Solar Orbiter's first Venus flyby: Overview of RPW, MAG, and EPD in-situ observations and results from VGAM2 (:

Lina Z. Hadid,
RPW, MAG and EPD teams

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RPW meeting
30/11/2021

RPW

EPD/STEP

MAG

Astronomy & Astrophysics

Solar Orbiter's first Venus flyby: observations from the Radio and Plasma Wave instrument

L. Z. Hadid[1], N. J. T. Edberg[2], T. Chust[1], D. Píša[3], A. P. Dimmock[2], M. W. Morooka[2], M. Maksimovic[4], Yu. V. Khotyaintsev[2], J. Souček[3], M. Kretzschmar[5], A. Vecchio[4,6], O. Le Contel[1], A. Retino[1], R. C. Allen[7], M. Volwerk[8], C. M. Fowler[9], L. Sorriso-Valvo[2,10], T. Karlsson[11], O. Santolík[3,12], I. Kolmašová[3,12], F. Sahraoui[1], K. Stergiopoulou[2], X. Moussas[13], K. Issautier[4], R. M. Dewey[14], M. Klein Wolt[6], O. E. Malandraki[15], E. P. Kontar[16], G. G. Howes[17], S. D. Bale[9,18], T. S. Horbury[19], M. Martinović[20], A. Vaivads[2,21], V. Krasnoselskikh[5], E. Lorfèvre[22], D. Plettemeier[23], M. Steller[8], Š. Štverák[24,25], P. Trávníček[9,25], H. O'Brien[19], V. Evans[19], V. Angelini[19], M. C. Velli[26], and I. Zouganelis[27].

Energetic Ions in the Venusian System: Insights from the First Solar Orbiter Flyby

R. C. Allen[1], I. Cernuda[2], D. Pacheco[3], L. Berger[3], Z. G. Xu[3], J. L. Freiherr von Forstner[3], J. Rodríguez-Pacheco[2], R. F. Wimmer-Schweingruber[3], G. C. Ho[1], G. M. Mason[1], S. K. Vines[1], Y. Khotyaintsev[4], T. Horbury[5], M. Maksimovic[6], L. Z. Hadid[7], M. Volwerk[8], A. Dimmock[4], L. Sorriso-Valvo[4,9], K. Stergiopoulou[4], G. B. Andrews[1], V. Angelini[5], S. D. Bale[10,11], S. Boden[3,12], S. I. Böttcher[3], T. Chust[7], S. Eldrum[3], P. P. Espada[2], F. Espinosa Lara[2], V. Evans[5], R. Gómez-Herrero[2], J. R. Hayes[1], A. M. Hellín[2], A. Kollhoff[3], V. Krasnoselskikh[13], M. Kretzschmar[13,14], P. Kühl[3], S. R. Kulkarni[3,15], W. J. Lees[1], E. Lorfèvre[16], C. Martin[3,17], H. O'Brien[5], D. Plettemeier[18], O. R. Polo[2], M. Prieto[2], A. Ravanbakhsh[3,19], S. Sánchez-Prieto[2], C. E. Schlemm[1], H. Seifert[1], J. Souček[20], M. Steller[8], Š. Štverák[21], J. C. Terasa[3], P. Trávníček[10,21], K. Tyagi[1,22], A. Vaivads[4,23], A. Vecchio[6,24], and M. Yedla[3,19]

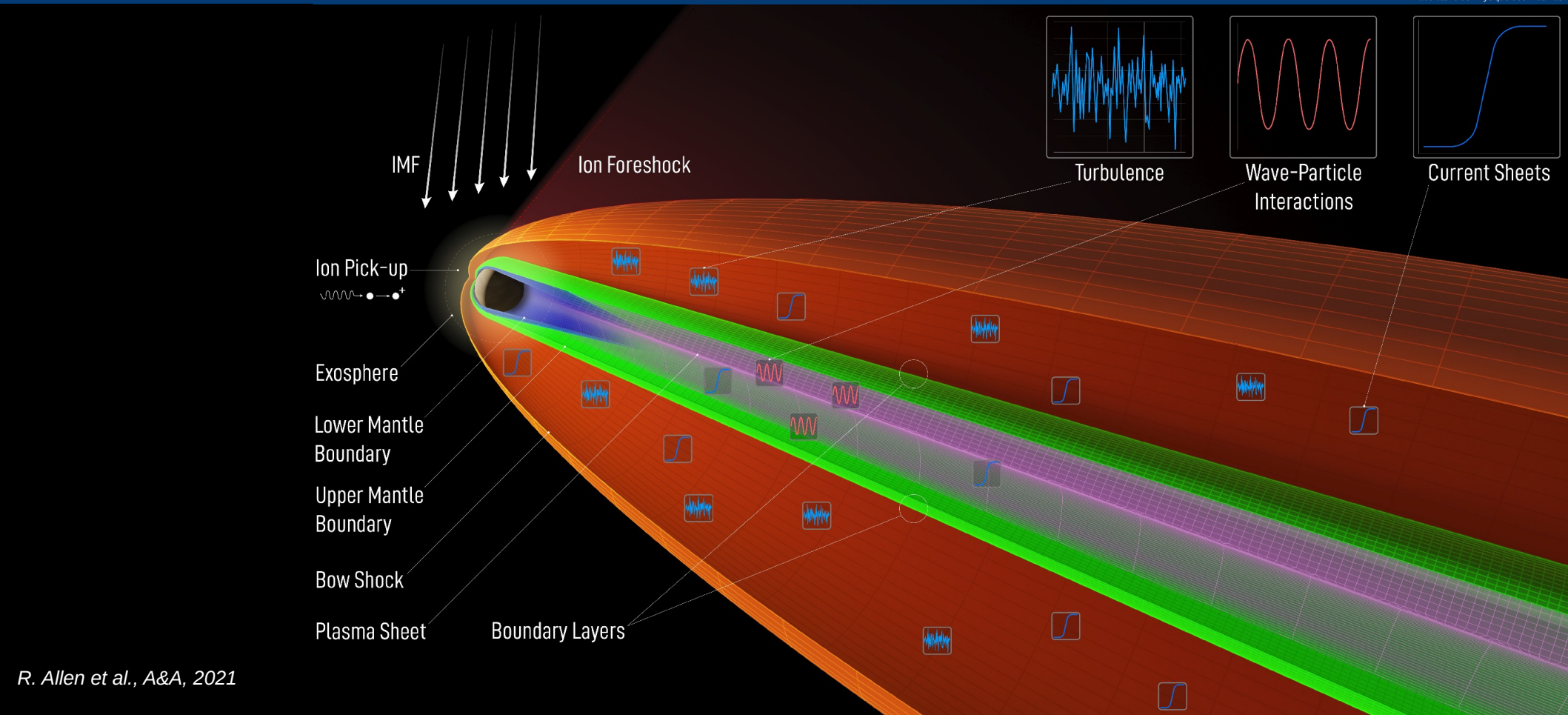
Solar Orbiter's first Venus Flyby:

MAG observations of structures and waves associated with the induced Venusian magnetosphere

M. Volwerk[1], T. S. Horbury[2], L. D. Woodham[2], S. D. Bale[3], C. Simon Wedlund[1], D. Schmid[1], R. C. Allen[4], V. Angelini[2], W. Baumjohann[1], L. Berger[8], N. J. T. Edberg[6], V. Evans[2], L. Z. Hadid[5], G. C. Ho[4], Yu. V. Khotyaintsev[6], W. Magnes[1], M. Maksimovic[5], H. O'Brien[2], M. B. Steller[1], J. Rodriguez-Pacheco[7], and R. F. Wimmer-Scheingruber[8]

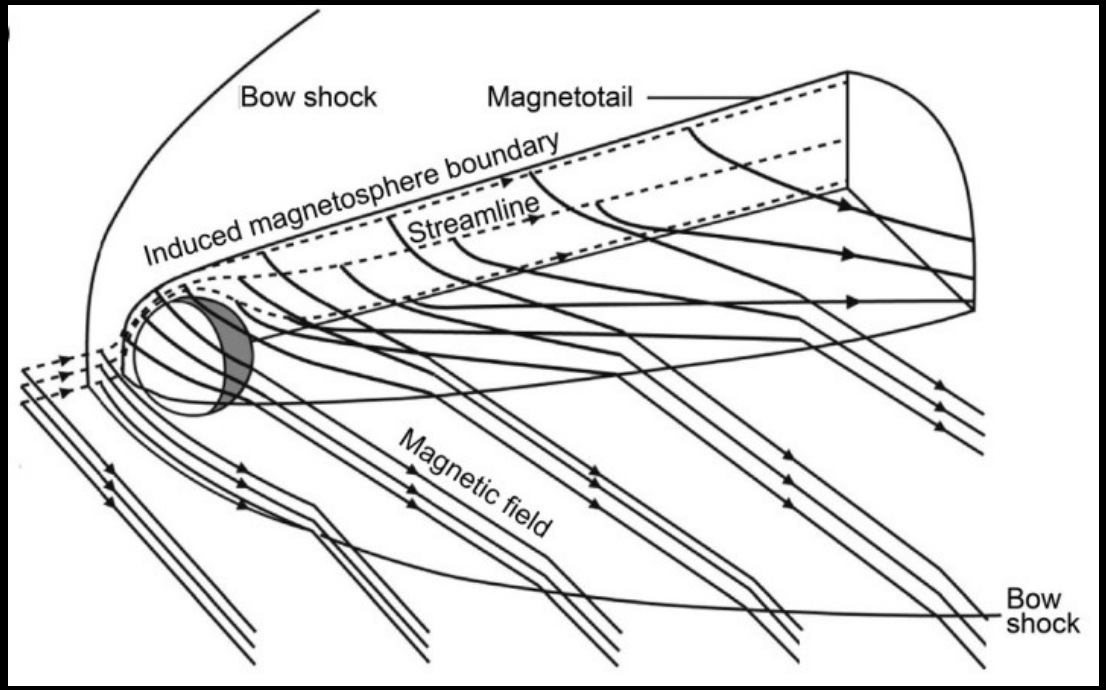
Solar Orbiter’s in situ observations during the first flyby of Venus

LPP
Laboratoire de Physique des Plasmas



R. Allen et al., A&A, 2021

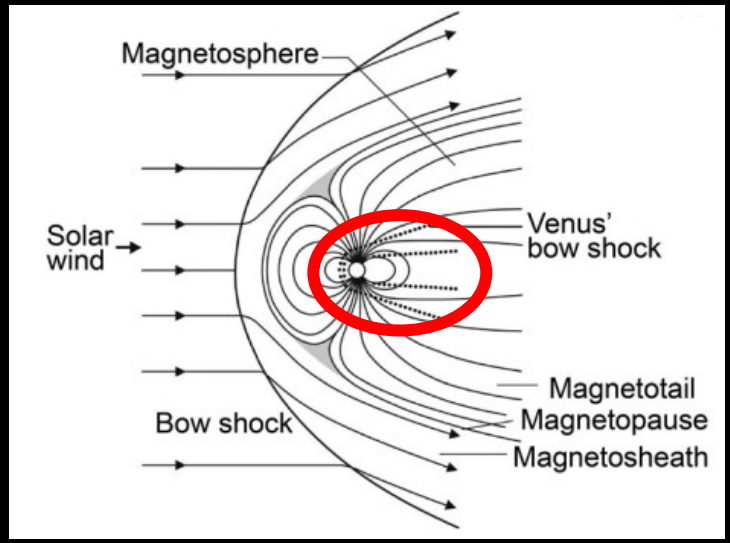
Induced magnetosphere of Venus



Y. Futaana et al., Space Sci. Rev., 2017

Since 1960's:

Flyby missions: *Mariner 2, 5, 10; Galileo, Cassini*
Landers: *Venera 4-16*
Orbiters: *Pioneer Venus, Venus Express, and Akatsuki*
Atmospheric probes



Mariner 10: study of the magnetic field fluctuations far downtail ~ 70 R_V

Pioneer Venus Orbiter: the only spacecraft that carried a plasma wave instrument (4 channel electric field receiver).

Solar Orbiter: A first opportunity to study the fields fluctuations In Venus induced magnetosphere down to ~ 100 R_V

Solar Orbiter Venus flyby #1: 27/12/2020

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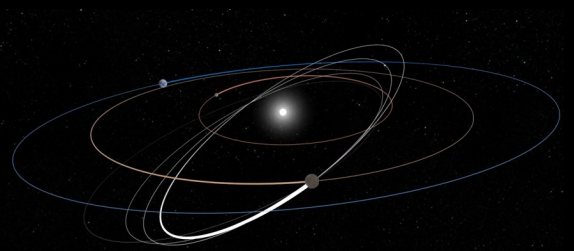
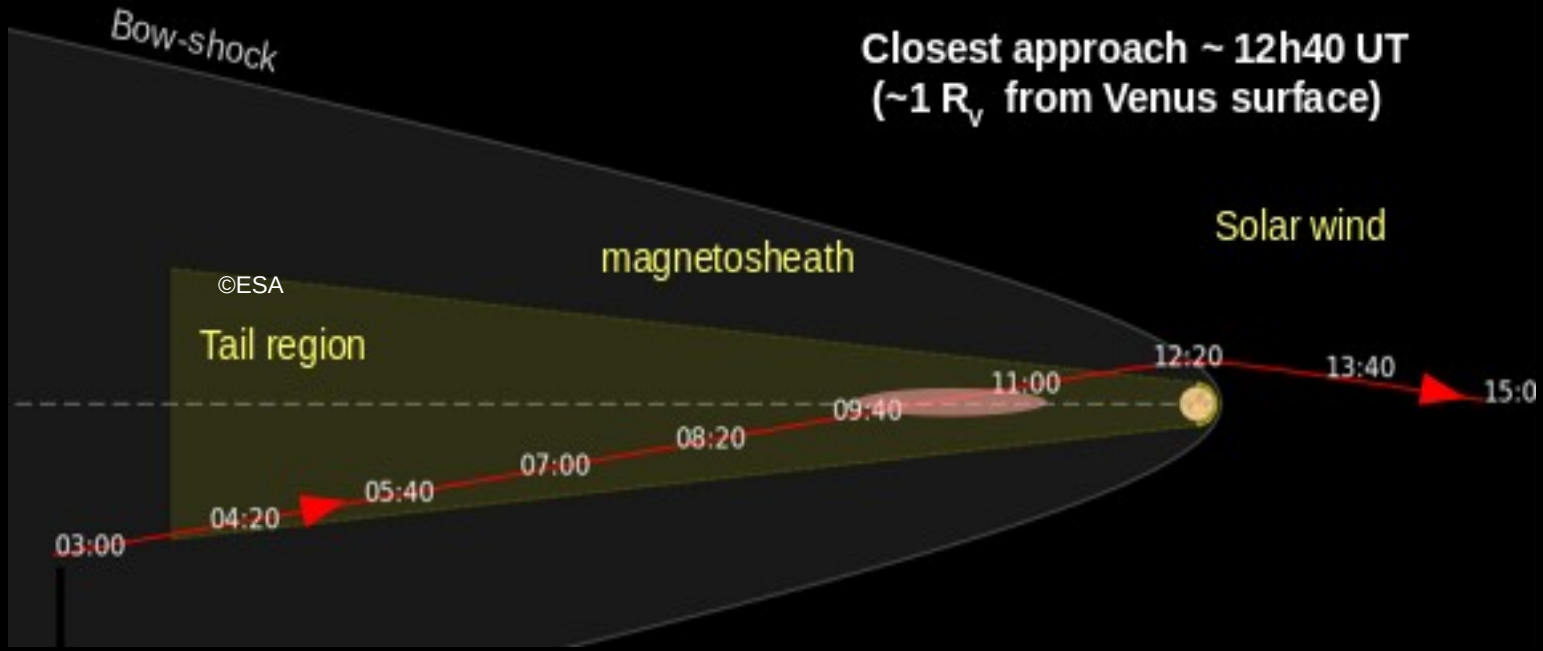
Solar mission to explore the inner heliosphere and the polar regions of the Sun!

8 gravity-assists manoeuvres
(7 Venus and 1 Earth)

Solar Orbiter 1st Venus flyby





Operational in-situ instruments: MAG, RPW and EPD/STEP

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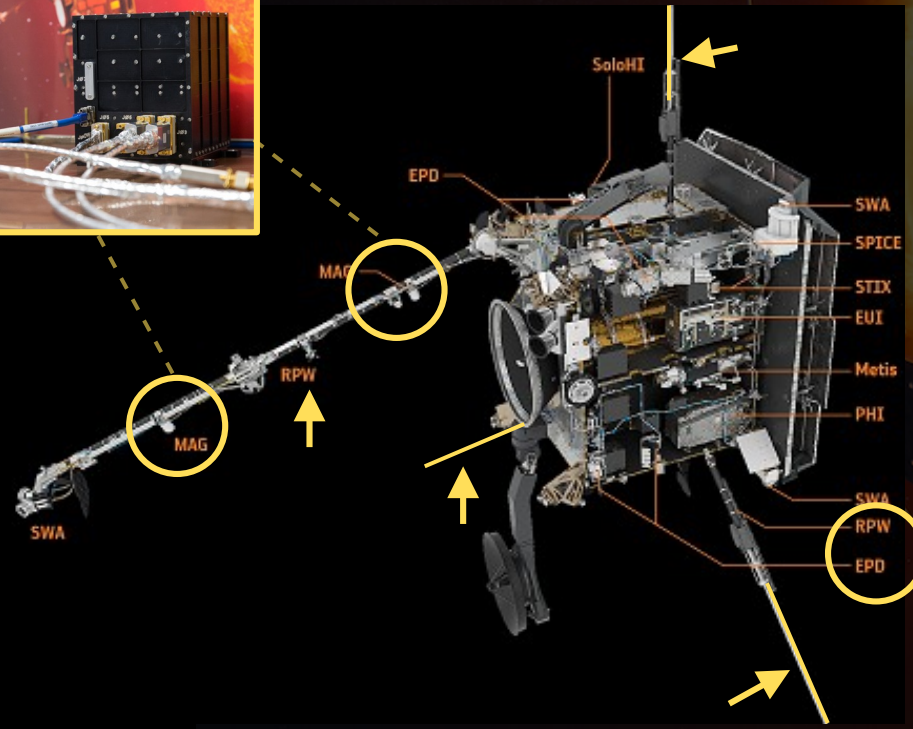
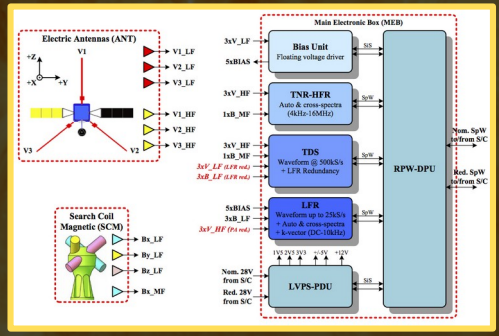
Magnetometer/MAG
(PI: T. S. Horbury)

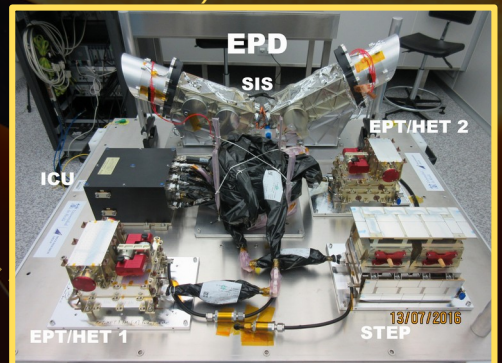


Radio and Plasma Wave consortium:
Electric field antenna, Search-Coil magnetometer
& the main electronic box (PI: M. Maksimovic)



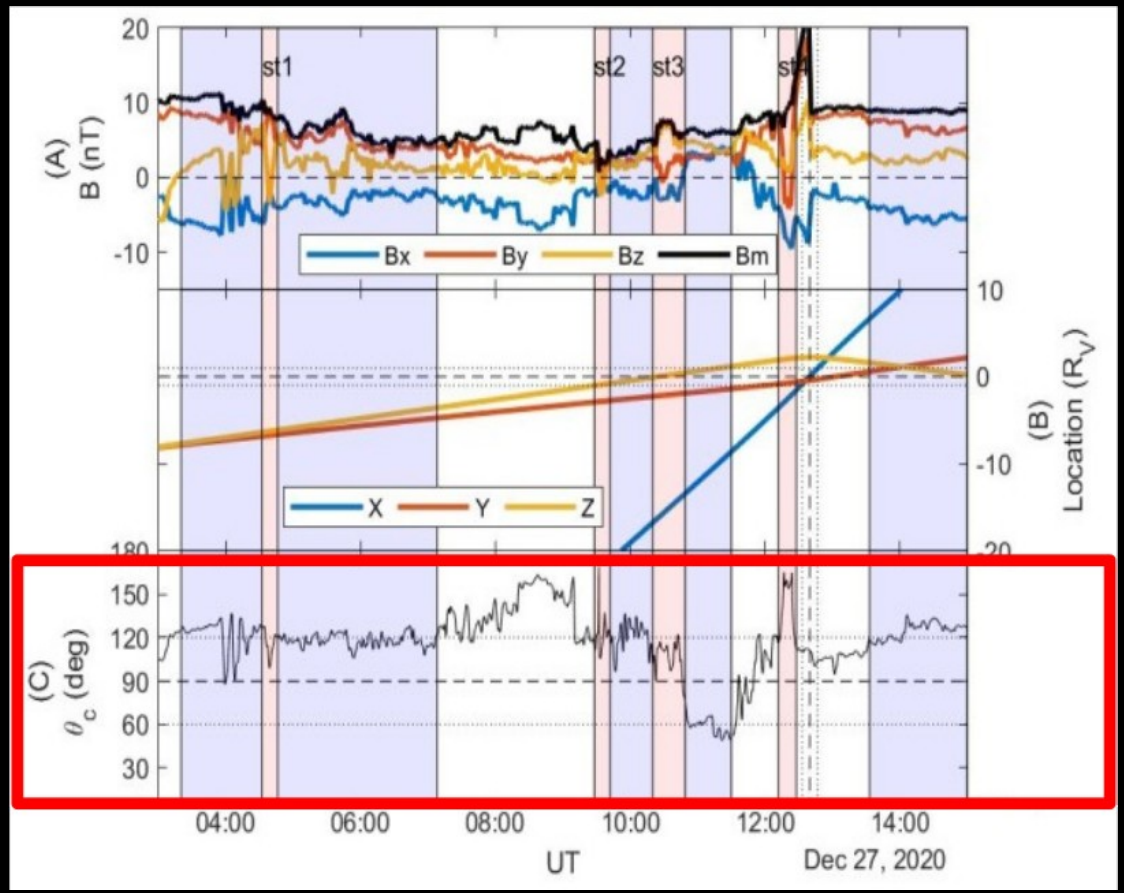
E: ~DC - 16 MHz
B: 1Hz -1 MHz

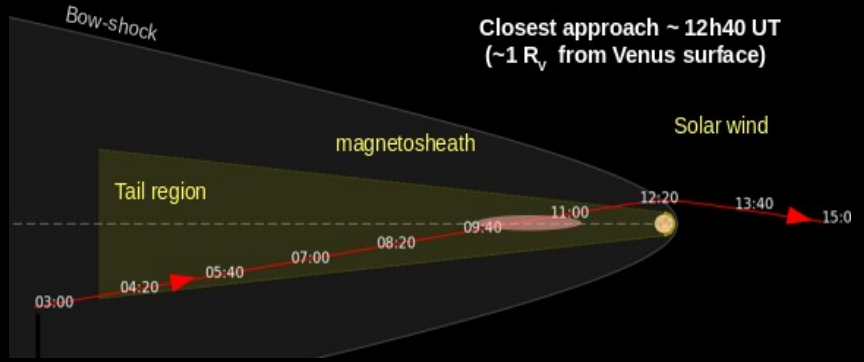
Energetic Particle Dectector (EPD) /
SupraThermal Electrons and Protons (STEP)
(PI: J. Pacheco)



STEP:
Ions: 4-80 keV

Structure of Venus' induced magnetosphere





Cone angle

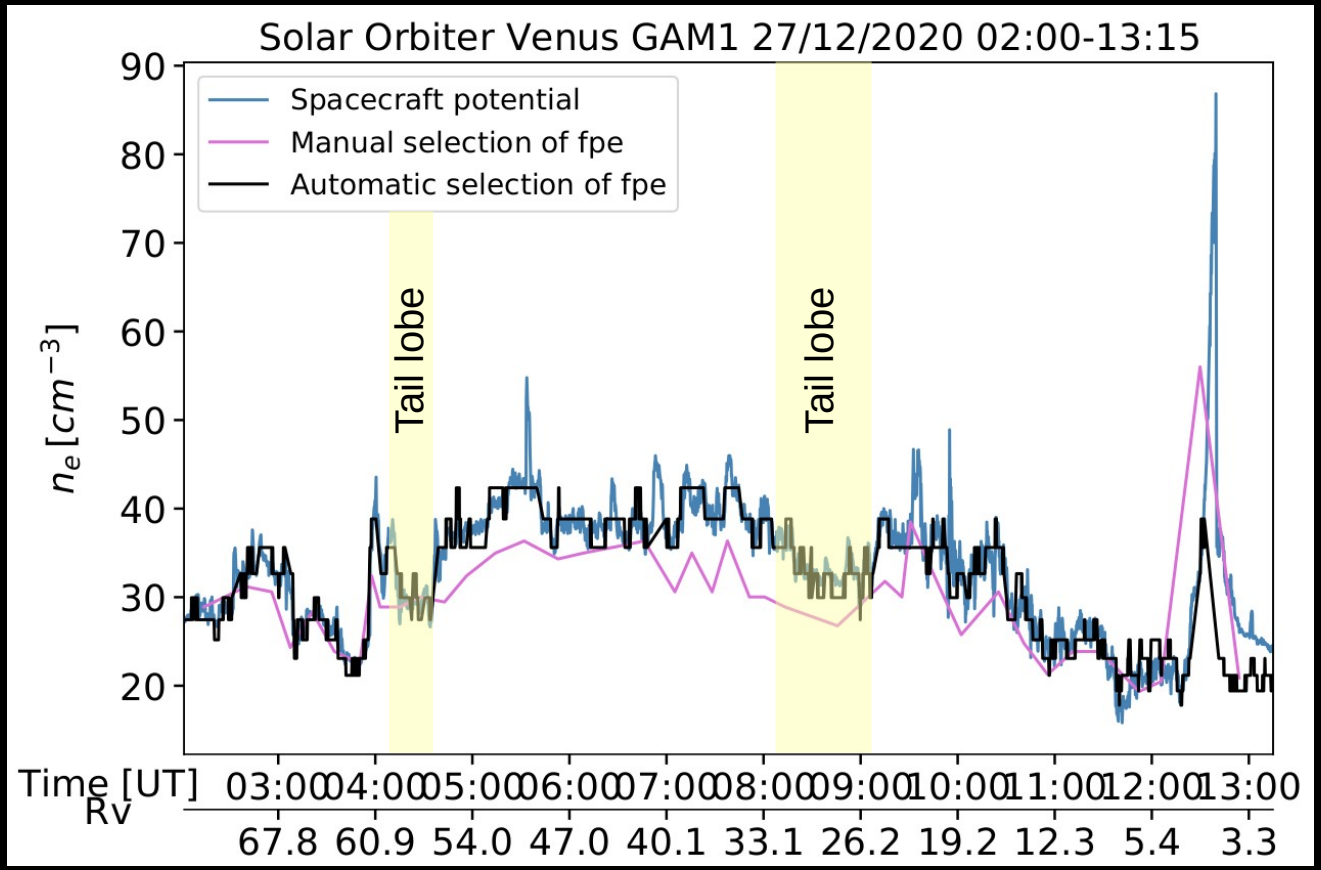
$\Theta_c = 0^\circ / 180^\circ$ → sunward/anti-sunward

$\Theta_c = 90^\circ$ → perpendicular to the Venus-Sun line

$$\theta_c = \tan^{-1}\left(\frac{\sqrt{B_y^2 + B_z^2}}{B_x}\right),$$

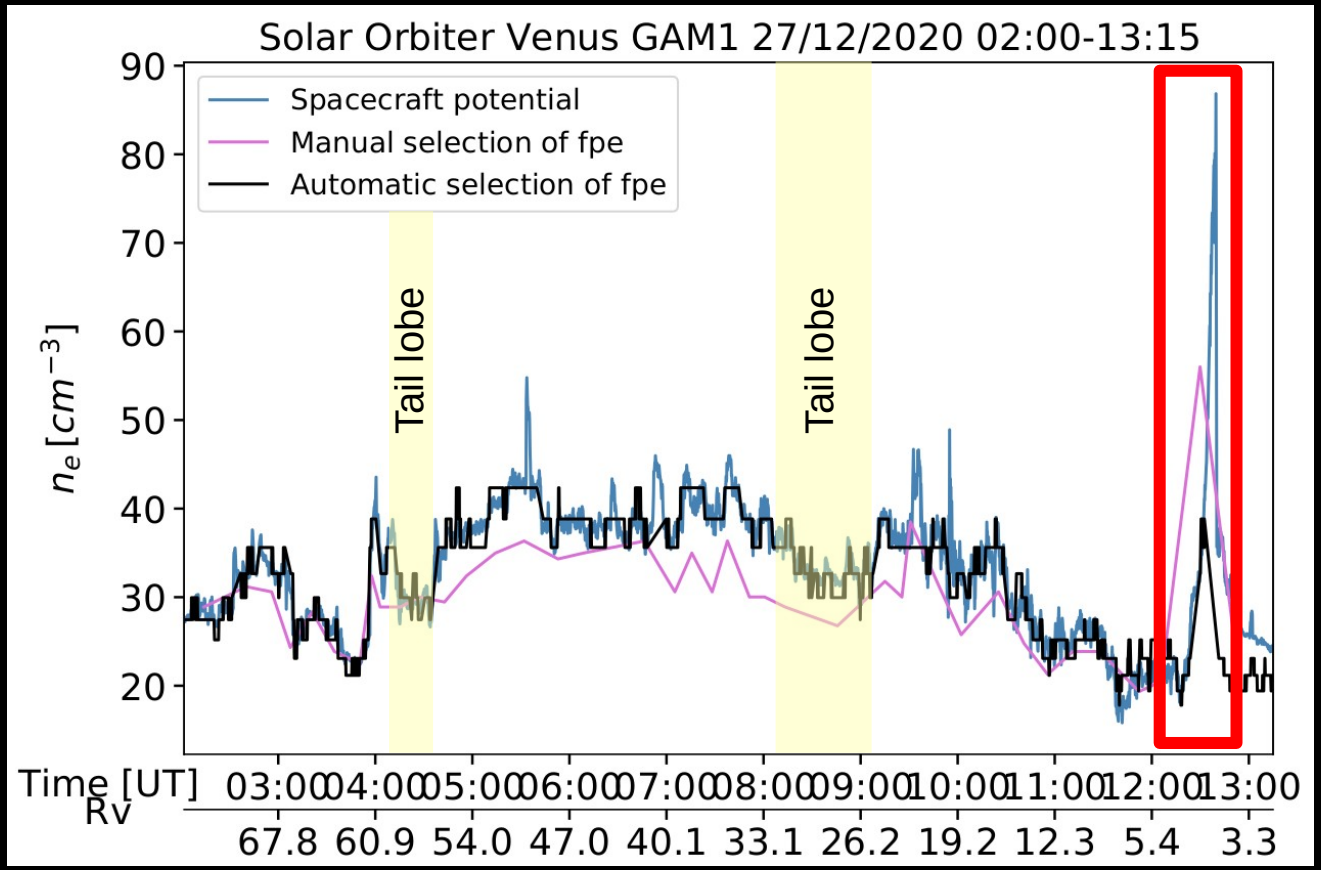
Adapted from
M. Volwerk et al., A&A, 2021

Large structure of the induced magnetosphere



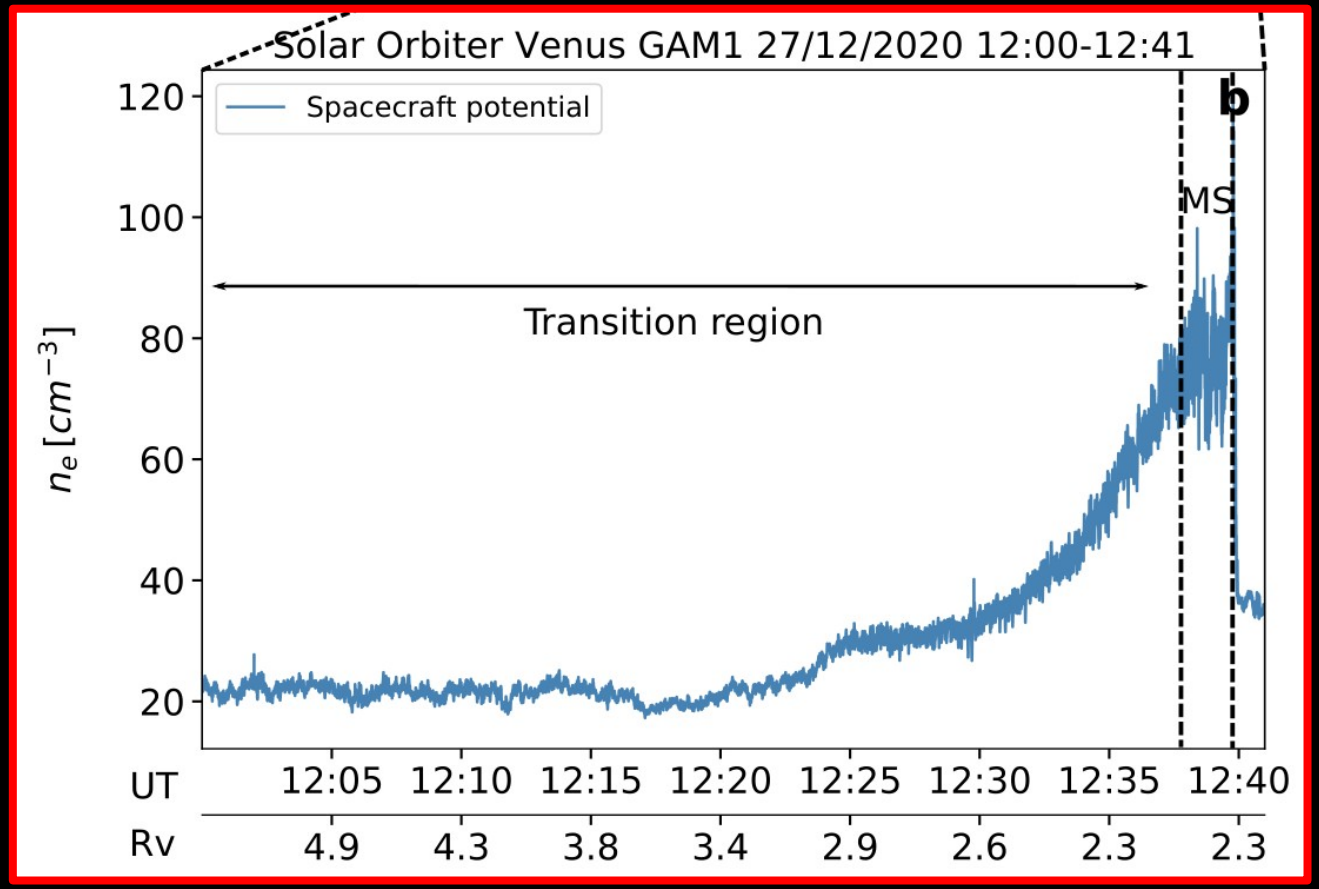
L. Z. Hadid et al., A&A, 2021

Large structure of the induced magnetosphere



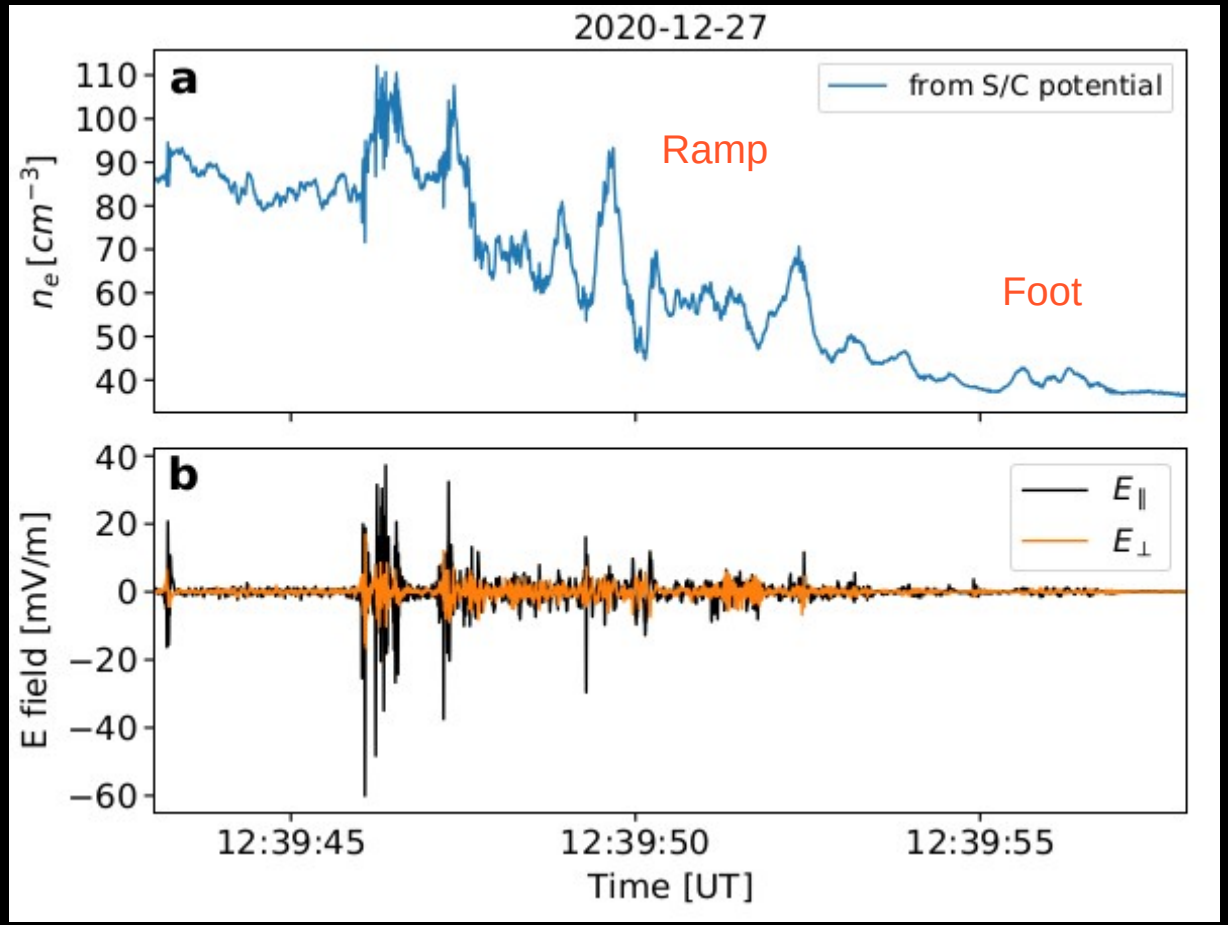
L. Z. Hadid et al., A&A, 2021

Large structure of the induced magnetosphere



L. Z. Hadid et al., A&A, 2021

Bow-shock structures and waves



Presence or “shock-ripples” [Gingell et al. 2017, Johlander et al. 2018] or large amplitude whistler waves [Wilson et al. 2017]

L.Z. Hadid et al. A&A, 2021
A. Dimmock et al., A&A, 2021, submitted

Magnetic and electric field power spectra from the RPW instrument

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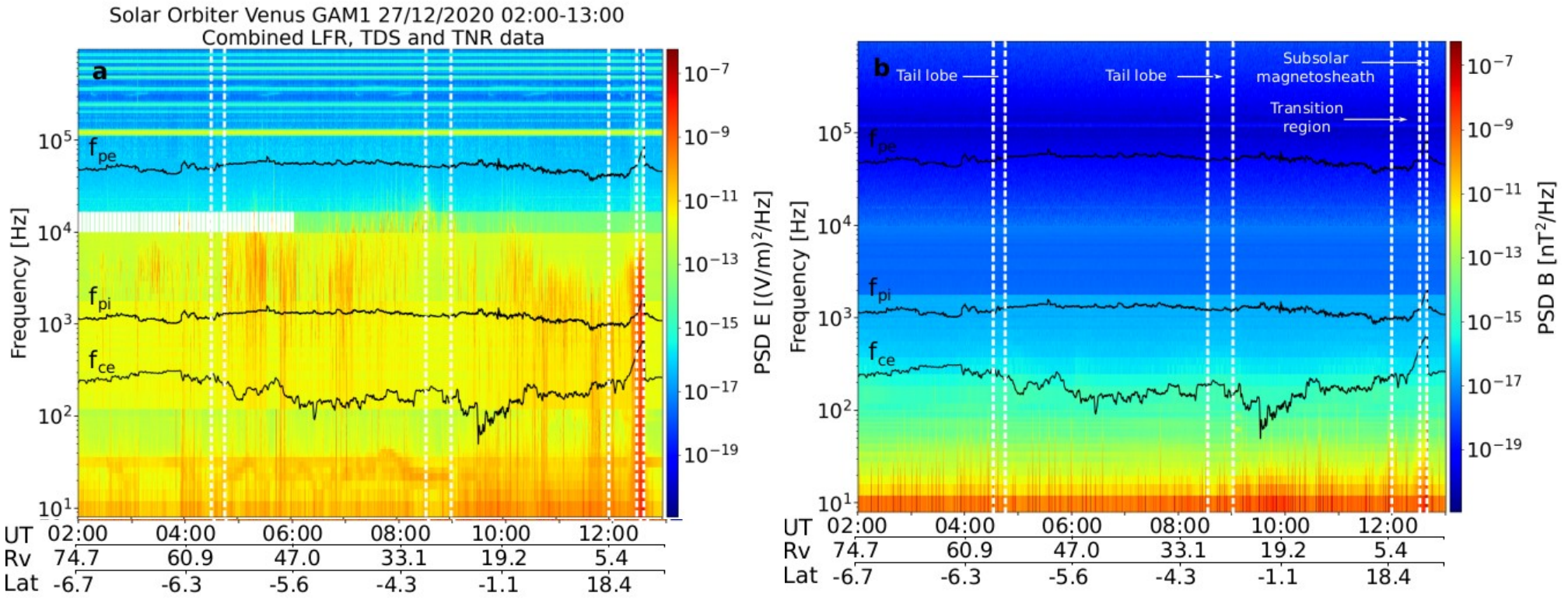
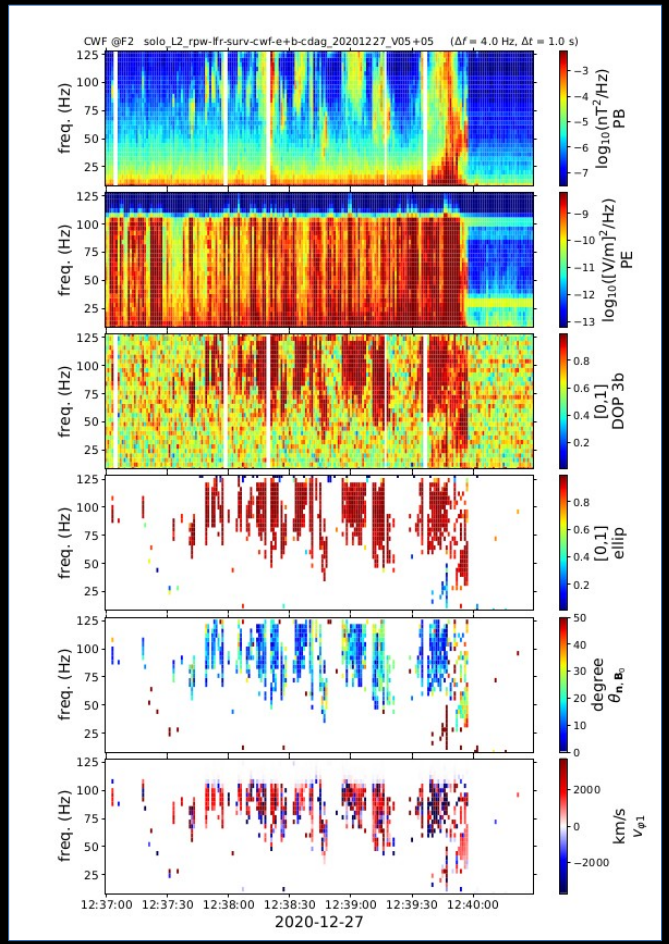


L. Z. Hadid et al., A&A, 2021

Whistler waves in the magnetosheath



Dominance of electromagnetic, circularly polarized whistler waves

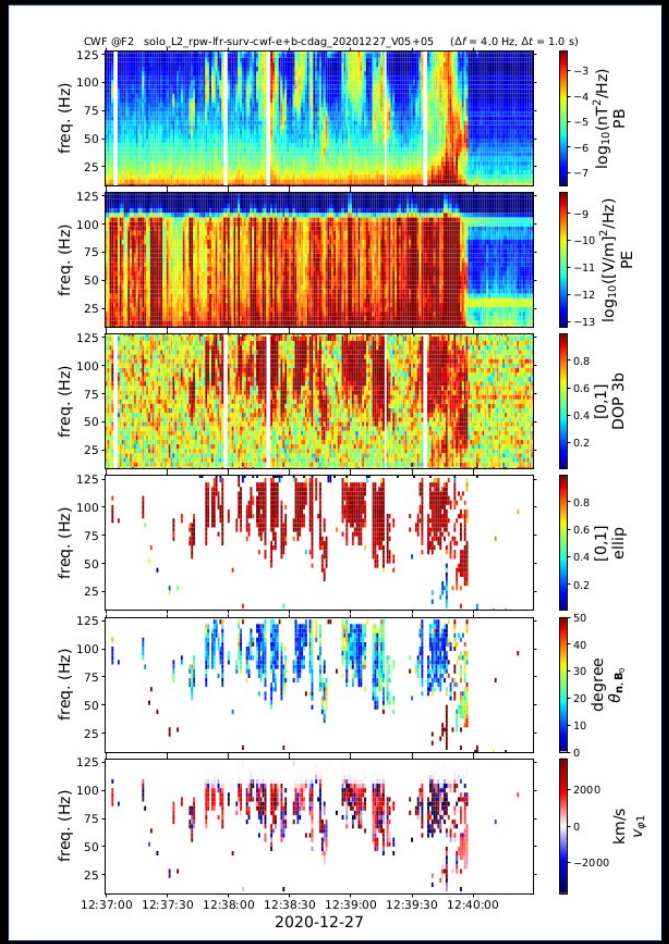
Degree of Polarization (DOP) ~ 1
→ Presence of a single plane wave

Ellipticity ~ 1
→ Circularly polarized wave

$\Theta_{n.B}$~ 15°
→ wave normal vector is parallel to $\mathbf{B_0}$
$\mathbf{\Theta_{n.B}}$ <90°
→ n and B0 point in the same direction → right hand polarized wave

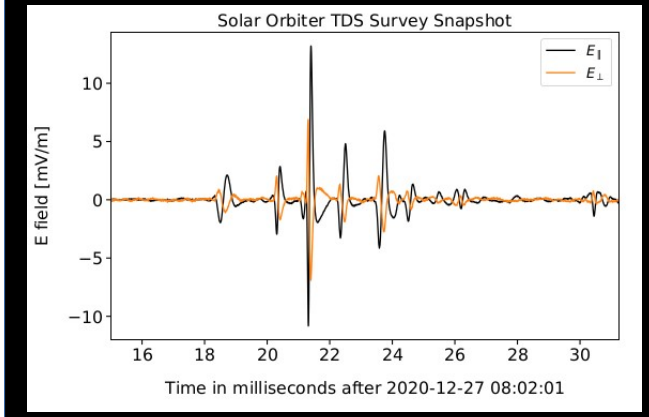
L. Z. Hadid et al., A&A, 2021

High frequency electrostatic waves in the magnetosheath

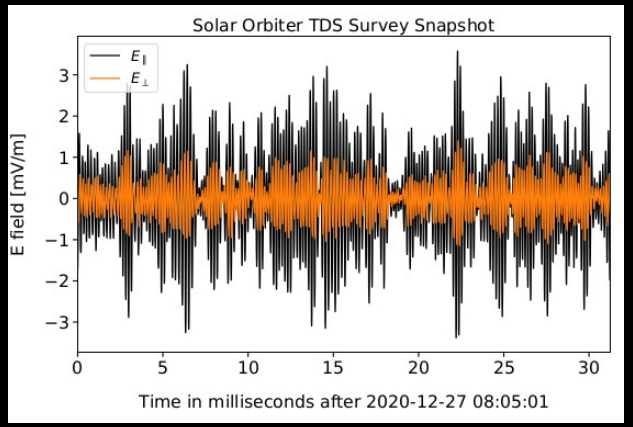


Dominance of electromagnetic, circularly polarized whistler waves

Solitary waves (~2 kHz)

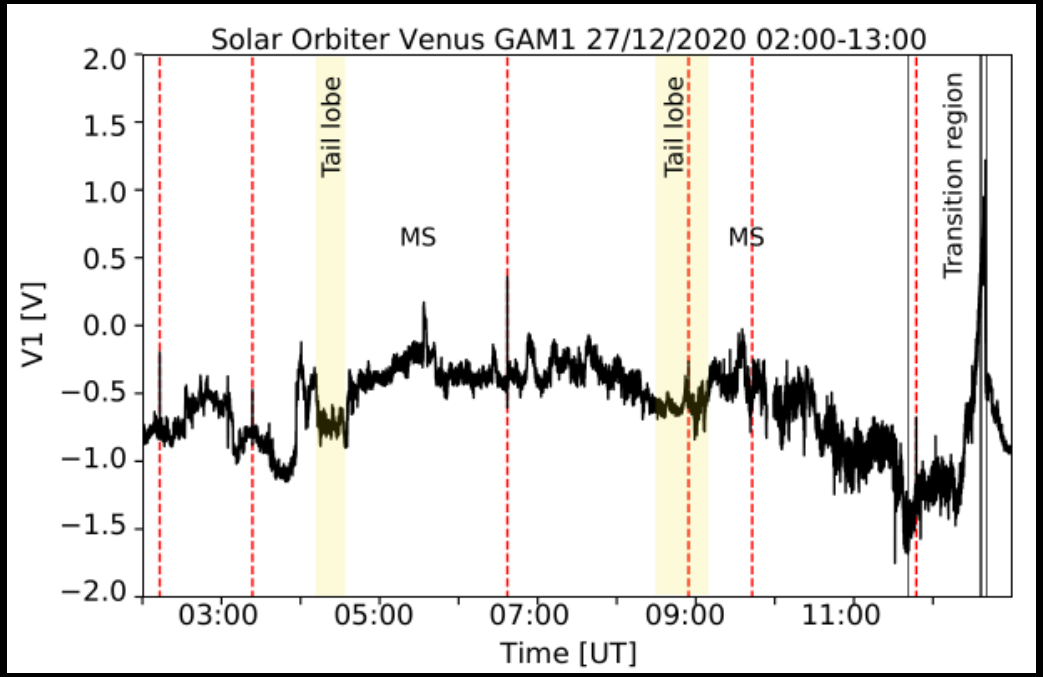


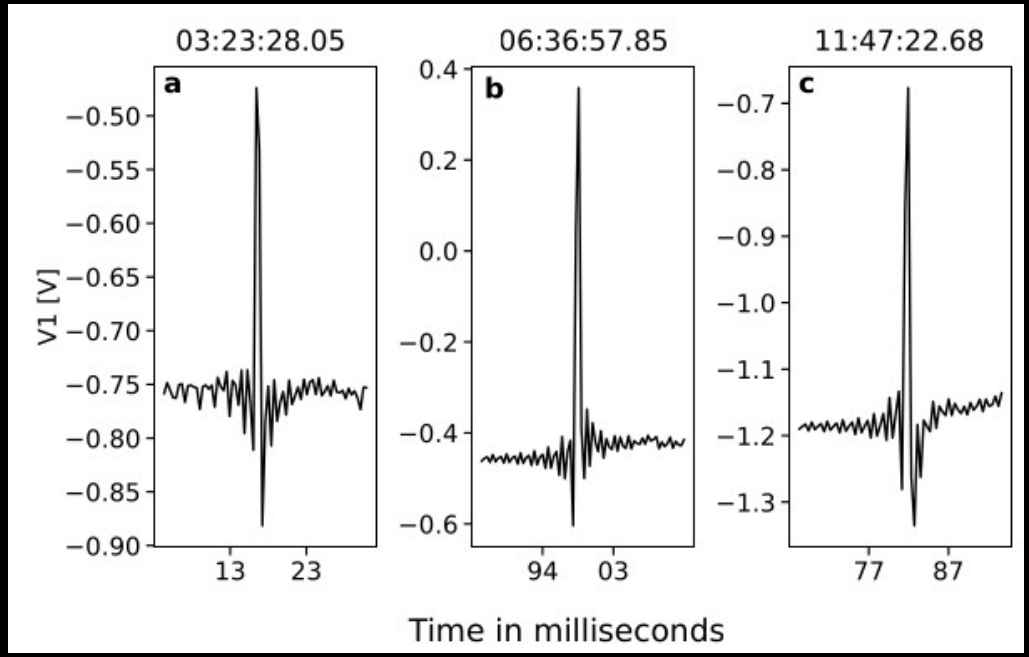
Electrostatic waves (Ion acoustic waves ~10 kHz)



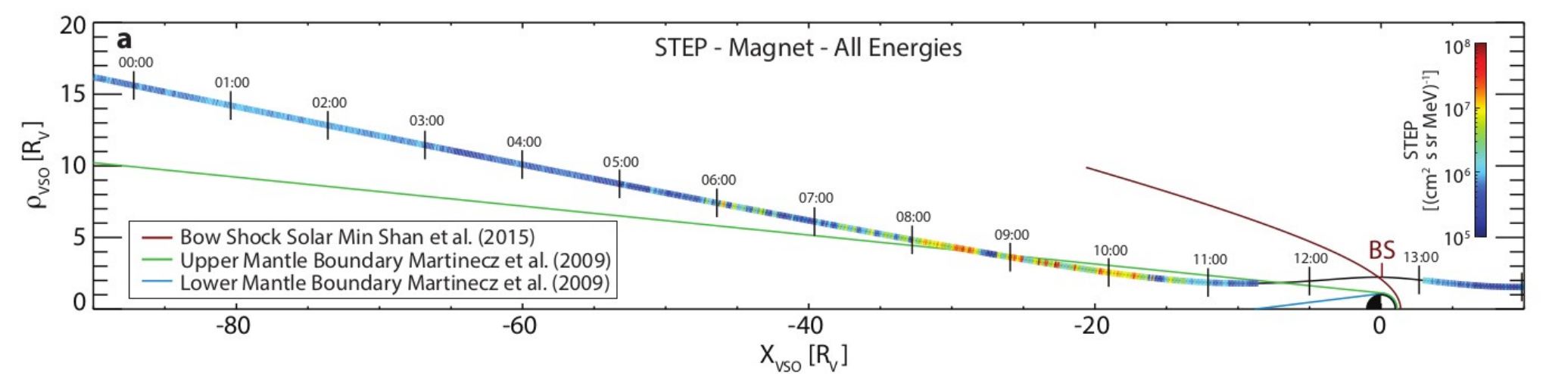
L. Z. Hadid et al., A&A, 2021

Dust impacts





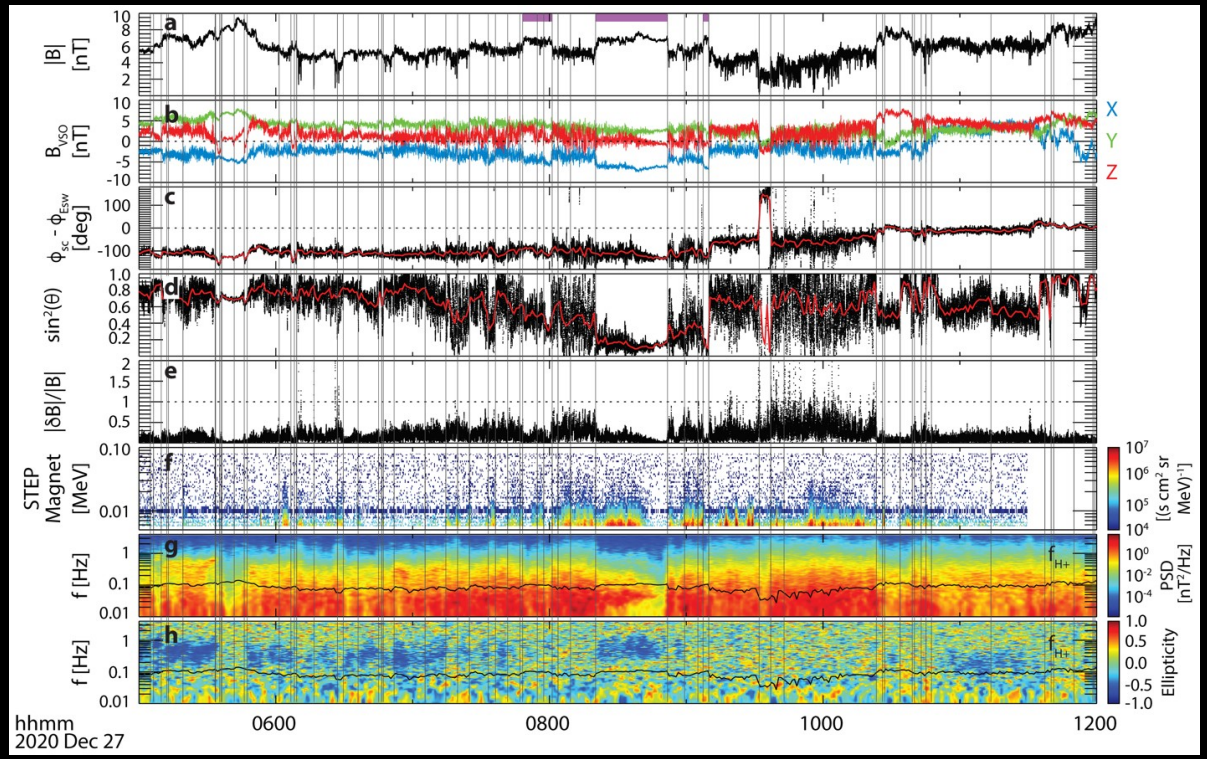
Bursty energetic ion enhancements in the magnetotail and foreshock



R. Allen et al., A&A, 2021

Enhancement of the suprathermal flux (~30 keV) near
the empirical upper mantle boundary and the foreshock-region

Main processes leading to particles acceleration



R. Allen et al., A&A, 2021

1) Convective solar wind electric field

2) Pick-up ions processes

3) Turbulence

4) Wave-particle interactions (ion-cylotron waves and high frequency electrostatic waves)

5) Boundary layer heating

6) Current sheet acceleration

Solar Orbiter’s in situ observations during the first flyby of Venus

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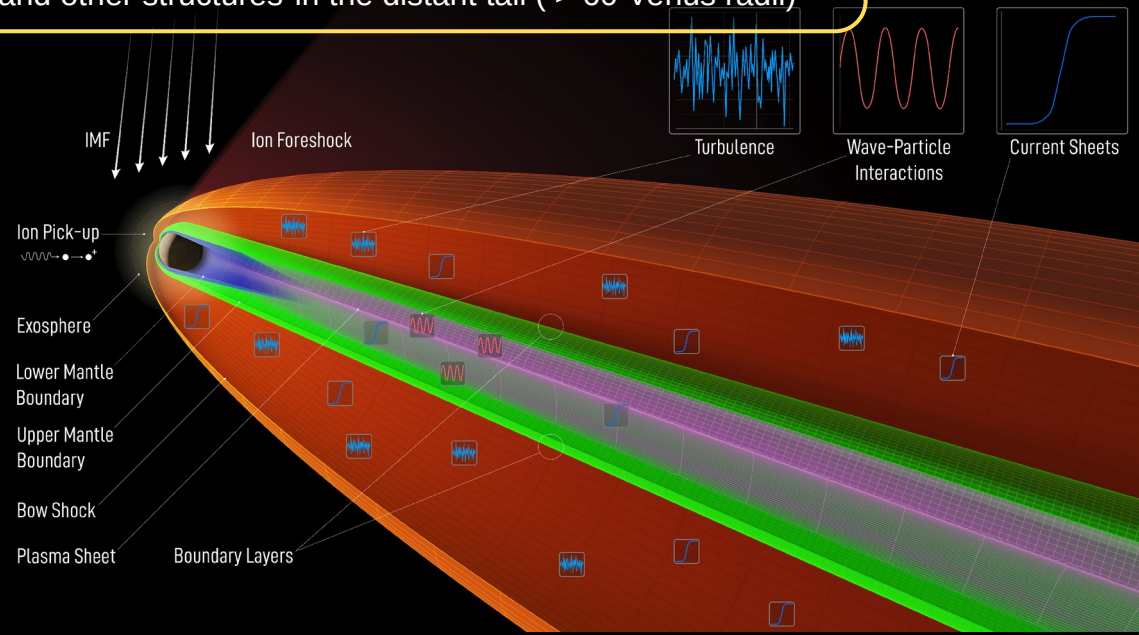
1. Large scale magnetic field structure

- Boundary crossings: bowshock, ion composition boundary, plasmasheet
- Bow-shock geometry: clear quasi-perpendicular bow-shock
- Draping of the magnetic field over North pole
- Evidence of plasmoids/fluxrops, magnetic reconnection site and other structures in the distant tail (> 60 Venus radii)



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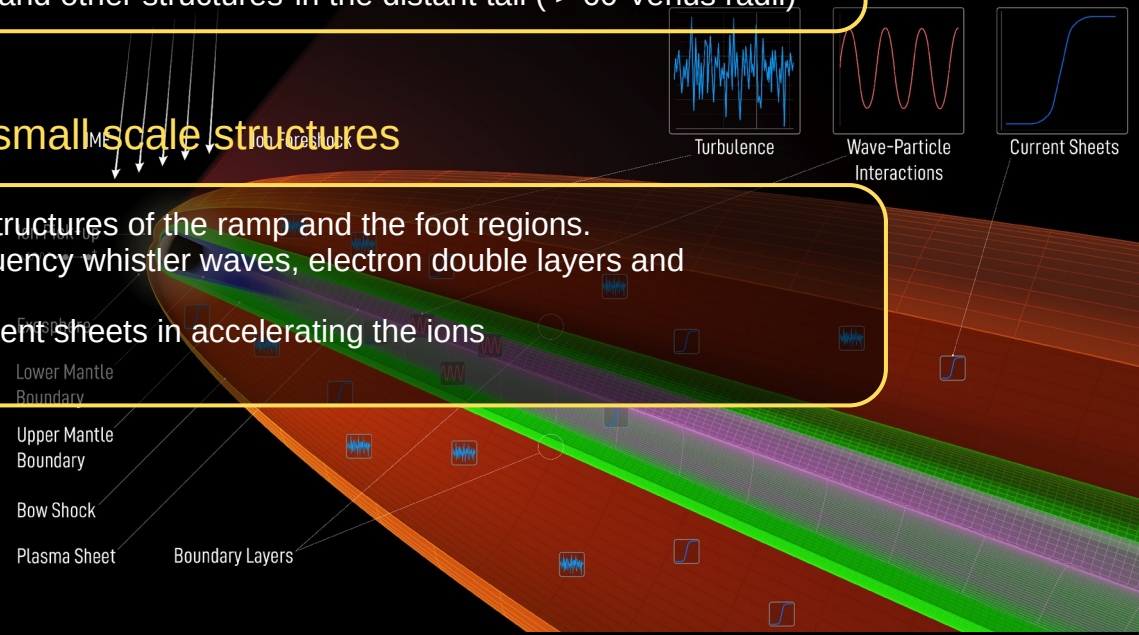
2. Wave properties, acceleration processes and small-scale structures

- Bow-shock: whistler waves and electric and magnetic sub-structures of the ramp and the foot regions.
- Magnetosheath: presence of ion cyclotron waves, high frequency whistler waves, electron double layers and electrostatic waves.
- Potential role of turbulence, ICWs, boundary layers and current sheets in accelerating the ions
- Dust impacts



Solar Orbiter's *Astronomy & Astrophysics* special issue and more...

Laboratoire de Physique des Plasmas

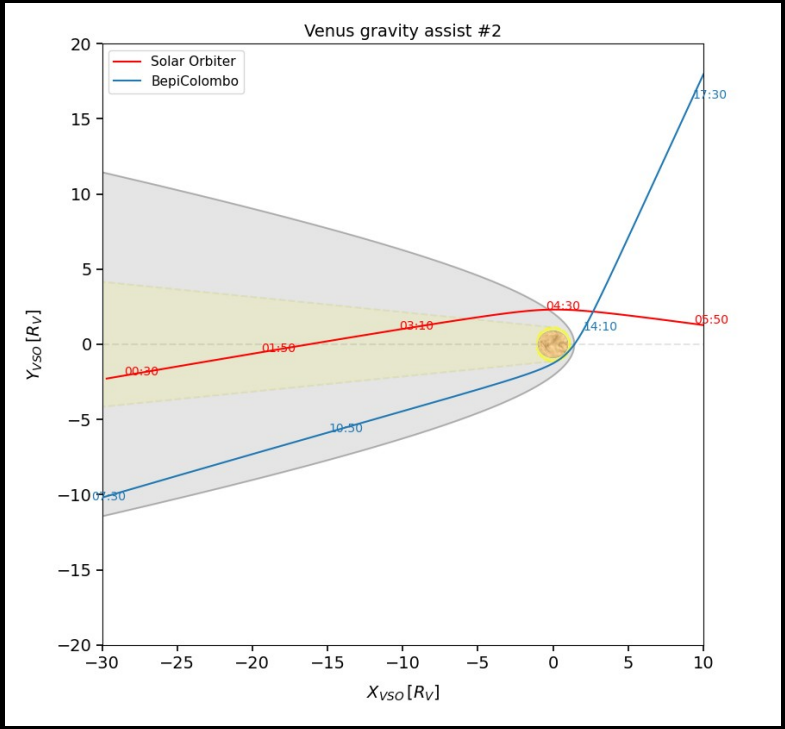
Overview papers

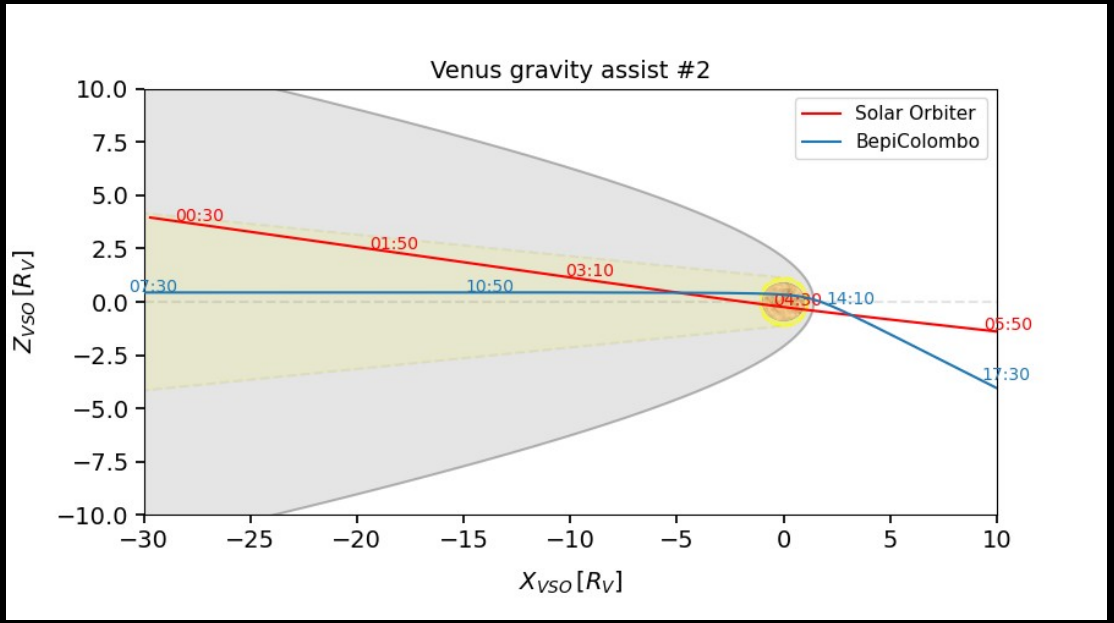
1. MAG: *"Solar Orbiter Venus 1 flyby: Magnetometer observation"*, ***M. Volwerk*** *et al., accepted*
2. EPD: "*Energetic Ions in the Venusian System: Insights from the First Solar Orbiter Flyby"*, ***R. Allen*** *et al., accepted*
3. RPW: "Solar Orbiter's first Venus flyby: observations from the Radio and Plasma Wave instrument", **L. Z. Hadid** et al., accepted

Detailed studies

1. Structures at bow-shock of Venus, **A. Dimmock** et al., submitted
2. Turbulence and intermittency in Venus induced magnetosphere, **L. Sorriso-Valvo** et al., in prep
3. Comparisons between the electron number densities and simulations of SW-Venus interaction, **K. Stergiopoulou** et al., in prep
4. Dust impacts statistics, **M. Morooka** et al. In prep

Solar Orbiter's second Venus flyby: August 09, 2021



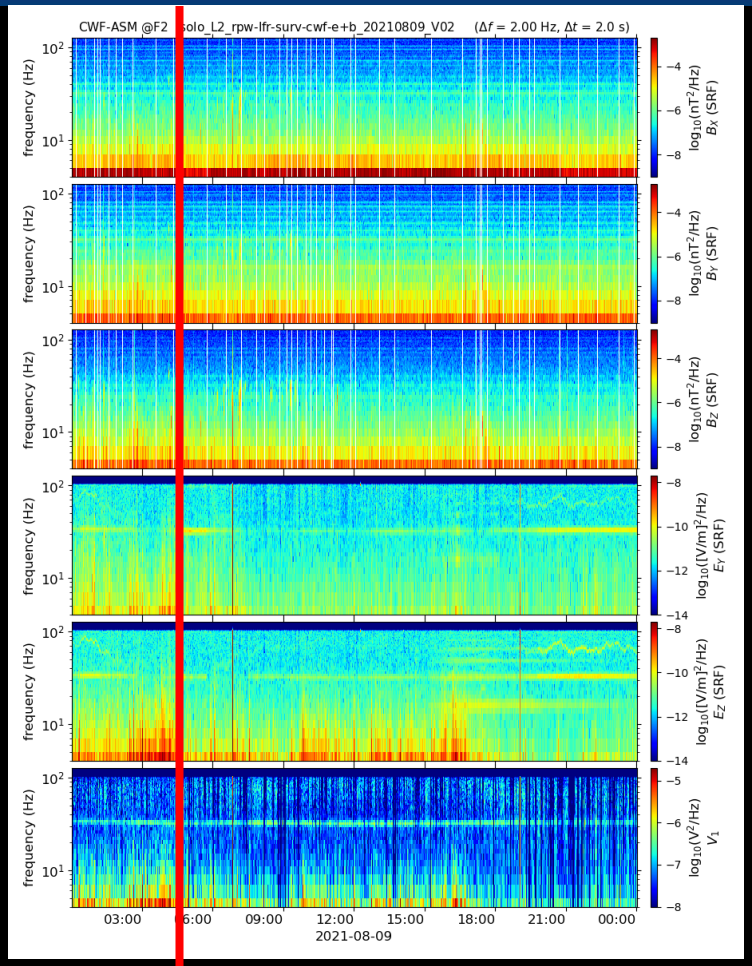


CA SolO ~ 2.3 R_V (2021-08-09 ~ 04:43)

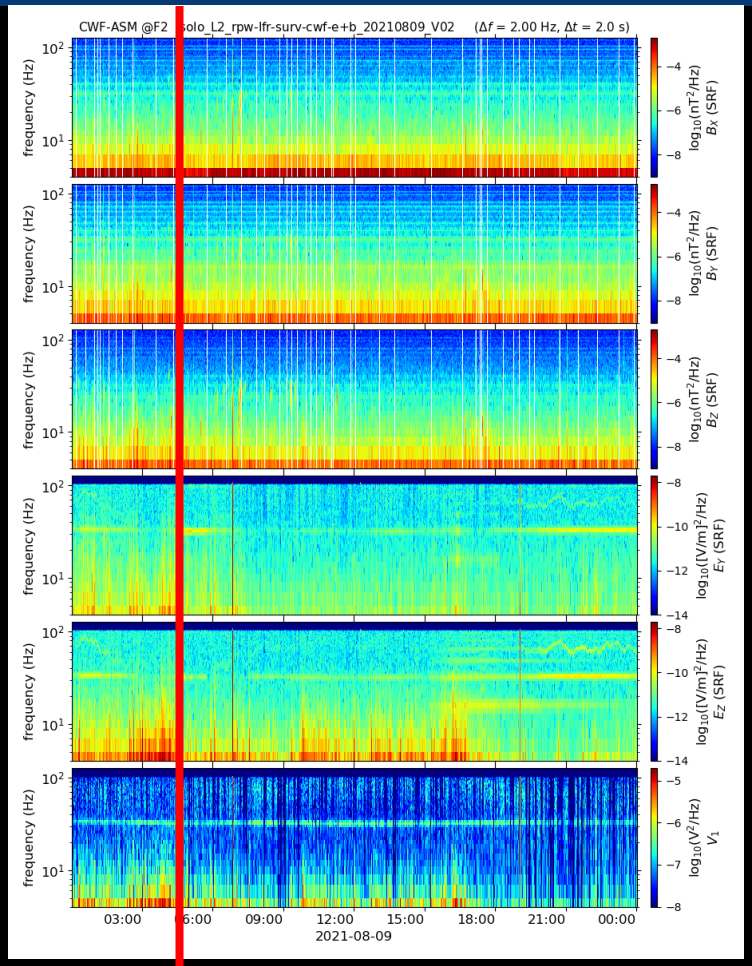
CA Bepi ~ 1.1 R_V (2021-08-10 ~ 13:51)

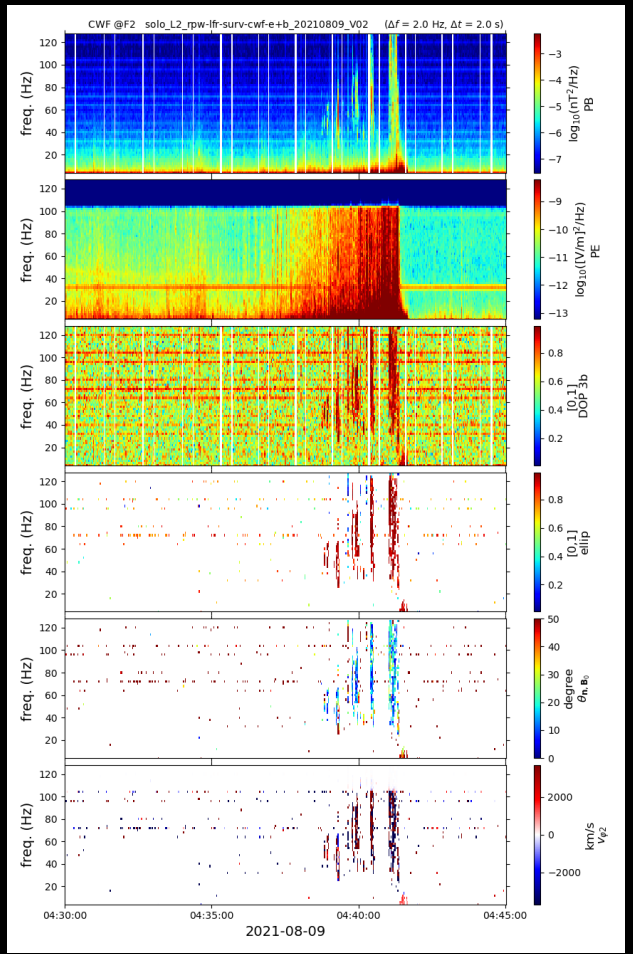
Solar Orbiter’s VGAM2: preliminary LFR data

Laboratoire de Physique des Plasmas



Solar Orbiter’s VGAM2: preliminary LFR data





Solar Orbiter's VGAM2: preliminary EPD data

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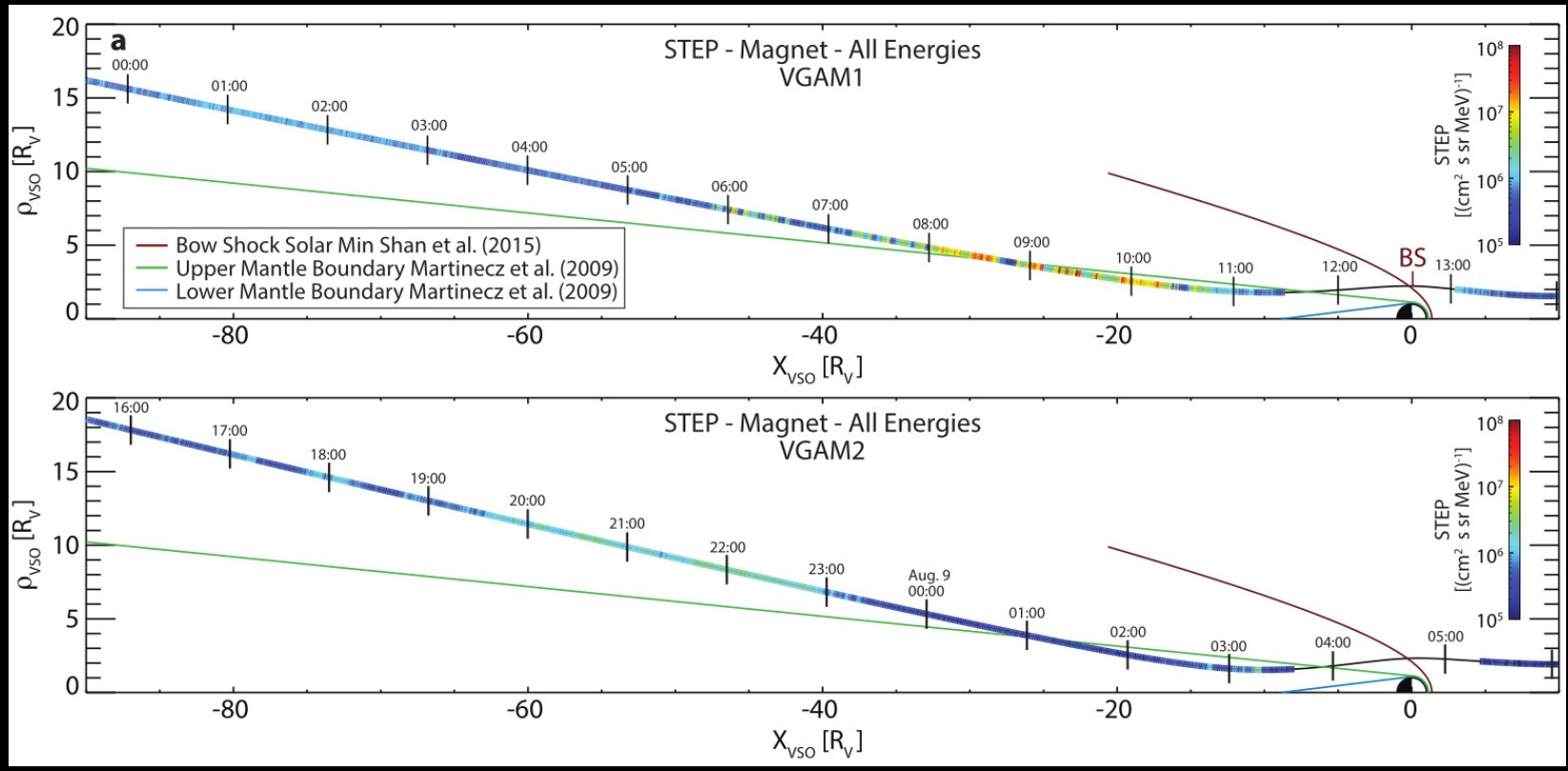
VGAM1

VGAM2




Thank you!
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