Contents

SCIENCE/TECHNICAL/MANAGEMENT

1 Proposal Summary

- **Objectives and significance:** We investigate the origins and implications of the F10.7 index of solar activity as a guide to the nature of the solar magnetic cycle. This index has provided the cleanest view of the onset of Cycle 24 and is thus the most sensitive of the existing global indices.
- **Technical approach and methodology:** We study time series of F10.7 in the context of other indices showing the solar cycle, including multiwavelength observations from Japan. In addition we make use of the Nobeyama Radioheliograph observations at 17 and 34 GHz to understand the physical origin of the F10.7 increase seen clearly from 2009 in the general absence of spots.
- **Perceived impact:** F10.7 provides an exceptionally clear indication of solar cyclic variation during minimum periods. The exceptionally low activity levels during the current solar minimum reveal it to have the least confusing competition. We can take advantage of this to disentangle the physical sources of the F10.7 variation, and implications for total solar irradiance (TSI), in the absence of spots or even much plage.
- **Relevance:** This proposal responds to NASA's Strategic Goal 3B, "Understand the Sun and its effects on Earth and the solar system." Specifically our research is directed towards answering the question "How and why does the Sun vary?"
- **Plan:** We propose a two-year effort. The *first year* will basically be devoted to calibrating and comparing global solar indices during the current minimum. During the *second year* we hope to identify the cause of the new-cycle increase of F10.7, which has happened prior to sunspot formation this time, and to apply this knowledge to the photosphere (TSI, shape) and to interior dynamics.

2 Introduction

Since 1947 there have been routine daily measurements of the flux of microwaves from the Sun at wavelengths between 3 and 30 cm (frequencies between 10 and 1 GHz). This emission comes from the upper chromosphere and the low corona and has multiple sources. The two most important mechanisms are thermal bremsstrahlung (free-free emission) and thermal gyroemission (essentially the same physics, but due to electron acceleration on the magnetic field, rather than on plasma ions). These mechanisms give rise to enhanced radiation when the temperature, density, and magnetic field increase, so the microwave radiation is a good measure of general solar activity. As strong magnetic fields are located in specific regions that can live for weeks and often recur at or near the same location for months (perhaps even years), there is a strong rotational signal in the emission superposed on a solar cycle variation of a background activity level. At solar minimum, especially a deep one as we now experiencing, the effect of active regions largely disappears and we observe a sort of "solar ground state."

As the radio flux measurements (as opposed to the sunspot number) are less dependent on (human) observers and their observing techniques, and because they are relatively immune to instrumental and atmospheric differences, they may be a truer and more objective measure of solar activity (to the extent that we can reduce this complex concept to a single number per day). The decades-long flux record could throw light on the important issue of the long-term variation of solar activity. The solar microwave flux measurement is absolute; making an absolute measurement is always difficult and considerable uncertainty and debate surrounded these measurements early on, before being settled by international cooperative work in the late 1960s (Tanaka et al., 1973). By observing the radio flux from supernova remnants (Cassiopeia-A, Cygnus-A, and Virgo-A) one can verify the constancy of the calibrations derived from special-purpose receivers.

The longest-running series of observations is that of the 10.7 cm (2800 MHz) flux (often simply referred to as F10.7). This began with A. E. Covington in Ottawa, Canada in April 1947 and is maintained to this day (and hopefully much longer) at Penticton, British Columbia (Covington and Medd, 1954), with the current observations being made by K. Tapping. There are three measurements per day with small systematic (and poorly understood) differences. One can either average all three, or as in this work only use the noon value (for Penticton at 20:00 UT, since 1991). Figure 1 shows how F10.7 is varying during the (current) Cycle 23/24 minimum period, along with other key indices.

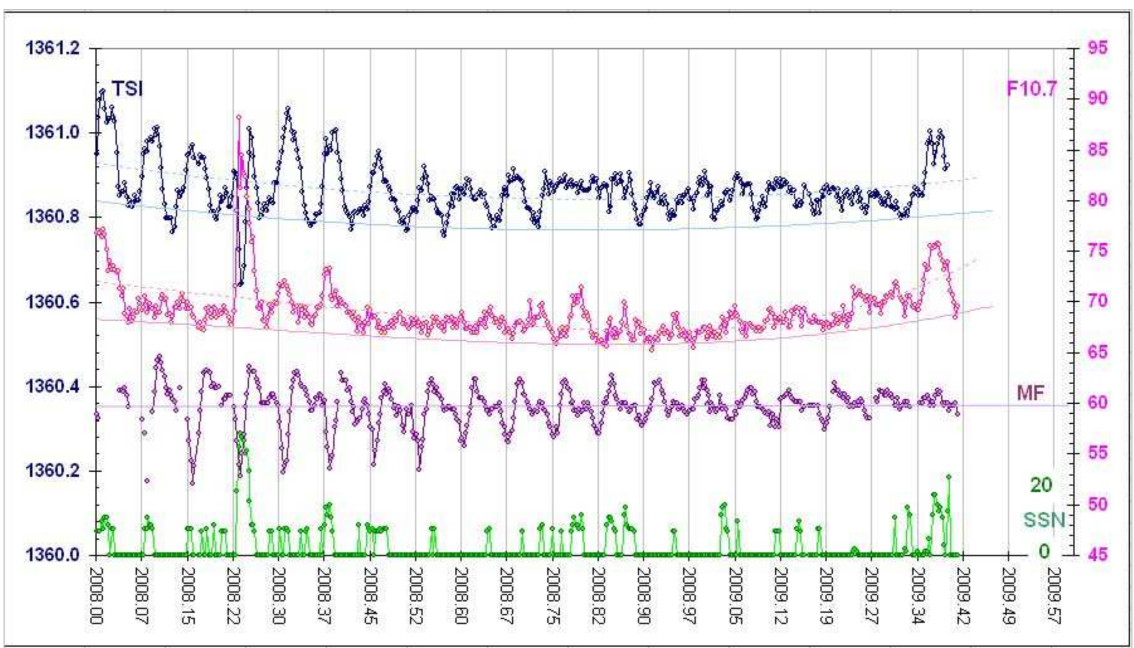

Figure 1: Four key global solar indices during the Cycle 23/24 minimum: upper, the total solar irradiance (TSI) from SORCE/TIM (Kopp et al., 2005); lower, F10.7; lower still, mean magnetic flux (MF); bottom, sunspot number (SSN). F10.7 (second from top) has been increasing since about the beginning of 2009.

Layout of the proposal: In Section 3 we give an overview of the indices used to characterize solar-cycle variabiility. In Section 4 we describe the basic plan, which is to take advantage of the unusual conditions in the Cycle 23/24 minimum to learn about new forms of solar global variability, making use of the existing microwave observations but with special care taken in understanding

Table 1: Solar Global Indices

Index	Nature	Source
TSI	Total Solar Irradiance	Various spacecraft (e.g. SORCE)
F10.7	Microwaves	Dominion Radio Astrophysical Observatory
SSN	Sunspot number	Various ground-based measures
Sunspots	Areas	San Fernando, USAF, others
Plage Index	Ca plage area	San Fernando
MF	Mean magnetic flux	Wilcox Solar Observatory
Ca II	UV spectrum	Mt. Wilson
Mg II	EUV spectrum	Satellite
PSI	Photometric sunspot index	Various
MWPI , MWSI	Various measures	Mt. Wilson Solar Observatory
MWO	Various measures	Wilcox Solar Observatory
Radio	Fixed frequencies	RSTN, Japan
Solar Wind	Density, speed, B_r, etc.	Various spacecraft
Geomagnetic proxies	Composites	Terrestrial magnetometers
Heliospheric	Cosmic rays	Neutron monitors

their calibrations and those of the indices we compare with. Finally in Section 5 we discuss a remarkable set of observations that we speculatively relate to the unusual behavior of the current minimum period, namely the possibility of *secular* changes in sunspot properties.

3 Global indices of solar variability

The solar cycle, as discovered by Schwabe, made its appearance known via the systematic variation of sunspot properties. We continue to characterize solar variability with sunspot area measurements and with derived sunspot numbers (SSN) defined in different ways. Since Schwabe's day, many new signatures of the solar cycle have emerged. We believe that the best of these indices, in terms of sensitivity and stability of calibration, come from the microwave observations. Section 4.1 gives the reasons for this. The most-studied of these is the widely used F10.7 index (the standard total solar flux density at 10.7 cm wavelength or 2.80 GH), but there is other information across the radio spectrum. Table 1 lists many of the most important indices (8 primary ones and 7 other more complicated and/or derived ones).

Relating the other signatures to TSI may help to understand its physical nature. The standard decomposition of the TSI signal into quiet Sun, spots, plage, and active network (e.g. Hudson, 1988) does not appear to work well during these conditions. The quality of the data justify an effort to extend this decomposition, ie to identify the sources of TSI variation during a "super minimum" of the Cycle 23/24 type.

In general a major objective of the proposed activity is to improve our quantitative knowledge of these indices. The variations of some are so large that Sun-Earth distance corrections are actually unnecessary, but others are much more subtle. For the TSI itself as measured on SORCE (Kopp et al. 2005) this correction needs to be made orbit-by-orbit, and the residuals may have precisions in

Table 2: Variation at 23/24 minimum, peak-to-peak

Index	Large excursion	Rotation	Background
TSI	331 ppm	$\sim$100 ppm?	$\sim$30 ppm
F10.7	30%	$<$10%?	$\sim$3%
SSN	NA	NA	NA

the parts-per-million range. For our chosen prime index, the F10.7, the relative amplitude of the solar variability is about 10^3 times larger than in the TSI (Table 2. The F10.7 precision is such that the monthly means for the the most recent year have a standard deviation below 1 SFU (one SFU = 10^{-22} W(m^{2}Hz)$^{-1}$), of order 1%. In spite of these very different variation amplitudes, each index sensitively shows the presence of plage (F10.7) or faculae (TSI). We return to a discussion of these variations in Section 4.2.

The fixed-frequency radio observations from Japan provide an under-utilized resource. Since the 1950s these observations, at frequencies 1, 2, 3.75, and 9.4 GHz, have continued uninterrupted. They are calibrated absolutely by reference to a pyramidal horn receiver, for which there is a complete theoretical description (Tanaka et al., 1973). These frequencies span the part of the spectrum most sensitive to gyroresonance (Figure 2, left), and will therefore help in disentangling this component (if any) of the microwave emission at 10.7 cm or 17 GHz.

4 Solar Microwave Variability

4.1 The *S*-component

The solar radio continuum reflects any emission from the quiet Sun, plus what has traditionally been called the “*S*-component” (*S* for ”slowly varying”). The contributions to the *S*-component are predominantly free-free emission, with some level of contribution from thermal gyroresonance emission in the cm wavelength range (Kakinuma and Swarup, 1962; Tapping, 1987; Tapping and Detracey, 1990). The solar brightness temperature in the cm range is of order 10^4 K, which reflects the average temperature of structures at $\tau \sim 1$ distributed across the features that we know about (quiet Sun, network, plage, etc). The gyroresonance component produces a spectral excess in the few-GHz range, as seen in the early results of Figure 2 (left). We note that modern observations with the Nobeyama Radioheliograph are at 17 and 34 GHz, would be almost purely free-free emission; see White et al. (2006) for a discussion of the quiet Sun at mm wavelengths. Figure 2 (right) shows an image example, taken from the 10-minute archive data. The *S*-component sources can be seen as bright plage near the equator; the image shows many other features, including polar faculae, filaments, and Venus.

The free-free component of F10.7 comes from the simple bremsstrahlung mechanism for which the optical depth scales as $n_e^2/T^{3/2}$. As a result, for a given line of sight, the observed total brightness temperature can be readily calculated from the run of temperature and electron density as a function of height. The problem is that well-understood models of the dynamic atmospheric structures in plage, network, and sunspots are not readily available, at least for cm wavlengths; Loukitcheva et al. (2004) and White et al. (2006) discuss these problems for the mm-wave continuum.

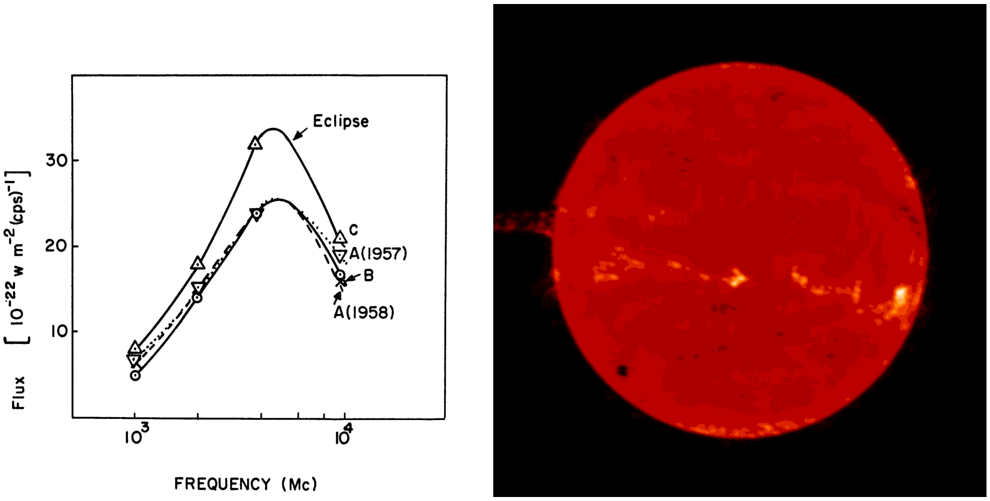

Figure 2: *Left:* The spectrum of the *S*-component, as measured by Kakinuma and Swarup (1962). *Right:* An image from the Nobeyama Radioheliograph at 17 GHz, showing several features including the planet Venus (dark object at lower left); image of 05:50 UT 8 June 2004. The *S*-component at maximum comes mainly from the active regions (the bright near-equatorial sources here).

The gyroresonance mechanism renders the corona optically thick in thin layers at locations where the gyrofrequency is a low subharmonic of the observing frequency. As a result there are localized regions of high brightness temperature contributing to the integrated flux.

Nobeyama observations cover the past two minimum periods, one "normal" one and the current one. File images from solar minimum show very little of the structure seen in Figure 2 (right) and we do not know at present know how to identify the *S* component at minimum. This is a major objective of the proposed effort, since this component appears to have been far more sensitive than other measures in terms of showing the increase at the onset of Cycle 24, as described below. Nobeyama radioheliograph observations are at a sufficiently high frequency that at solar minimum, gyroresonance effects are not important. Therefore these data provide a daily, calibrated and objective record of the sun's free-free emission from which its spatial characteristics (and their variation) can be inferred.

4.2 Comparison of F10.7 with other indices in 2008-2009

Figure 1 compares total irradiance from SORCE, F10.7, and the sunspot number SSN. It is clear from this figure that daily or monthly averages of SSN under conditions this inactive are not very precise. The other two indices show well-measured variations, but mostly different ones. "Well-measured" here means with small scatter from point to point, so that the variations are well resolved – note that this does not apply to SSN because of the lack of spots. The standard decomposition of the TSI signal into quiet Sum, spots, plage, and active network (e.g. Hudson, 1988; Foukal and Lean, 1988) does not appear to work well during these conditions. The quality of the data justify an effort to extend this decomposition, ie to identify the sources of TSI variation during a "super minimum" of this type.

The present minimum period displays strikingly different forms of solar variability as compared with more normal times. Figure 1 intercompares TSI as seen by SORCE since the beginning of

2008, with F10.7, the sunspot number SSN, and the mean magnetic field MF. The very infrequent sunspot occurrences give the SSN variation an on/off character. Because the sampling is limited by the detectability of discrete spots, and it must be non-linear or in some sense noisier during times of low activity. F10.7 and the TSI, on the other hand, show continuous variability at 1-day sampling, so we can examine the fluctuations in detail. We note the following features:

- F10.7 leads the other indices in clearly showing the upturn into Cycle 24.
- TSI does not reflect the F10.7 increase; there is no clear occurrence of sunspot-related dips that might be associated with plage development.
- TSI shows rotational modulation, but with *negative* excursions even in the absence of spots.
- F10.7 shows steady periods of extremely low variance even while TSI exhibits clear rotational modulation.

These properties suggest that the plage-like components of TSI might be more important at solar minimum. These occur even in the absence of sunspot-related TSI "dips" (Willson et al., 1981), as would be expected from the morphology of spot and plage occurrence. Enhanced network (e.g. Zwaan, 1987) might also be suggested as the origin of the TSI modulations, but in that case why does F10.7 not show them? Numerous ephemeral regions too weak to detect individually might also be invoked, but in this case why does TSI not reflect the rise seen in F10.7? These considerations imply that our standard decomposition of the TSI variability is too simplistic, and that additional, physically distinct mechanisms will need to be identified. We believe that the imaging observations of the Nobeyama Radioheliograph, and the broadband radio variability, will aid in this identification.

4.3 Polar brightenings

At 17 GHz the polar regions have anomalous brightness (Kundu and McCullough, 1972; Kosugi et al., 1986). We illustrate this with Figure 3, from Nindos et al. (1999). The possible association of these brightenings with polar faculae (Sheeley, 2008) would immediately suggest itself, except that the polar regions only appear to have brightenings only in the 17-81 GHz region (Kundu and McCullough, 1972; Kosugi et al., 1986). It is not clear what the photometric contributions at 10 cm (F10.7) and in TSI might be. We will undertake an analysis of these features.

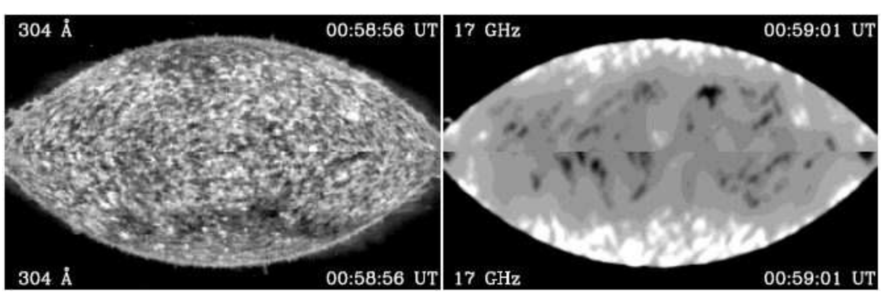

Figure 3: The 17 GHz polar brightenings (right) compared with 304Å (left) for 1997 March 19 (from Nindos et al., 1999) (middle solar latitudes omitted in this representation).

The interest in the polar brightenings are further enhanced by their close association with the polar magnetic field strength. Figure 4 shows the excess brightness temperature (from a baseline of 1.08 10^4 K) as a function of time compared with the solar polar field measured at Wilcox Solar Observatory (WSO). The sign of the brightness excess has been taken as that of the polar magnetic field. There is no explanation for this relationship and we propose to seek one. Both the solar-cycle variation and the annual B_0 angle modulations match closely. In addition there is a clear rotational modulation of the microwave signal in the polar cap, which is not seen in the WSO data due to the need for a 30-day smoothing. The Nobeyama polar field proxy is less noisy than the magnetograph measurements and could provide a basis for real-time, accurate polar field data for use in model calculations of the solar wind based of the photospheric magnetic field, where now a simple annual wave is artificially imposed.

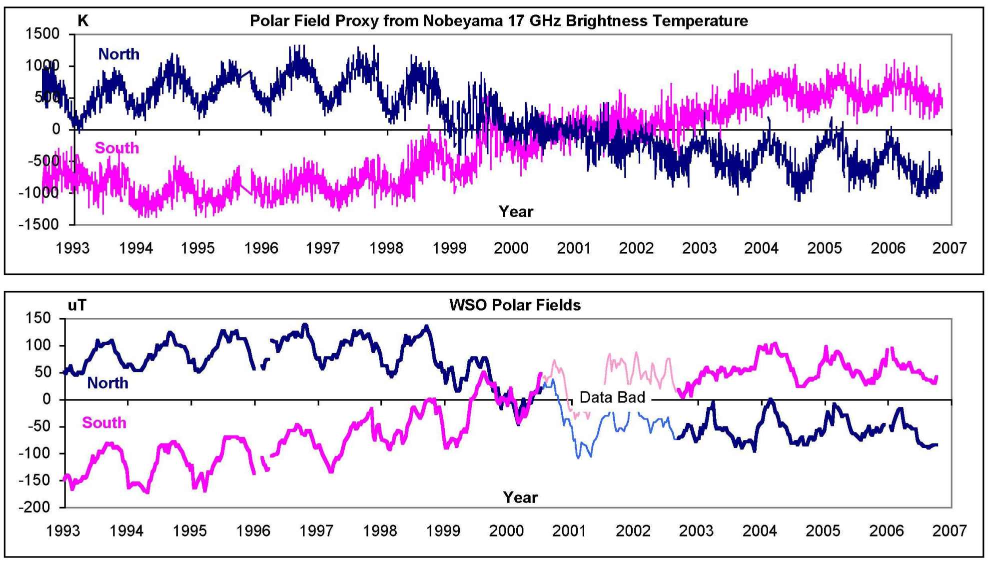

Figure 4: Comparison of Nobeyama polar brightness temperatures with WSO polar fields.

4.4 Behavior of faculae

The routine observations of the San Fernando Observatory (e.g. Chapman et al., 1996) have provided striking documentation of the different behavior of faculae and spots in the the current minimum. Figure 5 shows these data. That these data show a much lower level of faculae in the current minimum is not understood and not generally known. We do not know to what extent this striking effect is real, or whether there may be a calibration issue. We propose to work with the data providers (San Fernando Observatory) as well as to compare with other indices for the clarification of this issue. Is the current minimum unique in terms of faculae? Is this difference perhaps related to the difference between ACRIM and PMOD TSI composites? We propose to study the calibration from a unified point of view to seek answers to these issues.

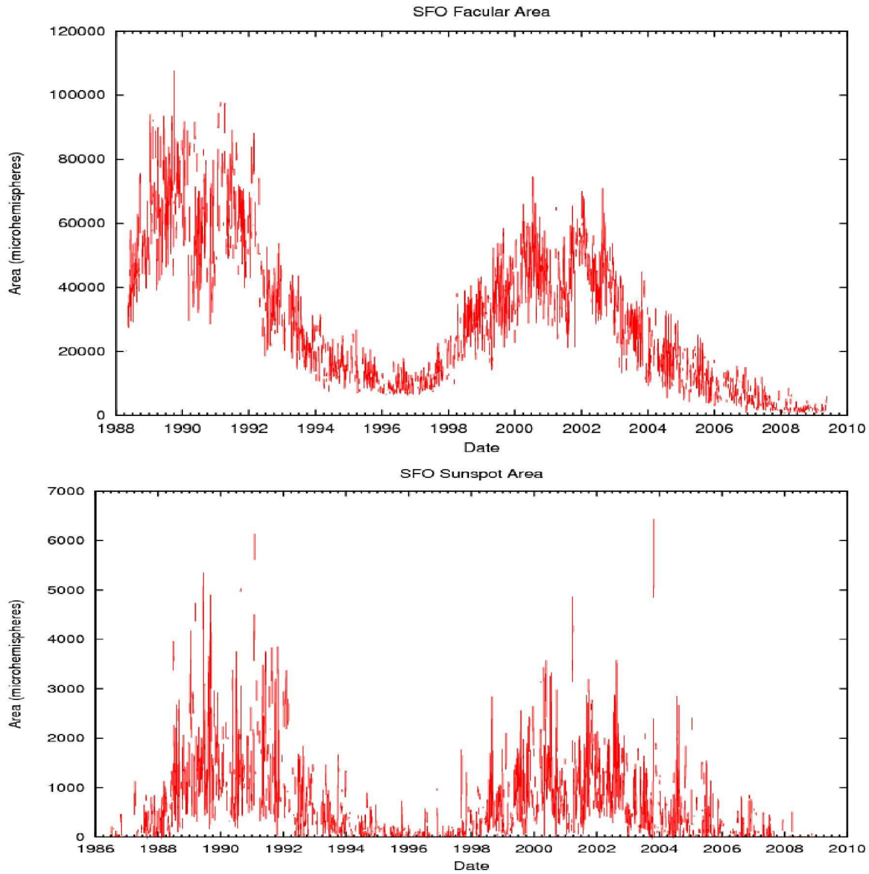

Figure 5: San Fernando Observatory observations of faculae (from Ca II) and spot area for the past two cycles. Note the absence of the facular signature in the current minimum, and its substantial presence in the previous one.

5 Secular variation of sunspot properties?

Careful photometry by Albregtsen et al. (1984) showed that sunspots have a secular variation across the cycle, in the sense that the umbral brightness increases systematically from beginning to end of a maximum (Figure 6, left). The observations extended over the two maxima from 1968 to 1983. This effect (the cycle-dependent brightness variation) has had no satisfactory explanation, even though the brightness increase amounted to as much as 20%. More recently Penn and Livingston (2006) have found something even more remarkable, namely that the magnetic field varies systematically along with the sunspot brightness. These measurements are made with direct Zeeman splitting in an umbral Fe I line (1564.8 nm), for which the splitting is complete at umbral field intensities. These data extend over 1990-2006 and also reveal a brightness increase of more than 20% over this time range – but apparently *secular* rather than periodic. Figure 6 (right) shows these variations, as derived from the full database obtained by Livingston. Penn and Livingston (2006) find umbral temperature increases of 73 K yr^{-1}, consistent with Maltby's results, and a decrease of the magnetic intensity of 52 G yr^{-1}. They comment "If.... the field strengths continue to decrease... then the number of sunspots in the next solar cycle would be reduced by roughly half." The observers, led by P. Maltby and W. Livingston, have unimpeachable reputations for observational work; there is little doubt in the community as to the validity of these observations even if there is no explanation yet forthcoming

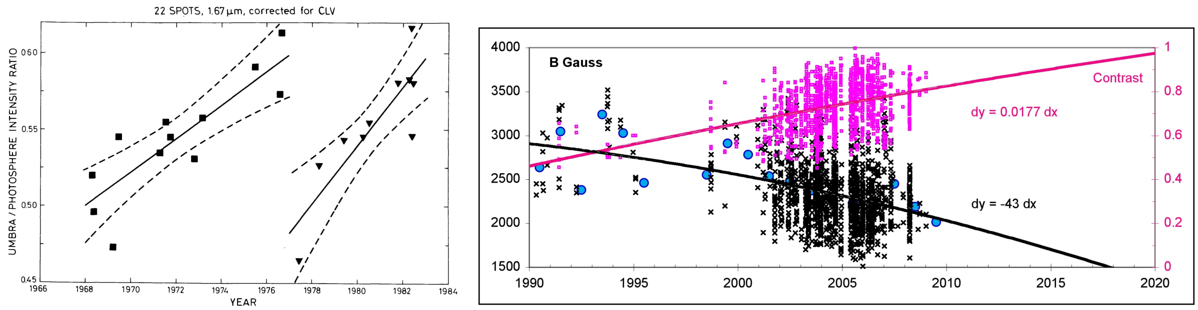

Figure 6: *Left:* Sunspot brightness increases recorded by Albregtsen et al. (1984); *Right:* Livingston database of sunspot brightness, again over about two cycles, but in this case showing a comparable *secular* variation. The plot shows both the increase of sunspot brightness, and the complementary decrease of the magnetic flux density.

Figure 7 illustrates something that must be closely related to this photometric result. It is the simple correlation of sunspot number versus F10.7. The data points since 1996 (the recent maximum) clearly lie outside the scatter range of the points prior to that time, which extend back to 1951. The discrepancy occurs across the board, for both large and small values. This excludes an interpretation in terms of non-linearity for small spots, for example. It is clear from this that a systematic variation of sunspot properties is occurring as we watch, and the first major spots of Cycle 24 will be extremely interesting from the point of view of the secular variations that have been observed. It is tempting to associate Livingston's sunspot brightening (and decreasing magnetism) with the remarkable properties of the current minimum.

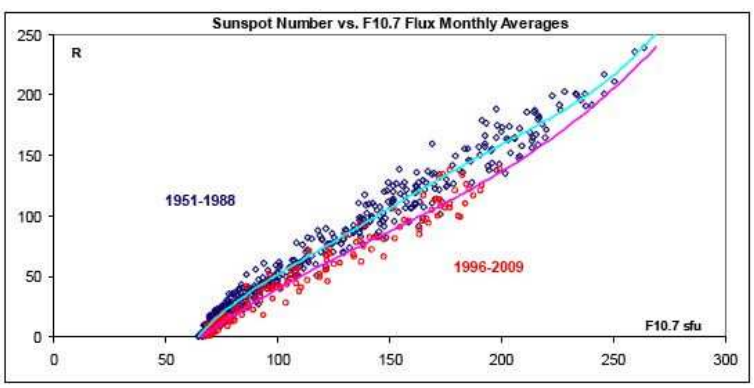

Figure 7: Correlation of F10.7 with SSN, showing the general deviation at all levels for the recent cycle.

This discrepancy between the current maximum and the previous ones, calibrated against F10.7, lends support to the suggestion from Livingston's sunspot measurements, namely that there is a secular variation. We show this also in Figure 8, which plots the ratio of observed and calculated sunspot number over the entire time span of the microwave observations.

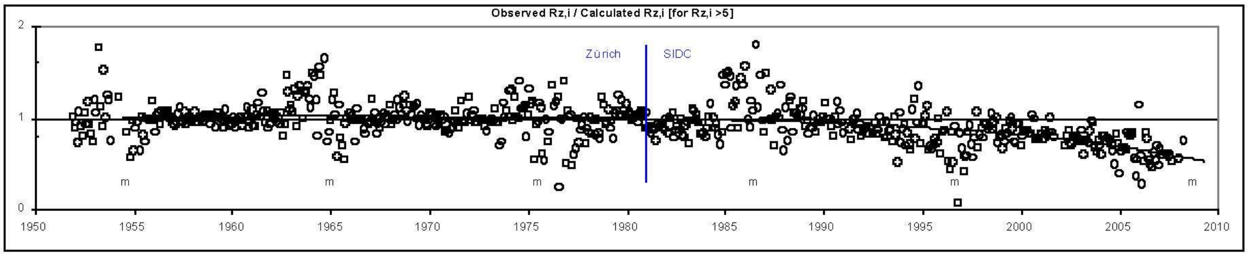

Figure 8: Ratio of observed and calculated versions of R_Z, showing the discrepancy that has been growing over the recent decade.

6 Summary

The current solar minimum is distinctly unusual in many ways, and at the time of proposal submission the increase to the next maximum had not appeared except, possibly, in terms of a weak increase in the F10.7 index. F10.7 is in general one of the cleanest and best-maintained indices, and its advantages include high contrast for magnetically active areas of various kinds (including the polar brightenings). The free-free opacity that is the main source of F10.7 at minimum is well understood quantitatively. In addition to the 10-cm (2.8 GHz) record, there is also a comprehensive database from Japan that has multiple fixed frequencies (1, 2, 3.75, and 9.4 GHz). We will use these data, as well as Nobeyama imaging data at 17 GHz, to help decipher the distinctly different low-level variability seen during the Cycle 23/24 minimum. We will then apply the knowledge gained to develop empirical methods for understanding this minimum and future solar variability. This will increase our understanding of the TSI variation, which is dominated at solar maxima by spots and faculae.

7 Research Plan

7.1 First Year

- Analyze the polar brightenings seen at 17 GHz during the Cycle 23/24 minimum.
- Establish calibrated global indices emphasizing radio data, as in the example of Figure 8; apply this to a definitive analysis of the unusual variation observed in the 23/24 minimum.
- Reduce and analyze Nobeyama imaging data to identify the spatial distribution of the *S*-component sources seen during the clear turn-up interval in early 2009.

7.2 Second Year

- Characterize the physics of the microwave *S*-component in the context of the known variability components of the TSI, and learn thereby whether or not this unique solar minimum will allow us to identify additional TSI compoenents.
- Search for photospheric counterparts of the unique solar-minimum variation terms. This analysis will include e.g. SOHO/MDI, GONG, or other sources of synoptic white-light data,

as well as RHESSI/SAS imaging and shape measures. The objective here will be to understand the solar global impacts of the variations seen at solar minimum, in the absence of confusing magnetic effects.

- Apply the knowledge gained to develop empirical methods for understanding future solar variability. This work will include the polar magnetic signatures developed by Svalgaard and Cliver.

8 The Investigators

The PI of this proposal, **Hugh Hudson**, has a long-standing interest in solar global variability. His contributions in this area include extensive work on the total solar irradiance. Hudson (1988) provides an overview of the early work on the ACRIM instrument on board the Solar Maximum Mission. More recently he has been working with precise measurements of solar oblateness and other global characteristics via the RHESSI optical observations (Fivian et al., 2008). Co-I **Leif Svalgaard** will carry out the bulk of the work. His interests broadly cover the subjects of solar magnetism (the Wilcox Solar Observatory), global solar variability, the solar wind, and the geomagnetic field, for example in the recognition of the sector structure of the solar wind. His prediction Svalgaard et al. (2005) of a small Cycle 24 appear to be on track. This work is based on his interest in solar polar fields, which currently motivate his work with the Nobeyama Radioheliograph data. Co-I **Gordon Hurford** has extensive experience in radio astronomy and in the precise interpretation of data from synthesis imagers (the VLA and OVRO radio data, and RHESSI X-rays and γ-rays in particular). He will provide advice on issues concerning radio astronomy. The non-U.S. Scientific Collaborators for this effort are **Kiyoto Shibasaki** (Nobeyama Radioheliograph) and **Ken Tapping** (Dominion Radio Astrophysical Observatory). These are the leading experts in the databases we will be studying (Nobeyama imaging, Japanese fixed-frequency monitoring, and the definitive F10.7 index), and in addition work actively in the interpretation of these data on a routine basis.

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Curriculum Vitae

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Infrared astronomy
Solar flares and CMEs
Solar coronal physics
Solar infrared/submillimeter astronomy
Solar radius
Solar energy distribution

Publications and presentations

Selected papers

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- Sterling, A. C. & Hudson, H. S. *Yohkoh SXT observations of X-ray "dimming" associated with a aalo coronal mass ejection*, ApJL 491, 55 (1997)

- Canfield, R. C., Hudson, H. S., and McKenzie, D. E., *Sigmoidal morphology and eruptive solar activity*, Geophysics. Res. Letters 26, 627 (1999)

- Khan, J. I. & Hudson, H. S. *Homologous sudden disappearances of transequatorial interconnecting loops in the solar corona*, GRL 27, 1083 (2000)

- Hudson, H. S., *Implosions in Coronal Transients* ApJ 531, L75-L77 (2000)

- De Pontieu, B., Martens, P. C. H., and Hudson, H. S., *Chromospheric damping of Alfven waves* ApJ 558, 859 (2001)

- Hudson, H. S., and Warmuth, A., *Coronal loop oscillations and flare shock waves* ApJ 614, L85, (2004)

- Hudson, H.S., Wolfson, C.J., and Metcalf, T.R., *White-light flares: A TRACE/ RHESSI overview* Solar Phys. 234, 79 (2006)

- Fivian, M. D., Hudson, H. S., Lin, R. P., Zahid, H. J., *A large excess in apparent solar oblateness due to surface magnetism* Science 322 (5901), 560 (2008)

Full listings

http://sprg.ssl.berkeley.edu/∼hhudson/publications.html
http://sprg.ssl.berkeley.edu/∼hhudson/presentations.html

Curriculum Vitae

Leif Svalgaard

Personal:

Birth: Copenhagen, Denmark, May 11, 1942
Address: 1592 Western Avenue, Petaluma, CA 94952
Telephone: +1-707-762-7213
E-Mail: leif@leif.org

Education:

Baccalaureate: Gladsaxe Gymnasium, Denmark, Science, 1961.
Undergraduate: Copenhagen University, Denmark, Physics, B. Sc, 1964.
Graduate: Copenhagen University, Denmark, Geophysics, Mag. Scient. 1968.

Employment:

Danish Meteorological Institute, Copenhagen (1964-1968).
A/S Regnecentralen, Software Developer (1969-1971)
Stanford University, Senior Research Associate (1972-1978)
Lockheed, Plainfield, NJ, Chief Programmer (1979-1983)
SEMA Group, Brussels, Belgium, Ingenieur en Chef (1984-1993)
T.O.S.C, Houston, TX, Director of Development (1994-1998)
Pentasafe, Houston, TX, Senior Developer (1999-2000)
AFRL, Hanscom AFB, MA, Research Contractor (2001-2003)
STEL, Nagoya University, Toyokawa, Japan, Visiting Professor (2004)
Stanford University, CA, HMI Team Member (2009-present)

Panels and Committees:

NASA/NOAA Panel for Prediction of Solar Cycle 24 (2006-2009).

Research Interests:

Solar Magnetic Fields and Indices
Geomagnetic Activity and Indices
Historical and Long-Term Solar and Geomagnetic Data

Selected Papers and Presentations

Svalgaard, L., *Recalibration of the Sunspot Number and Consequences for Predictions of Future Activity and Reconstructions of Past solar Behavior*, Solar Activity During the Onset of Solar Cycle 24, Dec, 2008, Napa CA, 2008. (Plenary talk).

Svalgaard, L. & E. W. Cliver, *The InterHourly-Variability (IHV) Index of Geomagnetic Activity and its Use in Deriving the Long-term Variation of Solar Wind Speed*, Journal of Geophysical Research, vol. 112, A10111, doi:10.1029/2007JA012437, 2007.

GORDON HURFORD - CV

Professional Preparation

B.Sc.	McGill University (1959-63)	First Class Honours in Physics
M.A.	University of Toronto (1963-1964)	(Theoretical) Physics
	Massachusetts Inst. of Technology (1964-66)	(Nuclear) Physics
Ph.D.	California Institute of Technology (1968-74)	(Space) Physics

Appointments

1998–	Research Physicist, Space Sciences Laboratory, University of California, Berkeley.
1977-98	Assoc Scientist --> Senior Scientist & Member of the Professional Staff, Solar Astronomy, Caltech.
1974-77	Research Fellow, Solar Astronomy, Caltech.
1968-74	Graduate Student, Space Radiation Lab, Caltech
1966-68	Lecturer, Physics Department, Xavier College, Sydney, Nova Scotia

Selected Publications

Proposal-related:

- D.E. Gary, G.J. Hurford, **Radio Spectral Diagnostics** in Solar and Space Weather Radiophysics**,** ed: D.E. Gary and C.U. Keller, Kluwer Academic Publishers, 71-87, 2004.
- Zirin, H., Baumert, B.M. and Hurford, G.J., **The Microwave Brightness Temperature Spectrum of the Quiet Sun**, Ap.J. 370, 779-783, 1991.
- G.J. Hurford, **Solar Radio Observations**, in The Sun: A Laboratory for Astrophysics, ed: J. T. Schmelz and J. C Brown, Kluwer Academic Publishers, 297-313, 1992.
- D.E. Gary, G.J. Hurford, **Coronal Temperature, Density and Magnetic Field Maps using the Owens Valley Solar Array**, Ap.J. 420, 903-912, 1994.
- G.J. Hurford, R.B. Read, H. Zirin, **A Frequency-Agile Interferometer for Solar Microwave Spectroscopy**, Solar Phys, 94, 413-, 1984.
- Marsh, K.A. and Hurford, G.J., **High Spatial Resolution Solar Microwave Observations,** Ann. Rev. Astron. Astrophys. 20, 497-516, 1982
- Wannier, P.G., Hurford, G.J. and Seielstad, G.A., **Interferometric Observations of Solar Limb Structure at 2.6 millimeters,** Ap.J.264, 660-666, 1983.

Other:

- G.J. Hurford, R.A. Schwartz, S. Krucker, R.P. Lin, D.M. Smith, N. Vilmer, **First Gamma-Ray Images of a Solar Flare**, Ap.J. 595, L77-L80, 2003.
- G.J. Hurford, E.J. Schmahl, R.A. Schwartz, A.J. Conway, M.J. Aschwanden, A. Csillaghy, B.R. Dennis, C. Johns-Krull, S. Krucker, R.P. Lin, J. McTiernan, T.R. Metcalf, J. Sato, D.M. Smith, **The RHESSI Imaging Concept**, Solar Phys. 210, 33-60, 2002.
- E.J. Schmahl, G.J. Hurford, **Observations of the Size Scales of Solar Hard X-Ray Sources**, Solar Phys., 210, 273-286, 2002.

Synergistic Activities

- 1998-present: As Imager Scientist, led the efforts in optical design, calibration and data analysis software for RHESSI, a NASA mission for imaging/spectroscopy of solar x-rays and gamma-rays.
- 1997-1998: Member, NAS-NRC Task Group on Ground-Based Solar Research
- 1995-present: Charter participant in the development of the Frequency-Agile Solar Radiotelescope
- 1993-1998: Conceived and co-developed the Solar Radio Burst Locator, an automated system for monitoring solar activity at microwave wavelengths
- 1980-1998: Conceived and co-developed the Owens Valley Frequency-Agile Interferometer and its evolution into the Owens Valley Solar Array, for microwave imaging/spectroscopy of solar flares and active regions

DR. HUGH HUDSON: CURRENT AND PENDING SUPPORT

A. Current Support

Project Title:	*High Energy Solar Spectroscopic Imager (HESSI) Investigation* P.I.: Robert Lin
Sponsor and POC:	NASA Goddard Space Flight Center; NAS5-98033
Period and Amount:	11/19/97-11/29/11; $60,829,711
FTE Work Years:	.25

Project Title:	*Solar Limb Astrometry with RHESSI*
Sponsor and POC:	NASA Goddard Space Flight Center; NNX07A141G
Period and Amount:	03/12/07-03/11/10; $325,881
FTE Work Years:	.75

B. Pending Support

Project Title:	*Solar Astronomy and Photometry with RHESSI*
Sponsor and POC:	NASA Shared Services Center
Period and Amount:	10/01/09-09/30/11; $328,893
FTE Work Years:	.25

DR. GORDON HURFORD: CURRENT AND PENDING SUPPORT

A. Current Support

Project Title:	*High Energy Solar Spectroscopic Imager (HESSI) Investigation*
Sponsor and POC:	NASA Goddard Space Flight Center; NAS5-98033 P.I. Robert Lin
Period and Amount:	11/19/97-11/29/11; $60,829,711
FTE Work-Years:	.50

Project Title:	*Software and Data Management Planning for the Frequency Agile Solar Radiotelescope*
Sponsor and POC:	National Radio Astronomy Observatory; 322667
Period and Amount:	10/01/08-09/30/09; $27,583
FTE Work-Years:	0.08

Project Title:	*Statistical Survey of Hard X-Ray Footprints in Solar Flares*
Sponsor and POC:	NASA Goddard Space Flight Center; NNX07AH74G
Period and Amount:	12/01/06-11/30/08; $143,491
FTE Work-Years:	0.17

B. Pending Support

Budget Narrative

For each year of this two-year project, we ask for funding for two months' salary for the PI (Hugh Hudson), six months' salary for the co-I Leif Svalgaard, and one week for co-I Gordon Hurford. Svalgaard will serve as a Visiting Research Physicist at Berkeley during this project. We also intend to employ Berkeley undergraduate student(s), to be named later, for small projects associated with the research. We request funding for visits to our foreign collaborators (Kiyoto Shibasaki and Ken Tapping). A visit to San Fernando Observatory is also likely but this is a local trip. At Nobeyama we will learn how to work with the imaging and radiometric databases, and at both NRO and DRAO we hope to achieve a deep understanding of the calibrations of the fixed-frequency radiometric observations.

We anticipate receiving this award as a grant.

Facilities and Equipment

All of the research described here will be carried out using existing facilities and equipment at the Space Sciences Laboratory and elsewhere. The Space Science Laboratory provides office space and other infrastructure for this work.

Summary of Personnel and Work Effort

	Role	Year 1	Year 2
Hudson	PI	.17	.17
Hurford	CO-I	.02	.02
Vstg Research Physicist	CO-I	.50	.50
Undergraduate Student	Student	.46	.46