James Clerk Maxwell Telescope
The James Clerk Maxwell Telescope (JCMT) is one of the world’s leading astronomical observatories. For more than 25 years it has served the UK and international communities with unique and forefront capabilities that have blazed the trail in submillimetre astronomy, consistently leading the world in productivity and impact. In addition, the JCMT pioneered many operational innovations, including flexible scheduling and the provision of data reduction pipelines. Now equipped with the world’s fastest submillimetre mapping camera, SCUBA-2, it ideally complements ALMA and provides a rich addition to the legacy of Herschel, and is poised to deliver world-leading science for several years to come.

Despite these successes, the UK’s funding agency for astronomy, the Science and Technology Facilities Council (STFC), can no longer support the JCMT beyond 30th September 2014. This decision follows a review process and reflects the evolution of the UK’s suite of observational capabilities in a tightly-constrained financial environment. The observatory is therefore being offered to the global astronomical community through this Announcement of Opportunity.

We encourage anyone who is interested in participating in the JCMT beyond 1st October 2014 to review this Prospectus and submit an Expression of Interest. There are no preconceptions or constraints: we welcome parties wishing to take over the operation of the entire observatory, parties interested in becoming minor partners, and any other permutation. We are willing to consider any and all possibilities. Details of the facilities being made available and the process for registering your interest are all described in this document.

The JCMT is a highly-productive, world-leading observatory with unique observational capabilities for submillimetre astronomy. It is being offered at a time when Herschel has successfully completed its mission and as ALMA ramps up towards full science operations. ALMA’s high sensitivity within small fields
is a perfect complement to the JCMT’s wide-field instruments. We invite you to consider this unprecedented opportunity to gain access to forefront submillimetre capabilities at a time when this part of the spectrum is being opened up for exploitation, and to participate in the new discoveries that will surely emerge.
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1. Introduction

The James Clerk Maxwell Telescope (JCMT), through a focus on scientific excellence, is to be the most efficient and advanced ground-based submillimetre astronomical facility in the world, supporting the prime scientific programmes of the partner countries. It aims to:

- allow users world-wide the opportunity to participate in a wide range of astronomical study by providing:
  - a suite of common-user, state-of-the-art instruments;
  - a range of observing methods;
  - a telescope of surface, pointing and tracking capability commensurate with the highest-frequency instruments available;
  - a high level of support at the telescope;
- maintain an extremely reliable level of operation with a target of loss of time due to faults being restricted to less than 5% of clear time; and
- be efficient and cost-effective.

This ambitious mission statement was approved by the JCMT Board in 1995, and is still apposite: it has been fulfilled in every respect.
The JCMT was operated for more than 25 years as a partnership between the UK (55%), Canada (25%) and The Netherlands (20%). As majority partner, the JCMT is owned by the UK funding agency for astronomy, the Science and Technology Facilities Council (STFC). The Netherlands withdrew from the partnership in March 2013 and Canada will do so in September 2014, in both cases to redirect limited resources to the support of ALMA. Following a review process, and due to financial pressures, STFC decided in May 2012 that it could no longer provide operational support for the JCMT beyond 30th September 2014. The observatory and its instruments and associated support equipment are therefore being offered to the global astronomy community through this Announcement.

Nevertheless, the JCMT is, by any objective measure, the world’s most productive ground-based facility for submillimetre astronomy. This elite status can be attributed to the following factors:

- **its location**: Mauna Kea is one of the best submillimetre observing sites in the world, and certainly the very best in the northern hemisphere;

- **its dish**: at 15m, the JCMT is the largest single-dish submillimetre telescope in the world, and has an active programme of surface control to maintain its accuracy;

- **its instrumentation**: the JCMT has benefited from an aggressive programme of innovative instrumentation to produce leading-edge instruments with unique capabilities. SCUBA, one of the most successful astronomical instruments ever built, was the prime example of this and its successor instrument, SCUBA-2, has followed in the same tradition;

- **its software**: the JCMT boasts a comprehensive suite of tools to optimise the observing programme and to provide users with publication-quality data products; and

- **its staff**: without whose talent and dedication none of the above would be possible.

All of these factors are discussed more fully in the following sections.
The James Clerk Maxwell Telescope Prospectus

2. THE TELESCOPE AND SITE

The JCMT is a classical Cassegrain telescope on an altitude-azimuth mount. It currently provides:

- primary reflector diameter 15m
- sky access from –40° to +90° declination
- pointing accuracy to ±1.5–2” in right ascension and declination
- active 3-axis focus maintenance using lookup tables for elevation and temperature
- surface accuracy typically <25μm rms
- control of the dish surface using holographic imaging and panel adjusters
- passive dome ventilation
- a Gore-Tex membrane for environmental protection
The primary reflector is composed of 276 individual panels, each of which consists of a thin aluminium skin bonded to a lightweight honeycomb matrix, attached at three points to the backing structure of the antenna. The homologous backing structure is designed to maintain a parabolic figure as gravity distorts the antenna as it tips to different elevations. The sub-reflector, or secondary mirror, can be adjusted in three axes to compensate for changes in focus and in the figure of the primary. In addition, the secondary can be tilted or chopped in two axes in order to perform sky background cancellation.

The accuracy of the surface is monitored using a holographic imaging system, with a dedicated receiver at the JCMT’s Cassegrain focus. The alignment of the individual panels can be adjusted by means of actuators at the mounting points. The rms surface accuracy is typically less than 25µm, with a best value of 22µm.

In order to protect the telescope from the environment, the entire structure is enclosed within a building that co-rotates with the antenna. During normal operation a membrane (which we believe to be the world’s largest piece of Gore-Tex) is deployed in front of the antenna. The membrane is transparent at millimetre and submillimetre wavelengths. In addition to providing protection from the wind, the membrane reflects visible and near-infrared radiation, allowing daytime astronomical observations, including direct observations of the Sun itself.

The facility is situated at the summit of Mauna Kea, on the island of Hawaii, at an altitude of 4092m. This is one of the best sites in the world for submillimetre astronomy, and certainly the very best in the northern hemisphere: the JCMT’s current instruments (§3) routinely operate in the spectral windows at 450µm, 850µm and 1.1mm, although previous instruments have worked at both shorter and longer wavelengths. A dedicated Water Vapour Monitor samples the line-of-sight emission in the 183-GHz H₂O line and is used both to track observing conditions and to enable extinction correction of photometric data.
The average weather loss, due to prohibitive opacity and closure of the dome due to snow, is ~14%. This is subject to a distinct seasonal pattern on Mauna Kea, with the winter months being more vulnerable to losses. Flexible scheduling, described in §4, enables rapid switching between programmes to match the prevailing conditions, significantly reducing the susceptibility of the observatory’s science programme to weather.

W51, in Aquila, is a region of massive star formation. The background is a mid-infrared Spitzer image whilst the blue overlay is a submillimetre image obtained with SCUBA-2 at 850µm. 

*Image credit*  
Spitzer/GLIMPSE, JAC
In the submillimetre regime, astronomical instruments fall into two broad categories: heterodyne receivers, which use high-frequency radio techniques to measure individual spectral lines at very high spectral resolution; and photometric imagers, which use long-wavelength infrared techniques to measure continuum emission across a filter passband.

**Spectroscopic instrumentation**

The JCMT’s current suite of common-user heterodyne receivers is listed in Table 1. RxA3 is our poor-weather receiver, providing the observatory with a continuing operational capability when the opacity is prohibitive at higher frequencies (c.20% of the time on average). HARP is the world’s first array receiver in the 345-GHz atmospheric window, and has established itself as the instrument of choice for submillimetre spectral mapping. RxWD is our high-frequency receiver and can only be used in excellent weather conditions; it was upgraded in 2007 with new mixers developed for ALMA, and according to at least one observer is the most sensitive single-dish receiver in the world in the 690-GHz band. All three receivers use ACSIS, a multi-channel and highly-configurable correlator with bandwidth up to 2 GHz, as their backend spectrometer.

**Table 1**

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Spectral Range (GHz)</th>
<th>Array Format</th>
<th>Channels per Pixel</th>
<th>Sideband Configuration</th>
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<td>1</td>
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<tr>
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<td>Single</td>
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<tr>
<td>RxWD</td>
<td>630–710</td>
<td>1</td>
<td>2</td>
<td>Single</td>
</tr>
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</table>

**Continuum instrumentation**

The JCMT’s impact on world astronomy has come primarily through its continuum receiver, SCUBA. As the world’s first common-user submillimetre camera, this instrument opened up the submillimetre region of the spectrum to a broad community of users and thereby revolutionised our knowledge in several
key areas of astronomy: in particular, being sensitive to cold dust, it led to major advances in our understanding of how planets, stars and galaxies form. Building on this success, SCUBA was replaced by a successor instrument, SCUBA-2, in 2011. SCUBA-2 features 5,000 pixels at each of two wavelengths, 450µm and 850µm, based on transition-edge superconductor technology: the combination of increased per-pixel sensitivity, a larger field of view achieved through a novel optical design, and near-instantaneous sampling of the focal plane offers a mapping speed two orders of magnitude higher than the original SCUBA, enabling a range of astrophysical investigations that could never have been undertaken previously (Holland et al., 2013). A dedicated science programme to exploit this unique capability, the JCMT Legacy Survey, is described below (§6).

Finally, two instruments that will operate in conjunction with SCUBA-2 are being commissioned as this Prospectus is being written: a polarimeter (POL-2) and a Fourier transform spectrometer (FTS-2). These ancillary instruments will bring exciting new capabilities to the JCMT beyond that offered by SCUBA-2 alone: the polarimeter will provide magnetic field orientation and dust polarisation properties which are crucial for star-formation studies, and the spectrometer will provide both dust emission spectral indices and an alternative handle on line contamination of photometric data. The combination of SCUBA-2 and its ancillary instruments offers scientific capabilities unrivalled by any observatory in the world.
If a new operator or operating partnership takes over the operation of the JCMT, the operating model will be entirely at the new entity’s discretion. Nevertheless, the merits of building on an existing, successful system should be carefully considered before any changes are introduced. In this section, the operational model currently in use at the JCMT is described.

The JCMT is a common-user observatory in which community astronomers are awarded time through a peer-reviewed proposal process. The telescope is staffed at night by a visiting observer (an astronomer from one of the approved projects) and a staff member to operate the telescope (called a Telescope Systems Specialist, TSS). Two personnel at the summit is the minimum permissible for safety reasons.

The JCMT’s mission statement (§1) alludes to a high level of user support. All visiting observers are assigned a staff scientist who fills the role of Support Astronomer. The duties of the Support Astronomer are:

- to assist with all logistical arrangements;
- to assist with the observation planning;
- to accompany the observer to the telescope for the first night of the observing run;
- to be available by telephone for the remainder of the observing run;
- to assist the observer with the reporting and data reduction software; and
- to meet with the observer at the conclusion of the run to review the outcome.
The Support Astronomers are sometimes also invited by the users to participate in the post-run data analysis, and their names often appear on publications as a result. Thus the high level of support is beneficial to the telescope, to the observer, and to the support staff, and this is one of the major reasons for the JCMT’s high level of success.

The JCMT operates a novel flexible-scheduling system that was designed to enhance the completion of the highest-ranked projects within the constraint posed by the variable observing conditions on Mauna Kea. Indeed, the JCMT was amongst the first telescopes in the world to adopt flexible scheduling and it has been an unqualified success with our user community. A number of software tools have been created to support this operating mode:

- an observation preparation tool (OT);
- standard libraries of observing sequences;
- real-time, automatic matching of observing programmes to weather conditions;
- fast switching between instruments and modes;
- data-driven reduction pipelines ($§5$) for all modes of all instruments;
- OT and data reduction pipeline available off-island;
- automatic, comprehensive feedback to and from remote PIs; and
- fast, web-based access to raw data and reduced data products.

Supported by these tools, flexible scheduling has been an enormous success for the JCMT and has been a major contributing factor to the escalating productivity in recent years ($§8$).
All JCMT instruments, both spectroscopic and imaging, are accommodated by the same Starlink-based pipeline infrastructure. The pipeline runs continually during the observing night, allowing the observer to monitor instrument performance and data quality and providing quick feedback on observation progress, including co-adding of multiple observations. This pipeline was a prerequisite for the implementation of flexible scheduling.

The pipeline is also designed to run off-line at a PI’s university to generate near-publication quality products for all instruments without human intervention. The acquisition system is designed such that all the information needed to reduce the data is stored in the data headers, including the PI’s scientific intent and the observing mode defined for the telescope.

Fully-automated data processing is handled by the Canadian Astronomy Data Centre (CADC). CADC host the raw data archive and also provide the processing infrastructure. The observatory is responsible for writing the data reduction algorithms and for scheduling the reduction jobs that run on the CADC system. Reduced data products are made available to the user within 24 hours of the data being acquired, and multi-night (project) products can also be generated on demand: this fast feedback of reduced data products to PIs is essential to provide all the information they need to be able to adjust their observing programmes and to maximise the scientific return from their observations. This processing and archiving infrastructure can potentially continue to be provided to a new operator of the JCMT in return for a contribution to CADC’s operating costs.
Within the past decade, nearly the entire instrumentation suite at the JCMT has been replaced or upgraded. This massive programme of transformation was driven by the scientific requirement for statistically-significant sample sizes in most areas of submillimetre astronomy opened up by the original SCUBA instrument, from dust-enshrouded galaxies in the early universe to debris discs around nearby stars. Accordingly, the new instruments HARP, ACSIS and SCUBA-2 were optimised for wide-field submillimetre mapping in both spectral line and continuum modes. Equipped with these new capabilities, the JCMT is the world’s fastest submillimetre mapping instrument.

The science programme exploiting these new capabilities is the JCMT Legacy Survey (JLS). The JLS has been allocated 65% of the telescope time and is composed of seven distinct survey projects (Table 2); the remaining 35% of the telescope time is reserved for conventional, PI-led projects. The JLS is of the highest scientific calibre: all the surveys promise to be uniquely powerful levers for the exploitation of the growing range of public survey datasets and a springboard for the exploitation of ALMA, Herschel, JVLA, LOFAR, JWST and the SKA. The knowledge gained from the JCMT Legacy Survey will have far-reaching benefits for the whole of astrophysics.

Recent highlights from the JLS and other projects observed with the JCMT are presented in the following sections. These highlights only scratch the surface of what is possible with the JCMT and its unique set of instruments: notwithstanding the excellent science described below, there is insufficient time up to September 2014 to complete the full set of SCUBA-2 surveys as originally envisaged. In all cases, continued operation of the JCMT would enable these science opportunities to be more thoroughly exploited.

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**Table 2**

<table>
<thead>
<tr>
<th>Project</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Gould Belt survey</td>
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<tr>
<td>Galactic plane survey</td>
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<tr>
<td>Outer galaxy survey</td>
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<tr>
<td>Nearby galaxies survey</td>
<td>21</td>
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<tr>
<td>Cosmology survey</td>
<td></td>
</tr>
<tr>
<td>Spectral line survey</td>
<td>38</td>
</tr>
</tbody>
</table>
Submillimetre cosmology

The submillimetre waveband provides a unique window on the most active phases of galaxy formation in the distant universe. The most actively star-forming galaxies, at all redshifts, are highly obscured by dust and as a result are bright far-infrared sources. Such systems are cosmologically important as they host a large fraction of the total star formation at high redshifts ($z > 1–3$) and dominate the extragalactic submillimetre sky. This numerous population was first detected over a decade ago using SCUBA (Smail et al., 1997; Hughes et al., 1998; Barger et al., 1998); statistical studies of the population, however, have been limited by the modest grasp of ground-based observatories and the poor resolution of space-based instruments.

Equipped with SCUBA-2, the JCMT is the pre-eminent ground-based submillimetre survey instrument, roughly two orders of magnitude faster for wide-field mapping than any other operational camera/telescope combination. The SCUBA-2 Cosmology Legacy Survey is exploiting this capability to undertake a survey of 5–10 square degrees of sky to mJy flux limits (Figure 1) with the goal of detecting the thousands of high-redshift starbursts and active galactic nuclei needed to understand the significance of the dust-obscured phase in the growth of galaxies and super-massive black holes. This survey, and more ambitious studies which may be developed by a new operator, will provide unique insights into the earliest phases of galaxy formation and evolution (e.g., Geach et al., 2013).
Nearby galaxies

The JCMT plays a leading role in tracing the distribution and physical properties of the molecular gas and dust in nearby galaxies. JCMT data provided the first evidence of excess 850-µm continuum emission in low-metallicity environments (Galliano et al., 2003, 2005), whose physical origin remains under active investigation. Multi-frequency spectral line data from the JCMT have been essential for investigating the density and temperature of the molecular gas and their variations with environment (e.g., Israel, 2009). More recently, the JCMT Nearby Galaxies Legacy Survey (NGLS) is the largest survey (155 galaxies) of molecular gas with sub-kiloparsec resolution (Wilson et al., 2009, 2012). The NGLS is also observing many of these same galaxies in dust continuum emission with SCUBA-2, providing images of the cool dust emission with unprecedented sensitivity and resolution (Figure 2). The JCMT’s high spatial resolution is critical for comparing the content of the interstellar medium with star formation properties: it is possible to distinguish between arm and interarm regions while providing resolved measures of the gas-to-dust mass ratio and a recalibration of the CO-to-H$_2$ conversion factor in galaxies. These properties are essential to building a complete understanding of the links between star formation and the dense interstellar medium in present-day galaxies.

**Figure 2**

Two views of the nearby spiral galaxy M66: (Left) Optical image, with the 850-µm image overlaid in red; (Right) the 850-µm data only. The density of cold dust follows the spiral structure of the galaxy. Image credit NGLS team.
**Star formation**

Deep within dark molecular clouds, the next generation of young stars is forming out of cold dense gas and dust. Submillimetre continuum emission from cold dust can trace compact structures associated with the very youngest stars, revealing the number and arrangement of such objects within a cloud. The JCMT pioneered such work with SCUBA, the first submillimetre continuum camera, revealing the youngest known protostars and pre-stellar cores.

With SCUBA-2, entire populations of protostars within a single cloud can be imaged rapidly. The Gould Belt Survey (Ward-Thompson et al., 2007) uses SCUBA-2 to map the high-column-density areas of nearby clouds to determine the character of the pre-stellar and protostellar populations and the relationships between these populations and their parent molecular clouds. Not all clouds in the Gould Belt will be imaged within the available time and there is therefore an outstanding opportunity for a new operator of the JCMT to build on and extend this work beyond 2014. Figure 3 shows one image from this survey, a 1.2°-long image of the Integral Shaped Filament (ISF) in the Orion Molecular Cloud at 850µm. The very high sensitivity of SCUBA-2 has enabled the individual protostars in Orion to be easily detected as compact bright objects. Also seen clearly here are the numerous intertwined sub-filaments in the ISF, with a large population of protostars and pre-stellar cores. The latest theories based on data from Herschel hypothesise that pre-stellar cores form mostly along filaments such as the ISF (André et al., 2010; Molinari et al., 2010). SCUBA-2 is highly sensitive to both cores and filaments, working at longer wavelengths and with superior resolution to Herschel. Its 850- and 450-µm data can probe the temperature and opacity characteristics of the emitting dust, thereby enabling very accurate probes of the masses of these star-forming objects. Sources found in SCUBA-2 images such as this make ideal targets for follow-up with ALMA.
Debris discs

Debris discs are made of the ‘fallout’ from collisions among planetesimals, and if viewed externally, the Sun’s Kuiper Belt today would show a very faint, quiescent example of this phenomenon. Other nearby main-sequence stars, however, show spectacular bright dusty belts, indicating very diverse evolutionary paths of otherwise similar stars. Early confirmation that such active belts exist around mature stars was made with optical coronagraphs, but the pioneering SCUBA camera on JCMT made the first image gallery across wide-ranging spectral types, and confirmed that the dusty debris constitutes the tiniest component (of sub-lunar mass) known in extrasolar planetary systems (Holland et al., 1998; Wyatt, 2008). The parent body populations can be much more substantial than in today’s Solar System, and unexpected results include an association of such planetesimals with low-mass planets, and sometimes survival of the colliders to ages much greater than that of the Sun. This places debris disc research centrally in the picture of how planets form, evolve and become habitable — if this is indeed possible in cases suggesting prolonged heavy bombardment. Figure 4 shows the nearby disc system of epsilon Eridani against the faint extragalactic background, and combines the wealth of information from two broadband SCUBA images. A classic youthful solar system analogue is revealed, with dust in the vicinity of the planets brightening into a surrounding ring, within which are seen clumps that were interpreted as gravitational resonances with a Neptune-like planet. An ongoing campaign with SCUBA-2 has confirmed clumps as co-moving with the star and will soon give a measure of their orbital rotation, and thus a hoped-for first detection of an ‘ice giant’ planet by this new technique.
The Venusian atmosphere

JCMT observations have contributed to fundamental discoveries regarding the chemistry and dynamics of the Venus middle atmosphere. State-of-the-art submillimetre heterodyne receivers and the capability to observe arbitrarily close to the Sun (including solar transit observations in June 2012, see Figure 5) are particularly suited to unique investigations of the Venus atmosphere. Since 2000, JCMT observations of Venus have:

- characterised the dynamics and thermal structure of the extremely variable nightside upper atmosphere;
- discovered unanticipated SO₂/SO layers 30km above the main sulfate cloud layers (Sandor et al., 2010);
- identified large secular variations in the chemistry (HDO, CO, HCl, SO₂, SO), thermal structure and dynamics (Doppler winds) of the middle atmosphere (Clancy et al., 2012);
- determined the vertical distribution of the key HCl species in the middle atmosphere;
- detected ClO, the primary catalytic agent responsible for photochemical stability of the CO₂ atmosphere; and
- obtained unique solar transit measurements of supersonic flow across the full (circum-disk) terminator of the Venus upper atmosphere.

All of these measurements represent new discoveries that challenge previous interpretations of the Venus middle atmosphere. For example, the JCMT discovery of increasing SO₂ and SO abundances in the Venus middle atmosphere disproved model predictions that SO₂ could not be photochemically produced above the cloud layers. The JCMT (and more recently, the Venus Express spacecraft) observed behaviours of these upper level SOₓ layers have stimulated new photochemical modelling efforts (further constrained by H₂SO₄ upper limits provided by JCMT observations), which indicate more complex and perhaps aerosol-affected photochemistry for this region. Productivity with the JCMT continues to be high, with several papers in preparation based on recent results.
Black holes

A long-standing goal in astronomy is to resolve and image a black hole with Schwarzschild-radius resolution. Until recently, the resolving power required for such work was not available — the black hole with the largest apparent angular size, SgrA*, subtends only 10 micro-arcseconds. Successful Very Long Baseline Interferometry (VLBI) observations at a wavelength of 1.3mm on long baselines to the JCMT, however, have now demonstrated that direct imaging of a black hole event horizon is within reach. These observations have confirmed the existence of structure at the scale of the event horizon in the SgrA* black hole (Doeleman et al., 2008). Similarly compact structure has been resolved at the base of the well-studied extragalactic jet in M87, leading to the conclusion that the jet is launched by a prograde accretion disc orbiting a spinning black hole (Doeleman...
et al., 2012; Figure 6). These results, in which the JCMT has played a critical role, are radically changing our views of what is possible in the study of black holes and present an exciting scientific opportunity. Building on this work, an international group is extending the current 1.3-mm VLBI network to include new millimetre and submillimetre facilities to create a global array called the Event Horizon Telescope (EHT). Because of its vital geographic location, the JCMT can continue to be a pivotal element in this new array, including an extension to 0.8-mm VLBI observations that will provide the highest angular resolution possible from the surface of the Earth.
Notwithstanding the successes described in the previous section, the JCMT’s scientific potential, based on the mapping advantages of SCUBA-2 and HARP, will not be fully exploited by 30th September 2014. Excellent science opportunities therefore remain: the JCMT will continue to provide a rich, extremely important and complementary observational capability in the post-Herschel context and with ALMA entering routine operations.

The Herschel Space Observatory has been an overwhelming success: it has produced extremely-sensitive, large-area continuum maps covering the wavelength range 70–500µm. The complementarity with SCUBA-2 arises from the different wavelengths and spatial resolutions of the two facilities: SCUBA-2 probes colder material and reaches the Rayleigh-Jeans tail for warmer emission, essential for breaking the degeneracy between dust temperature and emissivity. Indeed, it is only by combining data from Herschel and SCUBA-2 that the full scientific potential of both can be realised. In addition, the larger aperture of the JCMT enables the submillimetre background at 450µm to be explored beyond Herschel’s confusion limit, allowing the JCMT to separate individual faint sources which remain blended and confused in the Herschel maps.

With fifty 12-m antennas, ALMA will provide an extremely powerful probe of millimetre and submillimetre emission throughout the universe. Despite this vast new capability, there are two reasons why continued operation of single-dish telescopes is scientifically important as we enter the ALMA era:

- single-dish telescopes can do important science that ALMA, being an interferometer, will not address; and
- single-dish telescopes underpin ALMA observing programmes, making them much more efficient and so maximising the return from investment in ALMA.
The JCMT, equipped with SCUBA-2, collects hundreds of times more energy than the whole ALMA array. This ability to multiplex the focal plane makes single dishes the technique of choice for wide-field imaging with moderate angular resolution. In addition, by virtue of its design as a sensitive interferometer, ALMA will not be used for wide-area surveys: the minimum time to map one square degree, for example, is about 45 hours. Quite apart from the operational cost of such a project, observing time on ALMA is highly competitive and time allocation committees will quite rightly assume that large-area surveys to complement ALMA observations will be undertaken with focal-plane arrays on single dishes, which are ideally equipped to do just that.

As well as the exciting scientific results that follow from wide-field studies by themselves, as described in the previous section, they also provide crucial background work to support high-resolution studies with ALMA. Just as in the optical/infrared domain, in which 4-m class telescopes with wide-field cameras provide sources for detailed follow-up on larger apertures (WFCAM on UKIRT being the archetype), so large-area submillimetre surveys will detect sources for high-resolution follow-up and establish their natal environments. Access to single-dish survey instruments will significantly strengthen the competitiveness of astronomers using ALMA.

These arguments were recognised in the US decadal survey of 2010, “New Worlds, New Horizons in Astronomy and Astrophysics,” and were used to endorse the
construction of a new single-dish submillimetre telescope, CCAT, to be built in northern Chile near the ALMA site. Between September 2014 (when the JCMT becomes available) and the completion of CCAT, if it is built, there exists a powerful niche for the JCMT. Exploiting this niche, especially through ambitious, expanded mapping programmes beyond the present JCMT Legacy Survey, will put a new JCMT community in a commanding position for securing ALMA time and for placing ALMA results into larger context.

This photograph, taken from the Subaru Telescope on Mauna Kea, shows the JCMT on the right, the Caltech Submillimeter Observatory on the left, and the glow from the erupting Pu‘u O‘o volcanic vent in the distance.

Photo: R. Morris, Subaru
**Community demand**

The standard measure of community demand for access to an observatory is its subscription rate, i.e., the ratio of time requested to time available. The JCMT’s subscription rate for the past 5 years is provided in Table 3. As noted in §6, telescope time at the JCMT has been split between survey science and PI science since HARP/ACSIS came on line in 2007, and these subscription rates therefore apply only to the PI portion of the time. During semesters 08B through 11B, during the hiatus between SCUBA and SCUBA-2, only the spectroscopic instruments were offered and the subscription was between 2 and 3.6; the subscription increased dramatically once SCUBA-2 was offered in 12A.

<table>
<thead>
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<tr>
<td>10A</td>
<td>1.9</td>
</tr>
<tr>
<td>10B</td>
<td>2.3</td>
</tr>
<tr>
<td>11A</td>
<td>2.8</td>
</tr>
<tr>
<td>11B</td>
<td>2.0</td>
</tr>
<tr>
<td>12A</td>
<td>5.6</td>
</tr>
<tr>
<td>12B</td>
<td>5.7</td>
</tr>
<tr>
<td>13A</td>
<td>4.4</td>
</tr>
</tbody>
</table>

**Operational performance**

The operational fault rate is defined as the ratio of time lost to technical faults to the available clear time (which is total time less weather losses and closures for engineering work). Each fault at the JCMT is filed at the time of occurrence and has an associated time loss, which is automatically logged by the observation management system. Table 4 indicates that the fault rate has been consistently below 5% for the past five years, as required by the observatory’s mission statement (§1). The one exception to this is 2011, the year in which SCUBA-2 was released for science observing: it is normal to experience a temporary increase in faults when new and complex systems are added to the observatory. Through diligent bug fixes and workarounds, these faults were gradually remediated and the fault rate has declined significantly since then.
More generally, there are no known issues that would constrain the continued operation of the JCMT for many years. An engineering data package providing technical data, maintenance procedures and other engineering issues can be provided to prospective proposers on request.

**Productivity**

In common with other observatories, we use the number of refereed papers in the scientific literature to characterise the JCMT’s productivity. The historical record of this metric is shown in Figure 7. The publication count was extremely high during the years the original SCUBA was on the telescope (1998 to 2005), demonstrating the productivity of this instrument, and has risen again over the past few years: new records were set in both 2011 and 2012. This trend looks set to continue through the next few years as JCMT Legacy Survey papers based on SCUBA-2 data begin to appear in the literature.
Comparative studies

The metrics described above are specific to the JCMT, and although they indicate temporal trends in demand and productivity, they do not by themselves provide an objective comparison against other observatories. Such comparisons appear in the literature from time to time. A compilation of citations to high-impact papers in 1999, for example, only two years after SCUBA was commissioned, ranked SCUBA second only to the Hubble Space Telescope, beating all other ground and space facilities, let alone any single instrument. More recently, a survey by Trimble & Ceja (2008) of publications and citations over specific time periods for a large number of observatories placed the JCMT first in the world amongst submillimetre and millimetre telescopes according to all three metrics they used: number of papers, number of citations, and citations per paper. Studies such as these have specific methodologies and the results require careful interpretation, but the JCMT was nevertheless ranked at the top of its class by a very wide margin.
There are well-equipped mechanical and electronics workshops within the JCMT building (welding, drill press, lathe, vertical mill, oscilloscopes, signal analysers, signal generators, etc.). These facilities are primarily for emergency repairs and trouble-shooting. Any fabrication work is undertaken at the Joint Astronomy Centre (JAC) in Hilo (see §10), which has a more comprehensive range of workshop facilities.

The JCMT is part of an observatory community on Mauna Kea, and many shared services are provided through the University of Hawaii Institute for Astronomy in return for an annual contribution. These include: maintenance of the summit access road; snow clearing in winter; operation of the mid-level facility at Hale Pohaku (food, lodging, library); the Mauna Kea Weather Center; and provision of utilities and a data communications network. There are a number of avenues for high-speed connections to the US mainland and elsewhere; the Southern Cross Network, for example, provides 1 Gb/s service to Seattle and thence to the rest of the world.
As with any telescope, the cost of operating the JCMT is strongly dependent on the choice of operating model, and any new operator or operating partnership will have to decide for itself how it wants to operate the telescope. At one extreme, it could continue to be run with the current suite of instruments and with a high level of technical and user support, providing capabilities for a wide range of survey and PI science projects in both continuum and spectroscopy modes; at the other, it could be streamlined to focus exclusively on survey science with a single instrument. The operational cost is vastly different in these two scenarios, and there is a continuous spectrum of possibilities in between. In this section, the cost of operating the JCMT in its current, general-purpose, high-support mode is presented as a reference point and, for illustration, an estimate is also provided for a low-cost operating model.

The JCMT and the United Kingdom Infrared Telescope (UKIRT) are both operated by the Joint Astronomy Centre (JAC) in Hilo, Hawaii. The provision of operational support for two telescopes using common engineering and software groups confers a number of advantages and has resulted in a highly-agile and cost-effective arrangement in which both telescopes are individually inexpensive to operate in comparison with other high-altitude, world-class facilities. STFC’s support for UKIRT is scheduled to cease on 30th September 2013, one year earlier than for the JCMT, and it is therefore assumed here that cost-sharing with UKIRT will no longer be possible.

With that assumption, the cost of operating the JCMT under its current operational model is provided in Table 5. These numbers are actual costs incurred in FY12/13.

Staff costs have been presented in three categories for convenience. The JAC has 12 staff members who directly support JCMT operations: an Associate Director, a Head of Operations, two instrumentation specialists, four research astronomers, a data analyst and three TSSs. The three TSSs work shifts of 5 nights on, 10 nights off to provide complete coverage. There are 25 staff who provide technical support

<table>
<thead>
<tr>
<th>Staff Category</th>
<th>$k</th>
</tr>
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<tbody>
<tr>
<td>JCMT operations staff</td>
<td>1,231</td>
</tr>
<tr>
<td>Technical support staff</td>
<td>1,711</td>
</tr>
<tr>
<td>Director and administrative staff</td>
<td>918</td>
</tr>
<tr>
<td>Requisitions</td>
<td>1,739</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5,599</strong></td>
</tr>
</tbody>
</table>
across a range of disciplines: mechanical, electronic, cryogenic and software. Finally, the Director is responsible for the overall strategy and operation of the institution and is supported by 6 administrative staff covering finance, HR, computing services and safety.

The requisitions costs associated with operating the JCMT are dominated by two items: electricity for the JAC building and the observatory (29%) and liquid cryogens for use at the summit (11%); the remainder is spread over a range of smaller items.

The cost of operating the JCMT reflects the comprehensive suite of scientific capabilities and the high level of technical and user support demanded by the ambitious mission statement in §1. As noted above, however, it would be entirely at the discretion of a new operator to adopt a different mission and to operate the JCMT under a different operational model. To offer some guidance for this we have developed a low-cost operating model for comparison. Its basic assumptions are:

- exclusively survey science, with SCUBA-2 as the sole operational instrument
- three TSSs to operate the telescope at the summit, as at present, with a visiting observer
- significantly reduced technical support
- no archive or user support; raw data provided directly to users
• no instrumentation development or facility upgrades
• administrative functions already in place with new operator
• rented office accommodation

The annual operating cost for this model has been estimated at $2.4M, as opposed to $5.6M for the current operation (Table 5). Although even less expensive operating models can certainly be devised, we judge this to be the lowest cost consistent with an acceptable scientific return. We emphasise that this is presented here for illustrative purposes only, to provide prospective new operators with a sense of the range of options: indeed, there is a continuous spectrum of possibilities between these two numbers according to the choice of operating model. We would be pleased to advise any prospective proposers.
In 2011, the Director set up a panel to study whether there are world-leading science cases for the JCMT up to 2020 and beyond, and to recommend telescope modifications and new instrumentation that would be required. The panel surveyed the worldwide context of submillimetre astronomy and conducted a broad community consultation. They concluded that there exist a number of compelling science cases for operating the JCMT into the 2020 era, including wide-area continuum and spectral-line surveys for galactic science and, for extragalactic science, large-scale, low-resolution spectroscopic surveys to complement the deep imaging surveys that are being carried out by SCUBA-2.

Two modifications to the telescope were studied by the panel: replacement of the current top end with a larger, fixed secondary to increase the field of view from 8' to more than 30', and replacement of the surface with the technology developed for ALMA to improve the sensitivity at the shortest wavelengths. Of these, the former was by far the higher priority.

Three instrument concepts were studied, the highest priority being a new camera with of order 100,000 pixels to exploit the larger field of view. There was also strong community support for a high-resolution spectroscopic camera, specifically for galactic studies, with of order 100 pixels. In the longer term, the panel considered that the greatest impact of an enhanced JCMT would be achieved with a large-format, multi-object, low-resolution ($10^3$) spectroscopic camera.

It is clear from the panel’s work that further development of the facility to enhance and extend its capabilities is both technically feasible and scientifically compelling. Whilst the potential of the current instrumentation suite is by no means exhausted, the JCMT is ripe for further development and continued contributions to front-line astronomy for several years to come.
The observatory site on Mauna Kea is sub-leased by STFC from the University of Hawaii (UH). At the conclusion of STFC-funded operations on 30th September 2014, the existing sub-lease will be terminated and title to the observatory and responsibility for the site will transfer from STFC to UH.

In this Announcement of Opportunity we seek a new entity to take over the operation of the JCMT as a UH-owned observatory. The new entity will operate the telescope under a Facilities Use Agreement with UH. The University is eager to see a continuation of the scientific use of the facility and is looking forward to negotiating a use agreement under terms similar to the current agreement with STFC.

The existing JCMT user communities in the UK and Canada are both interested in collaborating with the new operating entity. Prospective proposers may wish to bear this in mind as a possibility.
All STFC-owned assets associated with the JCMT are being offered to the global astronomy community through this Announcement. These include:

- the telescope, dome and associated support equipment;
- all of the instruments and associated support equipment; and
- all of the control, data acquisition and data reduction software.

Any combination or subset of the above is possible. For example, a group that wants to operate the JCMT exclusively in wide-field imaging mode using SCUBA-2 would not be expected to also operate the spectroscopic instruments. Another group might wish to take one of the heterodyne instruments for spectroscopy on a different telescope. We are open to any and all possibilities.

As noted in §10, the JCMT is operated by the Joint Astronomy Centre (JAC), an STFC organisational unit based in Hilo. The JAC building and its facilities are also available, and any parties bidding to take over the operation of the observatory may wish to consider also acquiring the JAC or leasing some space in it.

The JCMT’s talented and dedicated staff will be laid off by STFC on 30th September 2014 and are, in principle, available to be employed on 1st October by a new operating organisation. Retention of the present staff for the continued operation, maintenance and development of the observatory would clearly be an enormous asset to a new operator.

There will be no acquisition cost associated with taking over the operation of the observatory. The JAC building, however, has commercial value and we seek to sell it to the new operator of the JCMT or, alternatively, to other entities.

Parties interested in taking over the operation of the observatory, or in taking a share in the observatory as part of an operating partnership, or in acquiring some subset of the JCMT’s assets, or in purchasing or renting space in the JAC building,
are invited to submit an Expression of Interest (EoI). Such EoIs should describe:
- what is being proposed (taking over the entire observatory, joining as a minor partner, etc.),
- what legal entities are involved, and
- whether your interest is contingent on obtaining funds, with appropriate details.

The deadline for submission of EoIs is 15th September 2013. Given the challenging timeline, advance notice of intent to submit an EoI is strongly requested. All submissions will be regarded as confidential. EoIs should be submitted in pdf format to the Director JAC at the address in the following section.

The next steps beyond that date depend on the level of response to this Announcement.
To learn more about the JCMT or this opportunity, please contact the Director of the observatory:

Professor Gary Davis  
Director, Joint Astronomy Centre  
tel +1 (808) 969-6504  
email director@jach.hawaii.edu

More information is also available at the following URLs:

Home page ...................... http://www.jach.hawaii.edu/JCMT/  
Telescope ...................... http://www.jach.hawaii.edu/JCMT/telescope/  
Continuum instruments ........ http://www.jach.hawaii.edu/JCMT/continuum/  
Spectroscopic instruments ...... http://www.jach.hawaii.edu/JCMT/spectral_line/  
Legacy survey ................ http://www.jach.hawaii.edu/JCMT/surveys/  
Publication lists ............. http://www.jach.hawaii.edu/JCMT/publications/references/  
Newsletter .................... http://www.jach.hawaii.edu/JCMT/publications/newsletter/  
Annual reports .............. http://www.jach.hawaii.edu/JCMT/publications/annual_reports/  
Public outreach ............ http://outreach.jach.hawaii.edu/  
Abbreviations and acronyms

CADC    Canadian Astronomy Data Centre  
EHT     Event Horizon Telescope  
EoI     Expression of Interest  
GBS     Gould Belt Survey  
JAC     Joint Astronomy Centre  
JCMT    James Clerk Maxwell Telescope  
JLS     JCMT Legacy Survey  
NGLS    Nearby Galaxies Legacy Survey  
OT      Observing Tool  
S2CLS   SCUBA-2 Cosmology Legacy Survey  
SONS    Survey of Nearby Stars  
STFC    Science and Technology Facilities Council  
TSS     Telescope Systems Specialist  
UH      University of Hawaii  
UKIDSS  UKIRT Infrared Deep Sky Survey  
UKIRT   United Kingdom Infrared Telescope  
VLBI    Very Long Baseline Interferometry  

Acknowledgements

The science highlights in §6 were provided by several teams in the JCMT observing community. We acknowledge with gratitude the following individuals: Dr James Di Francesco, Dr Jane Greaves, Dr Brad Sandor, Dr Ian Smail, Dr Remo Tilanus, Dr Derek Ward-Thompson and Dr Chris Wilson.

All images courtesy JAC unless otherwise noted.

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