# The planets of the binary star HD 75747

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So far it has been assumed that the star system HD 75747, also known as HR 3524 or RS Chamaeleontis (RS Cha), has only *one* companion. A gravitational wave at 13.86 $\mu$Hz is calculated from the orbital period of 1.67 days. The decoding of the phase modulations of the GW shows *eleven* companions. The orbital times fit very well with the predictions of Dermott's law, an improved version of the Titus-Bode rule.

## 1 Introduction

Decades of observations could not solve the mysteries of the binary system HD 75747. What is certain is that two stars $Aa1$ and $Aa2$ orbit each other in just 1.66988 days. In [1] one assumes a companion of large masses, whose orbital period is either 13 days or 24 days or 74 days. In [2] one suspects pulsations caused by tidal forces.

The binary system emits a gravitational wave (GW) of frequency 13.8622 $\mu$Hz. The measurement procedure is described in [4] [5] and is not repeated here. The long-term analysis of the GW over a period of twenty years shows several results:

- Eleven planets orbit the binary system. They can be distinguished because each causes a periodic Doppler shift of the GW with a different frequency.
- The modulation index $a$ of all phase modulations is remarkably large. The earth orbit data allow the calculation of the propagation speed of the GW.
- The frequency drift of the binary star system is measured precisely.

Electromagnetic wave observations [1] allow the calculation of $f_{GW}$ in 2013, but not the frequency drift. Analysis of historical data from the year 2000 requires a reliable initial value for $f_{GW}$. At the expected frequency, the spectrum shows *no* maximum. The lack of a prominent spectral line is not a problem for the MSH method because it hardly reacts to the signal amplitude and possible amplitude modulations.

## 2 The order of measurements

As we know the expected value $f_{GW}$, the signal is filtered with a bandwidth of 0.4 nHz in order to minimize interference from neighboring GWs. This dispenses with all energy components that are transported by sidebands (phase modulation produces sidebands). Initially, we have to accept an inaccurate result due to the low amplitude and poor S/N. The aim of this first step is to assess the frequency stability of $f_{GW}$ over a period of twenty years and to roughly eliminate the *slow* modulations that may cause it.

- A phase modulation (PM) with $f_{mod} > 10^{-9}$ Hz can often be recognized by its curved shape. From the curvature, we determine an approximate value for $f_{mod}$.

- In the case of a linear progression, it is unclear whether it is generated by a constant frequency drift or a very low-frequency PM ($f_{mod} < 10^{-9}$ Hz) with a suitable phase position.

Before all other measurements, these possible modulations must be roughly eliminated. To achieve this, one iterates the modulation index and the phase of the low-frequency PM until the intervals between two zero crossings of the sine wave match.

Next, one compensates the inevitable PM with $f_{orbit} = 31.8$ nHz generated by the earth's orbit. As a result, more energy is concentrated on $f_{GW}$, the signal amplitude and the accuracy of the frequency measurement increases because the information contained in the sidebands improves the result. In addition, you will be informed about the direction from where the GW arrives. As with all higher-frequency PM, the modulation index and phase are iterated until the amplitude of $f_{ZF}$ reaches a maximum value.

After this preliminary work, the detective work begins: Planets force the GW source to orbit the common center of gravity and each planet modulates $f_{GW}$ at a different frequency. The corresponding sidebands are usually far away from $f_{GW}$ and are suppressed because of the low bandwidth of the signal processing (BW$<$ 0.4 nHz). It's pointless to look for the individual sideband frequencies in the surrounding noise since there are no clues for frequency and amplitude. And if anyone spots suspicious lines, it would be even more difficult to prove that the frequencies found are part of the GW in terms of amplitude and phase. The MSH method [9] [5] does these tasks in a completely different way.

It is helpful to know the orbital data of *one* planet, because then Dermott's empirical law [8] provides clues for the orbital periods of other planets in this binary system. Although these estimates are quite rough, the *capture range* of the iteration is sufficient to determine the exact value. Vertical dips in figure 1 may occur when the additional planet corrects the frequency and/or phase of already known planetary orbits. This can simulate a temporary constant frequency. The noise for n>200 arises because the calculations are performed with 64-bit floating-point numbers, the value range of which covers a maximum of 15 significant decimal places. It is not possible to calculate linearity errors more precisely.

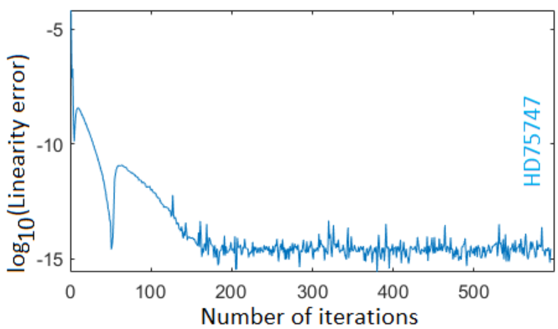


Figure 1): *Convergence behavior of the iteration of the MSH method. The vertical axis shows how the total error in calculating the orbital data of HD75747's seventh planet decreases after a few iterations.*

Previous studies have shown that binary stars often have many planets. Assuming that there are eight planets and that each causes a PM with the modulation index $a = 3$, the total energy of the GW is distributed over a total of about $8 \cdot 2 \cdot 3 + 1 \approx 50$ spectral lines in the vicinity of $f_{GW}$, which disappear in the noise because of the rather small amplitudes. Therefore, at an early sdays of the analysis, it is pointless to look for conspicuous lines in the spectrum. This changes in the course of the analysis because the amplitude of $f_{GW}$ increases with each detected planet. The energy of many sidebands is then transferred to the central spectral line. Symmetrical structures like in figure 2 can indicate other, previously undiscovered planets.

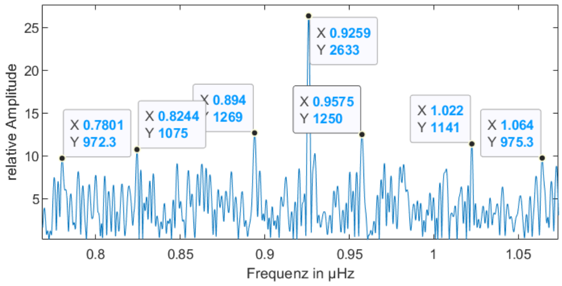


Figure 2): *The spectrum of $f_{ZF} = 1/300$ hours shows symmetrical structures after about a thousand iterations. These could be sidebands created by unknown planets from HD75747. With each discovered planet the S/N improves.*

## 3 Results

Assuming that all phase modulations are generated by planets, the binary system $Aa$–$Ab$ of the GW source HD75747 has eleven planets.

- Planet $B$ with the orbital period $P_B = 12.68$ days ($f_B = 912.55$ nHz). This value is mentioned in [1] as a possible solution. The parameters $a_B = 1.735$ and $\phi_B = 2.4224$ are discussed from section 5 onwards.
- Planet $C$ with $P_C = 24.12$ days ($f_C = 479.86$ nHz) in accordance with a suggestion in [1]. $a_C = 2.0824$ und $\phi_C = 4.6692$.
- Planet $D$ with $P_D = 81.72$ days ($f_D = 141.64$ nHz). The value given in [1] is 9% smaller than the value measured here. $a_D = 3.2812$ und $\phi_D = 4.2325$.
- Planet $E$ with $P_E = 163.25$ days ($f_E = 70.90$ nHz). $a_E = 2.24708$ und $\phi_E = 3.7781$.
- Planet $F$ with $P_F = 309.77$ days ($f_F = 37.36$ nHz). $a_F = 4.14599$ und $\phi_F = -0.331966$.
- Planet $G$ with $P_G = 563.81$ days ($f_G = 20.53$ nHz). $a_G = 0.8741$ und $\phi_G = 0.46876$.
- Planet $H$ with $P_H = 2.714$ years ($f_H = 11.67$ nHz). $a_H = 1.2814$ und $\phi_H = 0.9891$.
- Planet $J$ with $P_J = 4.682$ years ($f_J = 6.768$ nHz). $a_J = 0.66904$ und $\phi_J = 2.3268$.

- Planet $K$ with $P_K = 16.137$ years ($f_K = 1.964$ nHz). $a_K = 2.8718$ und $\phi_K = 3.6939$.

- Planet $L$ with $P_L = 19.865$ years ($f_L = 1.595$ nHz). $a_L = 3.777$ und $\phi_L = 1.172$.

- Planet $M$ with $P_M = 39.186$ years ($f_M = 0.809$ nHz). $a_M = 10.521$ und $\phi_M = 3.4901$.

After compensation of all PM with the frequencies $f_B ... f_M$ mentioned above, the residual ripple of $f_{ZF}$ is so low that the existence of further planets with $P < 1000$ years is improbable. The short database of only 20 years does not allow to determine even longer time constants.

As expected, $f_{GW}$ is also phase modulated with $f_{orbit} = 31.68754$ nHz. $a_{orbit} = 2.1082$. From the phase angle $\phi_{orbit} = 1.8197$ it follows that here on Earth, we receive maximum blueshift on every $365 \cdot \phi_{orbit}/2\pi$ =106th day of the year $f_{GW}$. According to [7], this should already take place on the 55th day of the year (measurement error $\approx 14\%$).

On January 1, 2000, the frequency of the GW source was 13.8622 $\mu$Hz. The drift of the GW is $\dot{f}_{GW} = 5.27 \times 10^{-18}$ Hz/s. So far, the drift has not been measured with electromagnetic waves.

In retrospect, it is confirmed that it is important to eliminate *all* PM: With PM, the Bessel function $J_0(a)$ is a measure for the amplitude of the carrier frequency $f_{GW}$. An unmodulated GW has an amplitude of 100%. With special values of the modulation index like $a_1 = 2.4$ or $a_2 = 5.5$ the amplitude of the carrier frequency decreases to extremely low values. Some planets cause a PM with such an unfavorable modulation index that the spectral line at $f_{GW}$ is hardly recognizable in the original data. Compensating the PM with the MSH method allows the amplitude of the GW to rise back to 100%, improving the S/N significantly. The vicinity of $f_{ZF}$ is filled with the distorted spectra of previously undiscovered GWs of similar frequency (Figur 3).

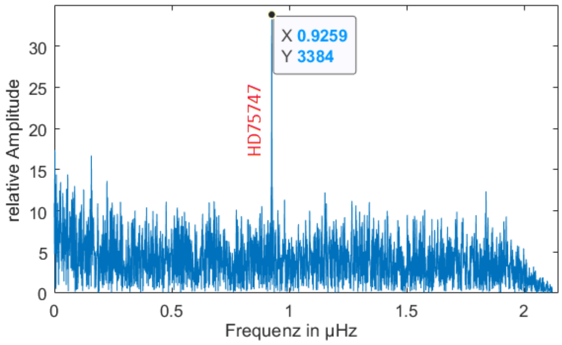


Figure 3): *Spectrum of the GW of HD75747 after changing the frequency to $f_{ZF} = 1/(300$ hours) and compensating for the phase modulations by all eleven planets. The amplitude of the carrier frequency of the GW is very large (S/N $\approx$ 14) because it now contains the energy content of all compensated sidebands (constructive interference).*

## 4 Dermott's Law

For a long time people have been looking for reasons for obvious connections between the orbital periods $P$ of planets. The approach comes from Dermott [8]

$$P_n = P_0 \cdot c^n \tag{1}$$

with $n = 1, 2, 3, 4...$ Adding a space for a hypothetical planet to $n = 3$ results in the figure 4 with $P_0 = 6.727$ days and $c = 1.882$. For the relation of Dermott and the older Titius-Bode series there is no deeper justification. After a few conversions and with an additional correction factor, exactly the same results are obtained for the TB series as with Dermott's rule, but a total of four factors have to be adjusted empirically. That makes TB less believable. Dermott's law provides good initial values when searching for unknown planets. At $n = 3$, despite an intensive search, no PM is found that indicates a planet with an orbital period of $P \approx 45$ days.

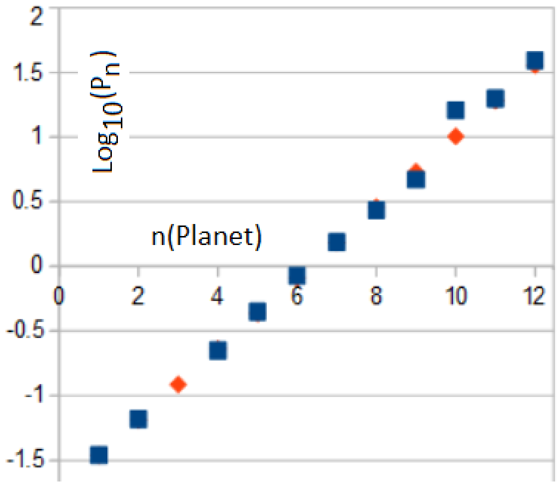


Figure 4): *The logarithm of the orbital period of the planets (in years) of HD75747 as a function of their order. The actual values (blue) hardly differ from Dermott's law (red). The discrepancy at* $n = 10$ *remains another mystery.*

## 5 Notes from an astronomical point of view

A word of caution: The MSH method measures phase modulations of $f_{GW}$. In the following we assume that the Doppler effect caused by planets are the only reason for the PM of the GW source.

If one translates the abstract results of the iteration determined in section 3 into astronomical terms, the following relationships apply: All time specifications refer to the beginning of the analyzed data chains on 2000-01-01 and apply under the condition that the corresponding celestial bodies describe circular orbits. The phase shift $\phi$ indicates at what later point in time the instantaneous frequency of the GW is blue-shifted to the maximum. Then one has to add the frequency deviation $\Delta f$ produced by the Doppler effect to the average frequency $f_{GW}$. The results of the compilation given above may be evaluated independently of one another because all PM are linearly superimposed.

All results mentioned in section 3 are reproducible.

## 5.1 Earth orbit causes a PM

The earth's orbit around the sun generates a phase modulation with the frequency $f_Y = 31.178328$ nHz. The largest blue shift of $f_{GW}$ is measured at $365 \cdot \phi_Y/2\pi = 106$th day of the year. The greatest red shift is measured on the 288th day; if the GW comes from the source *HD75747*, the redshift should reach its maximum value on day 238 [7]. This corresponds to a measurement error of 14%.

From the modulation index of a PM $a_Y = \Delta f_Y / f_Y$ follows $\Delta f_Y = 66.8$ nHz – an unexpectedly large frequency deviation that cannot be explained with previous assumptions. This value means that the instantaneous frequency of the GW oscillates between $f_{GW} - \Delta f_Y$ and $f_{GW} + \Delta f_Y$ over the course of the year.

It is commonly assumed, without proof, that any GW travels at the speed of light. Then we get for the maximum value of the Doppler shift:

$$\Delta f_Y = f_{GW} \cdot \left( \sqrt{\frac{c + v_{orbit}}{c - v_{orbit}}} - 1 \right) \approx f_{GW} \cdot \frac{v_{orbit}}{c} \approx f_{GW} \cdot 10^{-4} \tag{2}$$

The actually measured value is about 48 times larger! A measurement error of this magnitude can be ruled out after careful examination. What is causing the discrepancy? The formulas of the PM and the Doppler effect are well founded and confirmed a million times. What remains is the correction of the assumption, that GWs propagate at the speed of light. The calculation of the instantaneous frequency uses the longitudinal Doppler effect, in which the frequency is corrected relativistically. For maximum blueshift applies

$$f_{GW} + \Delta f_Y = f_{GW} \sqrt{1 - \left( \frac{v_{orbit}}{c} \right)^2} \cdot \frac{1}{1 - \frac{v_{orbit}}{v_{GW}}} \approx \frac{f_{GW}}{1 - \frac{v_{orbit}}{v_{GW}}} \tag{3}$$

The position of HD75747 is far south of the ecliptic plane ($\delta = -79°$ 04' 12"). Therefore, the Earth is approaching this target with the maximum speed $v_{orbit} = 8.5 \times 10^3$ m /s. If we transform the equation (3)

$$\frac{v_{orbit}}{v_{GW}} = 1 - \frac{f_{GW}}{f_{GW} + \Delta f_Y} = 4.796 \times 10^{-3} \tag{4}$$

we may use this intermediate result to calculate

$$v_{GW} = \frac{v_{orbit}}{4.796 \times 10^{-3}} = 1.77 \times 10^6 \ \frac{m}{s} \approx \frac{1}{170} c. \tag{5}$$

This result is much lower than the speed of light and is valid for $f_{GW} \approx 14$ $\mu$Hz. Possibly $v_{GW}$ depends on the frequency (dispersion) and the gravitational field in the area. That's still speculation. After all, values smaller than $c$ were measured earlier [9,10].

### 5.2 The Planet *B*

Decoding the PM of the GW shows that the planet $B$ orbits the GW source $Aa$–$Ab$ with the orbital period $P_B = 12.68$ days. Assuming a circular orbit, it follows from the phase angle $\phi_B = 2.4224$ that this companion produces maximum blueshift of $f_{GW}$ on $12.68 \cdot \phi_B/2\pi$ =5th day after 2000-01-01.

From the modulation index $a_B = \Delta f_B/f_B = 1.735$ of the PM, we calculate the maximum frequency deviation $\Delta f_B = 1583$ nHz. This maximum value of the periodic frequency shift of $f_{GW}$ is the result of the Doppler effect, because the GW source rotates around the center of gravity of the system. This measured value cannot be explained with previous assumptions: The ratio $f_{GW}/\Delta f_B \approx 8.8$ contradicts the maximum value that results from the previous assumptions of the theory of relativity (equation 2).

The calculation of the radial velocity is the task of classical astronomy. Considering the GW source $Aa$–$Ab$ as a star and the planet $B$ as a companion, Kepler's third law provides the orbital equation for the two-body system.

$$4\pi^2(r_A + r_B)^3 = GT^2(m_{Aa} + m_{Ab} + m_B) \tag{6}$$

The radii refer to the center of gravity of the trio and the center of gravity theorem $(m_{Aa}+m_{Ab})r_A = m_B r_B$ applies (the other planets are ignored here). With the assumed masses [1] $m_{Aa} = 1.823 m_{\odot}$, $m_{Ab} = 1.764 m_{\odot}$ and $m_B \approx 0.41 m_{\odot}$ we calculate $r_A = 2.6 \times 10^9$ m and the orbital velocity $v_A = 14.9 \times 10^3$ m/s (The orbital speed of $B$ is about 8.5 times higher and not measurable because the planet $B$ does not emit any GW).

Analogous to the equations (4) and (5) we get

$$v_{GW} = \frac{14.9 \times 10^3 \ m \ s^{-1}}{0.1025} = 145.2 \times 10^3 \ \frac{m}{s} \approx \frac{1}{2066} c. \tag{7}$$

With $m_B \approx 13 \cdot m_{\odot}$ one would get the same result as in equation 5. Such a massive star could only be overlooked if it were a black hole. What now?

## 6 Summary

From a communications point of view, decoding the phase modulations of $f_{GW}$ is a standard task of digital signal processing. The signal has a good S/N (figure 3), the receiving antenna is insensitive to earth quakes. No assumptions are needed at any stage of decoding. There is no computationally intensive comparison with pre-calculated patterns (search templates) based on model assumptions.

The opposite is true for the interpretation of the results from an astronomical point of view: The high values for the frequency deviation ($\Delta f$) can only be explained by the assumption that gravitational waves at low frequencies around 10 $\mu$Hz are considerably slower than the speed of light. The processing of this question is not yet complete.

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