the stomatal clusters seen in the *flp* mutant[3]. One exciting consideration, however, has not been emphasized here. FAMA belongs to a family of gene-transcription factors that have a 'basic helix–loop–helix' structure[1] and act with MYB proteins to regulate several processes in *Arabidopsis* development[11]. Will the long-awaited *FLP* gene encode (or regulate) an MYB protein?

Bergmann and colleagues' study not only uncovers a new function for YDA, it also provides a powerful tool for identifying genes that control stomatal development and pattern formation. Further studies are needed to define the gene's function and to identity the components of the YDA cascade. Undoubtedly, we have a long but exciting way to go, but also the tools to take us there. ■

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Solar physics

Hidden magnetism

Jan Olof Stenflo

Observations of the Hanle effect have revealed the existence of small-scale 'hidden' magnetic flux on the quiet Sun. The magnetic-energy density of this hidden flux is much larger than previously thought.

Magnetic fields have occupied centre stage in solar physics for the past several decades, and have come to be regarded as the key ingredient for a unified understanding of solar phenomena. It may therefore come as a surprise that, after all these years, the magnetic-energy density in the solar atmosphere might have been seriously underestimated — as Trujillo Bueno *et al.*[1] conclude on page 326 of this issue.

The spectrum of radiation from the Sun can be resolved into a series of lines corresponding to different atomic transitions. In the presence of a magnetic field, these spectral lines can split into multiple polarized components — this is the Zeeman effect and it has been used to diagnose the magnetic fields on the Sun since it was first introduced[2] to astrophysics by George Ellery Hale in 1908. Ever smaller magnetic structures have been revealed, and there is no end in sight. In fact, the magnetic flux seems to have a fractal structure, with an almost scale-invariant, self-similar pattern[3] (Fig. 1). According to theoretical predictions based on magnetoturbulence, the structuring should continue for several orders of magnitude beyond the scales that have so far been resolved.

But the Zeeman effect as a diagnostic tool is 'blind' to magnetic fields that are tangled on scales too small to be resolved. Below the scale of the achievable angular resolution, the contributions to the Zeeman-effect polarization from opposite-polarity components within a tangled magnetic field cancel each other; so an unresolved mixed-polarity field leaves no 'footprint' in the Zeeman-split spectral lines. For this reason, a vast amount of solar magnetic flux has possibly remained hidden from view.

Trujillo Bueno *et al.*[1] have used a different approach. The alternative tool is the Hanle effect, a coherence phenomenon discovered[4] by Wilhelm Hanle in 1924. This effect was of great significance in the early development of quantum mechanics, because it demonstrated the principle of the coherent superposition of quantum states, and the nature of decoherence when the degeneracy of the quantum states is partially lifted as weak magnetic fields are introduced[5]. In the context of solar physics, the Hanle effect refers to the set of polarization effects that are caused by the coherent scattering of the radiation in the Sun's atmosphere under the influence of an external magnetic field. The symmetry properties of the Hanle effect with respect to the orientation of the magnetic field are entirely different from those of the Zeeman effect. Thus an unresolved, tangled magnetic field leaves a polarimetric footprint for the Hanle effect, while being invisible to the Zeeman effect.

Although the Hanle effect was introduced decades ago as a tool to gain information on the elusive, turbulent solar magnetic field[6] (and a lower limit of 10 gauss on the turbulent field strength was determined straight away), further progress was limited by the insufficient polarimetric precision of the instruments available. The polarization amplitudes sought are small (typically at the level of 0.1% or less), because the anisotropy of the radiation field in the solar atmosphere is so small. But the wealth of polarization phenomena caused by the coherent scattering of the Sun's radiation at last became fully accessible with the introduction a decade ago of the Zurich Imaging Polarimeter, ZIMPOL[7], with which the polarimetric noise could be dramatically reduced. Using ZIMPOL, the electro-optically modulated polarization signal is 'demodulated' into four image planes, which correspond to the different polarization states needed to form the full Stokes vector (which contains the complete polarization information).

With the polarimetric accuracy of one part in 10^5 that is routinely reached with ZIMPOL, combined with high spectral resolution, an astounding variety of spectral structures can be seen throughout the whole solar spectrum. This linearly polarized spectrum — which has been called the 'second solar spectrum', because it bears so little resemblance to the ordinary intensity spectrum — is a veritable treasure trove of all kinds of coherence phenomena[8]. The different polarized structures in the second solar spectrum are affected to various degrees, through the Hanle effect, by the 'hidden' magnetic fields in the solar atmosphere. Differential effects can then be used as diagnostics.

However, the proper quantitative interpretation of the Hanle signatures in the solar spectrum is a tricky business. The polarization amplitudes observed unfortunately depend on details of how the spectral line is formed — including the details of the structure of both the atom/molecule and of the solar atmosphere, as well as the way in which the polarized radiation is transported through the atmosphere. Trujillo Bueno *et al.*[1] have brought the theory of line formation to a new level: they have modelled the Hanle effect for spectral lines from atoms and molecules using a three-dimensional radiative-transfer code and a model of the Sun's atmosphere obtained from simulations of the star's surface convection. They find much higher magnetic-energy densities than in previous investigations, both because of their more realistic three-dimensional approach and because they introduce a more realistic probability distribution function for the turbulent field strengths, rather than using a single-value field.

This work is a pleasing example of how different areas of astrophysics can be brought together to achieve a scientific objective: Trujillo Bueno *et al.* have combined high-precision spectro-polarimetry, coherency effects in atomic physics, advanced techniques in radiative-transfer theory and simulations of magnetoconvection. The information that can be retrieved about the Sun's magnetism is, however, model-dependent, and will remain so for the foreseeable future, because the small-scale magnetic structures in question will not be resolved even with the next generation of

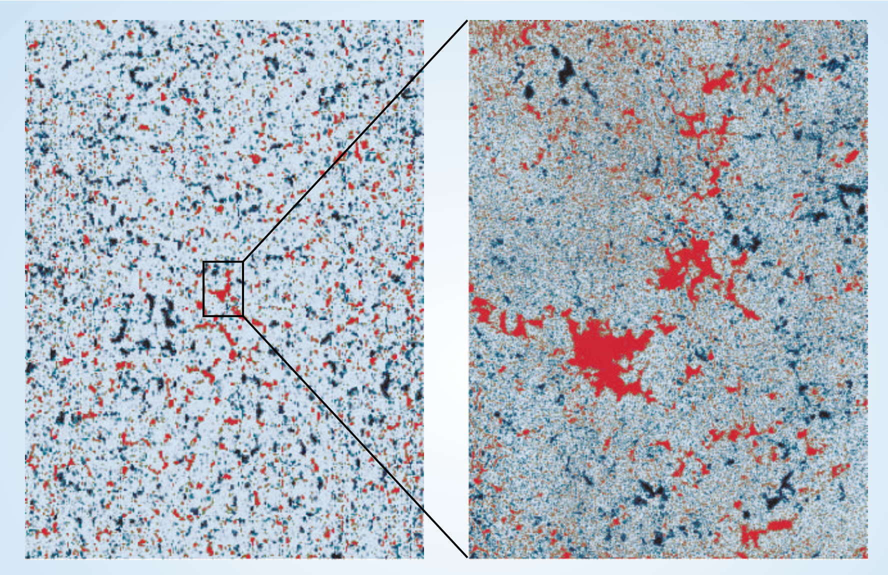

Figure 1 **The fractal-like pattern of magnetic fields on the quiet Sun. The enlarged image on the right (courtesy of Göran Scharmer, from the Swedish Solar Telescope on La Palma) covers 1% of the area of the left panel (from the Kitt Peak Observatory). These maps represent the patterns of circular polarization in the Sun's radiation caused by the Zeeman effect. The red and blue patches represent flux of opposing magnetic polarities, separated by the grey voids of seemingly no flux. Observations made using the Hanle effect now reveal[1] that these grey regions are not voids at all, but are teeming with turbulent fields that carry a significant density of magnetic energy.**

telescopes. Still, with the wealth of new diagnostic information available through the second solar spectrum, we can expect to see major advances in our understanding of the Sun's hidden magnetism in the years to come. ■

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Developmental biology

Heading away from the rump

Ray Keller

How does our rump come to be separated from our head, instead of being right behind our ears? Studies of the elongation of the developing embryo reveal some remarkable underlying mechanisms.

The early vertebrate embryo consists of a relatively featureless ball of thousands of cells, which reshapes itself to form a head at one end, a rump or tail at the other, and an elongated trunk in between. Much of this reshaping is accomplished by a group of cells called chordamesodermal cells. In the early embryo, they form a wide but short area just behind the future head, and this region narrows during development while simultaneously elongating in the head-to-rump (anterior–posterior) direction (Fig. 1a, overleaf)[1]. These movements, called convergence and extension, or convergent extension, occur when the cells become redistributed by converging on the embryo's midline through a process called intercalation, forming a narrower but longer tissue[2]. The cells intercalate by becoming polarized transversely in a bipolar manner, producing mobile protrusions called lamellipodia on their right and left surfaces that pull the cells between one another.

On page 364 of this issue, Ninomiya, Elinson and Winklbauer[3] offer insights into how this all comes about. They show in frogs that the patterning events that occur along the anterior–posterior axis also polarize cell-intercalation activity and thereby, at a stroke, align trunk extension with anterior–posterior polarity.

Although much is known about the patterning of the head, trunk and tail tissues along the anterior–posterior axis[4], regulation of the convergent-extension movements that shape these tissues is less well understood[5]. One important unknown is how the local, polarized cell behaviour underlying these movements is globally aligned with the anterior–posterior array of tissues such that convergent extension pushes the head away from the rump.

Ninomiya *et al.*[3] have addressed this problem. They first show that cells have an anterior–posterior positional identity that regulates their position along the anterior–posterior axis. When aggregates of anterior and posterior cells, labelled to keep track of their origin, were dissociated, mixed together and reaggregated, the cells recognized one another by their anterior–posterior level of origin, and sorted themselves into the correct position. Second, the authors found that the cells seem to use these position-related differences to switch on cell intercalation. In these experiments, intercalation occurred only in regions of contact between tissues originating at different anterior and posterior levels, not between tissues of the same level of origin (Fig. 1b). Significantly, extension occurred along the same axis as the mismatch of anterior–posterior levels.

Finally, Ninomiya *et al.*[3] show that these position-dependent activities are related to the expression of two genes — called *Xenopus Brachyury* (*Xbra*) and *chordin* — that also regulate the anterior–posterior fate of cells. These genes are expressed in trunk tissues in 'countergradients' — *Xbra* expression is low anteriorly and high posteriorly, and *chordin* expression has the reverse pattern (Fig. 1b). Knowing that increasing concentrations of the signalling molecule activin boost the expression of *chordin* and reduce that of *Xbra*, the authors investigated whether graded activin treatment could also induce the position-dependent, intercalation-triggering activities.

They found that convergent extension occurred between strongly and moderately induced cell aggregates and between moderately and weakly induced ones, but not between two strongly induced or two weakly induced aggregates. Again, extension occurred along the same axis as the mismatch between strongly induced (equivalent to anterior) and weakly induced (equivalent to posterior) tissues; this is also the axis of differential gene expression. Although activin is a useful protein for these experiments, in the embryo it is more likely that a related signalling molecule called nodal, and its inhibitor lefty, are involved in the graded anterior–posterior gene expression[6,7], and perhaps in the graded properties that trigger intercalation.

All in all, these results are a major advance, but inevitably pose questions. What are the anterior–posteriorly graded cell properties? They might reflect differ-