Searching for Stellar Counterparts to ALFALFA Ultra-Compact High Velocity Clouds with WIYN / pODI

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Overview

While simulations of structure formation in a ΛCDM universe predict large numbers of low-mass dark matter halos, observational campaigns have not yet found sufficient numbers of faint, low-mass galaxies to match the models. The ALFALFA neutral hydrogen (HI) survey has detected a sample of isolated ultra-compact high-velocity clouds (UCHVCs) with kinematic properties that make them likely members of the Local Volume. The UCHVCs have properties similar to other known ultra-faint dwarf galaxies like Leo T (at 1 Mpc, HI masses of ~10^5-10^6 M_{sun}, HI diameters of ~2-3 kpc, and dynamical masses of ~10^7-10^8 M_{sun}). We have begun a campaign to obtain deep optical images of the UCHVCs using the pODI camera on the WIYN 3.5m telescope. Here we describe a method of searching for optical counterparts to the UCHVCs. **We show an example of the pODI data and also demonstrate our method using the recently-discovered UCHVC counterpart Leo P.**

Filtering & Smoothing

We follow the examples of Walsh et al. (2009) and Adams (2014) and apply the CMD filter shown in Figure 1 to our photometric data, sampling a set of distances between 300 kpc and 2.5 Mpc. Filter membership is defined as the star itself or any part of its 1-σ photometric error bars falling within the boundaries of the filter; this results in a wider filter with fainter magnitudes. We then smooth the (RA, Dec) distribution of the filtered stars by binning the positions into a 2-dimensional grid, and convolve the grid with a Gaussian distribution with a FWHM chosen to represent the expected spatial scales of observed compact dwarf galaxies like Leo T and Leo P. Pixels with higher values have higher densities of stars, and we expect a dwarf galaxy to have a relatively large continuous area of pixels with high counts. **See Figure 4 for an example of the results of this process for Leo P.**

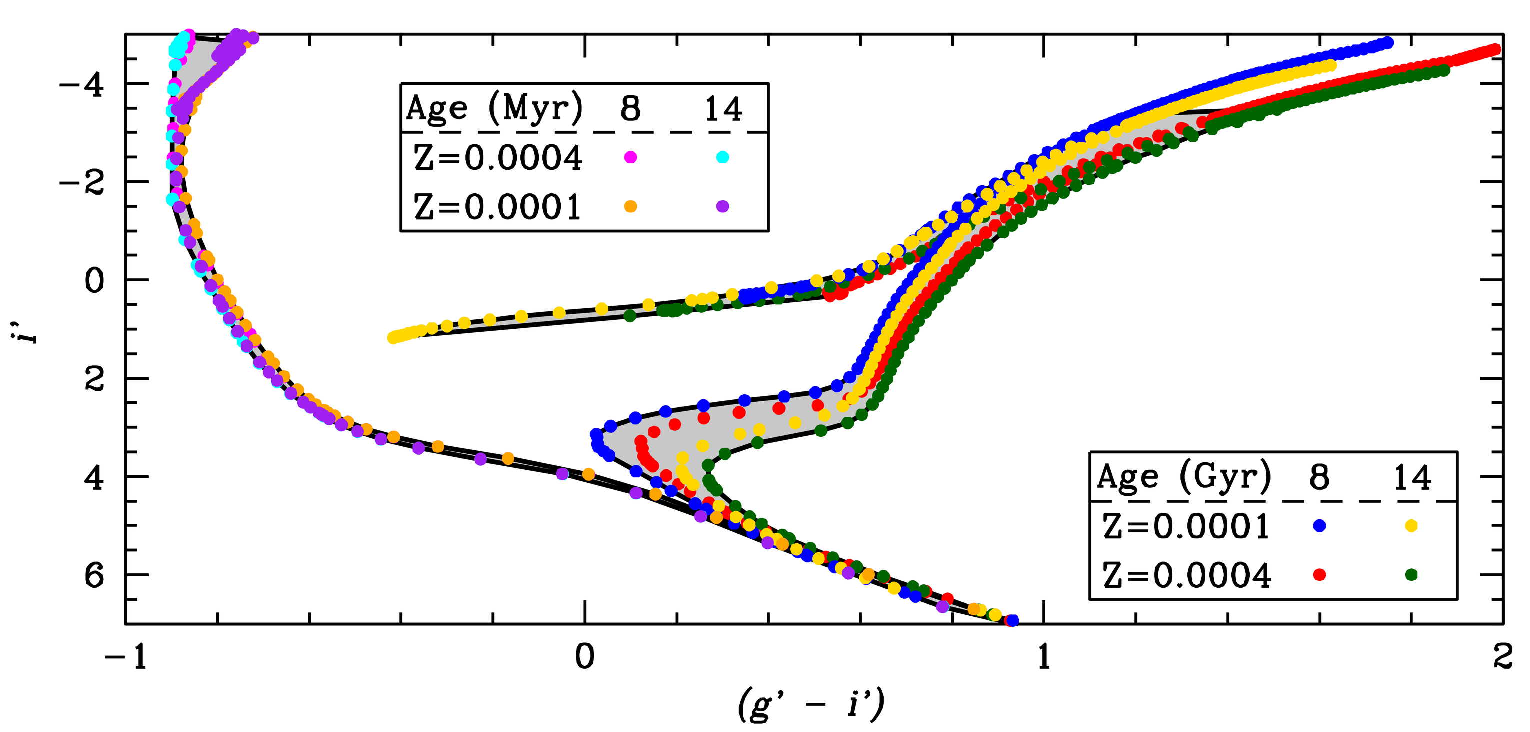

Figure 1: Color-magnitude filter construction. From Girardi et al. (2004), we select isochrones with metallicities Z = 0.0004 and Z = 0.0001, and ages representative of both young and old stellar populations. Using the g' and i' isochrones, we define the young and old population color-magnitude filters to be (roughly) the greatest extent allowed by these isochrones, ignoring the AGB for the older populations, and everything after the MS turnoff for the younger population. The final filter regions are shaded gray.

Data Acquisition & Reduction

We use the WIYN pODI camera to obtain g' and i' images of the UCHVC targets identified in ALFALFA. Currently the pODI camera has a 24' x 24' field-of-view (FOV) and a pixel scale of 0.11" pixel^{-1}. Beginning in 2015 the upgraded ODI camera will have a FOV of ~48' x 48'. Typical exposure times are 2700s each in g' and i'. Raw images from WIYN/pODI are transferred to the ODI Portal, Pipeline, and Archive (ODI-PPA) at Indiana University and processed using the QuickReduce pipeline (Kotulla 2014) to remove the instrumental signature. Images are then illumination-corrected, scaled, and stacked. SDSS stars are used to photometrically calibrate the data. Sources are identified with the IRAF task DAOFIND and the source lists in g' and i' are matched. We remove extended sources from the matched list, and calculate calibrated g'_0 and i'_0 magnitudes for the remaining point sources. The 5-σ limit on a point source in a typical image in our data set is ~25 mag in both g' and i'. **We show an example image below.**

WIYN/pODI Image Example: AGC226067

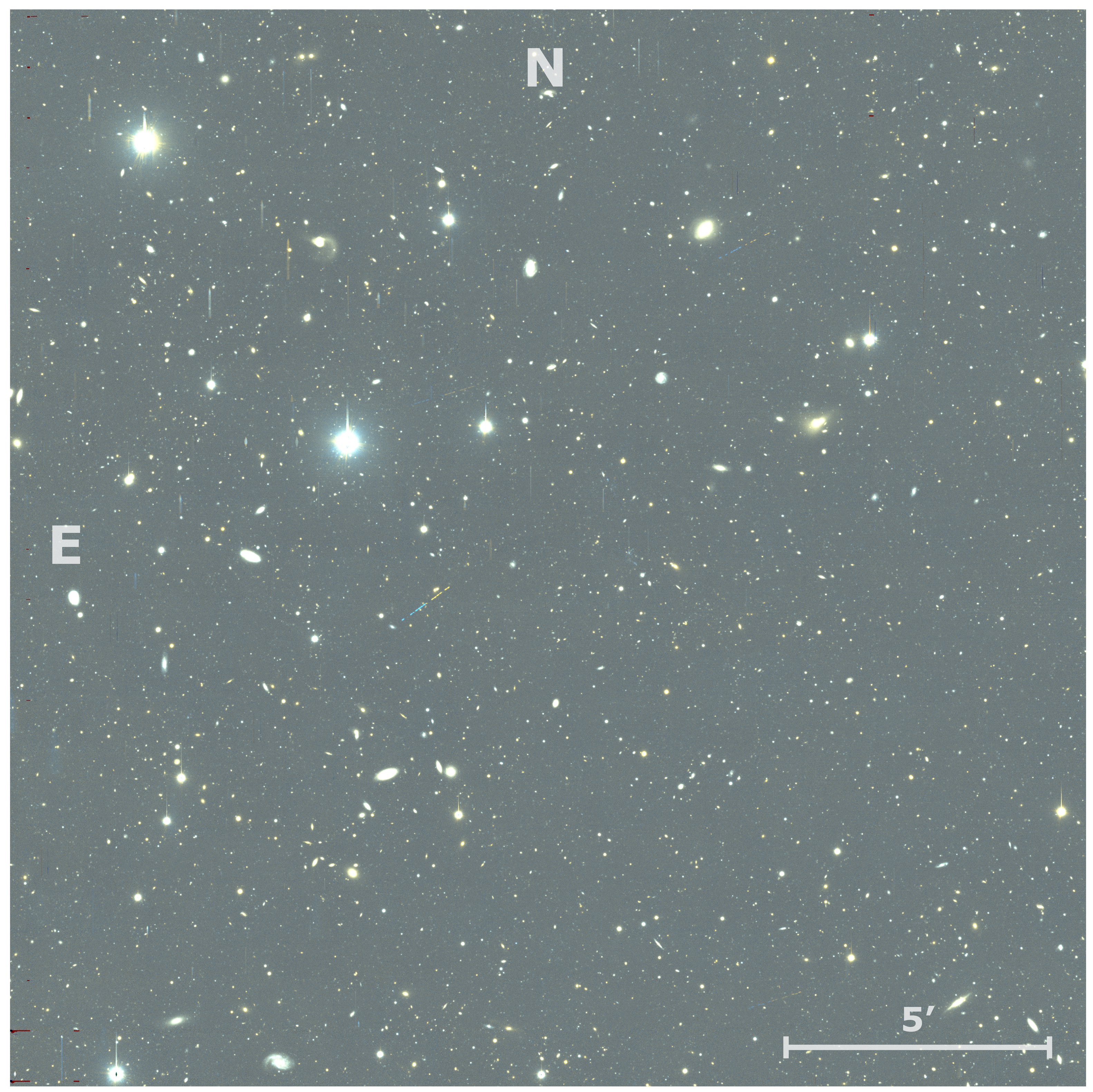

Figure 2: WIYN pODI $g'i'$ image of AGC226067. An example 20'x20' image from our UCHVC observing campaign (see Adams et al. 2013). Exposure times in each filter are 2700 seconds. Both the g' and i' image have ~0.7" seeing, and have a 5-σ detection limit of 25.5 mag and 24.8 mag, respectively. The ALFALFA detected HI cloud associated with AGC226067 is ~5 arcmin in size, with a mass of 2 x10^5 M_{sun}, and is approximately centered in the field.

Leo P: A Case Study

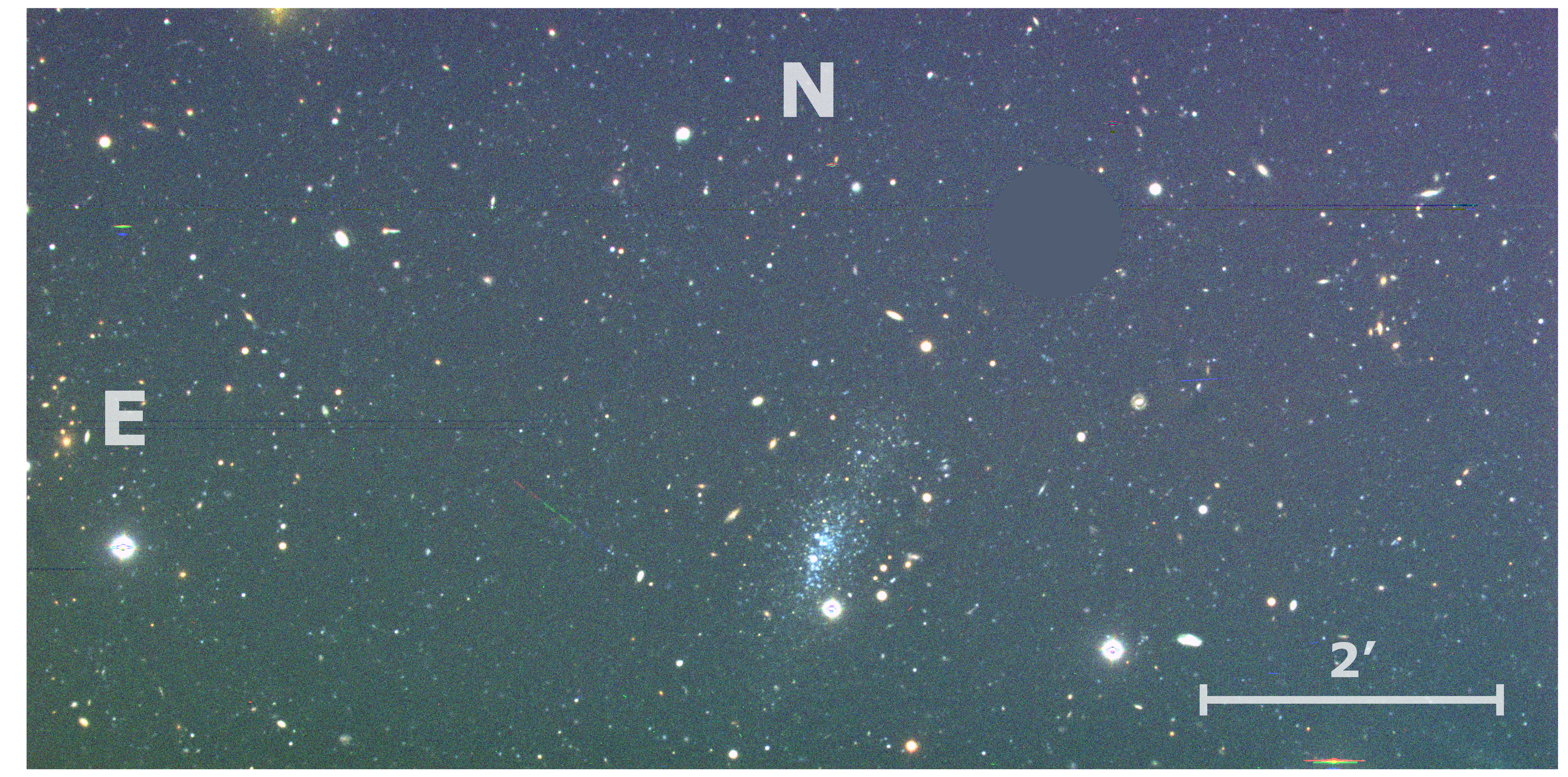

Figure 3: WIYN Minimosaic *BVR* image of Leo P. An example of a stellar counterpart to a UCHVC, Leo P was imaged in March 2012 (Rhode et al. 2013). We converted the Minimosaic *BVR* data to g' and i' photometry and used this field as a test of our method. **(see Figure 4)**

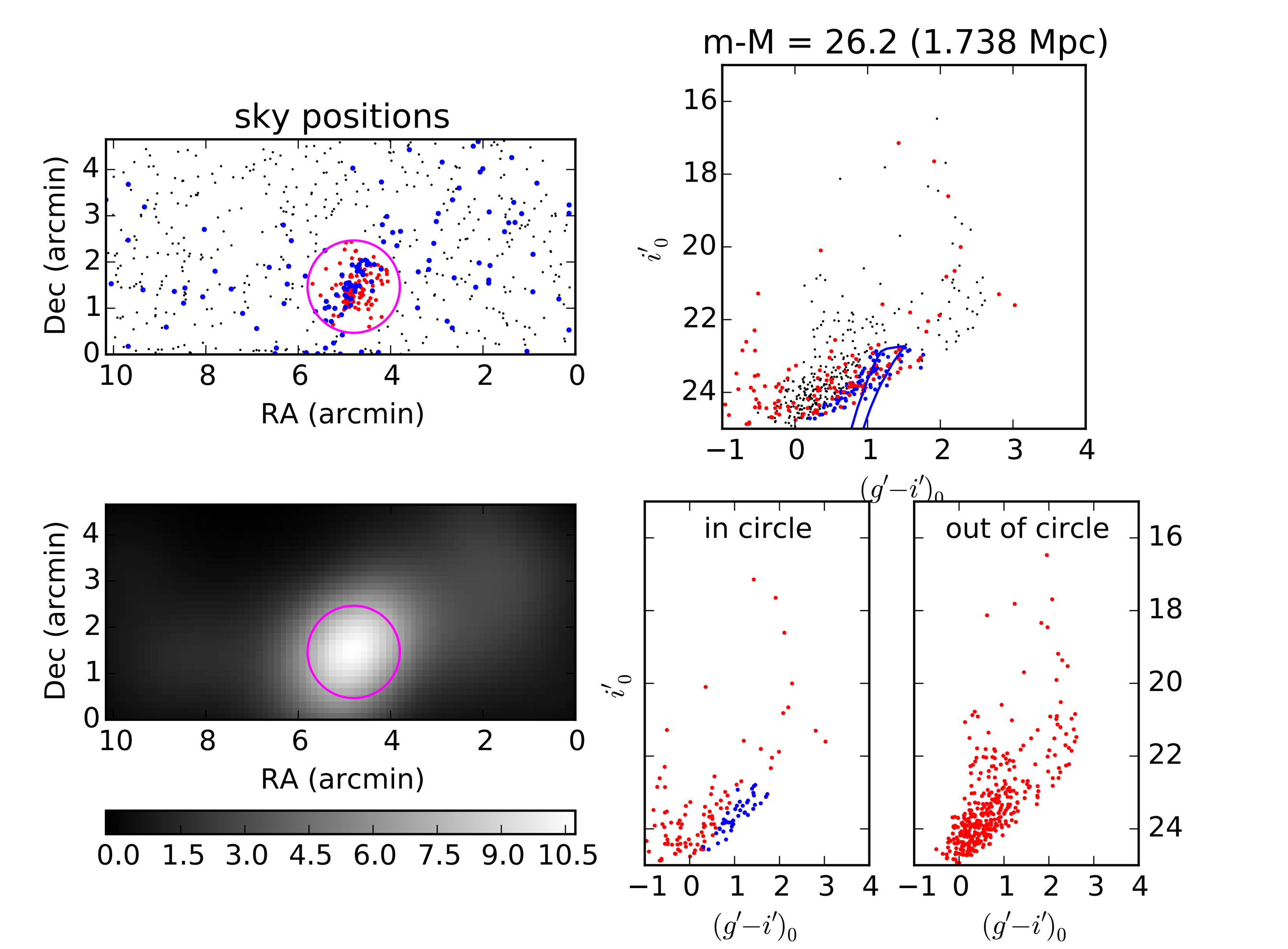

Figure 4: Method applied to Leo P. With the old population (RGB) filter shifted to Leo P's distance modulus of 26.2 (McQuinn et al. 2014), we select stars in the CMD filter (blue points) and place a 2 arcmin diameter circle at the peak shown in the bottom left panel. Red points are stars inside the circle but not in the filter. We also include a CMD of stars inside and outside of the circle.

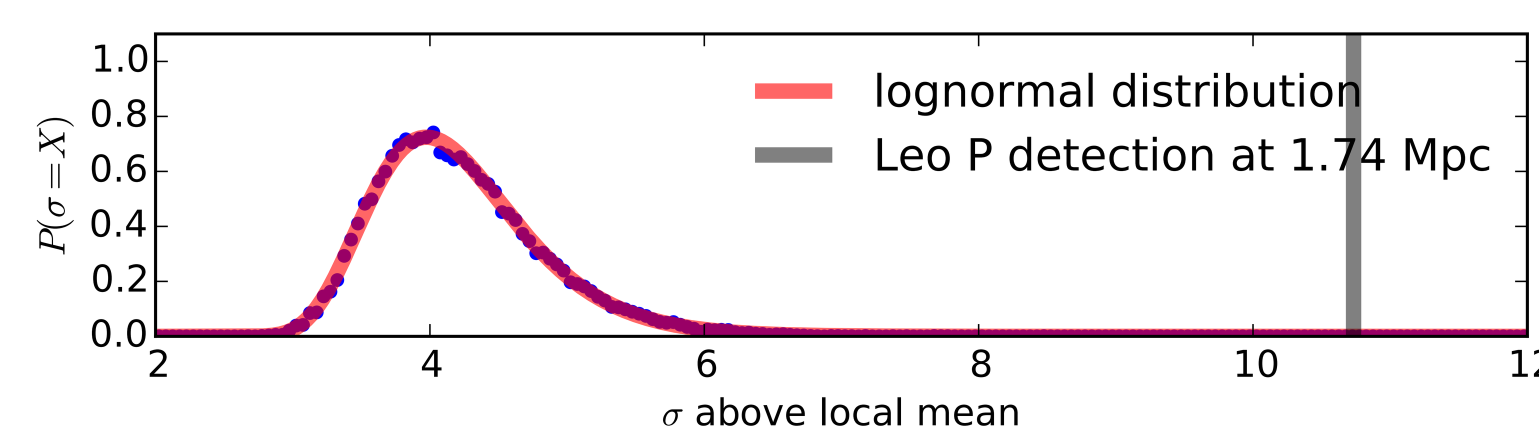

Figure 5: Significance testing. To check the significance of the detection, we create 25000 uniformly randomly distributed samples with the same number of points as we found in the filter and measure the peak σ value for each sample. We binned these peak values (blue points) and overlaid a probability distribution function with parameters derived directly from the data (red line). The data is well fit by a lognormal distribution. We also see that the Leo P detection is more significant than 100% of the random samples.

References

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