Clusters of Galaxies from MUNICS, the Munich Near-Infrared Cluster Survey

We present a new structure finding technique specialized for photometric redshift catalogues which we developed on the basis of the well known friends-of-friends algorithm. We tested the plausibility of the resulting galaxy group and cluster catalog with the help of colour-magnitude diagrams as well as a generalised likelihood- and Voronoi-approach.
We use this extended friends-of-friends algorithm to detect groups and clusters of galaxies in the Munich Near-Infrared Cluster Survey (MUNICS). Our final catalogue contains a total of 162 structures with mean redshifts $0.13 \leq z \leq 1.34$ with a few spectroscopic verifications.

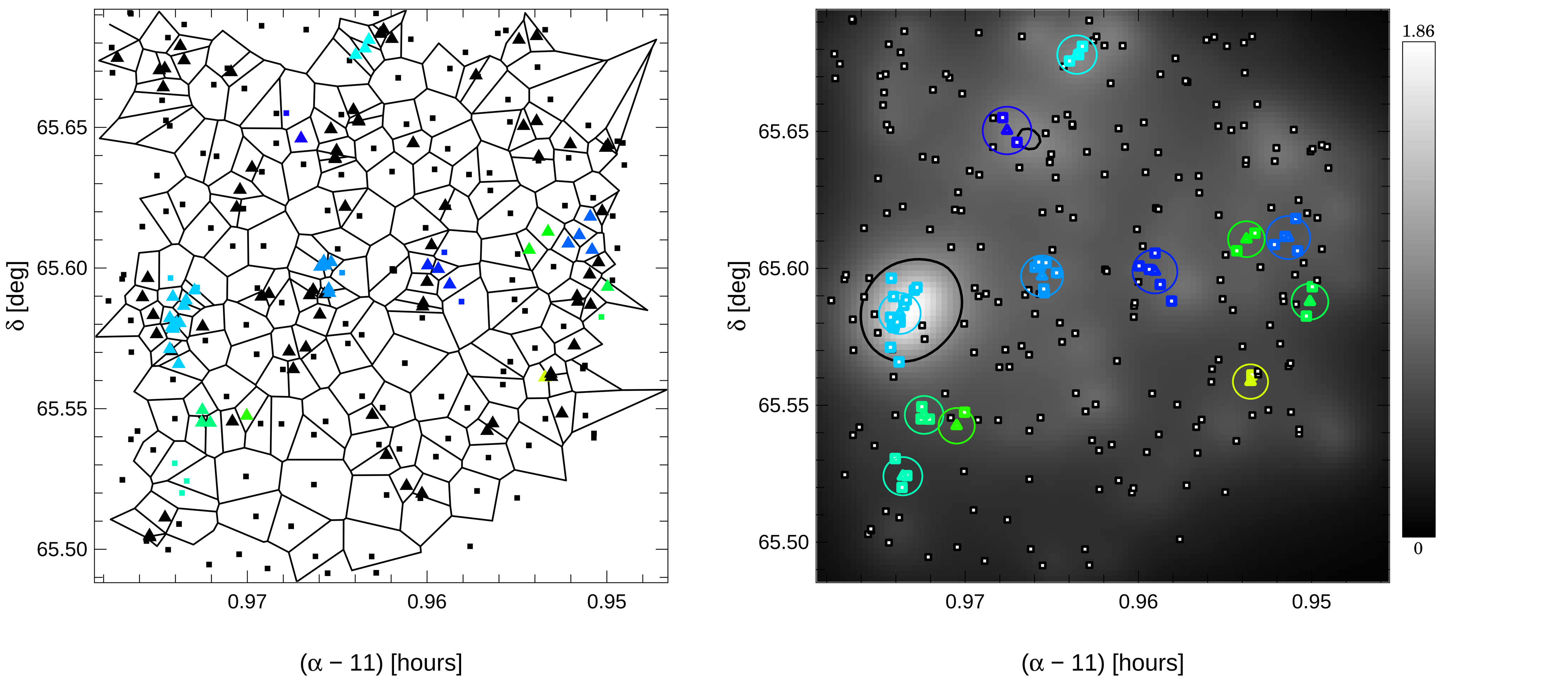
The Extended Friends-of-Friends Algorithm

So far, friends-of-friends algorithms (Huchra & Geller, 1982) were designed to find galaxy groups and clusters by looking for number density enhancements in spectroscopic redshift surveys or numerical simulations (Nolthenius & White, 1987).
Due to the comparatively large uncertainties of photometric redshifts, the original friends-of-friends technique has to be modified for application to photometric redshift surveys like MUNICS. This "extended friends-of-friends" algorithm (Botzler et al., 2004) incorporates the following features:

- It takes into account that galaxies have redshift errors.
- The algorithm looks for friends compatible with an a priori redshift on a redshift grid, spanning the depth of the survey.
- After running on the grid, the code unifies structures found in individual redshift bins, if structures have at least one member in common.

The Munich Near-Infrared Cluster Survey (MUNICS)

The Munich Near-Infrared Cluster Survey (MUNICS) is a wide-field medium-deep imaging survey in the near-infrared and optical initially described in Drory et al. (2001) and Snigula et al. (2002). Dedicated follow-up spectroscopy is available for $\sim$ 600 galaxies (Feulner et al., 2003). The main part of the survey consists of 10 fields . For all these fields photometry in K', J, I, R, V and B is available, with limiting magnitudes ranging from $K' \simeq 19.0$ to $B \simeq 24.0$ (50% completeness for point sources). The total area of this part of the survey is 1146.3 square arcmin (or 0.32 square degrees).



*Voronoi and likelihood maps for a $z \simeq 0.60$ extended friends-of-friends structure in one of the MUNICS fields. **Left panel:** Voronoi tessellation map for all galaxies compatible with $z = 0.60$. Squares mark underdense cells, triangles symbolize overdense cells. All members of structures found by the extended friends-of-friends algorithm are plotted coloured. **Right panel:** Likelihood map for $z_i = 0.60$ (greyscales; white signifies higher likelihoods) Black contours signify areas with an enhanced likelihood of $\ln L \geq 1$. The likelihood scale is shown to the right. The graphic also depicts all galaxies compatible with the grid redshift (squares). All members of extended friends-of-friends structures are again plotted coloured. The structure centers and $1r_c$ apertures are marked by coloured triangles and rings. The large cluster to the left is verified using six spectroscopic members.*

Most of the research so far has been focused on field galaxy evolution (Drory et al., 2001, 2003, 2004; Feulner et al., 2003, 2005). However, the survey is also ideally suited (and was indeed initially designed) for detecting clusters of galaxies out to redshifts of unity.

Galaxy Clusters in MUNICS

We use the extended friends-of-friends algorithm described above to search for structures (groups and clusters) in the MUNICS catalogue.
As shown in the Figures, we use a number of tools which allow the optimisation of the cluster finding parameters, as well as a rough separation of plausible clusters from any spurious detections. These tools include the creation of Voronoi tessellations (e.g. Ramella et al. 2001) and the calculation of the likelihood (e.g. Postman et al. 1996) for having a cluster at a given coordinate in the dataset.
The final MUNICS structure catalogue contains a total of 162 structures with mean redshifts $0.13 \leq \overline{z} \leq 1.34$ (Botzler et al., 2005). This corresponds to a mean structure number density of $6.5 \cdot 10^{-4} h^3 \mathrm{Mpc}^{-3}$ within the most sensitive redshift range for MUNICS structures $0.3 \leq \overline{z} \leq 0.8$, and a flat cosmology with $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$. Considering a spurious detections rate of about 40% (Botzler et al., 2004), this density reduces to $3.9 \cdot 10^{-4} h^3 \mathrm{Mpc}^{-3}$, a value that agrees well with the typical group densities of $(10^{-5} - 10^{-3})\, h^3 \mathrm{Mpc}^{-3}$, and is higher than the characteristic cluster densities of $(10^{-6} - 10^{-5})\, h^3 \mathrm{Mpc}^{-3}$ (Bahcall, 1999).

Of the 33 structures having enough spectra to try a verification, 15 (45.5%) are confirmed, only one structure is proven spurious. For the remaining 17 candidates no conclusions about their authenticity can be drawn yet.
In summary our algorithm has shown to be a very efficient tool for structure finding, capable of detecting real structures in photometric redshift datasets. In contrast to Voronoi based cluster finders, it can also be applied to sparsely sampled galaxy surveys. Furthermore, unlike any likelihood-based techniques, our algorithm does not include cluster models, and thus is relatively unbiased towards atypical structures.

References

Bahcall N. A., 1999, in Formation of Structure in the Universe Clusters and superclusters of galaxies. p. 135

Botzler C., Snigula J., Bender R., Feulner G., Goranova Y., Hopp U., 2005, MNRAS, submitted

Botzler C. S., Snigula J., Bender R., Hopp U., 2004, MNRAS, 349, 425

Drory N., Bender R., Feulner G., Hopp U., Maraston C., Snigula J., Hill G. J., 2003, ApJ, 595, 698

Drory N., Bender R., Feulner G., Hopp U., Maraston C., Snigula J., Hill G. J., 2004, ApJ, 608, 742

Drory N., Bender R., Snigula J., Feulner G., Hopp U., Maraston C., Hill G. J., Mendes de Oliveira C., 2001, ApJL, 562, L111

Drory N., Feulner G., Bender R., Botzler C. S., Hopp U., Maraston C., Mendes de Oliveira C., Snigula J., 2001, MNRAS, 325, 550

Feulner G., Bender R., Drory N., Hopp U., Snigula J., Hill G. J., 2003, MNRAS, 342, 605

Feulner G., Goranova Y., Drory N., Hopp U., Bender R., 2005, MNRAS, 358, L1

Huchra J. P., Geller M. J., 1982, ApJ, 257, 423

Nolthenius R., White S. D. M., 1987, MNRAS, 225, 505

Postman M., Lubin L. M., Gunn J. E., Oke J. B., Hoessel J. G., Schneider D. P., Christensen J. A., 1996, AJ, 111, 615

Ramella M., Boschin W., Fadda D., Nonino M., 2001, 368, 776

Snigula J., Drory N., Bender R., Botzler C. S., Feulner G., Hopp U., 2002, MNRAS, 336, 1329

C.S. Botzler, J. Snigula, R. Bender, G. Feulner, Y. Goranova, U. Hopp

Universitäts–Sternwarte München & Max–Planck–Institut für extraterrestrische Physik