# Star-galaxy separation strategies for WISE-2MASS all-sky infrared galaxy catalogs

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## Motivation

We have shown in Kovács et al. (2013) that the observational strategy of the WISE survey may be harmful for the galaxy samples we wish to create, and inhomogeneities show up as consequences of varying sensitivity or other observational effects. In order to clean our WISE-only galaxy catalog, we add 2MASS colors and demonstrate that clean and complete galaxy catalogs are accessible at the expense of loosing a small fraction of the galaxies. We find that $93\%$ of the WISE objects within W1<15.2 mag have a 2MASS PSC match, and that Support Vector Machines (SVM) and special color cuts are equally efficient classifiers of objects in our multicolor data set. Note that the WISE W1 magnitude limit we define is lower than the $5\sigma$ detection limit for W1. However, this cut makes comparisons to previous WISE catalogs easier, and helps to avoid large-scale inhomogeneities which potentially contaminate deeper WISE galaxy catalogs.

## Preparation and map making

### Problems with WISE galaxy maps:

1. over-densities along stripes caused by moon-glow contamination
2. gradient in galaxy number density as a function of Galactic latitude
3. meaningful stellar contamination ($\sim 7\%$)
4. strange cross-correlation signals with CMB

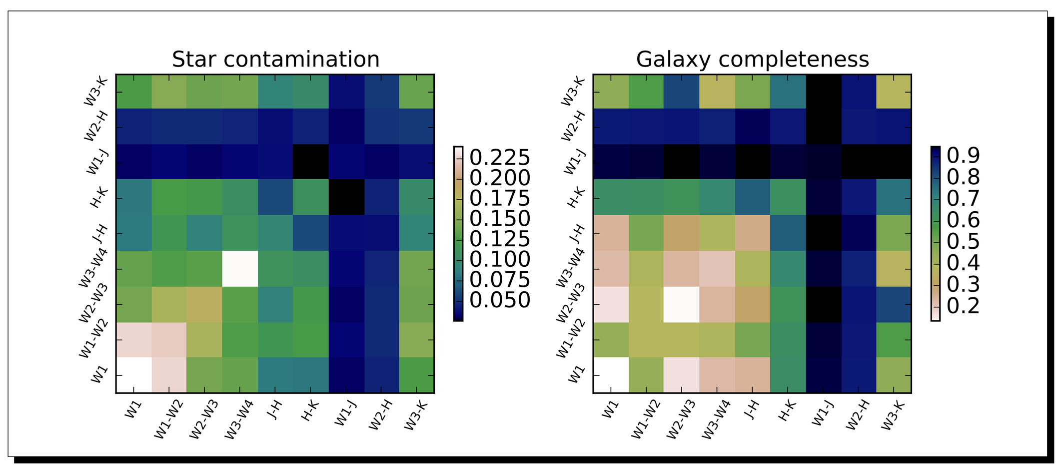


Figure: Contamination and completeness achieved by pairwise combinations of WISE and 2MASS colors and magnitudes. W1-J is clearly the dominant classifier.

### Creation of improved catalogs:

1. training samples based on SDSS classification
2. exhaustive SVM runs using combinations of WISE and 2MASS colors and magnitudes
3. W1-J color was found to be the most effective separator between stars and galaxies
4. further analyses of sample completeness and contamination as a function of W1 brightness
5. adaption of the simple W1-J<-1.7 cut for the lowest contamination with high completeness

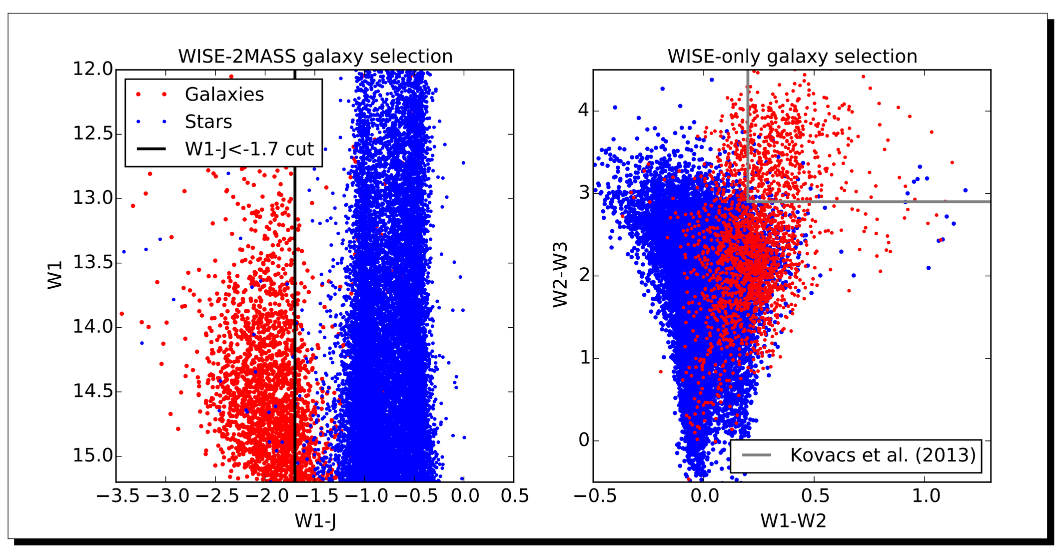


Figure: Color-color planes indicate that even a linear cut in W1-J separates stars and galaxies effectively. See the previous galaxy selection in the gray box for comparison.

## WISE-2MASS vs. WISE-only galaxy selection

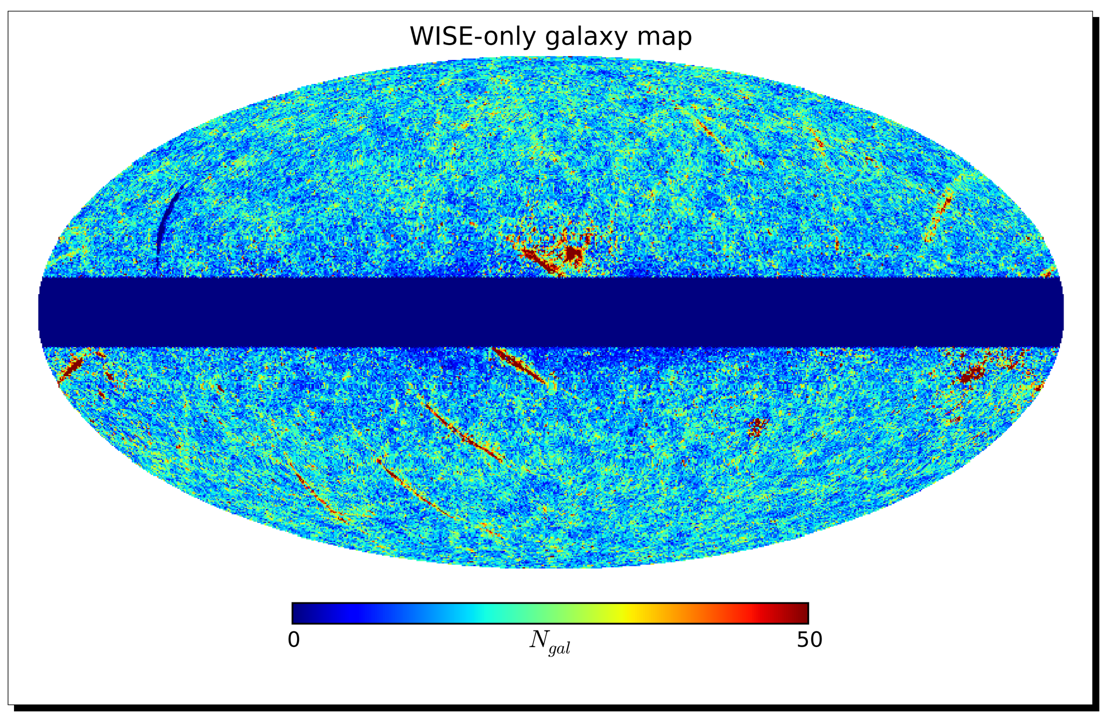


Figure: WISE galaxy catalog by Kovács et al. (2013) with $z_{med} \approx 0.15$ median redshift, and obvious contamination.

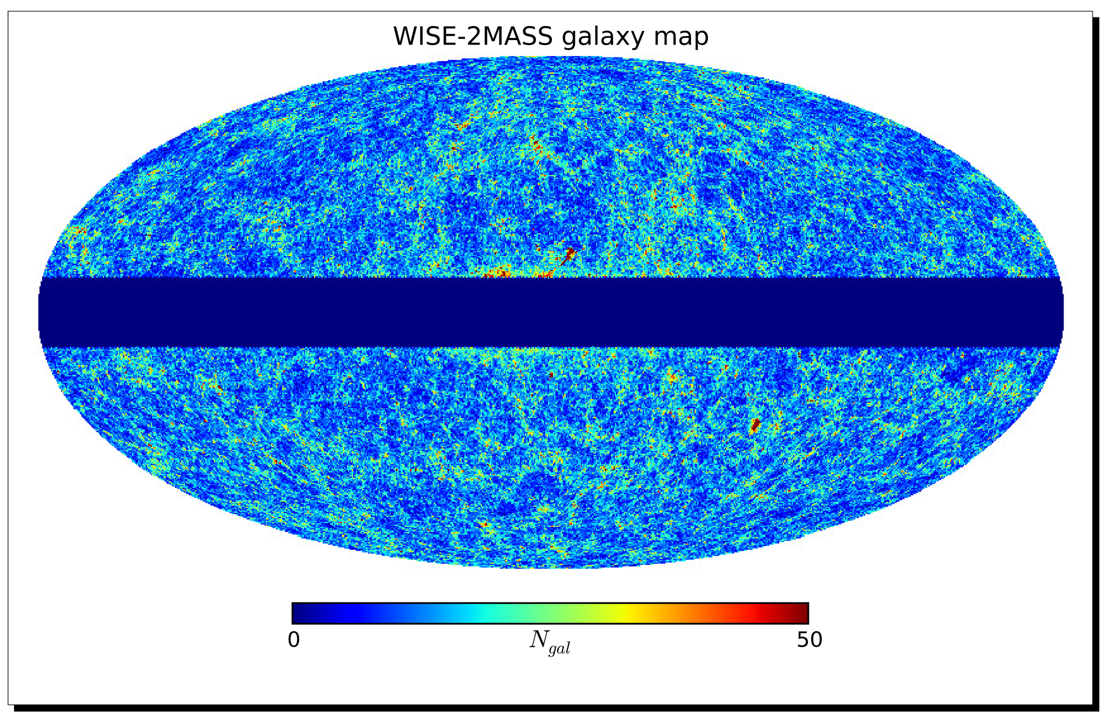


Figure: WISE-2MASS galaxy catalog with $z_{med} \approx 0.14$ median redshift, and an extra J<16.5 cut for uniformity.

### Differences & similarities

1. both galaxy catalogs trace the low-redshift Universe at z<0.30 with $\sim 2$ million objects
2. the principal upper flux limit for both data sets is W1<15.2 in order to deal with high signal-to-noise detections
3. no galaxy number count gradients in the WISE-2MASS catalog
4. stripe-like over densities of the WISE catalog in pixels of high 'moon-lev' flag value disappear in WISE-2MASS
5. the WISE galaxies were separated from stars using W1, W2, and W3 colors, while the new catalog requires only W1 for WISE
6. the estimated stellar contamination is $\sim 7\%$ for WISE, while only $\sim 1\%$ for WISE-2MASS
7. the completeness of the WISE-2MASS catalog is $> 70\%$, whereas the WISE-only selection identifies only $\sim 21\%$ of the galaxies available

Table: Star contamination and galaxy completeness as a function of flux limits and analysis methods. We apply a $W1 > 12.0$ lower flux cut in each case.

| Method | W1 | J | Cont. | Comp. | $N_{gal}$ |
|---|---|---|---|---|---|
| SVM | <14.5 | - | $3.4\%$ | $92.1\%$ | $1.2 \cdot 10^6$ |
| W1-J | <14.5 | - | $1.6\%$ | $84.4\%$ | $1.1 \cdot 10^6$ |
| SVM | <15.0 | - | $2.6\%$ | $93.4\%$ | $2.3 \cdot 10^6$ |
| W1-J | <15.0 | - | $1.4\%$ | $82.7\%$ | $2.1 \cdot 10^6$ |
| SVM | <15.2 | - | $3.1\%$ | $93.6\%$ | $6 \cdot 10^6$ |
| W1-J | <15.2 | - | $1.8\%$ | $78.6\%$ | $5 \cdot 10^6$ |
| SVM | <15.2 | <16.5 | $2.8\%$ | $85.9\%$ | $3 \cdot 10^6$ |
| W1-J | <15.2 | <16.5 | $1.2\%$ | $70.1\%$ | $2.4 \cdot 10^6$ |

## Extensions: photo-z, stellar mass, gravitational wave formation rate

### Collaborators: Maciej Bilicki, László Gondán, Gergely Dálya, Péter Raffai

We aim to prepare and extend the WISE-2MASS galaxy catalog for gravitational wave (GW) follow-up studies. Such a catalog will be an extension to the existing *Gravitational Wave Galaxy Catalog* (GWGC) at redshifts z<0.03, given the increasing sensitivity of gravitation wave detector networks. We use machine learning tools, in particular the ANNz photometric redshift estimator package to obtain the approximate distances of the WISE-2MASS galaxies. We then estimate stellar masses of the galaxies with the same code. Our reasonably accurate estimates of distance and mass are the inputs of our simple model for GW emission rate calculation. We will make this value added catalog public.

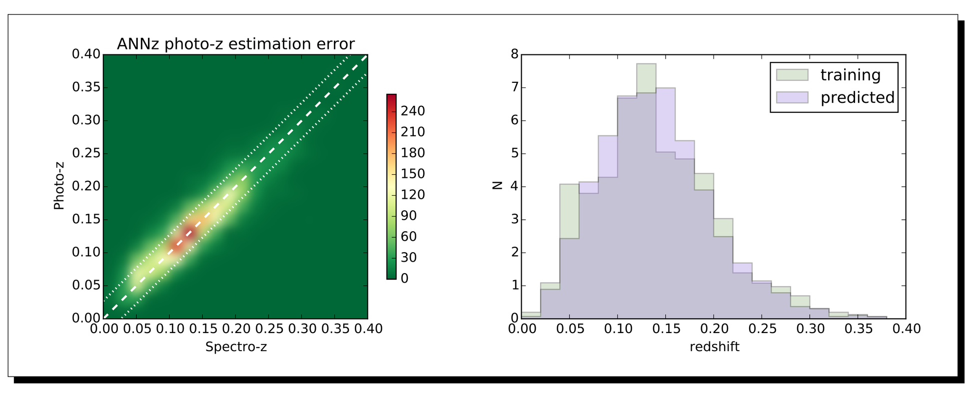


Figure: WISE-2MASS-SuperCOSMOS photo-z with GAMA spec-z for training, and errors $\sigma_z(1+z) = 0.027$

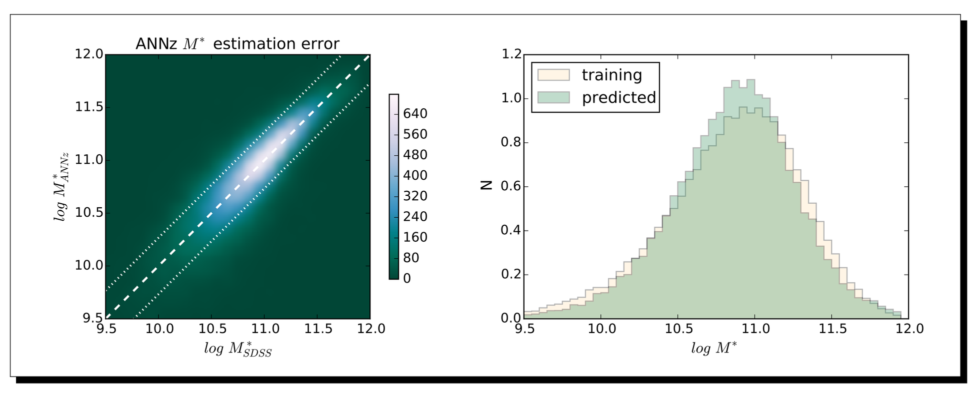


Figure: WISE-2MASS stellar masses with SDSS MPA-JHU $M^*$ data for training. The typical relative error is $\sim 2.5\%$.

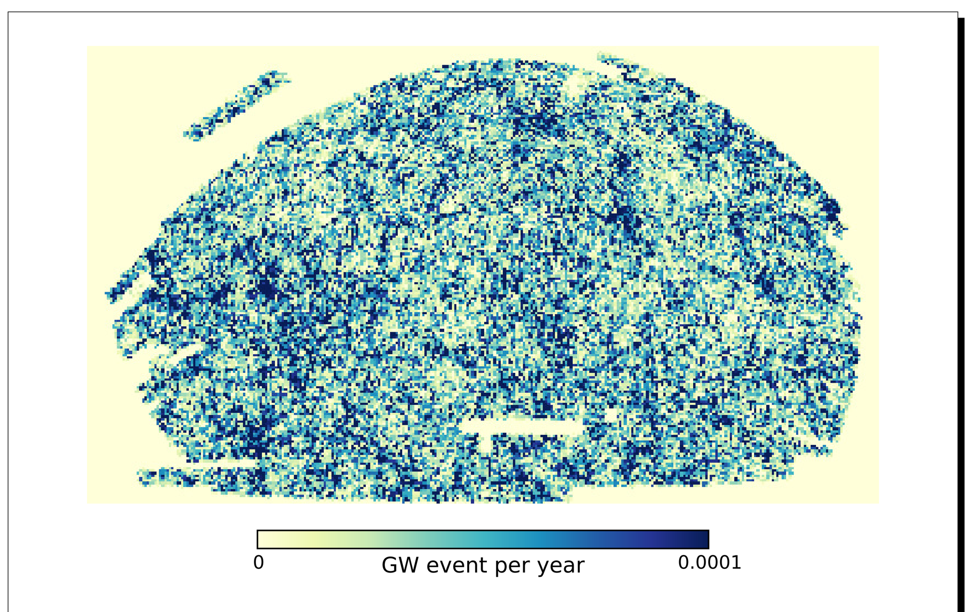


Figure: Estimated GW emission rates.

### Expectations for GW detection:

Table: GW source formation rates in WISE-2MASS galaxies for black hole (BH) and neutron star (NS) binaries, based on optimistic estimates for formation, and a combination of all GW experiments.

| | Formation $[yr^{-1}]$ | Detection $[yr^{-1}]$ |
|---|---|---|
| NS-NS | 20.91 | 0.004 |
| BH-NS | 0.99 | 0.024 |
| BH-BH | 2.27 | 0.152 |
| Total | 27.17 | 0.174 |