Highlights of Spanish Astrophysics XII, Proceedings of the XVI Scientific Meeting of the Spanish Astronomical Society held on July 15 - 19, 2024, in Granada, Spain. M. Manteiga, F. González Galindo, A. Labiano Ortega, M. Martínez González, N. Rea, M. Romero Gómez, A. Ulla Miguel, G. Yepes, C. Rodríguez López, A. Gómez García and C. Dafonte (eds.), 2025

WEAVE first science

Balcells, M.[1,2,3], and the WEAVE Instrument Consortium

[1] Isaac Newton Group, Apartado 321, 38700 Santa Cruz de La Palma, Spain
[2] Instituto de Astrofísica de Canarias, 38200 La Laguna, Spain
[3] Universidad de La Laguna, 38200 La Laguna, Spain

Abstract

WEAVE, the powerful multi-object spectrograph recently installed on the William Herschel Telescope (WHT), started science observations in October 2023. Over 500 hours of science observations have been taken with the Large Integral Field Unit (LIFU) mode in the first ∼10 months of observations, sharing nights with further technical and commissioning work on the multi-object and mini-integral-field modes. With processed data flowing to the scientists since February 2024, we are getting valuable feedback for the preparation of a second full processing of all the science data taken to date, and are encouraged by the preparation of the first science papers based on WEAVE data.

1 Introduction

In the early 2010s the Isaac Newton Group of Telescopes[1] (ING) started planning for the provision of a next-generation spectroscopic facility for the WHT. The overarching goal was to provide the ING community with a massive multi-object spectroscopic capability for the scientific exploitation of large space and ground-based facilities such as Gaia, LOFAR and Apertif. This vision emerged after community consultations and took into account European-wide policy recommendations from the Astronet Roadmap for European Astronomy [8] and the European Telescope Strategy Review Committee 2010 report [20].

We have reported on these developments at previous SEA meetings [6, 7]. Here, we cover the status of the WEAVE instrument after the delivery of the first science data to scientists, and cover future plans.

[1] www.ing.iac.es

2 Instrument overview

The WEAVE instrument is described elsewhere in these proceedings [11]. Its development from conception to design has been detailed in several conference papers, and we refer the reader to those for further information ([4, 9, 10, 21, 15]), while the most recent comprehensive description of the instrument and its planned surveys are given in [16].

In short, WEAVE was designed to make use of the widest available field of view at the WHT prime focus, i.e., 2-degree diameter [1][2], and has a matched multiplex of 960 in MOS mode using a double pick-and-place system using a tumbler with a design similar to that of the 2dF positioner at the Australian National Observatory [17]. In addition to the MOS mode, WEAVE hosts a wide-format integral-field unit with 90 arcsec diameter (LIFU) and 20 small integral-field units (mIFU; ∼10 arcsec diameter) that can be positioned over the entire 2-degree field of view. Fibres feed a two-arm spectrograph that delivers spectral resolutions of 5000 or 20,000 (2500 or 10,000 for the LIFU, owing to larger fibre diameters).

3 Science observations

3.1 First-light science

An early demonstration of WEAVE's scientific capabilities was obtained through the first-light observations, taken in October-November 2022. With the WEAVE LIFU commissioning near completed and showing good performance, the LIFU was pointed to NGC 7318a,b in the core of the Stephan's Quintet galaxy group, and data were taken in low and high resolutions, using a 6-point dither pattern. The processed data demonstrated the scientific potential of the LIFU owing to its wide field of view and its broad wavelength coverage. One of several analyses of the data, and the first refereed paper based on WEAVE data, combined WEAVE FL spectroscopy with LOFAR and VLA radio data to study the nature of the shock seen in the intra-group medium [3].

3.2 Science verification programme

The WEAVE science verification programme (SV) was launched in 2019. SV had the purpose of allowing scientists to explore the instrument performance as compared to other instruments. Proposers were also encouraged to seek for early science opportunities.

The programme was open to both survey teams and to the broad ING community. Of particular interest to the WEAVE instrument team were those scientific programmes exploiting WEAVE modes that were not being planned in any of the WEAVE surveys. The complete programme comprised 28 projects with MOS, 4 projects with mIFU, and 11 projects with LIFU. All instrument modes were covered except for high-resolution 'blue' with the mIFU input mode.

At the time of writing, the LIFU SV programmes are completed. Observations were conducted between May and July 2023. We made all of the SV data available to scientists,

starting February 2024, after the first cycle of processing. Feedback from scientists highlighted the high quality of the data, while also noting needed improvements. See Sec. 4.

3.3 Regular science observations

Routine science observations started in October 2023, using the LIFU mode.

As of July 2024, a total of 466 observing blocks (OB) had been completed, amounting to 430 hours of observation time on the sky. This includes 315 hours for WEAVE surveys, and 115 hours for Open Time programs.

3.4 Open time

WEAVE is a survey instrument, but ING emphasizes the importance of offering ample access to the ING community through open time (OT) allocated by the three national time-allocation committees. Because OT programmes are typically shorter and more diverse, they broaden the science scope of the telescope and typically lead to scientific discovery on shorter timescales than surveys. A 70% – 30% split between surveys and OT is being implemented, after subtracting time for technical work and for the International Time Programme[2] (ITP).

We are pleased to report that the integration of surveys and OT ran smoothly from its first implementation in semester 23B. OBs from surveys, from OT and from ITP coexist in the database, and the automatic scheduler does a good job at balancing the sources so that the time given to each stream on a given semester do not deviate from the agreed fractions. The observing managers make small adjustments as needed. Observed OBs from all streams are transferred to CASU, processed and eventually made available to proposers.

4 Data

Due to the complexities of WEAVE and its calibration procedures, the WEAVE Project developed a full pipeline as part of the instrument data system [18], and a custom-made archive to facilitate scientific exploitation of the data. The data system was developed, and is operated, by the Cambridge Astronomical Survey Unit (CASU[3]). Processing comprises two pipelines, a *core processing system* (CPS) and an *advanced processing system* (APS). CPS, developed by CASU, removes the instrumental signature, performs spectral extraction, wavelength calibration and sky subtraction; spectral cubes are generated for LIFU and mIFU data sets. APS, developed at IAC, extracts science-ready products such as kinematics, line strengths and stellar parameters. A dedicated archive [19] serves WEAVE data to WEAVE scientists, and will be used for scheduled data releases from the WEAVE surveys.

A key milestone for the project was the start of delivery of reduced data to scientists. This started in February 2024. Data taken since May 2023 had been automatically processed through CPS, and manually processed through APS. The data products were available to

[2]https://www.iac.es/en/observatorios-de-canarias/international-scientific-committee
[3]http://casu.ast.cam.ac.uk/

scientists at CASU's distribution platform, the Operational Repository (OR). This triggered a flood of feedback to CASU that was instrumental in identifying issues and bugs. A second global processing of all available data is due to become available to scientists in late 2024.

The level of data quality reached to date is shown in Fig. 1, which portraits stellar kinematics results of APS for a nearby massive elliptical galaxy. Other results, from the science verification campaign, are shown elsewhere in this volume, e.g.,[13].

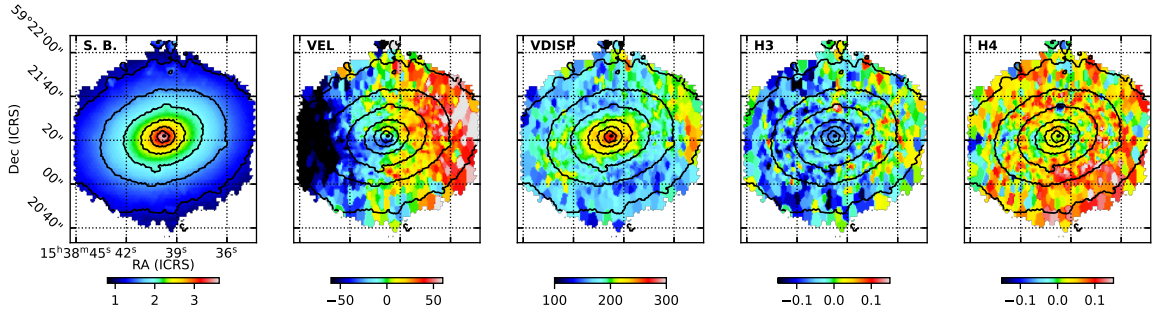

Figure 1: Stellar kinematic maps for NGC 5982, a massive elliptical galaxy with a core spinning orthogonal to the main body. Shown are results of running pPXF within APS, on CPS cubes from the second processing of November 2024 (see text). For this figure, APS was re-run with Voronoi binning imposing a SNR lower limit of 30. The peculiar core kinematics is clearly detected, despite the LIFU large fibre diameters of 2.6 arcsec. While the spectral line-spread functions are still being refined, the high-order kinematic maps H3 and H4 bear good resemblance with those of the SAURON survey [12] in the area of overlap.

5 Next steps

With a large body of science observations already taken and being processed, the extensive scientific potential of WEAVE has been established, at least for its LIFU modes. A stand-down is being organised for the second half of 2024 to allow for refinements to the optical alignment of the spectrograph to be carried out: the spectrograph will then deliver spatial and spectral focus fully within specifications for the more demanding MOS and mIFU modes.

Once this work is completed, plans are to continue commissioning of the MOS and mIFU modes, followed by SV and routine observations for those modes in 2025.

Acknowledgments

I'd like to thank all members of the WEAVE instrument and science teams for bringing WEAVE to the start of scientific exploitation. In this paper on science data, I especially thank the observers group at ING who took all of the data, and the CASU team at Cambridge for their tireless dedication to providing science-ready data to WEAVE scientists.

The Isaac Newton Group of Telescopes is operated on behalf of the UK Science and Technology Facilities Council (STFC) the Nederlanse Organisatie voor Wetenschappelijk Onderzoek (NWO), and the Instituto de Astrofísica de Canarias (IAC).

Funding for the WEAVE facility has been provided by UKRI STFC, the University of Oxford, NOVA, NWO, Instituto de Astrofsica de Canarias (IAC), the Isaac Newton Group partners (STFC, NWO, and Spain, led by the IAC), INAF, CNRS-INSU, the Observatoire de Paris, Rgion le-de-France, CONCYT through INAOE, the Ministry of Education, Science and Sports of the Republic of Lithuania, Konkoly Observatory (CSFK), Max-Planck-Institut fr Astronomie (MPIA Heidelberg), Lund University, the Leibniz Institute for Astrophysics Potsdam (AIP), the Swedish Research Council, the European Commission, and the University of Pennsylvania. The WEAVE Survey Consortium consists of the ING, its three partners, represented by UKRI STFC, NWO, and the IAC, NOVA, INAF, GEPI, INAOE, Vilnius University, FTMC Center for Physical Sciences and Technology (Vilnius), and individual WEAVE Participants. Please see the relevant footnotes for the WEAVE website[4] and for the full list of granting agencies and grants supporting WEAVE[5].

References

[1] Ágocs, T., et al. 2010, in Ground-based and Airborne Instrumentation for Astronomy III, Proc. SPIE, 773563

[2] Ágocs, T., et al. 2014, in Ground-based and Airborne Instrumentation for Astronomy V, Proc. SPIE, 914773

[3] Arnaudova, M. I., et al., 2024, MNRAS, 535, 2259.

[4] Balcells, M., Benn, C. R., Carter, D., et al. 2010, in Ground-based and Airborne Instrumentation for Astronomy III, Proc. SPIE, 7735, 77357G

[5] Balcells, M. 2014, EAS Pub. Ser., 67, 227

[6] Balcells, M. 2015, in Highlights of Spanish Astrophysics VIII, 776

[7] Balcells, M. 2023, in Highlights of Spanish Astrophysics XI, 370

[8] ASTRONET infrastructure roadmap, 2009, http://www.astronet-eu.org/IMG/pdf/Astronet-Book_light.pdf

[9] Dalton, G., Trager, S. C., Abrams, D. C., et al. 2012, in Ground-based and Airborne Instrumentation for Astronomy IV, Proc. SPIE, 8446, 84460P

[10] Dalton, G., Trager, S. C., Abrams, D. C., et al. 2014, in Ground-based and Airborne Instrumentation for Astronomy V, Proc. SPIE, 9147, 91470L

[11] Domínguez-Palmero, L., et al. 2024, this volume.

[12] Emsellem, E., Cappellari, M., Peletier, R. F., et al. 2004, MNRAS, 352, 721

[13] Falcn-Barroso, J., et al. 2024, this volume.

[14] Hess, K. M., Falcón-Barroso, J., Ascasibar, Y., et al. 2020, AAS, 235, 459.03

[15] Hughes, S., et al. 2022, in Ground-based and Airborne Instrumentation for Astronomy IX, Proc. SPIE, 12184, 121846J

[4] `https://weave-project.atlassian.net/wiki/display/WEAVE`

[5] `https://weave-project.atlassian.net/wiki/display/WEAVE/WEAVE+Acknowledgements`

[16] Jin, S., Trager, S. C., Dalton, G., et al. 2024, MNRAS, 530, 2688

[17] Lewis, I., et al. 2002, MNRAS, 333, 279

[18] Lewis, J., et al. 2019, in Highlights of Spanish Astrophysics X, 606

[19] Molinari, E, et al. 2016, in Multi-Object Spectroscopy in the Next Decade: Big Questions, Large Surveys, and Wide Fields. Proceedings of a conference held at Teatro Circo de Marte, Santa Cruz de La Palma, Canary Islands, Spain on 2-6 March 2015. Edited by Ian Skillen, Marc Balcells, and Scott Trager. ASP Conference Series, Vol. 507. San Francisco: Astronomical Society of the Pacific, 125

[20] Report of the European Telescope Strategy Review Committee, 2010, http://www.astronet-eu.org/IMG/pdf/PlaquetteT2_4m-final-2.pdf

[21] Terrett, D. L., Lewis I. J., Dalton, G., Abrams, D. C., et al. 2014, SPIE, 9152, 216