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Supporting Information for

Generation of Turbulence in Kelvin-Helmholtz Vortices at the Earth's Magnetopause: Magnetospheric Multiscale Observations

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Additional Supporting Information (File uploaded separately)

The second Supporting Information contains a Matlab code for the single-spacecraft method to estimate wave vectors, translated from the IDL version developed by Bellan (2016).

Introduction

The supporting information includes solar wind and interplanetary magnetic field conditions surrounding the two MMS events studied in the paper (Figures S1 and S2). It also contains results (Figures S3-S5) from Bellan's single-spacecraft method to estimate wave vectors (Bellan, 2016) applied to synthetic magnetic field and current density data taken by a virtual spacecraft passing through a simulated three-dimensional Kelvin-Helmholtz (KH) vortex, as reported by Nakamura (2020).

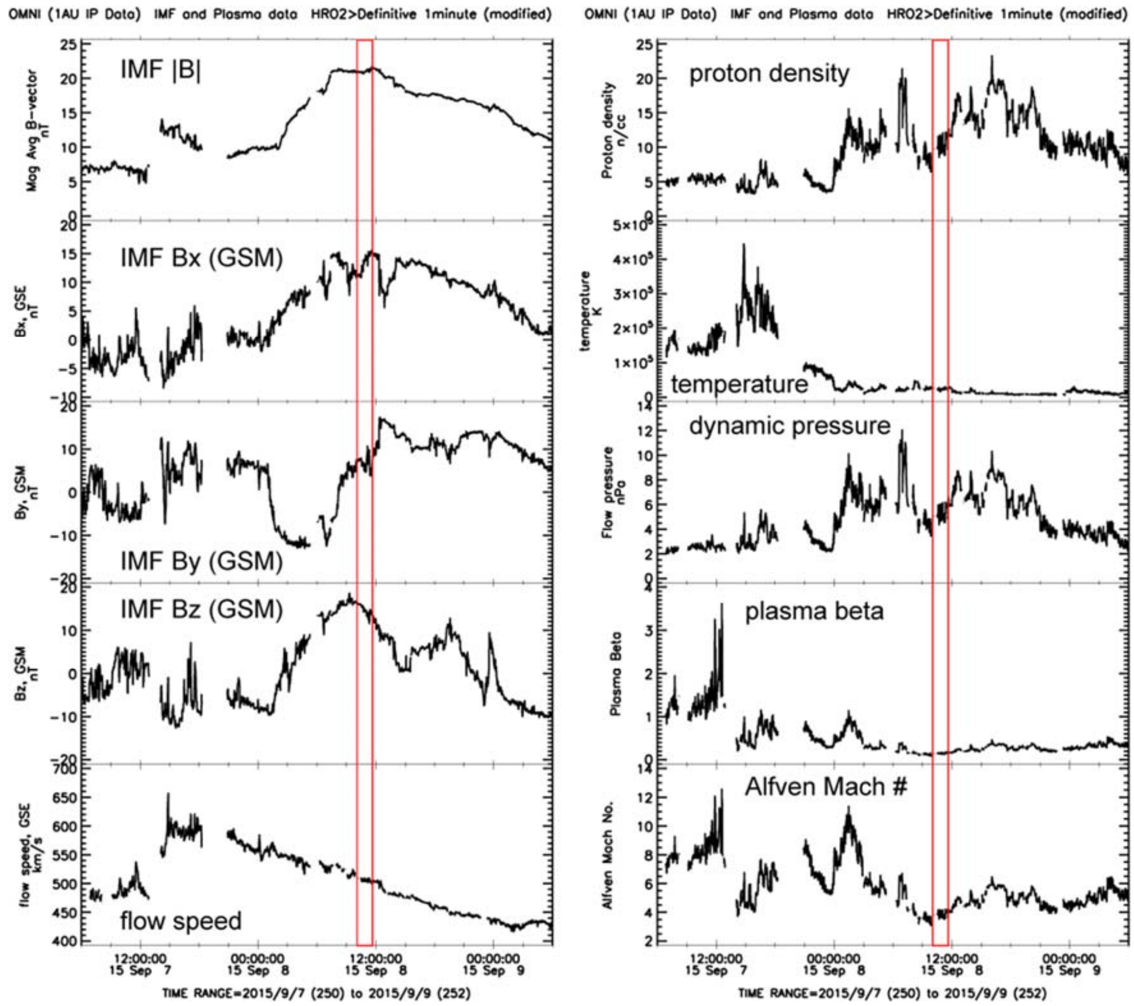

Figure S1. Solar wind and IMF conditions based on the OMNI database over a 2-day period from 2015-09-07, 0600 UT to 2015-09-09, 0600 UT, surrounding the MMS KHI+RX event on 2015-09-08. The red box marks the time interval studied in the main text.

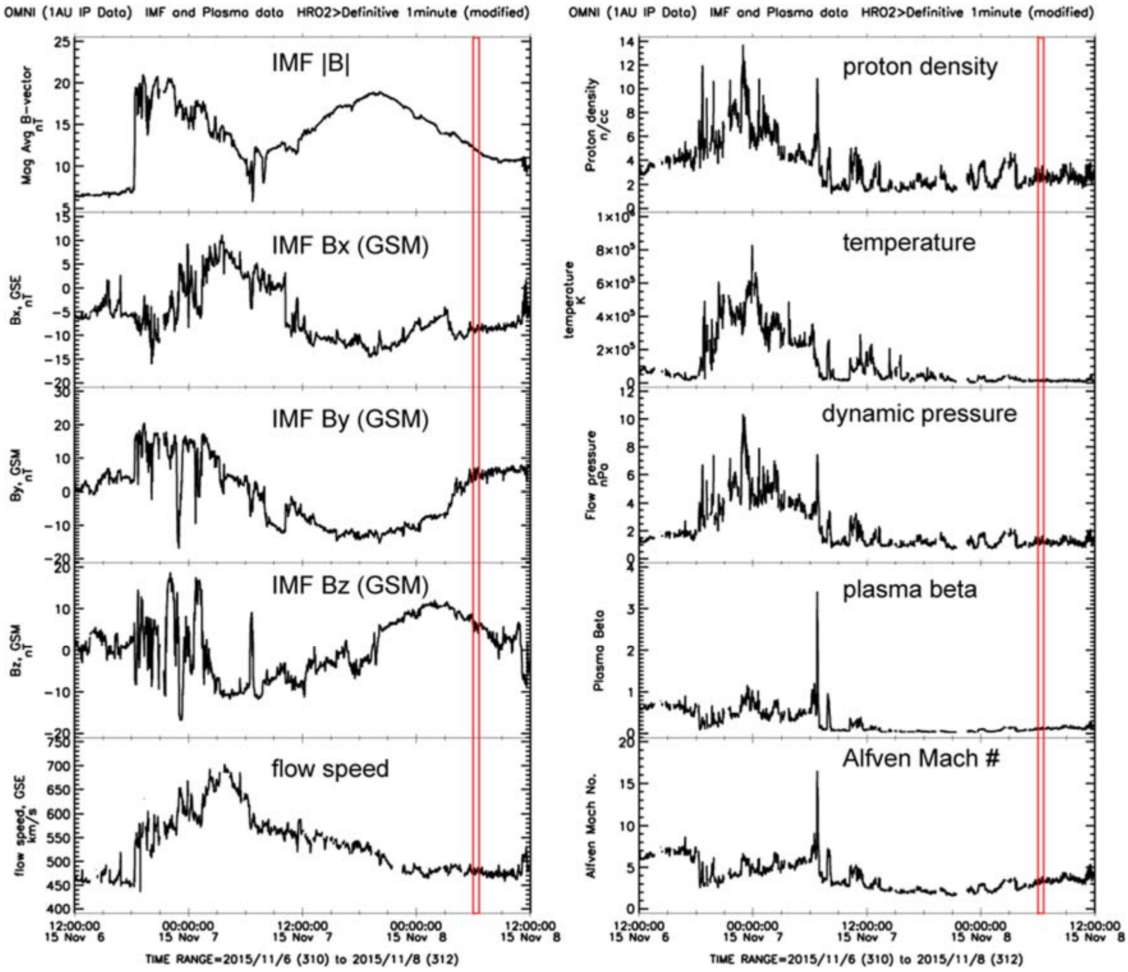

Figure S2. Solar wind and IMF conditions based on the OMNI database over a 2-day period from 2015-11-06, 1200 UT to 2015-11-08, 1200 UT, surrounding the MMS RX-only event on 2015-11-08. The red box marks the time interval studied in the main text.

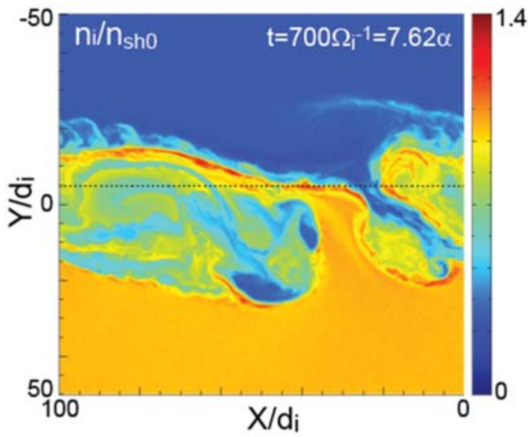

Figure S3. Density structure in a Kelvin-Helmholtz vortex from a three-dimensional (3D), fully kinetic simulation reported by Nakamura (2020). Simulated data taken from right to left along the virtual spacecraft path (dotted line) at y = $4.8d_i$ are used as input for Bellan's method.

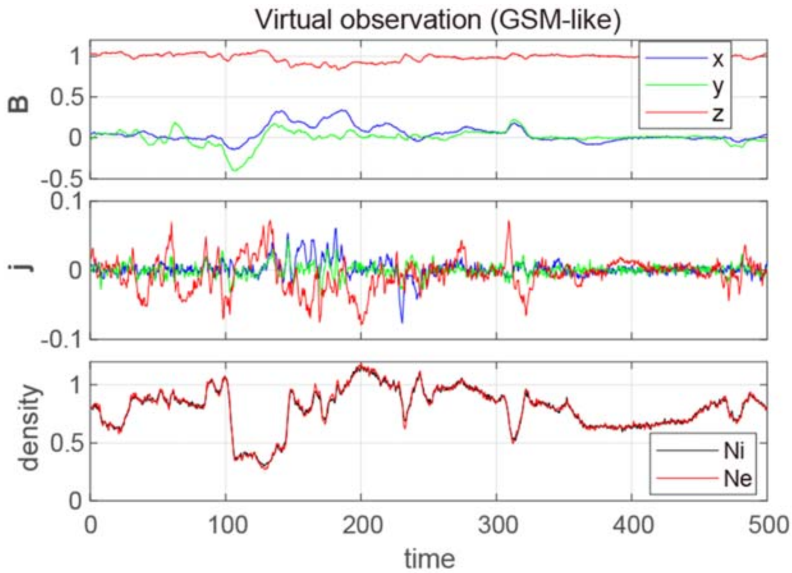

Figure S4. Virtual spacecraft measurements along the path shown in Figure S3, of which the magnetic field and current density are used as input for Bellan's method. The coordinate system is similar to that of GSM, with the x axis sunward and along the nominal magnetopause, the y axis duskward or normal to the magnetopause, and the z axis northward. See Nakamura, Hasegawa, et al. (2017) for details on the initial conditions and normalizations.

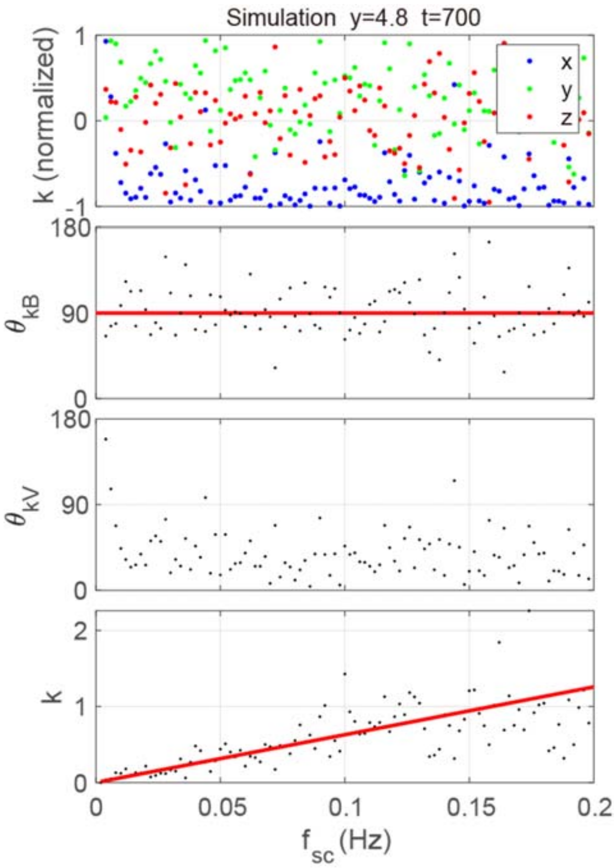

Figure S5. Properties of the k-vectors derived from Bellan's method (Bellan, 2016) applied to the virtual spacecraft data shown in Figure S4 in the same format as in Figure 5. The orientations of k-vectors and relationship between the magnitude of the wave number and spacecraft-frame frequency are very similar to those actually observed in the MMS KH instability event on 8 September 2015. Note that in the Nakamura, Hasegawa, et al. (2017) simulation, magnetic field fluctuations in KH vortices are of tangled 3D flux tubes resulting from vortex induced reconnection. Thus, the similarity of the magnetic power spectrum and k-vector properties between the simulation and MMS observation is consistent with our argument that the observed magnetic fluctuations are probably not of propagating waves but of tangled reconnected flux tubes advected by the background flow.

Table S1. Time intervals used to create the average magnetic spectra shown in Figure 3a.

Interval ID	Start time of the interval (UT)	End time of the interval (UT)
1	1007:10	1008:00
2	1008:30	1009:30
3	1009:40	1010:25
4	1010:40	1011:25
5	1011:35	1012:20
6	1012:45	1013:40

7	1014:00	1014:40
8	1015:00	1016:00
9	1016:10	1017:45
10	1018:00	1019:15
11	1020:10	1021:45
12	1022:15	1023:00
13	1023:20	1025:00
14	1025:35	1026:25
15	1026:40	1027:20
16	1027:40	1029:30
17	1029:45	1030:10
18	1030:40	1031:40
19	1032:05	1032:40
20	1033:00	1034:00
21	1034:45	1035:10
22	1035:35	1036:10
23	1036:40	1038:05
24	1039:35	1040:50
25	1041:10	1042:50
26	1043:20	1044:30
27	1045:00	1046:20
28	1046:40	1048:30
29	1049:00	1050:40
30	1051:30	1053:00
31	1053:30	1055:20
32	1055:40	1057:20
33	1058:00	1059:15
34	1059:40	1100:15
35	1100:37	1101:10
36	1102:20	1102:50
37	1103:10	1104:20
38	1105:15	1106:30
39	1107:00	1107:50
40	1108:10	1109:35
41	1109:55	1110:45
42	1111:05	1112:15
43	1112:35	1114:25
44	1114:55	1116:35
45	1117:15	1117:45
46	1118:05	1119:20
47	1120:00	1121:45
48	1121:50	1122:50
49	1123:15	1123:45
50	1124:25	1125:05
51	1126:05	1126:35