Abstract

In this personal account of the author's experiences of creativity in Science, an introduction to the basic features of the Sun is first given. This is followed by comments on various attitudes to science and on the nature of creativity, as well as a memorable experience of meeting a well-known local poet John Glenday. Then it is pointed out that modern science reveals a truly extraordinary universe, and examples are given from studies of the Sun. Finally, comments are made about the roles of teams in creativity and of the possible influence of Science on Christian life. It is concluded that the way of the scientist can be questioning, open, sensitive and lead to a profound sense of beauty, wonder and humility.
1. Introduction

I apologise in advance for the lack of philosophical or intellectual content in this paper, since I have not read any articles on the philosophy of imagination or creativity. I certainly do not write on behalf of scientists as a whole or about the nature of science in general, but instead just offer a personal description of what the creative process has meant to me personally in my own scientific research. My research area concerns the Sun and I have the privilege to be part of an active Solar Theory Group of nearly thirty people in Applied Mathematics at St Andrews University.

Reasons that have been proffered by others for studying the Sun include its profound influence on the Earth and the fact that, as our closest star, it is of great importance for astronomy as a whole, since many fundamental processes can be studied in great detail on the Sun. However, my main reason for studying the Sun is simply that I am fascinated and intrigued by it.

You may wonder why an applied mathematician studies the Sun. Well, traditionally there has been a very close link between mathematics and astronomy. For example, James Gregory (1638-1675), who was the first regius professor of mathematics in St Andrews and to whom we shall return later, was not only the co-founder with Isaac Newton and Leibniz of the calculus but also invented the reflecting telescope. An applied mathematician builds mathematical models of physical processes and so describes them in mathematical language. This enables him or her to obtain a much deeper understanding and so try to explain why and how the processes take place.

2. The Sun

Let me then introduce to you the Sun. It is a “spherical ball” of gas, a phrase which I shall mention in Section 5. Held together by gravity, its radius is 700 Mm or a hundred times the radius of the Earth (where 1 Mm = 10^6 metres). Its age is 4.6 billion years, whereas the age of the universe is 13.7 billion years (where 1 billion = 1000 million). Its chemical composition is 91% hydrogen, 8.9% helium, and much smaller contributions from the other elements such as carbon, oxygen and iron. Its distance from the Earth is 93 million miles.

For the overall structure of the Sun, the interior includes a core (where the energy is generated by thermonuclear reactions) and a turbulent convection zone, occupying the outer third of the interior. The atmosphere includes the photosphere, which is the thin surface layer marking the top of the convection zone, and the corona, which is the outer atmosphere stretching to the Earth and beyond.
The photosphere (Figure 1) has a temperature of 6000 degrees Kelvin and possesses sunspots, often in pairs, which are dark because they are cooler than the normal photosphere. In 1908 it was discovered that sunspots are sites of very strong magnetic fields (with strengths of about 3000 gauss), and so they are now known to represent sites where a large tube of magnetic field arches up through the surface from the interior.
The corona, which comes from the Latin for crown, may be seen during an eclipse of the Sun (Figure 2), when the Moon covers up the glare of the solar surface. A huge surprise in 1940 was the discovery that the temperature of the corona is about a million degrees, very much hotter than the photosphere.

In 1995 the Solar and Heliospheric Observatory (or SOHO) was launched as a collaborative European Space Agency/NASA joint space mission. It is orbiting the Sun in phase with the Earth at a point called the L1 point, where the gravitational pulls of the Sun and Earth balance. Able to observe the Sun continuously with a large number of instruments, it is revolutionising our understanding of the Sun in many ways. An image of the photosphere today (the day of the conference) from SOHO of the photosphere (Figure 3a) reveals two bands of sunspots, one north of the equator and one south of the equator. A simultaneous observation of the magnetic field in the photosphere (Figure 3b) has white regions where the magnetic field is directed towards you and black regions where it is directed away. The magnetic patterns around sunspots can be seen clearly.
Figure 3. Images from the SOHO satellite today of (a) the photosphere and (b) the photospheric magnetic field.
3. Attitudes to Science

Several attitudes to science have arisen, such as: that it is wrong (since it contradicts the bible); or that it is all-powerful (so that there is no need for religion); or that it is cold and irrational (and so irrelevant to matters of the spirit). Let us examine each of them in turn.

The first attitude is that the bible explains the world and so science is wrong. As well as misunderstanding the nature of the bible, I feel this also misunderstands the nature of science. Indeed there are many examples where the Church has dismissed science and so lost touch with many genuine seekers after truth. (Are Christians in danger of doing so today over matters such as GM or gene therapy?)

One such example is sunspots, which were originally discovered by the Chinese in 800 BC, but were then forgotten through the dark ages. Indeed, orthodox Christian theology in the middle ages held that the Sun is perfect, without blemish, following Aristotle’s ideas. However, in 1610 Galileo and others rediscovered sunspots with the newly invented telescope. In 1633 he was tried by the Inquisition on a charge of heresy, essentially over the right of a scientist to teach and defend his beliefs (although ostensibly over the Copernican view of the Solar System). In a shameful act he was made to kneel down and publicly recant.

Another example of the Church dismissing science is closer to home. James Gregory (after whom my Gregory Chair was named) was elected a Fellow of the Royal Society in 1668 at the age of 30 and was appointed during the same year as the first regius professor of mathematics in St Andrews. He was given the upper hall of the University Library, which lies directly above the room we are meeting in now, as his place of work. Figure 4 shows him in this upper hall, with a north-south line on the floor, along which he lined up his telescope. It also shows an early pendulum clock on the wall (which can still be seen upstairs) and there is a moveable bracket on the wall to which the telescope was attached.

Figure 4. The upper hall of the library where James Gregory worked in St Andrews.
James Gregory was a popular teacher and students flocked to his lectures, which may have made his colleagues jealous, since students at the time paid their professors directly. However, in 1674 he left with the words “The affairs of the observatory of St Andrews were in such bad condition, the reason of which was, a prejudice the masters of the university did take at the mathematics. After this, my salary was also kept back from me, and scholars of most eminent rank were violently kept from me, contrary to their own wills, the masters persuading them that their brains were not able to endure it”.

Presumably, the masters referred to in the clause that I have italicised includes the professors at St Mary’s College, so I hope that Trevor Hart is better disposed to me today than they were to James Gregory!

To me science is neither right or wrong. It sometimes perhaps deals with absolute truth (such as in pure mathematical theorems), but usually it seeks an understanding that is provisional – always being questioned or improved and continually evolving. For example, sunspots were once thought to be planets or clouds of smoke or slag from a burning Sun, or mountain-tops above an ocean of lava, or holes in the clouds above a solid crust inhabited by beings, all of these ideas now being discredited. Furthermore, Kelvin made the statement that “Heavier-than-air flying machines are impossible” in 1985, while the IBM chairman in 1945 expected a world market for 15 computers! So scientists can often be mistaken.

In future, I expect that there will be far-reaching discoveries on the nature of life, on the workings of the mind, and on the origin of the universe. But, as Christians, we should welcome these discoveries since they reveal to us more of the nature of God’s handiwork. However, society as a whole has a responsibility, in my view, to become more informed about these discoveries (such as genetic modification or gene technology) and to use them for good rather than for selfish purposes.

Richard Bauckham in his excellent opening lecture mentioned “creation from nothing”, but there is more in this phrase than meets the eye. For example, our normal idea of creation assumes the passage of time, with a time before the act of creation merging continuously into a time after creation: however, in modern cosmology both time and space were created at the big bang, so how does that effect our theology of creation? Furthermore, modern physics has something to say about the notion of “from nothing”, since quantum fluctuations of a vacuum may create both matter and anti-matter from nothing.

The purpose of science to me is not to rival God, but to enhance our appreciation and understanding of the cosmos. The attitude of humanity to the universe should not be lordliness but reverence.
There are many similarities between scientific and Christian knowledge. For me, there is an underlying unity, since they give us overlapping glimpses of the mind of God. Indeed, we need a vision of Christianity that is wide enough to embrace science rather than keep it at bay. Aquinas tried to merge Christianity and the Aristotelian science of the time, but this synthesis was broken apart at the Renaissance. Perhaps now is the time to try and bring them back together more robustly, but such an undertaking would need to involve scientists as well as theologians.

The third attitude to Science is that it is cold, rational, logical and mechanical, undertaken by computers and emotionless people in white coats, so that it has nothing to do with the humanities or religion. But to me scientific research in practice at its core involves creativity, leaps of faith, intuition, imagination and often fills me with a sense of beauty and wonder.

4. The Nature of Creativity

For me, there are many ideas continually buzzing around in my subconscious, and occasionally one of them suddenly appears and I have the choice to focus on it. This is the creative moment. It may come at any time – when I am jogging or gardening or walking or pondering in my office.

How can I cultivate such creativity and keep it alive amidst the pressures of modern life? Four conditions can help. The first is to develop a habit of questioning everything – the principles, the basis of a piece of work, the hidden assumptions behind it. Of course, such a questioning attitude does need to be balanced by having faith and acceptance of many aspects of a topic too – of trusting in what others have found. The second, and probably most important condition, is to create the environment and the space within which creativity may blossom. Indeed, this is the condition which is most endangered and stifled by the current emphasis on productivity and endless assessment and by the pressures in universities to do more and more. In my case, summer vacations in the USA have been blissful scientific retreats where many new ideas have been born.

A third condition is to spend time keeping informed and up-to-date in my field. A final condition is simply to work hard, learning the techniques, knowledge and skills that are essential to nurture the creative spark into a fully formed idea. Perspiration follows inspiration, but both are essential. Perspiration without the inspiration leads only along well-worn lines, whereas inspiration without perspiration is unproductive.

An interesting fact is that new scientific ideas often occur to different people simultaneously, as if the moment is ready for a new direction. Also, occasionally old ideas are rediscovered by those who were unaware of them.

5. Meeting with a Poet

Robert Crawford, a professor of English here at St Andrews, asked me to take part in a project entitled “Contemporary Poetry Meets Contemporary Science”. After I agreed, he put me in touch with a poet, called John Glenday, and so we met for lunch one day in September. Over lunch we compared the activities of creating science and creating poems.
I had never met a poet before and had only rarely read poetry, and so it was a real privilege and pleasure to meet John. Rather than a clash of cultures, to me it was more a meeting of minds and of kindred spirits.

I have a strong desire to understand the complexity and subtlety of processes at work on the Sun and to communicate my understanding to students and colleagues. Similarly, John seems to have a keen awareness of and care for the world, and a desire to understand and communicate in new pithy ways.

For me, ideas continually float around in my mind. Occasionally, one takes on a life of its own and crystallises. I often know the general direction I want to take and can see the general goal, but it may take many weeks or even years to work out the detailed steps, many of which often take me in unexpected directions. I have to work really hard, using all the skills and mathematical techniques at my disposal.

For John Glenday, the creative process appears to be very similar. He has an initial spark of inspiration and then it surprised me that it takes him typically two months of hard work to complete a poem. Also, he often has a sense of the poem taking on its own life.

After our lunch, John was commissioned to write a poem, arising out of our discussion. Reading a book of his poems after our meeting was a delight. His words are carefully weighed and full of subtle meaning, often surprising and revealing themselves after pondering and re-reading. Many of his poems are concerned with life, death and time. So I waited patiently for the new poem and two months later it arrived by e-mail with the following touching message: “I had an interesting time producing this poem, which has turned out to be almost wilfully unscientific. There are more poems in the pipeline. For the ideas, the central influence was as much your belief, Eric, as your work. That impressed me greatly. For any branch of science or art, its only interest to me is to what extent it reflects our humanity. I saw that clearly in your work and I felt privileged you shared it with me”. The poem is as follows.

**CIRCADIAN**

Rise over me
in the morning;

lay yourself under me
as the darkness breaks;

then ferry me like death,
like sleep, like memory,

back through the hidden
workings of the night

to a place where everything
lies buried, and begins.
The poem has the Sun as its theme, though not even mentioned by name. It reflects to me the importance of humanity and the daily support we receive. It is quite short, but the words are precious and economical. I enjoyed savouring their meaning. It is a combination of a love poem and a religious poem, with a hint of myth. I liked the idea of the one who is always there, even though not seen, and the thought of being ferried back to the start of a new day or to the source of life.

Last week a second poem arrived from John Glenday. My mention during our lunch of the Sun having a circular shape had reminded him of Leonardo da Vinci’s attempt (Figure 5) to describe Vitruvius’ idea that the human shape embodies perfect forms (circles and squares).

Figure 5. Leonardo da Vinci’s drawing.
John’s accompanying email said: “This illustration is you, Eric fitting perfectly inside the (would it were so!) perfect geometry of mathematics and the circumference of the Sun and in touch with both. I frequently feel I am working with absolutely nothing as raw material – and somehow always manage to create something from it”. The poem is as follows:

VITRUVIAN

for Eric Priest

There was the time I tried
picturing the circumference of the soul,
but the best I could manage

was a shimmery, milk-blue sun,
like an oversized thought bubble,
or a zero with my height;

which immediately reminded
me of that hoop he once transcribed
through a sweep of his sepia arms,

as he reached out beyond the trammel
of himself and caught hold of nothing
with both hands.

This is to me a highly effective attempt at describing our relationship with the creative act. Picturing the circumference of the soul was for me trying the impossible, at least what had previously seemed impossible – something you often do in scientific research. The shimmery milk-blue Sun refers to an x-ray picture of the Sun. At the last verse, I laughed out loud – at the idea of reaching beyond the shackles of my own limitations, and catching nothing or may be something that is very worthwhile – the creative act. So, I am very grateful to John for a memorable experience.

6. More about the Sun

Modern science reveals an extraordinary universe, which often produces a sense of mystery and beauty, so let me tell you a little more about the Sun. The fact that the coronal temperature is a million degrees implies that the corona is not a normal gas but is a so-called plasma, which is the fourth state of matter. We are all familiar with the usual three states of matter, namely, solid, liquid and gas. You transfer from one state to another by increasing the temperature, so that, for instance, ice becomes water and then changes into water vapour. However, when the temperature of a gas is increased enough it becomes a plasma (or an ionised gas).

A plasma behaves quite differently from a normal gas since it interacts in an intimate and subtle way with a magnetic field. Indeed, the corona is thought to be heated and structured by the magnetic field.

Until recently, the main way to view the corona was to wait for a solar eclipse when the glare of the photosphere is covered up by the Moon and the corona shows up in
light from the photosphere being scattered towards us. As the temperature of an object increases it becomes bluer, but, if the temperature is a million degrees, the object becomes so ‘blue’ that it emits mainly in the form of x-rays. (This explains the reference to a “shimmery milk-blue sun” in the above poem Vitruvian). Thus, if we are able to observe the Sun with a special telescope that detects extreme ultraviolet or x-ray emission, which comes only from the corona, then we are able to obtain an image of the whole corona without having to wait for an eclipse.

Indeed such an image from SOHO today I show in Figure 6, in which regions above the sunspots in Figure 3, called active regions, show up as bright because they are heated by the strong magnetic field. A close-up of the internal structure of such an active region (Figure 7) from the TRACE satellite reveals the incredibly and beautiful structure of the corona with the plasma aligned along the intricate magnetic field.
The corona can also be imaged by creating an artificial eclipse using a telescope, called a coronagraph, that has a disc covering up the Sun’s surface. For example, on SOHO there is a coronagraph which has detected huge ejections of plasma and magnetic field (Figure 8). These ejections take two or three days to reach the Earth and can cause the aurora borealis and disrupt communications or even put space satellites out of operation.

Figure 8. An eruption from the Sun observed with the LASCO coronagraph on board the SOHO satellite.
7. Other Thoughts

Studying the Sun for some may involve lying on a beach, but for me it involves the much more pleasurable activity of playing with mathematical equations. The equations of “magnetohydrodynamics” are shown in Figure 9 and describe the interaction between a magnetic field and a plasma. They are written in an elegant shorthand with a strange mixture of Roman and Greek characters and to me are as beautiful as anything I have seen on the Sun, or elsewhere in the universe for that matter. It is with these equations that we are able to try and describe the physical behaviour of the Sun.

Most modern science is undertaken in groups or teams, often of two or three people. This considerably enhances creativity and is partly responsible for the current vibrancy of scientific research. In a group different people perform different roles and bring different skills, experiences and ideas. Most of my own work has been collaborative, much of it involving three special long-term collaborators, whose friendship is especially treasured. One of the most enjoyable activities is brainstorming and sharing idea with research students, postdocs or visitors. The keys to effective collaboration are, like a strong marriage, skills of sensitive listening and communicating, as well as each bringing something distinctive to a common endeavour. It is interesting to note that much research in the humanities is, by contrast, a more solitary and surely more difficult activity, although in earlier times schools of thought in the arts were perhaps more common. In music or theatre, on the other hand, the group nature of creativity is often central.

Figure 9. The equations of magnetohydrodynamics.

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\begin{align*}
\frac{\partial \mathbf{B}}{\partial t} & = \nabla \times (\mathbf{v} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B} & \text{Induction Equation} \\
\frac{\partial \rho}{\partial t} + \rho \nabla \cdot \mathbf{v} & = 0 & \text{Mass Conservation} \\
\rho \frac{\partial \mathbf{v}}{\partial t} & = -\nabla p + j \times \mathbf{B} + \rho \mathbf{g} + \text{Viscous Terms} & \text{Motion} \\
\frac{\rho^\gamma}{\gamma - 1} \frac{\partial}{\partial t} \left( \frac{p}{\rho^\gamma} \right) & = \nabla \cdot \left( \kappa \nabla T \right) - \rho^2 Q(T) + \nabla \cdot \mathbf{H} & \text{Energy} \\
p & = \frac{R \rho T}{\mu} & \text{Gas Law} \\
\nabla \cdot \mathbf{B} & = 0 & \text{Gauss’ Law}
\end{align*}
\]

where \( \mathbf{B} \): the magnetic field strength, \( \mathbf{j} \): current density, \( \mathbf{v} \): plasma velocity, \( \eta \): magnetic diffusivity, \( t \): time, \( T \): temperature, \( \rho \): density, \( P \): pressure
In science there are different branches or means of working, such as experimentation, computer experimentation, observational discovery, basic theory and modelling. Imagination and creativity is needed to make a success of each. Furthermore, much scientific creativity is constrained by observations, which is what makes solar physics (with a myriad of observations) inherently more difficult than, say, cosmology (with relatively few observations). Too many constraints can inhibit creativity, but a moderate number of constraints can act as a greater stimulus for creativity than when there are few constraints. An analogy here is in music, where, for example, the guidelines of the classical form produced such amazing music in the last quartets of Beethoven.

Science has also had an influence on my own Christian beliefs. Science is not static, but continually evolves, and in a similar way the Christian life is a voyage or a pilgrimage. In Science, you question everything; many questions cannot be answered immediately and so the response is often a patient waiting or a sense of mystery; when grappling with the answers, it is essential to have integrity and be true to yourself. In a similar way, many people believe the claims of Christianity not when they are forced to do so, nor when they are proved mathematically, but when they resonate with your experience and feel right. For me, it is indeed possible to be a Christian in a scientific world, provided I am open to the insights of science and responsive to the hand of the maker in the universe.

8. Conclusions

Part of being alive or human for me is nurturing creativity and listening to the still small voice. In order to be scientifically creative, the two most important prerequisites are to create space for the key ideas to be born and to complement this by sheer hard work.

Science is not wrong or cold or rational or bad or all-powerful. Rather, the way of the scientist is questioning, open, sensitive, listening, and it can lead to a profound sense of beauty, wonder and humility. “Now we see through a glass darkly, but then face to face.”