Towards the Measurement of Coronal Magnetic Fields

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**Abstract.** Measurements of components of the vector magnetic field in the solar corona can potentially yield information critical to our understanding of coronal structure, dynamics and heating. I briefly review the magnetic information contained in forbidden coronal emission lines, which appear to have the highest potential to address some outstanding problems in coronal physics, especially those related to the storage and release of magnetic free energy. In practice, measurements of the full Stokes vector of lines of magnetic dipole (M1) character can only constrain both the line-of-sight field strength, $B_\parallel$, through the longitudinal Zeeman effect seen in Stokes $V$ profiles, and the direction of the vector field projected onto the plane-of-the-sky, through the analysis of resonance scattering-induced linear polarization seen in Stokes $Q$ and $U$, in the so-called “strong field” regime of the Hanle effect. Coupled with additional data and models, such polarimetry can reveal information on coronal magnetic fields, including current systems, unobtainable by other means available now or in the near future. In special cases where the “atomic alignment” is known and line-of-sight integration problems are unimportant, even the vector field can in principle be recovered. Stereoscopic measurements may ultimately provide a reliable way to invert data in the general case. I discuss the current challenges presented by such measurements, and mention some recent progress made in the development of the needed instrumentation.

1. **Introduction**

The magnetic fields generated by dynamo action in the solar interior emerge through the solar photosphere, where they are buffeted by turbulent convective motions. The resulting injection of electromagnetic energy into the higher atmospheric layers results in forcing and heating of these layers, driving essentially all coronal phenomena, from heating mechanisms acting on the smallest scales, to large scale eruptions of magnetic flux seen as coronal mass ejections (CMEs).

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Measurements of the coronal magnetic field are badly needed to answer many outstanding questions. How good are specific MHD models of coronal structures, e.g., those for prominences, helmet streamers and their cavities? What is the nature of the change in coronal magnetic structure that accompanies the 11-year solar cycle's switch of magnetic polarity? How good are field extrapolations based upon vector-field measurements in the photosphere? What can we learn from discrepancies between extrapolated and measured magnetic fields? What can we learn about current systems in the corona, and the physical state of the corona as it responds to injection of magnetic energy from below? Can one develop techniques for predicting the probability that CMEs will be launched from a given set of coronal and/or photospheric magnetic-field measurements? Can one determine similar techniques for flares? Fortunately, such measurements appear to be within reach, thanks largely to significant advances in IR detectors over what was possible in the 1970s, and to the potential promise of new generations of reflecting coronagraphs.

While magnetic fields can in principle be sensed using a variety of techniques, the focus here is on the use of forbidden magnetic dipole (M1) transitions which require a coronagraph or eclipse. I briefly review the current status of this area. Much more detail can be found in the literature. The reader can refer to Judge et al. (2001) for a historical review of the general problem of measuring magnetic fields in the corona, methods that may be used, and the justification for the choice of M1 lines; The volume edited by Kuhn and Penn (1995) focuses considerable attention on the potential for infrared work in coronal physics, again using M1 lines; Judge (1998) searched theoretical solar spectra for M1 lines favorable for such measurements; a landmark detection of the Zeeman effect in coronal lines was made by Lin, Penn and Tomczyk (2000); Building on early work by Charvin, House, and especially Sahal-Bréchot, the theory of emission line polarization applied to coronal M1 transitions is presented by Casini and Judge (1999, henceforth CJ99).

2. A brief review of the formation of M1 lines

The formation of M1 lines in the corona involves solution of a set of NLTE statistical equilibrium equations for the magnetic sub-state populations of ions impacted by thermal particles and irradiated by the anisotropic solar disk radiation, in the presence of magnetic fields. In terms of the general quantum theory of scattered radiation from atomic ions in the presence of a magnetic field (e.g., Landolfi & Landi Degl’Innocenti 2003), coronal M1 lines are formed under some special (simplifying) conditions. First, the radiation field of interest, being optically thin, can be treated as fixed by the lower solar atmosphere, and can be taken directly from observations. It can be assumed to be unpolarized. Next, there is a natural ordering in energy:

\[ \text{Natural linewidth} \ll \text{Zeeman splitting} \ll \text{Doppler width} \approx \left( \frac{kT_i}{m_e c} \approx \frac{1}{10^4} \right) \hbar \omega, \]

where the central wavelength of the M1 line is \( \lambda = 2\pi c/\omega \). The first inequality means that the magnetic sub-states are fully split (Sahal-Bréchot 1977), the lines are formed in the so-called "strong field" limit of the Hanle effect, and
the atomic density matrix is diagonal in \((M,M')\) (i.e. no coherences), in the
standard wavefunction basis. In the irreducible tensor basis (Sahal-Bréchot 1977, CJ99),
the diagonality translates to \(\rho^K_0 = 0\) if \(Q \neq 0\). The second inequality
implies that the Zeeman-induced wavelength-dependent components of Stokes profiles
can be expanded using a Taylor series expanded to leading orders only.
These conditions lead to the set of explicit formulæ for the emission coefficients
(in the frame defined by the local magnetic field) for the Stokes vectors of an
M1 transition (e.g., Fe XIII 1.0747 \(\mu\)m), listed in section 4 of the paper by
CJ99. To highlight the diagnostic information contained in M1 line profiles,
these expressions are reproduced here. \(\varepsilon_i^{(i)}\) refers to the \(i\)th component of the
emission coefficient for Stokes vector \(i\), and \(j\) refers to the leading contributor to
the Taylor series expansion of the emission coefficient in wavelength (or energy):

\[
\varepsilon_0^{(0)}(\omega, \hat{k}) = C_{J_1 J_0} \phi(\omega - \omega) \left[ 1 + D_{J_1 J_0} \sigma_0^2(\alpha_0 J) \mathcal{T}_0^2(0, \hat{k}) \right],
\]

\[
\varepsilon_i^{(0)}(\omega, \hat{k}) = C_{J_1 J_0} \phi(\omega - \omega) D_{J_1 J_0} \sigma_0^2(\alpha_0 J) \mathcal{T}_0^2(i, \hat{i}),
\quad (i = 1, 2)
\]

\[
\varepsilon_3^{(1)}(\omega, \hat{k}) = -\sqrt{3} \omega_L C_{J_1 J_0} \phi'(\omega - \omega) \left[ \tilde{g}_{\alpha_0 J, \alpha_0 J_0} + E_{J_1 J_0} \sigma_0^2(\alpha_0 J) \right] \mathcal{T}_0^1(3, \hat{k})
\]

where \(C_{J_1 J_0} = h \omega / 4\pi N_{\alpha_0 J} A(\alpha_0 J \rightarrow \alpha_0 J_0)_{M1}\) is the emission coefficient (ignoring
stimulated emission) for the unpolarized transfer problem. The factors \(D_{J_1 J_0}\) and
\(E_{J_1 J_0}\) depend only on the angular momenta of the initial and final states of the
transition. \(\phi(\omega - \omega)\) is the line profile (in angular frequency units), \(\phi'(\omega - \omega)\) its
derivative wrt \(\omega\), and \(\omega_L\) the Larmor frequency. \(\tilde{g}_{\alpha_0 J, \alpha_0 J_0}\) is the Landé \(g\)-factor
of the transition. Note that, the leading orders in the Taylor expansion are 0 for
\(i = 0, 1, 2\) \((I, Q, U)\) and 1 for \(i = 3\) \((V)\). Hence the magnitude of the Stokes \(V\)
profile is a factor \(\omega_L (\phi' / \phi) \sim \omega_L / \Delta \omega_D\), where \(\Delta \omega_D\) is the Doppler width of the
line. The first order \(V\) term is many times smaller than the zeroth-order \(I, Q\)
and \(U\) terms. The scaling factor increases linearly with \(\lambda\).

The solutions of the statistical equilibrium equations enter equations (1)-(3) via the
atomic density matrix \(\rho^K_0(\alpha_0 J)\), \(K = 0, 2\), represented here simply as
the population density of the upper level \(N_{\alpha_0 J}\), and the “atomic alignment”
\(\sigma_0^2(\alpha_0 J) = \rho_0^2(\alpha_0 J) / \rho_0^2(\alpha_0 J)\). In the absence of circularly polarized incident radiation, the
\(K = 1\) component of \(\rho^K_0(\alpha_0 J)\) is not generated, and does not contribute to the
scattered radiation.

The tensors \(\mathcal{T}_0^K\) (here I drop the subscript “M1” used by CJ99) relate
the geometry of the magnetic field direction onto the LOS and the reference
direction for linear polarization measurements. In terms of the angles \(\Theta_B\) – the
inclination angle of the magnetic field along the LOS, and \(\gamma_B\) – the angle
between the reference direction for linear polarization measurements and \(\mathbf{B}\),
both projected onto the plane-of-the-sky (“POS”), they are

\[
\mathcal{T}_0^2(0, \hat{k}) = \frac{1}{2 \sqrt{2}} (3 \cos^2 \Theta_B - 1),
\]

\[
\mathcal{T}_0^2(1, \hat{k}) = \frac{3}{2 \sqrt{2}} \cos 2 \gamma_B \sin^2 \Theta_B,
\]

\[
\mathcal{T}_0^2(2, \hat{k}) = -\frac{3}{2 \sqrt{2}} \sin 2 \gamma_B \sin^2 \Theta_B, \quad \text{and}
\]

\[
\mathcal{T}_0^1(3, \hat{k}) = \sqrt{\frac{3}{2}} \cos \Theta_B.
\]
It is important for the following discussion to note that the alignment \( \sigma_0^2(\alpha_0 J) \) depends implicitly on the scattering and magnetic geometry – especially the height of a point above the photosphere, on the limb darkening function, and on the influence of a variety of collisional processes. For example, in the limit of strong (thermal) collisions, \( \sigma_0^2(\alpha_0 J) \) approaches zero. It is identically zero for special orientations of the magnetic field direction relative to the local direction to Sun center (the “Van Vleck” angle). It can approach a value comparable to the anisotropy factor of the incident radiation field, which can be of order unity (e.g., CJ99, equation 31), and can be positive or negative.

2.1. Diagnostic potential of M1 lines - ideal case

Let us imagine observations of M1 lines from one observatory, and that accurate maps of the Stokes profiles are available. Assuming (initially) that only one point contributes to the emission along a given LOS, we can ask: which properties of the coronal magnetic field can in principle be recovered from the Stokes profiles of M1 lines?

First, consider the \( Q, U \) profiles \((i = 1, 2)\). Their energy (or wavelength) dependence is identical to the \( I \) profile \((i = 0)\). Also, independently of the atomic alignment, \( \sigma_0^2(\alpha_0 J) \), the direction of the magnetic field in the LOS relative to the reference direction is given by \( \gamma_B = -\frac{1}{2}\arctan(U/Q) \), and has an associated \( \pm 90^\circ \) ambiguity. These properties led to the use of linear polarization measurements in the 1970s (e.g., Querfeld 1977, Arnaud 1982, Arnaud & Newkirk 1987) using relatively broad filters which did not resolve the line profiles, to examine the LOS field properties. This technique, applied to data with relatively poor angular resolution (\(~30 \times 30 \text{ arcseconds}^2\)) is still being used today (e.g., Habbal, 2003), but it has yet to be fully exploited using the imaging capabilities of new instruments.

Additional diagnosis of the emergent light in terms of magnetic properties of the corona requires knowledge of the atomic alignment, \( \sigma_0^2(\alpha_0 J) \). If \( \sigma_0^2(\alpha_0 J) \) were known \textit{a priori} for a given observation, measurements of \( I, P = \sqrt{Q^2 + U^2} \) could then be used to write \( P/I \) in terms of \( \sin^2\Theta_B \), from which \( |\Theta_B| \) could be determined with ambiguities of \( \pi \). With \( \gamma_B \) from above, the direction of the magnetic field is then known to within these ambiguities. The Stokes \( V \) to \( I \) profiles contain information on the LOS component of the magnetic field: again with prior knowledge of \( \sigma_0^2(\alpha_0 J) \), the modified magnetograph formula (equation 41 of CJ99) relating \( V \) to the derivative of \( I \) can be used to arrive at \( |B|\cos\Theta_B \). Taken together, it can be concluded that the M1 lines can in principle yield the vector magnetic field to within the \( 90^\circ \) ambiguity in the angle of the field projected on to the LOS, but \textit{only under these special conditions}.

2.2. Diagnostic potential of M1 lines - practical cases

Why then, does the abstract say that only the LOS component of the field strength and the direction of the component in the LOS can be generally determined from data from one viewpoint (e.g., earth-bound observatories)? Two important issues are involved: First, given just observations consisting of maps of the M1 polarization, the atomic alignment cannot be written down \textit{a priori}, simply because the position of the emitting plasma along the LOS and the collisional depolarization rates are not known. These two parameters essentially
determine the atomic alignment. Observations show that the alignment is significant (fractional linear polarizations $P/I$ of tens of percent have been routinely measured, e.g. Querfeld 1977). Second, the line-of-sight ("LOS") integration cannot be ignored. Both of these problems negate in practice the possibility of solving for $|\Theta_B|$ from $P/I$ measurements.

Consider first the case where LOS integration problems might be ignored. Then, the measured values of $P/I$ can yield only the product of the alignment factor with $\sin^2\Theta_B$ (combining equations 1,2,5 and 6). The $V/I$ measurements yield $B\cos\Theta_B$ times an alignment- and $\cos^2\Theta_B$- dependent correction factor (eq. 41 of CJ99). In effect, only the product $B\cos\Theta_B$ and $\gamma_B$ are then known (with the requisite ambiguity in the latter) from the observations, $\Theta_B$ is undetermined. One might then try to determine the alignment term by some calculations along the LOS, but then one faces the problem that it depends not only on the geometric considerations, but is also quite strongly dependent on collisions, and hence particle densities, which serve to depolarize the levels and reduce the alignment. For example, the ratio of the intensities of the $J = 2 \rightarrow 1$ and $J = 1 \rightarrow 0$ M1 transitions in Fe XIII at 1.0798 $\mu$m and 1.0747 $\mu$m respectively, are in fact sensitive to electron densities in the solar corona (e.g. Penn et al., 1994), showing that such issues are important in a practical sense. One might be tempted to invoke the filamentary nature of the corona, as determined from data obtained with the best EUV imagers (e.g., Aschwanden et al. 2000), to argue that LOS confusion is less important than if coronal plasma is more homogeneously distributed. However, these filaments are unresolved by the EUV instruments which have $\approx 1$ arcsecond angular resolution. Filamentary structures genuinely help the LOS integral problems only if it is spatially resolved in the POS. At the angular resolution of existing and anticipated coronagraphs, the confusion issue will be present.

The other case, when LOS integrations cannot be ignored but the alignment is somehow known, is surely academic, since it would require us to be able to specify the alignment factor along the LOS, which is an unlikely scenario. Nevertheless, it can be seen that the above analysis would break down anyway, even if just two structures contributed to the Stokes vector along each line of sight, because one has just one measurement of $P/I$ from which to try to determine two values of $\sin^2\Theta_B$.

Given these complications, it seems best to avoid the idea of diagnosing the magnetic structure from inspection or inversion of maps of M1 Stokes data obtained from just one observatory. Instead it would seem more profitable to rely on forward calculations of the M1 data and make direct comparisons with them. In this regard, very recent calculations of M1 Stokes parameters performed with some new solutions for coronal magnetic structures involving current sheets from Fong, Fan and Low (2002), indicate that the $Q,U,V$ parameters of the lines are indeed sensitive to the presence of the current sheets, even under quite homogeneous (radially symmetric) thermal conditions. The lines indeed show promise for addressing the nature of free energy stored in the corona.

I should mention the one potential simplification in the interpretation of the Stokes profiles of M1 coronal lines. Unlike the photosphere, the magnetic field essentially fills the coronal volume: the plasma $\beta$ (the ratio of plasma to magnetic pressure) is $\ll 1$. Thus, unless the emitting plasma is concentrated
into thin current sheets where $|\nabla \times \mathbf{B}|$ is large but $|\mathbf{B}|$ is very small, the QUV Stokes profiles reflect conditions where the field strength is $\approx B_0$ where $B_0$ characterizes the volume filling field strength.

2.3. Diagnostic potential of M1 lines- Stereoscopic observations

It is worth noting that, as proposed by J. Kuhn (private communication, 1999), stereoscopic observations of M1 lines will greatly help in the determination of the magnetic structure of the corona, if they can be made. For example, the positions of the dominant contributor to the emergent Stokes vectors along each LOS can be determined. This knowledge helps enormously in determining the alignment factor. While the exact framework in which the inverse problem (determination of $\mathbf{B}$ from sets of stereoscopic observations) has still to be developed, it is obvious that the specific problems associated with LOS integrations and lack of knowledge of the atomic alignment factors can to a significant extent be addressed. I envisage posing the problem so that the vector magnetic field, alignment factors and some other thermodynamic properties are solved for at each point in a given volume.

We are far from realizing true stereoscopic capabilities. Solar rotation might help, if it can be shown that evolution of the features can be ignored. This will not always be the case (if ever), thus a dedicated spacecraft instrument will be needed in addition to the ground-based efforts which are under way (see below).

3. Photon budgets, coronagraph noise

For the foreseeable future, measurements of M1 lines will be made only from the ground. Judge et al. (2001) assessed the merits of various M1 lines observable from the ground, as diagnostics of magnetic fields in the corona. The following estimates of exposure times were modified\(^1\) from those derived by Judge et al. (2001). They are determined from photon-noise alone, ignoring atmospheric and instrumental scattered light:

$$t_I \approx 0.002 \text{s} \left( \frac{\text{snr}}{3} \frac{1''}{\text{px}} \frac{40}{D} \right)^2 \frac{1}{\lambda} \frac{20}{I} \frac{10}{E} \frac{N_\lambda}{7},$$

$$t_{Q,U} \approx 20 \text{s} \left( \frac{\text{snr}}{3} \frac{1''}{\text{px}} \frac{40}{D} \frac{0.01}{(Q \text{ or } U)/I} \right)^2 \frac{1}{\lambda} \frac{20}{I} \frac{10}{E} \frac{N_\lambda}{7},$$

$$t_V \approx 2000 \text{s} \left( \frac{\text{snr}}{3} \frac{1''}{\text{px}} \frac{40}{D} \frac{10}{B_{||}} \frac{1.5}{g_{eff}} \right)^2 \frac{1}{\lambda^3} \frac{20}{I} \frac{10}{E} \frac{N_\lambda}{7},$$

where px is spatial pixel size [arcsec], $D$ is the telescope objective diameter [cm], $B_{||}$ is the LOS field strength [G], $\lambda$ the wavelength [$\mu$m], $I$ the wavelength integrated line intensity, [erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$], at 1 $\mu$m this is numerically the same as the brightness in milliarcseconds of the disk intensity, $E$ is the total efficiency [%],

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\(^1\)I have here corrected a factor of 10 error made in converting energy to photon fluxes by Judge et al.- the value $1.1 \times 10^{12}$ in their Table 5 should read $1.1 \times 10^{13}$ ph cm$^{-2}$ s$^{-1}$ sr$^{-1}$, the incorrect value was erroneously used by Judge et al. in their discussion.
Towards the Measurement of Coronal Magnetic Fields

443

and $N_\lambda$ is the number of wavelength pixels across the FWHM of the line. \textit{snr} is the desired signal-to-noise ratio.

At 1 \(\mu\text{m}\) and with \(D = 40\text{cm}\), \(\lambda/D \equiv 0.5\) arcseconds. The above figures therefore have values of \(px\) that are twice the diffraction limit. To make Stokes \(V\) profile measurements in a reasonable observing time (say 5 minutes), one should observe with pixel sizes factors of several larger than this.

These figures show why measurements of the Zeeman effect in the corona have been very difficult to obtain, but of course they are only a part of the story. Coronal observations are complicated by the proximity of the solar disk, which is 5 orders of magnitude times brighter than the solar corona, and by the presence of atmospheric seeing and scattering resulting in a large and temporally varying polarized background. Such observations require the use of a coronagraphic instrument with very low scattered light and which occults the solar disk.

Recent work with D. Elmore has shown that under the best conditions at a good coronagraphic site, in this case Mauna Loa, the background is compatible with photon noise limited signals. In this case the above exposure times may not be unreasonable. However, under conditions of brighter, fluctuating, polarized backgrounds, the exposure times will be substantially higher. For example, under upslope wind conditions that occur later in the day (after 19:00 UT) at Mauna Loa, the coronagraph data show evidence for strongly polarized flashes associated with the passage of particles or “bugs” through the telescope beam. Such “bugs”, when present, have to be dealt with carefully, because they can induce spurious signals via polarization crosstalk. This source of noise may be especially problematic when, as is the case for the M1 emission lines, some of the Stokes parameters \((I, Q, U)\) exceed the others \((V)\) by orders of magnitude.

I note that the desired solar signals increase with telescope diameter \(D\) as \(D^2\), but the number of “bugs” crossing a beam of diameter \(D\) per unit time scales with \(D^1\), and the duration of the flash from each bug also scales with \(D^1\). Work is currently in progress to determine how best to deal with such noise.

4. New initiatives to measure coronal magnetic fields

I am aware of three groups currently aiming to develop the new instrumentation needed for the measurement of M1 lines

- the University of Hawaii SOLAR-C project, the basis of which is a 50 cm diameter reflecting coronagraph on Haleakala (Kuhn et al. 2002),

- the HAO coronal magnetic field initiative, currently focusing on focal plane instrumentation prior to the development of a new instrument devoted to the synoptic measurement of M1 lines in the corona, focusing on the 1 \(\mu\text{m}\) region,

- the NSO-led ATST project (http://atst.nso.edu/), the next large telescope for solar physics in the US.

All three projects take advantage of the benefits available by observing in the infrared region (see, e.g., Kuhn & Penn 1995): all other factors being equal, IR lines have enhanced Zeeman sensitivity; there are strong infrared lines (Fe XIII
1.0747, 1.0798 μm; Si IX 3.9343 μm which has recently been measured by Judge et al. 2002); the atmospheric and instrumental scattering and polarization is reduced compared with visible light; seeing is substantially improved. The last two points make possible observations closer to the solar limb than usually available at visible wavelengths. This will be important for answering some of the questions posed in the Introduction. It is worth noting that some of the problems associated with significant alignment factors are reduced naturally by observing lines farther into the infrared region: atomic and solar properties conspire to enhance the role of collisions and reduce the role of photo-excitation, thereby reducing the alignment. The SOLAR-C project has already detected coronal light, and holds significant promise for performing the needed ground work for the much larger ATST which will begin operations hopefully ca. 2010. The ATST and HAO projects have a significantly different emphasis: ATST, with its 4m diameter, has the capability of capturing the high signal-to-noise data required for the Stokes V polarimetry in very little time, and for revealing relatively high spatial resolution images (1 × 1 arcseconds², perhaps smaller) of relatively small regions (3 × 3 to 5 × 5 arc-minutes² areas) of the solar corona. In contrast, HAO's initiative ultimately aims to build a new 0.5m-1m coronagraph exclusively for infrared emission line measurements in the corona near 1 μm, including the Hanle-sensitive line of He I at 1.0830 μm, and to obtain synoptic images of the entire corona. S. Tomczyk has developed a novel quad beam splitting filter designed to obtain simultaneous measurements of orthogonal polarization states both on and off-band, sidestepping some of the important cross-talk problems. Initially this instrument with a new 1024 × 1024 camera (on order) will be tested at NSO's 20cm coronagraph (built by R. Smartt) at Sacramento Peak Observatory. The overall plan is that experience with this instrument will enable HAO, with the solar community, to develop and build a new coronagraph which will form the next centerpiece of HAO's historic coronal observing system. The physical problems that can be addressed by the ATST and HAO projects certainly overlap to some degree, but the synoptic emphasis of the HAO project cannot be achieved with the ATST. The close-up view of the corona promised by ATST at high time cadence is something only an instrument with a large aperture can achieve.

5. Conclusions

The solar and solar-terrestrial communities need to constrain magnetic fields within the corona, because much of the important physical phenomena are driven by the free energy contained within the coronal magnetic field and its interaction with solar plasmas. The M1 lines offer one useful avenue that should be pursued. Recent work supports use of the 3.028 and 3.934 micron lines, so both the SOLAR-C and ATST projects, being based on reflecting telescopes, present us with a real opportunity, not only for its own sake, but for space weather applications, and to complement other efforts attempting to understand the role of magnetic fields in the corona (e.g. radio work). At HAO we aim to obtain routine (daily) measurements of the 1.0747, 1.0798 μm Fe XIII lines, and the He I 1.0830 μm lines, and our emphasis has been in the development of focal plane instrumentation, complementing the SOLAR-C and ATST projects.
Acknowledgments. I am very grateful for D. Elmore for providing data from Mauna Loa’s Mk IV K-coronameter, to Roberto Casini for his usual careful critique of this manuscript, and to them and Steve Tomczyk and B.C. Low for their continued interest and work in support of coronal magnetometry at HAO. I am indebted to the (other) conference organizers for the invitation to speak and for generous financial support to attend the meeting.

References

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Discussion

V. BOMMIER: From a theoretical point of view, in the “strong field” regime of the Hanle effect, the linear polarization Stokes parameters Q and U are sensitive to the full magnetic field direction projected on the plane of the sky. The linear polarization is also sensitive to the direction of the magnetic field relative to the line of sight.
P. JUDGE: I took the liberty of addressing this question in the text, because it fit so nicely into the narrative- please refer to sections 2.1 and 2.2.