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LSC

STROBE-X and LIGO

(some potential common science on transients)

Alessandra Corsi

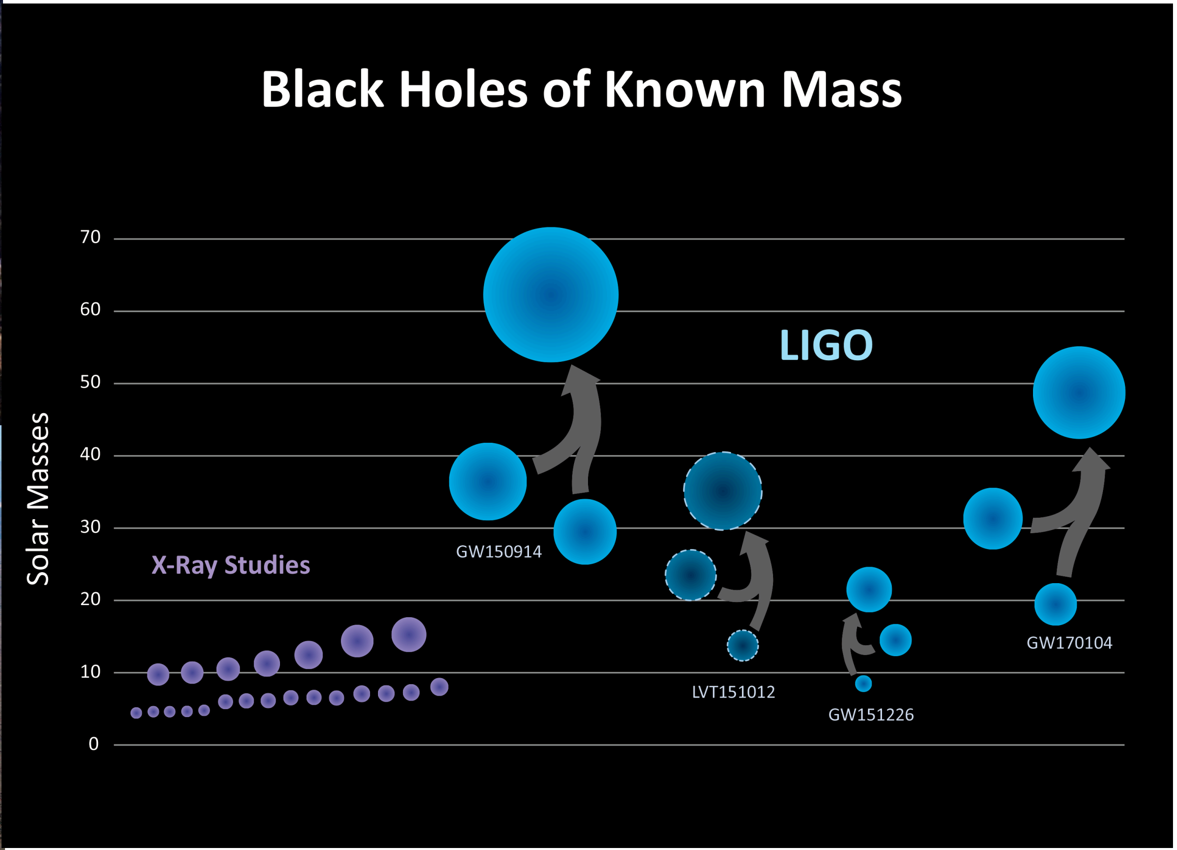
On behalf of the LIGO Scientific Collaboration

LIGO-G1701838

STROBE-X Science Meeting – 9/2017 – Lubbock TX

Welcome to the era of GW astrophysics!

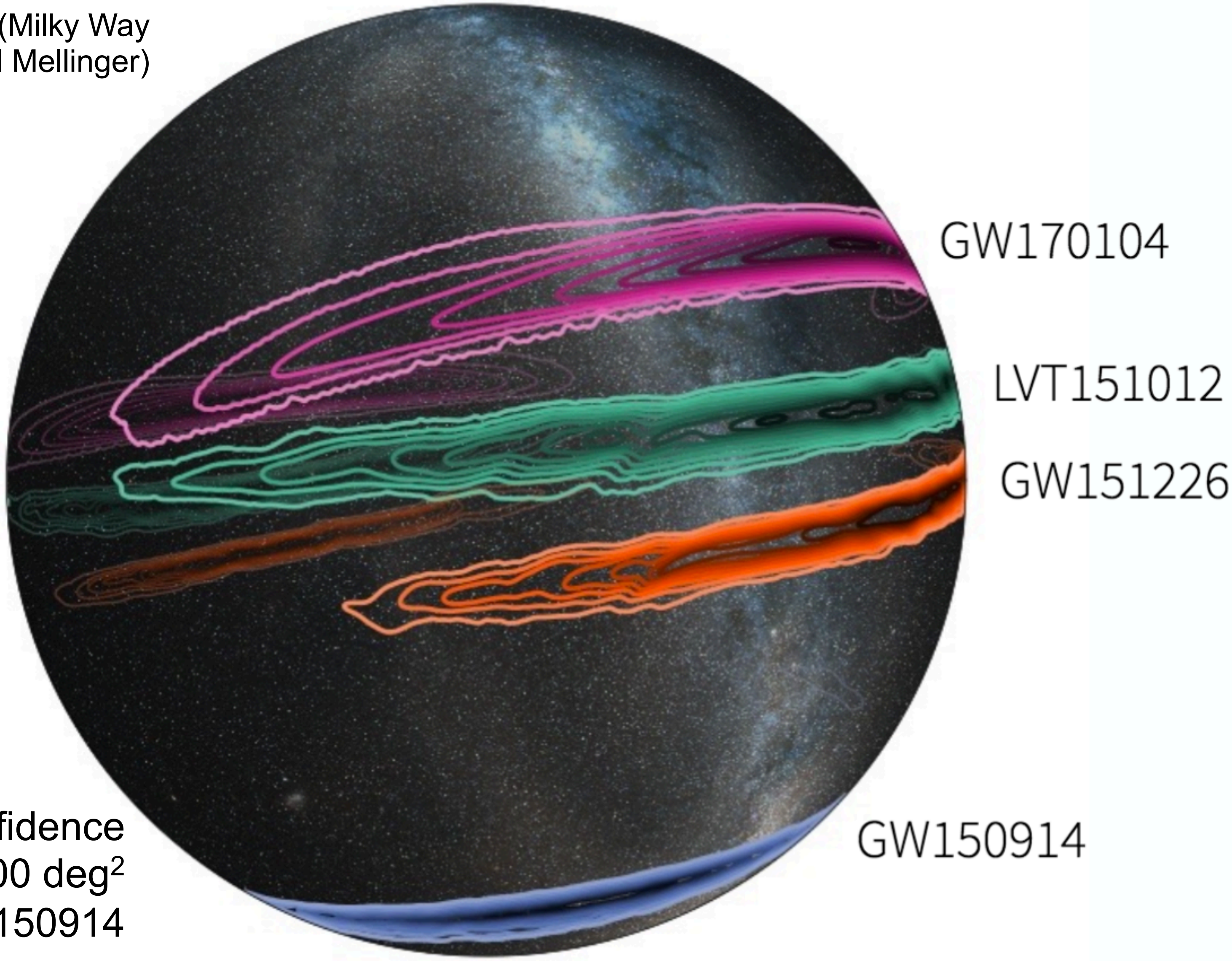
So far, 3 confirmed BBH mergers in Advanced LIGO O1/O2.



LSC/Sonoma State University/Aurore Simonnet

Sky localization

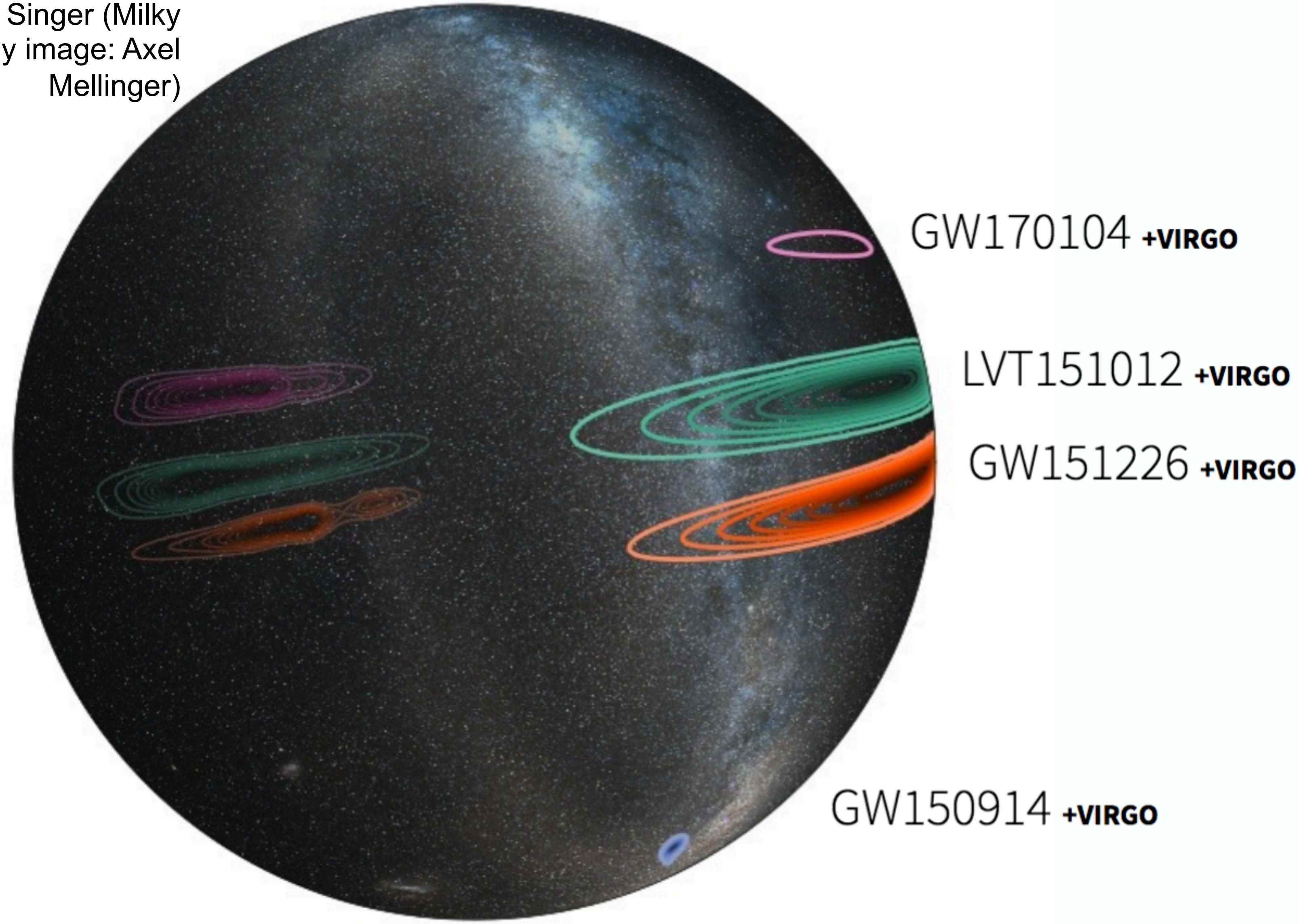
LSC/Leo Singer (Milky Way
image: Axel Mellinger)



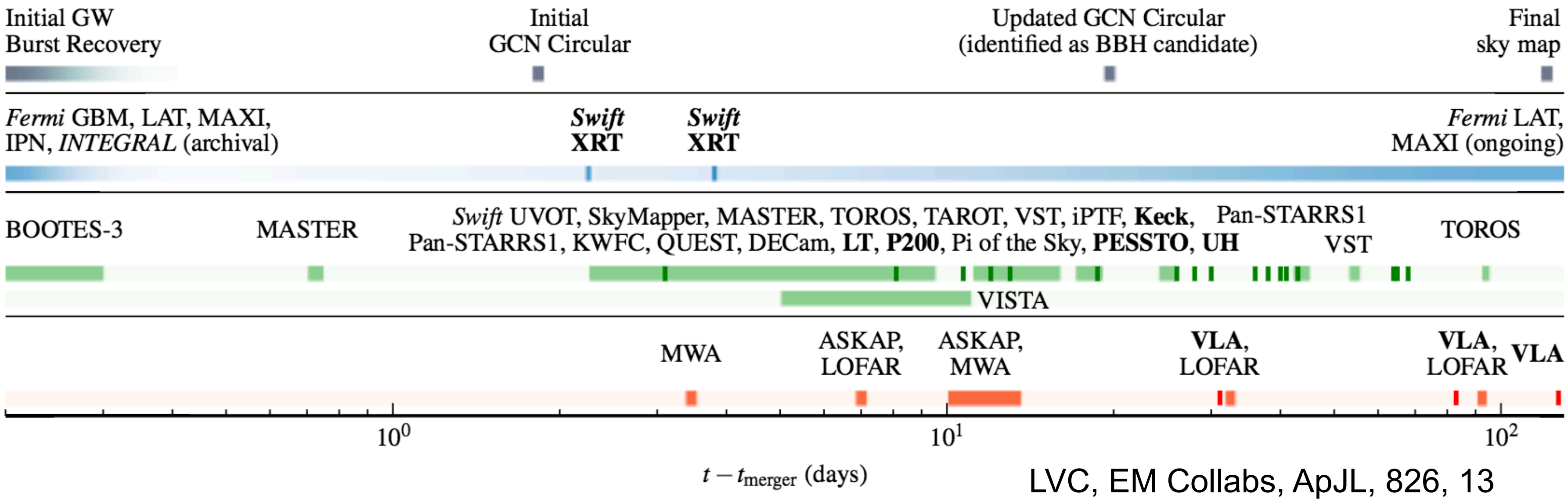
90% confidence
region about 600 deg^2
for GW150914

Simulated sky localization with Virgo

LSC/Leo Singer (Milky Way image: Axel Mellinger)

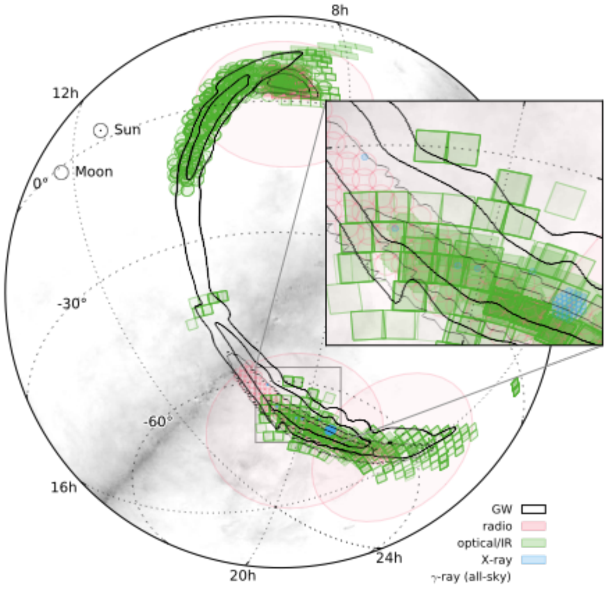


GW150914 EM follow-up

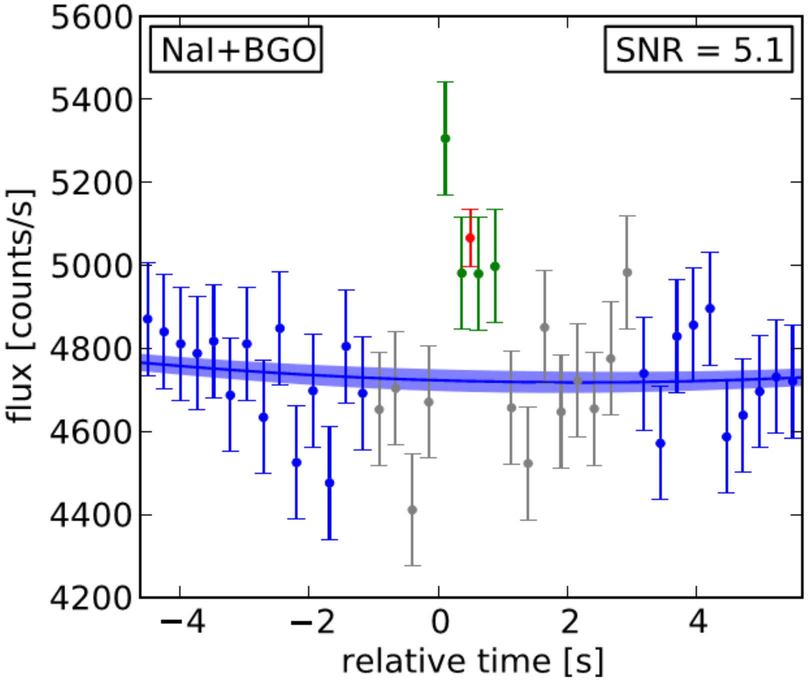


LVC, EM Collabs, ApJL, 826, 13

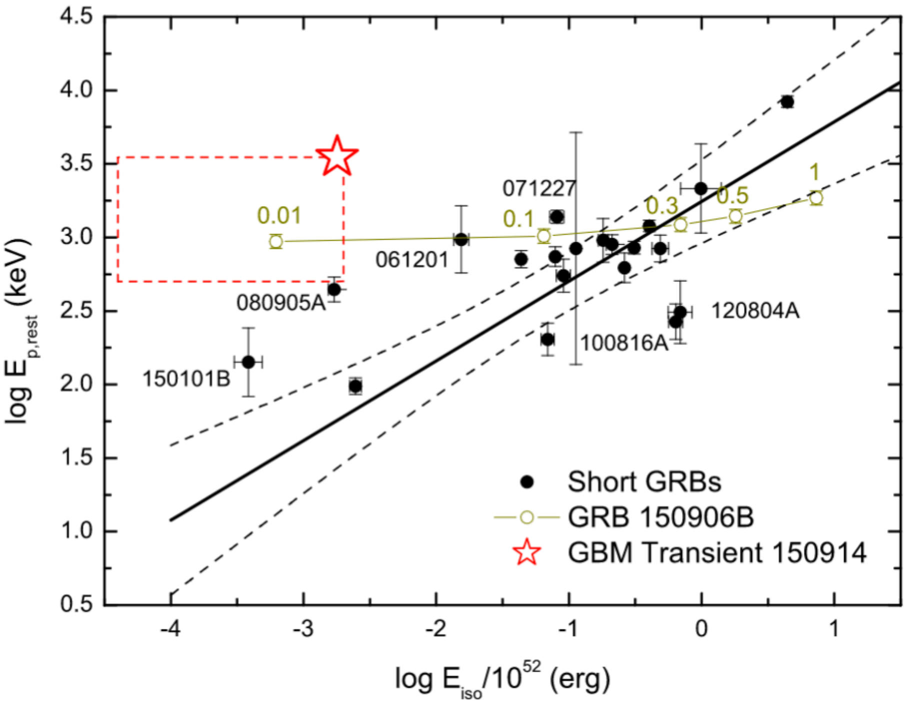
- Consortium between LIGO-Virgo and 63 teams using ground and space facilities.
- Gamma-ray, X-ray, optical, infrared, and radio wavelengths.



BBH gamma-ray counterpart?



- γ-ray signal (0.2% FAP) lasting ~1s in Fermi/GBM (>50 keV), 0.4 s after BBH merger (Connaughton et al. 2016, ApJ, 826, 6).
- Not detected by Fermi/LAT (Ackermann et al. 2016, ApJ, 823, L2) or Integral (75 keV – 2 MeV; Savchenko et al. 2016, ApJ, 820, 36).



γ-ray transient associated with GW150914 compared with short GRBs in the luminosity-E_{peak} plane (Li et al. 2016, ApJ, 827, L16).

August 2017 update on LIGO O2

◆ **A very exciting LIGO-Virgo Observing run.**

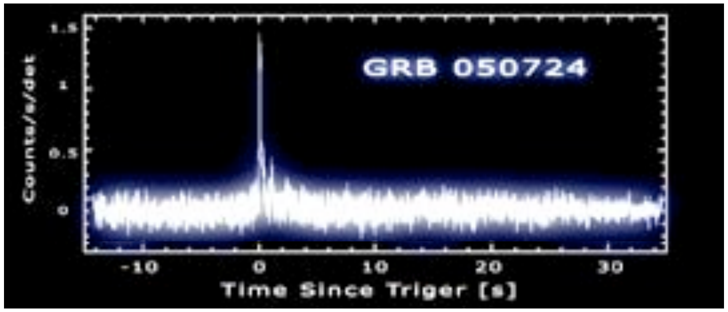
◆ **O2 began on 30 November 2016 and ended on 25 August 2017**. The achieved sensitivity across the run has been typically in the range 60 – 100 Mpc.

◆ **Virgo** operating together with LIGO **since August 1, 2017**.

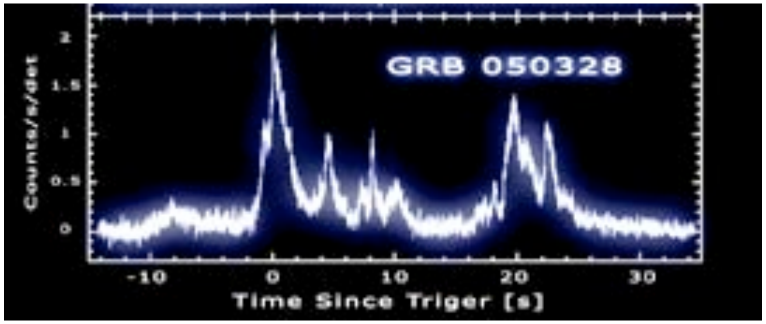
◆ **Some promising GW candidates have been identified** in data from both LIGO and Virgo during our preliminary analysis, an shared with astronomical observing partners.

◆ **We are working hard to assure that the candidates are valid GW events**. It will require time to establish the level of confidence needed to bring any results to the scientific community.

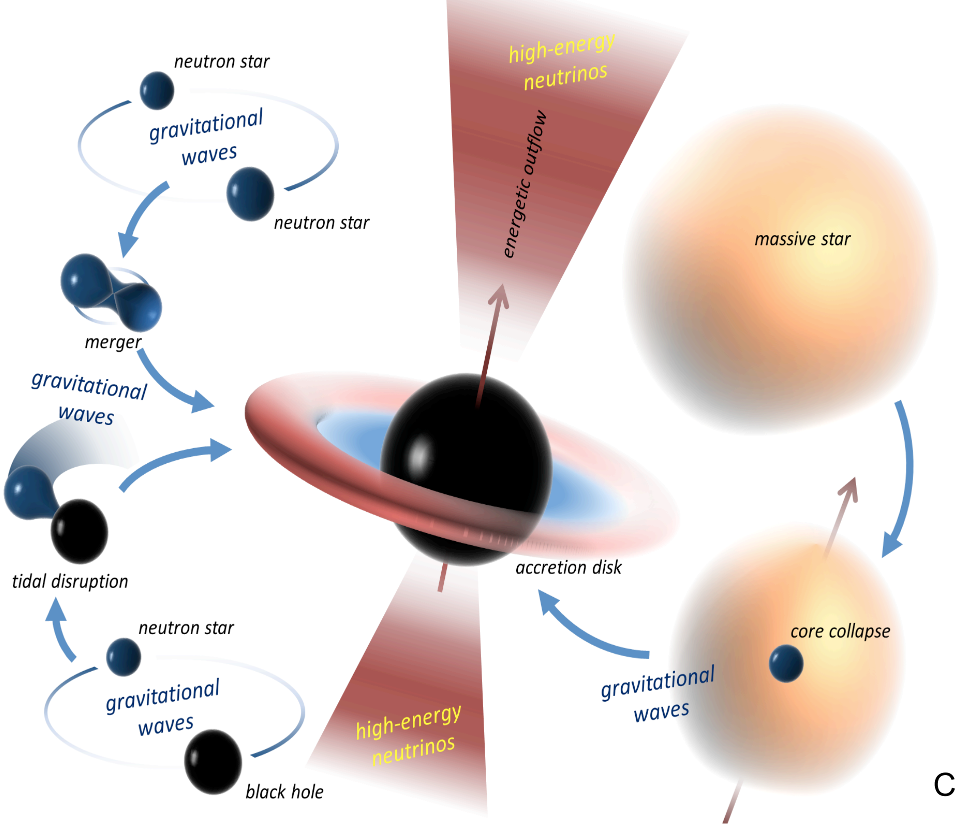
BHs are nice but NSs matter…



Credit: NASA

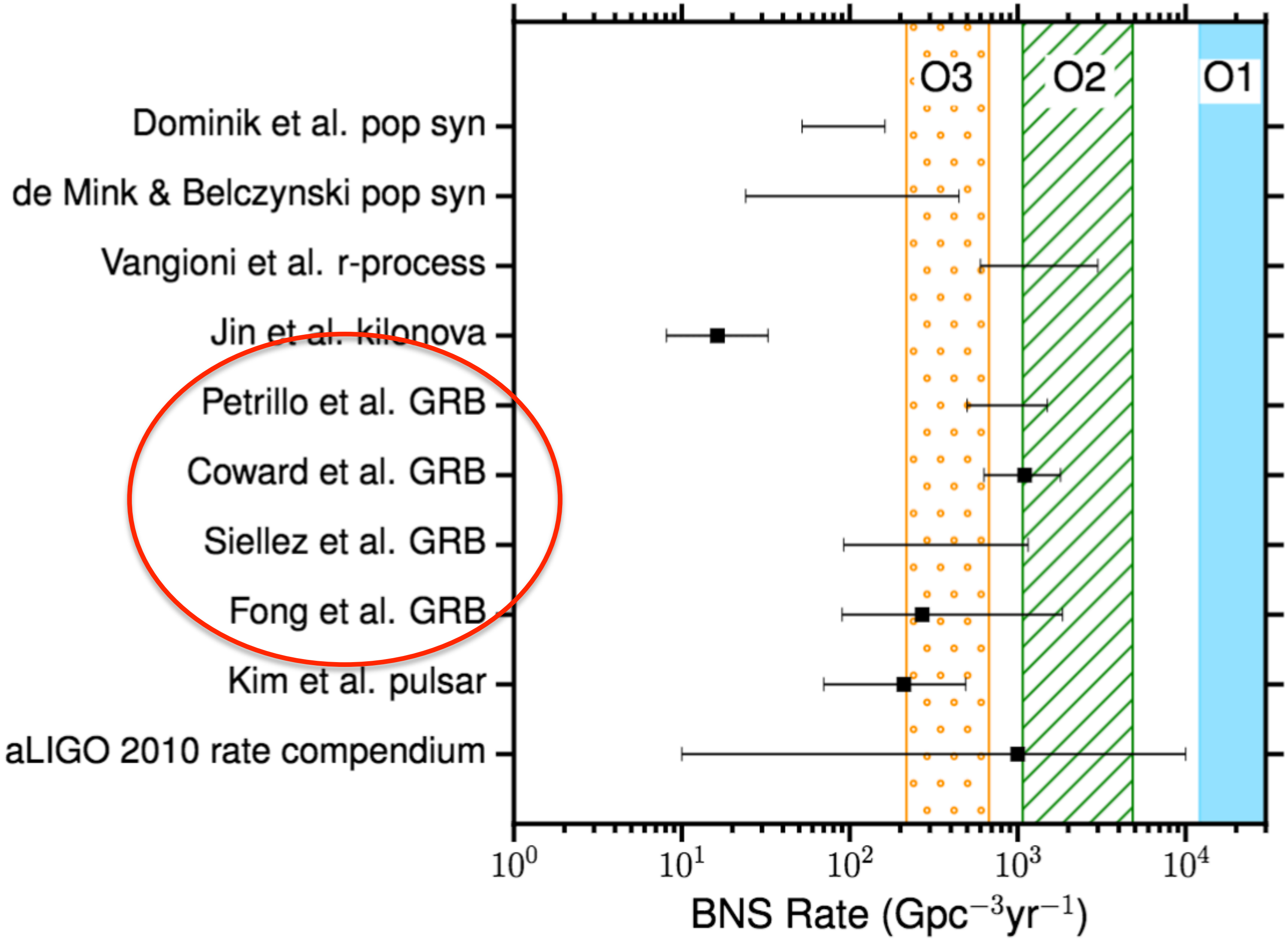


Credit: NASA



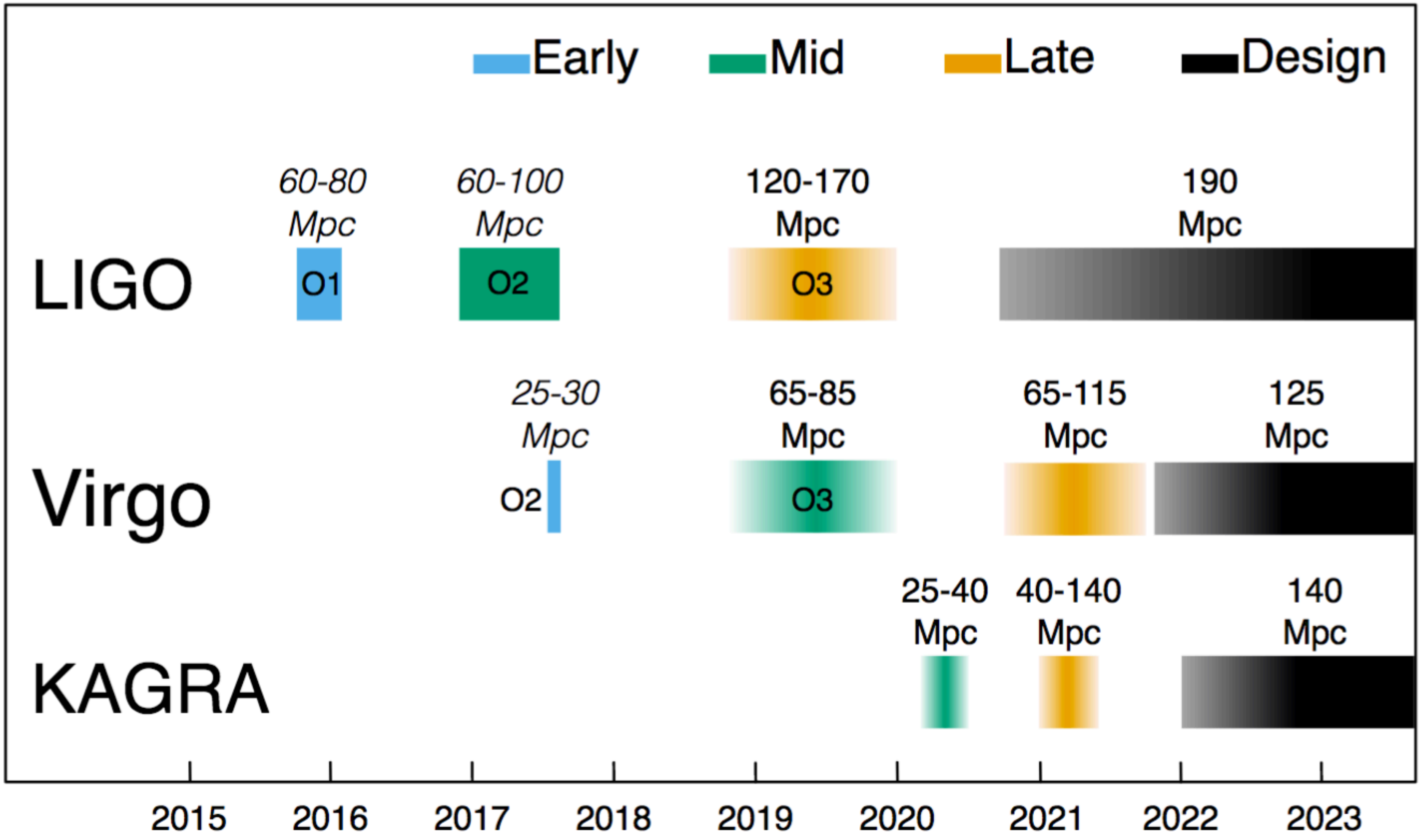
Credit: I. Bartos

Constraints on BNS rates



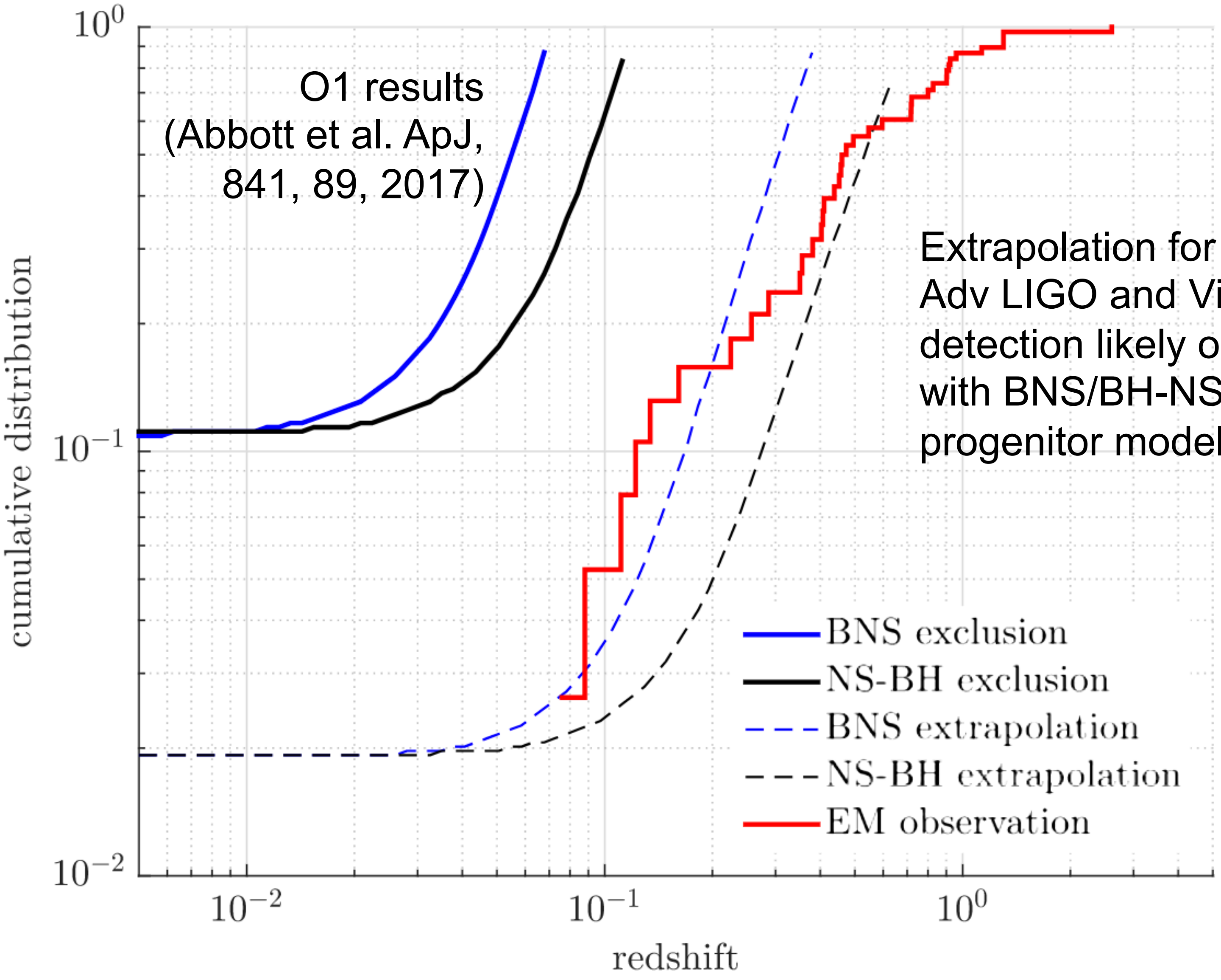
Abbott et al. 2016, ApJ, 832, L21

Expected progress in the near future



Abbott et al., Living Reviews in Relativity 19, 1 (2016)

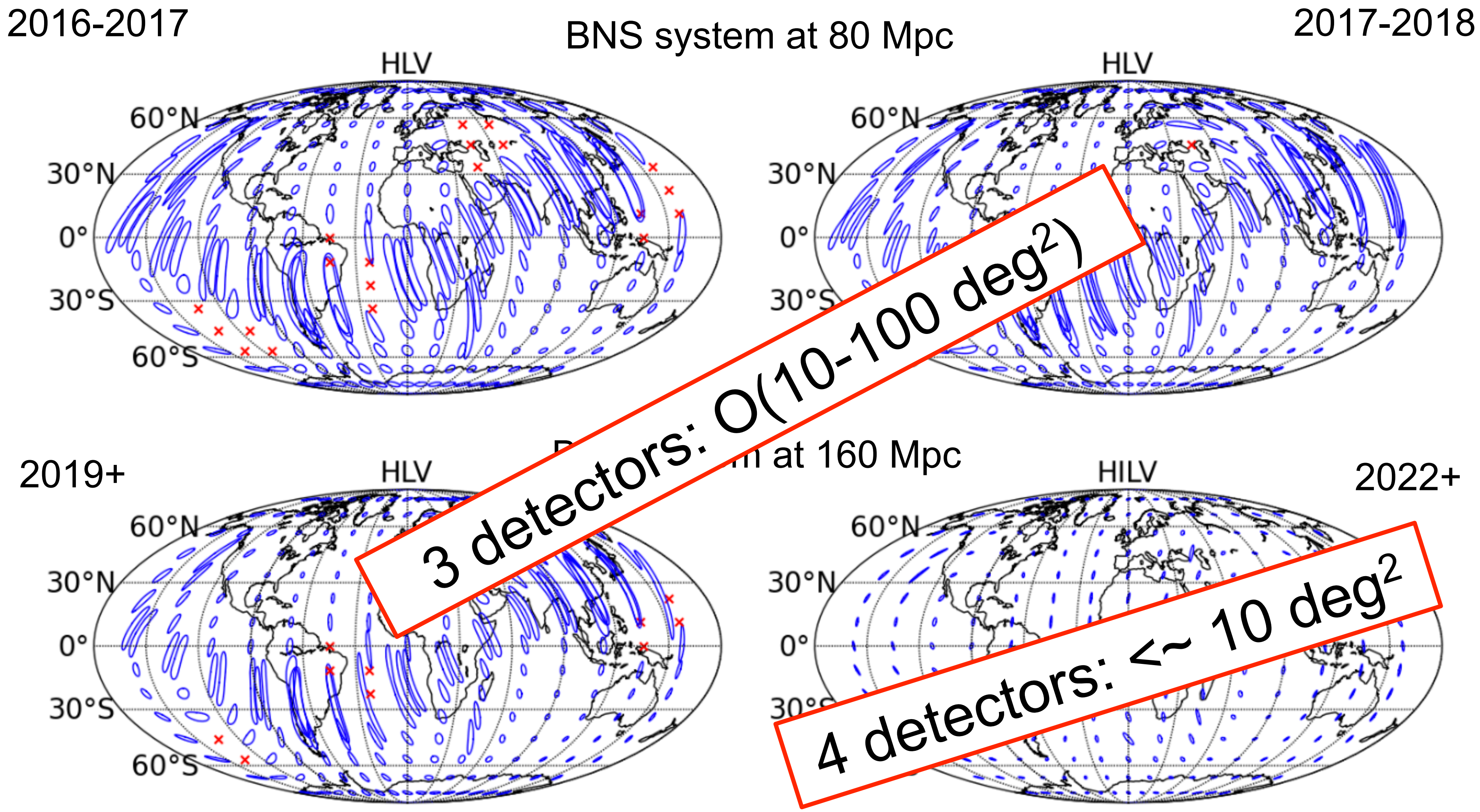
BNS/BH-NS gamma-ray triggered searches



O1 results
(Abbott et al. ApJ,
841, 89, 2017)

Extrapolation for 2 yrs of Adv LIGO and Virgo: detection likely or tension with BNS/BH-NS progenitor model

BNS: prospects for improved localizations


2016-2017

BNS system at 80 Mpc

2017-2018

2019+

m at 160 Mpc

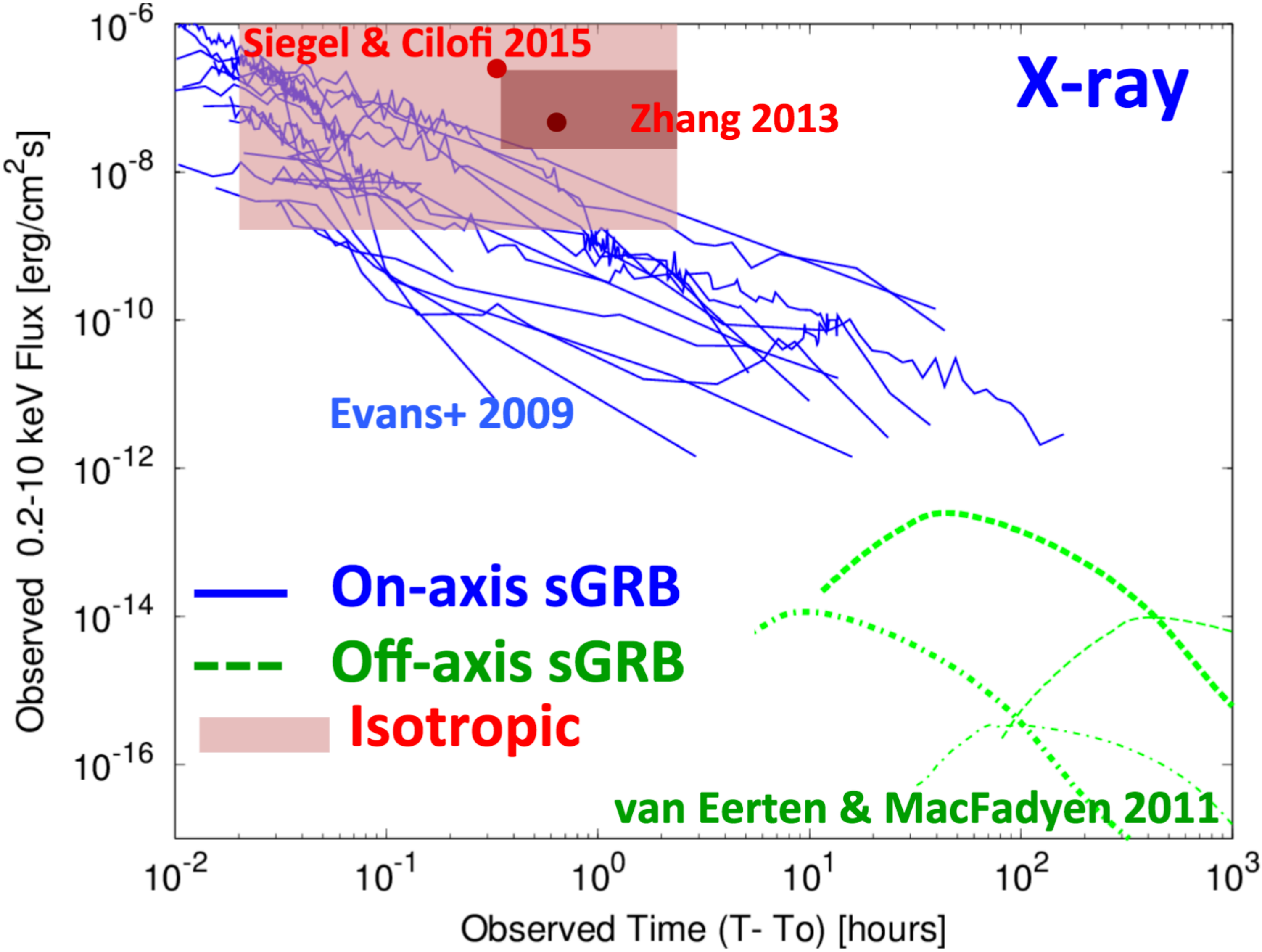
2022+

3 detectors: O(10-100 deg^2)

4 detectors: <~ 10 deg^2

Abbott et al., Living Reviews in Relativity 19, 1 (2016)

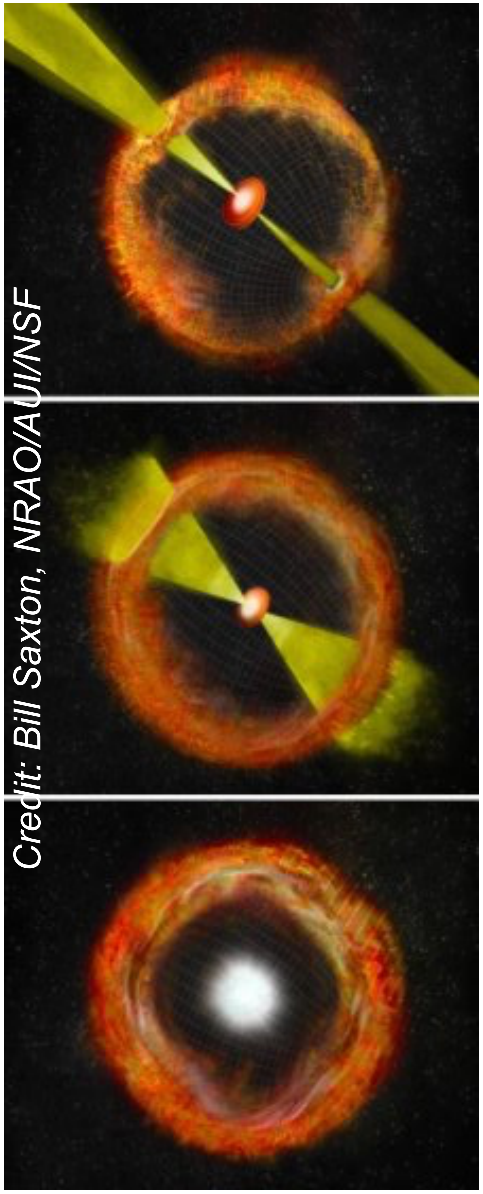
BNS / BH-NS GW-triggered X-ray follow-up



Assumed distance of 200 Mpc, various model parameter assumptions

Figure from Branchesi et al.

GWs bursts and core-collapse events



Credit: Bill Saxton, NRAO/AUI/NSF

$$\boxed{\mathbf{R_{GRB} \approx R_{GRB,obs}(1-\cos\theta_j)^{-1}}}$$

Extreme collapse (optimistic): ~$10^{-2} M_\odot c^2$ in GWs → <100 Mpc

$R_{LGRB,obs} \approx 1\ (\mathrm{Gpc})^{-3}\ \mathrm{yr}^{-1}$

$(1-\cos\theta_j)^{-1} \approx 65$ (i.e. $\theta_j \approx 10$ deg)

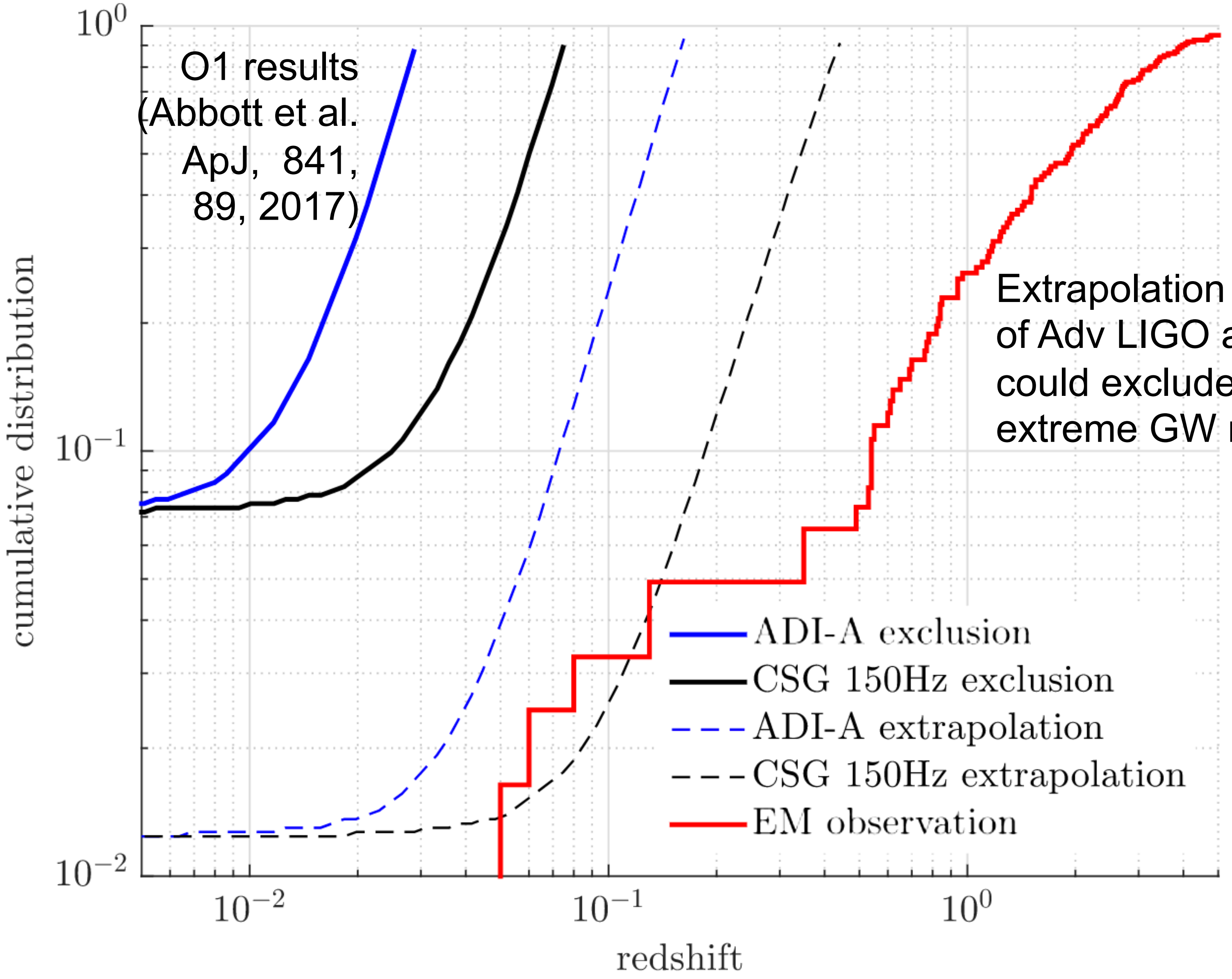
$R_{LGBR} \approx 0.3\ \mathrm{yr}^{-1}$ at ≤ 100 Mpc (only 1-2 in 100 with γ-rays)

$R_{LLGRB,obs} \approx 100\text{-}400\ (\mathrm{Gpc})^{-3}\ \mathrm{yr}^{-1}$ (Virgili et al.2009,MNRAS,329, 91).

$R_{LLGRB,obs} \approx R_{LLGRB} \approx 0.4\text{-}2/\mathrm{yr}$ at ≤100 Mpc

Galactic core-collapse SNe: $R_{SN,MW} \approx$ 1-3/Century.

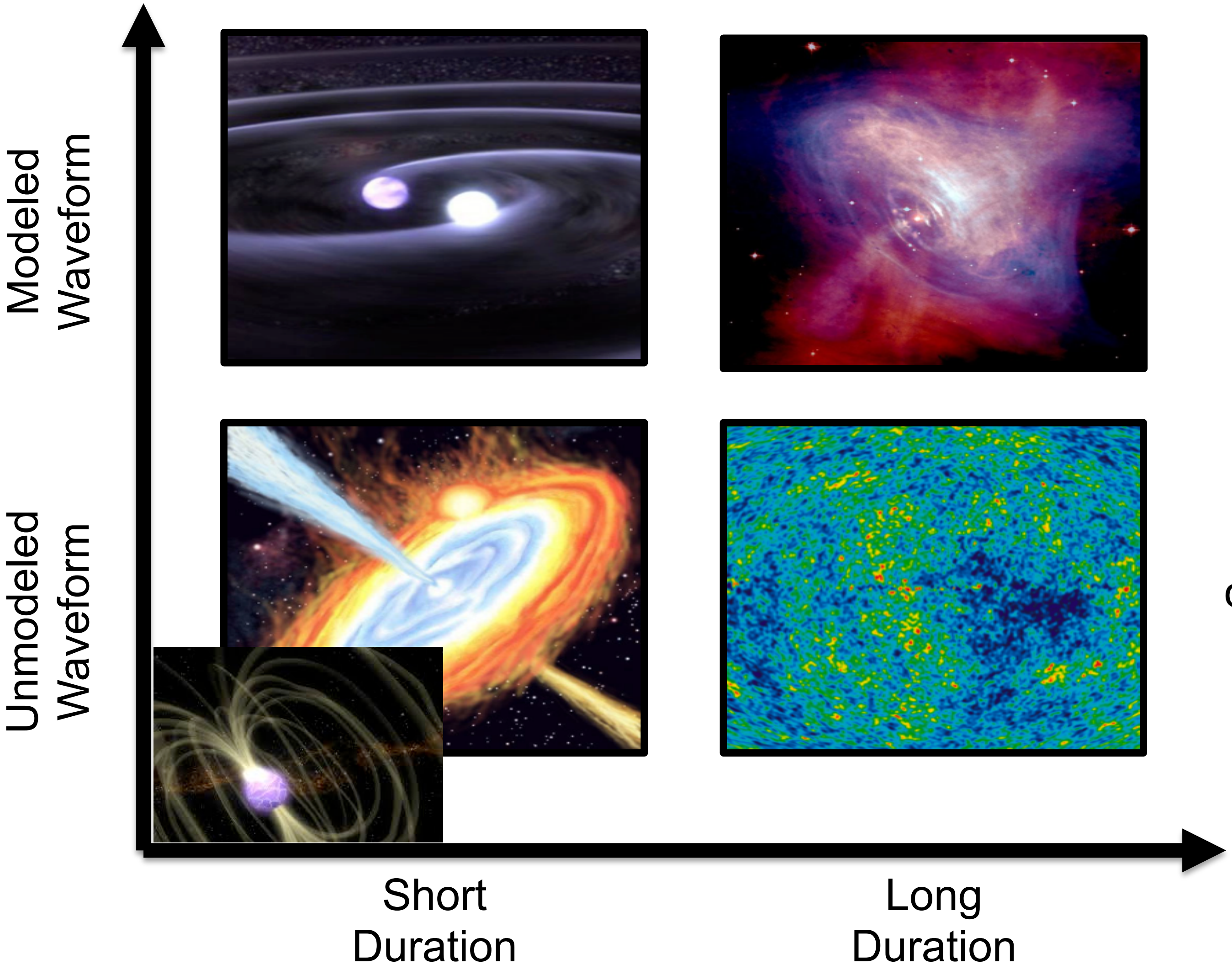
Core collapse γ-ray triggered searches



O1 results (Abbott et al. ApJ, 841, 89, 2017)

Extrapolation for 2 yrs of Adv LIGO and Virgo: could exclude most extreme GW models

A zoo of possibilities, a “bright” future…



Modeled Waveform

Unmodeled Waveform

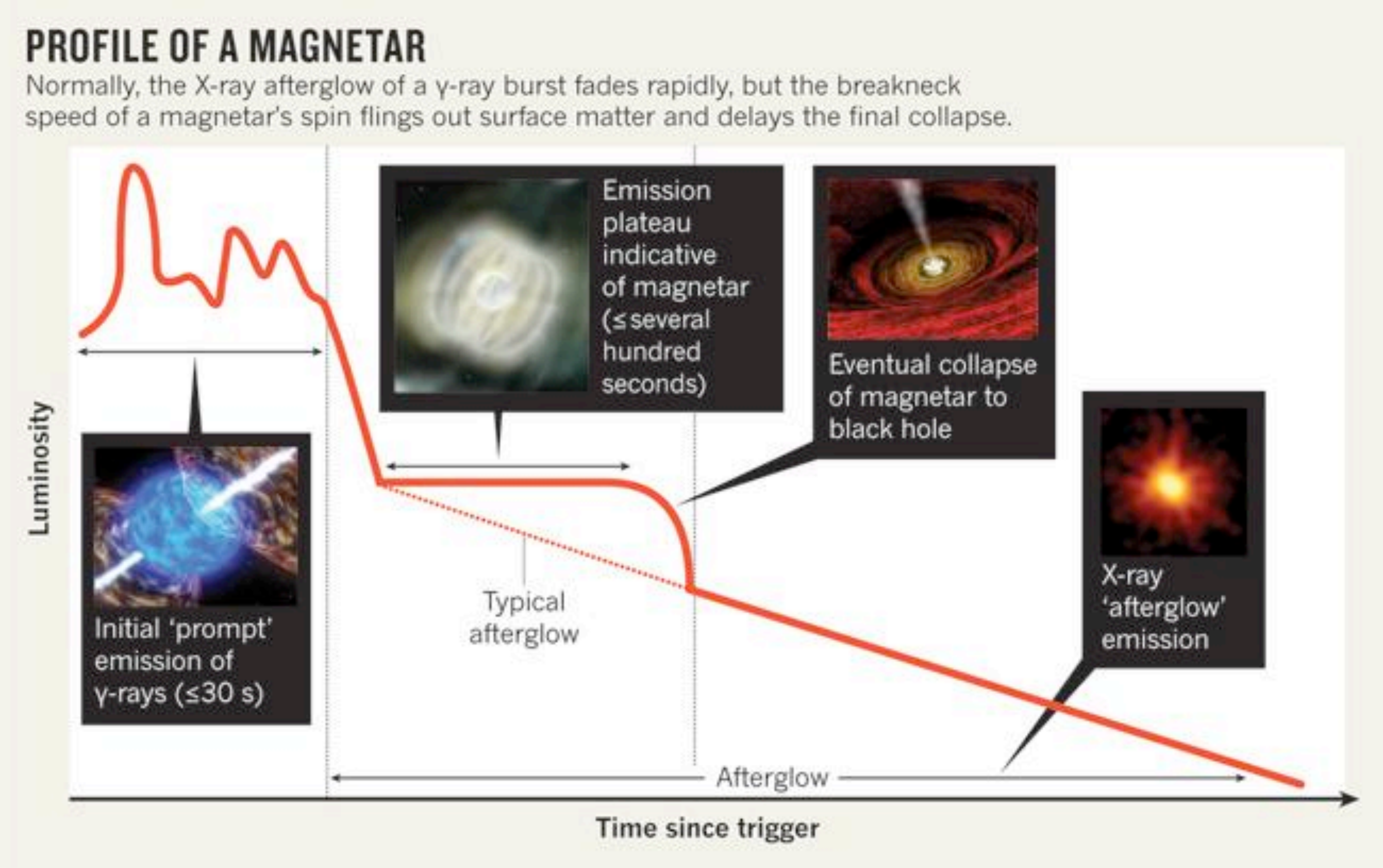
Short Duration

Long Duration

Matched filter

Excess power, cross-correlation

Longer duration transients?



PROFILE OF A MAGNETAR

Normally, the X-ray afterglow of a γ-ray burst fades rapidly, but the breakneck speed of a magnetar's spin flings out surface matter and delays the final collapse.

Initial 'prompt' emission of γ-rays (≤30 s)

Emission plateau indicative of magnetar (≤several hundred seconds)

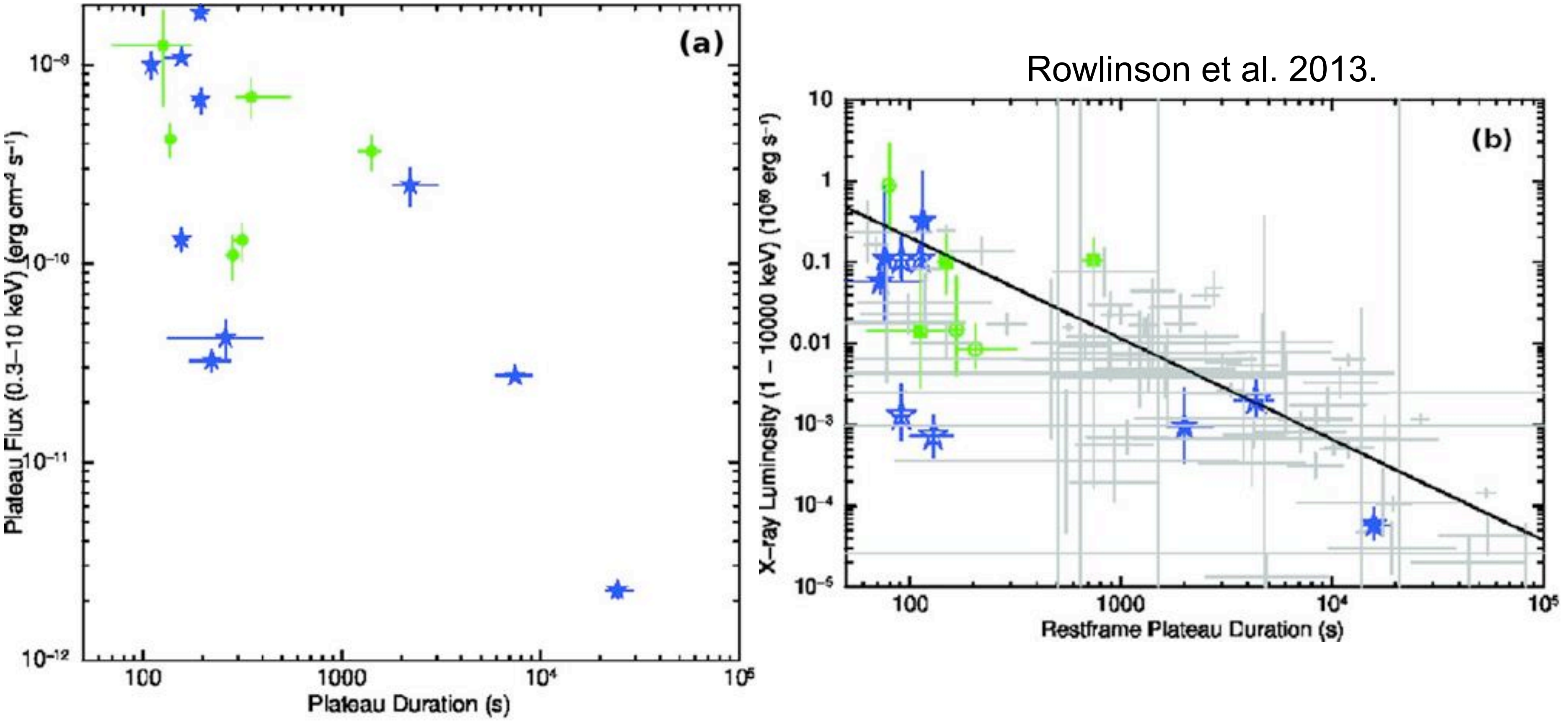
Eventual collapse of magnetar to black hole

X-ray 'afterglow' emission

Typical afterglow

Nature 468, 15 (2010)

Nature of post-merger/explosion remnant



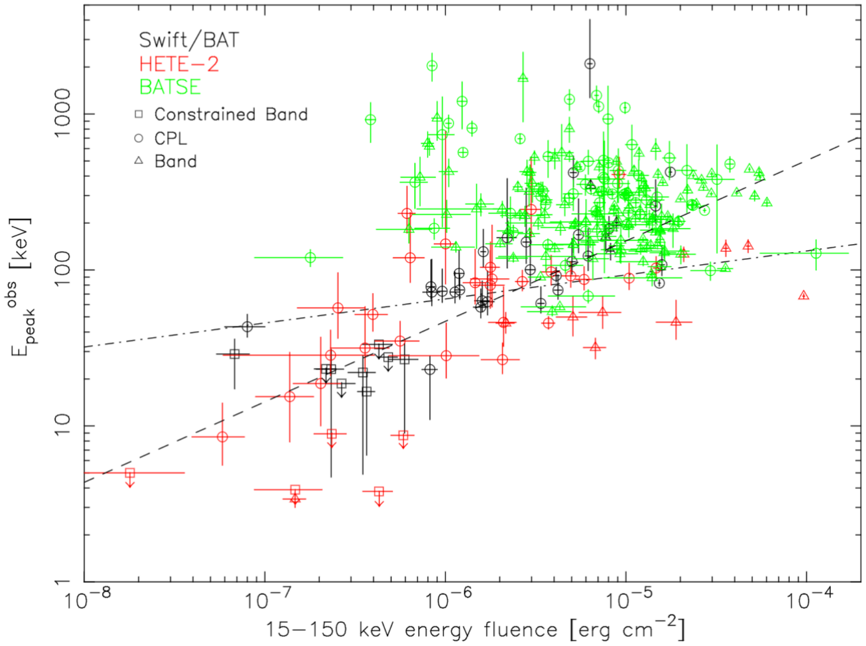
Rowlinson et al. 2013.

a) **SGRB plateau unabsorbed flux versus duration**. Blue stars have two or more significant breaks in their light curves, green circles have one break.

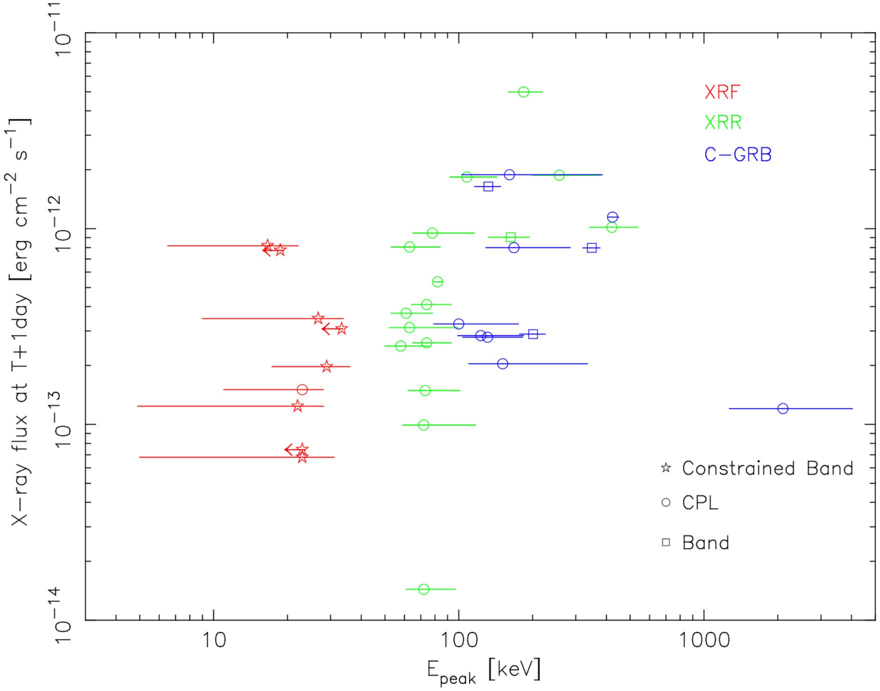
b) **Plateau luminosity**, with known z (filled symbols) or average z=0.72 (open symbols), versus rest-frame duration. Light grey are LGRBs. Black line is luminosity / duration correlation for SGRB and LGRB samples.

Nature of X-ray flashes

- XRFs resemble GRBs in almost every way, except that the flux comes mostly from X-rays instead of gamma-rays (Heise et al. 2003; Barraud et al. 2003; Sakamoto et al. 2005).
- Rate measured using the HETE-2 sample 10x that of the classical GRBs and 1/10 that of low-luminosity long GRBs (Pelangeon et al. 2008).
- Off-axis emission from structured jets?



Sakamoto et al. 2008



Summary

- Welcome to the era of GW astrophysics.
- More BBH detections to be expected.
- BBH are nice but NS matter… A broad community is looking forward to NSs and EM follow-up.
- We need a high-energy mission providing both triggers and follow-up capabilities for Advanced LIGO (and Virgo).

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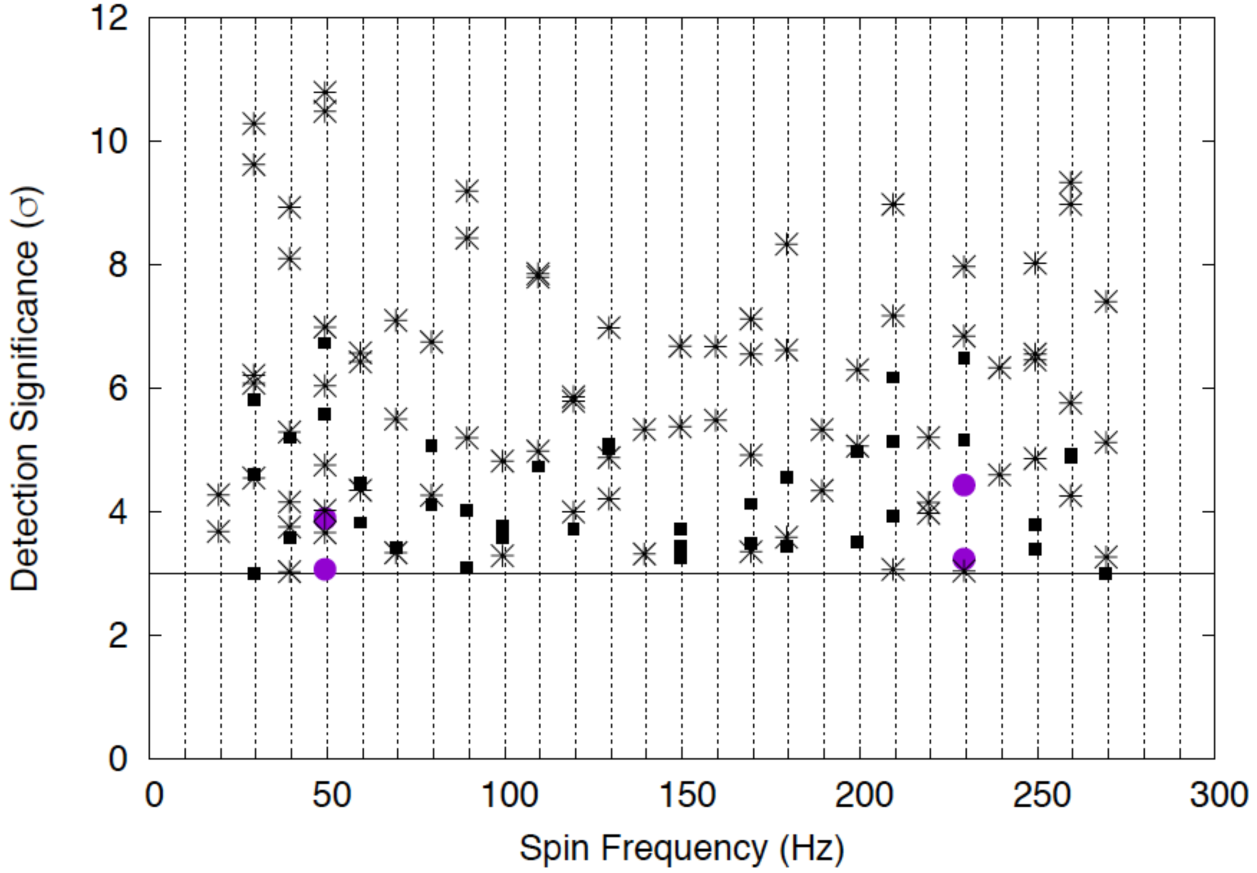
TO APPLY AND FOR MORE INFO VISIT:

http://www.depts.ttu.edu/phas/Academics/Graduate_Program/Prospective_Students/index.php

Periodicity during plateau phase?

Rowlinson et al. 2017



◆ Vertical grid lines: spin frequency.

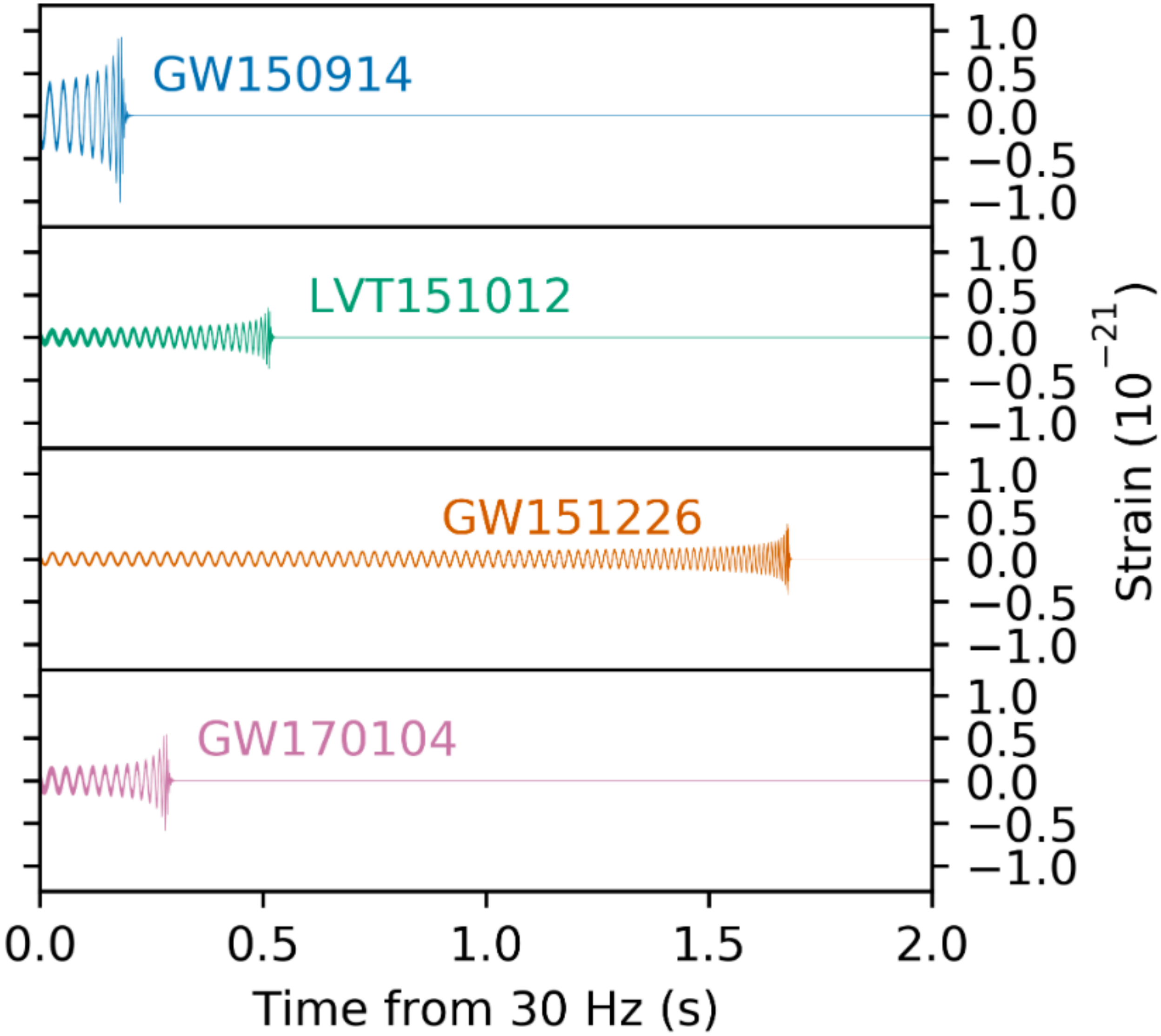
◆ Horizontal line → 3σ threshold for a detection.

◆ Purple circles have rms amplitude of 14%, black squares 21%, gray asterisks 28%.

◆ Below 14% rms amplitude no detections.

Simulated time series with same sampling time, number of photons (following Poisson) and duration of the original Swift/XRT time series. Simulated time series contain an injected sinusoidal signal whose phase evolves in time.

Advanced LIGO results so far



Credit: LSC

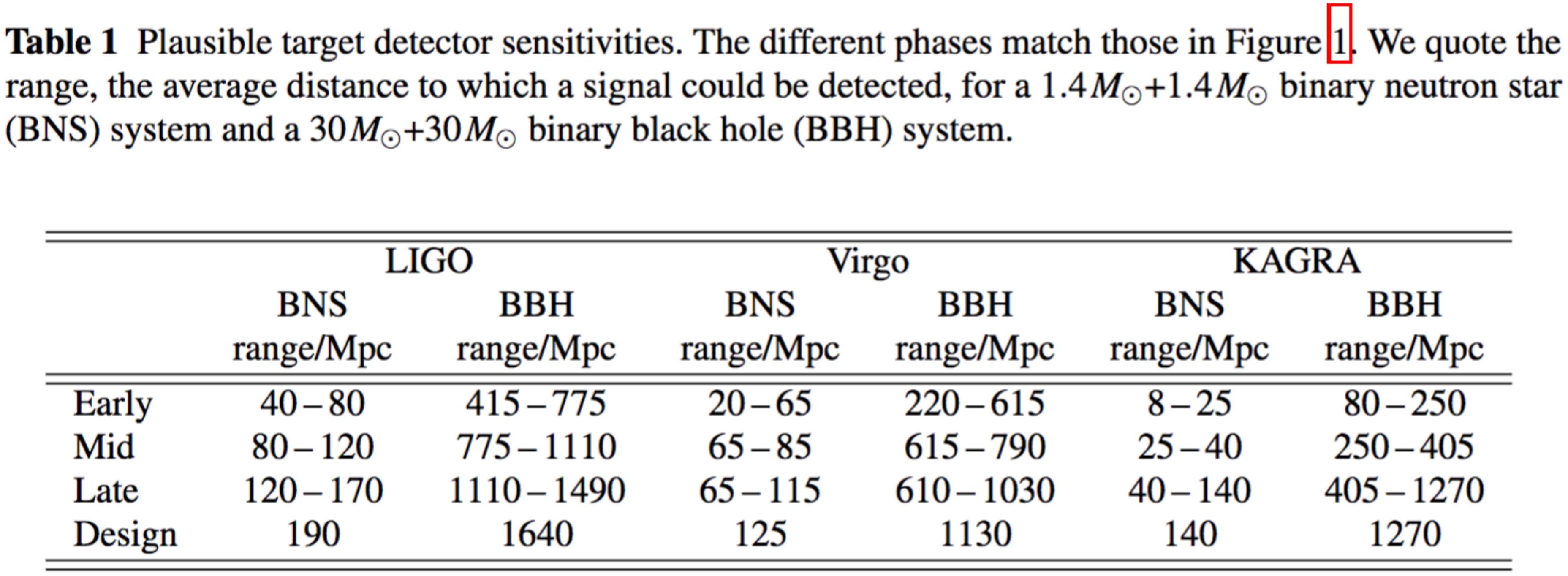
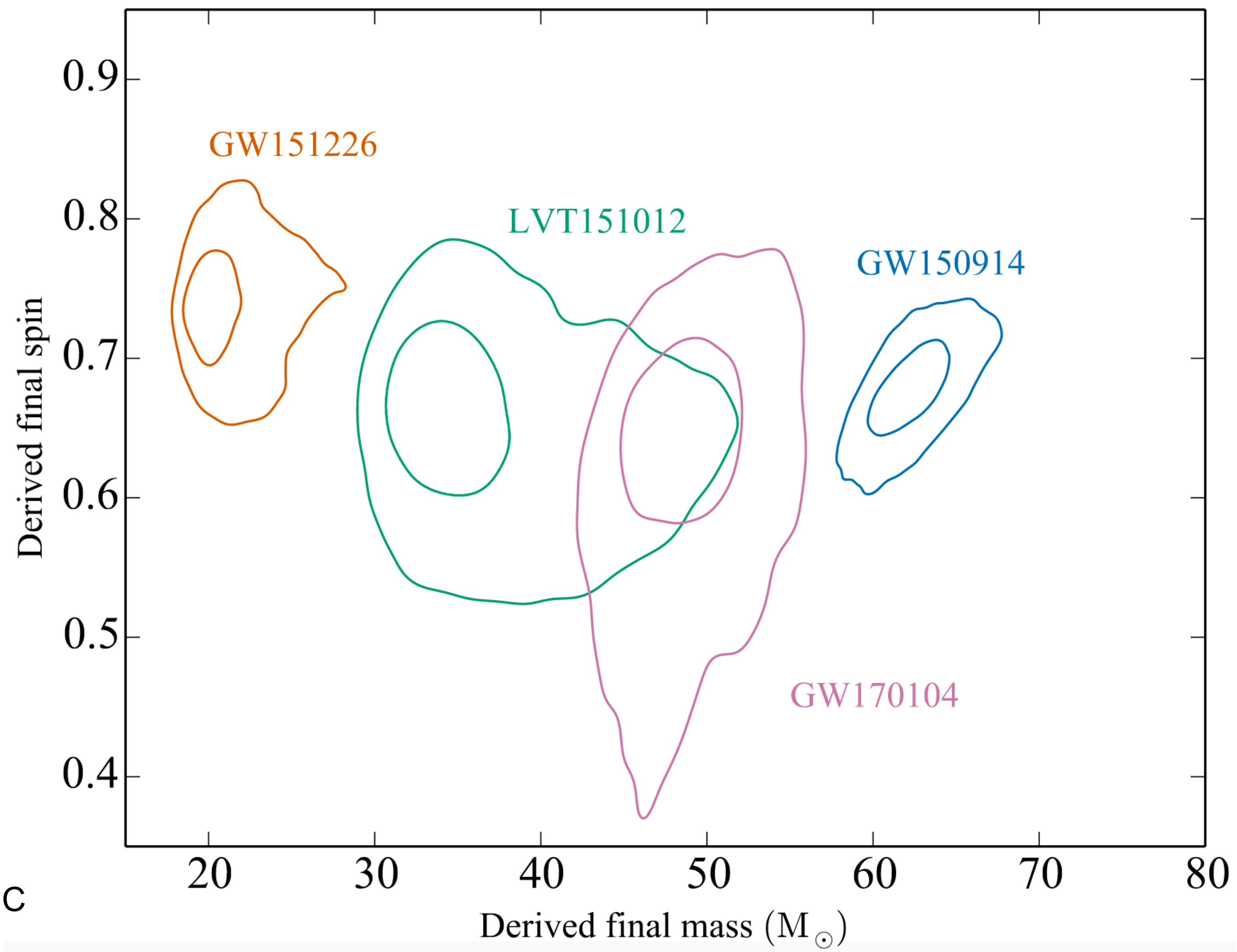


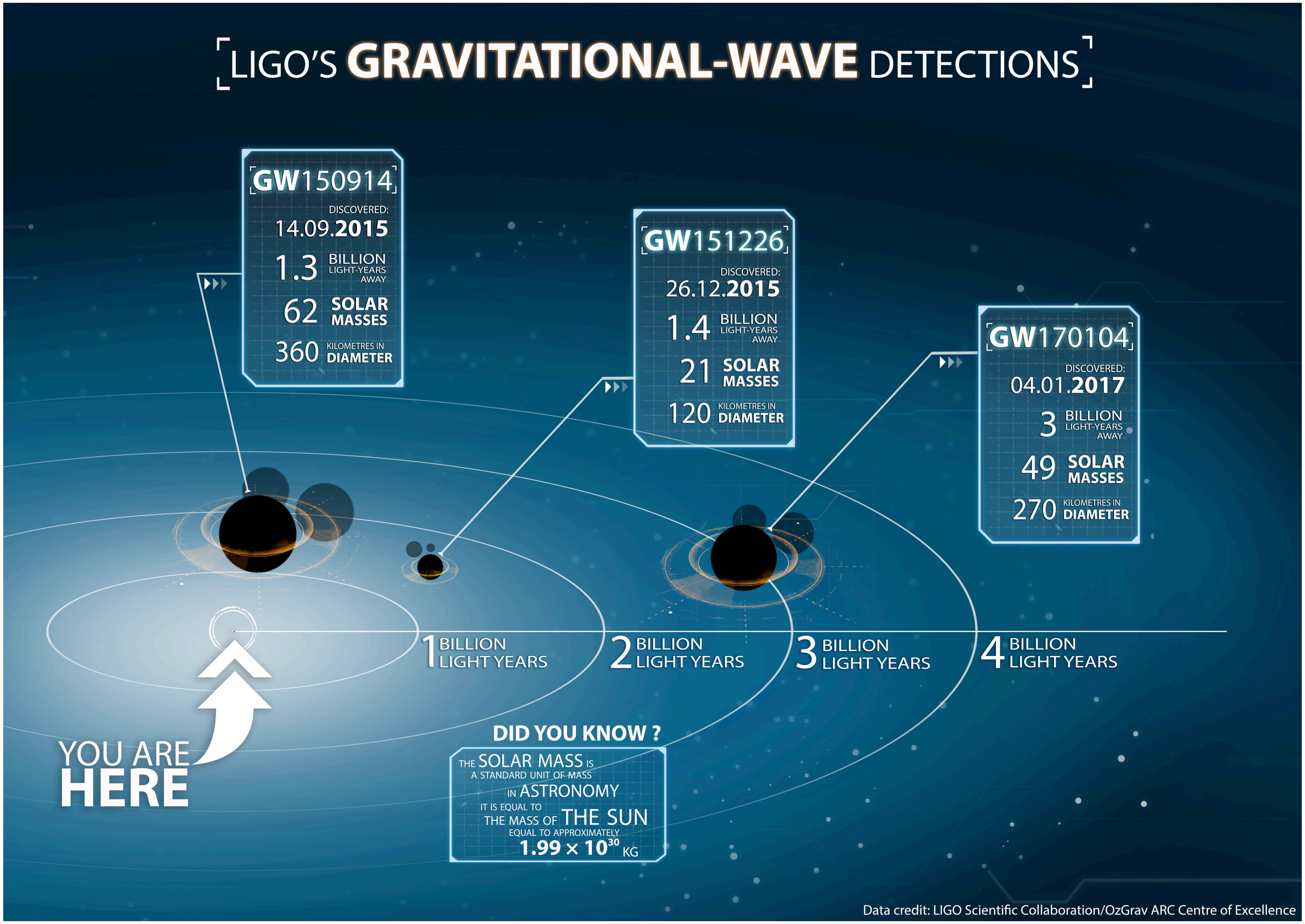
Table 1 Plausible target detector sensitivities. The different phases match those in Figure 1. We quote the range, the average distance to which a signal could be detected, for a $1.4M_\odot + 1.4M_\odot$ binary neutron star (BNS) system and a $30M_\odot + 30M_\odot$ binary black hole (BBH) system.

	LIGO		Virgo		KAGRA	
	BNS range/Mpc	BBH range/Mpc	BNS range/Mpc	BBH range/Mpc	BNS range/Mpc	BBH range/Mpc
Early	40 – 80	415 – 775	20 – 65	220 – 615	8 – 25	80 – 250
Mid	80 – 120	775 – 1110	65 – 85	615 – 790	25 – 40	250 – 405
Late	120 – 170	1110 – 1490	65 – 115	610 – 1030	40 – 140	405 – 1270
Design	190	1640	125	1130	140	1270

Abbott et al., Living Reviews in Relativity 19, 1 (2016)


0.9
0.8
0.7
0.6
0.5
0.4
20
30
40
50
60
70
80
Derived final spin
Derived final mass ($M_\odot$)
GW151226
LVT151012
GW150914
GW170104

Credit: LSC



LIGO'S **GRAVITATIONAL-WAVE** DETECTIONS

GW150914
DISCOVERED:
14.09.**2015**
1.3 BILLION LIGHT-YEARS AWAY
62 **SOLAR MASSES**
360 KILOMETRES IN **DIAMETER**

GW151226
DISCOVERED:
26.12.**2015**
1.4 BILLION LIGHT-YEARS AWAY
21 **SOLAR MASSES**
120 KILOMETRES IN **DIAMETER**

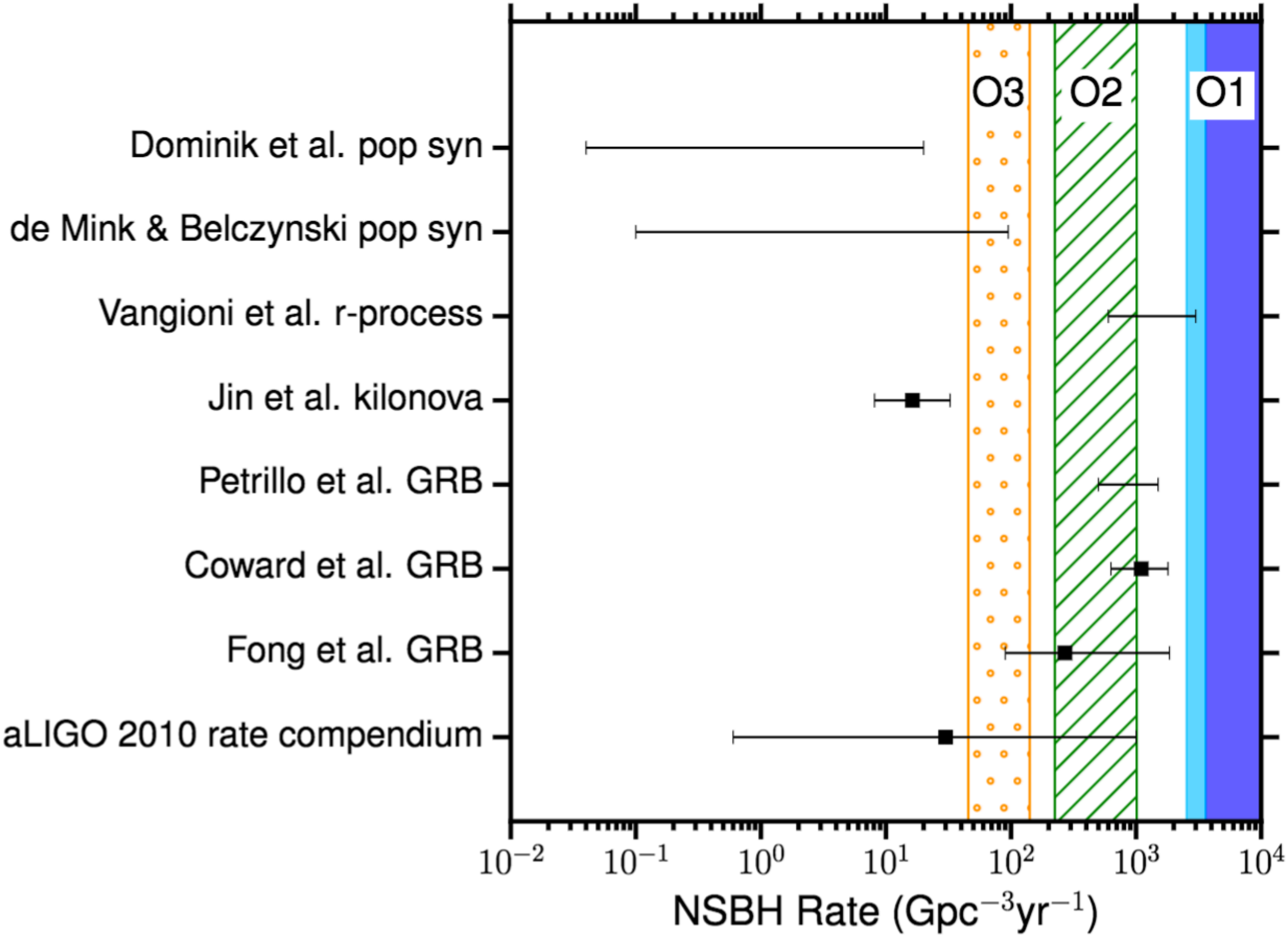
GW170104
DISCOVERED:
04.01.**2017**
3 BILLION LIGHT-YEARS AWAY
49 **SOLAR MASSES**
270 KILOMETRES IN **DIAMETER**

DID YOU KNOW ?

THE SOLAR MASS IS A STANDARD UNIT OF MASS IN ASTRONOMY
IT IS EQUAL TO THE MASS OF THE SUN
EQUAL TO APPROXIMATELY **1.99×10^{30}** KG

Data credit: LIGO Scientific Collaboration/OzGrav ARC Centre of Excellence

Current constraints on BH-NS rates



Dark blue: 5-1.4 $M_\odot$
Light blue:10-1.4 $M_\odot$

LVC, 2016, ApJ, 832L, 21