Transient follow-up with the Liverpool Telescope

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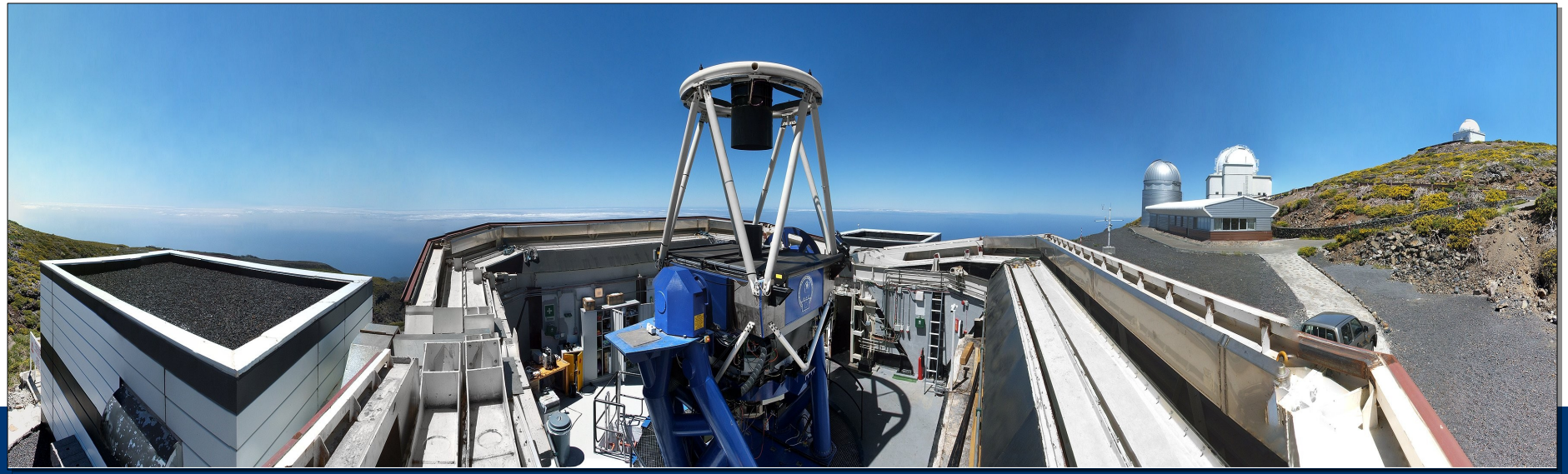
Liverpool Telescope group:
Robert Barnsley, Stuart Bates, Neil Clay, Jon Marchant, Chris Mottram, Helen Jermak, Andrzej Piascik, Robert Smith, Iain Steele

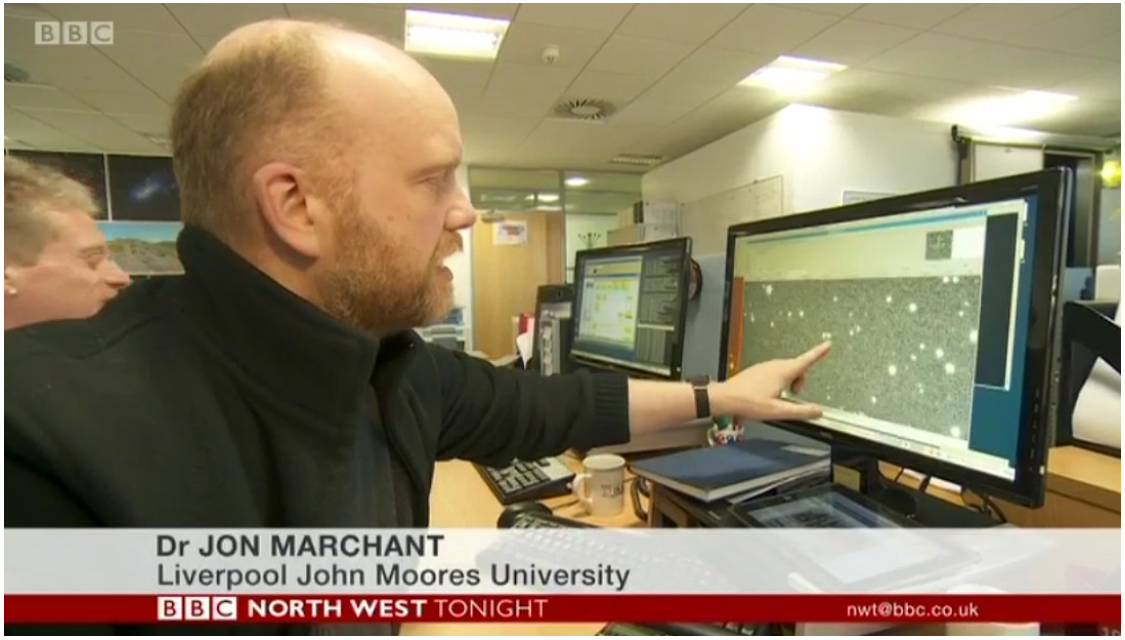
2-metre fully robotic telescope located at the ORM on La Palma

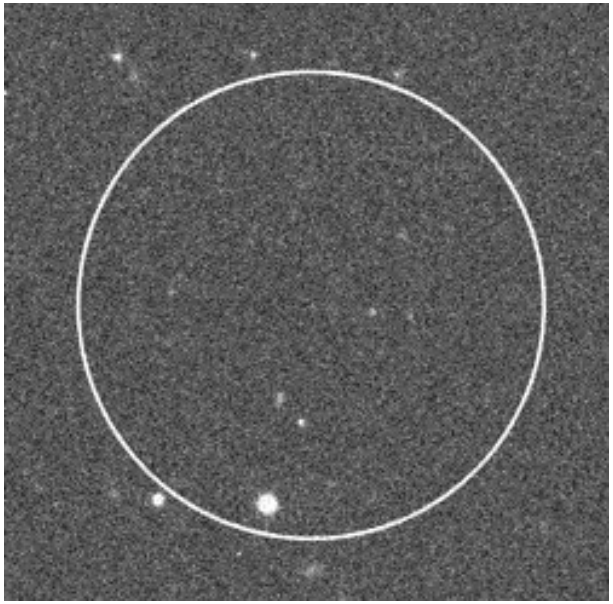


Common-user facility

- In semester 2016A (Jan - Aug):
  - 280 hours for internal use by Liverpool JMU staff
  - 280 hours available for UK users through PATT
  - 150 hours for Spanish users through CAT
  - 50 hours CCI international time
  - Up to 50 hours OPTICON
  - 150 hours for education via National Schools Observatory (http://www.schoolsobservatory.org.uk)
  - 90 hours pre-purchased by individual projects (e.g. Gaia tracking)

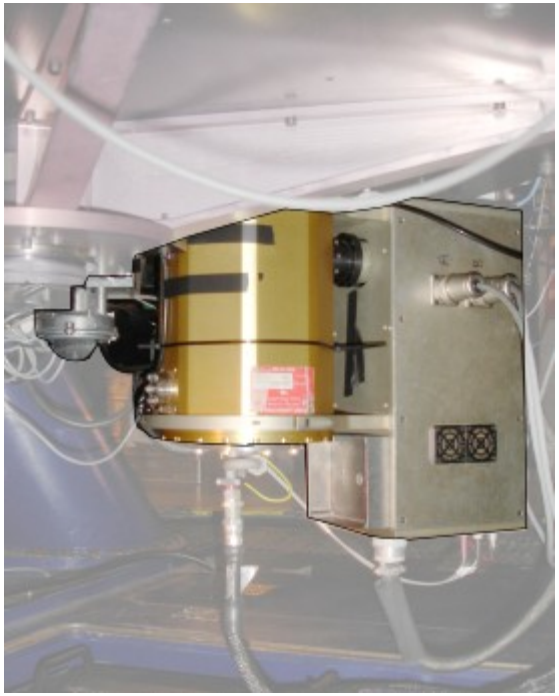
Gaia tracking





Gaia is imaged by the LT ~nightly in order to precisely determine its position, which informs the astrometric calculations

LT Instruments

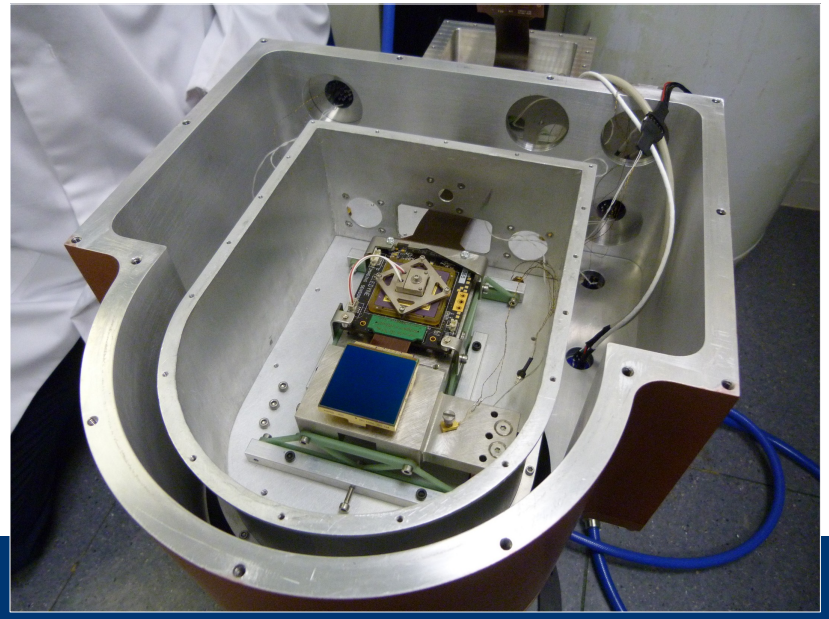


IO:I (near-IR)

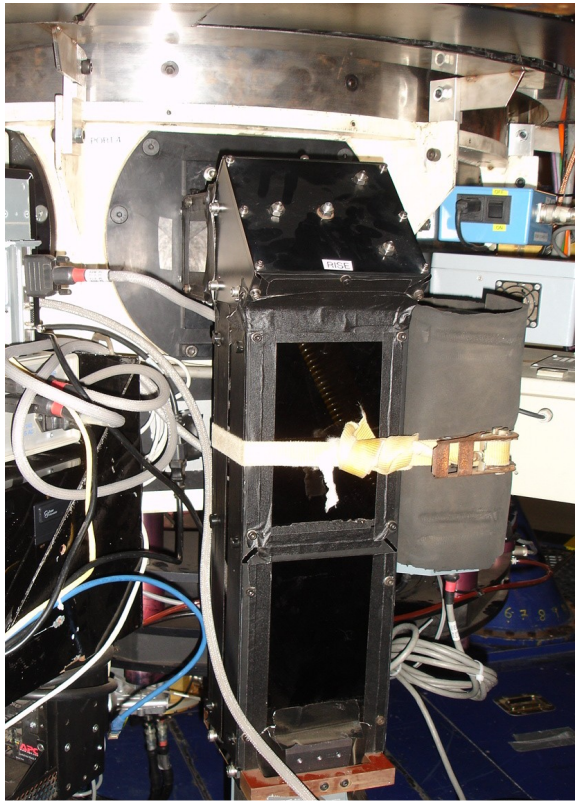
- 2048 x 2048 Hawaii-2RG array (1.7μm cutoff)
- J, **H**, or J+H split ***BUT*** fixed filter (i.e. no filter wheel – would require new cryostat)
- Pixel scale: 0.18 arcsec
- FOV: 6 x 6 arcmin

IO:O (optical)

- *Our work-horse imager*
- 4096 x 4112 pixel e2v CCD
- Filters: u'g'r'i'z' + BV + 5 Hα's
- Pixel scale: 0.15 arcsec
- FOV: 10 x10 arcmin
- Readout time
  - 37 sec (1x1 binning)
  - 13.5 sec (2x2 binning)



LT Instruments

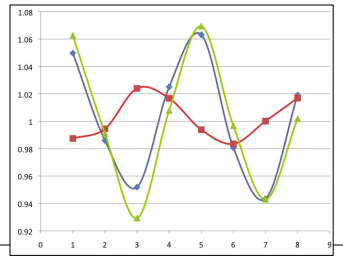


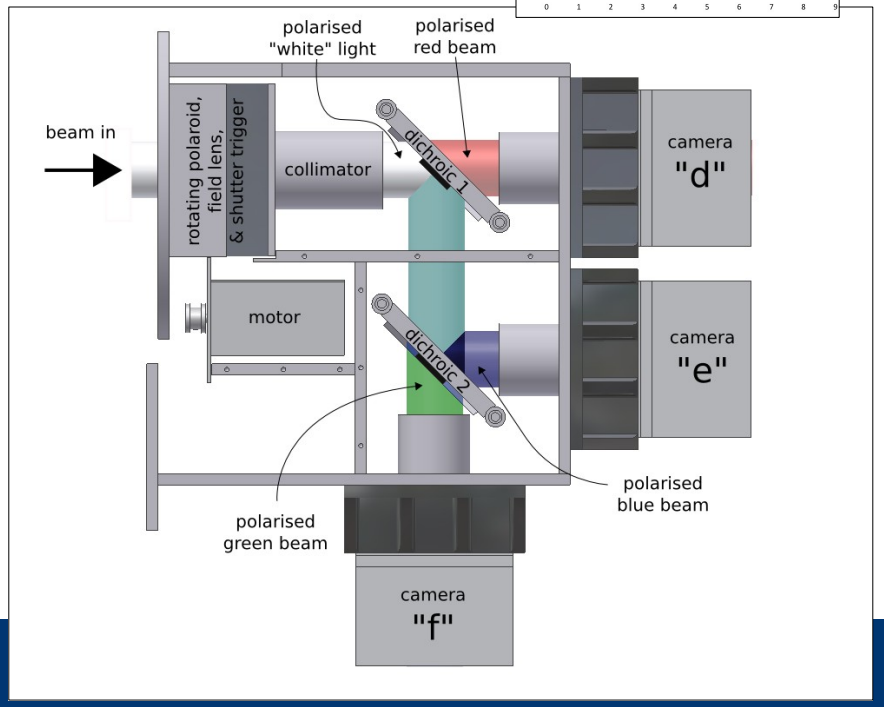
RISE

- 1024x1024 px frame-transfer CCD
- >0.8 sec exposures; no readout overhead
- Fixed "V+R" filter
- Pixel scale: 0.54 arcsec
- FOV: 9.2 x 9.2 arcmin FOV

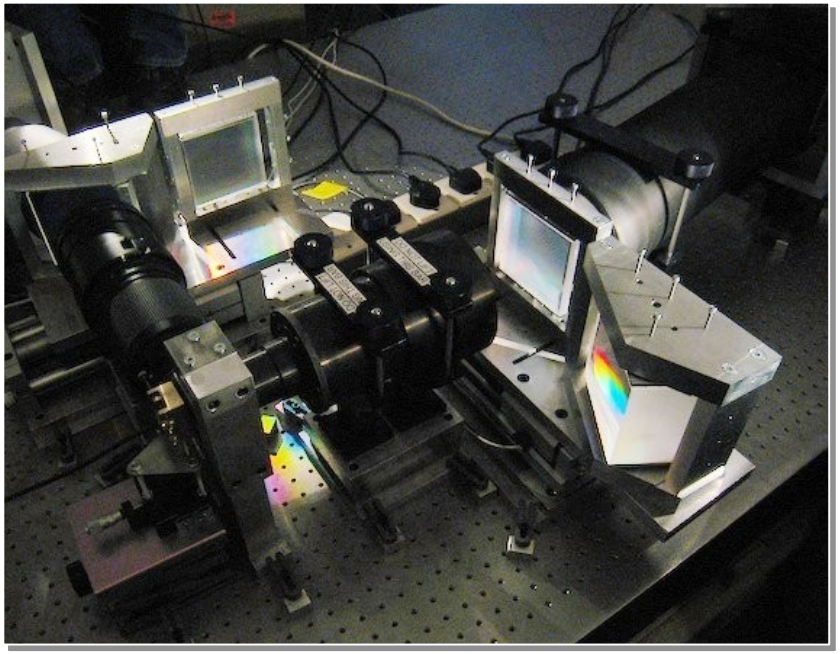
RINGO3 (polarimeter)

- Rotating polaroid; two dichroics
- Three 512x512 pixel EMCCDs
  - Red: 760-1000 nm
  - Green: 650-750 nm
  - Blue: 350-640 nm
- Pixel scale ~0.47 arcsec
- FOV ~ 5 arcmin





LT Instruments



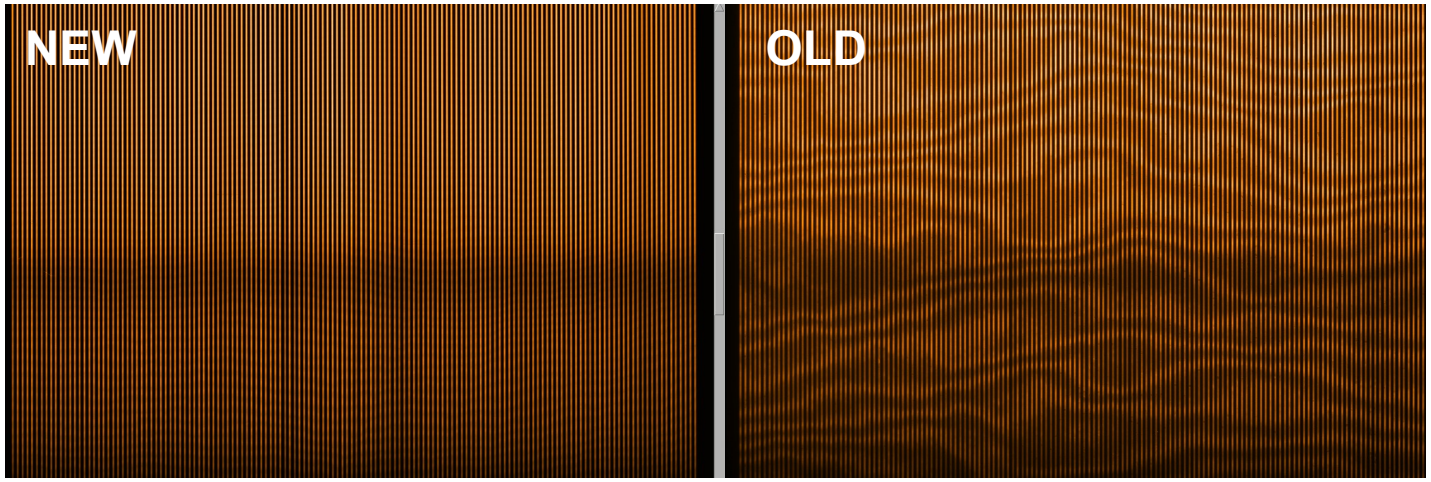
FRODOspec

- Dual-beam fibre-fed IFU
- R~ 2500:
  λ range 390-570 + 580-940 nm
- R~ 5000:
  λ range 390-510 + 580-800 nm
- 12x12 lenslet arrays
- Pixel scale: 0.82 arcsec
- IFU FOV: 9.8 arcsec

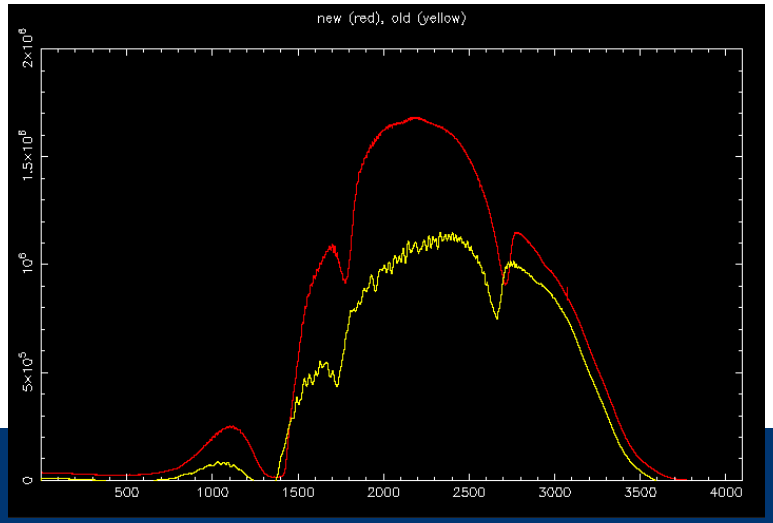
SPRAT

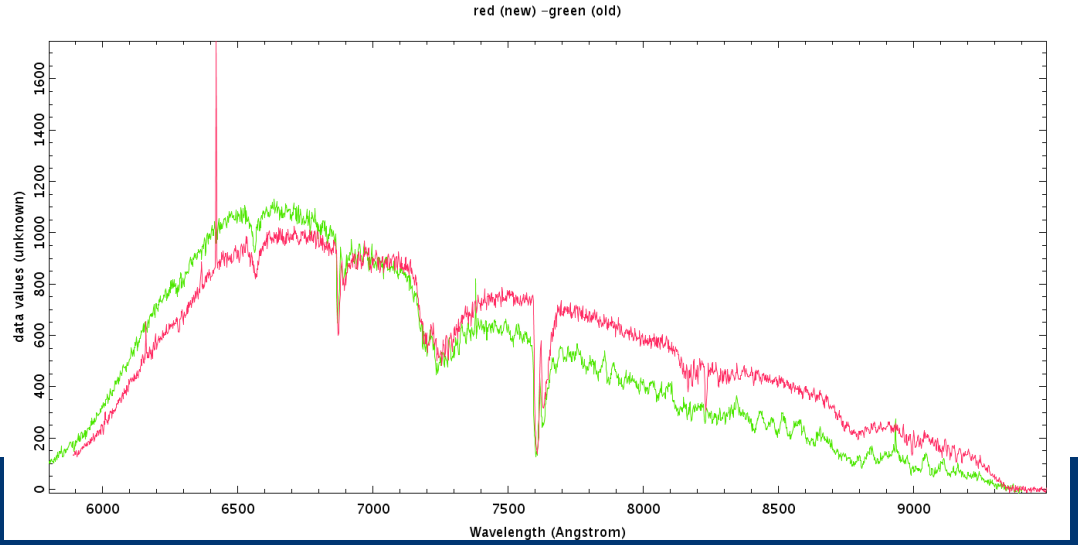
- Long-slit optical spectrometer
- Slit and grism deployable
- R ~ 350; λ range 400-800 nm
- Slit width: 1.8 arcsec
- Pixel scale: 0.44 arcsec
- Acquis. FOV: 7.5 x 1.9 arcmin

FRODOspec red CCD upgrade

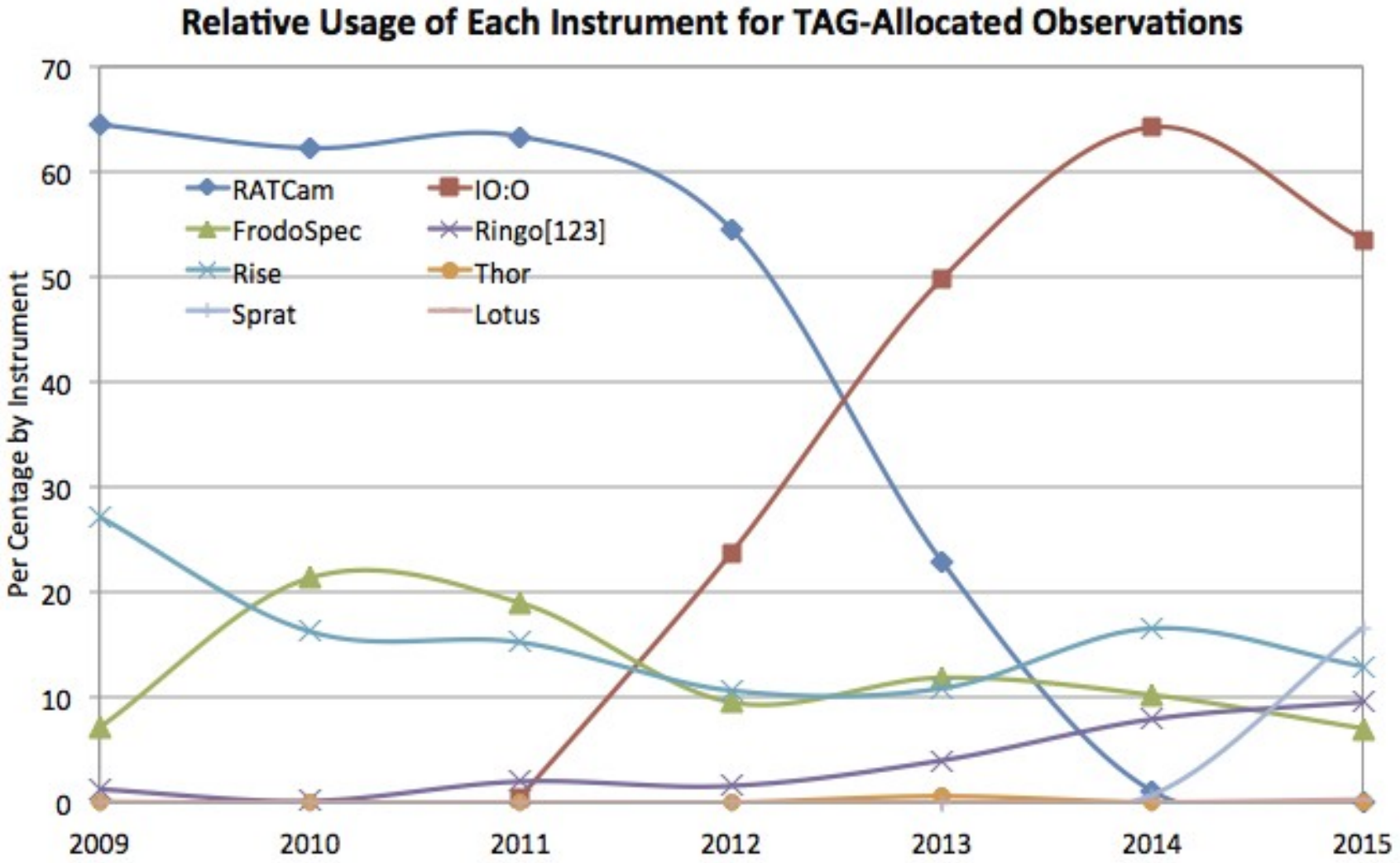


Left: Throughput curves. Right: on-sky comparison of spectrophotometric standard



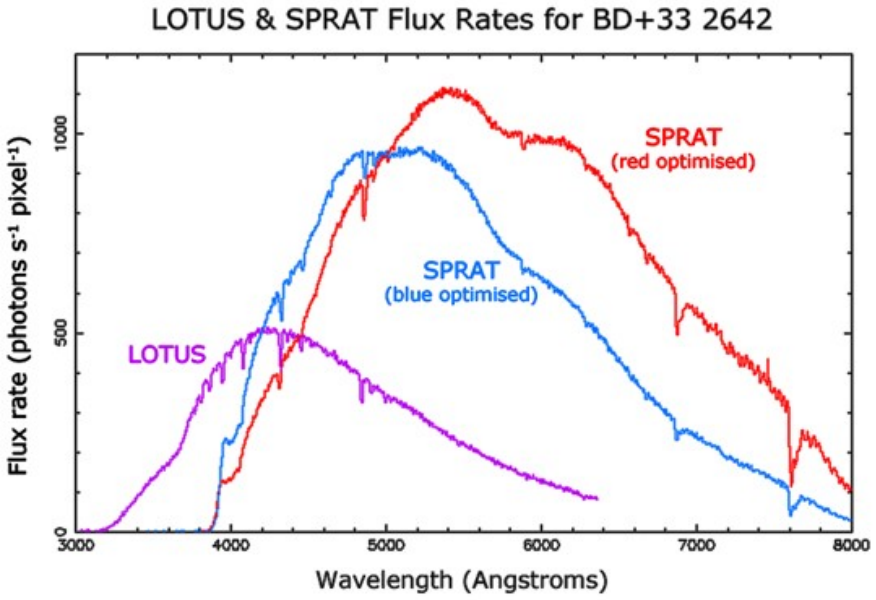


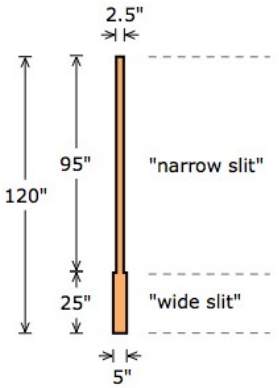
LT Instrumentation: relative usage



LT Instruments

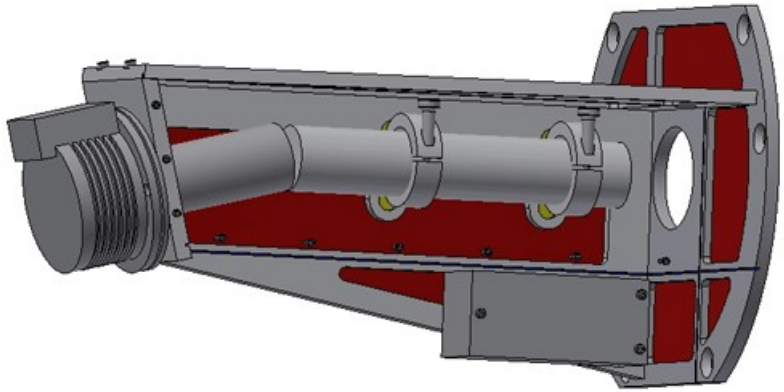
New in semester 2016a...

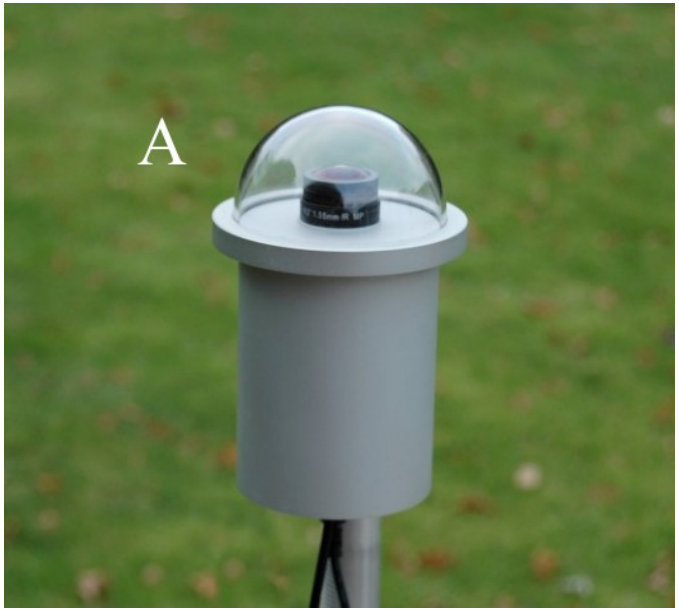




LOTUS

- Low resolution optical- near UV spectrograph
- Very simple, low cost: no moving parts
- R~300: λ range 320 – 630 nm
- 2.5" and 5" slit widths
- Pixel scale: 0.6 arcsec





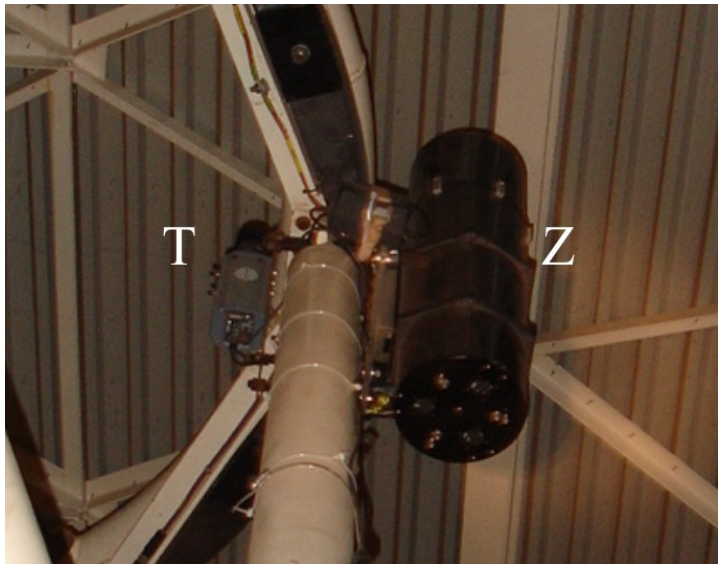
LT Instrumentation

Skycams

- **Skycam-A:** Oculus all-sky camera with a fisheye lens; stars down to ~6th mag
- **Skycam-T:** Medium field – 85 mm lens; 9º field; 32” pixels; down to ~13-14th mag
- **Skycam-Z:** Zoomed – Orion optics AG8 telescope; 1º field; 3”/pixel; down to ~18th mag

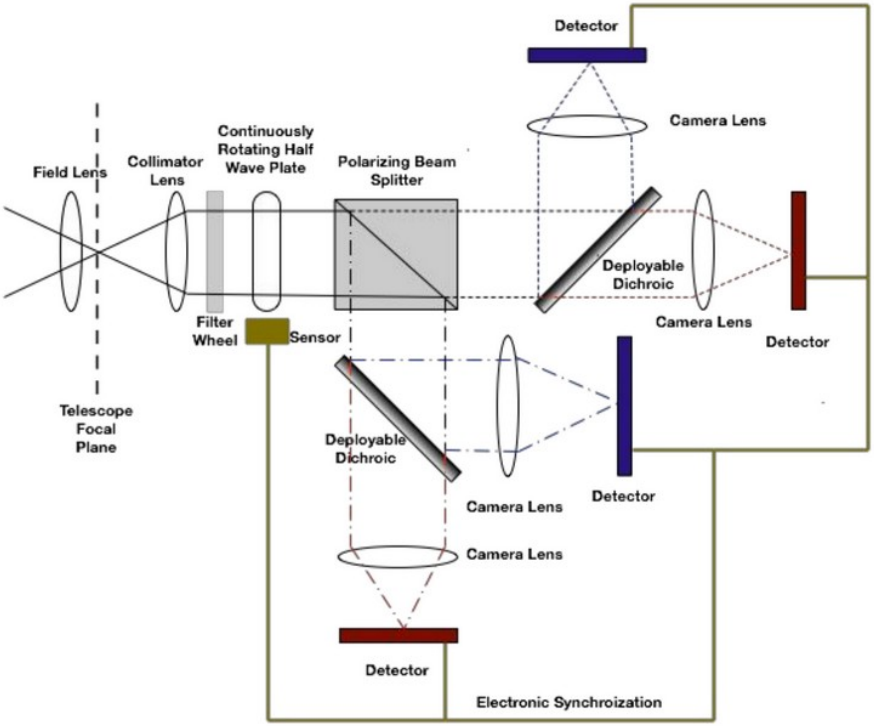
- **Skycams T and Z:** Andor ikon-M DU934N-BV
- No filters; CCD QE from ~400-800 nm

- Huge database of wide field data, available to users



Proposed instrumentation: MOPTOP

- A Multiwavelength OPTimized Optical Polarimeter for time domain astrophysics
- Application for funding submitted to RS Paul Instrument Fund for start 04/2016



- Fast rotating element for high time resolution
- Deployable dichroics for simultaneous measurement in two colours
- Dual-camera configuration: 's' and 'p' polarization states on separate cameras to minimize systematic errors and provide highest possible sensitivity
- 1% polarization accuracy for V=18.5 over full 8' FoV
- sCMOS detectors: rapid readout, low read noise, higher sensitivity than EMCCDs

Proposed instrumentation: RISE3

- RISE3 – a 3-colour rapid-readout instrument for transits, occultations and possibly GRBs. RINGO3-like design with dichroics and three CCD cameras

- *Poll of users:*
  - Multi-camera affair preferred to filter wheel – likely to be more stable, and affords simultaneous photometry (GRBs?)
  - Field of view important: would be limited to about 13 arcmin by tertiary mirror (though this could be replaced).
  - PSF and thus pixel scale/sampling not important: most users will defocus to minimise flat-fielding errors.
  - Super-fast frame rate not vital: roughly 1 image/second probably good enough for most users.
  - Zero dead time a must.

- If MOPTOP proposal is successful, RINGO3 EMCCD detectors could be repurposed for this project, significantly reducing the cost

Robotic Control System

Scheduler decision-making based on:

1. Proposal science priority (A, B or C).
2. Repeat observations have a higher priority than one-off observations.
3. Urgent observations have a higher priority.
4. Ratio of current elevation versus highest possible elevation that night.
5. Matching of actual (seeing/lunar) conditions to those requested (*night is designated photometric or non-photometric at start by duty officer*).

Calibrations:

- Standards:
  - Observed every ~3 hours; sets for *photometric* and *non-photometric*
  - **Spectrophotometric standards with all three spectrographs**
  - Background standards used for monitoring when *no science groups available (rare).*
- Twilight flats obtained most mornings/evenings.

RTML submission of observations (ToO)

RTML – form of XML; allows users to communicate directly with software running on the telescope

One Way:

- only allow details of an observing request (RA, Dec, filter, texp) to be sent to the telescope via an RTML message from the user.

Two Way:

- upload observing request but also send back info to the user, e.g. observation complete, data available at this URL, etc.

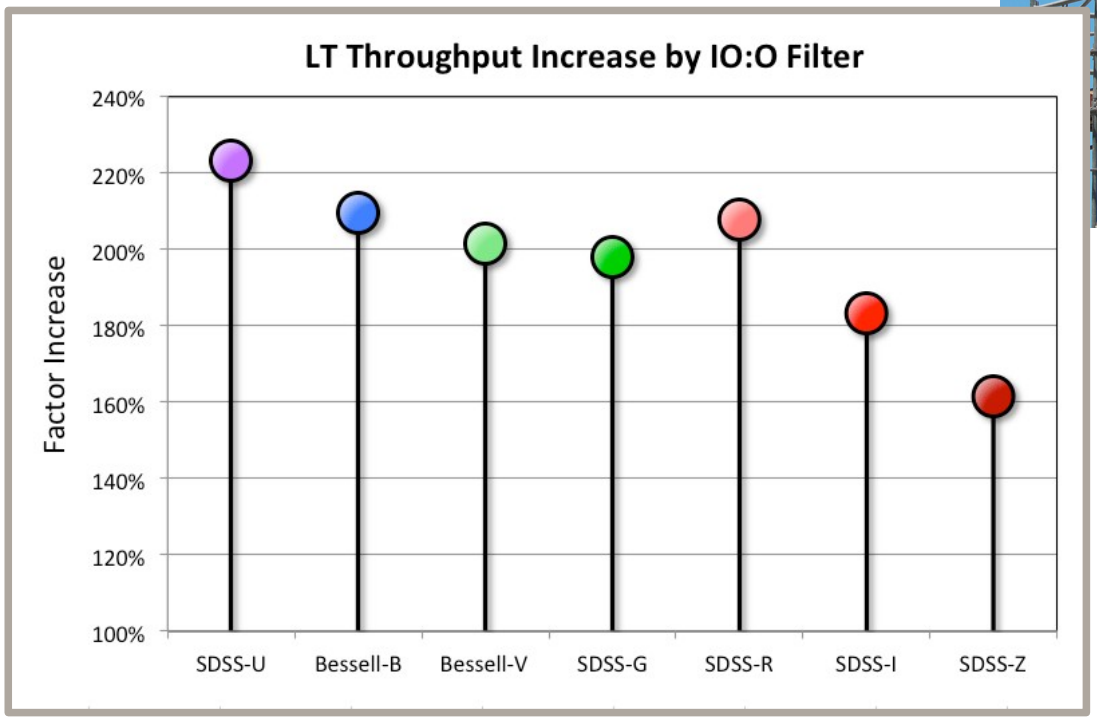
Currently, we either supply users with a command line utility or we set up a (bespoke) web page for them to fill in. Both allow the user to send RTML messages to the Telescope Node Agent (TEA).

Two flavours of RTML submission:

- ***Immediate override*** – e.g. GRBs
- ***Load into Telescope Phase2*** – e.g. Microlensing.

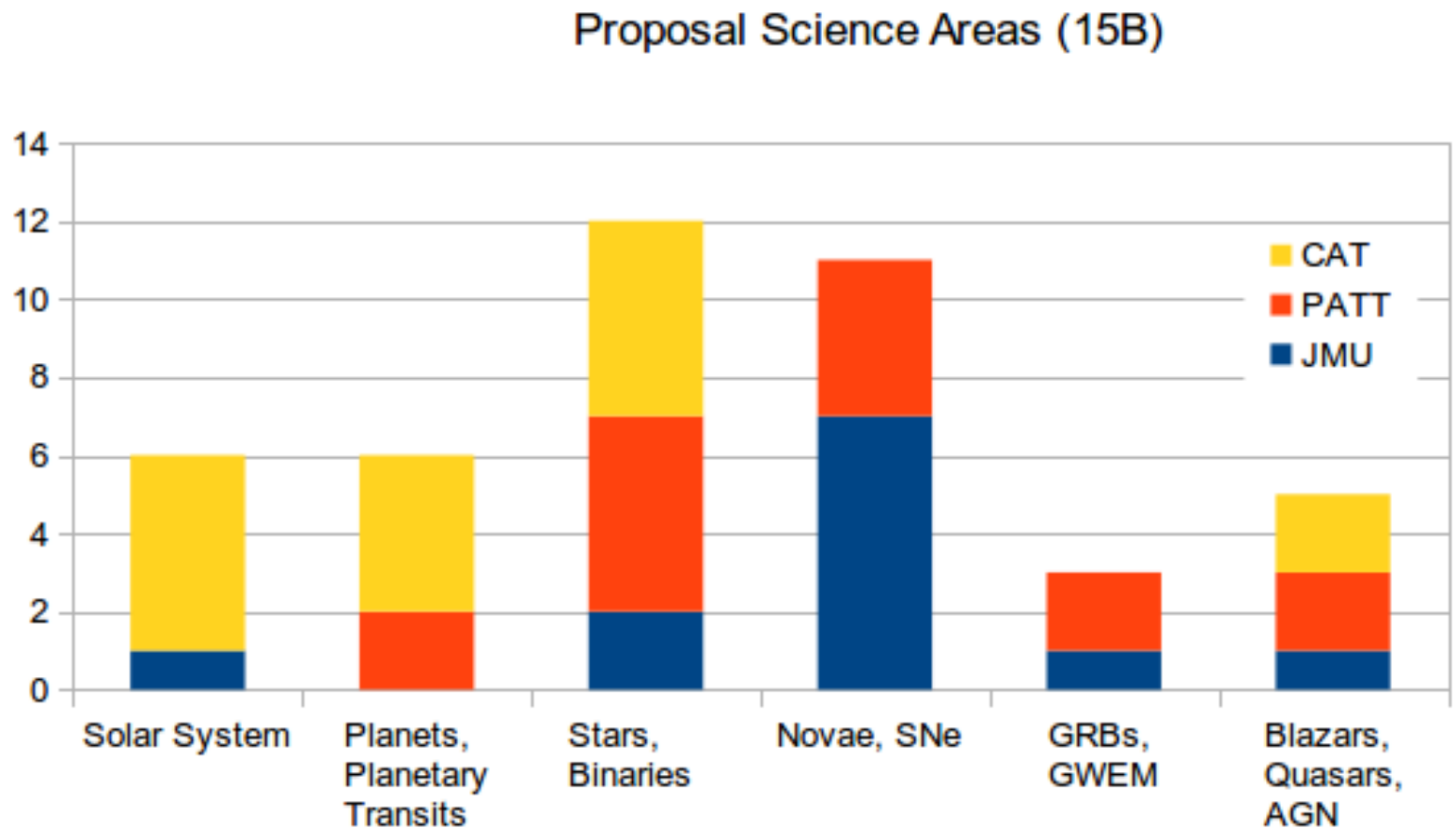
Mirrors realuminised this summer

- Primary, secondary and Skycam-Z mirrors all recoated using ING facilities
- First time the secondary has been treated: originally coated with a protective silicate layer which was difficult to remove safely
- The man who applied the layer (David Jackson, retired) was flown out to remove it!



Remarkable throughput increase, particularly at the blue end

Proposals by science area (15B)

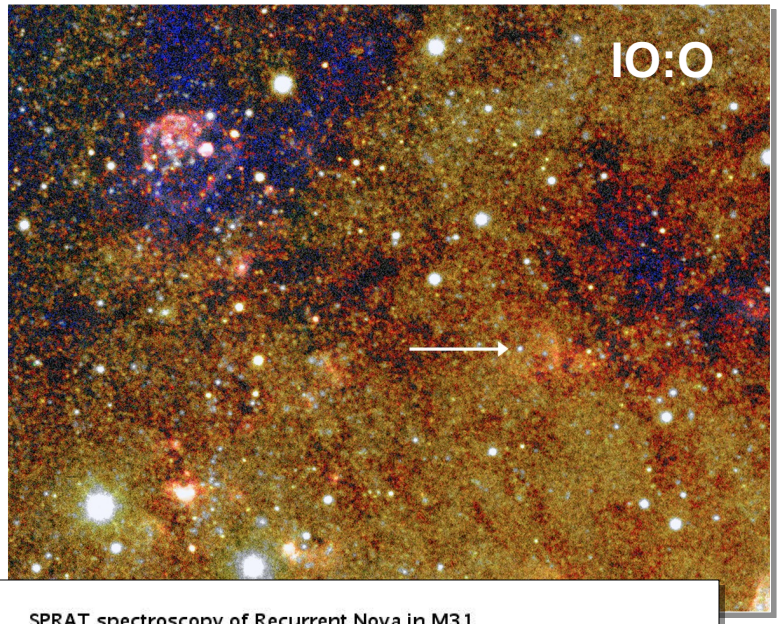


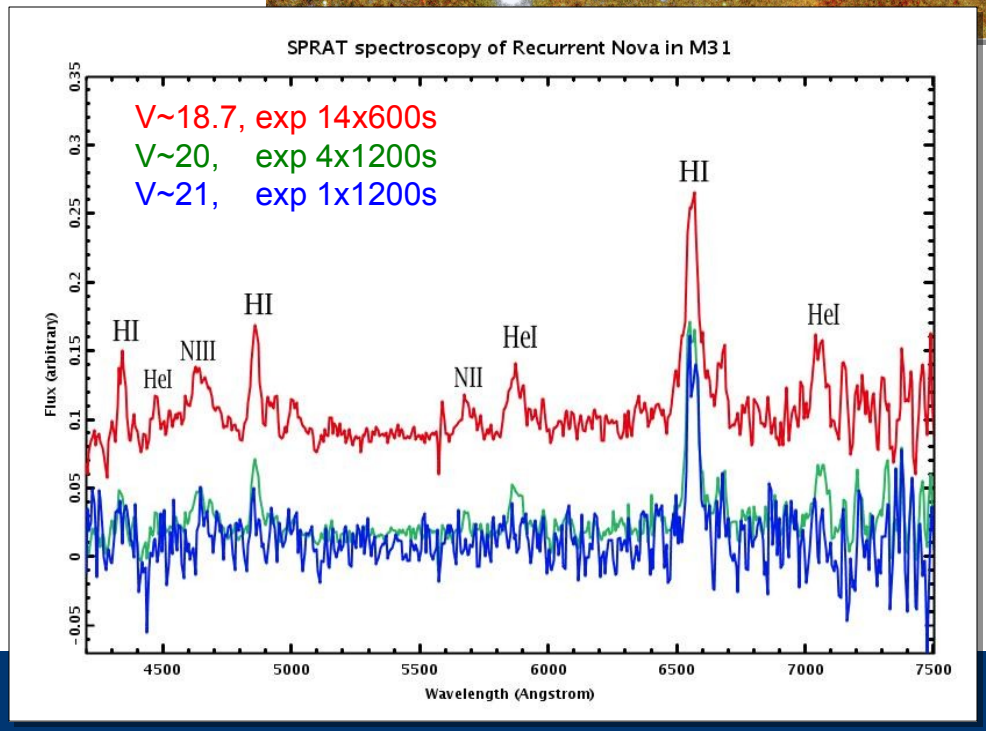
LT Science

A Recurrent Nova in M31

(Darnley, Williams, Bode et al. 2014)

- **LT being used to monitor a recurrent nova with an unprecedented 1 year inter-eruption timescale** (is typically 10-100 yrs)
- Discovered in 2008; White dwarf + Red Giant/Super Giant binary..
- *Outburst on 2nd Oct. 2014 discovered at the LT!*





TOP: Multi-colour imaging with IO:O. BOTTOM: Follow-up spectroscopy with SPRAT on 3rd, 4th, 5th Oct 2014 showing the tell-tale H, He and N lines of a 'He/N' nova in eruption

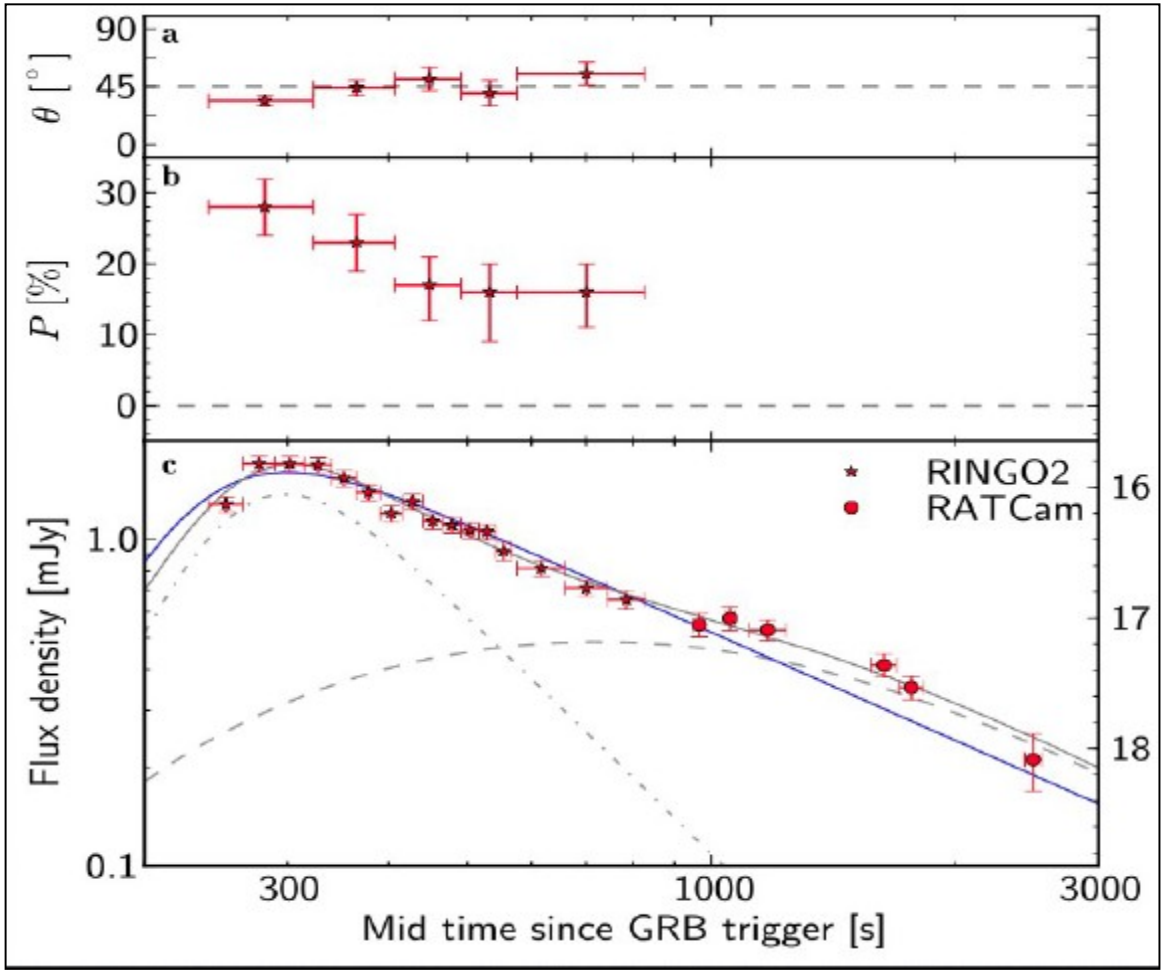
LT Science

GRB Monitoring - Polarisation

(Mundell, Kopac, Arnold et al. 2013, Nature)

- Rapid decrease in flux accompanied by decrease in polarisation *BUT* – polarisation angle remains constant implying stable magnetic field surrounding GRB jet.

- *Rapid-response polarimetry monitoring of GRBs continues…*



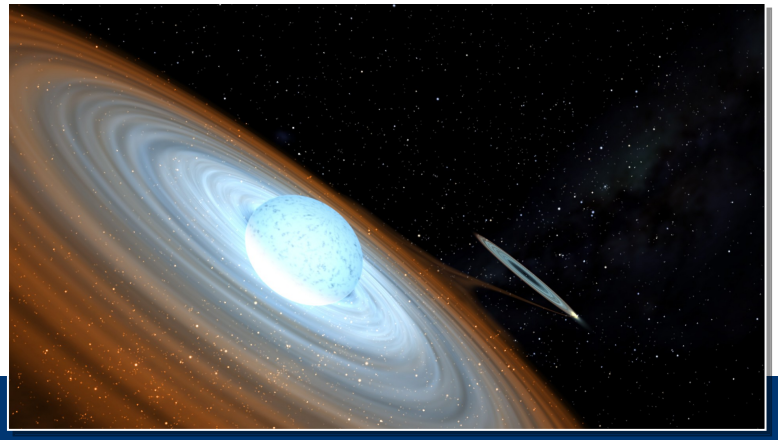
TOP: Polarisation position angle.
MIDDLE: Percentage Polarisation.
BOTTOM: Flux density.

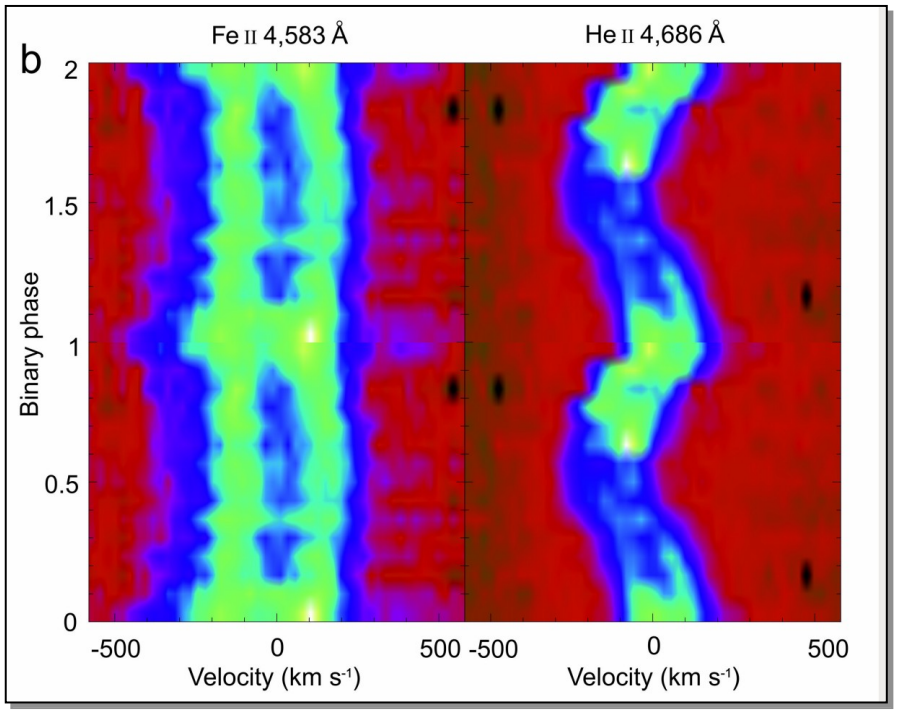
LT Science

BE/Black Hole binary system discovered with FRODOspec

(Caseres et al. 2014, Nature)

- Spectroscopic monitoring and modelling indicates the companion of the Be star is a 3.8-6.9 solar mass Black Hole.
- Be-star companion usually a neutron star; first time a BH has been observed in such a system

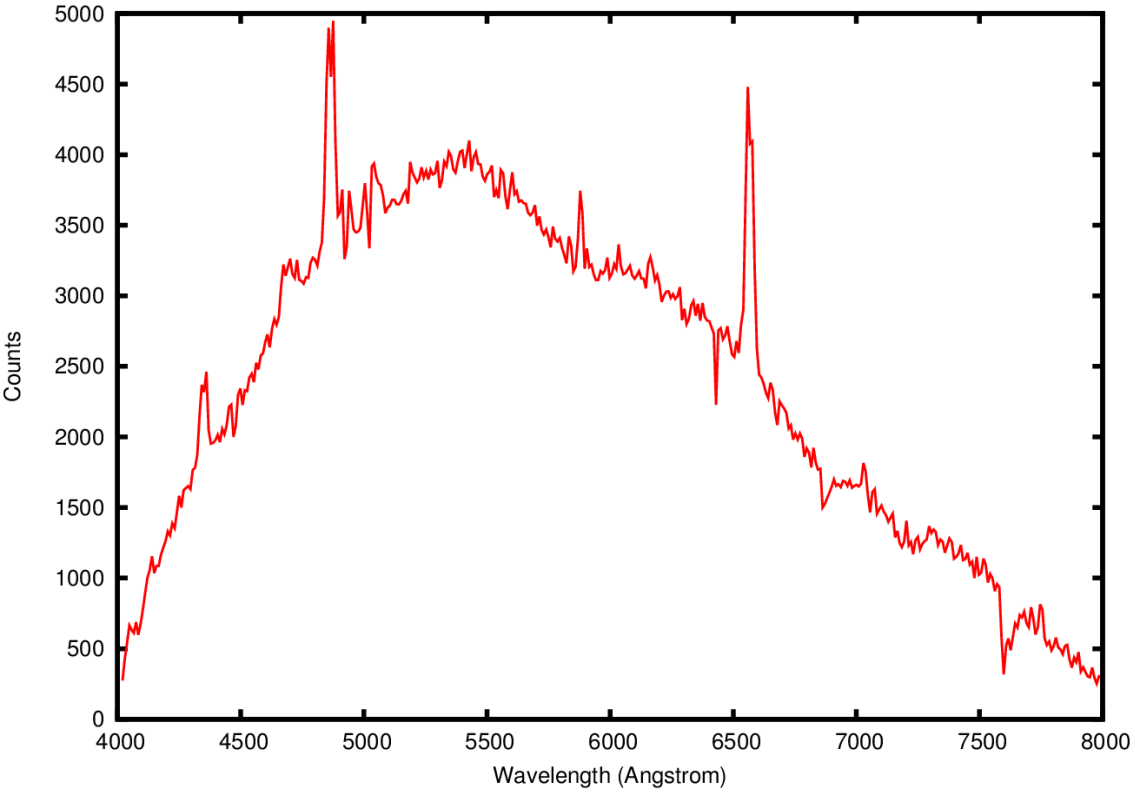




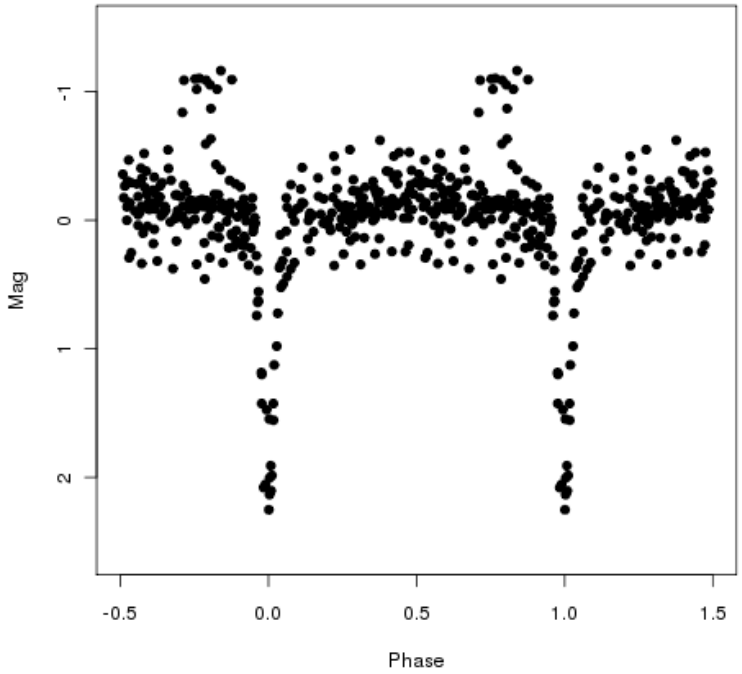
ABOVE: Trailed intensity images showing orbital evolution of emission lines through two orbital cycles.

Transient follow-up: CVs

e.g. ASAS-SN15nv



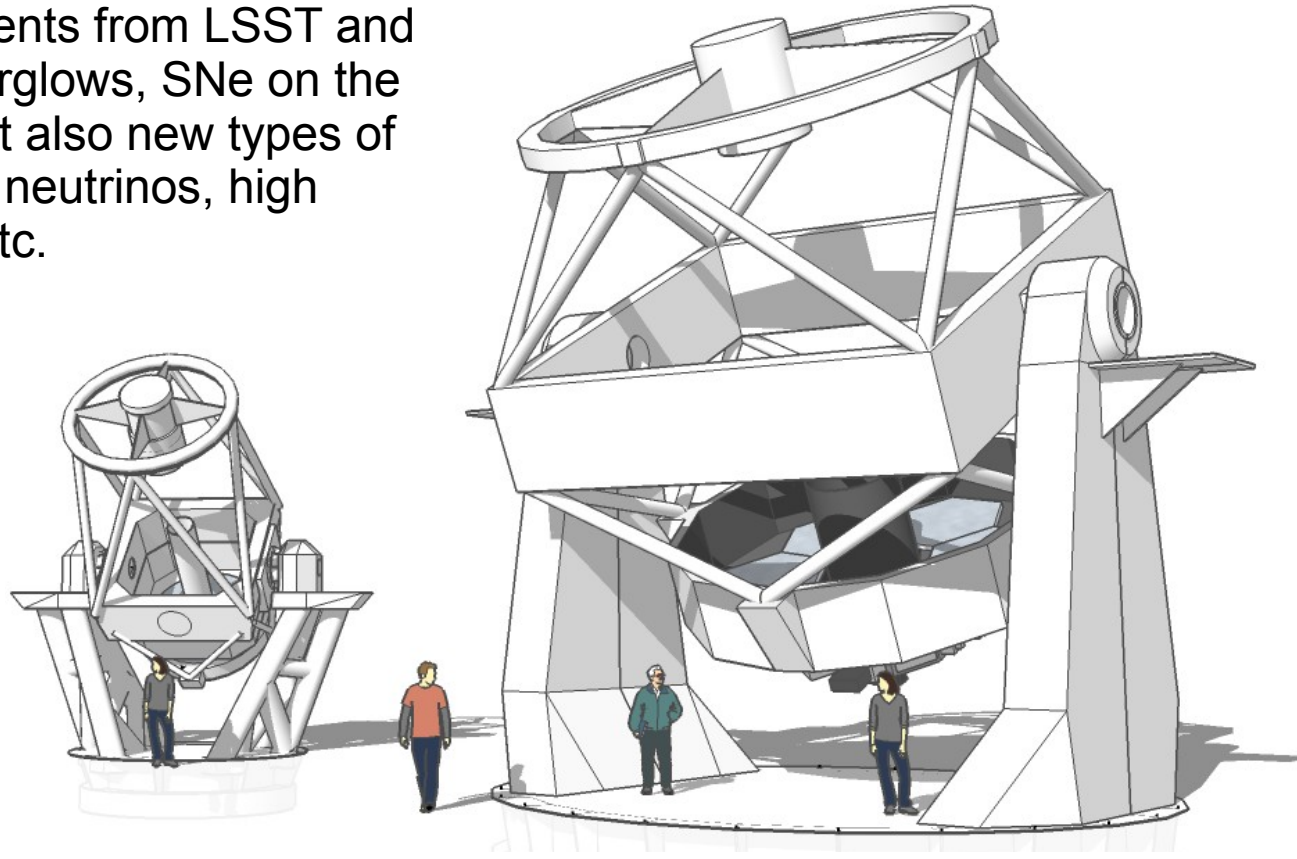
1500s SPRAT spectrum of V~17.5 object
showing characteristic double-peaked lines of H-rich CV



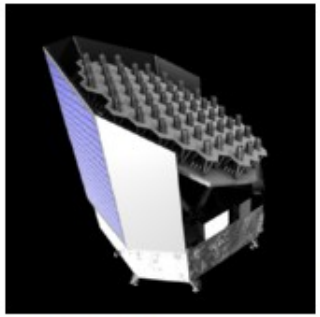
Eclipse lightcurve from
vsnet-alert 18954

The Future: Liverpool Telescope 2

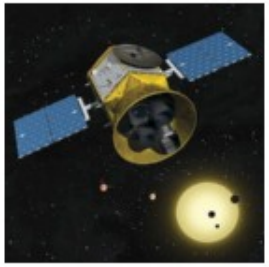
- 4 metre optical telescope; commissioning in early 2020s; sited in La Palma
- Rapid follow up of transients from LSST and other facilities; GRB afterglows, SNe on the rise, exoplanets, etc., but also new types of transients: GW sources, neutrinos, high energy (CTA) sources, etc.



The right time for a new follow-up telescope

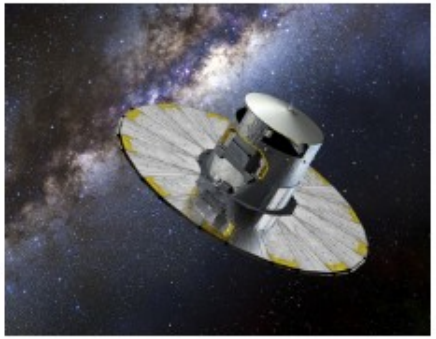


PLATO: launch 2022



TESS: launch 2017

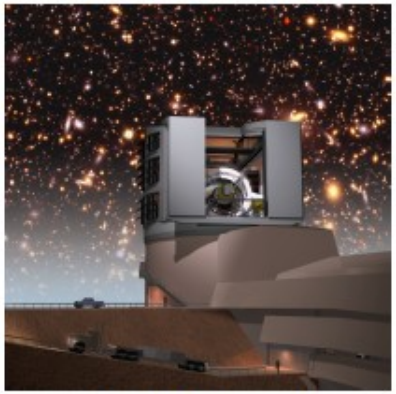
SVOM: launch 2021



Gaia catalogue published 2020

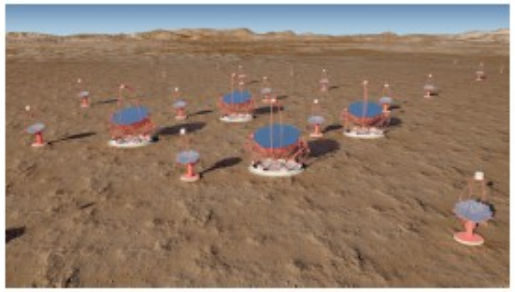
ALIGO/aVirgo full sensitivity 2022

LT2 (~2020)



LSST: science first light 2021

CTA completed ~2023



SKA phase 1 completed 2020

Summary

- The LT is a world-leading facility for time domain science
  - Flexible scheduling capability
  - Diverse instrument suite

- Telescope time available for UK and international users
- http://telescope.livjm.ac.uk
- http://www.facebook.com/liverpooltelescope

- LT2 is designed to be a major follow-up facility for the LSST era
  - Serious design work currently underway
  - Total cost ~ €23M
  - 10 per cent of project cost already obtained from Canarian government
  - Currently a partnership between IAC and LJMU: we welcome discussion with other potentially interested parties

- http://telescope.livjm.ac.uk/lt2/