DIFFUSE INTERPLANETARY RADIO EMISSION FROM A POLAR CORONAL MASS EJECTION

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MOTIVATION

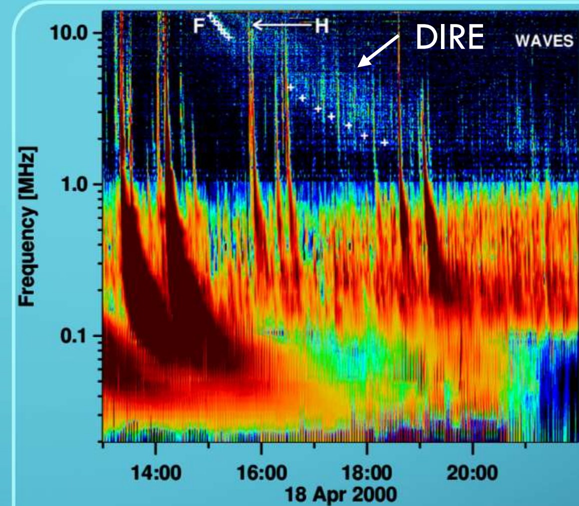
- Decameter-hectometric (DH) Type II bursts forming at or extending to frequencies below the ionospheric cutoff (~15 MHz) are associated with CMEs that are faster and wider on average
- DH Type II bursts generally originate from the active region belt where high magnetic free energy can be stored to power the fast and wide CMEs
- A polar CME, whose source is located outside the active region belt is associated with a type II-like burst.
- The burst is diffuse and different from normal type II burst from the nose of flank of the CME-driven shock
- We call this diffuse interplanetary radio emission (DIRE) and show that the radio emission originates from the shock flanks interacting with streamers.

THE DIRE EVENT

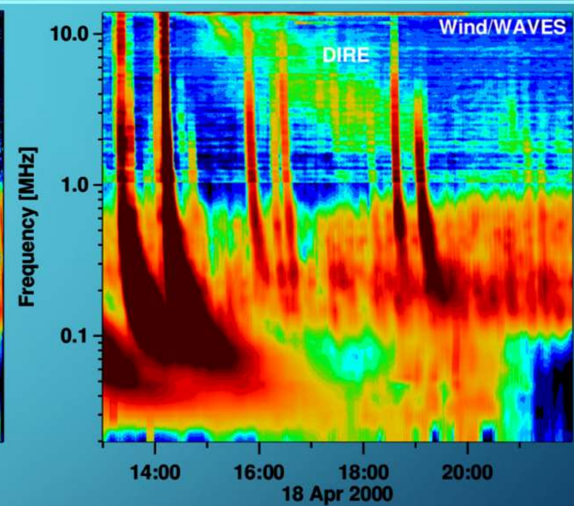
- The 2000 April 18 DIRE event observed by Wind/WAVES
- Fundamental-Harmonic (F-H) structure at the start (15 UT) of DIRE then the two components merge to form a broadband spectrum

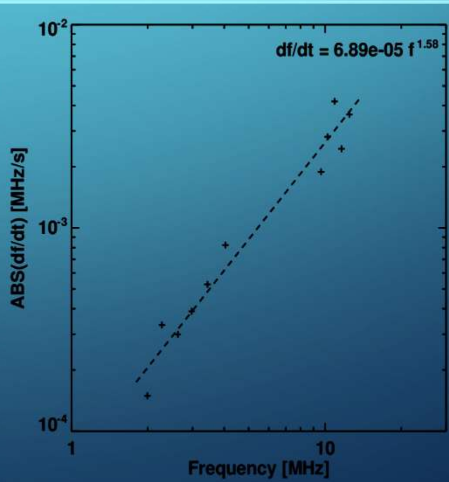
- The radio emission ends at ~19 UT, < 2 MHz
- DIRE has a series of bursts resembling type III storm but with a narrower bandwidth (~3.5 MHz at 17:30 UT).
- Measured drift rate of DIRE envelope is 0.039 MHz s^{-1}, within the drift-rate range of DH type II bursts

High time resolution



Low time resolution



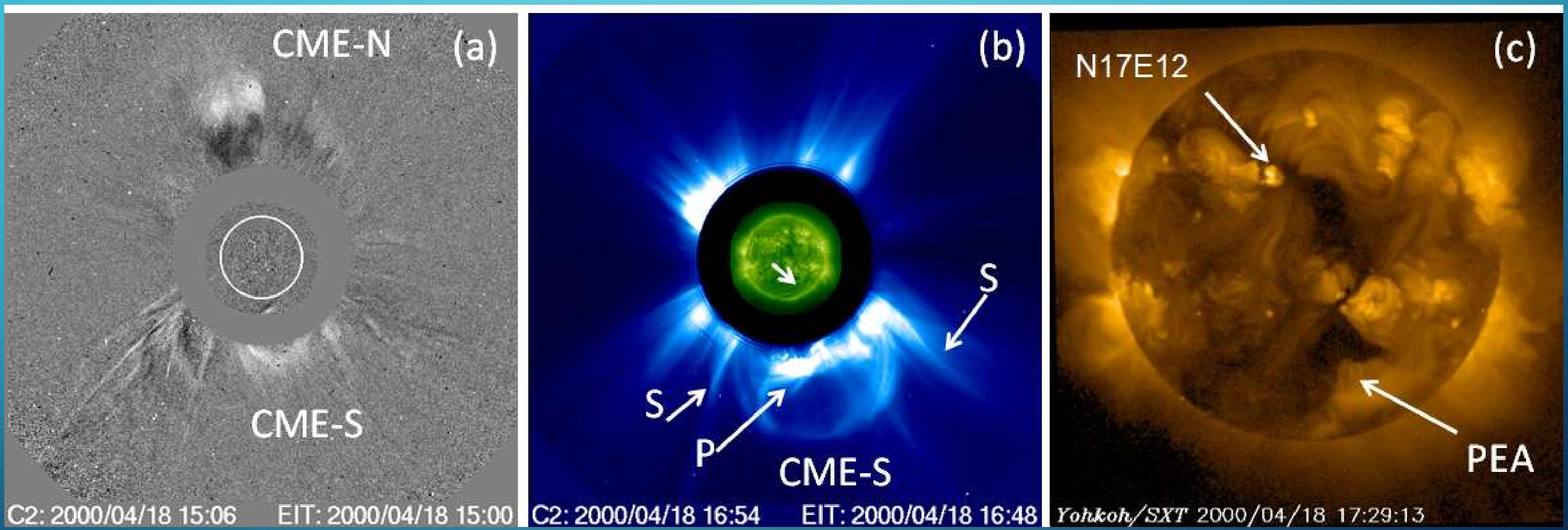


Drift rates measured at "+" points on the dynamic spectrum.

df/dt = 0.039 MHz/s at f = 14 MHz

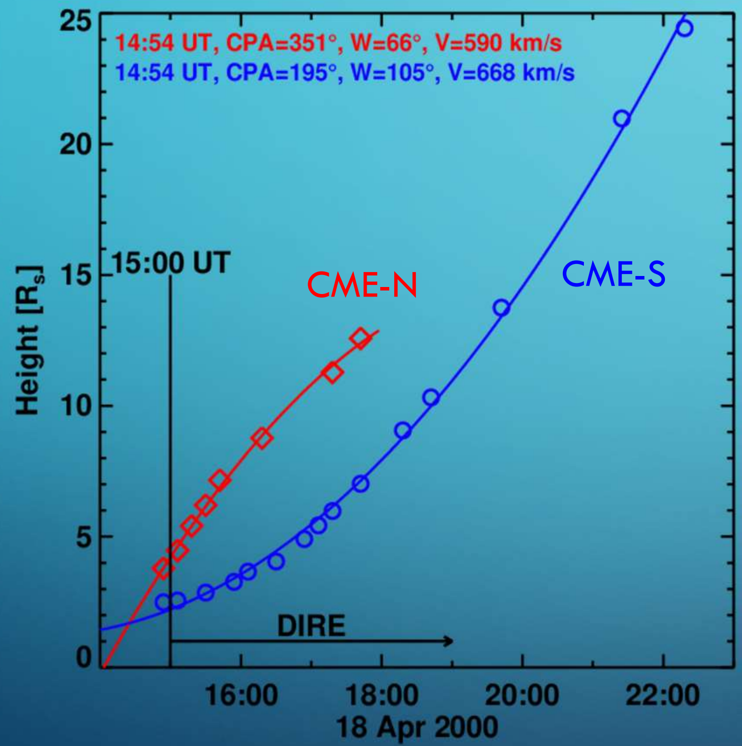
Decreases at lower frequencies

SOLAR SOURCE OF THE ASSOCIATED CME



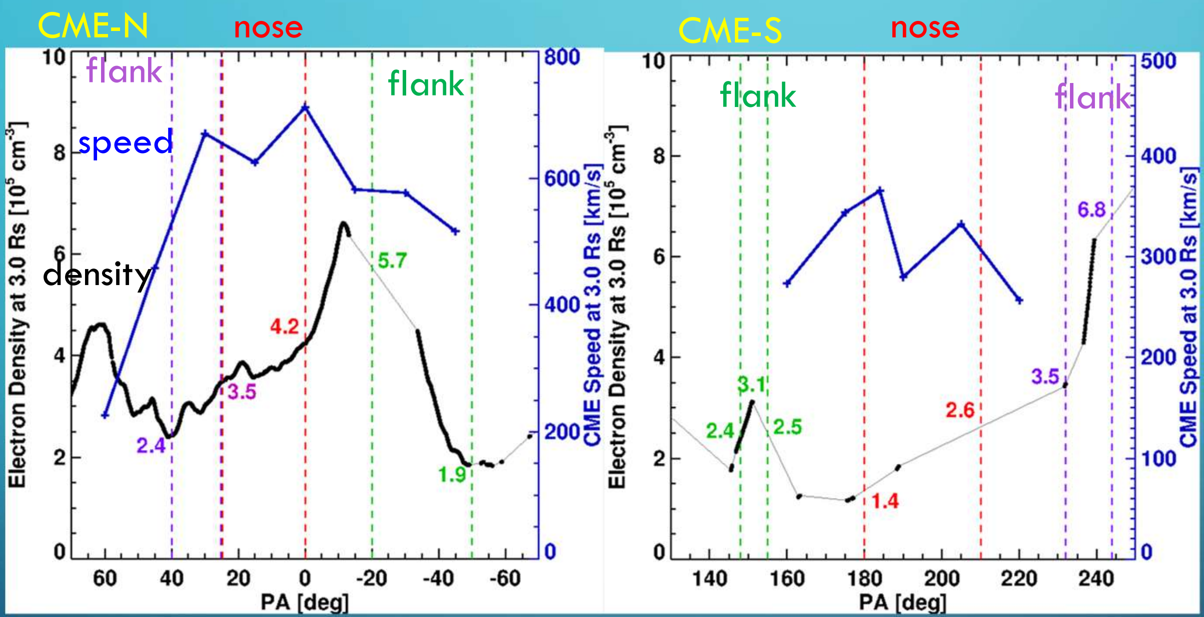
- Two CME candidates, appearing at the same time in LASCO FOV
- CME-N from a compact region (N17E12)
- CME-S is a polar-crown prominence (P) eruption (S50W30), which deflects streamers (S) at the flanks

CME KINEMATICS



- Height-time plots of CME-N (red) and CME-S (blue).
- CME-N was rapidly decelerating while CME-S was accelerating.
- It was not possible track CME-N beyond ~13 Rs
- CME-S is faster (average speed within LASCO FOV: 688 km/s vs. 590 km/s)

ELECTRON DENSITIES AHEAD OF CMEs

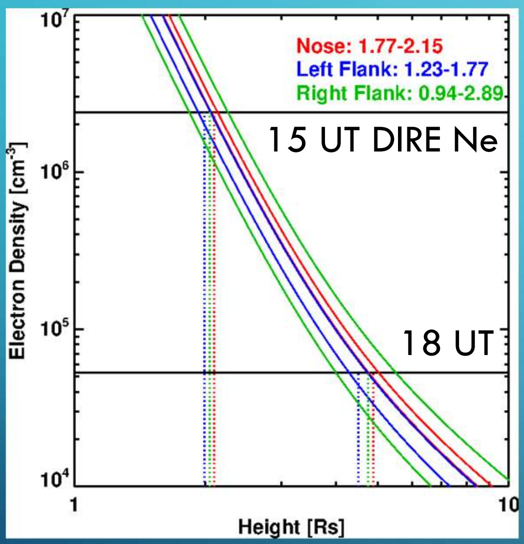


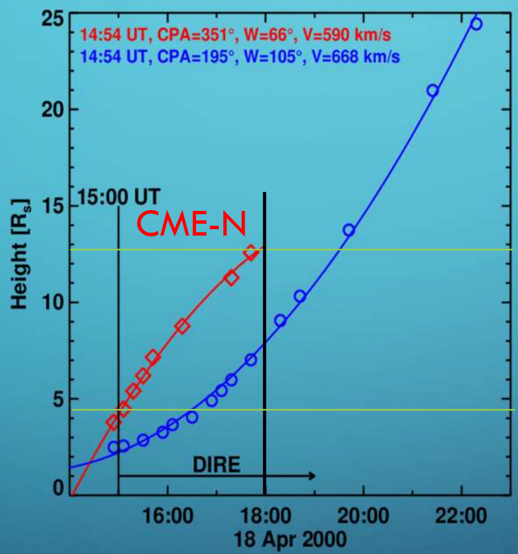
Densities obtained using a polarized brightness image obtained by LASCO before the CMEs of interest were launched

- Electron densities at 3 Rs derived from polarization brightness images at many position angles in the corona before the CMEs were launched.
- CME speeds at various position angles are overlaid
- The numbers indicate the electron densities at the boundaries of the nose and flank regions (in 10^5 cm^{-3})
- We force the Leblanc et al. (1998) model to yield density values in this Fig when r = 3 Rs

RADIAL PROFILES OF ELECTRON DENSITY

CME-N



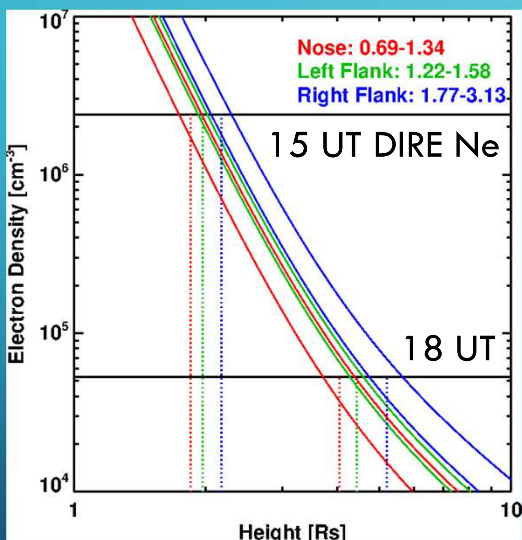


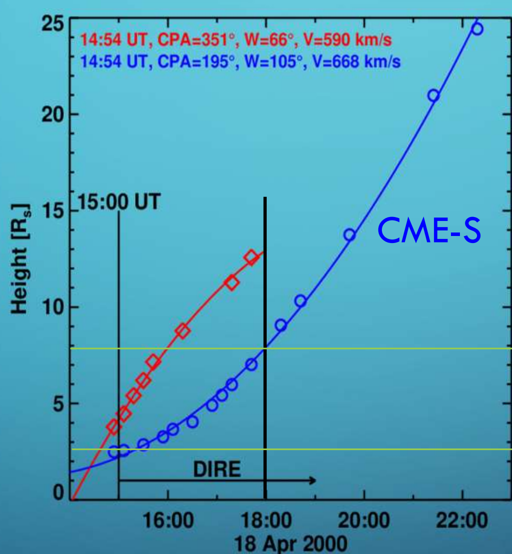
Range of multipliers at the nose and flanks to be used with the Leblanc et al. (1998) radial density profile so that it matches the observed densities at 3 Rs

- Assuming fundamental plasma emission, the source densities at 3 UT and 18 UT are obtained as: **2.4×10^{6} cm^{-3} and 5.3×10^{4} cm^{-3}**
- Such a density prevails around 2 Rs in the pre-event corona.
- From the height-time plot we see that the nose of CME-N is already at ~4 Rs. It is unlikely that the flanks extend down to ~2 Rs at 15:00 UT
- Towards the end of the DIRE event, say 18:00 UT, the emission frequency is ~2 MHz, so the local plasma density is ~5.3×10^{6} cm^{-3}.
- Such a density prevails at a distance of ~5 Rs. However, around this time, the CME-N nose is already at ~12.5 Rs and flanks are not discernible down to 5 Rs, where the DIRE needs to originate if CME-N is responsible.
- Therefore, we can rule out that CME-N is responsible for the DIRE emission.

RADIAL PROFILES OF ELECTRON DENSITY

CME-S

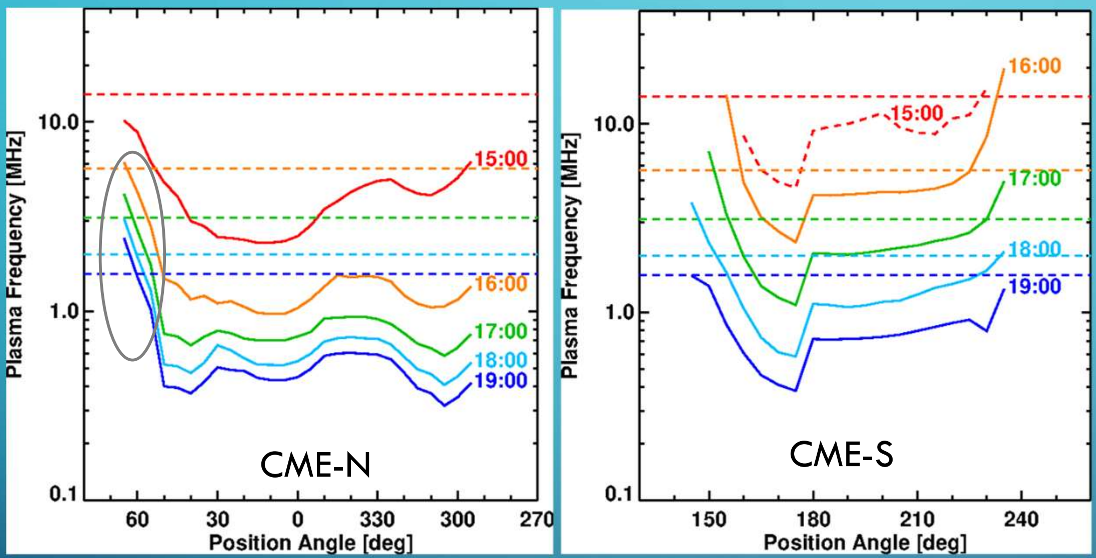




Range of multipliers at the nose and flanks to be used with the Leblanc et al. (1998) radial density profile so that it matches the observed densities at 3 Rs

- The required density for DIRE prevails around 2 Rs in the pre-event corona.
- From the height-time plot we see that the nose of CME-S is at ~2.5 Rs at DIRE onset. It is likely that the flanks extend down to ~2 Rs at 15:00 UT
- Towards the end of the DIRE event, say 18:00 UT, the emission frequency is ~2 MHz, so the local plasma density is ~5.3×10^{6} cm^{-3}.
- Such a density prevails at a distance of ~4.5 Rs. However, around this time, the CME-S nose is at ~7.5 Rs and the flanks are discernible down to 4.5 Rs
- Therefore, we can confirm that CME-S is responsible for the DIRE emission.

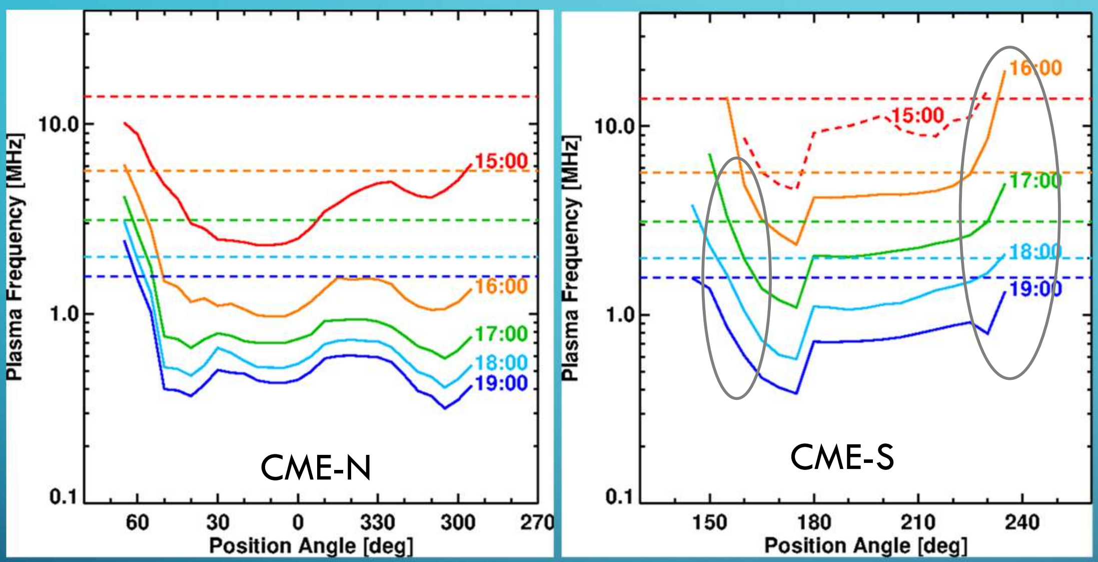
PLASMA FREQUENCY VS. POSITION ANGLE



- Plasma frequencies around the CME position angles plotted at various times during the DIRE event.
- The horizontal dashed lines represent the DIRE frequencies at the fundamental
- DIRE originates where a horizontal line intersects the plasma frequency curve of the same color.

- The onset of the DIRE emission cannot be explained by CME-N because the emission frequency represented by the horizontal dashed line at the onset does not intersect with the plasma frequency.
- Beyond 16:00 UT, the emission frequency matches the plasma curve at position angles >60^o. Since the central position angle of CME-N is 10^o, this implies a CME width >100^o, which is larger than the observed width of CME-N. Furthermore, the speed at PA=60^o falls to 200 km/s and to even lower values beyond that.
- Thus, we confirm that CME-N is not responsible for the DIRE event.

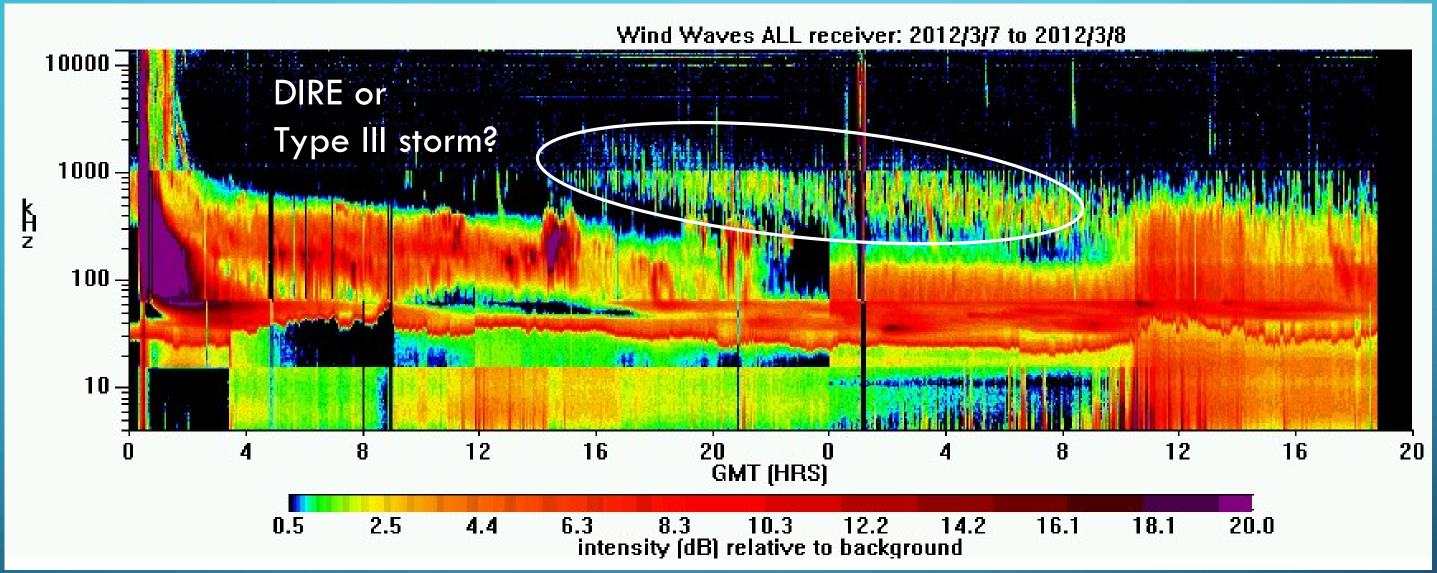
PLASMA FREQUENCY VS. POSITION ANGLE



- Plasma frequencies around the CME position angles plotted at various times during the DIRE event.
- The horizontal dashed lines represent the DIRE frequencies at the fundamental
- DIRE originates where a horizontal line intersects the plasma frequency curve of the same color.

- In the case of CME-S, all the DIRE lines intersect with the plasma lines from the onset to the end of the DIRE event at the right flank (at PA >225º).
- On the left flank, the DIRE line at the onset does not intersect the 15:00 UT plasma line. Starting at 16:00 UT, the DIRE lines intersect both the right and left flanks. This suggests that the observed DIRE has contributions from both the flanks beyond ~16:00 UT.
- This may be the reason we see the fundamental and harmonic components separated in the beginning (contribution comes only from the right flank).
- After 16:00 UT, the fundamental and harmonic merge because of contributions coming from different sections of the shock, making the emission broadband.

IS DIRE A TYPE III STORM?



- Sometimes a diffuse emission accompanies intense type II bursts, interpreted by Liu et al. (2013) as a type III storm.
- We think these are similar to DIRE origination from the flanks evidenced by the higher frequencies and drift rate similar to type II. DIRE also has a narrow bandwidth compared to type III storms.
- DIRE is associated with an eruption; type III storm is not

STREAMER INTERACTION

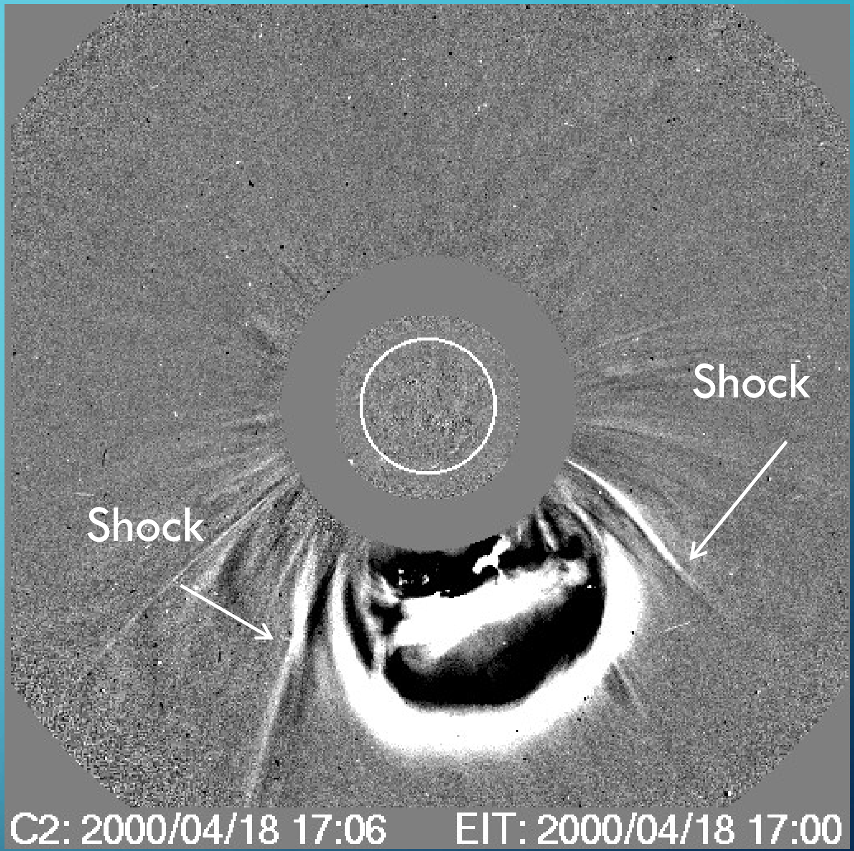
- Shock speed V is related to the type II drift rate:

  $V = 2L(1/f)(df/dt)$ (1)

- $L = r/\alpha$ is the density scale height for a density varying as

  $N(r) \sim r^{-\alpha}$.

- The measured drift rate is 0.039 MHz s^{-1}. at f= 14 MHz
- $\alpha \sim 4$ around 14 MHz plasma level
- At r = 2, L = 0.5 Rs, so V = 1940 km/s in eq (1), which is not observed.
- Taking the deprojected flank speed as ~400 km/s, L= 0.1 Rs
- Such scale heights occur when shock crosses streamer stalks of size ~0.1 Rs
- While the flank region has low Alfven speed due to the presence of the streamer, the nose region has much higher Alfven speed because the ambient medium is tenuous in the polar region. Therefore, there is no type II burst from the nose region.



This is the first time a polar CME is associated with shock-accelerated particles/electrons

SUMMARY

- We have presented a diffuse interplanetary radio emission (DIRE) caused by electrons accelerated in shock flanks where they interact with streamers
- Although DIRE appears similar to type III storms, they differ in bandwidth, drift rate, and the involvement of an eruption
- This is the first time a polar CMEs has been found to drive a shock and accelerate electrons to keV energies to produce DIRE
- We confirm interaction with streamers from the scale height estimation

ACKNOWLEDGMENTS

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