The Arecibo Pisces-Perseus Supercluster Survey

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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 $< 50 \text{ Mlyr}$

The Local Group is NOT at the center (except to us).
Large scale structure < 1 Glyr

Pisces-Perseus Supercluster

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

Atlas of the Universe
Large scale structure < 1 Glyr

Pisces-Perseus Supercluster

“A Metagalactic Cloud” between Perseus and Pegasus
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Atlas of the Universe
The Pisces-Perseus Supercluster
The Pisces-Perseus Supercluster

Atlas of the Universe

UAT19.06
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 513, 71
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: \( V_{\text{obs}} = H_0 D \)
where \( H_0 \) is Hubble’s “constant” and \( D \) is distance in Mpc

\( H_0 \approx 70 \text{ km/s/Mpc} \)
Deviations from Hubble Flow

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

“Peculiar velocities”

\[ V_{\text{obs}} = V_{\text{Hubble}} + V_{\text{pec}} \]

\( V_{\text{pec}} \) includes components of:
- Orbital motion in cluster/group
- Infall/outflow from regions of over/under-density
- “noise” on the pure Hubble flow

Trace \( V_{\text{pec}} \) ⇔ Trace mass

Tully et al 2014 Nature
Large scale structures produce local departures from the smooth Hubble expansion so that

\[ V_{\text{obs}} = V_{\text{hubble}} + V_{\text{pec}} \]
Large scale structures produce local departures from the smooth Hubble expansion so that

\[ V_{\text{obs}} = V_{\text{hubble}} + V_{\text{pec}} \]

Clusters produce large departures due to orbital motions

\[ V_{\text{obs}} = V_{\text{hubble}} + V_{\text{orb}} + V_{\text{pec}} \]
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

Infall from foreground

Infall from background (backflow)
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.
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"

\[ V_{obs} = V_{Hubble} + V_{pec} \]
\[ V_{Hubble} = H_0 D \]
\[ V_{pec} = V_{obs} - H_0 D \]

• 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 $v_{\text{Helio}}$ 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 $+23 < \text{Dec} < +35$
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.

Foreground galaxies accelerated towards PPS => higher $V_{\text{obs}}$

Background galaxies falling back => lower $V_{\text{obs}}$
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