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Simulation of Stellar Orbits in the Galaxy: An Application of Semi-Empirical Models to Universal Gravitation

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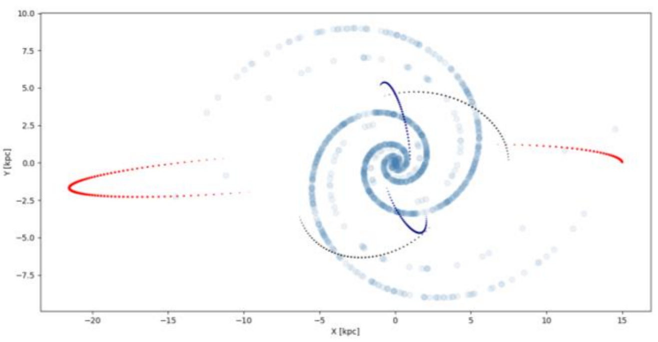
Graphical Abstract



Abstract.

Starting from Universal Gravitation, applying some mass distribution models based on the morphology of the Milky Way, we wrote an algorithm using the Python language that allowed us to model the spiral arms together with the stellar orbits. The orbital profiles can confirm the fact that the stars oscillating above and below the galactic disk contribute to the formation of the spiral arms, which are regions of greater gravitational potential that behave like waves of density. A location prone to higher rate of star formation.

Methods

From the observational models of mass distribution in the bulge, disk and galactic corona regions, we can describe their respective velocity distributions.

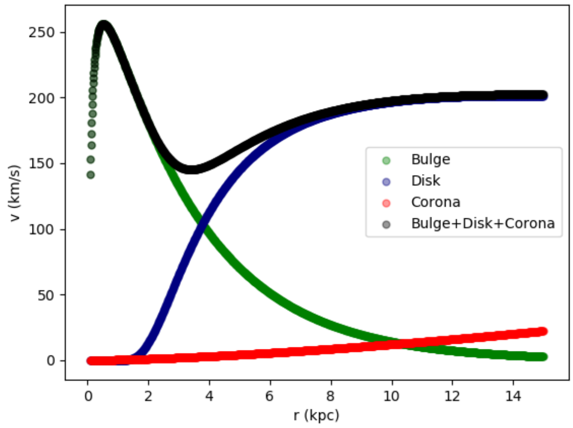
Mass Distributions	Velocity Distributions
$\rho(r)_{Bulge} = \dfrac{M_{Bulge}}{2\pi r}\dfrac{b_0}{r + b_0^3}$	$v(r)_{Bulge} = \dfrac{\sqrt{G\, M_{Bulge}\, r}}{r + b_0}$
$\sigma(r)_{Disk} = \dfrac{2\pi d_0^2 \sigma_0}{r^2}$	$v(r)_{Disk} = \sqrt{\dfrac{G \cdot \gamma(\sigma(r)_{Disk}\, \pi\, r^2)}{r}}$
$\rho(r)_{Corona} = \rho_{cg} \cdot \dfrac{1}{1 + \left(\dfrac{r}{h_0}\right)^2}$	$v(r)_{Corona} = \sqrt{4\,\pi\, G\, \rho_{cg}\, h_0^2}\ \left[1 - \left(\dfrac{h_0}{r}\right) \arctan\left(\dfrac{r}{h_0}\right)\right]$

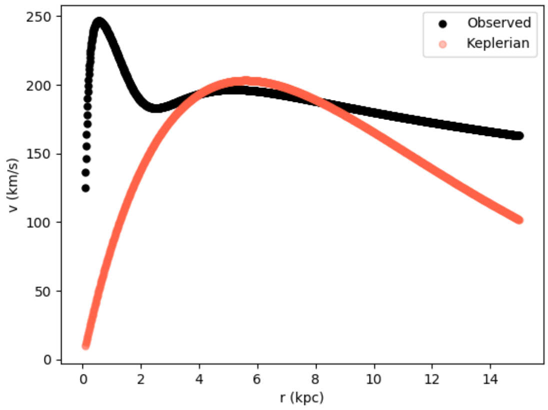
Table 1: *Mass and Velocity Distributions Models* – Reference [3] .

With this, we can obtain the total velocity dispersion and construct a rotation curve of the Galaxy.

$$v = \sqrt{v^2(r)_{Bulge} + v^2(r)_{Disk} + v^2(r)_{Corona}}$$

Results and Discussion





The Dark Matter on the Galaxy Scenario: The abrupt difference between the azimuthal speeds of stars that are farthest from the galactic center in relation to what is observed reveals that mass is lacking to accelerate them at this distance. To this matter, undetectable electromagnetically, is attributed the name of Dark Matter. Not postulating the presence of this Dark Matter means that a reformulation of Newton's Second Law must be made. A rather bold proposition! Mordehai Milgrom, in 1983, proposes a modification in Newton's second law, a more general formulation which could also plausibly explain the profile of rotation curves, without there being any need to postulate the existence of Dark Matter. The stars and all hydrogen present at the farthest borders of the visible disk of the Galaxy have extremely low accelerations.

Modeling the spiral arms

A shape for the spiral pattern naturally flows with a Gaussian behavior (Junqueira-2013), a real feat for the manifestation of an azimuth symmetry, which is expected by the conservation of angular momentum.

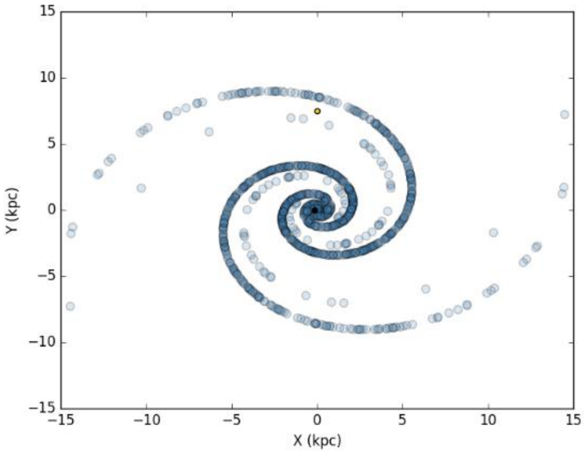
$$\frac{\vec{F}}{m} = -\vec{\nabla}\Phi$$

$$\int \frac{v^2}{r}\, dr = \int \frac{d\Phi}{dr}\, dr$$

$$\Phi\,(r, \Psi, t) = D\, e^{i\,[\Psi(r) - (\Omega\, t + \theta)]}$$

Assuming that the mass distribution does not vary in time, not taking into account the speed of rotation of the spiral arms.

$$\Psi(s) = \frac{k}{\tan(\alpha)}\, ln\left(\frac{s}{d_0}\right)$$



Based on what is observed, it is predicted that the spiral arms are regions of propagation of the gravitational potential that trap interstellar gas and dust, contained in a resonance interface of the stellar orbits.

This dispersed mass tends to agglomerate in these valleys of gravitational potential, which may lead to the formation of denser gas clouds (the protostars), making these regions an attractive place for a maternity of large stars, therefore very bright.

Modeling the stellar orbits

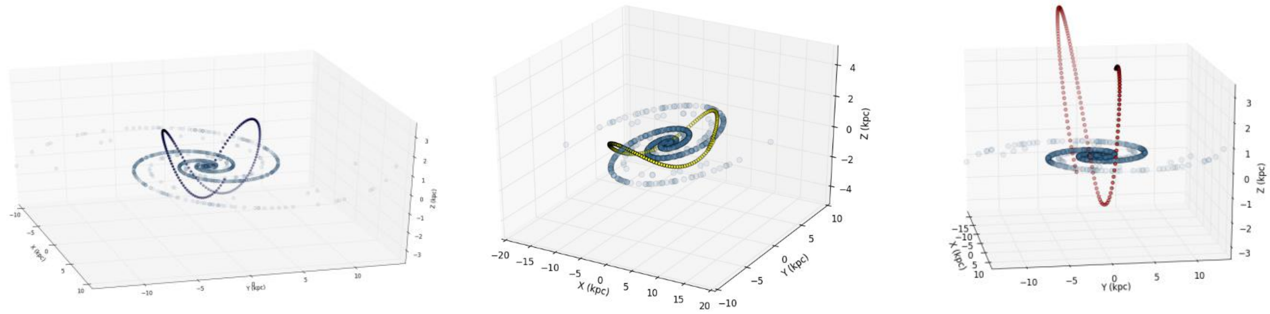
$$\vec{\nabla} \cdot \vec{g} = -4\pi\, G\, \rho(s)$$

$$a_s = -4\,\pi\, \frac{\sqrt{1-\epsilon^2}}{\epsilon^3}\, \rho_{cg} \cdot s_o \int_0^{\arcsin(\epsilon)} sen^2(\beta) \cdot e^{\frac{-\frac{1}{\epsilon}\sqrt{s^2\, sen^2(\beta) + z^2\, tan^2(\beta)}}{a_0}}\, d\beta$$

$$a_z = -4\,\pi\, \frac{\sqrt{1-\epsilon^2}}{\epsilon^3}\, \rho_{cg} \cdot z_o \int_0^{\arcsin(\epsilon)} tan^2(\beta) \cdot e^{\frac{-\frac{1}{\epsilon}\sqrt{s^2\, sen^2(\beta) + z^2\, tan^2(\beta)}}{a_0}}\, d\beta$$

(Reference- [1]): Orbiting profiles in bulge, disk and corona.

Through the Simpson's numerical method, we obtain the solutions of the integrals, consequently the accelerations in the adopted cylindrical symmetry, and finally, we apply these results in the equations of motion of the kinematics.



Conclusions

From the simulation, we can see how often the Sun crosses the galactic disk in an orbital period. There is a correlation between this periodicity and the eras of mass extinction on Earth. In particular, in the Cretaceous period, which marked the extinction of dinosaurs by an asteroid.

Considering that the Sun is surrounded by the Kuiper belt and the Oort cloud, regions of concentration of objects of varying sizes, the likelihood of one of these objects coming towards the Earth during the passage of the Sun near some spiral arm increases greatly.

In these regions, there is an intense gravitational disturbance coming from young stars who live very little and create an environment not conducive to life in their neighborhoods.

References

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