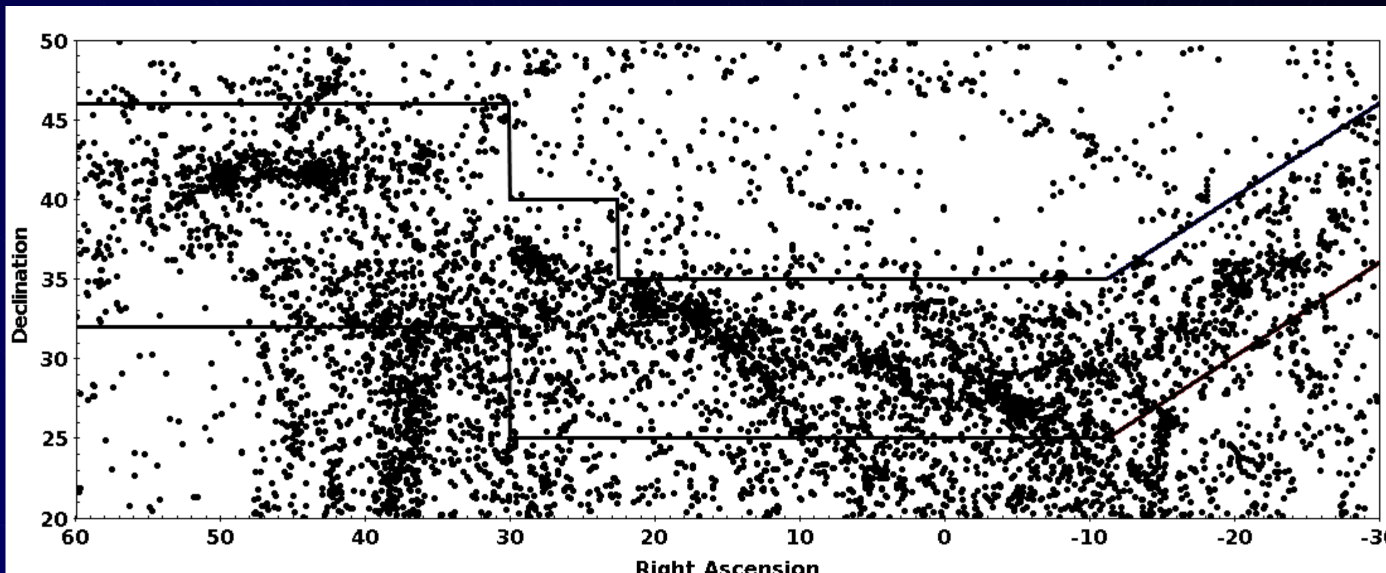
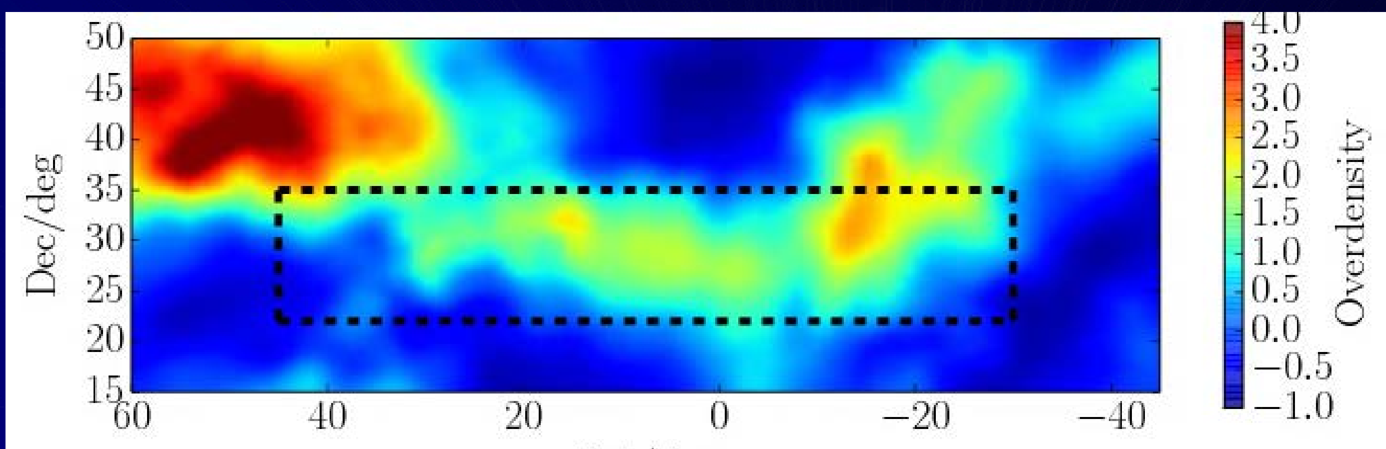
The Arecibo Pisces-Perseus Supercluster Survey





June 2019

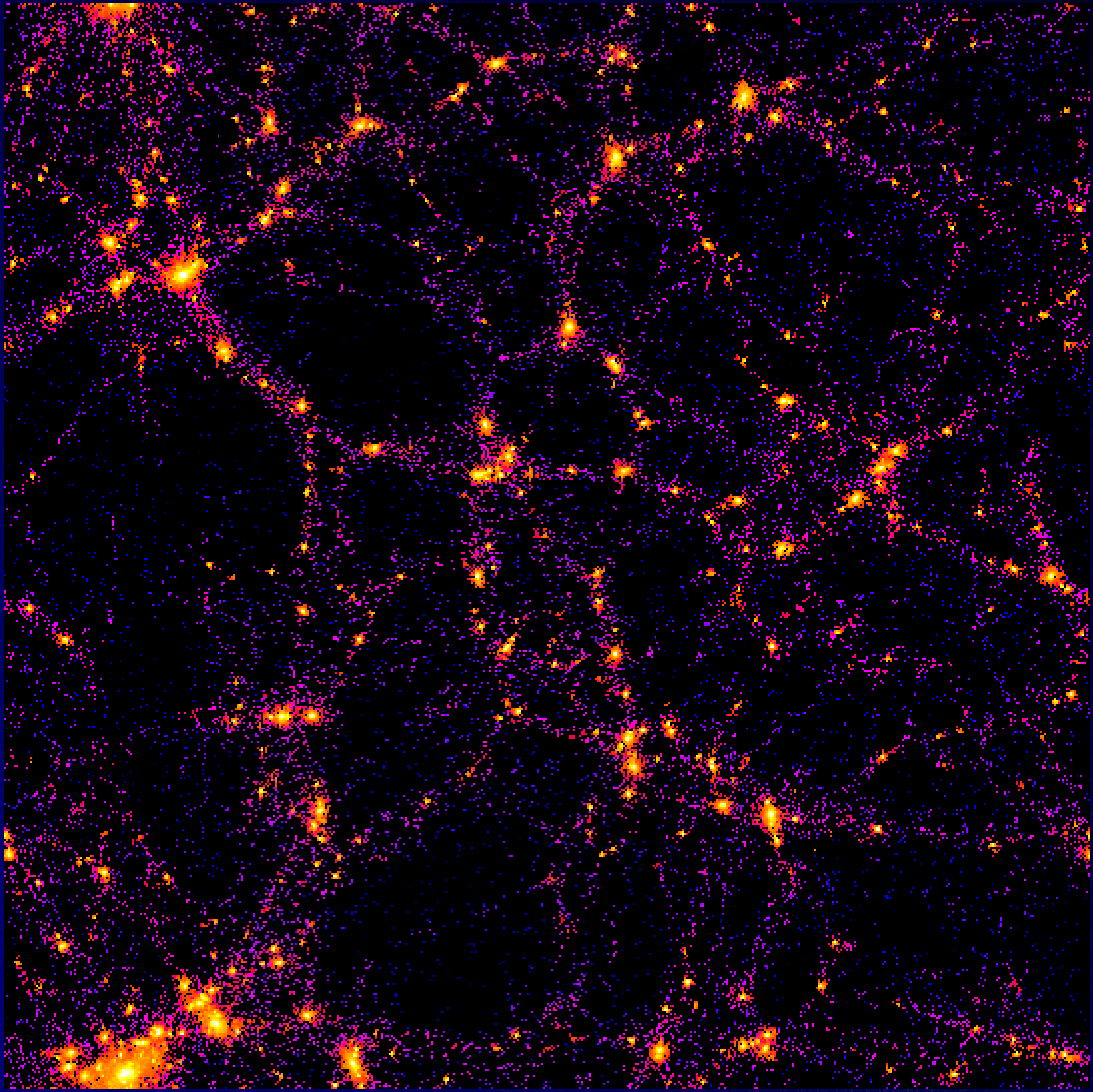
Martha Haynes

Cornell University

UAT19.06

ALFALFA

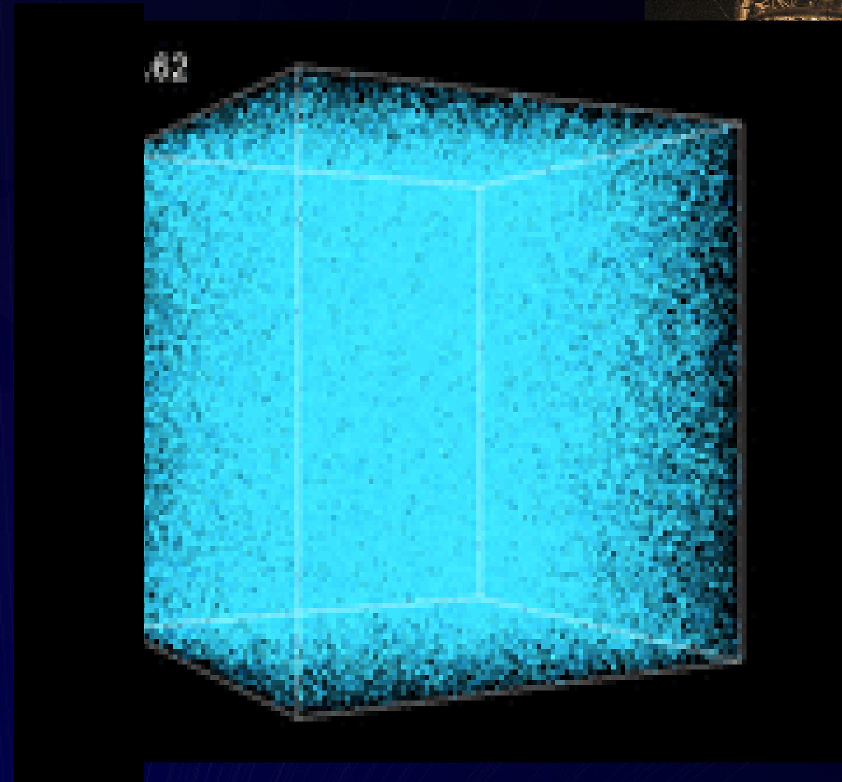
Large scale structure in the Universe

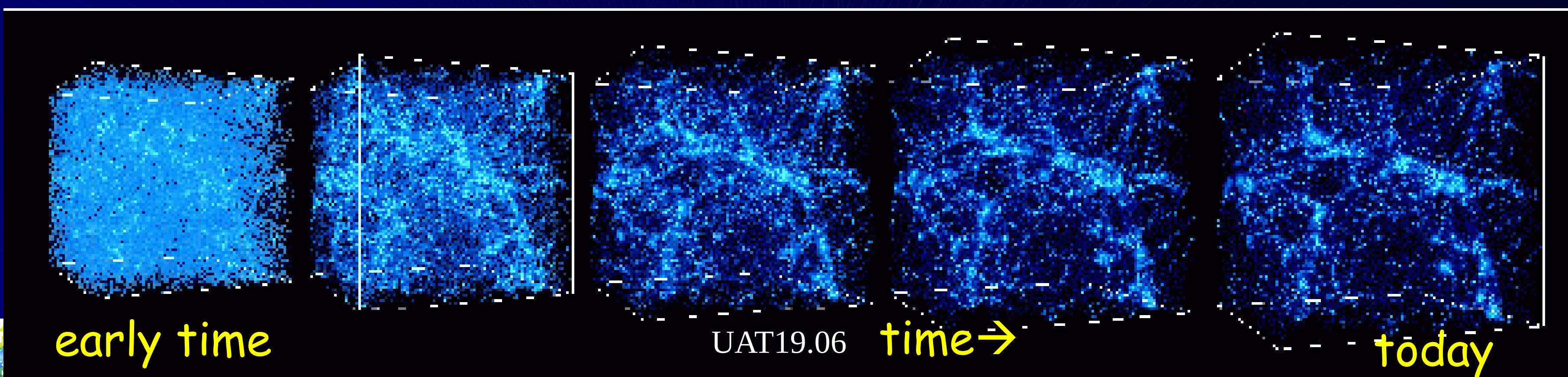


- Galaxies cluster into groups, clusters and superclusters
- Galaxies avoid voids.
- The distribution of matter is not homogeneous.

Large scale structure

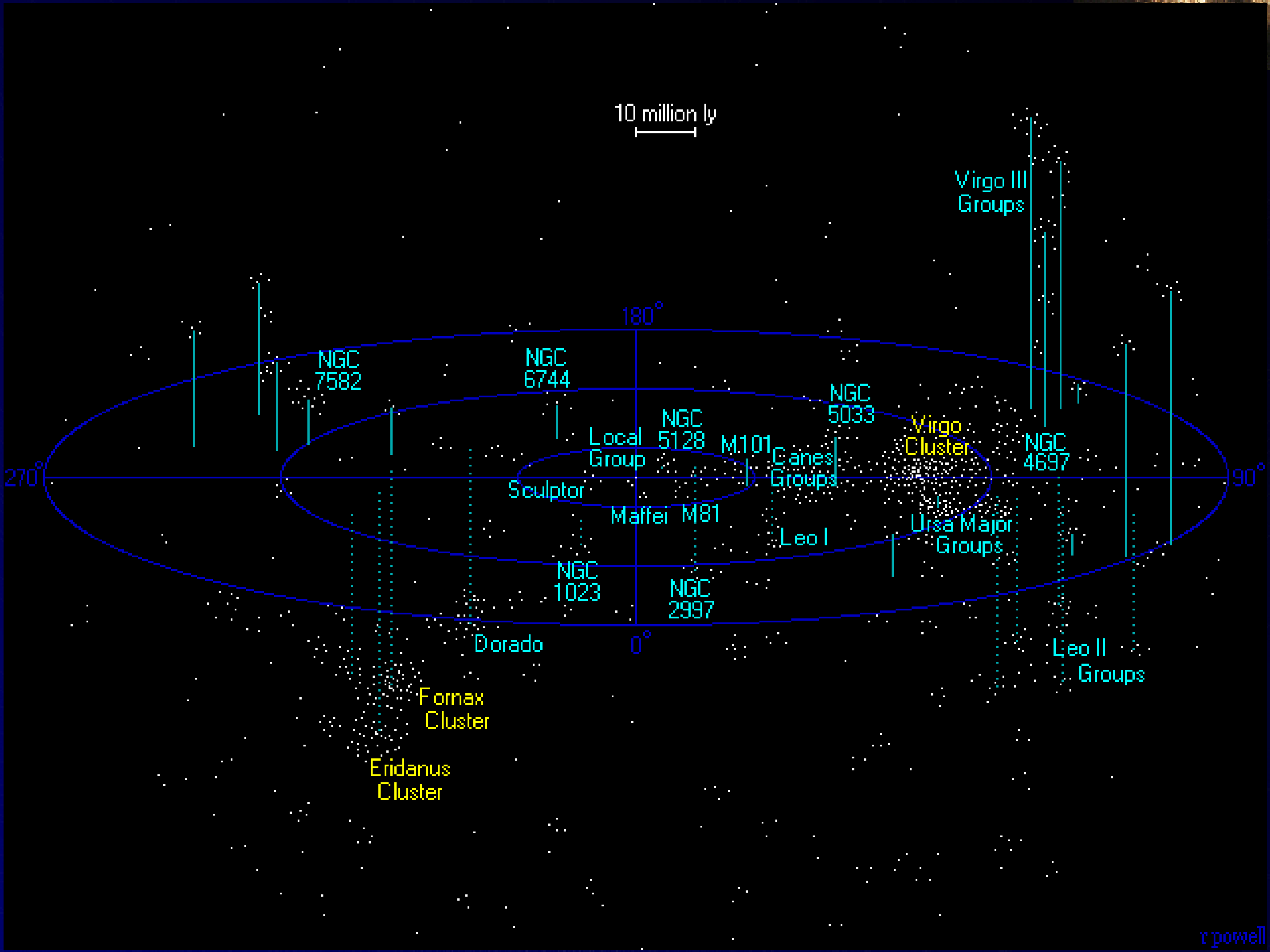
- How did the structures we see today form and evolve?
- Do our cosmological models predict this behavior?
- Can they give us any insight into how and why this structure develops?





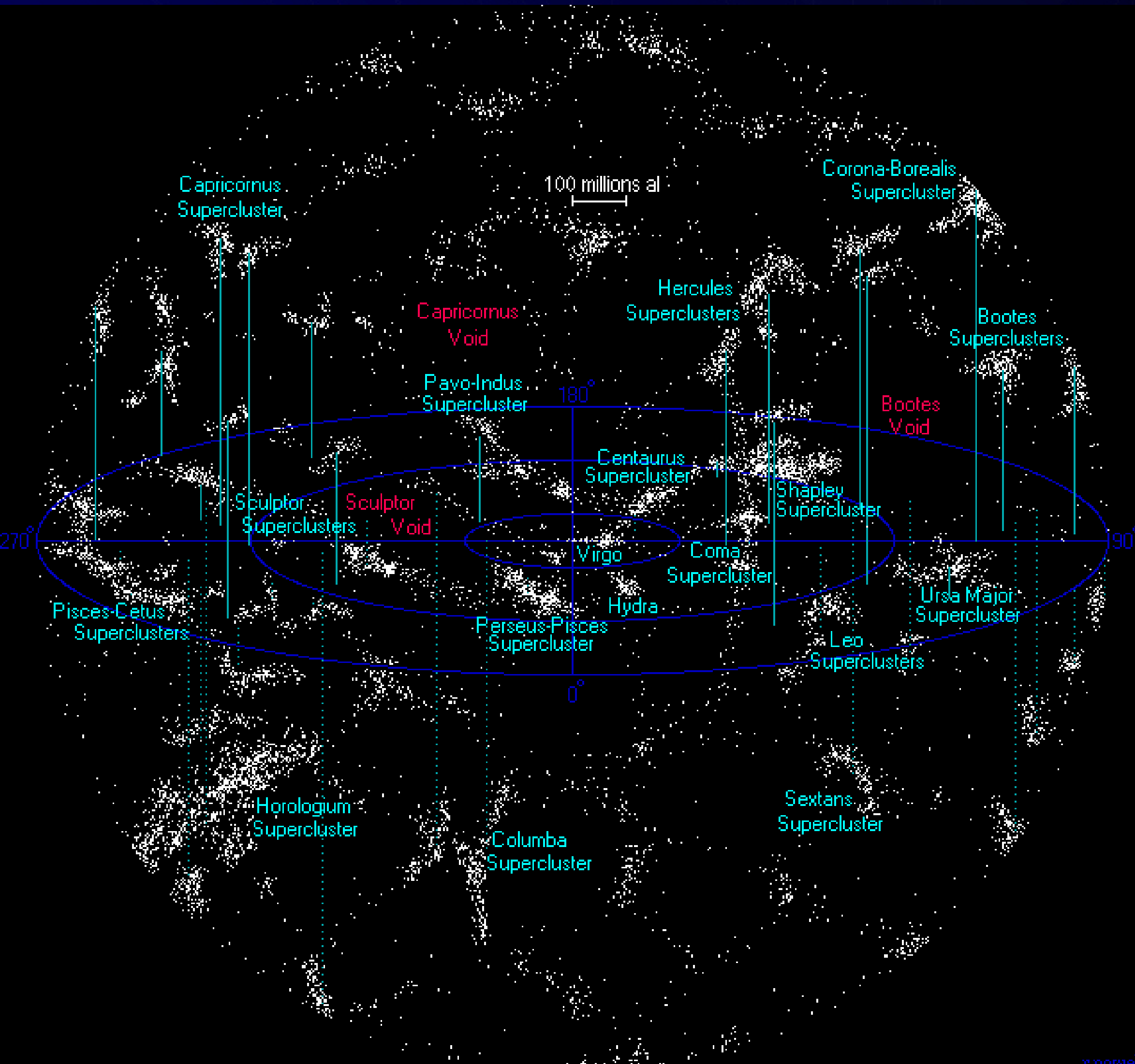
Large scale structure < 50 Mlyr

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



Atlas of the Universe

Large scale structure < 1 Glyr



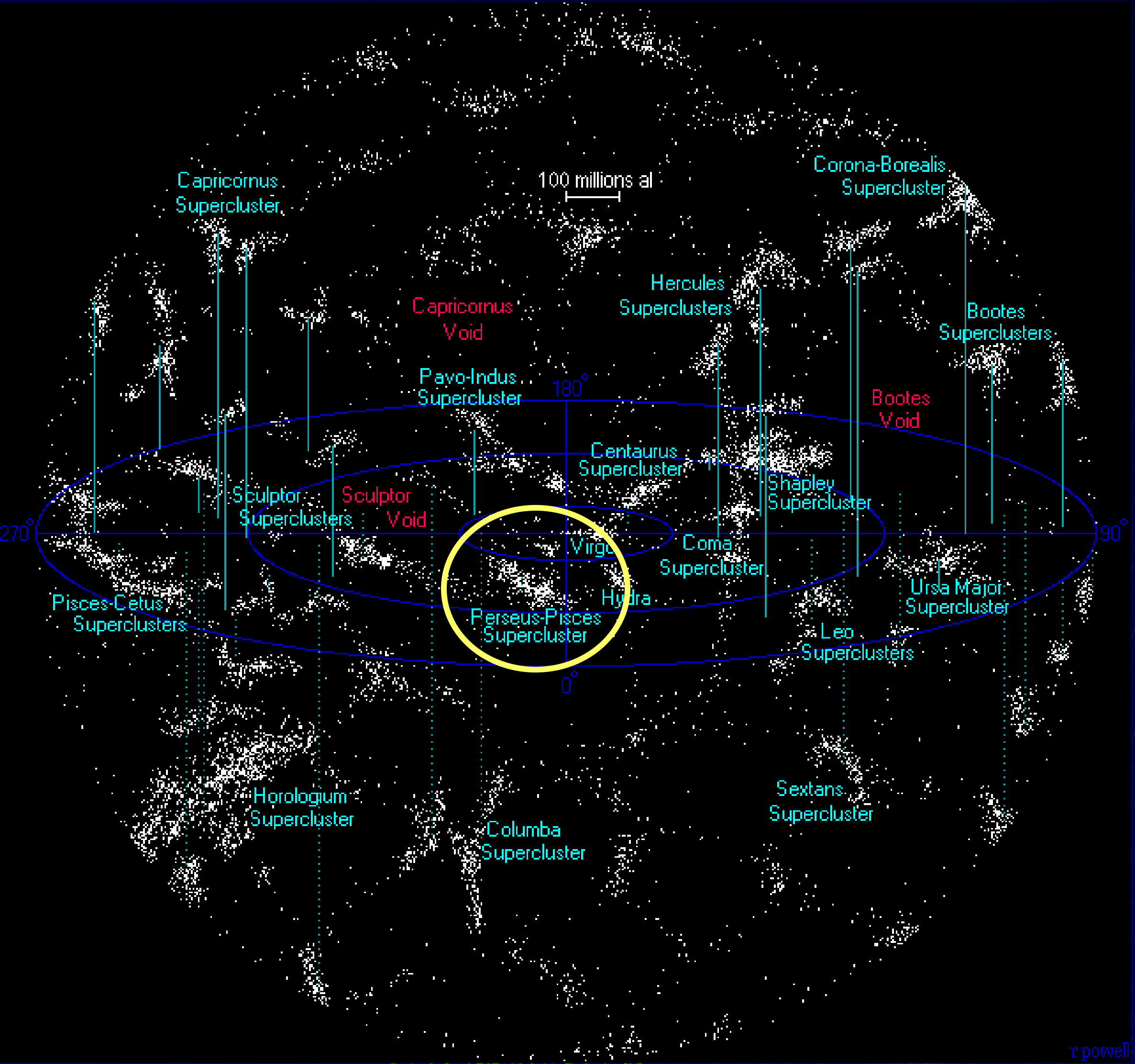
Pisces-Perseus Supercluster

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

Atlas of the Universe

ALFALFA

Large scale structure < 1 Glyr



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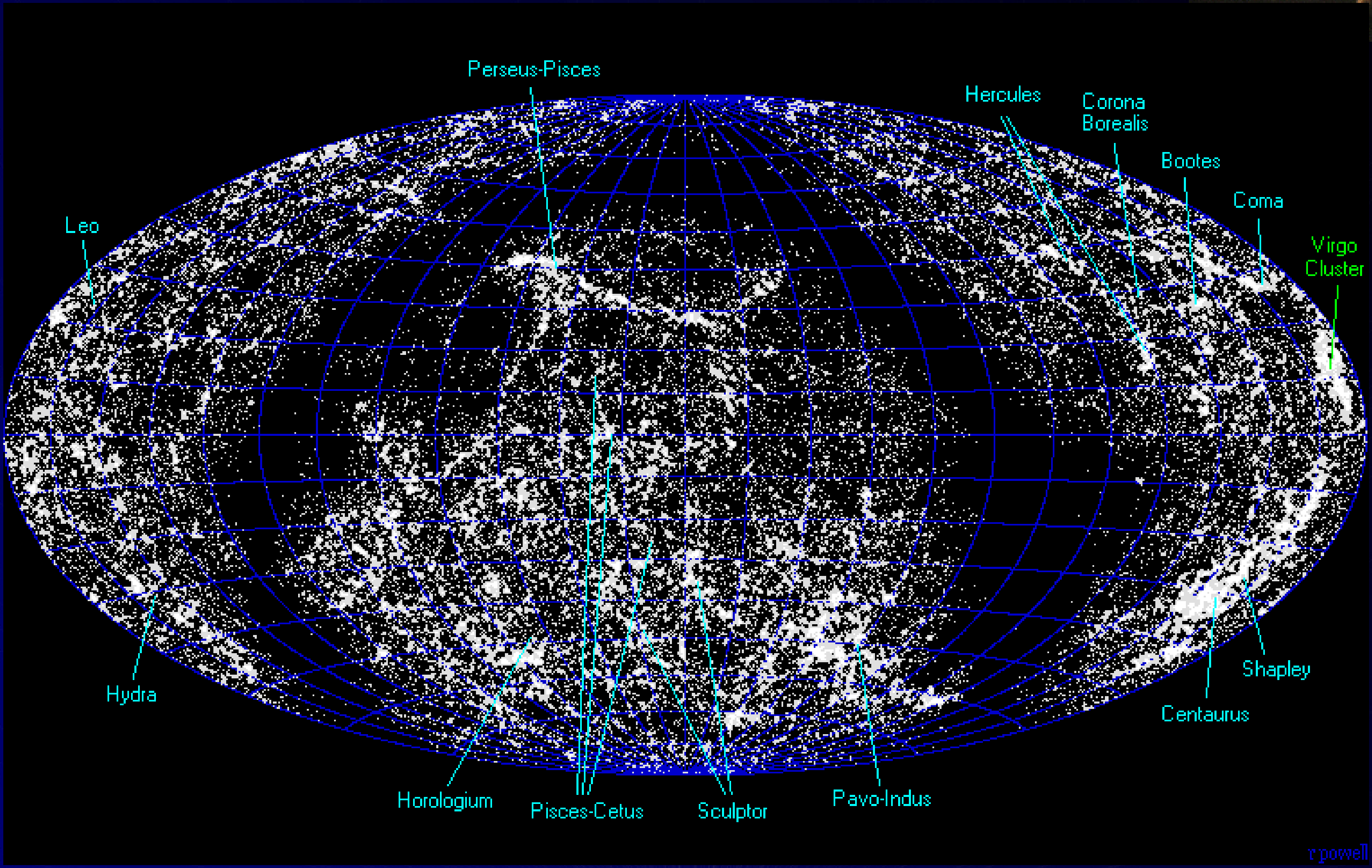
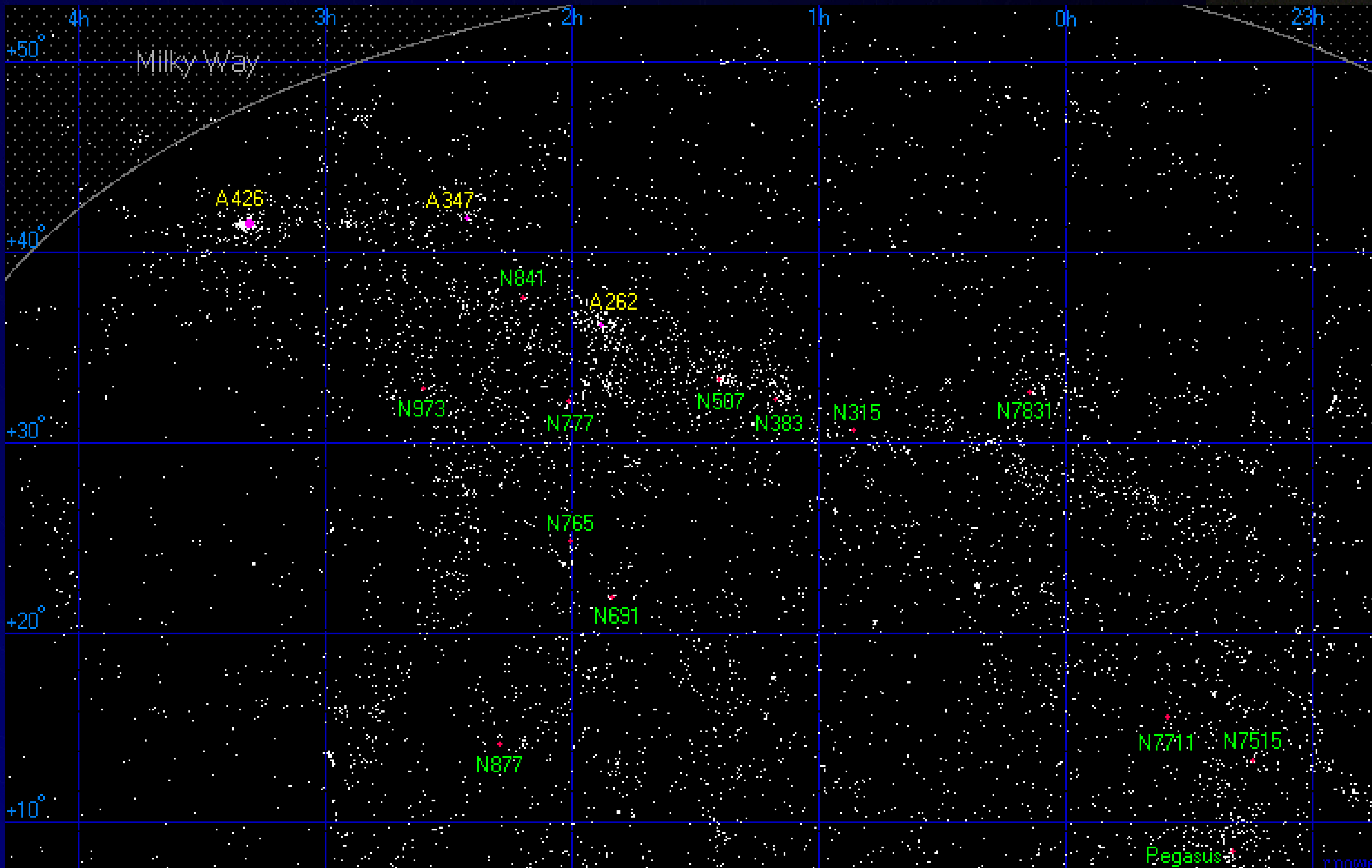
Atlas of the Universe

The Pisces-Perseus Supercluster



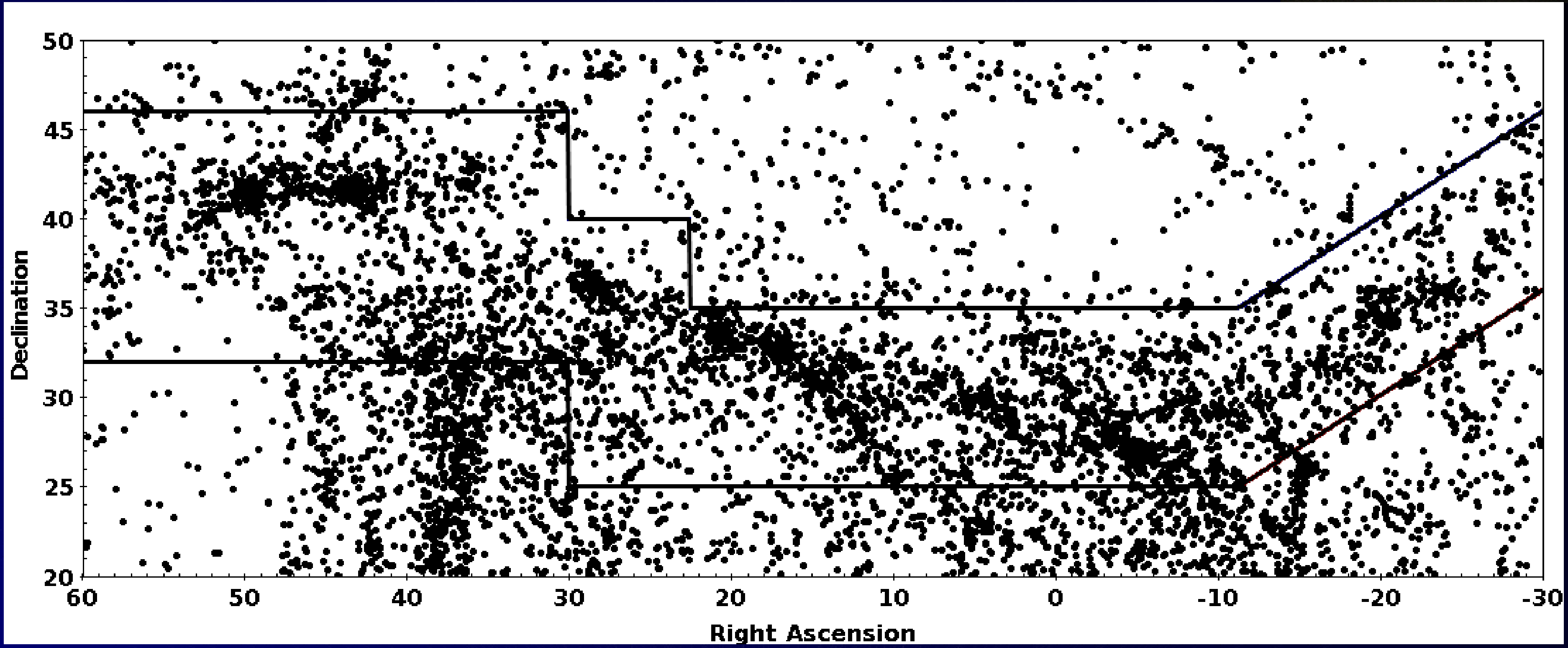
Atlas of the Universe

The Pisces-Perseus Supercluster



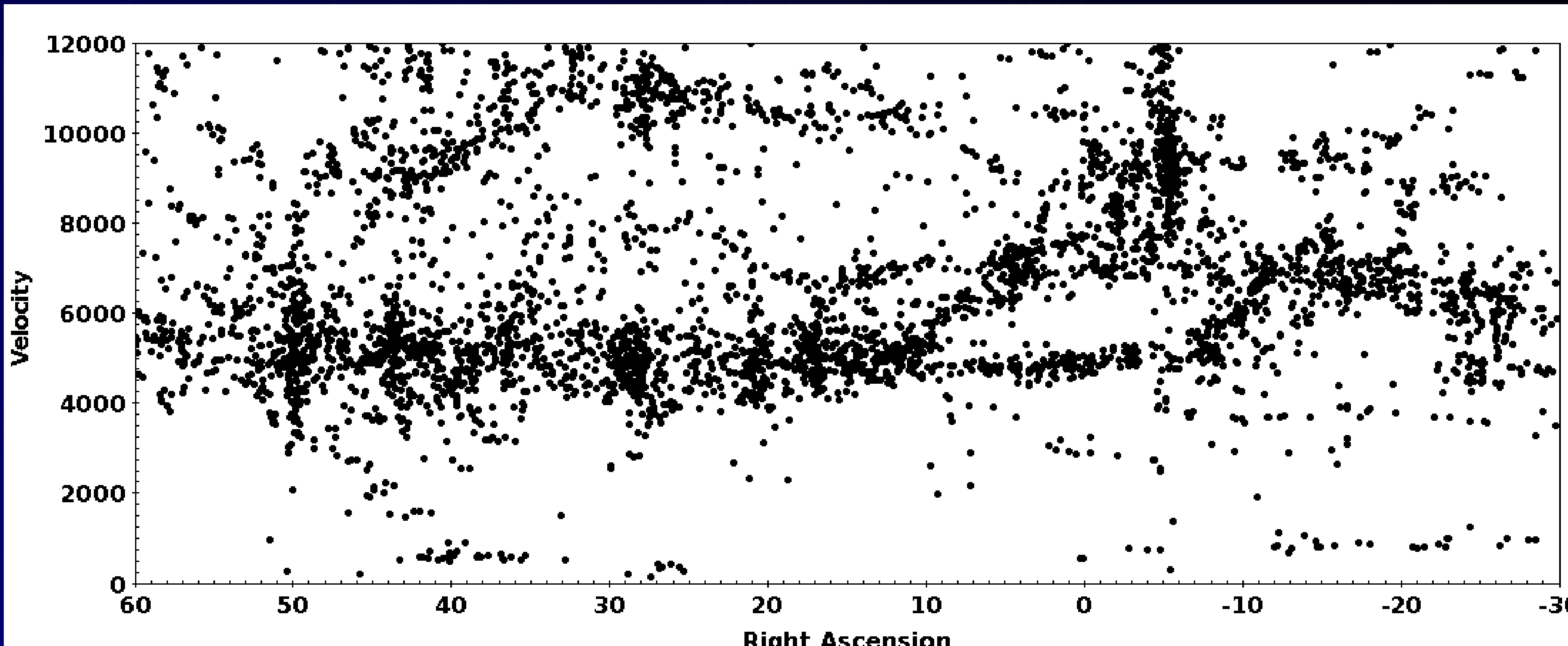
Atlas of the Universe

The Pisces-Perseus Supercluster



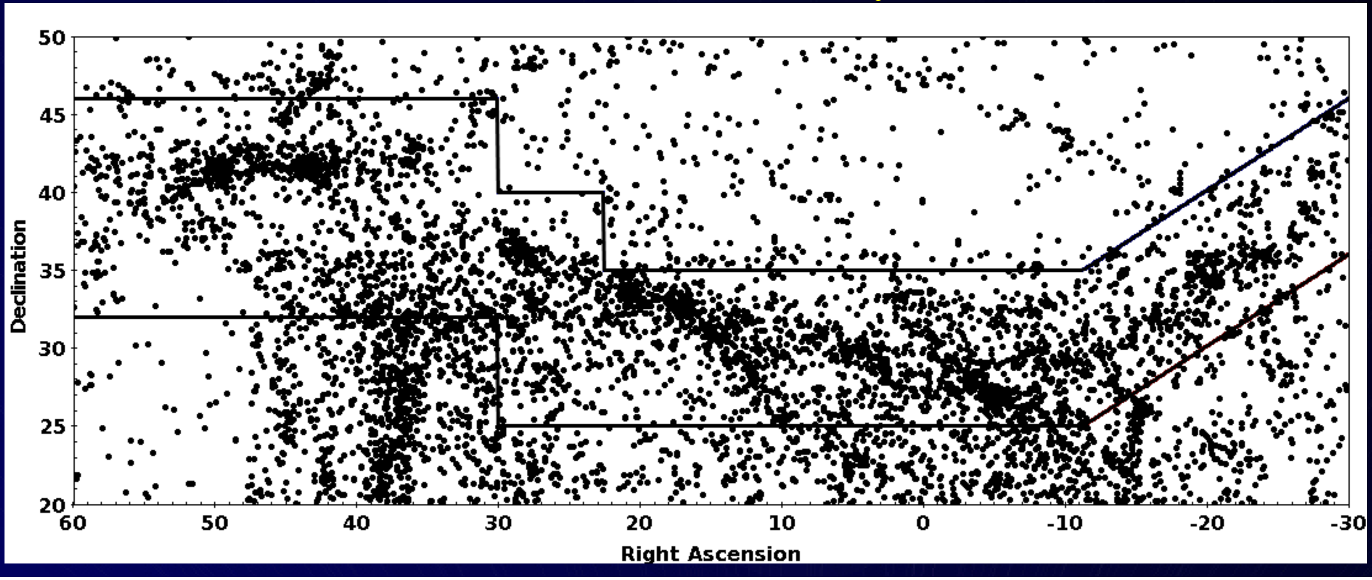
- Each black dot represents a galaxy with a measured redshift of cz < 12000 km/s
- The black lines define the region of the "main ridge" of the PPS.

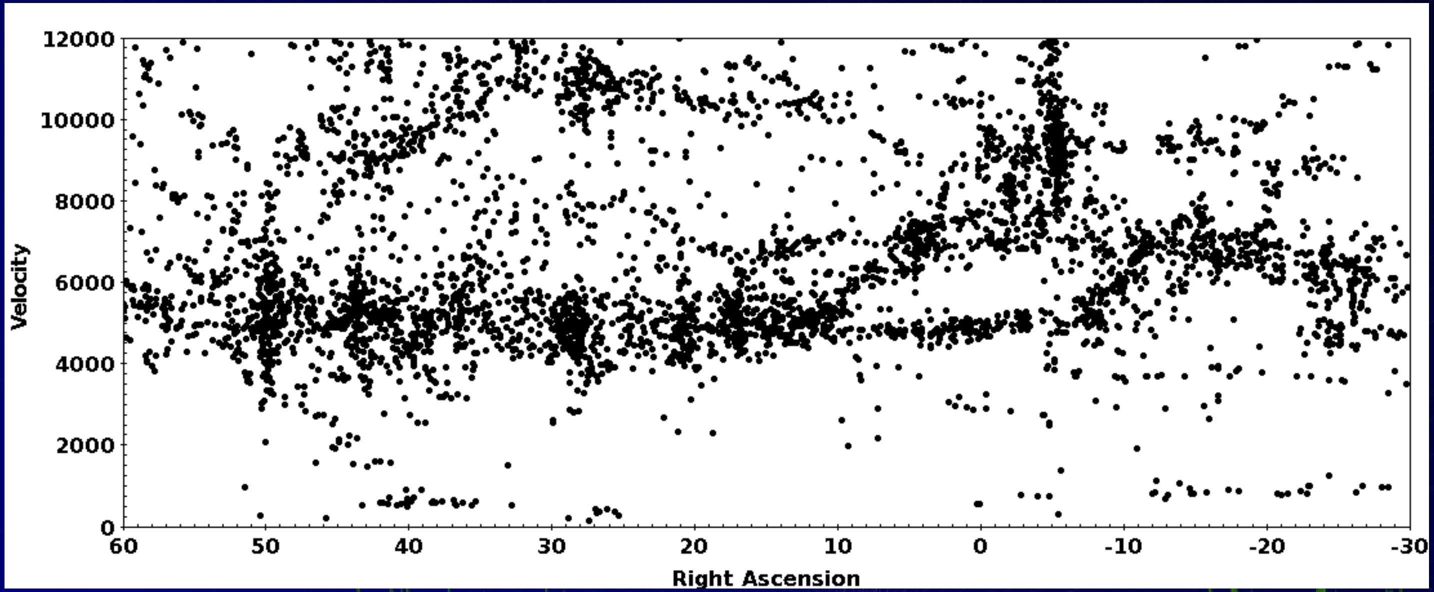
The Pisces-Perseus Supercluster



- 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.

The Pisces-Perseus Supercluster

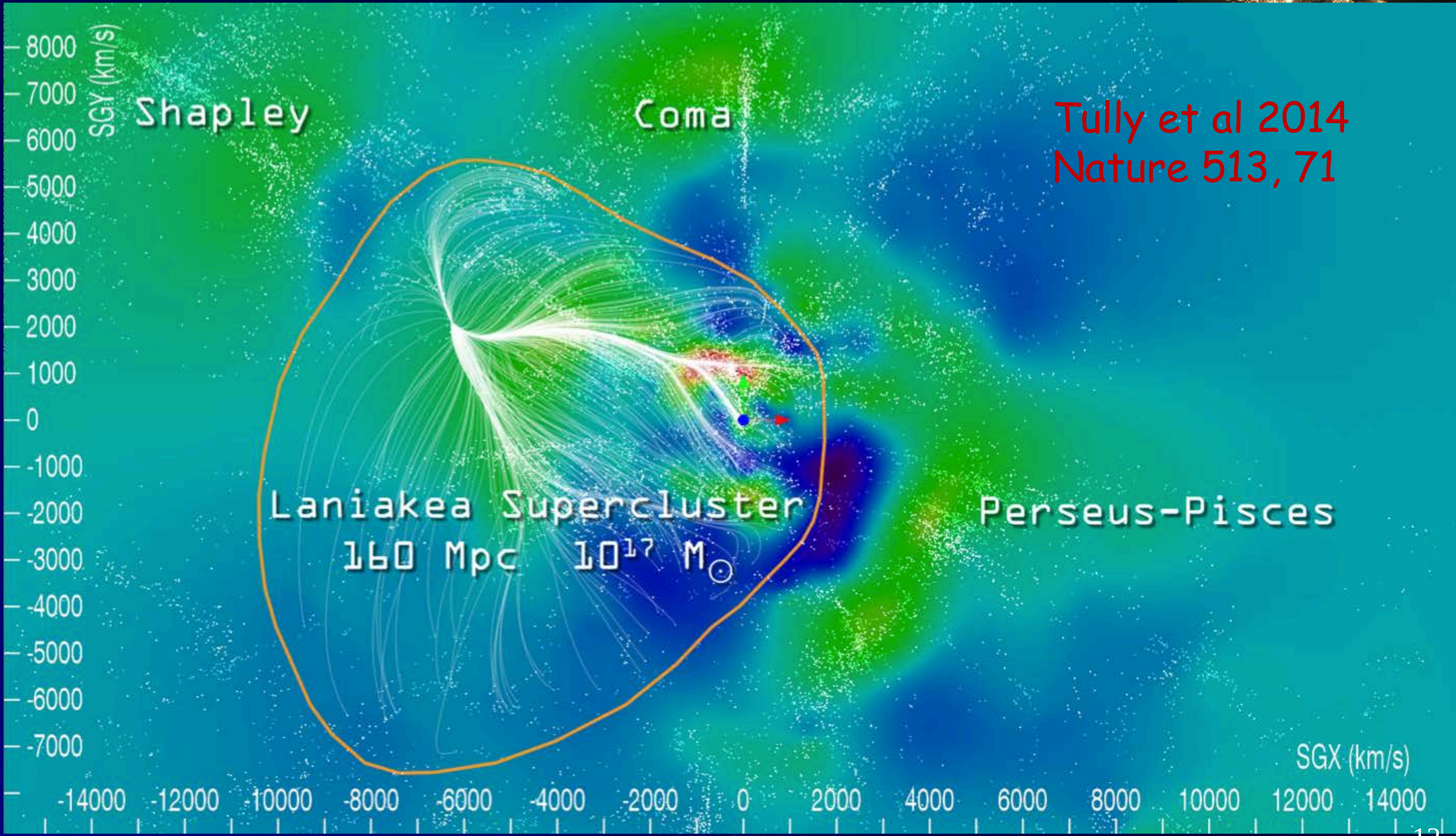




PPS is a relatively linear structure oriented almost perpendicular to the line of sight.

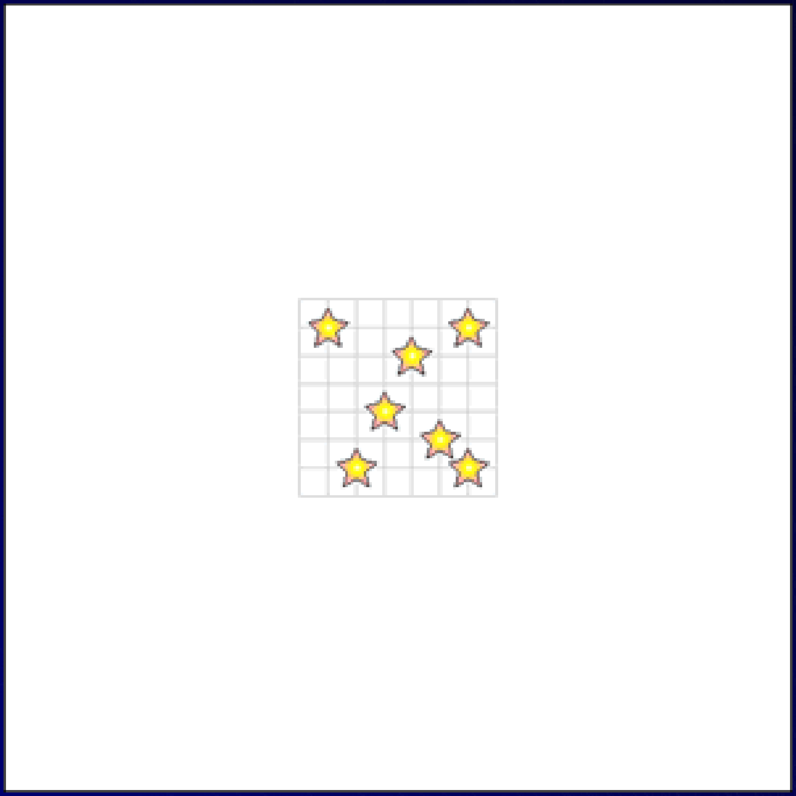
"filament"

The Pisces-Perseus Supercluster



Tully *et al* 2014 Nature

Smooth Hubble Flow



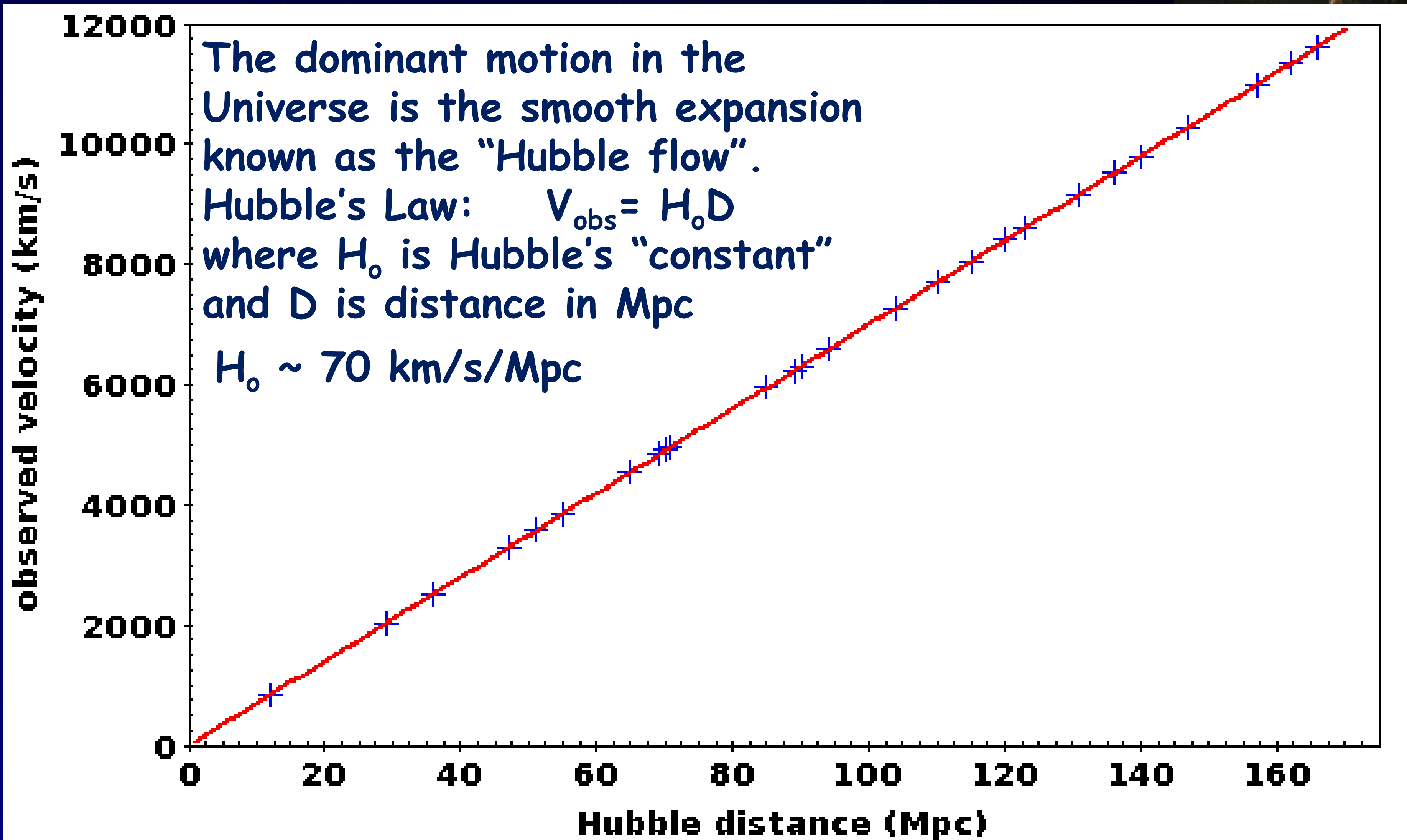
- The dominant motion in the universe is the smooth expansion, known as the Hubble Flow.

↕

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

But: galaxies cluster !

Smooth Hubble Flow



The dominant motion in the Universe is the smooth expansion known as the "Hubble flow".

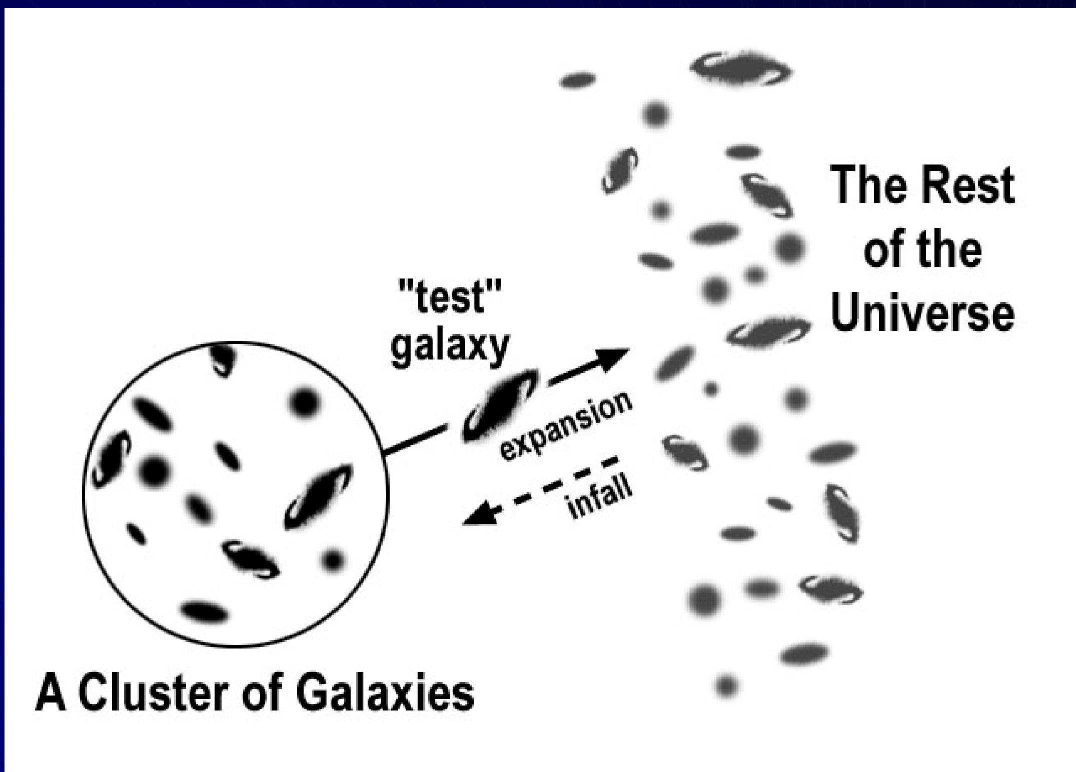
Hubble's Law: $V_{obs} = H_o D$

where H_o is Hubble's "constant" and D is distance in Mpc

$H_o \sim 70$ km/s/Mpc

Deviations from Hubble Flow

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



"Peculiar velocities"

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

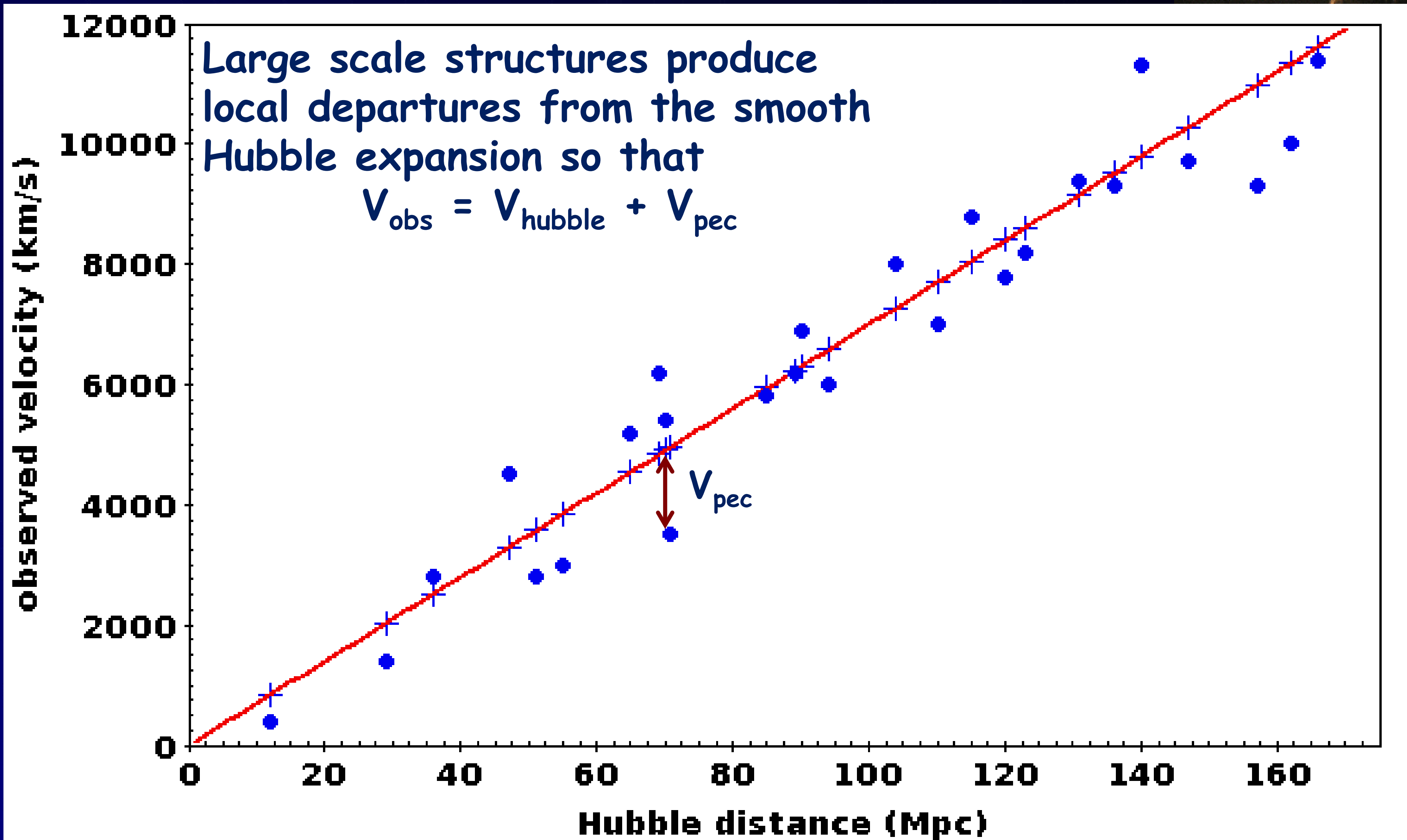
V_{pec} includes components of:

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

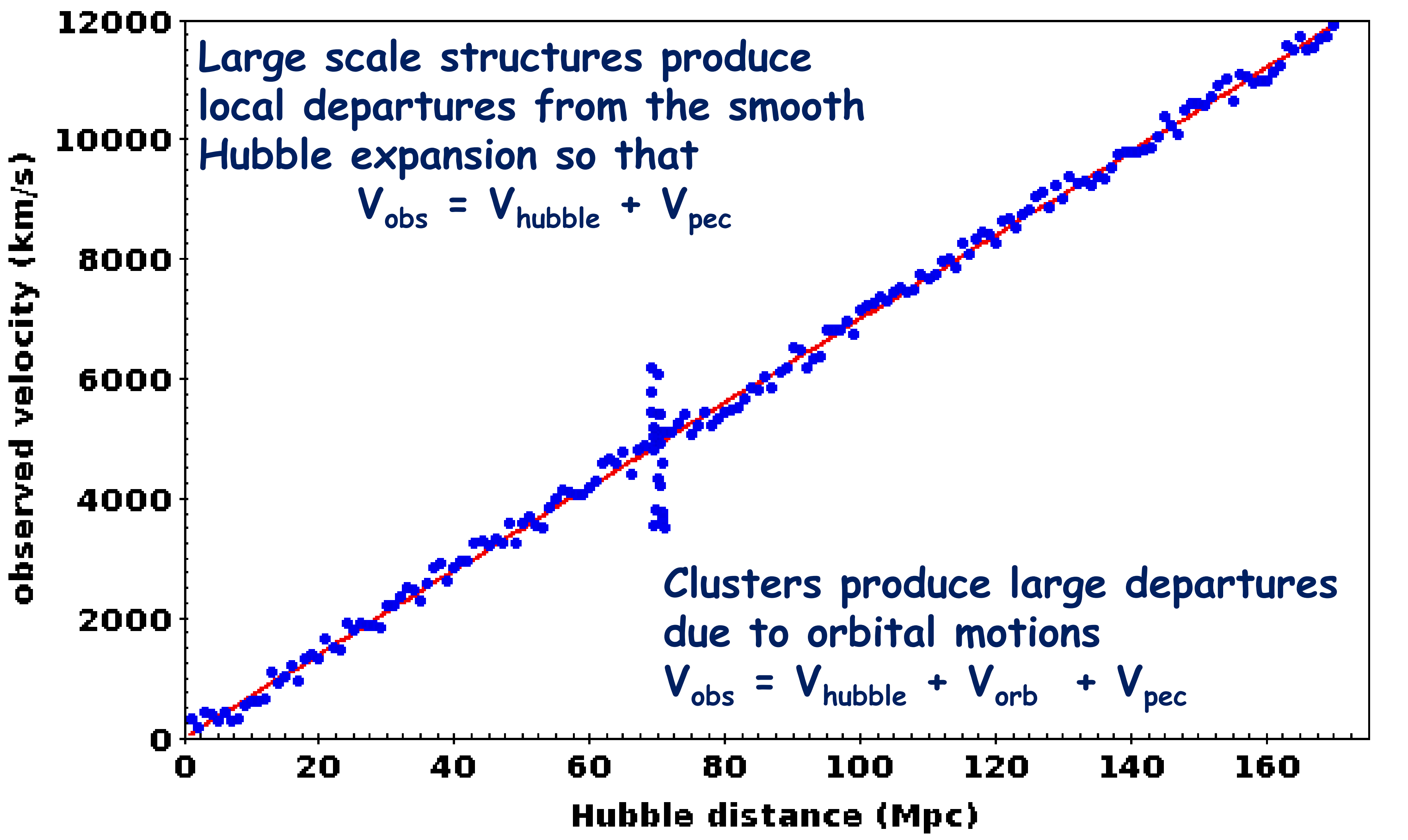
Trace V_{pec} ⇔ Trace mass

Tully *et al* 2014 Nature

Peculiar Velocities



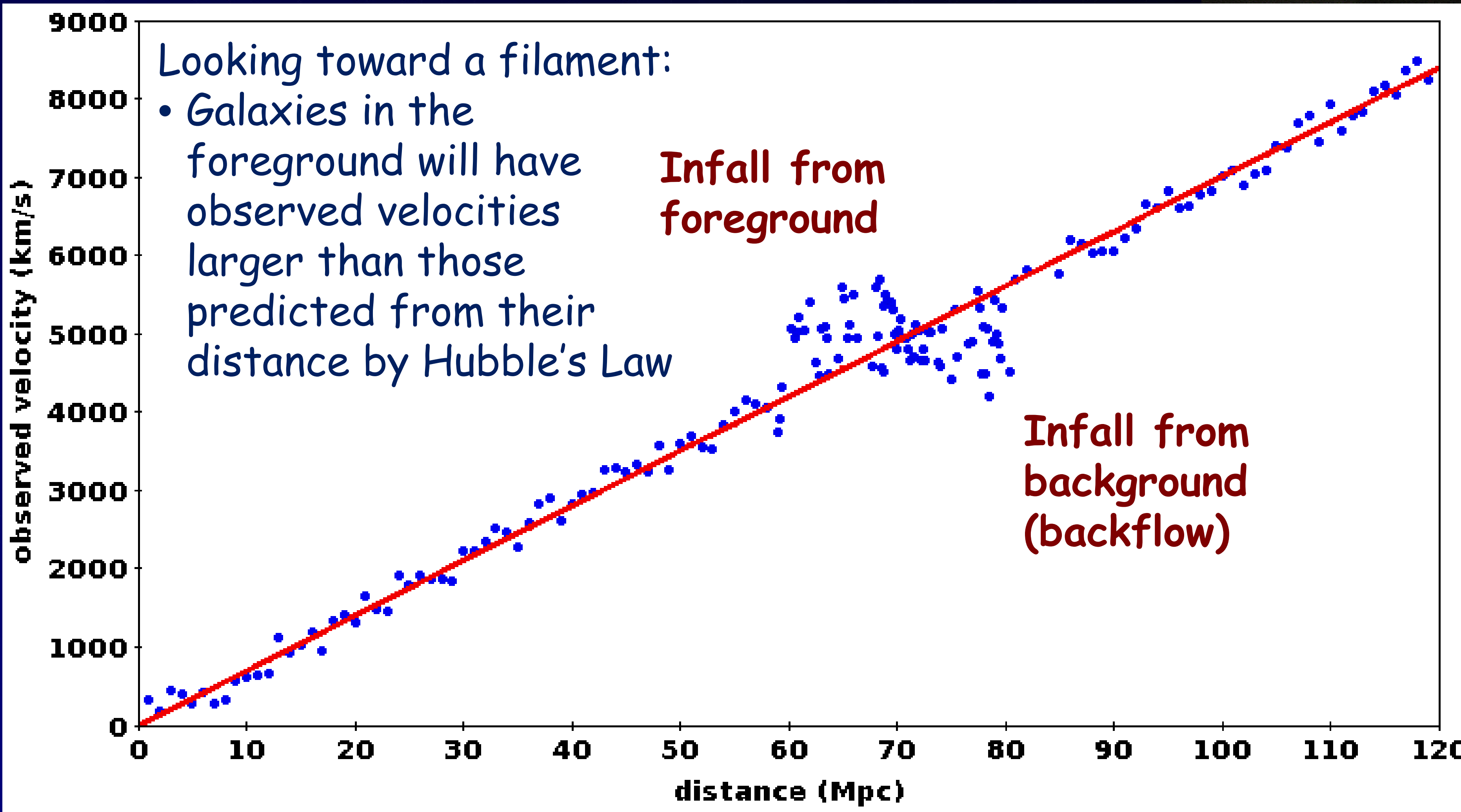
Signature of a cluster



Signature of infall/backflow

Looking toward a filament:

- Galaxies in the foreground will have observed velocities larger than those predicted from their distance by Hubble's Law



Measuring peculiar velocities

"Peculiar velocities"

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

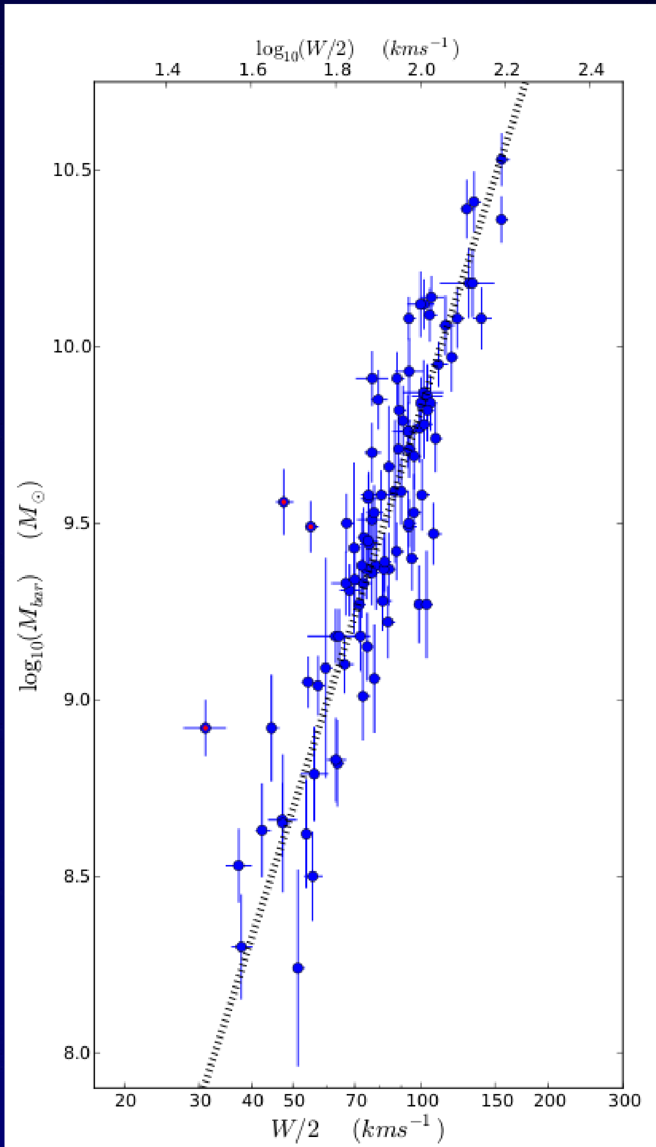
$$V_{Hubble} = H_o D$$

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

- 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.



Baryonic Tully-Fisher Relation (BTFR)

- The rotational velocity of a disk galaxy is related to its baryonic mass.

- The BTFR can be used to predict the galaxy's baryonic mass if its rotational velocity is measured.

- This is turn allows the possibility to predict the distance to the galaxy independent of the redshift.
  - Predict velocity from distance
  - Compare to observed velocity
  - Recover "peculiar velocity"

Papastergis+ 2016 A&A 593, A39

BTFR => Peculiar Velocities

"Peculiar velocities"

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

$$V_{Hubble} = H_o D$$

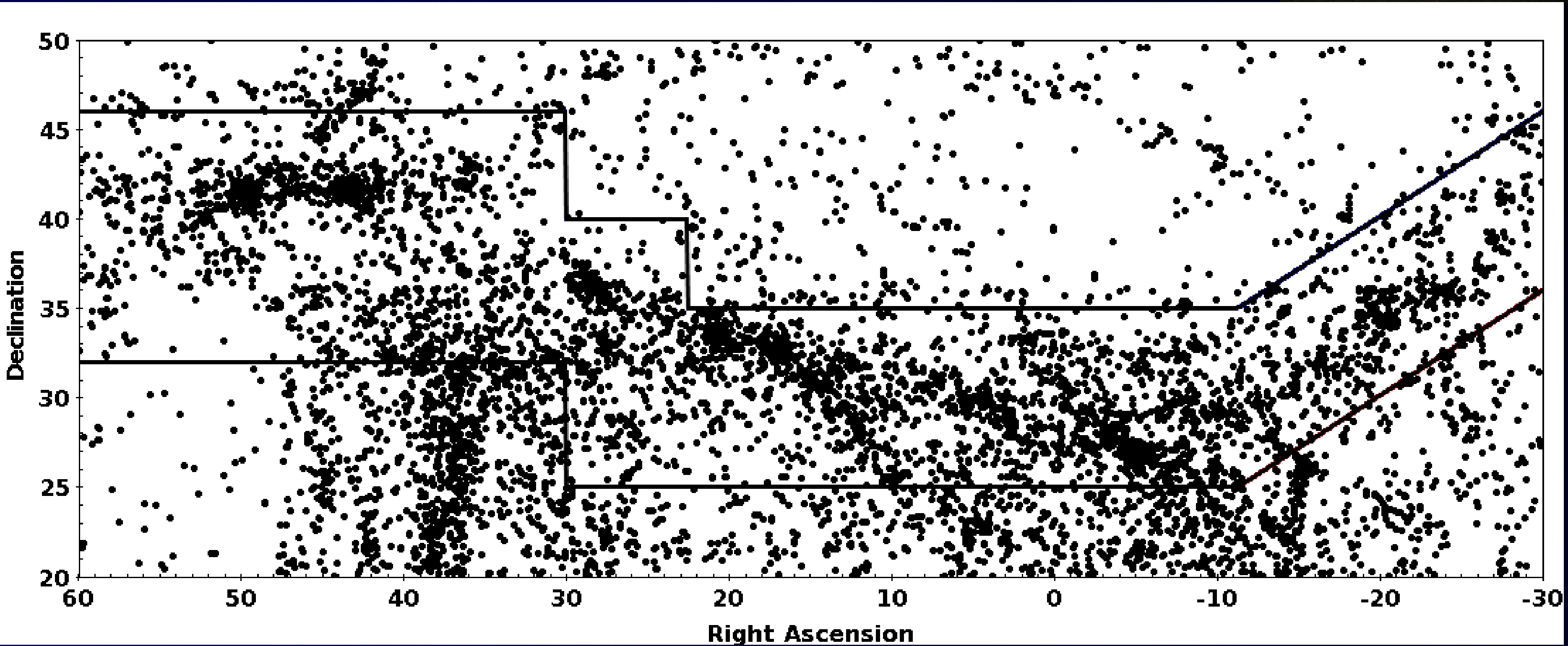
$$V_{pec} = V_{obs} - H_o D$$

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

This is what the APPSS aims to do.

(of course, it's more complicated in practice than it sounds)

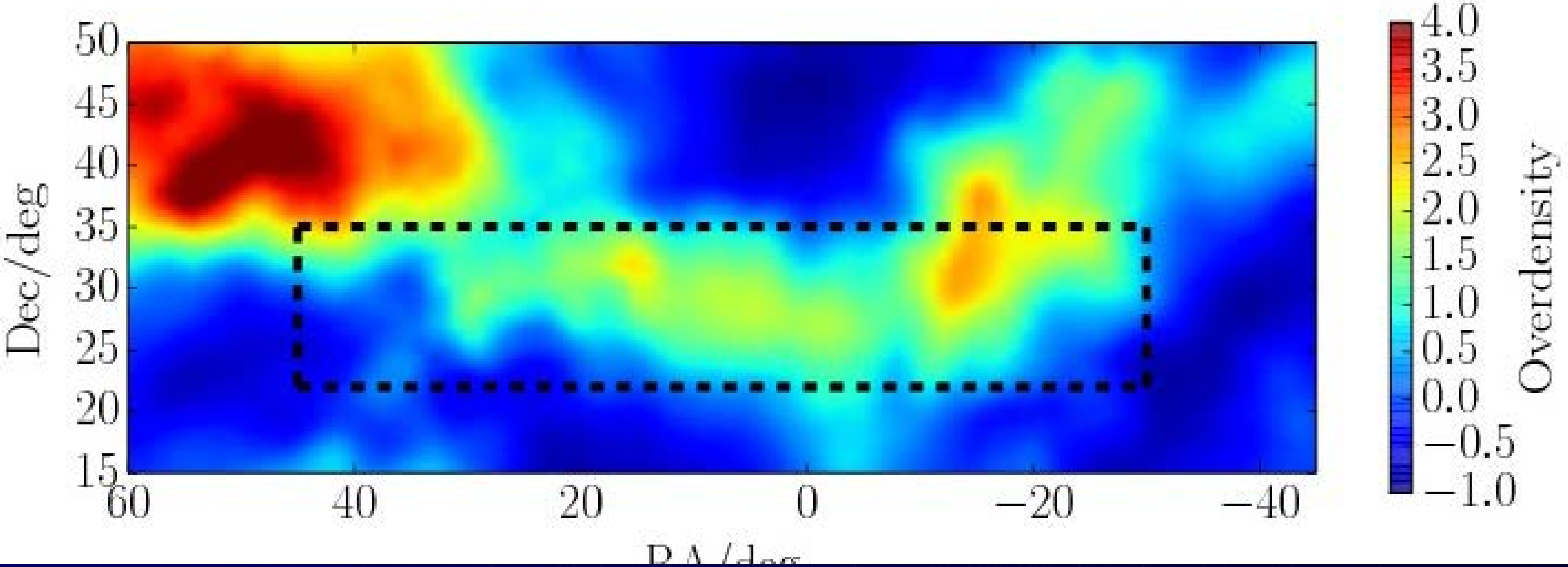
The Pisces-Perseus Supercluster



Strong overdensity of galaxies
Nearly perpendicular to the line of sight

The Arecibo Pisces-Perseus Supercluster Survey

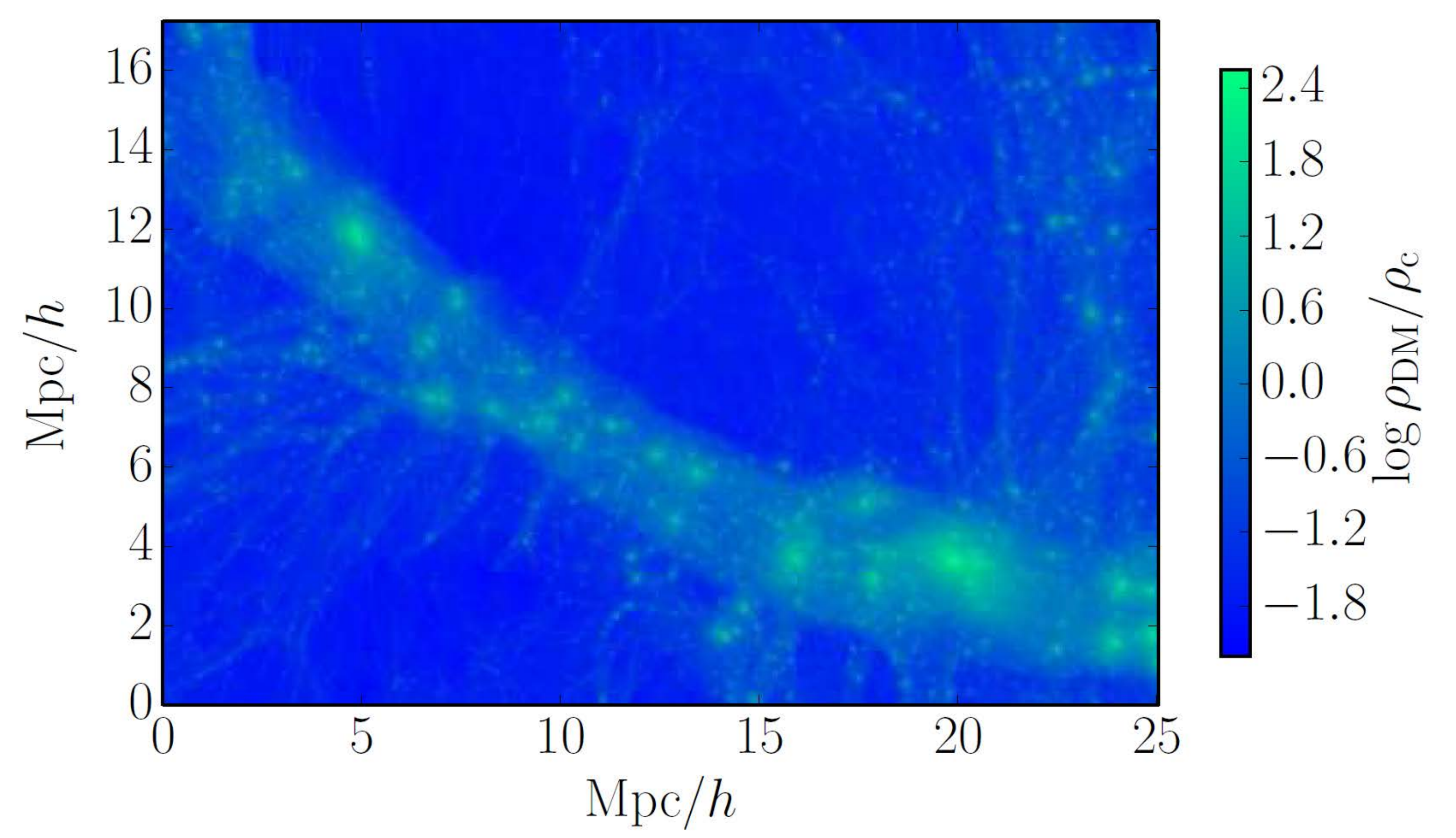
The APPS survey or the APPSS



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

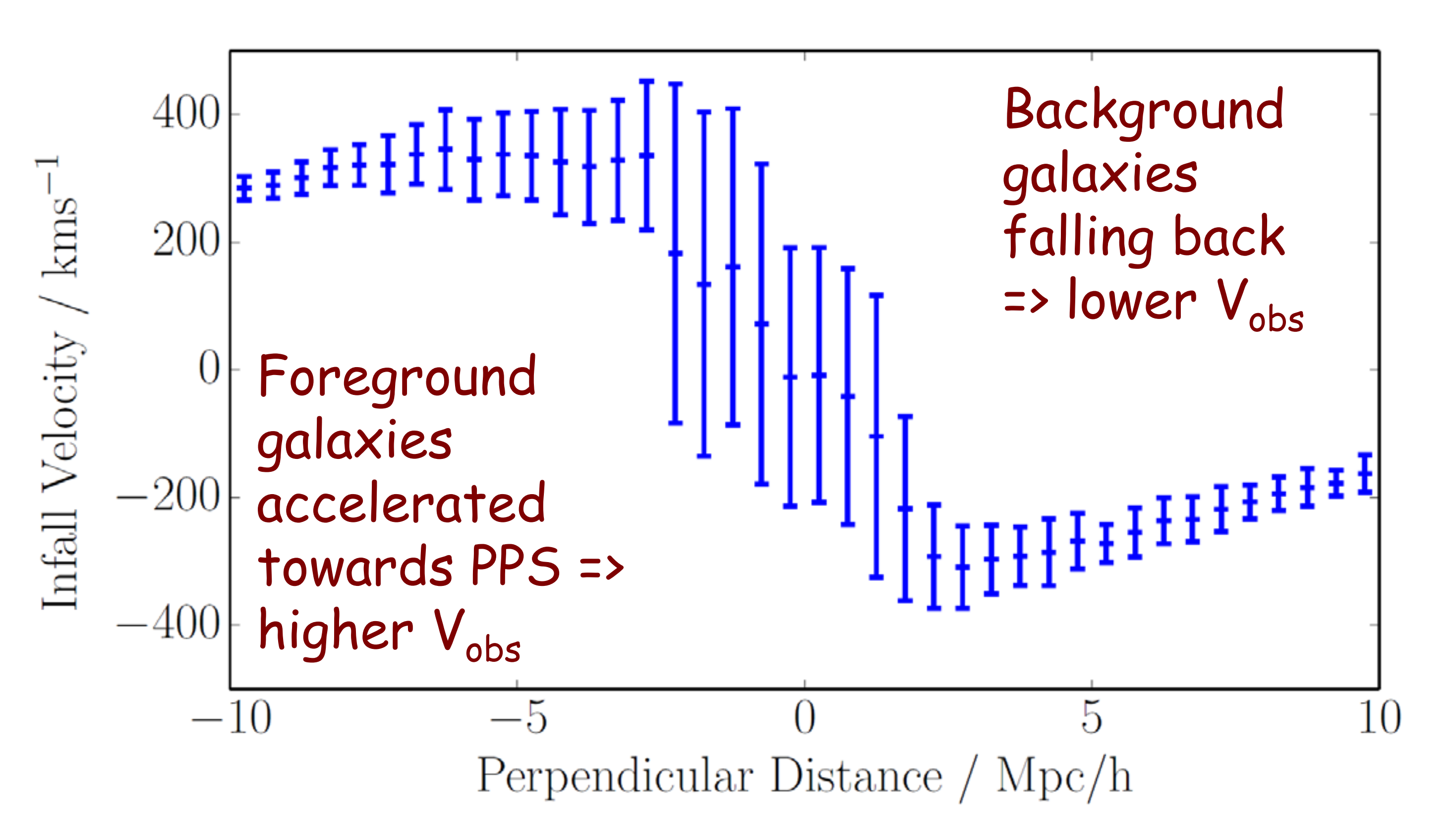
A Filament in the Illustris Simulation



Stay tuned for Jeremy's talk on simulations

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.

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 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