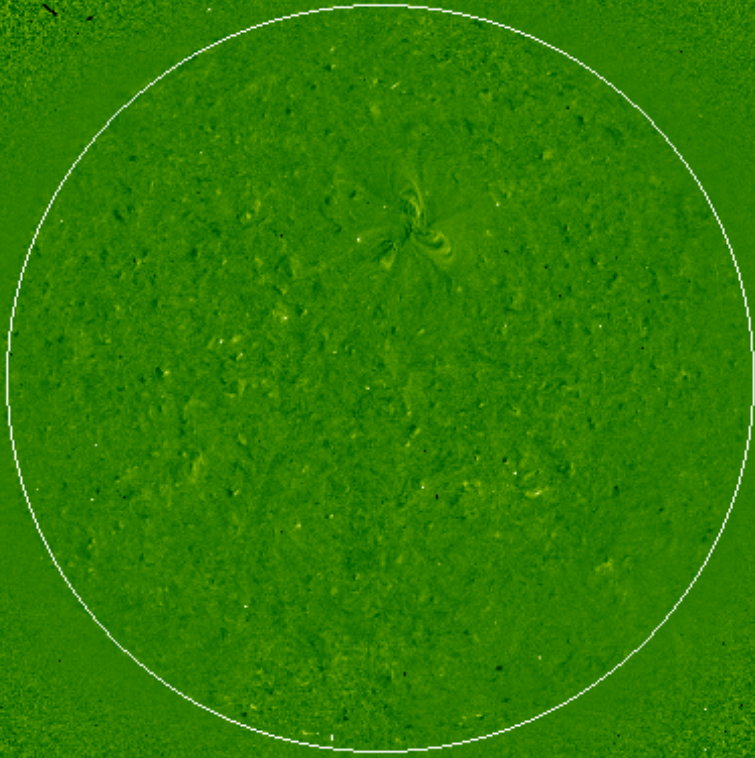


250 km/s



# EIT Waves



70 km/hr

P. F. Chen



NANJING UNIVERSITY, China

# Moreton wave

## *H $\alpha$* Observation

Moreton et al. (1961)

Moreton waves are associated with big flares

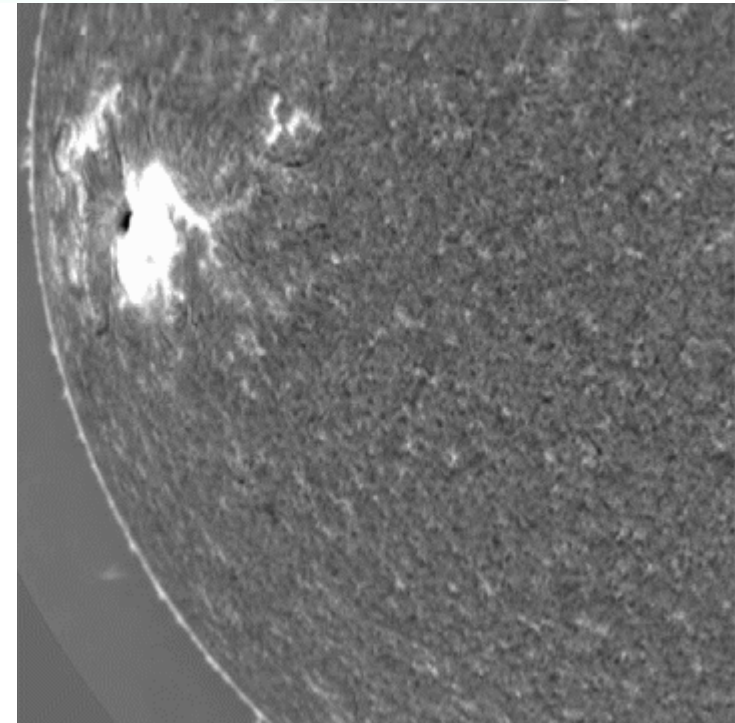
Propagation velocity:  $\sim 1000$  km/s

Propagation distance:  $5 \times 10^5$  km

## Theoretical Explanation

Uchida (1968; 1974):

Fast-mode wave in the corona



Credit: ISOON

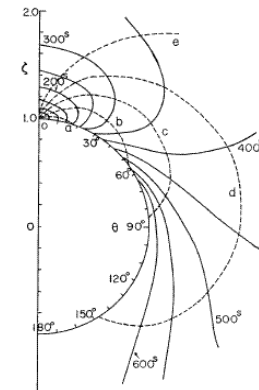
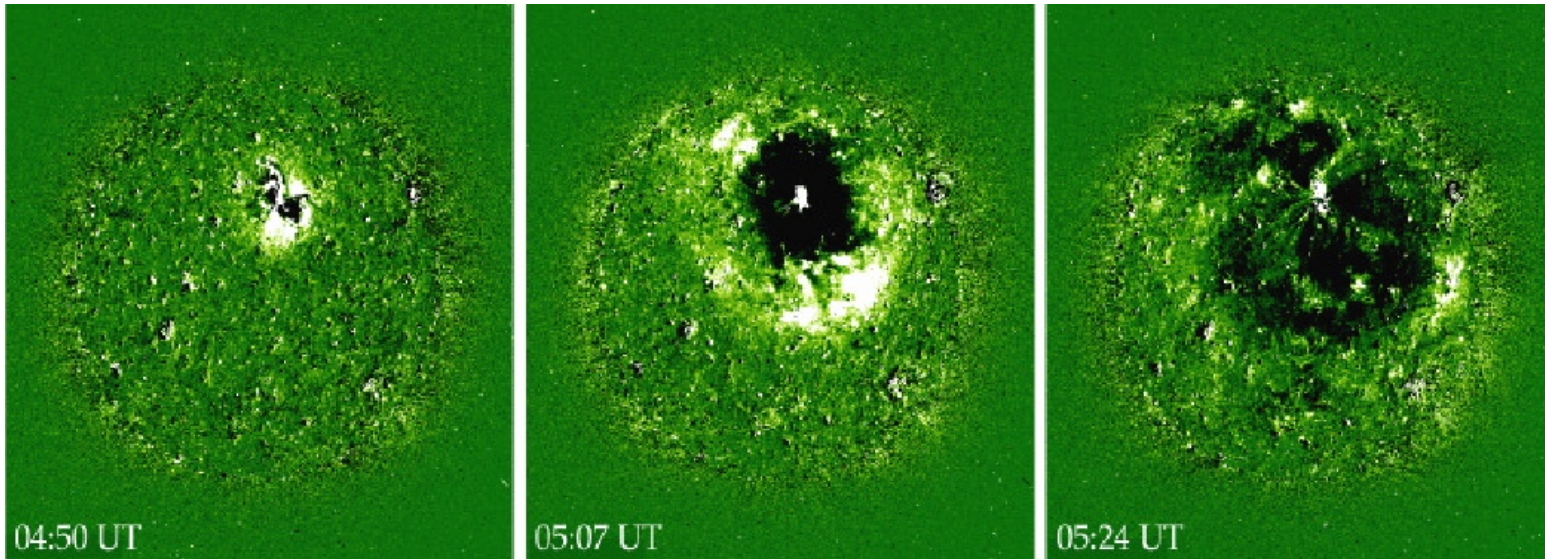


Fig. 4. Representative paths of wave-packets (dashed lines) and the shape of wavefront expanding in time (solid lines) from a source located at  $\zeta = 1$ , and  $\theta = 0$  in a model corona with  $\beta_0^2 = 2 \times 10^{-2}$ . The wavefronts are labeled with the time lapsed after the explosion, and the  $\Omega^2$ -values for the paths  $a, b, c, d$ , and  $e$  are  $6.3 \times 10^4$ ,  $2.0 \times 10^5$ ,  $6.6 \times 10^5$ ,  $2.1 \times 10^6$ , and  $6.9 \times 10^6$ , respectively.

# Discovery of EIT Wave + Dimming

SOHO/EIT 195 Å



## EIT Wave

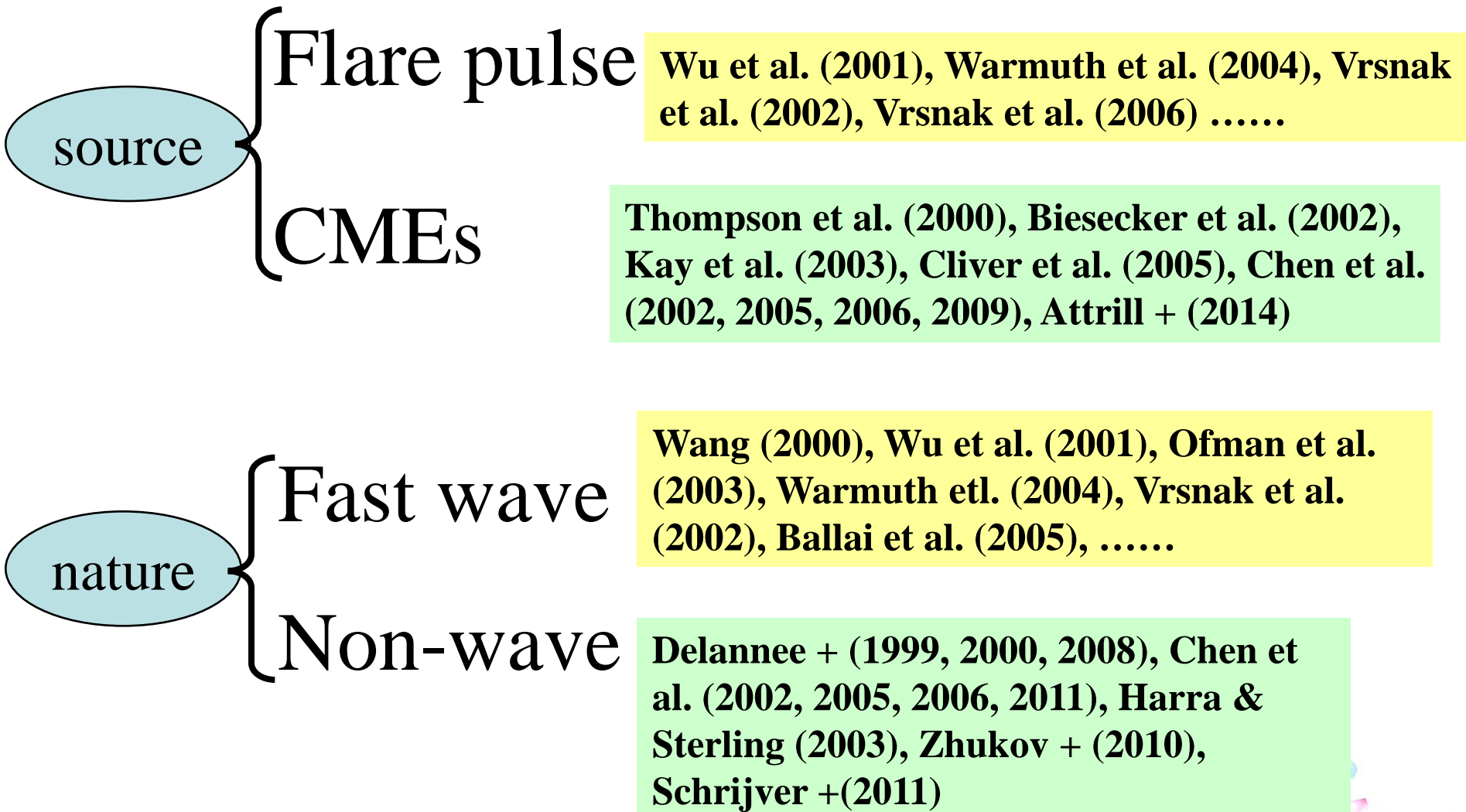
Thompson et al. (1998)

Large-scale coronal wave [Veronig+\(2010\)](#)

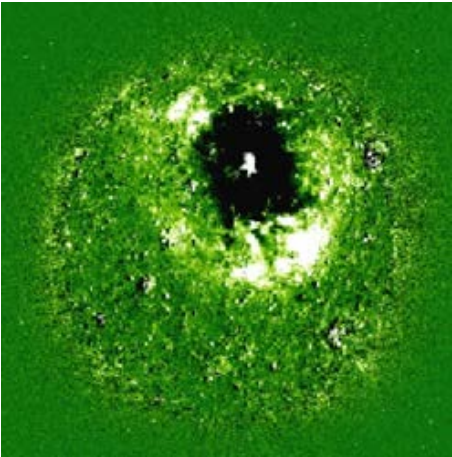
Coronal Bright Fronts (CBF) [Gallagher+\(2010\)](#)

Coronal Propagating Fronts (CPF) [Schrijver+\(2011\)](#)

# Debates

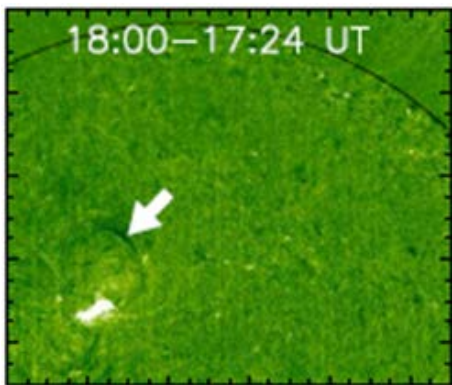


# What is the Driving Source?



**Half** EIT wave events are associated with **B-class flares**

Cliver et al. (2005)



**Without** CME, even an **X-class** flare is **not** associated with EIT wave

Chen (2006)

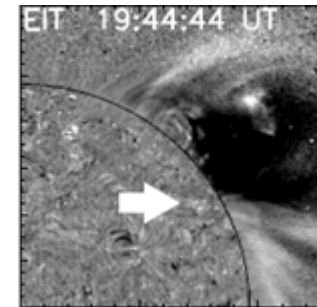
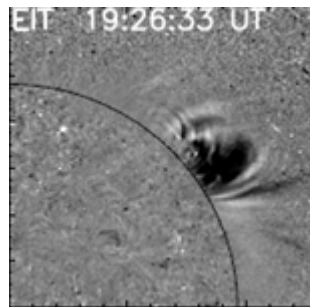


# CME-EIT wave relation

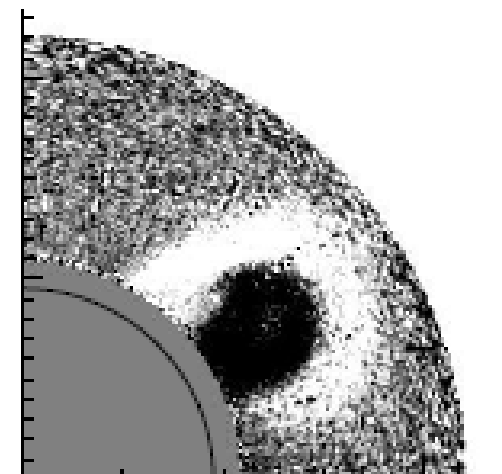
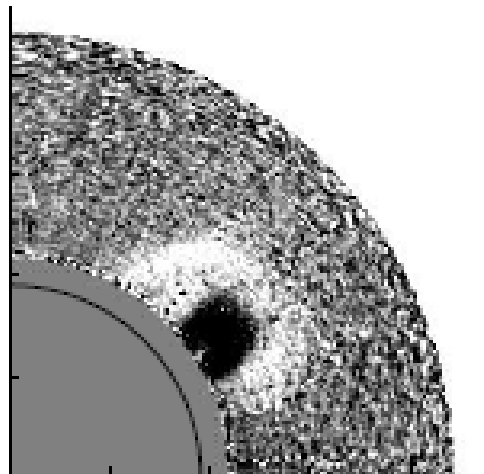
P. F. Chen (2009, ApJ, 698, L112)

Dai et al. (2010, ApJ, 708, 913)

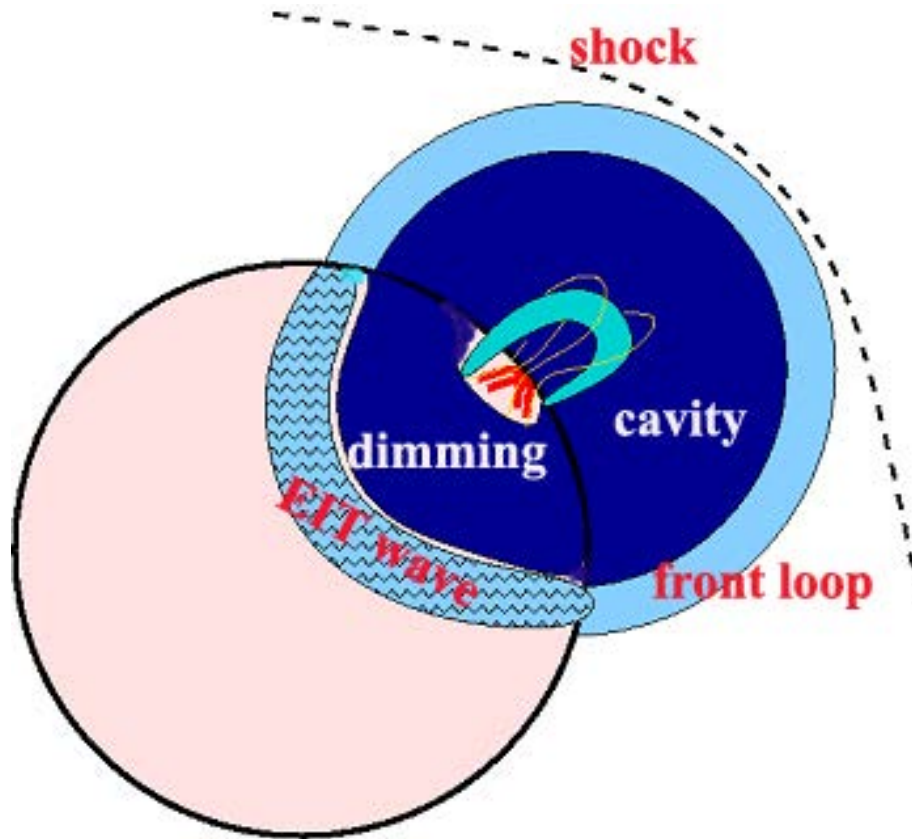
EIT images



Mauna Loa  
Coronagraph



# CME-EIT wave relation



**Chen & Fang (2005, IAUS, 226, 55)**

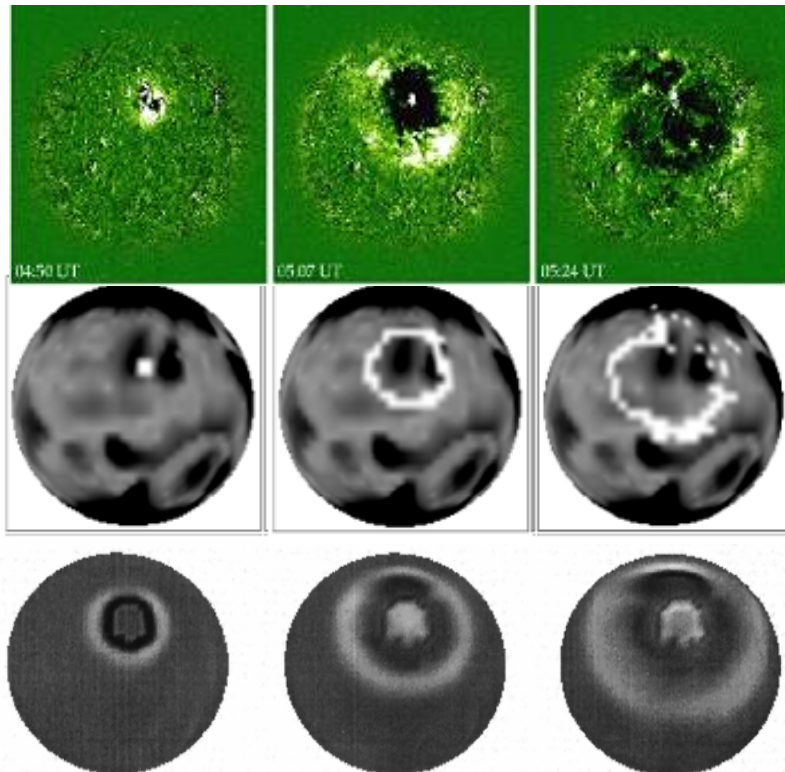


# What Is the Nature?



Fast-mode wave

coronal Moreton wave



**Thompson et al. (1998)**

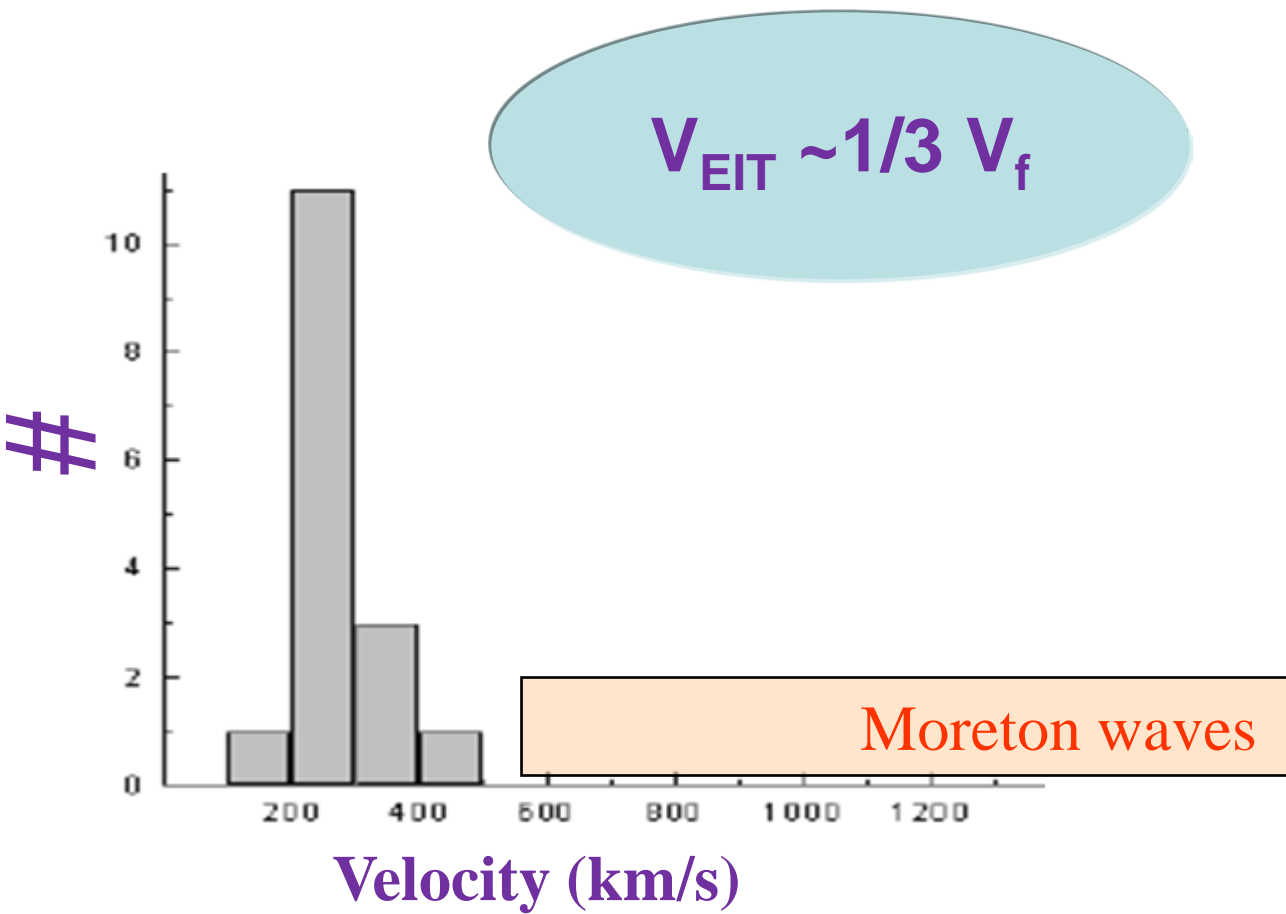
**Y.-M. Wang (2000)**

**Wu et al. (2001) Zheng et al. (2002)**

**Ofman (2003) Warmuth & Mann (2005),  
Grechnev et al. 2008; Pomoell et al. (2008),  
Veronig et al., (2008), Gopalswamy et al.  
(2009), Long et al. (2009), Patsourakos et al.,  
2009; Kienreich et al. (2009), Temmer et al.  
(2011), Zheng et al. (2014)**



# Drawback 1 of Fast-mode Wave Model



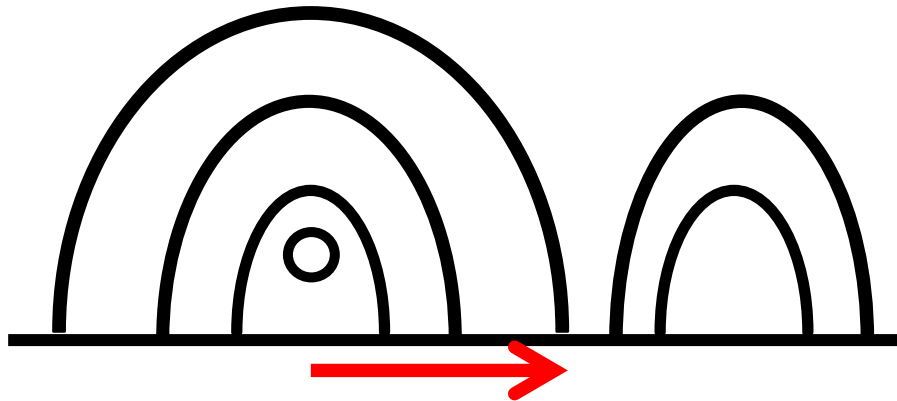
**Klassen et al. (2000)**  
**Muhr + (2014)**

**Moreton + (1961)**  
**Eto et al. (2002)**  
**Zhang + (2011)**  
**Gunawan + (2014)**



# Drawback 2 of Fast-mode Wave Model

EIT wave stops at  
magnetic separatrix

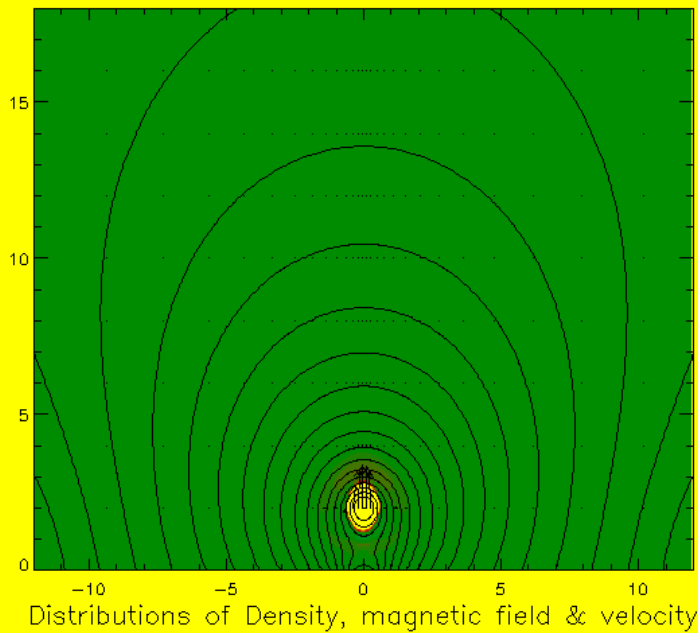
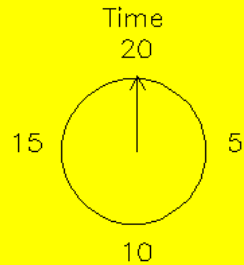


Delannée & Aulanier (1999)

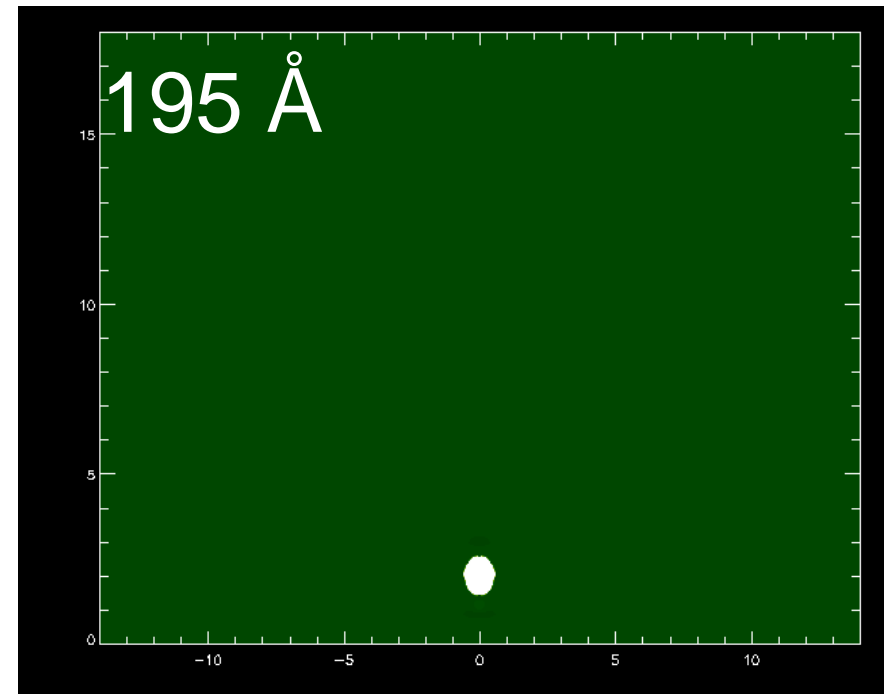


# Our Field-line Stretching Model

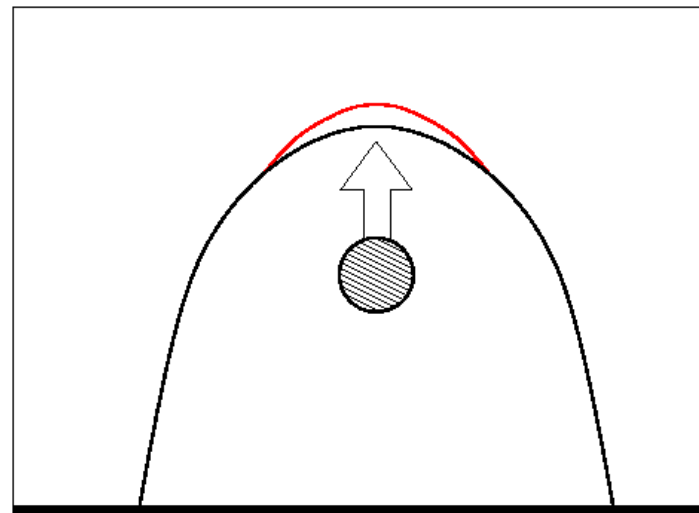
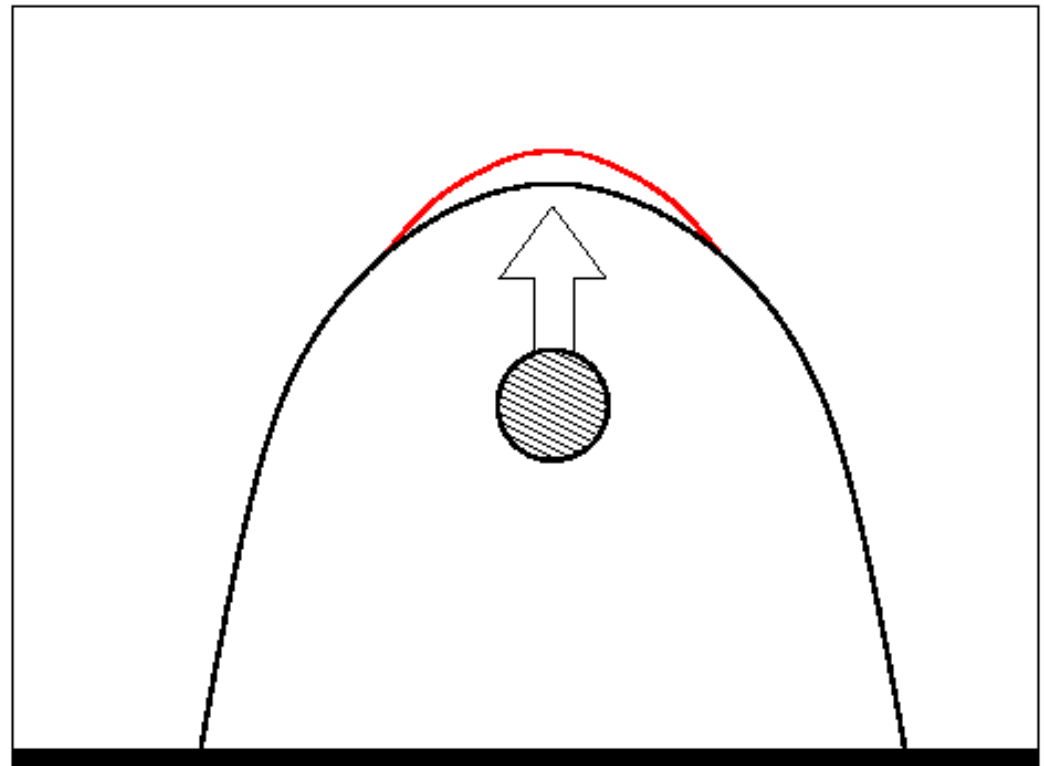
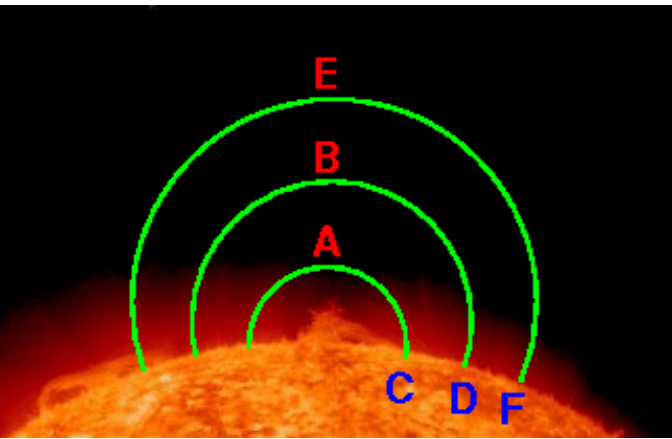
Chen, Wu, Shibata, & Fang (2002); Chen, Fang, & Shibata (2005)



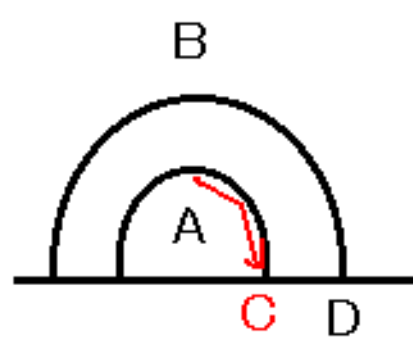
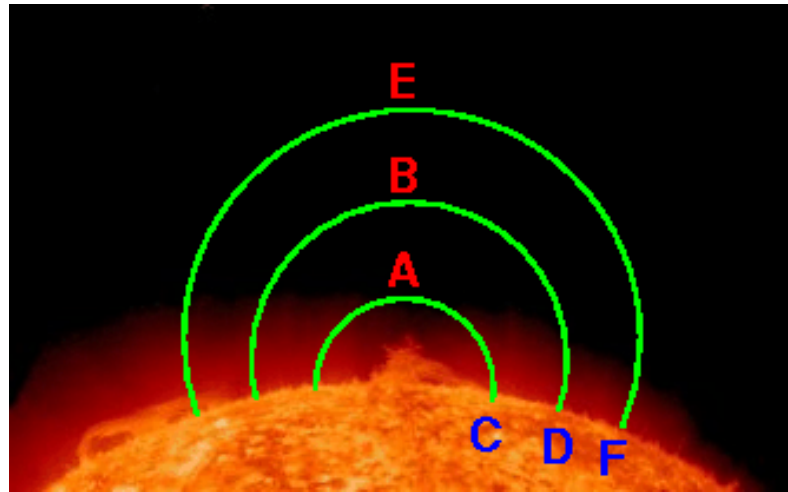
Coronal Moreton wave 775 km/s  
EIT wave 250 km/s



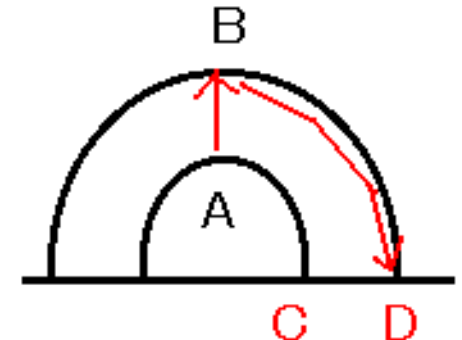
# Our Field-line Stretching Model



# Our Field-line Stretching Model



t1

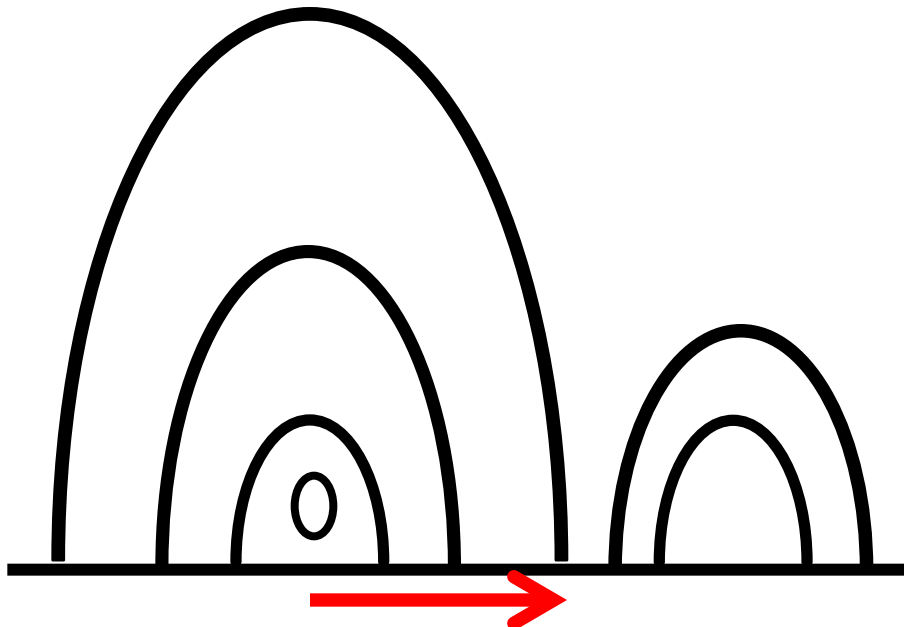


t2

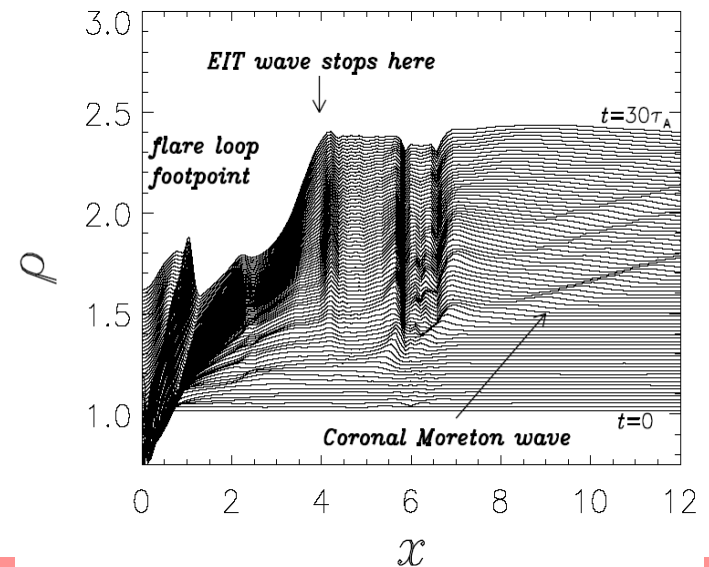
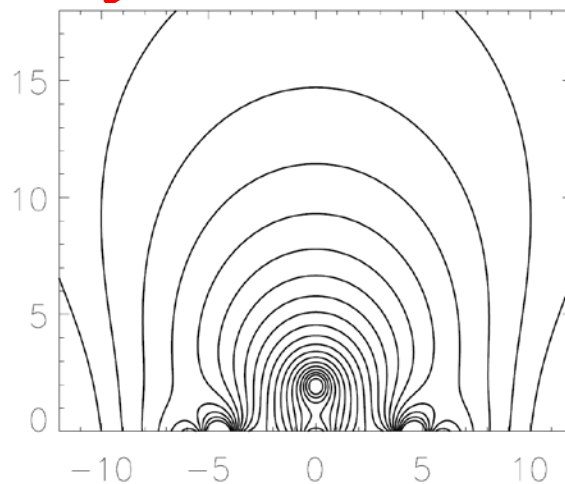
$$\Delta t = \left( \frac{AB}{v_f} + \frac{BD}{v_A} \right) - \frac{AC}{v_A}$$

$$V_{EIT} = \frac{CD}{\Delta t} = \left( \frac{1}{v_f} + \frac{\pi}{2v_A} \right)^{-1} \approx 0.34v_f$$

# Why EIT Wave Stops near Magnetic Separatrix



Chen, Fang, & Shibata (2005)

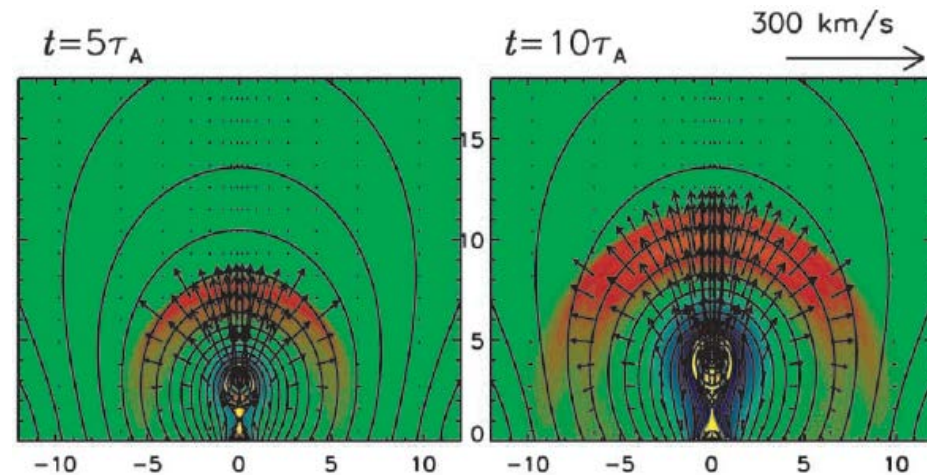


# A Full View of EIT Waves

**Chen et al. (2002, 2005)**

1. Coronal Moreton waves  
due to piston-driven shock
2. “EIT waves”

Diffuse, due to successive stretching of closed field lines.



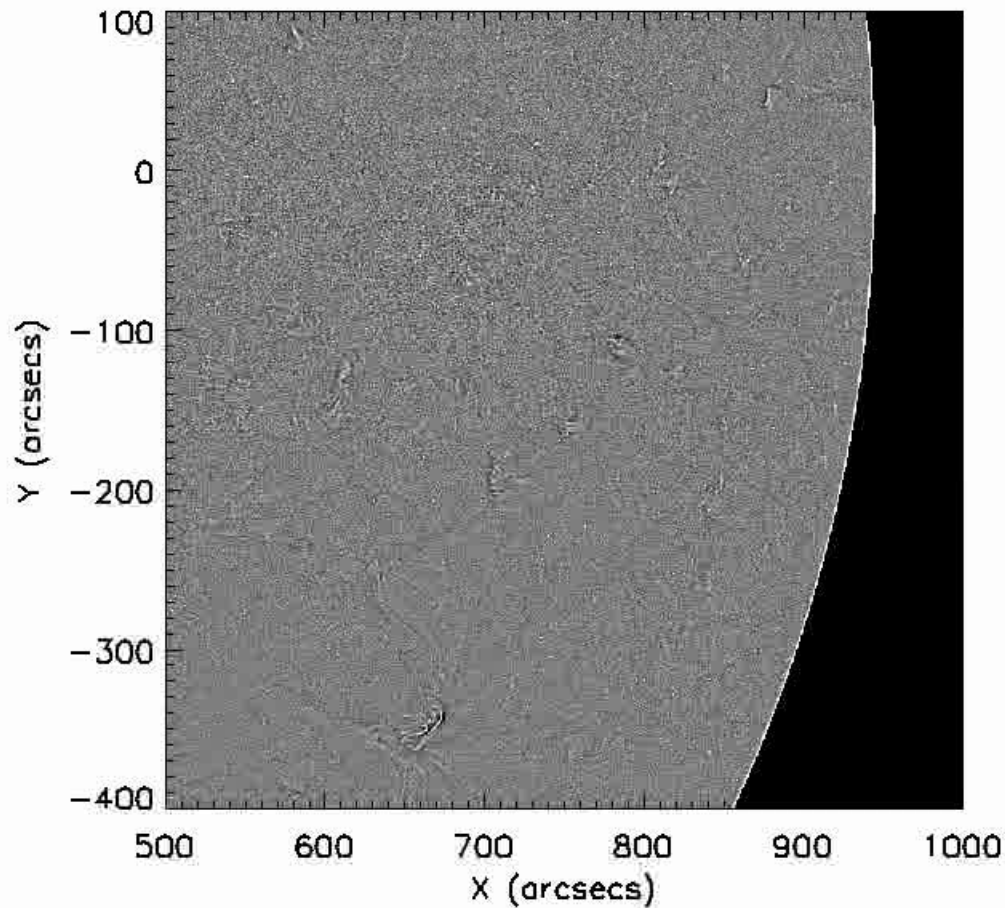
**EIT telescope missed the faster one  
because of low time cadence, 15 min**

**Later , STEREO/EUVI (2.5 min)  
could not detect two waves either.**

# SDO/AIA Era

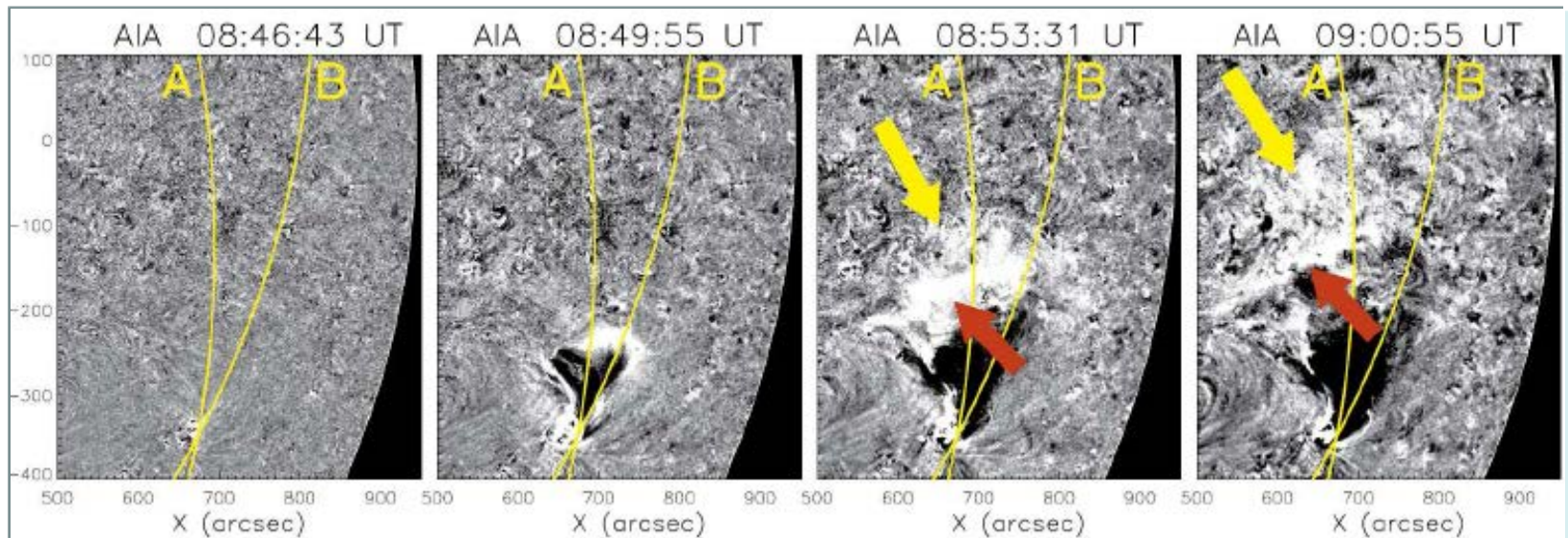
Chen, P. F. & Wu, Y. (2011, ApJ, 732, L20)

27-Jul-2010 08:45:07



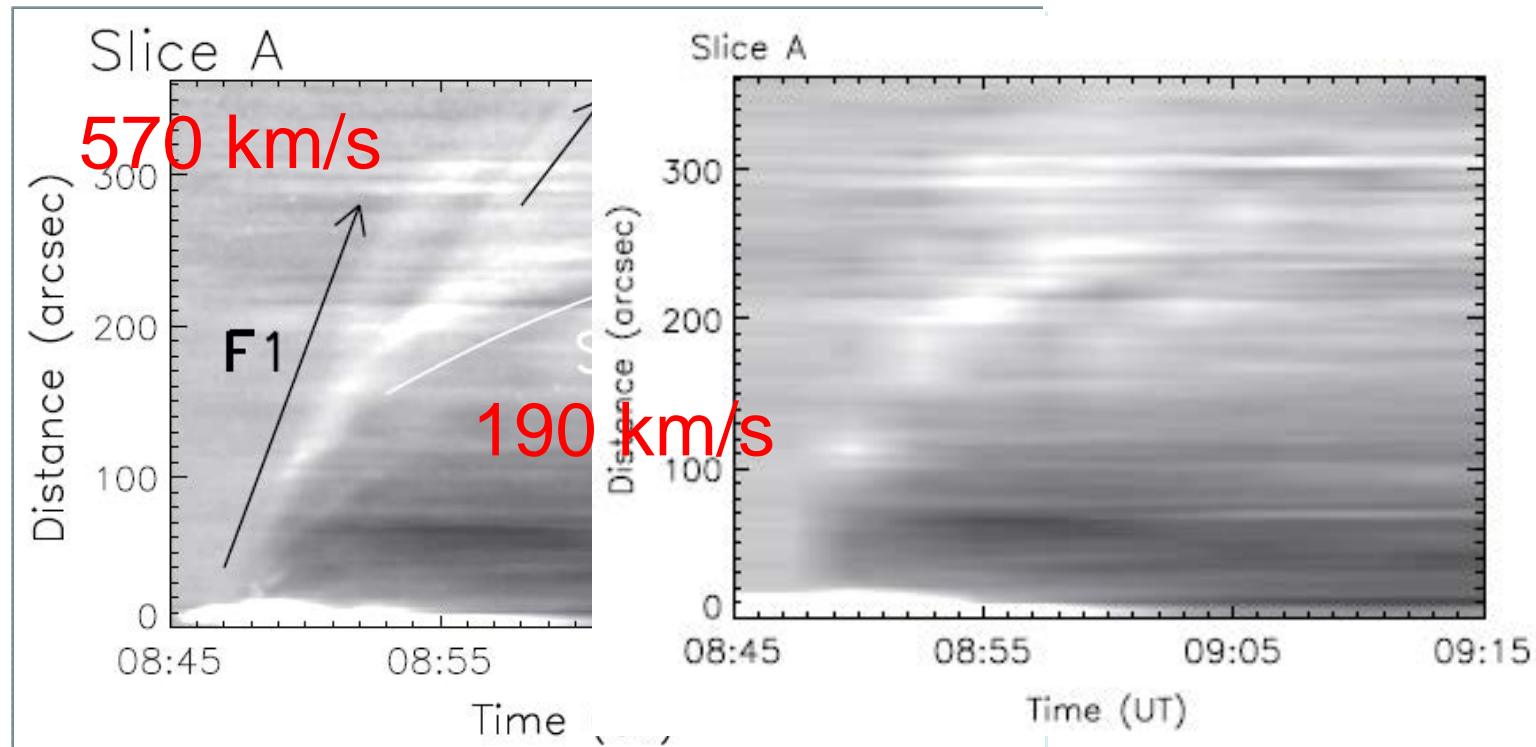
# SDO/AIA Era

**Chen, P. F. & Wu, Y. (2011, ApJ, 732, L20)**



# SDO/AIA Era

Chen, P. F. & Wu, Y. (2011, ApJ, 732, L20)

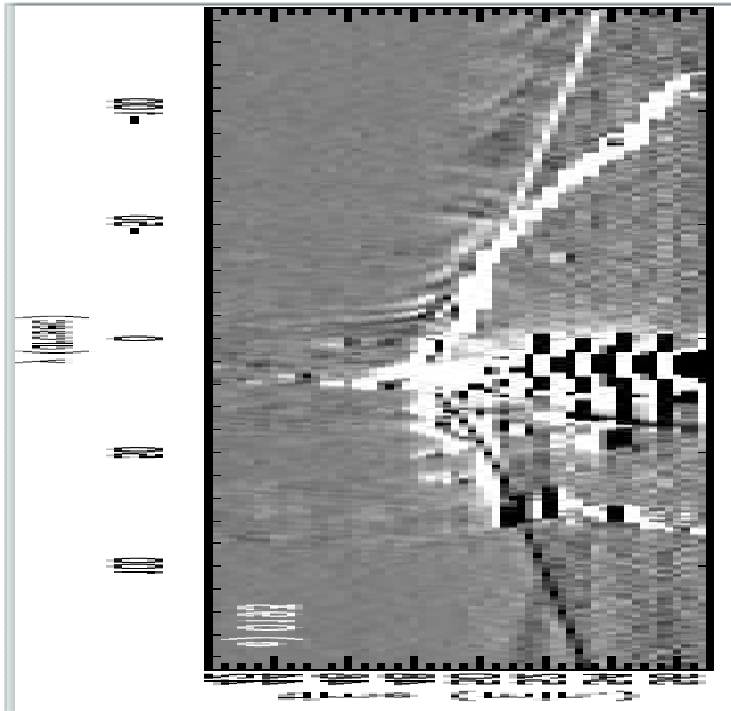


# SDO/AIA Era

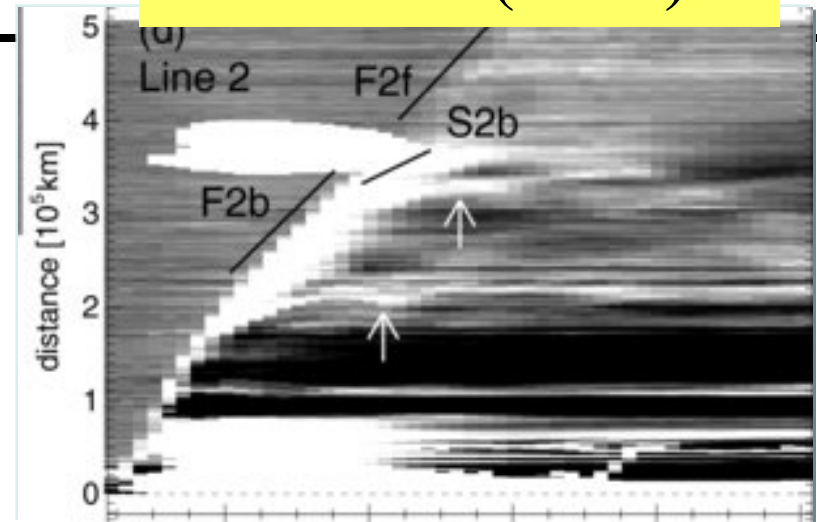
Schrijver et al. (2011)

Cheng et al. (2012)

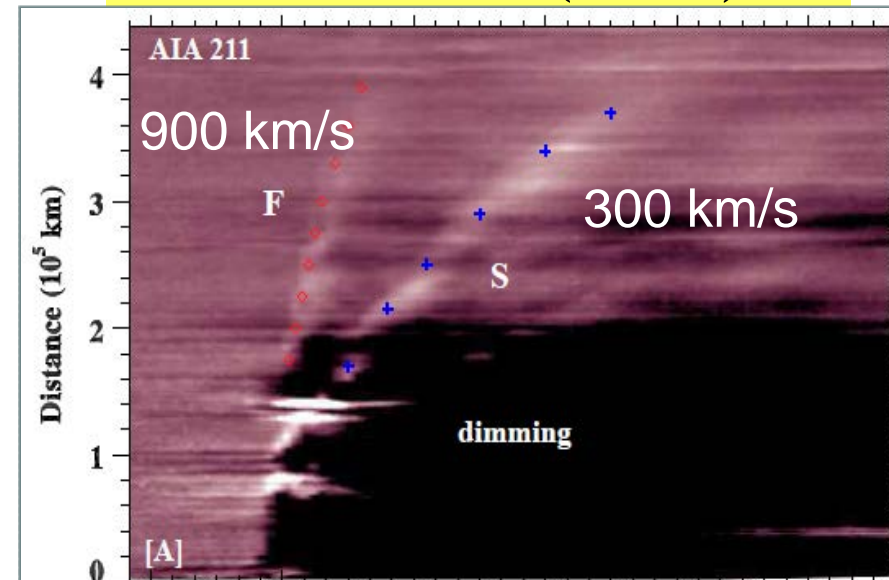
Shen et al. (2012, 2013)



Asai et al. (2012)

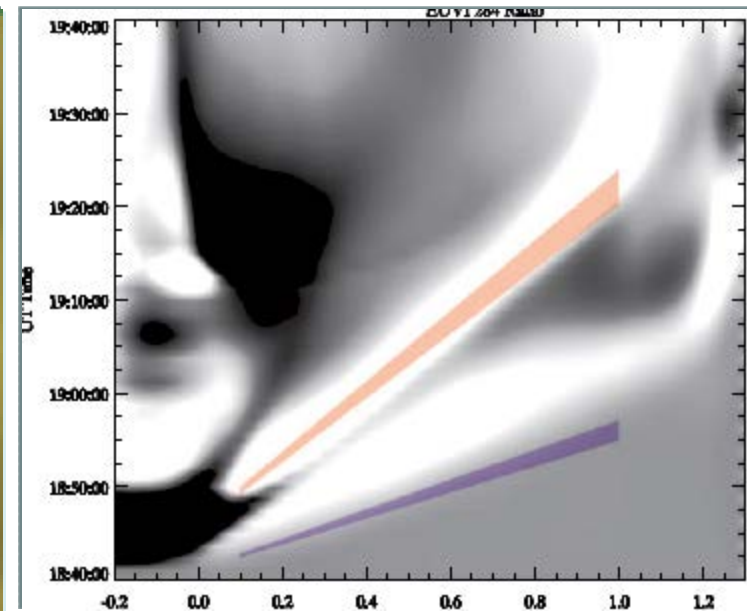
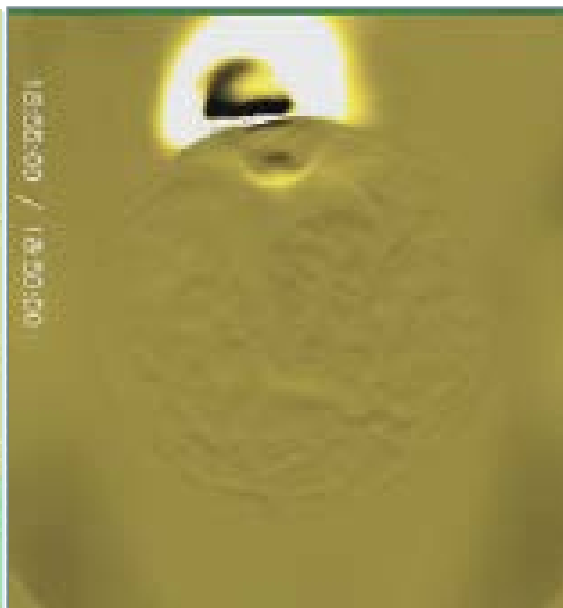
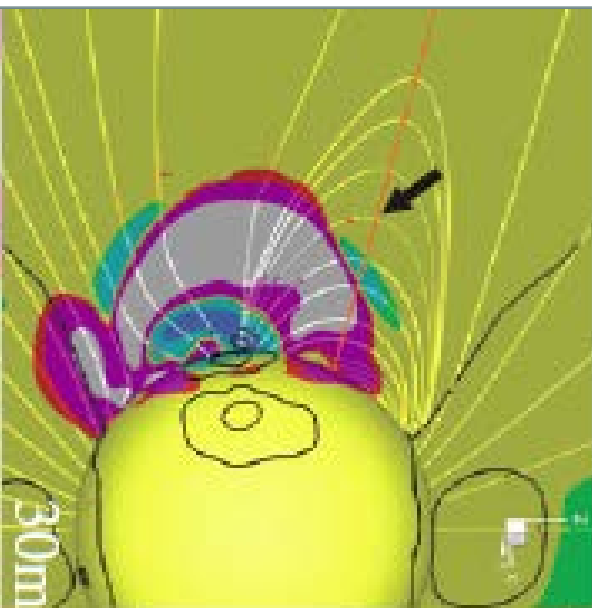


Kumar et al. (2013)

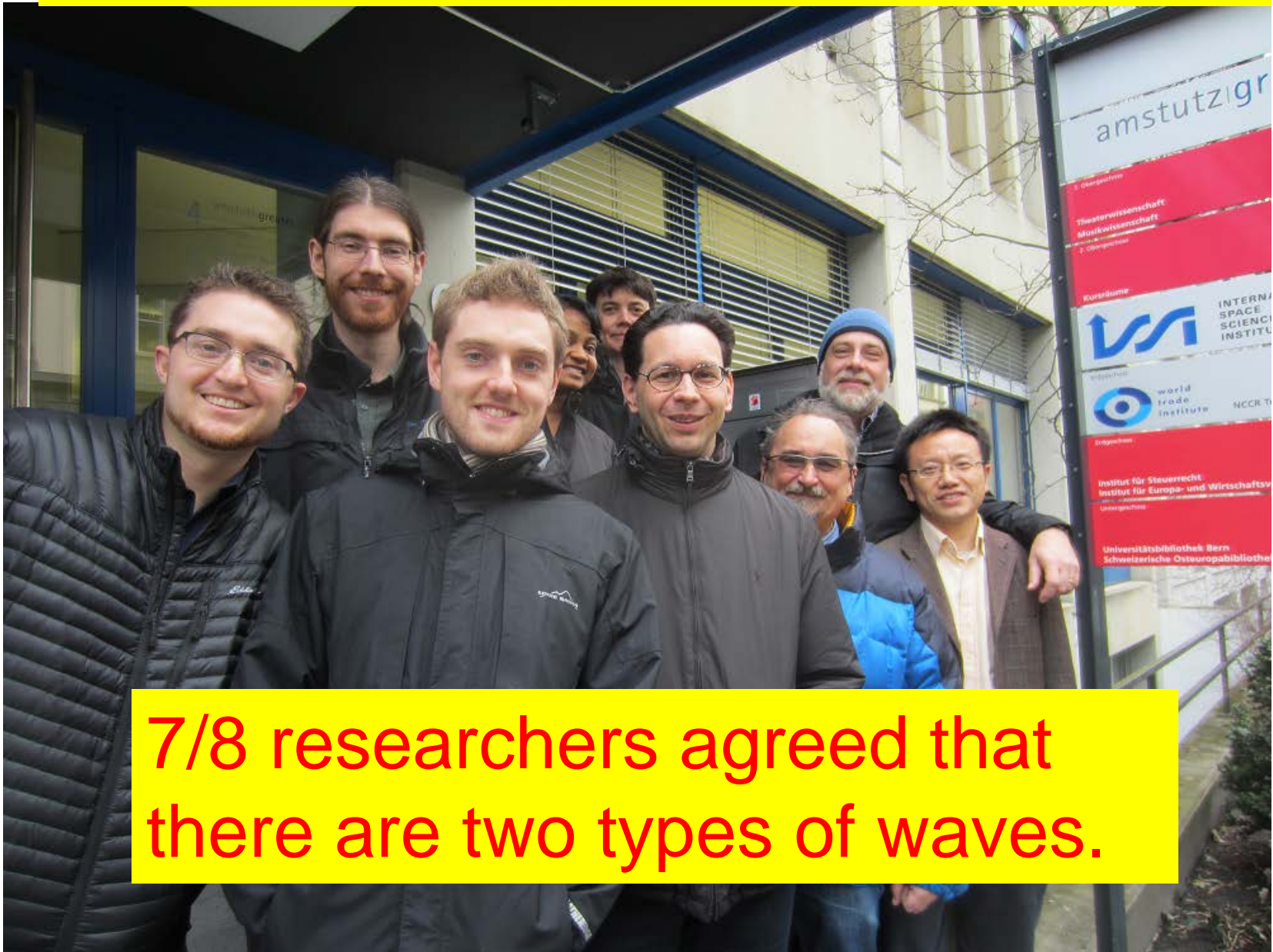


# 3D MHD Simulations

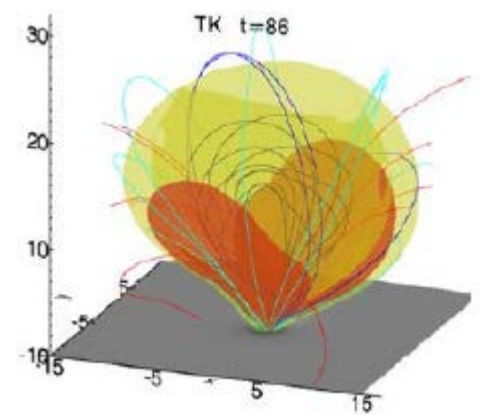
Downs, Roussev et al. (2011, 2012)



# The 1<sup>st</sup> ISSI meeting on EIT wave in Jan 2014



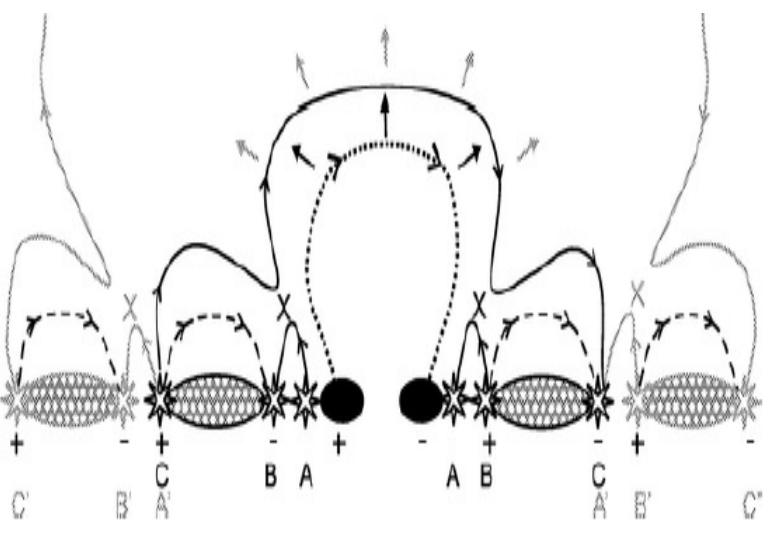
# Other Anti-Fast-mode-wave Models



**Delannée et al. (2008)**

Current shell between the twisted core field and the potential envelop field.

**Wills-Davey + (2007), Wang + (2009)** Slow-mode wave



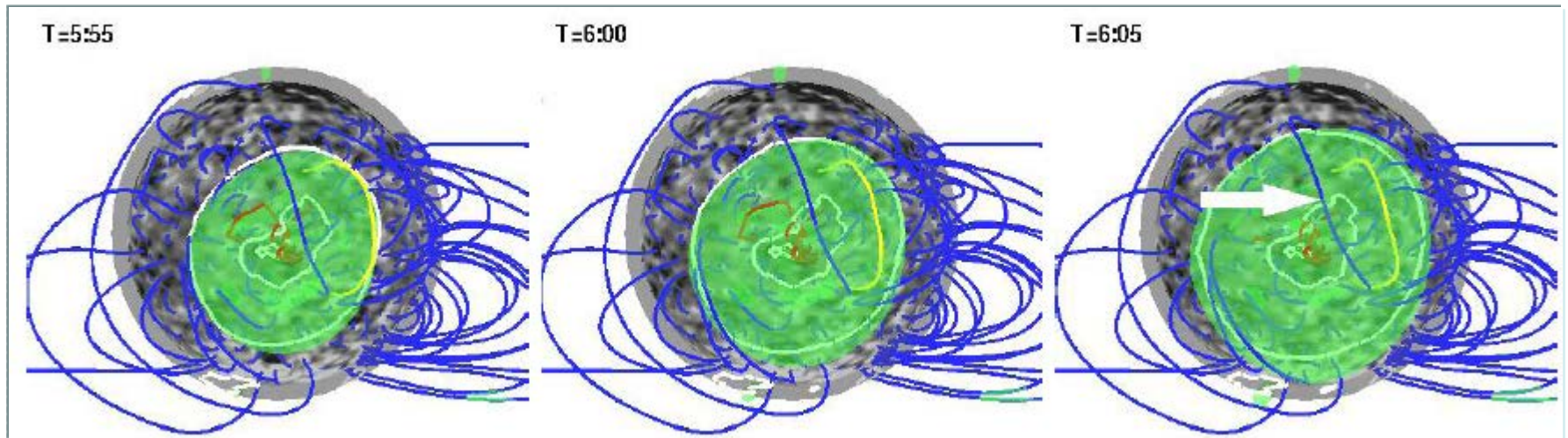
**Attrill et al. (2007)**

Successive reconnection



# 3D MHD simulations

Cohen et al. (2009)



# Is there Consensus now?

**No!**

## Reason 1: Too many names

EUV wave **Foley +(2003), .....**

Large-scale coronal wave **Veronig+(2010)**

Coronal Bright Fronts (CBP) **Gallagher+(2010)**

Coronal Propagating Fronts (CPF) **Schrijver+(2011)**

Large-scale Coronal Propagating Fronts (LCPF) **Nitta+(2013, 2014)**

.....

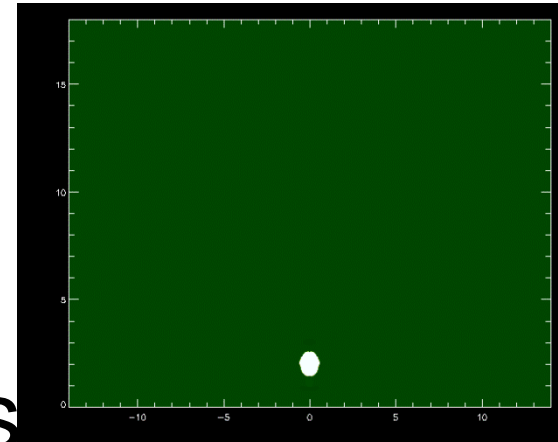


# Is there Consensus now?

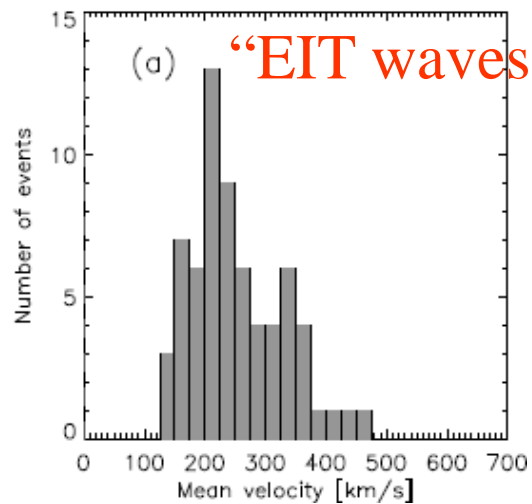
**No!**

**Reason 1:** Too many names

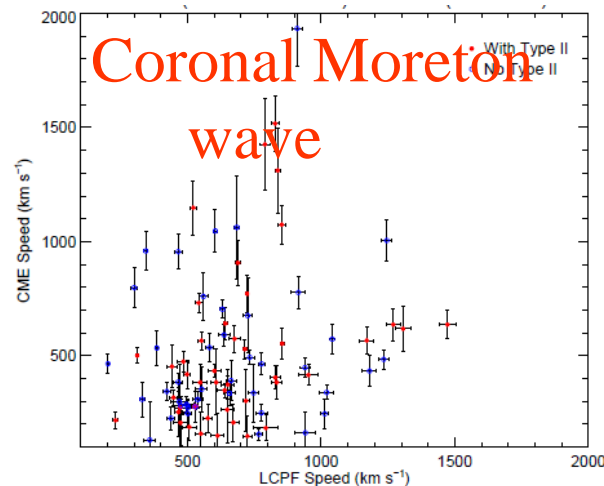
**Reason 2:** Confusing two waves



**Muhr + (2014)**



**Nitta + (2014)**

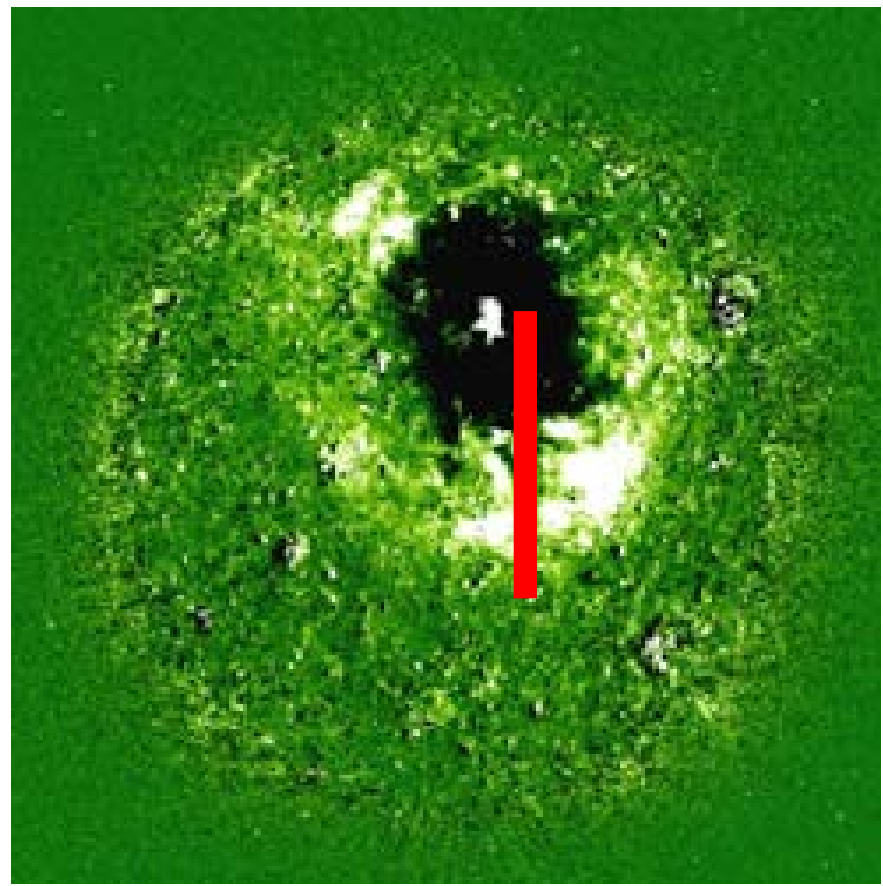


1. Coronal Moreton waves
2. “EIT waves”



# What can be done further?

## 1. SDO+IRIS



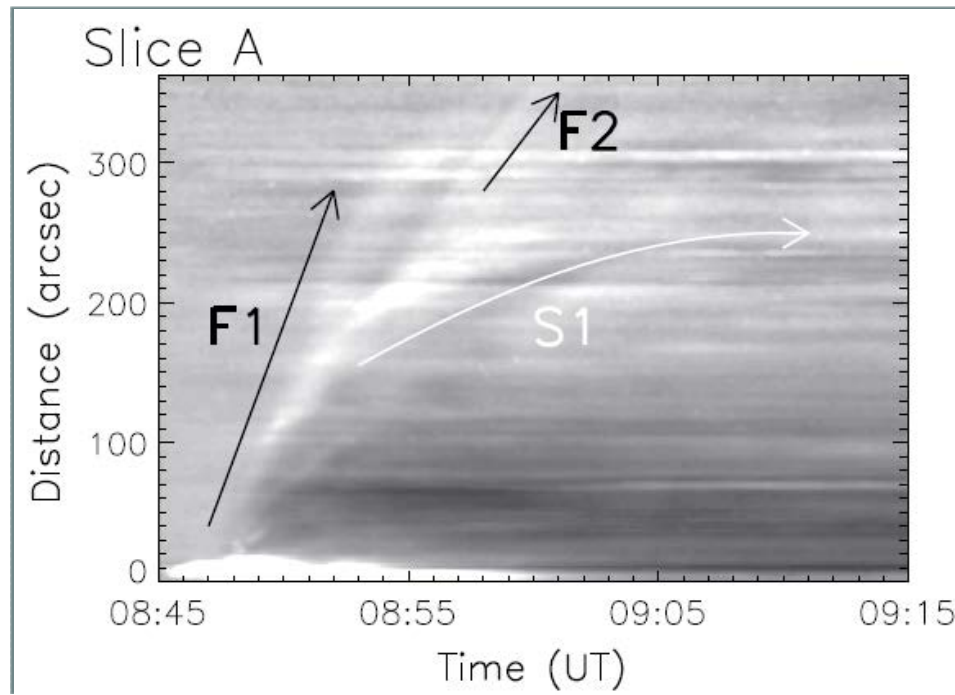
**Jin + (2009)**

**Harra + (2011)**



# What can be done further?

## 2. Coronal Seismology

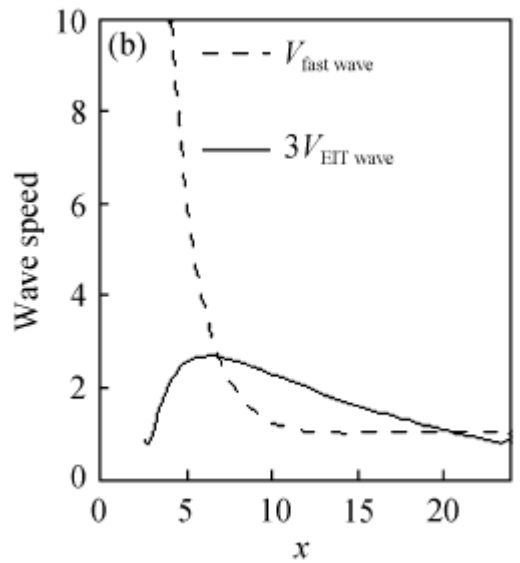
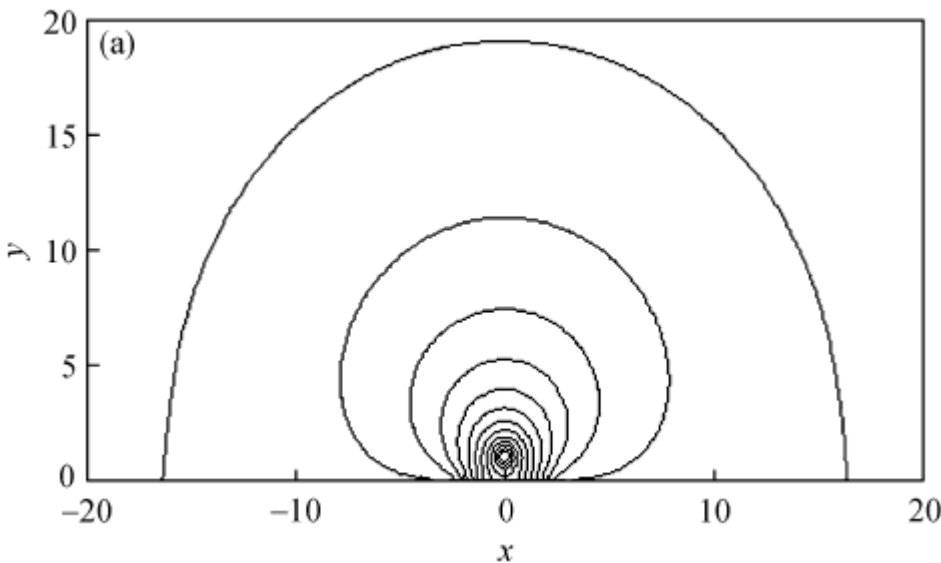
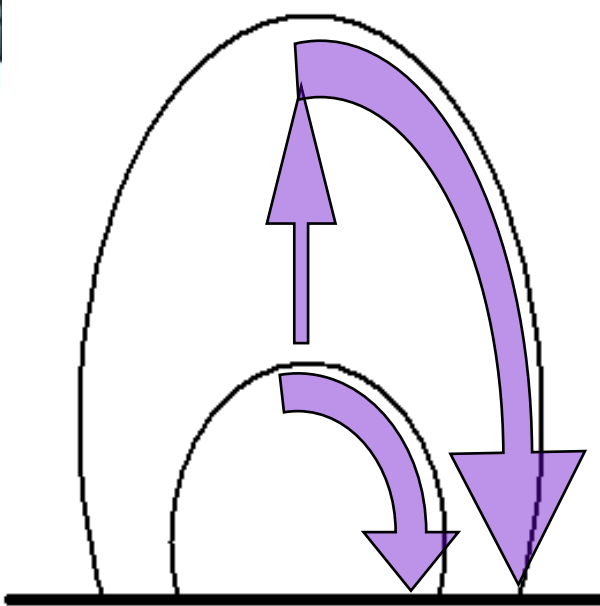


Long et al. (2013, SP) **B=8 G**



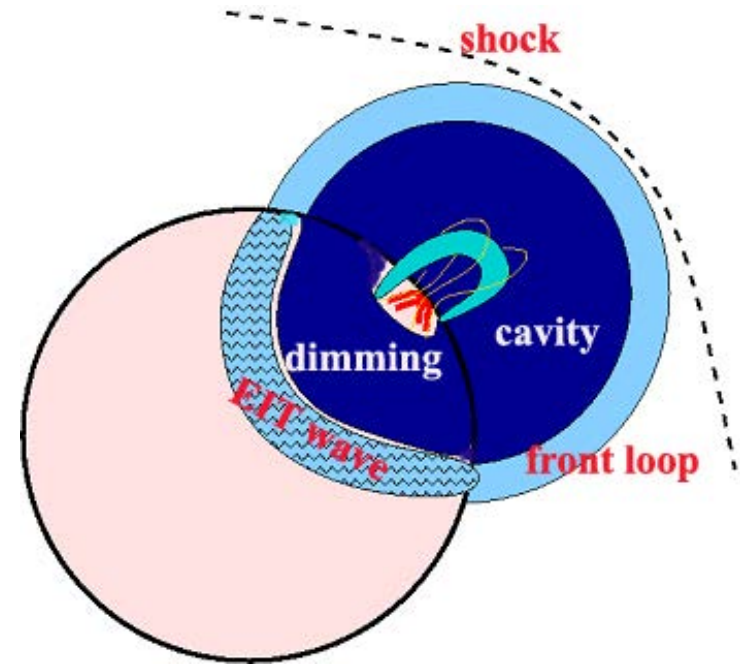
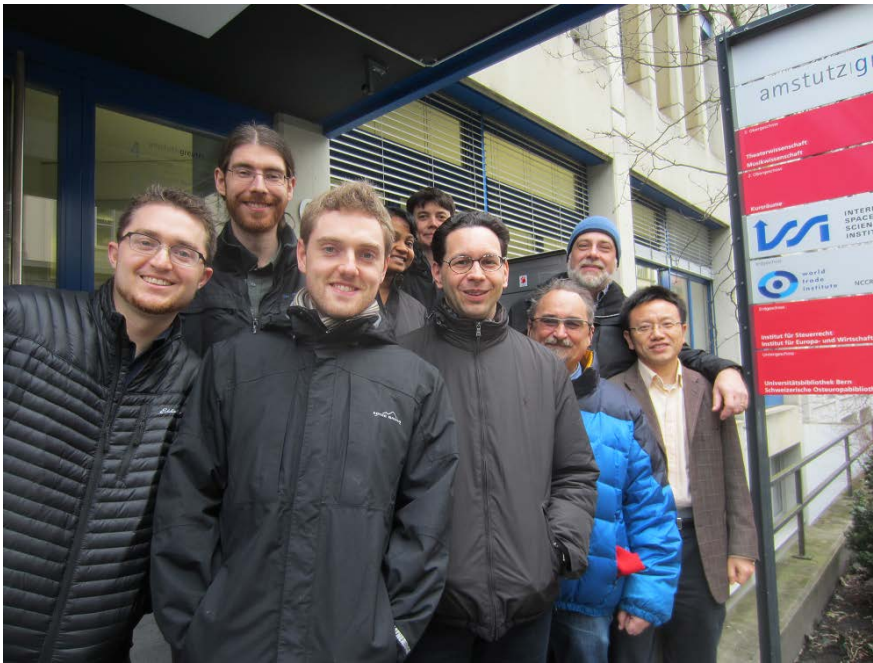


**Chen (2009, Science China (G), 52, 1785)**



# What can be done further?

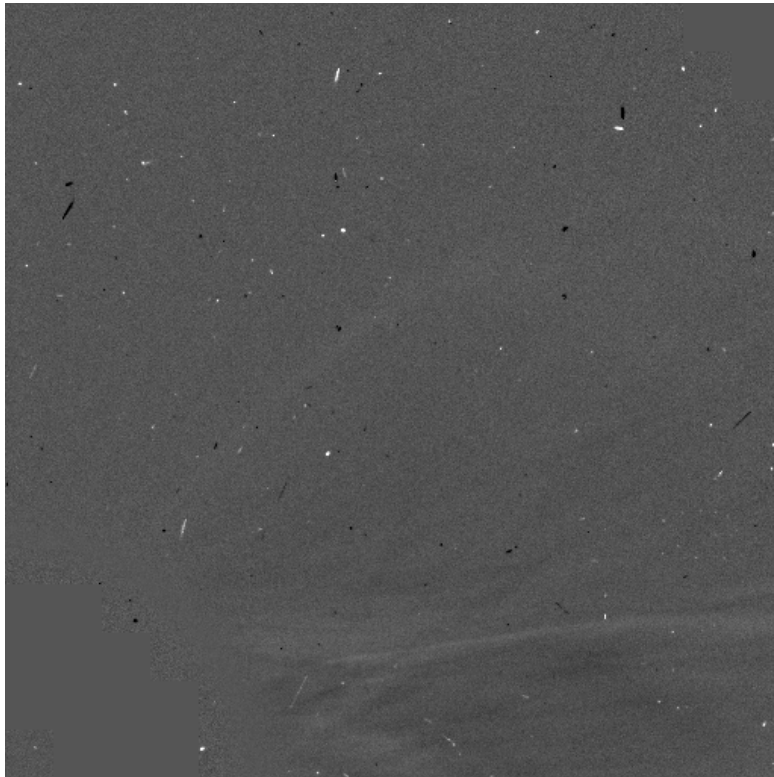
## 3. Nature of the second wave



The second wave → CME loop



Chen, P. F. (2009, ApJ; 2011, LRSP)



For those fast CMEs  
(for example,  
 $V=2000$  km/s), the  
real mass motion  
velocity may be just  
 $700$  km/s.

