Interplanetary CMEs and Shocks into the Earth's Vicinity: Observations and Analytical Modeling

V. Ontiveros[1]

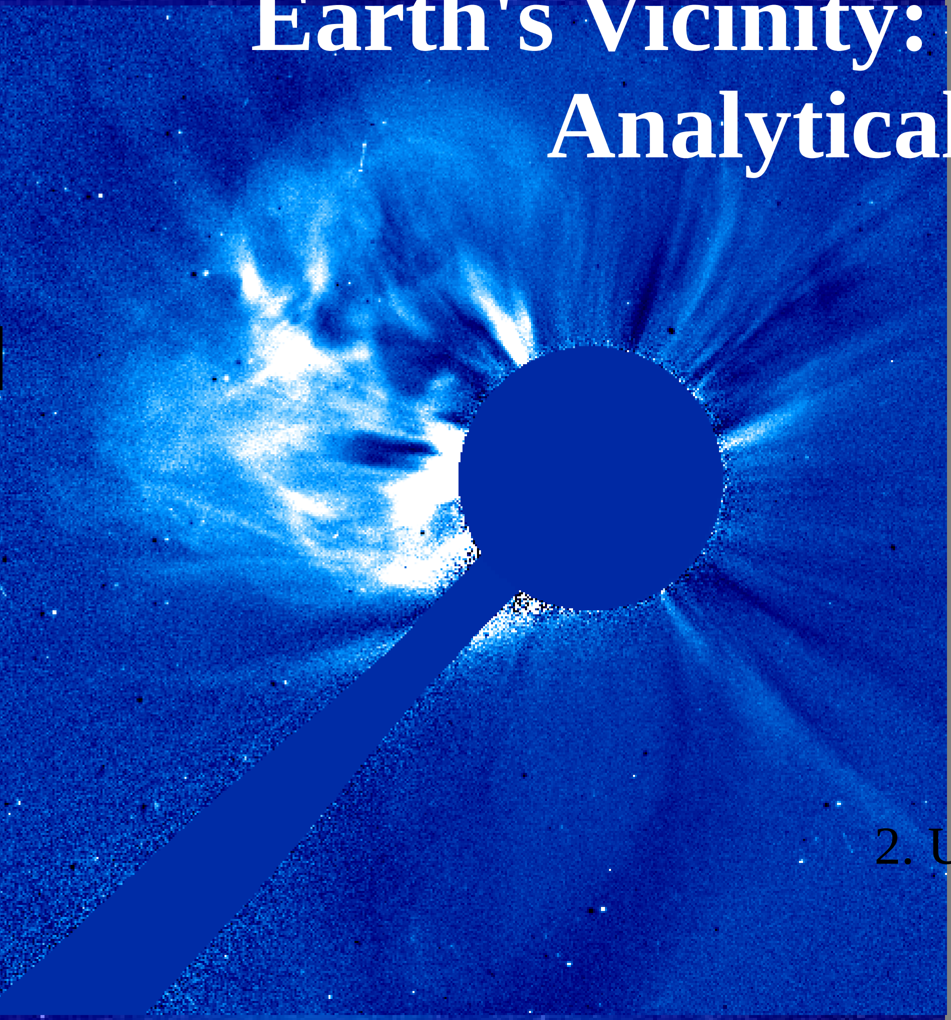
S. Patsourakos[1]

P. Corona-Romero[2]

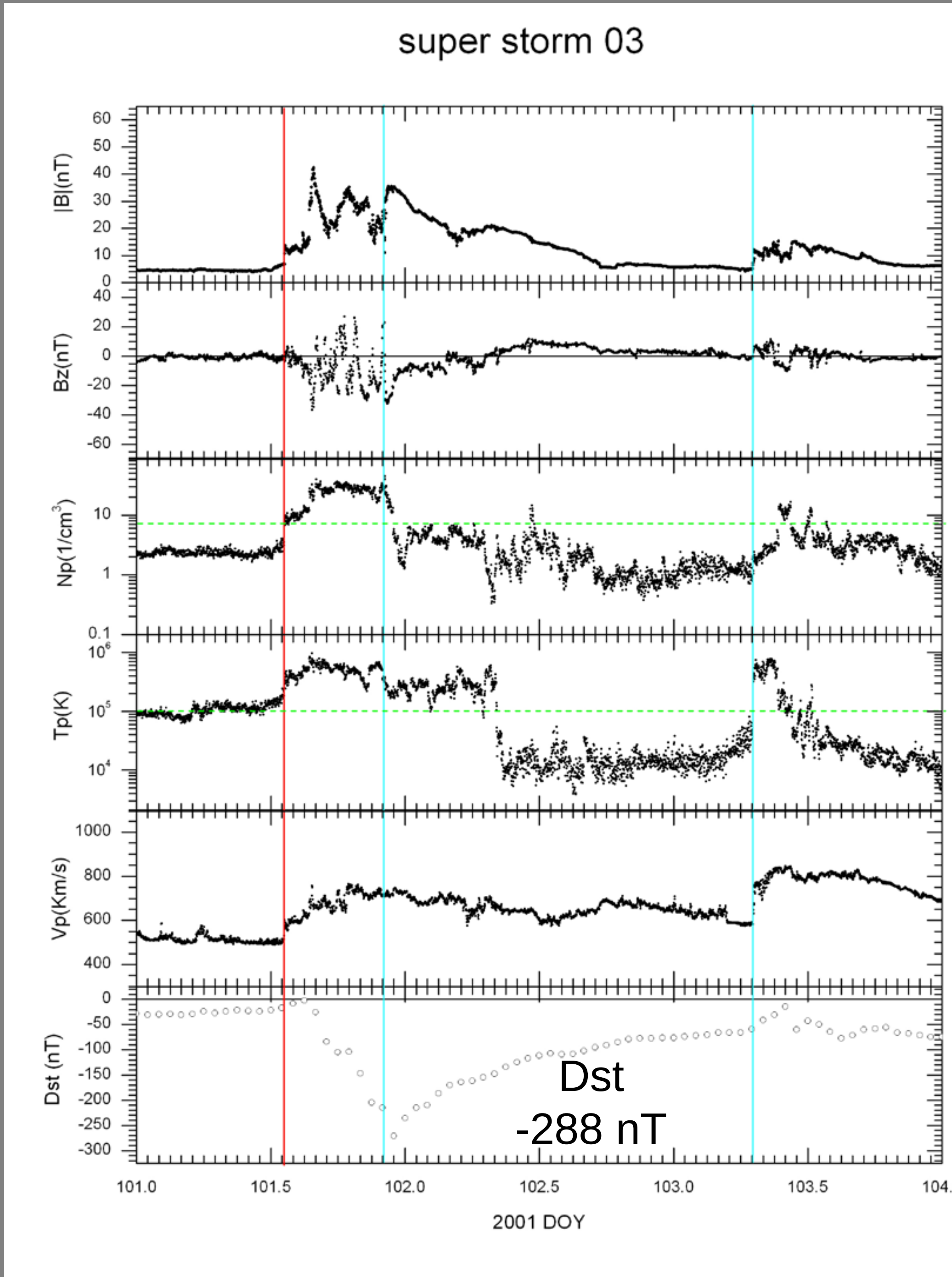
J.A.Gonzalez-Esparza[2]

1. University of Ioannina, Greece.

2. Universidad Nacional Autonoma de Mexico



SOHO/LASCO C3 – CME May 5th, 1999



Why?

CMEs are the primary mechanism driving IP shocks at 1 AU (~80%)

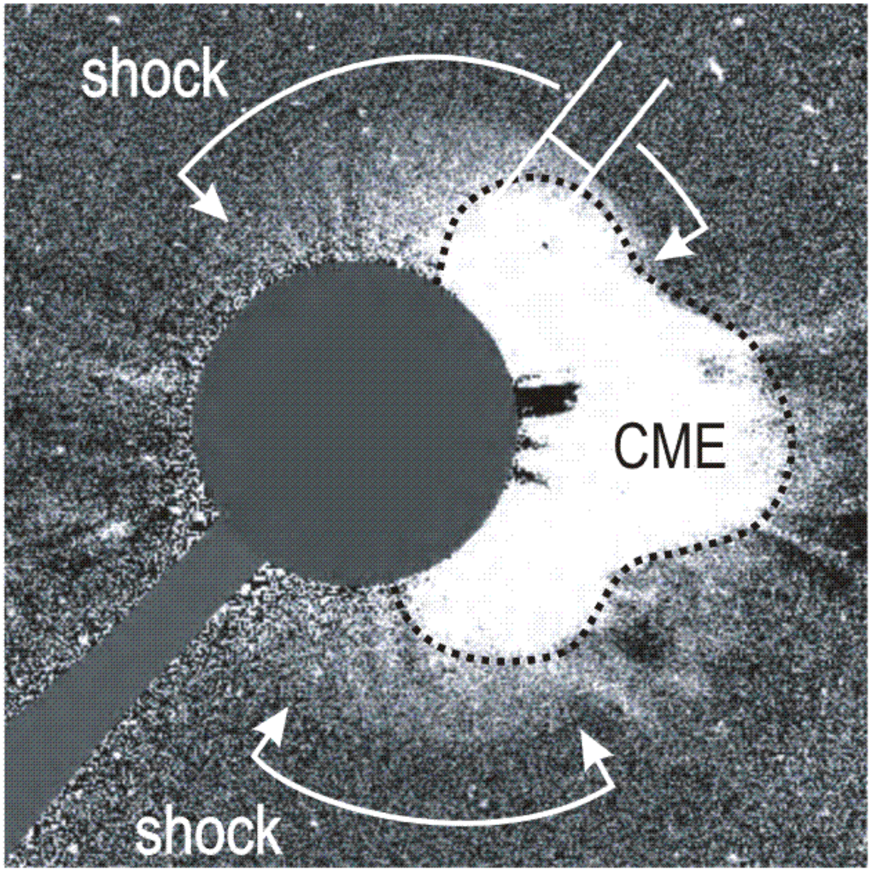
Lindsay et al., 1994

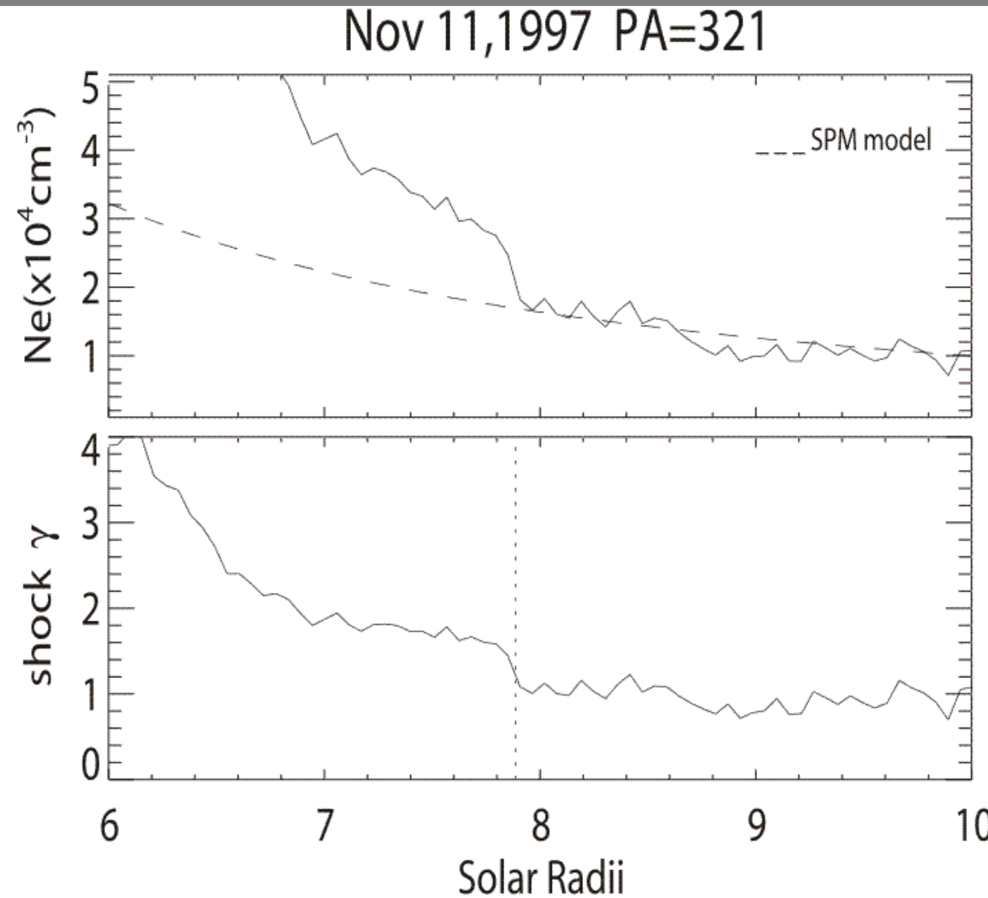
For the previous raising phase of the solar cycle:

IP shock involved in 75 % of Intense GS

Ontiveros &Gonzalez-Esparza JGR, 2010

How early are we able to detect and measure these perturbations?

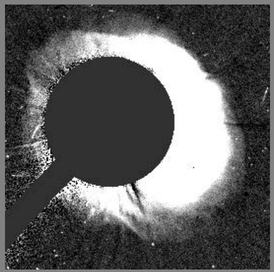




Ontiveros & Vourlidas, 2009, ApJ

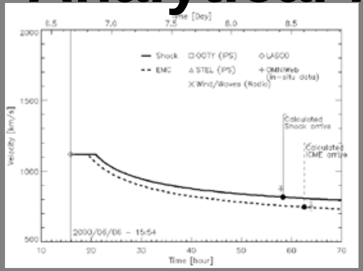
WORK OVERVIEW

Calibrated WL images[1]



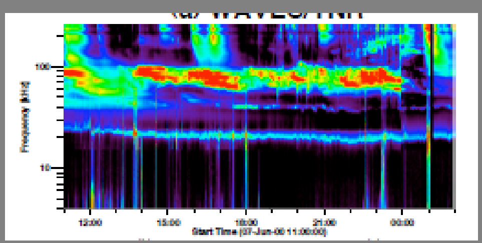
- ✓ CME kinematic information.
- ✓ CME total mass and mean density.
- ✓ ~Δt for the CME mass accretion.
- ✓ CME-shock density compression ratio (Γ_{sh}).

Analytical model[2]



- ✓ 1D hydrodynamic model.
- ✓ CME & shock speed in their IP evolution.
- ✓ CME-like perturbation inputs:
  - speed, density and temperature jumps.
  - injection time.

Type II radio burst[3]



- ✓ Estimation of ICME/shock propagation speed through km Type II emission.
- ✓ Previous work on the selected events show good agreement between radio, IPS and in-situ observations (Gonzalez-Esparza et. al, 2009).

- To use the estimated values form WL images to constraint the values of the model inputs.
- To compare the Γ_{sh} with the estimated by the model

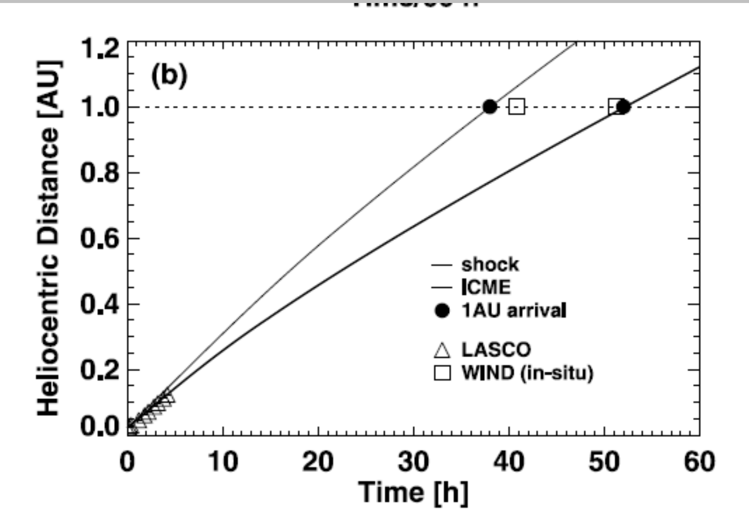
- To compare the speed profiles, and arrival time resulting form the model with the estimated values form the radio analysis and in-situ values.

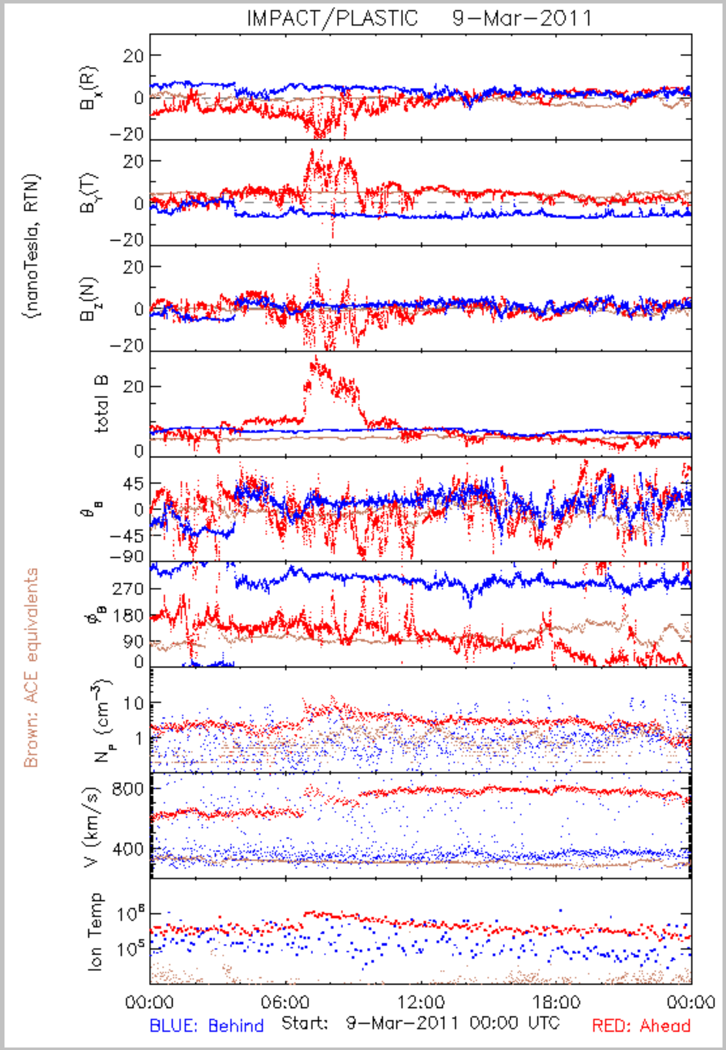
In-situ Arrival & Analytical Model

The analytical model from Corona-Romero and Gonzalez-Esparza (JGR, 2011) is based on the interaction region between two fluids (work surface, WS), using the conservation of linear momentum flux.

For the interaction of the CME with the solar wind, it is considered that the WS position matches the shock-sheath interface.

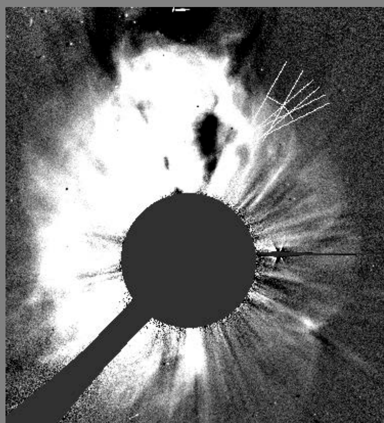
It requires initial information of CME about: density, velocity, total mass and energy release rate. This values are obtained by coronograph images.





IP EVOLUTION-ANALYTICAL MODEL

Jun 06, 2000



Speed= 1119 km/s

Mass= 1.43×10^{16}gr

1.81×10^{16}gr

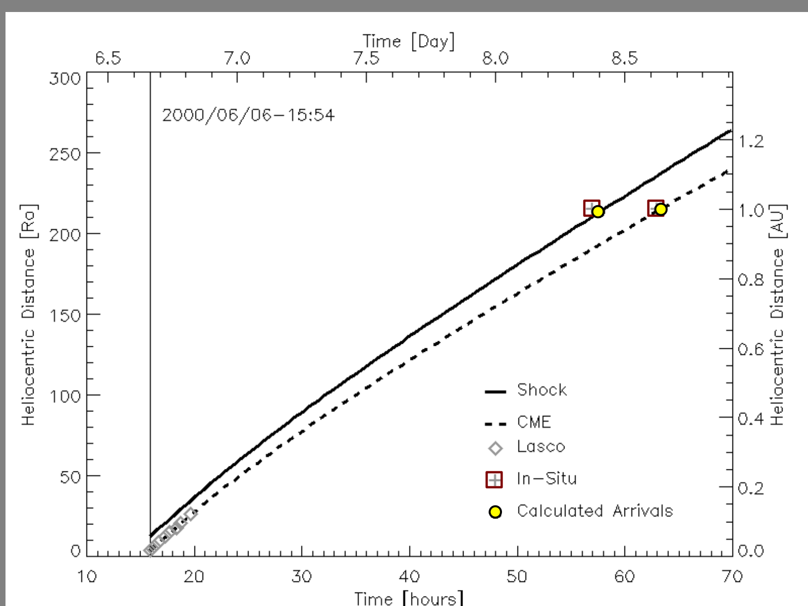
Δt= 1.4 hrs (min)

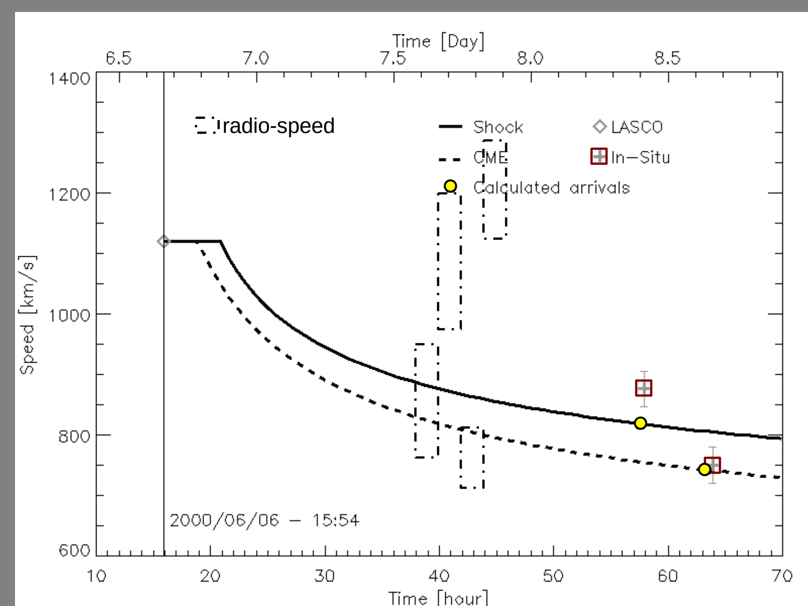
2.8 hrs (max)

Γ_{sh}= 1.8-2.3

RADIO ANALYSIS

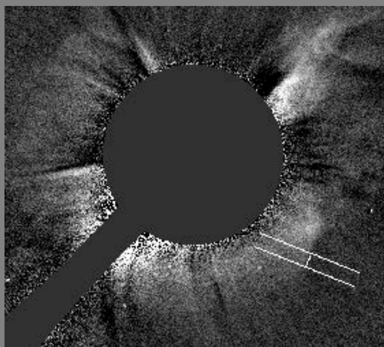
initial time	final time	speed
7 Jul 14:06	7 Jul 15:42	827±90
7 Jul 16:01	7 Jul 17:54	1062±81
7 Jul 18:20	7 Jul 19:50	760±40
7 Jul 20:17	7 Jul 21:52	1091±167
7 Jul 22:45	7 Jul 23:59	1119±288





IP EVOLUTION- ANALYTICAL MODEL

Mar 29, 2001



Speed= 942 km/s

Mass= 1.4×10^{15}gr

2.8×10^{15}gr

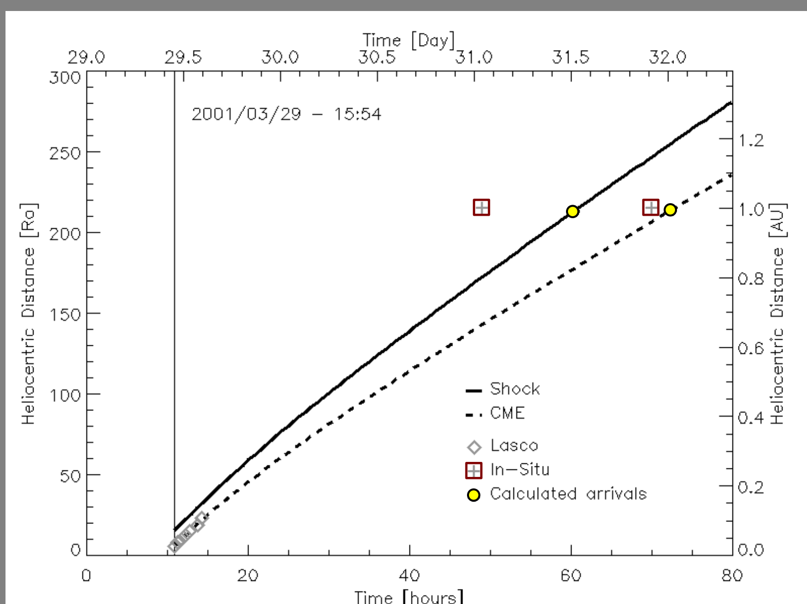
Δt= 1.6 hrs (min)

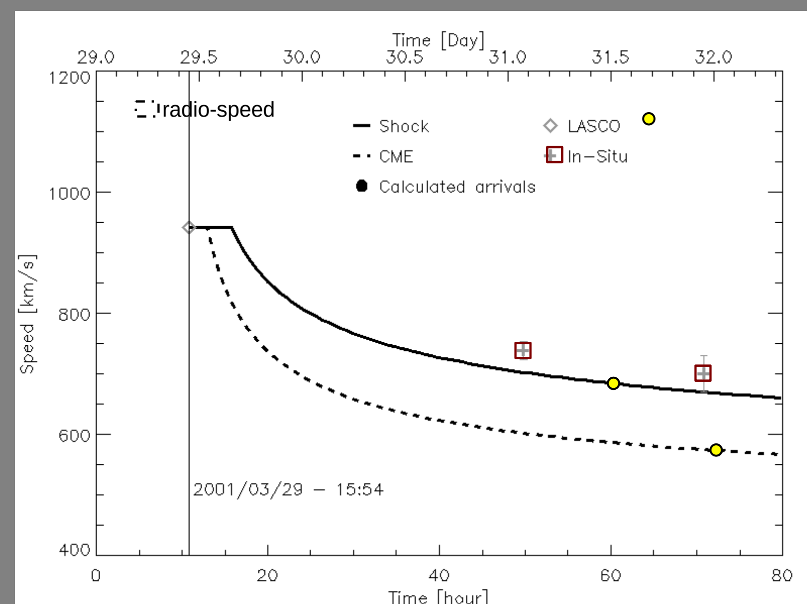
1.9 hrs (max)

Γ_{sh}= 1.8

RADIO ANALYSIS

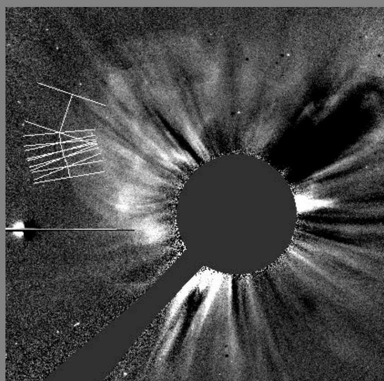
initial time	final time	speed
29 Mar 18:21	29 Mar 19:28	1274±20





IP EVOLUTION- ANALYTICAL MODEL

Apr 26, 2000



Speed= 1006 km/s

Mass= 2.5×10^{15}gr

6.9×10^{15}gr

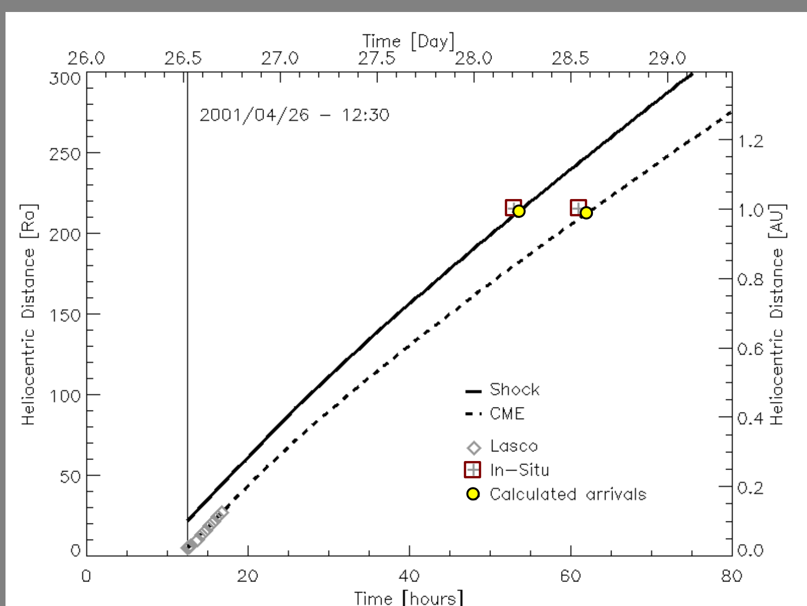
Δt= 2.0 hrs (min)

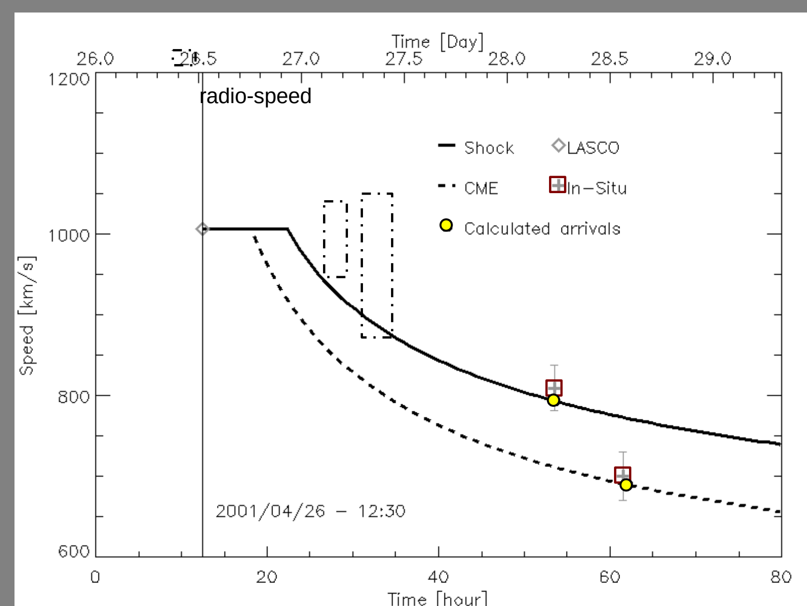
3.8 hrs (max)

Γ_{sh}= 2.0-2.6

RADIO ANALYSIS

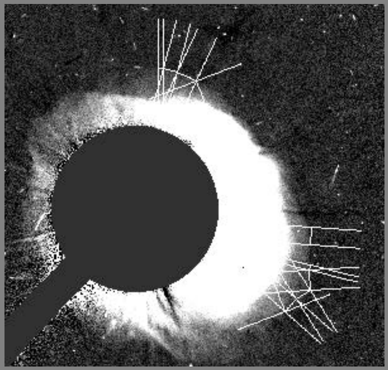
initial time	final time	speed
27 Apr 03:31	27 Apr 05:42	926±10
27 Apr 14:57	27 Apr 17:24	909±50
27 Apr 19:00	27 Apr 21:30	544±10





IP EVOLUTION- ANALYTICAL MODEL

Nov 04, 2001



Speed= 1810 km/s

Mass= $2.5x10^{15}$gr

$6.9x10^{15}$gr

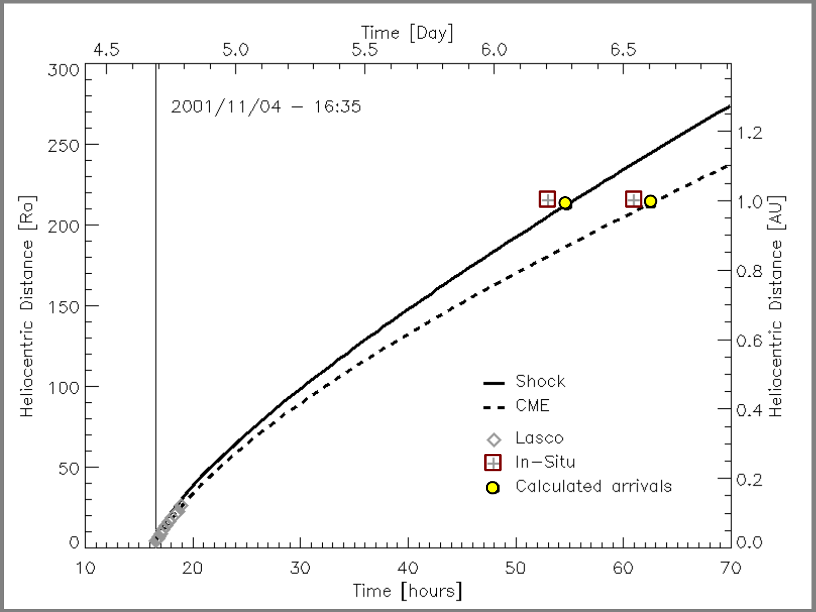
Δt= 0.25 hrs (min)

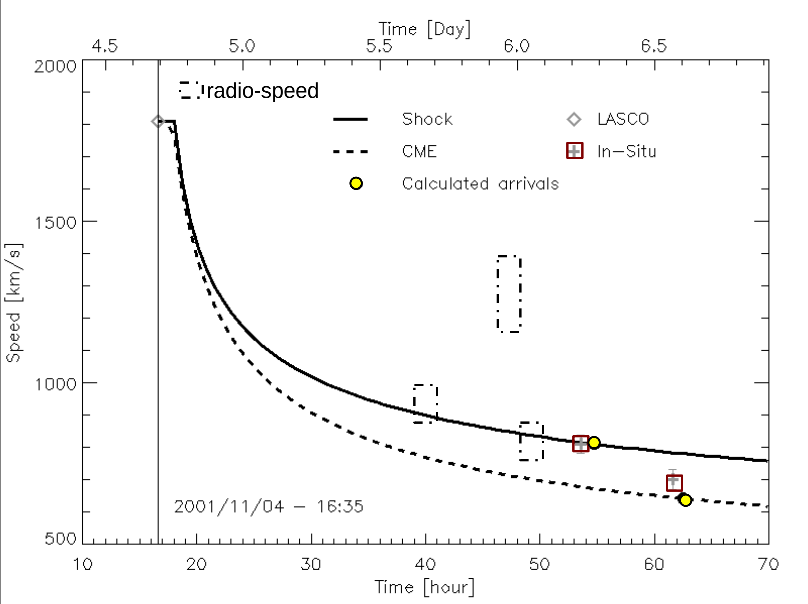
0.45 hrs (max)

Γ_{sh}= 1.9-2.4

RADIO ANALYSIS

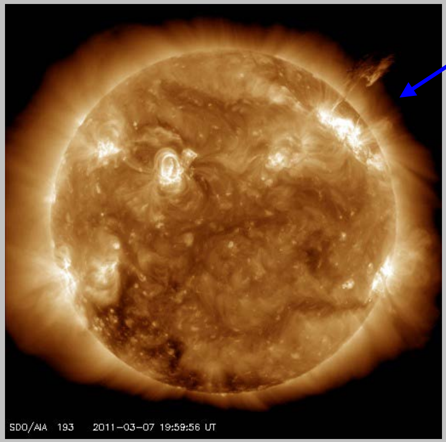
initial time	final time	speed
5 Nov 20:08	5 Nov 22:27	934±20
6 Nov 00:18	6 Nov 01:39	1090±50
6 Nov 02:26	6 Nov 03:47	658±24





March 7th, 2011 CME

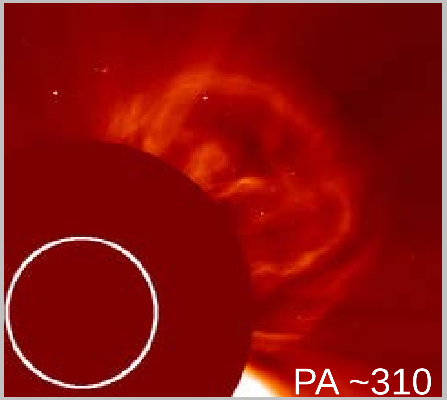
AIA 193



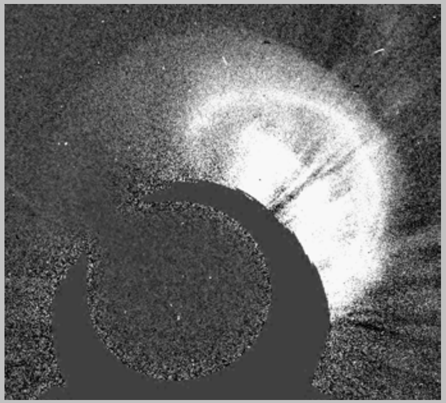
AR:
N24W58

Flare:
C2.3(19:32)

LASCO C2

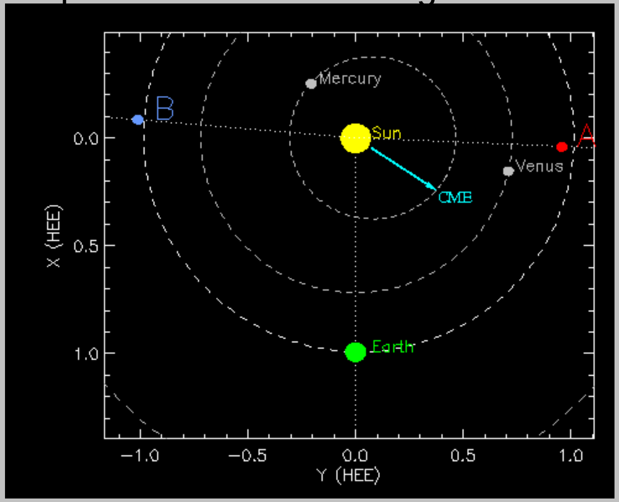


COR2 B



STEREO A and B positions

Sep. w/Earth A: 87 deg - B: 95



This case:
Fast CME March 7ty, 2011 (19:40 UT)
Remote observations:
AIA LASCO C2 C3
STEREO A & B COR1 COR 2 Hi1
Modeling:
Solar Corona Raytrace (SCR) Forward modeling
→"real" HT plots
Analytical model for comparing arrival time
of CME-shock at 1 AU (HD)

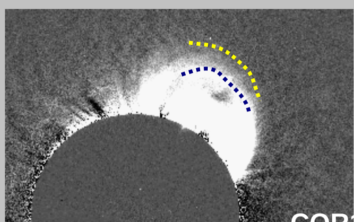
COR 1 & 2

COR1 B

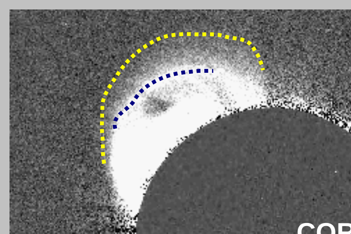
COR1 A

COR2 B

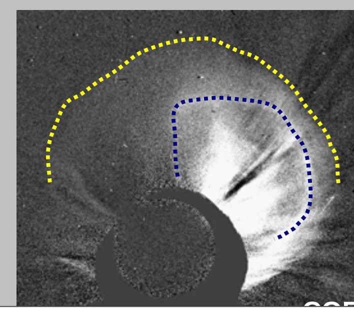
COR2 A

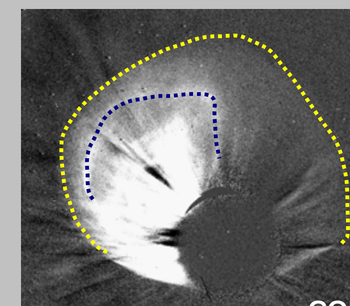


COR1

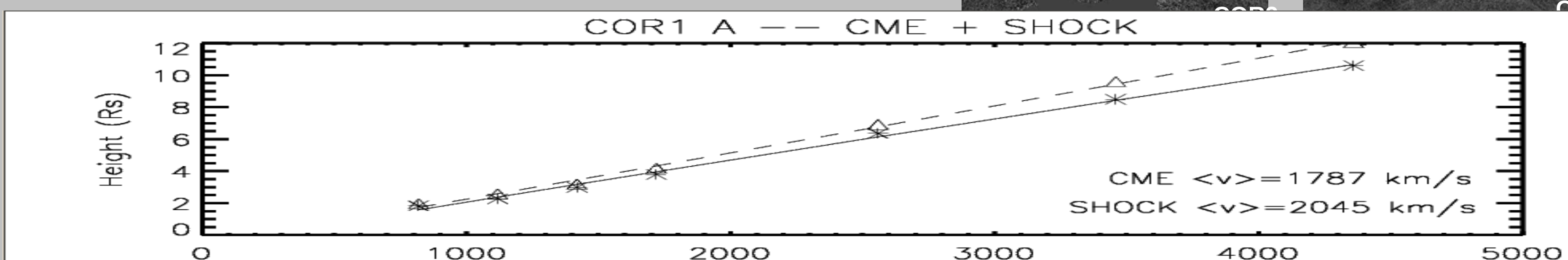


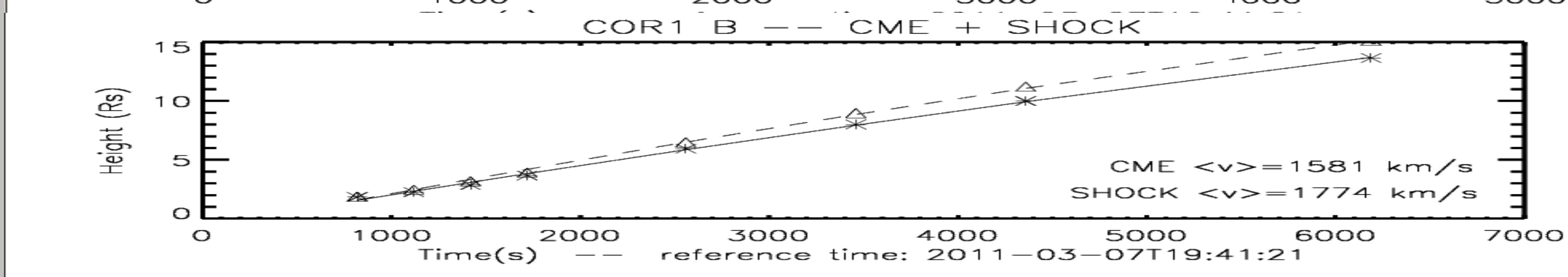
COR1





COR2

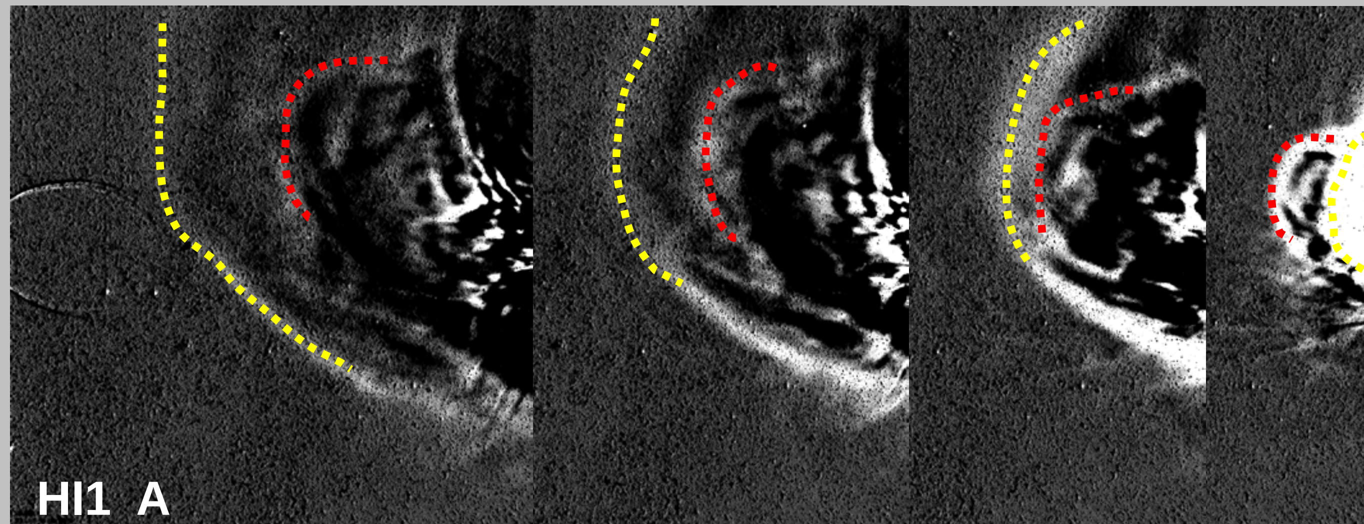


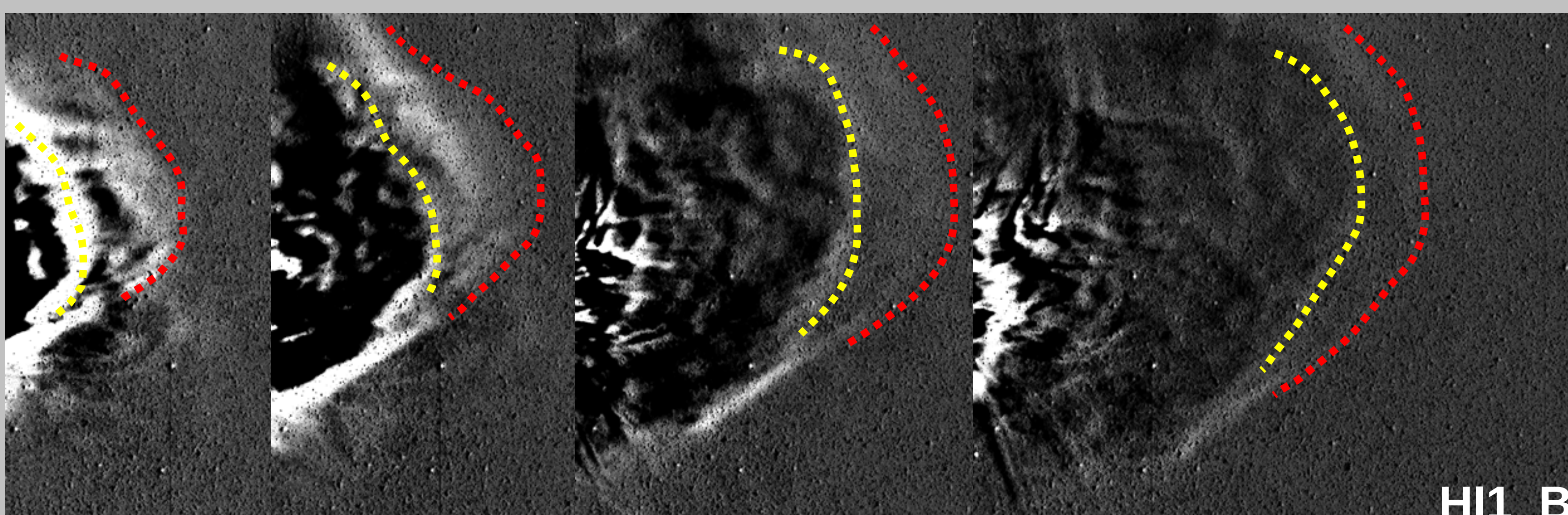


HI 1

Our CME

Previous CME

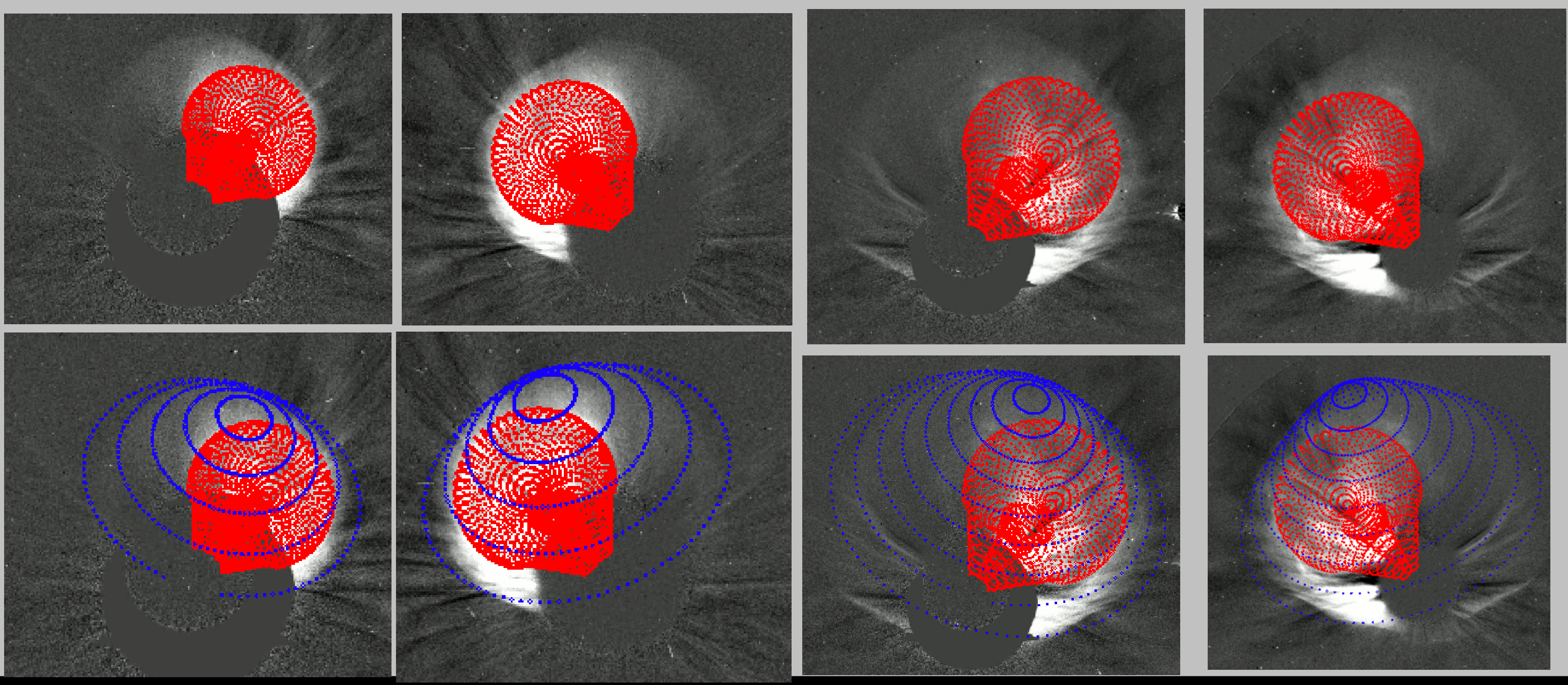




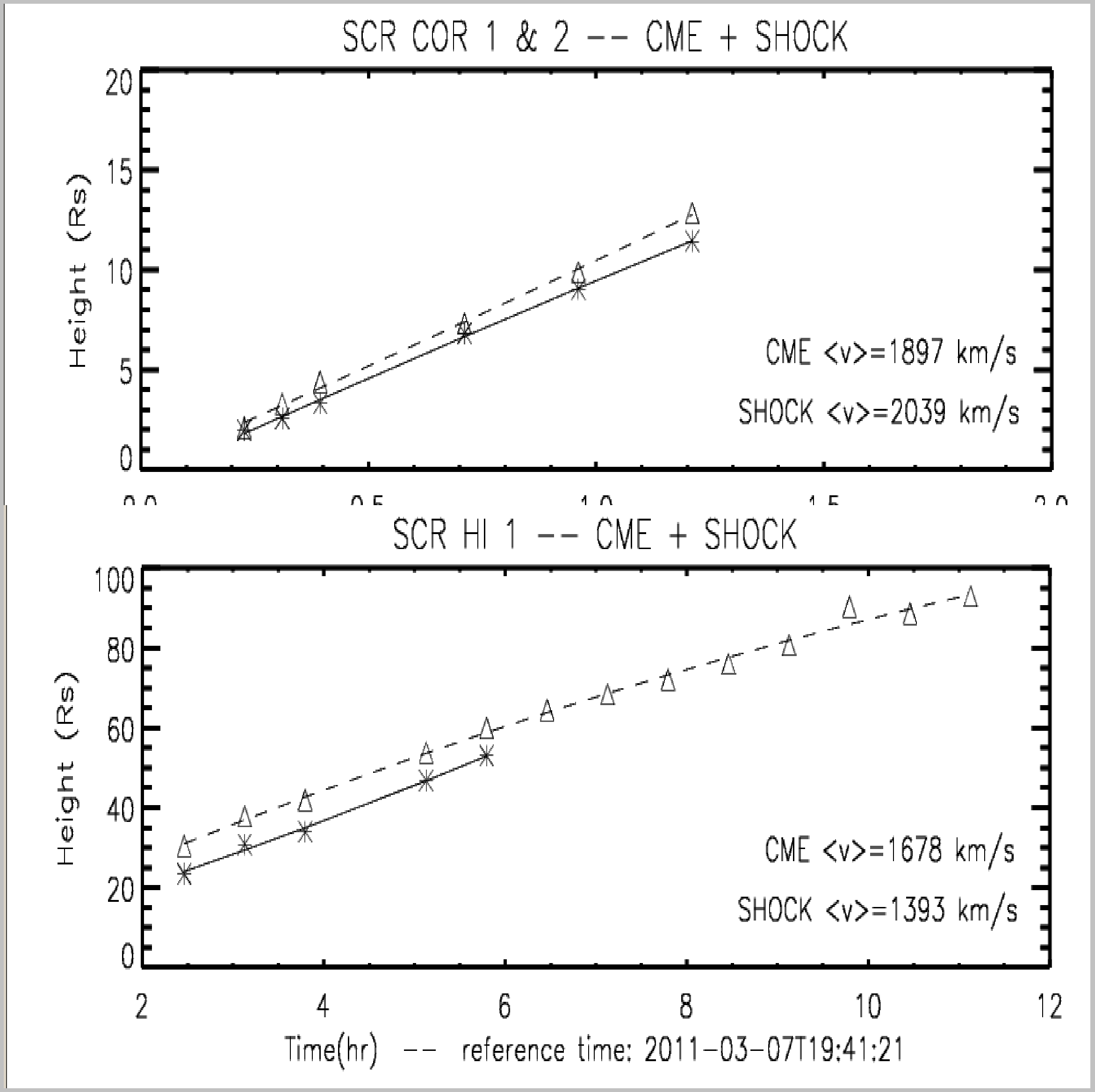
Solar Corona Raytrace

Simulated white light images for a CME and a bow-shock model observed through different lines of sight. (Thernisien et.al, 2009)

•Using the SC*Raytrace* program we calculate the 2D brightness of 3D CME and shock-like structures as seen by the LASCO C3 coronograph.



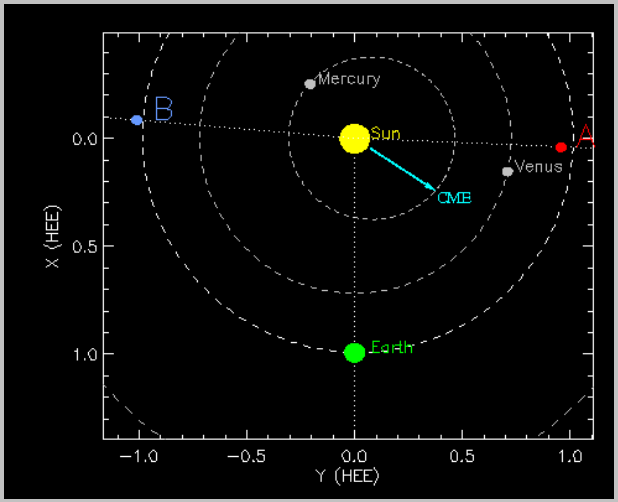
SCRaytrace



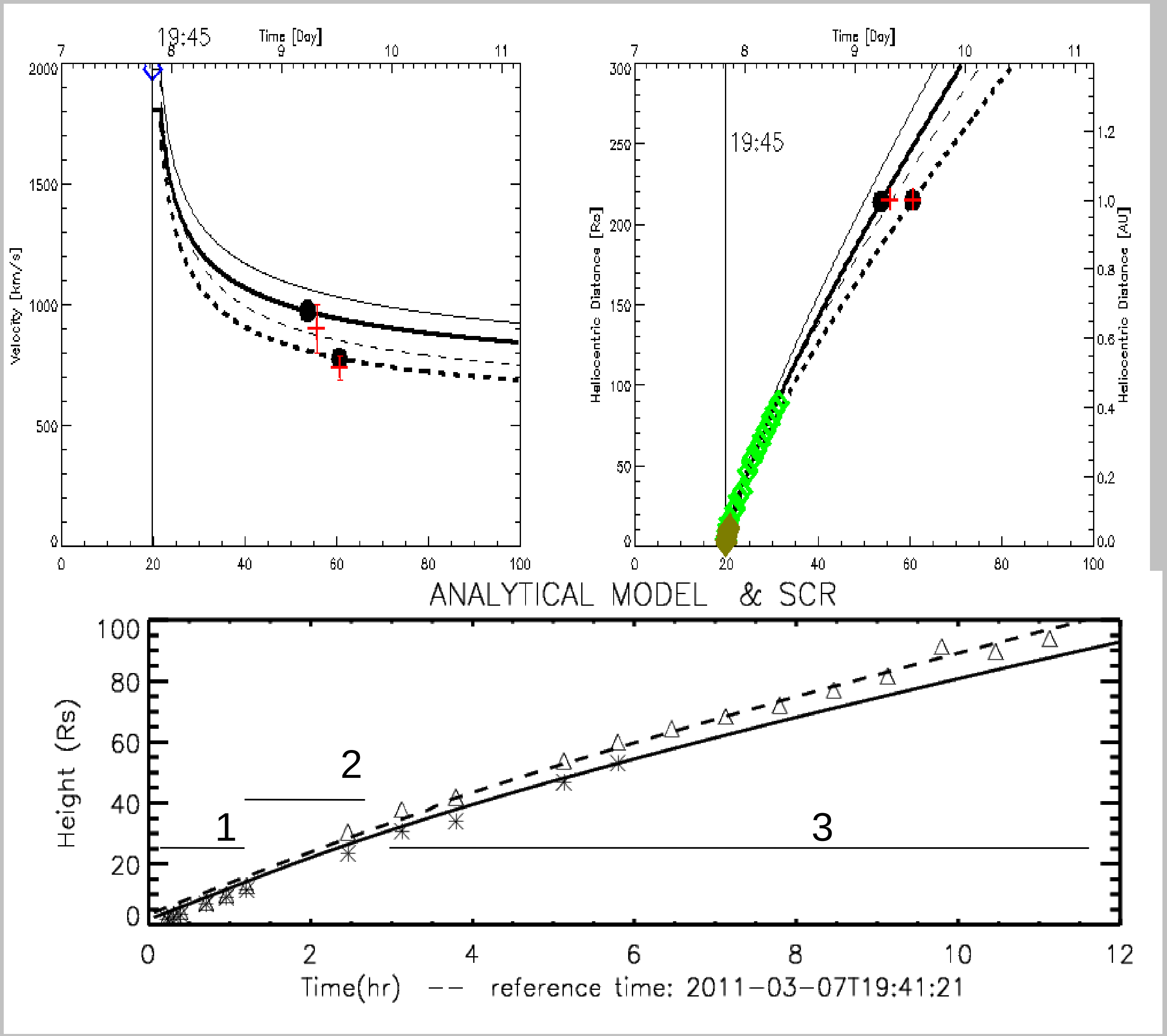
linear speed (km/s)

Telescope	CME	SH
AIA	279	
LASCO	17701889	
COR A	17872045	
COR B	15811784	
HI 1 A	12181289	
HI 1 B	925	939

SCR	CME	SH
CORs	1897	2039
HI 1	1678	1393



In-situ Arrival & Analytical Model



(1) The model shows that initially the fast ICME propagates at about a constant speed and drives the shock (driving stage)

(2) until it reaches certain distance from which it decelerates and decouples from the shock (decoupling process).

(3) Then the ICME and its shock decelerate (decaying stage).

SUMMARY & CONCLUSIONS

4 fast-halo, Earth-directed CMEs and their interplanetary counterpart. All of them with a significant evidence of shock signatures for each event on the white light.

We analyzed the speed evolution of these events trough a 1D hydrodynamical mode.

The inputs for the analytical model were consistent with the range of values estimated from the WL images.

The results from the model show good agreement with the in-situ observations of the arrival time of the IP shock and ICME .

Each corresponding IP-shock was previously analyzed by its Km Type II radio emission, but the speed comparison is not conclusive

A a single spacecraft measurements of the evolution of the CME & Shock, will result on an underestimation of their dynamical values, and more likely to reduce the effectiveness of modeling the CME-shock system evolution in the IP medium.

USING STEREO:

The well preserved morphology of the CME flux-rope allow us to distinguish its evolution even when its HI images are imposed over a pre-event.

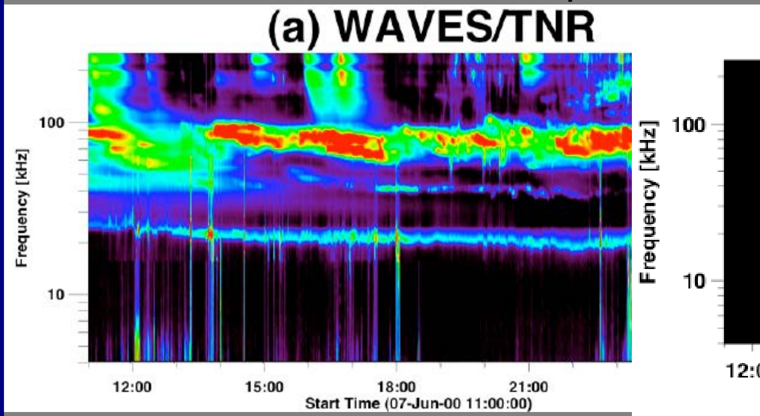
Using forward modeling, we found evidence of self-similar expansion of the shock and the CME up to 30 solar radii,

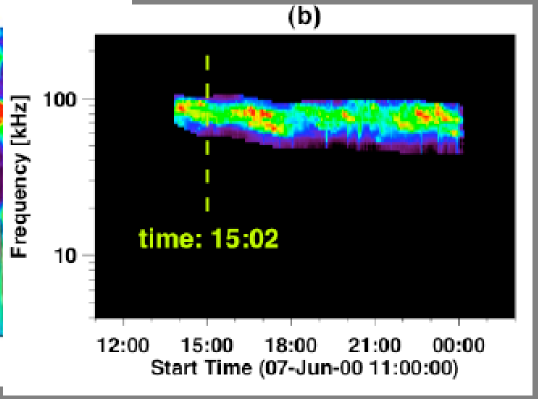
“Real” HT plots have a good agreement, for the initial stages of the ICME-shock, as well as the in-situ arrival time for the shock at STEREO A spacecraft.

The predicted decoupling time from the model between the shock and the CME look in good agreement with the observed deceleration phase of the CME in the SCR results.

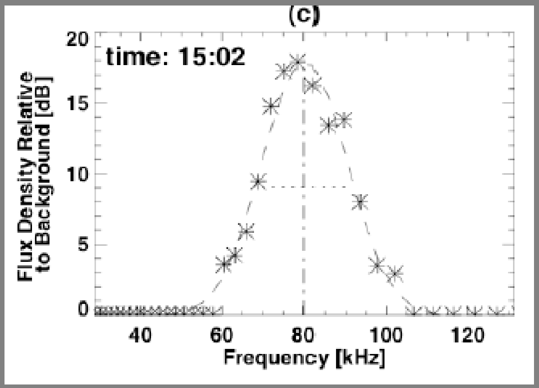
SPEED EVOLUTION TII RADIO BURST

Radio burst isolated from the TNR dynamic spectrum





Profile of the flux density vs the observed frequency



$$V\ \alpha\ (slope)\ r_0(n_0)^{1/2}$$

If considering sub-intervals, the speed solutions tend to converge