Solar Physics Division of the American Astronomical Society

The Coronal Courant

Image Credit: Antimodular Research

Artist Rafael Lozano-Hemmer's "Solar Equation" pg 40

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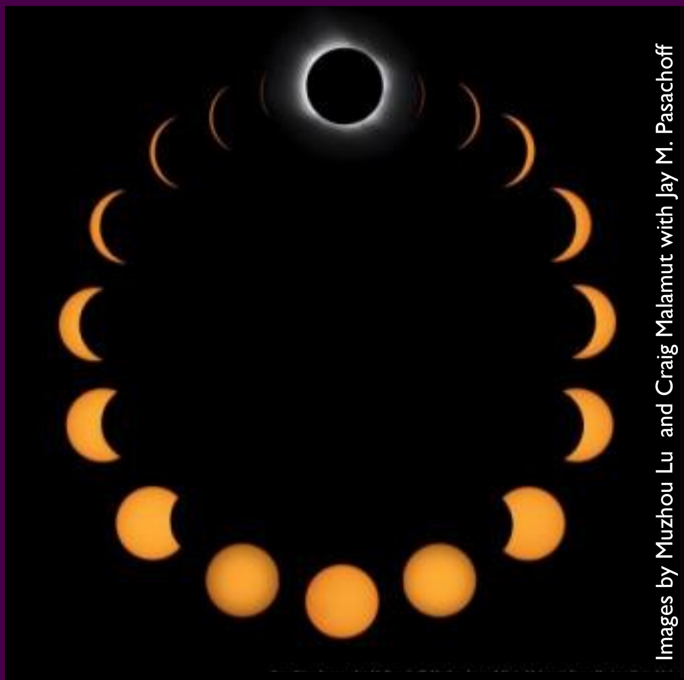
INTERFACE REGION IMAGING SPECTROGRAPH

IRIS

NASA LMSAL LMS&ES ARC SAO UiO MSU LSJU

Interface Region Imaging Spectrograph (IRIS) NASA Small Explorer by Bart De Pontieu, LMSAL pg 9



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MISSION STATEMENT

The Coronal Courant is a newsletter/zine for students. The target audience will be both students within the solar community as well as students with no access to solar physics education. We hope to serve the more advanced undergraduates and graduate level students who have started to build specific interests and expertise, as well as students from high school level on up through early undergraduate years where students may not have declared their interests yet.

The purpose of this newsletter/zine is to provide scientific and technical articles, descriptions of the scientific experience, news and announcements pertaining to students, career information, listing of student activities (student talks, papers, summer projects, and theses), mission and satellite descriptions, data analysis and modeling techniques, a picture gallery, web link directories, fun stuff, and whatever else people want to submit. In other words, we offer a little of this, a little of that, and something for everyone!!!

Both faculty and students are invited to submit.

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The Scientist as Entrepreneur

Peter Foukal, Heliophysics Research, Inc.

A great strength of US science is the multiplicity of funding sources and different kinds of employment open to young researchers. Yet I still see Letters to the Editor complaining about limited opportunity for tenure track employment. When I was a post–doc at Caltech and Harvard in the 1970's I used to write the same kind of letters. For instance, when a particle physicist friend was appointed to an assistant professorship at Harvard partially supported by a DOE grant, I suggested to George Field and NASA that some of the SkyLab funding at the Center for Astrophysics be used to create faculty positions in solar physics. It eventually happened, but I wasn't the lucky beneficiary! After a few years of frustrating lobbying for a tenure track position located somewhere I wanted to live, I realized that I'd be better off *creating* the kind of situation I wanted.

"… I realized that I'd be better off *creating* the kind of situation I wanted."

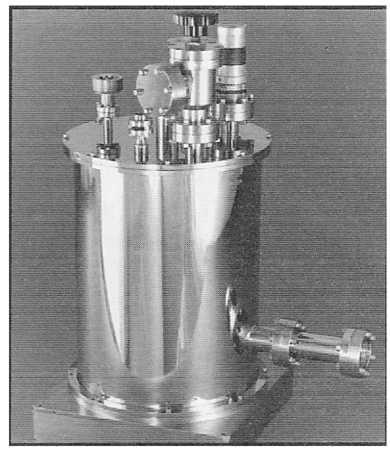
This opportunity would have been unheard of in any other country besides the US. But I liked the idea of running my own show and in 1978 I left Harvard to join a start-up, Atmospheric and Environmental Research, Inc, that had just been formed by some Harvard atmospheric physicists. One of the principals, Mike McElroy, was instrumental in promoting the nascent international Global Change agenda, and AER prospered. But in 1985, I decided to go off on my own with two young engineers, Peter Miller and Cliff Hoyt, who shared my interest in commercializing ideas we had on measurement and control of light. The new company was christened Cambridge Research and Instrumentation, Inc.

We rented a little windowless lab/office in Cambridge and my father, a graphic artist, contributed our letterhead logo. Our location happened to be across the street from American Science and Engineering, Inc., the 1950's MIT spin off led by Bruno Rossi and Riccardo Giacconi. AS&E was a poster child for what scientific entrepreneurship could achieve. Its x-ray imaging technology led the way both in astrophysics, and also in airport inspection and industrial quality control. Giacconi won the Physics Nobel Prize for his work, and AS&E had about 200 employees, so we had a shining example to guide us.

My wife, Elisabeth, learnt accounting and kept CRI's books on a part time basis. She continued her employment in software just in case CRI proved less successful than I envisioned. We had two little children and a third one coming, and the only way to get a line of credit from the bank was to put our house on the line. Exciting stuff when you are young…

At AER and later at CRI I obtained funding for solar research from the NSF, NASA, DOD and also NOAA. This was new at the time, and I am grateful to several forward-looking Program Directors at these agencies, like Dennis Peacock, Dick Donnelly and Bill Wagner, for being willing to give this new initiative a try. Over the next years I was fortunate to attract several skilled post docs like Larry Petro, Lee Fowler, and Tom Moran to join my fledgling group, and also find some excellent post-bachelor's students like Brad Behr, who wanted time off before astronomy grad school at CIT.

In the 1980's and 1990's we were amongst the heaviest users of Sac Peak and Kitt Peak, developing new photometric methods to study solar magnetic structures, photospheric heat flow, and irradiance variation. We were the first to use the new 2-D IR arrays to image the photosphere. We also developed Stark effect techniques for detecting solar plasma electric fields. Another major project in the early 1990's was the digitization of archival Ca K plates taken at Mt Wilson. This required hiring a reliable employee in Los Angeles who was willing to spend many months in the basement of Hale Observatories using the ccd digitizer and software we had developed at CRI, to reduce plage areas on about 18,000 plates. Morgan Harman made an important contribution to solar studies by carrying out this task with great dedication.

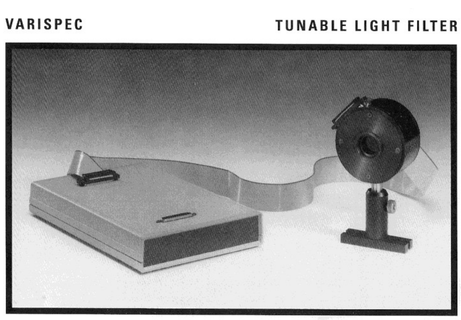


The CRI CryoRad cryogenic radiometer developed for detector calibrations and basic metrology.

Our irradiance research led to an interest in new light flux measurement techniques, particularly cryogenic radiometers. We improved the mechanical design and developed sensitive ac bridge electronics for these sophisticated instruments, and received orders for the national standards of light and detector calibration for the US (NIST), Germany (PTB), Canada (NRC) , France, Switzerland, Japan and many other nations. Several NIST staff like Jon Geist, Ed Zalewski and Al Parr, provided helpful ideas and funding.

Detector calibrations using the cryo-radiometers required more stable light sources than lamps could provide. So we improved a NIST design for a servo system that removed flicker from lasers, and commercialized that. These laser stabilizers became a staple of detector calibration labs and we shipped hundreds worldwide. Some of our product development work was funded under the Small Business Innovation Research Program, and our success in commercializing the products earned us a NASA SBIR Achievement award.

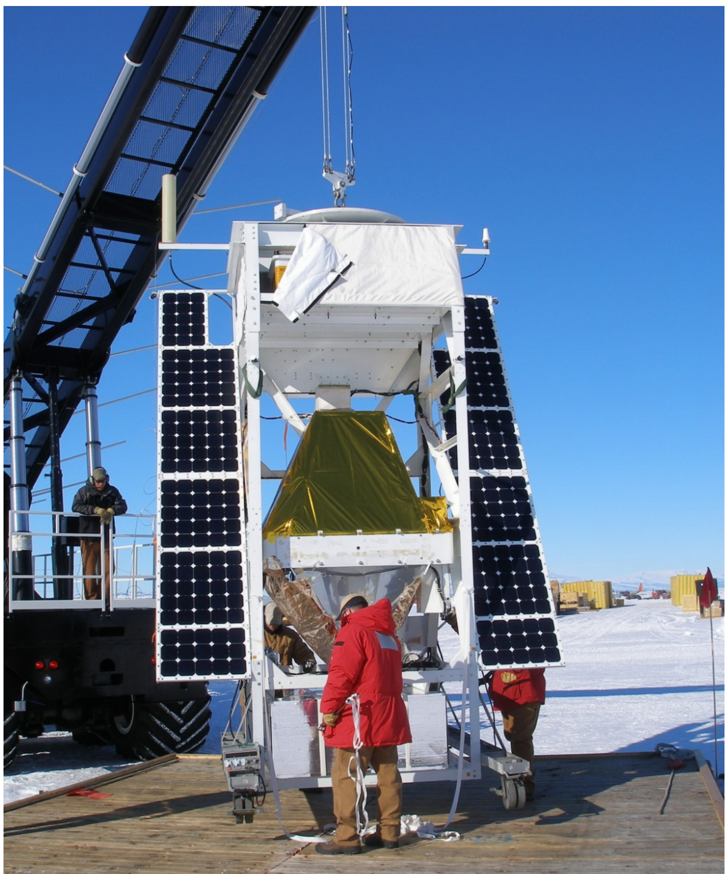
A commercial cryogenic radiometer and stabilizer system built by L-1 Standards and Technology Inc. under license from CRI was used recently to correct the value of the total solar irradiance by the University of Colorado's Laboratory for Atmospheric and Space Physics. We had suggested the importance of cryo-radiometry to characterize flight radiometers many years ago, but it was to LASP's credit that they implemented this technique on flight hardware; the correction they found was large enough to even warrant a January 27th 2011 editorial in *Nature*!



The VariSpec liquid crystal birefringent tunable filter developed at CRI for applications in biomedical, industrial and remote sensing applications.

A desire to reduce reliance on expensive electro-optic crystals in our laser stabilizers motivated us to experiment with liquid crystal (LC) optics. This led to the development of rapidly tunable LC birefringent filters and polarization analyzers which found applications in telecom, remote sensing and biomedical imaging. These CRI VariSpec filters are now used widely in fluorescence microscopy and in-vivo imaging for cancer research, for instance. The many technical hurdles required to produce these innovative products were surmounted mainly by Peter Miller and Cliff Hoyt, two very capable engineers who had joined me in forming CRI.

These new products were exciting but they took CRI into fields far from my expertise. Also, as the company grew, management responsibilities for our 20 employees increased to a point which led me and my wife to sell the firm to a group of investors in 1999. CRI has since expanded to over 60 employees; in December 2010 it merged with Caliper Life Sciences, Inc., a large, publicly traded biomedical imaging corporation, and its facilities are moving to Hopkinton, MA. This merger will ensure that the ideas we hatched as scientist entrepreneurs 25 years ago will reach their full potential in helping people worldwide through improved biomedical imaging, and also by reducing the US trade deficit!



The Solar Bolometric Imager being prepared for launch in 2006 from McMurdo Base, Antarctica.

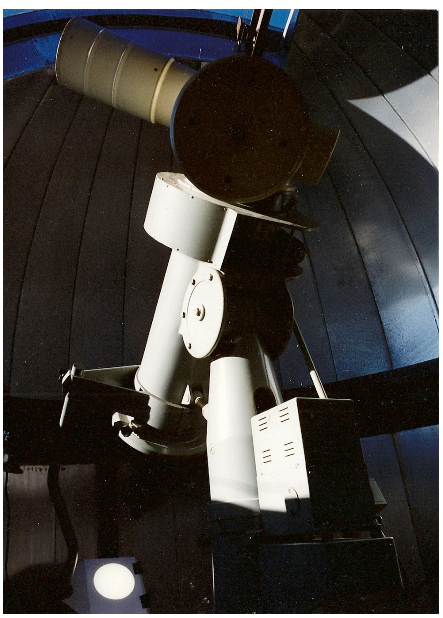
I was able to concentrate on solar research again, incorporating in 2002 as Heliophysics, Inc., and working from home (no more commuting!). A focus has been the Solar Bolometric Imager (SBI) an innovative solar telescope that images in integrated light with flat spectral response from the UV into the IR. We had developed it for irradiance studies with Scott Libonate at CRI and it was prepared for balloon flight by Dave Rust and Pietro Bernasconi's group at the Johns Hopkins Applied Physics Laboratory. The SBI has since obtained thousands of photospheric images in two successful flights from Ft Sumner (and a less successful one from McMurdo in Antarctica); it provides the logical next step in NASA flight instrumentation required to fully understand solar irradiance variation.

A career in science entrepreneurship remains unusual. Several solar astronomers now work for small private research consortia like those pioneered by Karen and Jack Harvey, by Sara Martin or by Northwest Research. Solar astronomers have also founded successful commercial firms, like Tom Baur's Meadowlark Optics. But I am not aware of any besides CRI where solar research was combined successfully with a line of commercial products. It is a path that more young scientists should consider. Looking back over the 32 years since I left Harvard, I feel that entrepreneurship enabled me to achieve my potential as a scientist as well as if I had pursued an academic career, without the concessions on location that such an academic career would probably have required.

"A career in science entrepreneurship remains unusual. … Entrepreneurship enabled me to achieve my potential as a scientist as well as if I had pursued an academic career …"

Our solar research at AER and CRI led to well over 100 refereed papers, including cover articles in *Science*, *Nature*, and *Scientific American*. I even found time (by rising very early for 5 years!) to write my text "Solar Astrophysics", first published in 1990. I was able also to contribute to the solar community by serving on various NASA, NSF and NAS committees, and by leading the NSF SUNRISE program that provided funding for irradiance research for about a decade. A radiometry workshop that I organized at AER in 1985 has expanded into NEWRAD, the major international radiometry meeting, now attracting almost 200 participants biennially. I don't think I would have done much different things from a base at a university or major lab.

Running a small business certainly takes time, but so do teaching and serving on faculty committees, or administrative duties at industrial or government labs. My experience teaching Astro 10 to science majors at Harvard gave me respect for the time investment required to design and present a course. The reward was meeting bright students like James Kasting, who has gone on to an impressive career in planetary astronomy. It would have been nice to train graduate students in observational solar physics, but that is my only regret.



Viewing the Sun with the 15 cm Zeiss coude telescope at EPSO.

Instead, I built the small East Point Solar Observatory in our little town near Boston in 1995 and used it to offer a summer astronomy program for 9-14 year olds. NASA Outreach funding enabled me to hire a high school teacher to help out, and we attracted up to 40 youngsters. I continue to use EPSO to look at the sun on clear days, a habit I learnt from Hal Zirin, which I recommend to all solar astronomers. It is good to be reminded of what it is we are studying!

The East Point Solar Observatory operated by Heliophysics, Inc in Nahant, MA.

"… you can design your own career and do satisfying research outside of the conventional tracks of a university, government or industrial lab."

In summary, I hope my experiences will help young scientists realize that you *can* design your own career and do satisfying research outside of the conventional tracks of a university, government or industrial lab. It *is* advisable to develop your credentials in one of these more conventional environments before venturing out on your own. Entrepreneurship, like any career path, can be stressful and it isn't for everyone. But if you like a challenge it can be very rewarding.

CRI principals (1990). Left to right they are: Elisabeth Foukal (CFO), Peter Miller (Chief Electrical Engineer), Cliff Hoyt (Chief Mechanical Engineer), and PVF (CEO).

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For more info: http://www.heliophysics.com

Interface Region Imaging Spectrograph (IRIS) NASA Small Explorer

Bart De Pontieu
Lockheed Martin Solar & Astrophysics Laboratory, Palo Alto

1. What is the solar interface region?

The chromosphere and transition region (TR) form a complex interface region between the solar surface and corona. Almost all of the mechanical energy that drives solar activity and solar atmospheric heating is converted into heat and radiation within this interface region, with only a small amount leaking through to power coronal heating and drive the solar wind. The chromosphere requires a heating rate that is between one and two orders of magnitude larger than that of the corona. Yet despite the importance of the interface region for solar activity, the heating of the corona, and the genesis of the solar wind, the chromosphere and TR have received much less attention than the photosphere or corona. This is in part because the interface region is highly complex. The transition between high and low plasma β occurs somewhere between photosphere and corona, so that in the interface region, the magnetic field and plasma compete for dominance (with a variety of impacts on, e.g., waves such as mode coupling, refraction and reflection). Within this region, the density drops by 6 orders of magnitude, the temperature rapidly increases from 5,000 to 1 million K, with strong gradients across the magnetic field evident from high resolution images of the chromosphere (see Fig. 1).

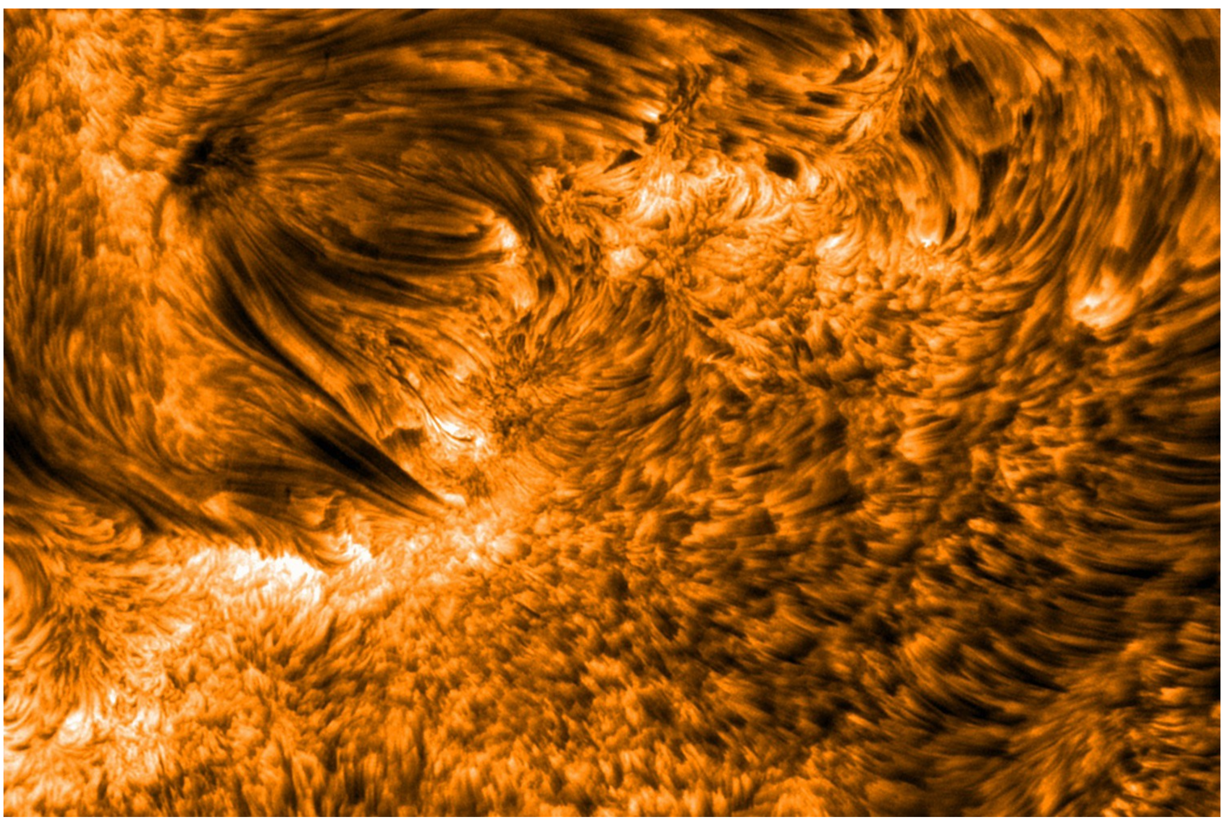

Figure 1: Hα line center image taken at the Swedish Solar Telescope on 16-June-2003 showing the fine scale structuring of the upper chromosphere, with the thinnest fibrils having diameters less than 200 km.

The plasma transitions from partially ionized in the chromosphere (which leads to a variety of interesting plasma physics effects) to fully ionized in the corona, and shows evidence of supersonic and super-Alfvenic motions. To top it off, the chromosphere is partially opaque, with non-local thermodynamic equilibrium (non-LTE) effects dominating the radiative transfer, so that interpreting the radiation, and determining the local energy balance and ionization state, is non-intuitive and requires advanced computer models. The highly dynamic nature of the chromosphere, as observed with Hinode and ground-based telescopes, further complicates attempts to better understand the interface region. This is both because high cadence observations are required (better than 15 seconds), and because the ionization state of some elements (e.g., hydrogen) reacts only slowly to changes in the energy balance, and thus depends on the history of the plasma. IRIS will exploit recent advances in novel, high throughput and high resolution instrumentation, efficient numerical simulation codes, and powerful, massively parallel supercomputers, to open a new window into the physics of the interface region.

2. What is IRIS?

IRIS is the Interface Region Imaging Spectrograph small explorer (SMEX) which is being built for NASA by Lockheed Martin Solar & Astrophysics Laboratory (LMSAL) in Palo Alto with Alan Title as a principal investigator, and with major contributions from NASA Ames, Smithsonian Astrophysical Laboratory (SAO), Montana State University (MSU), Stanford University and the University of Oslo. The primary goal of the Interface Region Imaging Spectrograph (IRIS) explorer is to understand how the solar atmosphere is energized.

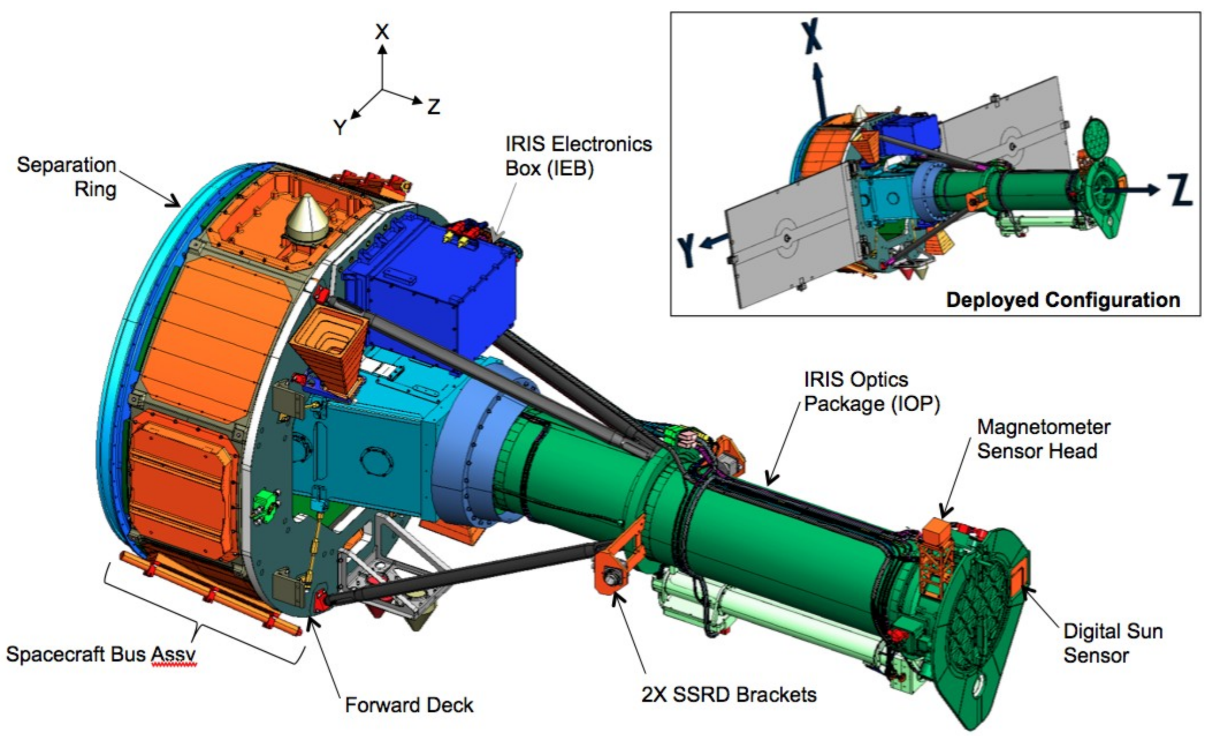

Figure 2: Schematic view of IRIS showing the 20 cm UV telescope, with and without solar panels (for clarity). The spacecraft is on schedule to be launched in December 2012 in a polar, sun-sychronous orbit with 98 degree inclination and a height of 620x670 km, to maximize eclipse-free viewing. This is an orbit that is similar to Yohkoh, TRACE and Hinode. It allows for 8 months of continuous observations per year.

The IRIS investigation combines advanced numerical modeling with a high resolution UV imaging spectrograph. IRIS will obtain UV spectra and images with high resolution in space (1/3 arcseconds) and time (1s) that are focused on the chromosphere and transition region. The IRIS instrument is a multi-channel imaging spectrograph with a 20 cm UV telescope. IRIS will obtain spectra along a slit (1/3 arcsec wide), and slit-jaw images. The IRIS spectra will cover temperatures from 4,500 K to 10 MK, with the images covering temperatures from 4,500 K to 65,000 K. The CCD detectors will have 1/6 arcsec pixels. IRIS will have an effective spatial resolution between 0.33 and 0.4 arcsec and a maximum field of view of 170 by 170 arcsec. The far-UV (FUV) channel covers two passbands, one from 1332-1358 Å and another from 1390-1406 Å, both with 40 m Å resolution and an effective area of 1.8 cm^2. The near-UV (NUV) channel covers: 2785-2835 Å with 80 mÅ resolution and an effective area 0.25 cm^2. IRIS will also obtain slit-jaw images in four passbands: 1335 Å and 1400 Å in the FUV with 40 Å bandpass each, and 2796 Å and 2831 Å in the NUV with 4 Å bandpass. IRIS will have a high data rate (0.7 Mbit/s on average) so that the baseline cadence is: 5s for slit-jaw images, 1s for 6 spectral windows, including rapid rastering to map solar regions.

Ion Spectrum	λ	Δλ	Log T	Estimated Count Rate (counts/s/line/spatial pixel)			Detector
	Å	mÅ	K	Quiet Sun	Active Region	Flare	
UV Spectra (effective area of 1.8 cm^2 for far-UV, 0.25 cm^2 for Mg passband, continuum is 1 Å) †: Count rates for Mg II wing, h and k are in counts/s/spectral pixel/spatial pixel							
Mg II wing	2820	25	3.7-3.9	3500†	12500†	12500†	3
O I	1356	12.5	3.8	60	165	410	1
Mg II h	2803	25	4.0	1400†	5400†	20000†	3
Mg II k	2796	25	4.0	1800†	7300†	15000†	3
C II	1335	12.5	4.3	670	4300	45000	1
C II	1336	12.5	4.3	920	5700	55000	1
Si IV	1403	12.5	4.8	170	3000	3e6	2
Si IV	1394	12.5	4.8	370	6000	9e6	2
O IV	1401	12.5	5.2	50	230	4e5	2
O IV	1400	12.5	5.2	10	70	1e5	2
Fe XII	1349	12.5	6.2	20	50	500	1
Fe XXI	1354	12.5	7.0	10	40	4e4	1
UV Slit-Jaw Images				**Estimated Count Rate (counts/s/pixel)**			
Effective area 0.003 cm^2 with 4 Å FWHM filter for Mg II; 0.45 cm^2 with 40 Å FWHM for far-UV.							
Mg II wing	2831		3.7-3.9	1800	4100	4100	4
Mg II k	2796		4.0	450	2100	5100	4
C II	1335		4.3	500	1600	16000	4
Si IV	1400		4.8	380	1500	3e5	4

Figure 3: Count rates for the strongest spectral lines observed with IRIS for three targets (quiet Sun, active region and flare) as estimated from spectral atlas data. Count rates assume a filling factor of 1/3 (i.e., assuming thin linear structures). Count rates will scale with the actual (unknown) filling factor of the Sun.

IRIS will have thermal coverage from the photosphere (neutral lines, wings of Mg II h/k) through the chromosphere (Mg II h/k) and transition region (C II, Si IV, O IV) into the corona (Fe XII and Fe XXI), as can be seen from Figure 3. This will allow us fully trace and identify the connections between all regions in the solar atmosphere. The high throughput of the instrument will allow short exposure times that enable measurements of the intensity, Doppler shift (down to 1 km/s) and line width. Deeper exposures will also reveal the full shape of the spectral line profiles (e.g., asymmetries). The short exposure times and flexible rastering schemes (Figure 5) will allow rapid scans of small regions on the Sun at very high spatial resolution of order 0.33-0.4 arcseconds. IRIS will function as a microscope to instruments onboard Hinode and SDO, which have a spatial and temporal resolution that is significantly reduced compared to IRIS. For example, IRIS can take a full spectral raster across 6 arcsec and context slit-jaw imaging at 0.33 arcsec resolution within the time it takes SUMER or EIS to expose one slit position (~20s) at 2 arcsec resolution (Figure 4).

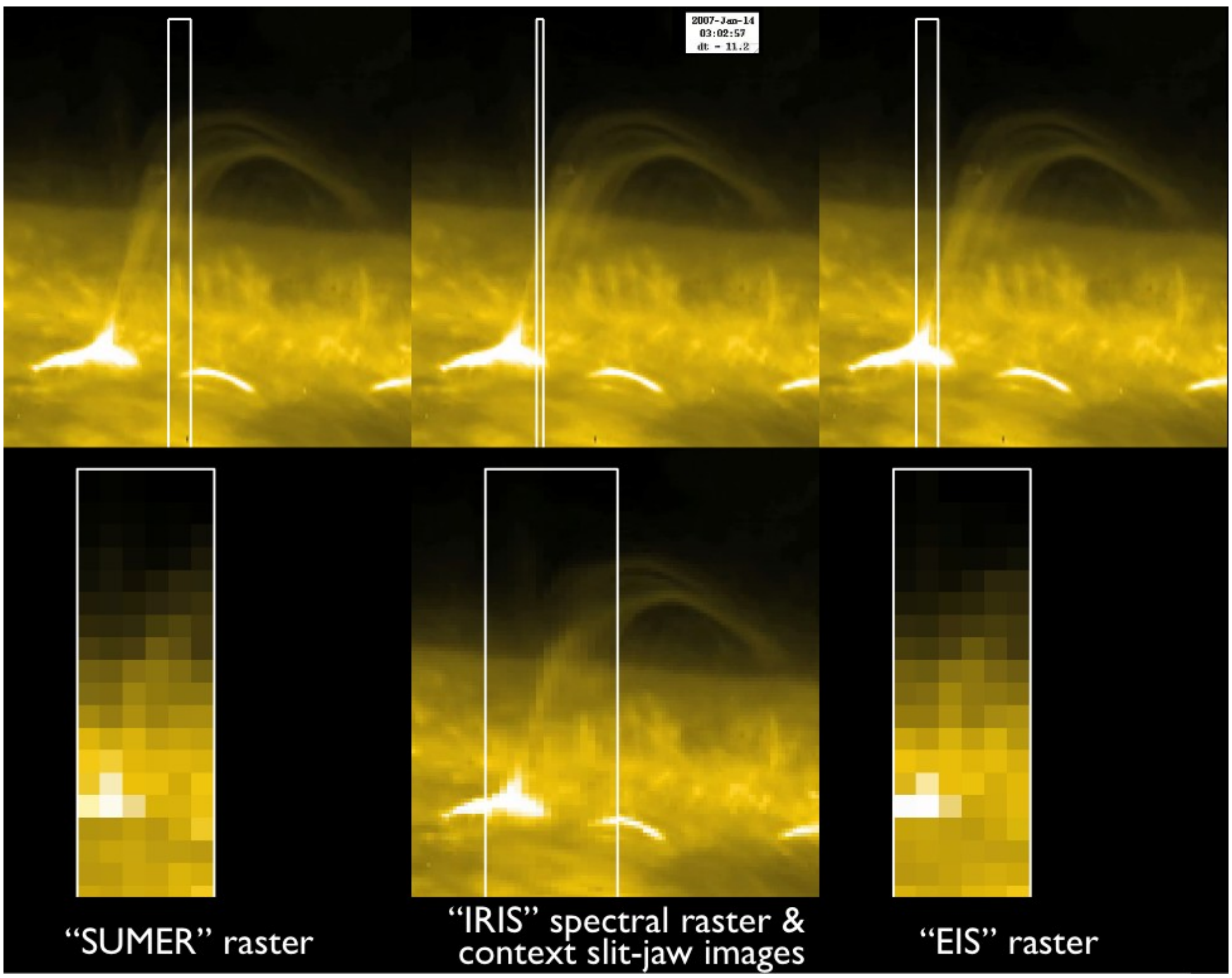

Figure 4: IRIS will allow faster rasters at higher spatial resolution than current instruments. The top row shows an example of a chromospheric image (taken with Hinode) showing a reconnection event, with SUMER, IRIS and EIS slit superimposed. The bottom row shows the observables SUMER, IRIS and EIS would produce given their spatial and temporal resolution. SUMER and EIS take full spectral rasters with 1 arcsecond wide slits at temporal resolutions of order 120-180s. IRIS takes a rapid raster with a 1/3 arcsecond wide slit at a cadence of 20 s and simultaneous slit-jaw images at a cadence of 5 s, and allows a full view of the event at a cadence that captures the dominant dynamics. A movie of this figure is available at http://iris.lmsal.com

The sparse raster option will allow rapid scans of much larger areas, which can be used, for example, for flare or CME watch programs (see Figure 5). The simultaneous slit-jaw images will have broader passbands, so they will contain a mixture of continuum and upper chromospheric (Mg II k) or transition region (C II, Si IV) emission. The upper chromospheric and transition region contributions are estimated to be in excess of 50% of the total emission of the passbands. IRIS will be operated in a manner that is similar to TRACE and Hinode, with observing programs uploaded 5 times per week, and the data made publicly available within a day of the observation. We will operate IRIS in full coordination with Hinode and SDO. To augment the IRIS data, we will have a special focus on coordination with ground-based observations that obtain chromospheric spectral line profiles over a large field of view (using Fabry-Perot interferometers). The Mg II h/k lines are optically thick lines, so require careful analysis for a proper interpretation. This can be done using 3D radiative MHD models and non-LTE radiative transfer diagnostic tools such as MULTI and RH (see section 3).

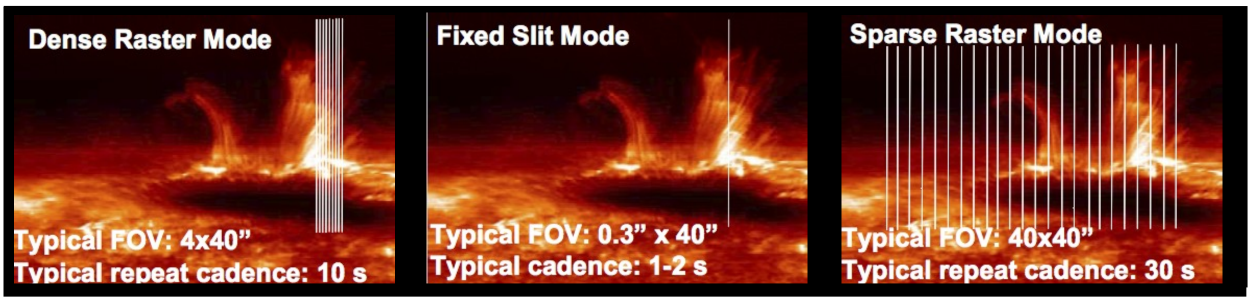

Figure 5: High throughput allows for rapid rasters of high S/N spectra that enable line centroid velocity determination down to 1 km/s precision within 1 s exposures for the brightest lines.

3. What science questions will IRIS address?

The IRIS science investigation is centered on 3 themes of broad significance to solar and plasma physics, space weather, and astrophysics, aiming to understand how internal convective flows power atmospheric activity:

1. Which types of non-thermal energy dominate in the chromosphere and beyond?

2. How does the chromosphere regulate mass and energy supply to corona and heliosphere?

3. How do magnetic flux and matter rise through the lower atmosphere, and what role does flux emergence play in flares and mass ejections?

While there are many candidate processes for the heating of the solar atmosphere, we do not understand their relative roles in the energy balance of the chromosphere and corona, or how the heating in the chromosphere and corona are connected. The fundamental problem of how non-thermal energy from below the surface is transported and released to shape the dynamic solar atmosphere involves many detailed questions. What is the mechanism that drives atmospheric heating: currents, reconnection from braiding, waves, electron beams? How much of the energy flux associated with the recently discovered weak magnetic fields that continuously emerge makes it into the corona and solar wind? In what forms does most energy travel upward? How important are braiding and torsional motions (as observed with Hinode and ground-based telescopes) by footpoint displacements to the solar atmosphere? Where do the motion induced currents run and where are they most strongly dissipated? What mechanism drives chromospheric jets or spicules, and how much plasma is heated to coronal temperatures in association with those jets? Do these events carry enough mass into the corona to dominate the coronal mass balance? What role do the variety of MHD waves play in transporting and depositing non-thermal energy?

The combination of co-temporal and co-spatial IRIS spectra and images of lines formed in the chromosphere, transition region and corona at cadences as fast as 1s and spatial scales below 0.5 arcsec will be a powerful tool to address many of these outstanding issues and questions. The Mg II h and k spectra and images will allow us to probe chromospheric heating mechanisms in much more detail than current ground-based or space-based observations can. Given their large formation height range, we will also be able to use the Mg II h and k lines to trace waves or disturbances from the photosphere into the upper chromosphere and study wave generation (e.g.., Alfven waves, which have been linked to the acceleration of the solar wind), propagation, refraction, wave mode coupling and shock wave formation. The simultaneous TR and coronal measurements will enable tracing of disturbances (waves or jets) into the higher temperature regimes, and study the impact of such disturbances on the energy balance of the outer solar atmosphere. Comparisons with magnetic field measurements from Hinode, SDO or ground-based telescopes, and numerical models or field extrapolations will be used to study the importance of topology and currents on the dynamics and energetics of the chromosphere and corona.

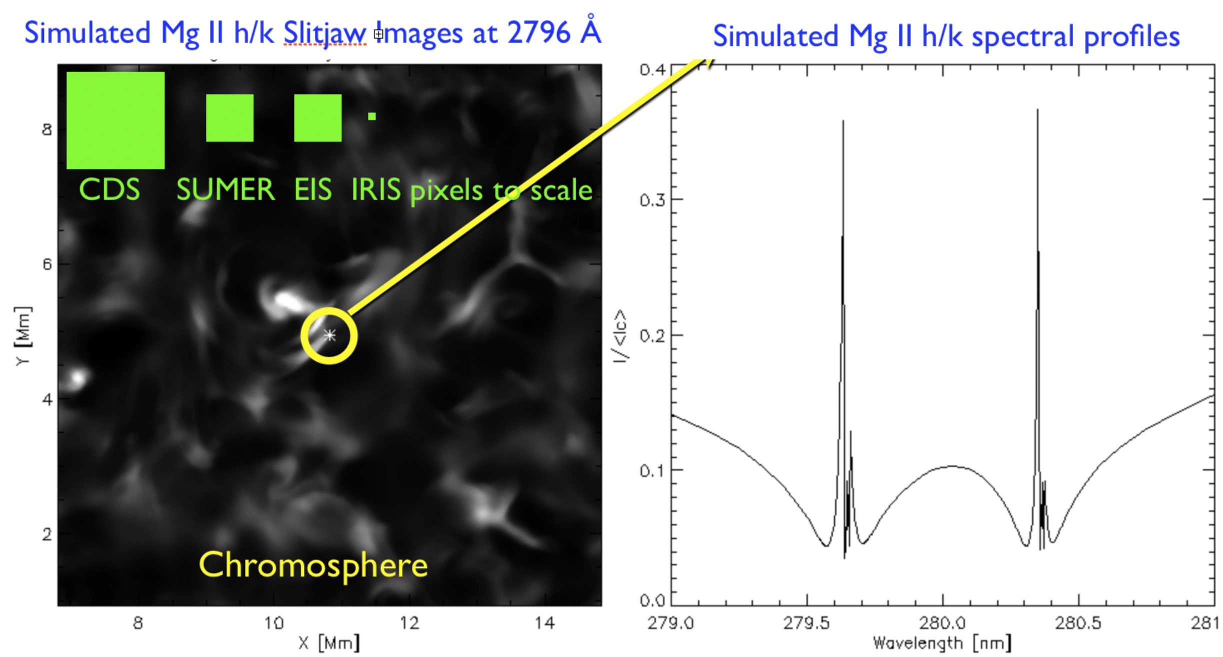

Figure 6: Example showing synthetic slit-jaw images and spectral profiles in Mg II h/k by using MULTI_3D on snapshots of 3D radiative MHD simulations from the University of Oslo (BIFROST). Courtesy Mats Carlsson (UiO/ITA).

In summary, the IRIS science investigation will focus on combining IRIS data with Hinode, SDO and ground-based observations, together with numerical MHD and multi-fluid plasma simulations to develop a comprehensive picture of the flow of energy and mass in the solar atmosphere. Given the complexity of the interface region, the interplay between observations and simulations will be very important. The IRIS science investigation has a strong theory/numerical modeling component. State-of-the-art radiative 3D MHD numerical simulations and synthetic (non-LTE) diagnostics in, e.g., optically thick lines like Mg II h/k, will allow detailed comparisons with IRIS observables. Such comparisons of observed and synthetic observables are key to interpreting the IRIS data, and ultimately determining the non-thermal energization of the solar atmosphere (see Figure 6).

4. What is the current status of IRIS?

IRIS was selected by NASA in June 2009 and work started in September 2009. After a system requirements review in January 2010 and a partial design review in May 2010, we have recently successfully completed the critical design review in December 2010, and remain on track for launch in December 2012. In June 2010, Orbital Sciences was selected to provide the launch vehicle, the Pegasus XL, the same rocket that put TRACE and a whole range of other small explorers (e.g., IBEX) into orbit. The Pegasus is dropped from an airplane that takes off from Vandenberg Air Force base in California.

Many mechanical and electronic parts, drawings and designs are being re-used from the successful TRACE, Hinode, SECCHI and AIA/HMI programs. For example, the IRIS telescope, built at SAO, is based on the design of one of the AIA telescopes. The spectrograph is being built by MSU and LMSAL, whereas NASA Ames will provide mission operations support. The data handling and pipeline will be based on the existing HMI and AIA data pipelines, with Stanford University playing a major role. Data will be downlinked through an X-band antenna at ground stations in Svalbard in Norway (funded by the Norwegian Space Centre) and in Alaska and other NASA sites.

The numerical modeling aspects are provided by a strong team of co-investigators, with major contributions from the University of Oslo. We have had several small-scale workshops to prepare 3D radiative MHD and non-LTE radiative transfer diagnostic codes for production runs. We plan to provide the synthetic observables and physical variables of various numerical simulation runs to the community after launch. This will be made available as part of the IRIS data archive, for which we have an open data policy.

More information about IRIS can be found at http://iris.lmsal.com/. If you have questions or comments feel free to contact Bart De Pontieu at bdp@lmsal.com.

High-Resolution Imaging of the 2010 Total Solar Eclipse at Easter Island

Craig Malamut, Wesleyan University '12, Muzhou Lu, Williams College '13
Prof. Jay M. Pasachoff, Williams College
eclipse@williams.edu

The focus of our research last summer was the solar corona. In order to study the solar corona, we traveled to Easter Island to take high-resolution photographs of the total solar eclipse. Using images taken throughout totality, we hope to better understand certain features of the corona.

Introduction

A total solar eclipse offers a rare and valuable opportunity to study the structure, composition and behavior of the solar corona. On a typical day, the Sun's photosphere outshines the faint corona a million to one, preventing any chance to collect data from the corona. Coronagraphs, such as the Large Angle Spectrometric Coronagraph (LASCO) aboard the Solar and Heliospheric Observatory (SOHO), block the brightest regions of the Sun, but can only study the outer corona. During a total solar eclipse, however, the Moon acts as an occulting disk, revealing all the regions of the corona and chromosphere.

On July 11, 2010, our team successfully observed a total solar eclipse from Easter Island, providing us with thousands of high-resolution images. We are working with Miloslav Druckmüller, Hana Druckmüllerová, and Wendy Carlos, all of whom have processed our images. The image processing has revealed fine details of the corona unseen by current satellites.

Preparation

In the weeks leading up to the eclipse, much preparation was needed to ensure a successful and organized trip. Due to shipping costs and limited manpower, we had to be selective in the equipment we would bring to Easter Island. We decided to take two tracking mounts, five tripods, four laptops, seven telephoto lenses, and seven cameras. Additionally, much of the equipment required a large amount of supplementary equipment including chargers, cables, and the like. In order to reduce the number of tripods, we had the Williams College machinist, Larry Mattison, construct a dovetail with twin tripod heads for the top of our telescope. In doing so, we were able to fit three cameras onto one tracking mount.

After collecting and shipping the equipment, we prepared the settings for the camera for eclipse day. We decided to operate three cameras manually and four with computer software. This way, if the computer software malfunctioned, we would still have images. For the computer software, we used the program Solar Eclipse Maestro designed by French amateur astronomer Xavier Jubier. With Solar Eclipse Maestro we were able to write scripts that would automatically change settings on our Nikon Digital Single-Lens Reflex (dSLR) cameras and take photographs at regular intervals. The software also calculated important information about the eclipse (e.g., umbral duration, time of maximum eclipse) based on our location and time. Miloslav Druckmüller of Brno University of Technology had designed scripts that we used, but the scripts took photographs for a total of one minute and thirty seconds. The duration of the Easter Island eclipse was four minutes and forty-five seconds, so we augmented the script.

We assigned one camera to each of our four laptops. We had learned from previous students and our own experiences that operating two or more cameras with one computer often resulted in skipped images. We also noticed during test runs that images taken too closely together would result in skipped images. A large part of the preparation of the scripts consisted of properly spacing out images in order to make time for the CCD to read out to the chip. We also used faster memory chips, on the order of 32 megabytes per second.

In addition to spacing our images apart, we also inserted a large variety of images with different parameters. To see all parts of the corona, one needs to take exposures of varying length (Figure 1). Shorter exposures capture the brightest, most interior parts of the corona, while underexposing the dimmer, outer regions. Conversely, longer exposures reveal the dimmer regions of the corona, while overexposing the bright inner corona. Therefore, the Druckmüller script had a large range of exposure lengths that would allow us to see all parts of the corona. Further, at the suggestion of Wendy Carlos, we included a finer variation in exposure lengths in an effort to see a smoother transition through the inner and middle regions of the corona. As a result, exposure lengths did not jump from 1/250 of a second to 1/500 of a second, but instead, from 1/250 to 1/300 to 1/400 to 1/500 of a second. We also added rapid bursts of photographs during second and third contact to capture the fleeting Baily's beads and diamond-ring effect. In case we had translucent cloud cover on eclipse day, we prepared a script that was exactly the same as the original script except it had four times the exposure length for each image.

Figure 1. Different exposure lengths reveal different parts of the corona. At the top, a picture of the corona with an exposure length of 1/500 second. Middle image has an exposure length of 1/125 second. Bottom image has an exposure length of 1/15 second.

Eclipse Day

Before sunrise on eclipse day we finally had a long enough period of clear skies to align one of our tracking mounts. We were not able to perfect the alignment, so during the eclipse, one of us had to regularly adjust the mount. Another person had to manually control the other mount through the duration of the eclipse. To ensure the mounts did not move and to reduce vibrations in the tripod, we wedged each leg into the ground. We also piled heavy pieces of concrete onto the base of the legs to further reduce vibrations.

The night before, we had run final tests of each of the four scripts. We had discovered that our Nikon D90's performed the best with Solar Eclipse Maestro (that is, they skipped the fewest pictures), so we put the three D90's on the best lenses. The Nikon D700 worked satisfactorily with Solar Eclipse Maestro, so we assigned it to the last computer-operated spot. The Nikon D200 and Nikon D3 were operated manually. For the manually operated cameras, we used two 600 mm f/4 Nikon lenses with teleconverters. One lens had a 1.4x teleconverter and the other had a 2x teleconverter.

Our location to observe on Easter Island was chosen for practical reasons. Though we would have liked the ideal shot of the eclipse shining above the iconic Moai statues, we needed a location with security, access to electricity, and minimal hazards. Unfortunately, the remote fields where the Moai were located did not meet those specifications. Instead, we set up in the backyard of our hotel.

During the eclipse, everything went very smoothly. The sky was partly cloudy, but fortunately, a large, cloudless patch passed over us during all of totality and most of the partial phases. We took dark frames, bias images, and flat fields both before first contact and after fourth contact. In the end, we had over 600 images of totality and over 3000 images altogether. We saved them in a Nikon RAW image file format called NEF (Nikon Electronic Format) and as high-quality JPEGs. We made sure to immediately create several backups on laptops and external hard drives.

After the Eclipse

While we were still on Easter Island, we sent a totality image to Steele Hill at NASA's Goddard Space Flight Center. He combined our photo with one from the Naval Research Laboratory's Large Angle and Spectrometric Coronagraph (LASCO) aboard ESA's Solar and Heliospheric Observatory (SOHO) and one in the 171 Å wavelength (Fe IX, ~10^6 K) from NASA's Solar Dynamics Observatory (SDO) to make a composite image (Figure 2). When the LASCO image of the outer corona and the SDO image of the photosphere are combined, they leave an annular gap that our totality image fills. All three photographs were taken at roughly the same time. Even with just the unprocessed image, one can clearly see features of the corona connecting across the images.

From the composite image, we can see mild activity in the solar corona. Four large streamers extend from the sides of the Sun. Compared to last year's eclipse images, there seems to be more activity, suggesting that the Sun is coming out of solar minimum. This evidence is further supported by flash spectroscopy done by Greek astronomers Aris Voulgaris, Thanasis Economou, and John Seiradakis showing stronger Fe XIV lines than in the 2009 total solar eclipse. Stronger Fe XIV indicates a hotter corona (>10^6 kelvins). Images taken immediately after second contact and before third contact show the thin, reddish chromosphere. From those images, we can clearly see several prominences protruding from the chromosphere (Figure 3).

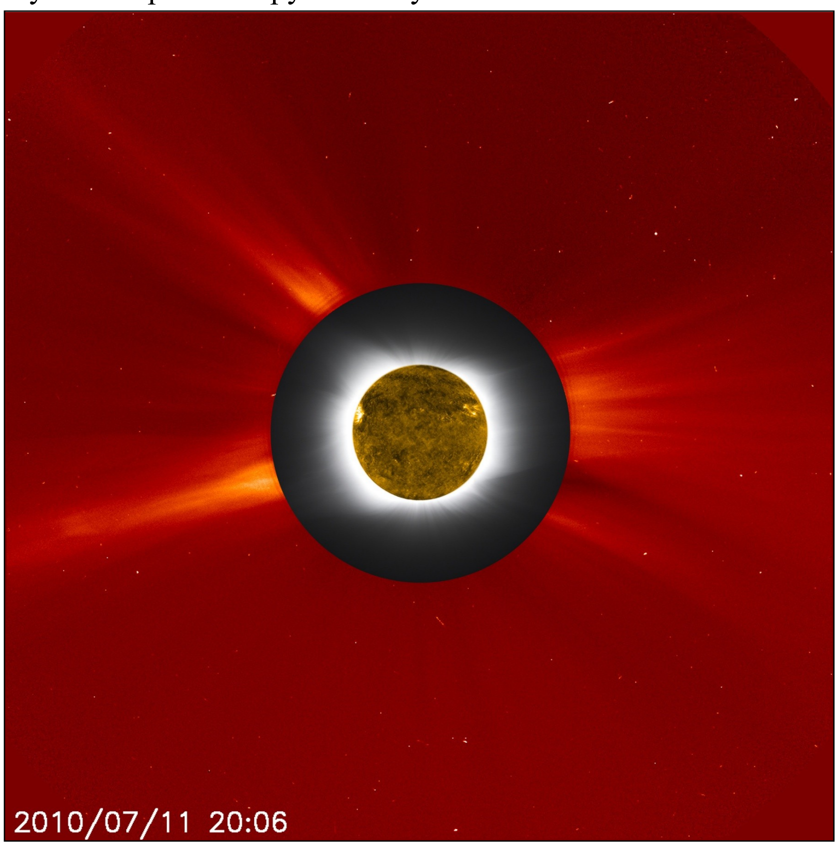

Figure 2. Steele Hill of NASA's Goddard Space Flight Center created a composite of our photo with one from the LASCO aboard SOHO around it and one from SDO in the 171 Å wavelength (Fe IX, ~10^6 K) covering the dark lunar disk. Our image is the black and white annulus near the center of the composite image.

Upon returning from the expedition, we sorted through the images and sent the appropriate files to Miloslav Druckmüller, Hana Druckmüllerová, and Wendy Carlos. The image processing has been completed and appears in Figure 4. We have compared our processed data with images from past solar eclipses and with near-simultaneous images from solar spacecraft. We compared our images with images taken the same day but in a different place along the path of totality to see coronal changes over the 90-minute interval.

Figure 3. Above is an image of the chromosphere taken right before second contact. The white bulge in the center is the diamond in the diamond-ring effect produced when sunlight passes through a single valley in the Moon's edge. The pink area is the chromosphere, a thin, gaseous envelope immediately above the photosphere. To the right and left of the "diamond," two reddish prominences are visible extending from the chromosphere.

Acknowledgments

We would like to thank Prof. Jay Pasachoff, who organized this expedition and made this research possible. Thank you to Xavier Jubier, Miloslav Druckmüller, Hana Druckmüllerová, Wendy Carlos, Caroline Ng, Larry Mattison, Mark Sood, and Edgar Hereveri for their advice and help along the way. Thank you to Edilia Cerda of the Cerro Tololo Inter-American Observatory and 1080 for assisting in shipping, National Geographic for lending lenses, and Nikon Professional Services and Jim Lillie of Williams College's Office of Information Technology for the camera loan. We also thank Williams College, Wesleyan University, the Keck Northeast Astronomy Consortium, and NASA's Massachusetts Space Grant for funding our research.

An early version of this article appeared in the proceedings of the Keck Northeast Astronomy Consortium Student Research Conference," where KNAC includes the following 8 small colleges: Williams, Wesleyan, Wellesley, Middlebury, Colgate, Vassar, Haverford, and Swarthmore. Malamut was a visiting summer fellow at Williams College as part of KNAC's NSF REU program.

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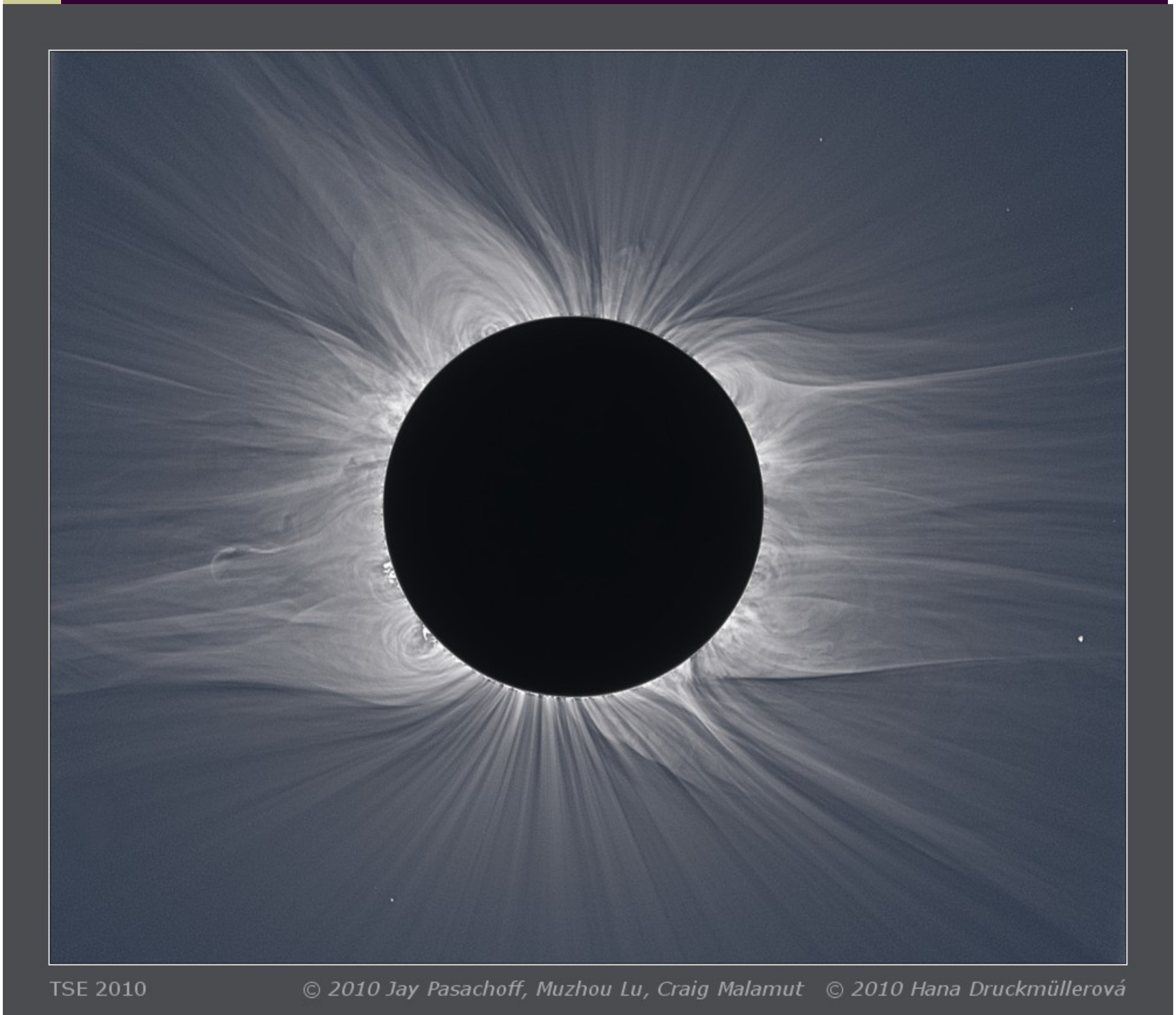


Figure 4. From the July 11, 2010, total solar eclipse viewed from Easter Island, a composite of several dozen images, selecting various appropriately exposed parts of widely bracketed eclipse images to cover a dynamic range of over 1000 in brightness. (Computer composite by Hana Druckmüllerová from images by Muzhou Lu and Craig Malamut with Jay M. Pasachoff)

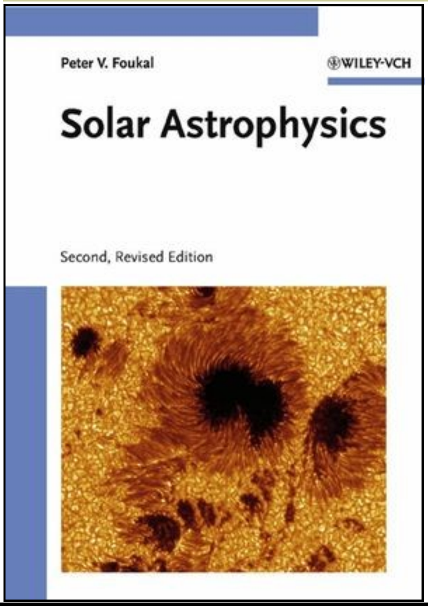
Cover Image: A montage of partial eclipse images taken through an ND5 neutral-density filter and an unfiltered, single totality image. (Images by Muzhou Lu and Craig Malamut with Jay M. Pasachoff).

This research was since published in *ApJ*: *The Astrophysical Journal*, 734:114 (10pp), 2011 June 20

Structure and Dynamics of the 2010 July 11 Eclipse White-Light Corona

J. M. Pasachoff, V. Rušin, H. Druckmüllerová, M. Saniga, M. Lu, C. Malamut, D. B. Seaton, L. Golub, A. J. Engell, S. W. Hill, and R. Lucas

New and Recent Books

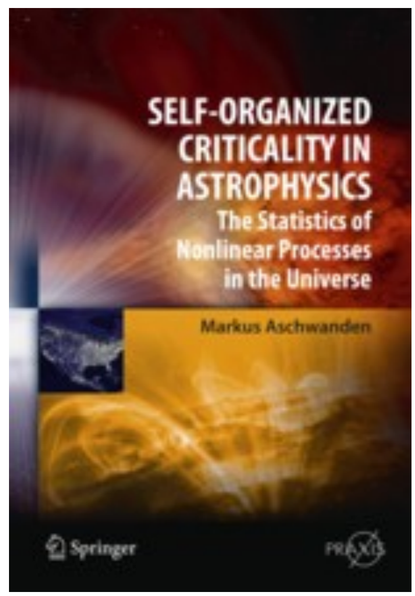


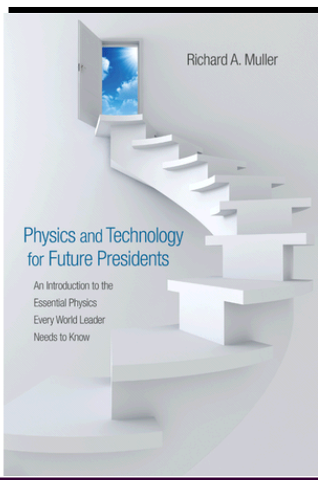
Solar Astrophysics 2nd Revised Edition *by Peter V. Foukal*
ISBN-13: 9780521861496 May 2004 (Wiley)
http://www.wiley.com/WileyCDA/WileyTitle/productCd-3527403744.html

This revised edition describes our current understanding of the sun -- from its deepest interior, via the layers of the directly observable atmosphere to the solar wind, right out to its farthest extension into interstellar space. It includes a comprehensive account of the history of solar astrophysics, along with an overview of the key instruments throughout the various periods. In contrast to other books on this subject, the choice of material deals even-handedly with the entire scope of important topics covered in solar research. The author makes the advances in our understanding of the sun accessible to students and non-specialists by careful use of relatively simple physical concepts. An incisive, reliable, and well-structured look at all that is fascinating and new in studies of the sun.

Note: a 3rd edition is in preparation for late 2012.

***Self-Organized Criticality in Astrophysics* The Statistics of Nonlinear Processes in the Universe** *by Markus Aschwanden*
ISBN: 978-3-642-15000-5 1st Edition: Jan. 2011 (Springer)
http://www.springer.com/astronomy/book/978-3-642-15000-5
The concept of 'self-organized criticality' (SOC) has been applied to a variety of problems, ranging from population growth and traffic jams to earthquakes, landslides and forest fires. The technique is now being applied to a wide range of phenomena in astrophysics, such as planetary magnetospheres, solar flares, cataclysmic variable stars, accretion disks, black holes and gamma-ray bursts, and also to phenomena in galactic physics and cosmology. Self-organized Criticality in Astrophysics introduces the concept of SOC and shows that, due to its universality and ubiquity, it is a law of nature. The theoretical framework and specific physical models are described, together with a range of applications in various aspects of astrophysics. The mathematical techniques, including the statistics of random processes, time series analysis, time scale and waiting time distributions, are presented and the results are applied to specific observations of astrophysical phenomena.
Students can contact the author regarding how to obtain his books.



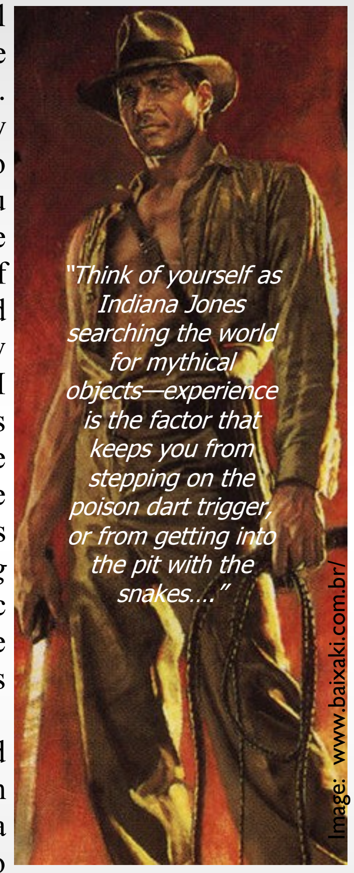


***Physics and Technology for Future Presidents* An Introduction to the Essential Physics Every World Leader Needs to Know** *by Robert A. Muller* ISBN: 9780691135045 (Princeton Univ. Press)
http://press.princeton.edu/titles/9226.html
Text for a renowned university class at UC Berkeley:
http://physics.berkeley.edu/academics/Courses/physics10/teaching/Physics10/PffP.html
From the physics of energy to climate change, and from spy technology to quantum computers, this is the only textbook to focus on the modern physics affecting the decisions of political leaders and CEOs and, consequently, the lives of every citizen. How practical are alternative energy sources? Can satellites really read license plates from space? What is the quantum physics behind iPods and supermarket scanners? And how much should we fear a terrorist nuke? The book explores critical physics topics: energy and power, atoms and heat, gravity and space, nuclei and radioactivity, chain reactions and atomic bombs, electricity and magnetism, waves, light, invisible light, climate change, quantum physics, and relativity. Muller engages readers through many intriguing examples, helpful facts to remember, a fun-to-read text, and an emphasis on real-world problems rather than mathematical computation.

Be Prepared For the Most Spectacular Show Off Earth - A Charge To The Next Generation

Scott McIntosh (mscott at ucar.edu)

It's time to strap yourself in. Be prepared for the rollercoaster ride that is the life of a research scientist. One that is filled with self-doubt, frustration, confusion, and lots of writing - but enough of the good stuff. The massive job you have in front of you is to learn how to navigate the massive hyper-dimensional space of theory, observation, data analysis, and instrumentation, while staying alive to fight another day. As if that weren't enough, you will also have to learn to how to keep your chin up (physically and motivationally), as well as maintain the ability to look forward in the face of adversity. Of course, there's always a catch; much of these "skills" only come by experience.



Think of yourself as Indiana Jones searching the world for mythical objects - experience is the factor that keeps you from stepping on the poison dart trigger, or from getting into the pit with the snakes....hold on. It is something that can only develop over time. With practice, and largely through the trial and error of making some wrong turns, you will learn to realize when you are heading down the wrong path (hopefully before you have a huge metaphorical boulder crashing down on you). As someone that started off working largely on theory - there is not much observing of the Sun from the west of Scotland - that migrated into data analysis and interpretation by way of simulation, I can tell you from experience how important it is to find what you enjoy and where your strengths are. I realized quickly that I enjoyed the challenge of figuring out what I was seeing, fathoming out what the photons were telling us about the underlying physics and challenging the prevailing "wisdom" of the literature. Now, with *STEREO* imaging the other side of the Sun, *Hinode*'s amazing detail, the *SDO* image tsunami, and the *Interface Region Imaging Spectrograph* (*IRIS*) to come, the wealth of breakthrough scientific observations of our star are coming thick and fast, and you are the vanguard of your generation. It is your turn to figure out what the photons are telling us - and to rewrite what we think we know.

Early in my ride I remember being criticized for being too broad, and that I worked on too many apparently disparate projects (nothing much has changed really - just look at my publication list). There was a profound concern that I'd get lost, not get enough papers out, and fail to land that next post-doc position. At that time I was lucky enough to have a position in NCAR's Advanced Study Program (ASP) that has the remit to explore on your own - with all of the pitfalls too - and I took full advantage of that to change the direction of my research from UV/EUV spectral diagnostics and the "Differential Emission Measure" problem to study something that really caught my interest - the chromosphere. Why did (almost) nobody study this weird spiky part of the Sun's atmosphere? I found out fast. The chromosphere is a massively complex

> ***"I can tell you from experience how important it is to find what you enjoy and where your strengths are."***

interface between the photosphere and corona where the hydrodynamic forcing of the convective interior and magnetism of the corona meet and, as a result, almost anything can happen. So, to cut a long story short, with me being a competitive person, and always up for a challenge, I decided that I wanted to look at chromospheric waves in the quiet sun and sunspots to use them as a probe of the plasma that they travel through.

One thing led to another, I left NCAR for a European Space Agency post-doc at GSFC where I also worked as a scientific planner for *SOHO*. This exposed me to how missions work, brilliant project scientists, more enthusiastic and imaginative young scientists, and some very different scientific ideas. A later stay at Southwest Research Institute in Boulder taught me the skills of mission building and proposal writing - another of the essential survival skills in our field, and one that in the current funding climate is even more important. On the research front we soon started to learn a great deal about the behavior of the different flavors of chromospheric waves and how some of them tied to the constantly evolving magnetic field. Indeed, we soon identified that the low-frequency waves appeared to relentlessly turn on and off around the strong magnetic concentrations of the supergranular network in what we called "acoustic portals." The portals turned out to be (thanks to some great work by friends) the signature of something observed since long before anyone even knew that the Sun had a corona; spicules. I recall spicule being considered a dirty word when I first heard it in the community, and some of that attitude persists, irrespective of the indications in contemporary data.

At the same time I had something of an epiphany, the process switching the waves off and on was the relentless emergence, transport and reconnection of the "magnetic carpet." It was truly a ubiquitous (one of my catchwords) process occurring all over the Sun, all of the time - it was about the same time that we coined a phrase "you can't turn this sh&t off!" to describe what we were seeing. This spawned our current investigation of energy transport into, and through, the chromosphere and while acoustic portals didn't have the energy to the solve THE problem (heating the corona) we did learn a lot.

With the launch of *Hinode* we rapidly noticed that the magnetic network, seen in relief against the limb, had a different kind of spicule, what is now known as a "Type-II" spicule, because it was finer, faster, taller (in coronal holes at least), and faded quicker than its sibling. We thought that the very rapid fading was a signature that these things got heated through the Calcium passband very quickly (of the order of 10 seconds). Following these observational clues that type-II spicules were something *really* different, we started to think about what their signature in the upper atmosphere might look like. Soon we identified a weak, high-velocity asymmetry of UV and EUV line profiles seen in magnetic network and plage regions through emission lines formed at transition region and coronal temperatures. The properties of the line profile asymmetries qualitatively matched where, when, and what we saw in the distribution of Type-II spicule properties - see, that experience with UV spectroscopy came in handy! Prior to the launch of *SDO* we were able to use *TRACE, Hinode/XRT,* and *STEREO* imaging observations to compare these spectral diagnostics with weak propagating disturbances (rooted in the same magnetic regions as the Type-IIs) that travel into the coronal at a broad range of temperatures and at very similar speeds. Based on these imaging observations, we had a strong hunch of what we might see with the increased cadence, improved signal-to-noise, and reduced scattered light of *SDO's* Atmospheric Imaging Assembly (AIA). It was a matter of biding our time, and that was a nerve-wracking launch! After a few weeks of engineering operations we got a chance to run our joint *SDO*/*Hinode* observing sequence and soon we had identified the one-to-one relationship between Type-II spicules, spectral asymmetries, the heating and insertion of plasma into the corona - appearing as the propagating disturbances in the coronal images. I make it sound easy, but many, many (often frustrating) hours went into the initial analysis of the combined data sets. While this is a really exciting development, and a ground-breaking look at the coupled energetics of the solar atmosphere many things remain unknown about this process like: what is driving and heating the plasma that appears as a Type-II spicule? and what happens to the inserted hot plasma? Just the first of these issues is bound to keep us busy for some time, but you can bet we'll let the observations and our intuition be the guide.

So, what is the message? Here are the basics. You don't know where you are going, or how you are going to get there. Heck, I don't know where I am going, I just follow my instinct and the little observational clues that experience allows me to connect. It is not a bad thing to take on (too) many projects - who knows if, or when, they will recombine. Follow your instinct, don't accept the prevailing wisdom. If you head towards the abyss, learn from it. If you make a positive step, store it, learn from it and think about the next step up that hill.

"Follow your instinct, don't accept the prevailing wisdom."

Fortunately for you, we are at a time when we are spoiled with detailed observations of our Star, when the Sun and solar activity have a new perspective in the eye of the general public (thanks in no small measure to *SOHO* and *SDO*), and when the coupling of the different layers of the solar atmosphere is becoming increasingly obvious, and harder to blissfully ignore - just like the chromosphere was only 10 years ago! Think about the Sun's atmosphere as an interconnected system. You're gonna have to probe it with observations and analysis from a host of different platforms in combination with detailed numerical modeling to complete the physical picture. Just remember that the inter-connectivity of this system is going to affect all manifestations of solar activity at some level, from the continuous mass and energy supply to the corona and solar wind, through to CME initiation and passage into the heliosphere. Bottom line, challenge the literature, follow your instinct and the clues that the Sun presents - you can't fail without gaining vital experience - and here is your warning to strap in, because it might be a bumpy ride! Good luck!

Thanks to my wife and kids for putting up with me, my many collaborators, colleagues, and friends that have helped and worked with me over the years, but especially to (and in no particular order) Bart De Pontieu, Stuart Jefferies, Bob Leamon, and Steve Tomczyk.

Solar Physics at the Max-Planck Institute for Solar System Research, Germany

Hannah Schunker, Thomas Wiegelmann, Sami Solanki

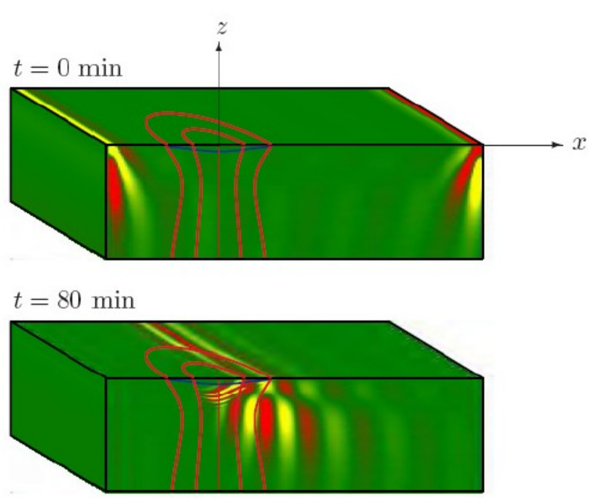
Solar research

The Max Planck Institute for Solar System Research (MPS) does exactly what its name says, study the various bodies of the solar system. Since 98% of the solar system's mass lies in the Sun, our host star gets a lot of attention, with almost all aspects of the Sun being scrutinized. Currently, a total of approximately 70 scientists, of which 20 are PhD students, are happily investigating the Sun at the MPS (about the same number of scientists at the MPS are taking care of all the other bodies of the Solar System). These numbers are set to grow in the next few years as efforts to investigate the Sun's interior are intensified.

Topics of research cover the entire Sun and current research programs include, but are not limited to: studies of the solar interior (using helioseismology and MHD simulations), solar atmosphere, solar magnetic field, Heliosphere, solar radiation and energetic particles and their influence on Earth, cosmic radiation and the physics of Sun-like stars. MPS scientists lead the development of space-, balloon-borne and ground based instruments. They are also involved in international observing campaigns and carry out intensive data-analysis, numerical modeling and theory in the areas of solar and stellar magnetohydrodynamics, solar plasma physics, corona modelling as well as solar variability and climate.

The Solar group has a long history in developing instrumentation for, e.g., ULYSSES (1990), SOHO (1995), STEREO (2006) and SUNRISE (2009). Currently the group runs the German Data Centre for the Solar Dynamics Observatory (SDO) and is heavily involved in future missions such as SOLAR ORBITER and PLATO.

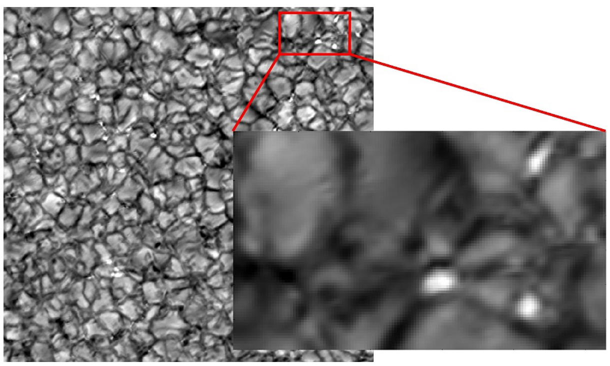
Recent research highlights



Sunspot Seismology

The subsurface structure of sunspots and the subsurface flows in solar convection are strongly constrained using helioseismology. The picture shows snapshots from a numerical simulation of a wavepacket (shades of red, green and yellow) propagating through a model sunspot whose magnetic field is outlined by the red curves. Recent progress in helioseismology at the MPS are summarized in Gizon et al.: 'Local Helioseismology: Three-Dimensional Imaging of the Solar Interior', 2010, ARAA, 48, 289

Sunrise



The Sun's magnetic building blocks have been fully resolved with the balloon-borne mission Sunrise, the largest solar telescope ever to leave the Earth's surface. It was launched in June 2009 from ESRANGE Space Center in Kiruna (Sweden-upper picture). The helium balloon holding one million cubic meters of gas lifted the solar observatory into the sky up to a height of 37 kilometers.

The bottom picture shows surface granulation, and bright points (inset), with a diameter of about 100 km observed with the Sunrise/IMaX instrument. Sunrise fully resolved the magnetic field in such structures allowing new insights into energy transport into the upper atmosphere along such features.
First results of the Sunrise-mission have been recently published in a special issue of Astrophysical Journal Letters. For an overview about the mission and introduction to the science results see: Solanki et al.: 'SUNRISE: Instrument, Mission, Data, and First Results', 2010, ApJ, 723, L127. A re-flight of Sunrise is planned for 2012.

Graduate school and career opportunities

The MPS provides excellent research conditions and career opportunities for interested graduate students and Postdocs and regularly offers competitive fellowships for both. The research program for PhD-students is associated with a 3-year-PhD course within the International Max Planck Research School on Physical Processes in the Solar System and Beyond run in close cooperation with the universities of Braunschweig and Göttingen. The teaching language is English. The program starts each January and the review of applications begins July of the preceding year. So far 95 students from 40 countries have received their Doctorate since the graduate school was founded in 2002. A number of MPS PhD students and Postdocs were awarded scientific prizes and hold attractive positions in different parts of the world.

If you have questions please contact:

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Dieter Schmitt schmitt@mps.mpg.de (for the Graduate School)

The Institute

Left: Current institute building.

The institute is situated among rolling hills (top left picture), but plans are afoot to move into a brand new building (bottom right picture) now being designed, which will be located next to the physics department of the University of Göttingen about 30 km from the current location. This bustling and picturesque town with its beautiful historical centre is well known for hosting the highest density of Nobel laureates in the world. The MPS is one of over 80 Max Planck Institutes in Germany constituting the Max Planck Society, which is considered to be one of the best research institutions worldwide.

Below: New institute building (winning design).
The institute will move here in 2014.

Left: The 'Gänseliesel' in Göttingen. It is a tradition that PhD students kiss this girl after graduating.

Links for further information:

Max-Planck-Institute for Solar-System Research: 'http://www.mps.mpg.de/en/'

Solar Department: 'http://www.mps.mpg.de/en/forschung/sonne/'

Graduate School: 'http://www.solar-system-school.de/'

The Solar Magnetic Cycle: Past, Present, and Future

A very short review (from the point of view of a kinematic dynamo modeler) on what we know, how we came to know it, and how we are using it to predict what comes next

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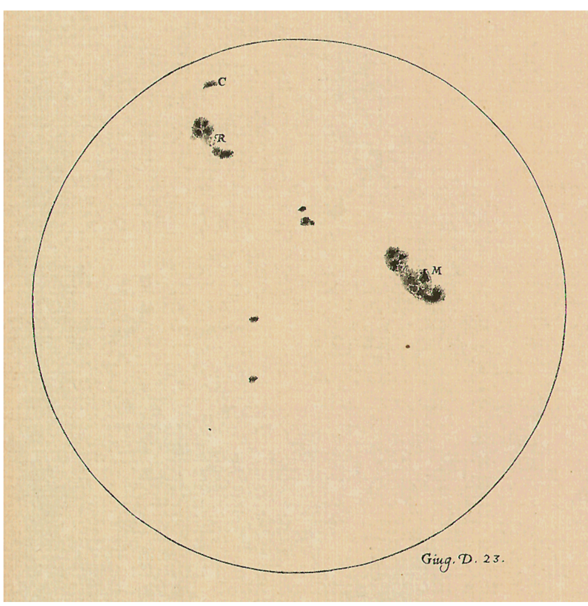
amunoz@cfa.harvard.edu

Introduction

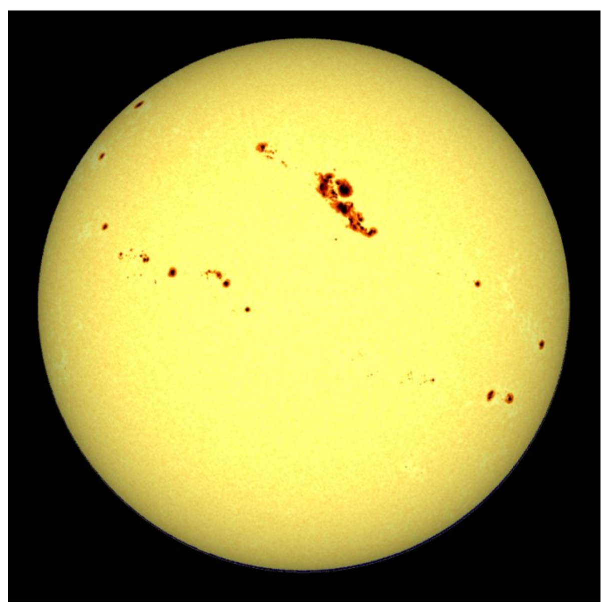
Since the dawn of time the Sun has been an object of fascination for mankind. Giver of life, light and heat -- its worship as a deity has been part of most of the major polytheistic religions of the world. During much of our history, the Sun was considered to be constant and immutable, but this is not really the case – in reality, the Sun is a fascinating physical object with a rich variety of phenomena spanning all kinds of time and length-scales. Having to choose among them, I decided to write a short review focusing on the solar cycle: the nearly decadal process which takes the Sun from a quiet period into an increasingly active phase and back, defining almost completely the dynamics of the interplanetary environment.

Main Characteristics: A Historical Perspective

The first step towards the discovery of the solar magnetic cycle was the observation of sunspots. Although the first recorded indication of sunspot observation goes as far back as 27 B.C. by Chinese astronomers, it was not until the invention of the telescope that detailed observations were performed by Galileo Galilei, Thomas Harriot, and Christoph Scheiner, David and Johannes Fabricius. Once sunspots had been observed, it was only a matter of time before improvements of the telescope setup and tracking mechanism would allow for fairly accurate drawings of them (see Fig. 1).



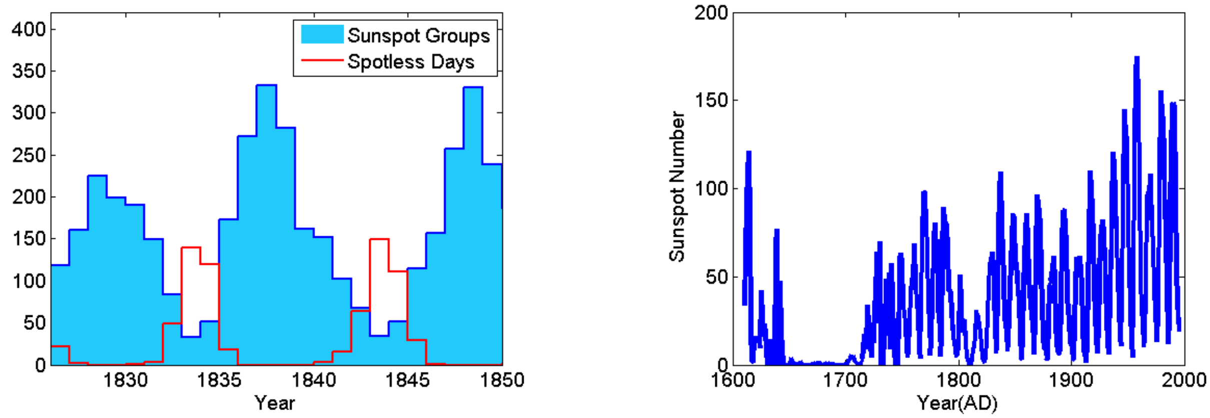
(a)



(b)

(a) Original sunspot drawing by Galileo Galilei. Image taken from The Galileo project. (b) SOHO/MDI white light image of the Sun.

The next step was the discovery of the cycle itself by Samuel Schwabe (1844). Schwabe was trying to find whether there was a planet inside Mercury's orbit (tentatively called Vulcan). He believed that by carefully observing the Sun and keeping track of sunspots, Vulcan could be observed while in transit. Although the search for Vulcan was not fruitful, after more than two decades of observation Schwabe noted the nearly decadal periodicity of the number of sunspots present at any given time on the surface of the Sun (see Fig. 2-a). After looking at historical records and expanding our sunspot database, we now know that there is also an important amount of inter-cycle variation (both in terms of cycle amplitude and duration; see Fig. 2-b).



(a) (b)

Figure 2. (a) Graphic representation of Schwabe's original data (1844) showing three sunspot cycles and their associate minima. (b) Smoothed sunspot number during the last 400 years. Besides the nearly decadal oscillations, it's clear that not all cycles have the same amplitude or duration.

Soon after the discovery of the sunspot cycle, Richard Carrington (1858) noted the equatorward migration of the latitude of emergence of sunspots with the progress of the cycle, starting from mid-latitudes – result which was further refined by Gustav Spörer (1861). The best way of visualizing this characteristic was first introduced by Edward and Annie Maunder (1904) and involves plotting sunspot locations for each solar Carrington rotation and stacking such plots in time (Fig. 3), this synoptic map (also known as butterfly diagram because of the distinct pattern formed by sunspot migration) is one of the chief observational constraints for models of the solar cycle.

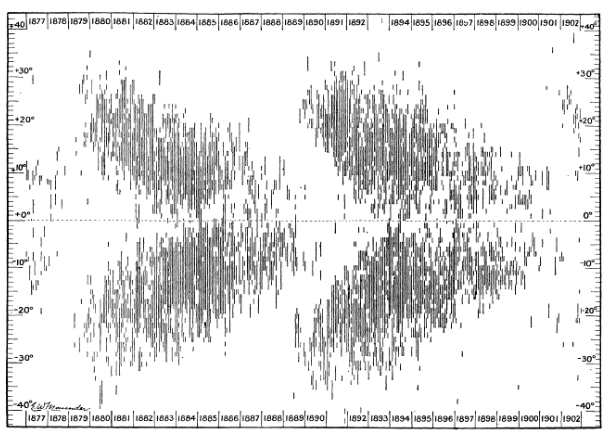
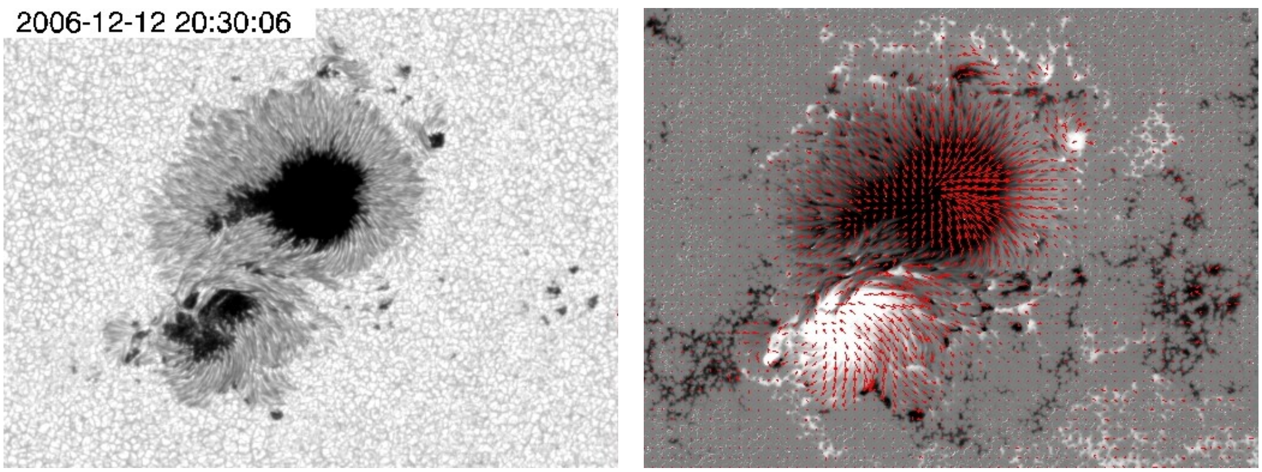


FIG. 8.—DISTRIBUTION OF SPOT-CENTRES IN LATITUDE, ROTATION BY ROTATION. 1877–1902.

Figure 3. Butterfly diagram published by Edward and Annie Maunder (1904) showing the equatorward migration of active latitudes as the cycle progresses. This process begins anew each cycle, with the first sunspots of the cycle appearing at mid-latitudes.

The magnetic nature of the solar cycle was finally discovered by George Hale (1908) using spectral line splitting in the presence of strong magnetic fields (commonly known as Zeeman effect; Zeeman 1897); thanks to this phenomenon, and by comparing the line splitting measured on the Sun with laboratory experiments, Hale was able to estimate the strength of the magnetic field inside sunspots. Furthermore, after devising a way of measuring the line of sight component of the magnetic field, Hale observed that sunspot groups are really large scale bipolar regions (also known as Active Regions due to their correlation with large releases of energy in form of flares and coronal mass ejections; ARs). This typical magnetic configuration is shown in Fig. 4, where we can see a white light image showing two sunspots (Fig. 4-a) and their associated magnetic field (Fig. 4-b) as measured by the Solar Optical Telescope aboard the *Hinode* spacecraft.



(a) (b)

Figure 4. (a) White light image taken by *Hinode*/SOT showing two sunspots. (a) Vector-magnetogram of the same region showing the bipolar nature of the associated sunspots. White (black) corresponds to positive (negative) line of sight polarity. The little red arrows show a calculation of the field components perpendicular to the line of sight. Images taken from the *Hinode* website.

Hale and his collaborators also discovered that most ARs have the following properties (Hale et al. 1919):

- The magnetic field of most active regions of a given hemisphere has the same East-West orientation and this orientation reverses across the equator (commonly known as Hale's law).
- Active regions present a systematic tilt with respect to a line parallel to the equator such that the leading (east-most) polarity is closer to the equator (commonly known as Joy's law).
- The polarity of active regions (and the Sun's global magnetic field) reverses from cycle to cycle, such that two sunspot cycles correspond to a full magnetic cycle.

Presently, after several decades of surface magnetic field observations, we have accumulated a wealth of information about the solar magnetic cycle and its main characteristics. These characteristics are beautifully captured in the magnetic butterfly diagram (see Fig. 5), obtained by averaging the surface magnetic field in longitude for each Carrington rotation and stacking the averages in time. Reproducing this magnetic butterfly diagram is a necessity for any model of the solar magnetic cycle.

For more details on the solar cycle, its discovery and its characteristics please refer to the review by Hathaway (2010).

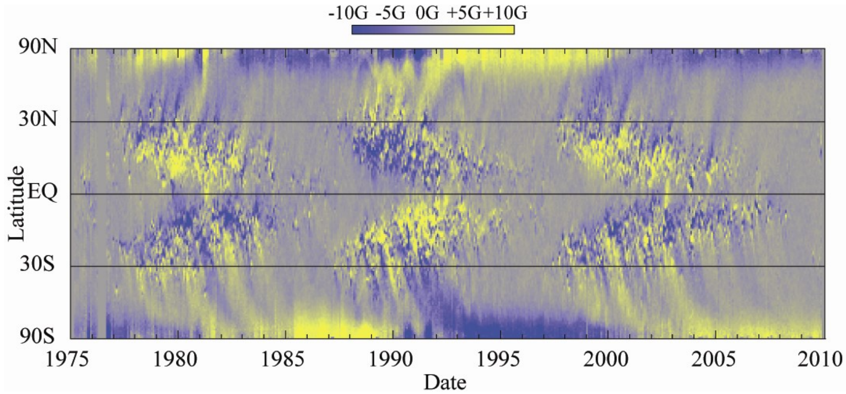


Figure 5. Longitudinally averaged magnetic field at the surface of the Sun. Yellow (blue) represents positive (negative) magnetic polarity. This 'Butterfly Diagram' captures the essential characteristics of the solar magnetic cycle: Emergence of active regions (sunspots) which migrates towards the equator as the cycle progresses, transport of diffuse magnetic field towards the poles, and polarity reversals from cycle to cycle and across the equator. Image courtesy of David Hathaway.

Kinematic Dynamo Models as Tools for Understanding the Solar Cycle

Current understanding of the solar magnetic cycle has been achieved through the use of different models (each with its own strength and weaknesses). The most prominent types are kinematic dynamo models (see review by Charbonneau 2010), surface flux-transport simulations (see review by Sheeley 2005), thin flux-tube simulations (see review by Fan 2009) and full Magneto-Hydrodynamic simulations of the Solar Convection Zone (see review by Miesch 2005). In this review I will focus on kinematic dynamo models because (on top of them being my field of expertise) they give us the most holistic picture of the different stages of the cycle.

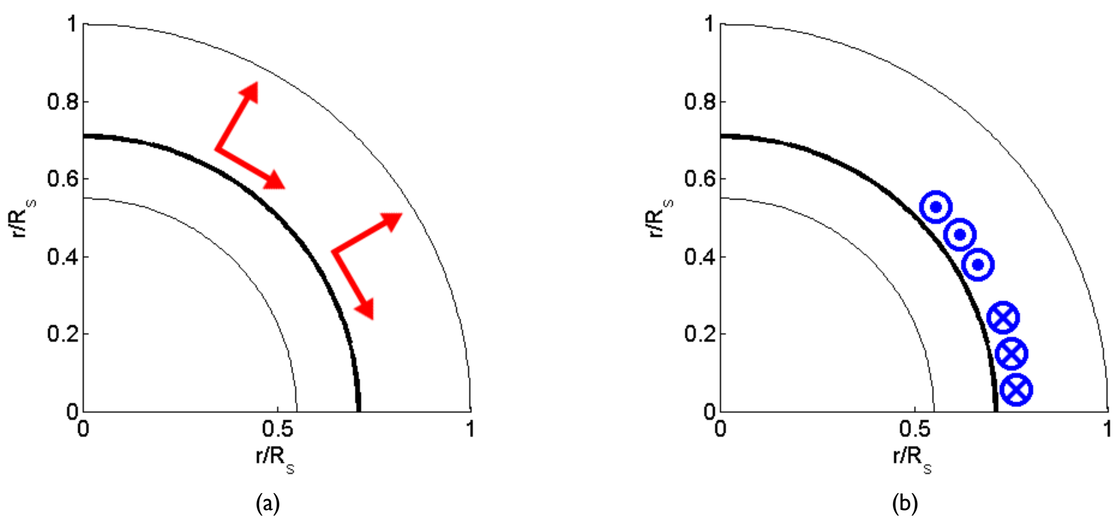


Figure 6. Important terminology: (a) The poloidal components of a field are those confined to the meridional plane, B_r and B_q. (b) The toroidal component is normal to the meridional plane, B_f (i. e., in the direction of rotation).

In order to understand the solar cycle, kinematic dynamo models use a prescribed set of physical ingredients, mainly related to plasma motions inside the convection zone (hence the name kinematic), to evolve the large-scale magnetic cycle with time. These ingredients are:

- **Differential Rotation:** Its basic characteristics are the fast rotation (smaller period) of the equator with respect to the poles and the solid body rotation of the radiative region at a rate somewhere between those of the equator and the poles (see Fig. 7-a). It is believed to be the main source of energy for the solar magnetic cycle because it shears the large-scale poloidal magnetic field of the Sun (poloidal means field confined to the meridional plane, B_r and B_q; see Fig. 6-a), to create the strong toroidal belts (toroidal means normal to the meridional plane, B_f; see Fig. 6-b) from which active regions emerge.

- **Meridional Flow:** Measured only in the top 10% of the convection zone as a predominantly poleward flow, it is commonly defined as a single cell flow in dynamo modeling – with poleward flow in the top half of the convection zone and equatorward flow in the bottom half (see Fig. 7-b). It is believed to be responsible for setting the speed of the migrating toroidal belts at the bottom of the convection zone, from which sunspots emerge, giving shape to the wings of the butterfly diagram. It also plays, in combination with turbulent diffusivity, an important role in setting the period and amplitude of the cycle, as well as determining the nature of surface magnetic field dynamics (affecting the amount of flux cancelation across the equator and flux accumulation at the poles).

- **Turbulent Diffusivity:** This ingredient captures the diffusive effect that convective turbulence has on the large scale magnetic field. It sets the properties of the transport process in combination with the meridional flow, helping determine the amplitude and period of the cycle as well as defining the characteristics of surface magnetic field dynamics.

- **Poloidal Field Source:** magnetic source mainly responsible for the recreation of the poloidal field from which the solar cycle starts. There are several mechanisms which could be playing such a role. Among others, we have the interaction of the large scale toroidal field with helical convective motions (the mean-field a-effect; Parker 1955), the emergence and decay of tilted bipolar Active Regions (Babcock-Leighton mechanism; BL; Babcock 1961; Leighton 1969), the propagation of magnetostrophic waves (Schmitt 1987), and rotational instabilities in the interface between the convection and radiative zones (also called tachocline; Dikpati and Gilman 2001).

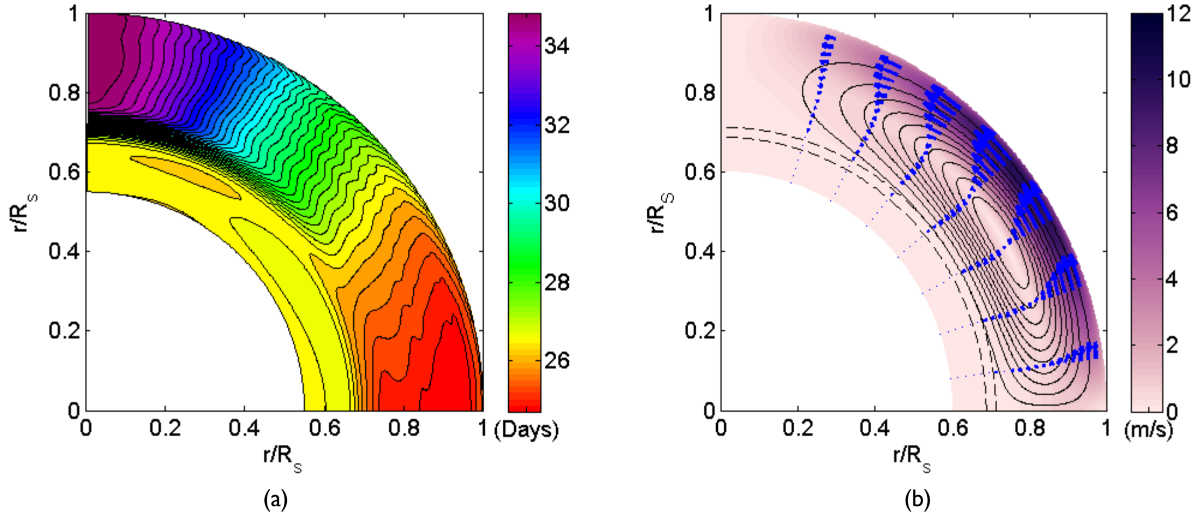


Figure 7. (a) Solar Differential rotation period. Different colors mark the time it takes for a particular layer to perform one revolution around the rotation axis. The most important characteristics are an equator which rotates faster than the poles, a core which rotates almost uniformly and a region of strong shear in the interface between the radiative and convection zones (commonly referred to as the tachocline). (b) Solar Meridional circulation. Arrows mark the direction and amplitude of the flow, colors show the amplitude of the flow, and contours highlight the streamlines followed by the plasma. Data taken by the Global Oscillation Network Group (GONG): differential rotation data courtesy of Rachel Howe and meridional flow data courtesy of Irene González-Hernández.

The Solar Magnetic Cycle: Current Understanding

In a nutshell, the solar magnetic cycle is a process in which the magnetic field switches from a configuration which is predominantly poloidal (confined to the meridional plane, B_r and B_q; see Fig. 6-a) to one which is predominantly toroidal (normal to the meridional plane, B_f; see Fig. 6-b) and back, drawing on the available energy in solar plasma flows. This transfer of energy is possible thanks to the nature of the solar plasma: due to its high conductivity (low resisitivity) and the length-scales involved, the interaction of the magnetic field with the plasma flows is more important than the dissipation of the field due to ohmic losses; this has as a consequence that the magnetic flux is conserved or “frozen” in the moving plasma (Alfvén 1942).

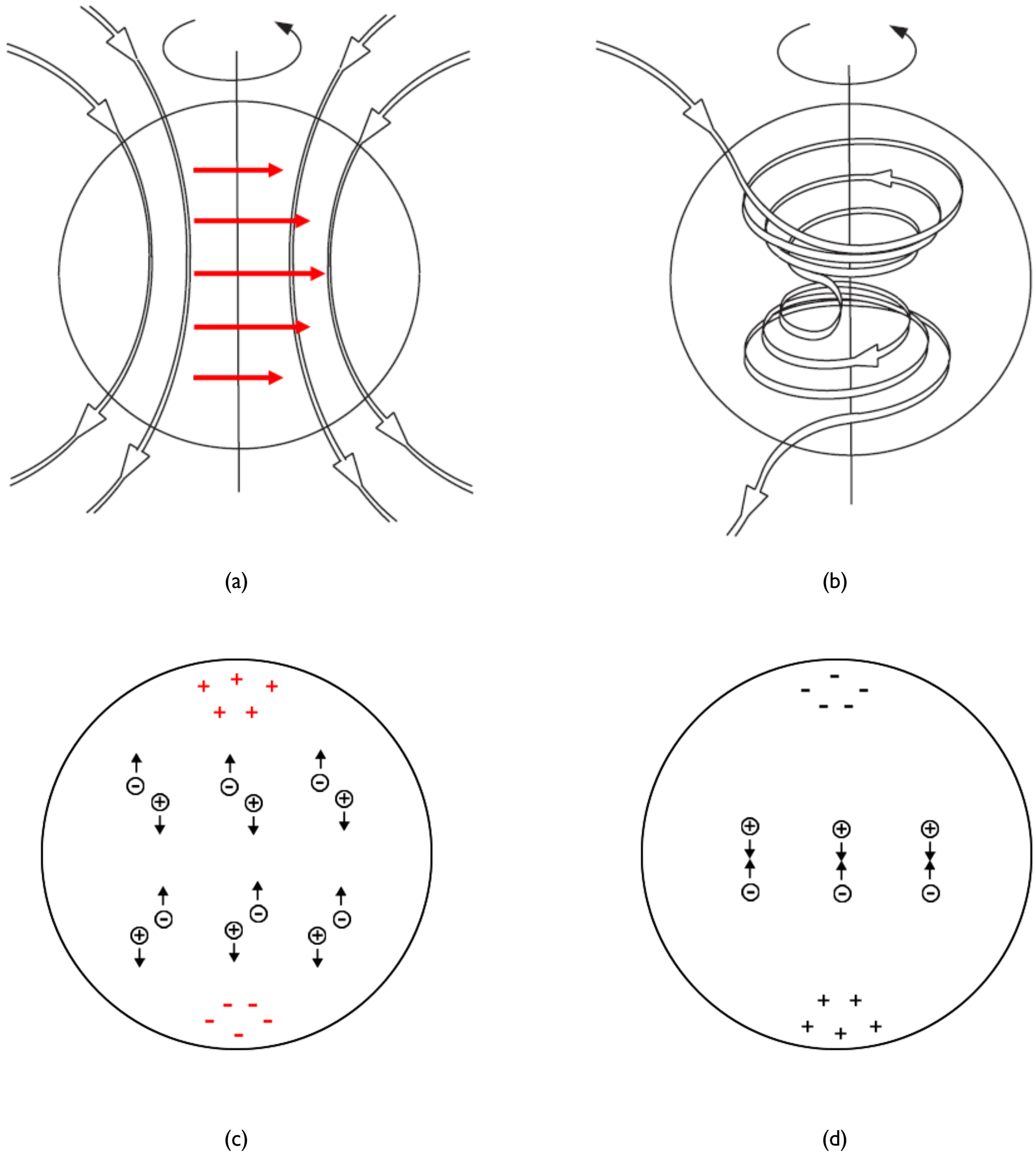


Figure 8. Phases of the solar magnetic cycle. The cycle starts with the shearing of a large scale dipolar field by differential rotation (a), producing a series of strengthened toroidal belts (b). These belts become buoyantly unstable giving rise to the eruption of flux-tubes, which are imparted a systematic tilt by the Coriolis force as they rise through the convection zone. Eventually, these flux-tubes pierce the surface in the form of tilted bipolar active regions (c), where they are acted upon by meridional flow and turbulent convection, resulting in cross-equatorial cancelation and polar accumulation of flux (d). The accumulation of net flux at the poles cancels and reverses the old solar dipole moment and sets the stage for the next cycle. Figures (a) and (b) courtesy of J. J. Love (1999).

The process responsible for the first part of the cycle (poloidal $\longrightarrow$ toroidal) relies on the fact that the Sun doesn't rotate uniformly. During this phase, differential rotation shears the large scale poloidal field resulting in the production of large scale toroidal belts of opposite sign across the equator (see Figs. 8-a and 8-b). These toroidal belts then act as the source of active regions which, due to this antisymmetry across the equator, match Hale's law.

As opposed to the first part of the cycle where there is a dominant process taking place, there are several mechanisms which could be playing a role on the second phase of the cycle (toroidal → poloidal; see above). In this review I will focus on the role of active region emergence and decay (BL mechanism) for two reasons: it is believed to be the most prominent among all sources of poloidal field regeneration, and it lies at the core of model-based predictions of the solar cycle. The BL mechanism resides on the fact that active regions have a systematic hemispheric orientation and tilt (Hale's and Joy's laws; see above). This means that the leading polarity of most active regions is closer to the equator than the following polarity (see Fig. 8-c). Given that this orientation is opposite in each hemisphere, there is a net cancelation of flux across the equator and a net accumulation of open field on the poles, which produces the cancelation and reversal of the poloidal field closing the cycle (see Figs. 8-c and 8-d). Another way of understanding this process is in terms of the magnetic moment: due to their systematic orientation and tilt, most active regions in a cycle will carry a dipole moment of the same sign (and of opposite sign as that of the old cycle's dipole moment). After a cycle's worth of active region emergence and diffusive action, higher order moments would have decayed leaving a new bipolar field as the starting point for the next cycle.

For more details on the solar cycle and kinematic dynamo models please refer to the review of Charbonneau (2010).

Solar Cycle Predictions

One of the main goals of modern solar physics is increasing our predicting capability of events associated with the Sun and its magnetic field. One of the aspects of this effort is predicting solar cycle characteristics (amplitude, duration, minimum characteristics, etc.). So far, these predictions have focused exclusively on cycle amplitude and are usually separated into three categories:

- **Extrapolation Methods:** These methods are based on the assumption that the long term evolution of the solar cycle has well defined regularities which can be elucidated from historic solar data. Different statistical and spectral methods, as well as neural networks (among others) fall in this category.

- **Precursor Methods:** These methods rely on the fact that while a cycle is going on, the next one is in the making. Their main objective is to find those quantities which better correlate with the properties of the future cycle as early as possible. The solar polar field and different geomagnetic indicators are among the most popular quantities used by precursor methods.

- **Dynamo Model Predictions:** This type of predictions involves a direct application of the models that are traditionally used for understanding the underlying mechanisms of the solar magnetic cycle. They rely on the assumption that the model in question is correct, and require the accurate prescription of model ingredients and the assimilation of historic data.

All in all, there were more than 50 predictions for the amplitude of sunspot cycle 24 (for a compilation of the different predictions please refer to Pesnell 2008). Looking at them in detail, one realizes that (regardless of the category) predictions tend to span a very large array of possibilities. Although one may be tempted to dismiss predictive efforts because having 50 or so widely different predictions means that someone is bound to be right, there is an important difference between predictions for sunspot cycle 24 and predictions for other cycles which came before: the arrival of dynamo model predictions.

Up until now, our understanding of the cycle didn't play a major role in solar cycle prediction. Because of this, there was no way of elucidating why a particular approach would yield a more accurate prediction than another. This time however, our very understanding is being put into the trial of predicting the cycle; this time, being wrong will teach us as much (or maybe more) about our models as being right.

For more information about solar cycle predictions please refer to the reviews by Hathaway (2010) and Petrovay (2010).

Acknowledgements

As I was writing this short review, I realized how important and useful are the "Living Reviews in Solar Physics" for me. I want to thank everyone involved in making them happen (editors, writers, staff, etc.). The reviews represent an invaluable tool for students and researchers in solar physics. The same applies to NASA/ SAO Astrophysics Data System (ADS; another crucial tool for astrophysical research). Finally, I want to acknowledge NASA's Living with a Star program for funding me through the grant NNX08AW53G to Montana State University/Harvard-Smithsonian Center for Astrophysics.

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Science Communication

C★C★S
THE CENTER FOR COMMUNICATING SCIENCE
STONY BROOK UNIVERSITY

A new science journalism graduate program has started at Stony Brook University in the School of Journalism in cooperation with The Center for Communicating Science. The Center for Communicating Science is the only one of its kind in the country and is co-sponsored by Brookhaven National Laboratory and Cold Spring Harbor Laboratory. Innovative courses are offered for current and future scientists. These courses teach how to communicate science effectively with the public, public officials, the media, potential funders and employers, and colleagues in other specialties. One innovative technique pioneered by actor Alan Alda is to teach improvisational acting methods to scientists so that they better connect with their audience.

http://www.centerforcommunicatingscience.org/

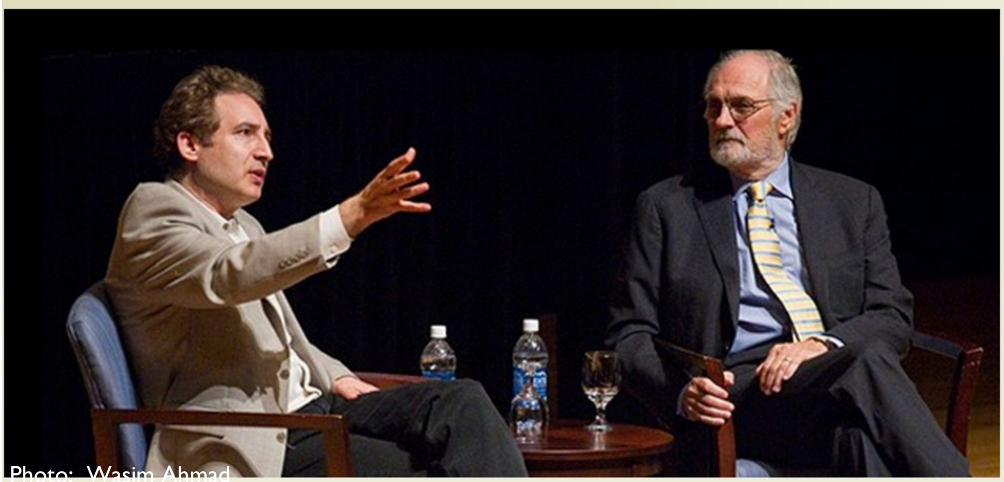


Photo: Wasim Ahmad

Center's opening event Provost's lecture: Physicist Brian Greene and Alan Alda discuss the process of communicating science and the excitement of the scientific story. "**Why Communicating Science Matters**" September 23, 2010 (with brief intro about The Center for Communicating Science @ Stony Brook University). http://www.youtube.com/watch?v=N_5_o69TGiY

More Science Communication with Alan Alda

" The Art of Science Communication "

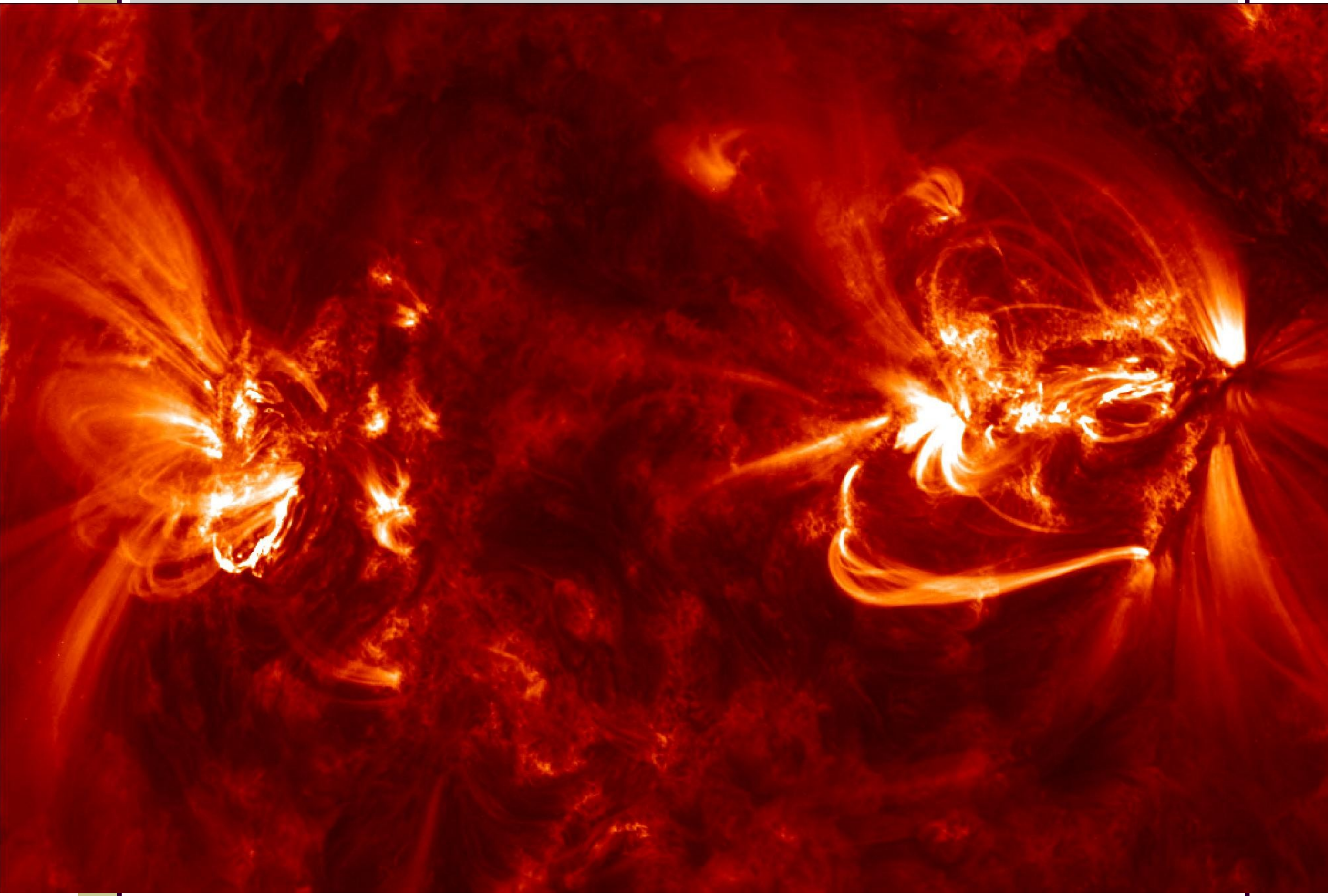
Alan Alda speaks at McGovern Institute for Brain Research at MIT

http://techtv.mit.edu/videos/8977-alan-alda-the-art-of-science-communication

Improvisation for Scientists: Workshops by Alan Alda and the Center for Communication Science (with scientists at Brookhaven National Laboratory)

http://www.youtube.com/watch?v=JtdyA7SibG8

Software: ESA JHelioviewer



JHelioviewer is open-source visualization software for the sun. It has access to 15+ years of SOHO data and high resolution SDO data. The software runs on Windows, Mac, and is available in Multi-Platform JAR format. JHelioviewer is part of the ESA/NASA Helioviewer Project.

http://www.jhelioviewer.org
http://www.jhelioviewer.org/demo.html

"Solar Equation": The High-Tech Scientific and Interactive Art of Artist Rafael Lozano-Hemmer

Artist Rafael Lozano-Hemmer achieved a major tour-de-force in his work, "Solar Equation.'" He brought the sun closer to the heart of the public during the "Light in Winter" Festival in Federation Square, Melbourne, Australia, June 4th – July 4th 2010, and gave people a way to reach up and "touch" the sun. He built a maquette of the sun 100 million times smaller than the real thing in the form of a floating tethered aerostat, which was also the world's largest captive balloon. He suspended it, with the help of tethering and helium gas, over a town square of a major city and strategically placed it within the urban landscape. Using five projectors, he projected real NASA SOHO and SDO images of the sun onto it. If that wasn't enough, he designed an app used on your iPad, iPod, or iPhone (thank you Steve Jobs!) where any given user can manipulate the variables in the mathematical equations and in real time affect the dynamics of the simulations and visualization. Together the community interacted with the solar maquette, affecting changes and displaying various images of solar phenomena such as turbulence and solar flares.

As the artist points out, each culture on the planet that ever lived has had some sophisticated relationship with the sun. In some instances its folklore, in others, a culture may have worshipped a sun god. The artist describes the plethora of solar images as being the representative images of our time. Each era has their symbolic images. These are ours.

> "The sun used to be seen in a very iconic way, and a symbolic way, and a mythical way. Today we're beginning to see it more as a representation of non-linear processes. I'm very interested in thinking about that as a new kind of referential imagery of our time. So the solar equation is a way to faithfully represent those phenomena in a scale that is more urban."
>
> – Rafael Lozano-Hemmer (RLH) in "Mathematics as Media"

The artist also sees the work as an "urban embodiment" of mathematics. The nonlinearity and non-repeatability become part of the artistic process. "It's humbling, as an author, to let your work go out of control," says Lozano-Hemmer. In terms of the mathematics beneath the simulations, "Solar Equation" consists of reaction diffusion equations, Perlin noise, and particle systems, in addition to the NASA imagery. The iPhone, iPod, and iPad app allows a user to choose parameters in the equations as well as select different fluid dynamic visualizations with different properties or modes to display and manipulate. These include granulation, convection, spots, plasma, displacement, colloid, dissipation, and phototropy. Lozano-Hemmer is interested in growing the mathematical side of the platform for future installations. "We're going to take it to other cities, and as

"Solar Equation": The High-Tech Scientific and Interactive Art of Artist Rafael Lozano-Hemmer

we get more time we're going to add some more equations like Navier-Stokes and fractal flames."

The artist indicates there is a dark side to the sun.

> "… there's a sheer force and violence associated with these explosions that I hope comes through the piece … But I like that this light comes out of this enormous destruction, and that destruction is also creation because of the creation of matter. So many of the very important narratives of art in general can be, you know, sort of played off the sun."
>
> -RLH in "Mathematics as Media"

The artist specializes in "large-scale interactive installations in public spaces." People spend a lot of time in public space. As he points out, people like to promenade. His artwork is intended to not only be "spectacular," but it builds a level of "engagement and interactivity for people" while challenging them on many fronts, and in particular, to think about the sun differently than they usually do. They may think about the traditional in a new paradigm or develop their own interpretation.

> "While pertinent environmental questions of global warming, drought, or UV radiation might arise from the contemplation of this piece, Solar Equation intends to likewise evoke romantic environments of ephemerality, mystery and paradox, such as those from Blake or Goethe. Every culture has a unique set of solar mythologies and this project seeks to be a platform for both the expression of traditional symbolism and the emergence of new stories. Just like the installation depends on the world's brightest projectors to exist, conceptually the piece is open for the public to make their own symbolic projection and interpretation. Some might experience the work as a traditional son-et-lumiere spectacle, others as a didactic visualization of natural forces, while others as a call to action to harness the sustainability of solar power."
>
> -RLH ("Solar Equation" project website)

Besides, how else are we going to see the sun come out at night? 😊

Bring "Solar Equation" to your city!!!

If real interest contact the editor at: solarstudentnews@aol.com for more information.

For a future installation of "Solar Equation," would you be interested in participating in an accompanying public symposium? Contact solarstudentnews@aol.com.

Rafael Lozano-Hemmer, "Solar Equation", 2010. Federation Square, The Light in Winter Festival, Melbourne, Australia. Interactivity with iPhone app.

Comments are invited: e-mail the editor at solarstudentnews@aol.com. As the solar scientific community or as a student, what do you think? The editor will make sure the artist gets your comments (just say whether you would like to remain anonymous).

Web Links:

Project Solar Equation: http://www.lozano-hemmer.com/solar_equation.php

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"Mathematics as Media: An Interview with Rafael Lozano-Hemmer" Scott McQuire interview http://spatialaesthetics.unimelb.edu.au/projects/large-screens-and-the-transnational-public-sphere/interviews/mathematics-as-media-an-interview-with-rafael-lozano-hemmer

Artist: http://www.lozano-hemmer.com/

PDF: http://www.lozano-hemmer.com/texts/downloadable/SolarEquation2LQNB.pdf

Web Videos of the event:
http://www.lozano-hemmer.com/videos/solarequation_hd.mov
http://www.lozano-hemmer.com/videos/SolarEquation_ABC_hd.mov

Get the app from itunes: http://itunes.apple.com/app/solar-equation/id375165357?mt=8

Solar Equation Picture Gallery


Photo by Airstar


Photo by Antimodular Research


Photo by Antimodular Research

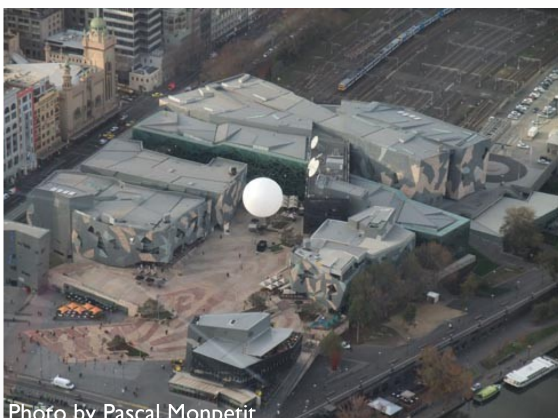


Photo by Pascal Monpetit


Photo by Antimodular Research

Learn more about Rafael Lozano-Hemmer's latest (2011) solar art piece:

"Flatsun"

http://www.lozano-hemmer.com/flatsun.php

The Making of a Scientist - Part 3

Loren W. Acton

It is still remarkable to me, and I would guess to everyone else, that Loren Acton spent eight days in orbit in the space shuttle Challenger on a mission called SPACELAB 2. Normally, a bearded guy with only one fully functional eye (and that one color blind) does not get to do such things. Well, it happened like this. Recall that I was working at the Lockheed Palo Alto Research Lab, a tiny part of the huge Lockheed Aircraft Corporation. Somewhere way up in the Lockheed "head shed" was an engineer who was a member of the National Academy of Engineering. In July 1973 the NAE and NAS organized a conference for NASA on scientific uses of the space shuttle, and the Lockheed NAE member was asked to suggest a Lockheed scientist to participate. Somehow (it pays to be on good terms with your management!) the appointment filtered down to me – and I jumped at the chance!

In retrospect, the two-week meeting at Woods Hole, MA promised and planned a whole lot of things for science from the shuttle that never came to pass. The humans aboard made the shuttle a very expensive and inefficient platform for remote sensing experiments like solar astronomy, and the early flights, e.g., SPACELAB 2, demonstrated this in spades. Then the Challenger disaster in January 1986 brought the whole edifice of using the shuttle as an observing platform in the so-called "sortie mode" crashing down. The scientific community and the Congress had been sold a real "bill of goods" on the space shuttle as low-cost access to space. Keeping humans healthy and safe in space is, and always will be, very expensive. We should have seen it coming. Beware of self-delusions regarding things you WANT to be true.

> ***"Do not hesitate to serve on federal study or mission-definition committees in your field."***

What I brought home from Woods Hole was the revelation that NASA planned to fly ordinary scientists, like me (!), on the shuttle as Payload Specialists. I had also been a party to informing NASA what sort of solar experiments should be flown on early shuttle flights. In particular, we had advised deployment of a small, full-disk, solar telescope operating in the visible with polarimetric capabilities for measuring magnetic fields. Later (1977) this recommendation resulted in the selection of the Lockheed Solar Optical Universal Polarimeter (SOUP) for flight on shuttle flight number 12, designated as SPACELAB 2. (Lesson: Do not hesitate to serve on federal study or mission-definition committees in your field.)

One Friday night over beer, after submission of the SOUP proposal but before selection, I suggested to Alan Title, SOUP principal investigator (PI), that if SOUP were chosen, I would like to fly with it as a Payload Specialist. Alan indicated that that would be all right with him. We discovered that once the SPACELAB 2 payload of 13 disparate experiments was put together by NASA and the Investigators Working Group (IWG) was formed, NASA had not yet established the rules for selection of Payload Specialists. Now it was up to us to figure out how to do this since ours was the first Spacelab mission to be organized.

The IWG met and quickly recognized that the solar experiments could profit most from in-flight scientific expertise. The other experiments were largely controlled from the ground or were straight forward enough as not to require specialized scientific knowledge. So, the 3 solar PIs were tasked to craft a Payload Specialist requirements document … and I volunteered to write the first draft. It was a good draft, adopted by the IWG and NASA with few changes. It did not mention unnecessary requirements such as normal color vision. There was a brief flurry of telexes to the NASA administrator when a rumor surfaced that NASA was considering replacing at least some Payload Specialists with career Mission Specialist astronauts. (This has pretty much been the case since the Challenger accident.) In the end, history records that John-David Bartoe and Loren Acton were selected as the prime SPACELAB 2 Payload Specialists with Dianne Prinz and George Simon as backups.

All of this took place in 1978, with SPACELAB 2 scheduled for launch in early 1981. Thanks to delays in the shuttle program, we finally achieved orbit on July 29, 1985. I got to play astronaut for seven years. It was a thoroughly fine experience to work with totally competent people for such a long time on such a fascinating project.

Our mission was not without its moments. The first launch attempt on July 12, 1985, aborted on the pad at T-3 seconds because of the slow opening of some important valve. On July 29 there was no end of difficulties with weather (in Spain) and booster computers. We were held on the pad for four hours and launched only at the very end of our window. Then, about five minutes out, our number 2 main engine was shut down by on-board computer because its two temperature sensors both failed high. We did an “abort to orbit” on the two remaining engines – 50 miles low and after dumping 1000 pounds of maneuvering fuel.

Despite all manner of problems with soft- and hardware, the mission was judged an outstanding scientific success. The crew was awarded the 1985 Spaceflight Achievement Award by the American Astronautical Society. The most important achievement of SOUP was the clear demonstration of how flows in the photosphere gather the magnetic fields into inter-granular lanes.

Yours truly was blind-sided on orbit in a couple ways. I had expected the experience to be sort of like a camping trip in space with my friends. Rather, I overdosed on responsibility to the point that enjoyment and fun were very much downgraded from my anticipation. Secondly, it turned out that I did a poor job of following check lists and made several serious blunders that degraded some scientific results. I chalk this failure up to overconfidence and an inadequate training protocol. As a result, I was pretty depressed by the time we landed after eight days. Even today, 25 years later, the gaffes haunt me.

All in all, the SPACELAB 2 episode was a fabulous opportunity and has subsequently opened many doors. If you get the chance to fly, do NOT pass it up.

“If you get the chance to fly, do NOT pass it up.”

Caption: A happy scientist shortly after being chosen to fly as a Payload Specialist on the SPACELAB 2 mission.

My next (and last) edition of the Making of a Scientist will deal with Yohkoh and Montana State University.

Missions You Should Know About

David McKenzie, Montana State University

How much do you know about solar physics discoveries from space-borne missions? Of course, you know all about SDO and STEREO and Hinode, and you've watched the movies from SOHO and TRACE. But with all the press coverage and public relations for these missions we often overlook that these missions are, to some degree, following up on previous observations.

It's interesting to review the predecessors, partly because doing so reminds us of how *new* much of our knowledge really is. So this series of articles will attempt to introduce the student reader to solar space missions of the past few decades, missions that I feel students should know about. To kick off this retrospective, let's look at the Solar Maximum Mission. SMM was the powerhouse mission of the 1980s, and many of today's thesis advisors (and their advisors) were involved in the data analysis and interpretation.

The Solar Maximum Mission (nicknamed "Solar Max") was launched February 14, 1980. That's thirty years, almost to the day, before SDO. The primary goals were focused on solar flare research, and so most of the instruments were designed for remote sensing of energetic radiations:

- Gamma-ray Spectrometer (GRS). Non-imaging detector to make spectra and time profiles from the highest-energy photons, produced by near-relativistic particles, and high-energy neutrons. Also included hard X-ray detectors, so the range of GRS sensitivity spanned 10-140 keV, and 0.3-100 MeV.

- Hard X-ray Burst Spectrometer (HXRBS). Another non-imaging spectrometer, accepted and analyzed photons with energies between 20 keV and 255 keV, from the whole Sun, with reasonably good time resolution.

- Hard X-ray Imaging Spectrometer (HXIS). The first imager for the Sun's hard X-rays. Similar in concept to Yohkoh's HXT, and RHESSI.

- Bent Crystal Spectrometer (BCS). You know that crystals will diffract X-rays, and therefore you can use them to make a spectrum. By slightly bending the crystal, the spectrum can be "spread out" across the detector, and higher spectral resolution can be achieved. BCS covered wavelengths from 1.7 to 3.2 angstroms, for spectral lines from calcium and iron that are formed at temperatures 2-60 MK(!).

- Flat Crystal Spectrometer (FCS). Again, X-ray spectra via crystal diffraction. But FCS traded spectral resolution to cover a wider spectral range: 1.4-22 angstroms.

- Ultraviolet Spectrometer/Polarimeter (UVSP). Measure four spectral lines simultaneously. Or, measure the red/blue wings of two lines, simultaneously, to get Doppler measurements of speed. With the rotatable retarder, get Zeeman splitting (i.e., magnetic measurements) in the UV.

- Coronagraph/Polarimeter (C/P). Think of the LASCO coronagraph on SOHO, but with a smaller field of view.

- Active Cavity Radiometer Irradiance Monitor (ACRIM). Measuring the total radiative output of the Sun, from the infrared through the ultraviolet. Remember the "solar constant"? Well, it ain't.

It was a great set of instruments for studying the high-energy solar activity, but there was drama. After just a few weeks in orbit, some of the electronics in FCS failed. Later, C/P and HXIS also had troubles which reduced their abilities to make observations. But the near-fatal blow came from the spacecraft's attitude control system: surge protectors on three of the four gyros blew their fuses. Since the circuit breakers couldn't be reset, it seemed that none of the imaging instruments would be able to observe, after just nine months of observations. The non-imaging GRS, HXRBS, and ACRIM could still take data; but still... [Lesson: use resettable circuit breakers whenever possible.]

The Solar Maximum Mission was built around NASA's "multi-mission spacecraft" bus, a modular design that was intended to fit inside the cargo bay of the space shuttle. (Suppose you want to bring the satellite back down and refurbish it, or stick it in a museum. That's the idea.) Because of this design, SMM was capable of being repaired in orbit, by astronauts walking in space. Maybe it sounds commonplace now, but in the 1980s this had never been done. SMM was the first attempt, in 1984. The actual repairs to the electronics went smoothly, but capturing the tumbling spacecraft was a nerve-wracking, nail-biting, suspenseful two days. There's a reason why we think of astronauts as heroic. And the ground crew of SMM too, who wrestled with the broken attitude control to stabilize it just long enough for the shuttle to grab Solar Max.

So was it worth the trouble? What did we get from Solar Max? SMM observed for another *five years* after the repair, so I'd say it was a success. Including the 3.5-year period without the gyros, nearly 15,000 flares were studied by SMM, until the mission ended in November 1989. SMM's observations spanned the decay of solar cycle #21, the mid-1980s solar minimum, and the sharp rise of cycle #22. ACRIM's data demonstrated that the Sun's total output varied over the span of the magnetic activity cycle, and even suggested that solar output could be linked to variations in Earth's climate. Coronal mass ejections had first been identified just ten years prior, and the C/P observations of CMEs really helped to put our understanding onto a firm foundation, by making high-quality image sequences of some 1350 CMEs, including speeds, accelerations, mass and energy budgets, and morphologies. Based on these observations, and comparisons with the flare observations, we now know that flares don't "cause" CMEs, nor vice versa: they are both manifestations of large-scale magnetic field reconfigurations, though SMM did demonstrate quite clearly that the CME launch precedes the flare onset as a general rule. The shocks formed in the inner heliosphere by propagating CMEs are still a topic of intense study, because of the ramifications for particle acceleration—it's a primary science objective of NASA's new Solar Probe Plus, in fact. Similarly, the HXIS observations led the way to a better understanding of the processes that occur during magnetic field relaxation (via reconnection) following an eruption—the bright post-eruption coronal arcades with which we are familiar from Yohkoh/SXT, SOHO/EIT, TRACE, and Hinode/XRT were first clearly identified, and systematically studied, with the HXIS data. It is through the study of these arcades that we have built a large amount of our understanding of magnetic reconnection in the corona. However, the presence of that million-degree plasma at coronal heights was a novel discovery. Before SMM, some flare spectra had indicated blueshifts in the X-ray emission lines, a feature that became known as *chromospheric evaporation*. SMM's spectra made great strides in constraining the models of chromospheric evaporation, first of all by demonstrating that it truly exists, but more particularly by yielding thousands of measurements of when it exists, and at what temperatures, and for how long in a given flare. The data helped to determine the relative importance of thermal conduction versus beamed energetic electrons for heating the chromosphere. Similarly, radiation due to energetic ions and relativistic electrons had been characterized for only a handful of flares prior to SMM, and so the puzzles of how/when/where particles are accelerated, and ultimately thermalized, were wide-open questions. These questions still drive the analyses of RHESSI observers and numerous numerical modelers. Likewise, the UVSP and HXIS observations significantly improved our understanding of the evolution of active regions, and the buildup of energy before flares. These observations demonstrated that UV, radio, and X-ray intensities typically increased before flares, although identification of the "flare trigger" was not conclusive. Such an identification remains a sought-after goal, because in principle it would lead to the ability to predict the ignition of a flare or eruption.

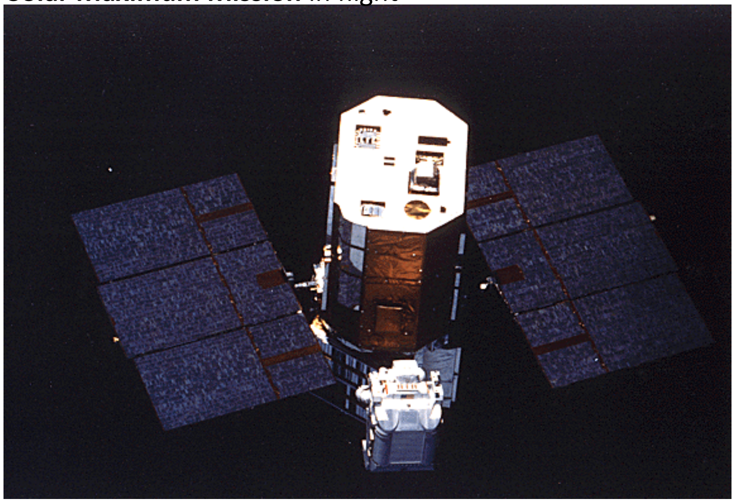
This article only scratches the surface of the rich developments that SMM brought to our field. I hope I've given an indication of SMM's importance to studies of magnetic reconnection, chromospheric evaporation, particle acceleration, and space weather. In the next installment of this series, we'll examine another mission that made real breakthroughs for solar physics, and touch upon some of the questions that are still open. Students: if you'd like to know more about SMM, ask your advisor. Or better yet, ask your advisor's advisor--they'll get a kick out of that.

Sources:

"The Many Faces of the Sun: A Summary of the Results from NASA's Solar Maximum Mission", edited by Keith T. Strong, Julia L. R. Saba, Bernhard M. Haisch, and Joan T. Schmelz; published by Springer-Verlag in 1999.

"Chronological Encyclopedia of Discoveries from Space", by Robert Zimmerman; published by Oryz Press in 2000.

Solar Maximum Mission in flight



NASA JSC Image Library

Some **Solar Maximum Mission** links**:**

http://heasarc.nasa.gov/docs/heasarc/missions/solarmax.html

http://solarscience.msfc.nasa.gov/SMM.shtml

http://smm.hao.ucar.edu/smm/smmcp_cme.html

http://space.jpl.nasa.gov/msl/QuickLooks/smmQL.html

SPOTLIGHT: Joint UTSA/SwRI Graduate Physics Program

Since 2004, a physics graduate program has been offered in partnership between the University of Texas San Antonio (UTSA) and Southwest Research Institute (SwRI). UTSA is the second largest component university of The University of Texas System, with an enrollment of more than 28,000 students. SwRI's Space Science and Engineering Division is a leader in space physics research with major involvement in numerous NASA missions. The participation by SwRI offers students a chance to be involved in many of the most exciting ongoing NASA missions (Cassini, New Horizons, TWINS, ACE, Ulysses, STEREO, IBEX) and future missions (e.g., Juno, MMS, RBSP).

UTSA/SwRI graduate students can engage in data analysis and instrument design & calibration, and even lead their own projects. Some past or current projects include (for example): analysis of Cassini observations of Titan's atmosphere, design of a new ion mass spectrometer, interpretation of the first New Horizons measurements from Jupiter's magnetotail, and investigation of the Saturn's

E-Ring, a torus of ionized water surrounding the planet in space. During one year, the students in our laboratory class got to perform the calibration on one of the IBEX instruments now flying and obtaining phenomenal new observations of the interstellar boundary.

The deadlines for application: 1 October 2011 for entry in Spring 2012, 1 February 2012 for entry in Fall 2012. Application procedures and additional information:
Visit http://www.utsa.edu/graduate/index.html
Or contact Professor Mihir Desai at mdesai@swri.edu or +1 210 522 6754. You can also talk directly to current graduate students at spacestudents@swri.edu (+1 210 522 4288).
Financial support is available to students through Research Assistantships while conducting research for SwRI's Space Science and Engineering Division (http://www.swri.edu).

Our areas of space physics include:
- Solar & Heliospheric physics
- Magnetospheric physics
- Space Science instrumentation
- Planetary Science
- Space Weather

Website is http://physics.utsa.edu.

Women in Science

New Workplace Policies from the NSF and the White House Support Working Scientists in Career Life-Balance

Sept. 26, 2011. The White House and the National Science Foundation have announced new workplace flexibility policies. The 10 year plan is called the "NSF Career-Life Balance Initiative." It is designed to give more family-friendly flexibility to working scientists in an effort to retain women scientists who are balancing career and family. This includes updates to grant suspensions, parental leaves, supplemental salaries, and tenure clock extension policies.

http://www.whitehouse.gov/the-press-office/2011/09/26/white-house-and-national-science-foundation-announce-new-workplace-flexi

Student Opportunity: Conferences for Undergraduate Women in Physics

Registration Now Open for the 2012 Conferences for Undergraduate Women in Physics (application due 11/15/11)
http://www.aps.org/programs/women/workshops/cuwip.cfm

Conferences for Undergraduate Women in Physics (CUWIP) are three-day regional conferences for undergraduate physics majors. The 2012 conferences will run Friday evening, January 13 through Sunday afternoon, January 15, 2012. For 2012, there will be six regional conferences; students are encouraged to apply to the nearest conference.

* Case Western Reserve, Cleveland, Ohio *
* Stanford University, Stanford, California *
* Texas A&M in College Station, Texas *
* University of Tennessee - Knoxville, Tennessee *
* University of Washington, Seattle, Washington *
* Yale University, New Haven, Connecticut *

In most cases, full support will be provided for room and board. Physics departments are strongly encouraged to provide support for travel; however, students should apply for travel reimbursement if their department is unable to support them. The application deadline is November 15, 2011.

Brief History of Early Space Exploration in Postage Stamps.
By Dr. Alexei A. Pevtsov

Where do I come from? From the Past.
Where do I go? To the Future,
Life is a rapid, treacherous river that crosses plains and hills, summers and winters.
You enter it in one place, and you leave in the other.

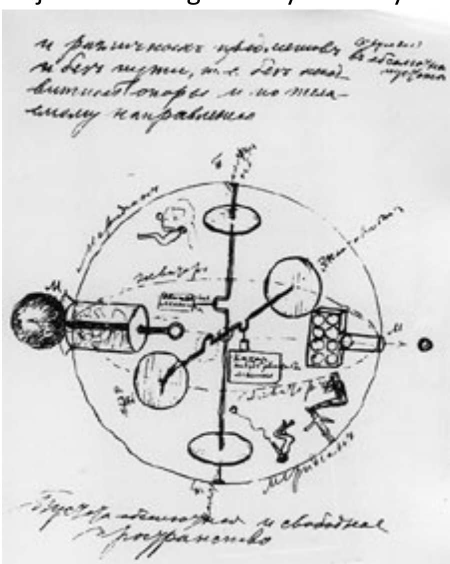
1971. I – still a young boy – was looking through a window of my parents' flat, observing the world. It was a cold, winter evening - one of those evenings when the air is so still and crisp that it feels frozen solid. The sun had set about an hour ago, but the streets were still full of cars and buses going back and forth with their headlights on. Many people also braved the cold out on the sidewalks. Some were lazily strolling along brightly lit glass windows of department stores; others were rushing to finish their shopping before the night sets in. High above this street clatter, a bright red star shone its light through the vast emptiness of cosmos. This strange red star in sky above my small hometown in northern Russia was the planet Mars. The first interplanetary probe made a soft landing on the surface of this planet that same year (December 2, 1971).

This observation of planet Mars coinciding with news about Mars' probes had sparked my interest in astronomy and marked the beginning of my stamp collection on space exploration. Some of the first stamps in that collection are two postage stamps commemorating Mars-2 and Mars-3 planetary probes.

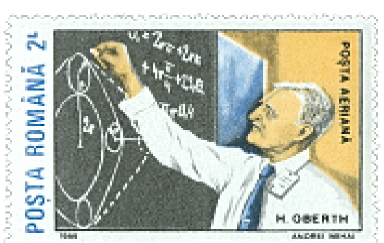
Looking at stamps is akin of examining history. It is amazing how much we, humans, had achieved in respect to space exploration in such short period of time. It is all started … well, one can argue about that, but my first postage stamp in space exploration collection commemorates Jules Verne's "From the Earth to the Moon" (this stamp was issued by Czechoslovakia).

Scientific research that led to space flight is attributed to three "founders" of modern rocketry: Konstantin Tsiolkovsky (1857-1935), Robert Goddard (1882-1945), and Hermann Oberth (1894-1989).

Konstantin E. Tsiolkovsky worked as a math teacher at high school in a small Russian town near Moscow. In his “free time” he did several amazing things: in 1894 he had designed a monoplane which subsequently flew in 1915; in 1897, he had developed the first Russian wind tunnel. Later, he published an article on Investigating Space with Rocket Devices (1898), the rocket equation (1903), a theory of multistage rockets (1929), and ideas for space greenhouse and airlock (1932). Cuban postage stamp on the right shows a portrait of Konstantin Tsiolkovsky and a strange object to the right. Only recently I have found that this is a scaled-down reproduction of Tsiolkovsky’s drawing dating back to 1883 (see left). What this drawing depicts are humans floating in free space, airlock (on the left), impulse thruster (shooting small balls on the right), and gyroscope in the middle of a sphere. Image on the right is the postage stamp issued by Poland that depicts 1903 rocket design by Tsiolkovsky and his rocket equation. A small box with a human siluet in the front portion of his rocket is a water tank to mitigate the acceleration effects on human body during rocket launch. A knot-looking fuel line was designed for rocket’s stability.



Robert H. Goddard did extensive experiments with liquid-fuel rockets. In 1915, being a professor at Clark University in Worcester, MA he theorized that rocket can fly in vacuum. He received a small grant from the Smithsonian Institution to conduct his rocket experiments, and in 1922 he had started working on a liquid-fuel rocket design that used gasoline and liquid oxygen. The idea of liquid-fuel rocket was suggested independently by Tsiolkovsky, Goddard, and Hermann Oberth, but it was Goddard who had launched the world first liquid-fuel rocket on March 16, 1926. Sadly, Goddard’s work had received very little attention from the US Government, and R. Goddard was even ridiculed by news media for his idea of space flight. In 1930 he had moved to Roswell, New Mexico, where he had continued his experiments. Unfortunately, R, Goddard believed in secrecy and preferred not to discuss his work with other researchers in U.S. In May 1933, the American Interplanetary Society (AIS) launched its liquid-fuel rocket from Staten Island, New York. The rocket was patterned after the VfR (Verein fur Raumschiffahrt) Repulsor series of rockets brought from Germany. In U.S. the work of R. Goddard was not recognized until early 1960th. If you happen to drive through Roswell, New Mexico plan to visit Roswell Museum and Art Center that has a small exhibit recreating Robert Goddard’s workshop.



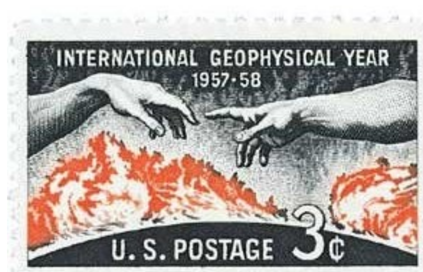
Hermann Oberth is known for his fundamental work on “The Rocket into Planetary Space” which he published in 1923 - one year after his Doctoral dissertation on rocketry was rejected by the University of Munich. Independently, he and K. Tsiolkovsky had arrived to a similar idea of multi-stage rockets. In early 1930th he had hired a young assistant, Werhner von Braun, with whom he worked on V2 project, first in Germany and later in U.S.

In 1930th rocket experiments were conducted in Germany, Soviet Union, U.S. and several other European countries. In Russia, this early rocketry research was led by a gifted rocket scientist Fridrikh Tsander (1887-1933). On August 17, 1933 the first Russian liquid-fuel rocket of his design, GIRD-9, had reached altitude of 400 meters. Unfortunately, F. Tsander had died from typhoid fever the very same year. In 1924, he wrote about the idea of using solar sail: “for flight in interplanetary space I am working on the idea of flying, using tremendous mirrors of very thin sheets, capable of achieving favorable results.” In the same article he put forward the notion of Earth-orbiting space stations.

Fast forward to the end of World War II…
In 1945 Operation Paperclip brought hundreds of German scientists to Fort Bliss, Texas. They began working at nearby White Sands Missile Range on the V-2 rockets that had already arrived from Germany. This work was led by German scientist Wernher von Braun. One still can see fragments of old V-2s on display in rocket park in front of Museum of Space History in Alamogordo, New Mexico.

In Russia, the work on rockets was led by Sergey Korolev, who, before his tragic death in 1966, was known to general public simply as “Chief Designer”. While leading Russian rocket program, he published his technical papers under the assumed name of “Professor K. Sergeev”.

It is interesting how this early work on artificial Earth satellites was affected by military interests of both nations. In Russia, Korolev’s design bureau was developing the Soviet first intercontinental ballistic missile (ICBM). In early 1954, Korolev sent Soviet government the Report on an Artificial Satellite of the Earth, where he had proposed that R-7 ICBM that his design bureau was working on can be used to launch artificial satellites. In U.S., there were two developments: one aimed on launching a civilian satellite during the International Geophysical Year (IGY) and the other to build reconnaissance satellites for military. Interestingly, the idea of launching science satellite was suggested as the way to circumvent existing international treaties. In 1952, a working group at Massachusetts Institute of Technology had issued a report outlining that military satellite orbits passing over the territory of Soviet Union would be a violation of national sovereignty. A few years later, other panel had advised the President Eisenhower on possible solution: launch a small science satellite and establish the principle of “freedom of space”. The military satellites that would follow will be using this principle to fly over Soviet Union without violating international treaties. This principle has been adopted soon after the panel recommendations.



On October 4, 1954, following to a U.S.-sponsored initiative, the ruling body of the International Geophysical Year issued a resolution calling for launch of science satellite during IGY in 1957-58. In 1955, the U.S. national committee for the IGY had issued a feasibility report for launch of American science satellite. A month later, Russian Academician Leonid Sedov hold a press conference in Copenhagen, Denmark, where he announced that Soviet Union will be launching science satellite during IGY too. At that time, however, the feasibility of Russians launching a satellite was considered very low by majority of Western scientists. On July 5, 1957, the Central Intelligence Service (CIA) had reported that a Russian satellite can be launched as early as September 17, which indeed was the original target date for Sputnik launch. Still, both Russian and American programs had experienced technical difficulties.

On August 27, 1957, Soviet Union announced the first successful launch of its R-7 ICBM (conducted on August 21, 1957). It followed by second launch on September 7, 1957, and on October 4, 1957, Soviet Union launched the Earth's first artificial satellite, Sputnik-1 (weight 83.6 kg). One month later (November 3, 1957), Soviet Union launched second satellite, Sputnik-2 (weight 508 kg). Sputnik 2 was the first satellite with a living organism on board. Dog Laika was launched to study effects of weightlessness and radiation as a first step to future human flights. Because of failure in separation of the last stage, the thermal control system could not maintain temperature inside the pressurized cabin, and the dog had died from overheating after a few hours on orbit.

Sputnik 2 had a suite of scientific instruments, which detected the outer radiation belts in Northern hemisphere. There were, however, no ground tracking stations in the Southern hemisphere, and so, the global nature of radiation belts was not immediately understood. Australia had recorded signals from Sputnik 2, but had refused to cooperate on data analysis. Instead, Australia requested Soviet Union to provide telemetry codes to decipher signals from Sputnik 2; understandably, Soviet Union had declined to do so. This incident prompted U.S.S.R. to develop a fleet of research ships that were dispatched to Southern hemisphere for satellite tracking during later launches. This Cuban stamp shows the flagship of this fleet, "The Cosmonaut Yuri Gagarin".

On December 6, 1957, first stage of the Vanguard rocket lost trust 2 seconds after the launch and exploded. The launch was highly publicized, and many newspapers nicknamed failed satellite as "Flopnik" or "Kaputnik" (a play on the Russian word "Sputnik").

On January 25, 1958, Soviet Union had attempted to launch the first probe to the Moon. This launch had failed.

On January 31, 1958, U.S. had launched its first artificial satellite, Explorer 1 (weight 4.8 kg). The instruments on board of Explorer 1 led to discovery of the Van Allen Radiation Belt.

With these first satellite launches a new age of space exploration has begun. What had followed are human flights, race to the Moon, communication satellites, orbital space stations, and planetary exploration, as depicted on these DDR (Deutsche Demokratik Republik), and U.S. stamps.

Stamps shown on this panel (from lower-left to the right) commemorate first man in space, cosmonaut Juri Gagarin and his Vostok rocket, first space walk by Alexei Leonov, Proton 1 satellite (weight 12,2 tons) to study galactic cosmic rays and gamma-rays, communication satellites Molnya, Luna 10 spacecraft that became the first artificial satellite of the Moon in 1966 and Luna 16 spacecraft that returned sample of lunar soil in September 1970, Soyuz 4 and 5 spacecraft that achieved the first successful docking and transfer of crew between spacecraft, Soyuz 6, 7, and 8 (flying in formation) and Soyuz 9 (long duration flight). Upper-left stamp shows Venera 5 (Venues 5 probe) that delivered a capsule that had descended through Venus atmosphere on parachute. And the upper-right stamp is a space station of the future.

U.S. stamps shown on the next panel (upper-left to right) commemorate lunar landing, Space Shuttle Columbia in flight,   Skylab, Pioneer 11 launched to study Jupiter, Saturn and interstellar space, and Copernicus (OAO-3) satellite for UV and X-ray astronomy. These stamps were designed by Robert T. McCall , American artist who has documented in his paintings all major NASA achievements and has created several postage stamps for U.S. postal service. When visiting the National Air and Space Museum in Washington DC, stop by six-story-tall McCall's The Space Mural -- A Cosmic View.

Bob and I had an hour-long telephone conversation in early July 2009: I told him about my collection of postage stamps, and he described me how he works on stamps and how he started painting on space travel. He died on March 5, 2010 at age 90.

Thirty five years later:

2006. I - now a grown man – was standing on a hill in a southern part of the Kyushu island and watching the launch of SOLAR-B/Hinode- a mission to study our nearest star, the Sun.   Later that week, after I returned from the launch, I found a small commemorative envelope lying on the top of the desk in my office at NASA Headquarters in Washington DC. This envelop is now one of the most treasured items in my stamp collection.

Learn more about the Solar Physics Division of the American Astronomical Society:

http://spd.aas.org/

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