VEX MAG

Upstream Proton Cyclotron Waves at Venus from Venus Express MAG

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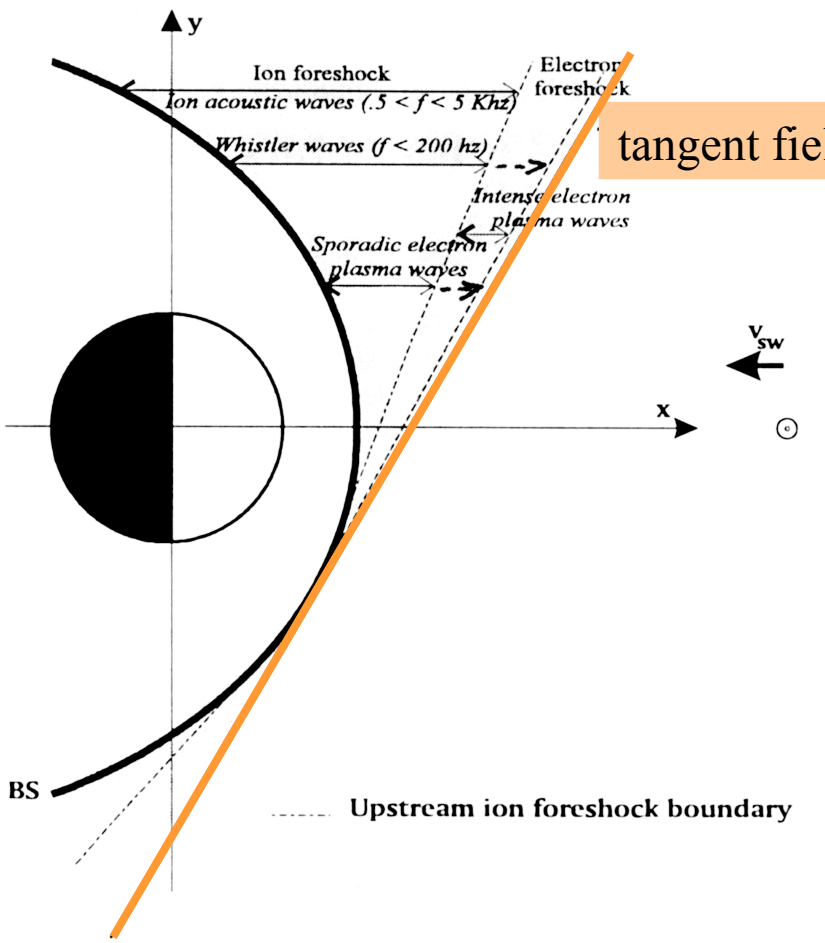
Outline

- What are upstream Proton Cyclotron Waves and why important? (PCW)
- Previous study: long term observations near Solar MIN by MAG
- PCWs implication for exospheric planetary hydrogen
- B field conditions and generation mechanisms
- PCW long term observations near Solar MAX by MAG
- Comparison Solar Min – Solar Max

Upstream Proton Cyclotron Waves



(from Greenstadt et al. 1995)

- **Proton Cyclotron Waves in UPSTREAM region: from pick-up planetary ions**

- **PCWaves with gyrofreq. Ω_i**

=> observed in SC frame at

(Brinca, 1991)

$$\omega_{sc} = n\,\Omega_i \qquad (n=1)$$

=> only for PLANETARY ions

- **Not a foreshock phenomenon, i.e. observation also upstream of FS boundary**

Upstream Ion Cyclotron Waves

Importance of UPSTREAM ion (proton) cyclotron waves:

earliest observable PRECURSOR of approaching planet

proof of loss of exospheric particles (hydrogen) directly to Solar Wind

loss: NOT constant over age of Solar system (early Sun: higher UV!)

evolution of Venus exosphere in age of Solar System …. ?

@ Venus: Pioneer Venus Orbiter (1978 – 1992) :

proton cyclotron w. not seen UPSTREAM, only in magnetosheath

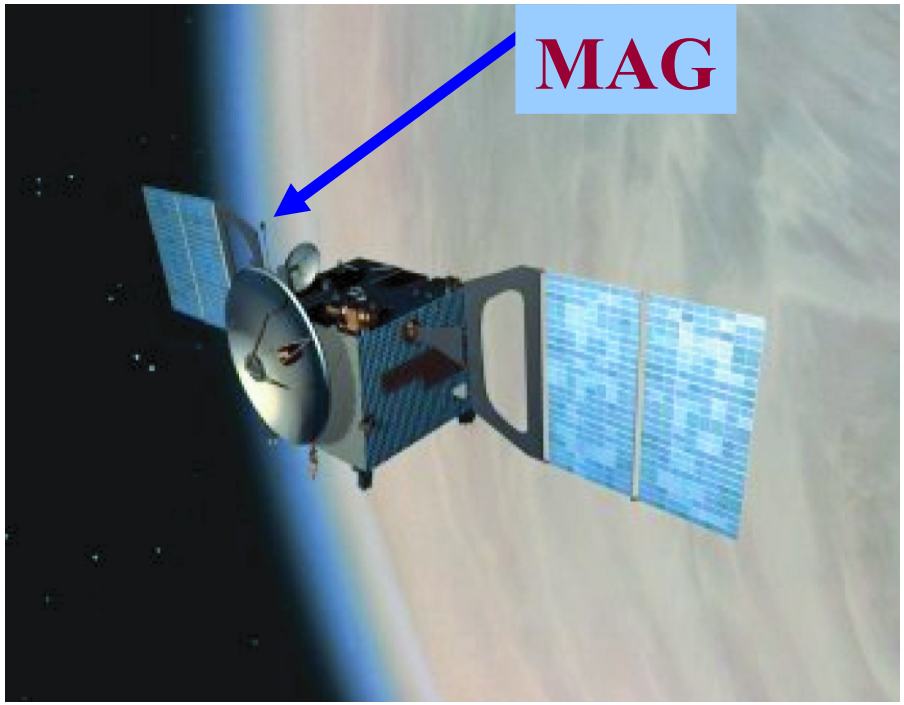
@ Mars: many observations

Phobos-2 (CT.Russell), MGS (D. Brain, C. Mazelle, C. Bertucci)

@ Comets: water group ion cyclotron waves at e.g.

Halley, Grigg-Skjellerup

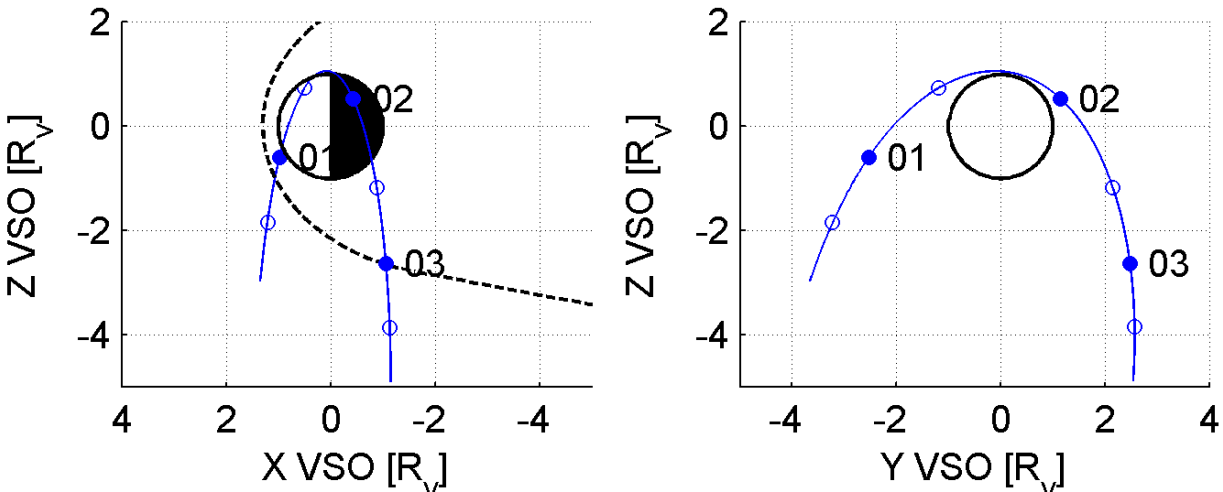
Venus Express Mission



- ESA "atmospheric" mission to Venus
  May 2006 – November 2014
- Magnetometer (MAG) on 1m boom
  (magnetically non-clean SC !)
  MAG data: 1 Hz, 24 hrs/day

  also: plasma instrument (ASPERA)
- SC orbit: polar, ellipse
  peric.~ 250 -350 km
  @ 78°N
  apoc.~ 66 000 km
  P = 24 hrs
  Orb. plane FIX in space
  => rotating in VSO-frame in 1 Venus-yr

Venus Express S/C in VSO coord.; 2006-06-16 (DOY 16



PCW cases: characteristics (1)

at Venus:

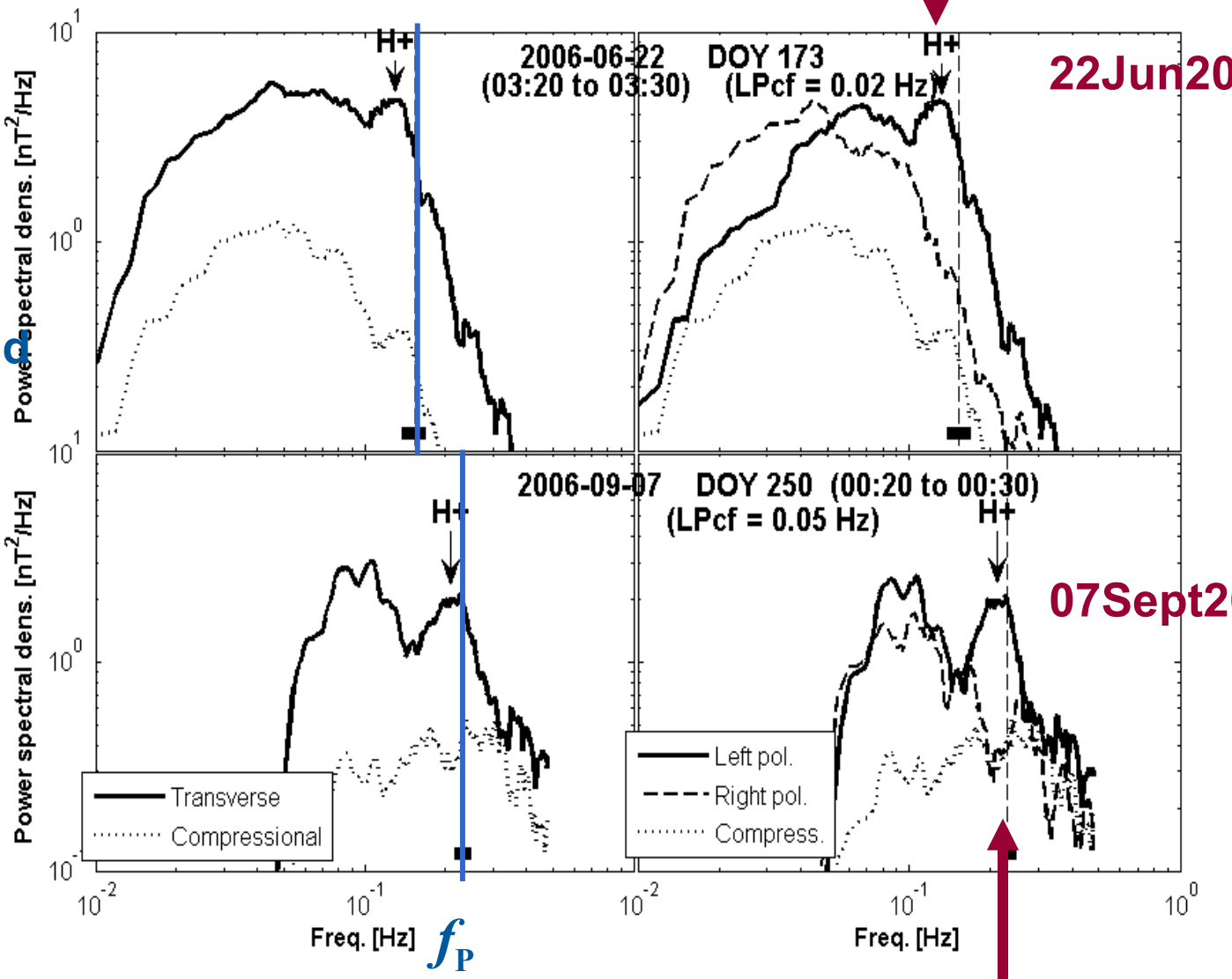
B~ 5-40nT

f_P ~ 0.076-0.61 Hz

P ~ 1.2 - 14 s

Enhanced left hand pol. transverse power near f_P

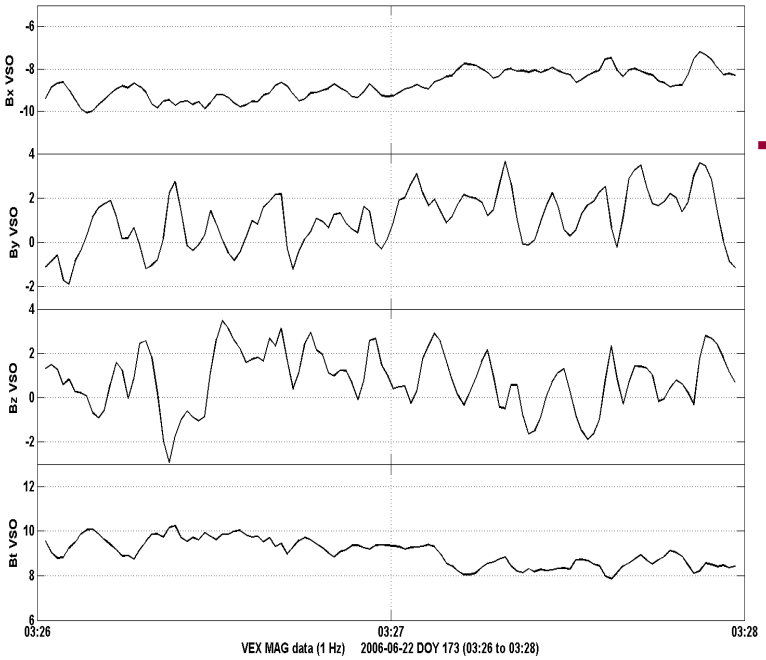
- **Other specifics: highly polarized highly elliptical small angle of prop. with mean Bfield**

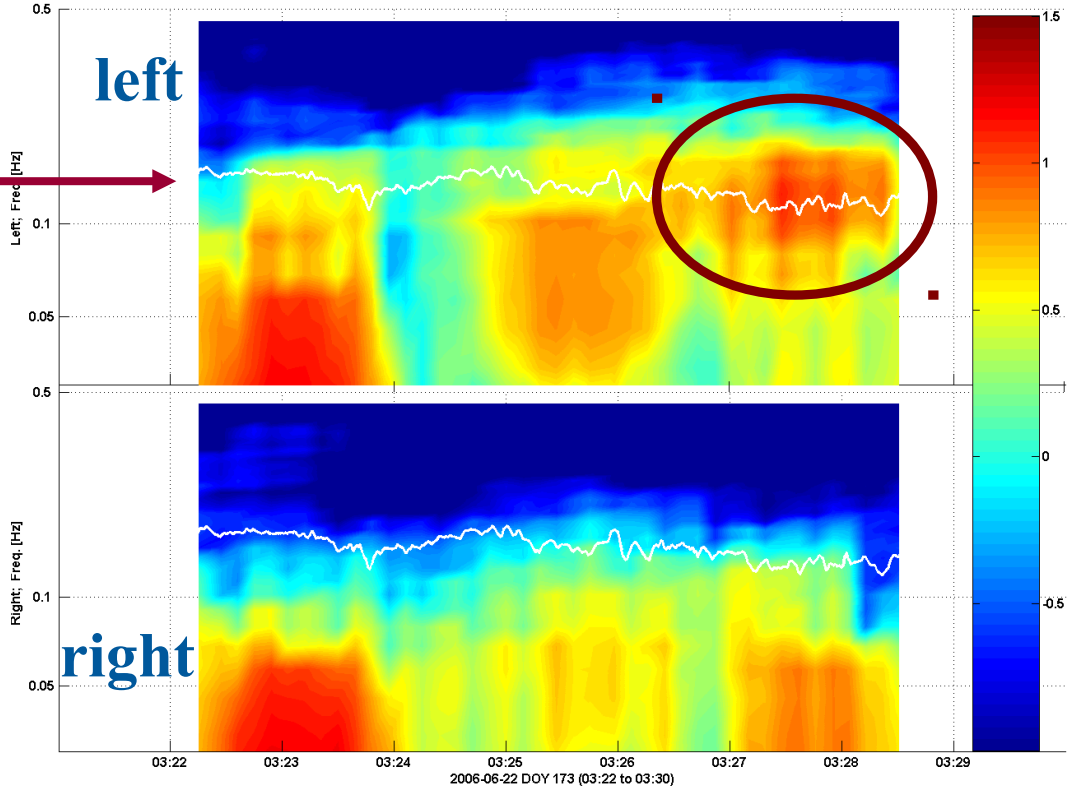


PCW cases: characteristics (2)

e.g. 22-06-2006

wave form in VSO





Delva et al., GRL 2008

Delva, Bertucci et al., PSS 2008

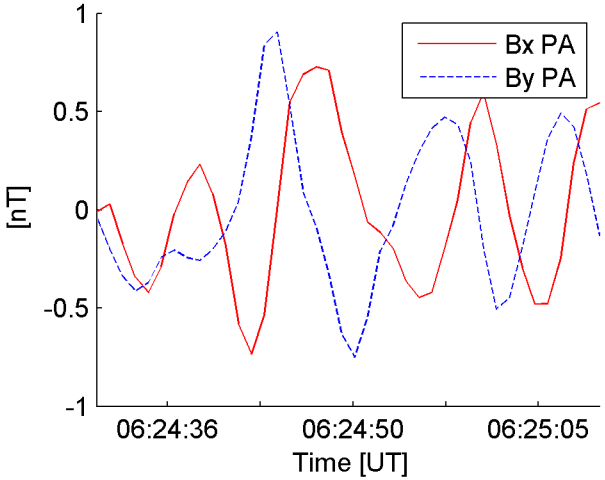
dynamic spectrum of left/ right transverse component

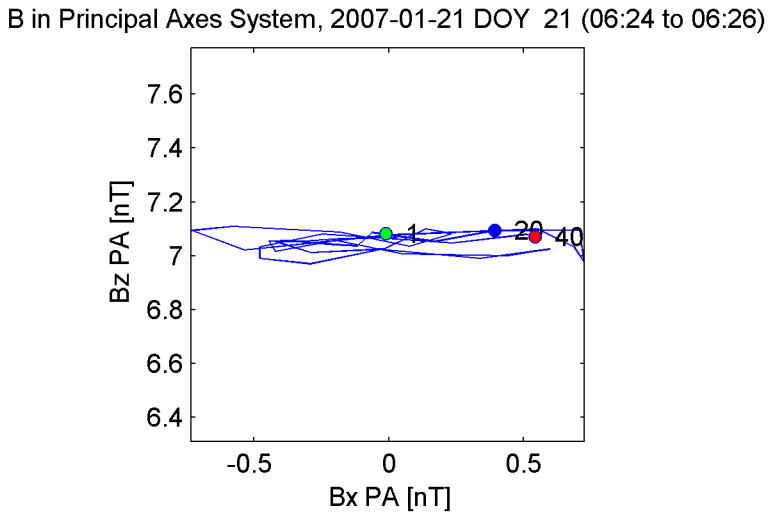
white line: local PC f_P

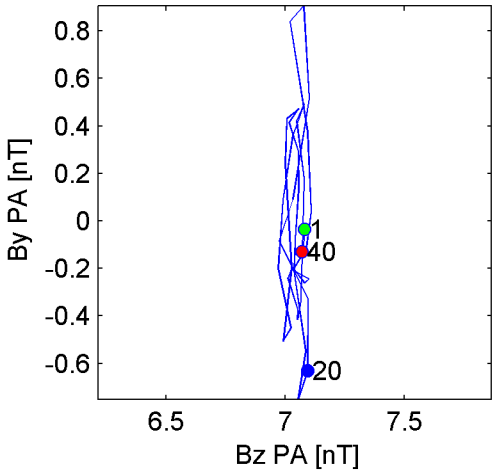
PCW cases: characteristics (3)

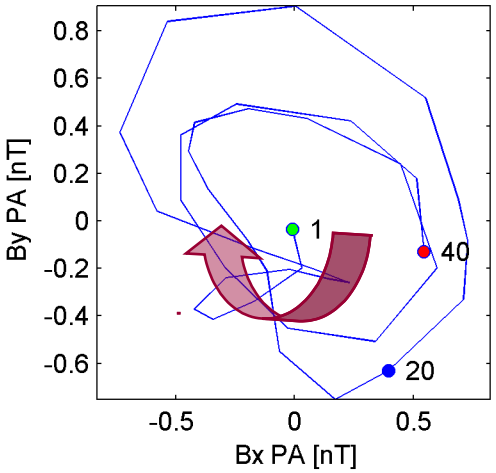
IWF

e.g. 21-01-2007: in principal axes system
(x: largest EV, z smallest EV)









Venus PCW obs. Solar Min (1)

- **Statistical study: 2006 May 10 – 2007 Aug 10**

2 Venus years (450 orbits = 450 days) MAG observations

- use data out (10 min) of BS and up to 4 hrs out of BS

- calculate power spectra in 10 min intervals,

transverse comp. in left- and right hand comp.

- cond. ellipticity < -0.5 at local proton cyclotron freq.

(i.e. left hand polarized, elliptic wave)

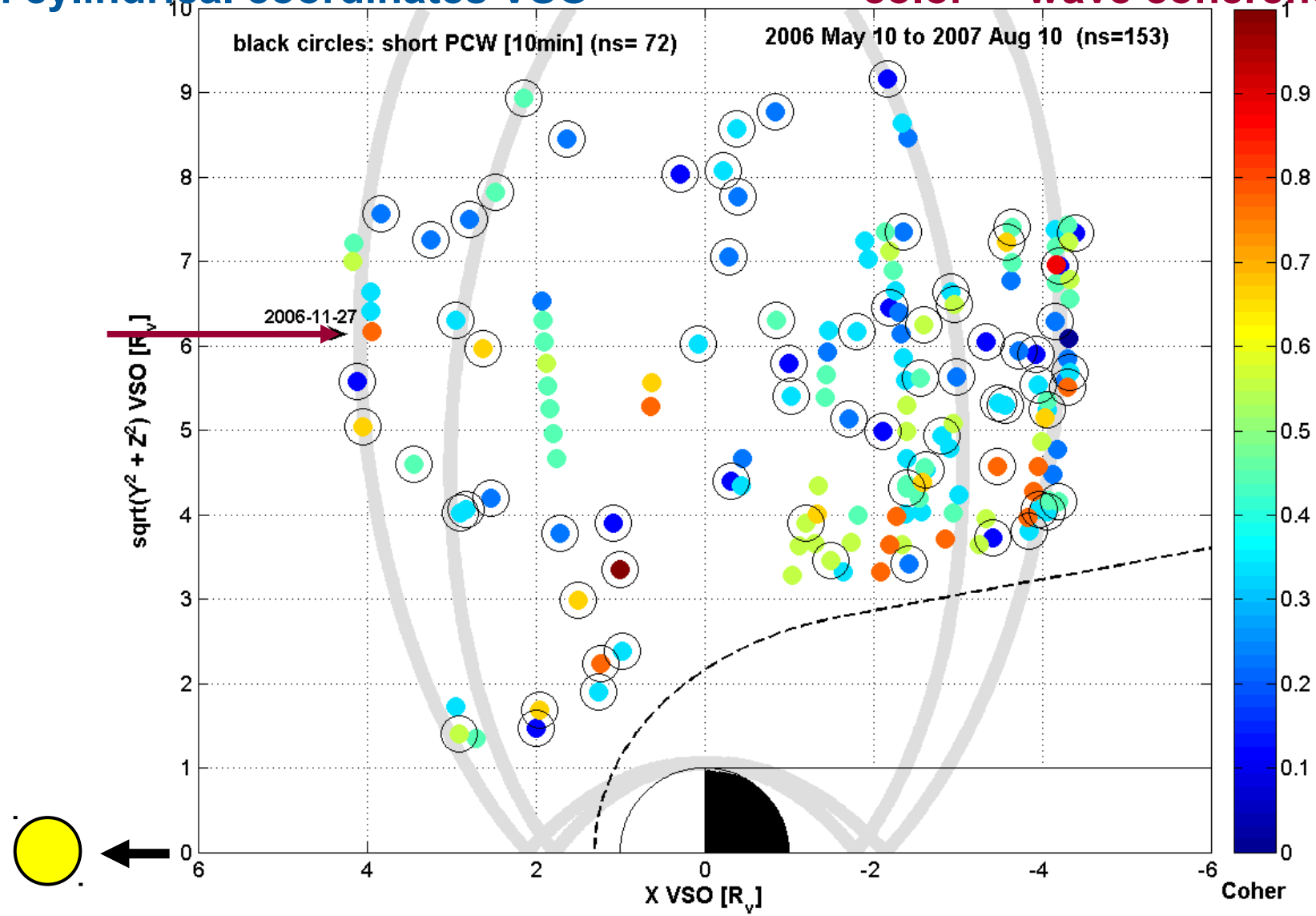
=> 153 cases of 10 min intervals, up to 4 hrs out of BS

=> PCW observation positions in space:
up to 4 Venus radii upstream
up to 9 " " distance from Venus-Sun line

Venus PCW obs. Solar Min (2)

In cylindrical coordinates VSO

color ~ wave coherence



High coherence & long duration also toward Sun

Venus PCW obs. Solar Min (3)

In electromagn. cosys VBE:

X//(-Vsw),

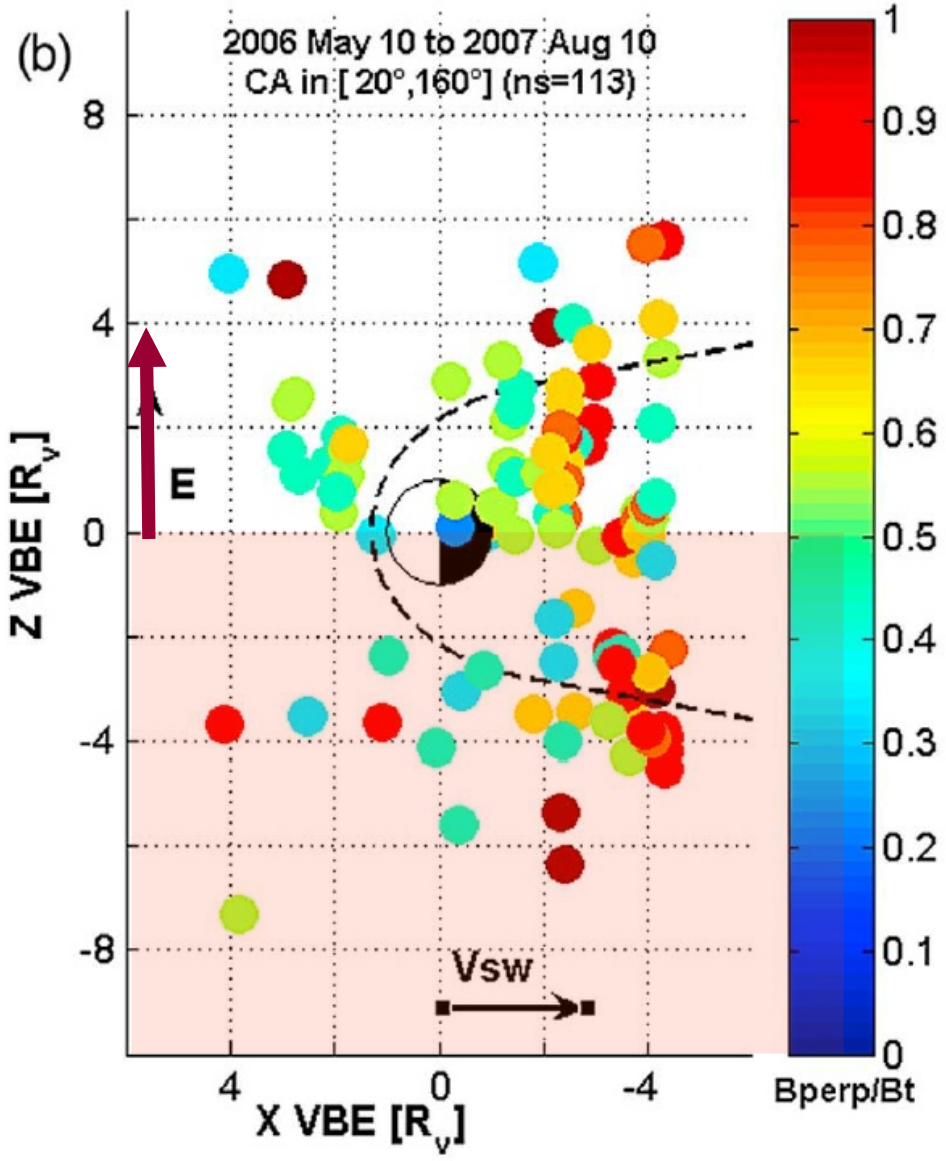
Y//Bperp,

Z//(E=-Vsw x B)

⇒ **NO asymmetry with dir. of E-field in PCW occurrence**

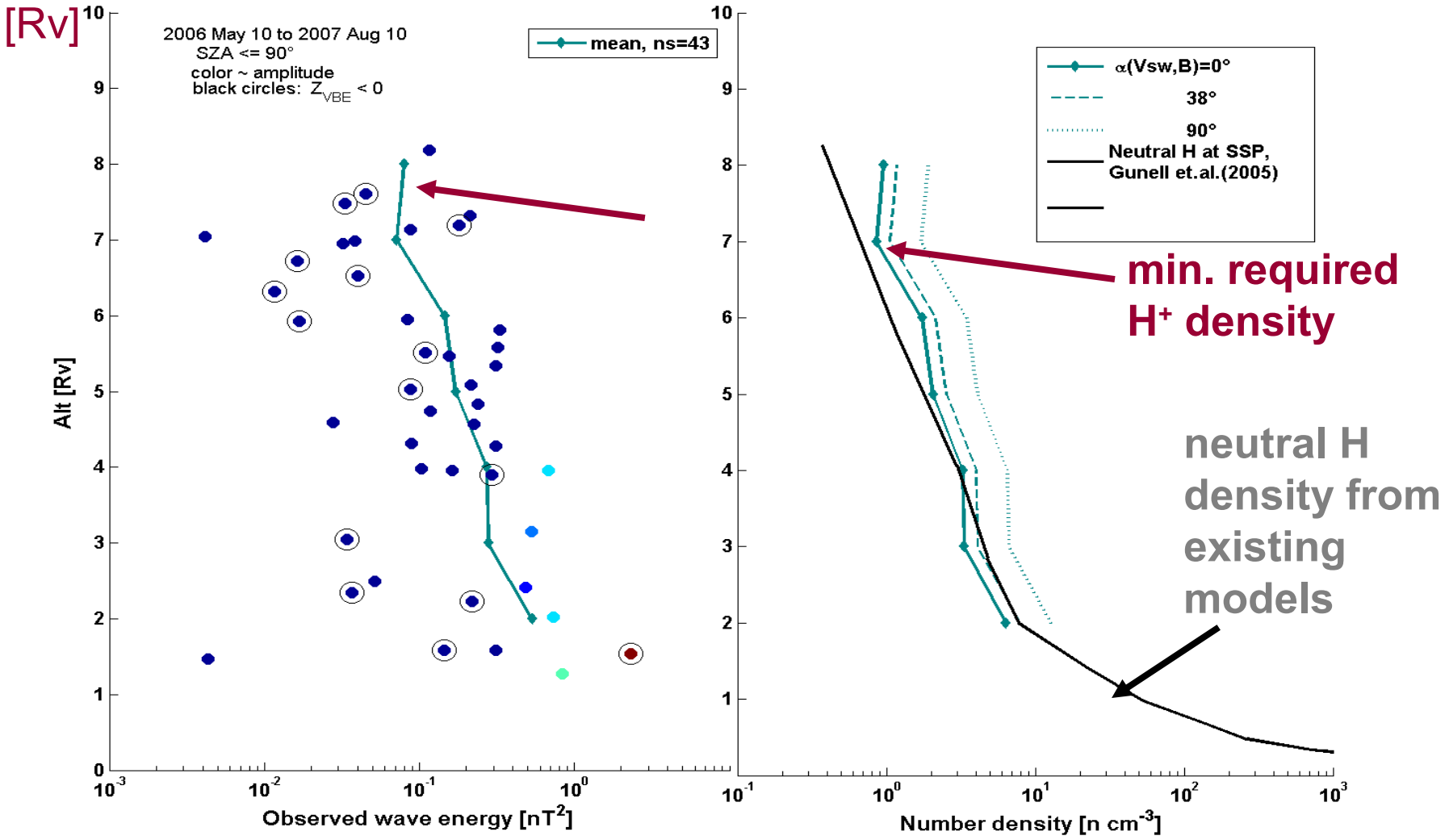
⇒ **PCWs are everywhere**

⇒ **generated from freshly ionized planetary protons**



Implications on H exosphere (1)

- **Wave energy (only for SZA <=90°); only planetary ions -> required H^+ density,** **(Huddleston & Johnstone, 1992)**



Implications on H exosphere (2)

PCWs till high altitudes (~ 8 Rv)

Ion pick-up everywhere

Loss rate of H^+ to Solar Wind

- **Wave energy -> ion-density**

  Loss rate ~ 1.4 - 5.6 x 10^{23}/sec from pick-up

  (Loss-rate through the wake ~ 10^{25}/sec (lower limit)
  Barabash et al. 2007, Nature)

Number density of neutral H exopshere

Substantial local H^+ density:

2 cm^{-3} at 5 Rv

1 cm^{-3} at 8 Rv

=> LARGE reservoir of local neutral planetary H must be available

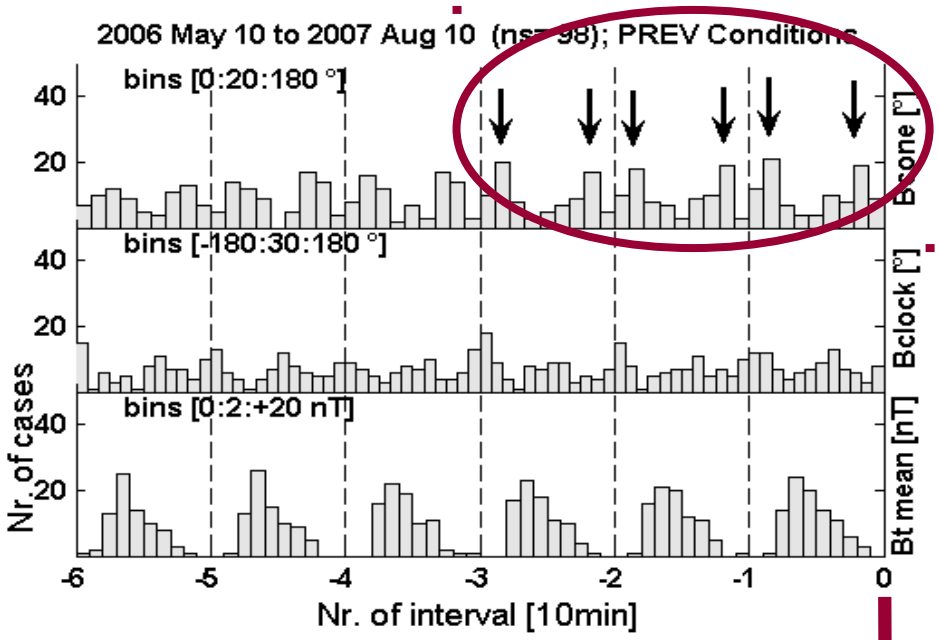
=> extended neutral hydrogen exosphere !

PCWs and B-field conditions (1)

IWF

PCW occurrences :

- **Under quasi // conditions of Vsw and B**
- **Mainly for stable cone angles**
- **Disturbance of stable cone angle => disappearance of PCWs**



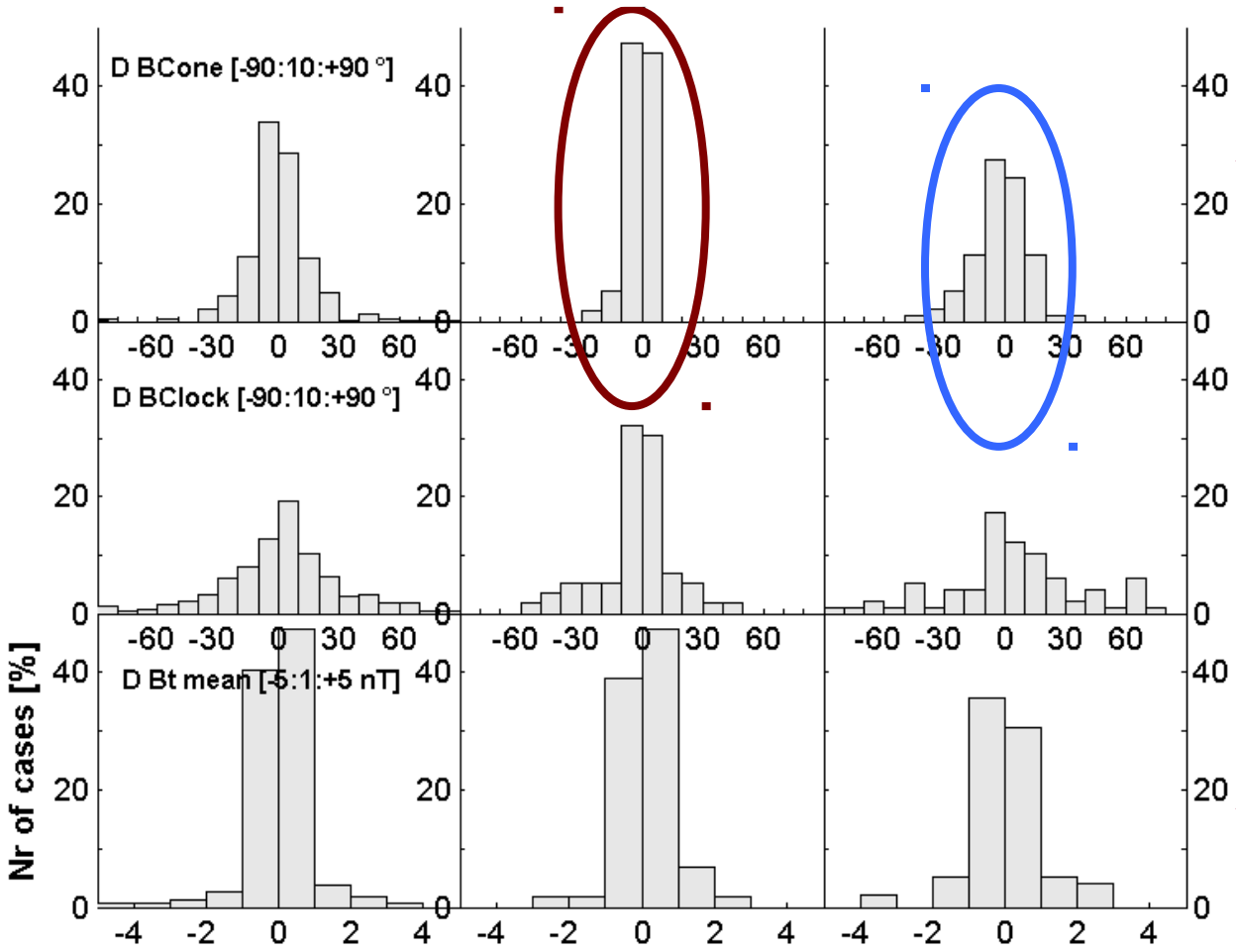
B-field conditions 1 hr previous to start of PCW occurrence

PCWs and B-field conditions (2)

IWF

Comparison of variability of B-field:

Previous (<=1hr) During After PCW observation



differences from subsequent 10min intervals

PCWs and B-field conditions (3)

- mainly under quasi- (anti-) parallel conditions of Vsw and B

=> mainly from parallel beam of newborn planetary ions injected into SW

=> wave generation through ion-ion resonance mechanism, fast wave growth already for low ratio of newborn ions relative to SW background

- stable quasi-parallel conditions to maintain waves, waves have more pronounced cyclotron wave characteristics
- for more perpendicular configurations of Vsw and B: different mechanism and less effective gradual transition between both mechanisms (Delva et al., JGR 2011)
- waves generated at initial ionization of planetary hydrogen

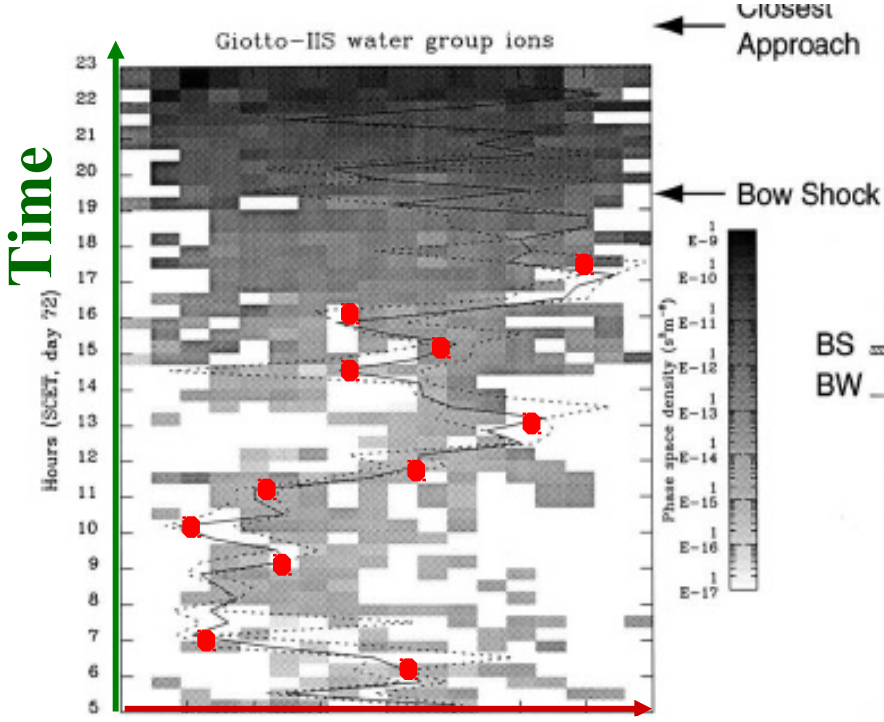
ICWs and B-field conditions (4)

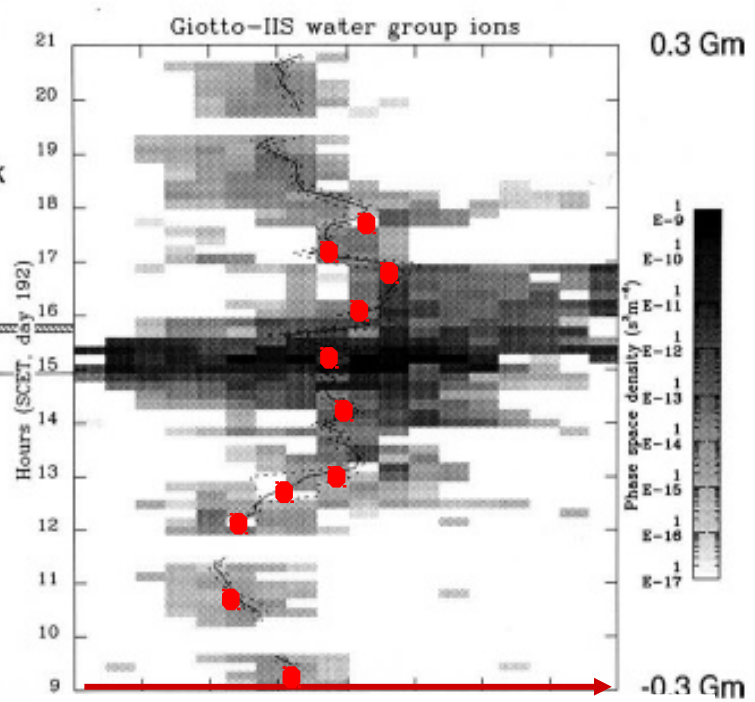
IWF

Similar observations at Comets (Mazelle, Neubauer, Coates, etc):

Halley:
highly variable gas-prod.
" " pitch angle
-> short ICW obs.

Grigg-Skjellerup:
low but steady gas-prod.
stable cone angles in (45-115°)
-> long ICW obs.





Coates & Jones, PSS 2009

Fig. 5. (a) at c… respectively at CS … Gm … ng position (sol … from Coates et … erlaid, wave,

PCW observations Solar Max (1)

- Highest sunspot nr. in Solar Cycle 24 (so far): 2012 May
- MAG data (1 Hz) of 2 Venus years (2011 Mar 01 to 2012 May 31)
  - 450 orbits (450 days)
  - use data out (20 min) of BS and up to 4 hrs from BS
  - calculate power spectra in 10 min intervals,
    transverse comp. in left- and right hand comp.
  - cond. ellipticity < -0.5 at local proton cyclotron freq.
    (i.e. left hand polarized, elliptic wave)

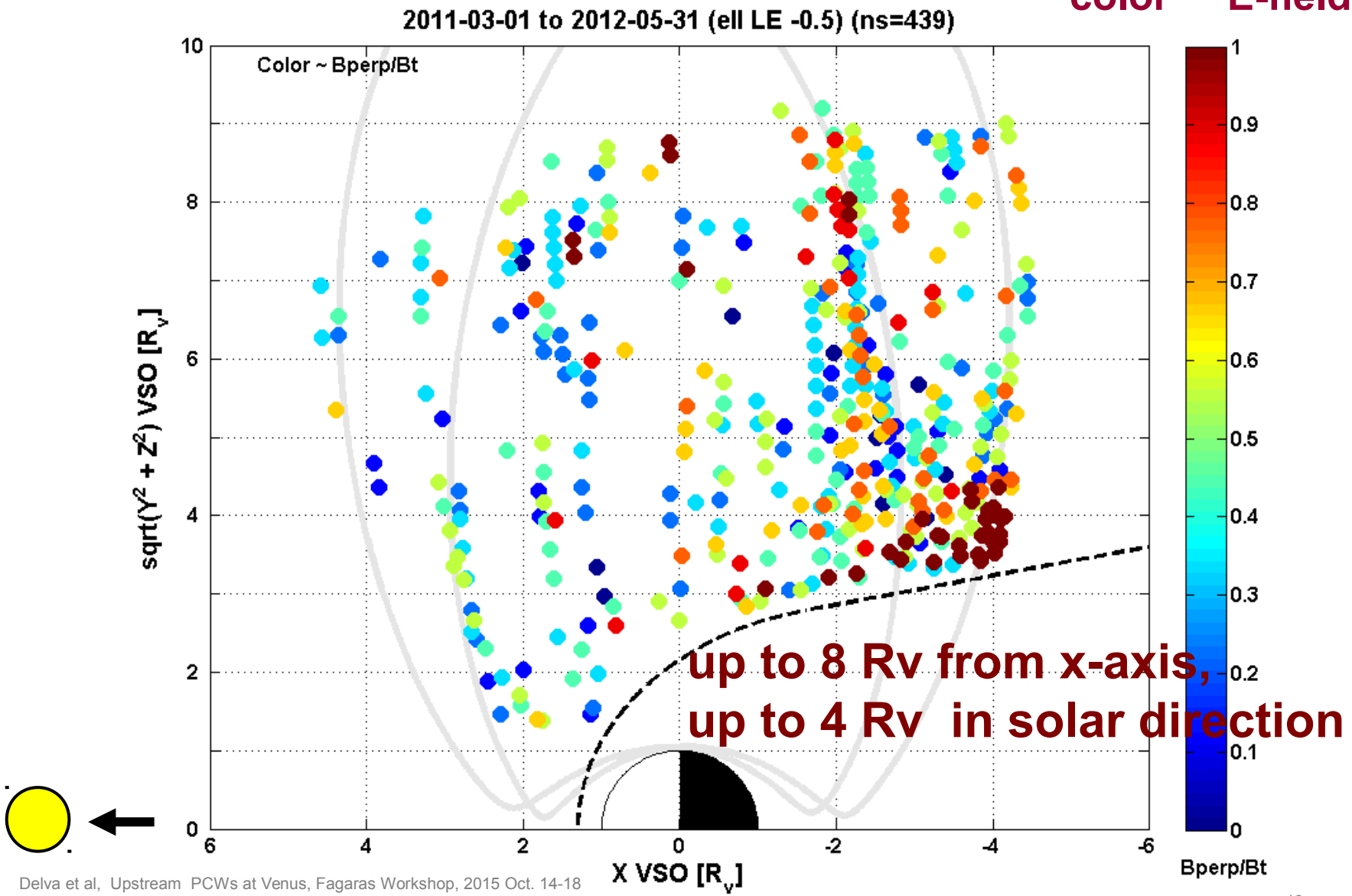
- 439 cases of 10 min intervals with PCWs
  i.e. 156 single intervals and 98 cases with duration >= 20 min
  (38 % are long occurrences)

PCW observations Solar Max (2)

IWF

In cylindrical coordinates VSO

color ~ E-field



PCW observations Solar Max (3)

- 156 short occurrences (10 min only),

  but 98 longer occurrences (>= 20 min), i.e. 38% long occurrencies

- B-field conditions? mainly

  small (<45°) or

  large (> 135°) cone angles

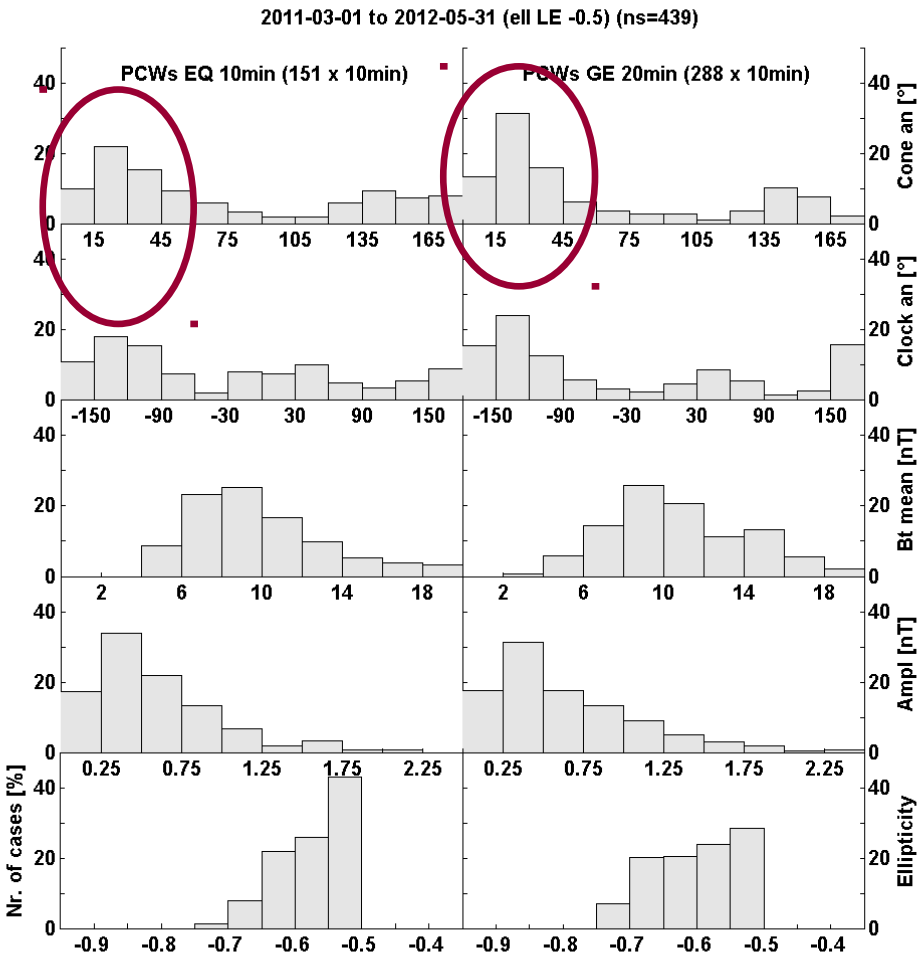
  i.e. quasi-(anti-)parallel

  Vsw and B

BUT:

preference for anti-parallel cond.

(theory: symmetry expected !)



Comparison Solar Min to Max (1)

- **Comparison to solar MIN:**
  - **PCW observation positions: similar to solar min**
  - **439 cases at solar max >> 153 cases at solar min (10min)**
  - **38 % are longer occurrences > 25 % at solar min**
  - **for solar min: parallel and anti-parallel cond. equally available**
  - **near solar max: clear preference for anti-parallel cond.**

BUT: from THEORY: NO difference between // and anti-// cond.

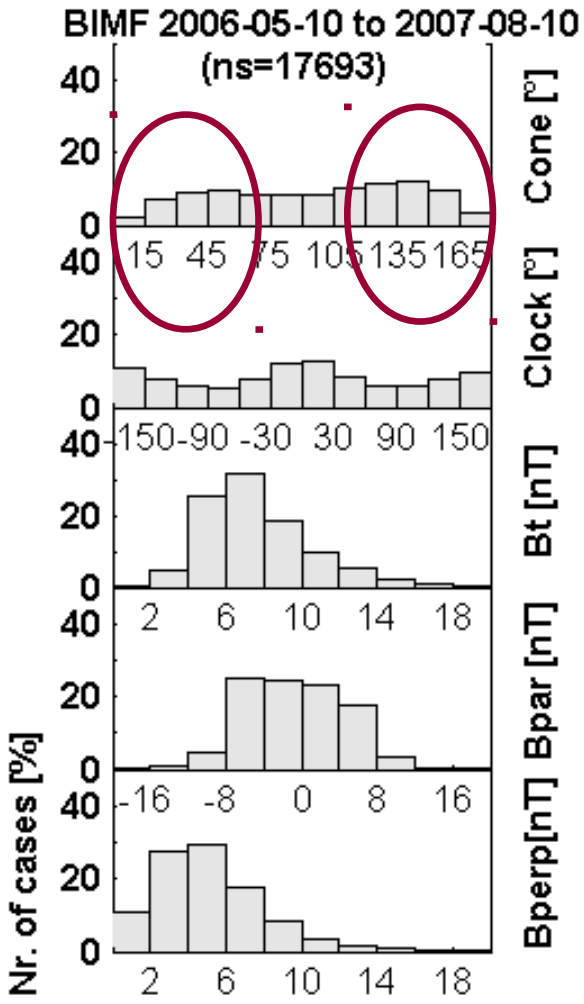
WHY:

- **MORE PCWS near solar MAX ?**
  Not expected, because solar max has LESS STABLE B-field
- **Why no symmetry for parallel or anti-parallel Vsw and B ?**

Comparison Solar Min to Max (2)

- **Check IMF conditions in PURE Solar Wind without PCWs:**

Solar MIN



Solar MIN:

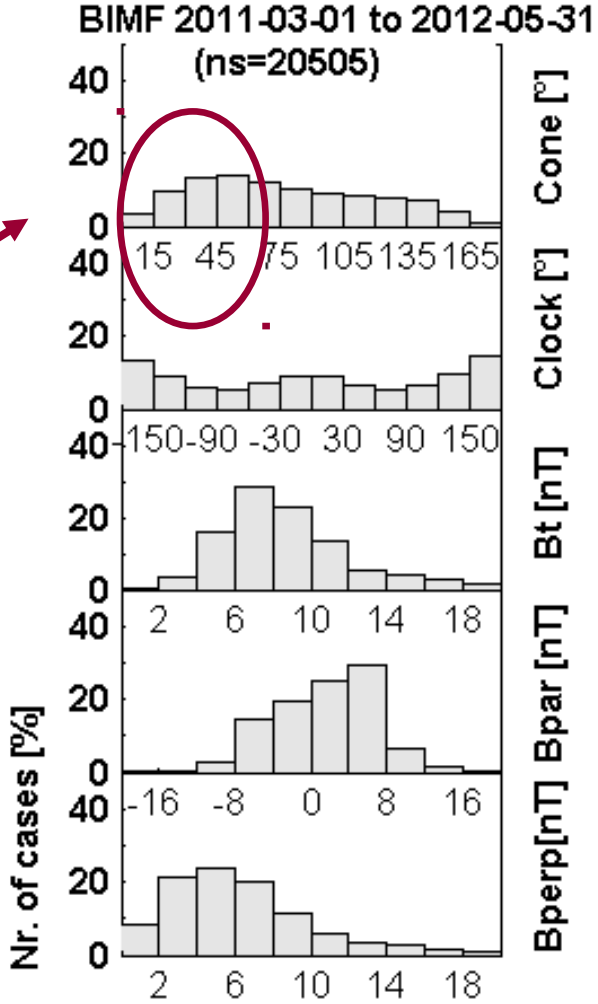
slightly more parallel Vsw and B (outward field)

Solar MAX:

Significantly more ANTI-parallel Vsw and B (inward field)

WHY …?

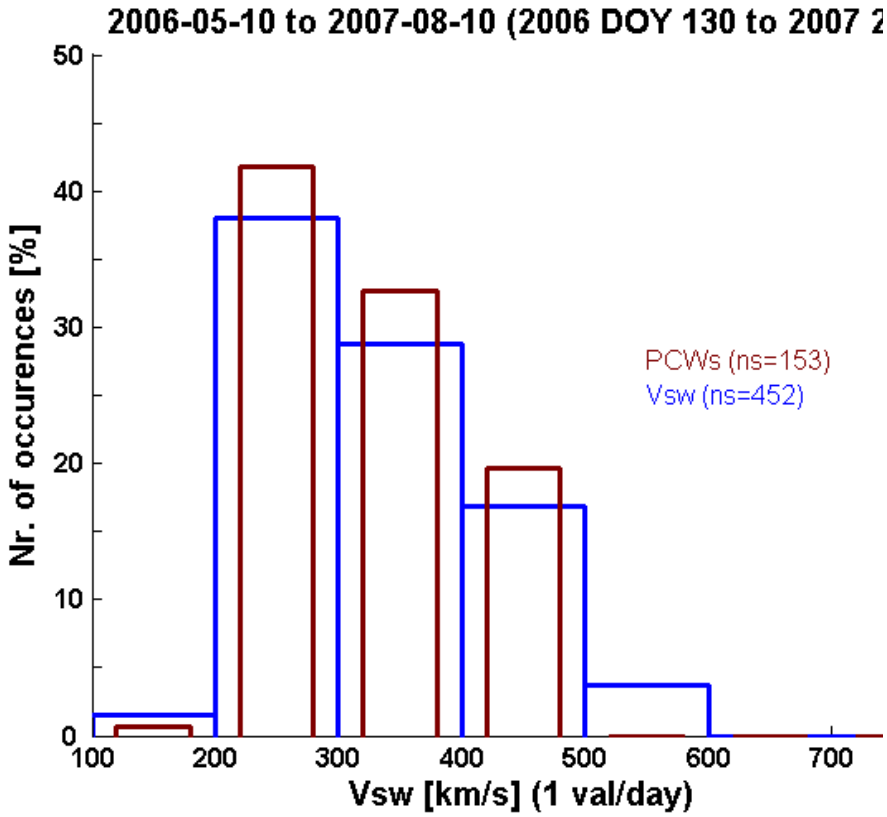
Solar MAX



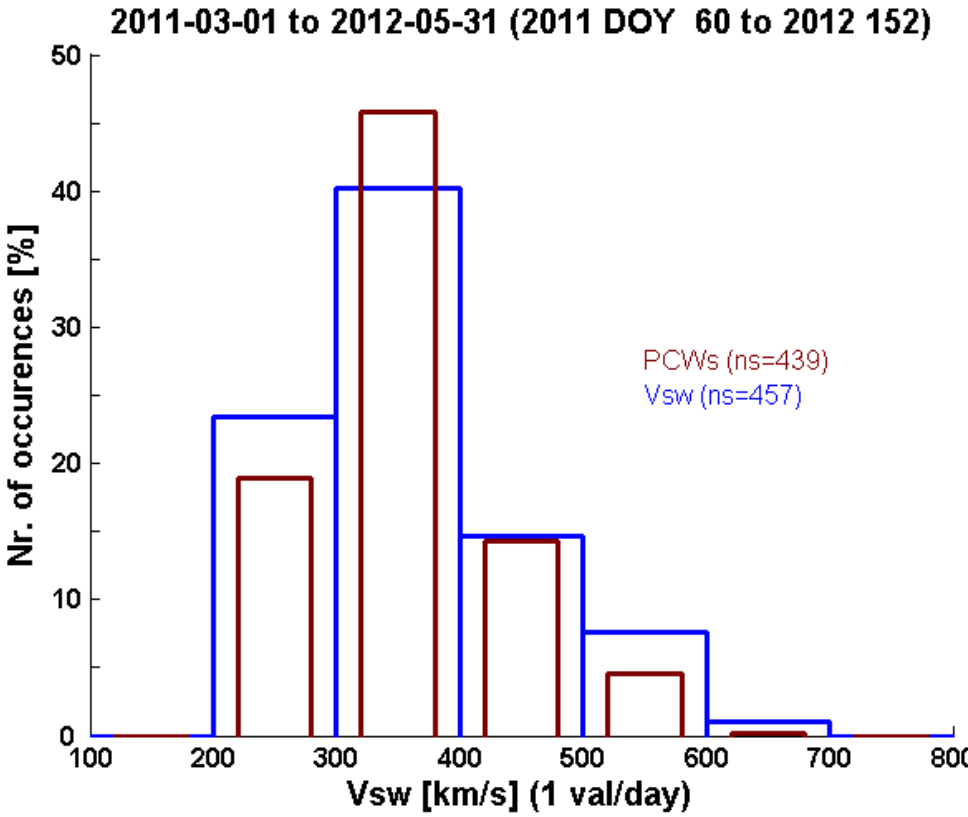
Comparison Solar Min to Max (3)

- Vsw conditions from PLASMA data (ASPERA)

Solar MIN



Solar MAX

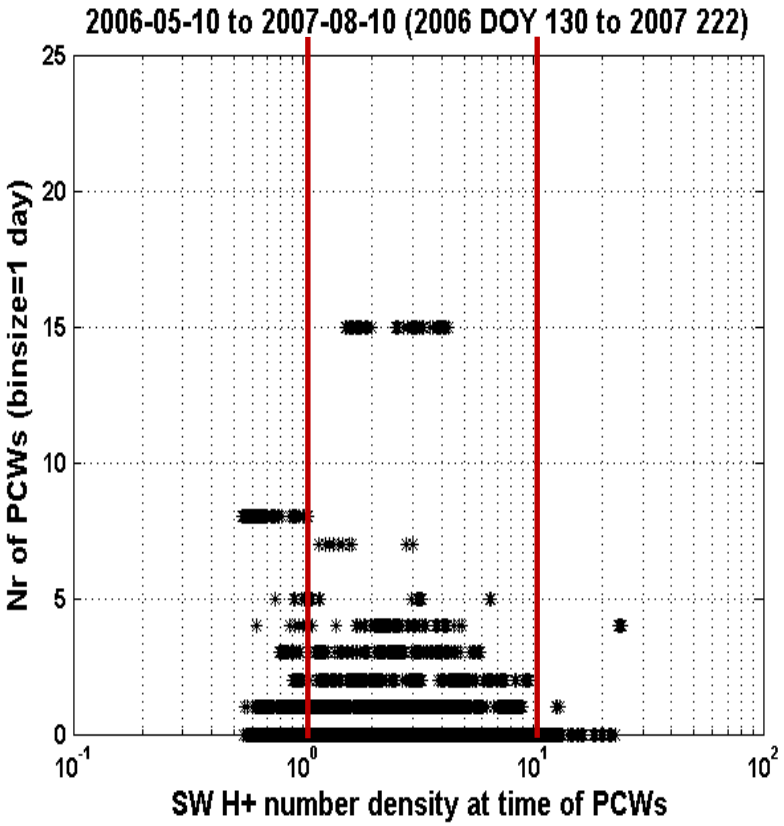


=> PCWs preferably for LOW Vsw <= 400 km/s

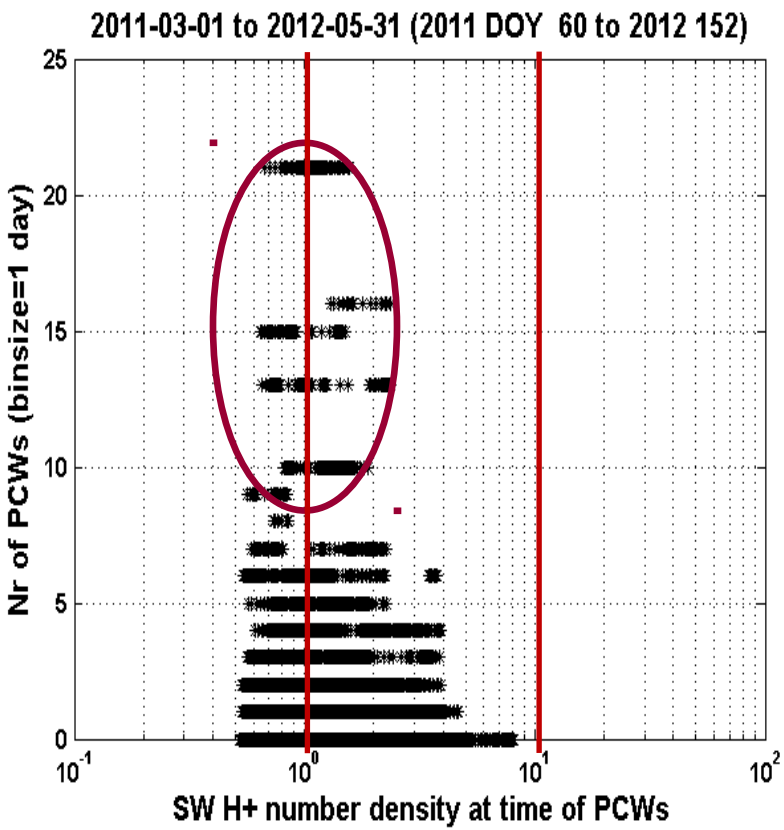
Comparison Solar Min to Max (4)

- H^+ density in SW for days with PCWs from PLASMA data (ASPERA)

Solar MIN



Solar MAX



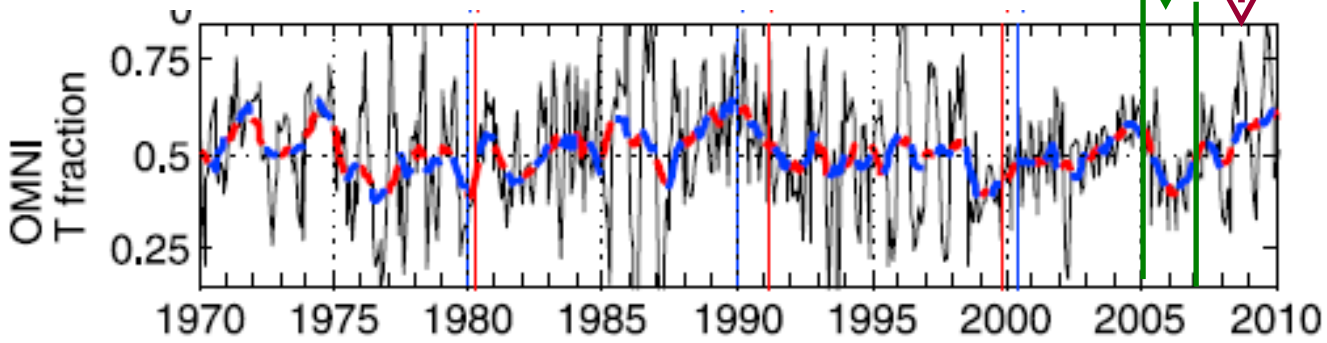
⇒ MORE for LOW SW H^+ density

Explanations (1)

Asymmetry in SW conditions near solar MAX: why?

- End of Solar Cycle 23: 2005 – 2007: more field AWAY from Sun ("Towards" fraction < 0.5) (SC obs. in ecliptic plane)
- Raising Phase of Solar Cycle 24: 2009 – 2010: more field TOWARD Sun (T fraction > 0.5)
- Sol. C. 24: southward tilt of heliospheric current sheet increases, northern hemisph. has INWARD B-field

=> Venus orbit mainly above current sheet => INWARD B-field



Mursula and Virtanen, JGR 2012, Fig. 3 bottom panel

Figure 3. T-sector occurrence ratios T/(T + A) for Pioneer 10 and 11, Voyager 1 and 2 and OMNI data. Thin line: 27-day averages; thick colored line: 13-rotation running means stepped every 27 days. Blue (red) color indicates that the probe was above (below) equator. Vertical blue (red) lines mark the northern (southern) polar field reversal times according to Wilcox Solar Observatory.

Explanations (2)

More PCWs (~ factor 3) near solar MAX: why ?

- **Solar Cycle 24:** **McComas et al.** (Astroph. J., 2013) :
  "weakest solar wind of the space age and the current "mini" solar maximum"
  - extremely low sunspot numbers
  - extremely low SW proton density (0.5 x value of 2005)
- **EUV-effect on Venus hydrogen exosphere?**

- Solar Min: sufficient ionisation & new born ions to generate PCWs:
  >= 0.01 % of density ratio (plan. ions to SW protons) (Cowee, 2012)
- THIS solar MAX:
  solar EUV: 1.5 to 2.0 x higher flux (SOHO CEM observ.)
  => 40% higher nr. density of planetary H^+ at higher altitudes
  (Lichtenegger et al., 2013)

=> density ratio : factor 1.4/0.5 ~ 3 larger than in solar min.

Conclusions Solar Min & Max

- **Asymmetry in parallel (more) and anti-parallel conditions of PCWS:**

  due to solar wind B-field asymmetry only

  "bashful ballerina":

  southward tilt of heliospheric current sheet during increasing phase of Solar Cycle 24 and northern hemisphere with inward B-field

- **Relative density of planetary newborn protons to SW background is important parameter for PCW generation:**

  for higher ratio, more PCWs grow to observable amplitudes

  Near Max. of Solar Cycle 24:

  ratio is 3 x higher than in previous Solar Min,
  ~ 3 x more PCWs observed

Delva et al, Upstream PCWs at Venus, Fagaras Workshop, 2015 Oct. 14-18