



The 8th Community Community Coordinated Modeling Center Workshop



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THE DRAG-BASED MODEL

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General classification of space-weather models

- The DBM: a „tool“ for prediction of ICMEs propagation in the heliosphere → primary task for space-weather forecasting
- modeling and forecasting can be divided:
 - a) purely empirical/statistical methods
 - b) kinematical-empirical methods
 - b/c) analytical (M)HD-based models (DBM)
 - c) numerical MHD-based models

The DBM hypothesis

- The DBM hypothesis at large heliocentric distances:
 - the Lorentz force ceases in upper corona
 - ICME dynamics is solely governed by interaction with solar wind (ambient) ← observational facts:
 - fast CME → decelerate
 - slow CME → accelerate
 - collisionless environment:
 - low viscosity
 - low resistivity → dissipative processes are negligible
 - momentum and energy are transferred by magnetosonic waves

The DBM equations in general form

- At heliocentric distances beyond $R \geq 15 r_s$:
- net acceleration (drag is dominant): $a = a_L + a_g + a_d$
- equation of motion in quadratic form (Cargill, 2004):

$$R''(t) = -\gamma(R)[R'(t) - w(R)]|R'(t) - w(R)|$$

- parameter γ :

$$\gamma \propto C_d \frac{A \rho_{SW}}{M} \quad \begin{aligned} &\bullet \text{ for } R \gg 1r_s \Rightarrow \\ &M = M_i + M_v = \text{const.} \end{aligned}$$

- LDB density expression (Leblanc et al., 1998):

$$n_0(R) = \frac{k_2}{R^2} + \frac{k_4}{R^4} + \frac{k_6}{R^6} \quad \text{for } R > 1.8$$

$$k_2 = 3.3 \times 10^5 \text{ cm}^{-3}, k_4 = 4.1 \times 10^6 \text{ cm}^{-3}, k_6 = 8.0 \times 10^7 \text{ cm}^{-3}$$

Solar wind perturbation

- stationary and isotropic
- density flux conservation
- unperturbed solar-wind speed becomes:

INPUT:
 $w(R), w_\infty, \gamma_\infty$

$$w_0(R) = w_\infty \left(1 + \frac{k_4/k_2}{R^2} + \frac{k_6/k_2}{R^4} \right)^{-1}$$

$[w_\infty = \lim_{R \rightarrow \infty} w_0(R)]$

- total solar-wind speed with perturbation term $w_p(R)$:

+ „Cone geometry“:
 $A \propto R^2$

$$w(R) = \begin{cases} w_0(R) + w_p(R), & R_1 < R < R_2 \\ w_0(R), & \text{otherwise} \end{cases}$$

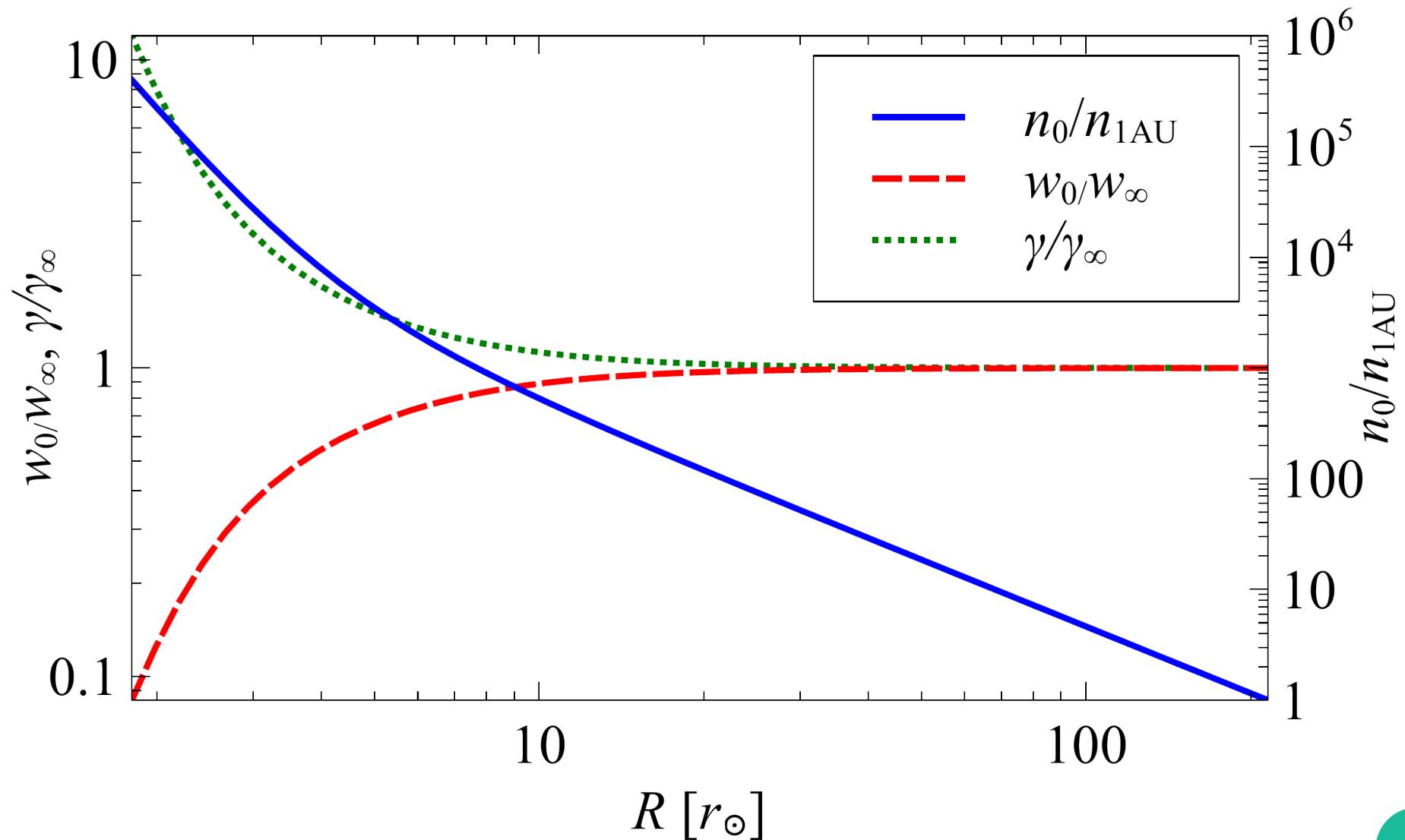
- leads to:

$$\gamma(R) = \frac{\gamma_\infty}{w(R)}; \quad n(R) = \frac{k_2}{R^2} \frac{w_\infty}{w(R)}$$

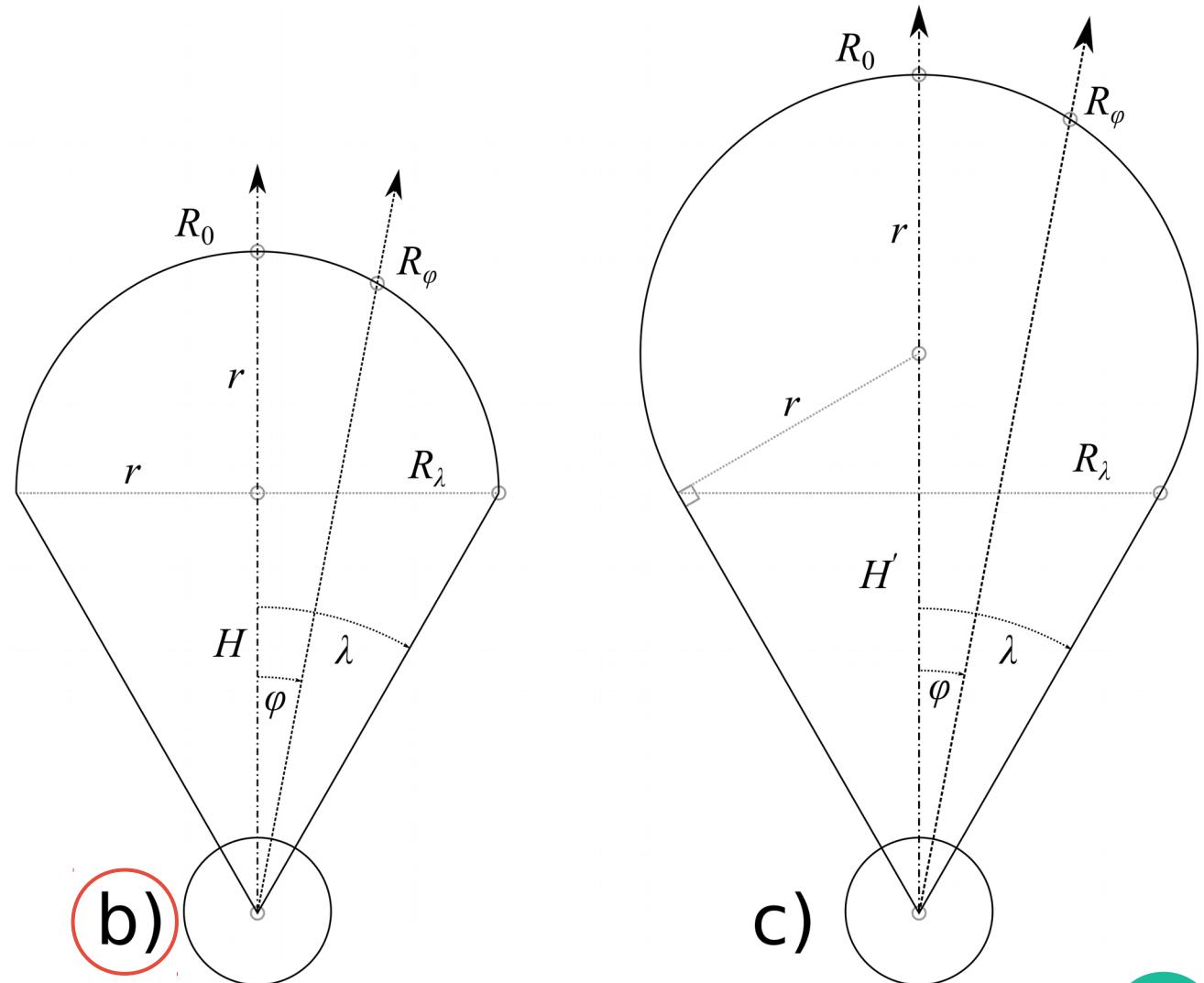
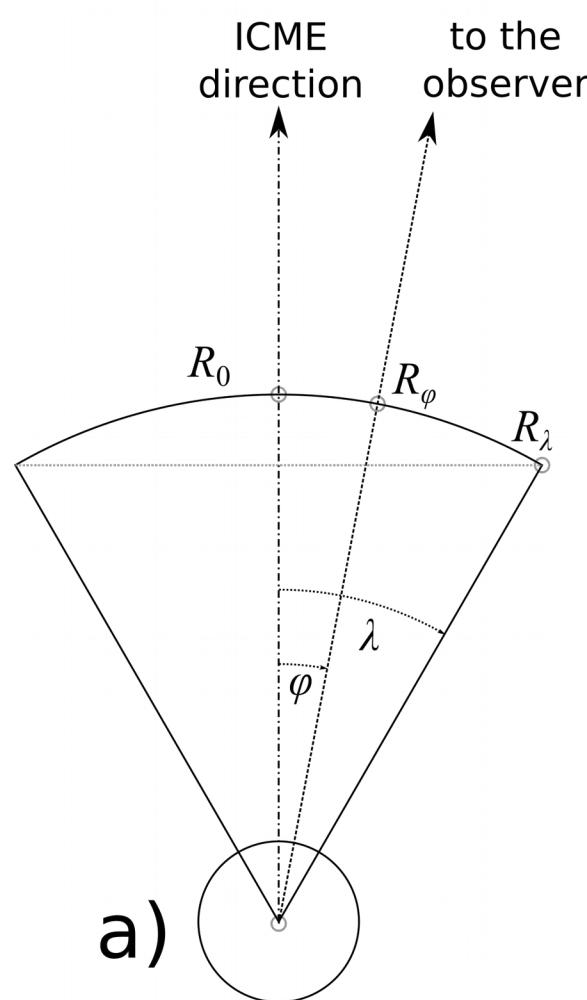
$$[\gamma_\infty = \Gamma \times 10^{-7} \text{ km}^{-1}]$$

$$[\gamma_\infty = \lim_{R \rightarrow \infty} \gamma(R)]$$

Parameter γ , SW density and speed

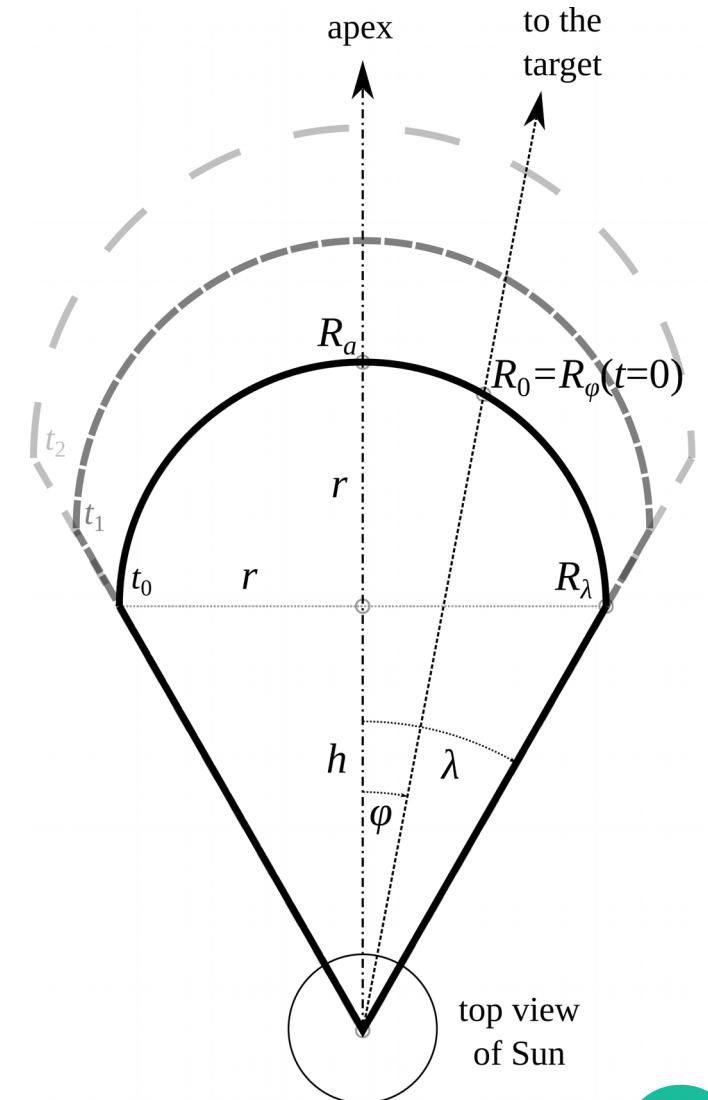


Options of ICME cone-geometry



DBM with constant w and self-similar CME geometry

- solar-wind speed w :
 - isotropic and constant
→ parameter γ is constant as well
- „self-similar“ CME expansion:
 - the initial cone-shape of CME is preserved during its interplanetary propagation
- for a given set of input parameters the model provides the ICME Sun-“target” transit time, the arrival time, and the impact speed



Basic $w=const.$ & SS-expansion

(<http://oh.geof.unizg.hr/~tomislav/CDBM-SS/>)

Forecasting the Arrival of ICMEs: The Drag-Based Model with constant solar wind speed and self-similar CME expansion

Basic DBM Advanced DBM Documentation

CME take-off **date**: Apr ▾ 8 ▾ 2016

CME take-off **time (UTC)**: 15 ▾ h 10 ▾ min

y - constant drag parameter: $\times 10^{-7} \text{ km}^{-1}$

w - constant solar wind speed: km/s

R₀ - starting radial distance of CME: r_{Sun}

v₀ - speed of CME at R_0 : km/s

Select target from the list:

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Zadnja obnova stranice: 8.4.2016.

Advanced $w=const.$ & SS-expansion (<http://oh.geof.unizg.hr/~tomislav/CDBM-SS/>)

Forecasting the Arrival of ICMEs: The Drag-Based Model with constant solar wind speed and self-similar CME expansion

Basic DBM Advanced DBM Documentation

CME take-off **date**:

CME take-off **time (UTC)**:

y - constant drag parameter: $\times 10^{-7} \text{ km}^{-1}$

w - constant solar wind speed: km/s

R₀ - starting radial distance of CME: r_{Sun}

v₀ - speed of CME at R_0 : km/s

λ - CME's angular half-width: deg

φ_{CME} - central meridian distance of source region: deg

Select target from the list:

© Tomislav Žic, Hvar Observatory, 2013

Zadnja obnova stranice: 8.4.2016.

Results $w=const.$ & SS-expansion (<http://oh.geof.unizg.hr/~tomislav/CDBM-SS/>)

Forecasting the Arrival of ICMEs: The Drag-Based Model with constant solar wind speed and self-similar CME expansion

Results | Kinematic plot | CME geometry plot | Documentation

Output:

CME arrival at target (date & time): **14.04.2016 at 18h:12min**
Transit time: **50.20 h**
Impact speed at target (at 1 AU): **634 km/s**

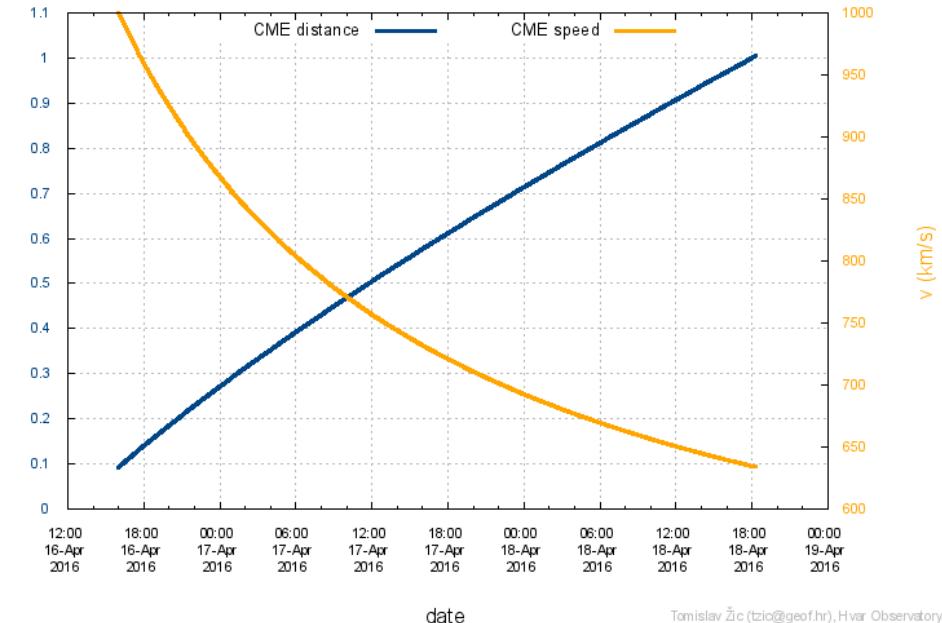
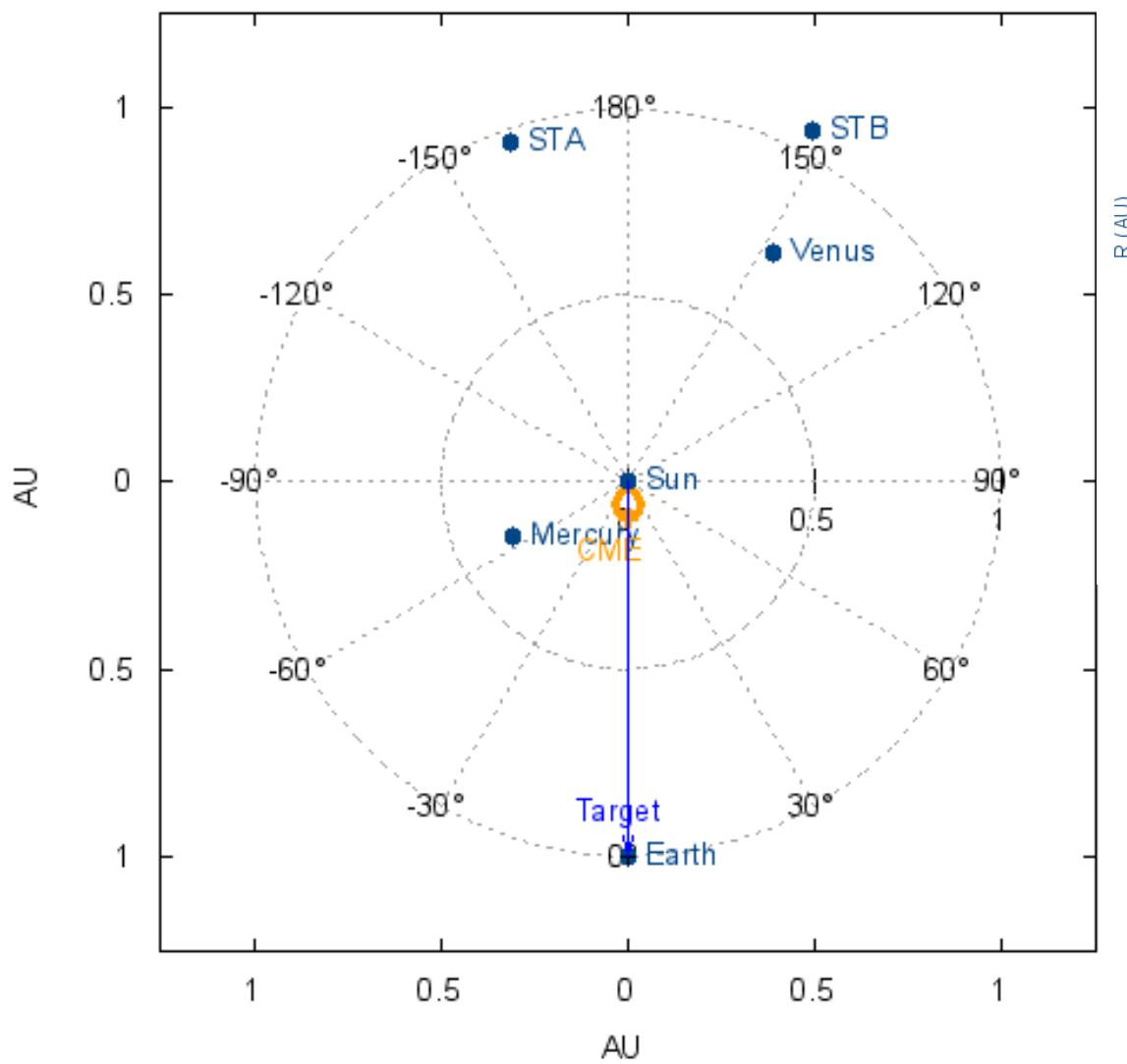
Input parameters:

CME take-off date & time: **12.04.2016 at 16h:00min**
 $y = 0.2 \times 10^{-7} \text{ km}^{-1}$, $w = 450 \text{ km/s}$,
 $R_0 = 20 r_{\text{Sun}}$, $v_0 = 1000 \text{ km/s}$, $\lambda = 30^\circ$, $\varphi_{\text{CME}} = 0^\circ$
 $R_{\text{target}} = 1 \text{ AU}$, $\varphi_{\text{target}} = 0^\circ$

Calculated in 3.15 seconds.

Plots $w=const.$ & SS-expansion

(<http://oh.geof.unizg.hr/~tomislav/CDBM-SS/>)



↑ UP: Propagation of '+ CME' point in geometry plot
← LEFT: Ecliptic plane cross-section of CME propagation

Online applications of DBM with $w=const.$ & SS-expansion

Community Coordinated Modeling Center

Forecasting the Arrival of ICMEs: The Drag-Based Model with constant w and γ

Basic DBM | Advanced DBM | Documentation

CME take-off date: Apr. 8, 2016

NASA Goddard Space Weather Research Center

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Important Disclaimer Notice

If you are looking for the official U.S. Government forecast for space weather, please go to NOAA's Space Weather Prediction Center (<http://www.swpc.noaa.gov>). This "Experimental Research Information" consists of preliminary NASA research products and should be interpreted and used accordingly.

CME Arrival Time Scoreboard

CME arrival time predictions from the research community

The CME Scoreboard (developed at the Community Coordinated Modeling Center) provides real-time forecasts for the arrival of coronal mass ejections (CMEs) to Earth. It includes:

- quickly view all forecasts at once in real-time
- compare forecasting methods when the event has arrived

>>Click here to go to the CME Arrival Time Scoreboard

CME Propagation Models

This is a subset of space weather forecasting CME propagation models (see the CME arrival time Scoreboard). If you would like to register your prediction models/techniques, details All prediction methods are welcome and all are encouraged.

CME shock arrival forecast

- BHV (Bameier-Hessman-Venzmer) Model (Bameier and Schaeffer, 1998)
- EIS (Ecliptic Evolution) Model (Mostl et al., 2015)
- ESA (Empirical Shock Arrival) Model (Gopalswamy et al., 2001, 2005)
- HDM/HD (HAFv.3 + 3D/HD) Model (Wu et al., 2011)
- HAFv.3 (Hessman-Antiochos-Fairfield) Model (Hessman et al., 2000)
- SADM (Shock Arrival Model) (Nulu et al., in preparation)
- SPFM (Feng and Zhou, 2009) and SPMD (Zhou and Feng, 2014)
- STOA (Shock Time of Arrival) (Dyer et al., 1984, 2004, Fry et al., 2001, McKinnon et al., 2001)
- WSA-ENLIL + Cone Model (Ostrikov et al., 2004)
- Ballistic projectile

CME arrival forecast

- BHV (Bameier-Hessman-Venzmer) Model (Bameier and Schaeffer, 1998)
- DBM (Drag Based Model) (Vršnak et al., 2013)
- DBM + ESWF (Drag Based Model + Empirical Solar wind Forecast) (Vršnak, COMESEP automated system (CME Alert Geomag24) (Cresby et al., 2012)
- DBM + Cone (CME Arrival Time Copasway et al., 2000, 2001)
- Expansion-Space-Time Cone Model (Srivastava, 2005)
- WSA-ENLIL + Cone Model (Ostrikov et al., 2004)
- HalfTemp (Jackson et al., 2010, 2011)
- HI-map technique (Shelley, 2008, Rouillard et al., 2008, Davis et al., 2009, Tappin et al., 2010)
- HI (Tappin-Howard) Model (Tappin and Howard, 2009, Howard and Tappin, 2010)
- Ballistic projectile

Example output:

Kinematic evolution

Animation

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Hvar Observatory - Forecasting the Arrival of ICMEs:

<http://oh.geof.unizg.hr/DBM/dbm.php>

Main Menu

- Home
- Project Description
- Consortium
- Alert System
- Alert System Help
- News
- Publications
- Meetings
- Jobs
- Links
- Frequently Asked

System overview

The COMESEP alert system consists of a network of alert tools connected to a central node in charge of:

1. dispatching the alerts among the different tools;
2. presenting a survey of the current alerts to the users,
3. archiving the past alerts

The data exchange between the central node and the different tools is implemented through SOAP web service interface. The central node is also in charge of the alert generation and management, and it interacts with the different tools through appropriate tools.

The figure hereunder is a flow diagram of how the different tools interact with each other through the three levels of the COMESEP alert system:

1. First level producers

2. Second level managers

3. Third level alerters

ESA Expert Service Center for Solar & Heliospheric Weather:

<http://swe.uni-graz.at/index.php/services/cme-forecast>

Space Weather Database Of Notifications, Knowledge, Information (DONKI):

<http://kauai.ccmc.gsfc.nasa.gov/DONKI/>

CME Arrival Time Scoreboard – NASA Space Weather Research Center:

<http://swrc.gsfc.nasa.gov/main/cmemodels>

(courtesy of Leila M. Mays)

CCMC Contact:
Leila Mays
(M.Leila.Mays@nasa.gov)

Forecasting the Arrival of ICMEs: The Drag-Based Model

CME take-off date: Apr. 8, 2016

CME take-off time (UTC): 16 h 47 min

R_0 - starting radial distance of CME (AU): 20

V_0 - speed of CME at R_0 (km/s): 1000

Γ - drag parameter (10^3 km^3): 0.2

w - asymptotic solar wind speed (km/s): 450

R_{target} - target heliocentric distance (AU): 1

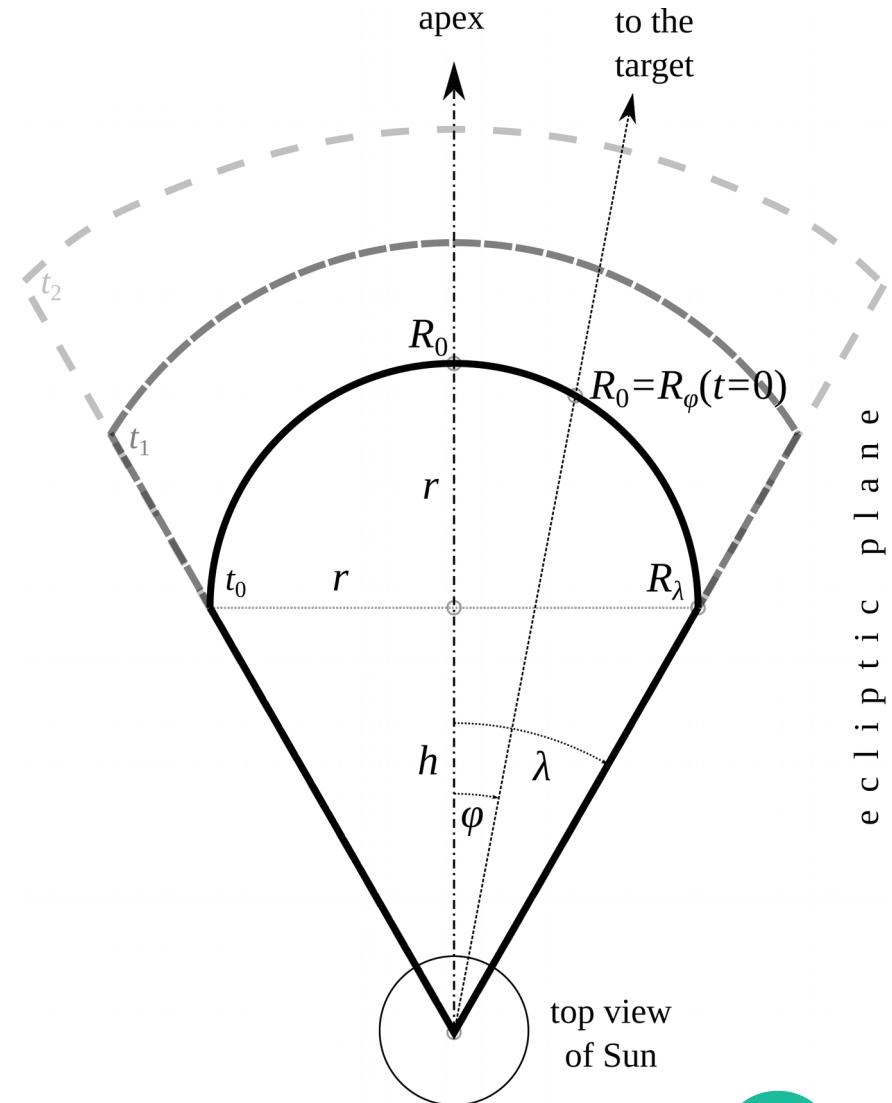
Calculate | Reset

Drag Based Model has performed 3054 successful calculations (since 26.12.2012).

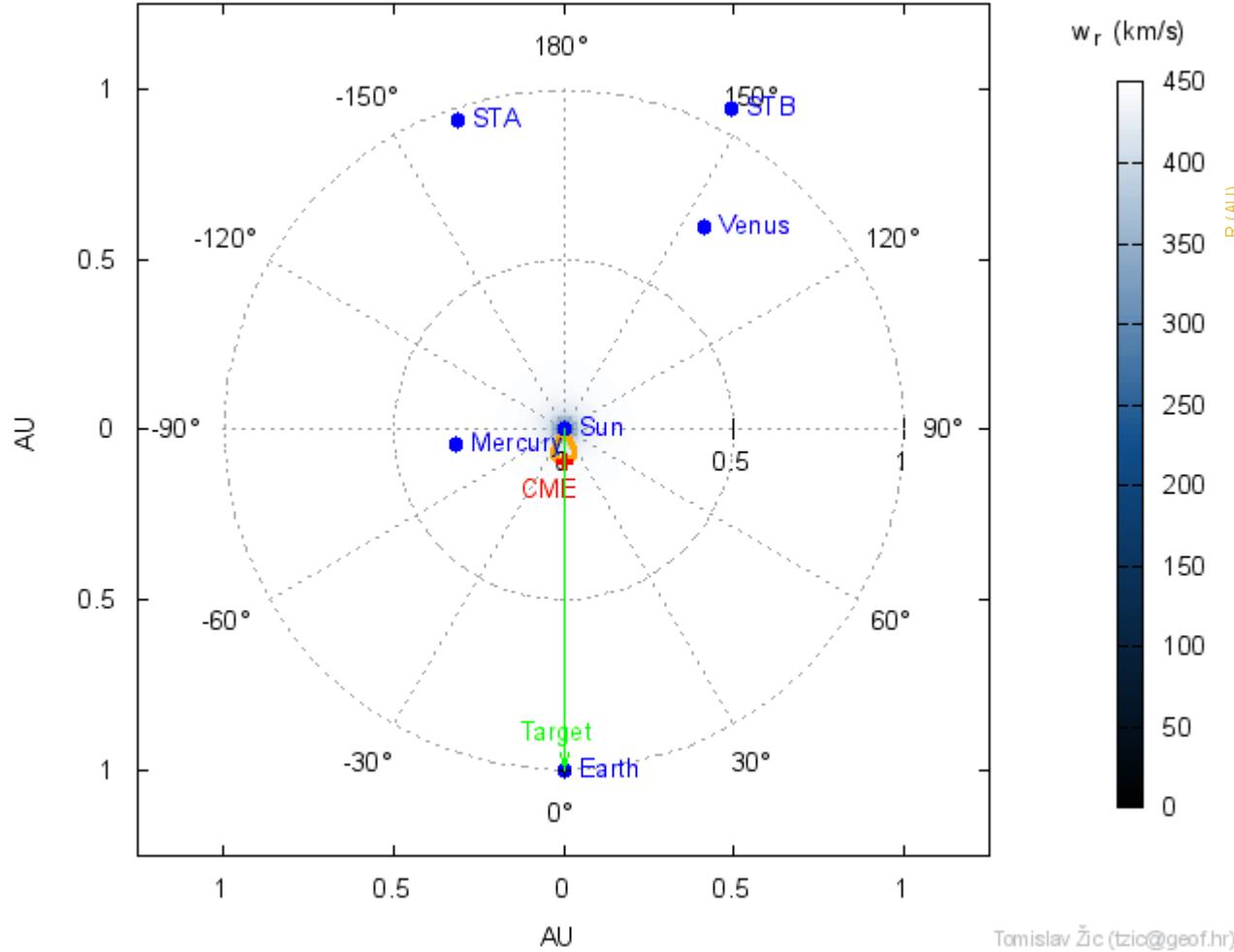
Observatory Hvar Observatory IAGA IAHM COMESEP Heli Observatory, 2014

DBM with $w(R)$ and CME leading-edge flattening

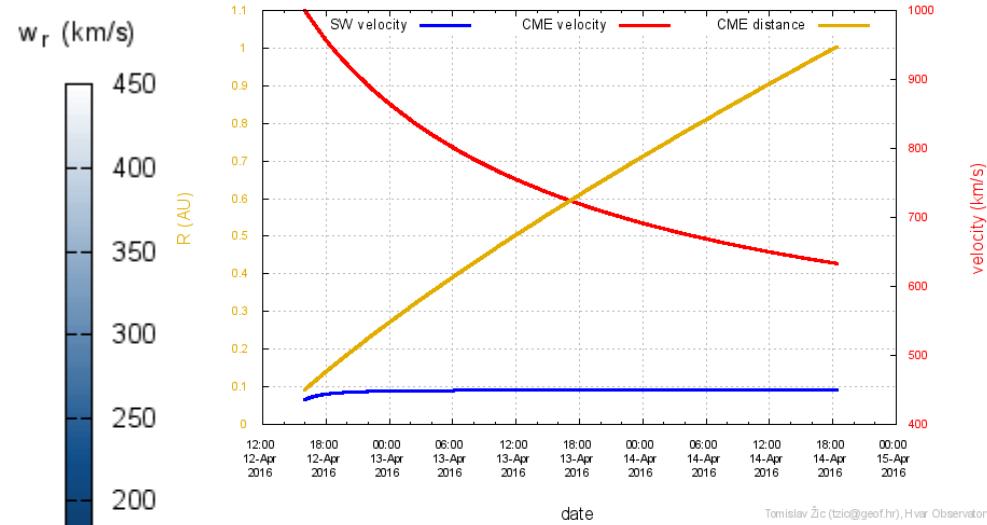
- solar-wind speed w :
 - is radially dependent: $w(R)$
→ parameter γ becomes function of radial distance as well: $\gamma(R)$
- each CME leading-edge segment propagates independently
→ the initial cone-geometry flattens



Plots $w(R)$ & CME edge flattening (<http://oh.geof.unizg.hr/~tomislav/DBM/>)



- LEFT: Cross-section of CME propagation in ecliptic plane
- RIGHT: Propagation of '+ CME' point in geometry plot



Output:

- CME arrival at target (date & time): 14.04.2016 at 18h:20min
- Transit time: 50.35 h
- Impact speed at target (at 1 AU): 633 km/s

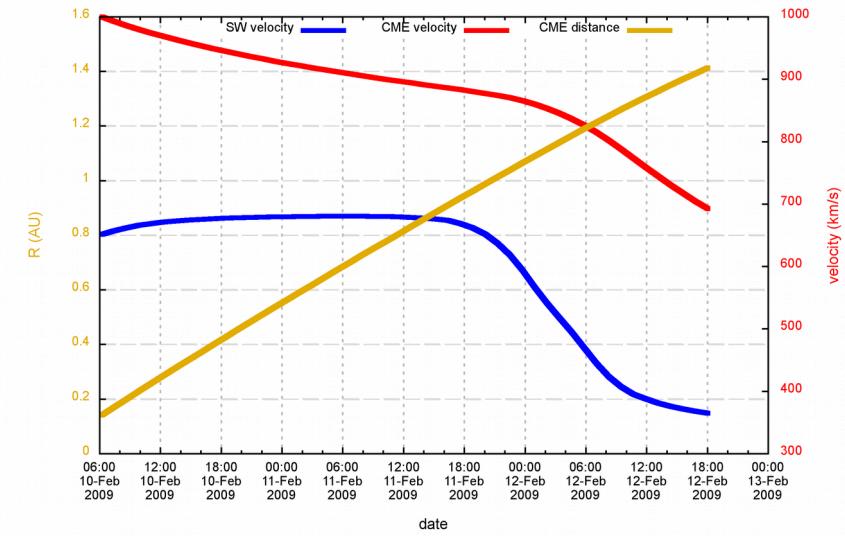
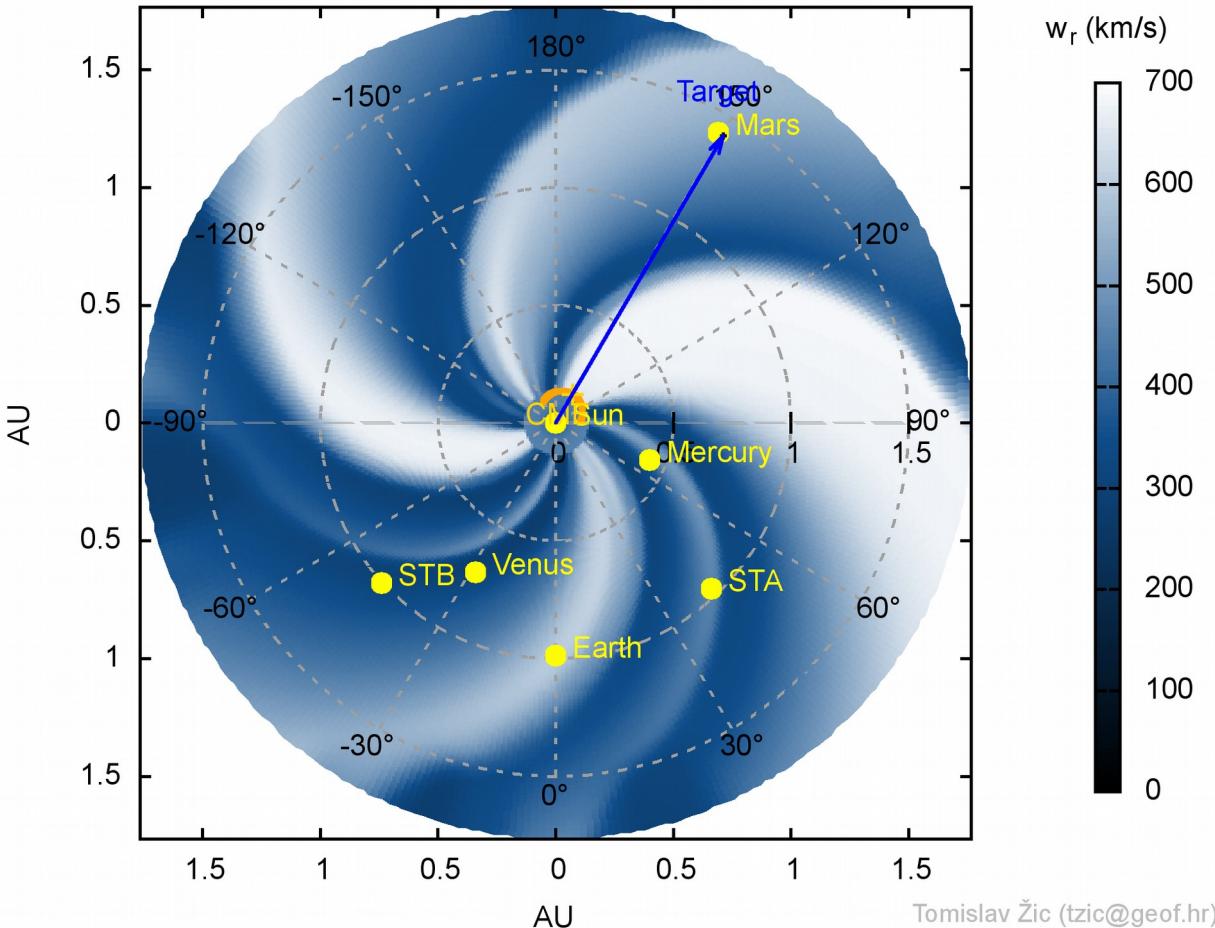
Input parameters:

- CME take-off date & time: 12.04.2016 at 16h:00min
- $\gamma_\infty = 0.2 \times 10^{-7} \text{ km}^{-1}$, $w_\infty = 450 \text{ km/s}$,
- $R_0 = 20 r_S$, $v_0 = 1000 \text{ km/s}$, $\lambda = 30^\circ$, $\varphi_{\text{CME}} = 0^\circ$
- $R_{\text{target}} = 1 \text{ AU}$, $\varphi_{\text{target}} = 0^\circ$

Calculated in 13.48 seconds.

Example of DBM + ENLIL model

(<http://oh.geof.unizg.hr/~tomislav/DBM-ENLIL/>)



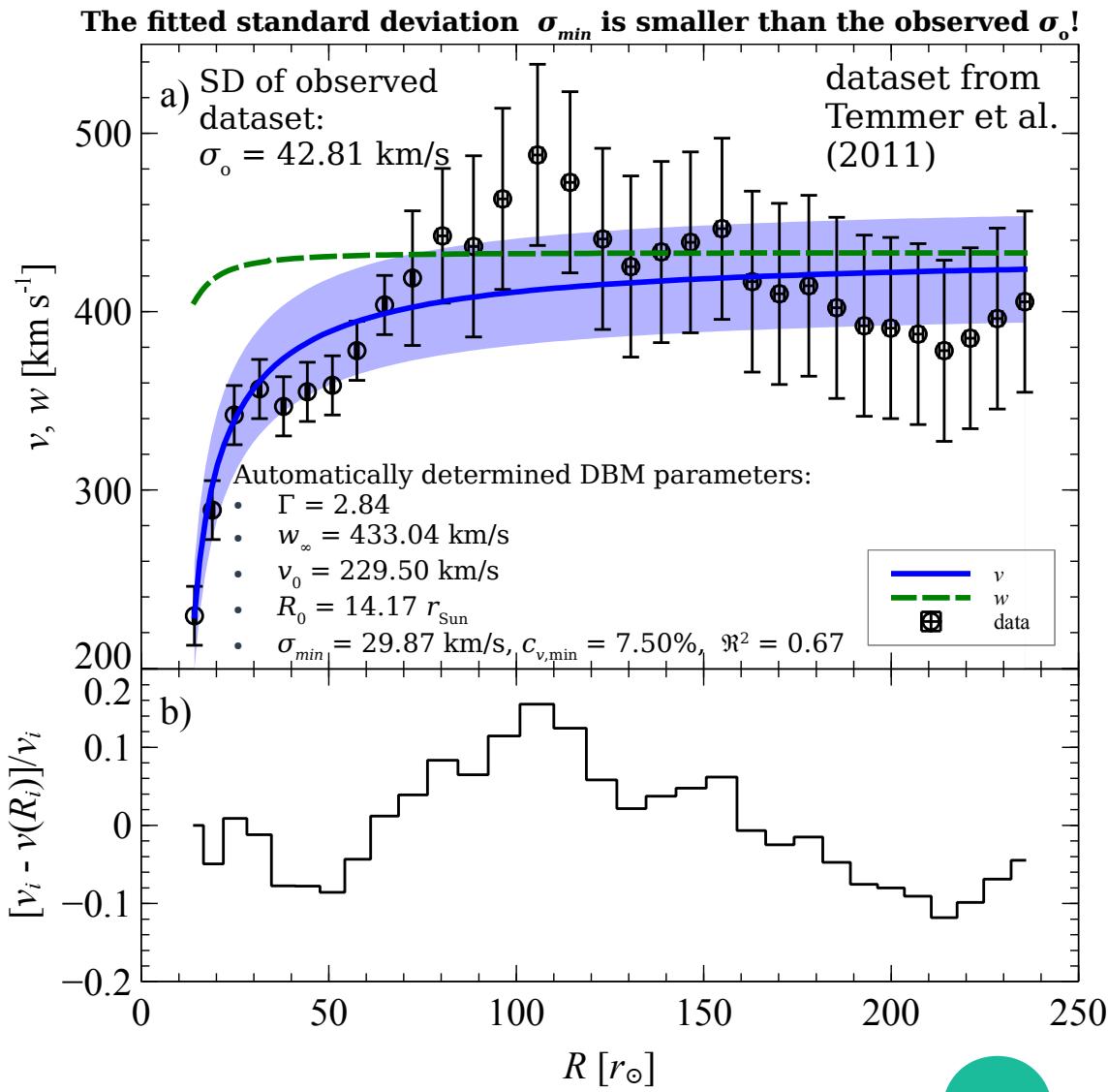
$w(R), \gamma(R) \rightarrow$ CME-edge flattening

- drag parameter: $\Gamma = 0.2$
- initial CME distance: $R_0 = 31 r_s$
- initial CME speed: $v_0 = 1000 \text{ km/s}$
- CME half-width: $\lambda = 60^\circ$
- launching CME meridian distance: $\varphi = 150^\circ$
- target: Mars

- LEFT: Cross-section of CME propagation in ecliptic plane. The CME take-off time: February the 10th, 2009 at 06:13 UT.
- RIGHT: Propagation of '+ CME' point in geometry plot

Automatic Fitting

- INPUT: observed ICME dataset:
 $\{(R_0, v_0), \dots, (R_N, v_N)\}$
 - OUTPUT: DBM parameters
 $(\Gamma, w_\infty, R_0, v_0)$
 - The least-square fitting (LSF):
 - successive variation of DBM parameters → minimal deviation between observed v_i and DBM-calculated speeds $v(R_i)$:
- $$\sigma(\Gamma, w_\infty, R_0, v_0) = \sqrt{\frac{1}{(N+1)} \sum_{i=0}^N [v_i - v(R_i)]^2}$$
- $\sigma_{\min} \rightarrow$
 → the best $(\Gamma, w_\infty, R_0, v_0)$
- for real-time space-weather forecasting (successive fitting as ICME propagates)



Conclusion

- The drag-based model is useful because:
 - it is simple, fast and versatile
 - its accuracy is not worse in comparison to the other advanced models (Vršnak et al., 2014)
 - it is suited for a fast real-time space-weather forecasting (Žic et al., 2015)
- Drawbacks:
 - the magnetic field/Lorentz force is not included in the DBM
 - CME-CME interaction is problematic for calculation
 - the DBM is not basically designed for usage in a complex heliospheric environment
(Will DBM + ENLIL provide better forecasting results?)

**Thank you
for your
attention!**

References

- Borgazzi, A., Lara, A., Echer, E., Alves, M.V.: 2009, *Dynamics of coronal mass ejections in the interplanetary medium*. Astron. Astrophys. 498, 885 – 889.
- Cargill, P.J.: 2004, *On the Aerodynamic Drag Force Acting on Interplanetary Coronal Mass Ejections*. Solar Phys. 221, 135 – 149.
- Davies, J.A., Harrison, R.A., Perry, C.H., Möstl, C., Lugaz, N., Rollett, T., Davis, C.J., Crothers, S.R., Temmer, M., Eyles, C.J., Savani, N.P.: 2012, *A Self-similar Expansion Model for Use in Solar Wind Transient Propagation Studies*. Astrophys. J. 750, 23.
- Gopalswamy, N., Lara, A., Lepping, R.P., Kaiser, M.L., Berdichevsky, D., Cyr, O.C.S.: 2000, *Interplanetary acceleration of coronal mass ejections*. Geophys. Res. Lett. 27, 145 – 148.
- Lara, A., Borgazzi, A.I.: 2009, *Dynamics of interplanetary CMEs and associated type II bursts*. In: N. Gopalswamy & D. F. Webb (ed.) IAU Symposium, IAU Symposium 257, 287 – 290.
- Leblanc, Y., Dulk, G.A., Bougeret, J.-L.: 1998, *Tracing the Electron Density from the Corona to 1 au*. Solar Phys. 183, 165 – 180.
- Lugaz, N., Hernandez-Charpak, J.N., Roussev, I.I., Davis, C.J., Vourlidas, A., Davies, J.A.: 2010, *Determining the Azimuthal Properties of Coronal Mass Ejections from Multi-Spacecraft Remote-Sensing Observations with STEREO SECCHI*. Astrophys. J. 715, 493 – 499.
- Möstl, C., Davies, J.A.: 2012, *Speeds and Arrival Times of Solar Transients Approximated by Self-similar Expanding Circular Fronts*. Solar Phys., 77.
- Owens, M., Cargill, P.: 2004, *Predictions of the arrival time of Coronal Mass Ejections at 1AU: an analysis of the causes of errors*. Annales Geophysicae 22, 661 – 671.
- Schwenn, R., dal Lago, A., Huttunen, E., Gonzalez, W.D.: 2005, *The association of coronal mass ejections with their effects near the Earth*. Ann. Geophys. 23, 1033 – 1059.
- Thernisien, A.: 2011, *Implementation of the Graduated Cylindrical Shell Model for the Three-dimensional Reconstruction of Coronal Mass Ejections*. Astrophys. J. Supp. 194, 33.
- Thernisien, A.F.R., Howard, R.A., Vourlidas, A.: 2006, *Modeling of Flux Rope Coronal Mass Ejections*. Astrophys. J. 652, 763 – 773.
- Vršnak, B.: 2001, *Deceleration of Coronal Mass Ejections*. Solar Phys. 202, 173 – 189.
- Vršnak, B., Žic, T.: 2007, *Transit times of interplanetary coronal mass ejections and the solar wind speed*. Astron. Astrophys. 472, 937 – 943.
- Vršnak, B., Žic, T., Falkenberg, T.V., Möstl, C., Vennerstrom, S., Vrbanec, D.: 2010, *The role of aerodynamic drag in propagation of interplanetary coronal mass ejections*. Astron. Astrophys. 512, A43.
- Vršnak, B., Žic, T., Vrbanec, D., Temmer, M., Rollett, T., Möstl, C., Veronig, A., Čalogović, J., Dumbović, M., Lulić, S., Moon, Y.-J., Shanmugaraju, A.: 2013, *Propagation of Interplanetary Coronal Mass Ejections: The Drag-Based Model*. Solar Phys. 285, 295 – 315.
- Žic, T., Vršnak, B., Temmer, M.: 2015, *Heliospheric Propagation of Coronal Mass Ejections: Drag-based Model Fitting*. Astrophys. J. Supp. 218, 32.