The role of multi-spacecraft analysis in the investigation of solar influences in the heliosphere

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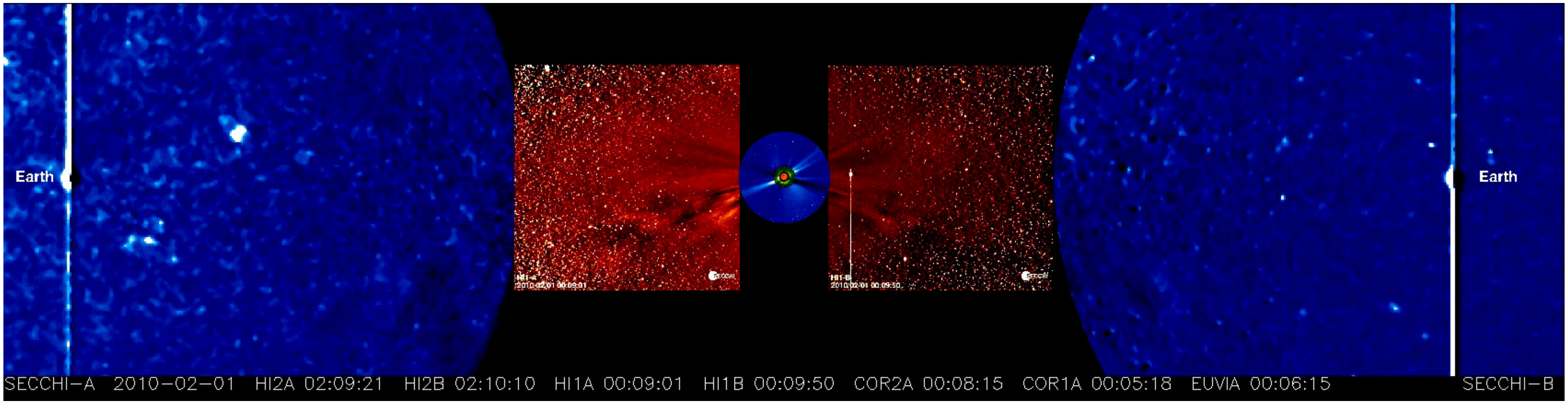
Solar influences in the heliosphere

Solar phenomena, like fast solar wind streams and coronal mass ejections, often having far-reaching effects in the heliosphere and can be readily observed both near to the Sun and at large solar distances.

Our understanding of the solar origins of these events and their subsequent evolution benefits from the analysis of complementary datasets.

The scope of multi-spacecraft analysis has vastly increased in recent years, from predominantly being case studies of CMEs to wider scale statistical studies during times of low solar activity.

Coronal Mass Ejection observations from the Sun to Earth



Opportunities for multi-spacecraft study

Many heliospheric observations currently available:

- remote sensing and *in situ*
- range of fields of view
- multiple vantage points

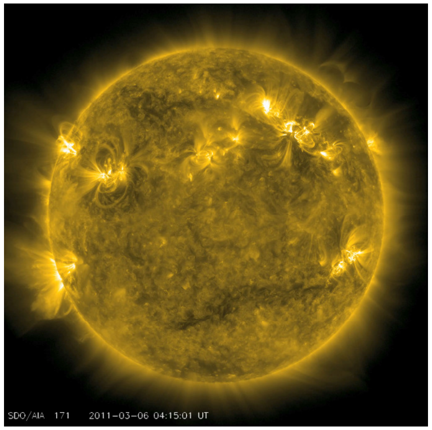
Unique observations

In 2011, the two STEREO spacecraft will be separated by more than 90°. Together with observations from SOHO and SDO, we will have a 360° view of the Sun for the first time.

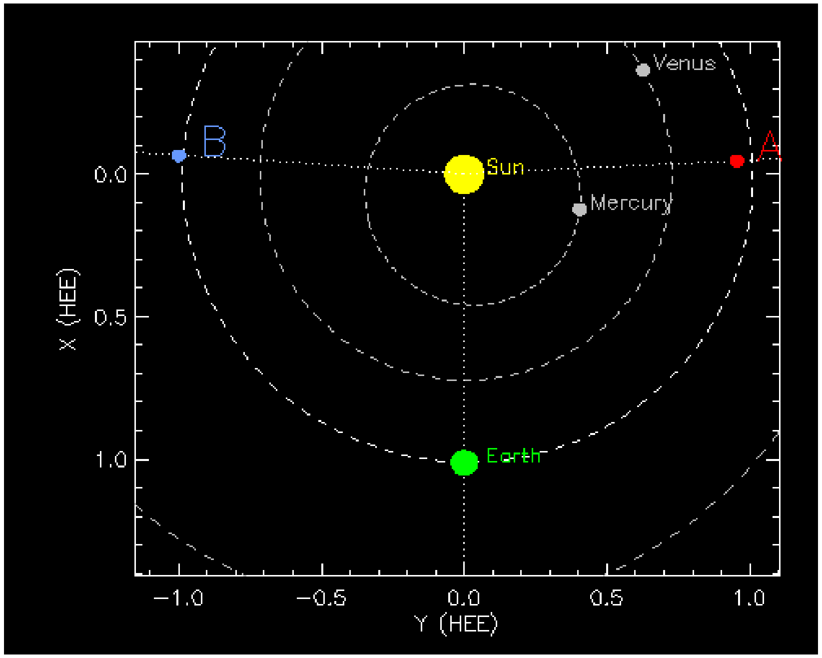
Preparation of new analysis techniques

Solar Orbiter is due for launch in 2018 and will be capable of remote sensing and in situ observations from its orbit closer to the Sun than ever before (0.28 AU).

Solar eruptions from SDO



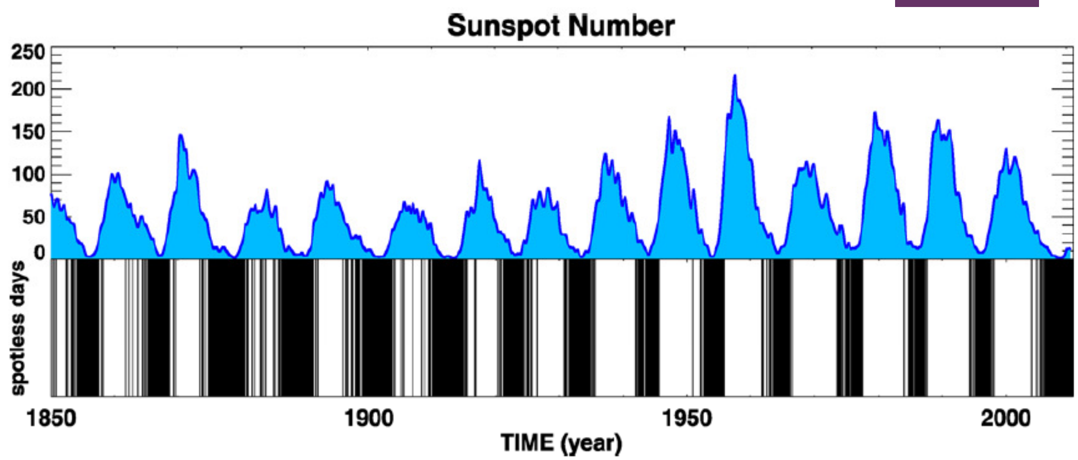
Current positions of STEREO spacecraft



Evolution of coronal holes and associated solar wind streams

Multi-spacecraft, statistical study of coronal hole evolution and the consequences for associated solar wind streams during a period of prolonged low solar activity.

Coronal holes differed during this minimum compared to the previous one. Low latitude coronal holes were still relatively large and remained important sources of fast solar wind streams.



Mean sunspot number from 1850 to June 2010 (top). Days with no spots are identified by black bars at the bottom.

Year	1976	1986	1996	2006	2007	2008	2009
Sunspot number	12.6	13.4	8.6	15.2	7.6	2.9	3.1

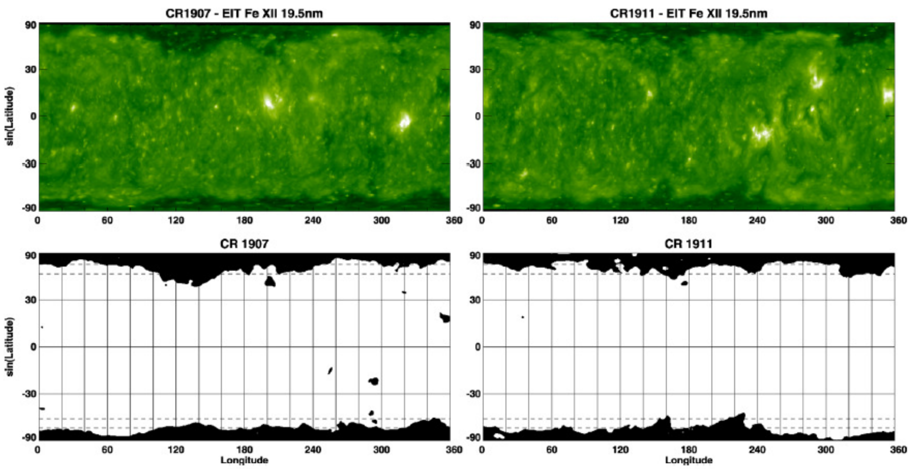
Yearly mean sunspot number for solar minima.

The slow decline of solar cycle 23 and slow rise of cycle 24 resulted in a very long period of low solar activity, which lasted from 2006 to the end of 2009.

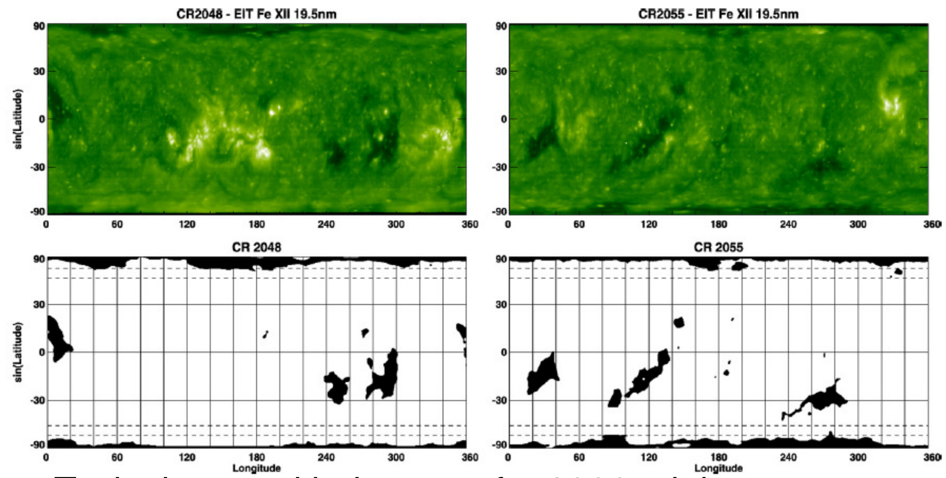
De Toma et al., Sol. Phys., 2011, *in press*

Coronal holes during solar minima

EUV synoptic maps (top) and corresponding coronal hole maps (bottom).



Typical coronal hole maps for 1996 minimum.



Typical coronal hole maps for 2006 minimum.

In the previous solar minimum in 1996, large polar coronal holes extended down below 50° solar maximum.

Estimated maximum area of coronal holes in 1996:

Northern polar hole: 7.9 - 8.1%
Southern polar hole: 6.9 – 7.1%
Low latitude holes: < 0.5%

During the recent minimum, starting around 2006, polar coronal holes were smaller than in 1996 and more patchy in their appearance.

Estimated maximum area of coronal holes between 2006 – 2009:

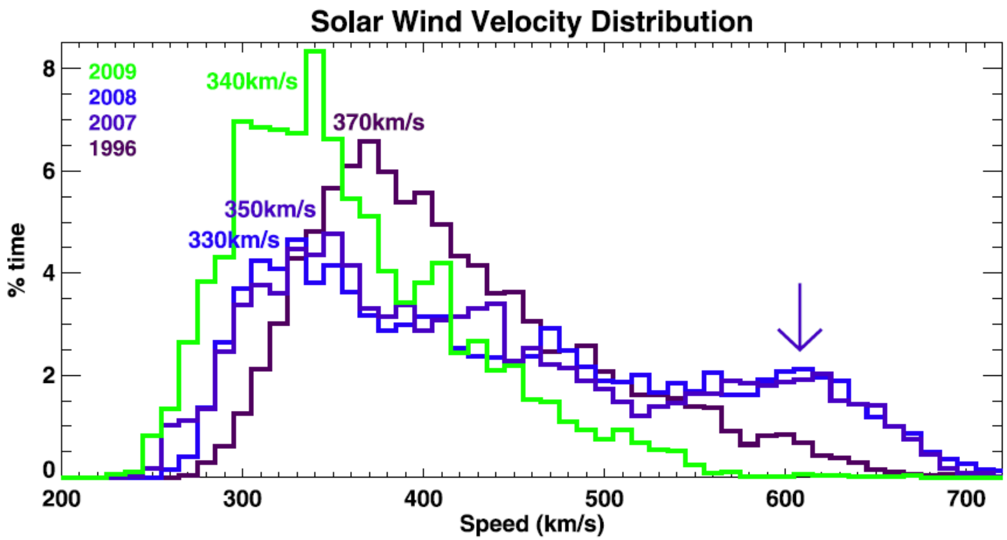
Northern polar hole: 4.4 – 4.7%
Southern polar hole: 5.3 – 6.0%
Low latitude holes: 2 – 3%

De Toma et al., Sol. Phys., 2011, *in press*

Consequences for the solar wind

Year	1976	1986	1996	2006	2007	2008	2009
Solar wind speed ($km\,s^{-1}$)	445.4	452.8	422.7	429.5	439.7	448.5	364.4
$\|\mathbf{B}\|$ (nT)	5.48	5.76	5.11	5.03	4.48	4.24	3.93

The yearly mean solar wind speed measured by the ACE and WIND satellites near the Earth and the magnitude of the IMF for the previous minima and in recent years.



Histogram showing the solar wind distribution

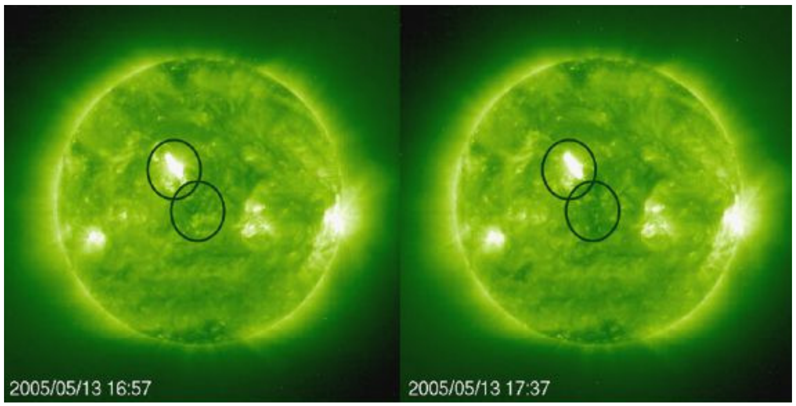
Clear shift in the distribution to lower velocities in 2009 with speeds above 360 km s^{-1} systematically less frequent than in 1996.

In 2007 and 2008, the distribution was almost bimodal with a primary peak at slightly lower velocities than in 1996 and a secondary peak near 600 km s^{-1} due to recurrent high speed streams from low latitude coronal holes.

EUV images from multiple spacecraft with different fields of view are combined to show a significant reduction in the area of polar coronal holes during the recent solar minimum. Changes in coronal hole size and location during the prolonged minimum are clearly seen in the *in situ* solar wind velocity observations at 1 AU.

De Toma et al., Sol. Phys., 2011, *in press*

From the Sun to the Earth: The 13 May 2005 coronal mass ejection

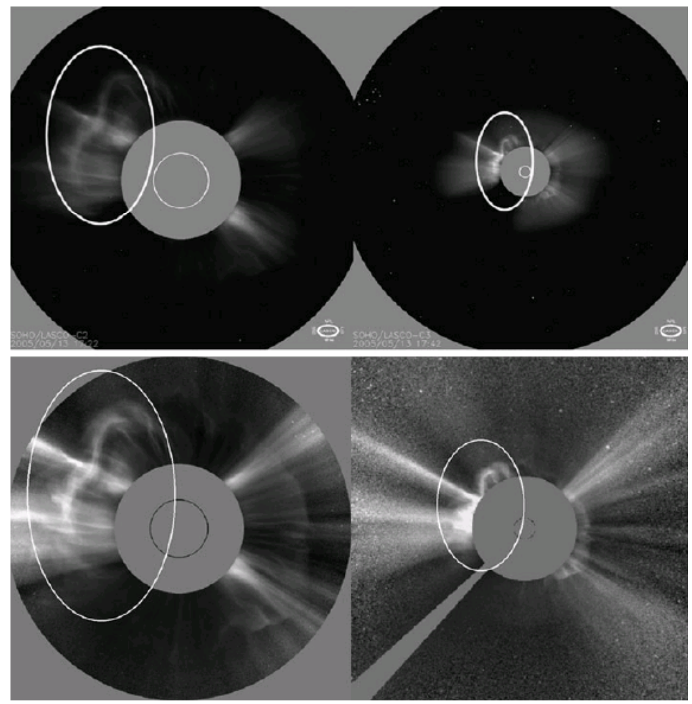


EUV images of the solar source of 13 May 2005 CME (bright) and associated dimming region (dark).

Multi-instrument, multi-technique study of 13 May 2005 CME

- Origin
- Development
- Propagation
- Terrestrial impact

Two separate CMEs merging together?

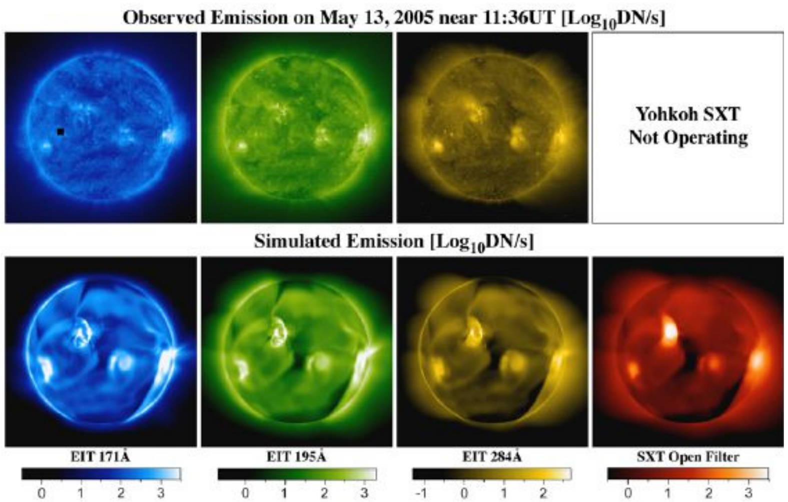


Coronagraph images of 13 May 2005 CME. Using the Standard LASCO processing technique (top), advanced processing technique (bottom).

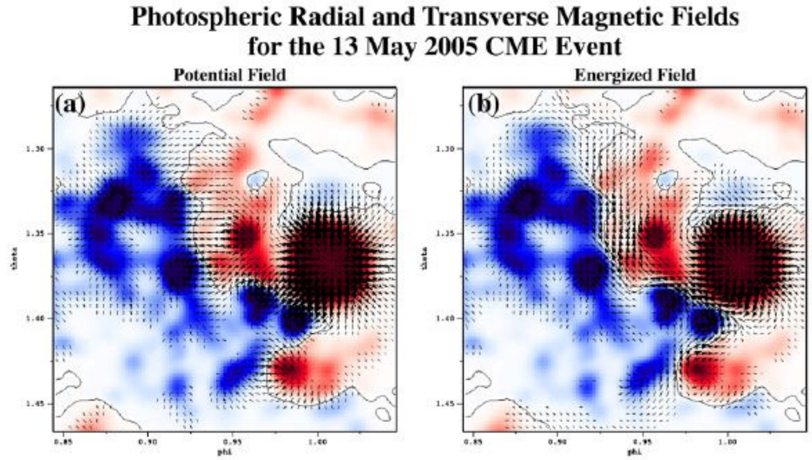
Bisi et al., Sol. Phys., 265, 49, 2010

Building the bigger picture

The large range of observations is useful for development of models of solar surface energetics and the energisation of the magnetic field.



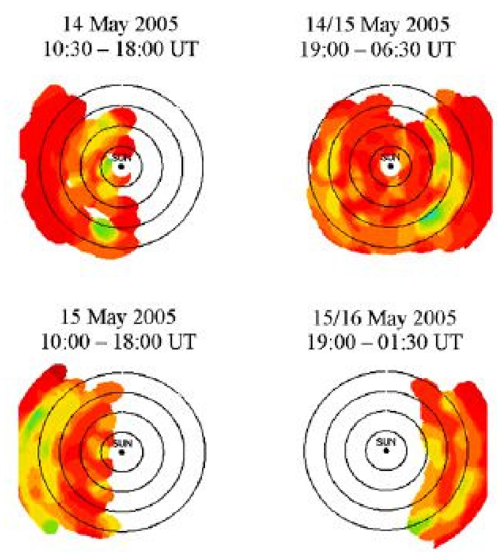
A quantitative comparison between observed (top) and simulated (bottom) emission for 13 May 2005 CME.



Simulated "vector magnetograms" showing the magnetic field in the photosphere. Intensity map: radial component (red: positive, blue: negative). Arrows: transverse magnetic field.

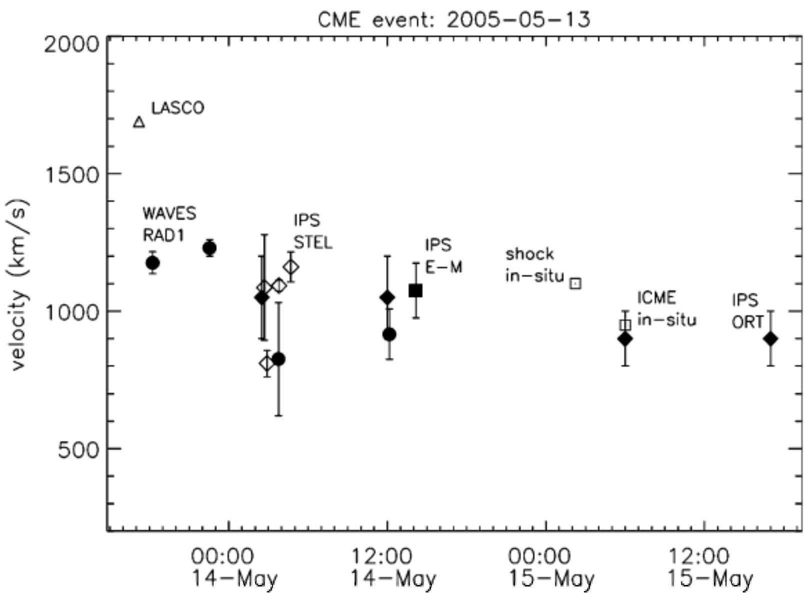
Using interplanetary scintillation to probe the inner heliosphere is a valuable but often under-used technique in multi-spacecraft studies.

g-maps from Ooty observations of IPS allowing the ICME to be tracked as it propagates through the inner heliosphere beyond the coronagraph FOV.



Bisi et al., Sol. Phys., 265, 49, 2010

Combining multi-spacecraft observations



Temporal evolution of 13 May 2005 CME speed, combining data from near the Sun (SOHO/LASCO), the inner heliosphere (type II radio bursts and IPS) and at 1 AU (WIND).

The combination of speed determinations from different instruments shows a gradual deceleration of the CME as it propagates in interplanetary space.

Bisi et al., Sol. Phys., 265, 49, 2010

This study aims to bring together as much data as possible on all aspects of the 13 May 2005 CME.

Outcomes:

- groundwork laid for full MHD models of EUV and active region magnetic field modelling.
- demonstration of useful and original techniques in the context of multi-spacecraft study of space weather.
- Exploits under-utilised analysis techniques.

Preliminary study of the 13 May 2005 CME suggested that it was relatively “simple” solar eruption. Detailed study has revealed the complexities of this event. Similar studies of other CMEs that this is frequently the case.

Summary and conclusions

Multi-spacecraft analysis of solar phenomena allows us to construct the "bigger picture".

Advantages:

- view the same event/phenomenon from different perspectives
- study the origins and evolution of solar events
- approach is suitable for a wide range of events
    - case studies and large-scale statistical studies
    - explosive solar activity (CMEs) and periods of low solar activity

Unique opportunities for solar observations with the current locations of solar spacecraft → The Sun in 360°.

Development of new techniques for combining and analysing remote sensing and *in situ* observations is important with a view to upcoming missions, like Solar Orbiter.