Electromagnetic follow-ups of GW events

A. Melandri (INAF - Brera Astronomical Observatory)

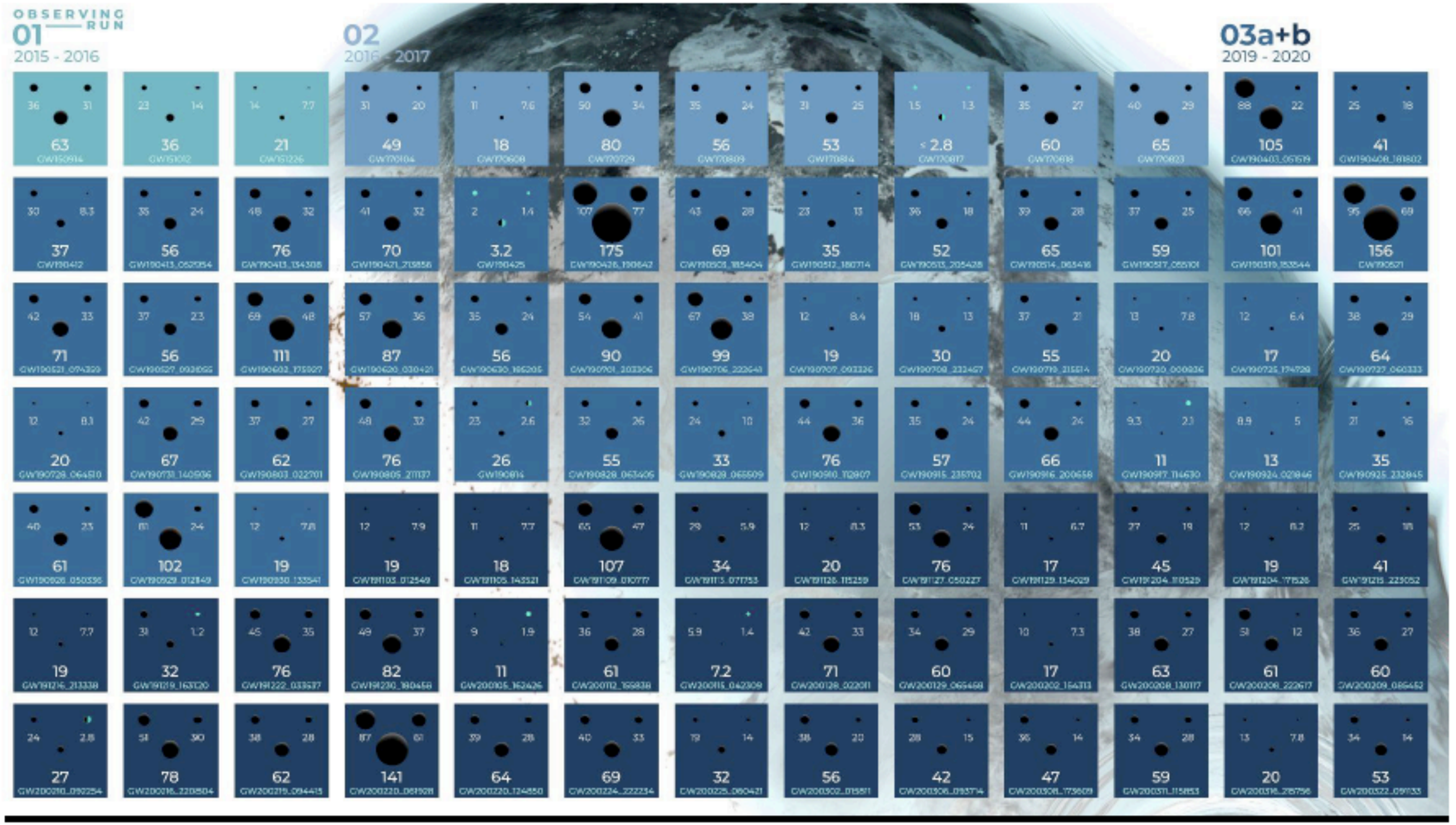
The gravitational-wave story

1916 Einstein predicts gravitational waves in general relativity

1974 First indirect evidence of gravitational waves from binary pulsars

2015 First observation of gravitational waves at the start of O1

Observing runs
O1: 2015–2016
O2: 2016–2017
O3: 2019–2020
O4: ~2022–2023



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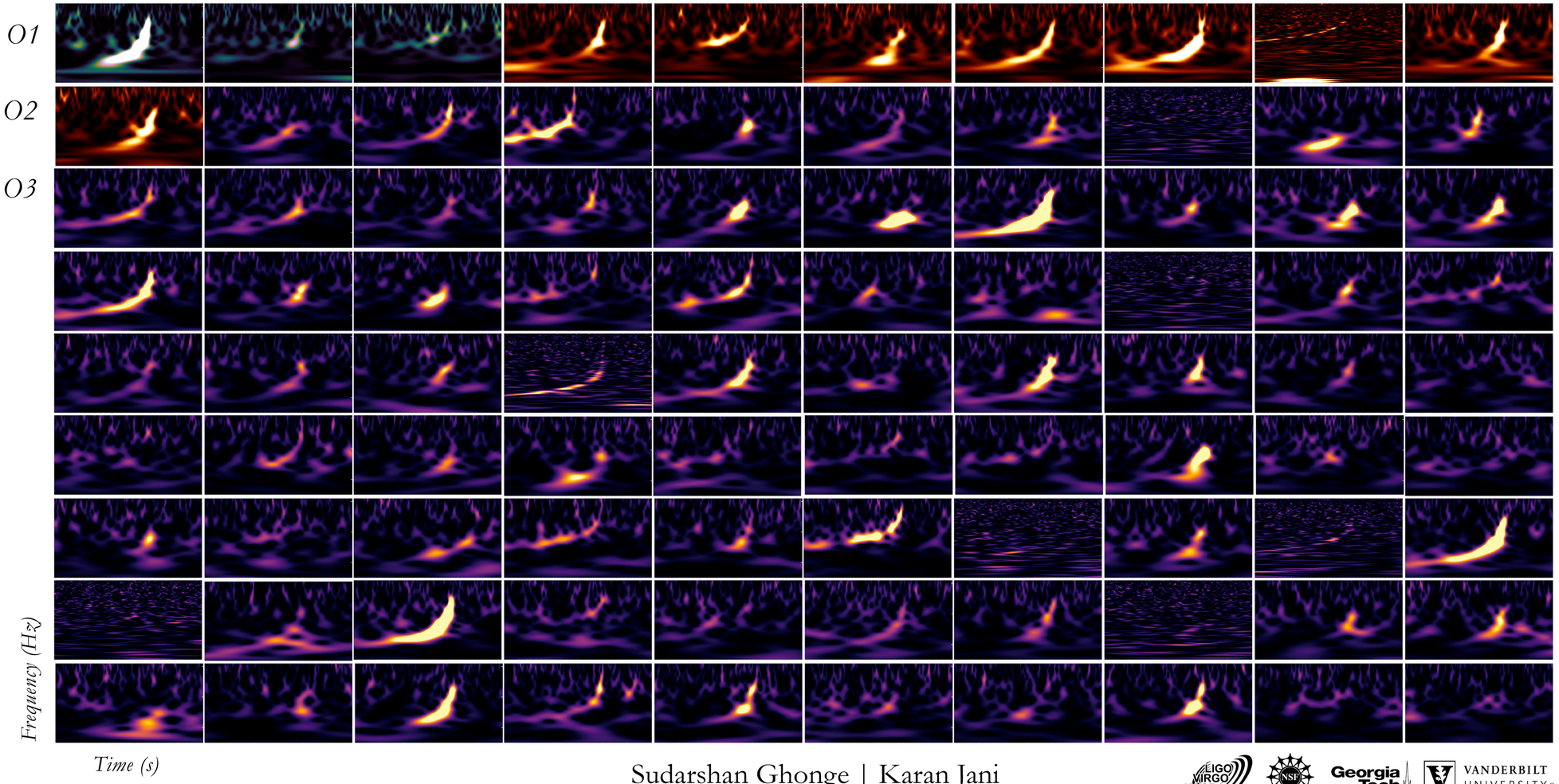
Gravitational-Wave Transient Catalog

Detections from 2015-2020 of compact binaries with black holes & neutron stars



Sudarshan Ghonge | Karan Jani

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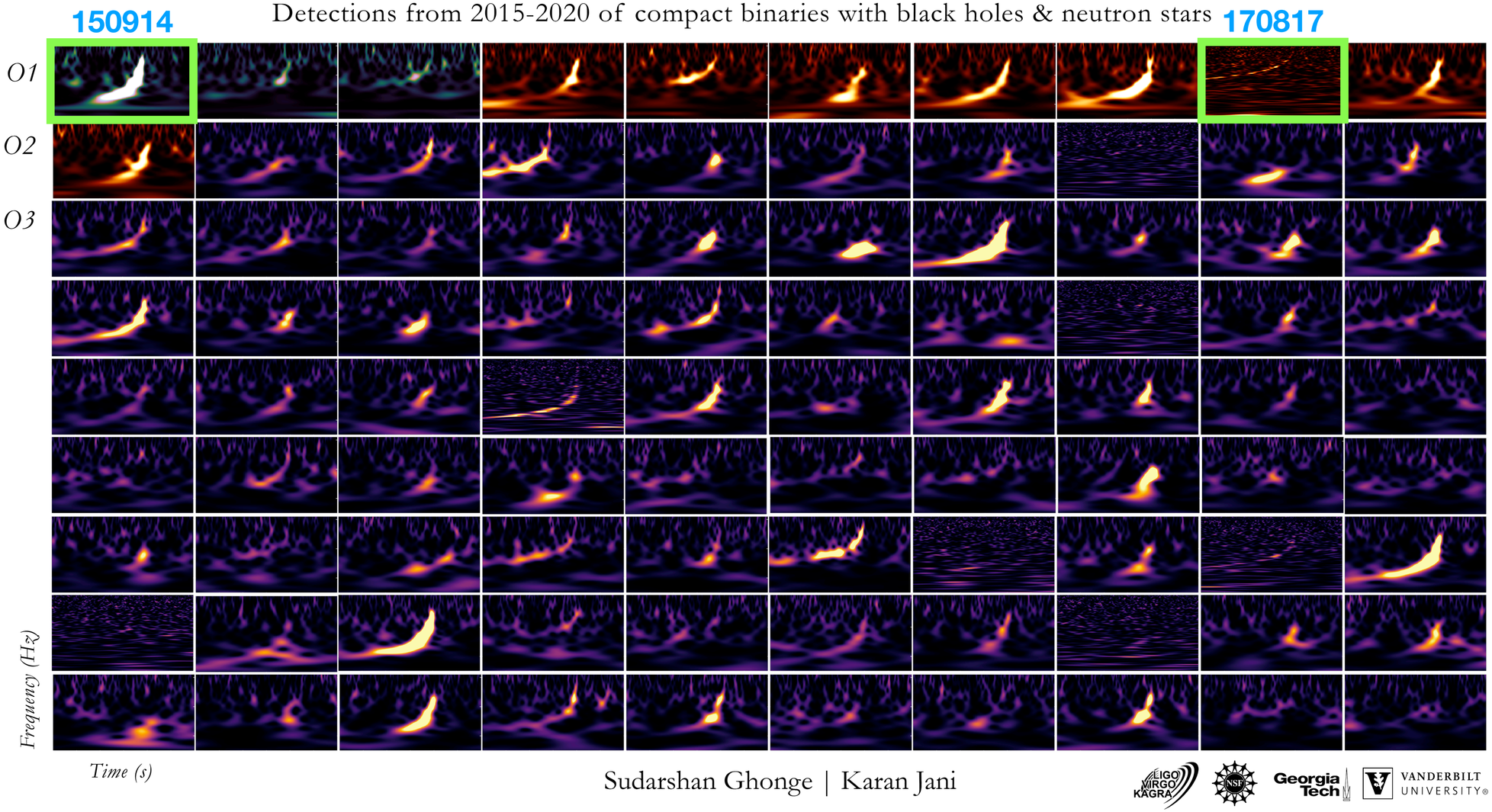
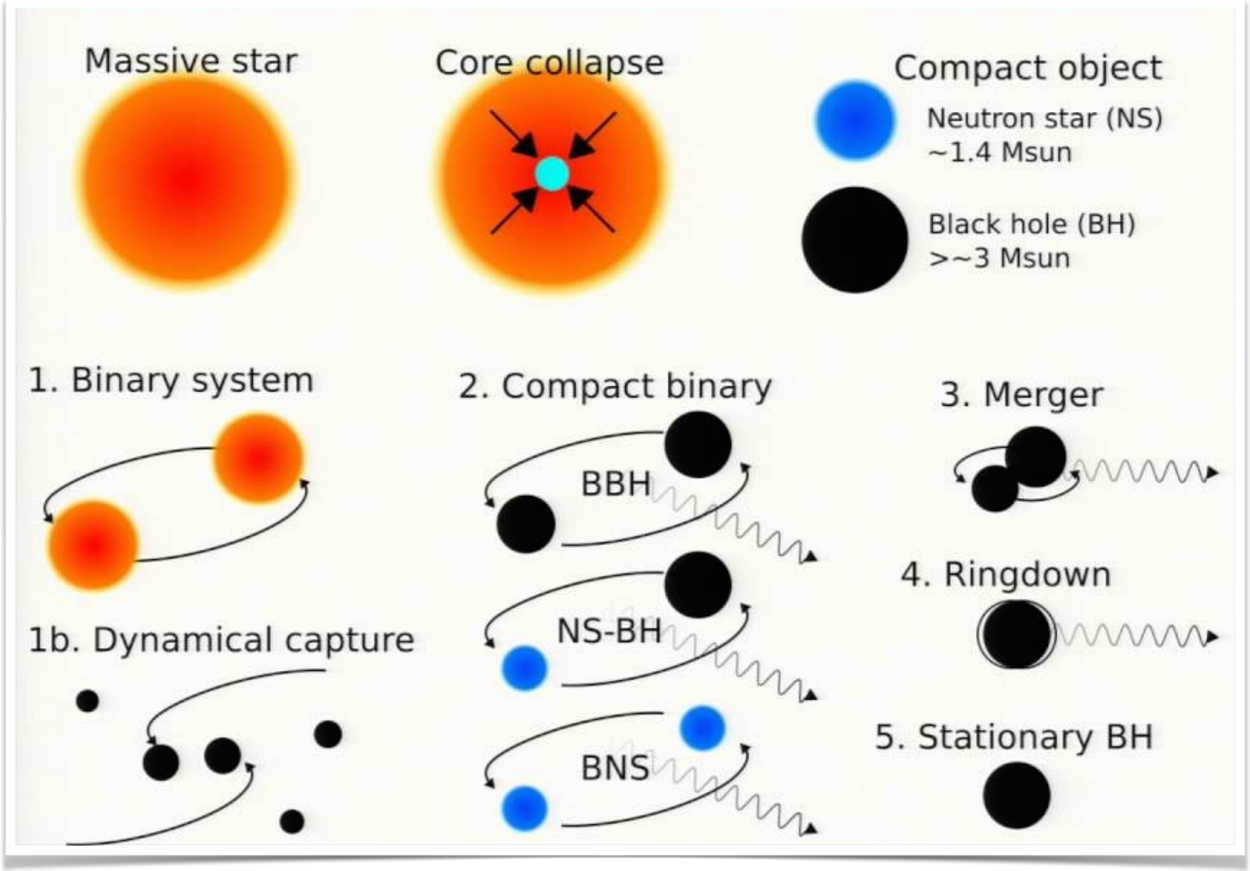
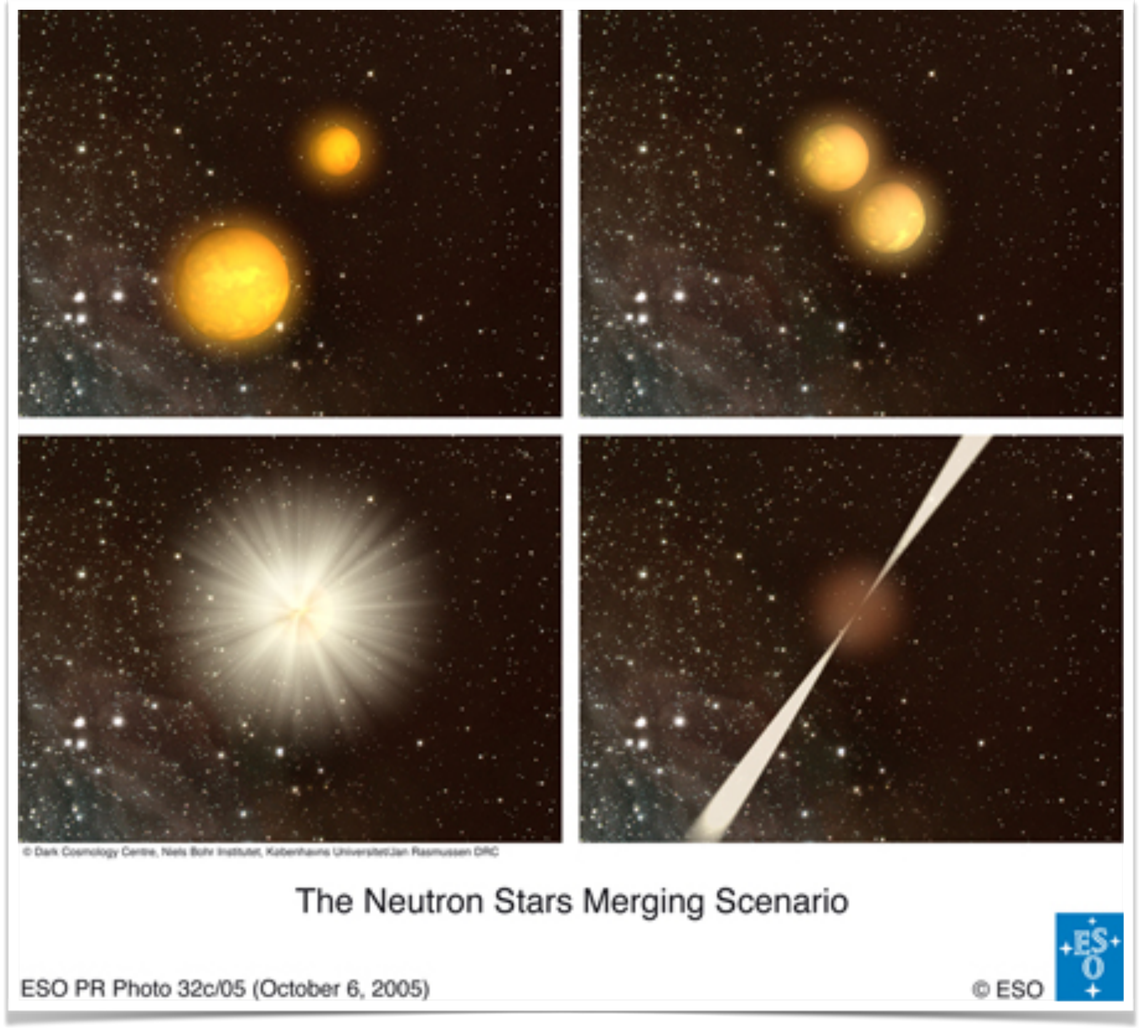


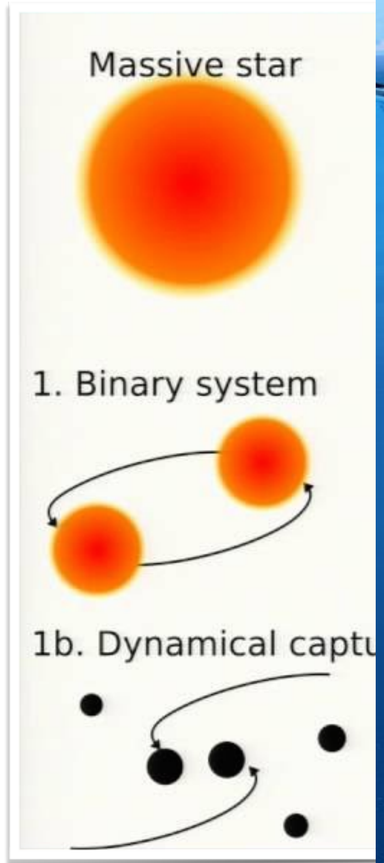
Sudarshan Ghonge | Karan Jani

LIGO VIRGO KAGRA · NSF · Georgia Tech · VANDERBILT UNIVERSITY

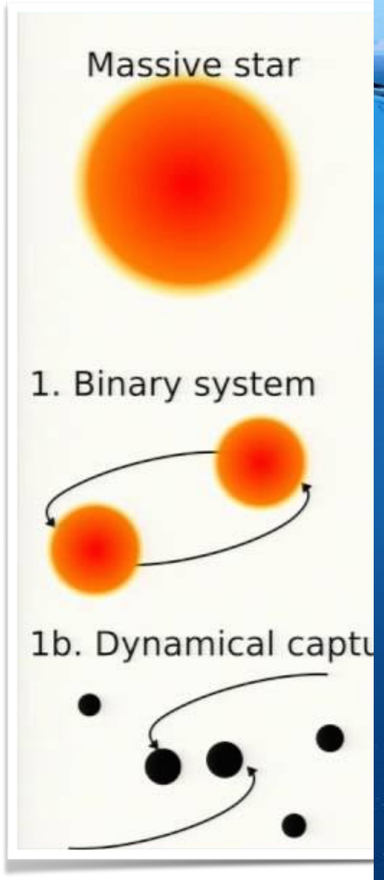
Compact Objects binary mergers






Massive star
1. Binary system
1b. Dynamical captu


nario
© ESO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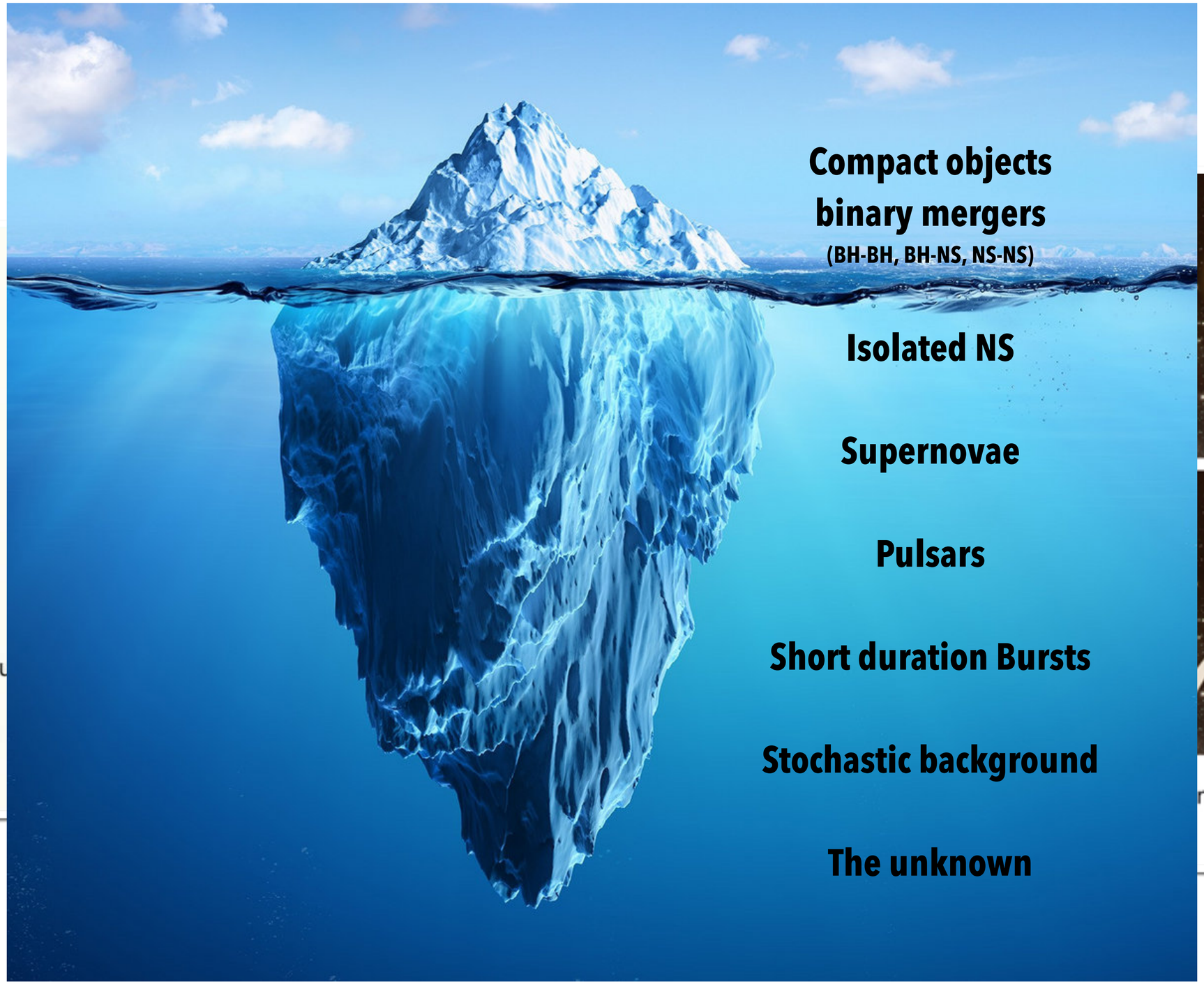
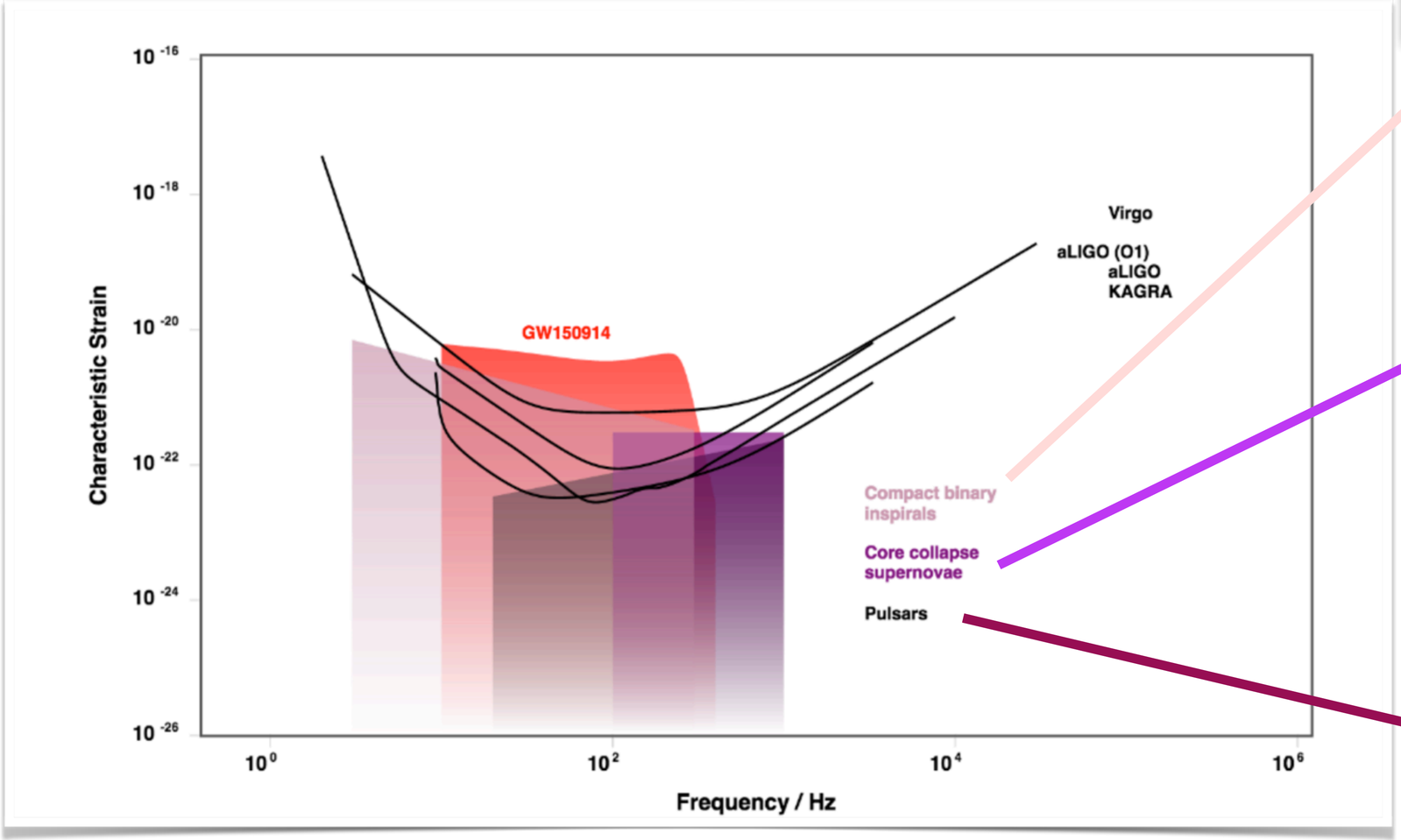

Compact objects
binary mergers
(BH-BH, BH-NS, NS-NS)
Isolated NS
Supernovae
Pulsars
Short duration Bursts
Stochastic background
The unknown


nario
© ESO

GW signals within 10-10000 Hz



Precise waveforms

Coalescence of binary system of neutron stars and/or stellar mass black holes

$E_{GW} \sim 0.02\ M_o c^2$

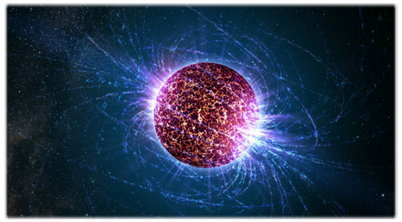
Core Collapse Massive stars

$E_{GW} \sim 10^{-8} - 10^{-4}\ M_o c^2$

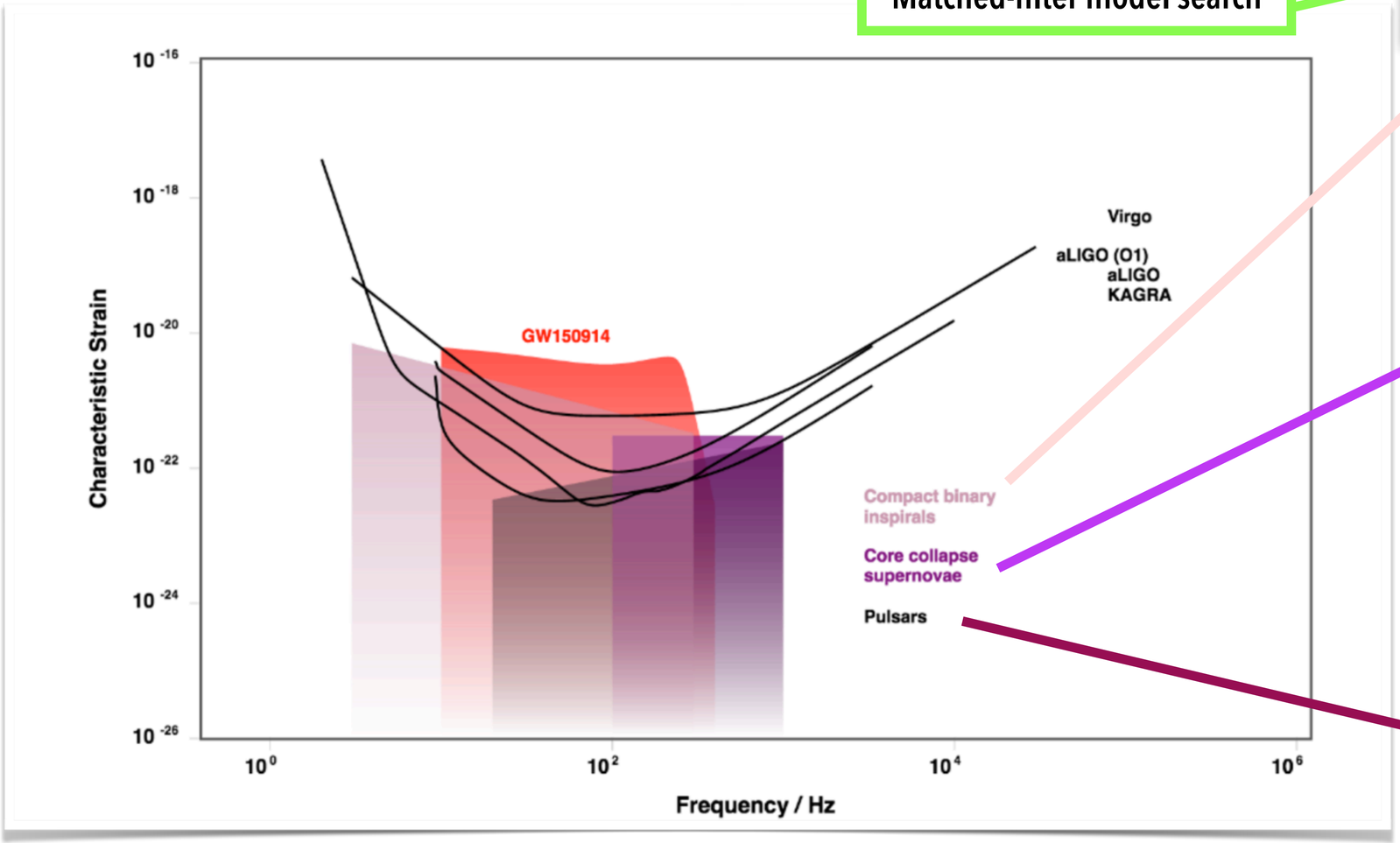
Uncertain waveforms

Isolated Neutron Stars

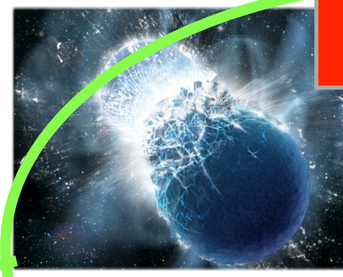
$E_{GW} \sim 10^{-16} - 10^{-6}\ M_o c^2$

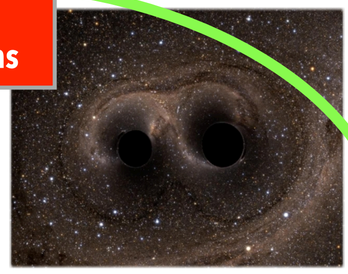


GW signals within 10-10000 Hz



Matched-filter model search





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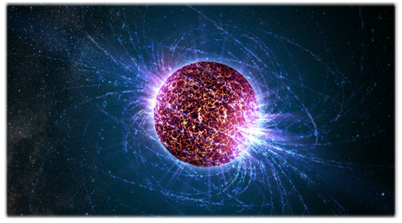

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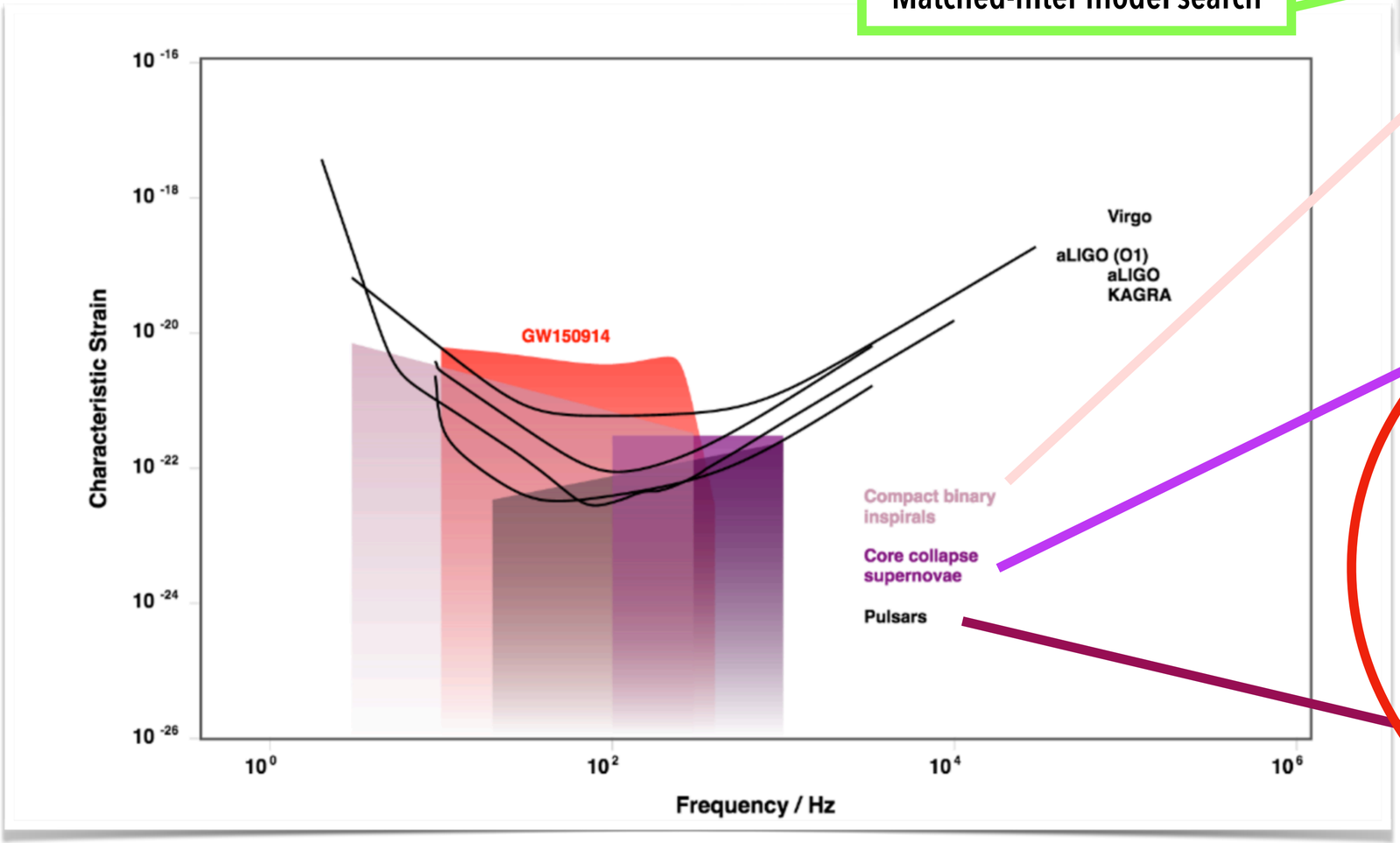

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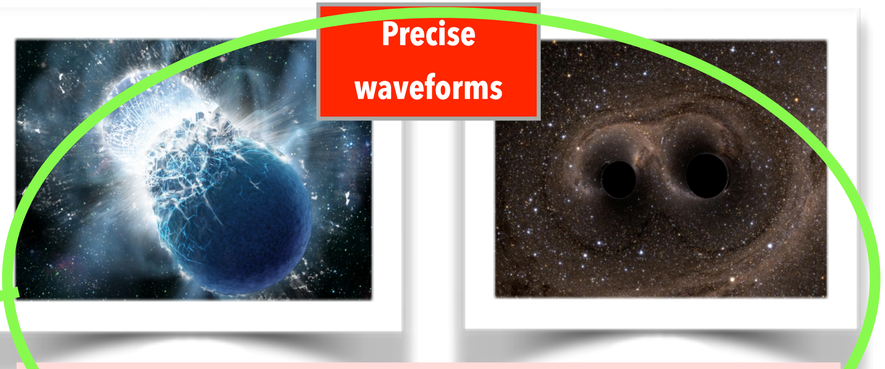

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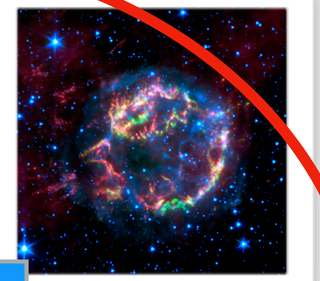

Uncertain waveforms

Isolated Neutron Stars

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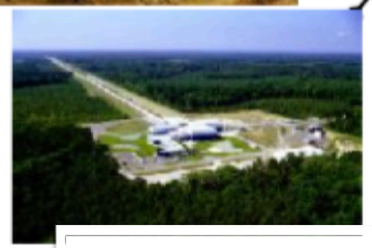
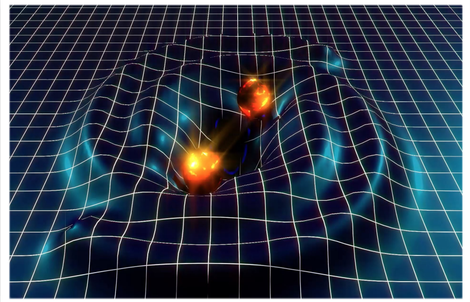
Unmodeled searches

The beginning of the GW era





PRL **116,** 061102 (2016)

Selected for a Viewpoint in *Physics*

PHYSICAL REVIEW LETTERS

week ending
12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]

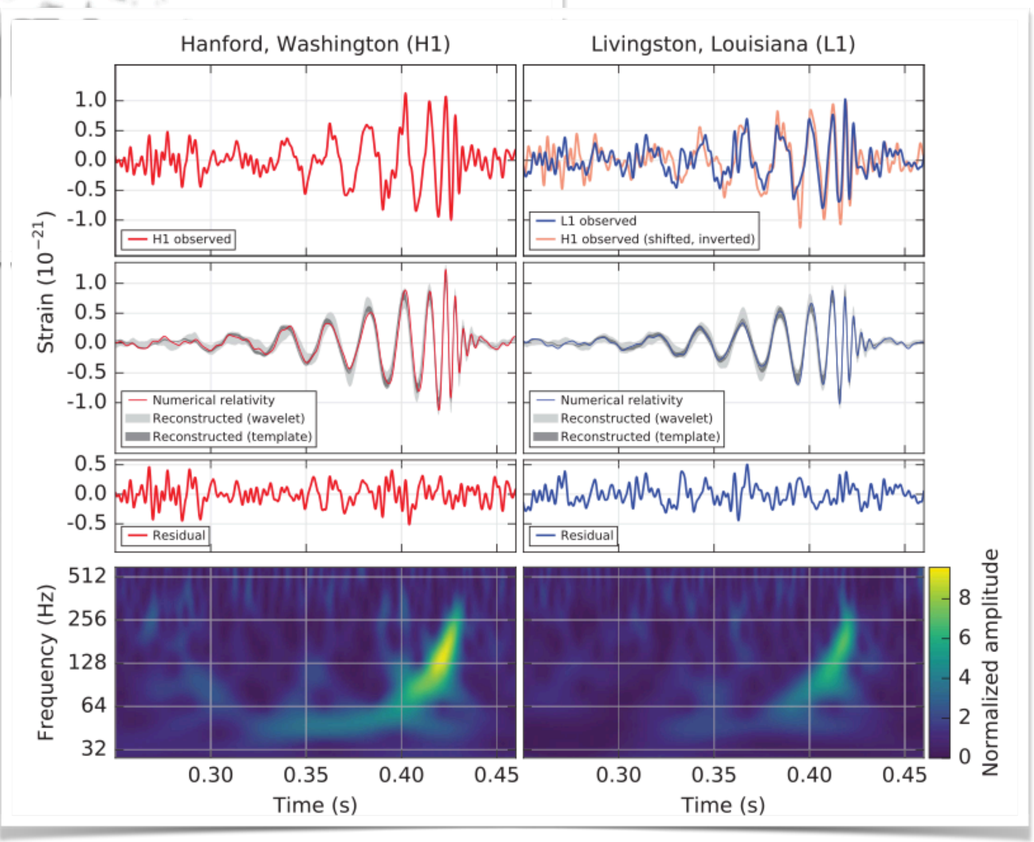
(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)

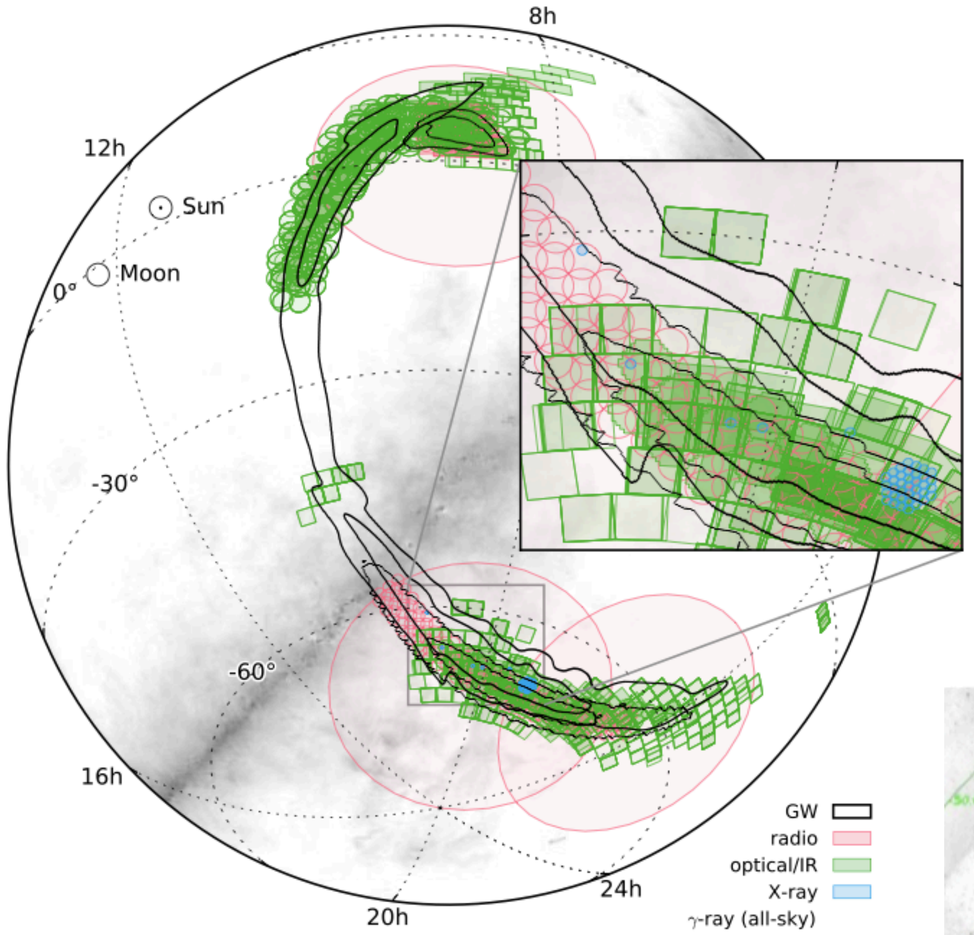
On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4}M_{\odot}$ and $29^{+4}_{-4}M_{\odot}$, and the final black hole mass is $62^{+4}_{-4}M_{\odot}$, with $3.0^{+0.5}_{-0.5}M_{\odot}c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

GW 150914



GW150914: a pointless EM search?

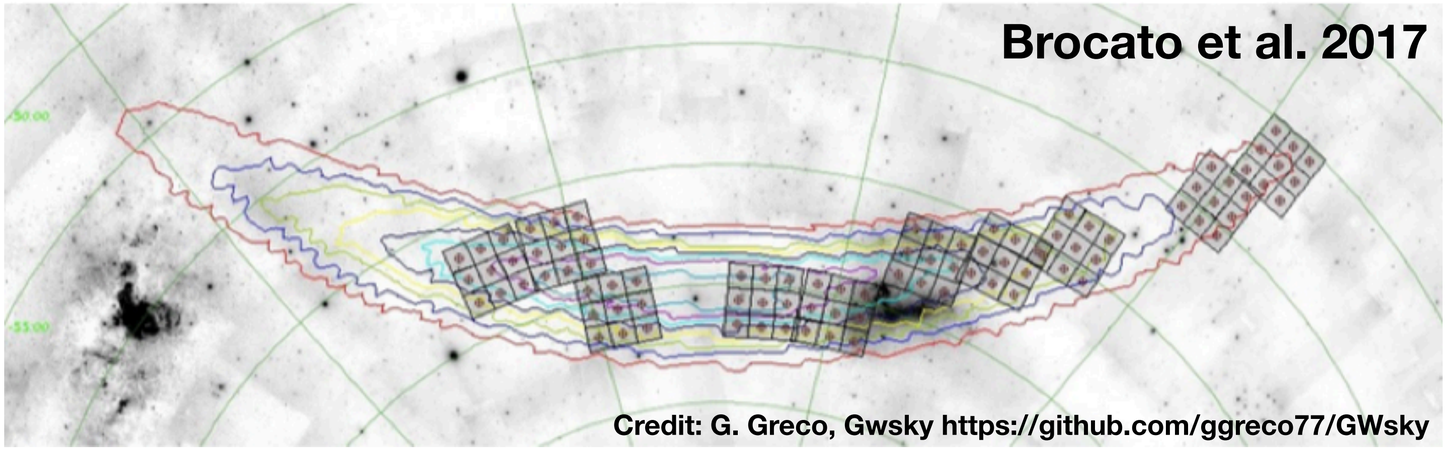


Abbott et al. 2016

600 deg² skymap from LIGO/Virgo
Huge observational effort, mainly with wide-field facilities

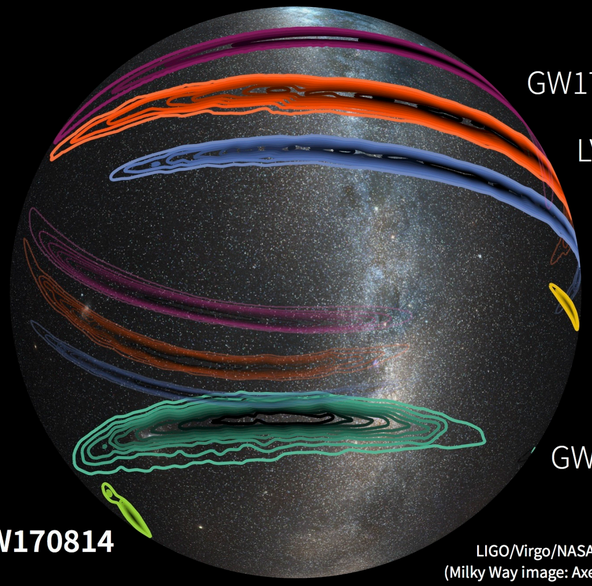
No EM counterpart found

<u>No EM counterpart expected from BHBH merger</u>
Expected EM counterparts for NSNS/NSBH merger:
Short GRBs (beamed emission)
Kilonovae (isotropic emission)

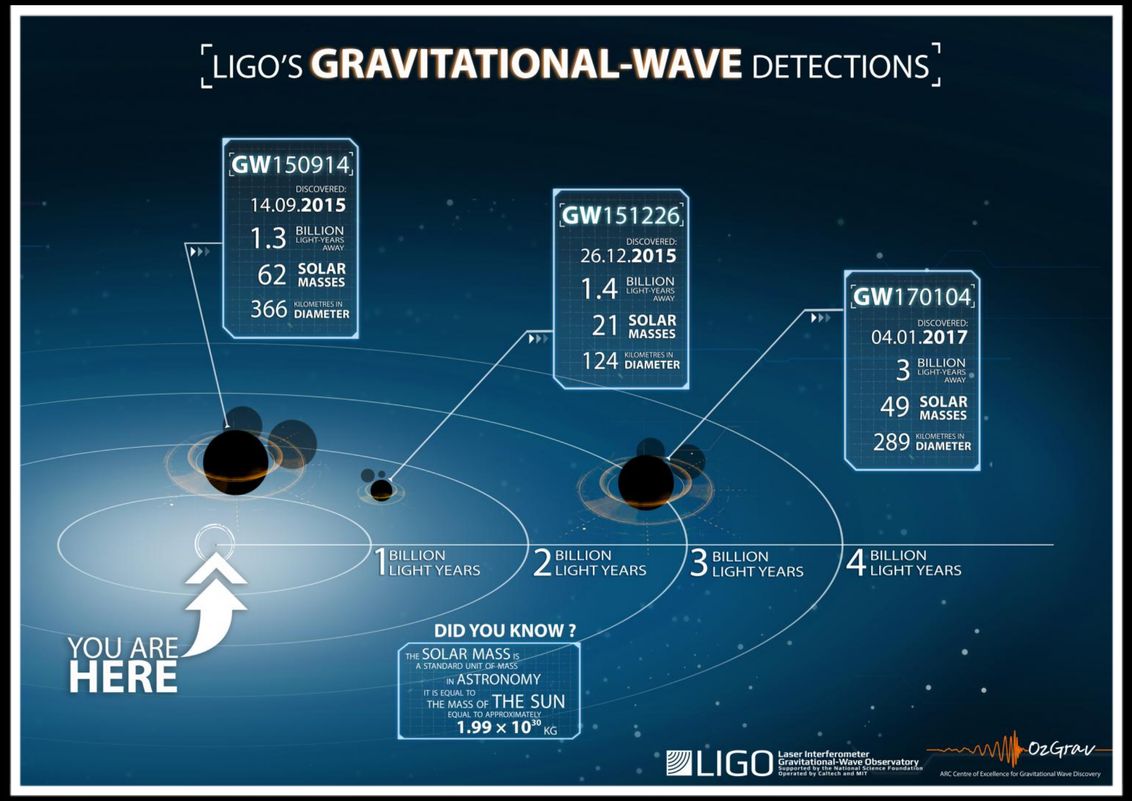


Brocato et al. 2017

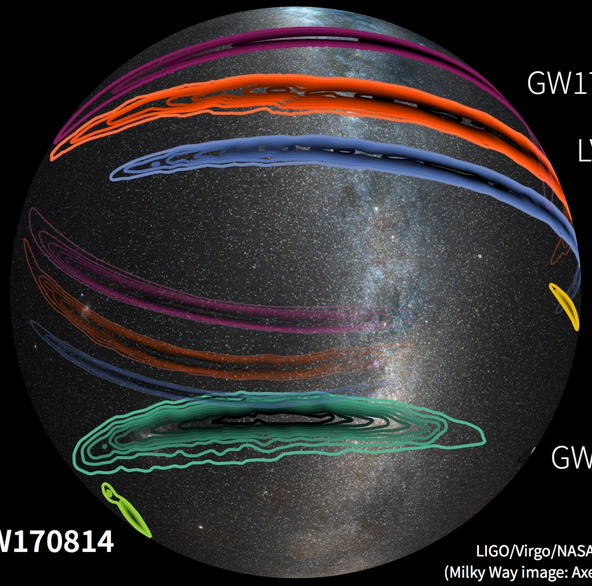
Credit: G. Greco, Gwsky https://github.com/ggreco77/GWsky



LIGO/Virgo/NASA/Leo Singer
(Milky Way image: Axel Mellinger)



Groping in the dark



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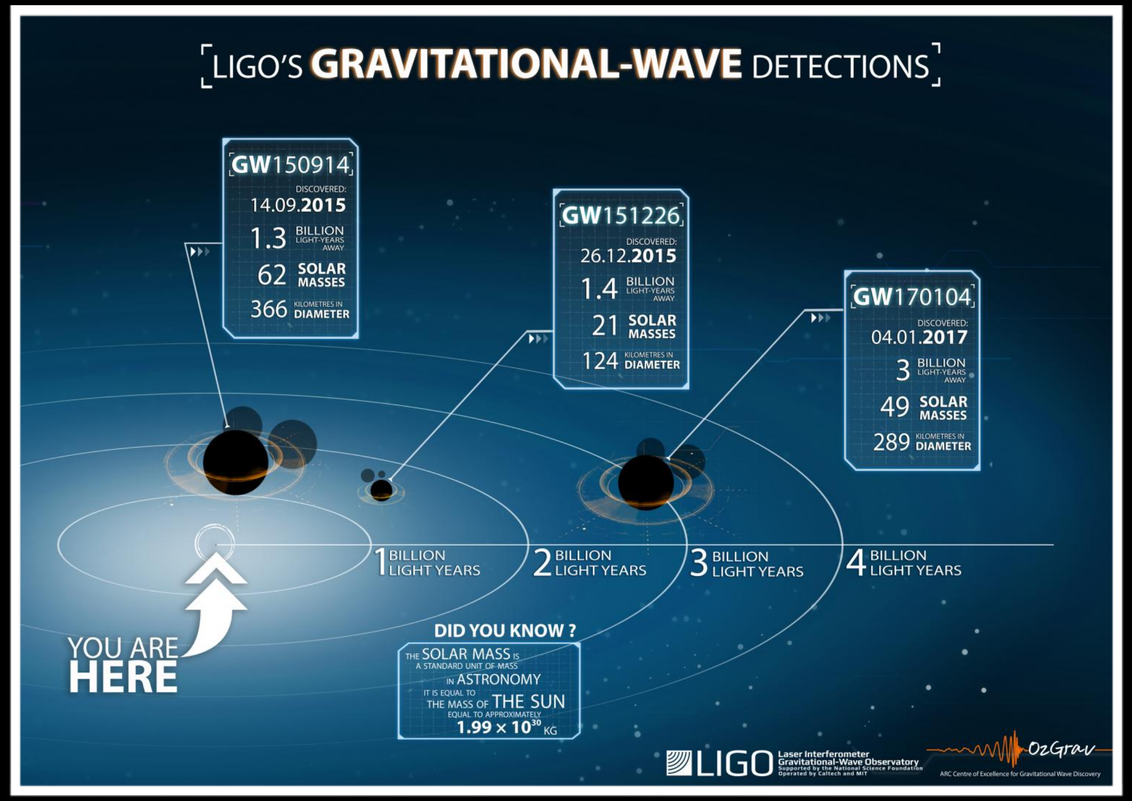

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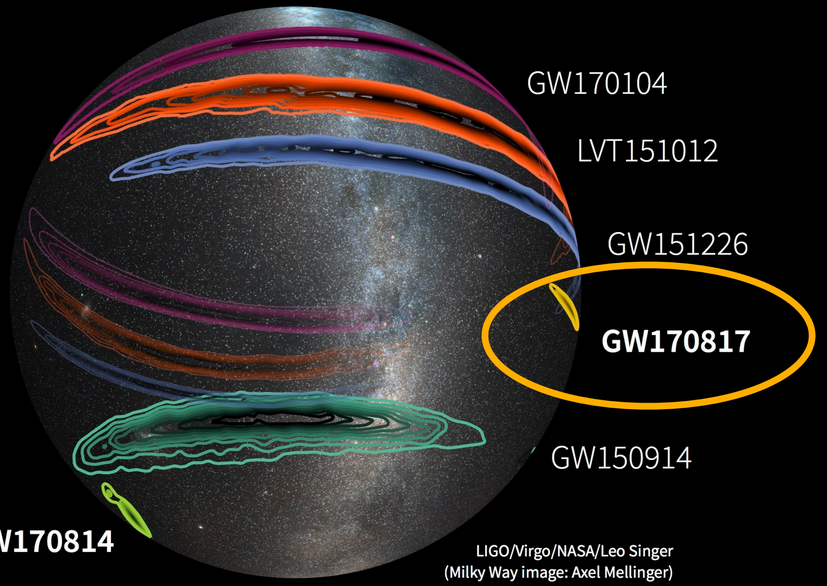

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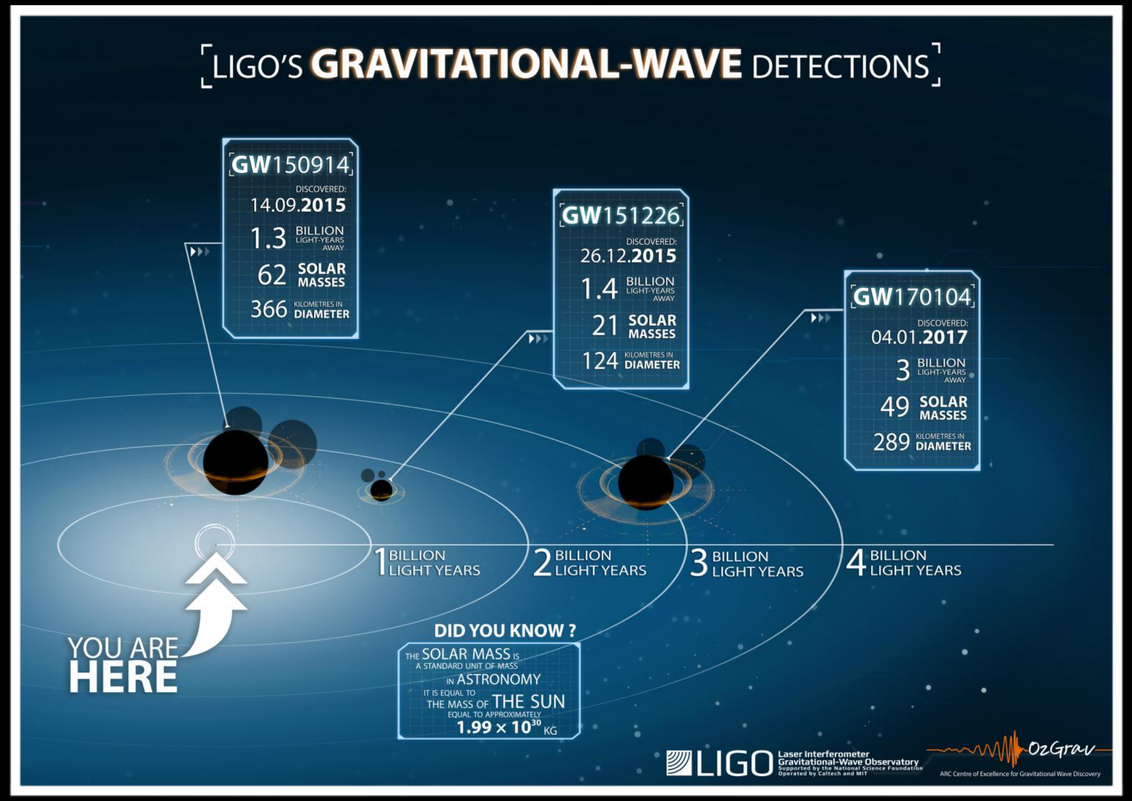
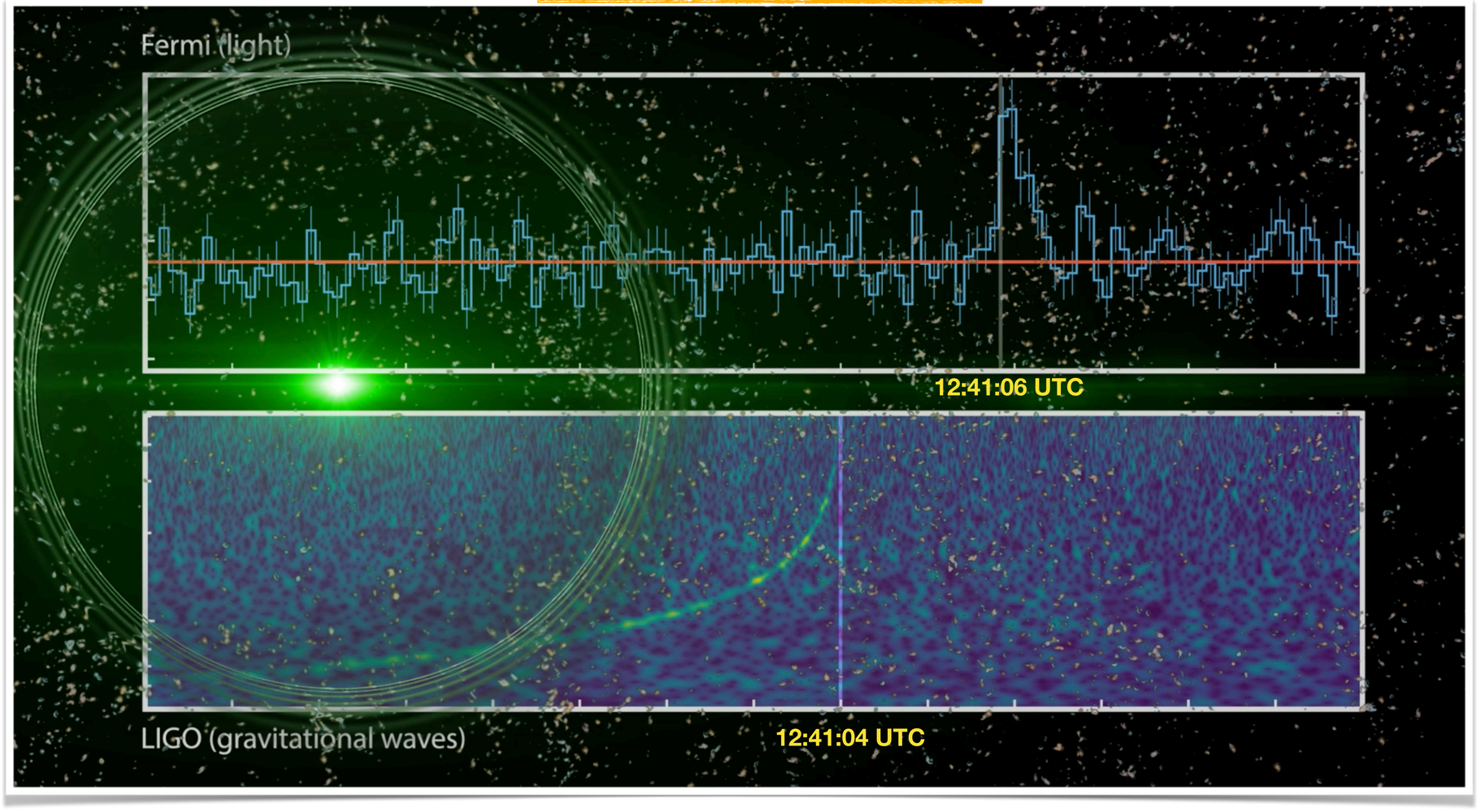
Game changer



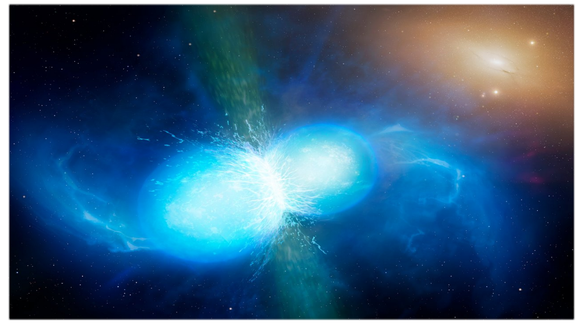
Groping in the dark

We have seen the light !!

GW170817 - GRB170817



NS-NS MERGER
@ 40Mpc!!!



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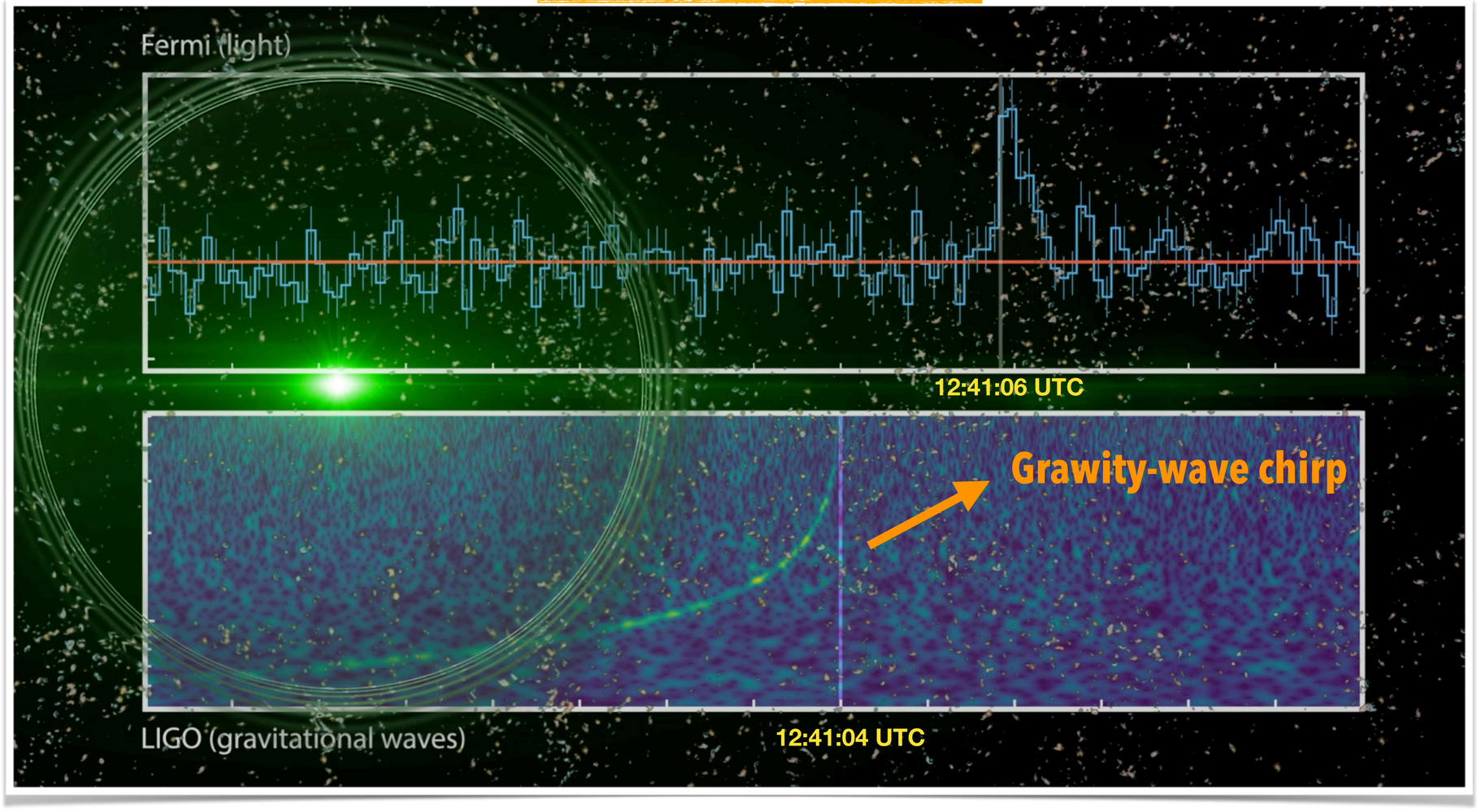

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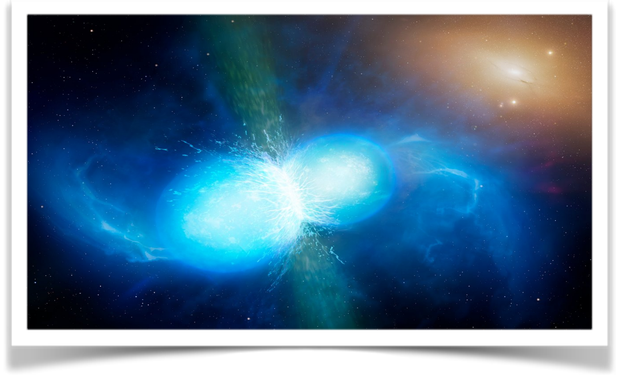

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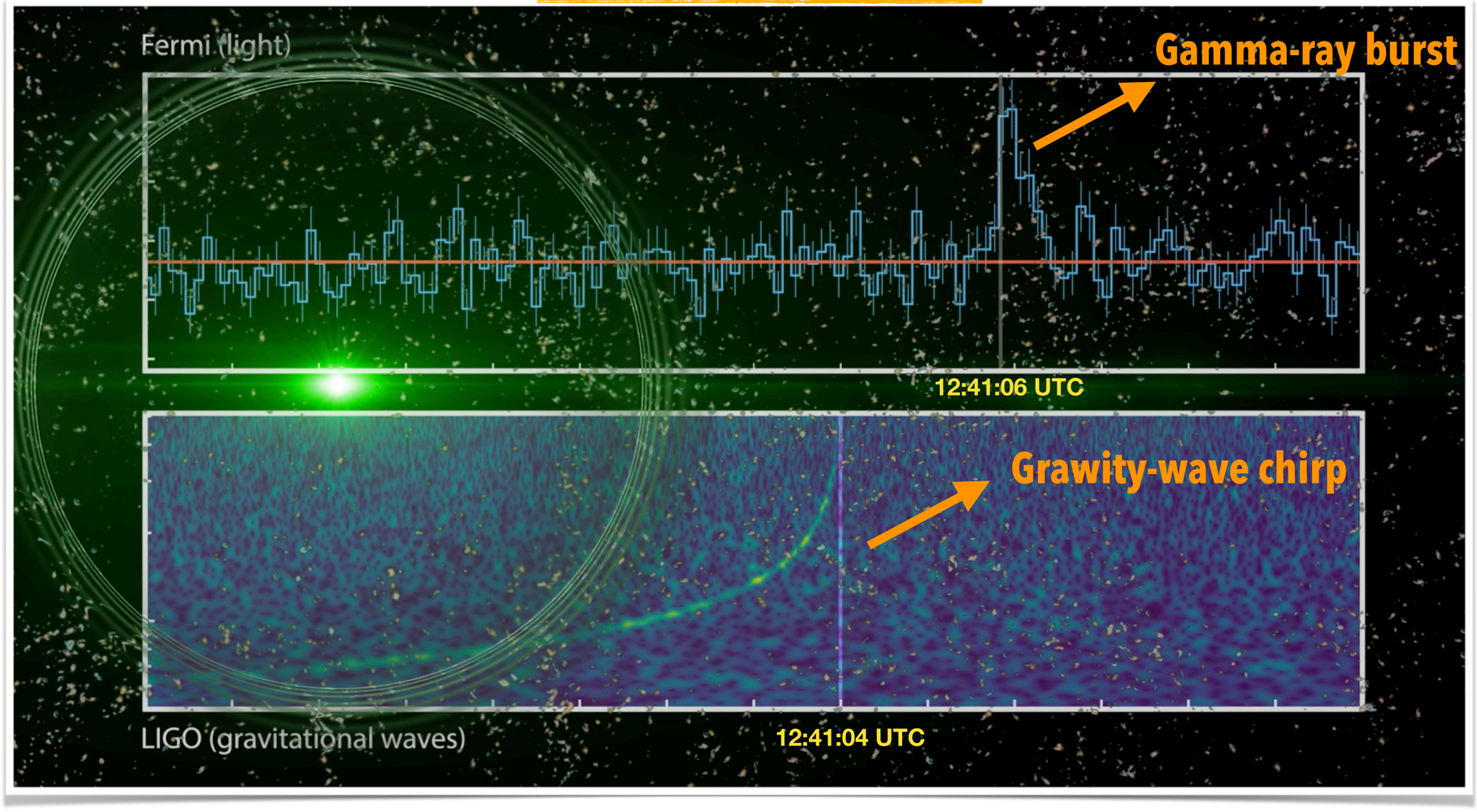

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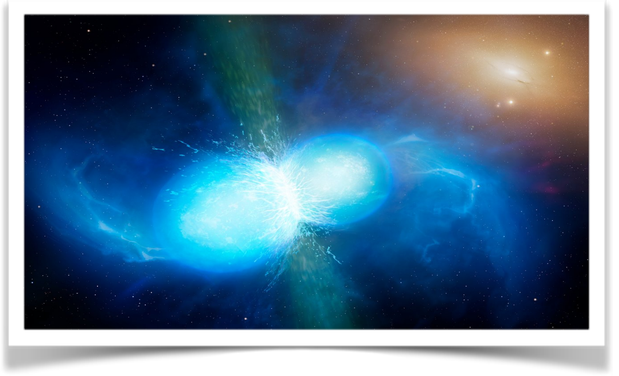
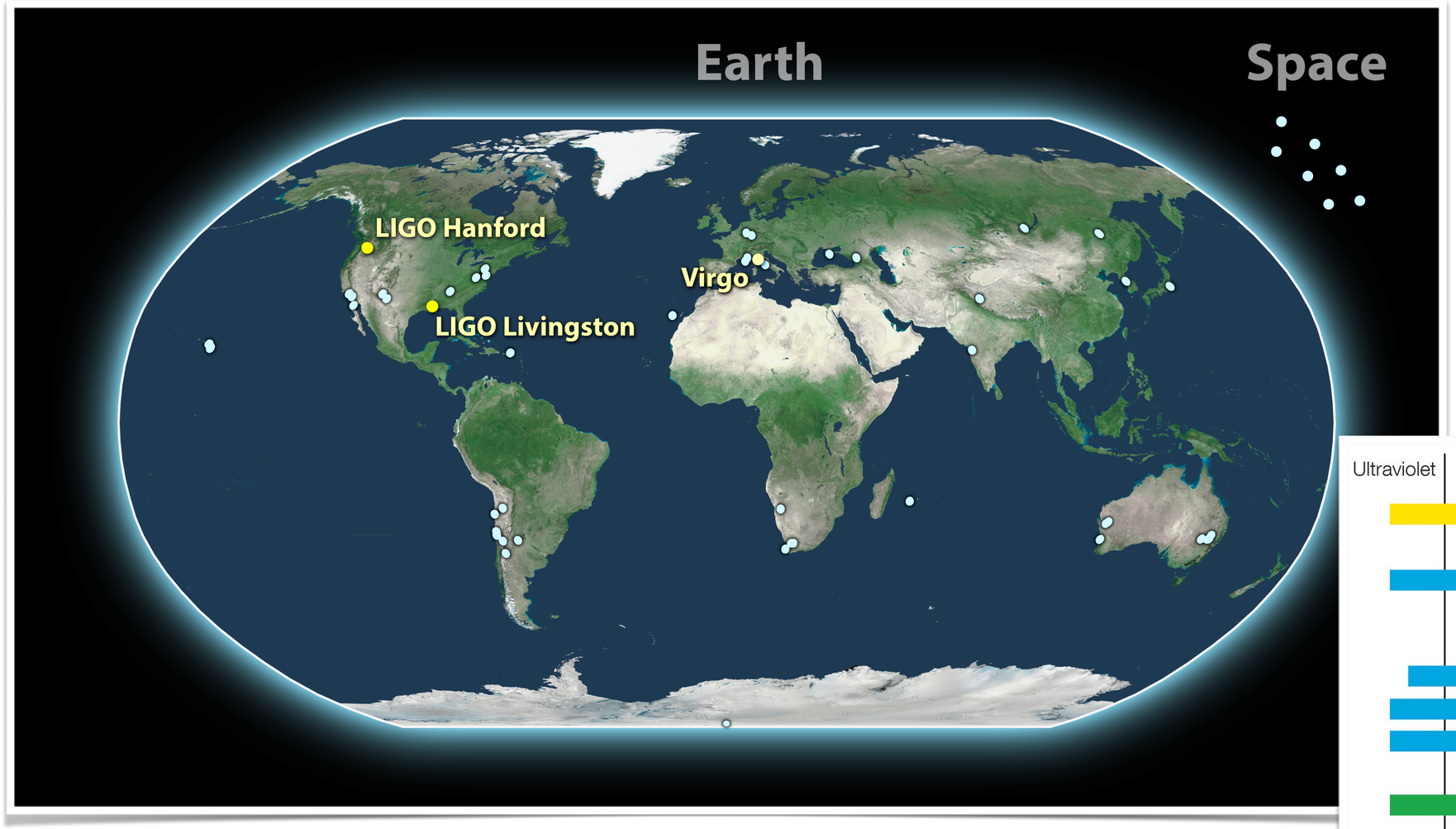
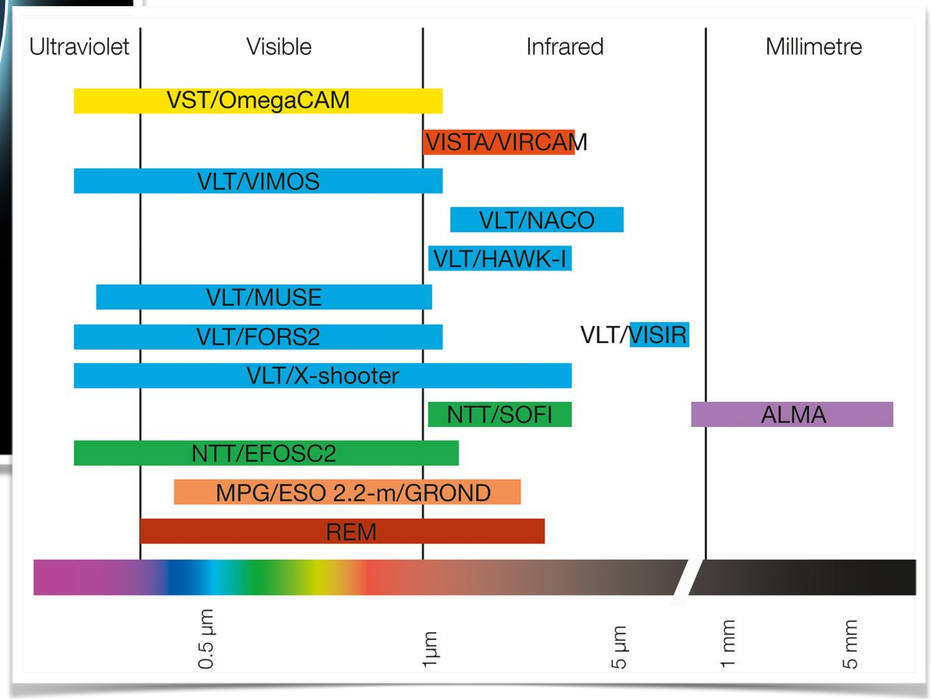


An impressive observational campaign



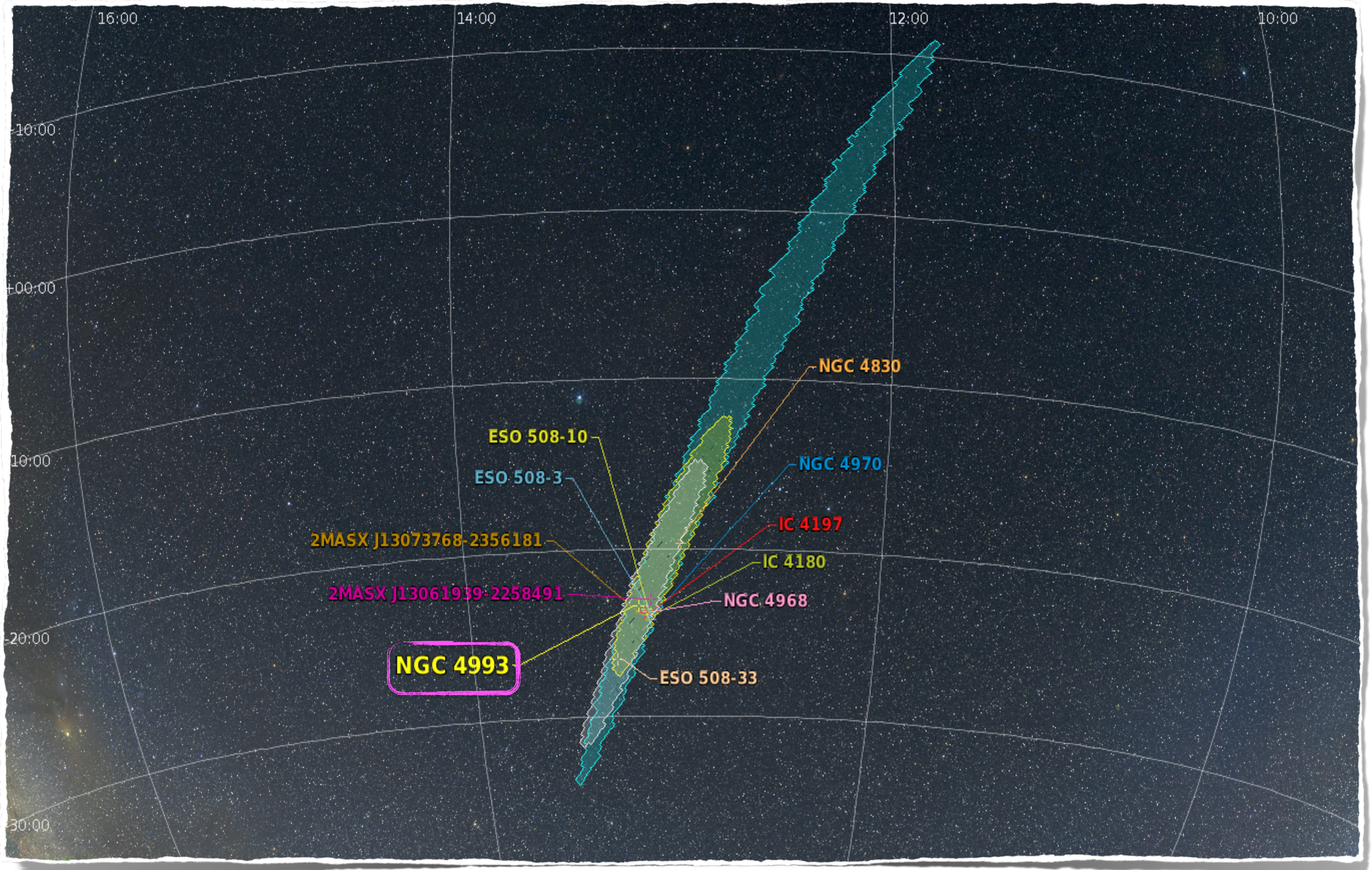
ESO ToO campaign



17
August

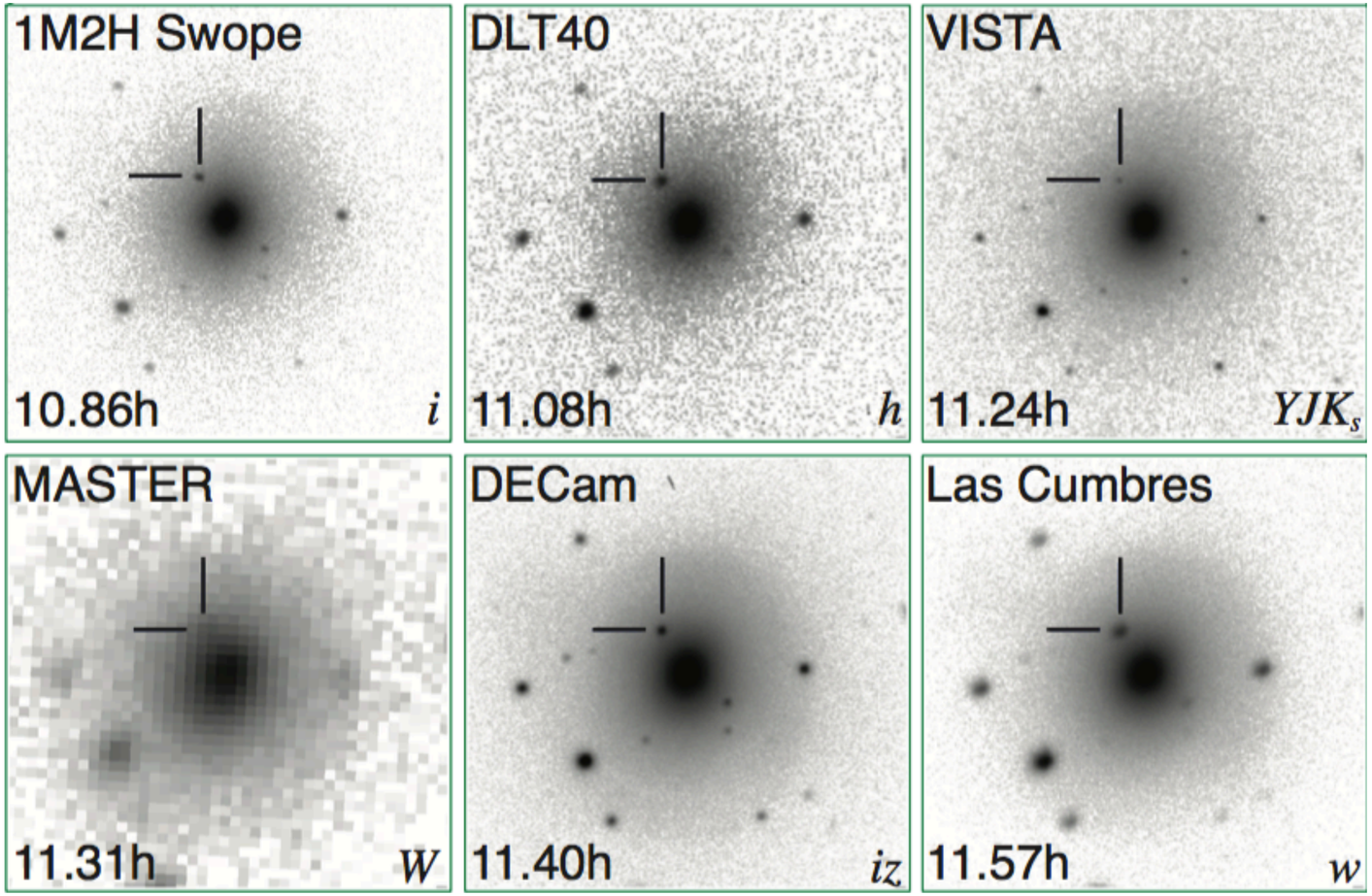
17:54:51 UTC

Powered by Aladin


16:00
14:00
12:00
10:00
-10:00
+00:00
10:00
-20:00
-30:00
NGC 4830
ESO 508-10
NGC 4970
ESO 508-3
IC 4197
2MASX J13073768-2356181
IC 4180
2MASX J13061939-2258491
NGC 4968
NGC 4993
ESO 508-33

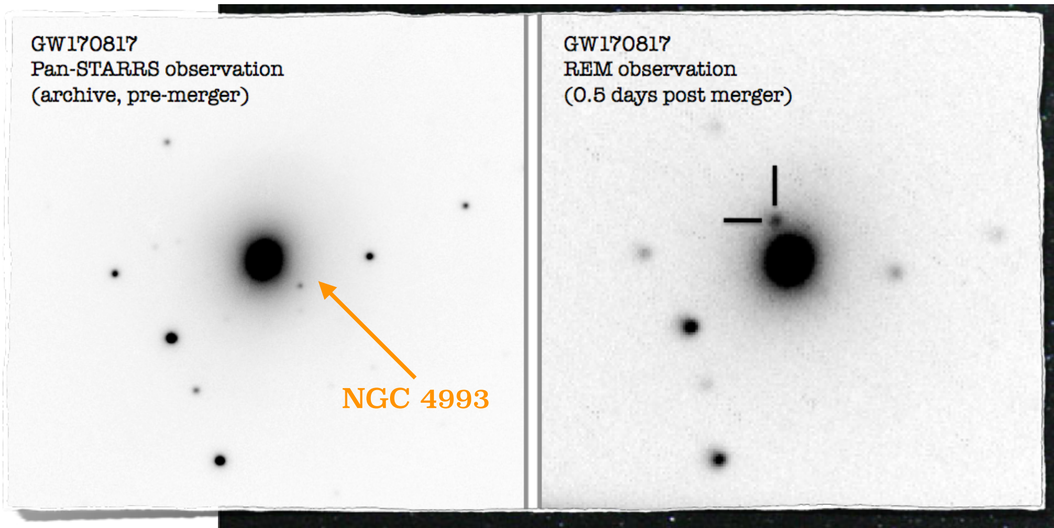
Optical counterpart in NGC 4993

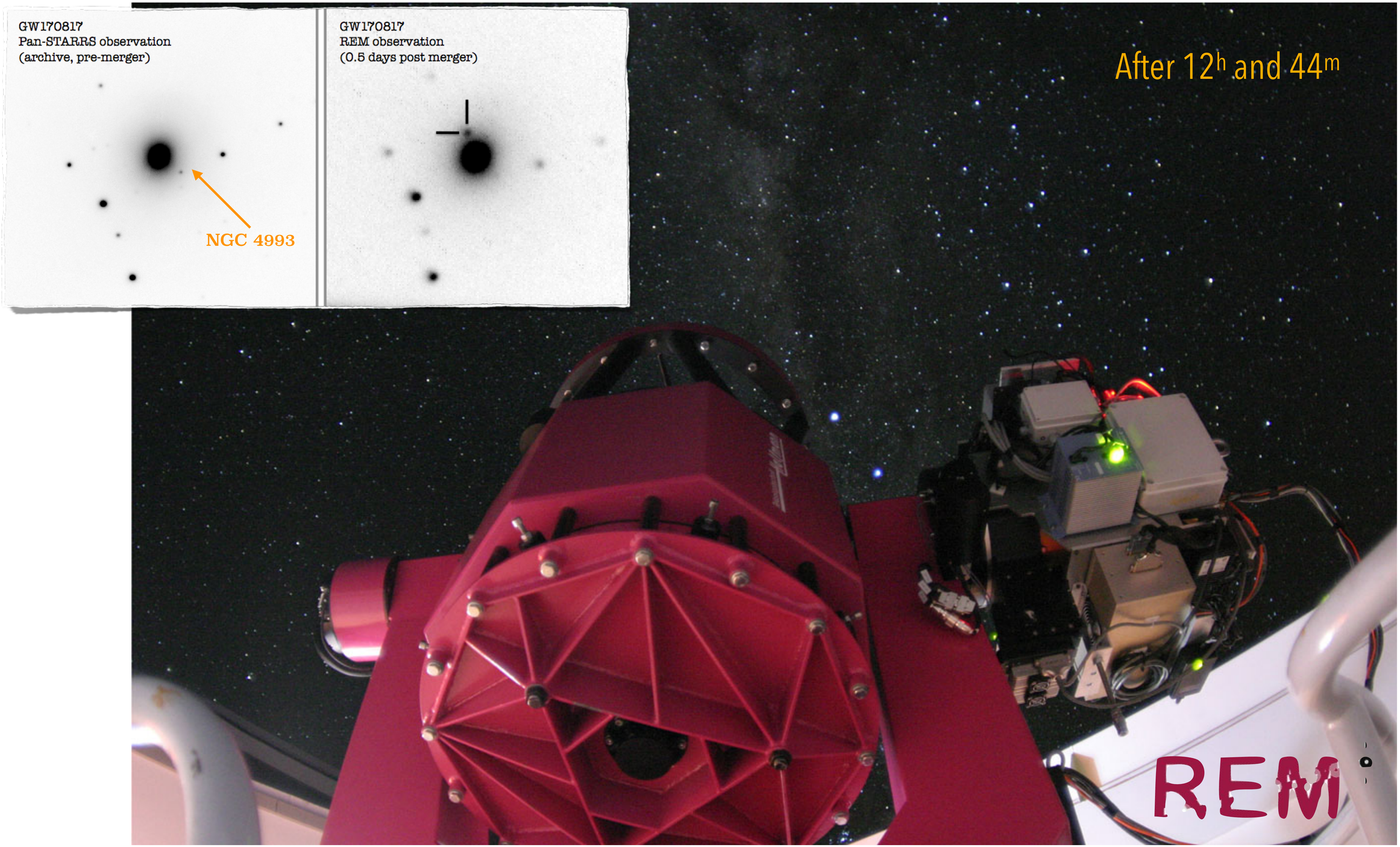
Coulter et al. (2017) | Valenti et al. (2017) | Tanvir et al. (2017)

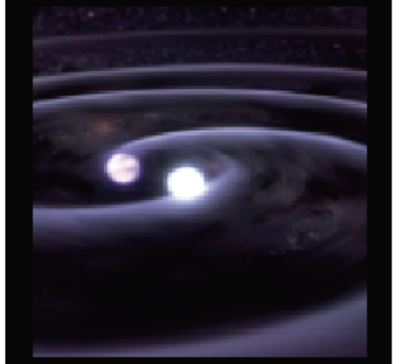


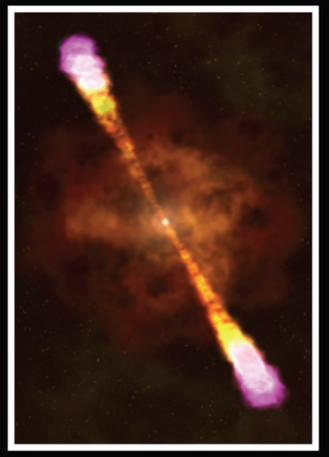
Lipunov et al. (2017) | Allam et al. (2017) | Arcavi et al. (2017)

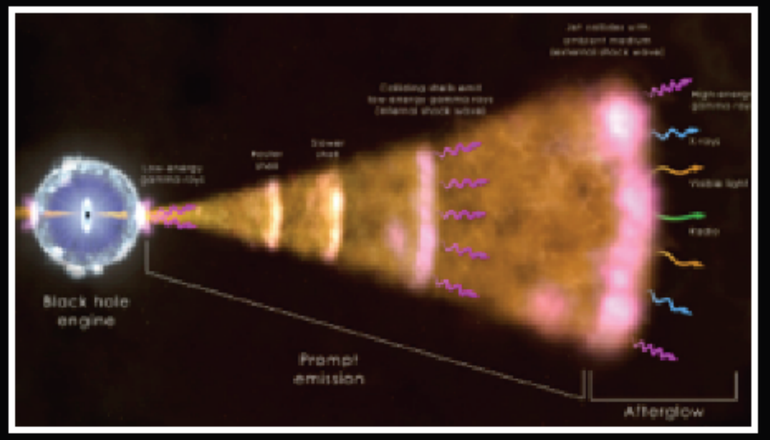
NGC 4993, S0 galaxy @ D = 41 Mpc, z = 0.00968 (Hjorth et al. 2017)


GW170817
Pan-STARRS observation
(archive, pre-merger)
NGC 4993
GW170817
REM observation
(0.5 days post merger)


GW170817
Pan-STARRS observation
(archive, pre-merger)
NGC 4993
GW170817
REM observation
(0.5 days post merger)
After 12h and 44m
REM







NS merger

Short GRB

X-ray

Radio afterglow

t0

1.7s

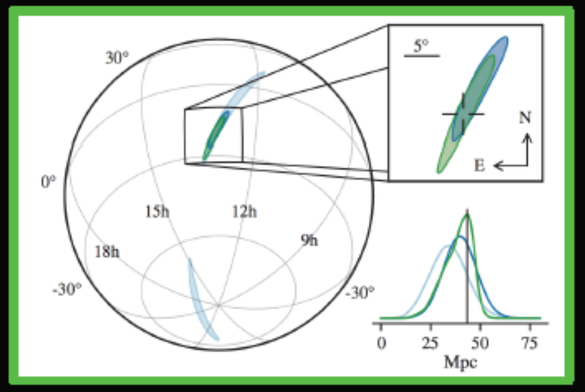
+5.23hrs

+10.87 hrs

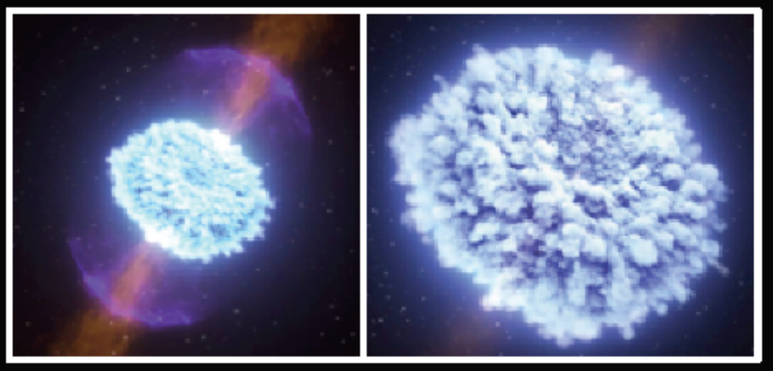
+9 days

+16 days

LHV sky localization



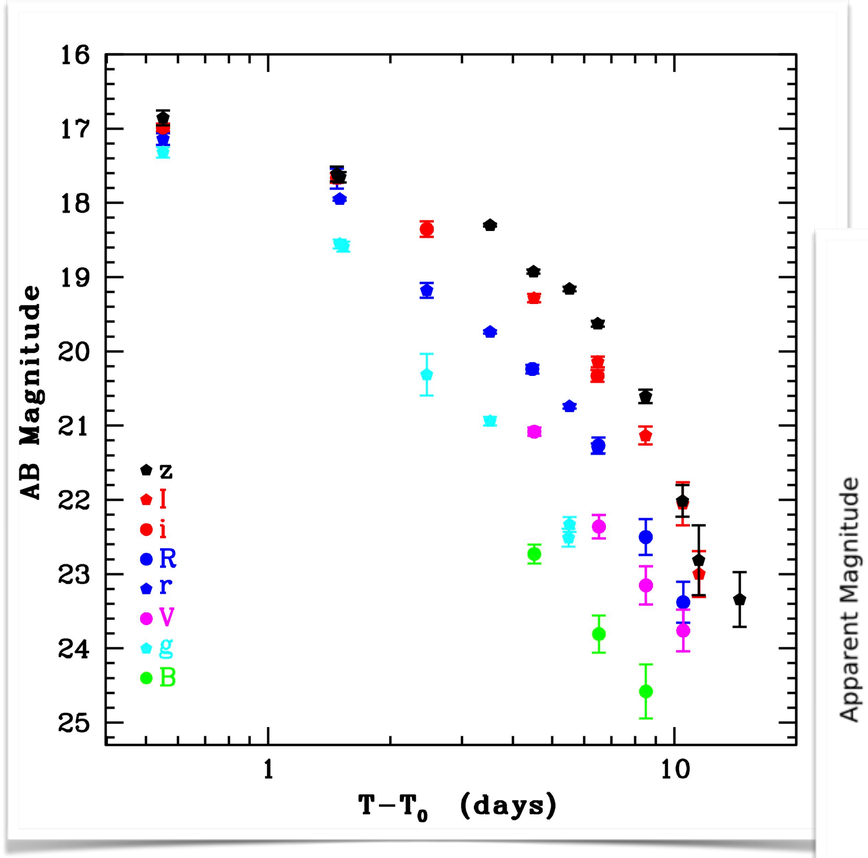
UV/Optical/NIR Kilonova



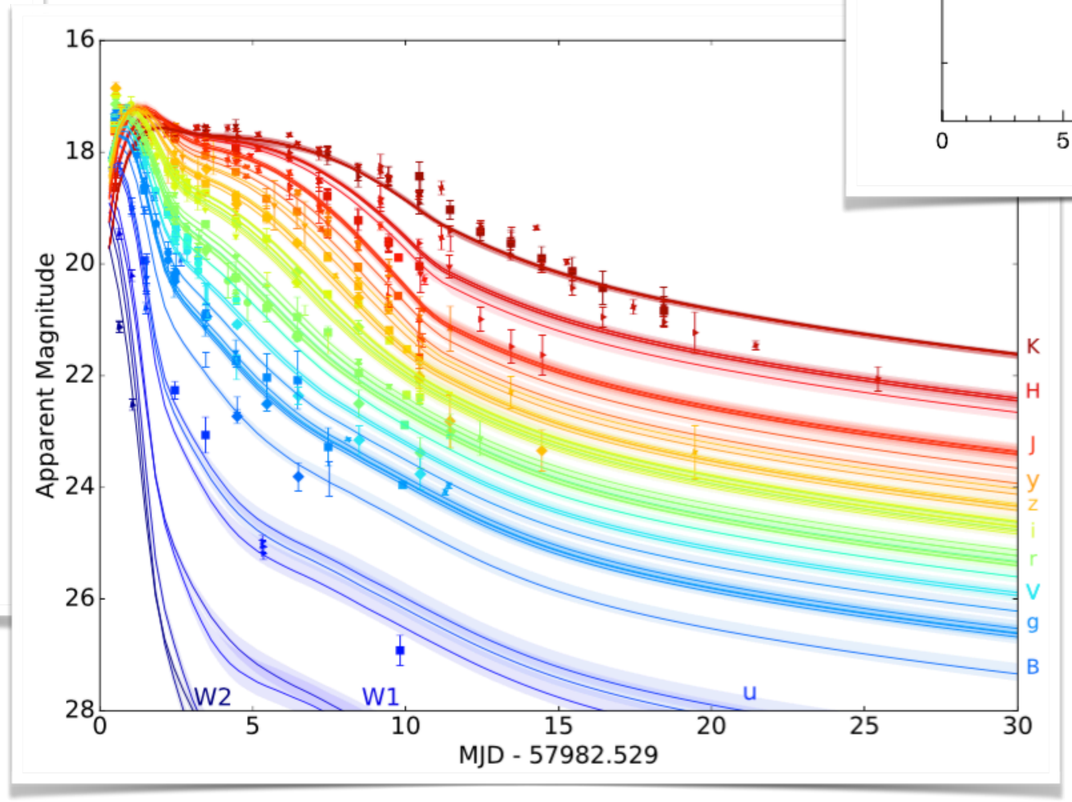
LVC + astronomers, ApJL, 848, L12

Multi-wavelength light curves

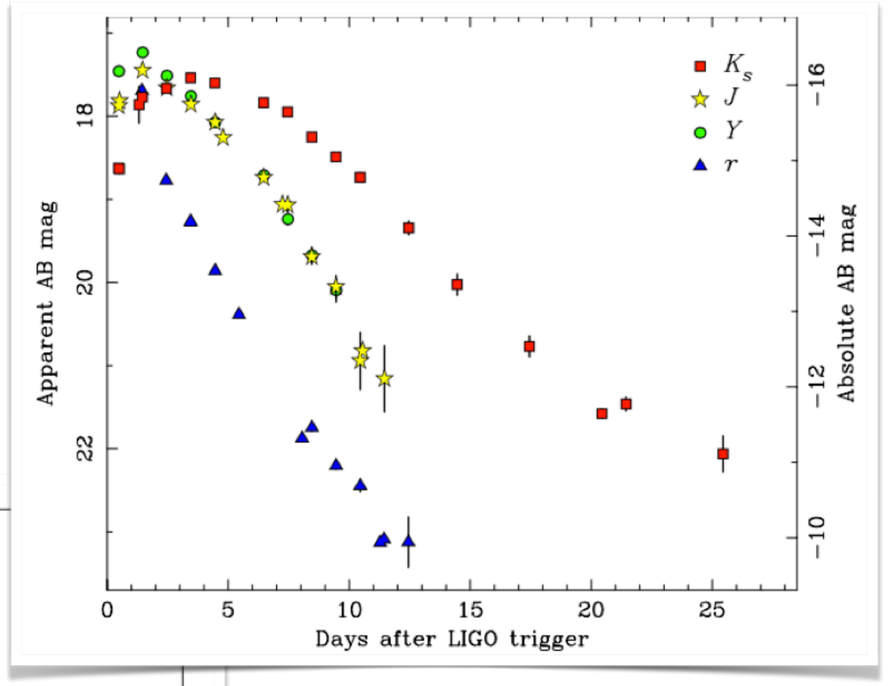
best fitted with multi-component KN model



Pian, D'Avanzo et al. (2017)



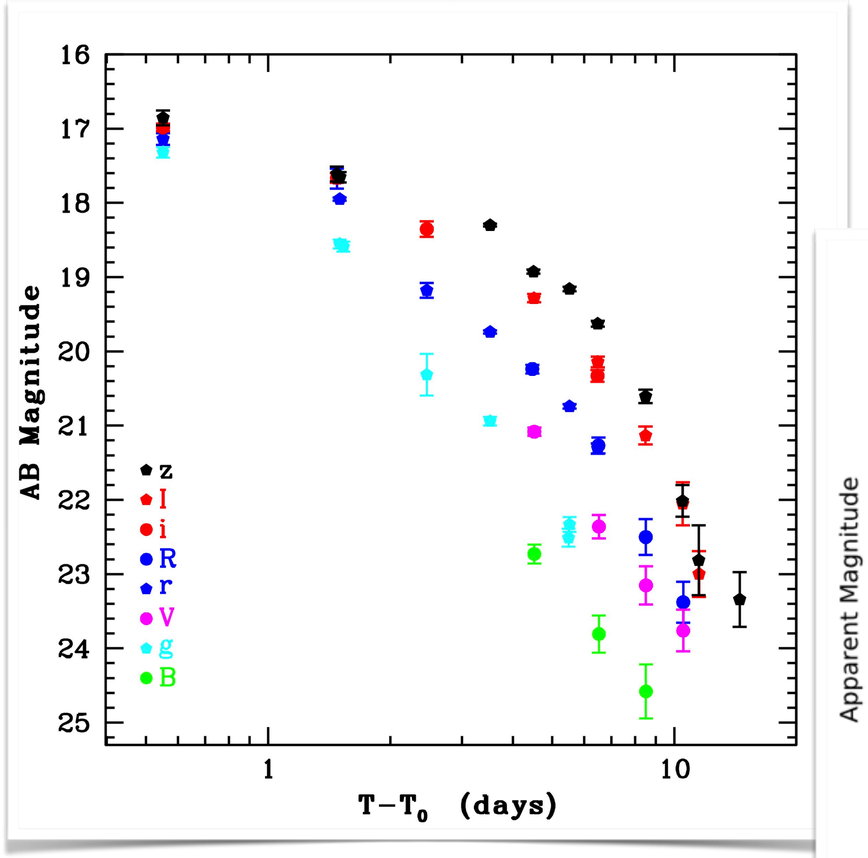
Villar et al. (2018)



Tanvir et al. (2017)

Multi-wavelength light curves

best fitted with multi-component KN model



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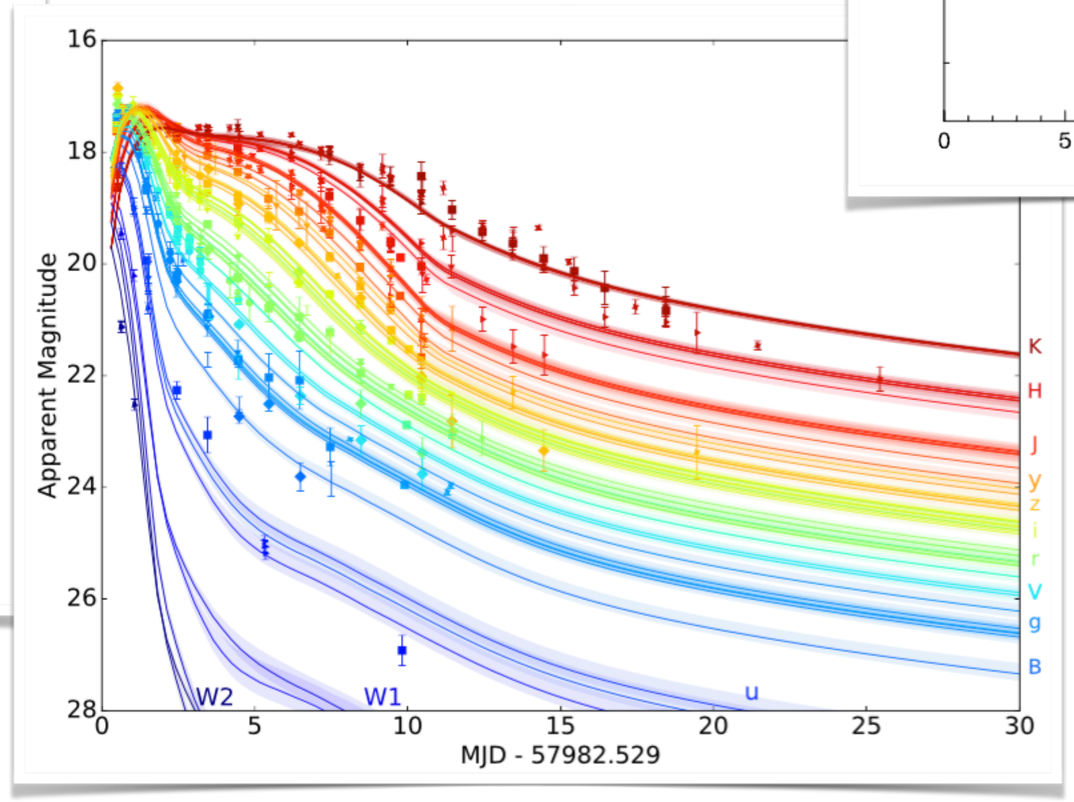

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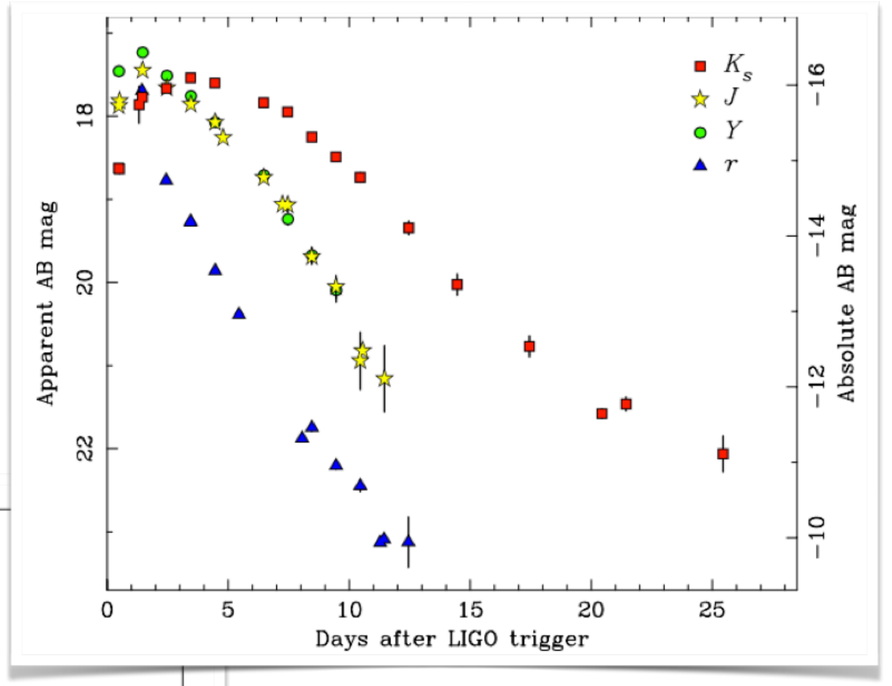


Tanvir et al. (2017)

see Granot's talk

Was KN170817 the first ?

GRB 080503

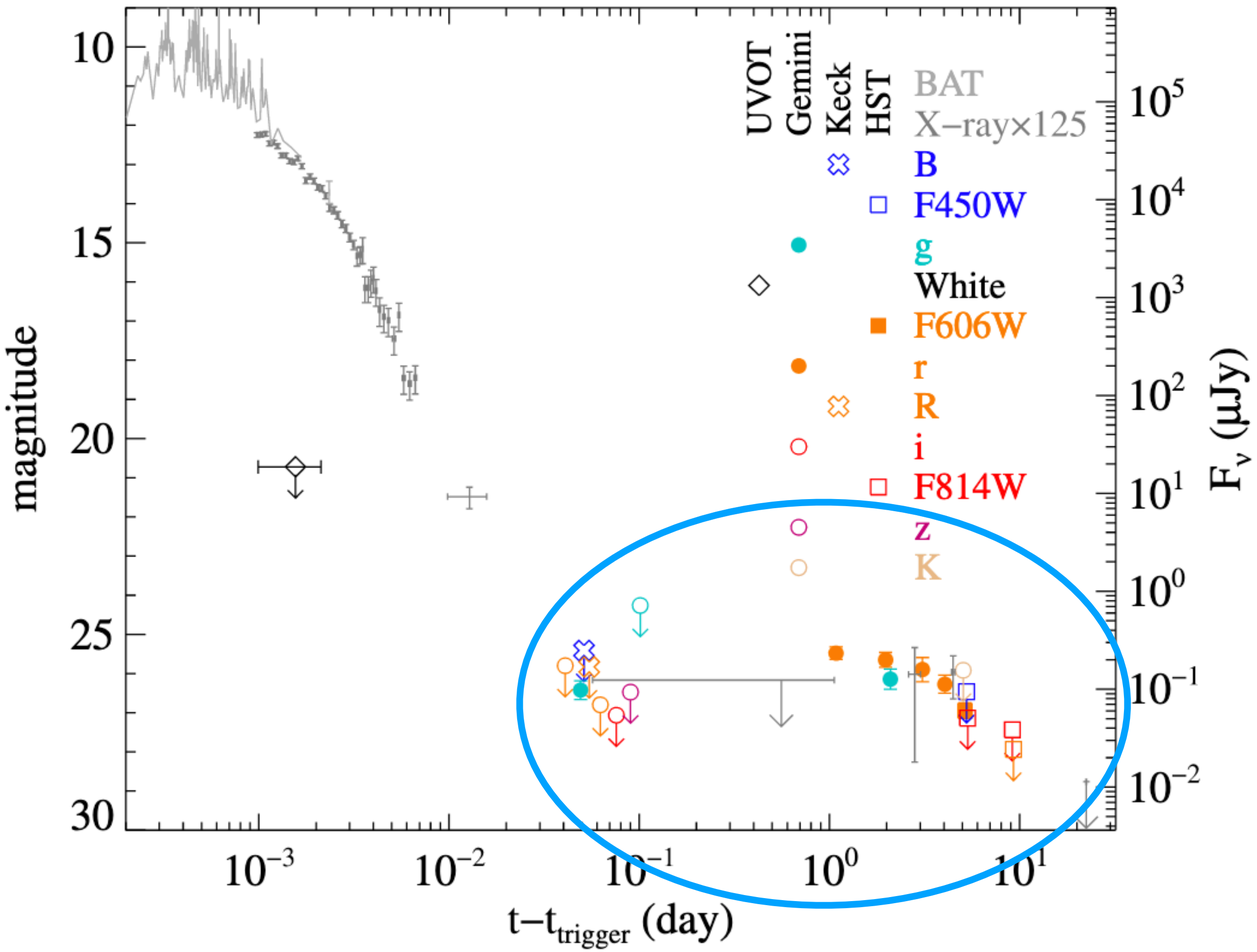
Optical/NIR excess in the late afterglow
Broadly consistent with X-ray emission (flare?)

"Nickel powered mini-SN" ??

But….explained reasonably also by other afterglow models

Poorly sampled

Perley et al. (2009)



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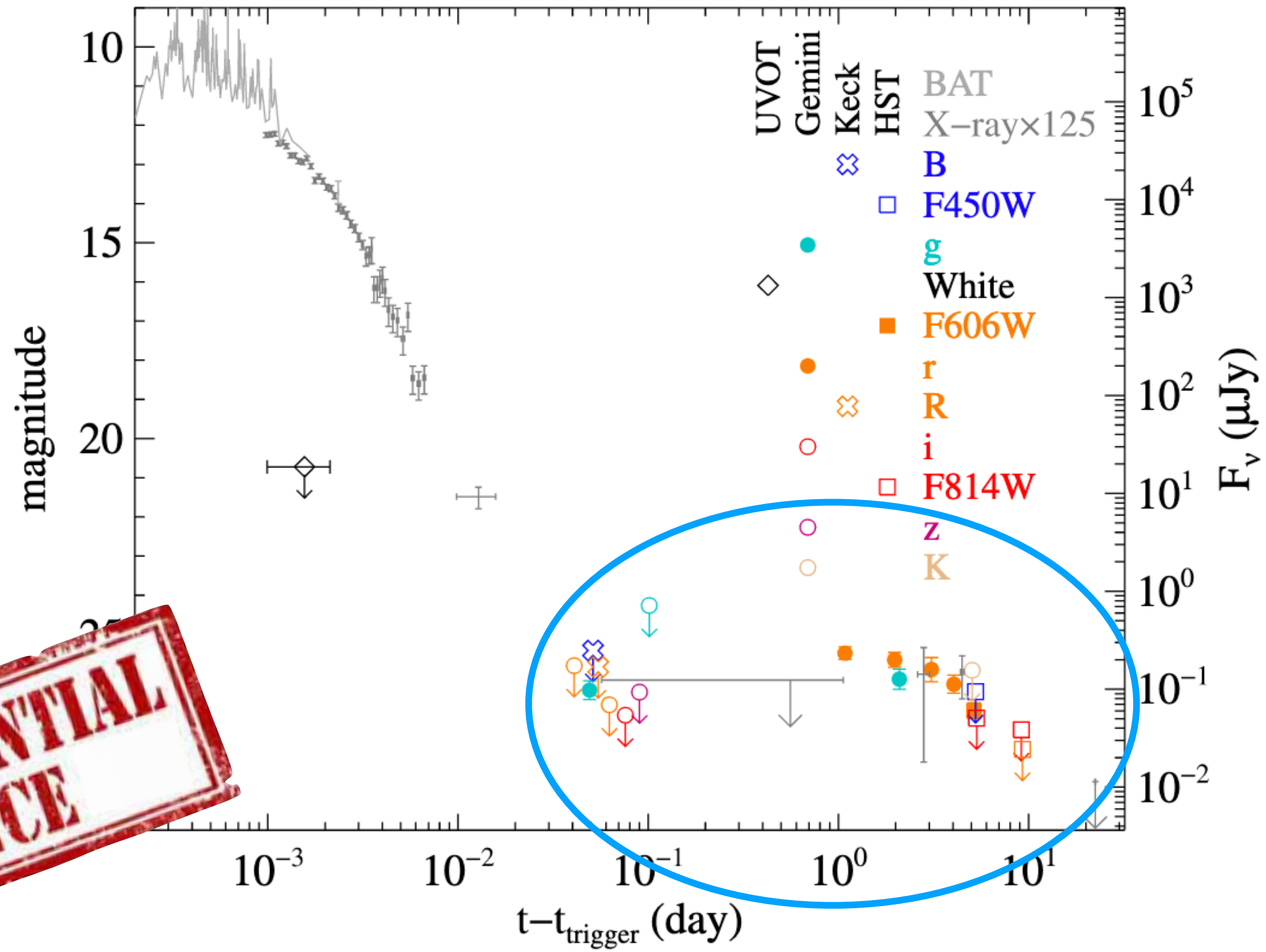

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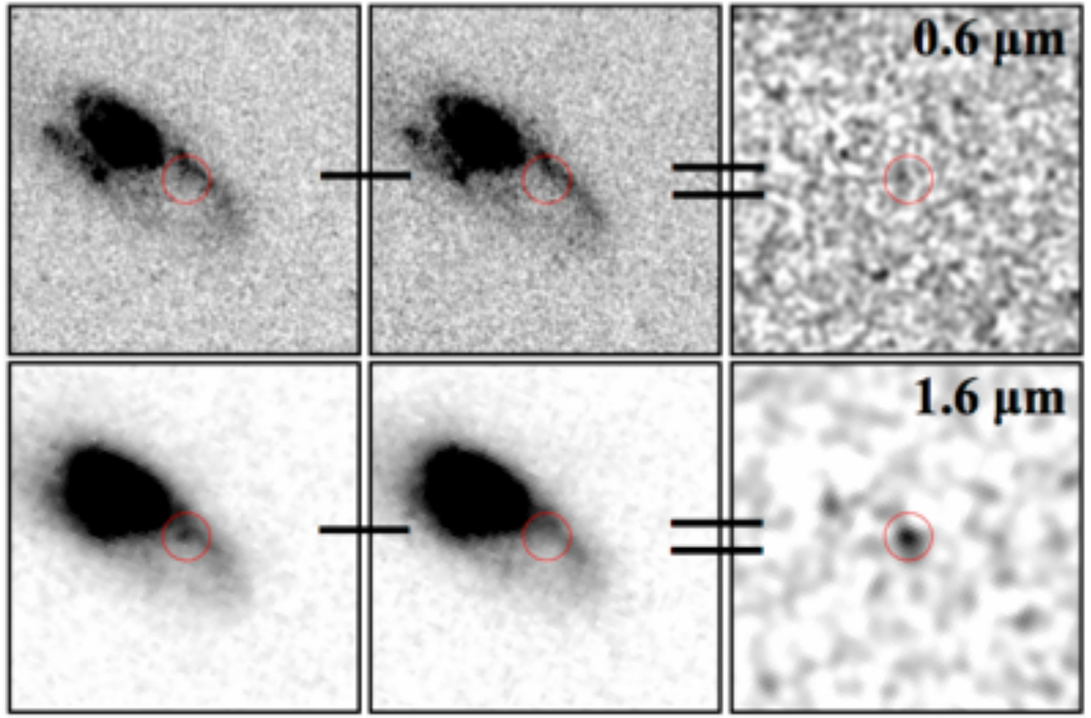
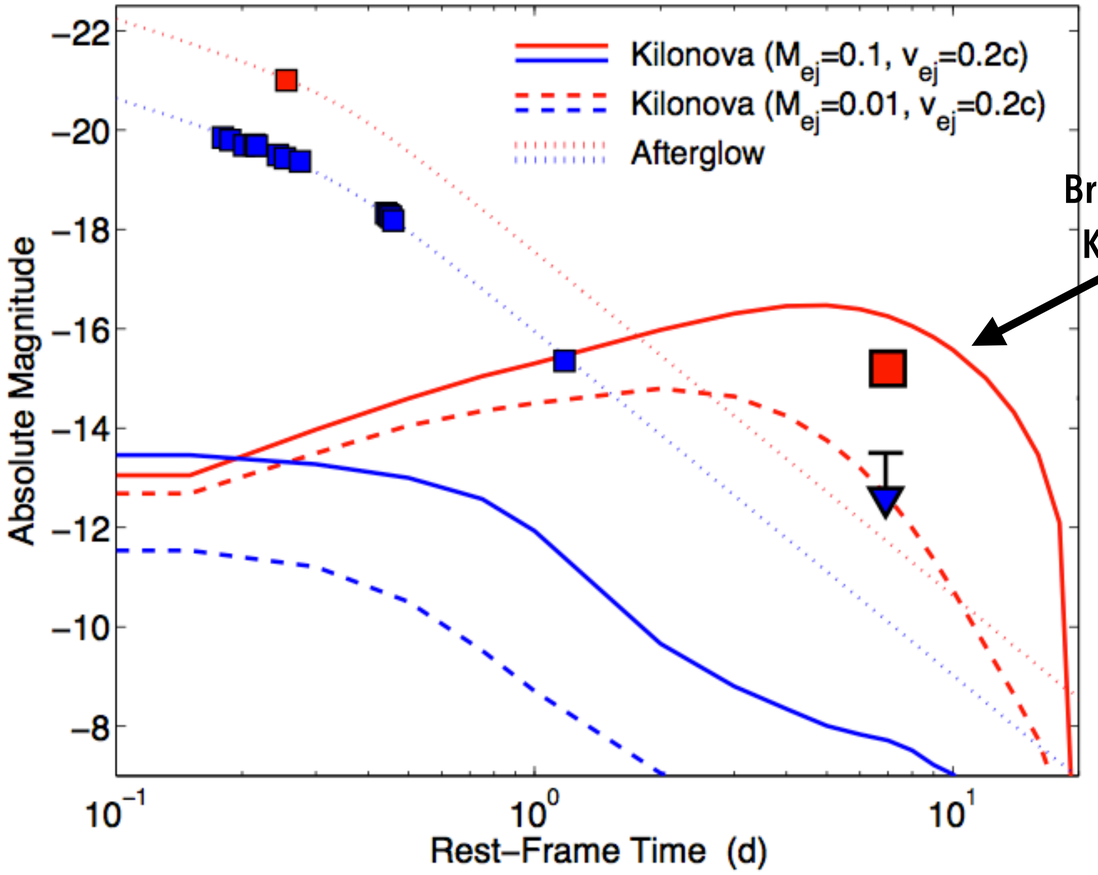
GRB130603B (z=0.356)



Tanvir et al. (2013), see also Berger et al. 2013



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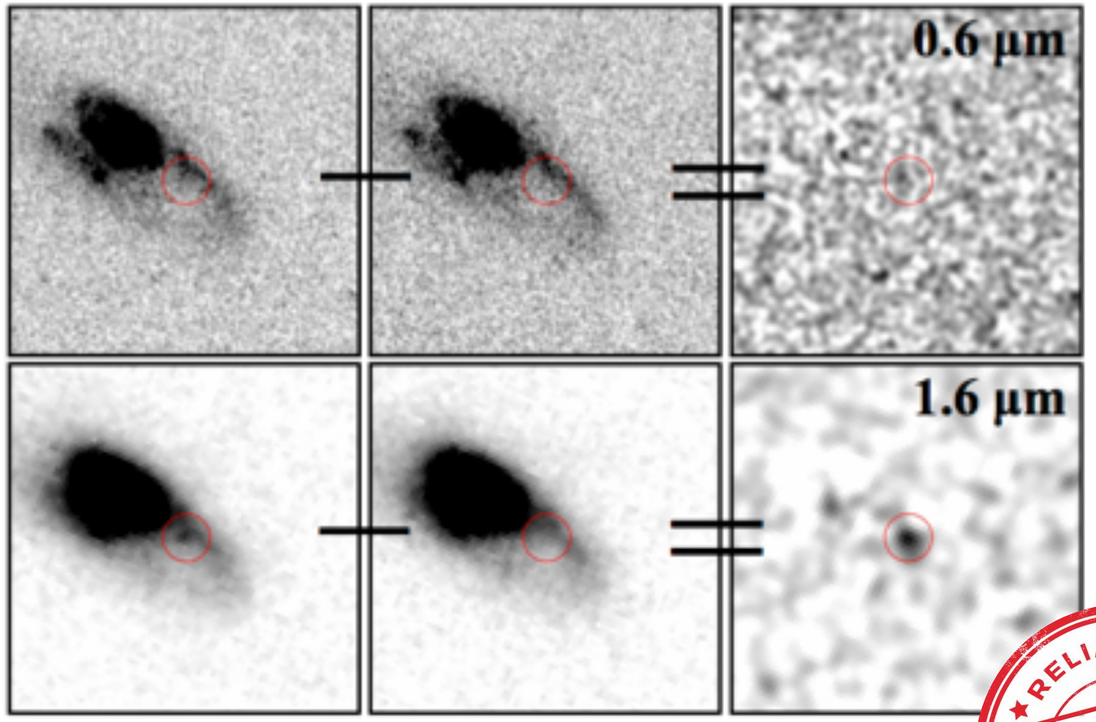

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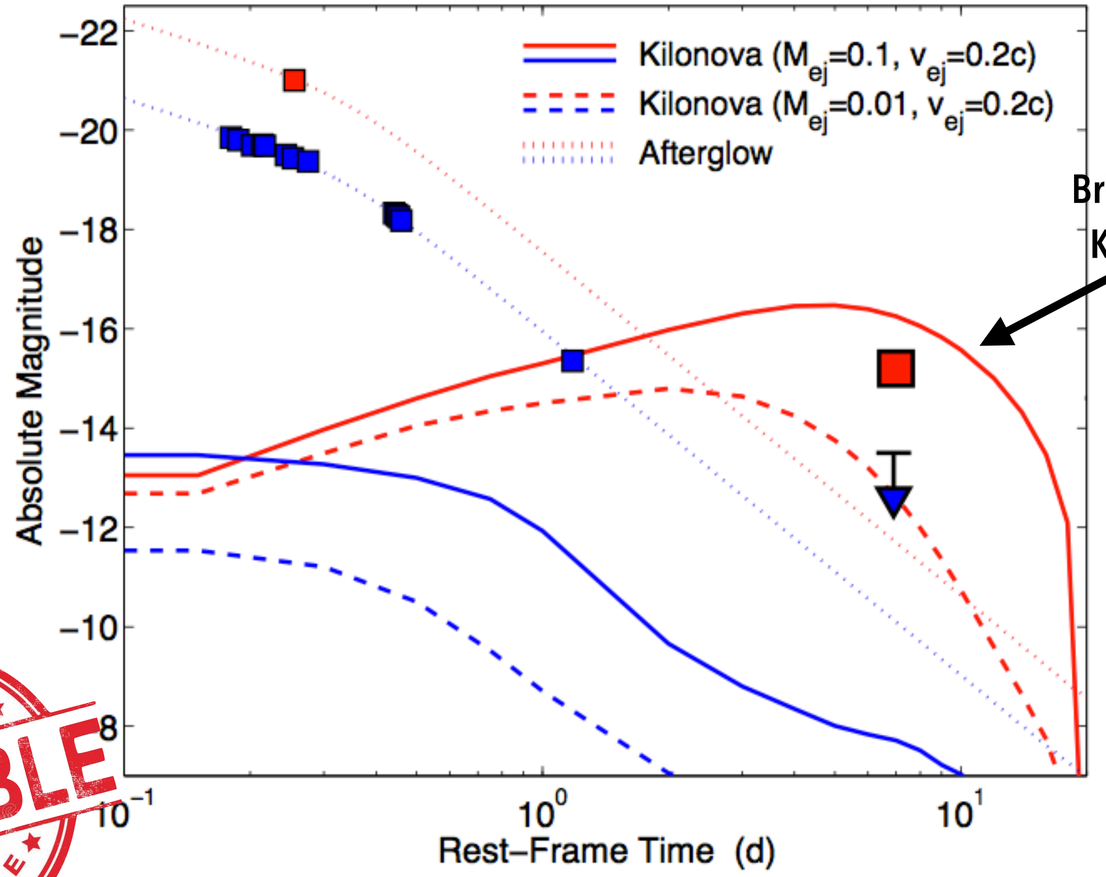

Brighter than KN170817

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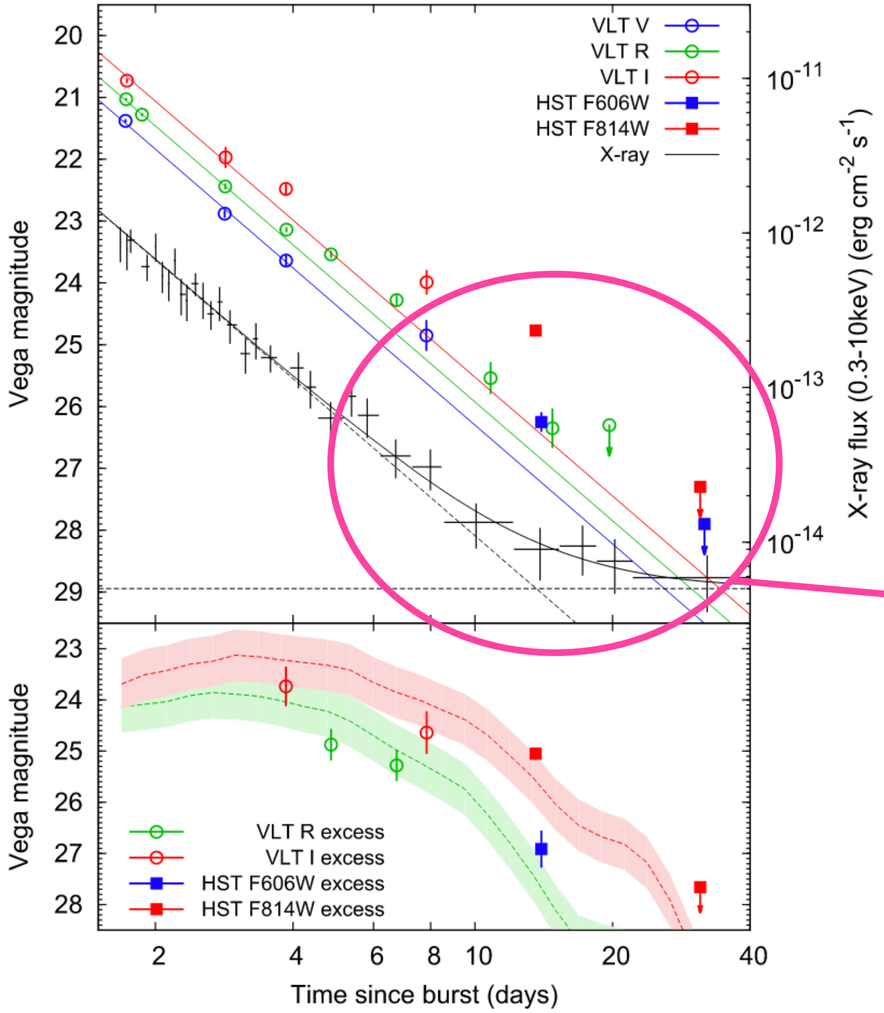
GRB 060614 (z=0.125)

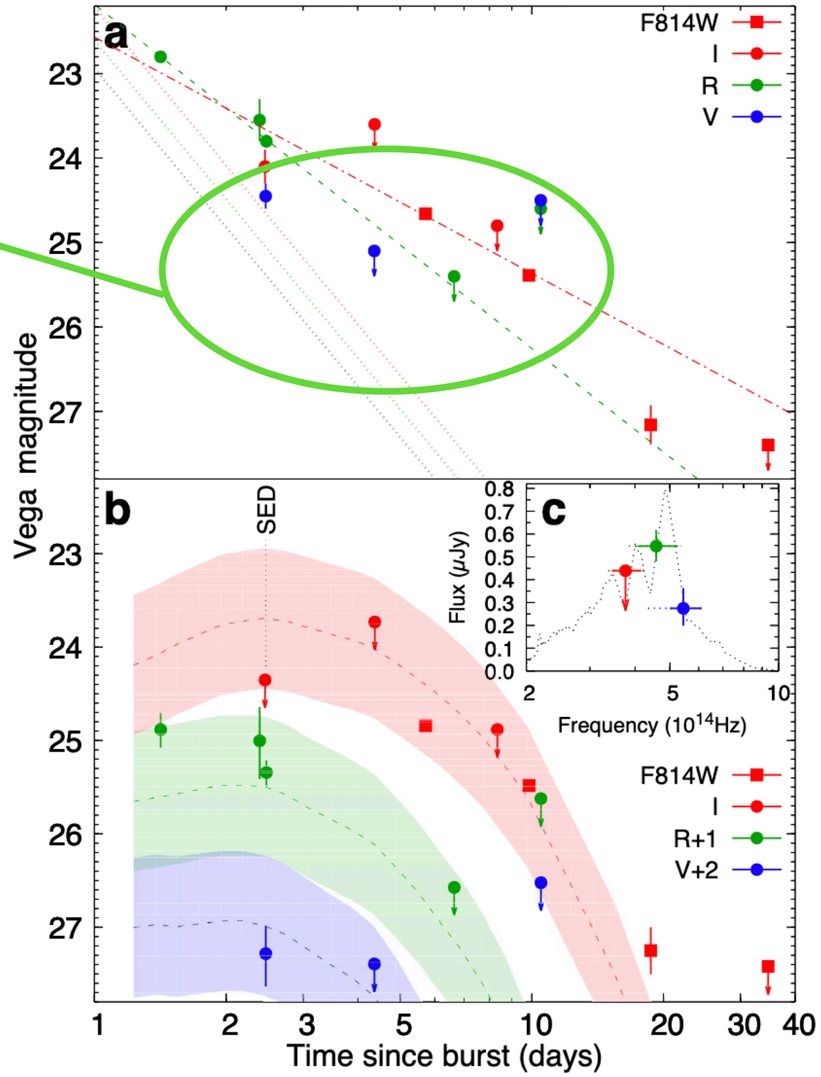


Jin et al. (2015), Yang et al. (2015)

NIR excess
X-ray flare at ~16 d
variability on a time scale of hours

NIR excess
X-ray flattening after ~12 d
underlying source?

GRB 050709 (z=0.160)



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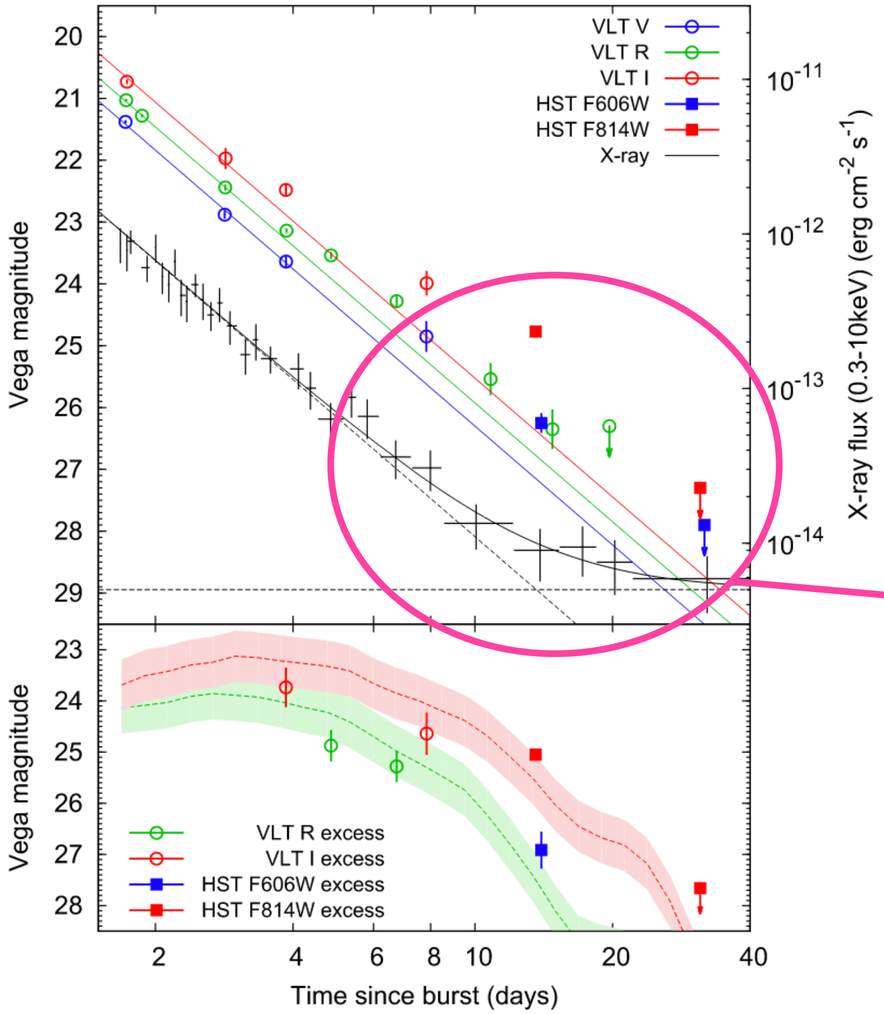

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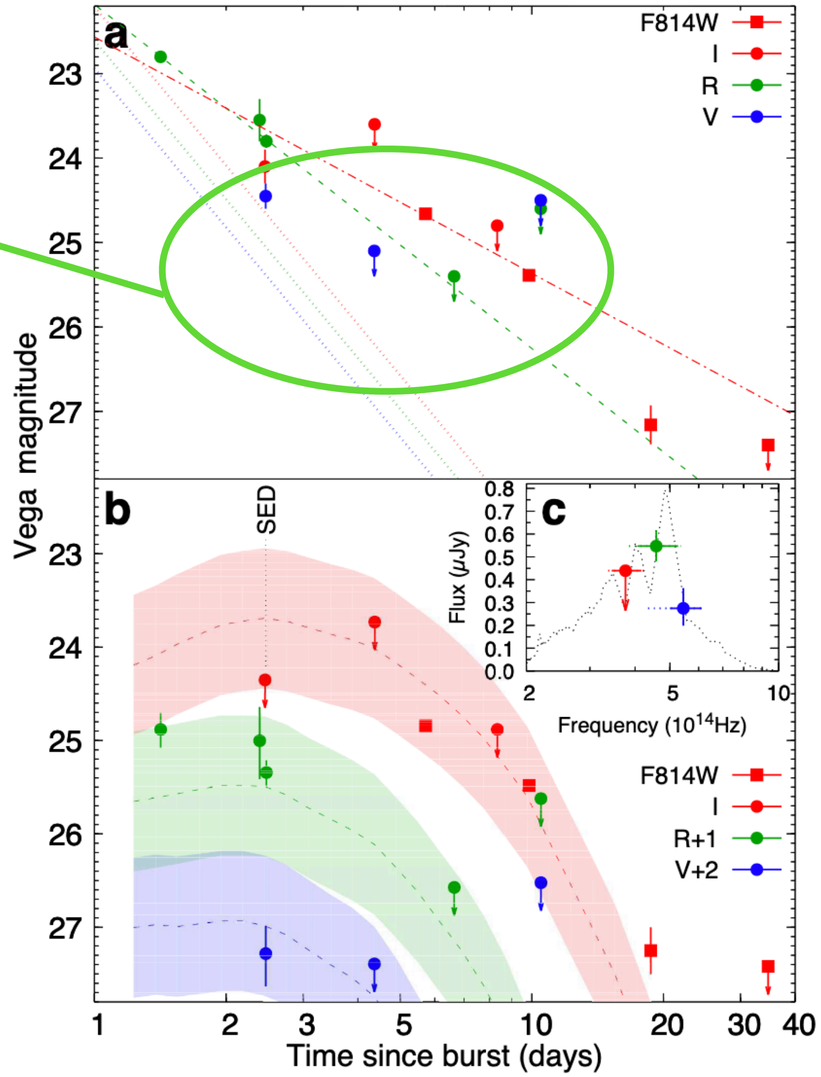

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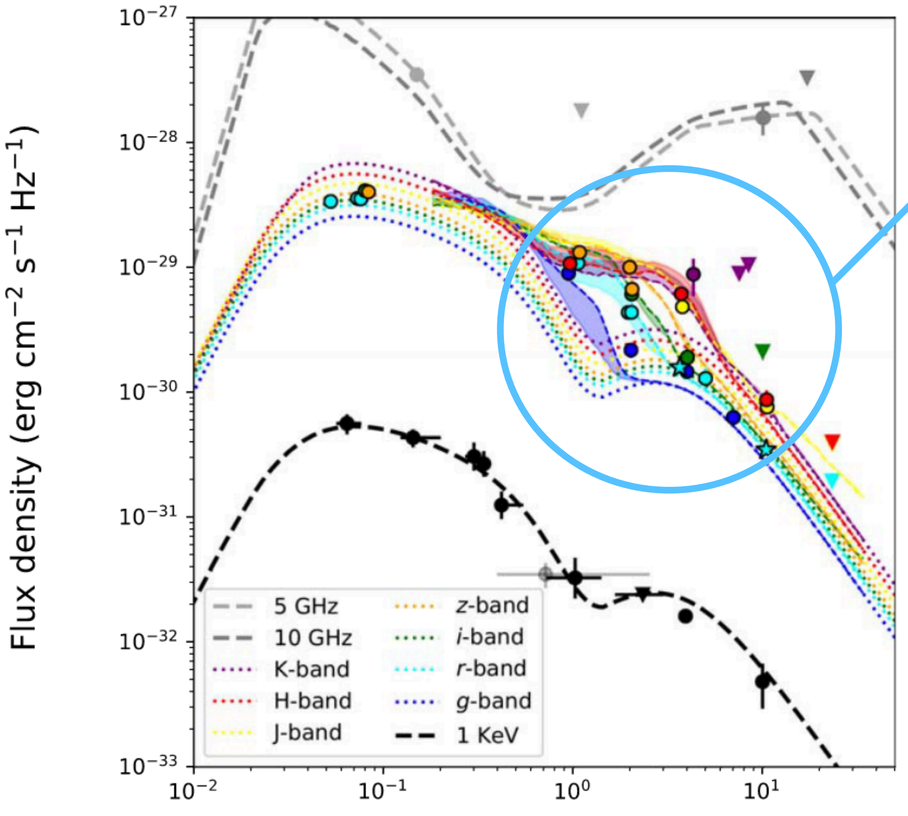
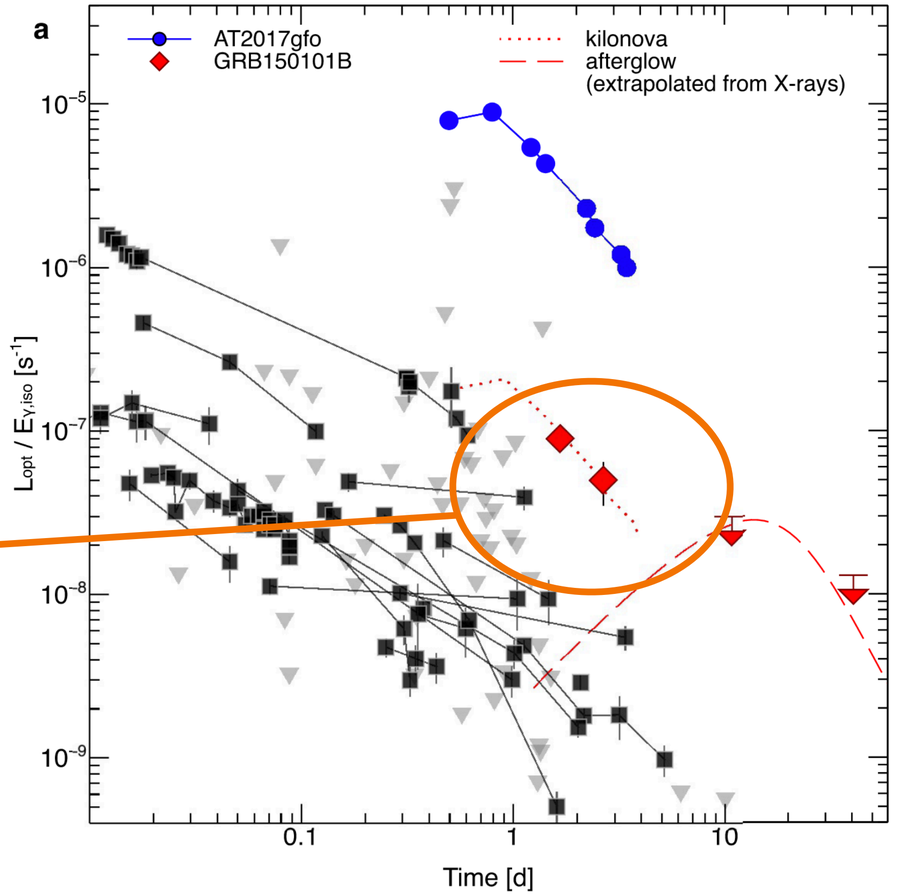


Optical/NIR excess
X-ray flattening and re-brightening
Kilonova model seems to work

Only two optical points
No color information
Uncertain

GRB150101B (z=0.134)



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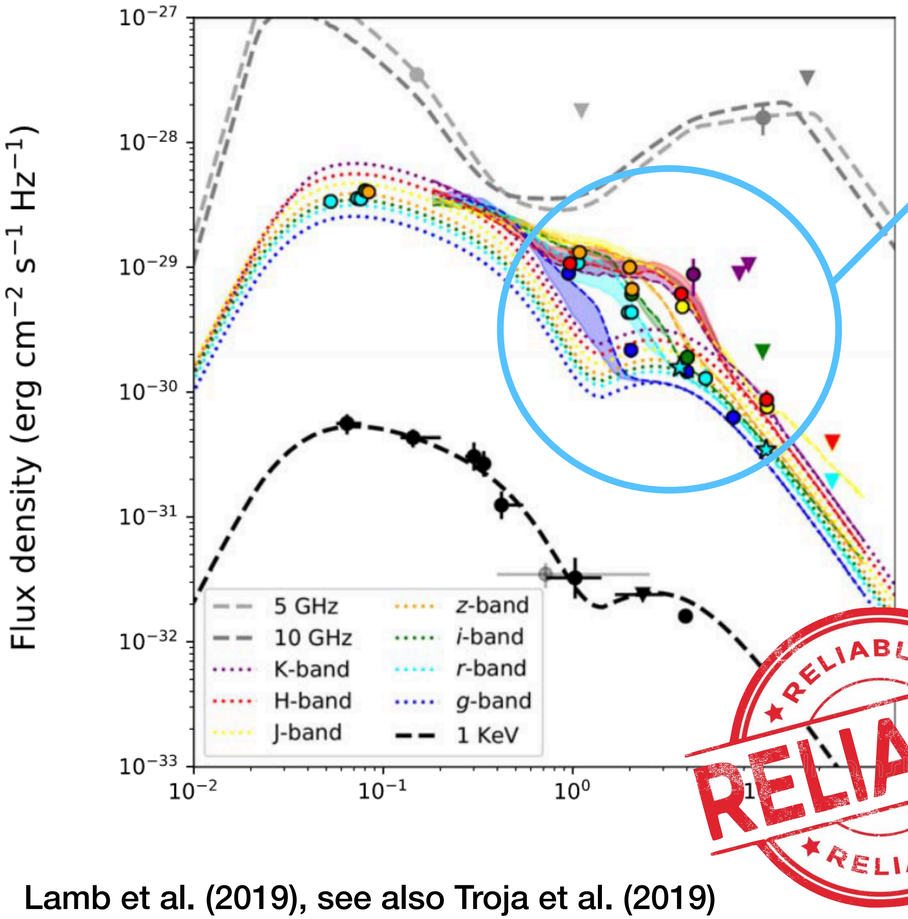

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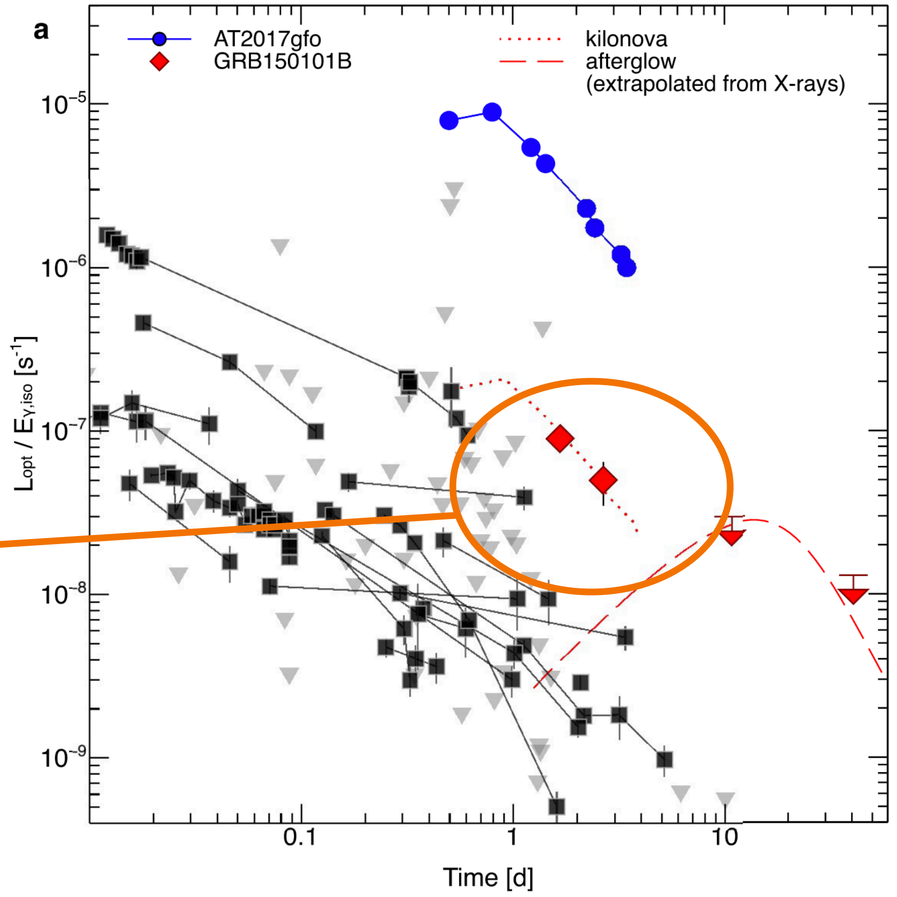

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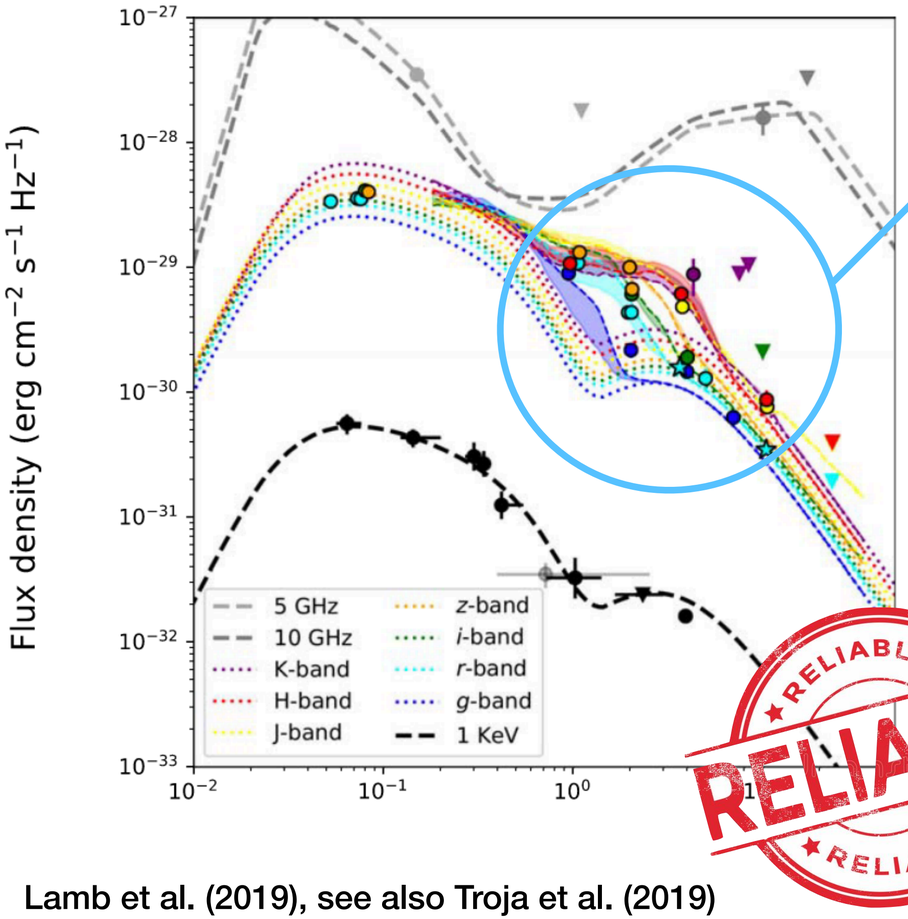

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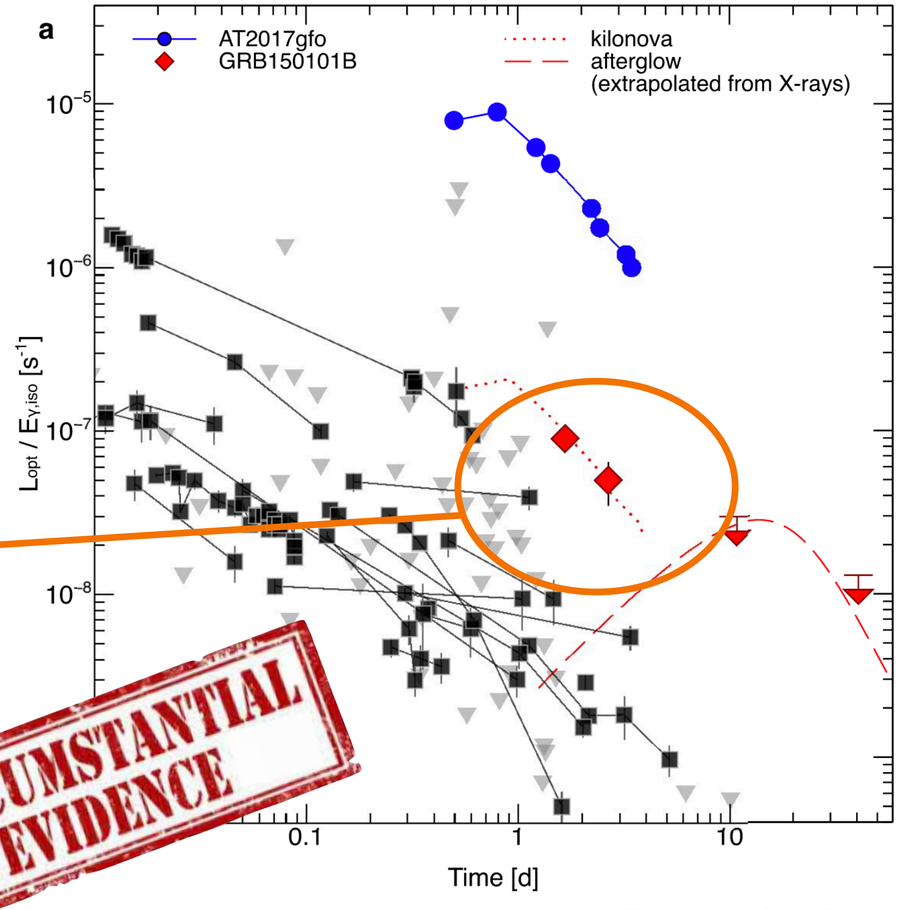

CIRCUMSTANTIAL EVIDENCE

Troja et al. (2018)

Summary

- EM counterparts of GW signals are real !!!

- **GW 170817 / GRB 170817A / AT2017gfo results:**
  - Definition and consolidation of successful follow-up strategies
  - First EM counterpart (at all wavelengths)
  - First unambiguous observational evidence for a kilonova
  - Evidence for kilonovae as a heavy elements factory
  - `Smoking gun' for short GRB progenitors
  - Clues on short GRB outflow geometry and properties: first evidence for a structured jet

- Several short GRBs show optical/NIR excess (KN signature?)

- The search for SGRB/KN events (old and new events) looks promising

- Many collaborations for follow-up observations

Ongrave

Pesstro

GraWITA

Gravitational waves @ INAF

VIN ROUGE

…and more

Summary

- Still a number of open issues :
  - how many KN types?
  - what is the origin of the blue component?
  - are KNe associated to every short GRB?
  - can KNe unveil the nature of the NS-NS remnant?

- We are ready for fast/multi-wavelength coordinated follow-up observations (we can do it)

- No good events in O3, waiting for O4 (higher rates of good events!!)

- “Reasonable” skymaps (<50 sqd) from BH-NS and NS-NS system are needed

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Thank you