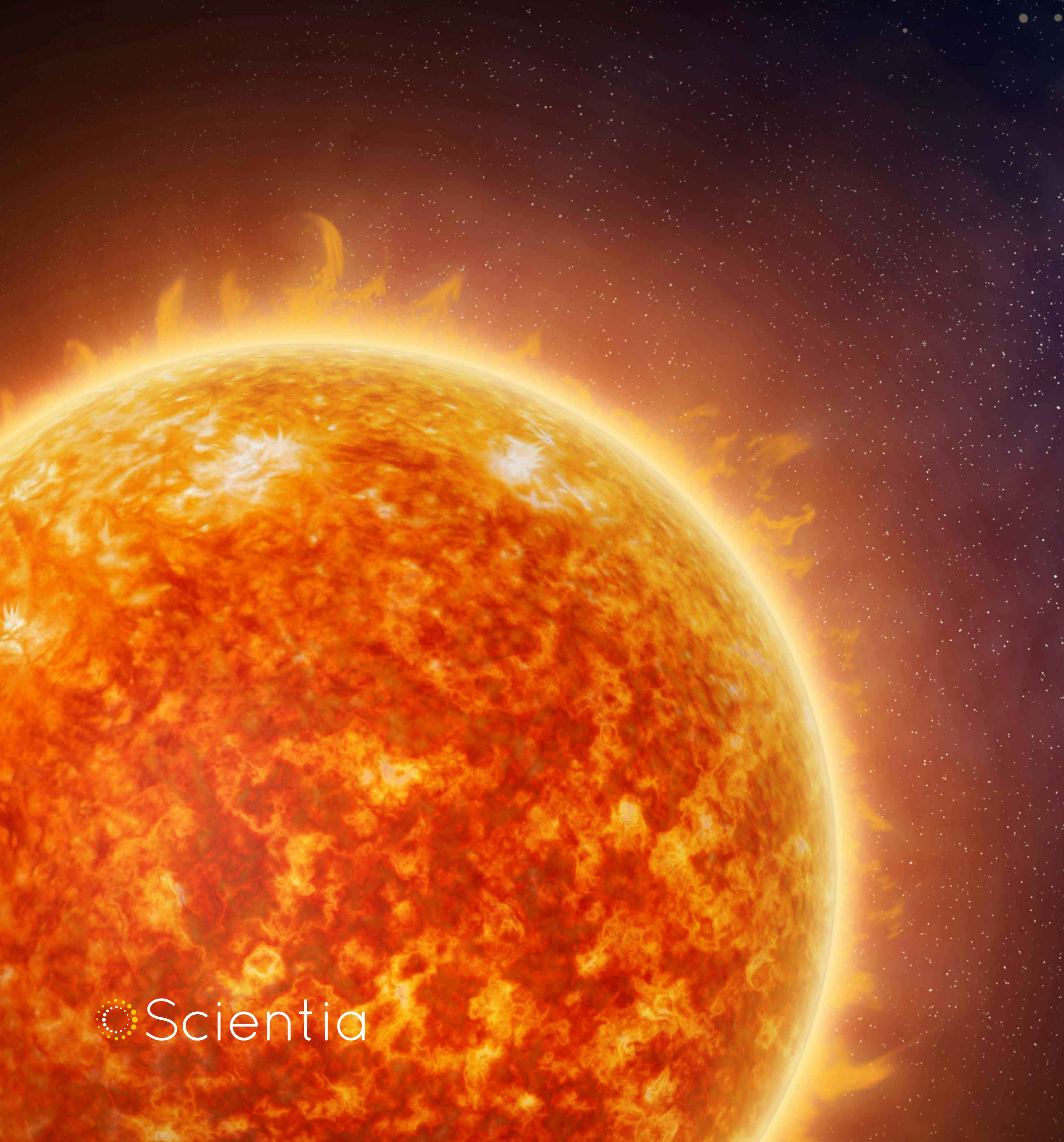
Studying Our Changing Sun by Getting to Know its Relatives

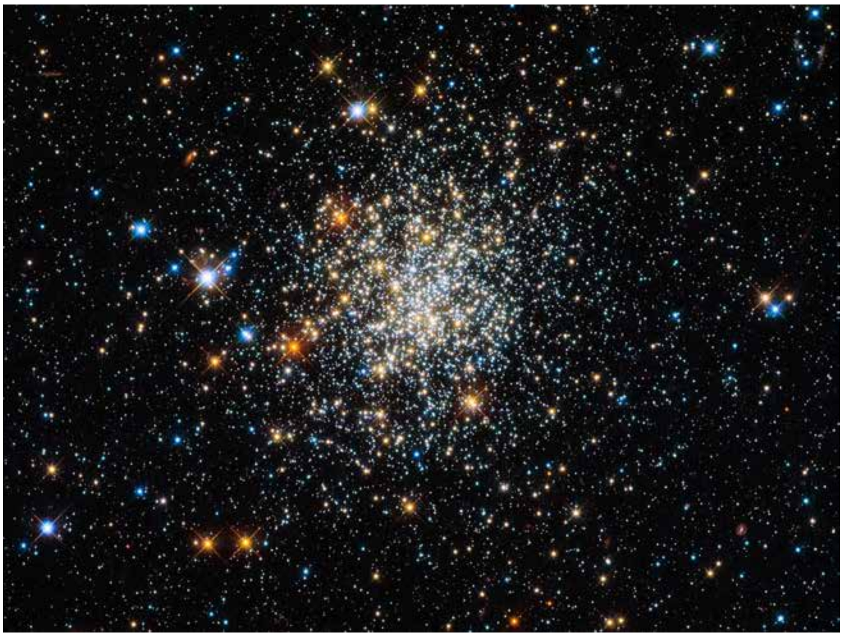
Dr Mark S. Giampapa



Scientia

STUDYING OUR CHANGING SUN BY GETTING TO KNOW ITS RELATIVES

Astrophysicist **Dr Mark Giampapa** of the National Solar Observatory with his team from astronomical centres in the US and Europe try to understand how the magnetic activity of the Sun evolves and how it will behave in the future. The team does this by exploring the characteristics of similar stars in the distant cosmos and using them as a measuring stick for the Sun's variability in the form of spots and flares over time.



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Looking at the Universe today, yesterday and tomorrow, both here in our galactic neighbourhood and out to the distant regions of space, the stars and nebulae seem to act in much the same way. However, this characteristic of uniformity over space and time helps Dr Mark Giampapa and his fellow astrophysicists at the National Solar Observatory explore the interior of the Sun, what it's made of, and the origin of its vast array of variability we see such as spots, flares, and other manifestations of magnetic field-related phenomena.

'The scientific motivation for my work is to gain insight on what our Sun may do next and what it may have done in the past,' Dr Giampapa explains. He says there are a number of ways scientists approach this topic. One angle is to study the Sun's past history – to examine the geological record here on Earth for traces of the Sun's magnetic activity, or to search through historical records for solar observations around the world. This can give us an idea of the Sun's past, at least as far as our data allow us to see.

Scientists can also directly measure solar activity prospectively, using high-precision instruments both on the ground and in space. 'Such data, combined with sophisticated computer modelling techniques, let us probe the structure of the Sun from its deep interior to just below its surface,' says Dr Giampapa. He and his group, however, prefer a different strategy – looking at distant stars that are similar to our Sun.

It turns out that our Sun is not very unusual in the Universe, except for the fact that, as Dr Giampapa puts it, 'the Sun has a solar system with a planet that has life on it asking questions about the universe.' However, there are countless stars in the Universe that are similar to the Sun, which don't happen to host pesky, questioning humans (as far as we know). Our Sun is what scientists call a yellow dwarf star – stars that are generally about 0.85 to 1.14 times the mass of our Sun and are energised primarily by the fusion of hydrogen atoms into helium atoms.

Yellow dwarf stars tend to emit particular frequencies (energies) of light according to the number of atoms of a given element and the conditions of the atmosphere, such as temperature and pressure. One pattern of specific frequencies emitted by these stars is called the Ca II H and K emissions. These signature emissions are due to calcium ions moving from high-energy states to low-energy states, releasing energy in the form of light. In other words, at the specific heat and composition of our Sun, some of the light emitted has characteristic frequencies that can be measured – a type of a starlight fingerprint.

Ca II H and K emissions arise from a special part of the Sun's atmosphere called the chromosphere. The chromosphere is just above the visible 'surface' or photosphere of the Sun, and is actually hotter than the

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underlying regions. Why it is hotter instead of cooler is a long-standing mystery, but solar physicists believe that energy from nearby magnetic fields heats the chromosphere and the overlying corona, which is even hotter.

Similarly-sized stars – such as yellow dwarves – can be expected to have similar spectral fingerprints. Although only about 5% of the stars in our galaxy are very similar to our Sun, this still equates to billions of candidates. Therefore, that what happens to these stars during their lives can also be expected to happen to our Sun. According to Dr Giampapa, ‘I observe stars like our own Sun to learn about the full range of activity our Sun may produce.’ In other words, looking across the Milky Way at stars similar to our Sun may enable Dr Giampapa’s team to predict what our Sun will do in the near future.

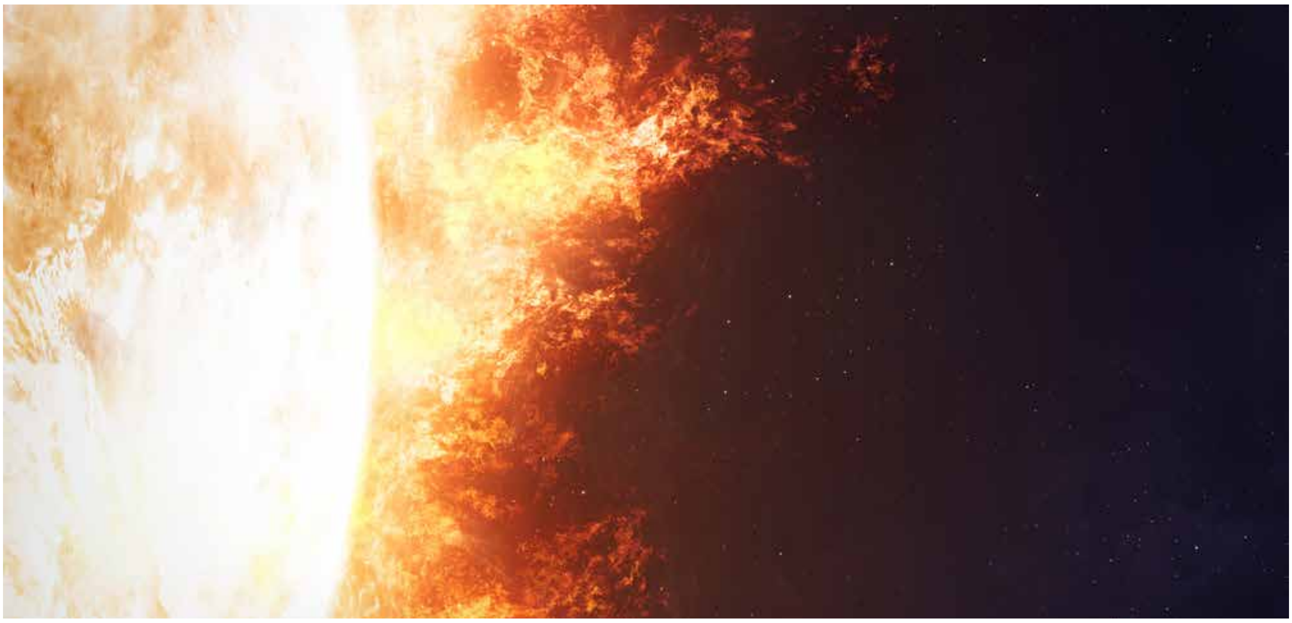
Our Sun’s Close Relatives

When searching for stars like our Sun, Dr Giampapa and his colleagues look for stars that have physical and chemical similarities to the Sun, what they call ‘solar twins’. Forty years of searching has yielded a number of candidates, but Dr Giampapa’s new favourites reside in a star cluster called Messier 67, or M67. Dr Giampapa’s team is particularly interested in M67 as it contains numerous stars that are about the same age and composition as our Sun.

The team has investigated M67 closely with ground-based telescopes at the WIYN Observatory (operated by the NOAO) and comparison observations of the Sun-as-a-star with the McMath-Pierce Solar Telescope Facility – previously operated by the National Solar Observatory. Their data, published in The Astrophysical Journal, revealed that of 60 sun-like stars they identified in M67, two-thirds of them had H and K emissions within the same range as our Sun. ‘Since these solar-like stars of M67 would be expected to be in different phases of their individual sunspot cycles, we can learn about the potential full range of activity that our Sun may exhibit at its current age by studying these stars,’ says Dr Giampapa. In fact, other researchers from Sweden and Canada actually identified one of these stars – M67-1194 – as having emissions almost identical to the Sun’s. It was also about the same age, about 4 billion years – a virtual solar twin! Remarkably, an Italian scientist called Anna Brucalassi and her collaborators discovered an exoplanet orbiting around this solar twin, with a mass at least a third that of Jupiter.

Dr Giampapa’s team also took notice of those stars that were not in the two-thirds that matched the Sun. There were some with emissions whose chromospheric energies were too high or too low compared to the Sun. They wanted to know whether these stars had higher (or lower) energy output due to some variation in the stars’ magnetic energy, such as increased (or decreased) sunspot activity, or was it perhaps something else, like a variation in stellar rotation.

The team wanted to understand whether there was something about the increased or decreased magnetic activity that could possibly be analogised to our Sun during periods in recorded history. For example, had similar fluctuations occurred in our Sun, which may have led to historic warming or cooling intervals, such as the extended period of high solar activity that coincided with the Medieval Warm Epoch? In other words, if the higher activity of some M67 sun-like stars was due to increased rotational speed, then that perhaps wouldn’t be applicable to the Sun – as the Sun can’t suddenly start rotating faster. But if the increased energy output was due to



increased sunspot activity or flares, then that may be something to think about. In either case, Dr Giampapa and his team wanted the answer and they found it.

In another paper published in The Astrophysical Journal, Dr Giampapa and his colleagues reported their data from 15 sun-like stars in M67 that they observed using the European Southern Observatory's Very Large Telescope ('VLT') located high in the mountains of Paranal, Chile. They employed what is called the 'Ultraviolet Visual Echelle Spectrograph' – the UVES – an advanced machine that can see very weak stellar signals.

Using the VLT, the team collected energy data on the sun-like stars of interest and compared this data with the same energy fingerprint of the Sun, by collecting light that reflected off Jupiter's moon Ganymede. Much of Ganymede is covered with water ice, so it serves as a good reflector of the Sun's light. It is also at a good distance from Earth, allowing scientists to get an idea of what the Sun might look like from distant space. The team's comparison showed that stars with a fingerprint similar to that of the Sun were rotating at similar speeds. On the other hand, stars with higher magnetic energies were rotating at higher speeds. Basically, because these stars were rotating faster than the Sun, they were producing more magnetic activity due to sunspots and flares.

Why these stars are rotating faster at an age near that of the Sun is yet to be determined. Perhaps it has something to do with their size, or perhaps it has to do with the magnetic properties of their atmospheres. Whatever it is, it's something for Dr Giampapa and his team to investigate further, perhaps by looking at a broader sample of sun-like stars, some that are a little warmer or a little cooler, or a little larger or a little smaller, and correlating other parameters with those of the Sun. As we've learned from other explorers of the unknown: 'The truth is out there'. And Dr Giampapa is hot on its trail.

The Next Steps in Solar Research

In 2009, NASA launched the Kepler spacecraft to search for other planets capable of sustaining life. With a powerful Schmidt telescope located in stable Earth orbit, Kepler scoured the heavens for years and produced exciting data on thousands of planets orbiting hundreds of stars in our galaxy. But like all machines, Kepler started to wear out and lost a couple of its reaction wheels, so it can't remain stable enough to continue its original mission.

In an effort to make use of its remaining capability, Kepler was repurposed by NASA and turned into a veritable guest observatory. Kepler's new mission – termed 'K2' – is to be let out to planetary, stellar, extragalactic, and solar system scientists. Scientists can submit proposals for what they want Kepler to photograph, and if it's feasible, they might get some time on the telescope. Dr Giampapa and his colleagues are already on board.

'The kind of data we can obtain with K2 on the solar-type stars in M67 would have been impossible to obtain on the ground in terms of quality and uninterrupted continuity over a period of about 75 days,' says Dr Giampapa. He should know – he's tried it from more than one high-powered land-based telescope. His team has a K2 project coming up to look at some of the same sun-like stars in M67 to add to the data they have already collected. They can then extend the investigation of the brightness variability of the stars to even higher precisions than are possible with Earth-based systems.

'We are also planning to use large telescopes, such as the LBT (Large Binocular Telescope) in Arizona and the VLT in Chile, coupled with their powerful spectrographs, to measure more accurately the activity parameters that characterise the "Suns of M67",' explains Dr Giampapa. Since M67 is at a near-equatorial location in the sky, this makes it accessible to Earth-based telescopes in both hemispheres. But at about 2700 light years away, Dr Giampapa says that the sun-type stars in M67 are relatively faint. Therefore, using a space telescope such as K2 is ideal for acquiring much higher-quality data as it orbits above Earth, and thus avoids a lot of the interference associated with the atmosphere.

Ideally, Dr Giampapa wants to organise a dedicated program with suitable instruments to monitor this cluster several times a month, to trace the sunspot cycles of these stars and compare them to those of our Sun. 'This kind of program will become more feasible as robotic telescope technology advances and costs for moderate-aperture facilities decline,' he says. In this way, we can begin to better understand the array of phenomena exhibited by humanity's most important star, by understanding the lives of its closest relatives.

Meet the researcher

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Dr Mark Giampapa received his PhD in Astronomy from the University of Arizona in 1980. After this, Dr Giampapa carried out postdoctoral research at the Harvard-Smithsonian Centre for Astrophysics from 1980 to 1982. Since 1997, Dr Giampapa has been a tenured astronomer at the National Solar Observatory, as well as an Adjunct Astronomer & Lecturer in Astronomy at the University of Arizona. The National Solar Observatory is managed for the National Science Foundation in the United States by the Association of Universities for Research in Astronomy. Dr Giampapa's research interests include stellar dynamos, stellar cycles and magnetic activity, exoplanet system characterisation, and asteroseismology. He is currently interested specifically in unravelling the past and future evolution of the Sun through studying similar-sized stars at various distances from the Earth. Dr Giampapa has authored or co-authored nearly 200 articles, both in peer-reviewed journals and other professional publications. He is also a member of American Astronomical Society, including its Solar Physics Division, as well as the International Astronomical Union. Aside from his interest in outer space, Dr Giampapa also enjoys being closer to Earth as a certified private pilot, rated for single engine aircraft.

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