# Analysis of the eclipsing times variations of an evolved binary

**M.N. Ramos**[1,2], L. Gramajo[2,3], C.A. Giuppone[2,4]

(1) Facultad de Matemática, Astronomía, Física y Computación, Famaf, UNC
(2) Observatorio Astronómico de Córdoba, UNC
(3) Consejo Nacional de Investigaciones Científicas y T´ecnicas (CONICET)
(4) Instituto de Astronomía Teórica y Experimental, CONICET - UNC

The Eclipsing Timing Variations (ETV) technique permits an indirect determination of orbital parameters of a circumbinary planet orbiting an eclipsing binary star. In this work, we show preliminary results on the analysis of the eclipsing binary star QS Virginis in search of an explanation for the variations in its orbital period. This system has been analyzed before but, there are no reliable explanations for the signal.

Using an analytical model and minimizing strategy, we find the orbital parameters of this body, that correspond to the best-fit. We test two strategies for estimating the uncertainties and, lastly, we analyze how the best fits changes as a function of the observational set.

Facultad de Matemática, Astronomía, Física y Computación

Universidad Nacional de Córdoba

Observatorio Astronómico de Córdoba

# Motivation and previous works

In the present around 5000 planets have been discovered [1] albeit a fraction of them have circumbinary orbits (~5% [2]). A particular set contains **circumbinary planets that orbit close evolved binary stars** (see Fig. 1) with periods of a few hours, that still is on discussion. These systems are detected indirectly by the **Eclipsing Timing Variations** (ETV or LTT) technique.

The chosen system for analysis is **QS Virginis** (EC13471-1258, [3], see Fig. 2). This binary has previous analyses [4][5][6] but the **proposed explanations have been discarded** by new observations or stability studies [5][6][7]. Presently, there are new observations that has not been analyzed in search for an explanation of the ETV signal [8].

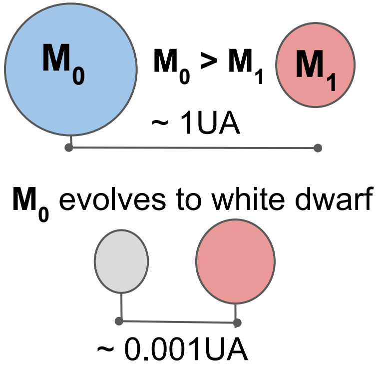


Figure 1. Scheme for the formation of an evolved binary star.
Planets in circumbinary orbit that survive the stellar evolution can affect the position of the barycenter of the binary, **producing an ETV signal**. This variation has been modelled by [9].

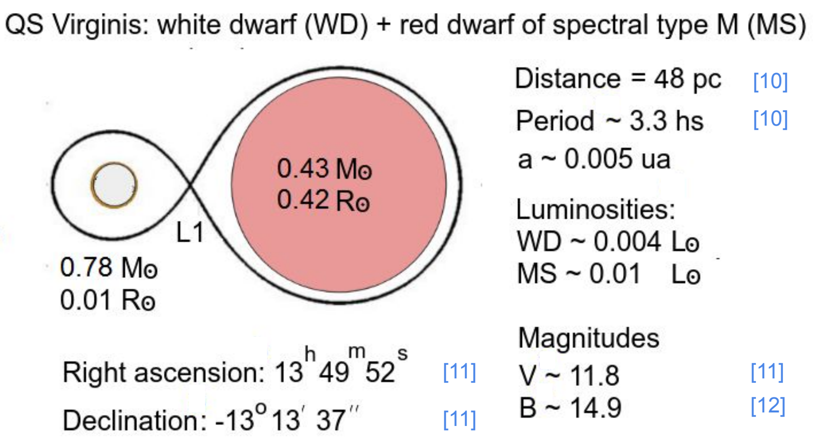


Figure 2: Schematic and physical properties of QS Virginis.

We make a **temporal analysis of the determination process of orbital parameters** in the ETV technique.

Our objective is to **design a strategy to model the presence of an additional body** and study the dispersion of orbital fits as observations are added. We study this evolution and **discuss the sensitivity of the fits as a function of the dataset**.

# Metods

Construction of the (O-C) diagrams

Using the data published by [8], which contains **105 eclipsing times**, we built the (O-C) diagrams as a function of a linear and quadratic ephemeris. On this poster, **we only analyse the result from the linear ephemeris**.

Building of the **best-fit**

We minimize the residue function WRMS using consecutively a **genetic algorithm** [13][14] to explore the parameter space and a **simplex** algorithm [15][16] to refine the result. The set of resulting parameters is the **best-fit.**

Estimation of the uncertainties

They are determined independently, first using a bayesian method **MCMC** [17] and then a **Grid method**. The last consists of making fits with the simplex algorithm, fixing one parameter value in the vicinity of the **best-fit** and fitting the rest. Then **we compare the resulting WRMS values against the** $\mathbf{WRMS_{1\sigma}}$ to estimate the uncertainties.

Analysis of the solution

Removing, chronologically, the eclipses and making fits with the simplex algorithm allow the **study of how the parameters change as a function of the dataset**.

# Results

## (O-C) diagrams and the best fits

In Fig. 3 the (O-C) diagrams and their best fit are shown. The residues present an **additional signal.**

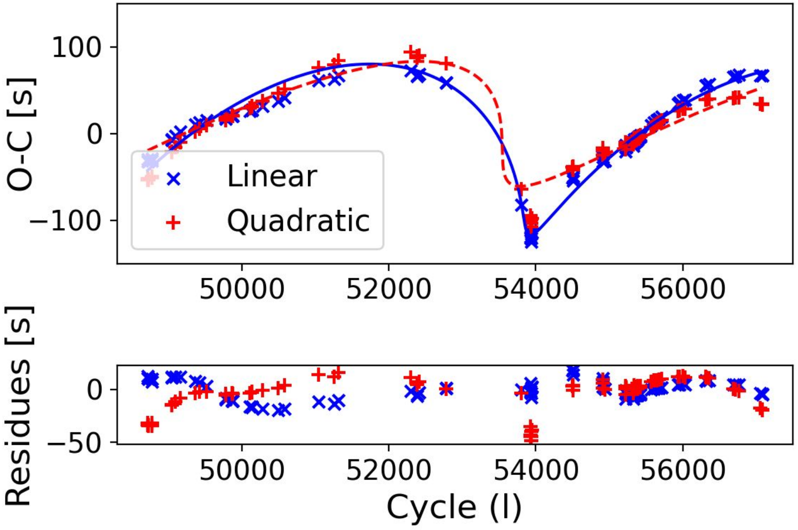


Figure 3. ***Upper panel:*** (O-C) diagrams built using a linear (x) and quadratic (+) ephemeris and their best fits in continuous and dashed lines, respectively. ***Lower panel***: Residues with the same color scheme as the upper panel.

## Uncertainties estimation: MCMC

The region near to the global minima of the WRMS **have secondary minima** that prevents the algorithm to converge.

We filter the chains that mix on the global minima and estimate uncertainties. The result is **a sub-estimation of the uncertainties**. (<1% percentage error) for each orbital parameter.

## Uncertainties estimation: Grid method

This strategy **produces more compatible uncertainties** with the values of the parameters previously proposed in the literature (Fig. 4)

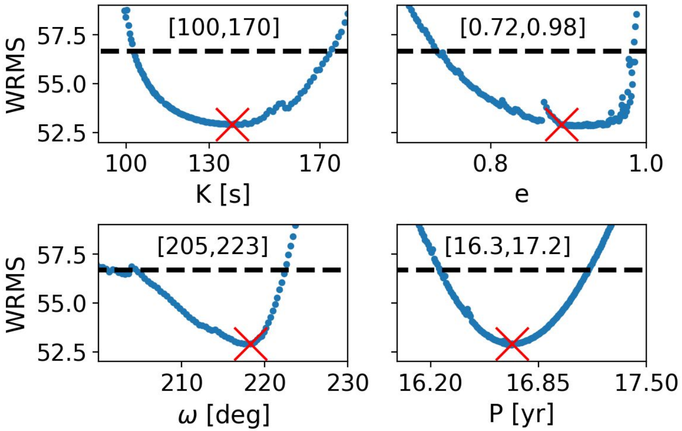


Figure 4. WRMS vs. fixed values for the parameters (4 are shown for clarity). The dashed line represent the value of WRMS1$\sigma$, the **brackets show the estimation of uncertainties**. The red crosses are the values of the **best-fit**.

## Analysis of the solution

After obtaining several fits as a function of the observational set, we note that **the parameters have a considerable variance** (Fig. 5). This indicates that **there are not enough observations** to constrain the third body's parameters.

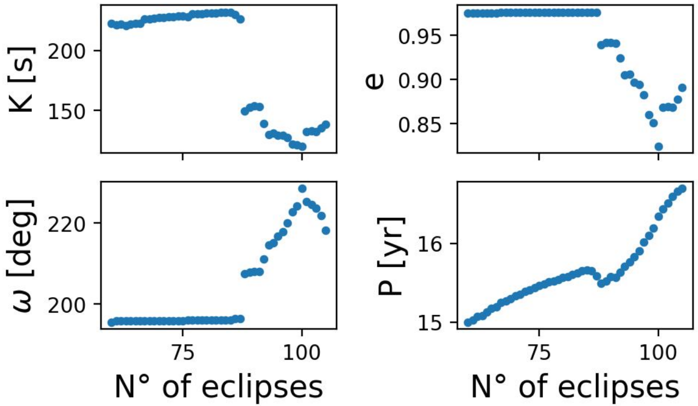


Figure 5. Variation of some orbital parameters of the third body as a function of the dataset. K:semi-amplitude, e:eccentricity, ω:argument of periapsis and P:orbital period.

## Conclusions

We designed

- Algorithm to build the (O-C) diagram
- Algorithm to find the best orbital fit
- Strategies to estimate the uncertainties of the parameters
- An analysis of the variation of the parameters vs. the dataset

Results for QS Virginis

- The residues contain an additional signal
- The grid-method is the most robust to estimate the uncertainties
- The parameters vary significantly as a function of the observational set
- A future analysis with a complete and updated observational set will allow to better understand the system

**References and contact**:

https://bit.ly/3uPzxKa, matias.ramos@mi.unc.edu.ar