JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

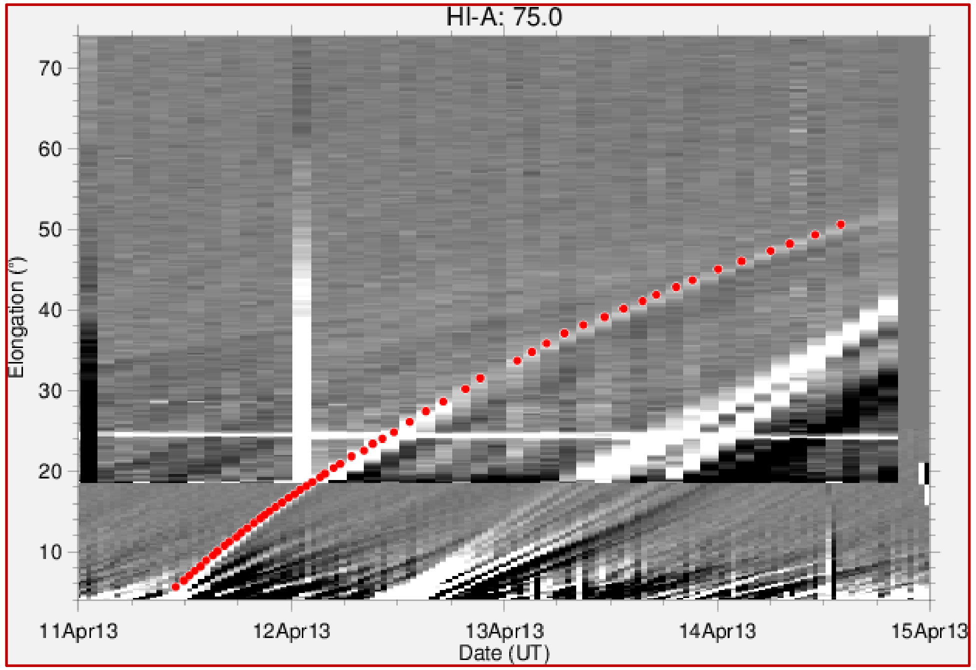
A potential near real-time algorithm for CME propagation utilizing heliospheric imaging observations

Evangelos Paouris[1,2] and Angelos Vourlidas[2]

1: George Mason University, Fairfax, VA, USA
2: Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA

Evangelos.Paouris@jhuapl.edu

Transformation of elongation angles to radial distances



https://www.helcats-fp7.eu/catalogues/event_page.html?id=HCME_A__20130411_01

1. Fixed-Phi (Sheeley et al., 1999,2008; *Kahler and Webb, 2007; Rouillard et al., 2008*)

$r_{FP} = d \cdot \sin(a) / \sin(a+\varphi)$

2. Harmonic Mean (*Lugaz et al., 2009*)

$r_{HM} = 2d \cdot \sin(a) / (1 + \sin(a+\varphi))$

3. Self Similar Expansion (*Lugaz et al., 2010; Davies et al., 2012*)

$r_{SSE} = d \cdot \sin(a) \cdot (1 + \sin(\lambda)) / (\sin(a+\varphi) + \sin(\lambda))$

Once first three values (radial distances) are available we apply the **two-phase kinematics**:

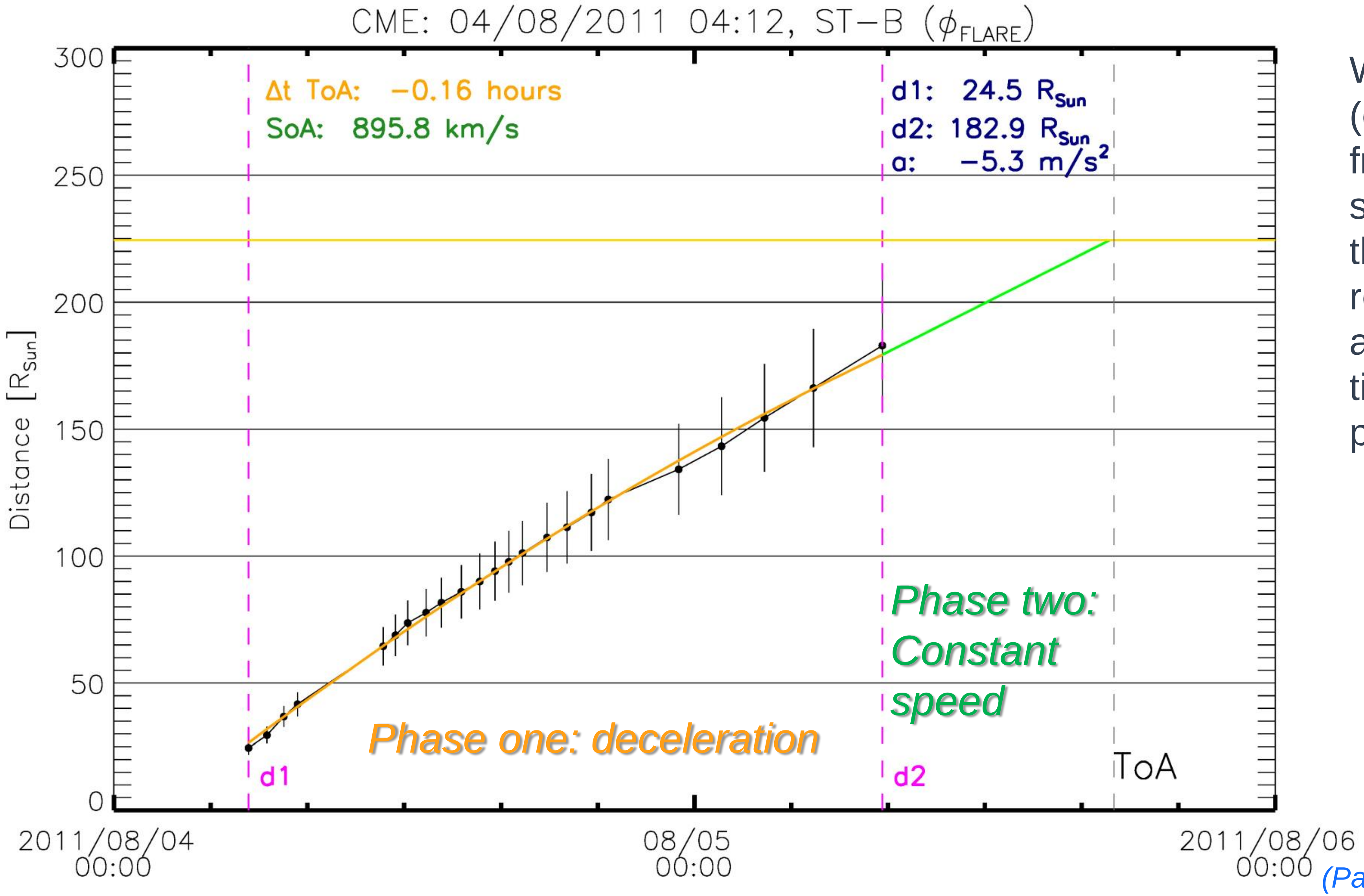
Phase One: Acceleration or Deceleration from d_1 to d_2 and

Phase Two: Constant speed movement

$$r(t) = c_1 t_{d_1-d_2}^2 + c_2 t_{d_1-d_2} + c_3$$

(Paouris and Vourlidas, 2022; Submitted in SW)

Example of how our algorithm works



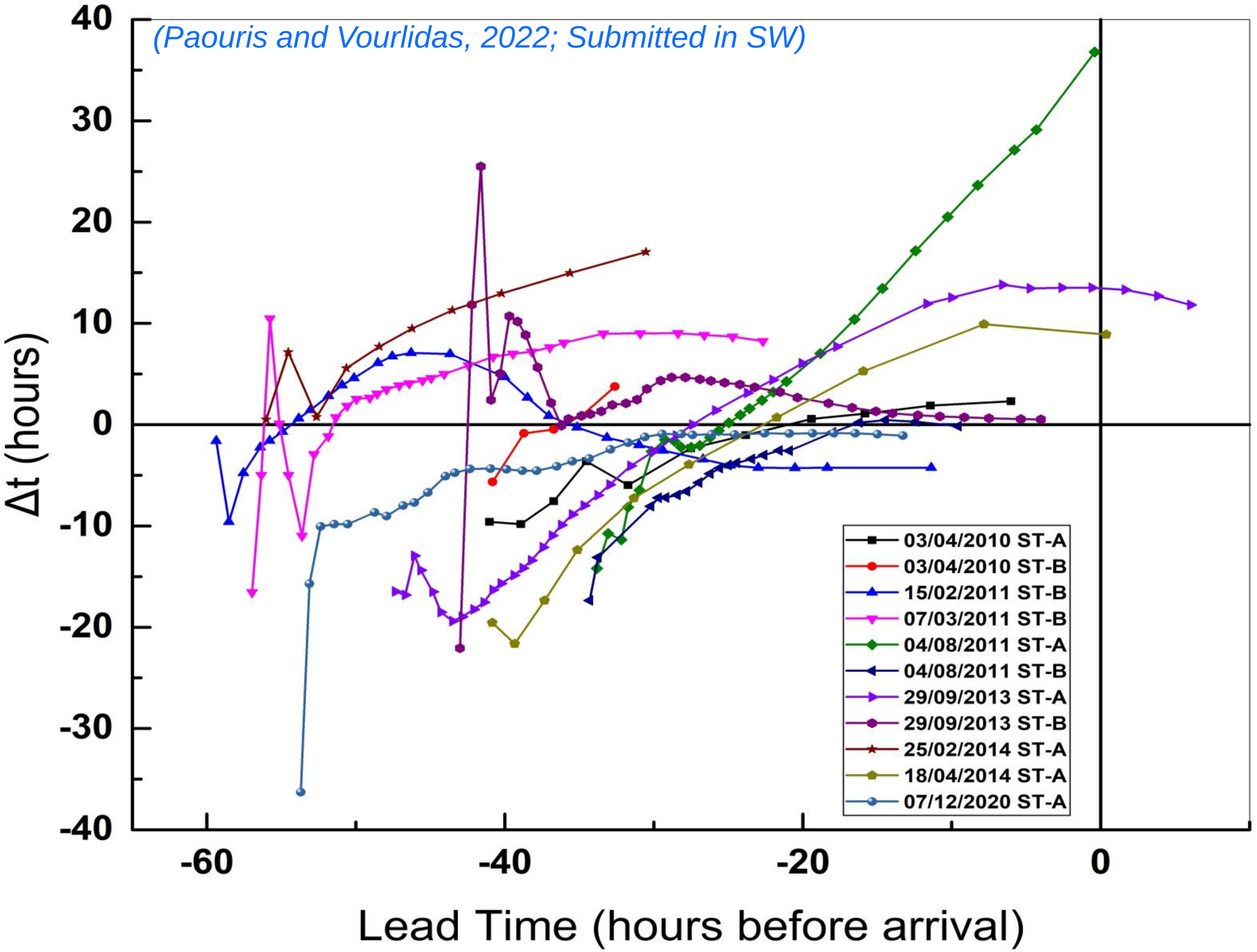
We calculate the acceleration (or deceleration) of the CME from a 2nd order polynomial fit starting always from the first three points and we are repeating the calculations adding one radial distance at a time up to the last available point.

(Paouris and Vourlidas, 2022; Submitted in SW)

Time-of-Arrival error vs. Lead Prediction Time

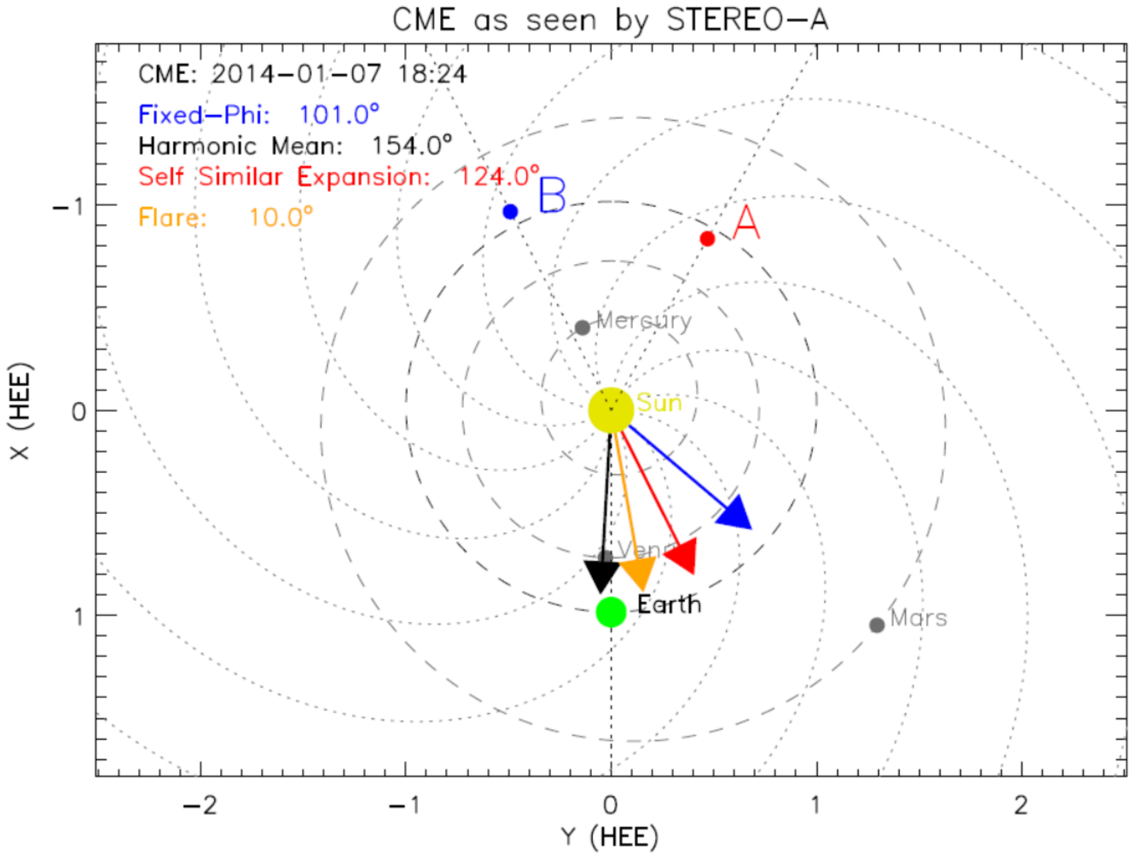
- 11 cases of HM approximation + flare site assumption
- All cases has Δt < 1 hour for at least one run of our model

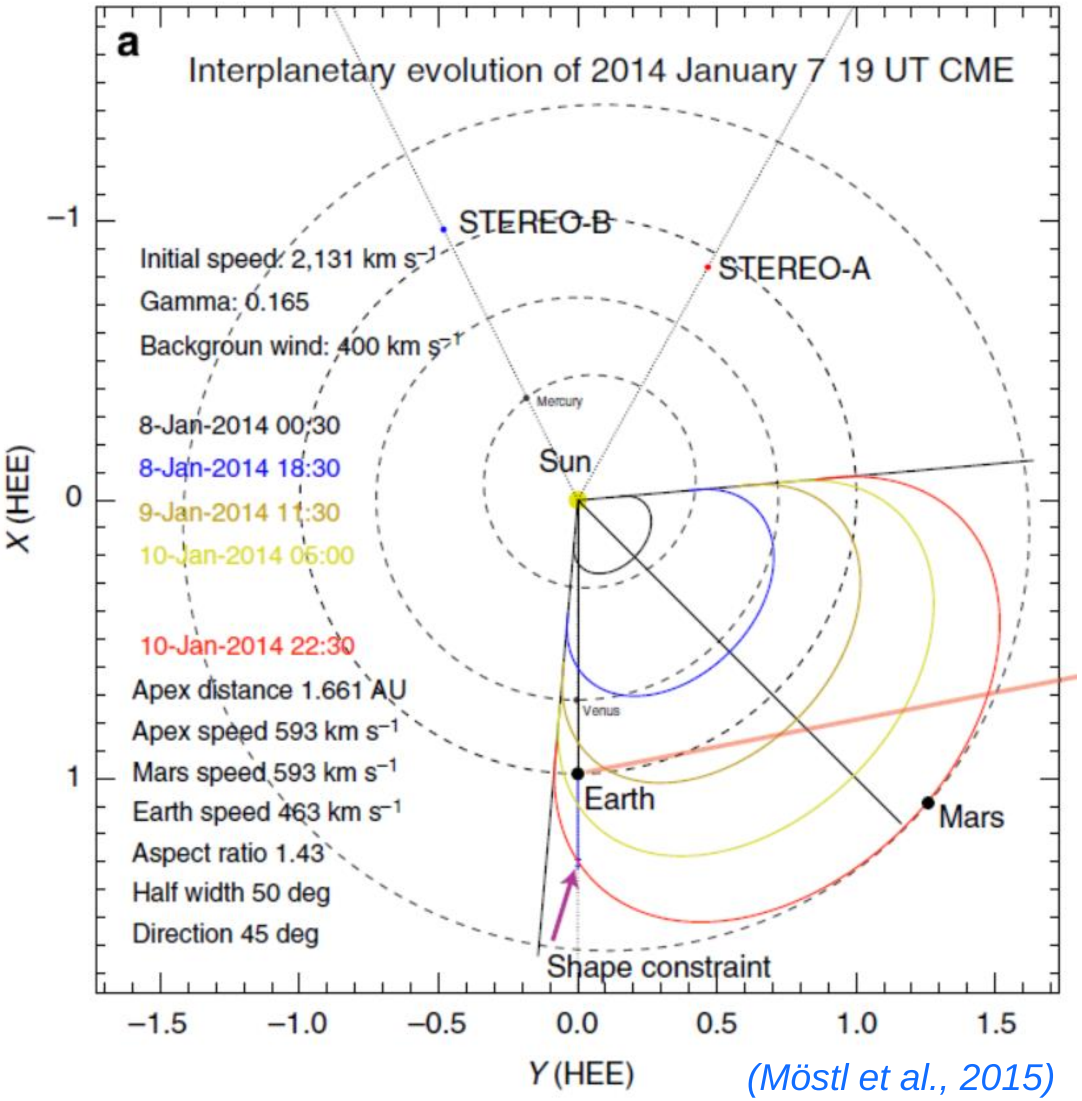
- Many cases are "flattening" around the horizontal line Δt = 0



A first attempt for arrival at Mars

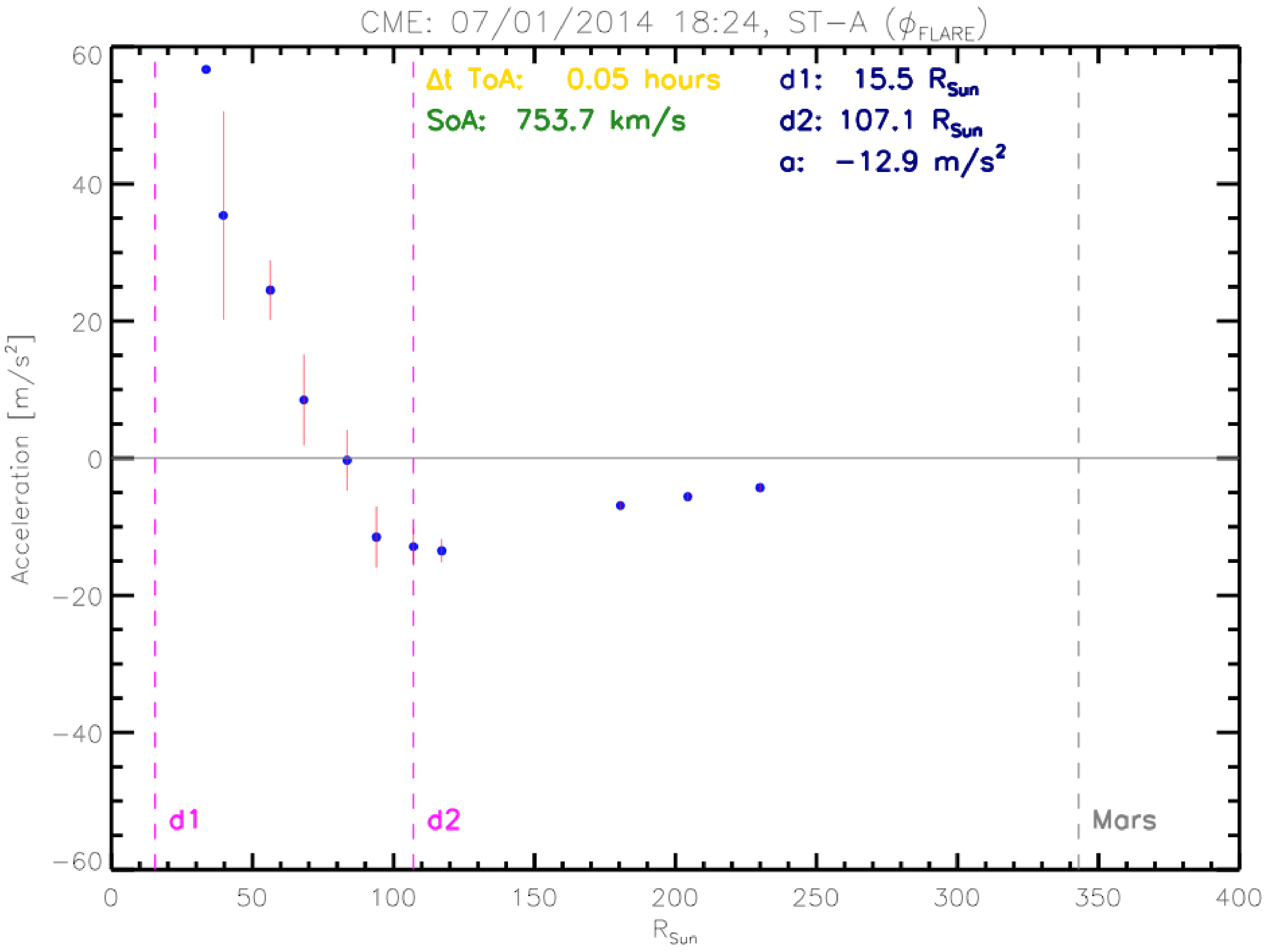
Event selection
CME Jan 7, 2014 @ 18:24UT
Arrival at Earth: Jan 9, 2014 @ 19:39UT
Arrival at Mars: Jan 10, 2014 @ 22:30 ± 1 h





(Möstl et al., 2015)

A first attempt for arrival at Mars



- Elongation angles [9.12°,53.88°]
- Δt errors [-33.33, +96.34] hours
- Optimal **Δt = 0.05 h = 3 min** for $[d_1,d_2]$ = [15.5, 107.1] R_{sun} utilizing the HM approximation

Conclusions - Take home messages

- The heliographic longitude of the flare site combined with the *two-phase kinematics* provides better results in contrast to the constant propagation direction and speed methods.
- It is possible to forecast the ToA (and SoA) of a CME at Earth (or at Mars) with a Δt < 1 hour.
- 21 cases (of a total 50) have absolute errors < 52 minutes.
- We tested our methodology for a L5 scenario (i.e., 57° and 67° respectively): in both cases the Δt is < 50 minutes
- For a “wider” L5 scenario with 7 cases available we found a MAE of 0.96±0.52 hours: we have the proof-of-concept for accurate and early space weather forecasts, in terms of ToA, of a future L5 mission.
- There are many cases where when we use all possible HI observations our two-phase kinematics approach tends toward an error in the ToA (flattening) that approaches the horizontal line of Δt = 0.
- In real-time mode the ToA is updated as new HI data are becoming available: the Δt is unknown until the arrival of the CME at target.
- We need more events (expand our list) to test our methodology.

Caveats:

- The projection effects and the limitations of the mathematical equations of FP, HM and SSE approximations (*critical angles*) can lead to unreasonably high accelerations or SoAs.

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY