Solar Physics – under review

Relation between Type II Bursts and CMEs Inferred from STEREO Observations

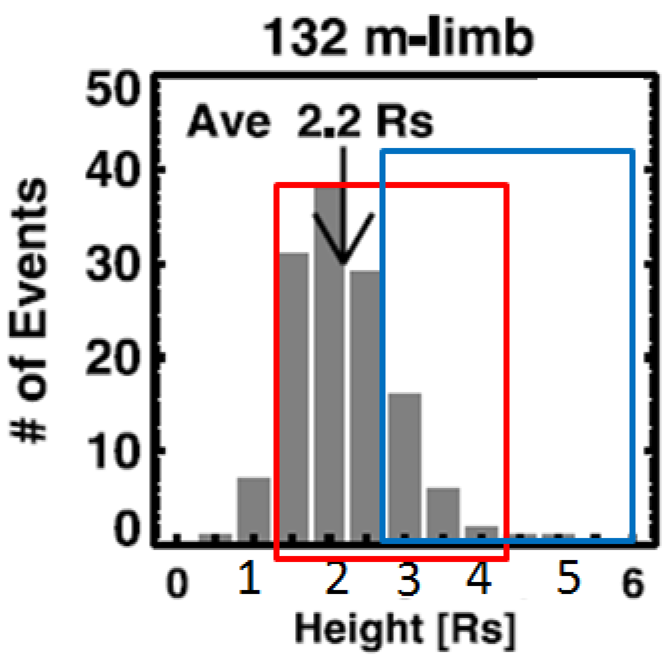
N. Gopalswamy, W. Thompson, J. Davila, M. Kaiser
NASA Goddard Space Flight Center, Greenbelt, MD
S. Yashiro
Interferometrics, Herndon, VA
P. Mäkelä, G. Michalek
The Catholic University of America, Washington, DC
J.- L. Bougeret
Paris Observatory, Meudon, France
R. Howard
Naval Research Laboratory, Washington, DC

STEREO SWG February 3-5, 2009 Pasadena

Motivation

- CME leading edge at metric type II burst onset: the height of shock formation
- LASCO: CME leading edge associated with ~130 limb type IIs 2.2 Ro [Gopalswamy et al., 2005, JGR] – extrapolation of height-time
- ~1.6 Ro for type II bursts in GLE events
- Exploit COR1 capability: minimal or no extrapolation (FOV inner edge ~1.4 Ro)
- LASCO/C2 misses the early evolution
- Explain the universal drift-rate spectrum

Motivation:
CME height at metric type II onset is generally extrapolated. SECCHI/COR1 can solve this problem

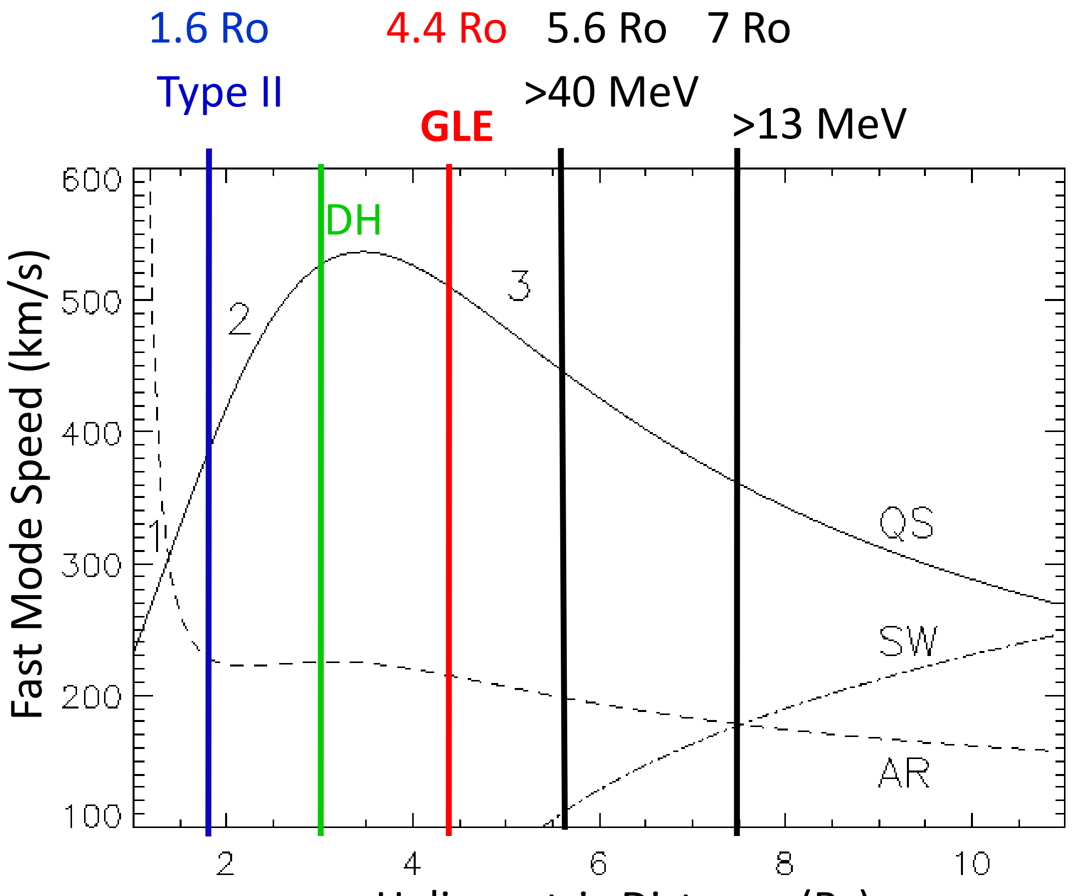


SECCHI/COR1 LASCO/C2

More type II bursts have spatial overlap with CMEs

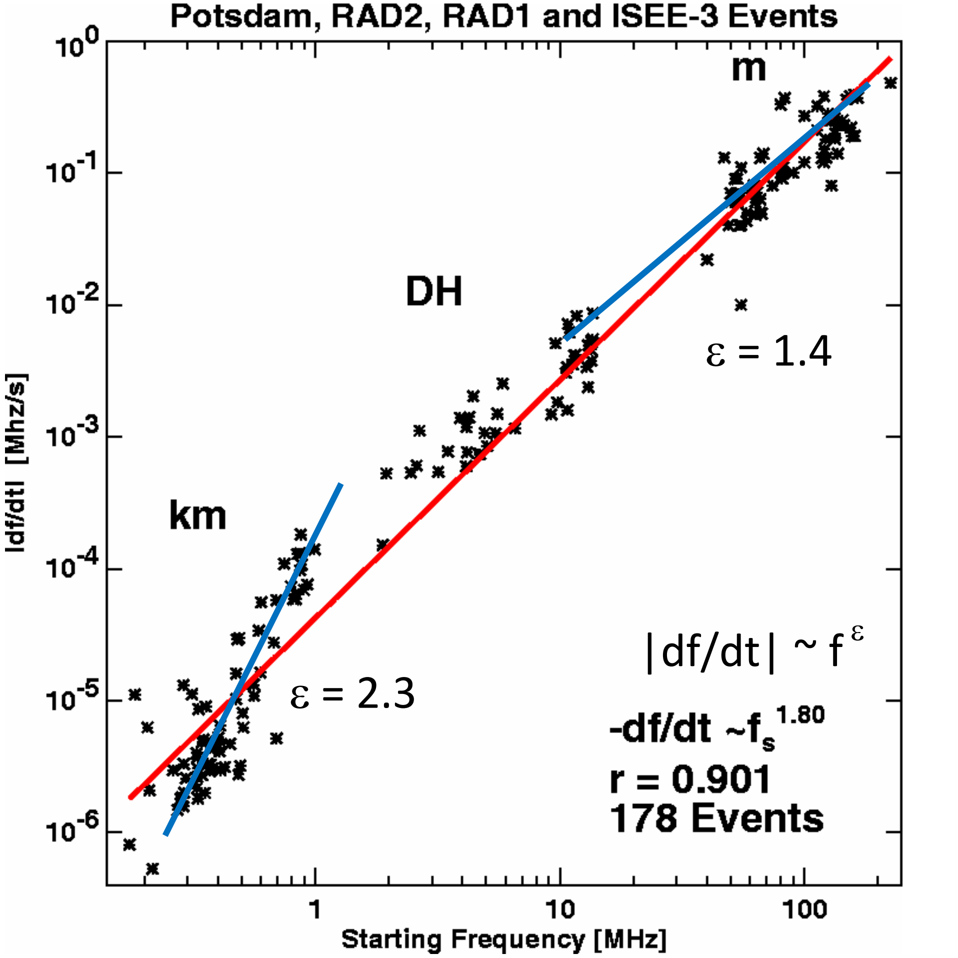
Gopalswamy et al. 2005

Onset of Shock, Type II, Particle Release



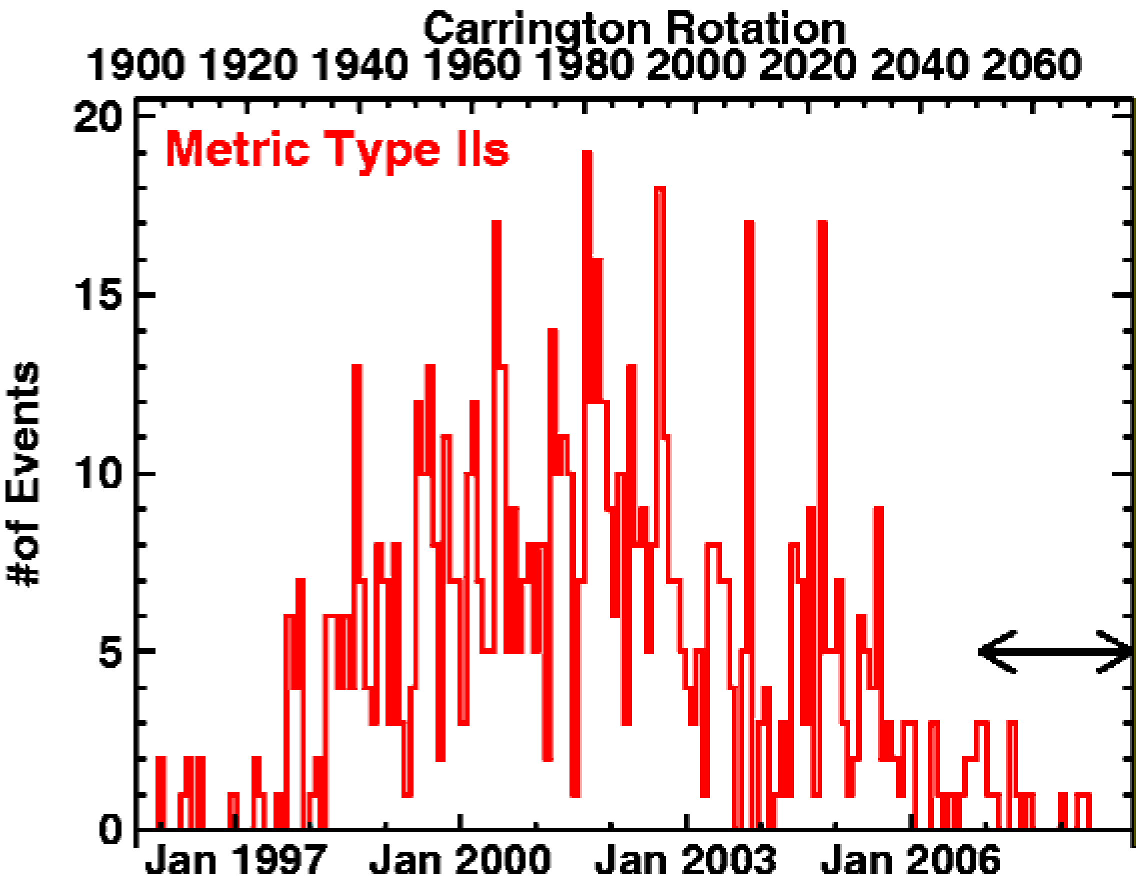
Gopalswamy et al., 2001, 2008

Speed increase in the metric corona



Aguilar-Rodriguez et al., 2005; Vrsnak et al., 2001

Overview



10 m type IIs

6 had SWAVES (DH)

1 m to km (interplanetary)

8 in 2007

2 in 2008

Mostly small S/C separation (0 – 50 degrees)

No type II since 4/26/08

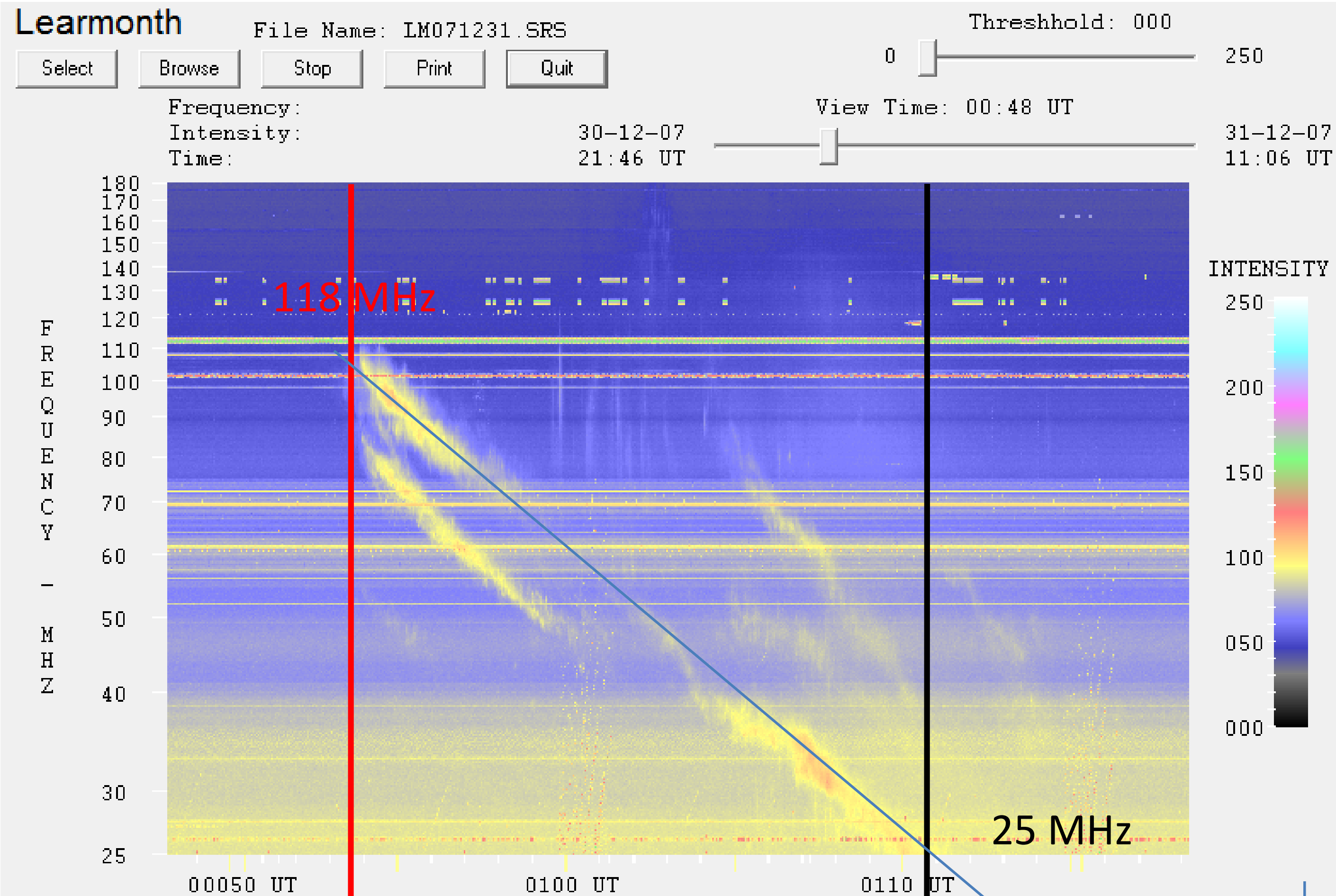
Metric type II and CME Properties

Date	Time range	$f_e - f_s$ (MHz)	df/dt MHz/s	DH II	V_C km/s	V_L km/s	W deg	AR flr Loc	BE AE AB deg
07/01/25	06:47 - 06:50	25-40	0.083	23:30	DG	1367	360	0940 C6.3 S08E90	0.16 0.39 0.54
07/02/19	00:18-00:21	30-45	0.2	N	186	DG	DG	0943 C1.1 S12E16	0.12 0.80 0.91
07/05/19	12:51-13:18	38-167?	0.25	13:05	1624	958	106	0956 B9.5 N07W06	2.1 5.9 8.6
07/05/22	14:36-14:55	25-82?	0.05	N	356	544	108	0956 B3.9 N02W42*	3.1 6.0 9.1
07/05/23	07:22-07:33	25-180	0.07	N	609	679	90	0956 B5.3 N02W55*	3.2 6.0 9.2
07/06/03	09:28-09:42	28-84	0.15	Y?	491	467	71	0960 C5.3 S08E67	3.9 7.1 11.0
07/08/06	09:16-09:21	25-94?	0.08	N	333	379	66	966 C1.5 S05E41	9.8 13.5 23.3
07/12/31	00:53-01:11	30-118?	0.11	01:22	771	995	164	0980 C8.3 S08E81	22.8 21.2 44.0
08/03/25	18:52-19:00	25-60	0.07	19:20	773	1103	90	0989M1.7 S13E78	23.7 23.5 47.1
08/04/26	14:12-14:22	25-45?	0.024	14:15	335	515	281	?? B3.8 N08E09	24.0 25.6 49.5

General Results

- Extremely weak flares: 4 B, 5 C & 1 M
- Energetic CMEs: $< V_{LASCO} >$ ~774 km/s, W ≥66°
- V_m ~ 534 km/s V_{DH} 808 km/s V_{mkm} 1367 km/s
- $V_{COR1} < V_{LASCO}$ [2 exceptions: 1 impulsive]
- Six of the 10 metric type II bursts had CME observation when the burst was in progress

Metric Type II



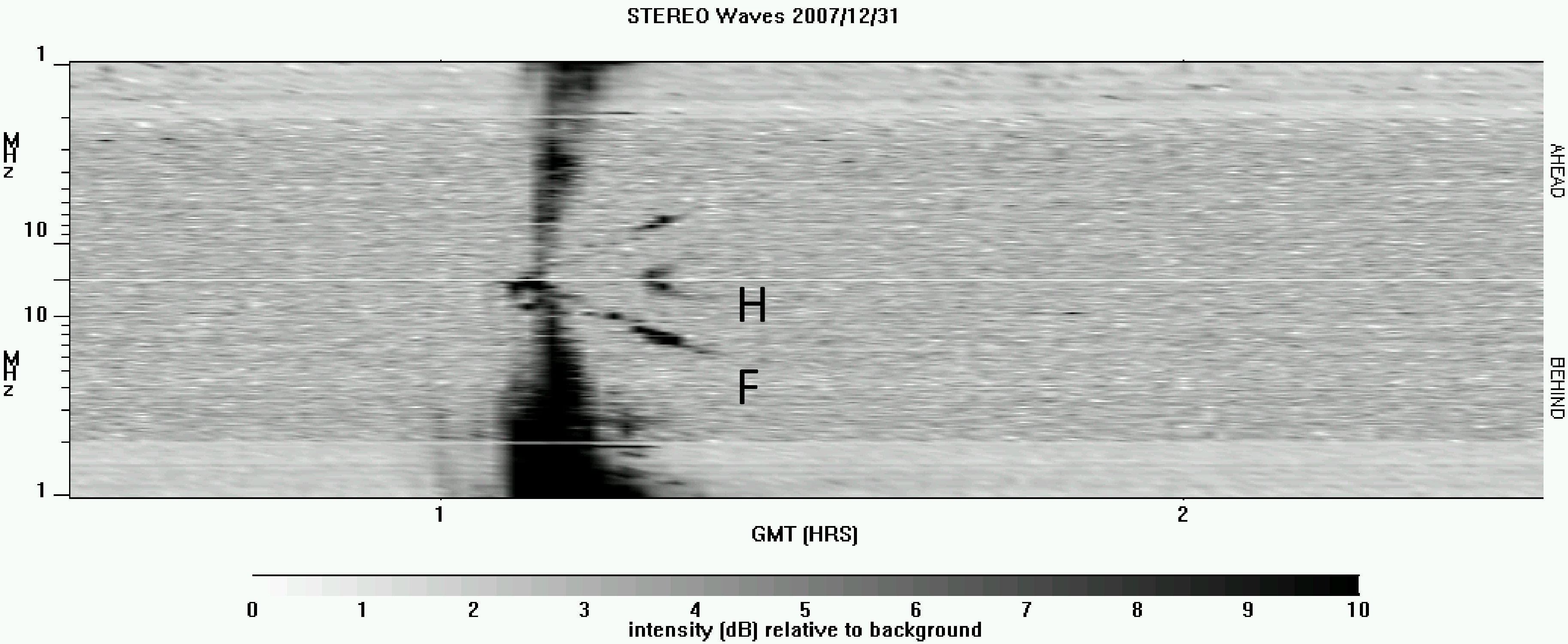
00:52

01:12

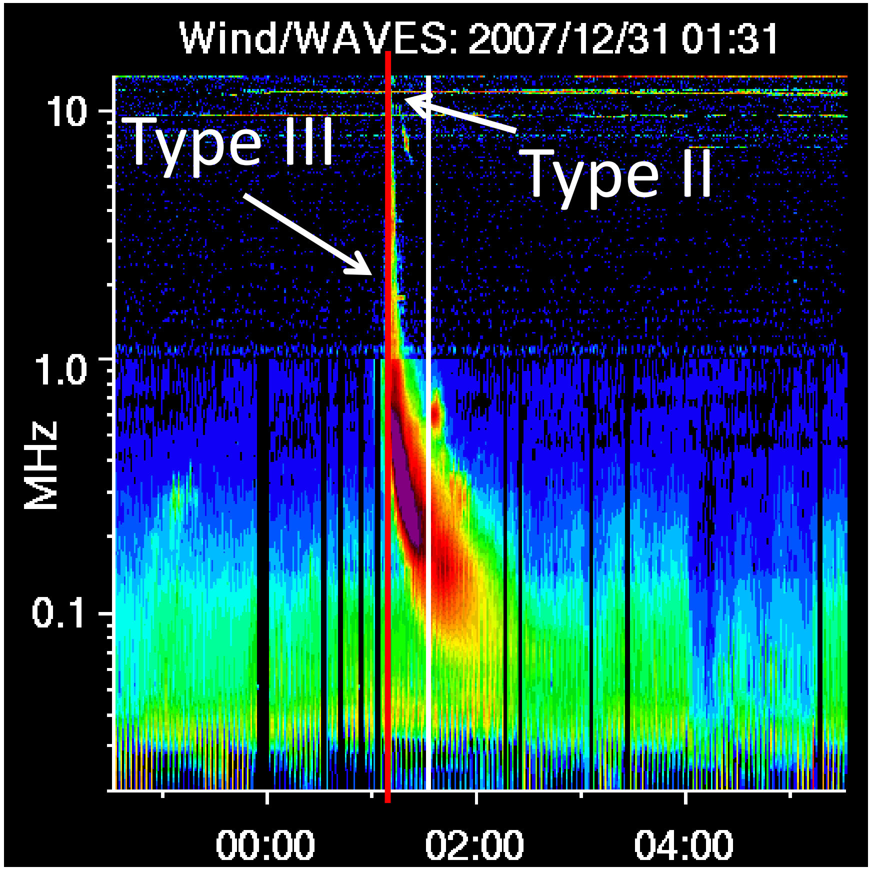
01:22 DH Type II end

df/dt ~0.1 MHz/s

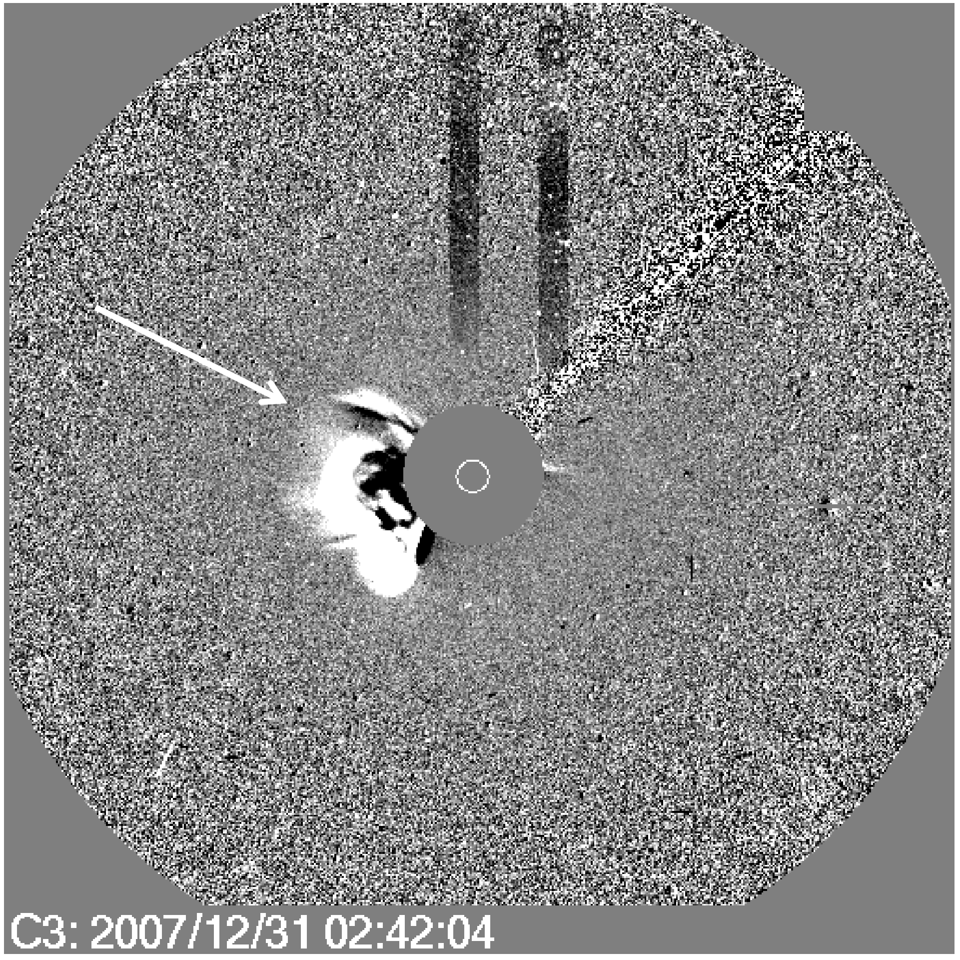
SWAVES Type II



DH Type II

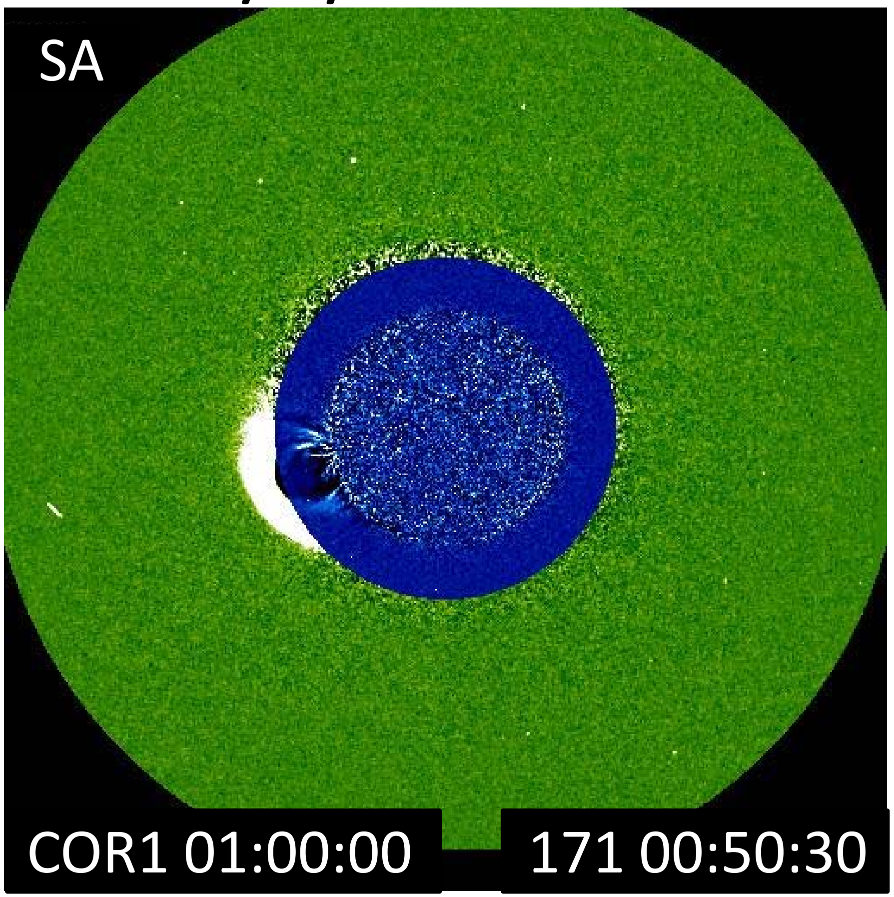

Wind/WAVES: 2007/12/31 01:31
10
1.0
0.1
MHz
Type III
Type II
00:00
02:00
04:00


Shock?
C2: 2007/12/31 01:31
EIT: 2007/12/31 01:25

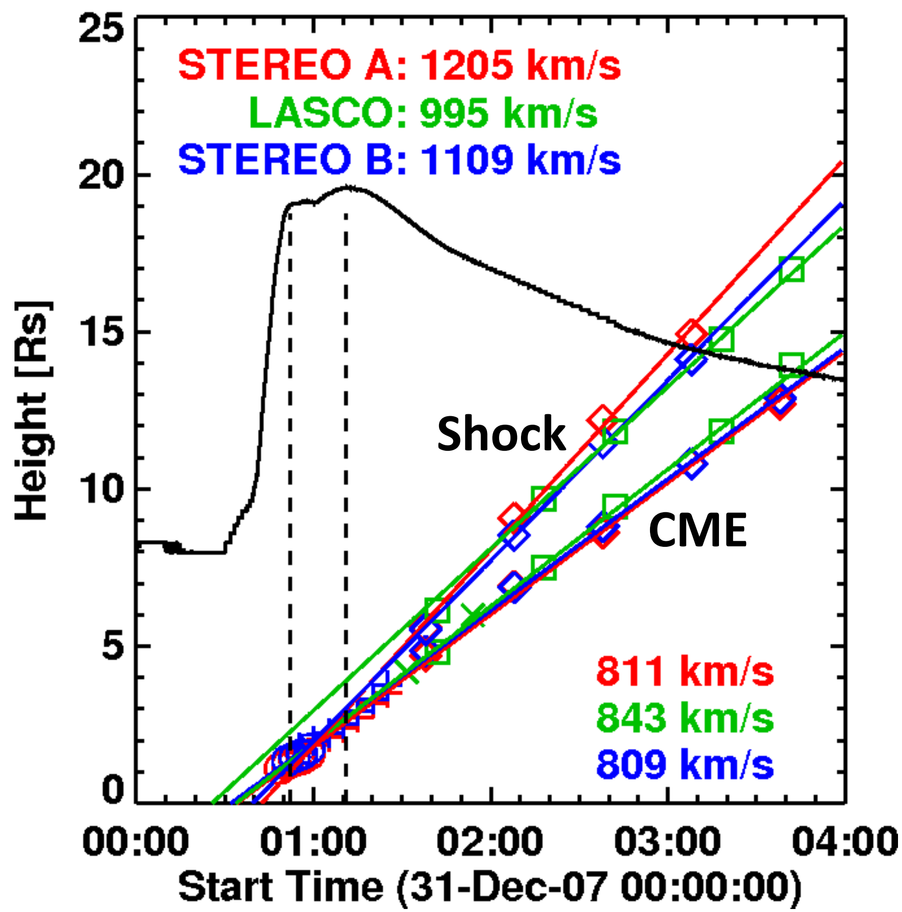

C3: 2007/12/31 02:42:04

CME at the Time of Type II

2007/12/31 COR1 & EUVI



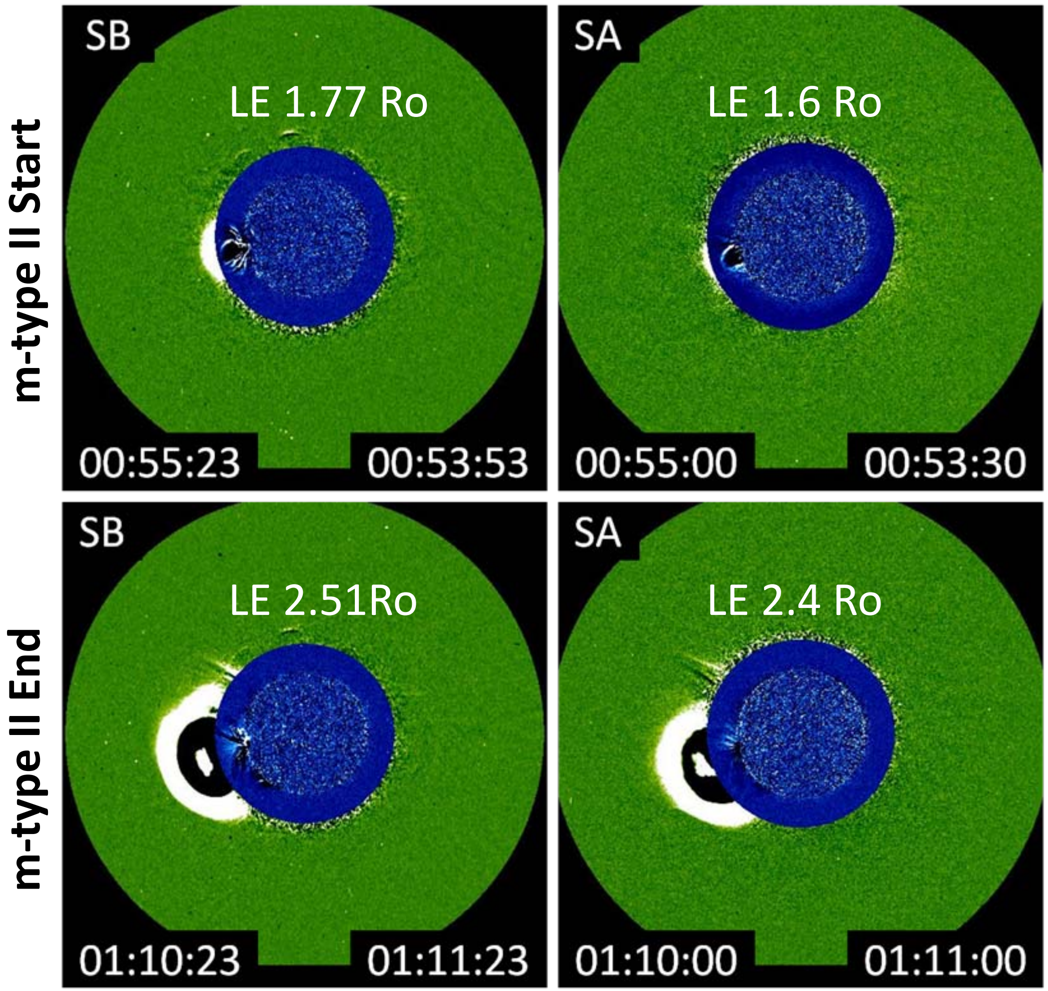
2007/12/31 00:52 - 01:12



SA, E, SB View: E101, S08E81, E58

1.4 Ro

COR1 + EUVI 284 images of the CME

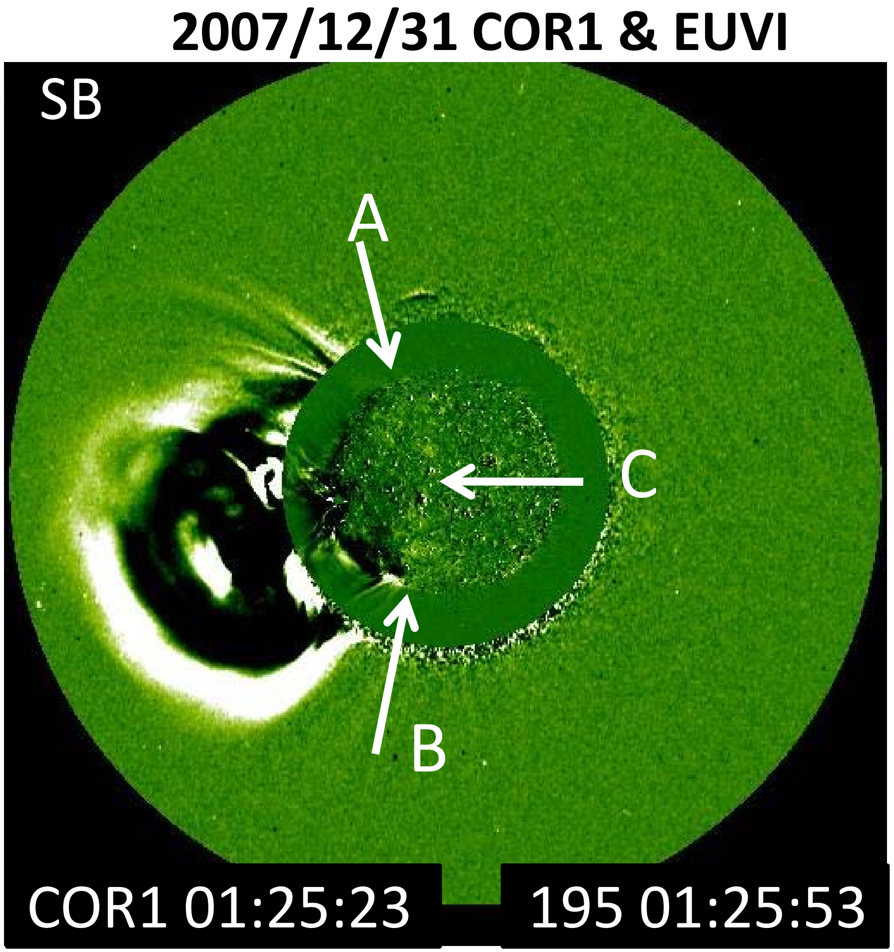


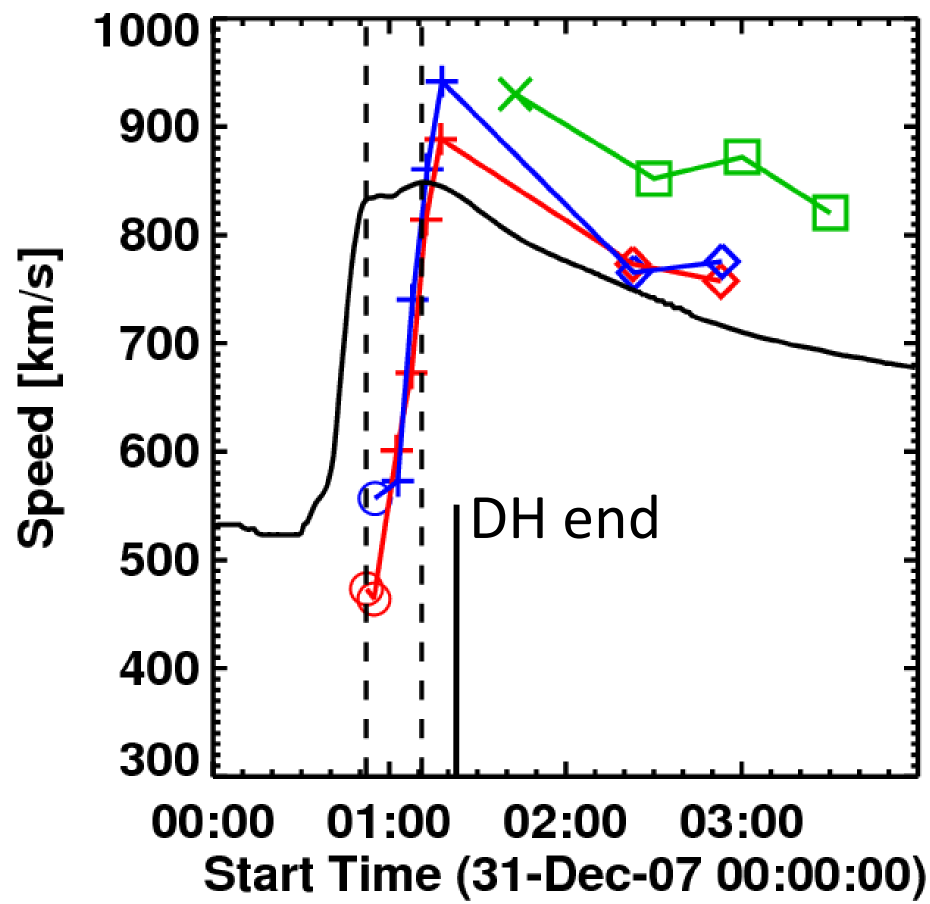
COR1/EUVI images available at several instances during type II

The CME was in the height range 1.4 – 3.3 Ro when the type II started in the metric domain and ended in the DH domain

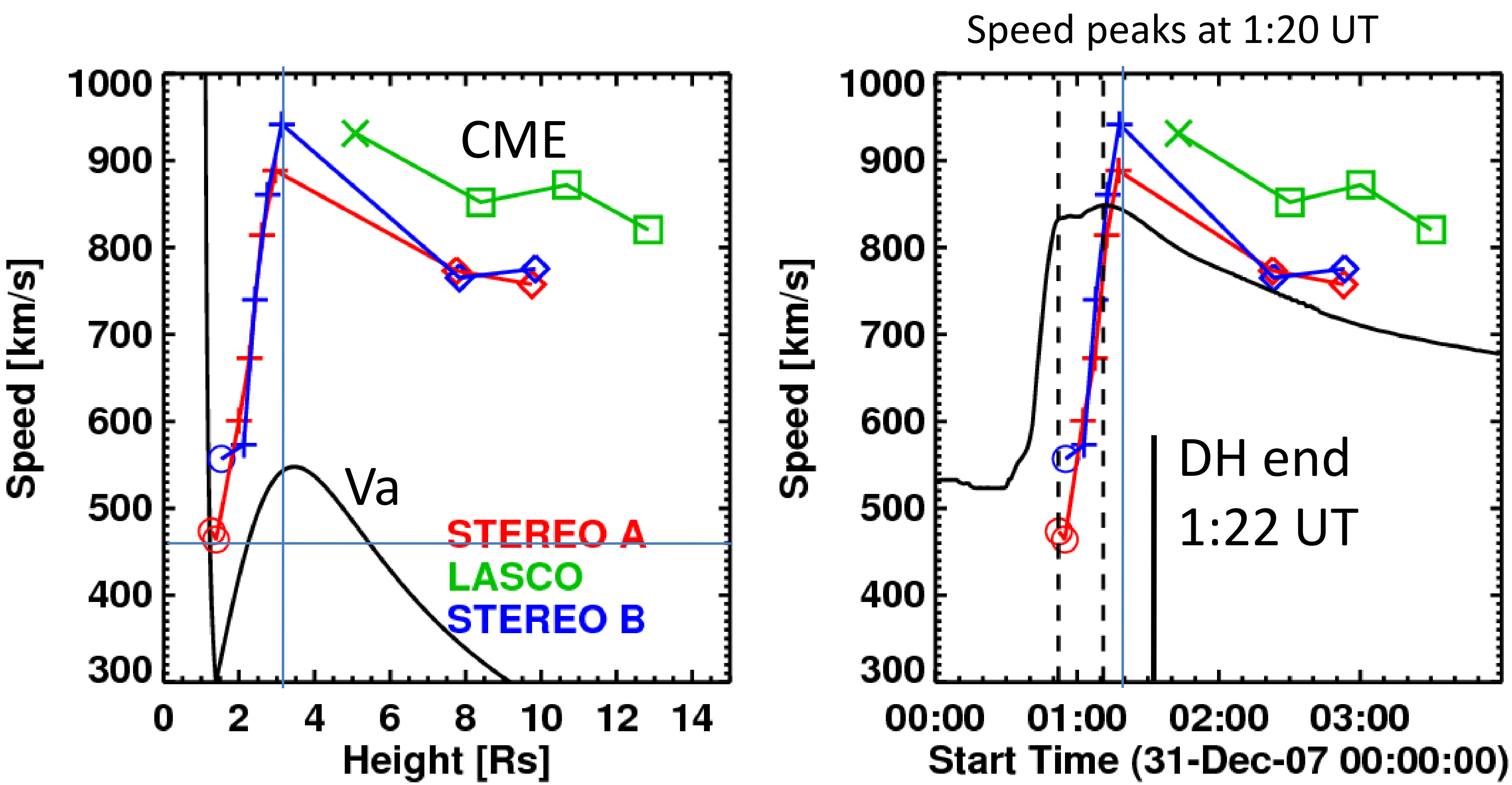
Disturbances around the CME became clear after the type II ended

Disturbance Surrounding the CME

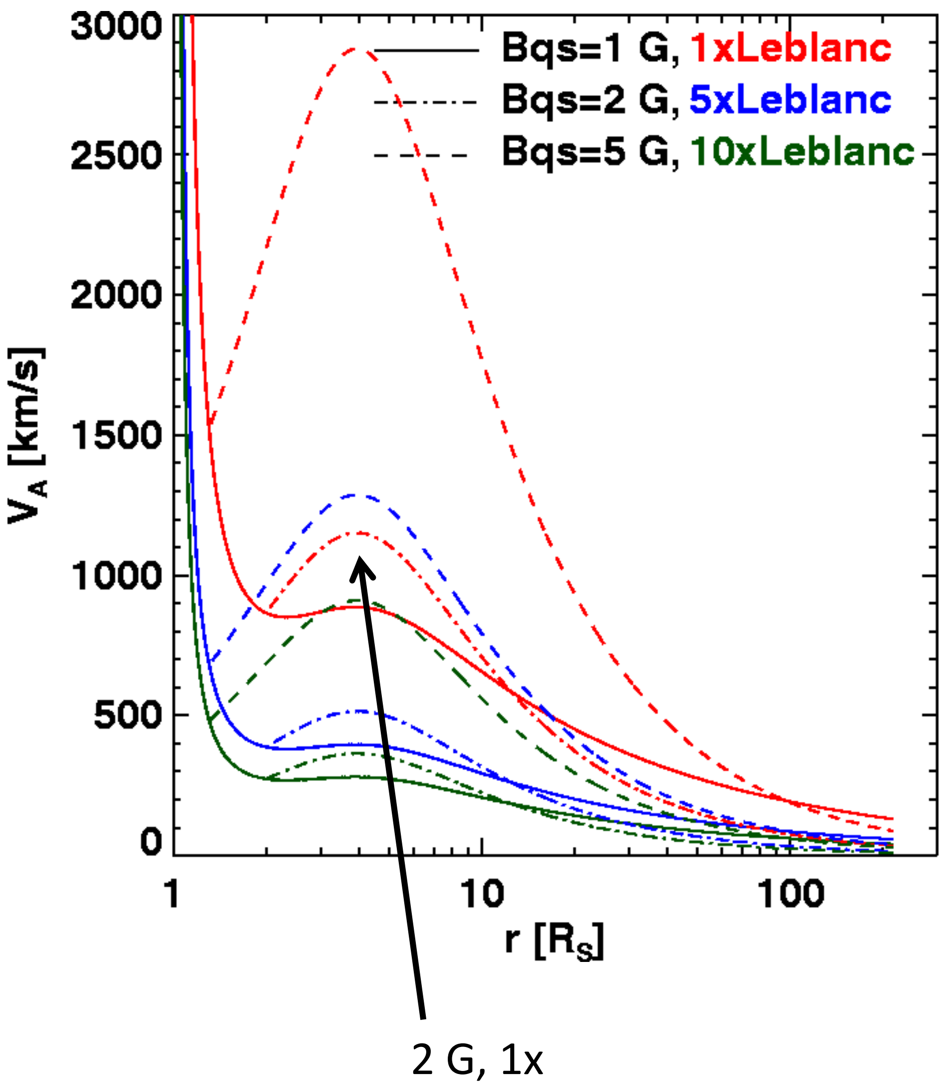




CME Speed & Va Profiles



Alfven Speed can vary by a factor of 5



$N = 3.3\times10^5\ r^{-2} + 4.1\times10^6 r^{-4} + 8.0\times10^7\ r^{-6}\ \mathrm{cm}^{-3}$

Speed increase in the metric corona

Shock travels with a speed V emitting at successively lower f determined by the local plasma density:

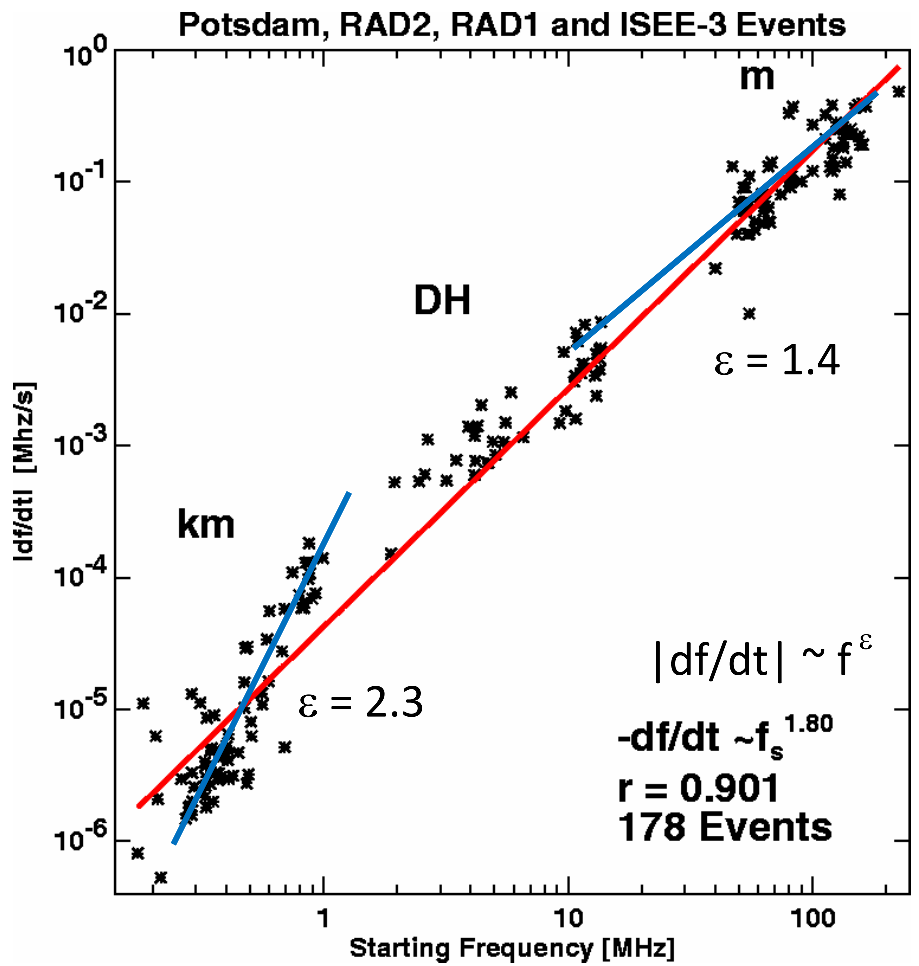
$n \sim r^{-\alpha}$ or $f \sim r^{-\alpha/2}$

$|df/dt| = V(df/dr) \sim Vf^{(\alpha+2)/\alpha} = Vf^2$
if V=const. & α =2 (Vrsnak et al., 2001)

V may be slowly varying far away from the Sun, but not in the COR1 FOV

α=2 may not be true

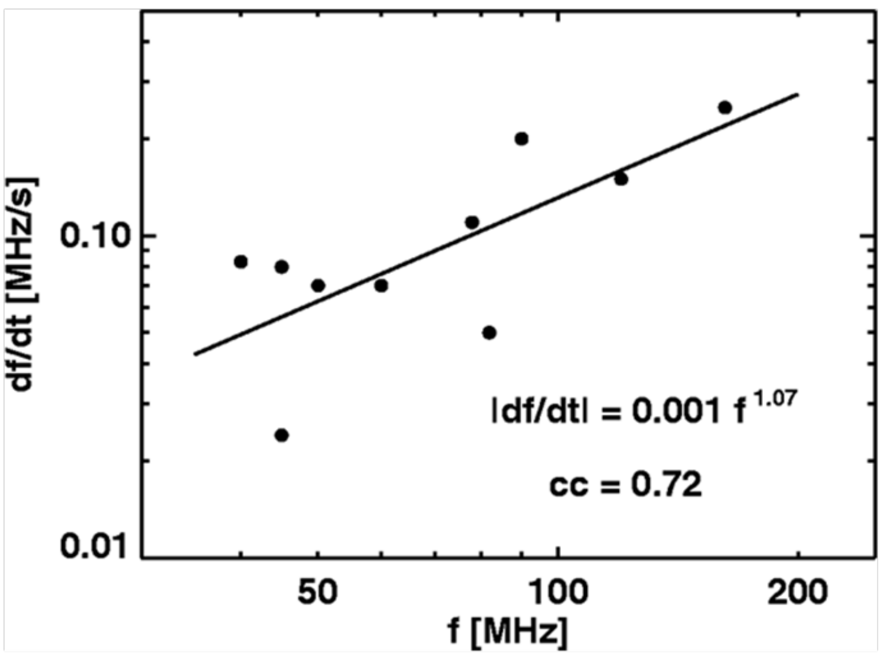
Deviations imply speed increase near the Sun and decrease in the IP medium



Drift – Rate Spectrum (metric)

If speed varies as $V \sim r^{-\beta} \sim f^{2\beta/\alpha}$ [since $f \sim r^{-\alpha/2}$]

$|df/dt| \sim f^{(\alpha+2\beta+2)/\alpha} = f^{\varepsilon}$ with $\varepsilon = (\alpha+2\beta+2)/\alpha$



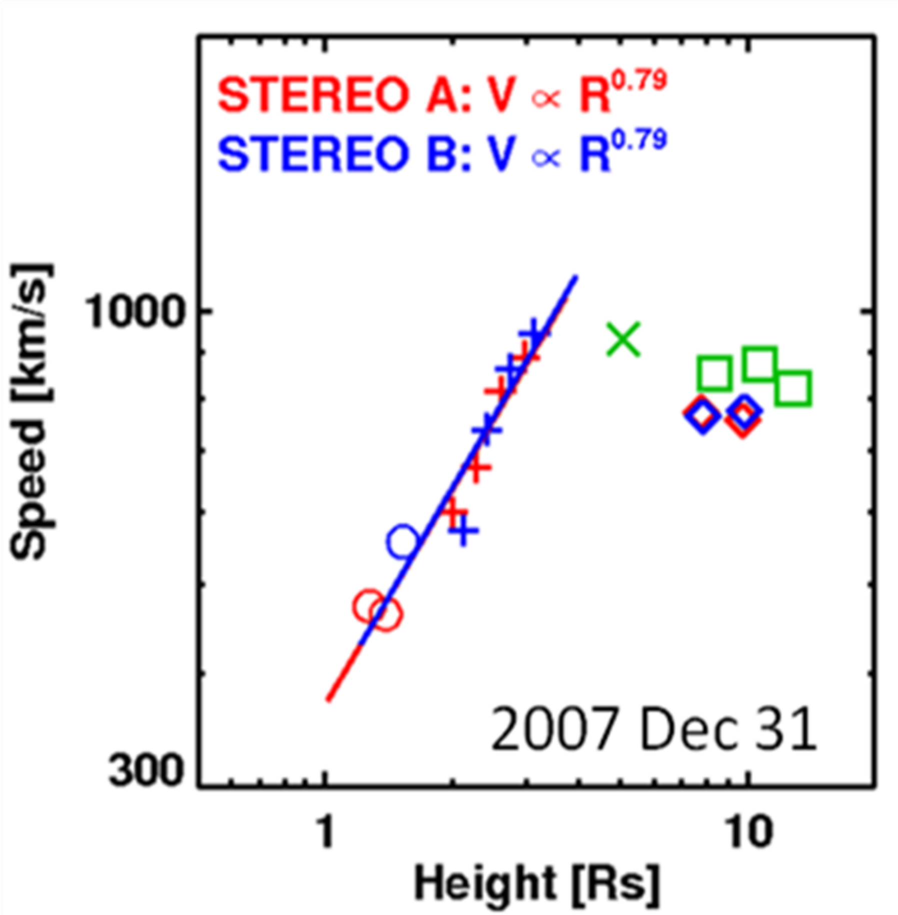
$\varepsilon = (\alpha + 2\beta + 2)/\alpha$

$\beta = -0.79 \rightarrow \varepsilon = 1.04$ for $\alpha = 6$

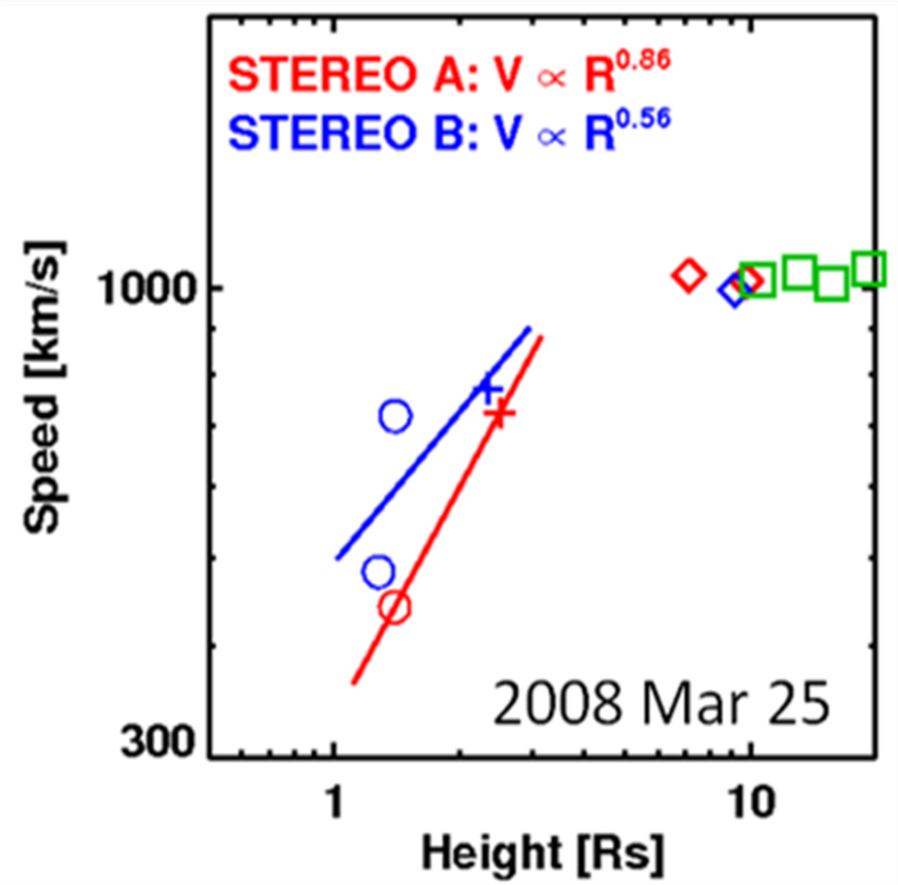
$\beta = -0.86 \rightarrow \varepsilon = 1.05$

Consistent with the observed $\varepsilon = 1.07$

$\beta = -0.79$



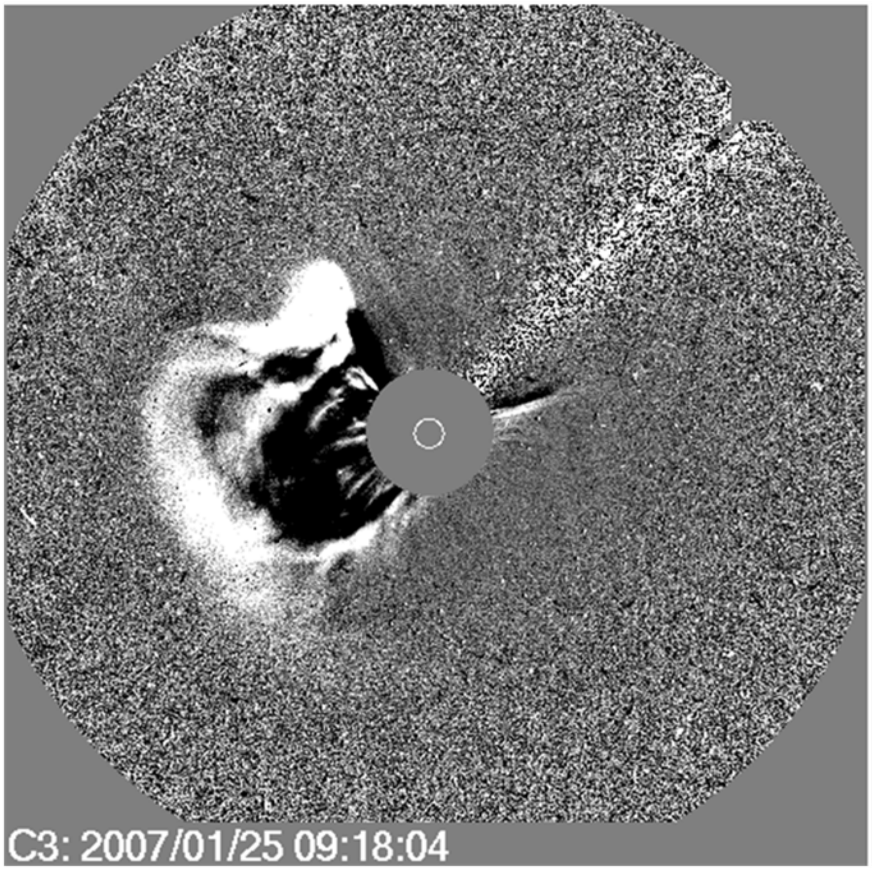
$\beta = -0.86$ STEREO A Limb View

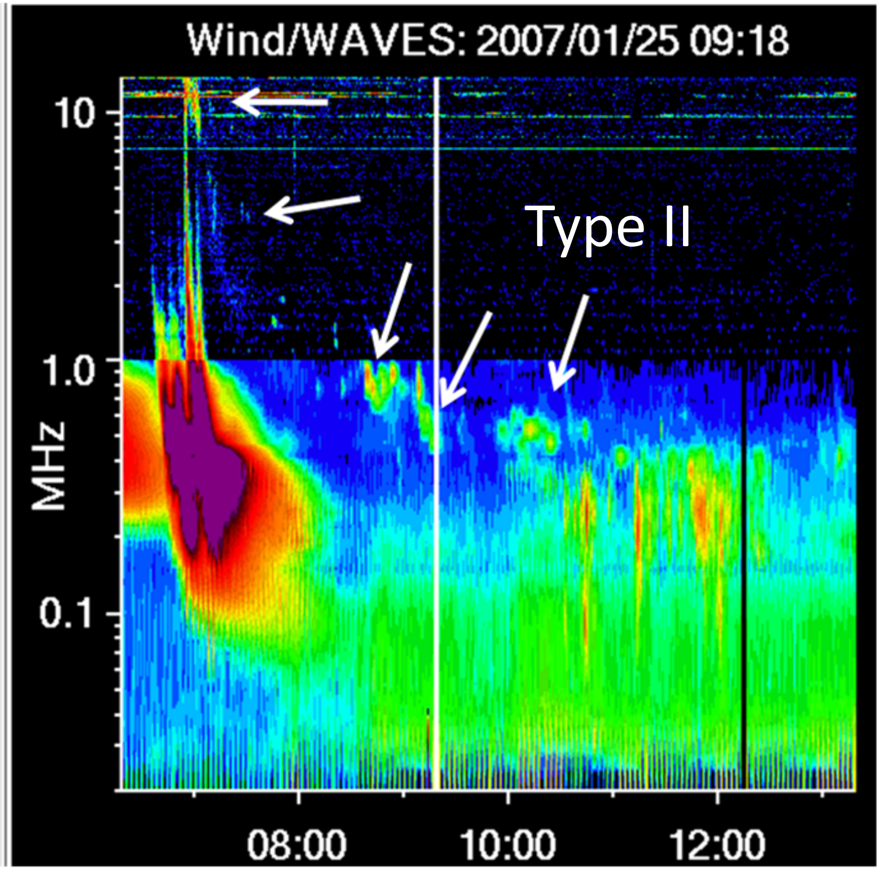


Low frequency Part

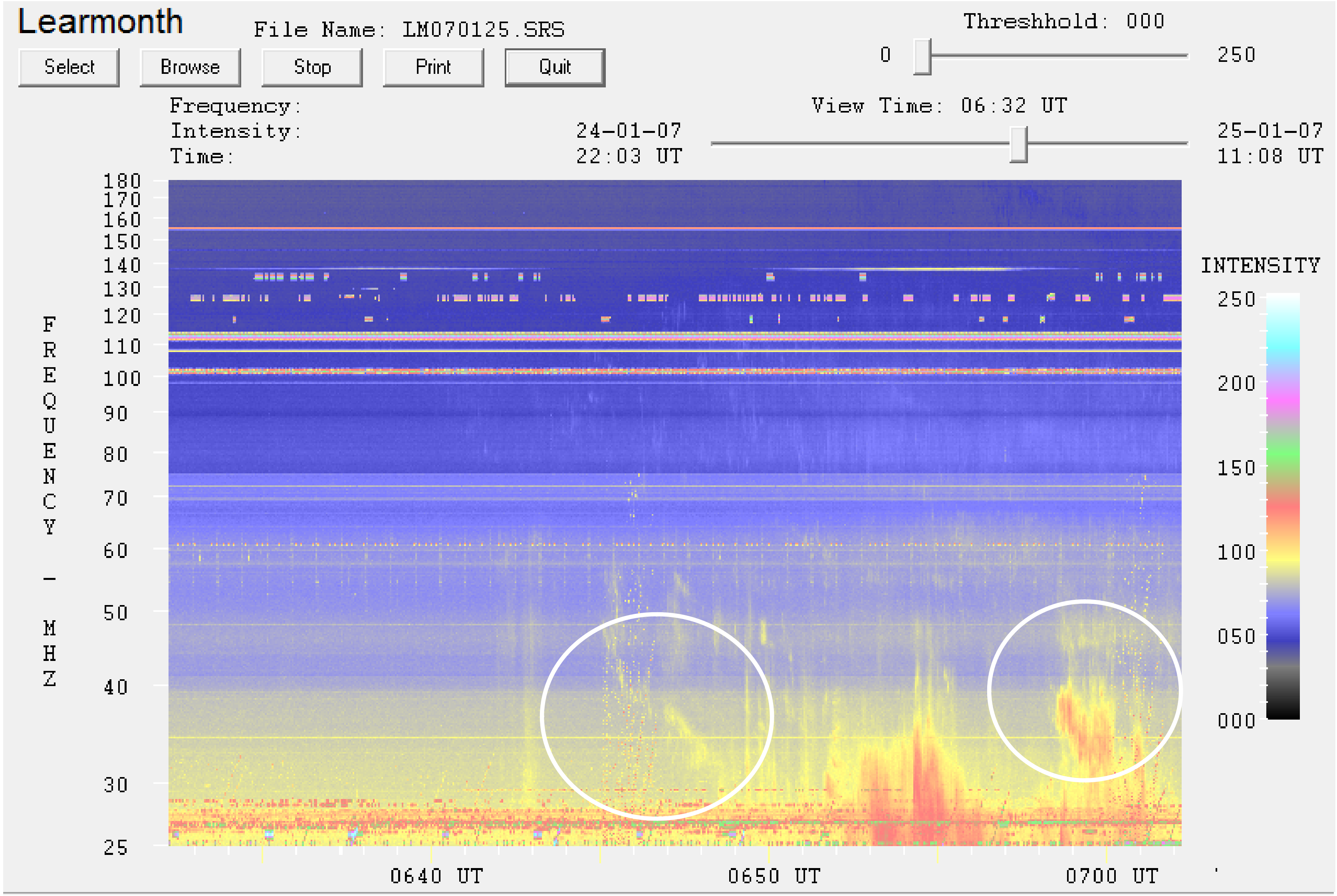
- If speed varies as $V \sim r^{-\beta} \sim f^{2\beta/\alpha}$ [since $f \sim r^{-\alpha/2}$]
- $|df/dt| \sim f^{(\alpha+2\beta+2)/\alpha} = f^{\varepsilon}$ with $\varepsilon = (\alpha+2\beta+2)/\alpha$

IP Type II


C3: 2007/01/25 09:18:04

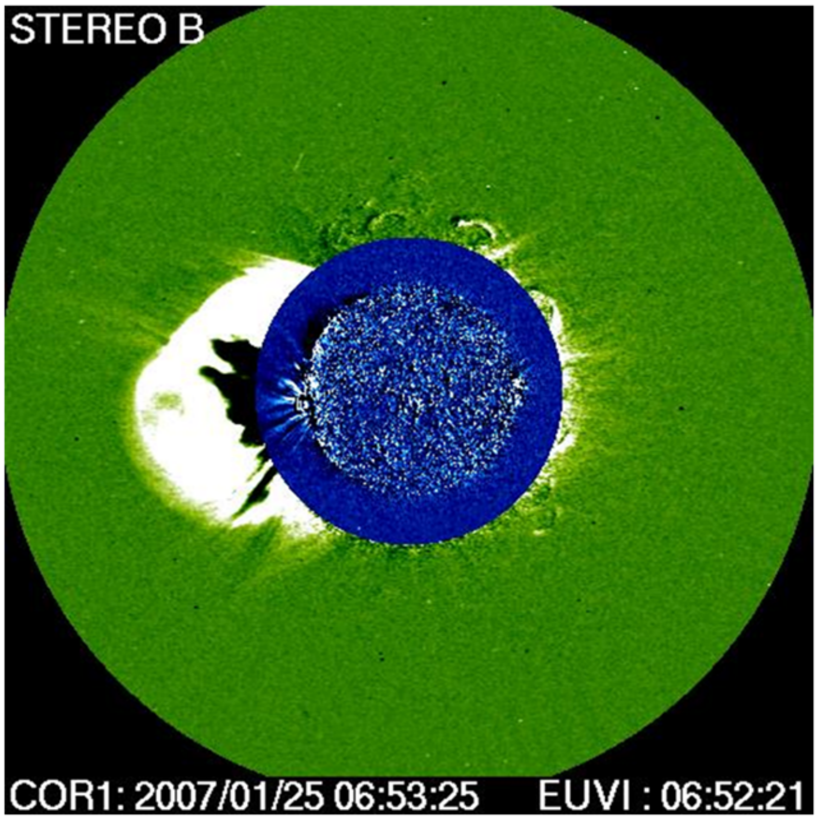

Wind/WAVES: 2007/01/25 09:18
10
1.0
0.1
MHz
Type II
08:00
10:00
12:00

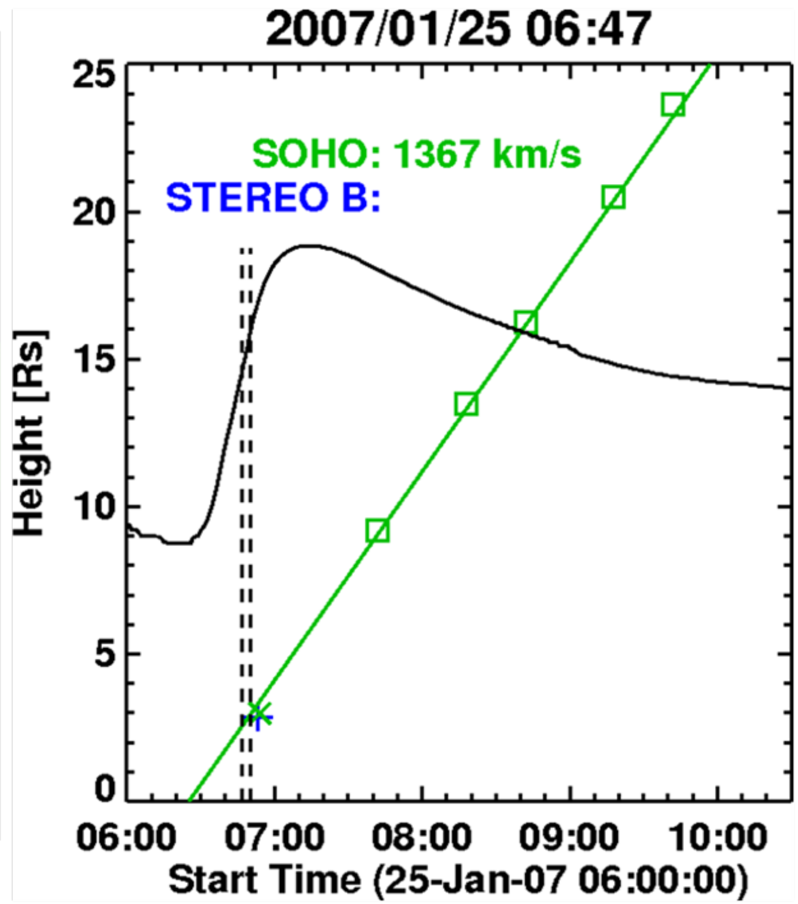
Type II not Reported!



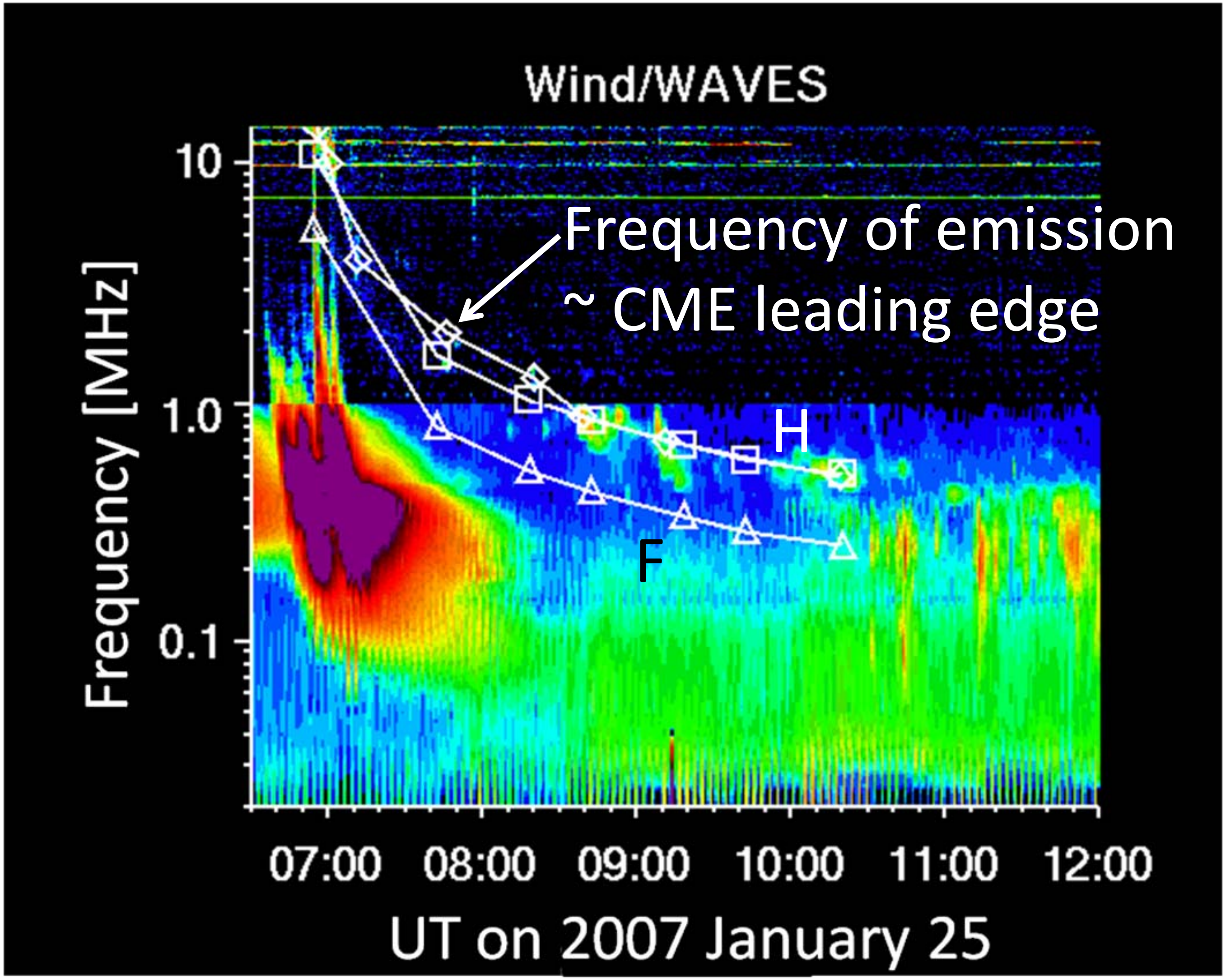
40 – 24 MHz   0.08 MHz/s

metric to kilometric Type II





Combining dynamic Spectrum with CME Height –Time



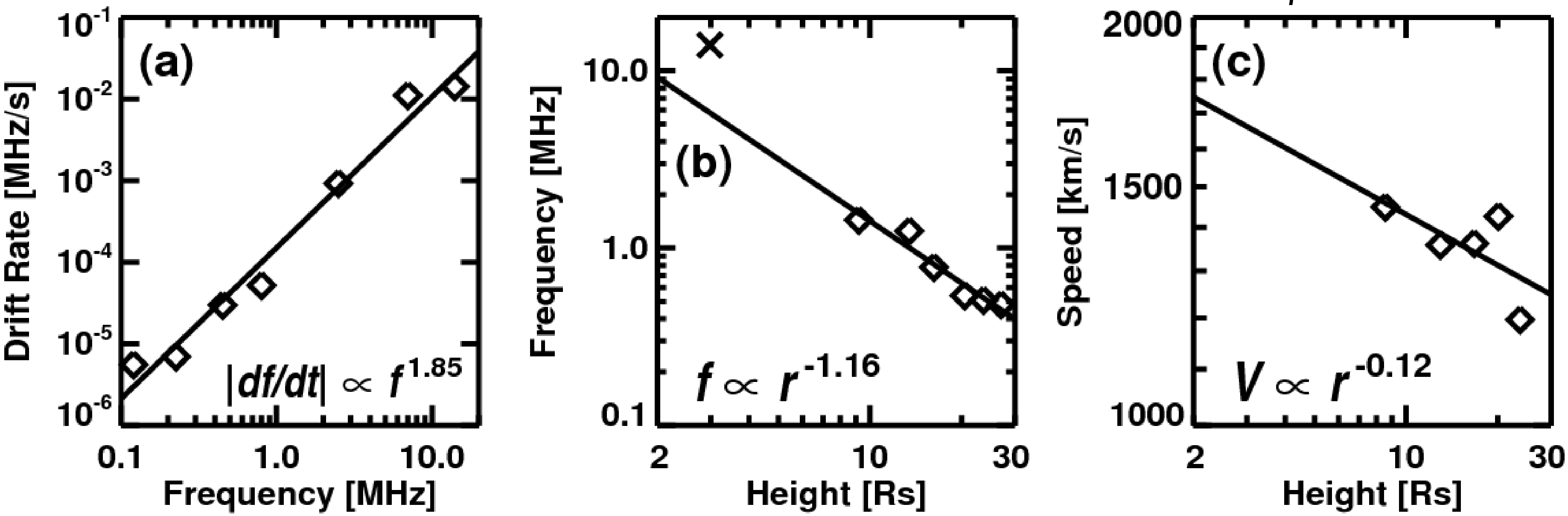
$\varepsilon = (\alpha + 2\beta + 2)/\alpha$

$\beta = 0.12 \rightarrow \varepsilon = 1.97$ for $\alpha = 2.32$

Consistent with the observed $\varepsilon = 1.85$

$\beta = 0, \alpha = 2 \rightarrow \varepsilon = 2$ Speed is ~constant within C3 FOV

$\beta = +0.12$

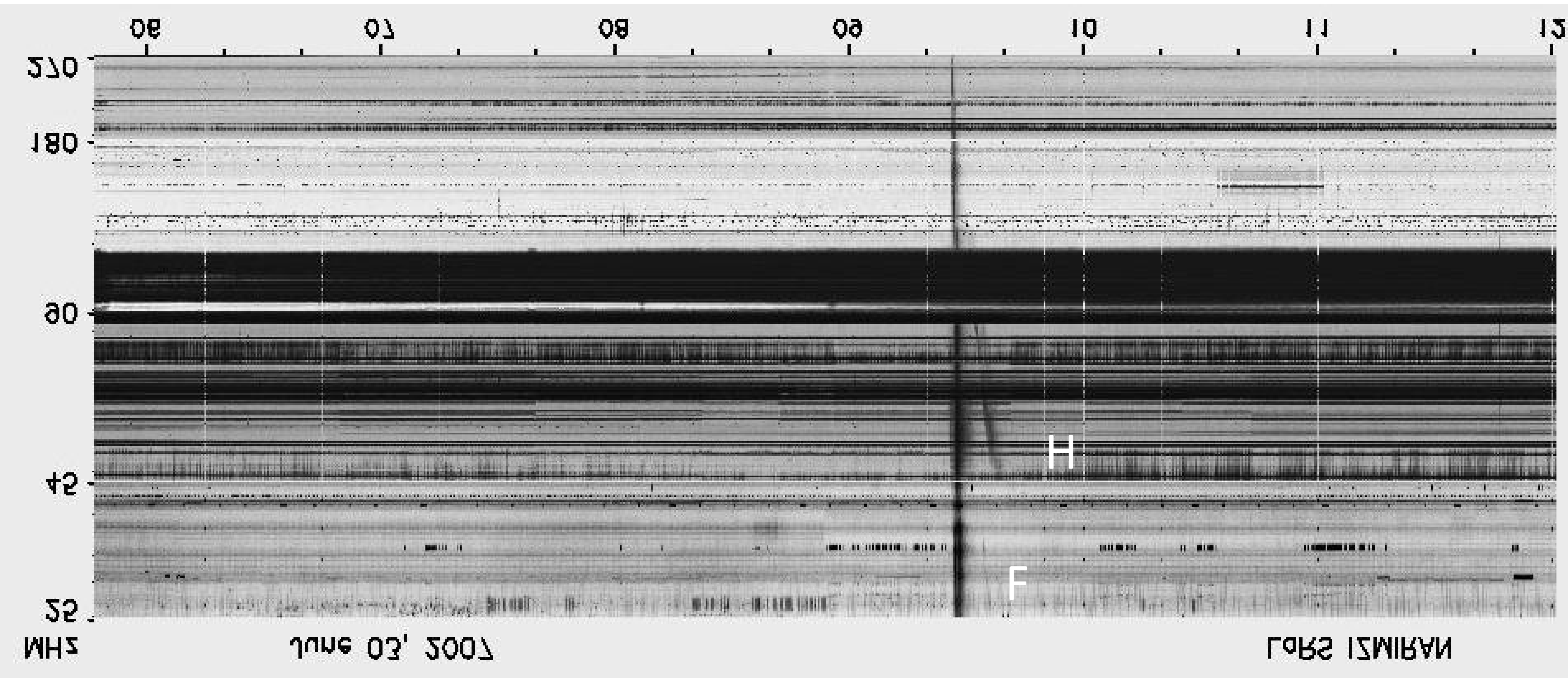


Confirms r dependence of density. $\alpha = 2.32$

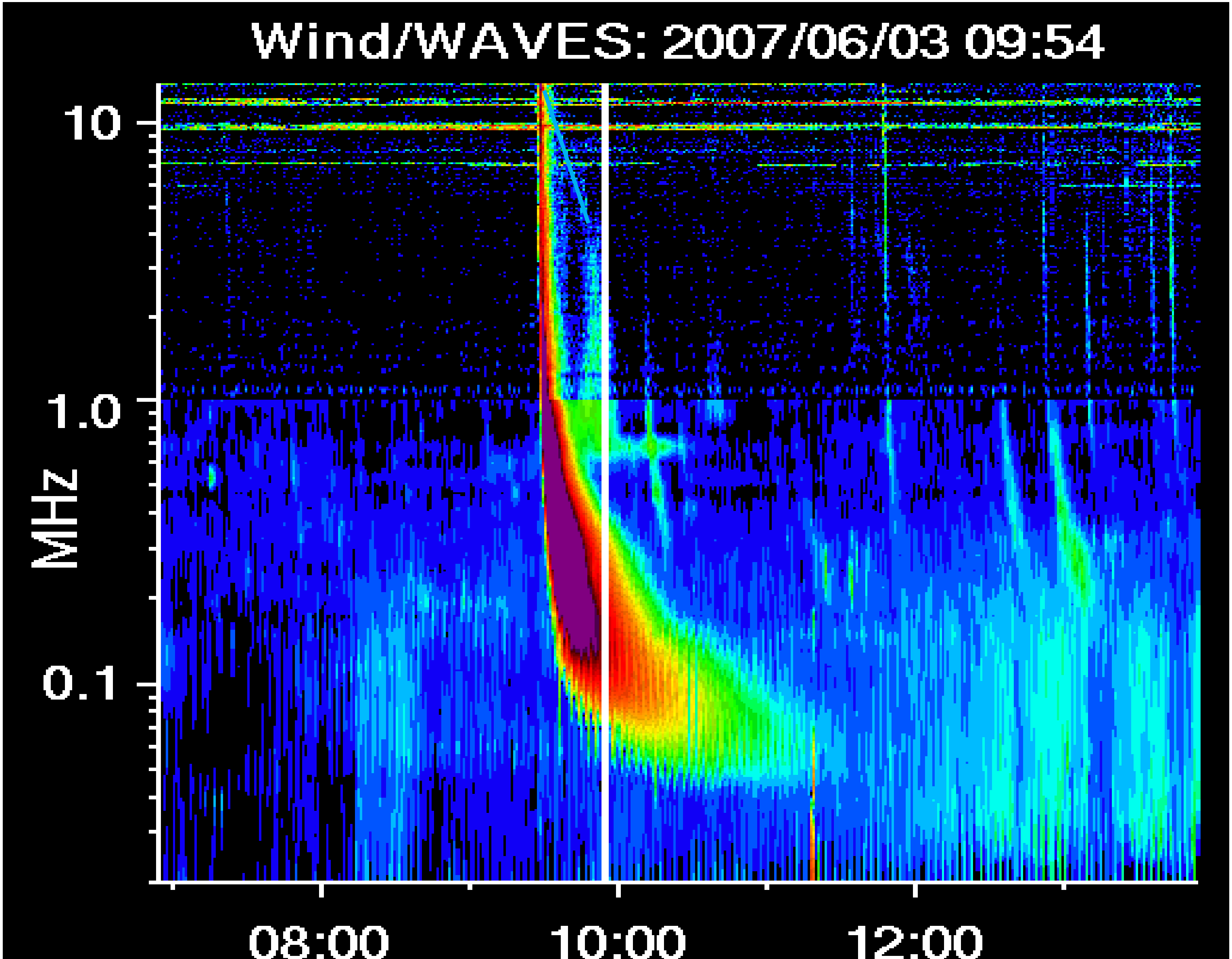
Try this with HI

Impulsive Event

IZMIRAN



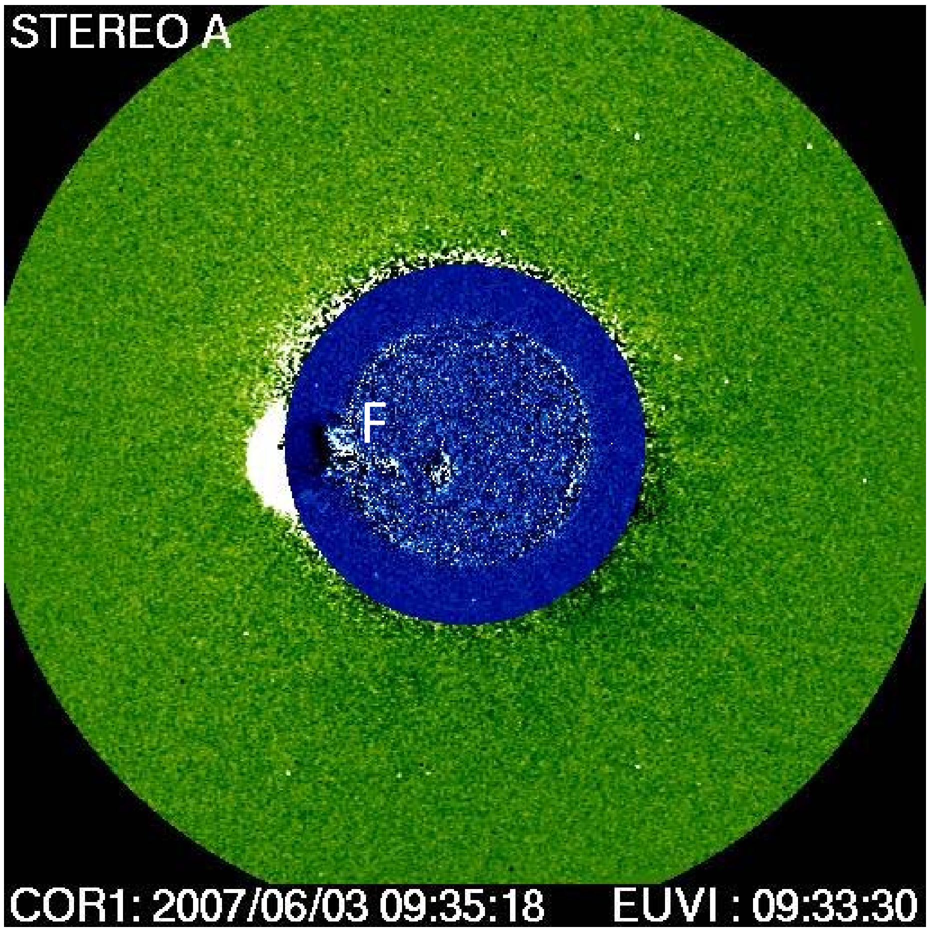
2007 June 3

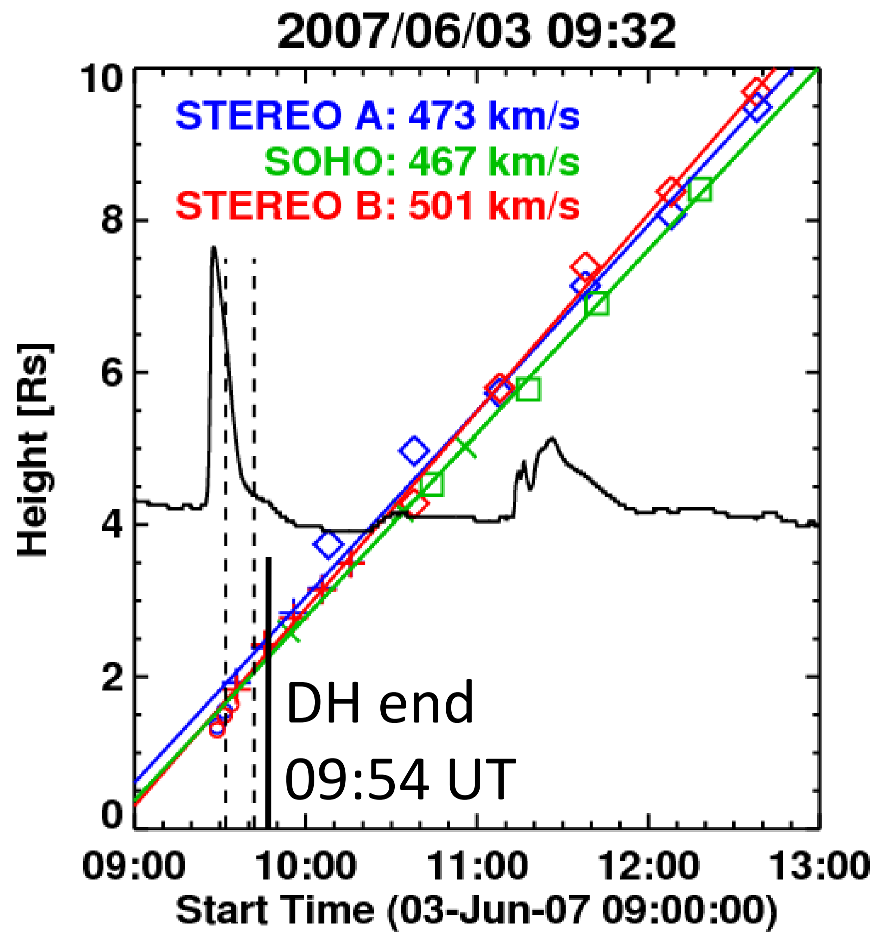


Wind/WAVES: 2007/06/03 09:54
10
1.0
0.1
MHz
08:00
10:00
12:00

Impulsive Events

CME observed when metric type II in progress

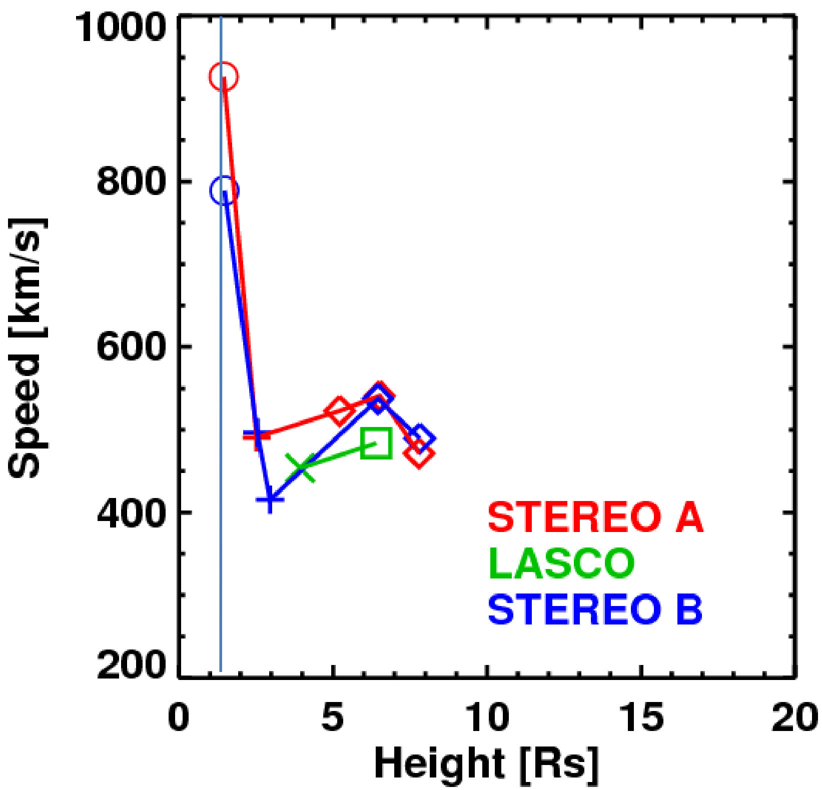




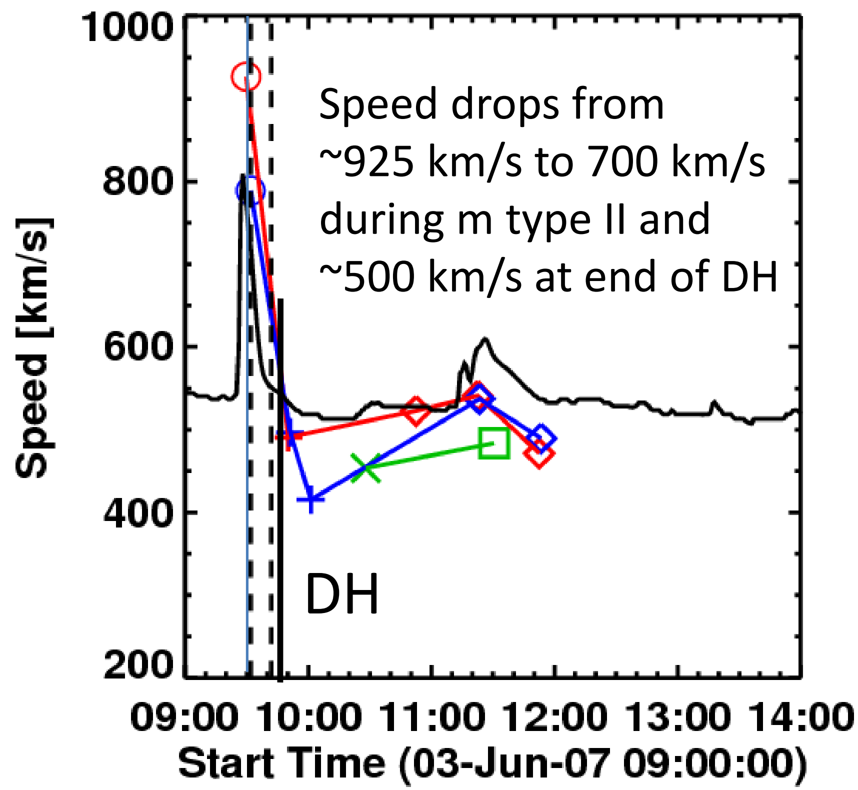
CME at a height of 1.87 Rs @09:33

Impulsive Events

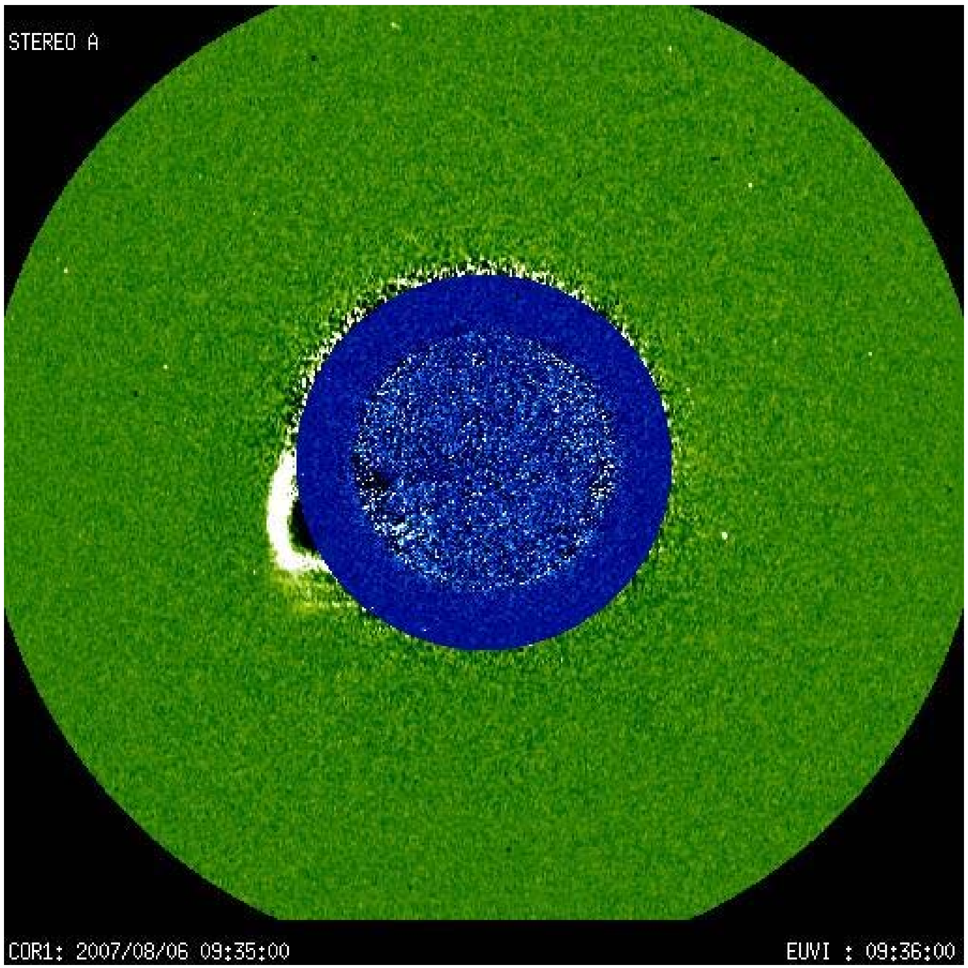
CME peak speed at 1.5 Ro!

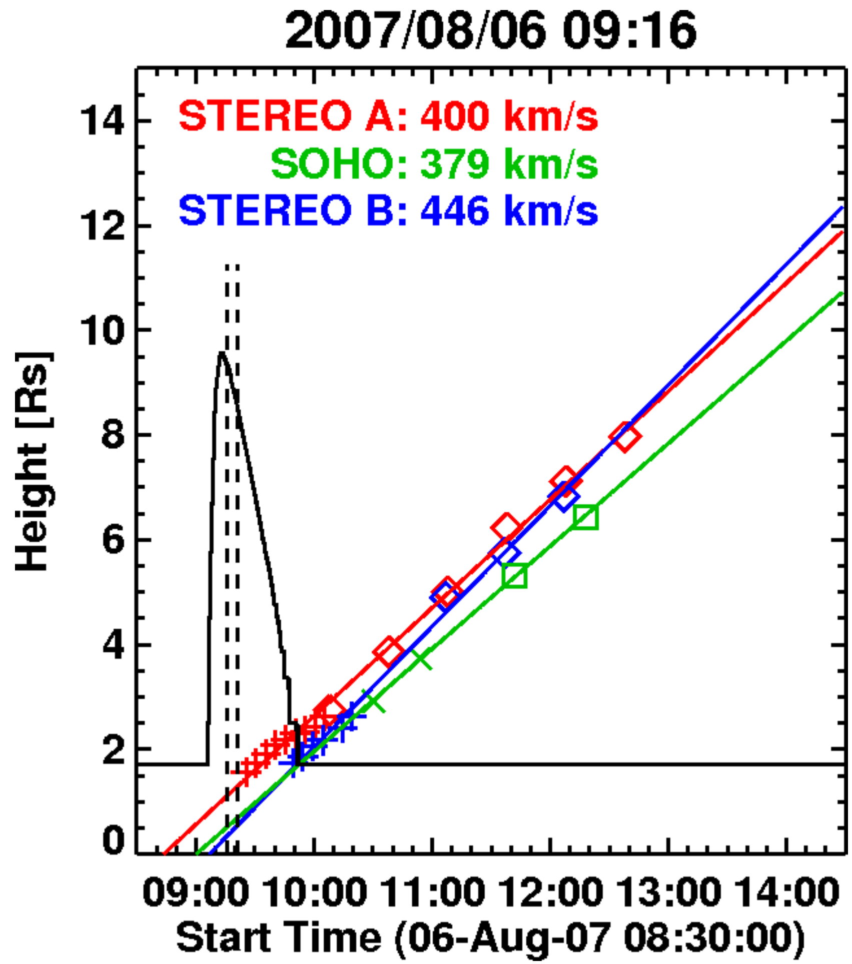


Type II start near flare peak, speed peak



Close connection between CME speed and SXR flare light curve even for an impulsive event

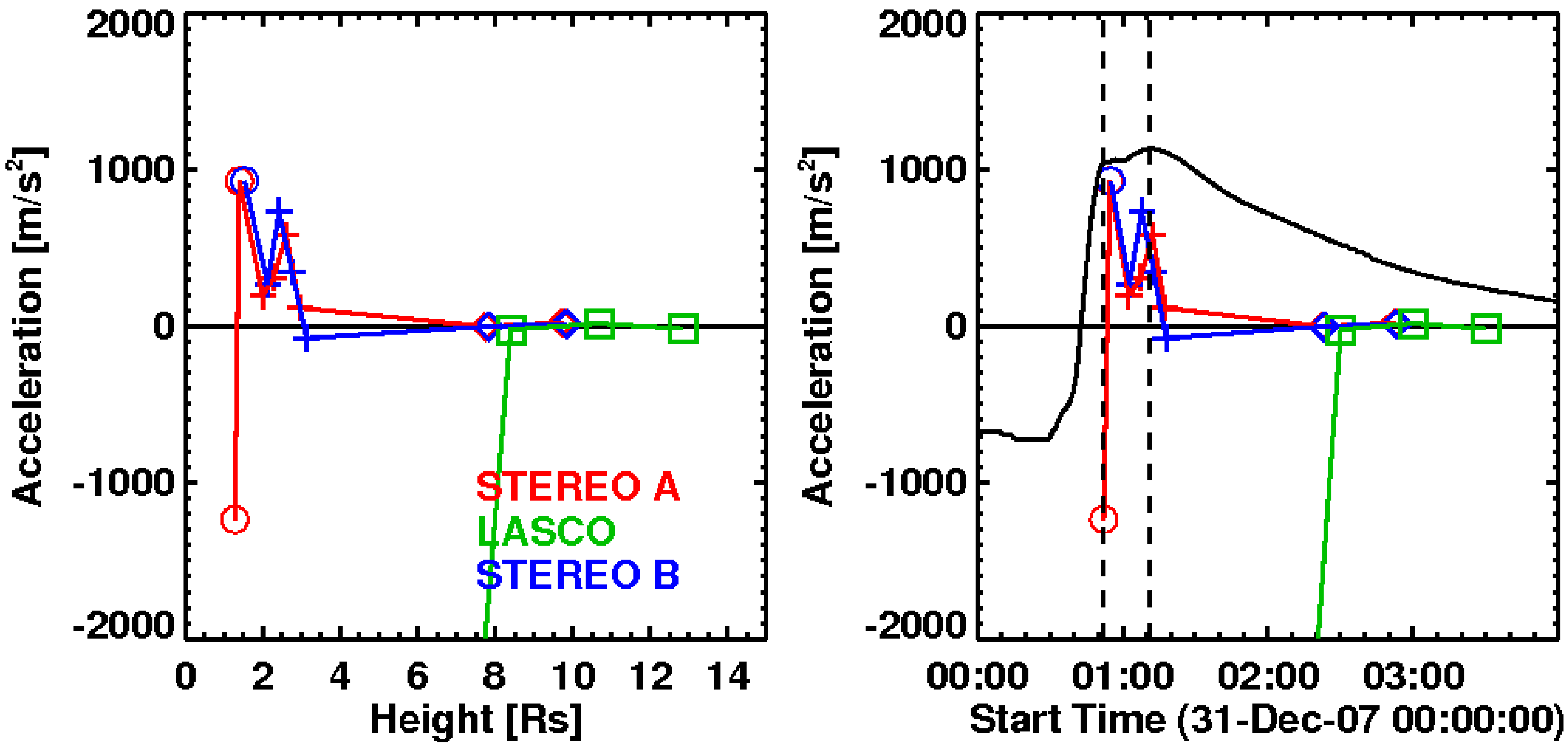

STEREO A
COR1: 2007/08/06 09:35:00
EUVI : 09:36:00


2007/08/06 09:16
STEREO A: 400 km/s
SOHO: 379 km/s
STEREO B: 446 km/s
Height [Rs]
0
2
4
6
8
10
12
14
09:00 10:00 11:00 12:00 13:00 14:00
Start Time (06-Aug-07 08:30:00)

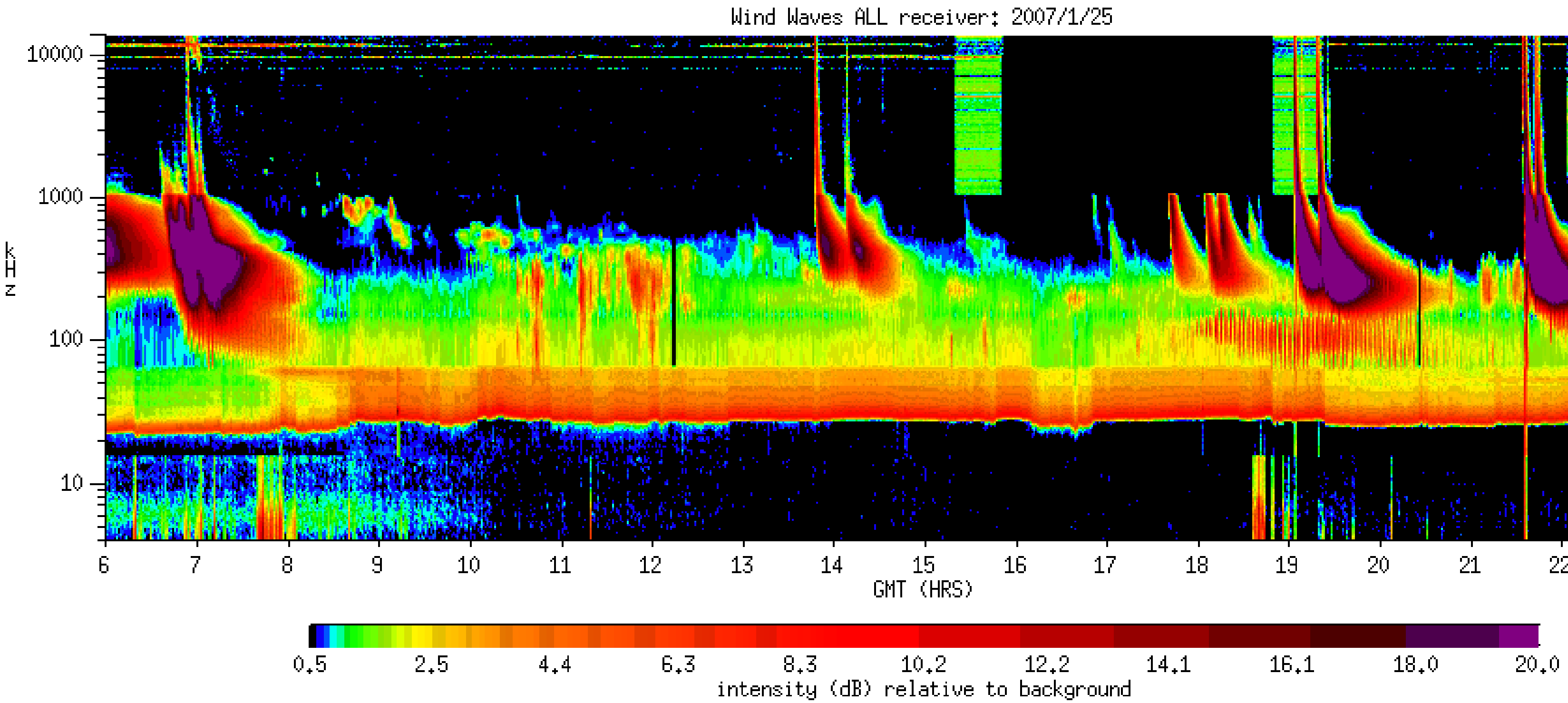
Summary

- Metric type II burst starts at a height where the VA is minimum (~1.4 Ro)
- The CME height at type II onset ~1.5 Ro compared to 2.2 Ro from LASCO
- Min to Max density variation (factor of 4)?
- LASCO does not capture initial speed variation?
- Type II ends when the shock becomes subcritical or dissipates
- Deviations from the universal drift rate spectrum are a direct consequence of the CME speed increase in the inner corona and decrease in the IP medium
- GOES light curve and CME speed follow each other even for impulsive flares

Double Peak in the 20071231 Event



http://cdaw.gsfc.nasa.gov/pub/yashiro/stereo/movie/20071231_cor1rdswaves.html


Wind Waves ALL receiver: 2007/1/25
10000
1000
100
10
kHz
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
GMT (HRS)
0.5
2.5
4.4
6.3
8.3
10.2
12.2
14.1
16.1
18.0
20.0
intensity (dB) relative to background