Using EIT Waves For Coronal Seismology

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Overview

- EIT Waves
    - Observations.

- STEREO observations of EIT wave from 13th Feb 2009.

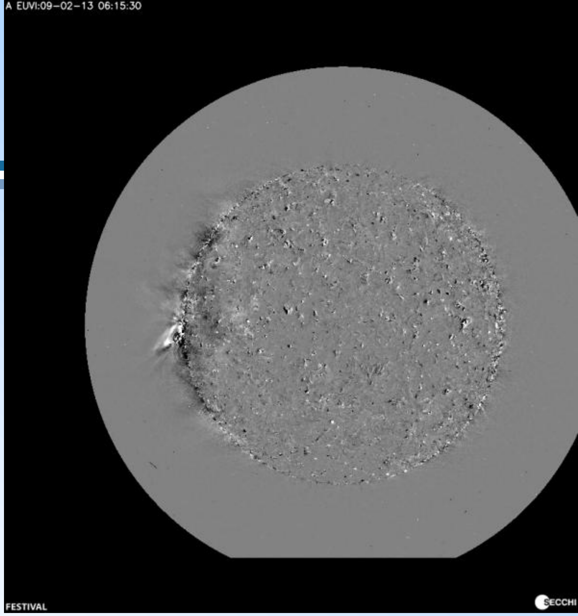
- How can we measure coronal B using EIT waves?

- Measuring temperatures, densities and wave velocities using STEREO and Hinode.

- Estimating B.

- Conclusions and discussion.

EIT waves



•Coronal "EIT wave" transients, are moving fronts of increased emission observed in the EUV.

•First observed in mid 90's (Moses et al. 97, Dere et al. 97, Thompson et al. 98).

•Velocities of the order 100-500 km s^{-1}

•Originate from ARs (Often flaring, but with no significant correspondence to flare size).

•Associated with CMEs, coronal transient dimmings, type II radio bursts and a chromospheric counterpart.

•The physical nature of the EIT wave is highly contentious. Ideas include:

1. Fast mode waves (Thompson et al. 1999).
2. successive opening of magnetic field lines (Chen et al. 2002).
3. Current sheet heating between the erupting flux rope and surrounding field (Delannee et al 2008).
4. Etc.. (See Patsourakos et al. 2009 for a thorough review).

Observations

•On 13th Feb 2009 the STEREO satellites observed an EIT wave event from two view points separated by ~90º.

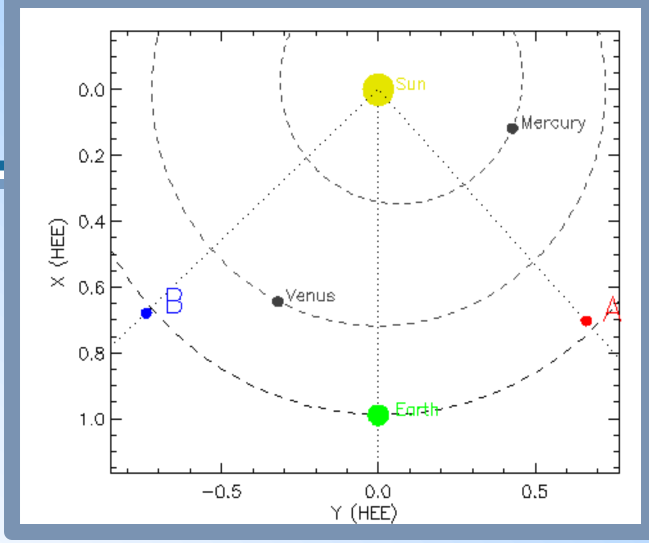
•Emerged from NOAA AR 1012.

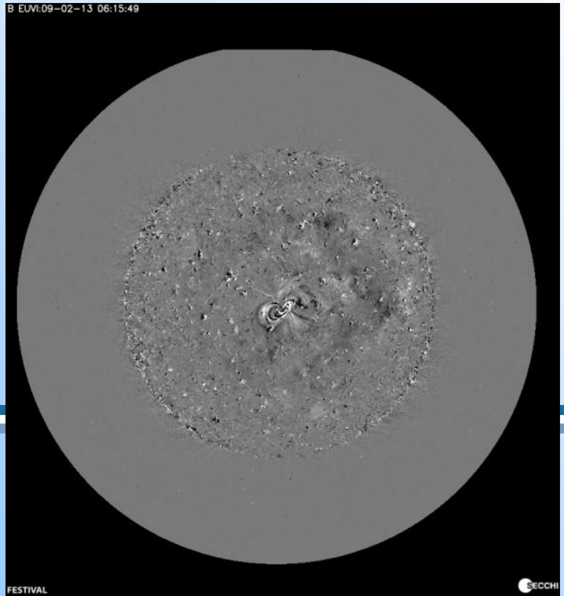
•Observed on disk in STEREO B; on-limb in STEREO A.

•Preflare conditions observed in STEREO ~05:25 UT.

•We assume the wave is a fast mode wave (See, Uchida (1968), Ofman and Thompson 2002, Patsourakos 2009).

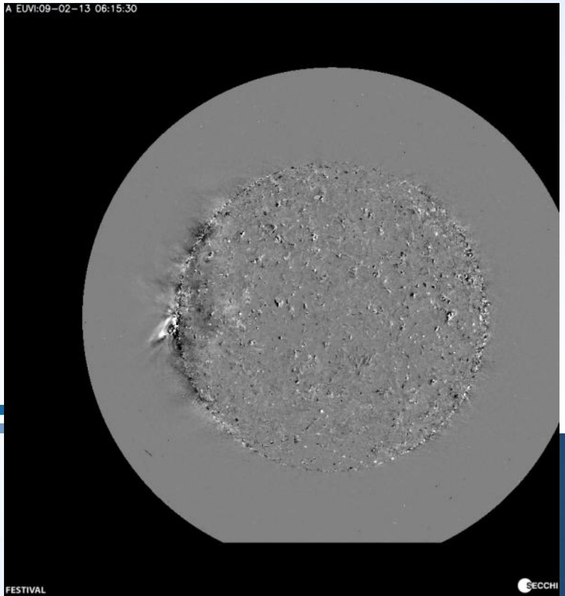
•With this assumption, we can use the wave to infer coronal charateristics.





B

A



Wave model

- In general a fast mode wave speed is given by:

$$v_f^2 = \frac{1}{2}\left(v_A^2 + c_s^2 + \sqrt{\left(v_A^2 + c_s^2\right)^2 - 4v_A^2 c_s^2 \cos^2\theta} \right)$$

- Alfven velocity:

$$v_A = \frac{B}{\left(\mu_0 \rho\right)^{1/2}}$$

- Local Sound speed:

$$c_s = \left(\frac{\gamma P}{\rho}\right)^{1/2}$$

- θ is the angle between the wave vector and magnetic field. The dependence on θ is weak (See Wang 2000). As the magnetic field is quasi radial in the low corona, θ is approximately 90°.

- Therefore,

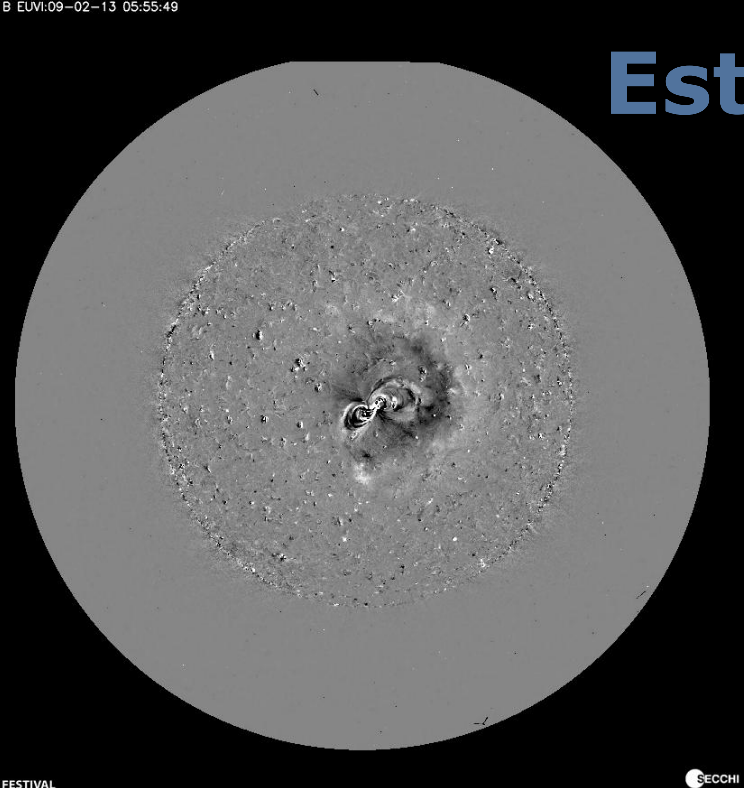
$$v_f^2 \approx v_A^2 + c_s^2$$

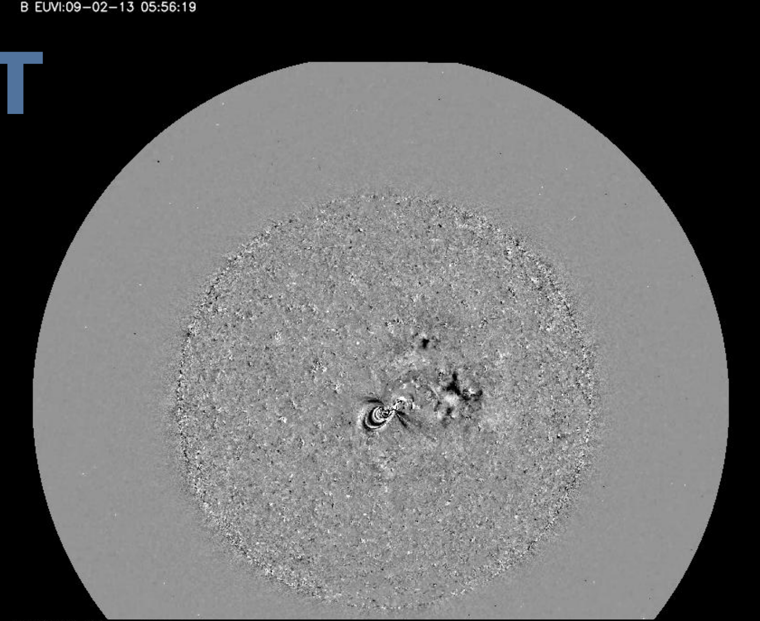
- With assumptions we have four unknowns: v_f, B, n, T

- Can we estimate B?

$$B = \left[\left(v_f^2 + \frac{\gamma K T}{\mu m_p}\right)\mu_0 \rho\right]^{1/2}$$

Estimating T

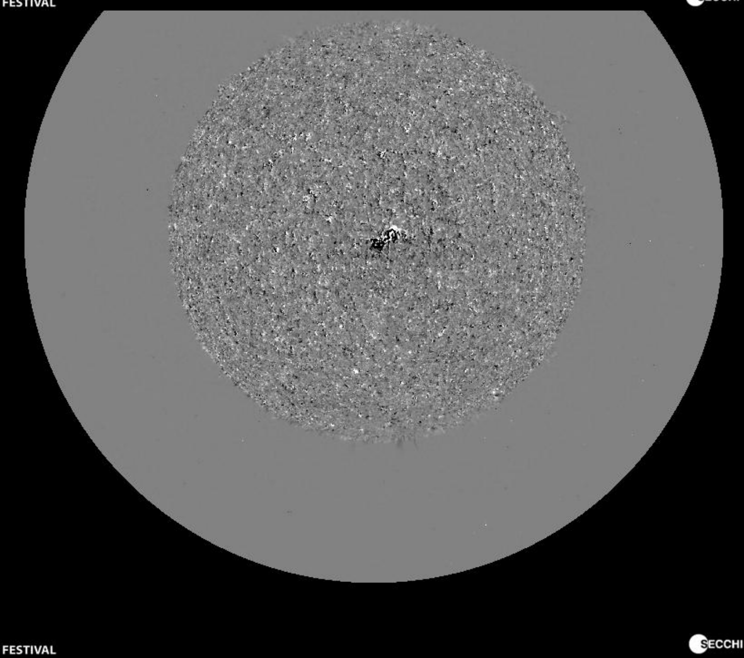




Observed in:

195 Å

171 Å



304 Å

284 Å

Highest contrast of the wave seen in 195 Å & 171 Å
~T = 1-1.5 MK

Measuring Density

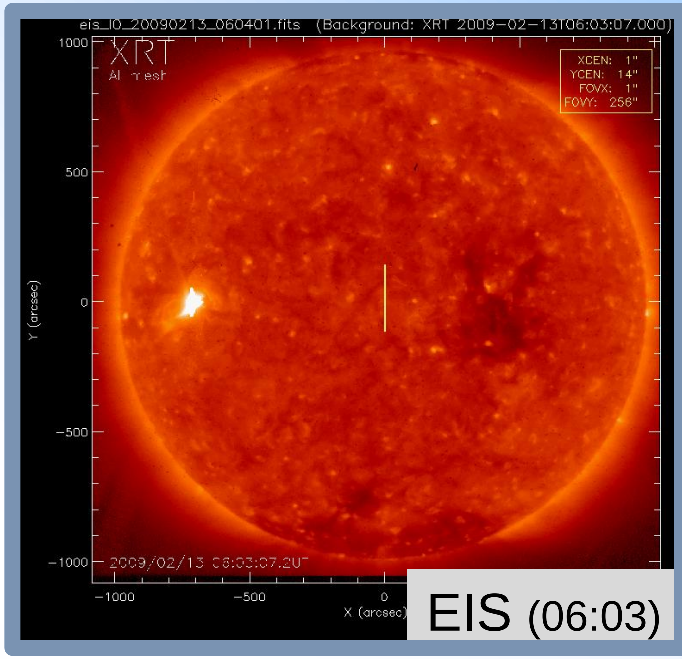
•We use Hinode EIS to measure the density in the quiet sun.

•At 06:03 UT Hinode EIS made observations including the Si X (205 - 261 Å) density sensitive line pair.

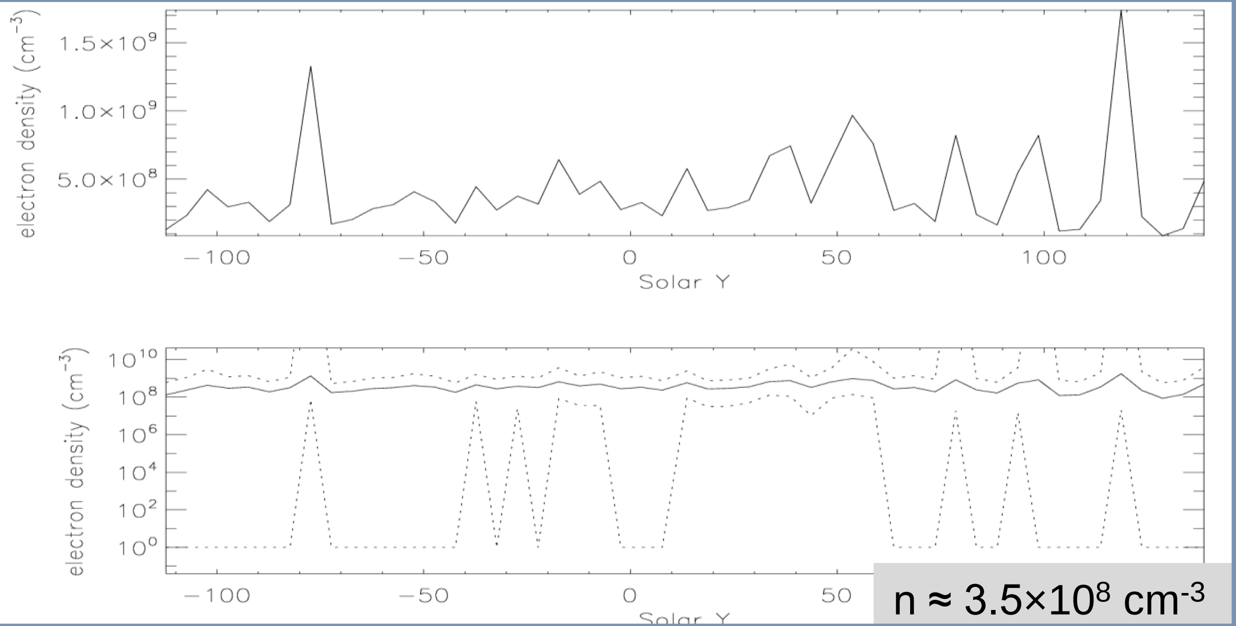
•The Si X lines have a similar formation temperature as the Fe XII 195 Å line.

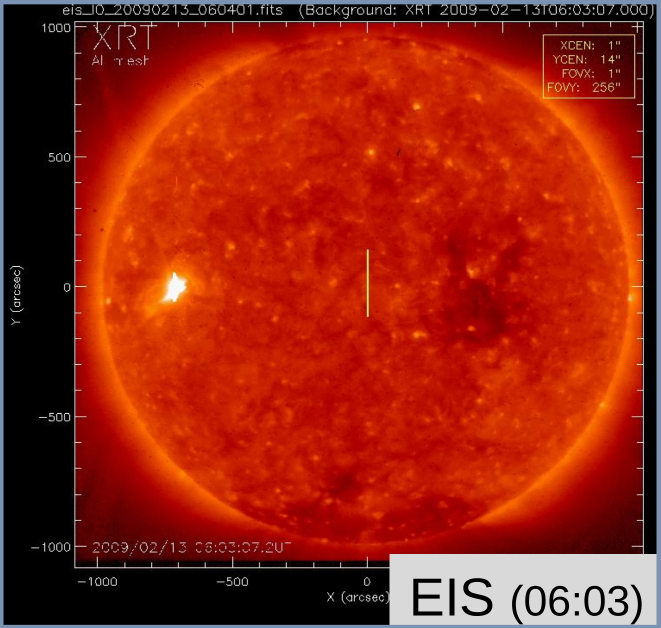
•There were no temperature sensitive lines observed with EIS at this time.

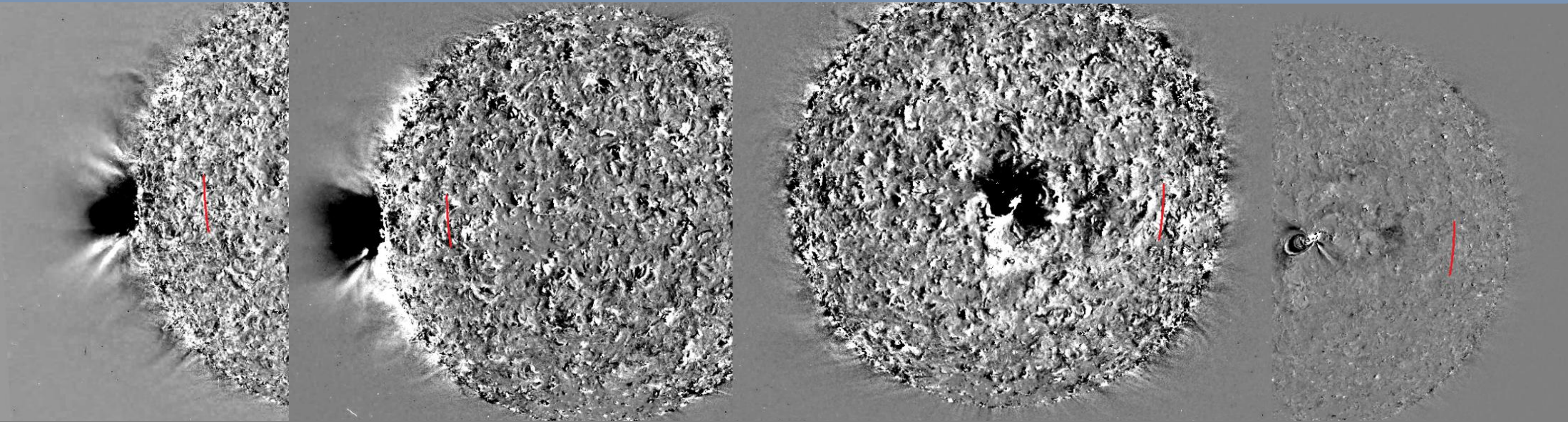
•EIS estimated the density to be ~ 3.5×10^{8} cm^{-3} .



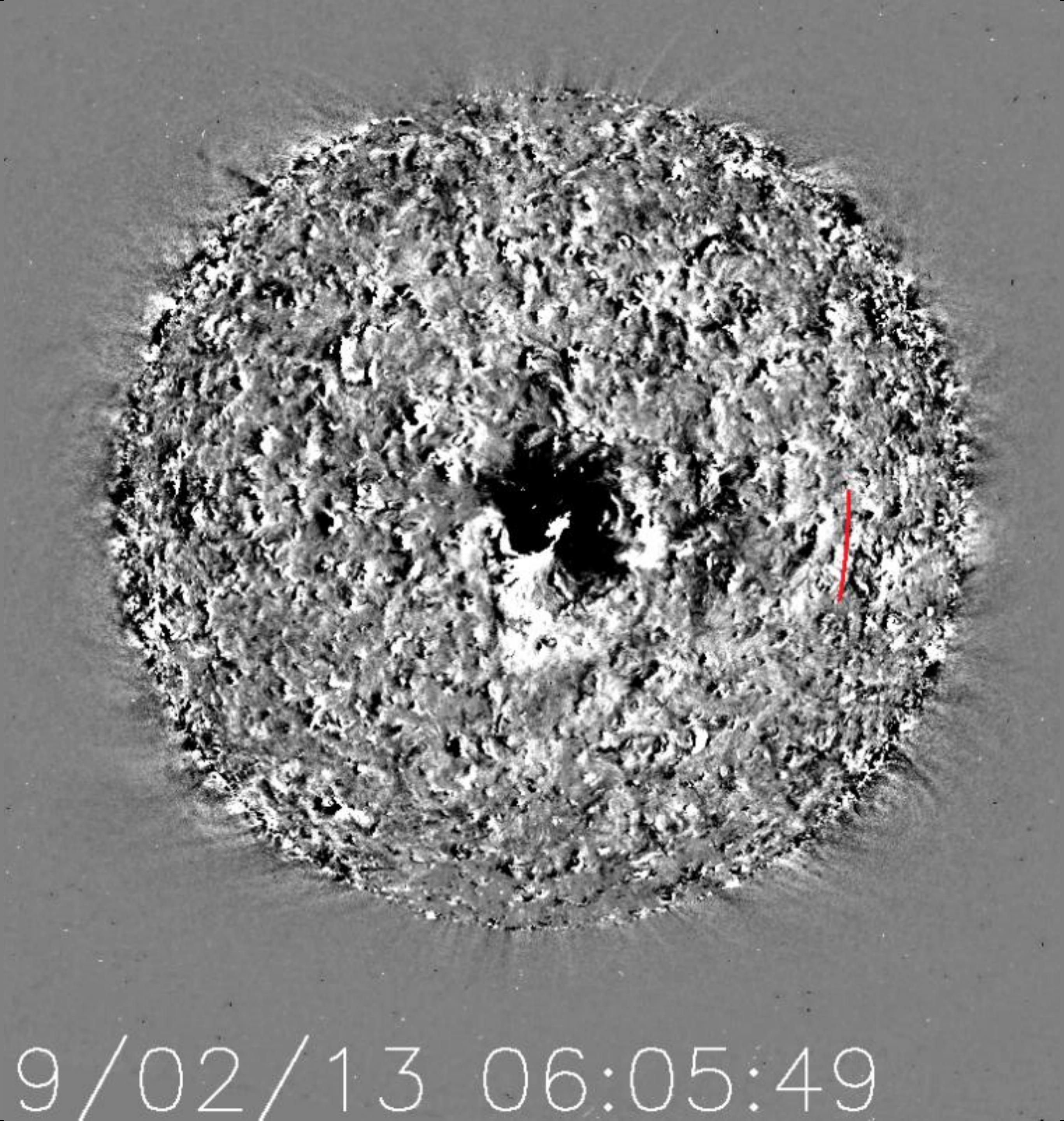
EIS density measurements



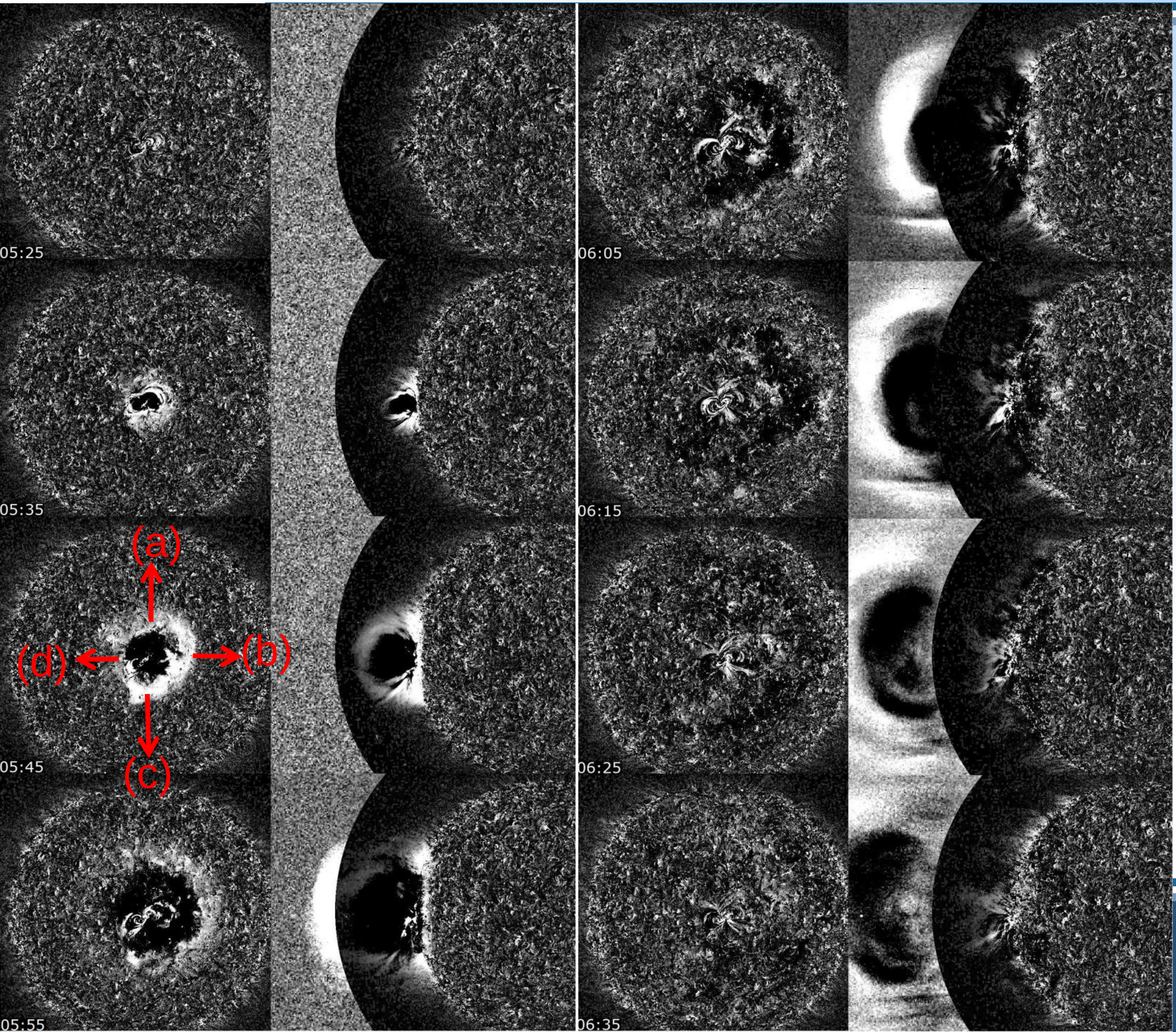




171 A (06:06) 195 A (06:05) 195 B (06:05) 171 B (06:11)


9/02/13 06:05:49

Measuring velocity



Velocities:

(a) 247±10 km s^{-1}

(b) 238±10 km s^{-1}

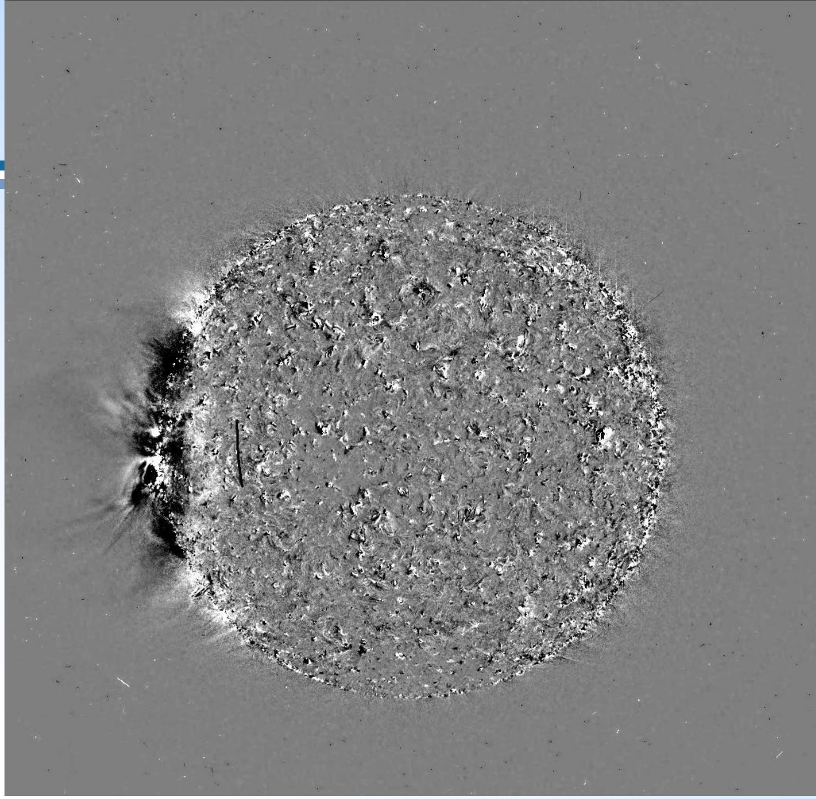
(c) 225±9 km s^{-1}

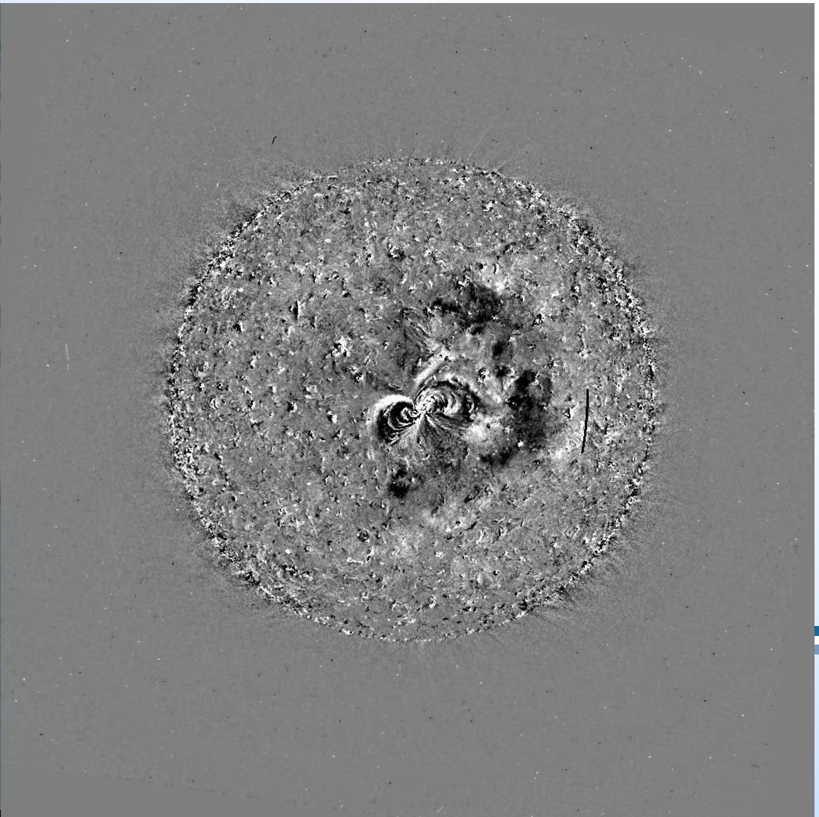
(d) 96±30 km s^{-1}

Typical Results

Input parameters:

Temperature : 1.5×10^{6} K
Number Density : 3.5×10^{8} cm^{-3}
Wave Velocity : 247 km s^{-1}





Results:

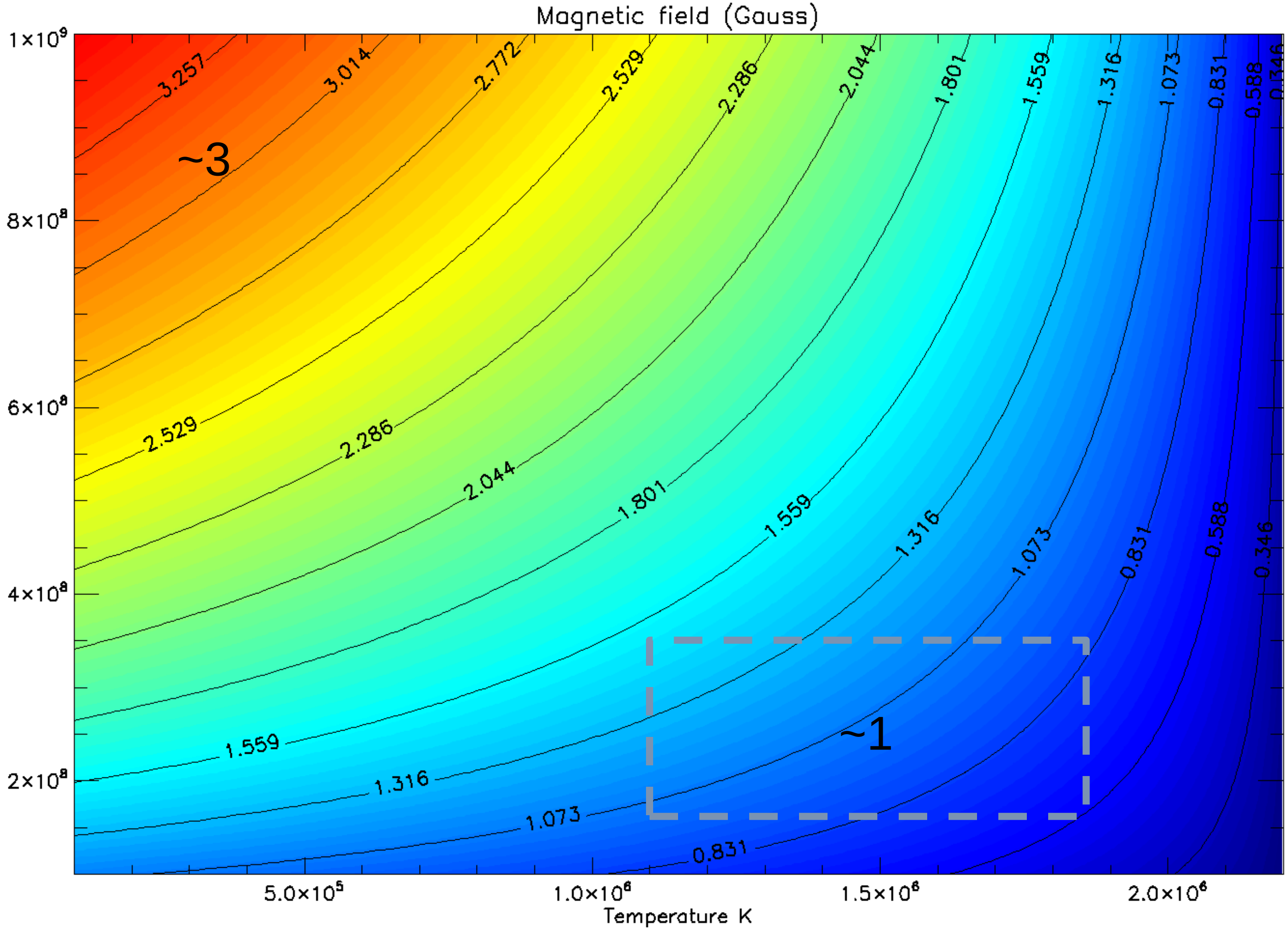
Sound Velocity : 203 km s^{-1}
Quiet sun magnetic field :1.2 G
Plasma Beta :1.4

Variation of B with T and n (v_{fast}=247 km s^{-1})

1.0×10^9

n cm^{-3}

1.0×10^8



1.0×10^5 T K 2.2×10^6

Conclusions

•We use STEREO observations of the 13th Feb 2009 EIT wave event to measure the velocity (~247±10 km s^{-1}) and constrain the temperature (1-1.5 MK) of an EIT wave.

•We use Hinode EIS to estimate the quiet sun density ($n \approx 3.5\times10^{8}$ cm^{-3}) adjacent to the EIT wave front.

•We assume that the EIT wave is a fast mode wave.

•Using these quantities we estimate the quiet sun coronal magnetic field to be ~1.2G, and the plasma β ~1.4.

•N.b. If the EIT wave speed is smaller than the local sound speed (~200 km s^{-1}) the EIT wave cannot be the fast mode wave - important.

•Multi-instrument observations of EIT waves provide an effective method for estimating coronal properties through coronal seismology.