The day-side magnetopause as seen by Cluster: A case study and a statistical report

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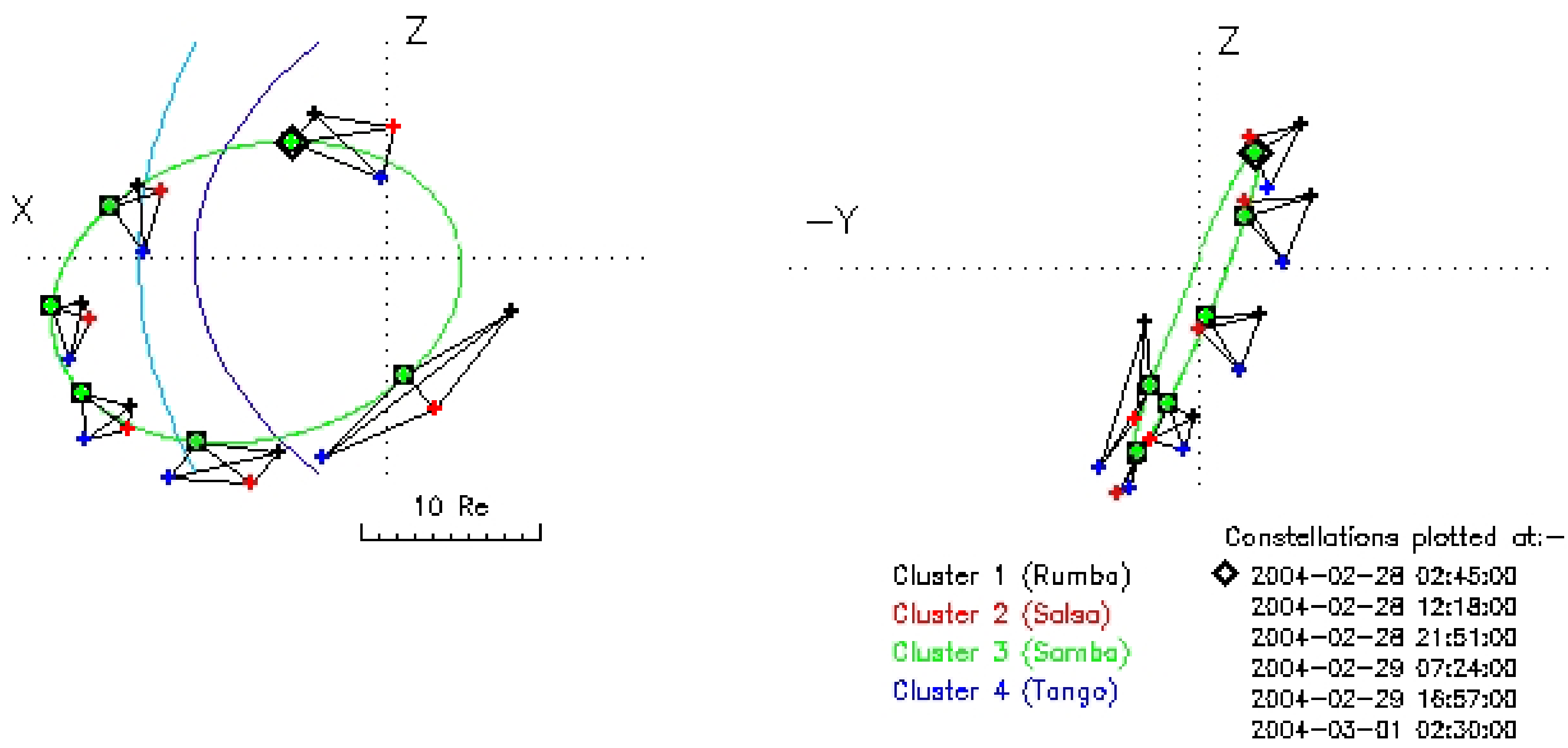
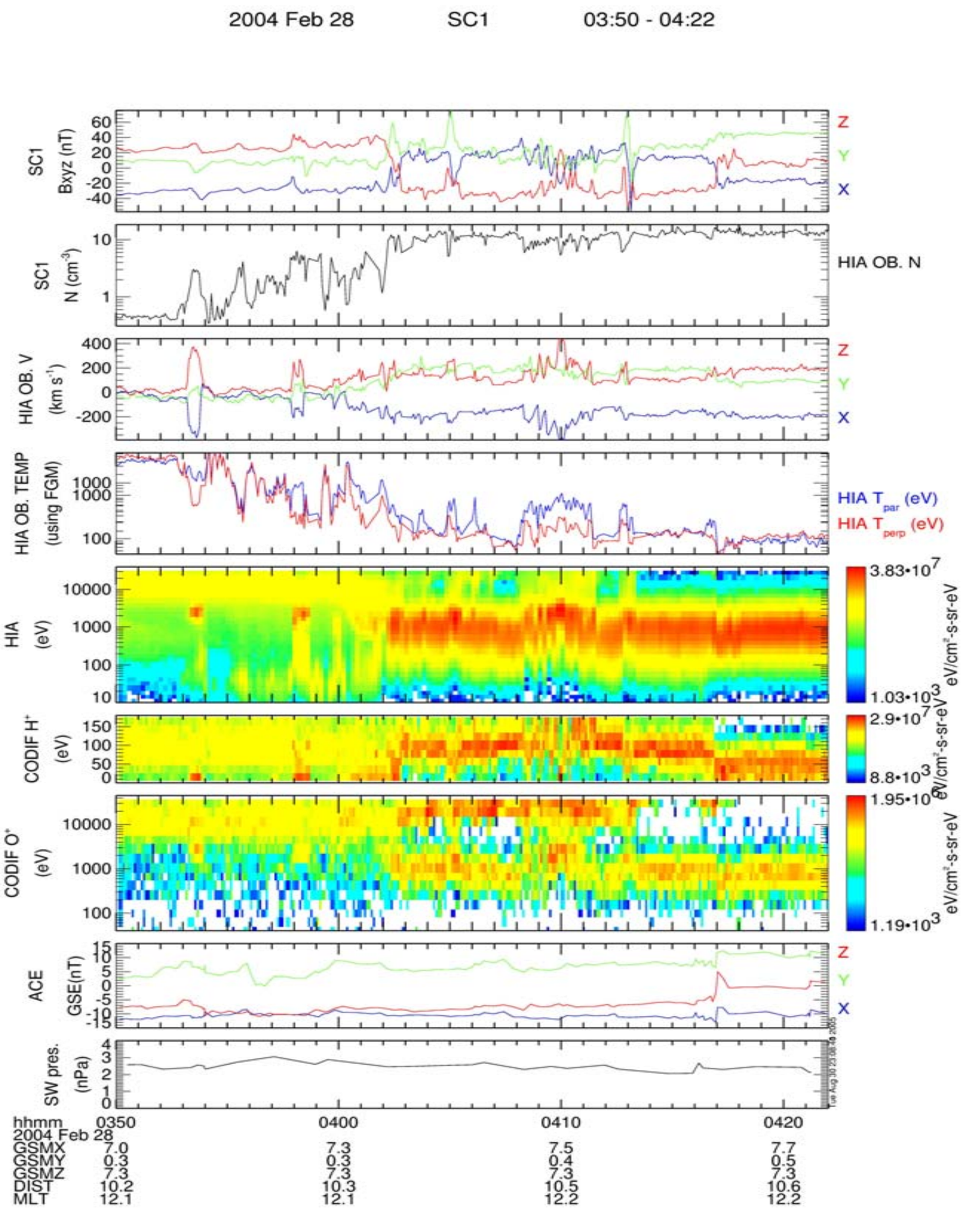
Objectives:

- to present a case of day-side (outbound) MP crossing by Cluster, for which we study the geometrical and dynamical properties of this discontinuity layer.
- to check the results obtained by different methods for consistency
- to show a statistical report about the tangential versus rotational character of the day-side magnetopause for crossings in spring of 2004.

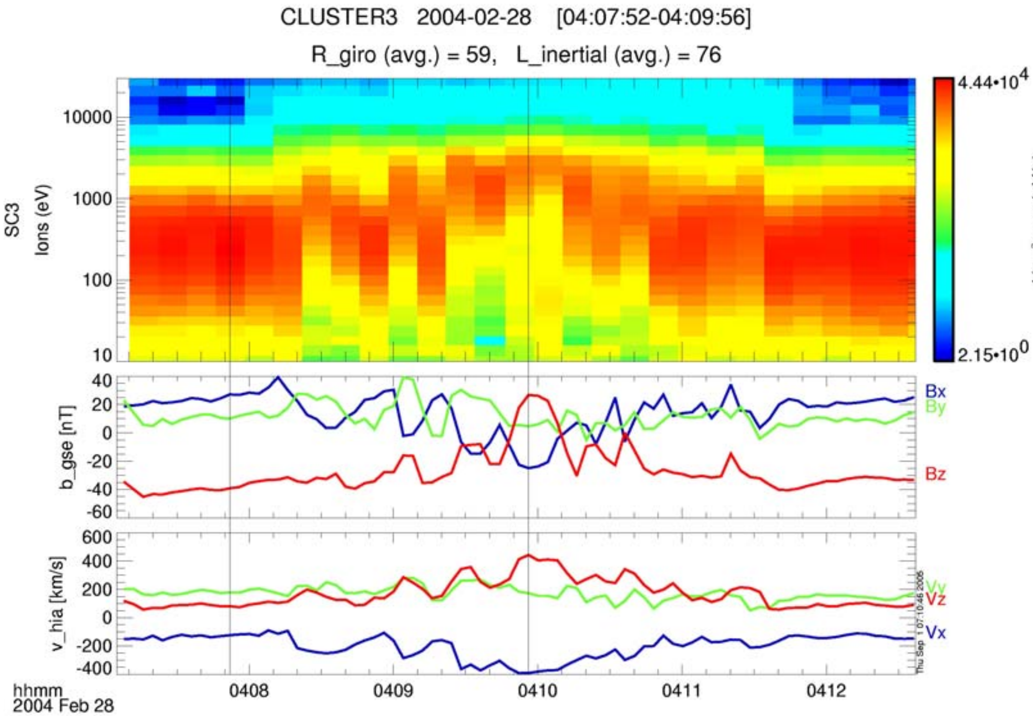
- The selected case is an outbound day-side crossing on 28th of February 2004. As often in that period, due to the changes in Cluster orbit - which result in a apogee below the ecliptic in the summer - the exit from the magnetosphere in the northern hemisphere is below the magnetic cusp, permitting the study of the day-side magnetopause.
- The statistical report - at the end - will refer to this type of orbit.





- We cared about a proper alignment between ACE and Cluster measurements (see magnetic field at 04:17).
- Notice the presence of many FTE events (e.g. 03:54, 03:58, 04:02, 04:05 etc).
- There were a lot of Oxygen ions for this event. For a quick look of the true counts one should observe the highest energy channels.

- First exit, from M-Sphere to M-Sheath at 04:02. There is a superimposed FTE right at that time. Due to this feature, we could not expect a good RD identification.
- Due to the back and forth MP movements the satellite enters again through a complex transitions the discontinuity around 04:08.
- At 04:10 the magnetic field level corresponding to the M-Sphere is reached.
- Despite the complex aspects of the transitions, the Walen test produced good results for SC3, consistent with the southward IMF orientation and with the Oxygen presence in the M-Sheath.

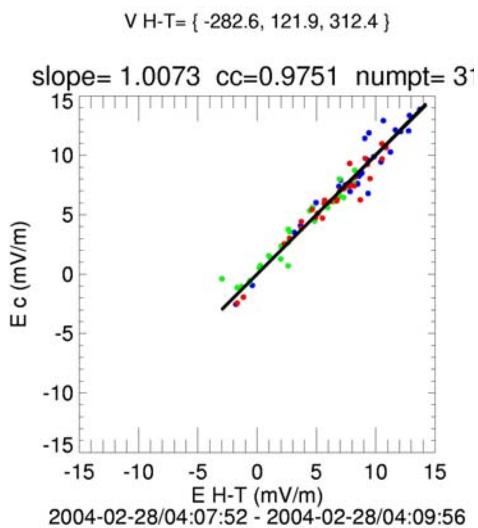


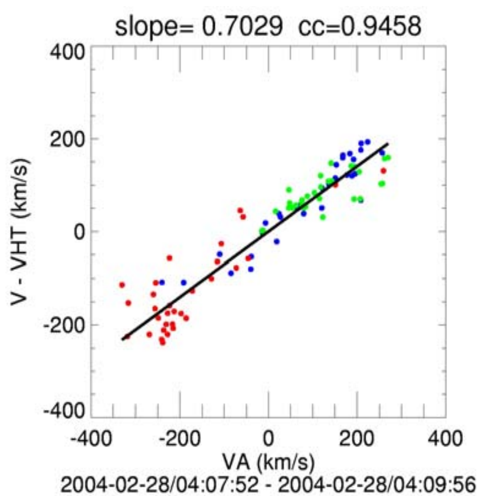
- Precautions for Walen test:
  - we used Alfven velocity corrected for the plasma anisotropy
  - the par. and perp.temperatures were computed by use of the magnetic field (not by diagonalization). Despite this one point was rejected (out of 32) because α (plasma pressure anisotropy factor) was grater than 1

- We used the running density and did not rely on the formula ρ(1-α) = const. which is not allways experimentally verified.

  Usually, by performing the test in this way, one obtains a smaller slope for the fit.

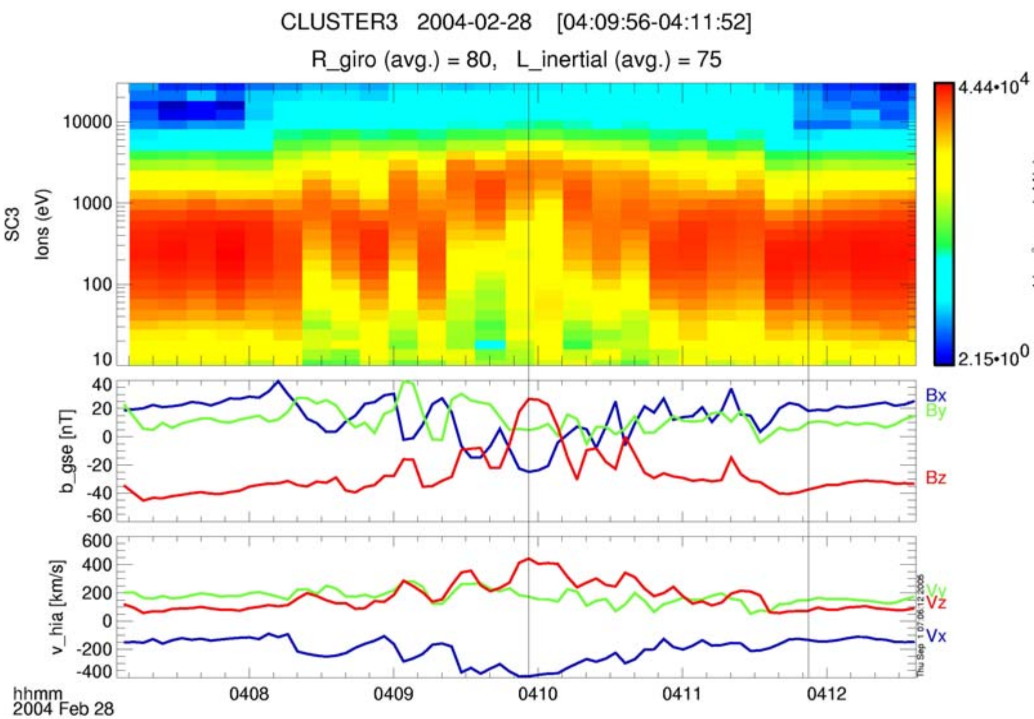
- For the DeHT analysis we used the MHD approx. E= -VXB

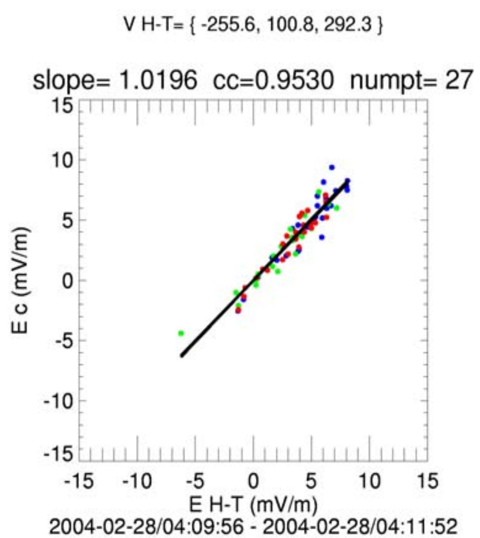


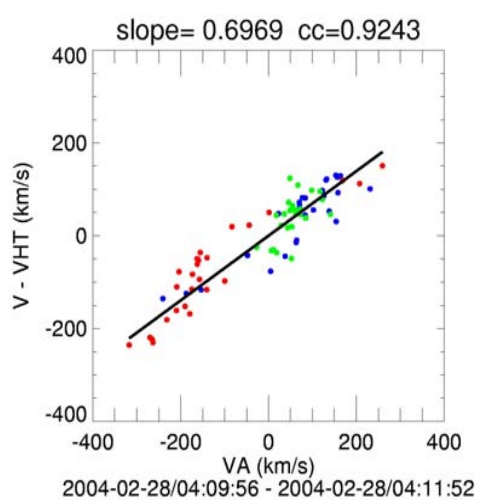


The DeHT plot presents the fit between the electric field in GSE and the convection electric field associated with a structure moving with the determined DeHT velocity.

The Walen plot shows the fit between the Alfven velocity components and the plasma velocity components in the DeHT frame. For an ideal RD the slope and the cc would be 1.







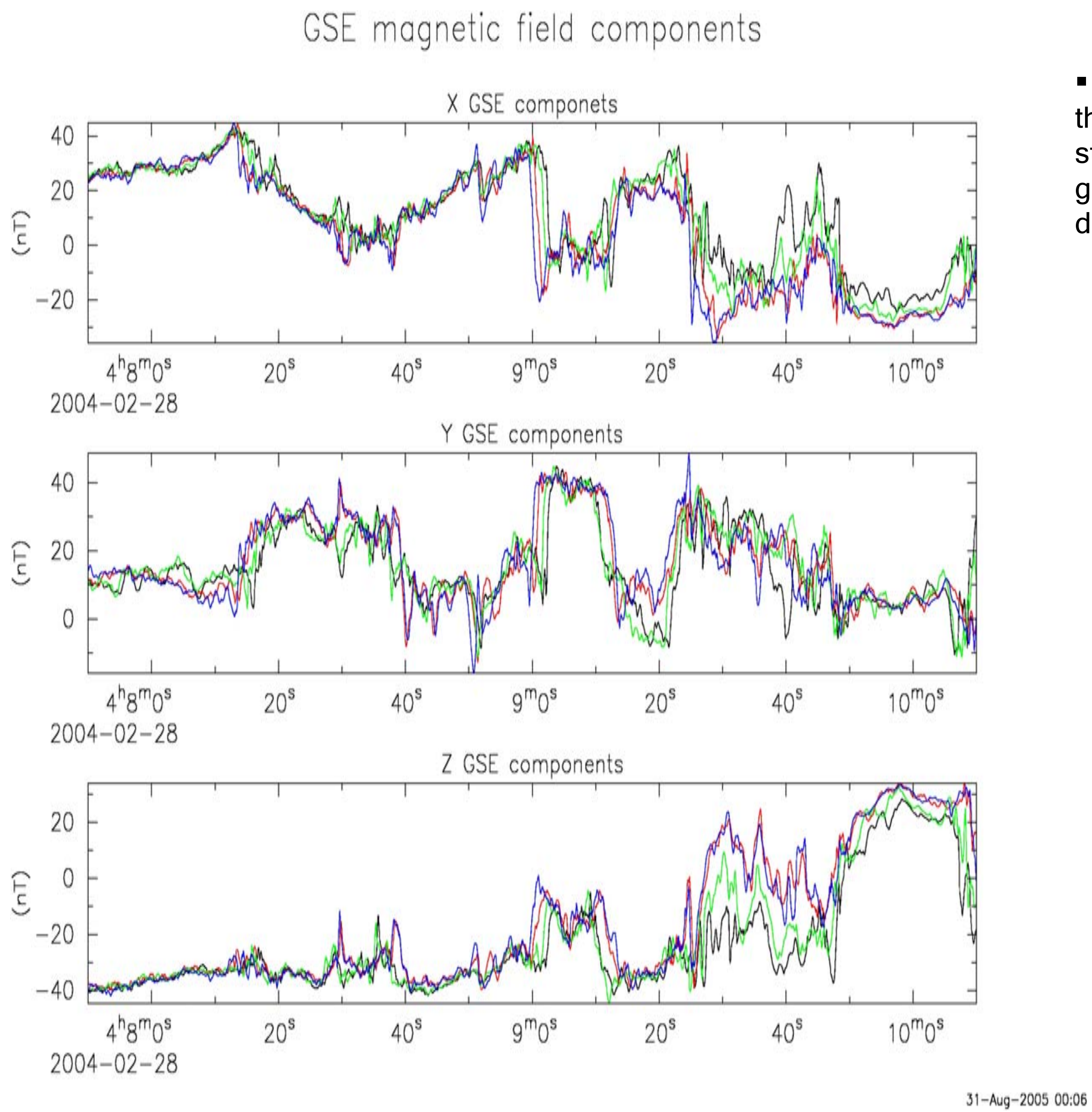
▪ For the return in the M-Sheath, the results of the tests are similar. In this case we have to exclude 3 points (out of 30) from the analysis because α was grater than 1

▪ For Cluster1 the results are poorer (for ex. Walen slope and cc of 0.583 and 0.869) and the points are more disperse. Possible explanations are the two data gaps in the HIA moments due to the on-board processor buffer saturation. Also, in that case, the time tags could not be correctly assigned to the data, and this we actually identified in our interval by comparing on-board HIA with ground computed CODIF densities.

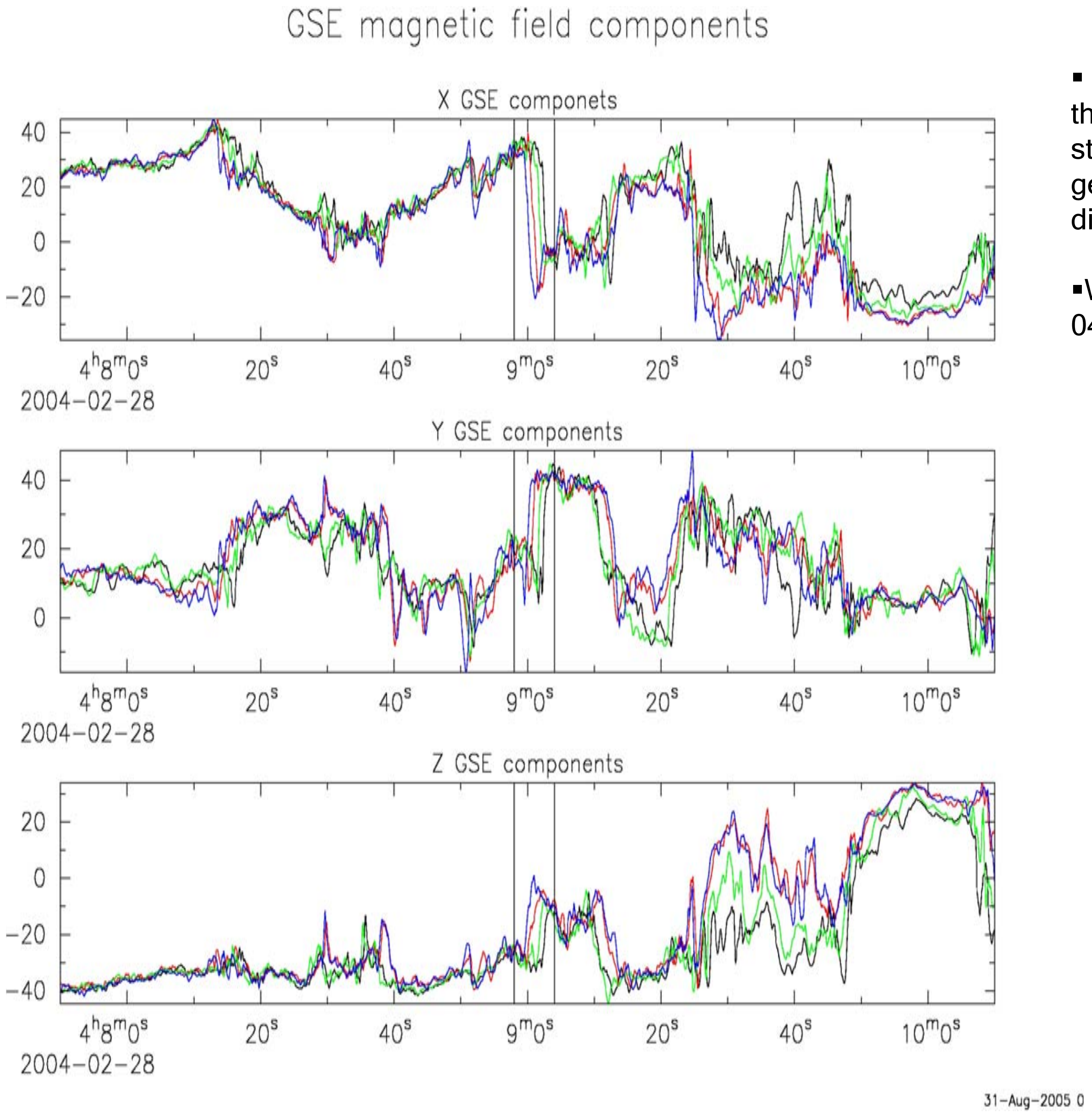
▪ The fact that the slope is not 1 in our Walen tests, could be a result of several factors:

- the abundant presence of heavy ions (Oxygen) - sometimes 0.5 particles/cm^3 numeric density. These ions are wrongly considered as protons by HIA and one would have to derive the single fluid moments from HIA and CODIF data and performe the Walen analysis for this single fluid. Unfortunately we could not test this hypotesis because on Cluster3 the CODIF sensor experienced a severe degradation starting at the end of 2003.
- another possibility is that the MP changed its orientation during our approx. 2min interval. We actually put in evidence such a change.
- time stationarity is another issue
- in doing the Walen test one could have sampled plasma that entered the magnetopause on a different location. The Walen test should measure the change of momentum experienced by one elementary plasma volume.

▪ Despite this complication one has a fairly good indication of an RD.

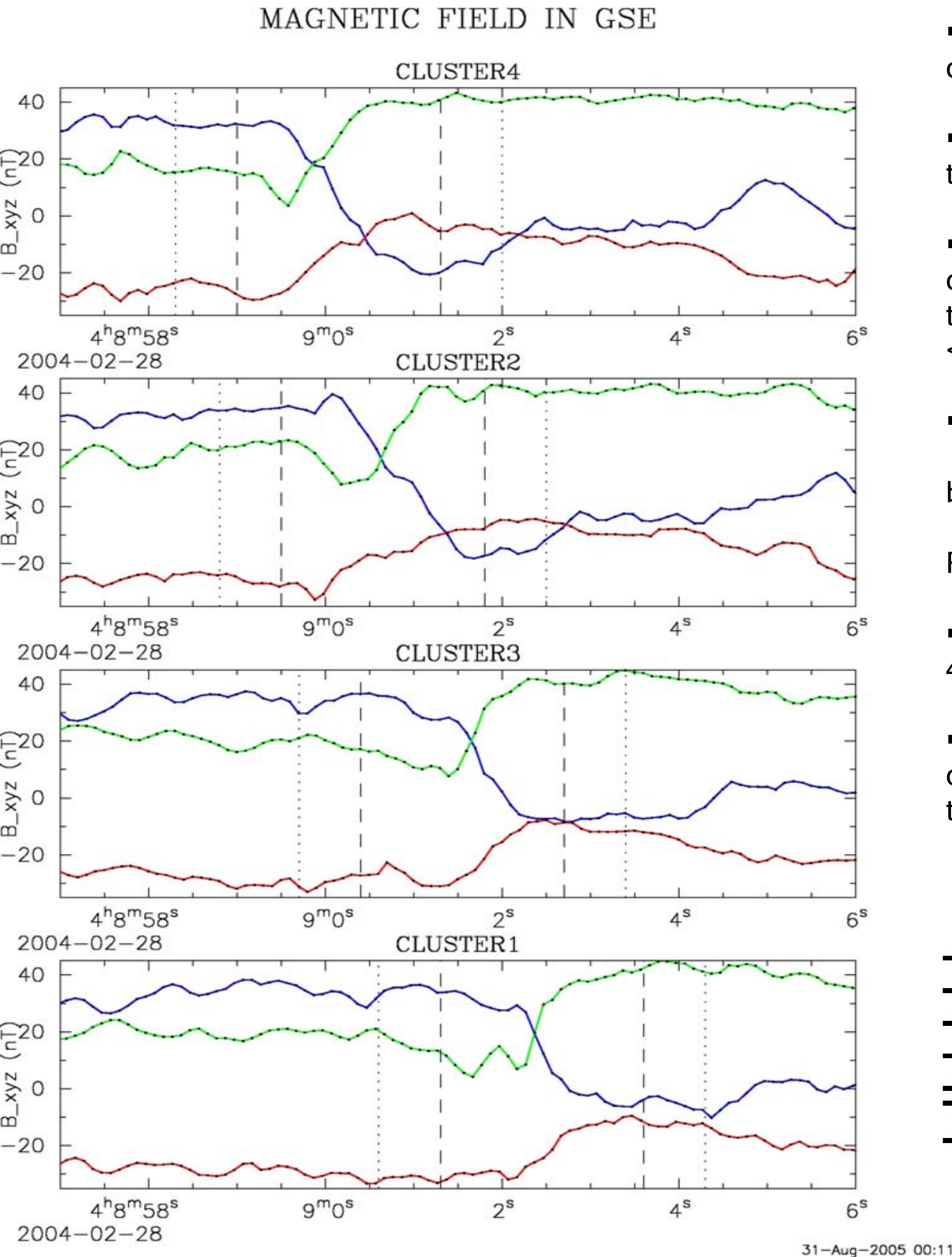


- The high resolution magnetic data (0.1 sec) for the inbound transition indicates a complex, fine structure which makes an analysis of the geometrical and dynamical propreties of the MP difficult.



- The high resolution magnetic data (0.1 sec) for the inbound transition indicates a complex, fine structure which makes an analysis of the geometrical and dynamical propreties of the MP difficult.

- We selected one clean partial transition around 04:09 for this purpose.



- We performed an MVA analyis to determine the orientation of the MP for this partial transition.

- For each SC we selected 8 nested intervals, centered on the transition

- Due to the instability and not-acceptable results for the un-constrained MVA analysis, we chose to impose the constraint that on average there is no magnetic normal component: <Bn> = 0.

- The reasons for that are:
  - we gain very much in stability (2 order of magnitude between inter. and maximum eigenvalues)
  - the necessary normal magnetic component, proper to the RD, should have a small value

- The average of the 8 normals for each satellite provides us 4 individual normals

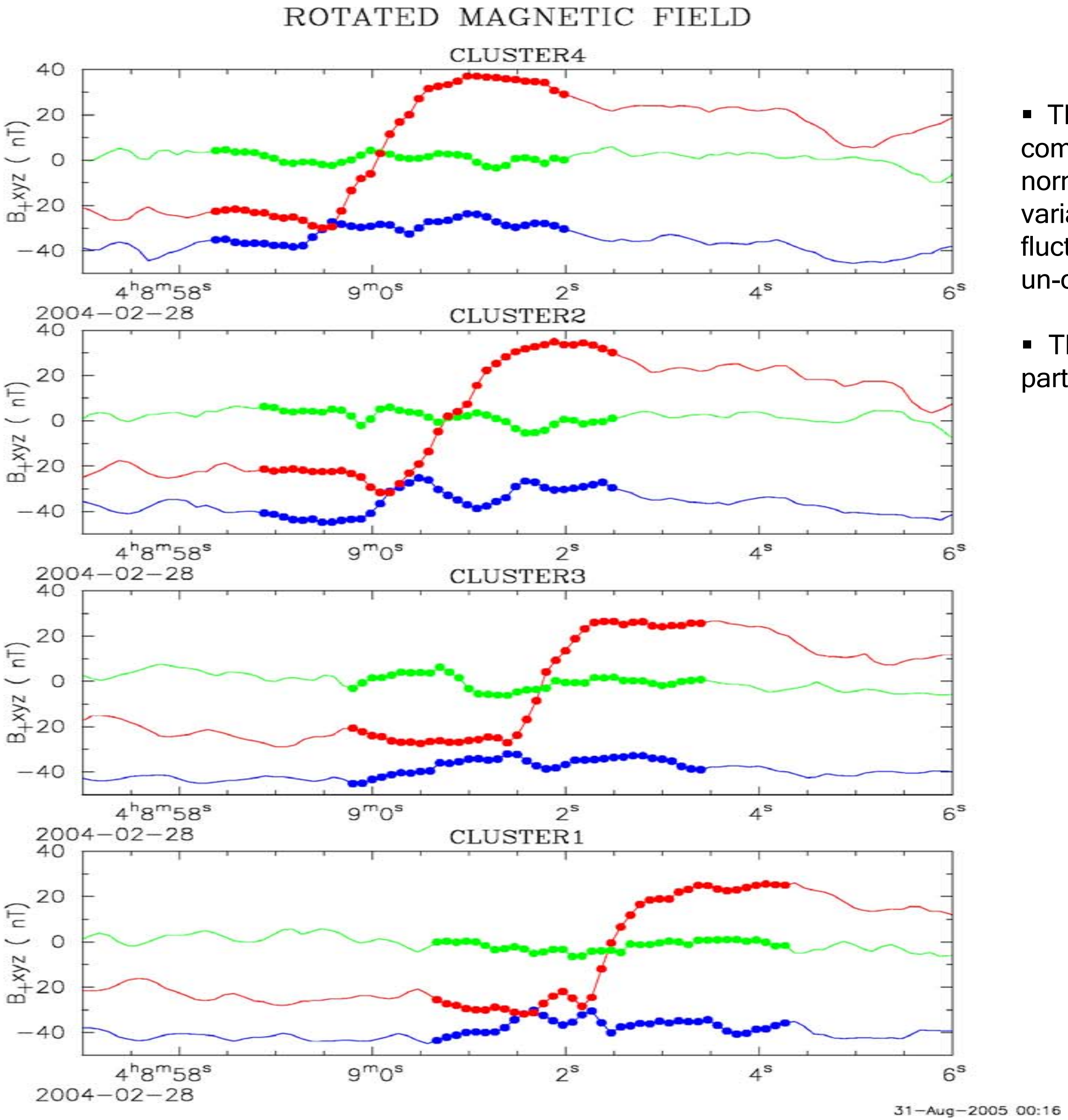
- Averaging again the 4 individual normals we obtain a common normal for all satellites.With respect to this direction, the individual directions are within approx. 5 deg.

Normal components in GSE

n1 =	[0.6177, 0.2856, 0.7326]
n2 =	[0.4698, 0.3054, 0.8283]
n3 =	[0.5628, 0.2888, 0.7744]
n4 =	[0.5496, 0.2693, 0.7908]
n ave=	[0.5511, 0.2879, 0.7832]

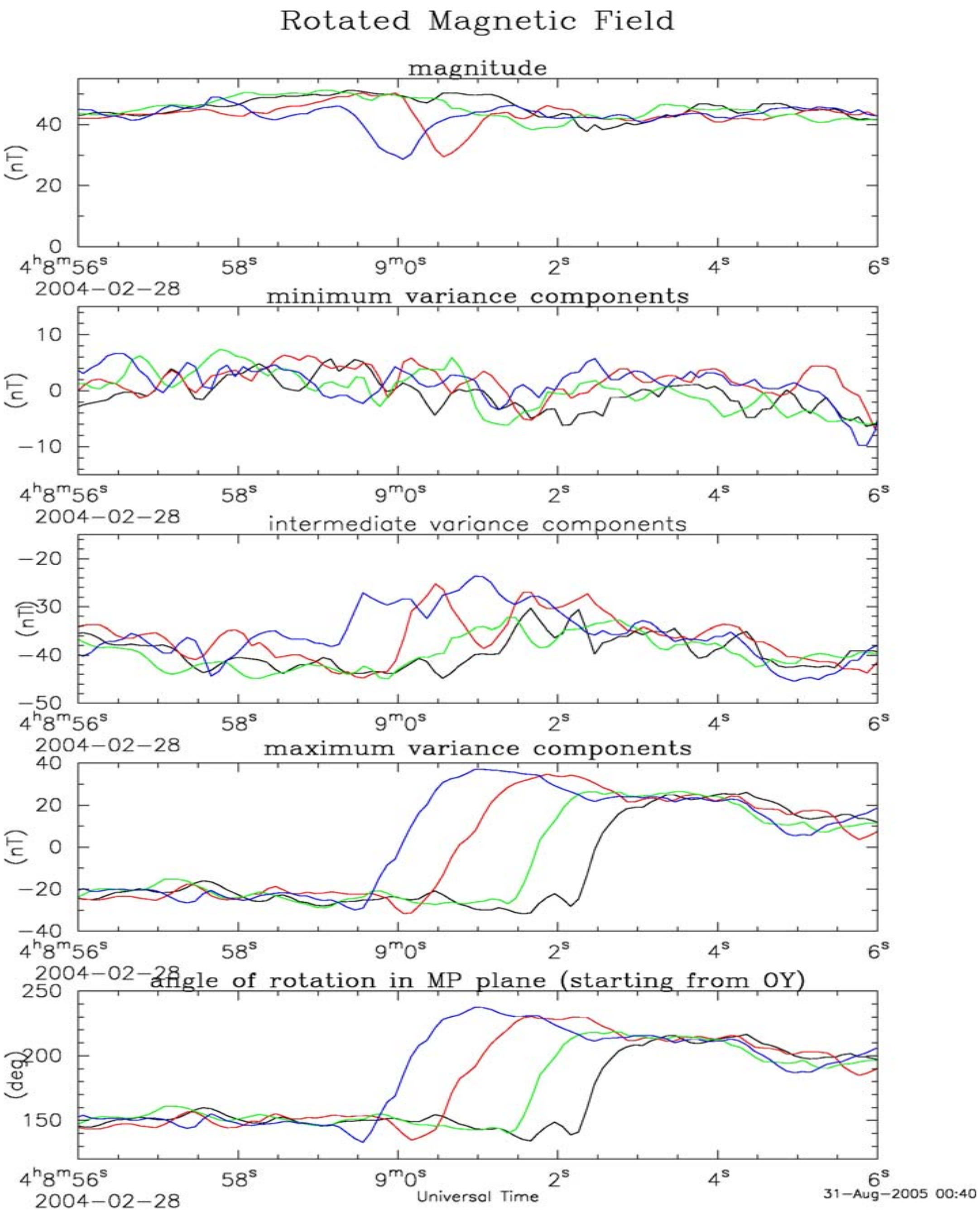
Angle between common and individual normals (degree)

	n1	n2	n3	n4
n ave	4.85	5.44	1.08	1.35



- The plots with the rotated magnetic field components with respect to the common normal n_ave show that the intermediate variance components (blue) have also small fluctuations, explaining the insuccess of the un-constrained MVA analysis.

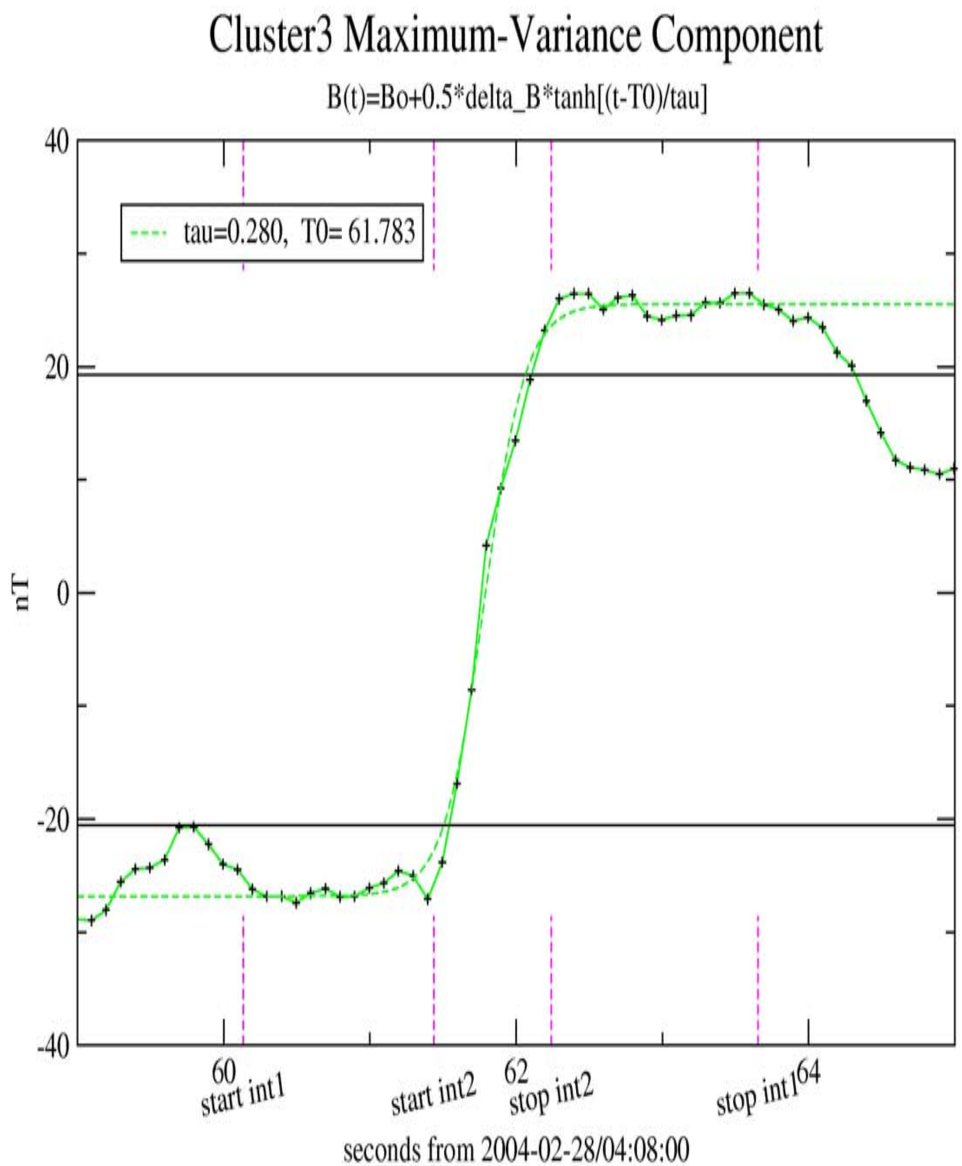
- The dots represents the points that participated in the MVA analysis.



- The overlaid traces of the magnetic field corresponding to all satellites indicate that the best componets to be used for a timing analysis are the maximum variance components and the angle of the rotation in the MP plane

- The last two pannels show also that these components are not nested and that before and after the transitions the levels are approx. the same for all SC.

- This suggests that we have actually completely cross a sublayer of the MP for which we could try to determine the normal, the velocity and the thickness.



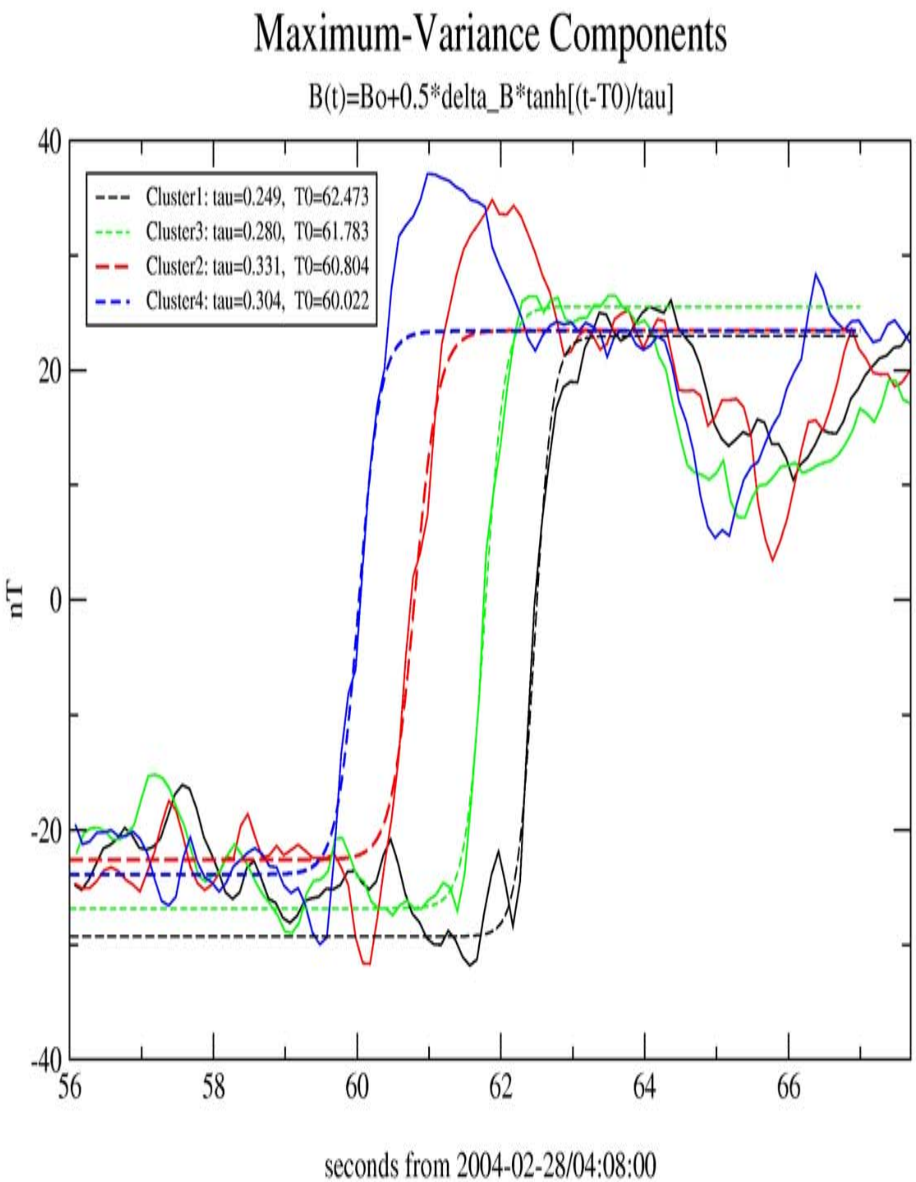
- For a better timing detemination between the satellites and also for a precise determination of the crossing durations we fitted the data.

- We followed the technique described in Haaland et al. (Ann. Geophy. 2004).

- We chose a tangential hiperbolic profile for the fit, searching for the parameters that describe the - and + ∞ levels, the central time To and the interval where most of the change in the magnetic field occurs (tau).

- In what follows, by crossing duration we mean the interval of 2*tau centred on the To.

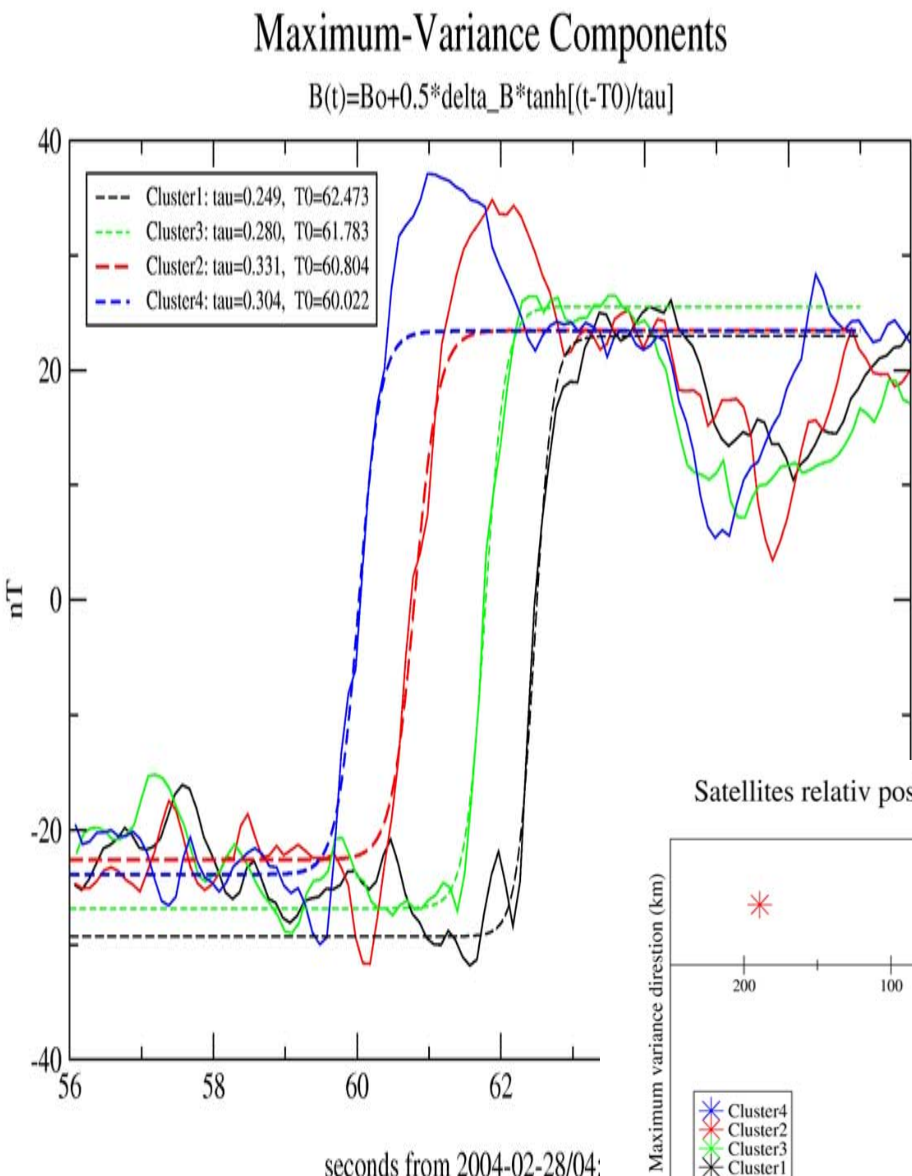
- In determining the fit parameters we followed a two step procedures:
  - the point at the transition and adiacent to it gives us a first values of the parameters (between start int1 and stop int1)
  - keeping the parameters that describe the - and + ∞ levels we re-ran the fit program only for the central points (between start int2 and stop int2) to obtain refined values for T0 and tau



- The fits for all SC were very good, allowing the precise determination of the timing and of the crossing durations.
- We have exluded from the fitting proccess the two bumbs right after the transition on SC4 and SC2, imposing in this way the fact that the satellites reach finally the same magnetic level.
- If we assume that the discontinuity is locally planar and moves with a constant normal velocity, than from the timing alone we could determine the orientation and magnitude of this velocity (CVA analysis). Then from the crossing durations we obtain the thickness as seen by each satellite
- If we assume that the discontinuity is planar and has a constant thickness we determine from the timing the normal and the thickness. Afterwards from the crossing durations we can compute the discontinuity velocities at each satellite level (CTA analysis)
- We could combine the two methods and obtain different results for velocity and thickness at each SC level.

Results ot the timing analysis

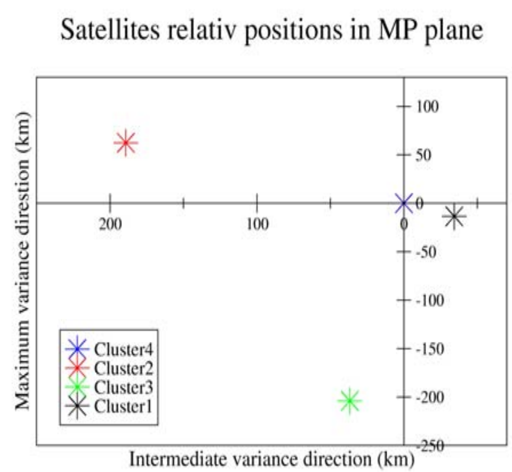
Satellite	SC4	SC2	SC3	SC1		
n cva	[0.5653, 0.2978, 0.7692]					
v cva	126.9 km/s					
d cva	77.1	84	71	63.2	73.8	km
n cta	[0.5494, 0.3677, 0.7503]					
v cta	124.98	114.79	135.7	152.59	132.02	km/s
d cta	75.99 km					
n cvt	[0.5577, 0.333, 0.7603]					
v cvt	122.56	122.59	121.82	130.42	124.35	km/s
d cvt	74.5	80.7	73	71	74.8	km

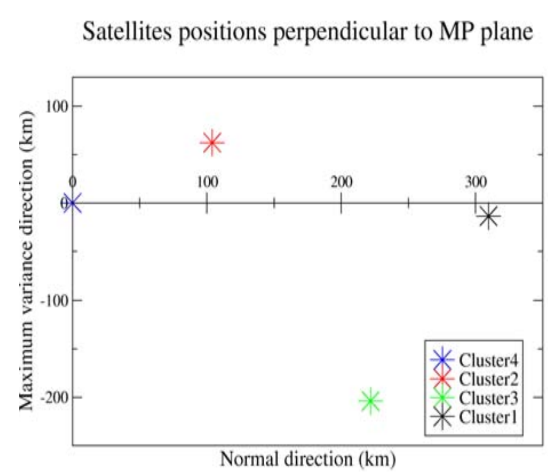


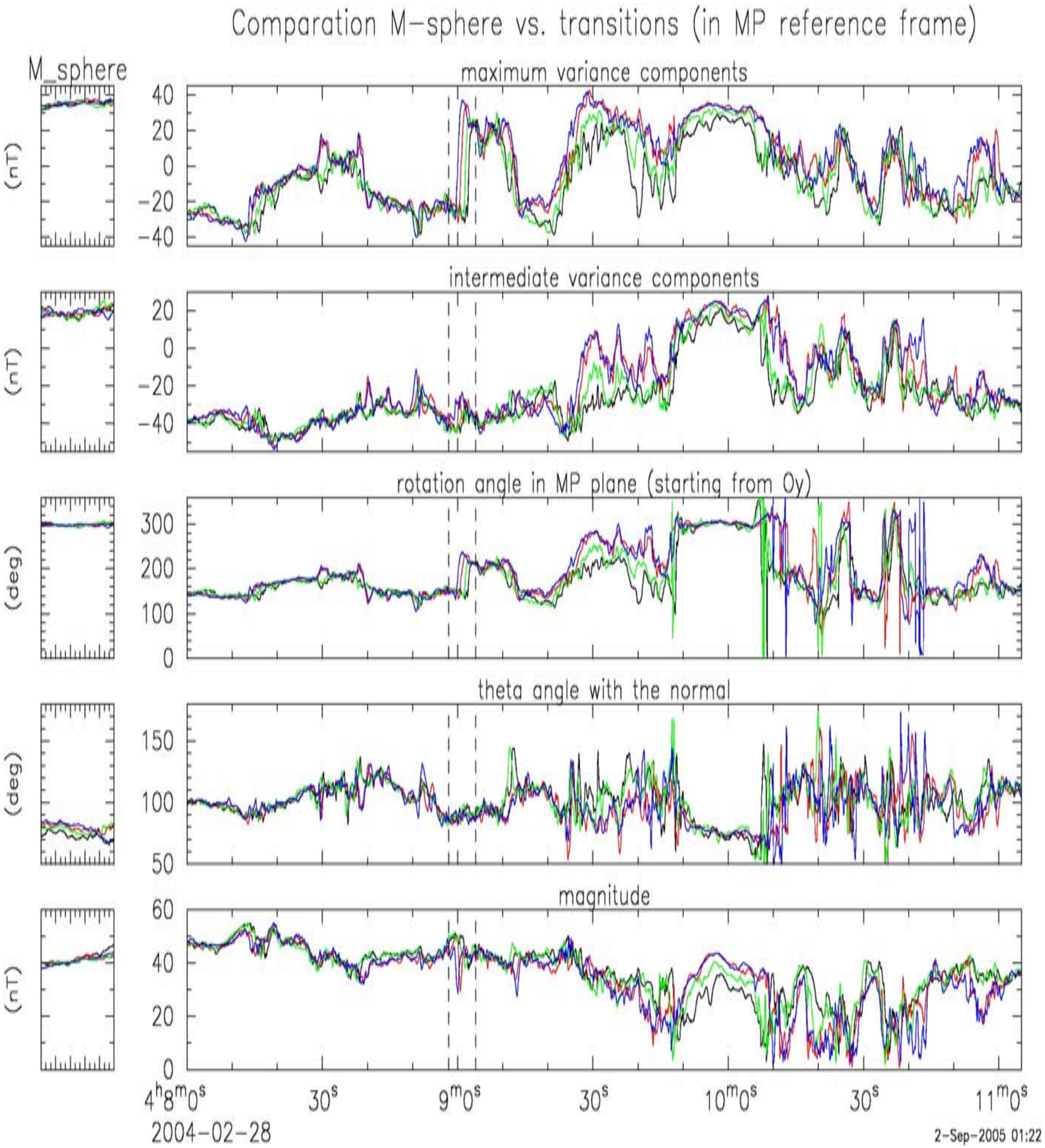
- A comparison between the results obtain for the MP normal by the single-spacecraft (MVA) method and a multi-spacecraft (timing) method inidicates a very good agreement.

Angle between normals from timing and MVA methods (degree)			
	n cta	n cva	n cvt
n ave	4.95	1.38	2.94

- From the relative positions of the Cluster constellation we can judge the nature of the two bumbs in the SC4 and SC2 maximum variance traces. We see that SC1 - the latest in the MP - and SC4 are approx. along the same normal but the bump dissapear in between these two crossings. As the two bumps are not nested we can say that they are time-variation signatures. Taking into account the drop in the magnetic module seen at SC4 and 3...







▪ The giro-radius at the time of our transition is approx. 55km and the ion inertial lenth approx. 70.5km. The proof that our crossing is only partial is crucial for the validity of MHD approx.

▪ A comparison between the M-Sphere magnetic levels and the field values for our transition shows that we have for sure a partial excursion in the MP (see the intermediate variance components which almost did not changed during our interval)

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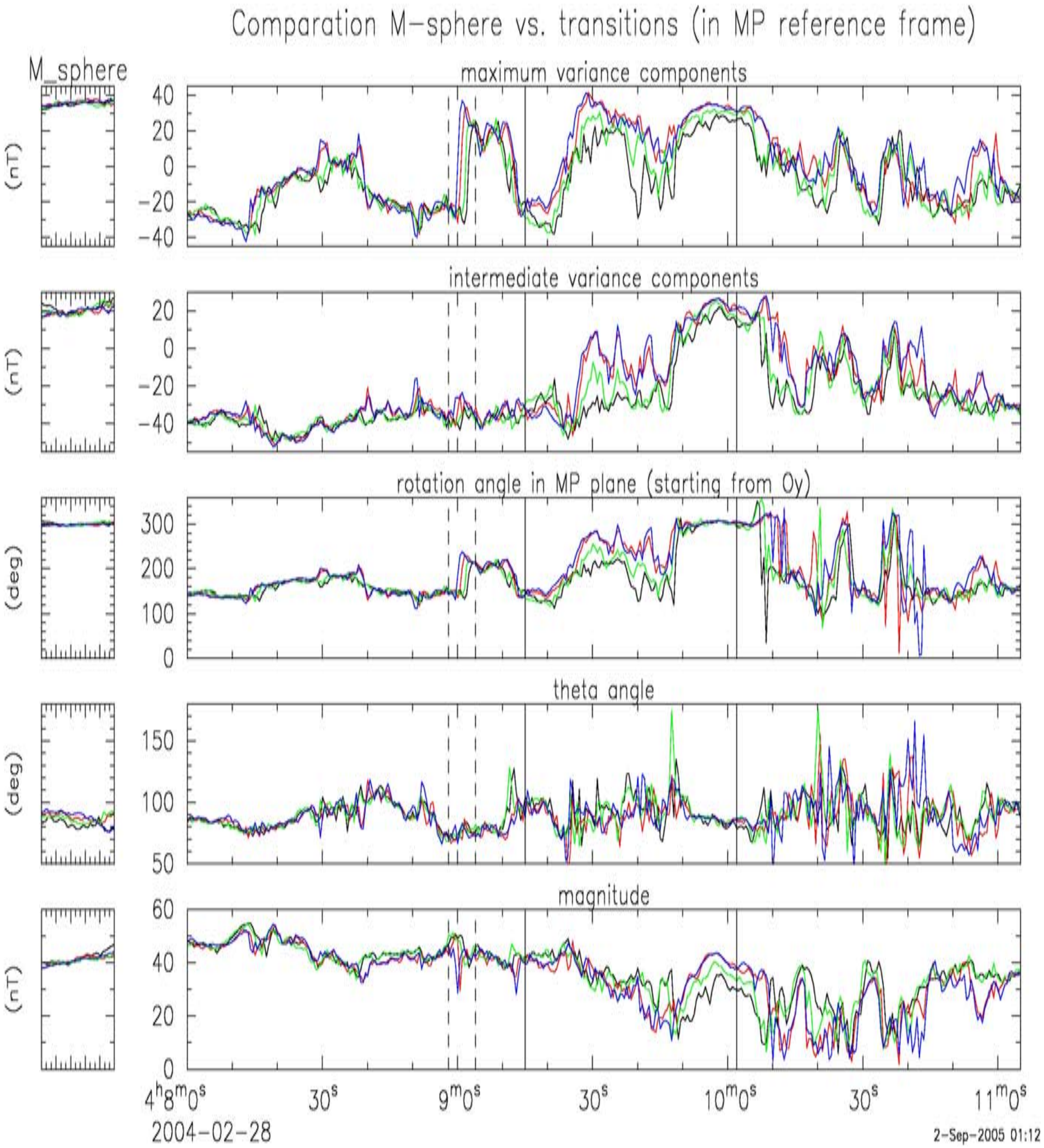

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▪We performed another MVA analysis on a larger interval that includes the big central transition to check how stable the normal was. In this case we use data of 0.5 sec. resolution and performed a nested unconstrained MVA for each SC (on 11 intervals). Again, the results are stable.

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Angle between common and individual normals (degree)				
	N1	N2	N3	N4
N_ave	4.69	5.6	3.11	2.04

▪ The angle between N_ave and n_ave is 16.77 deg. But the picture remained essentially the same so our statement that we have only a partial crossing is valid.

Summary and consistency checks

- We have a good agreement within the single spacecraft method (constrained MVA) of inferring the local orientation for the MP. The angles between the individual normals corresponding to each SC and the averaged direction are within approx. 5 degree
- The multispacecraft method (timing analysis) gives us close resuls to the previous one, again within 5 degree. The velocities obtained by using different assumptions like CTA and CVA are close and around 127 km/sec. The thickness values are around 75 km.
- One could do another consistency check that involves both magnetic field and plasma measurements on Cluster3. Here our deHT analysis essentially showed the data are consistent with a steady structure moving at a velocity of DeVT = [-282.6, 121.9, 312.4] km/sec. The component of this velocity along the normal should give us the MP velocity

DeHoffmann-Teller velocity normal to the MP					
	n ave	n cta	n cva	n ctv	
V HT*n	124	116.8	124	120.5	km/sec.

- According to the positive slope in the Walen test, the normal component of the magnetic field should be negative. Apart from the CTA method this is indeed the case:

Magnetic field component along the normal					
	n ave	n cta	n cva	n ctv	
Bn	-2.35	0.73	-1.44	-0.36	nT

- If we compute the scalar product between HIA measured velocity and the normal to the MP and correct it for the normal Alfven velocity one should obtain the velocity of the magnetopause. Again, apart from CTA method we obtained close results:

Cluster3 on-board HIA velocity normal to the MP (corrected from the normal Alfven velocity)					
	n ave	n cta	n cva	n ctv	
V HIA*n – VA n	117	149.7	119	134.4	km/sec.

The report covers the period between 9th of February and 8th of April 2004.
All the crossings are in the northern hemisphere and approx. at local magnetic noon.
We considered a DeHT test unsuccessful when the correlation coefficient was below 0.95
In judging the Walen test we pay attention to the dynamic range of the velocities (discard cases where the points corresponding to different components were acumulated in isolated clouds)

Total of crossings	52
Rotational discontinuities	17
Tangential discontinuities	31
Uncertain	4

	min	max	ave	0.6 – 0.7	0.7 – 0.8	0.9 – 1.0
Walen slope (module)	0.6183	0.8809	0.7108	10	3	4

	min	max	ave	0.85 – 0.90	0.90 – 0.95	0.95 – 1.0
Walen cc	0.8656	0.9929	0.9404	2	7	7