LOFAR observations of gravitational wave merger events and GRBs

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Supervised by Dr. Antonia Rowlinson, Dr. Jess Broderick and Prof. Ralph Wijers

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Gravitational waves (GWs) from compact binary mergers



BH + BH

BH + NS

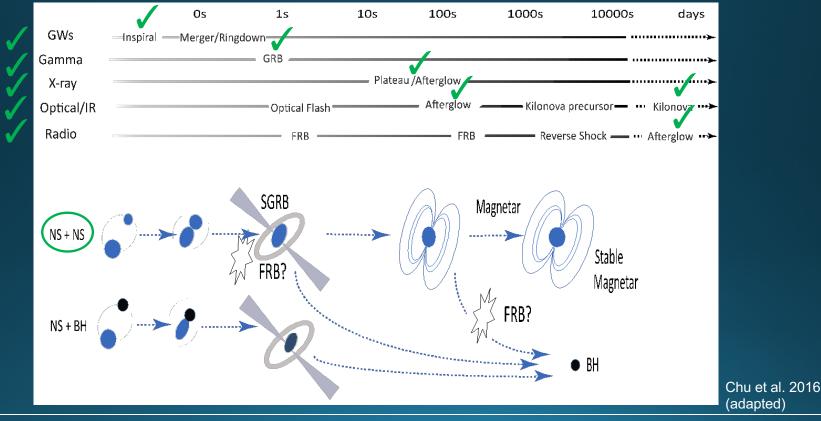
NS + NS

Multimessenger observations of GW170817

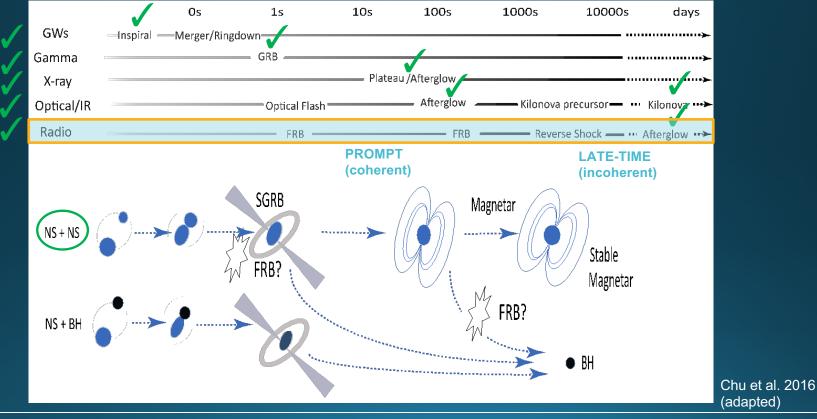
GW					
LIGO, Virgo					
<u></u>			_		
γ-ray Fermi, INTEGRAL, Astrosat, IPN, Insight-HXMT, Sw		Viad			
	III, AGILE, CALET, H.E.S.S., HAWC, KONUS-V	Vind			1 I I I I I I I I I I I I I I I I I I I
X-ray					
Swift, MAXI/GSC, NuSTAR, Chandra, INTEGRAL					
			1 1		
UV					
Swift, HST			••		
				1.1.	
Optical				•	-
Swope, DECam, DLT40, REM-ROS2, HST, Las Cur HCT, TZAC, LSGT, T17, Gemini-South, NTT, GRON	nbres, SkyMapper, VISTA, MASTER, Magella D. SOAR, ESO-VLT, KMTNet, ESO-VST, VIR	n, Subaru, Pan-STARBS1, T. SALT. CHILESCOPE, TOR	os.		
BOOTES-5, Zadko, iTelescope.Net, AAT, Pi of the S	ky, AST3-2, ATLAS, Danish Tel, DFN, T80S, E	ABA			
IR					
REM-ROS2, VISTA, Gemini-South, 2MASS, Spitzer,	NTT, GROND, SOAR, NOT, ESO-VLT, Ranat	a Telescope, HST			
Radio				/	
ATCA, VLA, ASKAP, VLBA, GMRT, MWA, LOFAR, I	.WA ACMA, OVRO, EVN, e-MERLIN, MeerKA	AT, Parkes, SRT, Effelsberg			
	10-2	10-1			101
-100 -50 0 50	10-2	10 ⁻¹	1)0	101
$t - t_c$ (s)		$t-t_c$ (days)	/	
/			1	/	

Abbott et al. 2017

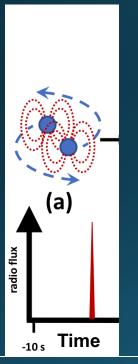
Possible evolutions and accompanying emission ✓ observed for GW170817



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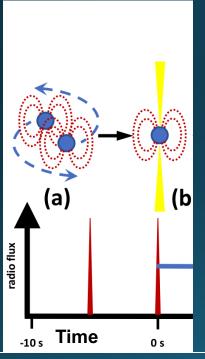


Prompt Radio Emission PRE-MERGER



- Interacting NS magnetic fields e.g. Lupunov & Panchenko 1996
- GW + plasma interaction e.g. Moortgat & Kuijpers 2003

Prompt Radio Emission MERGER

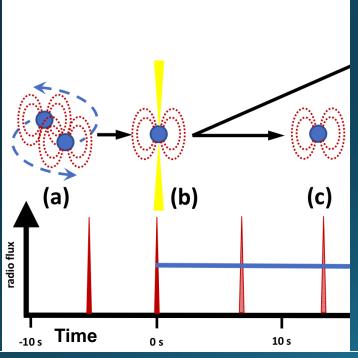


interactions within the relativistic jet

e.g. Usov & Katz 2000

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Prompt Radio Emission POST-MERGER



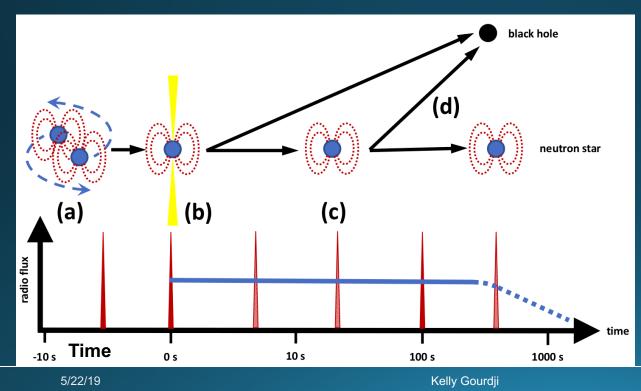
What is the merger remnant?

Key discovery space:

- jet launching mechanism
- NS equation of state (EOS)



Prompt Radio Emission POST-MERGER



Hypermassive NS collapse to BH → FRB? e.g. Falcke & Rezzolla 2014

Magnetar

- FRB-like emission
- Pulsar-like emission

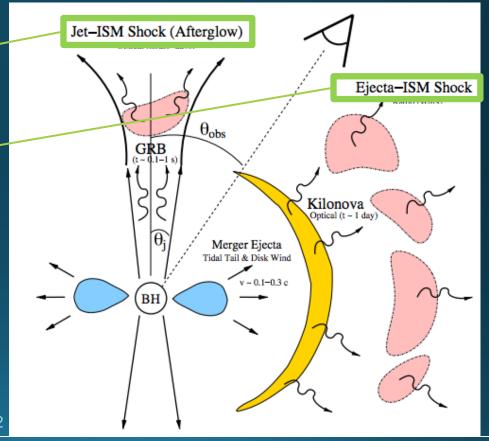
LOW-LATENCY REQUIRED!

Late-time radio emission ✓ observed for GW 170817

Jet afterglow: jet structure-

Dynamical ejecta afterglow: EOS

Afterglow brightness depends on ISM density.



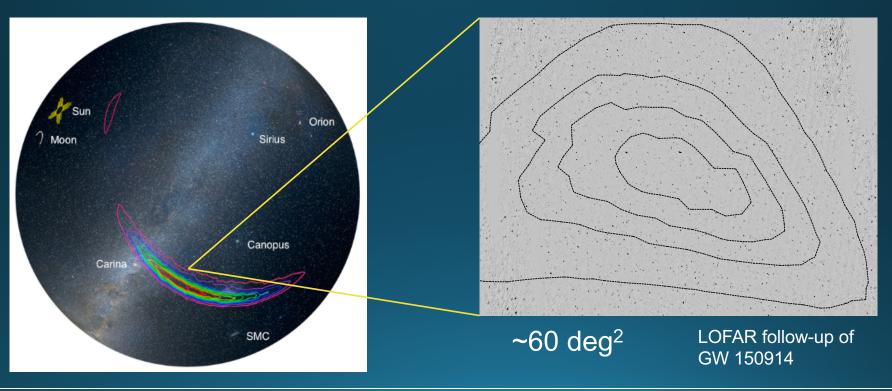
Adapted from Metzger & Berger 2012

LOFAR HBA observations



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Why LOFAR? Large instantaneous field of view

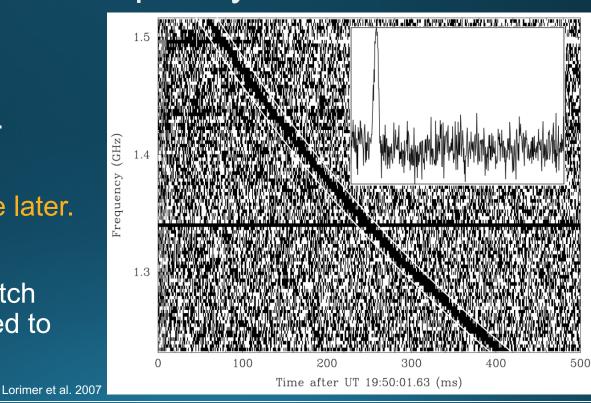


Why LOFAR? Low frequency

Dispersion delay scales inversely with frequency.

Lower frequencies arrive later.

Gives us a chance to catch coherent emission related to mergers!



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LOFAR rapid response

On source within <5 mins of trigger

Simultaneous beamformed + interferometric observations

Iofartest.control.lofar:8080/mom3/user/project/setUpMom2ObjectDetails.do?view=statushistorv ABP \sim Details 🕅 Close Window test-lofar > TARGET A > AARTFAAC-TRIGGERED > Target/1/TO 🥐 <u>Help</u> General Info Dataproducts **Reports and Remarks** Status History Parset Status Date Changed by finished 2017/04/10 09:13 UTC System, Qpid running 2017/04/10 09:10 UTC System, Opid scheduled 2017/04/10 09:07 UTC System, Qpid approved 2017/04/10 09:07 UTC System, Qpid opened 2017/04/10 09:07 UTC System, Qpid

See https://asterics2020.eu for more info.

LOFAR GRB triggers

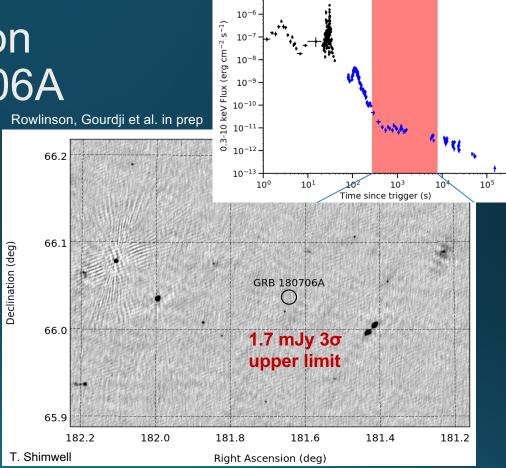
- GW detectors sensitive out to only z~0.04
- SGRBs typically $0.1 \le z \le 1$
 - higher dispersion delays
- Swift alerts issued in seconds

LOFAR Observation of long GRB 180706A

On source 4.5 minutes post-trigger!

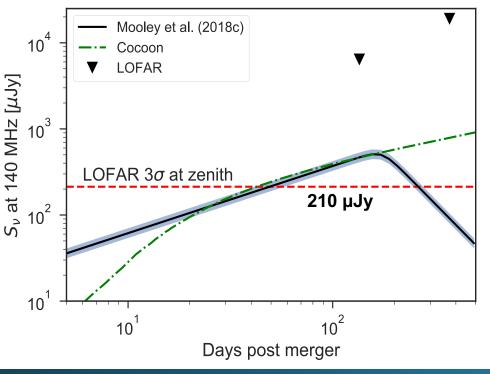
2-hr integration targeting pulsar-like emission

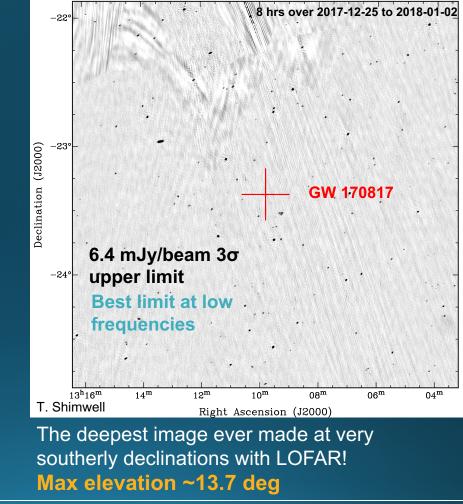
Three orders of magnitude deeper than the best previous study (Kaplan, Rowlinson et al. 2015).



Late-time observations of GW 170817

Broderick, Shimwell, Gourdji + in prep





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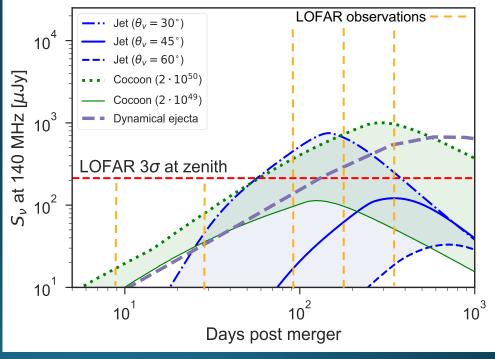
Late time follow-up

Searching for incoherent emission from afterglow.

- Our 225 minute images are reaching 0.5 mJy/beam noise before DDC
- Calibrated images created within 3 days



GW170817-like jet, 100 Mpc, 0.01 cm⁻³



Broderick, Shimwell, Gourdji et al. in prep

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Summary

Radio observations of BNS mergers can

- constrain the remnant
- tell us about the jet and neutron star(s) via the afterglow

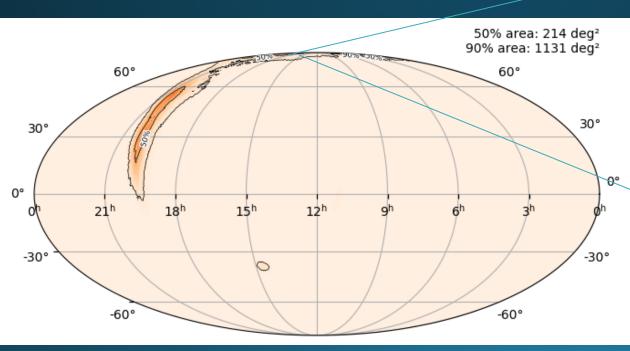
LOFAR telescope triggers (within minutes)

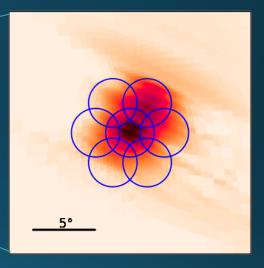
- on GW merger events
 - constrains existence of a magnetar
- on Swift GRBs

- Allows us to probe earlier timescales of compact mergers (sGRBs) and core-collapse supernovae (IGRBs)

ADDITIONAL SLIDES

S190426c – BH/NS candidate





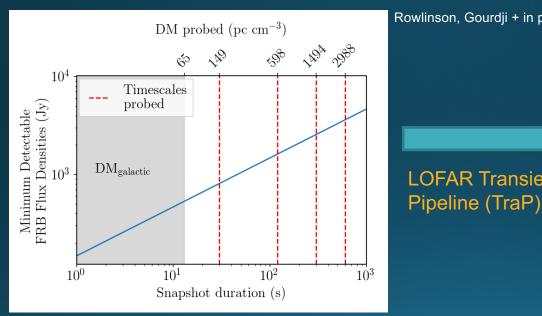
LOFAR covers ~22% of GW probability map

8 hour LOFAR observation

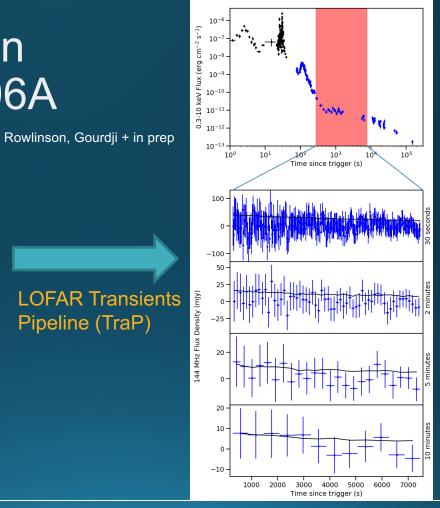
Looking ahead

- 6 triggers for O3 aLIGO/aVirgo + follow-up time
- Larger GW detector network
 - Smaller localization thus deeper images
- Lower latencies for GW alerts and LOFAR triggering
- triggers for GRB follow-up

LOFAR Observation of long GRB 180706A



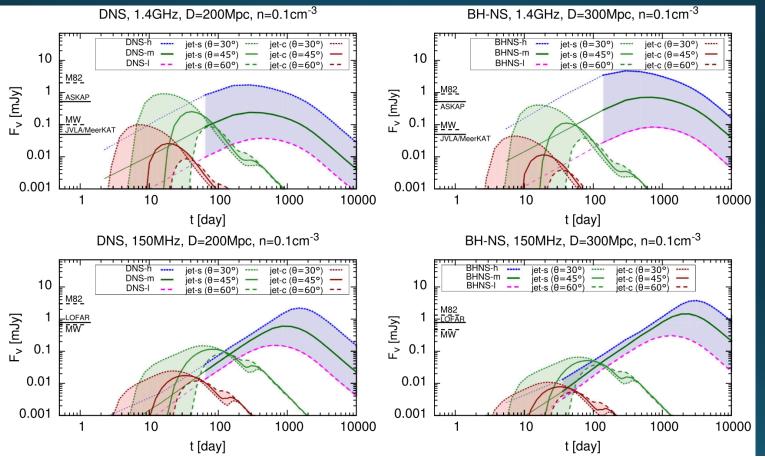




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Hotokezaka et al. 2019



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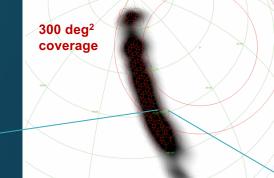
Kelly Gourdji

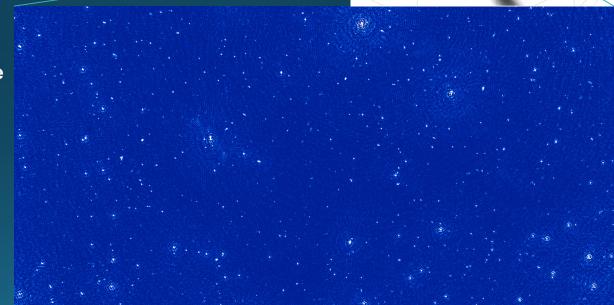
Late time follow-up

1 week, 1 month, 3 months, 6 months, 1 year timescales

Our 225 minute images are reaching 0.5 mJy/beam noise

We will go much deeper for well localized GW sources!





Thank you

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Low-frequency radio follow-up with the LOw Frequency ARray (LOFAR)



We collect data from 110-190 MHz