Multi-Wavelength Investigations of Solar Activity
Proceedings IAU Symposium No. 223, 2004
A.V. Stepanov, E.E. Benevolenskaya & A.G. Kosovichev, eds.

DOI: 10.1017/S1743921304006945

Eight Years of SOHO

Bernhard Fleck

ESA Research and Scientific Support Department
c/o NASA/GSFC, Mailcode 682.3, Greenbelt, MD 20771, USA e-mail:
bfleck@esa.nascom.nasa.gov

Abstract. Since its launch on 2 December 1995, the joint ESA/NASA SOHO mission has provided a wealth of information about the Sun, from its interior, through the hot and dynamic atmosphere, to the solar wind and its interaction with the interstellar medium. At the same time, SOHO's easily accessible images and movies have captured the imagination of the science community and the general public alike. This article summarizes some of the key findings from 8 years of SOHO.

1. Introduction

The Solar and Heliospheric Observatory (SOHO) is a project of international cooperation between ESA and NASA to study the Sun, from its deep core to the outer corona, and the solar wind (Domingo *et al.*, 1995). Detailed descriptions of the scientific payload, the ground system, science operations and data products together with a mission overview can be found in Fleck *et al.* (1995).

An unexpected loss of contact occurred on 25 June 1998. Fortunately, the mission could be completely recovered in one of the most dramatic rescue efforts in space (Vandenbussche, 1999). After the loss of the last gyro in December 1998, engineers at ESTEC and Matra Marconi Space developed new flight software that allowed gyroless operation of the spacecraft using the reaction wheel speed measurements to monitor and compensate for roll rate changes. This made SOHO the first three-axis-stabilised spacecraft to be operated without a gyro.

With over 2000 articles in the refereed literature, it is impossible to cover adequately all the exciting work that has been done in the past eight years. Here we can only touch upon some selected results.

2. Irradiance Variations

The total solar irradiance (TSI) is measured by VIRGO with two types of radiometers, allowing a first independent and internally consistent determination of possible long-term changes. Fröhlich & Lean (2002) compiled the composite TSI from 1978 through 2002 with an overall precision of order $0.05\,\mathrm{Wm}^{-2}$ and a secular trend uncertainty of ± 3 ppm/year. They did not find any significant trend of TSI over the past 24 years.

In recent years there has been significant progress in modeling the TSI variations. Krivova *et al.* (2003) reconstruct irradiance variations from model atmospheres for the quiet Sun, sunspot umbra, penumbra, and faculae, with a contrast depending on the magnetic field strength. The areas of faculae and network are determined empirically from MDI magnetograms, and the areas of sunspot umbrae and penumbrae from MDI intensity images. While some would argue that such a "superficialist" interpretation of the origin of irradiance variations ignores potentially important subsurface physics, the agreement between the model reconstructions and the observations is remarkable.

3. Solar Interior Dynamics and Flows

3.1. *Solar Models and Neutrino Flux*

For many decades the solar neutrino puzzle has been one of the most fundamental unsolved problems in astrophysics. Helioseismology, by putting ever more stringent constraints on the neutrino flux emitted by nuclear reactions in the core (e.g. Turck-Chièze *et al.*, 2001), has played a key role in solving this puzzle.

3.2. *Still no g-modes*

Gabriel *et al.* (2002) performed a critical statistical analysis of over five years of GOLF data and found no statistically significant evidence for g-mode oscillations in the observed range of 150–400 μHz. They could set a new upper limit for the velocity amplitudes at the solar surface of 6 mm/s. The previous upper limit based on work by the Phoebus group (Appourchaux et al., 2000) was 10 mm/s.

3.3. *Core Rotation*

Couvidat *et al.* (2003) derived the radial rotation profile of the deep interior of the Sun from the analysis of low-order GOLF and MDI sectoral modes ($l \leqslant 3$, $6 \leqslant n \leqslant 15$, $|m| = l$) and LOWL data ($l > 3$). After removing the effects of the latitudinal variation of the rotation in the convection zone, they obtain a flat rotation profile down to $0.2\,\mathrm{R}_\odot$.

3.4. *Convection Zone Rotation*

The nearly uninterrupted MDI data yield oscillation power spectra with an unprecedented signal-to-noise ratio that allow the determination of the frequency splittings of the global resonant acoustic modes of the Sun with exceptional accuracy. The inversions of these data have confirmed that the decrease of the angular velocity Ω with latitude seen at the surface extends with little radial variation through much of the convection zone, at the base of which is an adjustment layer, called the "tachocline", leading to nearly uniform rotation deeper in the radiative interior (Schou *et al.*, 1998). Further a prominent rotational shearing layer in which Ω increases just below the surface is discernible at low to mid latitudes.

3.5. *Tachocline Oscillations*

Using data from MDI and the GONG network, Howe *et al.* (2000b) detected changes in the rotation of the Sun near the base of the convection zone, with unexpected periods of $\approx$1.3 year near the equator, possibly faster ($\approx$ 1 year) at high latitudes. The 1.3-year periodicity is in stark contrast to the 11-year period of the sunspot cycle.

3.6. *Zonal Flows*

¿From f-mode frequency splittings of MDI data, Kosovichev and Schou (1997) detected zonal variations of the Sun's differential rotation, superposed on the relatively smooth latitudinal variation in Ω. These alternating zonal bands of slightly faster and slower rotation show velocity variations of about ±5 m/s at a depth of 2–9 Mm beneath the surface and extend some 10 to 15° in latitude. Later studies (e.g. Howe *et al.*, 2000a) showed that these relatively weak flows are not merely a near-surface phenomenon, but extend downward at least 60 Mm (some 8% of the solar radius), and thus are evident over a significant fraction of the nearly 200 Mm depth of the solar convection zone. Indeed, Vorontsov *et al.* (2002), by applying a novel inversion method to the MDI rotational splitting data of 1996–2002, found evidence that these zonal shear flows (or "torsional oscillations") can penetrate to the bottom of the convection zone.

3.7. *Meridional Flows*

Meridional flows from the equator to the poles have been observed before on the solar surface in direct Doppler shift measurements. The time-distance measurements by Giles *et al.* (1997) provided the first evidence that such flows persist to great depths, and therefore may play an important role in the 11-year solar cycle. They found the meridional flow to persist to a depth of at least 26 Mm, with a depth averaged velocity of 23.5±0.6 m/s at mid-latitude. Since then several methods of local helioseismology have been used to measure the meridional flows in the upper convection zone and their changes with the solar cycle. Haber *et al.* (2002) studied how meridional circulation varies with depth over time, and found surprising evidence of the appearance and evolution of a submerged meridional cell during the years 1998-2001, which arose in the northern hemisphere and disrupted the orderly poleward flow and symmetry about the equator that is typically observed.

3.8. *Solar Subsurface Weather*

The “ring diagram” analysis of MDI Dynamics data by Haber *et al.* (2002) has also revealed persistent patterns of large-scale flows in the upper convection zone. These results led to a new concept of “Solar Subsurface Weather” connecting the effects of the synoptic flows to the development of solar activity.

3.9. *Farside Imaging*

Just a little over 4 years after the launch of SOHO, Lindsey & Brown (2000) published an astonishing result: the first successful, holographic reconstruction of solar farside features from p-mode oscillations observed on the visible hemisphere with MDI. In the meantime, the astonishing has become routine, and the SOHO MDI offers daily farside images on the Web. Another method to monitor solar activity on the far side of the Sun was developed by the SWAN team (Bertaux *et al.*, 2000).

3.10. *Subsurface structure of sunspots*

The high-resolution data from MDI have allowed new investigations about the structure and flows beneath sunspots. Kosovichev *et al.* (2000) found sunspot “fingers” – long, narrow structures at a depth of about 4 Mm, which connect the sunspot with surrounding pores of the same polarity. Pores which have the opposite polarity are not connected to the spot. Zhao *et al.* (2001) detected strong converging and downward directed flows at depths of 1.5–5 Mm, which they tentatively identified with the downdrafts and vortex flows in cluster models of sunspots. In deeper layers, 6–9 Mm, the sunspot region is occupied by a ring of upflows with almost zero velocity at the center. Strong outflows extending more than 30 Mm are found below the downward and converging flows. Their analysis also suggests that sunspots might be a relatively shallow phenomenon, with a depth of 5–6 Mm, as defined by their thermal and hydrodynamic properties.

3.11. *Emerging active regions*

There have been several attempts to detect emerging active regions in the convection zone before they appeared on the surface (e.g. Kosovichev *et al.*, 2000). It was found that the emerging flux propagates very rapidly in the upper 20 Mm, with a speed exceeding 1 km/s. Early detection of emerging active regions, therefore, may prove difficult without probing deeper into the convection zone.

3.12. *Supergranulation*

By applying the new technique of time-distance helioseismology to high resolution MDI data, Duvall *et al.* (1997) were able to generate the first maps of horizontal and vertical flow velocities as well as sound speed variations in the convection zone just below the visible surface. By using long series (up to 9 days) of subsurface flow maps obtained from MDI Dynamics data by time-distance helioseismology, Gizon *et al.* (2003) have studied the global dynamics of the supergranular flow pattern. They concluded that it has a significant wave-like component that may explain why this pattern rotates faster than magnetic features in the photosphere.

3.13. *Solar Oblateness*

High precision MDI measurements of the Sun's shape and brightness obtained during two special 360° roll maneuvers of the SOHO spacecraft have produced the most precise determination of solar oblateness ever (Kuhn *et al.*, 1998). There is no excess oblateness. These measurements unambiguously rule out the possibility of a rapidly rotating core, and any significant solar cycle variation in the oblateness.

4. Transition Region and Corona

4.1. *UV and EUV Spectral Atlases*

A far-ultraviolet and extreme-ultraviolet spectral atlas of the Sun between 670 Å and 1609 Å, derived from observations obtained with the SUMER spectrograph, identifies over 1100 distinct emission lines, of which more than 150 had not been recorded or identified before (Curdt *et al.*, 2001). Brooks *et al.* (1999) present the extreme-ultraviolet spectrum as observed in normal incidence by CDS. It covers the wavelength ranges 308–381 Å and 513–633 Å. In all over 200 spectral lines have been measured and about 50% identified.

4.2. *Explosive Events and Blinkers*

Explosive events have been studied extensively by a number of authors (e.g. Innes *et al.*, 1997; Chae *et al.*, 1998), who provided strong evidence that these features are the result of magnetic reconnection. Harrison *et al.* (1999) present a thorough and comprehensive study of EUV flashes, also known as "blinkers" (Harrison, 1997), which were identified in quiet Sun network as intensity enhancements of order 10–40% using CDS.

4.3. *Active Region Dynamics*

EIT, SUMER, and CDS observations have clearly demonstrated that the solar transition region and corona are extremely dynamic and time variable in nature and that plasma flows play an extremely important role. A comprehensive investigation of active region flows by Kjeldseth-Moe and Brekke (1998) demonstrates that high Doppler shifts are common in active region loops. Strong shifts are present in parts of loops for temperatures up to 0.5 MK. While typical values correspond to velocities of ±50–100 km/s, shifts approaching 200 km/s have been detected. At temperatures $T \geqslant 1$ MK only small shifts are seen. Fludra *et al.* (1997) show that loops with different temperatures can co-exist within an active region, sometimes very close to each other, but not really co-spatial, i.e. they occupy different volumes.

4.4. *Coronal Hole Temperatures*

David *et al.* (1998) have measured the electron temperature as a function of height above the limb in a polar coronal hole. Temperatures of around 0.8 MK were found close to the limb, rising to a maximum of less than 1 MK at $1.15\,R_\odot$, then falling to around 0.4 MK at $1.3\,R_\odot$. In equatorial streamers, on the other hand, the temperature was found to rise constantly with increasing distance, from about 1 MK close to the limb to over 3 MK at $1.3\,R_\odot$.

Wilhelm *et al.* (1998) determined the electron temperatures, densities and ion velocities in plumes and interplume regions of polar coronal holes from SUMER spectroscopic observations. They find the electron temperature T_e to be less than 0.8 MK in a plume in the range from $r = 1.03$ to $1.60\,R_\odot$, decreasing with height to about 0.33 MKK. In the interplume lanes, the electron temperature is also low, but stays between 0.75 and 0.88 MK in the same height interval.

One of the most surprising results from SOHO has been the extremely broad coronal profiles of highliy ionized elements such as oxygen and magnesium (Kohl *et al.*, 1997, 1999). Kohl *et al.* (1998) and Cranmer *et al.* (1999a) present a self-consistent empirical model of a polar coronal hole near solar minimum, based on H I and O VI UVCS spectroscopic observations. While the protons are only mildly anisotropic above 2–3 $R_\odot$ and never exceed 3 MK, the O VI ions are strongly anisotropic at these heights, with perpendicular kinetic temperatures approaching 200 MK at 3 $R_\odot$ and $(T_\perp/T_\parallel) \approx 10$–100.

4.5. *Coronal Heating*

A promising theoretical explanation for the high temperatures of heavy ions and their strong velocity anisotropies is the efficient dissipation of high-frequency waves that are resonant with ion-cyclotron Larmor motions (Cranmer *et al.*, 1999b).

In long, uninterrupted MDI magnetogram series a continuous flux emergence of small bipolar regions has been observed (Schrijver *et al.*, 1997, 1998). Small magnetic bipolar flux elements are continually emerging at seemingly random locations. These elements are rapidly swept by granular and mesogranular flows to supergranular cell boundaries where they cancel and replace existing flux. The rate of flux generation of this “magnetic carpet” is such that all of the flux is replaced in about 40 hours (Schrijver *et al.*, 1998), with profound implications for coronal heating on the top side and questions of local field generation on the lower side of the photosphere.

4.6. *EIT Waves*

Thompson *et al.* (1998, 1999) have discovered large-scale transient waves in the corona, propagating outward from active regions below CMEs. They generally propagate at speeds of 200–500 km/s, traversing a solar diameter in less than an hour. Active regions distort the waves locally, bending them toward the lower Alfvén speed regions. On the basis of speed and propagation characteristics, Thompson *et al.* associate the “EIT waves” with fast-mode MHD waves. Another interesting aspect of these waves is their association with the acceleration and injection of high energy electrons and protons (Torsti *et al.*, 1999).

4.7. *Hot Loop Oscillations*

Kliem *et al.* (2002) have discovered strong Doppler shift oscillations in SUMER observations of hot loops above active regions. Wang *et al.* (2003) give an extensive overview of hot coronal loop oscillations and identify them with slow magnetoacoustic standing waves in the loops. The periods are typically around 10 to 20 minutes, with a comparable decay time scale. These new and previously unexpected results may help to understand the heating of coronal loops, and open a new area of “coronal seismology”.

5. Solar Wind

5.1. *Origin and Acceleration of the Fast Solar Wind*

Coronal hole outflow velocity maps obtained with the SUMER instrument in the Ne VIII emission line at 770 Å show a clear relationship between coronal hole outflow velocity and the chromospheric network structure, with the largest outflow velocities occuring along network boundaries and at the intersection of network boundaries (Hassler *et al.*, 1999). This can be considered the first direct spectroscopic determination of the source regions of the fast solar wind in coronal holes.

Proton and O^{5+} outflow velocities in coronal holes have been measured by UVCS using the Doppler dimming method (Kohl *et al.*, 1997, 1998; Cranmer *et al.*, 1999a). The O^{5+} outflow velocity was found to be significantly higher than the proton velocity, with a very steep increase between 1.5 and $2.5\,R_\odot$, reaching outflow velocities of 300 km/s already around $2\,R_\odot$.

5.2. *Acceleration and Origin of the Slow Solar Wind*

Time-lapse sequences of LASCO white-light coronagraph images give the impression of a continuous outflow of material in the streamer belt. Density enhancements, or "blobs" form near the cusps of helmet streamers and appear to be carried outward by the ambient solar wind. Sheeley *et al.* (1997), using data from the LASCO coronagraphs, have traced a large number of such "blobs" from 2 to over 25 solar radii. Assuming that these "blobs" are carried away by the solar wind like leaves on the river, they have measured the acceleration profile of the slow solar wind, which typically doubles from 150 km/s near $5\,R_\odot$ to 300 km/s near $25\,R_\odot$. They found a constant acceleration of about $4\,\mathrm{m\,s^{-2}}$ through most of the $30\,R_\odot$ field-of-view. The speed profile is consistent with an isothermal solar wind expansion at a temperature of about 1.1 MK and a sonic point near $5\,R_\odot$.

Raymond *et al.* (1997) found evidence for gravitational settling in UVCS data, i.e. a depletion of heavy elements in the static core regions of closed magnetic field. The abundance along the edges of the streamer ("legs") resemble elemental abundances measured in the slow solar wind, suggesting the identification of streamers as the source regions of that wind component.

6. CMEs and Space Weather

The LASCO team has compiled an extensive list and catalog of the more than 6000 coronal mass ejections observed with SOHO since launch (Yashiro *et al.*, 2004) . The online catalog (http://cdaw.gsfc.nasa.gov/CME_list/) documents the observed properties of all CMEs observed by LASCO, such as central position angle, angular width in the plane of sky, heliocentric distance with time, average speed, and acceleration.

Fox *et al.* (1998) describe the first ever end to end tracking of a space storm (6–10 January 1997 event), from its eruption on the Sun to its impact at Earth.

Gopalswamy *et al.* (2003) studied the solar cycle variations of various properties of CMEs for cycle 23 (1996-2002). Among other findings, they report an order of magnitude increase in CME rate from minimum (0.5/day) to maximum (6/day), and an increase of the mean and median speeds of CMEs from minimum to maximum by a factor of 2.

Moran & Davila (2004) present the first three-dimensional reconstructions of CMEs, which were obtained through polarization analysis of single-view LASCO images.

7. Heliosphere

Costa *et al.* (1999) determined the temperature T_0 of interstellar hydrogen in the inner heliosphere from SWAN H-cell ($11,500 \pm 1500\,\mathrm{K}$). This is significantly above the temperature of the interstellar He flow, requiring a strong heating of more than 3500 K at the heliosphere interface. They also measured a deceleration of the interstellar hydrogen at the heliopause of 3.5 ± 1.0 km/s.

Quémerais *et al.* (1999) determined the apparent interstellar hydrogen velocity in the up- and downwind direction to -25.4 ± 1 km/s and $+21.6 \pm 1.3$ km/s, respectively. Their new estimate of the upwind direction is $252.3^\circ \pm 0.73^\circ$ and $8.7^\circ \pm 0.90^\circ$ in ecliptic coordinates, which is off by about 3°–4° from the He flow direction.

8. Comets

SOHO is providing new measurements not only about the Sun. As of the end of June 2004 LASCO has detected over 800 comets, most of them so-called sun-grazers. One comet was discovered by SWAN in Ly-α emission (Mäkinen *et al.*, 2000).

¿From UVCS spectroscopic measurements of comet C/1996Y1, the solar wind speed at 6.8 $R_\odot$ could be determined (640 km/s). The outgassing rate of the comet was determined at 20 kg/s, implying an active area of the nucleus of only about 6.7 m in diameter and a mass of about 120,000 kg (Raymond *et al.*, 1998).

Mäkinen *et al.* (2001) used the SWAN instrument to monitor the break-up of comet C/1999 S4 (LINEAR). The total amount of water vapour observed by SWAN from 25 May through 12 August 2000 was estimated at 3.3×10^9 kg. Only about 1% of this was left on 6 August, when observations by the Hubble Space Telescope of the dying comet's fragments gave an estimate of the total volume of the fragments. Combining the two numbers gives a remarkably low value for the density - about 15 kg/m^3, compared with 917 kg/m^3 for familiar non-porous ice.

Combi *et al.* (2000) observed the structure and evolution of the hydrogen Ly-α coma of comet Hale-Bopp (1995 O1) during its perihelion passage in the spring of 1997. The coma was more than 100 million kilometers wide, far exceeding the great comet's visible tail. The water evaporation rate of Hale-Bopp was measured at more than 200 million tons per day. The SWAN observations of Hale-Bopp have also shown something else extraordinary — the biggest feature ever observed in our solar system, namely the shadow of comet Hale-Bopp's coma projected on the sky behind it.

The analysis of UVCS spectroscopic observations of comet C/ 2002 X5 (Kudo-Fujikawa) has revealed a quasi-spherical cloud of neutral hydrogen and a variable tail of ionized carbon (C^+ and C^{2+}) that disconnected from the comet and subsequently regenerated (Povich *et al.*, 2003). C^{2+} has never been observed in a comet before. The high abundance of C^{2+} and C^+ relative to water (24%) is unexplainable by photodissociation of carbon monoxide but instead attributed to the evaporation and subsequent photoionization of atomic carbon from organic refractory compounds present in the cometary dust grains.

Acknowledgements

The great success of the SOHO mission is a tribute to the many people — too many to name here — who designed and built the SOHO spacecraft and instruments, and to the many people who diligently work behind the scenes to keep it up and running. SOHO is a project of international cooperation between ESA and NASA.

References

Appourchaux, T., Froehlich, C., Andersen, B., *et al.*: 2000, *ApJ* **538**, 401
Bertaux, J.-L., Quémerais, E., Lallement, R., *et al.*: 2000, *GRL* **27**, 1331
Brooks, D.H., Fischbacher, G.A., Fludra, A., *et al.*: 1999, *A&A* **347**, 277
Chae, J., Wang, H. , Lee, C.-Y., Goode, P.R., and Schühle, U.: 1998, *ApJ* **497**, L109.
Combi, M.R., Reinard, A.A., Bertaux, J.-L., *et al.*: 2000, *Icarus* **144**, 191
Costa, J., Lallement, R., Quémerais, E., *et al.*: 1999, *A&A* **349**, 660

Couvidat, S., García, R.A., Turck-Chièze, S., *et al.*: 2003, *ApJ* **597**, L77
Cranmer, S.R., Kohl, J.L., Noci, G., *et al.*: 1999a, *ApJ* **511**, 481.
Cranmer, S.R., Field, G.B., and Kohl, J.L.: 1999b, *ApJ* **518**, 937.
Curdt, W., Brekke, P., Feldman, U., *et al.*: 2001, *A&A* **375**, 591
David, C., Gabriel, A.H., Bely-Dubau, F., *et al.*: 1998, *A&A* **336**, L90.
Domingo,V., Fleck, B., and Poland, A.I.: 1995, *Solar Phys.* **162**, 1.
Duvall, T.L., Jr., Kosovichev, A.G., Scherrer, P.H., *et al.*: 1997, *Solar Phys.* **170**, 63
Fleck, B., Domingo, V., and Poland, A.I. (eds.): 1995, The SOHO Mission, *Solar Phys.* **162**
Fludra, A., Brekke, P., Harrison, R.A., *et al.*: 1997, *Solar Phys.* **175**, 487
Fox, N.J., Peredo, M., Thompson, B.J.: 1998, *GRL*, **Vol. 25, No. 14**, 2461
Fröhlich, C., Lean, J.: 2002, *Astron. Nachr.* **323**, 203
Gabriel, A.H., Baudin, F., Boumier, P., *et al.*: 2002, *A&A* **390**, 1119
Giles, P.M., Duvall, T.L., Jr., and Scherrer, P.H.: 1997, *Nature* **390**, 52.
Gizon, L., Duvall, T.L., Jr., Schou, J.: 2003, *Nature* **421**, 43
Gopalswamy, N. Lara, A., Yashiiro, S., Nunes, S., Howard, R.A.: 2003, ESA SP-535, 403
Haber, D.A., Hindman, B.W., Toomre, J., *et al.*: 2002, *ApJ* **570**, 855
Hassler, D.M., Dammasch, I., Lemaire, P., *et al.*: 1999, *Science* **283**, 810.
Harrison, R.A.: 1997, *Solar Phys.* **175**, 467.
Harrison, R.A., Lang, J., Brooks, D.H., and Innes, D.E.: 1999, *A&A* **351**, 1115.
Howe, R., Christensen-Dalsgaard, J., Hill, F., *et al.*: 2000a, *ApJ* **533**, L163
Howe, R., Christensen-Dalsgaard, J., Hill, F., *et al.*: 2000b, *Science* **287**, 2456
Innes, D.E., Inhester, B., Axford, W.I., and Wilhelm, K.: 1997, *Nature* **386**, 811.
Kjeldseth-Moe, O., Brekke, P.: 1998, *Solar Phys.* **182**, 73.
Kliem, B., Dammasch, I.E., Curdt, W., Wilhelm, K.: 2002, *ApJ* **568**, L61
Kohl, J.-L., Noci, G., and Antonucci, E., *et al.*: 1997, *Solar Phys.* **175**, 613.
Kohl, J.-L., Noci, G., Antonucci, E., *et al.*: 1998, *ApJ* **501**, L127.
Kohl, J.-L., Esser, R., and Cranmer, S.R., *et al.*: 1999, *ApJ* **510**, L59.
Kosovichev, A.G., Duvall, T.L., and Scherrer, P.H.: 2000, *Solar Phys.*, **192**, 159
Kosovichev, A.G., Schou, J.: 1997, *ApJ* **482**, L207.
Krivova, N.A., Solanki, S.K., Fligge, M., Unruh, Y.C.: 2003, *A&A* **399**, L1
Kuhn, J.R., Bush, R.I., Scheick, X., Scherrer, P.H.: 1998, *Nature* **392**, 155
Lindsey, C., Braun, D.C.: 2000, *Science* **287**, 1799
Mäkinen, T., Bertaux, J.-L., Combi, M.R., Quemerais, E.: 2001, *Science* **292**, 1326
Mäkinen, T., Bertaux, J.-L., Laakso, H., *et al.*: 2000, *Nature* **405**, 321
Moran, T.G., Davila, J.M.: 2004, *Science* **305**, 66
Povich, M.S., Raymond, J.C., Jones, G.H., *et al.*: 2003, *Science* **302**, No. 5652, 1949
Quémerais, E., Bertaux, J.-L., Lallement, R., and Berthé, M.: 1999, *JGR* **104**, 12 585.
Raymond, J.C., Fineschi, S., Smith, P.L., *et al.*: 1998, *ApJ* **508**, 410.
Raymond, J.C., Kohl, J.K., Noci, G., *et al.*: 1997, *Solar Phys.* **175**, 645
Sheeley, N.R. Jr., Wang, Y.-M., Hawley, S.H., *et al.*: 1997, *ApJ* **484**, 472.
Schou, J., Antia, H.M., Basu, S., *et al.*: 1998, *ApJ* **505**, 390.
Schrijver, C.J., Title, A.M., Harvey, K.L., *et al.*: 1998, *Nature* **394**, 152.
Schrijver, C.J., Title, A.M., van Ballegooijen, A., *et al.*: 1997, *ApJ* **487**, 424
Thompson, B.J., Gurman, J.B., Neupert, W.M., *et al.*: 1999, *ApJ* **517**, L151.
Thompson, B.J., Plunkett, S.P., Gurman, J.B., *et al.*: 1998, *GRL* **25**, 2465
Torsti, J., Kocharov, L., Teittinen, M., and Thompson, B.J.: 1999, *ApJ* **510**, 460.
Turck-Chièze, S., Couvidat, S., Kosovichev, A.G., *et al.*: 2001, *ApJ* **555**, L69
Vandenbussche, F.C.: 1999, *ESA Bull.***97**, 39
Vorontsov, S.V., Christensen-Dalsgaard, J., Schou, J., *et al.*: 2002, *Science* **296**, 101
Wilhelm, K., Marsch, E., Dwivedi, B.N., *et al.*: 1998, *ApJ* **500**, 1023.
Wang, T.J., Solanki, S.K., Curdt, W., *et al.*: 2003, *A&A* **406**, 1105
Yashiro, S., Gopalswamy, N., Michalek, G., *et al.*: 2004, *JGR*, submitted
Zhao, J., Kosovichev, A.G., Duvall, T.L., Jr.: 2001, *ApJ* **557**, 384