IMF direction derived from cycloid-like ion distributions observed by Mars Express

M. Yamauchi, **Y. Futaana**, R. Lundin, S. Barabash, M. Holmström (IRF-Kiruna, Sweden)

A. Fedorov, J.-A. Sauvaud (CESR, Toulouse, France)

R.A. Frahm, J.D. Winningham (SwRI, San Antonio, USA)

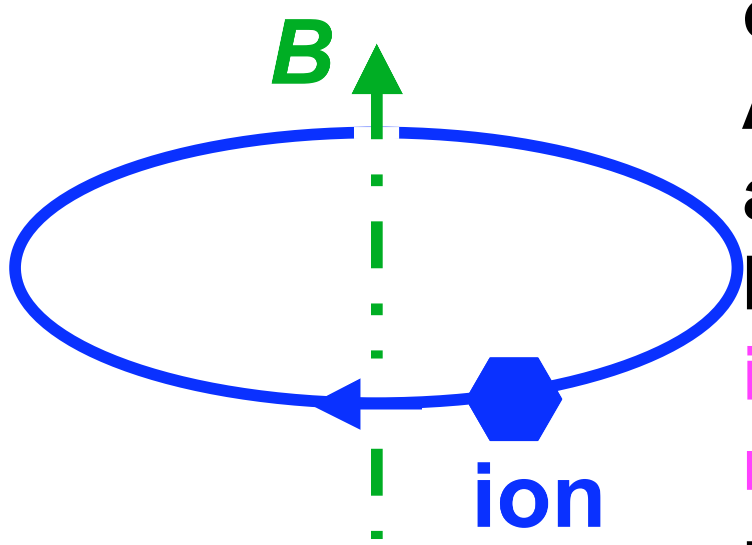
E. Dubinin (MPS, Katlenburg-Lindau, Germany),

E. Kallio (FMI, Helsinki, Finland)

and ASPERA-3 team

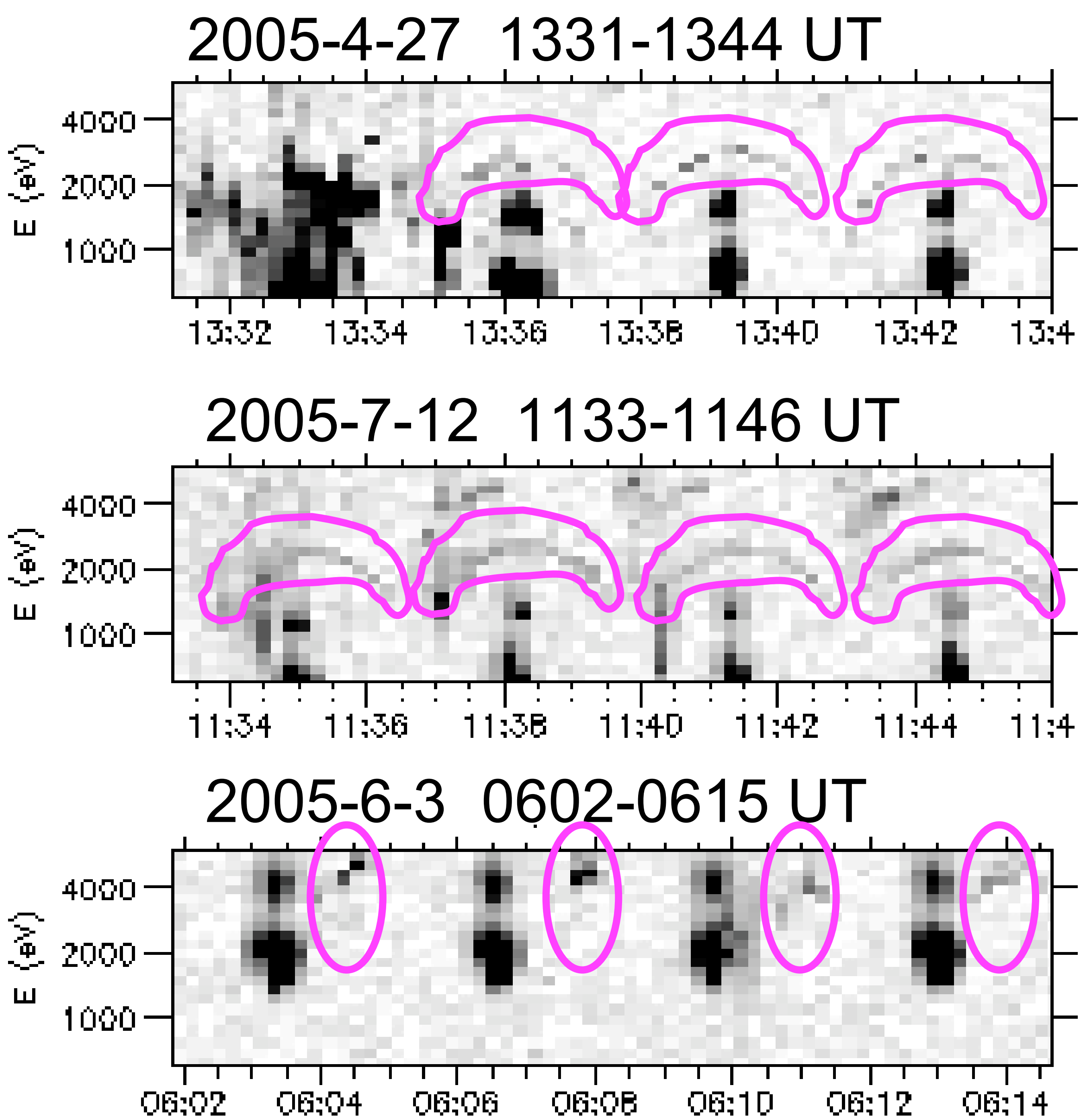
Motivation

To understand Mars Express (MEX) hot plasma and energetic neutral atom (ASPERA-3) data, it is important to have the magnetic field (***B***) measurement. However, MEX does not measure ***B*** (because of bureaucracy), and ***B*** is measured only on Venus Express. Therefore, any method to estimate ***B*** on MEX is helpful. Using Mars Global Surveyor (MGS) data is one method, but we here take another approach :

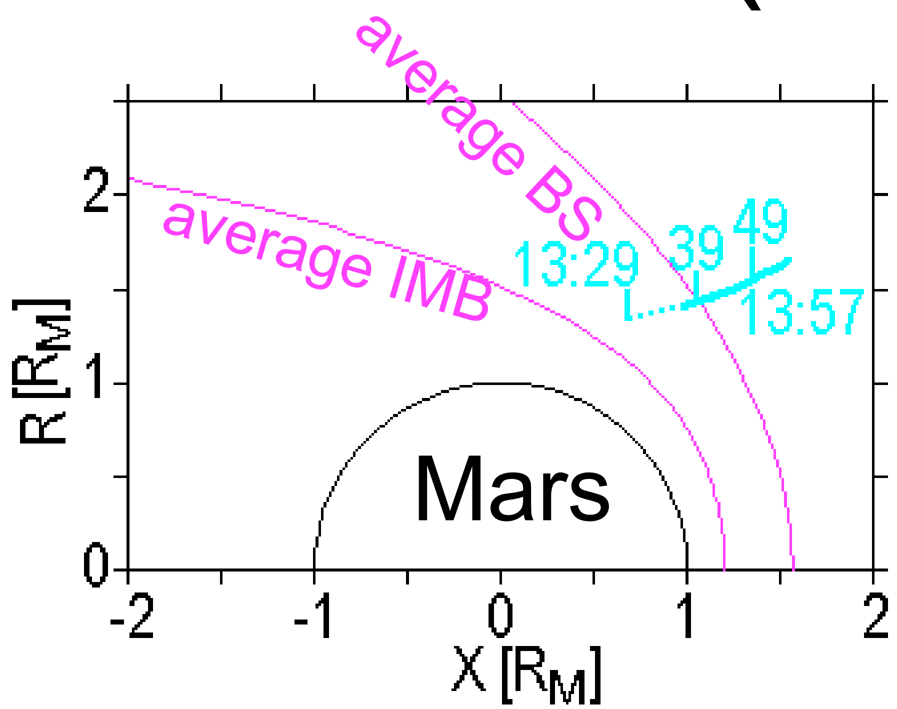


Analyze gyromotion of ions observed by ASPERA-3 ion mass analyser (IMA) because ion motion in velocity space is a ring! (spiral motion in real space)

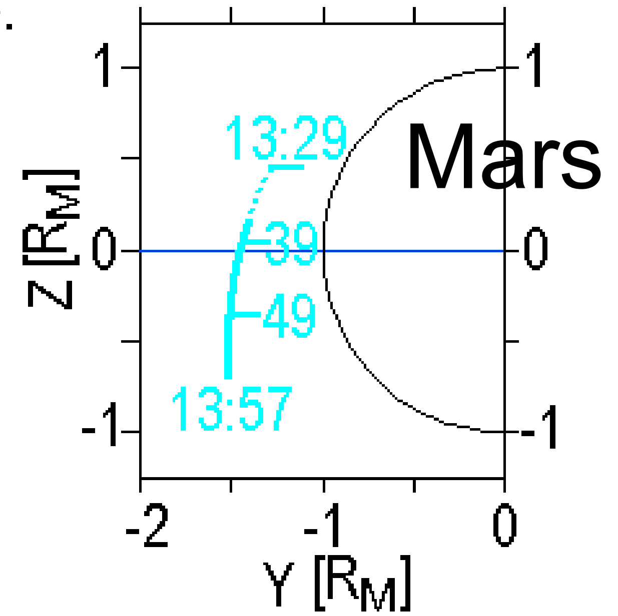
Actually, the ring distribution is the "clearest signature" among many interesting phenomena seen in IMA Quick Look (mass and azimuth are integrated)

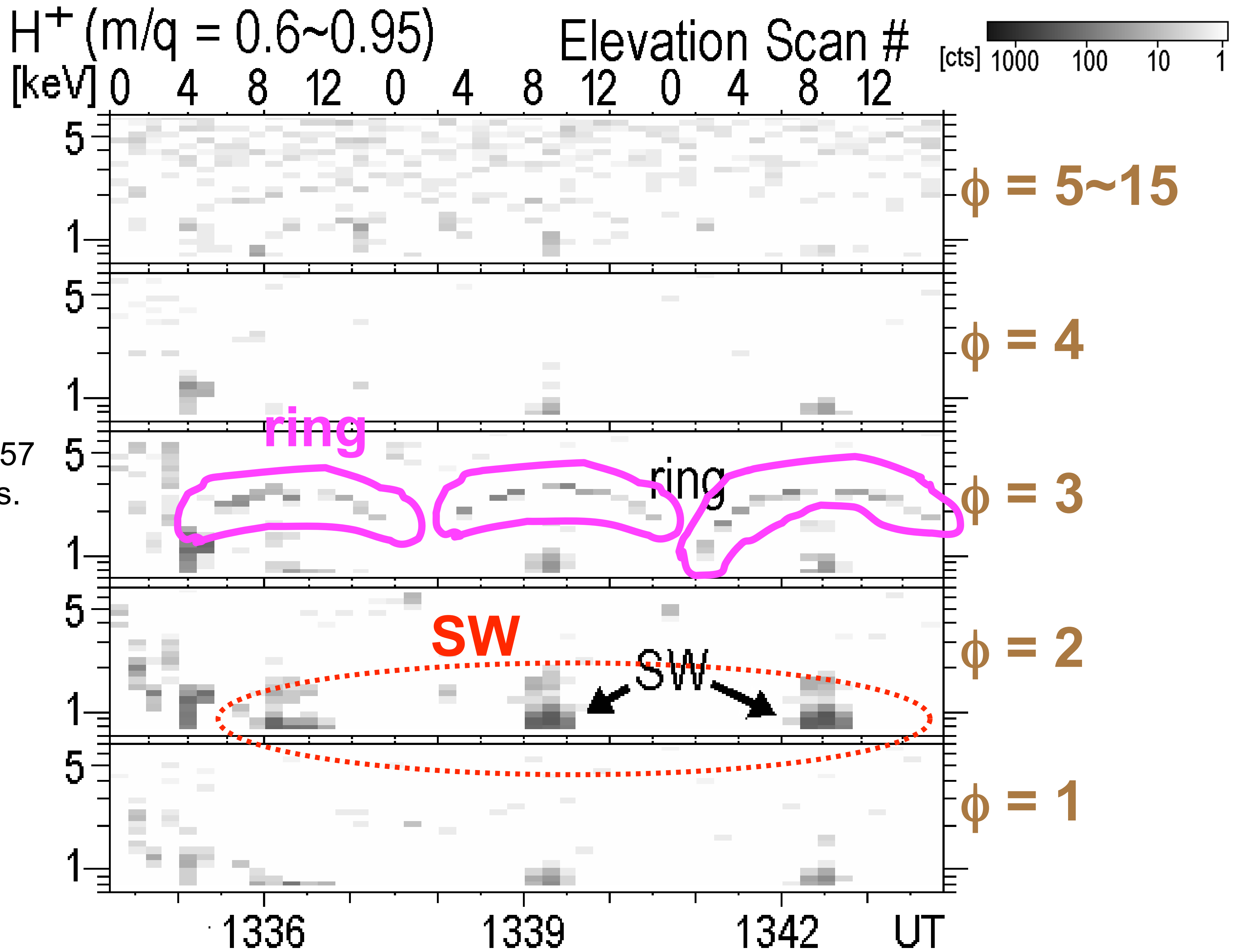


2005-4-27 (easy case) single azimuth plots



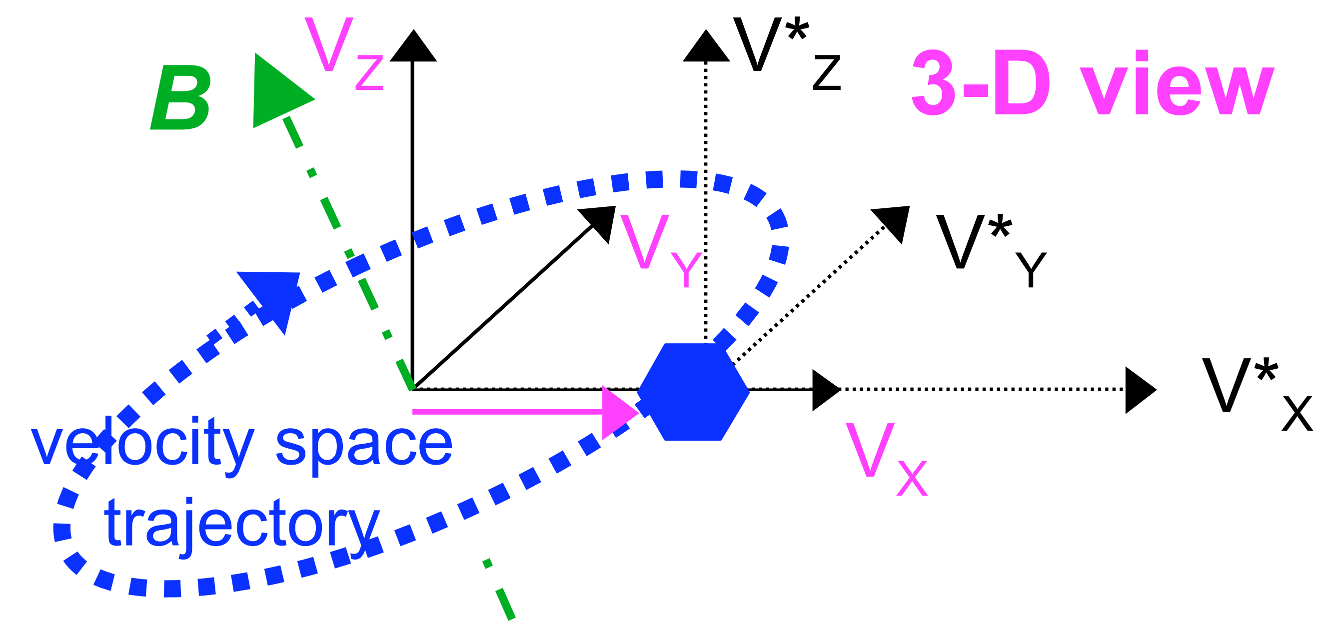
MEX orbit (light blue) during 1329-1357 UT in the cylindrical MSO coordinates. $R^2 = Y^2+Z^2$.





IMA energy-time spectrograms for proton cannel at 0.7-7 keV during 1334:00-1343:40 UT on 27 April 2005. Five different azimuthal sectors (ϕ) are presented except sector 0. The nearly 3-min cycle seen in the IMA data is due to the electric scan of the entrance direction from nearly -45° (elevation=0) to nearly +45° (elevation=15). The counts that are seen above the solar wind in the proton channel are due to contamination from alpha particles.

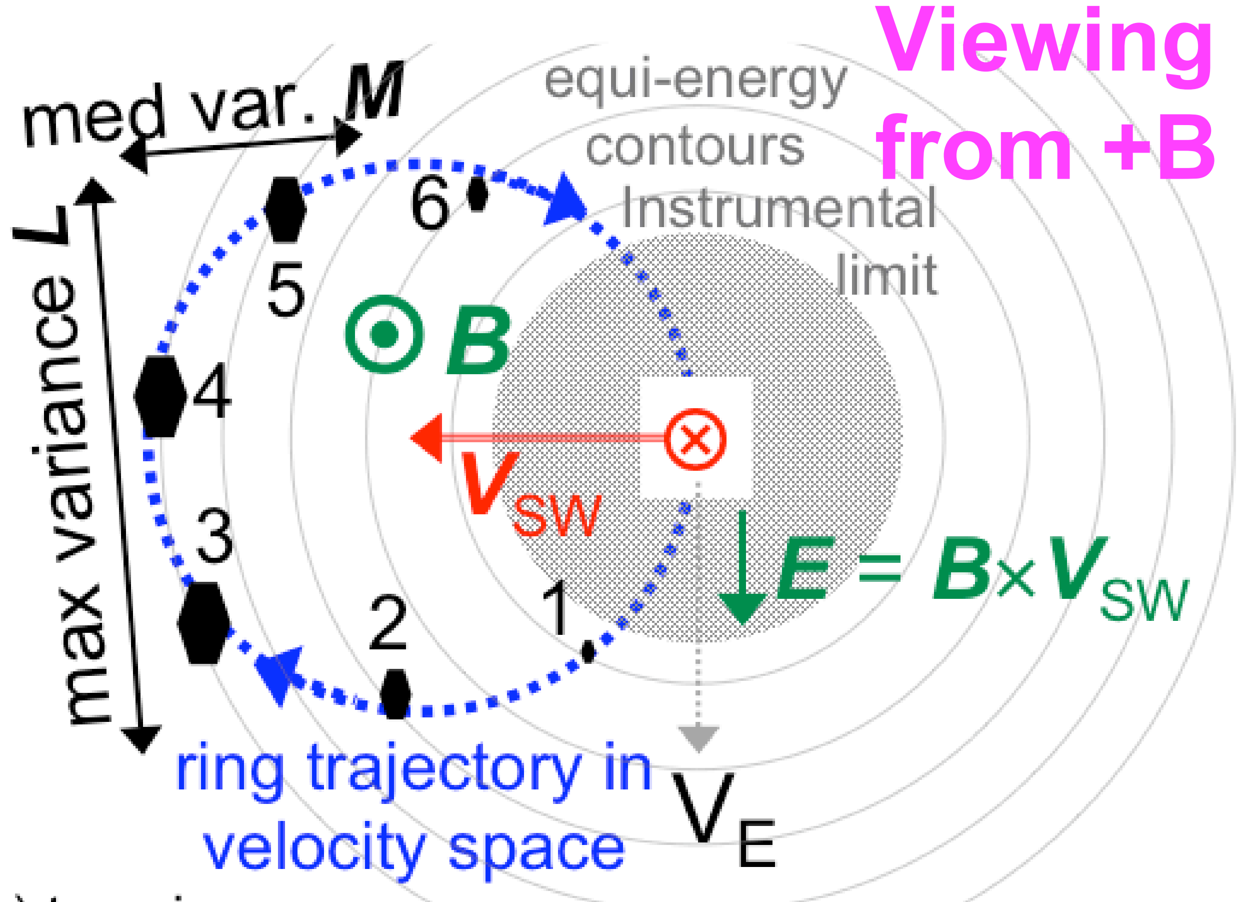
Ion motion with V_0=0



V (SW frame) = ***V**** (Martian frame) + $\boldsymbol{V}_{SW}$

Ions with **V_0=0** in **Martian frame** have an initial velocity -$\boldsymbol{V}_{SW}$ in **SW rest frame** where **E** (electric field) **=0**. Ions in **SW rest frame** make simple spiral trajectory (simple gyration + constant parallel velocity), i.e, **a simple ring** in velocity space as indicated by **blue dashed lines**.

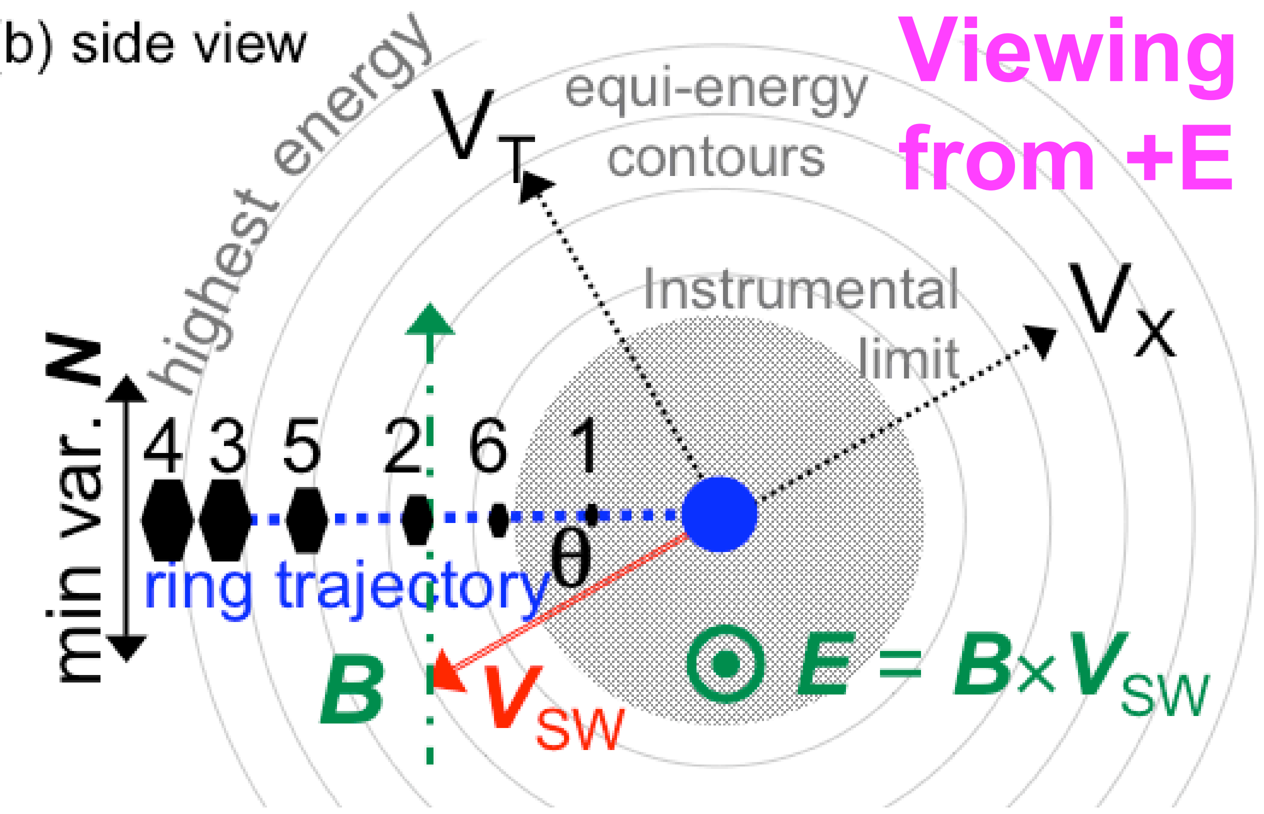
Ring = within a plane ⇒ the minimum variance direction (*N*) is parallel to B!



(a) top view

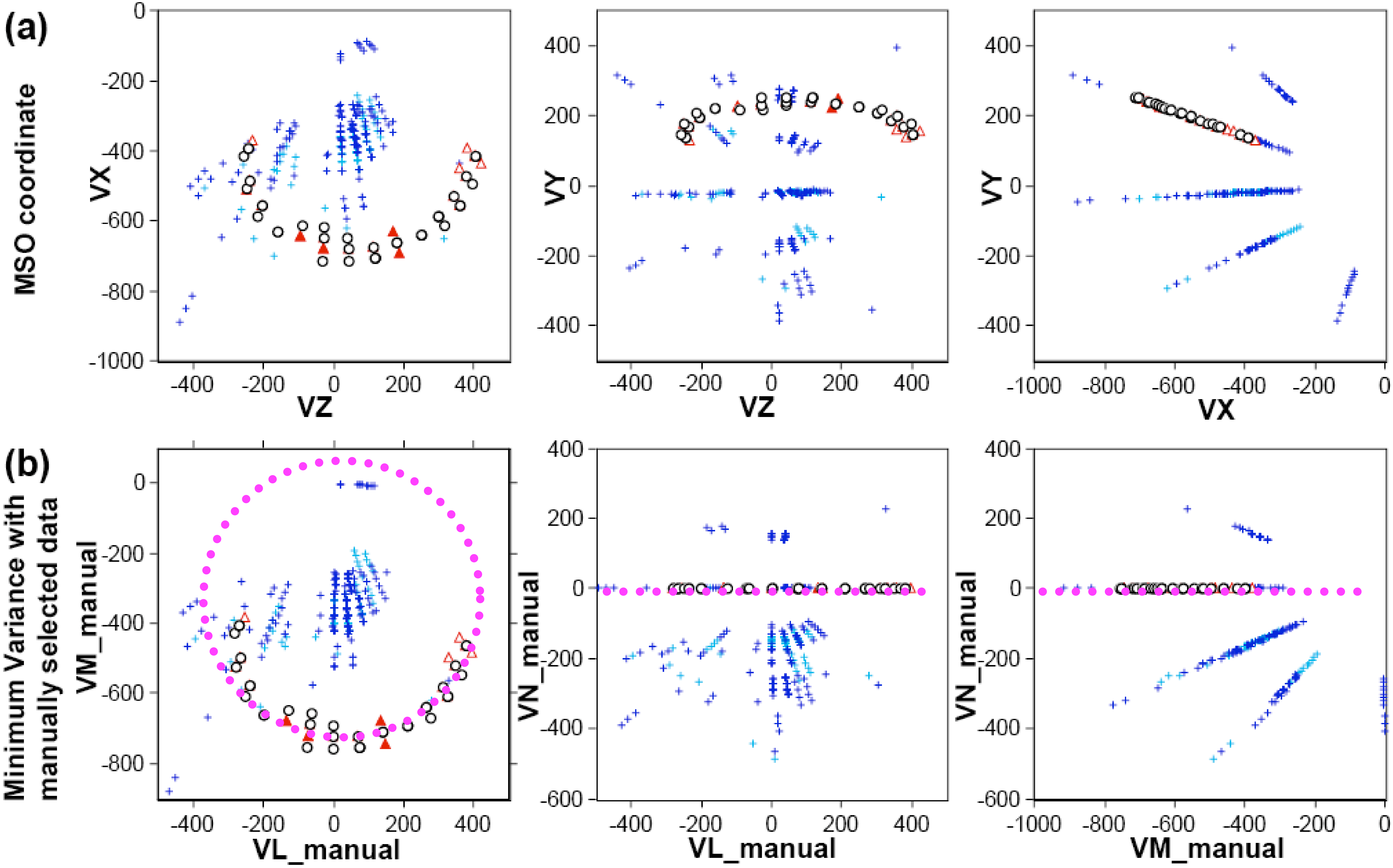
Initial ⊥ velocity to B is $V_0\cos\theta$

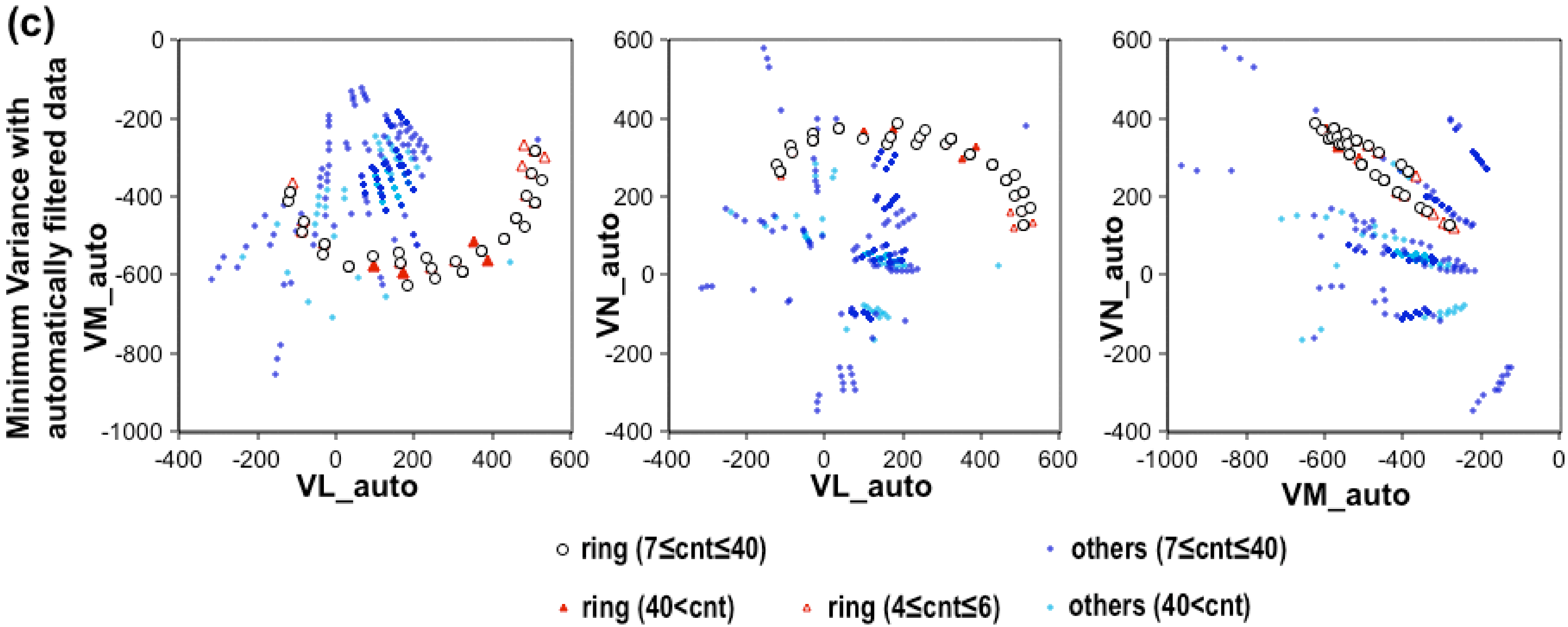
(b) side view



Velocity space plots of the data

2005-4-27, 1334-1357 UT





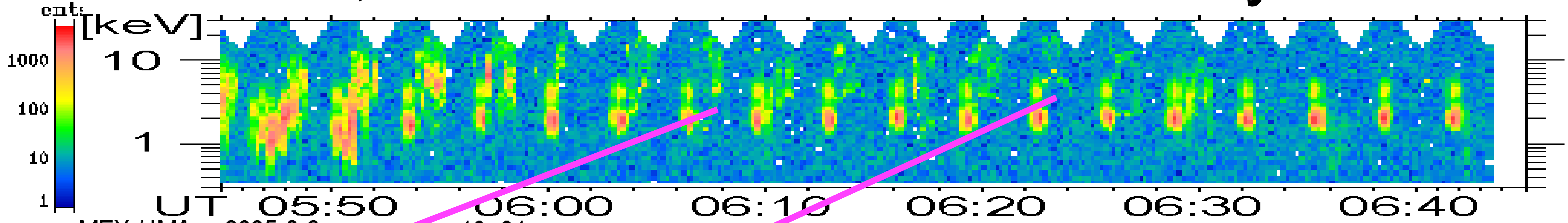
Velocity (in km/s) scatter plots of the H+ data (mass range 0.5-1.1: slightly contaminated by SW He++) during 1334-1357 UT, 27 April 2005, in (a) MSO coordinates, and maximum(L)-medium(M)-minimum(L) variance coordinates determined from (b) manually selected ring data, and (c) automatically filtered data during 1337-1357 UT. Azimuth=0 data are not shown (total 450 points).

The **circles** and **triangles** denote the points belonging to the **ring distribution** by a manual inspection, with **circles** corresponding to 7-40 counts, **filled triangles** corresponding to more than 40 counts, and **empty triangles** corresponding to 4-6 counts.

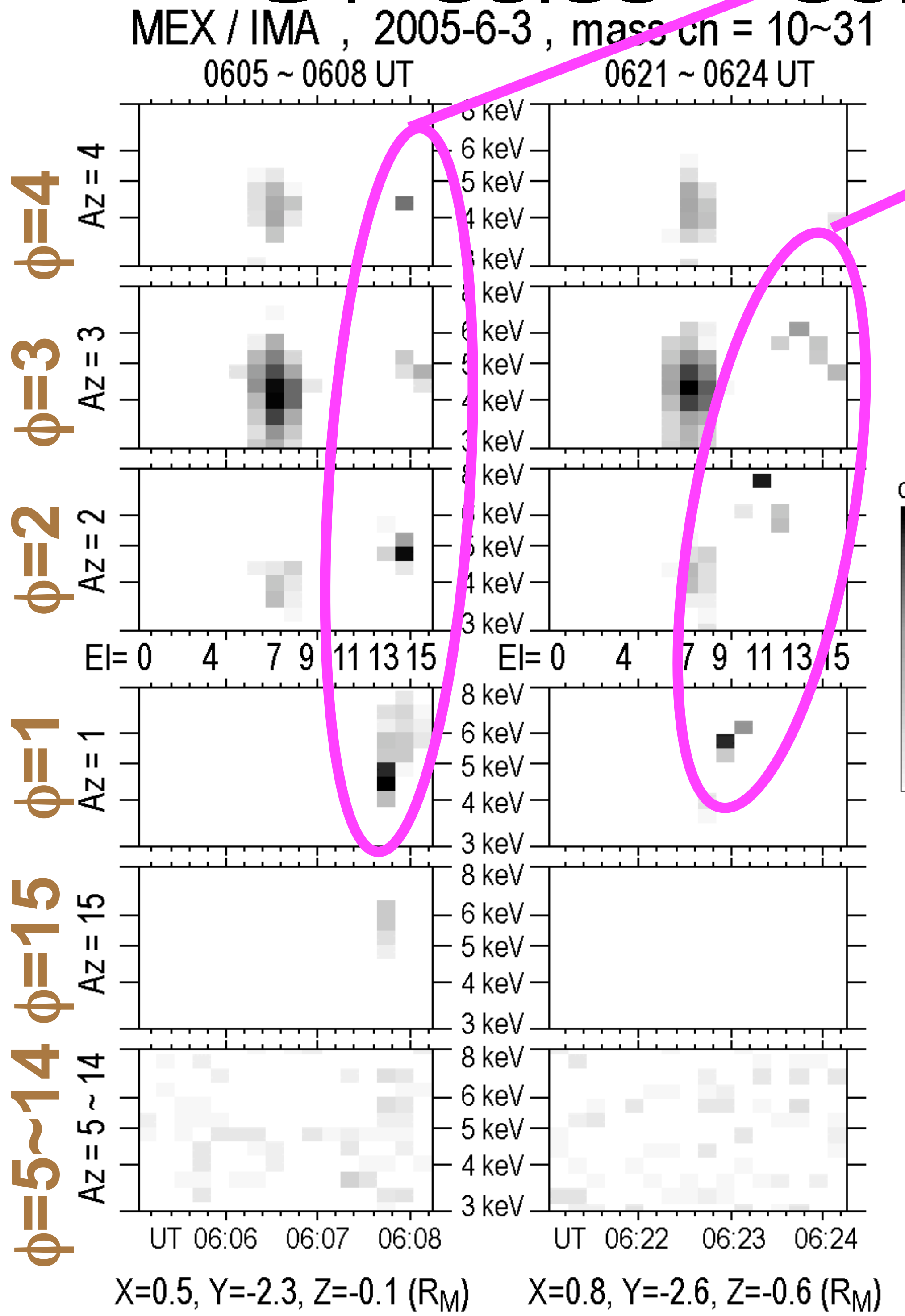
Non-ring data are shown using **plus** marks (**blue**: count is 7-40, **light blue**: count more than 40).

Coordinates given (b) arranges the ring data fitting to a circle best passing through the origin.

However, IMA orientation is not always ideal



IMA all-mass & all-azimuth data on **2005-6-3 , 0545-0645 UT**



Aligned in the azimuthal direction (points **2, 3, 4, 5** in the ion-motion illustration)

⇓

Linear alignment (small data range in **M** direction)

⇓

Minimum variance method gives clear L direction (// ±E), but not M & N directions.

⇓

We may not use **±N** as estimate of **B** direction, but

(1) E x V_{SW} gives B_Y/B_Z orientation !

(2) B_X/B (or θ) can be obtained intuitively

IMA light ion (H+ and He++) data (3~8 keV) for each azimuth at ~0608 UT & ~0623 UT

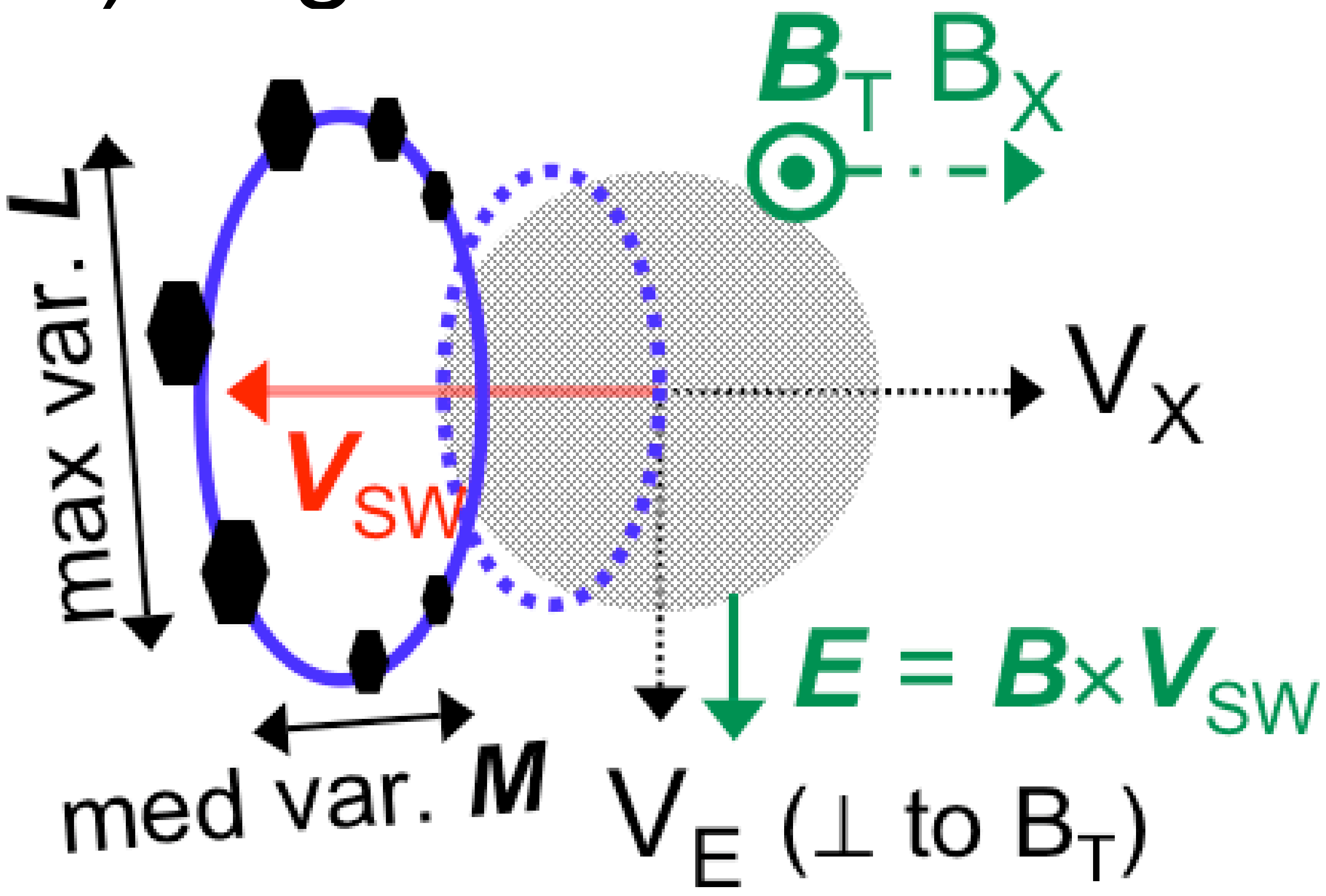
cf. beam-origin ($\mathbf{V}_0 \neq 0$) ring distribution case

Alignment direction of the ring data by IMA

≈ Maximum variance direction (L_X, L_Y, L_Z)

where $\mathbf{L_X << 1}$

⇒ $\boldsymbol{B}_T$=(0, B_Y, B_Z) // $\boldsymbol{V}_{SW}$ **x** $\boldsymbol{E}$ // (0, L_Z, -L_Y)



Sign of *B*

If ***L*** = evolution direction, sign(B_Z) = - sign(L_Y)

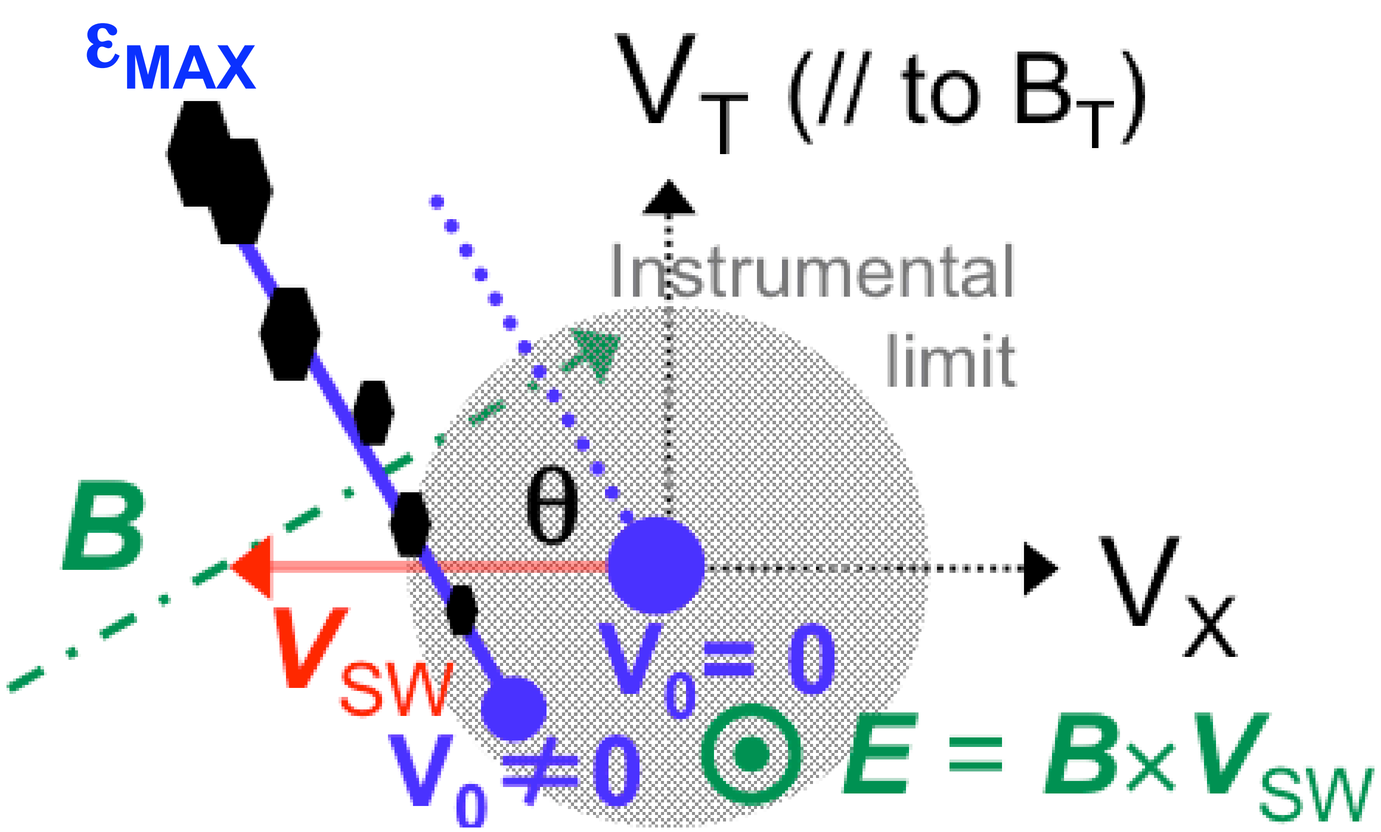
Tilt toward X (=θ)

* θ' = angle between max energy (ε_{MAX}) direction and solar wind direction
* Ratio **k** = V_{MAX}/V_{SW}= $(\varepsilon_{MAX}/\varepsilon_{SW})^{1/2}$

If V_0 = 0, two angles must be the same,

i.e., θ' = θ , and k = cos(θ)

⇒ **If cos(θ') = k , most likely θ = θ'**



Procedure & result

(1) Manually select the ring distribution.
(2) Apply the minimum variance method to determine **L**, **M**, and **N**.
If the ring data is well arranged into a partial circle, ±**N** // ***B***

If not,
(3) Examine $|L_X| < 0.3$. If yes, **L** // **-E**$_{SW}$.
If not, remove the direction that corresponds to the lowest energy from the selected set of data and re-calculate a new **L**.
(4) Manually obtain ε_{MAX} and θ'.
(5) Check if $\varepsilon_{MAX} / 4\varepsilon_{SW} \approx \cos^2(\theta')$ is satisfied.
If yes, we have $\theta \approx \theta'$, where $B_X/|B| = \sin(\theta)$.

(6) If possible, identify the evolution direction and determine the sign of **L** and **E**$_{SW}$. **B**$_T$ is parallel to **V**$_{SW}$ **x** **E**$_{SW}$.

Using (1)~(2) ⇒ Constant IMF for 2005-4-27 event

1336-1357 UT, **dawn-dusk oriented IMF, with X tilt ~ 20°**

Using (3)~(6) ⇒ Changing IMF for 2005-6-3 event

0608 UT, **northward IMF, X tilt ~ +35°~40°, Y tilt ~ -10°**

0613 UT, **northward IMF, X tilt ~ +35°, Y tilt ~ -45°**

0623 UT, **northward IMF, X tilt ~ +20°, Y tilt ~ -30°**

0633 UT, **X tilt > +40°**