HELCATS Deliverable D2.2

Report on the feasibility of automatic identification of CMEs in HI-1 data

Project Acronym: HELCATS

Project Title: Heliospheric Cataloguing, Analysis and Techniques Service

Grant Agreement Number: 606692

Start date of the Project: May 1, 2014

Project Duration: 3 years

Coordinator: Richard Harrison (STFC)

Lead Beneficiary for this Deliverable: ROB

Editor: L. Rodriguez

Authors: L. Rodriguez, S. Willems

Work-Package (WP)	WP 2
Task(s)	Task 2.2
Deliverable	D2.2

Due Date of Deliverable: Month	12

Issue Record				
Version	Date	Author(s)	Reason for Modification	Status
1	8-MAY-2015	L. Rodriguez, S. Willems	Version 1	Submitted

Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

TABLE OF CONTENTS

Contents

1. Introduction

The advent of wide-angle imaging of the inner heliosphere has revolutionised the study of the solar wind and, in particular, transient solar wind structures such as Coronal Mass Ejections (CMEs) and Co-rotating Interaction Regions (CIRs).

CMEs comprise enormous plasma and magnetic field structures that are ejected from the Sun and propagate at what can be immense speeds through interplanetary space, while CIRs are characterised by extensive swathes of compressed plasma/ magnetic field that form along flow discontinuities of solar origin that permeate the inner heliosphere.

With Heliospheric Imaging came the unique ability to track the evolution of these features as they propagate through the inner heliosphere. Prior to the development of wide-angle imaging of the inner heliosphere, signatures of such solar wind transients could only be observed within a few solar radii of the Sun, and in the vicinity of a few near-Earth and interplanetary probes making in- situ measurements of the solar wind. Heliospheric Imaging has, for the first time, filled that vast and crucial observational gap. HELCATS is a strategic programme that aims to empower the wider scientific community, by providing access to advanced catalogues - validated and augmented through the use of techniques and models - for the analysis of solar wind transients.

CMEs are intrinsically difficult to identify and trace in heliospheric imager data. The challenge of Task 2.2 consists not only in identifying all CMEs during the STEREO mission, but also to do so automatically, without human intervention. This report describes how we successfully arrived to fulfil this goal.

It is the first time that this is achieved successfully. This task used ROB extensive experience in autonomous detection of CMEs in coronagraph images from the SOHO/LASCO instrument and, more recently, from STEREO/COR2 (e.g. Robbrecht et al. 2009).

2. Method of automatic detection of CMEs in HI data

The technique used consisted on an adaptation of CACTus (http://sidc.oma.be/cactus/, see also Robbrecht and Berghmans, 2004) to HI data.

2.1 Basic image handling

The procedure is started with HI-1 level-2 images. A daily background is removed from the images. The black strips around planets are then isolated and a sigma_filter is applied with a larger box size, in order to replace the black strips by a smoothed version of the neighbouring pixels. The original and resulting images are show in in Figure 1.

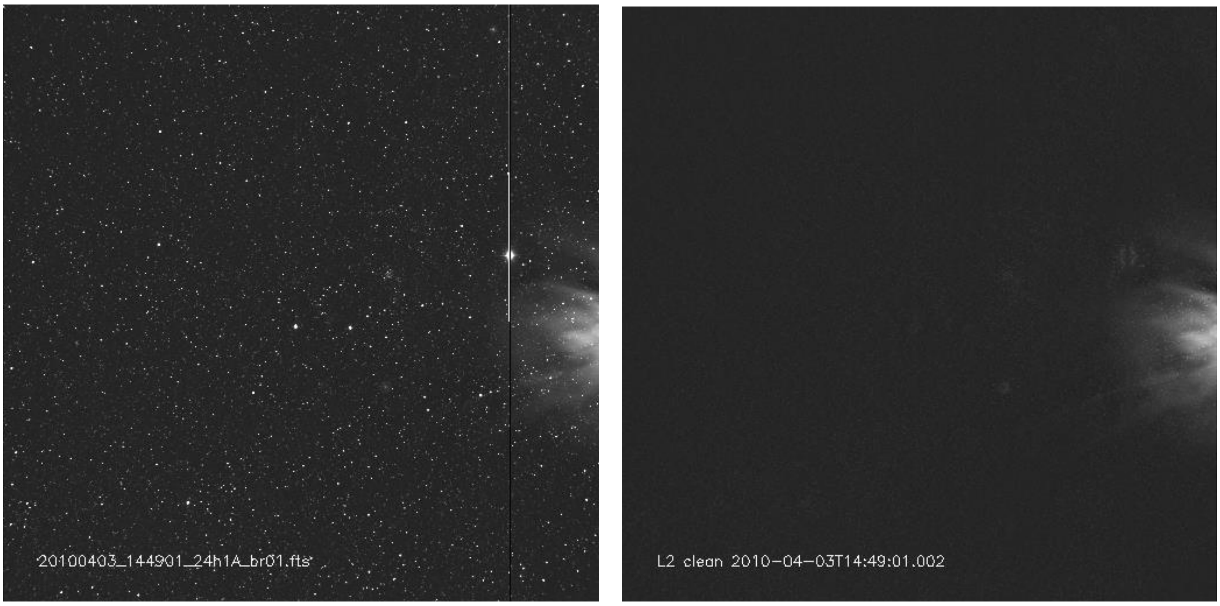

Figure 1. Example of a Level-2 image before (left panel) and after (right panel) cleaning.

2.2 Conversion to polar coordinates

This conversion is needed in order to be able to apply the Hough transform (Jähne 1977) to the images.

The conversion is done by means of the hi_align_image routine, in order to align all the images to the first one. Coordinates of the shifted images are now the same as in the first image. Conversion of HPC (Helioprojective-Cartesian) longitudes and latitudes into HPR (Helioprojective-Radial) position angle and elongation is done with wcs_conv_hpc_hpr. Finally, conversion of the elongations into projected distance is carried out.

In a polar image, the X-axis represents the angle from solar north (2° binned to a single pixel) and the Y-axis shows the projected distance from the Sun (10000 km/pixel), as shown in Figure 2.

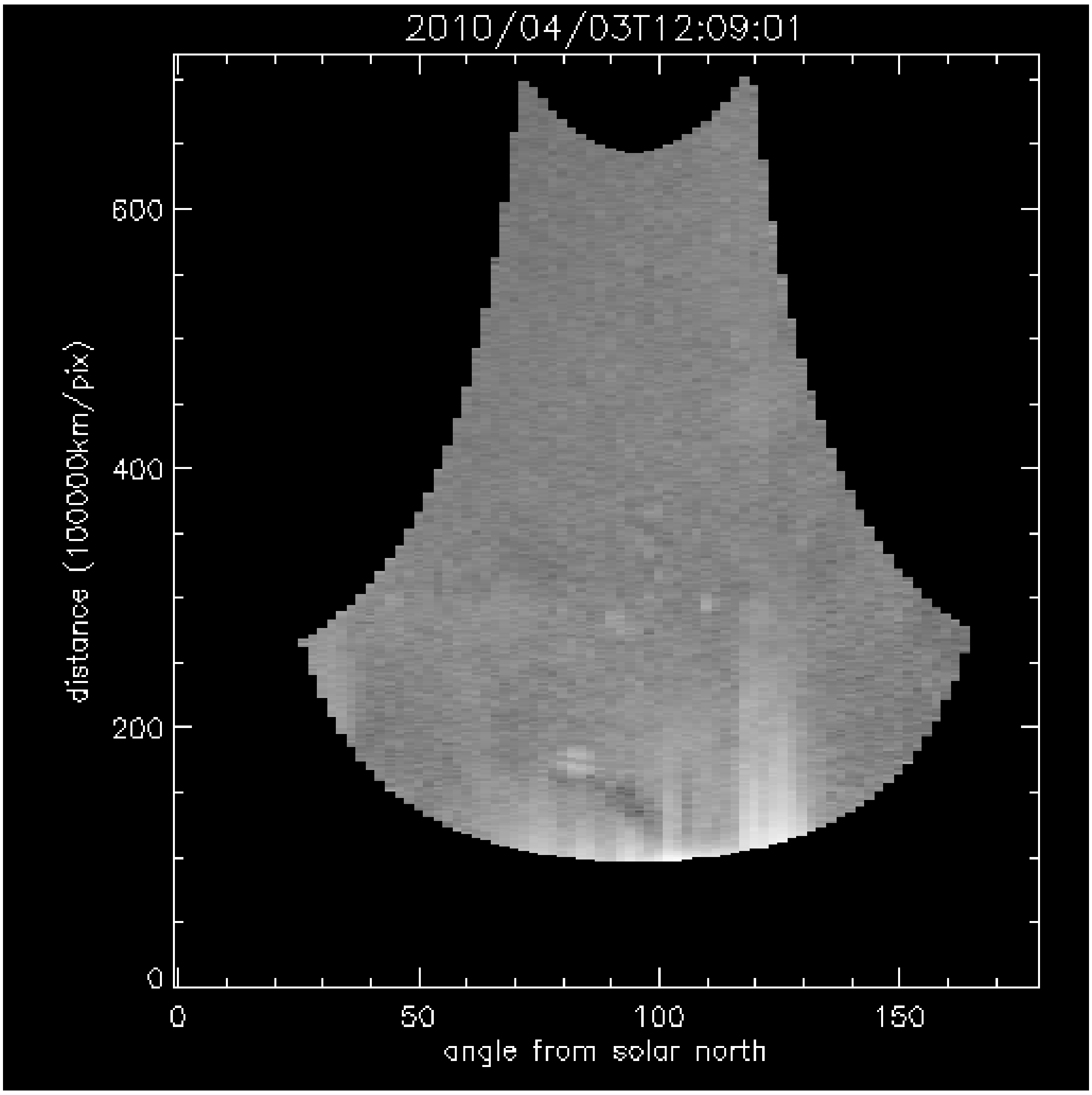

Figure 2. Example of an image converted to polar coordinates.

2.3 Difference images

Noise is removed from the images by filtering in time in the datacube. Next, running difference is applied to the images, see Figure 3.

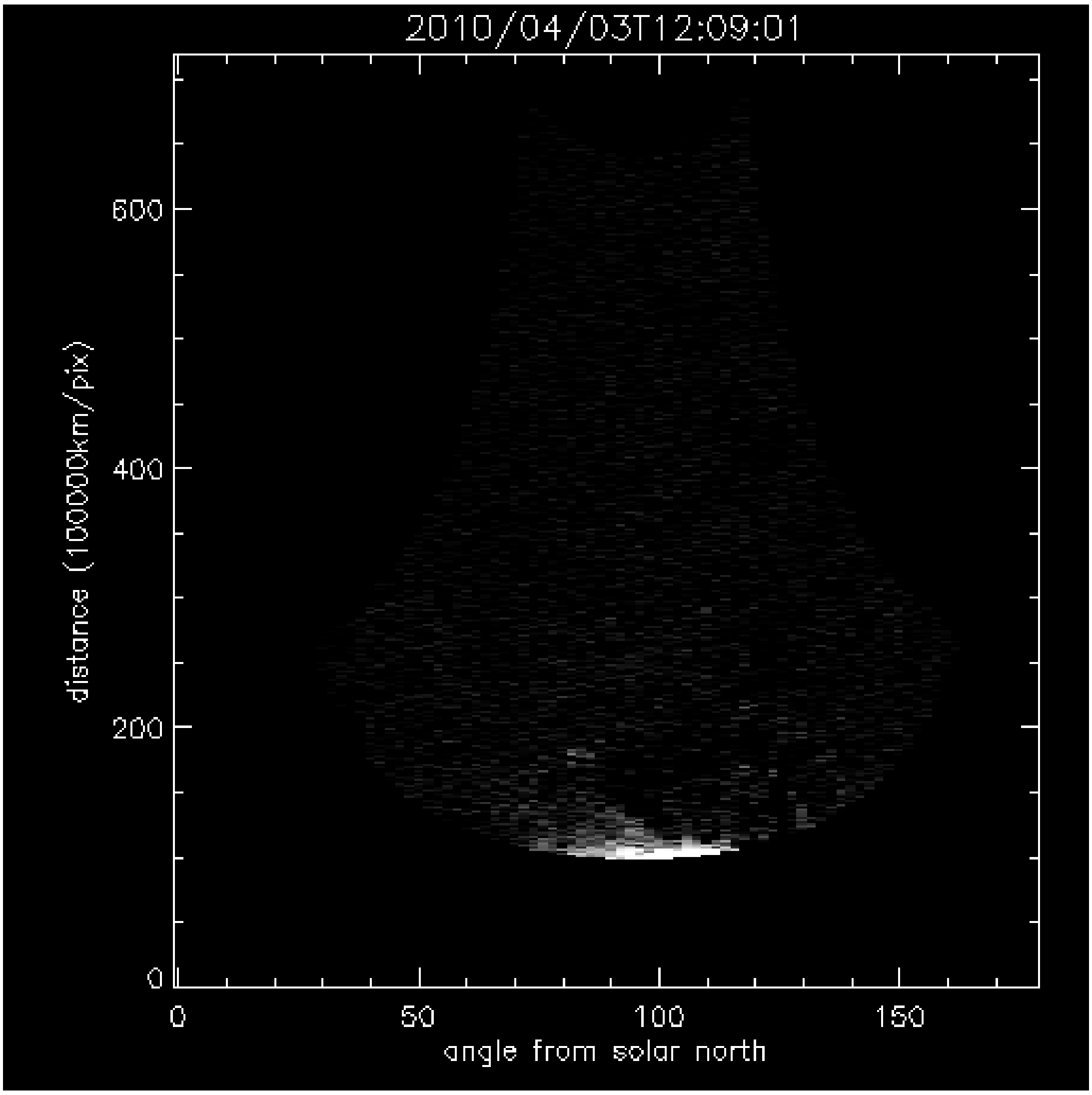

Figure 3. Example of a running difference polar image.

2.4 Application of the Hough transform

Prior to the application of the Hough transform, the images are converted into distance – time slices for each angle (Figure 4).

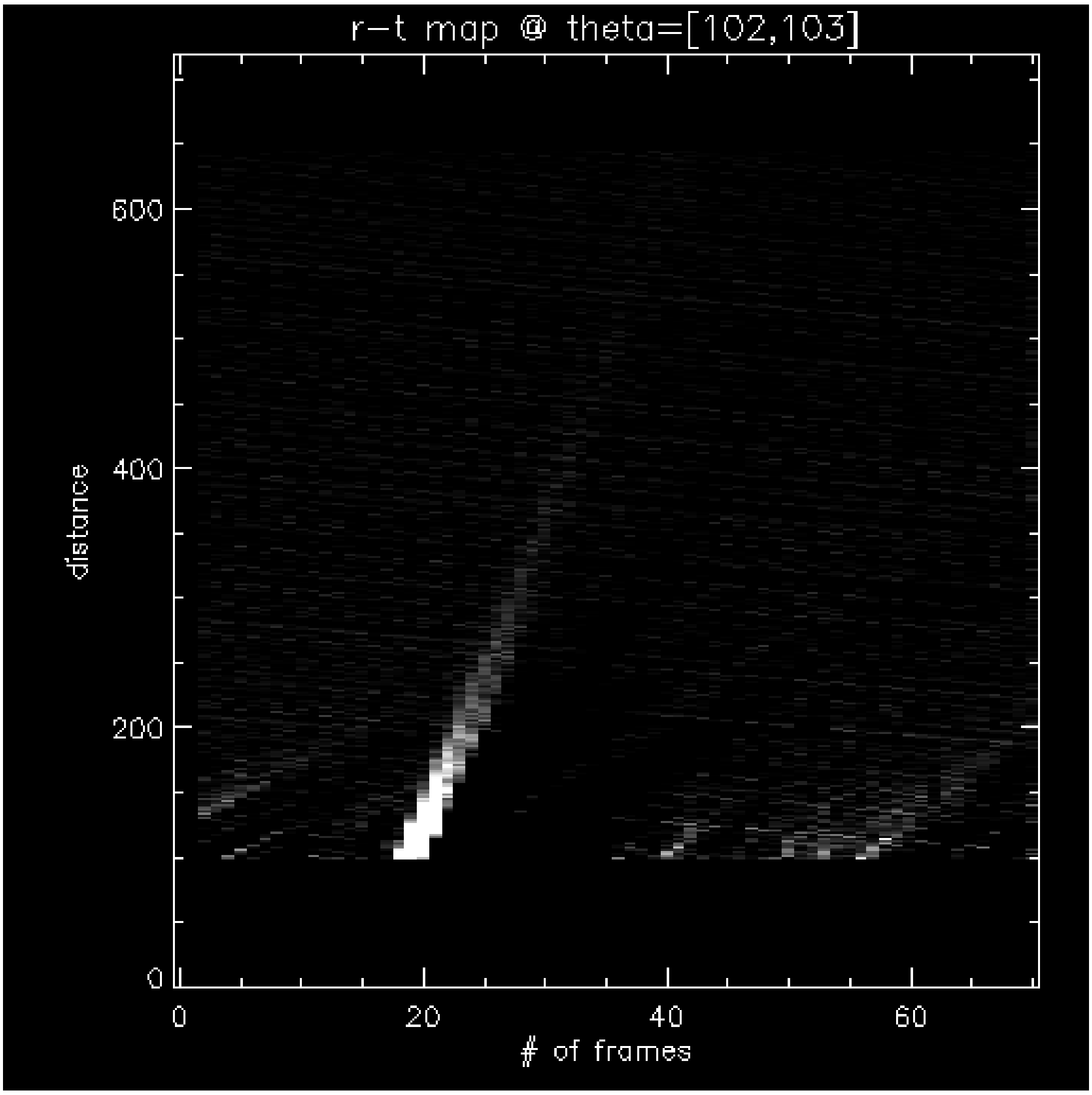

Figure 4. Example of a distance time (r – t) image.

Then the Hough transform is applied to these r – t maps at all angles. Speeds between 100 km/s and 2100 km/s are considered. This then yields a time vs. speed (t –v) map which is summed along the speed dimension to provide a time vs. angle (t – a) image, which contains all information about the CME. An example is shown in Figure 5.

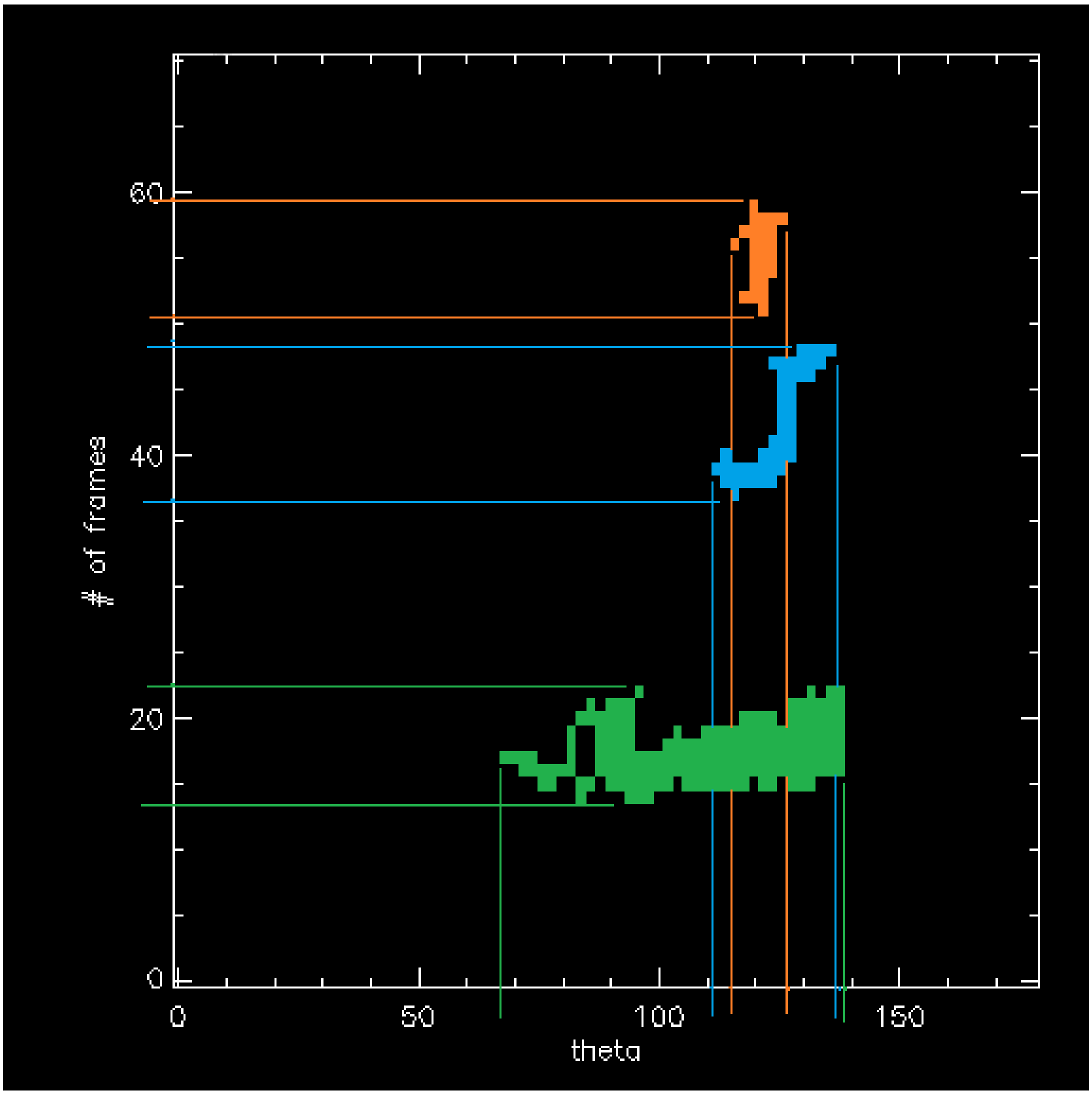

Figure 5. Example of a time vs. angle (t – a) map.

In the detection map, for each t – a pair a speed is associated. This speed corresponds to the ridge with contains the highest signal in the r-t slice. Each CME is associated with the median of the velocities placed in it. This results in velocity vs. angle (v – a) maps as shown in Figure 6. This is the final output of CACTus, in this way speed and angular width is computed for each CME

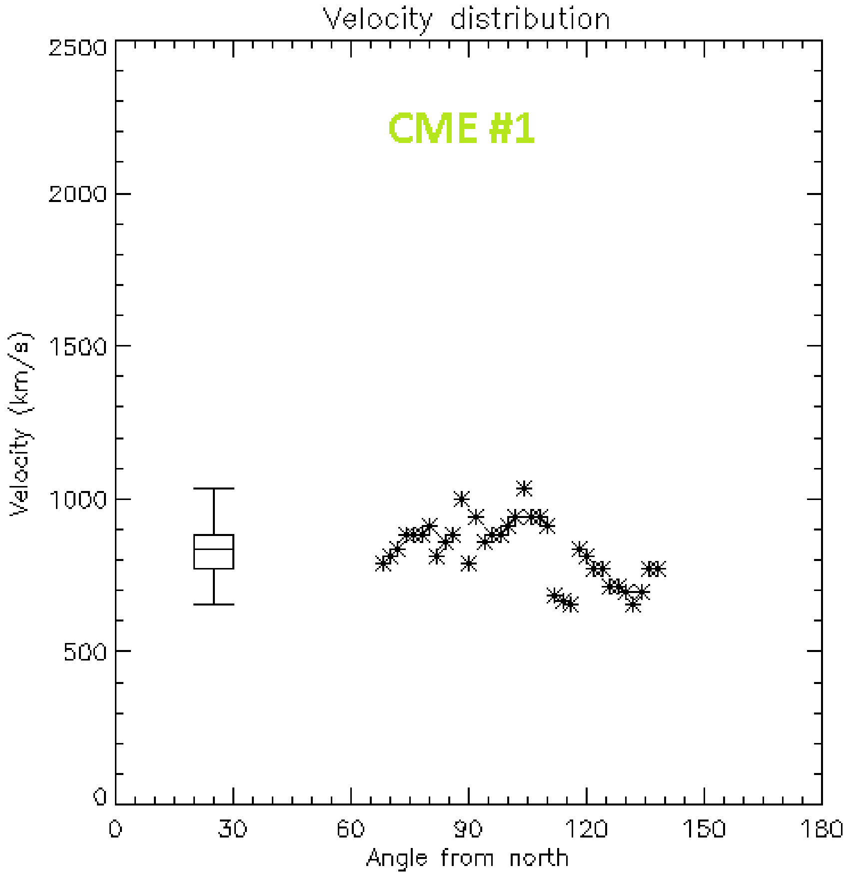

Figure 6. Example of a velocity vs. angle (v – a) map for a CME.

3. The automated CME catalog for STEREO-HI

The procedure described in the previous section is applied to all the STEREO data, both from STEREO-A and STEREO-B for the duration of the mission (2008 – 2014). An extract of the catalog is shown in Figure 7.

CACTus for STEREO/HI-1

A software package for 'Computer Aided CME Tracking' (adapted from CACTus)

CMEs detected by CACTus - /A/2008/08/

Show comparison with the Manual catalog and other level images

```
:Issued: Sun Mar 15 17:18:21 2015
:Product: CACTus catalogue for HI
#--------------------------------------------------------------------
# Instrument: SECCHI-A | Detector: hi_1
# Minimal CME width: 0010
#
  first hi_1: 2008-07-31T00:09:01.006   20080731_000901_24h1A_br01.fts
  last  hi_1: 2008-08-31T23:29:01.112   20080831_232901_24h1A_br01.fts
#
#--------------------------------------------------------------------
# Output: Detected cmemap with the following characteristics:
#
#    CME: CME number
#   Flow: Flow number. Flows are suspicious detections,
#          their color in the detectionmap is dark blue
#     t0: first apparition in field of view
#     pa: principal angle, counterclockwise from North (degrees)
#     da: angular width (degrees),
#    NPA: Northernmost propagation angle (degrees),
#    SPA: Southernmost propagation angle (degrees),
#      v: median (projected) velocity (km/s)
#     dv: variation (1 sigma) of velocity over the width of the CME
#   minv: lowest velocity detected within the CME
#   maxv: highest velocity detected within the CME
#
# CME |        t0        | pa | da | NoPA| SuPA|  v  |  dv | minv| maxv
  0012|2008/08/31 10:09| 0100| 016| 0092| 0108| 0350| 0042| 0300| 0431
  0011|2008/08/31 00:09| 0109| 062| 0078| 0140| 0491| 0074| 0354| 0668
  0010|2008/08/21 12:49| 0067| 014| 0060| 0074| 0285| 0035| 0222| 0319
  0009|2008/08/20 07:29| 0080| 044| 0058| 0102| 0215| 0015| 0181| 0236
  0008|2008/08/17 22:09| 0083| 010| 0078| 0088| 0300| 0006| 0292| 0307
  0007|2008/08/17 00:49| 0082| 012| 0076| 0088| 0302| 0029| 0268| 0350
  0006|2008/08/13 00:09| 0070| 020| 0060| 0080| 1817| 0085| 1770| 1967
  0005|2008/08/11 06:49| 0079| 034| 0062| 0096| 1542| 0746| 0268| 1864
  0004|2008/08/10 18:09| 0080| 016| 0072| 0088| 0367| 0017| 0330| 0384
  0003|2008/08/07 16:09| 0098| 036| 0080| 0116| 0300| 0025| 0272| 0354
  0002|2008/08/04 05:29| 0111| 034| 0094| 0128| 0400| 0075| 0240| 0513
  0001|2008/07/31 08:49| 0067| 010| 0062| 0072| 0319| 0021| 0287| 0347
```

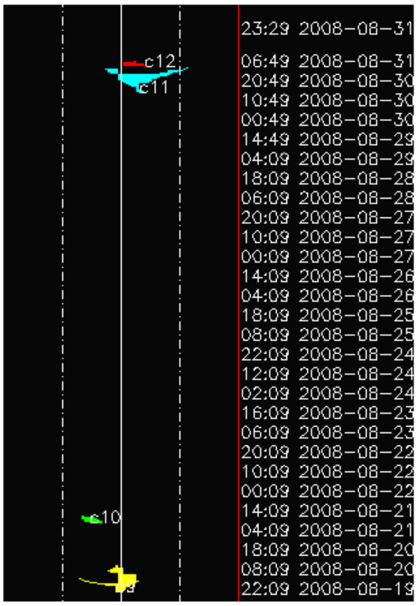

Figure 7. The automated CME catalogue constructed for STEREO-HI.

The catalogue will be made available online, each CME is clickable and leads to plots and movies.

4. Conclusions

In this deliverable it was shown how the automatic identification of CMEs in HI data was made possible by an adaptation of the CACTus technique to the data. A catalogue containing all the CMEs detected during the STEREO mission was built.

The outcome of the present study is positive, we have succeeded in creating an automated extraction of CMEs in HI data. The full catalogue will be fine-tuned and compared to the manual version.

References

Jähne, B. 1997, Digital Image Processing (Springer-Verlag), 463

Robbrecht, E., Berghmans, D., Automated recognition of coronal mass ejections (CMEs) in near-real-time data, A&A, 425, 1097-11062004