# MW-Gaia STSM

## Corrections to Jeans equation in non-equilibrium systems using Gaia DR2

Žofia Chrobáková, PhD student at the Instituto de Astrofísica de Canarias (Tenerife) spent 15 days (01-15/11/2019) at the Instituto Dei Sistemi Complessi (Roma) thanks to a GP1 STSM grant to collaborate with Dr. Sylos Labini.

The Jeans equation (Binney and Tremaine, 1987, Ch. 4.2 (4-29a)) is a tool commonly used to determine rotational velocities of galaxies and subsequently their masses and density profiles. However, the Jeans equation assumes that the studied system is axisymmetric and in equilibrium, which we know is not the case of the Milky Way. The Gaia DR2 data has shown that there are large scale gradients in all components of the velocity field and there are clear deviations from axisymmetry (Gaia Collaboration (2018), López-Corredoira and Sylos Labini (2019)). In this project, she studied the validity of this assumption and aimed to quantify the corrections to the mass estimation for mock galactic system in configuration close to equilibrium.

During the STSM, they studied two different mock galactic systems. First system consists of a thin rotating self-gravitating disk embedded in a spherical dark matter halo with an isotropic velocity dispersion. The second system consists of a self-gravitating rotating disk embedded in a thick and rotating self-gravitating disk: this is obtained as a result of an out-of-equilibrium simulation. She studied the time evolution of the two systems, while they were subject to no external forces, just their internal gravity. She compared the kinematics of the two systems - the velocity components in cylindrical coordinates and their respective dispersions. We also studied the dependence of rotational velocity on galactic height. Then, she compared the probability distribution functions (PDF) of radial and azimuthal velocities, which is not very often studied in astrophysics, but it provides much insight into the behaviour of the systems and tells us much about the differences.

Žofia Chrobáková also studied the application of the Jeans equation to both systems. She calculated the gravitational force of each system and computed the rotational velocity from it. Next, she calculated the rotational velocity from the Jeans equation, under the assumption of axisymmetry and equilibrium and compared these two quantities.

**Main achievements**

The most important result is the comparison of the rotational velocity calculated by two independent, completely different ways. We find that the difference between these two approaches is negligible at small distances where both systems are close to an equilibrium configuration, and it starts to manifest at distances larger than 100 kpc, where the second system is out-of-equilibrium. At such large distances, the difference is extremely high, the velocity calculated from the Jeans equation reaches much higher values and cannot be substituted by the real rotational velocity, calculated from the force. This is in relationship with radial velocity - they found that when the average radial velocity is around zero, the Jeans equation holds well, but as soon as the average radial velocity begins to rise, the Jeans equation produces wrong results. This tells us, that at large distances, the Galaxy is not in equilibrium and we should not treat it in such way.

The comparison of the two different Galactic systems also yielded interesting results. Especially the comparison of PDFs showed that there are significant differences. However, comparison with observational data is necessary in order to better understand what produces the obtained behaviour.

- ✓ We published one paper from the STSM: Gaia-DR2 extended kinematical maps. III. Rotation curves analysis, dark matter, and MOND tests. Chrobáková, Ž.; López-Corredoira, M.; Sylos Labini, F.; Wang, H. F.; and Nagy, R. A&A, October 2020, 642, A95.

Following the STSM, a productive collaboration with the host and their research group has been maintained. They worked together on several projects using Gaia DR3 to explore the Milky Way kinematics.

We discovered that the rotation curve of the Milky Way is significantly decreasing:

- ✓ Mapping the Milky Way Disk with GAIA DR3: 3D extended kinematic maps and rotation curve to ≈ 30 kpc. Wang, H. -F.; Chrobáková, Ž.; López-Corredoira, M.; Sylos Labini, F. ApJ, 2023, 942, 12.

and explored mass models that could explain these observations:

- ✓ Mass Models of the Milky Way and Estimation of Its Mass from the Gaia DR3 Data Set. Sylos Labini, F.; Chrobáková, Ž.; Capuzzo-Dolcetta, R.; López-Corredoira, M. ApJ, 2023, 942, 3.

In the future, the collaboration continues, working mainly on the off-disk kinematics of the Milky Way and other related projects.