

*Low-background photomultiplier array viewing the LUX time projection chamber (LUX collaboration).*



## Message from the Chair

The past year has seen many successes for our community. The articles within these pages present just a small fraction of the results we have delivered and the future projects we are leading. Within the severe financial constraints we face this is truly impressive and I have no doubt that the next few years will see astroparticle physics further transform our knowledge of the universe. Of course though, we wait with baited breath to see whether the government funding allocation and the Programmatic Review will deliver enough to enable us to meet our aspirations for the next few years.

But how well are we actually doing? What strengths and weaknesses does our community really possess? This coming year we will be conducting an IoP sponsored review of UK Astroparticle Physics. To begin with we will attempt to construct a snapshot of the present activity within the UK, through a survey<sup>1</sup> and other metrics of activity. In parallel, we will be seeking the opinions of scientists around the world with an online questionnaire<sup>2</sup>. The links are given below, but will be circulated widely in other emails and publications.

These will all be collated and summarised in a Report, for distribution hopefully around Easter. We hope to further demonstrate the excellent and important science we are doing. Similar endeavours in other areas of physics have been seen as highly successful, and influential at a higher level. Your support and enthusiasm for this initiative would be very greatly appreciated.

1 Census of UK Astroparticle Physics research:

<https://www.surveymonkey.com/s/LDCF23L>

2 International Review of UK Astroparticle Physics research

<https://www.surveymonkey.com/s/IOP-astroparticle-physics-review>

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## LUX draws a line under (some) light WIMPs

The Large Underground Xenon (LUX) experiment has just announced dark matter search results from an initial run of 85 live days in 2013 (arXiv:1310.8214, submitted to PRL). LUX features a double-phase Xenon detector operating at the 4850-ft level of the Sanford Underground Research Facility (South Dakota, USA). A year ago we reported on its installation within the shielding water tank at SURF (APP Newsletter November 2012) and commissioning progressed swiftly thereafter.

The elastic scattering of Weakly Interacting Massive Particles (WIMPs) with ordinary atoms would create low energy nuclear recoils, opening a route to the detection of galactic dark matter in the laboratory. With an active target mass of 250 kg, LUX provides extremely sensitive readout of two response channels for each interaction – scintillation light and ionisation charge. These allow the interaction site to be determined precisely, and so to select an inner fiducial volume of 118 kg which is self-shielded from external radiation by the peripheral liquid xenon. In addition, the dominant background of electron recoils – of which LUX registers only some two events per day at low energy – can be rejected by their higher ratio of ionisation to scintillation relative to the interesting nuclear recoils.

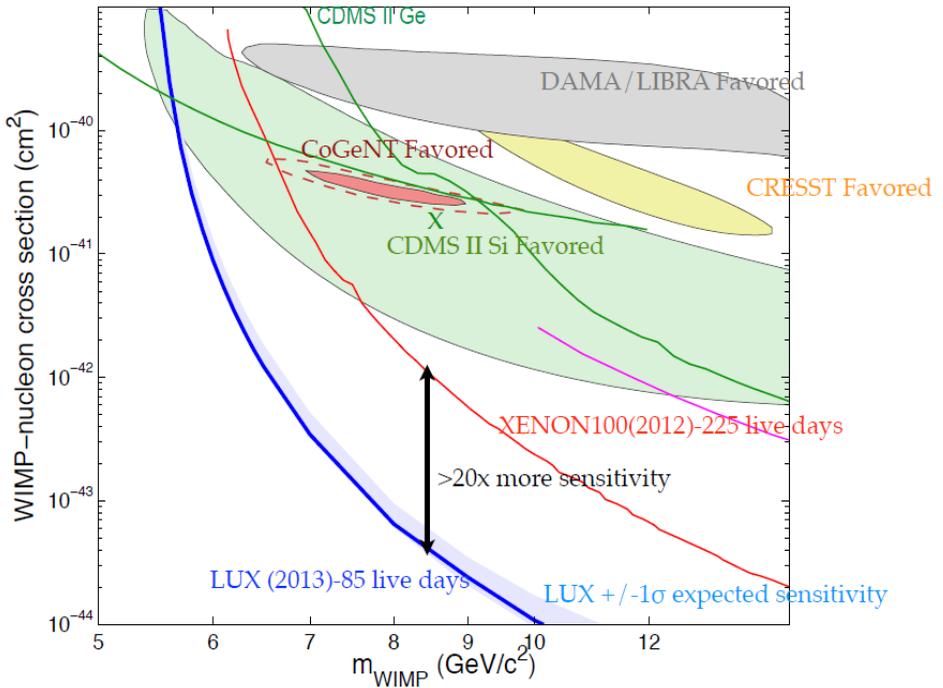
A statistical analysis of the 2013 LUX exposure confirms that the data are fully consistent with the ‘background-only’ hypothesis with no significant signal. This result places the most stringent limits on WIMP interactions to date, as shown in the figure below.

Although most previous experiments had failed to see evidence for WIMP interactions – notably the xenon-based ZEPLIN and XENON programmes – others such as CoGeNT (using cryogenic germanium) have reported signal-like excesses which some have interpreted as evidence for light WIMPs. ‘Xenophobic’ dark matter models have been crafted to try to reconcile the null results from the xenon experiments with those other ‘hints’.

This is now a harder circle to square: although the increase in exposure over that from previous world leader XENON100 is modest in this first run, the very low energy threshold of 4.3 keV achieved in LUX means that its sensitivity for light WIMPs is actually some 20 times higher. Were light WIMPs responsible for the CoGeNT excess, for example, then LUX should have detected some 1,500 nuclear recoils under standard assumptions – and it would take a very contrived explanation to reconcile these two results. Light WIMPs may well exist – just not those light WIMPs suggested by CoGeNT and others.

The collaboration, counting 19 institutes from the US, UK and Portugal, is now preparing the detector for a longer run and LUX will continue to shed light on dark matter in 2014/15. In parallel, the next-generation search LUX-ZEPLIN (LZ) is under development, to push deeper into the parameter space that WIMPs would more naturally inhabit.

Henrique Araújo, Imperial College London



*LUX results excluding WIMP-nucleon scalar cross sections above the blue line with 90% confidence. Lines represent experimental limits, while shaded regions indicate event excesses interpreted as signal (LUX collaboration).*

## The UK and the Cherenkov telescope array

The Cherenkov Telescope Array (CTA) is the next generation ground based observatory of very high energy ( $E > 10$  GeV) gamma rays. It will be a world observatory, with arrays of imaging atmospheric Cherenkov telescopes in the Northern and Southern Hemispheres to give all sky coverage, and consortium members already covering institutes in 26 countries. The Preparatory Phase of the CTA has continued apace this year with a site evaluation summary document along with site ranking and recommendations submitted to the site selection committee in October, and the preliminary design review having taken place in November.

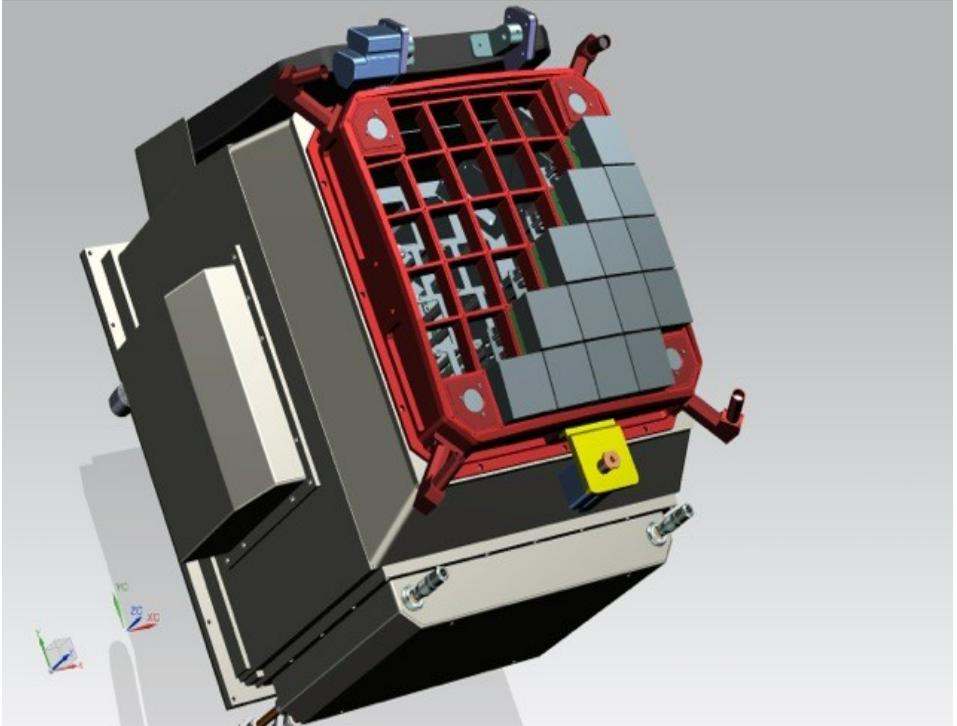
The observatory will cover over 4 orders of magnitude in energy by deploying complementary arrays of 4 Large Size Telescopes (LSTs) of 23 m diameter to obtain the lowest energy threshold; 25 Medium Size Telescopes (MSTs) of 12 m diameter to better the flux sensitivity by an order of magnitude to the current generation of instruments; and up to 70 Small Size Telescopes (SSTs) of 4 m diameter to capture the rarest, highest-energy events (up to several hundred TeV). It is these SSTs that the CTA-UK groups have focused their hardware efforts on, pioneering the investigation of a novel dual-mirror design to enable the use of smaller plate scale, less expensive, photosensor technology that will enable more large field of view telescopes to be built. The Compact High Energy Camera (CHEC) is a UK-led international project involving the Netherlands, the US and Japan to provide prototype cameras for the dual-mirror SST. CHEC is fully funded to construct two prototype cameras, exploiting Multianode Photomultipliers in the first phase and Silicon Photomultipliers in the second for the focal plane instrumentation. At the heart of CHEC are giga-sample per second digitisation modules based on an analogue sampling ASIC known as TARGET. Once complete CHEC will provide full waveform data of Cherenkov light illuminating the camera for hundreds of nanoseconds per event across all 2048 pixels covering a  $9^\circ$  field of view on the sky at an event rate of a few hundred Hz. The workshops of Durham, Leicester, Liverpool and Oxford are already busy with the construction of the mechanical components for CHEC and extensive electronics design and testing is underway across the globe. CHEC is firmly on track to be the first of the prototype SST cameras to be ready in 2015. CHEC will be deployed to a dual-mirror SST prototype telescope structure on Mt Etna, Sicily.

The coming year is greatly anticipated as it will see the results of the CTA site selection committee being released and is also the time when the physics working group will formulate plans for the use of proprietary observing time in the key-science programmes for galactic and extragalactic science, fundamental physics and multi-messenger astronomy. If the last decade of discoveries has taught us anything, now is a great time to become involved in CTA activities to

help develop the observing strategy and the CTA-UK family has been extended this year to cover a wide-range of scientific interests applicable to CTA with groups at Liverpool John Moores and King's College London joining CTA, and Central Lancashire in the process of applying.

*Michael Daniel, University of Liverpool*

For more information about CTA in the UK, see: <https://www.cta-observatory.ac.uk>

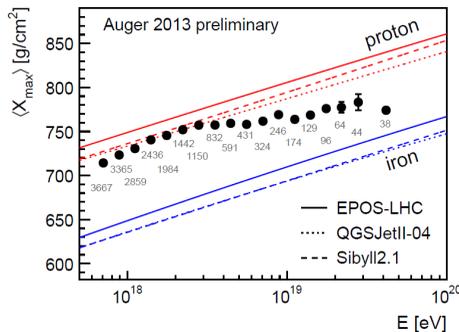


*CAD image of the first CHEC prototype, to be constructed in Spring 2014 (D. Ross, University of Leicester).*

## Ultra-High Energy Cosmic Rays

Interest in the study of ultra-high energy cosmic-rays continues to increase. The Pierre Auger Observatory, in which UK scientists still have a role despite the termination of support from STFC, remains a major source of data. A key question is ‘What is the mass of the cosmic rays at the highest energies?’ One way of estimating the mass is to compare the measurement of the depth of shower maximum,  $X_{\max}$ , with the predictions from Monte Carlo calculations now made using the latest information from the LHC as input. Additionally measurements of the cross-section in proton-proton collisions at a centre-of-mass energy of 57 TeV (P Abreu et al., Phys Rev Letters 109 062002 2012) have been made with the Auger instrument. The result is found to fit smoothly to the extrapolation of recent LHC data.

The latest results relating to the mass composition (reported at the International Cosmic Ray Conference held in Rio last July), are shown in Figure 1 (see arXiv:1307.5059 for further details).



*Figure 1: The mean depth of shower maximum measured using the fluorescence detectors of the Auger Observatory as a function of energy compared with predictions made with different models of shower development. The EPOS-LHC model is thought to be the best one to use and it is evident, if this is the case, that the mean mass of the particles increases with energy. A typical precision of  $X_{\max}$  measurement is  $\sim 25 \text{ g cm}^{-2}$ : the numbers show the events in each bin.*

Of course a key issue is the reliability of the input data to the Monte Carlo calculations as above  $10^{17}$  eV one is extrapolating to centre-of-mass energies up to 30 times that which will be eventually be reached at the LHC. In addition to the cross-section measurements, a further check on the validity of models has been made by comparing the manner in which the signal size in the water Cherenkov detectors falls off with distance with predictions. A comparison for one event is

shown in Figure 2 (left-hand diagram) while the average value of the ratio of the signal to prediction is shown in the right-hand figure.

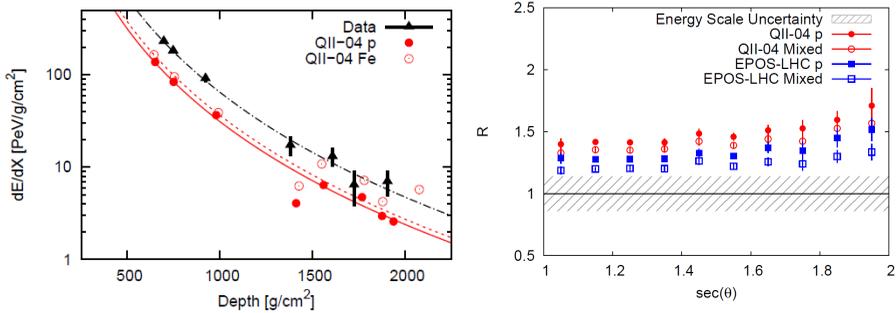


Figure 2: (left-side) A comparison of the signals measured in one event with prediction for two showers that have been selected because their development can be described equally-well by proton or Fe primaries. The ratio,  $R$ , of the signal measured at 1000 m (where a large fraction is due to muons) to that predicted for a range of models is shown in the right-hand diagram (See [arXiv:1307.5059](https://arxiv.org/abs/1307.5059) for further details).

There appears to be an excess of muons in showers over what is predicted and in the next phase of the Observatory, starting in 2016, a large number of muon detectors are to be constructed to elucidate this issue and so get a better handle on the mass composition and on hadronic interactions.

Cosmic rays lend themselves to Outreach opportunities. At the Observatory in Argentina over 75,000 people from 25 countries have attended presentations by a dedicated staff-member since 2001. For Outreach on a larger scale, cosmic ray data are made available on the public web site ([www.auger.org](http://www.auger.org)) in nearly real time. There are manuals showing how to work with and how to analyse this public data set and useful tools to provide insight at high-school level and above as to what is measured and how it is interpreted.

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## The Advanced LIGO (aLIGO) Project

The first generation of gravitational wave detectors comprised a network of instruments including the LIGO detectors in Hanford, WA (4 km and 2 km interferometers located in the same infrastructure) and Livingston, LA (4 km), the GEO-600 detector in Ruthe, Germany (600m) and the 3km VIRGO detector in Cascina, Italy. These detectors observed out to approximately 20 MPc and sampled roughly 100 galaxies within the Virgo supercluster. The typical neutron-neutron star binary coalescence rate per galaxy is 1/10,000 years and thus an event rate of 1/100 was estimated. During the 5th science run (2005-2007) no sources were observed although interesting upper limits on the ellipticity of neutron stars, the nature of gravitational radiation from the Crab pulsar and the origin of gamma ray bursts were set, resulting in over 100 journal articles.

But even before the end of the science run the R&D (figure 1) necessary for the next generation (or Advanced network) was well under way. Collaborators in the LIGO Scientific Collaboration were working on state-of-the-art hardware including: active seismic isolation systems to provide ultrastable optics

mirror suspensions fabricated from fused silica to provide the lowest thermal noise performance the use of low noise, high power, 1064 nm lasers to lower shot noise the use of advanced optical techniques such as signal recycling and squeezed light to provide optimised quantum noise performance mirrors with ultra-smooth figure and low thermal noise optical coatings, combined with the lowest optical absorption.

In the UK, the pioneering work of GEO600 on monolithic suspensions, signal recycling, in addition to the development of advanced coating R&D were important contributions to the advanced network.

Starting in late 2007 and ending in 2015, the Advanced LIGO (aLIGO) project will deliver three detectors to realise the advanced network. Two detectors will be installed in Hanford and Livingston, while the third detector is planned for operation in India around 2020. Once the US detectors are handed over the LIGO laboratory commissioning will begin. From 2015-2019 the detector sensitivity, and astrophysical reach, will be increased. Design sensitivity will be reached in 2019 and will allow neutron star inspirals to be observed out to 200MPc (figure 2). This will increase the event rate by factor of 1000 (sampling 100,000 galaxies) and will yield source rates of a few per month. At the same time the other detectors will also be upgraded (GEO-HF, Advanced Virgo). In addition, there is a new detector which will be operated at cryogenic temperature and located in the underground facility in the Kamioka mine, Japan. With the inclusion of the Japanese KAGRA detector, operational around 2018/19, and the third LIGO detector in India (2020), gravitational sources will be located to roughly 1 square degree across most positions on the sky, important for multi-messenger follow up by electromagnetic telescopes.

This is an exciting time in the gravitational wave community with the possibility of detecting the first sources of gravitational waves during science runs of the advanced detectors as early as 2016 (the centenary of Einstein's 2<sup>nd</sup> paper on gravitational radiation). This detection will open up the gravitational window on the universe. At the same time, R&D into cryogenic materials and advanced optical techniques are under way for the third generation of detectors which will increase sensitivity by a further factor of 10, and allow precision tests of strong field gravity and cosmology.

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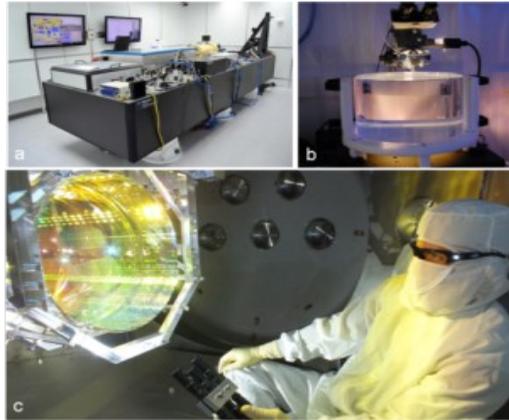


Figure 1. *aLIGO* installation photographs (a) 200W pre-stabilised laser (b) one of the 40kg fused silica test masses (c) installation of the mirror into the vacuum chamber.

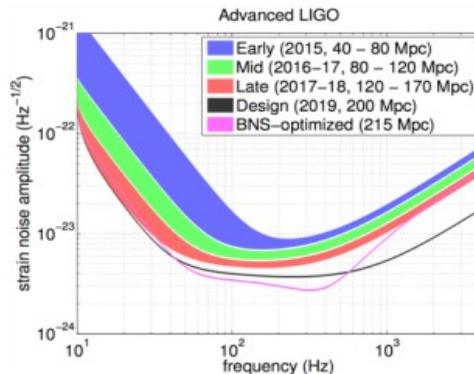


Figure 2. *aLIGO* commissioning timeline showing the design sensitivity (black) and the Binary Neutron Star (BNS) optimised (magenta) sensitivity curves.

## Meeting Report



October 31<sup>st</sup> and November 1<sup>st</sup> saw our Group lead the organisation of a Topical Discussion Meeting. Typically the IoP fund, rather generously, two of these prestigious meetings each year, and for us to claim one for Astroparticle Physics was quite a coup. Additional financial support was gratefully received from STFC, SUPA, Canberra and Hamamatsu. About 100 people attended the meeting, including many from overseas, and a large fraction of the UK community.

The meeting focused on our four main themes: Cosmic Rays, Dark Matter, Gravitational Waves and Very High Energy Gamma Rays. Slides from most of the invited talks are now available online: <http://tinyurl.com/pgcgz5o>. The meeting was opened by Grahame Blair of STFC and then featured two Keynotes by Roger Blandford and John Ellis, twelve invited talks and 24 further contributed talks, as well as posters. The strong UK roles and leadership in many major projects were highlighted, and opportunities for the areas to work more closely together to resolve some of the most important contemporary problems explored.

The main feature of the first morning was the announcement by the LUX collaboration of a new world leading sensitivity for the direct detection of dark matter (A. Currie's presentation, see also pg. 4 this newsletter), with particular importance in the low-mass region. Even though this had appeared only the night before on the arXiv, John Ellis had already incorporated the new limit into his own keynote talk. The prospects for discovery and then characterisation of dark matter with a new generation of instruments, using direct, indirect and accelerator techniques were discussed.

The rapid progress in gravitational wave detectors means a detection in the next few years seems inevitable. The excitement that this is causing, with the possibility of a fundamentally new way of doing astronomy, was the major feature of the afternoon sessions. Similarly, the next morning saw talks discussing how the Cherenkov Telescope Array, planning for construction to begin in 2014, will bring a transformational step-change to the quality of very high energy gamma ray data. The final sessions covered cosmic rays, especially recent exciting results from Auger, and evidence for cosmic neutrinos from experiments at the South Pole, as well as several very clear theoretical and cosmology talks.

Feedback from the meeting has been extremely positive, with the quality of the invited talks especially praised. The meeting has powerfully demonstrated how Astroparticle Physics, with major UK leadership, is poised to deliver some of the most remarkable discoveries in science. In his opening talk, Roger Blandford observed that the title of the meeting echoed a book by Nigel Calder published in 1969. Although a complete coincidence, this does seem peculiarly appropriate: *The Violent Universe: An Eyewitness Account of the New Astronomy*.

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## Upcoming Astroparticle Physics Meetings

### **Fri 14<sup>th</sup> Feb**

RAS Specialist discussion meeting  
Nucleosynthesis – It's origins and impacts  
<http://www.ras.org.uk/component/gem/?id=254>

### **Thursday March 20<sup>th</sup> 2013**

CTA Industries Day (see next page)  
Daresbury Laboratories

### **Monday 7<sup>th</sup> – Wednesday 9<sup>th</sup> April 2014**

IoP HEPP and APP joint meeting  
Royal Holloway University of London

## CTA Industry Day

The STFC Innovations Club are hosting an event at Daresbury Laboratories on March 20th 2014 on to discuss current developments and future R&D needs in the key areas of interest to The Cherenkov Telescope Array (CTA), the largest and most sensitive gamma-ray telescope in the world to

The £130M CTA arrays will be built on two sites, one in the northern hemisphere and one in the south, and will provide a deep insight into the non-thermal high-energy universe. The arrays are being planned and designed by an international collaboration of engineers, astronomers, physicists, industrialists and policy makers, and will operate as an open observatory supporting a wide astrophysics community.

CTA is currently in the preparatory design stage (2010-2014) and new technology and progress in fundamental engineering science are both required. These breakthroughs can only happen with the R&D collaboration of academic and industrial partners offering expertise in fields such as electronics, optics, engineering, infrastructure etc.

The workshop aims to pull together the interest from both the academia and industry in order to facilitate knowledge exchange (KE) between STFC-funded researchers working on CTA and industry with a view to exploiting synergies between CTA research and industry. It will further highlight funding opportunities to support KE relationships around the CTA project as well as provide an opportunity to hear a general update on the status of CTA and the anticipated UK role in the project.

For further information, see the STFC Knowledge Exchange website in January 2014, or contact: Vlad Skarda [vlad.skarda@stfc.ac.uk](mailto:vlad.skarda@stfc.ac.uk) or Paula Chadwick [p.m.chadwick@durham.ac.uk](mailto:p.m.chadwick@durham.ac.uk).

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This newsletter is also available on the web and in larger print sizes

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