First results of CME arrival time prediction at different planetary locations and their comparison to the in situ data within the HELCATS project

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4. Department of Physics, Division of Geophysics and Astronomy, University of Helsinki

Overview

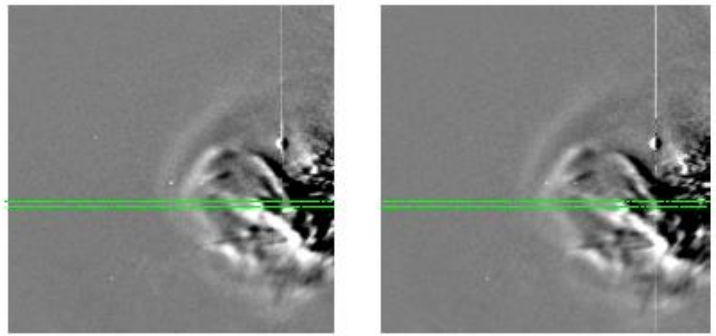
- ICME HI Cataloguing
- Geometrically Modelled Arrival Time
  - Cataloguing and Statistics
- In Situ ICME Catalogues
- Future Tasks and Directions
  - Comparing in situ data to modelled results

RAL CME Catalogue

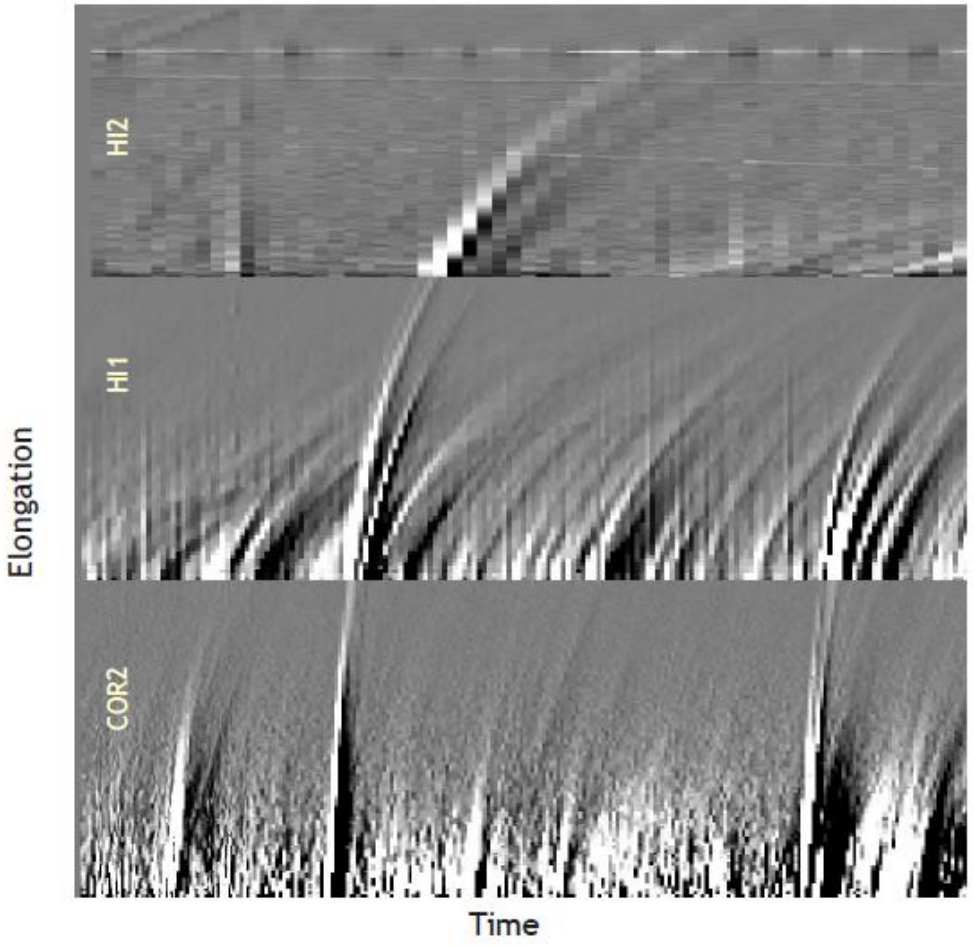
CME Identification & Tracking (Jmaps)

- Separate CME catalogues for STEREO-A/B from visual inspection of HI (2007-2013)
- Track CMEs, giving initial speeds and directions, in Jmaps.

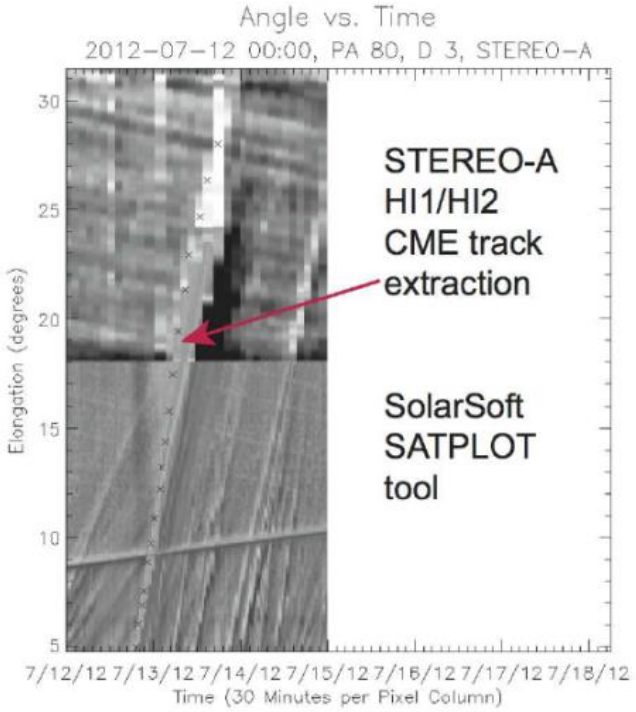
- Built stacking slices of difference images. Solar wind transients appear as white tracks in the time elongation plots (jmaps)



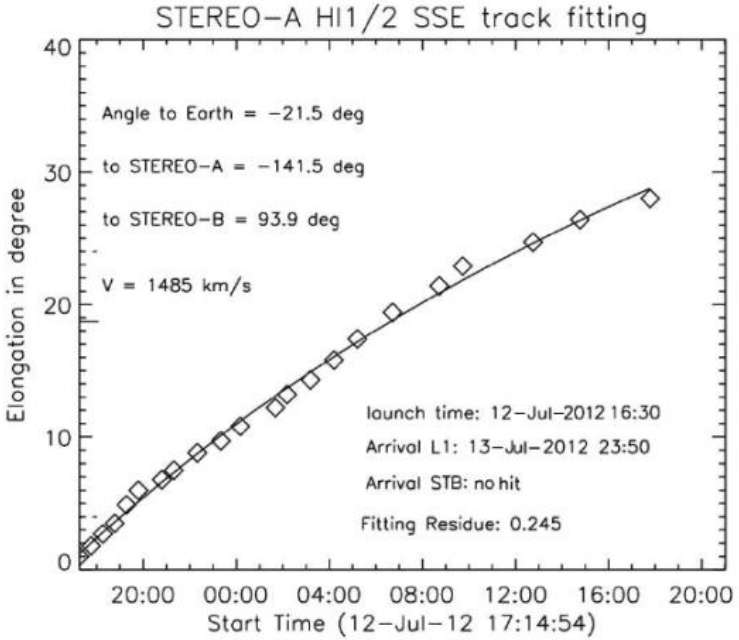
- Manual selection of points along the tracks yields the temporal variation in elongation angle of the feature's front

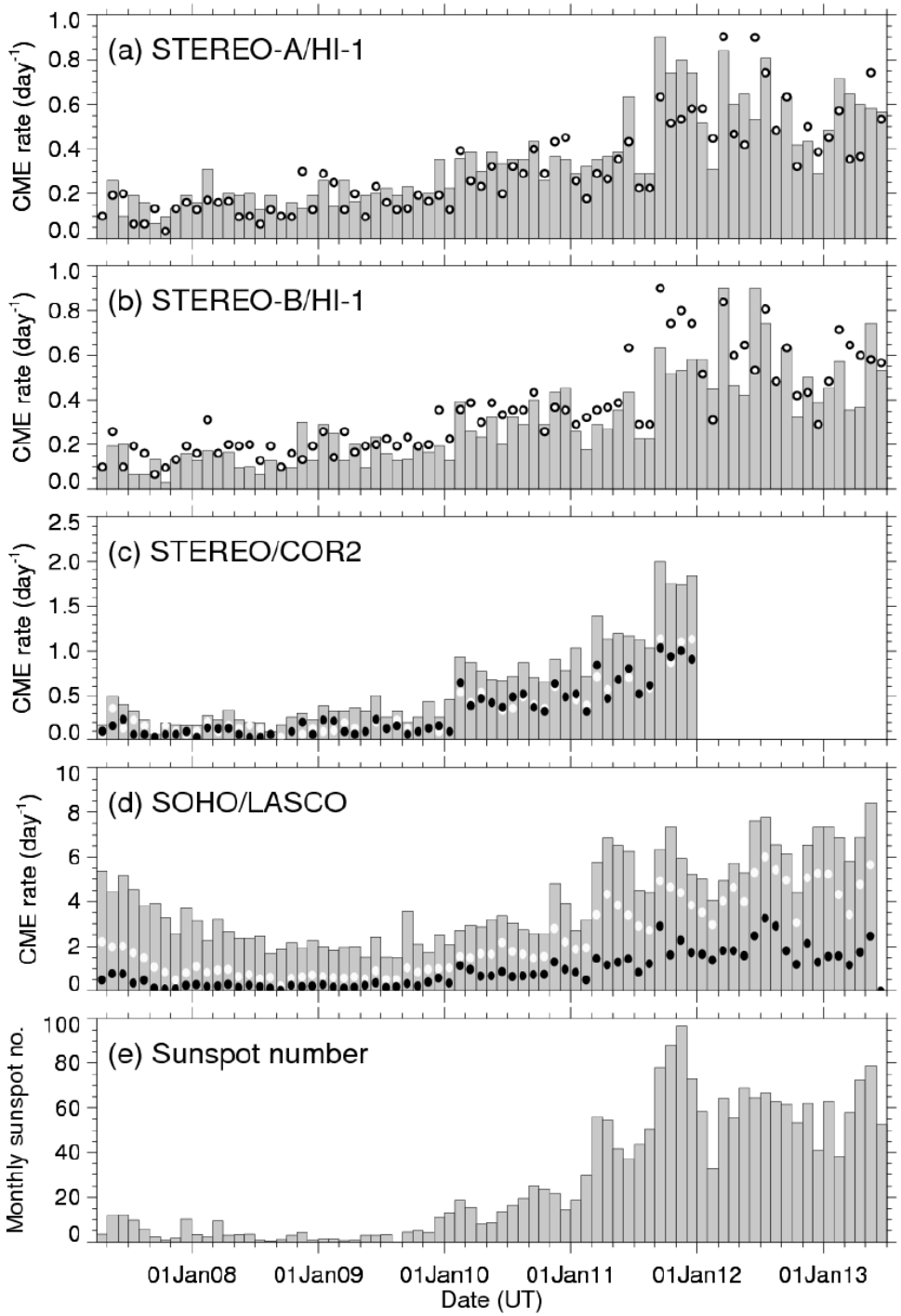


(a)


Angle vs. Time
2012-07-12 00:00, PA 80, D 3, STEREO-A
Elongation (degrees)
30
25
20
15
10
5
STEREO-A
HI1/HI2
CME track
extraction
SolarSoft
SATPLOT
tool
7/12/12 7/13/12 7/14/12 7/15/12 7/16/12 7/17/12 7/18/12
Time (30 Minutes per Pixel Column)

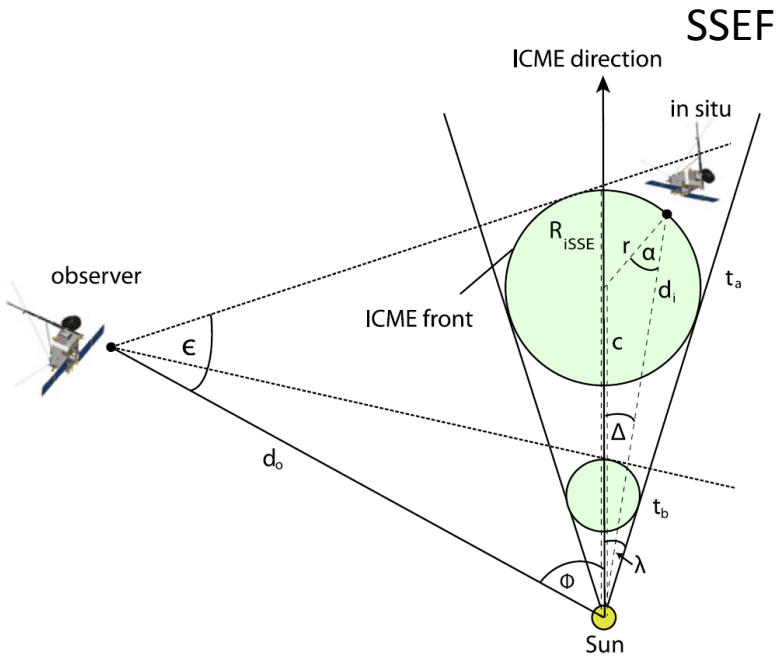
(b)


STEREO-A HI1/2 SSE track fitting
Elongation in degree
40
30
20
10
0
Angle to Earth = -21.5 deg
to STEREO-A = -141.5 deg
to STEREO-B = 93.9 deg
V = 1485 km/s
launch time: 12-Jul-2012 16:30
Arrival L1: 13-Jul-2012 23:50
Arrival STB: no hit
Fitting Residue: 0.245
20:00 00:00 04:00 08:00 12:00 16:00 20:00
Start Time (12-Jul-12 17:14:54)


(a) STEREO-A/HI-1
(b) STEREO-B/HI-1
(c) STEREO/COR2
(d) SOHO/LASCO
(e) Sunspot number
CME rate (day^{-1})
Monthly sunspot no.
01Jan08
01Jan09
01Jan10
01Jan11
01Jan12
01Jan13
Date (UT)

Geometrical modelling

- Define transient geometry as viewed by a single observer and produce best-fit estimates of propagation direction and radial speed
- Shown to be as successful as more complex methods for deriving arrival times



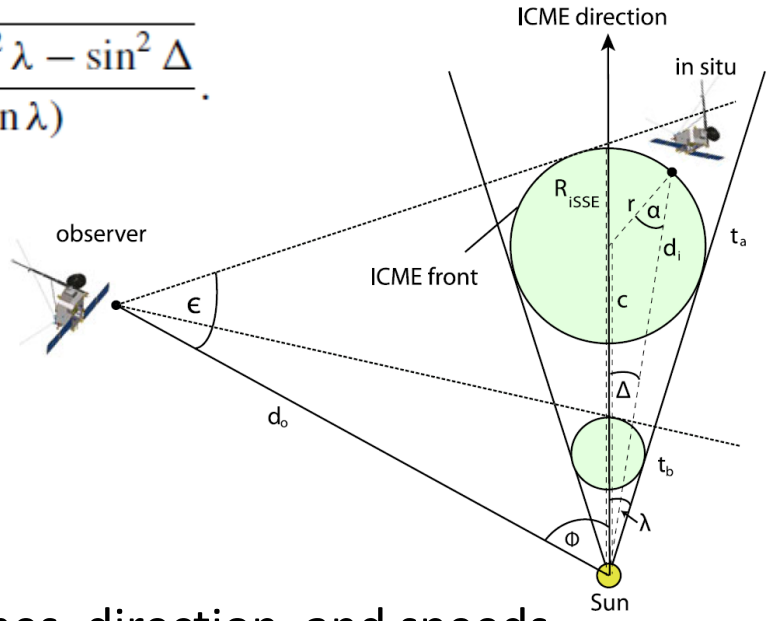
$$\epsilon(t) = \cos^{-1}\left(\frac{-bc + a\sqrt{a^2+b^2-c^2}}{a^2+b^2}\right)$$

$$R_{SSE} = \frac{d_o \sin(\epsilon(t))(1+\sin\lambda)}{\sin(\epsilon(t)+\phi)+\sin\lambda}$$

Deriving In Situ Arrival Time

generate a catalogue of CME arrival time estimates at Mercury, Venus, Earth, Mars and Saturn

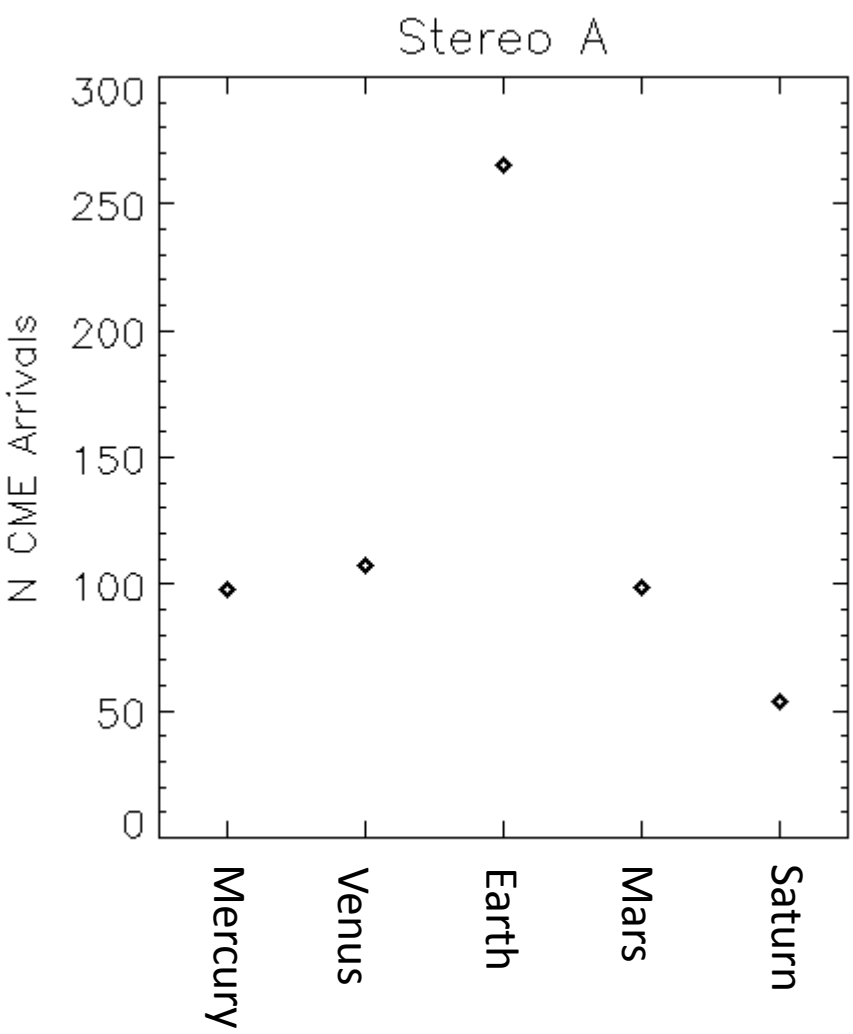
- Corrected speed = $V_{iSSE} = V_{SSE}\dfrac{\cos\Delta + \sqrt{\sin^2\lambda - \sin^2\Delta}}{(1+\sin\lambda)}.$
- Arrival = distance/speed

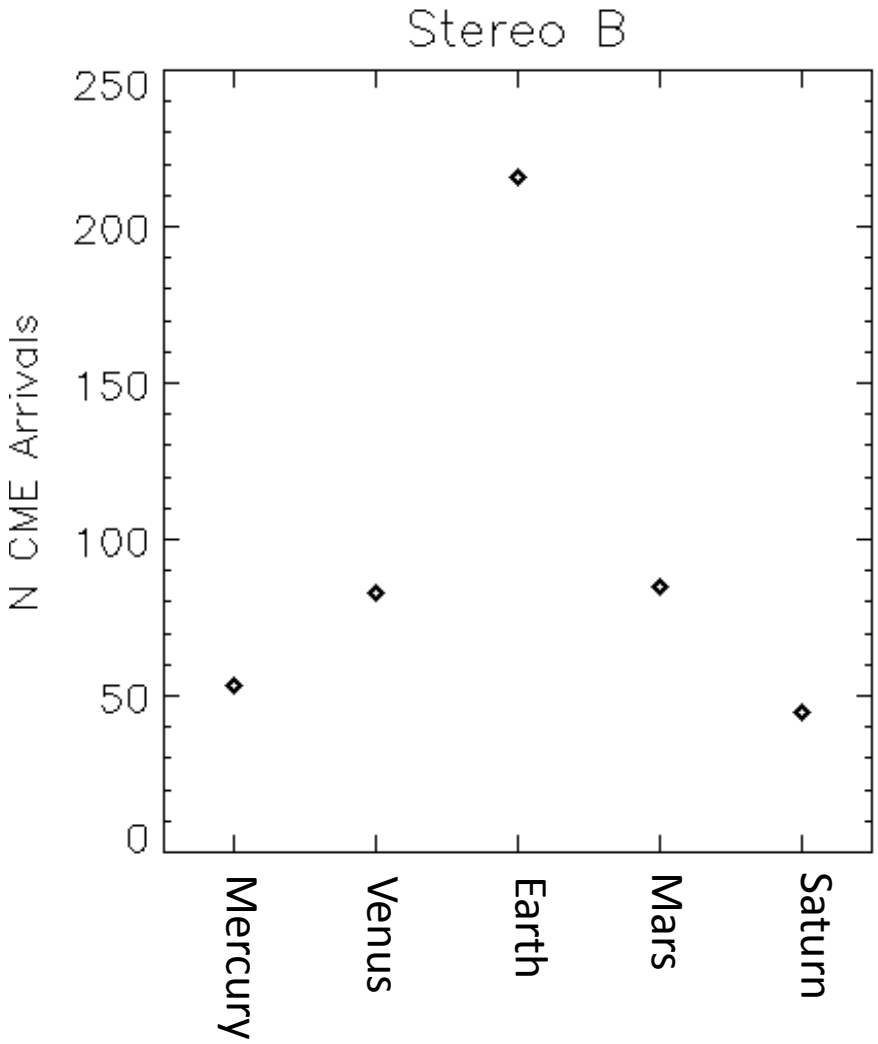


- 803 STEREO A, 696 STEREO B – Launch times, direction, and speeds.
- We are only interested in CMEs in the solar equatorial plane and can be fitted: A-596 B-501
- Hits in situ target (delta<lambda (30 degrees))

Some results

Number of events:

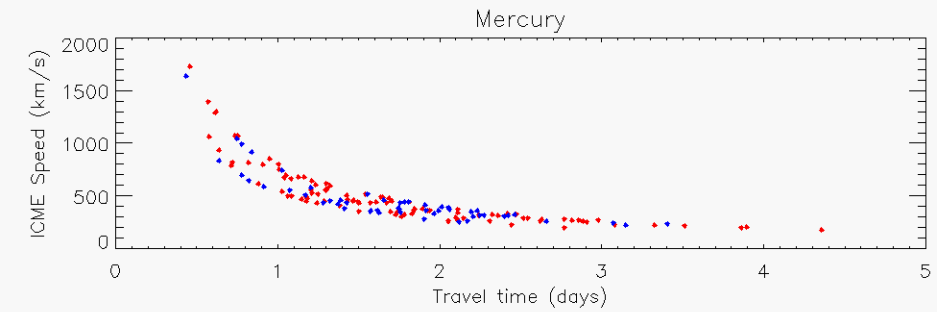


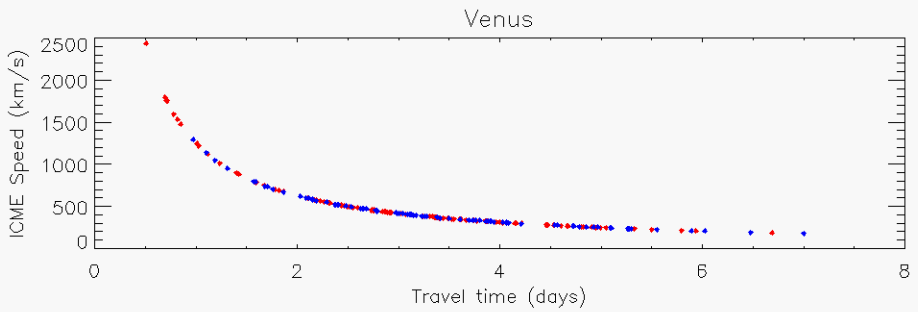


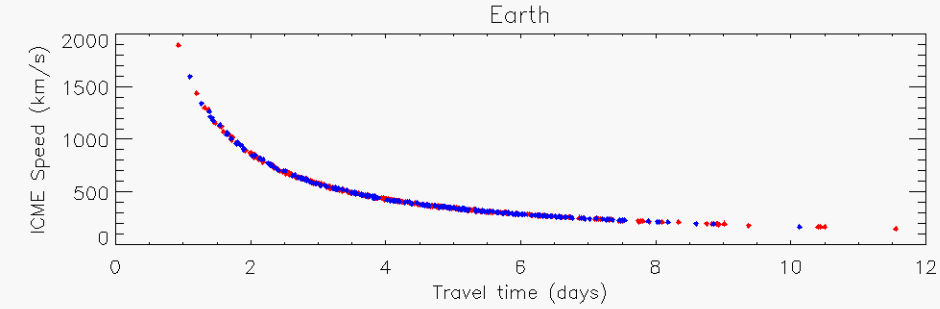
STEREO-A_EARTH_ARRIVALS_SSEF30_V01.txt - Notepad

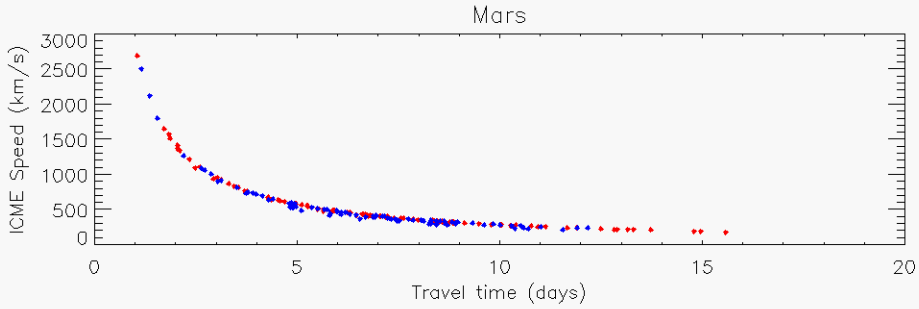
File Edit Format View Help

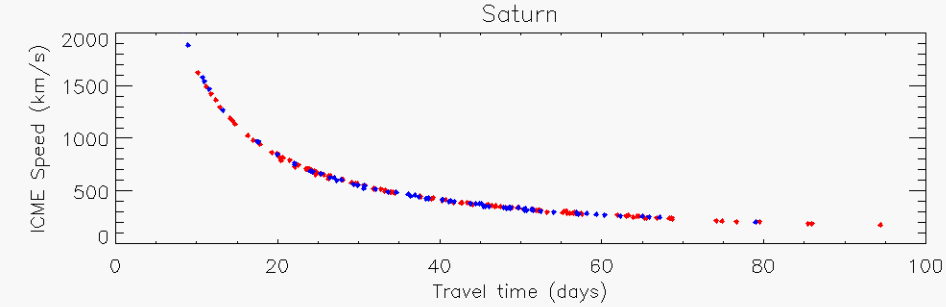
```
VARIABLES:
        1: id-Unique CME identifier
        2: delta of CME apex to target (which is difference in longitudes between central
        CME direction and target location)
        3: ICME corrected speed at target location
        4: ICME arrival time at target location
        5: target distance from Sun in AU
        6: target latitude in degrees HEEQ
        7: target longitude in degrees HEEQ


HCME_A__20071220_01    20.0    260    2007-12-26T15:10Z 0.98381397    -1.49703    -0.00000
HCME_A__20080213_01    23.0    271    2008-02-19T22:16Z 0.98730455    -6.74196    -0.00000
HCME_A__20080409_01    25.0    214    2008-04-17T14:31Z 1.00178489    -5.99623     0.00000
HCME_A__20080521_01    20.0    266    2008-05-28T09:35Z 1.01229287    -1.84155     0.00000
HCME_A__20080602_01    28.0    261    2008-06-08T22:02Z 1.01429036    -0.48398     0.00000
HCME_A__20080607_01    24.0    277    2008-06-14T05:50Z 1.01505733     0.20600    -0.00000
HCME_A__20080721_01     4.0    363    2008-07-26T08:32Z 1.01602762     4.95954    -0.00000
HCME_A__20080807_01    29.0    194    2008-08-16T15:02Z 1.01405248     6.24936    -0.00000
HCME_A__20080820_01    27.0    194    2008-08-28T15:08Z 1.01189079     6.85920     0.00000
HCME_A__20080913_01    21.0    282    2008-09-19T23:37Z 1.00592248     7.21837     0.00000
HCME_A__20081004_01    26.0    221    2008-10-12T15:21Z 1.00007217     6.51011     0.00000
HCME_A__20081010_01    15.0    301    2008-10-16T01:45Z 0.99845856     6.17808    -0.00000
HCME_A__20081013_01    13.0    242    2008-10-19T23:40Z 0.99772329     6.00601     0.00000
HCME_A__20081103_01    21.0    383    2008-11-07T14:54Z 0.99195488     4.13042    -0.00000
HCME_A__20081202_01    17.0    240    2008-12-08T15:15Z 0.98597380     0.77709    -0.00000
HCME_A__20081212_01    29.0    312    2008-12-17T23:52Z 0.98444476    -0.63029    -0.00000
HCME_A__20081218_01     6.0    304    2008-12-23T14:26Z 0.98394015    -1.32583    -0.00000
HCME_A__20081228_01     3.0    318    2009-01-01T23:12Z 0.98341889    -2.51562    -0.00000
HCME_A__20090101_01    25.0    228    2009-01-09T01:10Z 0.98329567    -3.10690     0.00000
HCME_A__20090107_01     9.0    272    2009-01-13T12:04Z 0.98329136    -3.74771     0.00000
HCME_A__20090109_01    16.0    332    2009-01-14T04:52Z 0.98332847    -3.94857    -0.00000
HCME_A__20090131_01     6.0    363    2009-02-04T14:36Z 0.98519745    -5.95568     0.00000
HCME_A__20090308_01    21.0    308    2009-03-13T10:06Z 0.99250875    -7.24928     0.00000
HCME_A__20090310_01    10.0    289    2009-03-16T04:23Z 0.99312888    -7.23474    -0.00000
```

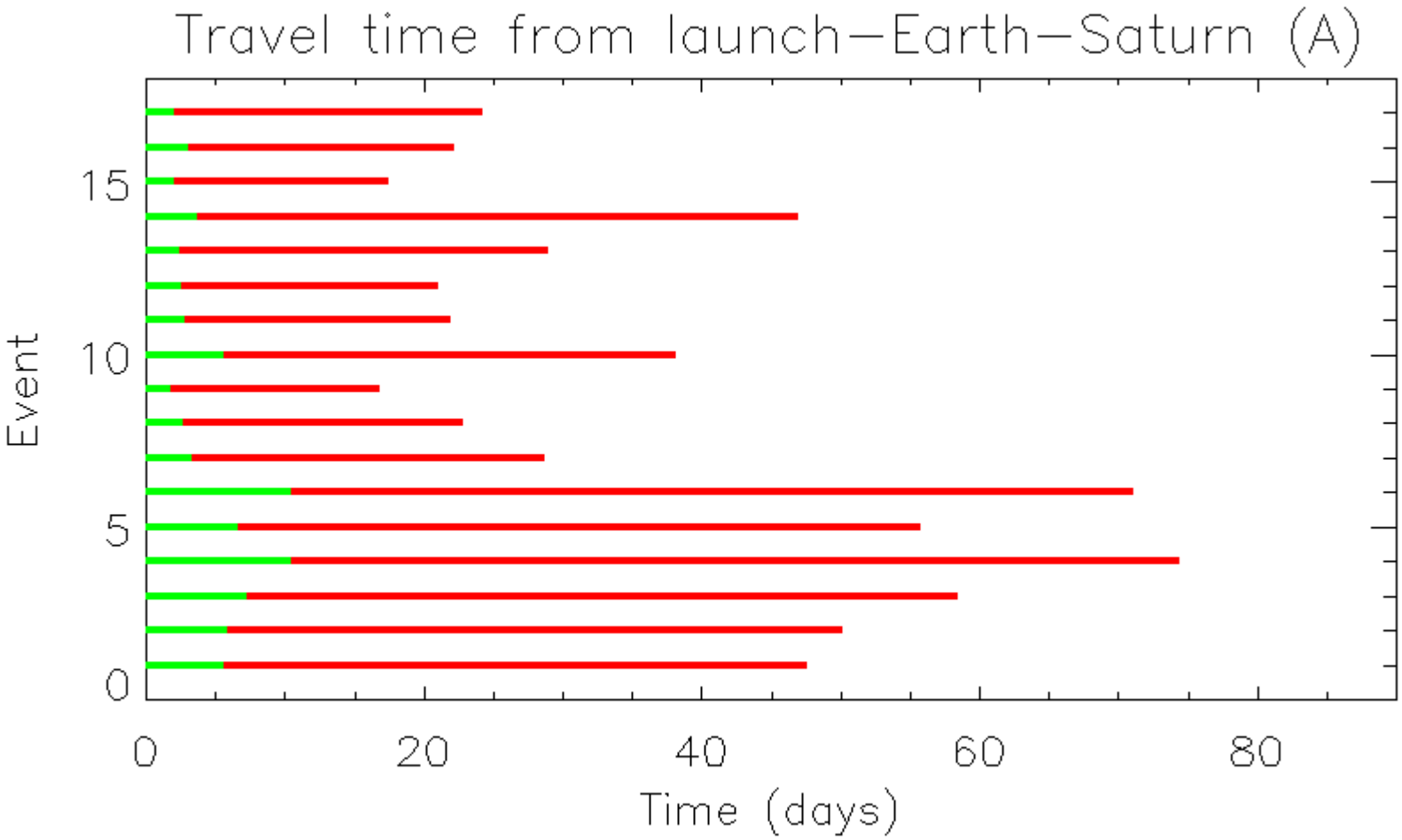

Mercury
ICME Speed (km/s)
2000
1500
1000
500
0
0
1
2
3
4
5
Travel time (days)


Venus
ICME Speed (km/s)
2500
2000
1500
1000
500
0
0
2
4
6
8
Travel time (days)


Earth
ICME Speed (km/s)
2000
1500
1000
500
0
0
2
4
6
8
10
12
Travel time (days)


Mars
ICME Speed (km/s)
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
Travel time (days)


Saturn
ICME Speed (km/s)
2000
1500
1000
500
0
0
20
40
60
80
100
Travel time (days)


Travel time from launch–Earth–Saturn (A)
Event
0
5
10
15
0
20
40
60
80
Time (days)

In Situ Catalogues

- NASA Wind list: Nieves-Chinchilla
- STEREO: Lan Jian
- VEX/MES: Simon Good (Imperial)
- Manual list from VEX/MES

NASA Wind list

http://wind.nasa.gov/index_WI_ICME_list.htm

Wind ICME List

2013

	ICME[1] start time	(Shock)	MO[2] start/end time	FR/FRL/E[3]	MO start/end time	ICME end time	Bmax[4]	Vsw[5]	Vexp[6]	
#	[Year Doy MM/DD HH:MM]	S	[Doy MM/DD HH:MM]		[Doy HH:MM]	[Doy MM/DD HH:MM]	nT	km/s	km/s	Data
0	2013 017 01/16 23:31	--	017 01/17 14:52	(FR)	018 12:14	018 01/18 12:14	17.10	386.2	-26.0	P
1	2013 019 01/18 22:47	--	019 01/19 00:14	(FR)	019 16:47	019 01/19 16:47	6.04	434.1	27.5	P
2	2013 019 01/19 16:47	Y	019 01/19 22:47	(E)	020 10:47	020 01/20 10:47	8.93	428.6	2.1	P
3	2013 076 03/17 05:31	Y	076 03/17 14:09	(FRL)	076 23:59	078 03/19 16:04	13.79	616.2	1.8	P

- Start/end ICME time: Start ICME time is defined by the IP forward shock or sheath signatures; End ICME time is defined by IP reverse shock, or end of magnetic obstacle
- Magnetic obstacle (MO) start/end time. The MO is characterized as: Flux-Rope (rotation in a magnetic field component), Flux-Rope-Like (partial rotation in a magnetic field component), Ejecta (magnetic field signatures without well defined rotation)
- 140 events 2007-2013 (covers 1994-2014)

STEREO

List of Interplanetary Coronal Mass Ejections (ICMEs) Observed by STEREO A/B

#	STEREO	Start time [Year Doy Month/Day HH:MM]	Magnetic obstacle (~ flux rope) start time[1]	End time	Ptmax [pPa]	Bmax [nT]	Vmax [km/s]	ΔV^2 [km/s]	Group[3]	Comment
				2006						
1	A & B	2006 348 12/14 14:12	2006 348 12/14 23:04	2006 349 12/15 14:08		18 (20)				plasma data data gap, like Group 3 event
				2007						
1	A	2007 14 1/14 12:11	2007 14 1/14 14:39	2007 15 1/15 7:34		15				plasma data data gap, like Group 1 event
2	B	2007 14 1/14 12:24	2007 14 1/14 13:59	2007 15 1/15 7:37		14.8				

- Compiled by Lan Jian
- The ICMEs are identified based on inspection of a combination of signatures: enhancement of total perpendicular pressure, a stronger than ambient magnetic field, relatively quiet and smooth magnetic field rotations, a declining solar wind speed, a low proton temperature [Jian et al., 2006a, 2013].
- At least three of the above features were required to identify an ICME.
- ICME start time, plus magnetic obstacle start and end times
- 167 STEREO A, 133 STEREO B

VEX/MES: Simon Good (Imperial)

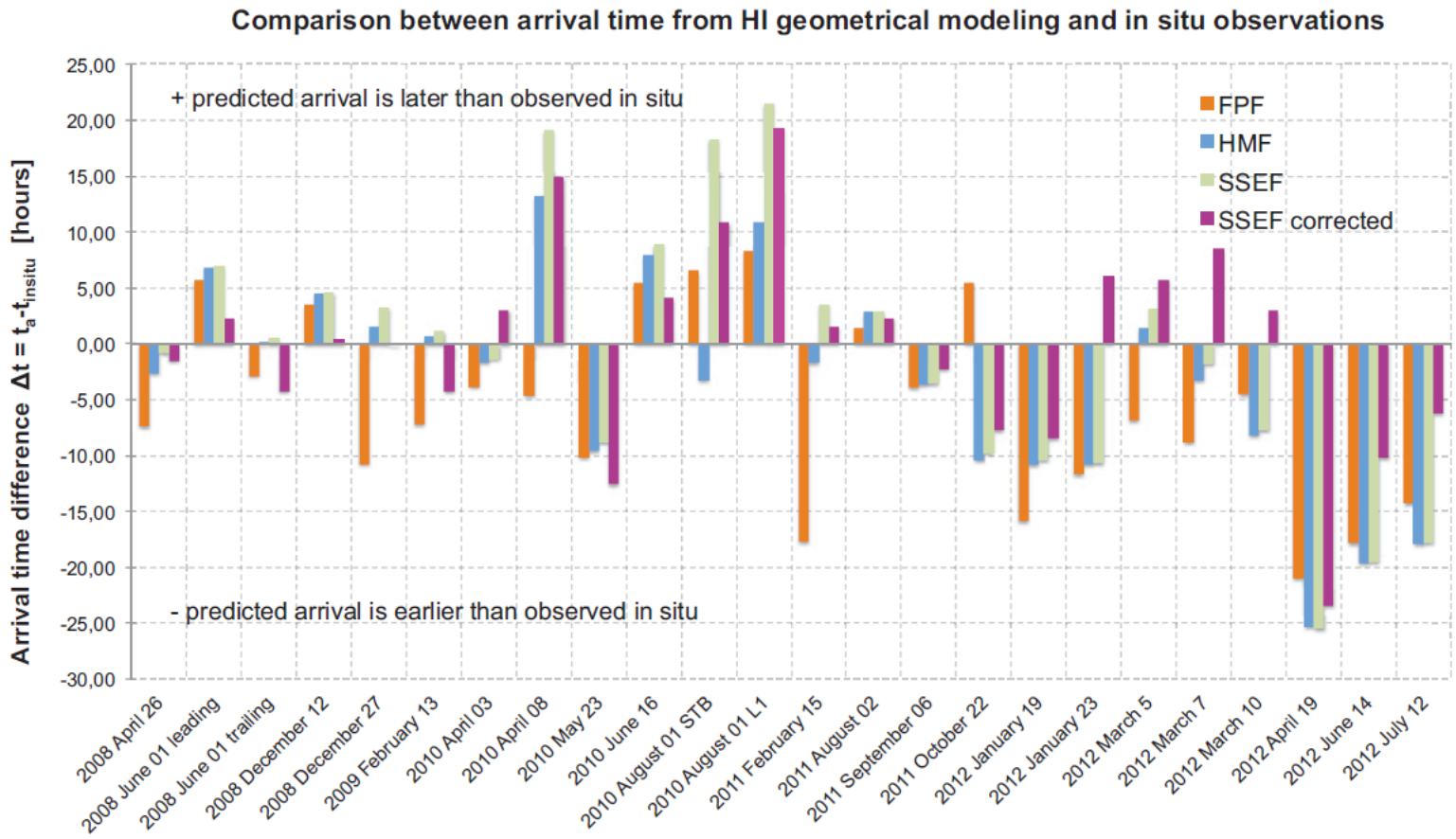
- Venus Express and Messenger start and end time of the MC flux rope/magnetic driver for each event, the duration of the event at the spacecraft, and the maximum field strength observed within the event.
- VEX: 108
- MES: 41

VEX/MES Manual identification

- Using threshold in B of > 3 sigma to highlight regions of enhanced field
- Manually identify shock, ICME start/end times
- Cloud Like, Single, Multi, Complex
- VEX: 153 shocks (2007-2013)
- MES: 23 shocks (2011-2012)

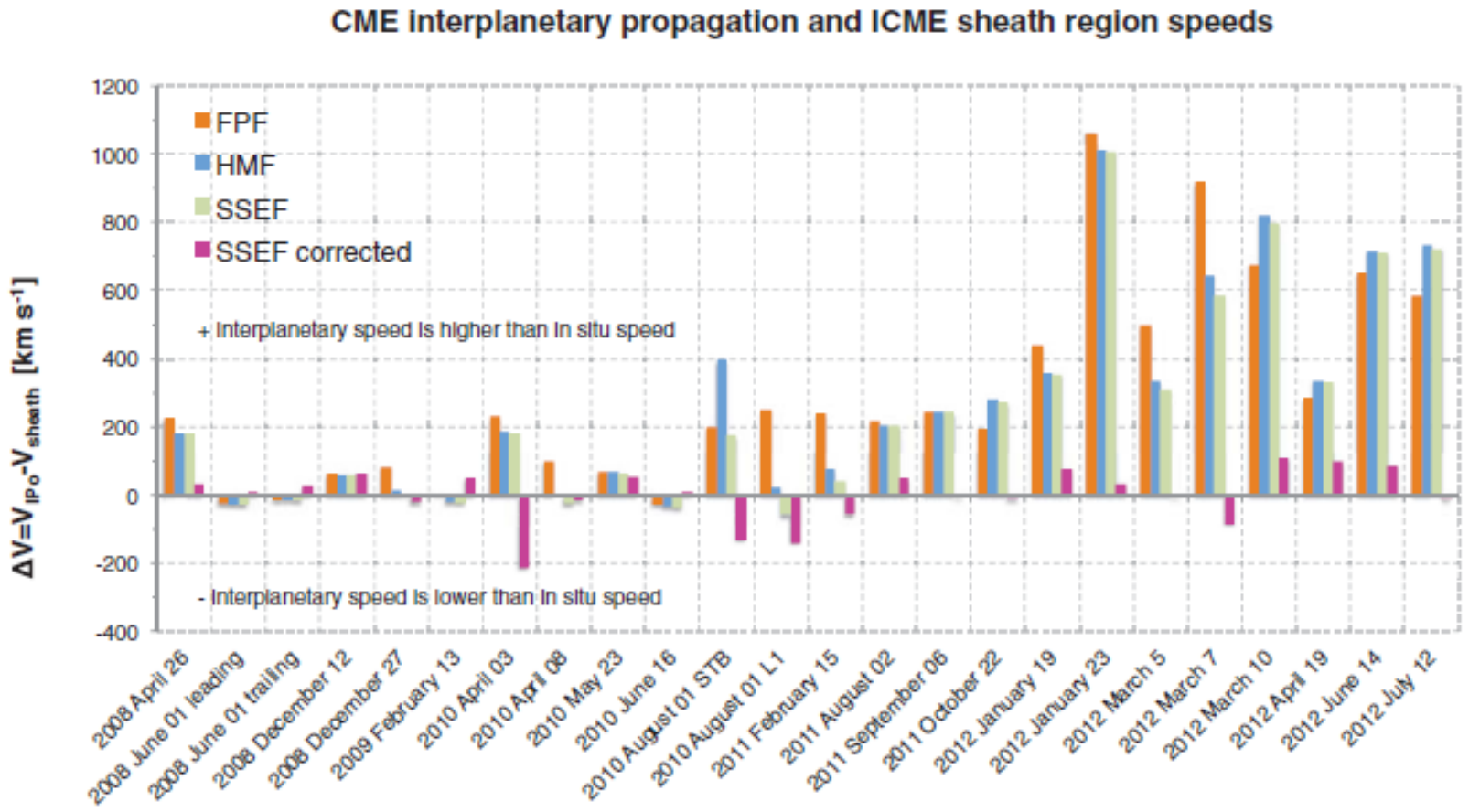
Comparing Predicted Arrival with In Situ Data

- Möstl et al, 2014
  - 22 CMEs 2008-2012
  - Predicted to in situ arrival difference 8.1 ± 6.1 hr



Comparing Predicted Arrival with In Situ Data

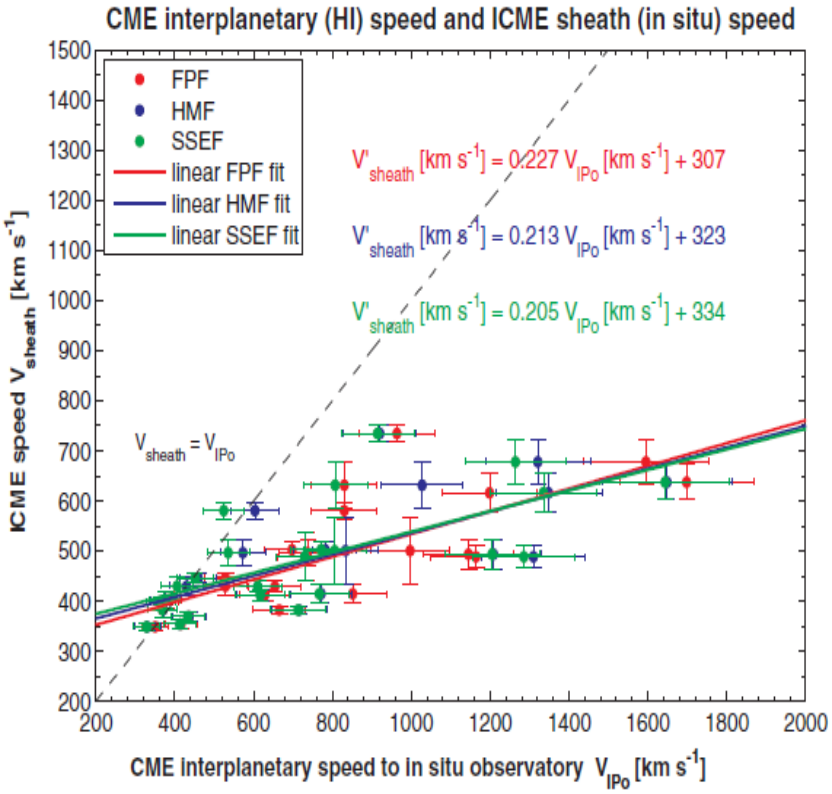
- Speed consistent to within 284 ± 288 km/s

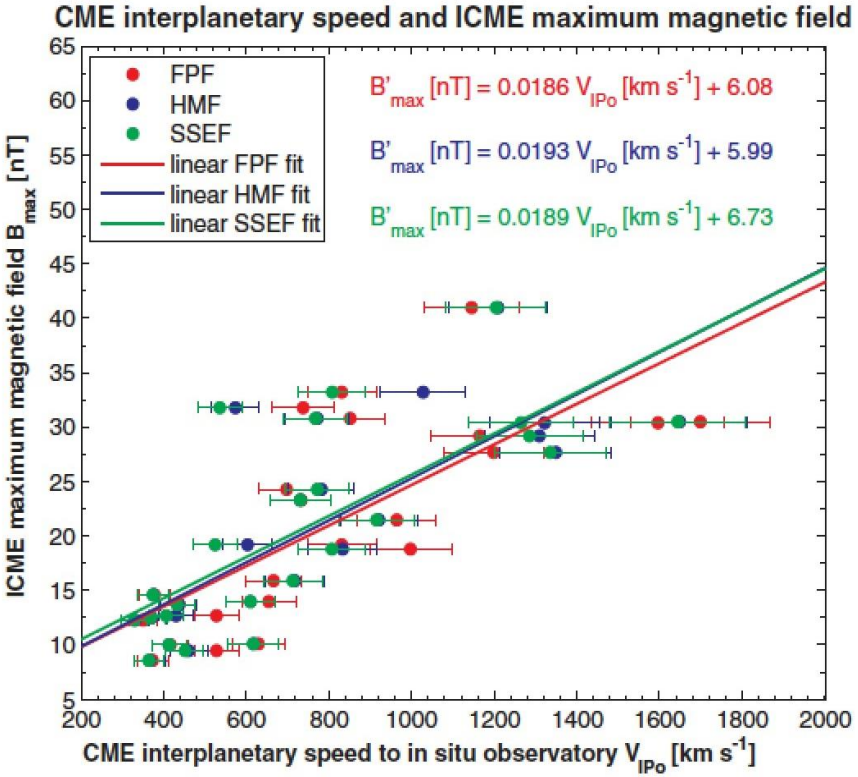


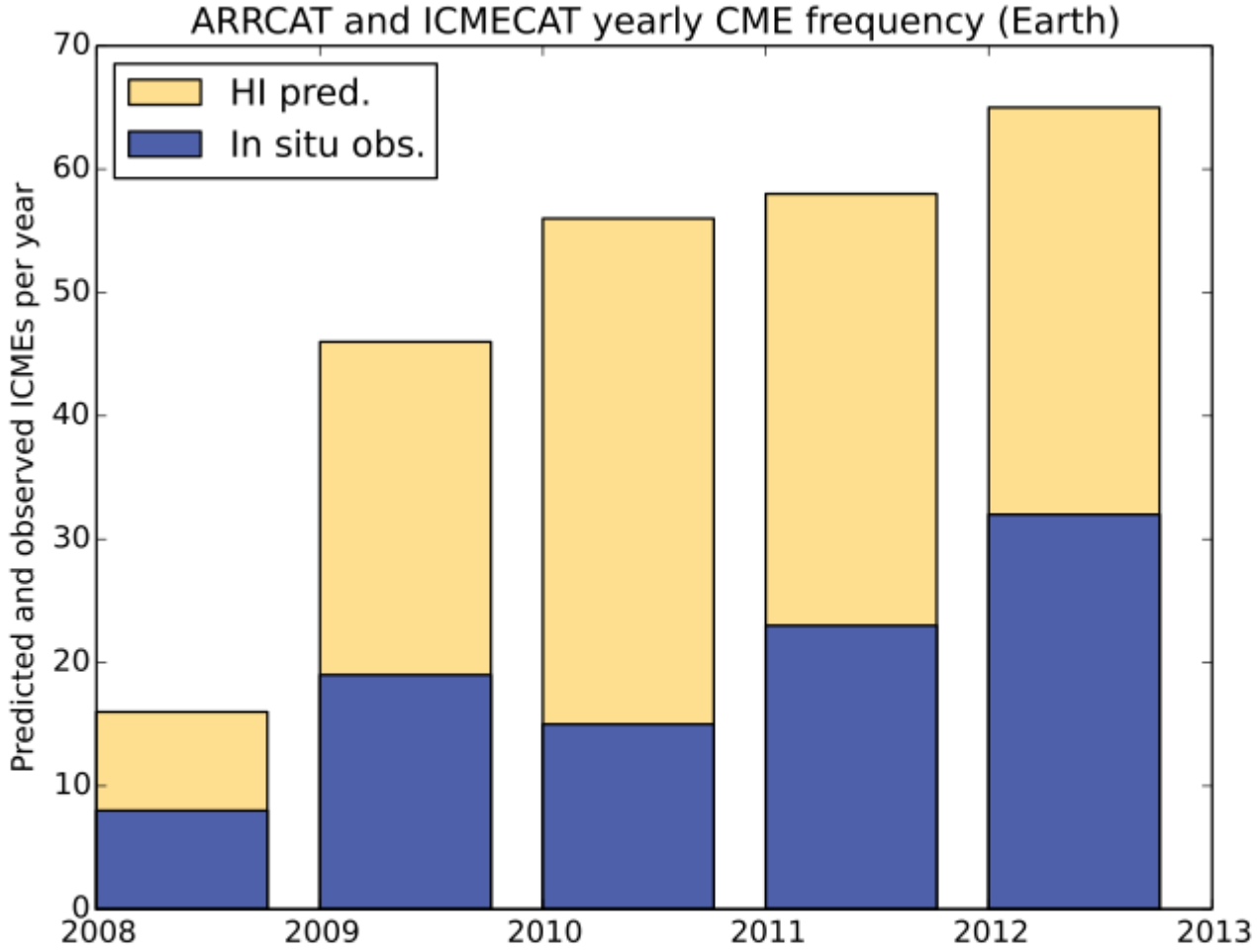
Comparing Predicted Arrival with In Situ Data

- Empirical corrections improve performance to
  - 6.1 ± 5 hr for arrival times
  - 53 ± 50 km/s for speeds

Magnetic field strength is correlated with IP speed







- Jan 2008– Jun 2013: **266 HI (STA)** predictions of Earth arrivals vs. **107 ICMEs detected at Earth**
- produce list of ICMEs that are predicted by SSEF but are not detected – why?

Future Tasks

- What factors effect arrival time prediction
  - Angular half-width in SSEF
  - Assumption of constant speed
  - How does the length of tracking affect in situ arrival times (ideally want long as possible lead times, but the longer the lead time the more chance for inaccuracy)
- Hits and Misses, why! 266 predicted arrivals (from one HI imager) to 107 detected ICMEs at Earth.

The End