An Extended List of Galaxies for Gravitational-Wave Searches in the Advanced Detector Era

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Outline

Motivation

Main motivation: to support EM follow-up efforts. Most important parameters are B *mag*, z and possibly IR magnitudes (they correlate with the stellar mass of the galaxy [1]).
Recently more galaxy catalogs became available for the same purpose such as CLU [2], our project is independent from them.

Catalog used in the initial detector era: GWGC [3]

- Contains 53,255 galaxies
- Complete out to 40 Mpc

Higher completeness (even out to $\sim$ 300 Mpc) is needed in the advanced detector era. [4]

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[1] Wen, X-Q., Wu, H., Zhu, Y.-N. et al., 2013, MNRAS, doi:10.1093/mnras/stt939

[2] Gehrels, N., Cannizzo, J. K., Kanner, J. et al., 2015, submitted to ApJ http://arxiv.org/abs/1508.03608

[3] White, D. J., Daw, E. J. & Dhillon, V. S., 2011, Class. Quantum Grav., **28** 085016

[4] Evans, P. A, Osborne, J. P., Kennea, J. A. et al., 2015, astro-ph/1506.01624

Catalogs used

2MASS XSC [1]

- 1,646,844 galaxies
- contains no distances or B-band magnitude

2MPZ (value added, 2MASS + WISE + SuperCOSMOS) [2]

- 928,353 galaxies
- photometric redshift and B-band magnitude for every galaxy

HyperLEDA [3]

- 836,388 galaxies
- we improved galaxy-quasar separation and left out quasars

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[1] http://www.ipac.caltech.edu/2mass/

[2] Bilicki, M., Jarrett, T. H., Peacock, J. A. et al., 2014, ApJS, **210** 16 pp.

[3] http://leda.univ-lyon1.fr/

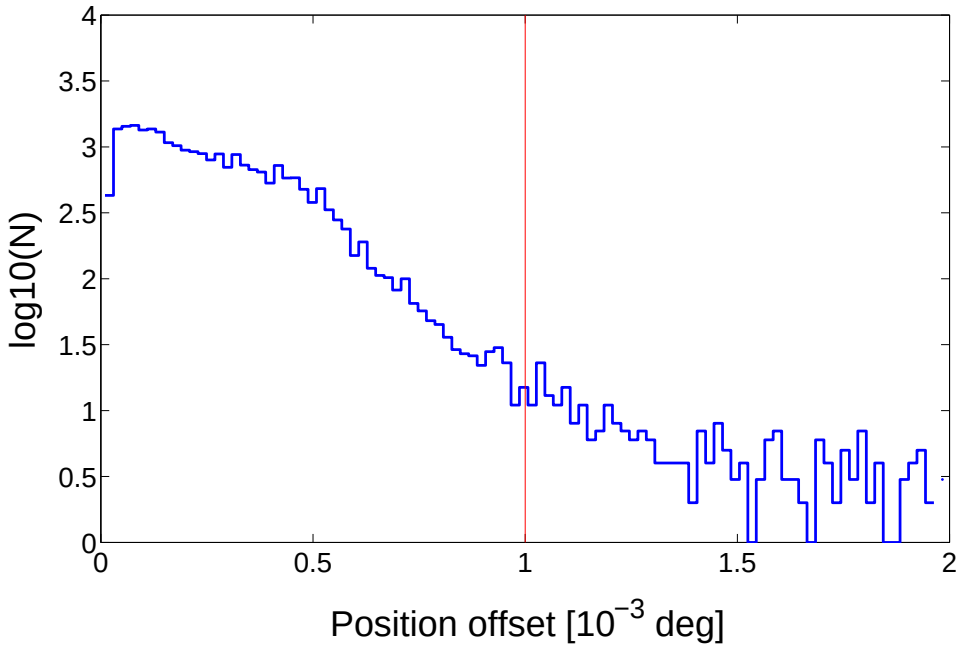
Filtering out duplicate galaxies

We have used a k-d tree algorithm. It quickly eliminates large portions of the search space, have $\mathcal{O}(\log n)$ time complexity for nearest neighbour search.

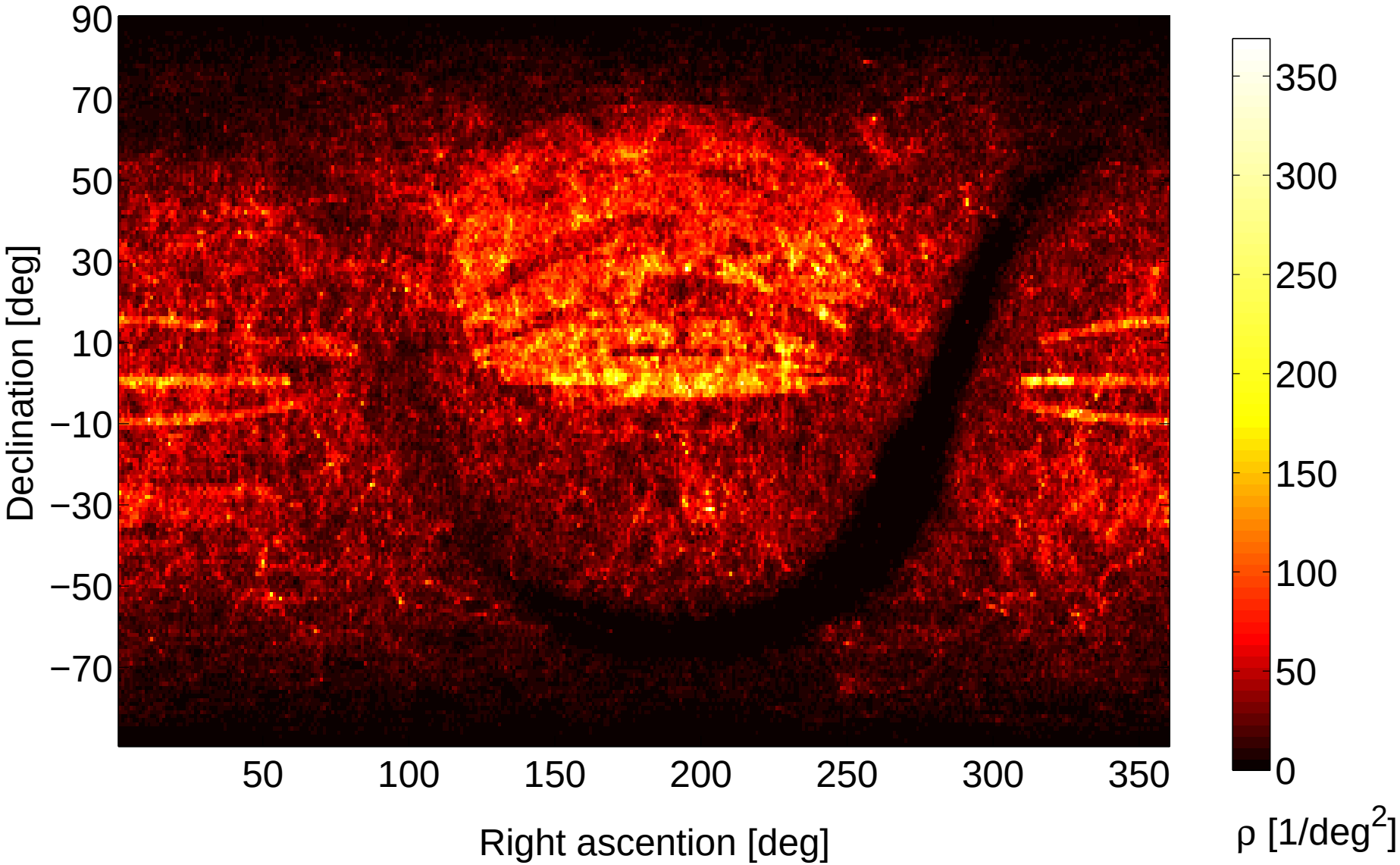
Criterion: position offset $< 0.001°$

B mag or z based filters were not used since they only had a very minor effect.

$\Rightarrow$ The final catalog contains 2,068,841 galaxies.



Density of galaxies



Filling in missing data

2MASS galaxies do not have B mag and $z \rightarrow$ 2MPZ

We have a non-LIGO member machine learning-expert in our group (R. S. de Souza).

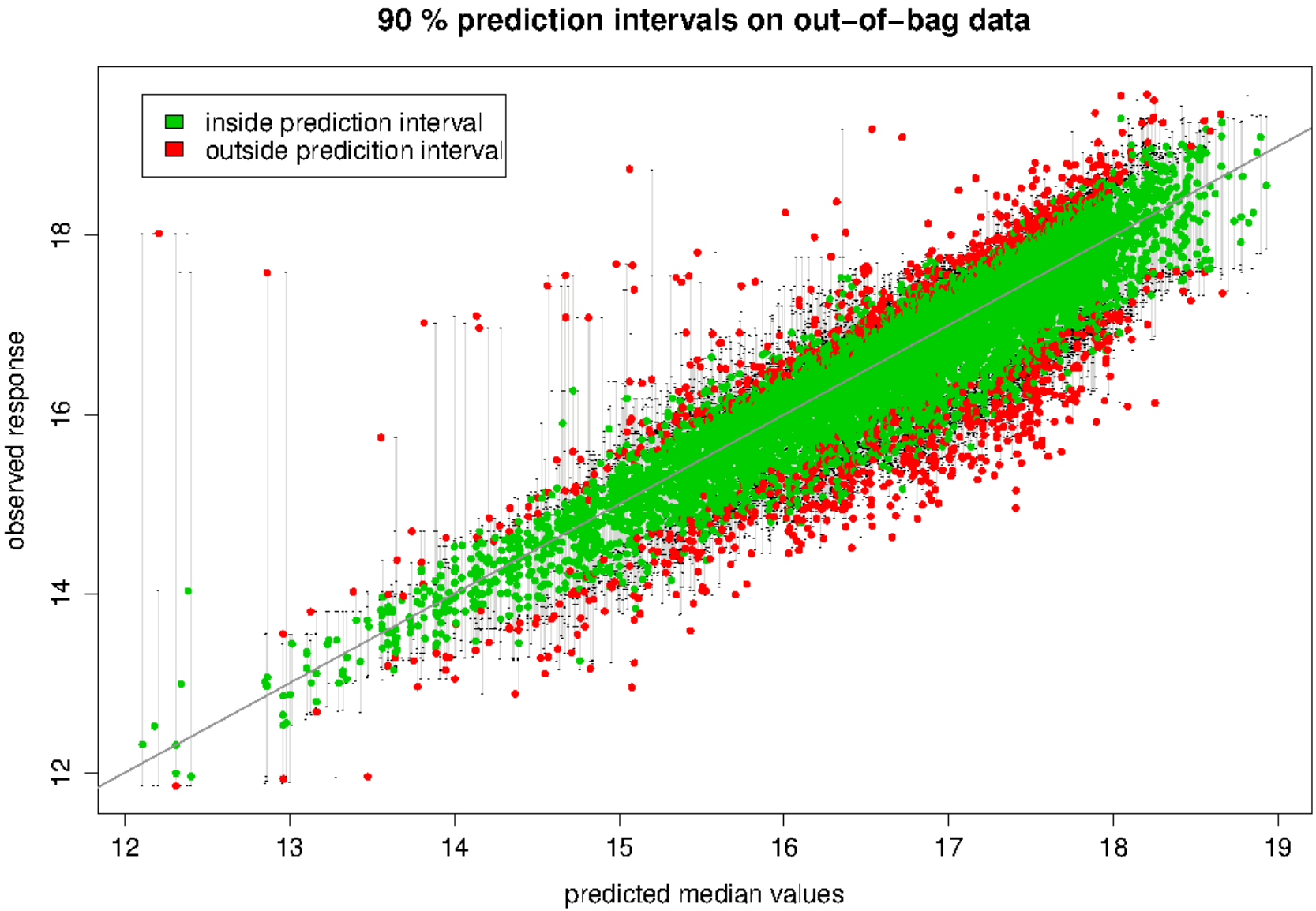
Random forest algorithm: a robust methodology, requires little fine tuning. [1]

Enlarging the teaching sample: the precision enhances slowly and it becomes computationally costly

Teaching sample: 10,000 2MPZ galaxies, learning based on J, H, K magnitudes

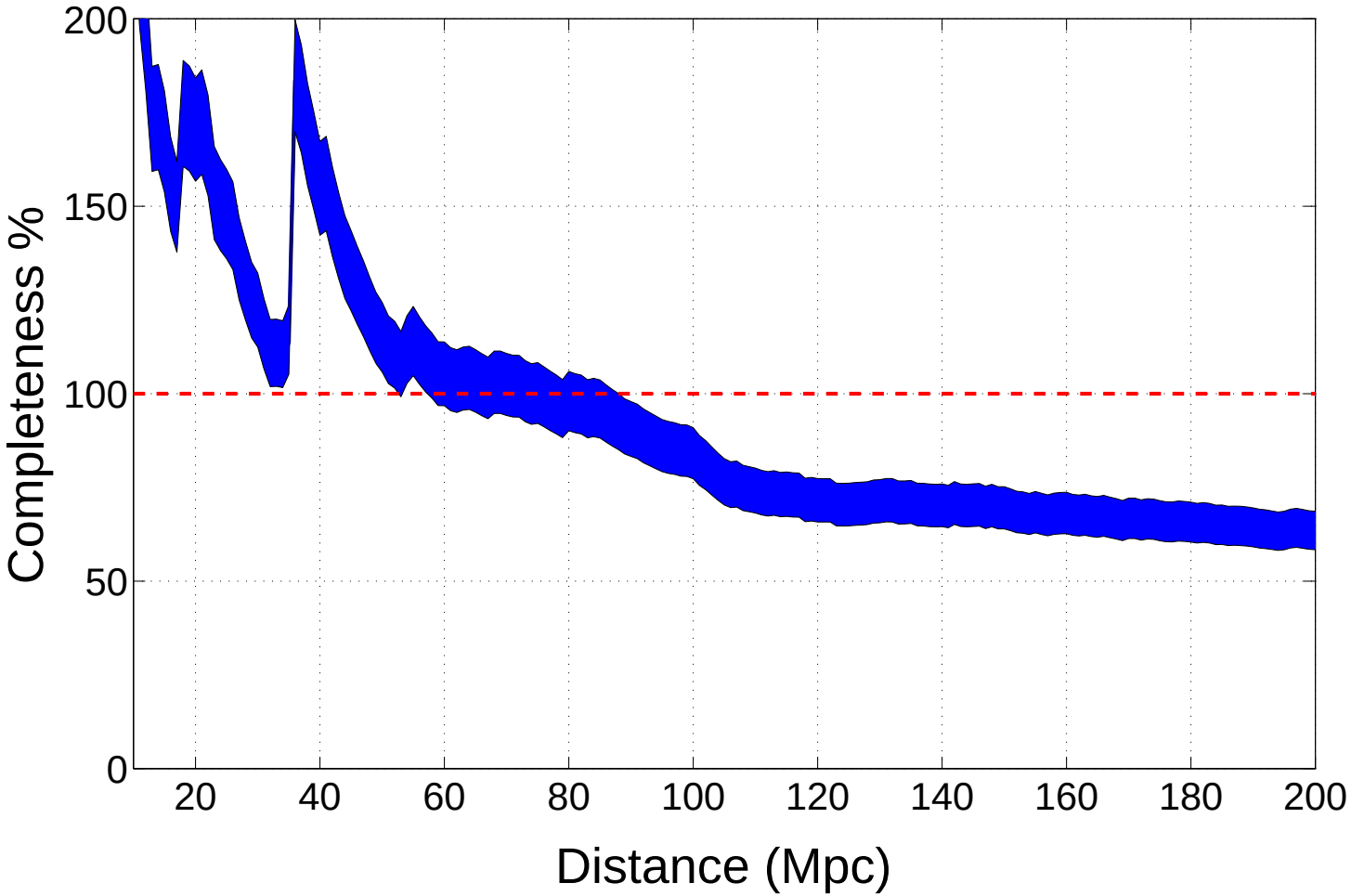
[1] Meinshausen, N., 2006, Journal of Machine Learning Research, 7 983

Filling in missing data



Completeness

Using the same method as in the GWGC paper. [1]
Blue luminosity density: $(1.98 \pm 0.16) \cdot 10^{-2}$ L_{10} Mpc^{-3}. [2]



At 300 Mpc:
53%

[1] White, D. J., Daw, E. J. & Dhillon, V. S., 2011, Class. Quantum Grav., **28** 085016
[2] Kopparapu, R. K., Hanna, C., Kalogera, V. et al., 2008, ApJ, **675**, 1495

Summary and comparison with other catalogs

	GWGC [1]	CLU [2]	GLADE
No. of galaxies	53,255	?	2,068,841
Completeness % at 60 Mpc	60	100	104 ± 7
Completeness % at 120 Mpc		80	71 ± 5
Completeness % at 180 Mpc		40	65 ± 5

Other advantages:

- Value-added with B *mag* and z data
- We are working on associating stellar masses to each galaxy
- We have a working pipeline to associate any other parameters relevant for the Collaboration

[1] White, D. J., Daw, E. J. & Dhillon, V. S., 2011, Class. Quantum Grav., **28** 085016

[2] Gehrels, N., Cannizzo, J. K., Kanner, J. et al., 2015, submitted to ApJ http://arxiv.org/abs/1508.03608

Website

You can download the catalog and read its documentation using this website:

`aquarius.elte.hu/glade`