

# The Latest Results from the LIGO-Virgo O3 Observing Run



Ben Farr  
on behalf of the

LIGO-G1901973 LSC & Virgo Collaboration



# LIGO Scientific Collaboration



The image displays a wide array of logos from institutions involved in the LIGO Scientific Collaboration. The logos are arranged in a dense, grid-like pattern. Key institutions visible include Caltech, MIT, Stanford University, the University of California Berkeley, and the Max-Planck-Institut für Gravitationsphysik. The logos also represent a diverse range of international universities and research centers, including those from Australia, Europe, Asia, and the Americas. Some logos are accompanied by text in multiple languages, reflecting the global nature of the collaboration.

# Status of Ground-Based GW Astronomy

<https://monitor.ligo.org/gwstatus>

[https://www.gw-openscience.org/detector\\_status/](https://www.gw-openscience.org/detector_status/)

LIGO Hanford <b>SCIENCE</b> Duration: 0d 09:58:59 (prev: nohoft) Last updated at 0:06	LIGO Livingston <b>NOHOFT</b> Duration: 0d 00:26:00 (prev: science) Last updated at 0:06	Virgo <b>SCIENCE</b> Duration: 0d 07:44:52 (prev: hoftok) Last updated at 0:06	Kagra <b>NOHOFT</b> Duration: 2d 15:35:00 (prev: unknown) Last updated at 0:06	Fri Nov 08 2019 <b>0:06:28</b> 1257235606	LDAS 14 OK Last updated at 0:06
DMT 15 OK Last updated at 0:06	Low-latency Data 2 / 46 WARNING Last updated at 0:06	LIGO Data Replicator 14 OK Last updated at 0:06	DetChar Summary 2 / 23 WARNING Last updated at 0:06	DetChar Jobs 1 / 16 UNKNOWN Last updated at 0:06	DetChar-Omicron Jobs Call Alex Urban 13 / 155 CRITICAL 41 / 155 UNKNOWN Last updated at 0:06
GraCEDb 1 OK Last updated at 0:06	LVAAlert 2 OK Last updated at 0:06	GraCEDb Playground 1 OK Last updated at 0:06	DQSegDB 15 OK Last updated at 0:06	NDS 36 OK Last updated at 0:06	ligoDV Web 7 OK Last updated at 0:06
gstLAL Inspiral Call Chad Hanna 1 / 2 CRITICAL	CIS 2 OK	EMFollow 2 OK	PyCBC Live 1 OK	Auth 27 OK	iDQ 30 OK

GWOSC Calendar Today Yesterday Observing Run 1 Summary Observing Run 2 Summary

## Gravitational-Wave Observatory Status

Please select a day from the calendar above to see archived or current status.

Information is available for dates after November 30, 2016. The Advanced LIGO and Advanced Virgo detectors are currently in the third observing run, known as O3, which began April 1, 2019. Summaries of previous observing runs are available in the menu above. For overviews of LIGO and Virgo observing runs, see the [O3 schedule](#) or [arXiv:1304.0670](#).

- [Today's Summary Page](#)
- [Virgo Status Page](#)
- [Current Status \(GWSTAT\)](#)
- [LIGO/Virgo Alerts \(GraceDB\)](#)

LIGO Hanford LIGO Livingston Virgo GEO600

This page is a product of the [Gravitational Wave Open Science Center](#). Please contact us with questions or comments.

<https://gracedb.ligo.org/>

**GraceDB — Gravitational-Wave Candidate Event Database**

<http://chirp.sr.bham.ac.uk/>



LIGO-G1901973

# LIGO-Virgo's 3<sup>rd</sup> Observation Run

O3 began on April 1, 2019.

Mid-run commissioning break started Oct 1 2019 at 15:00:00 UTC.

- Scattered light mitigation.
- Hanford squeezing improvements.
- Virgo power increased from 18W to 26W.

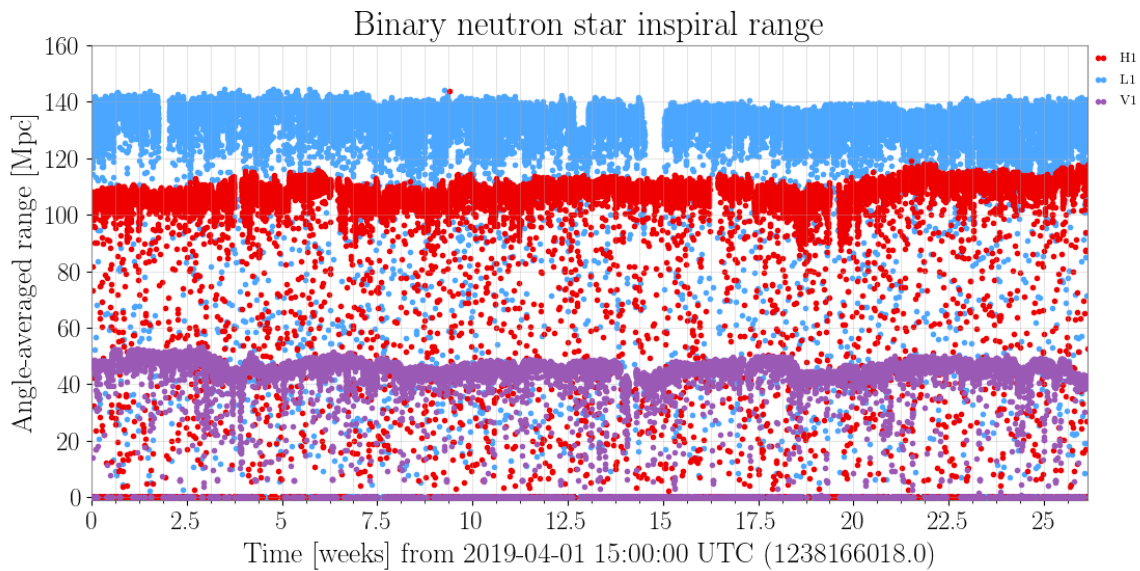
LIGO/Virgo/KAGRA Memorandum of Agreement signed Oct 4.

O3b began Nov 1 at 15:00:00 UTC, and will end April 30, 2020.

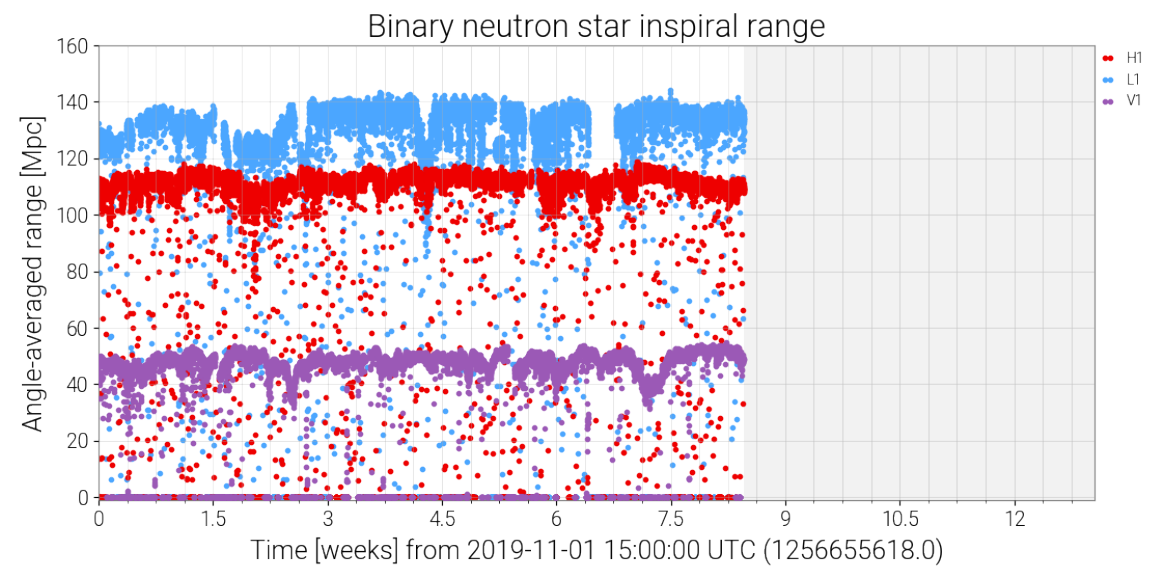
# LIGO-Virgo's 3<sup>rd</sup> Observation Run

O3a

O3b



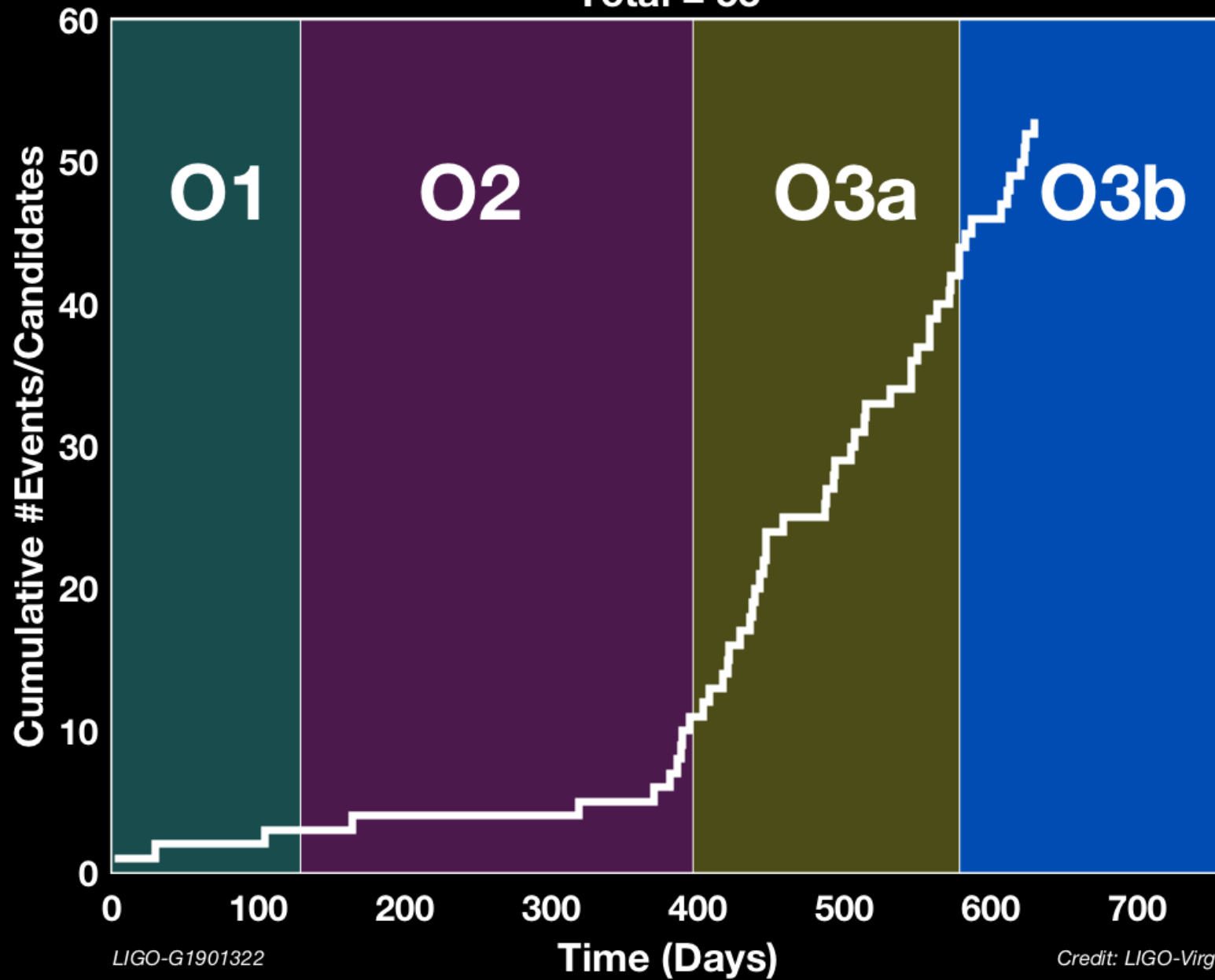
April 1 - October 1, 2019



November 1, 2019 - April 2020

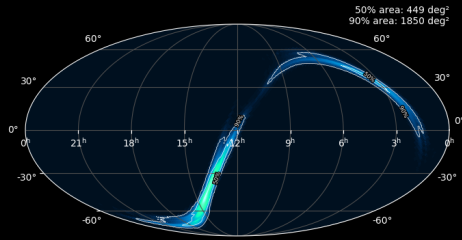
# Cumulative Count of Events and (non-retracted) Alerts

Total = 53

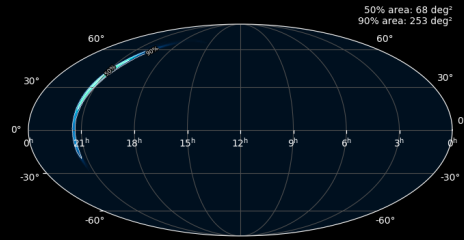


# O3 so far

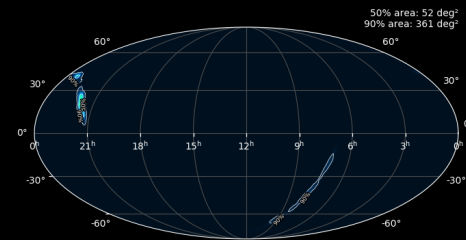
<https://gracedb.ligo.org/latest>



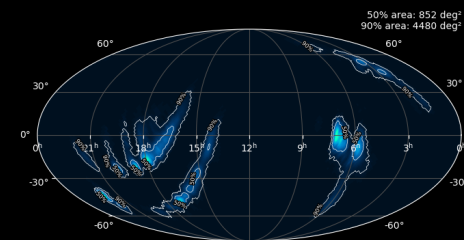
S191222n



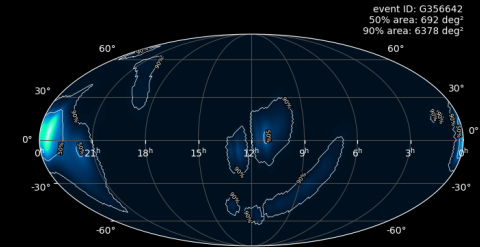
S191216ap



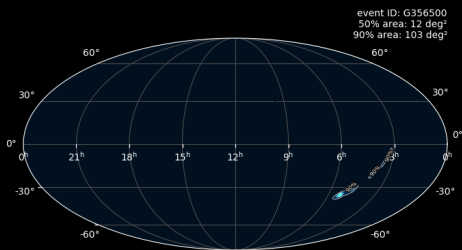
S191215w



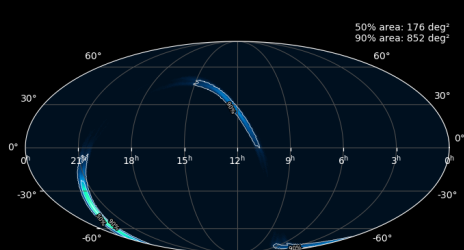
S191213g



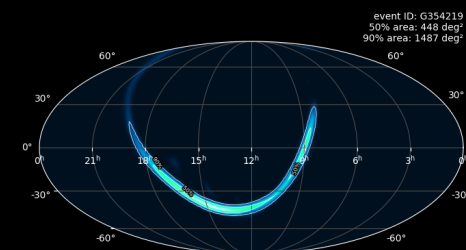
S191205ah



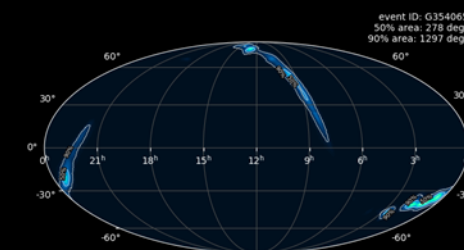
S191204r



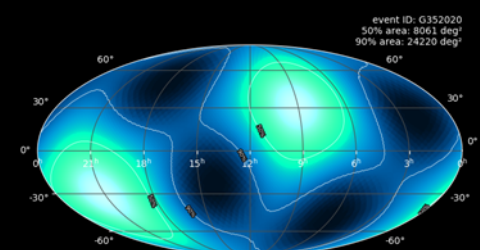
S191129u



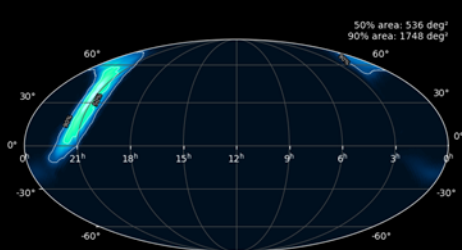
S191109d



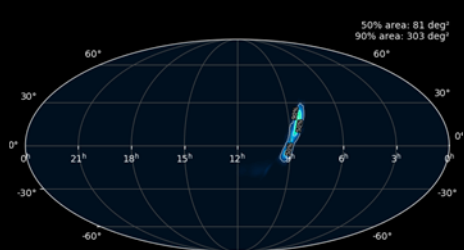
S191105e



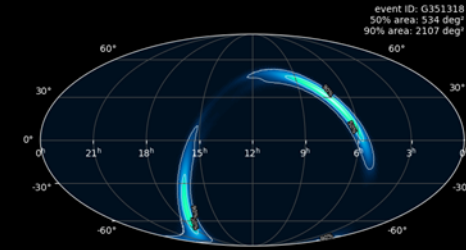
S190930t



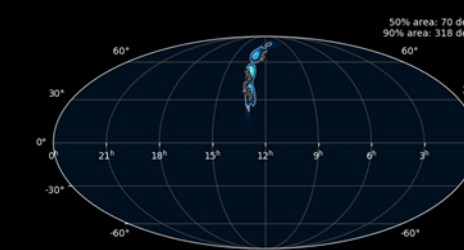
S190930s



S190924h



S190923y



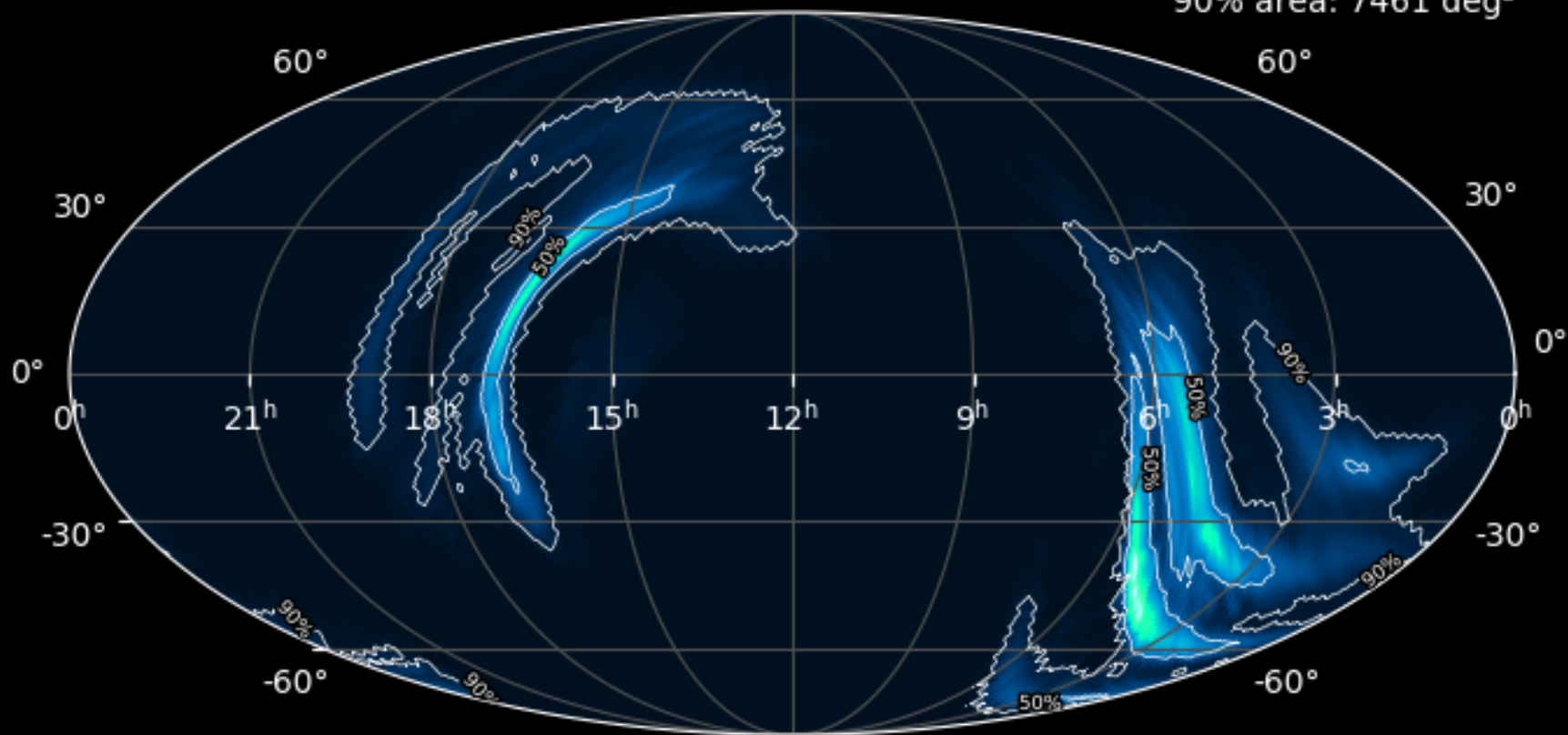
S190915ak

LIGO-G1901973

etc.

# S190425z

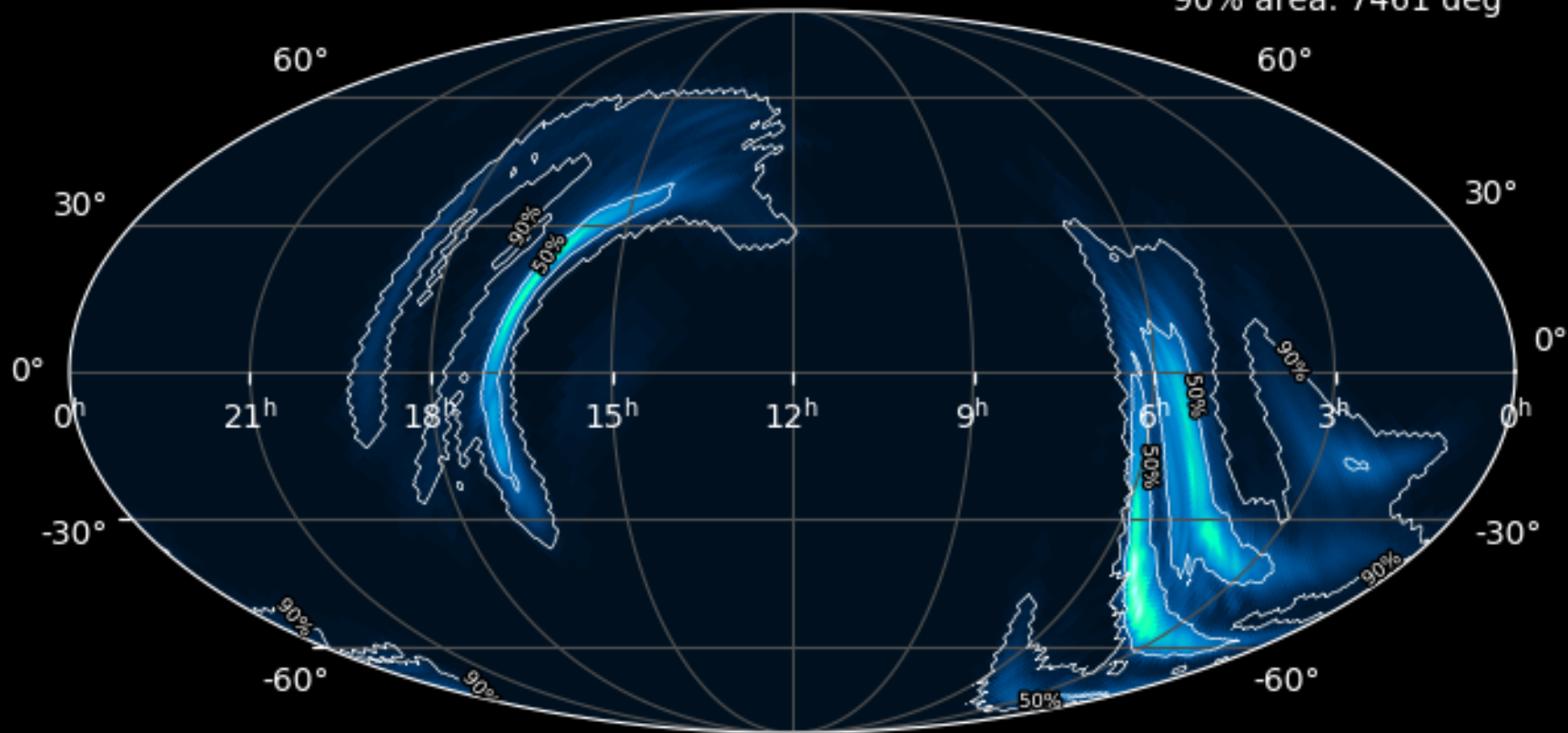
50% area: 1378 deg<sup>2</sup>  
90% area: 7461 deg<sup>2</sup>





# GW190425

50% area: 1378 deg<sup>2</sup>  
90% area: 7461 deg<sup>2</sup>



**GW190425: Observation of a compact binary coalescence with total mass  $\sim 3.4 M_{\odot}$**

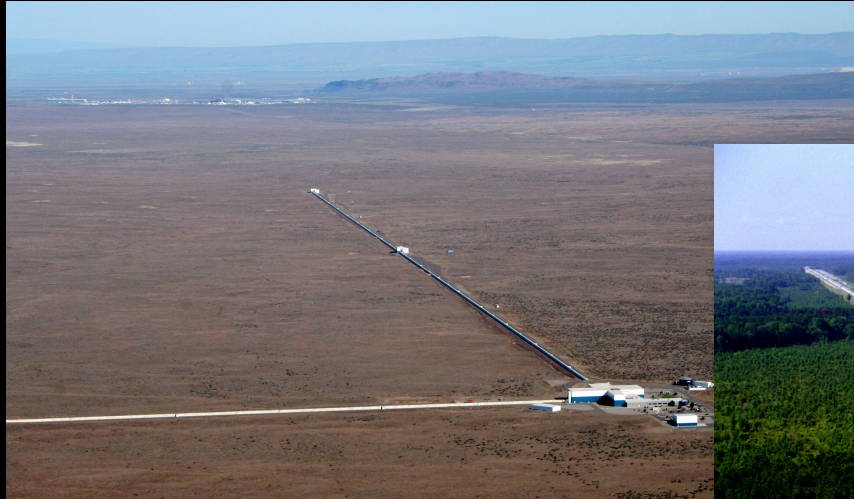
THE LIGO SCIENTIFIC COLLABORATION,<sup>1</sup> THE VIRGO COLLABORATION,<sup>2</sup>

Paper submitted to ApJL and available at  
<https://dcc.ligo.org/LIGO-P190425/public>

Data available from the Gravitational Wave Open Science Center:  
[https://www.gw-openscience.org/eventapi/html/O3\\_Discovery\\_Papers/GW190425/v1/](https://www.gw-openscience.org/eventapi/html/O3_Discovery_Papers/GW190425/v1/)

# GW190425: Network State

## LIGO Hanford



Offline for 2h

## LIGO Livingston



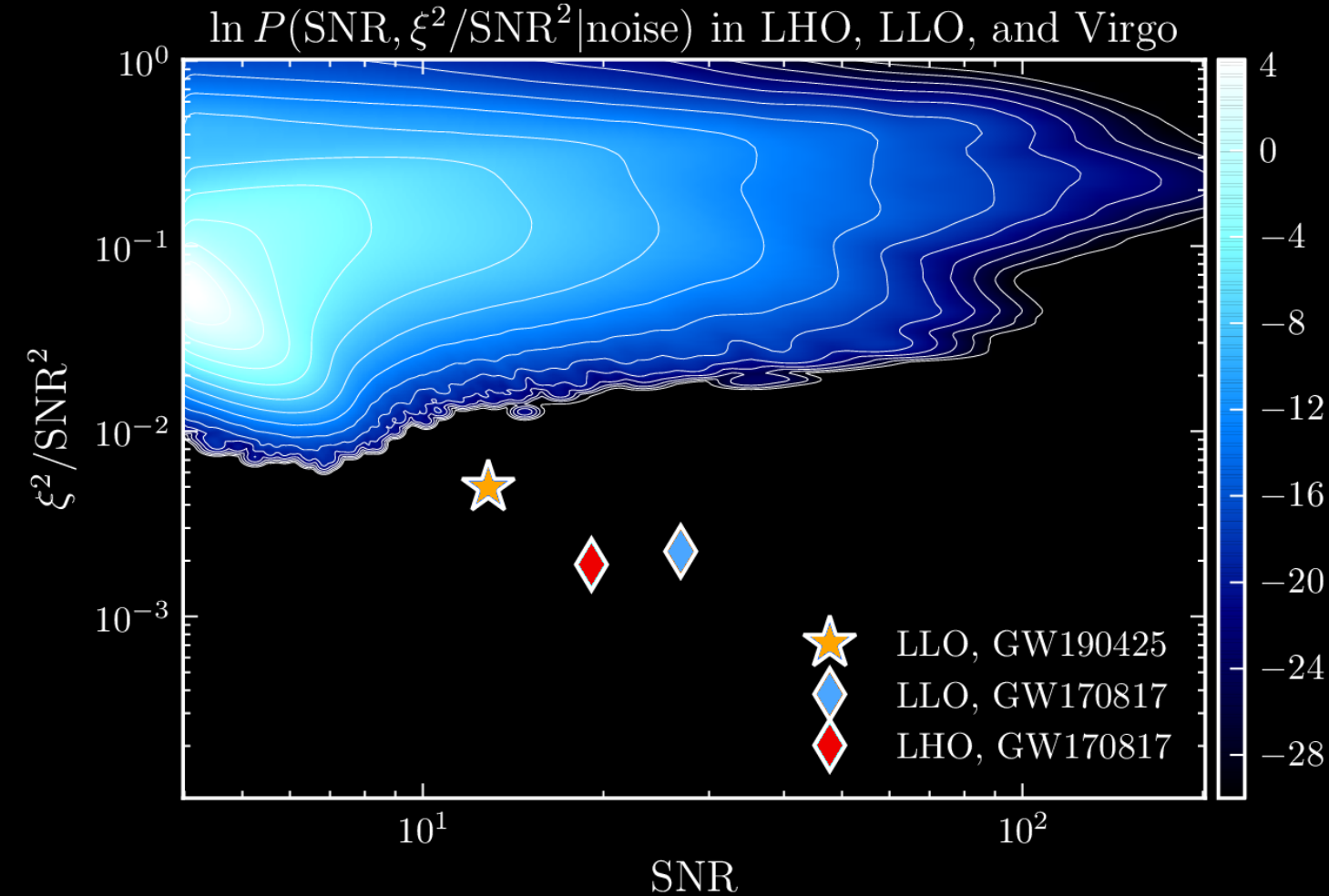
Online for 30h  
BNS Range: 135 Mpc

## Virgo



Online for 14h  
BNS Range: 48 Mpc

# GW190425: Confidence



**SNR**

LIGO Livingston: 12.9

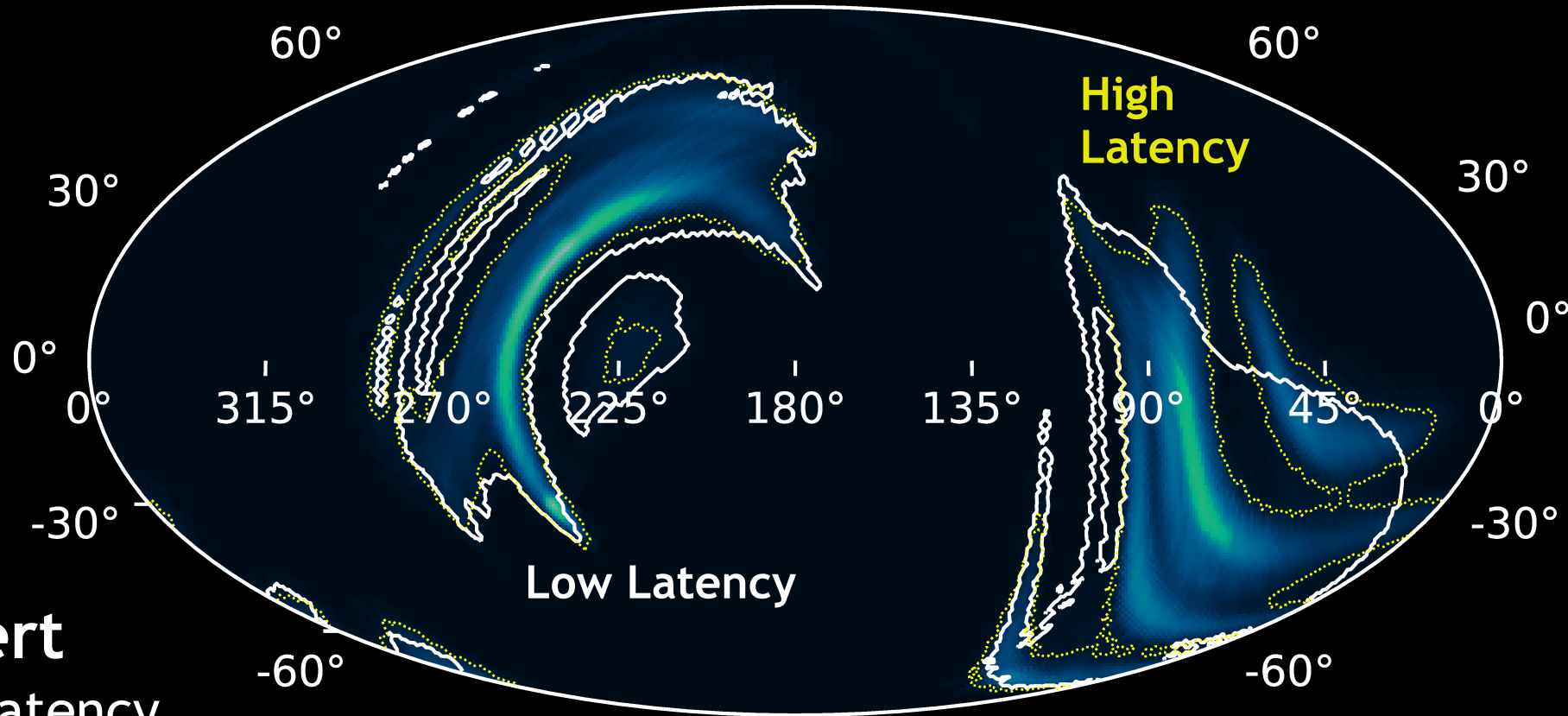
Virgo: 2.5

**Low-latency FAR**

1 per 69,000 years

No comparable background events  
in the advanced-detector era.

# GW190425: Localization



## Initial Alert

43 minute latency

BNS w/ >99% probability

90% region: **10,200 sq. deg.**

Distance: **110 - 200 Mpc**

## Update

31 hour latency

90% region: **7,461 sq. deg.**

Distance: **115 - 197 Mpc**

## Final

90% region: **8,284 sq. deg.**

Distance: **88 - 228 Mpc**

# GW190425: Follow-up

Final localization:

8,284 sq. deg.

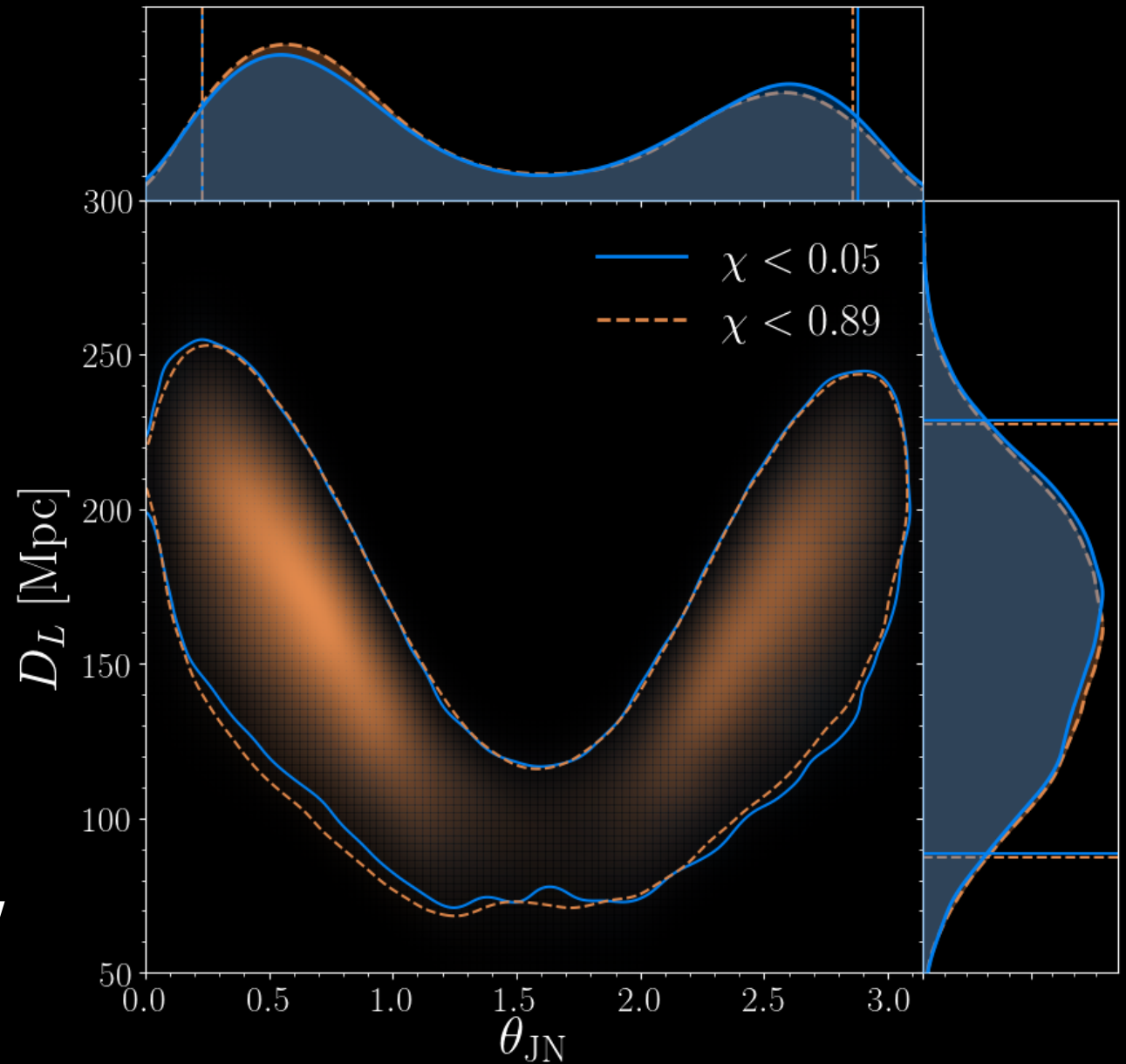
88 - 228 Mpc

Extensive follow-up efforts:

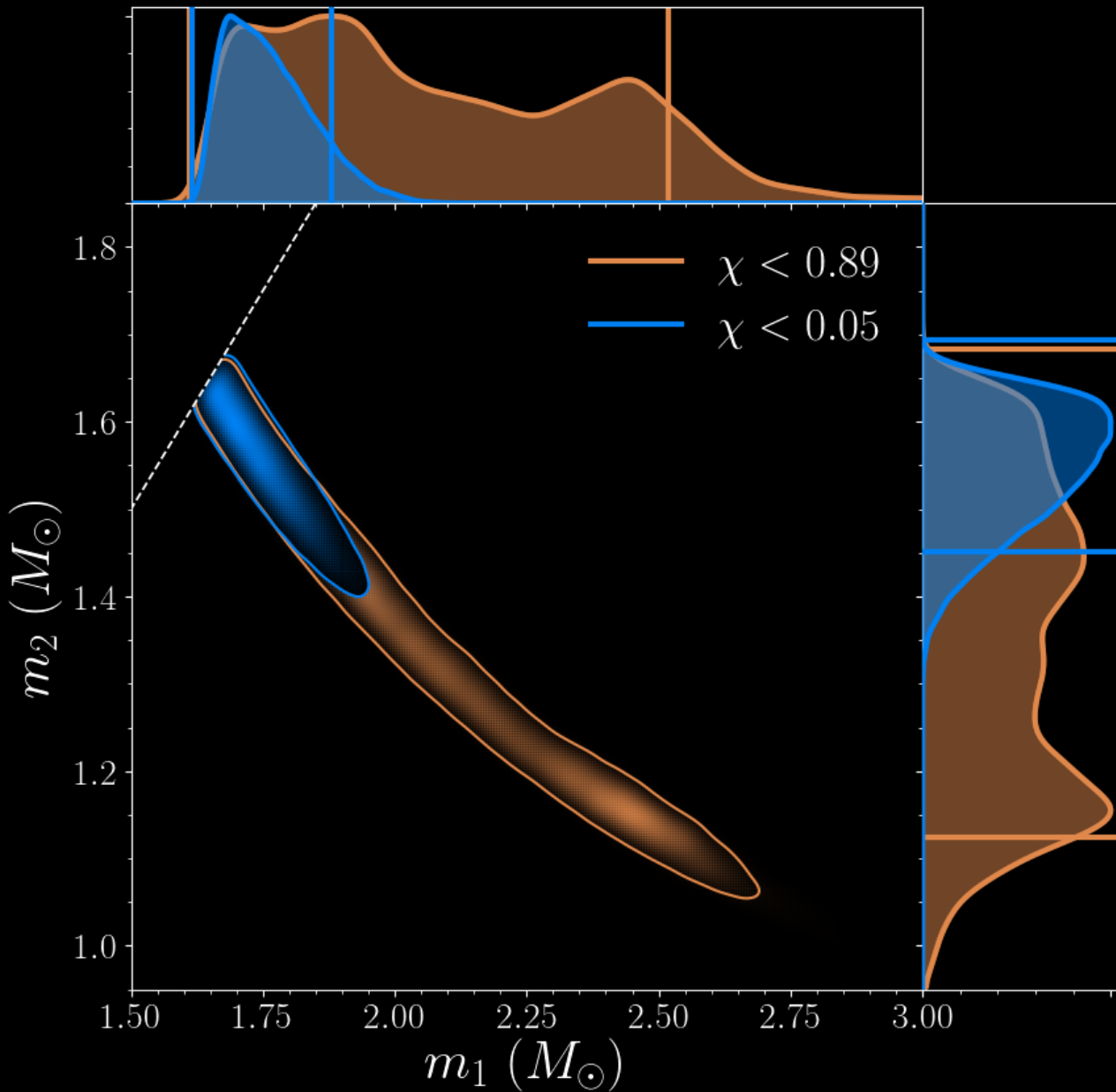
118 circulars

No reported EM transients appear  
to be associated with GW190425

No constraints on inclination from GW



# GW190425: Masses



## Primary

Low-spin prior:  $1.62 - 1.88 M_\odot$

High-spin prior:  $1.61 - 2.52 M_\odot$

## Secondary

Low-spin prior:  $1.45 - 1.69 M_\odot$

High-spin prior:  $1.12 - 1.68 M_\odot$

Assuming a BNS...  
@  $5\sigma$  of galactic BNS population

# GW190425: Masses

## Field Formation

Might suggest a BNS pop. formed w/  
sub-hour orbital periods.

Belczynski *et al.* 2002 *ApJ* 572 407

Ivanova *et al.* 2003 *ApJ* 592 475

Dewi & Pols 2003 *MNRAS* 344 629

## Dynamical Formation

MS pulsars up to  $2 M_{\odot}$  found in globular clusters

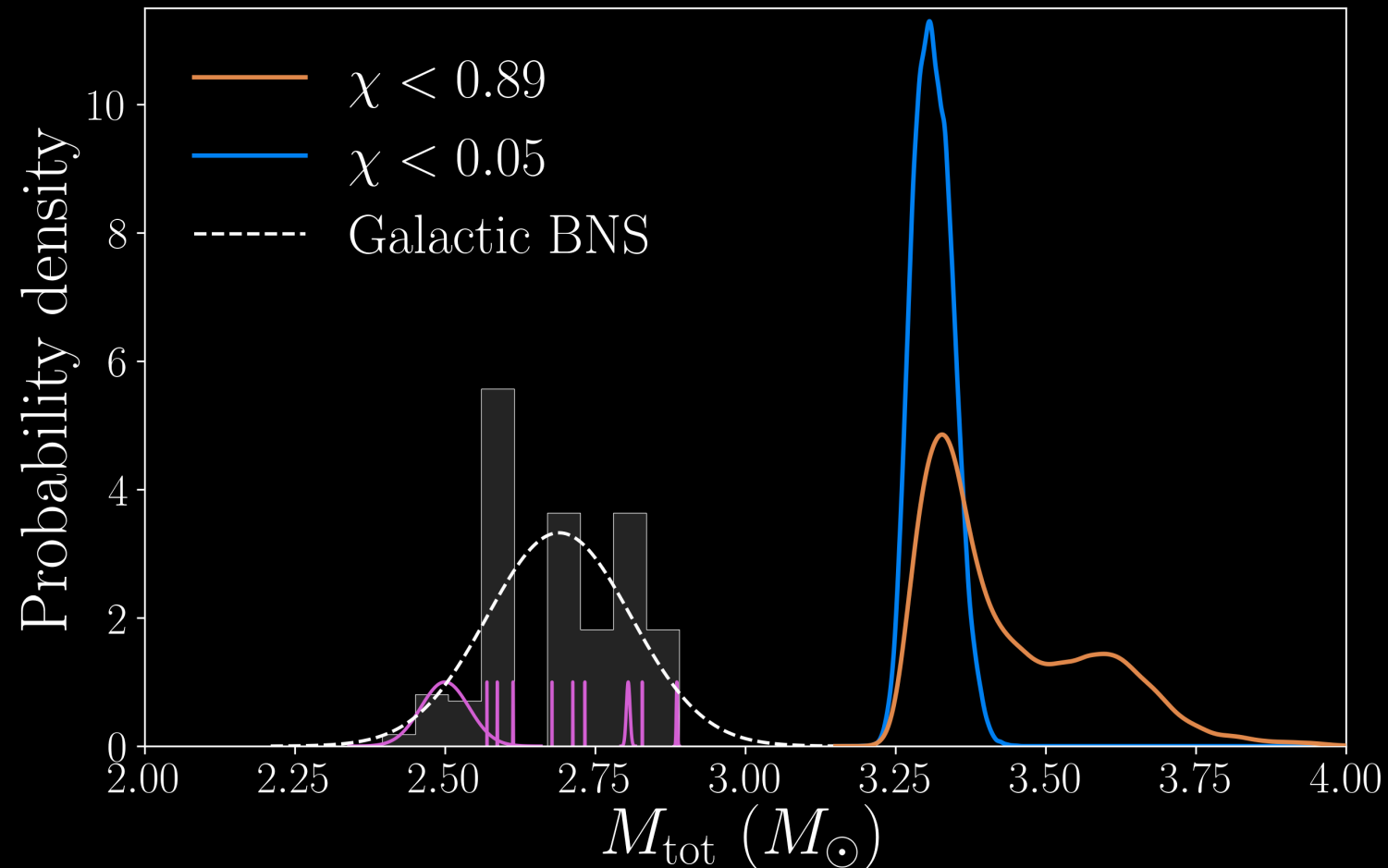
Ransom *et al.* 2005 *Science* 307 892

Freire *et al.* 2008 *ApJ* 679 1433

BNS contributions expected to be minimal

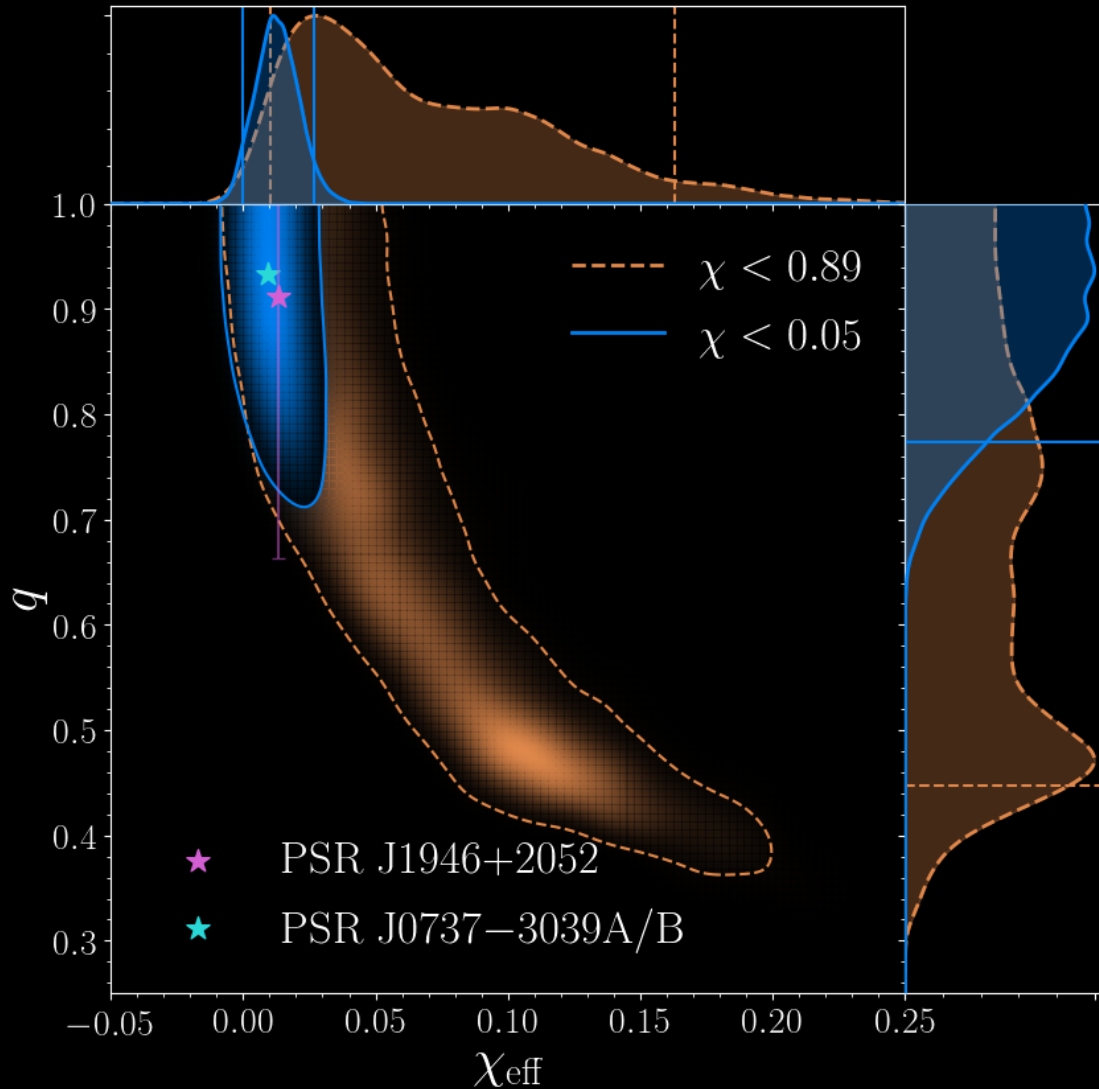
Belczynski *et al.* 2018 *A&A* 615 A91

Ye *et al.* 2019 arXiv:1910.10740





# GW190425: Spins

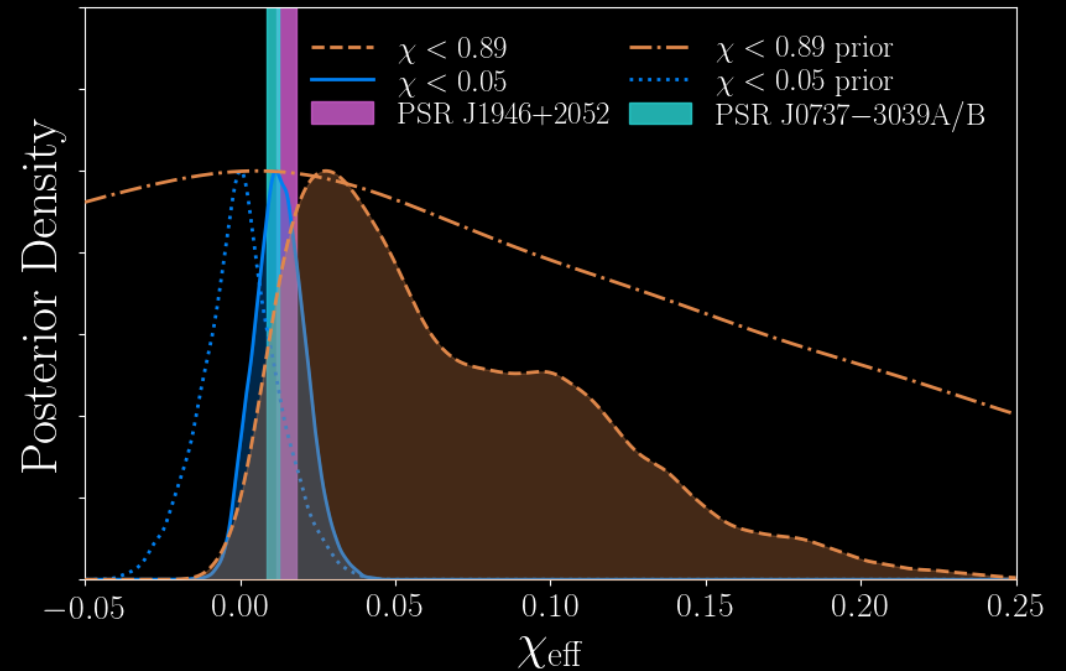


Effective spin

$$\chi_{\text{eff}} = \frac{\left(m_1 \vec{s}_1 + m_2 \vec{s}_2\right) \cdot \hat{L}_N}{m_1 + m_2}$$

Broad spin priors allow for a large mass ratio

Data consistent with negligible spin



# GW190425: Astrophysical Rates

BNS merger rate from GWTC-1:

$$R_{\text{GWTC-1}} = 110 - 2520 \text{ Gpc}^{-3}\text{yr}^{-1}$$

Assuming GW190425 & GW170817 from same uniform-in-component mass dist.:

$$R = 250 - 2470 \text{ Gpc}^{-3}\text{yr}^{-1}$$

Treating GW190425 & GW170817 independently (a la Kim *et al.* 2003 *ApJ* 584 985)

$$R_{170817} = 110 - 2500 \text{ Gpc}^{-3}\text{yr}^{-1}$$

$$R_{190425} = 70 - 1510 \text{ Gpc}^{-3}\text{yr}^{-1}$$

$$R = R_{170817} + R_{190425} = 290 - 2810 \text{ Gpc}^{-3}\text{yr}^{-1}$$

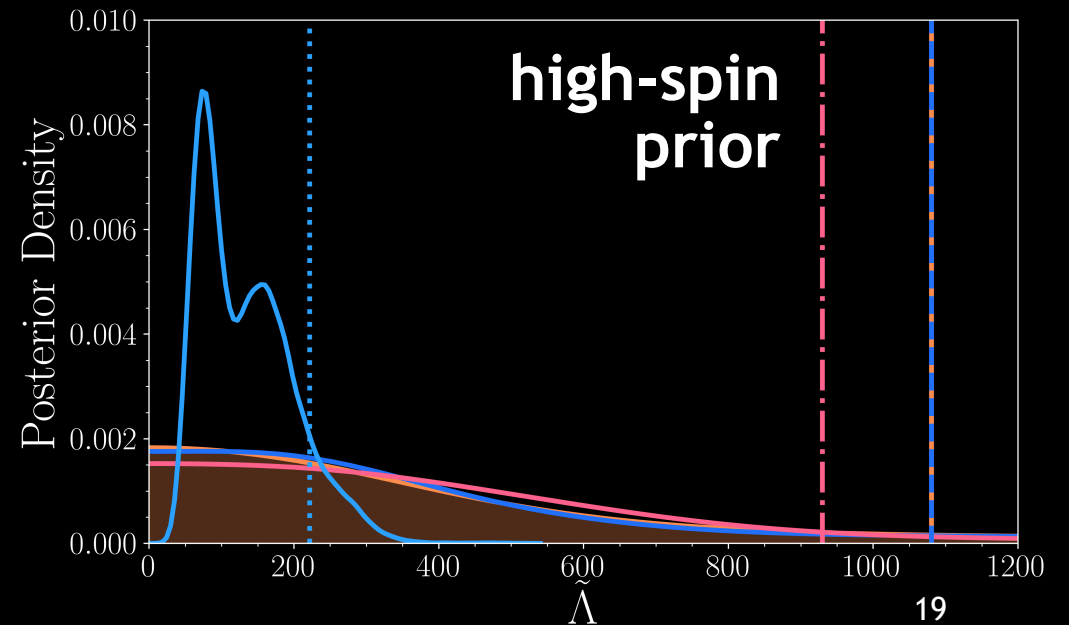
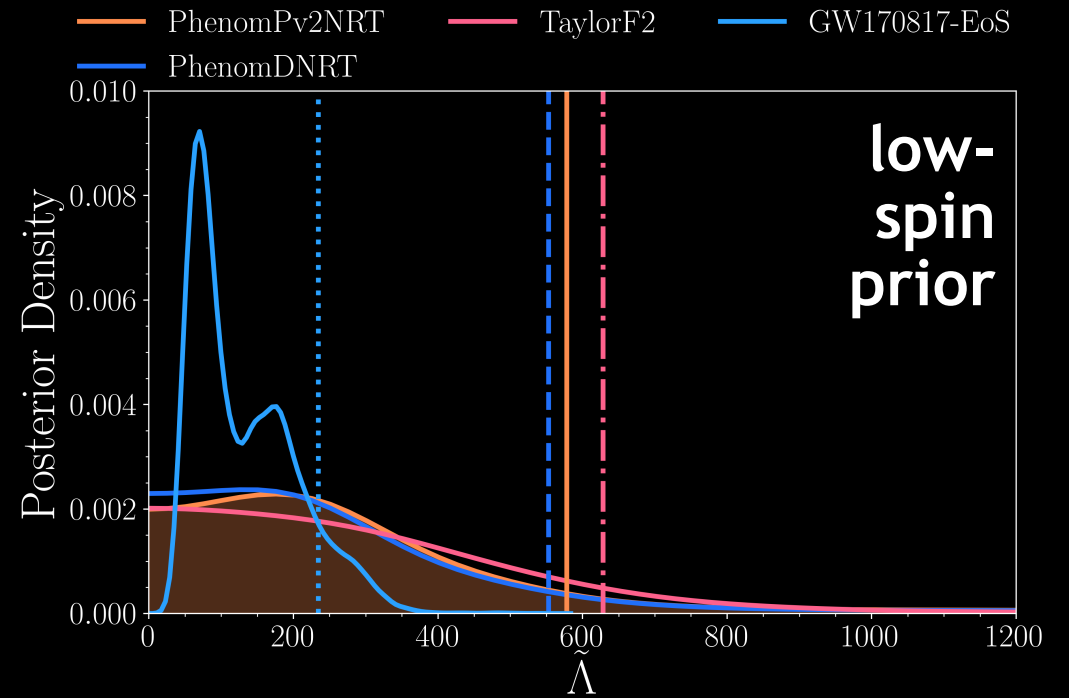
# GW190425: Matter Effects

No confident detection of matter effects  
i.e., can't rule out point-particle model

Constraints poorer than GW170817

No additional information on EoS

No sensitivity to post-merger signal



# Conclusions

GW190425 is...

the first demonstration of single-detector detection.

likely the second BNS detection with gravitational waves.

an outlier of observed galactic BNS population.

O3 event rates are consistent with predictions.

More to come...

# Thank You

# Extra Slides

# Expected Detections

Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	$2^{+8}_{-2}$	$0^{+19}_{-0}$	$15^{+19}_{-10}$
O4	HLVK	$8^{+42}_{-7}$	$2^{+94}_{-2}$	$68^{+81}_{-38}$
		Area (deg <sup>2</sup> ) 90% c.r.	Area (deg <sup>2</sup> ) 90% c.r.	Area (deg <sup>2</sup> ) 90% c.r.
O3	HLV	250 – 310	310 – 390	250 – 340
O4	HLVK	29 – 48	48 – 69	33 – 47
		Comoving Volume (10 <sup>3</sup> Mpc <sup>3</sup> ) 90% c.r.	Comoving Volume (10 <sup>3</sup> Mpc <sup>3</sup> ) 90% c.r.	Comoving Volume (10 <sup>3</sup> Mpc <sup>3</sup> ) 90% c.r.
O3	HLV	90 – 130	590 – 1000	11000 – 19000
O4	HLVK	43 – 71	400 – 560	6400 – 10000

# GW190425: Confidence

