The role of LOFAR in the era of gravitational wave astronomy

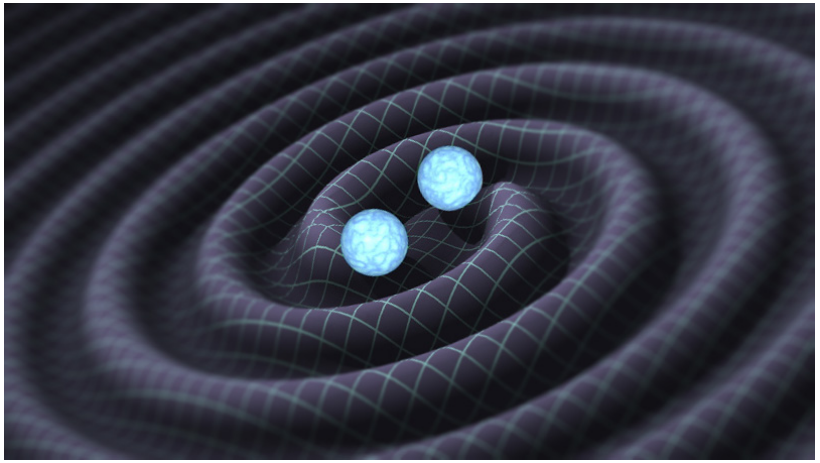
Antonia Rowlinson

11th May 2016

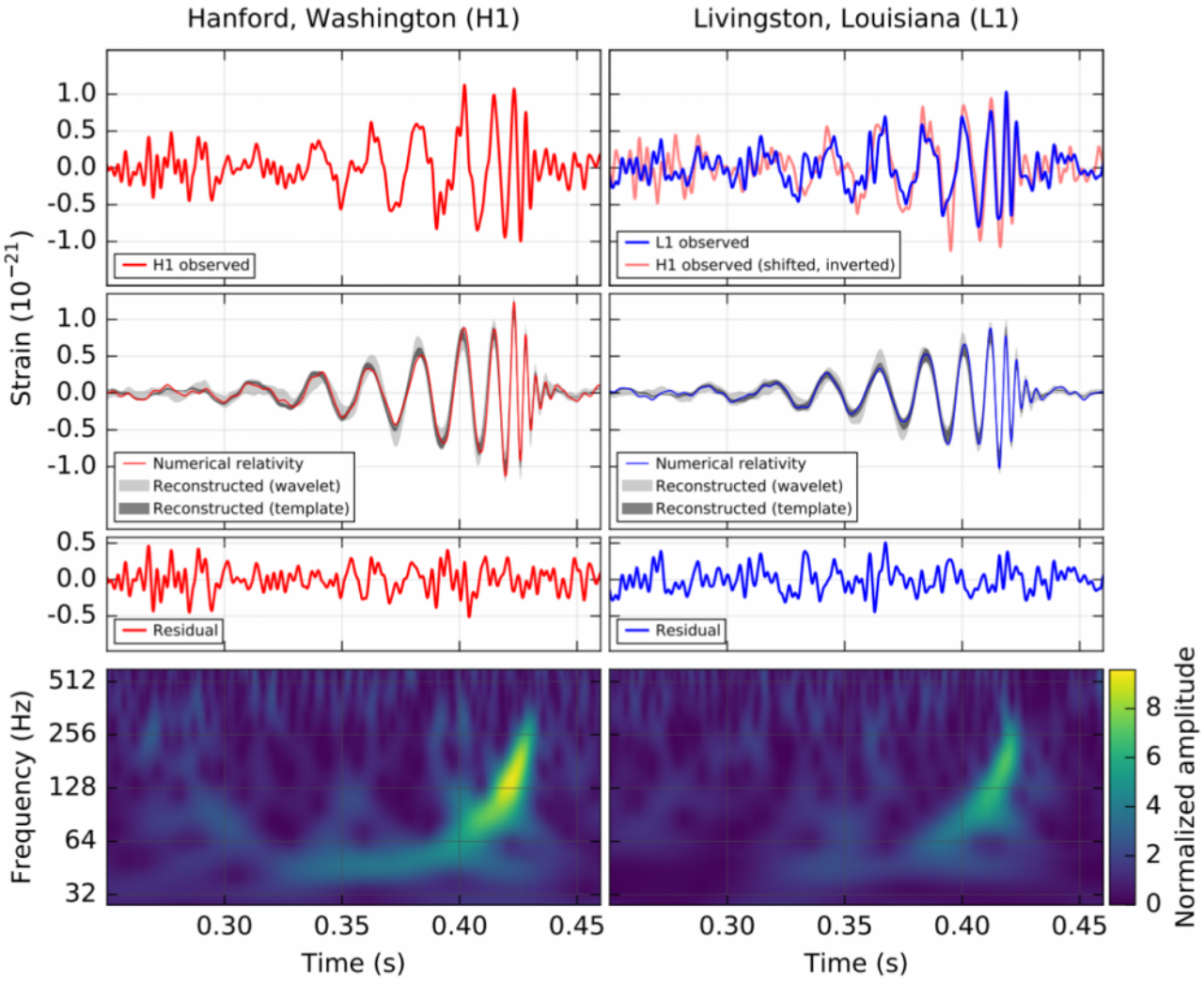
Thanks to Jess Broderick
& the LOFAR-LIGO follow-up team

Compact Binary Mergers

- Detectable as:
  - Short GRBs?
  - Gravitational wave sources



Enter the era of multi-messenger transient astronomy

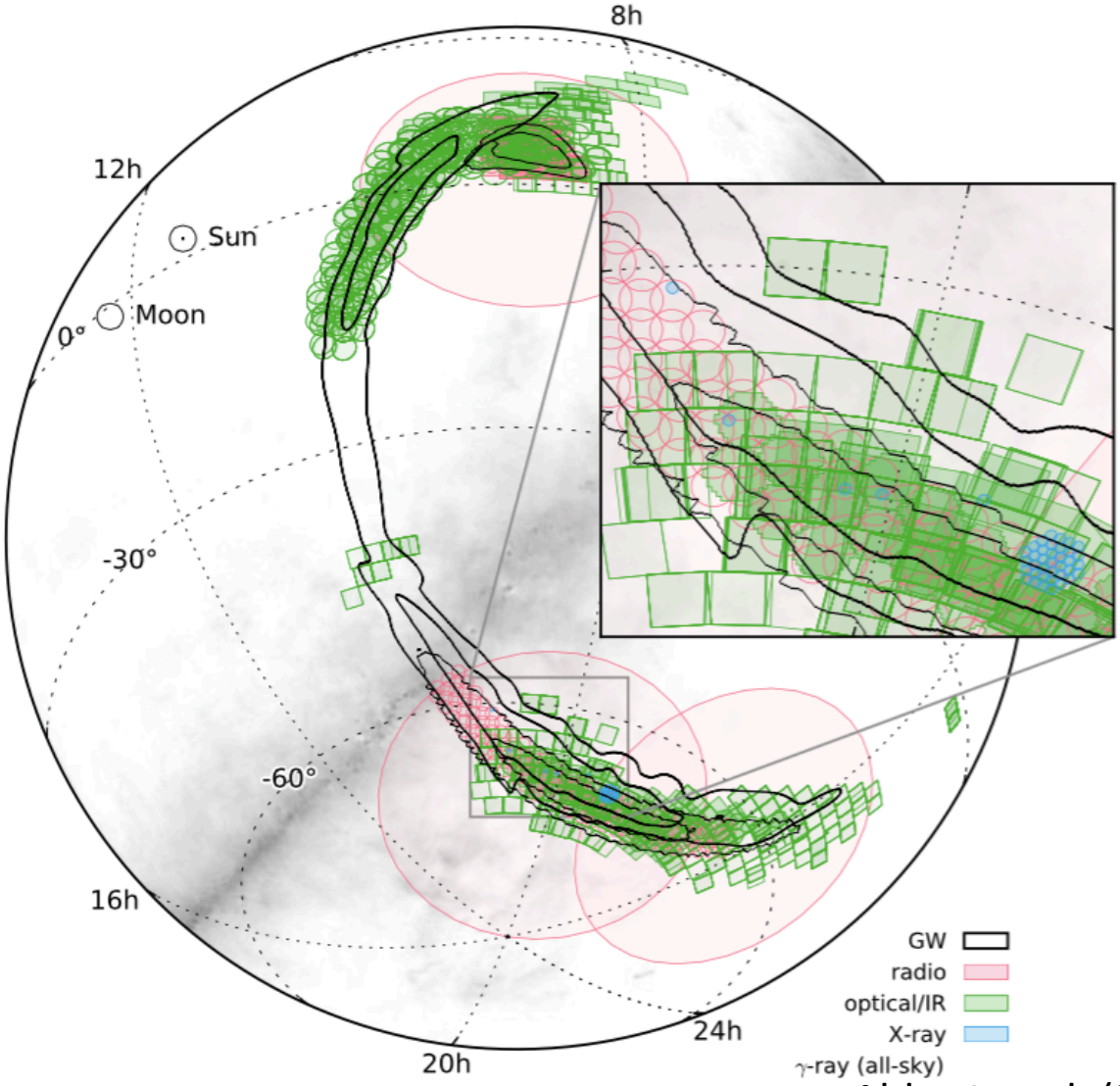


Detection of GW 150914

- Distance of ~400 Mpc
- Masses of 36 and 29 $M_\odot$
- 3 $M_\odot$ of energy released
- Final remnant mass 62 $M_\odot$

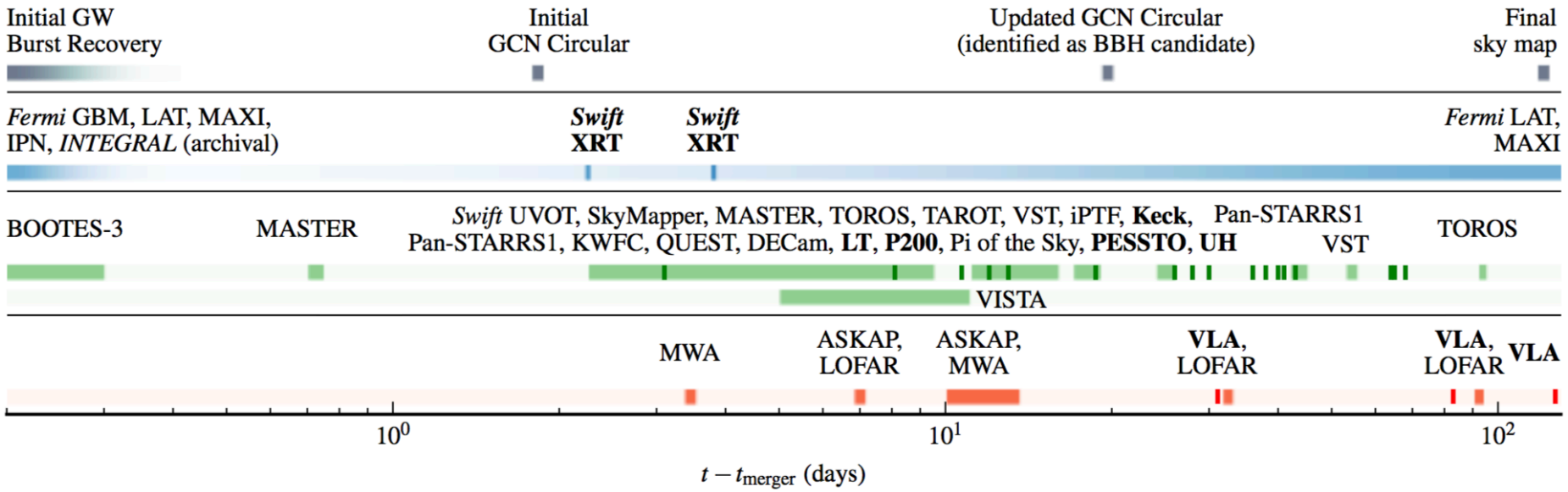
Abbott et al. (2016a)

25 EM facilities responded…



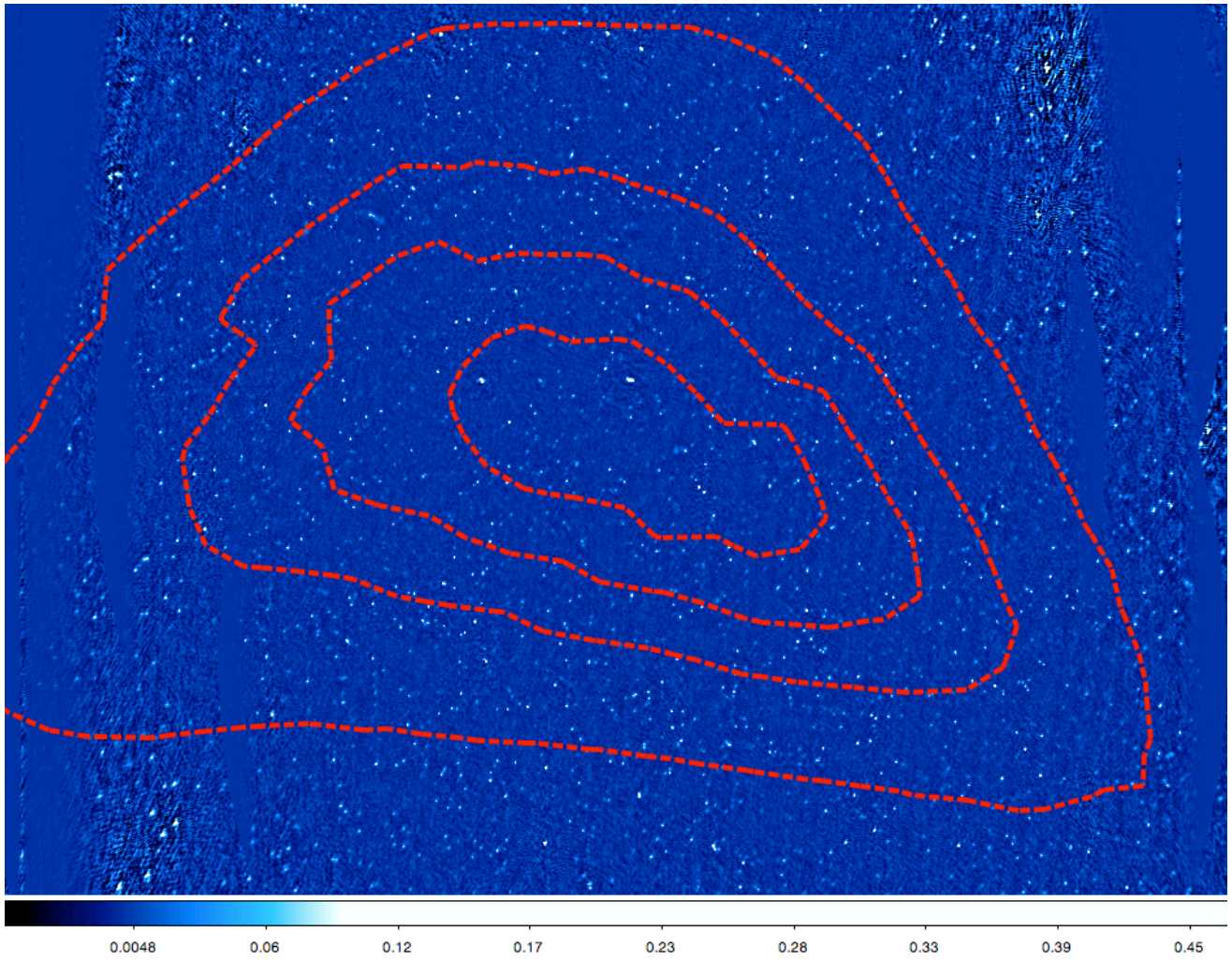
Abbott et al. (2016b, ApJL accepted)

Follow-up timescales



Abbott et al. (2016b, ApJL accepted)

LOFAR Observations



LOFAR DDT4_004
P.I. Jess Broderick

Mosaic of 8 SAPs at 145 MHz with a bandwidth of 11.9 MHz centred on cWB "hot spot"

RMS noise ~2.5 mJy and >2000 sources

Contours:
cWB probability map

Timescales:
- 1 week
- 1 month
- 3 months

Targeting synchrotron counterparts

TITLE: GCN CIRCULAR
NUMBER: 18364
SUBJECT: LIGO/Virgo G184098: LOFAR follow-up
DATE: 15/09/24 21:59:56 GMT
FROM: Peter Jonker at SRON/RU <p.jonker@sron.nl>

J. Broderick (ASTRON), P.G. Jonker (SRON/RU), R.P. Fender (Oxford), A. Rowlinson (UvA, ASTRON), R.A.M.J. Wijers (UvA), B.W. Stappers (Manchester) report on behalf of the project:

On Sept 21, 2015, starting at 06.00 of the localization error range at d the Advanced LIGO trigger G184098 wi Low-Frequency Array [LOFAR] Telescop with the High-Band Antennas (HBA) at (bandwidth 11.9 MHz). In this config simultaneous beams on the sky, where approximately 12 deg^2 (beam FWHM 3. given below:

1) 132.500000 5.166667 08:50:00.00 +
2) 135.287125 5.166667 09:01:08.91 +
3) 129.712875 5.166667 08:38:51.09 +
4) 131.106458 7.572944 08:44:25.55 +
5) 131.106458 2.760389 08:44:25.55 +
6) 133.893542 7.572944 08:55:34.45 +
7) 133.893542 2.760389 08:55:34.45 +
8) 128.319333 2.760389 08:33:16.64 +

The observations cover roughly 50 sq was observed for a total of 3 hr wit pre-processing. These fields will be exposures, on provisional time-scale is ongoing.

TITLE: GCN CIRCULAR
NUMBER: 18424
SUBJECT: LIGO/Virgo G184098: LOFAR follow-up
DATE: 15/10/19 21:03:56 GMT
FROM: Antonia Rowlinson at U van Amsterdam

J. Broderick (ASTRON), P.G. Jonker (SRON/RU) Rowlinson (UvA, ASTRON), R.A.M.J. Wijers (UvA (Manchester) report on behalf of the LOFAR Tran project

On Oct 16, 2015, starting at 03.41 (UTC), we obs of the localization error range at declinations larg the Advanced LIGO trigger G184098 with the ILT Low-Frequency Array [LOFAR] Telescope). The with the High-Band Antennas (HBA) at a centre f (bandwidth 11.9 MHz). In this configuration, the I simultaneous beams on the sky, where each bea approximately 12 deg^2 (beam FWHM 3.9 degre given below:

1) 132.500000 5.166667 08:50:00.00 +05:10:00.
2) 135.287125 5.166667 09:01:08.91 +05:10:00.
3) 129.712875 5.166667 08:38:51.09 +05:10:00.
4) 131.106458 7.572944 08:44:25.55 +07:34:22.
5) 131.106458 2.760389 08:44:25.55 +02:45:37.
6) 133.893542 7.572944 08:55:34.45 +07:34:22.
7) 133.893542 2.760389 08:55:34.45 +02:45:37.
8) 128.319333 2.760389 08:33:16.64 +02:45:37.

The observations cover roughly 50 square degre was observed for a total of 3.7 hr with 10s time re pre-processing.

This is the second set of observations of these fi run on Sept 21, 2015 (GCN 18364). The fields wi more with the same exposures, on a provisional t months from now. Analysis is ongoing.

TITLE: GCN CIRCULAR
NUMBER: 18690
SUBJECT: LIGO/Virgo G184098: LOFAR follow-up
DATE: 15/12/14 16:54:15 GMT
FROM: Antonia Rowlinson at U van Amsterdam <b.a.rowlinson@uva.nl>

A. Rowlinson (UvA, ASTRON), J. Broderick (ASTRON), P.G. Jonker (SRON/RU), R.P. Fender (Oxford), R.A.M.J. Wijers (UvA), B.W. Stappers (Manchester) report on behalf of the LOFAR Transients Key Science project

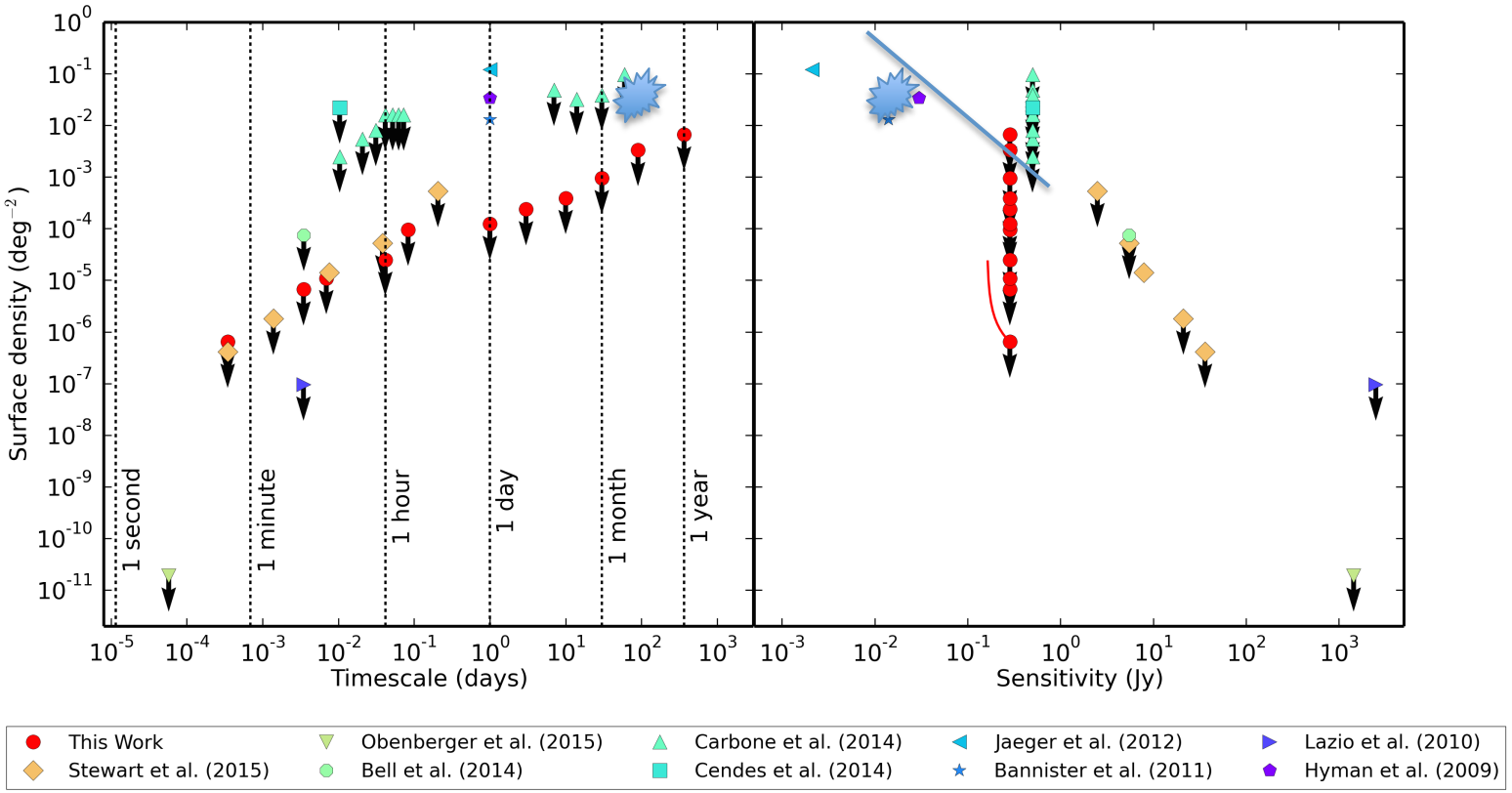
On Dec 14, 2015, starting at 02.00 (UTC), we observed a large fraction of the localization error range at declinations larger than 0 degrees of the Advanced LIGO trigger G184098 with the ILT (International Low-Frequency Array [LOFAR] Telescope). This is the final set of LOFAR observations of these fields, our other two runs were completed on Sept 21, 2015 (GCN 18364) and Oct 16, 2015 (GCN 18424). The observations were obtained with the High-Band Antennas (HBA) at a centre frequency of 145 MHz (bandwidth 11.9 MHz). In this configuration, the ILT can provide 8 simultaneous beams on the sky, where each beam has a field of view of approximately 12 deg^2 (beam FWHM 3.9 degrees). The beam centres are given below:

1) 132.500000 5.166667 08:50:00.00 +05:10:00.0
2) 135.287125 5.166667 09:01:08.91 +05:10:00.0
3) 129.712875 5.166667 08:38:51.09 +05:10:00.0
4) 131.106458 7.572944 08:44:25.55 +07:34:22.6
5) 131.106458 2.760389 08:44:25.55 +02:45:37.4
6) 133.893542 7.572944 08:55:34.45 +07:34:22.6
7) 133.893542 2.760389 08:55:34.45 +02:45:37.4
8) 128.319333 2.760389 08:33:16.64 +02:45:37.4

The observations cover roughly 50 square degrees in total. Each field was observed for a total of 3.7 hr with 10s time resolution after pre-processing.

Analysis is ongoing.

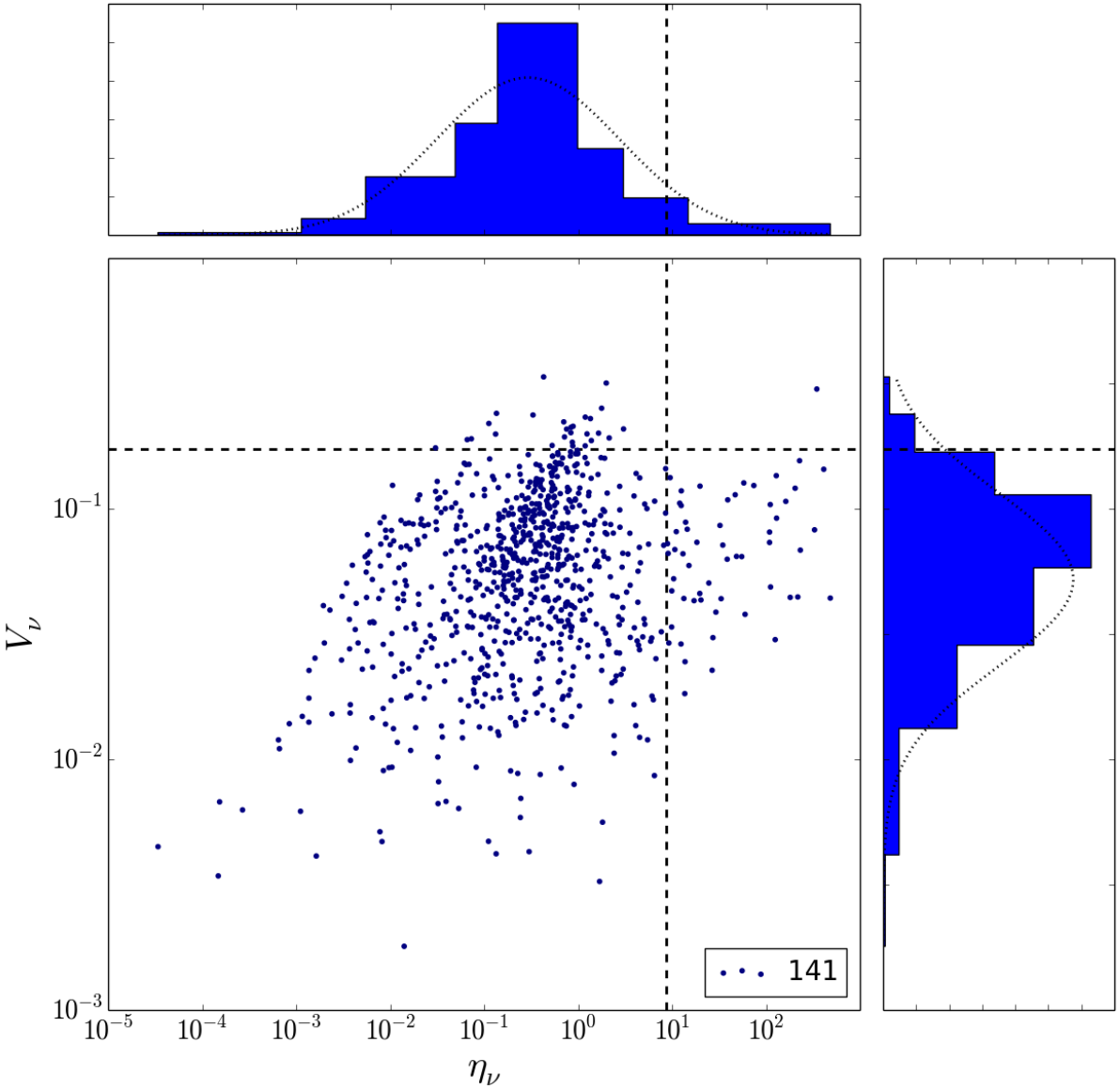
Expected transient rates



- Surveyed ~50 square degrees on a 3 month timescale with 6 sensitivity of 15 mJy at 145 MHz
- We expect <14 transients in the field

Rowlinson et al. (2016)

Transient and Variability Analysis



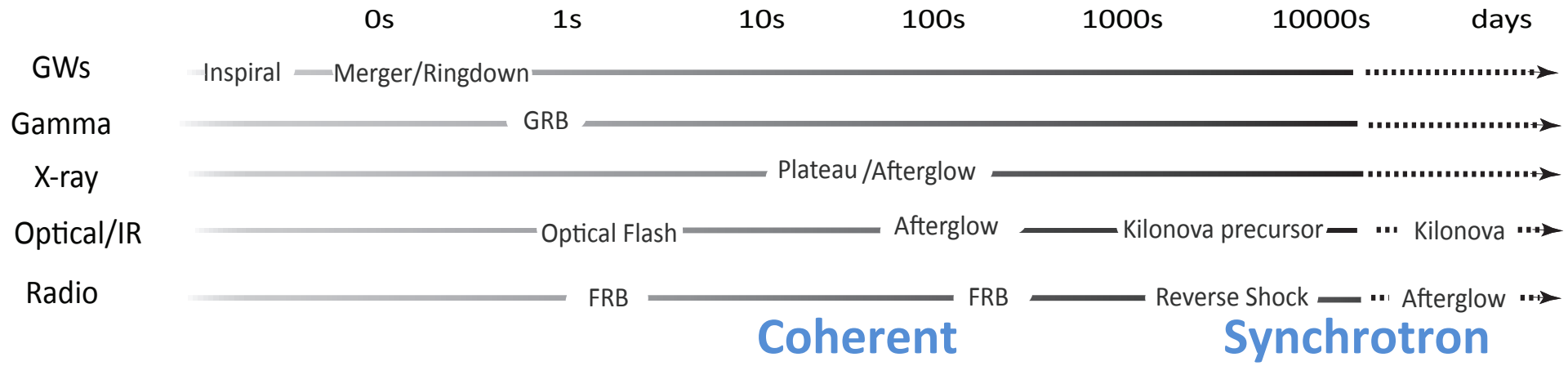
Processed using the LOFAR Transients Pipeline (Swinbank et al. 2015)

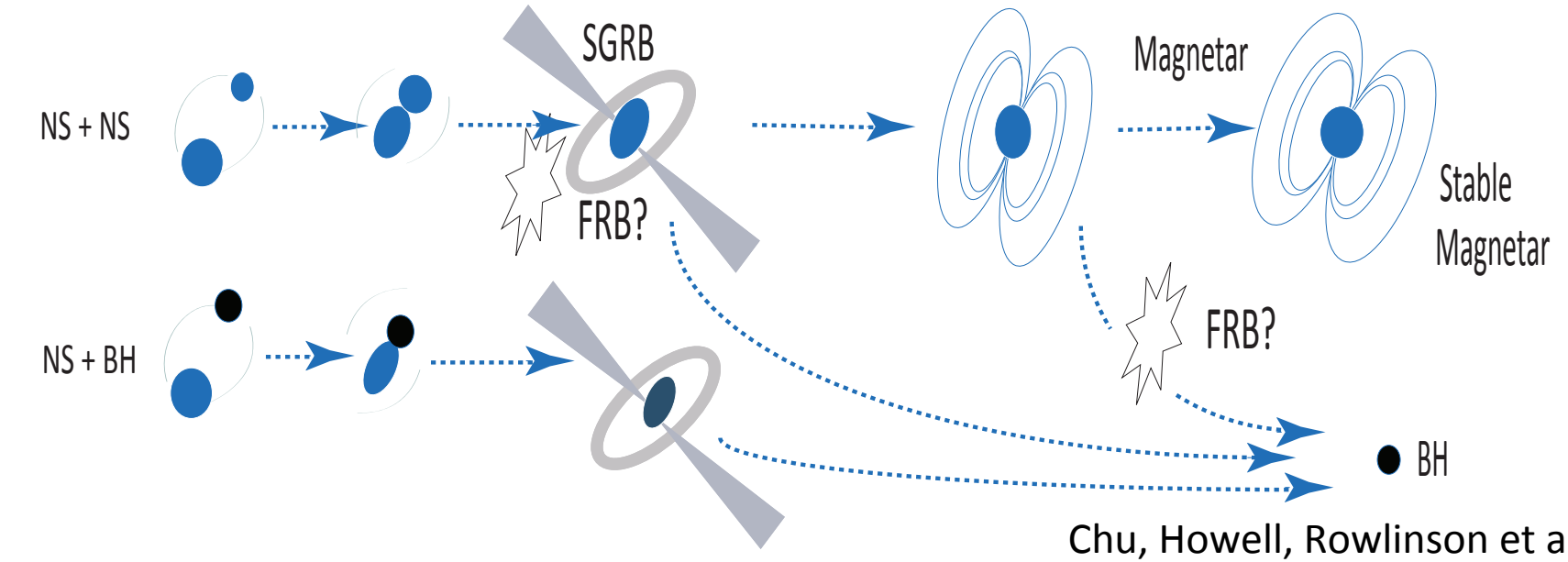
No convincing transient sources detected above a 6σ detection threshold

1 variable source detected – a known scintillating pulsar

Detailed analysis on-going

Expected emission





Chu, Howell, Rowlinson et al. (2015)

Summary

- Gravitational waves have been detected from a binary black hole merger although very uncertain expectations for EM counterparts

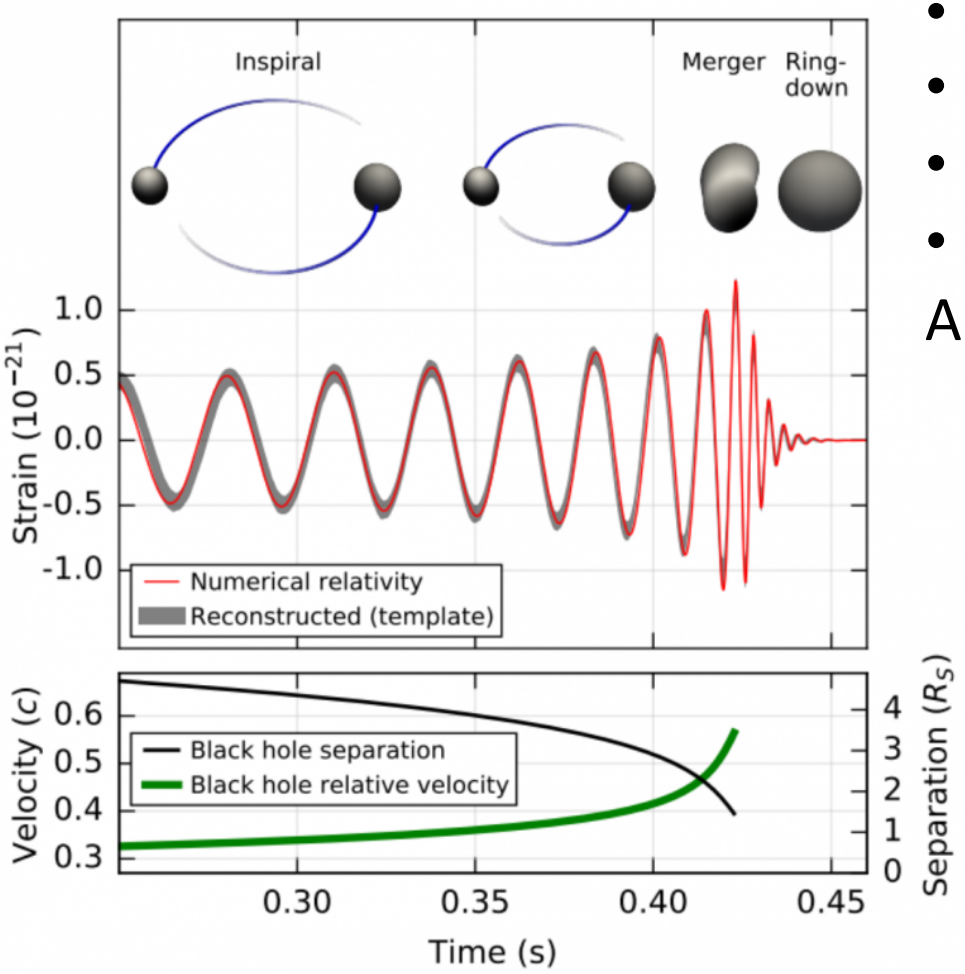
- LOFAR is one of 3 wide field radio facilities currently chasing these events (and only one in the Northern Hemisphere)

- Only a matter of time to get a neutron star merger (and known EM counterparts)

- LOFAR can chase the late-time synchrotron, but key discovery space is for coherent emission – requiring a rapid response mode for LOFAR

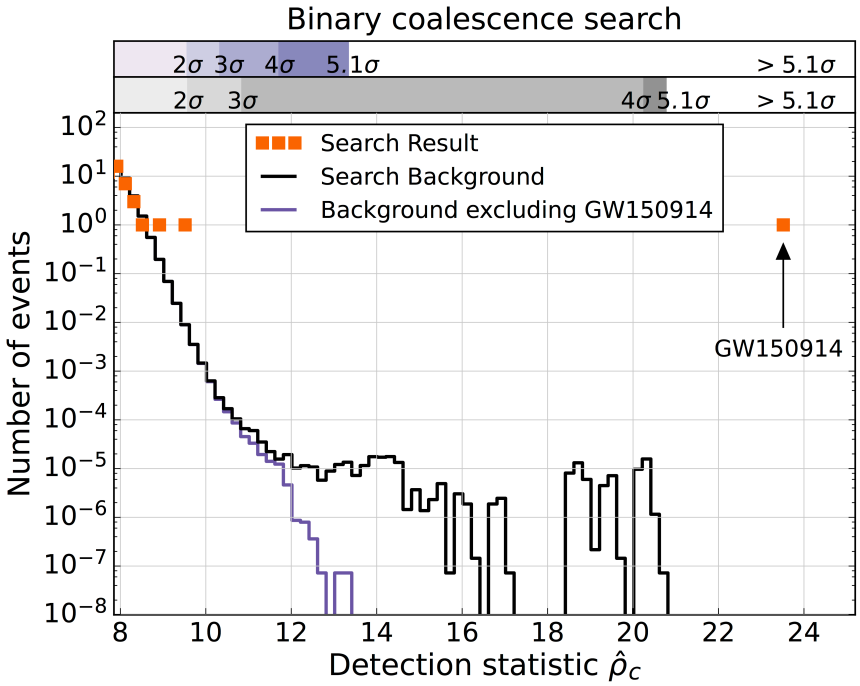
SPARE SLIDES

Detection of 2 black holes merging

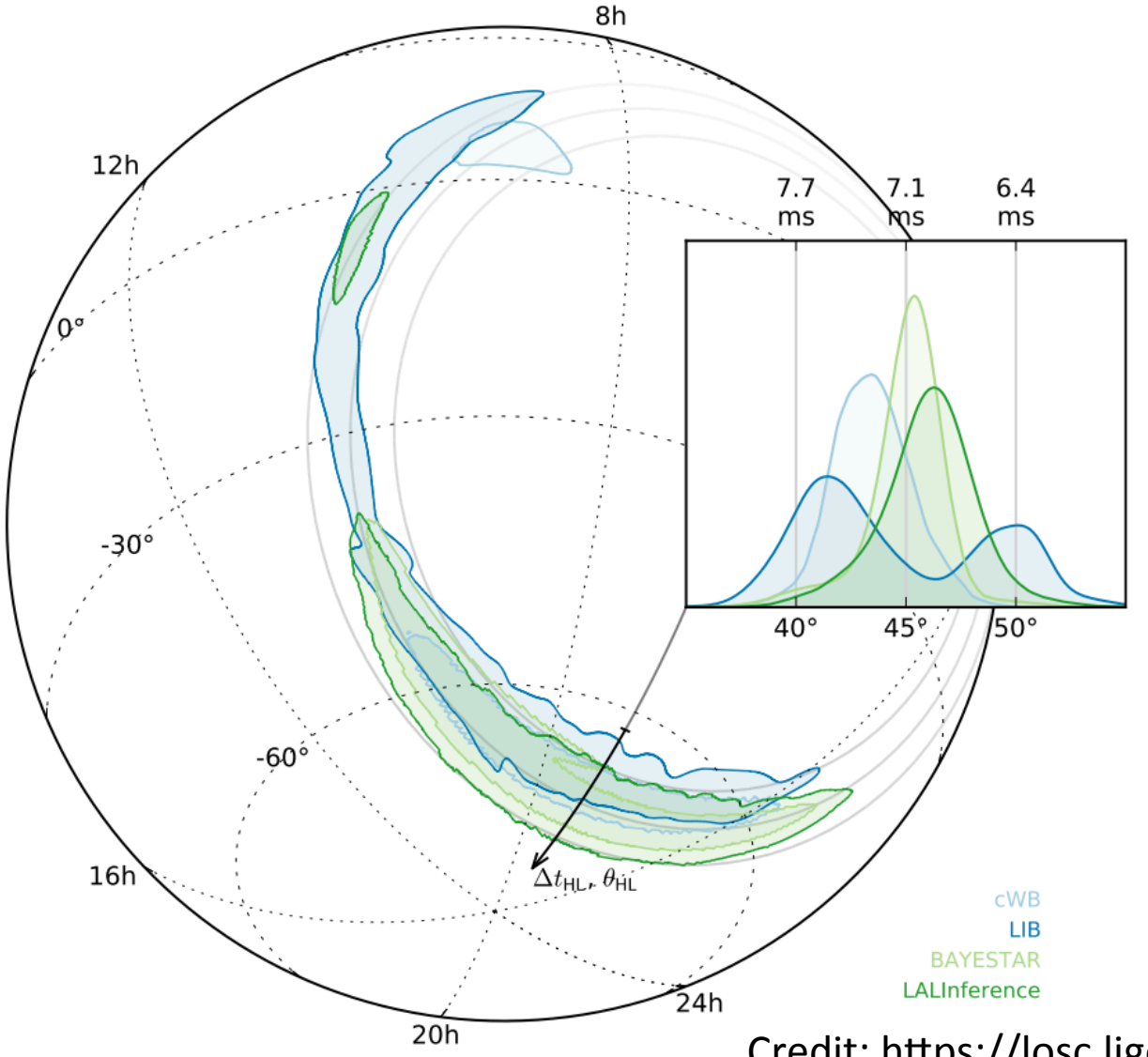


- Distance of ~400 Mpc
- Masses of 36 and 29 $M_\odot$
- 3 $M_\odot$ of energy released
- Final remnant mass 62 $M_\odot$

Abbott et al. (2016)



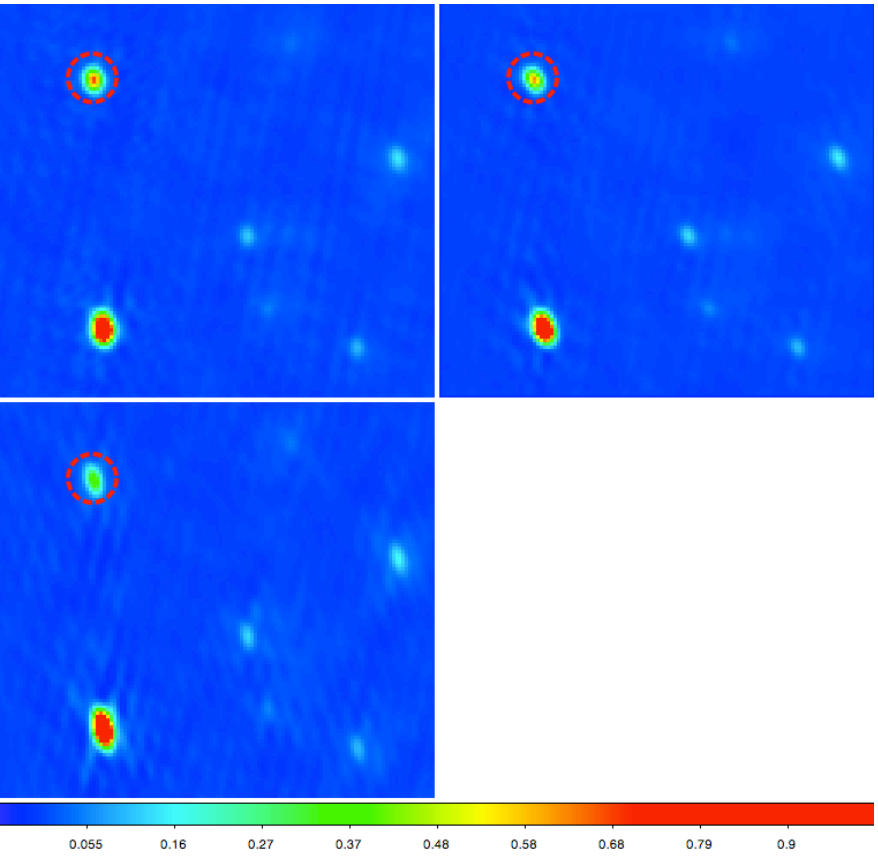
GW 150914: position constraints

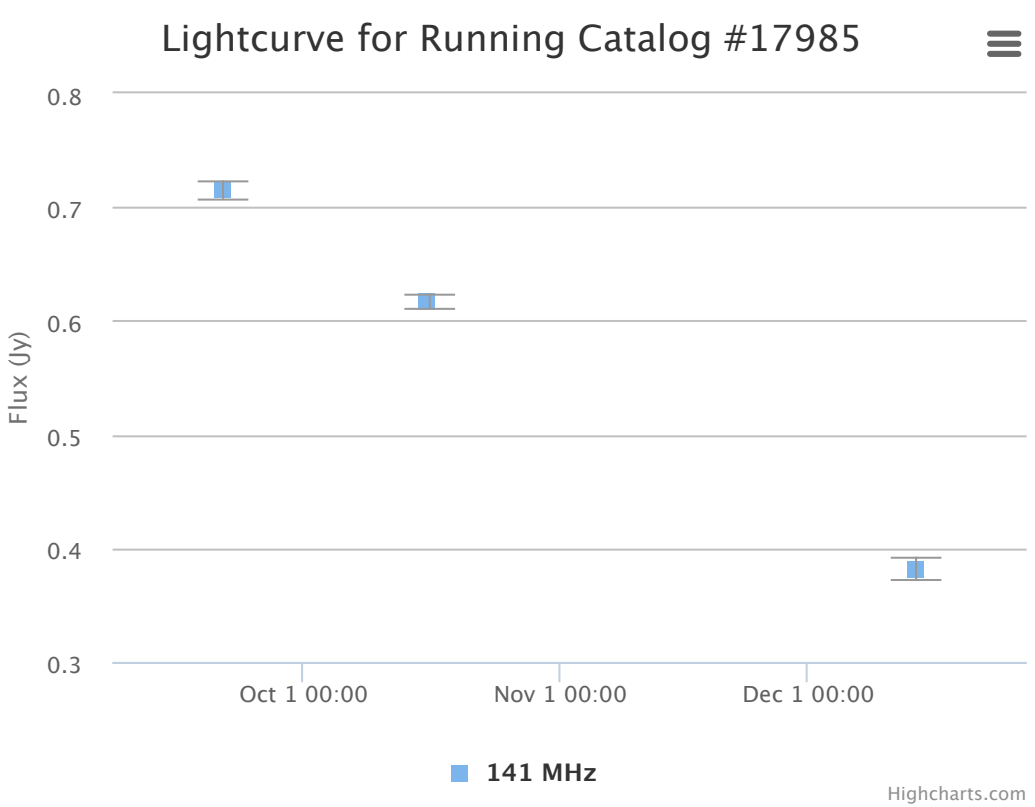


- cWB and LIB pipelines available
- cWB was the triggering pipeline

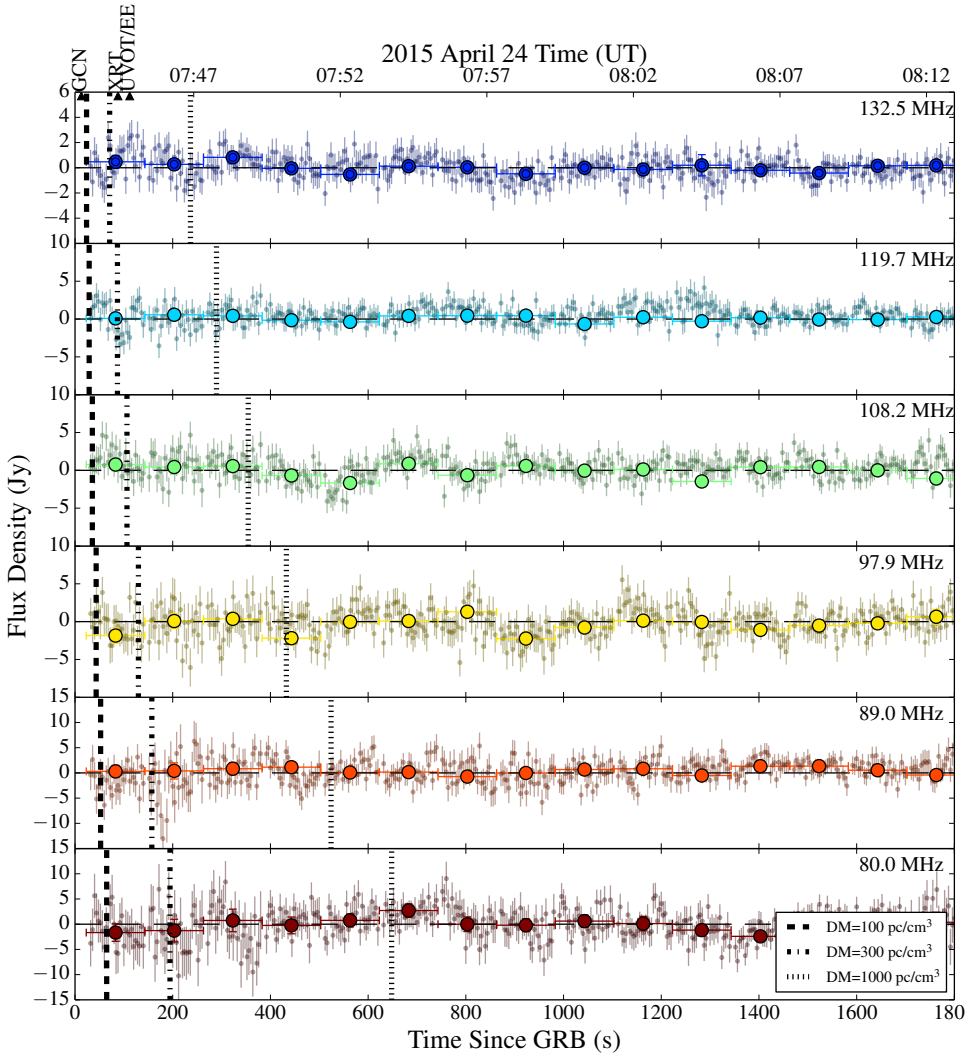
Credit: https://losc.ligo.org/events/GW150914/

Variable source: PSR B0834+06

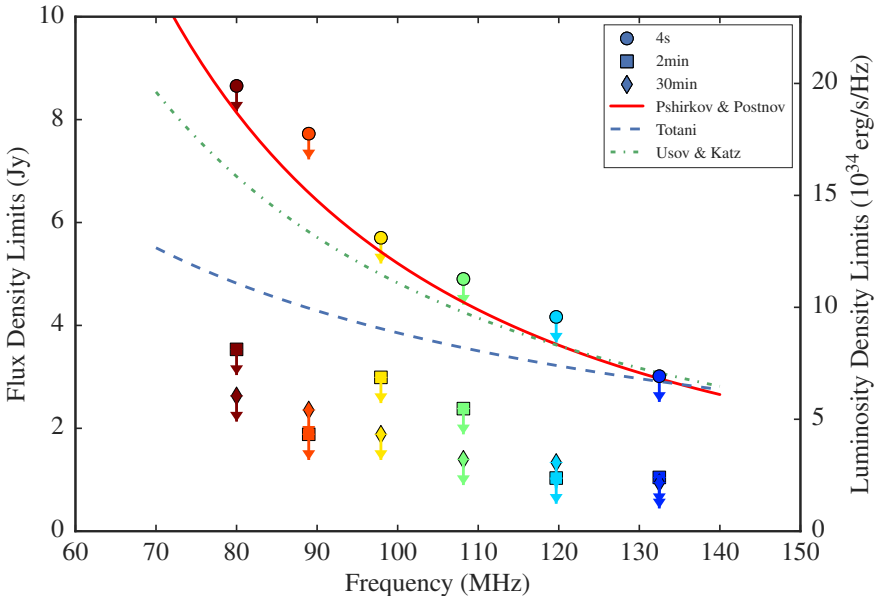




Short GRB 150424A
(MWA triggered observation)

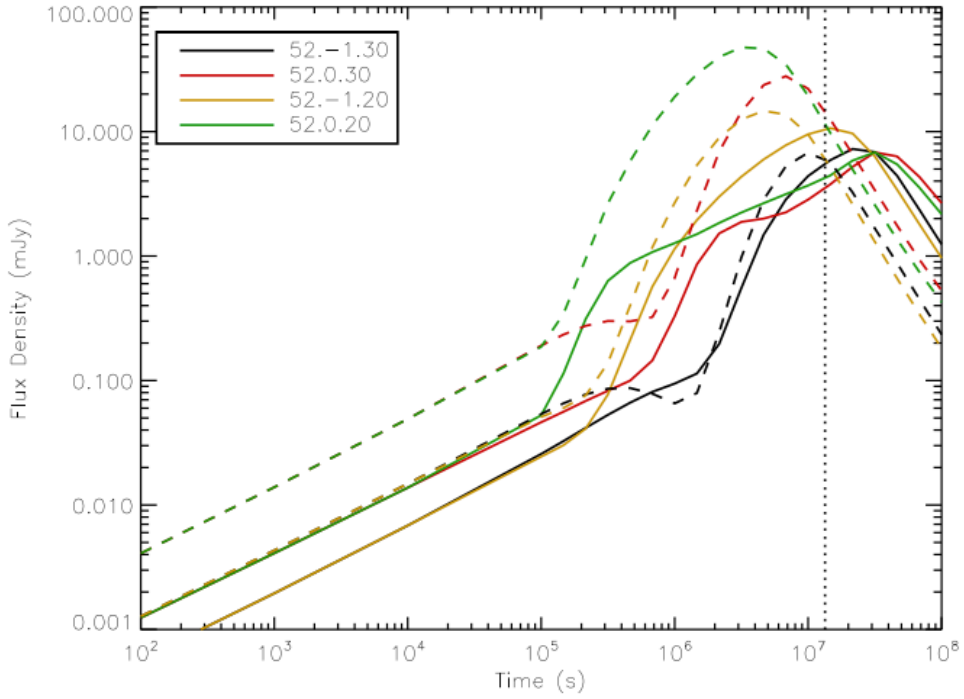


- 26 seconds after GRB
- 10 seconds after VOEvent
- Redshift > 0.7



Kaplan, Rowlinson et al. (2015)

Maybe late-time low frequency emission from BH-BH mergers?



150 MHz lightcurves predicted assuming a typical (but optimistic) synchrotron afterglow following a GRB

Morsony, Workman & Ryan (2016)

Modeling the Afterglow of GW150914-GBM

Brian J. Morsony[1⋆], Jared C. Workman[2], Dominic M. Ryan[3]
[1] *Department of Astronomy, University of Maryland, 1113 Physical Sciences Complex, College Park, MD, 20742-2421, USA*
[2] *Dept. of Physical and Environmental Sciences, Colorado Mesa University, Grand Junction, CO, 81501, USA*
[3] *Dept. pf Astronomy, University of California, Berkeley, 501 Campdell Hall #3411, Berkeley, CA, 94720-4311, USA*

18 February 2016

Electromagnetic Afterglows Associated with Gamma-Ray Emission Coincident with Binary Black Hole Merger Event GW150914

Ryo Yamazaki[1], Katsuaki Asano[2], Yutaka Ohira[1]
[1] *Department of Physics and Mathematics, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara 252-5258, Japan*
[2] *Institute for Cosmic Ray Research, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8582, Japan*

ELECTROMAGNETIC COUNTERPARTS TO BLACK HOLE MERGERS DETECTED BY LIGO

Abraham Loeb[1]
Draft version February 24, 2016

SHORT GAMMA-RAY BURSTS FROM THE MERGER OF TWO BLACK HOLES

Rosalba Perna[1], Davide Lazzati[2], Bruno Giacomazzo[3,4]
[1]Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY, 11794, USA
[2] Department of Physics, Oregon State University, 301 Weniger Hall, Corvallis, OR 97331, USA
[3] Physics Department, University of Trento, via Sommarive 14, I-38123 Trento, Italy and
[4] INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, via Sommarive 14, I-38123 Trento, Italy
Draft version February 17, 2016