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HELCATS WP7 Update - overview

Dr. Jonathan Eastwood

HELCATS month 18 meeting, 3-4 November 2015, Helsinki, Finland

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Work Package 7 (reminder)

Assessing the complementary nature of radio measurements of solar wind transients

- *Duration*: Months 10 – 36
- *Participants*: Imperial, ROB, STFC
- *Work package leader*: Jonathan Eastwood (Imperial)

- *Objectives*:
  - To identify and analyse potentially-geoeffective solar wind events that are observed by both HI and IPS, and use IPS to augment the HI observations.
  - To identify and analyse solar wind transients that are observed by both HI and in radio, and add value to the HI data by establishing/cataloguing the relationships between them.

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Motivation (reminder)

- Recognising that radio observations are associated with heliospheric transients, this work package links **Inter-Planetary Scintillation** and **Type II radio emission** to the established Heliospheric Imager observed events.

- **IPS**: Solar wind density; solar wind speed can be retrieved if signals from the same radio source are received at spatially-separated receiver sites

- **Type II radio emission**: generated at shocks driven by coronal mass ejections, frequency corresponds to (harmonics) of the local plasma frequency, which is a function of density. Coordinated analysis of HI data and radio burst observations has been performed only on a case-by-case basis (e.g. Magdalenic et al., 2014; Harrison et al., 2012)

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Tasks and deliverables (reminder)

- **T7.1** - Identifying and analysing potentially-geoeffective solar wind events that are observed by both HI and IPS [Months: 10-36] STFC
- **T7.2** - Identifying and analysing solar wind transients that are observed by both HI and in Type II radio burst emission [Months: 10-36] IMPERIAL, ROB

- **D7.1** : Catalogues of EISCAT and LOFAR IPS data events and of S/WAVES events, both extending throughout the STEREO HI Mission timeline [month 27]
- **D7.2** : Report of initial comparison between IPS events and HI events. [month 30]
- **D7.3** : Report of initial comparison between solar radio-burst events and HI events. [month 30]

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High level strategy for WP7 (reminder)

- Start month 10
- Initial construction of catalogues, in the context of initial work on the HI catalogue (D7.1)
- Identification of events for case study and detailed analysis
- Analysis of case studies (D7.2 and D7.3)
- Feedback into main HELCATS catalogue (precise format TBD)

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WP7 overview summary

- WP7 well underway
  - PDRA hired at Imperial to work exclusively on HELCATS (Krupar, start July 2015)
  - Considerable prior experience in the analysis of space radio data (CPD: internally funded to attend radio summer school in Glasgow)

- T7.1 – work effort has focused on cataloguing and development of new and improved software to assist analysis

- T7.2 – analysis of a detailed case study has been completed, being prepared for publication. Has helped define process by which full catalogue will be constructed.

- Now present updates and aspects of the science specific to individual tasks

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HELCATS WP7 Task 7.1 Update Interplanetary Scintillation

Dr. Jonathan Eastwood on behalf of Dr. Mario Bisi

HELCATS month 18 meeting 3-4 November 2015, Helsinki, Finland

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Task 7.1 overview

Task 7.1 (led by STFC), comprises the identification and analysis of potentially-geoeffective solar-wind events that are observed by both the Heliospheric Imager (HI) and IPS.

Regarding Task 7.1, work effort has focused on the cataloguing and development of new and improved software to assist analysis.

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Task 7.1 activities (performed by STFC)

- IPS data are not uniformly available (the radio-telescope systems used here run on a campaign basis only for observations of IPS)

- First necessary to establish the data availability working from the catalogues of CMEs and CIRs/SIRs provided by WP2 and WP5, respectively.

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Task 7.1 cataloguing

All the EISCAT IPS data for the STEREO era have now been sorted. Bad and/or problematic observations have been sifted and removed.

Approximately half of the STEREO era data has been analysed with the UCSD IPS tomography.

- IPS analyses program enables all of the available data to be analysed using an automated mode which finds the CME events.
- Made use of an older version of the software.
- Now intend to run analysis for the entirety of the STEREO era with the most-up-to-date versions of the CAT and the visualisation routines (see below).
- Currently considering best strategies to approach the SIR aspects of Task 7.1

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Task 7.1 software

- With a data catalogue now coming online, work is now focusing on the development of new software that can be used to batch process the event list and thus make efficient progress in pursuit of the overall project goals.

- Software development
  - IDL scripts for directly plotting the IPS P-Point into the STEREO HI field of view have been rewritten and now run much more simply via the updated geometrical routines available in SSW-IDL.
  - Superior to various ad hoc work-around scripting that has previously been used by e.g. Dorrian et al. and Hardwick et al.
  - Porting of the IPS data-analyses cross-correlation package to new processing machines at STFC raised various technical issues, most of which have now been resolved with final testing currently ongoing.

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Task 7.1 software (continued) and outputs

- Enhancing software development.
  - Script for finding the CME (negative-lobe) signatures in a systematic way from the analysed cross-correlation EISCAT data is being developed.
  - In collaboration with B. Jackson (UCSD), the latest IDL visualisation routines for tomography are being implemented at STFC,
  - Supplemented by discussions and meetings arranged in conjunction with the Third Remote Sensing of the Inner Heliosphere & Space Weather Applications Workshop in Mexico.

<u>Presentations at international meetings and conferences:</u>

Third Remote Sensing of the Inner Heliosphere & Space Weather Applications Workshop, Morelia, Mexico, 20-24 October 2015

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Task 7.1 next steps

- Near term:
  - Issues pertaining to software reliability are expected to be rapidly resolved, and the development of enhancing software is underway.
  - By the end of the calendar year it is anticipated that the IPS-ENLIL code will be updated whereby the current small errors in solar rotation will be corrected as well as enhanced visualisation routines.

- Medium term:
  - More generally, effort is expected to focus on cataloguing in the first instance through the first half of 2016.
  - It is expected that good progress to a complete and consistent analysed data set of the available EISCAT/ESR and LOFAR IPS data throughout the STEREO mission period to date will be made.

- Follow on work
  - Complex interacting CME events will also be identified as targets for future study in the final part of the project.
  - Two case studies have been identified that may also bear significant insight and these will also be pursued as a secondary objective.

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HELCATS WP7 Task 7.2 Update
Type II emission

Dr. Jonathan Eastwood

HELCATS month 18 meeting 3-4 November 2015, Helsinki, Finland

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Type II radio emission (Task 7.2)

Identifying and analysing solar wind transients that are observed by both HI and in Type II radio burst emission

- Combining STEREO solar radio-burst, coronagraph and HI observations enables unique study of the propagation of shock waves and their drivers (CMEs), as well as interaction of fast CMEs, all the way from the low corona to 1 AU.

- Solar radio-burst observations cover a broad frequency domain corresponding to different distances from the Sun.

- Key advantages of space-based radio measurements
  - effectiveness in tracking CMEs between coronagraph and HI FOV
  - analysis of events where fast CMEs interact.

- Also consider complementary nature of ground based radio (Krupar attended solar radio summer school in Glasgow to support this)

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Type II radio emission (Task 7.2)

- Initial effort has focused on two parallel activities
  - Detailed case study of a well-observed specific event
  - Construction of the foundations of the radio catalogue

- Here we show an initial case study which illustrates how radio data might be used. A deep understanding of initial case studies enable sensible strategies for surveying the data
  - Magdalenic (5 March 2012)
  - Krupar (29 Nov – 1 Dec 2013)

- Here focus on 29 November 2013 – 01 December 2013
  - Strong radio signature seen by multi-s/c
  - Analyse frequency drift and direction finding
  - Coronagraph imaging
  - Heliospheric imaging
  - CME encountered by MESSENGER and STEREO A (radial alignment)

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Case study 29 November – 1 December 2013

- Well observed coronal mass ejection
- Strong radio emission observed by both STEREO spacecraft
  - Specifically at low frequencies – allows direction finding techniques to be used.
- CME was
  - imaged in COR2
  - And imaged in HI
  - And measured in situ by MESSENGER at Mercury
  - And measured in situ by STEREO-A
- Comprehensive insight
  - Cuts across nearly all the HELCATS activities and work packages

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Case study 29 November – 1 December 2013

- CME kinematic properties studied in four independent ways:

- Radio data
  - height/time profiles based on density modelling
  - triangulation using the radio data from both stereo spacecraft together

- HI data
  - height/time analysis contained in the WP2 catalogue for this event (with input from STFC (Davies/Barnes/Byrne))

- In situ measurements
  - CME shock arrival time at STEREO-A and MESSENGER (with input from WP4 IMPERIAL (Forsyth/Good))

- Coronagraph images (height/time analysis and speed profiles)
  - Output of the automated SEEDS algorithm
  - Graduated Cylindrical Shell model (WP3 input from GOTTINGEN (Bothmer/Pluta/Mrotzek))

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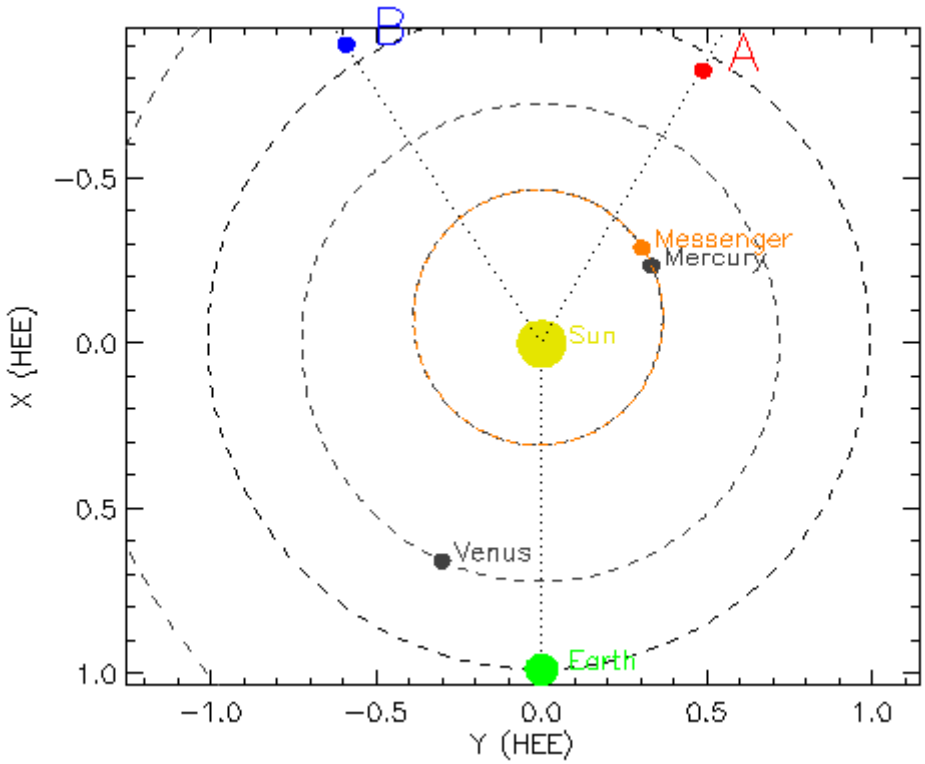
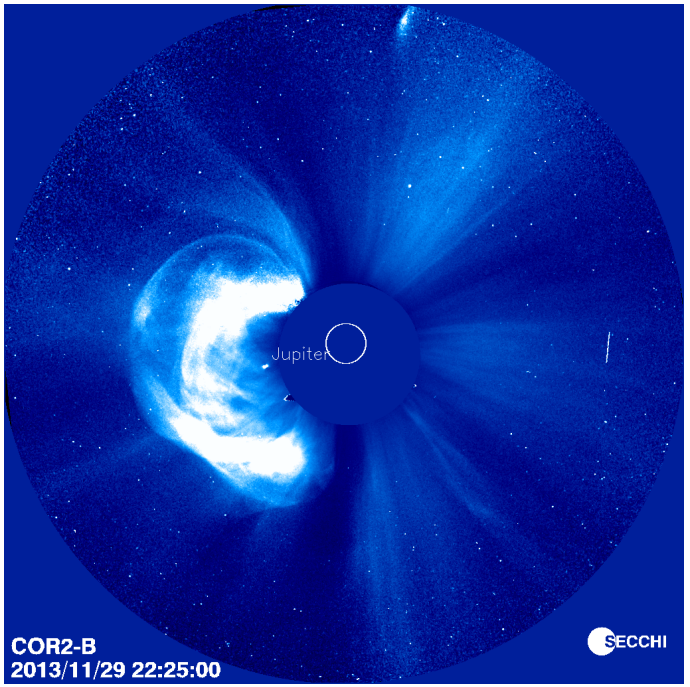
Context: remote sensing





Coronagraph

- CME liftoff at ~20:00 on 29/11/2013
- Directed towards STEREO-A, imaged by STEREO-B in e.g. COR2

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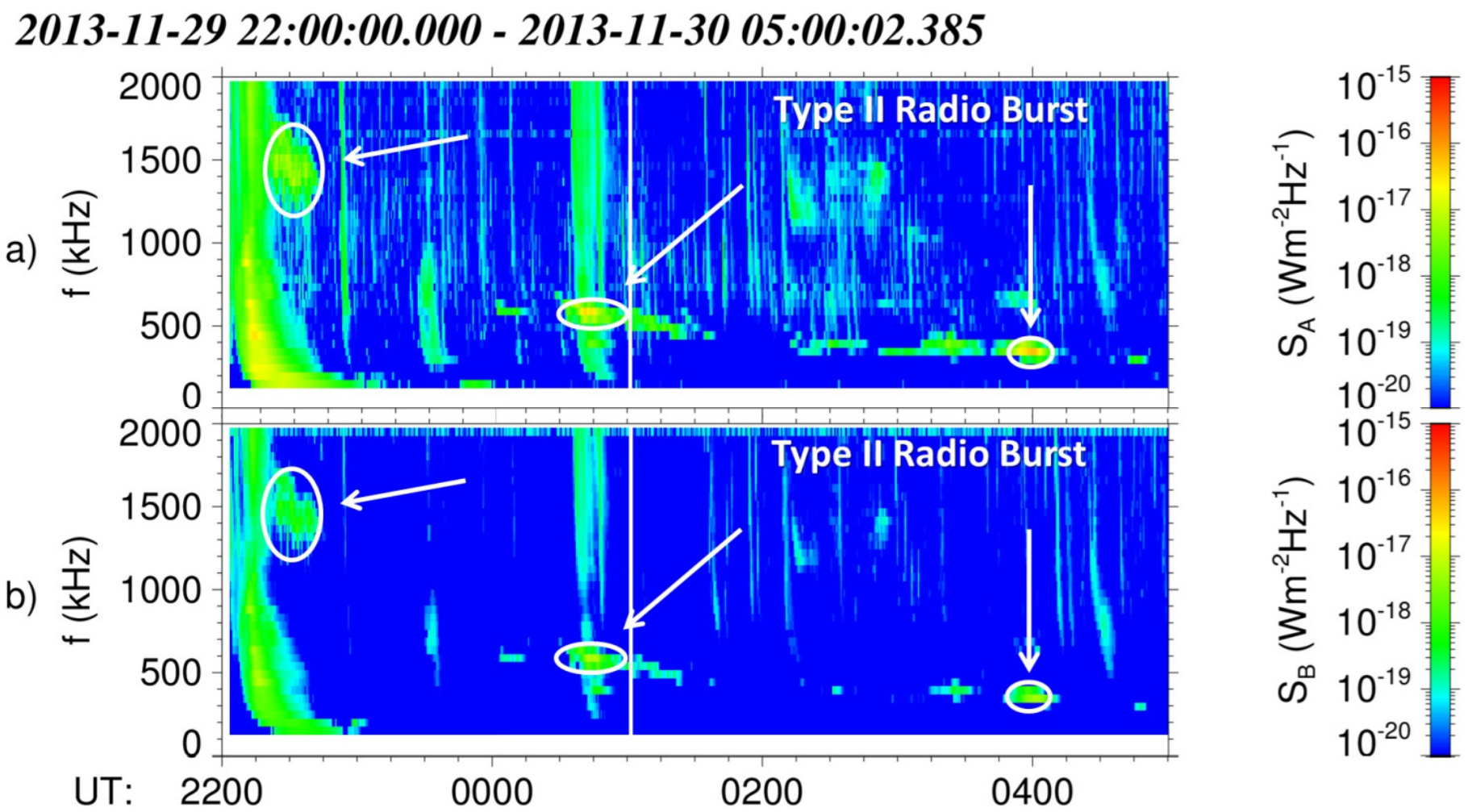
Radio observations



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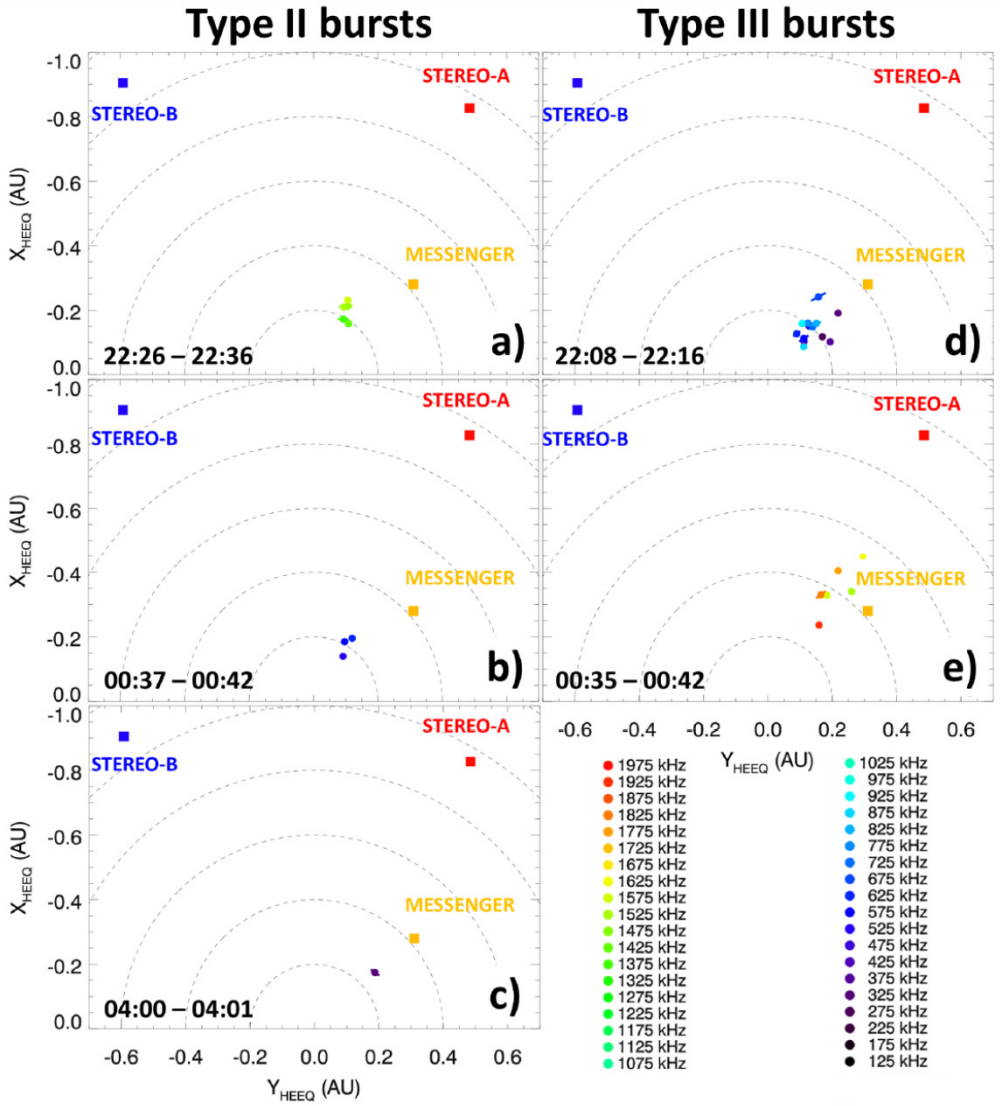
Direction finding analysis



Radio source locations of type II (left) and type III (right) bursts for ve time-frequency intervals. Circles show intersections between wave vector directions from STEREO-A and STEREO-B in the XY_{HEEQ} plane.

Colors denote frequencies. Segment lines indicate accuracy of the triangulation.

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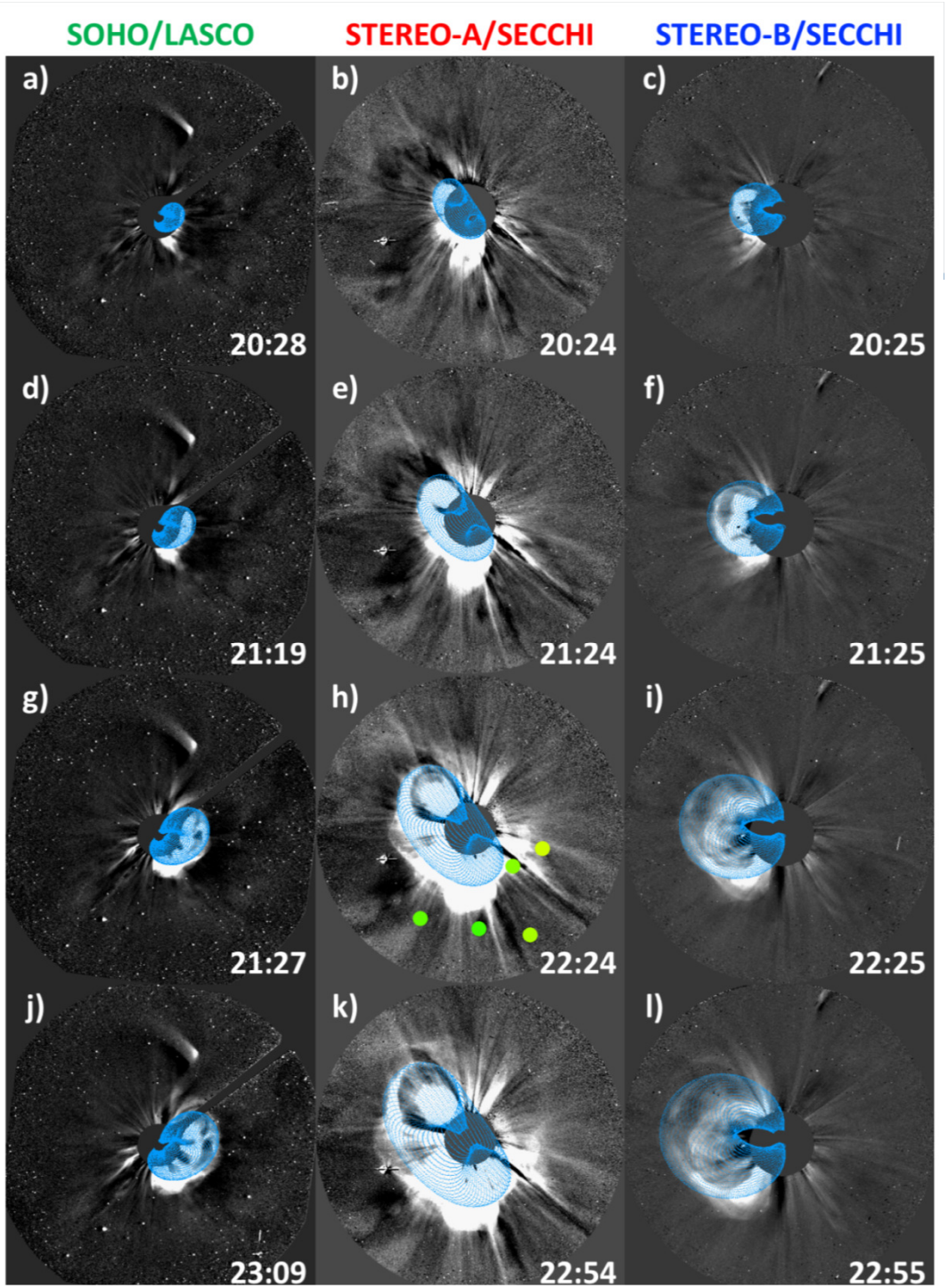
Coronagraph analysis

SOHO/LASCO/C3 and STEREO/SECCHI/Cor2 white-light coronagraph images with results of the GCS model.

Radio locations of the type IIa burst are
denoted by circles in panel h.
Colors represent frequencies



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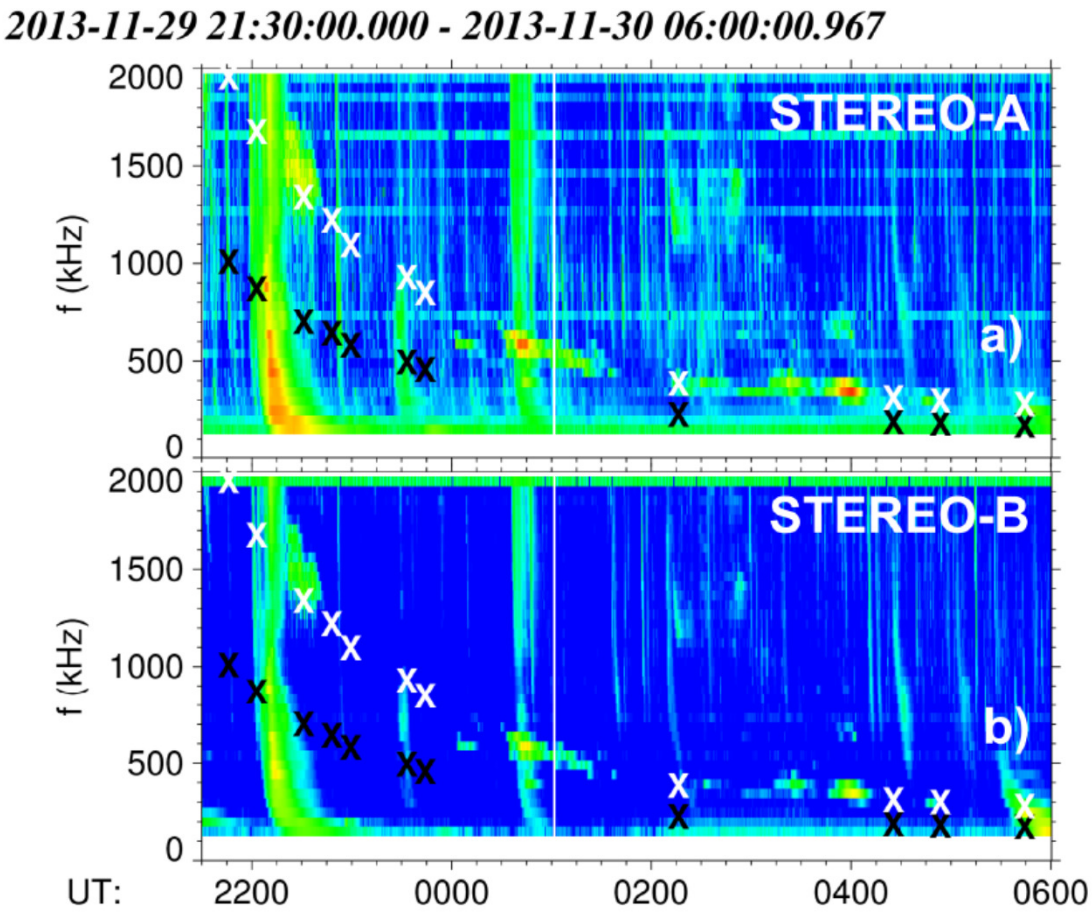
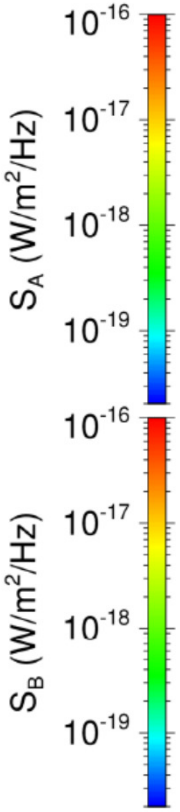
Radio observations with optical modelling results





Black and white crosses denote results of the GCS model (before 2013-11-30 00:00 UT) and the SSEF technique (after 2013-11-30 00:00 UT) assuming the fundamental and harmonic emission, respectively.

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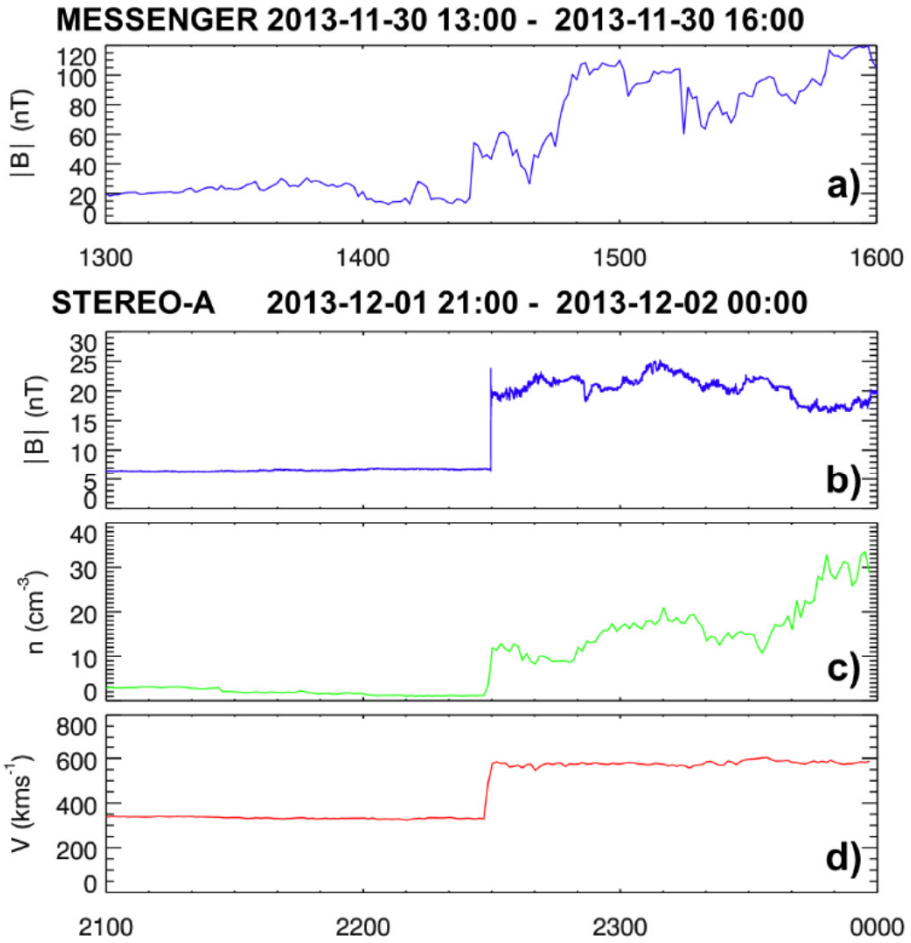
In situ measurements – MESSENGER and STEREO A

Magnetic field strength measured by MESSENGER between 2013-11-30 13:00 UT and 2013-11-30 16:00 UT.

Magnetic field magnitude; solar wind density and bulk speed recorded by STEREO-A between 2013-12-01 21:00 UT and 2013-12-02 00:00 UT.



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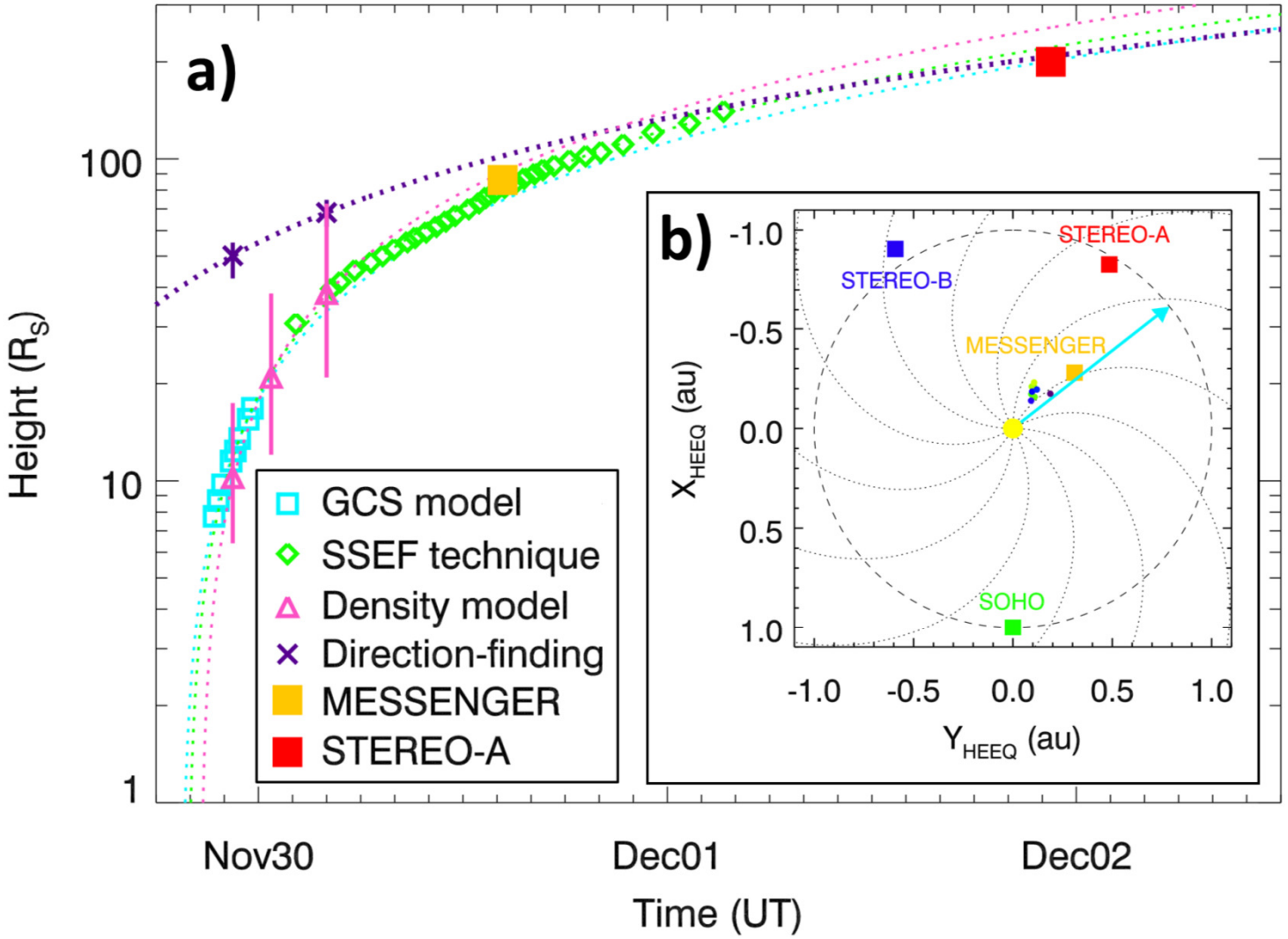
CME kinematics – results



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CME kinematics - results

Table 1: CME kinematics

	Time	Height ($R_\odot$)	v (kms^{-1})
GCS model[a]	11/29 21:24 – 11/29 23:39	7.7 – 16.8	761 ± 13[e]
SSEF technique[b]	11/29 13:38 – 11/30 08:17	35 – 145	841 ± 7[e]
Density model[c]	11/29 22:26 – 11/30 04:01	10.2 – 38.2	987 ± 31[e]
Direction-finding[b]	11/29 22:26 – 11/30 04:01	50 – 68	635[e,f]
Sun – STEREO-A	11/29 20:00 – 12/01 22:30	1 – 206	784[e,f]
Sun – MESSENGER	11/29 20:00 – 11/30 14:30	1 – 86	888[e,f]
MESSENGER – STEREO-A	11/30 14:30 – 12/01 22:30	86 – 206	724[e,f]

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Case study conclusions

- In this well-observed event:
- Very good agreement between radio (height time from density model) and
  - Coronagraph GCS modelling (cross-over to WP3)
  - HI SSEF modelling (cross-over to WP2)
  - In situ measurements (cross-over to WP4)

- Direction finding shows the correct direction and qualitative behaviour
  - Discrepancy in apparent height remains to be determined

- Other notes
  - SEEDS performs poorly in height/time calculations
  - Main radio emission is harmonic, not fundamental, in this event
  - Radio data can be used to accurately constrain the kinematics of this CME
  - Rapid analysis compared to e.g. GCS
  - Unfortunately no ground based radio data available

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Cataloguing

- Starting point is the WP2 database (1000+ events), and WP3 kinematic analysis of HI data

- 24hr duration plots centered on the HI time have been created
  - STEREO-A, STEREO-B and Wind radio data
  - Input/ review provided by ROB (Magadalenic)
  - Would like to overplot on the radio data the height-time profile of each HI observation
  - Proof of concept demonstrated by the case study
  - Also include ground based radio data as well (secchi.obspm.fr)
  - *Thank you to STFC WP2/3 for all their help so far*

- But frequency of most radio emission corresponds to coronal height inside HI field of view
  - Difficult to associated signatures in radio (esp. if Type III occurring)
  - Therefore also need coronagraph data and catalogue

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Cataloguing

- We are first using the Goettingen catalogue
  - Only contains a subset of events (200+) where GCS can be used (bright events)
  - Now starting to use the entire CME list (CACTus) but this is automatically generated…
  - Ideally require height-time profile so that they can be overplotted on the radio data plots
  - *Thank you to Goettingen WP3 for all their help so far*

- End result
  - Table of radio parameters for each event
    - What information to specifically include is to be determined
    - Qualitative? Quantitative?
  - But also a figure for each HI event – how to include on the HELCATS website?

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Task 7.2 outputs (since month 10)

Presentations at international meetings and conferences:

National Astronomy Meeting, Llandudno, Wales, 5-9 July 2015

Solar Orbiter/Solar Probe Plus Meeting, Florence, Italy, 2-4 September 2015

Fall AGU meeting, San Francisco, USA, 14-18 December 2015

Manuscript:

Type II bursts and Coronal Mass Ejections, Krupar et al., 2015, Ap. J.L., to be submitted

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Task 7.2 next steps

- Near term:
  - Case study results are now being prepared for publication. Submitted by the end of the calendar year (published in early 2016 hopefully!)
- Medium term:
  - Catalogue work is ongoing.
  - Looking to automate production where possible
  - First version anticipated in early 2016.
  - Initial top-level statistics (e.g. occurrence, duration, brightness *etc.*) available for review by month 24.
- Follow on work
  - Assessment and exploration of which CMEs are most radio-loud
  - More routine comparison of kinematics from optical/radio/in situ measurements
  - Selection of case studies covering interacting CME events.