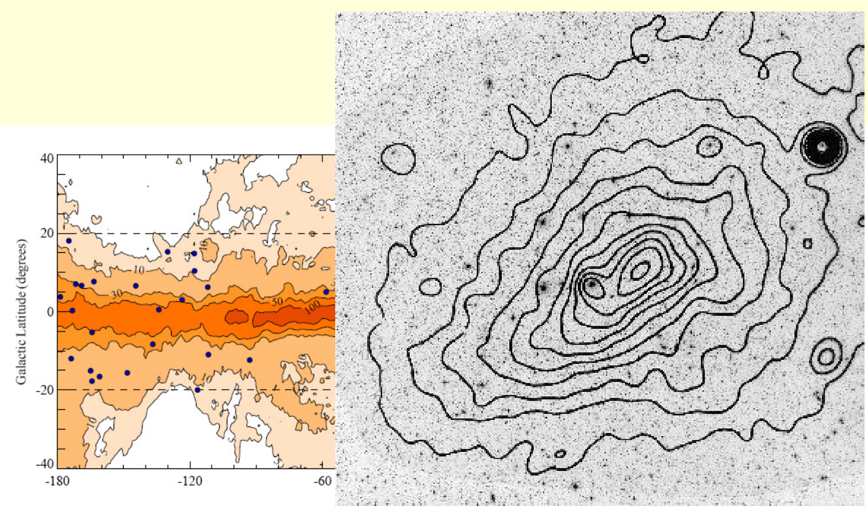


Fig. 16. Distribution in Galactic coordinates of the 76 by Ebeling et al. [129] so far spectroscopically confirmed X-ray clusters (solid dots) of which 80% were previously unknown. Superimposed are Galactic HI column densities in units of 10^{20} cm^{-2} (Dickey & Lockman 1990). Note that the region of relatively high absorption ($N_{\mathrm{HI}} > 5 \times 10^{21}$ cm^{-2}) actually is very narrow and that clusters could be identified to very low latitudes



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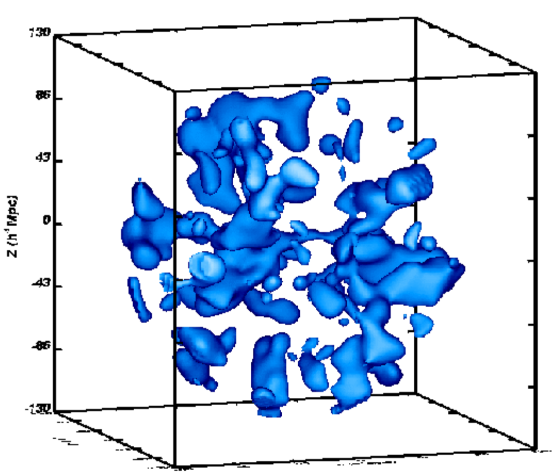
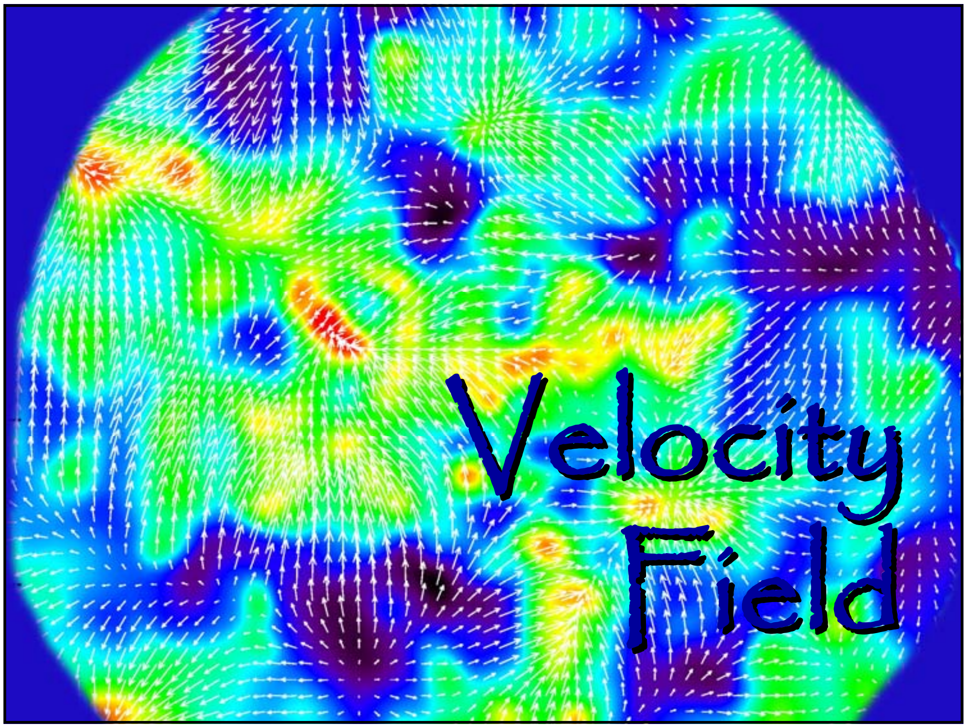
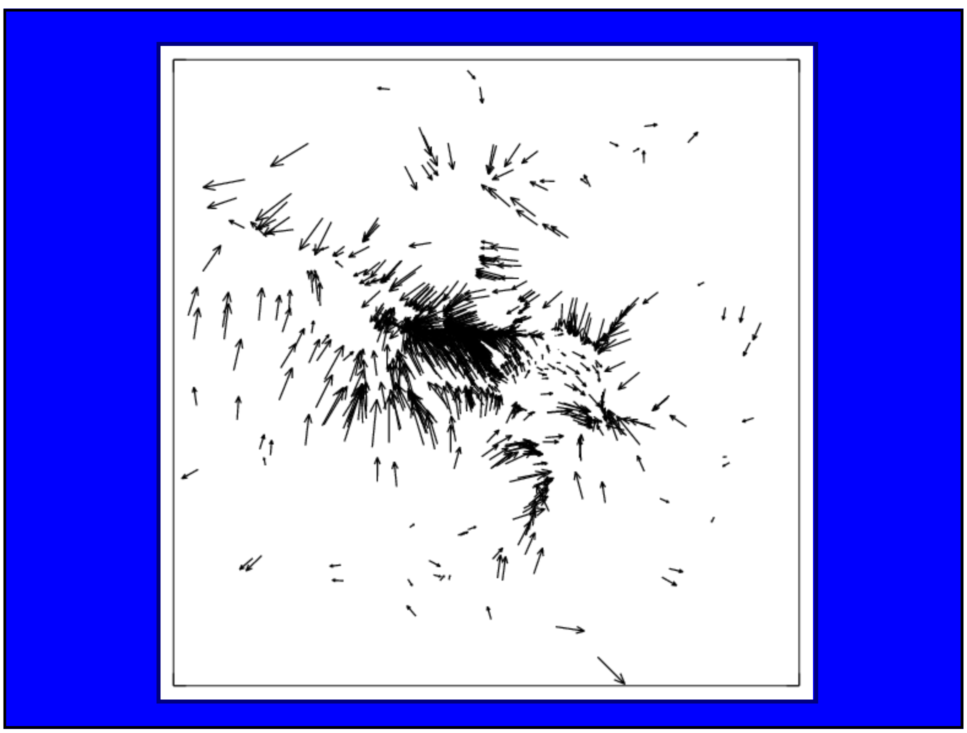
PSCz Survey

Dynamics:

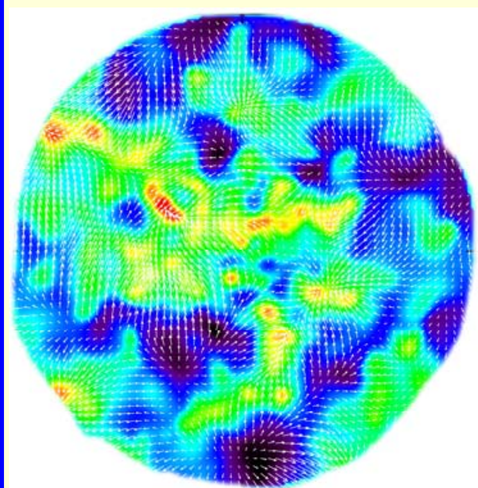



Velocity
Field

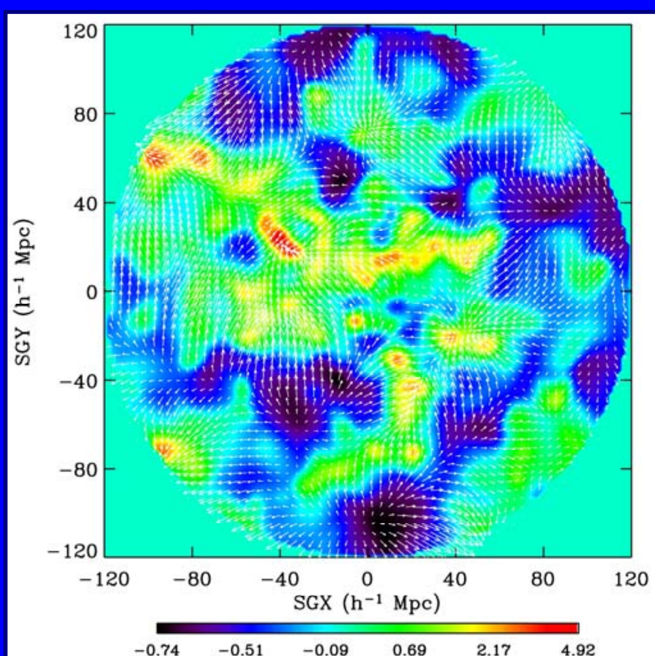


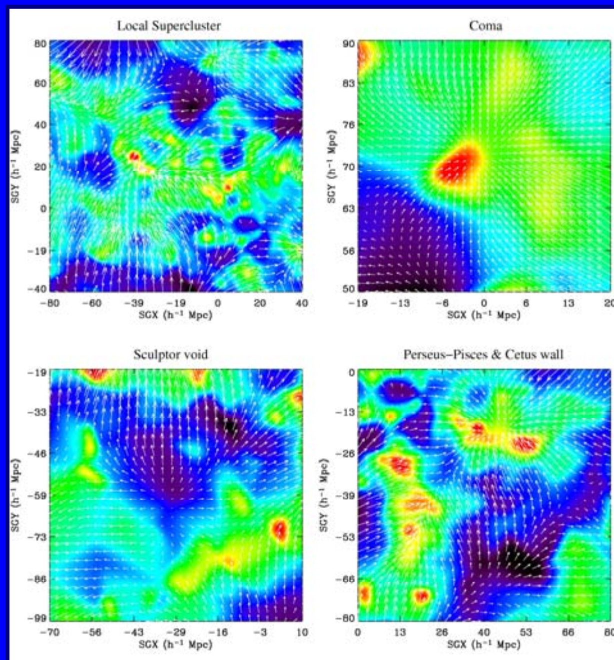
PSCz Flow Field

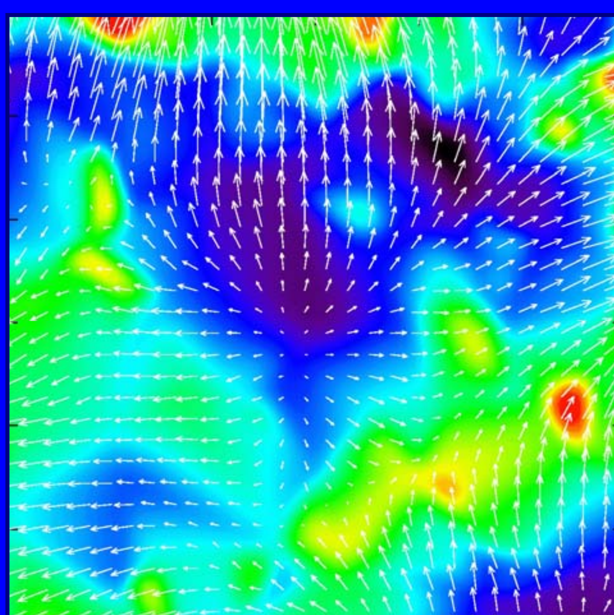
- Flow throughout the volume restored (assuming no shell-crossing)
- Restored velocities volume-weighted
- Shot-noise suppressed



PSCz, velocity+density field

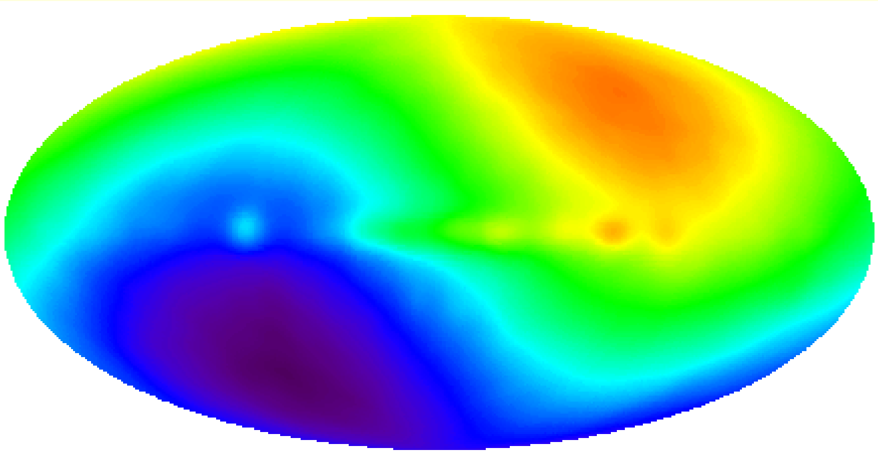


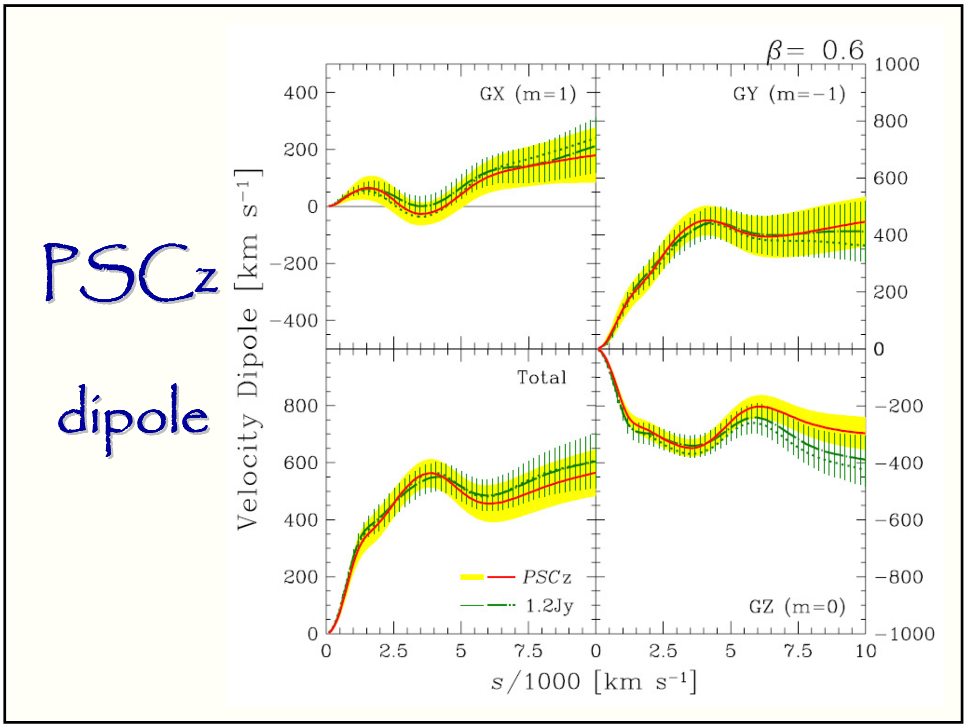

Local Supercluster
Coma
Sculptor void
Perseus–Pisces & Cetus wall
SGX (h⁻¹ Mpc)
SGY (h⁻¹ Mpc)

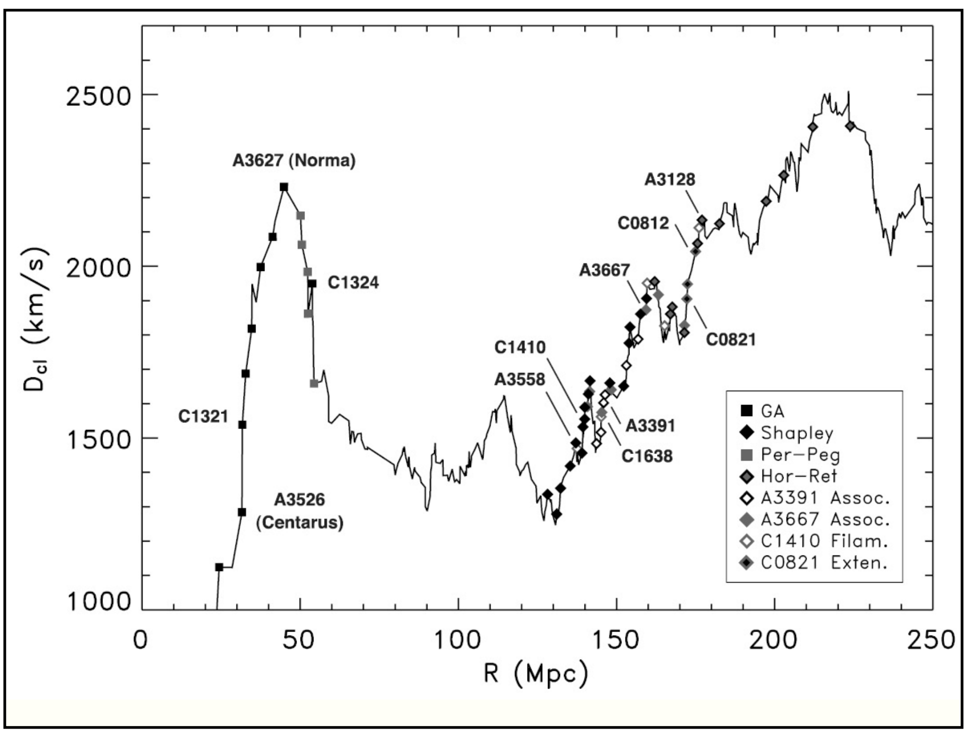


Cosmic Dipoles

The CMB Dipole




PSCz
dipole
β= 0.6
GX (m=1)
GY (m=−1)
Total
GZ (m=0)
Velocity Dipole [km s⁻¹]
s/1000 [km s⁻¹]
PSCz
1.2Jy

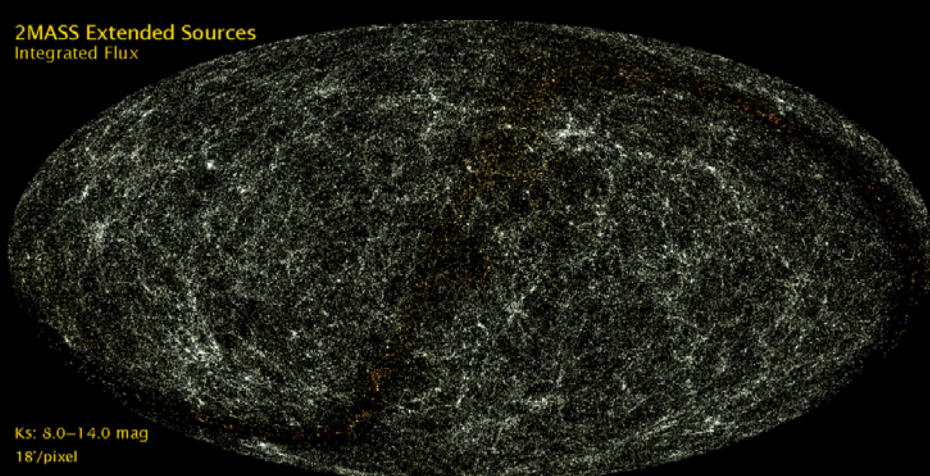

A3627 (Norma)
C1324
C1321
A3526
(Centarus)
A3128
C0812
A3667
C0821
C1410
A3558
A3391
C1638
GA
Shapley
Per−Peg
Hor−Ret
A3391 Assoc.
A3667 Assoc.
C1410 Filam.
C0821 Exten.
D_cl (km/s)
R (Mpc)

2MASS survey

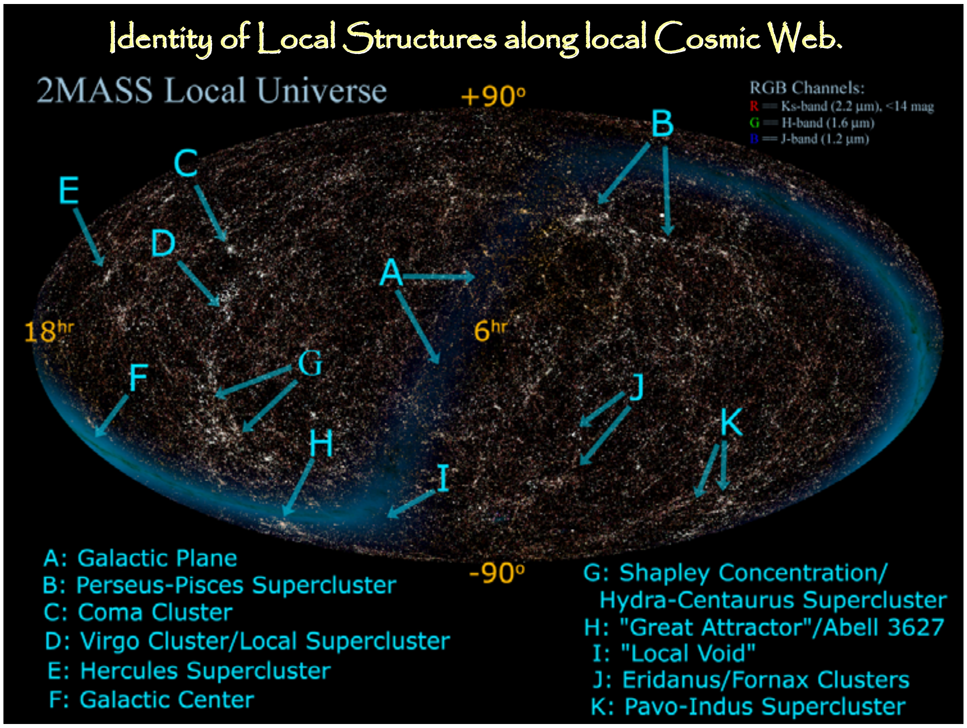
- 2MASS all-sky survey:
  ground-based near-infrared survey whole sky,
  J(1.2 μm), H(1.6 μm), K(2.2 μm)
- 2MASS extended source catalog (XSC):
  1.5 million galaxies
- unbiased sample nearby galaxies
- photometric redshifts: depth in 2MASS maps,
  "cosmic web" of (nearby) superclusters spanning
  the entire sky.

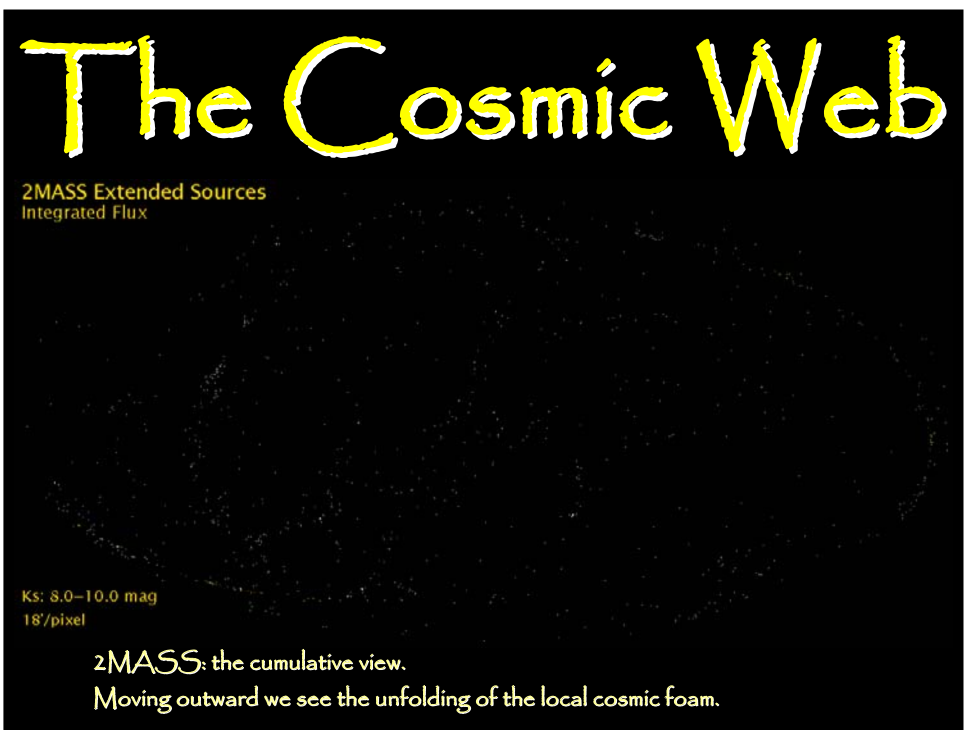
courtesy: T. Jarrett

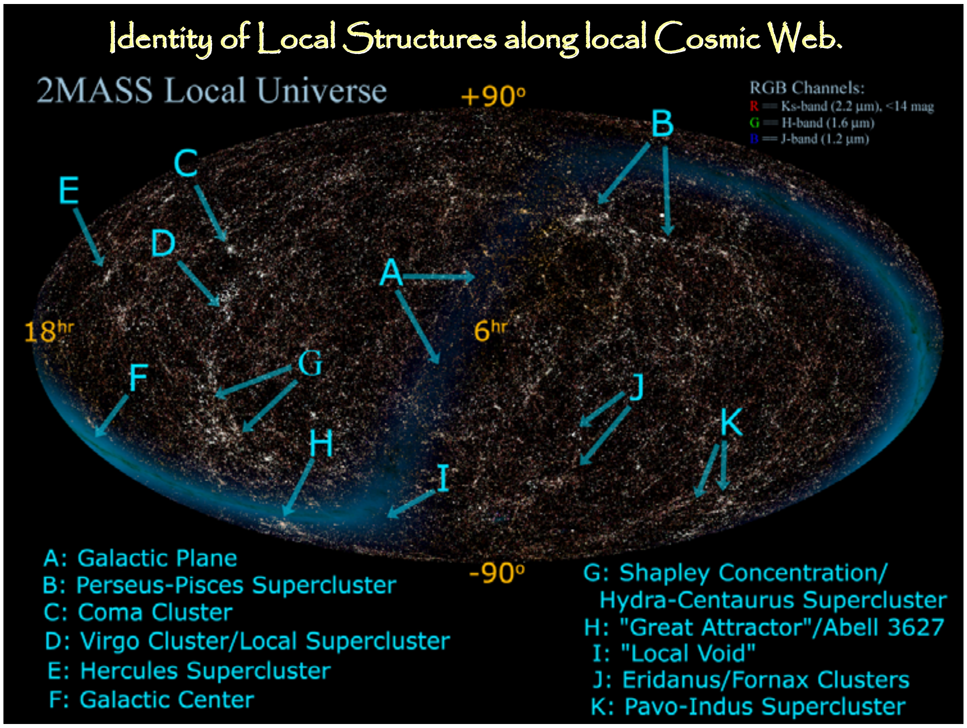
The Cosmic Web

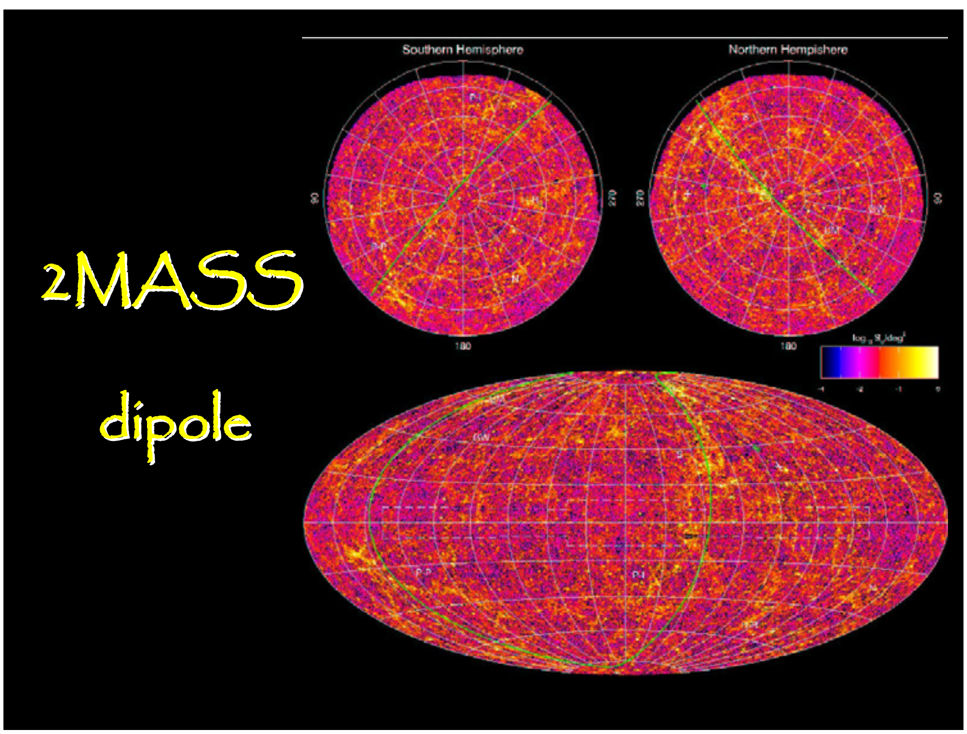


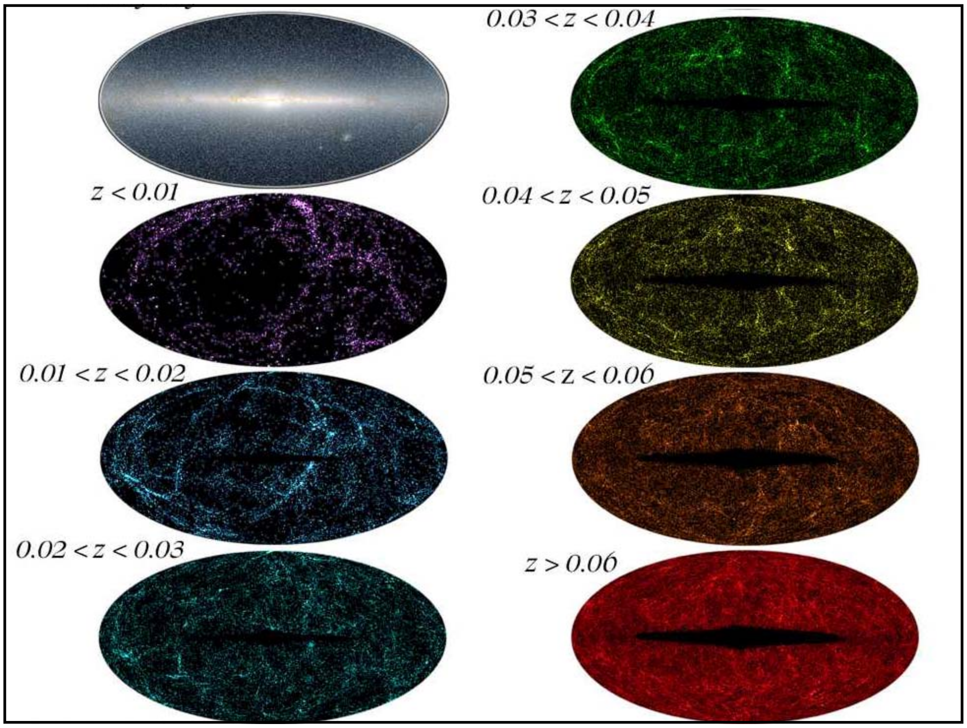
Looking around us we already see the unmistakable signatures of an intriguing foamlike matter distribution in our immediate Cosmic Vicinity.


Identity of Local Structures along local Cosmic Web.
2MASS Local Universe
+90°
-90°
18hr
6hr
RGB Channels:
R = Ks-band (2.2 µm), <14 mag
G = H-band (1.6 µm)
B = J-band (1.2 µm)
A
B
C
D
E
F
G
H
I
J
K
A: Galactic Plane
B: Perseus-Pisces Supercluster
C: Coma Cluster
D: Virgo Cluster/Local Supercluster
E: Hercules Supercluster
F: Galactic Center
G: Shapley Concentration/
Hydra-Centaurus Supercluster
H: "Great Attractor"/Abell 3627
I: "Local Void"
J: Eridanus/Fornax Clusters
K: Pavo-Indus Supercluster

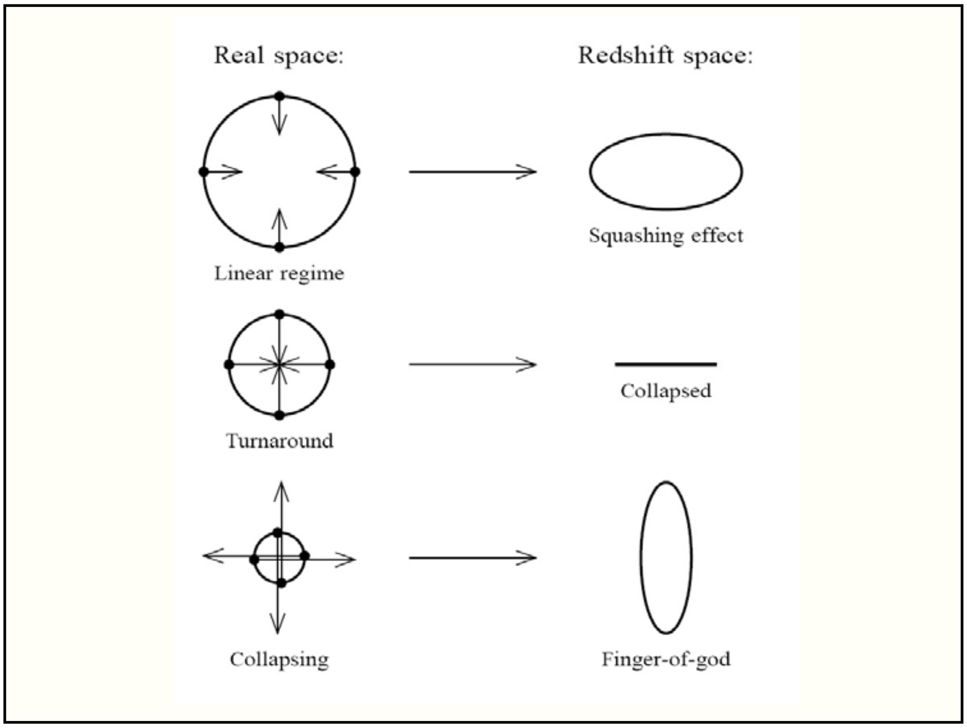

The Cosmic Web
2MASS Extended Sources
Integrated Flux
Ks: 8.0–10.0 mag
18'/pixel
2MASS: the cumulative view.
Moving outward we see the unfolding of the local cosmic foam.

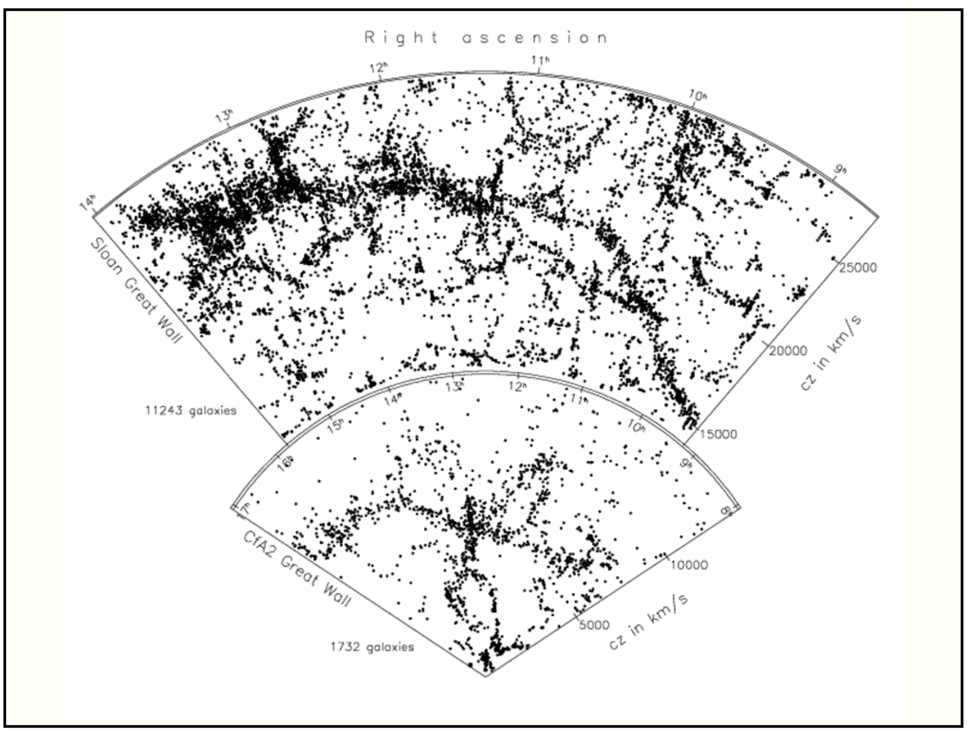

Identity of Local Structures along local Cosmic Web.
2MASS Local Universe
+90°
RGB Channels:
R = Ks-band (2.2 µm), <14 mag
G = H-band (1.6 µm)
B = J-band (1.2 µm)
B
C
E
D
A
18hr
6hr
G
F
J
K
H
I
-90°
A: Galactic Plane
B: Perseus-Pisces Supercluster
C: Coma Cluster
D: Virgo Cluster/Local Supercluster
E: Hercules Supercluster
F: Galactic Center
G: Shapley Concentration/
Hydra-Centaurus Supercluster
H: "Great Attractor"/Abell 3627
I: "Local Void"
J: Eridanus/Fornax Clusters
K: Pavo-Indus Supercluster


Southern Hemisphere
Northern Hempishere
2MASS
dipole



Redshift Space Distortions


Real space:
Redshift space:
Squashing effect
Linear regime
Collapsed
Turnaround
Collapsing
Finger-of-god


Right ascension
Sloan Great Wall
11243 galaxies
CfA2 Great Wall
1732 galaxies
cz in km/s
25000
20000
15000
10000
5000