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P1_3 Solar Centrifuge: the role of spin against self gravity

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Abstract

Stars, just like most astronomical bodies, exhibit the property of spin. This can be due to minor fluctuations in the radial density during their formation or possible collisions. There comes a point where the centrifugal force exceeds the self gravitating force of a star: "The break up point". We calculate the disruption angular speed at the suns surface to be: $\Omega_{dis} = 6.3 \times 10^{-4}$ rad/s. This corresponds to a total force of 5.5×10^{32} N required for such event.

Introduction

Planets tend to spin along the same rotational axis as the star they orbit. In the solar system, this follows except for Venus [2] and Uranus [1] whom rotate about their rotational axis in retrograde. Uranus orbits at an extreme tilt: almost to the point where its rotational axis is perpendicular to the plane of the Solar system. This is believed to be due to a collision with smaller objects early during its formation. Venus was theorised to originally spin in the same direction as the sun and the rest of the planets. It's axis of rotation subsequently changed due to tidal effects and the atmospheric tidal forces experienced from the Sun.

Stellar disruption

We can quantify the rotational force by examining the centrifugal force: $F_{rot} = m\Omega^2 r$. Where Ω is the angular velocity and m and r are the mass and the radius of the rotating body respectively. This force acts from the centre of the star out towards the surface. The self-gravitating force of a body is defined by:

$$F_{sg} = \frac{Gm^2}{r^2}. \tag{1}$$

This equation is just a shortened version of Newton's law of gravitation using $m_1 = m_2$.
An astronomical body would become disrupted and essentially break if $F_{rot} > F_{sg}$. We assume that the body is in free space and has no net force pulling it in any other direction. Therefore, we define the point at which the two forces equate as the 'breaking point'. Only taking into account mechanical energy:

$$\Omega_{dis} = \sqrt{\frac{Gm}{r^3}}. \tag{2}$$

Calculations and Discussion

Since the Sun changes its rotational direction to go from prograde to retrograde every few hundred of years [5], we start our calculations by assuming that the Sun's angular velocity conforms to 0. Now, by using equation (2), we calculate the angular velocity required to disrupt the Sun to be $\Omega_{dis} = 6.3 \times 10^{-4}$ rad/s . This uses the

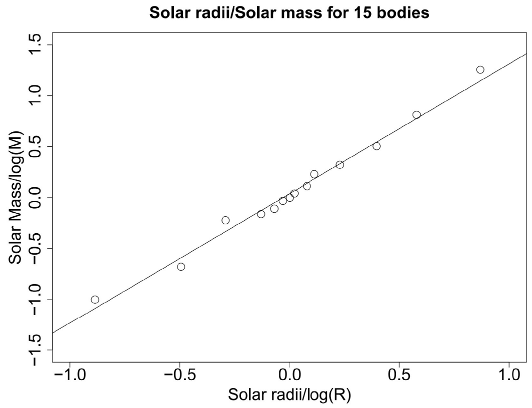

Figure 1: Log of solar masses against solar radii for 15 known stars.

current M_{sun} and r_{sun} [3]. We also assume the star has a uniform density profile.

To justify not needing to change the radius of the Sun, (due to the changes in angular momentum,) we created a graph of 15 stellar bodies that have known radii and mass [3] (Figure 1). Note that we have an underlying assumption that the density profile of the star is constant. There is an approximate linear relation (shown as units of solar mass increase, the units of solar radii increase at the same rate). Since we assume a constant mass in our calculations for Ω_{dis}; approximating the radii to be constant is acceptable.

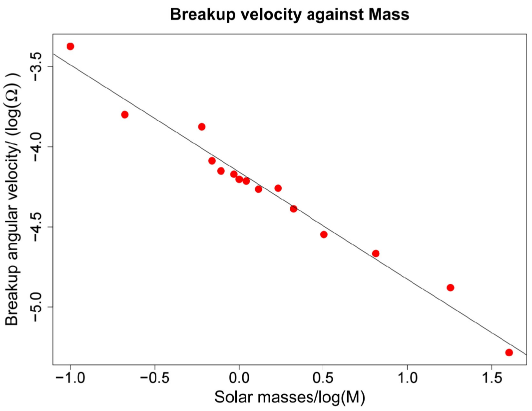

Figure 2: Log of solar masses against angular velocity.

The angular velocity corresponds to a tangential velocity: $v_t = 4.4 \times 10^5$ m/s by using the formula $v_t = r\Omega$. Comparing this to the current spin of the sun at it's equator (by calculating the angular speed from its rotational period, $\Omega_{now} = 2.7 \times 10^{-6}$ rad/s) [4] we see that the tangential velocity must increase by a factor of 230 to experience any sort of disruption. The total force required to replicate this simulation can be computed using either equation (1) or (2) by substituting in our angular velocity: 5.5×10^{32}N. We acknowledge that if you weren't to use our simple model, the point where $F_{rot} = F_{sg}$ would be larger since the radii would indeed increase.

Conclusion

From Figure 2, we see that as the mass of a star increases, the disruption angular velocity decreases. This is may be due to minor instabilities deeper into the star creating a ripple effect, disrupting it more the closer we are to the surface. We also calculated the angular velocity required to 'break up' the sun and compared this to its current value. Possible events causing such a scenario could be the impact Andromeda may have on the Milky Way when they collide, or possible AGN jets being oriented towards stars. For future work, it would be useful to introduce the change in radii at different speeds as well as including a density profile of the Sun.

References

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