

In search of a new era of UK X-ray astronomy

Poshak Gandhi and colleagues report on today's successful science and the strategy needed to build tomorrow's UK X-ray astronomy community.

X-ray astronomy is our gateway to the hot universe. More than half of the baryons in the cosmos are too hot to be visible at shorter wavelengths. Studying the extreme environments of black hole and neutron star vicinities also requires X-ray data. With the successful launch of India's *AstroSat* in 2015, and the few – but transformative – results from Japan's short-lived *Hitomi* mission in 2016, a new window has been opened into high-sensitivity fast timing and high X-ray spectral resolution. Together with the all-sky survey missions expected soon, X-ray astronomy is now exploring new parameter space.

The UK has been at the forefront of this field since the 1970s and has traditionally punched above its weight in science return relative to the size of its X-ray community. But flat-cash science budgets and the rising costs of cutting-edge space missions bring diminishing roles for the UK in terms of both payload development and future science exploitation. To review the novel science possibilities enabled by recent and upcoming missions, and to discuss how to pave the way for X-ray astronomy in the UK, an RAS Specialist Discussion Meeting on "Timing and spectroscopy in the new era of X-ray astronomy" was held at Burlington House on 10 February 2017.

Half a century

X-ray astronomy is a little over 50 years young, having begun in 1962 with the launch of the first X-ray sounding rockets and the discovery of extrasolar X-ray sources (Giacconi *et al.* 1962). Compared to a more mature field such as optical astronomy, which began in earnest with the first refracting telescopes designed by Lippershey and improved upon by Galileo around 1610, X-ray astronomy is still only in its tweens – and it is experiencing growing pains. There is currently an explosion of data and results over the entire X-ray

spectral regime, extending in energy from ~0.1–100 keV. Driving this growth are international observatories probing deeper and wider in imaging, spectroscopy and, soon, polarimetry. February 2016 saw the launch of the JAXA-led *Hitomi* space mission, opening up an era of high spectral resolution X-ray astronomy with microcalorimeters. *AstroSat* had been launched less than five months before, rejuvenating the possibilities for high-sensitivity rapid X-ray timing. Time-domain studies have been at the heart of X-ray astronomy since the early days; this field will undoubtedly continue to mature with the high quality of data sampling now available.

The opacity of the atmosphere means that X-ray astronomy can only be done from space, and space can be unforgiving. Contact was lost with *Hitomi* after just 37 days, as a result of a chain of events culminating in an uncontrolled spin and ultimate satellite break-up (JAXA 2016). This was a particular blow for the community, given the launch failure of *Astro-E* (in 2000) and the coolant leak in *Suzaku* (in 2015), both of which were also carrying microcalorimeters. However, data from a handful of targets before failure ensured *Hitomi*'s legacy and showcased the spectacular potential of high-resolution X-ray astronomy.

Posters and themes

A total of 10 posters were displayed throughout the day (table 1). The morning saw talks covering new prospects on both timing and spectroscopy, while the afternoon focused on upcoming missions culminating in a community discussion.

The meeting began with a tribute to Neil Gehrels led by **Julian Osborne** (University of Leicester). Neil passed away on 6 February, just four days prior to the meeting. Osborne commented on Neil's enormous contribution to high-energy astrophysics, and reminded us that he was an energetic man with a keenness to say yes to new proposals. His leadership style was inclusive and decisive, and this played a significant part in the substantial impact of the *Swift* mission. Osborne's tribute was followed by a few moments of silence from the audience.

X-ray timing

Strong flux variability over a broad range of timescales is a fundamental characteristic of compact accreting sources. Hence fast-timing studies are widely used in X-rays to study accretion. For 16 years, starting in late 1995, NASA's Rossi X-ray Timing Explorer (*RXTE*) mission was the X-ray timing workhorse, with its fast response and wide sky coverage. It was responsible for discovering high-frequency oscillations in compact accretors, as well as the evolutionary connection between accreting millisecond X-ray pulsars and isolated radio pulsars. Its frequent monitoring and flexible scheduling transformed our understanding of accretion cycles in transient binaries.

..... **"X-ray astronomy is still only in its tweens and is experiencing growing pains"**

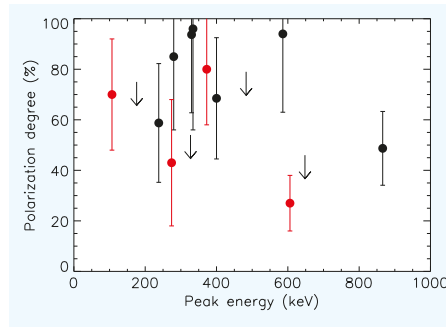
RXTE's demise in early 2012 left the X-ray community with a significant handicap.

AstroSat is in many respects the successor to *RXTE*. Launched in 2015

by the Indian Space Research Organisation (ISRO), the mission has a broadband response over at least ~0.5–100 keV. It additionally carries an ultraviolet imaging telescope (UVIT), making it a truly multiwavelength mission, and India's first astronomy-dedicated satellite. **AR Rao** (Tata Institute of Fundamental Research, Mumbai) delivered a presentation on its status. All instruments are functioning nominally, although calibration and observing efficiency optimization continues. All instruments can operate in event mode, though UVIT has a strict count limit and low observing efficiency. Background calibration of the wide area Sky Survey Monitor is also ongoing. Recent results of note include the serendipitous capture of a reported black hole binary outburst on the first day (Yadav *et al.* 2016), detection of a multitude of gamma-ray bursts (Rao *et al.* 2016) and polarization studies (e.g. Rao *et al.* 2016, Chattopadhyay *et al.* 2017, figure 1). The first international (10%) open call for observing came out in summer 2017, and we can expect a steady stream of results over the coming months and years.

ESA's premier X-ray mission in orbit, *XMM-Newton*, continues to perform well after almost two decades in space. **Adam Ingram** (Anton Pannekoek Institute,

1 AstroSat polarization degree measurements of gamma-ray bursts as a function of peak energy. The black points represent the bursts detected by the CZTI instrument and the red points denote earlier measurements by GAP and INTEGRAL. (Chattopadhyay *et al.* 2017)



Netherlands) showed the power of its fast timing mode, presenting the best evidence that quasi-periodic oscillations (QPOs) are driven by Lense–Thirring precession. This evidence comes from observations of a modulation of the fluorescence Fe $K\alpha$ emission line on the QPO frequency in an outbursting galactic black hole binary (Ingram *et al.* 2016). This is a new probe of the strong gravity regime in the vicinity of the black hole, which we can expect to be exploited in the future using high-throughput, pile-up free instruments such as AstroSat, NuSTAR (NASA, launched 2012), NICER (NASA, launched June 2017) and eXTP (led by China, to launch before 2025).

Accretion is an inherently broadband phenomenon and in restricting oneself to X-rays, much information is lost. **Vik Dhillon** (University of Sheffield) reviewed the ongoing revolution in optical fast timing. In particular, the ULTRACAM instrument (Dhillon *et al.* 2007) has been at the forefront of fast optical observations coordinated with X-rays. Whereas optical delays of order ~ 10 s from reprocessing of X-rays in the accretion disc and companion star in X-ray binaries have been known for some time (e.g. Muñoz-Darias *et al.* 2007), an increasing number of studies are revealing the presence of much shorter subsecond optical delays in outbursting binaries, interpreted as evidence for jet and hot flow emission (e.g. Kanbach *et al.* 2001, Gandhi *et al.* 2008, Durant *et al.* 2011). Such multi-wavelength fast timing has been difficult to coordinate, but should become easier in the future with more instruments. In particular, Dhillon reviewed the powerful new instrument HiPERCAM (Dhillon *et al.* 2016), a simultaneous five-channel imager capable of frame rates up to 1600 Hz. HiPERCAM was first used on the William Herschel Telescope on La Palma in October 2017 and is due to move to the 10.4 m Gran Telescopio Canarias in January 2018. Optical fast timing is one field where the UK currently has world-leading instrument access.

At the high end of the compact object mass spectrum, active galactic nuclei (AGN) may be considered scaled up cousins of stellar-mass X-ray binaries. If

accretion is scale-invariant, both ends of the mass spectrum can shed light on the underlying physics, though this remains controversial. **Ian McHardy** (University of Southampton) presented details of large ongoing programmes to study correlated optical and X-ray variability in AGN. Intriguingly, the observations have revealed optical and ultraviolet lags (with respect to X-rays) that are significantly longer than those predicted by standard accretion disc theory. The lags scale with wavelength as expected, but are larger than model expectations by a factor

of ~ 3 (McHardy *et al.* 2014, Edelson *et al.* 2015). Modifications to mass, accretion rate and/or disc temperature may explain this unexpected result. Coordinated long-term monitoring and multiwavelength missions such as AstroSat can drive this field forward with the requisite sampling over months to years.

New prospects in X-ray spectroscopy

X-ray spectrometers now routinely sample a broad range covering one or two decades in energy, from ~ 0.5 –100 keV and more. This is much broader than is possible in optical bands. However, X-ray spectrometers lag far behind the optical in terms of spectral resolution. The best instruments in this regard currently flying are the grating spectrometers on Chandra and XMM-Newton with energy resolution ($E/\Delta E$) of ~ 1000 around 1 keV, but only ~ 160 around the important Fe $K\alpha$ fluorescence emission at 6.4 keV (which is covered by Chandra alone). The X-ray community has long awaited the age of microcalorimeters in orbit, capable of far superior energy resolution at high energies. Following the failure of Astro-E and the X-ray spectrometer on board Suzaku, Hitomi was expected to deliver on this promise.

The microcalorimeter (the Soft X-ray Spectrometer, or SXS) did indeed perform spectacularly in orbit for the first month of Hitomi's short life. The first SXS observations were carried out through a closed gate valve that reduced its sensitivity greatly. Despite this, first-light observations of the Perseus cluster probed a previously

1 Poster presentations

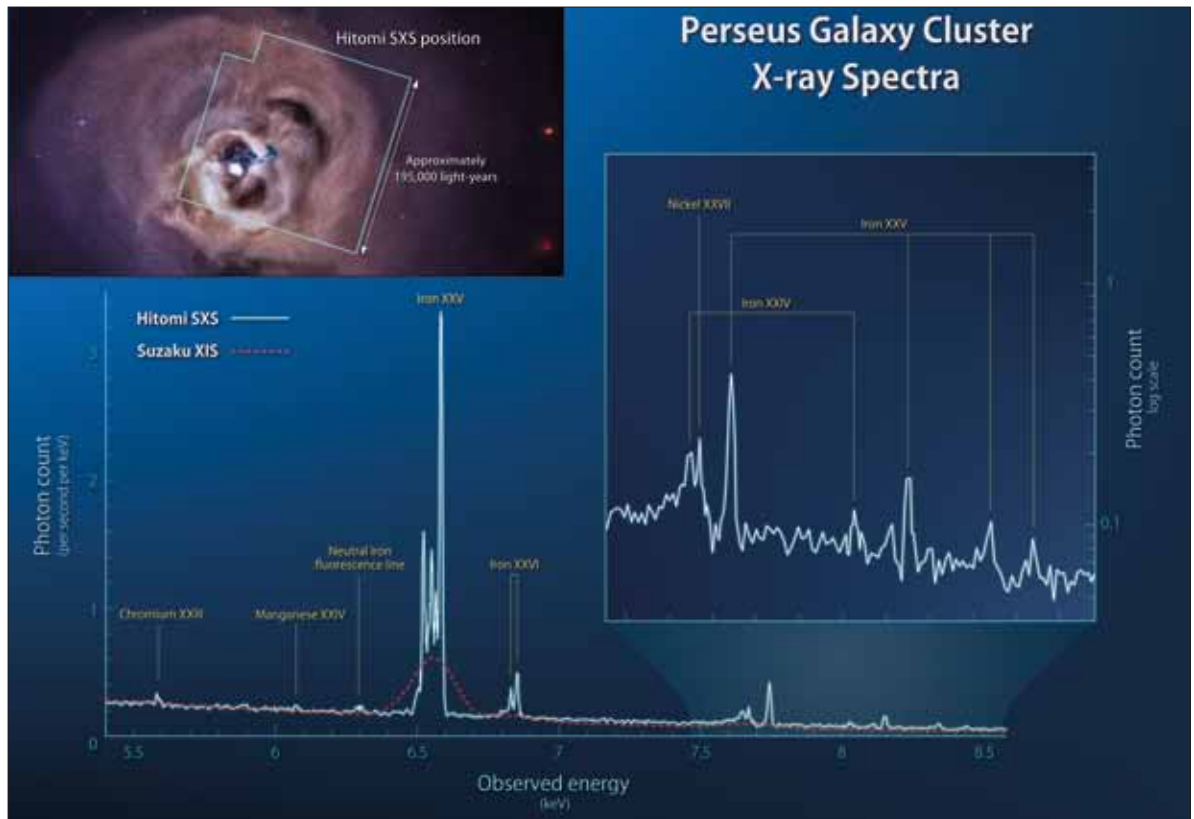
- Aru Beri** (Univ. Southampton): Thermo-nuclear X-ray bursts in rapid succession in 4U 1636-536 with AstroSat-LAXPC
- Peter Boorman** (Univ. Southampton): The X-ray Baldwin effect in Compton-thick AGN
- Graziella Branduardi-Raymont** (MSSL): SMILE (Solar wind Magnetosphere Ionosphere Link Explorer): X-ray imaging of the Sun–Earth connection
- Douglas Buisson** (Univ. Cambridge): X-ray and ultraviolet variability of active galactic nuclei with Swift
- Jiachen Jiang** (Univ. Cambridge): Testing the nature of black holes with X-ray spectra
- Michael Johnson** (Univ. Southampton): Prospects for galactic X-ray binaries with LSST
- Peter Kosec** (Univ. Cambridge): Investigating the evolution of the dual AGN system ESO 509-IG066
- Julian Mayers** (Univ. Sussex): XCS, the XMM Cluster Survey – it's not just about clusters
- Julian Osborne** (Univ. Leicester): The SVOM rapid-response multiwavelength GRB observatory
- Silvia Zane** (UCL), XIPE consortium: XIPE: the X-ray Imaging Polarimetry Explorer

unsampled regime, achieving a spectral resolution of $\Delta E \sim 4.5$ eV at ~ 6 keV. A surprisingly quiescent intracluster medium was found based upon the narrow widths of emission lines from ionized metal species, implying the presence of some mechanism to suppress turbulent motions in the cluster gas (figure 2; Hitomi Collaboration 2016). Another much awaited result from the mission was the search for a signature of dark matter annihilation. Whereas several recent studies have detected tentative hints of a signal around 3.5 keV (e.g. Bulbul *et al.* 2014, Boyarsky *et al.* 2014), Hitomi's first-light data ruled out the presence of a corresponding narrow emission feature at 99.7% confidence (Hitomi Collaboration 2017). A nearby charge exchange transition could potentially account for the observed excess in low spectral resolution data.

Andy Fabian (University of Cambridge) reviewed Hitomi's findings, telling the audience what a privilege it was to be able to work on the Hitomi data, and reminding everyone that it is exceedingly rare for first-light observations from any mission to result in high-impact publications. This underscores the enormous untapped potential of high spectral resolution X-ray observations.

Ultraluminous X-ray sources (ULX) have long been considered to be intermediate-mass black holes, a missing link between X-ray binaries and AGN. This view has been largely overturned over the past

2 Hitomi's spectrum of the Perseus cluster core. A complex of ionized species, in particular the strong Fe lines, are resolved and found to have a line-of-sight velocity dispersion of $164 \pm 10 \text{ km s}^{-1}$. This is the tightest constraint yet, far superior to CCD spectra (red dashed curve), and places strong limits on the influence of turbulence within the intracluster medium (Hitomi Collaboration 2016). (Background image: NASA Chandra X-ray Observatory. NASA Goddard Space Flight Centre)



few years based upon a number of observations. In particular, the discovery of pulsations in a ULX in the starburst galaxy M82 showed that at least some of these objects must be neutron stars, and hence have masses under $\sim 2M_{\odot}$ (Bachetti *et al.* 2014). Consequently, their high luminosities $L_{\text{X-ray}} \sim 10^{40} \text{ erg s}^{-1}$ imply that they must be accreting at super-Eddington rates. Strong outflows are expected in such a regime, and **Ciro Pinto** (University of Cambridge) presented recent evidence of the presence of winds in several ULXs. This work exploits the high spectral resolution of the XMM-Newton gratings at soft X-ray energies, finding blueshifted absorption features characteristic of outflowing gas at speeds of about $0.2c$. Pinto further presented an orientation-dependent unification model for hyper-accreting stellar-mass compact objects, with hard X-rays emerging preferentially along the axis of an optically thick disc wind, and softer energies dominated at increasing inclination angles due to reprocessing (Pinto *et al.* 2017). Such observations give important insight into the super-Eddington accretion regime.

What is the future for high spectral resolution X-ray astrophysics after Hitomi? **Richard Kelley** (NASA Goddard Space Flight Centre) showed us the planned roadmap for Hitomi's successor. Currently named XARM (X-ray Astronomy Recovery Mission), Kelley delivered the news that the mission has approval from both JAXA and NASA and is to be launched by ~ 2021 . In June 2017, ESA announced that it would participate in the mission. XARM is scaled

down from Hitomi, in that there will be no hard X-ray instrumentation. Below 10 keV, the soft X-ray telescope, imager and microcalorimeter will be retained, making it superior to all other missions in terms of spectral resolution at energies of several keV (figure 3). Lessons learnt from Hitomi in terms of project organization, operations and in-orbit performance will be incorporated from the start. Kelley also stressed the fact that the UK had, historically, played a leading role in building its own X-ray mission with Ariel V in the 1970s (see the article by Ken Pounds on page 6.29). That mission went on to make some fundamental discoveries including the detection of ionized Fe in intracluster plasma (Mitchell *et al.* 1976), and we are only just (~ 40 years on) beginning to probe the dynamics of this hot gas with microcalorimeters. He ended by showing that we are entering a golden era of X-ray microcalorimeters, with steady improvements in energy resolution over the past ~ 30 years following a progression similar to Moore's Law.

On the long-term horizon, ESA's Athena (Advanced Telescope for High ENergy Astrophysics) will be the premier observatory in terms of sensitivity and high spectral resolution. **Paul Nandra** (Max Planck Institute for Extraterrestrial Physics, Germany) reviewed the current status of the mission, which is expected to launch around 2028. With collecting area of 2 m^2 (1 keV) sampling the field of view with 5 arcsec pixels, an integral field unit of transition edge sensors with spectral resolution a factor of ~ 2 better than Hitomi and a large field of view

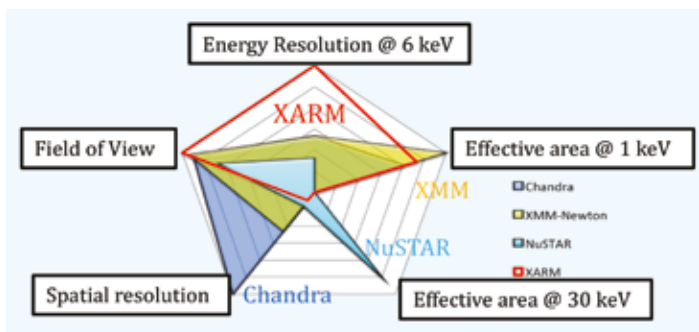
spanning 5 arcmin (equivalent diameter), additionally combined with a wide-field imager (40 arcmin), Athena's science is expected to be transformational (Nandra *et al.* 2013, Willingale *et al.* 2013, Meidinger *et al.* 2016). The project is currently in Phase A, with mission adoption expected in 2020. The UK's main role in the mission is in the Wide Field Imager, but Nandra stressed that it was surprising to see the UK not playing a stronger role in the mission compared to other ESA partners.

Future missions and strategies

The afternoon session continued the theme of future synergies and strategies with presentations on wide-field X-ray imaging, polarimetry and timing. **Arne Rau** (Max Planck Institute for Extraterrestrial Physics) reviewed the current status of eROSITA, which will be the primary instrument on board the Russian SRG (Spectrum–Roentgen–Gamma) satellite. The instrument is ready and has been delivered for launch from Baikonur in 2018. eROSITA (Merloni *et al.* 2012) will carry out the deepest all-sky X-ray surveys so far in the energy range of 0.3–10 keV. Cosmological parameter estimation through detection and study of all massive galaxy clusters is a key science driver for the mission, but eROSITA will also detect more than 3 million AGN, galactic compact objects and 500 000 stars. In addition, it is expected to be sensitive to a huge range of variables and transients including, for instance, about 1000 tidal disruption events over four years.

Silvia Zane (University College London)

3 Parameter space covered by various X-ray missions. Increasing distance from the centre indicates improvement in any given parameter. XARM is expected to be superior in terms of spectral resolution at energies of a few keV. (M Tashiro)



discussed the prospects and importance of various (concept) missions for X-ray polarimetry (XIPE, IXPE, eXTP) and high-resolution X-ray timing (eXTP, STROBE-X) capabilities to study neutron stars. X-ray polarimeters such as on board the X-ray Imaging Polarimeter Explorer (XIPE), a concept mission proposed for ESA M4, and the enhanced X-ray Timing and Polarimetry (eXTP) mission, endorsed for launch in 2024–25 by the Chinese National Academy of Sciences (CNAS), will open a completely new window to study the geometry of X-ray emitting plasmas. This is expected to lead to significant breakthroughs in our understanding of, for example, the strength and geometry of neutron star magnetospheres, particle acceleration processes, accretion discs, and the equation of state of ultradense matter. Zane also highlighted the impact of a high-throughput X-ray timing mission such as eXTP or STROBE-X, a NASA probe-class mission proposed within the context of the Decadal Survey 2020, to study general relativistic effects around black holes and the dense matter equation of neutron stars.

Giorgio Matt (Roma) followed this and discussed the design, status and key science questions to be addressed by the Imaging X-ray Polarimetry Explorer (IXPE; Weisskopf *et al.* 2016). This mission concept was selected by NASA in the Small Explorer Program for launch in 2020 and is currently in exploratory phase. Matt also stressed the immense potential of obtaining a full, comprehensive view of X-ray sources with a mission such as IXPE that provides simultaneous energy, imaging, timing and polarization information.

As chair of the Astronomy Advisory Panel for the UK's Science and Technology Facilities Council (STFC/AAP), **Paul O'Brien** (University of Leicester) was invited to give us his viewpoint of how high-energy astrophysics fitted within STFC priorities and how the X-ray community could best interact with AAP. O'Brien reminded us that the UK share of global space science and astronomy papers far outstrips the proportion of papers in other broad comparator fields including physics,

chemistry, engineering and mathematics. In other words, the UK is delivering world-class science in astronomy and space science.

The latest (2016) AAP community consultation exercise revealed that exploitation funding remains the highest concern; this issue was raised repeatedly during the day. ESO remains the top-ranked priority for the community, followed closely by high-performance computing. While diversity in observing facilities is considered impor-

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tant, we are at the limit of a viable, world-leading astronomy programme in terms of funding. The growing scale of astronomy experiments requires astronomy grant

panel (AGP) funding to increase, but the reality is that observing time available to UK astronomers continues to decline as we withdraw from observatories and as telescopes become more specialized. Support is strong for the ESA chosen missions, such as PLATO and Athena, and the UK Space Agency (UKSA) is likely to support whichever mission tops the M4 selection in late 2017, since the UK is involved in all the short-listed candidates. But the community is concerned that the overall level of payload funding is not in accord with our pro-rata ESA subscription spend. O'Brien emphasized the need for a balanced portfolio of ground-based observing facilities in order to best exploit the UK investment in existing and future space missions.

Mike Cruise (University of Birmingham) began his talk by reminding the audience that he was not presenting the official view of UKSA: it had been unable to send a representative to attend the meeting. He gave an overview of what UKSA funding covers (in addition to our ESA subscription) with regard to new proposals for space mission involvement, including initial studies, hardware development beyond a certain technology readiness level, and in-orbit operations. UKSA is now part of BEIS (the Business, Energy and Industrial Strategy ministry). Space activity is worth £13.7 billion to the UK economy, of which about 2.2% is spent on science programmes, and about 0.1% constitutes science payload funding for ESA programmes. All

proposals for new missions are discussed at the UKSA Science Programme Advisory Committee, and the grant award is set by the Space Projects Peer Review Panel. Science quality is only one of the criteria assessed for any new proposal; timeliness, economic impact, risk, science return to the UK and outreach also matter.

The UK contributes about 8.7% to the ESA budget and has supported all the missions selected by ESA and supported by STFC. The "dual key" system agreed between UKSA and STFC has worked well. The UK has, historically, generated about twice the science outcomes that its percentage ESA budget share would suggest. However, Cruise personally considers that we are currently reaping the benefits of past investments, and the UK grants for payload instruments agreed in the past few years will not buy us leading positions in future space missions. Cruise ended his presentation by exhorting the audience to get on ESA committees and to help develop strong government/societal cultural support for pure science. There is no formal bar to larger space science expenditure, but it is incumbent upon the community to demonstrate its relevance.

Community discussion

It is clear that we face tough choices. Funding is not getting any easier, and current grant levels cannot guarantee the UK a leading position in future space missions. As such, the UK X-ray community risks missing out on the ongoing global revolution in the field.

As part of the run-up to the meeting, the organizers had issued an open online survey including the following questions: "Are you satisfied with the development and support of X-ray astronomy in the UK? What more should we be doing as a community?" Some thought-provoking answers were received. One person emphasized the need for an established presence on funding panels (e.g. fellowship and grant panels) as well as those able to lobby for government spending. This was highlighted as being important for ensuring that there are enthusiastic and experienced scientists who continue to drive innovation with the next generation of missions.

Another comment recognized the importance of Athena for the community, but also pointed out that it is a long way off. In addition, most existing X-ray facilities are working well past their design lifetime, so new opportunities must be sought, where possible. China potentially offers fruitful opportunities in the near term, including the recently announced Einstein Probe capable of 3600 degree squared field-of-view monitoring for transients using lobster-eye mirrors, set to launch in 2021.

However the fact that UKSA does not support bilateral missions with other nations excludes the UK from such dynamic space programmes. Arguably, the UK has a world lead in lobster-eye technology, but without these collaboration possibilities, is being left behind.

UK leadership in the field was brought up repeatedly during the meeting, from the UK-led Ariel V mission in the 1970s to participation in ongoing major observatories. Bibliometrics (see table 2) show that the UK continues to publish in a leading position in the field of X-ray astrophysics, on a par with other countries that have led their own missions in recent decades. This has been possible largely due to close collaborations with other nations (either through mission team memberships at the level of individual scientists, or through ESA participation), which we must continue to nurture.

While most large missions allow international participation through open proposal calls after an initial period of restrictive access, it must be recognized that some of the most exciting and important discoveries occur during this

initial period when a new region of parameter space is being prised open. By awaiting open calls, we not only risk missing out on participating in some of the most stimulating discoveries, but there is also the danger of early mission failure. Both these aspects were exemplified by the case of Hitomi. Despite ESA participation, only a handful of UK-affiliated astronomers were able to participate in the high-profile science papers that resulted from the early observations.

With this background, the day's discussion ended by asking: "What more should we be doing as a community?" The organizers proposed that as a first step, UK X-ray astronomers should come together as a cohesive community. Only such a community can make its voice heard in major support and funding requests; it may also bring good representation on relevant grant committees and science-policy panels.

While there was consensus that such an approach is worthwhile, there was no agreement on the best way to achieve it. Creating an equivalent of the AAS/HEAD (High

2 X-ray publications

country	no. of publications
USA	12848
Germany	5520
UK	4611
Italy	3567
Japan	2508
India	1052

Number of astronomy publications mentioning "X-rays" over period 2012–16, as a function of author affiliation by country. The UK is the only country in this list not to have launched its own X-ray mission in the past ~40 years. (Retrieved from NASA's ADS 8 February 2017.)

Energy Astrophysics Division of the American Astronomical Society) within the RAS was one suggestion. Although HEAD works as a coherent subgroup within the AAS, this was considered to be divisive in the UK context by several members of the audience. However, such groups are not without

precedent. One example is the UK Planetary Forum (UKPF), which is affiliated to the RAS, receives RAS support for meetings and website, and demonstrates that it is possible to strengthen a community as a subgroup without being divisive.

Another issue raised was the need to foster the next generation of X-ray astronomers and instrument builders. However, there was a mood of pessimism among the audience, given diminishing prospects for postdoc positions (e.g. the removal of STFC postdoctoral fellowships, flat-cash grant level income of STFC, uncertainty with regard to continued EU funding). Ensuring X-ray astronomy representation on funding panels was seen as especially important in this regard.

Finally, the possibility of bilateral buy-ins from the X-ray astrophysics community as a whole was raised. There are several near-term missions including XARM, SVOM (China–France, due to launch 2021), Einstein Probe and more that could be candidates for this. Another option proposed in Paul Nandra's presentation was strengthened

UK support for Athena. All of these options were considered likely to be prohibitively expensive given funding realities. As a counterpoint, however, the example of the Large Synoptic Survey Telescope (LSST) was raised. The UK bought in as an international partner to the LSST Consortium for ~\$25 million in 2013, at a time of sustained flat-cash funding. This was possible because of the wide remit of LSST, which encompasses an enormous range of science themes and hence garnered broad community support. If we are to make the same case for X-ray astronomy support, then we similarly need to demonstrate the relevance of X-ray studies for a variety of broad research areas within astrophysics. An example of this is an ongoing programme of coordinated observations between Chandra, XMM-Newton (both orbiting Earth) and Juno (in orbit around Jupiter), demonstrating the synergy between astronomy, planetary science and space plasma physics for understanding Jupiter's plasma and magnetic conditions. In a similar context, the SMILE mission (ESA–China, currently in Phase B) was presented as an instance of collaboration between astronomers and planetary scientists that could rewrite our understanding of the impact of the Sun on the Earth's magnetic environment.

Conclusions

X-ray astronomy is undergoing a global renaissance of sorts with new sensitive fast-timing missions in orbit, wide-field imaging and polarimetry missions on the horizon, and a recent taste of high spectral resolution studies. If the immense science output from the first-light observations of Hitomi is anything to go by, major breakthroughs are ahead as we open up wide new swathes of observational parameter space. If the UK is to play a leading role in this renaissance, we must make our voices heard to pave the way forward despite a climate of dwindling funding possibilities. We suggest that the first step is for UK X-ray astronomers to unite to ensure that the importance and excitement of the science are communicated effectively, not only to the relevant panels, but also to the wider scientific community and to the public. How we achieve this is up to us. ●

AUTHORS

Poshak Gandhi, University of Southampton, UK; Nathalie Degenaar, Anton Pannekoek Institute, Netherlands; Chris Done, University of Durham, UK; Mike G Watson, University of Leicester, UK.

MORE INFORMATION

UK X-ray astronomy Twitter feed: @UKXrayastro

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REFERENCES

Bachetti M *et al.* 2014 *Nature* **514** 202
 Boyarsky A *et al.* 2014 *Phys. Rev. Letts* **113** 251301
 Bulbul E *et al.* 2014 *Astrophys. J.* **789** 13
 Chattopadhyay T *et al.* 2017 *Astrophys. J.* submitted, arXiv:1707.06595
 Dhillon V *et al.* 2007 *Mon. Not. R. Astron. Soc.* **378** 825
 Dhillon V *et al.* 2016 *Proc. SPIE* **9908** 0Y
 Durant M *et al.* 2011 *Mon. Not. R. Astron. Soc.* **410** 2329

Edelson R *et al.* 2015 *Astrophys. J.* **806** 129
 Gandhi P *et al.* 2008 *Mon. Not. R. Astron. Soc.* **390** L29
 Giacconi R *et al.* 1962 *Phys. Rev. Letts* **9** 439
 Hitomi Collaboration 2016 *Nature* **535** 117
 Hitomi Collaboration 2017 *Astrophys. J.* **837** L15
 JAXA 2016 *Hitomi Experience Report* http://global.jaxa.jp/projects/sat/astro_h/files/topics_20160524.pdf
 Ingram A *et al.* 2016 *Mon. Not. R. Astron. Soc.* **461** 1967
 Kanbach G *et al.* 2001 *Nature* **414** 180
 McHardy I M *et al.* 2014 *Mon. Not. R. Astron. Soc.* **444** 1469

Meidinger N *et al.* 2016 *Proc. SPIE* **9905** 2A
 Merloni A *et al.* 2012 arXiv:1209.3114
 Mitchell RJ *et al.* 1976 *Mon. Not. R. Astron. Soc.* **175** 29
 Muñoz-Darias T *et al.* 2007 *Mon. Not. R. Astron. Soc.* **379** 1637
 Nandra K *et al.* 2013 arXiv:1306.2307
 Pinto C *et al.* 2017 *Mon. Not. R. Astron. Soc.* **468** 2865
 Rao AR *et al.* 2016 *Astrophys. J.* **833** 86
 Weisskopf M C *et al.* 2016 *Proc. SPIE* **9905** 17
 Willingale R *et al.* 2013 arXiv:1307.1709
 Yadav JS *et al.* 2016 *Astronomers' Telegram* **9515** 1