SMEI: Design and Development of an Earth-Orbiting All-Sky Coronagraph

Bernard V. Jackson*[a], P. Paul Hick**[a], A. Buffington***[a], R. Gold****[b], G.M. Simnett*****[c], C.J. Eyles******[c], M.P. Cooke*******[c] and N.R. Waltham********[d]
[a]Center for Astrophysics and Space Sciences, University of California at San Diego,
[b]Johns Hopkins University/Applied Physics Laboratory
[c]School of Physics and Space Research, University of Birmingham, UK
[d]Space Science Department, Rutherford-Appleton Laboratory, Chilton, UK

ABSTRACT

The Air Force/NASA Solar Mass Ejection Imager (SMEI) was launched January 6, 2003, and is now recording whole sky data on each 100-minute orbit. Precise photometric sky maps of the heliosphere around Earth are expected from these data. The SMEI instrument extends the heritage of the HELIOS spacecraft photometer systems that have recorded CMEs and other heliospheric structures from close to the Sun into the anti-solar hemisphere. SMEI sweeps the sky every orbit by viewing the sky away from Earth using CCD camera technology. To optimize the information derived from this and similar instruments, a tomographic technique has been developed for analyzing remote sensing observations of the heliosphere as observed in Thomson scattering. The technique provides 3-dimensional reconstructions of the heliospheric solar wind density. The tomography is capable of analyzing time-dependent phenomena such as evolving corotating heliospheric structures and more transient, discrete events such as coronal mass ejections (CMEs). This improved analysis is being applied to the SMEI data.

Keywords: Coronal mass ejections, CME-corotating region interactions, tomography, three-dimensional reconstruction

1. INTRODUCTION

The Coriolis spacecraft was launched on the morning of January 6, 2003, from Vandenberg Air Force Base into a Sun-synchronous polar terminator orbit, with on board the Solar Mass Ejection Imager (SMEI)[1-8] and a rotating radiometer instrument (*Windsat*) intended to measure ocean surface wind speeds (Figure 1). The instrument has seen ‘first light’, and is operating successfully, providing near-full-sky data on each 100-minute orbit (Figure 2).

SMEI is designed to map large-scale variations in heliospheric electron densities from Earth orbit by observing Thomson-scattered sunlight from within the heliospheric volume. Conceived as an all-sky coronagraph[1,2], SMEI views the outward flow of structures in the solar atmosphere. These include solar coronal mass ejections (CMEs), corotating structures (streamers), and other solar wind density enhancements (or depletions) such as the density variations behind shock waves. SMEI is a an experiment primarilly intended to demonstrate the feasibility of forecasting the arrival of transient heliospheric structures at Earth that nominally take two to five days to travel 1 AU from the Sun. To achieve this, SMEI is operated as a high-precision differential photometer with unprecedented accuracy. The instrument may be regarded as a successor to the heliospheric imaging capability demonstrated by the zodiacal light photometers[9,10] on the HELIOS spacecraft[11,12]. Analyses of these and other remote sensing data[13,14,15,16] show that the location of these structures can be determined using tomographic modeling techniques that estimate their distance in each direction by their line-of-sight rearrangement and change in brightness caused by outward flow.

Telescopes and Instrumentation for Solar Astrophysics, edited by Silvano Fineschi, Mark A. Gummin,
Proceedings of SPIE Vol. 5171 (SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.513469

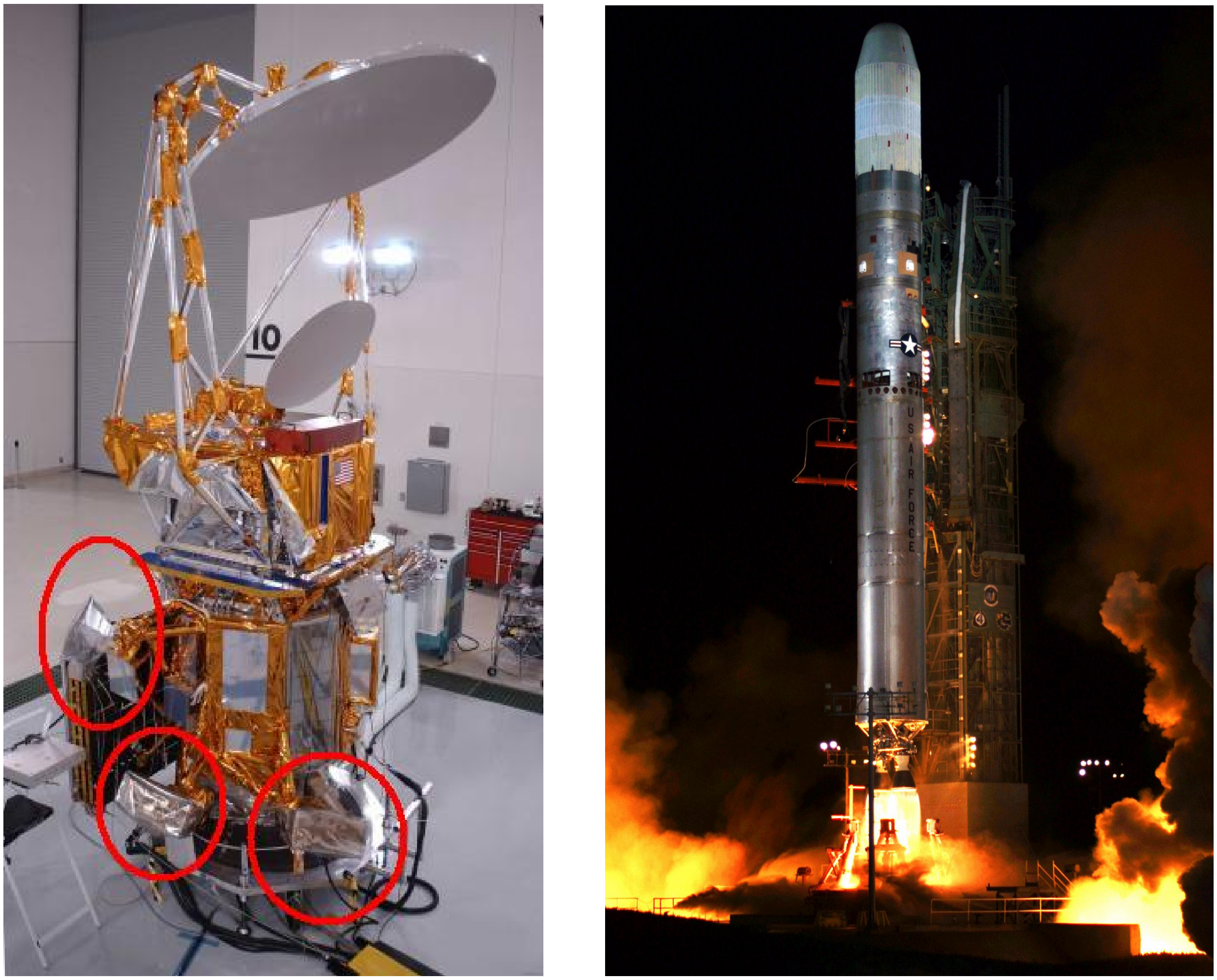

Figure 1 (a) Coriolis spacecraft with the Solar Mass Ejection Imager (SMEI) instrument on board prior to launch. The three instrument camera baffles (circled). (b) Titan II launch of the Coriolis spacecraft on 6 January 2003 with on board SMEI and WindSat.

Of most interest to the Air Force and other forecast facilities such as NOAA is the ability to view and forecast the arrival of heliospheric structures at Earth. This potential aspect of the SMEI data has provided the impetus for the 3D reconstruction of the heliosphere in real time. There have been numerous attempts to reconstruct coronal structures in the corona and heliosphere in three dimensions. These techniques, reviewed elsewhere[14,15], have been motivated by attempts to determine heliospheric structure morphology in order to determine their physics, their dynamics and most recently to forecast their arrival at Earth using remote sensing techniques.

The SMEI instrument[7,8] is a joint effort between the University of Birmingham, UK, the University of California at San Diego, Rutherford laboratory, UK, the Air Force Research Laboratory Space Vehicles Directorate, Boston University, and Boston College. Most of the original UCSD SMEI design concept was retained and the bulk of the SMEI hardware was designed and built at the University of Birmingham. SMEI incorporated a CCD camera design (with the CCD chip optical properties required for SMEI) that was available from Rutherford Laboratory. UCSD designed and tested the SMEI prototype and flight-mirror optics, and built and tested an early prototype baffle employing a proprietary Martin

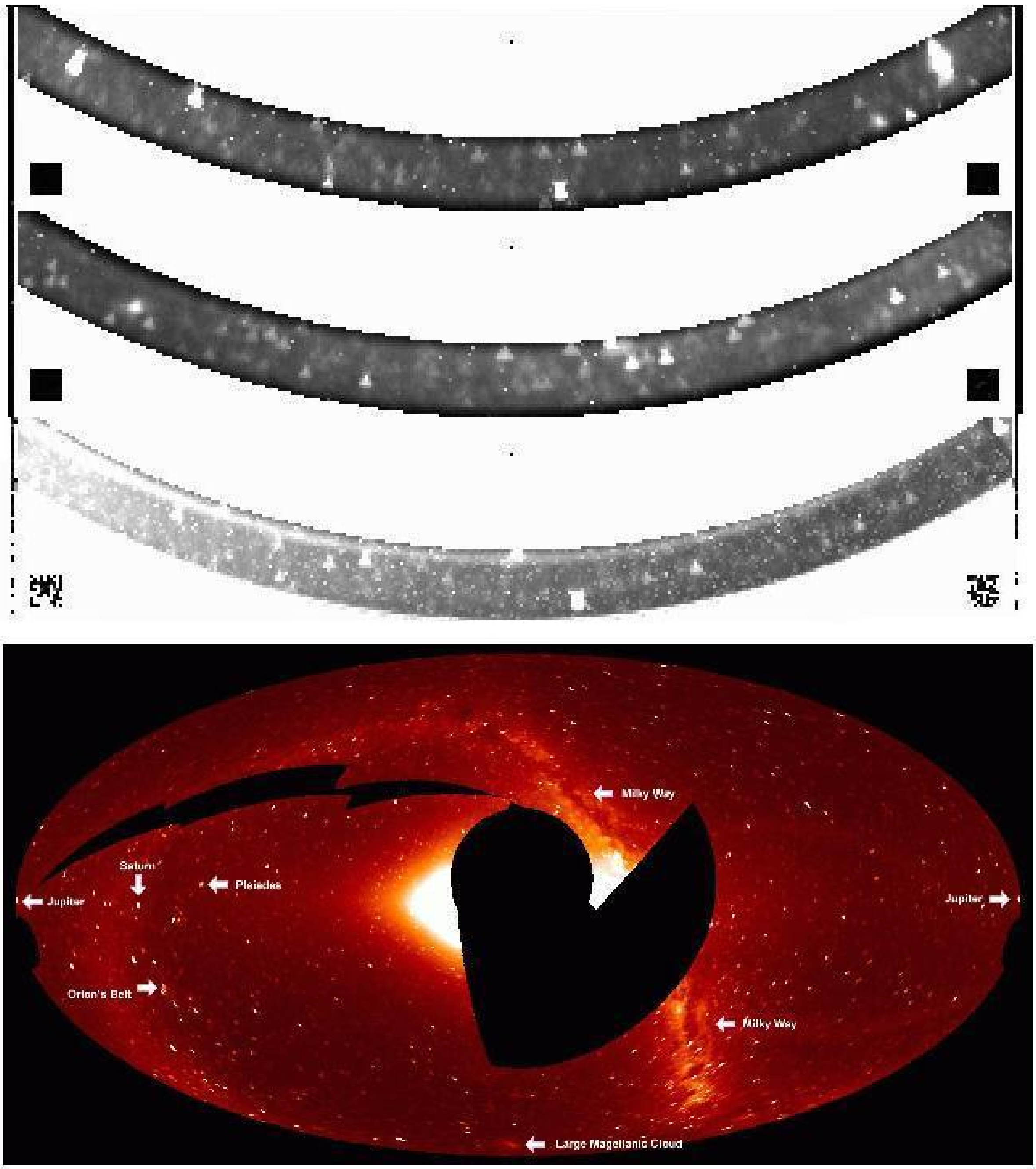

Figure 2. (a) Top: SMEI 3°×60° image frames from each of the three cameras arranged in order from top to bottom, the one that views farthest from the Sun to nearest. The Sun is located towards the left in each image frame. (b) Bottom: A full orbit's worth of frames are registered onto a sky map (here shown as a full-sky Hammer-Aitoff projection) and together build a composite view of the sky over that orbit. Various bright features are labeled on the map. Blank areas are regions that were excluded from the composite either because they were not accessible to the cameras during the orbit, were too close to the Sun and thus too bright, or were contaminated by high-energy particle enhancements (the slash across the upper left of the image).

Black coating (Martin Marietta Company, 1977) developed for the WIND spacecraft. UCSD tested a prototype baffle built at the University of Birmingham and tested the flight-model baffles[17]. UCSD helped test the prototype and flight cameras and certified them for use on SMEI. AFRL, with help from Boston University, the University of Birmingham, and UCSD, has provided management of the SMEI development and, more recently, data processing and preparation of SMEI data products.

2. SUMMARY

The Solar Mass Ejection Imager (SMEI)[1-8] with its superior imaging capability will be able to image heliospheric structures and reconstruct density with approximately 1°×1° heliospheric latitude-longitude spatial resolution and a 90-minute temporal cadence. Although structures near the Earth can be more accurately reconstructed than can those more distant from it, we expect that other instruments (STEREO) may operate during the same times as SMEI. If so these other instruments may help fill in heliospheric regions not observed well from the CORIOLIS spacecraft in order to help complete the SMEI far-field view.

ACKNOWLEDGEMENTS

The work of B.V. Jackson, P. P. Hick and A. Buffington was supported at the University of California at San Diego by AFOSR grant F49620-01-1-0054, by subcontract F19628-00-C-0029 from the U.S. Air Force and NASA grant NAG5-134543. The SMEI team comprises the following individuals: (at AFRL) R. Radick, P. Holladay, J. Johnston, T. Kuchar, D. Mizuno, J. Mozer, S. Price, and D. Sinclair; (at UCSD) B. Jackson, A. Buffington, and P. Hick; (at UB) G. Simnett, M. Cooke, C. Eyles, J. Tappin; (at Rutherford Appleton Laboratories) N. Waltham; and (at BC) D. Webb. Other participants have included S. Keil (National Solar Observatory), S. Kahler, R. Altrock (AFRL), and P. Anderson (BU).

REFERENCES

1. B.V. Jackson, H.S. Hudson, J.D. Nichols, and R.E. Gold, “Design considerations for a ‘solar mass ejection imager’ on a rotating spacecraft”, in *Solar System Plasma Physics*, J.H.Waite Jr., J.L. Burch and R.L. Moore, eds., *Geophysical Monograph* **54,** 291-297, 1989.
2. B. Jackson, R. Gold, and R. Altrock,, “The Solar Mass Ejection Imager”, *Adv. Space Res.* **11**, 377-381, 1991.
3. B.V. Jackson, D.F. Webb, R.C. Altrock and R. Gold, “Considerations of a solar mass ejection imager in a low-earth orbit”, in: *Eruptive Solar Flares*, Z. Svestka, B.V. Jackson, and M.E. Machado (eds.), Springer-Verlag, Heidelberg, 322-328, 1992.
4. S.L. Keil, R.C. Altrock, S. Kahler, B.V. Jackson, A. Buffington, P.L. Hick, G.M. Simnett, C.J. Eyles, D. Webb, and P. Anderson, “The solar mass ejection imager (SMEI)”, *SPIE.Proc.* **2804,** 78-89, 1996.
5. S.L. Keil, R.C. Altrock, S.W. Kahler, B.V. Jackson, A. Buffington, P.L. Hick, G. Simnett, C. Eyles, D.F. Webb and P. Anderson, “The solar mass ejection imager (SMEI): development and use in space weather forecasting”, in *Solar Drivers of Interplanetary and Terrestrial Disturbances*, K.S. Balasubramaniam, S.L. Keil and R.N. Smartt eds., ASP Conference Series **95**, 158-166, 1996.
6. B.V. Jackson, A. Buffington, P. Hick, S.W. Kahler, S.L. Keil, R.C. Altrock, G.M. Simnett, and D.F. Webb, “The solar mass ejection imager”, *Phys. Chem. Earth* **22,** 441-444, 1997.
7. C.J. Eyles, G.M.S. Simnett, M.P. Cooke, B.V. Jackson, A. Buffington, P.P. Hick, N.R. Waltham, J.M. King, P.A. Anderson, P.E. Holladay, ‘The Solar Mass Ejection Image (SMEI)’, *Solar Phys.*, in preparation, 2003.
8. B. V. Jackson, A. Buffington, P. P. Hick , S.W. Kahler, E. Cliver, S. Price, J. Johnston, P. Anderson, P. Holladay, D. Sinclair, T. Kuchar, D. Mizuno, S.L. Keil, R. Radick, J. Mozer, R.C. Altrock, R. Gold, G.M. Simnett, C.J. Eyles, M.P. Cooke, N.R. Waltham, D.F.Webb, ‘The Solar Mass Ejection Imager (SMEI): The Mission’, *Solar Phys.*, in preparation, 2003.
9. C. Leinert, H. Link, E. Pitz, N. Salm, and D. Knuppelberg, “The Helios zodiacal light experiment (E9)”, *Raumfahartforschung*, **19**, 264-267, 1975.
10. C. Leinert, E. Pitz, H. Link, and N. Salm, “Calibration and in-flight performance of the zodiacal light experiment on Helios”, *Space Sci. Instrum.* **5,** 257-270, 1981.
11. B.V. Jackson and C. Leinert, “HELIOS images of solar mass ejections”, *J. Geophys. Res.* **90,** 10759-10769, 1985.

12. B.V. Jackson, "Imaging of coronal mass ejections", *Solar Phys.* **100,** 563-575, 1985.
13. B.V. Jackson, P.L. Hick, M. Kojima, and A. Yokobe, "Heliospheric tomography using interplanetary scintillation observations, 1. Combined Nagoya and Cambridge data", *J. Geophys. Res.* **103 (A6),** 12049-12068, 1998.
14. B.V. Jackson, and P. Hick, "Three dimensional tomography of heliospheric features using global Thomson scattering data", *Adv. Space Research*, **25 (9)**, 1875-1878, 2000.
15. B.V. Jackson, and P. Hick, "Time dependent tomography of heliospheric features using global Thomson-scattering data from the helios spacecraft photometers during times of solar maximum", *EOS*, **81**, S353, 18-22 June, 2000.
16. B.V. Jackson , P.P. Hick and A. Buffington, "Time-dependent tomography of heliospheric features using interplanetary scintillation (IPS) remote-sensing observations," *Proc. Solar Wind 10,* Pisa, June 17-21, submitted, 2002.
17. A. Buffington, B.V. Jackson and P.P. Hick, 'Calculations for and laboratory measurements of a multistage labyrinthine baffle for SMEI', *SPIE Proc.* **4853**, 490, 2002.

* bvjackson@ucsd.edu; Phone: 858-534-3358; fax: 858-534-2294; WWW: http://cassfos02.ucsd.edu/solar/projects.html#projects; Mail Code 0424, UCSD, 9500 Gilman Drive, La Jolla, CA 92093-0424

** pphick@ucsd.edu; Phone: 858-534-8965; Fax: 858-534-0177

*** abuffington@ucsd.edu; Phone: 858-534-6630; Fax: 858-534-7051

**** rob.gold@jhuapl.edu; Phone: 240-228-5412; Fax: 240-228-1093

***** gms@star.sr.bham.ac.uk; Phone: 44-121-414-6469; Fax: 44-121-414-3722

****** cje@star.sr.bham.ac.uk; Phone: 44-121-414-6462; Fax: 44-121-414-3722

******* mpc@star.sr.bham.ac.uk; Phone: 44-121-414-6469; Fax 44-121-414-3722

******** n.r.waltham@rutherford.ac.uk; Phone: 44-123-544-6500; Fax 44-123-544-3722