MMS observations of ion cyclotron waves in the solar wind

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Outline

• Introduction on STEREO observations of ICW in the solar wind

• Open questions on wave energy sources
  • Generation mechanism
  • Energy sources: local vs remote

• MMS to study on the waves at 1 AU
  • Need to avoid the foreshock regions where there are abundant upstream waves
  • Select events based on MAG observations, then examine the plasma data during these events (e.g. temperature anisotropy, etc)

• Three case studies with MMS data:
  • Case 1 & 2: plasma data indicates $T_{\text{para}} > T_{\text{perp}}$
  • Case 3: plasma data indicates $T_{\text{perp}} \geq T_{\text{para}}$
An example of ICW observed by STEREO

- Ion cyclotron waves (ICWs) were observed by STEREO in the solar wind far away from any planetary or cometary sources.

- Generally, these waves have nearly field-aligned propagation, left-handed (LH) or (RH) right-handed circular polarization, and frequencies (in local plasma frame) below the proton gyro-frequency.
Open questions on wave energy sources

• In the solar wind, there are mainly three types of ion-driven instabilities responsible for parallel-propagating ICWs:
  • ion cyclotron instabilities driven by ion component with temperature anisotropies greater than 1,
  • parallel firehose instabilities driven by ion temperature anisotropies smaller than 1,
  • ion/ion magnetosonic instabilities driven by the relative drift between two ion components.

• High quality plasma data is needed to examine the possible unstable mode with dispersion analysis and check if the prediction agrees with the observed wave mode.

• Wave properties may also provide information on the possible energy sources:
  • In the solar wind frame, the waves due to ion cyclotron instability have left-handed polarization, while the waves due to firehose and ion/ion magnetosonic instabilities have right-handed polarization.
• The LH waves are generated by a proton component with temperature anisotropy, i.e. ion-cyclotron instability.
• The RH waves are generated by ion component relative flows, i.e. magnetosonic instability.
This study found 6 out of the 10 events with instabilities and 4 of them have the observed wave mode in agreement with that predicted by linear dispersion analysis.
Possible remote sources

• Performed case studies on a special group of events with the left-handed and right-handed waves observed simultaneously in the spacecraft frame

• Under the assumption that LH and RH waves were generated by the same source remotely in the inner heliosphere, we can estimate the Doppler-shift frequencies and also the location of the source region.
Heliocentric distance variations

- From multi-spacecraft observations (MESSENGER, VEX and STEREO) at 0.3, 0.7, and 1 AU, the wave power and wave frequencies in both spacecraft frame and plasma frame are found to decrease with heliocentric distances slightly.
Wave property variations IMF cone angle

- When $|\text{cone}| > 30$ deg, the waves are more elliptically polarized and have larger propagation angle with larger IMF cone angle.

- This indicates the waves are created in region with smaller cone angles, e.g. cone $< 30$ deg
Statistical and case studies with MMS data

• In one month of MMS (2017/12), over a hundred events selected, and about 42 events lasting longer than 10 min (i.e. ICW storm events), but only very few of them have plasma data available.
  • Far from the shock, occurred outside 23 Re
  • Outside the foreshock region
  • The longest event lasts over 2hr, but no plasma data for it
• Need to obtain more cases studies with both fields and plasma data.
MMS observations: case 1, Ti\_para > Ti\_perp
MMS observations: case 2, Ti_{para} > Ti_{perp}
MMS observations: case 3, Ti_perp > Ti_para
Longest event observed by MMS: no plasma data
Concluding Remarks

• ICWs have been observed extensively from 0.3 to 1 AU by multiple missions.

• Both scenarios of remote or local energy sources have been examined by previous studies and they both have some supportive and inconsistent facts.

• To further understand the sources of these waves, we use high quality field and plasma measurements of MMS to determine the wave propagation properties and plasma instabilities.
  • For case 1 & 2, there are strong temperature anisotropy due to $T_{\text{para}} > T_{\text{perp}}$, leading to magnetosonic instability
  • For case 3, some wave intervals are associated with ion cyclotron instability due to $T_{\text{perp}} > T_{\text{para}}$, while some wave intervals have no temperature anisotropy and could be remotely generated.