Dynamics of coronal mass ejections in the interplanetary medium in two dimensions

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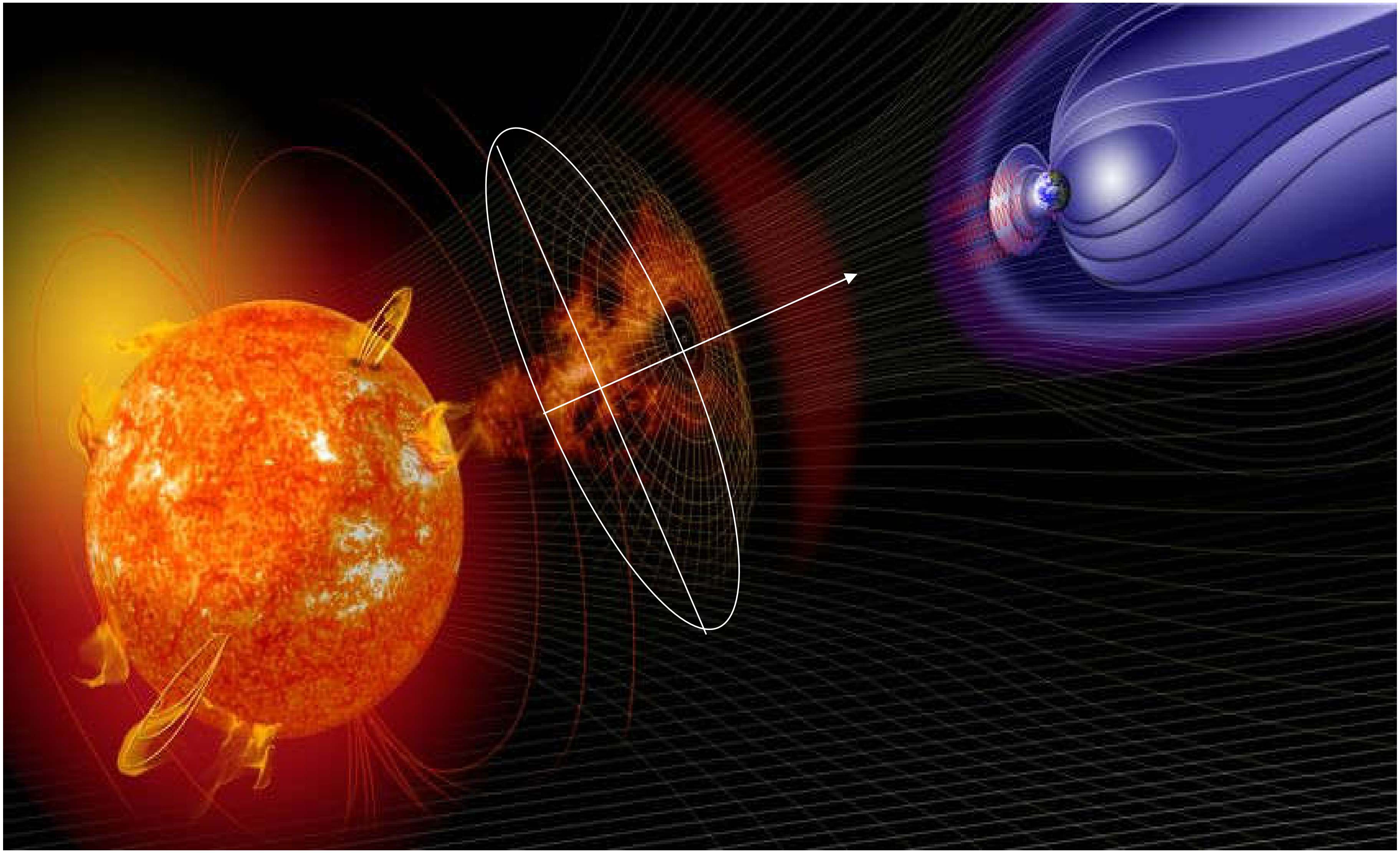
Introduction

- *We propose a model in 2-D as a extension of the 1-D work of Borgazzi et al. (2009)*
- *It consist of a description in 2-D for position/speed of every point of the leading edge of a propagating ICME, as a function of the position/speed of the ICME's center of mass.*
- *The model is based on a aerodynamical scheme of propagation where the effects of any magnetic field are neglected)*



Two-parts framework

1) Differental equation for motion of the center of mass of the ejecta.

Density of the solar wind

Speed of flow of the solar wind

$$\frac{1}{2} C_d A \rho_{sw} (U_{cm} - U_{sw})^2 = m_{cme} U_{cm} \frac{dU_{cm}}{dr_{cm}}$$

Effective cross-sectional surface area

Drag coefficient

Speed of the ICME

Mass of the ICME

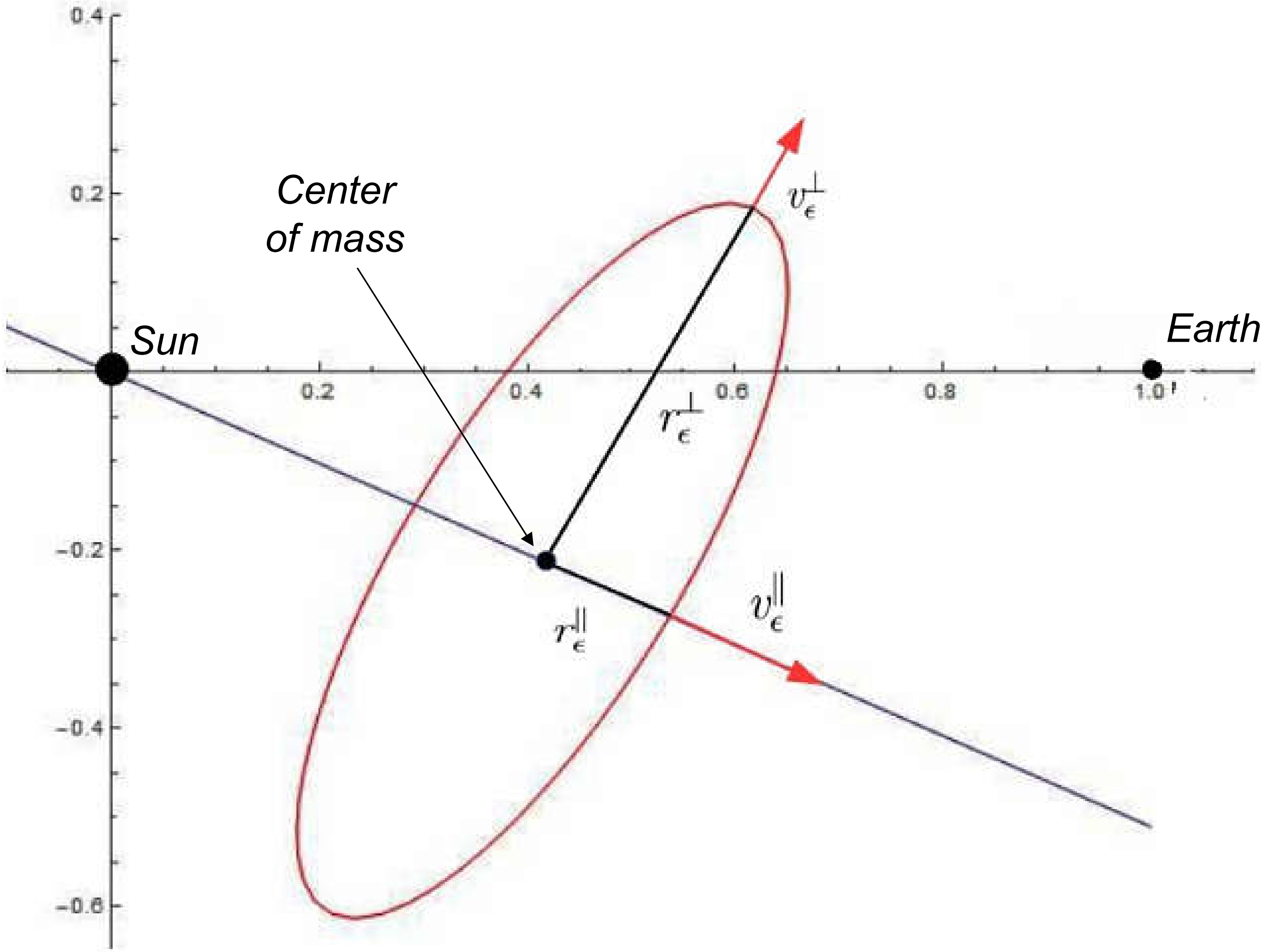
Resolving the last equation for the ICME speed, we get:

$$\boxed{\begin{aligned}-\frac{C_d \pi a}{2m_{cme}}[-C_0(\frac{1}{r}-\frac{1}{r_0})+\frac{2C_0}{\kappa}\ln(\frac{r}{r_0})+\frac{2C_0\beta}{\kappa(\alpha-1)}(r^{\alpha-1}-r_0^{\alpha-1})+\\ +\frac{1}{\kappa^2}(r-r_0)+\frac{2\beta}{\kappa^2\alpha}(r^{\alpha}-r_0^{\alpha})+\frac{\beta^2}{\kappa^2(2\alpha-1)}(r^{2\alpha-1}-r_0^{2\alpha-1})]=\end{aligned}}$$

$$\boxed{=\frac{U_{sw}}{U_0-U_{sw}}-\frac{U_{sw}}{U-U_{sw}}+\ln\frac{(U-U_{sw})}{U_0-U_{sw}}.}$$

Where the inicial conditions (r_0, U_0) are related with a further state (r, U); κ and C_0 are constants from the expressions for the expansion.

2) Ellyptical form for the leading edge of the CME and profiles for the position and the speed for any point of it.



$$r_\epsilon^{||} = \beta r_{cm}^{\alpha}$$

Parallel expansion ratio

(Bothmer & Schwenn, 1998; Liu et al.,2005)

$$r_\epsilon^{\perp} = \frac{r_{cm}}{\kappa}(1 + \beta r_{cm}^{\alpha-1}) + C_0$$

Perpendicular expansion ratio

(Dal Lago et al., 2003; Schwenn et al., 2005; Gopalswamy et al., 2009)

If we take the derivatives of these expressions, we get:

$$u_\epsilon^{||} = \alpha\beta r_{cm}^{\alpha-1} U_{cm}$$

Parallel expansion speed

$$u_\epsilon^{\perp} = \frac{U_{cm}}{\kappa}(1 + \alpha\beta r_{cm}^{\alpha-1})$$

Perpendicular expansion speed

$$
\begin{aligned}
-\frac{C_d \pi a}{2m_{cme}}[-C_0(\frac{1}{r} - \frac{1}{r_0}) + \frac{2C_0}{\kappa}\ln(\frac{r}{r_0}) + \frac{2C_0\beta}{\kappa(\alpha-1)}(r^{\alpha-1} - r_0^{\alpha-1}) + \\
+\frac{1}{\kappa^2}(r - r_0) + \frac{2\beta}{\kappa^2\alpha}(r^{\alpha} - r_0^{\alpha}) + \frac{\beta^2}{\kappa^2(2\alpha-1)}(r^{2\alpha-1} - r_0^{2\alpha-1})] = \\
= \frac{U_{sw}}{U_0 - U_{sw}} - \frac{U_{sw}}{U - U_{sw}} + \ln\frac{(U - U_{sw})}{U_0 - U_{sw}}.
\end{aligned}
$$

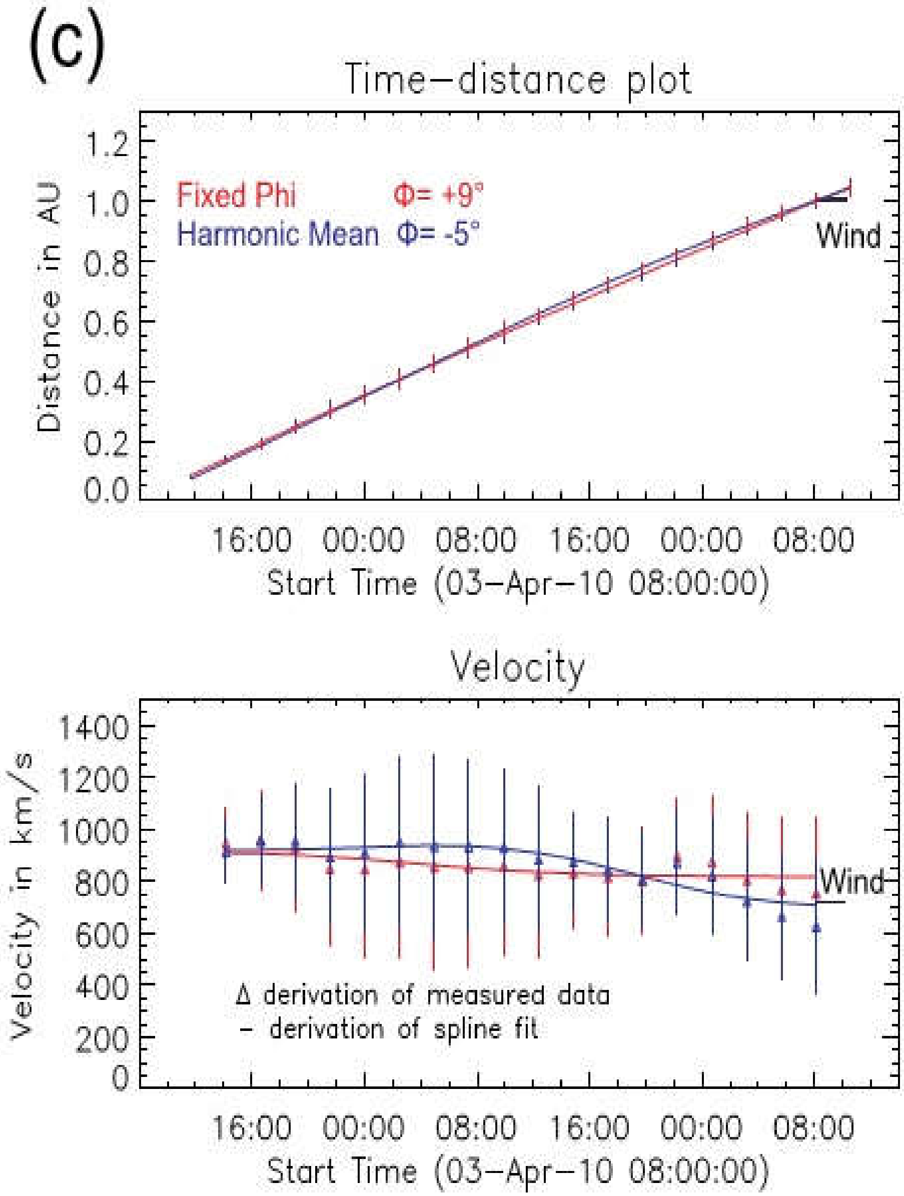
$$
r_\epsilon(r_{cm}) = \frac{1}{\sqrt{\left(\frac{cos(\theta)}{\beta r_{cm}^{\alpha}}\right)^2 + \left(\frac{sen(\theta)}{\frac{r_{cm}}{\kappa}(1+\beta r_{cm}^{\alpha-1}) + C_0}\right)^2}} \quad U_\epsilon(r_{cm}, U_{cm}) = \frac{1}{\sqrt{\left(\frac{cos(\theta)}{\alpha\beta r_{cm}^{\alpha-1} U_{cm}}\right)^2 + \left(\frac{sen(\theta)}{\frac{U_{cm}}{\kappa}(1+\alpha\beta r_{cm}^{\alpha-1})}\right)^2}}
$$

The equation of movement and the profiles have free four parameters:

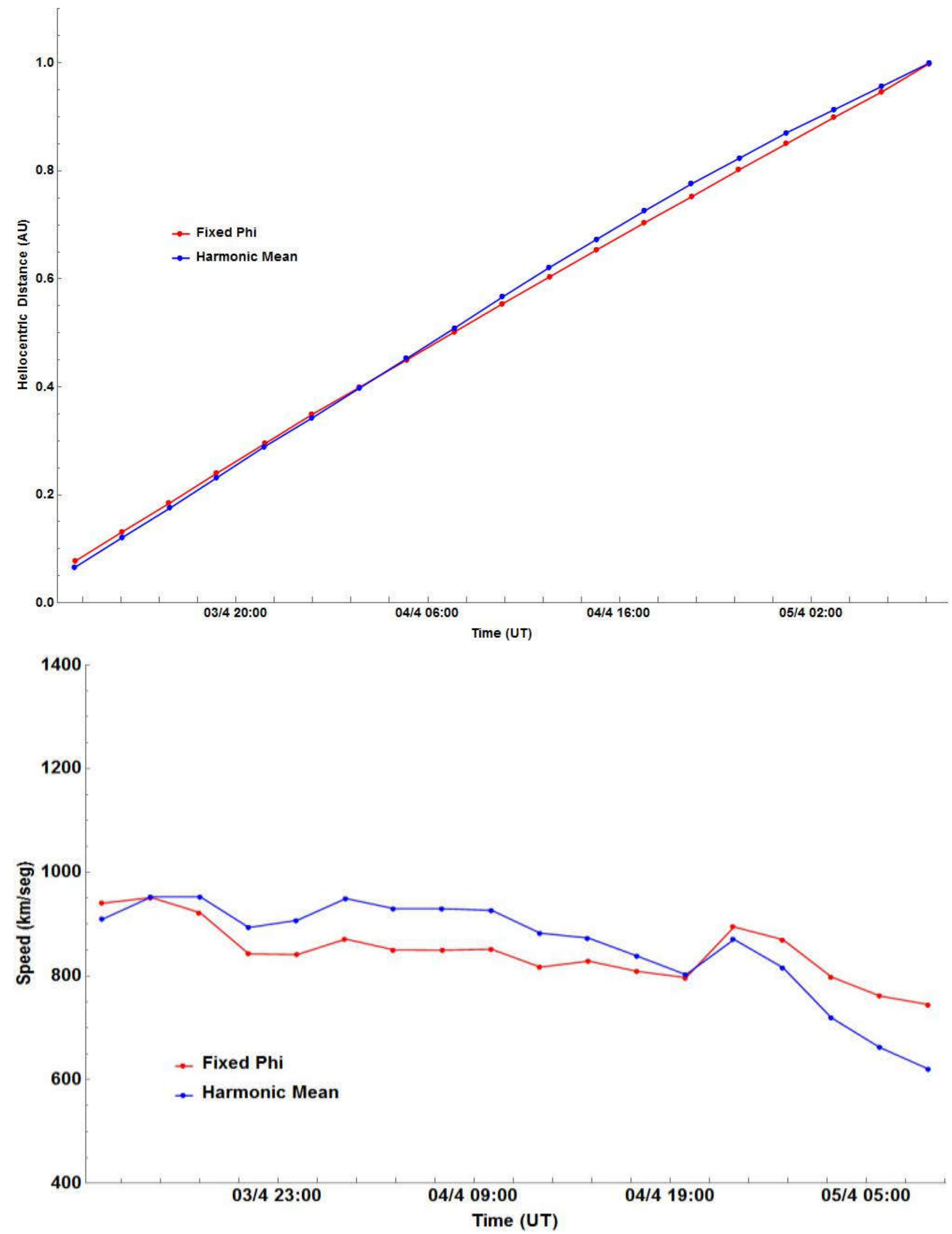
$\alpha = 0.78 \pm 0.10$;
$\beta = 0.24 \pm 0.01$ (Bothmer y Schwenn,1998)

$m_{cme} \in [1.0 \times 10^{11} – 4.0 \times 10^{13}]$ kg (Chen, 2011)

$C_d \in [0.0 – 1.0]$ (Subramanian et al., 2012)

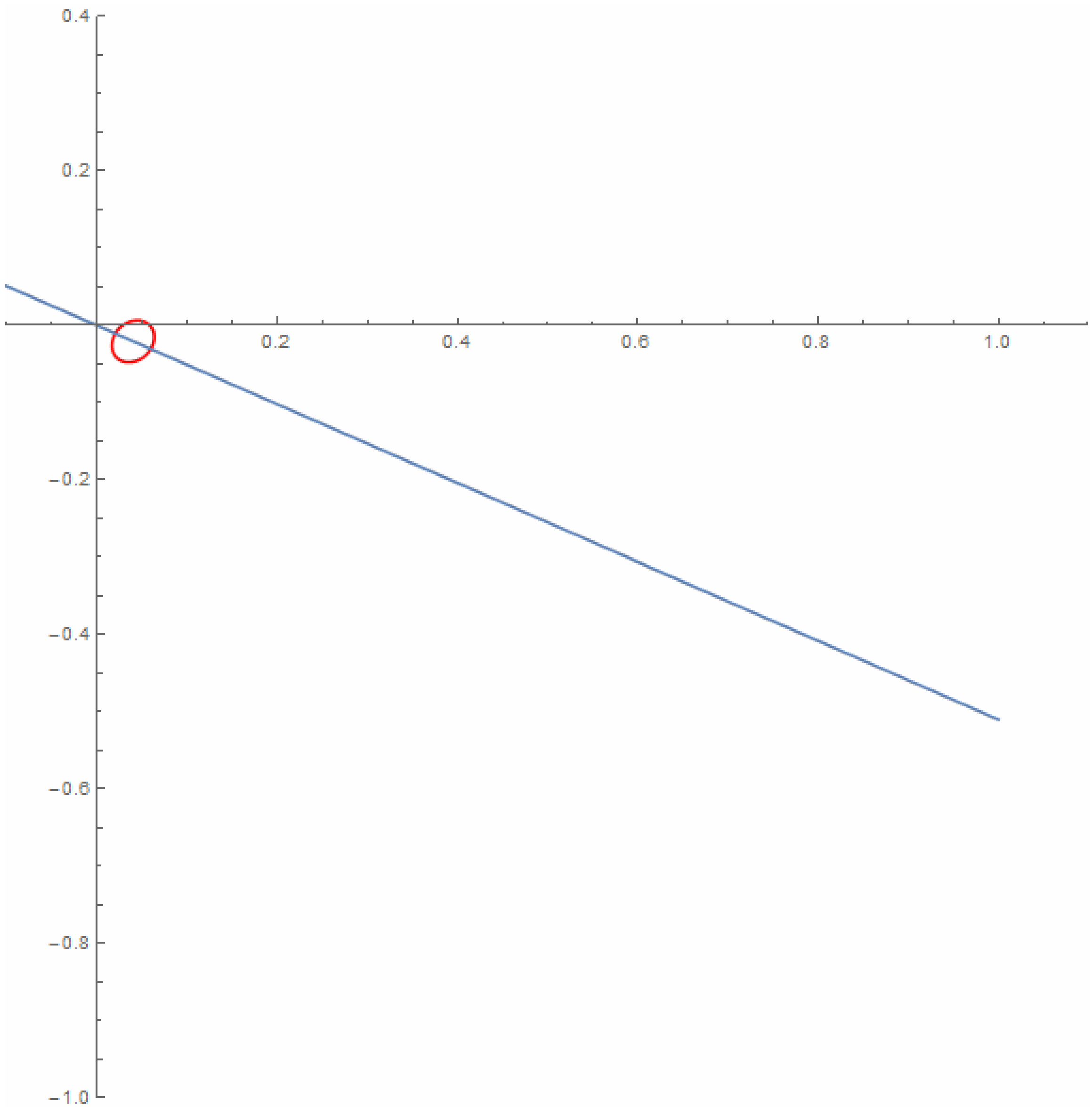


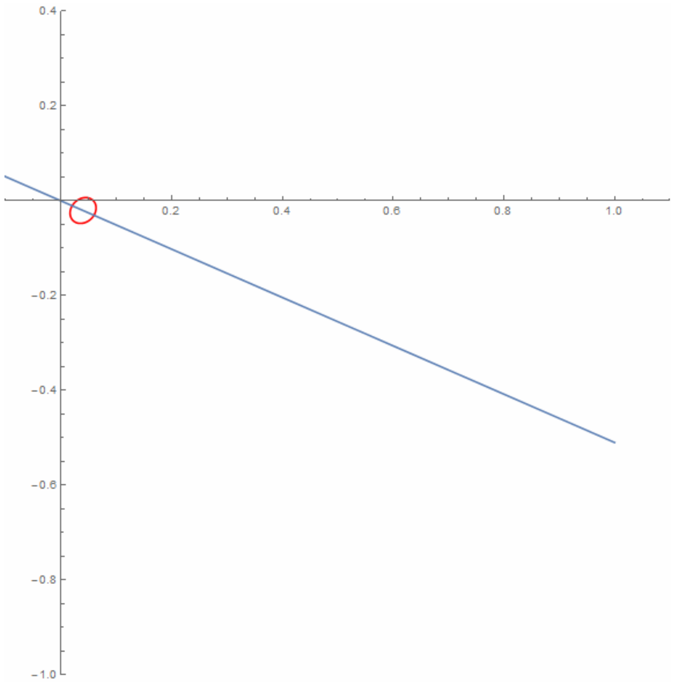
Observational data reported by Möstl et al. (2010)



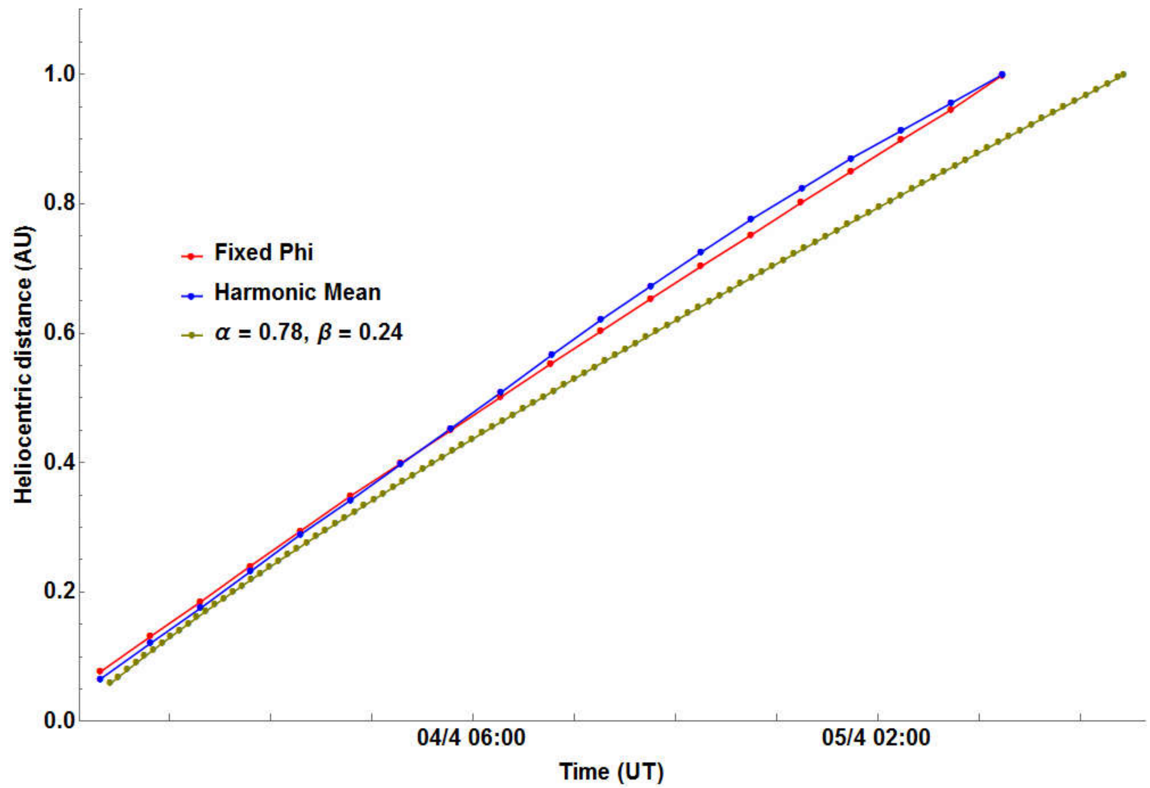
Digitalization of data

Our results:



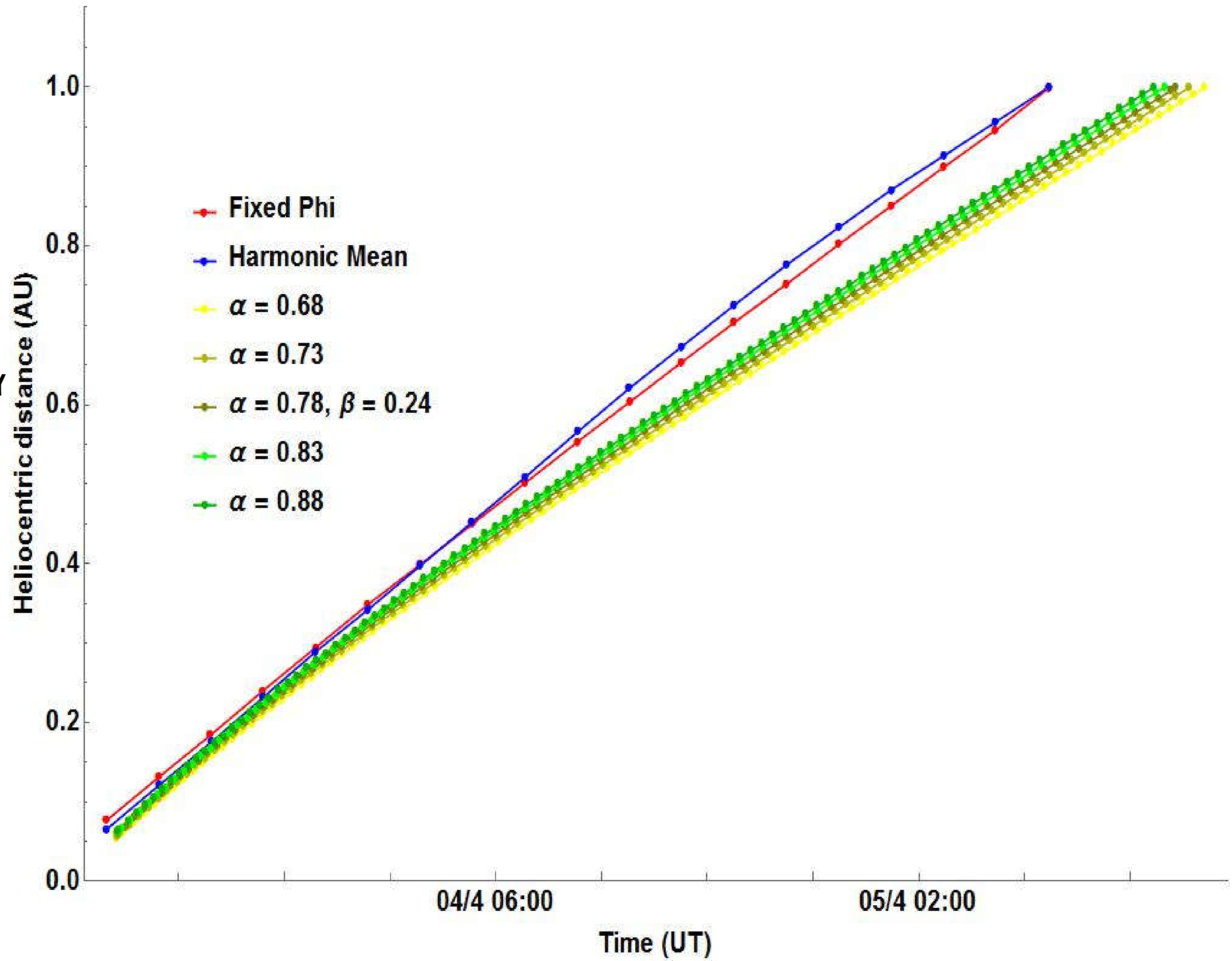


We tested the model, with the data of the April 3rd 2010 event, using the mean values for α and β, the average value reported by Vourlidas et al. (2002) and C_d = 1.0.

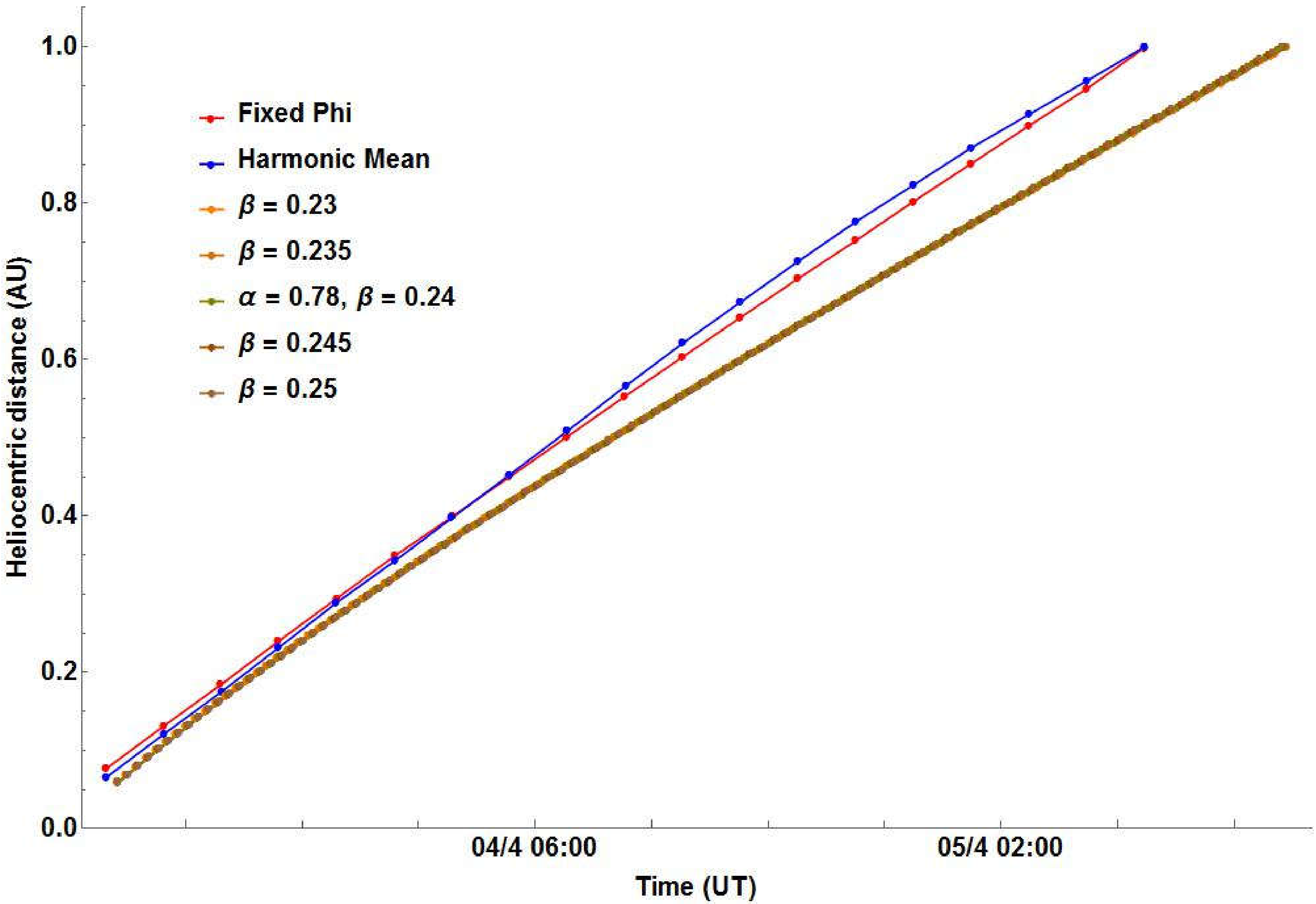


Our results:

In this plot, are presented the variations of the α parameter, leaving the other 3 parameters as a constant.

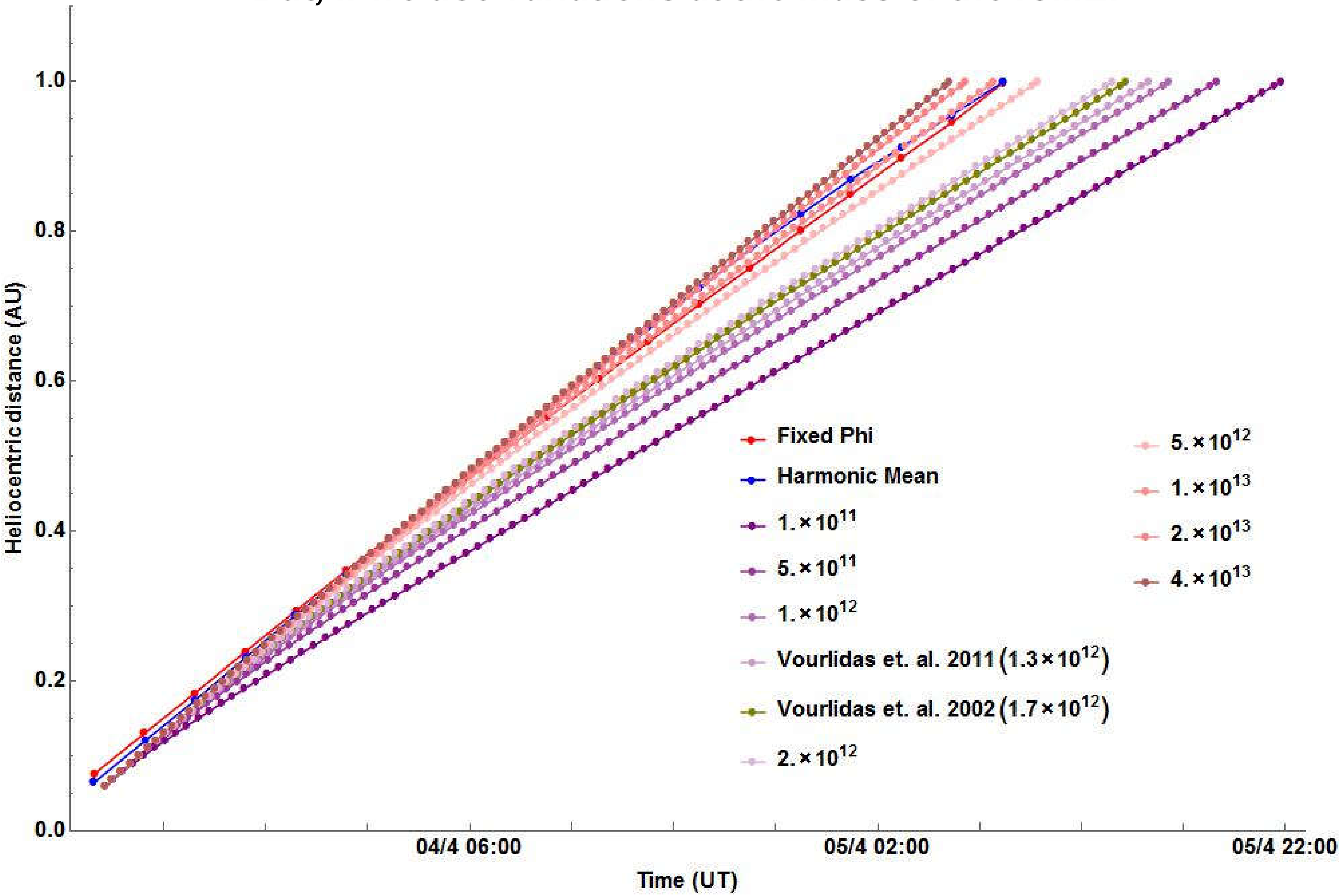


Now, if we use different values for β, leaving all the other parameters as a constant:



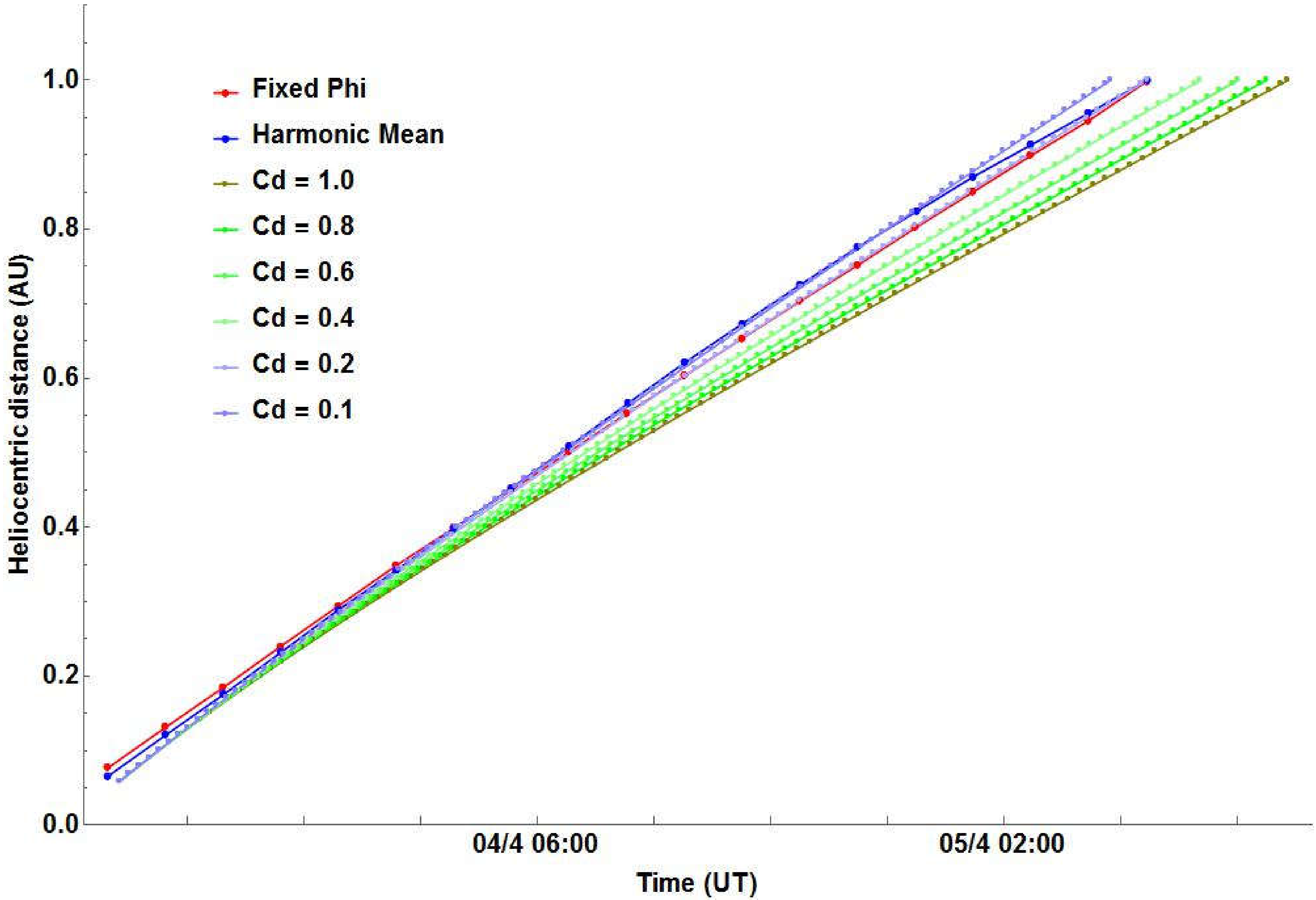
The same trend as with α…

But, if we use variations at the mass of the ICME:



The bigger the value for the mass, the better the consistency between the model and data.

And here, we have the variations in the model, of C_d:



The smaller the value of C_d, the better the fit!!!

Summarizing:

- *We have developed a two-dimensional model that explains the dynamics of a ICME.*
- *The position and the speed of any point at the leading edge is given by the model.*
- *We have consistency between observations and the model, using large values for the ICME's mass and small values for the C_d .*

As a future work, we want to:

1) *Use a C_d varying with the heliocentric distance (Subramanian et al., 2012).*
2) *Apply the model to a large number of observed events.*
3) *Extend the model to three dimensions.*

Thank you very much for your attention!