Image credit: NASA/WMAP Science team, NOIRLab / NSF / AURA / J. da Silva / Spaceengine, NASA/Goddard Space Flight Center, IceCube Collaboration

Finding the one: identifying the host of compact binary mergers



arXiv: 1612.01471
arXiv: 2604.28132

Hsin-Yu Chen

TEXAS
The University of Texas at Austin

Collaborators: Daniel Holz, Alberto Salvarese

Korea–Italy Workshop on MMA and Cosmology, October 2026

$$cz = H_0 D$$

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With redshift and distance
we can measure H_0.

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we can measure H_0.

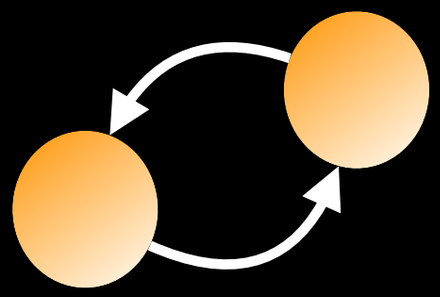
Measuring the distance is straightforward
in gravitational-wave signals.

Standard sirens: distance determined from gravitational-wave observations

$$cz = H_0 D$$

Standard sirens: distance determined from gravitational-wave observations

$$cz = H_0 D$$



Standard sirens: distance determined from gravitational-wave observations

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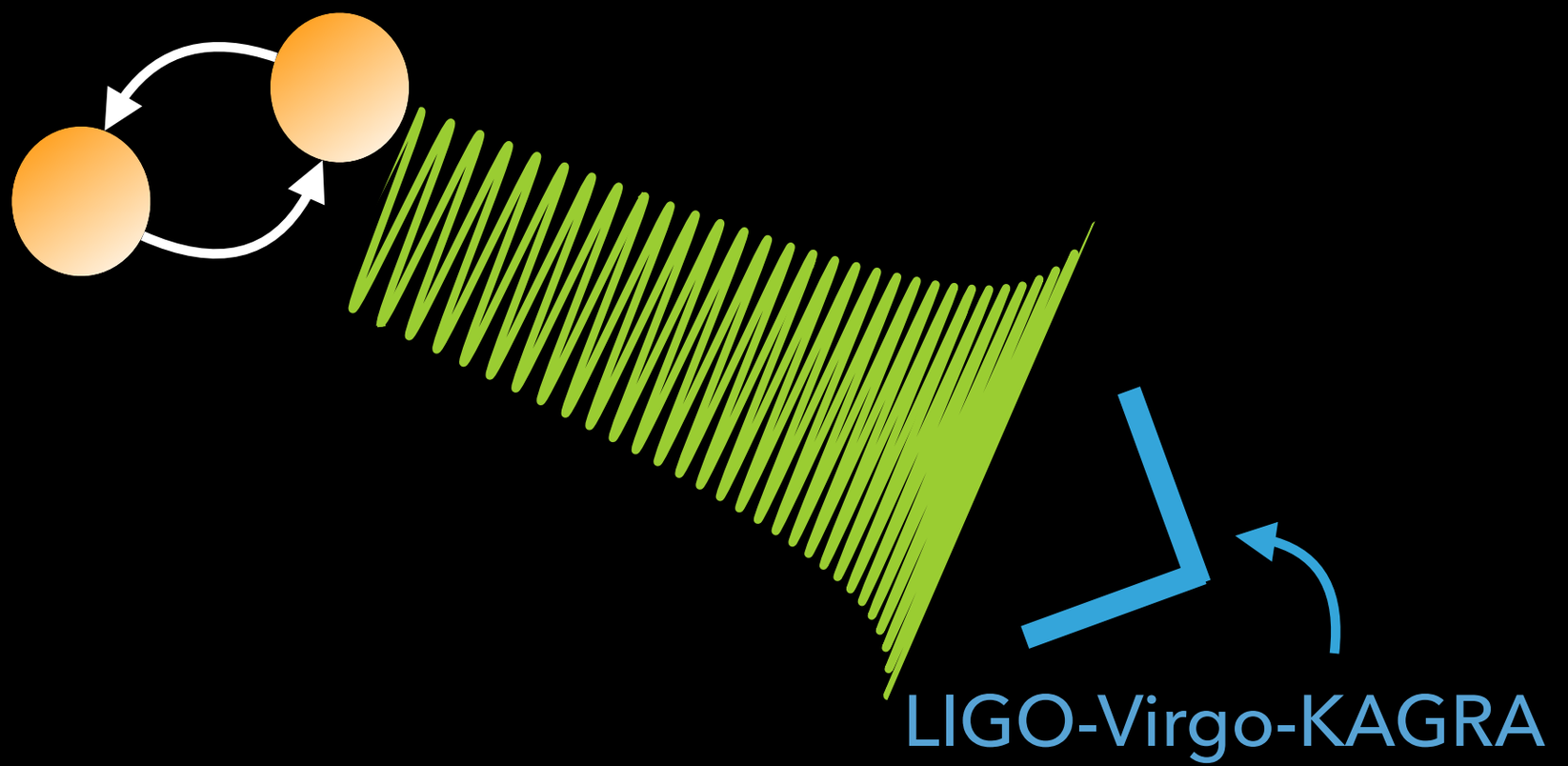

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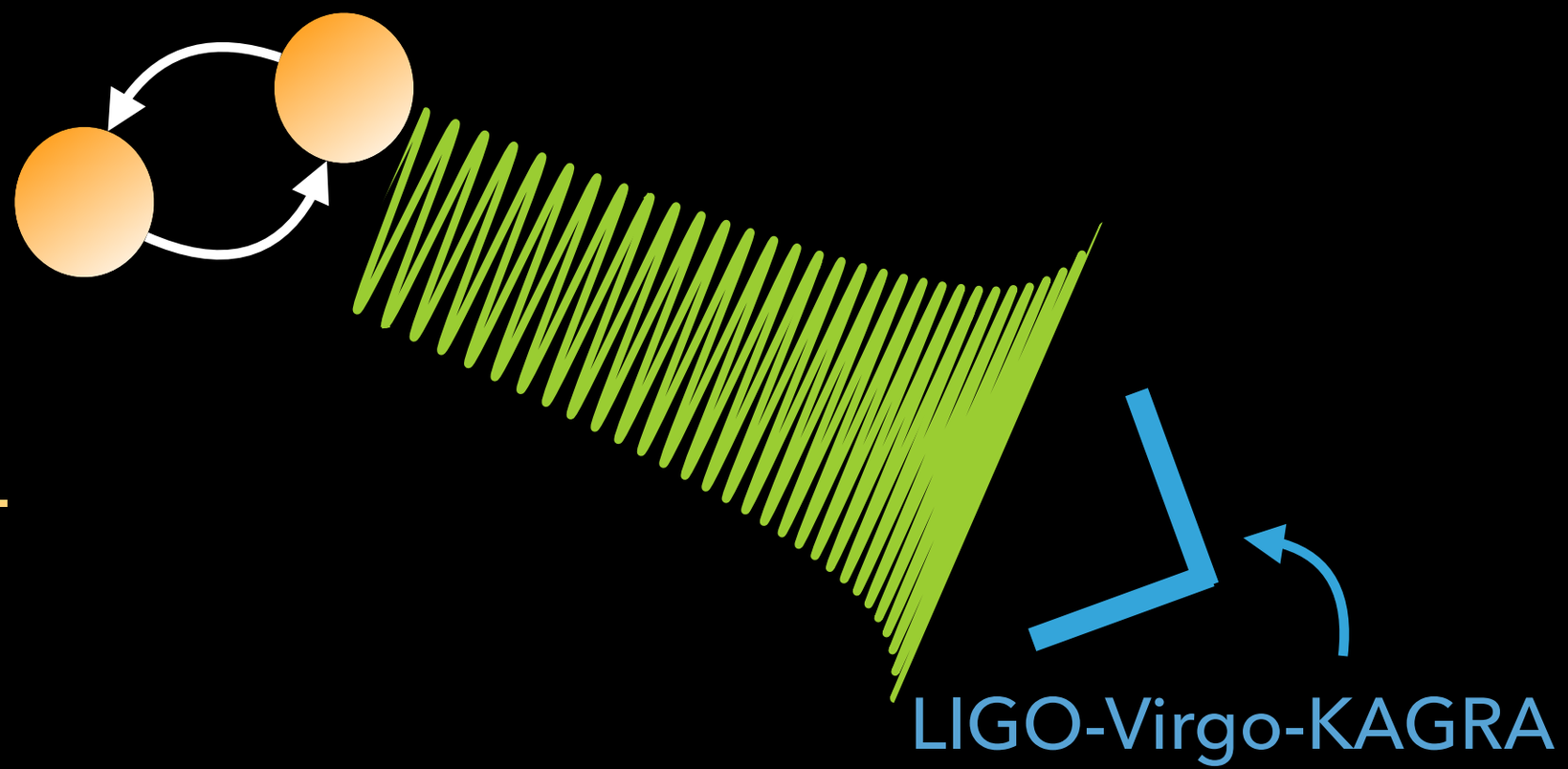

Standard sirens: distance determined from gravitational-wave observations

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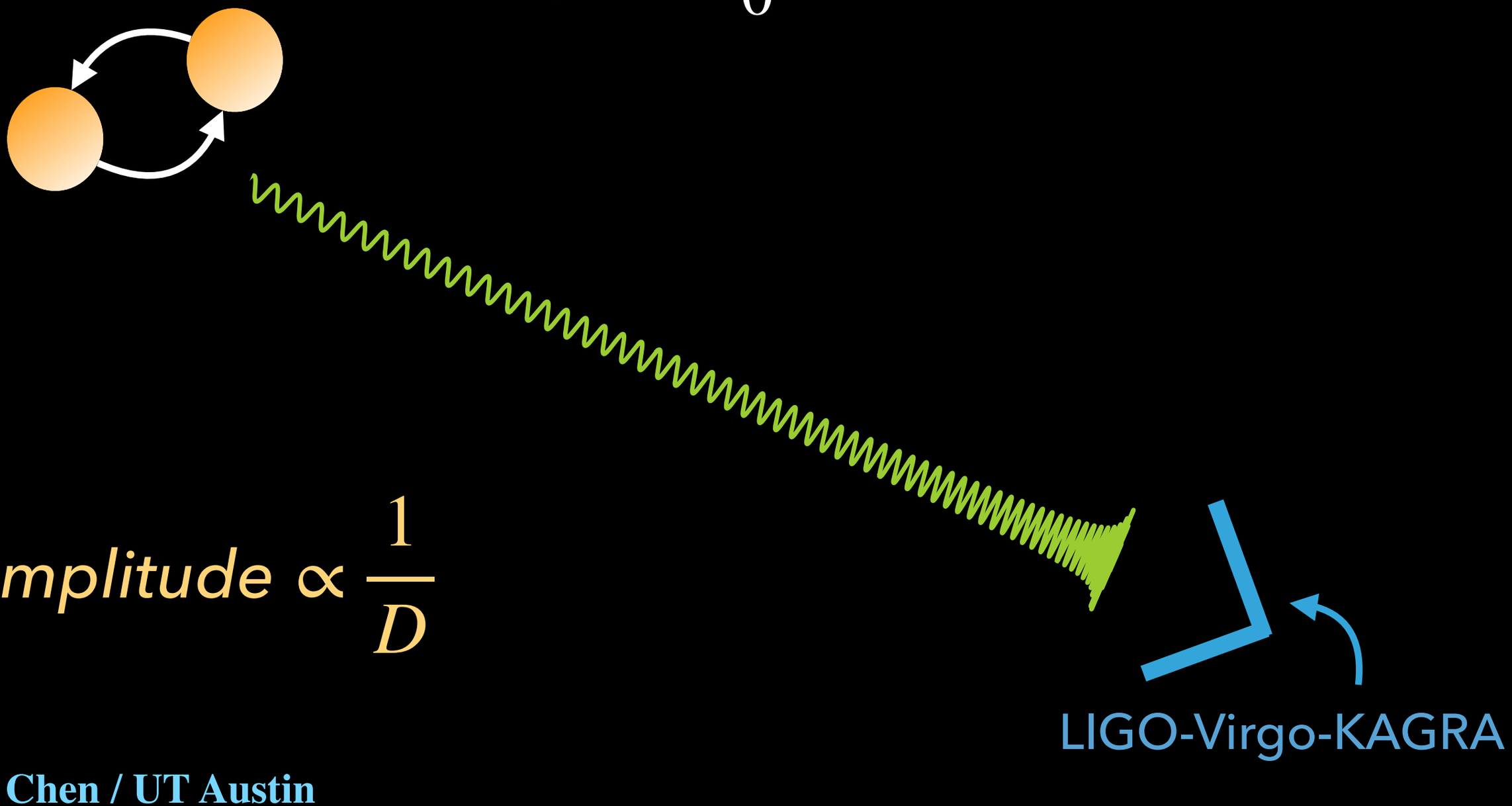
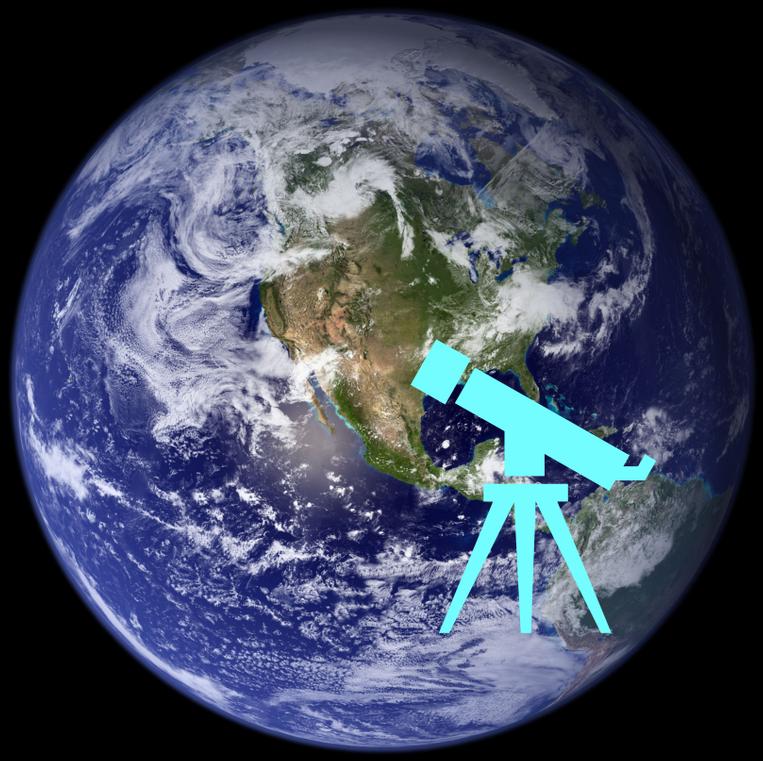
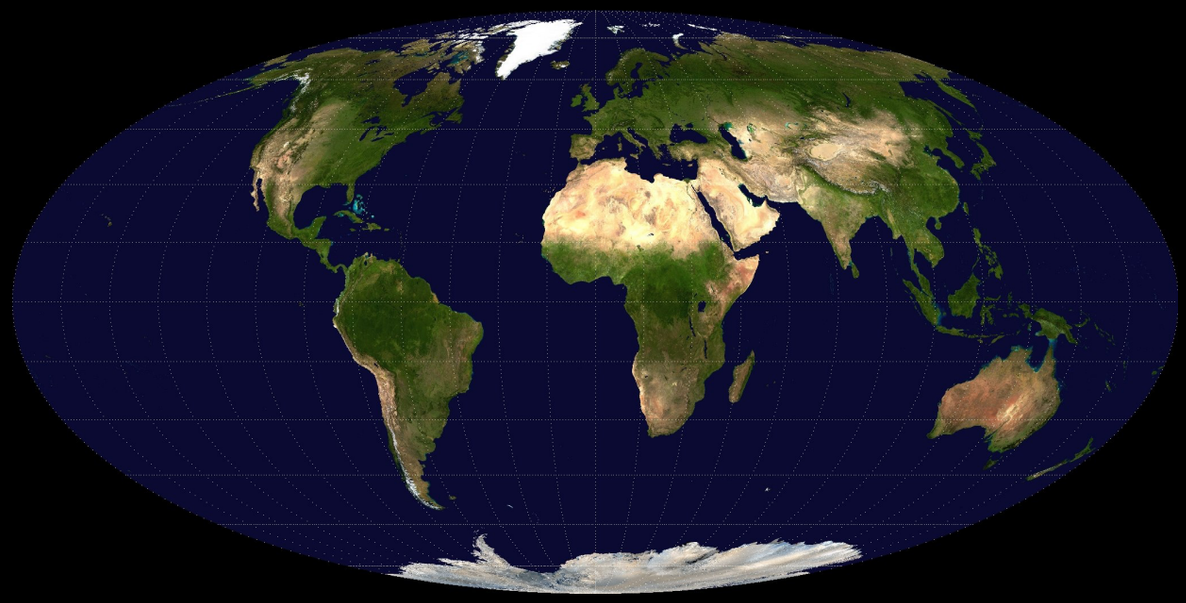


$$\textit{Amplitude} \propto \frac{1}{D}$$

Image credit: NASA, ESA, and R. Foley

Determine redshifts for standard sirens: Multi-messenger observations





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Determine redshifts for standard sirens: Multi-messenger observations

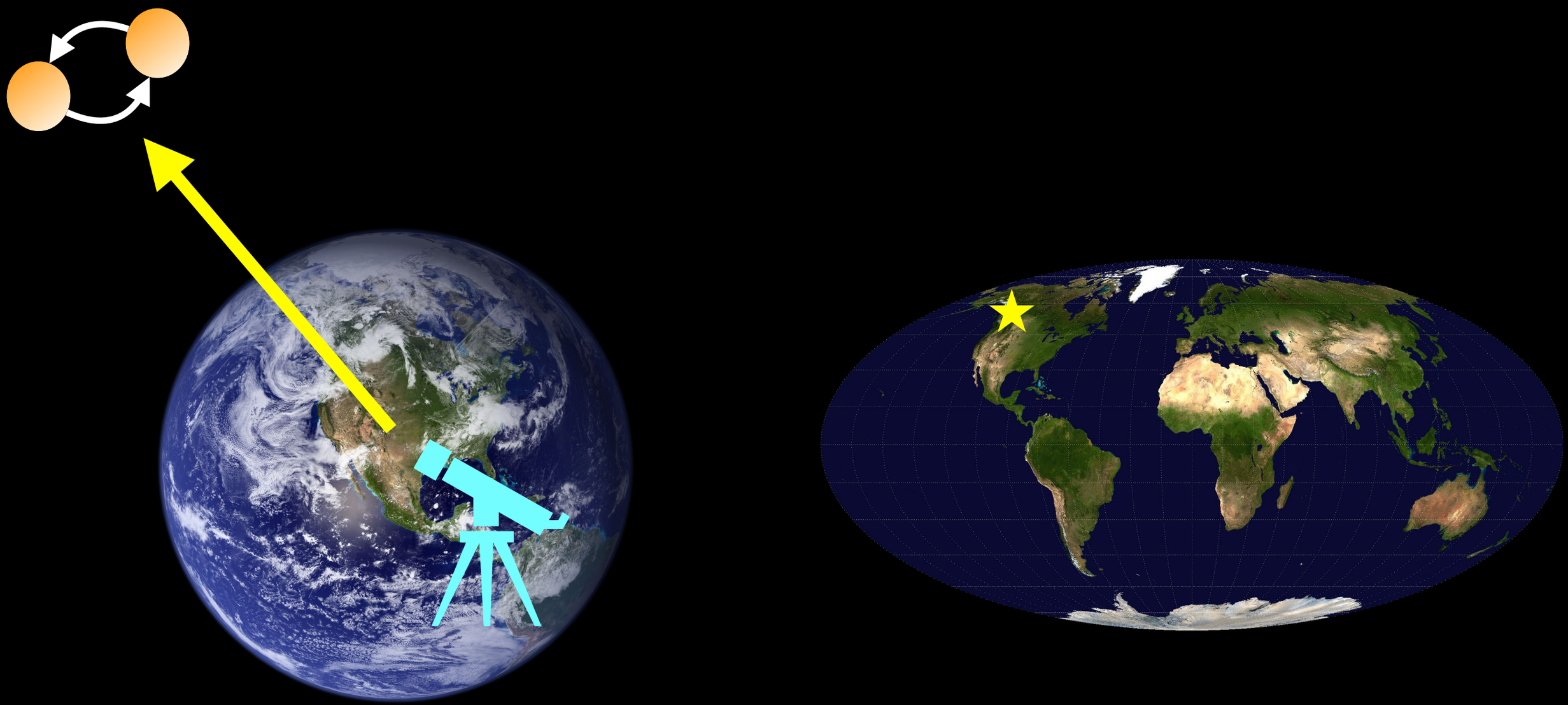

Image credit: NASA, ESA, and R. Foley

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Determine redshifts for standard sirens: Multi-messenger observations

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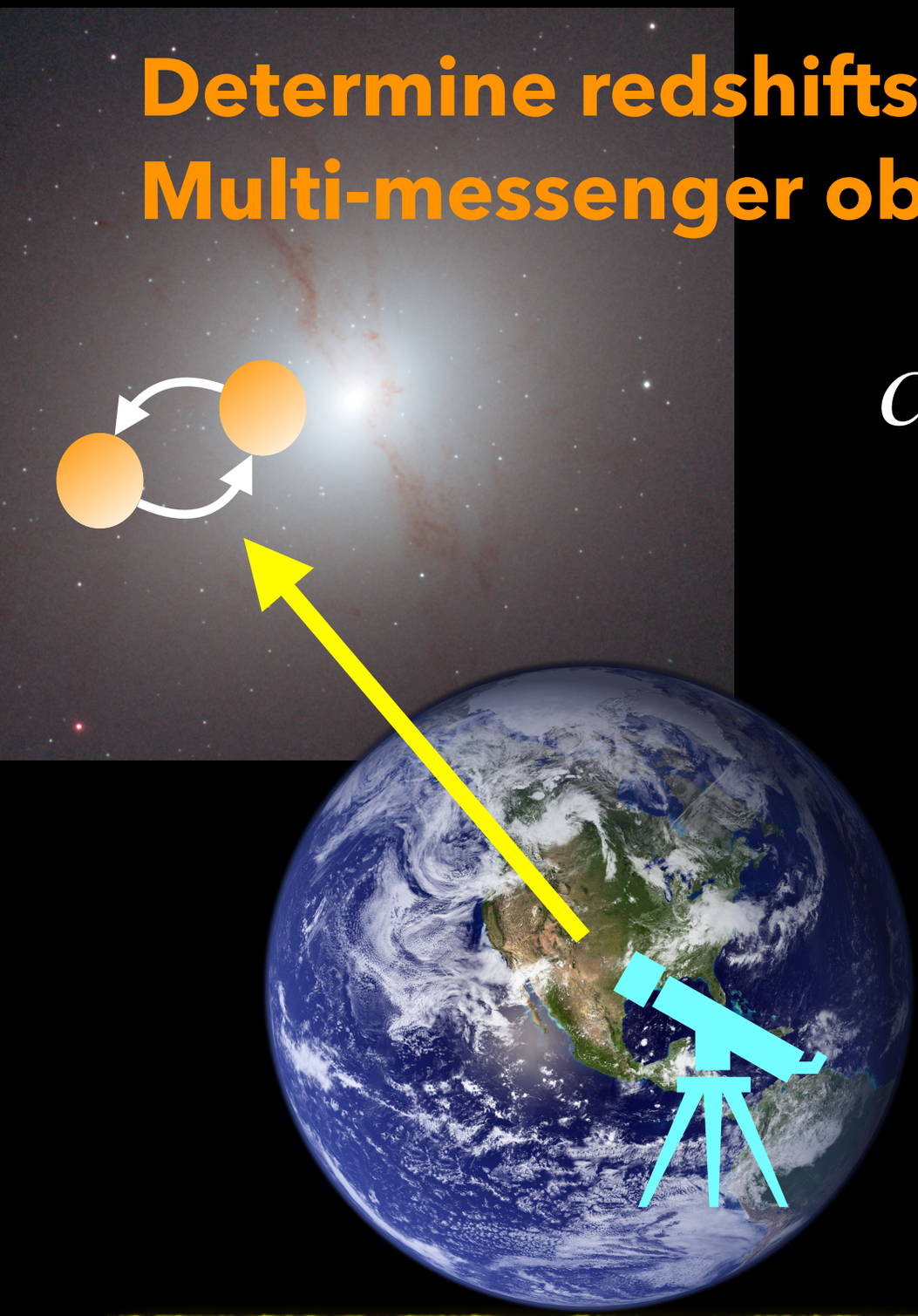



Bright siren: The precise electromagnetic localization allow for the identification of the hosts and the measurement of the redshifts.

Schutz, Nature (1986) / Holz & Hughes, ApJ (2005)

Image credit: NASA, ESA, and R. Foley

Determine redshifts for standard sirens: Multi-messenger observations

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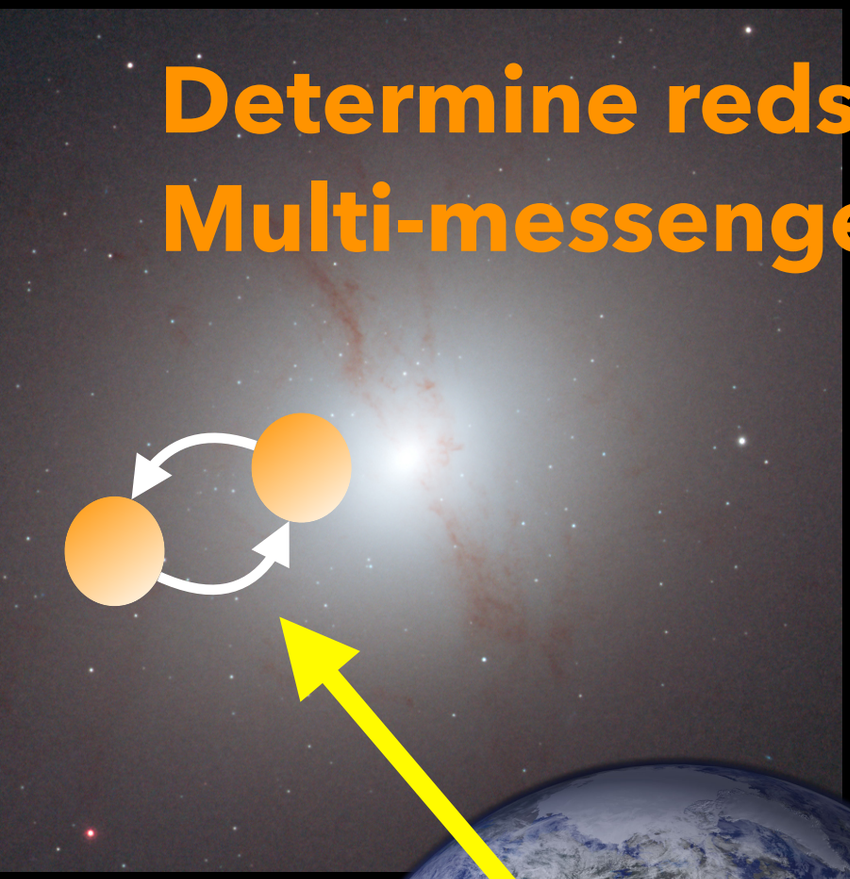

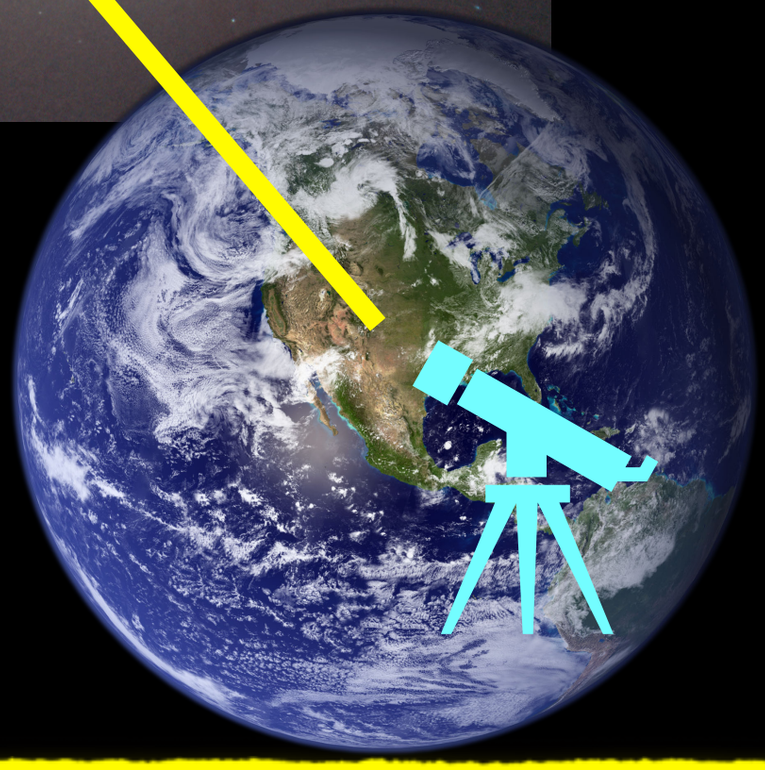



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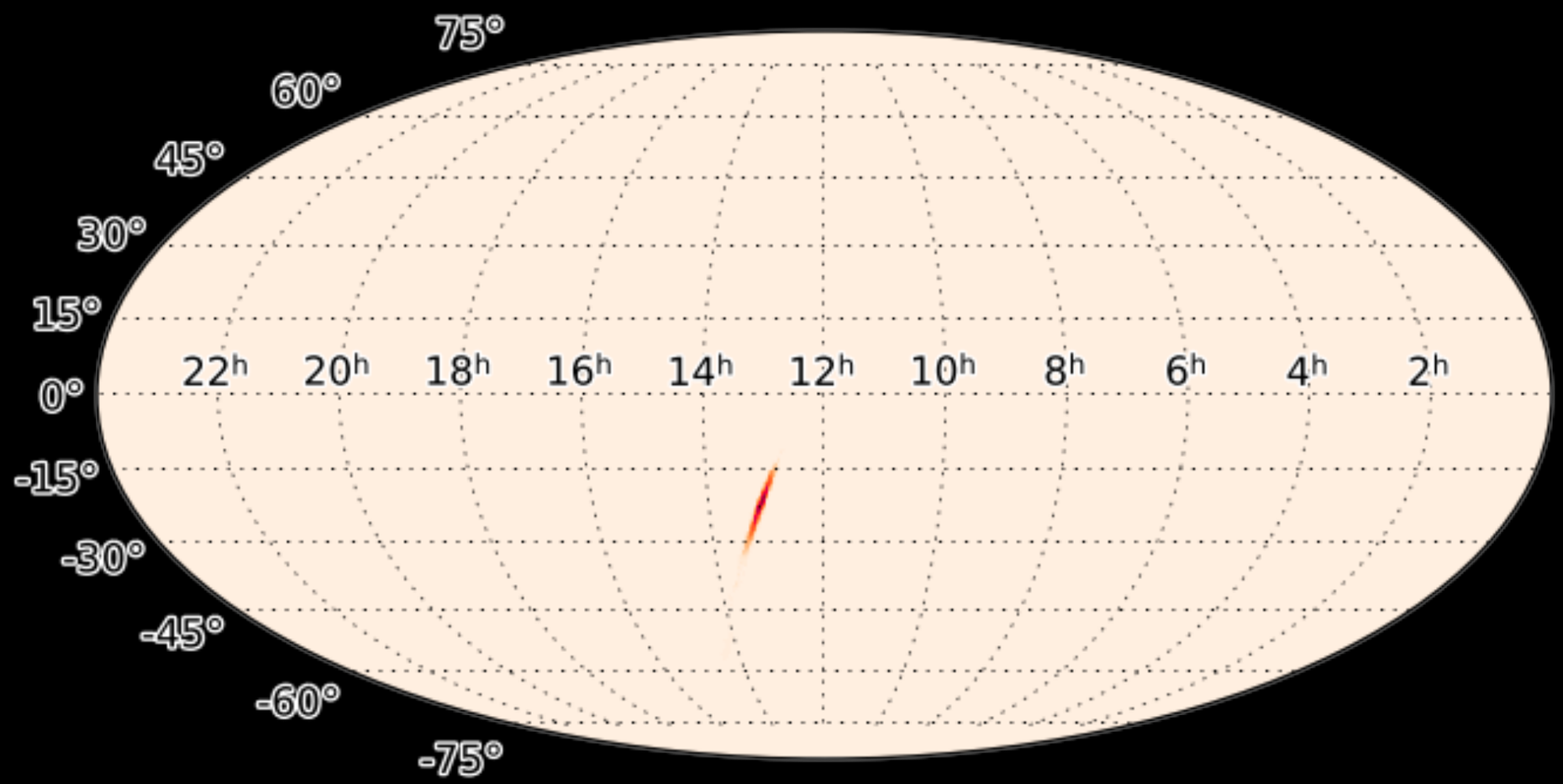
Image credit: 1M2H Team / UC Santa Cruz & Carnegie Observatories / Ryan Foley

Application on GW170817

Abbott et al., ApJL (2017)



LIGO-Virgo localization

Image credit: 1M2H Team / UC Santa Cruz & Carnegie Observatories / Ryan Foley

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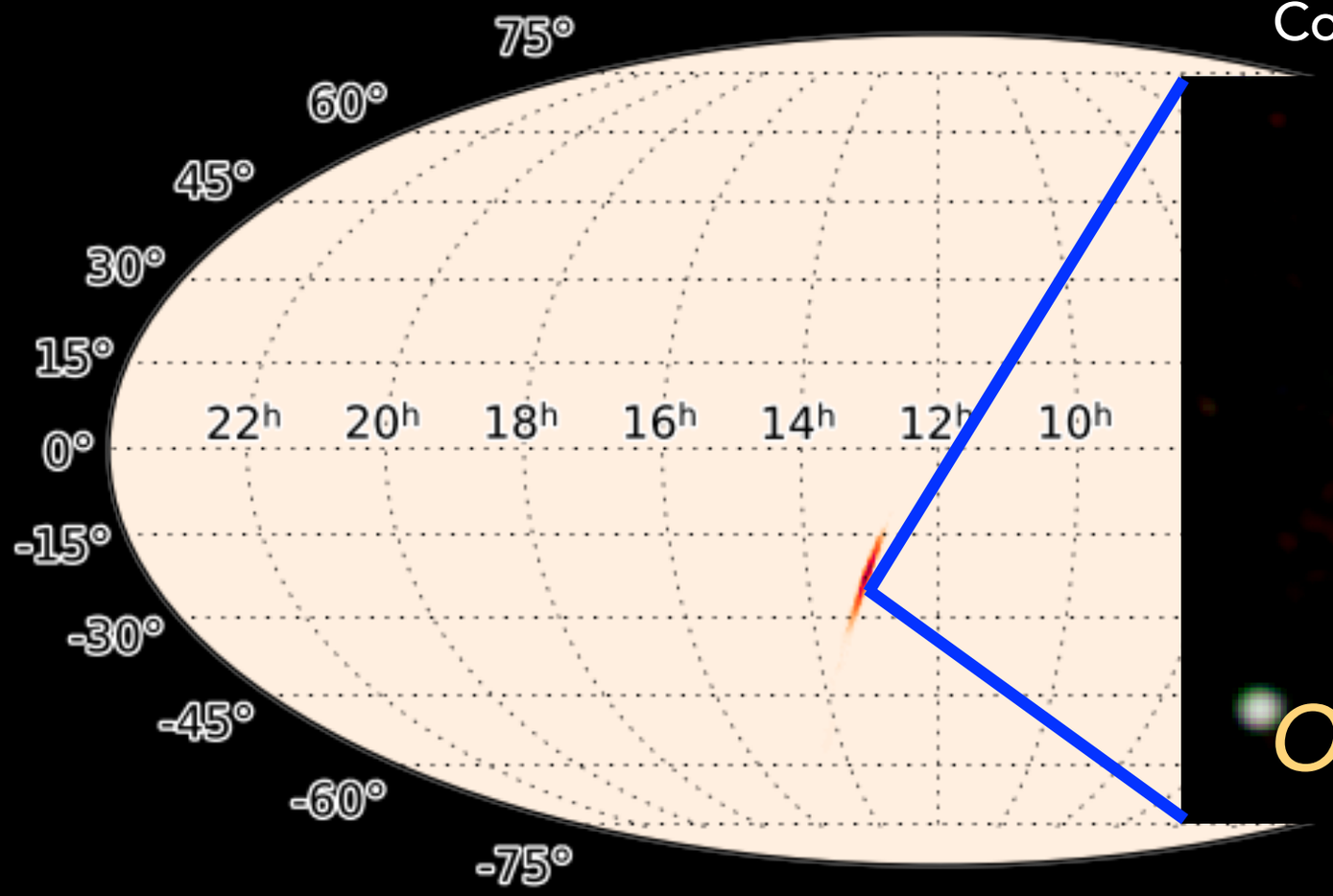

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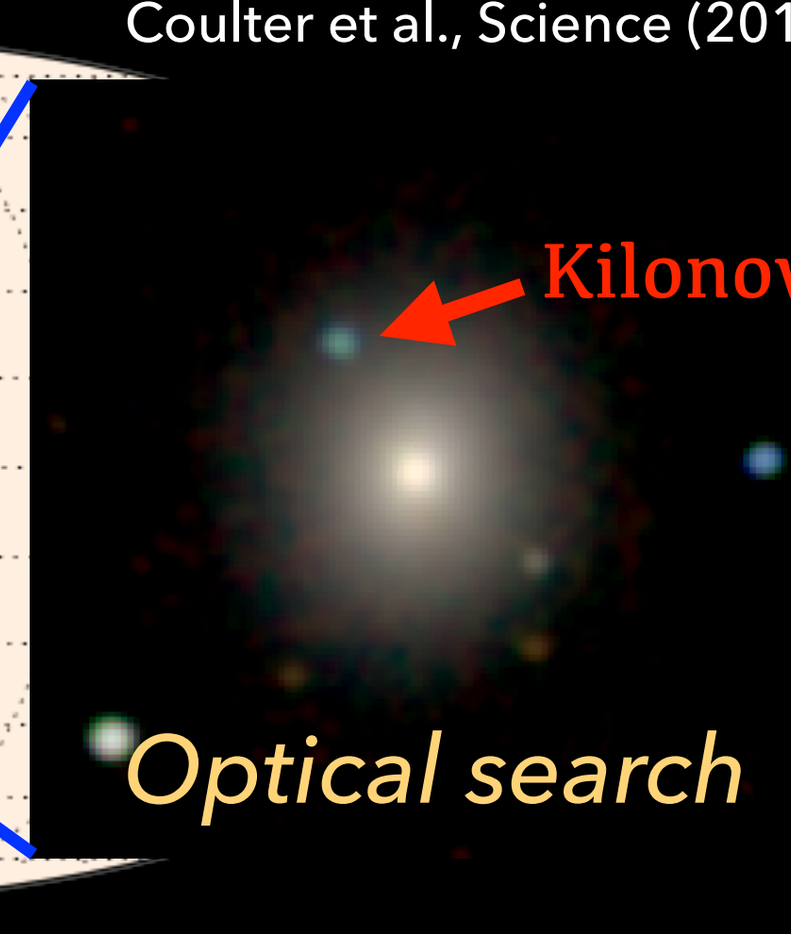
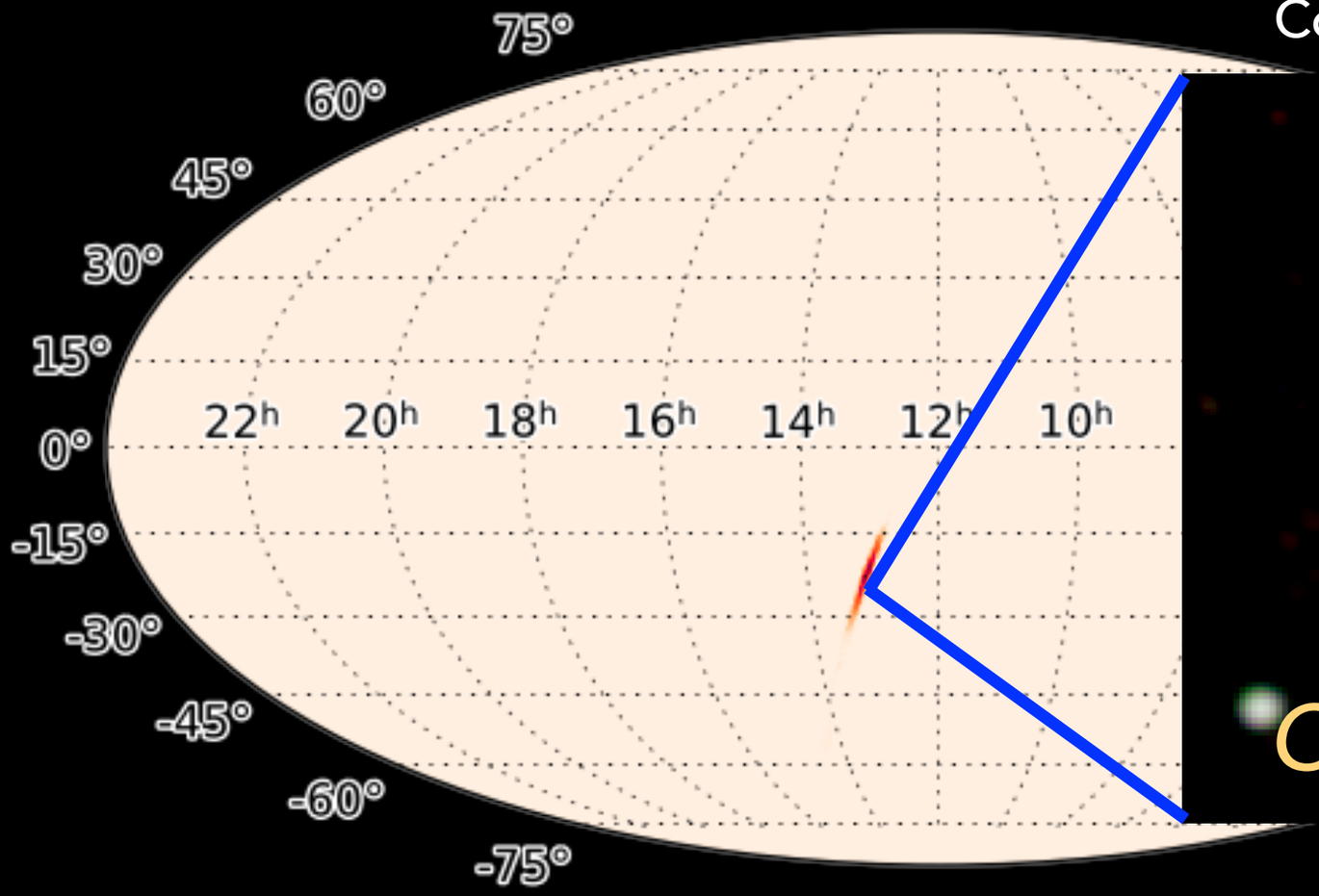


Optical search

Image credit: 1M2H Team / UC Santa Cruz & Carnegie Observatories / Ryan Foley

Application on GW170817

Abbott et al., ApJL (2017)



LIGO-Virgo localization

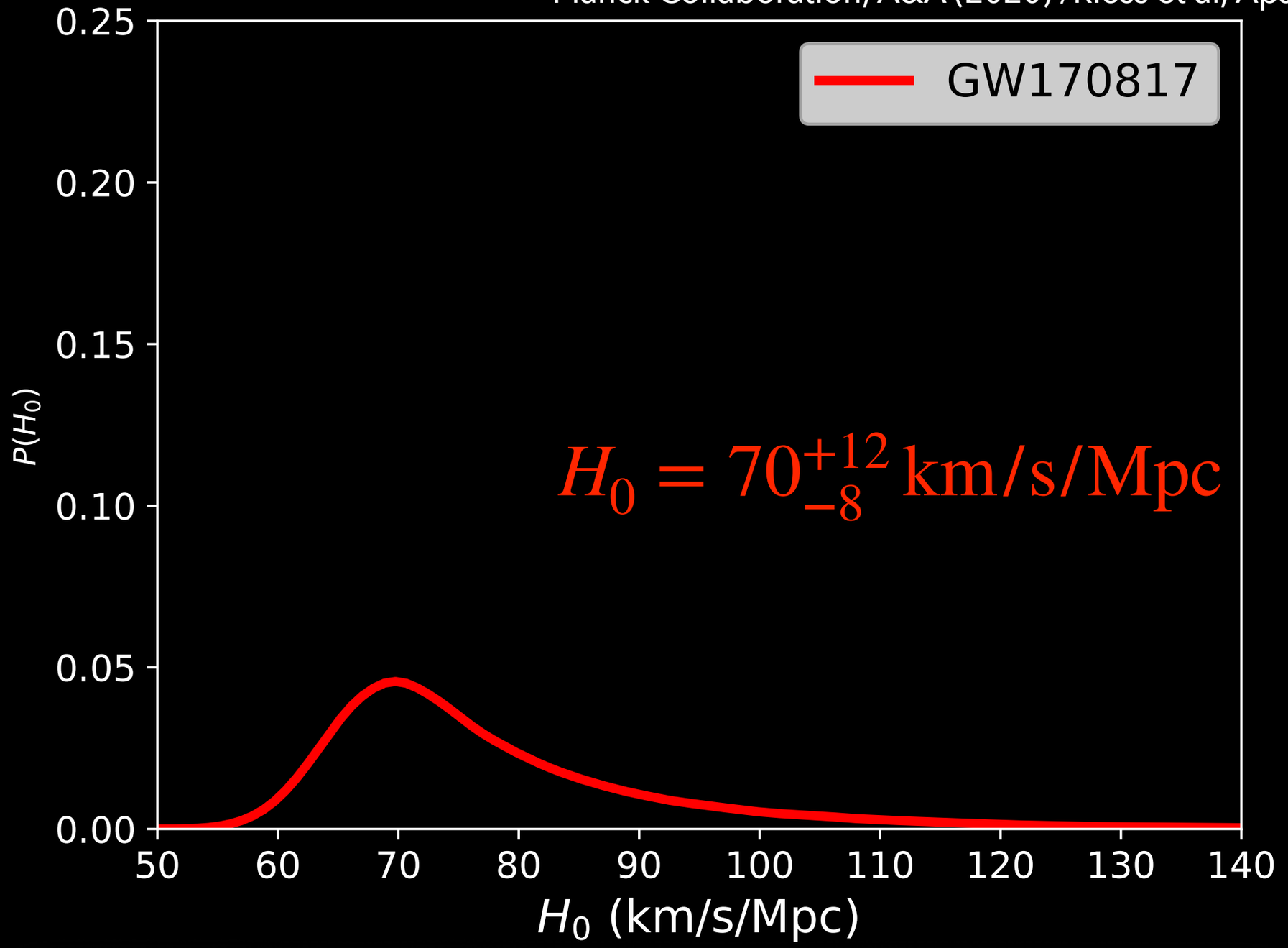
Coulter et al., Science (2017)



The discovery of kilonova AT 2017gfo enabled the association with the host galaxy NGC4993.

Application on GW170817

Adapted from Abbott et al., Nature (2017) /
Planck Collaboration, A&A (2020) /Riess et al, ApJL (2022)



First application of the standard siren method

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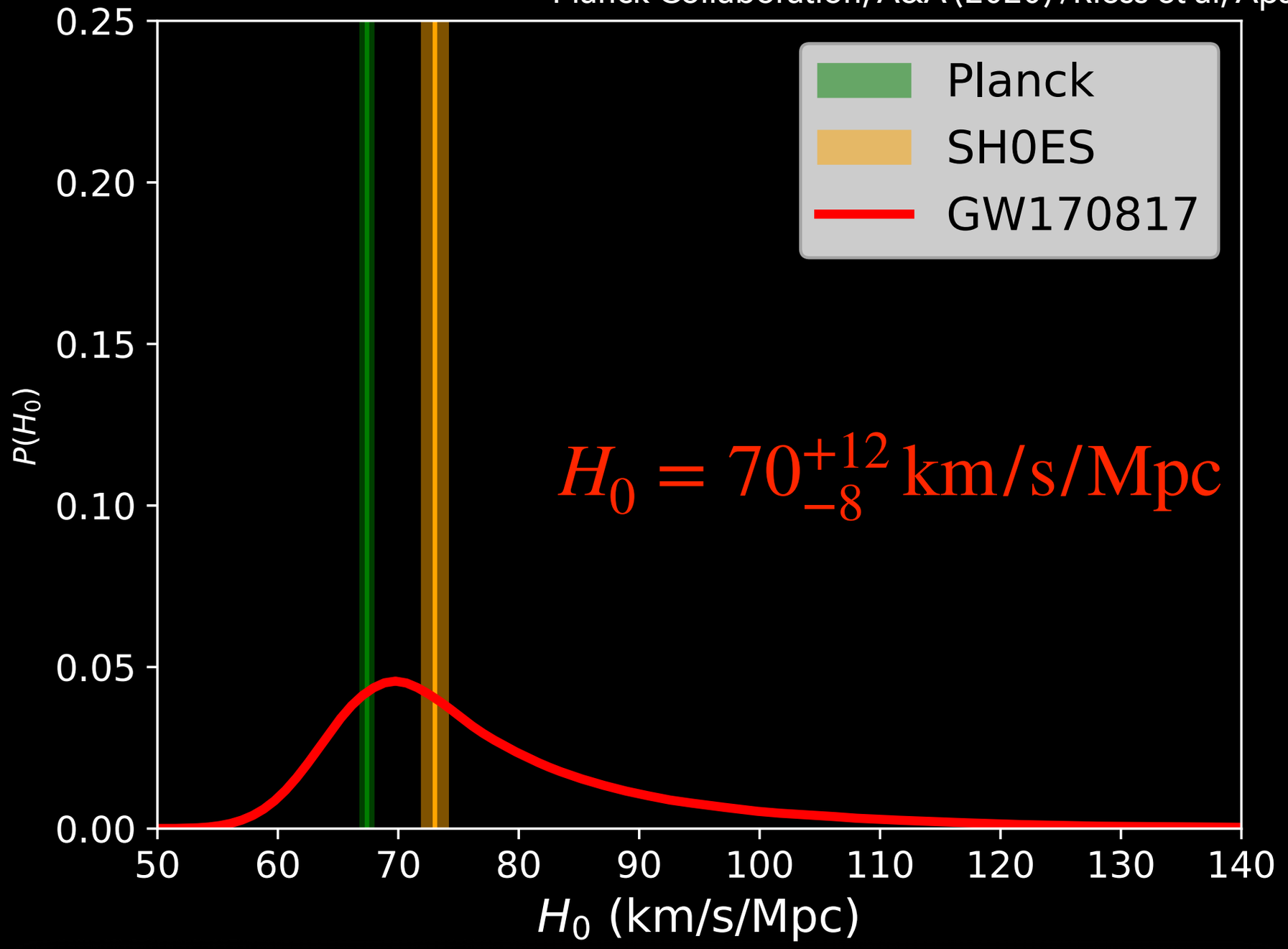

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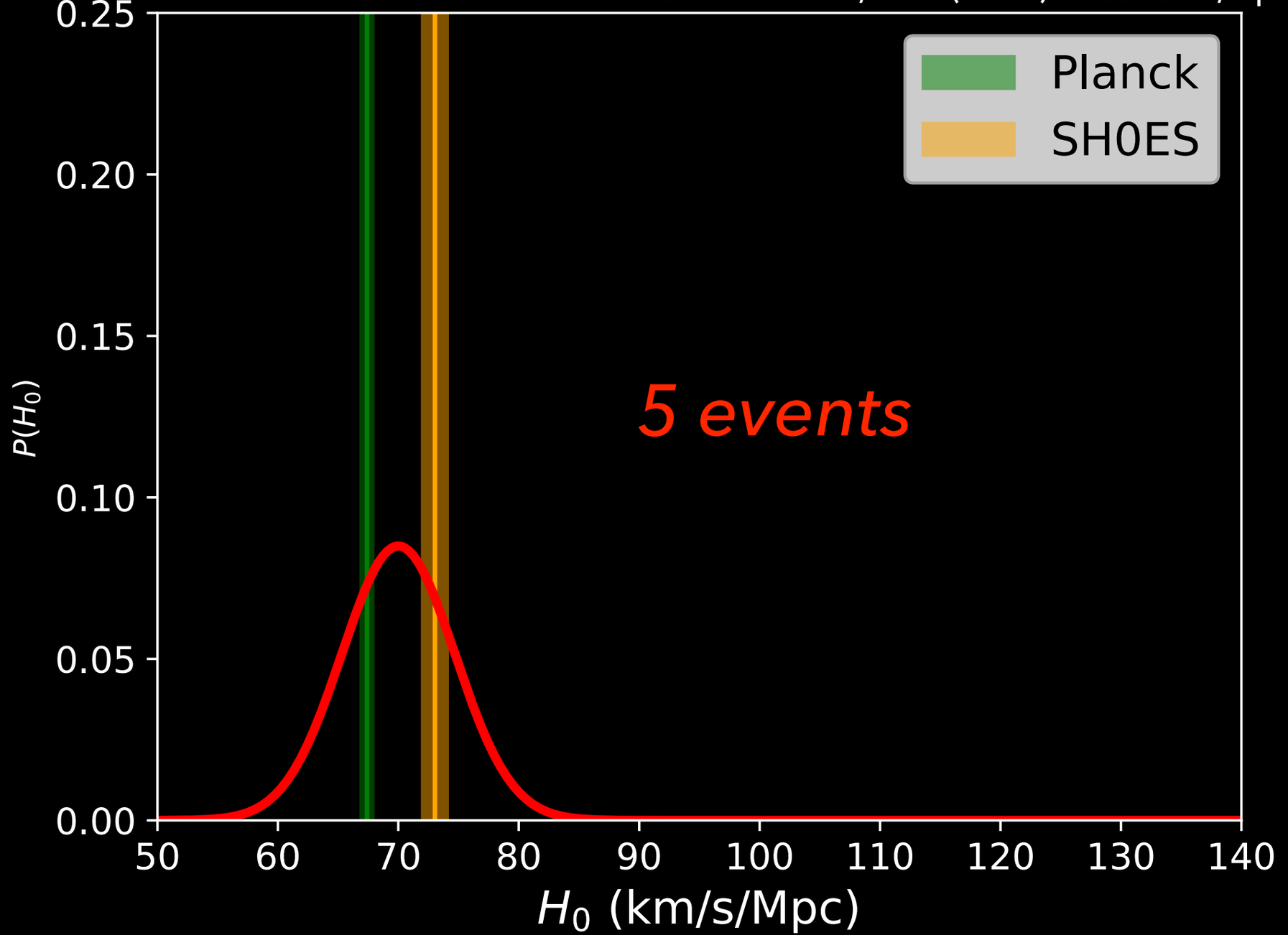
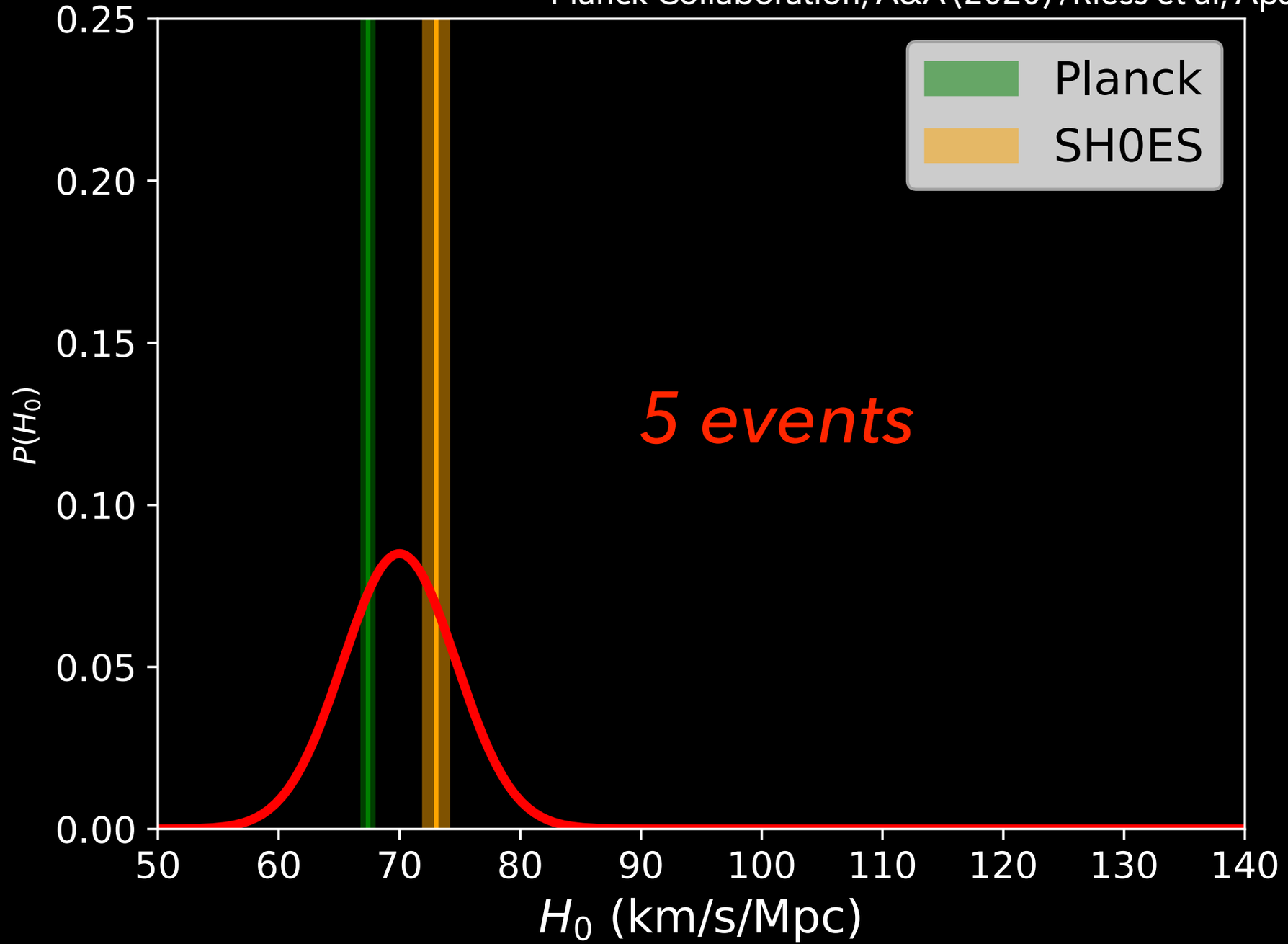


As more multi-messenger events are collected

Adapted from Chen et al, Nature (2018) /
Planck Collaboration, A&A (2020) /Riess et al, ApJL (2022)



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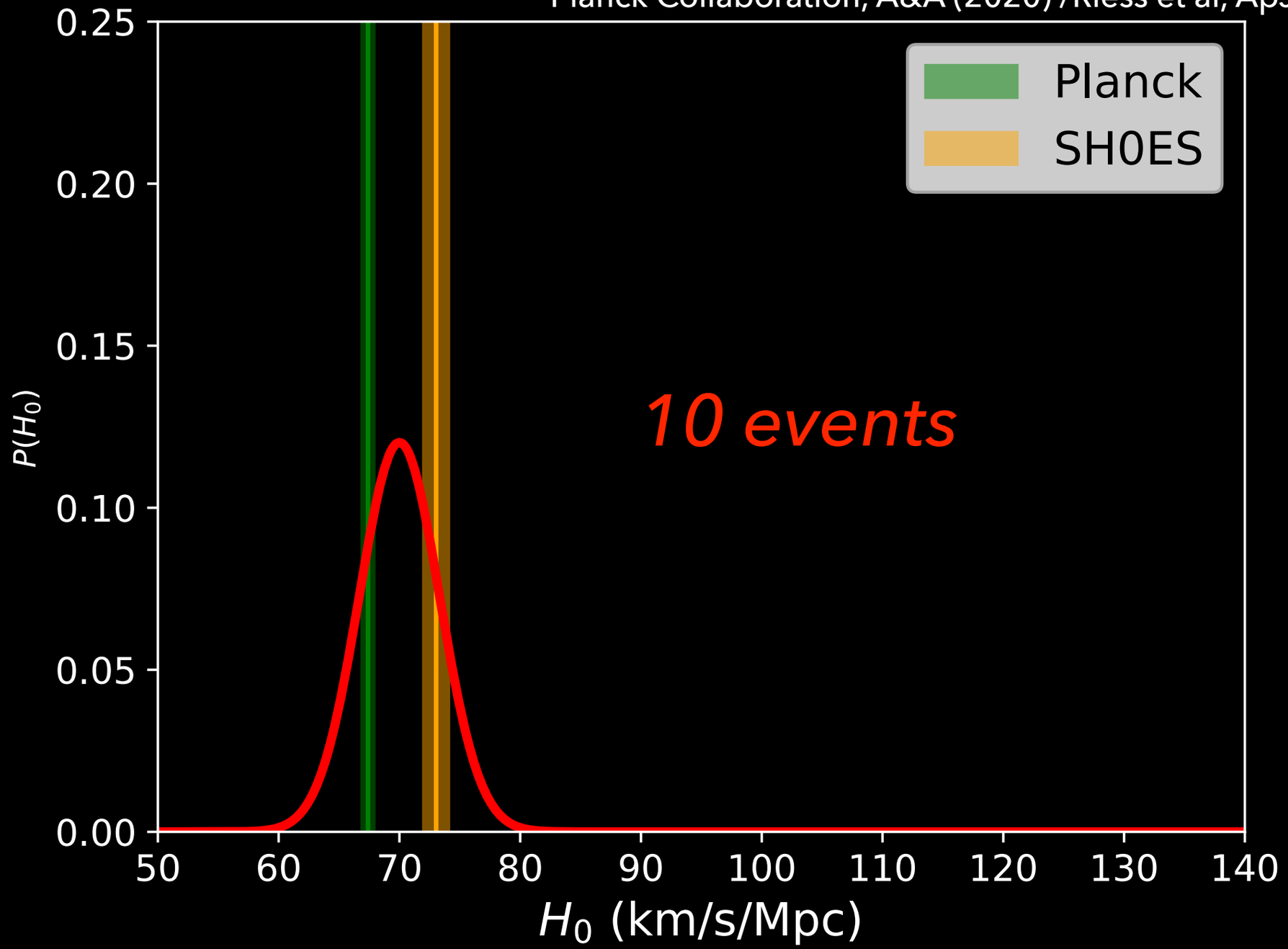

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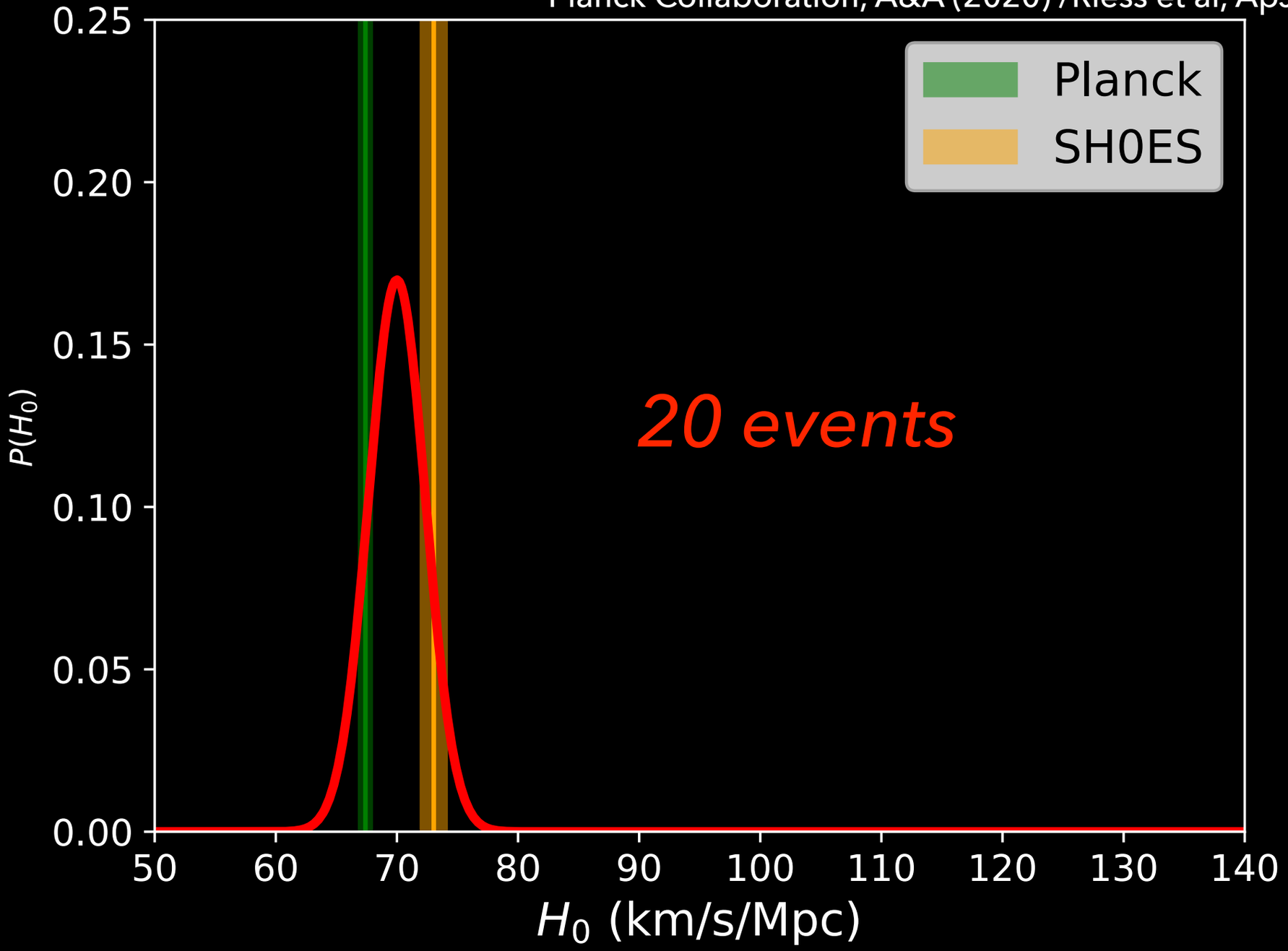

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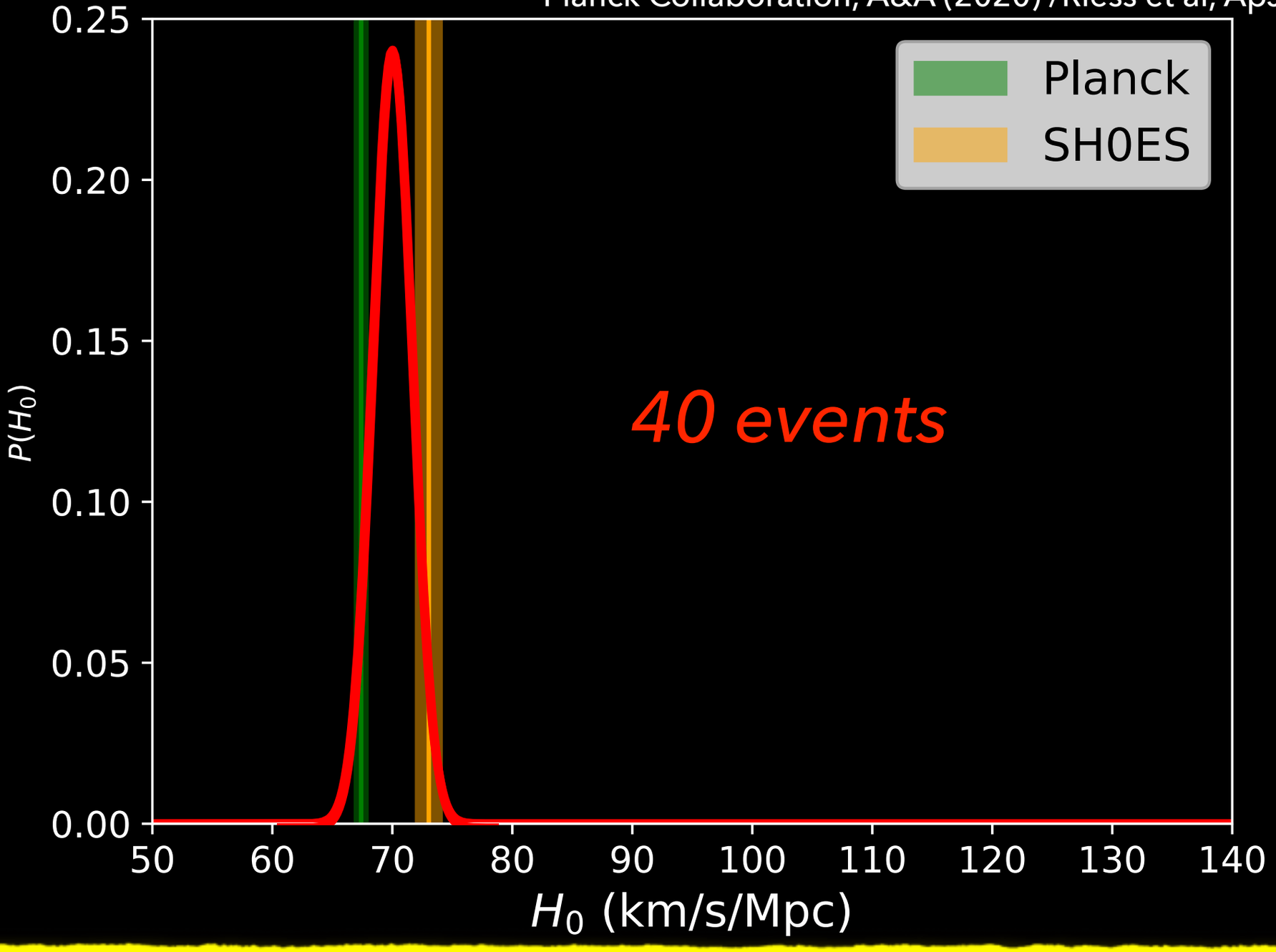

H_0 can be measured to ~2.5% with 40 multi-messenger events.

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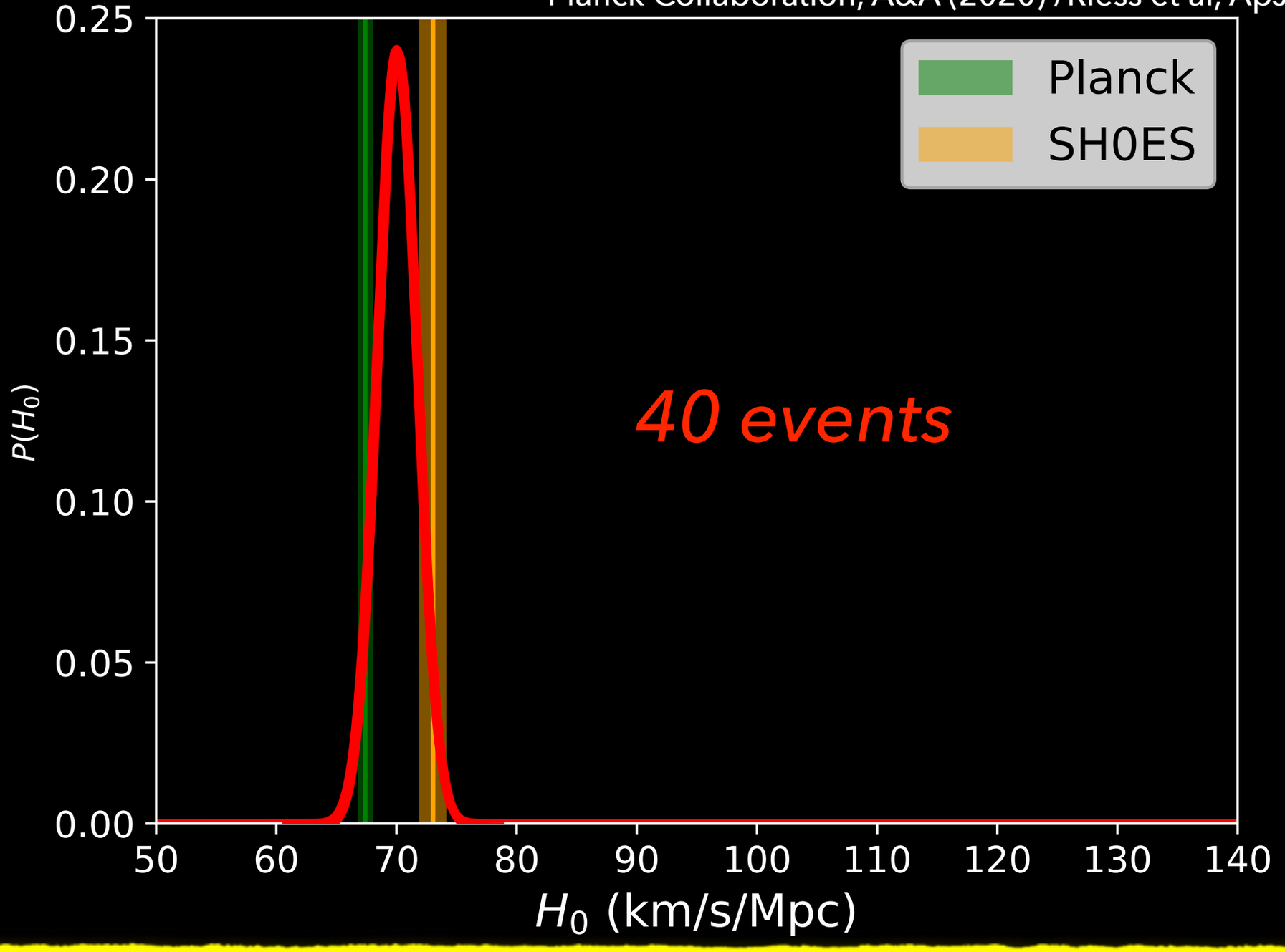

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Letter | Published: 17 October 2018

A two per cent Hubble constant measurement from standard sirens within five years

Hsin-Yu Chen ✉, Maya Fishbach & Daniel E. Holz

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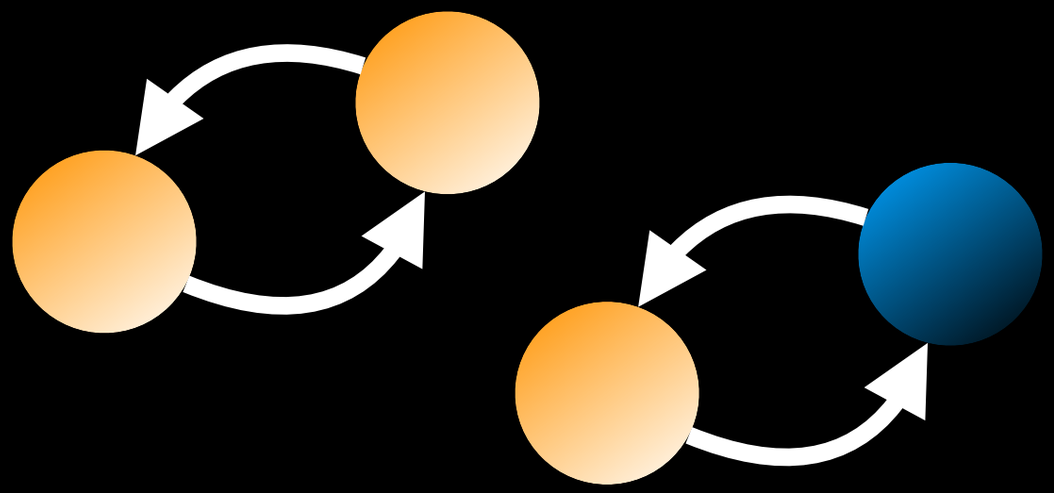
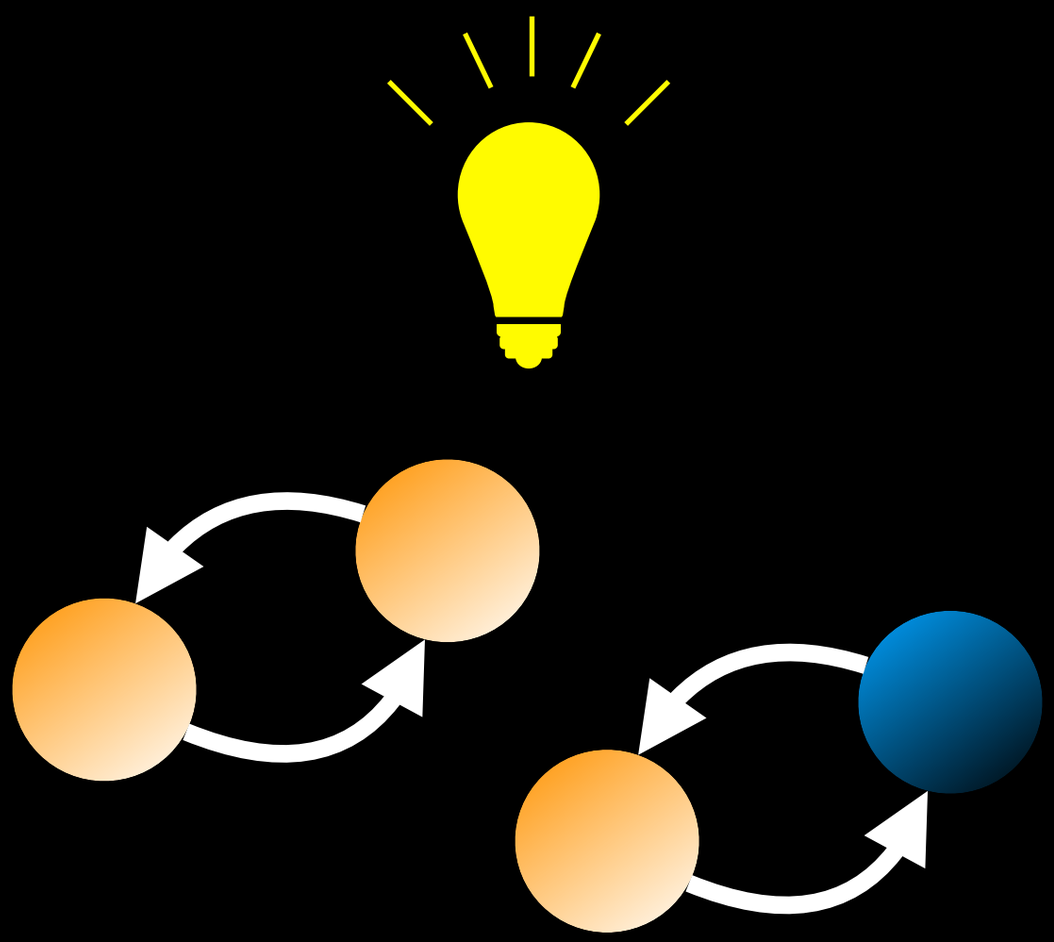
???

The binary neutron star merger astrophysical rate is unexpectedly low (start to create tension with short GRBs).

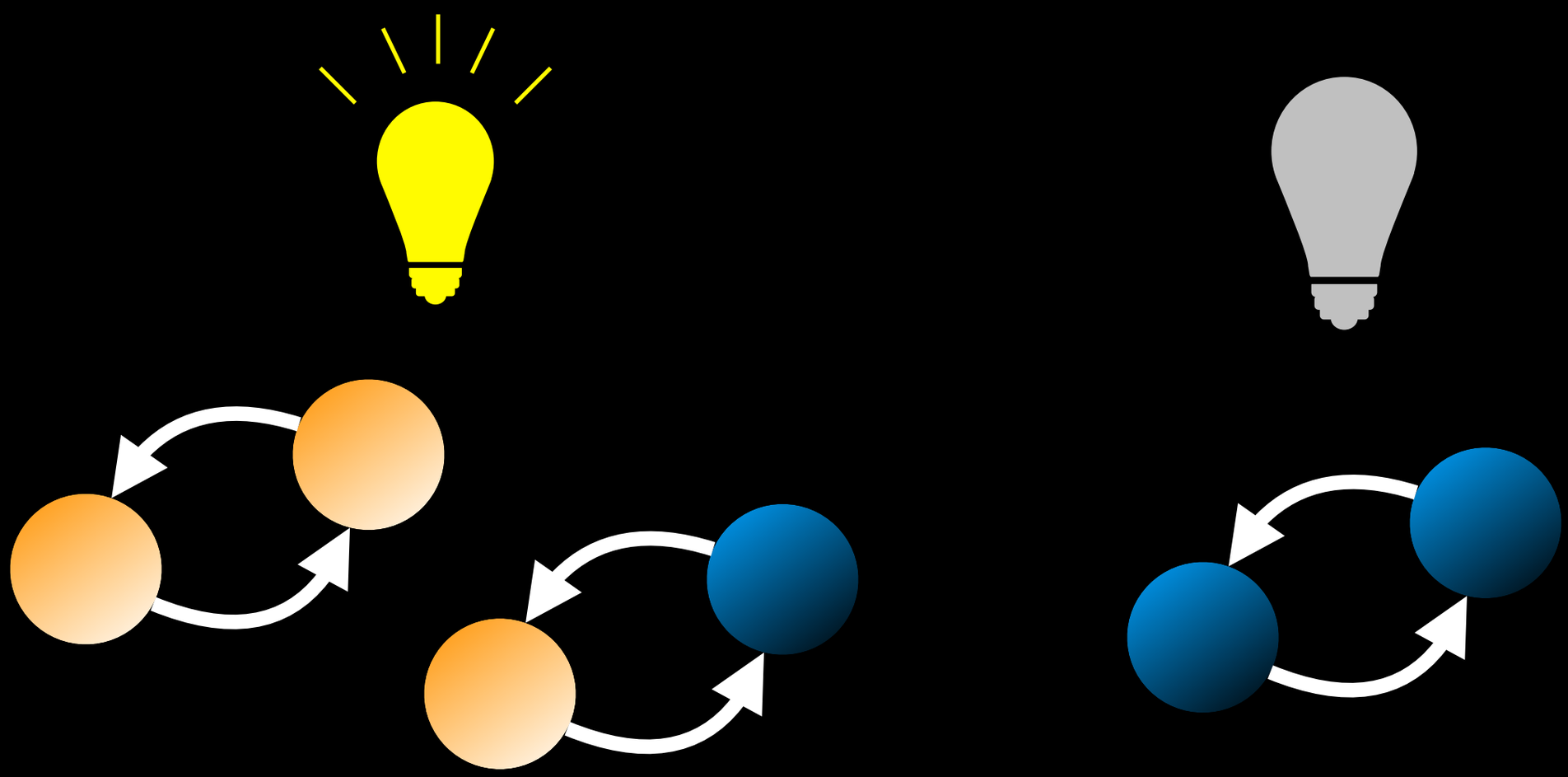


Around 5 detections



Around 5 detections

<u>One</u> with electromagnetic counterpart.



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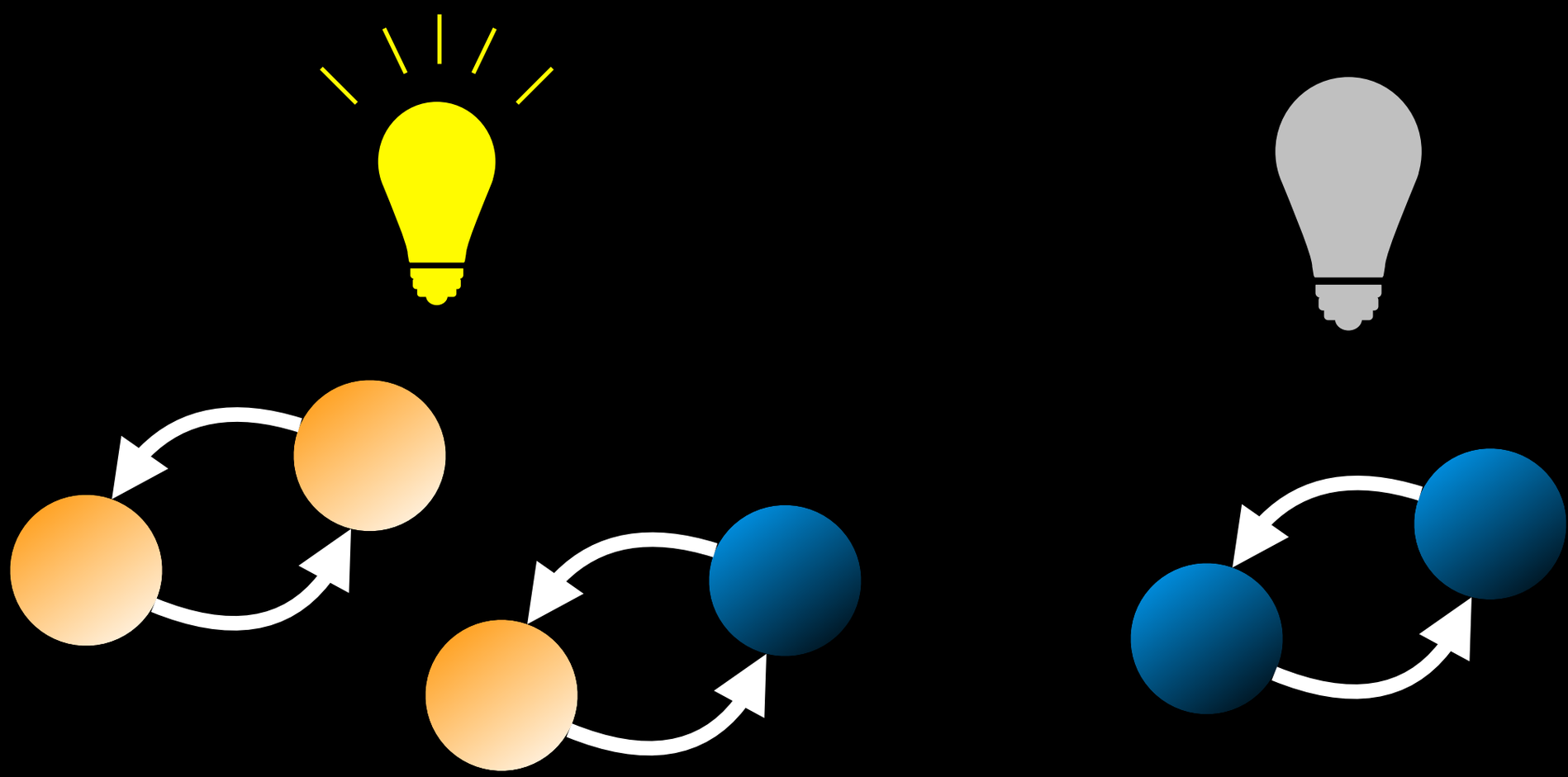
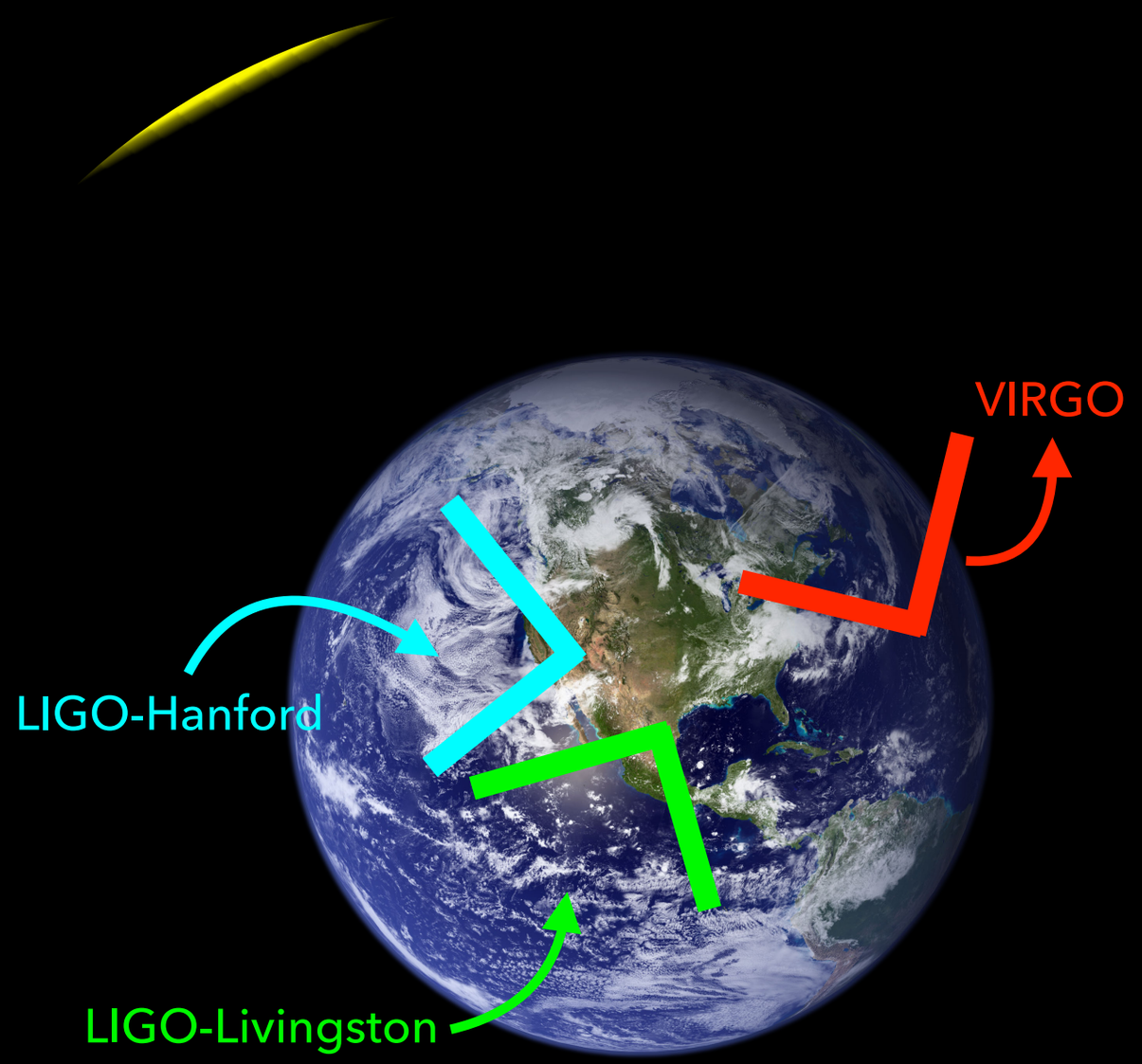


Around 5 detections

<u>One</u> with electromagnetic counterpart.

>400 detections

Determine redshifts for standard sirens



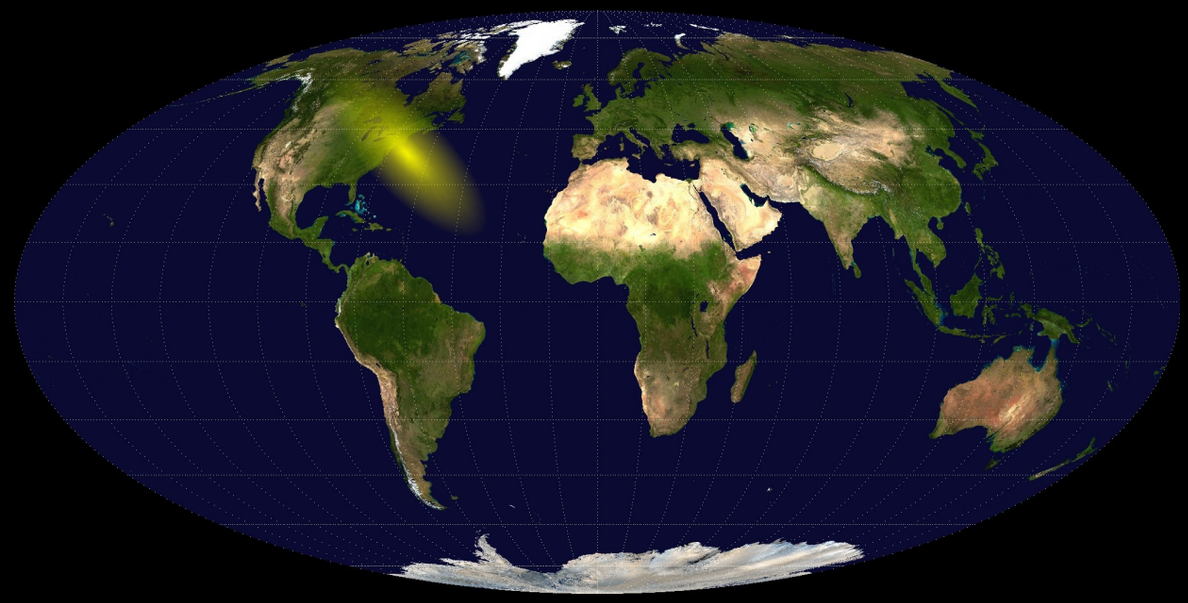


Image credit: NASA

Image credit: NASA

Determine redshifts for standard sirens

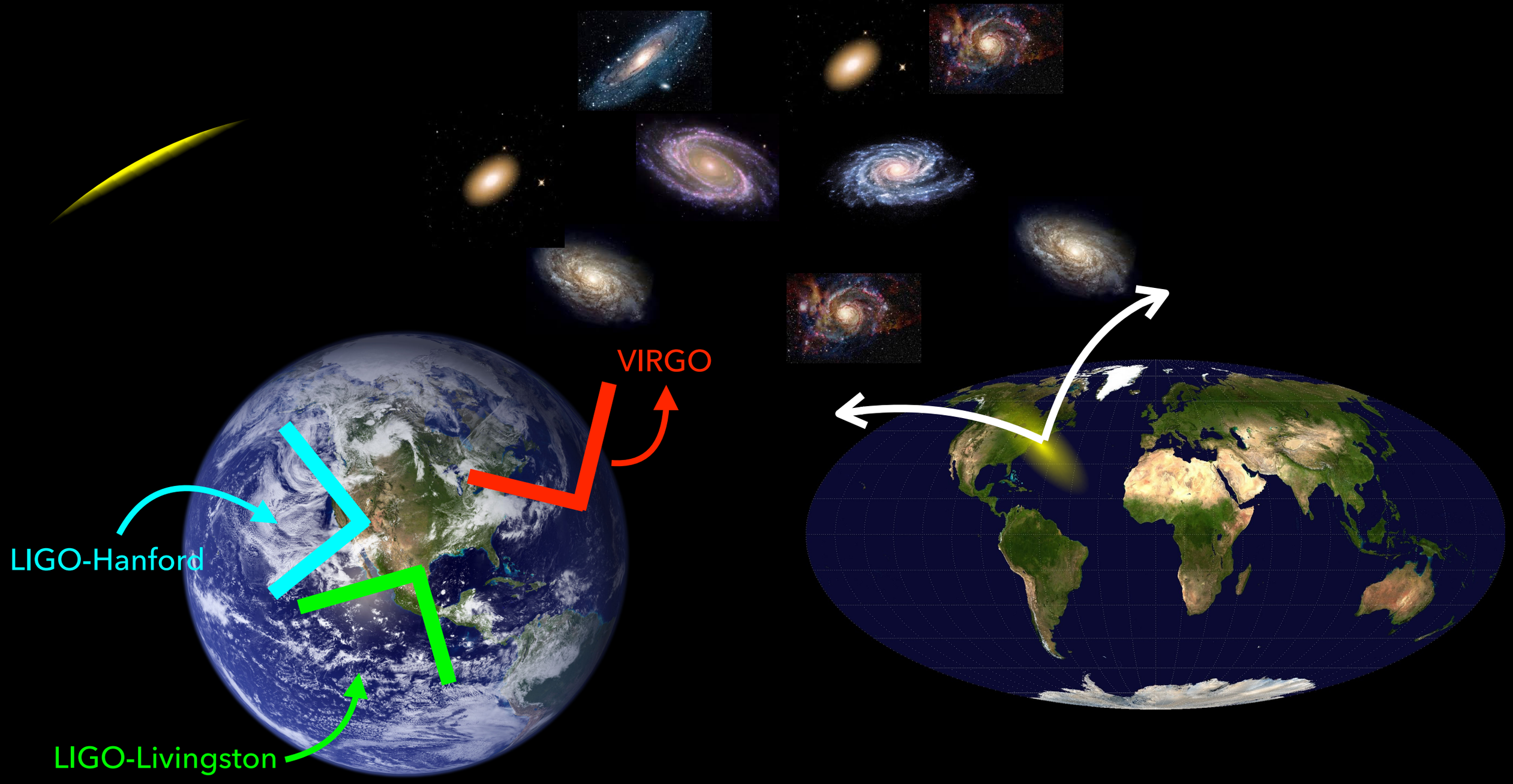


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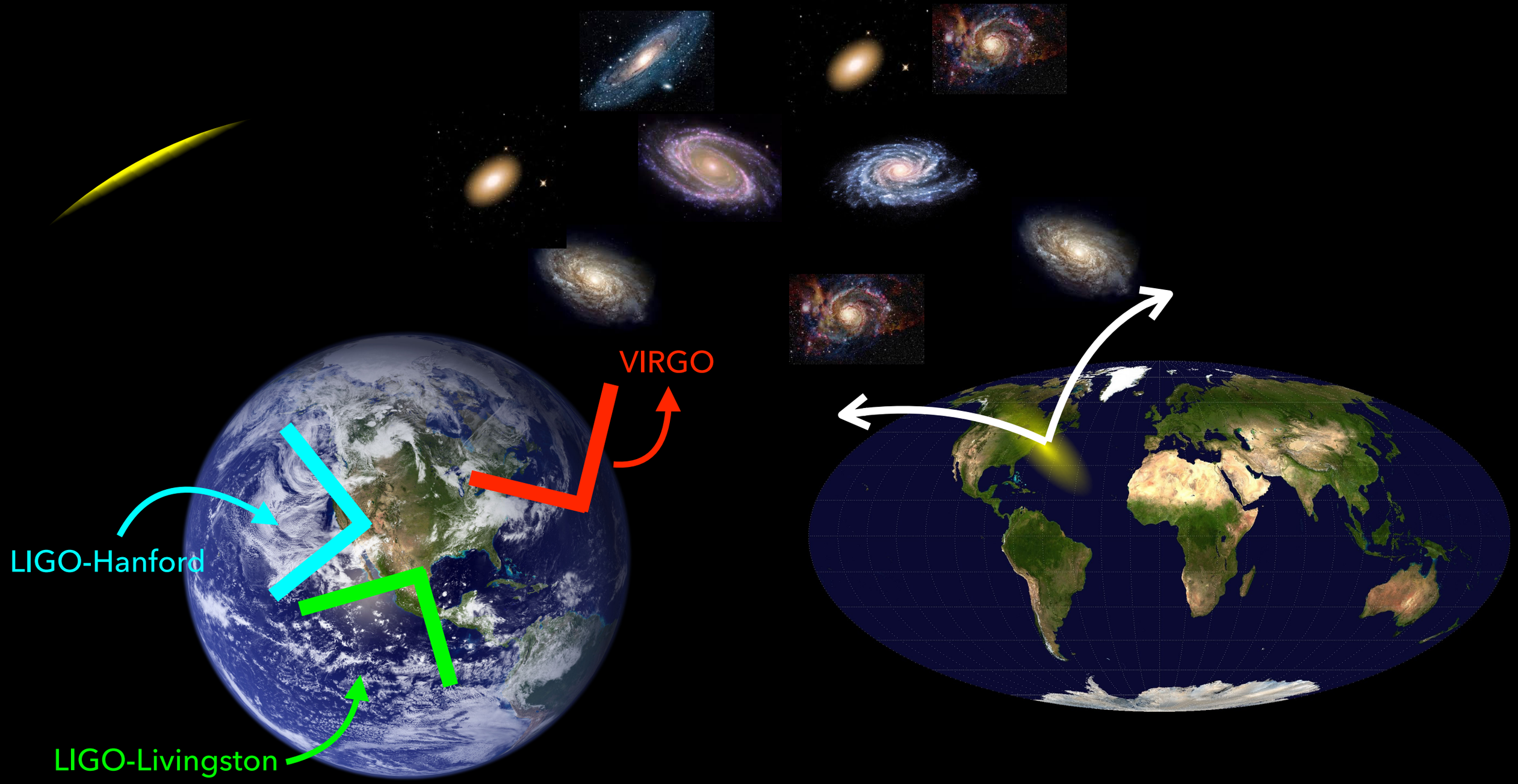
Image credit: NASA

Determine redshifts for standard sirens



Dark siren: Statistically combine the redshifts of all possible galaxies.

Schutz, Nature (1986), Del Pozzo, PRD (2011)

Issues with dark sirens

Hsin-Yu Chen / UT Austin

Issues with dark sirens

Incompleteness of galaxy catalog

Issues with dark sirens

Incompleteness of galaxy catalog

Incorrect weighting of host galaxies

Issues with dark sirens

Incompleteness of galaxy catalog

Incorrect weighting of host galaxies

Uninformative due to too many galaxies!

Dark siren: Statistically combine the redshifts of all possible galaxies

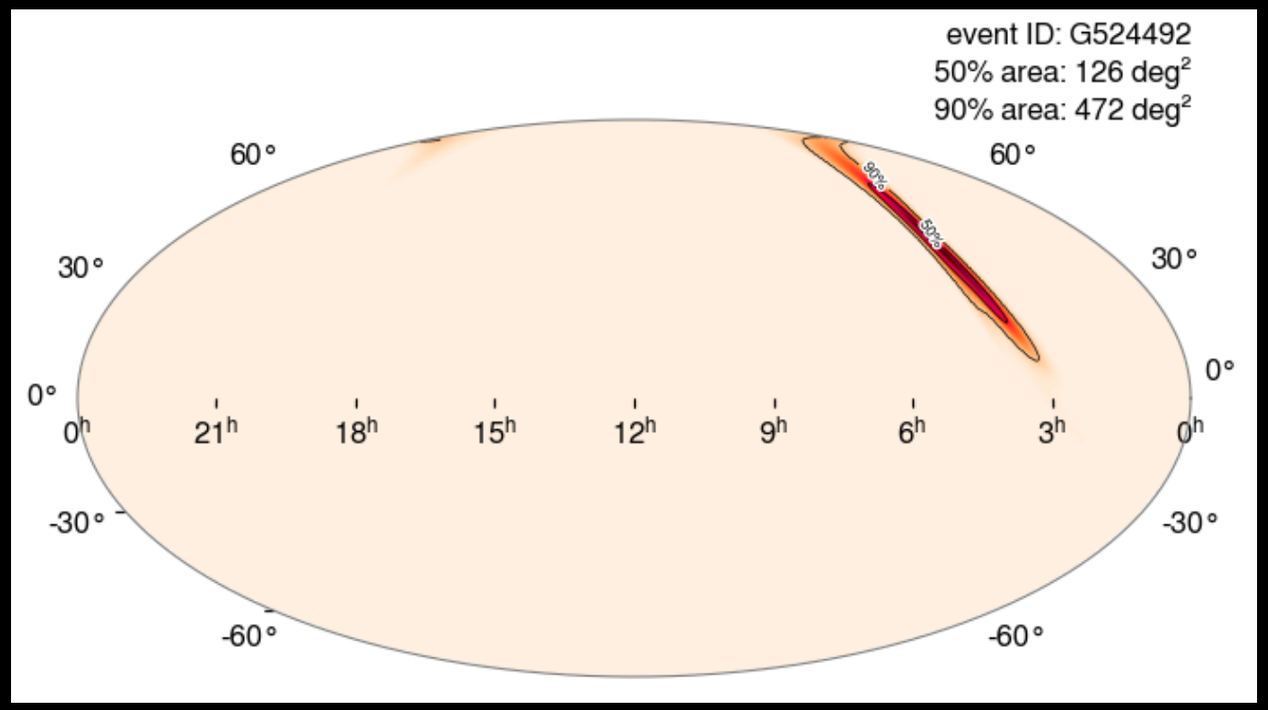


Image credit: LVK

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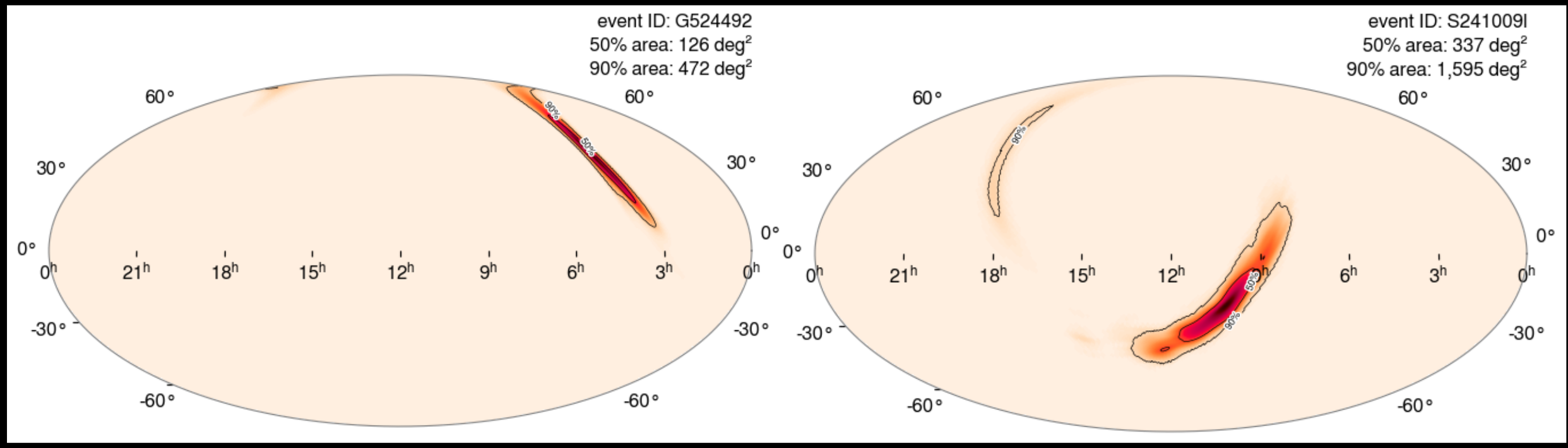
Dark siren: Statistically combine the redshifts of all possible galaxies



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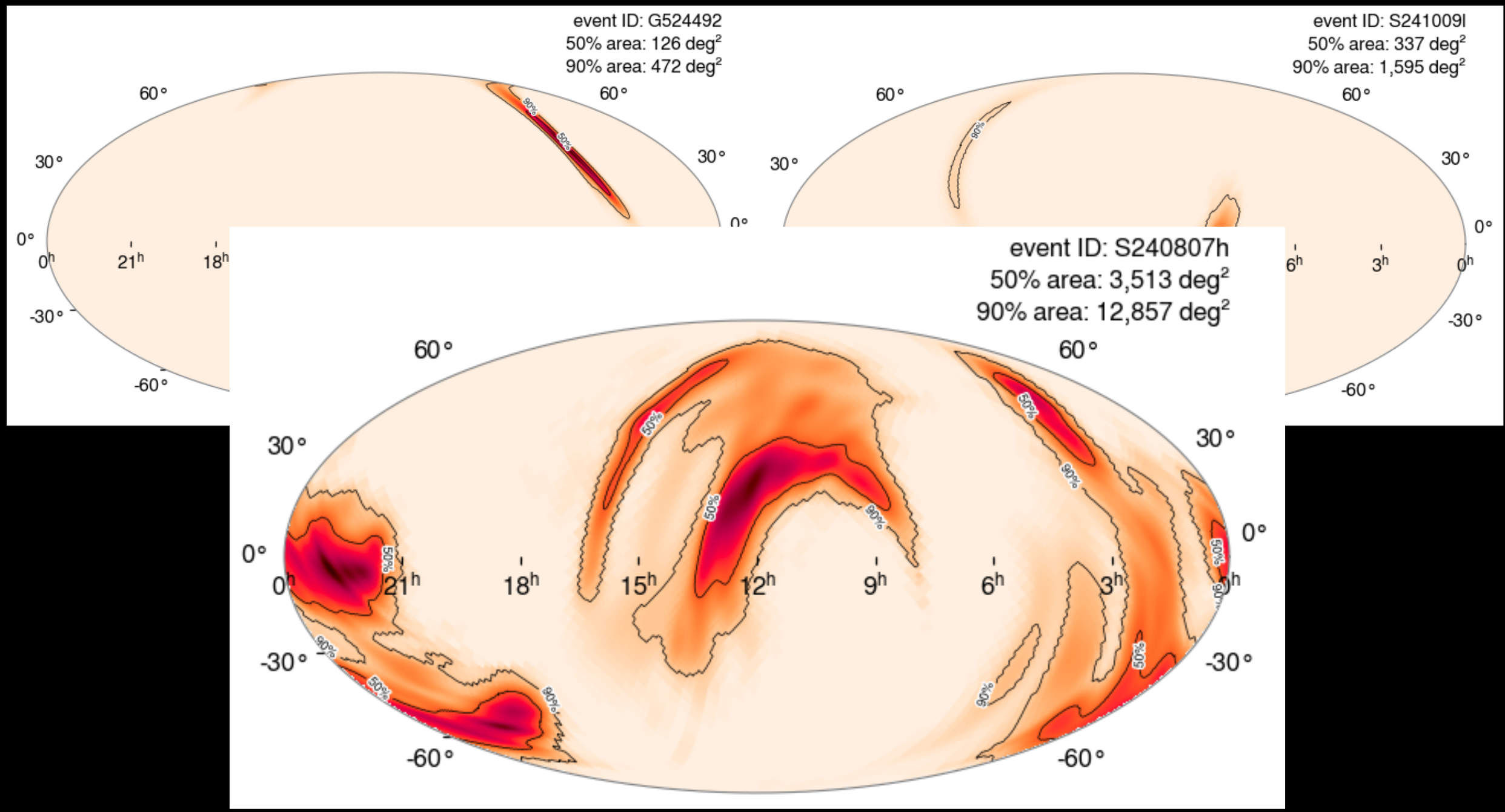

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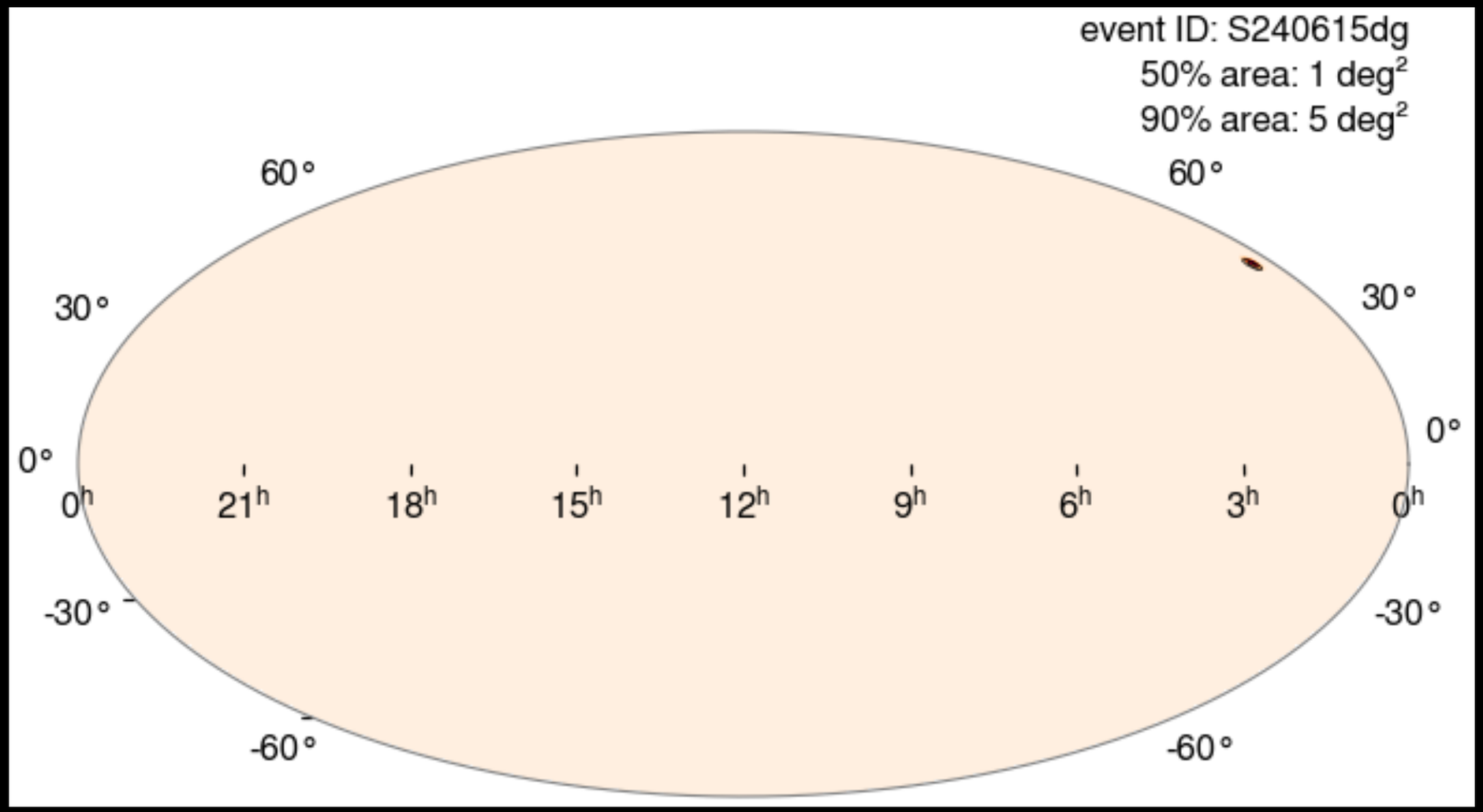

Hsin-Yu Chen / UT Austin

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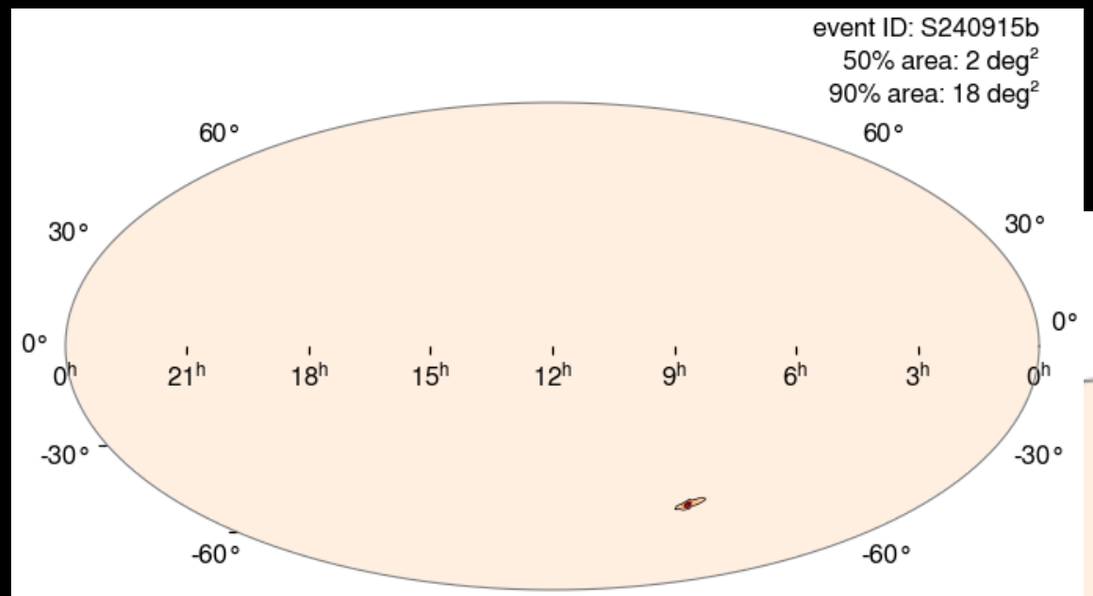

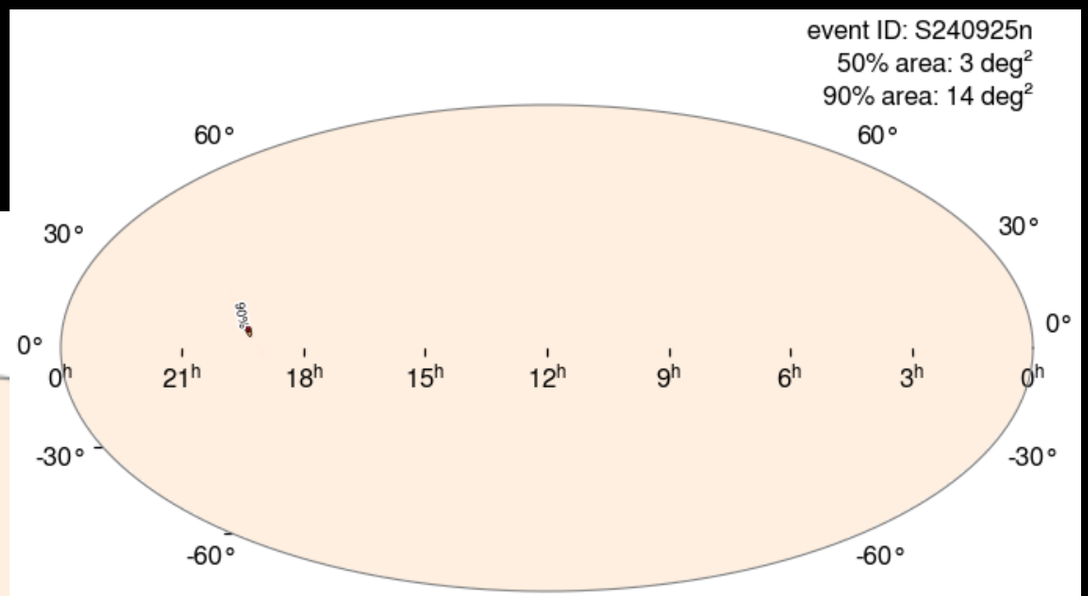

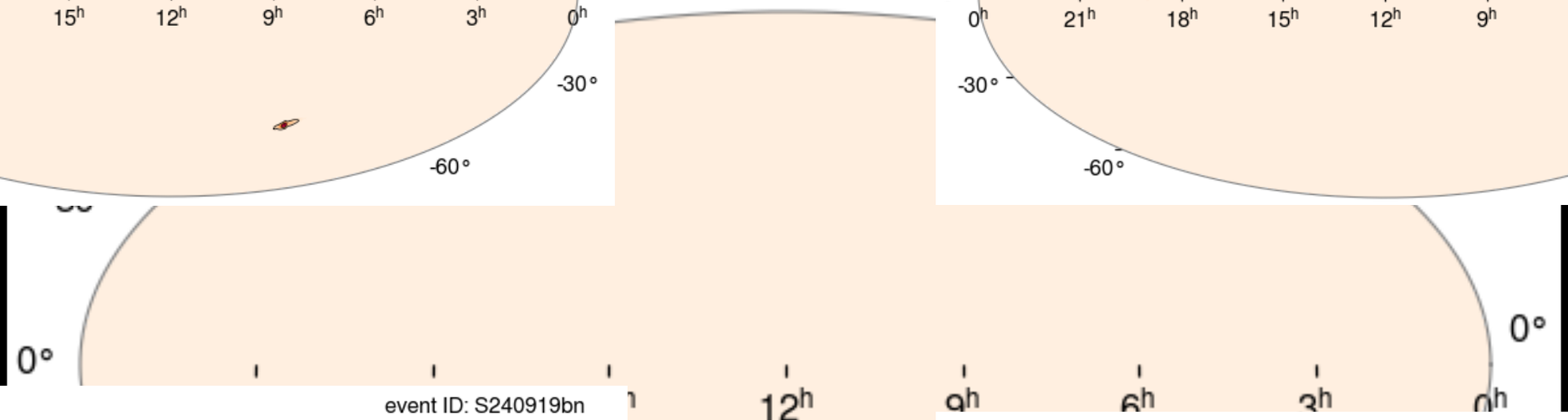

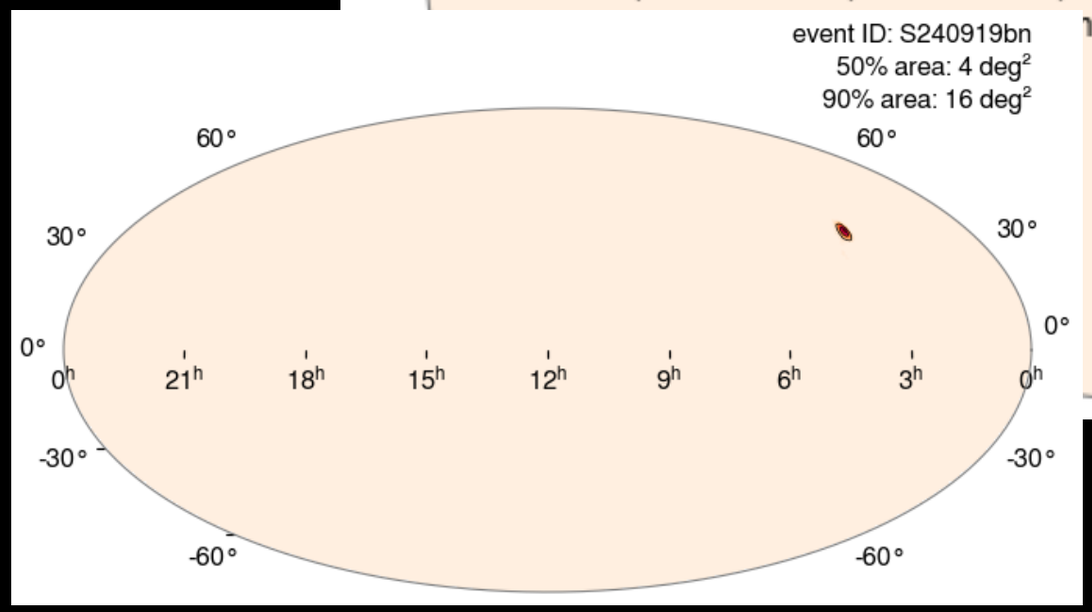

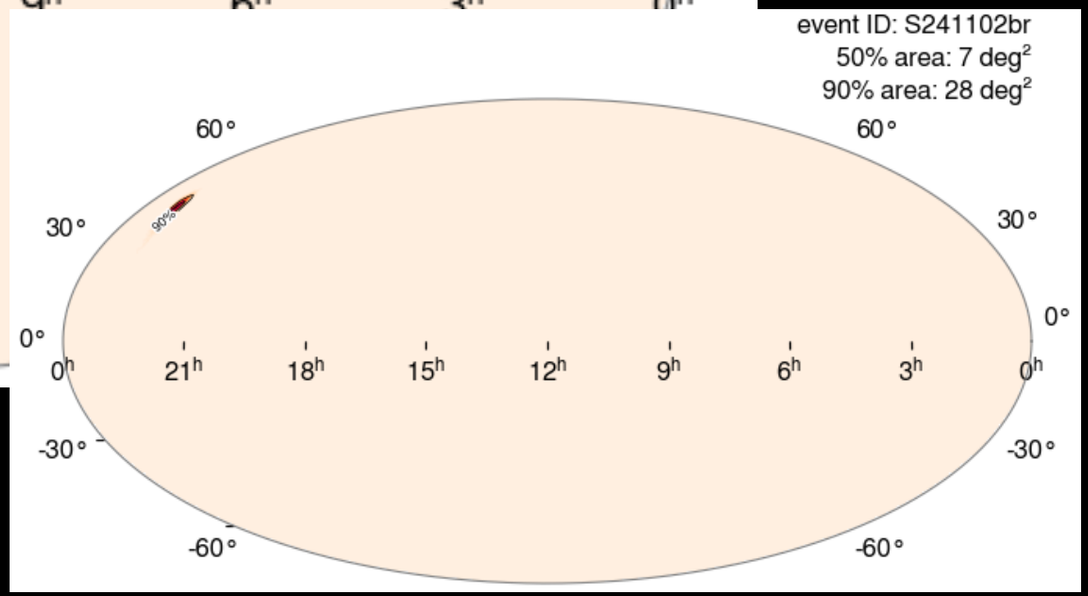

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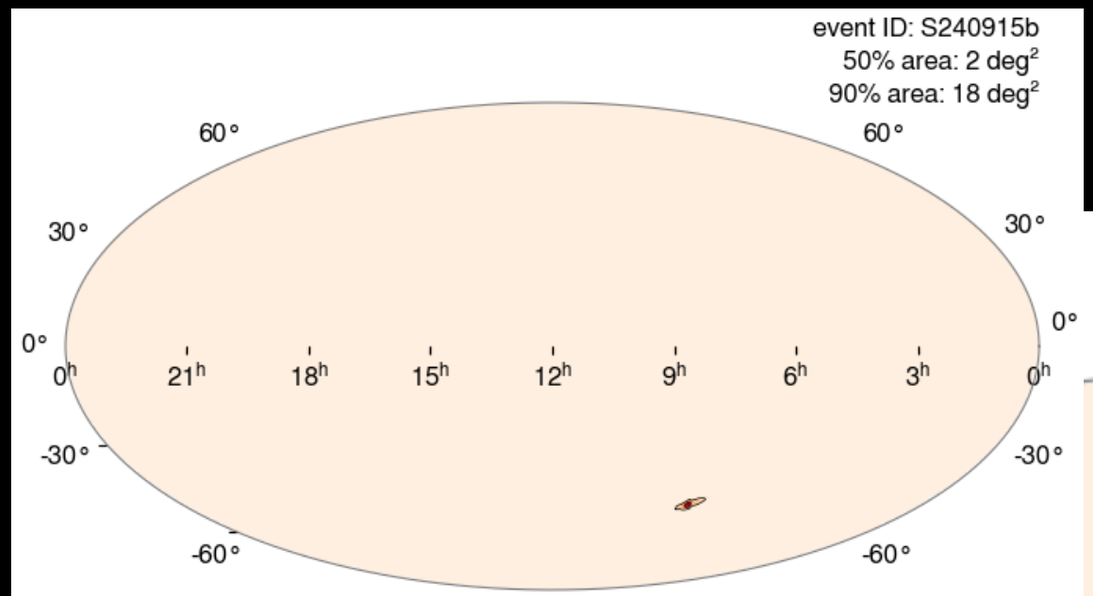
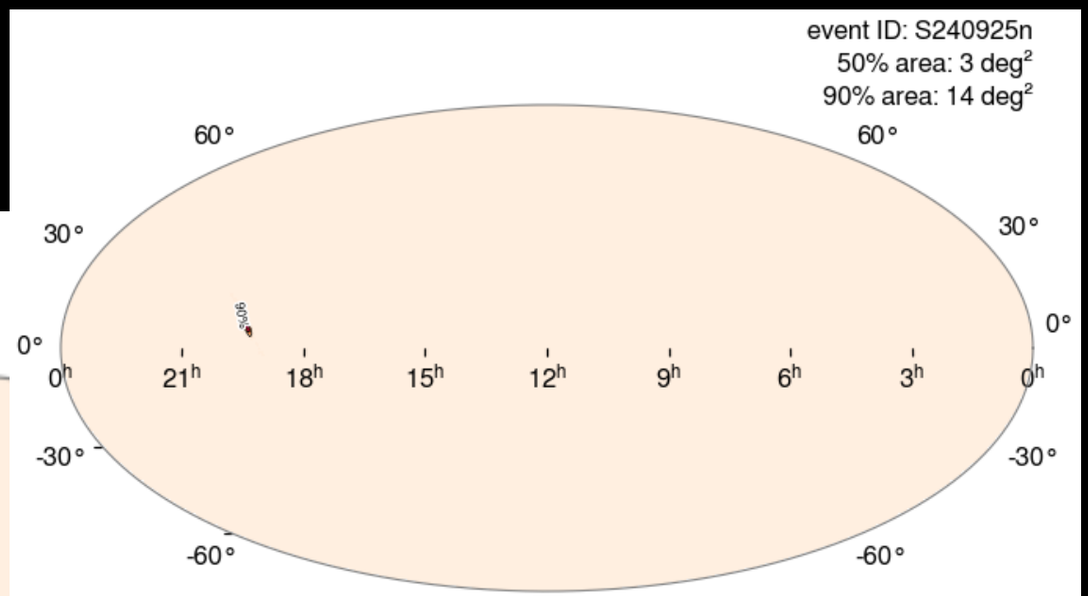
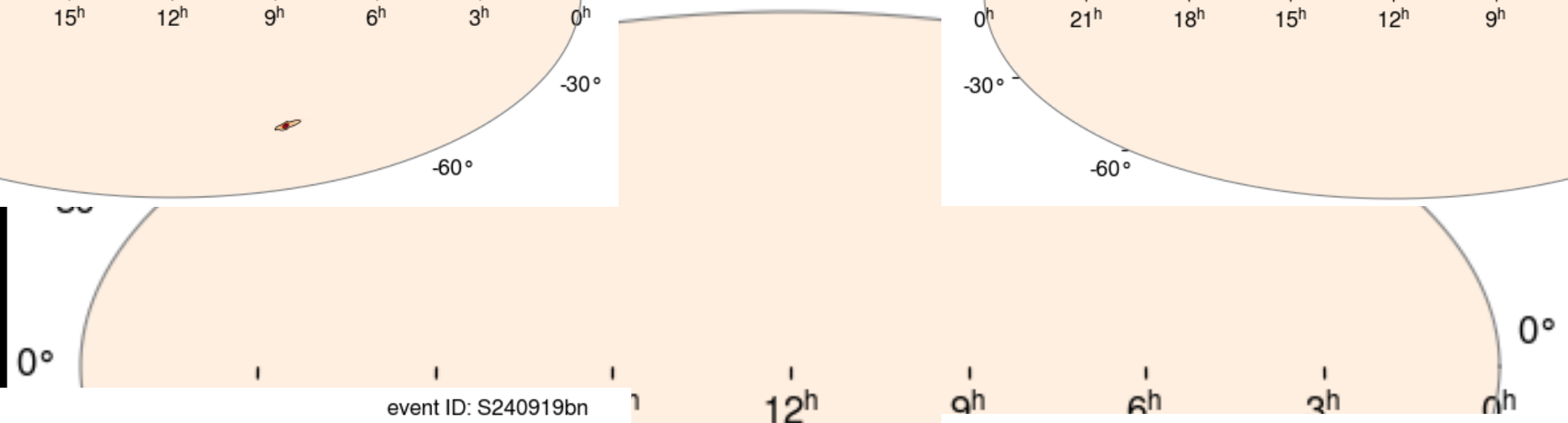
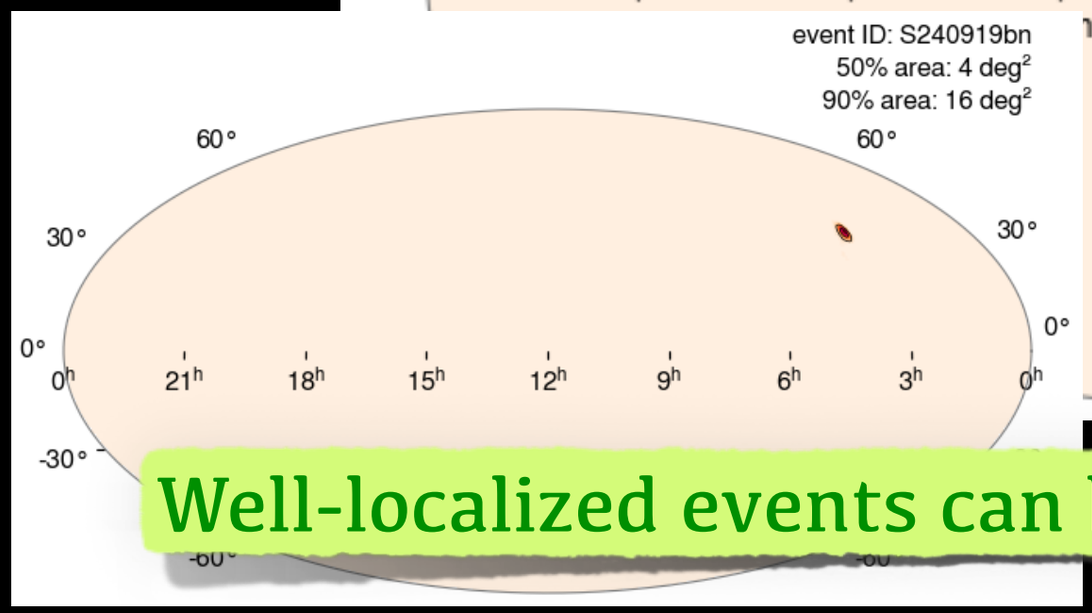
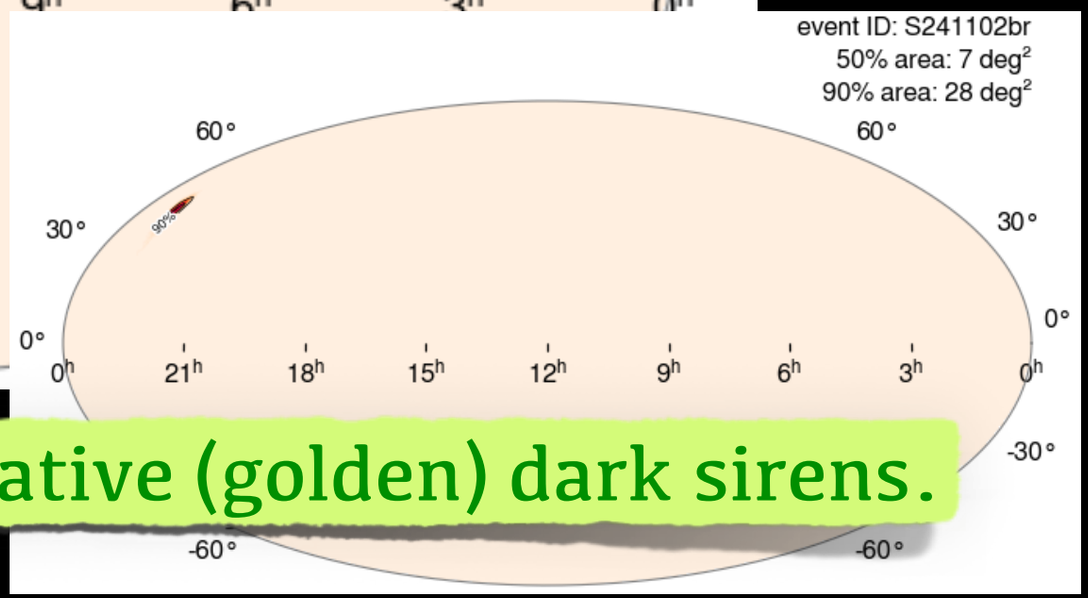










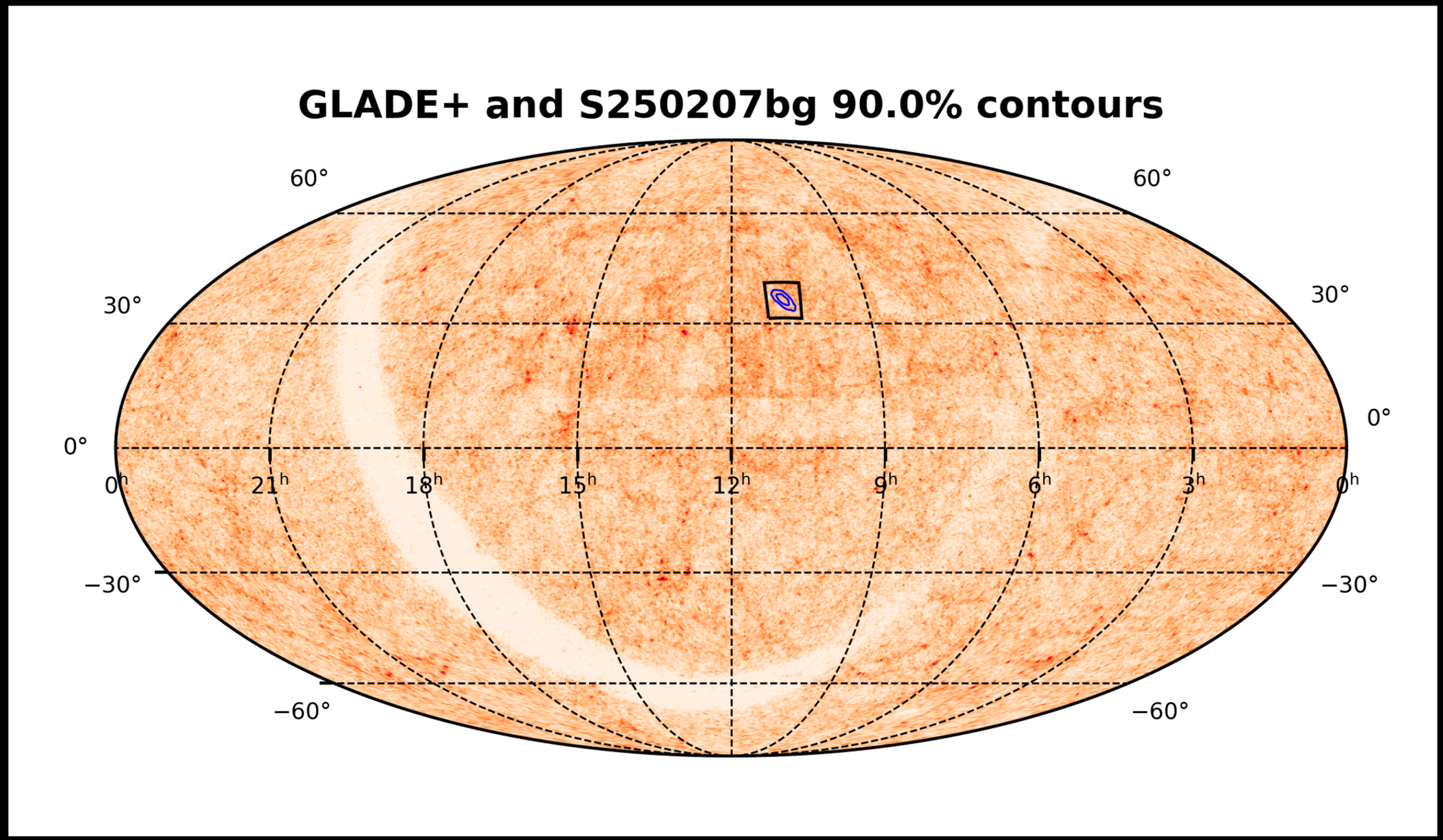
Well-localized events can be informative (golden) dark sirens.

Five BBH events in O3 and O4 were localized to $< 10^5\,\mathrm{Mpc}^3$

Five BBH events in O3 and O4 were localized to $< 10^5\,\mathrm{Mpc}^3$

<1000 galaxies

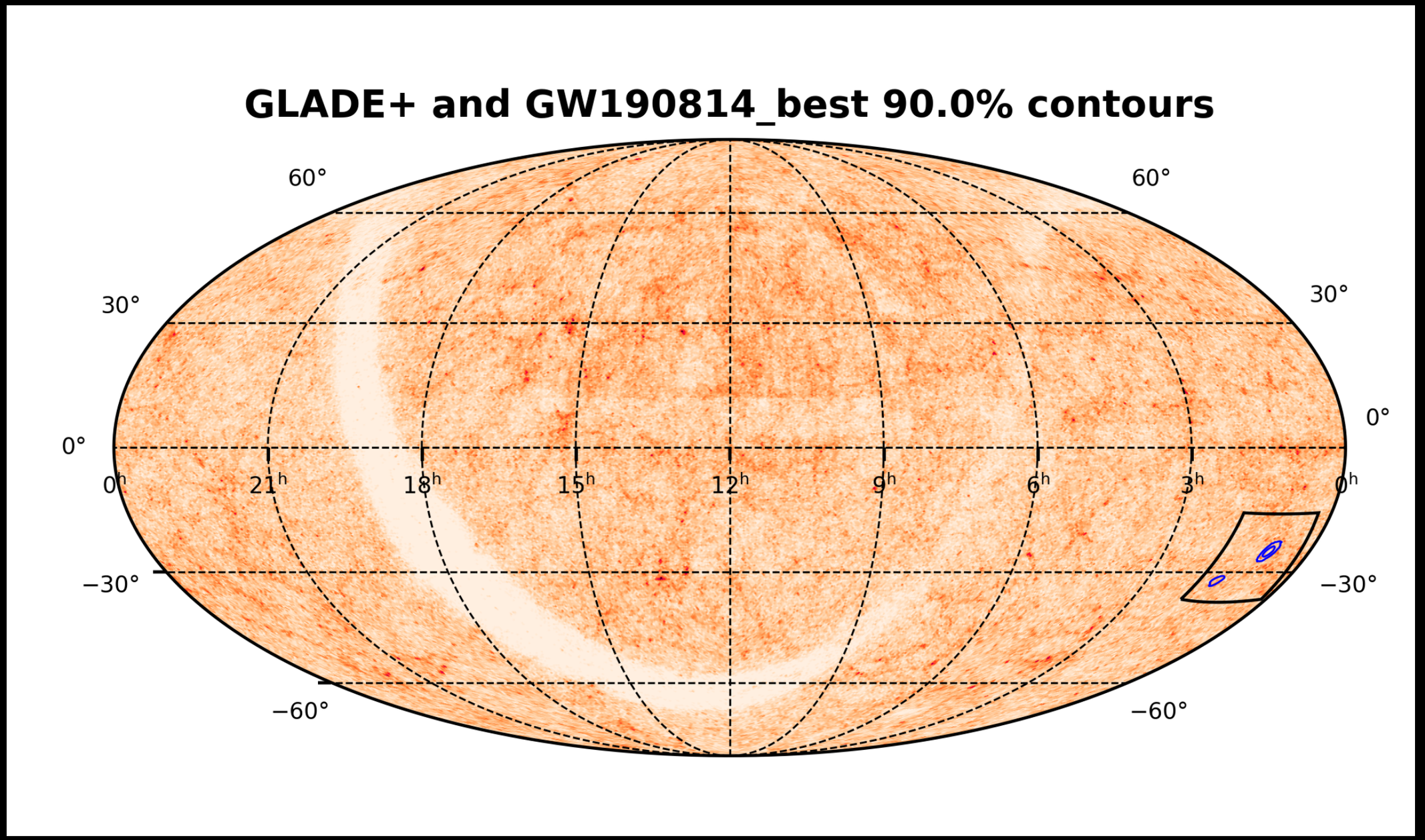
S250207bg



19 deg^2 /180 Mpc /18000 Mpc^3

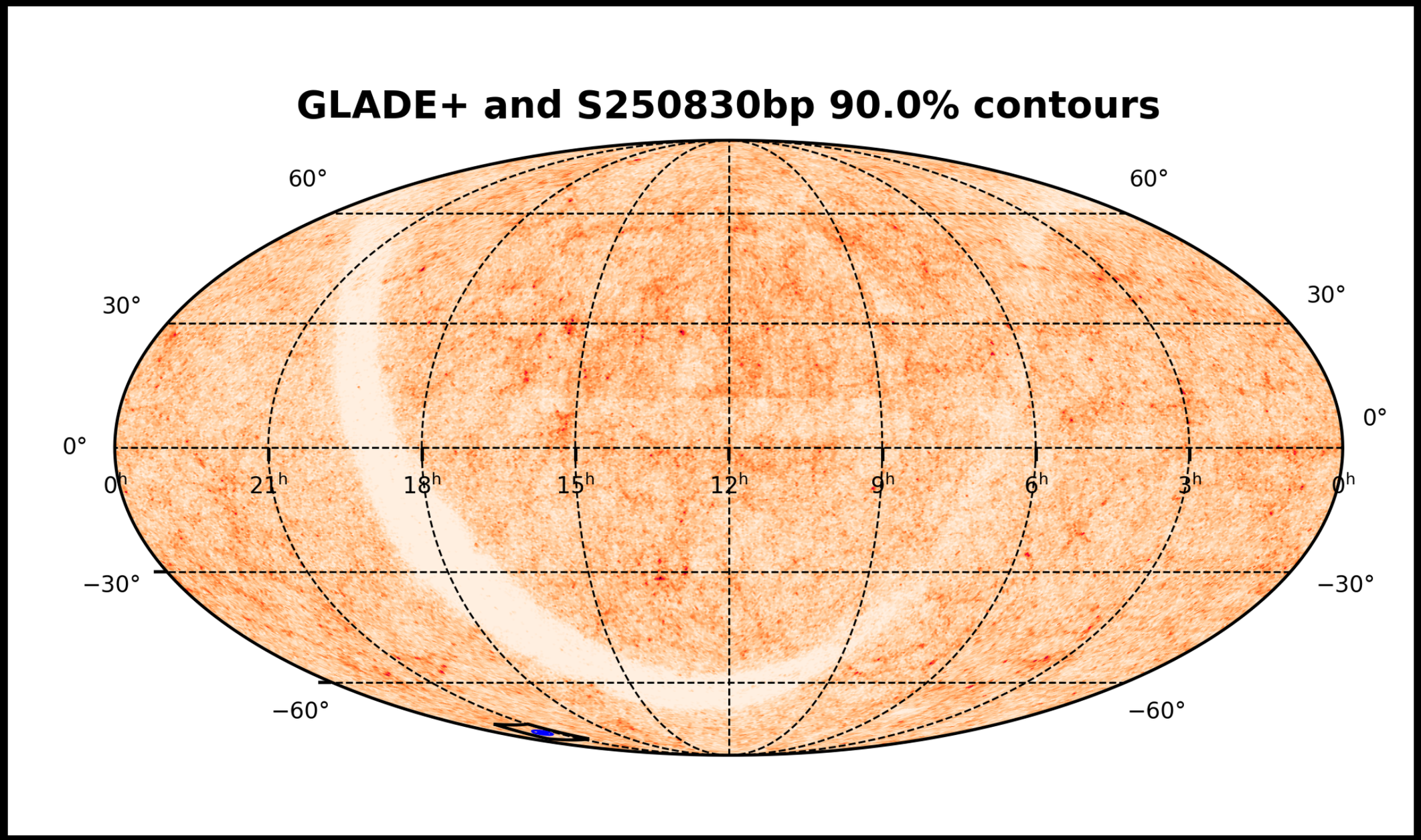
Hsin-Yu Chen / UT Austin

GW190814



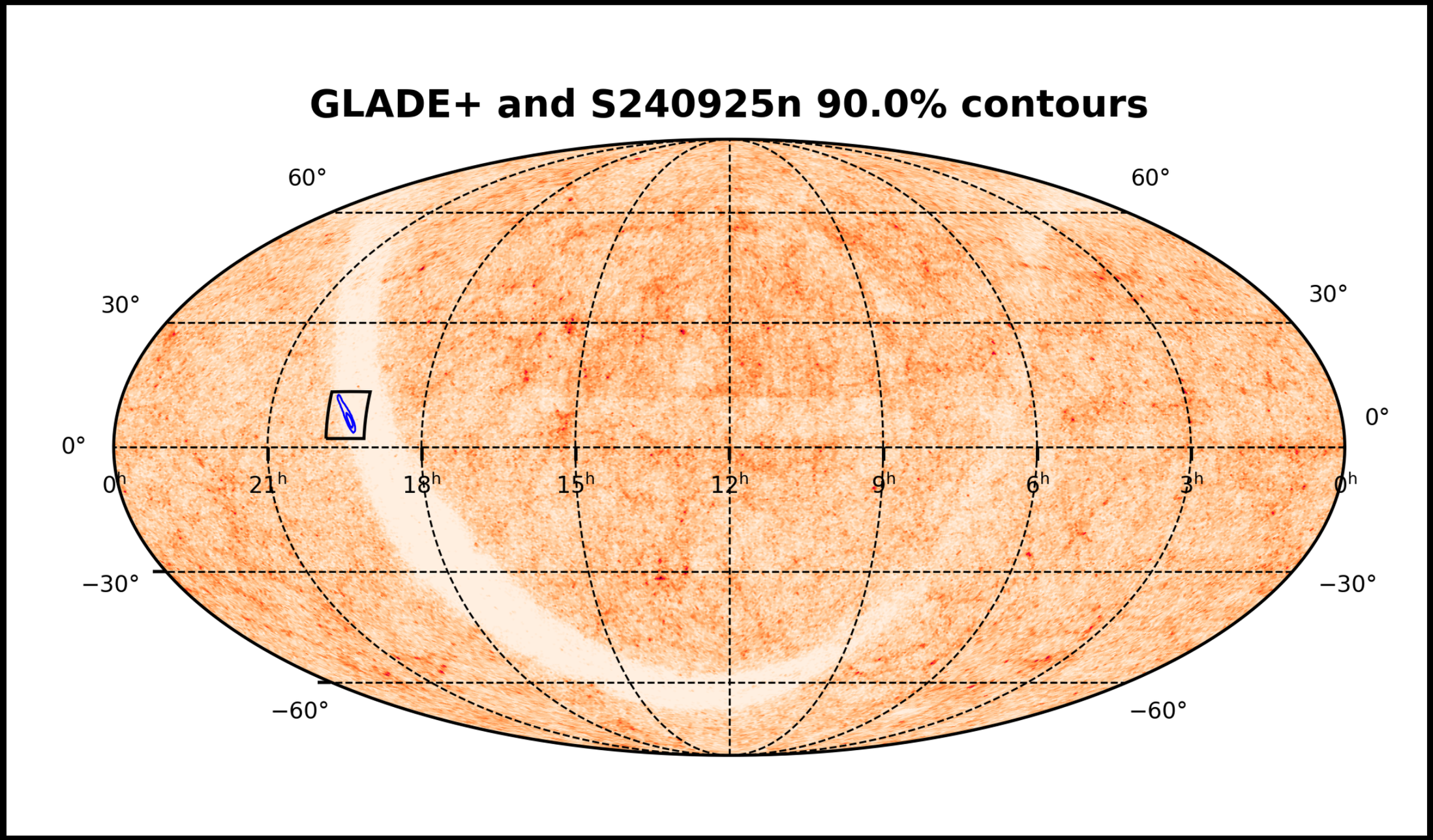
19 deg^2 /240 Mpc /24000 Mpc^3

S250830bp



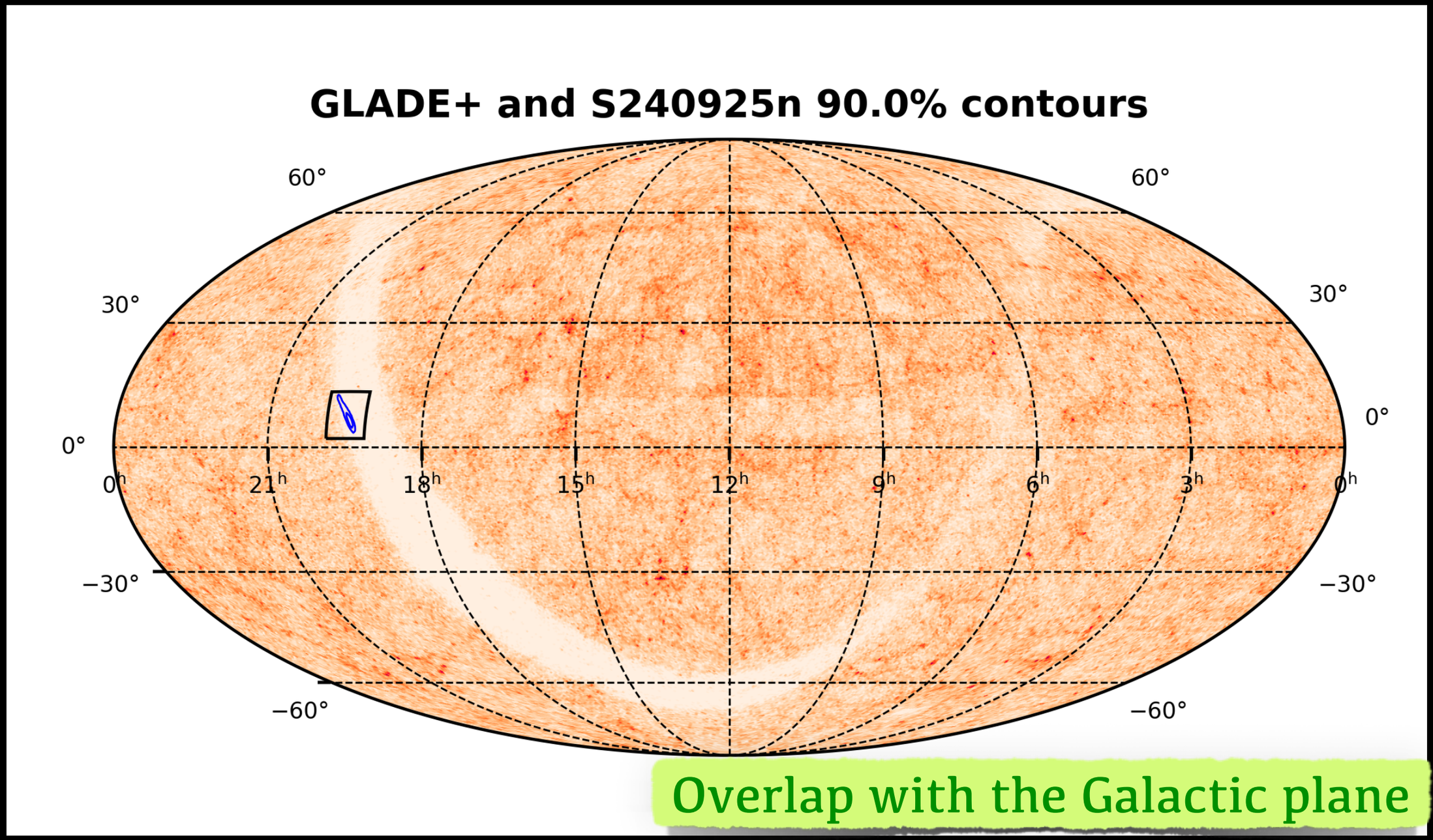
4 deg^2 /430 Mpc /33000 Mpc^3

S240925n



14 deg^2 /330 Mpc /77000 Mpc^3

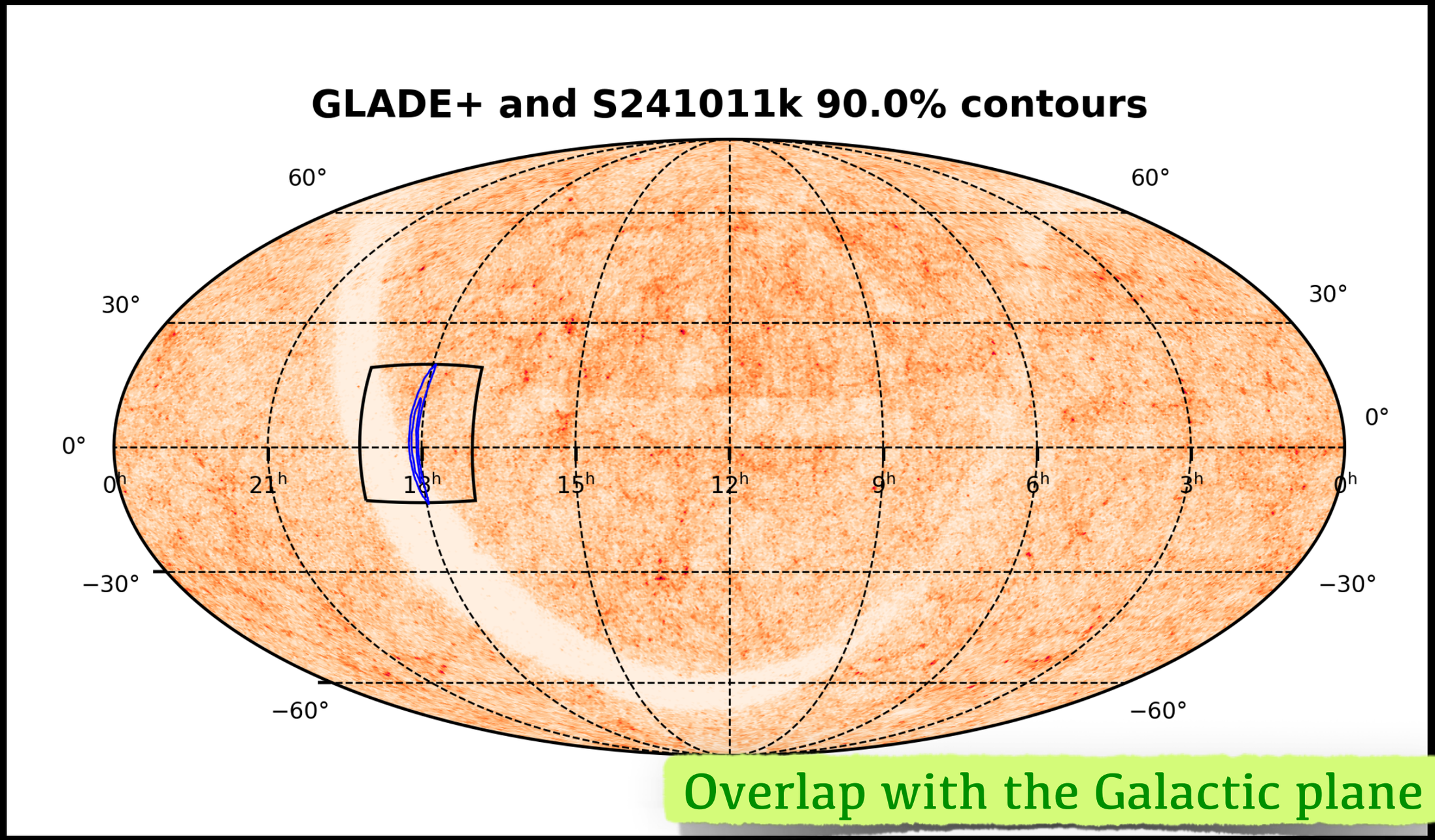
S240925n



Overlap with the Galactic plane

14 deg^2 /330 Mpc /77000 Mpc^3

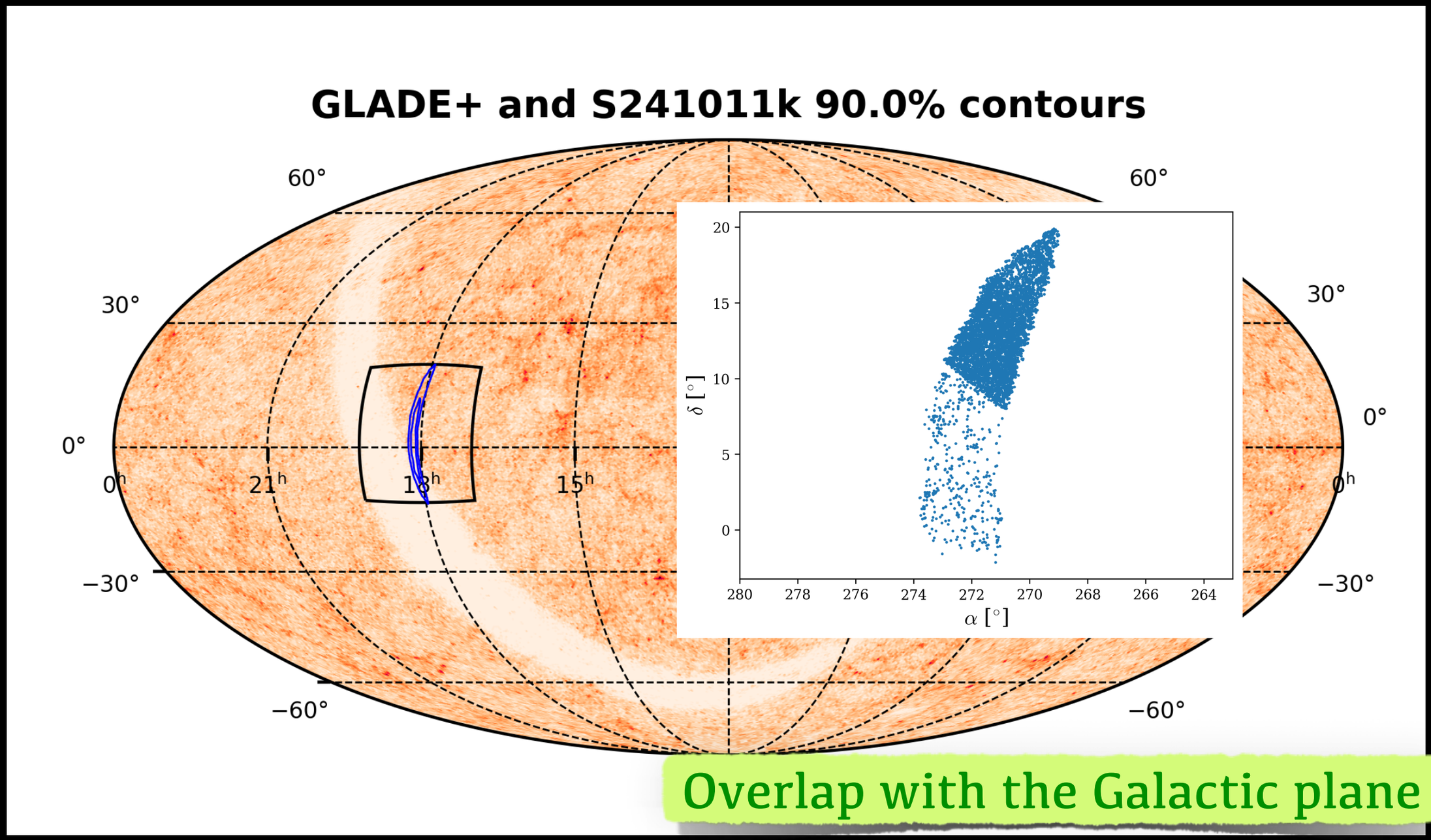
S241011k



Overlap with the Galactic plane

72 deg^2 /210 Mpc /100000 Mpc^3

S241011k



Overlap with the Galactic plane

72 deg^2 /210 Mpc /100000 Mpc^3

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Not all galaxies have an equal chance of hosting binary black hole mergers

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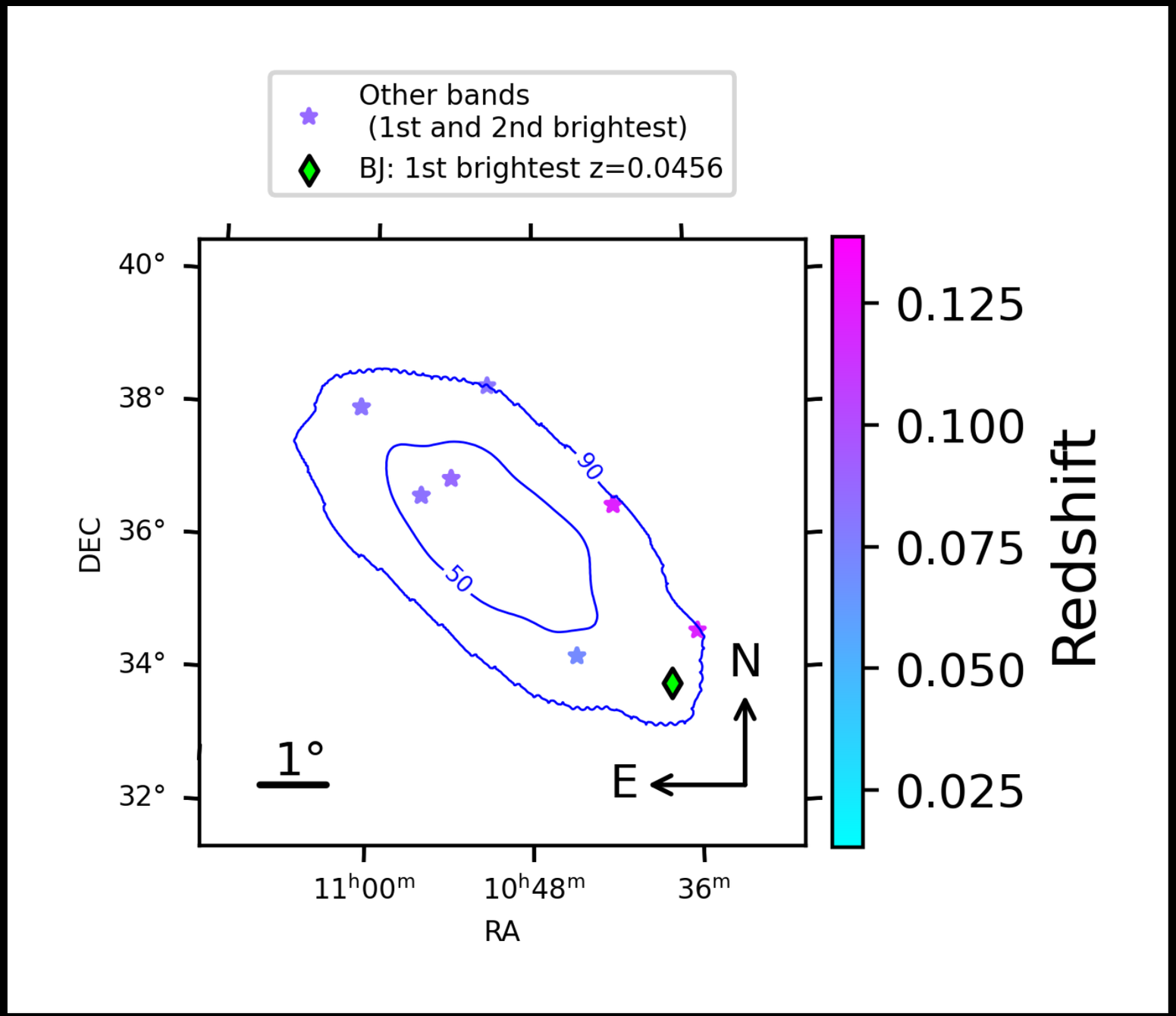
Brighter galaxies trace large scale structure and can serve as the tracers of the location of the host (cluster)

Not all galaxies have an equal chance
of hosting binary black hole mergers

Brighter galaxies trace large scale
structure and can serve as the tracers
of the location of the host (cluster)

No incompleteness issue
since they are bright

S250207bg



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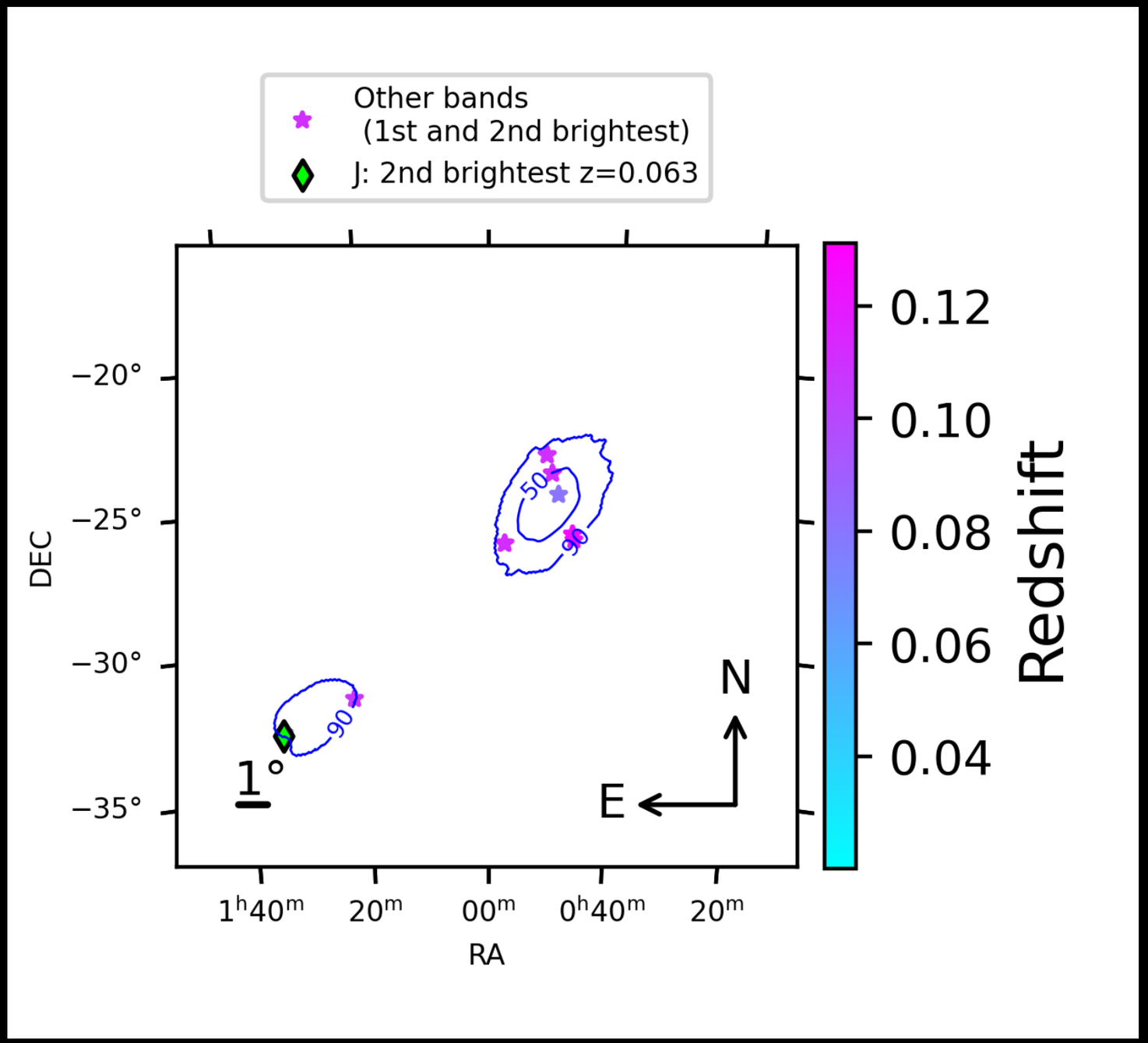
GW190814



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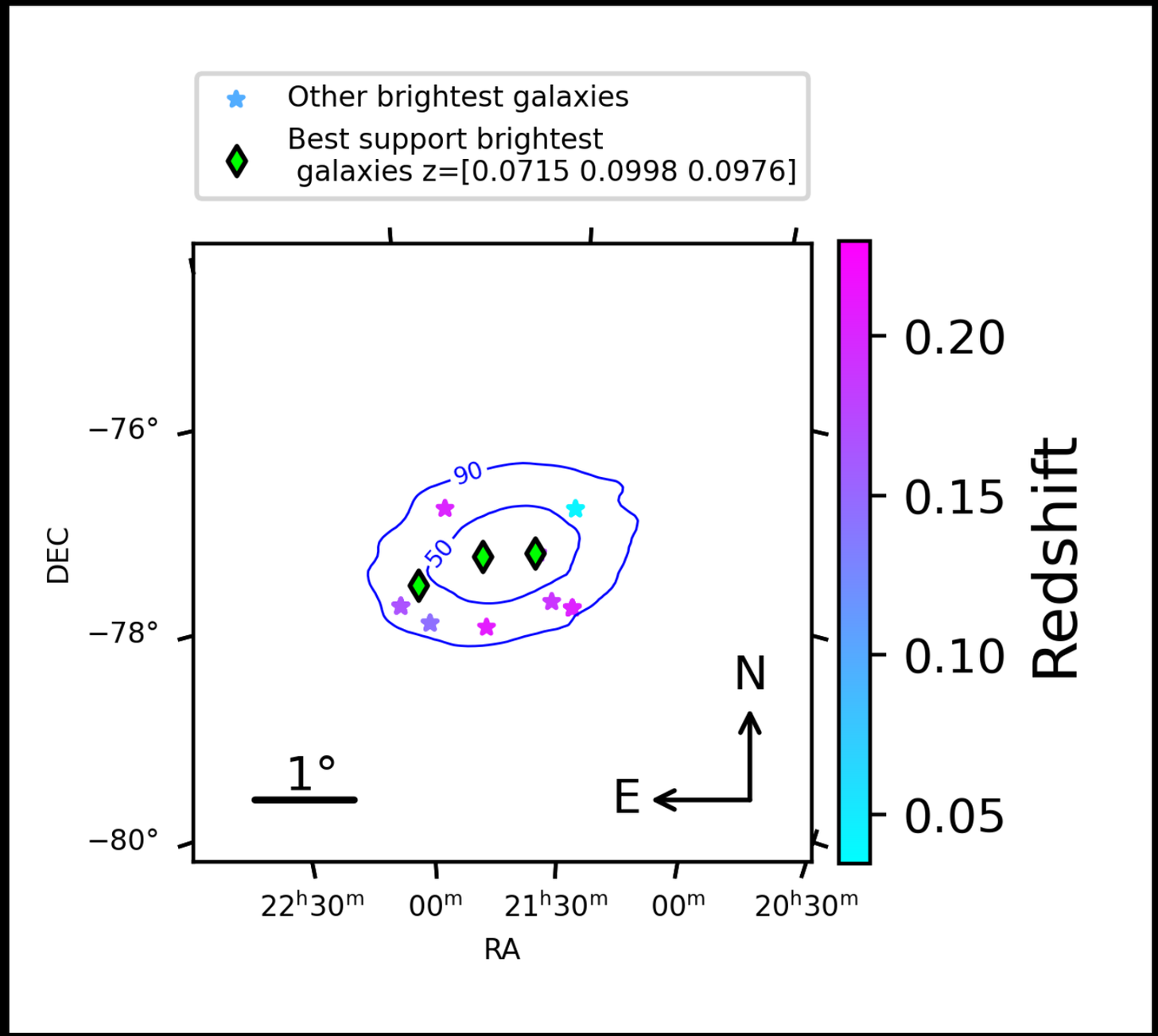
S250830bp



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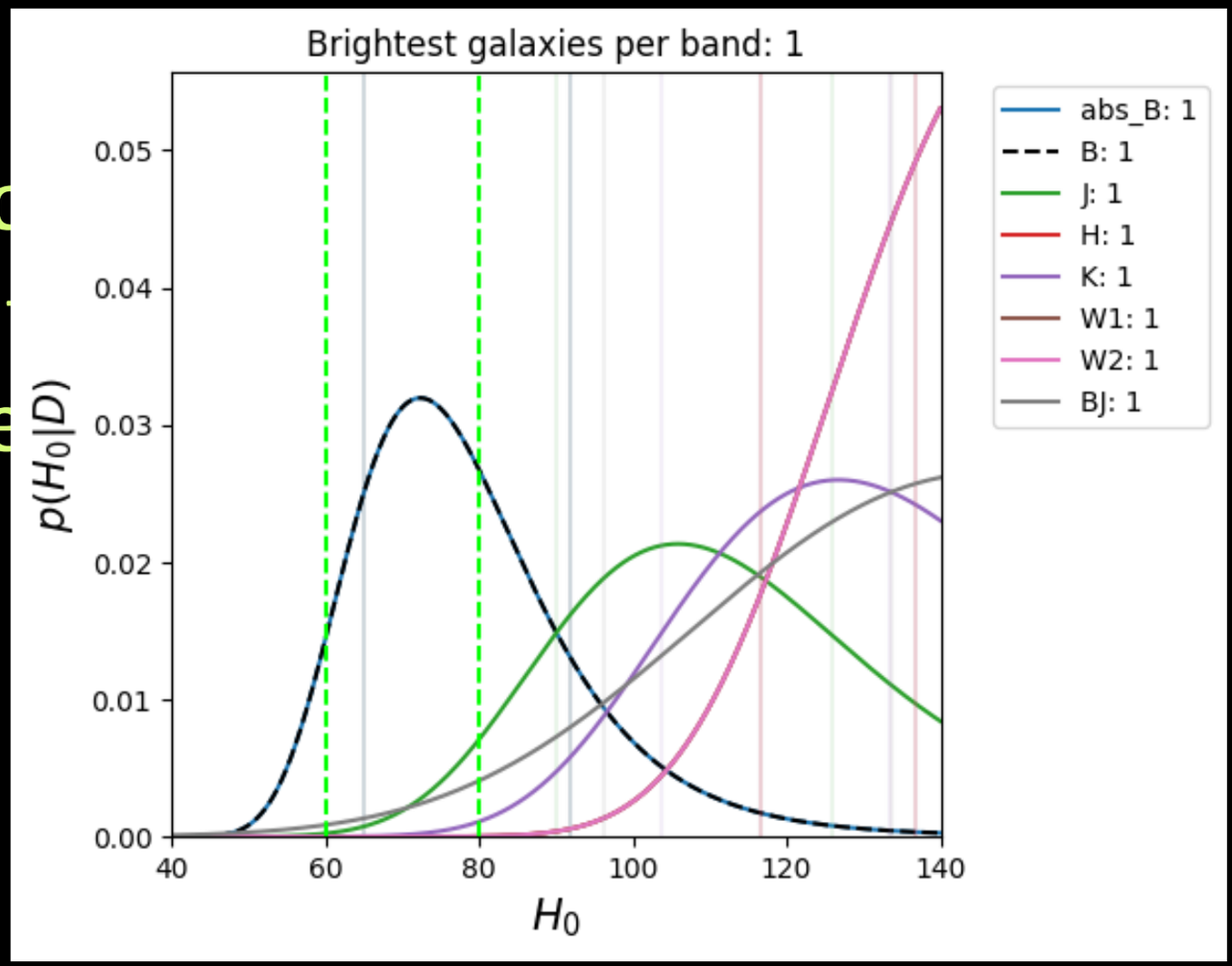
Among these structure tracers

Among these structure tracers

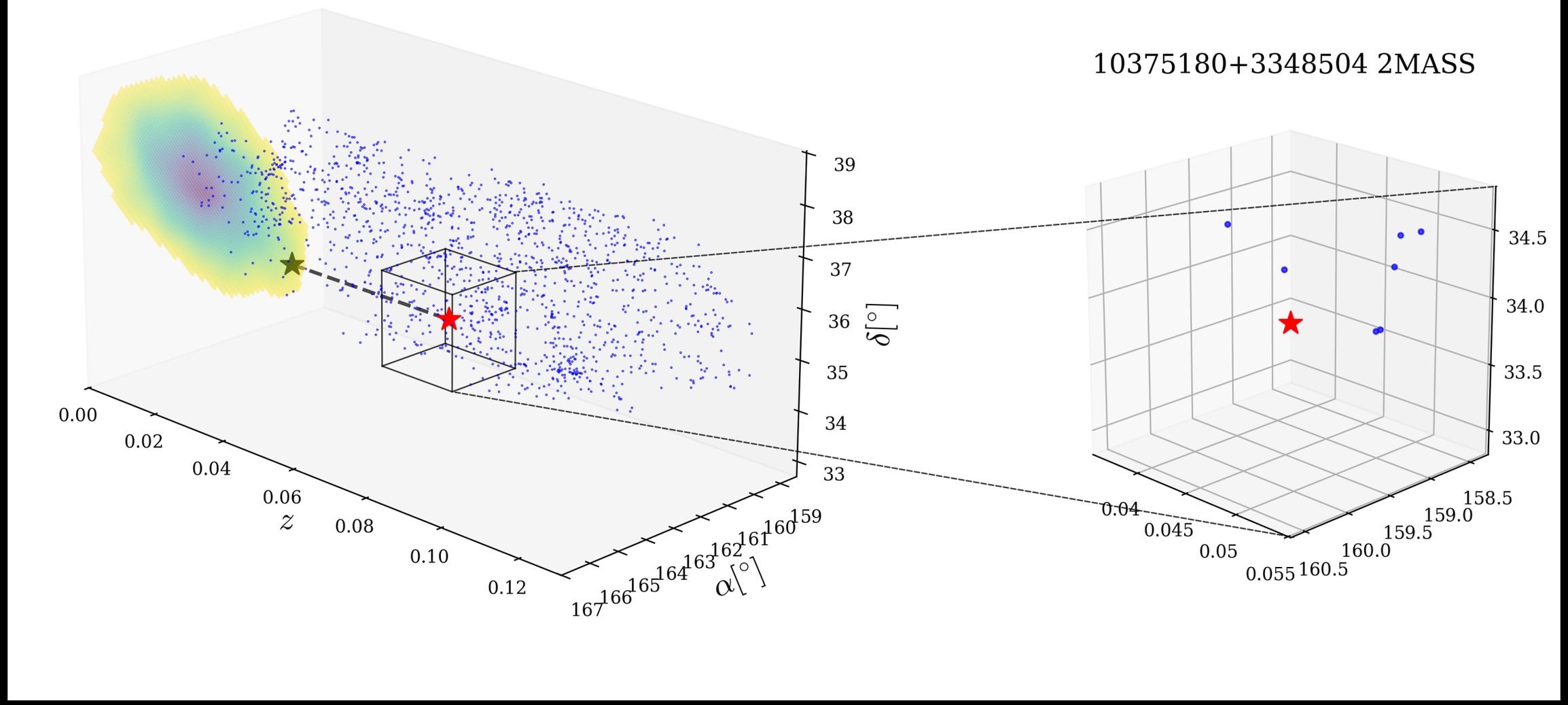
The chance that they also lie at redshifts that give reasonable H_0 is low—unless they are the real hosts.

Among these structure tracers

The chanc
redshifts
low—unle



S250207bg



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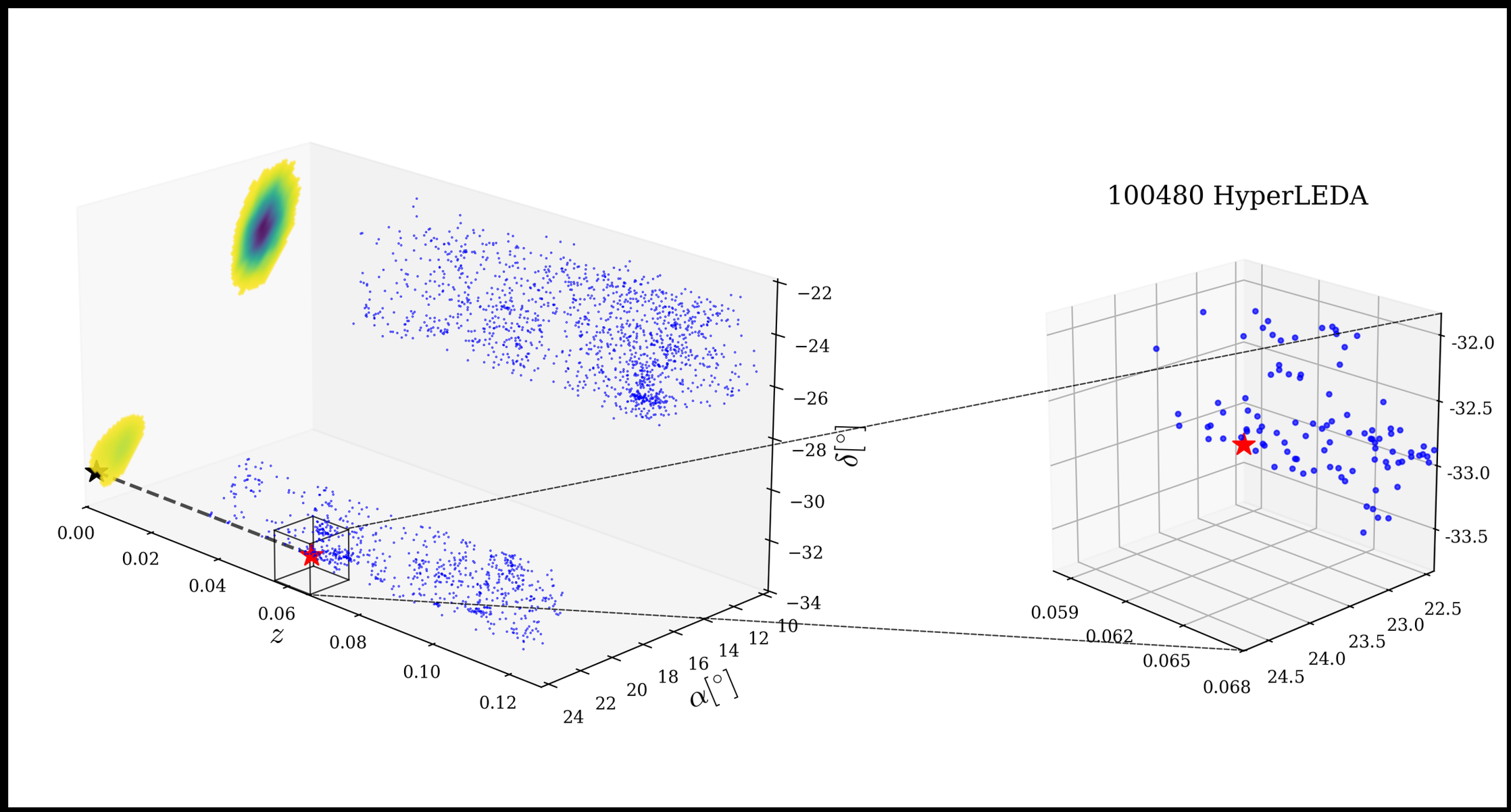
GW190814



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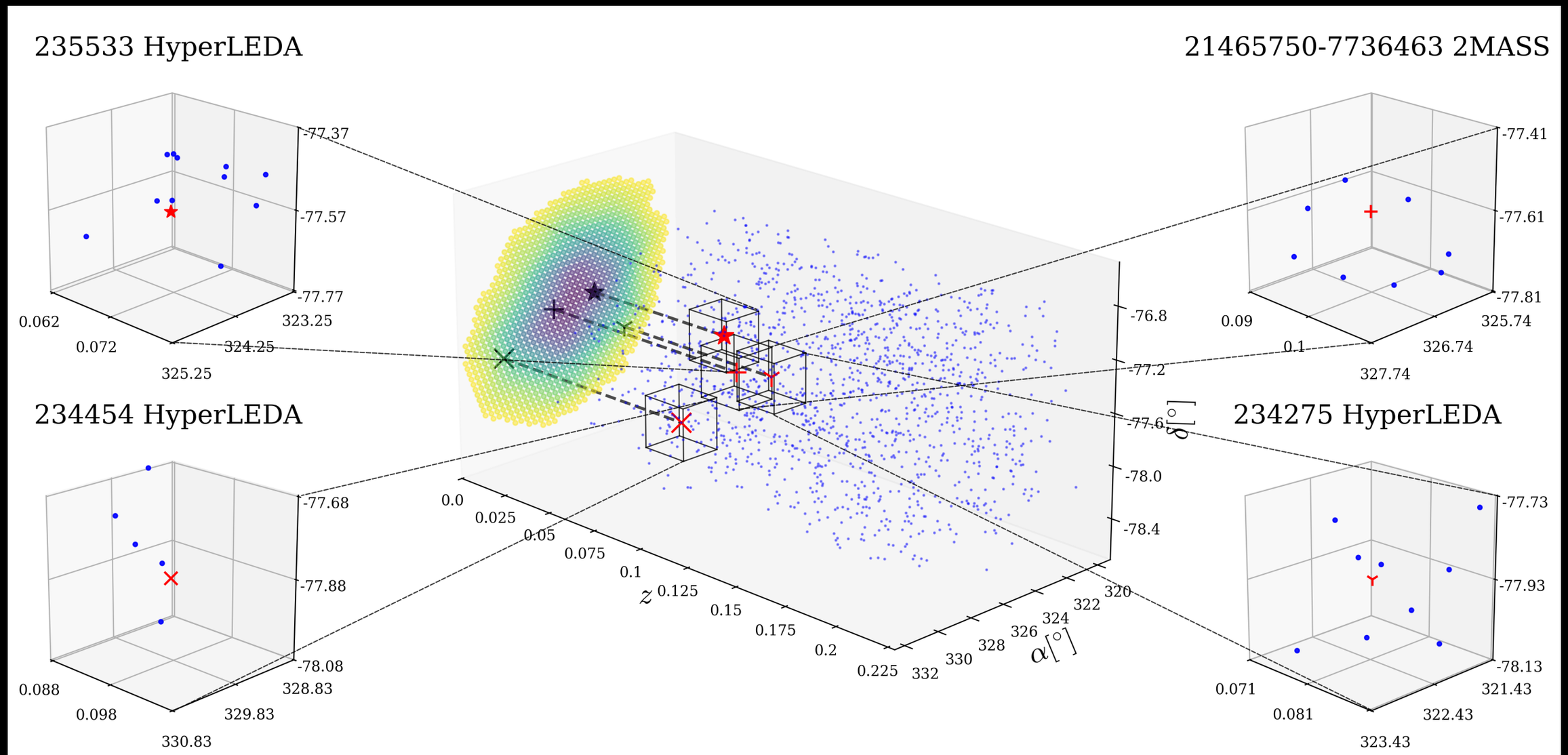
S250830bp



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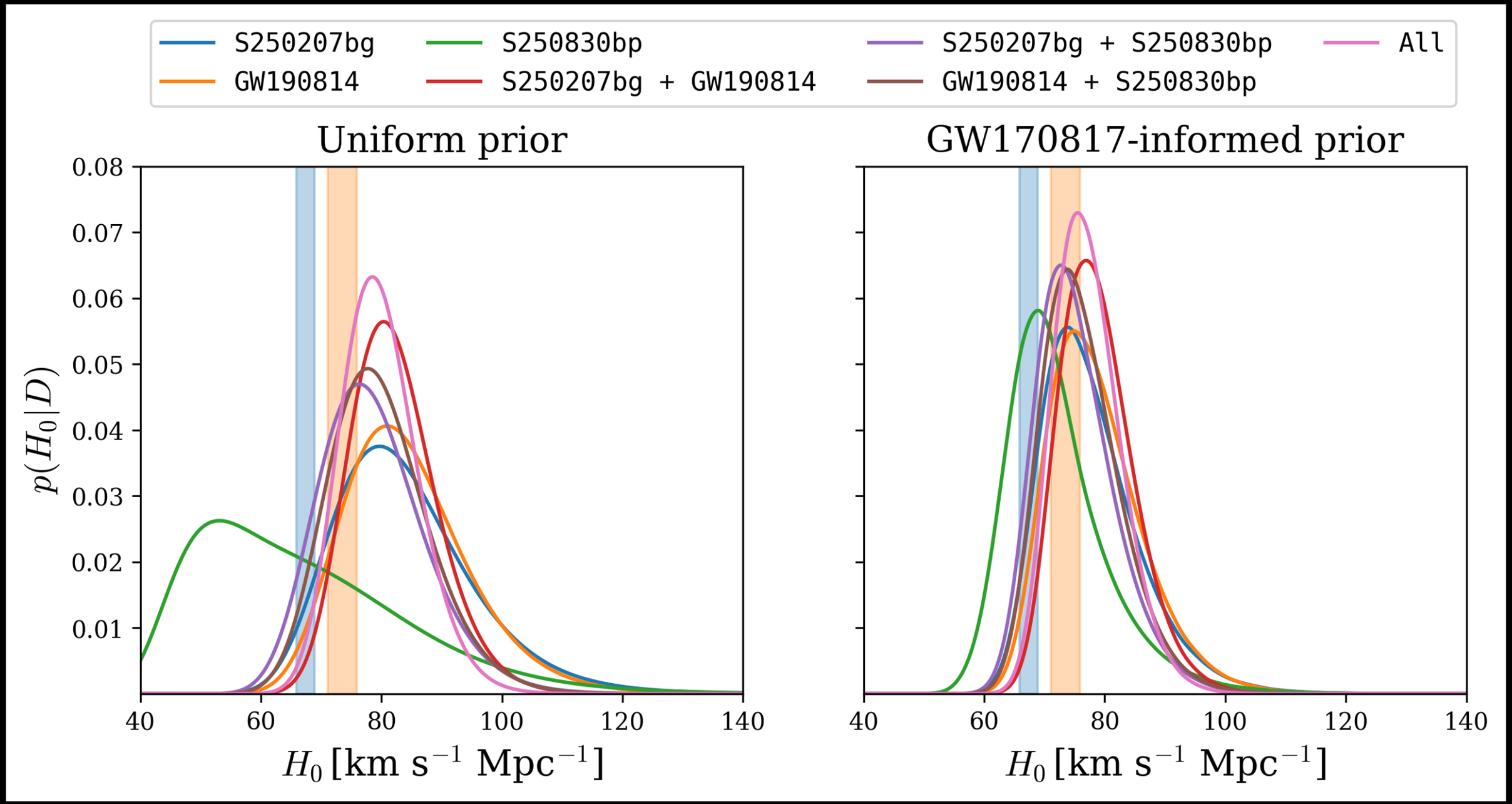
If assuming they are the real host (clusters)



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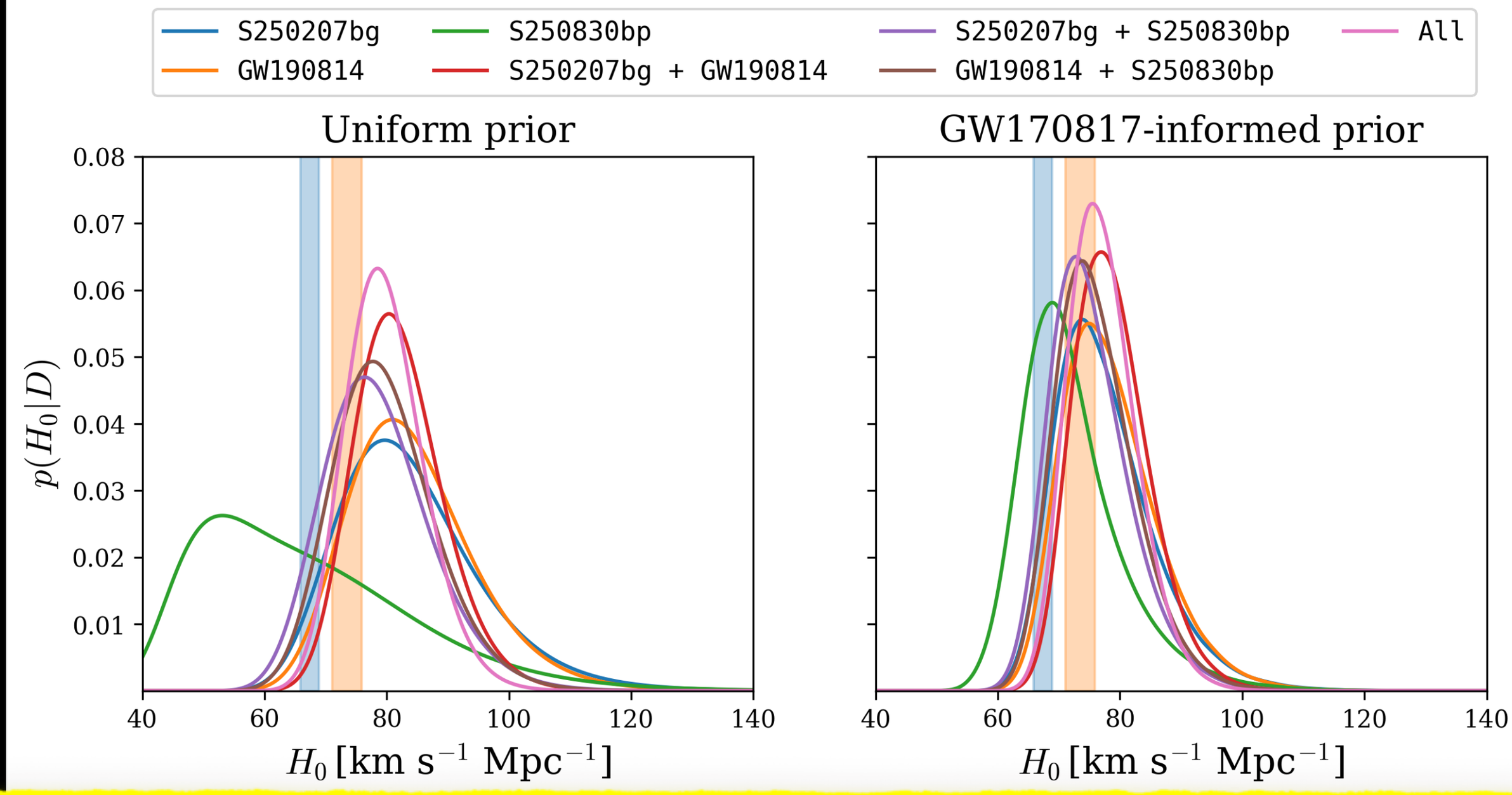

~8% measurements. More precise than GWTC-5 spectral+dark sirens.

Some more thoughts

Some more thoughts

Binary black hole mergers may trace dimmer galaxies instead

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Then it’s more likely we found NO galaxy association.

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Then it’s more likely we found NO galaxy association.

The fact that we found association for all three events may already suggest otherwise.

Some more thoughts

Some more thoughts

AGN may contaminate the results.

Some more thoughts

AGN may contaminate the results.

The results don’t change after the removal of AGNs.

Some more thoughts

Some more thoughts

Which color band to search for hosts?

Some more thoughts

Which color band to search for hosts?

We searched in all different bands.

Summary

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-A new standard siren approach:

1. Well-localized events
2. Bright galaxies
3. Reasonable H_0 range

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-A new standard siren approach:

1. Well-localized events
2. Bright galaxies
3. Reasonable H_0 range

-Joint inference of H_0 and host properties (potentially with mass of the system taken into account).