The Bow Shock and Foreshock – Some Perspectives

Meudon, September 9, 2024

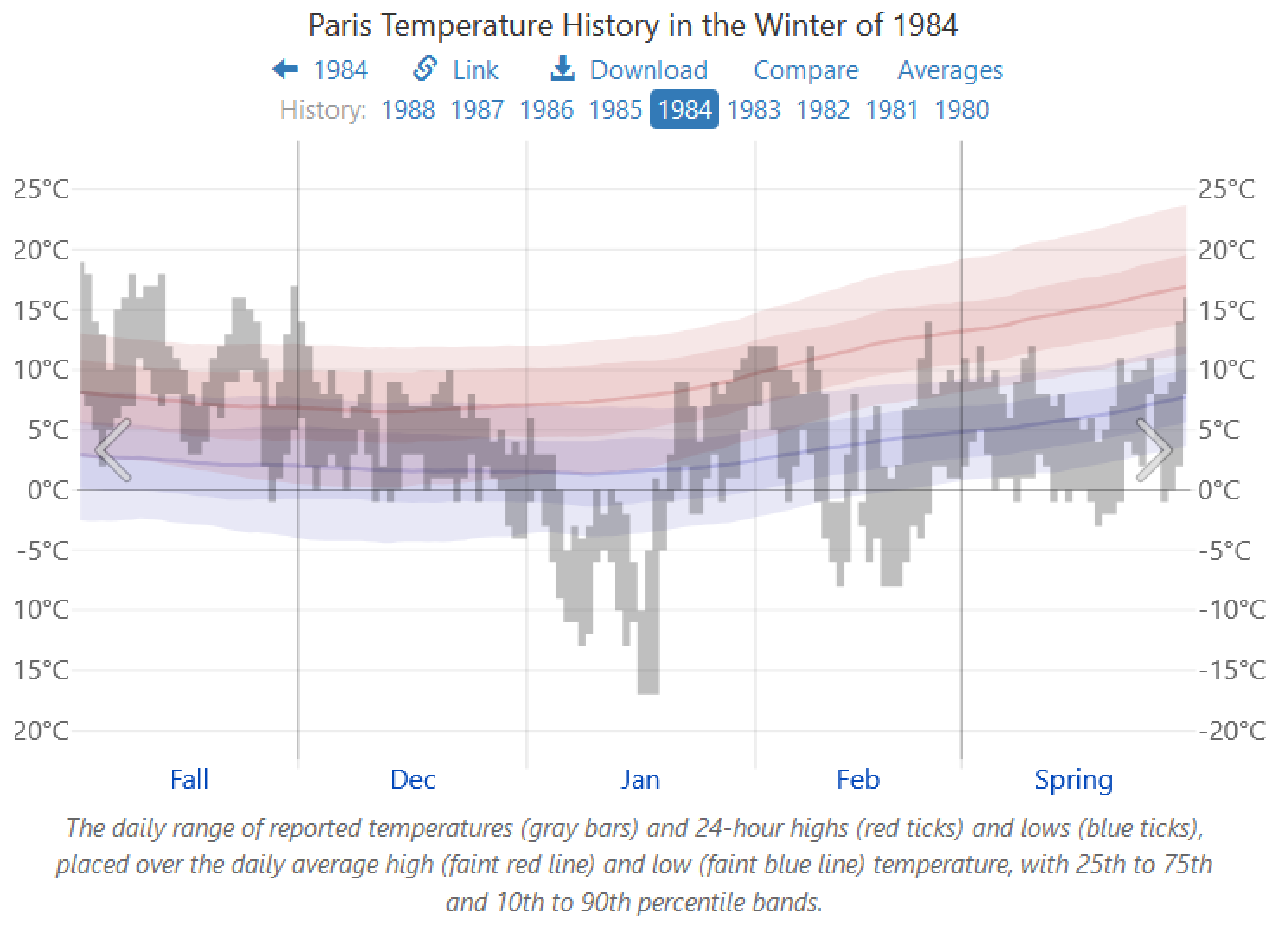
David Burgess

Queen Mary University of London

Queen Mary
University of London

With thanks to … many colleagues!

1985 or 1986?



Paris Temperature History in the Winter of 1984

The daily range of reported temperatures (gray bars) and 24-hour highs (red ticks) and lows (blue ticks), placed over the daily average high (faint red line) and low (faint blue line) temperature, with 25th to 75th and 10th to 90th percentile bands.

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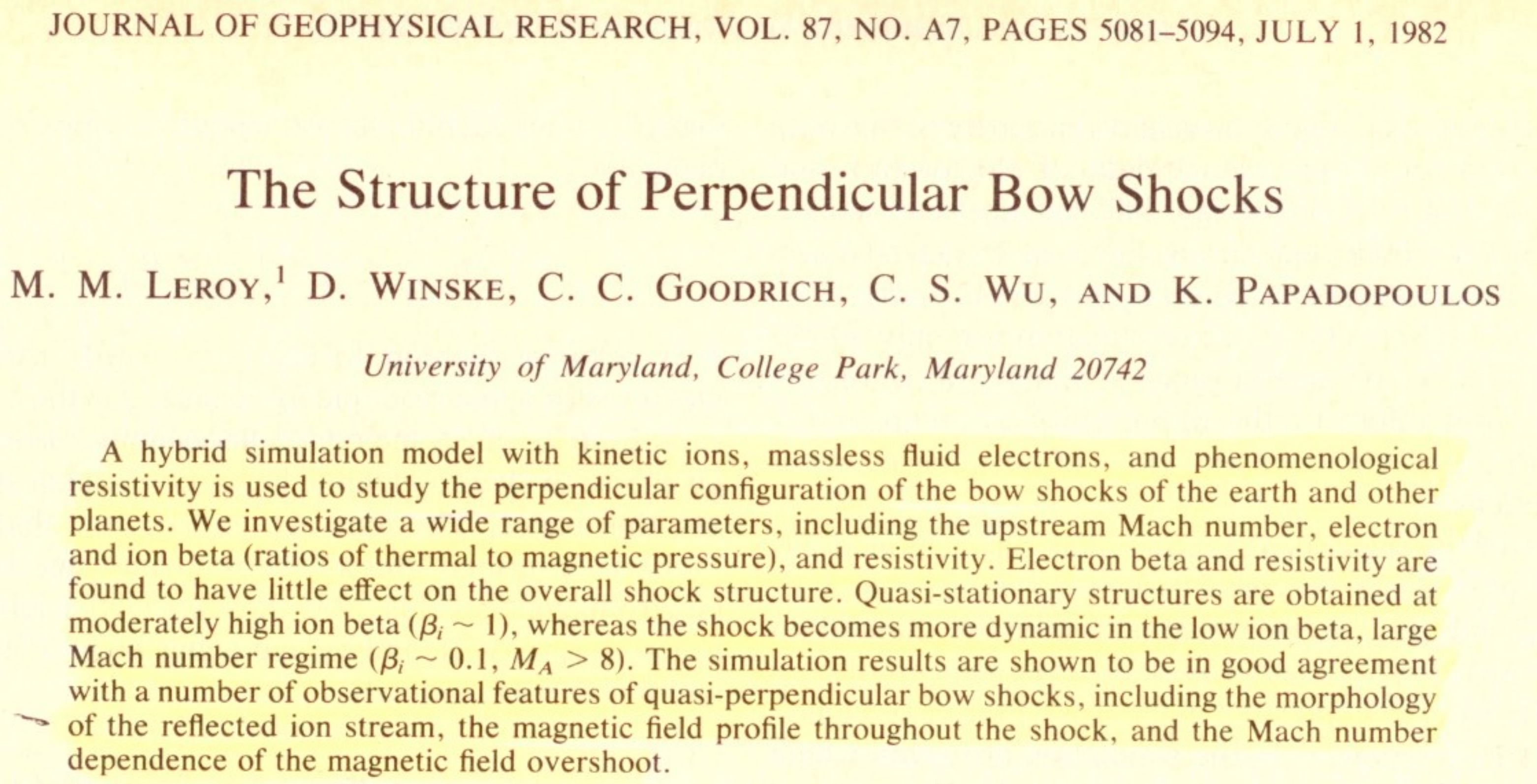
CENTRE DE CALCUL
I.N.A.G.
TOUR d'OBSERVATION
SOLEIL-TERRE
RADIO ASTRONOMIE
SPATIALE
L.A.M.
AMPHITHÉATRE
BIBLIOTHÈQUE



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 87, NO. A7, PAGES 5081–5094, JULY 1, 1982

The Structure of Perpendicular Bow Shocks

M. M. LEROY,[1] D. WINSKE, C. C. GOODRICH, C. S. WU, AND K. PAPADOPOULOS

University of Maryland, College Park, Maryland 20742

A hybrid simulation model with kinetic ions, massless fluid electrons, and phenomenological resistivity is used to study the perpendicular configuration of the bow shocks of the earth and other planets. We investigate a wide range of parameters, including the upstream Mach number, electron and ion beta (ratios of thermal to magnetic pressure), and resistivity. Electron beta and resistivity are found to have little effect on the overall shock structure. Quasi-stationary structures are obtained at moderately high ion beta ($\beta_i \sim 1$), whereas the shock becomes more dynamic in the low ion beta, large Mach number regime ($\beta_i \sim 0.1$, $M_A > 8$). The simulation results are shown to be in good agreement with a number of observational features of quasi-perpendicular bow shocks, including the morphology of the reflected ion stream, the magnetic field profile throughout the shock, and the Mach number dependence of the magnetic field overshoot.

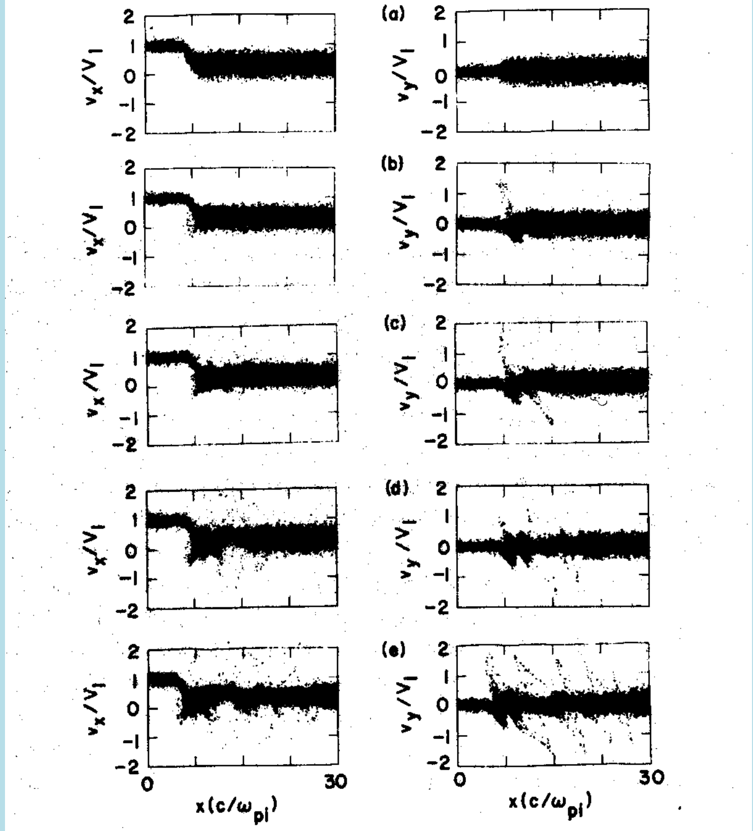
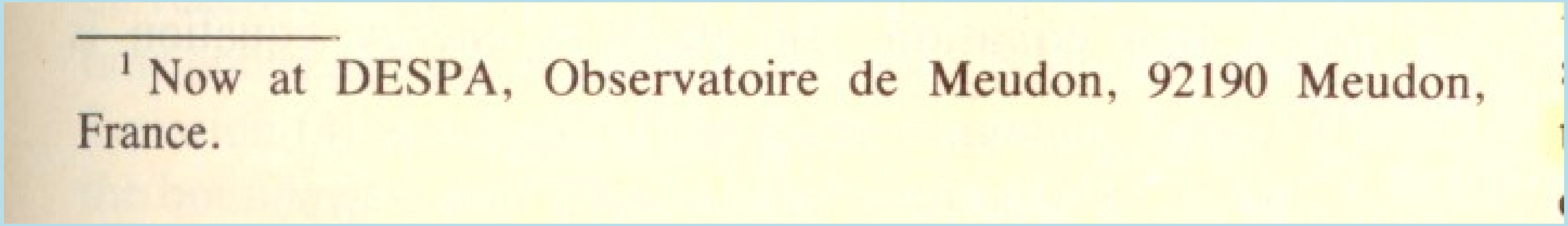


Fig. 1. v_x versus x and v_y versus x phase space for $M_A = 6$, $\beta_{e1} = \beta_{i1} = 1$ at (*a*) $t = 0$, (*b*) 1.3 ω_{ci}^{-1}, (*c*) 2.6 ω_{ci}^{-1}, (*d*) 5.2 ω_{ci}^{-1}, and (*e*) 9.6 ω_{ci}^{-1}.



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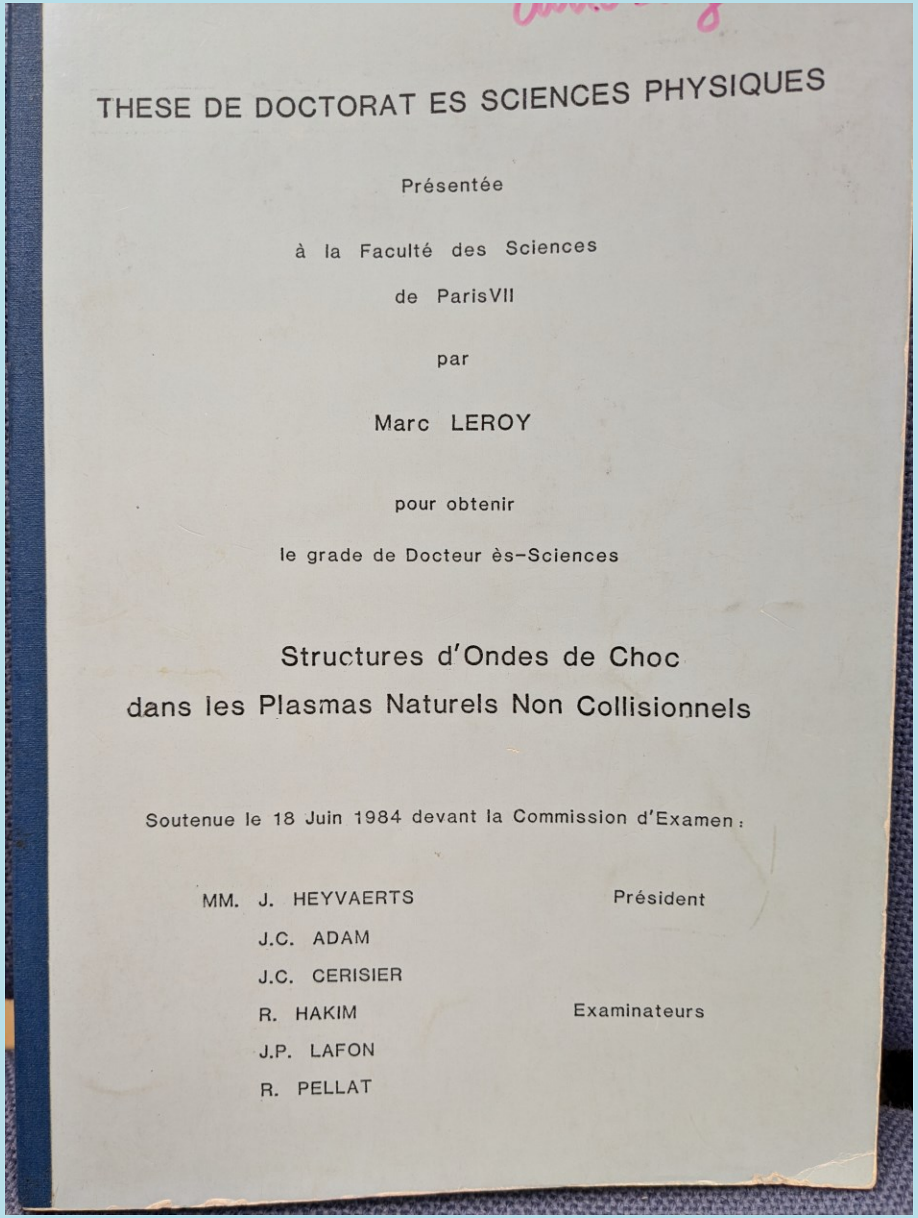
[1] Now at DESPA, Observatoire de Meudon, 92190 Meudon, France.



THESE DE DOCTORAT ES SCIENCES PHYSIQUES

Présentée

à la Faculté des Sciences
de Paris VII

par

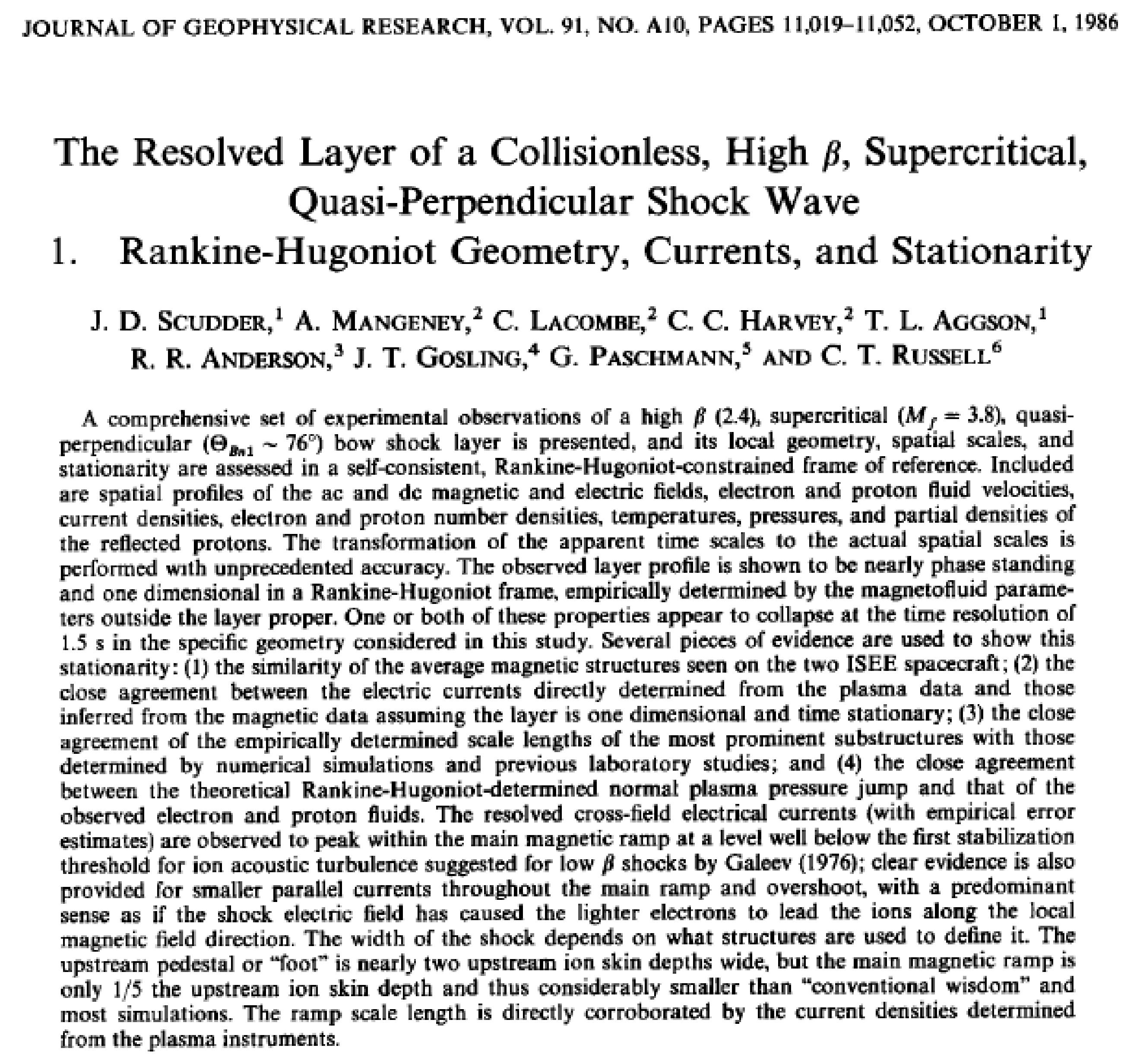
Marc LEROY

pour obtenir
le grade de Docteur ès-Sciences

Structures d'Ondes de Choc dans les Plasmas Naturels Non Collisionnels

Soutenue le 18 Juin 1984 devant la Commission d'Examen :

MM. J. HEYVAERTS	Président
J.C. ADAM	
J.C. CERISIER	
R. HAKIM	Examinateurs
J.P. LAFON	
R. PELLAT	



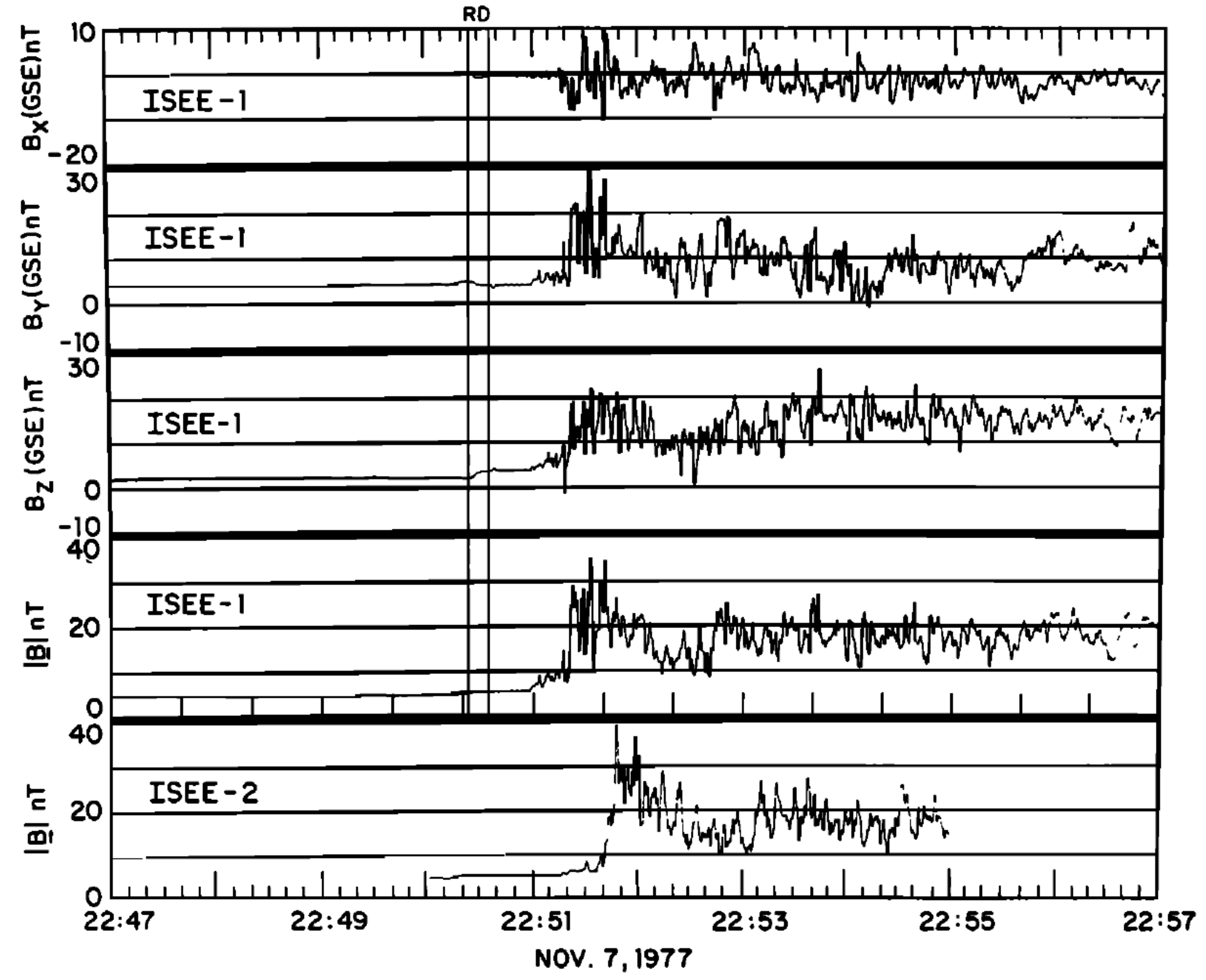
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 91, NO. A10, PAGES 11,019–11,052, OCTOBER 1, 1986

The Resolved Layer of a Collisionless, High β, Supercritical, Quasi-Perpendicular Shock Wave

1. Rankine-Hugoniot Geometry, Currents, and Stationarity

J. D. SCUDDER,[1] A. MANGENEY,[2] C. LACOMBE,[2] C. C. HARVEY,[2] T. L. AGGSON,[1]
R. R. ANDERSON,[3] J. T. GOSLING,[4] G. PASCHMANN,[5] AND C. T. RUSSELL[6]

A comprehensive set of experimental observations of a high β (2.4), supercritical ($M_f = 3.8$), quasi-perpendicular ($\Theta_{Bn1} \sim 76°$) bow shock layer is presented, and its local geometry, spatial scales, and stationarity are assessed in a self-consistent, Rankine-Hugoniot-constrained frame of reference. Included are spatial profiles of the ac and dc magnetic and electric fields, electron and proton fluid velocities, current densities, electron and proton number densities, temperatures, pressures, and partial densities of the reflected protons. The transformation of the apparent time scales to the actual spatial scales is performed with unprecedented accuracy. The observed layer profile is shown to be nearly phase standing and one dimensional in a Rankine-Hugoniot frame, empirically determined by the magnetofluid parameters outside the layer proper. One or both of these properties appear to collapse at the time resolution of 1.5 s in the specific geometry considered in this study. Several pieces of evidence are used to show this stationarity: (1) the similarity of the average magnetic structures seen on the two ISEE spacecraft; (2) the close agreement between the electric currents directly determined from the plasma data and those inferred from the magnetic data assuming the layer is one dimensional and time stationary; (3) the close agreement of the empirically determined scale lengths of the most prominent substructures with those determined by numerical simulations and previous laboratory studies; and (4) the close agreement between the theoretical Rankine-Hugoniot-determined normal plasma pressure jump and that of the observed electron and proton fluids. The resolved cross-field electrical currents (with empirical error estimates) are observed to peak within the main magnetic ramp at a level well below the first stabilization threshold for ion acoustic turbulence suggested for low β shocks by Galeev (1976); clear evidence is also provided for smaller parallel currents throughout the main ramp and overshoot, with a predominant sense as if the shock electric field has caused the lighter electrons to lead the ions along the local magnetic field direction. The width of the shock depends on what structures are used to define it. The upstream pedestal or "foot" is nearly two upstream ion skin depths wide, but the main magnetic ramp is only 1/5 the upstream ion skin depth and thus considerably smaller than "conventional wisdom" and most simulations. The ramp scale length is directly corroborated by the current densities determined from the plasma instruments.


RD
10
-20
B_X(GSE)nT
ISEE-1
30
0
-10
B_Y(GSE)nT
ISEE-1
30
0
-10
B_Z(GSE)nT
ISEE-1
40
20
0
|B| nT
ISEE-1
40
20
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|B| nT
ISEE-2
22:47
22:49
22:51
22:53
22:55
22:57
NOV. 7, 1977

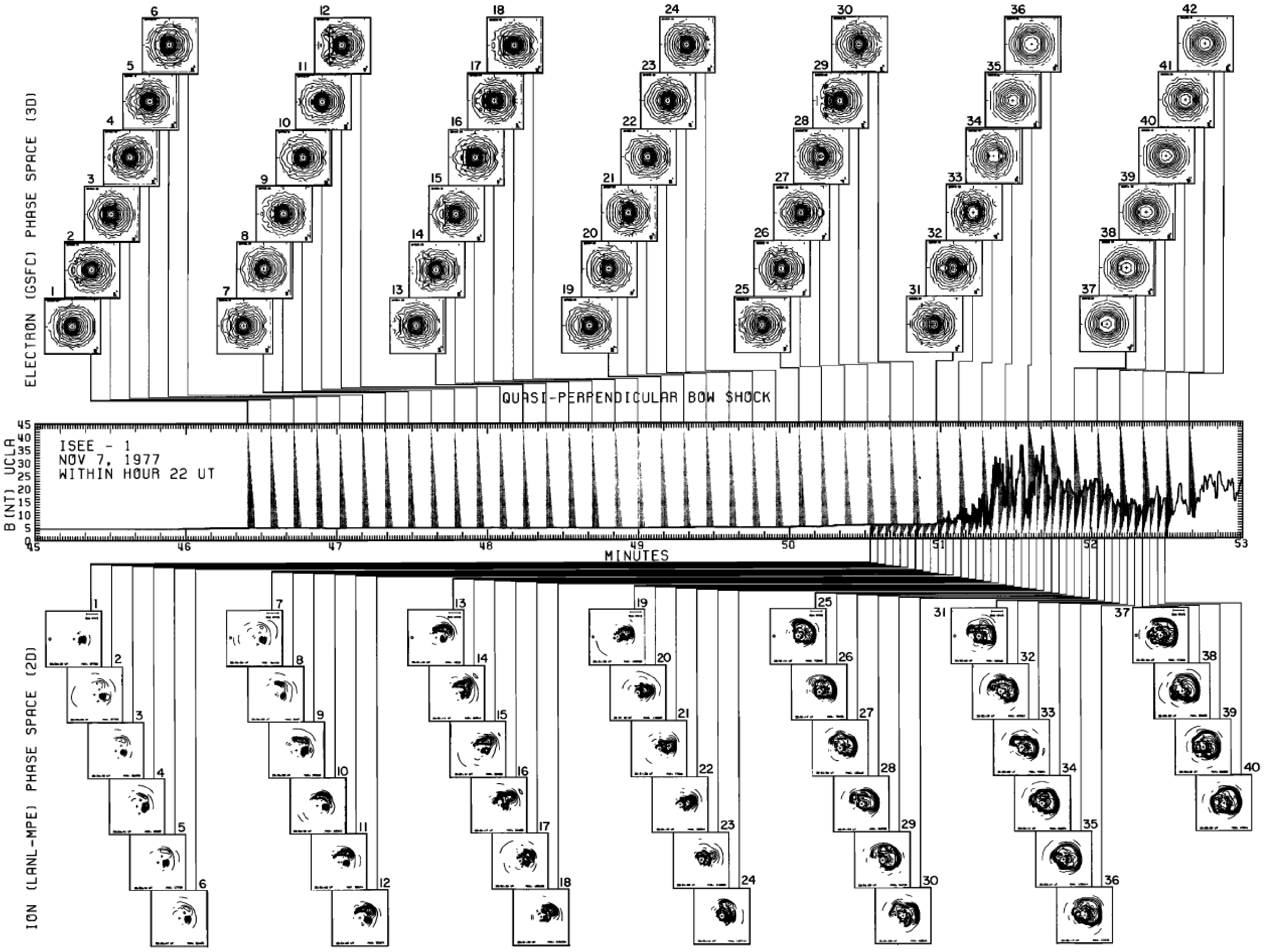
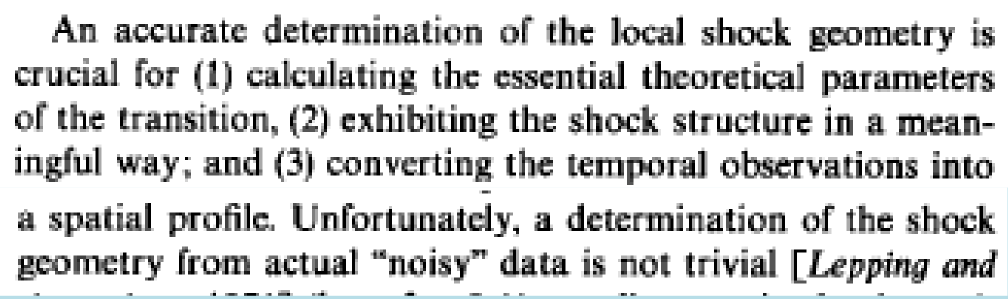
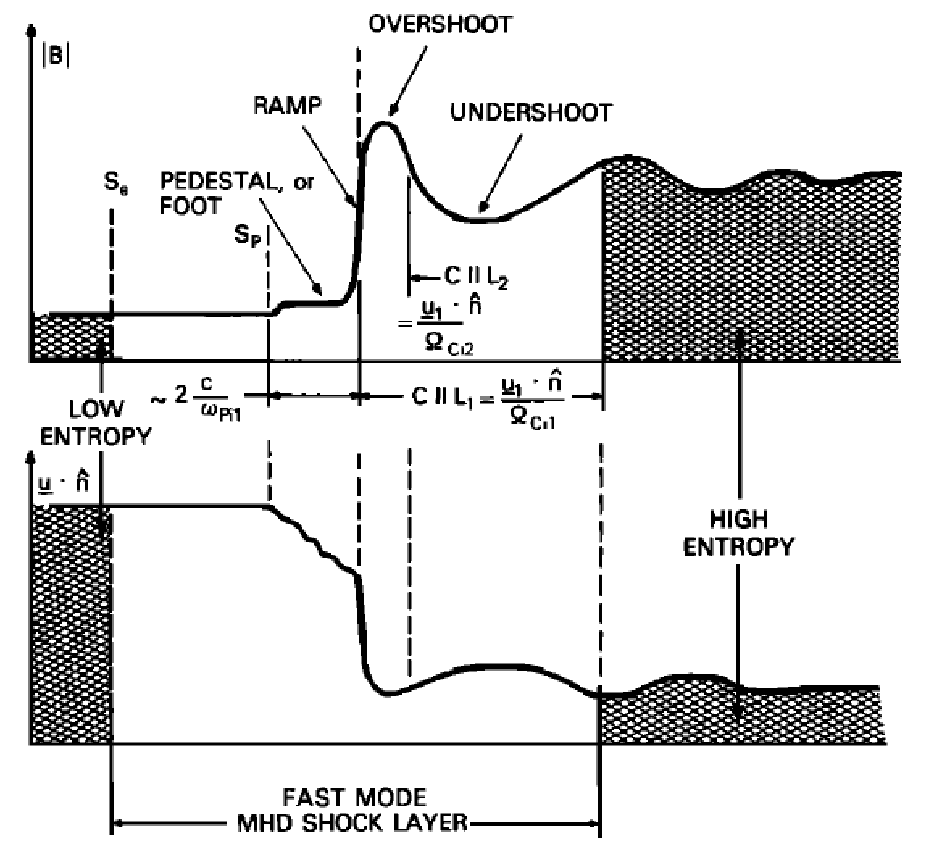
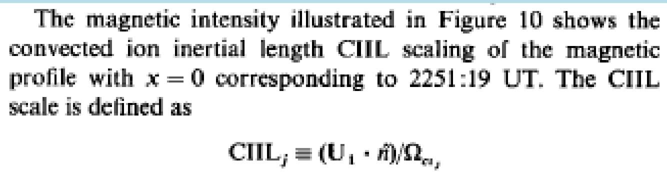


Plate 1. Electron and ion phase space variations throughout the vicinity of the shock. The phase space pictures of the electrons and ions are derived respectively from the Goddard VES and the LANL/MPE fast plasma experiments. Shaded wedges above and below the magnetic profile indicate the time-averaging interval implied in the data collection of electron and ion phase space samples of the insets above and below the magnetic trace, respectively.



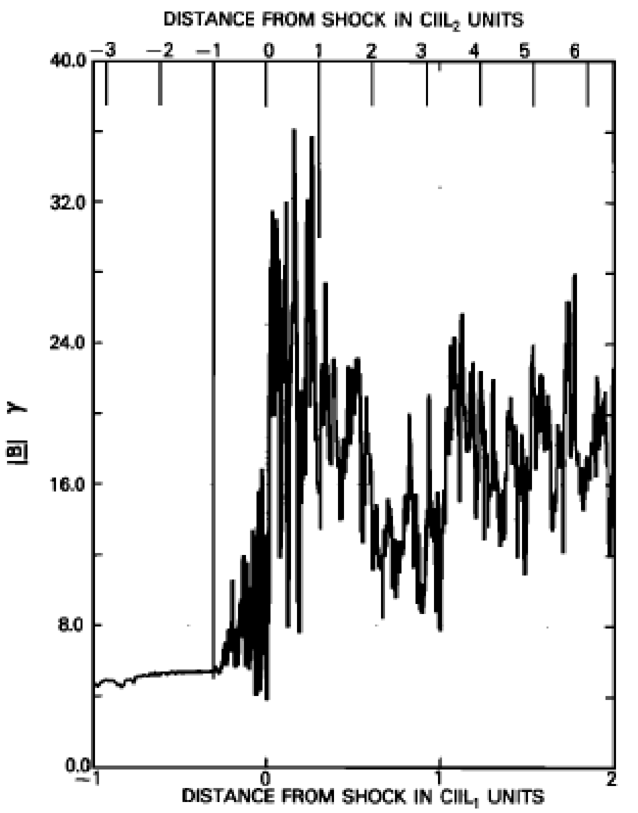
An accurate determination of the local shock geometry is crucial for (1) calculating the essential theoretical parameters of the transition, (2) exhibiting the shock structure in a meaningful way; and (3) converting the temporal observations into a spatial profile. Unfortunately, a determination of the shock geometry from actual "noisy" data is not trivial [*Lepping and*

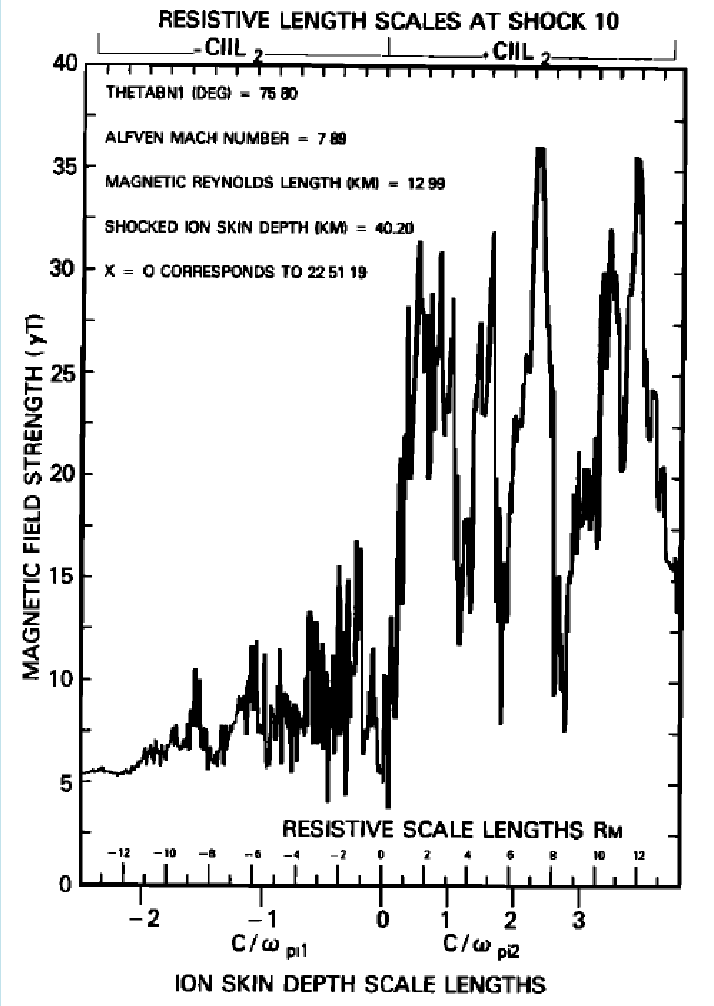




The magnetic intensity illustrated in Figure 10 shows the convected ion inertial length CIIL scaling of the magnetic profile with $x = 0$ corresponding to 2251:19 UT. The CIIL scale is defined as

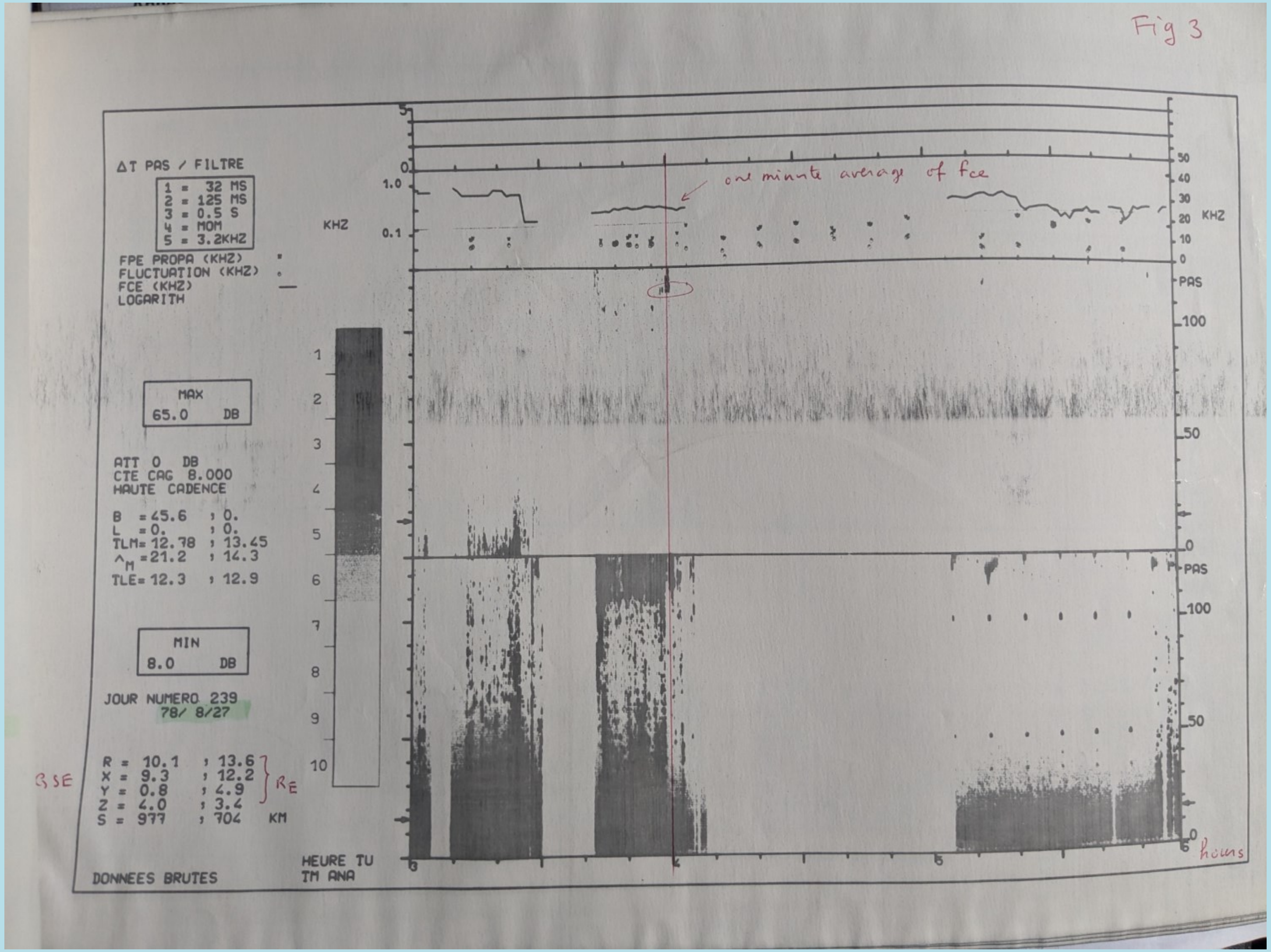
$$\mathrm{CIIL}_j \equiv (\mathbf{U}_1 \cdot \hat{n})/\Omega_{ci},$$





ISEE Sounder experiment

Fig 3



ΔT PAS / FILTRE
1 = 32 MS
2 = 125 MS
3 = 0.5 S
4 = MOM
5 = 3.2KHZ

FPE PROPA (KHZ) ▪
FLUCTUATION (KHZ) ∘
FCE (KHZ) —
LOGARITH

MAX
65.0 DB

ATT 0 DB
CTE CAG 8.000
HAUTE CADENCE

B = 45.6 ; 0.
L = 0. ; 0.
TLM= 12.78 ; 13.45
Λ_M = 21.2 ; 14.3
TLE= 12.3 ; 12.9

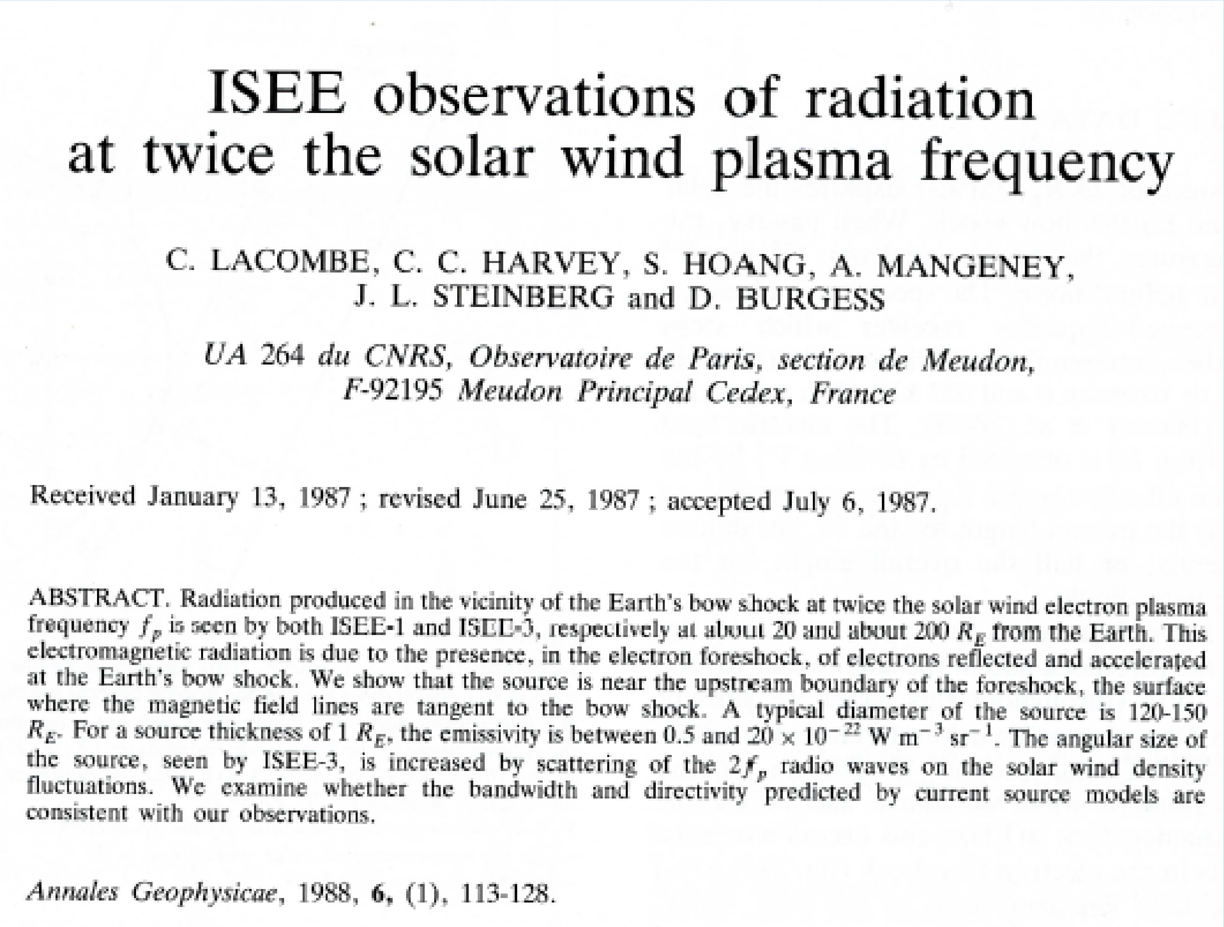
MIN
8.0 DB

JOUR NUMERO 239
78/ 8/27

GSE
R = 10.1 ; 13.6
X = 9.3 ; 12.2
Y = 0.8 ; 4.9
Z = 4.0 ; 3.4
S = 977 ; 704 KM
R_E

DONNEES BRUTES

one minute average of fce



ISEE observations of radiation at twice the solar wind plasma frequency

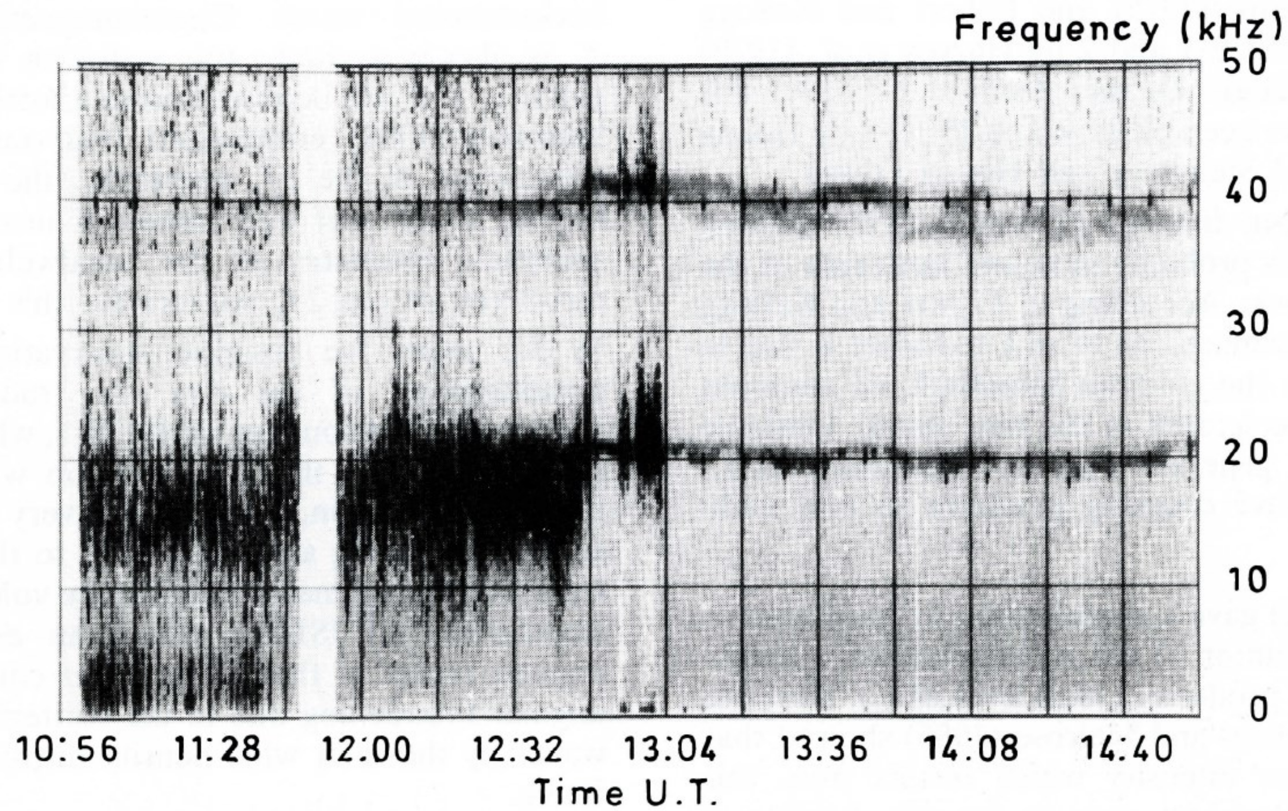
C. LACOMBE, C. C. HARVEY, S. HOANG, A. MANGENEY,
J. L. STEINBERG and D. BURGESS

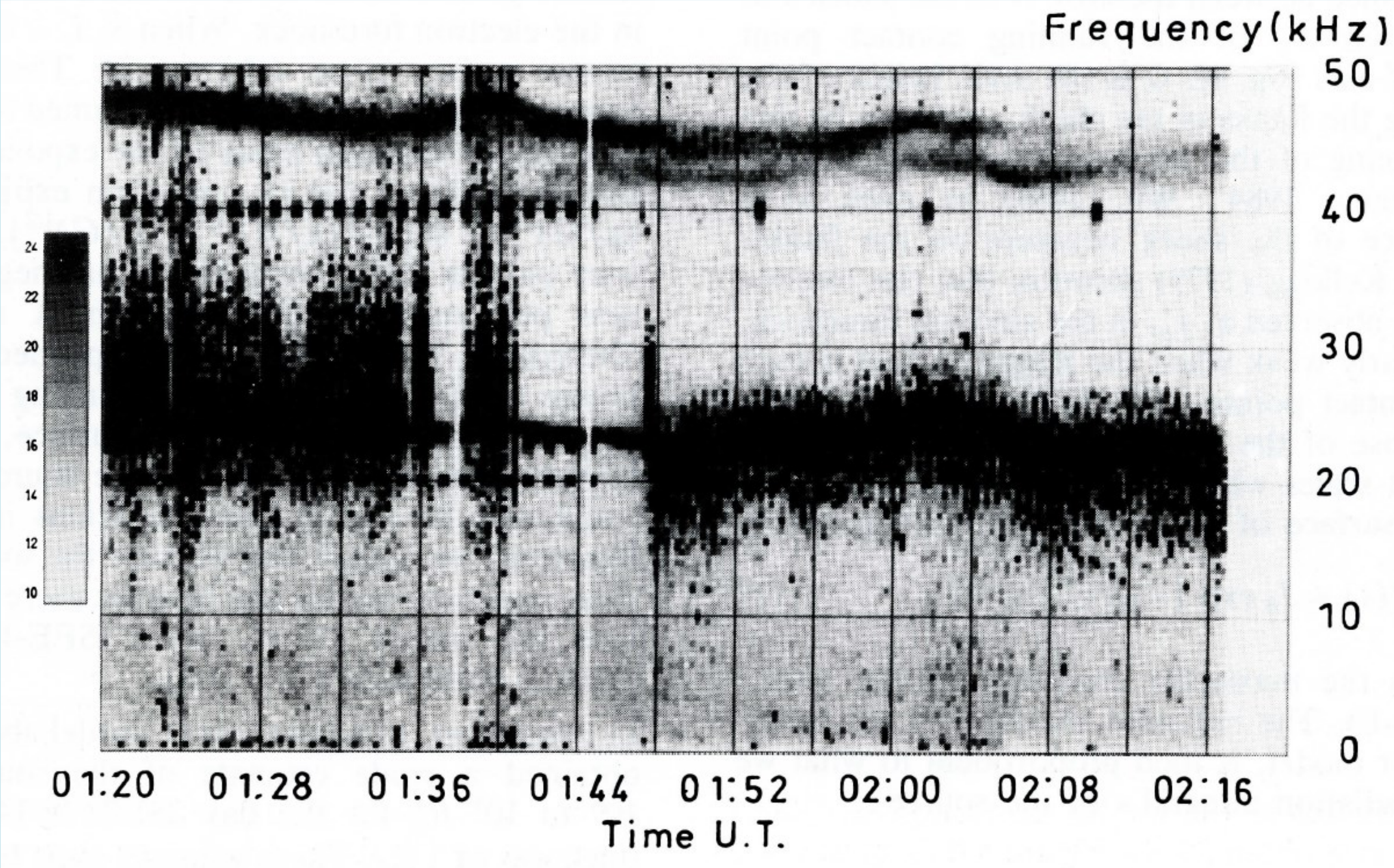
UA 264 du CNRS, Observatoire de Paris, section de Meudon,
F-92195 Meudon Principal Cedex, France

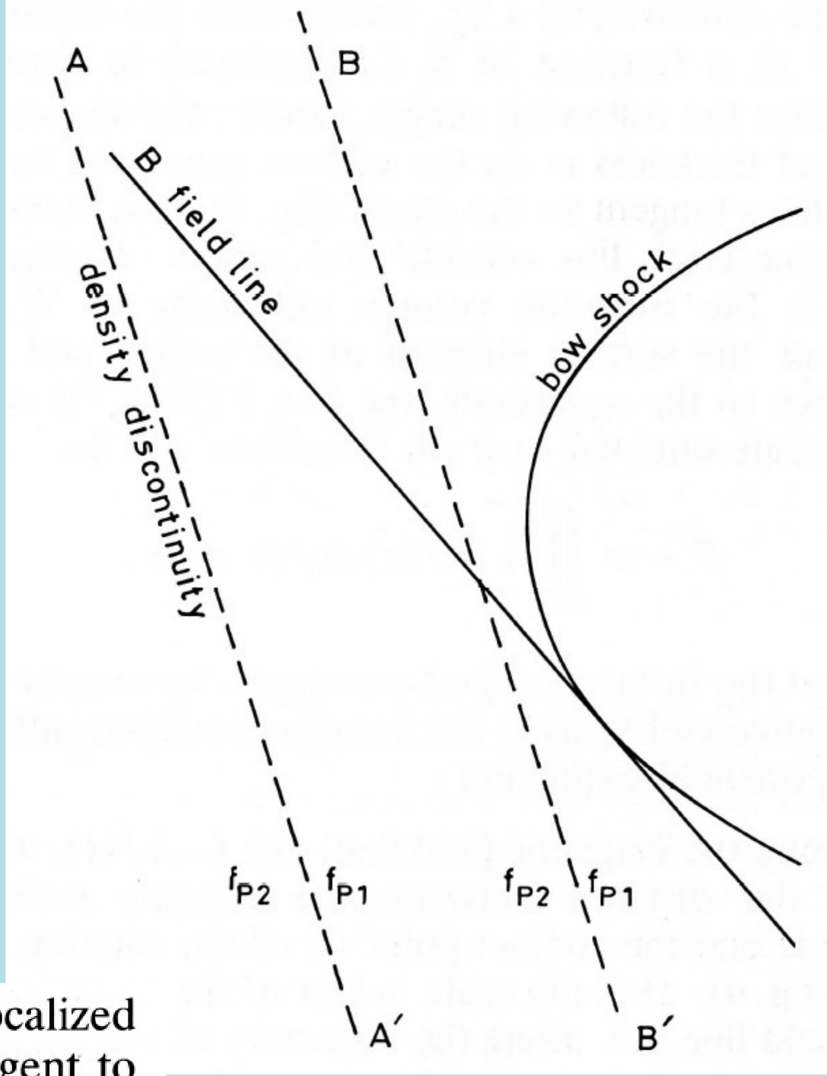
Received January 13, 1987 ; revised June 25, 1987 ; accepted July 6, 1987.

ABSTRACT. Radiation produced in the vicinity of the Earth's bow shock at twice the solar wind electron plasma frequency f_p is seen by both ISEE-1 and ISEE-3, respectively at about 20 and about 200 R_E from the Earth. This electromagnetic radiation is due to the presence, in the electron foreshock, of electrons reflected and accelerated at the Earth's bow shock. We show that the source is near the upstream boundary of the foreshock, the surface where the magnetic field lines are tangent to the bow shock. A typical diameter of the source is 120-150 R_E. For a source thickness of 1 R_E, the emissivity is between 0.5 and 20×10^{-22} W m^{-3} sr^{-1}. The angular size of the source, seen by ISEE-3, is increased by scattering of the $2f_p$ radio waves on the solar wind density fluctuations. We examine whether the bandwidth and directivity predicted by current source models are consistent with our observations.

Annales Geophysicae, 1988, **6**, (1), 113-128.



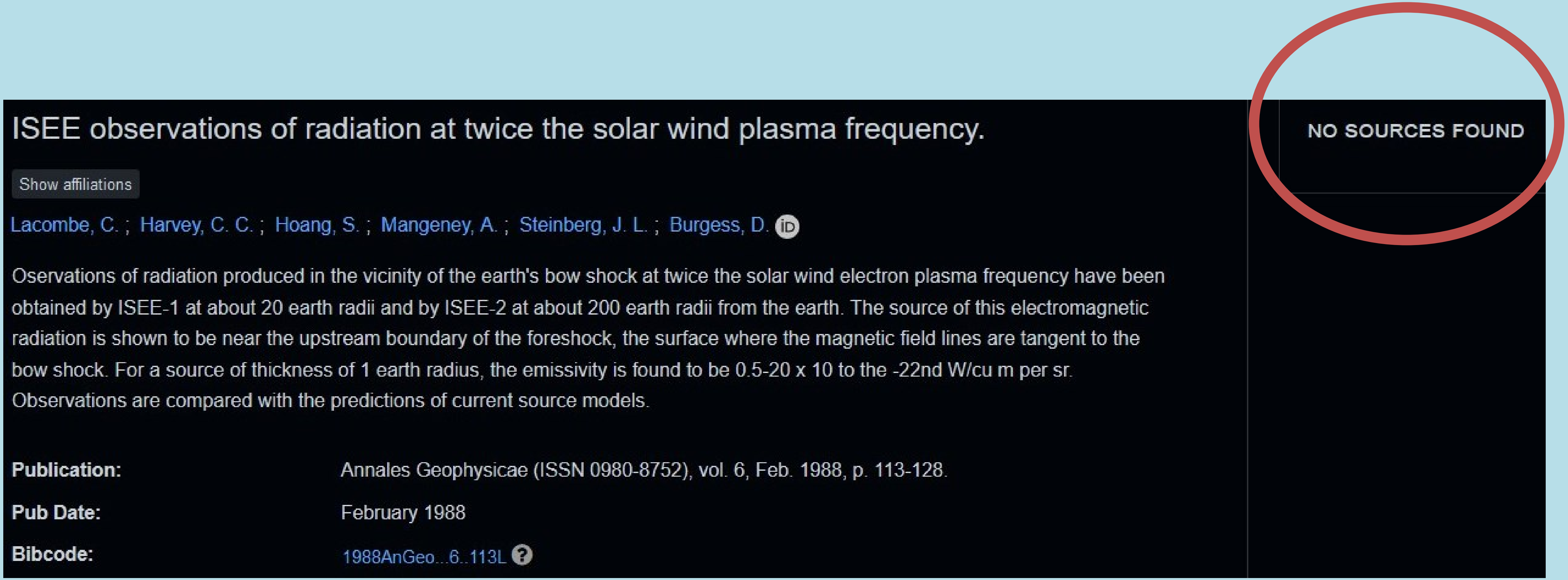




We conclude that the $2f_p$ radiation source is localized on the surface generated by the field lines tangent to the bow shock, out to distances of at least 20 R_E from the contact points with the shock. It is not generated in the whole foreshock. An upper limit of the source thickness is about 1 R_E. A typical dimension of the source is 60 R_E.

ADS entry

!!



ISEE observations of radiation at twice the solar wind plasma frequency.

NO SOURCES FOUND

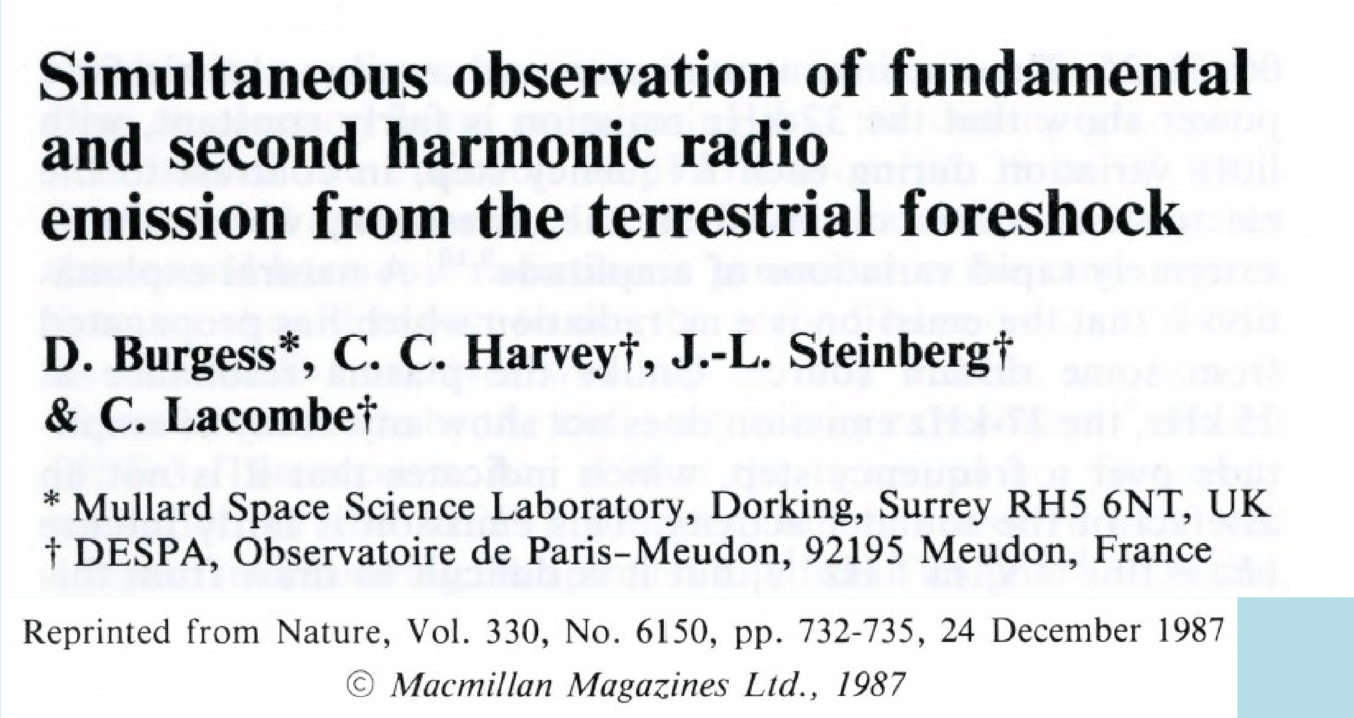
Lacombe, C. ; Harvey, C. C. ; Hoang, S. ; Mangeney, A. ; Steinberg, J. L. ; Burgess, D.

Oservations of radiation produced in the vicinity of the earth's bow shock at twice the solar wind electron plasma frequency have been obtained by ISEE-1 at about 20 earth radii and by ISEE-2 at about 200 earth radii from the earth. The source of this electromagnetic radiation is shown to be near the upstream boundary of the foreshock, the surface where the magnetic field lines are tangent to the bow shock. For a source of thickness of 1 earth radius, the emissivity is found to be 0.5-20 x 10 to the -22nd W/cu m per sr. Observations are compared with the predictions of current source models.

Publication: Annales Geophysicae (ISSN 0980-8752), vol. 6, Feb. 1988, p. 113-128.

Pub Date: February 1988

Bibcode: 1988AnGeo...6..113L

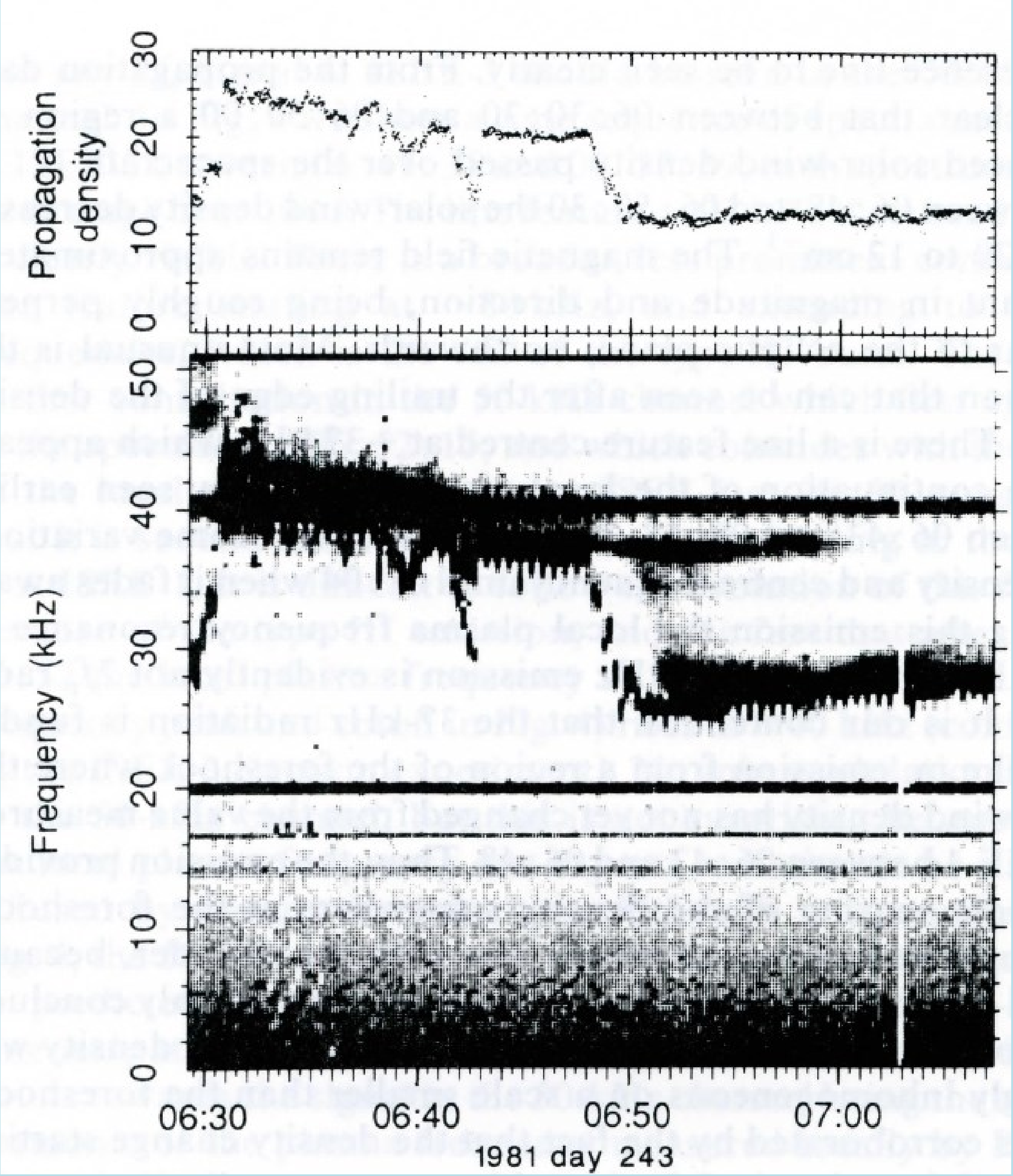


Simultaneous observation of fundamental and second harmonic radio emission from the terrestrial foreshock

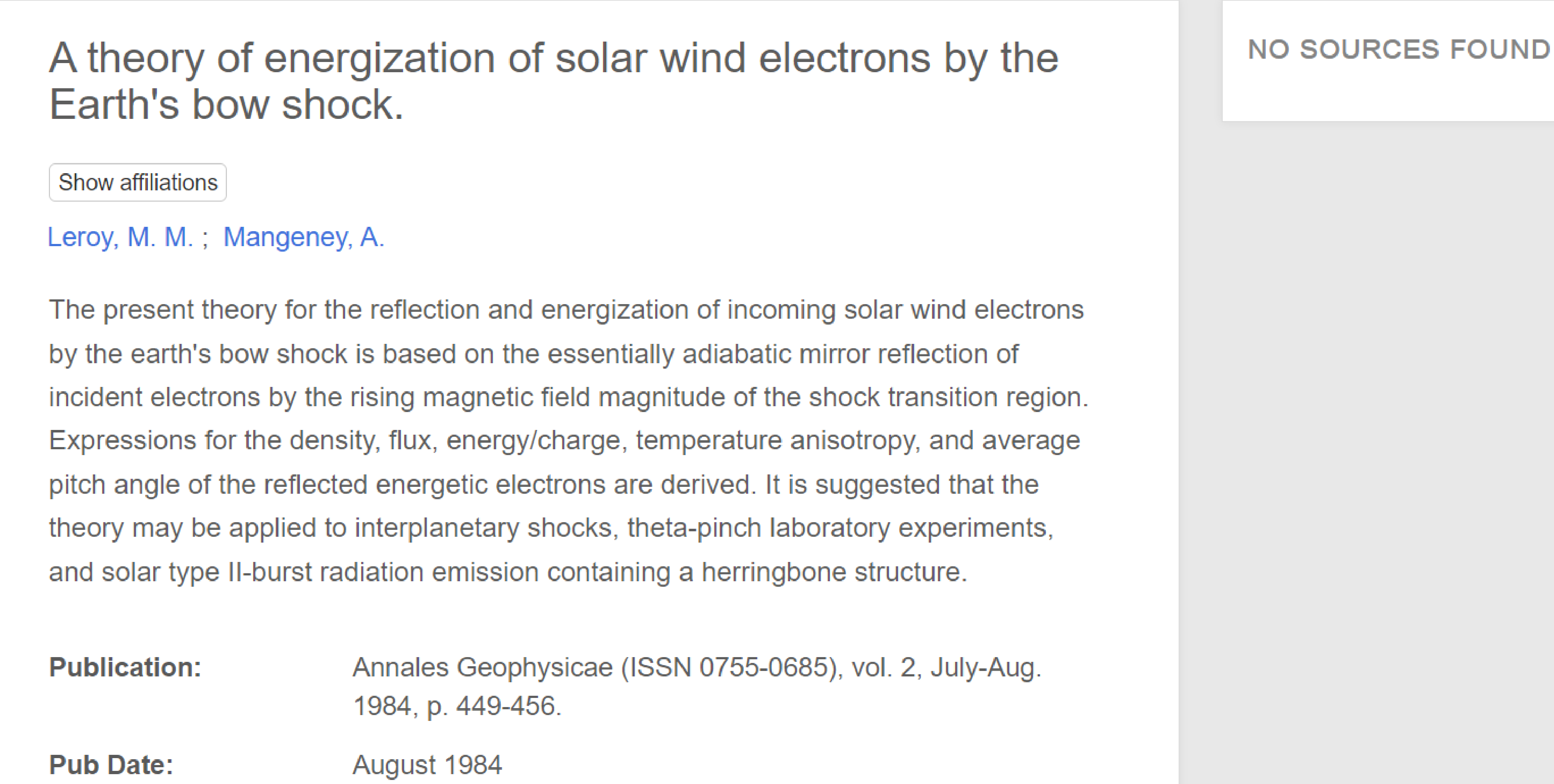
D. Burgess*, C. C. Harvey†, J.-L. Steinberg†
& C. Lacombe†

* Mullard Space Science Laboratory, Dorking, Surrey RH5 6NT, UK
† DESPA, Observatoire de Paris-Meudon, 92195 Meudon, France

Reprinted from Nature, Vol. 330, No. 6150, pp. 732-735, 24 December 1987



Electron acceleration by mirror reflection from bow shock - 1984

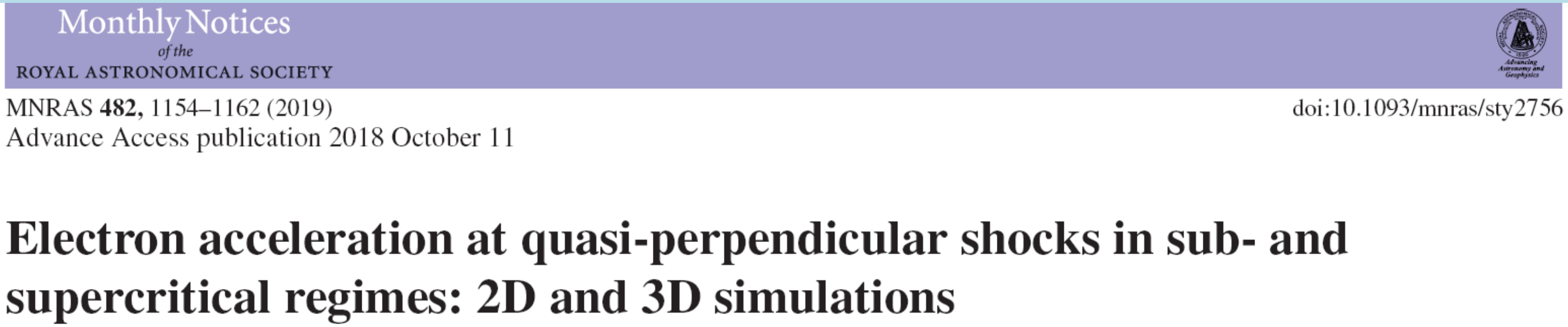


A theory of energization of solar wind electrons by the Earth's bow shock.

Leroy, M. M. ; Mangeney, A.

The present theory for the reflection and energization of incoming solar wind electrons by the earth's bow shock is based on the essentially adiabatic mirror reflection of incident electrons by the rising magnetic field magnitude of the shock transition region. Expressions for the density, flux, energy/charge, temperature anisotropy, and average pitch angle of the reflected energetic electrons are derived. It is suggested that the theory may be applied to interplanetary shocks, theta-pinch laboratory experiments, and solar type II-burst radiation emission containing a herringbone structure.

Publication:	Annales Geophysicae (ISSN 0755-0685), vol. 2, July-Aug. 1984, p. 449-456.
Pub Date:	August 1984



Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **482,** 1154–1162 (2019) doi:10.1093/mnras/sty2756
Advance Access publication 2018 October 11

Electron acceleration at quasi-perpendicular shocks in sub- and supercritical regimes: 2D and 3D simulations

D. Trotta★ and D. Burgess
Queen Mary University of London, School of Physics and Astronomy, London E1 4NS, UK

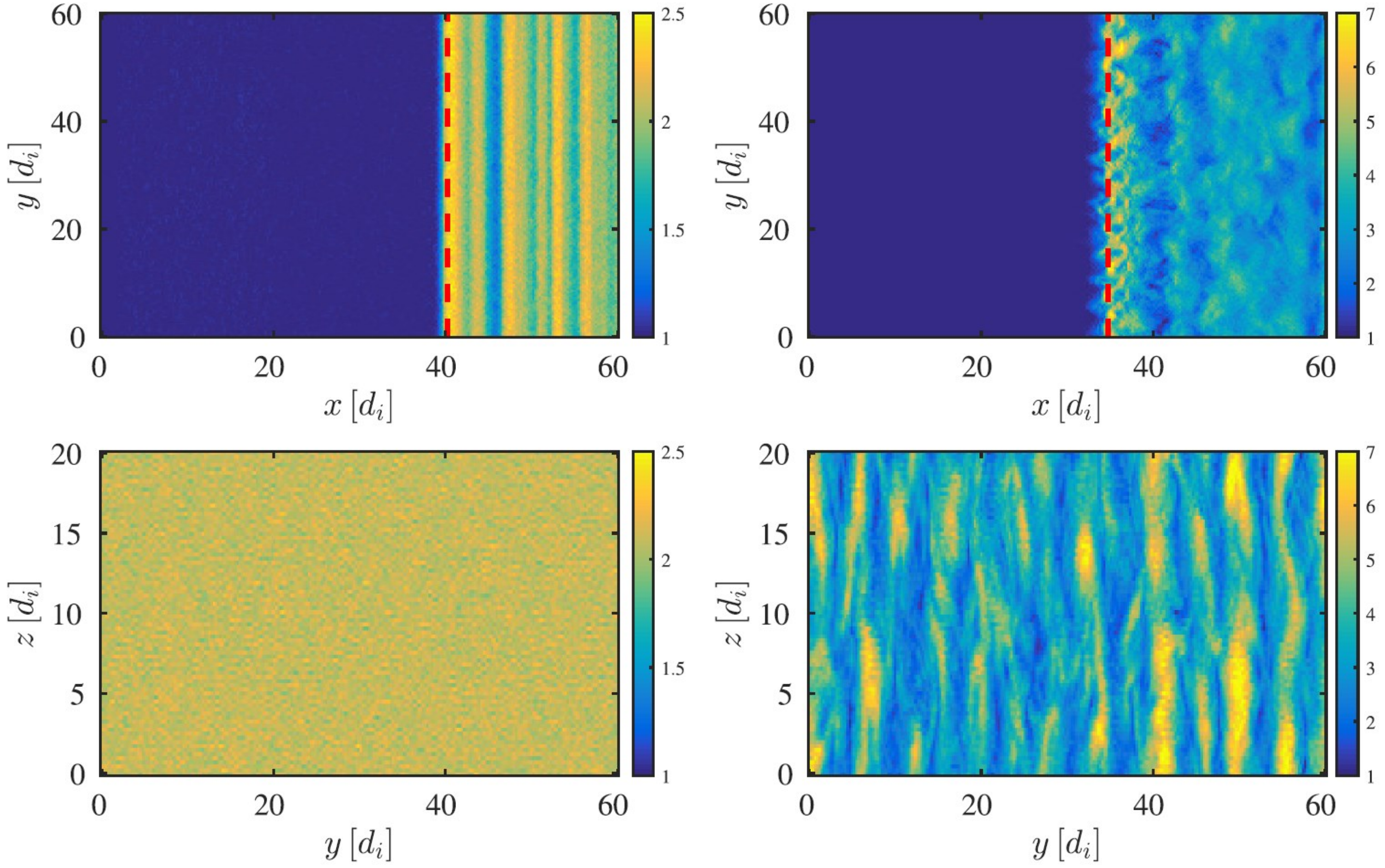
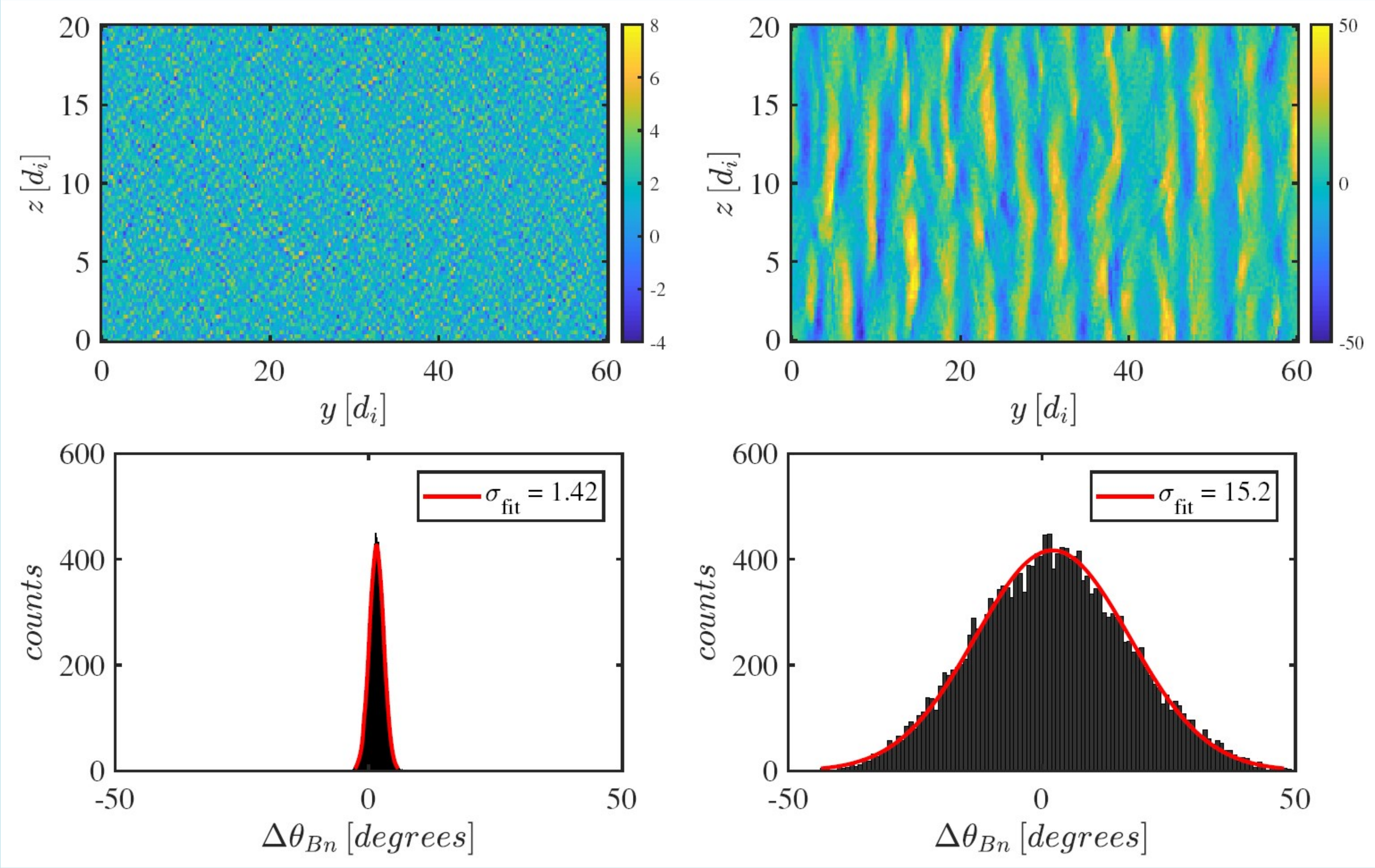


Figure 1. Magnetic field intensity plots for low (left) and high (right) Mach number shocks ($M = 2.9$ and 6.6, respectively). Top panels correspond to cuts of 3D data along $z = 10\,d_i$. The bottom panels correspond to cuts along the red dashed lines in the plots above. In both cases, the upstream θ_{Bn} is 87°.



20
15
10
5
0
$z\,[d_i]$
0
20
40
60
$y\,[d_i]$
8
6
4
2
0
-2
-4
20
15
10
5
0
$z\,[d_i]$
0
20
40
60
$y\,[d_i]$
50
0
-50
600
400
200
0
$counts$
σ_{fit} = 1.42
-50
0
50
$\Delta\theta_{Bn}\,[degrees]$
600
400
200
0
$counts$
σ_{fit} = 15.2
-50
0
50
$\Delta\theta_{Bn}\,[degrees]$

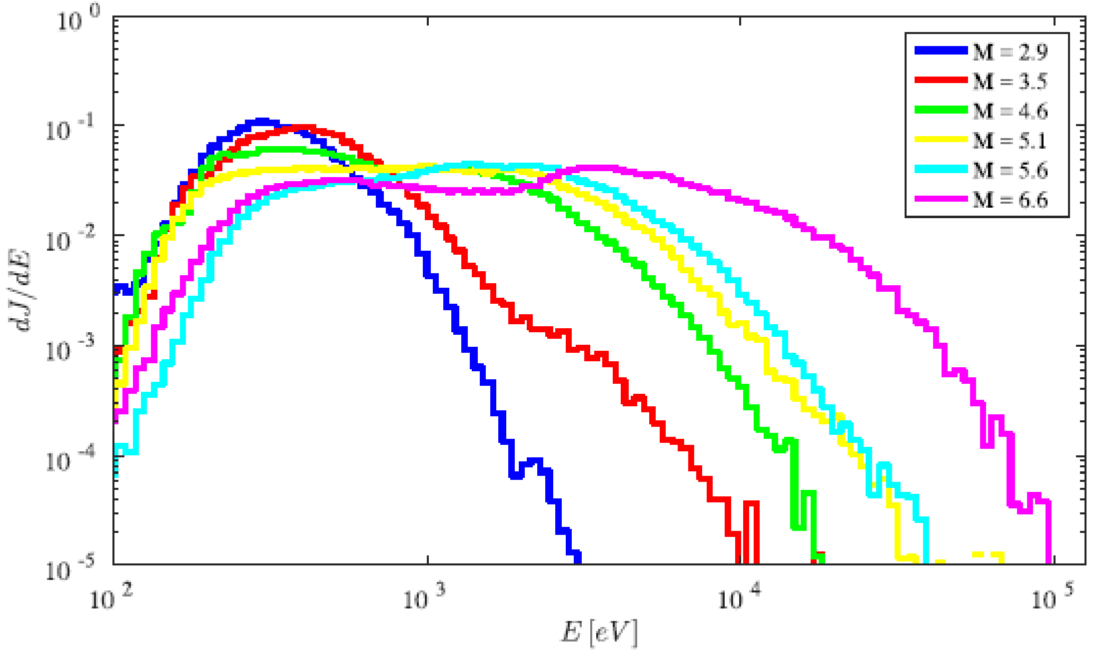


Figure 5. Comparison of final upstream electron energy spectra for 3D shocks with different Mach numbers. In all the cases the upstream θ_{Bx} is 87°.

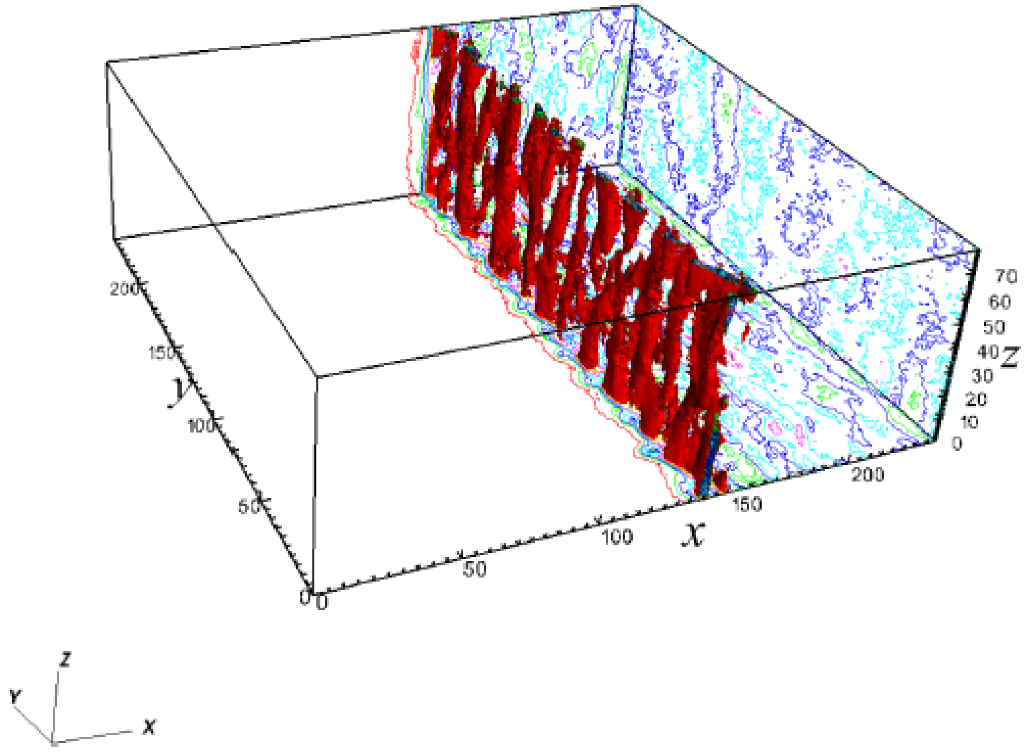
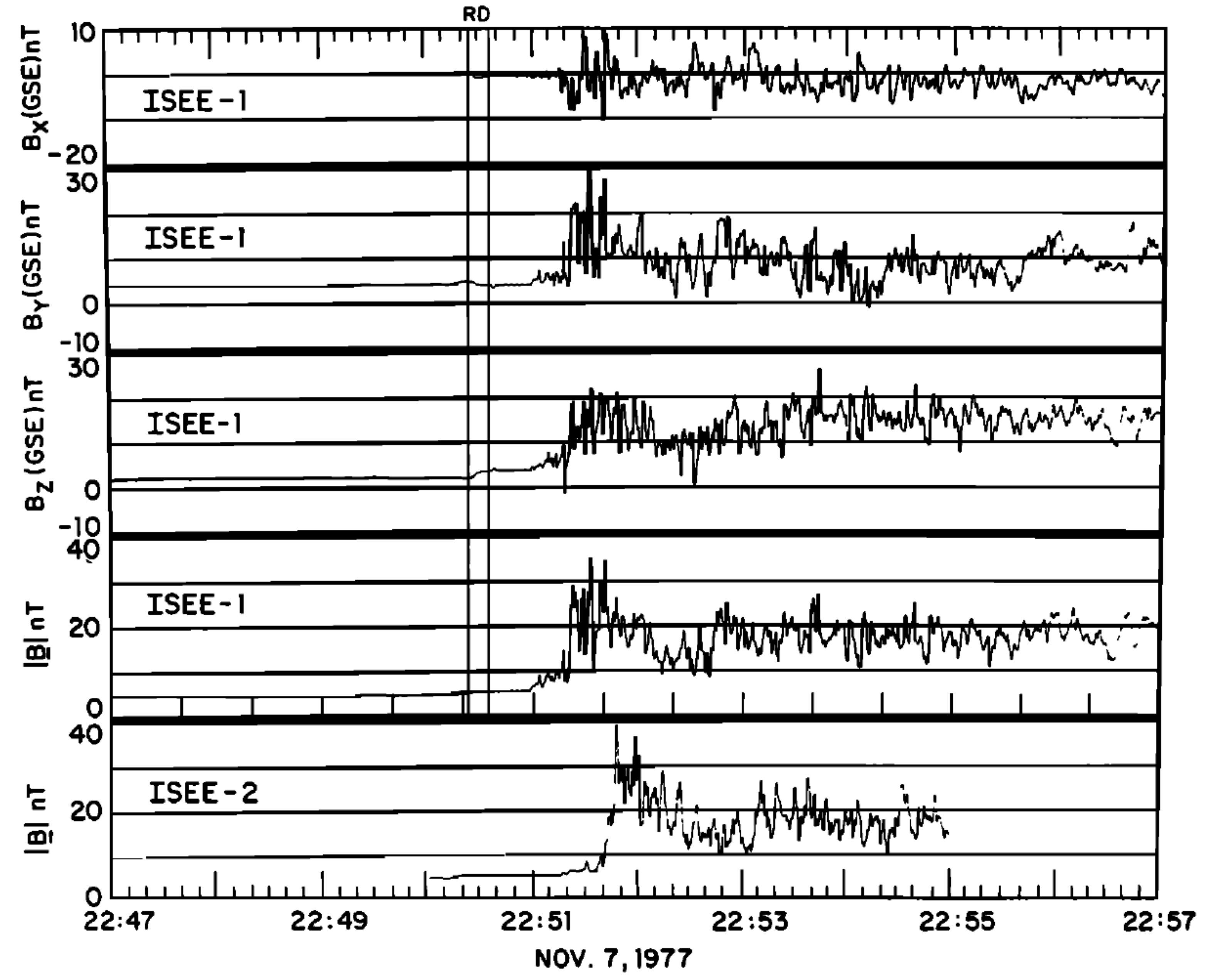


Figure 8. 2D contours and 3D isocontours of magnetic field magnitude for a 3D hybrid shock simulation ($M = 6.6$).

Theta_Bn = 87; Upstream electron distribution: T = 10^5 K Kappa = 4


RD
10
-20
Bx(GSE)nT
ISEE-1
30
0
-10
By(GSE)nT
ISEE-1
30
0
-10
Bz(GSE)nT
ISEE-1
40
20
0
|B| nT
ISEE-1
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ISEE-2
22:47
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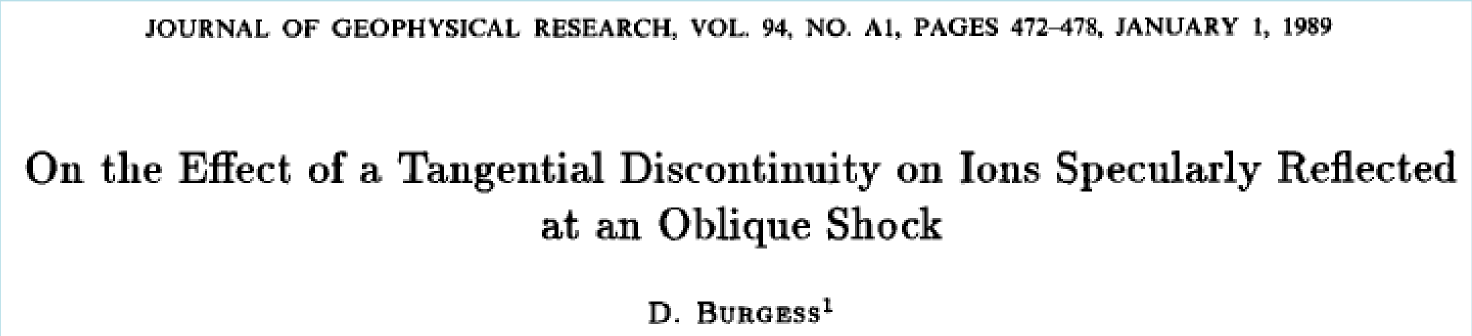
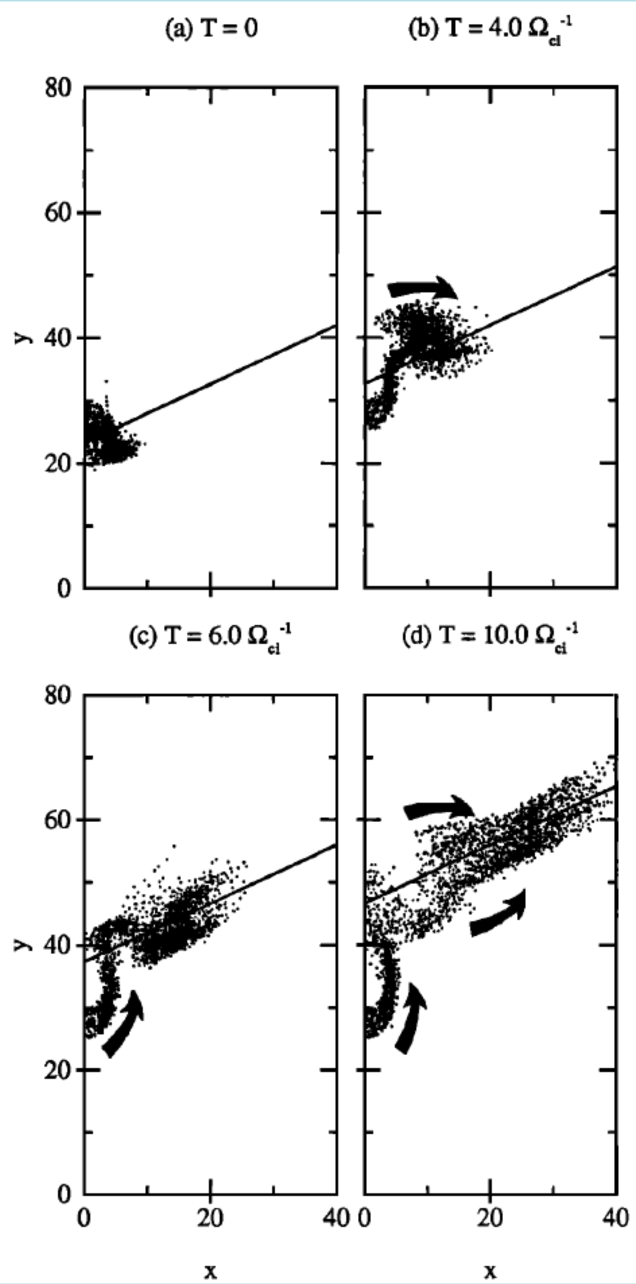
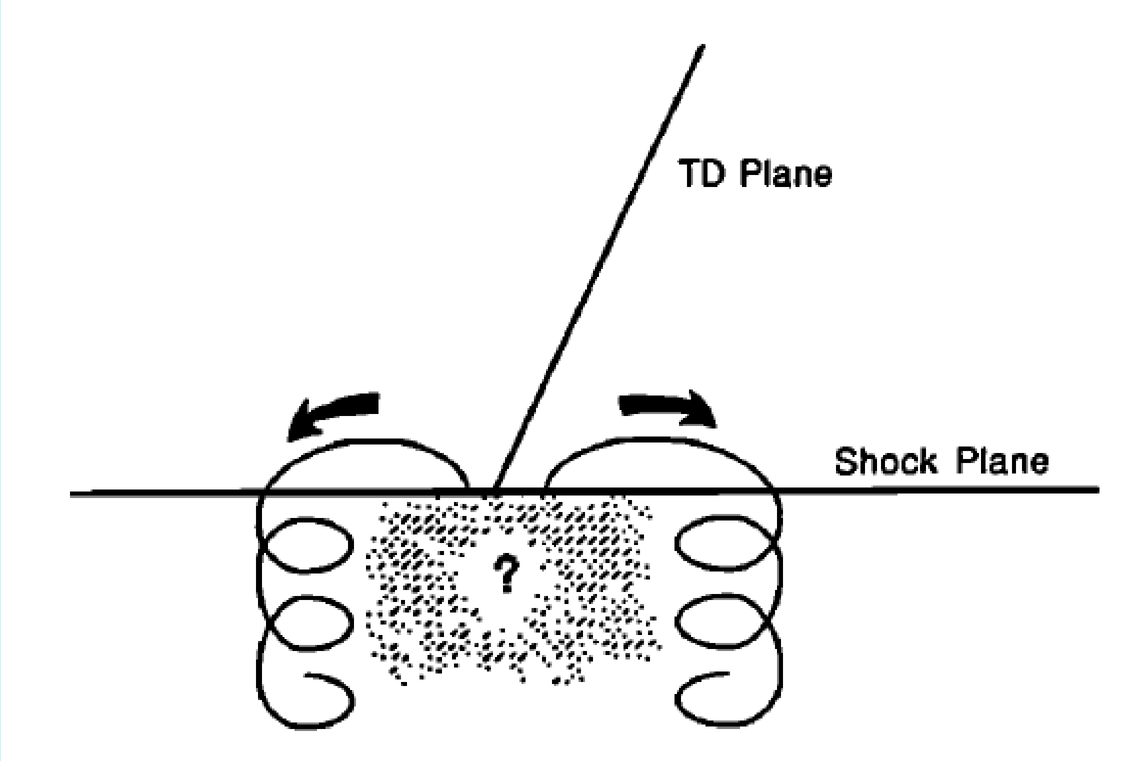
22:57
NOV. 7, 1977


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 94, NO. A1, PAGES 472–478, JANUARY 1, 1989

On the Effect of a Tangential Discontinuity on Ions Specularly Reflected at an Oblique Shock

D. Burgess[1]

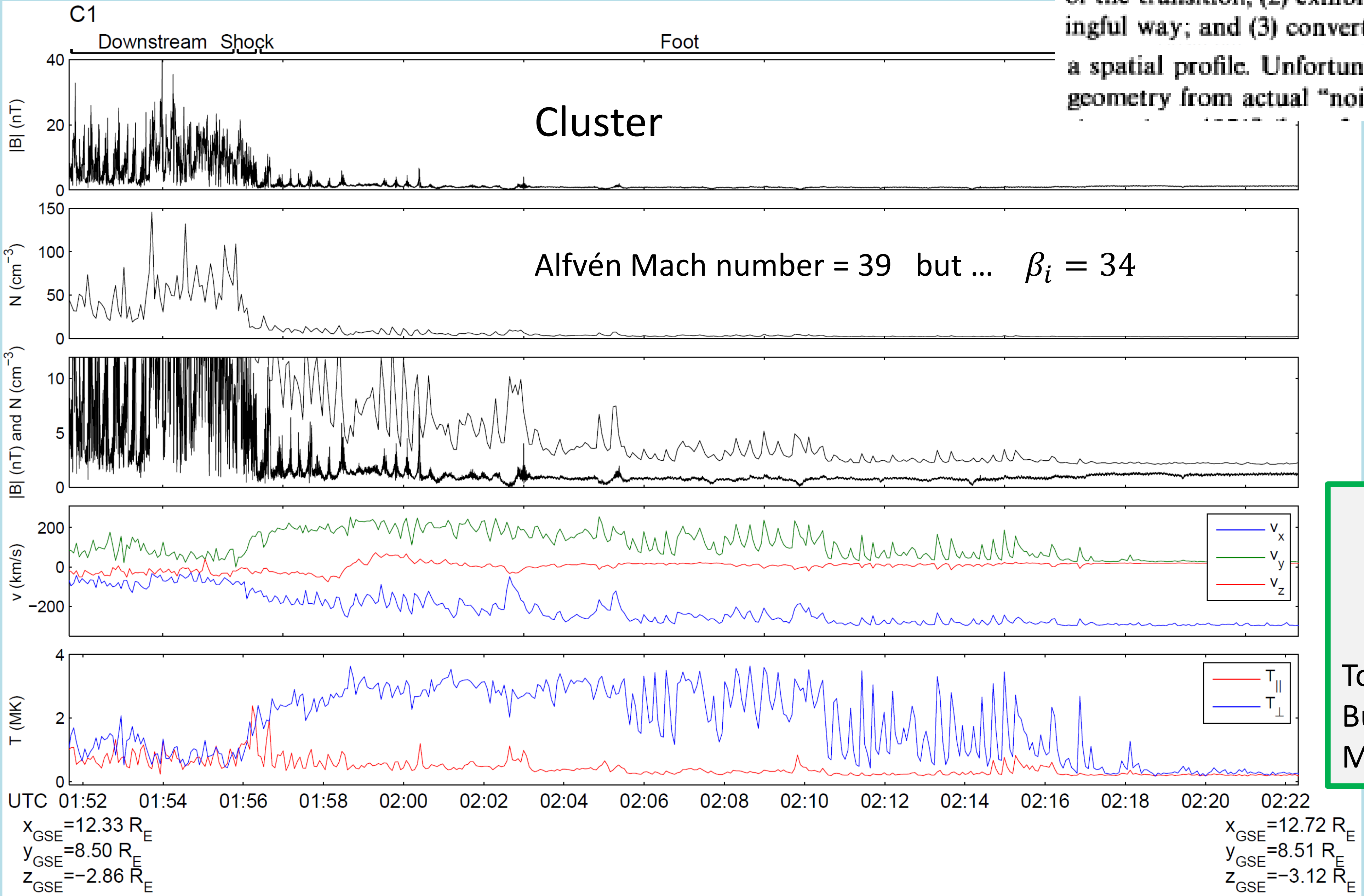




Space or Time?

An accurate determination of the local shock geometry is crucial for (1) calculating the essential theoretical parameters of the transition, (2) exhibiting the shock structure in a meaningful way; and (3) converting the temporal observations into a spatial profile. Unfortunately, a determination of the shock geometry from actual "noisy" data is not trivial [*Lepping and*

Scudder et al 1986



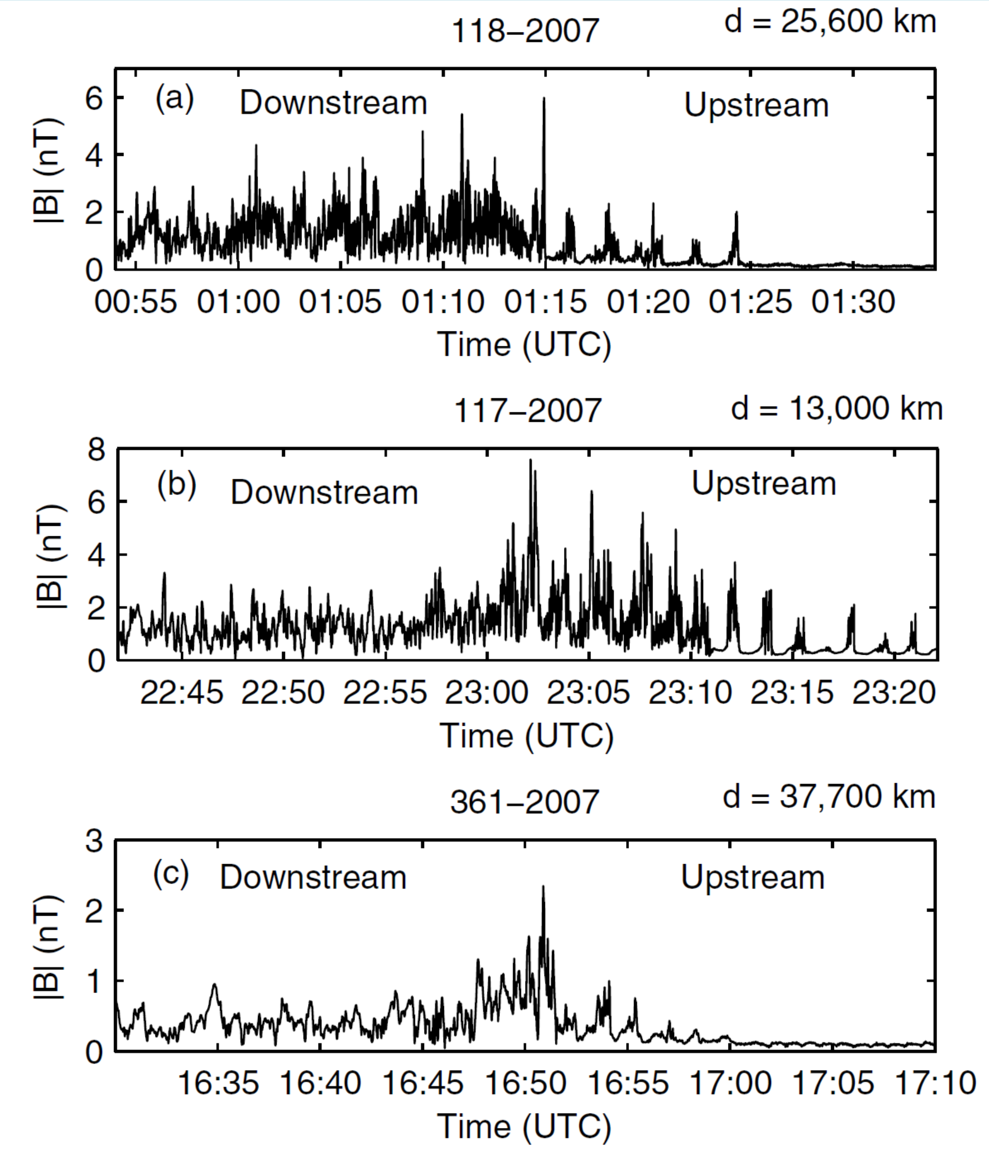
Cluster

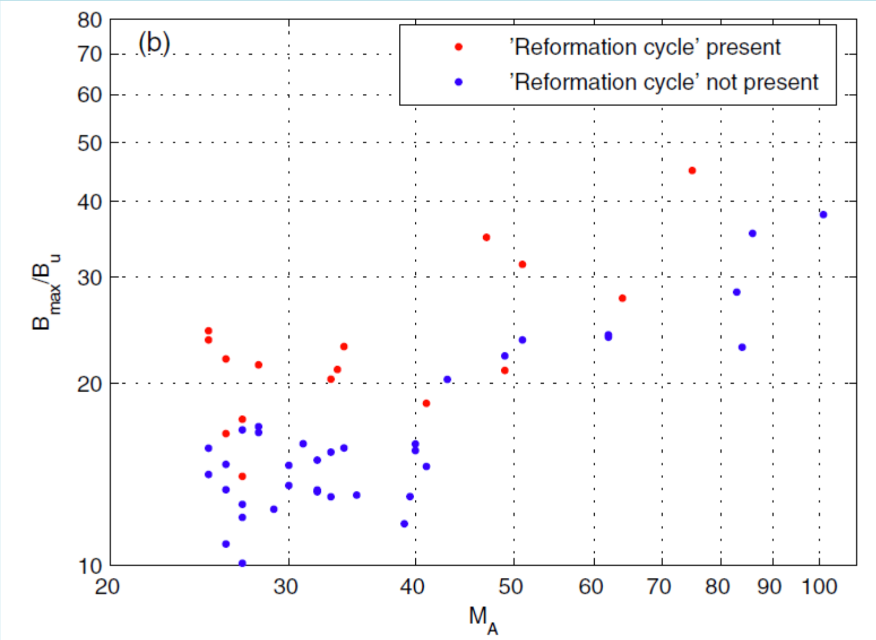
Alfvén Mach number = 39 but … $\beta_i = 34$

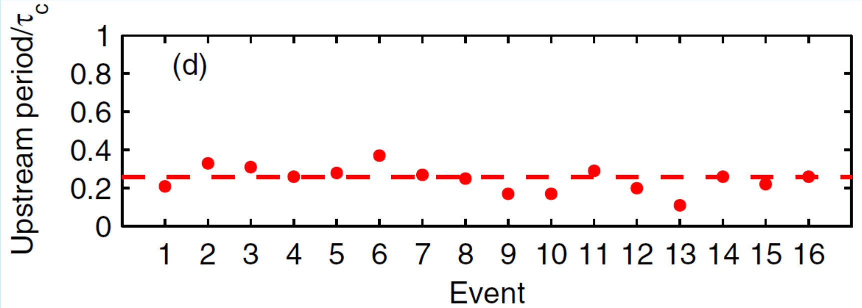
The Dynamics of Very High Alfvén Mach Number Shocks in Space Plasmas, APJL 2017

Torbjörn Sundberg, David Burgess, Manfred Scholer, Adam Masters, and Ali H. Sulaiman

Cassini bow shock observations



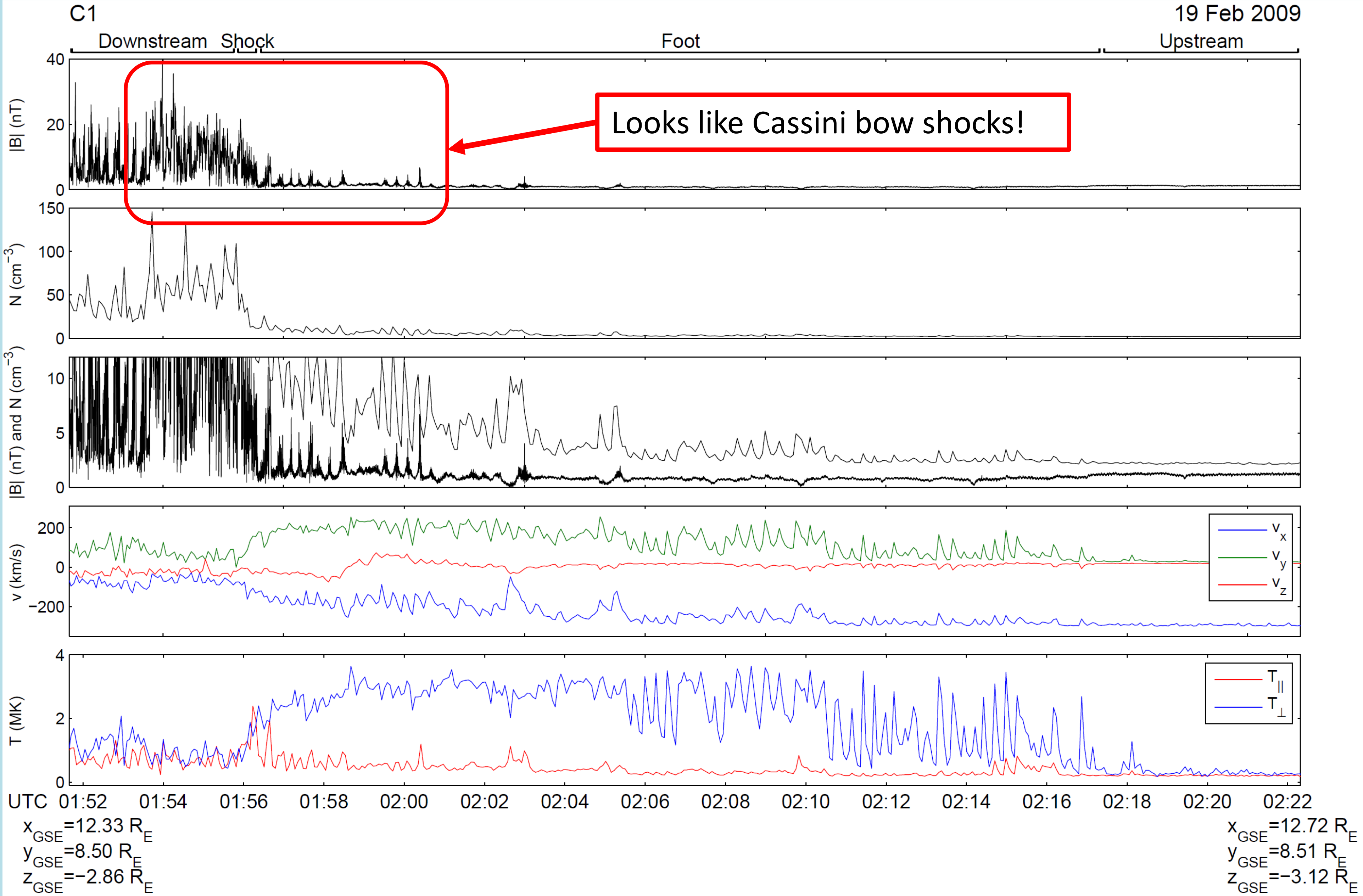




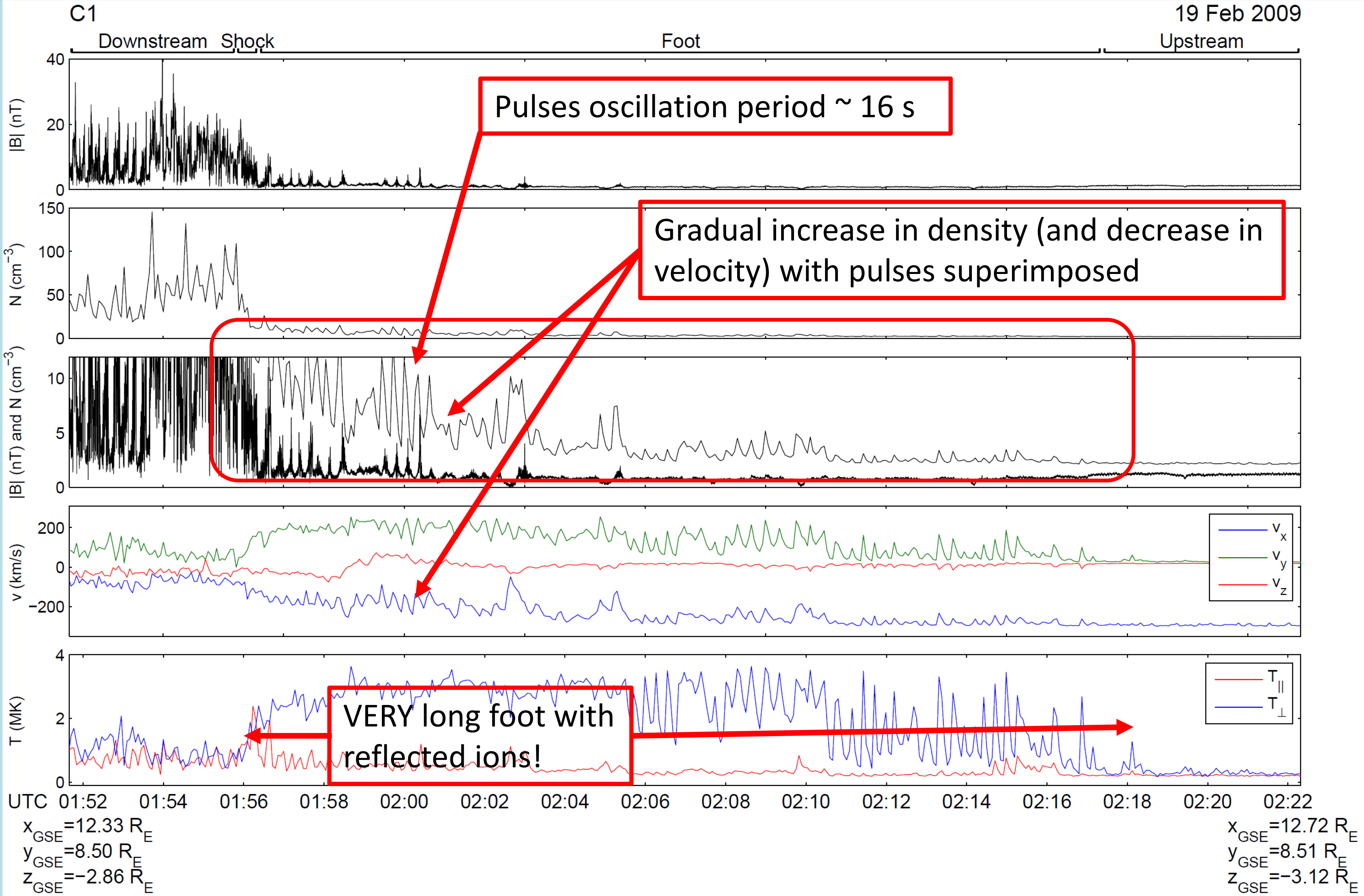
Quasiperpendicular High Mach Number Shocks, PRL, 2016

A. H. Sulaiman, A. Masters, M. K. Dougherty, D. Burgess, M. Fujimoto, and G. B. Hospodarsky

Cluster



Looks like Cassini bow shocks!



Pulses oscillation period ~ 16 s

Gradual increase in density (and decrease in velocity) with pulses superimposed

VERY long foot with reflected ions!

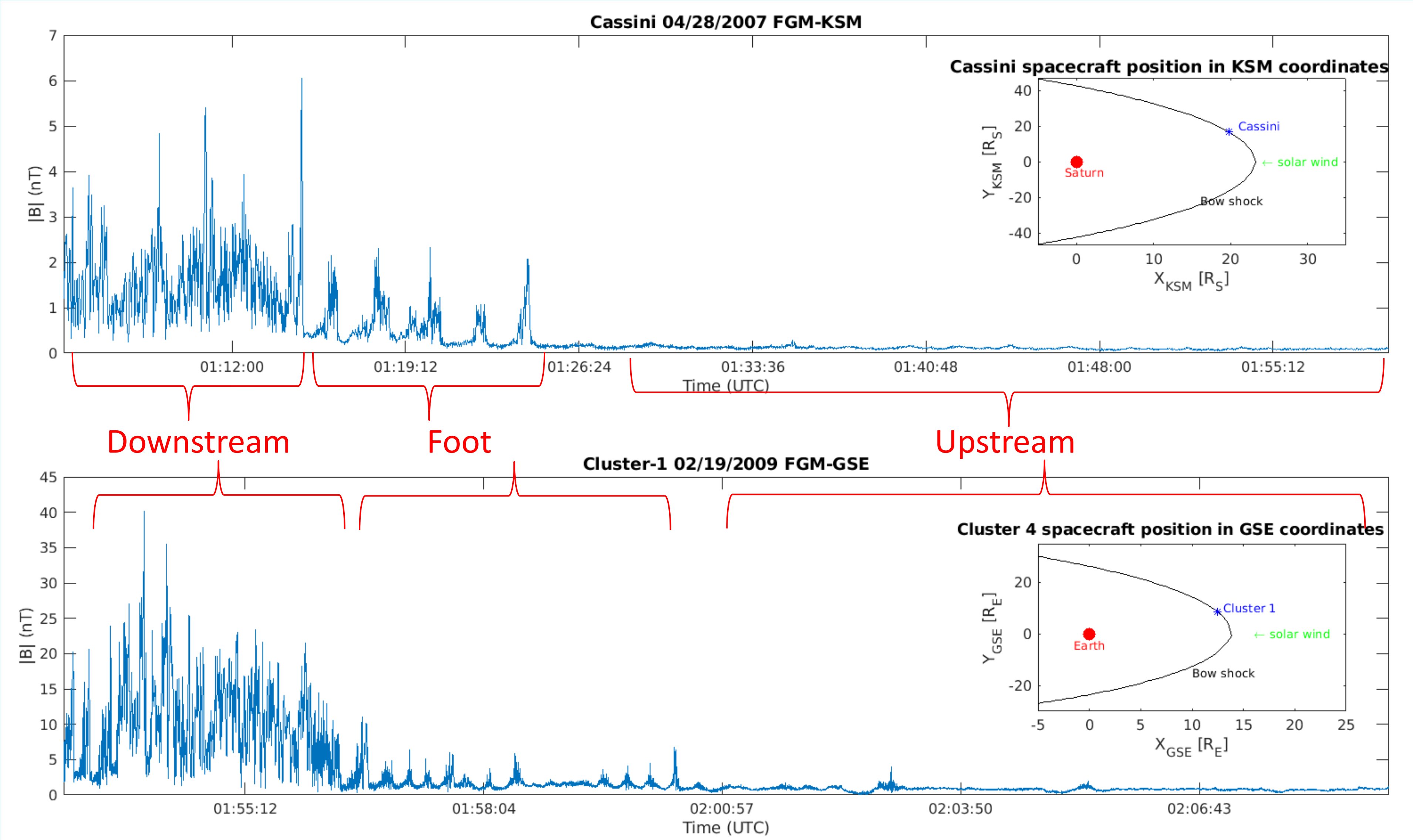
Comparing Cluster and Cassini

Cassini

Ma = 74, ϑBn =61°

Cluster

Ma=39, ϑBn=85°

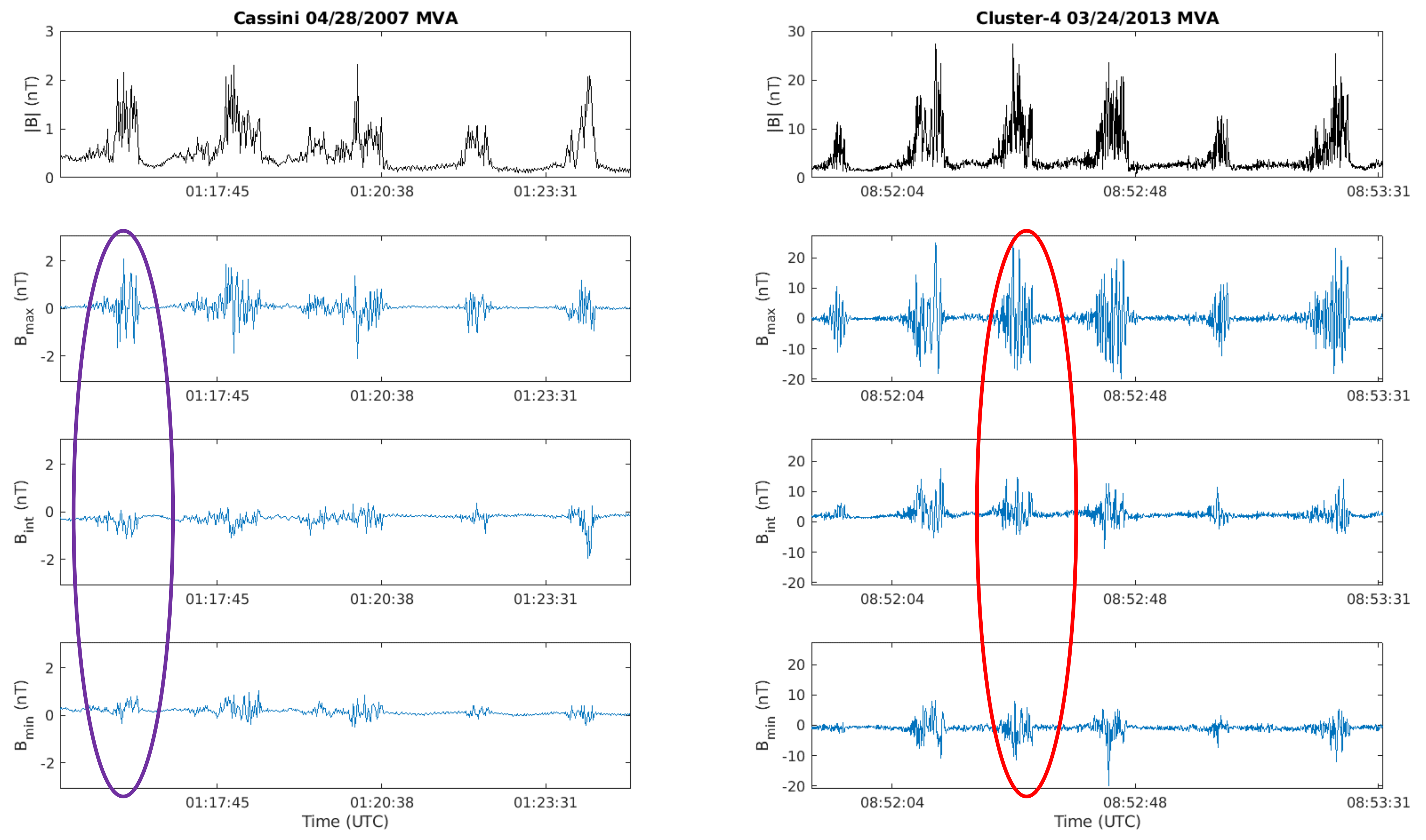


Upstream magnetic bursts

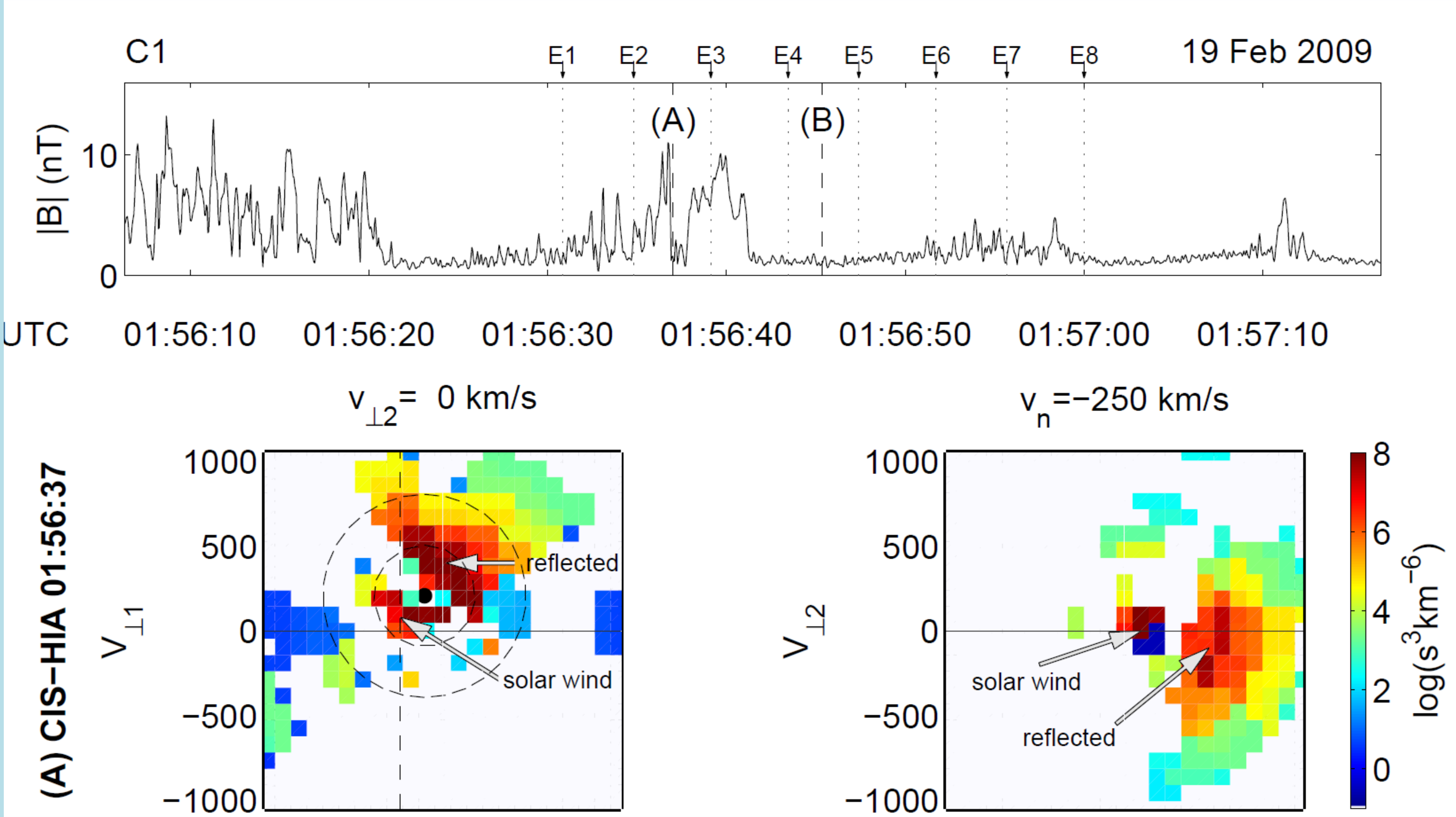
Minimum variance analysis

Both shock events consistent

Bursts have “wave packet” structure with **single**/**multiple** perturbation direction(s)



Reflected ions – continuously present



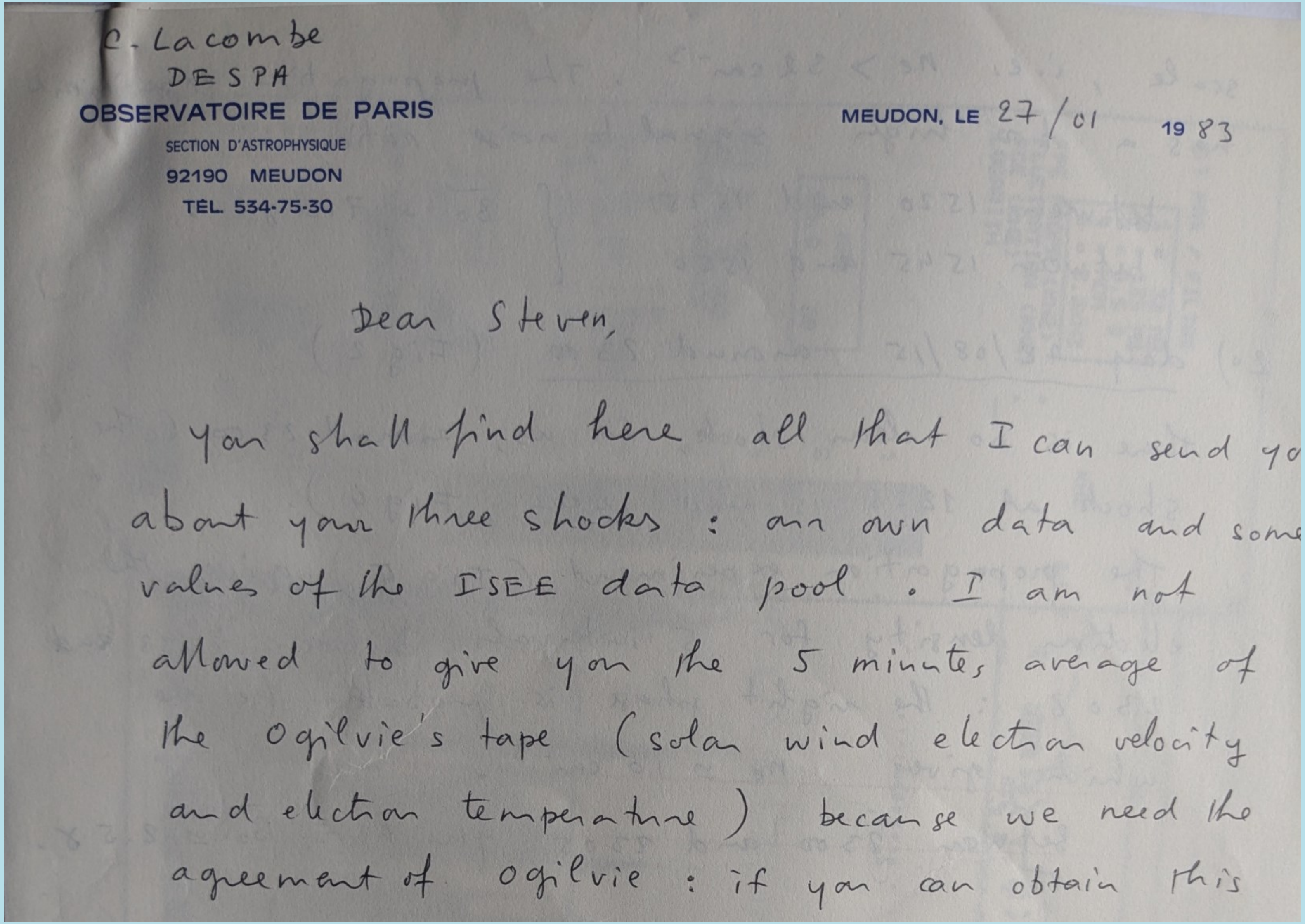
Space or Time?

If a shock is a steady structure with waves on top ….

- Which is better – space or time?

- But what controls the shock speed seen by s/c?

- For high beta – shock is more gasdynamic
- Is there a selection bias?



C. Lacombe
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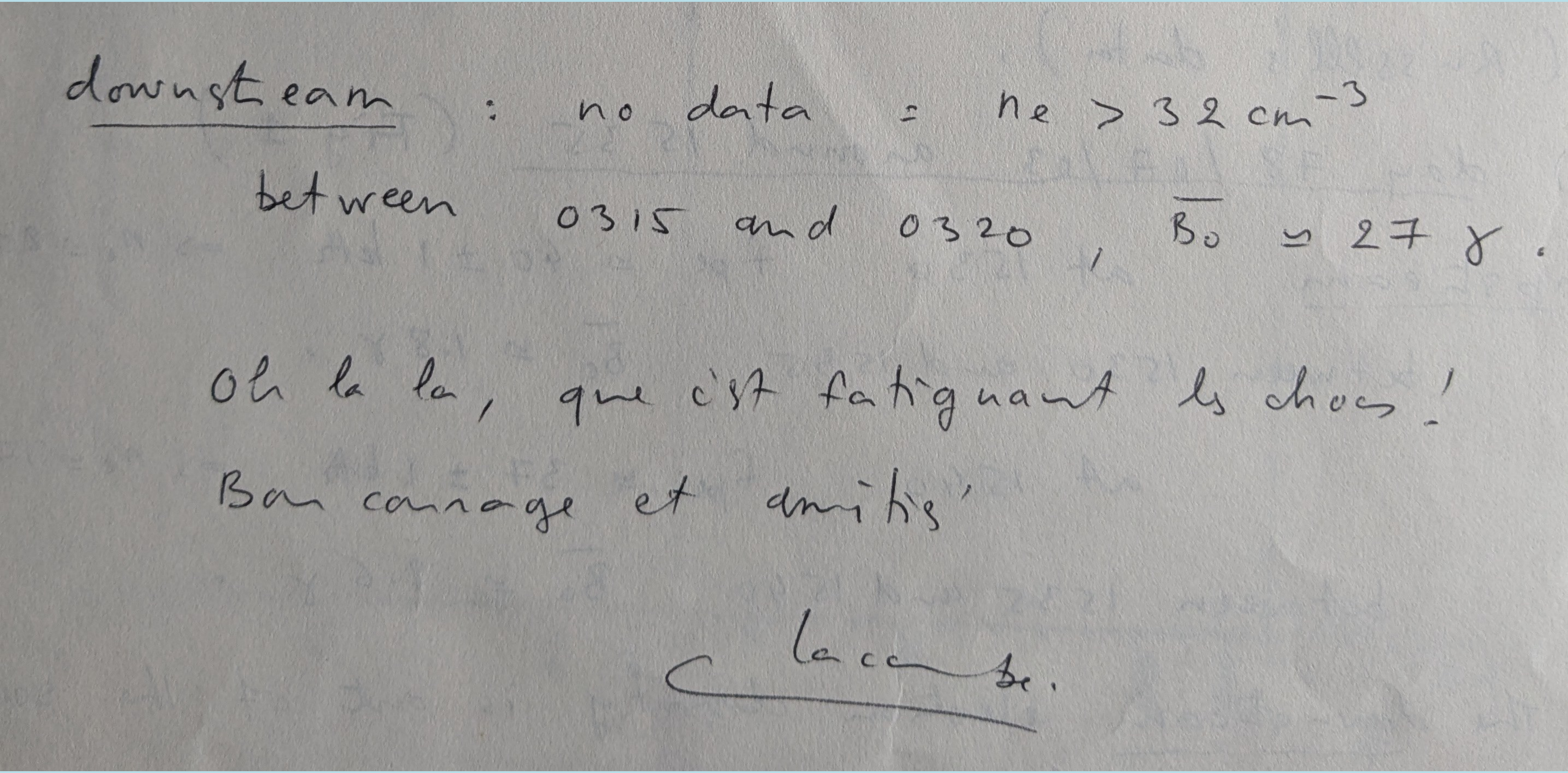
SECTION D'ASTROPHYSIQUE
92190 MEUDON
TÉL. 534-75-30

MEUDON, LE 27/01 1983

Dear Steven,

You shall find here all that I can send yo
about your three shocks : our own data and some
values of the ISEE data pool . I am not
allowed to give you the 5 minutes average of
the Ogilvie's tape (solar wind electron velocity
and electron temperature) because we need the
agreement of Ogilvie : if you can obtain this



<u>downsteam</u> : no data = $n_e > 32\ \text{cm}^{-3}$

between 0315 and 0320, $\overline{B_0} \simeq 27\,\gamma$.

Oh la la, que c'est fatiguant les chocs !

Bon courage et amitiés

Lacombe.

FIN