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THE EXO-PLANETARY SYSTEM OF 55 CANCRI AND THE TITIUS-BODE LAW

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RESUMEN

El reciente descubrimiento de un quinto planeta ligado a 55 Cancri (Fischer et al. 2007) nos ha motivado a investigar si este sistema exo-planetario se ajusta a alguna una forma de la ley de Titius-Bode (TB). Encontramos que una simple relación TB exponencial reproduce muy bien los cinco semiejes mayores observados siempre y cuando se asigne el número 6 al planeta con el semieje más grande. Esta forma de contar deja un vacío en la posición $n = 6$, una situación curiosamente reminiscente a la ley TB en nuestro propio sistema planetario, antes del descubrimiento de Ceres. La aplicación de una ley T-B exponencial a 55 Cancri nos permite predecir la existencia de un planeta con $a \approx 2.0$ AU y con un período de $P \approx 1130$ días localizado en la gran brecha entre $a = 0.781$ AU ($P = 260$ días) y $a = 5.77$ AU ($P = 5218$ días) correspondientes a los dos más grandes períodos observados. Con menos certeza, también predecimos un séptimo planeta en $a \approx 15$ AU con $P \approx 62$ años.

ABSTRACT

The recent discovery of a fifth planet bound to 55 Cancri (Fischer et. al 2007) motivated us to investigate if this exo-planetary system fits some form of the Titius-Bode (TB) law. We found that a simple exponential TB relation reproduces very well the five observed major semi-axis, provided we assign the orbital $n = 6$ to the largest a. This way of counting leaves empty the position $n = 5$, a situation curiously reminiscent of TB law in our planetary system, before the discovery of Ceres. The application of an exponential TB relation to 55 Cancri allows us to predict the existence of a planet at $a \approx 2.0$ AU with a period of $P \approx 1130$ days located within the large gap between $a = 0.781$ AU ($P = 260$ days) and $a = 5.77$ AU ($P = 5218$ days). With less certainty, we also predict a seventh planet at $a \approx 15$ AU, with $P \approx 62$ years.

Key Words: planetary systems — planets and satellites: general — stars: individual (55 Cancri)

1. INTRODUCTION

The two hundred year old saga of the Titius-Bode law is well known (see Nieto 1972 for a well documented review). Since the discovery by Bode, in 1782, that the Titius relation "predicted" the major semi-axis of Uranus, a frantic search for "the lost planet" at position $n = 5$ was initiated at various European observatories. The discovery of Ceres by Piazzi on the night of January 1st, 1801, with the major semi-axis predicted by TB, and the fact that the satellites of Jupiter, Saturn and Uranus also follow a TB relation, initiated a debate about the meaning of TB which is still alive nowadays. Is the TB law a matter of chance (Lynch 2003; Dubrulle & Graner 1994; Neslušan 2004)? Is it consequence of the early physical conditions in the protoplanetary disk (Graner & Dubrulle 1994)? Is it a reflection of a process of dynamical relaxation in a system of planets subject to their mutual gravitational perturbation (Hayes & Tremaine 1998; Hills 1970; Ovenden 1975)?

Because of the previous considerations and in view of the growing number of multiple exo-planetary systems, we decided to check whether the

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TABLE 1

PROPERTIES OF 55 CANCRI

Apparent visual magnitude	5.96
Hipparcos parallax	79.8 ± 0.84 mas
Distance	12.5 ± 0.13 parsecs
Absolute visual magnitude	5.47
Effective Temperature	5234 ± 30K
Rotation velocity $v \sin i$	2.4 ± 0.5 km s^{-1}
Luminosity	0.6 $L_\odot$
Spectral type	G8V/K0V
Mass	0.94 ± 0.05 $M_\odot$

55 Cancri system, for which a fifth planet has been recently announced (Fischer et al. 2007), follows the TB law.

The traditional TB relation is essentially a geometric progression in the number n, the running number of a planet according to its distance to the central star. This geometric relation can be represented by an exponential in n.

We tried to represent our planetary system by an exponential in n and found a good fit. Having verified that an exponential fit for the Solar System was a good approximation we tried to represent the 55 Cancri system also by an exponential TB. The exponential fit to the 55 Cancri system was very good (with a coefficient of correlation $R^2 = 0.997$) when we assigned the number $n = 6$ to the largest major semi-axis observed. The vacancy left at $n = 5$ leads us to propose the existence of a new planet with a major semi-axis $a \approx 2$ AU.

2. THE 55 CANCRI SYSTEM

The star 55 Cancri (55 Cnc = HD 75732 = HR3522 = HIP 43587) is a well observed nearby star; in Table 1 we list some of its parameters taken from the paper by Fischer et al. (2007). In Table 2 the observed parameters for its planetary system are listed, including the year of discovery of each planet. Note in this table the enormous spacing between planets $n = 4$ and $n = 5$, whose major semi-axes are, respectively, less than 1 AU and more than 5 AU, and whose periods are 260 days and 5218 days.

3. THE TITIUS-BODE LAW

The equation

$$a = 0.4 + 0.3 \times 2^n \qquad (a \text{ in AU}) \qquad (1)$$

represents the classical Titius-Bode law. Note the peculiar ordering system: Mercury corresponds to $n = -\infty$, Venus to $n = 0 \ldots$

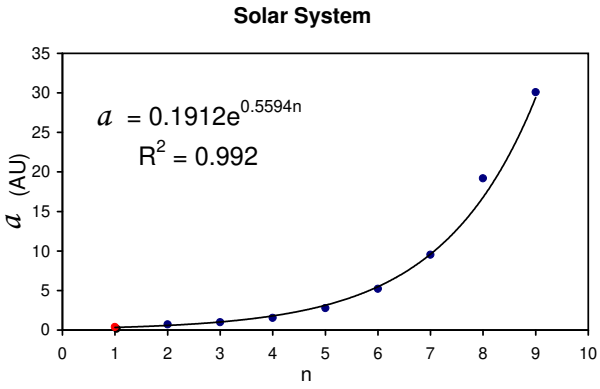

Fig. 1. An exponential TB fit to the Solar System. This fit includes major semi-axis from Venus ($n = 2$) up to Neptune ($n = 9$). Note that the extrapolation of equation to $n = 1$, gives $a(1) = 0.335$ AU, close to the observed value $a = 0.387$.

In the equation

$$a = 0.1912 \quad e^{0.5594n}. \qquad (2)$$

we present our best exponential fit to the Solar System excluding Mercury and Pluto, but including Uranus and Neptune. Our exponential TB fit to the Solar System excludes Mercury because in the traditional TB relation not only it is given an orbital number $n = -\infty$, devoid of any physical meaning, but also the value of the constant (0.4) is arbitrarily chosen to give the approximately correct values of a for Mercury and the Earth. At the other end of our planetary system we exclude Pluto not only because of its pathological orbit, but also because we do not know if it is an object from the Kuiper belt, captured into the region of the outer planets, or a satellite ejected from Neptune; in any case its present orbit has followed a dynamical evolution different from that of the rest of the planets.

In Figure 1 we plot equation (2), and we mark the position of the orbital $n = 1$. Note that although equation (2) does not include the value of a for Mercury, it predicts orbitals close to the observed ones up to Neptune, $n = 9$. The traditional TB relation gave a good fit up to Uranus, but a very poor one for Neptune. Our exponential TB relation gives a poor representation for Uranus, but a good one for Neptune.

4. THE TITIUS-BODE AND THE 55 CANCRI EXO-PLANETARY SYSTEM

If we plot, as we do in Figure 2, the major semi-axis of the five known planets versus n, we note that

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TABLE 2

OBSERVED PROPERTIES OF THE 55 CANCRI EXO-PLANETARY SYSTEM*

n	1	2	3	4	5
Year of discovery	2004	1996	2002 (1)	2007	2002 (2)
Observed semiaxis major (AU)	0.038 $\pm 1.0 \times 10^{-6}$	0.115 $\pm 1.1 \times 10^{-6}$	0.24 $\pm 4.5 \times 10^{-5}$	0.781 ± 0.007	5.77 ± 0.11
Period (days)	2.817 $\pm 1 \times 10^{-4}$	14.651 $\pm 7 \times 10^{-4}$	44.344 $\pm 7 \times 10^{-3}$	260 ± 1.1	5218 ± 230
$M \sin i$ (Jovian masses)	0.034 ± 0.0036	0.824 ± 0.007	0.169 ± 0.008	0.144 ± 0.04	3.835 ± 0.08

*Taken from Fischer et al. 2007.

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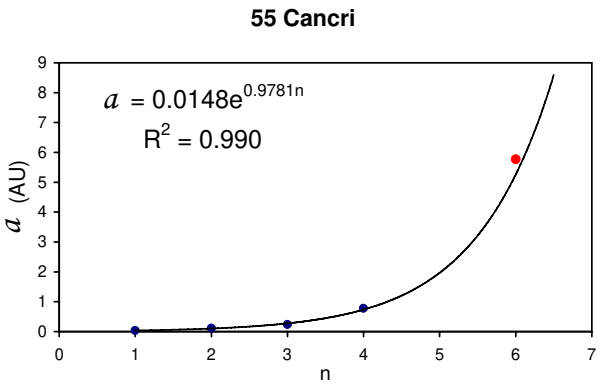

Fig. 2. An exponential TB fit to the four closest planets in the 55 Cancri system. Note that the extrapolation to $n = 6$ corresponds to a major semi-axis close to the observed one.

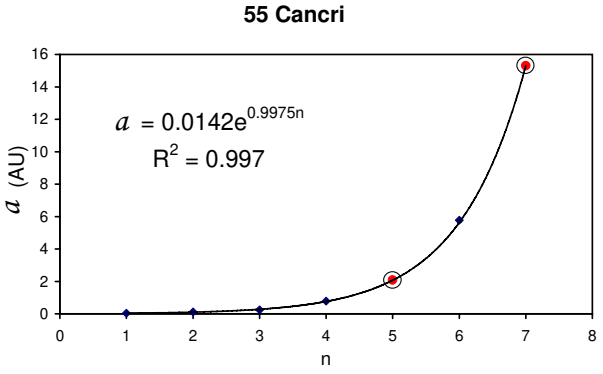

Fig. 3. The TB exponential fit to the 5 observed planets of 55 Cancri, where we count the farthest observed one as $n = 6$. Planets $n = 5$ and $n = 7$, predicted by TB, are shown as open circles.

the more distant planet, $n = 5$ falls very far from any reasonable exponential fit to the 4 closest planets ($n = 1, 2, 3, 4$). However, if we assume that planet 5 has not been discovered, and we fit the first 4 planets with an exponential we see that the extrapolation of this relation to $n = 6$ ($a \approx 5.24$ AU) turns out to be close to the observed value ($a = 5.77$ AU). Figure 3 shows the best fit for the distribution of the observed major semi-axes of the first four planets and the fifth one, now occupying orbital number 6.

This fit is

$$a = 0.0142 \quad e^{0.9975n} \quad (R^2 = 0.997) \qquad (3)$$

This equation "predicts" the existence of a fifth planet at $a \approx 2$ AU and, with less certainty, a seventh one at $a \approx 15$ AU.

In Table 3 we list the observed elements of 55 Cancri system as well as the TB fit and the two new planets predicted by the Titius-Bode law.

5. CONCLUSIONS

In the present paper we showed that the exponential Titius-Bode law holds for the 4 closest planets of 55 Cancri and that its extrapolation fits well the major semi-axis of the fifth planet, provided it is assumed that it occupies the sixth orbital.

The Titius-Bode law is valid for the exo-planetary system 55 Cancri, and may be valid for other exo-planetary systems as well.

Having found another planetary system where the Titius-Bode law is valid makes it rather unlikely that it is due to chance.

The Titius-Bode law allows us to predict two new planets for the 55 Cancri system:

$a \approx 2.0$ AU $\quad P \approx 3.1$ years

$a \approx 15.0$ AU $\quad P \approx 62$ years

TABLE 3

THE TITIUS-BODE FIT TO THE 55 CANCRI SYSTEM AND THE TWO NEW PLANETS

n	1	2	3	4	5	6	7
Observed semiaxis major (AU)	0.038 $\pm 1 \times 10^{-6}$	0.115 $\pm 1.1 \times 10^{-6}$	0.24 $\pm 4.5 \times 10^{-5}$	0.781 ± 0.007		5.77 ± 0.11	
Titius-Bode (AU)	0.039	0.104	0.283	0.768	**2.08**	5.643	**15.3**
Period (days)	2.817 $\pm 1 \times 10^{-4}$	14.651 $\pm 7 \times 10^{-4}$	44.344 $\pm 7 \times 10^{-3}$	260 ± 1.1	**1130**	5218 ± 230	**22530**

The existence of two hot Jupiter-like planets ($n = 1, 2$), in this system opens the problem of how to understand the persistence of the Titius-Bode law against the phenomenon of planet migration.

The validity of TB for the 55 Cancri exoplanetary system does not yet help to understand the physics behind it. However, it may help to discover new planets by paying special attention to periodic signals in the radial velocities at values close to the predicted periods.

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