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The study of coronal mass ejections travel time to the Earth

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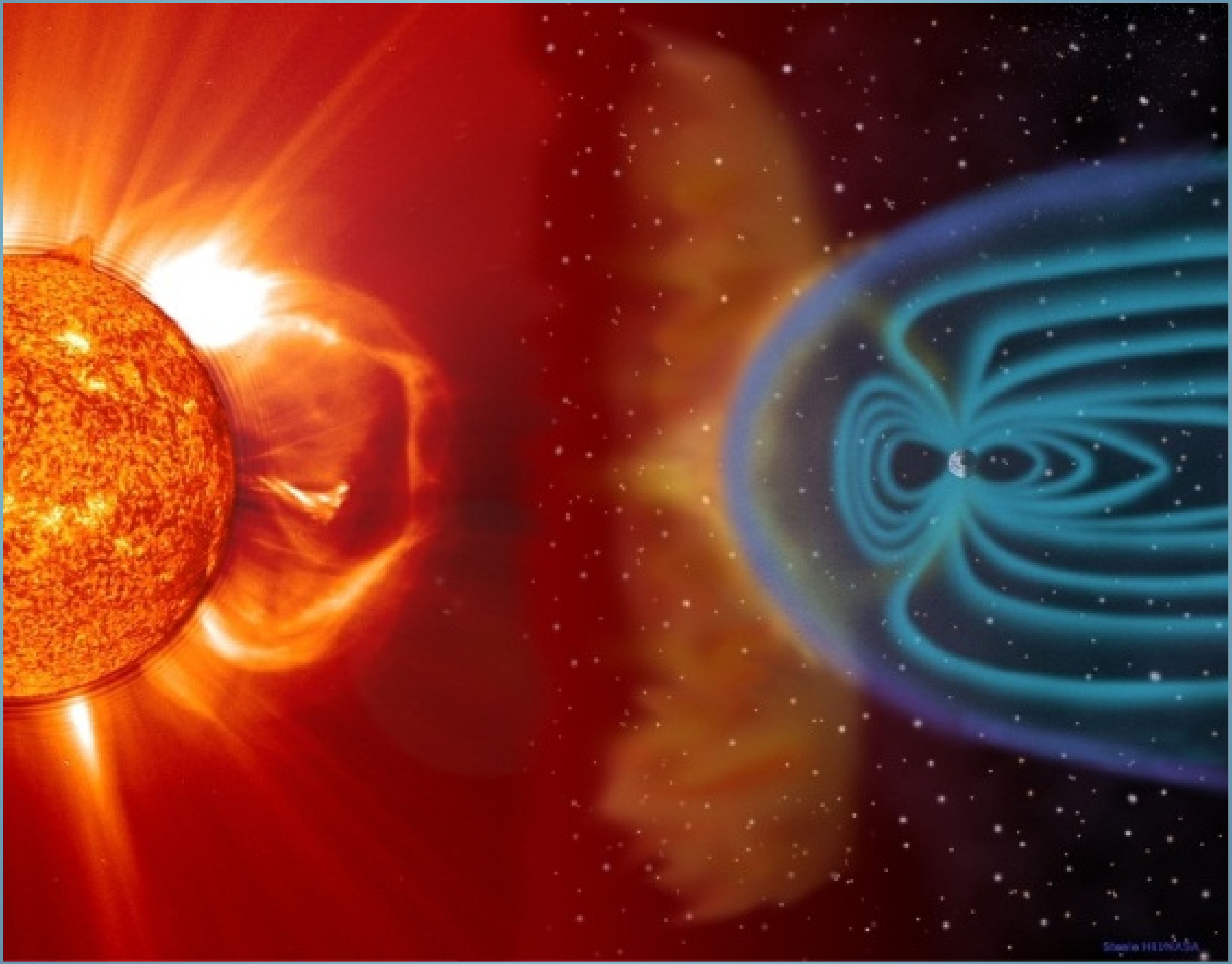
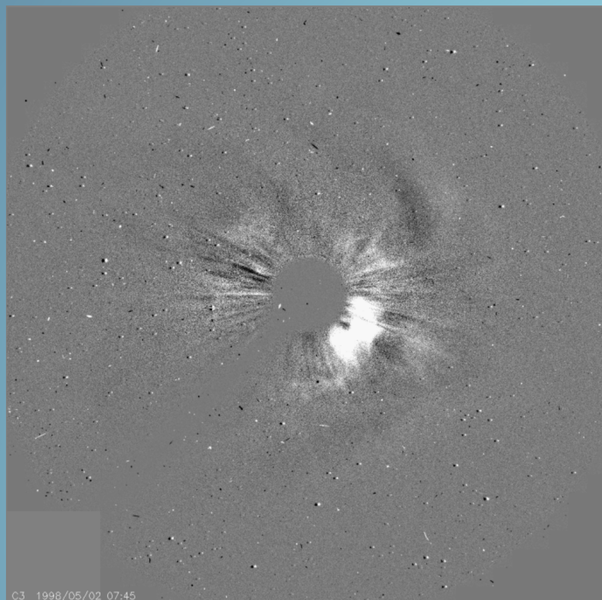
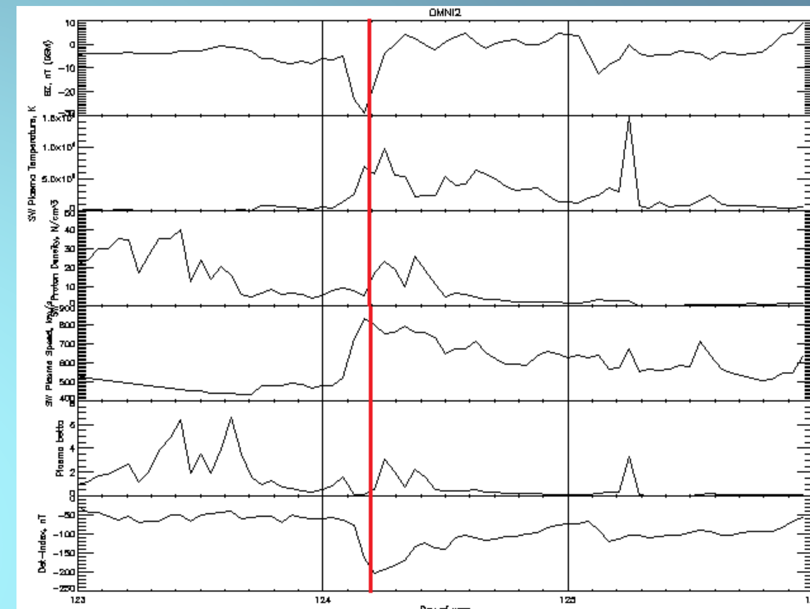
Context of events - Inner heliosphere



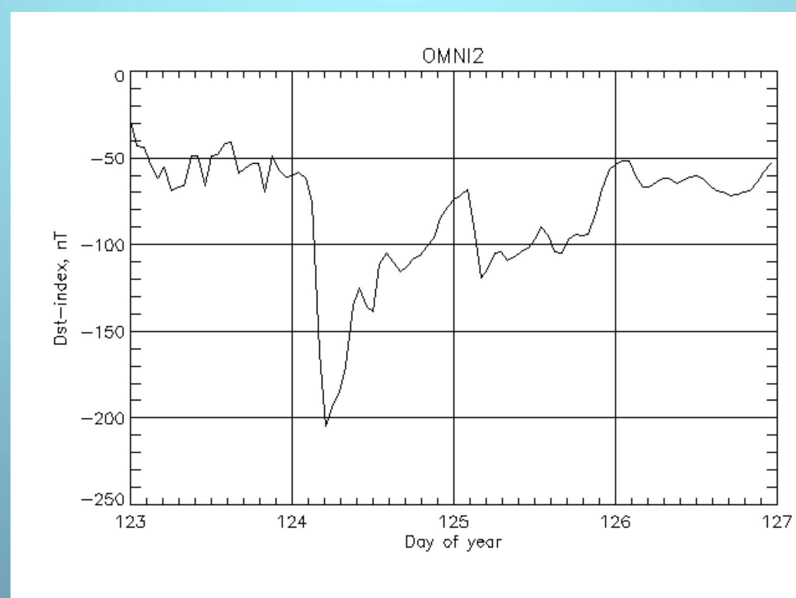
Data description



CME



ICME



Geomagnetic storm

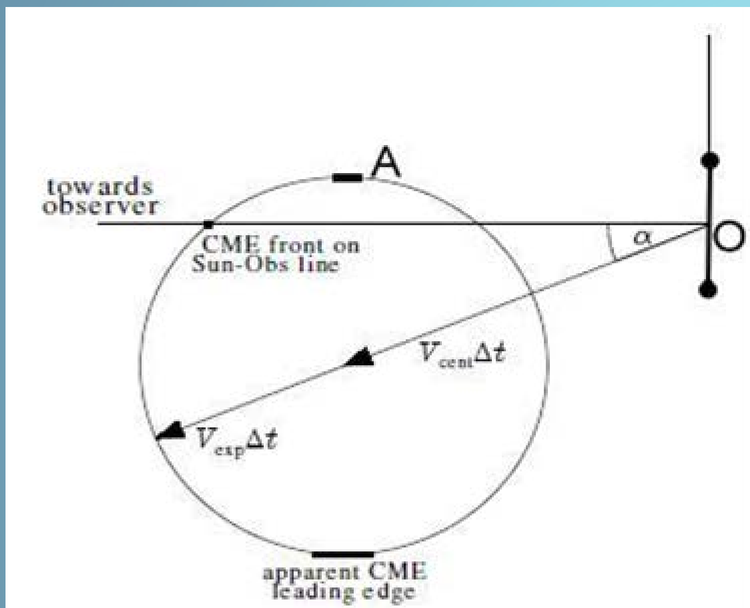
Correlated events

Date/Time DD.MM. YYYY/hh.mm	CME Type	Vproj (CME Speed)	Start time for source	Source location	AR number	Disturbance (UT) (DD/MM-HH/MM)	Period start-end ICME (UT) (DD/MM-H)	Vmax ICME (km/s)	Date/Time-Vmax (DD/MM-H (UT))	Vavg ICME (km/s)	Dst min (nT)	Date/Time (DD/MM-H (UT))
01.05.1998 23:40	FH	519.6931	22:36	S16W12	08210	04/05-02:15	04/05-10:00 04/05-23:00	833	04/05-04:00	542	-205	04/05 -05:00
02.05.1998 05:31	FH	552.1566	04:48	S17W24	08210	04/05-02:15	04/05-10:00 04/05-23:00	833	04/05-04:00	542	-205	04/05 -05:00
02.05.1998 14:06	FH	885.8982	13:31	S17W24	08210	04/05-02:15	04/05-10:00 04/05-23:00	833	04/05-04:00	542	-205	04/05 -05:00

Tabel of the correlated events CME (May 1st – 2nd 1998) – ICME – geomagnetic storm (May 4th 1998).

- http://cdaw.gsfc.nasa.gov/CME_list/ (identification of the CME, Halo type)
- http://lasco-www.nrl.navy.mil/daily_mpg/ (identification of the source of CME)
- http://www.solarmonitor.org/ (obtaining the source location (latitude and longitude)).

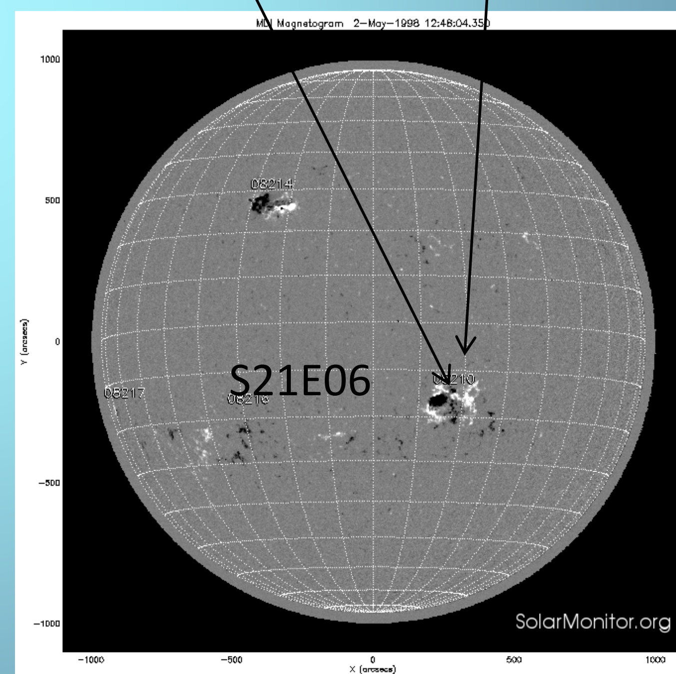
Model description and speed calculation



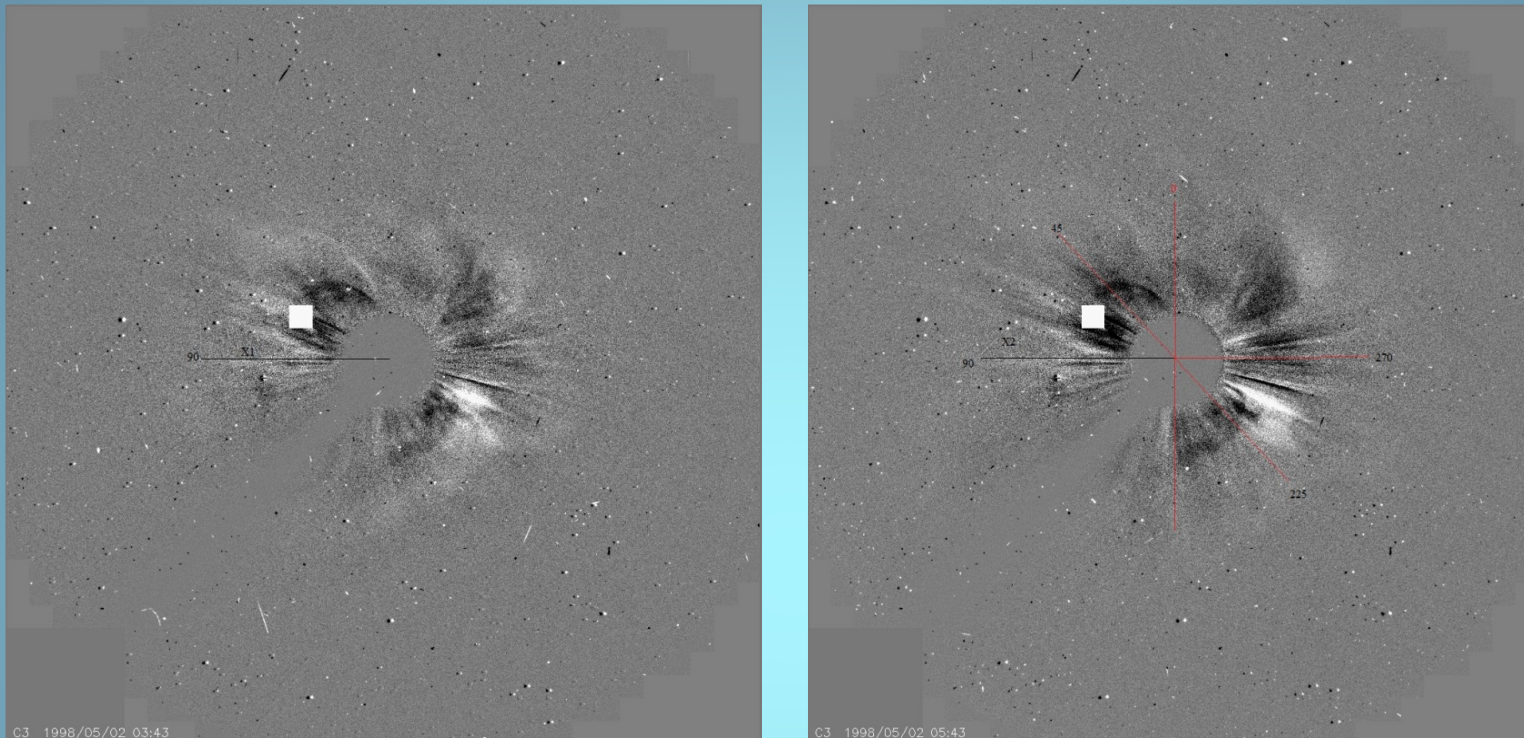
A simple sketch of a spherical CME which expands self-similar. The center is assumed to propagate radially away from the Sun. Adapted from Srivastava et al. (2009).

$$V_{tt} = \left[V_{cent} \cdot \cos\alpha + \sqrt{V_{exp}^2 - V_{cent}^2 \cdot \sin^2\alpha} \right] \cdot \cos\beta$$

$$V_{proj} \cdot \cos\beta = V_{cent} \cdot \sin\alpha + V_{exp}$$



Speed calculation



Successive running difference images (LASCO-C3) recorded on May 1, 1998 at 03:43 UT (left panel) and 05:43 UT (right panel). The lines outline the directions in which the expansion speeds were calculated.

$$V = \frac{X_2 - X_1}{t_2 - t_1}$$

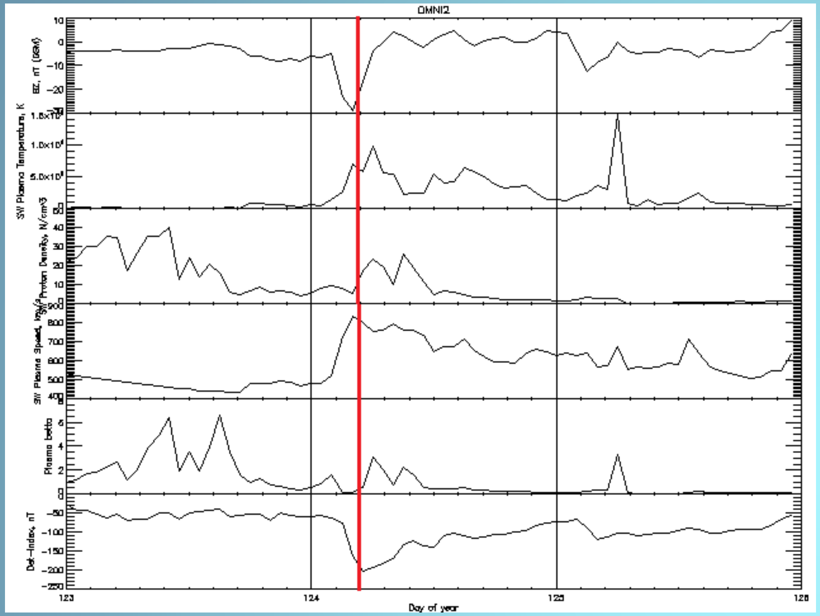
on each direction

→ V_{avg}

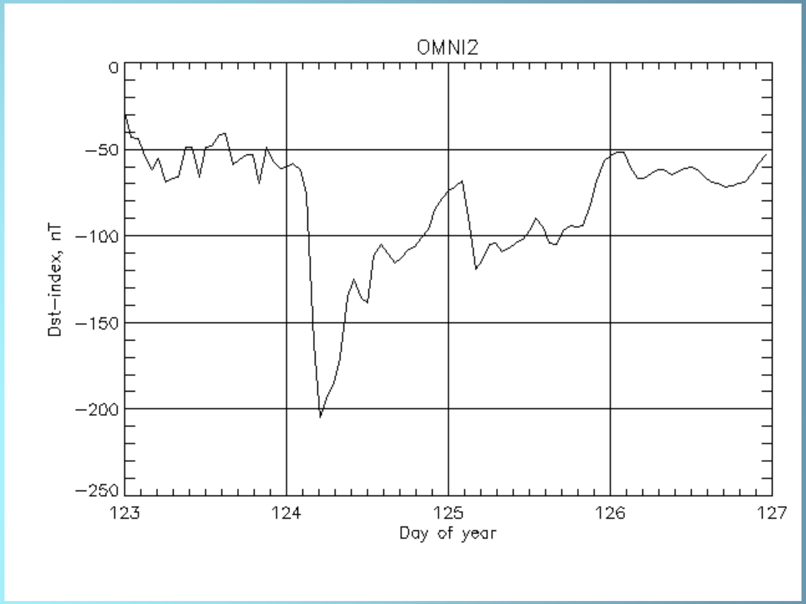
of every CME

→ $V\ \mathrm{exp}$

Case 1: Geomagnetic storm associated with three CMEs



In-situ data of ICME on 04 May 1998 (OMNIWeb)



Values of Dst on 03-04 May, 1998 (OMNIWeb)

Case 1: Geomagnetic storm associated with three CMEs

d(45-225) (solar radii)	d(45-225) (km)	d(0-180) (solar radii)	d(0-180) (km)	d(90-270) (solar radii)	d(90-270) (km)	Obtained speed (45-225) (km/s)	Obtained speed (0-180) (km/s)	Obtained speed (90-270) (km/s)	Average speed
20.81	14473355	21.09	14668095	23.35	16239925				
23.96	16664180	25.32	17610060	27.64	19223620	608.5625	817.2125	828.8041667	751.5263889
30.32	21087560	29.74	20684170	31.83	22137765	614.3583333	426.9597222	404.7423611	482.0201389
29.58	20572890	30.38	21129290	31.77	22096035				
32.71	22749805	33.46	23271430	35.16	24453780	566.9049479	557.8489583	613.9960937	579.5833333
35.19	24474645	36.86	25636130	37.57	26129935	513.3452381	703.7797619	498.8556548	571.9935516
12.69	8825895	14.92	10376860	11.71	8144305				
16.29	11329695	19.02	13228410	19.31	13430105	732.1052632	833.7865497	1545.555556	1037.149123
20.68	14382940	23.01	16003455	25.38	17651790	848.1236111	770.8458333	1172.690278	930.5532407

Calculation of the average speed (last column) of each CME associated with the geomagnetic storm on 04 May, 1998.

Case 1: Geomagnetic storm associated with three CMEs

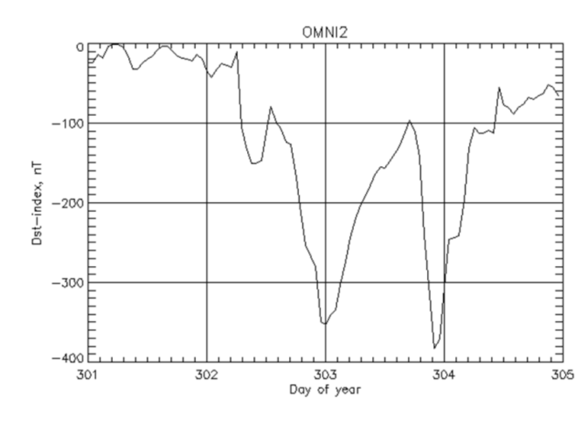
Travel time comparison

CME (LASCO/C3)	V_{proj} (km/s)	Obtained time (h)	$V_{avgICME}$ (km/s)	Obtained time (h)	V_{tt} (km/s)	Obtained time (h)	Real time from ACE (h)
01.05.1998	519.6931	79.373	542	76.107	600.812	68.657	46.283
02.05.1998	552.1566	74.707	542	76.107	333.266	123.774	39.266
02.05.1998	885.8982	46.562	542	76.107	503.861	81.867	35.3

Calculation of the real propagation speed to Earth for three CMEs, registered on May 01 (23:40 UT), 02 (05:31 UT) and 02 (14:06 UT) 1998.

- A possible explanation for the large difference between values obtained in delay time and real one (registered at ACE), may be the interaction of events in interplanetary space and/or interaction with other events (eg. high-speed coronal streams).

Case 2: Geomagnetic storm associated with one CME



Values of Dst on 28-31 October, 2003 (OMNIWeb)

Obtained speed (45-225) (km/s)	Obtained speed (0-180) (km/s)	Obtained speed (90-270) (km/s)	Average speed (km/s)
2376.291	2202.416	2901.13	2493
1250.934	2072.01	743.798	1355.581

Calculation of the average speed of the CME observed on 28 October, 2003.

Case 2: Geomagnetic storm associated with one CME

CME (LASCO/C3)	Vproj (km/s)	Obtained time (h)	Vavg ICME (km/s)	Obtained time (h)	Vtt	Obtained time (h)	Real time from ACE (h)
28.10.2003	1681.597	24.530	1034	39.89	2131.603	19.351	17.483

Calculation of the real propagation speed to Earth for the CME recorded at 11:30 on 28 October, 2003, in LASCO-C2.

- CME's travel time to Earth, obtained from the sphere model of a CME is close to the real travel time at ACE. This demonstrates that the CME extended symmetrically CME and propagated on a radial direction, supporting slight acceleration in interplanetary space.

Summary

- In the first case (geomagnetic storm of 04 May 1998), the best travel time was obtained with the projected speed → what we observe in LASCO images for halo CMEs are the shocks of these CMEs which propagates at the same speed in all directions.
- For the second case, the most appropriate to the real travel time is the travel time obtained with the sphere model of an CME → if the CMEs are symmetric (halo almost symmetrical), the sphere model gives a fairly accurate estimate of the travel time of CMEs to the Earth (there may be slight acceleration or deceleration into interplanetary space).

Summary

- In the case of asymmetric CMEs, the sphere model does not give an accurate estimate of the propagation time of CMEs to Earth; a possible explanation of the great differences between values obtained in delay time and real-registered time at ACE, may be interaction of CMEs events into interplanetary space and/or interaction with other events (eg, high-speed current from solar wind).


Thank you!