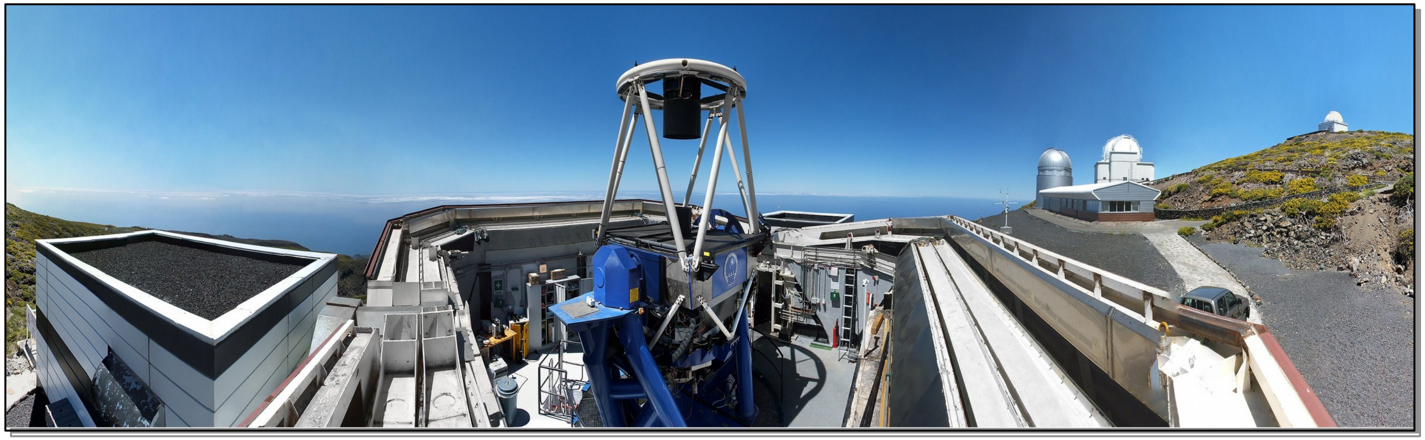
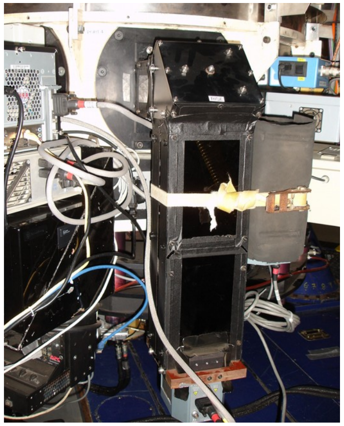


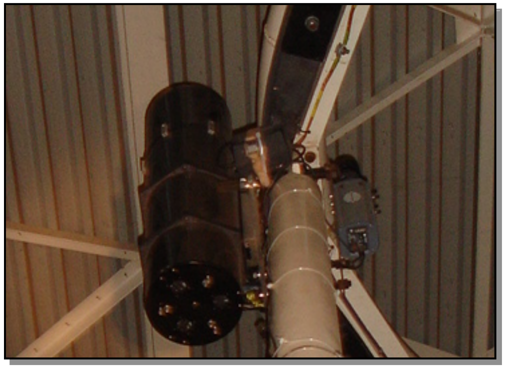
Multimessenger follow-up with the Liverpool Telescope

Chris Copperwheat

Liverpool Telescope group:
S.Bates, N.Clay, H.Jermak, M.Lam, J.Marchant, C.Mottram, A.Piascik, R.Smith, I.Steele

Collaborators:
D.Bersier, M.Bode, C.Collins, M.Darnley, D.Galloway, A.Gomboc, S.Kobayashi, G.Lamb, A.Levan, P.Mazzali, C.Mundell, E.Pian, D.Pollacco, D.Steeghs, N.Tanvir, K.Ulaczyk, K.Wiersema





LT Instruments

IO:O: 10x10 arcmin optical imager. 12 position filter wheel

IO:I: 6x6 arcmin H-band imager

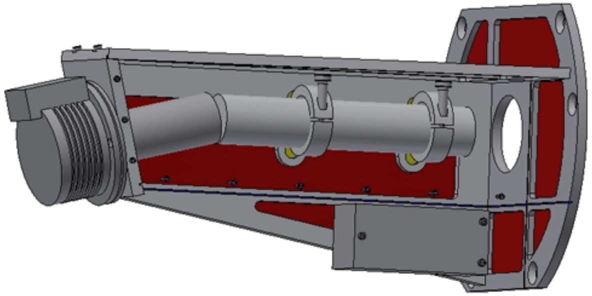
RINGO3: Three arm fast polarimeter

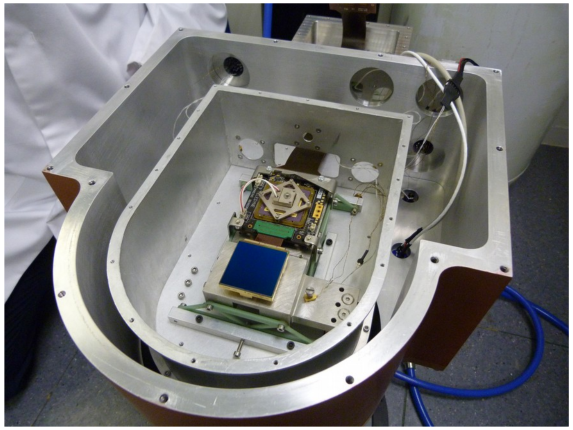
RISE: Fast photometer

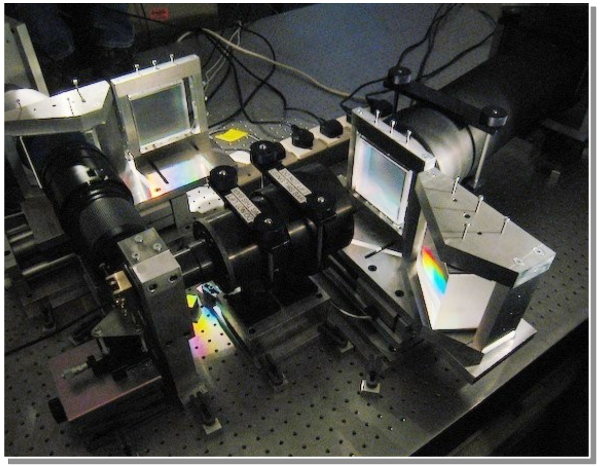
SPRAT and **LOTUS:** Low-res optical and UV spectrographs

FRODOspec: IFU intermediate resolution spectrograph

Skycams: 9^{o} field down to R~12
1^{o} field down to R~18





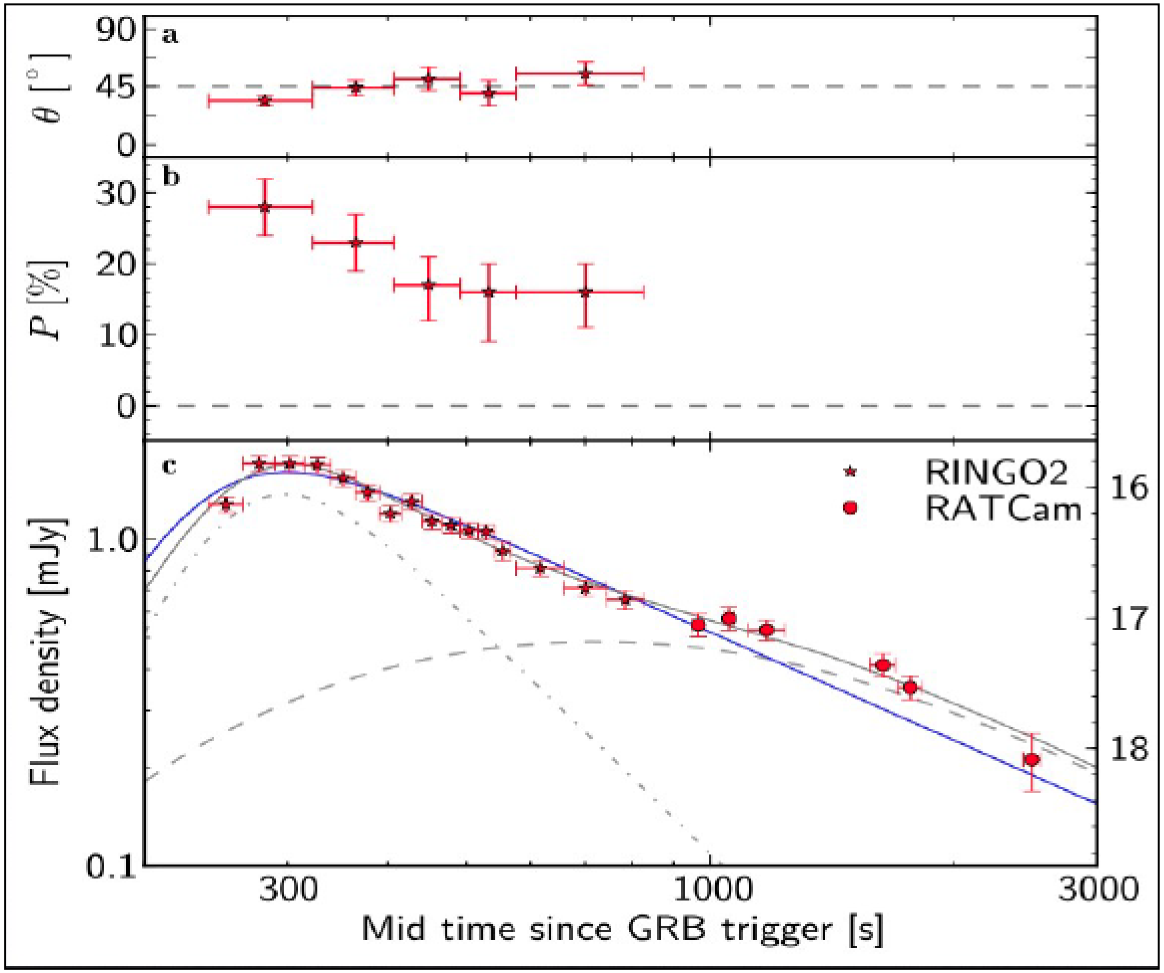


GRB Monitoring - Polarisation

(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…*

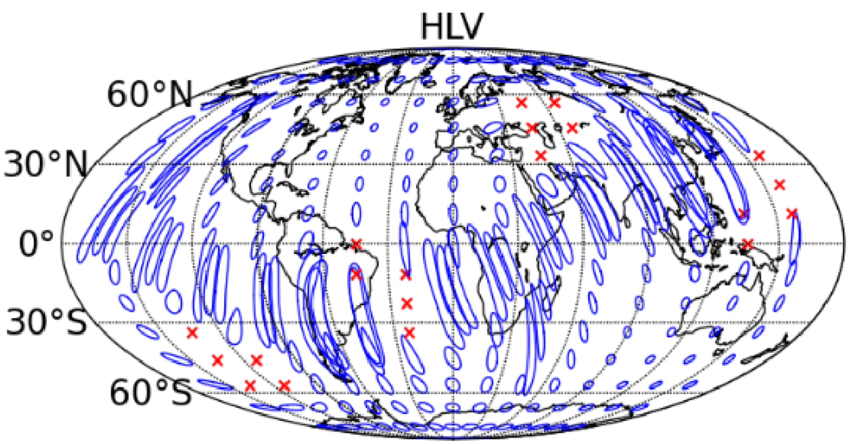


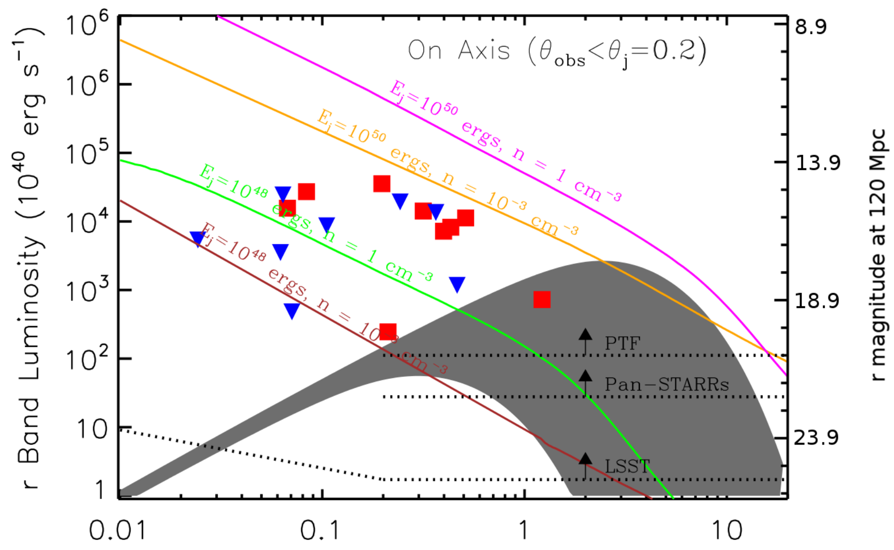
TOP: Polarisation position angle.
MIDDLE: Percentage Polarisation.
BOTTOM: Flux density.

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)

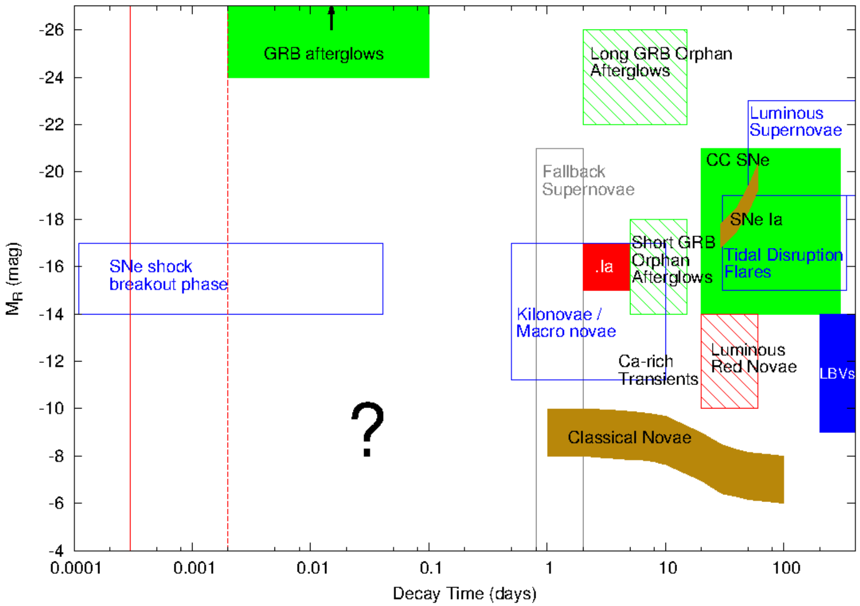
(Adapted from Metzger and Berger, 2012)

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)

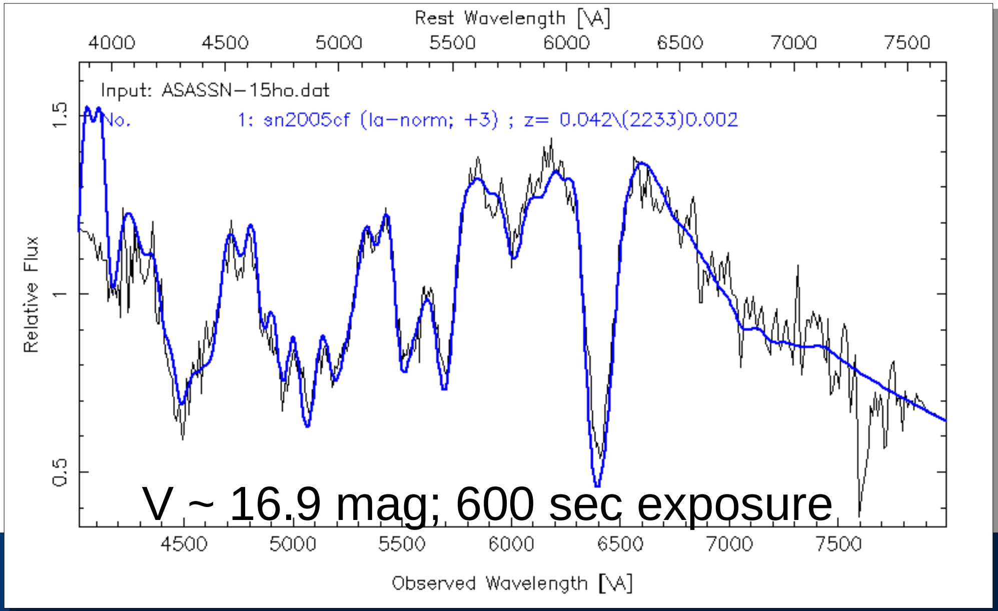
Multi-messenger example: GW151226 campaign

- 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

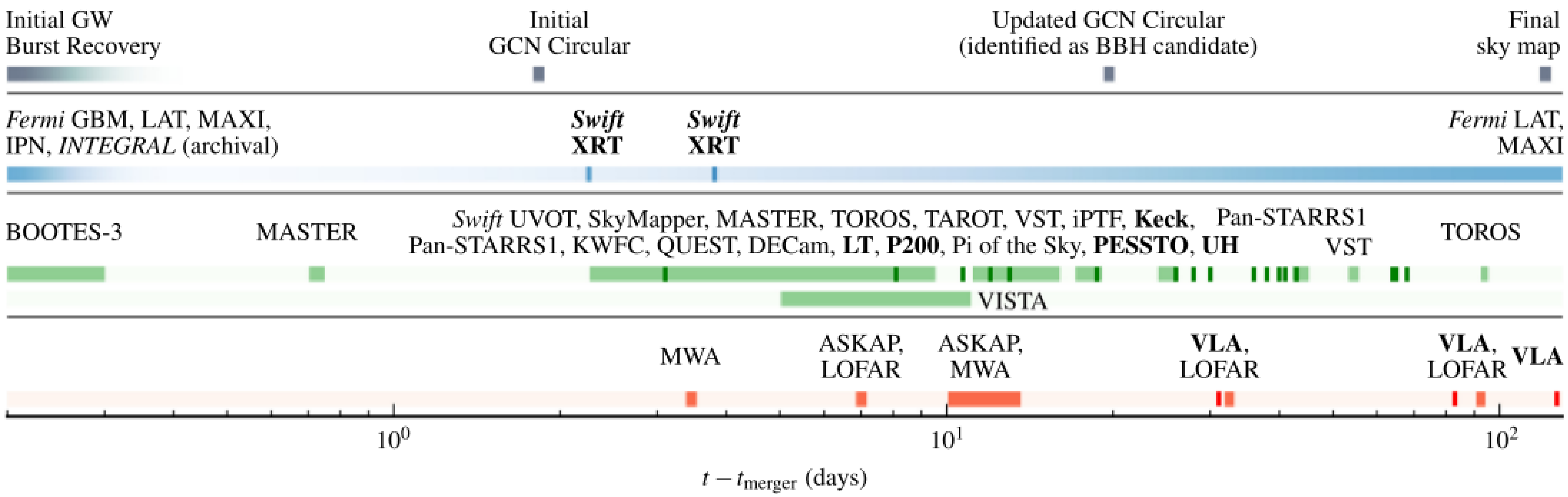
SPRAT

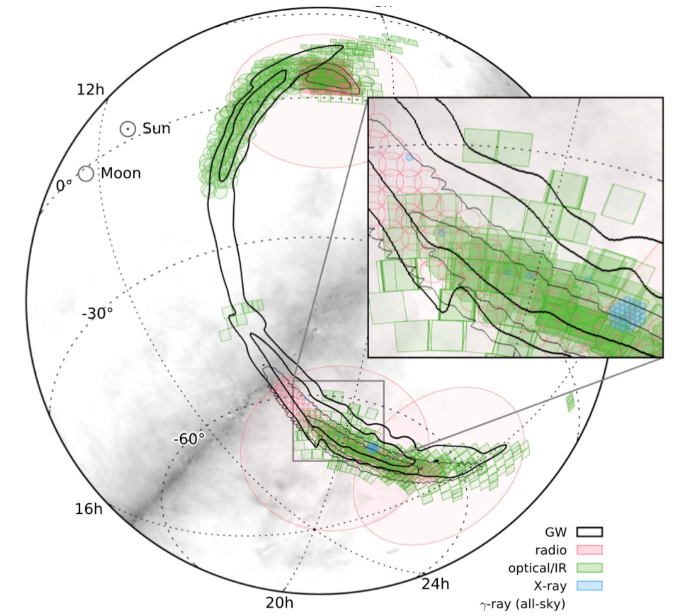
- Long-slit optical spectrometer
- Slit and grism deployable
- R ~ 350; λ range 400-800 nm
- Slit width: 1.8 arcsec
- Pixel scale: 0.44 arcsec
- Acquis. FOV: 7.5 x 1.9 arcmin

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)*



GW150914 campaign





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

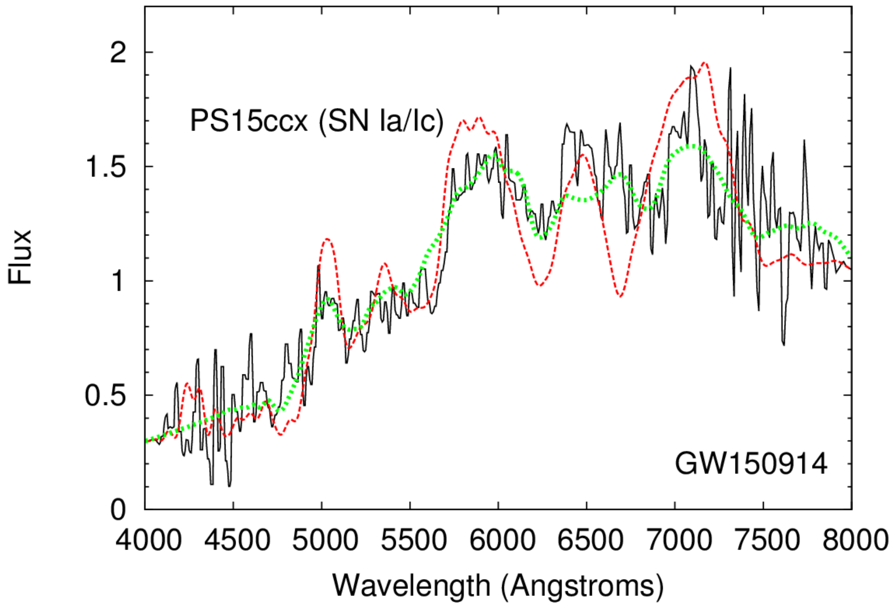
29 candidates classified (iPTF: Kasliwal et al. 2016, Pan-STARRS: Smartt et al. 2016)

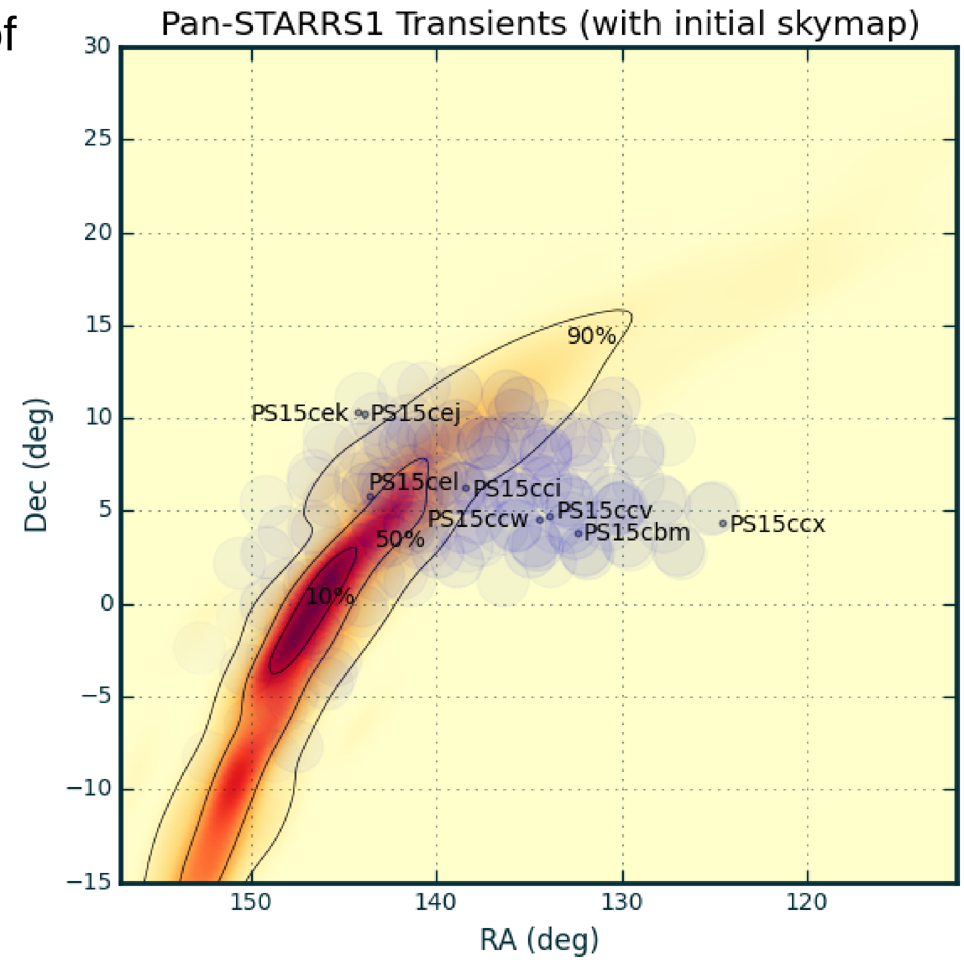
Abbott et al. 2016

GW150914: LT contribution

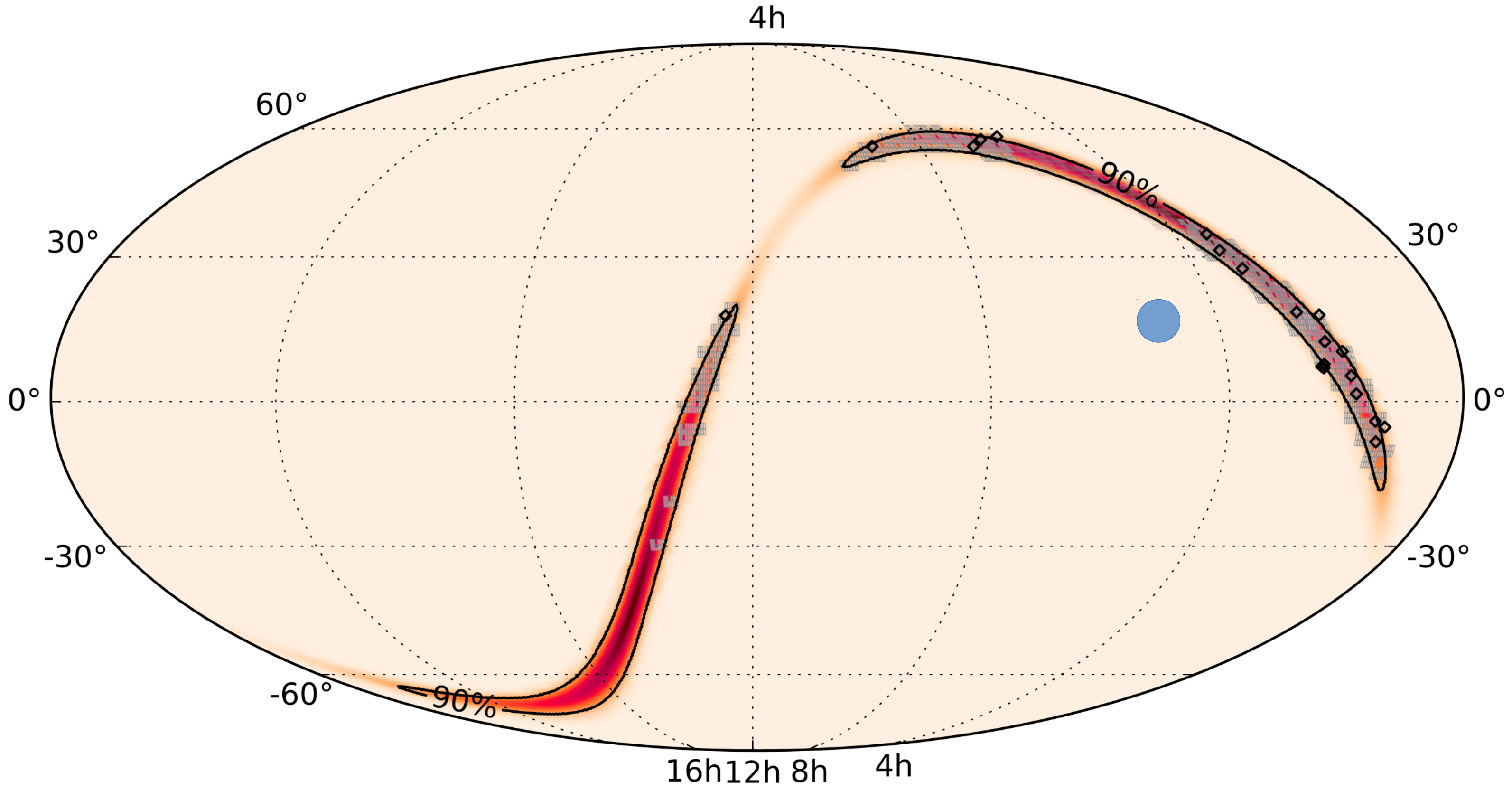
La Palma not well placed for follow-up of this event

Spectrum of one candidate obtained in twilight





GW151226 campaign



iPTF fields overlaid on LIGO skymap

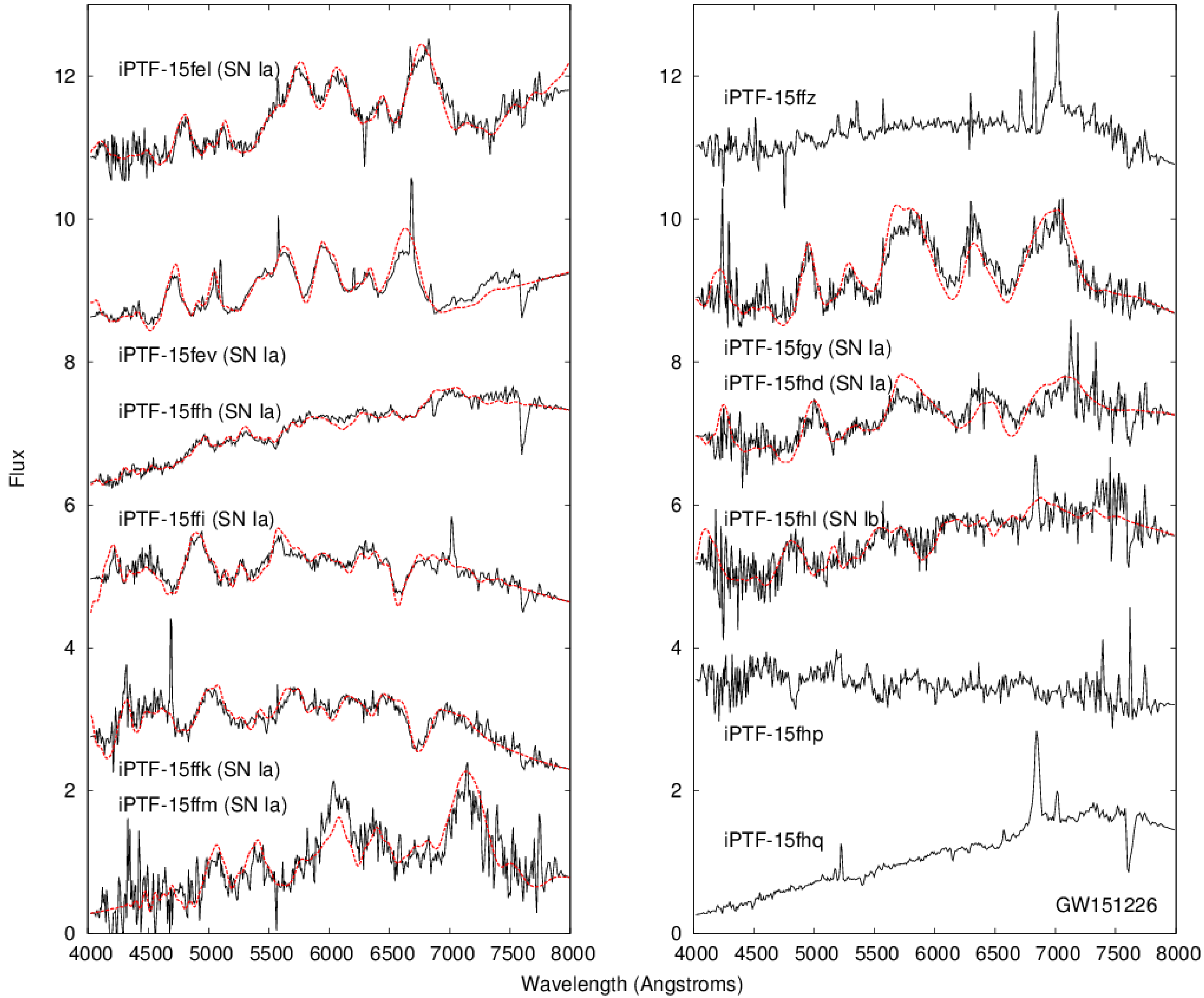
GW151226: LT contribution

Candidate ID	Comments
iPTF-15fed	No transient detected to limiting magnitude of R~19.1
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~0.07
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~19.5
MASTER OTJ020906	No transient detected to limiting magnitude R~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)

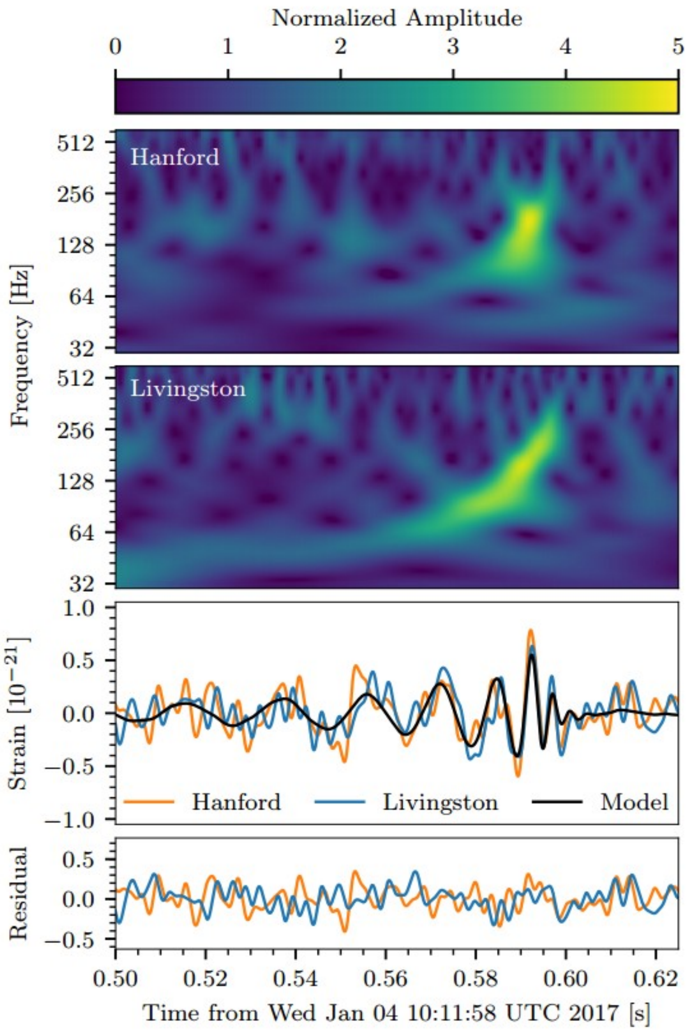
Some non-detections: transient faded below background galaxy level



Copperwheat et al. 2016

GW170104 campaign

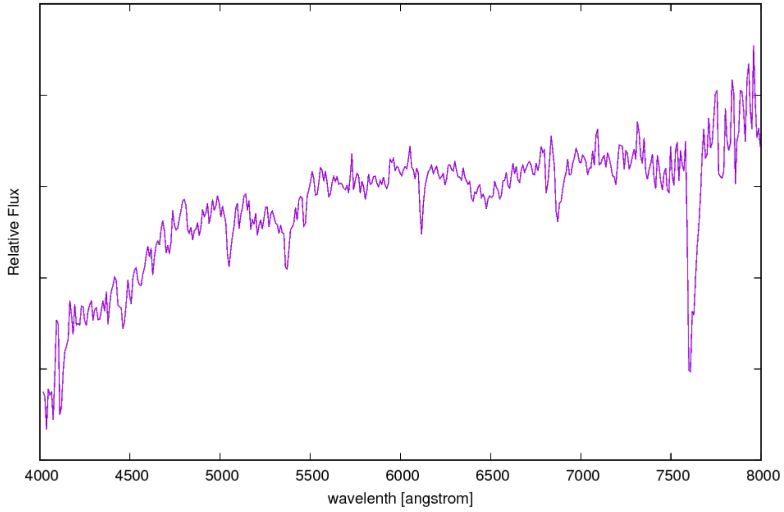
GROWTH
Global Relay of Observatories Watching Transients Happen



Well located for follow-up from La Palma
Many viable transient candidates to pursue

Unfortunately poor weather limited our participation

Four candidates observed. Three galaxy/AGN
One potential Supernova Ic (iPTF17bv)



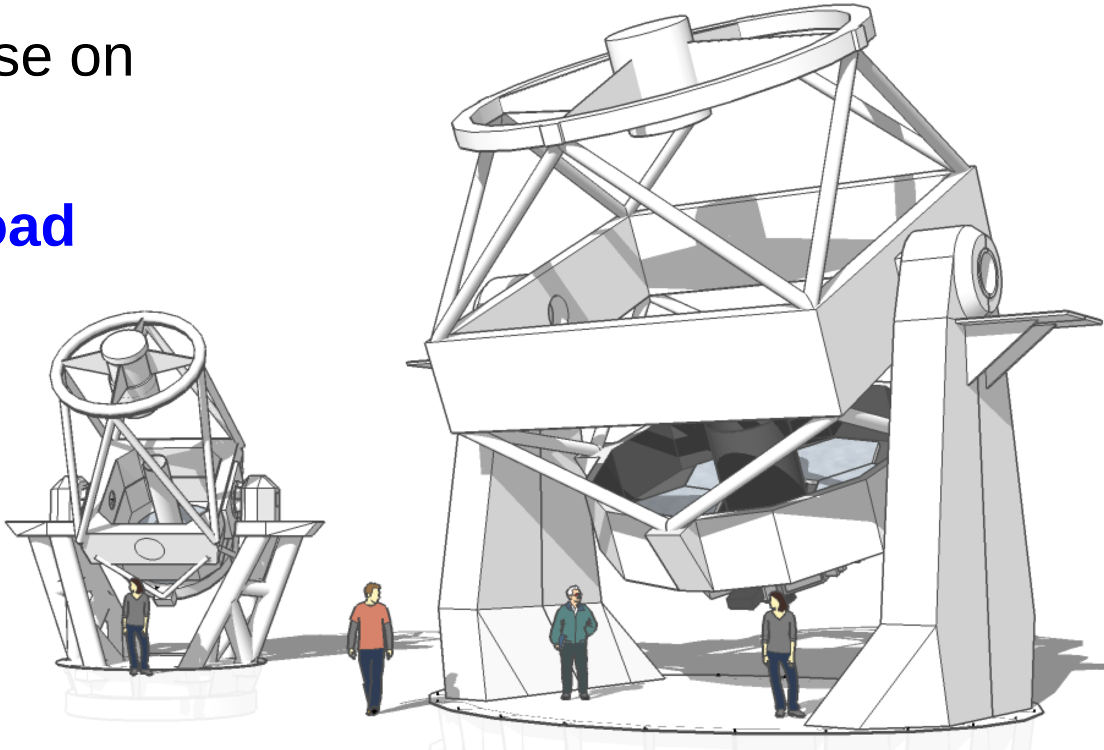
Participation in O2 campaign continues...

Conclusions from early aLIGO campaigns

- 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.
- ***OPTICON funded project currently underay to develop modular SPRAT for deployment on telescopes across the continent***

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



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

O1 follow-up: Copperwheat et al., 2016, MNRAS, 462, 3528
(arXiv:1606.04574)

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