# Probing the Alfvén speed profile using type II radio bursts.

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**1.Abstract**: Type II radio bursts can be produced when a coronal mass ejection (CME) traveling faster than the local plasma speed of the ambient medium produces a shock. From the drift rate of type II bursts it is possible to calculate the velocity of the CME. We present a statistical survey of type II radio burst events during 2012-2013. Using radio observations we determine speeds of CME shocks as a means of setting limits on the Alfvén speed profile of the interplanetary medium as a function of distance from the sun. In particular we use observations from the WAVES instruments onboard the twin Solar TErrestrial RElations Observatory (STEREO)[1] spacecraft, as well as onboard the WIND[2] spacecraft. We pay special attention to the normalization of the density models used to fit the type II bursts through the use of in-situ measurements.

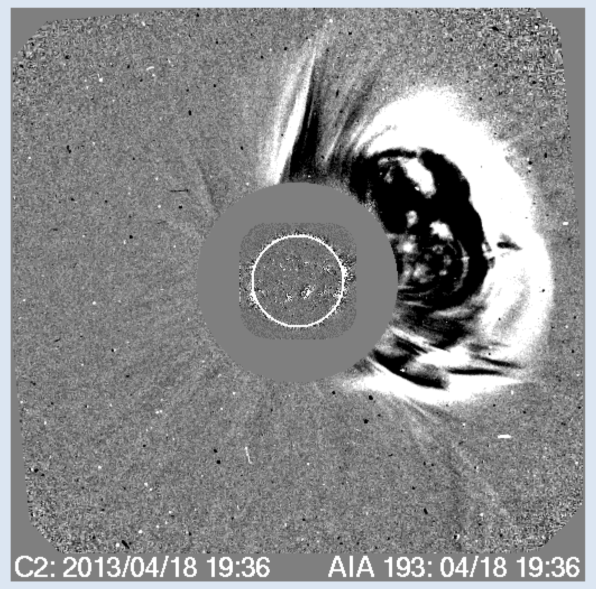


**Figure 1.** A white light coronograph of a CME.

2. **Introduction**: Type II radio bursts are the result of electrons accelerated in CME shocks. The frequency f of the emission is at the local plasma frequency ($f_p$), which is dependent on the electron density of the surrounding plasma ($n_e$) by $f_p \approx 9000\sqrt{n_e}$.[3] In type II radio bursts the frequency of the emission is observed to slowly drift to lower frequencies, indicating a movement from areas of higher density to lower density. Knowledge of the density upstream of these shocks as well as a model of the density profile are needed to translate this drift rate to distance from the sun. Therefore this drift rate tells us the speed at which the shock is propagating. With knowledge of the height of the radiated burst emission, we determine regions of shock formation in the interplanetary medium. Knowledge of these shock formation regions would provide insight into the validity of models of plasma speed as a distance from the sun, which are in turn important for accurate prediction of arrival times of CMEs at Earth and thus prediction of geomagnetic phenomenon which can cause damage to both satellites in Earth orbit but also the power infrastructure on Earth.

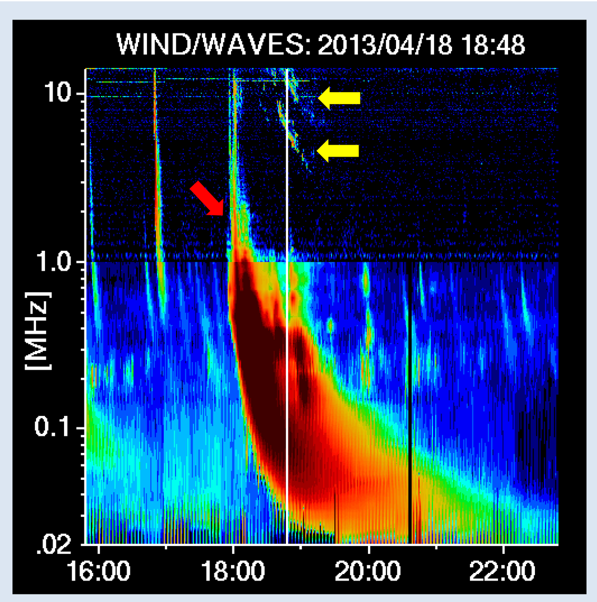


Figure 2. A radio spectrogram of type II (yellow arrows) and type III (red arrow) radio bursts. The type II burst in this case has both a fundamental (lower) and harmonic (upper) component.

**3. Type II Fitting:**
- Fit performed following Reiner et al. (2007)[4]
- Frequency drift rate:
  $(df/dt) = v_R\,(df/dR)$
  - $v_R$ is the radial velocity
  - Density model determined by Leblanc's 1998 model[5]
- Since density varies as $R^{-2}$ and $f \approx \sqrt{n_e}$, graph of 1/f is linear
- Fit of 1/f graph gives $v_R$ as slope
- Events taken from WAVES type II event list[6]
- Bright features, such as type III radio bursts, removed due to faintness of type IIs.

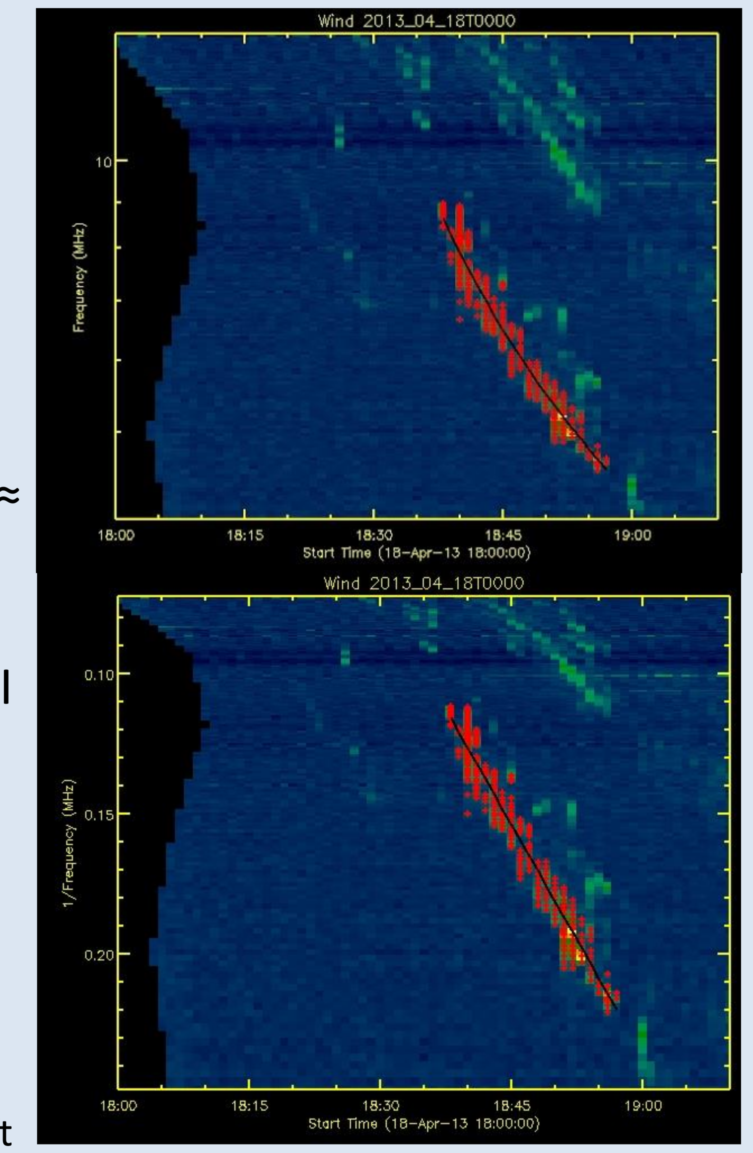


**Figure 3**. Fit of type II fundamental. Above: Normal fit of data. Below: Inverse frequency fit of data. Black features to left of both graphs is a removed type III.

**4. Normalization of $n_e$:**
- STEREO A/B and WIND in situ data at 1 AU.
- Proton densities upstream of CME shock arrival used to anchor density models at a distance of 1 AU.
- Assumes electrically neutral solar wind: $n_p = n_e + n_\alpha$
- Only useful in halo (i.e. head on) events.
- Ambiguity when CME arrival coincides with a stream interaction region or magnetic cloud.

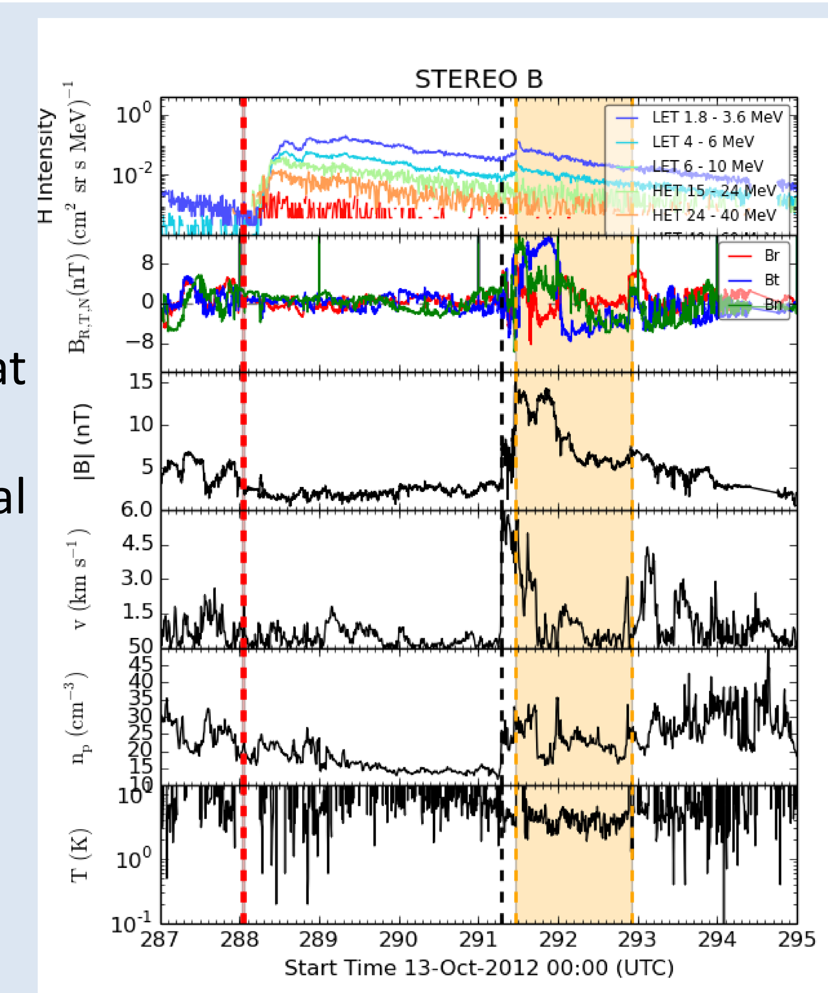


**Figure 4.** An eight day summary of in-situ data from STEREO B. Red dotted horizontal line indicates observation of type II, black horizontal line indicates detection of a shock, orange region indicates a magnetic cloud.

**5. Results:**

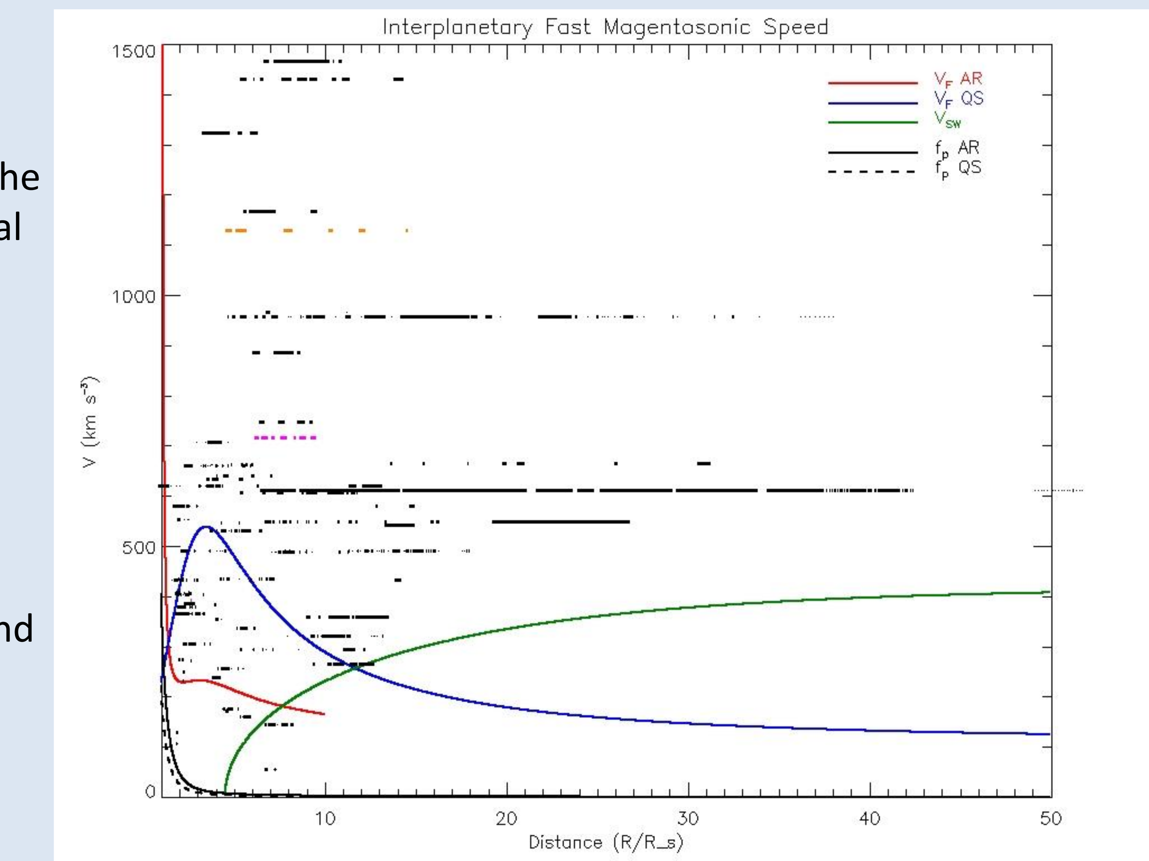


**Figure 5**. Results from 2012 and 2013 with heights and speeds of the type II events, horizontal intermittent lines, alongside modelled plasma speed profiles, indicated by top right legend. For the type II events, orange and magenta indicate matching normalized and unnormalized results respectively, and black lines are other unnormalized results.

- Normalized data (orange) consistent with models of plasma speed as a function of distance from sun.
- Only a few events for STEREO A/B suited to in situ normalization:

2012 & 2013 Event Breakdown: 64 Total events
Only 13 halo or partial halos from the perspective of STEREO A/B of which:
5 had ambiguous type II features which could not be fit; 3 had ambiguous in situ data (either no shock detected, overlap with magnetic storm, or overlap with a stream interaction region); 3 resulted in unphysical calculated speeds, indicating potential need for multiple anchor points on normalization; and 2 resulted in speeds and heights consistent with existing models of coronal plasma speeds.

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