LSST:UK Newsletter 14 (August 2021)

LSST:UK Consortium

Introduction

August in LSST-land means the annual Project and Community Workshop (PCW), and this year, for the second time, it ran online, rather than in sweltering Tucson. Slides and recordings from the 2021 PCW can be found on the workshop website, with fifty of the latter also to be found in a dedicated YouTube channel. I list a few of the highlights below, while those wanting a ~1 hour summary of the full week may wish to watch the video of the wrap-up session.

The wrap-up session concluded with an announcement by Steve Kahn that he will be stepping down in the spring as Director of the Rubin Observatory Construction Project. As he notes, Steve has devoted almost two decades to LSST, undertaking a range of crucial leadership roles, in the camera team and then in the overall project. He became Director in 2013, at roughly the time that we began serious discussion of potential UK participation in LSST, and, from the outset, he was an enthusiastic supporter of the idea of a strong UK involvement, aiding development of a plan for that through a long series of discussions with the US and UK funding agencies and the leadership of the LSST:UK Consortium. So, we in the UK owe him a particular debt of gratitude in addition to the more general thanks due from the worldwide Rubin LSST community for the commitment and leadership that he has shown in guiding this huge project towards reality over such a long period. Steve will be taking up a new position as Dean of the Division of Mathematical and Physical Sciences at the University of California, Berkeley.

One of the topics discussed at the PCW was the impact of satellite constellations on Rubin LSST science, and Andy Lawrence provides a summary below of the many developments in this important area over the past year, while, in our final item, Dan Weatherill describes some of the experimental work on CCD resistivity that he and colleagues in Oxford have been undertaking under the aegis of Work Package 3.9 of the Phase B programme.

Those with ideas for future newsletter items should contact the LSST:UK Project Managers (@ George Beckett and @ Terry Sloan lusc_pm@mlist.is.ed.ac.uk), while everyone is encouraged to subscribe to the Rubin Observatory Digest for more general news from the US observatory team.

@ Bob Mann

The 2021 Project and Community Workshop

This year's Project and Community Workshop took place on 9-13 August, with more than 800 participants registered for the five days of online sessions. A full programme covered all aspects of the Rubin LSST, from plenary presentations on the status of construction and of operations planning, to parallel sessions covering a wide range of topics from safe construction during a pandemic to community engagement to synergies with other projects. Contributions by LSST:UK members included talks by Ken Smith on Lasair in the alert brokers session, presentations by Aaron Watkins and Ryan Jackson in the one on low surface brightness science and by Chris Lintott in the session on citizen science for science and engagement, while future UK plans were included in summaries presented in the discussion of Independent Data Access Centres and in the Rubin Science Platform developer meet-up.

Perhaps the most significant announcement during the PCW came from Bob Blum in the operations update, who noted that the Observatory is currently working towards a survey start date of **1 April 2024**. There remains some uncertainty in that date. In his construction status update, Victor Krabbendam had detailed how the critical path in the overall project schedule had evolved during the Covid pandemic, resulting in a current projection that construction will finish at some point between January and June 2024. The current planned survey start date is, then, at the mid-point of that interval, the width of which should narrow by early 2022, since much of the uncertainty relates to the work of one contractor, whose progress to completion should become clearer on that timescale.

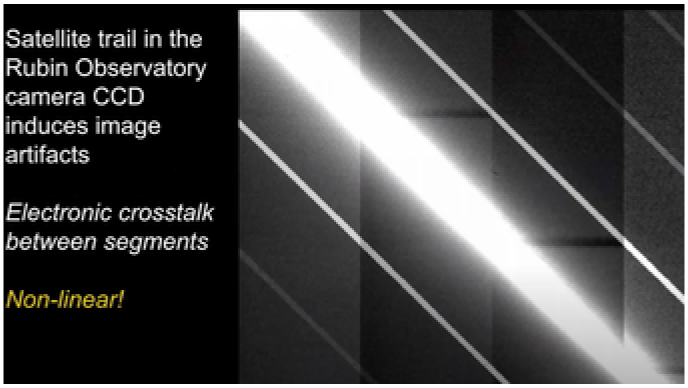
One of the main themes of the workshop was the optimisation of the survey strategy, with three sessions covering: (a) the Phase 1 recommendation from the Survey Cadence Optimisation Committee (whose draft report is also now available); (b) the next set of cadence simulations, guided by that recommendation; and (c) some of the input provided to the cadence optimisation process by individual Science Collaborations. The survey strategy will remain a major topic of study within the Rubin LSST community for some time to come, with the final optimisation steps awaiting analysis of commissioning data in 2023. For example, the reduced readout time resulting from a switch to one exposure per visit would improve survey efficiency significantly, but two exposures will remain the default plan until it can be seen how well cosmic rays and satellites can be removed from single exposures taken during commissioning.

@ Bob Mann

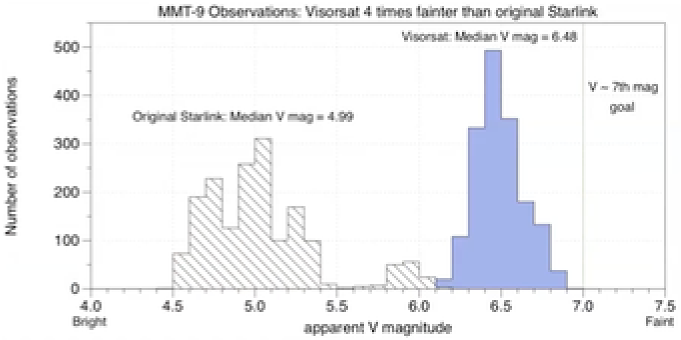
Mega-constellations update

A year ago in this newsletter, Bob Mann reported on the likely impact that satellite megaconstellations would have on the Legacy Survey of Space and Time. What has happened since? Well, a lot of discussions and debates and studies have gone on, but meanwhile SpaceX and OneWeb have continued launching satellites, and it still looks like a serious issue for the Rubin Observatory. In 2018 there were around 2,000 active satellites. Today there are just over 4,000. SpaceX plan up to 42,000 satellites, and the recent JASON report indicates that there might well be 100,000 satellites by the end of the decade. A paper by Tony Tyson and others showed that every LSST image would have a streak, and often several. Furthermore, unless satellites can be kept to fainter than 7th magnitude, electronic cross talk will result in multiple sub-streaks.

At the recent PCW meeting, a session was dedicated to this issue, the recording of which can be seen here. The image below, from a lab simulation with LSST-CAM, illustrates the cross-talk problem, which Tony Tyson and Andrew Bradshaw explained is a non-linear effect and very hard to correct for.



Meanwhile Rubin staff have actively engaged with Rubin engineers. The "Darksat" experiment didn't really work, as this makes thermal problems for the satellite. The "Visorsat" experiment seems more promising (see picture below) but still doesn't reach the 7th magnitude limit needed to avoid severe cross-talk, let alone solve the problems for radio astronomy or amateur astronomers. As Tony Tyson stressed at the PCW session, although SpaceX engineers have been very co-operative, we have no idea whether future satellite operators will be equally co-operative. At a recent talk at the RAS NAM meeting, Stuart Eves gave an interesting industry perspective, and stressed that all the discussed mitigations would make little economic sense to satellite builders, giving them extra headaches and costs.



Rachel Street summarised discussions from the recent SATCON2 workshop. The SATCON2 working groups have expanded to include policy issues and the rights of indigenous people, but also presented plans for a "resource hub" with data and tools which will hopefully allow astronomers to predict the passage of satellites, identify trails in images, and so on. Ephemeris data as currently published (in so called "two line elements" or TLEs) won't be accurate enough to predict the passage across a spectrograph slit. Facilities may then need an extra "boresight" telescope to spot things coming. Of course all this work has a real cost - a classic case of environmental damage externalising costs. Some people favour the idea of working towards a "polluter pays" model, while others feel this will just lead to a mentality of "pay the fine and carry on".

While engaging with satellite companies is obviously important, everybody agrees that we have to simultaneously work on public awareness, and on working with policy makers to improve the international regulatory framework. As many of you will know, I have tried to do my bit for public awareness, with my non-technical book "Losing The Sky", associated live event, and some popular press attention. On the policy front, a number of people have been working with their own governments (for example here in the UK led by Robert Massey at the RAS), and the Dark Quiet and Quiet Skies report has been presented to the UN Committee on the Peaceful Uses of Outer Space (COPUOS). I have also been personally involved in a legal case. The Viasat Corporation and others appealed to the US Court of Appeals against the most recent order of the Federal Communications Commission (FCC) grant Starlink licenses, on the grounds that it should have been subject to an Environmental Assessment under the US NEPA law. My feeling is that this is exactly correct, so I wrote an "Amicus Brief", with help from Meredith Rawls from the Rubin Observatory, and Moriba Jah, the well known space environmentalist from the University of Texas, and a considerable number of community contributors. Unforunately it will take some time before this winds it way through the legal system, but meanwhile if you are interested you can find it here.

@ Andy Lawrence

Measuring CCD Resistivity

The resistivity of a material is likely a familiar property to the readers already, and one of the current experimental activities in WP3.9 is using indirect optical measurements to constrain the resistivity of LSST sensors, so in this brief note I wanted to explain why this is an important property for CCDs and how we approach measuring it in a working device non-destructively. The explanations will be brief and lacking in detail, but as always if there are any questions or further interest in this topic please don't hesitate to get in touch with me at daniel.weatherill@physics.ox.ac.uk or the WP3.9 lead, Prof Ian Shipsey ian.shipsey@physics.ox.ac.uk.

Resistivity in Silicon

Silicon is most useful to us due to its semiconducting properties, and some patterned semiconductor devices (for example MOSFETS) might be described simplistically as operating as devices whose resistance can be altered dynamically by applications of potential difference. It's quite clear then why we might care about the resistivity of the material these devices are built on, because in a transistor it will determine several important performance characteristics. In a CCD, though, we don't have any patterned transistor structures within the pixels of the device, only at the output amplifiers. It turns out that resistivity also has important consequences for imaging in the pixels. Firstly, and most importantly, the resistivity of a semiconductor depends strongly on the doping introduced. The devices we use in the LSST camera are so-called "n-channel" devices where the signal charges are the minority carrier electrons, which means the silicon substrate we start from in constructing them is p-type silicon. A rough but reasonably accurate expression for the resistivity of the silicon is given by:

1 / (q p)

where q is the charge on an electron, p is the concentration of holes, and is the mobility of holes. The concentration of holes at increases exponentially with the number of acceptor sites introduced by doping, and the mobility of holes itself also depends (though much more weakly) on the doping. It is clear, then, that a less doped device has higher resistivity. For high precision astronomy sensors, for reasons I will describe below, we desire very high resistivities, typically p >= 5000 Ohm cm. This implies very low doping densities, the exact numbers depending on what dopant is used and operating temperature, but in the region of Na ~ (1E12-1E13) cm^-3. It turns out that these low doping densities are almost impossible to achieve in silicon typically used for commercial device construction (constructed epitaxially e.g. via some vapour deposition process), and so for thick CCDs we need to use so-called "bulk" silicon, usually produced using the high-purity float zone technique (https://en.wikipedia.org/wiki/Float-zone_silicon), though some varieties of Czochralski process silicon might be suitable (https://en.wikipedia.org/wiki/Czochralski_method).

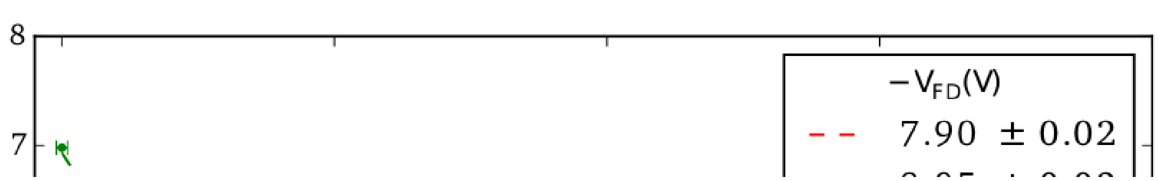
Resistivity for Astronomical Sensors

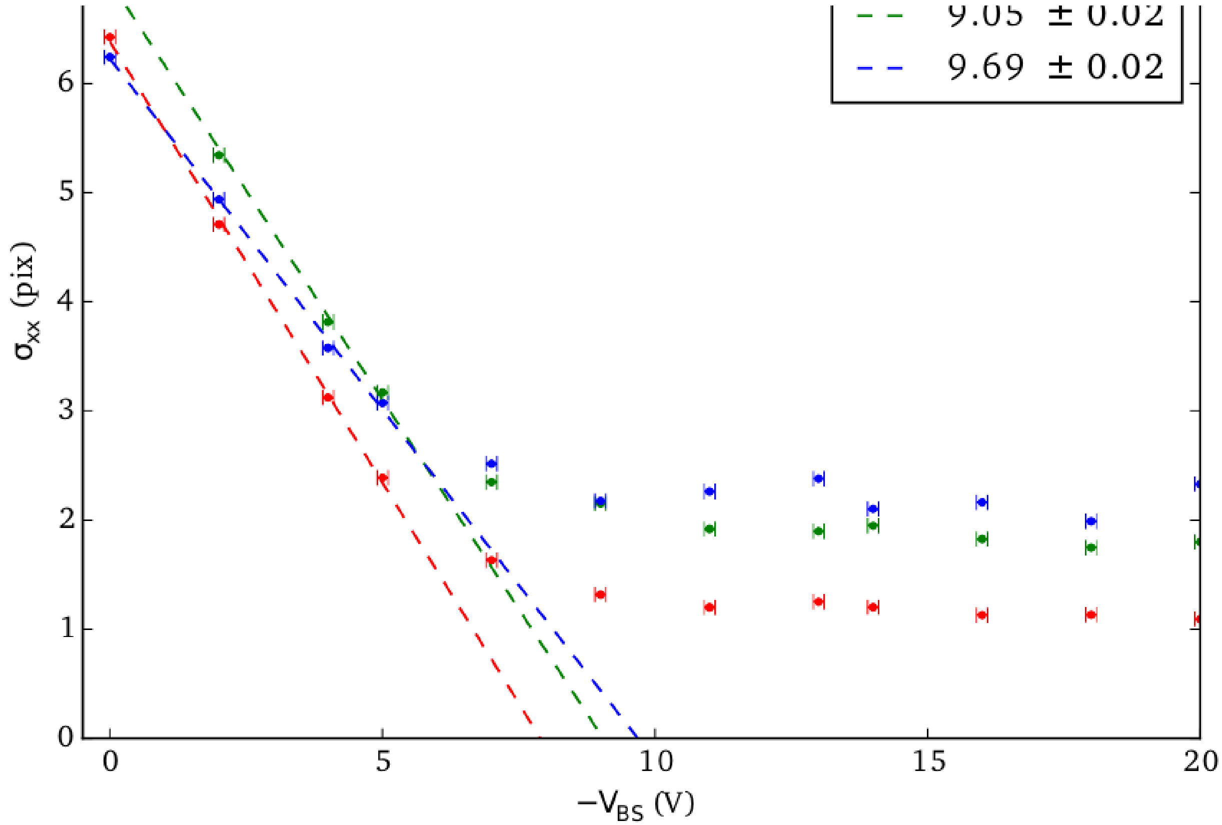
The primary reason we need high resistivity for thick CCD sensors is to allow us to produce high electric fields across the device with minimal leakage current (via a simple application of Ohm's law). We need these high electric fields in a thick, back illuminated device, because most of the photo-electrons are produced near the back surface of the device and have to traverse the full depth of the sensor before being collected and read out. During this traversal they are subject to thermal diffusion, and this is the dominant mechanism for increasing the width of the detector PSF in such a sensor. By applying a high electric field across the device, we give these electrons a "push" towards the collection points, reducing the traversal time and hence decreasing the width of the detector PSF.

It is also worth noting that the phenomenon of "tree rings" – fixed pattern circular anomalies that appear in images at shorter wavelengths (https://iopscience.iop.org/article/10.1088/1748-0221/12/05/C05015) - is believed to be a consequence of spatially varying resistivity across the silicon crystal from which the device is constructed.

Device Resistivity Measurement

It is, of course, quite easy in a standard semiconductor device lab to measure the resistivity of a prepared device or test structure. We just put it on a semiconductor probe station, drop a few needles onto it and use a standard Kelvin resistance measurement technique. As you can imagine, this is not possible to do on a finished LSST sensor including its incredibly fragile anti-reflection coating without destroying the device irreparably. In addition, the resistivity of a single crystal of silicon depends on the direction you measure it in, and we are primarily interested in the resistivity in the depth direction of the device, which is somewhat harder to measure using a standard technique. We have a probe station in the OPMD lab, but we are not (hopefully!) in the business of destroying working production sensors. In addition, for our purposes we don't need a highly accurate resistivity measurement, just a reasonable "ball park" number to be useful. A technique developed originally by S. Holland (https://ieeexplore.ieee.org/document/1185186) is used to indirectly determine an approximate resistivity optically. It was mentioned above that detector PSF will decrease with increasing applied voltage, because the electron transit time will reduce. However, this was assuming a device already fully depleted, meaning without the presence of the majority carriers. If we apply very low voltages instead of the high ones we typically use in operation, eventually the device will not be fully depleted, and regions of majority carriers will develop which screen out the electric field. We will then observe a drastic change in the device PSF, which we find by projecting a single small spot onto the device and measuring its width. By finding the applied voltage at which this occurs we can tell where the onset of full depletion is, and knowing the device thickness, we can use a simplified model of the pn-junction of the device to determine from this measurement what the resistivity (and, importantly for simulation work, doping) of the substrate is.





The Figure shows previous work by myself on measuring this property on a CCD261 device from e2v, which is in many ways similar in construction to the e2v CCD250 used in the LSST focal plane. The qualitative change in gradient indicates the different operating regimens of field free (at low applied bias) and full depletion (at high applied bias). The resistivity of the CCD261 measured was estimated at 6600+700-600 Ohm cm, and we expect the LSST device to be higher still. Tracing down the line for the field free regimen we can find the full depletion voltage. We have had some slight hardware issues in the lab with our vacuum system over the last few weeks, but we anticipate that we can produce a similar (and indeed much more thorough) survey of the LSST devices in the next few weeks.

@ Daniel Philip Weatherill

Forthcoming meetings of interest

The schedule of forthcoming meetings remains relatively quiet, though the dates for the next DESC Sprint Week have been confirmed as 25th–29th October 2021. This meeting will run in a hybrid format, with options to join virtually or from one of two meeting hubs that are being set up at Princeton University (USA) and at AstroParticule et Cosmologie (France). More details should appear soon on the DESC wiki (DESC membership login required).

Note that the current list of forthcoming meeting is always available on the Relevant Meetings page. You may also wish to check information held on the LSST organisation website LSST-organised events and the LSST Corporation website

@ George Beckett
