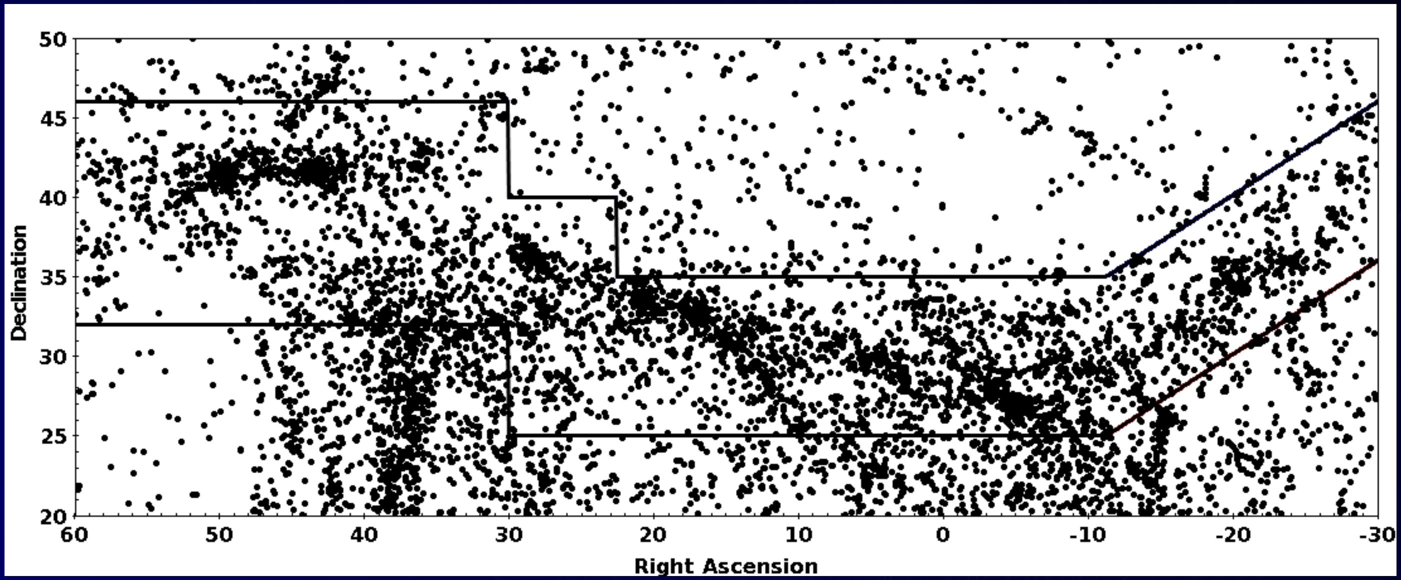
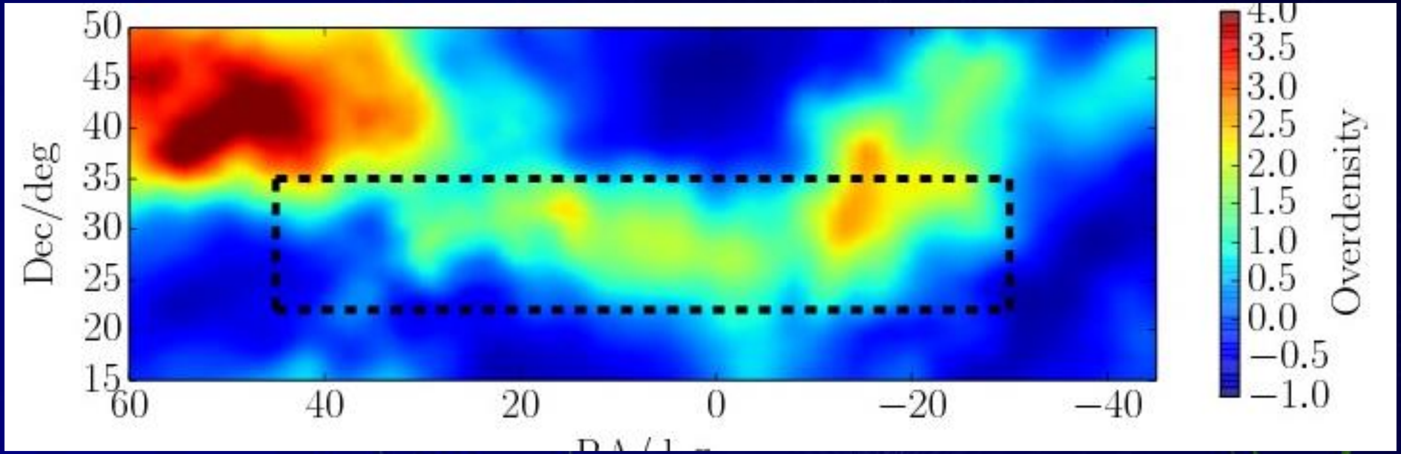
The Arecibo Pisces-Perseus Supercluster Survey



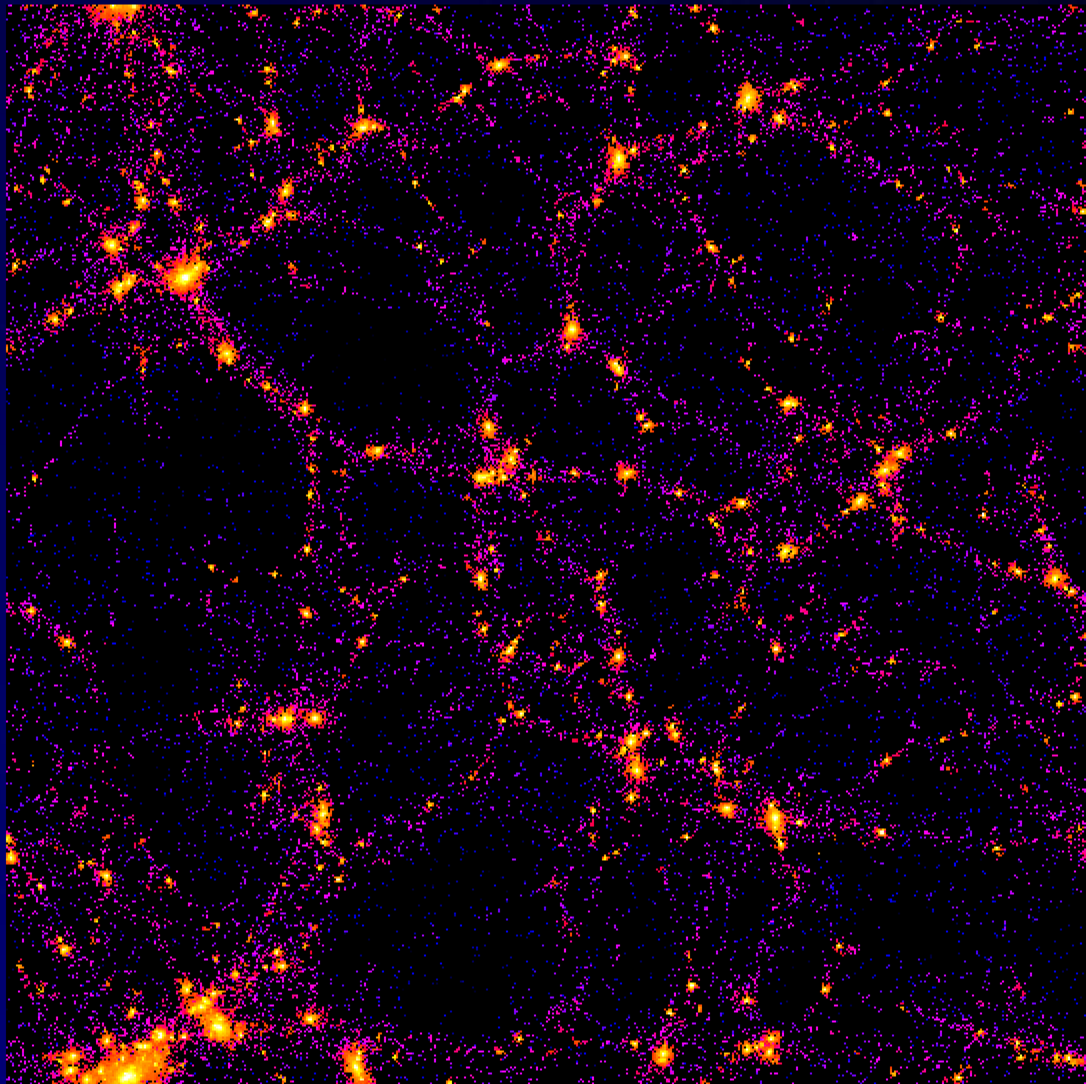


UAT 16.06

Martha Haynes

Cornell University

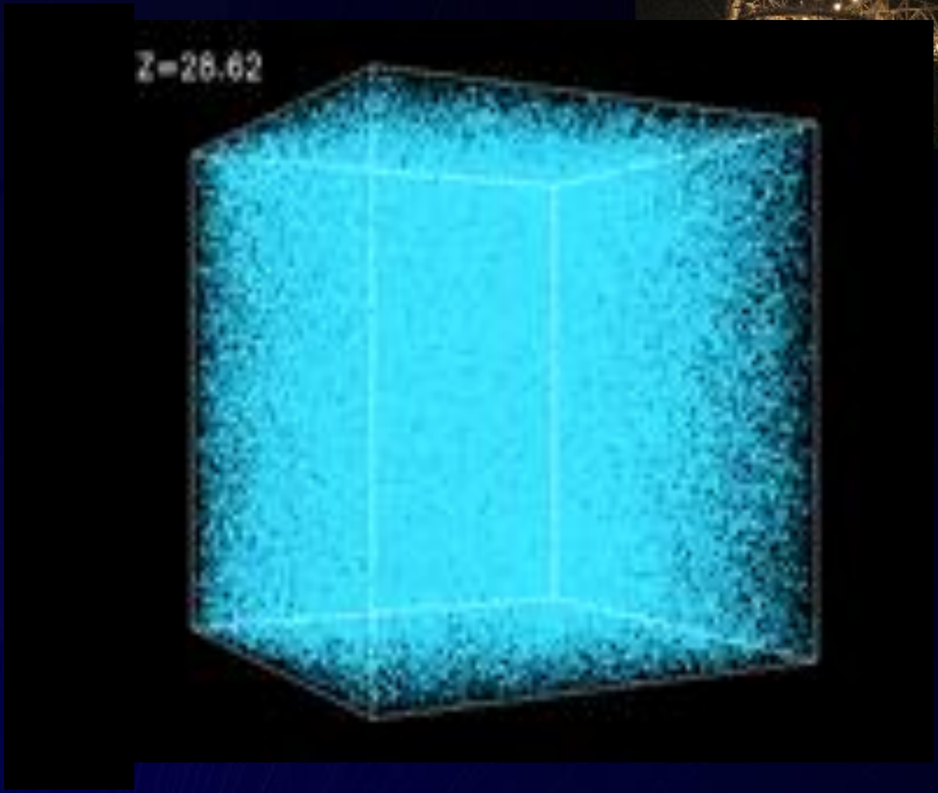
Large scale structure in the Universe

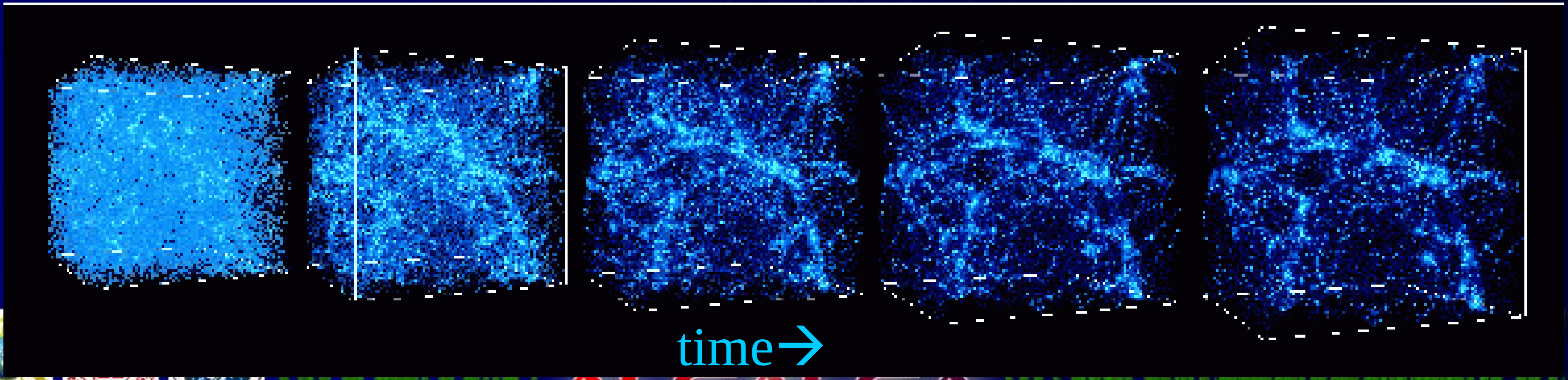


- Galaxies cluster into groups, clusters and superclusters
- Galaxies avoid voids.

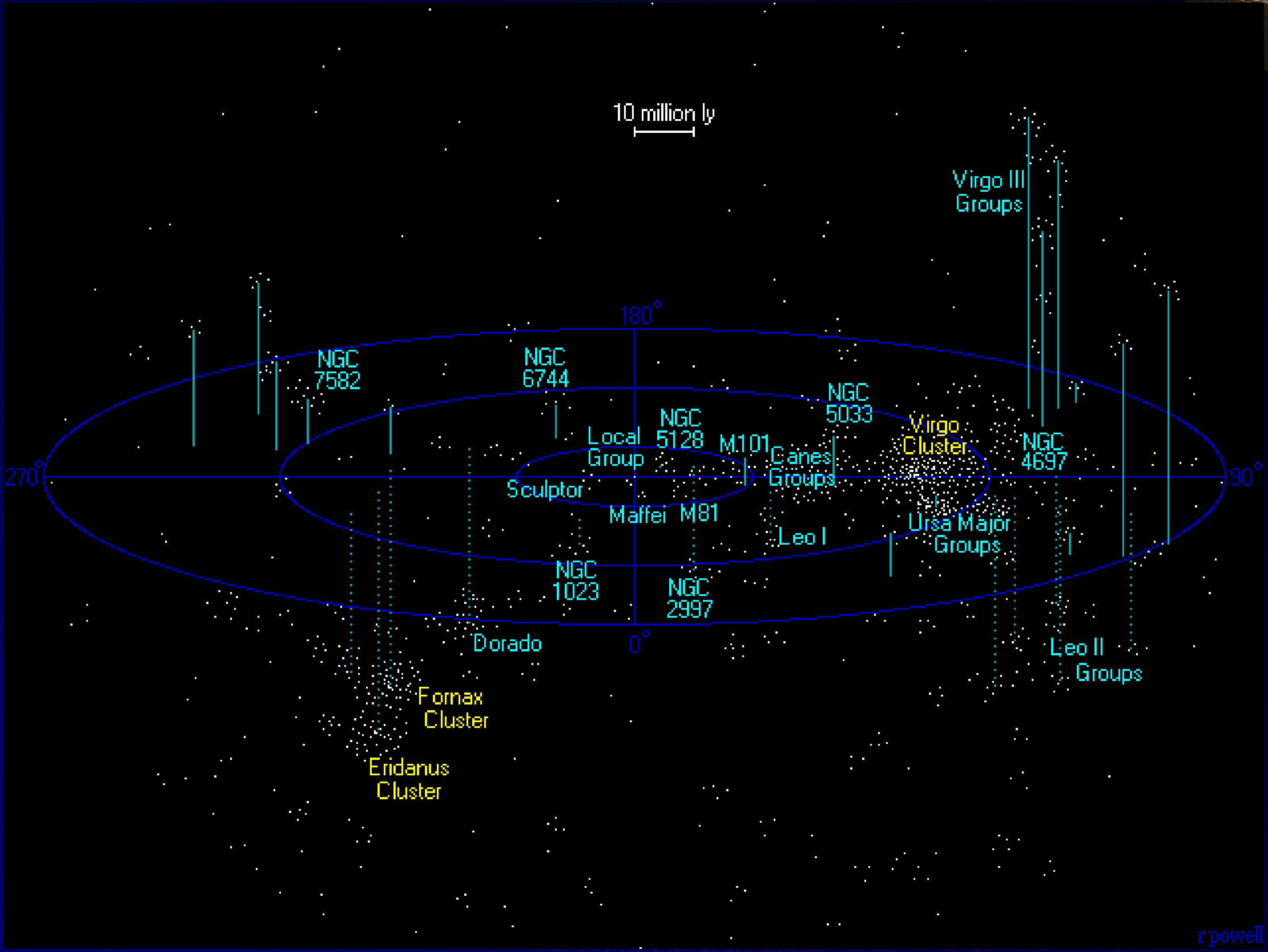
Large scale structure

- How did the structures we see today form and evolve?
- Do cosmological models predict this behavior?
- Can they give us any insight into how and why this structure develops?



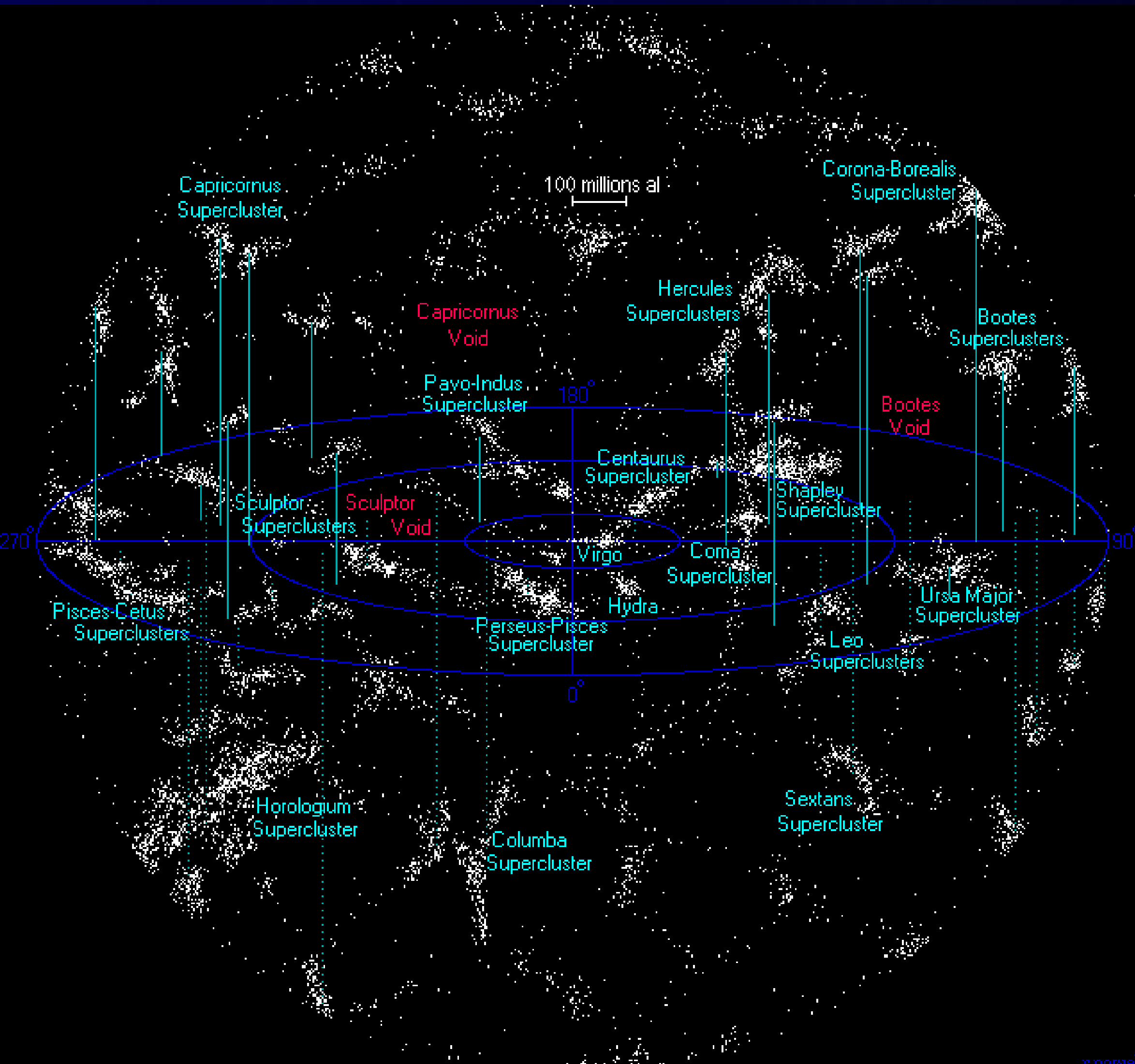


Large scale structure < 50 Mlyr



Atlas of the Universe

Large scale structure < 1 Glyr

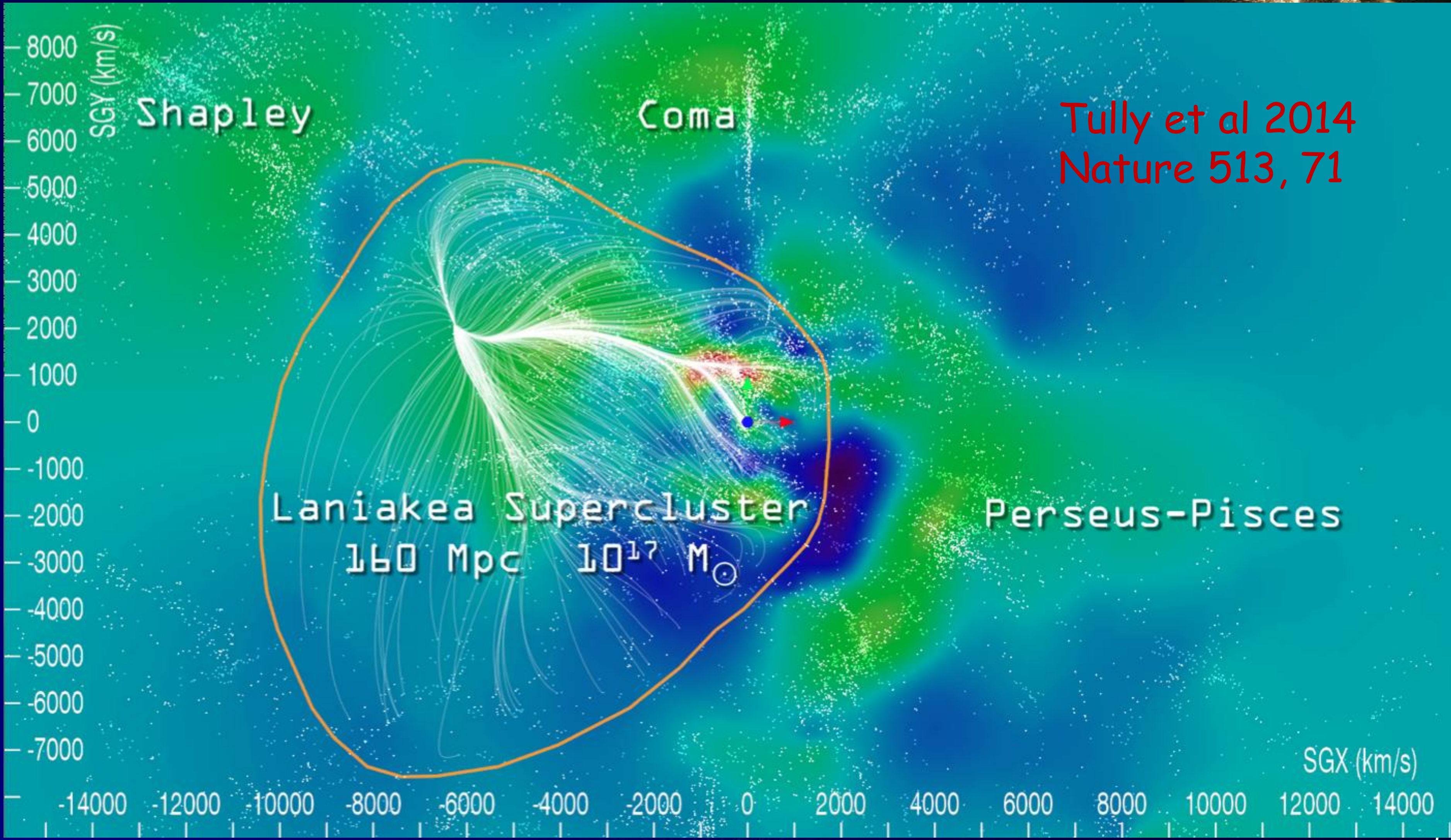


Pisces-Perseus Supercluster

"A Metagalactic Cloud between Perseus and Pegasus" Bernheimer (1932 Nature)

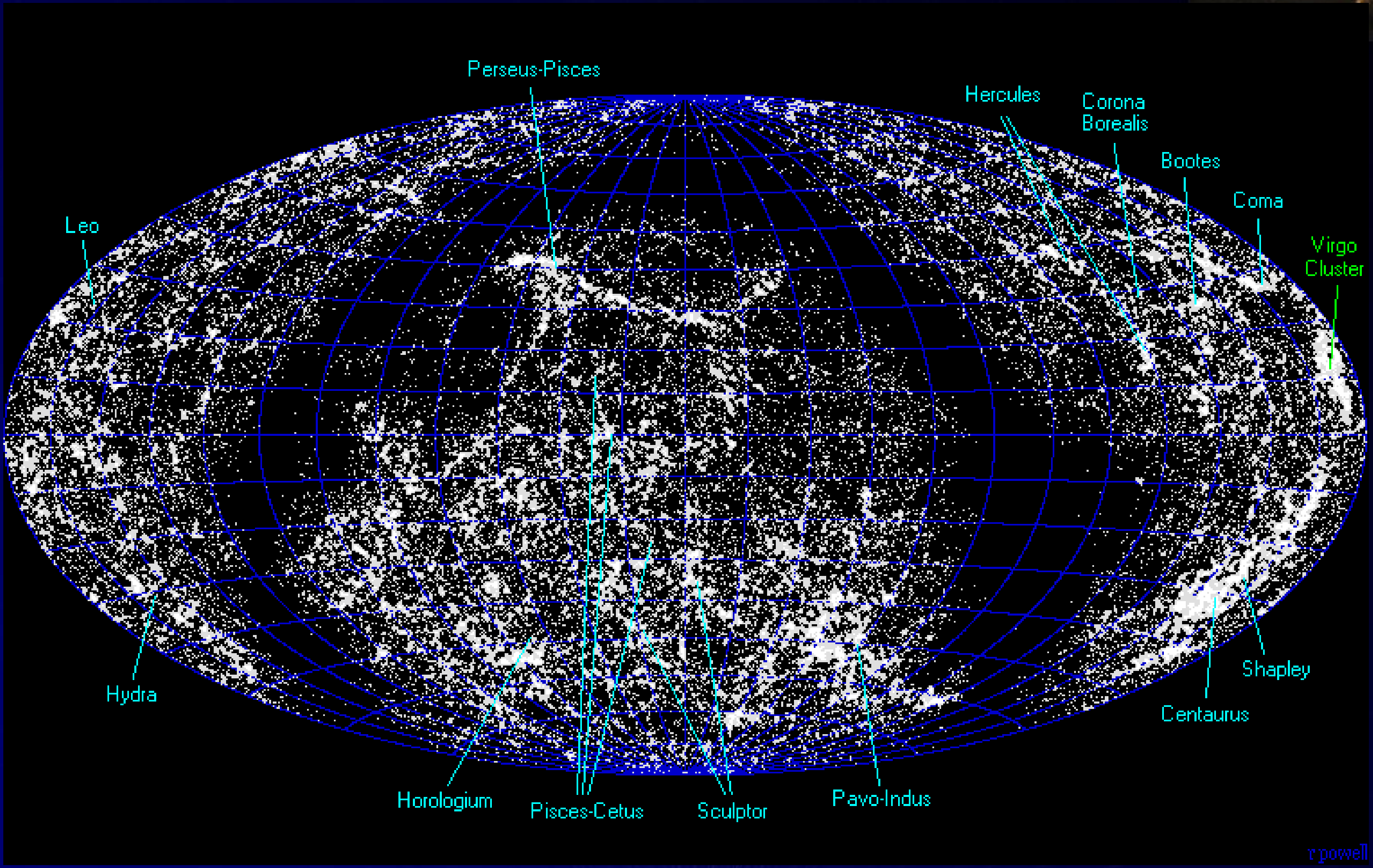
Atlas of the Universe

The Pisces-Perseus Supercluster



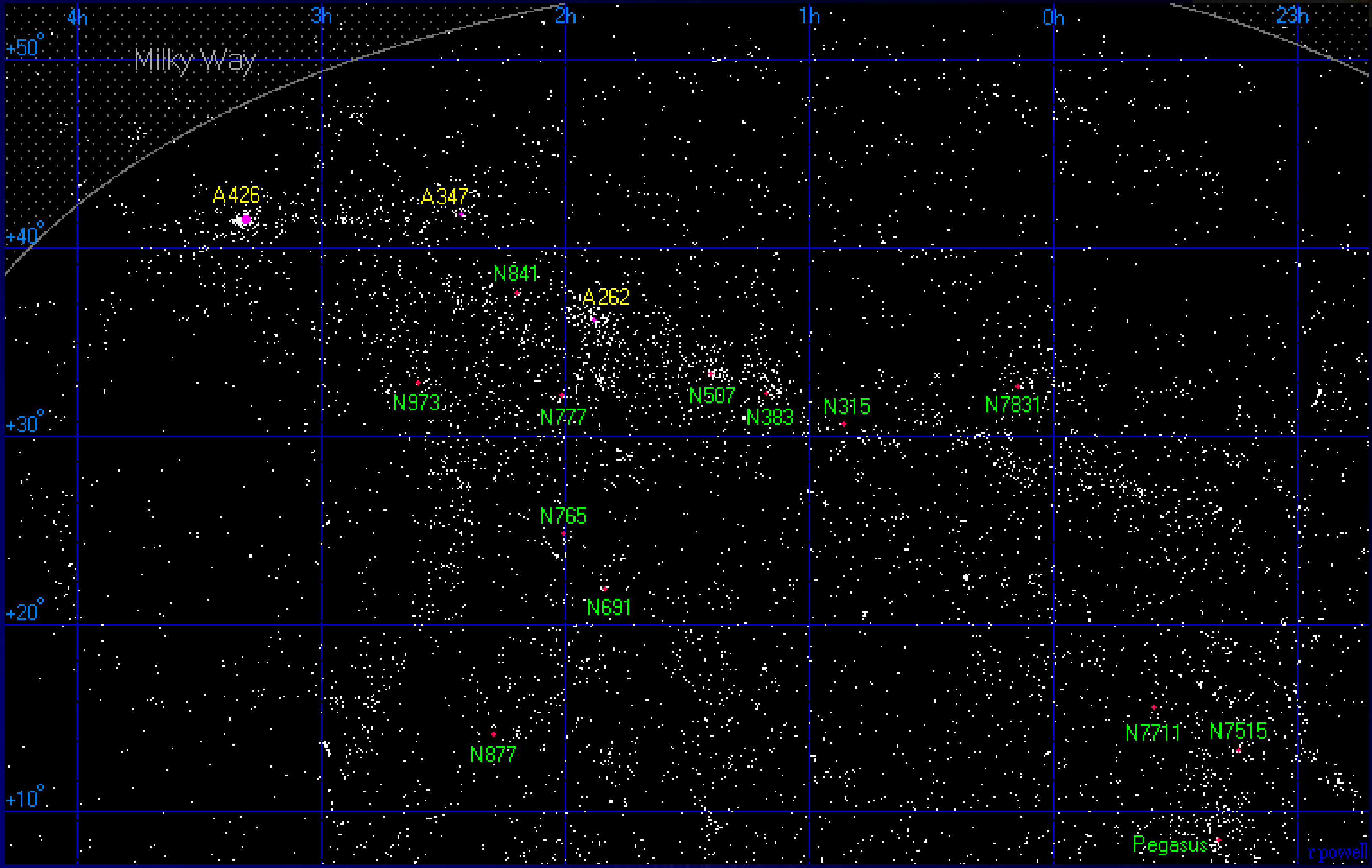
Tully *et al* 2014 Nature

The Pisces-Perseus Supercluster



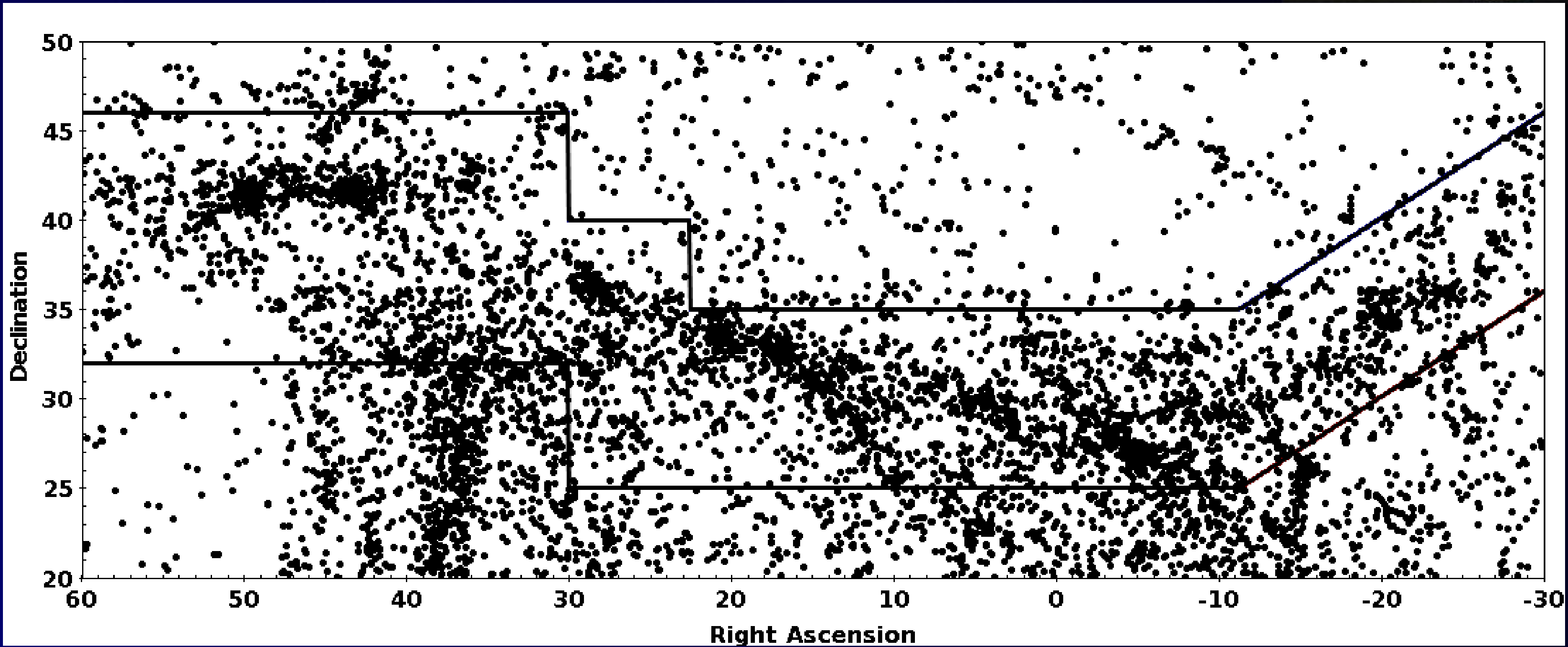
Atlas of the Universe

The Pisces-Perseus Supercluster



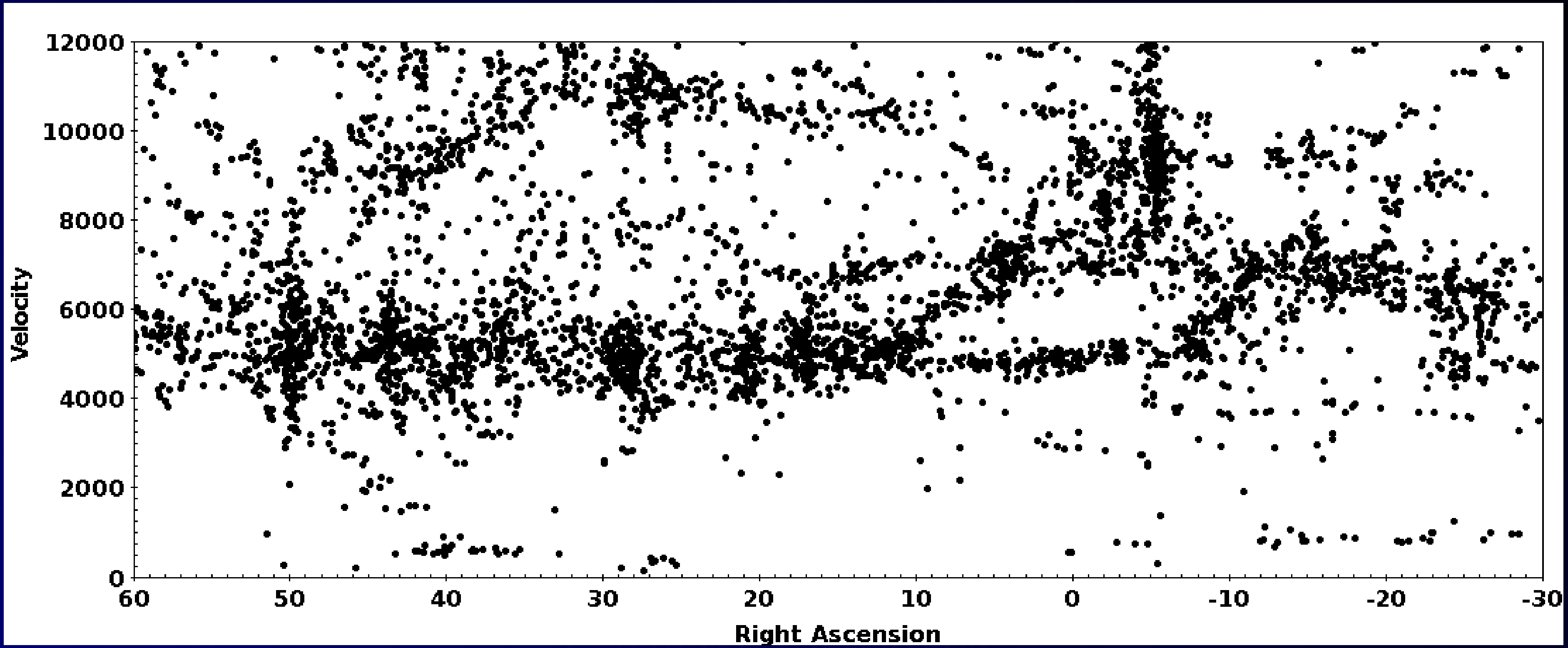
Atlas of the Universe

The Pisces-Perseus Supercluster



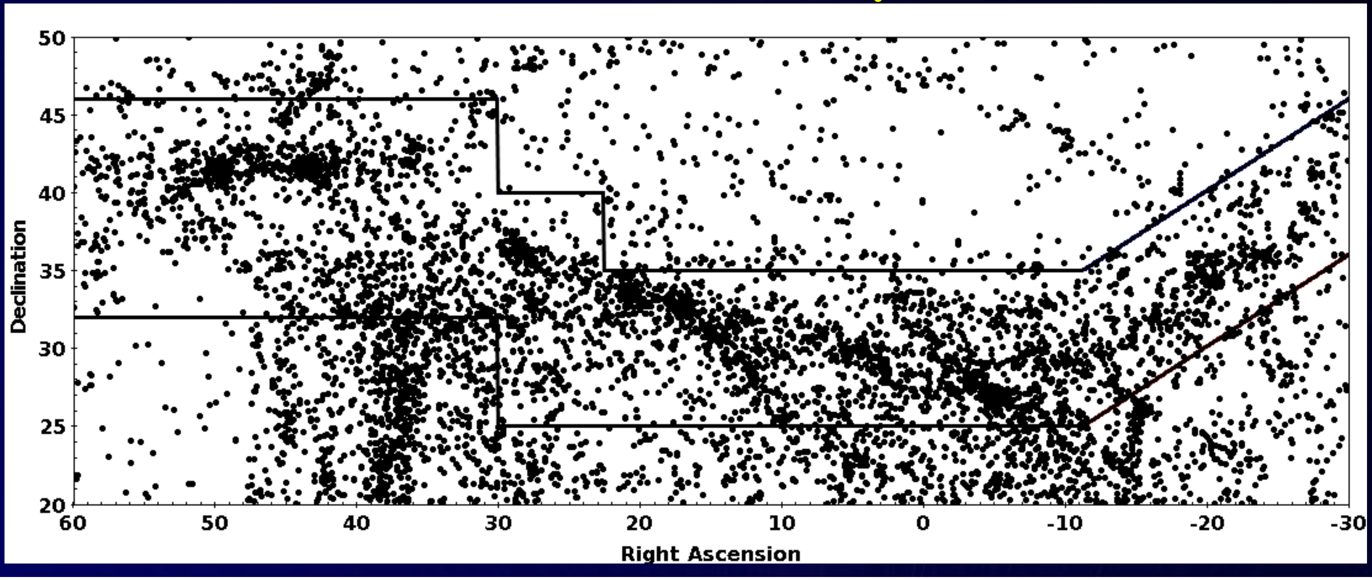
See SH#1

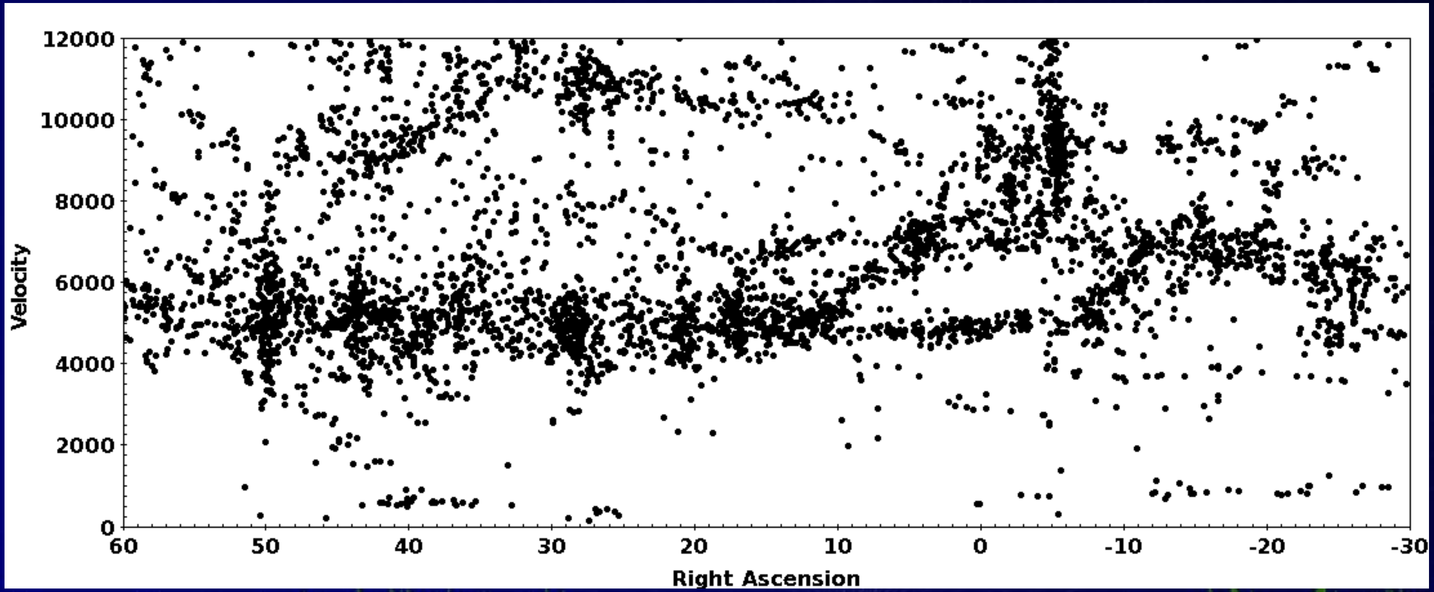
The Pisces-Perseus Supercluster



See SH#1

The Pisces-Perseus Supercluster



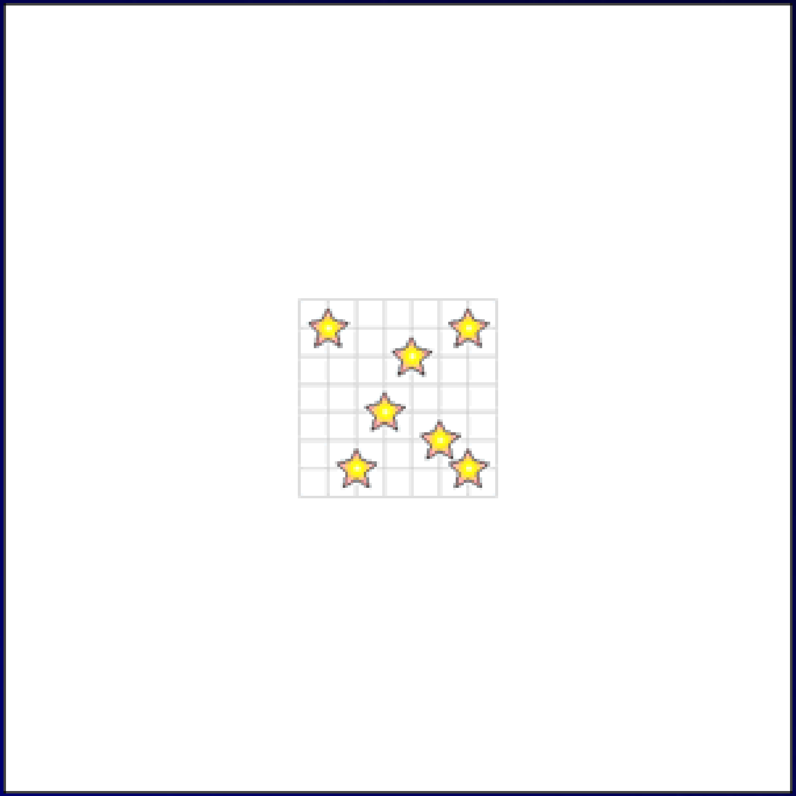


Main clusters/groups in PPS

Name	Common Name	R.A.(J2000) (deg)	Dec(J2000) (deg)	cz (km/s)
N7343	Pegasus	339.7	34.0	6000.
Abell 2634		354.6	27.0	9400.
Abell 2666	Pegasus	357.7	27.2	8000.
N 383	Pisces	16.9	32.4	4800.
N 507		20.5	33.3	4700.
Abell 262		28.2	36.2	4800.
Abell 347		36.5	41.9	5600.
Abell 426	Perseus	49.7	41.5	5500.

See SH#1

Smooth Hubble Flow

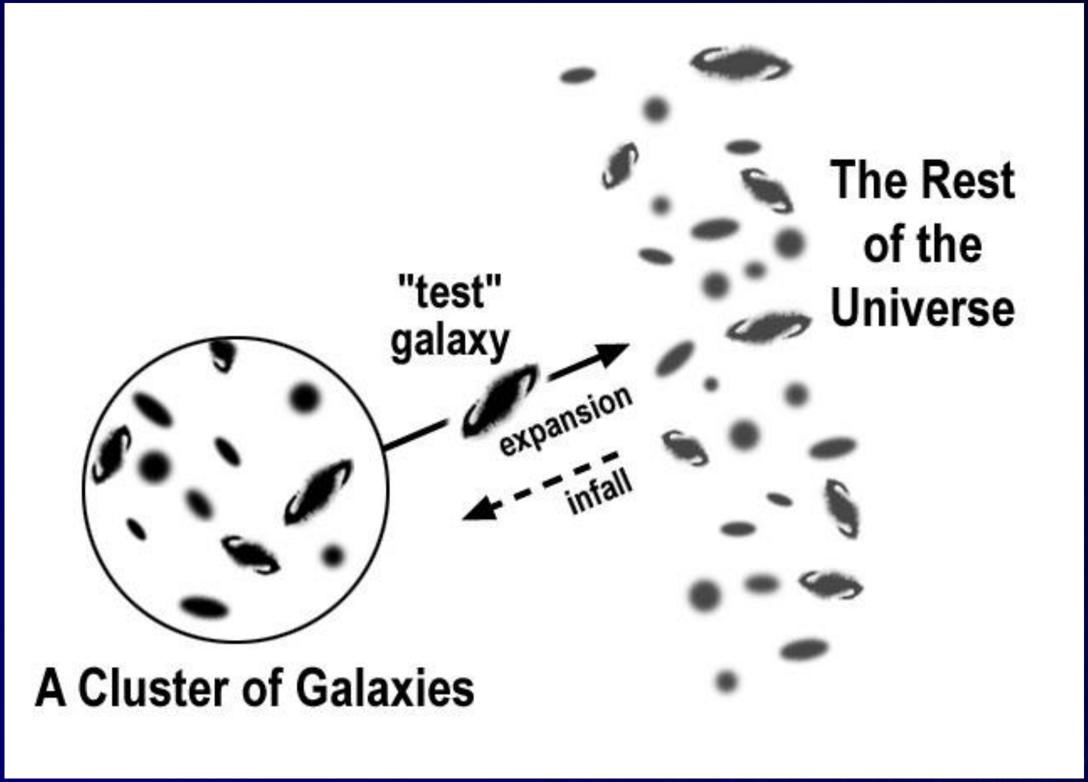


- The dominant motion in the universe is the smooth expansion, known as the Hubble Flow.

↕

- Cosmological principle: On large scales, the universe is homogeneous and isotropic.

Deviations from Hubble Flow



"Peculiar velocities"

$$V_{obs} = V_{Hubble} + Vpec$$

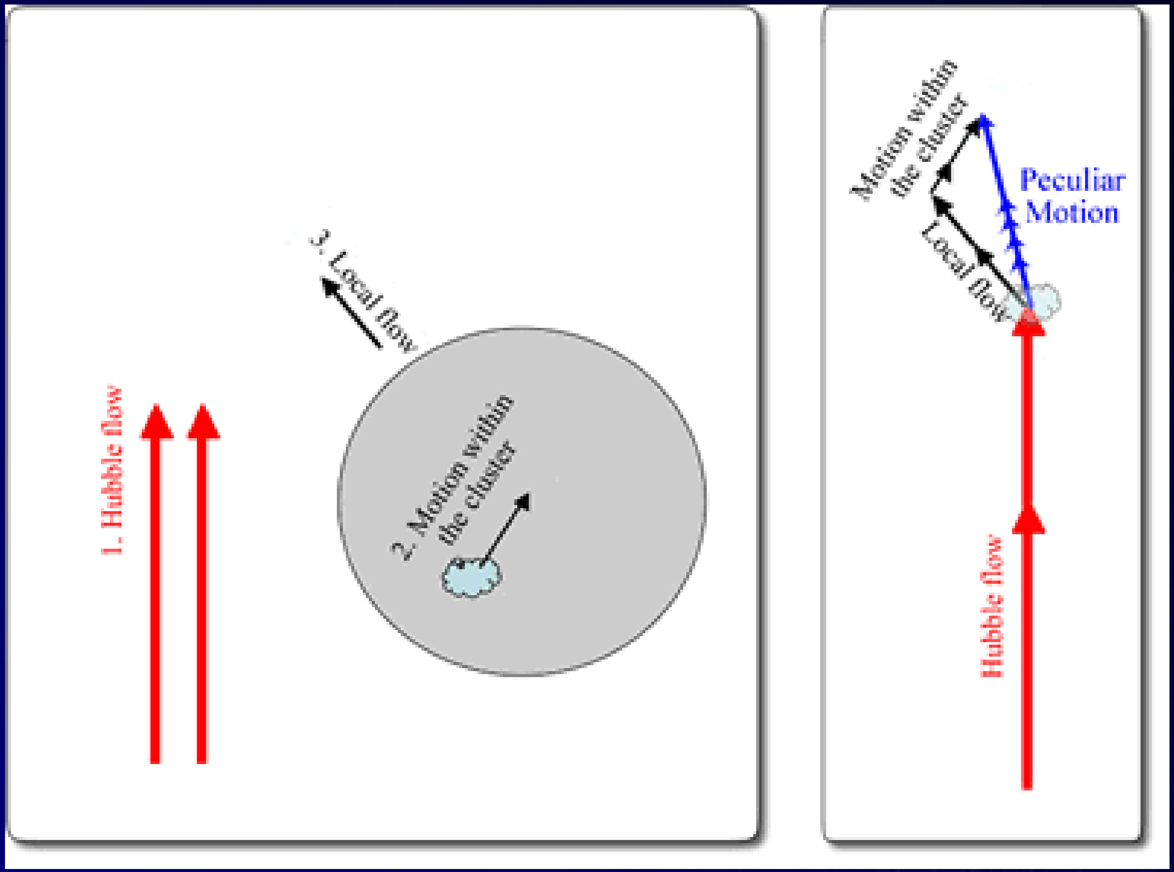
V_{pec} includes components of:

- Orbital motion in cluster/group
- Infall/outflow from regions of over/under-density
- "noise" on the pure Hubble flow

Trace V_{pec} ⇔ Trace mass

Tully *et al* 2014 Nature

Deviations from Hubble Flow



"Peculiar velocities"

$$V_{obs} = V_{Hubble} + Vpec$$

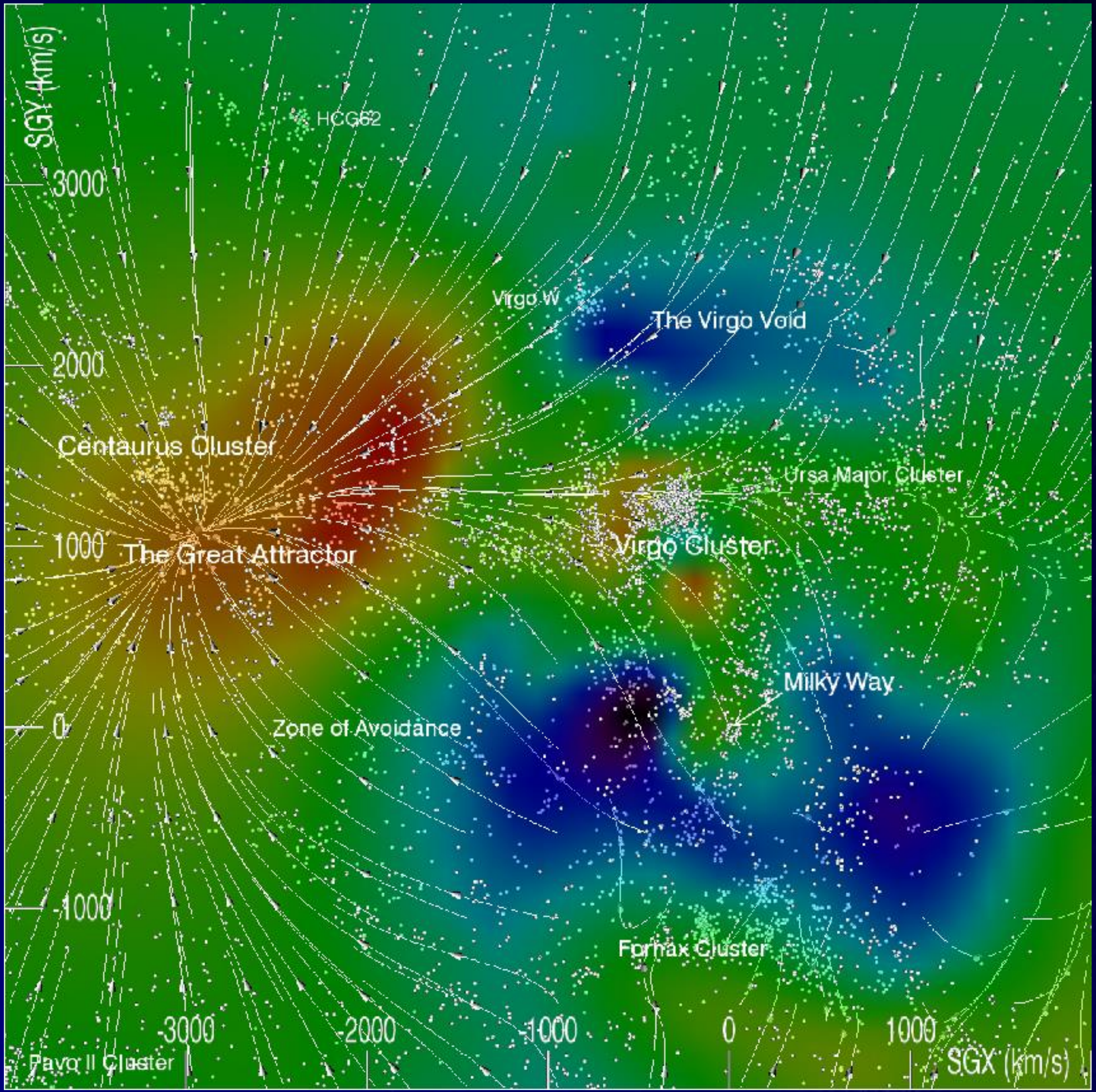
V_{pec} includes components of:

- Orbital motion in cluster/group
- Infall/outflow from regions of over/under-density
- "noise" on the pure Hubble flow

Trace V_{pec} ⇔ Trace mass

Tully *et al* 2014 Nature

"Peculiar velocity: field => mass



"Peculiar velocities"

$$V_{obs} = V_{Hubble} + Vpec$$

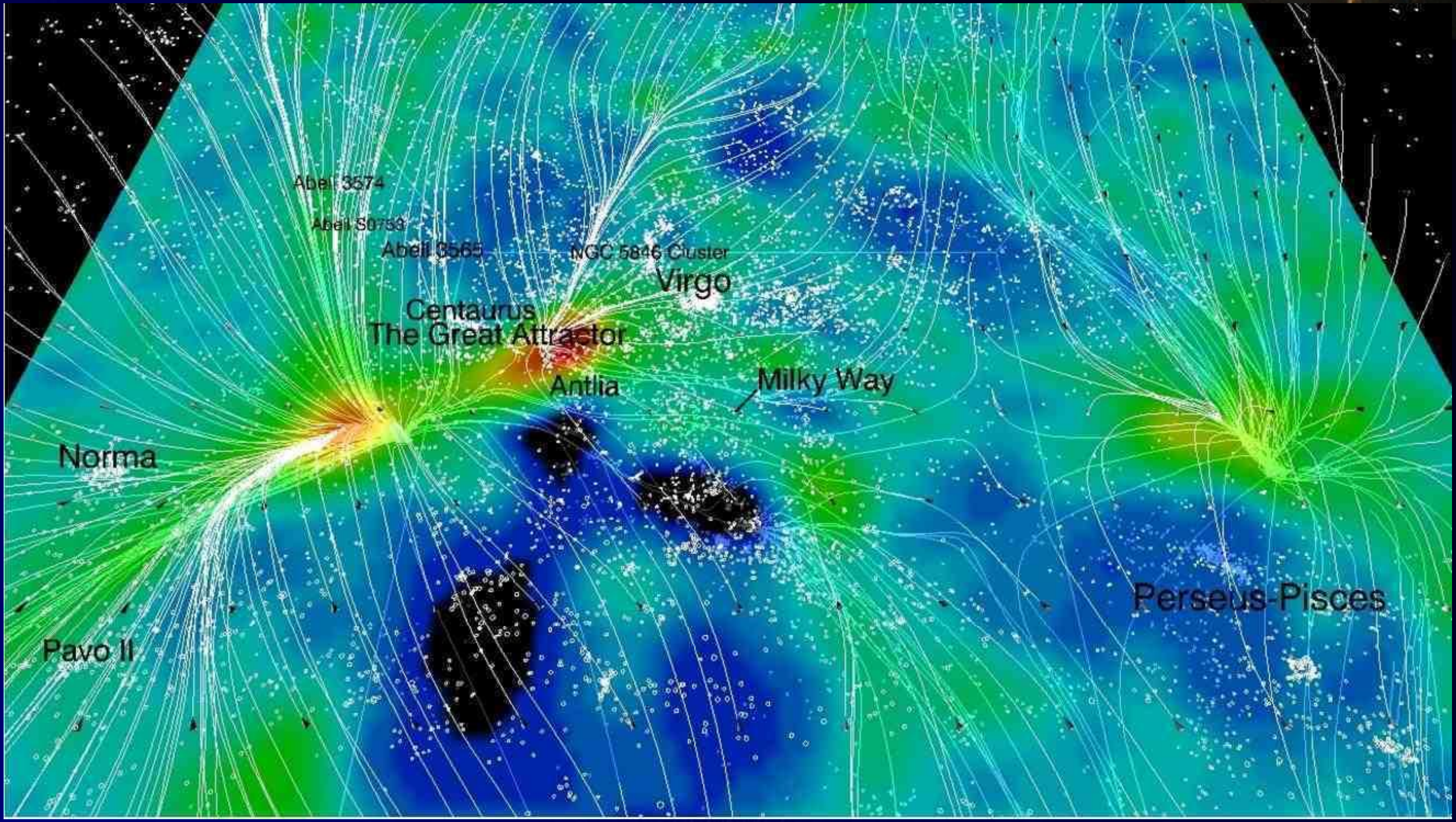
V_{pec} includes components of:

- Orbital motion in cluster/group
- Infall/outflow from regions of over/under-density
- "noise" on the pure Hubble flow

Trace V_{pec} ⇔ Trace mass

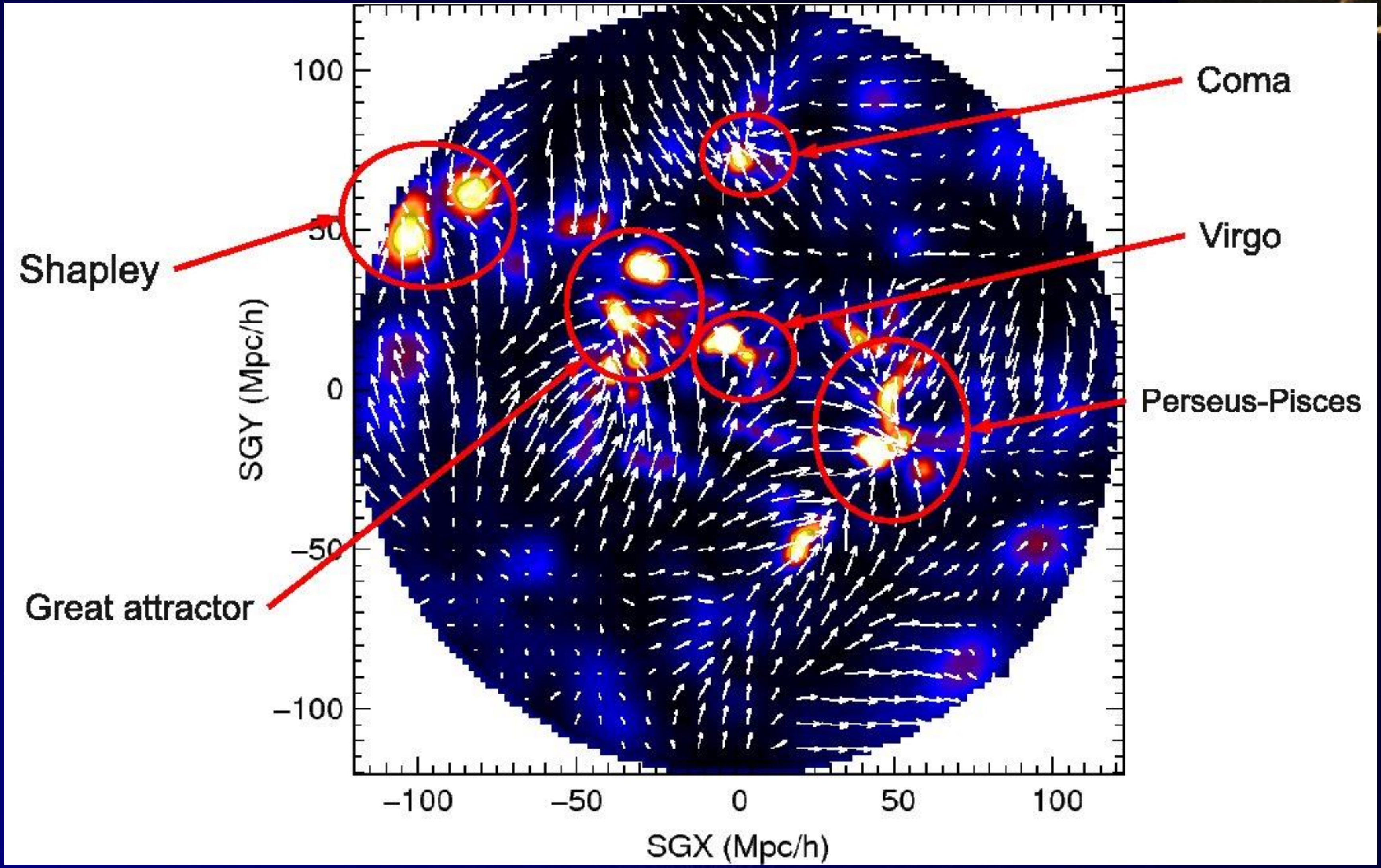
Tully *et al* 2014 Nature

The Pisces-Perseus Supercluster



Tully *et al* 2014 Nature

Velocity field from CosmicFlows



Measuring peculiar velocities?

"Peculiar velocities"

$$V_{obs} = V_{Hubble} + V_{pec}$$

$$V_{Hubble} = H_o D$$

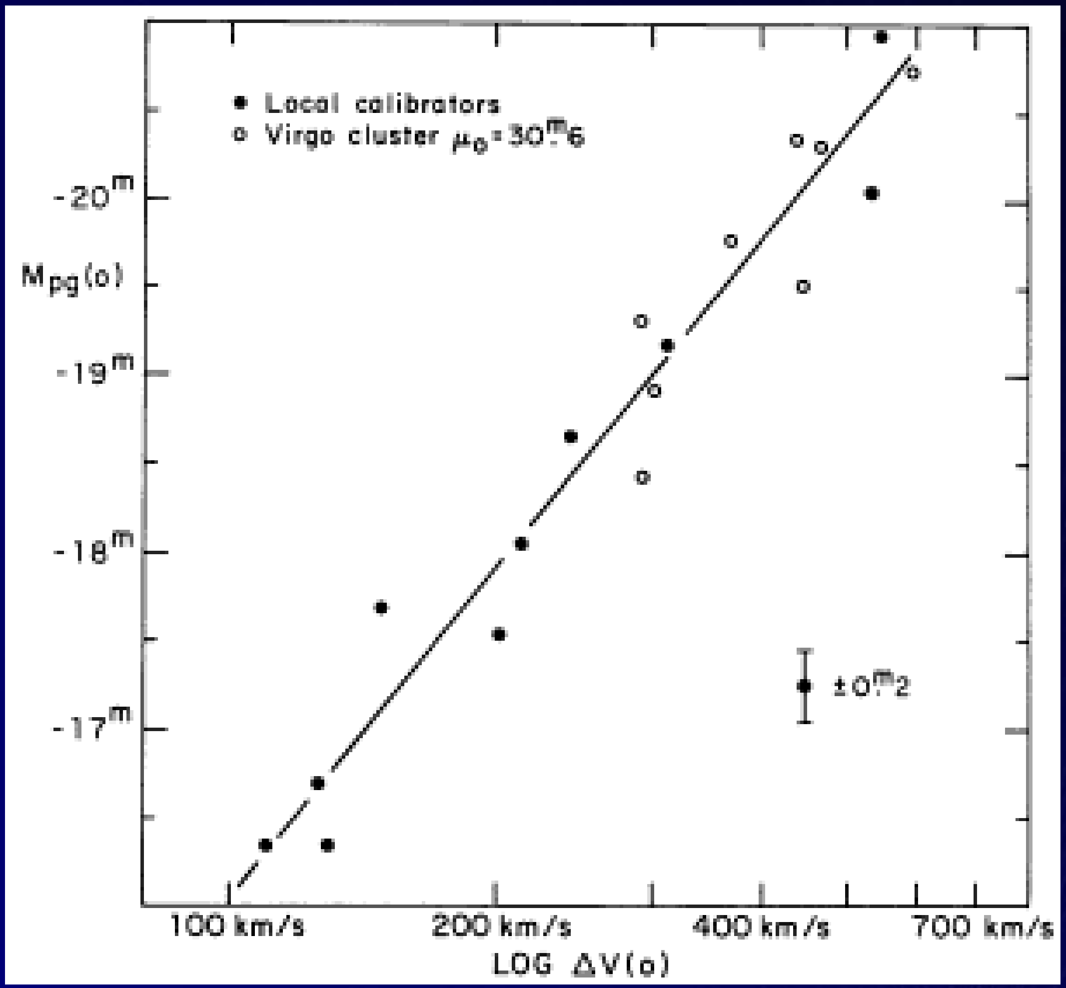
$$V_{pec} = V_{obs} - H_o D$$

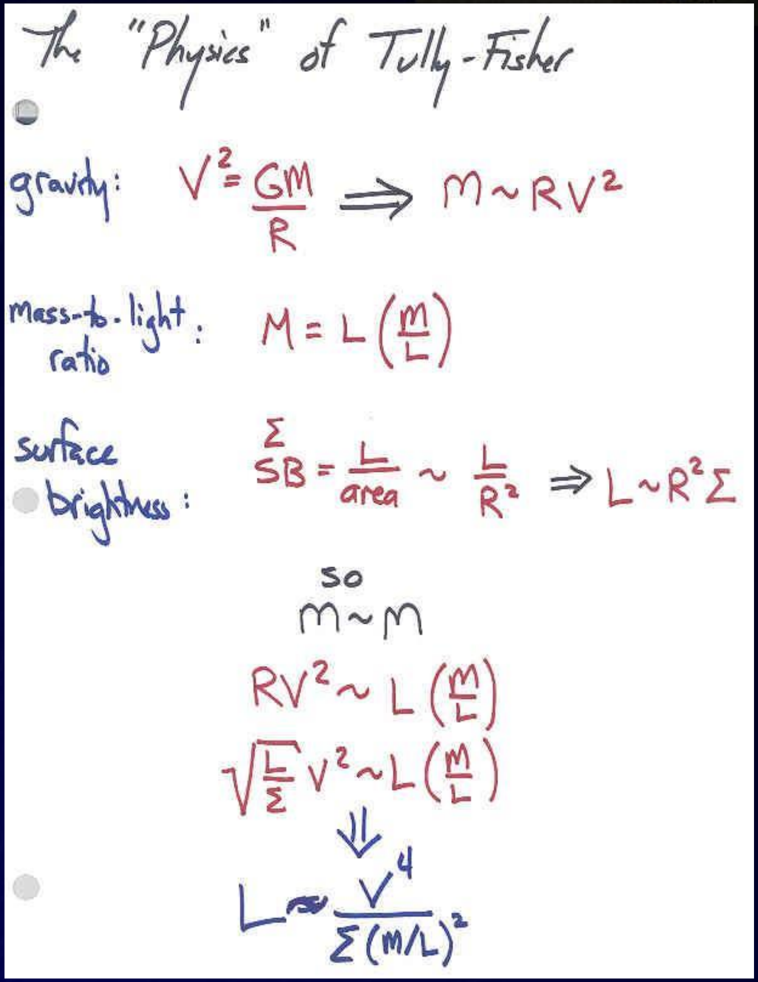
- Observe the recessional velocity
- Measure the distance by a redshift-independent method
- Estimate the Hubble velocity expected for a galaxy at that distance.
- The difference between the observed and expected recessional velocity is the peculiar velocity.

The method we use to estimate the distance depends on:

- the type of galaxies we study;
- their distance from us;
- how accurate we need the distance to be;
- the investment of telescope time needed to achieve the result.

Tully-Fisher relation

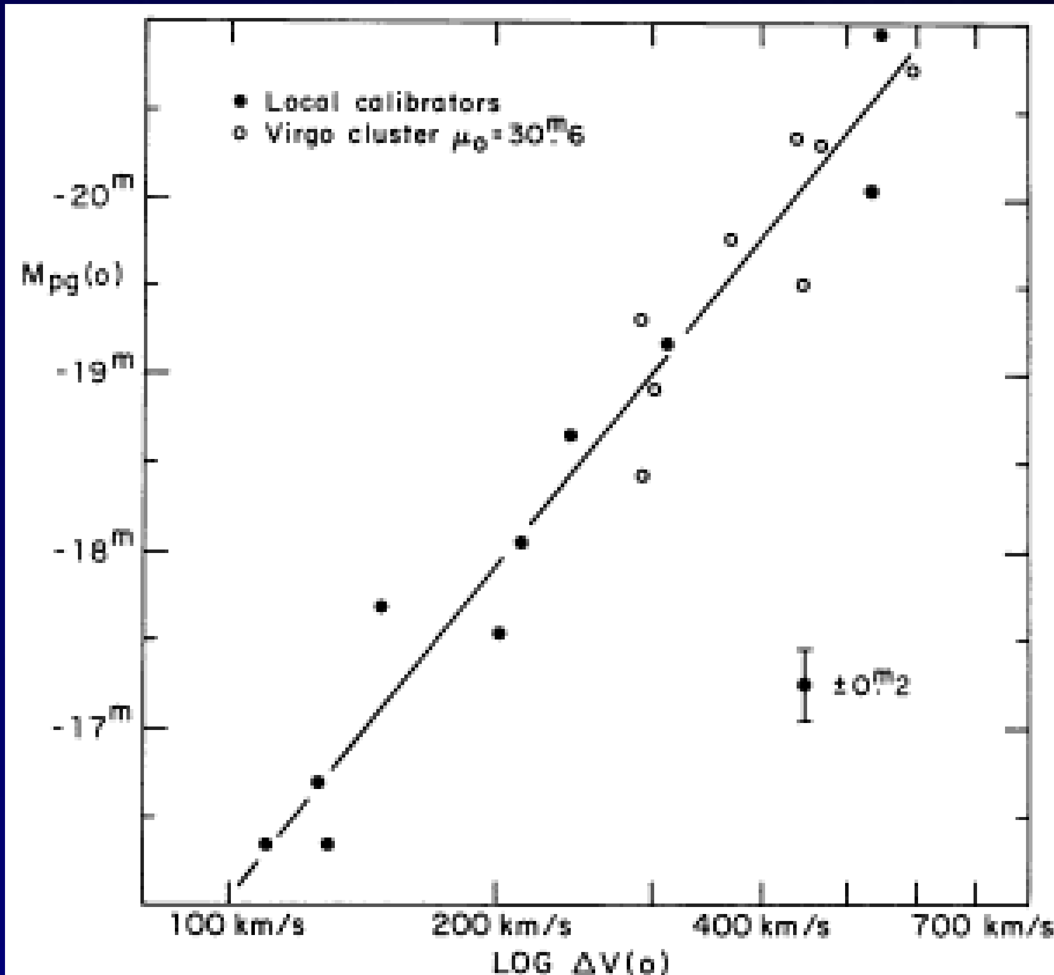




Tully & Fisher, 1977, A&A 54, 661

http://burro.astr.cwru.edu

Tully-Fisher relation



$$L \sim \frac{V^4}{\Sigma (M/L)^2}$$

if: $\Sigma (M/L)^2 = \text{constant}$

$L \sim V^4$ since $M \sim -2.5 \log L$

$M \sim -10 \log v$

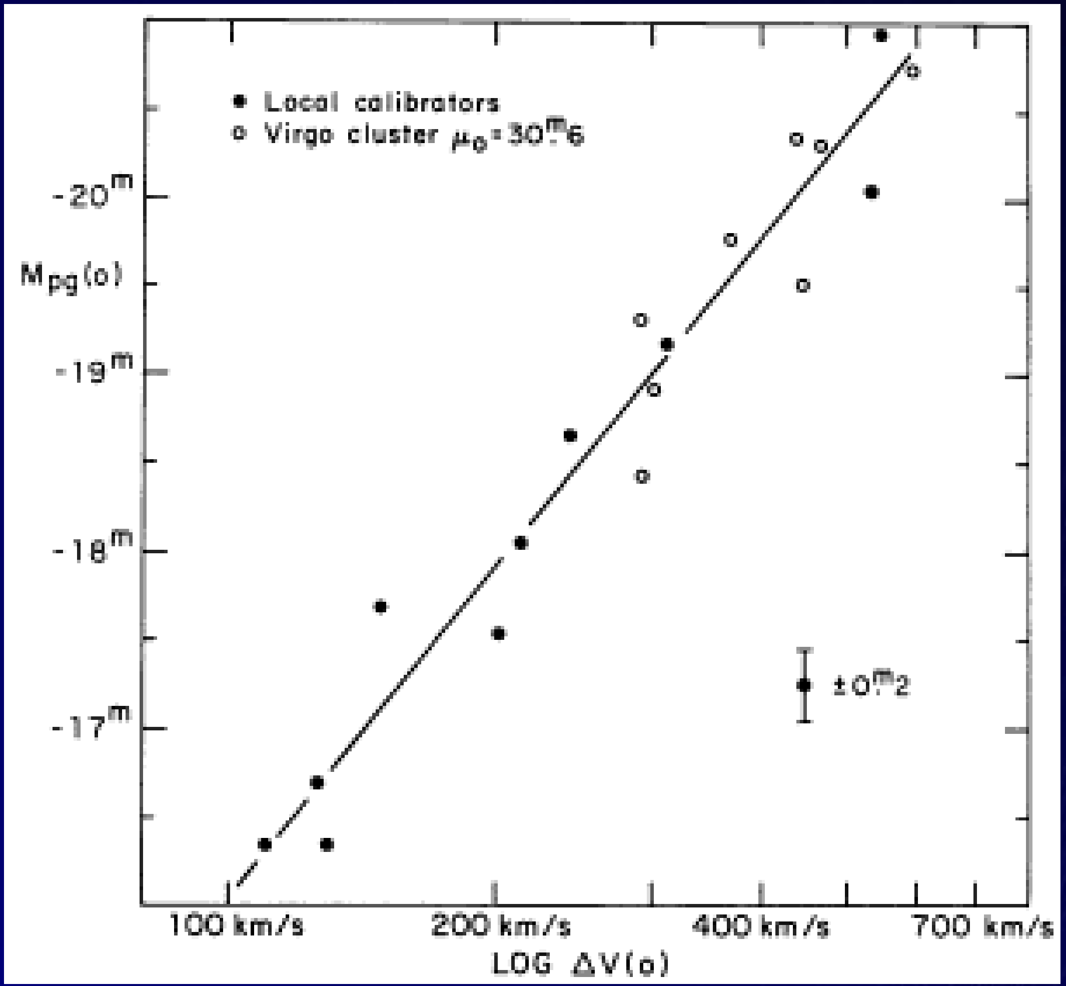
↑ mag, not mass

- is it reasonable that $\Sigma \sim$ constant?
- is it reasonable that $(M/L) \sim$ constant?
- is it reasonable that $\Sigma (M/L)^2 \sim$ const?

Tully & Fisher, 1977, A&A 54, 661

http://burro.astr.cwru.edu

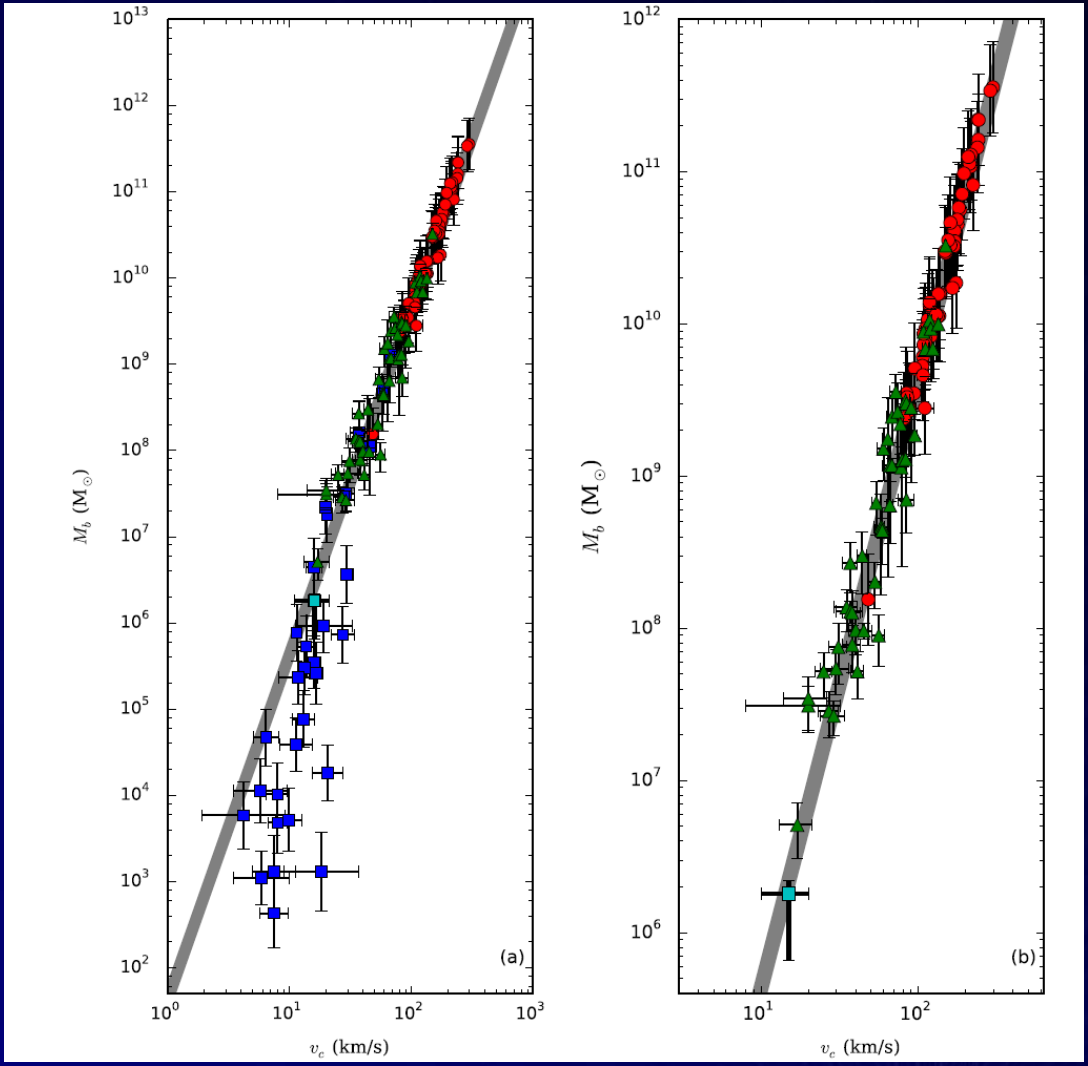
Tully-Fisher relation



Tully & Fisher, 1977, A&A 54, 661

- Observe the HI 21 cm emission profile:
  - Measure V_{obs}
  - Measure W_{obs} (width of 21 cm profile)
- Obtain an image of the galaxy
  - Measure total brightness (apparent magnitude m)
  - Measure the apparent axial ratio b/a
- Make lots of corrections to get rotational velocity and absolute magnitude
- Use TFR to get distance

The Baryonic Tully-Fisher Relation

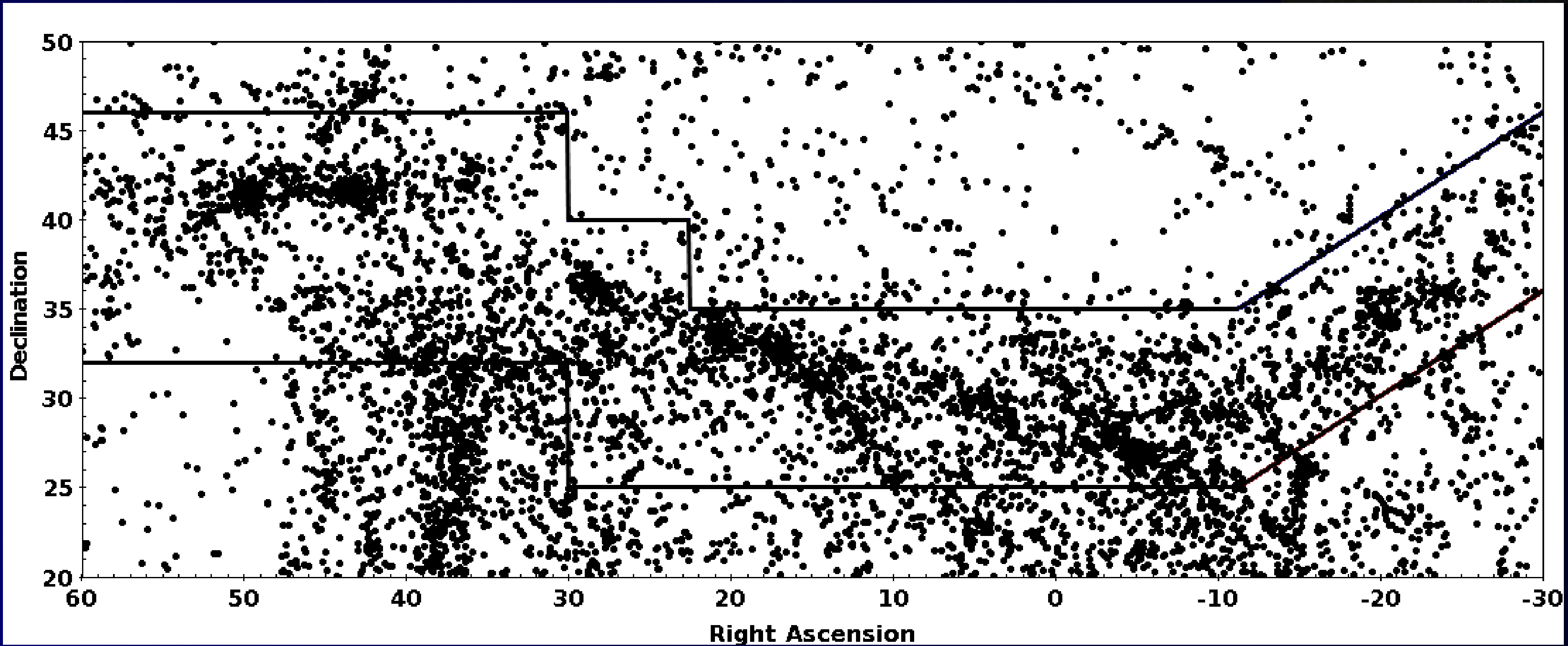


Bernstein-Cooper, Cannon et al 2014 AJ 148, 35

- Recent works substitute stellar mass for absolute magnitude.
- For star-forming galaxies of stellar masses below 10^9 $M_\odot$ the HI mass exceeds the stellar mass.
- Define the baryonic mass as the sum of the stellar and HI masses.

Note: some authors correct for He or H_2 abundance; watch definition!

The Pisces-Perseus Supercluster



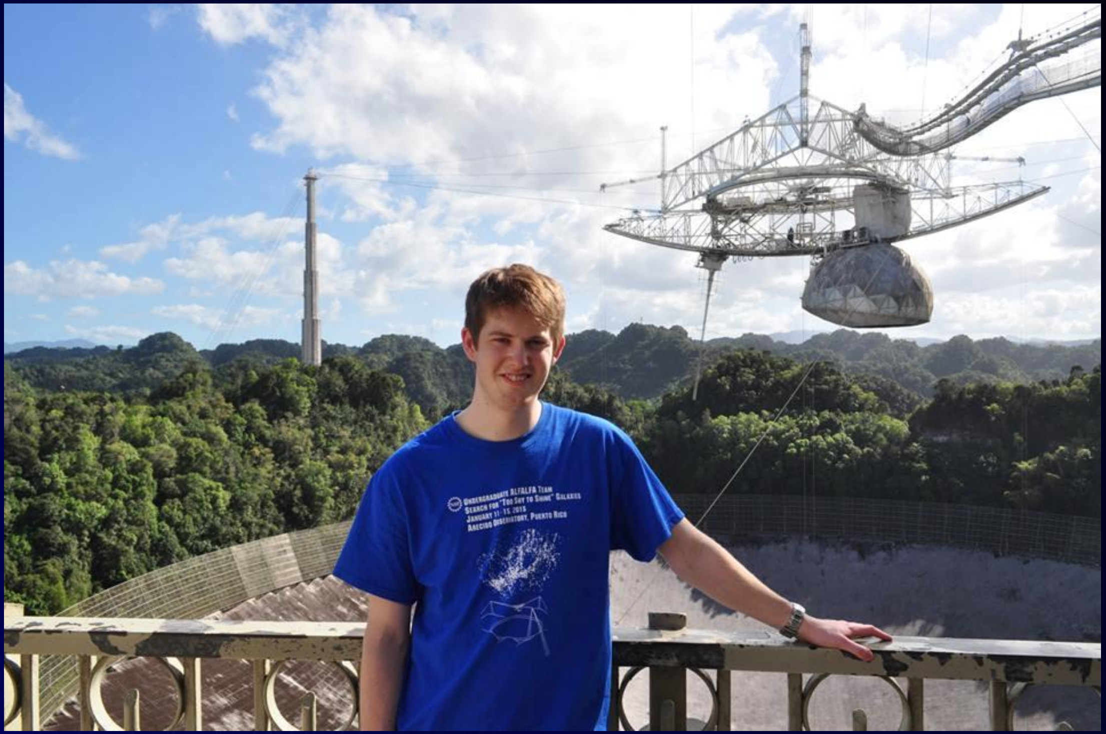
See SH#1

The Arecibo Pisces-Perseus Supercluster Survey

- Aims to measure the infall/backflow into PPS using the BTFR

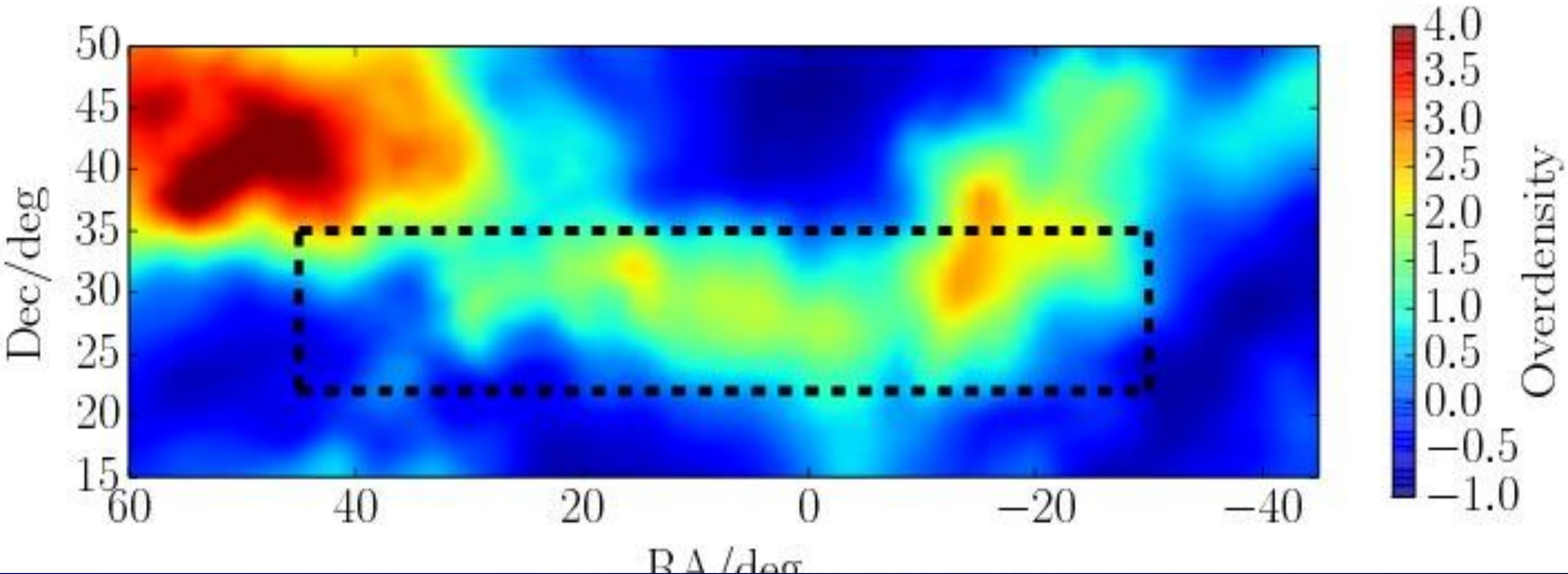
- In addition to ALFALFA, more galaxies!

- Mike Jones (almost) PhD



The Arecibo Pisces-Perseus Supercluster Survey

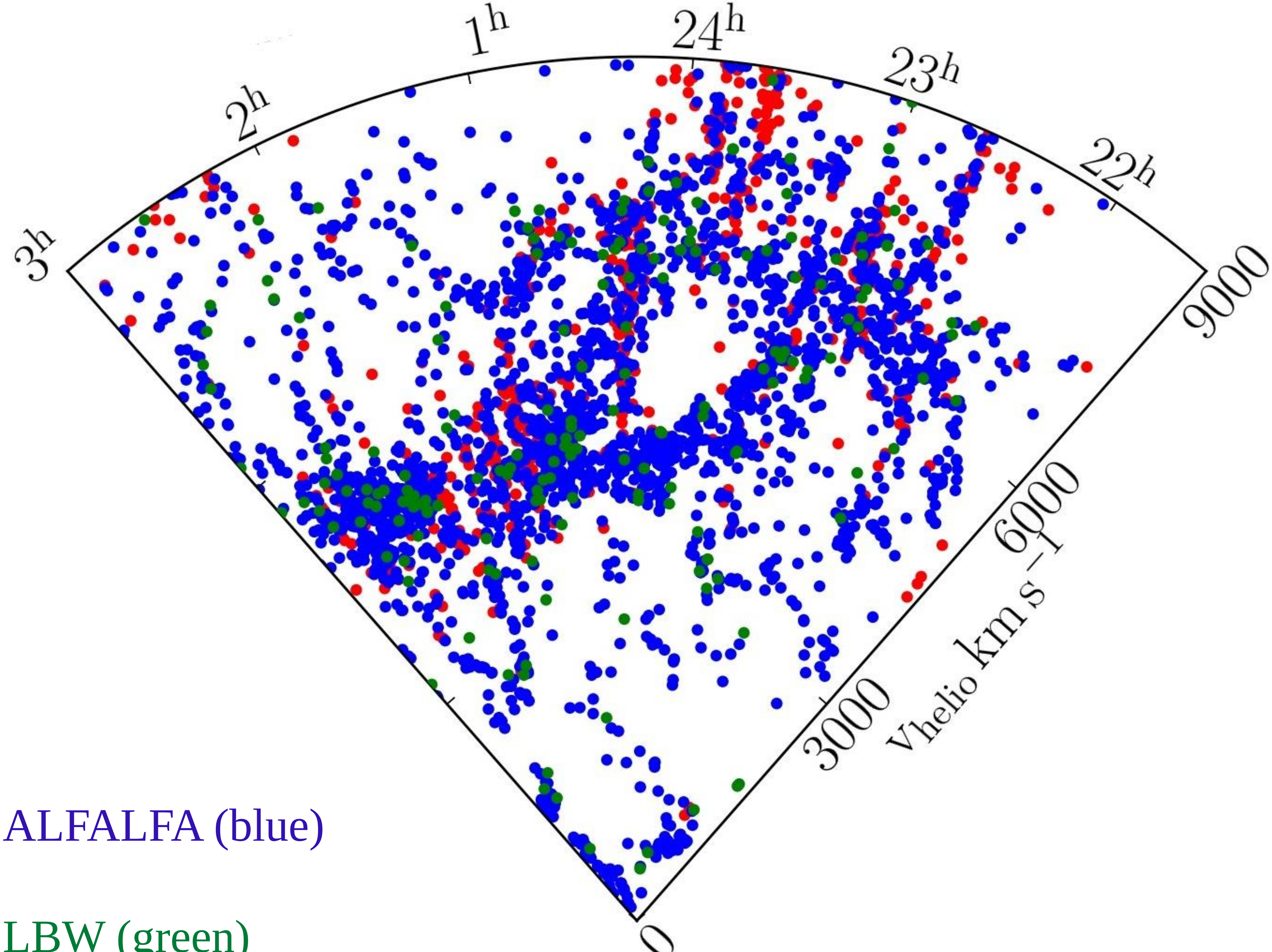
The APPS survey or the APPSS



Mean overdensity over the v_{Helio} range (4000,8000) produced by interpolating between 2MRS overdensity map points (Erdogdu+ 2006)

The black dotted rectangle outlines our target area:
22h < RA < 3h and +23 < Dec < +35

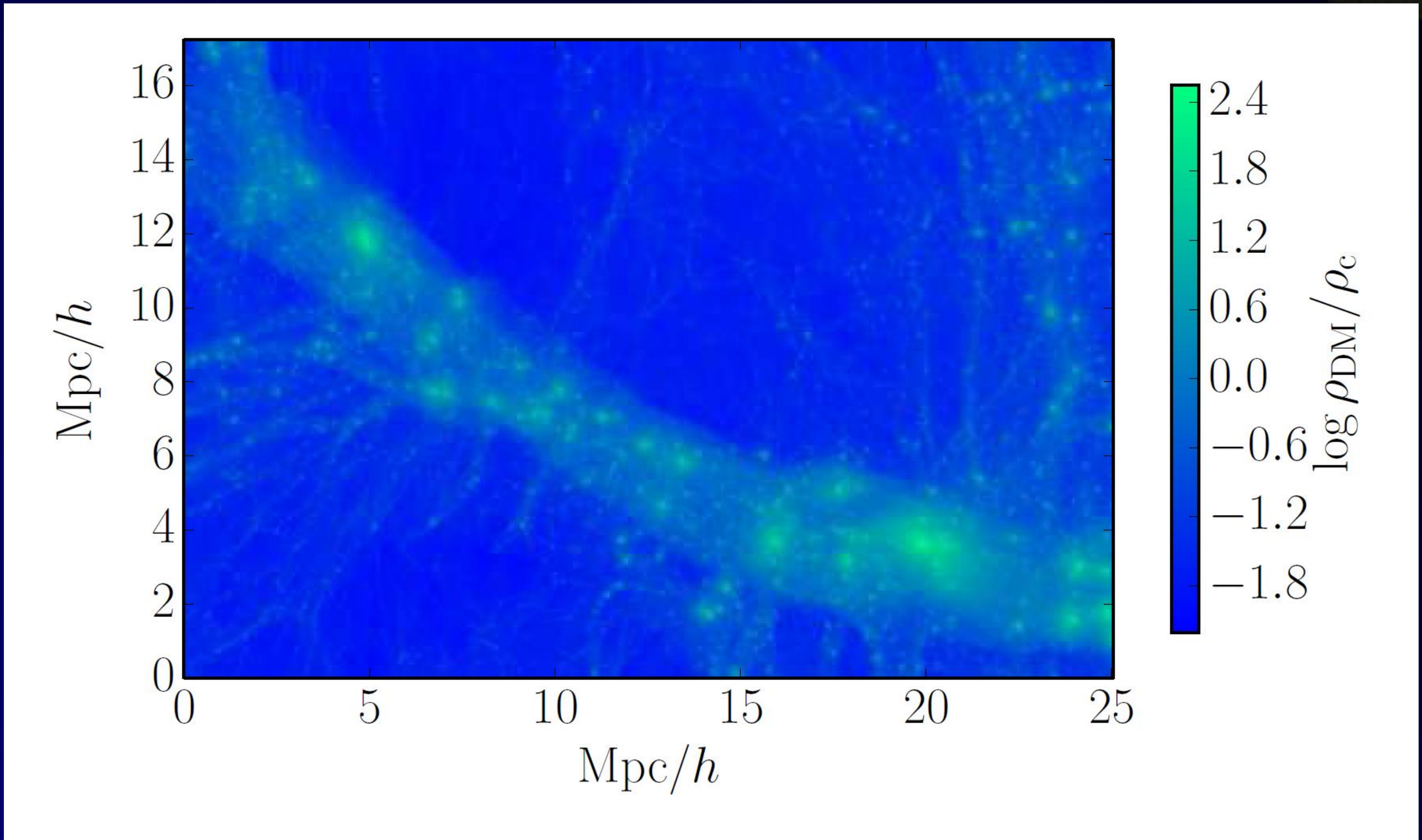
ALFALFA



ALFALFA (blue)

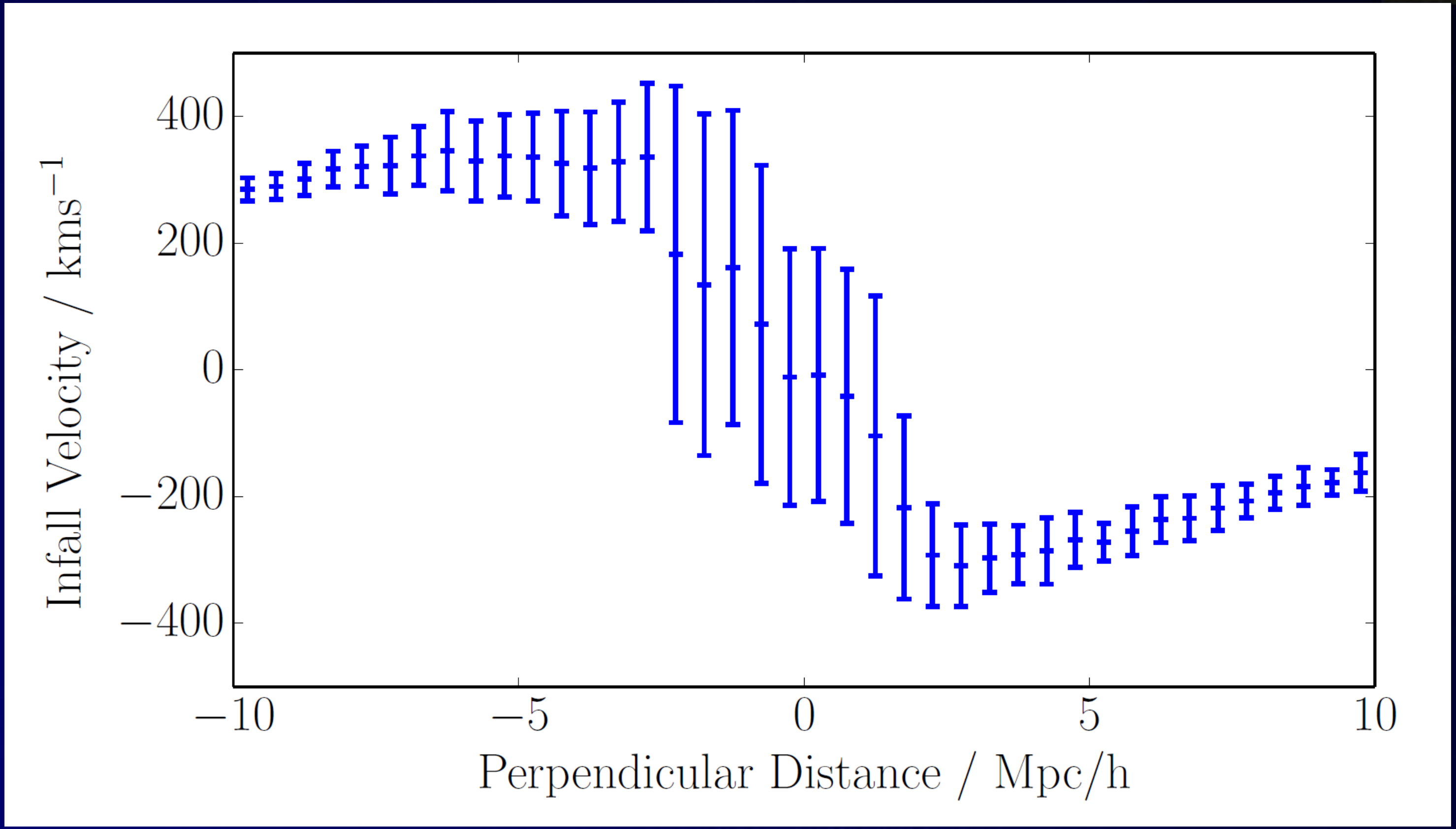
LBW (green)

Filaments in the Illustris Simulation



Here is an example of a filament in the Illustris simulation

Filaments in the Illustris Simulation



Here is the expected infall and backflow around that filament.

APPSS Survey Objective

- Measure BTFR distances and peculiar velocities to a large sample of galaxies in the PPS
- Look for infall and backflow onto the PPS overdensity
- Measure the mass per unit length of the supercluster.
- Compare the result to the predictions of numerical simulations.

Measuring Infall onto PPS

- Peculiar velocity measurements are tricky because of all the corrections that have to be made.
- The uncertainty in the BTFR distance on an individual galaxy is probably 25-30%. For a distance of 5000 km/s, that is a velocity error of > 1000 km/s!
- We need to be able to average/bin galaxies to reduce the uncertainty.
- We need more galaxies with BTFR distances!
- Comparison with simulations will allow us to place limits on the results, in the presence of uncertainty, sample bias, and statistics.

APPSS LBW proposal

- Explore fainter SDSS/GALEX objects which are very blue and have sample range of AbsMag, r_d, SB => are they in the volume or not?
  - Identify PPS targets meeting SDSS spectroscopic sample and blue (NUV-r), but not in a.70
  - Conduct LBW survey of these targets
    - Measure HI flux densities, recessional velocities and velocity widths
  - Measure magnitudes and axial ratios of detections
    - Calculate stellar masses and inclinations
    - Calculate baryonic masses (stars+gas)
    - Calculate rotational velocities (corrected for inclination)

- Explore dependence of HIMF/WF across range of environments sampled
- Using BTFR to measure infall onto PPS ridge

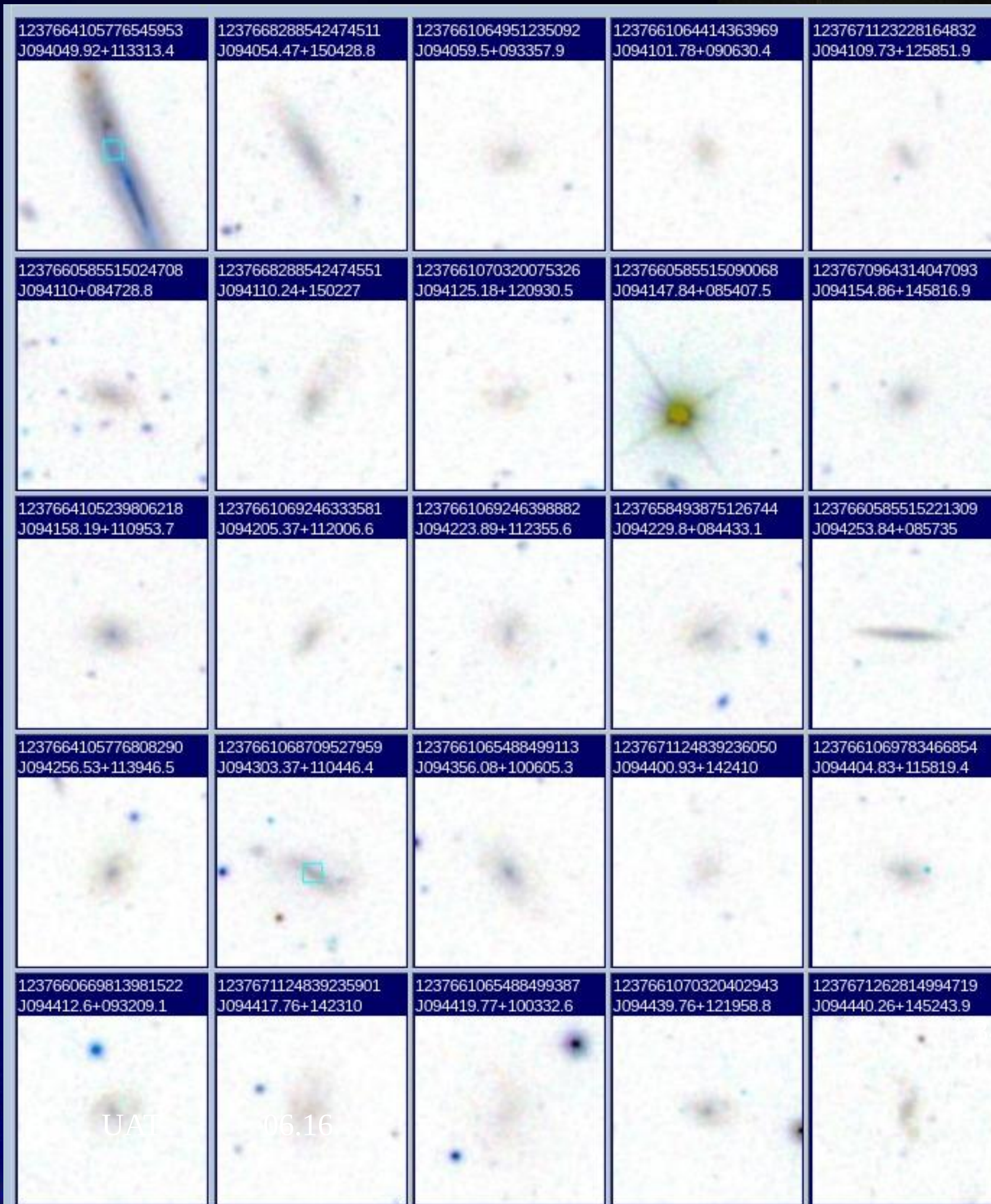
Culling blue SF galaxies in the SDSS

```
Query 19
SELECT
  p.objid, p.ra, p.dec,
  p.cModelMag_u,p.cModelMag_g,p.cModelMag_r,p.cModelMag_i,p.cModelMag_z,
  p.petroMag_r, p.petroR50_r, p.petroR90_r,
  p.expRad_g, p.expRad_r,expRad_i,p.expAB_g,p.expAB_r,p.expAB_i,
  p.fracDeV_g,p.fracDeV_r,p.fracDev_i,
  p.extinction_g, p.extinction_r, p.extinction_i,
  p.lnLDeV_r,p.type
FROM PhotoPrimary as p
WHERE
  p.ra >= 140 AND p.ra <= 175  AND
  p.dec >= 8 AND p.dec <=16 AND
  p.cModelMag_r > 16.5 AND p.cModelMag_r < 23. AND
  p.cModelMag_i > 16.5 AND p.cModelMag_r < 23. AND
  p.fracDeV_r < 0.8 AND
  p.cModelMag_r < 21.0 AND p.cModelMag_r > 17.5 AND
  (p.cModelMag_g - p.cModelMag_i) < 0.6 AND
  (p.cModelMag_g - p.cModelMag_i) > -0.5 AND
  p.expRad_g > 3 AND p.expRad_r > 3 AND p.expRad_i > 3 AND
  p.petroR50_r > 3 AND
  p.lnLExp_r > (13.81+p.lnLDeV_r) AND
  p.type = 3
order by p.ra
```

This is query I used; now also use GALEX FUV/NUV photom.

APPSS results

- Query returns a lot of lsb, blue galaxies but also bogus objects.
- Further refinement GALEX+examination to pick best targets
- Our LBW observtions show than in fact, many of these objects are actually in target redshift range!
- More observations coming (we hope!)



The Arecibo Pisces-Perseus Supercluster Survey

The APPS survey or the APPSS