ISEST

Working Group 2: Theory

Report for recent progresses

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BRIEF HISTORY

- kick-off meeting of the ISEST program: June 2013, Hvar Observatory, Croatia
- four groups were defined, which became a backbone of the ISEST program:

✓ WG1: Data
✓ WG2: Theory
✓ WG3: Simulation
✓ WG4: Event Campaign

(Later on, three more groups were added: WG5 Bs Challenge, WG6 Solar Energetic Particles, WG7 MiniMax Campaign)

THE OVERALL AIM AND GOALS OF WG2

The overall aim of WG2 is to advance our comprehension of the physical background of Earth-affecting solar transients

The main goals are:

- to improve our understanding of the structure and evolution of CMEs, including magnetic flux ropes and driven shocks, as well as their origin;
- to improve comprehension of coronal/heliospheric dynamics of CMEs, including the interaction with ambient solar wind and interplanetary magnetic field, causing deceleration/acceleration and deflections;
- to get a better insight into how long does the Lorentz force dominate over the aerodynamic drag force, including the estimation of the drag parameter and/or the dimensionless drag coefficient;
- to improve our capability in modelling and forecasting the southward magnetic field component (Bs) inside a CME;
- to compare the theoretical results with observations, e.g., 1 AU transit time, impact speed, impact magnetic field, etc.;

ACTIVITIES ---- WORKSHOPS RELATED TO WG2 (A REVIEW)

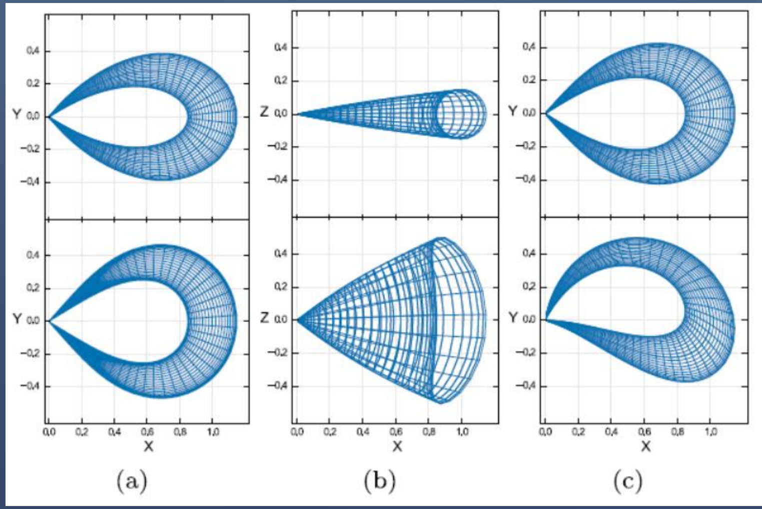
- 2013.06.17-20: Hvar, Croatia (“kick-off”)
- ……
- 2016.04.17-22: Vienna, Austria (EGU, a few sessions)
- 2016.05.22-26: Japan (JpGU, a session)
- 2016.06.06-10: Bulgaria (VarSITI2016 General Symposium)
- 2016.07.31-05: Beijing, China (AOGS, a session)
- 2016.08.18-19: Beijing, China (mini ISEST workshop)
- 2016.09.26-30: Hvar, Croatia (14^{th} Hvar Astrophysical Colloqium)
- 2017.04.23-28: Vienna, Austria (EGU, a session)
- 2017.05.20-25: Japan (JpGU-AGU, a session)
- 2017.06.26-28: USTC, Hefei, China (workshop on solar eruptions)
- 2017.07.10-15: Irkutsk, Russia (Second VarSITI General Symposium)
- ……

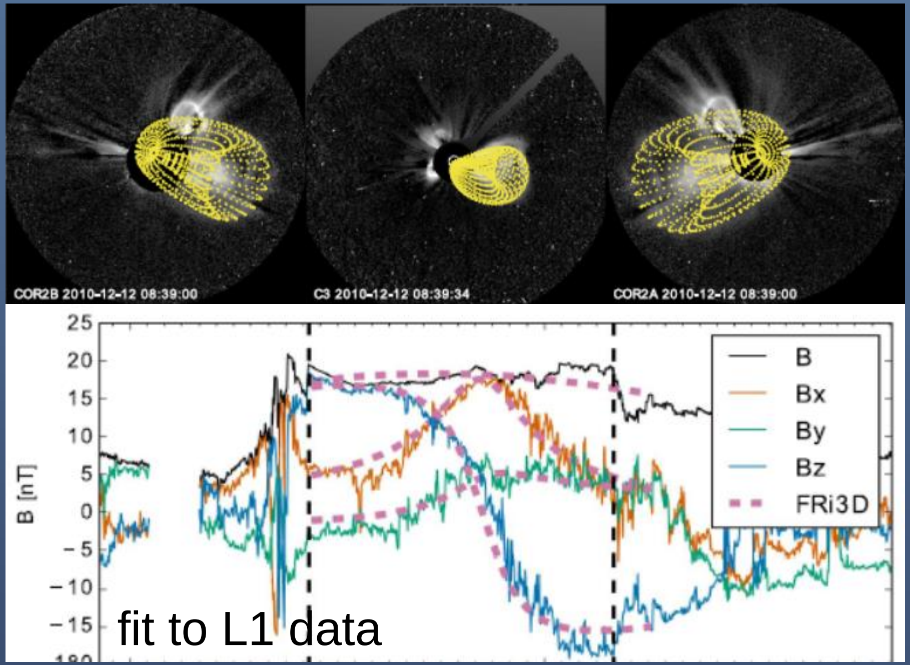
ACTIVITIES ---- RESEARCH PROGRESSES (2016 -)

- Structure and origin of CMEs
  - Semi-empirical 3D flux rope models for CMEs: FRi3D (Isavnin ApJ 2016) and 3DCORE (Möstl+ in preparation 2017)
  - Magnetic field twist of solar magnetic flux ropes (Liu R+ ApJ 2016; Wang W+ NatComm accepted 2017) and interplanetary magnetic clouds (Wang Y+ JGR 2016a)
  - Condition for successful solar eruptions: flare-rich but CME-poor ARs, e.g., 12192, quasi-homologous CMEs, etc. (Liu L+ ApJ 2016, 2017)

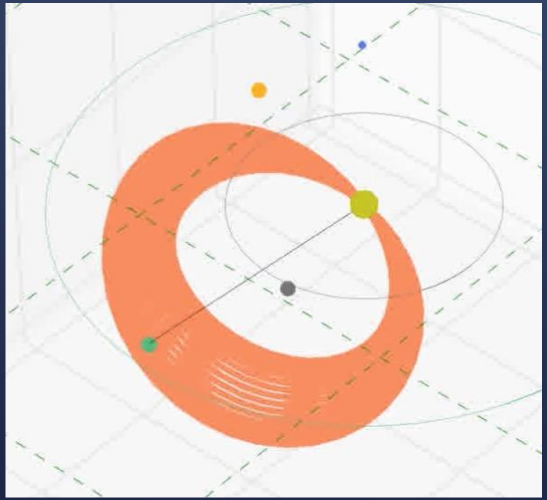
Semi empirical flux rope models

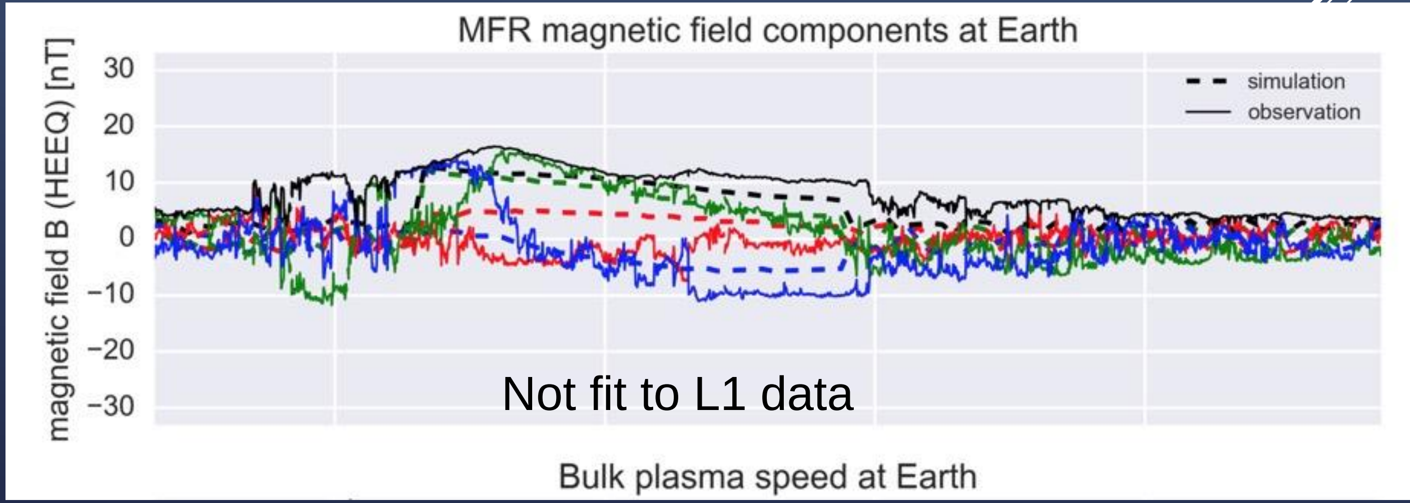
- FRi3D (Isavnin ApJ 2016)





- 3DCORE (Möstl et al. 2017 in preparation)



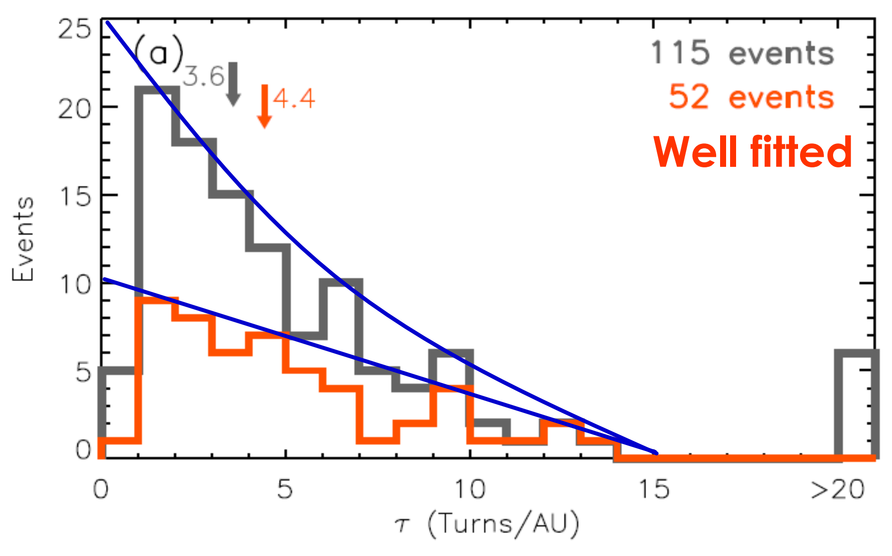


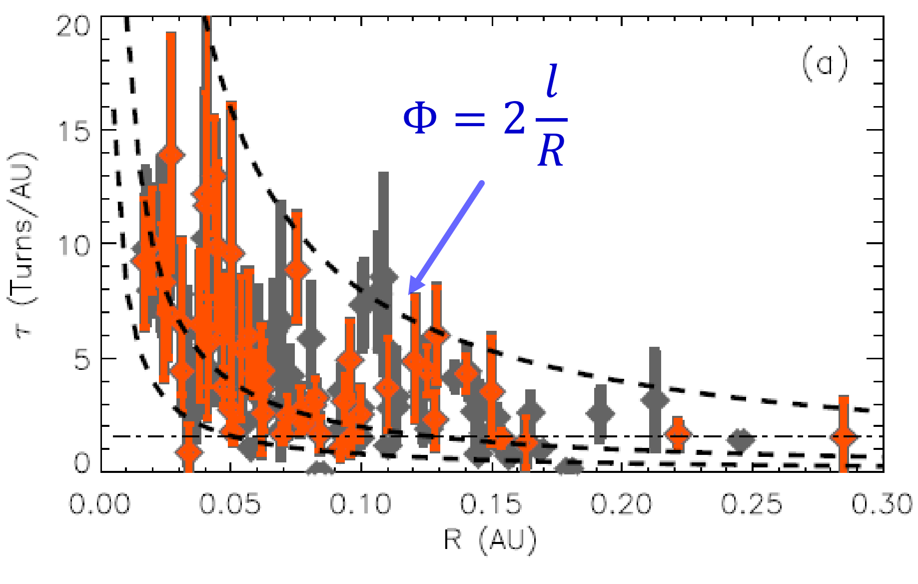
Statistical results of the twist of interplanetary magnetic clouds at 1 AU

Wang Y., et al., JGR, 121, 9316-9339, 2016

Using velocity modified uniform-twist force-free flux rope model

- **Upper limit**: about 6 turns/AU → $\Phi < 30\pi$ (<15 turns)
- **Median value**: about 1.6 turns/AU → $\Phi \sim 8\pi$ (4 turns)
- **Most probable value**: 0.4 – 0.8 turns/AU → $\Phi \sim 2\pi - 4\pi$ (1 – 2 turns)
- 77% of the events with $\Phi > 4\pi$ (>2 turns)
- Most MCs are highly twisted
- $2l/R$ seems to be the upper boundary (sufficient condition) for unstableness

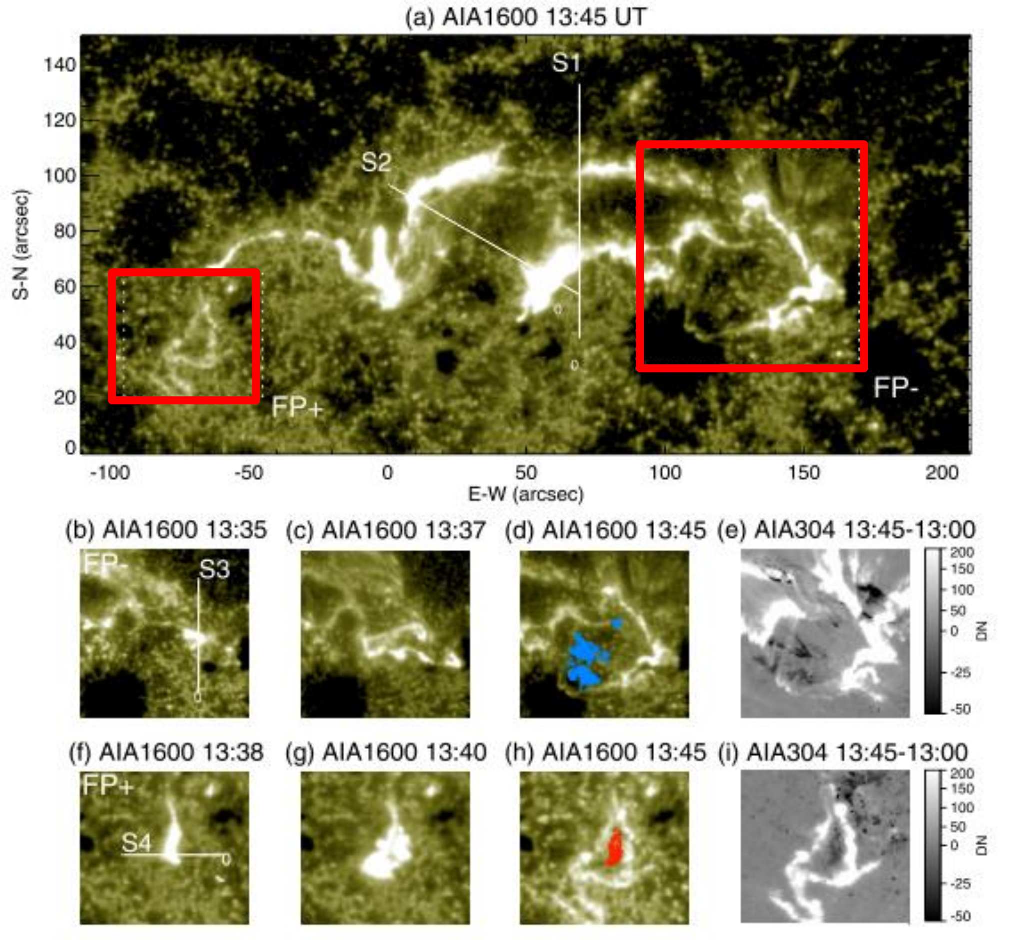


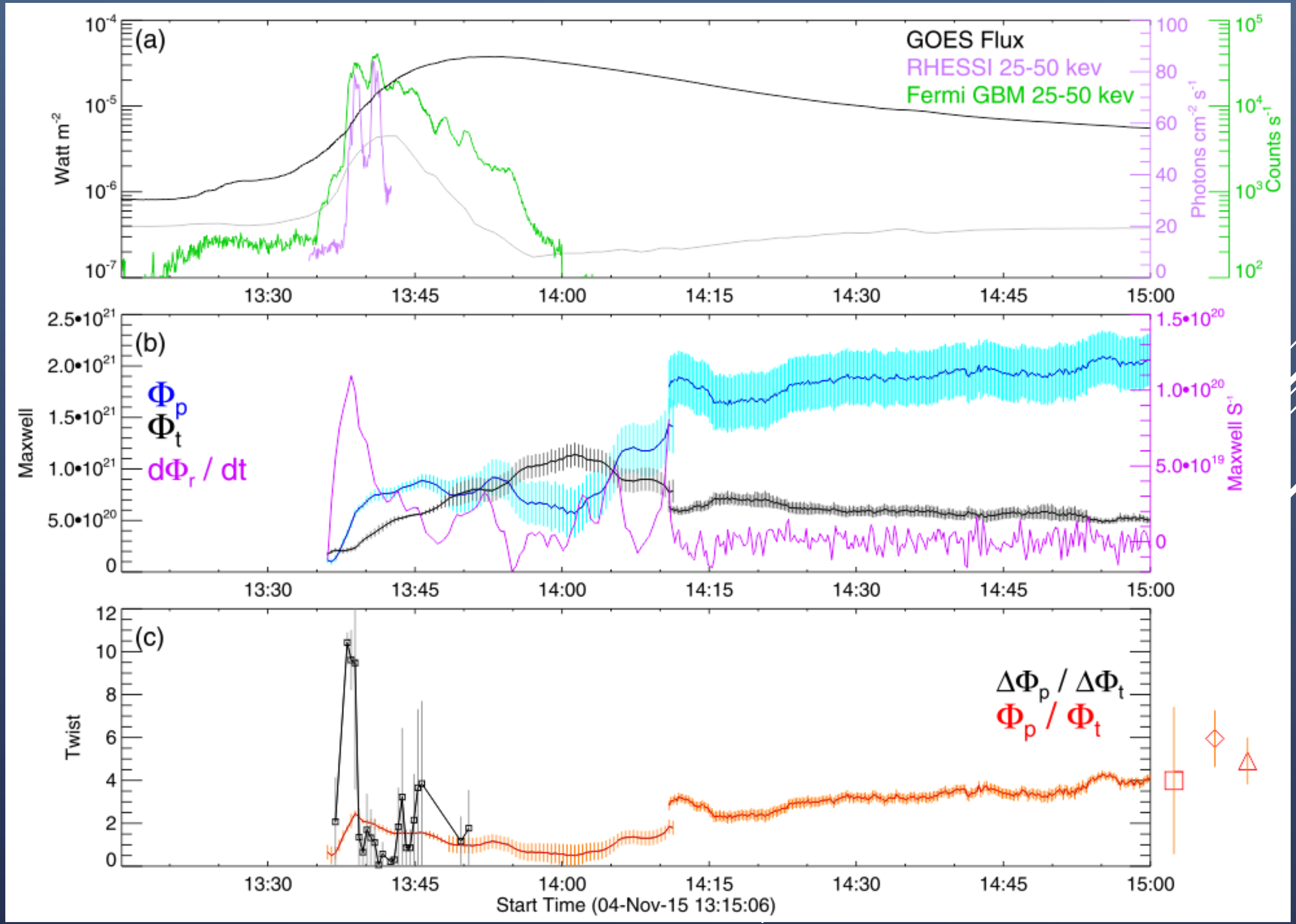


Highly twisted magnetic flux rope forming during a eruption

Wang W., R. Liu, Y. Wang, et al., Nature Communications, Accepted, 2017

Investigate the formation of a MFR with the aids of various models





- **A seed flux rope may be necessary for the production of a highly twisted flux rope!**

ACTIVITIES ---- RESEARCH PROGRESSES (2016 -)

- Dynamics of CMEs
  - Nature of collisions of CMEs by 3D-collision model and simulations (Shen F+ SciRep 2016; Mishra+ ApJ 2016; Mishra+ ApJS 2017), see reviews (Lugaz+ SoPh 2017; Shen F+ SoPh 2017) ---- a talk by W. Mishra on Tuesday (11:00-11:30)
  - Deflected propagation of CMEs: DIPS model (Wang Y+ JGR 2016b; Zhuang B+ ApJ 2017), ForeCAT model including rotation (Kay+ ApJ 2016)
  - Rotation of CMEs (Fan Y ApJ, 2016)
  - Poloidal plasma motion inside magnetic clouds (Zhao A+ SoPh 2017; Zhao A+ ApJ 2017)

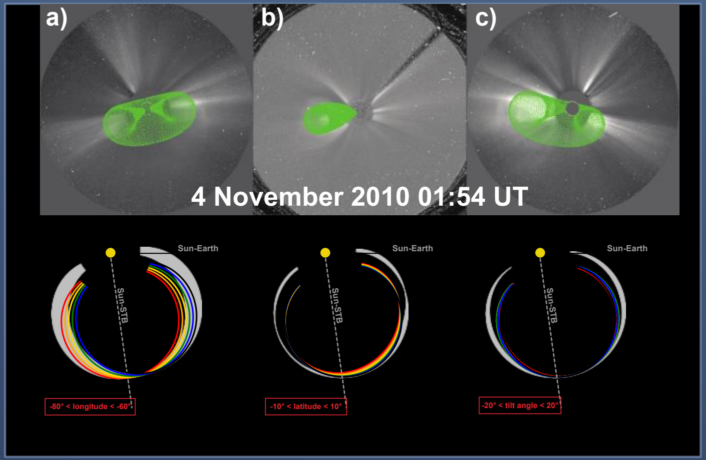
ACTIVITIES ---- RESEARCH PROGRESSES (2016 -)

- Drag force related issues, including arrival time prediction
  - DBM started to be frequently employed tool used to understand better various aspects of the heliospheric dynamics of CMEs (e.g., Wang Y+ JGR, 2016b and references therein);
  - Arrival time prediction: neural network (Sudar+ MNRAS 2016), ElEvoHI+DBM (Rollett+ ApJ 2016; Amerstorfer+ ApJ 2016)
  - Development of ensemble DBM modelling (analogous to ENLIL)
  - Comparison of different propagation models (Zhao X+ ApJ 2016)

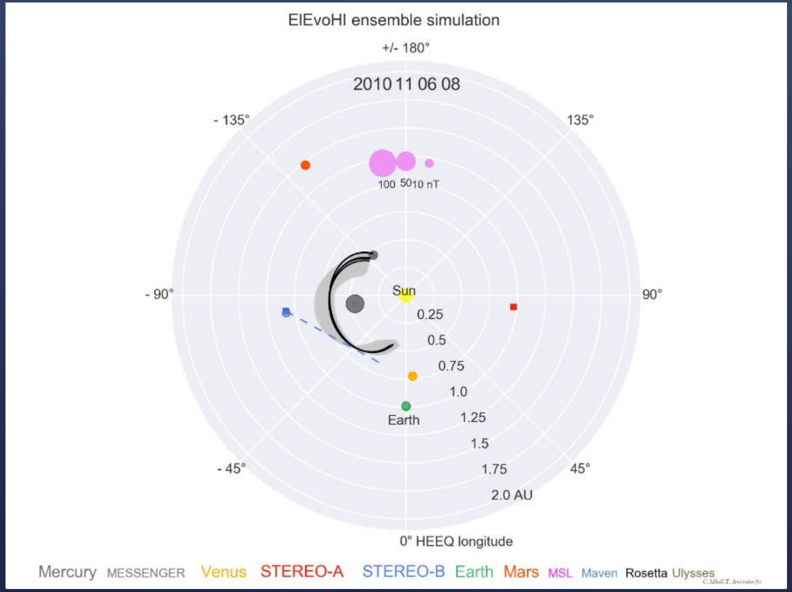
ELEVOHI – THE ELLIPSE EVOLUTION MODEL BASED ON HI DATA

(T. Rollett et al. 2016)

ElEvoHI = Elliptic Conversion + DBM fitting + Ellipse Evolution model



T. Amerstorfer et al. in prep.



Information about the geometrical shape of the CME within the ecliptic are extracted from **GCS modeling**.

→ ellipse aspect ratio
→ angular half width
→ direction of motion

HI elongations are converted to distance using the **Elliptic Conversion (ElCon) method**

→ time-distance profile

DBM fitting is applied to HI time-distance profile between 30 and 100 solar radii. (additional data: real time solar wind speed from 1AU)

→ gamma parameter
→ solar wind speed

All parameters gained are now fed into the **Ellipse Evolution (ElEvo**, *Möstl et al. 2015*) **model** to predict CME arrival.

Input:

→ coronagraph data (shape)
→ HI data (kinematics)
→ In situ real time data (range for background solar wind speed)

Output:

→ arrival time and speed at any target

New work

Ensemble Forecasting of a Halo CME Using Heliospheric Imagers
(Amerstorfer, T., Möstl, C., Temmer, M., Hess., P., Mays, L., Lowrance, P, in prep. for Space Weather)

DRAG BASED ENSEMBLE MODEL (DBEM)

Dumbovic, M., Calogovic, J., Vrsnak, B., Temmer, M., Mays, L.M., and Veronig, A. (In preparation)

= probabilistic (ensemble) modeling applied to drag based model (DBM):

Input:

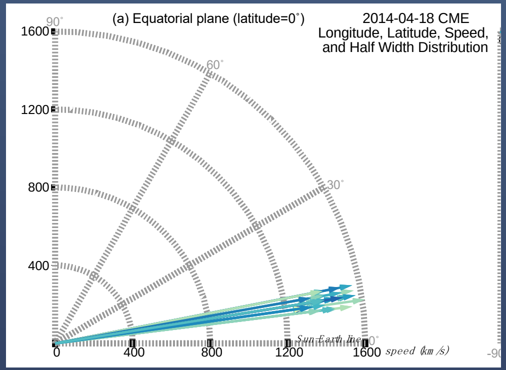
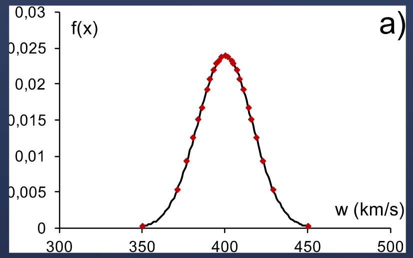
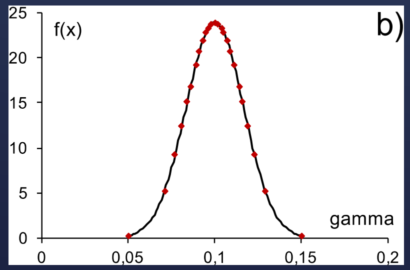


Figure 3 from Mays et al., 2015, SolPhys

Ensemble of CME measurements:

Each ensemble member has different start time, initial speed, longitude and half width

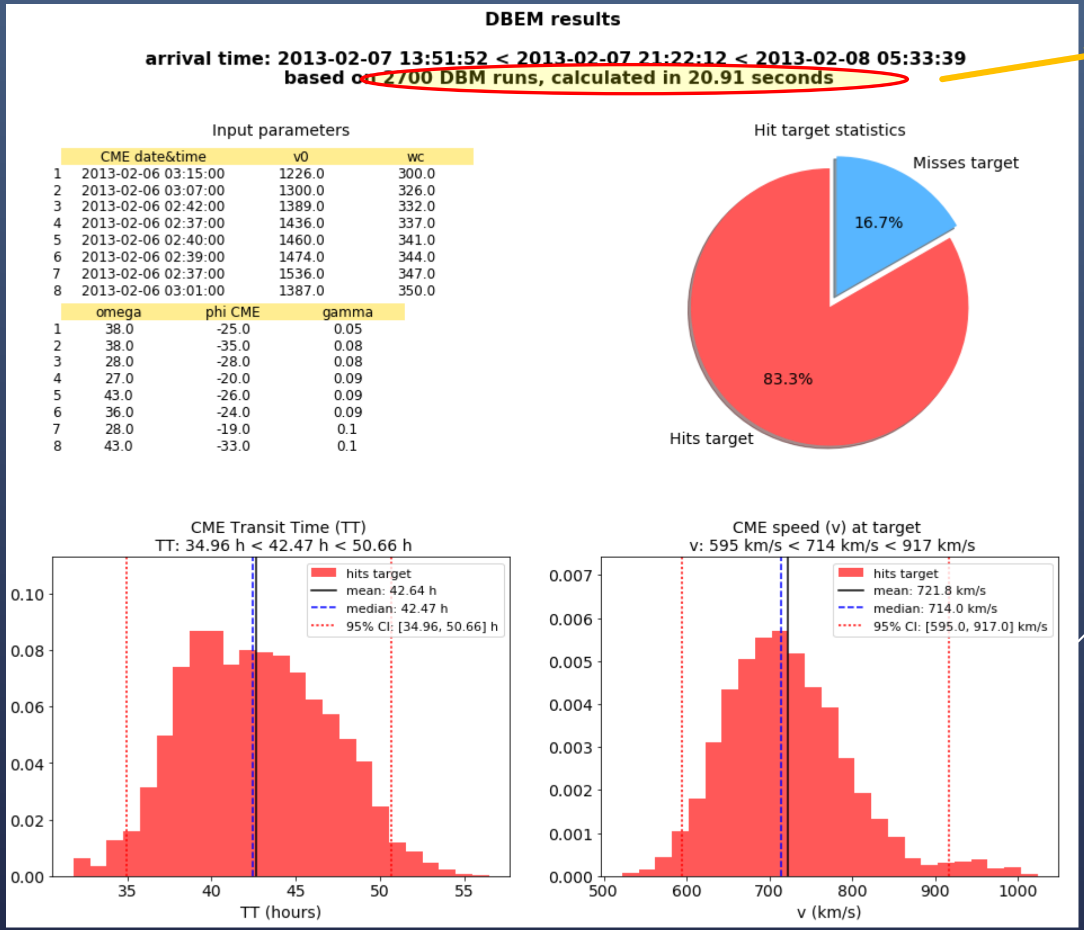




Solar wind speed and gamma parameter:

Are substituted with "synthetic measurements" produced under assumption that they follow normal distribution

Output:



HIGHLIGHTED: Very fast!

Probability of arrival (hit) is calculated as a number of ensemble members that hit divided with the total number of ensemble members

Transit time and arrival speed are given as distributions (only for ensemble members that hit!) with mean median and 95% confidence interval. Median value is taken as most likely.

DRAG BASED ENSEMBLE MODEL (DBEM)

Performance and comparison with ENLIL

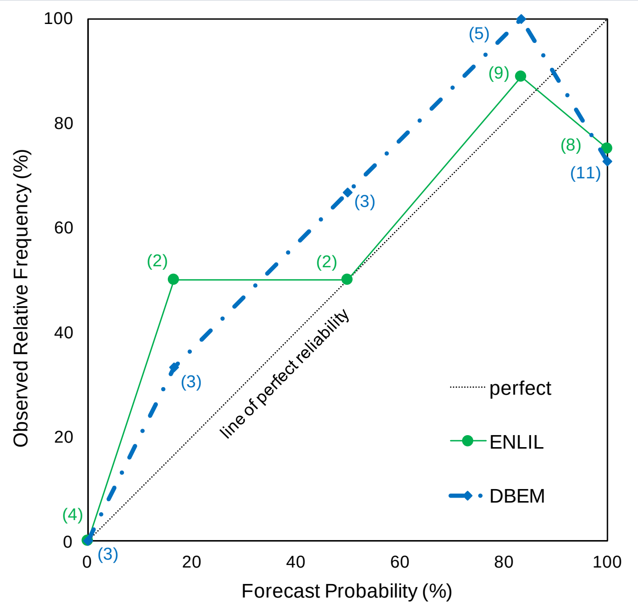
Based on sample and ENLIL performance presented in Mays et al., 2015, SolPhys

HIT STATISTIC

		DBEM	ENLIL
No of hits	a	16	16
No of misses	c	0	0
No of false alarms	b	4	3
No of correct rejections	d	5	6
No of events	N=a+b+d	25	25
Correct rejection rate	d/(b+d)	55,56%	66,67%
False alarm rate	b/(b+d)	44,44%	33,33%
Correct alarm ratio	a/(a+b)	80,00%	84,21%
False alarm ratio	b/(a+b)	20,00%	15,79%
Brier score	BS	0,17	0,18

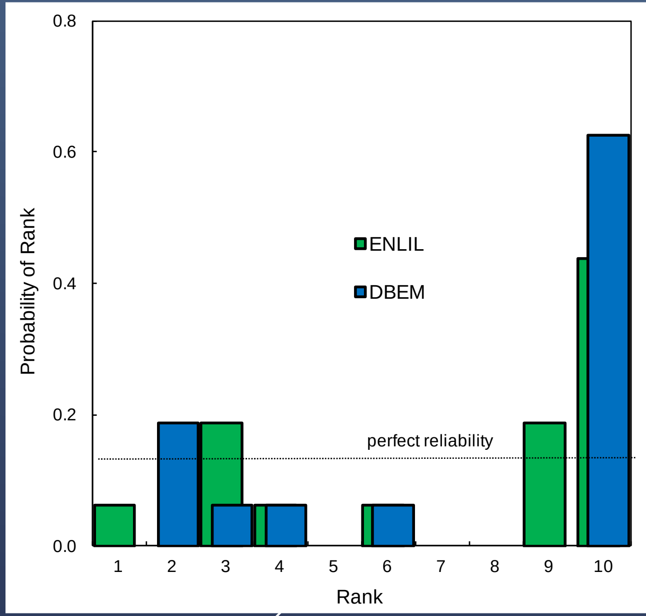
THE RELIABILITY DIAGRAM:

How well the model predicts the probability of arrival?



THE RANK HISTOGRAM:

Do observations fall within predicted distributions?



=> ENLIL and DBEM perform similarly; number of false alarms should be reduced; fast CMEs predicted to arrive too early

ACTIVITIES ---- RESEARCH PROGRESSES (2016 -)

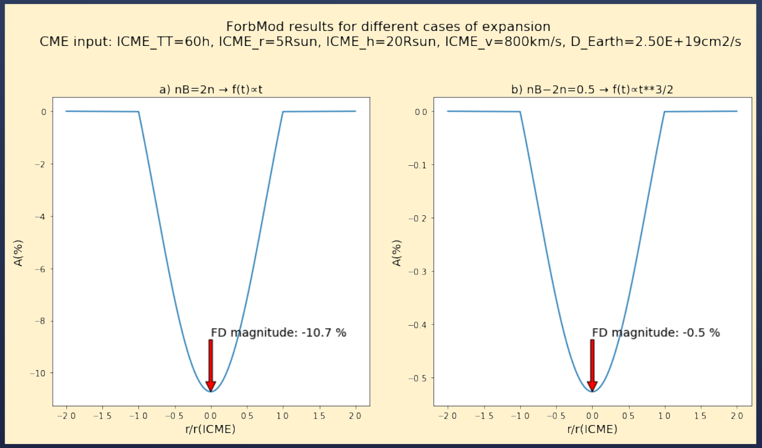
- Others
  - Forbush decrease model for expanding CMEs (FORBMOD; Dumbovic+ In preparation)

    analytical model to describe the flux rope-part of Forbush decrease based on perpendicular diffusion of particles into the flux rope, taking into account expansion

$$U(r,t) = U_0\left(1 - J_0(\alpha_1 r)\mathrm{e}^{-\alpha_1^2 f(t)}\right)$$

Particle density inside the flux rope at distance r from the FR center (in units of FR radius) and at time t (from the FR eruption)

The radial part is given by Bessel function:
For each flux rope the shape of Forbush decrease will be symmetric and constrained to the spatial extent of the flux rope



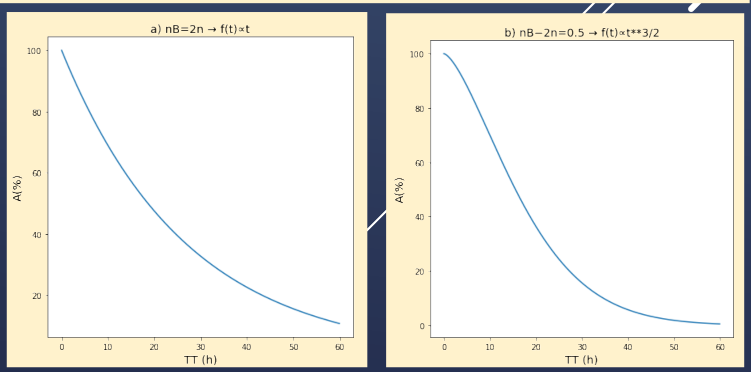
The time-dependent part is given by exponential function which describes the competing mechanisms of diffusion and expansion (diffusion increases the density, whereas expansion decreases it):
-> depends on the type of the diffusion (only self-similar diffusion regarded)

$$h(t) = \left(\frac{R(t)}{R_0}\right)^n$$

General behavior of the flux rope radius (h(t)=a, n=n) and magnetic field strength (h(t)=B, n=n_B) for self-similar expansion
Demoulin et al, 2008

1. $n_B = 2n \longrightarrow f(t) \propto t$
2. $n_B > 2n \longrightarrow f(t) \propto t^x, x > 1$ (special case: $n_B - 2n = 0.5 \longrightarrow f(t) \propto t^{\frac{3}{2}}$)
3. $n_B < 2n \longrightarrow f(t) \propto t^x, x < 1$ (special case: $n_B - 2n = -0.5 \longrightarrow f(t) \propto t^{\frac{1}{2}}$)
4. special case: $n_B - 2n = -1 \longrightarrow f(t) \propto \ln(at+1)$

2 cases of expansion:



WG2 RELATED TALKS AT THIS WORKSHOP

Mon 15:00-15:20 Development of a Daily Solar Major Flare Occurrence Probability Model Based on Vector Parameters from SDO/HMI, by Daye Lim

15:20-15:40 Application of Convolution Neural Network to the forecasts of flare classification and occurrence using SOHO MDI data, by Eunsu Park

Tue 09:00-09:20 Constraining CMEs and Shocks by Observations and Modelling throughout the inner heliosphere, by Andrei Zhukov

11:10-11:30 Assessing the collision nature of coronal mass ejections in the inner heliosphere, by Wageesh Mishra

Session WG2&3

14:00-15:00 Progress of MHD Simulations for the Interplanetary Propagation of Coronal Mass Ejections, by Christina Verbeke*(Theme-setting speaker)

15:00-15:20 Iterative 3-D MHD ENLIL Modeling Using Interplanetary Scintillation (IPS) Observations, by Bernard Jackson

15:20-15:40 Data-driving evolving models of the solar corona, by Mark Cheung

16:10-16:30 Response of the Earth's magnetosphere and ionosphere to the small-scale magnetic flux rope in solar wind by the global MHD simulation, by Kyung-Sun Park

16:30-16:50 CME dynamics using STEREO and LASCO observations: the relative importance of Lorentz forces and solar wind drag, by Nishtha Sachdeva

Wed 10:00-10:20 Evolution a coronal mass ejection from the Sun to Mercury, Venus, Earth and beyond, by Yuming Wang

16:10-16:30 Gravitational instability on propagation of MHD waves in astrophysical plasma, by Alemayehu M. Cherkos

Thu 10:20-10:40 Shock location and CME 3D reconstruction of the first spatial resolved solar type II radio burst with LOFAR, by Pietro Zucca