Orbital Dynamics of GG Tauri

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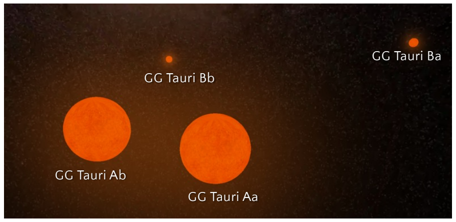
Abstract

The GG Tauri (GG Tau) system is a quadruple hierarchical star system, where GG Tauri Aa and GG Tauri Ab form a binary system that is orbited by the binary system formed by GG Tauri Ba and Bb. These young stars, about 1.5 million years old, are in their T Tauri phase and have not fully condensed. We used Kepler's Laws of Planetary Motion and the N-body numerical simulation REBOUND to study the orbital dynamics of the GG Tauri system. First, we simulated the stars without particles, first for 50000 years, then a billion years, to see if its stable. Then, we added particles of negligible mass to represent dust particles in the range of the observed circumbinary disk. We then simulate for 5 million years to see which particles remain in the system in order to find possible locations of planets. Even with these preliminary results we noticed that after just 5 million years, less than 1% of the particles remain in the system, and the region of the disk expanded

Introduction

The GG Tauri (GG Tau) system is a quadruple hierarchical star system, where GG Tauri Aa and GG Tauri Ab form a binary system that is orbited by the binary system formed by GG Tauri Ba and Bb. These young stars, less than 2 million years old, are in their T Tauri phase and have not fully condensed.



Previous observations have shown that GG Tauri Aa is about 379.63 light years away from Earth, GG Tauri Aa and Ab orbit 35 AU apart, GG Tauri Ba and Bb orbit about 207 AU apart, and there is about 10.1" separation between GG Tauri A and GG Tauri B, so the systems orbit about 1400 AU apart from each other.

The system is intriguing because these close and young stars. This dynamic system is a hotbed for planet and star formation due to its unusual two circumbinary disks and young age of only 1.5 million years

Our objective is to use Kepler's Laws of Planetary Motion and N-body numerical simulations to study the orbital dynamics of the GG Tauri system, and to find a region where planets can form

Methodology

We used Kepler's Laws of Planetary Motion and the N-body numerical simulation REBOUND to study the orbital dynamics of the GG Tauri system. Using the simulation, we found the energy error, the orbits of all four stars, the periods of GG Tau Aa and Ab around each other, GG Tau Ba and Bb around each other, and the GG Tau A system around the GG Tau B system. Using another similar simulation, we simulated the circumbinary disk of GG Tau A with 2000 randomly placed particle in the observed region of the disk and ran the simulation for a million years, tracking the number of particles that remain.

$$T^2 = \frac{4\pi^2}{G(M_1+M_2)}a^3$$

Kepler's Third Law
T: Orbital Period
G: Universal Gravitational Constant
M_1: Mass of object 1
M_2: Mass of object 2
a: Semi-major axis

$$F_g = G\frac{M_1 M_2}{r^2}$$

Universal Law of Gravitation
F_g: Universal Gravitational Constant
M_1: Mass of object 1
M_2: Mass of object 2
r: Distance between the objects

$$\Delta E = \frac{E-E_0}{E_0}$$

Relative Energy Error
ΔE = Relative Energy Error
E = Current Energy
E_0 = Initial Energy

Results

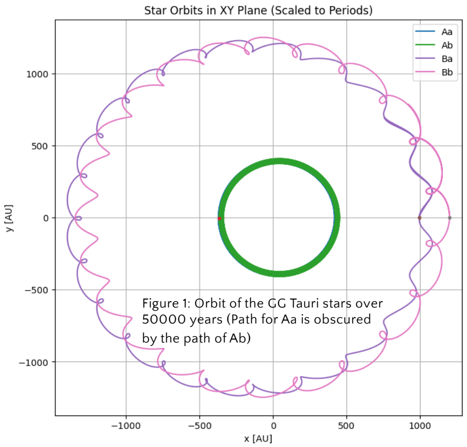
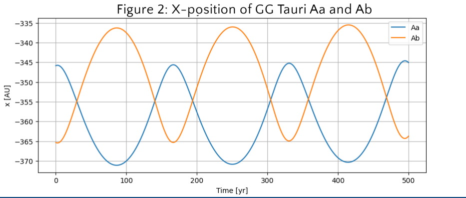


Figure 1: Orbit of the GG Tauri stars over 50000 years (Path for Aa is obscured by the path of Ab)

Figure 2: X-position of GG Tauri Aa and Ab



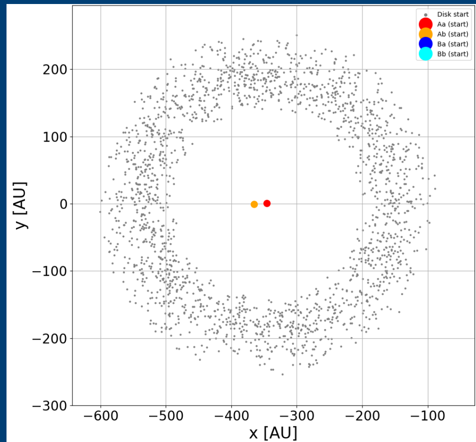


Figure 3: Starting position of GG Tauri and 2000 particles in circumbinary disk

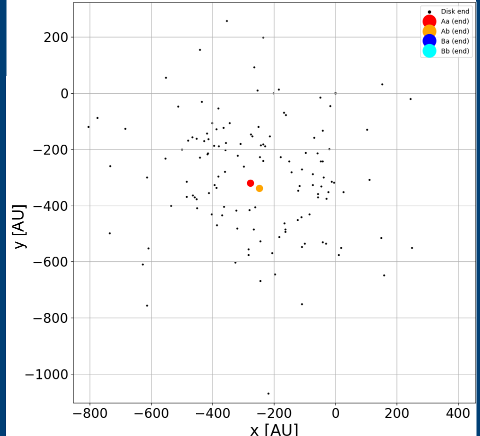


Figure 4: End position of GG Tauri and 2000 particles in circumbinary disk after 10 million years

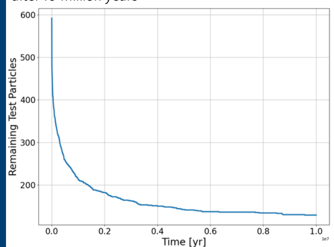


Figure 5: Survival of 2000 test particles survival over 10 million years

Conclusion

- The energy error of our simulations is to the order of 10^{-12} over a billion years.
- The orbit is stable over long periods of time, as shown by figure 1.
- It appears to be that this hierarchical structure keeps the system stable, where GG Tau B orbits GG Tau A like an ordinary binary system, while the stars in GG Tau B and GG Tau A orbit each other in their respective binaries, effectively bypassing the ordinarily chaotic nature of multistar systems.
- The accuracy of the setup is verified by figure 2, where the period of GG Tau Aa and GG Tau Ab around each other is about 160 years, consistent with the literature.
- Over the course of 10 million years, the region where particles in the circumbinary disk orbit GG Tau A expanded from about 80 AU wide to about 500 AU wide, as shown by figures 3 and 4.
- However, about 5% of the particles of the circumbinary disk remain, as shown by figure 3.
- For the first 1000 years, no particles are ejected, and very few particles are incinerated, if any.
- The survival of particles appears to asymptotically approach a value, indicating that their orbits are stable and are possible places that planets form, a key point of interest in the GG Tauri system

References

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Acknowledgments

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