Time Domain Astronomy with the Liverpool Telescope

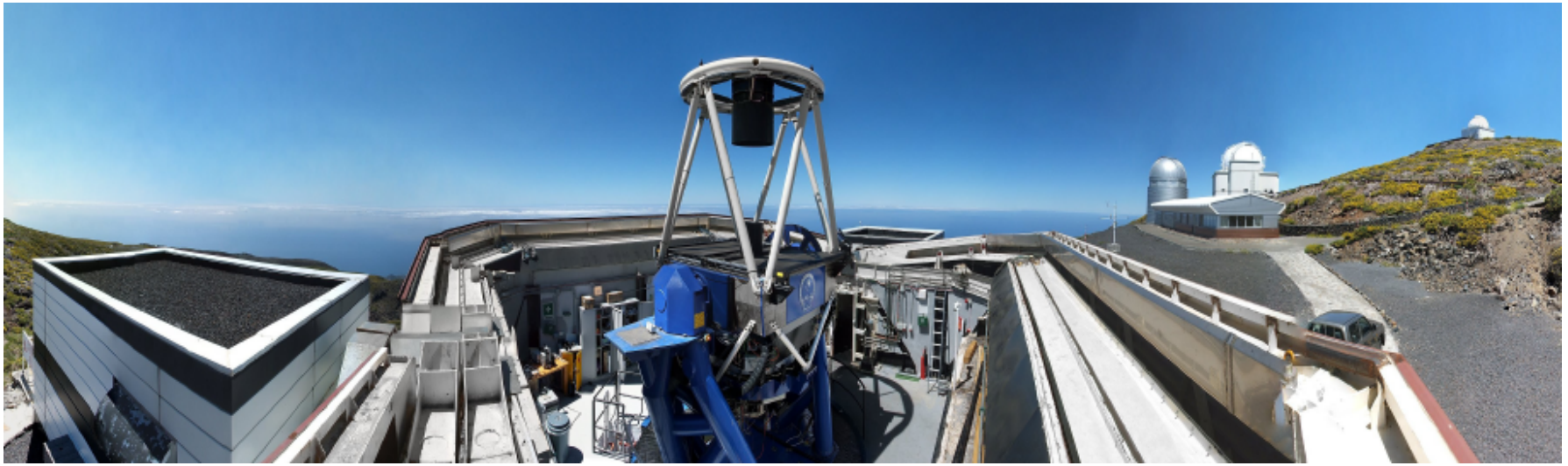
LIVERPOOL JOHN MOORES UNIVERSITY

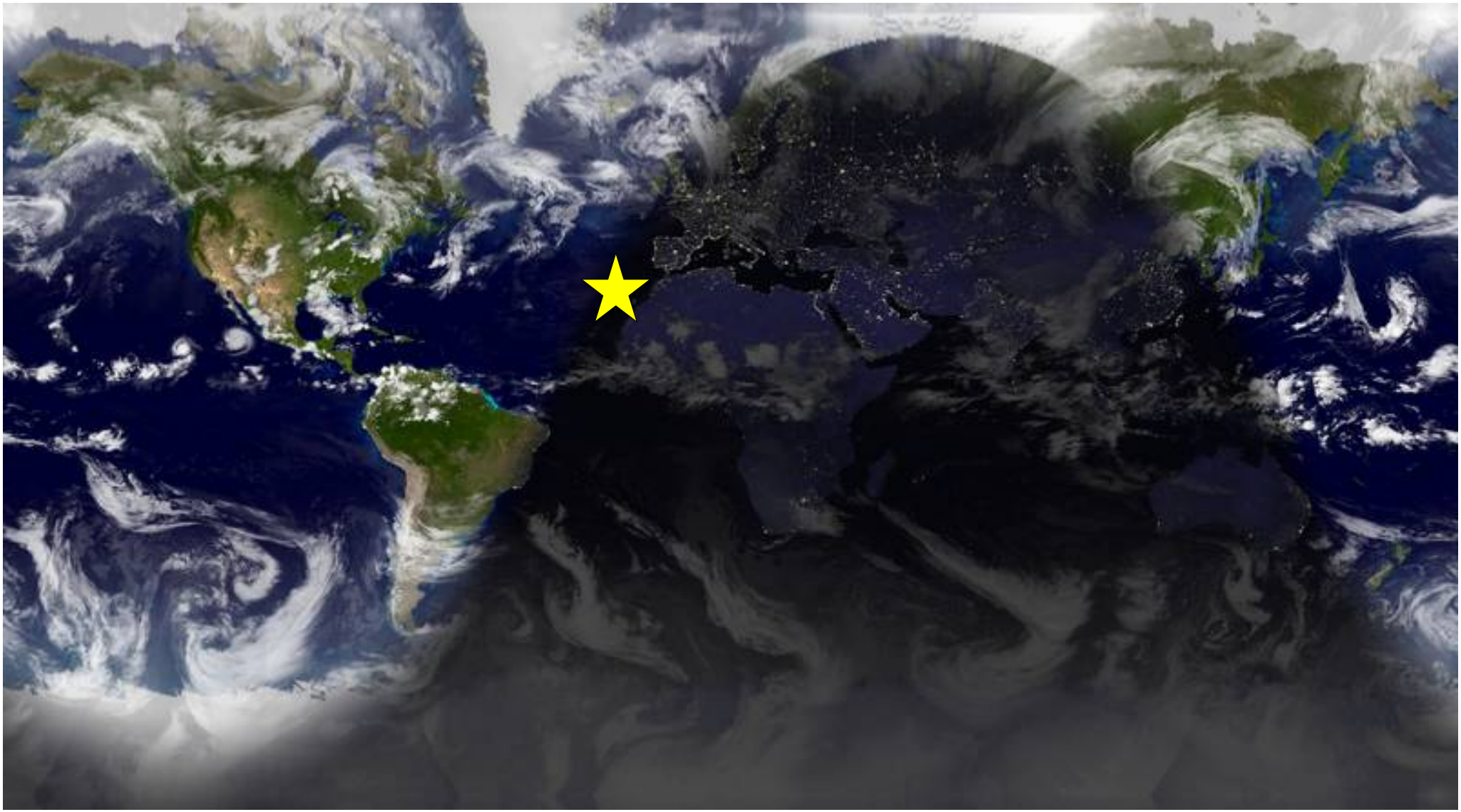
Daniel Perley

(on behalf of Chris Copperwheat and the LJMU LT team)

Introduction

2-meter fully robotic telescope located on La Palma (Canary Islands)





Introduction

Operations started 2004

Common user facility, operated by Liverpool John Moores University (UK)

Observing time shared between LJMU and supporting partners:

- 280 hours for internal LJMU users
- 280 hours for general UK users
- 150 hours for Spanish users
- 50 hours CCI international time
- Up to 50 hours for European users (OPTICON)
- 150 hours for education via National Schools Observatory
- 90 hours pre-purchased by individual projects (e.g. Gaia tracking)

Robotically Scheduled

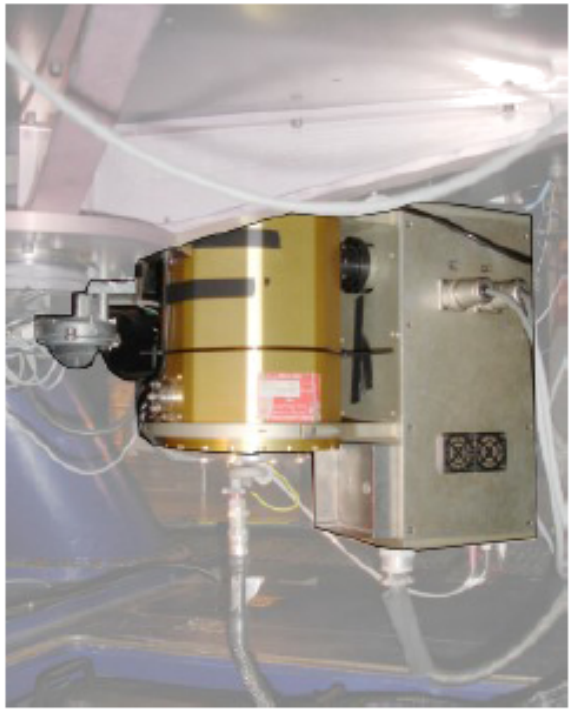
Scheduler decision-making based on:
1. Proposal science priority (A, B or C).
2. Repeat observations have a higher priority than one-off observations.
3. Urgent observations have a higher priority.
4. Ratio of current elevation versus highest possible elevation that night.
5. Matching of actual (seeing/lunar) 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
- Background standards used for monitoring when no science groups available.
- Twilight flats (IO:O): obtained most mornings/evenings.

Instrument Suite

IO:O	Optical Wide Field Camera
IO:I	Near-Infrared Camera
RISE	Fast-readout Wide Field Camera
RINGO3	Three-band Optical Polarimeter
SPRAT	SPectrograph for the Rapid Acquisition of Transients
LOTUS	LOw-cosT Ultraviolet Spectrograph
FRODOSpec	Fibre-fed RObotic Dual-beam Optical Spectrograph

LT Instruments

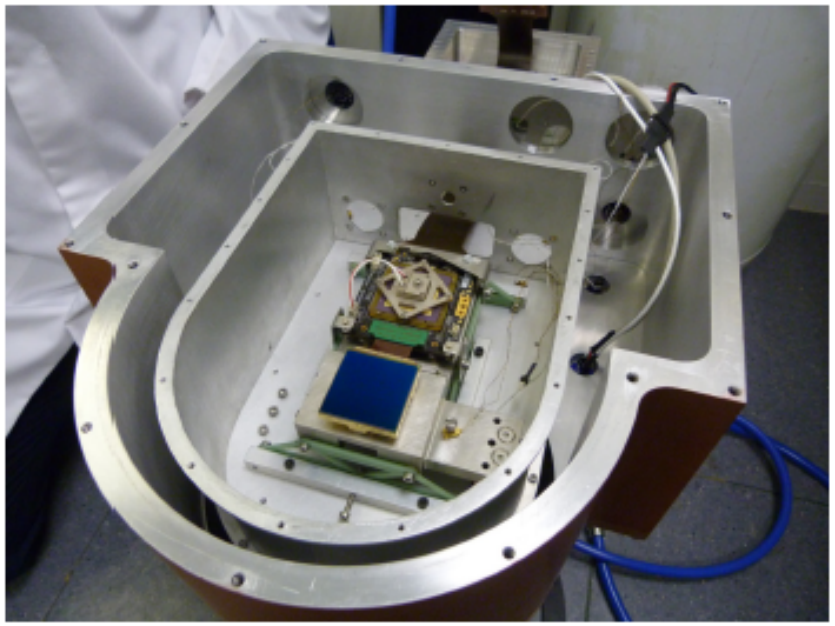


IO:O (optical)

- *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

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



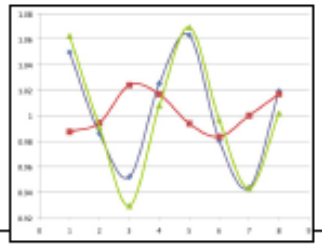
LT Instruments

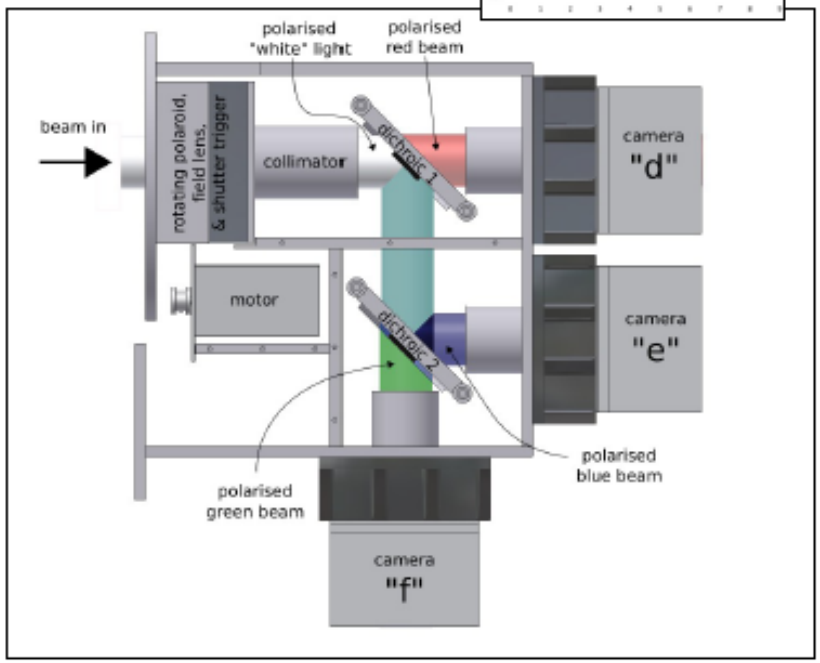
RISE

- 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

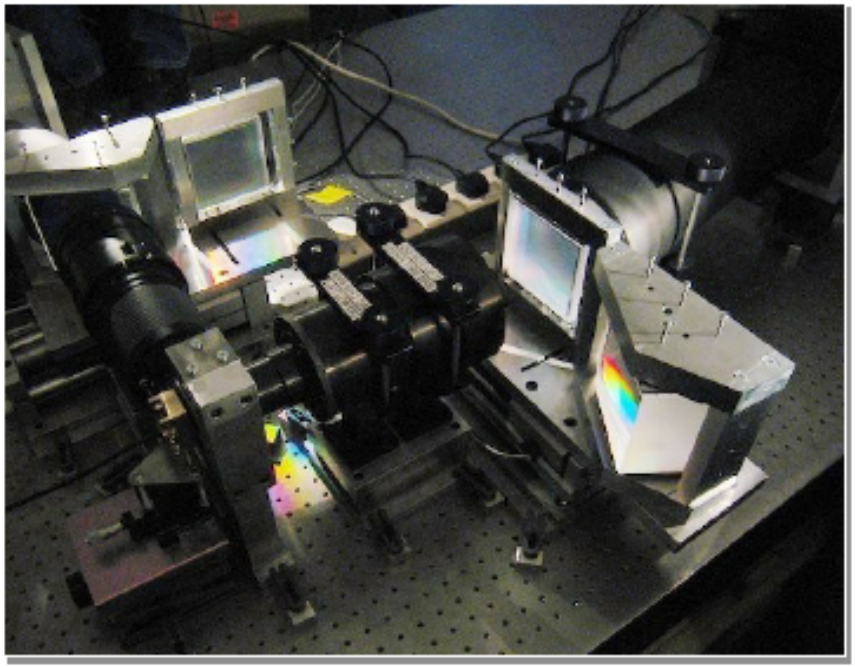
RINGO3 (polarimeter)

- 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



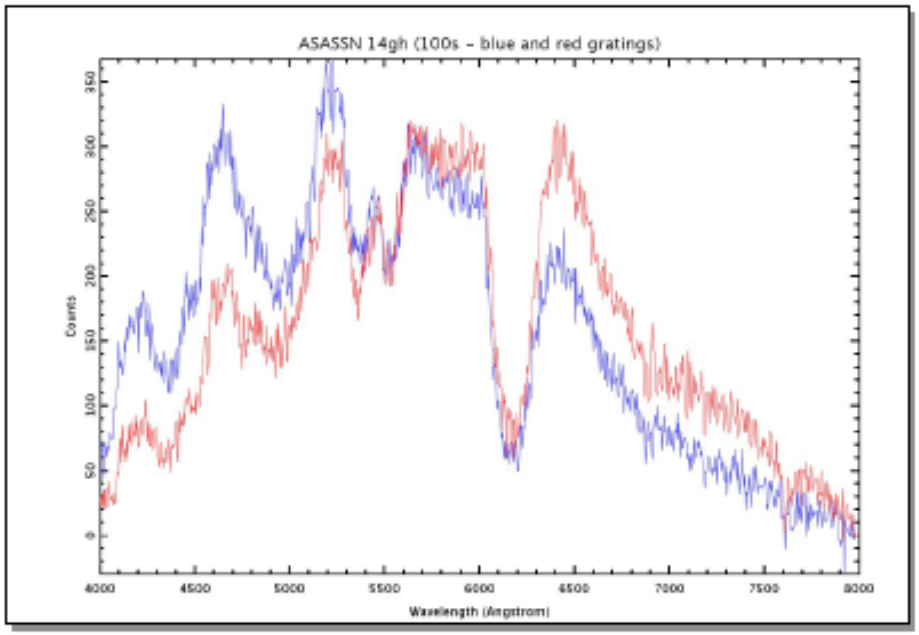
FRODOspec

- 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

LT Instruments: SPRAT

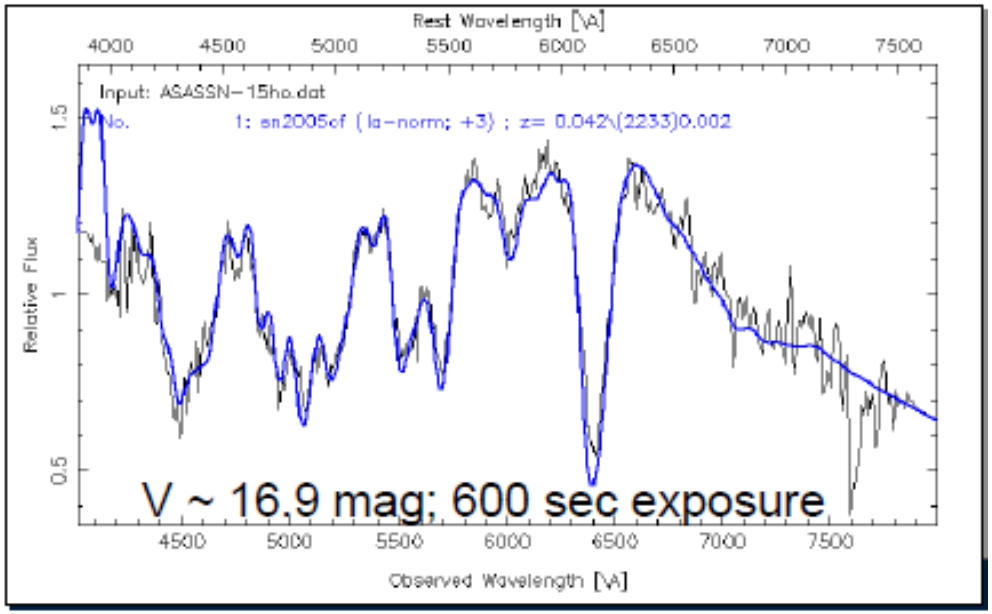


SPRAT – *designed for characterization of transients*

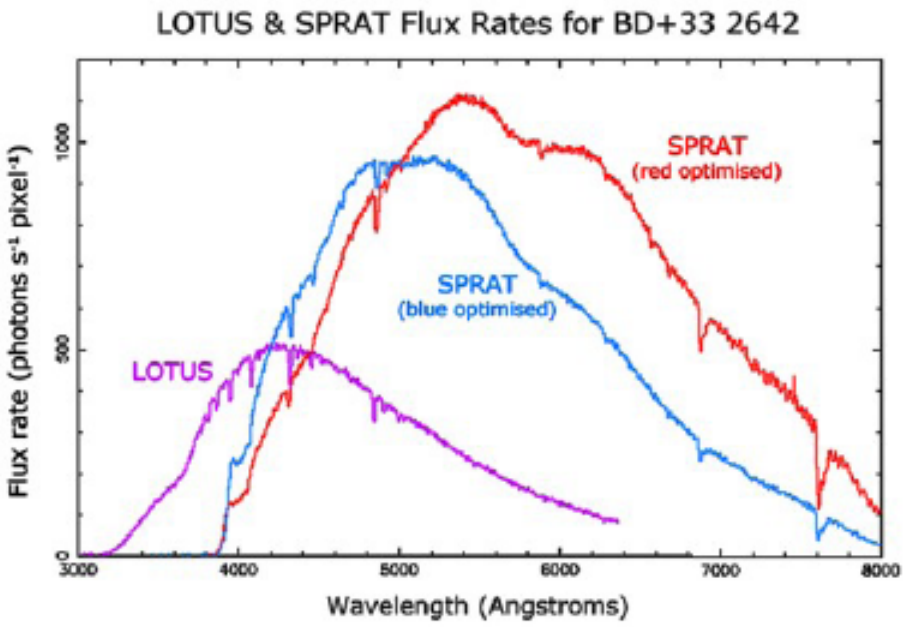
Targeting spectroscopy of V~19 mag stars in 500 sec

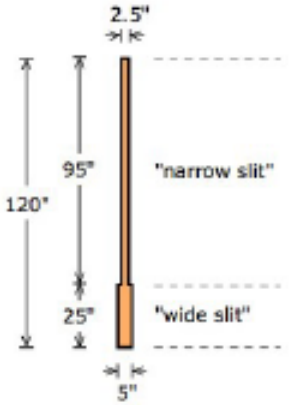
Above: Adjustable grism angle allows user to optimise spectroscopy in the red or blue

Right: calibrated SPRAT spectrum of ASASSN-15ho observed within 12 hours of ATEL announcement on 21-04-15. Object classified as a type Ia at 4 days post maximum. *Data courtesy: A. Piascik (LJMU)*



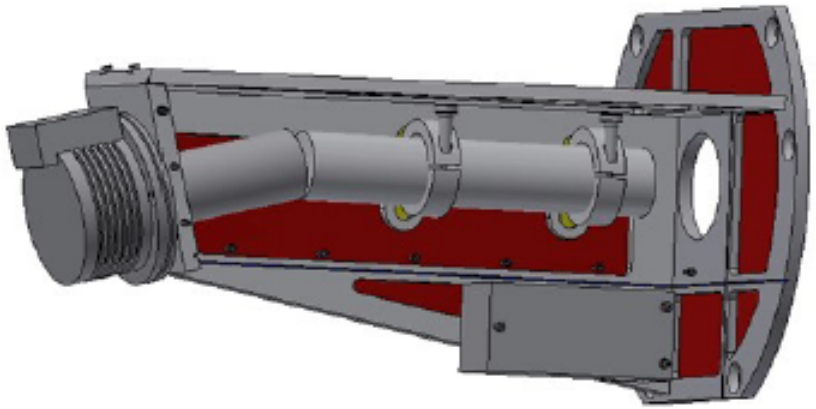
New LT Instruments





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
- Wavelength uncertainty <4 angstroms



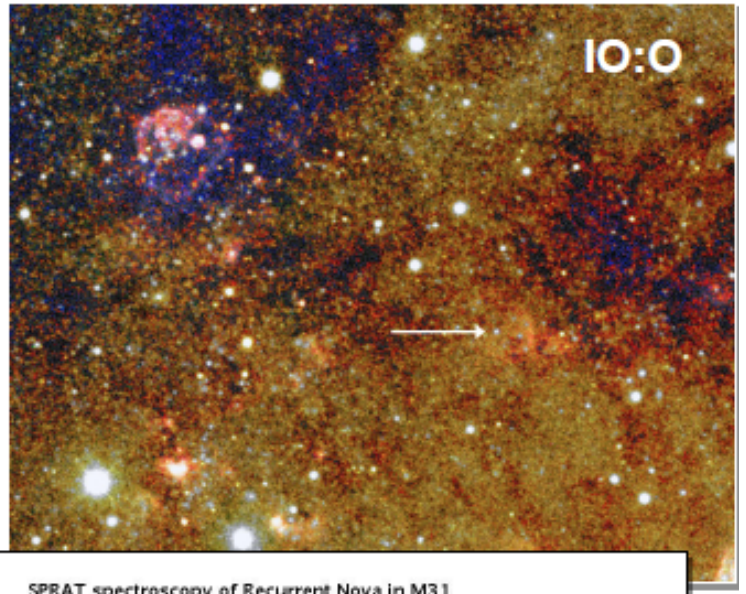
LT Science Highlights

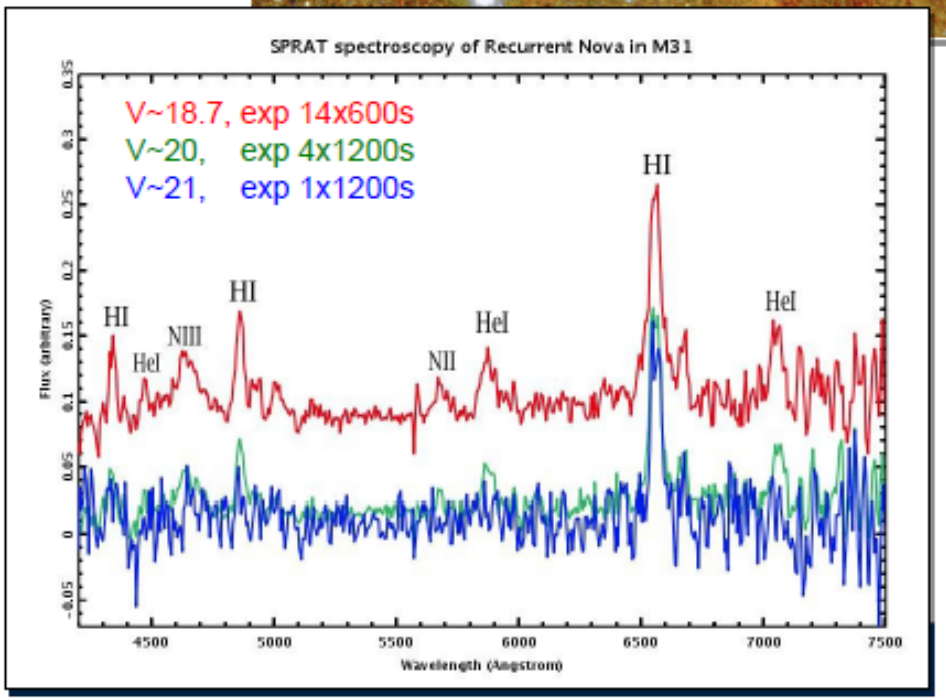
A Recurrent Nova in M31

(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





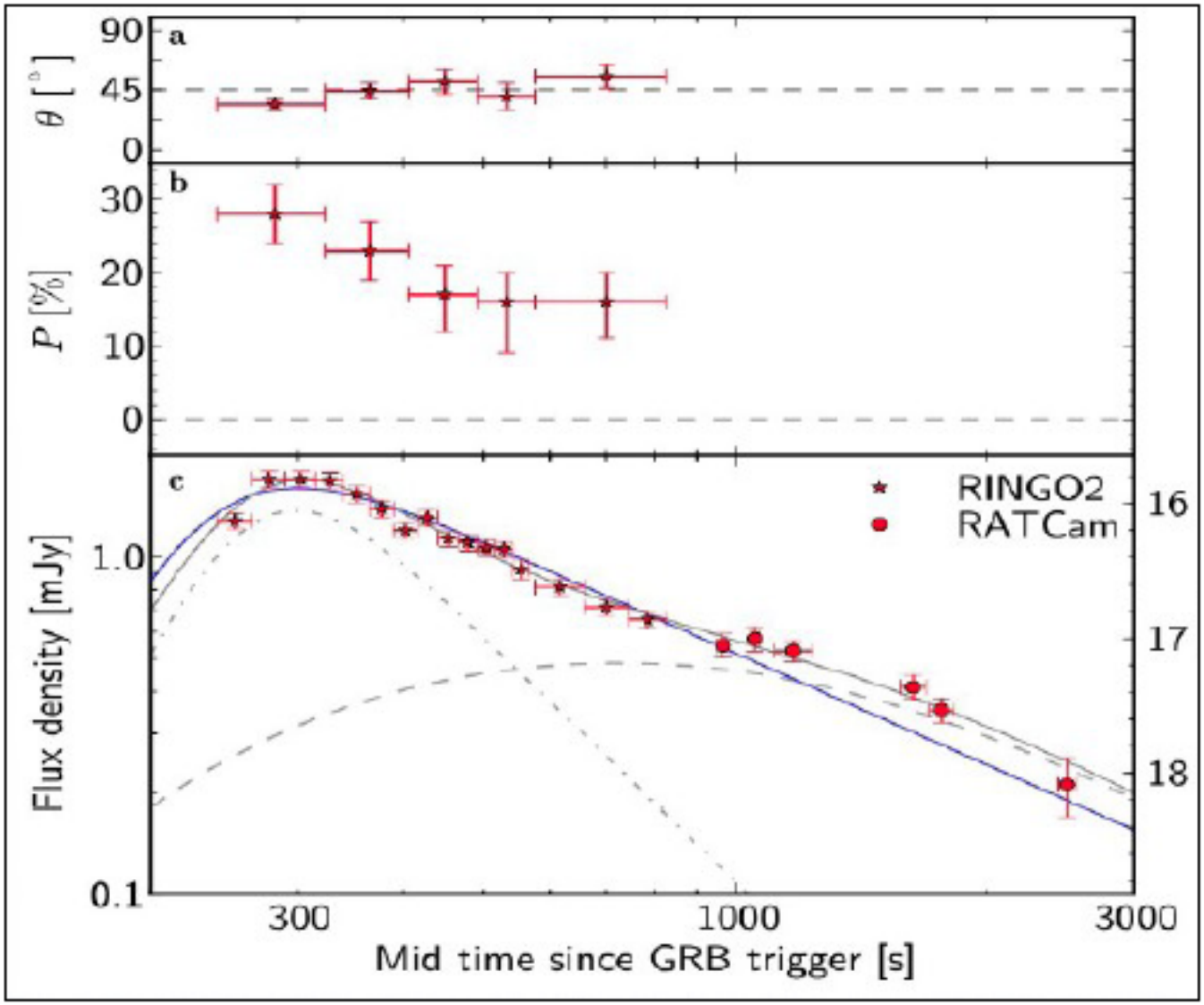
LT Science Highlights

GRB Monitoring - Polarisation

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

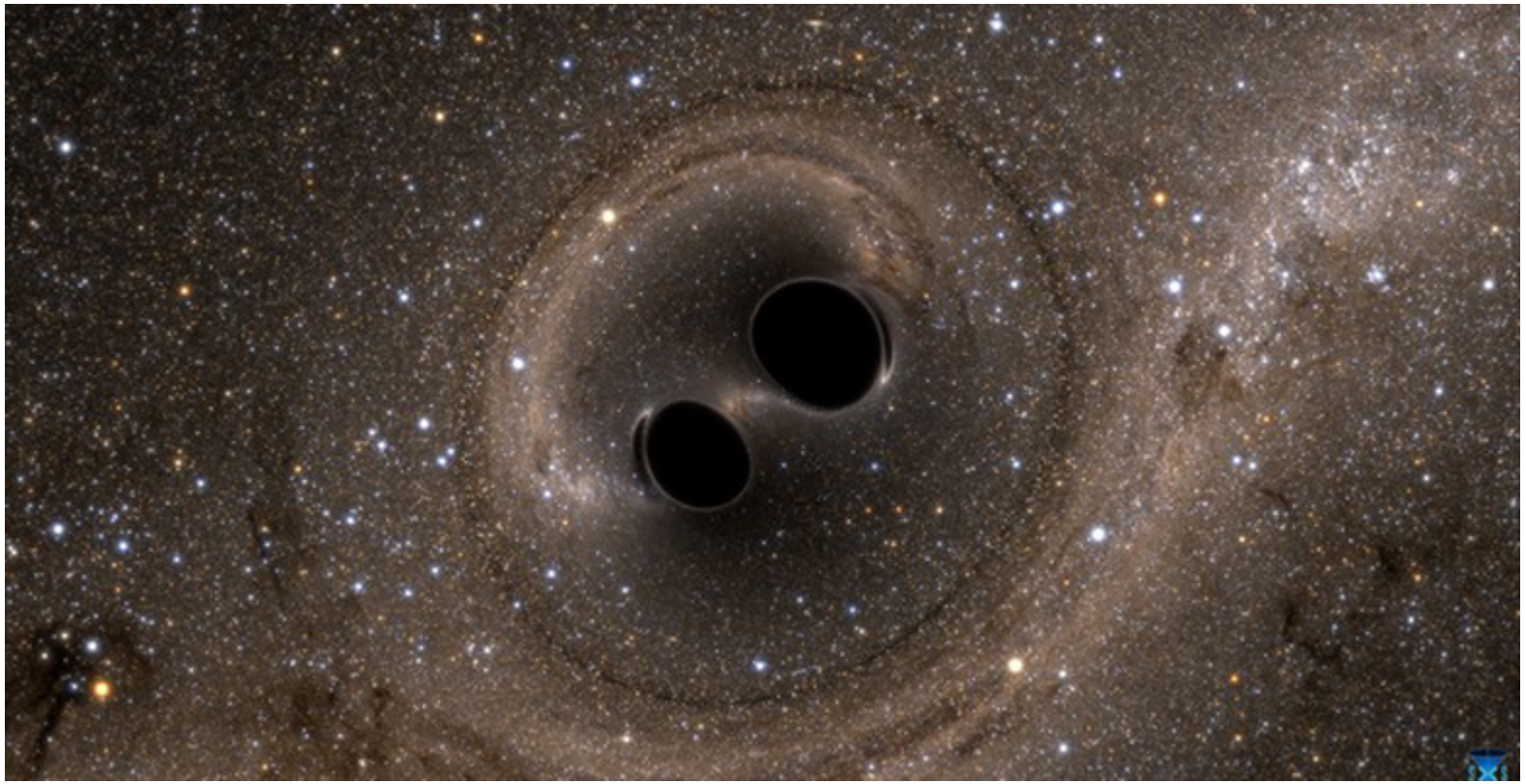
- Rapid decrease in flux accompanied by decrease in polarisation *BUT* – polarisation angle remains constant implying stable magnetic field surrounding GRB jet.

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



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

LT Science Highlights



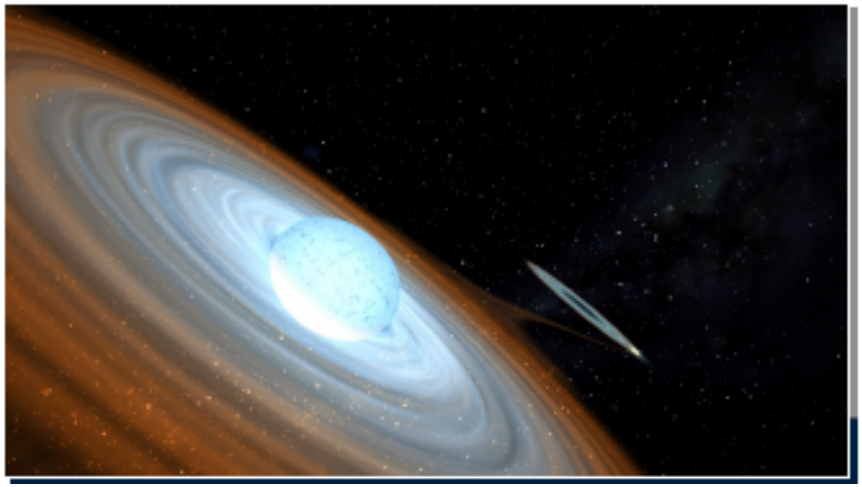
Follow-up/classification of ~10 iPTF-identified optical transients in error circle of GW151226

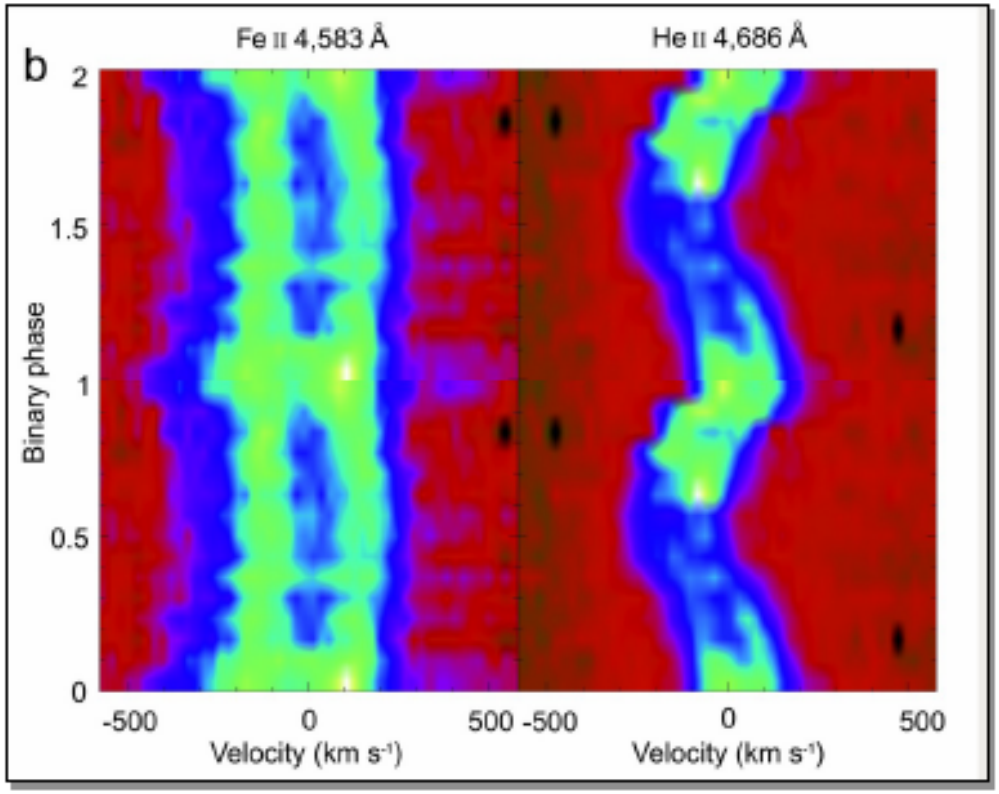
LT Science Highlights

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

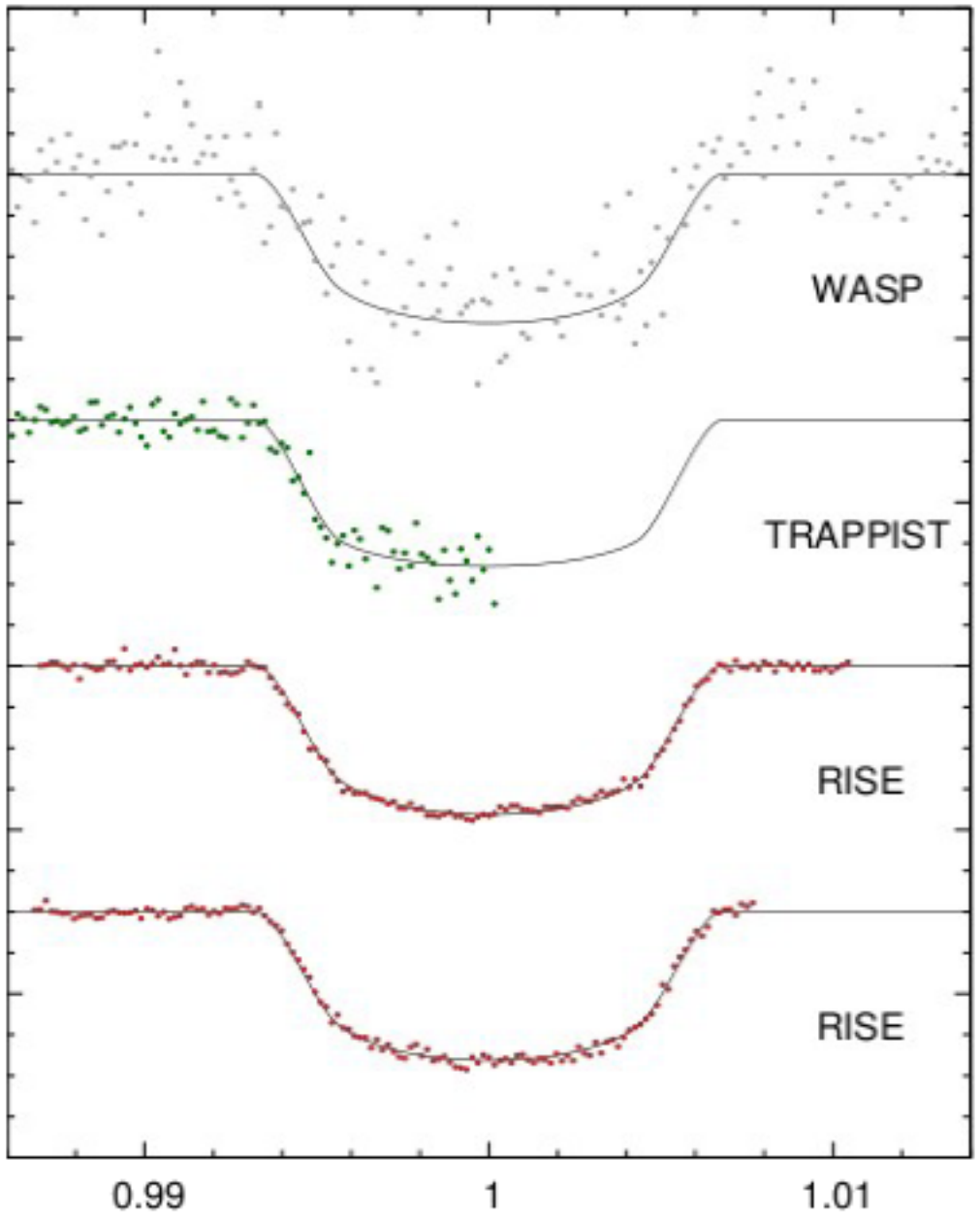
LT Science Highlights

Discovery of sub-Jupiter-mass Exoplanet WASP-84b

(Anderson et al. 2014)

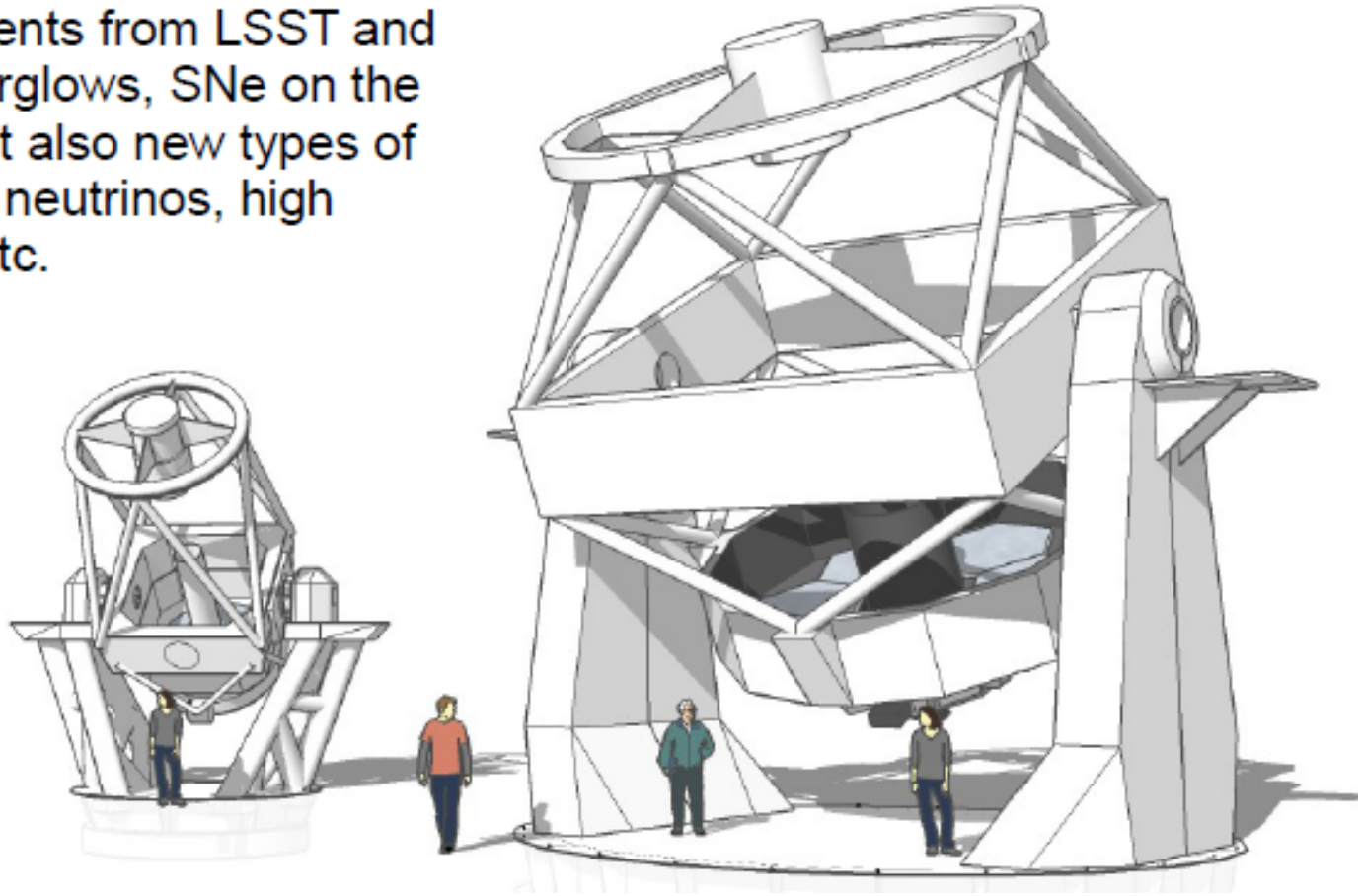
- WASP discovery; RISE used to refine orbital parameters.
- 8.5 day orbit around K-dwarf
- Almost 6300 RISE images obtained over two epochs.

RIGHT: Transit light-curves from WASP, TRAPPIST (0.6m robotic telescope), and RISE on the LT.



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.



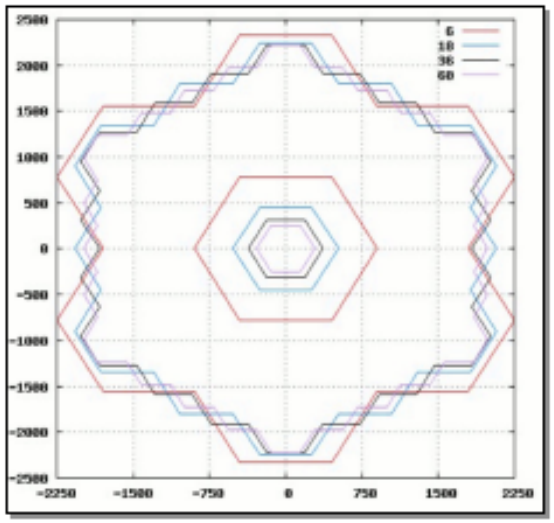
Liverpool Telescope 2

Build on the strengths of (and lessons learned from) the LT

- Increased slew rate: light-weight segmented mirror design
  - Target acquired and taking data in <30 sec?
- A greater spectroscopic capability than the LT
  - First-light instrument: optical-IR high-throughput R~500 + R~5000 spectrometer?
- Retain option for future development; larger instrument suite
- Complement (not replace?) the LT; feed off discoveries made with LT in real time

Science & Tech case under development

- See white paper: Copperwheat et al., (2015) (arXiv:1410.1731)



ABOVE: Segmented primary options.
BELOW: Possible new wide-field imager for the LT

Liverpool Telescope 2

Summary

• The **Liverpool Telescope** is a robotic 2m telescope in the Canary Islands, designed and built for time-domain science
• Flexible scheduling capability
• Diverse instrument suite: optical and NIR, imagers and spectrographs
• Telescope time available for users from the UK, Spain and beyond
• http://telescope.livjm.ac.uk/

• **Liverpool Telescope 2** 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, seeking additional potential partners
• http://telescope.livjm.ac.uk/lt2/