Distribution of mass of the protoplanetary disk HL Tau

Distribución de Masa del Disco Protoplanetario de HL Tau

Nidia Yiseth Buitrago Carreño¹, Nicanor Poveda Tejada¹*, Nelson Vera-Villamizar¹

¹Grupo de Astrofísica y Cosmología, Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia

Received: 24 Nov 2015     Accepted: 26 Feb 2016  Available Online: 29 Feb 2016

Abstract

A recent image of ALMA, of the protoplanetary disk around the star HL Tau, shows that the disc consists of several bright concentric rings separated by gaps. There is a hypothesis that these gaps are due to the presence of planets, but there are some difficulties with this interpretation: The planets are too close, generating orbital instability and should not exist planetary formation processes so advanced because the star is too young. This paper shows that the gaps are an effect of the distribution of matter of the disk. In most models assume that the disc consists of a continuous distribution of matter and gas, however, by orbital resonance effect, the disc has an internal structure: It is a superposition of distribution functions that give rise to the characteristic shape of the disc. The mass distribution is obtained, and a preliminary study of the orbits is done, finding that they are stable.

Keywords: Solar and Extrasolar System, Orbital Dynamics

1. Introduction

In 2014 the ALMA (Atacama Large Millimeter/Submillimeter Array) team showed a picture (Figure 1) of the star HL Tau (J2000 04:31:38.45 18:13:9.0), product of continuous emission in the band 6 (211-275 GHz).

In the image several concentric rings appear: rings of gas and dust, emitting radiation which are separated by a gap (dark area), which is due to the existence of a planet, massive enough, to capture the matter found around [1].

How to cite: Buitrago, N., Poveda, N., Vera-Villamizar, N., Distribution of mass of the protoplanetary disk HL Tau, TECCIENCIA, Vol. 11 No. 20, 67-70, 2016
DOI: http://dx.doi.org/10.18180/tecciencia.2016.20.9
But there are difficulties with this interpretation, since the existence of gaps involves orbital resonance phenomena, which lead to stable orbits, for example, it suffices that two planets are at a greater distance to 3.5 RH (Hill's radii) \[2\] without however, the gaps are too close to each other, which implies interaction of planets each other, generating an orbital instability which would destroy the observed gaps.

The disc matter distribution along the radius \(0 < r \leq R_0\) (AU), gives rise to the ring structure by a superposition of \(R_n(r)\Theta(\theta)\) basis functions given by:

\[
\rho(r, \theta) = \sum_n m_n R_n(r) \Theta(\theta)
\]

where \(n\) is the number of stable and closed orbits, and \(m_n\) the mass contained in each element. The radial distribution of matter is described in [4],

\[
R_n(r) = \left(\frac{2}{na_s}\right)^{2n+1} \frac{1}{(2n)!} r^{2n} e^{-2n/a_s}
\]

being \(a_s = ka_\odot\), a parameter, \(k = M_s/M_\odot = 0.55\) \([5]\) and \(a_\odot = 0.0292705\) \([6]\) see Figure 2(a). The zenithal distribution, Figure 2(b), is:

\[
\Theta_n(\theta) = 2\pi |Y_{n-1}^{n-1}(\theta, \phi)|^2 \sin\theta.
\]

2. Protoplanetary disk model

The estimated radius of protoplanetary disk of HL Tau, the image from ALMA (ESO/NAOJ/NRAO) is \(R_0 = 117.5\) AU with a total mass \(M_0 = 0.135M_\odot\). Initially image of 1800×1800 pixels is transformed to grayscale; \(0^\circ \leq \phi < 360^\circ\) sweep was made.

The major and minor semi-axes of the ellipse were determined by the minimum points, which are \(\phi = 45.26^\circ, 134.65^\circ, 225.17^\circ, 315.13^\circ\); it is known that the separation should be \(n = (1,3,5,7)\) times 45, by \(\phi/n\) ratio obtain the position angle photography: \(45.04898 \pm 0.07806\) giving rise to an image of 2546×2546 pixels. Using the expression for ellipticity \(\cos(\phi)=b/a\), by minimum sweep the average inclination angle of \(\phi = 46.82687^\circ\) established; finally an image of 1622×1617 pixels, obtained (Figure 3.)
In the image a sweep of $0^\circ \leq \phi < 360^\circ$ is made, for each $0 < R \leq R_0$ (AU), obtaining a profile of luminosity-distance, Figure 4.

To suppress the effect of brightening the gas due to the presence of the star, a brightness-density conversion is made by the relationship $\rho \sim L^{3.5} - \exp(-r/12.8482) + 0.036446$, which depends on the variation of temperature $T \sim r^{-0.43}$, obtaining the distribution of matter, $\rho(r, \pi/2)$ given by equation (1); the area under the curve corresponds to the mass of the disk, Figure 5.

An adjustment is made by least squares to obtain the terms of mass $m_n$ in equation (1). The red line corresponds to the setting and the masses obtained a computer simulation using the algorithm of Barnes-hut with the integrator IAS15 of rebound [7] develops, is that the orbits are stable for extremely long time, in the Figure 6 orbits and the Hill's radius of objects shown. The main objects are at 17.07, 20.77, 41.76, 75.98, 101.33 with mass $\geq 1 M_J$. 

**Figure 2** (a) Radial distribution of matter and (b) zenithal distribution.

**Figure 3** Protoplanetary disk projected image.

**Figure 4** Profile normalized light-distance.

**Figure 5**: Distance density profile.
3. Conclusions

The observed gaps in the protoplanetary disk HL-Tau are not due to the existence of planets but is an effect of the distribution of matter in the disk, in this model the disc has a discontinuous structure as a series of concentric toroids, rather than a matter continuous distribution. The orbits of the objects obtained are stable.

Acknowledgements

We thank the Dirección de Investigaciones (DIN) of the Universidad Pedagógica y Tecnológica de Colombia (UPTC).

References


