



The Sky Tonight: A New View of the Changing Sky

Lecture 6: The State of Our Universe

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The first released images from the Vera C. Rubin Observatory were released in the summer of 2025. Produced by a new, giant telescope in Chile, they showed a unique view of the Universe, showing galaxies in a new light, and capturing thousands of asteroids swarming across the Solar System, as well as a few early supernovae.

Mostly, though, it was the size of the images that impressed, taking advantage of the Charles Simonyi telescope's giant field of view, 3.5 degrees across and thus large enough to contain the full Moon 40 times over. This scale is made possible by clever optics and the world's largest astronomical camera, with a chip containing 3200 megapixels, and over the next ten years it was designed to carry out a cosmos-defining project: the Legacy Survey of Space and Time.¹

This way of working, where one large (and often expensive) survey provides data for a variety of purposes to a large community of astronomers, is surprisingly modern. The traditional model sees astronomers competing with each other to apply for time on a telescope, which is in the gift of a Time Allocation Committee usually made up of peers. Successful applicants get their allocation of nights, and were handed control of an often expensive facility for their allocated slot². My PhD, two decades ago, involved multiple trips to Hawai'i, for example, using the James Clerk Maxwell Telescope to look at the chemistry of nearby star forming regions.

This approach has its benefits – I learnt an enormous amount from these trips, and by putting astronomers in the loop one can react to changing conditions and incoming data in

¹ The full credit is something like the Legacy Survey of Space and Time carried out by the Vera C. Rubin Observatory with the Charles Simonyi telescope, funded by the US National Science Foundation and the US Department of Energy's Office of Science, with additional support from international partners including the UK Science and Technology Facilities Council. I'll just say 'Rubin' or 'LSST', likely interchangeably.

² In most cases, sensible Telescope Operators sat between visiting astronomers and the controls!

real time. But it is undoubtedly inefficient; on the one hand it might make sense to mix different programs across a single night³, and on the other one could be desperately unlucky.

My (successful) former DPhil student, Tobias Géron made many trips to the Canary Islands to observe bars in galaxies, prevented from gathering a single photon by clouds, covid, a snowstorm, a volcano and eventually the most easterly tropical storm ever to form in the Atlantic.

As telescopes have increased in cost, from the previous 1m, 2m and 3m diameter mirrors to the current generation of 8m instruments and beyond, the pressure to make best use of telescopes has increased. Surveys have also proved incredibly effective, from the Sloan Digital Sky Survey's three-dimensional map of the cosmos made from nearly a million local galaxies, to WASP's wide-eyed search for planets around other stars, to the Zwicky Transient Factory's harvesting of supernovae.

Hence Rubin's genesis in the first decade of the century as the Large Synoptic Survey Telescope⁴. Large as in the size of the mirror – at 8.4m across, built in the famed mirror lab in the basement of the University of Arizona's football stadium, it's as big as the largest single mirrors ever produced – and in that spectacular field of view, but it's 'synoptic' that is the important world. This is a survey designed to do everything, all at once.

The fiducial design had the telescope scanning the whole sky accessible to it every three nights. In practice, different science cases require different cadence – asteroid hunters would like images an hour or two apart to catch their rapidly moving quarry, while cosmologists would prefer the telescope to stare at particular patches and sky to build up deeper images. The survey will produce both a string of transient alerts, perhaps ten million a night, drawing attention to anything which has moved, changed brightness or which has suddenly appeared, and a set of deep images released annually.

When originally scheduled, this lecture was timed for the start of the survey itself, and I hoped to take advantage of the transient stream to give you a review of what the telescope had found in the previous few days. Sadly, since those first images were released last year the telescope has been beset with delays. Mostly, there have been problems maintaining a stable, crisp image across the entire field of view – something that's particularly important for the cosmological experiments planned for the data. Improvements to software and hardware, particularly to ventilation in the dome, meant that the survey officially started a few months ago, only for an unprecedented snowstorm to fall across the Chilean desert, causing devastating flash floods and preventing access to the site for many weeks⁵.

Such delays are inevitable for any major project, especially one with a new design and on the cutting edge of technology. Instead of this week's results, let me tell you instead what we're planning. The science of Rubin can be organised under four broad pillars.

³ An approach usually known as 'queue' observing, where the observatory selects from a series of pre-approved programs hour by hour, depending on conditions.

⁴ LSST, just like Legacy Survey of Space and Time.

⁵ It may be relevant that Tobias – the student who had such bad luck in the Canaries – now works as a LSST fellow....

Firstly, the Solar System. This will be the first to bear fruit, with up to five million new asteroids detected in the first year or so after survey start⁶. A major motivation for funding LSST was an unprecedented ability to spot near-Earth asteroids, and in particular objects that might one day collide with us, but it is the chance to complete a census of the rest of the Solar System that is really exciting. Rubin has already found its first comet – 2026 N2 P/LSST, on a 5.4 year orbit around the Sun – and the first science paper from the telescope is a study of 3I/ATLAS, last year's remarkable interstellar visitor to the Solar System.

Second, transients. In the first month of proper operation, Rubin will find more supernovae than have been discovered previously in all of human history. As well as their use for cosmology, which we will come on to below, these dramatic explosions are test beds for exotic physics, as well as playing an important role in understanding the history of star formation in the galaxy. Repeated observations with a telescope the size of Rubin should provide new insights to the early phases of such events; SN 2026gzf, for example, discovered elsewhere but easily apparent in early Rubin images taken in March and April early this year, is an unusual supernova which has already attracted much attention. It appears to be an extreme member of an unusual class of transient known as a 'shock breakout', where we see the effect of the explosion on the star's previously calm surface before we see the explosion itself.

Third, and making good use of the supernova catalogue, cosmology. Rubin is squarely aimed at two of the biggest mysteries in modern physics – the fact that we don't know what most of the stuff in it is made of, postulating the presence of 'dark matter', and that we don't know what is driving the apparent rapid acceleration of the Universe's expansion, something usually credited to a hypothetical 'dark energy'. Measuring the brightness of type 1a supernovae will allow scientists to track how the expansion of the Universe is changing. The hope is that, over the period of the cosmos's history traced by the Rubin survey, we might find evidence of a change in the strength of this dark energy, a clue to whatever physics has produced it.

For dark matter, the supernova survey is useful. But Rubin will also discover thousands of gravitational lenses, which will allow us to plot the distribution of matter within individual galaxies and clusters. It will also support a massive program of studying 'weak lensing', the distortion of the shape of distant galaxies by interlying dark matter. Detected statistically, this provides a strong constraint on the amount of dark matter in the Universe, as well as its distribution, something which can be tested against modern cosmological simulations. In this, Rubin will be aided with sharper but shallower surveys carried out by space-based telescopes, including ESA's *Euclid* and NASA's *Nancy Roman Space Telescope*, which launched on August 30th and is now on its way to its station.

The fourth and final pillar is the study of our local galaxy, the Milky Way. Here, it's the aperture and sky coverage of the LSST survey that matters, with Rubin capable of tracing the position of even faint stars. It has already discovered a new, faint dwarf in the process of being consumed by the Milky Way, and understanding our galaxy's cannibalistic past is a

⁶ As no one has completed a survey of the sky with such a large telescope, we need first to build up template images of the stellar sky, so that moving objects stand out.

significant part of the expected scientific return. Around forty such objects are expected to be discovered by Rubin, adding greatly to our understanding of these faint and diffuse objects.

Returning to those First Look images, one can see the wealth of information in just a single shot with the magnificent LSST Camera. Each of the bright galaxies is surrounded by a halo of faint light; this glimpse of the low surface brightness Universe, where a galaxy's history of merging and interacting is written in the debris which surrounds the main body of the galaxy. Learning to read these histories will take us time, but it is clear there is information there. Equally, every background source adds to the catalogue of galaxies in the Universe, every lens to our understanding of the distribution of matter, and every single supernova and asteroid to our burgeoning catalogues of the transient Universe. Thought I haven't given you the sky tonight, perhaps these images give us a sense of what's coming very soon – the sky at night, tomorrow.

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References and Further Reading

There are lots of details and tools for exploring Rubin data at <https://rubinobservatory.org>

For the full background, the (now slightly out of date) Rubin Science Book (<https://arxiv.org/abs/0912.0201>) made the case for the observatory.

Rubin observations of 3I/ATLAS are described in Chandler...Lintott et al, ApJL, 2006, 1001, 2, L35: <https://ui.adsabs.harvard.edu/abs/2026ApJ..1001L..35C/abstract>

For SN 2026gzi, see O'Connor et al., ApJL, 1006, 1, L13: <https://ui.adsabs.harvard.edu/abs/2026ApJ..1006L..13O/abstract>

For Aquarius IV see Cerny et al., RNAAS, 10, 8, 239: <https://ui.adsabs.harvard.edu/abs/2026RNAAS..10..239C/abstract>