Transient follow-up with Liverpool Telescope 2

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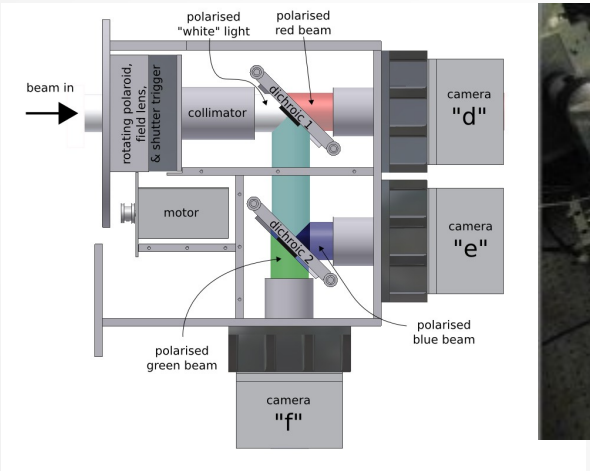
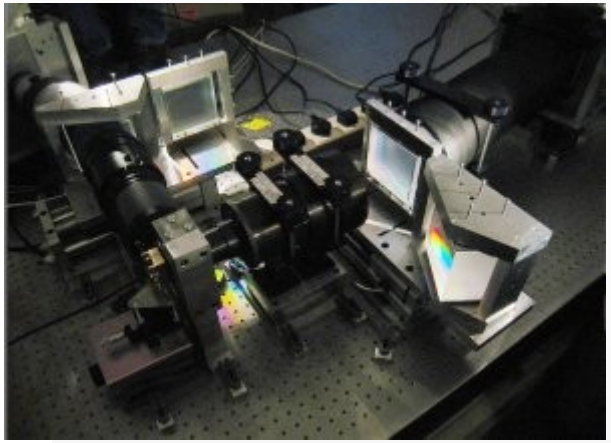
The Liverpool Telescope

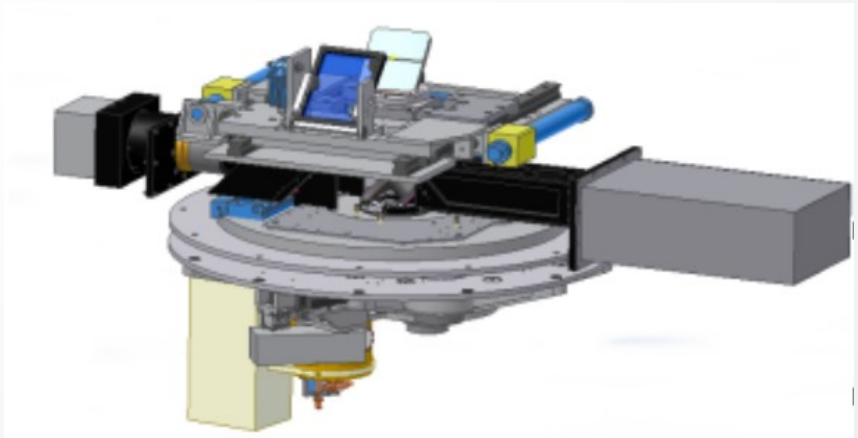
- The Liverpool Telescope is a robotic 2m alt-az telescope currently in operation on La Palma
- Not 'remote controlled' – operated autonomously without night-time supervision
- Software decides what and how to observe and is responsible for safe operation of telescope throughout the night
- Flexible nature of LT observing modes makes it ideal for time domain work
- High-impact science
  - 36 citations/paper average (for papers > 3yr old)
  - 14 publications in Nature/Science (86 citations on average)

Liverpool Telescope Instrumentation

- **IO O**: Main imaging camera: 10' FoV; 12 optical filters
- **FRODOspec**: 12x12 0.82" lenslet IFU.
  - R~2500/5500; 400 < λ < 940nm
- **RINGO3**: Fast-readout tri-band polarimetry
- **RISE**: Rapid readout (0.6sec) photometry; 10' FoV
- **IO THOR**: High cadence photometry (~7ms); 2.25' FoV







Coming soon:

- **IO I**: Infrared (Y, J, H) imager. 6X6' FOV
- **SPRAT**: R~500 spectrograph

Liverpool Telescope 2

- The Liverpool Telescope is now a mature facility which is expected to stay competitive until at least 2020
- LJMU has committed £200,000 to fund the feasibility study for a successor 'Liverpool Telescope 2' facility, to come into operation ~2020
- No real preconceptions, other than that LT2 will build on the key strengths of LT
  - Low operational cost (robotic observing): 10.5 staff, £500k/year or £10k/paper
  - Rapid response to transient alerts (avg ~180s) due to robotic observer and telescope design. GRB follow-up a science highlight
  - Instrumentation: diverse suite, instrument changes within the night, rapid deployment of new concepts

Transient science in 2020+

- LSST (and the other synoptic surveys) will provide
  - Large, unbiased and statistically complete samples
  - Very early detections (many objects like SN2011fe). New parameter space
  - CC SNe: progenitors (pre-explosion imaging), relative frequencies of rare subtypes, unusual environments
  - Potentially new types of stellar explosions (combined with radio, high energy, GW, neutrino detections)
  - Many photometric monitoring programmes running on the LT currently – these data will be provided 'for free' by next gen synoptic surveys

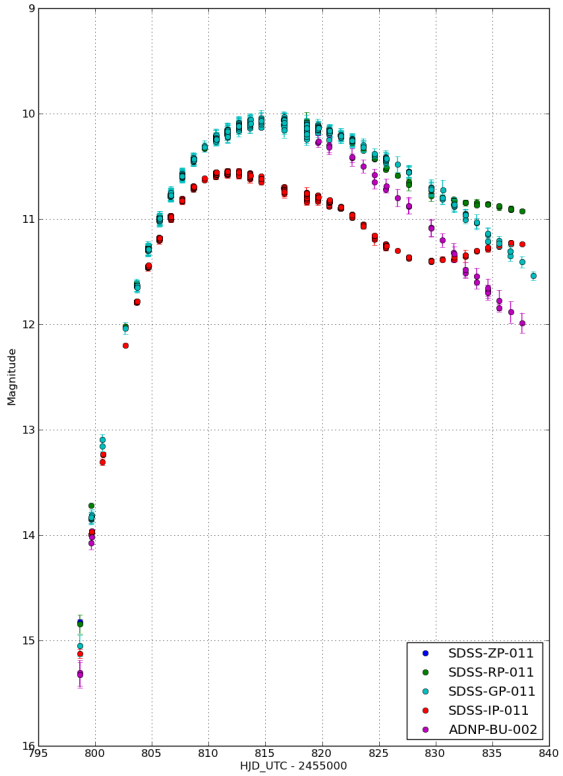
- Will not provide
  - Spectroscopy (low R for classification, intermediate R for most science)
  - Photometry optimised to the SN light curve: LSST 3-4 days between visits (even longer for same filter)
  - High cadence observations at early time and over peak

Transient spectroscopy in 2020+

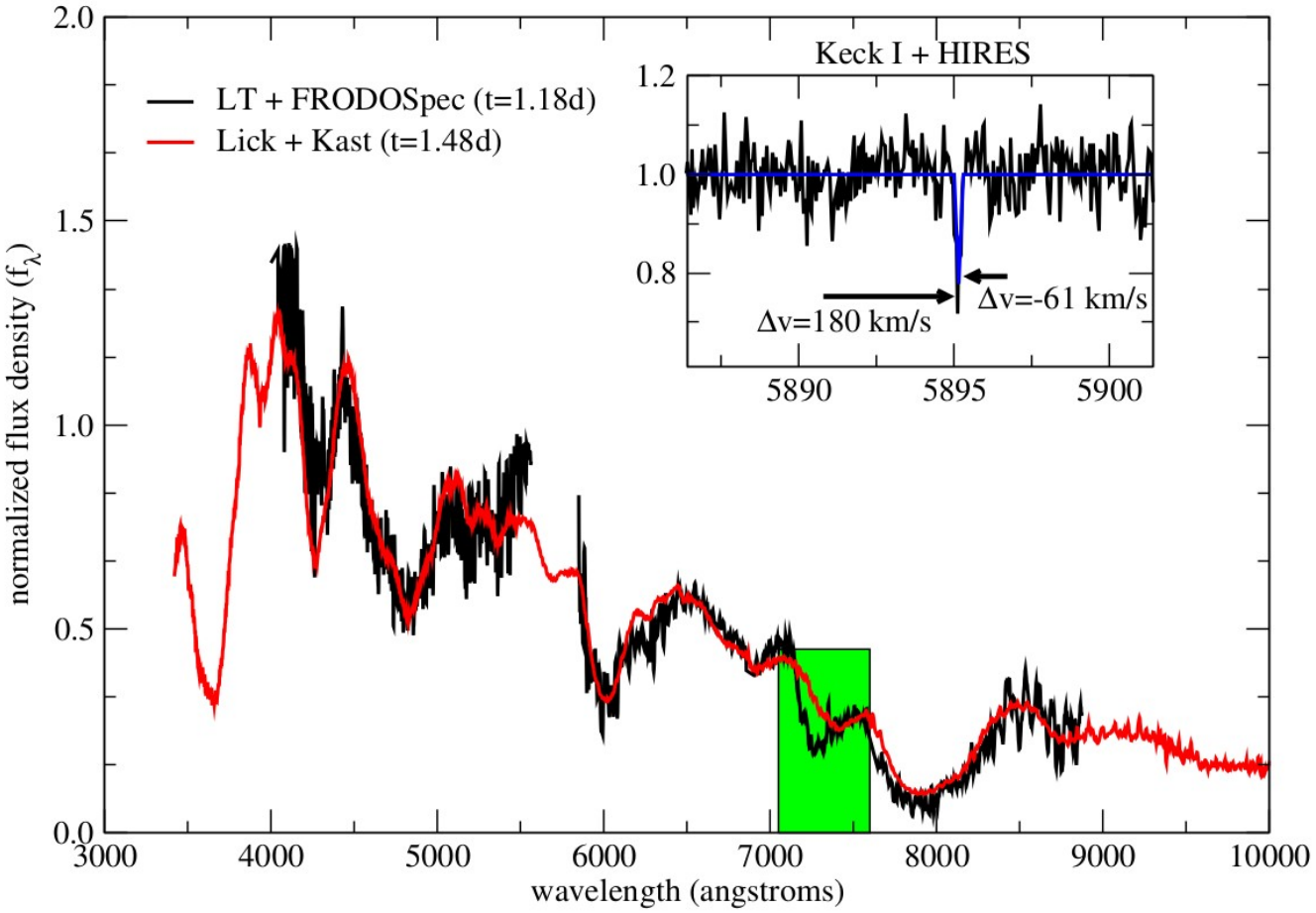
- Current synoptic surveys such as PTF provide large numbers of transients detected at early times
- Spectroscopic follow-up is the bottleneck
  - Only ~10% of PTF detections get a spectral classification
- The need for flexible spectroscopic follow-up will become even more acute in the next decade
  - LSST will issue ~2e6 alerts per night! Even accounting for variable stars and NEOs, still 1000s of targets

- Programmes like PESSTO are showing that large scale optical follow-up of transients with 4m class telescopes can be very productive.
- A telescope dedicated primarily to transient spectroscopy with the speed and flexibility of robotic operations would be a powerful tool

Early time spectra of SN2011fe



Light curve (Fulton/LCOGT/PTF)



High velocity OI feature detected in LT+Frodospec spectrum, 1.18 days after explosion (Nugent et al. 2011)

Fast-fading transients

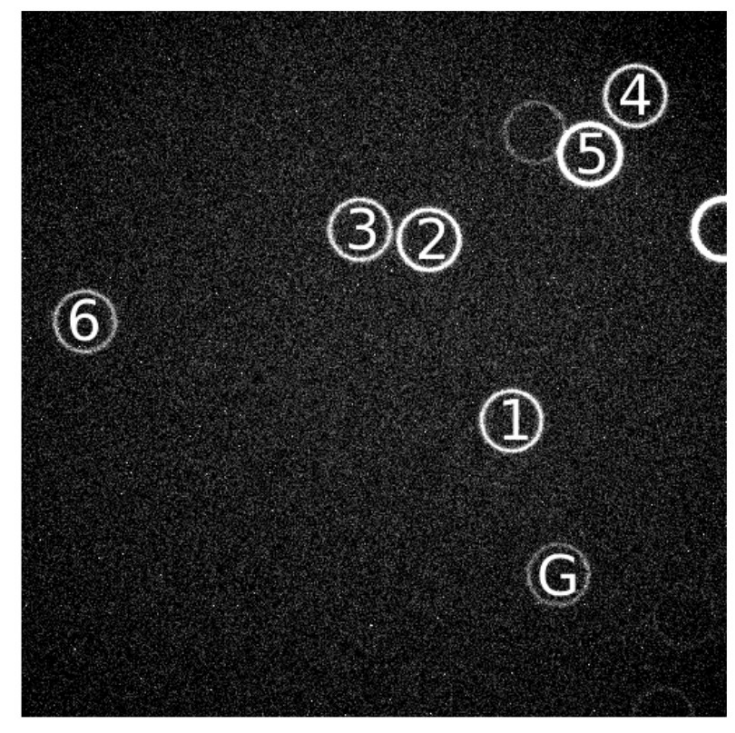
- The rapid response of the LT and flexible instrumentation suite has made GRB follow-up a core strength of the science programme

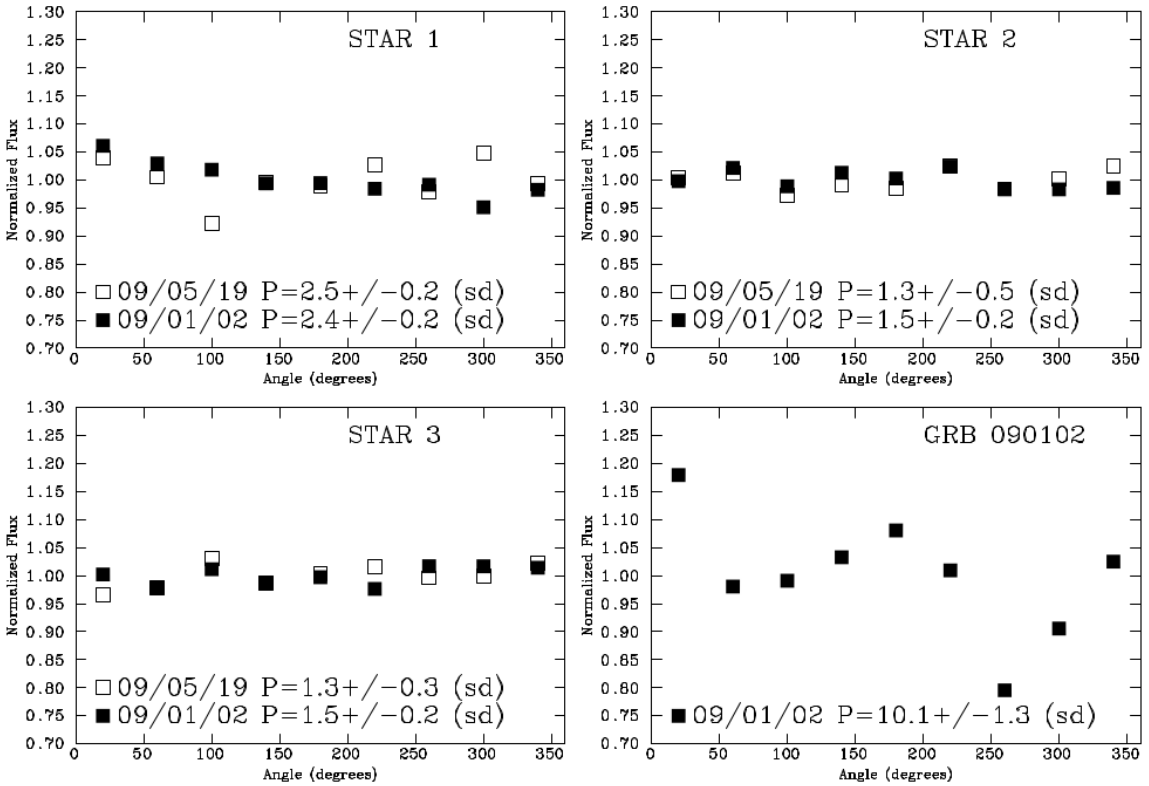
- Still plenty of GRB science in 2020+ for 4m class facilities:
  - Low to intermediate z bursts
  - GRB-supernova associations
  - Prompt phase – particle acceleration, radiation processes, internal shocks
  - Short GRBs – nature of the binary merger components
- Instrument:
  - Spectroscopy perhaps best left for 8m-class follow-up
  - Multiband imager like GROND. Opt/IR for SED. Polarimetry?

- Rapid response requires a triggering facility, ideally from a dedicated Swift successor like SVOM
- Detection of many orphan afterglows with LSST also likely

GRB Polarimetry

- 60s observation of GRB090102 obtained with imaging polarimeter RINGO starting 160.8s after receipt of trigger



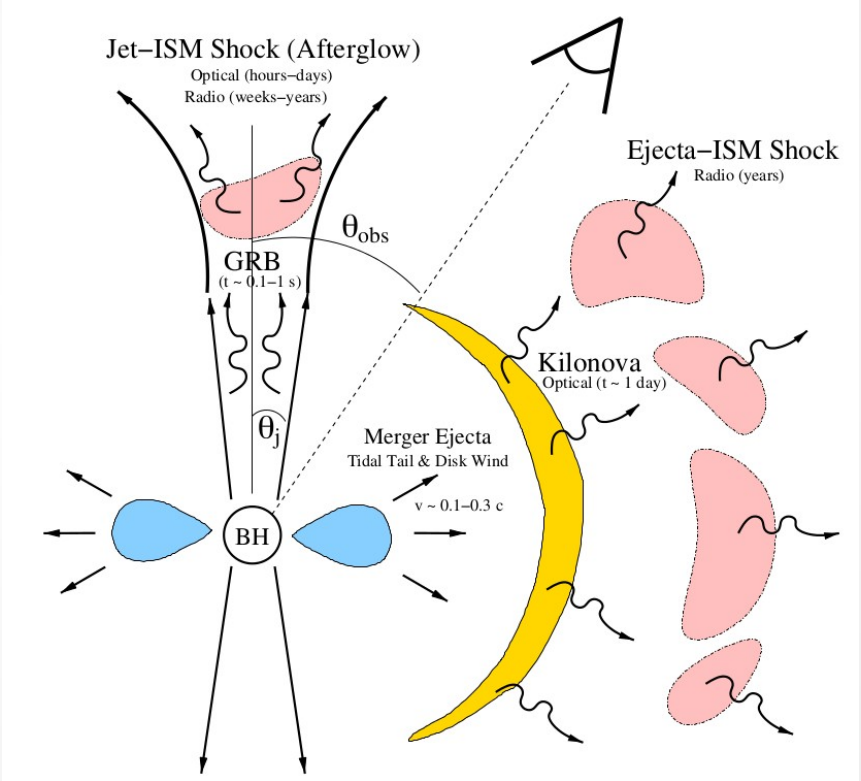


Early optical emission polarised at the level of 10 ± 1 per cent, indicating the presence of large scale fields in the expanding fireball (Steele et al., 2009)

GW electromagnetic counterparts

- Detection of counterpart is important for both validation of the detection and elucidation of the source. aLIGO full sensitivity ~2022
- The main complications are localisation of the GW detection (very poor) and the rapidly fading nature of the prompt emission

- For an NS-NS or NS-BH merger, counterpart consists of
  - sGRB - prompt emission and afterglow, harder to detect further off axis
  - 'kilonova' - SN like, isotropic component powered by radioactive decay of heavy elements synthesised in ejecta (GRB130603B, Tanvir et al. 2013)
  - Non-thermal radio afterglow. Long time delay



Metzger and Berger (2012)

Variability across the EM spectrum

- **X-ray**: LOFT is a ESA M3 candidate (launch ~2022)
  - Wide Field Monitor: X-ray transient detections and triggers
- **Optical**: Gaia final catalogue will be published in 2020
  - 1e9 stars with accurate positions and distances, limited photometry and very limited spectroscopy
  - Millions of variables and binaries. Statistically complete samples, rare subclasses...
- **Radio**: SKA full science operations 2020 (phase 1), 2024 (phase 2)
  - Pulsars, RRATs, AXPs, SGRs, NS-NS binaries, synchrotron emission from jets, coherent emission from flare stars, brown dwarfs and hot Jupiters...
- **High energies**: Cherenkov Telescope Array begins construction ~2018
  - Northern site: AGN, GRBs, clusters
  - Southern site:Galactic centre, SNR, pulsars, SFR, XRBs

Liverpool Telescope 2

- Liverpool Telescope 2 will be a robotic telescope designed for extremely rapid follow-up of transients detected by other facilities

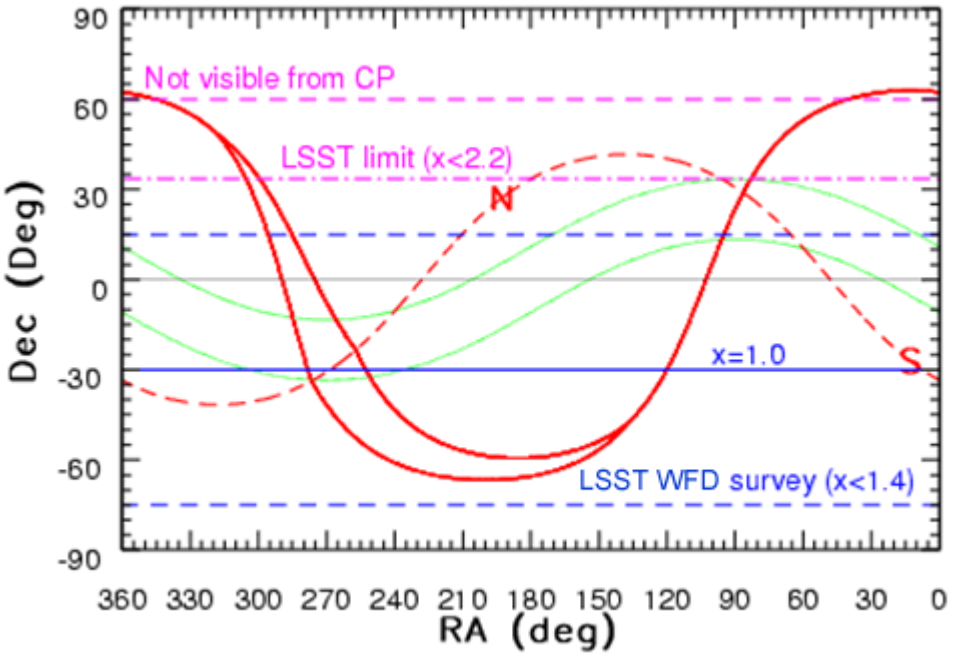
- Fast slewing: aiming to be taking data within 30 seconds of alert
  - Includes blind pointing, mirror settling and mechanical movement of enclosure
  - Does not include acquisition of target onto IFU/slit
  - Excellent open loop tracking performance (image elongation no greater than 0.2" in ten minutes) so we don't have to be slowed down by autoguider
  - Important for fast-fading transients, but also reduced overhead for efficient monitoring of large numbers of targets

- The most pressing follow-up need will be for intermediate resolution (R<10,000) spectroscopy
  - Main instrument will be an opt/IR spectrograph, down to at least 2 micron
  - Focal stations for simultaneous mounting of at least 4 other instruments

- Aperture of 4 metres will put us at the bright end for LSST follow-up, but still 100s of targets per night!

Site

- Northern and southern sites both viable for our science: synoptic transient surveys in both hemispheres, targets from space facilities, GW detections over whole sky, etc.
- Some important infrastructure will be in the south, but LSST for example will cover the sky up to +15 in dec, so northern telescopes will still have a significant follow-up role.
- At this stage our preferred site is La Palma, and we are developing this option in close collaboration with the IAC



From La Palma:

Dec -30°, 1.5h TOT at airmass < 2.0

Dec -20°, 4h TOT at airmass < 2.0
1h TOT at airmass < 1.5

Dec -10°, 6.5h TOT at airmass < 2.0
4h TOT at airmass < 1.5

Novel instrumentation

- EM (electron multiplying) CCDs are seeing increasing use at various observatories
  - Effectively zero read noise
  - Spectroscopic format chips imminent

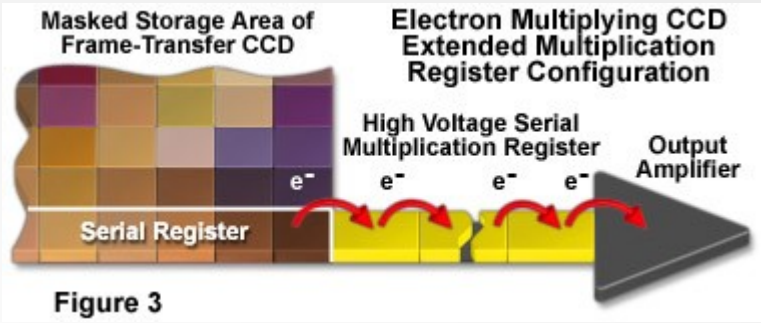


Figure 3

- CMOS detectors
  - Very fast. QE historically a problem, things now improving
- MKIDS: Microwave Kinetic Inductance Detectors
  - Surface impedance of superconductor changed by incident photon through kinetic inductance effect
  - Photon counting with spectral information
  - Largish arrays now possible, although energy resolution still poor (R~10-15)
  - As you go to larger arrays the key challenges are computational and cooling

Summary

- We intend to build a new 4m class telescope to come into operation at the beginning of the next decade
- Our preferred site is the ORM on La Palma
- Telescope will be fully robotic with all the versatility that entails
- Time domain science with a focus on transients
- Very rapid response for fast-fading objects
- Intermediate resolution spectroscopy, but provision for a diverse instrument suite
- Future of LT? We would hope to keep it operational. Replace instrument suite with prime focus wide field (2x2 deg) camera?

LT2 website: **http://telescope.livjm.ac.uk/lt2/**

Optical design studies currently in progress

Science white paper later this year