AFRL-AFOSR-JP-TR-2020-0012

Constraining ICME Magnetic Field Orientations: Murchison Widefield Array measurements

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09/21/2020
Final Report

Air Force Research Laboratory
Air Force Office of Scientific Research
Asian Office of Aerospace Research and Development
Unit 45002, APO AP 96338-5002

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
21-09-2020	Final	30 Sep 2017 to 29 Sep 2018

4. TITLE AND SUBTITLE
Constraining ICME Magnetic Field Orientations: Murchison Widefield Array measurements

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA2386-17-1-4126

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
John Morgan

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
CURTIN UNIVERSITY OF TECHNOLOGY
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AOARD
UNIT 45002
APO AP 96338-5002

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/AFOSR IOA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-AFOSR-JP-TR-2020-0012

12. DISTRIBUTION/AVAILABILITY STATEMENT
A DISTRIBUTION UNLIMITED: PB Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The groundbreaking work on Interplanetary Scintillation Studies with the MWA is now also formally part of the work of the new grant. This is important since, as discussed above, a single dataset can be used for both polarimetric and IPS studies, and we have now shown unambiguously in our unpublished work that IPS observations give key information on where on the sky the column density in the heliosphere is highest, allowing us to know a priori where a Faraday Rotation detection might be found.

15. SUBJECT TERMS
coronal mass ejection, magnetic field, Murchison widefield array

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			KIM, TONY
Unclassified	Unclassified	Unclassified	SAR		19b. TELEPHONE NUMBER *(Include area code)* 315-227-7008

Final Report for AOARD Grant FA2386-17-1-4126

"**Constraining ICME Magnetic Field Orientations. Murchison Widefield Array Measurements.**"

Apr 3 2018

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Period of Performance: 09/30/2017 – 09/29/2018

Abstract: This final reports details the Curtin University Contribution to a one year extension to the three-year grant awarded to Curtin University in connection with the three-year grant led by MIT-Haystack (FA9550-14-1-0192). The scope of the Curtin contribution is to provide expertise on the MWA. Curtin University is the owner and operator of the MWA and so the institution is perfectly placed to provide this expertise. Dr Morgan is the only Curtin Staff member paid out of this grant and he liases with scientific and engineering colleagues as appropriate, as well as collaborators on this grant in the US and elsewhere. Further reports have been submitted by MIT/Haystack, as well as as a detailed presentations given by Colin Lonsdale.

Progress Report

It is possible to remotely sense the orientation of magnetic fields in CME plasma using polarimetric radio imaging. Synchrotron emission from early-stage CMEs will exhibit linear polarization with an E-vector orientation that is intrinsically perpendicular to the sky plane component of the field. Independently, the linear polarization of background radio sources will be Faraday-rotated upon passage through interplanetary CME (ICME) plasma, yielding information on the line of sight component of the field. Such observations have hitherto been difficult, because they are optimally made at low radio frequencies, must be sensitive, and require high dynamic range. New technology for low frequency imaging arrays now permits contemplation of an operational capability for such measurements.

The Murchison Widefield Array (MWA) in Western Australia is exceptionally well suited for such work. Its layout is optimized for high fidelity imaging on short timescales, coupled with an extraordinarily wide field of view, on the order of 1000 deg2. The MWA features 128 independent phased-array "tiles" operating in the 80-300 MHz range, and entered active service as a user facility in July 2013.

The aim of this grant is to demonstrate the feasibility of radio polarimetric remote sensing of ICME magnetic field orientations, via MWA imaging both of synchrotron radiation from CME plasma, and Faraday rotation of background emission passing through ICME plasma.

Since September 2014, Dr Morgan has been committed 33% towards the current AOARD project. During this time he has contributed his own expertise, effort and resources, as well as providing a conduit to more extensive knowledge of the MWA among personnel in the Curtin Institute for Radio Astronomy. This has been vital in identifying and overcoming the significant technical challenges inherent in a project such as this. In particular Dr Morgan recognised the problem of coherence loss due to differential delays. Correcting these issues has led to a substantial increase in imaging Dynamic Range (DR) with the MWA: from ~1000 to ~70000.

In this one-year extension, Dr Morgan has continued to provide direct effort towards almost all aspects of the project, including preliminary calibration, data reduction and imaging of the data used for prompt emission studies, as well as software development of diagnostic tools for confronting the

dynamic range problem.

During the period of performance of this grant, the work led by Divya Oberoi and his students, to which Dr Morgan has contributed significantly, has now made possible the generation of such high-DR images in an entirely automated fashion.

Further work, as yet unpublished, has focussed on using IPS to determine precisely where in the Field of View of the MWA any CME is located. By observing precisely the same patch of sky, one sidereal day apart, once when a CME is predicted to be in the Field of View, and once when normal conditions are expected, we have shown that the MWA can map out the location of the CME on the sky with unprecedented detail for IPS observations. This work is now being prepared for publication and will form the basis of investigations that can continue into the new grant.

Dr Morgan has also maintained and provided access to computing resources for all personnel working on this project.

A further two years has now been funded by AFOSR (award FA9550-18-1-0473). Dr Morgan will continue to contribute to the effort to improve the achievable dynamic range with the MWA, particularly in the interpretation of the deep investigations of the MWA data, and how these errors may be mitigated. Dr Morgan will also continue to lead the effort to conduct polarimetry on ICMEs.

The groundbreaking work on Interplanetary Scintillation Studies with the MWA is now also formally part of the work of the new grant. This is important since, as discussed above, a single dataset can be used for both polarimetric and IPS studies, and we have now shown unambiguously in our unpublished work that IPS observations give key information on where on the sky the column density in the heliosphere is highest, allowing us to know a priori where a Faraday Rotation detection might be found.

List of Publications and Significant Collaborations that resulted from your AOARD supported project: In standard format showing authors, title, journal, issue, pages, and date, for each category list the following:

a) papers published in peer-reviewed journals,
McCauley, Patrick I., Iver H. Cairns, John Morgan, Sarah E. Gibson, James C. Harding, Colin Lonsdale, and Divya Oberoi. "Type III solar radio burst source region splitting due to a quasi-separatrix Layer." *The Astrophysical Journal* 851, no. 2 (2017): 151.

McCauley, Patrick I., Iver H. Cairns, and John Morgan. "Densities probed by coronal Type III radio burst imaging." *Solar Physics* 293, no. 10 (2018): 132.

b) papers published in peer-reviewed conference proceedings,

Oberoi, Divya, Atul Mohan, Surajit Mondal, Rohit Sharma, Akshay Suresh, Leonid Benkevitch, Colin J. Lonsdale, John Morgan, Patrick McCauley, and Iver Cairns. "Solar science at metric radio wavelengths: Coming of age." *Proceedings of the International Astronomical Union* 13, no. S340 (2018): 145-146.

Lonsdale, C., et al. "Solar imaging using low frequency arrays." *arXiv preprint arXiv:1802.01778* (2018).

c) papers published in non-peer-reviewed journals and conference proceedings,
N/A

d) conference presentations without papers,
National Korean Space Weather Meeting (invited)

e) manuscripts submitted but not yet published, and

Mondal, Surajit, Atul Mohan, Divya Oberoi, John S. Morgan, Leonid Benkevitch, Colin J. Lonsdale, Meagan Crowley, and Iver H. Cairns. "Unsupervised generation of high dynamic range solar images: A novel algorithm for self-calibration of interferometry data." arXiv preprint arXiv:1902.08748 (2019).

f) provide a list any interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.

N/A

DD882: As a separate document, please complete and sign the inventions disclosure form.

Attached