Liverpool Telescope 2 and LSST

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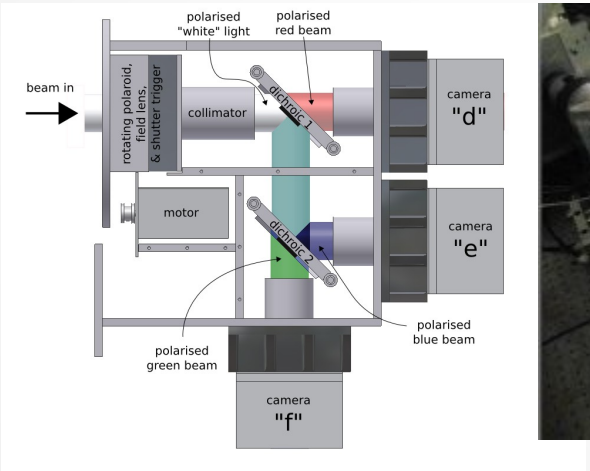
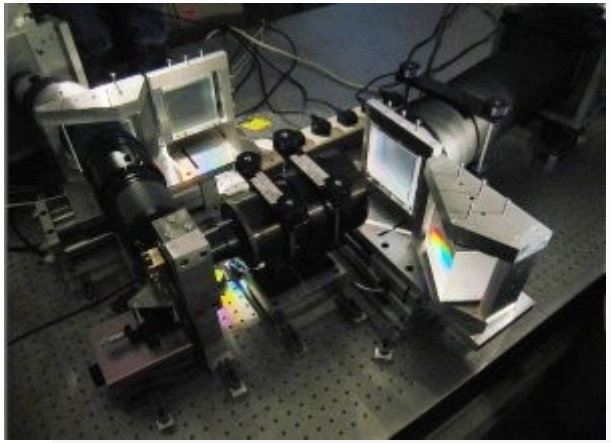
The Liverpool Telescope

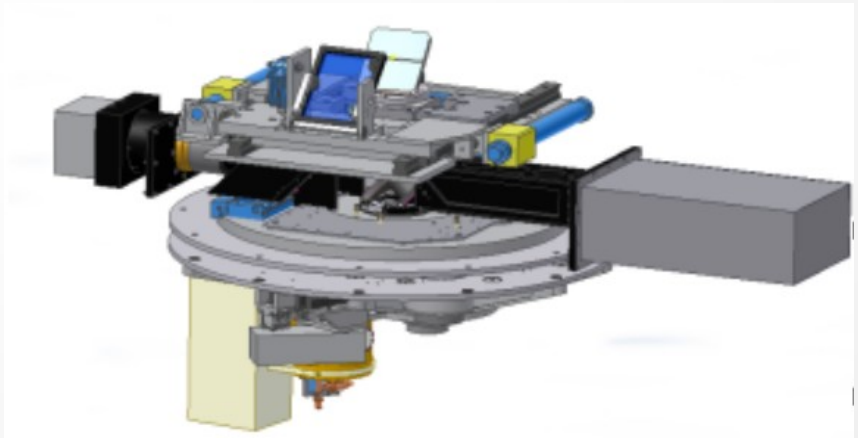
- The Liverpool Telescope is a robotic 2m alt-az telescope currently in operation on La Palma
- Not 'remote controlled' – operated autonomously without night-time supervision
- Software decides what and how to observe and is responsible for safe operation of telescope throughout the night
- Flexible 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:

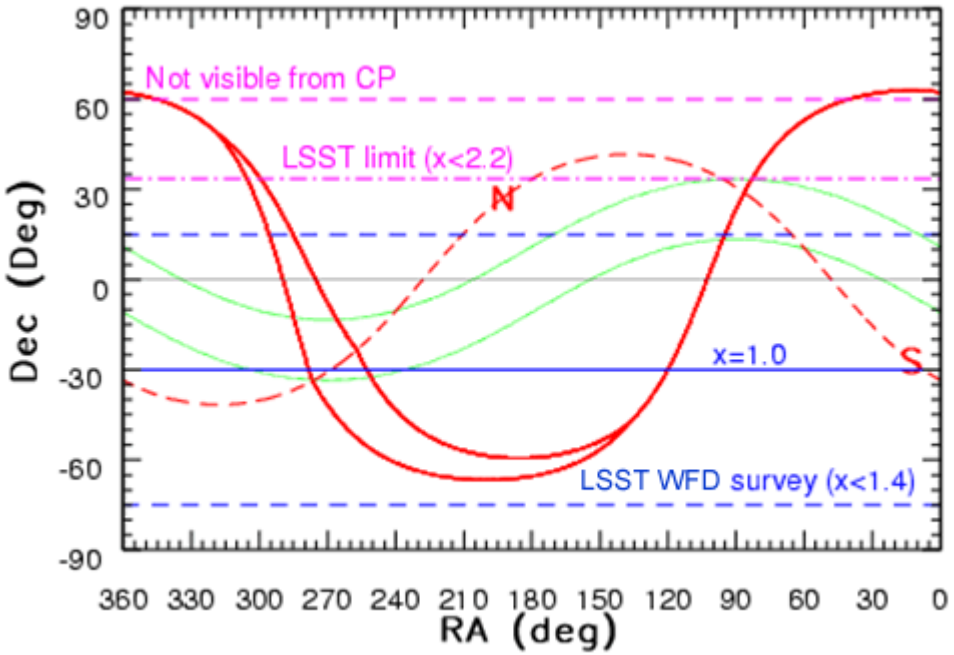
- **IO I**: Infrared (Y, J, H) imager. 6X6' FOV
- **SPRAT**: R~500 spectrograph

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

Site

- LSST follow-up a motivation for the LT2 project from the start, so initially we were inclined towards a southern site
- As we progressed it became clear that our science case doesn't obviously favour one hemisphere over the other
- At this stage our preferred site is La Palma, and we are developing this option in close collaboration with the IAC
- LSST wide-fast-deep survey will cover the sky up to +15 in dec, so northern telescopes will still have a significant follow-up role



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

Supernovae

- 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)

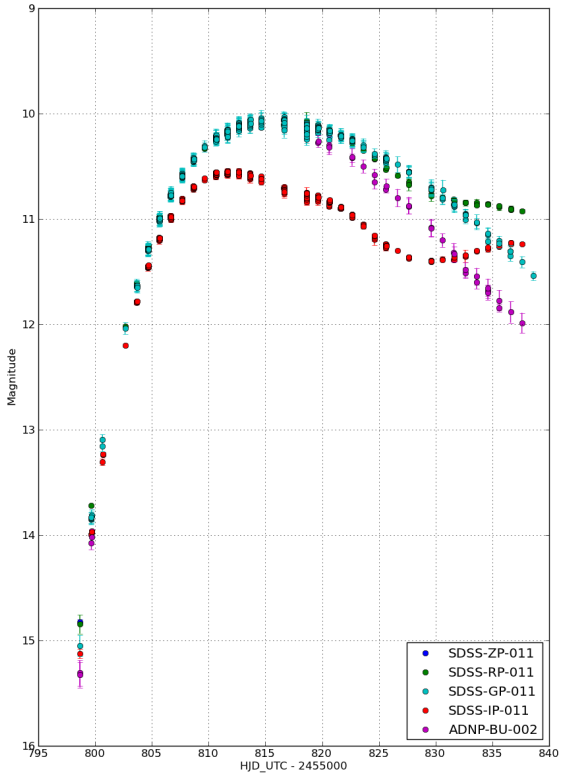
- Will not provide
  - Spectroscopy (low R for classification, intermediate R for most science)
  - Photometry optimised to the SN light curve: LSST 3-4 days between visits (even longer for same filter)
  - High cadence observations at early time and over peak

Transient spectroscopy

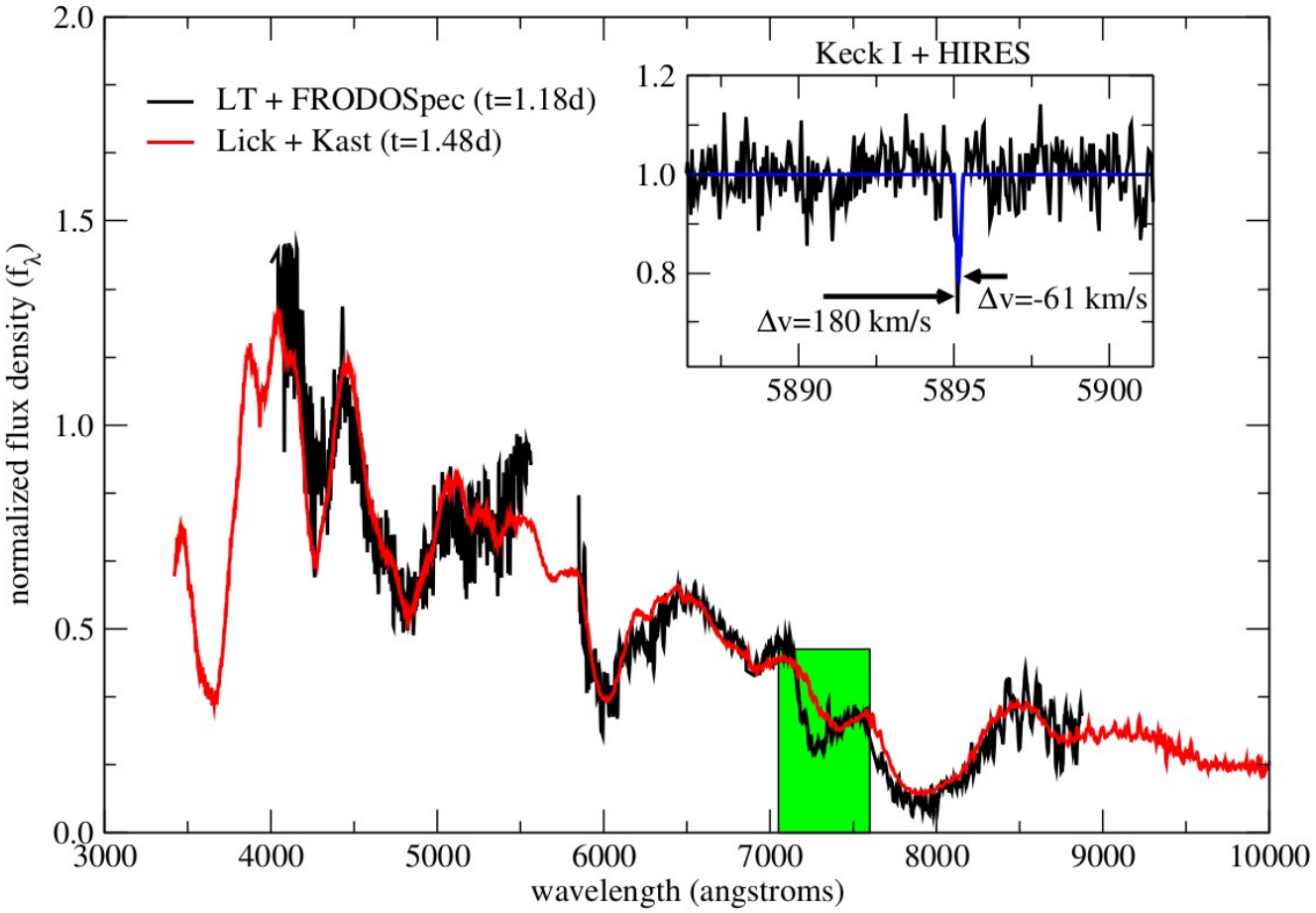
- Current synoptic surveys such as PTF provide large numbers of transients detected at early times
- Spectroscopic follow-up is the bottleneck
  - Only ~10% of PTF detections get a spectral classification
- The need for flexible spectroscopic follow-up will become even more acute in the LSST era

- 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)

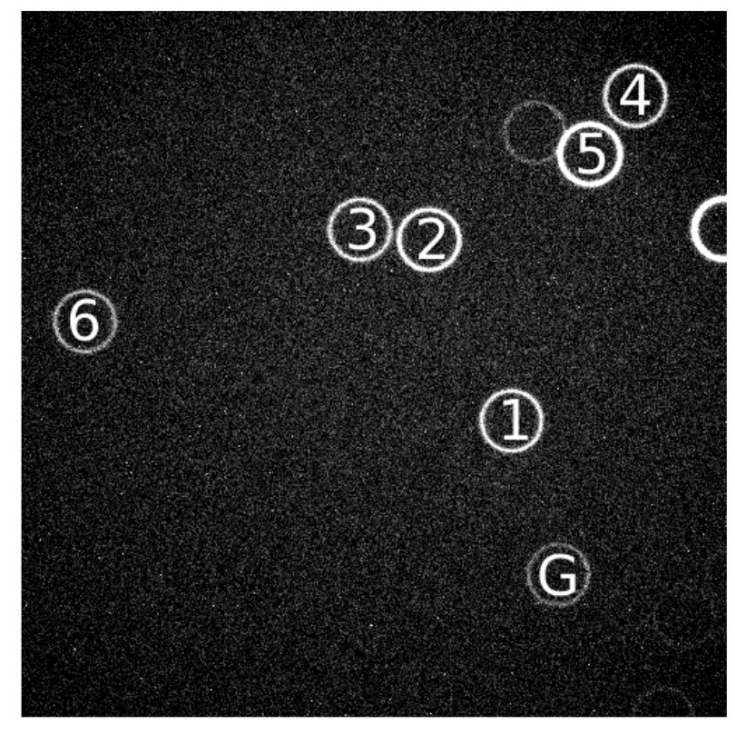
Fast-fading transients

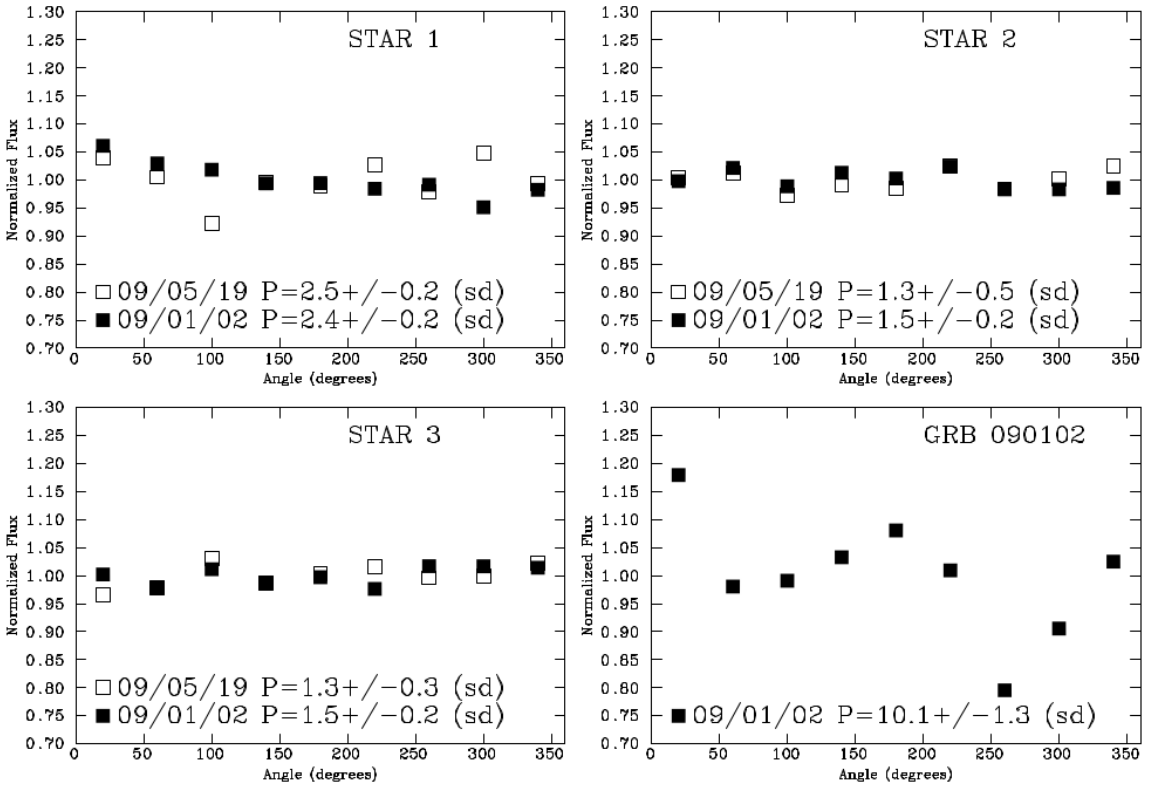
- GRB science an LT strength due to rapid response capability.
- GRB science 2020 for 4m class facilities:
    - Low to intermediate z bursts
    - GRB-supernova associations
    - Prompt phase – particle acceleration, radiation processes, internal shocks
    - Short GRBs – nature of the binary merger components
- Instrument: perhaps a multiband imager like GROND. Opt/IR for SED. Polarimetry?

- Will require a Swift successor like SVOM to provide triggers
- Or detection of orphan afterglows with LSST?

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)

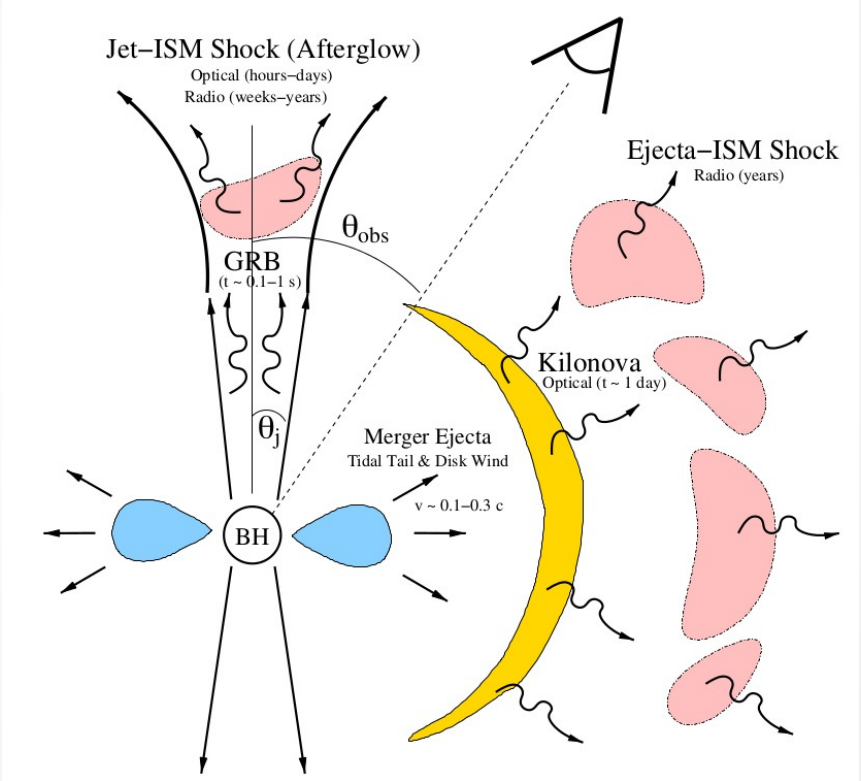
Variability across the EM spectrum

- **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

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)

Telescope Design: key drivers

- Clear aperture of at least 4 metres diameter should give us more targets than we can cope with in the LSST era

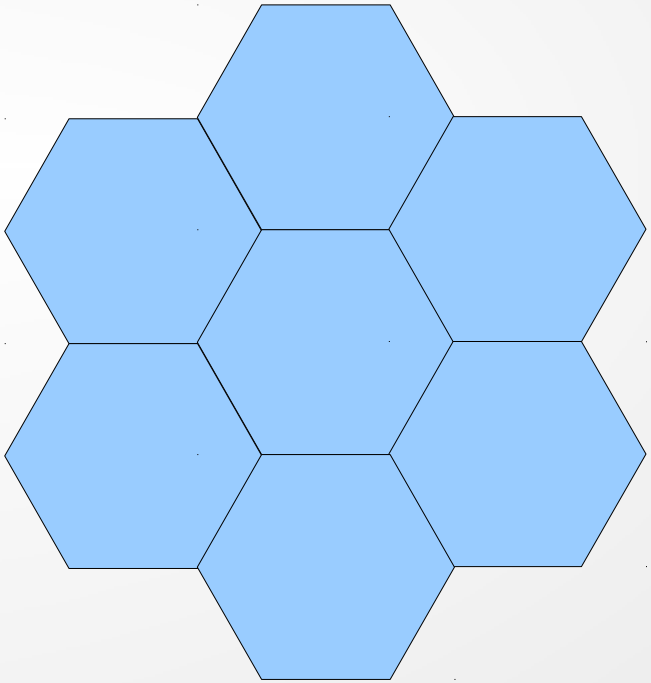
- Main instrument will be an intermediate dispersion spectrograph (R<10,000), optical/ infrared to at least 2 micron
- Focal stations for at least five instruments

- Average target acquisition 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

Telescope Design: flexible aspects

- Focal ratio between f/4 and f/10
  - Acceptable plate scale for spectrograph over this range
- FoV > 15' diameter
  - Our science doesn't require wide field imaging or MOS
- Segmented primary? Potentially much lighter!
- Phasing a segmented mirror is difficult (costly)
- If spectroscopy is our focus, then perhaps we can compromise a bit on image quality
- Optimise IQ to site median seeing (~0.8")?



- Preliminary optical design studies currently underway, results before end of year

Novel instrumentation

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

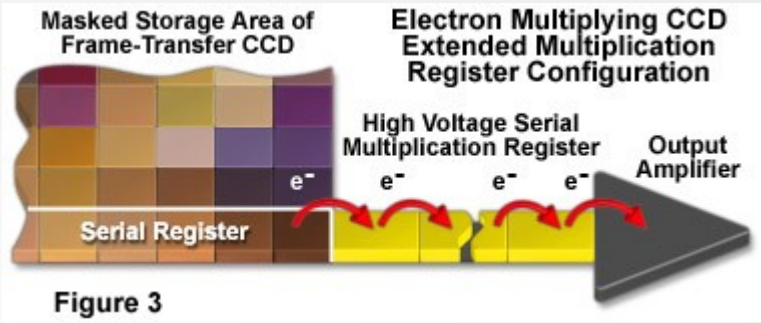


Figure 3

- 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