Foreshock and planetary size: A Venus-Mars comparison

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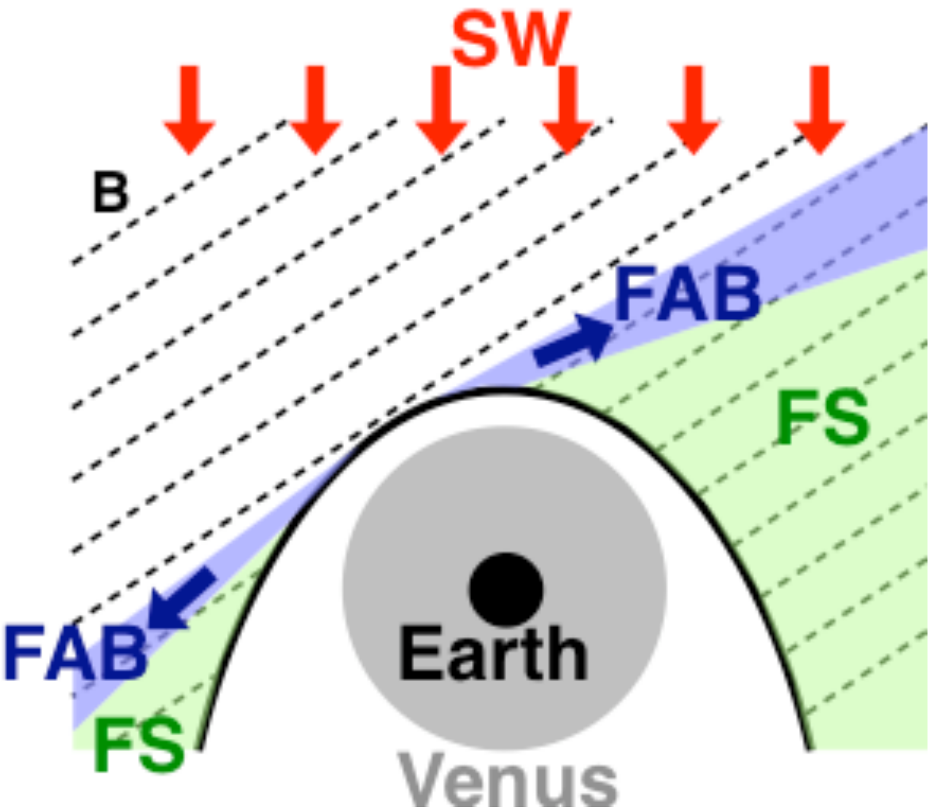
Outline

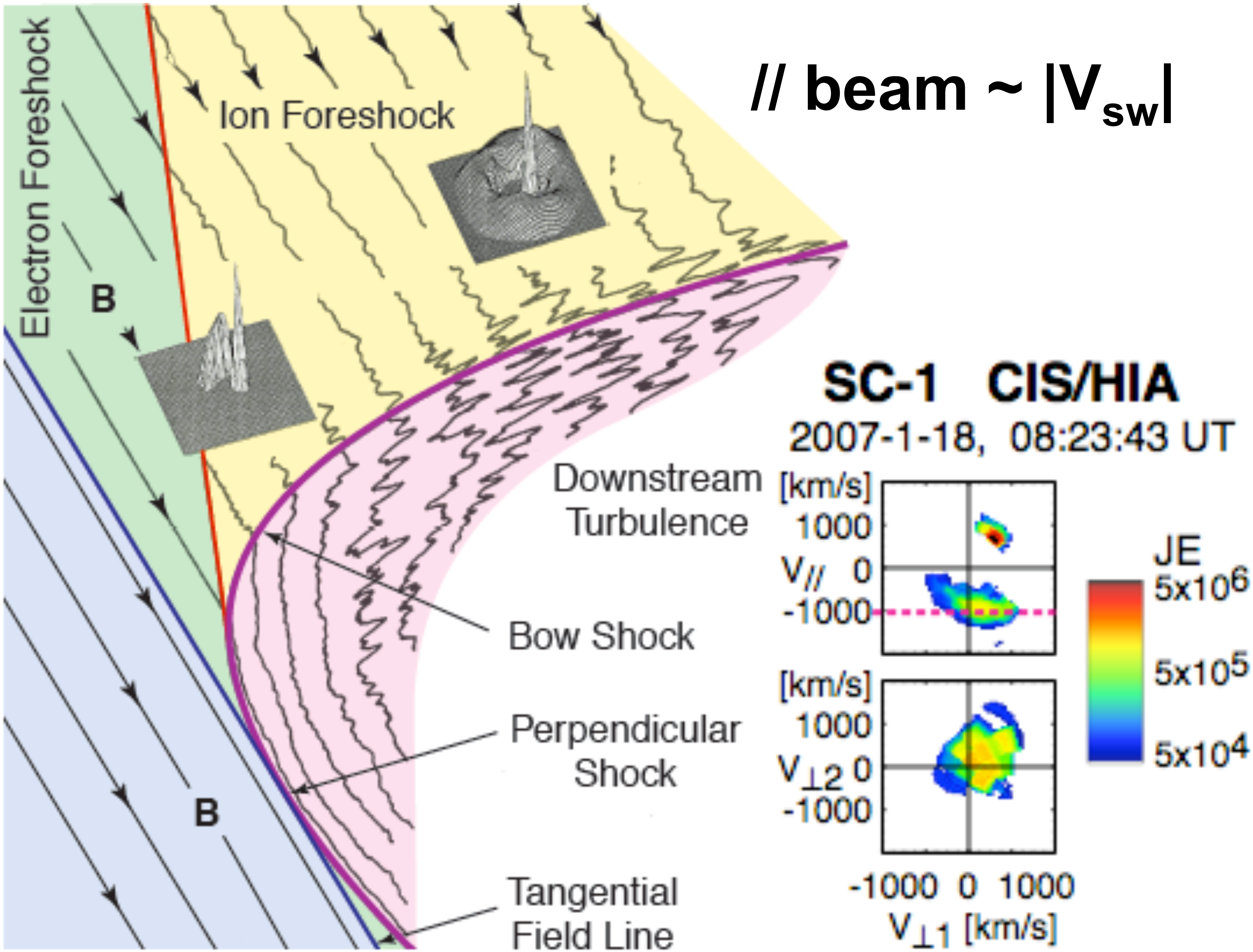
1. **Introduction**: Earth's knowledge
2. **Venus** (similar to Earth)
3. **Mars** (Different from Venus/Earth)



FAB: field-aligned beam

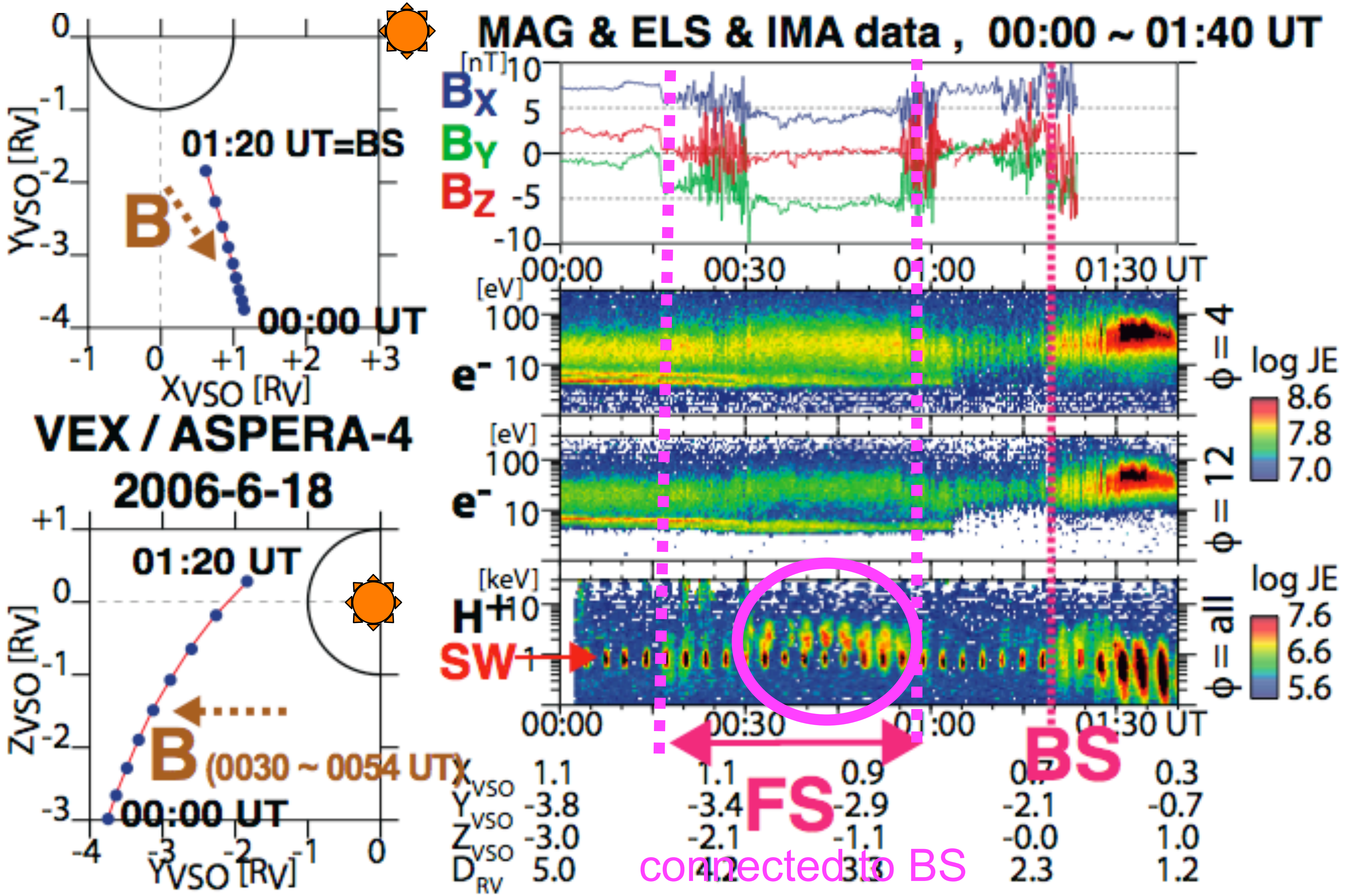
FAB + FS: foreshock

// beam ~ $|V_{sw}|$

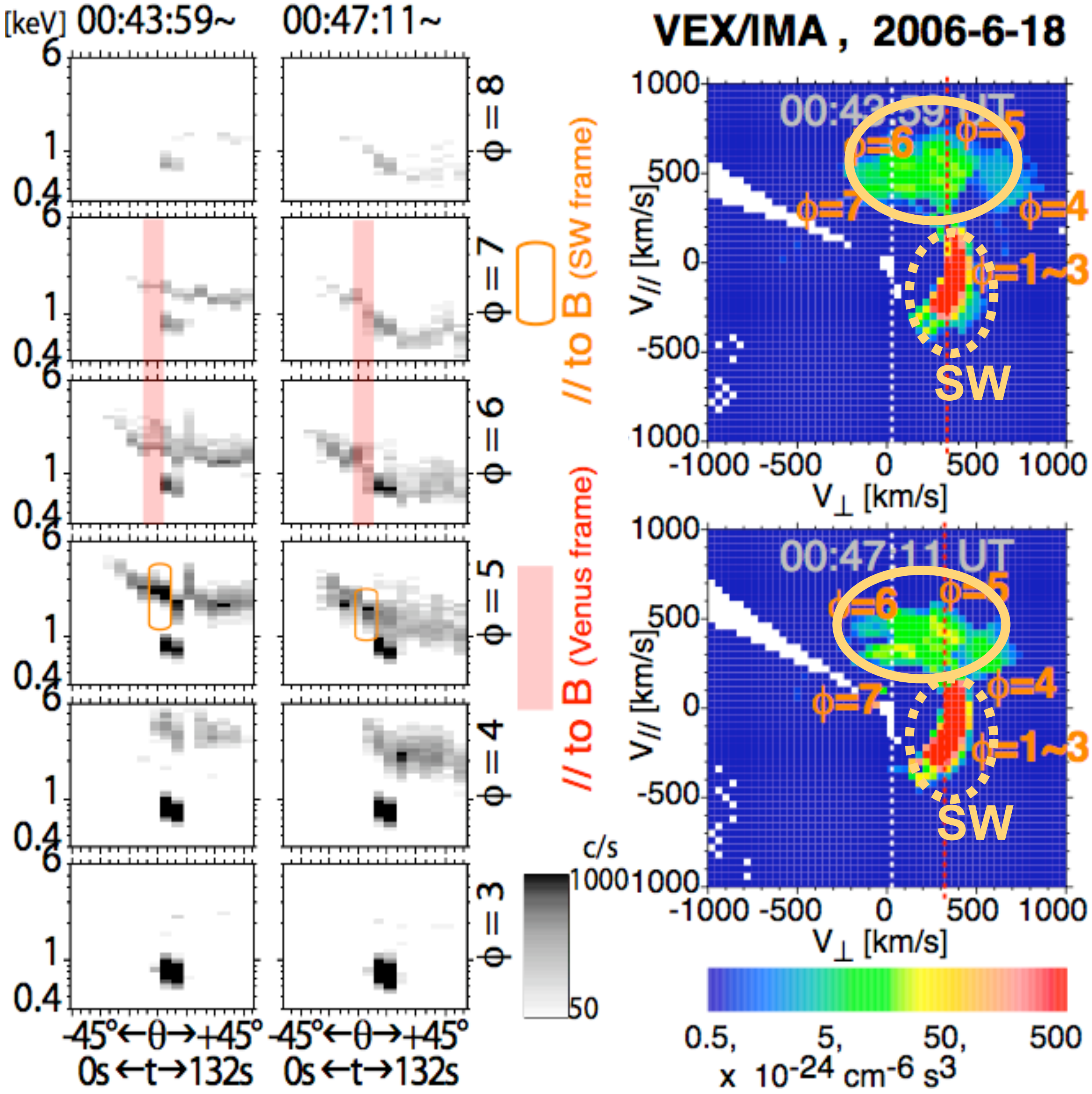


Electron Foreshock
Ion Foreshock
B
B
Downstream Turbulence
Bow Shock
Perpendicular Shock
Tangential Field Line
SC-1 CIS/HIA
2007-1-18, 08:23:43 UT
[km/s]
1000
$V_{//}$ 0
-1000
[km/s]
1000
$V_{\perp 2}$ 0
-1000
-1000 0 1000
$V_{\perp 1}$ [km/s]
JE
$5x10^6$
$5x10^5$
$5x10^4$

Venus (VEX)



VEX / ASPERA-4
2006-6-18
01:20 UT=BS
00:00 UT
01:20 UT
B
B (0030 ~ 0054 UT)
XVSO [RV]
YVSO [RV]
ZVSO [RV]
MAG & ELS & IMA data , 00:00 ~ 01:40 UT
BX
BY
BZ
[nT]
[eV]
[keV]
e-
H+
SW
φ = 4
φ = 12
φ = all
log JE
8.6
7.8
7.0
7.6
6.6
5.6
00:00
00:30
01:00
01:30 UT
FS
BS
connected to BS
XVSO 1.1 1.1 0.9 0.7 0.3
YVSO -3.8 -3.4 -2.9 -2.1 -0.7
ZVSO -3.0 -2.1 -1.1 -0.0 1.0
DRV 5.0 4.2 3.3 2.3 1.2



Same as the Earth

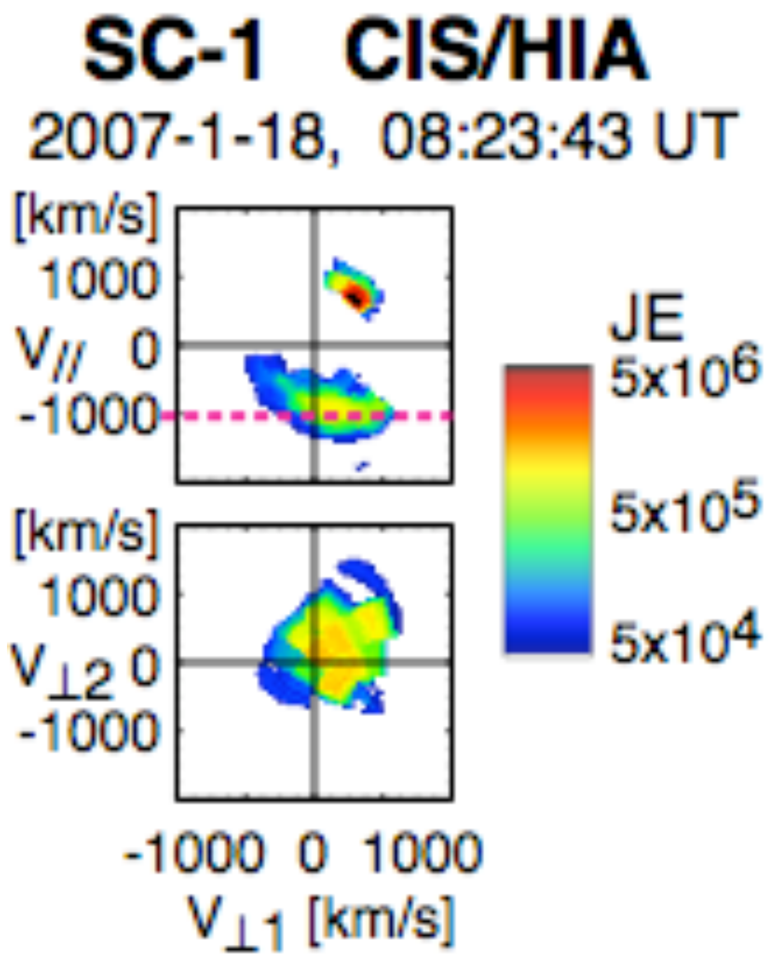
1. Field-aligned H^+.

2. Gyrating H^+ with large $V_{//}$.

cf. Earth

$V_{\perp 1}$ - $V_{//}$ (projection at $V_{\perp 2}$=0)

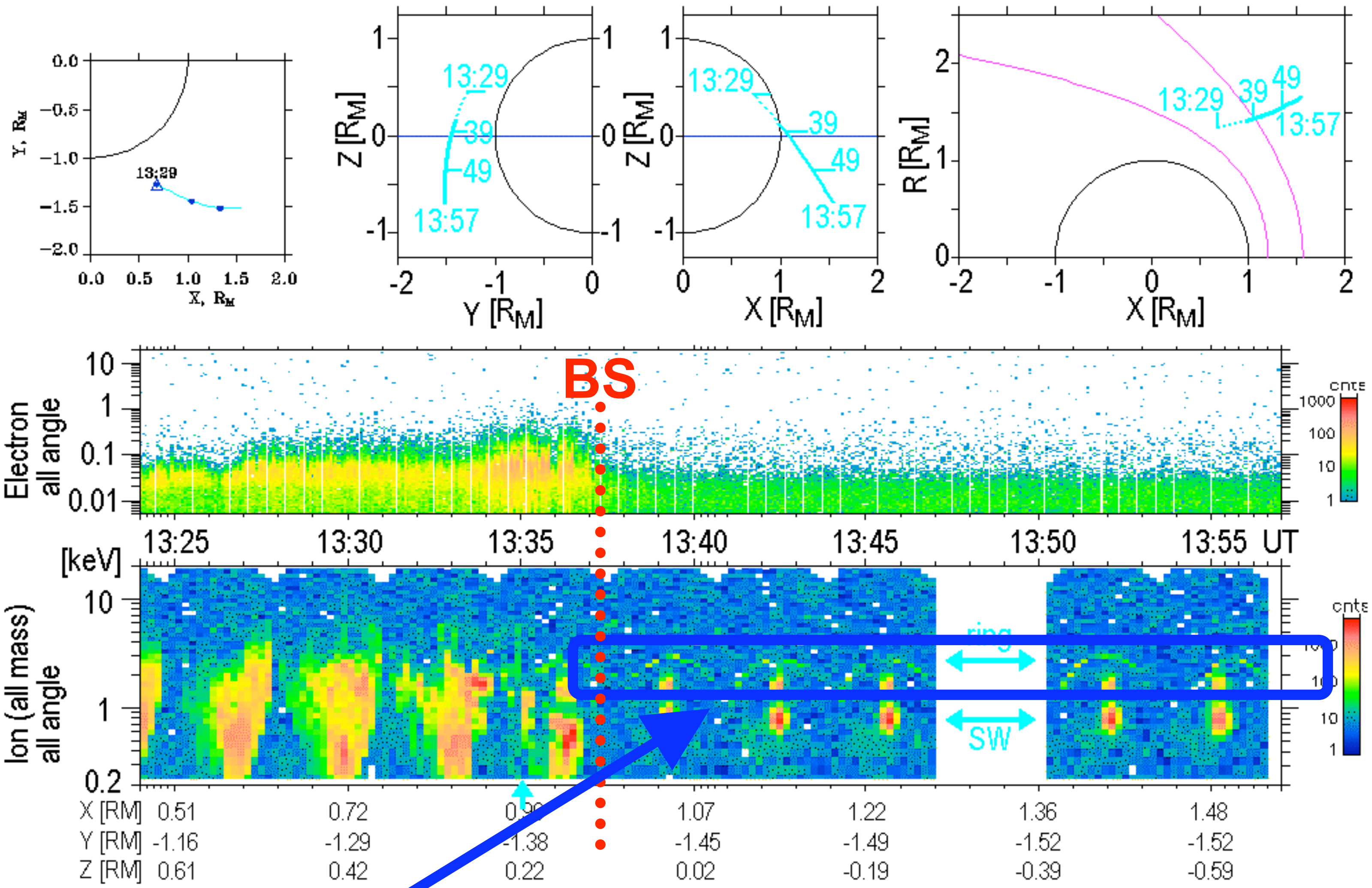
$V_{\perp 1}$ - $V_{\perp 2}$ (cut at $V_{//}$=-1000 km/s)



Venus foreshock ≈ Earth foreshock

How about Mars?

Quite different from Venus:



(1) only "ring" distribution

(2) no "foreshock" signature (examined ~ 500 traversals)

Venus-Mars difference: (1) parameters

(1) Alfvén Mach number (M_A)

x $\Rightarrow$ (2) Gyroradius (r_g) / Bow-shock radius (R_S)

(3) Inertia length (c/ω_{pi}) / Bow-shock size (R_S)

SW parameter	R_S (BS radius)	M_A ($\propto n^{1/2}V/B$)	c/ω_{pi} ($\propto n^{-1/2}$) & $c/\omega_{pi}R_S$	r_g ($\propto V/B$) & r_g/R_S
Venus	**1**	**1**	**1 & 1**	**1 & 1**
Mars	**~ 0.5**	**~ 1.4**	**~ 3 & ~ 5**	**~ 4 & ~ 8**

For Mars: **R_S ~ 5000 km** for Martian Subsolar

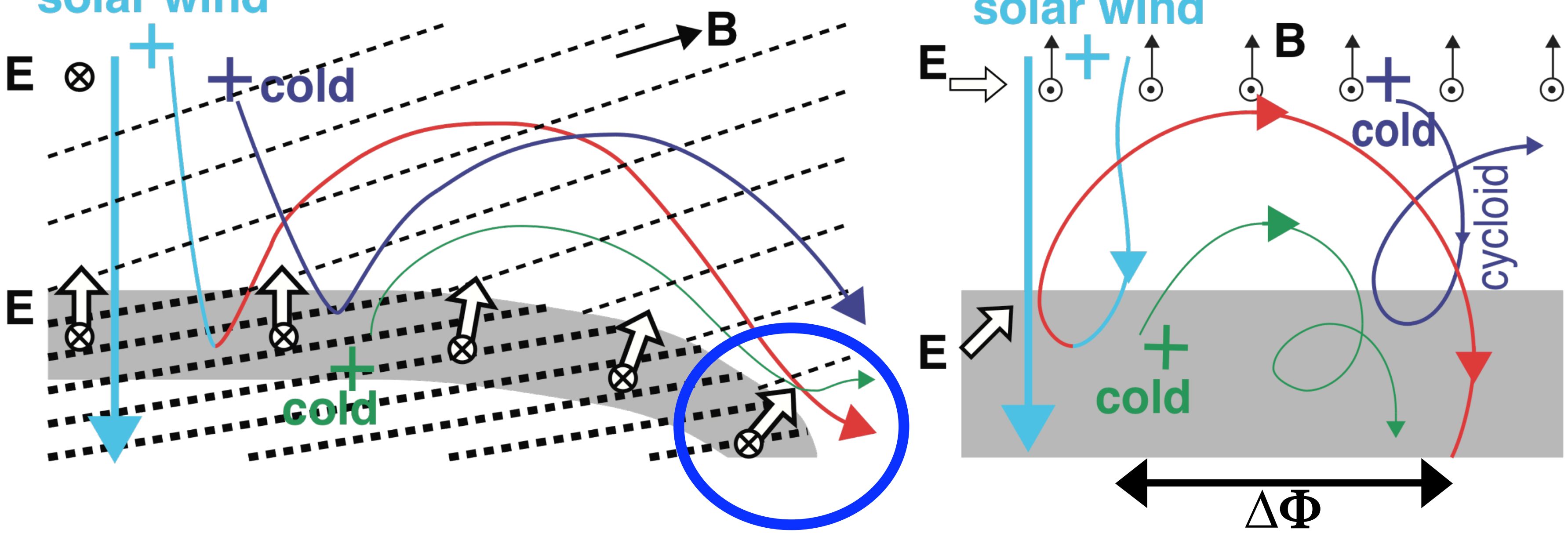
2 keV H^+ under 6 nT $\Rightarrow$ **r_g = 1000 km**

5/cm^3 H^+ $\Rightarrow$ **c/ω_{pi} = 100 km**

1. solar wind, 2&3. bow-shock cold ion, 4. sneak out

$\Delta V_{//} \ll V_{//}$ (yes), $\Delta V_{//} \ll V_{//}$ (yes), $\Delta V_{//} \sim V_{//}$ (no),

(a) Subsolar Bow Shock



Due to the finite curvature, some ions do not re-enter

Venus-Mars difference: (2) cold H+

(1) Gravity: **Venus > Mars**

$\Downarrow$

(2) Exosphere: **Venus < Mars**

$\Downarrow$

(3) newly born H+: **Venus << Mars**

(This is clear from the difference in “ring distribution”)

$\Downarrow$

(4) cold H+ at Bow shock: **Venus << Mars**

(High density cold H+ is observed only for Mars)

Venus - Mars difference (summary)

(1) Alfvén Mach number (M_A)

(2) Gyroradius (r_g) / Bow-shock radius (R_S)

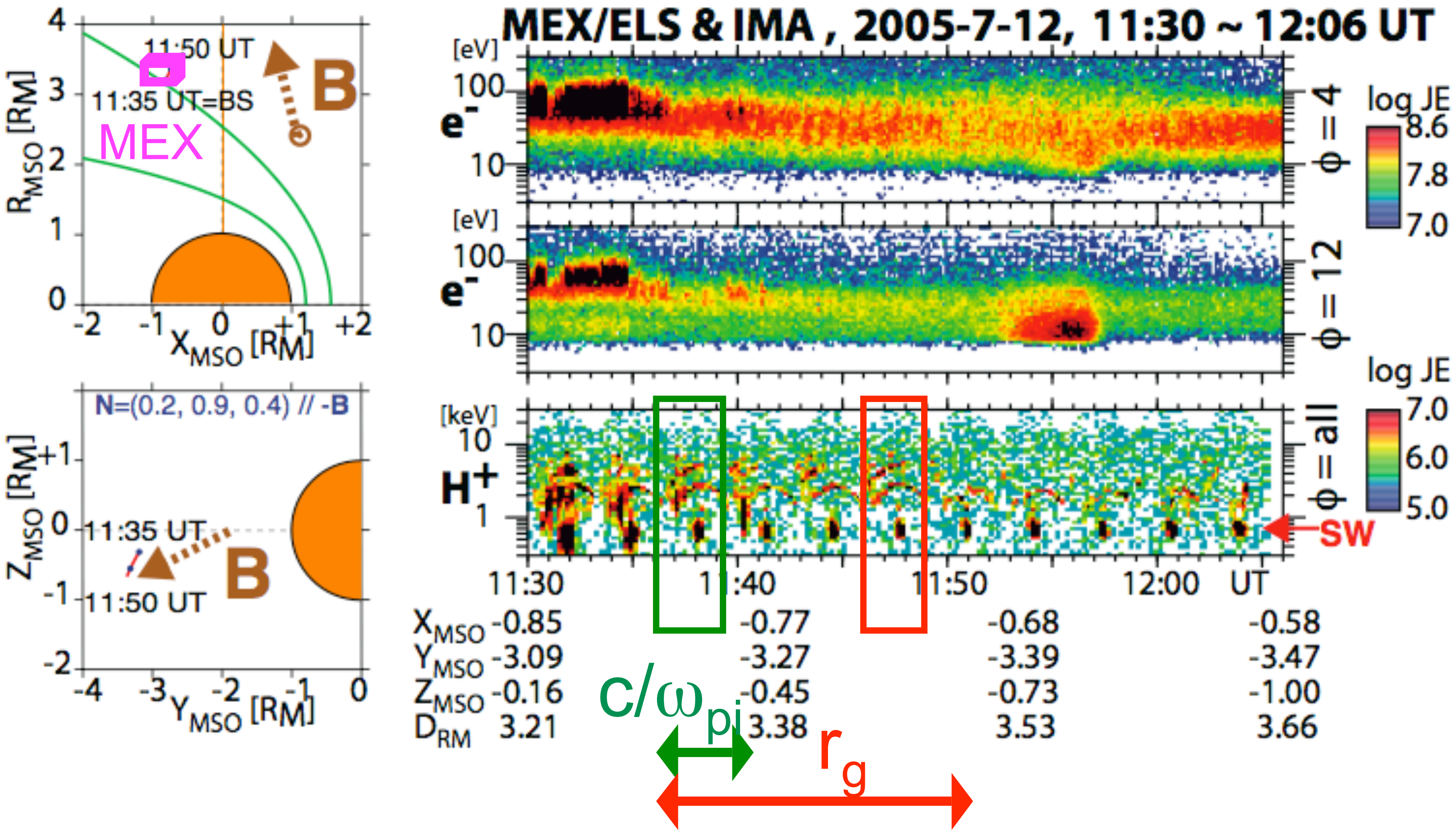
(3) Inertia length (c/ω_{pi}) / Bow-shock size (R_S)

(4) Cold ion inside Bow-shock

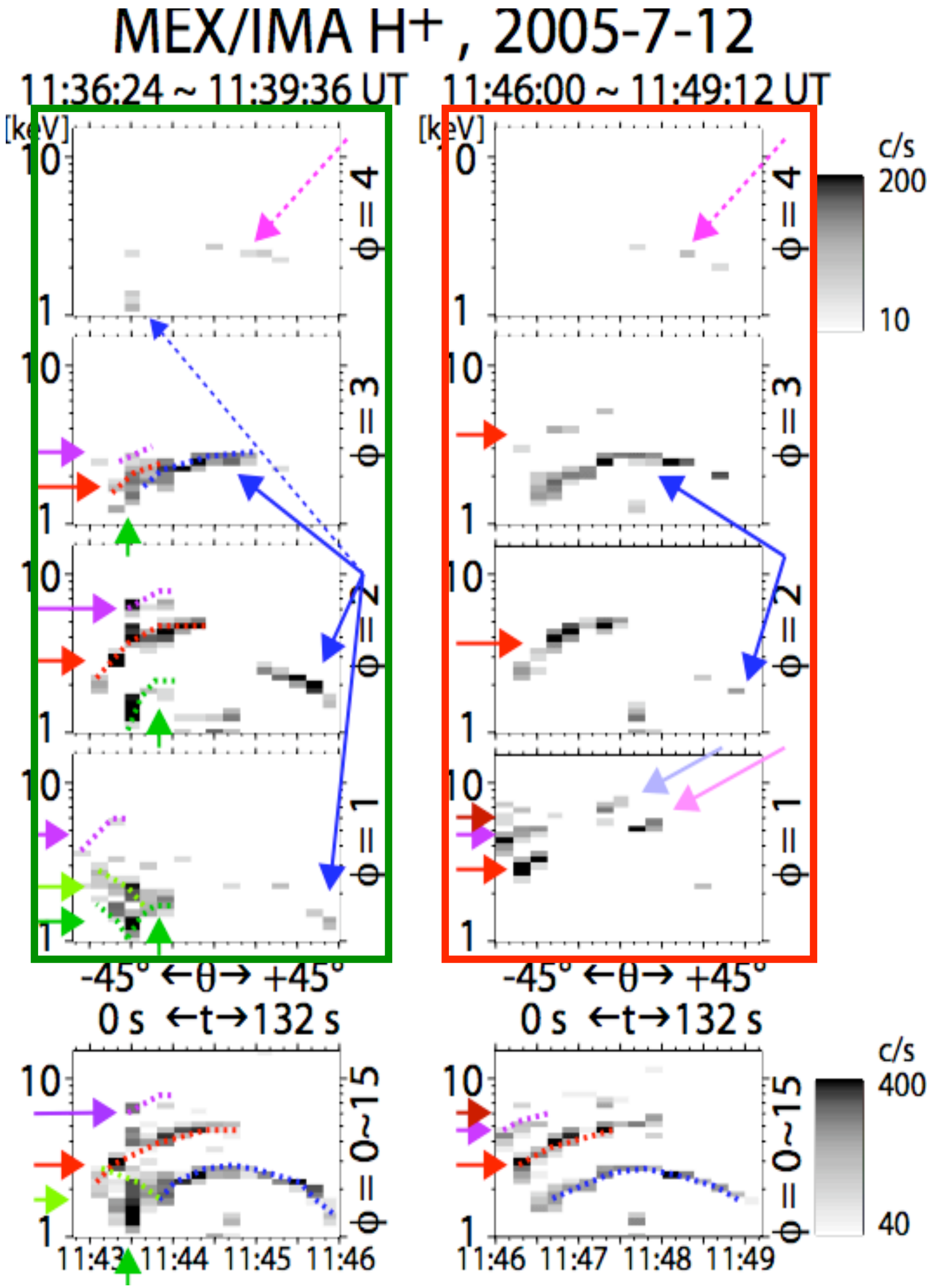
parameter	R_S	M_A	$c/\omega_{pi}R_S$	r_g/R_S	cold H+ at BS
Venus	**1**	**1**	**1**	**1**	**very little**
Mars	**~ 0.5**	**~ 1.4**	**~ 5**	**~ 8**	**a lot**

⇑ ?　　⇑ ?

Examine close to the Bow Shock



We sometimes observed “multiple-ring” structure.

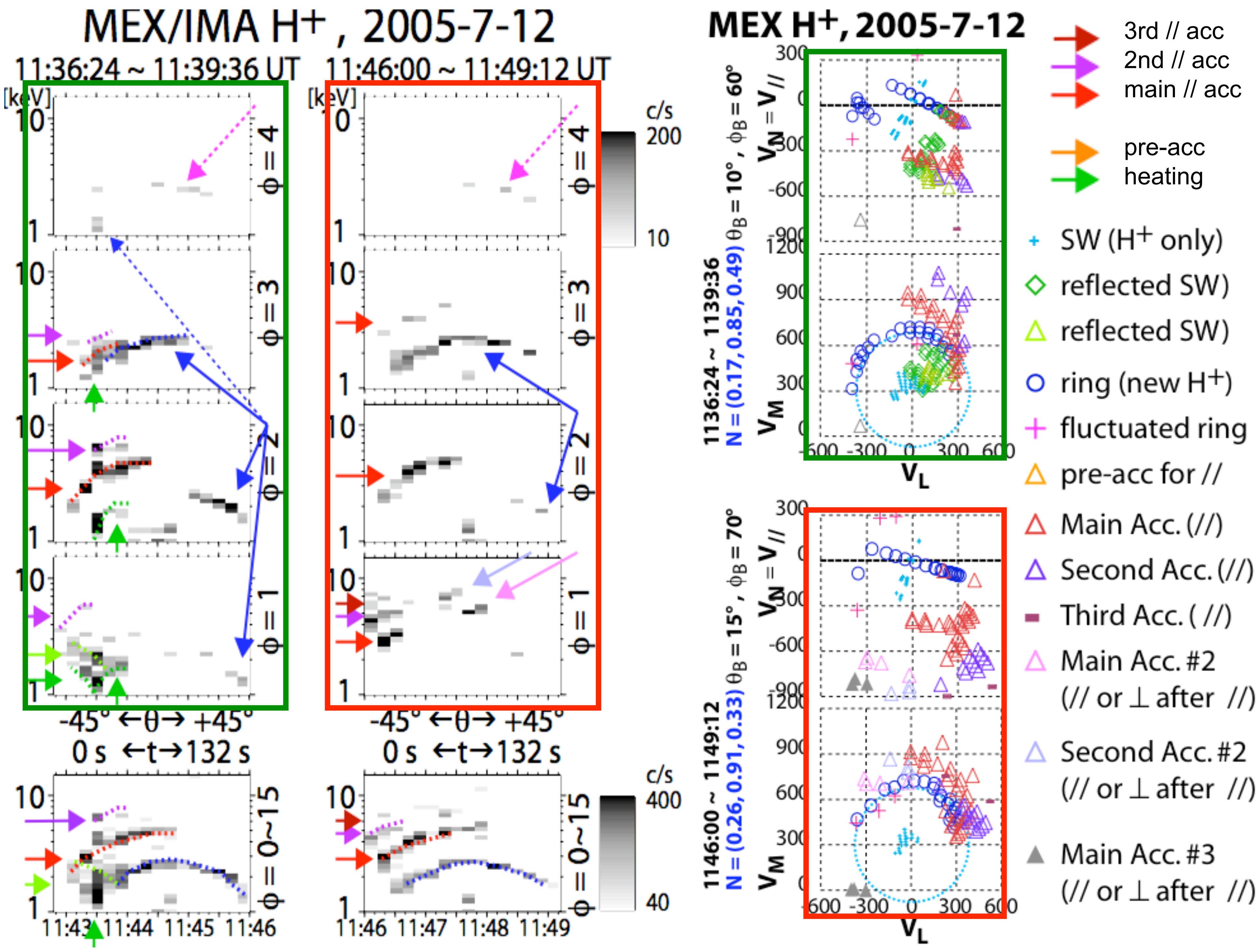


Three types of accelerated ions

beyond r_g
= pickup ions
⇒obtain B direction

beyond c/ω_{pi}
within r_g
= reflected ions

within c/ω_{pi}
= foot ions



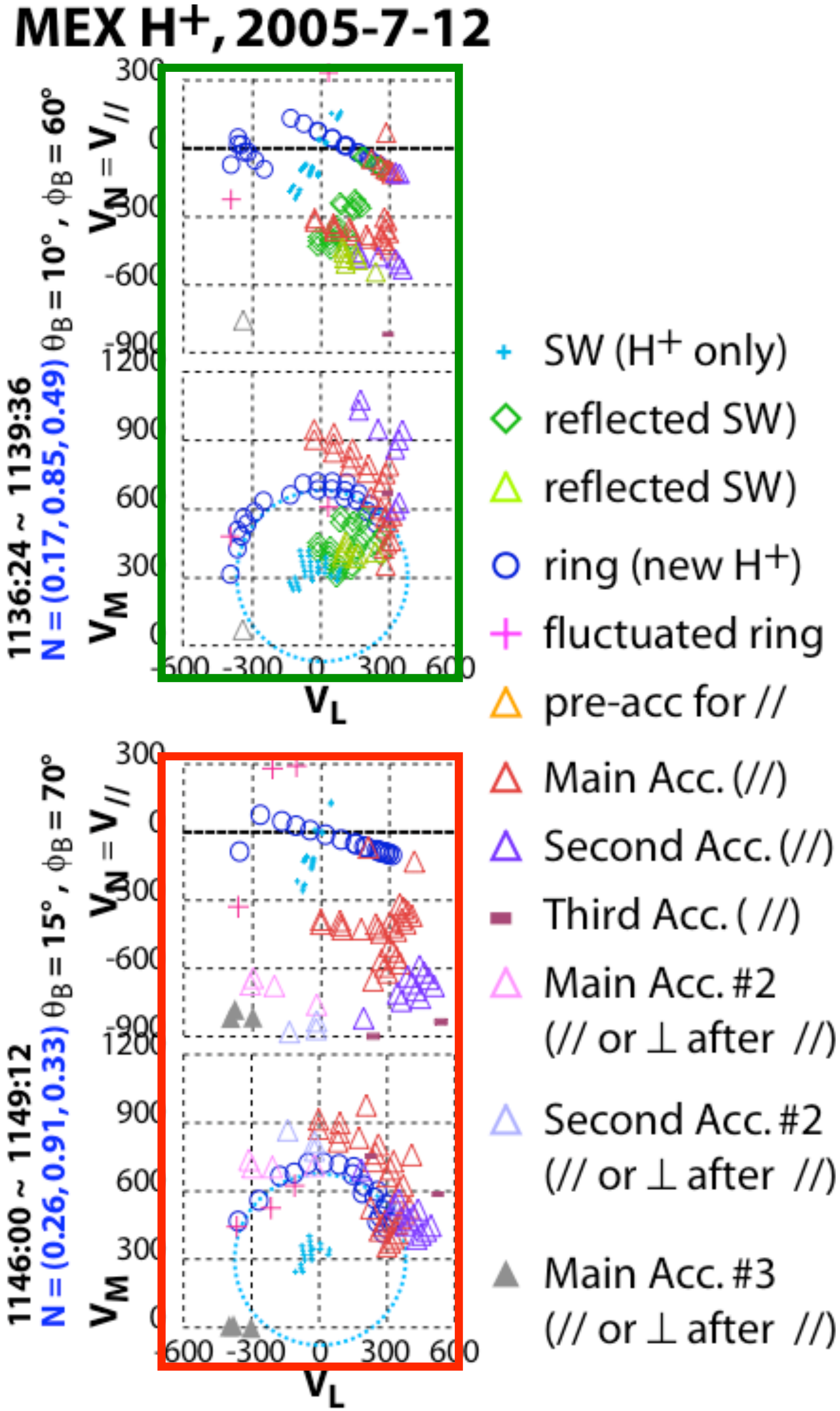
MEX/IMA H+ , 2005-7-12
11:36:24 ~ 11:39:36 UT
11:46:00 ~ 11:49:12 UT
[keV]
φ = 4
φ = 3
φ = 2
φ = 1
c/s
200
10
-45° ←θ→ +45°
0 s ←t→ 132 s
φ = 0~15
c/s
400
40
11:43 11:44 11:45 11:46
11:46 11:47 11:48 11:49
MEX H+, 2005-7-12
1136:24 ~ 1139:36
N = (0.17, 0.85, 0.49) θB = 10°, φB = 60°
1146:00 ~ 1149:12
N = (0.26, 0.91, 0.33) θB = 15°, φB = 70°
VN = V//
VM
VL
3rd // acc
2nd // acc
main // acc
pre-acc
heating
SW (H+ only)
reflected SW)
reflected SW)
ring (new H+)
fluctuated ring
pre-acc for //
Main Acc. (//)
Second Acc. (//)
Third Acc. (//)
Main Acc. #2
(// or ⊥ after //)
Second Acc. #2
(// or ⊥ after //)
Main Acc. #3
(// or ⊥ after //)

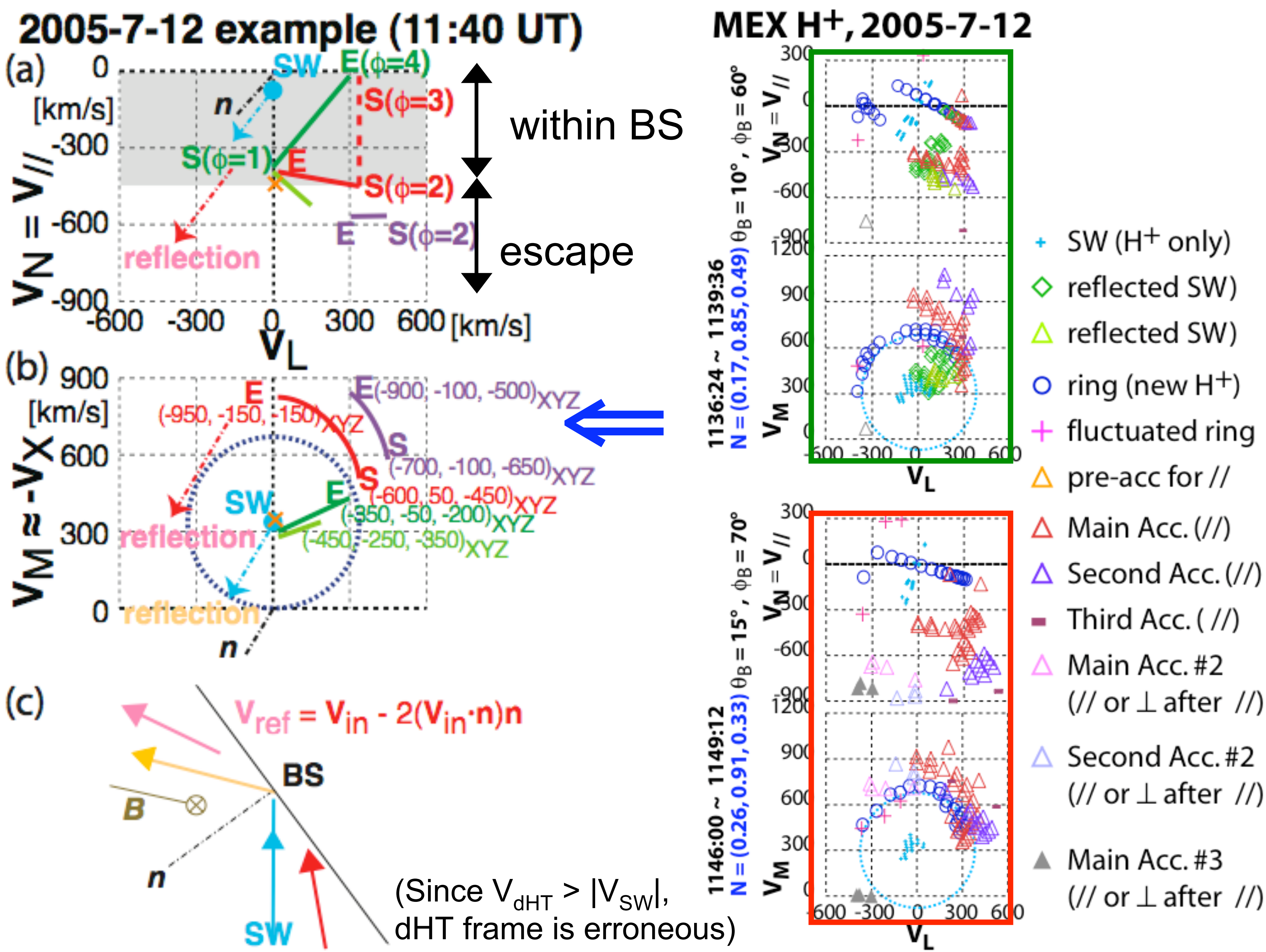
Multiple acceleration

green: foot
blue: primary ring
red: 1st branch
purple: 2nd branch
brown: 3rd branch

Gyro-phase bunching

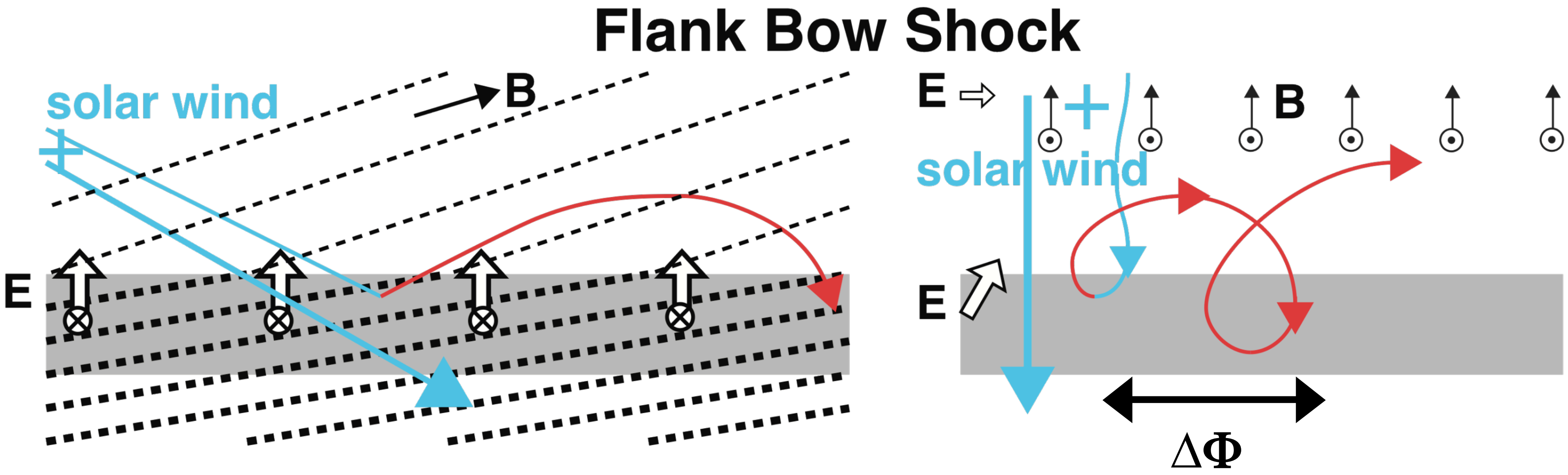
red: half gyro
purple: one third gyro





2005-7-12 example (11:40 UT)
(a)
(b)
(c)
within BS
escape
reflection
$V_{ref} = V_{in} - 2(V_{in} \cdot n)n$
BS
(Since $V_{dHT} > |V_{SW}|$,
dHT frame is erroneous)
MEX H+, 2005-7-12
1136:24 ~ 1139:36
N = (0.17, 0.85, 0.49) θB = 10°, φB = 60°
1146:00 ~ 1149:12
N = (0.26, 0.91, 0.33) θB = 15°, φB = 70°
SW (H+ only)
reflected SW)
reflected SW)
ring (new H+)
fluctuated ring
pre-acc for //
Main Acc. (//)
Second Acc. (//)
Third Acc. (//)
Main Acc. #2
(// or ⊥ after //)
Second Acc. #2
(// or ⊥ after //)
Main Acc. #3
(// or ⊥ after //)

SW Reflection ⇒ convert $V_\perp$ to $V_{//}$ in SW frame



The observed multiple ring structure is well explained by multiple specular reflection.

But, **why is it observed outside the foot region?**

⇓

no : Finite bow shock size compared to r_g.

yes: Cold ion in the bow shock

⇒ This may explain “non-specular reflection” at subsolar.

Special features for Mars

- Energy is stepping (due to reflection?)
- Gyro-bunching effect (due to short distance?) with gradual $\perp$ acceleration (why?)
- Two different scale length
- No specular reflection near the bow shock (need to confirm)

Venus ≈ Earth

No internal magnetic field.

Planet is the same size as the Earth

$\Downarrow$

Smaller bow shock size than the Earth, yet MHD regime.

Effect of cod ions in the bow shock can be ignored.

Mars ≠ Earth

No internal magnetic field.

Planet is smaller than the Earth.

$\Downarrow$

The bow shock size is too small to treat with MHD.

Effect of cod ions in the bow shock cannot be ignored.

Ending (add Earth)

(1) Alfvén Mach number (M_A)

(2) Gyroradius (r_g) / Bow-shock radius (R_S)

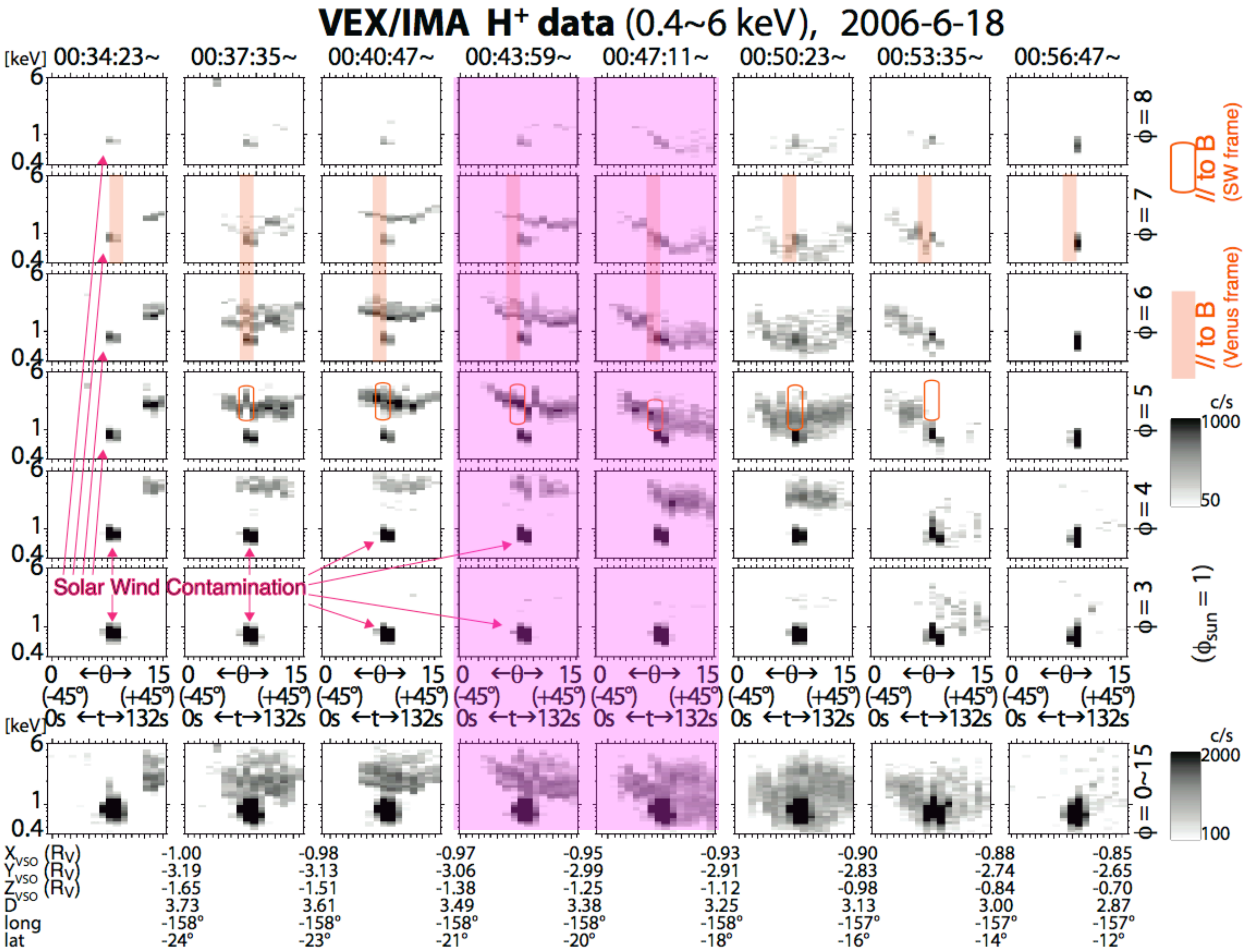
(3) Inertia length (c/ω_{pi}) / Bow-shock size (R_S)

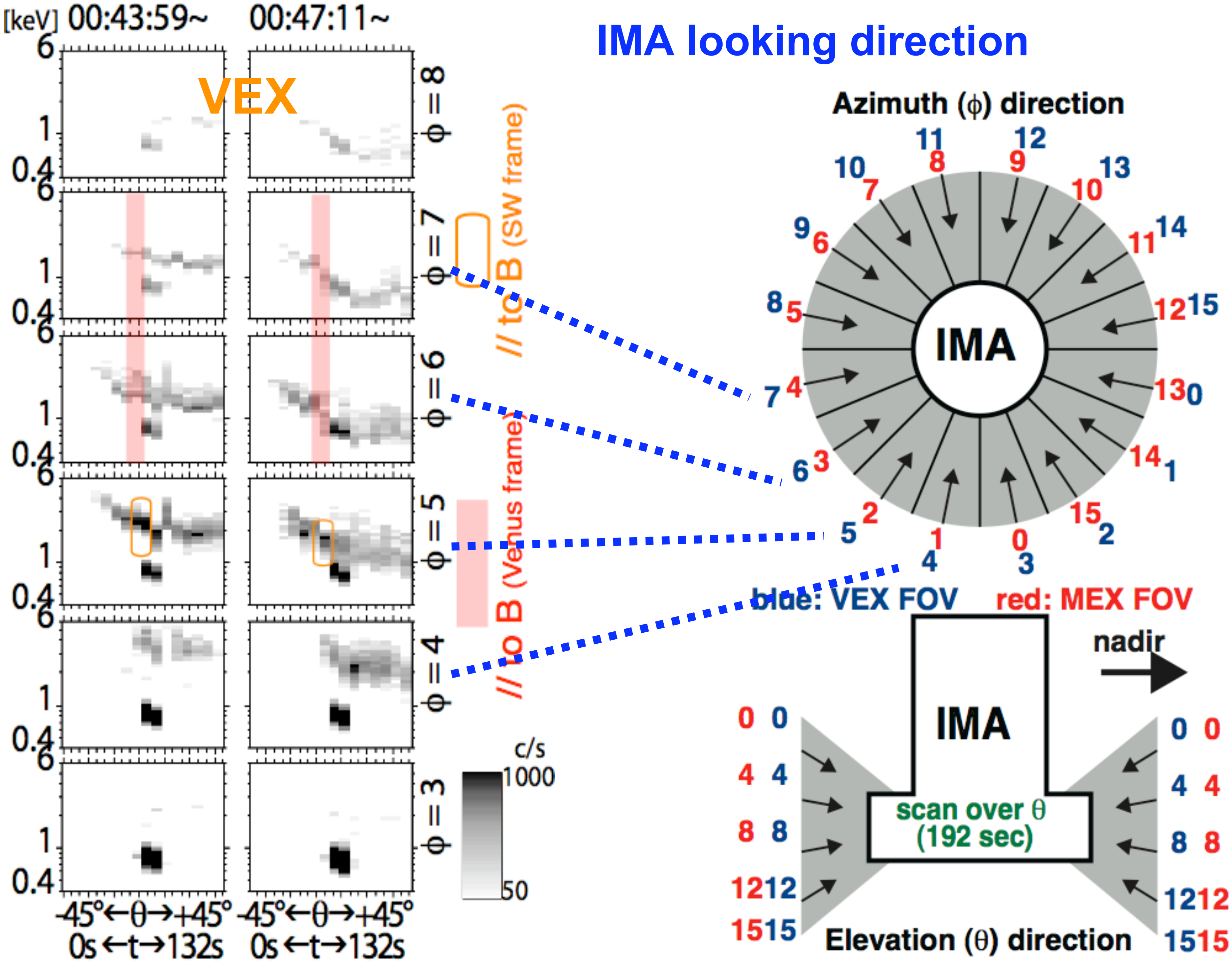
(4) Cold ion inside Bow-shock

parameter	R_S	M_A	$c/\omega_{pi}R_S$	r_g/R_S	cold H+ at BS
Earth	**5**	**~ 1.2**	**~ 0.3**	**~ 0.4**	**no**
Venus	**1**	**1**	**1**	**1**	**very little**
Mars	**~ 0.5**	**~ 1.4**	**~ 5**	**~ 8**	**a lot**

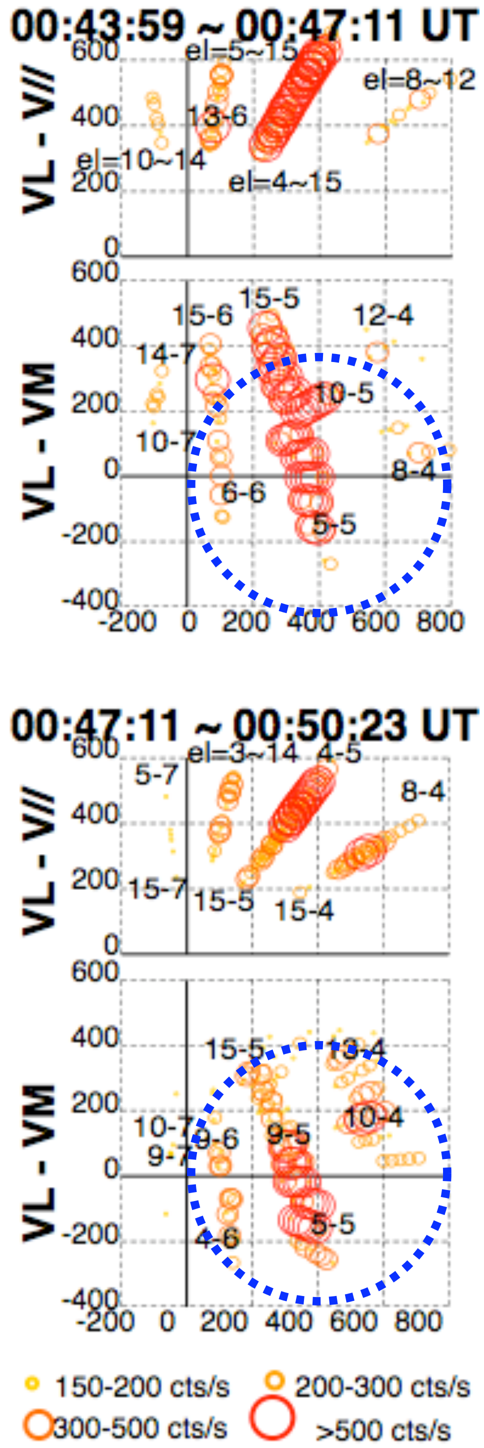
				⇑	⇑
				?	?

End

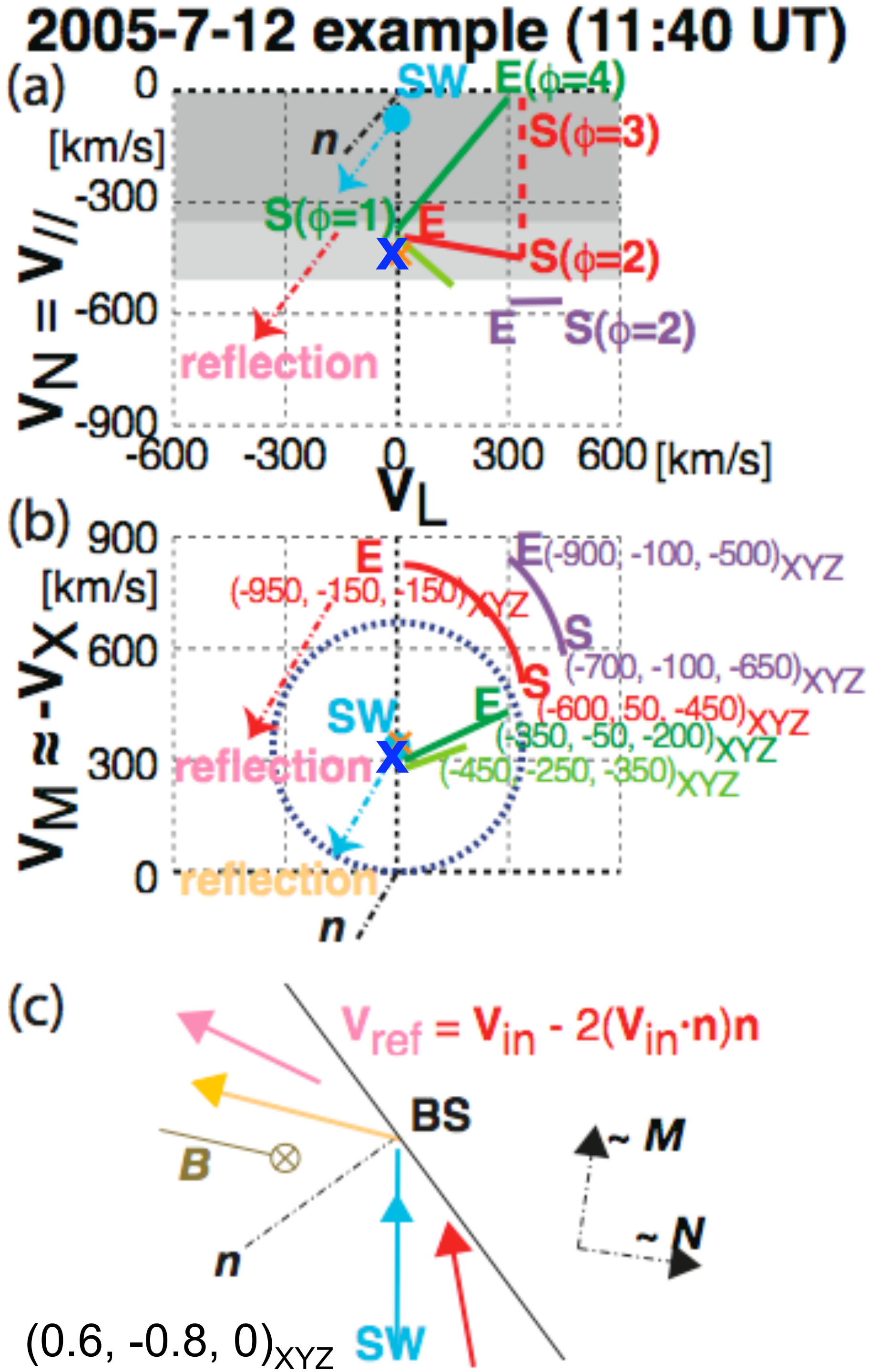

VEX/IMA H+ data (0.4~6 keV), 2006-6-18
[keV]
00:34:23~
00:37:35~
00:40:47~
00:43:59~
00:47:11~
00:50:23~
00:53:35~
00:56:47~
φ = 8
φ = 7
φ = 6
φ = 5
φ = 4
φ = 3
φ = 0~15
// to B (SW frame)
// to B (Venus frame)
c/s
1000
50
2000
100
(ϕ_{sun} = 1)
Solar Wind Contamination
0 ←θ→ 15
(-45°) (+45°)
0s ←t→ 132s
X_{VSO} (R_V) -1.00 -0.98 -0.97 -0.95 -0.93 -0.90 -0.88 -0.85
Y_{VSO} (R_V) -3.19 -3.13 -3.06 -2.99 -2.91 -2.83 -2.74 -2.65
Z_{VSO} (R_V) -1.65 -1.51 -1.38 -1.25 -1.12 -0.98 -0.84 -0.70
D 3.73 3.61 3.49 3.38 3.25 3.13 3.00 2.87
long -158° -158° -158° -158° -158° -157° -157° -157°
lat -24° -23° -21° -20° -18° -16° -14° -12°



IMA looking direction
[keV] 00:43:59~
00:47:11~
VEX
φ = 8
φ = 7
φ = 6
φ = 5
φ = 4
φ = 3
// to B (SW frame)
// to B (Venus frame)
-45°←θ→+45°
0s←t→132s
c/s
1000
50
Azimuth (φ) direction
IMA
blue: VEX FOV
red: MEX FOV
nadir
scan over θ
(192 sec)
Elevation (θ) direction


00:43:59 ~ 00:47:11 UT
VL - V//
VL - VM
el=5~15
el=8~12
13-6
el=10~14
el=4~15
15-6
15-5
12-4
14-7
10-5
10-7
8-4
6-6
5-5
00:47:11 ~ 00:50:23 UT
el=3~14
4-5
5-7
8-4
15-7
15-5
15-4
13-4
10-4
10-7
9-6
9-5
9-7
4-6
5-5
150-200 cts/s
200-300 cts/s
300-500 cts/s
>500 cts/s

Multiple-Reflection



S → E

S: toward BS from left

E: toward BS from right

S → E

S&E: toward BS from left

S → E

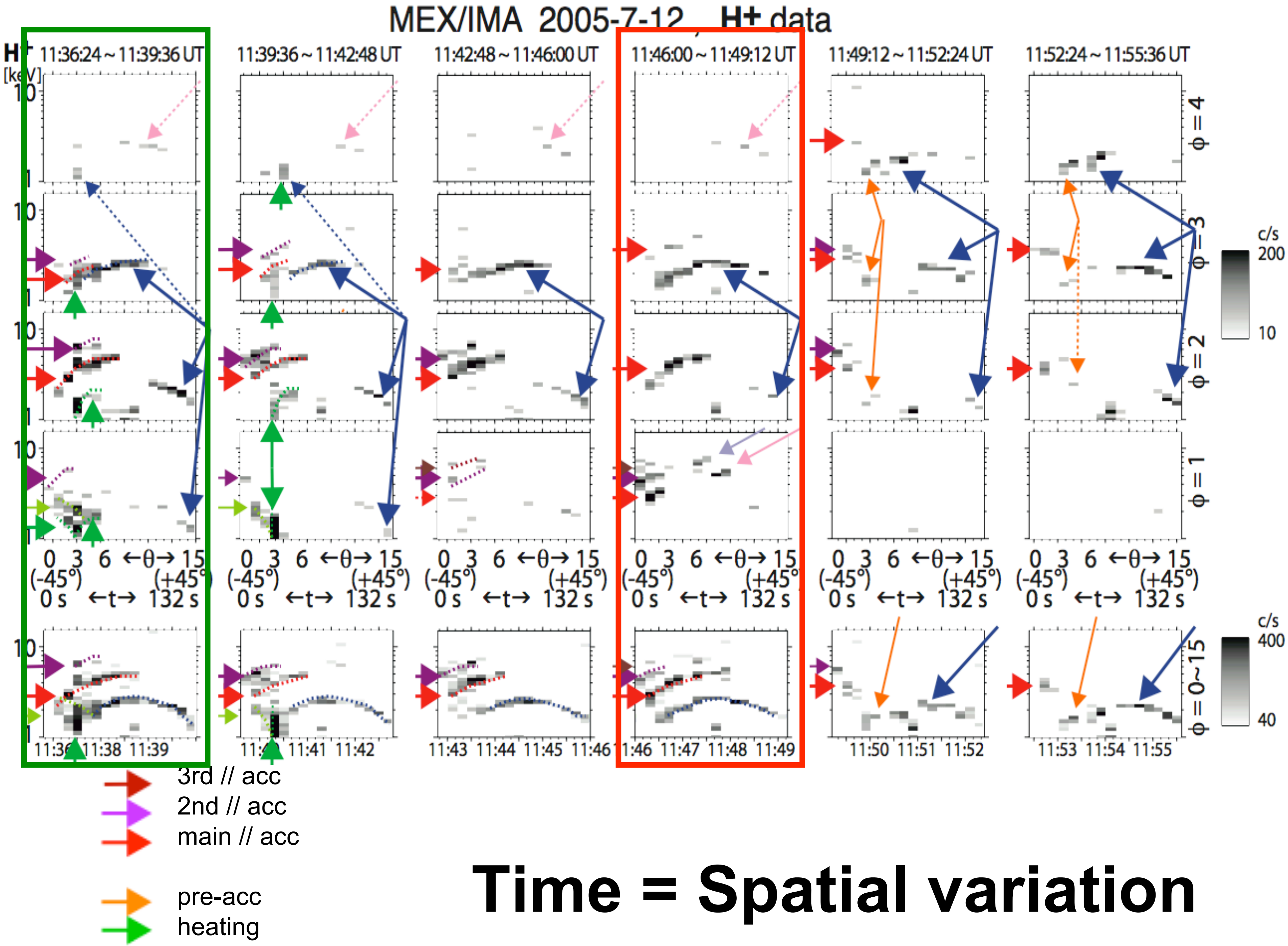
S ~ $\boldsymbol{V}_{HT}$ = along BS

E: along BS

S → E

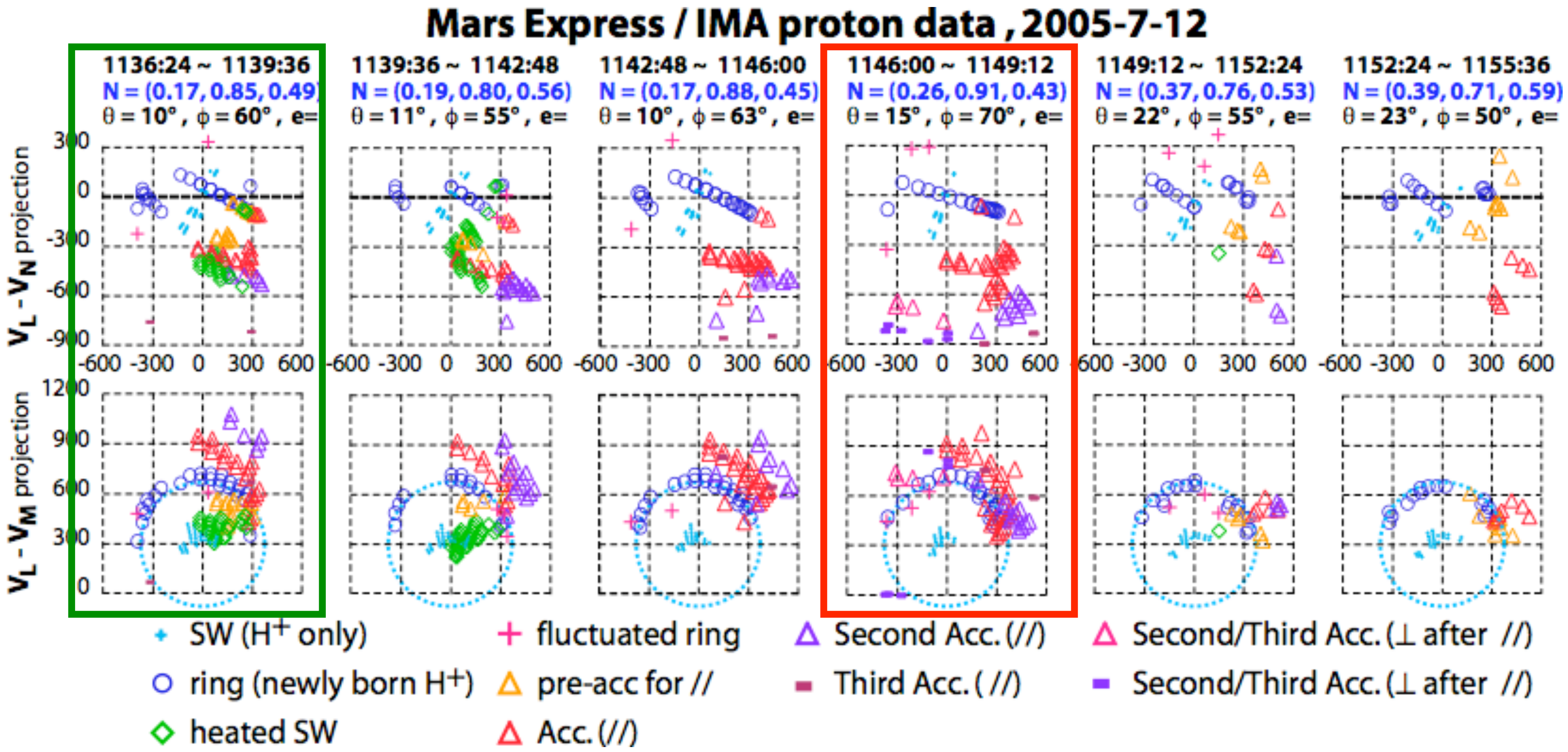
S: along BS

E: toward BS



Time = Spatial variation

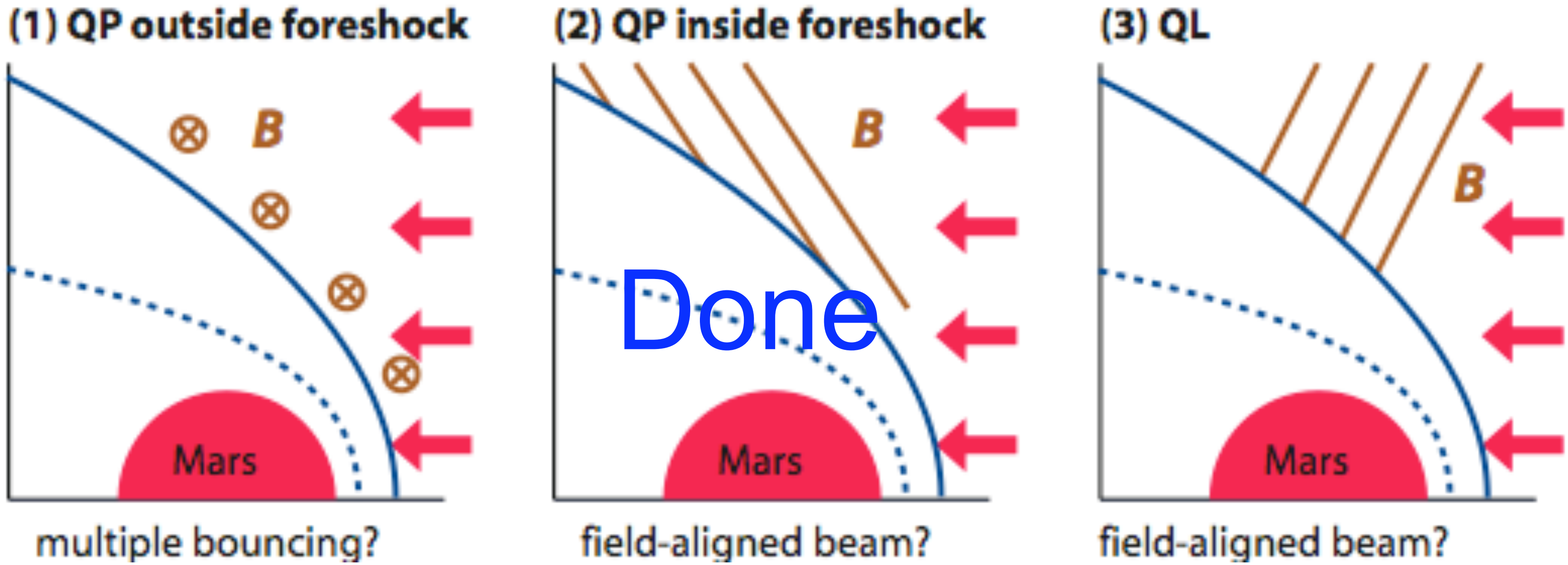
Classifying counts in // and ⊥ directions



B (N-direction) is estimated from minimum variance method applied to the ring distribution

Time = Spatial variation

Three configurations (on-going work)



2005-7-29
2005-8-3

2005-7-12

2005-8-5

Summary

Venus Express / ASPERA-4 often observes back-streaming H^+ in the foreshock region of Venus, in a similar ways as the Terrestrial foreshock, i.e., field-aligned component, and intermediate (gyrating) component

Mars Express / ASPERA-3 (same instrumentation as VEX) did not observe similar ions in the Martian foreshock region beyond the foot region. Instead, it shows different type of acceleration in the foot region, indicating the ion trajectory (history) during its gyromotion.

The finite gyroradius effect makes Mars a perfect laboratory to study acceleration processes.