Coronal Magnetometry: Building Tools for Discovery

A proposal for an ISSI International Team in Space Science

Magnetism defines the complex and dynamic solar corona. Twists and tangles in coronal magnetic fields build up energy and ultimately erupt, hurling plasma into interplanetary space. These coronal mass ejections (CMEs) are transient riders on the ever-outflowing solar wind, which itself possesses a three-dimensional morphology shaped by the global coronal magnetic field. Coronal magnetism is thus at the heart of any understanding of the origins of space weather at the Earth. We are now at a watershed moment: telescopes using infrared, visible, and radio magnetometry are obtaining unprecedented observations, and future large telescopes are under development that will revolutionize our understanding of coronal magnetism.

The ISSI international team is an ideal forum for subjects that have great potential for growth, but that could benefit from a concerted effort to draw together the different strands of research happening around the world. Coronal magnetometry is clearly such a subject. We propose to build an international team that brings together observers from the various wavelength regimes and modelers to help interpret these novel observations. Many magnetometric observables are integrated through an optically-thin corona, leading to potential ambiguities. We will address this by utilizing forward analysis of MHD models to test and develop robust magnetometric diagnostics. A major goal will be to expand the FORWARD solarsoft IDL tree developed by the 2008-selected ISSI international team (led by S. Gibson), which currently enables reproduction of infrared polarimetric observables from MHD models. We will incorporate polarimetric observables at other wavelengths and consider how these observations might be combined to diagnose the 3D coronal magnetic field. The future will see the simultaneous operation of multi-frequency, next-generation coronal magnetometric telescopes. This team will play a critical role in making sure we are prepared when that vision is realized.

1. Scientific Rationale

Timeliness. For decades we have observed the magnetic field at the solar surface (photosphere) with ever-increasing spatial and temporal resolution. From these observations we have learned and continue to learn about how magnetic flux emerges and evolves over multiple time scales. Magnetic fields in the solar atmosphere, especially in the corona, dominate force balance, controlling plasma structure and dynamics. Until very recently, our knowledge of these coronal magnetic fields was limited to what we could infer from

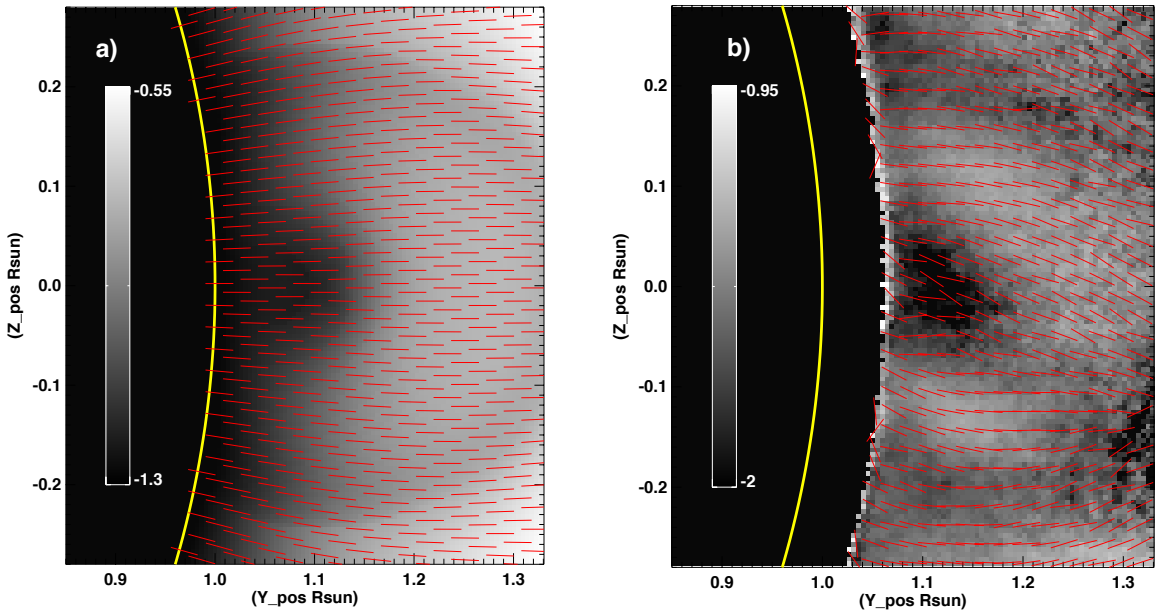

Fig. 1.— Line-of-sight-integrated Stokes linear polarization (P/I) for (a) forward-modeled twisted magnetic spheromak flux-rope configuration and (b) CoMP observations of April 21, 2005 southwest cavity. Axis of flux rope appears as a central dark region surrounded by a bright ring of predominantly planar field. Direction of Stokes linear polarization vectors (integrated through the LOS) is shown as red lines. The occulting disk of CoMP in (b) extends to $1.05R_{\odot}$. From Dove *et al.* (2011).

observations at the solar surface and of coronal plasma morphology. This is no longer the case. Novel observations are now available to measure coronal magnetic fields using visible and infrared (IR) magnetometry, including the Coronal Multichannel Polarimeter (CoMP) (Figure 1), the Optical Fiber-bundle Imaging Spectropolarimeter (OFIS), and the green line (FeXIV 530.3 nm) Coronal Magnetograph (CorMag). Future telescopes will take these observations to the next level, with high resolution/sensitivity IR observations (the Advanced Technology Solar Telescope (ATST) and Coronal Solar Magnetism Observatory (COSMO)), and dedicated solar radio observations (the Frequency-Agile Solar Radiotelescope (FASR)). Such observations are bound to be paradigm-changing, since we have reached a point where theories of solar coronal magnetohydrodynamics (MHD) have extended beyond what, up until now, has been possible to observationally test.

Methodology. To test MHD theories, observations are needed that pinpoint the strength and topology of the time-evolving vector coronal magnetic field. A range of visible, radio and infrared measurements may be made: the visible and infrared observations probe

magnetic fields at different temperatures and to higher heights in the coronal atmosphere than the radio can, while the radio observations, which do not require an occulting disk, provide information in the lower corona and chromosphere.

Magnetic field strength: The storage and release of magnetic energy in the corona is a fundamental plasma physics process, motivating the measurement of the magnitude of the magnetic field vector. This can be obtained in regions of strong magnetic fields using radio thermal gyroresonance emission – unambiguously at the solar limb (*Brosius and White* 2006), and utilizing a model for temperature on the solar disk. During solar eruptions, nonthermal gyrosynchrotron emission can also be fit to models to predict magnetic field strengths (*Bastian et al.* 2001). More generally, in regions of both strong and weak fields, magneto-acoustic waves (at various wavelengths) provide an independent diagnostic of magnetic field strength when combined with a model for density (e.g., *Tomczyk et al.* (2007)). Line-of-sight (LOS) magnetic field strength, integrated through the optically-thin corona, may also be obtained from the infrared emission of magnetic dipole lines (*Lin et al.* 2004), or alternatively from free-free emission in radio (when combined with a density model).

Magnetic field direction: In order to quantify magnetic helicity, and to locate topological features such as magnetic null points and current sheets before and after an eruption, it is necessary to have information about the direction of the magnetic field vector. The linear polarization signal of scattered light (e.g., infrared or visible) is also sensitive to the angle between the LOS and the magnetic field vector, and becomes weak when the field is primarily along the LOS (see Figure 1) or at the "Van Vleck" polarization null angle between the magnetic field vector and the solar vertical (*House* (1977)). Identification of such linear polarization nulls can be used to tightly constrain the morphology of the magnetic structure (*Judge et al.* 2006). Moreover, if observations are obtained simultaneously at multiple radio frequencies, a "depolarization sheet" can be deduced above active regions indicating magnetic field that is perpendicular to the line of sight (*Riyabov et al.* 2005).

Forward modeling: Many of these coronal field diagnostics require information about density and/or temperature, and those that depend upon optically-thin emission are subject to superposition of structures along the observer's line of sight. These issues may be addressed via forward modeling, that is, the input of physical MHD quantities (e.g., vector magnetic field, density, temperature, and velocity) determined from a model into a forward code designed to reproduce magnetometric observations. Such forward analyses could be used either to directly compare a model's prediction to observations, or more generally to test whether the observations can distinguish between different models.

The 2008-2010 ISSI International Team on Prominence Cavities developed a suite of solarsoft IDL forward modeling codes to enable side-by-side comparisons of model predictions

and data. This FORWARD tree includes a set of analytic magnetohydrodynamic models (*Gibson and Low* 1998; *Lites and Low* 1997; *Low and Hundhausen* 1995; *Gibson et al.* 2010) and the capability to incorporate the output from any numerical MHD simulation or potential-field extrapolation, enabling modeling of magnetic structures ranging in size from that of active regions to the global corona. The output of these models can be translated into a broad range of observables, from white light to EUV to coronal Stokes polarimetry parameters in the infrared (Figure 1). To date five papers have employed the FORWARD code tree to study the three-dimensional morphology and plasma properties of solar coronal cavities (*Gibson et al.* 2010; *Dove et al.* 2011; *Schmit and Gibson* 2011; *Kucera et al.* 2012; *Reeves et al.* 2012). The tree has broad applicability to coronal observations in general, and is a powerful tool for distinguishing between theoretical models through side-by-side comparison of their predictions to coronal data. It is also designed for ongoing expansion.

Goals. The overarching goal of this international team will be to develop the FORWARD code to predict multi-wavelength magnetometric observables for various MHD models, and to consider how observations at the different wavelengths can be combined to effectively choose between models and ultimately reconstruct the three-dimensional coronal field. We will achieve this goal in three steps:

1) Expand FORWARD codes to radio and visible wavelength magnetometry: as Figure 1 illustrates, we have successfully modeled the Stokes vector as observed in the infrared by the CoMP telescope. We will further interface the FORWARD codes with existing radio ray-tracing codes, as well as with code modeling visible (green line) polarimetry.

2) Obtain predicted observables at a range of wavelengths for MHD models of the global coronal magnetic field (e.g. from potential-field-source-surface extrapolations), and from models of active regions and prominences.

3) Compare these predictions to existing data (e.g., CoMP, OFIS, CorMag), and intercompare observables for different wavelengths. Consider how different observables might be combined to constrain the coronal field most effectively, taking full advantage of capabilities of future instruments such as ATST, COSMO, FASR, and potentially other large coronal magnetometric telescopes around the world or in space.

2. Plans and Justification for ISSI International Team

Team. Our team possess a range of observing and modeling expertise. Several of the team members, including the leader, were involved in the ISSI team on coronal cavities so the adaptation of existing codes to general coronal magnetometry will be straightforward. Other

new members of the team provide detailed knowledge of coronal magnetometric observations at multiple wavelengths, as well as of MHD models and forward modeling in general (see bibliography and attached CVs). Together we represent six countries, more than half of which are ESA member states. Our members include: **Sarah Gibson, U.S. (Leader); Urszula Bąk-Stęślicka, Poland; Tim Bastian, U.S.; Alessandro Bemporad, Italy; Silvano Fineschi, Italy; Therese Kucera, U.S.; Jeff Kuhn, U.S.; Christophe Marqué, Belgium; Laurel Rachmeler, U.K.; Kathy Reeves, U.S. (self-funded member); Steve Tomczyk, U.S; Stephen White, U.S.; Mei Zhang, China.**

ISSI added value. It was the experience of the 2008 cavity team that the ISSI model of a small group, meeting in person and with clear objectives, was extremely effective for getting things done. We plan to have two one-week meetings. At the first meeting (Winter 2012/2013) we will modify the FORWARD codes to incorporate radio and visible observables, and compare forward-modeled magnetic structures to existing data and with a consideration of how multi-wavelength observations might be used together to choose between models. At the second meeting (Summer/Fall 2013) we will finalize plans for publications, and design a strategy for utilizing data from future telescopes most effectively. We will use ISSI computing facilities primarily for web and email access, as we expect team members to bring laptop computers for coordinated analysis. We will maintain a dedicated website to facilitate ongoing research, including processed data, model output, etc. We request financial support as standardly given for ISSI teams: local support for all team members plus transportation expenses for the team leader. We may invite additional experts to our meetings at no additional cost to ISSI, for example, Hui Li from Purple Mountain Observatory, who represents Chinese interest in developing a large ground-based coronal magnetic telescope.

Expected output. The coronal magnetic field data that will be obtained over the next decade will be unprecedented, and new discoveries are sure to be made. There are challenges to be met in interpreting these data, and our team will play a critical role in developing tools and techniques to address these challenges in a manner that spans wavelength regimes and brings together complementary multi-wavelength diagnostics. In addition to publications likely to arise from existing-data/model comparisons, our group will prepare a review of expectations for coronal magnetometric assets to be deployed over the next five-years, and a consideration of the next-generation of space-based magnetometric assets. The insight we stand to gain from such observations, pertaining to how magnetic energy is stored and ultimately released in spectacular solar eruptions, is key to understanding a wide range of analogous dynamic phenomena throughout space physics.

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Education:
2002: MSc, solar physics, Astronomical Institute, University of Wrocław, Poland
2007: PhD, solar physics, Astronomical Institute, University of Wrocław, Poland

Professional Background:
2002 – 2007: PhD student, Astronomical Institute, University of Wrocław
2007 – present: researcher, Astronomical Institute, University of Wrocław
2011 – 2012 (10 months total) – Visiting Scientist, High Altitude Observatory, Boulder, USA

Other activities:
2008 – LOC member, “Interpretation of asteroseismic data”, Wrocław HELAS Workshop

Recent Publication:

- **Bąk-Stęślicka, U**., Mrozek, T; Kołomański, S., 2011, *Energy release during slow long duration flares observed by RHESSI,* Solar Physics, 271, 75-89
- Jakimiec, J., **Bąk-Stęślicka, U.,** 2011, *Determination of electron density and filling factor for soft X-ray flare kernels*, Solar Physics, 272, 91-100
- Kołomański, S., Mrozek, T., **Bąk-Stęślicka, U.,** 2011, *RHESSI observations of long-duration flares with long-lasting X-ray loop-top sources*, A&A, 531, A57, 1-11
- **Bąk-Stęślicka, U.,** Kołomański, S., Mrozek, T., 2011, *Coronal mass ejections associated with LDE flares of slow rise phase*, Central European Astroph. Bull. 35, 135-144

Public Outreach:
2002 - present: public lectures at Astronomical Institute, University of Wrocław
2002 - present: participation in annual Lower Silesian Science Festival
2008 - present: organizer of annual Lower Silesian Science Festival in Astronomical Institute, University of Wrocław
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EDUCATION

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APPOINTMENTS

2009-present	Assistant Director, National Radio Astronomy Observatory
2002-2008	Scientific Editor, The Astrophysical Journal
2000-present	Adjunct faculty member, Astronomy Dept., University of Virginia
1999-2000	Visiting Professor, Paris University 7 and Paris Observatory
1995-present	Astronomer, National Radio Astronomy Observatory

PROFESSIONAL SOCIETIES

International Astronomical Union (IAU)
International Union of Radio Science (URSI)
American Geophysical Union (AGU)
American Astronomical Society (AAS)
Community of European Solar Radio Astronomers (CESRA)

RESEARCH INTERESTS

Solar and stellar radiophysics; solar chromosphere and corona; solar and stellar flares; coronal mass ejections; coronal and interplanetary radio bursts; solar wind and heliosphere; radio emission from planets and exoplanets; wave propagation in random media; radiative processes; interferometry; data inversion

PUBLICATIONS

More than 200 scientific and technical publications and abstracts in periodicals and books.

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02/2006:	Ph.D. in Astronomy at the Arcetri Astrophysical Observatory, Florence, Italy. Thesis: "UV Spectroscopy of Coronal Plasmas and its application to different structures"; supervisor: Dr. G. Poletto (poletto@arcetri.astro.it).
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09/2007 – 06/2011:	Research Astronomer at the INAF-Turin Astrophysical Observatory (temporary staff).

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Scientific interests:

XUV Spectroscopy of the Solar Corona and Solar Wind; determination of physical parameters of Coronal Streamers and Coronal Mass Ejections; comparison between plasma parameters derived via *remote-sensing* techniques and *in situ* parameters measured by Ulysses instruments; Earth – Sun connections and Space Weather; XUV Spectroscopy of Sungrazing Comets and determination of comet parameters; SOHO/UVCS data reduction and analysis with the Data Analysis Software (DAS), SOHO/LASCO data reduction with IDL and the Solar Software (SSW). Stereoscopic 3D reconstructions of prominences with data acquired by the STEREO/EUVI telescopes. Off-limb observations of the low corona with the HINODE/EIS spectrometer.

Selected Publications:

"The Role of Streamers in the Deflection of Coronal Mass Ejections: Comparison between STEREO Three-dimensional Reconstructions and Numerical Simulations", Zuccarello F.P., **Bemporad A.**, Jacobs C., et al. ApJ, 744, 66, 2012.

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"Spectroscopic detection of turbulence in post-CME Current Sheets", **Bemporad A.**, ApJ, 689, 572, 2008.

"Reconnection in a slow Coronal Mass Ejection", Poletto G., **Bemporad A.**, Landini F., Romoli M., Ann. Geoph., 26, 3067, 2008.

"Magnetic Reconnection processes induced by a CME expansion", **Bemporad A.**, Poletto G., Landini F., Romoli M., Ann. Geoph., 26, 10, 2008.

"Low-frequency Lyman-α power spectra observed by UVCS in a polar coronal hole", **Bemporad A.**, Matthaeus W. H., Poletto G., ApJL, 677, 137, 2008.

"A Comprehensive Study of the Initiation and Early Evolution of a CME from UV and White Light Data", **Bemporad A.**, Raymond J. C., Poletto G., Romoli M., ApJ, 655, 576, 2007.

"Density and magnetic field signatures of interplanetary 1/f noise", Matthaeus W. H., Breech B., Dmitruk P., **Bemporad A.**, Poletto G., Velli M., Romoli M., ApJL, 657, 121, 2007.

"A review of SOHO/UVCS observations of sungrazing comets", **Bemporad A.**, Poletto G., Raymond J. C., Giordano S., Planetary & Space Sc., 55, 1021, 2007.

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"Evidence for pyroxene dust grains in C/2001 C2 sungrazing comet", **Bemporad A.**, Poletto G., Raymond J.C., Advances in Space Research, Vol. 38, Issue 9, pp. 1972-1975, 2006.

"A new variety of CMEs: streamer puffs", **Bemporad A.**, Moore R., Sterling A. C., Poletto G., ApJL, 635, 189, 2005.

"UVCS observation of sungrazer C/2001 C2: possible comet fragmentation and plasma-dust interactions", **Bemporad A.**, Poletto G., Raymond J. C., Biesecker D. A., Ko Y. K., P. Lamy, Marsden B., Uzzo M., ApJ, v620, 2005.

"Evidence for the same hot plasma after CME events in both remote and in situ observations", Poletto G., Suess S., **Bemporad A.**, Zurbuchen T., Ko Y. K., ApJL, v613, L173, 2004.

"Temporal evolution of a Streamer Complex: Coronal and in situ Plasma Parameters", **Bemporad A.**, Poletto G., Suess S.T., Ko Y-K., Parenti S., Riley P., Romoli M., Zurbuchen T.Z., ApJ, v593, 2003.

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Scientific Programs and Projects

2003 - Project Scientist, Co-I of the METIS coronagraph for the Solar Orbiter mission
2006&10 Expedition Leader, Eclipse observations of K- and E-corona– Libya (2006); French Polynesia (2010)
2003 -09 Co-PI of the Sounding Rocket Coronagraphic Experiment (SCORE) for the HERSCHEL mission.
1995 -98 Mission Operations Lead Scientist, Co-I of the Ultraviolet Coronagraph and Spectrometer on SOHO.
1993 -97 Associate scientist of the UV Coronal Spectrometer for the Space Shuttle Sub-satellite SPARTAN.
1994 Co-I of a Scholarly Study on a New Method for Measuring Magnetic Fields in the Solar Corona.
1989 -91 NRC Research Associate, Solar Maximum Mission: Impact Polarization in Solar Ultraviolet Lines.

Education

1994 Ph.D. in Astronomy, Università di Firenze, Firenze, Italy;
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Selected Publications

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Fineschi, S., et al., 1994, *"Ultraviolet Coronagraph Spectrometer for the Solar and Heliospheric Mission: Optical Testings"*, SPIE, 2283, 3
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Fineschi, S. et al., 2003, *"Ultraviolet and Visible-light Coronagraphic Imager (UVCI)"*, Proc. SPIE, 4853, 162
Morgan, H., Fineschi, S, Habbal, S.R., Li, Bo, 2008, *"In Situ Spectroscopy of the Solar Corona"*, A&A,. 482, 981.
Khan, A., Belluzzi, L., Landi Degl'Innocenti , E., Fineschi, S., Romoli, M., 2011, *"Spectropolarimetric forward modelling of the lines of the Lyman-series using a self-consistent, global, solar coronal model"*, A&A 529, A12.

SARAH E GIBSON

Professional Preparation

Stanford University	Physics	BS	1989
University of Colorado	Astrophysics	MS	1993
University of Colorado	Astrophysics	PhD	1995

Appointments

2/01–Present	Scientist, HAO/NCAR
2/00–1/01; 4/98-1/99	Research Assistant Professor in Physics, Catholic University of America
1/99-1/00	NSF-NATO Postdoctoral Fellow, University of Cambridge
4/96-4/98	National Research Council Associate, NASA Goddard Space Flight Center
10/95-4/96	NCAR Postdoctoral Associate HAO/NCAR

Selected Relevant Publications

L. A. Rachmeler, S. E. Gibson, R. Casini, Interpreting coronal polarization observations, *ASP Conference Series, 2012*

K. K. Reeves, S. E. Gibson, T. A. Kucera, H. S. Hudson, Thermal properties of coronal cavities observed with the X-ray telescope on Hinode, *ApJ, 746, 146, 2012*

J. B. Dove, S. E. Gibson, L. A. Rachmeler, S. Tomczyk, and P. Judge, Coronal magnetometry: Observational signatures of magnetic flux ropes, *ApJ, 731, 1, 2011*

D. Schmit and S. E. Gibson, Forward-modeling cavity density: a multi-instrument diagnostic, *ApJ, 733, 1, 2011*

S. E. Gibson *et al.,* Three-dimensional morphology of a coronal prominence cavity, *ApJ, 724, 1133, 2010*

S. E. Gibson, T. Bastian, H. Lin, B. C. Low, and S. Tomczyk, Magnetically-driven activity in the solar corona: A path to understanding the energetics of astrophysical plasmas, *Astro2010 Decadal Survey Science White Papers, 94, 2009*

S. E. Gibson and Y. Fan, Coronal prominence structure and dynamics: a magnetic flux rope interpretation, *JGR, 111, CiteID A12103, doi:10.1029/2006JA011871, 2006*

Selected Professional Service

2010-Present	Member, Steering Committee of Solar and Space Physics Decadal Survey
2008-2011	Scientific Editor, Astrophysical Journal
2007-Present	Member/Vice-chair, Solar Observatories Council to the AURA Board
2008-2010	Chair: International Space Science Institute Prominence Cavities Team
2006-2010	Member: Heliophysics Subcommittee of NASA Advisory Council
2005-2009	Member: Advanced Technology Solar Telescope Science Working Group
2002-2005	Member: American Astronomical Society/Solar Physics Division Committee
2002-2005	Member: Space Studies Board/Committee on Solar and Space Physics

Professional Affiliations American Geophysical Union; American Astronomical Society; International Astronomical Union

Honors/Awards American Astronomical Society (Solar Physics Division) Harvey Prize 2005.

Therese A. Kucera

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March 2012

Education:

Ph.D. in Astrophysical, Planetary, and Atmospheric Sciences,
University of Colorado, 1993
Thesis Title: *Observations and Analysis of Solar Flares at Radio and Other Wavelengths*
M.S. in Astrophysical, Planetary, and Atmospheric Sciences,
University of Colorado, 1991
B.A. in Physics, Carleton College 1987

Positions Held:

11/01 – pres. Scientist, Solar Physics Laboratory NASA's Goddard Space Flight Center (GSFC)
10/08 - 9/09 Detail at NASA HQ as Solar and Heliospheric Physics Program Scientist
11/03 - pres. Deputy Project Scientist for the STEREO mission
11/01 - 09/08 Deputy US Project Scientist for the SOHO mission
11/01 - 12/03 Living with a Star Data Environment Project Scientist

11/95–11/01 Member of SOHO Science Team at NASA's GSFC. Served as operations scientist for CDS and SUMER instruments. Studied prominences, active regions; planned scientific observations; wrote data analysis software. Also on team of Spartan 201-5 White Light Coronagraph.

10/93–10/95 National Research Council Resident Research Associate at NASA's GSFC. Studied solar flare X-ray emission to test models of flare energy release and particle acceleration.

Selected Publications:

Kucera, T.A., Gibson, S.E., Schmit, D.J., Landi, E., and Tripathi, D., 2012, "Temperature and EUV Intensity in a Coronal Prominence Cavity and Streamer," Submitted.

Reeves, K.K.; Gibson, S.E., Kucera, T. A., Hudson, H.S., and Kano, R., 2012, "Thermal Properties of a Solar Coronal Cavity Observed with the X-Ray Telescope on Hinode," *Astrophysics J*, **746**, 146.

Gibson, S. E., Kucera, T. A., Rastawicki, D., Dove, J., de Toma, G., Hao, J., Hill, S., Hudson, H. S., Marqu, C., McIntosh, P. S, *et al.*, 2010, "Three-dimensional Morphology of a Coronal Prominence Cavity" *Astrophysics J*, **724** 1133.

Kucera, T.A., and Landi, E., 2008, "An Observation of Low Level Heating in an Erupting Prominence," *Astrophysics J*, **673**, 611.

Kucera, T.A., and Landi, E., 2006, "Ultraviolet Observations of Prominence Activation and Cool Loop Dynamics," *Astrophysics J*, **645** 1525.

Short VITA

Jeffrey R. Kuhn

Born: 1 Nov. 1957: Columbus, Ohio, USA

Current Position:

Associate Director
Institute for Astronomy Haleakalà Division
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Education:

Ph.D. (Physics) Princeton - January 1981
M.S. (Physics) Princeton - June 1979
B.A. (Physics and Mathematics) Kalamazoo College - June 1977

Awards and Honors:

Von Humbolt Senior Researcher Prize (2010)
Phillips Distinguished Lecturer (1994, Haverford College)
Alfred P. Sloan Fellowship (1986)
Shenstone Prize (1980, Princeton)
Hornbeck Prize (1977, Kalamazoo)

Experience:

Astronomer, Institute for Astronomy, University of Hawaii (Aug. 1998 -)
Astronomer, NOAO/National Solar Observatory, (Jan. 1993 - July 1998)
Professor, Physics and Astronomy, Mich. State Univ. (Sept. 1992 -Aug. 1999)
Faculty Research Fellow, AFGL/National Solar Observatory (Fall 1990)
Visiting Research Assoc., Inst. Theor. Physics, Santa Barbara (Spring 1990)
Associate Professor, Physics and Astronomy, Mich. State Univ. (Sept. 1986 - 92)
Assistant Professor, Physics, Princeton University (Sept. 1982 - Aug. 1986)
Instructor, Physics, Princeton University (Sept. 1981 - Sept. 1982)
Lecturer, Physics, Princeton University (Jan. 1981 - Sept. 1981)

Research Interests:

Solar Astrophysics
Astrophysical Instrumentation and Techniques
Gravitation, Dynamics

Professional Society Memberships:

International Astronomical Union
American Astronomical Society
American Physical Society

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Curriculum Vitae

Experience

Jan. 2008 : **Research Assistant**
STCE-SIDC, Royal Observatory of Belgium

- In charge of the development and refurbishing of solar radio telescopes, Humain station, Belgium
- Research on radio signatures of shock waves, CMEs, flares

Jul. 2006–Dec. 2007 : **Research Assistant**
SIDC, Royal Observatory of Belgium

- Modeling of the EUV solar corona by raytracing - Modeling of the electron density and temperature distribution
- Software development for the Solar Weather Browser

Jan. 2006–Jun. 2006 : **Wetenschappelijk Medewerker**
CPA, K.U.Leuven - SIDC, Royal Observatory of Belgium

- Modeling of the EUV solar corona by raytracing - Modeling of the electron density and temperature distribution

Jan. 2003–Dec 2005 : **Research Associate**
USRA-Naval Research Laboratory, Washington DC

- CME studies in white light, EUV and radio - SEP and shock wave studies
- Modeling of the metric radio solar corona by raytracing - Modeling of the electron density and temperature distribution

Sept. 2001–Aug. 2002 : **Temporary Research and Teaching Assistant position (Astronomy for teachers)**
Paris Observatory

Academic Preparation

1998–2001 : Université Paris 6
PhD Thesis. Dec. 18th 2001 (mention très honorable). Supervisor Pierre Lantos

- Title: Coronal environment of quiescent and eruptive filaments: EUV, radio and coronagraphic observations

1997 : Université Paris 6
Post graduate diploma in Astrophysics (D.E.A)

1996 : Université Paris 6
Master's Degree in Physics (Maîtrise)

1995 : Université Paris 6
Science Degree in Physics (Licence)

1994 : Université Marne-la-Vallée
Associate of Science, Physics and Chemistry (D.E.U.G)

1992 : High School Diploma, Physics and Mathematics (Baccalauréat Section C)

LAUREL ANNE RACHMELER

Education

Bryn Mawr College	Physics	BA	2004
University of Colorado	Astrophysics	MS	2007
University of Colorado	Astrophysics	PhD	2010

Appointments

2012–2013	Postdoctoral Fellow, St. Andrews University, Scotland. Supervisor: Alan Hood
2010–2012	Postdoctoral Fellow, High Altitude Observatory, National Center for Atmospheric Research. Topic: forward modeling of coronal polarization. Supervisor: Sarah Gibson
2006–2010	Graduate Researcher, Center for Astrophysical and Space Astronomy, University of Colorado, Boulder. PhD title: Modeling Eruptive Coronal Magnetohydrodynamic Systems with FLUX (Field Line Universal relaXer). Supervisor: Craig DeForest

Research Interests

I am interested in the solar coronal magnetic field, specifically in the context of eruptions. My long-term goal is to study CME initiation configurations, determine ways to associate observational cases with specific theoretical models, and predict which eruption initiation mechanisms are most likely for a given coronal configuration.

Publications

L. A. Rachmeler, S. E. Gibson, and J. Dove. Polarimetric observational properties of the flux ropes and sheared field in the corona. *in preparation*.

L. A. Rachmeler, R. Casini, and S. E. Gibson. Interpreting coronal polarization observations. *accepted,* Astronomical Society of the Pacific Conference Series, 2012.

J. B. Dove, S. E. Gibson, L. A. Rachmeler, S. Tomczyk, and P. Judge. A Ring of Polarized Light: Evidence for Twisted Coronal Magnetism in Cavities. ApJ, 731:L1+, April 2011.

S. E. Gibson, T. A. Kucera, D. Rastawicki, J. Dove, G. de Toma, J. Hao, S. Hill, H. S. Hudson, C. Marqué, P. S. McIntosh, L. Rachmeler, K. K. Reeves, B. Schmieder, D. J. Schmit, D. B. Seaton, A. C. Sterling, D. Tripathi, D. R. Williams, and M. Zhang. Three-dimensional Morphology of a Coronal Prominence Cavity. ApJ, 724:1133–1146, December 2010.

L. A. Rachmeler, E. Pariat, C. E. DeForest, S. Antiochos, and T. Török. Symmetric Coronal Jets: A Reconnection-controlled Study. ApJ, 715:1556–1565, June 2010.

L. A. Rachmeler, C. E. DeForest, and C. C. Kankelborg. Reconnectionless CME Eruption: Putting the Aly-Sturrock Conjecture to Rest. ApJ, 693:1431–1436, March 2009.

Selected Oral Presentations

L. A. Rachmeler, et al. 'Forward modeling of Coronal Polarization', SDO-4 / IRIS / Hinode Workshop, Moneterey, CA, March 2012.

L. A. Rachmeler, et al. 'Forward modeling of Coronal Polarization', From the Heliosphere into the Sun, Bad Honnef Germany, Feb 2012.

L. A. Rachmeler. 'Coronal polarization and forward modeling', invited talk, SHINE workshop, July 2011.

L. A. Rachmeler. A series of four workshop talks including 'CoMP instrument and coronal polarization' and 'Polarimetric signatures of flux ropes and sheared fields', CIAS Forward Modeling workshop at the Observatory of Paris in Meudon, March 2011.

L. A. Rachmeler, C. E. DeForest. 'Fluxon modeling of energetic solar eruptions', HAO colloquium, September 2009.

Biographical Sketch:

Katharine K. Reeves

Professional Preparation

Reed College	Physics	BA	1996
Northeastern University	Physics	MS	1999
University of New Hampshire	Physics	PhD	2006

Appointments

Astrophysicist June 2006 - Present
Solar and Stellar X-ray Group
Harvard-Smithsonian Center for Astrophysics, Cambridge, MA

Research Assistant June 1999 - August 2002
Solar and Stellar X-ray Group
Harvard-Smithsonian Center for Astrophysics, Cambridge, MA

Publications

Recent relevant publications

Reeves, K. K., Gibson, S. E., Kucera, T. A., Hudson, H. S., and Kano, R. "Thermal Properties of A Solar Coronal Cavity Observed with the X-ray Telescope on Hinode," *Astrophysical Journal*, **746**, 146, 2012.

Gibson, S. E., Kucera, T. A., Rastawicki, D., Dove, J., de Toma, G., Hao, J., Hill, S., Hudson, H. S., Marque, C., McIntosh, P. S., Rachmeler, L., Reeves, K. K., Schmieder, B., Schmit, D. J., Seaton, D. B., Sterling, A. C., Tripathi, D., Williams, D. R. and Zhang, M. "Three-dimensional morphology of a prominence cavity", *Astrophysical Journal*, **724**, 1133, 2010.

Reeves, K. K., Linker, J. A., Mikić, Z. and Forbes, T. G, "Current Sheet Energetics, Flare Emissions, and Energy Partition in a Simulated Solar Eruption," *Astrophysical Journal*, **721**, 1547, 2010.

Reeves, K. K., Warren, H. P. and Forbes, T. G. "Theoretical Predictions of X-Ray and EUV Flare Emissions Using a Loss-of-Equilibrium Model of Solar Eruptions," *Astrophysical Journal*, **668**, 1210, 2007.

Reeves, K. K. "The Relationship Between Flux Rope Acceleration and Thermal Energy Release in a Model of Eruptive Solar Phenomena," *Astrophysical Journal*, **644**, 592, 2006.

Steven Tomczyk

Steven Tomczyk, born 23 Feb 1957, Elizabeth, New Jersey, USA

Curriculum Vitae

- Bachelor of Science in Astronomy, Villanova University, USA (1979)
- Master of Arts in Astronomy, University of California, Los Angeles, USA (1980)
- Ph.D. in Astronomy, University of California, Los Angeles, USA (1988)
- Since 1988, Scientist at the High Altitude Observatory of the National Center for Atmospheric Research, USA
- Presently Senior Scientist, High Altitude Observatory of the National Center for Atmospheric Research, USA

Professional

Dr. Tomczyk has over 20 years of experience in the development and application of instrumentation for remote sensing of the Sun from the ground and from space. He began his career developing instrumentation based on magneto-optical filters for the ground-based observation of the solar photospheric velocity field. These were used to constrain the rotation and hydrostatic structure of the deep solar interior. Later, he focused on the development of spectropolarimeters for measuring magnetic and velocity fields in the solar photosphere and chromosphere, including the Advanced Stokes Polarimeter, the Spectro-Polarimeter for INfrared and Optical Regions, the Interferometric Bidimensional Imaging Spectrometer, and the Helioseismic and Magnetic Imager. More recently, he has worked on instrumentation to measure velocity and magnetic fields in solar prominences and the solar corona (the Coronal Multi-channel Polarimeter and the Prominence Magnetometer). He is also developing the concept for a large aperture ground-based solar coronagraph dedicated to the synoptic observation of solar coronal magnetism and its relation to solar activity. He is presently a Co-I for the Helioseismic and Magnetic Imager to fly on the Solar Dynamics Observatory.

Relevant Publications

- The Advanced Stokes Polarimeter - A new instrument for solar magnetic field research, Elmore, D.F., Lites, B.W., Tomczyk, S., et al. (1992) *SPIE*, **1746**, 22.
- An instrument to observe low-degree solar oscillations, Tomczyk, S., Streander, K.V., Card, G.L., Elmore, D.F., Hull, H., Cacciani, A. (1995) *Solar Physics*, **159**, 1.
- A new precise measurement of the coronal magnetic field strength, Lin, H., Penn, M.J., Tomczyk, S. (2000) *ApJ*, **541**, L83.
- Spinor : visible and infrared spectro-polarimetry at the National Solar Observatory, Socas-Navarro, H., Elmore, D.F., Pietarila, A., Darnell, A., Lites, B.W., Tomczyk, S., Hegwer, S. (2006) *Solar Physics*, **235**, 55.
- Observation of Alfvén waves in the quiet solar corona, Tomczyk, S., McIntosh, S.W., Keil, S.L., Judge, P.G., Schad, T., Seeley, D.H., Edmondson, J., (2007), *Science*, **317**, 192.
- An instrument to measure coronal emission line polarization, Tomczyk, S., Card, G.L., Darnell, T., Elmore, D.F., Lull, R., Nelson, P.G., Streander, K.V., Burkepile, J., Casini, R., Judge, P.G. (2008) *Solar Physics*, **247**, 411.
- A coherence-based approach for tracking waves in the solar corona, McIntosh, S.W., de Pontieu, B., Tomczyk, S. (2008) *Solar Physics*, **252**, 321.
- The feasibility of large refracting telescopes for solar coronal research, Nelson, P.G., Tomczyk, S., Elmore, D.F., Kolinski (2008) *SPIE*, **7012**, 701231.
- Time-distance seismology of the solar corona, Tomczyk, S., McIntosh, S.W. (2009) *ApJ*, **697**, 1384.
- Large scale flows in prominence cavities, Schmidt, D.J., Gibson, S.E., Tomczyk, S., Reeves, K.K., Sterling, A.C., Brooks, D.H., Williams, D.R., Tripathi, D. (2009) *ApJ*, **700**, L96.

Curriculum Vitae

Stephen M. White

Business Address:
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Telephone: 505 853 6158 ; E-mail: Stephen.White@kirtland.af.mil

Employment and Appointments

Current position: **Senior Research Radio Astronomer**, Space Vehicles Directorate, Air Force Research Laboratory, 2009–

Co-Director, "Science, Discovery and the Universe" program of College Park Scholars (Living–Learning community for undergraduates), University of Maryland, 2006-2009

Associate Research Scientist, Department of Astronomy, University of Maryland, 1991-2009

Publications

Recent publications:

"*Forecasting $F_{10.7}$ with solar magnetic flux transport modeling*", Henney, C. J., Toussaint, W. A., **White, S. M.**, & Arge, C. N. Space Weather, 10, 2011, 2012

"*Solar Flares at Submillimeter Wavelengths*", Krucker, S., T. S. Bastian, C. G. Giménez de Castro, A. S. Hales, H. S. Hudson, J. Kašparová, K.-L. Klein, M. Kretzschmar, T. Lüthi, A. L. MacKinnon, S. Pohjolainen, G. Trottet, & **S. M. White**, Astronomy and Astrophysics Reviews, submitted, 2011.

"*The Relationship Between Solar Radio and Hard X–ray Emission*", **S. M. White**, A. O. Benz, S. Christe, F. Fárník, M. R. Kundu, G. Mann, Z. Ning, J.-P. Raulin, A. V. R. Silva-Válio, P. Saint-Hilaire, N. Vilmer, & A. Warmuth, Space Science Reviews, 159, 225, 2011

"*Measurements of the Coronal Acceleration Region of a Solar Flare*", S. Krucker, H. S. Hudson, L. Glesener, **S. M. White**, S. Masuda, J.-P. Wuelser, & R. P. Lin, Ap. J., 714, 1108, 2010.

Publications relevant to this proposal:

"*On the relationship between chromospheric emission, millimeter emission and the magnetic field*", Loukitcheva, M. A., S. K. Solanki, and **S. M. White**, Astronomy & Astrophysics, 497, 273, 2009.

"*Radio Measurements of the Height of Strong Coronal Magnetic Fields Above Sunspots at the Solar Limb*", J. W. Brosius & **S. M. White**, Astrophys. J. Lett., 641, L69, 2006.

"*Coronal Magnetic Field Measurements Through Gyroresonance Emission*", **S. M. White**, book chapter in **Solar and Space Weather Radiophysics**, eds. D. E. Gary & C. O. Keller, Kluwer Astrophysics and Space Science series, p. 89, 2004.

"*A Test for Coronal Magnetic Field Extrapolations*", J. Lee, **S. M. White**, M. R. Kundu, Z. Mikić, & A. N. McClymont, Astrophys. J., 510, 413, 1999.

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EDUCATION:

Oct. 1994 - Aug. 1999	**Ph.D. in Astrophysics** Beijing Astronomical Observatory, CAS, China
Sept. 1987 - Oct. 1990	**Master Degree in Astrophysics** Beijing Astronomical Observatory, CAS, China
Sept. 1983 - July 1987	**Bachelor Degree in Science** Peking University, China

APPOINTMENTS:

Jan. 2003 – now	**Professor** National Astronomical Observatory, CAS, China
Apr. 2004 – now	**Affiliate Scientist**
Oct. 2001 – Mar. 2004	**Project Scientist I**
Nov. 2000 – Oct. 2001	**Long-term Visiting Scientist** High Altitude Observatory, NCAR, Boulder, USA
Mar. 2000 – Oct. 2000	**Associate Professor**
May 1994 – Feb. 2000	**Assistant Professor**
Nov. 1990 – Apr. 1994	**Research Assistant** Beijing Astronomical Observatory, CAS, China

SELECTED PUBLICATIONS:

- J. Hao, M. Zhang, Hemispheric helicity trend for solar cycle 24, 2011, ApJ Letters, 733, L27
- C. Y. Wang, M. Zhang, A hemispheric helicity sign rule indicated by large-scale photospheric magnetic fields at three phases of solar cycle 23, 2010, ApJ, 720, 632
- M. Zhang, N. Flyer, The dependence of the helicity bound of force-free magnetic fields on the boundary conditions, 2008, ApJ, 683, 1160
- M. Zhang, Helicity observation of weak and strong fields, 2006, ApJ, 646, L85
- M. Zhang, N. Flyer, B. C. Low, Magnetic field confinement in the corona: The role of magnetic helicity accumulation, 2006, ApJ, 644, 575
- M. Zhang, B. C. Low, The hydromagnetic nature of solar coronal mass ejections, 2005, Annual Reviews of Astronomy and Astrophysics, 43, 103
- M. Zhang, B. C. Low, 2004, Magnetic energy storage in the two hydromagnetic types of solar prominences, ApJ, 600, 1043.
- M. Zhang, B. C. Low, 2003, Magnetic-flux emergence into the solar corona. III. The role of total helicity conservation, ApJ, 584, 479.