Construction of a highly complete catalog of galaxy groups/clusters from an all-sky spectroscopic survey in the local universe

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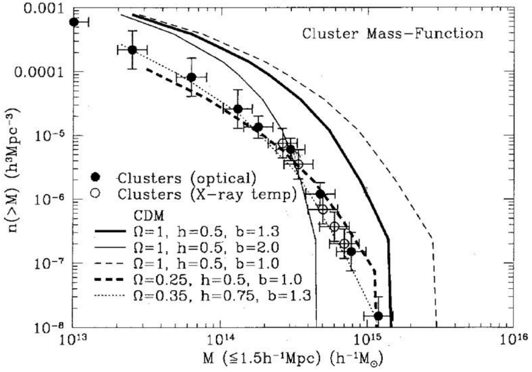
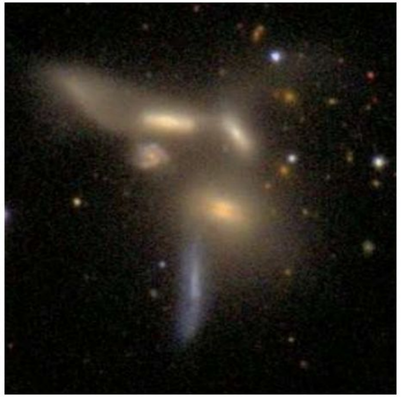
Galaxy groups/clusters in the local universe

- Why galaxy groups/clusters?
  - Cosmological probes - e.g. Cluster mass function
  - Densest environment of galaxies - e.g. Environmental effects on galaxy formation/evolution?
- Why local universe
  - The impact of dark energy on structure growth is strongest
  - observations of individual galaxies in great detail are possible for follow-up studies
- We need
  - Large volume (cosmological) simulation data
  - Wide, uniform spectroscopic galaxy survey data*

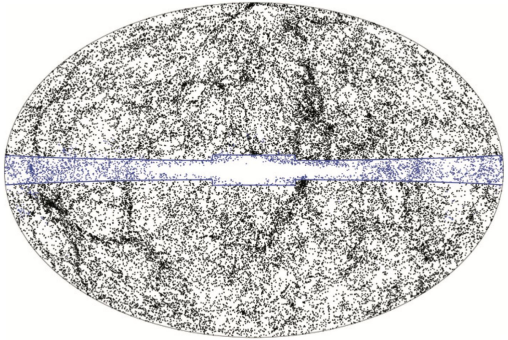
Bahcall and Cen (1993)





Alonso+(2012)

2MASS Redshift Survey (2MRS)


Huchra+(2012)

- 2MRS has mapped the distribution of galaxies in the local universe based on galaxy selection in the NIR from 2MASS.
  - Two Micron All-Sky Survey (2MASS) has mapped the all sky in the NIR J, H and K bands (complete Ks<~13.5)
  - 97.6% complete at Ks<11.75 and 91% sky coverage
  - 44,599 galaxies and |b|>5deg (>8deg toward the Galactic bulge)

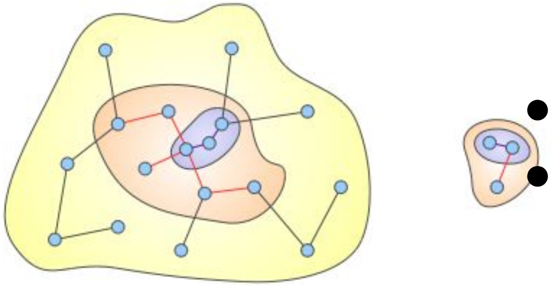
2MRS galaxy group/cluster catalog

- Lavaux & Hudson (2011)
- Tully (2015)
- Lu+(2016), Lim+(2017)
- Crook+(2017)
- Tempel+(2018)
- Lambert+(2020)

Group finding algorithm

- Lavaux & Hudson (2011) - Friends-of-friends (FoF)
- Tully (2015) - Halo-based group finder
- Lu+(2016), Lim+(2017) - Halo-based group finder
- Crook+(2017) - FoF
- Tempel+(2018) - Bayesian group finder (marked point processes)
- Lambert+(2020) - Graph-theory based FoF

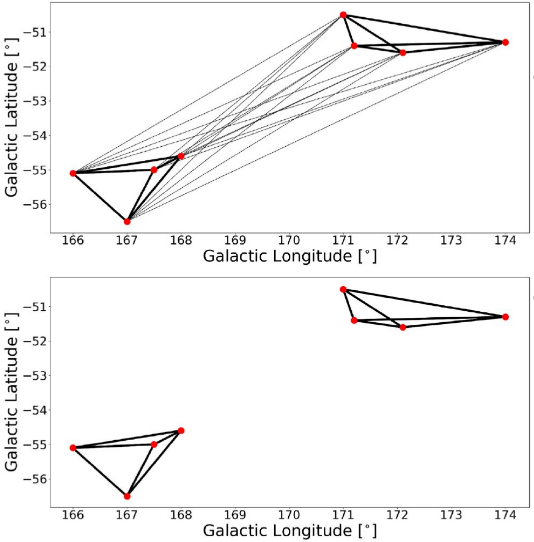
Friends-of-friends



cosmosim

- A variable linking-length percolation algorithm
- Two linking lengths should be introduced to take into account the redshift space distortion.
- These linking lengths are chosen somewhat arbitrary fashion.
- This algorithm can introduce systems that are not gravitationally bound.

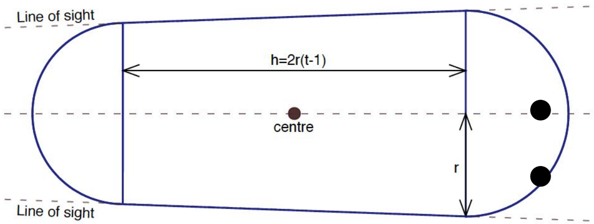
Graph-theory based FoF



Lambert+(2020)

- Drawbacks of the traditional FoF
  - A static parameter choice is unable to deal with the range in size, density, and dispersion of galaxy groups/clusters
  - The traditional FoF values all groups with the same confidence.
- A modified version of FoF that considers many different sets of linking lengths
  - With hard limits on the size of a FoF group (i.e. 2 Mpc, 3000 km/s)
  - To track galaxy-galaxy pairs through FoF runs of varying sets of linking length parameters (i.e. graph theory)
  - To weigh pairs depending on how often they appear in a same group among the runs

Bayesian group finder



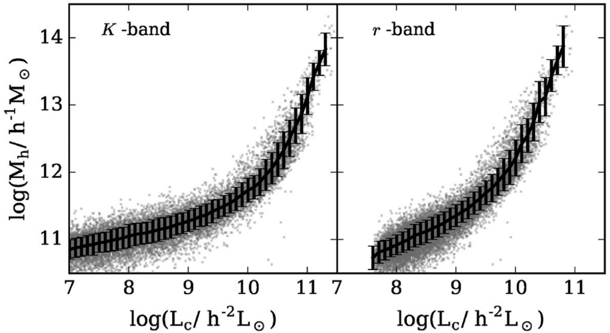
“Potato” that composes a cluster pattern (Tempel+2018)

- Probabilistic galaxy group detection algorithm
- Instead of focusing on the detection of points forming clusters, the spatial regions where those points belong to
- Based on marked point processes with interactions
- The probability becomes higher when there are more points in individual potatoes and potatoes are less overlapping.
- Implementable using Monte Carlo techniques

Halo-based group finder

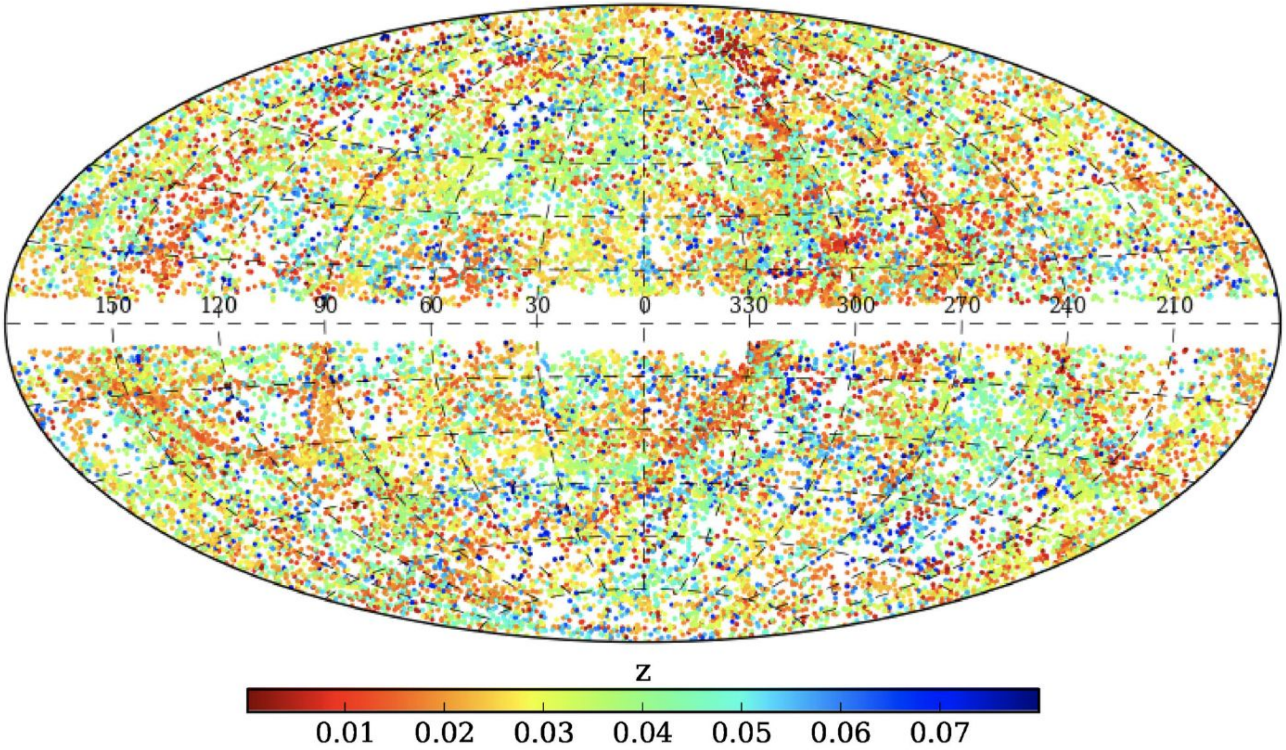
$$\frac{r_{180}}{\mathrm{Mpc}} = 1.33\, h^{-1} \left(\frac{M_h}{10^{14} h^{-1} M_\odot}\right)^{1/3} (1 + z_{\mathrm{group}})^{-1}$$

$$\frac{\sigma}{\mathrm{km\ s^{-1}}} = 418 \left(\frac{M_h}{10^{14} h^{-1} M_\odot}\right)^{0.3367},$$



- To identify groups based on dark matter halo properties
- Given knowledge of group mass, the group sizes (on the sky and along the line-of-sight) can be inferred, and galaxies within these sizes are group members.
  - The knowledge of group mass based on luminosity (and luminosity gaps in Lim+2017)
  - Iterative procedure until converged

2MRS Galaxy groups (Lim+2017)



2MRS Galaxy groups (Lim+2017)

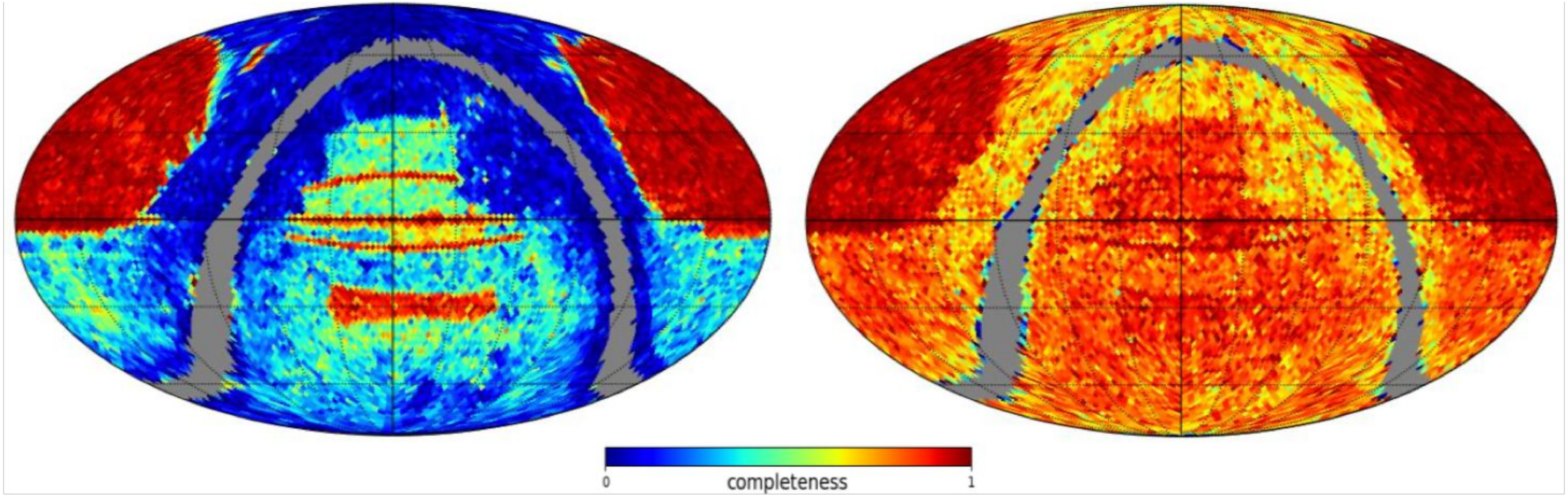
(1) group ID	(2) cen ID	(3) ra (deg)	(4) dec (deg)	(5) z	(6) $\log(M_h/h^{-1}\,M_{\odot})$	(7) N_{mem}	(8) f_{edge}	(9) i-o	(10) known as
1	15	187.74899	12.20402	0.00362	14.290	109	1.00	1	Virgo
2	486	243.52157	– 60.79748	0.01663	14.366	106	1.00	1	Norma
3	530	49.47894	41.53527	0.01748	14.297	92	1.00	1	Perseus
4	672	194.81308	27.97206	0.02476	14.639	88	1.00	1	Coma
5	386	192.33072	– 41.18290	0.01437	14.342	62	1.00	1	Centaurus
6	1094	258.01088	– 23.30095	0.03030	14.758	52	1.00	1	Ophiuchus
7	18	53.13952	– 35.56552	0.00492	14.097	48	1.00	1	Fornax
8	257	210.67554	– 33.83448	0.01527	14.534	47	1.00	1	–
9	608	17.31215	32.68145	0.01609	14.042	42	1.00	1	–
10	432	207.35991	– 30.43195	0.01628	14.220	41	1.00	1	–

Catalogue	Total galaxies	Total groups[a]	Total groups with reliable mass	$N^b = 1$	$N \geq 2$
2MRS(L)	43 249	30 937	18 650	13 311	5339

Spectroscopic completeness of the local universe

2MRS + SDSS

2MRS + SDSS + A-SPEC

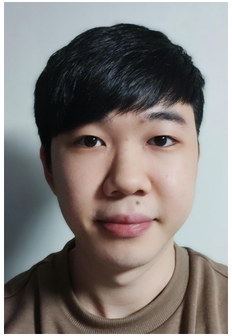


Completeness at Ks<13.75
(Jong Chul Lee)

(⚠️ could be out of date)

Test with A-Spec mock catalog (current status)

- Uchuu simulation (dark matter only)
  - (2000 Mpc/h)^3
  - 12800^3 particles
  - Mpart=3.27e8 Msun/h
- Galaxy painting
  - Simple abundance matching (Dr. Jihye Shin @ KASI)
  - Machine-assisted Semi-Simulation Model (Songyoun Park @ SNU)
  - Conditional luminosity function (Da Chan Kim @ CNU)
- Applications of group finding algorithms to the mock data
  - FoF, halo-based group finder
  - To optimize parameters (e.g. linking lengths, relations between luminosity and group mass) to find genuine groups/clusters
  - To forecast the impact of A-Spec on constructing a complete/reliable group/cluster catalog of the local universe



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