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Comparing the boundaries of interplanetary coronal mass ejections

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Introduction

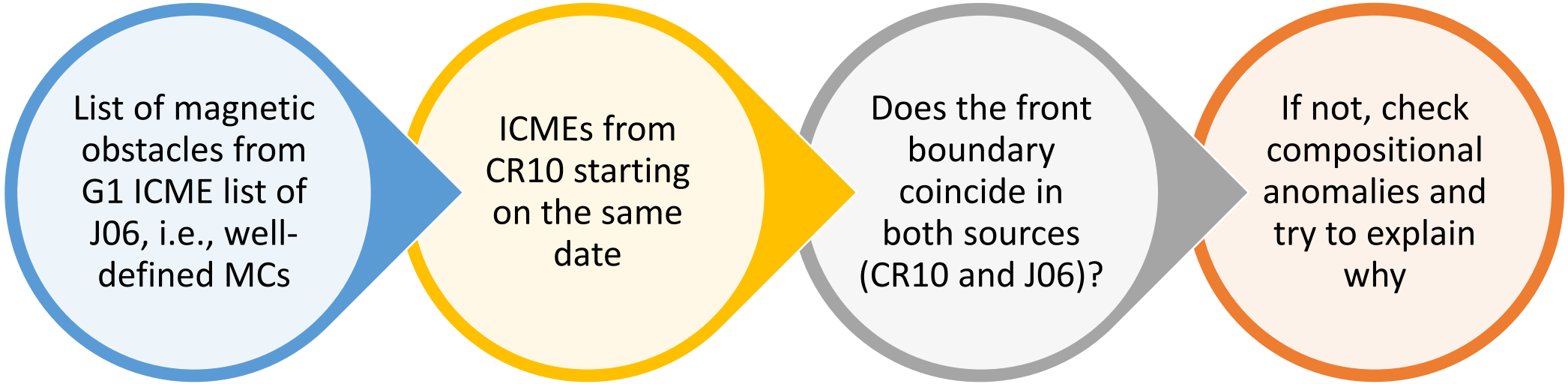
- Interplanetary mass ejections (ICMEs) are the material in the solar wind now believed to be the interplanetary counterpart of coronal mass ejections (CMEs)
- Signatures of ICMEs include:
  - Abnormally low proton temperature
  - Enhanced magnetic fields
  - Rotating magnetic field slowly through a large angle
  - Declining velocity
  - Low plasma beta
  - Low electron temperature
  - Bidirectional suprathermal electron strahls
  - Plasma compositional anomalies

  See for example the review Zurbuchen T.H. and Richardson I.G. (2006) In-Situ Solar Wind and Magnetic Field Signatures of Interplanetary Coronal Mass Ejections. In: Coronal Mass Ejections. Space Sciences Series of ISSI, vol 21. Springer, New York, NY:
- None of these features appears to be unique to ICMEs or by itself a sufficient condition to identify an ICME. Moreover, **the boundaries of the ICME are different when considering different signatures**

The starting point

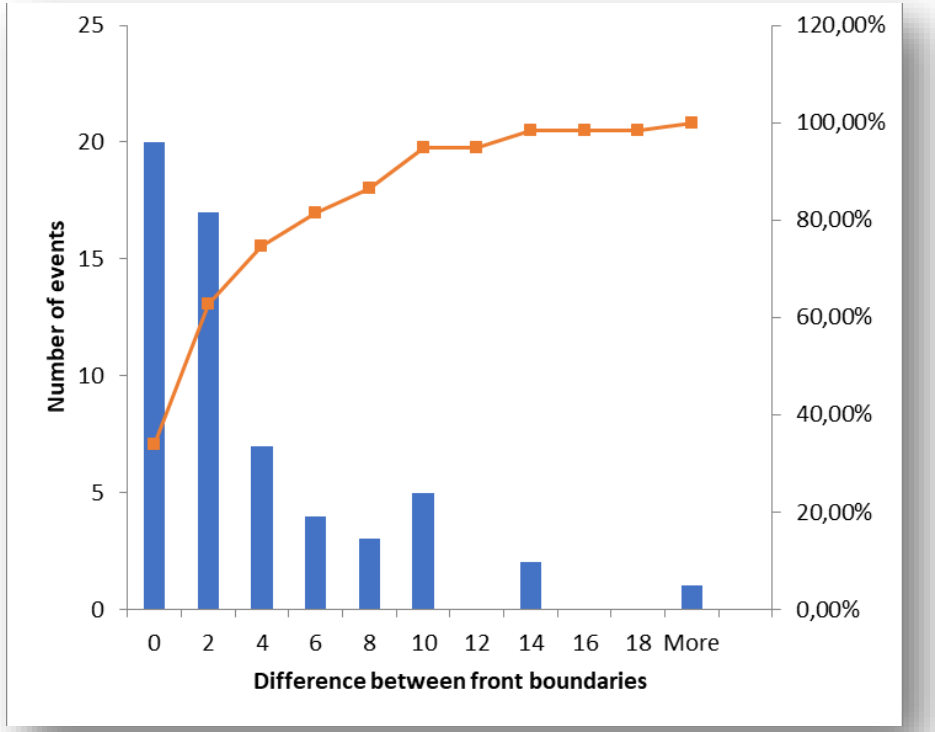
- We have started by considering the available ICMEs catalogues using ACE data:
  - Jian, L., Russell, C.T., Luhmann, J.G. et al., Properties of Interplanetary Coronal Mass Ejections at one AU during 1995 – 2004. Sol Phys 239, 393–436 (2006)**, after J06**
  - Cane, H. V., and Richardson, I. G., Interplanetary coronal mass ejections in the near-Earth solar wind during 1996–2002, J. Geophys. Res., 108, 1156 (2003), **after CR10**
- The definition of ICME is not the same in both cases
  - CR10 primary identifying signature is the occurrence of abnormally low proton temperatures ($T<T_{expected}$). Then they check magnetic field signatures
  - J06 set the boundaries of all ICMEs associated with the outer distinct plasma and magnetic field discontinuities. Thus, their ICMEs include the shock (if it occurs), sheath pile-up region and the ejecta driver. For all the events with apparent magnetic obstacle structures, they provide the start/end time of magnetic obstacle. There is a classification in three groups, considering the presence of MC signatures (clear signatures G1-> glancing encounters G3)

The Procedure



Does the front boundary coincide in both sources?

- We assume that the front boundary coincides when the difference between both sources is less or equal to 4 h
- Why?
  - Resolution of composition data from ACE/SWICS is 2 hours, i.e., any uncertainty in the boundaries with this data will be ±2 h
  - Considering the histogram of the difference (in hours) in the front bounday between both sources, we observe that ≈80% of events present a difference less than 4 h
- A sample of 16 events includes all the events where front boundary does not coincide in J06 and CR10

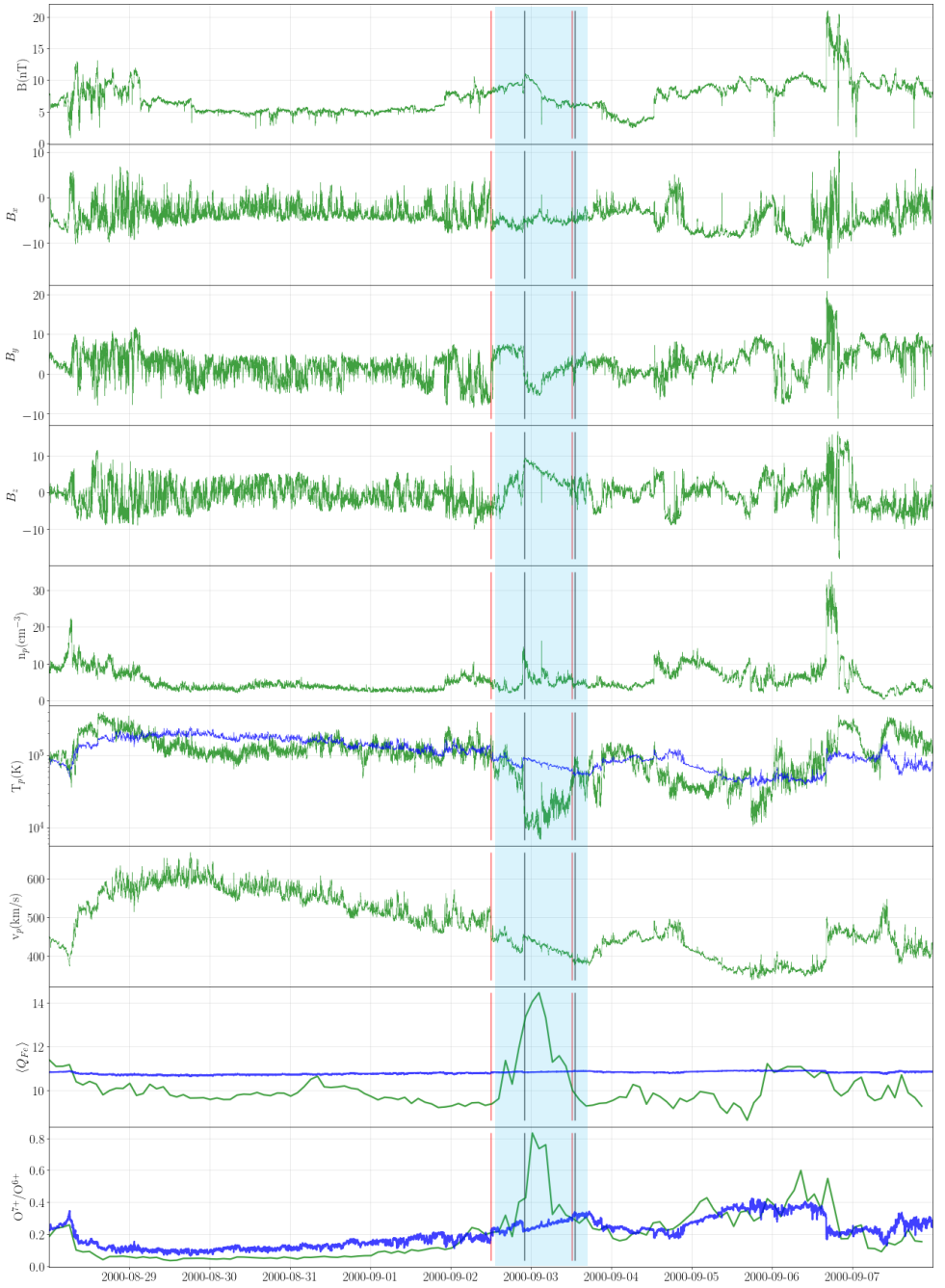


Some events as examples

- In the following slides we show some events as examples of the sample
- All the plots are in the same format:
  - From top to bottom panels show the magnetic field strength and GSM components, the proton density, temperature and speed, the average Fe charge state and the O^{7+}/O^{6+} ratio
  - Superimposed on the observed values are the expected values (as blue solid lines) inferred from the simultaneously observed solar wind, according to Table 1 of Richardson & Cane (2004)
  - The boundaries of the ICMEs according to RC10 appear as vertical black solid lines and those of the magnetic obstacle according to J06 in red
  - The blue area corresponds to ICME material, according to compositional anomalies

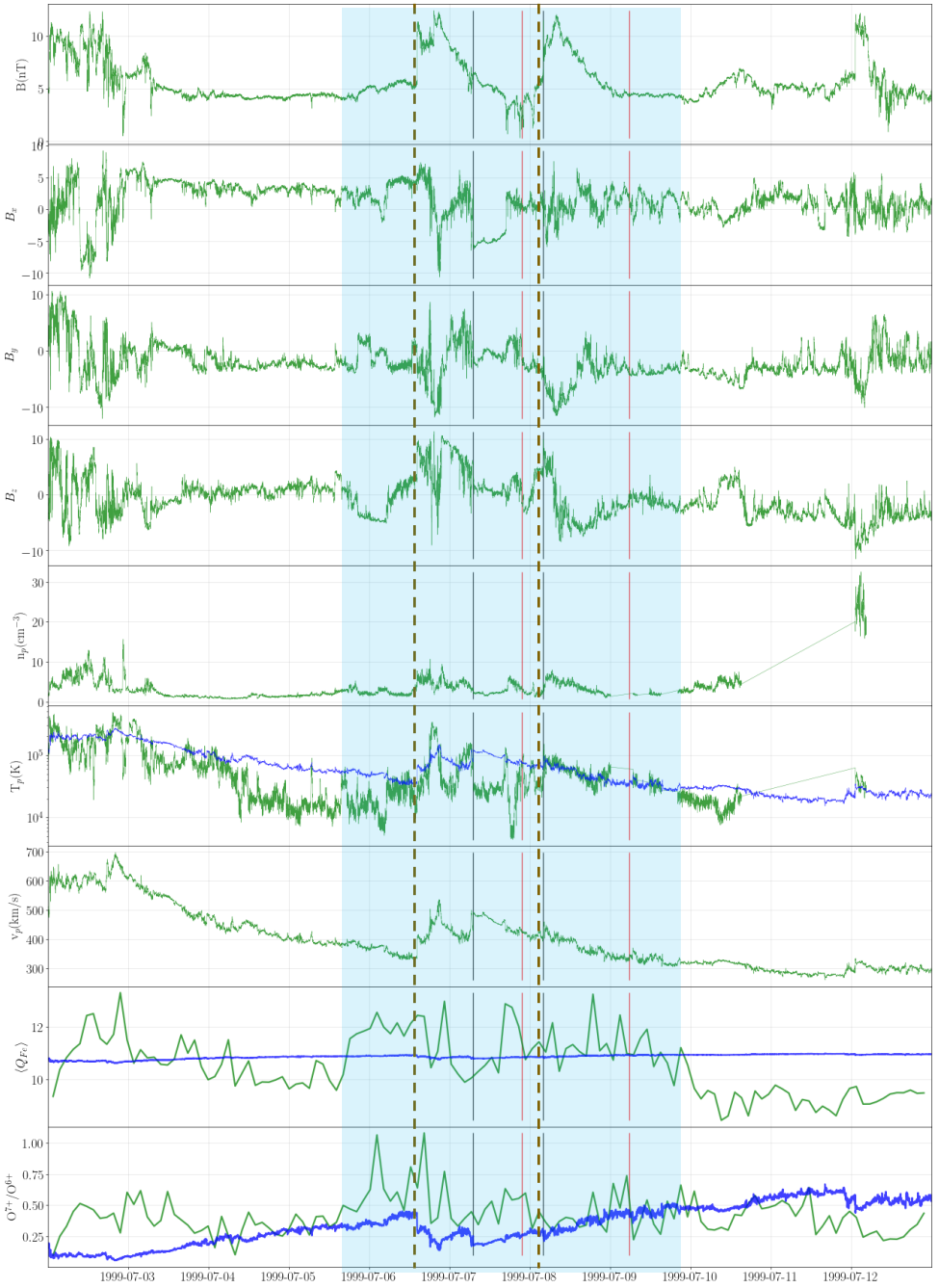
Event 2000 September 02

- The ICME is immersed in a fast stream
- The difference in the identification of the front is related to the interaction with the fast stream, which increases the proton temperature at the front boundary



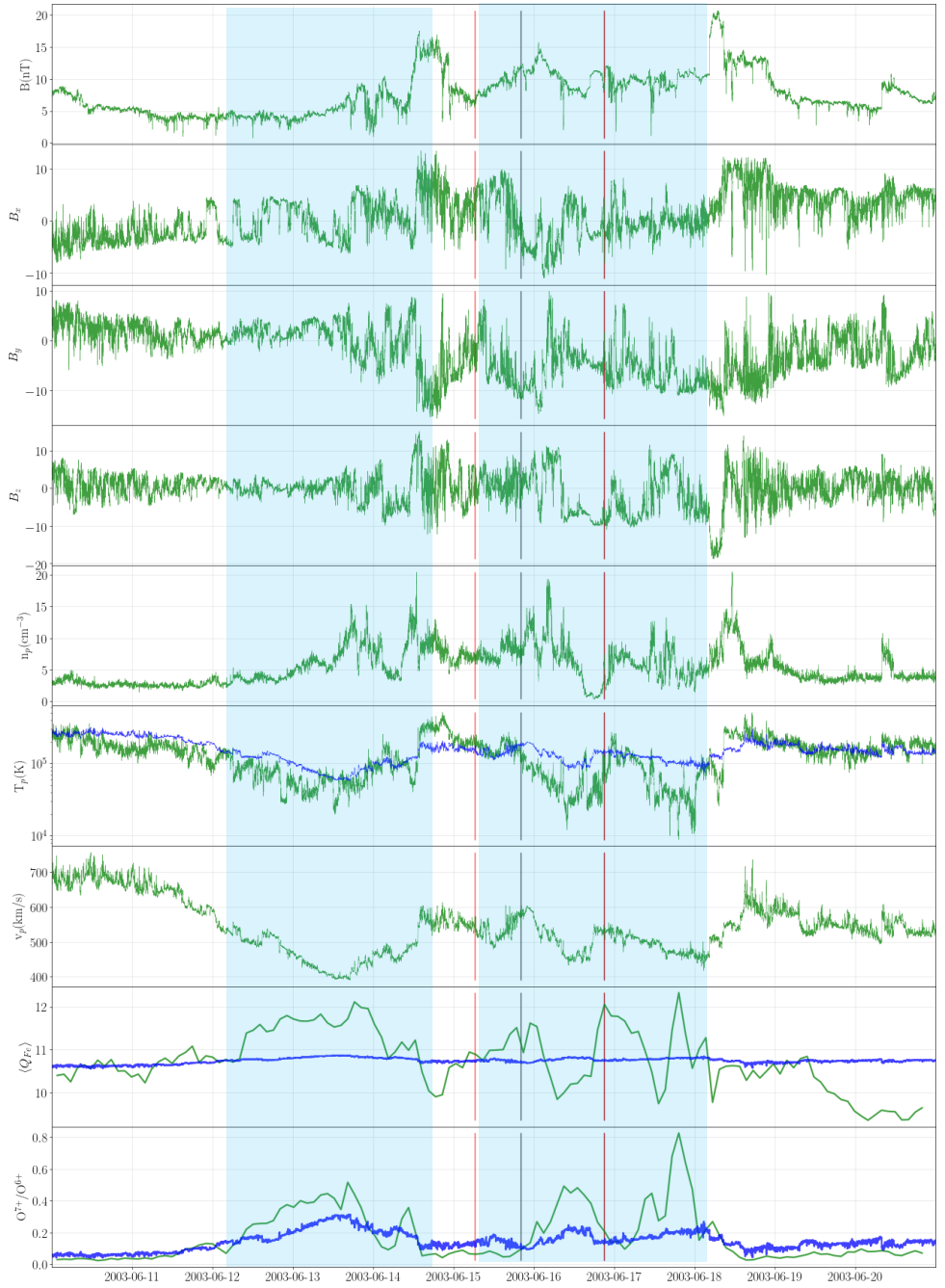
Event 1999 July 07

- Several interacting ICMEs (at least three) can be guessed within the blue area. Note the field discontinuities (dashed vertical lines)
- Solar wind parameters are consistent with CMEs overtaking a previous one (not previously identified)
- Interaction increases the temperature even inside the ICME material
- The differences between the boundaries from both sources are related to a complex event



Event 2003 June 15

- Two consecutive ICMEs clearly separated are immersed in fast streams from coronal holes
- Note the slow speed during the ICME intervals when compared to the external wind
- The fluctuating field inside the ICME intervals is the result of an advance interaction state
- Note the discrepancies between $<Q_{Fe}>$ and the O^{7+}/O^{6+} ratio in the second ICME interval



Conclusions and Open questions

- In all events where ICME front boundary does not coincide ($\Delta t > 4$ h) in both sources analyzed we have discovered some interaction between different interplanetary transients: ICME-ICME or ICME-fast stream
- Values of $<Q_{Fe}>$ and O^{7+}/O^{6+} ratio over expected values may provide a scenario where the boundaries determined by different plasma signatures (temperature or magnetic field) are modified in different ways due to the dynamic evolution of the ICME while traveling away from the Sun. Nevertheless, this evolution does not seem to modify the compositional boundaries

- Can $<Q_{Fe}>$ **and** the O^{7+}/O^{6+} ratio be considered as a sufficient condition for ICME material?
- And what about $<Q_{Fe}>$ and the O^{7+}/O^{6+} ratio providing opposite information?

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