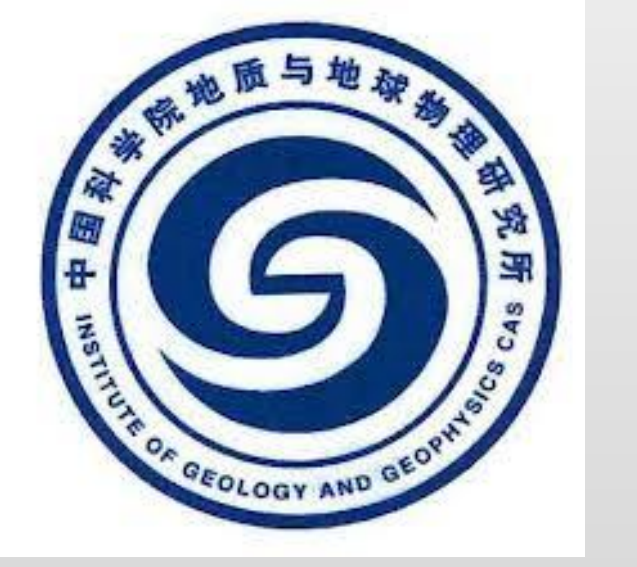


# An induced global magnetic field looping around the magnetotail of Venus

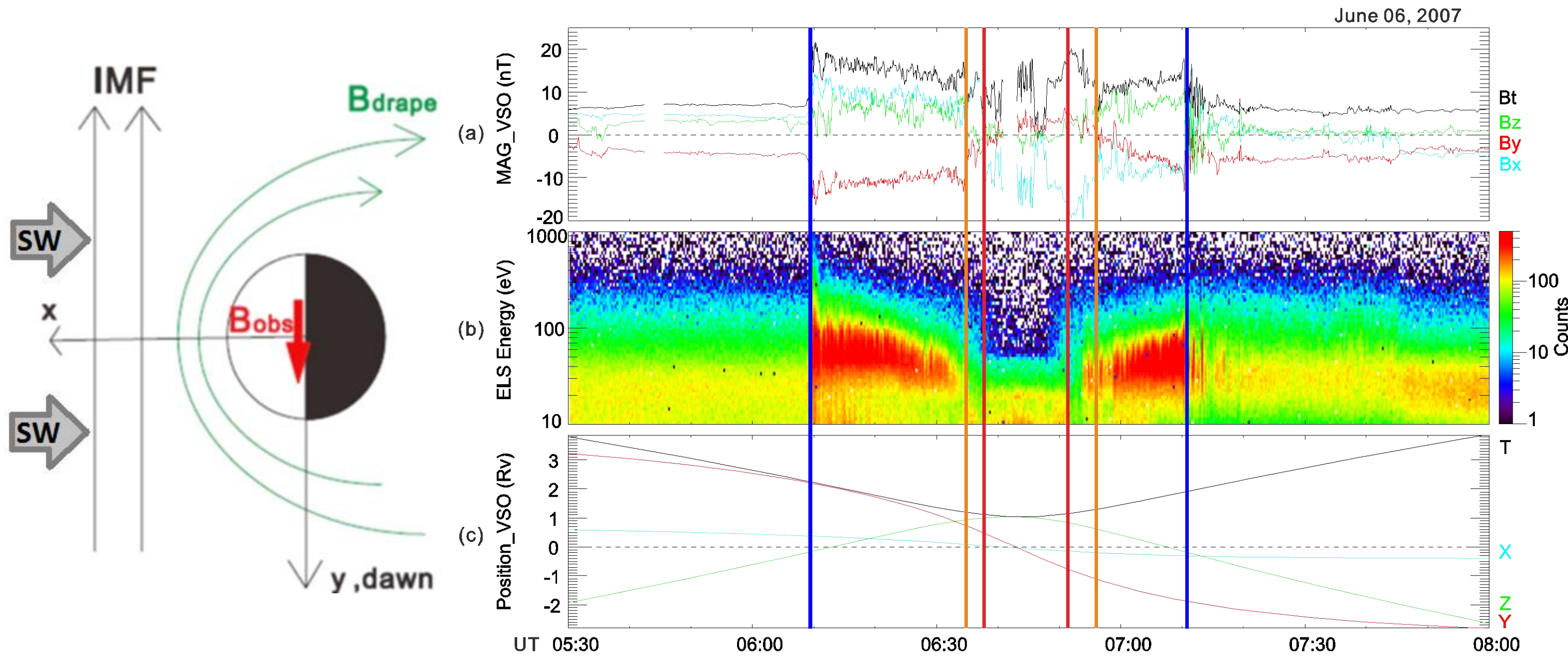


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Venus serves as the prototype of solar wind interaction with unmagnetized planetary bodies with atmospheres. It has no intrinsic dipole or crustal magnetic field; the only magnetic field is believed to be formed by the draped interplanetary magnetic field (IMF). However, the large-scale magnetic field observed over the north polar region of Venus has a bias in the dawnward direction and seemingly unresponsive to the IMF's direction. Here we show that besides the draped field, there is a second type of induced global magnetic field at Venus and the dawnward field is only a part of it. This global field has a distribution in a cylindrical shell around the magnetotail and a counterclockwise direction looking from the planetary tail toward the Sun, which demonstrates that there are two currents flowing out and in of the planet along the inner and outer boundaries of the looping field, respectively. [JGR, 2016, doi:10.1002/2015JA021904]

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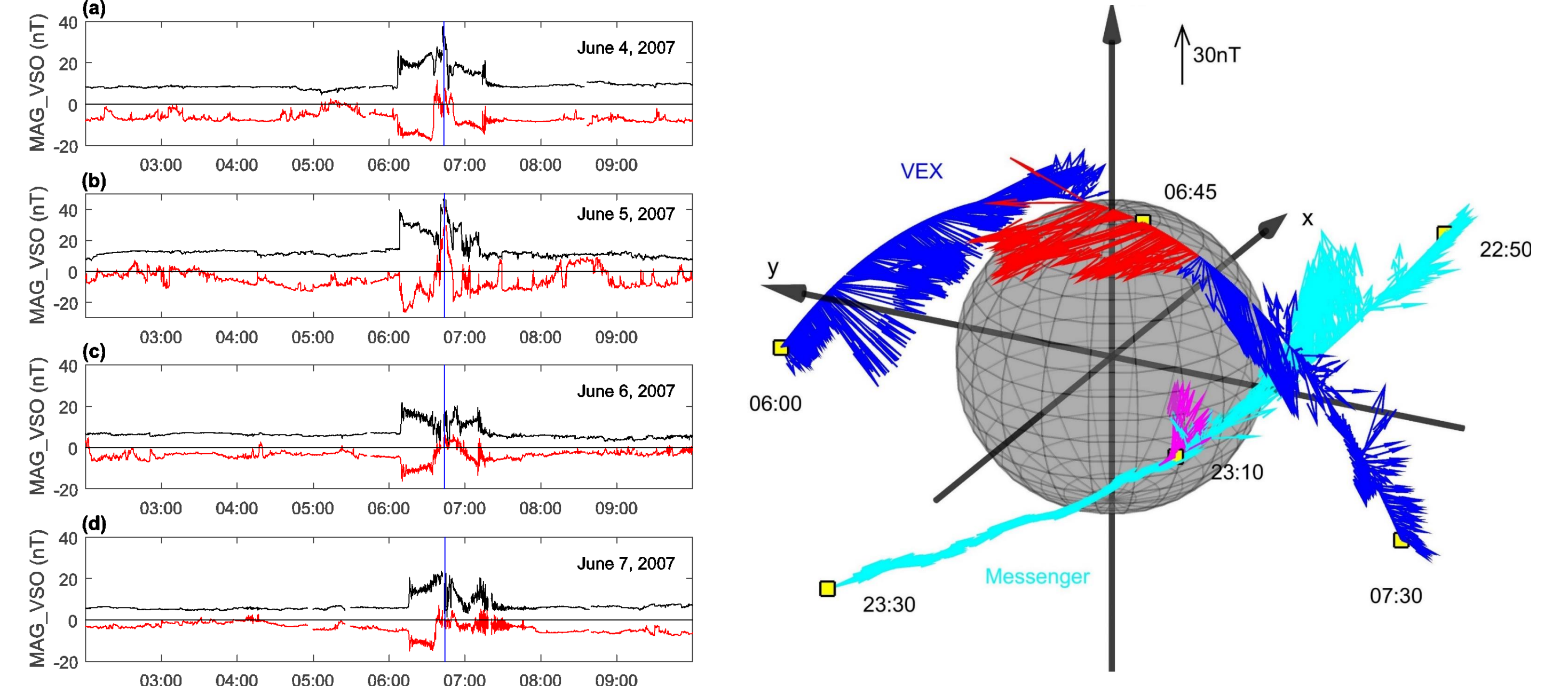
## large-scale downward magnetic field over north pole



It has been well established that the draped IMFs (green curves in left figure) form the induced magnetosphere and magnetotail [Saunders and Russell, 1986]. However, after the launch of VEX, downward large-scale magnetic fields have been frequently observed over north polar region at its periapsis. The downward field seems unresponsive to the IMF's direction (red arrow in left figure, an observation example in right figure).

Are the mysterious large-scale downward fields local phenomena?

## large-scale northward magnetic field over dusk equator

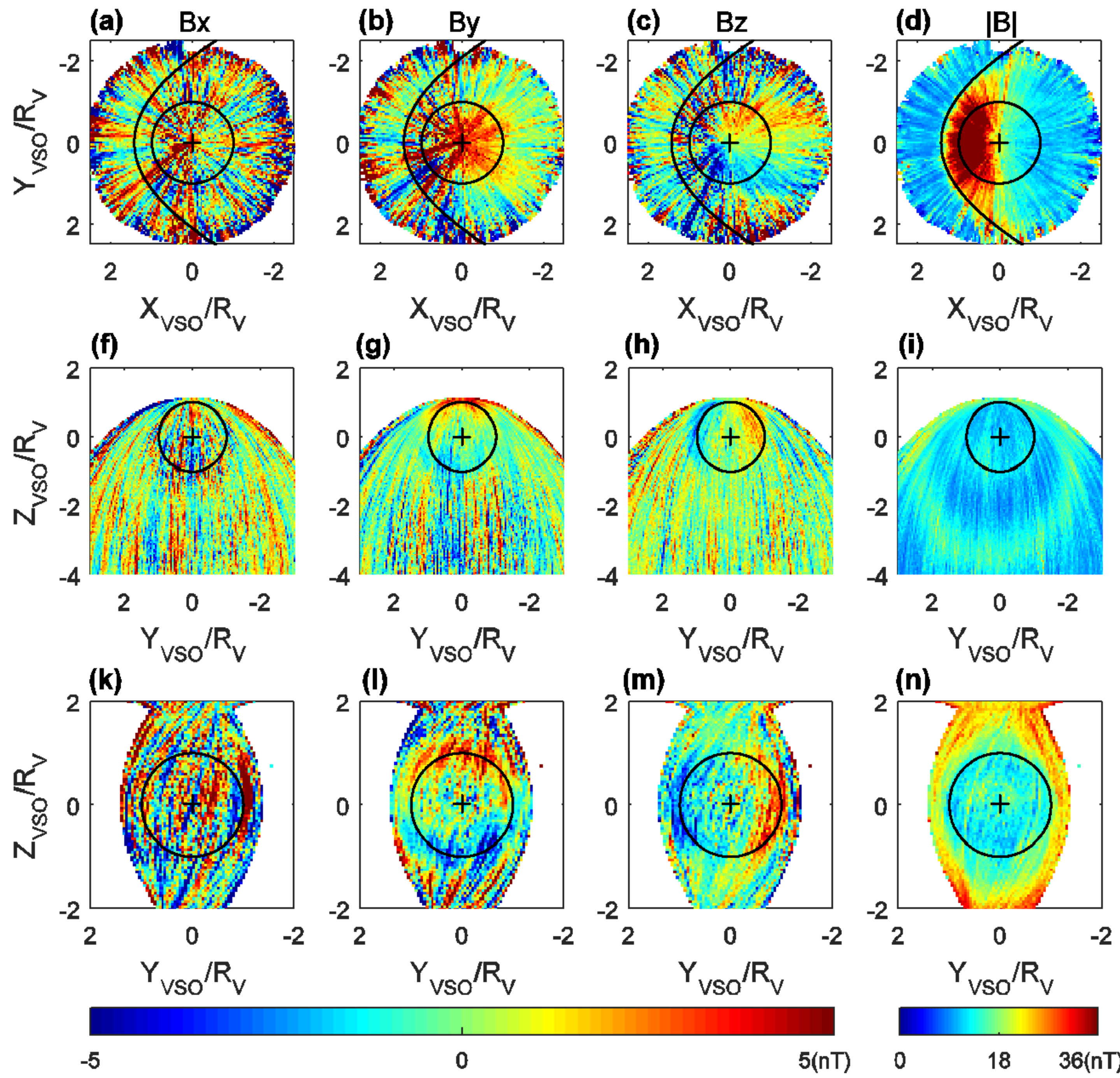


The downward fields are observed by VEX consecutively from 4 to 7 June (left figure). In the middle of this time period, Messenger flew by Venus over dusk equator and observed a large-scale northward field there (right figure). It is very likely that the downward field over north pole (red arrows in right figure) and northward field over dusk equator (magenta arrows in right figure) exist simultaneously.

Thus the downward and northward large-scale fields are probably from a same global phenomena. Proof?

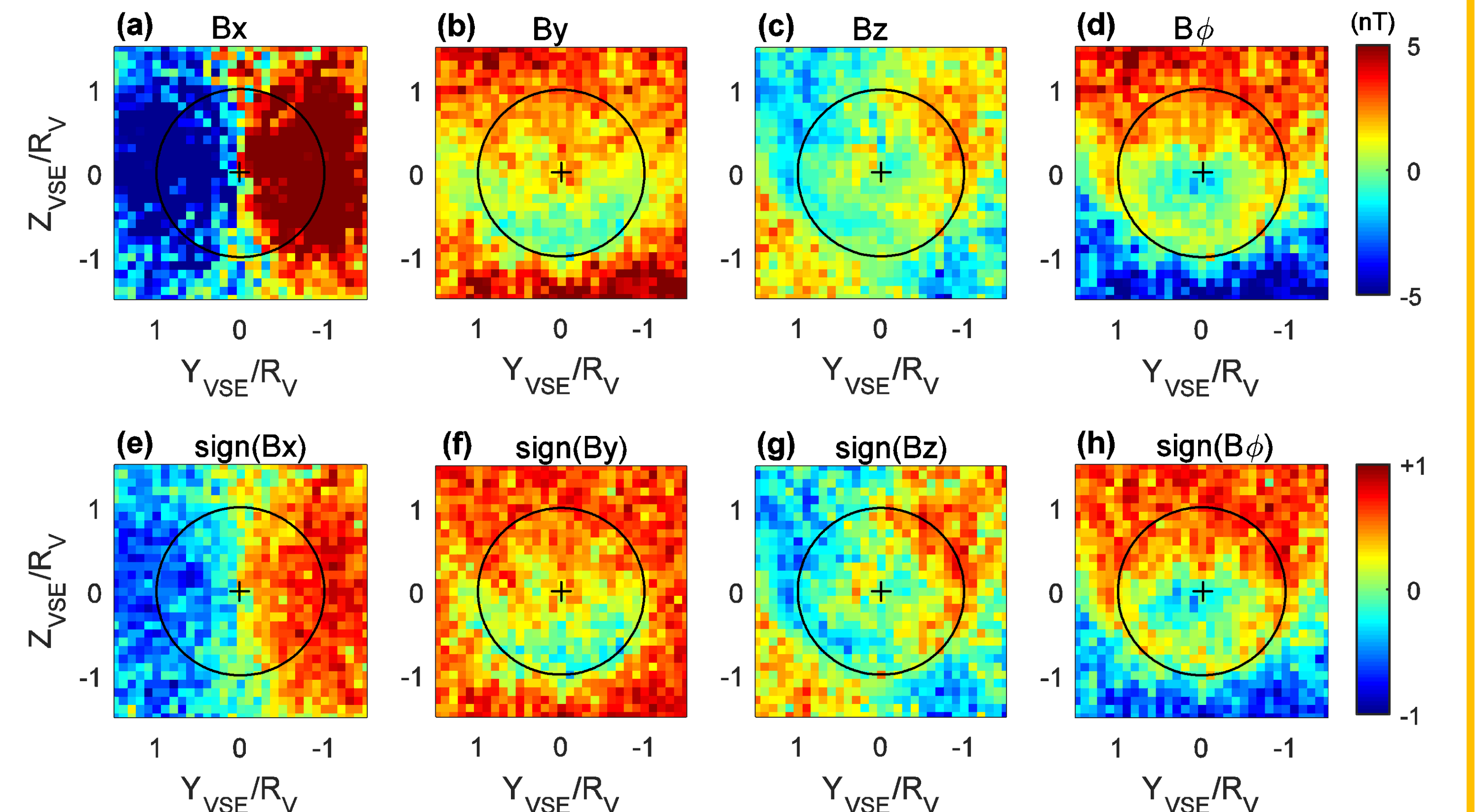
## Average magnetic fields around Venus

### Average magnetic field in VSO frame

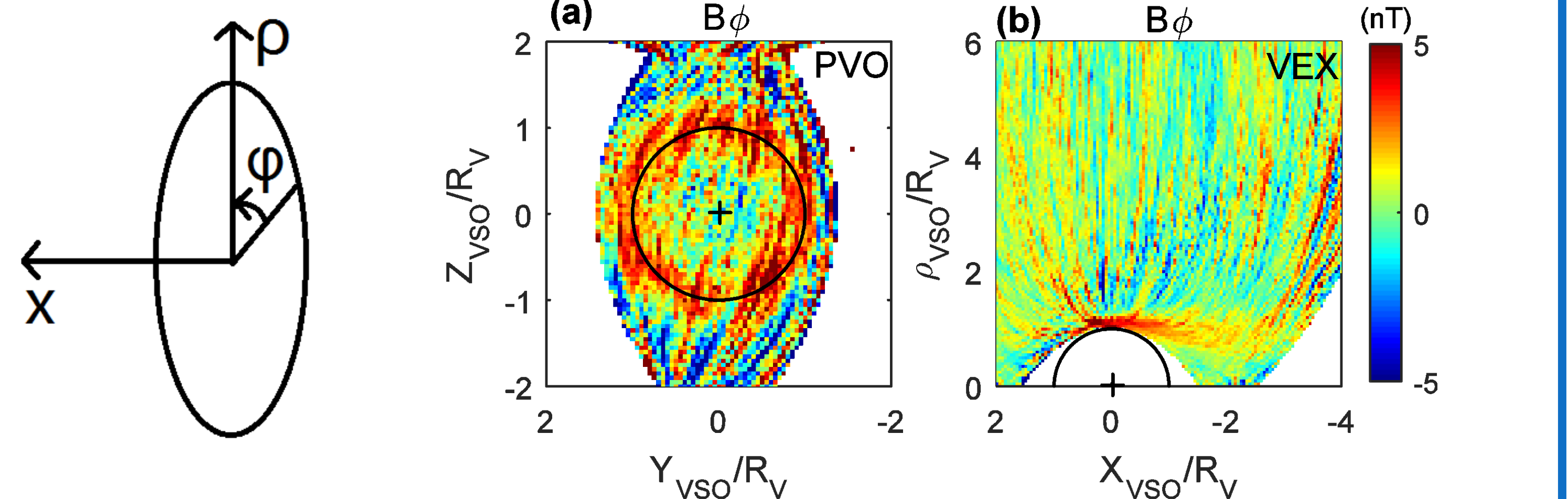


The average fields in the northern hemisphere observed by VEX (top) and on the nightside of Venus observed by VEX (middle) and PVO (bottom) are calculated by integrating the data along the +Z axis and the -X axis, respectively. Here the Venus-Solar-Orbiter (VSO) coordinates system is used, in which X points toward the Sun, Y is antiparallel to the planetary orbital motion, and Z points toward the north.

### Average magnetic field in VSE frame

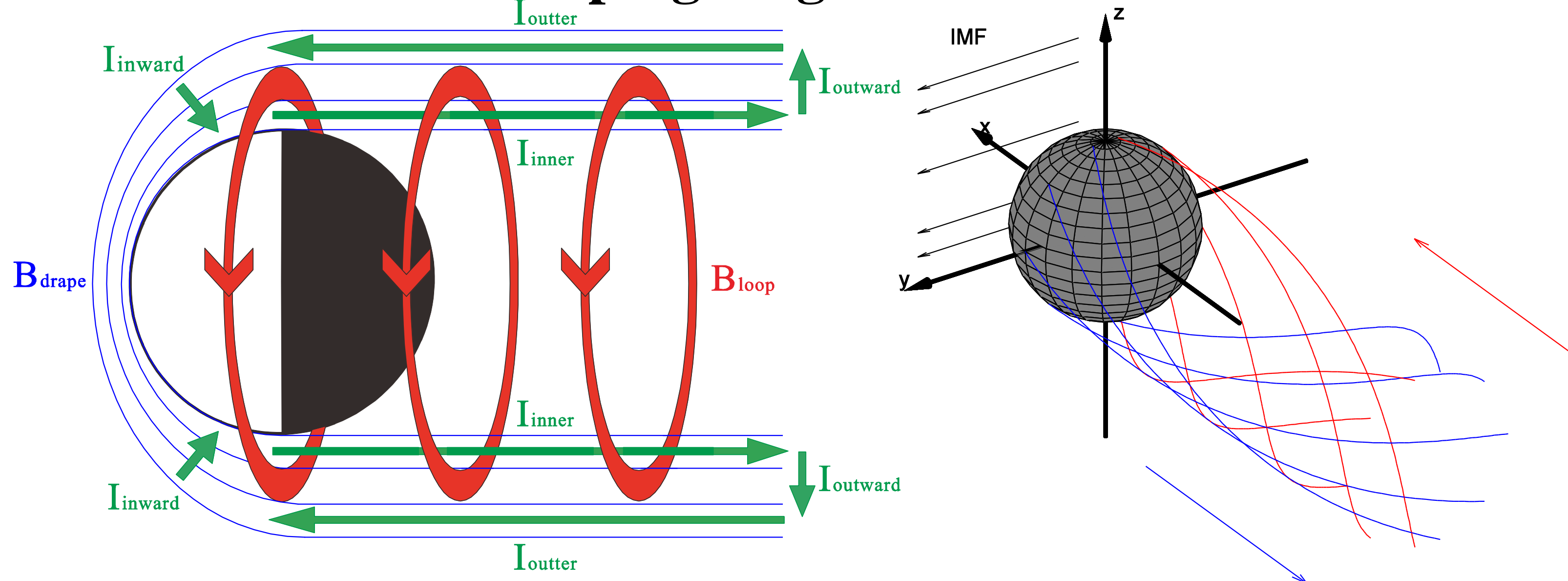


To study both the nightside looping and draped fields, the Venus-Solar-Electrical (VSE) coordinates system is used, in which X is antiparallel to the solar wind with a 5-degree aberration being removed, Y is parallel to the transverse IMF, and Z is parallel to the solar wind convection electrical field ( $E = -V_{SW} \times B_{IMF}$ ).



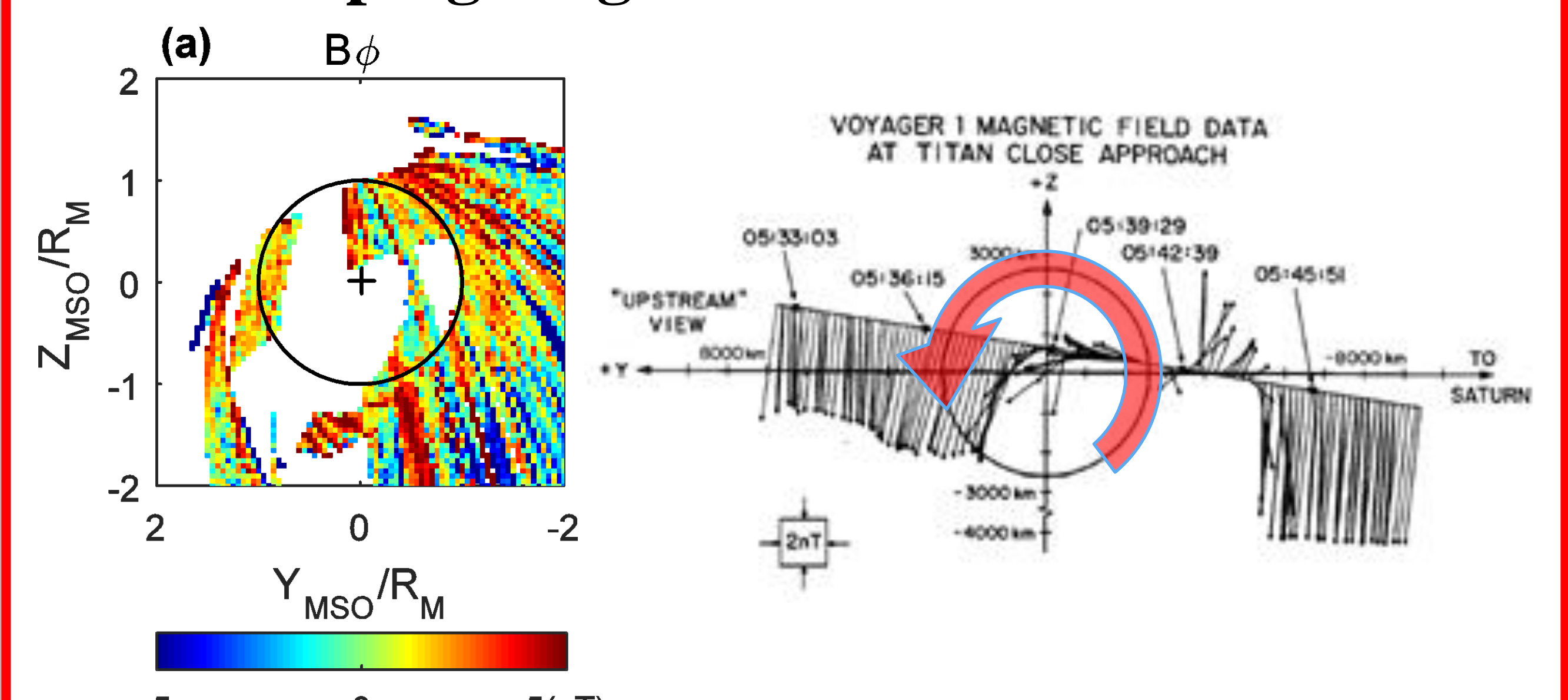
The looping magnetic field ( $B_\phi$ ) distributions observed by PVO in 1978-1988 and VEX in 2006-2014.

## Global looping magnetic field at Venus



Schematic illustration of the looping field (red cycles) and its current system (green arrows), and the magnetic field lines.

## Global looping magnetic fields at Mars and Titan



The looping field distribution observed around Mars by MGS in 1997-1998.

The magnetic fields observed near Titan by Voyager 1 [Ness *et al.* 1982, JGR].