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Mars plasma system response to space weather variability with solar cycle

Beatriz Sánchez-Cano

M. Lester, O. Witasse, P.-L. Blelly, et al.

bscmdr1@le.ac.uk

Credits: MEX VMC image

Outline

1. General description of the Mars' plasma system
2. Long-term solar cycle variability effects on Mars' ionosphere
   - Ionosphere modelling
3. Short-term solar cycle variability effects on Mars' ionosphere
   - Ionosphere modelling
   - ICME propagation throughout the solar system
   - ICME effects on Mars at high and low solar cycle phases

bscmdr1@le.ac.uk

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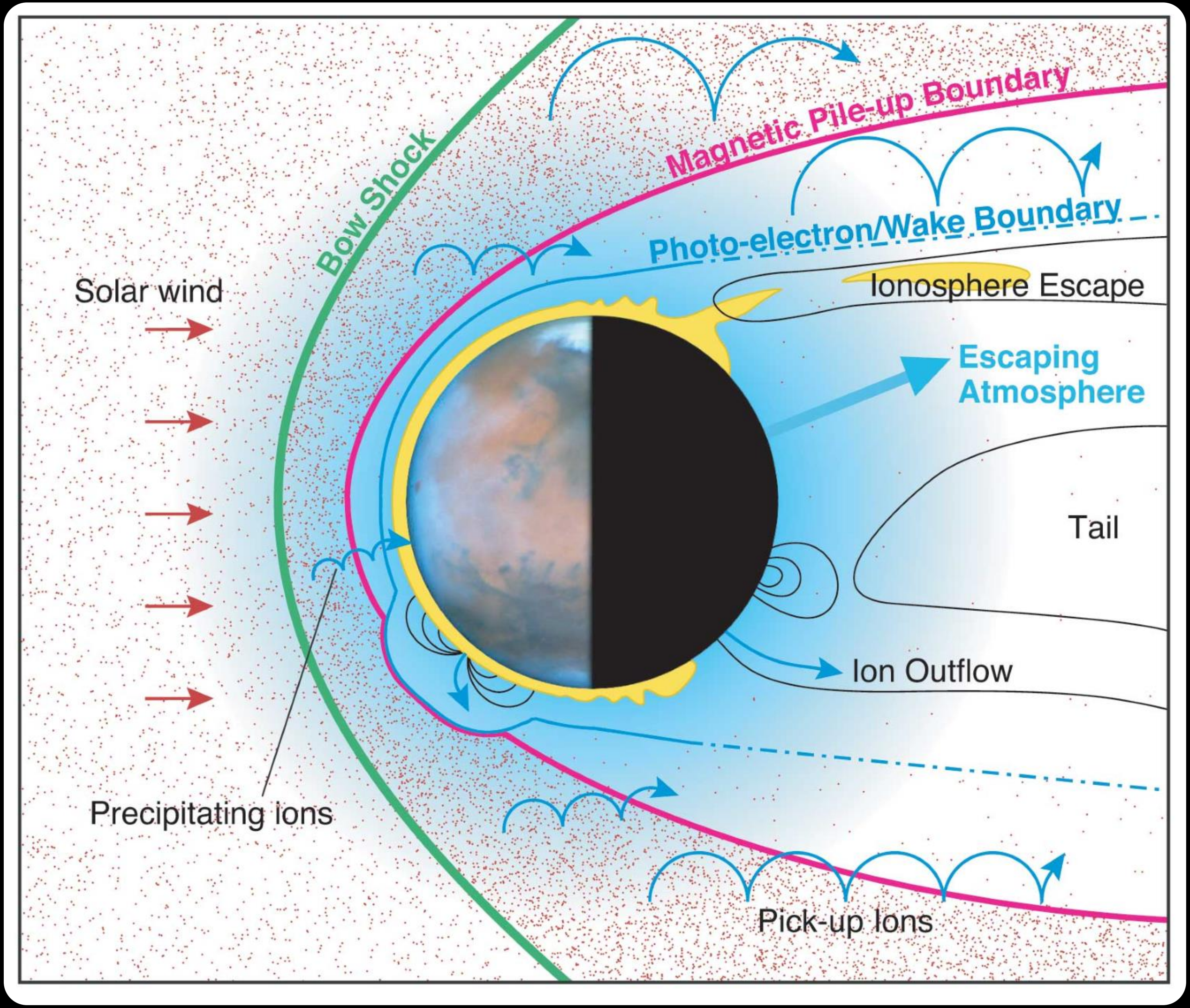
General description

bscmdr1@le.ac.uk

The Mars' plasma environment

Since Mars does not have a global intrinsic magnetic field, the Mars' upper atmosphere and ionosphere are the main obstacles that the solar wind finds at Mars.

Therefore, the "strength" of this obstacle is a determining factor to assess the behaviour of the Martian plasma with solar wind variability.



Credit: Fran Bagenal & Steve Bartlett, University of Colorado

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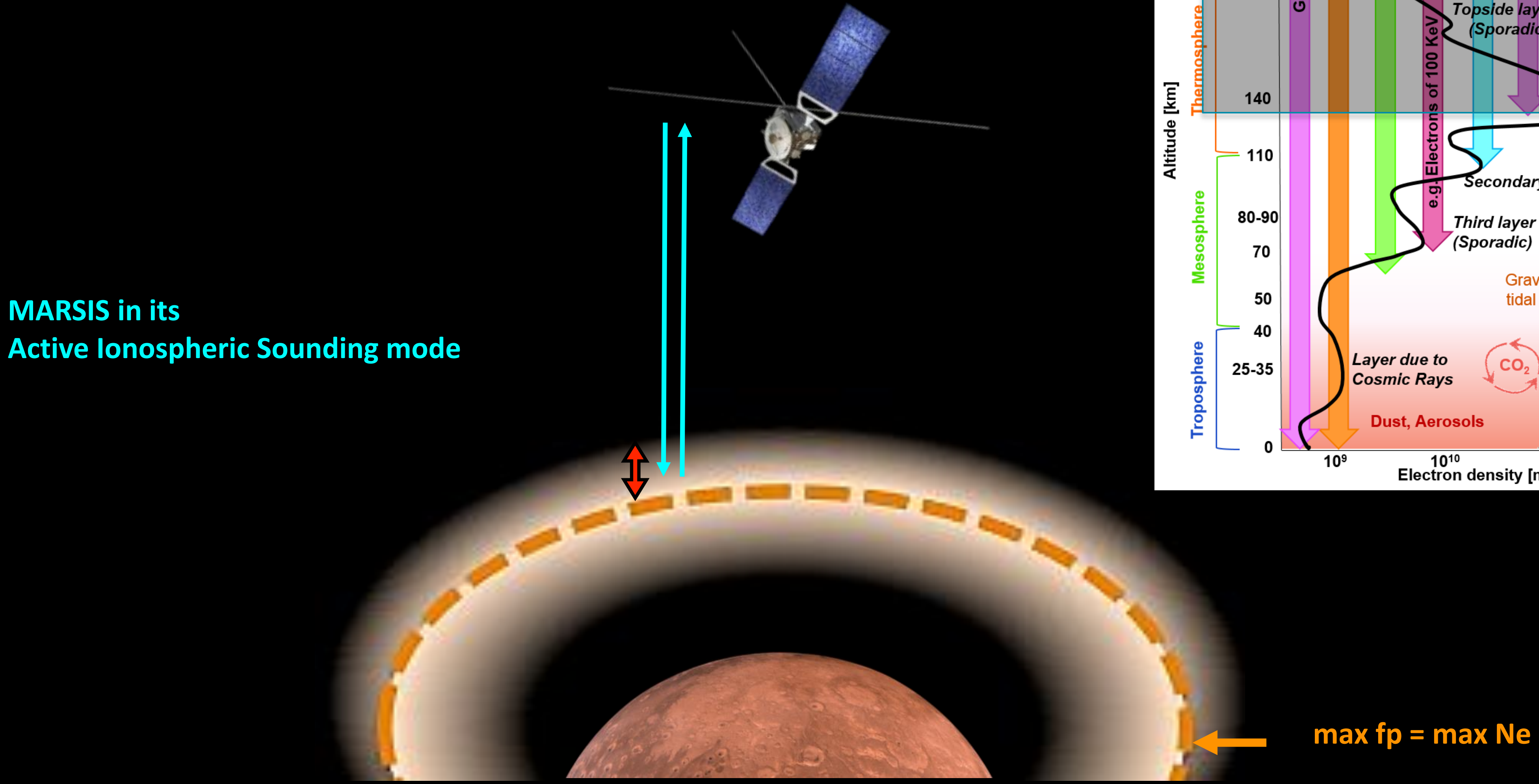
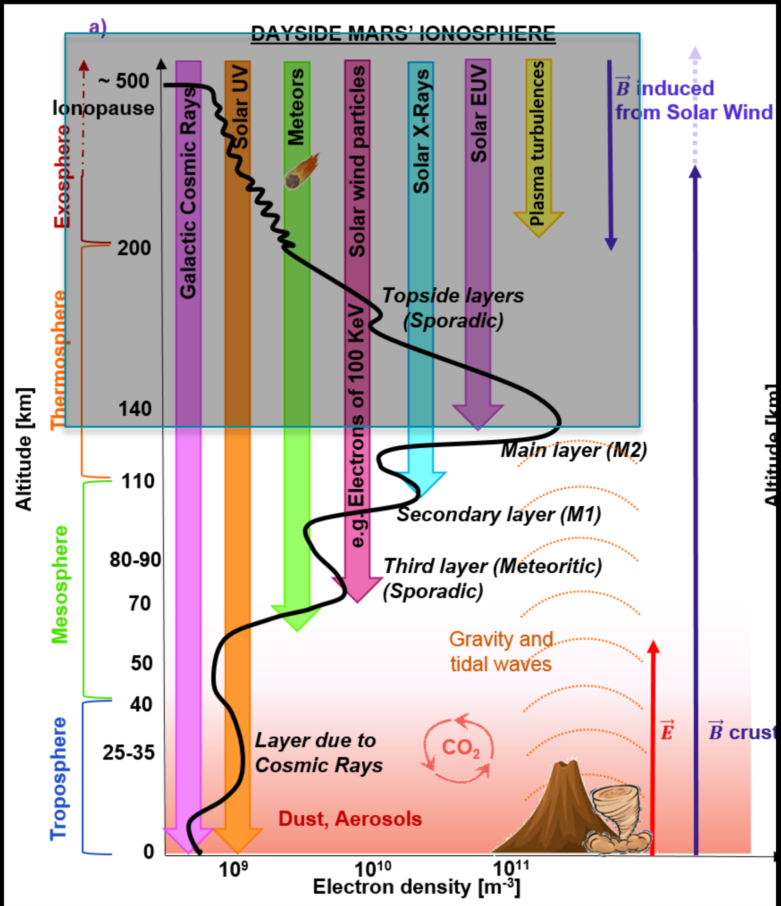
MARSIS-Mars Express radar





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Long-term variability

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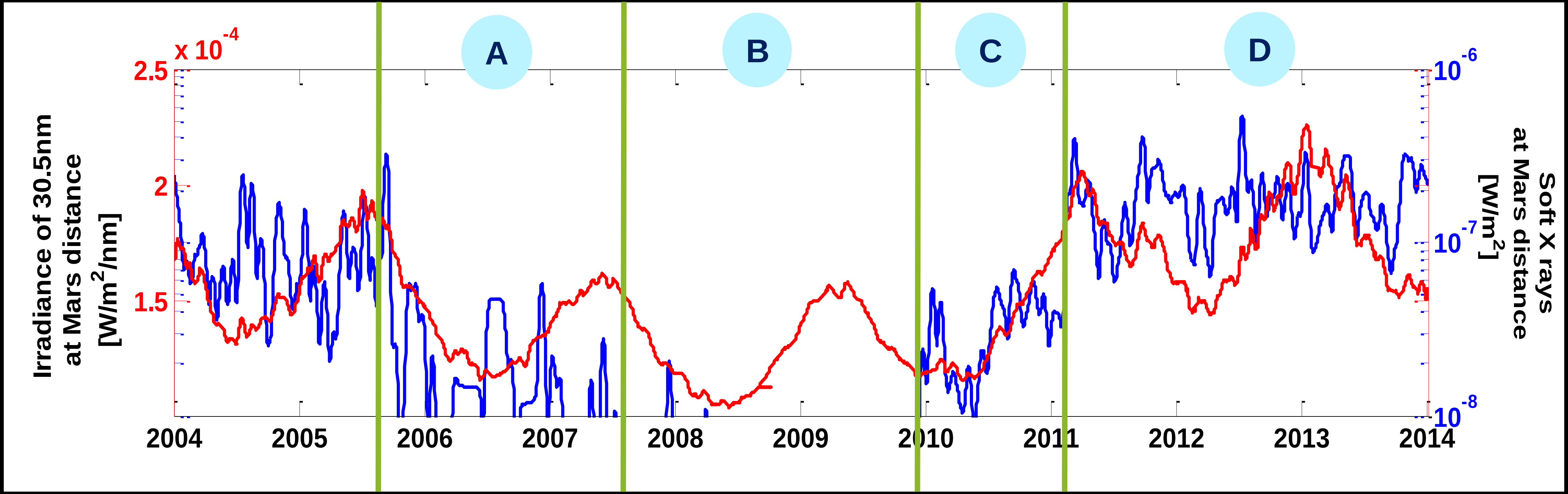
Solar cycle EUV and X-rays

EUV and soft X-ray play the major role in the formation of the ionosphere of Mars, and therefore, in the "strength" of the Martian obstacle to the solar wind



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Sanchez-Cano et al., 2015; 2016

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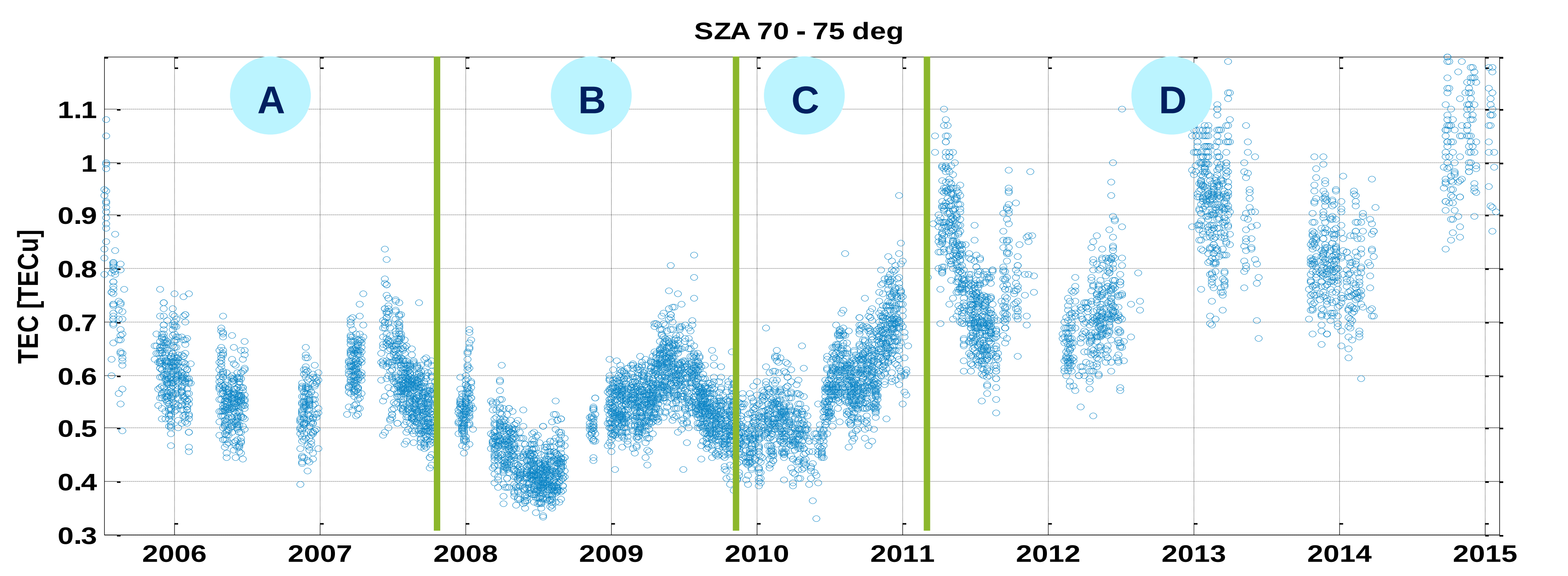
Solar cycle variations in the Martian ionosphere

Total Electron Content (TEC) of the full atmosphere gives us an idea of the strength of the Martian plasma obstacle that acts to deflect the solar wind flow.



SOLAR ACTIVITY LEGEND

A: Moderate declining phase
B: Low phase
C: Moderate increasing phase
D: High phase

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Data extended from Sanchez-Cano et al., 2016

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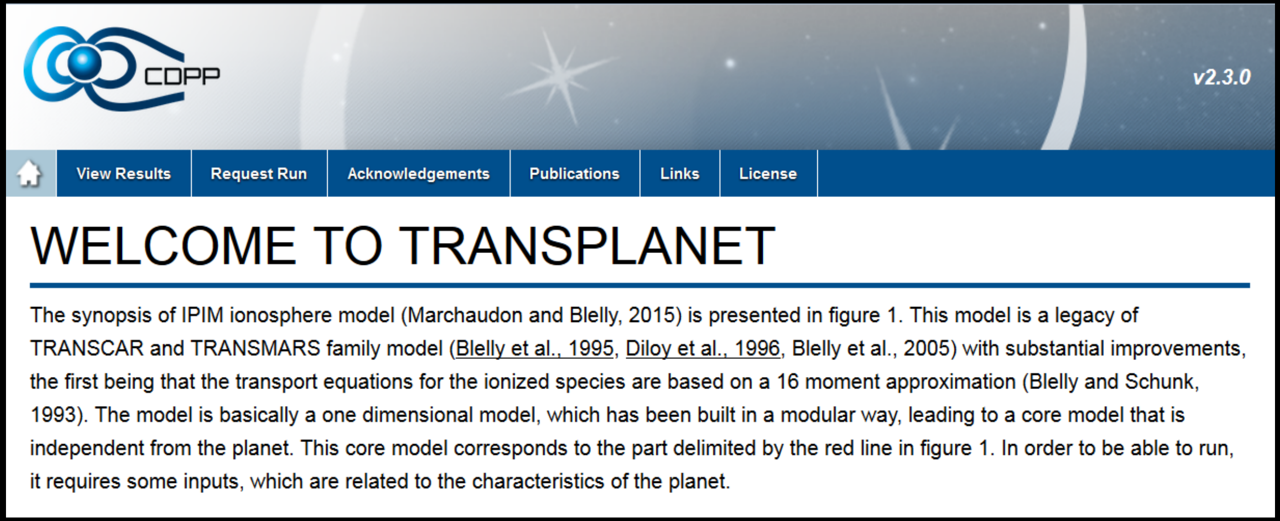
Ionospheric modelling: TRANSPLANET

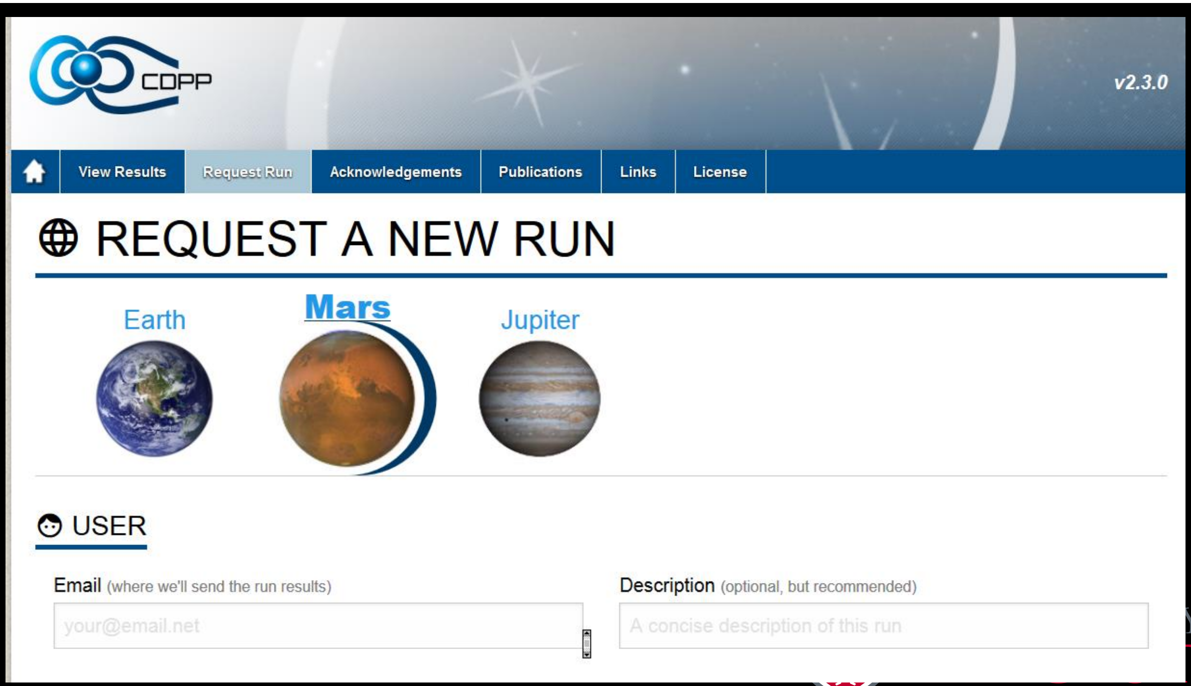
In order to study the space weather variability effect on the ionosphere of Mars, we have used the IPIM model in several studies

http://transplanet.irap.omp.eu/

IPIM is a one dimensional coupled kinetical model, which has been built in a modular way, leading to a core model that is independent from the planet.

The interment interface is very convenient because the model is very complex to run.





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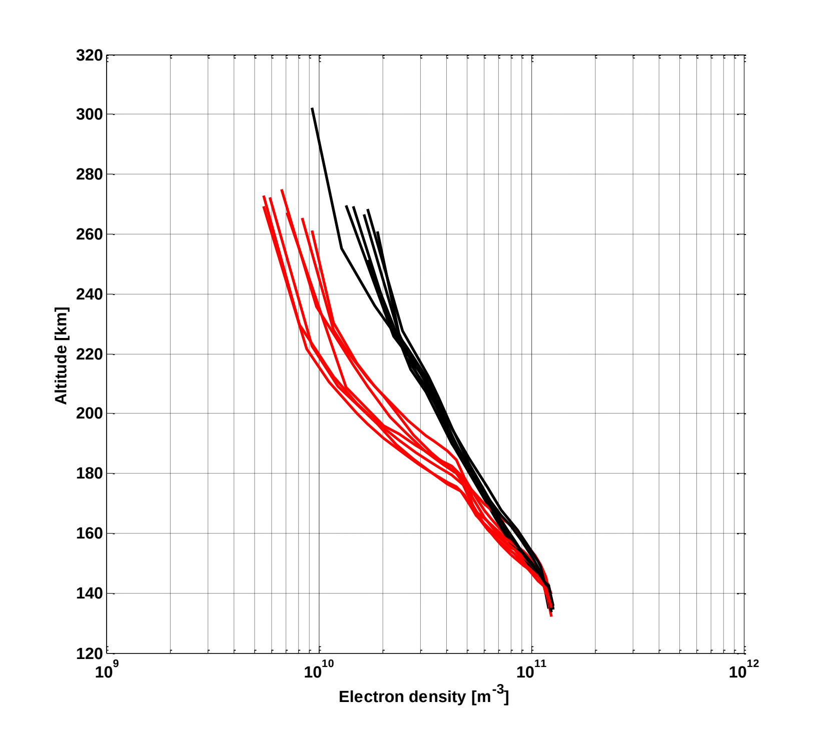
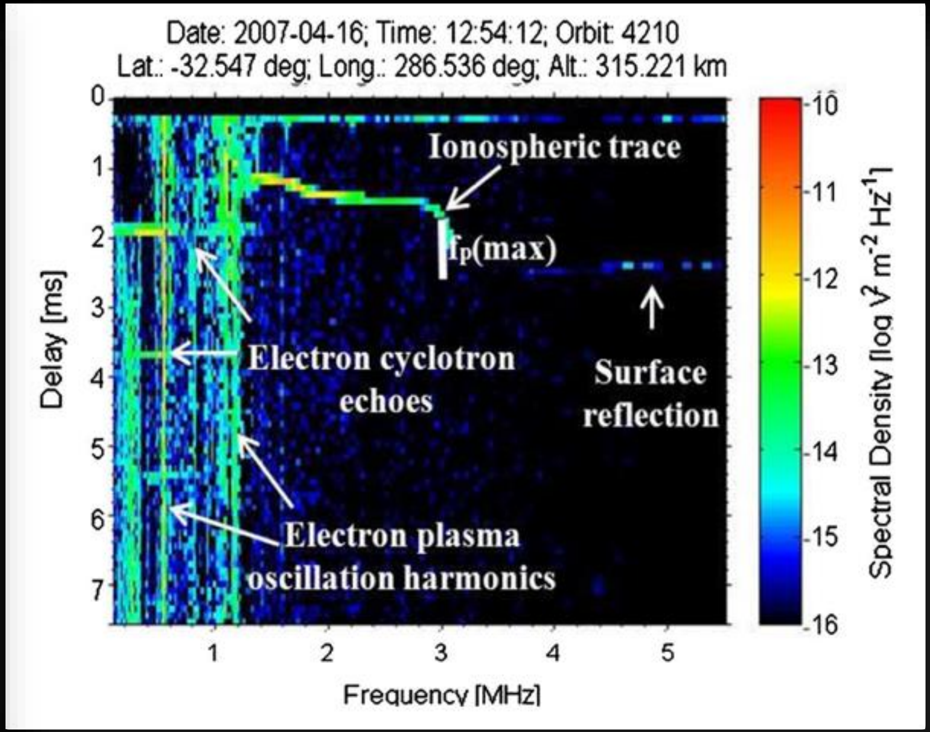
Case study I: solar cycle effect

Since the ionosphere was much weaker during the low solar activity phase, the thermal pressure of the ionosphere was very close to the magnitude of the dynamic pressure of the solar wind.

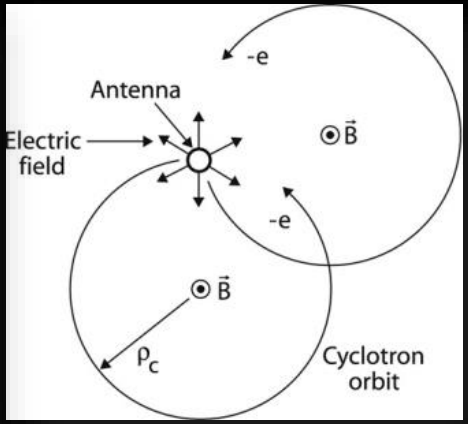
To evaluate the effect of this pressure relationship on the ionosphere, we selected profiles with similar conditions from 2 Mars Express orbits, a case study and made an ionospheric simulation.



Sanchez-Cano et al., 2015b



Sanchez-Cano et al., 2012



$$2\pi f = \frac{qB}{m}$$

Gurnett et al. 2008

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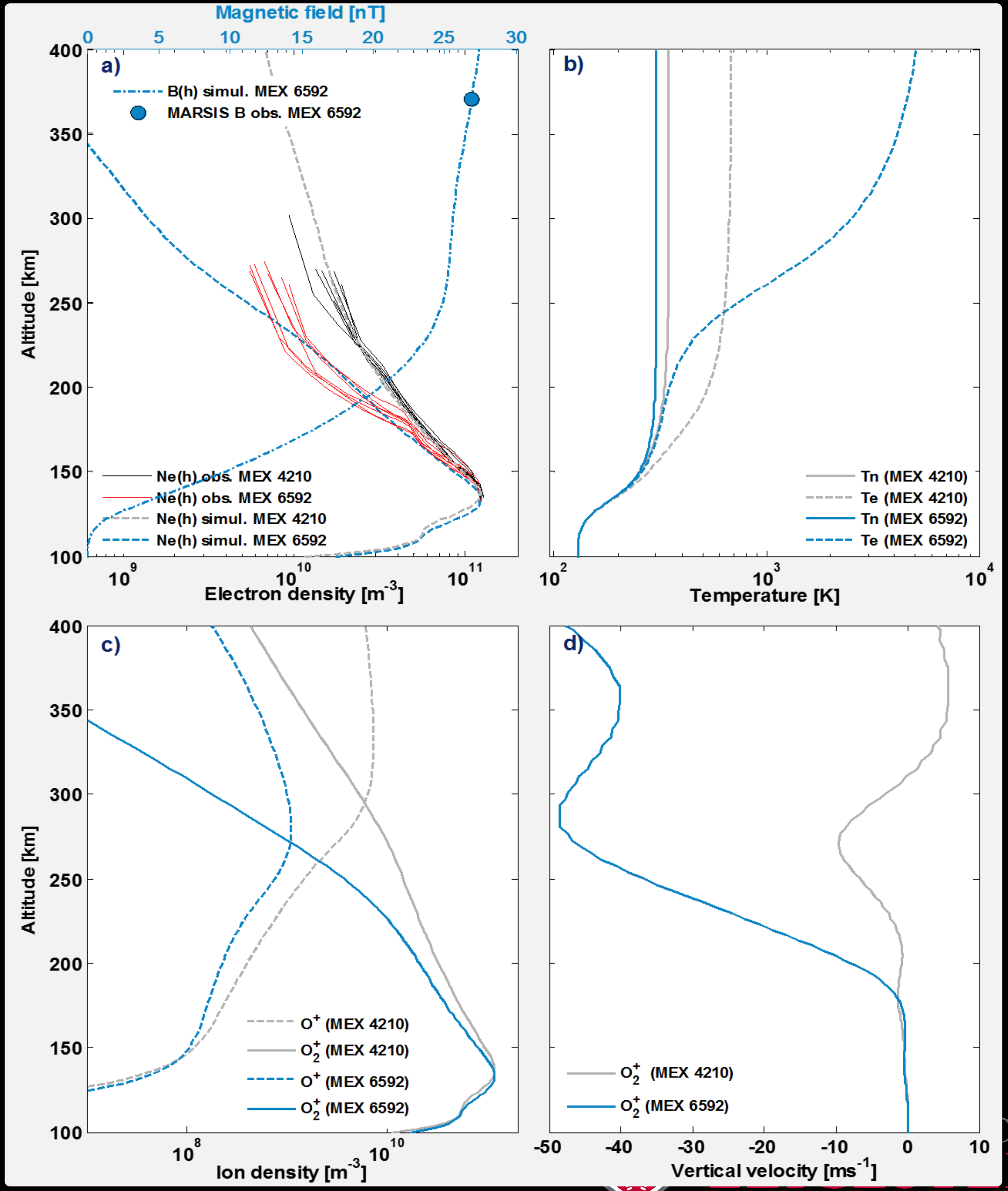
Case study I: solar cycle effect

We made a numerical simulation with the IPIM model to analyze the shape of the profiles with similar conditions, but at different phases of the solar cycle.

The low solar activity phase of the solar cycle leads to a general reduction of the topside ionosphere of Mars, which is mainly produced by a small and constant induced magnetic field in the dayside ionosphere of Mars.

For the same conditions:

- SZA= 45- 55 [deg]
- Heliocentric distance= 1.40 [AU]
- Ls=220 and 213 [deg]
- F10.7=69 [sfu]
- EUV= $1.5x10^{-4}$ [W/m^2]
- LAT=-40 and -63 [deg]
- LON=73 and 327 [East deg]



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Sanchez-Cano et al., JGR, 2015b

Short-term variability (I)

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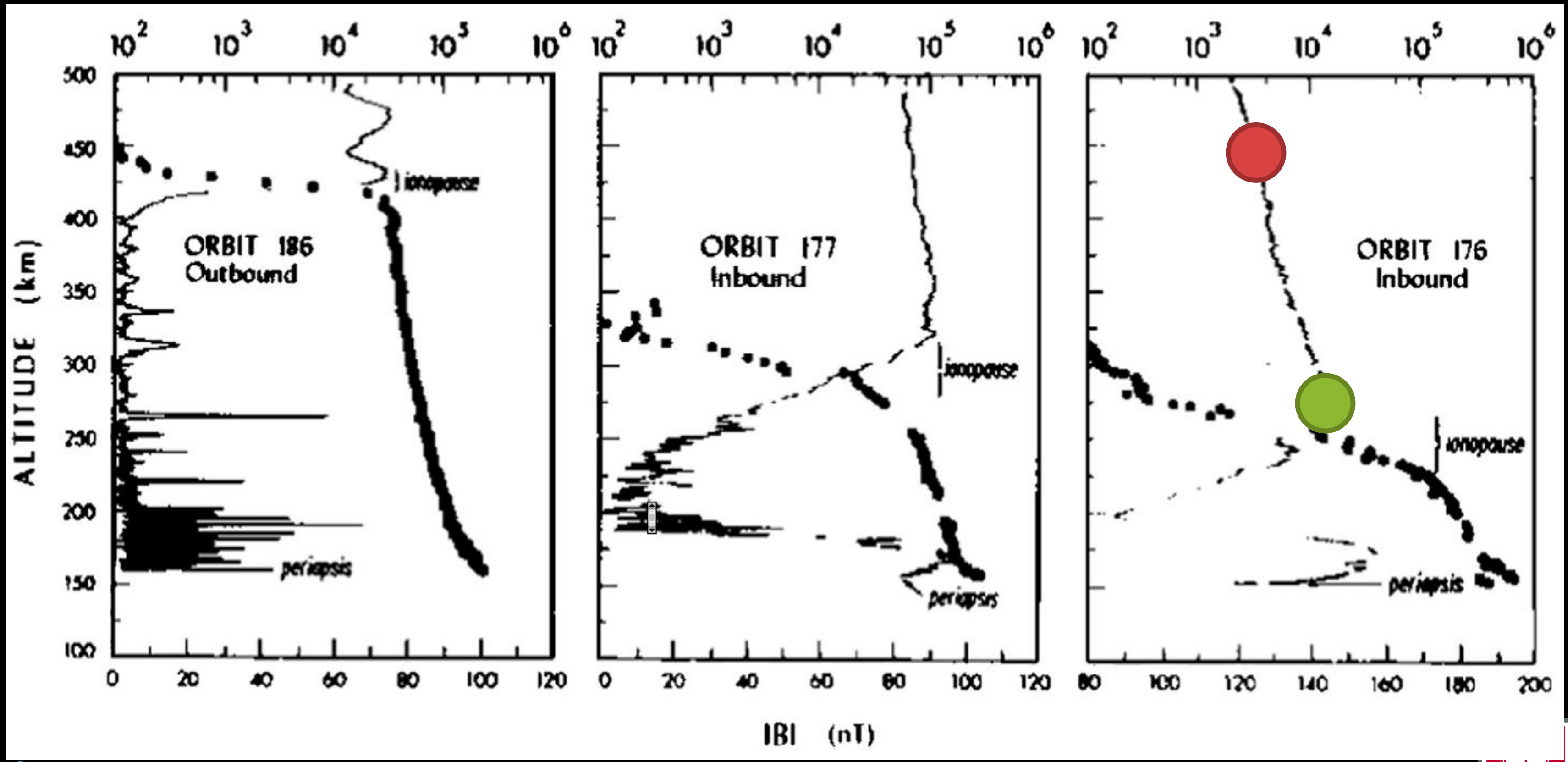
Case study II: effect of a solar event

It is well-known that the presence of an induced magnetic field in the top of the ionosphere creates a large reduction on the topside electron density profile. However, at Mars (before MAVEN), this was not possible to directly assess due to the lack of magnetometer on board Mars Express.



For the Mars case

MEX obs

??

VENUS---------Russell, 1992

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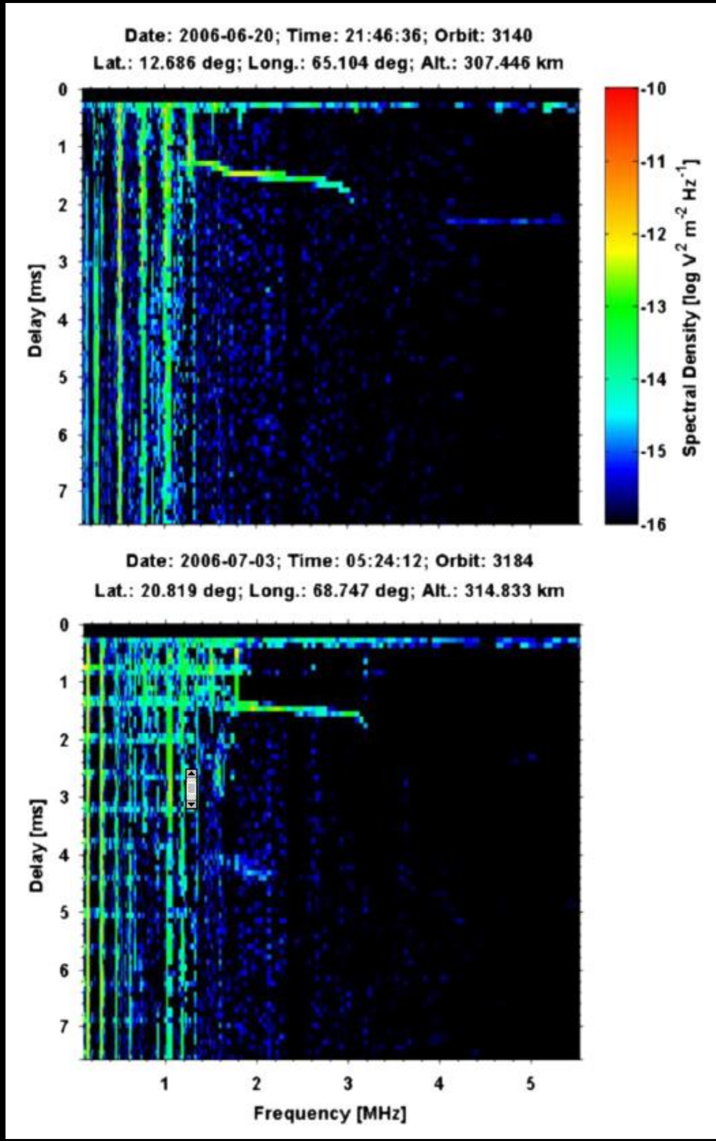
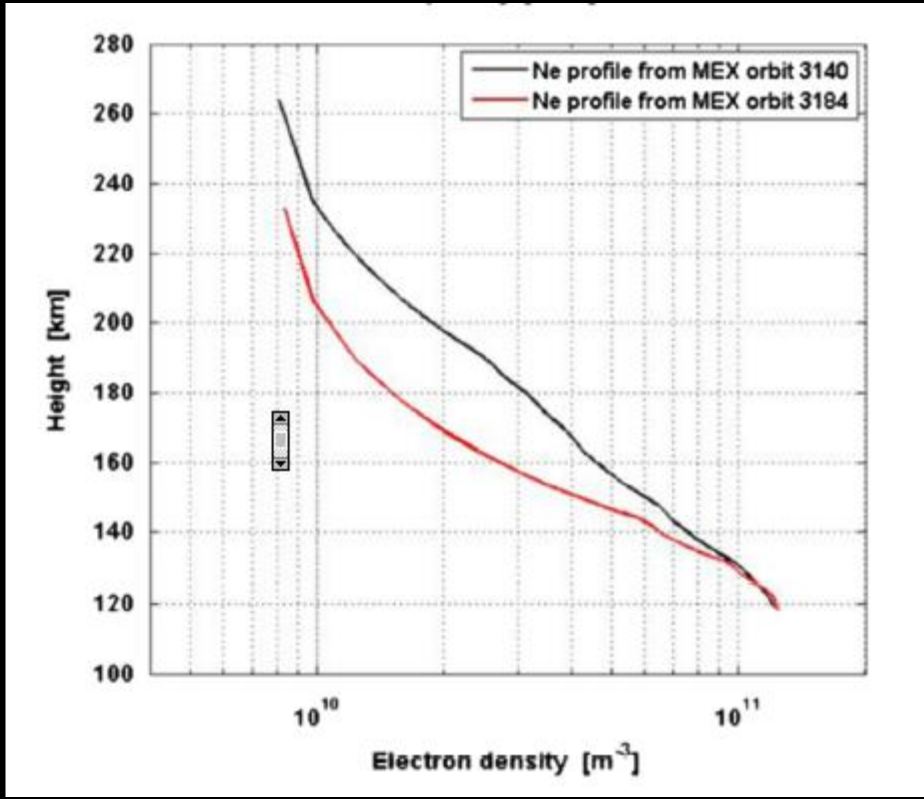
Case study II: effect of a solar event



We selected 5 consecutive Mars Express orbits over the same region of the planet, from June 2006 in which the radar MARSIS was working.

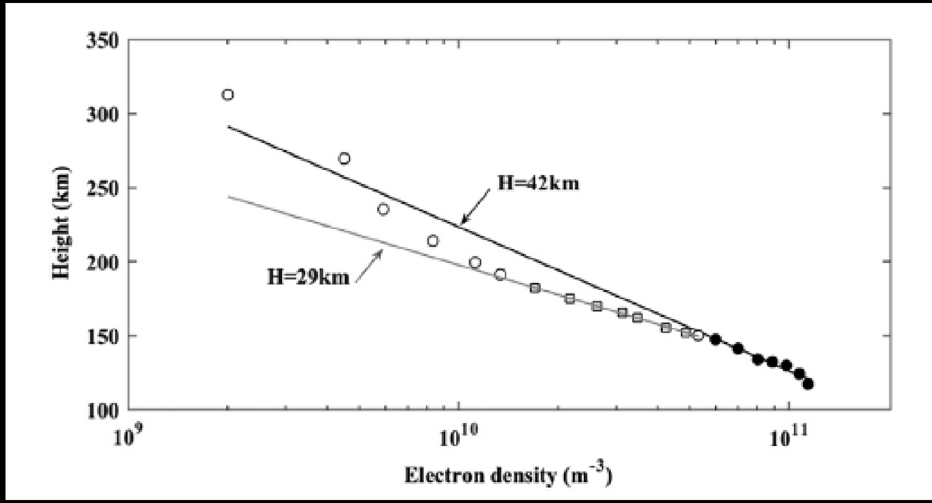
3 of the orbits were affected by a solar event (possible CIR), and MARSIS recorded some induced magnetic field at the spacecraft altitude.

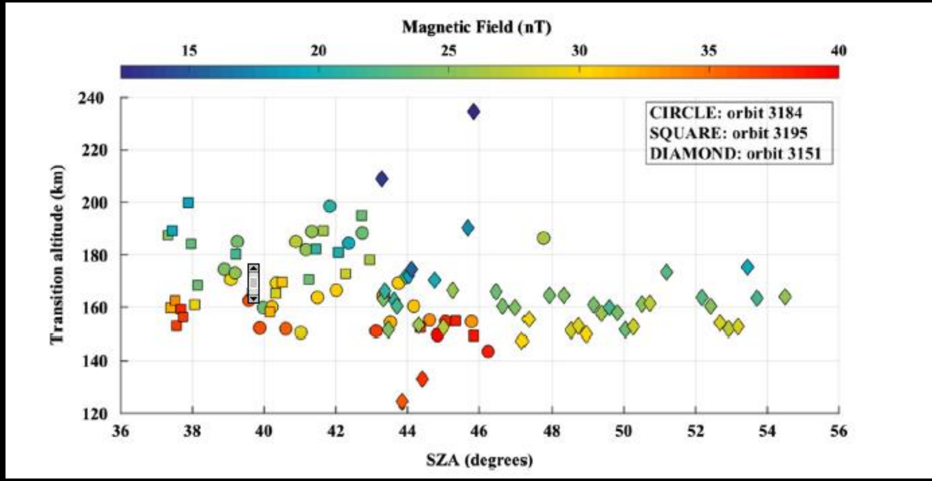
As a result, the vertical electron density profiles during the solar event, were notably affected.



Ramirez-Nicolas et al., PSS, 2016

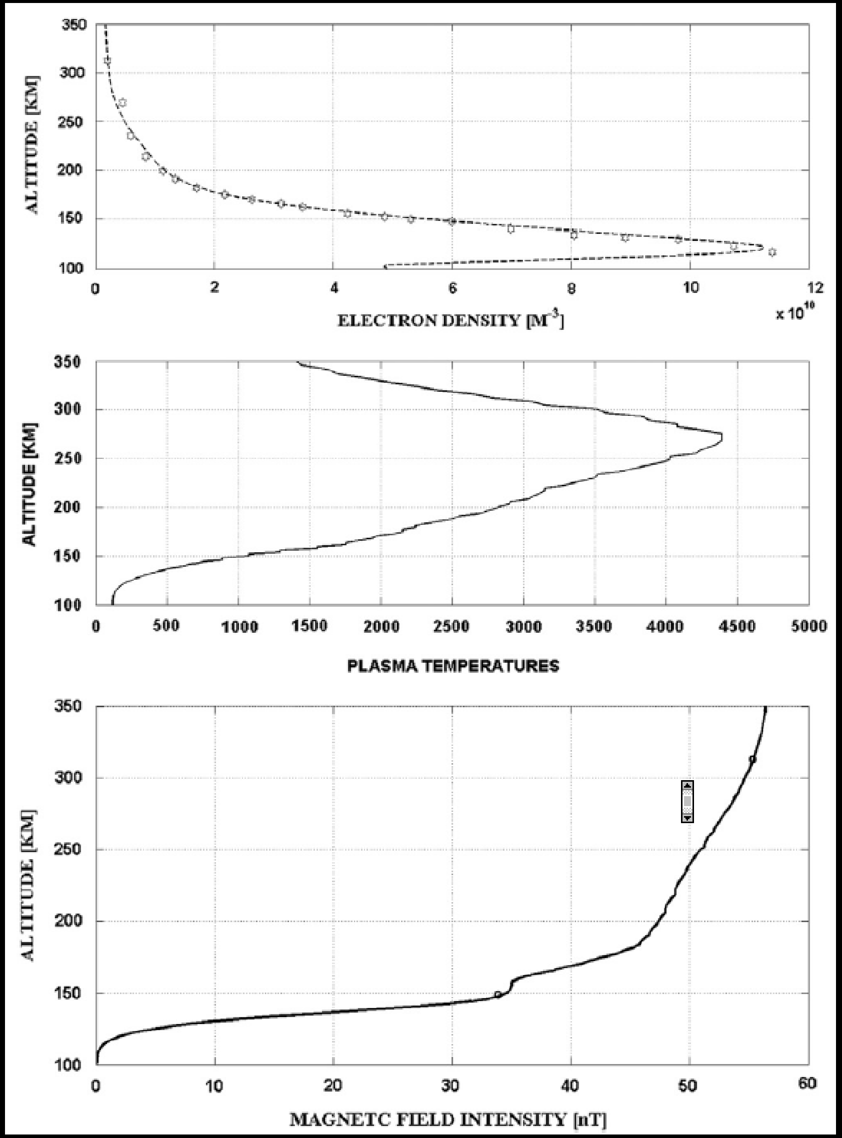
Case study II: effect of a solar event





Using some plasma properties from the electron density profiles (plasma scale height, transition altitude from photochemical to diffusive region, pressure balance…), we could estimated the B field magnitude at the transition altitude.

Finally, we performed an independent IPIM simulation, which confirmed our results.



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Ramirez-Nicolas et al., PSS, 2016

Short-term variability (II)

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ICMEs effect at Mars. (I) propagation

To evaluate the reaction of the Mars' plasma system, a good knowledge of the solar event that hit the planet is absolutely needed. Solar wind propagation modelling is many times a crucial factor.

CDPP

Propagation Tool

irap
astrophysique & planétologie

Welcome to CDPP/Propagation Tool

Tutorials : video (mov files)

- Introduction to the CDPP Propagation Tool (13M)
- Description of the propagation tool main interface (8M)
- Case 1: Using the tool in the Jmap Carrington/In situ mode (radial) (37M)
- Case 2: Using the tool in the Jmap tool click mode (radial) (39M)

Tutorials : video (mpeg files)

- Introduction to the CDPP Propagation Tool (46M)
- Description of the propagation tool main interface (47M)
- Case 1: Using the tool in the Jmap Carrington/In

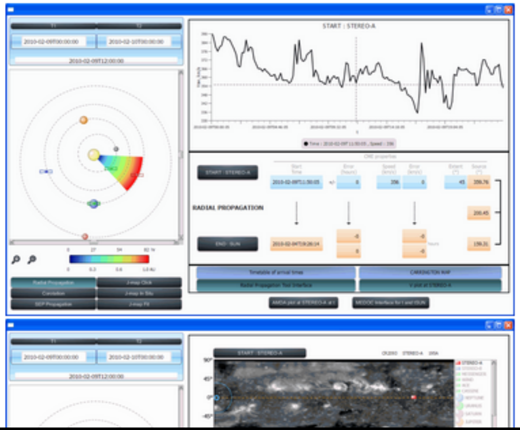
Launch the Propagation Tool

java 8: Mac users: please use Firefox or Safari

A new interactive tool accessible to the solar, heliospheric and planetary science communities to track solar storms, streams and energetic particles in the heliosphere. This tool was defined and developed by *IRAP* and *IAS* staff through a subcontract with *GFI informatique* and *CNES* financial support. It follows on from and is complementary to the propagation tool developed by the FP7 HELIO project.

The propagation tool allows users:

- to propagate solar eruptions (**CMEs**) radially sunward or anti-sunward (**Radial Propagation**),
- to propagate corotating structures (**CIRs**) in the heliosphere (**Corotation**),
- to propagate **solar energetic particles** along magnetic fields lines sunward or anti-sunward (**SEP Propagation**),



http://propagationtool.cdpp.eu/

bscmdr1@le.ac.uk

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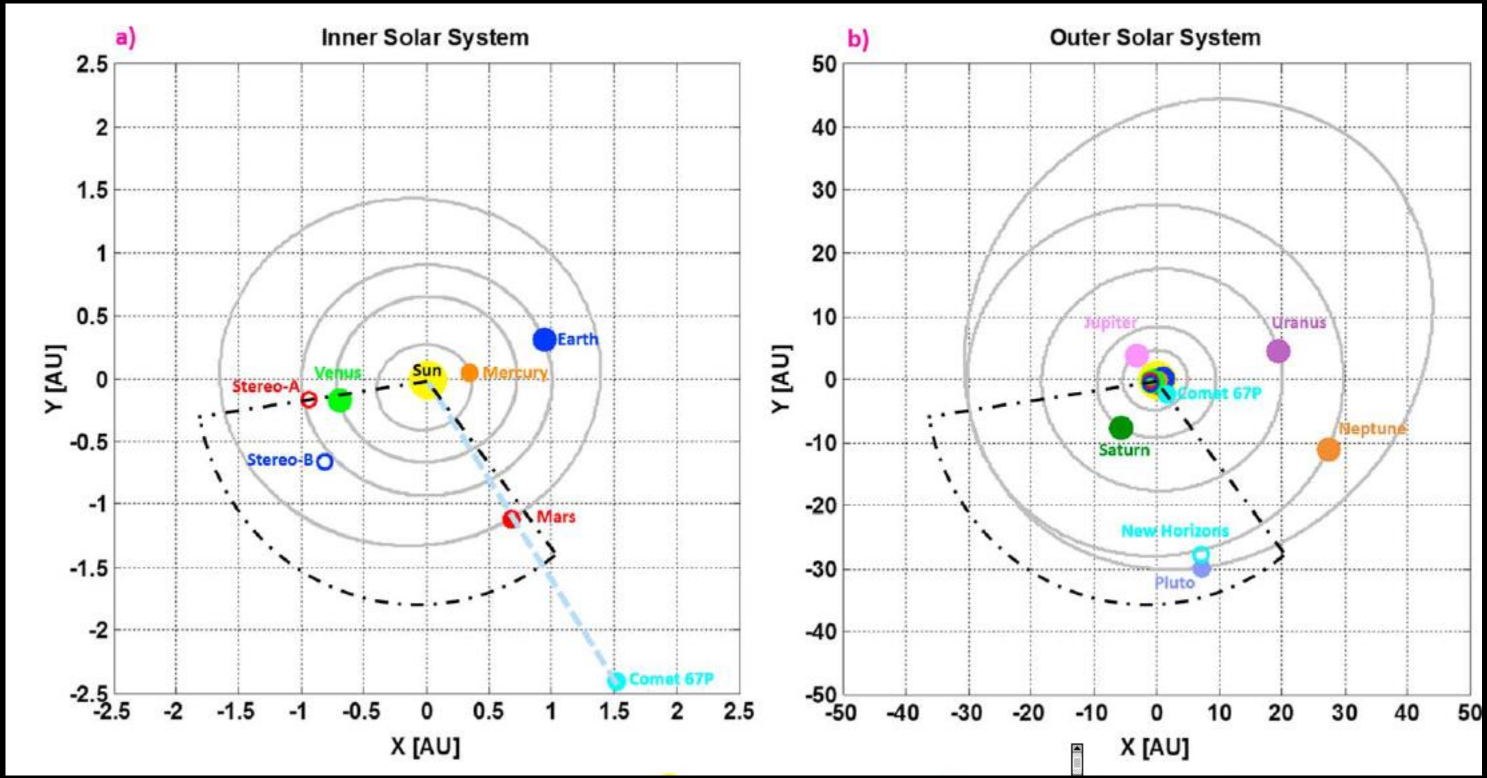
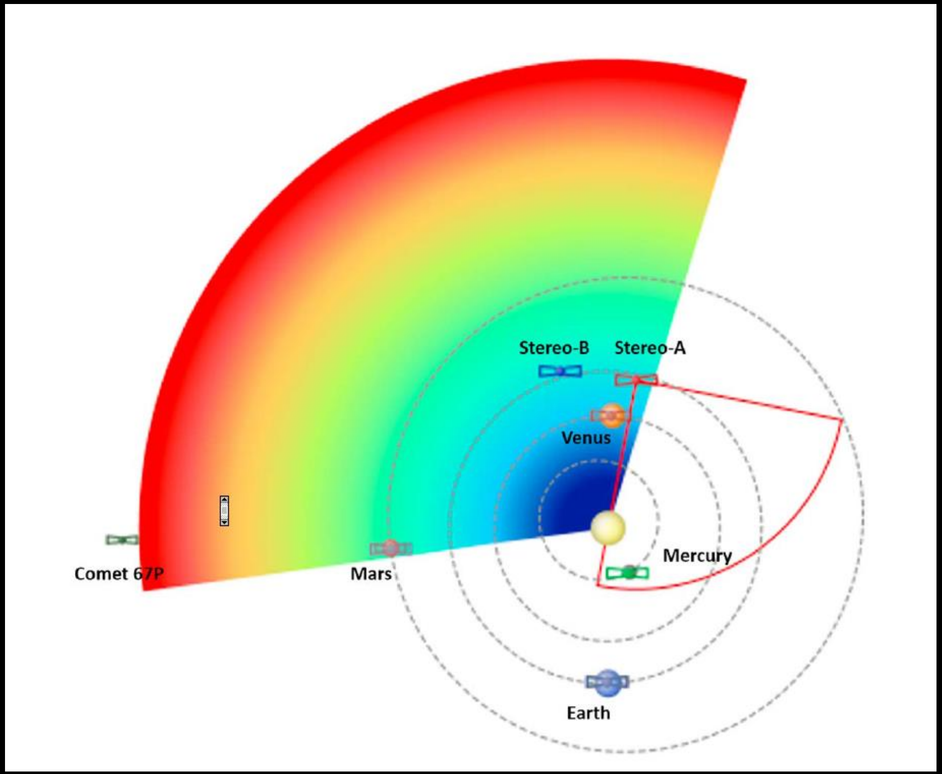
ICMEs effect at Mars. (I) propagation

We studied the propagation of a very large ICME that was ejected on October 14th, 2014 and hit several solar system bodies. One of the solar wind propagation models that we used was the CDPP propagation tool.





Witasse et al., JGR, 2017

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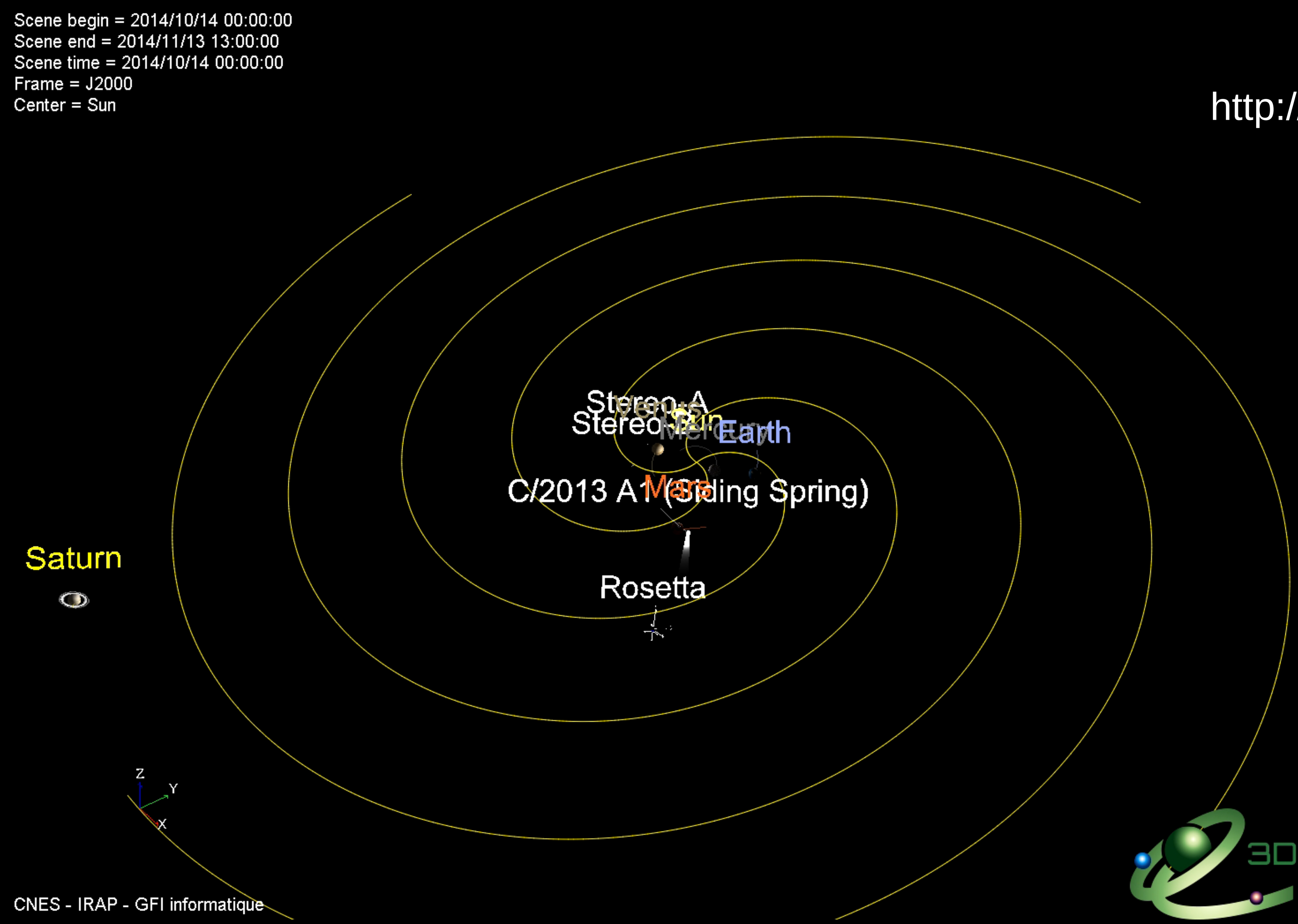
ICMEs effect at Mars. (I) propagation



http://3dview.irap.omp.eu/

Witasse et al., JGR, 2017

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ICMEs effect at Mars. (I) propagation

The CDPP predictions were very accurate and help us, together with the observations and a WSA-ENLIL+Cone solar wind simulation, to constrain the velocity, position and structure of the ICME in its journey throughout the full solar system.

Table 1. ICME Propagation Timeline

		Date and Time (UT)	Heliocentric Distance (AU)
Sun	Launch of the CME	14 Oct 2014 T18:30	
Venus	Putative arrival time from Venus Express housekeeping data	16 Oct 2014 T07:19	0.72
	CME associated shock/compression from WSA-ENLIL + Cone	16 Oct 2014 T09:00	
	CDPP propagation tool prediction	16 Oct 2014 T07:12	
STEREO-A	STEREO-A shock detection	16 Oct 2014 T20:00	0.96
	CME associated shock/compression from WSA-ENLIL + Cone	17 Oct 2014 T00:00	
	CDPP propagation tool prediction	16 Oct 2014 T20:57	
Mars	CME detection with Mars Express ASPERA data	17 Oct 2014 T15:45–22:50	1.41
	CME detection with MAVEN magnetometer data	17 Oct 2014 T22:53	
	FD onset with MSL RAD data (Plastic detector)	17 Oct 2014 T20:09	
	FD onset with HEND Mars Odyssey (DHD medium detector)	17 Oct 2014 T18:15	
	CME associated shock/compression from WSA-ENLIL + Cone	18 Oct 2014 T00:00	
	CDPP propagation tool prediction	17 Oct 2014 T22:51	
Comet 67P	CME detection with Rosetta magnetometer data	22 Oct 2014 T16:30	3.13
	CME detection with Rosetta ion data (solar wind proton energy)	22 Oct 2014 T17:24	
	FD onset with Rosetta SREM data (Channel 6)	22 Oct 2014 T14:24	
	CME associated shock/compression from WSA-ENLIL + Cone	22 Oct 2014 T09:30	
	CDPP propagation tool prediction	22 Oct 2014 T17:00	
Saturn	CME detection with Cassini-Huygens magnetometer data	12 Nov 2014 T18:55	9.94
	FD onset with Cassini-Huygens MIMI data	12 Nov 2014 T17:30	
	CME associated shock/compression from WSA-ENLIL + Cone	15 Nov 2014 T12:00	
	CDPP propagation tool prediction	12 Nov 2014 T16:09	
New Horizons	Time window based on solar wind speed (see text)	18 Jan to 14 Feb 2015	31.49
	Possible detection of the ICME in the SWAP data	21–29 Jan 2015	
	CME associated shock/compression from WSA-ENLIL + Cone, prediction for the distance of NH (see text)	8 Feb 2015	
	CDPP propagation tool prediction for 31.5 AU	24 Jan 2015	
Voyager 2	Possible MIR detection in the dynamic pressure and GCR data sets	Late Mar 2016	111.06

Witasse et al., JGR, 2017

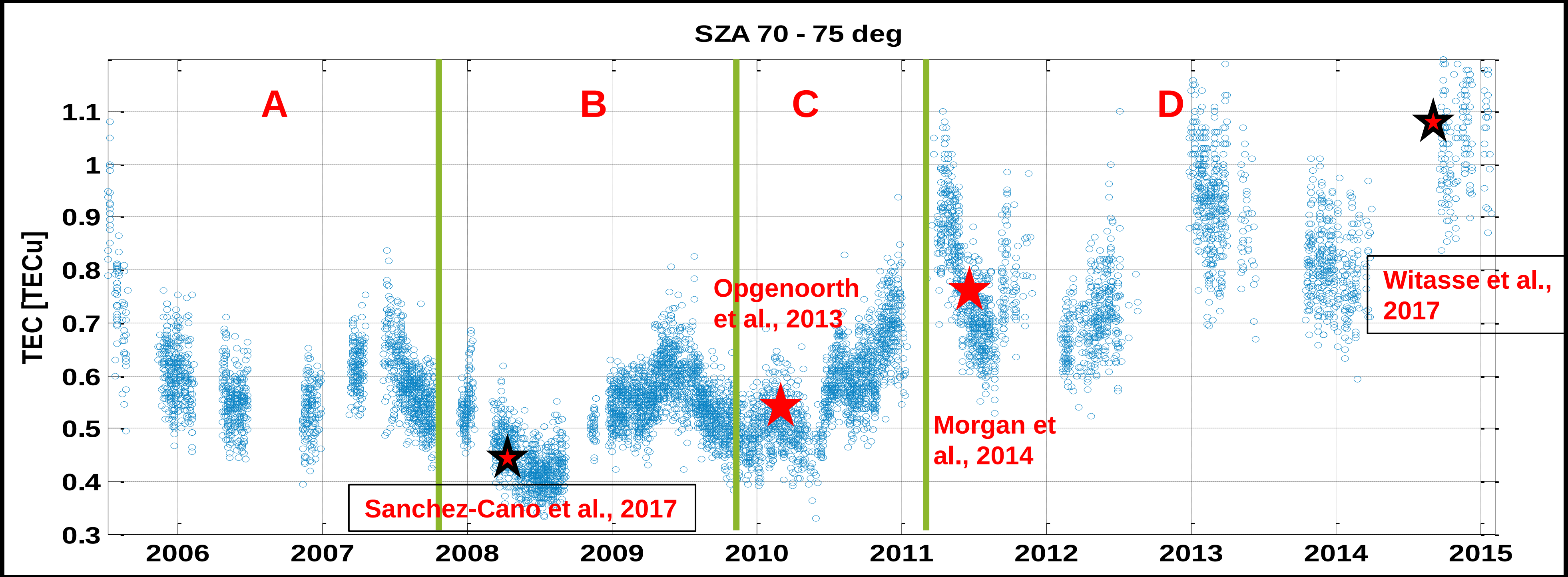
bscmdr1@le.ac.uk

ICMEs effect at Mars. (II) solar cycle effect

Two Interplanetary Coronal Mass ejections (ICME) have been selected, each one from the extremes of the solar cycle. In both cases, Mars Express was transiting the <u>dayside</u> (SZA=40-70 deg) and in the <u>North</u> hemisphere (no crustal fields).

More than double difference in TEC

Estimated level in 2003 [Crider et al., 2005]



Jakosky et al., 2015

TEC data extended from Sanchez-Cano et al., 2016

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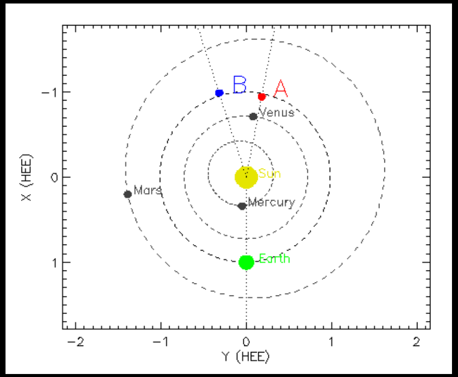
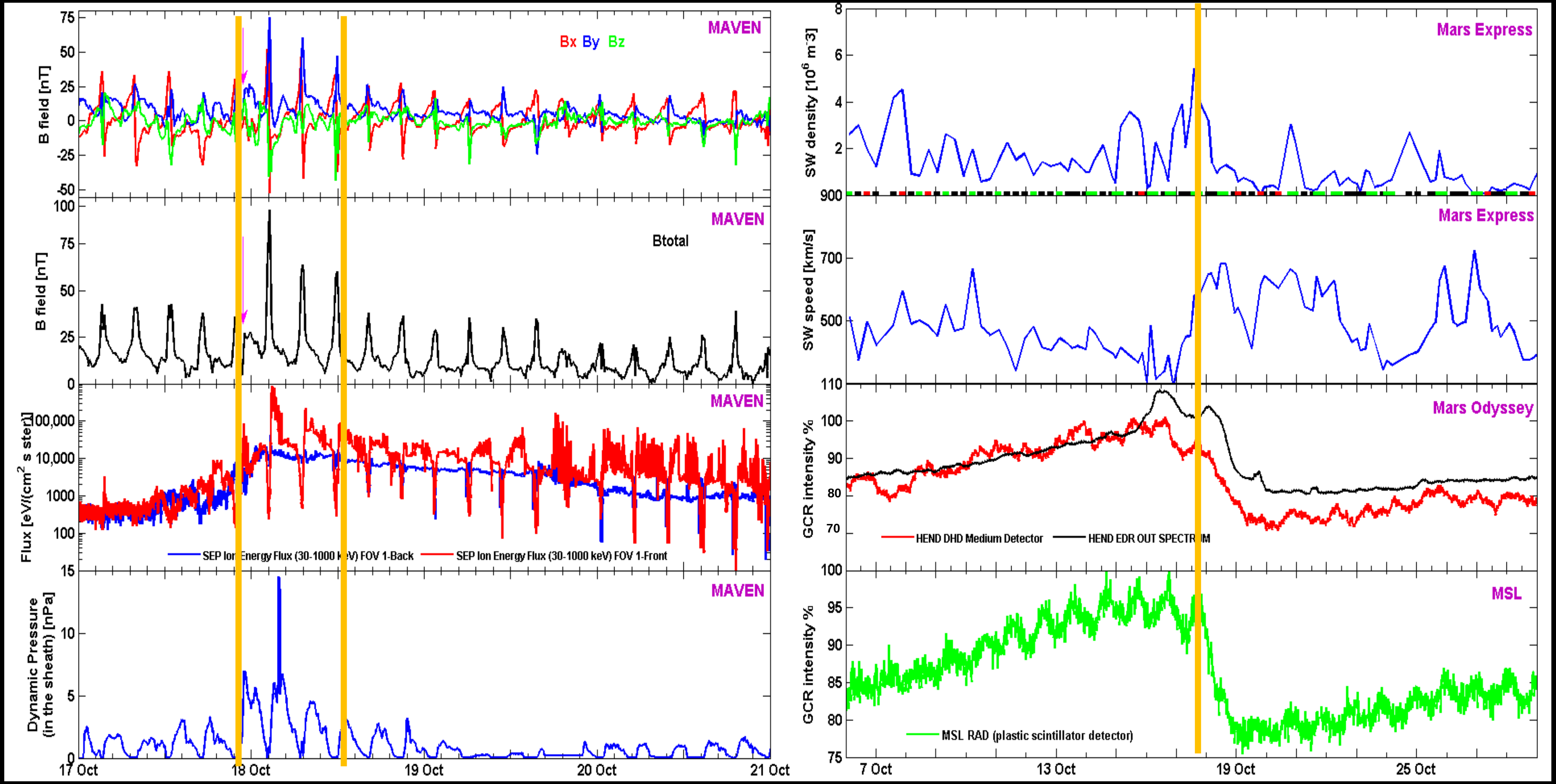
ICMEs effect at Mars. (II) HIGH solar activity

For this event,
there were not any satellites between the Sun and Mars.

Consequently, all the in-situ observations come from the vicinity Mars, where Mars Express, MAVEN, Mars Odyssey, and MSL all recorded the event





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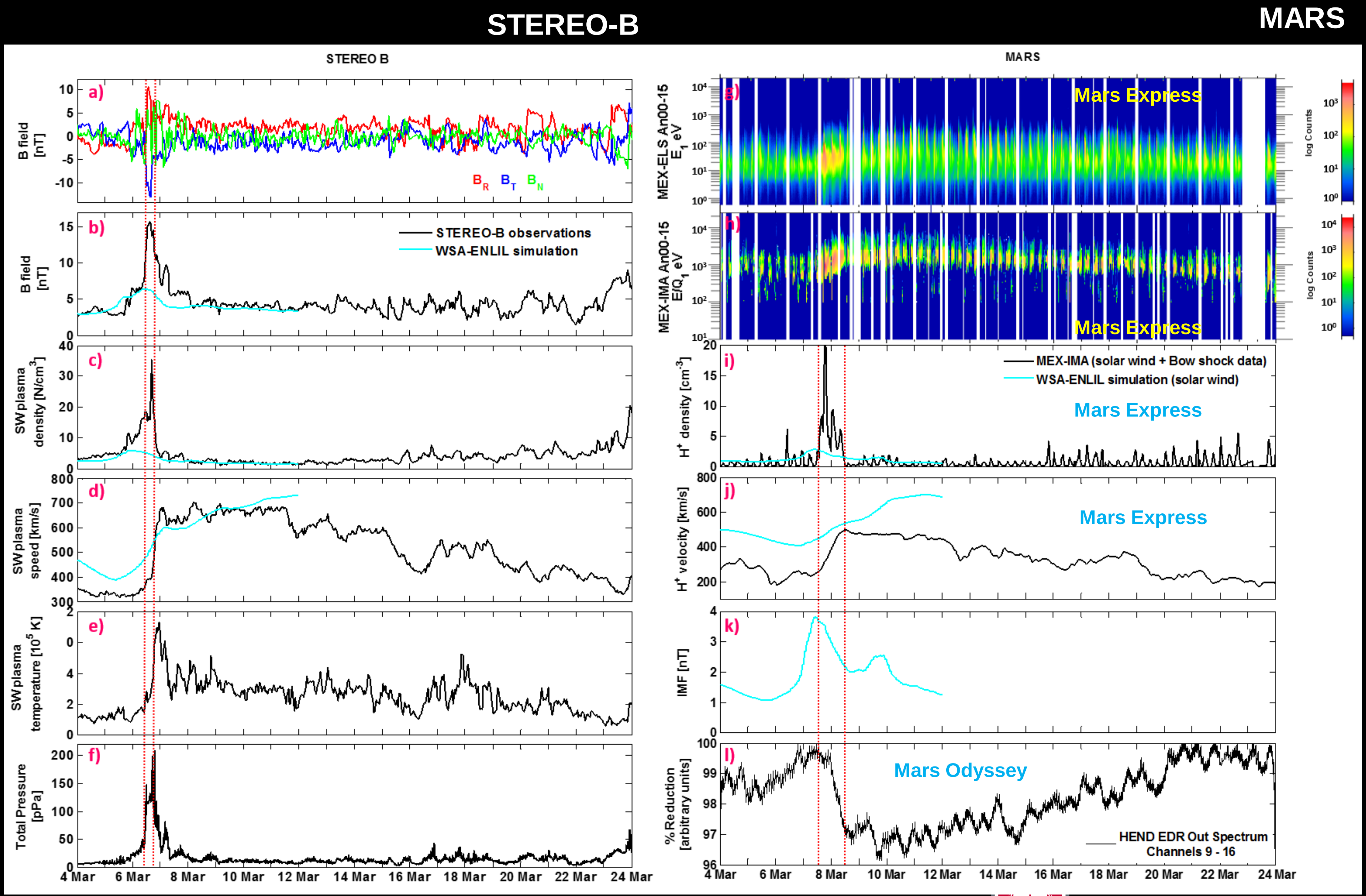
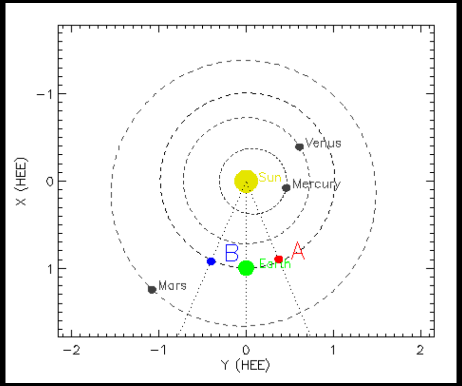
Witasse et al., JGR, 2017

ICMEs effect at Mars. (II) LOW solar activity

The ICME-like was detected by STEREO B satellite on 6th March, 2008. Just after, the solar wind increases abruptly to almost 700 km/s and lasted for ~15 days.

Mars, both events were observed by Mars Express and Mars Odyssey on 7th and 9th March, 2008 respectively





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Sanchez-Cano et al., JGR, 2017

Data processing

http://amda.irap.omp.eu/

bscmdr1@le.ac.uk

Cold plasma and induced magnetic field

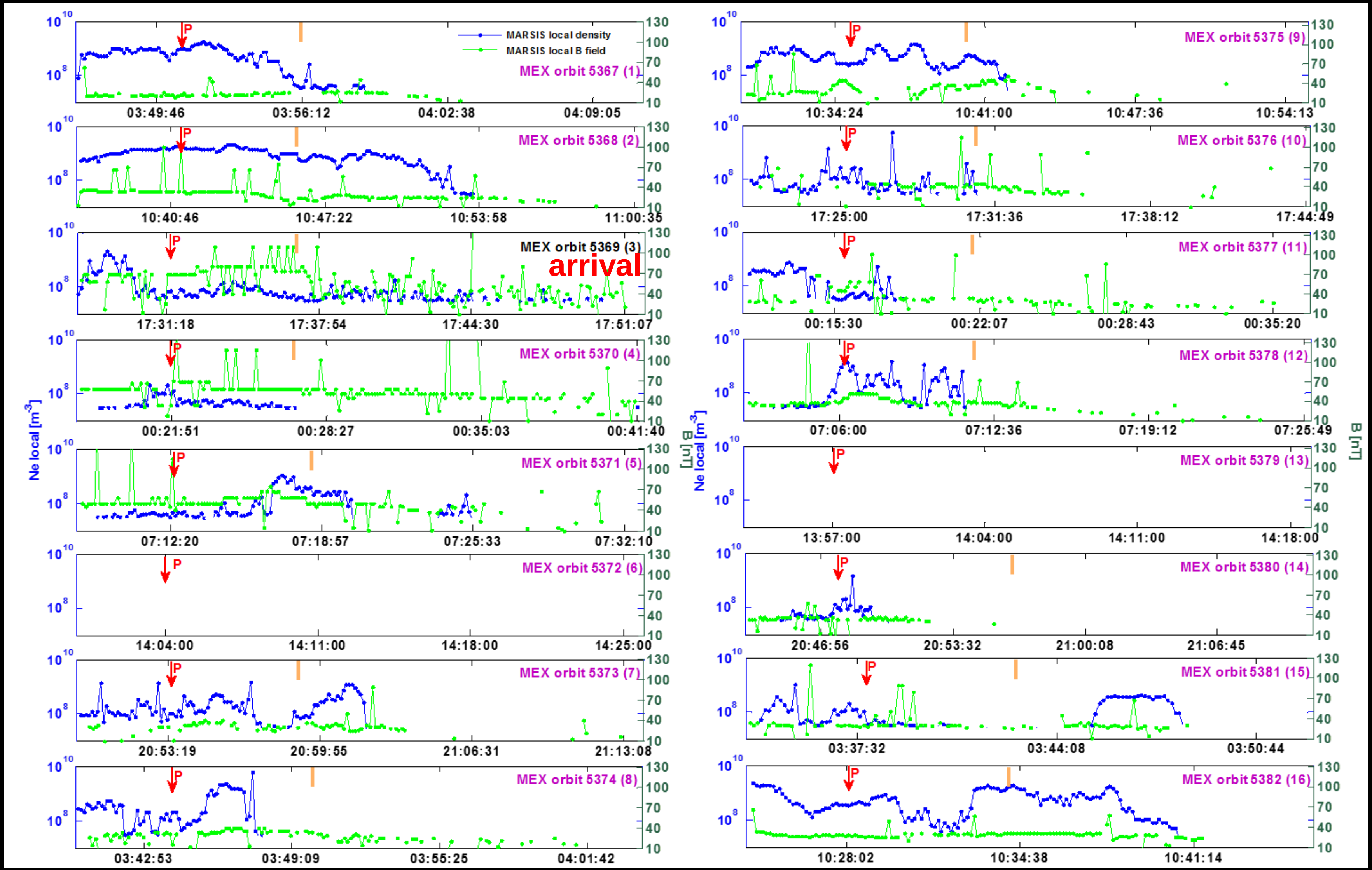
ICME-like:

- a clear compression of the magnetosheath-ionosphere system is found.
- As in high solar activity, the BS and the IMB are found much lower than expected.
- The ionosphere is found to be more compressed and with a larger induced magnetic field.

Fast stream:

- It also caused a compression in the Martian plasma system, although lower than the first event.
- It led to fast IMB boundary movements.

Ne local [m-3]



Induced magnetic field [nT]

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Sanchez-Cano et al., JGR, 2017

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Cold plasma and induced magnetic field at MEX

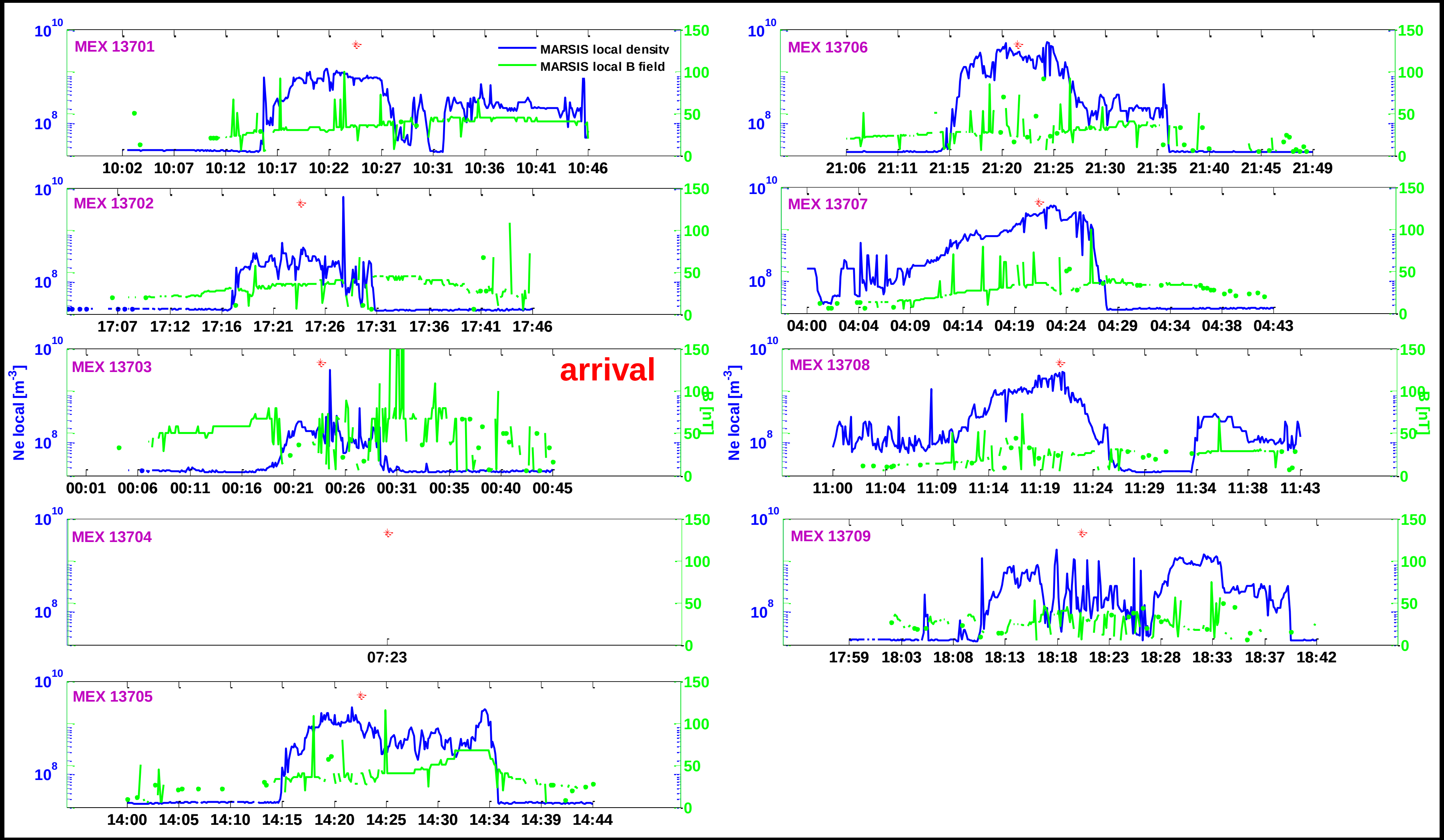
ICME:

- a clear compression of the magnetosheath-ionosphere system is found.
- The ionosphere is found to be more compressed and with a larger induced magnetic field.

Fast stream:

- The plasma system is recovered after few MEX orbits (~15h)
- No apparent effect on the system

Ne local [m-3]



Induced magnetic field [nT]

bscmdr1@le.ac.uk

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To conclude….

Lots of science works can be done (and usually in a much easier way) thanks to the several tools developed at IRAP. I remark:

(1) AMDA is a great tool that helps a lot with the data processing.
From the Mars perspective, I think the dataset is very complete, although from other bodies perspective, I think it would be good to have the full Rosetta RPC data set.

(2) The propagation tool is also great and works quite well, even when it was tested in a difficult and extreme case for the tool as in Witasse et al., 2017.

My suggestion would be to add New Horizons, and to get as output the speed as a function of the heliocentric distance.

(3) IPIM interface is very convenient because the model is quite complex to run.

(4) 3D view is also an interesting tool to help to visualize events.

bscmdr1@le.ac.uk

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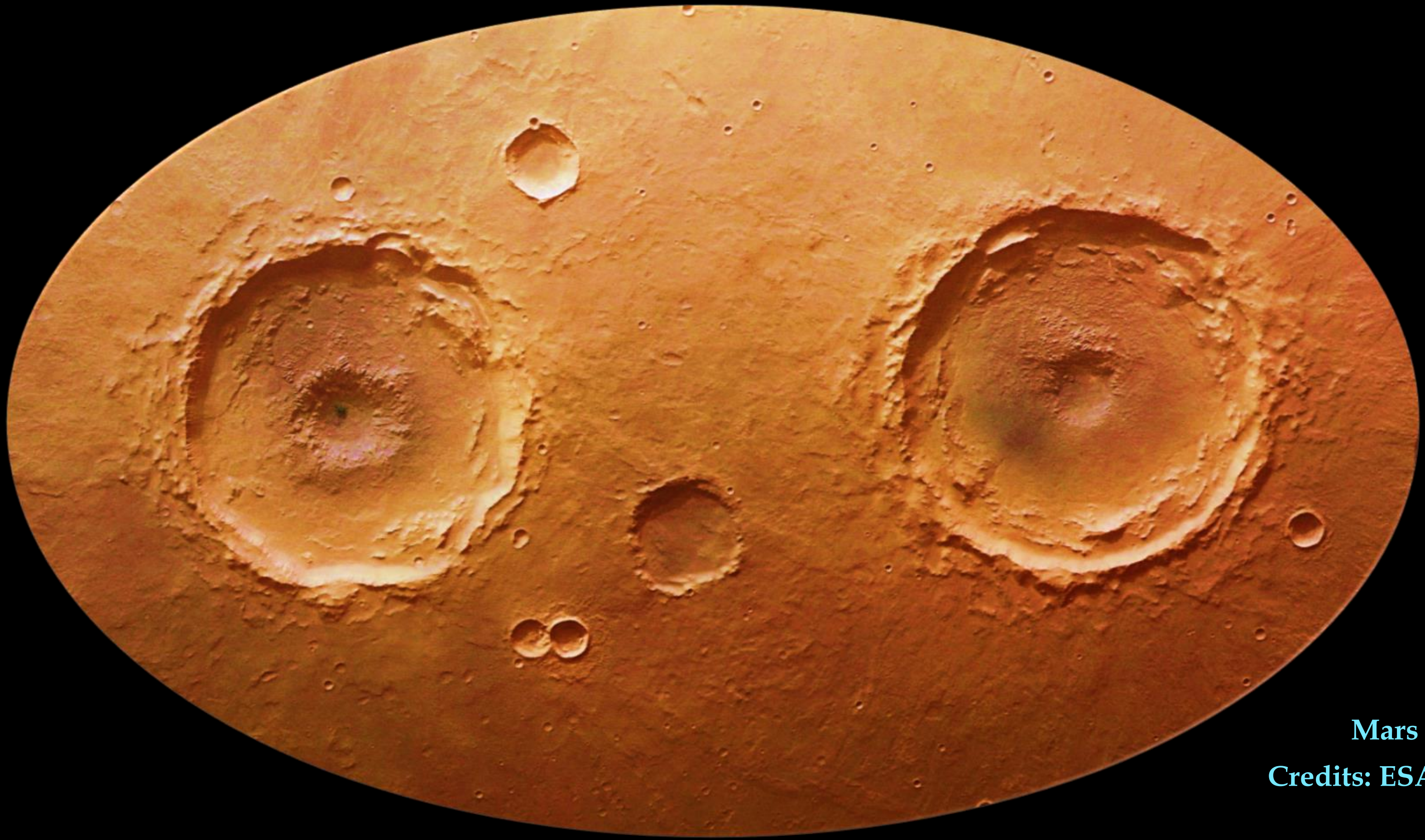
Thank you very much for your attention!!



Mars view from Mars Express

Credits: ESA/DLR/FU Berlin (G. Neukum)

bscmdr1@le.ac.uk

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