# Term Project # 2

Galactic Astronomy (Astr 511); Winter Quarter 2015
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This homework is based on two data files that contain information about a simulated sample of white dwarfs which mimics LSST observations. The sample generation, including various underlying assumptions, is described in the linked document (WDdraft.pdf). These data files (both are compressed using gzip utility) contain input information (LSSTsimWDtruth60.dat, 33 MB compressed) and observed properties (LSSTsimWDobs60.dat, 44 MB compressed). Both data files have identical number of data lines, and map onto each other (i.e., the n-th data lines in both files correspond to the same simulated star). The sample is defined by $r < 27.5$ and $b > 60°$, and includes 785,760 stars.

The truth data file (LSSTsimWDtruth60.dat) lists the following quantities:

- **ra dec:** right ascension and declination (J2000.0) in decimal degrees
- **u g r i z y:** "true magnitudes in LSST bandpasses (based on the Bergeron white dwarf models, no correction for the ISM extinction)
- **$M_r$:** absolute magnitude, $M_r$, in the $r$ band (drawn from the Harris et al. luminosity function)
- **log(g):** set to 8.0 for all stars
- **$v_R$, $v_\phi$, $v_Z$:** model velocity in galactocentric cylindrical coordinates ($R$ points away from the galactic center, $Z$ points towards the North Galactic Pole, and the coordinate system is right-handed; the Sun is at ($R$=8 kpc, $Z$=25 pc) and the local standard of rest rotates with $v_\phi$ = 220 km/s). The velocity distribution is drawn from the Bond et al. 2010 (ApJ, 716, 1) model.
- **T:** WD model type; 1=Hydrogen WD, 2=He WD (color tracks depend on this type), 10% of the population is randomly assigned T=2.
- **P:** Galactic population: 1=disk, 2=halo (population assignment and overall spatial distribution is drawn from the Jurić et al. 2008 (ApJ, 684, 287) model.

The observational data file (LSSTsimWDobs60.dat) lists the following quantities:

- **ra dec:** right ascension and declination (J2000.0) in decimal degrees

- **mObs, mErr; m=(u, g, r, i, z, y):** "observed magnitudes, generated by convolving truth magnitudes with expected LSST errors (not corrected for the ISM extinction). The expected errors are computed as described in the LSST overview paper (Ivezić et al. 2008; arXiv:0805.2366).

- **piObs, piErr:** trigonometric parallax and its expected error, in milliarcsec (the listed parallax is generated by convolving the true parallax with expected error; the true parallax is computed from true distance, with the latter determined from $M_r$ and true $r$). The parallax error is computed as described in the LSST overview paper (see section 3.3.3).

- **muRAObs, muDecObs, muErr**: the components of the proper motion vector in the R.A. and Dec directions, and the proper motion error (per coordinate), in milliarcsec/yr. The proper motion is generated using velocity from the first file and by convolving the true proper motion with the expected proper motion error (the latter is computed as described in the LSST overview paper, see section 3.3.3).

Using data from these two files, do the following:

**A)** Define a "gold parallax sample" by requiring a signal-to-noise ratio of at least 10 for the trigonometric parallax measurement (i.e., $piObs/piErr > 10$). Compute the distance and distance modulus from the parallax measurement ($D$/kpc=1 milliarcsec/$piObs$) and compare it to the distance modulus determined from $r$ and $M_r$ listed in the "truth file. Plot the distribution of the distance modulus difference and compute its median and root-mean-square scatter (hint: beware of outliers and clip at $3\sigma$!). Are they "interestingly" small? Is the distribution deviating from a gaussian? Would you expect it to? Why? How many white dwarfs would you expect in a "gold parallax sample" from the full LSST survey area of 20,000 deg$^2$ (hint: simply scale by the area because the distance cutoff is smaller than the thin disk scaleheight)? Plot the $(g - r)$ vs. $(u - g)$ color-color diagram (using observed photometry) for this sample. Does it look crisper than the SDSS distribution shown in the bottom left corner of fig. 23 in Ivezić et al. (2007, AJ, 134, 973)? Hint: look at the two bottom panels in fig. 24.

**B)** Using the "gold parallax sample" from **A**, estimate the absolute $r$ band magnitude as $Mobs = rObs - DMobs$, with the observed distance modulus, $DMobs$, determined using the "measured" trigonometric parallax, $piObs$. Plot $Mobs$ vs. $(gObs - rObs)$ color for stars with $T$=1 (i.e., hydrogen white WDs; while this is a shortcut based on model input, it is possible to photometrically distinguish hydrogen from helium WDs by considering their four-dimensional color loci; however, this is beyond the scope of this project and hence this shortcut). Fit a low-order polynomial to derive a photometric parallax relation, $M_r(g - r)$

(hint: you may want to first compute the median $M_r$ in about 0.1 mag wide bins of the $g - r$ color, and then fit a polynomial to these median values vs. $g - r$ bin value). How did you choose the order of your polynomial fit? In what range of $M_r$ and $(g - r)$ is your relation valid?

**C)** Define a "gold proper motion sample" by requiring $rObs < 24.5$. What fraction of this sample has the observed proper motion measured with a signal-to-noise ratio (to compute SNR: add the two proper motion components in quadrature and divide by the listed proper motion error) of at least 3? Apply your photometric parallax relation from **B** to estimate $M_r$ and distance (using $Mr$ and $rObs$). Use this distance to compute tangential velocity, $v_{tan}$ (of course, you also need the observed proper motion; be careful about units!). Define a candidate disk sample as stars with $v_{tan} < v_{tan}^{cutoff}$, and a candidate halo sample as stars with $v_{tan} > v_{tan}^{cutoff}$. Using $P$ from the truth file, plot the completeness and contamination for disk and halo samples as a function of $v_{tan}^{cutoff}$ for $0 < v_{tan}^{cutoff} < 500$ km/s (in steps of, say, 20 km/s). The completeness is defined as the number of (disk, halo) objects in the selected subsample divided by the total number of such objects, and contamination is the number of objects of the "wrong" type in the selected subsample divided by the total number in that subsample.

**D)** Using the "gold proper motion sample" from **C**, define a candidate disk sample by $v_{tan} < 150$ km/s, and a candidate halo sample by $v_{tan} > 200$ km/s. Using your results from **C**, estimate the completeness and contamination for each subsample. Using the $C$ method, compute the differential luminosity function for each subsample (this is the hardest part of this project!). Explain how did you get the normalization constant. Plot your results in a $\log(\Phi)$ vs. $M_r$ diagram (with error bars!), and overplot the true luminosity function listed in files WDlumfuncHalo.dat and WDlumfuncHalo.dat (the differential LF listed in the second column is expressed as the number of stars per pc$^3$ and mag; the LFs are slightly inconsistent with the Harris et al. due to a bug in simulations but, importantly, they do correspond to the "true LFs for the simulated sample). Comment on (dis)agreement between your $\Phi$ and the true $\Phi$ (which was used to generate the simulated sample).

**E)** A "byproduct" of the luminosity function determination in **D** is the spatial distribution of stars. Plot the results for disk and halo subsamples (i.e., $\ln(\rho)$ vs. $Z$, with error bars!). Compare these profiles to the spatial profiles you determined as a part of project #1 and comment.