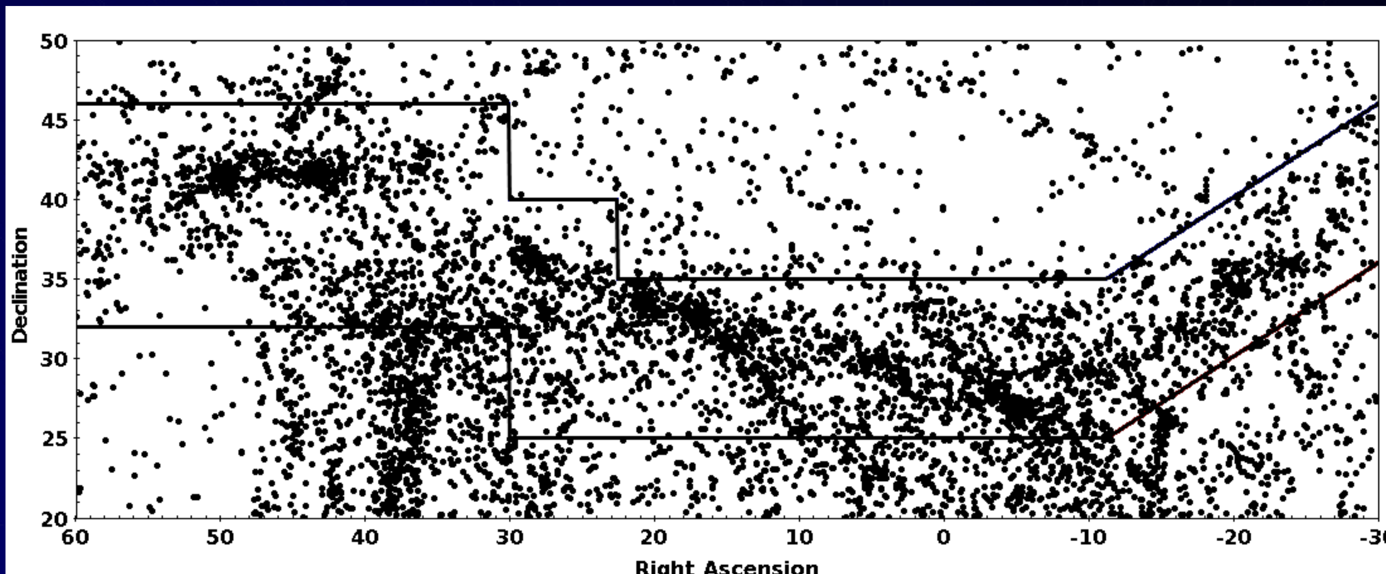
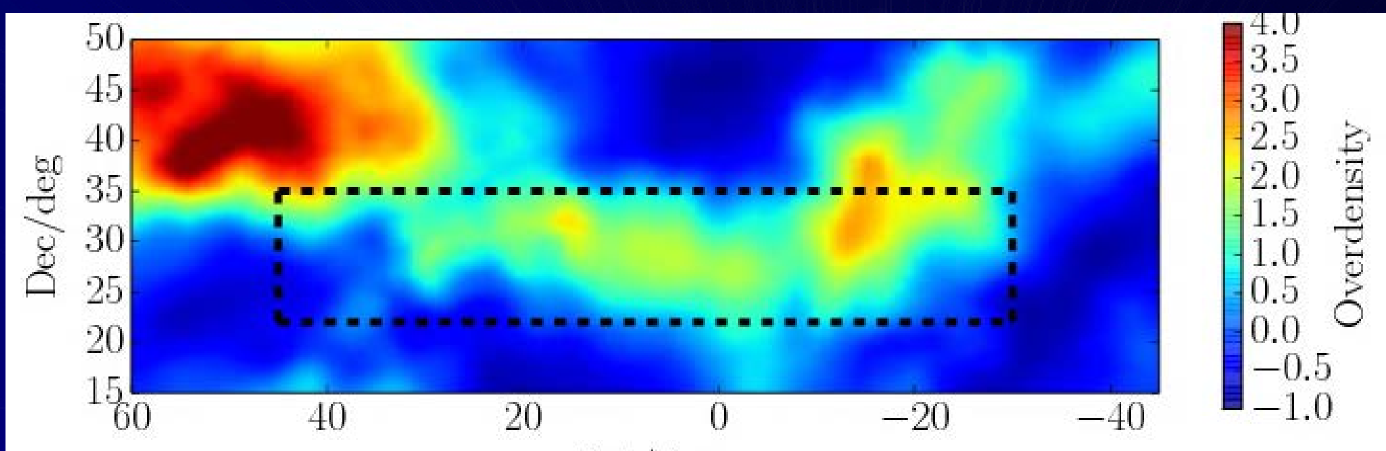
The Arecibo Pisces-Perseus Supercluster Survey





June 2018

Martha Haynes

Cornell University

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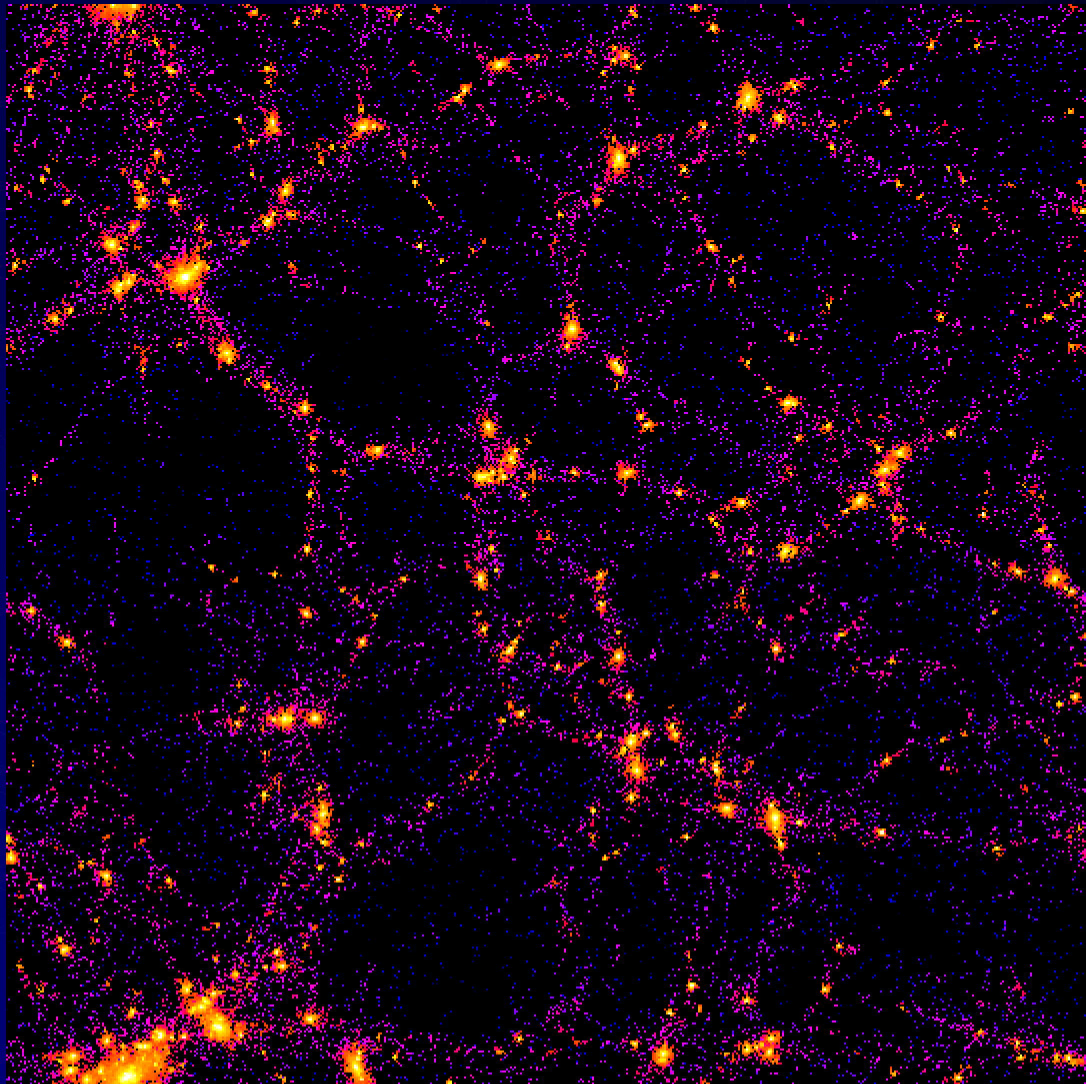
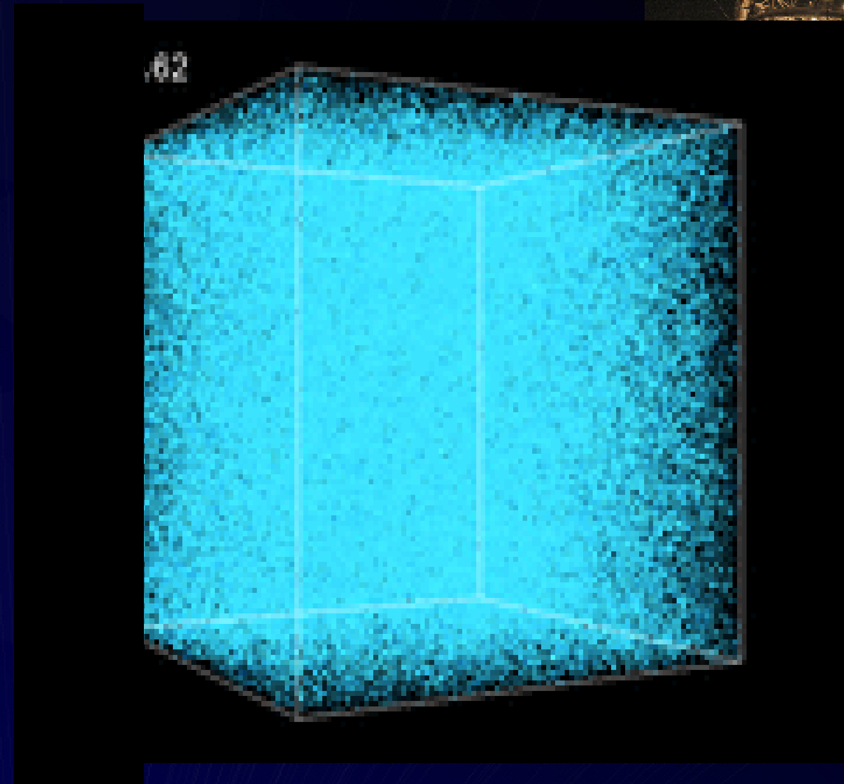
Large scale structure in the Universe

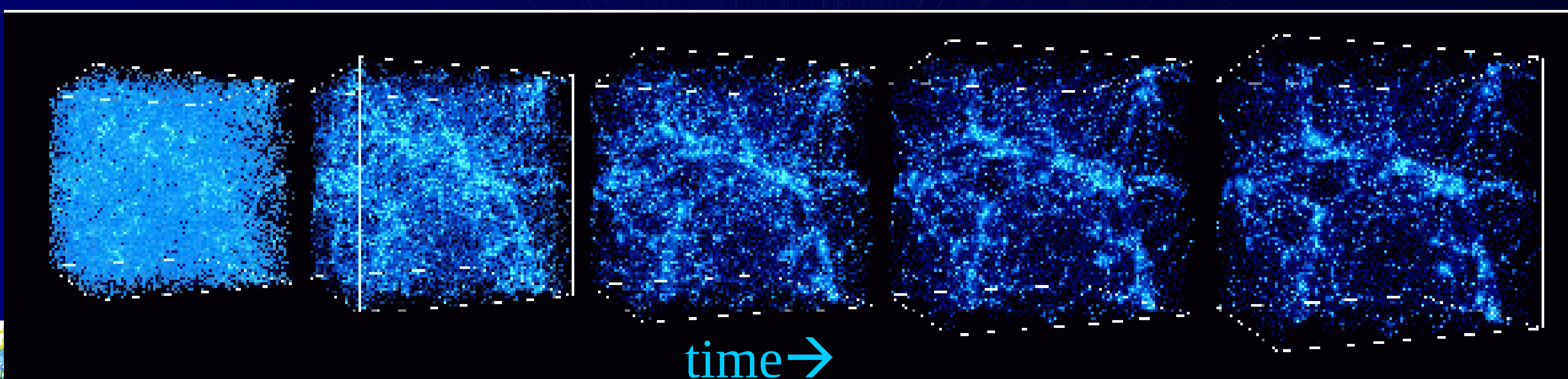


- Galaxies cluster into groups, clusters and superclusters
- Galaxies avoid voids.
- The distribution of matter is not homogeneous.

Large scale structure

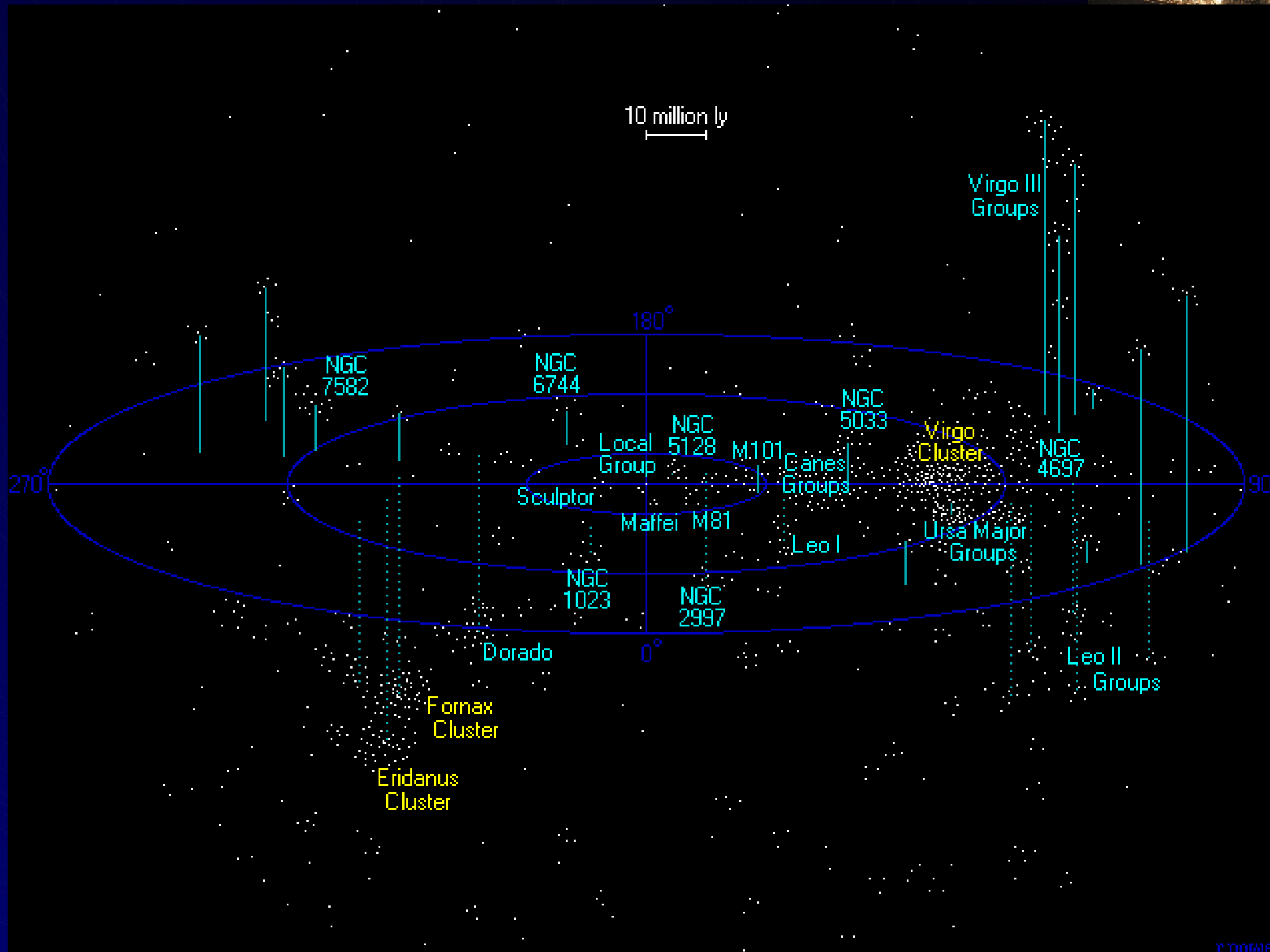
- How did the structures we see today form and evolve?
- Do our cosmological models predict this behavior?
- Can they give us any insight into how and why this structure develops?





Large scale structure < 50 Mlyr

The Local Group is NOT at the center (except to us).



Atlas of the Universe

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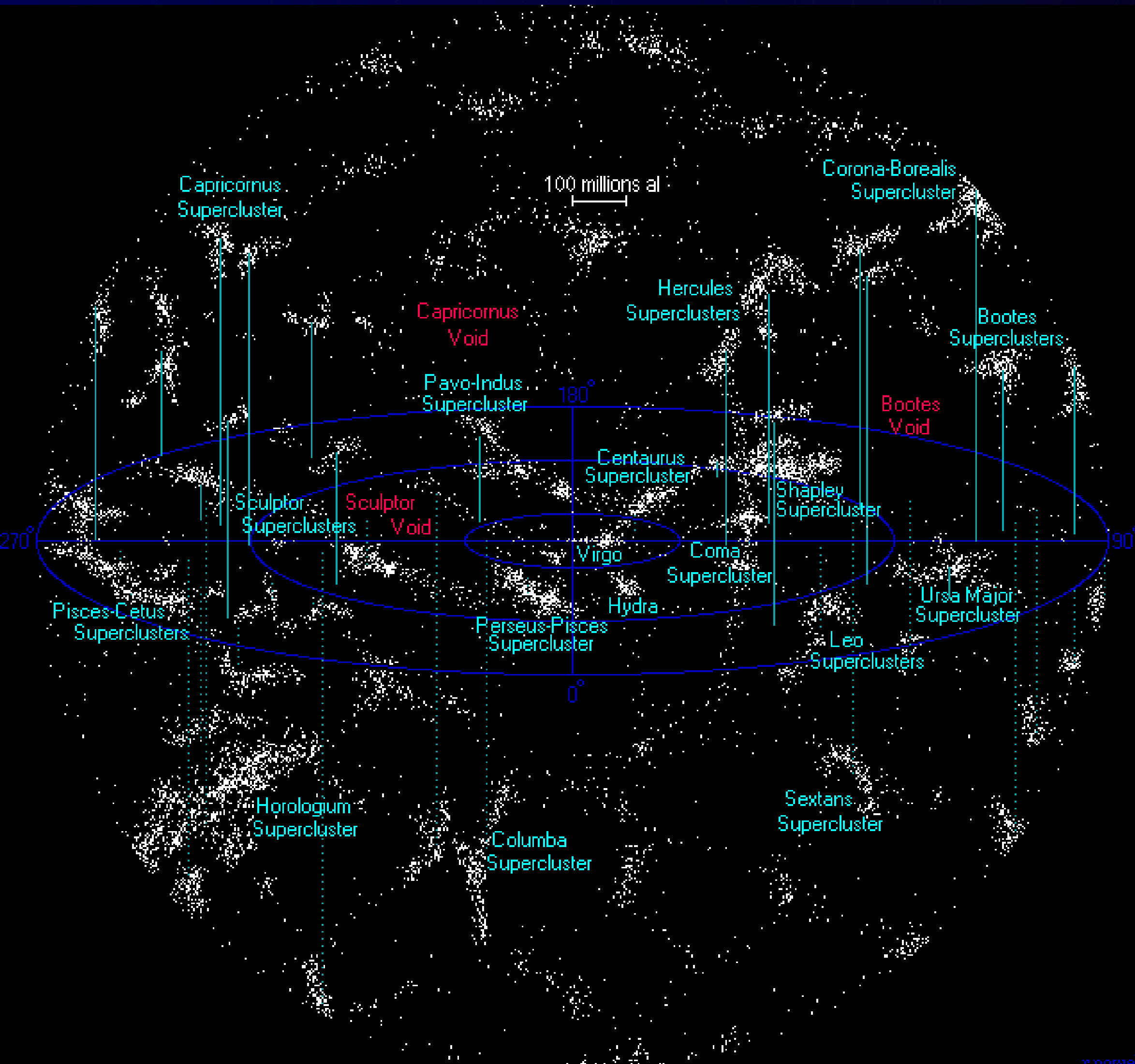
Large scale structure < 1 Glyr



Pisces-Perseus Supercluster

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

Atlas of the Universe

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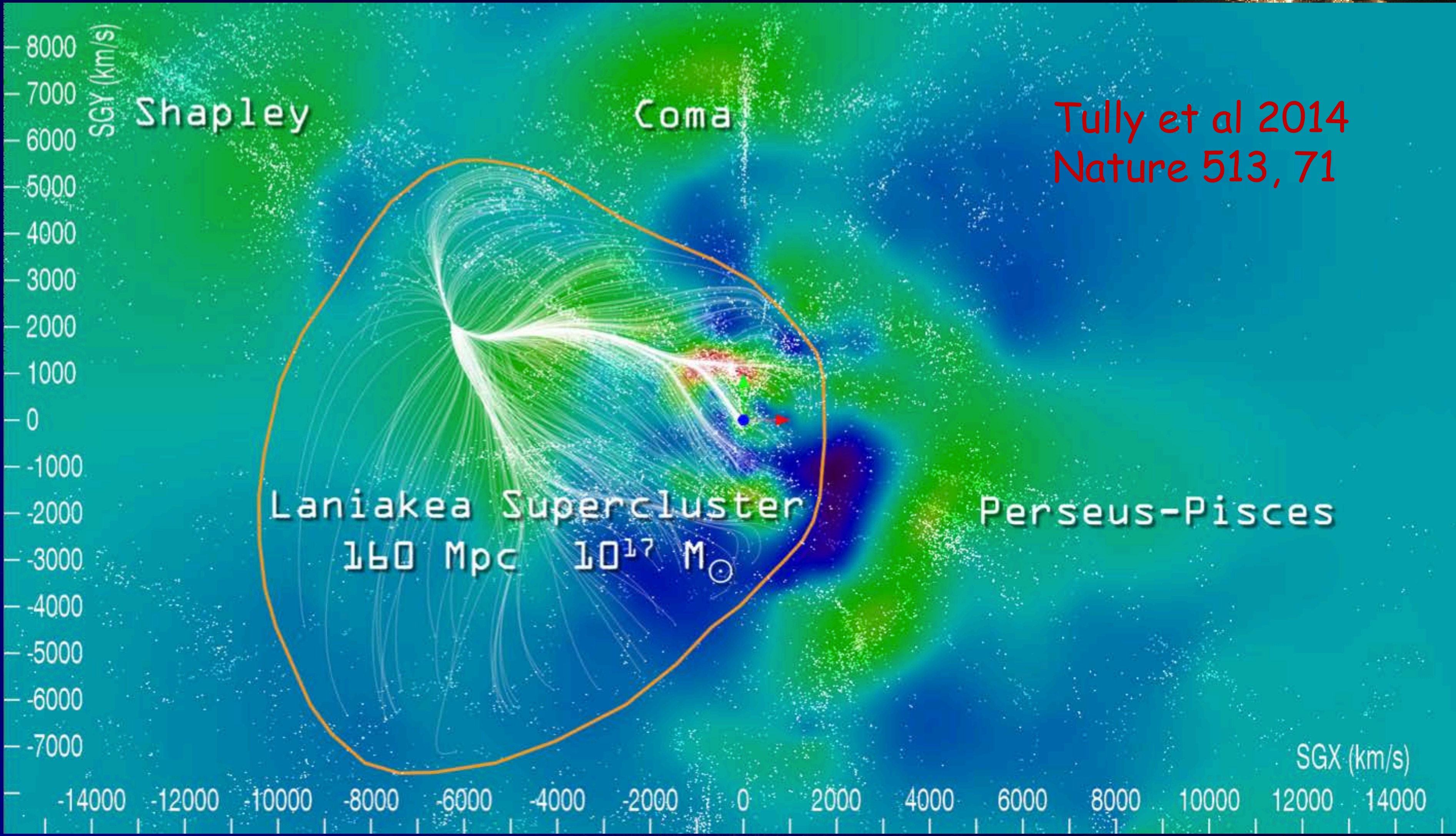
The Pisces-Perseus Supercluster



Tully *et al* 2014 Nature

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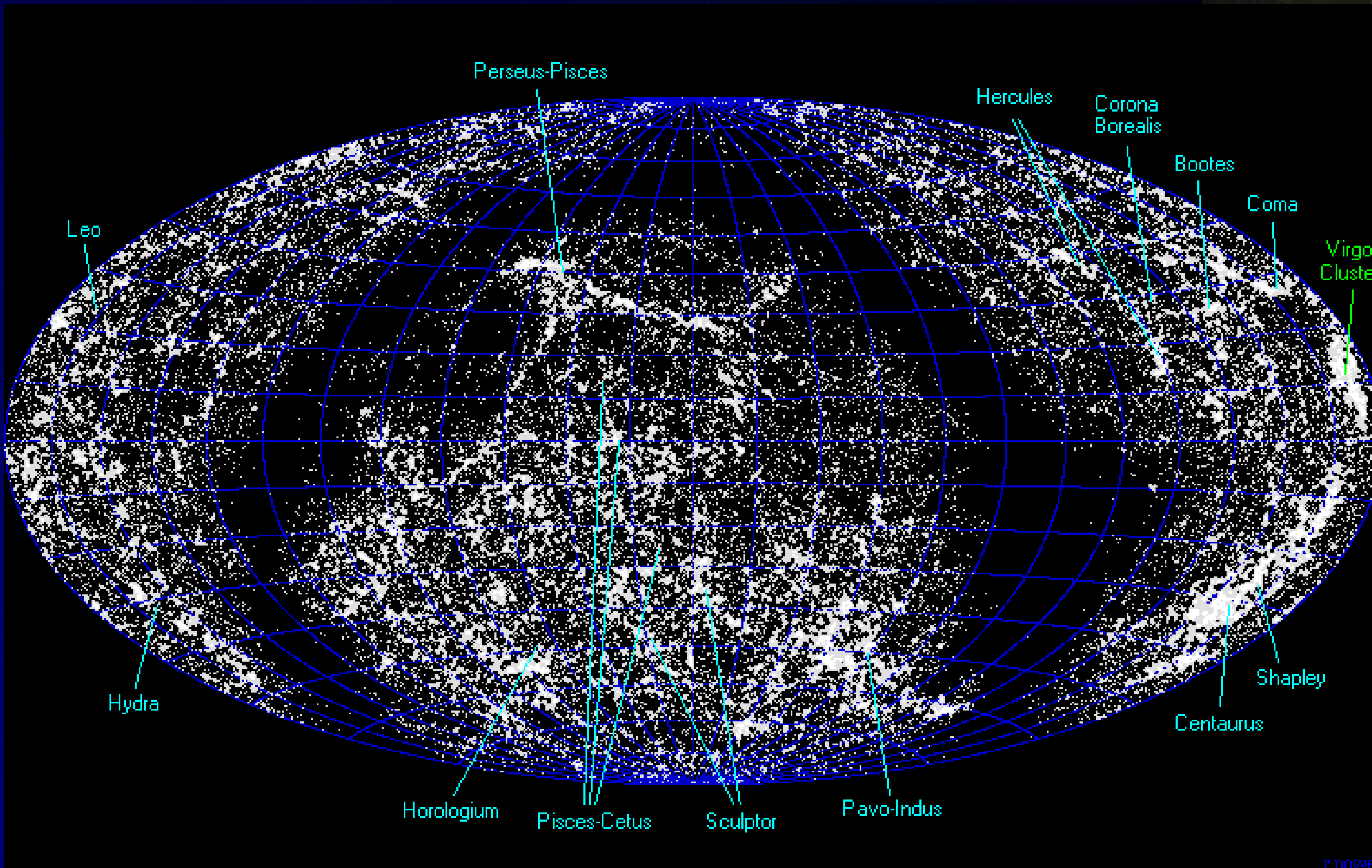
The Pisces-Perseus Supercluster



Atlas of the Universe

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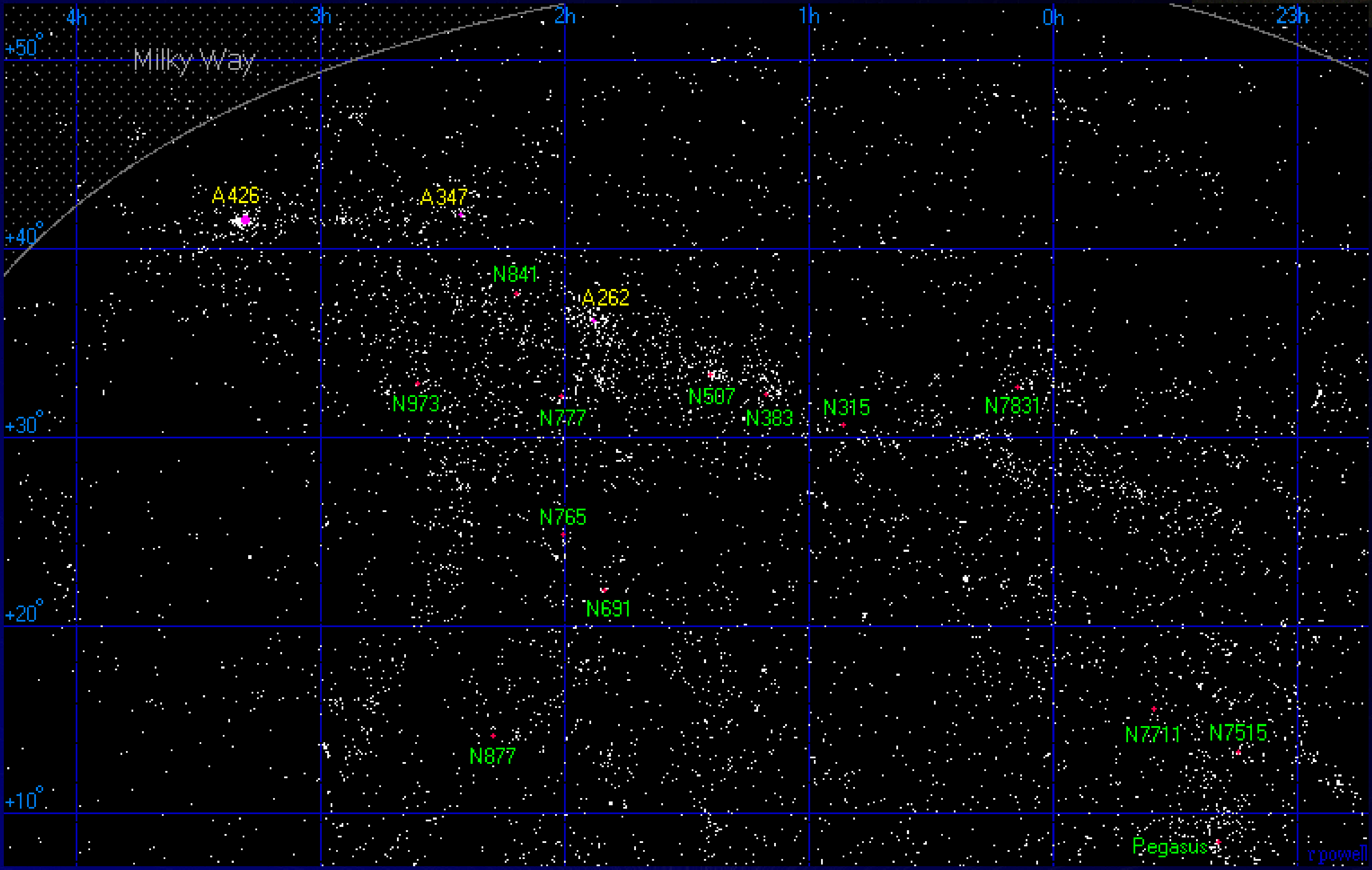
The Pisces-Perseus Supercluster



Atlas of the Universe

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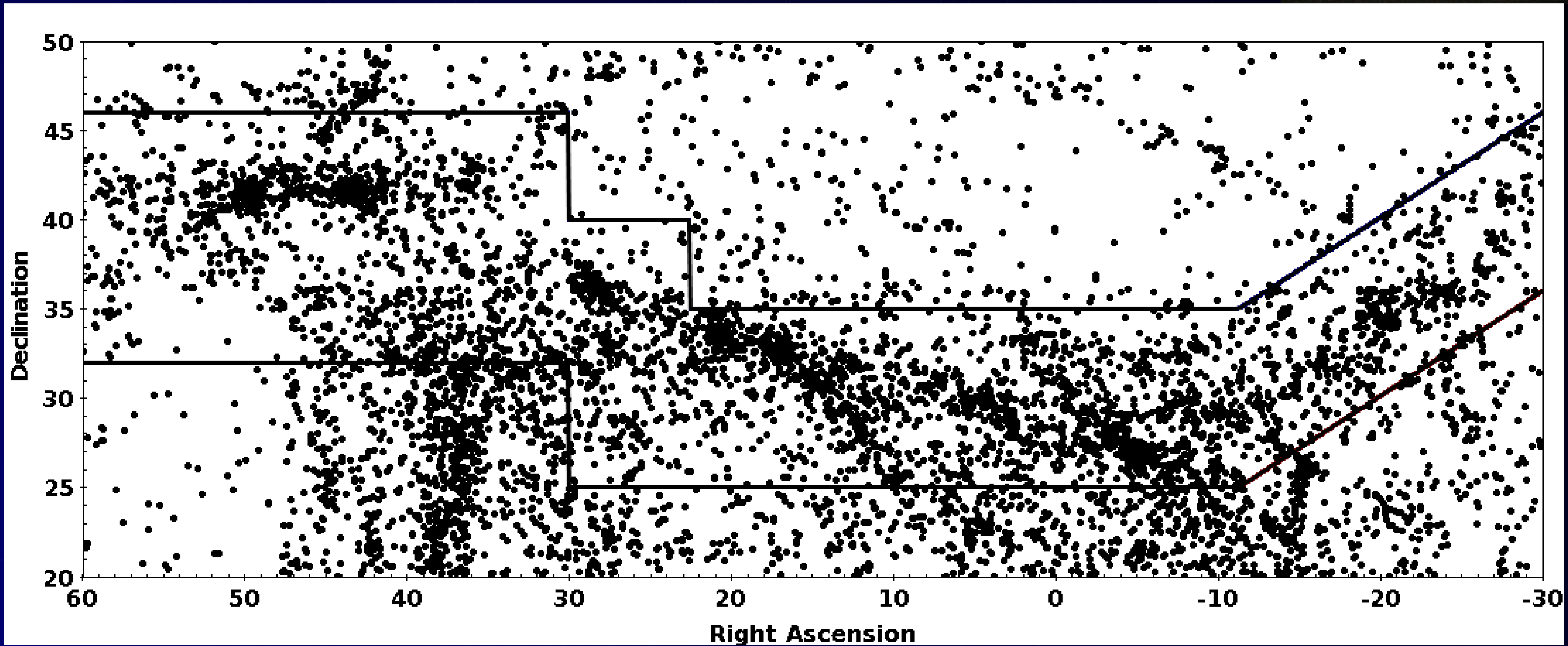
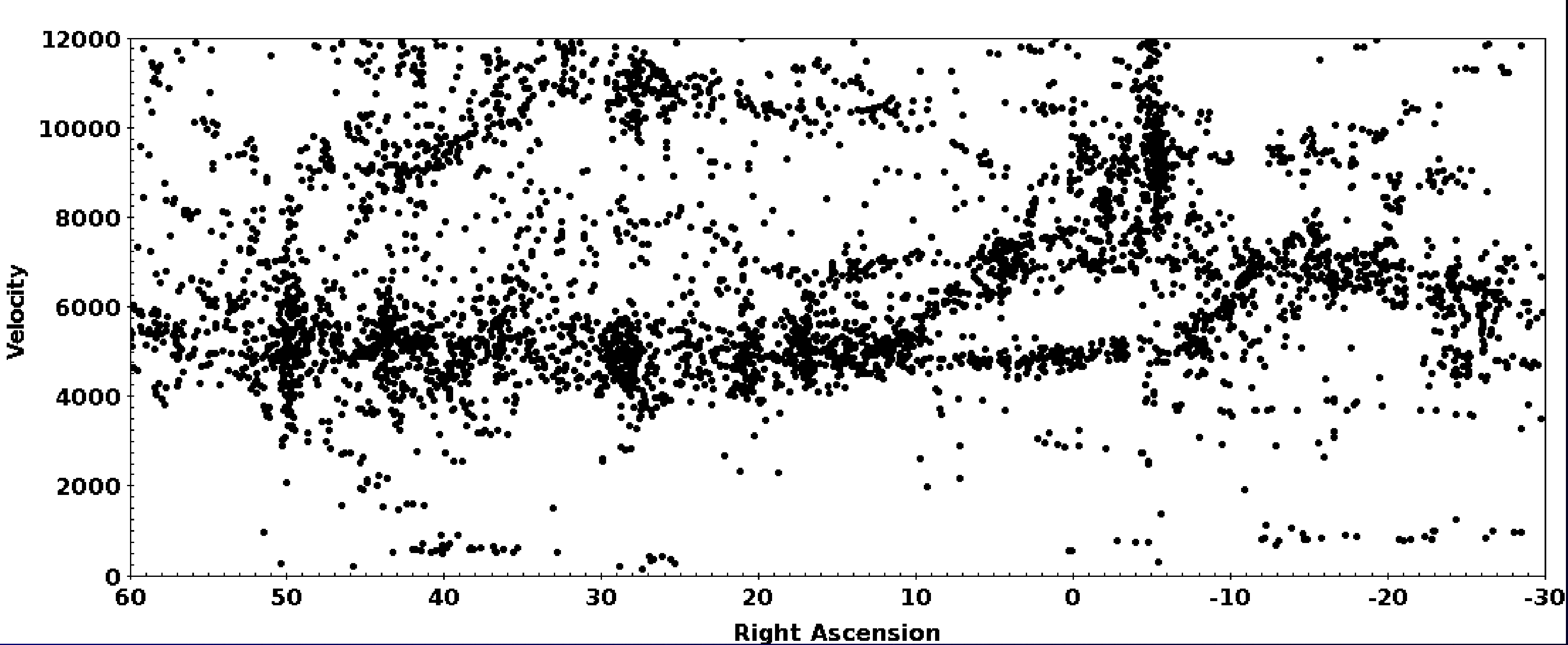
The Pisces-Perseus Supercluster



- Each black dot represents a galaxy with a measured redshift of cz < 12000 km/s
- The black lines define the region of the "main ridge" of the PPS.

The Pisces-Perseus Supercluster



- Each black dot represents a galaxy with a measured redshift of cz < 12000 km/s within the main ridge.
- Notice that this representation does not reflect the strong distance dependence of volume.

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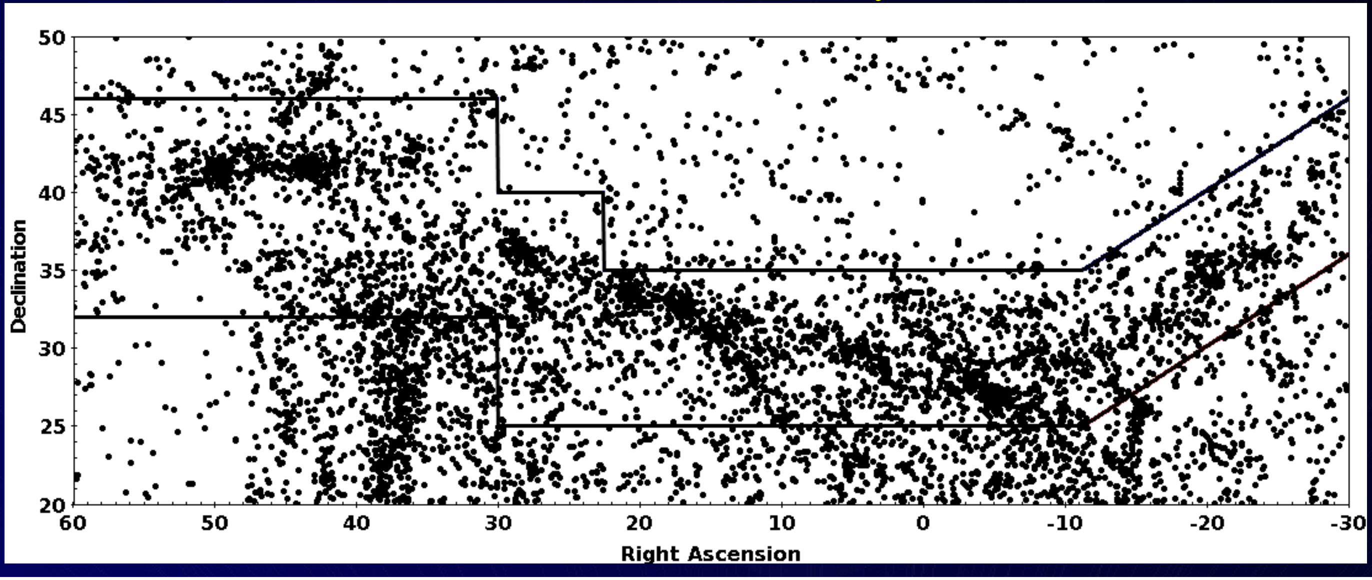
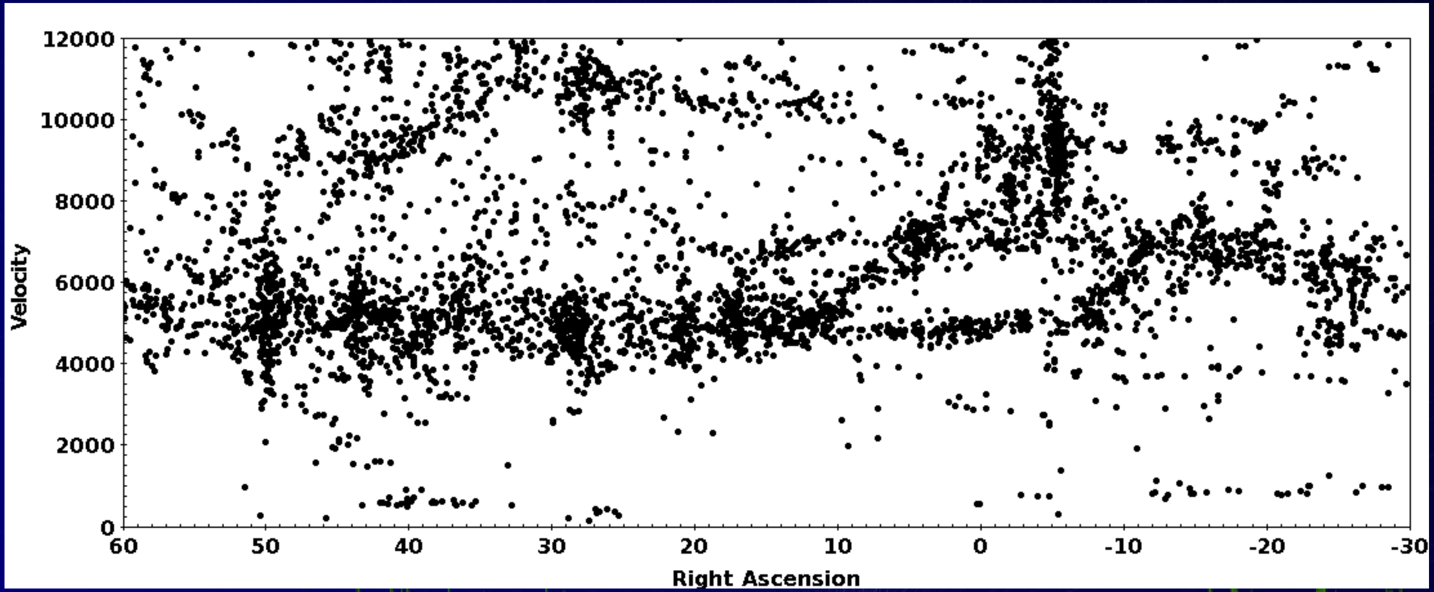
The Pisces-Perseus Supercluster





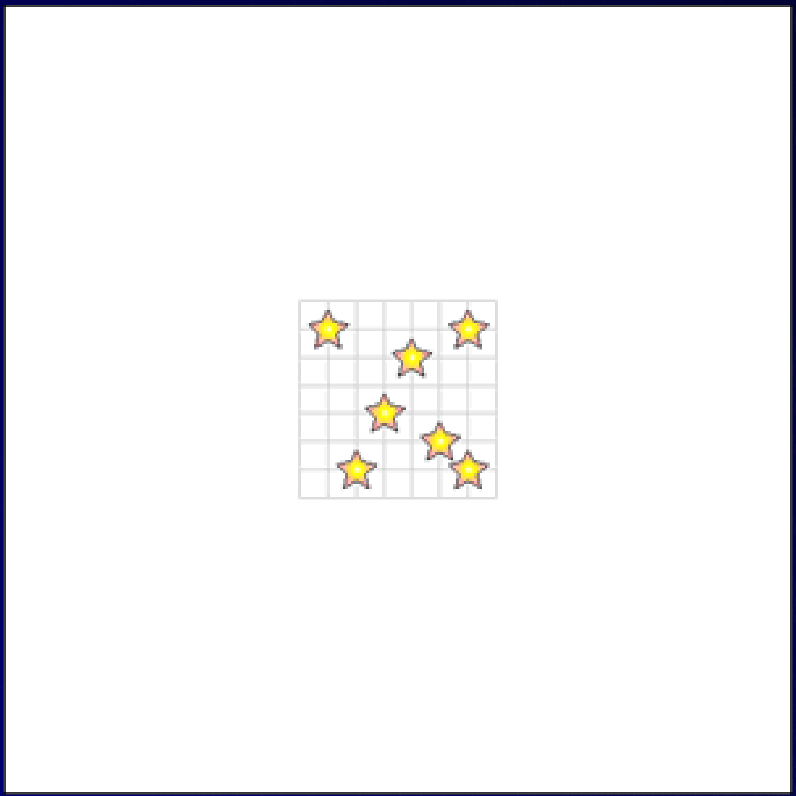
PPS is a relatively linear structure oriented almost perpendicular to the line of sight.

"filament"

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.

Smooth Hubble Flow



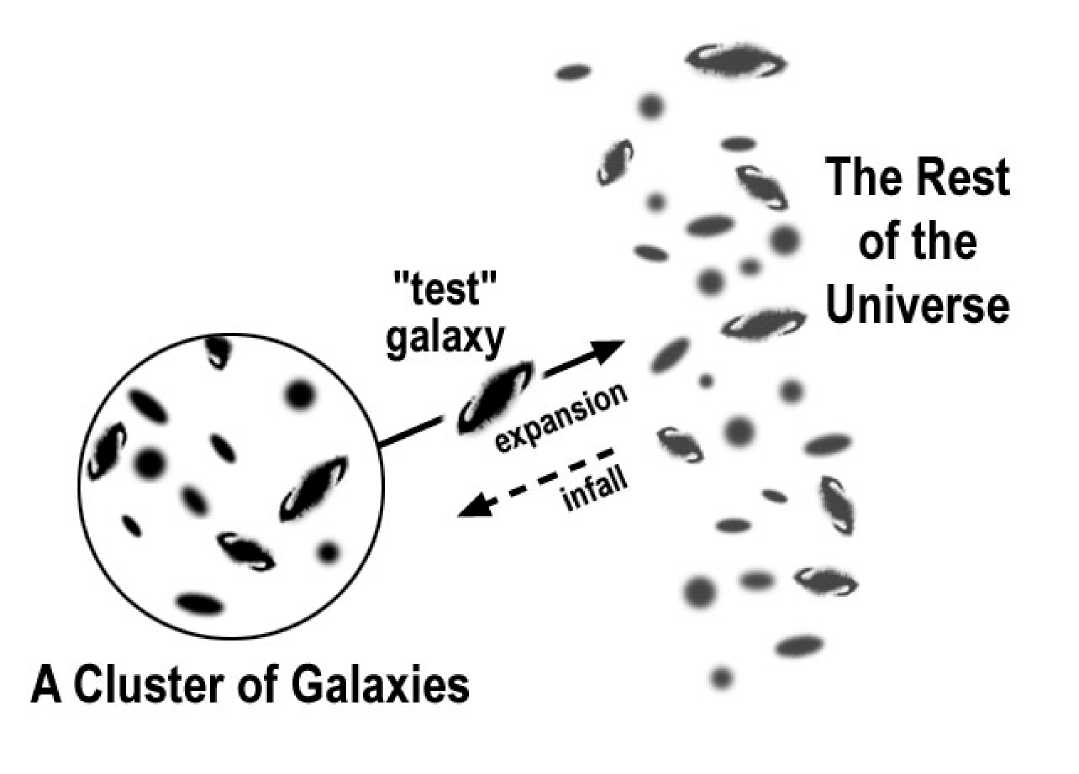
- The dominant motion in the universe is the smooth expansion, known as the Hubble Flow.

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

But: galaxies cluster !

Deviations from Hubble Flow

But on smaller scales, inhomogeneities in the density => perturbations in the gravity field => the velocity field.



"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

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Cluster Galaxy Motions

- Galaxies in long-lived “relaxed” clusters are gravitationally bound to the cluster and orbit its center of mass.

  https://www.youtube.com/watch?v=SKHWYi05eMs

- The orbital motions lead to the spread of galaxies in redshift space, even if they are all at (roughly) the same distance.

- We can use the orbital motions of the galaxies in a cluster to estimate the mass responsible for keeping the cluster in a stable, long-lived state.

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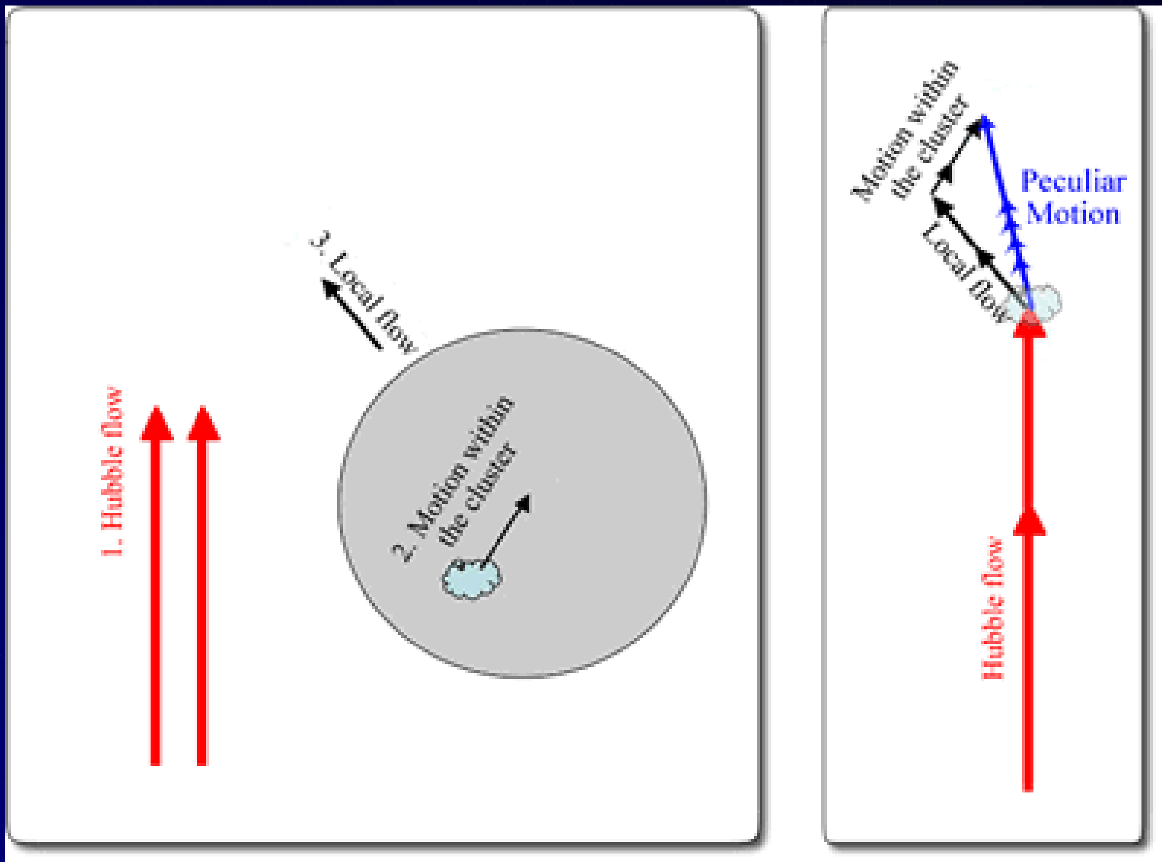
Deviations from Hubble Flow



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Trace V_{pec} ⇔ Trace mass

Tully *et al* 2014 Nature

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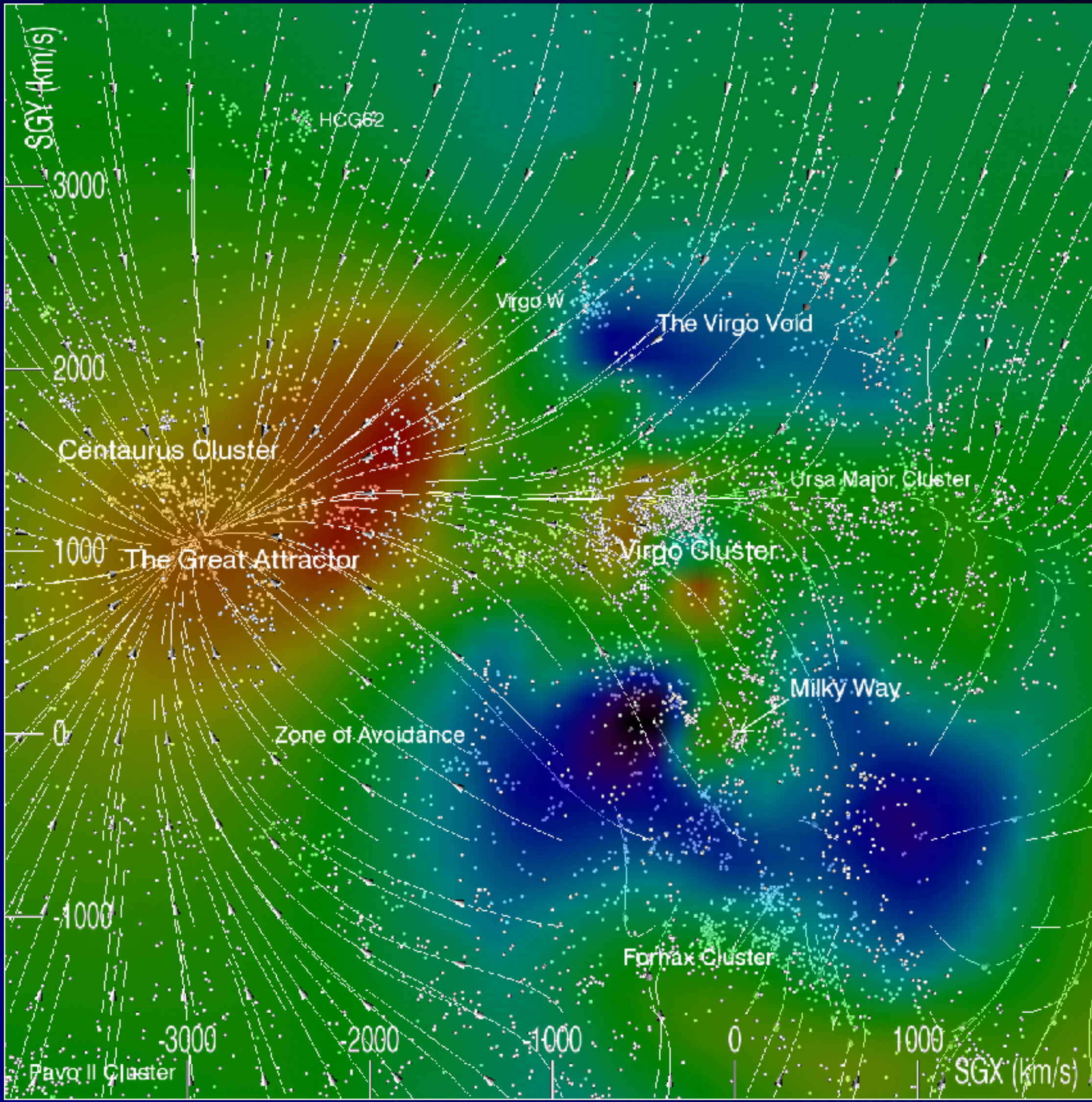
"Peculiar velocity: field => mass



<u>"Peculiar velocities"</u>

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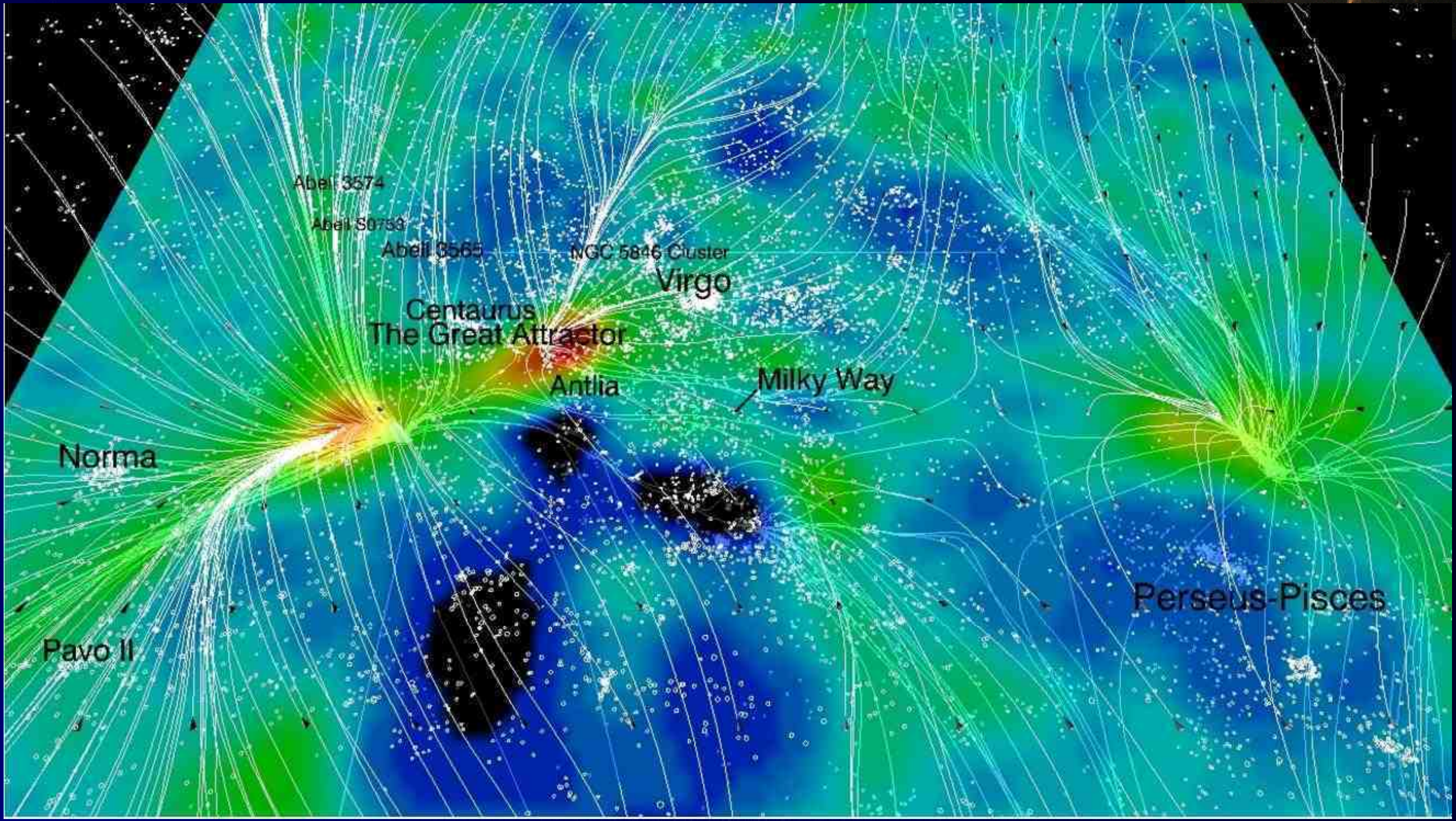
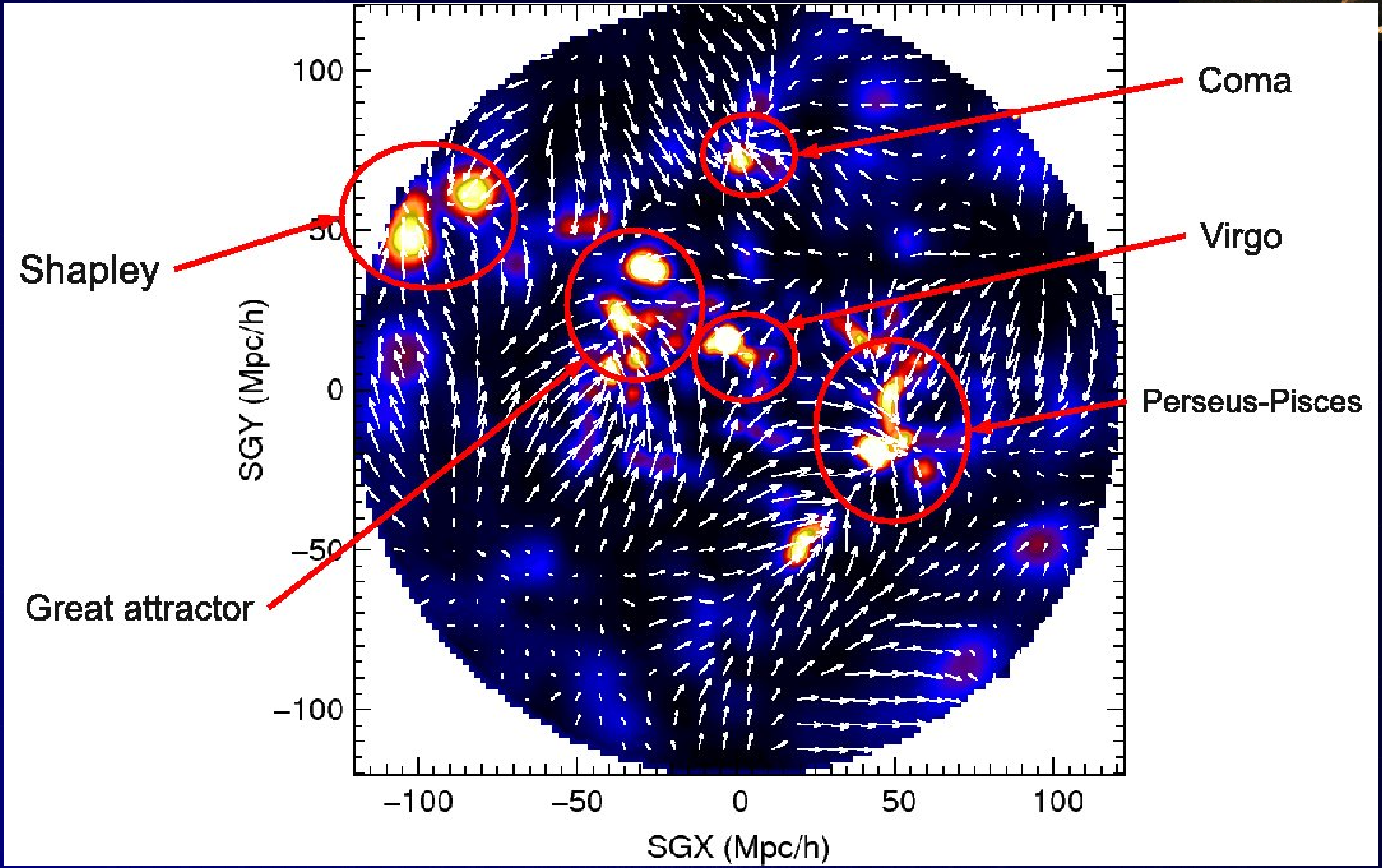
Tully *et al* 2014 Nature

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.

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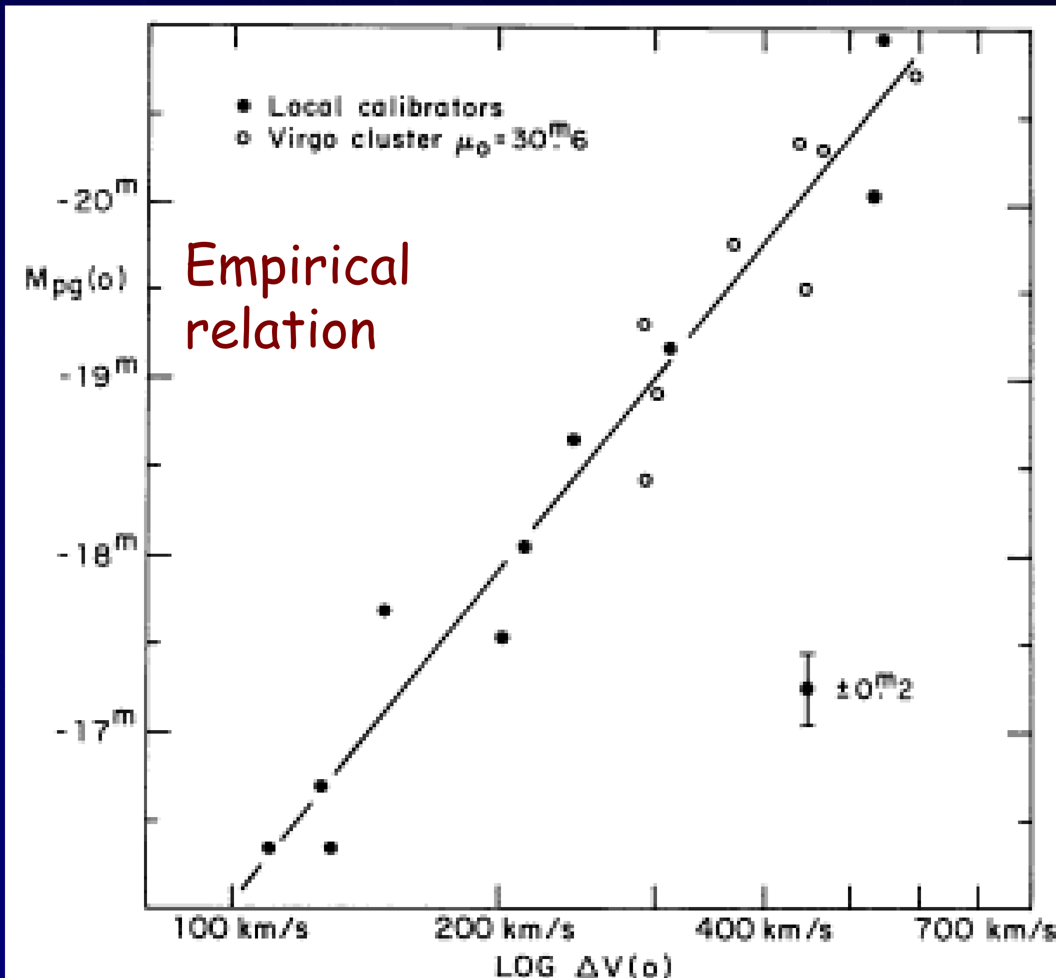
Empirical relation & physical basis?



The "Physics" of Tully-Fisher

- gravity: $V^2 = \frac{GM}{R} \Rightarrow M \sim RV^2$
- mass-to-light ratio: $M = L\left(\frac{M}{L}\right)$
- surface brightness: $\overset{\Sigma}{SB} = \frac{L}{\text{area}} \sim \frac{L}{R^2} \Rightarrow L \sim R^2\Sigma$

so

$$M \sim M$$

$$RV^2 \sim L\left(\frac{M}{L}\right)$$

$$\sqrt{\frac{L}{\Sigma}}\, V^2 \sim L\left(\frac{M}{L}\right)$$

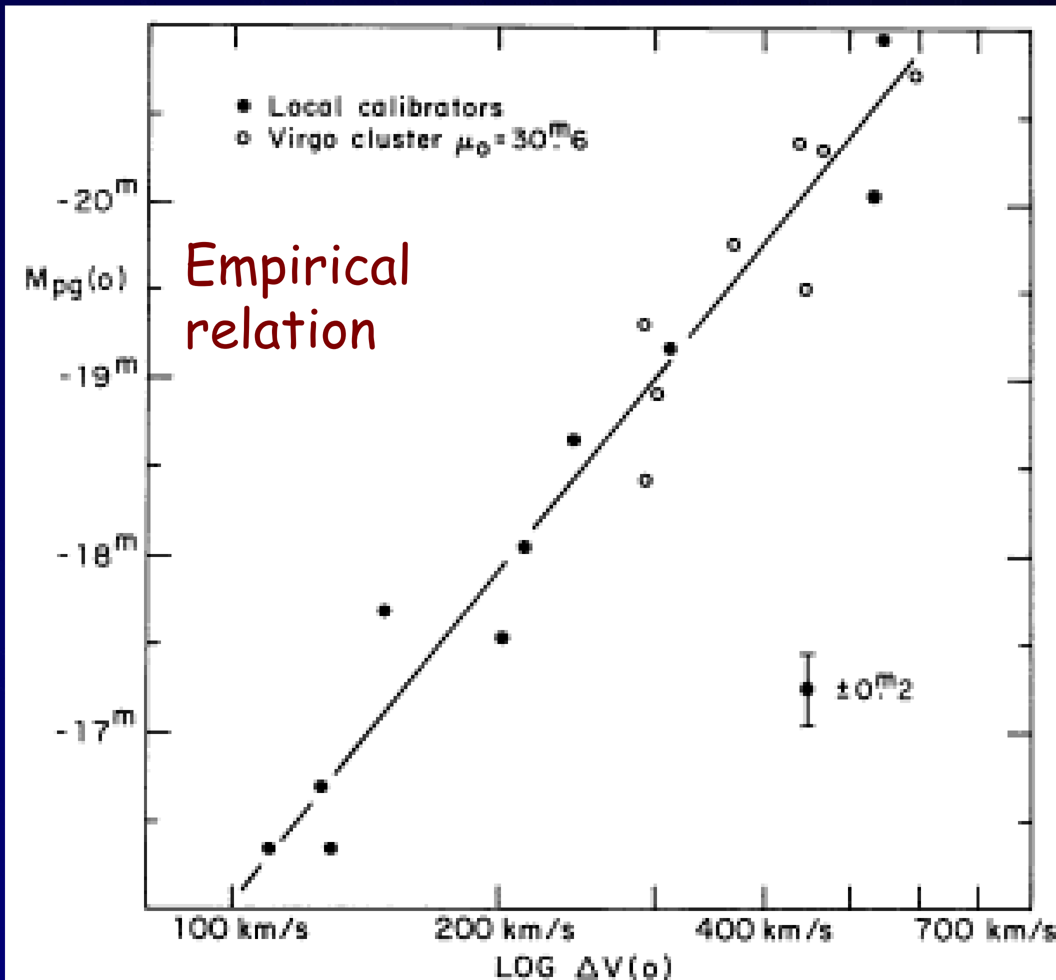
$$\Downarrow$$

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

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

http://burro.astr.cwru.edu

Empirical relation & physical basis?



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

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

Surface brightness

$L \sim V^4$

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

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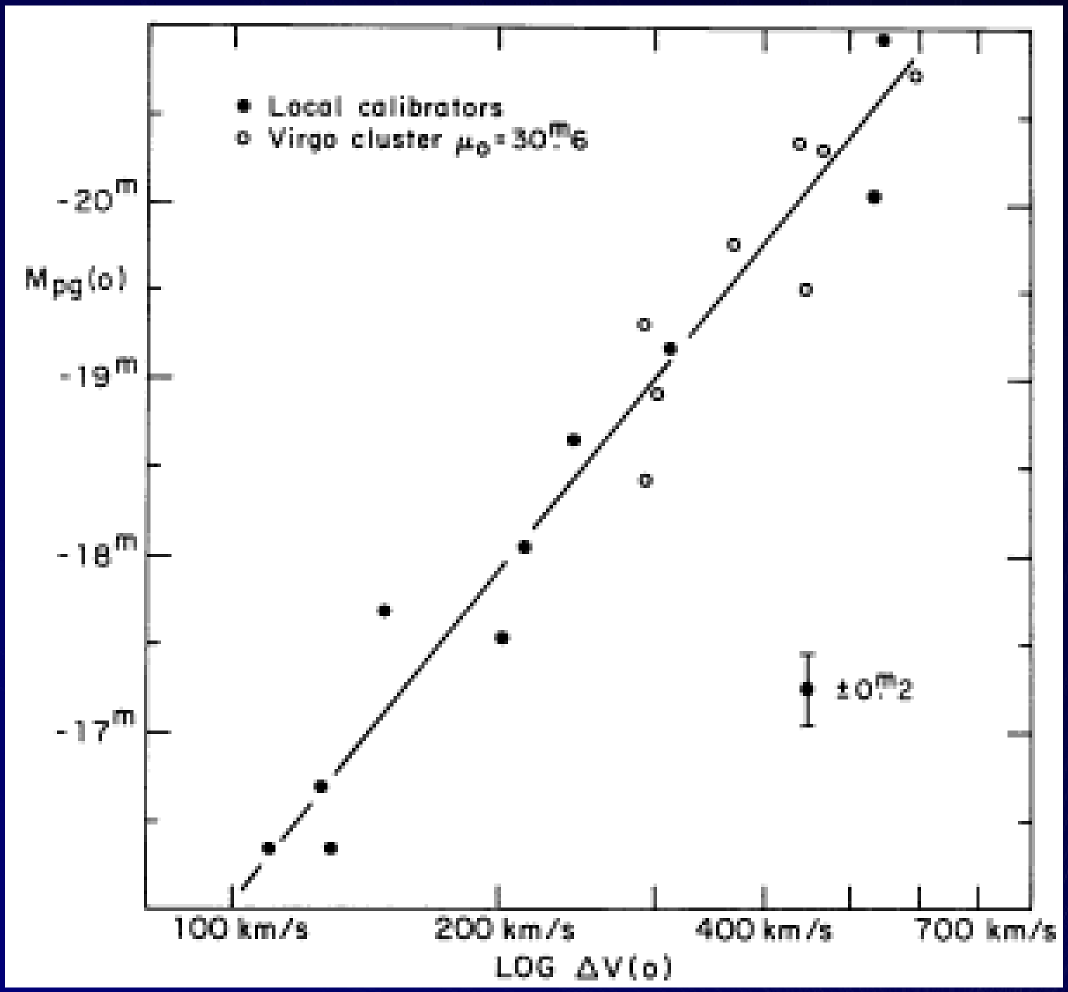
Tully-Fisher relation



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

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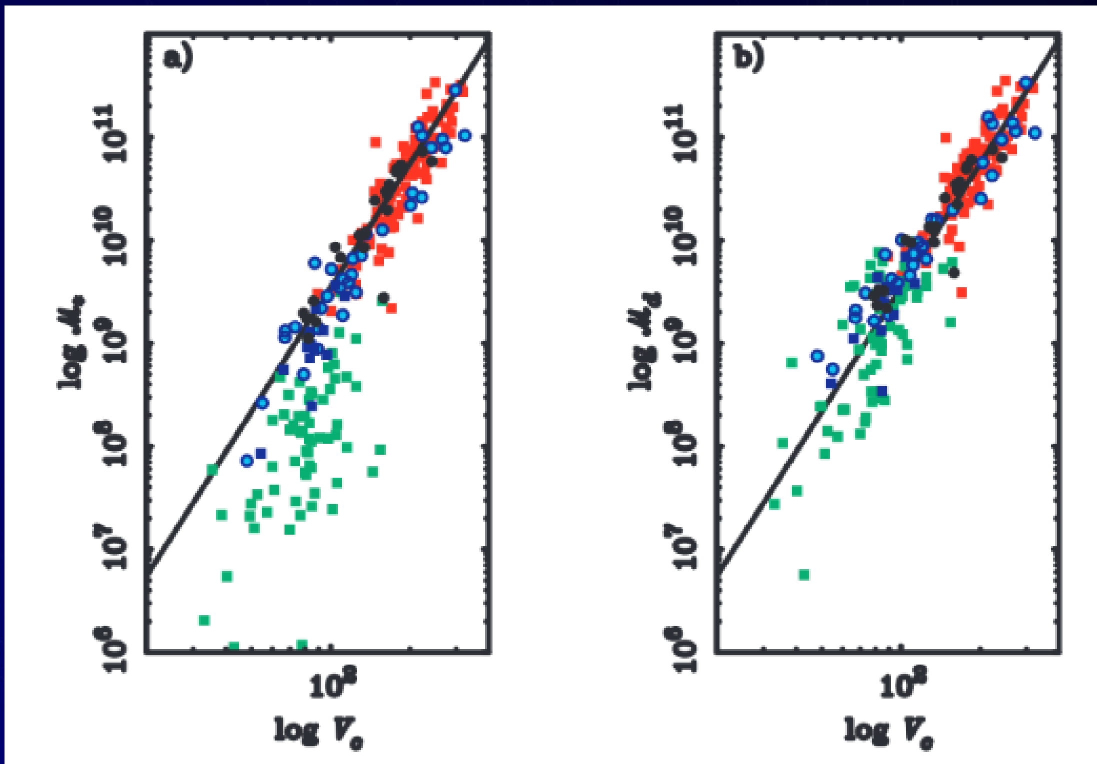
The Baryonic Tully-Fisher Relation



- 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.

Left: Stellar mass vs. rotational velocity
Right: Baryonic mass vs. rotational velocity
McGaugh et al. 2011, ApJ 533, L99

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

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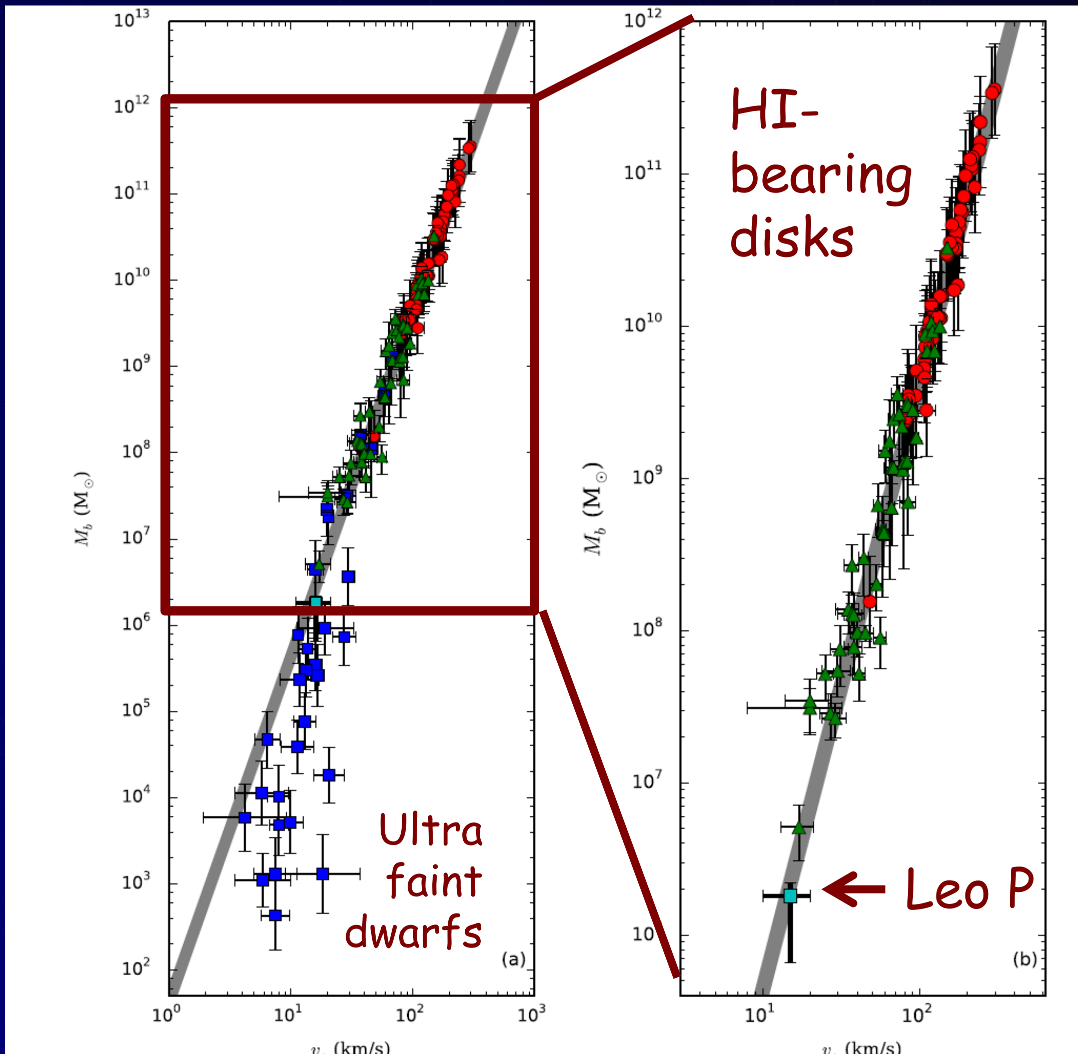
The Baryonic Tully-Fisher Relation



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

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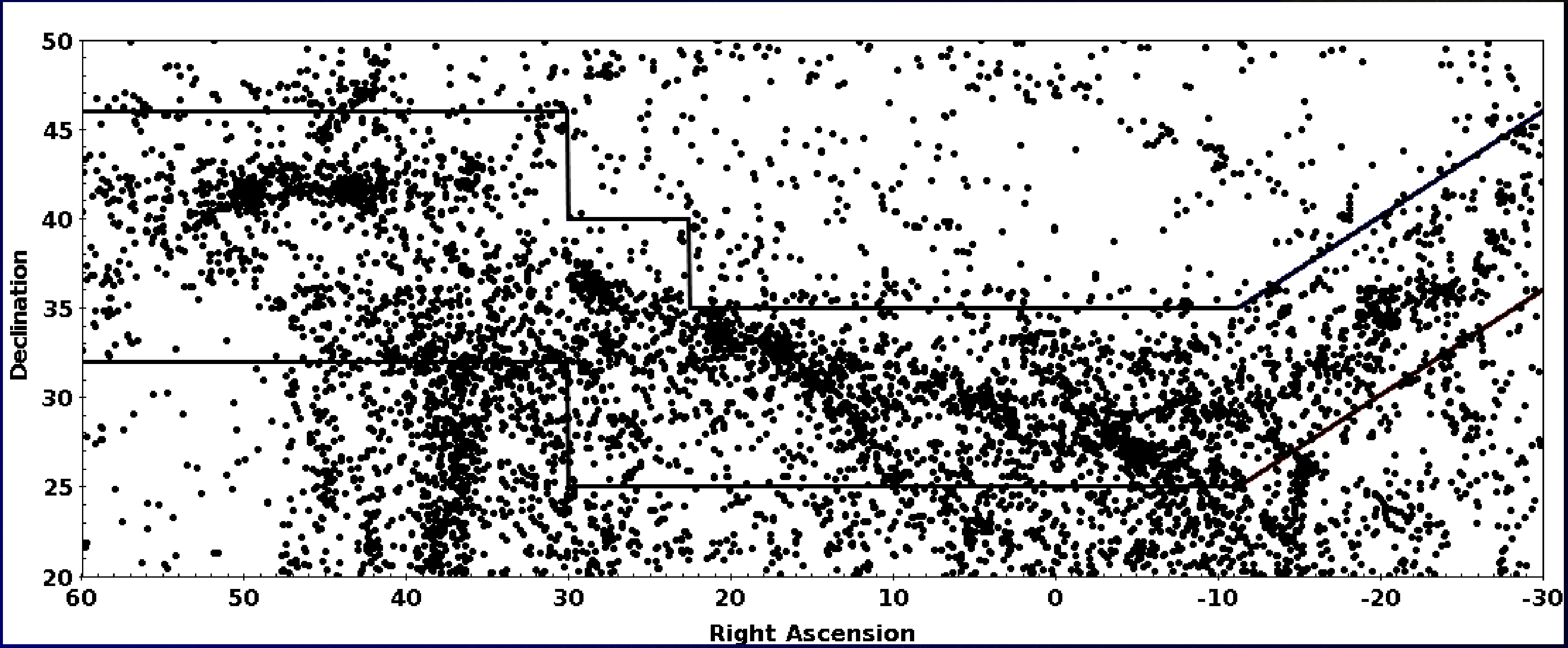
The Pisces-Perseus Supercluster



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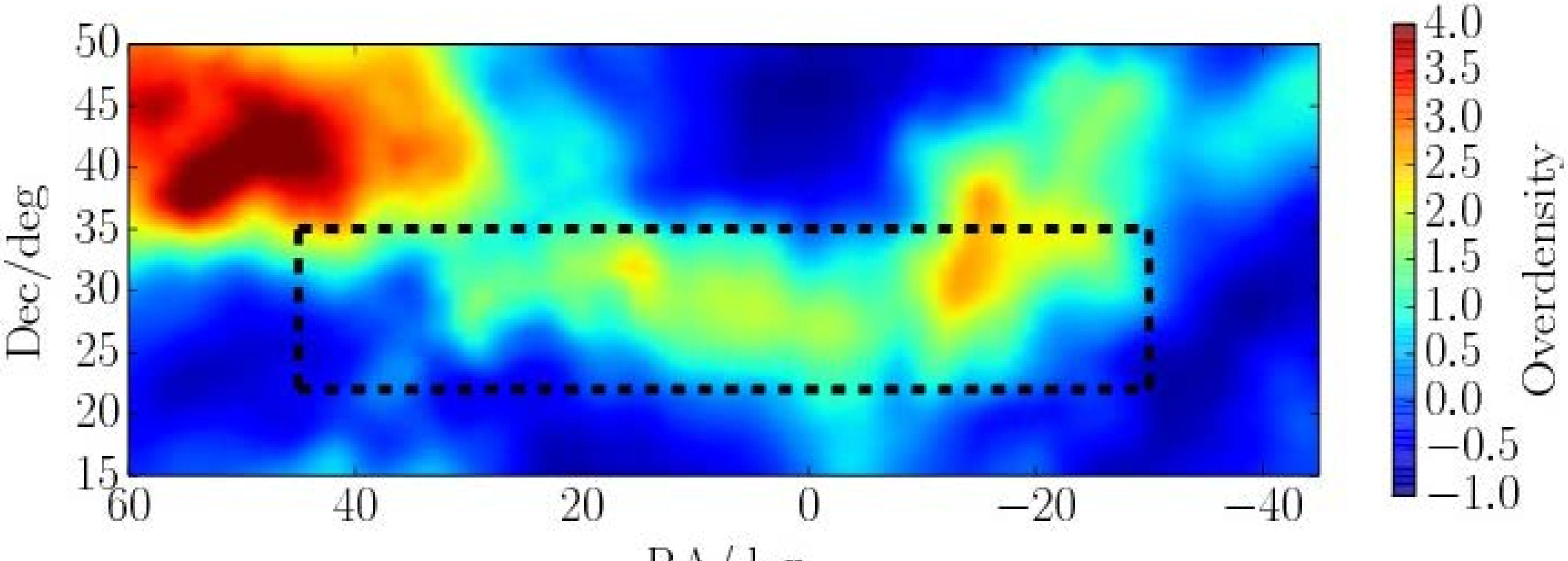
The Arecibo Pisces-Perseus Supercluster Survey

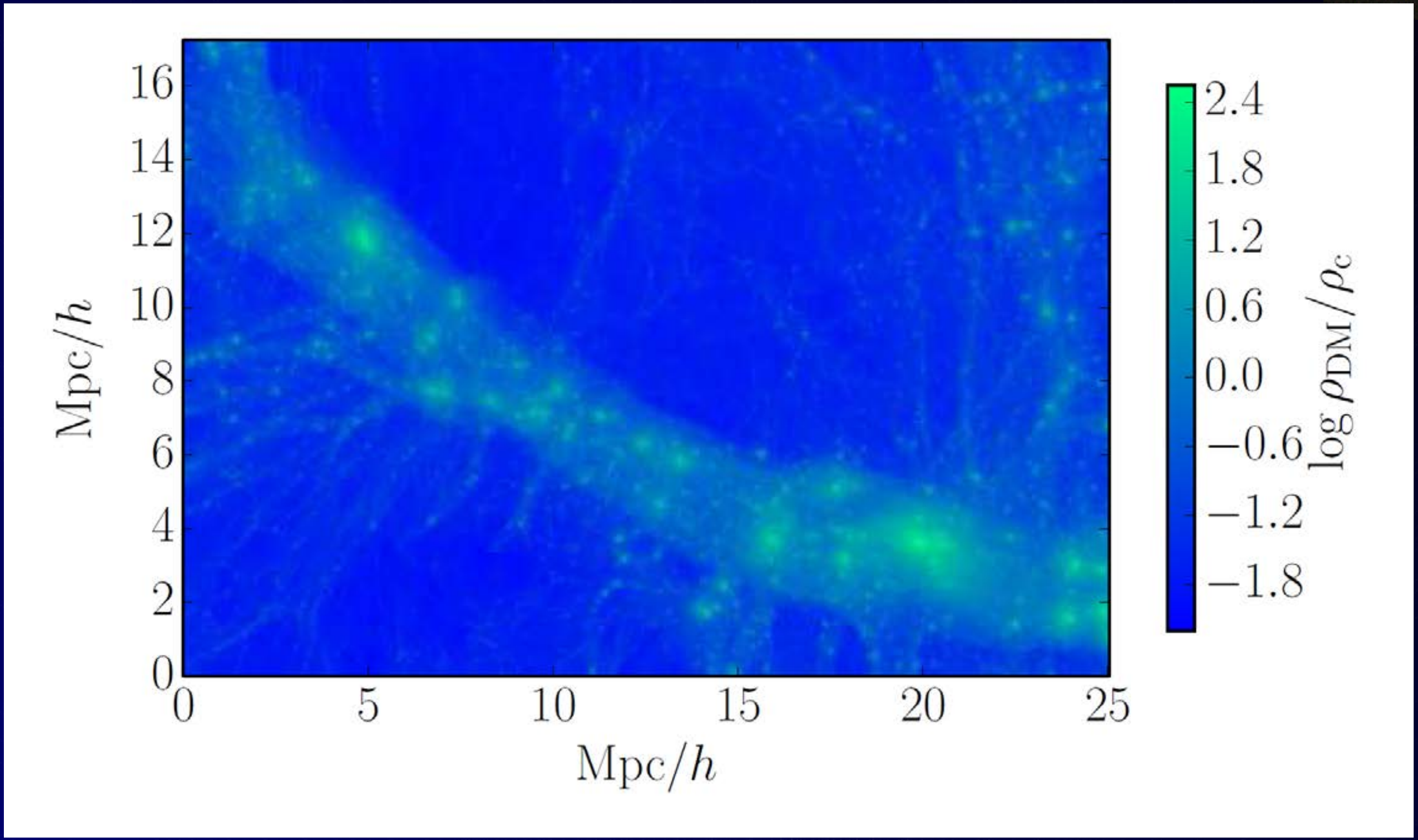
The APPS survey or the APPSS



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

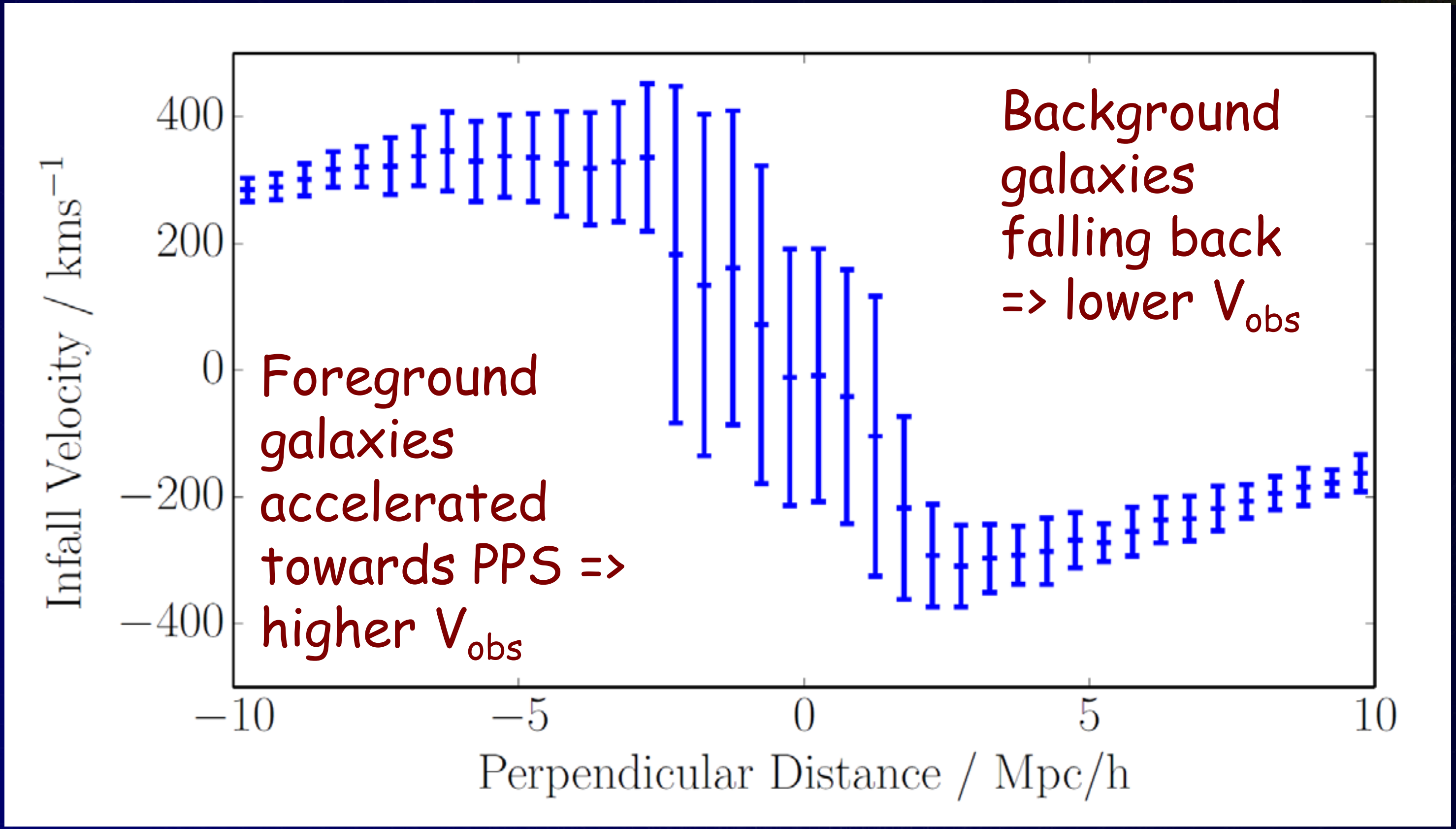
The black dotted rectangle outlines the main APPSS target area:
22h < RA < 3h and +23 < Dec < +35

Filaments in the Illustris Simulation



Here is an example of a filament in the Illustris simulation; it is actually smaller and of lower overdensity than PPS.

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.

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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.

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APPSS LBW Arecibo efforts

- 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 ALFALFA
  - Conduct LBW survey of these targets (Fall 2015, 2016)
    - 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

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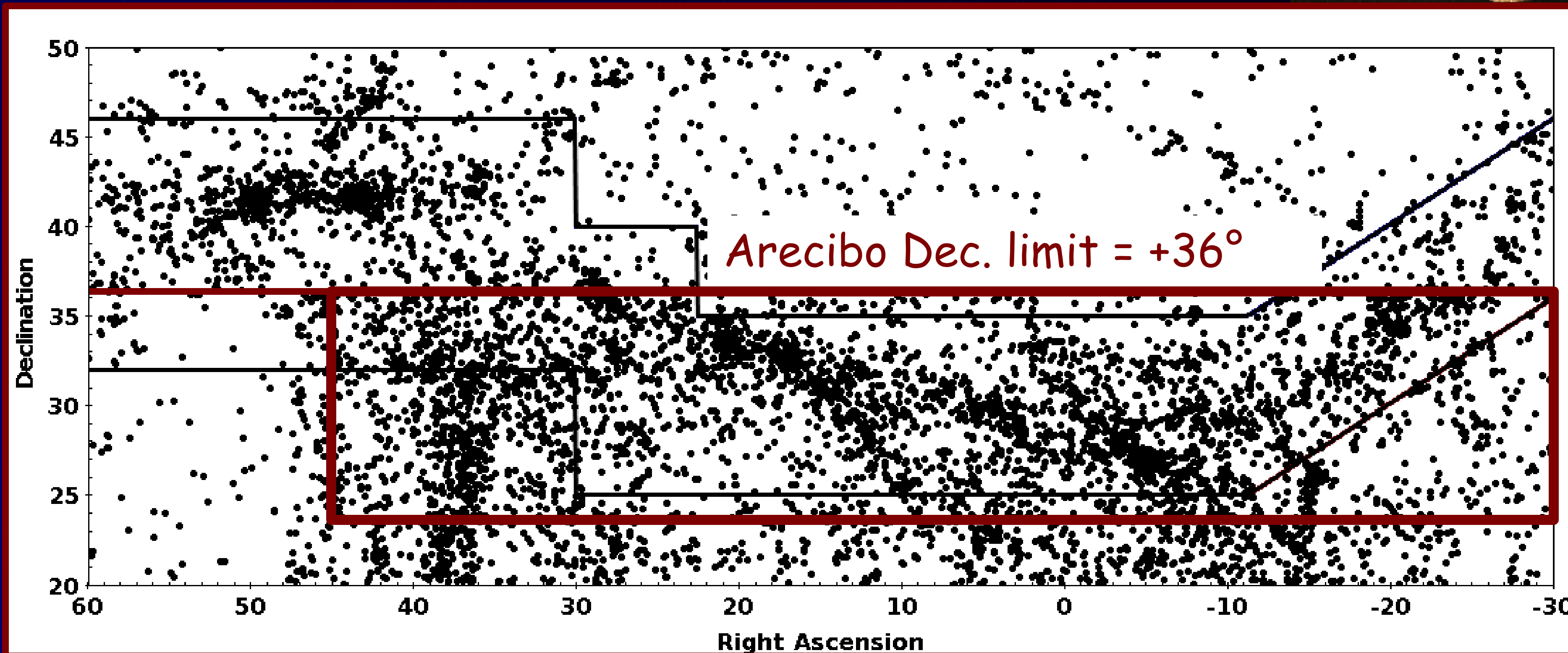
APPSS target region



We are also observing a few galaxies north of +36°with the Green Bank Telescope.