**Slide 1:**

The simplest picture for the motions of stars in our galaxy would be they moved on pure circular orbits

As we can see from this artistic illustration of the MW, in this barred spiral and nonsymmetric galaxy, such motions must be more than circular orbital motions. With the addition of time-dependent perturbation, the picture of MW Kinematics is complicated

**Slide 2:**

One of the tools astronomers use is the rotation curve

Our milky way has a flat rotation curve, look at the rotation frequency, we will see that our galaxy has differential rotation, as opposed to rotation of a rigid body.

From RC → ultimately derive the distribution of different mass component

Used as evidence of the existence of DM in galaxies

However, measuring it is hard due to some observation constraints.

The fact that we are co-moving with the Milky way makes measuring the relative motions challenging.

**Slide 3:**

In my thesis, we add to the conversation about MW kinematics by looking at the concept of Oort constants.

The Oort constants characterize the local velocity field near the Sun, describing the relative motions in radial and tangential directions wrt to the Sun.

Introduce GC, vlos and proper motions

GC is .

Vlos

Proper motion is the ratio between the relative tangential velocity and distance

In a 3D space, this proper motion is further broken down into longitude and latitude components

**Slide 4:**

Assuming XXX

Expanding velocity field, found vlos, proper motions in the two directions are sinusoidal with period = 180 degree

The schematic sketch: I have marked how this relative velocity in radial velocity varies as you sweep from l=0 to 360. Just based on the sign, we see a 180 cycle. A similar plot for mul will show a it is proportional to cos 2l

However, as the Sun in reality has non-circular v components. Strictly speaking, the reference in the Oort constants model is a hypothetical reference frame at solar radius but stays on a perfect orbit. Such a reference frame is called LSR.

Peculiar motion is

Correcting the circular motions, we find vlos, mul and mub are described by the following equations

As we can see, these three quantities are constrained by four parameters. These four parameters are the Oort constants, with each one of them corresponding to one aspect of the local velocity field: A represents XX, B stands for XX, C for and K for

Meanwhile, we can tell from the equations, the exact value of proper motion will be significant in deriving Oort constants

**Slide 5:**

To motivate our research, I want to briefly stress their connection to the larger MW kinematics.

The slope of local rotation curve, and the local rotation frequency can be written in terms of A and B

The gradient of the local radial velocity:

With accurate measurements of the Oort constants, we can better derive or test different rotational models for our galaxy

**Slide 6:**

However, there are some constraints and influence factors to measuring these constants to high precisions

Requires a massive proper motion catalog for stars just distant enough and enough sky coverage.

Non-axisymmetric potential and perturbations add noncircular velocity components. Thus we expect to see a deviation from the predicted model

The Sun is in one of the four major Spiral arms, where many stars are forming, moving in and out from the spirals. This high-density region adds streaming motions and random motions. (errors of order 5 km/s/kpc in A and B)

To resolve the first issue to some extent, I want to introduce Gaia, a space telescope that aims to create a proper motion and parallax catalog of unprecedented accuracy and multitud for the Milky Way. Second release

Two of previous recent work of Oort constants were either conducted when the much smaller early data release was available or did not give quantification on how data filtering criteria affect the result

**Slide 7:**

We aim to use DR2, but with careful consideration of how to sample from this database

Essentially, we want to answer this question: What is the best subset of stars to estimate Oort constants from observational data?

The result of this project hopefully can provide some guidance on how to derive Oort constants from a future larger database. Eg EDR3 and DR3

Our approach combines toy model simulation and analyzing the observational data

1. The toy model simulation helps us know what we should expect from theories under a relative idealized scenario and compare different sample criteria
2. Then, we look at Gaia DR2 to see how the observation data reflect the features predicated by the Oort constants and How what we find in simulation apply to observations

**Slide 8:**

In our toy model simulation, we treated stars as test particles under an axisymmetric MW potential defined by the MWpotential2014 model., assume the Sun stays on a circular orbit, (u0,v0,w0)=(0,0,0)

500,000 test particles are drawn from AGAMA's quasi-isothermal distribution function. The scale height of 0.4 kpcs, and the radial velocity dispersion is chosen as 10km/s.

This choice is to mimic a dynamically cold disk and reflect the general rotation of a thin MW disk

All test articles are sampled then integrated on their orbits over 10 gyr to come to equilibrium. The resulted distribution is shown in the plot on the right. As we can see, most of the stars reside far away from the solar vicinity. To increase near sun samples, we replicate the Sun’s position at four symmetric coordinates about the Galactic center

**Slide 9:**

I first present the result of the longitudinal proper motion and the effect of different choices on date selection based on galactic distance and latitude. The plots show the binned medians of proper motion divide by cos b

When the samples cover a more distant region from the Sun or a higher latitudinal region, the dispersion in longitudinal proper motion is larger as suggested from their error bars

And the residual profile in the lower panels suggests only when we zoom at within 1kpc from the Sun, the residual has a uniform distribution. In all the other three other choices of sampling criteria, the residual have significant dependence on l. This suggests that d<1kpc and b<20 are a good tracer for the Oort constants

**Slide 10:**

Now, we look at the line of sight velocity and proper motion in the latitudinal direction. We find vlos is similar to mul, having the best result when d<1kpc and |b|<20. While latitudinal proper motion has the most consistent result in a mid-range latitude. When we limited the samples to 1kpc, there are not as many stars in the middle range latitude region.

The schematic diagram on the right shows, that even though Oort constants assume horizontal motions only, because of Milky Way differential rotation, the relative position of stars from the Sun, varies as it orbits around the GC, thus the latitudinal proper motion is expected to vary with different galactic longitude. Our simulation result suggests the intrinsic vertical motions of stars add dispersion to the line-of-sight velocity and latitudinal proper motion caused by the differentiation rotation parallel to the MW midplane.

To derive the full sets of four Oort constants requires longitudinal proper motion and at least one of the two between vlos and lattitudinal proper motions.

Thus we conluced the longitudinal proper motion and line of sight velocities of the stars within 1kpc and |b|<20°: A = 15.62 ± 0.34, B = −12.78 ± 0.31, C = 1.31 ± 0.40, K = 0.24 ± 1.09 (km/s/kpc). The uncertainties of the parameters are determined from Monte-Carlo-Markov-Chain method.

This set of Oort constants give v\_circ at the solar orbit is 236.85 km/s with R\_⊙=8.34 kpc. As a comparison, the circular velocity scale chosen in the model is 240 km/s

**Slide 11:**

Next, I am going to present the result from analyzing Gaia DR2:

Similar to the 2018 and 2019 papers, we looked at the Main Sequence star only. On this Hertzsprung Russell diagram, the color of the stars reflect their age, and stars with similar age are expected to have similar kinematic properties in general

We used the following criteria to select near sun stars

Now, we write the equations introduced before, and define three new quantities:

\delta mul and \delta vlos and \delta mub

For each color group, we estimated the peculiar motions and the Oort constants

**Slide 12:**

Here I show the result of delta mul and delta mub for the bluest group and one of the redder stellar group. From these two plots, we can see that DR2 data confirms the Oort constants model. The error bars and deviations from the model suggest that redder and kinematically older stars have larger velocity dispersion and more non-circular orbital motion.

**Slide 13:**

We continue to look at the available radial velocity data in DR2. we find DR2 have 𝑣\_𝑙𝑜𝑠 mostly for the bluer stars. Similar to simulation, the dispersion in ∆𝑣\_𝑙𝑜𝑠 is larger than 〖∆𝜇〗\_𝑙, but smaller than 〖∆𝜇〗\_𝑏. Still, vlos in DR2 for the two most blue stellar groups are well described by Oort constants, A, C and K.

**Slide 14:**

On these four plots, I show the Oort constants we estimated for different groups and the results from the 2018 and 2019 papers. The error bars on our parameters are also estimated by using the Monte Carlo Markov chain method. Our results in general agree with Li’s result.

From the results above and in the previous two slides, we conclude the motions of bluer (younger) stars are generally closer to circular orbital motion which the constrained by the Oort constants model, thus being the more reliable tracers for Oort constants.

**Slide 15:**

We thus confirmed our methods to analyze Gaia dr2 data is reliable, and are ready to apply our result from the simulation to see how expanding to a larger region, 1kpc about the sun affects the measurements of Oort constants.

While the proper motion in the longitudinal direction is still well described by the Oort constants model, line of sight velocity and proper motion latitude shows significant deviations. Still In general, it seems that galactic distance is a less strict cut-off criterion than the Taylor expansion in the theoretical derivation implies.

**Slide 16:** In conclusion, my thesis look at Oort constants that describe local rotation motion, and they are connected to the rotation kinematics of the larger Milky Way by the rotation curve.

We review the methods to derive the Oort constants from test particle simulation and Gaia DR2 observational data, especially the choice on galactic distance and latitude constraints.

For the idealized simulation under the axisymmetric potential assumption, it is necessary to limit the distance within 1kpc and latitude range |b|<20.

Based on Gaia DR2 data, 𝜇\_𝑙 and 𝑣\_𝑙𝑜𝑠 of the relatively bluer (younger) stars within 500 pc from the Sun and lower than 20 latitudes are more reliable tracers to derive the Oort constants, suggesting their orbital motion are more approximately circular.

We also found that 𝜇\_𝑏 is not as reliable as the other two parameters to derive the Oort constants.

By usng the two bluest stellar groups Our estimated Oort constants are A = 15.52±0.22;B = -13.33± 0.17;C = -1.88±0.08; and K = -1.86±0.19 km/s/kpc. The slope of rotation velocity at solar orbit is -18.26 ± 0.28 km/s/kpc.

**Slide 17:**

Before I end, I want to say thank you to Dr. Juntai Shen from Shanghaijiaotong University for initially bringing me to this research, Dr. Zhaoyu Li for his always on-point research guidance and working across time-zone, and last but never the least, Prof. Karen Masters for her technical and nontechnical supports and encouragement throughout this long and special year.