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Contributions by R. G. Giovanelli to the Study of Magnetic Field Structures*

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Abstract

R. G. Giovanelli was appointed as a Visiting Scientist at Kitt Peak National Observatory for six months in both 1975 and 1979, and then for an entire year in 1981. These times proved fruitful to him as well as to the Observatory. The Vacuum Telescope and its 512-channel magnetograph had been completed and were operational. Complementing this was a new powerful 2D image analysis machine called the Interactive Picture Processing System (IPPS). For the first time, solar surface features could be quantitatively observed, usually to a seeing limited resolution composed of arcsec pixels, and then readily analysed as pictures. As is often the case, those who built the instruments remained preoccupied with their perfection, and it fell to Giovanelli to put these new tools to effective use. He did this in a series of research efforts reviewed in the present paper. Happily, he drew many of us in Tucson into his projects, injecting us with enthusiasm and enlarging our knowledge of solar physics in the process.

1. Motions in Magnetic Tubes

With the possible exception of the magnetic fields associated with sunspots, solar surface magnetic elements are never fully resolved because they are sub-arcsec in size and in practice observation resolution is limited by atmospheric seeing and optical imperfection. Filling factors for the smeared magnetic component run a tenth, or less. To sort out the magnetic from the non-magnetic Doppler velocities Giovanelli invented a clever scheme called the Line-Center-Magnetogram (LCM). The LCM method (Giovanelli and Ramsay 1971) makes use of the fact that the Zeeman polarization signal goes to zero when the detector (array) is centred in wavelength on the magnetic component of the spectrum line.

Giovanelli had long been curious about the apparent downflows of gas associated with magnetic tubes on the disc. To investigate this downflow as a function of height in the atmosphere and independent of spatial resolution or the confusion of oscillatory and granular velocities, he and C. Slaughter made a series of full disc 512 magnetograms with a single array positioned near line centre (i.e. the LCM technique) and utilizing spectral lines formed at differing heights. Solar rotation across the disc introduces a diagnostic Doppler shift. By employing full disc data there is

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immediate discrimination against the localized contribution of oscillatory motions and granulations. A visual inspection of these LCM records reveals that magnetic elements clearly disappear (or have a minimum contrast) in a band of heliographic longitudes corresponding to the mean Doppler shift of downflow appropriate to the spectrum line observed. Certain complications, such as that due to differential rotation, are eliminated if the position of the detector is displaced initially so that minimum contrast occurs along the central meridian.

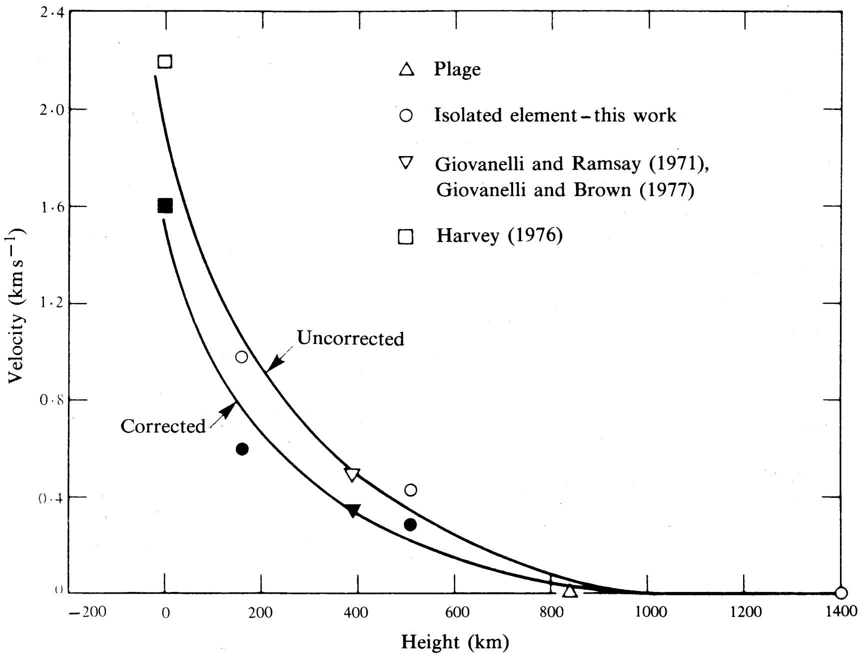

Fig. 1. Velocity of the steady component of gas flow in magnetic elements as measured in various lines, plotted against the approximate height of formation in the non-magnetic atmosphere. The lower curve is corrected for the wavelength shift of the reference integrated line profiles due to the brightness–velocity correlation, while the upper curve is the same except uncorrected. [From Giovanelli and Slaughter (1978).]

The Giovanelli and Slaughter (1978) results are summarized in Fig. 1. They found that the downflow of matter in magnetic tubes ranges from $0 \cdot 6\ \mathrm{km\,s^{-1}}$ at the lowest photospheric level, as sensed by C 9111, to near zero for the low chromospheric line of Ca II 8542. Giovanelli (1977) also provided a theoretical argument for the inflow of neutral gas into the tubes and its subsequent downflow.

Giovanelli next applied the LCM technique to the study of oscillatory motions and wave propagation in individual magnetic tubes. The expectation was that detailed measurements of oscillatory period and phase in the magnetic tubes relative to the surrounding non-magnetic gas would provide information on physical conditions within the tubes. For this work the Kitt Peak dual-channel magnetograph was employed with one channel sensing the Zeeman profile (as a LCM) and the other channel the unpolarized non-magnetic line profile. A servo-driven tipping glass plate served to keep the V Stokes profile signal at zero and thus tracked the magnetic component even when the filling factor was as small as a ratio of 20 : 1. To his surprise, and to a certain extent disappointment, it was found that the oscillatory behaviour of the gas within magnetic tubes mimicked closely its non-magnetic surroundings as shown in Fig. 2 (Giovanelli *et al.* 1978*b*). The hoped for probing of internal conditions in the tubes had failed. (On rereading the paper today no such failure is conveyed; this being a testimony to Giovanelli's positive perspective.)

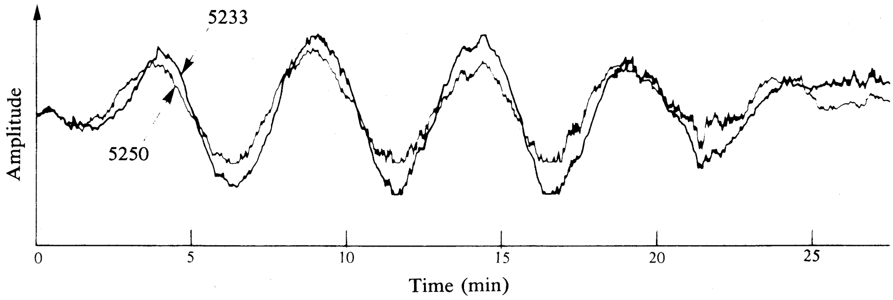

Fig. 2. A well-defined packet of oscillations observed simultaneously in Fe 5233 (non-magnetic) and Fe 5250 (magnetic-LCM technique) showing the similarity of the tracings and the fact that the magnetic and non-magnetic plasma is indistinguishable in terms of its response to oscillations. [From Giovanelli *et al.* (1978*b*).]

Table 1. Properties of umbral oscillations derived by the LCM technique [from Giovanelli *et al.* (1978*a*)]

These amplitudes can be compared with those found on the quiet disc which are approximately $1\cdot0$ km s^{-1}

Identification	r.m.s. velocity (km s^{-1})				Weighted
	Spot A	Spot B	10 Dec. 76	9 Mar. 77	mean
Hα	$\pm0\cdot49$	$0\cdot72$			$\pm0\cdot62$
b_1				$0\cdot20$	$0\cdot20$
5233 Å	$0\cdot11$	$0\cdot086$	$0\cdot12$		$0\cdot10$
5166 Å				$0\cdot17$	$0\cdot17$
5250 Å			$0\cdot055$		$0\cdot055$

Yet another application of the LCM technique involved the study of wave propagation in sunspot umbrae. In this instance the LCM method offered the advantage of complete freedom from the interference of scattered photospheric light into the dark umbrae. Again the dual-channel magnetograph was used with pairs of lines of differing origins being observed; e.g., Hα and Hγ, Hα and Fe 5233, or Fe 5233 and Fe 5250. The principal finding from this work was a substantial phase lag between chromospheric Hα and low level Fe 5233 (see Table 1), demonstrating that the waves are propagating outward (Giovanelli *et al.* 1978*a*). Another result was that within the wave periods to which the instrument was sensitive, say 7^s to 1000^s, the mechanical energy flux observed proved negligible as an agent for cooling the spot.

2. Unipolar versus Mixed-polarity Fields

Full disc magnetograms taken near sunspot minimum and near maximum obviously look dissimilar and Giovanelli attempted to quantify this difference. Specifically, he wanted to understand the solar cycle dependence of unipolar fields relative to mixed-polarity fields. In any region there will be found both N and S polarities. Giovanelli defined a region to be of *mixed polarity* if $0 \cdot 4 \leqslant B_{\text{minor}}/B_{\text{major}} \leqslant 1$; otherwise, it is *unipolar*.

From selected full disc magnetograms covering the years 1975–80, or minimum to maximum in the activity cycle, Giovanelli patiently sampled field strength areas as a function of solar latitude and date. To do this the data had to be destreaked (i.e. a certain line-by-line instrumental bias removed), displayed on the IPPS comptol and then measured. This required many tens of hours and in another place and era this consuming task would have been relegated to an assistant; however, Visiting Scientists are not so provisioned. Besides, it is certain Giovanelli considered this task so critical that his personal attention was a necessity.

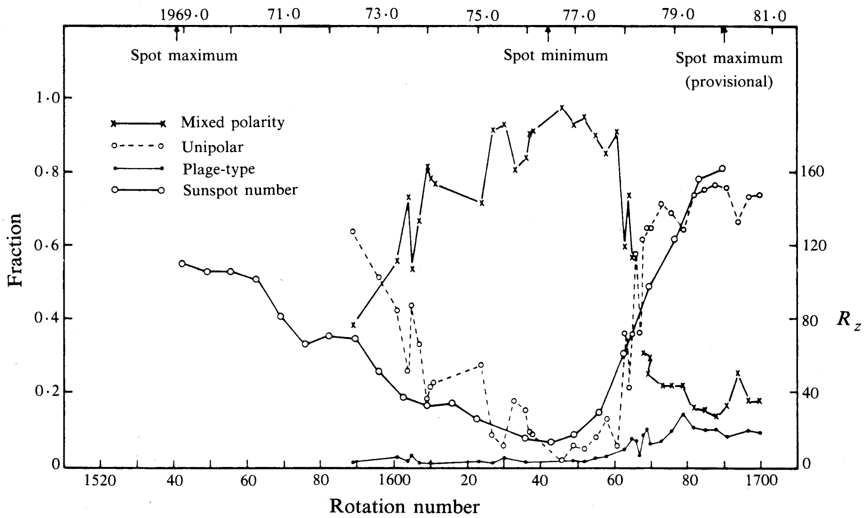

Fig. 3. Fraction of the solar surface area between $\pm 60°$ latitude occupied by various classes of field as a function of time. The sunspot number R_z is also plotted. [From Giovanelli (1982).]

In his paper 'On the relative roles of unipolar and mixed-polarity regions' (Giovanelli 1982) the field strengths and solar cycle dependence of these categories were summarized. Fig. 3, from that paper, clearly indicates the changing role of unipolar versus mixed polarity over the solar cycle. In this same study he also re-evaluated the strength of the hard-to-observe polar fields by recognizing them to be unipolar and then calibrating them by a comparison with analogous equatorial features and their centre-to-limb variation at the equator. The strength of polar fields is of interest because it has been proposed that strength is an observable precursor to the magnitude of activity in the following solar cycle.

3. Magnetic Canopies

Full disc magnetograms taken in the moderately strong line of Fe 8688 invariably display diffuse fringes of reverse polarity on the limbward side of plage regions away from disc centre. This fringing effect is even more pronounced in the high level line of Ca II 8542, but is almost absent in low lying C 9111.

Giovanelli became fascinated by this field fringing for which he coined the term 'canopy'. He sensed that the presence of these magnetic canopies ran counter to conventional concepts as to how magnetic fields emerge and loop into space above the surface. Instead of the usual loop geometry he hypothesized an extensive layering of field structure nearly parallel to the surface and perhaps only two or so scale heights above it, as shown in Fig. 4. To explore this idea, however, was to be no small undertaking. He needed help to make further clarifying observations (this being now physically impossible for him), and help on the problem of a suitable atmospheric model to better define the canopy heights. Harrison Jones expertly provided that assistance and collaborated with Giovanelli on a series of papers.

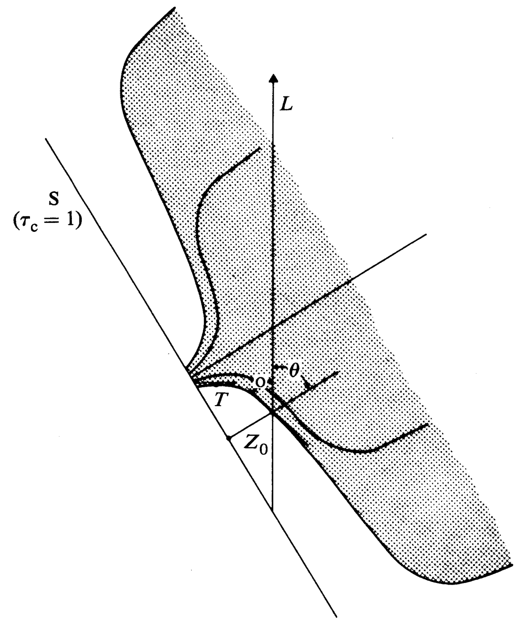

Fig. 4. Schematic diagram of the 2D field geometry characteristic of canopies. The problem was to deduce Z_0 given observed line-of-sight field strengths. [From Giovanelli and Jones (1982).]

In his first canopy paper Giovanelli (1980) made a case for the horizontal existence of fields beginning as low as 500–600 km above optical depth unity even in areas remote from where the fields emerged from the surface. Refined calculations allowed Giovanelli and Jones (1982) (see also Jones and Giovanelli 1982, 1983) to infer canopy heights as low as 150–250 km within some regions. In extensive areas the canopy base was found to be less than 400–500 km above $\tau = 1$. Some 20–30% of the solar surface near sunspot maximum was estimated to be covered by canopies with bases lying lower than 750 km.

The presence of low lying magnetic fields over much of the Sun's surface has not been accounted for in present day models of the chromosphere and transition zone. Their presence carries an implication that the conversion of acoustic energy to magneto-acoustic waves may occur much lower than currently believed (Jones 1985).

It was Giovanelli's opinion that the canopy concept led to even more heretical ideas: For example, suppose Hα fibrils do not map out the magnetic field lines as is generally supposed, but rather just the opposite: a fibril is where the field is not! He conjectured that a fibril is cooler than its surroundings and serves as the locus of condensed hydrogen just because it is field free. Similarly, the corona may extend all the way down to the temperature minimum, since there are fields there—the canopies—to heat the gas, and gas condensations in the transition region observed in the ultraviolet are there mainly because the magnetic fields are elsewhere. Further work will confirm, or deny, whether canopy fields prove as pervasive as he believed; and as important.

Acknowledgment

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