THE PIRATE FACILITY: AT THE CROSSROADS OF RESEARCH AND TEACHING

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RESUMEN

Describo el observatorio robótico de 0.43m que pertenece a la Open University PIRATE, ubicado en Mallorca. PIRATE es una instalación rentable que contribuye a la investigación astrofísica de actualidad y como una plataforma inspiradora para la educación a distancia para aprender ciencia práctica.

ABSTRACT

I describe the Open University-owned 0.43m robotic observatory PIRATE, based in Mallorca. PIRATE is a cost-effective facility contributing to topical astrophysical research and an inspiring platform for distance education students to learn practical science.

Key Words: telescopes — instrumentation: photometers — stars: planetary systems

1. GENERAL

The Physics Innovations Astronomical Telescope Explorer (PIRATE) was set up in 2007/8 as a pilot project funded by the Physics Innovations Centre of Excellence in Teaching and Learning (π CETL), one of a number of UK government-funded initiatives to drive innovation in higher education in the UK. The aim of the PIRATE project was to investigate the feasibility of teaching practical science to Open University (OU) distance learning students by providing real-time access to a remotely-controlled observatory. Although other robotic telescope projects were well-established at the time none catered for the particular needs of distance learning in higher education. The wide range of prior knowledge and experience encountered in the OU student cohort, and the fact that most OU students have to fit their part-time studies around other commitments, places additional demands on the selected teaching methods and tools.

2. SITE AND HARDWARE EVOLUTION

The opportunity for setting up an OU-owned and OU-operated robotic facility arose from an existing collaboration between the OU and the Observatori Astronòmic de Mallorca (OAM; N 39;38;34.31 E 02;57;03.34, 160 m above sea level), a teaching observatory near Costitx, in the rural heart of the Balearic Island of Mallorca. The OAM hosted the OU's popular residential school course in observational astronomy and planetary science between 2004 and 2011, a week-long event for groups of 20-40 participants, offered up to 8 times a year, thus serving over 1500 students. The OAM campus boasts a 100-seat planetarium, seven teaching domes equipped with 12 inch Schmidt-Cassegrain telescopes and CCD photometers, a catering block and the main observatory building with a computer lab, offices and control rooms for the main telescopes. In 2007 the OAM generously offered to also host a remotely controlled OU facility, providing essential infrastructure and basic maintenance in exchange for a share in the observing time. The observatory site was selected primarily for convenient access to a teaching campus rather than for its superior observing conditions. Statistically, about 2,000 hrs annually (50% of all nights) are usable for imaging and differential photometry, with the best season extending from late April to early October. The prevalent seeing is 2-3'' and the limiting magnitude is near 19 in V and R. High humidity is a feature of the Mediterranean climate and often forces an early shut-down, particularly for hardware fully exposed to the night sky.

PIRATE was set up initially in a simple rolloff shed on the roof of the catering building. The main optical tube assembly, a 14 inch f/10 Schmidt-Cassegrain (Celestron-14), and a 80 f/7.5 refractor serving as guide scope were mounted on a robotic German equatorial mount (Paramount ME²). The main imaging camera was an SBIG STL1001E which has a 1024 \times 1024 KAF-1001E CCD with pixel size 24, giving a 21' field of view and 1.2"/px plate scale. The camera came equipped with an 8 position filter

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 $^{^{2}}$ by Software Bisque



Fig. 1. PIRATE Mk 2 hardware in the Baader Planterium All-Sky dome. Photo by Juan Rodriguez, OAM.

wheel holding 5 broadband filters (Clear, and Johnson B, V, R, I) and 3 narrow-band filters (H_{α} , OIII, SII). The guider camera is an SBIG ST402ME. First light was achieved in March 2008.

Whilst the initial concept proved promising, the variable observing conditions in the winter season called for a more robust enclosure for better protection of the hardware from adverse weather, particularly from high humidity. Further funding in 2009 allowed PIRATE to move into a new 3.5m clam-shell dome by Baader Planetarium³ which replaced the existing older dome on the East Tower of the main observatory building. Operations in this dome, with the OTA, mount and cameras as described above, started in August 2009, and this configuration is known as PIRATE Mk 1 (Holmes et al. 2011; Lucas & Kolb 2011).

In August 2010 the main OTA was upgraded to a 17 inch, f/6.8 corrected Dall-Kirkheim astrograph (a Planewave SDK17). For a period of about one year this was operated with the ST1001E camera described above, i.e. with a plate scale of 1.7''/pxand 29' field of view. This configuration is referred to as PIRATE Mk 1.5. In August 2011 the main imaging camera was replaced with the current SBIG STX16803 which has a 4096 \times 4096 KAF16803 chip with pixel size 9, resulting in a 43' field of view and pixel scale 0.63''/px in binning 1. The CCD camera is equipped with a 5 position filter wheel holding 3 broadband filters (Baader R, G, B), an H α filter and a clear filter. This configuration is referred to as PIRATE Mk 2 (Busuttil et al. 2014, forthcoming) and shown in Fig. 1.

3. THE USE IN DISTANCE EDUCATION

PIRATE was designed to deliver real-time access for distance learners at undergraduate level with limited or no prior experience in observational astronomy. It was felt that the hands-on experience with live control of actual hardware provides a highly motivating and inspiring form of learning practical science. To replicate the collaborative environment and mode of working in traditional university teaching labs, as well as in astrophysical research projects, we made synchronous group working, mediated by conferencing software, an integral part of the learning activities with PIRATE — at the time a novel concept in the OU curriculum. The telescope control software required for this direct access mode to succeed in the OU context must be robust, versatile and intuitive to use. The curriculum cannot afford devoting much time to teaching a specialised command language or the interpretation of extensive diagnostic output.

The Windows-based automated observatory control software ACP^4 , widely used by amateur installations and AAVSO observers, offered the best access solution. The clearly laid out web interface serves multiple simultaneous users, displays vital status information and has easy-to-use web forms for submitting observing requests. ACP allows the user to control associated hardware such as the dome and camera cooler, and facilitates the browsing and downloading of acquired data and log files. More experienced students or researchers use PIRATE in a semi-autonomous mode with pre-completed observing plans for the entire observing session. Such observing plans can be submitted via the ACP web interface, and in practice expert users value the web interface as a convenient control tool often negating the need for remote desktop access to the control PC. PIRATE Mk 1 included bespoke software operating Phidgets to give students power control and dome control (Lucas & Kolb 2011). To enhance resilience this solution was abandoned with PIRATE Mk 2; the dome operation is now via ACP, and the student users are no longer given access to remote power switches.

OU students prepare for their real-time observing session with a two-hour long session on a simulator. This is a separate installation of ACP set up in simulator mode, on an independent server unrelated to PIRATE. The simulator has the same look and feel as the real PIRATE, except that no hardware is attached to it. Images returned to the user are synthetic frames populated with point sources

³http://www.baader-planetarium.com

⁴by DC-3 Dreams

at the appropriate catalogue positions and displaying realistic point spread functions. The simulator is a stand-alone tool and is also supplied as a publicly available teaching resource via The OpenScience Laboratory⁵ platform, under the name The Open-Science Observatory.

3.1. Real-time observing session

While the simulator activity is completed by each student on their own, the live observing sessions are tackled by observer teams of 2-4 students. The student team typically "meets" on Skype just before sunset, to discuss the session and distribute roles such as telescope operator, log keeper, data quality and environmental control monitor. Access to the ACP web interface is controlled via a booking and entry portal hosted by The OpenScience Laboratory. A Night-Duty Astronomer (NDA) is online and ensures that the facility is ready for use. The NDA remains on call throughout the session, but contact time is deliberately kept at a minimum. Depending on the level of the activity and experience of the observer team this could be limited to just occasional troubleshooting issues, or may include brief advice on observing techniques and interpretation of acquired data. In practice the NDA role may be split between a tutor who can conduct routine tasks behind the scenes, and an expert user (who is often a research user of PIRATE) who is contactable in the rare cases when a more complicated restart procedure is required. If sessions extend beyond midnight the observer teams are advised to contact the NDA only in extreme emergencies such when they cannot close the dome or verify independently that the dome is closed.

Observer teams can diagnose observing conditions from the PIRATE webpage⁶ which displays live data from a Boltwood cloud sensor, a domemounted Reinhardt⁷ weather sensor, an all-sky camera, and weather senor data from the sister observatory PTST (Planetary Transit Study Telescope, owned by Hamburg University) on the neighbouring observatory tower. A number of webcams, exterior and interior to the dome, some with pan/tilt/zoom control, audio and switchable IR beam, complete the immersive experience.

To preserve bandwidth during live observing sessions, bulk data transfer is discouraged until the morning when an automated transfer into the OUhosted PIRATE ftp data archive is initiated.

3.2. Student projects

The level 3 (final year equivalent) student projects aim at constructing the long-term, phased light curve of a periodic variable star detected by SuperWASP and coincident with a ROSAT X-ray sources (Norton et al. 2010). The groups observe the target over a period of 8 weeks up to 7 times in multiple broadband filters. The project outcome is a collaborative group report detailing the data acquisition, reduction, analysis and the scientific interpretation. Two subgroups of the 2010 cohort of level 3 students refined their project reports further and published their results in scientific papers (Faillace et al. 2013, Bruce et al. 2013), demonstrating that OU undergraduate student projects can deliver new scientific insights. At level 2 (second year) the projects have less time at the telescope and the emphasis shifts from in-depth analysis and interpretation to understanding the basic techniques required for data acquisition, and the outcome is a colourmagnitude diagram of up to three star clusters. A more detailed appraisal of the impact of a facility such as PIRATE in teaching practical science and preliminary results of a study on the effectiveness of teaching with PIRATE is given by Brodeur et al. (2014a, 2014b, this volume).

4. RESEARCH PROGRAMME

Despite its comparatively small aperture, PI-RATE is a research-grade instrument that delivers scientifically competitive research output. The opportunity to access a facility involved in cutting-edge astrophysical research is in turn a highly motivating factor for students using PIRATE in their course work. A natural research area for a wide-field photometric instrument such as PIRATE is the monitoring of variable sources or the search for transients, and PIRATE is involved in both of these fields.

The main research deployment of PIRATE has been the follow-up photometry of suspected transiting Jupiter-sized exoplanets identified by Super-WASP (Pollacco et al. 2006). PIRATE is targeting candidate sources singled out by the SuperWASP pipeline process and deemed worthy of further investigation after a manual quality check ("eye-balling"). The contribution of PIRATE and other similar facilities linked to SuperWASP such as TRAPPIST (Jehin et al. 2011) is to further constrain the transit timing and light curve shape, but primarily to exclude false positive events. These may arise from partially eclipsing binaries or blends of the target star with a fainter binary displaying deeper eclipses. The PI-RATE observing strategy was initially focussed on

⁵http://opensciencelab.ac.uk/

⁶http://pirate.open.ac.uk/ou.html

⁷http://www.reinhardt-testsystem.de/english/

obtaining high cadence, high-precision data covering a sizeable chunk of out-of-transit and in-transit light curve, including ingress and egress where possible. PIRATE Mk 1 achieved a light curve rms of 2.5 mmag with 30 sec exposures for a V = 11 mag star. Typically two sources were observed per observing night, one before and one after the pier flip, to avoid discontinuities across the pier flip. PIRATE contributed data to the discovery of WASP-54b and 56b (Faedi et al. 2013) and WASP-65b (Gómez Maqueo Chew et al. 2013). In the 2012 winnowing campaign PIRATE classified 90% of the observed 87 candidates (20 potential exoplanets, 27 blends, 5 grazing eclipsing binaries and 27 non-detections). To maintain throughput despite competing demands on telescope time the observing strategy changed in 2013 to focus on the recognition of blends. These can be identified with on/off photometry, a technique not ideal for planetary transit detection because of the amount of red noise present in many PIRATE light curves, including the discontinuity at pier flip.

PIRATE also runs a complementing science programme on transient sources. In the early years a monitoring programme of M31 resulted in a number of electronic telegram alerts on M31 novae. In 2013 PIRATE joined the Gaia science alert network aiming to provide photometric and spectroscopic followup data of transient sources discovered by the Gaia mission (Hodgkin et al. 2013). The Gaia science alert pipeline will generate VOEvents which will in turn trigger automated target-of-opportunity observations by PIRATE employing the ACP Scheduler software. Coordinated test observations of the network with PIRATE participation are underway (e.g. ASASSN-13aw = SN 2013dr; Wyrzykowski et al. 2013). The differential photometry provided by participating facilities is converted into absolute flux using the Cambridge photometry calibration server⁸. The calibration against a sample of about 20 - 100 +catalogue stars per field shows that the spectral response of PIRATE Mk 2 with Baader filters R, G and B is equivalent to the APASS r, V and g filters (see Smith et al. 2010 for details on APASS filters), respectively. The PIRATE Mk 1.5 system with Johnson filters I, R, V and B is equivalent to APASS filters i, r, V and g.

Serendipitous discoveries often outshine results of routine monitoring programmes. A deep exposure of M101 obtained by PIRATE in August 2011 only 4 hrs after the implied time of explosion of type Ia supernova 2011fe (Bloom et al. 2012) constitutes the earliest recorded post-SN image of M101. The upper flux limit on SN 2011fe from this chance observation places stringent constraints on the size of the progenitor system, effectively proving that the exploding star must have been a white dwarf, and that the companion star must have been more compact than a normal main-sequence star (Bloom et al. 2012, Nugent et al. 2011).

5. CONCLUSIONS

PIRATE is a small-aperture remotely-controlled telescope assembled mainly from off-the-shelf hardware and software components. Real-time access to PIRATE is used to great effect for the teaching of distance learning undergraduates. Remote laboratories represent important tools for teaching practical science at a distance, and robotic optical astronomical telescopes are a particularly versatile and powerful form of these. The Universe is the laboratory, and every new measurement may uncover a surprising new source or behaviour. PIRATE demonstrates that small facilities can deliver topical research output, and that undergraduates can have a share in astronomical research.

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⁸http://gsaweb.ast.cam.ac.uk/followup

⁹http://pirate.open.ac.uk/contacts.html