Heliophysics
Integrated
Observatory

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Heliospheric propagation tool Specification
Version 1.1

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Revision History

Version	Date	Released by	Detail
V1.0	2010-04-30	All	First draft in iteration within Toulouse before release
V1.1	2010-05-30	All	First wider release

Note: This is a working document that will evolve as we implement the propagation tool.

1 Introduction

As mentioned in the Description of Work (DoW) document, the main objective of this work package is to build spatial and temporal connections between heliospheric features. The first step in JRA2 is to investigate ways to automatically detect and describe heliospheric features, which populate the Heliophysics Feature Catalogue (HFC; cf. JRA WP2 organization document). The HFC will provide a complete description of the most relevant features for heliospheric science and will constitute a base on top of which heliospheric propagation tools may be used.

The objective of propagation tools is to provide scientists with information regarding the possible physical association between events or features that are observed at widely separated locations in both space and time. For instance, demonstrating one-to-one correspondence between events observed on Earth (e.g., geomagnetic storm) and at the Sun (e.g., solar flare) is far from being straightforward, even during solar minimum period.

The present document proposes and specifies heliospheric propagation tools, aimed at helping scientist in making such correspondence. The tools would be used in the context of the HELIO project either interactively by the user or in an automated fashion by the HELIO system. The structure is as follows:

- Simple science use-cases are utilized to illustrate the needs of the scientific community, i.e., which define the types of propagation tool and related requirements;
- Proposed tools and existing resources are then described, together with their technical characteristics, required inputs and outputs;
- Possible architectures and technical options for the implementation of heliospheric propagation tools within HELIO are then proposed.

1.1 Other relevant documents

HELIO Proposal Documents (e.g., Description of Work (DoW), etc.)
HELIO JRA WP2 organization

2 Scientific needs and requirements

In this section we illustrate the scientific need for heliospheric propagation tools utilizing several science use-cases for three major types of heliospheric features/events of interest to the community: (Interplanetary) Coronal Mass Ejection (CME/ICME), Corotating Interaction Region (CIR), and Solar Energetic Particle (SEP). Sub-section 1 gives a detailed use-case for ICME. Other sub-sections go along the same lines and are thus more succinct.

2.1 Common inputs/outputs and coordinate system

Common inputs and outputs that are dealt with in this document are typically (1) locations (of spacecraft or, e.g., feature on the Sun) and (2) times (of occurrence). For example, in the case of propagation of a CME from the Sun into the heliosphere, the location and time of lift-off of the CME on the Sun are the required, common inputs (whatever the propagation method) and the required, common outputs are a location and time of expected observation elsewhere in the heliosphere.

Universal time (UT) will be used within HELIO. For locations, appropriate coordinate systems for HELIO are currently being discussed in the context of other work packages. The propagation tools should make use of the coordinate system defined by HELIO. Propagation tools shall use heliocentric coordinate systems.

Ephemeredes for all objects considered within HELIO should be contained, and known, by default in the propagation tools. They are not further mentioned as inputs in the present document as this is a particularly obvious common input.

2.2 Tracking Coronal Mass Ejections (CME)

CMEs are mostly observed during solar maximum. Their large occurrence rate and the complexity of the corona during this period render their tracking through the heliosphere quite complex at such times. On occasion, they are also observed during solar minimum. In this later case, they are more isolated. They likely also interact less with their surrounding and are easier to observe in solar imaging data. For these reasons, tracking of CME through the heliosphere is easier during solar minimum. For sake of simplicity, this is what is assumed below.

For the present use-case, our starting point is the observation of an ICME. This ICME is taken to be observed *in situ* by a spacecraft orbiting Earth (or, e.g., the L1 Lagrangian point like the Advanced Composition Explorer (ACE) spacecraft). Our goal is to determine the origin of the CME on the Sun, and in particular its hemisphere of origin, its original total magnetic flux content and other general properties in order to study its evolution and alteration during its voyage to Earth.

In this framework, the goal of a propagation tool would thus be, from knowledge of the time of observation (T_1) and location (X_1, Y_1, Z_1) of the event in near-Earth space, to determine the origin of the event on the Sun's surface in terms of ejection/lift-off Time (T_0) and solar longitude and latitude (θ_0, φ_0) (R_0 of one solar radius is assumed).

From the literature and current work in the community, the following three strategies may be envisaged to obtain this information in the case of CMEs:

- Simple ballistic mapping;
- Global coronal and heliospheric simulations;
- Direct constraint by remote sensing observations;
- Direct constraint by multi-point *in situ* observations.

2.2.1 Simple ballistic mapping

Assuming that the bulk speed of the ICME did not vary over its course through the inner heliosphere, one easily obtains information about the origin of the CME on the Sun. The radial separation between Earth and the Sun corresponds to a time lag $\Delta T = (R_B - R_A)/V$, with V the solar wind speed – assumed to be constant – at point B and R_A and R_B the radial distances (from the Sun) of point A and point B (here point A is on the Sun's surface by definition: $R_A = 1\ R_S$ in solar Radii). Assuming the propagation was radial the event should have occurred along the central solar meridian (φ_0=0) at time $T0 = T1 - \Delta T$. Solar image data from this location and at that time may then be looked up by the scientist to search the origin of the ICME.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs: Event location (X_1,Y_1,Z_1) and time (T_1)
Analysis-type: Analytical.
$T0 = T1 - (R_B - R_A)/V$
Outputs: Location (φ_0, θ_0, R_0) and time (T_0), with ($\varphi_0 = \theta_0 = 0$, $R_0 = 1$ R$_S$)

2.2.2 Global coronal and heliospheric simulations

To track CMEs from the Sun to Earth, one may employ global coronal and heliospheric simulations such as those proposed by the Community Coordinated Modeling Center (CCMC, NASA, USA). The names and some details about the codes available at CCMC and in other institutes are given in section 3.1.2.

Such models can be used for CMEs if appropriate initial guess conditions at the Sun can be determined. However, such models may not be currently used to follow CMEs backward in a standard fashion, i.e., from the Earth back to the Sun.

In the context of a use-case where the starting point is a solar event, however, the implementation of appropriate initial CME properties in the models (i.e., constrained by solar observations) will permit to track the CME and to determine its impact on the inner heliosphere and its various objects.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs:
- Solar magnetograms
- CME initiation geometry
- Location (φ_0, θ_0, R_0) and time (T_0)

Analysis-type: Global simulations.
Coronal and heliospheric models solving MHD equations.
Outputs: Time of event passage (T_1) at given location (X_1,Y_1,Z_1) in the heliosphere.

2.2.3 Direct constraint by remote sensing observations

The Heliospheric Imagers onboard the recent STEREO NASA mission have provided the first white light observations of the inner heliosphere [*Howard et al.*, 2008]. Using in particular elongation (position in the field-of-view) versus time plots call "J-maps", HI observations have demonstrated great power in constraining the trajectory of two main types of events: CMEs and transient streamer blobs associated with CIRs [*Wang et al.*, 2008; *Rouillard et al.*, 2008; 2009]. In the context of CMEs, the difference images used for the J-maps highlight the passage of electron density enhancements in the field-of-view and thus typically show the leading edge of CMEs (i.e., sheath with enhanced densities) and possibly its trailing part, if compressed [e.g., *Rouillard et al.*, 2010].

Figure 1 below illustrates this capability. The left-hand part depicts the geometrical properties of the trajectory of a CME in the field-of-view of an the HI camera (here for STEREO-A) looking eastward from the Sun, together with the equation that relates the position angle (α) with the trajectory properties (v,β) as a function of time (t); here v is the assumed-constant CME speed and β is the trajectory longitudinal angle (in the appropriate heliocentric coordinate system). From J-maps showing the passage of a CME, it is possible to fit the trajectory of the CME in the J-map to the functional form given in Figure 1 (note that a typical J-map is illustrated later in Figure 4).

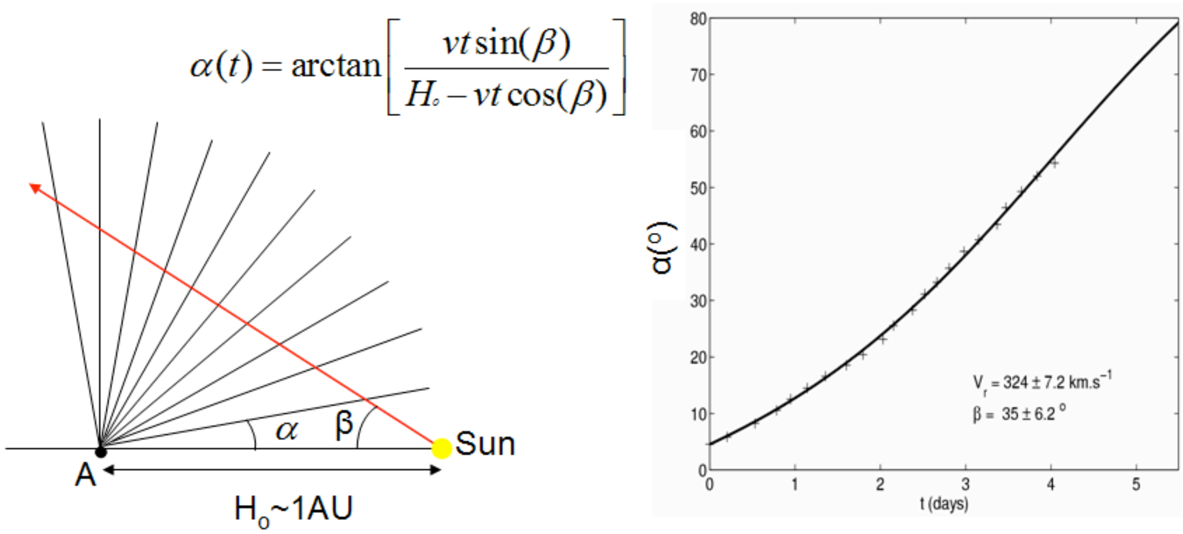

Figure 1. (Left) Illustration of the geometry of HI observations (here from STEREO-A spacecraft) during the passage of a CME in the field-of-view along the red arrow. The trace left in J-maps typically resembles the right-hand figure and the trajectory can be determined using a fit to the equation given at the top. See text for details. [From *A. P. Rouillard*, private communication]

This method is very efficient. It allows to constrain, directly from observations (HI J-maps), the trajectory of a CME, its time of lift-off at the Sun and its time of impact at any location along the trajectory. In other words, the propagation characteristics of the CME are directly constrained by observations rather than assumed from analytical or model calculations, with their associated limitations.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs:
- HI J-maps
- (possibly location and time)

Analysis-type: Analytical.
Fitting of trajectory functional form to actual trajectory in J-maps.
Outputs: Location (φ_0, θ_0, R_0) and time (T_0) of event lift-off at the Sun, as well as time of event passage (T_1) at any given location (X_1,Y_1,Z_1) in the heliosphere (along the trajectory).

2.2.4 Direct constraint by multi-point *in situ* observations

The final versions of the HELIO/JRA2 HFC should contain both "catalogues of events" and "catalogues of associated features". The propagation tools under consideration in the present document will be used to build such "catalogues of associated features". In some cases, however, the propagation methods mentioned here may not allow to determine appropriate associations between features/events. Yet, actual multi-point *in situ* observations may in such case point to a correlation despite the failure of propagation tools. In such cases, HFC "catalogues of associated features" based on such multi-point in situ observations ought to be constructed. Such catalogues may then be viewed as an independent "propagation tool" for given event (i.e., those contained in the catalogues).

For this method the required inputs, type of analysis and outputs are as follows:

Inputs: Event/feature time (T_0) and location (X_0,Y_0,Z_0) at Sun, or elsewhere in the heliosphere (event passage (T_0) at any given location (X_0,Y_0,Z_0)).
Analysis-type: Catalogue.
Search in catalogue of pre-determined event/feature association would be used.
Outputs: Location (φ_1, θ_1, R_1) and time (T_1) of event/feature at Sun, or else in heliosphere (event passage (T_1) at any given location (X_1,Y_1,Z_1)).

2.3 Following Corotating Interaction Regions (CIR)

CIRs are due to the overtaking of the slow solar wind from the vicinity of the Heliospheric Current Sheet (HCS) by the fast solar wind that emanates from the adjacent trailing coronal hole. The slow solar wind that is sunward of the HCS is what directly interacts with the trailing fast solar wind. As depicted in Figure 2, this interaction leads to the formation of a compression region (grey area) with enhanced density and magnetic field. Depending on the plasma properties and global geometry, forward and reverse shocks may form ahead and behind the compression region (long edges of the grey area in Figure 2). The magnetic field lines that thread the compression region extend "upstream" into both the uncompressed slow and fast solar wind.

CIRs are mostly observed during solar minimum when CMEs are rare and the HCS on the Sun is well defined. Because the solar structure is well defined they are observed in a recurrent fashion at the pace of the solar rotation period, with similar properties. During solar maximum this recurrent behaviour is not observed. The complexity of the corona still leads to the overtaking of slow by fast winds that emanate from various regions on the Sun. This more general form of compression region is called Stream Interaction Region (SIR). For sake of simplicity, we use the case of simple recurrent CIR for illustration in this document.

For the present use-case, our starting point is the *in situ* observation of a CIR at Earth (or L1). Our goal is to determine the origin of the CIR on the Sun, and potentially to determine whether this same CIR was observed at an other planet (e.g., Mercury, Venus, Mars) by a spacecraft.

As for CMEs, the strategies below are envisaged to obtain this information:

- Simple ballistic mapping;

- Global coronal and heliospheric simulations;
- Direct constraint by remote sensing observations;
- Direct constraint by multi-point *in situ* observations.

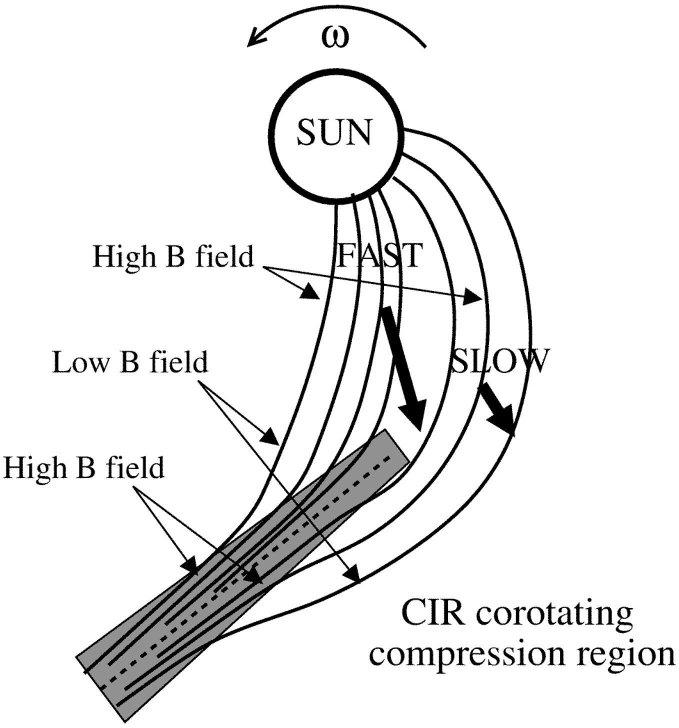

Figure 2. Illustration of a Corotating Interaction Region (CIR) with the high speed and low speed solar winds each side of the compression region (grey area). Forward and reverse shocks may form each side of the compression region (long edges of the grey area). [From *Lavraud et al.*, 2010]

2.3.1 Simple ballistic mapping

As illustrated in Figure 3, the radial separation between observation of a CIR at points A and B corresponds to a time lag that we may generalize as $\Delta t_1 = (R_B - R_A)/V$, with V the solar wind speed at point B (for example, where actual CIR observations are made) and R_A and R_B the radial distances of point A and point B (from the Sun). In parallel, we may estimate the time lag that corresponds to the propagation of a solar wind compression structure (the CIR) with longitude from point B to point A, and which stems from the ~27 day solar rotation period. This time lag is $\Delta t_2 = \alpha/\omega$, where α is the longitudinal angular separation between the two points (e.g., in degrees) and ω is the solar angular rotation speed (e.g., in degrees/s). The lag time to apply from point B to point A is thus $\Delta t = \Delta t_2 - \Delta t_1$.

This simple ballistic mapping permits to predict the time of observation of the structure at any point in the heliosphere (point A) based on the observation of a corotating structure (CIR) at point B.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs: Event location (X_1,Y_1,Z_1) and time (T_1)
Analysis-type: Analytical.
$T0 = T1 + \alpha/\omega - (R_B - R_A)/V$
Outputs: Location $(\varphi_0, \theta_0, R_0)$ and time (T_0), with $(\varphi_0 = \theta_0 = 0, R_0 = 1\ \mathrm{R_S})$

Note: One may also determine the probable geometry of a CIR from simple calculation of the magnetic Parker spiral orientation from a given point in the heliosphere (in and outwards). This method is given specifically in the context of SEP events in section 2.4.1.

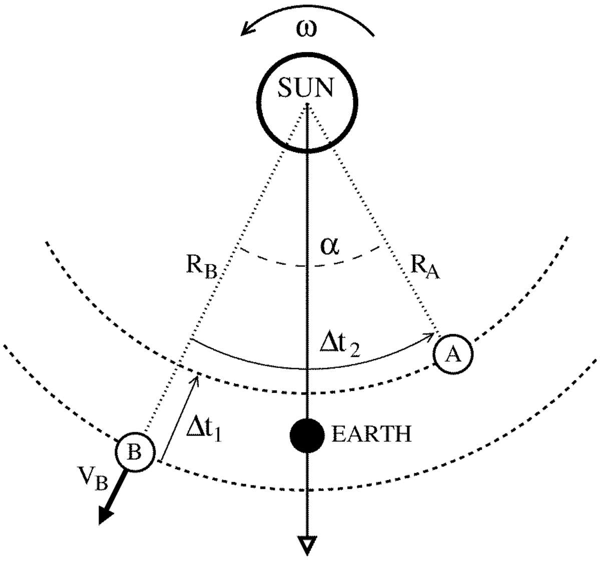

Figure 3. Schematic of a generalized time lag method applicable to multi-point measurements. Adapted from *Opitz et al*. [2009].

2.3.2 Global coronal and heliospheric simulations

To determine and thus follow the global topology of CIRs between the Sun and any point in the heliosphere, global coronal and heliospheric simulations such as those proposed by the CCMC are certainly efficient and in principle easy to use. It is more so than for CMEs since the HCS on the Sun (demarking slow and fast winds at the origin of CIRs) is well determined from just solar magnetogram data which are used as basic input for the models.

However, as for CMEs, such models may not be currently used to follow structures backward in a standard fashion, i.e., from the Earth back to the Sun.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs:
- Solar magnetograms.
- Location (φ_0, θ_0, R_0) and time (T_0).

Analysis-type: Global simulations.
Coronal and heliospheric models solving MHD equations.
Outputs: Time of event passage (T_1) at given location (X_1,Y_1,Z_1) in the heliosphere.

2.3.3 Direct constraint by remote sensing observations

CIRs are generally well identified in HI J-maps. The reason is that, as mentioned in section 2.2.3, streamer belt plasma blob ejections in the vicinity of the solar neutral/current sheet are easily seen in difference images because they produce variations in electron density (in addition to possible compression within CIRs). Such plasma blob ejections have been shown to occur in a recurrent fashion (with frequency of the order of ~12 hours), leaving clear converging or diverging tracks (STEREO-A and -B) in J-maps as a function of viewing geometry. However, the J-map fitting technique is not applicable to follow the "Parker-spiral" global geometry of CIRs since only the ejected blobs may be followed. These are only parcel elements embedded in the CIRs and have a rectilinear trajectory (as for CMEs) in the heliosphere. One may use HI observations, however, to determine the propagation of those blobs in the heliosphere, similarly to CMEs (section 2.2.3), as long as their signature is not too faint.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs:
- HI J-maps
- (possibly location and time)

Analysis-type: Analytical.
Fitting of trajectory functional form to actual trajectory in J-maps.
Outputs: Location (φ_0, θ_0, R_0) and time (T_0) of event near the Sun (helmet streamer), as well as time of event passage (T_1) at any given location (X_1,Y_1,Z_1) in the heliosphere (along the trajectory). Likelihood of hit by structure at given location is also a possible output.

2.3.4 Direct constraint by multi-point *in situ* observations

Similarly to 2.2.4, "catalogues of associated features" may be used for CIRs.

Inputs: Event/feature time (T_0) and location (X_0,Y_0,Z_0) at Sun, or elsewhere in the heliosphere (event passage (T_0) at any given location (X_0,Y_0,Z_0)).
Analysis-type: Catalogue.
Search in catalogue of pre-determined event/feature association would be used.
Outputs: Location (φ_1, θ_1, R_1) and time (T_1) of event/feature at Sun, or else in heliosphere (event passage (T_1) at any given location (X_1,Y_1,Z_1)).

2.4 Tracing Solar Energetic Particles (SEP)

Solar Energetic Particles (SEPs) are bursts of either ions or electrons in the suprathermal energy range (up to relativistic energies) that emanate from source regions generally located in the near vicinity of the Sun. Because of their very high energies, SEP can propagate almost freely, and in a matter of hours to minutes from the Sun to 1 AU, along heliospheric magnetic field lines.

The current paradigm has two types of SEP events: impulsive and gradual events. Impulsive events are thought to have their origin in flares while gradual events are likely associated with shocks driven by fast CMEs in the inner heliosphere (cf. Figure). Impulsive events are observed in a narrow cone of longitudes corresponding to observers magnetically well-connected to the site of the flare. Gradual events are, on the other hand, observed in a wider range of longitudes regardless of flares. For that reason, simple magnetic mapping is a good first-order method to determine the origin of SEP only for the impulsive cases. In the case of shock-driven SEP, more complex models are more appropriate.

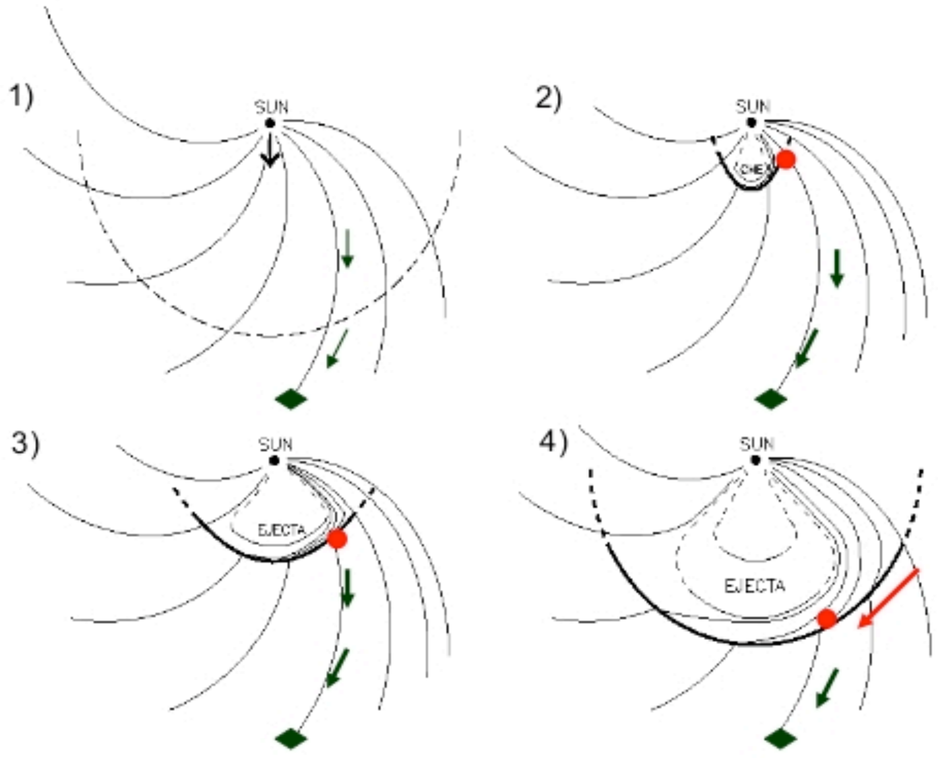

Figure 1.3. These four plots sketch how a shock generated by a CME propagates away from the Sun and expands in the interplanetary medium. Its front intersects the IMF and shock-accelerated particles stream away along them (upstream, green arrows). The red point identifies the point of the shock front that magnetically connects to the observer (identified by a green diamond); this point has been named cobpoint by Heras et al. (1995). The red arrow indicates that the cobpoint moves toward the nose of the shock (in this case) as the shock approaches the observer.

For the present use-case, our starting point is the *in situ* observation of a SEP at Earth (or L1). The goal is to determine the origin of the SEP and determine if, or which, flare or CME can be associated with it.

As for other structures before, the strategies below are envisaged to obtain this information:

- Simple ballistic mapping;
- Global coronal and heliospheric simulations;
- Direct constraint by remote sensing observations;
- Direct constraint by multi-point *in situ* observations.

2.4.1 Simple ballistic mapping

This simple ballistic mapping technique described for CIRs in section 2.3.1 is applicable to the tracing of SEPs. However, a possible simpler and more accurate way of tracing SEPs in the heliosphere is as follows.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs: Event location (X_1,Y_1,Z_1) and time (T_1)
Analysis-type: Analytical.
Parker spiral equation + diffusion equation
Outputs: Location (φ_0, θ_0, R_0) and time (T_0), with ($\varphi_0 = \theta_0 = 0$, $R_0 = 1$ R$_S$)

2.4.2 Global coronal and heliospheric simulations

Global Modeling:

Determining the path of SEPs requires knowledge of the global heliospheric magnetic field geometry. In the context of global heliospheric models such as those at CCMC, it is thus equivalent to tracking CIRs.

For this method the required inputs, type of analysis and outputs are as follows:

Inputs:
- Solar magnetograms.
- Location (φ_0, θ_0, R_0) and time (T_0).
Analysis-type: Global simulations.
Coronal and heliospheric models solving MHD equations.
Outputs: Time of event passage (T_1) at given location (X_1,Y_1,Z_1) in the heliosphere.

Solpenco model example:

The application assumes that the observer is located in the ecliptic plane. The following inputs need to be provided:

1) Heliocentric distance of the observer in the range 0.4 through 1.4 AU

2) Relative Heliolongitude of the parent event (flare or CME)

3) Shock transit time, in hours (i.e., the time interval the shock spends travelling from the Sun to the Earth)

4) Shock Width, in the range 40 through 140 degrees.

5) Mean Free Path, in AU (0.2/0.8). The transport conditions of energetic particles (specified by the mean free path of 0.5 MeV protons). With the present form of the model you can choose between 0.2 and 0.8 AU

6) Turbulence Foreshock Region (yes/no). In some events the arrival of the shock at the observer is characterized by an energetic particle flux enhancement (also called ESP event). Our model reproduces these SEP events by assuming a foreshock turbulent region.

→ Outputs are particle fluxes as a function of time at given locations and energies.

2.4.3 Direct constraint by remote sensing observations

Remote sensing observation-based techniques are not applicable for SEPs

2.4.4 Direct constraint by multi-point *in situ* observations

Similarly to 2.2.4, "catalogues of associated features" may be used for SEPs.

Inputs: Event/feature time (T_0) and location (X_0,Y_0,Z_0) at Sun, or elsewhere in the heliosphere (event passage (T_0) at any given location (X_0,Y_0,Z_0)).
Analysis-type: Catalogue.
Search in catalogue of pre-determined event/feature association would be used.
Outputs: Location (φ_1, θ_1, R_1) and time (T_1) of event/feature at Sun, or else in heliosphere (event passage (T_1) at any given location (X_1,Y_1,Z_1)).

2.5 *Summary of requirements*

Based on the above simple use-cases, we summarise below what we have gathered in terms of (1) which method may (best) apply, or not, for the three main structures illustrated, and (2) which inputs and outputs are required for each method.

2.5.1 Feature/method summary table

	Ballistic mapping	Global simulations	Direct HI observation	Multi-point *in situ* obs.
CME	Yes Simple but efficient for large CMEs	Yes, from Sun to planet/object. Other way around too complex	Yes Most reliable and efficient if structure well defined in images	Yes
CIR	Yes Simple but efficient large scale shape	Yes Most effective since initial conditions easy	Partial Only recurrent blob ejection with rectilinear trajectory	Yes
SEP	Yes Simple but efficient (may add diffusion??)	Yes	No	Yes

2.5.2 Input-output/method summary table

	Ballistic mapping	Global simulations	Direct HI observation	Multi-point *in situ* obs.
Common/basic inputs	Time in UT Coordinate system Ephemeredes			
Inputs	Location Time	Location Time Magnetograms (CME initiation geometry)	HI J-maps (possibly location and time)	Location Time
Outputs	Location Time	Location Time	Location Time Likelihood of hit by structure	Location Time
Method/data type	Analytical	Modelling – simulation	White-light difference images	Associated-events catalogue
Reference	E.g., Opitz et al. [2009]	Cf. e.g., NASA/CCMC	E.g., Rouillard et al. [2010]	HELIO JRA-2 Organization document

Alternative version

	Ballistic mapping	Global simulations	Direct HI observation	Multi-point *in situ* obs.
Common/basic inputs	Time in UT Coordinate system Ephemeredes			
Inputs	Location Time SW speed V	Location Time ΔT Magnetograms (CME initiation geometry)	HI J-maps (possibly location and time)	-Locations - At these different locations: ▪ Times of the events ▪ SW speed V
Outputs	Location Time ΔT	Location Time ΔT	Location Time (ΔT?) Likelihood of hit by structure	Location Time ΔT
Method/data type	Analytical	Modelling - simulation	White-light difference images	Associated-events catalogue
Reference	E.g., Opitz et al. [2009]	Cf. e.g., NASA/CCMC	E.g., Rouillard et al. [2010]	HELIO JRA-2 Organization document

3 Proposed tools and existing resources

In this section we make an inventory of existing resources for each type of method identified previously. We then specify the characteristics of the proposed tools in a more detailed fashion.

3.1 Inventory of existing resources

There are numerous resources that exist in the community and that allow to study heliospheric features and propagation. The resources typically belong to one of the four categories identified above:

- Simple ballistic mapping;
- Global coronal and heliospheric simulations;
- Direct constraint by remote sensing observations;
- Direct constraint by multi-point *in situ* observations.

3.1.1 Simple ballistic mapping

This simple ballistic mapping method described in 2.3.1 permits to predict the time of observation of a corotating structure at any point in the heliosphere (point A) based on the observation of a corotating structure (CIR) at point B. Even simpler lag time calculations permit to determine the probable ejection time of CMEs on the Sun (section 2.2.1). A third ballistic approach, combining Parker spiral magnetic field mapping and diffusion equation, was mentioned in the context of SEP events.

3.1.2 Global coronal and heliospheric simulations

Although global simulations in principle allow to determine the propagation of structures in the heliosphere, in practice a user interested in tracing a “random” feature back to the Sun has little chance that simulations exists for which either such tracing was made previously (e.g., WSA mapping for STEREO support at CCMC) or for which full (V, B, etc.) results from the simulation have been stored (e.g., the amount and resolution of CCMC data that are stored are generally low owing to obvious storage limitations).

Inventory of existing simulation codes of interest:

CCMC (WSA; PFSS; ENLIL; SWMF)
http://ccmc.gsfc.nasa.gov/
CCMC support to STEREO mission:
http://ccmc.gsfc.nasa.gov/stereo_support.php
CCMC support to THEMIS mission:
http://ccmc.gsfc.nasa.gov/ungrouped/extras/THEMIS_support.php

NASA Integrated Space Weather Analysis System (iSWA)

http://iswa.gsfc.nasa.gov/iswa/iSWA.html
Can access real-time plots of all data and models run at CCMC (don't think the results are saved further (to check).

FROMAGE: French simulations of full corona with streamer belts to come (need to contact Tahar Amari). Possibility to do mapping in the near-Sun corona like Wang-Sheeley-Arge (WSA) model?
http://www.solaire.obspm.fr/fromage/

NOAA Space Weather Service

NSO/GONG Potential-Field Source-Surface Model (PFSS) mapping from sub-Earth point:
http://gong.nso.edu/data/magmap/index.html
http://gong.nso.edu/data/magmap/mod5.html
Similar to CCMC mapping with WSA for STEREO era??
Is actual data from mapping accessible??

Solpenco for SEPs:
Model/simulation/transport equations
http://www.am.ub.es/~blai/indexsol.php
full report : http://www.am.ub.es/~blai/articles/SolpencoI_7.pdf
paper : http://adsabs.harvard.edu/abs/2006AdSpR..37.1240A

To be completed.

3.1.3 Direct constraint by remote sensing observations

An example of J-map derived from difference HI white-light images onboard STEREO is given in Figure 4. As is obvious there are both (1) recurrent and continuous small-scale structures observed close to the Sun (low elongation values), which are two faint to be observed farther away from the Sun, and (2) large-scale structures with strong coronal electron density variations that allow continued observation in the entire field-of-view (which means often past 1 AU). The method was already described in section 2.2.3. To summarize, the basic functionality of such a propagation tool constrained by actual observations would be as follows.

A – J-maps (which are generated on a regular basis) constitute the core dataset.
B – The functional form of the trajectory in the field-of-view (Figure 1) is the basic analytical formula to be used.
C – Traditional fitting methods are then applied to determine the trajectory parameters in the heliosphere (e.g., from predetermined trajectories or directly by user-clicking on J-map).
D – Outputs are determined from user queries, i.e., trajectory parameters, origin on the Sun, impact at Earth or other location in heliosphere. Yes/No/Maybe if likelihood of hit requested.

Fitting modules already available in several institutes (NRL/USA; RAL, UK)

To be done: identifying the J-maps resources

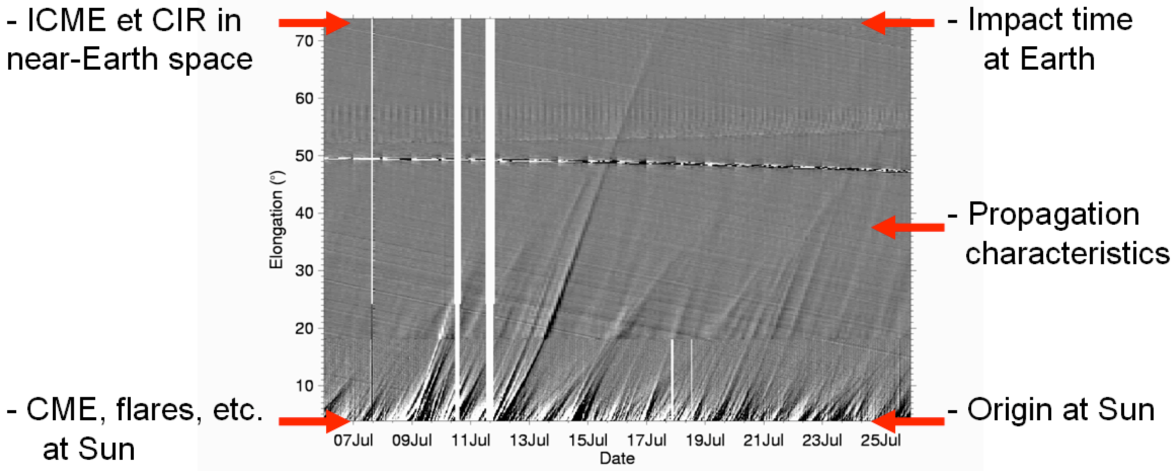

Figure 4. J-map built from HI-1 and 2 white-light observations onboard STEREO for the case of a CME (main track in middle of Figure) passing in the field-of-view of the cameras in July 2008. Fitting to such track (cf. Figure 2) allows to determine the trajectory and kinematics of propagation of a CME in the inner heliosphere and thus to determine their location and time of origin (on the Sun) as well as their impact time at other locations in the inner heliosphere (Earth or other planets/satellites).

3.1.4 Direct constraint by multi-point *in situ* observations

The Heliospheric Features Catalogues (HFC), together with associated events catalogues, which ought to be built in the context of the HELIO project will be the basis of such a "propagation tool". Continued addition of catalogues from various external sources, as well as continued extension of such associated-events catalogues by scientists, would be vital.

3.1.5 Other perspectives and collaborations

SOTERIA collaboration: using data assimilation to predict the solar wind speed and magnetic field. As an example of what they have in mind is the service provided by NOAA. They base their predictions on the WSA model and make no use of data assimilation. Their approach is completely different but the goal is similar.

3.2 Accessibility, characteristics and formats

The propagation tool of HELIO will need to access to data and services and to be able to exploit their products. In some reasonable part, the most used data could be ingested to a database attached to the propagation tool in order to favour good performances. Nevertheless, it will be necessary to access to external resources and this requires that protocols can be developed on the basis of standard metadata and formats.

3.2.1 Accessibility

To be done

3.2.2 Characteristics and formats

To be done

4 Requirements and specifications for the HELIO propagation tool

4.1 *Web services*

The propagation tool needs interoperable services for:

- accessing to data like the solar wind speed or the solar magnetograms;
- accessing to ephemerides
- performing coordinate and units transform

4.2 *Standard and metadata*

Common inputs/outputs:

- **Time**:
    - The *time* input need to be characterised by a metadata. HELIO would take benefits to adopt a standard for writing the time in order to avoid the use of set of metadata (units, time origin, …) rather than a unique one.
    - The time of occurrence of events/features will generally consist of a time interval, i.e., a start time and a stop time. The *time* input can be an individual time interval or a set of time interval listed in time-table corresponding to a list of events (derived from a catalogue for example). Note a standard for time-tables has been defined through a joint effort of CDPP, CAA, CESR and IC/QMUL. It use the time format CCSDS ASCII Calendar Segmented time code format (ISO8601) : 2008-02-26T15:00:23.123Z. The time-table is written inside an XML file compliant to the VOTable 1.1 format. A full description can be found at: http://cdpp2.cesr.fr/twiki/bin/view/AMDA/AmdaTimeTables
    - Additional time characteristic may be considered, like peak time, sub-sequence times, etc… But then, the
- **Location**:
    - The location needs to be described by a set of metadata including at least:
        - the units
        - the coordinated system
        - the name of observatory
    - a module for coordinate transform should be implemented inside or linked to the propagation tool.

Method and/or features specific inputs:

Ballistic mapping.

- **Solar Wind speed**:
    - The Solar Wind speed needs to be described by a set of metadata including at least:
        - the units
        - the coordinated system
        - the name of the instrument used or in some case the name of the dataset (e.g. the OMNI data provided by SPDF)

4.3 Protocol. Formulating the requests.

To be done