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# ACROM. Una herramienta para el análisis de curvas de luz cromáticas de CoRoT

## ACROM. A Tool for analysis of chromatic light curves from CoRoT

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**Abstract**— This work presents a first version of *Acrom*; a set of scripts written in python language for the analysis of exoplanet light curves registered in different colors by the CoRoT satellite. It contains functionalities for filtering, detrending, phase diagram and plotting. This work proposes a particular case of convolution to deal with the long-term trend of light curves; framed in general procedure described step by step. This tool has been tested in the analysis of this light curves with the purpose of exploring the achromatic nature of the planets discovered in this survey. The results obtained during the analysis of the chromatic light curves of some CoRoT exoplanets are presented in the respective section. These results allowed to verify the achromatic behavior of the planetary transits.

**Key Word** — Exoplanet, light curve, python, moving average, convolution, multicolor photometry, detrending, CoRoT.

**Resumen**— Este trabajo presenta la primera versión de *Acrom*; un conjunto de scripts escritos en lenguaje python para el análisis de curvas de luz de exoplanetas registradas en diferentes colores por el satélite CoRoT. Contiene funcionalidades para filtrado, detrending, diagrama de fase y graficación. Este trabajo propone un caso particular de convolución para tratar con la tendencia de largo término de la curva de luz; enmarcado en un procedimiento general que es descrito paso a paso. Esta herramienta ha sido probada en el análisis de curvas de luz con el propósito de explorar la naturaleza acromática de los planetas descubiertos en este survey. Los resultados obtenidos durante el análisis de las curvas de luz cromáticas de algunos exoplanetas CoRoT son presentados en la respectiva sección. Estos resultados permitieron verificar el comportamiento acromático de los tránsitos planetarios.

**Palabras clave** — Exoplaneta, curva de luz, python, promedio móvil, convolución, fotometría multicolor, detrending, CoRoT.

### I. INTRODUCTION

The CoRoT satellite (Convection, ROTation and planetary Transits) was in operation between 2006 and 2012 [1]. Although the satellite is not active, the information generated is currently the object of study in open and active areas of research such as planetary transits and asteroseismology.

The instrument implemented the functionality that allowed it to capture curves of light in three different colors (red, green and blue); The objective of such technical array is to facilitate the distinction between practically achromatic planetary transits and colored stellar fluctuations [2] that present events similar to planetary transits generating false alarms in the search of candidates in the survey [3].

These chromatic light curves constitute the main input of the present work in which the appropriate software tools have been developed to deal with this instrumental characteristic with the purpose of verifying the achromatic nature of the planetary transits in confirmed Corot exoplanets [4]. The development of this type of specific tools is necessary for the appropriate processing of light curves that, in addition to specific technical characteristics, may be affected by different types of noise; mainly of instrumental origin. This tool, which has been named *Acrom*, has focused on the long-term trend presented by the Corot light curves.

This tool, which has been named *Acrom*, has focused on the long-term trend that affects the light curves of CoRoT. The IPAC ASCII text files constitute the system entry. From this file we proceed to filter the light curve in sub-curves according to the three colors. Subsequently, the long-term trend is eliminated and the respective phase diagrams are generated. A functionality has been provided to graph the results that are obtained in each step.

### II. CHROMATIC LIGHT CURVES OF COROT

Within the present work framework is important to consider some technical characteristics of the COROT instrument.

Of particular interest is the satellite data capture module. In the array of the electronic sensors, the CCDs (Charge Coupled Device) A1 and A2 belong to the Asteroseismology Channel [5], and the E1 and E2 devices belong to the Exoplanet Channel. Just above the Exoplanet Channel is located a prism

that is responsible for generating light scattering to capture the data in the colors red, green and blue.

During its operational state, the satellite observed around 160,000 stars in the exoplanet channel. Among which were discovered 35 exoplanets confirmed to date. The Corot light curves can be obtained from the following official repositories:

- CoRoT Public Archive - Institute of Space Astrophysics (IAS), France. <http://idoc-corot.ias.u-psud.fr/>
- Strasbourg Astronomical Data Center, France. <http://vizier.u-strasbg.fr/viz-bin/VizieR?source=B/corot>
- NASA Exoplanet Archive, US. [http://exoplanetarchive.ipac.caltech.edu/applications/ETSS/CoRoT\\_exo\\_index.html](http://exoplanetarchive.ipac.caltech.edu/applications/ETSS/CoRoT_exo_index.html)
- CoRoT Public Archive - Astrobiology Center (CAB), Spain. <https://sdc.cab.inta-csic.es/corotfa/>

A Corot light curve in IPAC ASCII format consists essentially of two sections. The first part contains the metadata that describe the technical and physical characteristics of the data records. The second section contains the data records themselves; The chromatic light curves, in addition to the white flux column, also contain the columns corresponding to the red, green and blue flux.

These light curves are not exempt from noise effects. The main sources of noise are instrumental type: long-term trends and jumps. Long-term trends affect the light curve with a constant increase or decrease in intensity over the observation period; This is possibly due to the gradual deterioration of the sensors [1] [6].

The jumps are manifested as untimely and rapid variations of intensity caused possibly by the incidence of cosmic rays or other sudden high energy phenomena that saturate the electronic sensors of the instrument.

### III. IMPLEMENTATION

This work focuses on the processing of long-term trend by developing a specific tool framed in a procedure that addresses several sequential steps for the analysis of data. The current version does not deal with the setting of jumps and Limb Darkening. However, it allowed to verify the achromatic nature of several confirmed Corot exoplanets as noted in the corresponding section.

#### A. Procedure

For the mentioned approach, the following procedure has been proposed which is described step by step as follows:

1.- A light curve is entered in IPAC ASCII format; The records that meet the condition status (column)> 0 are filtered.

These measurements are considered defective according to the technical specifications of the mission in the metadata section.

2.- Subsequently, the light curve is separated in the colors red (r), green (g) and blue (b). The result is three ASCII files containing the Datehel time column and the respective column with the flow value  $Fr$ ,  $Fg$  or  $Fb$ .

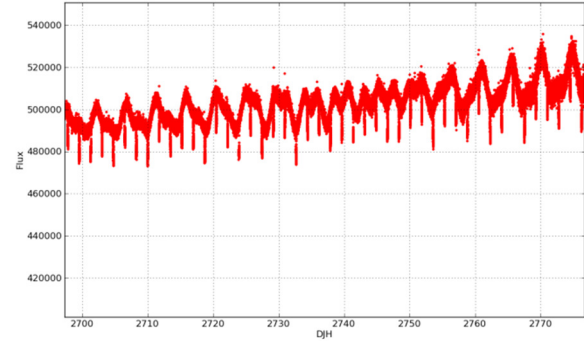


Figure 1. Segment of Corot 2b red sub-light curve after filtering process.

3.- Detrending. This work proposes the use of a particular convolution case known as moving averages to perform the detrending on each sub-light curve ( $r$ ,  $g$ ,  $b$ ) obtained in the previous step. The respective detrended flows are obtained and we denominate as  $FDr$ ,  $FDg$ ,  $FDb$ .

$$FDr(t) = \sum_{\tau=-n/2}^{\tau=n/2} \frac{1}{n} F_r(t + \tau) \quad (1)$$

$$FDg(t) = \sum_{\tau=-n/2}^{\tau=n/2} \frac{1}{n} F_g(t + \tau) \quad (2)$$

$$FDb(t) = \sum_{\tau=-n/2}^{\tau=n/2} \frac{1}{n} F_b(t + \tau) \quad (3)$$

where  $n$  is the number of points or records of each sample in the entire light curve. Each sample will have an average that is described by the component:

$$\frac{F_{r,g,b}(t + \tau)}{n} \quad (4)$$

$\tau$  is the temporal separation from the first point of each sample.

*Criterion of choice of  $n$  parameter:* In this work the  $n$  parameter has been chosen as the relation between the total number of points of the light curve and the total number of observation days

$$n = \frac{N_{total\ LC\ points}}{Total\ observation\ days}$$

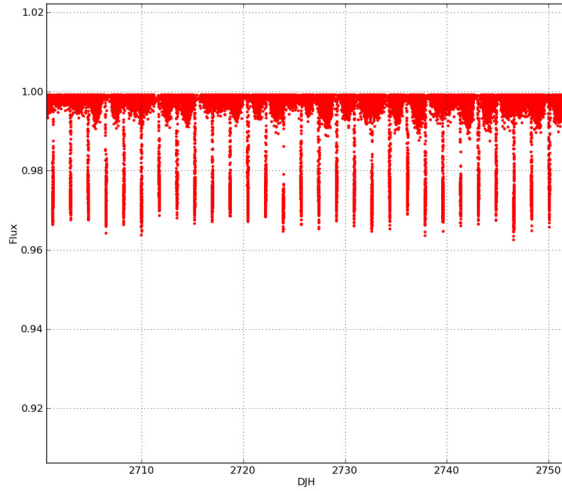


Figure 2. Segment of Corot 2b red sub-light curve after detrending and normalization algorithm.

4.- Each flux is normalized with respect to Mean.

$$FDN_r(t) = \frac{FD_r(t)}{M_r} \quad (6)$$

$$FDN_g(t) = \frac{FD_g(t)}{M_g} \quad (7)$$

$$FDN_b(t) = \frac{FD_b(t)}{M_b} \quad (8)$$

5.- The  $FDN_r, FDN_g, FDN_b$  fluxes still retain points that are not relevant for the analysis. ACROM resorts to the Sigma-Clipping removal algorithm.

Therefore, in each light curve we keep the data points that meet the following condition:

$$FDN_{r,g,b}(t) < Media - n * sigma \quad (9)$$

Where  $n$  is a factor that can be adjusted as necessary for the removal of irrelevant points; and Sigma is the Standard Deviation of the respective sub-light curve.

(5) At this point the result is 3 sub- light curves (r, g, b) in ASCII format with the columns Datehel and FDNr, g, b.

6.- In each sub-light curve we cut those transits with a stronger signal-to-noise ratio and construct the folded phase diagram. In this step we enter the parameters: orbital period and the number of points for the binning.

7.- The depth of the transit is obtained from the folded phase diagram of each sub-light curve. In this step the following criteria have been used [7]:

- Choice of a central transit point:

$$[t_i - 0.025D, t_i + 0.025D] \quad (10)$$

where  $D$  is the transit duration.

We obtain the  $M_f$  mean of this subset of points.

- Choice of non-transit intervals:

$$[t_i - 2.0D, t_i - 1.95D] \quad (11)$$

$$[t_i + 1.95D, t_i + 2.0D] \quad (12)$$

We obtain the  $M_i$  mean of this subset of points.

Considering the radius ratio of a planetary transit,

$$\frac{\sqrt{\Delta F}}{\sqrt{F}} = \frac{R_p}{R_*} \quad (13)$$

Finally, we obtain the depth of the transit by making the appropriate substitution:

$$\Delta F = M_i - M_f \quad (14)$$

$$F = M_i$$

(15)

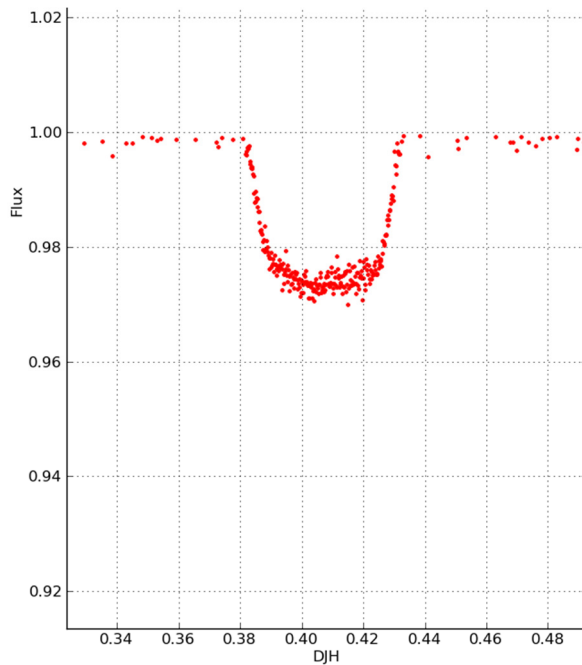


Figure 3. Folding phase diagram of Corot 2b red sub-light curve.

### B. Preliminary results

Acrom was used to verify the achromatic nature of some confirmed exoplanets by studying the depth of the transit in each of the sub-light curves of light  $r$ ,  $g$ ,  $b$  generated.

The results are presented in table 1.

Planet	$\frac{R_p}{R_*}$		
	$r$	$g$	$b$
CoRoT 1b	0.148	0.148	0.148
CoRoT 2b	0.164	0.161	0.164
CoRoT 3b	0.0652	0.06	0.0652
CoRoT 4b	0.094	0.094	0.094
CoRoT 5b	0.11	0.102	0.11
CoRoT 6b	0.114	0.105	0.114

Table 1. Radius ratios of CoRoT planets analysed for  $r, g, b$  colours.

For CoRoT exoplanets analysed, the results obtained allow verifying the independence of the transit depth respect to color. This result is consistent with other studies found in the literature that on the one hand seek to study the phenomenon

and on the other hand use the technique to rejection of false alarms [7] [8] [9] [10].

The depth of the transit in the green color presents a slight difference due to the smaller size of the section in the CCD destined to this flux and the higher dispersion that affects it [1].

### C. Technical information

The tool was developed in Python language version 2.6.5 and executed in Linux operating system Ubuntu 10.04 LTS. Using a two-core processor at 2.7 GHz each and a RAM of 4GB, the average execution time of each script is 15 seconds on a chromatic light curve with approximately 369,000 points.

Acrom is composed of the following specific scripts:

- acrom\_filter.py
- acrom\_detrending.py
- acrom\_cut.py
- acrom\_ph.py
- acrom\_plot.py
- acrom\_graph.py

## IV. CONCLUSIONS

This paper has described a software tool developed in Python language for the analysis of the chromatic light curves of exoplanets CoRoT which has been made available in the github portal under the GPL v3 license. It can be consulted in the following link: <https://github.com/djdorado/acrom>.

This tool was developed to confirm the achromatic nature of transits of CoRoT exoplanets. On the one hand, it facilitated the analysis tending to this purpose and on the other hand it allowed to verify this characteristic of the transits.

Although the tool focuses on the chromatic light curves of CoRoT, with a few modifications its use can be extended to the treatment of chromatic light curves from other surveys.

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