

Automation and modernization of legacy BiSON solar observatories with the BiSON:NG platform

S. J. Hale¹,¹^{*} E. Murray,¹ W. J. Chaplin¹,¹ Y. P. Elsworth,¹ R. Howe¹,¹ P. L. Pallé²
and E. J. Rhodes, Jr³

¹*School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK*

²*Instituto de Astrofísica de Canarias, and Department of Astrophysics, Universidad de La Laguna, s/n E-38205 San Cristóbal de La Laguna, Tenerife, Spain*

³*Department of Physics and Astronomy, University of Southern California, Los Angeles, CA 90089, USA*

Accepted 2026 August 10. Received 2026 July 13; in original form 2026 February 2

ABSTRACT

The Birmingham Solar Oscillations Network (BiSON) provides long-term, high-precision Sun-as-a-star radial-velocity observations for helioseismology. While most BiSON sites operate autonomously, two observatories at Observatorio del Teide, Tenerife, and at Mount Wilson Observatory, USA, have historically required daily on-site operation. We present the automation of these sites using the BiSON:NG next-generation observing platform, incorporating compact fibre-fed instrumentation and a modular, microservice-based control and data acquisition architecture. At both locations, new automated optical feeds and a common software framework have been deployed, enabling autonomous operation of the observing subsystems, including guiding, data acquisition, and instrument control, despite markedly different physical and operational constraints. The upgrades demonstrate that modern automation can be successfully integrated within existing and historic observatory infrastructure. Adoption of the BiSON:NG architecture reduces operational overhead, mitigates risks associated with hardware and software obsolescence, and supports sustainable operation of the network over the multi-decade time-scales required for helioseismic studies. The flexibility of the architecture also provides a pathway for future deployment of additional small-footprint observatories.

Key words: Instrumentation – instrumentation: photometers – techniques: spectroscopic – techniques: radial velocities – Sun: helioseismology – Sun: activity.

1 INTRODUCTION

The Birmingham Solar Oscillations Network (BiSON) makes high-precision radial-velocity measurements of the Sun-as-a-star. The network has operated across six sites since 1992 (W. J. Chaplin et al. 1996; S. J. Hale et al. 2016), and is currently undergoing a programme of planned infrastructure modernization (S. J. Hale 2019). Four of the sites operate as fully automated observatories, whilst two – at Observatorio del Teide, Izaña, Tenerife, and at Mount Wilson Observatory, Los Angeles, USA – require operators for daily observing. One aim of the modernization programme is to upgrade both of these sites to fully automated operation.

To support long-term sustainability and reduce operational overhead, BiSON is implementing a transition to a next-generation observing platform, hereafter referred to as BiSON:NG (S. J. Hale et al. 2020). BiSON:NG combines a compact, fibre-fed solar instrument with a modular, microservice-based control and data acquisition architecture, designed to minimize physical footprint and cost while enabling fully automated operation and incremental deployment across legacy sites.

In Section 2 we describe the automation of the BiSON site at Observatorio del Teide, where a new fibre-fed instrument, automated solar telescope, and weather enclosure have been deployed at the Solar Pyramid as part of the BiSON:NG upgrade. In Section 3 we present corresponding work completed at Mount Wilson Observatory, including installation of a new automated optical feed within the historic 60-ft Solar Tower and migration of the site to the BiSON:NG control architecture. Together, these upgrades demonstrate the deployment of a common, modular automation framework across legacy observatories operating under markedly different physical and operational constraints.

* E-mail: s.j.hale@bham.ac.uk



DML DOME Sky Treasure Chest v3

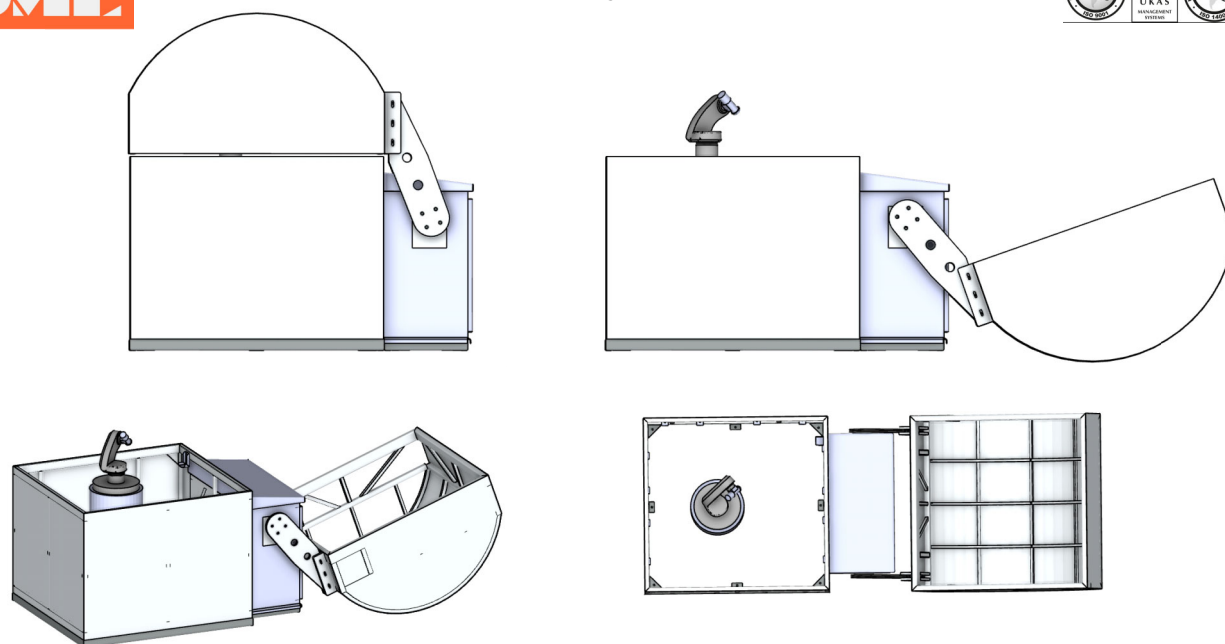


Figure 1. Robotic enclosure – DML DOME Sky Treasure Chest v3. A free-horizon enclosure designed and manufactured by DML Soluciones Técnicas. Fully constructed in aluminium with integrated thermal insulation. The ‘treasure chest’ mechanism provides a 180° opening, enabling a fully unobstructed horizon. The system includes position-controlled opening and closing, acoustic alert signalling during motion, and internal humidity control via an integrated dehumidifier. Environmental monitoring is provided through humidity, rain, and wind sensors, enabling fully automatic operation based on weather conditions. The enclosure supports remote control via API, allowing seamless integration into automated observatory control systems.

2 OBSERVATORIO DEL TEIDE, IZAÑA, TENERIFE

The Mark-I spectrophotometer at Observatorio del Teide, Izaña, Tenerife, was first commissioned in 1975 and became the inaugural site of the Birmingham Solar Oscillations Network in the early 1990s (S. J. Hale et al. 2016). The instrument operates from the Solar Pyramid, a tetrahedron-shaped building incorporating two external observing platforms, each supporting a coelostat. Observations at this site require an on-site observer to initiate and terminate observing sessions and to respond to changing weather conditions.

By contrast, the four fully automated BiSON solar observatories employ a more conventional observatory architecture, consisting of 4 m domes and large equatorial mounts supporting the combined telescope and instrument. The upgraded next-generation network, BiSON:NG, is designed to minimize physical footprint and cost, simplifying deployment while preserving full automation and scientific capability (S. J. Hale 2019).

A new ‘treasure chest’ weather enclosure, shown in Fig. 1, has been installed on the upper observing platform at the Pyramid, shown in Fig. 2. This enclosure is a fully autonomous system incorporating sensors for rain, wind, and humidity, and is controlled via a REST API over Ethernet. The enclosure is commanded to open and close at sunrise and sunset, but will also close, and re-open, automatically in response to environmental conditions. The new architecture incorporates fail-safe behaviours at multiple levels. In addition to closing in response to its onboard environmental sensors independently of the broader microservice layer, it will also close via watchdog if contact is lost with the wider system. On Linux-based devices, service health is monitored via systemd, which automatically restarts failed services. At the application level, service liveness is inferred from message timestamps, with timeouts flagging when expected telemetry is absent.

The optical feed is based on inexpensive off-the-shelf components, using a Sky-Watcher AZ-GTi telescope mount controlled by an on-board single-board computer and guide camera. The mount has been modified with limit switches to enable automatic position homing, and the guide camera is housed within a custom solar telescope chassis. Renders of the model design are shown in Fig. 3. The combined mount and telescope as installed on the pier inside the enclosure is shown in Fig. 4. The new fibre-fed instrument, currently operating alongside Mark-I in the apex observing room, is described by S. J. Hale et al. (2022).

The data acquisition and control system has also been modernized. Legacy systems employ a monolithic architecture in which a single computer manages all operational functions. In contrast, BiSON:NG adopts a microservice architecture, in which independent services are responsible for discrete tasks and encapsulated business logic – e.g. thermal control, guiding, data acquisition, data storage, monitoring and alerts, etc. This allows development, testing, and updates to be performed on a per-service basis (S. J. Hale et al. 2020). The modular approach permits services to run on the most appropriate Ethernet-connected hardware – whether a PC, microcontroller,



Figure 2. Left: The enclosure being lifted into place on the upper observing platform of the Pyramid. Right: Installation and system commissioning.



Figure 3. Left: An exploded view of a Sky-Watcher AZ GTi Alt-Az mount modified with limit switches for automatic position homing. Right: A custom solar telescope chassis supporting a solar fibre-feed, and on-board control and guiding. Not to scale.

or single-board computer – and reduces the risk of component obsolescence by allowing individual services to be replaced without impacting the wider system.

Communication between microservices is handled by MQTT (ISO 2016). Data are stored using InfluxDB (InfluxData 2013), and system status is visualized via a Grafana dashboard (Grafana Labs 2014). The control software is implemented in Python (G. Van Rossum & F. L. Drake 2009) on x86_64 platforms, and in C++ (ISO 2024) on embedded platforms such as microcontrollers, reflecting the differing constraints of the target environments. A block diagram of the system architecture, together with a representation of the approximate physical layout, is shown in Fig. 5. The entrance to the Pyramid is in the lower observing room. The PC on the ‘edge’ of the network for remote connection is in the control room. Upstairs leads to the instrumentation room housing the spectrophotometer and control systems, and a further door leads outside onto the upper observing platform supporting the enclosure and telescope.

The BiSON:NG control architecture was developed to address the specific requirements of the BiSON instrument suite, including integration with existing bespoke legacy hardware and support for embedded and microcontroller platforms alongside conventional x86 systems. General-purpose observatory control frameworks such as RTS2 (P. Kubánek et al. 2006) were considered; however, the requirement to support heterogeneous hardware environments including non-ASCOT-compatible legacy instrumentation, combined with a preference for minimal external dependencies in a small-team operational context, led to the adoption of the lightweight microservice approach built on established open standards (MQTT, InfluxDB). This approach provides the modularity and replaceability of components without introducing a large framework dependence on a codebase outside the team’s direct control.

Each BiSON site continues to operate as an independent data silo. Observing data are stored locally in InfluxDB and retrieved nightly by an automated process from the University of Birmingham via SSH. At Birmingham, the data archive is replicated across three on-site systems, including the University’s BlueBEAR HPC facility, which provides additional storage redundancy. This architecture ensures that a network outage at any individual site results in at most one day’s data retrieval delay, with no risk of data loss at the site itself. As sites are upgraded to the new architecture, real-time data fusion across sites will become a possibility.



Figure 4. The automated Sky-Watcher AZ GTi Alt-Az mount and solar telescope installed on a pier inside the weather enclosure.

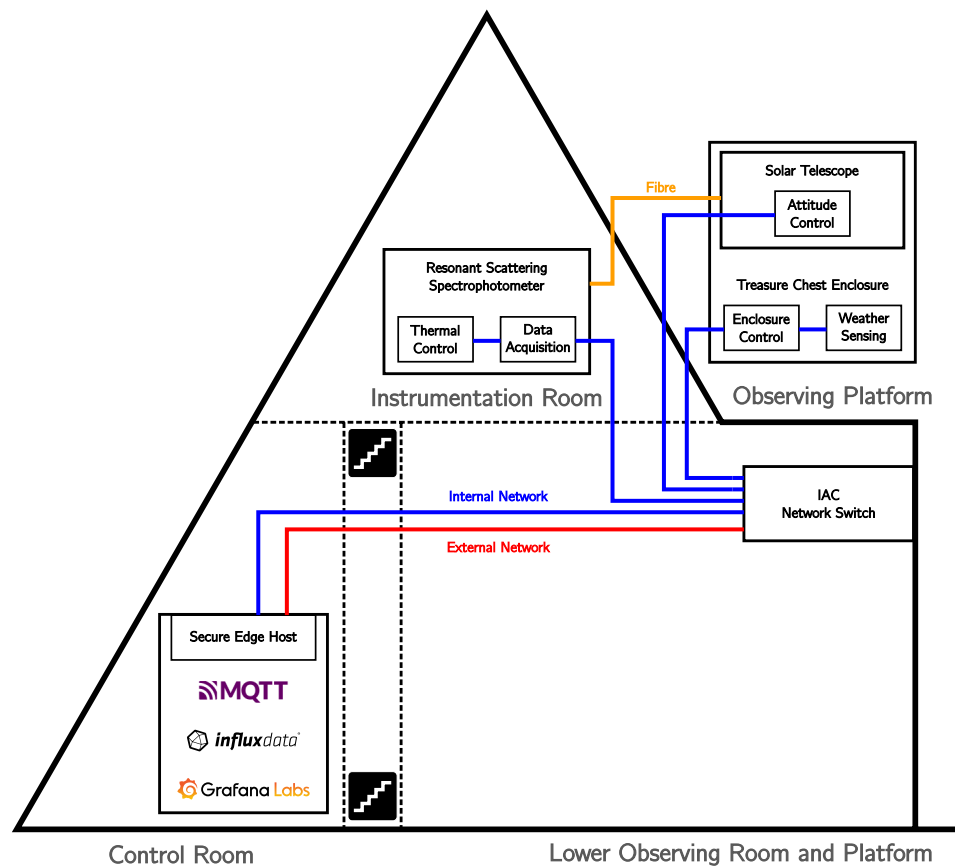


Figure 5. Block diagram of the Izaña system architecture, including approximate physical layout. The remotely accessible PC handling data storage is in the main control room. Instrumentation is contained within the upper apex room, with fibre-feed from the solar telescope inside the enclosure on the external observing platform. Internal and external network connections are separated by VLAN.



Figure 6. Left: The 60-foot Solar Tower Telescope observing platform and coelostat. Right: The automated Sky-Watcher AZ GTi Alt-Az mount and solar telescope installed on the aft-side of the second-flat pier.

3 MOUNT WILSON OBSERVATORY, LOS ANGELES, USA

The first BiSON instrument at Mount Wilson Observatory was installed in 1992 and subsequently upgraded to the current-generation instrument in 1996. The instrument operates from the 60-foot Solar Tower Telescope, constructed in 1908 and originally used to identify magnetic fields in sunspots.

As at Izaña, observations at this site have historically required an on-site observer to initiate and terminate observing sessions and to respond to changing weather conditions. Light is collected by a coelostat at the top of the tower and directed through the tower shaft down to the observing room below. Operation within such historically significant scientific infrastructure presents a distinct set of challenges. In 2018, issues with the coelostat guider electronics necessitated replacement of the optical feed with a semi-automated Sky-Watcher SolarQuest solar-tracking mount, together with a long optical fibre routed down the tower shaft to the observing room. The instrument was converted to fibre-optic operation using techniques developed for BiSON:NG (S. J. Hale et al. 2022).

The site has now been upgraded to the BiSON:NG standard, mirroring the configuration at Izaña, with a fully automated optical feed installed on the aft-side of the second-flat pier, shown in Fig. 6. This location provides a wide field of view, minimizing the required dome motion throughout the day, and avoids shadowing the coelostat, enabling volunteer work to begin on restoring the original spectroheliostat. The data acquisition system was also modified to ensure compatibility with the microservices architecture, eliminating the need for several legacy digital interface systems.

A block diagram of the system architecture, together with a representation of the approximate physical layout, is shown in Fig. 7. The entrance to the Solar Tower Telescope leads directly into the control room, on the right of the diagram. Through a corridor leads to the instrumentation room, which houses the spectrophotometer and control systems including the edge PC. Two new network switches were installed to provide network connectivity at the top of the tower, required for control of the guider. This connection is provided via optical fibre installed in the tower shaft, which is preferred for electrical isolation and protection against lightning strikes. The tower observing platform is accessed via an external staircase, leading to a mezzanine room and then finally the solar telescope on the upper level.

Figs 8 and 9 show the logged azimuth and altitude control performance of the guider, respectively, captured at Mount Wilson during commissioning on 2026 May 24. The guider camera uses a 6.287 mm by 4.712 mm Sony IMX477 sensor, with 1.55 μm square pixels in a 4056 by 3040 array. When coupled with an 80 mm focal length objective lens this produces an approximate field of view of 4.5° by 3.37° , where each pixel has about 4 arcsec field of view. The Sun has an extent of about 32 arcmin and so produces an image about 480 pixels in diameter on the camera.

The azimuth axis achieves a pixel error of 1.63 px_{rms} over the full observing period (6.6 arcsec_{rms}), or just 0.7 px_{rms} over a 3-h period away from the meridian. The maximum variation over a full day is about ± 5 pixels. The altitude axis performs better due to the smaller dynamic range of angular velocity. It is expected this could be improved further with optimization of the PID control.

The solar feed uses a 30 mm focal length objective lens to couple an image of the Sun into a 1 mm core diameter fibre. The solar image is about 0.28 mm in diameter, and the guider error corresponds to a drift of around 5.8 μm , comfortably holding the image on the centre of the fibre. Performance will be monitored over the following months to determine how well such consumer-grade mounts respond to full-time use.

All BiSON observing subsystems at Mount Wilson are now fully automated, including optical feed, guiding, data acquisition, and instrument control. Automation of the tower enclosure, and its associated weather response, is an active area of development in collaboration with the Mount Wilson Institute; however, the complexity of integrating modern automation with the historic tower structure has proven more challenging than initially anticipated.

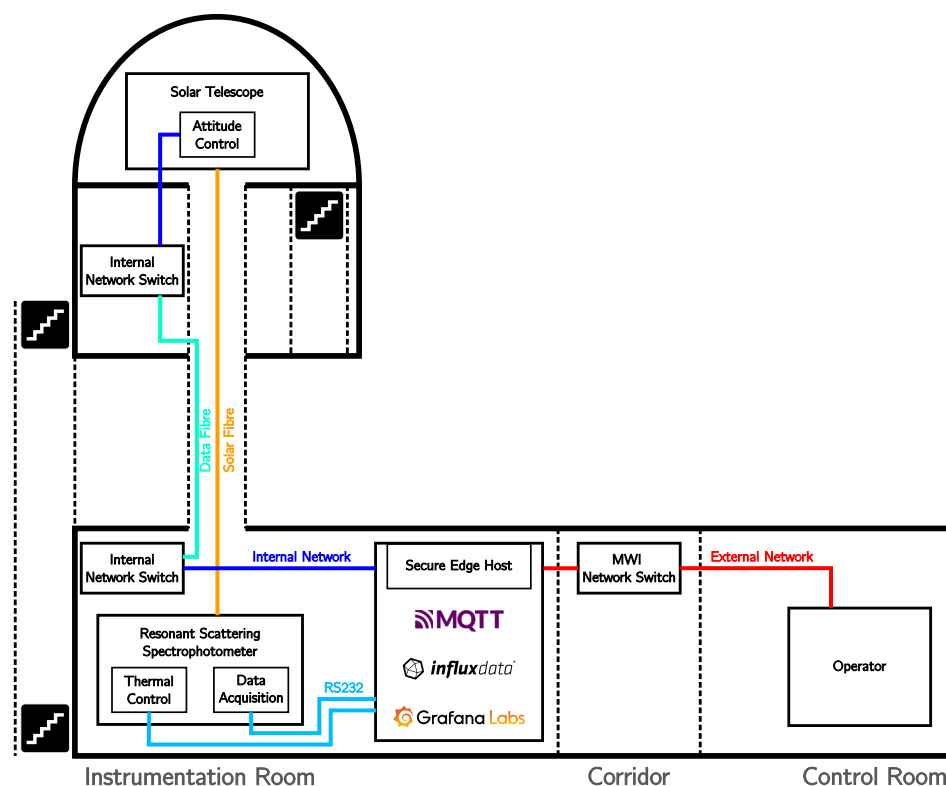


Figure 7. Block diagram of the Mount Wilson system architecture, including approximate physical layout. The remotely accessible PC handling data storage, and the instrumentation, are both contained within the main building instrumentation room of the tower. The solar telescope is housed in the observing room at the top of the tower, with fibre-feed down the tower shaft to the instrumentation room below. Internal and external network connections are separated by physical network infrastructure.

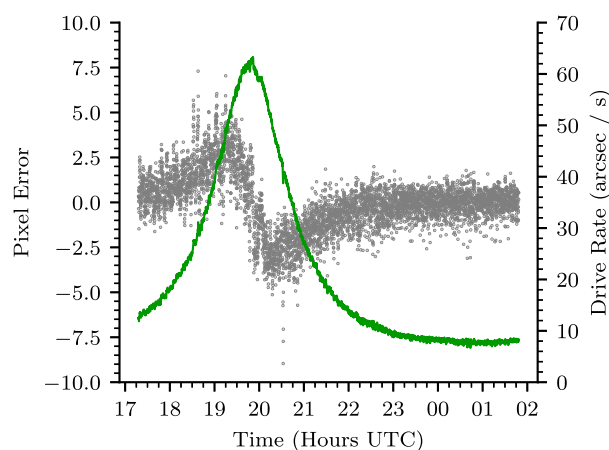


Figure 8. Azimuth axis guiding error. Pixel drift, indicated by the grey dots, is measured on the left axis. Axis motor drive rate, indicated by the solid line, is measured on the right axis. Error over the full observing period is $1.63 \text{ px}_{\text{rms}}$, or $6.6 \text{ arcsec}_{\text{rms}}$. Over a 3 h period away from the meridian this reduces to $0.7 \text{ px}_{\text{rms}}$. The maximum variation over a full day is about ± 5 pixels

The principal challenge is the existing tower enclosure drive system, which consists of a DC motor with no positional feedback, controlled only by open, close, and stop signals. The enclosure comprises two leaves, one motor-driven and one free-running, the latter being pushed by the driven leaf on contact, making precise positional control difficult without hardware modification. Replacing the drive motor with a digital servo system would provide the positional feedback required for full automation, but the complexity of this work has proven prohibitive in the near term. A pragmatic simpler solution is under development, using optical sensors to detect three fixed positions corresponding to the required daily movements of the enclosure. This will provide sufficient positional awareness for day-to-day automation. During this period, Mount Wilson Institute staff manually open and close the tower each day. Once the tower is opened, routine observing proceeds autonomously without further human intervention until weather events or sunset.

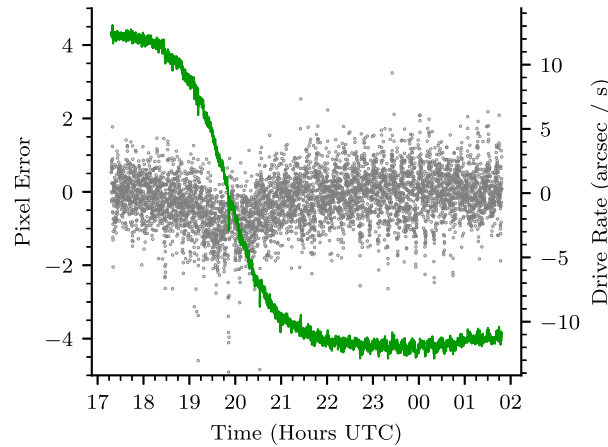


Figure 9. Altitude axis guiding error. Pixel drift, indicated by the grey dots, is measured on the left axis. Axis motor drive rate, indicated by the solid line, is measured on the right axis. Error over the full observing period is $0.74 \text{ px}_{\text{rms}}$, or $3 \text{ arcsec}_{\text{rms}}$. Over a 3 h period away from the meridian this reduces to $0.66 \text{ px}_{\text{rms}}$.

4 CONCLUSIONS

We have presented the successful automation of the remaining manually operated BiSON observing sites at Observatorio del Teide, and at Mount Wilson Observatory. At both locations, new fibre-fed optical systems and a common BiSON:NG control architecture have been deployed, enabling autonomous operation of the observing subsystems, including guiding, data acquisition, and instrument control.

These upgrades demonstrate that full automation of long-running solar observing facilities can be achieved using inexpensive, commercially available hardware combined with a modular, microservice-based software architecture. Crucially, this approach decouples observing functionality from site-specific infrastructure and hardware lifecycles, allowing legacy observatories to be modernized incrementally without wholesale replacement of existing facilities.

Prior to automation, observations at Izaña and Mount Wilson required on-site operators, limiting observing to periods when staff were available. At Mount Wilson, operations were typically suspended over the winter months, with operator availability constraining coverage during the remaining period. Quantitative assessment of duty cycle gains relative to the pre-automation baseline will be possible following an extended period of autonomous operation, and will be reported in future work.

Adoption of the BiSON:NG architecture substantially future-proofs the BiSON network against component obsolescence and evolving software dependencies, supporting sustainable operation over the multi-decade time-scales required for helioseismic studies. This modernization also reduces operational overhead and risk, strengthening the case for continued long-term network operations.

Elements of the BiSON:NG software architecture have additionally been deployed at the Narrabri site in New South Wales, Australia, demonstrating that the system can be rolled out independently of specific optical or mechanical upgrades. This flexibility allows sites with differing constraints and upgrade pathways to benefit from a common control and data acquisition framework.

Together, these developments complete a major stage in the modernization of the BiSON network and provide a transferable template for the automation and long-term sustainability of similar small-scale observatories. In addition to modernizing existing sites, the BiSON:NG architecture positions the BiSON network to support the future deployment of small-footprint helioseismic observatories. The combination of compact instrumentation and a scalable, modular control framework reduces the technical and operational barriers associated with establishing new observing locations, without reliance on site-specific infrastructure.

ACKNOWLEDGEMENTS

We would like to thank all those who have been associated with BiSON over the years. We particularly acknowledge the invaluable technical assistance at all our remote network sites.

During testing and commissioning at Izaña: Prof. Teodoro Roca, Antonio Pimienta, all the staff at the Instituto de Astrofísica de Canarias who have contributed to running the Mark-I instrument over many years, and the assistance of the Technical Maintenance team at the Observatorio del Teide. DML Soluciones Técnicas, Canary Islands, Spain, designed, manufactured, and installed the free-horizon robotic enclosure and developed its control system.

During testing and commissioning at Mount Wilson: All former and current members of the team of USC undergraduate observing assistants, and the assistance of the Mount Wilson Institute at Mount Wilson Observatory.

SJH, EM, WJC, YPE, and RH acknowledge the support of the United Kingdom Science and Technology Facilities Council (STFC) through grant ST/V000500/1.

PLP acknowledges the support (present) of the Spanish Ministry of Science, Innovation and Universities under the grant PID2023-146453NB-I00.

EJR acknowledges financial support provided by the BiSON Project to the University of Southern California (USC) for routine maintenance and repair to the BiSON data acquisition hardware. EJER also wishes to acknowledge financial support provided over the past 23 yr for undergraduate observing assistants by the following USC student support programs: the Provost's Undergraduate Research Fellowship (PURF), the Undergraduate Research Associates Program (URAP), the USC Dornsife Student Opportunities for Academic Research (SOAR) Program, the USC Dornsife Summer Undergraduate Research Fund (SURF) Program, and the Lick Scholarship Fund of the USC Department of Physics and Astronomy. EJER also wishes to acknowledge the Mount Wilson Institute for providing on-going access to the 60-Foot Solar Tower.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

DATA AVAILABILITY

All data are freely available from the BiSON Open Data Portal – <http://bison.ph.bham.ac.uk/opendata>. Data products are in the form of calibrated velocity residuals, concatenated into a single time series from all BiSON sites. Individual days of raw or calibrated data, and also bespoke products produced from requested time periods and sites, are available by contacting the authors.

REFERENCES

- Chaplin W. J. et al., 1996, *Sol. Phys.*, 168, 1
- Grafana Labs, 2014, Grafana: The open observability platform. Available at: <https://grafana.com/>
- Hale S. J., 2019, PhD thesis, School of Physics and Astronomy, University of Birmingham, UK, <https://etheses.bham.ac.uk/id/eprint/9010/>
- Hale S. J., Howe R., Chaplin W. J., Davies G. R., Elsworth Y. P., 2016, *Sol. Phys.*, 291, 1
- Hale S. J., Chaplin W. J., Davies G. R., Elsworth Y. P., 2020, in Guzman J. C., Ibsen J., eds, *Proc. SPIE Conf. Ser. Vol. 11452, Software and Cyberinfrastructure for Astronomy VI*. SPIE, Bellingham, p. 1145222
- Hale S. J., Chaplin W. J., Davies G. R., Elsworth Y. P., Howe R., 2022, *RAS Techn. Instrum.*, 1, 58
- ISO, 2016, ISO/IEC 20922:2016 – Information technology – Message Queuing Telemetry Transport (MQTT) v3.1.1. Available at: <https://www.iso.org/standard/69466.html>
- ISO, 2024, ISO/IEC 14882:2024 Programming languages – C++. Available at: <https://www.iso.org/standard/83626.html>
- InfluxData, 2013, InfluxDB: An open-source time series database. Available at: <https://www.influxdata.com>
- Kubánek P., Jelínek M., Vitek S., de Ugarte Postigo A., Nekola M., French J., 2006, in Lewis H., Bridger A., eds, *Proc. SPIE Conf. Ser. Vol. 6274, Advanced Software and Control for Astronomy*. SPIE, Bellingham, p. 62741V
- Van Rossum G., Drake F. L., 2009, Python 3 Reference Manual. CreateSpace, Scotts Valley, CA

This paper has been typeset from a $\text{\LaTeX}$ file prepared by the author.