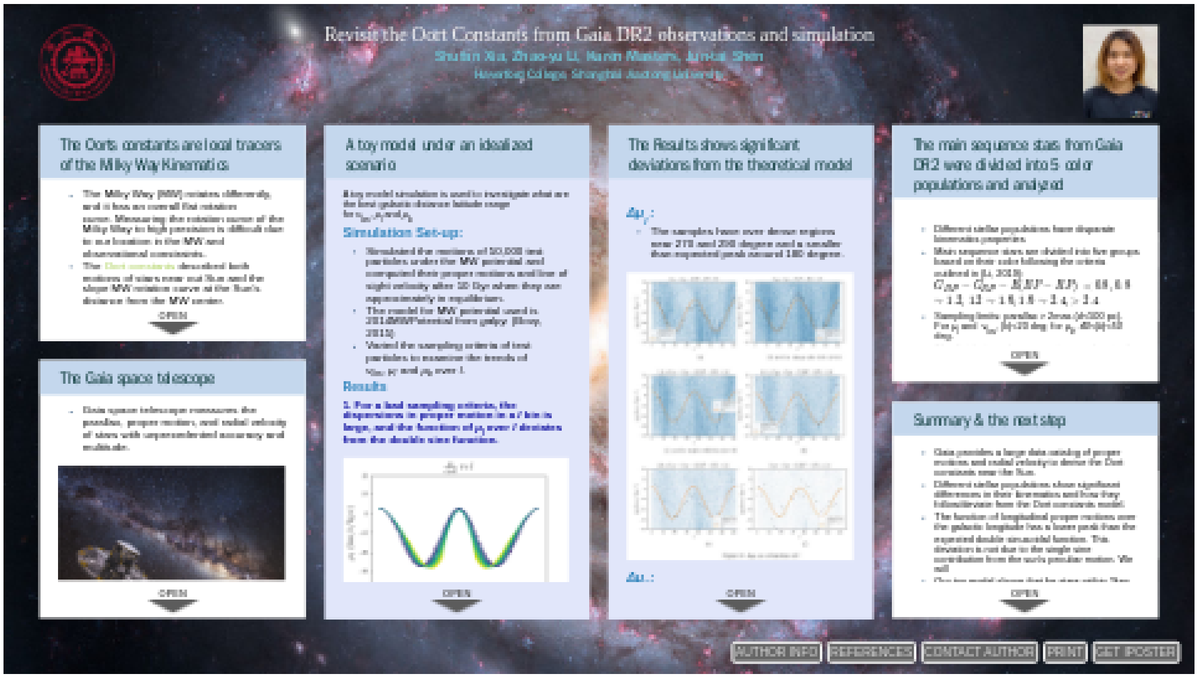
Revisit the Oort Constants from Gaia DR2 observations and simulation



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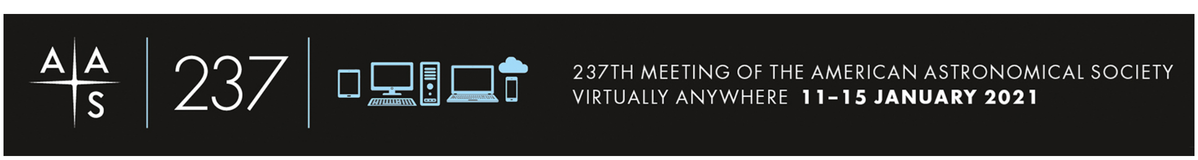


THE OORTS CONSTANTS ARE LOCAL TRACERS OF THE MILKY WAY KINEMATICS

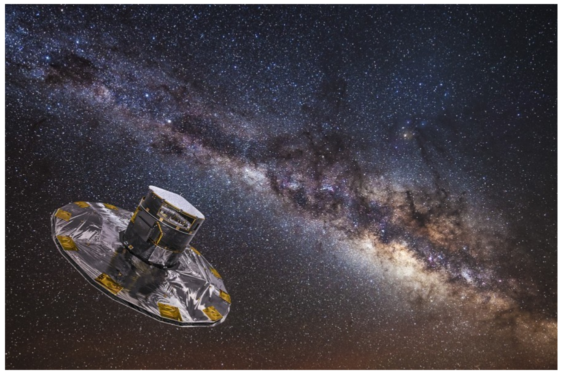
- The Milky Way (MW) rotates differently, and it has an overall flat rotation curve. Measuring the rotation curve of the Milky Way to high precision is difficult due to our location in the MW and observational constraints.
- The Oort constants (http://icc.dur.ac.uk/~tt/Lectures/Galaxies/TeX/lec/node42.html) described both motions of stars near out Sun and the slope MW rotation curve at the Sun's distance from the MW center.
- Assuming circular orbits and axisymmetric potential, expanding the velocity field in the solar vicinity shows proper motion in galactic longitude and latitude direction, μ_l and μ_b , as well as the line of sight velocity, v_{los}, have double sinusoidal dependence on the galactic longitude *l:*
- Key equations:
  $v_{los} = d(K + Ccos2l + Asin2l)$
  $\mu_l = (Acos2l - Csin2l + B)cosb + \frac{1}{d}(u_0 sinl - v_0 cosl)$
  $\mu_b = -(Asin2l + Ccos2l + K)sinb\ cosb + \frac{1}{d}[(u_0 cosl + v_0 sinl)sinb - w_0 cosb]$
  where *A, B, C,* and *K* are the Oort constants, and they represent the transverse shearing, vorticity, radial streaming, and divergence of the local velocity field. (Olling & Dehnen 2003)

Our Motivation and goals:

- Although there have been many studies on Oort constants, a systematic evaluation on the influence of different sample selection on the derived Oort constant is still lacking. So we will use a simple toy model to understand this effect, and then apply the simulation results on the Gaia observation to better constrain the Oort constants.

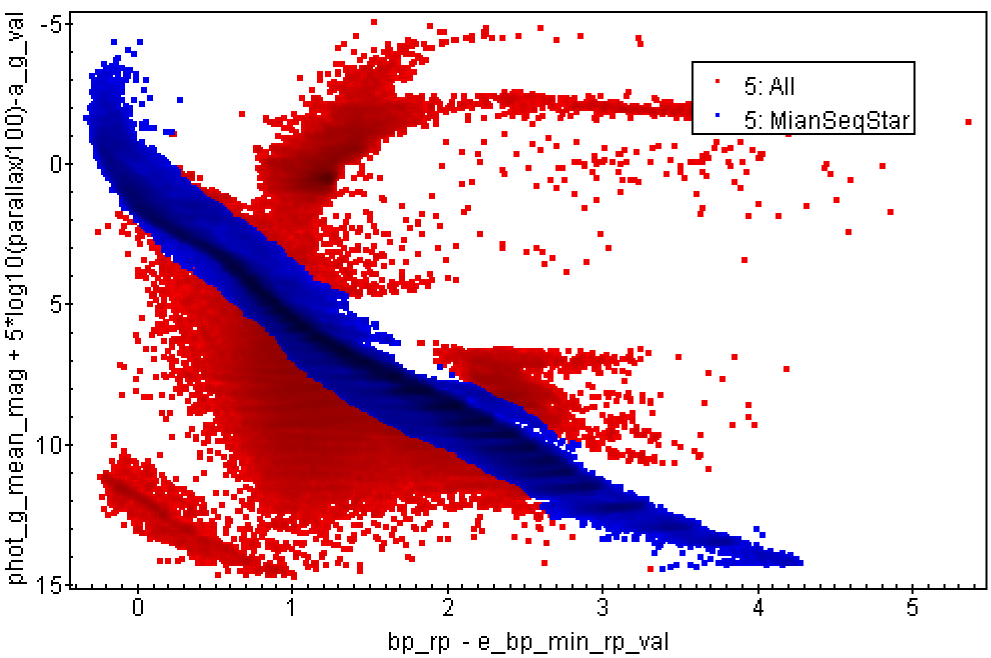
THE GAIA SPACE TELESCOPE

- Gaia space telescope measures the parallax, proper motion, and radial velocity of stars with unprecedented accuracy and multitude.



An artist's concept of the Gaia spacecraft. Credit: ESA.

- We used over 6 million Main Sequence Star near the Sun from ***Gaia DR2*** which holds the measurements of over 1.6 billion stars.



- We look forward to using the newly released ***Gaia EDR3*** data to derive the Oort constants.

A TOY MODEL UNDER AN IDEALIZED SCENARIO

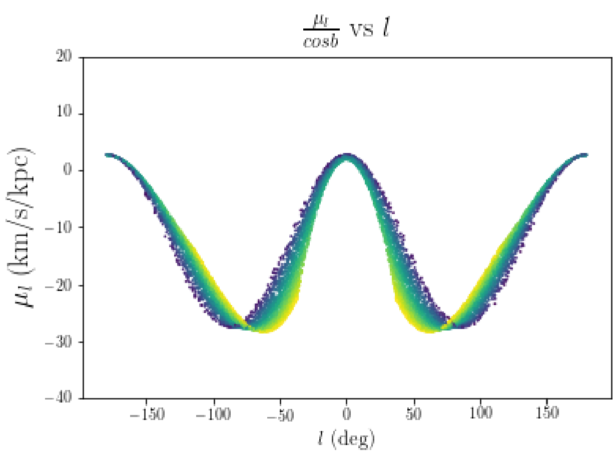
A toy model simulation is used to investigate what are the best galactic distance latitude range for v_{los}, μ_l and μ_b.

Simulation Set-up:

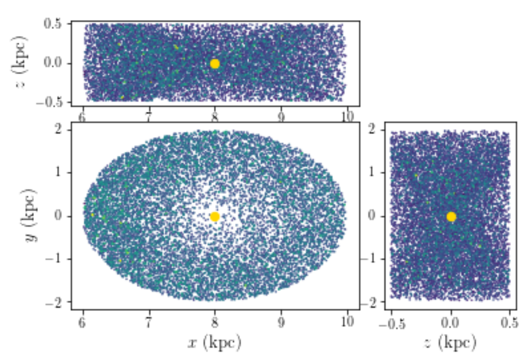
- Simulated the motions of 50,000 test particles under the MW potential and computed their proper motions and line of sight velocity after 10 Gyr when they are approximately in equilibrium.
- The model for MW potential used is 2014MWPotential from *galpy.* (Bovy, 2015)
- Varied the sampling criteria of test particles to examine the trends of v_{los}, μ_l and μ_b over *l.*

Results

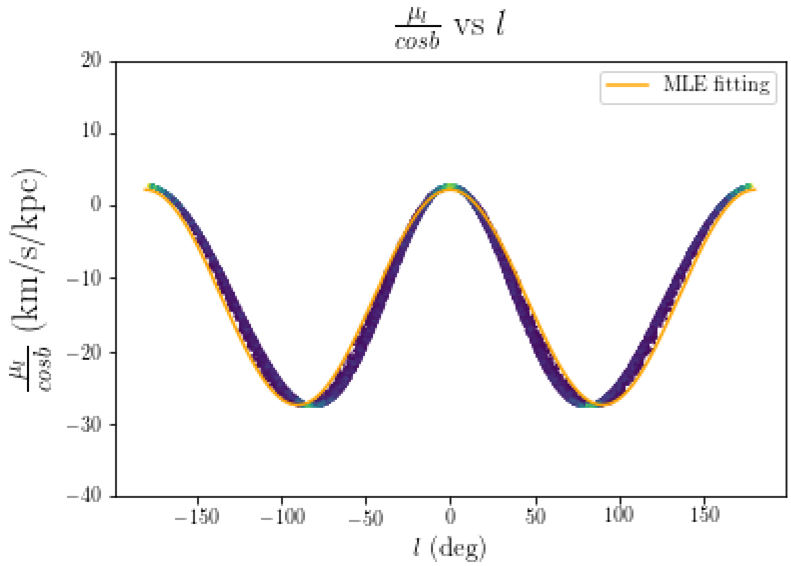
1. For a bad sampling criteria, the dispersions in proper motion in a *l* bin is large, and the function of μ_l over *l* deviates from the double sine function.



2. The line of sight velocity and longitudinal proper motions of stars within 2kpc from the Sun and with |*b*| *<20* deg are well described by the Oort constants double sinusoidal models.

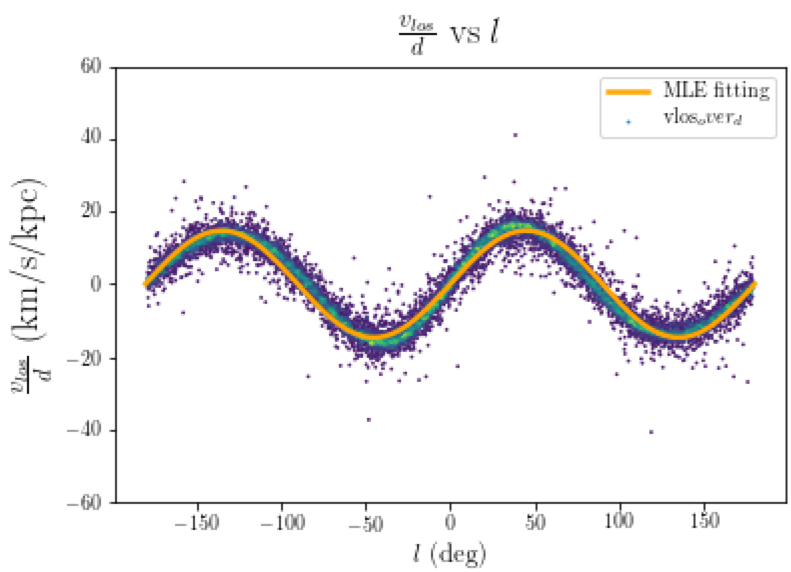


a) Spatial distribution of the test particles with *<2kpc*



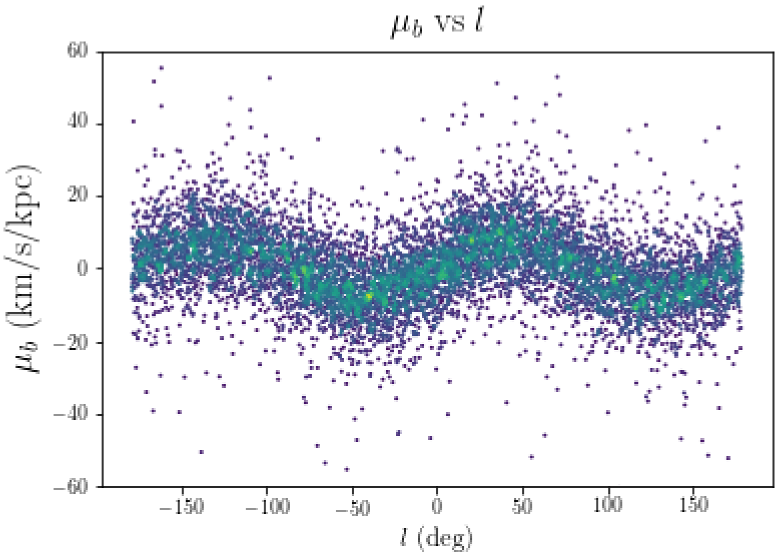
b) The function of v_{los} / d vs l for stars with *d<2kpc* and |*b*|*<20 deg*

The line of sight velocity shows larger dispersiona.



c) The function of v_{los} / d vs l for stars with *d<2kpc* and |*b*|*<20* deg

3. The proper motion in the latitude direction follows the double sinusoidal model for stars with *40<|b|<50* deg. μ_b shows larger dispersion.


μ_b vs l
μ_b (km/s/kpc)
60
40
20
0
−20
−40
−60
−150
−100
−50
0
50
100
150
l (deg)

THE RESULTS SHOWS SIGNIFICANT DEVIATIONS FROM THE THEORETICAL MODEL

$\Delta\mu_l$:

- The samples have over dense regions near 270 and 290 degree and a smaller than expected peak around 180 degree.

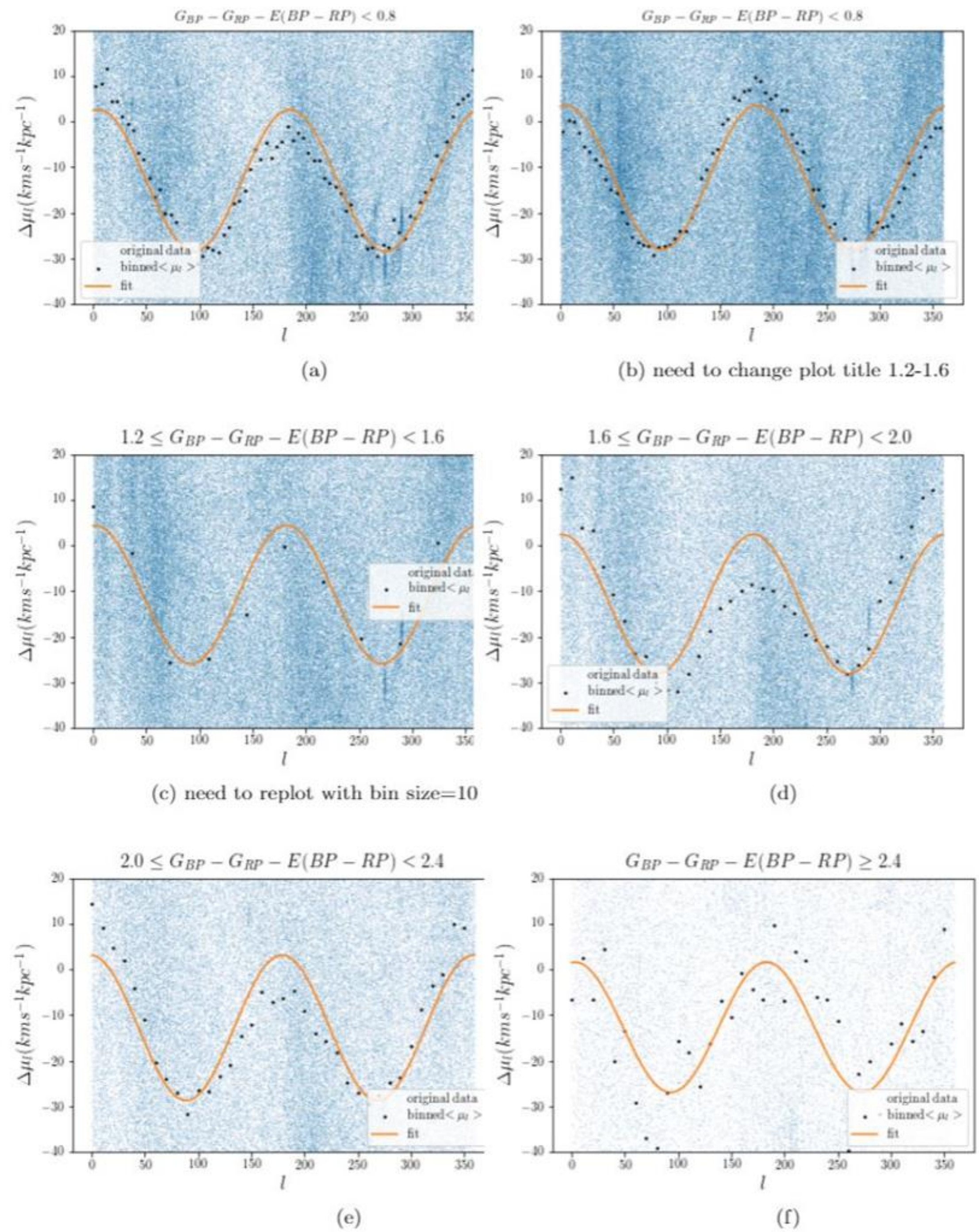
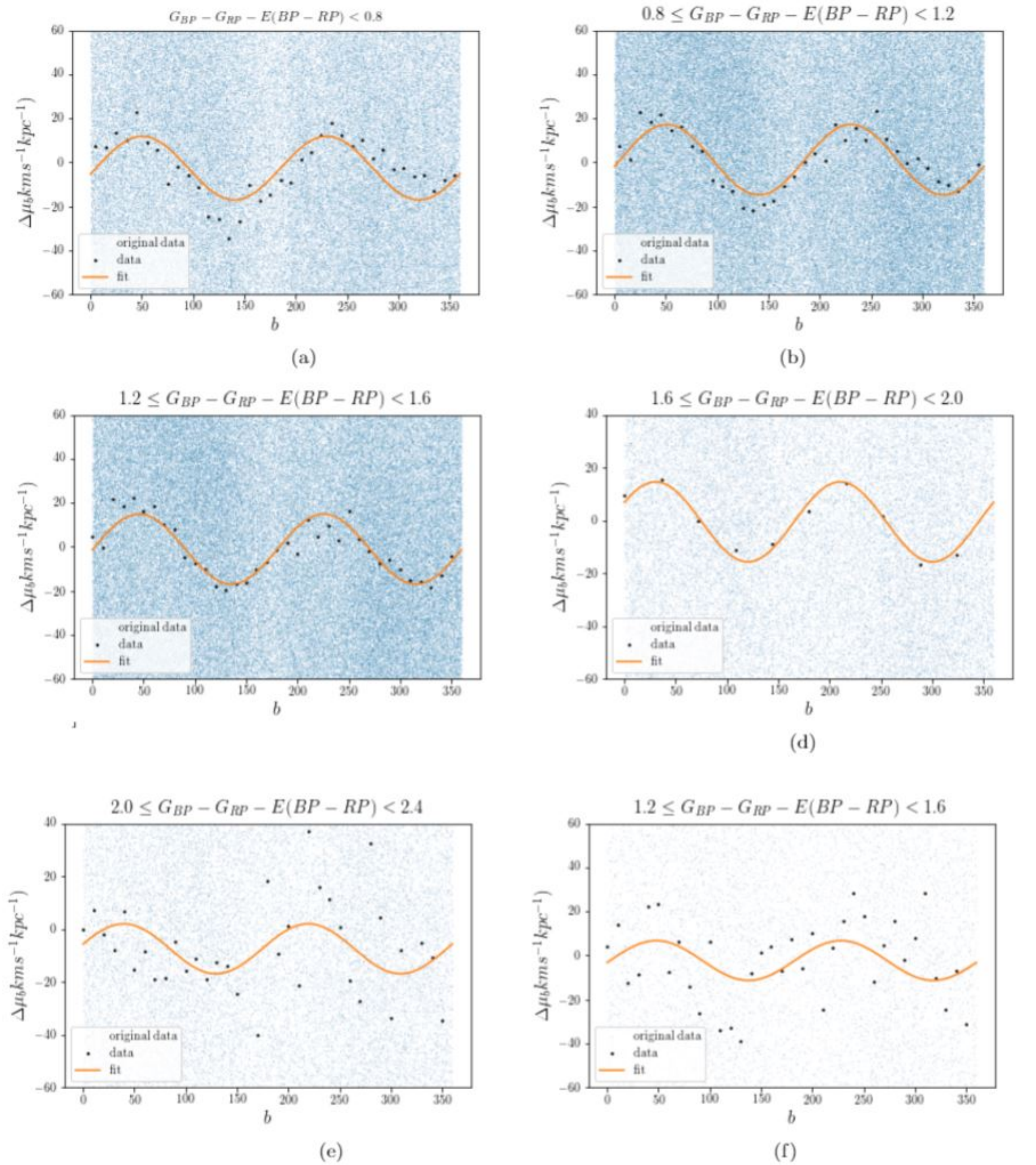


Figure 2: $\Delta\mu_l$ as a function of l

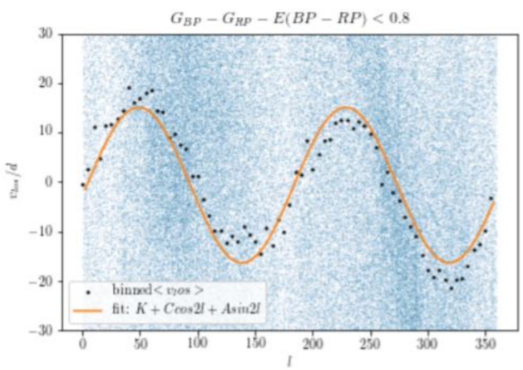
$\Delta\mu_b$:

The first three stellar populations show good agreement to the double sine functions. The other groups have fewer samples and more disparity and randomness in the latitudinal proper motion

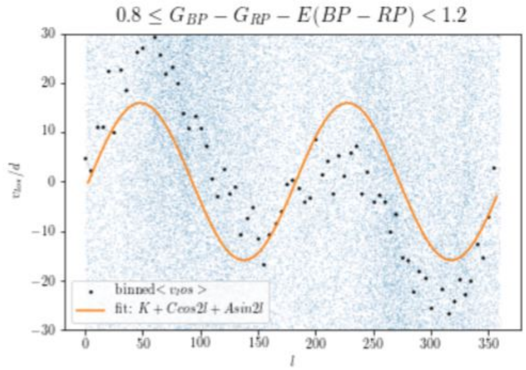


v_{los}:

- ***Gaia DR2*** only provides enough radial velocity for the reddest two stellar groups.
- The v_{los} vs l function of the second group shows the sinusoidal function shifts downward from the second peak around 200 deg.



(a) $G_{BP} - G_{RP} - E(BP - RP) < 0.8$



(b) $0.8 \leq G_{BP} - G_{RP} - E(BP - RP) < 1.2$

THE MAIN SEQUENCE STARS FROM GAIA DR2 WERE DIVIDED INTO 5 COLOR POPULATIONS AND ANALYZED

- Different stellar populations have disparate kinematics properties
- Main sequence stars are divided into five groups based on their color following the criteria outlined in (Li, 2019): $G_{BP} - G_{RP} - E(BP - RP) < 0.8, 0.8 \sim 1.2, 1.2 \sim 1.6, 1.6 \sim 2.4, > 2.4$
- Sampling limits: parallax > 2mas (*d*<500 pc). For μ_l and v_{los}, |b|<20 deg; for μ_b, *40<|b|<50* deg.
- The distribution of proper motions and v_{los} in the galactic longitude and latitude directions are plotted after correcting the solar peculiar motion with respect to the *LSR,* (u_0, v_0, w_0)
- We use their binned means to fit the models
- We used the Monte-Carlo-Markov-Chain method to estimate the uncertainties of the model parameters considering the results of $\Delta\mu_l$ and $\Delta\mu_b$, along with their errors propagated from the observational results, at the same time, where the log-likelihood is defined as:
- The reddest two stellar groups are the best tracers to derive the Oort constants. The bluer and younger stars show more deviation from the model.
- For the reddest group, we found the Oort constant are: $A = 15.3 \mp 1.5$, $B = -12.4 \mp 1.2$,, $C = -1.7 \mp 1.5$ and $D = -1.63 \mp 1.5$, all in the unit of km/s/kpc.

SUMMARY & THE NEXT STEP

- We evaluate the influence of different sample selection on the derived Oort constant by examining a simple toy model and applying the simulation results on the Gaia observation to constrain the Oort constants.
- Gaia provides a large data catalog of proper motions and radial velocity to derive the Oort constants near the Sun.
- Different stellar populations show significant differences in their kinematics and how they follow/deviate from the Oort constants model.
- The function of longitudinal proper motions over the galactic longitude has a lower peak than the expected double sinusoidal function. This deviation is not due to the single sine contribution from the sun's peculiar motion. We will
- Our toy model shows that for stars within 2kpc from the sun, their motions with respect to the sun follows the function described by the Oort constants.
- Even under the circular orbit and axisymmetiric potential, the line of sight velocity and proper motion in the latitudinal direction have larger dispersion than the longitudinal proper motion.

Questions on our list:

- How large the differences will there be in the derived Oort constants if we choose quite different sample selection criteria? first for our toy model and then for ***Gaia DR2*** data
- What accounts for the deviations we have seen in the Gaia data?

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REFERENCES

Bovy, J. 2015, ApJS, 216, 29, doi: 10.1088/0067-0049/216/2/29

Bovy, J. 2017, MNRAS, 468, L63, doi: 10.1093/mnrasl/slx027

Gaia Collaboration et al. (2016): Description of the Gaia mission (spacecraft, instruments, survey and measurement principles, and operations)

Gaia Collaboration et al. (2018b): Summary of the contents and survey properties.

Li, C., Zhao, G., & Yang, C. 2019, ApJ, 872, 205, doi: 10.3847/1538-4357/ab0104

Olling, R. P., & Dehnen, W. 2003, ApJ, 599, 275, doi: 10.1086/379278

http://icc.dur.ac.uk/~tt/Lectures/Galaxies/TeX/lec/node42.html
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