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

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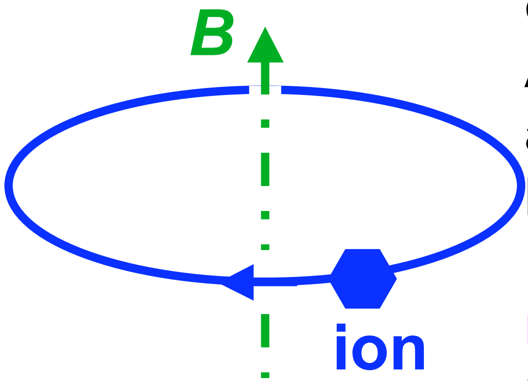
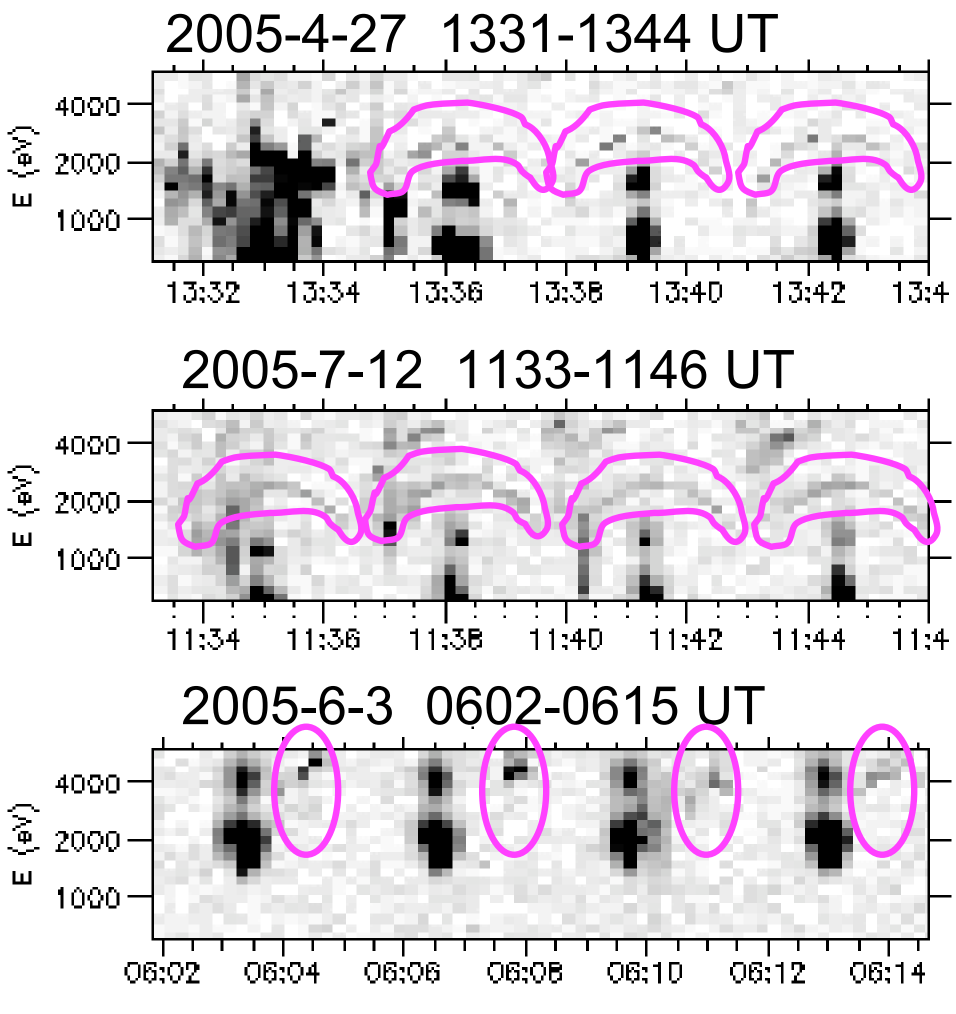
# Motivation

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 :

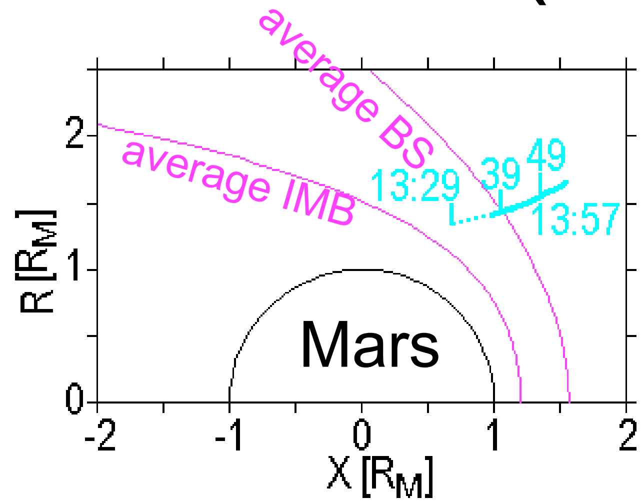



**Analyze gyromotion of ions observed by ASPERA-3 ion mass analyser (IMA) because ion motion in velocity space is a ring!** (spiral motion in real space)

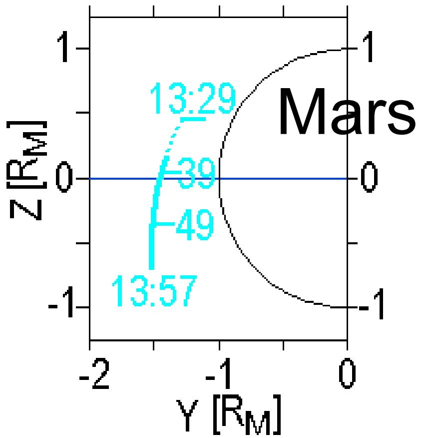
**Actually, the ring distribution is the "clearest signature" among many interesting phenomena seen in IMA Quick Look (mass and azimuth are integrated)**

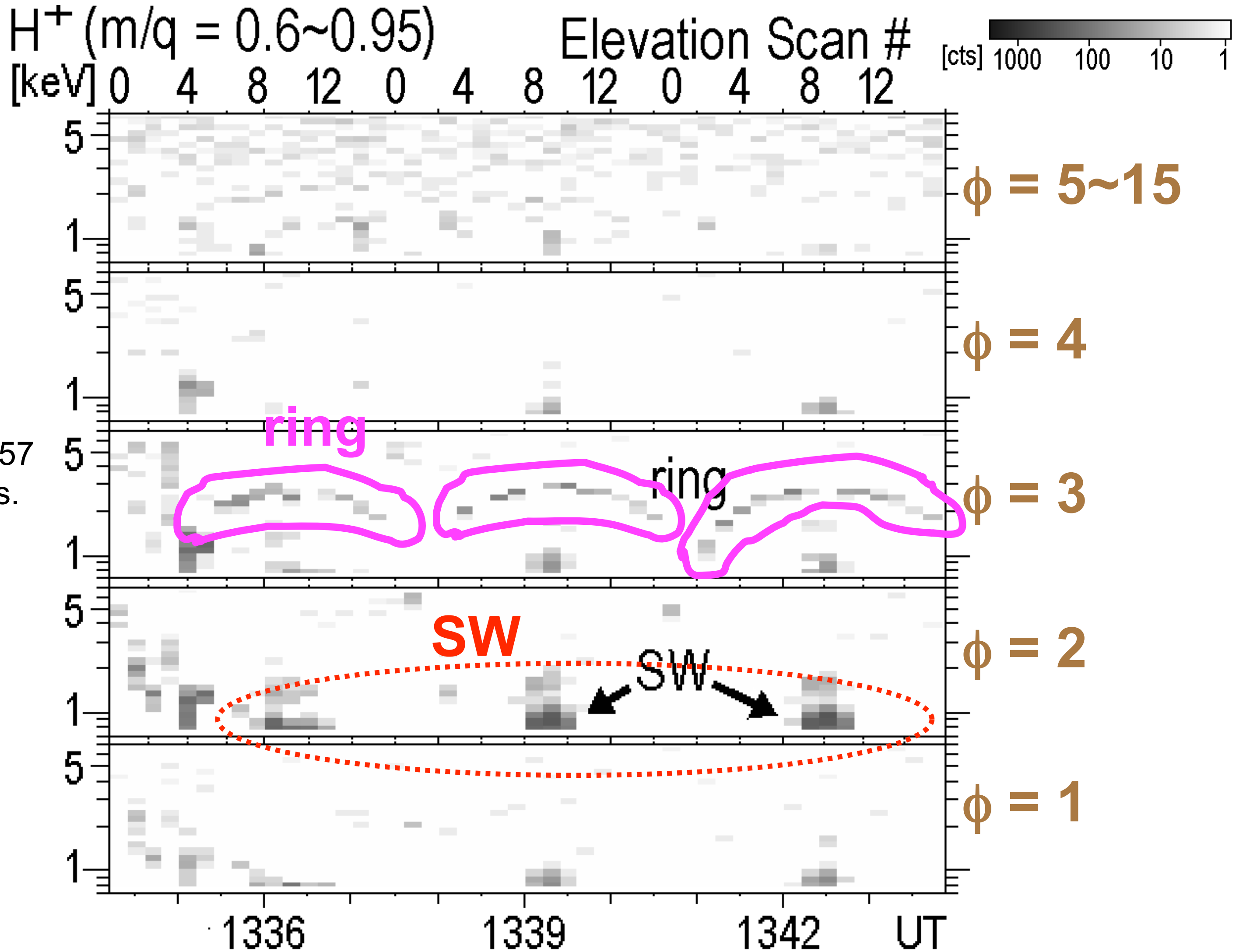


# 2005-4-27 (easy case) single azimuth plots



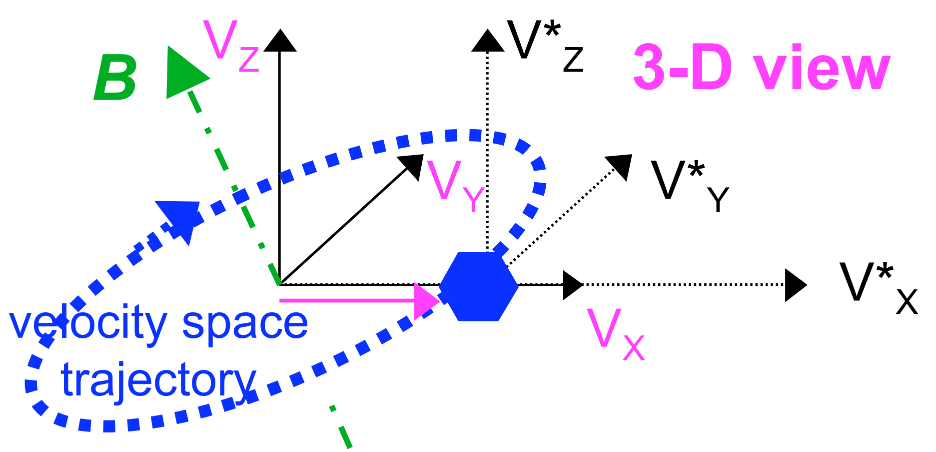

MEX orbit (light blue) during 1329-1357 UT in the cylindrical MSO coordinates. $R^2 = Y^2+Z^2$.



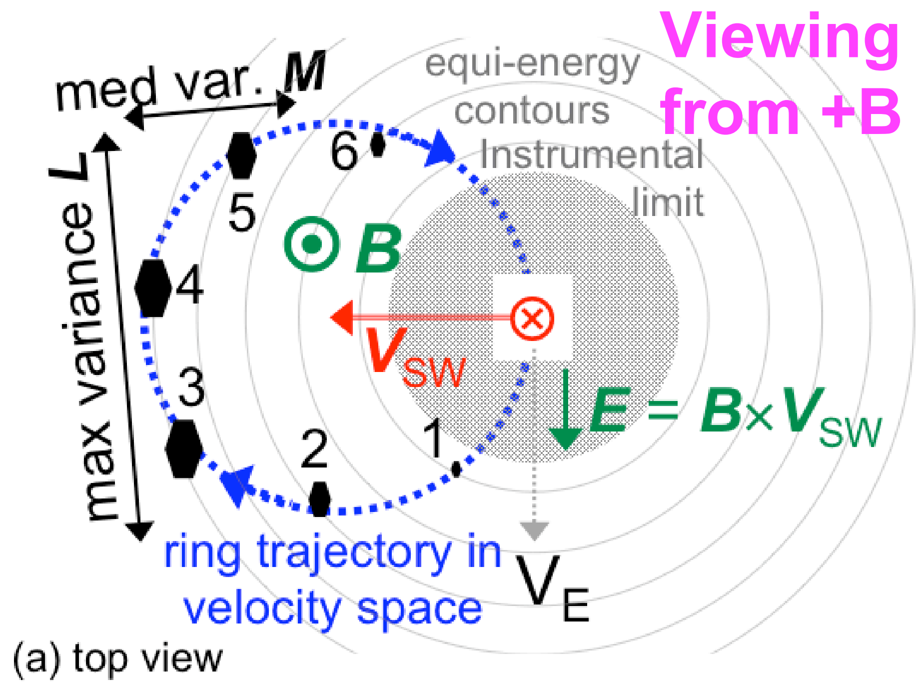




IMA energy-time spectrograms for proton cannel at 0.7-7 keV during 1334:00-1343:40 UT on 27 April 2005. Five different azimuthal sectors ( $\phi$ ) are presented except sector 0. The nearly 3-min cycle seen in the IMA data is due to the electric scan of the entrance direction from nearly -45° (elevation=0) 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

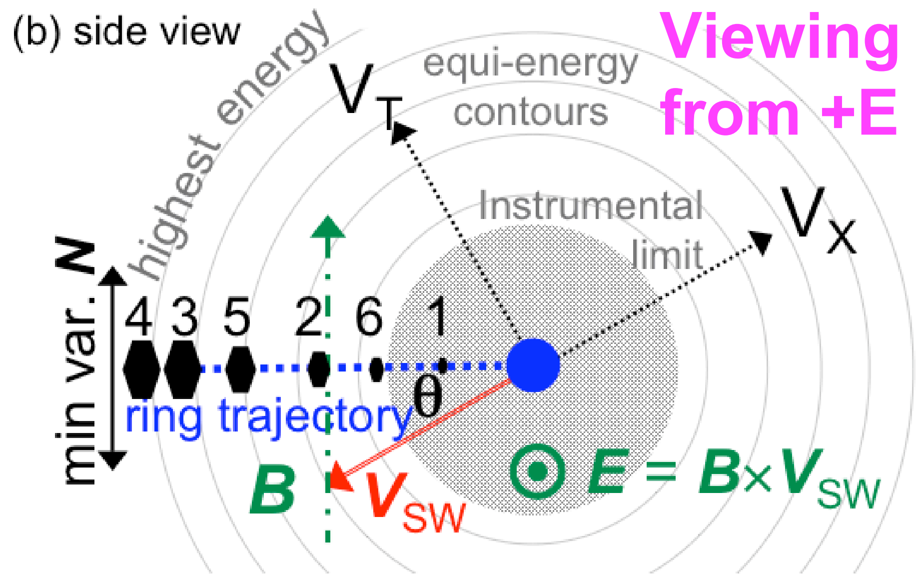



$\boldsymbol{V}$ (SW frame) = $\boldsymbol{V}^*$ (Martian frame) + $\boldsymbol{V}_{SW}$




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**.

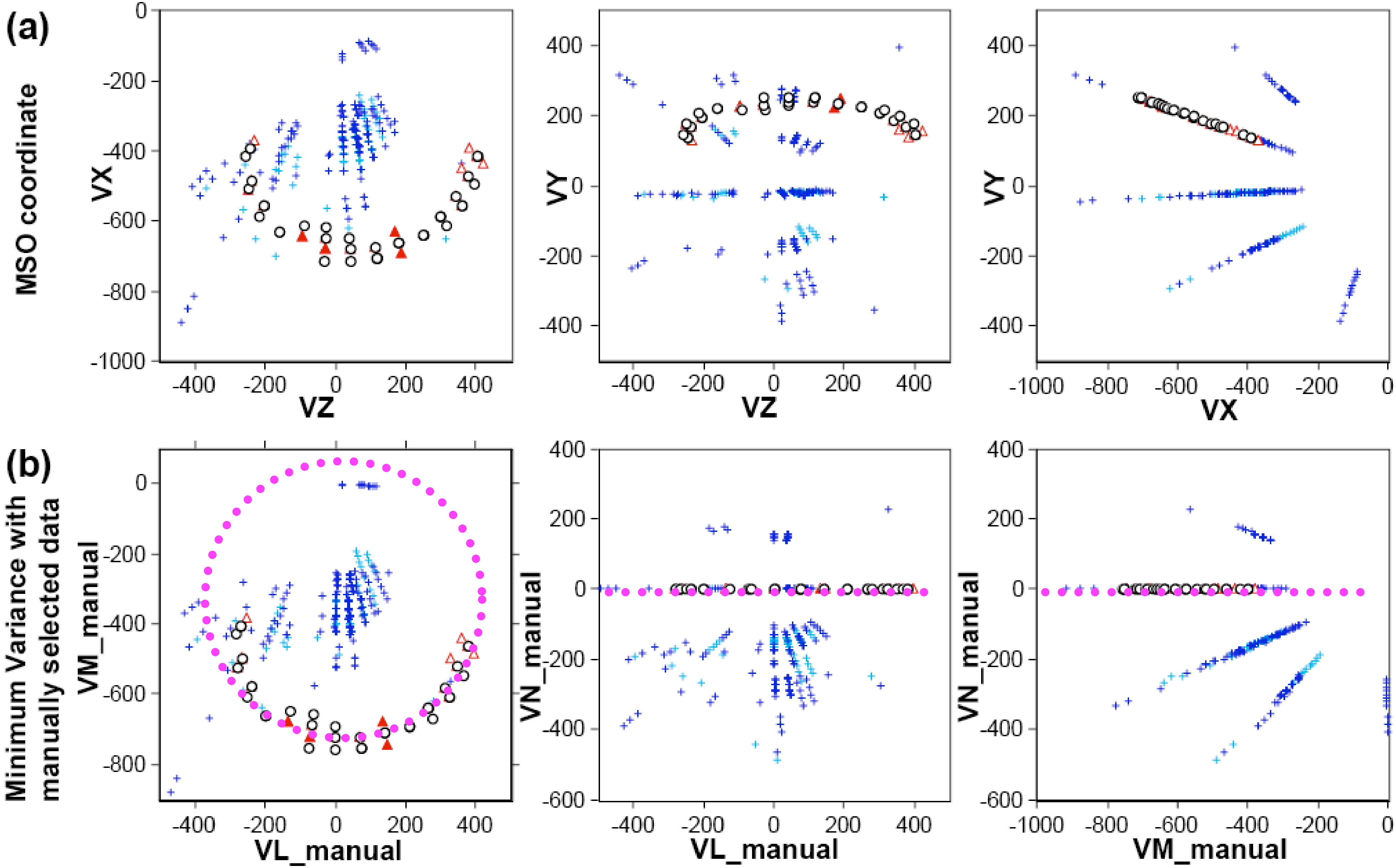
**Initial ⊥ velocity to B is $V_0\cos\theta$**

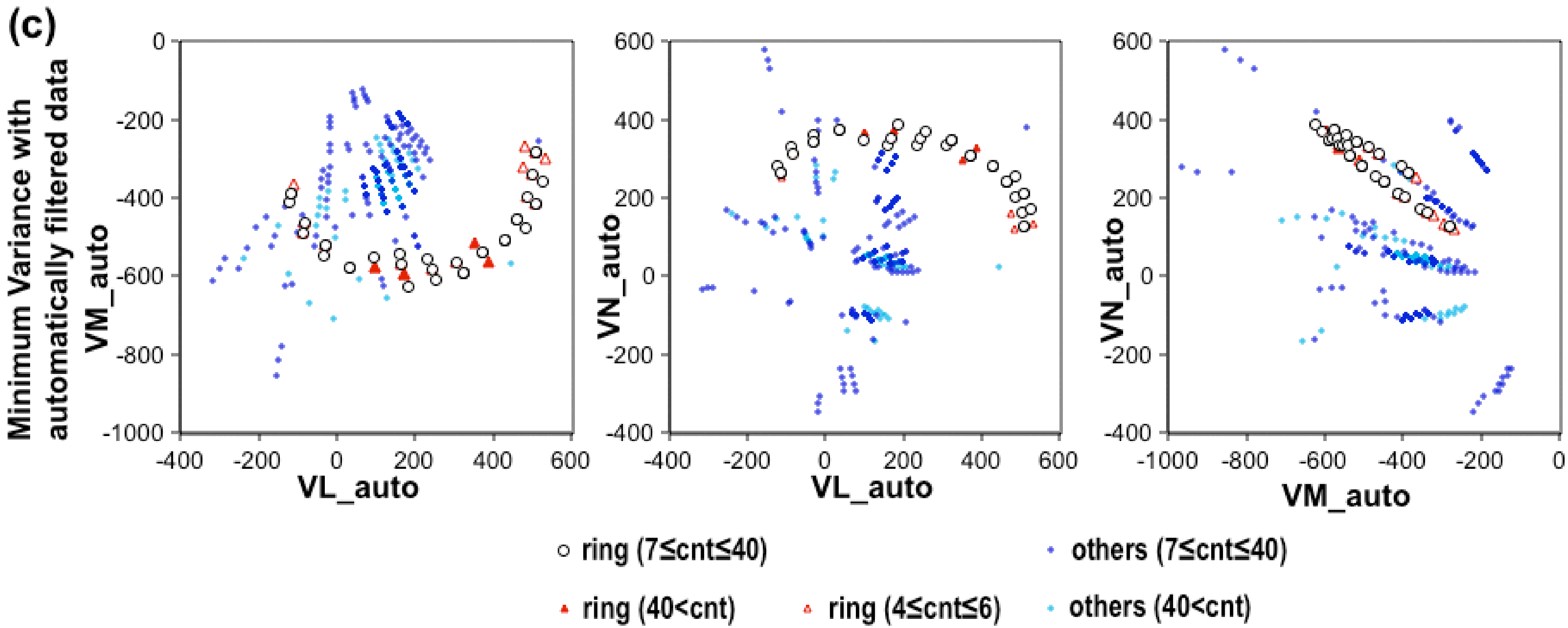



**Ring = within a plane ⇒ the minimum variance direction (*N*) is parallel to B!**

# Velocity space plots of the data

2005-4-27, 1334-1357 UT





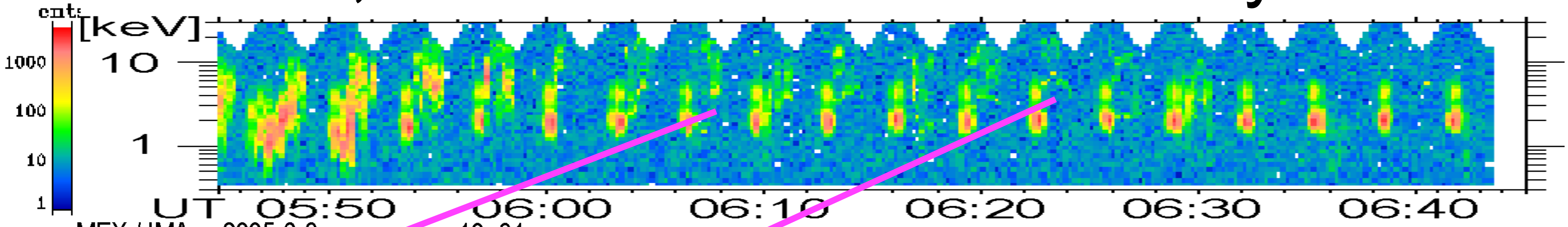

Velocity (in km/s) scatter plots of the H+ data (mass range 0.5-1.1: slightly contaminated by SW He++) during 1334-1357 UT, 27 April 2005, in (a) MSO coordinates, and maximum(L)-medium(M)-minimum(L) variance coordinates determined from (b) manually selected ring data, and (c) automatically filtered data 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.

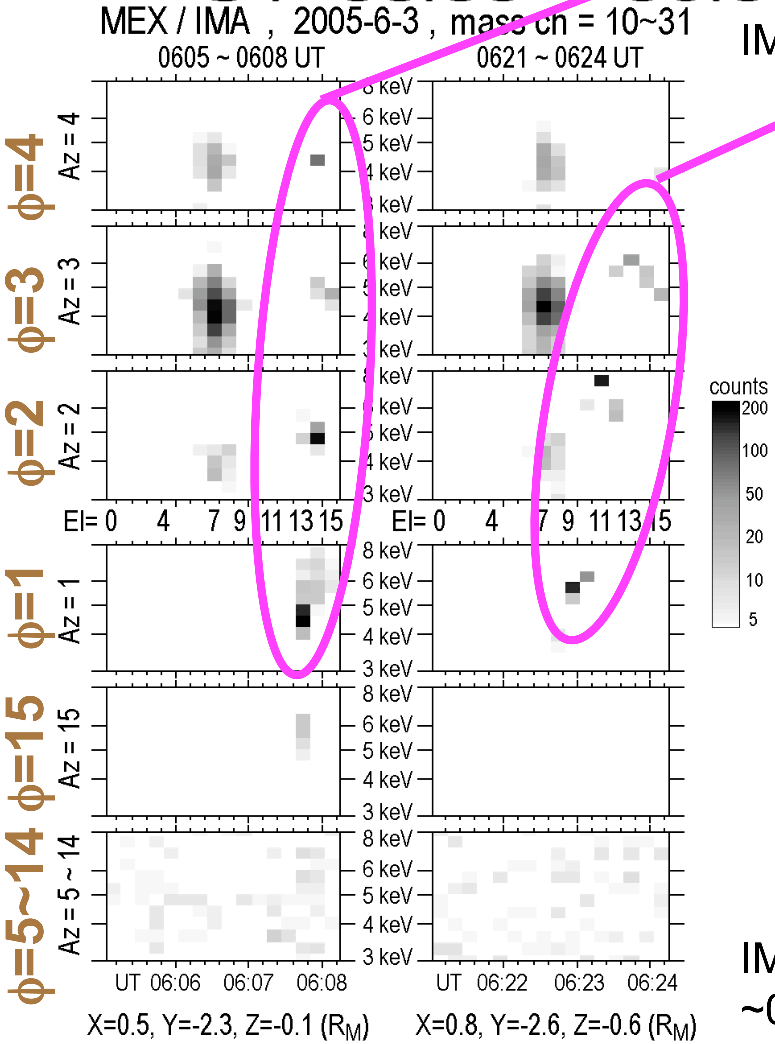
Non-ring data are shown using **plus** marks (**blue**: count is 7-40, **light blue**: count more than 40).

**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**




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

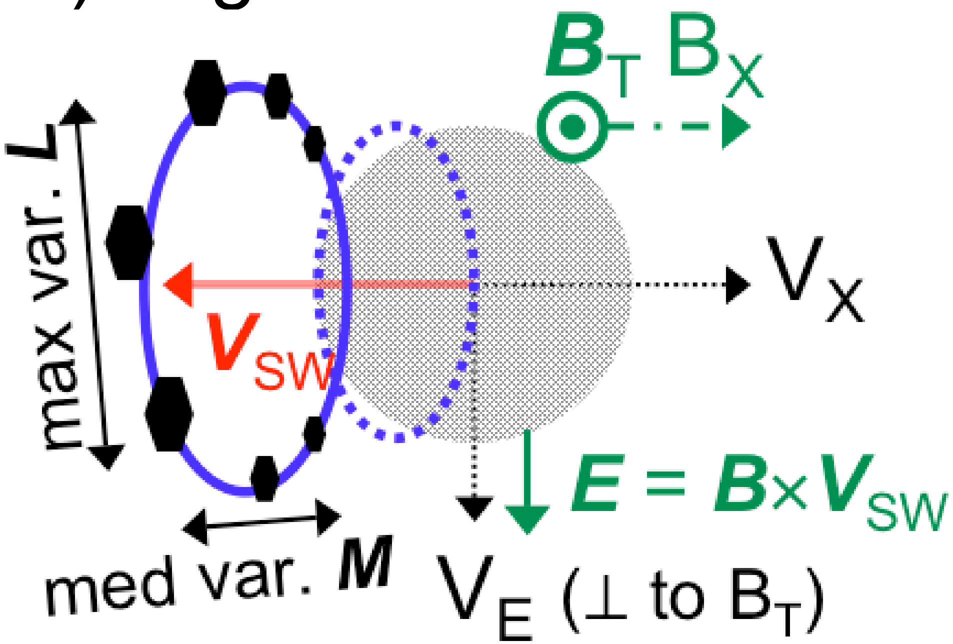
# cf. beam-origin ($\mathbf{V}_0 \neq 0$) ring distribution case

**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)**

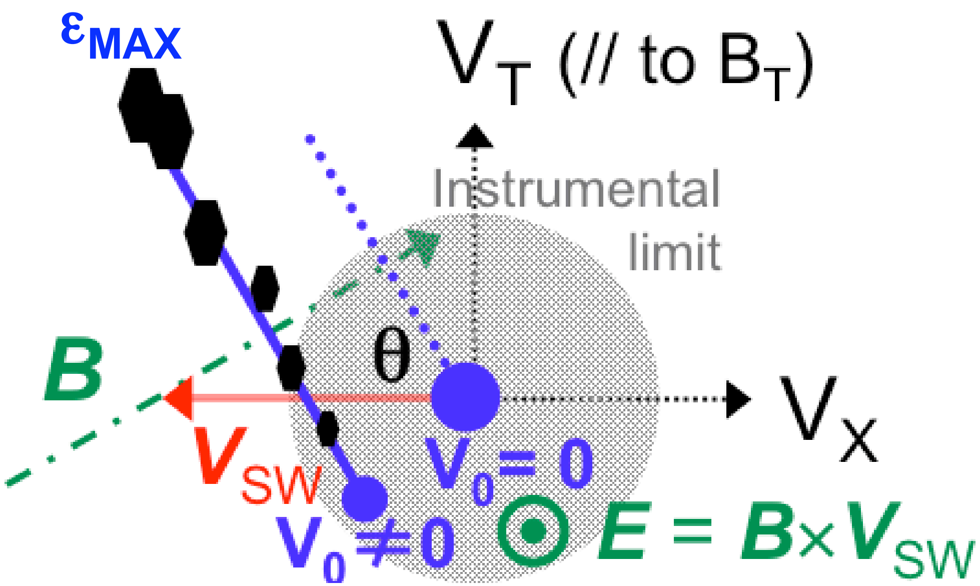
* **θ'** = angle between max energy ($\boldsymbol{\varepsilon}_{MAX}$) direction and solar wind direction

* Ratio **k** = $V_{MAX}/V_{SW}$= $(\boldsymbol{\varepsilon}_{MAX}/\boldsymbol{\varepsilon}_{SW})^{1/2}$

**If $\mathbf{V_0 = 0}$, 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 $\varepsilon_{MAX}$ and $\theta'$.
**(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°**