Multimessenger Transients and the Liverpool Telescope

A report on work during the first Advanced LIGO science run

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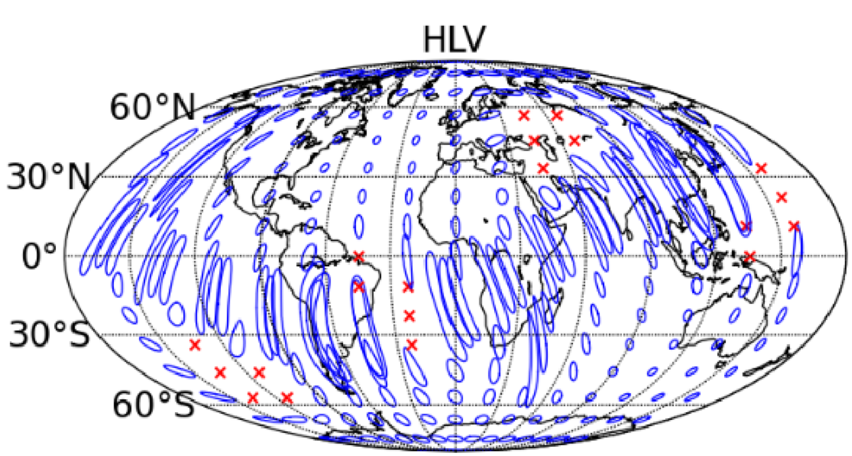
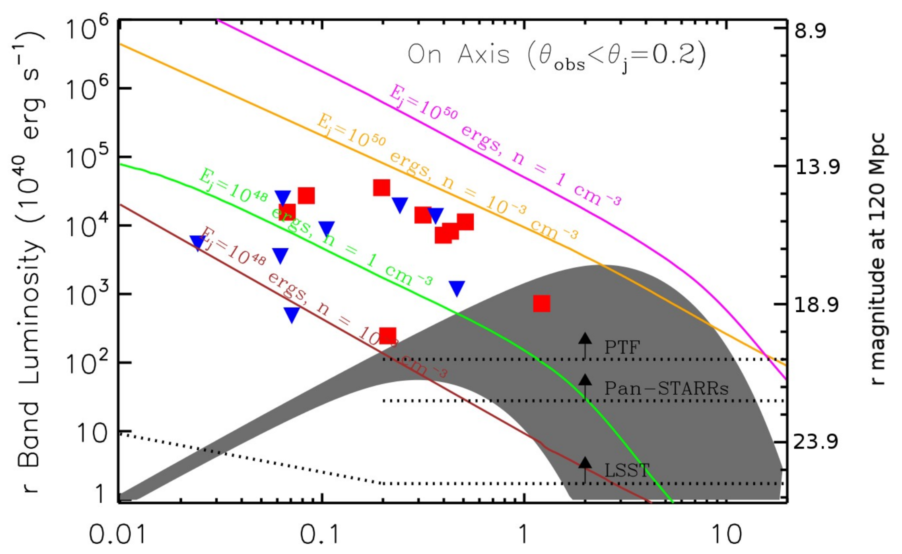
In the multi-messenger era, electromagnetic counterparts are

(a) poorly localised and (b) faint

So what is the role for 'small' optical/IR telescopes with ~arcmin fields-of-view?





(Commissioning and Observing Scenarios for the aLIGO and AdvVirgo GW Observatories, 2012)

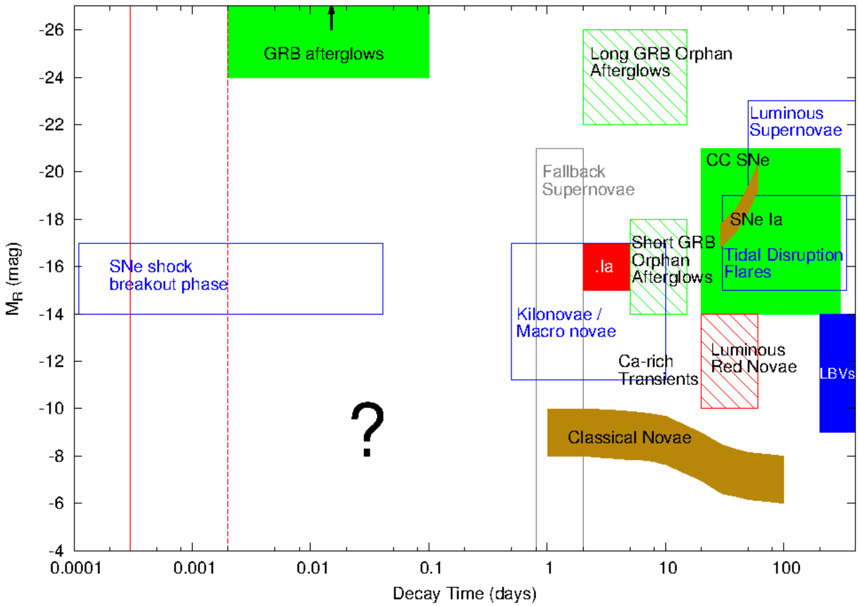
(Adapted from Metzger and Berger, 2012)

The 'follow-up gap'

Transient science has been revolutionised by the big synoptic surveys (iPTF, Pan-STARRS, MASTER, ASAS-SN...)

But our survey capacity has massively outpaced our capacity for follow-up

Only ~10 per cent of transients get a spectroscopic *classification*

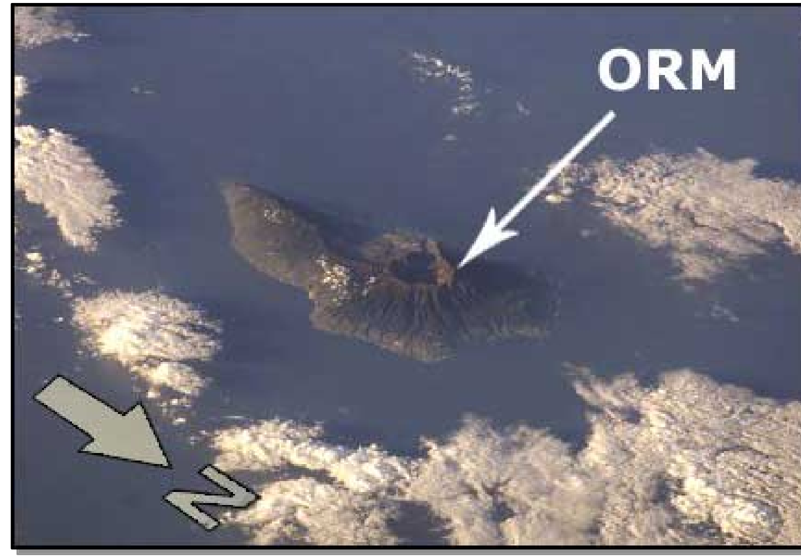


(Adapted from LSST science book)

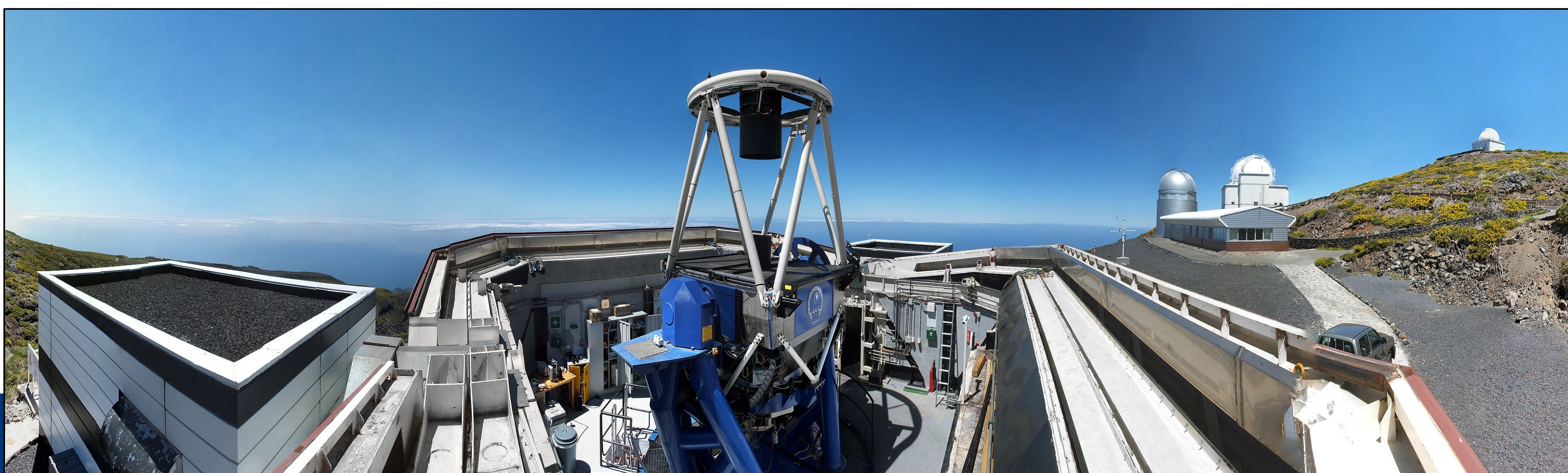
(An increasingly urgent problem as we approach the LSST era)

Multi-messenger example: GW151226 campaign

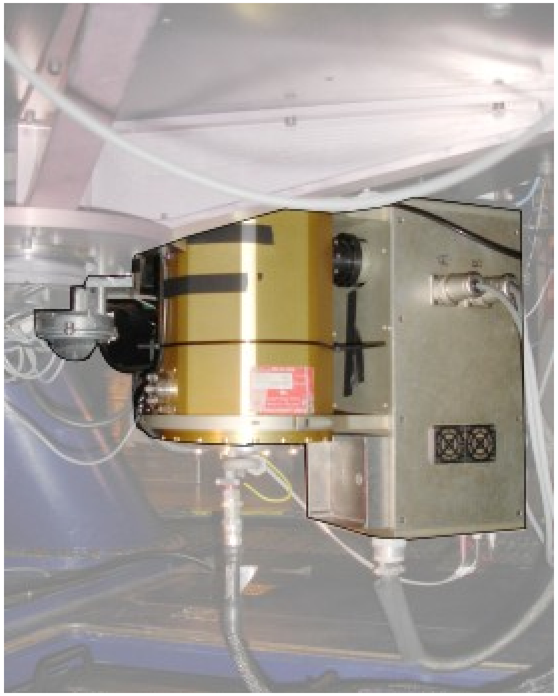
- 77 candidates reported to EM follow-up collaboration via GCN
- Firm classification for 37 candidates – just under 50 per cent
- A number of the rest faded by the time follow-up was attempted



The Liverpool Telescope is a 2-metre fully robotic telescope located at the ORM on La Palma

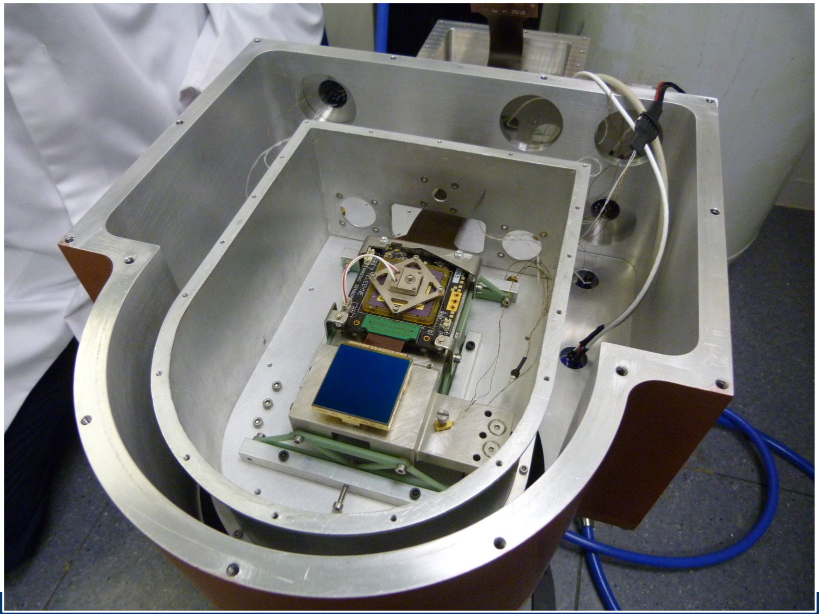


IO



IO:I (near-IR)

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

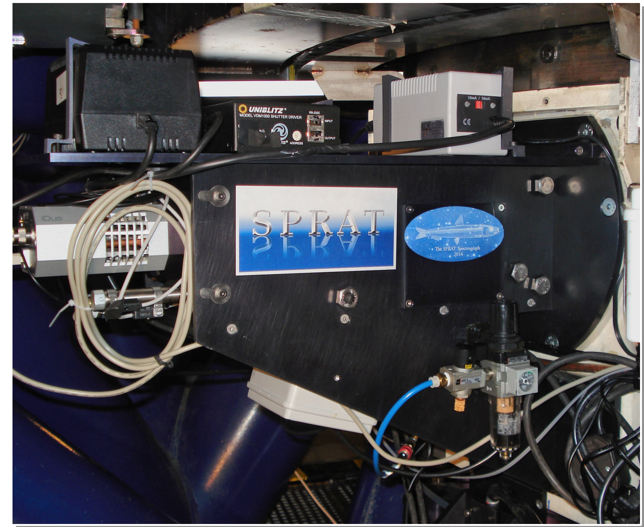


IO:O (optical)

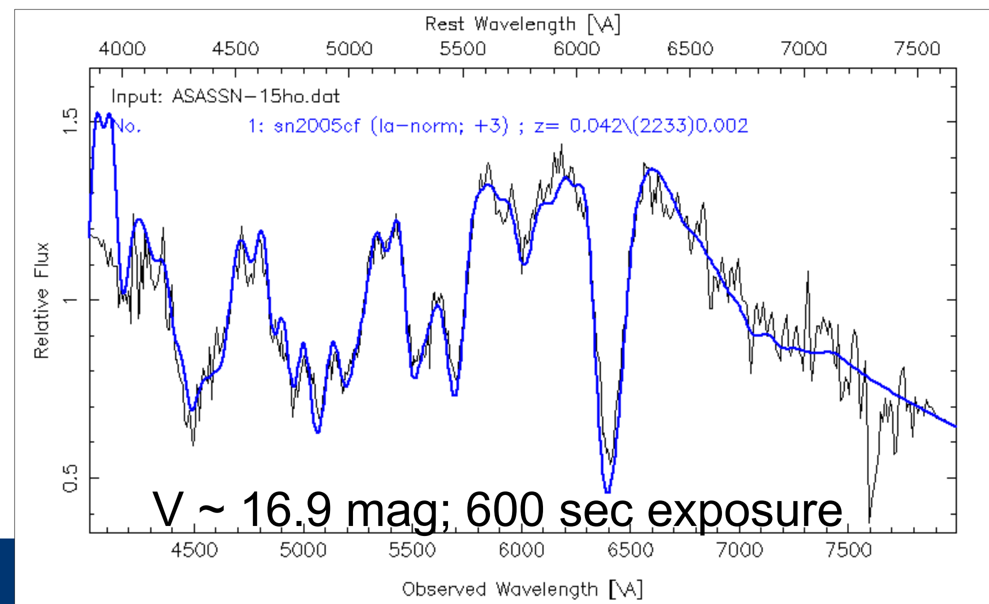
- *Our work-horse imager*
- 4096 x 4112 pixel e2v CCD
- Filters: u'g'r'i'z' + BV + 5 Hα's
- Pixel scale: 0.15 arcsec
- FOV: 10 x10 arcmin

SPRAT

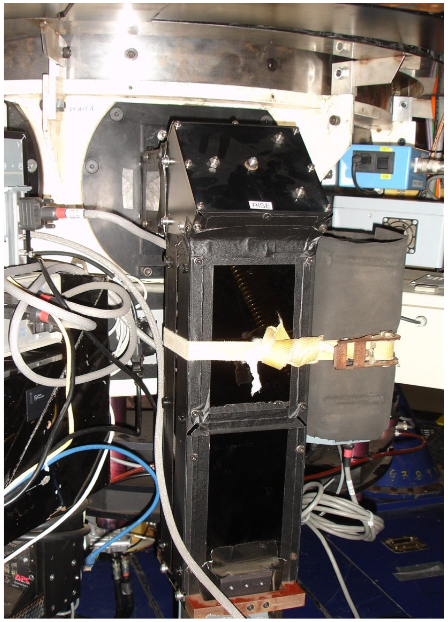
- Long-slit optical spectrometer
- Slit and grism deployable
- R ~ 350; λ range 400-800 nm
- Slit width: 1.8 arcsec
- Pixel scale: 0.44 arcsec
- Acquis. FOV: 7.5 x 1.9 arcmin



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)*

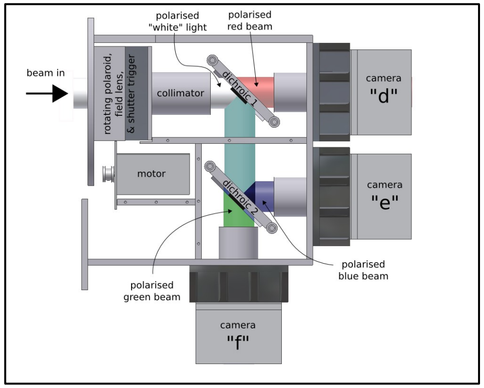


Other LT Instruments

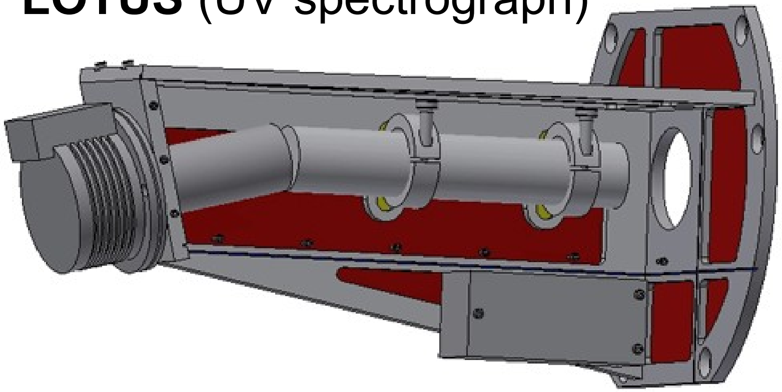


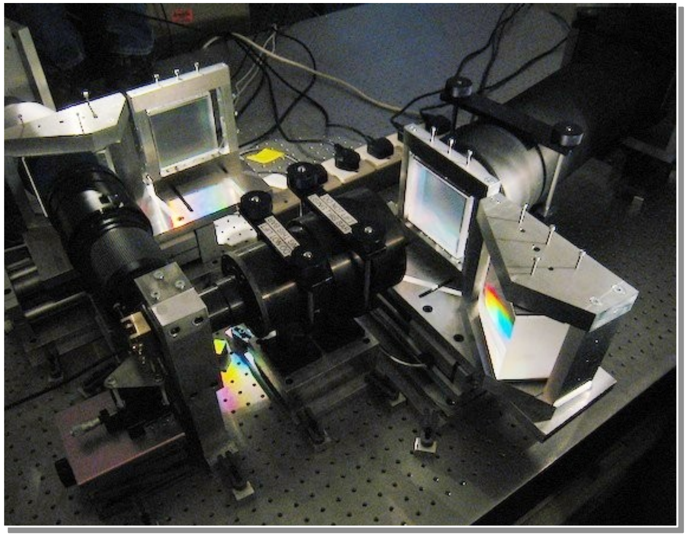
RISE
(Fast photometer)

RINGO3
(Three arm fast polarimeter)



LOTUS (UV spectrograph)



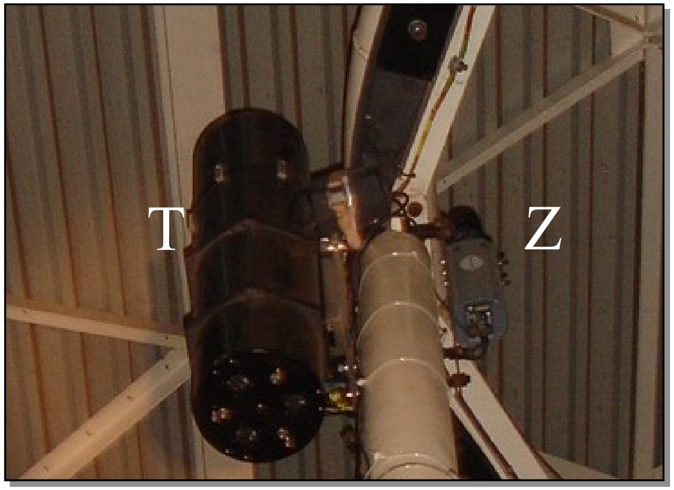


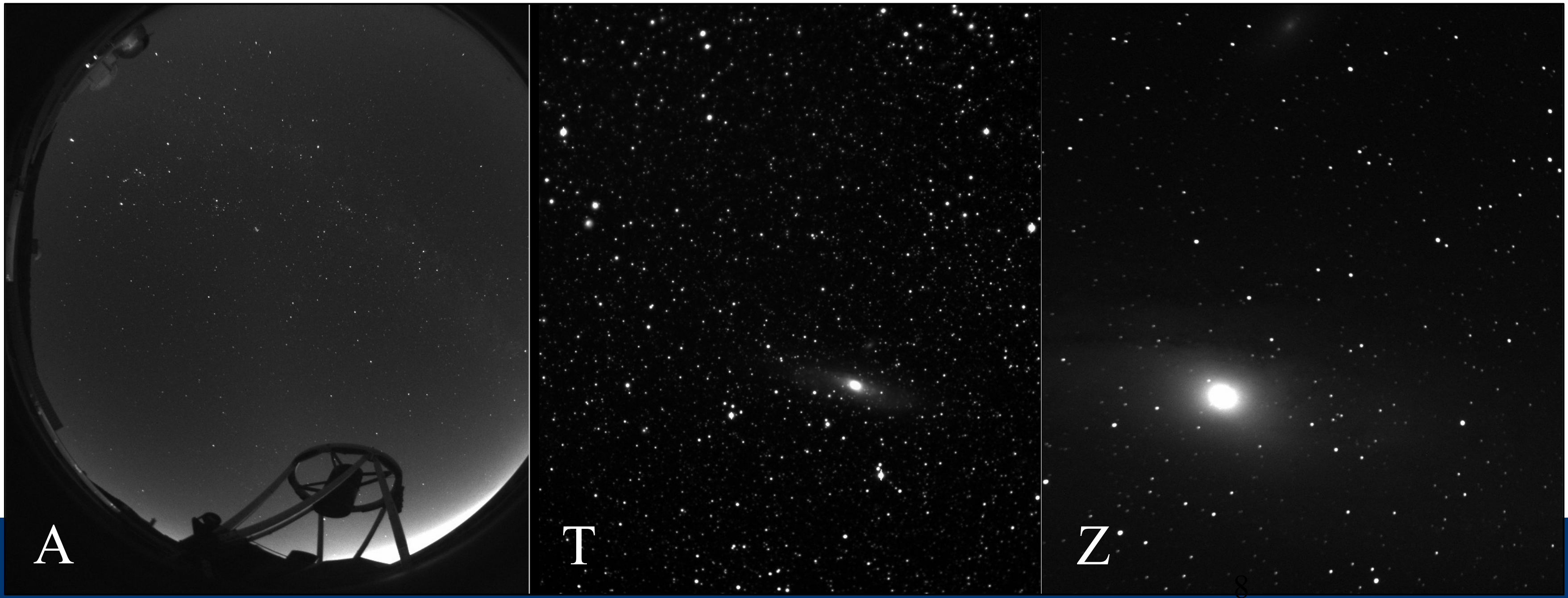
FRODOspec
(IFU intermediate resolution spectrograph)

Wide-field imaging: Skycams

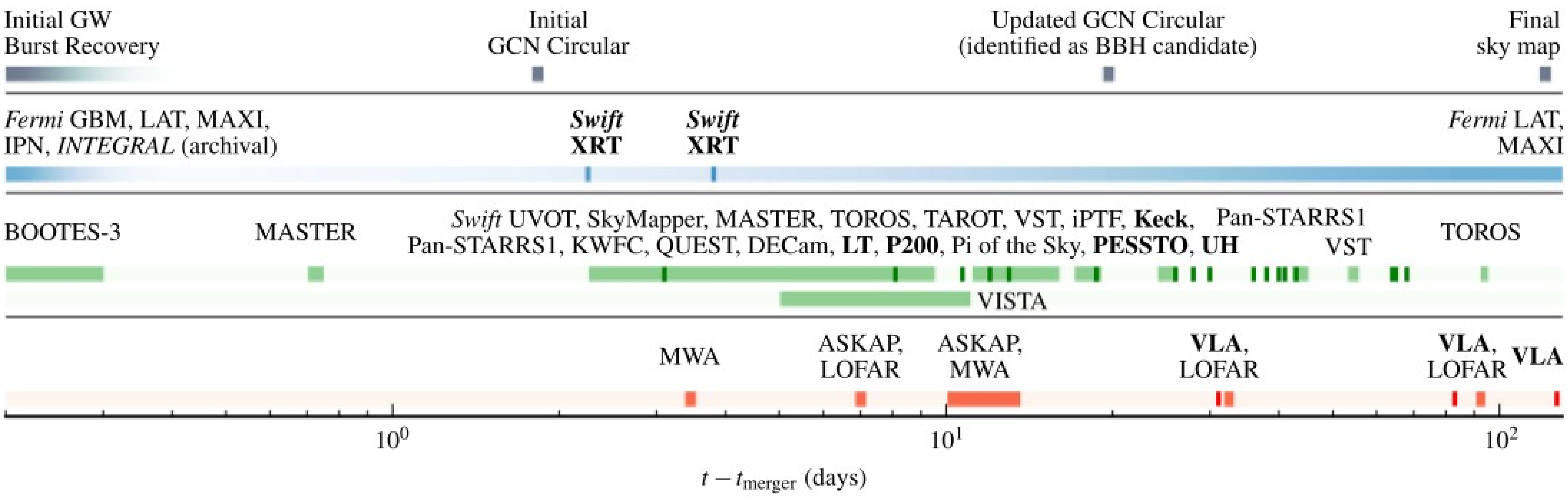
9° field, 90% complete down to R ~ 12th mag

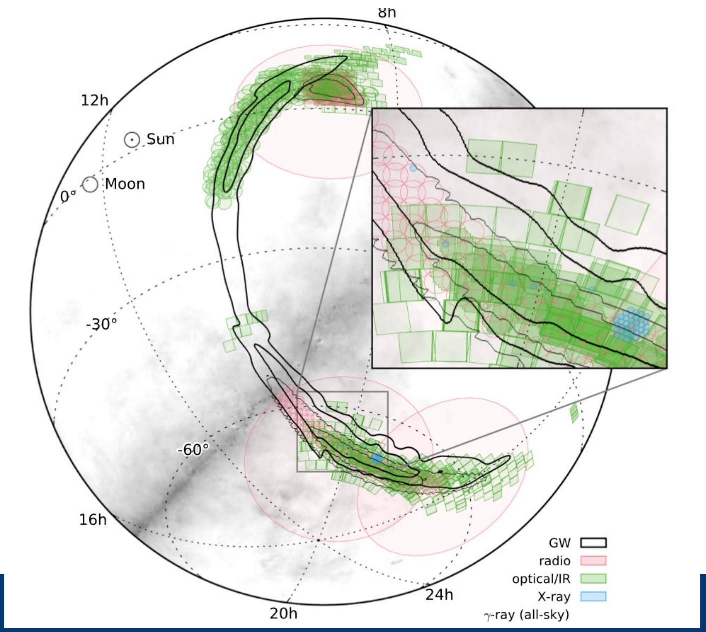
1° field; sensitive down to ~18th mag





GW150914 campaign





25 different teams particpated in the follow-up of this event.

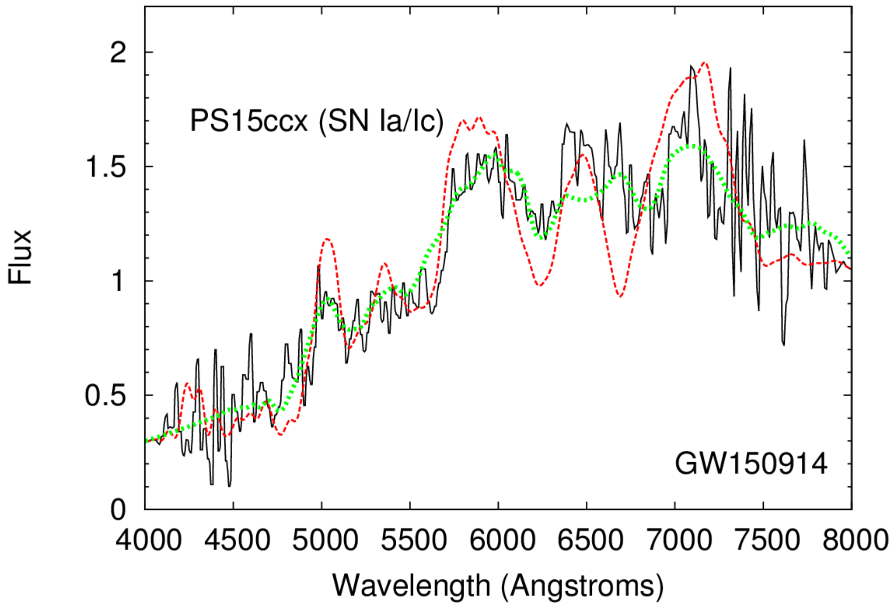
29 candidates classified (iPTF: Kasliwal et al. 2016, Pan-STARRS: Smartt et al. 2016)

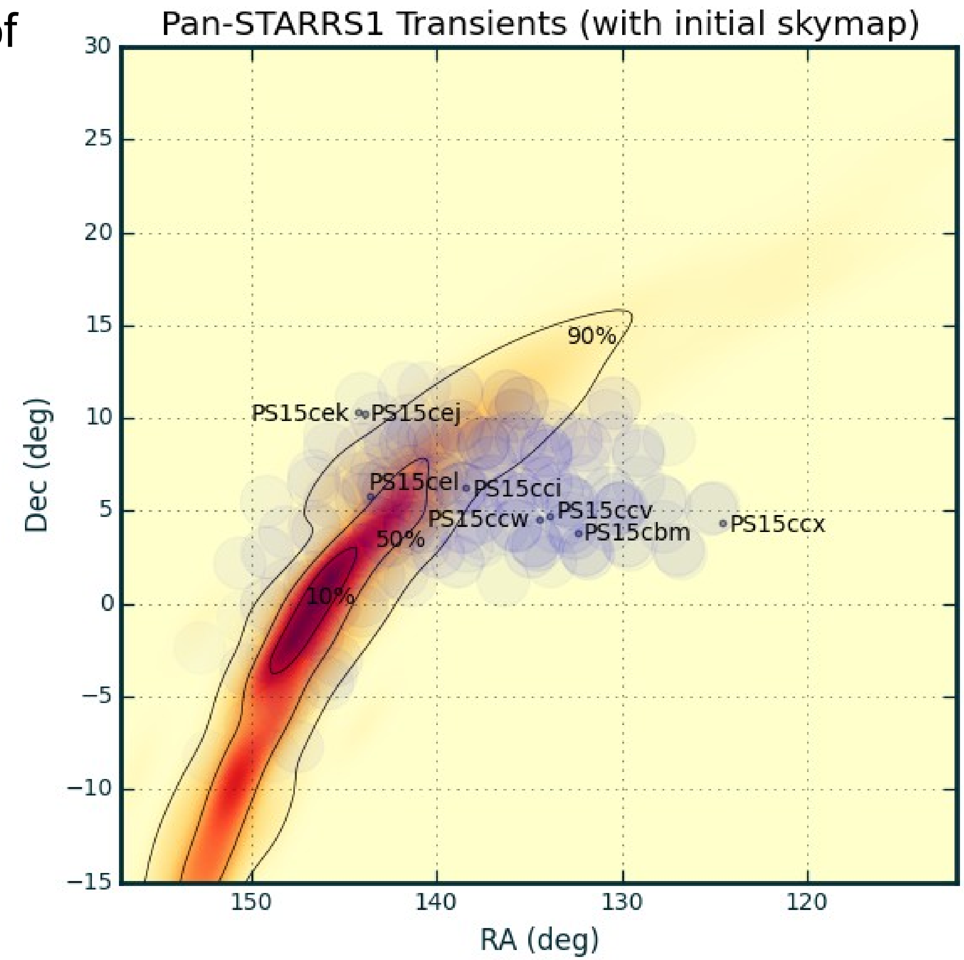
Abbott et al. 2016

GW150914: LT contribution

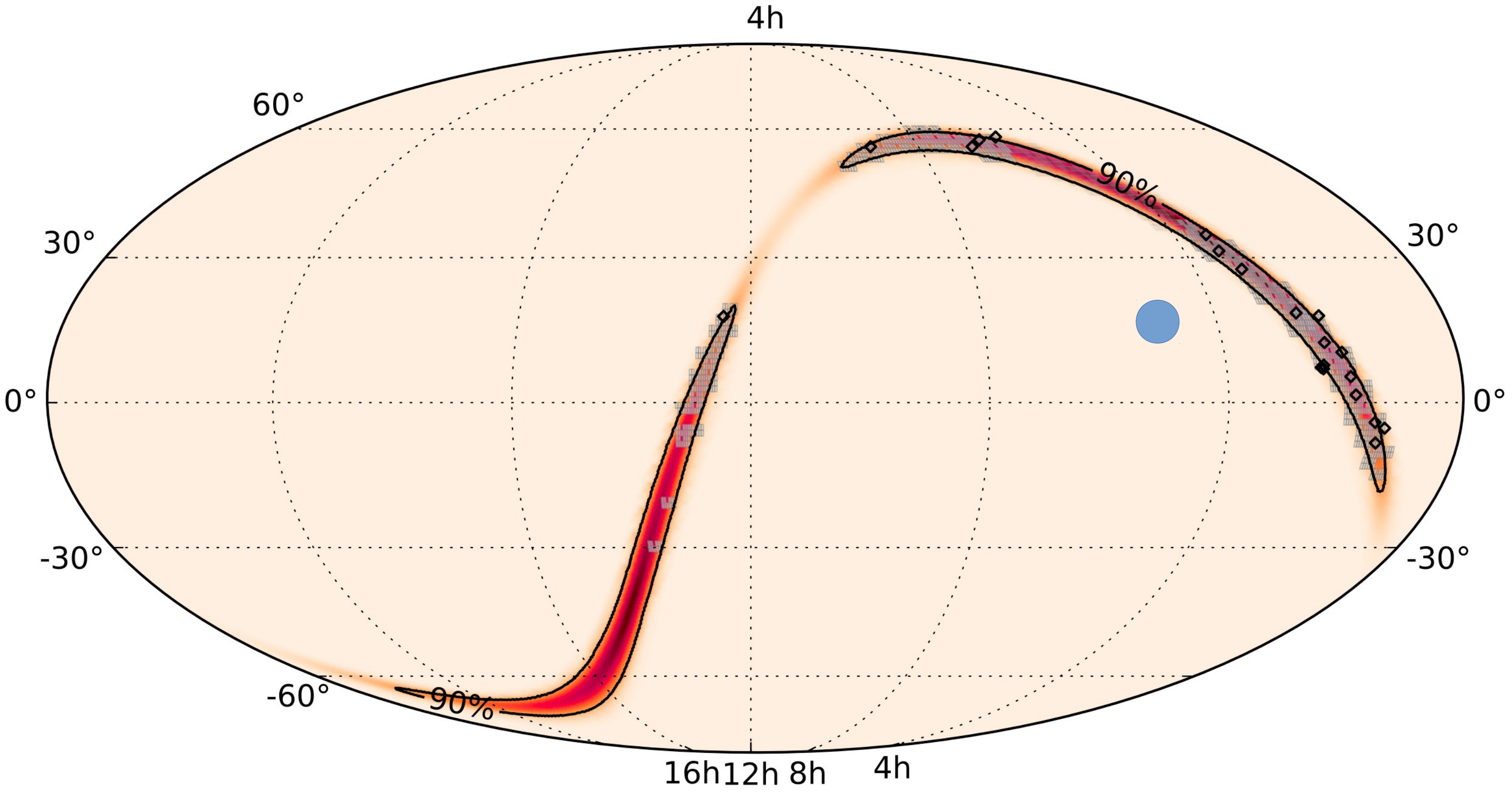
La Palma not well placed for follow-up of this event

Spectrum of one candidate obtained in twilight





GW151226 campaign



iPTF fields overlaid on LIGO skymap

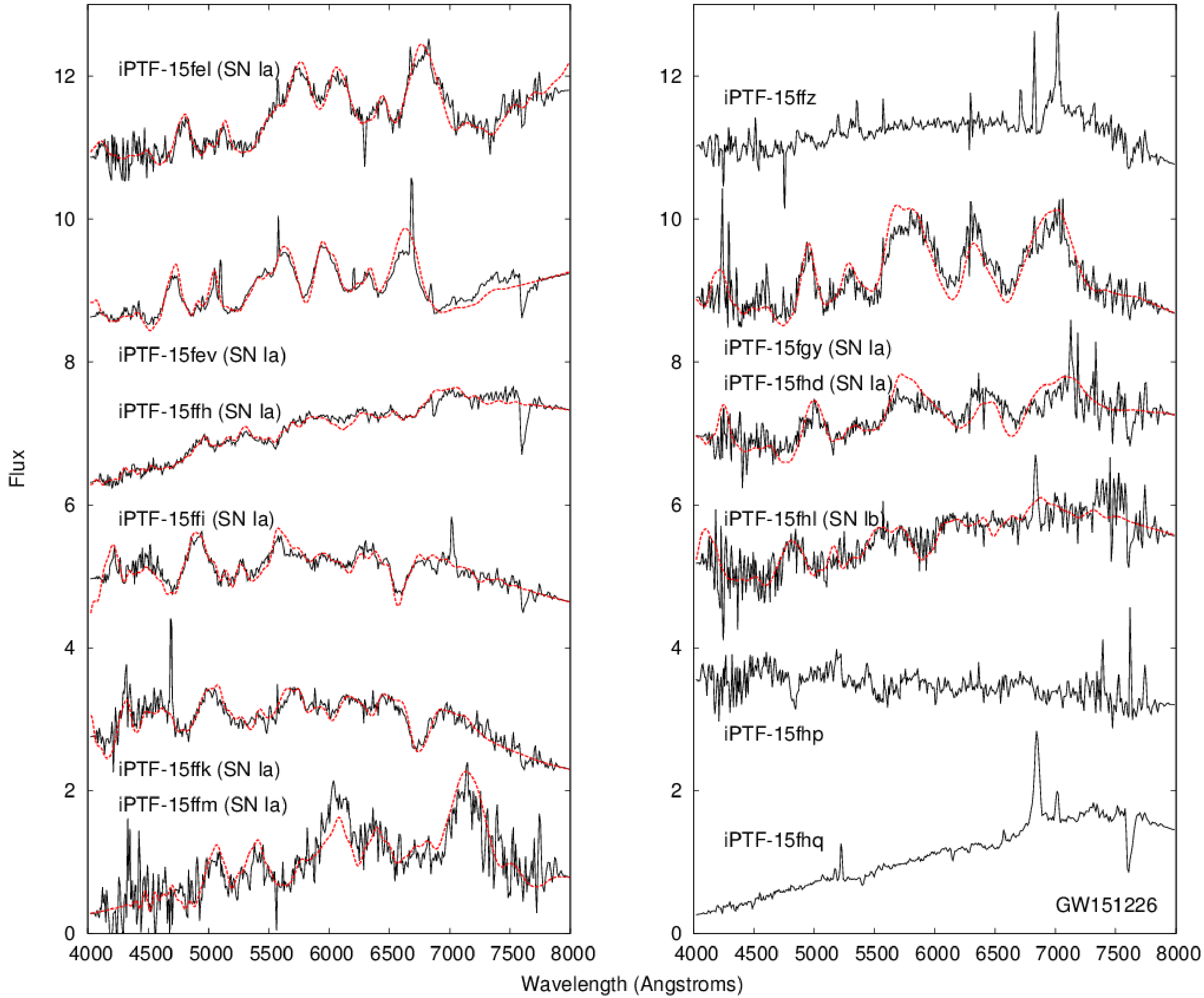
GW151226: LT contribution

Candidate ID	Comments
iPTF-15fed	No transient detected to limiting magnitude of $R\sim19.1$
iPTF-15fel	Supernova Type Ia, $z = 0.038$, $t = +40$ d, 97.7 per cent template fit
iPTF-15fev	Supernova Type Ia, $z = 0.023$, $t = +50$ d, 94.7 per cent template fit
iPTF-15ffh	Possible supernova Type Ia, $z = 0.061$ $t = +15$d
iPTF-15ffi	Supernova Type Ia, $z = 0.085$, $t = +3$ d, 89.1 per cent template fit
iPTF-15ffk	Supernova Type Ia, $z = 0.102$, $t = +5$ d
iPTF-15ffm	Supernova Type Ia, $z = 0.094$, $t = +36$ d
iPTF-15ffz	Emission lines consistent with AGN at $z\sim0.07$
iPTF-15fgy	Supernova Type Ia, $z = 0.076$, $t = +20$ d, 84.7 per cent template fit
iPTF-15fhd	Possible supernova Type Ia, $z = 0.091$, $t = +11$ d
iPTF-15fhl	Possible supernova Type Ib, $z = 0.043$, $t = +18$ d
iPTF-15fhp	Possible supernova Type Ic, $z = 0.129$, $t = +1$ d
iPTF-15fhq	Narrow emission lines, consistent with AGN at $z = 0.043$
iPTF-15fib	Slow moving asteroid
LSQ15bvw	No transient detected to limiting magnitude R$\sim$19.5
MASTER OTJ020906	No transient detected to limiting magnitude R$\sim$20
UGC 1410 transient	No transient detected. ID'd as minor planet 2 606 Odessa (Cenko et al. 2015; D'Avanzo, et al. 2015c)

17 candidates observed over ~1 week following LIGO trigger

Mostly supernovae – classification from SNID (Blondin & Tonry 2007)

Some non-detections: transient faded below background galaxy level



iPTF-15fel (SN Ia)
iPTF-15fev (SN Ia)
iPTF-15ffh (SN Ia)
iPTF-15ffi (SN Ia)
iPTF-15ffk (SN Ia)
iPTF-15ffm (SN Ia)
iPTF-15ffz
iPTF-15fgy (SN Ia)
iPTF-15fhd (SN Ia)
iPTF-15fhl (SN Ib)
iPTF-15fhp
iPTF-15fhq
GW151226
Flux
Wavelength (Angstroms)
0
2
4
6
8
10
12
4000
4500
5000
5500
6000
6500
7000
7500
8000

Conclusions from first aLIGO campaign

- Transient classification is at least as serious a problem as transient identification in the multi-messenger era.
  - Lack of low/intermediate resolution spectroscopic follow-up capacity
- Main contaminant based on this initial work seems to be supernovae – modern surveys efficient at eliminating other types of transient
- Many candidates have faded by the classification stage – rapid reporting of transients and rapid classification important
- With the right instrument, small telescopes can play a big role in this exciting science: 12 out of 37 classifications for GW151226 from 2-metre LT.

Current / near-future work

Rapid reaction

- We have developed a new interface for the LT, allowing observing groups to be submitted via a command line tool

- Closing the follow-up loop: spectroscopic follow-up of machine readable transient alerts with no human intervention

Expanding the classification network

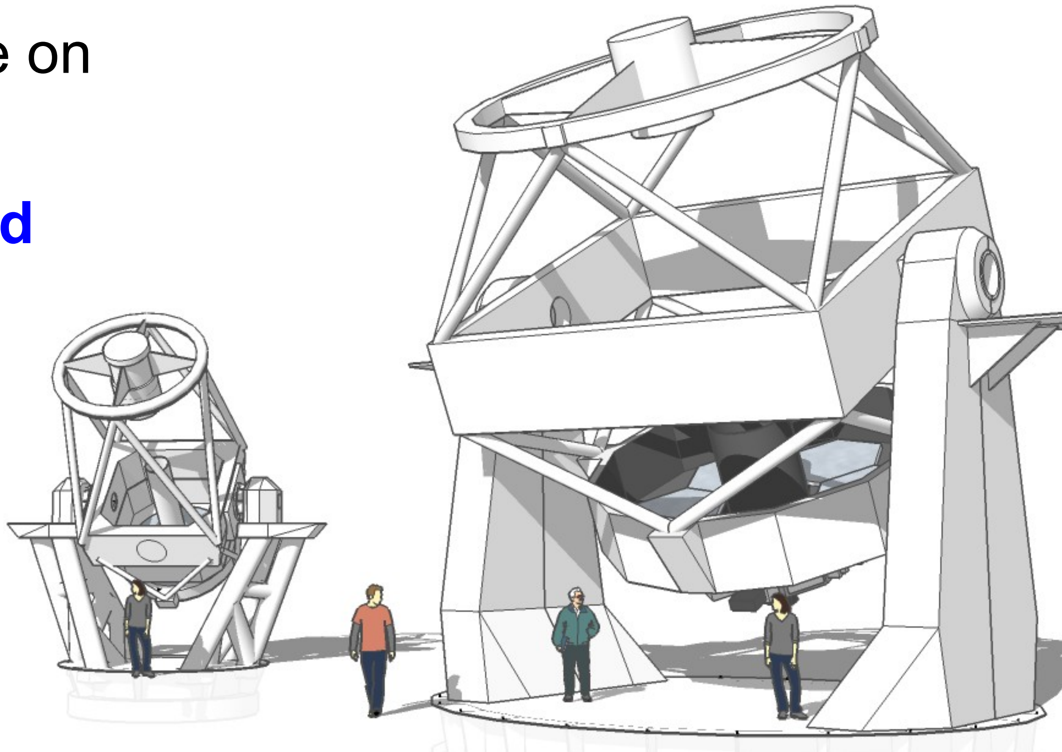
- We are in the process of appointing a new LT instrument scientist (OPTICON funded)

- Develop a cheap, modular version of SPRAT for small telescopes across the continent

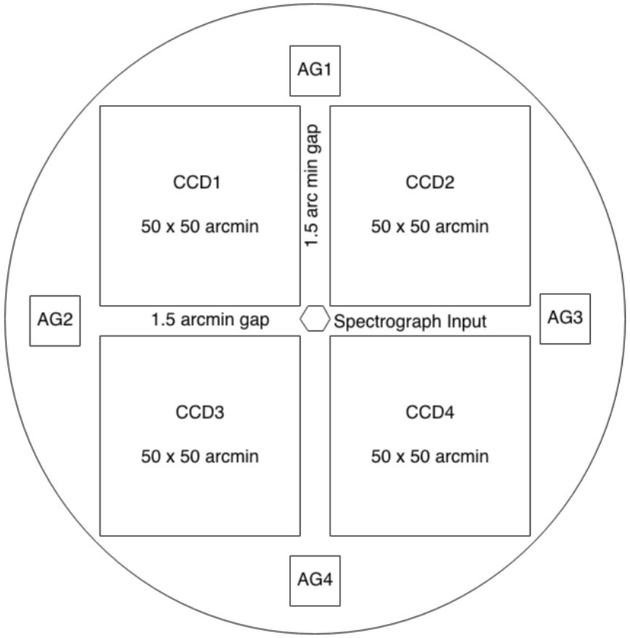
OPTICON

Large Robotic Telescope

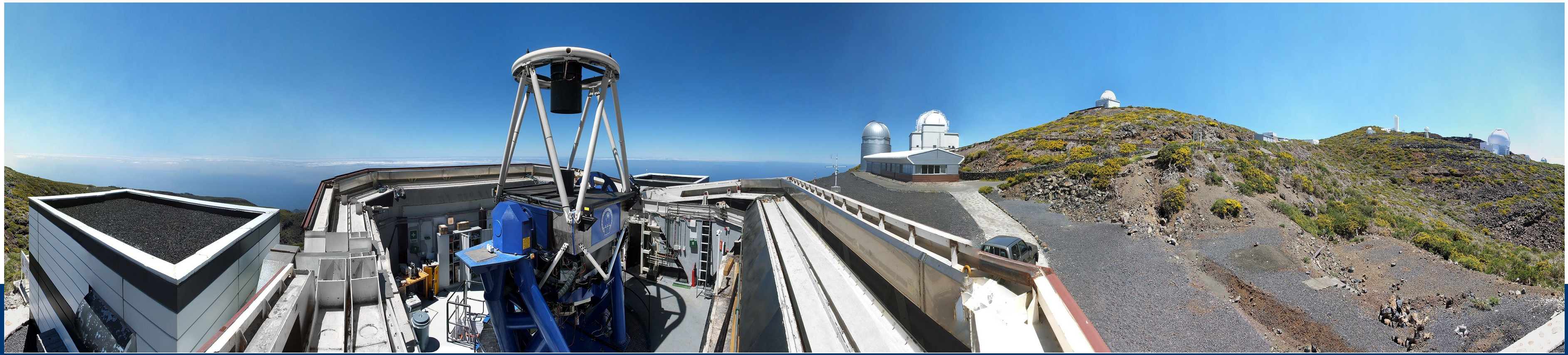
- A new, **4-metre class robotic telescope** for rapid follow-up of astrophysical transients. Largest robotic telescope in the world
- To be co-located with the LT on **La Palma**
- **First light ~2022** to capitalise on new discovery facilities
- **Versatile instrument payload** spectroscopy a core focus (X-shooter type instrument)
- **World-leading response time** for fast fading / fast evolving transients, efficient programmes



A new role for the LT



- 2-metre LT to stay operation and support science on 4-metre LRT
- Current instrument suite to be replaced with single prime focus imager
- 2x2 deg field for targeted surveys for poorly localised transients



Large Robotic Telescope: Copperwheat et al., 2015, ExA, 39, 119
(arXiv:1410.1731)

GW follow-up: Copperwheat et al., 2016, MNRAS, 462, 3528
(arXiv:1606.04574)

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