Title: Can LIGO Detect Daylight Savings Time?

Speakers: Reed Essick

Collection/Series: Charting the Future Symposium

Subject: Cosmology, Particle Physics, Strong Gravity

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Abstract:

An unavoidable part of studying astrophysics based on catalogs of detected events is quantifying the probability of detecting different types of events. I will briefly discuss the types of design considerations that go into constructing such estimates and how they will scale with larger catalog sizes. I will also introduce the wide variety of uses for such data products, including uncovering unexpected features within the data caused by the fact that humans build and operate the detectors.

Can LIGO Detect Daylight Savings Time?

Reed Essick
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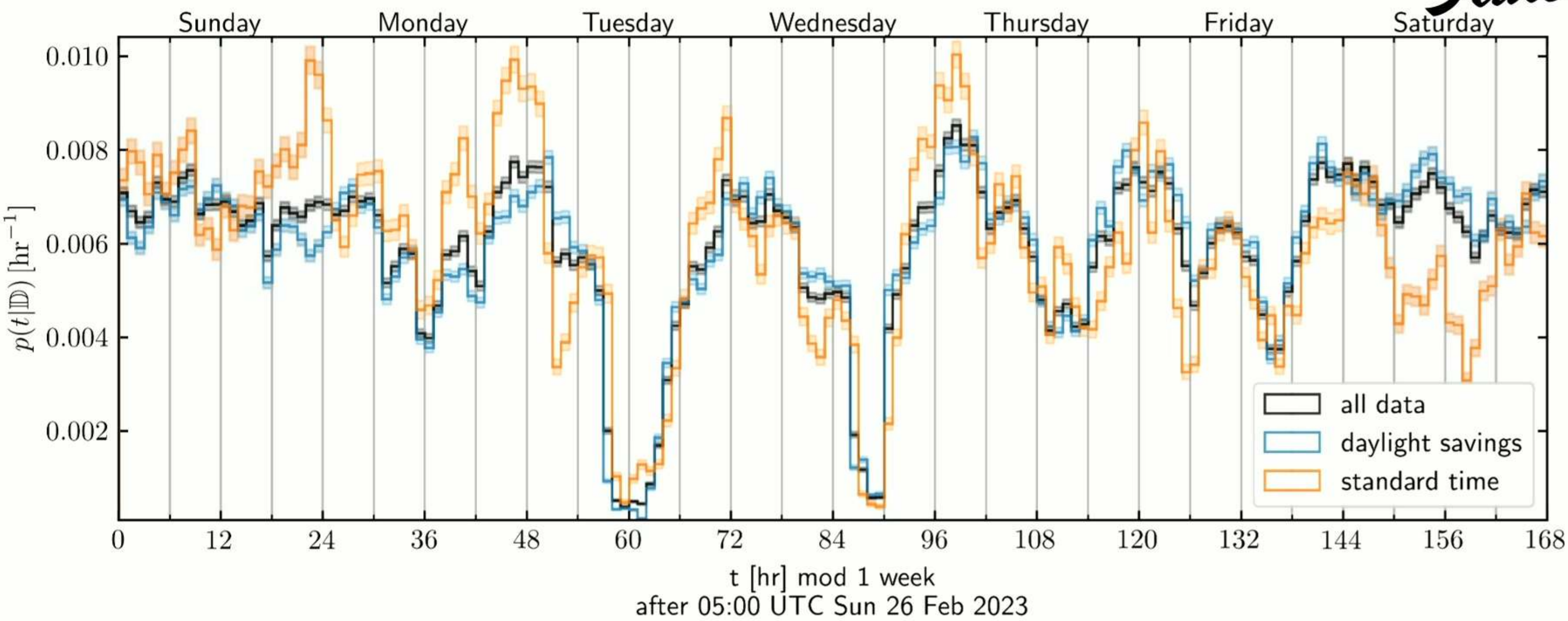
Slides



Outline

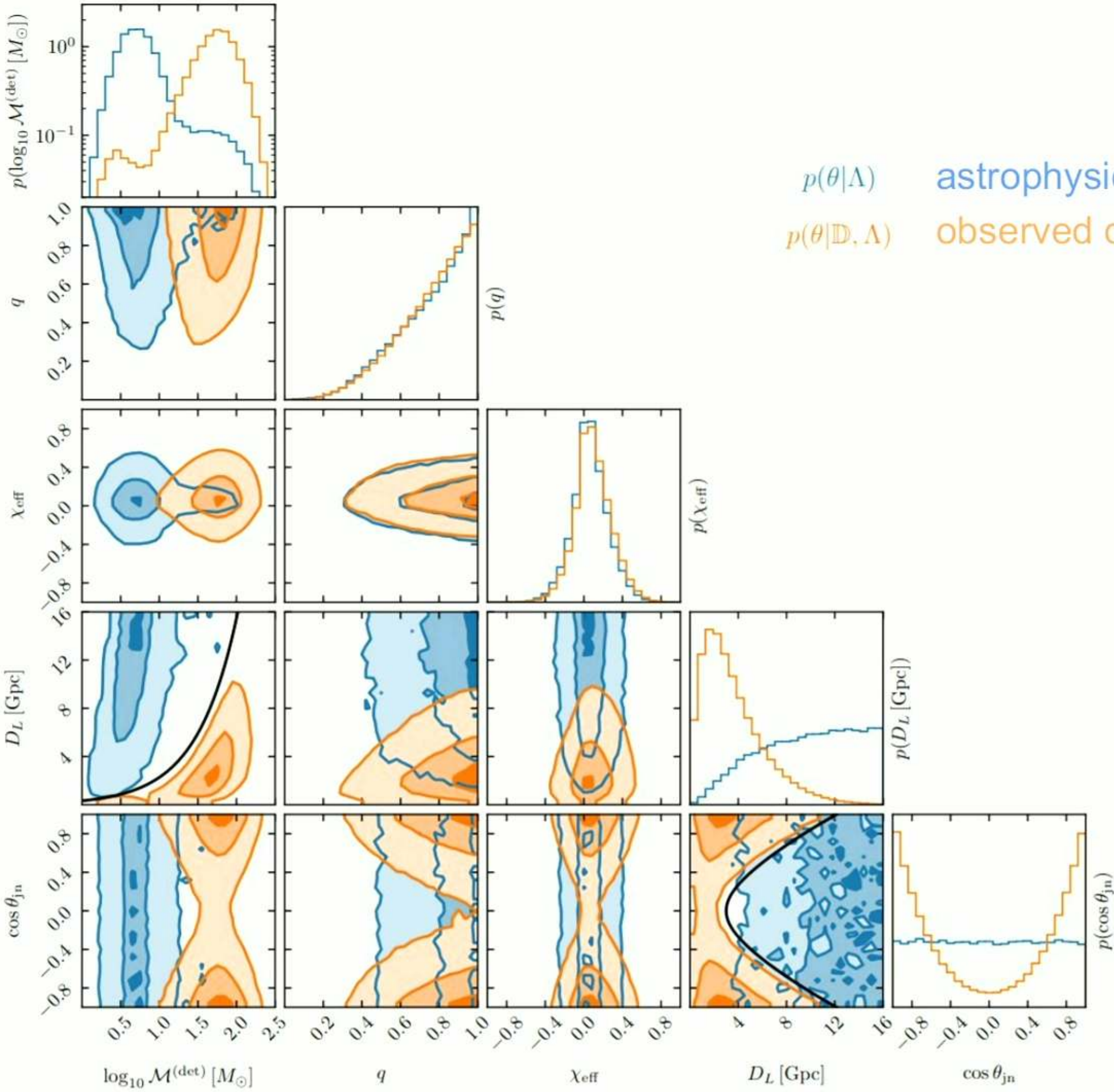
Why?

How?

What?

Why?

Essick+ (2025)



$p(\theta|\Lambda)$ astrophysical distribution

$p(\theta|\mathbb{D},\Lambda)$ observed distribution

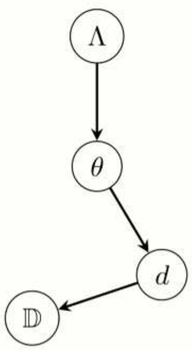
4

Why?

Essick & Fishbach (2024)

Physical $P(\mathbb{D}|d,\theta) = P(\mathbb{D}|d)$

$(\mathbb{D} \perp \theta \mid d)$



term-by-term cancellation

$$p(\Lambda|\{d_i, \mathbb{D}_i\}, N) = \frac{p(\Lambda)\prod_i^N \left[P(\mathbb{D}_i|\Lambda)^{-1}\int d\theta\, P(\mathbb{D}_i|d_i) p(d_i|\theta)p(\theta|\Lambda)\right]}{\int d\Lambda p(\Lambda)\prod_i^N \left[P(\mathbb{D}_i|\Lambda)^{-1}\int d\theta\, P(\mathbb{D}_i|d_i) p(d_i|\theta)p(\theta|\Lambda)\right]}$$

$$\propto p(\Lambda)P(\mathbb{D}|\Lambda)^{-N}\prod_i^N \int d\theta\, p(d_i|\theta)p(\theta|\Lambda)$$

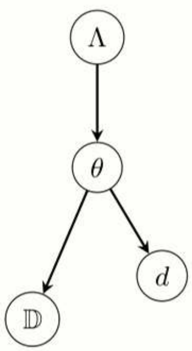
standard expression

$$P(\mathbb{D}|\Lambda) = \int d\theta\, p(\theta|\Lambda)\int dd P(\mathbb{D}|d)p(d|\theta)$$
$$= \int d\theta\, p(\theta|\Lambda)P(\mathbb{D}|\theta)$$

physical detection processes only have access to the data

Unphysical $P(\mathbb{D}|d,\theta) = Q(\mathbb{D}|\theta)$

$(\mathbb{D} \perp d \mid \theta)$



no cancellation

$$q(\Lambda|\{d_i, \mathbb{D}_i\}, N) = \frac{p(\Lambda)\prod_i^N \left[Q(\mathbb{D}_i|\Lambda)^{-1}\int d\theta\, Q(\mathbb{D}_i|\theta) p(d_i|\theta)p(\theta|\Lambda)\right]}{\int d\Lambda p(\Lambda)\prod_i^N \left[Q(\mathbb{D}_i|\Lambda)^{-1}\int d\theta\, Q(\mathbb{D}_i|\theta) p(d_i|\theta)p(\theta|\Lambda)\right]}$$

$$\propto p(\Lambda)\prod_i^N \int d\theta\, p(d_i|\theta)q(\theta|\mathbb{D},\Lambda)$$

fitting the "detected distribution"

$$q(\theta|\mathbb{D},\Lambda) = \frac{Q(\mathbb{D}|\theta)p(\theta|\Lambda)}{Q(\mathbb{D}|\Lambda)}$$

incorrectly models detection as independent of the data given the event's true parameters

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Why?

Essick & Fishbach (2024)

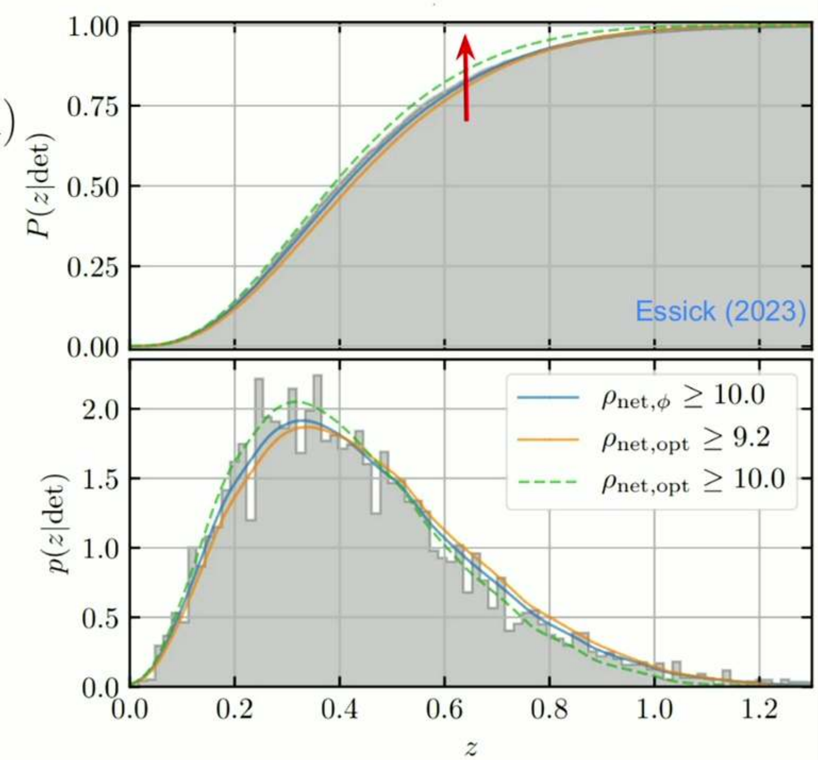
The physical model

$$p(\Lambda|\{d_i, \mathbb{D}_i\}, N) \propto p(\Lambda) P(\mathbb{D}|\Lambda)^{-N} \prod_i^N \int d\theta \, p(d_i|\theta) p(\theta|\Lambda)$$

is replaced by the unphysical approximation

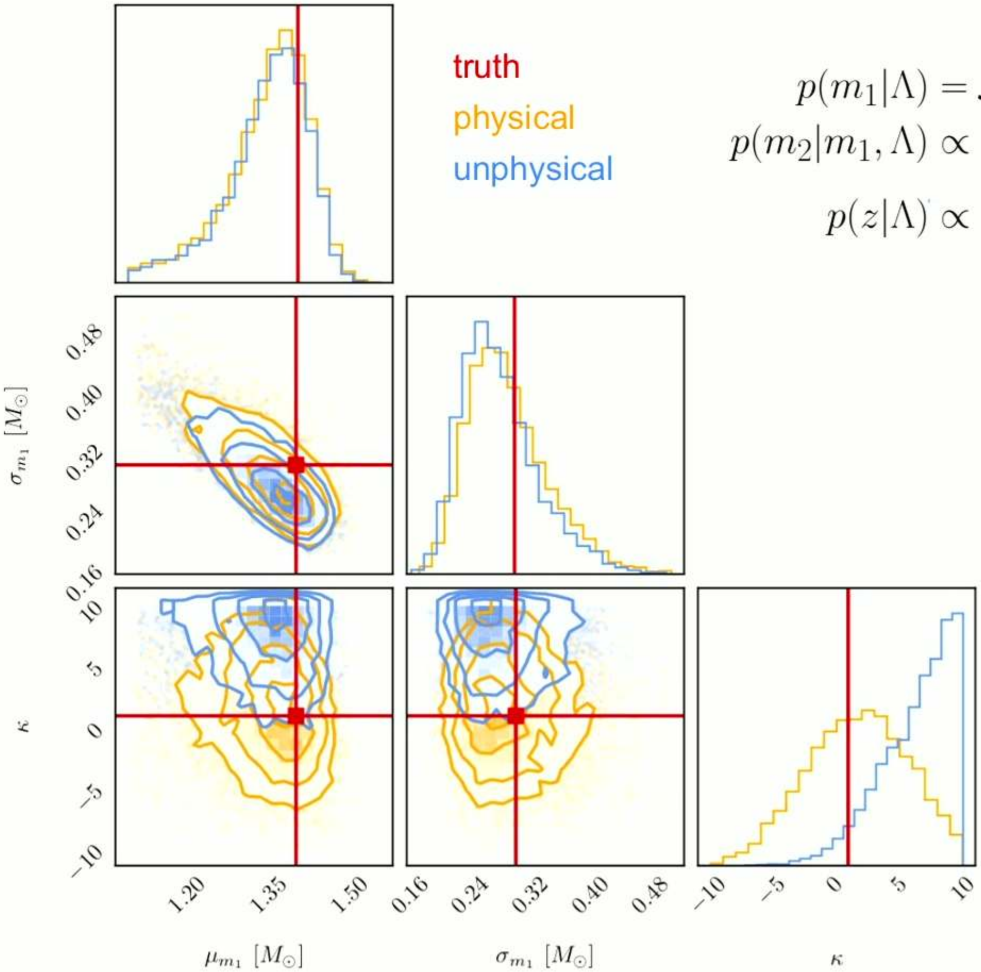
$$q(\Lambda|\{d_i, \mathbb{D}_i\}, N) \propto p(\Lambda) Q(\mathbb{D}|\Lambda)^{-N} \prod_i^N \int d\theta \, p(d_i|\theta) p(\theta|\Lambda)$$

which will tend to systematically underestimate the sensitivity to quiet signals.



Why?

Essick & Fishbach (2024)



$$p(m_1|\Lambda) = \mathcal{N}(\mu_{m_1}, \sigma^2_{m_1})\Theta(m_{\min} \leq m_1 \leq m_{\max})$$
$$p(m_2|m_1, \Lambda) \propto \Theta(m_{\min} \leq m_2 \leq m_1)$$
$$p(z|\Lambda) \propto \frac{dV_c}{dz}(1+z)^{\kappa-1}$$

selection is primarily against high-*z* systems, so the bias primarily affects the redshift-evolution

$$Q(\mathbb{D}|z) \ll P(\mathbb{D}|z) \Rightarrow \kappa \uparrow$$

in order to keep

$$K = \mathcal{K}P(\mathbb{D}|\Lambda) = \mathcal{K}\int d\theta\, p(\theta|\Lambda)P(\mathbb{D}|\theta)$$

approximately constant

Outline

Why?

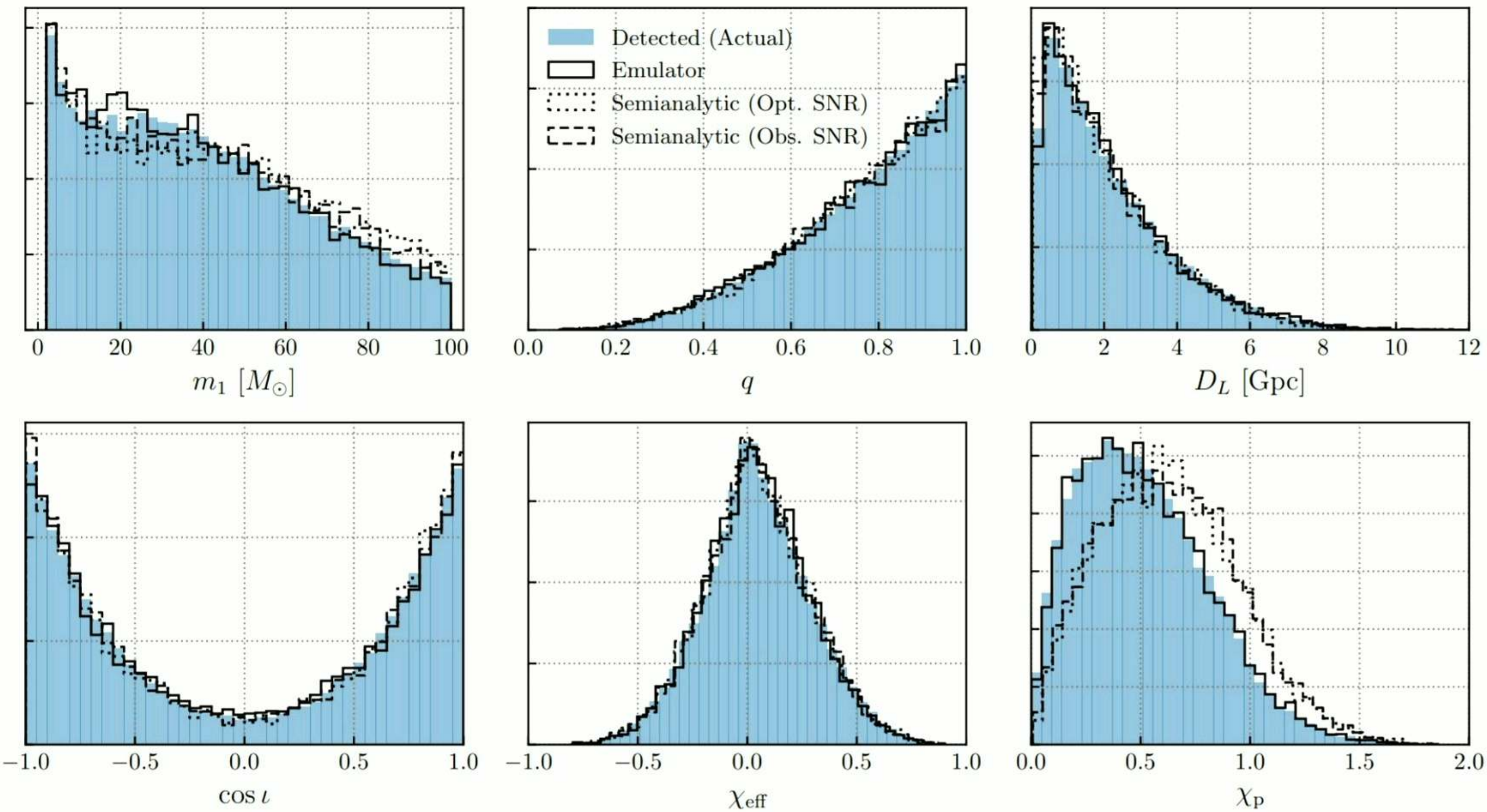
How?

What?

How?

Several approximations and emulators have been proposed.
None are perfect. All rely on real injections for training.

Callister+ (2024)



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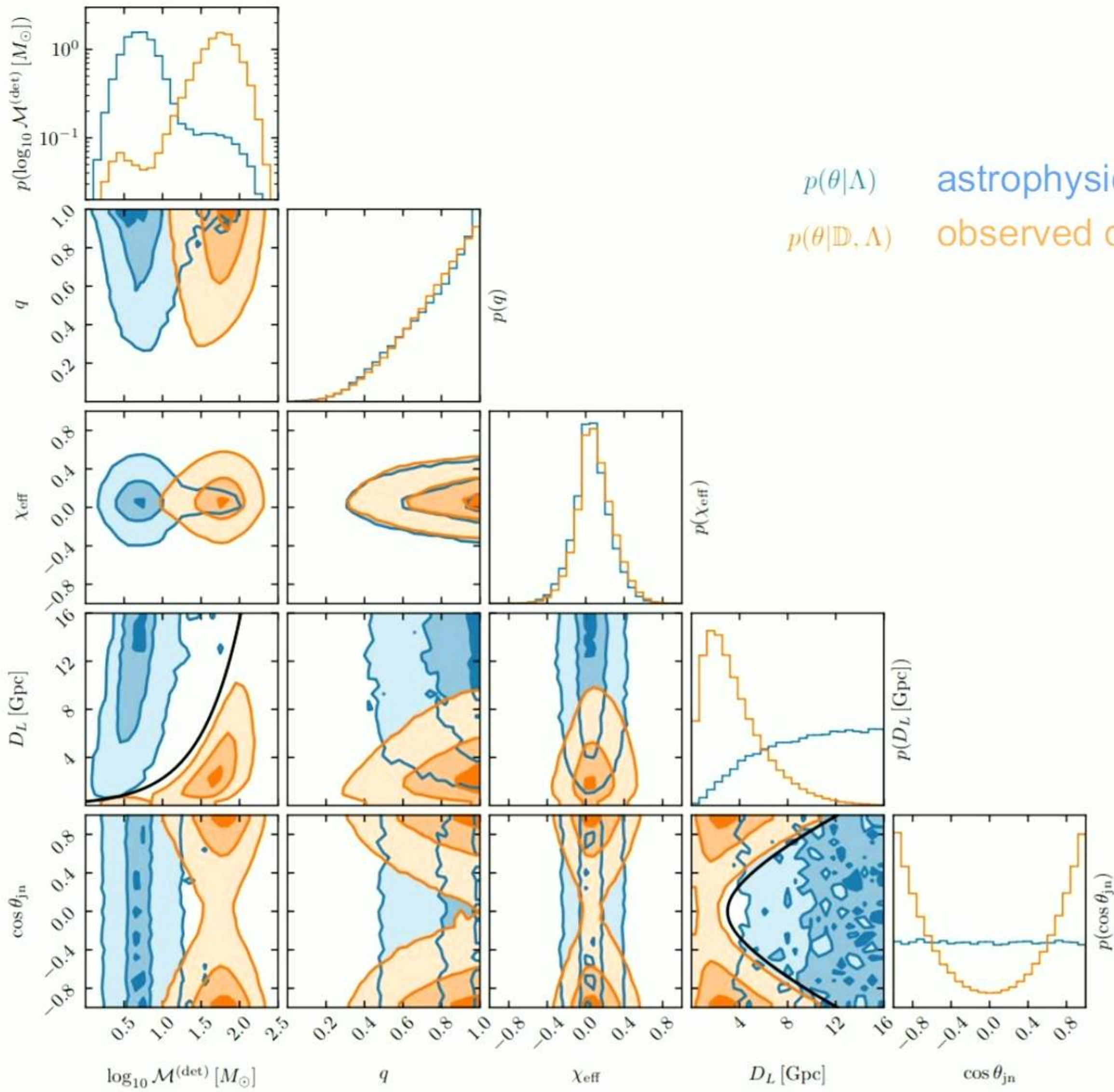
Why?

Essick+ (2025)

$p(\theta|\Lambda)$ astrophysical distribution

$p(\theta|\mathbb{D},\Lambda)$ observed distribution



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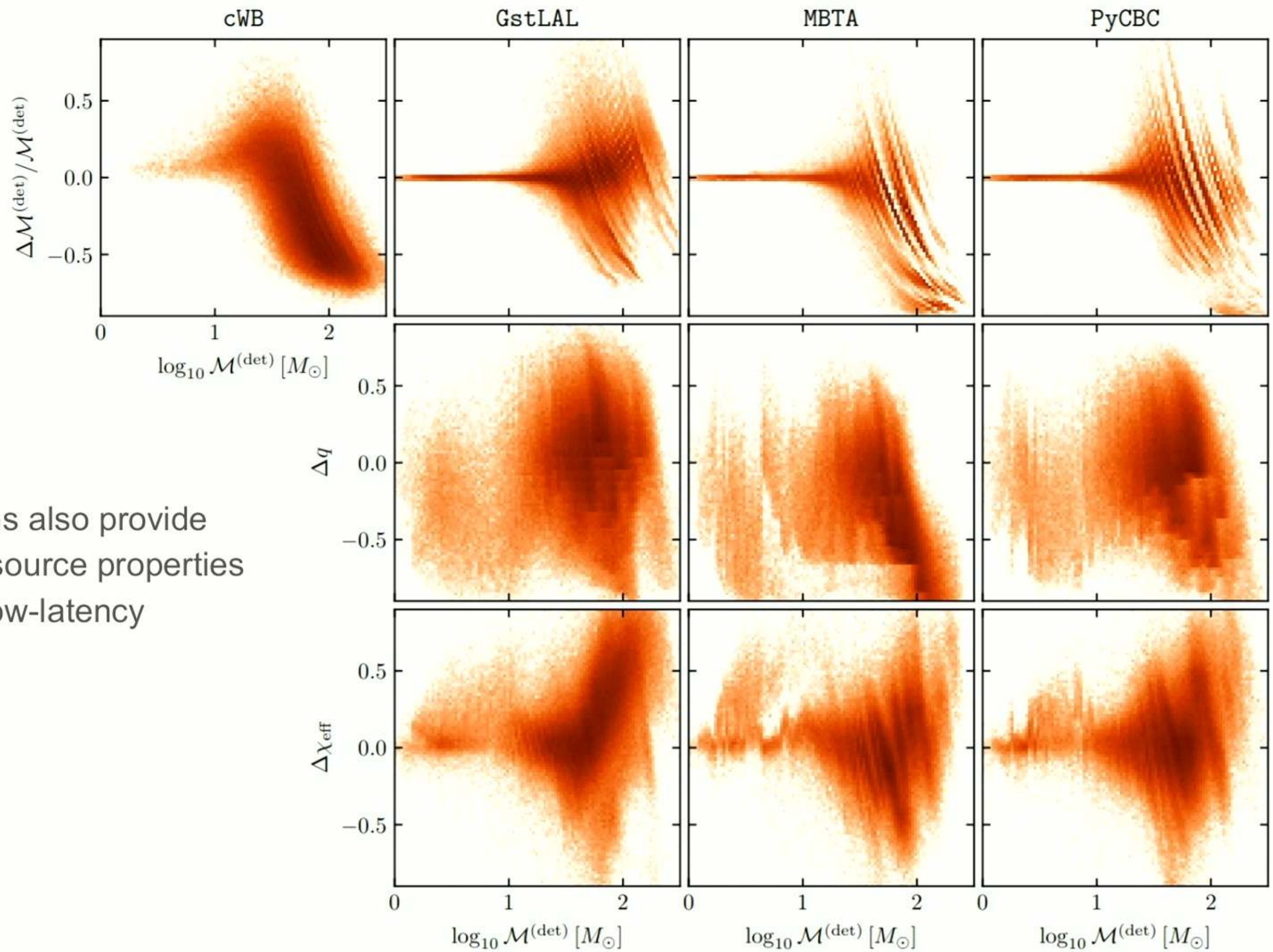
How?

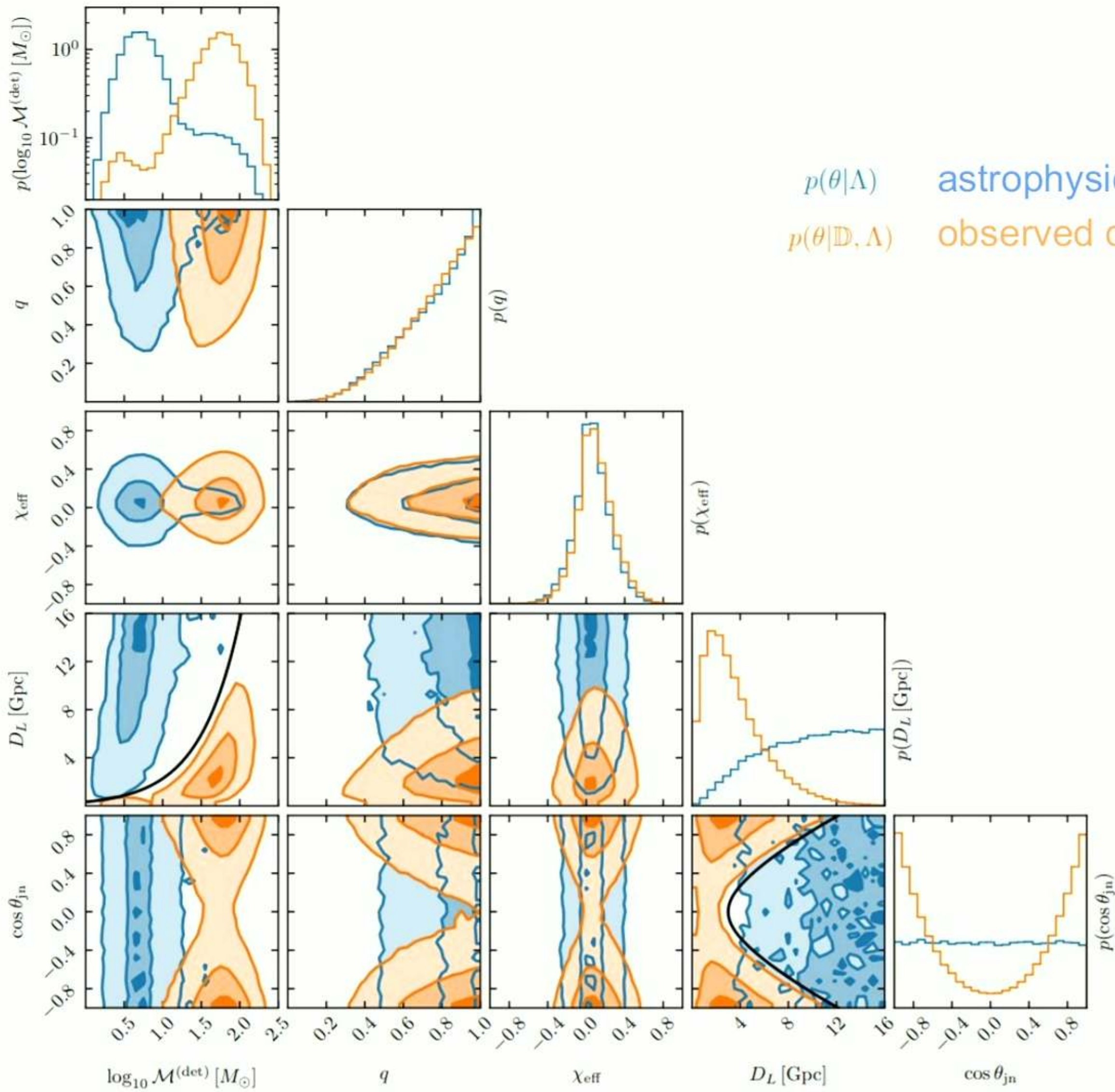


Essick+ (2025)

Real injections also provide insights into source properties available in low-latency

Why?

Essick+ (2025)



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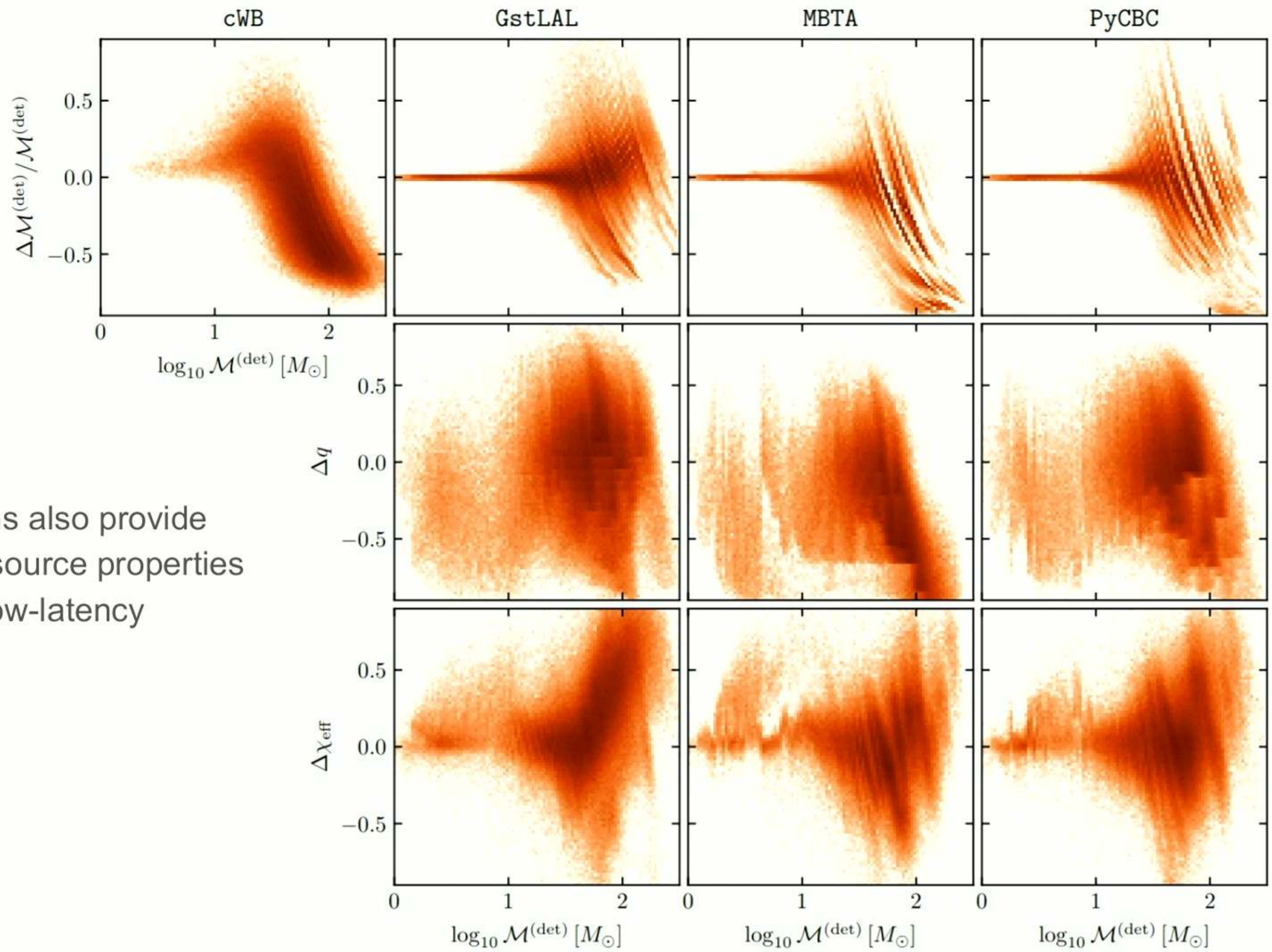

Essick+ (2025)

Real injections also provide insights into source properties available in low-latency

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How?

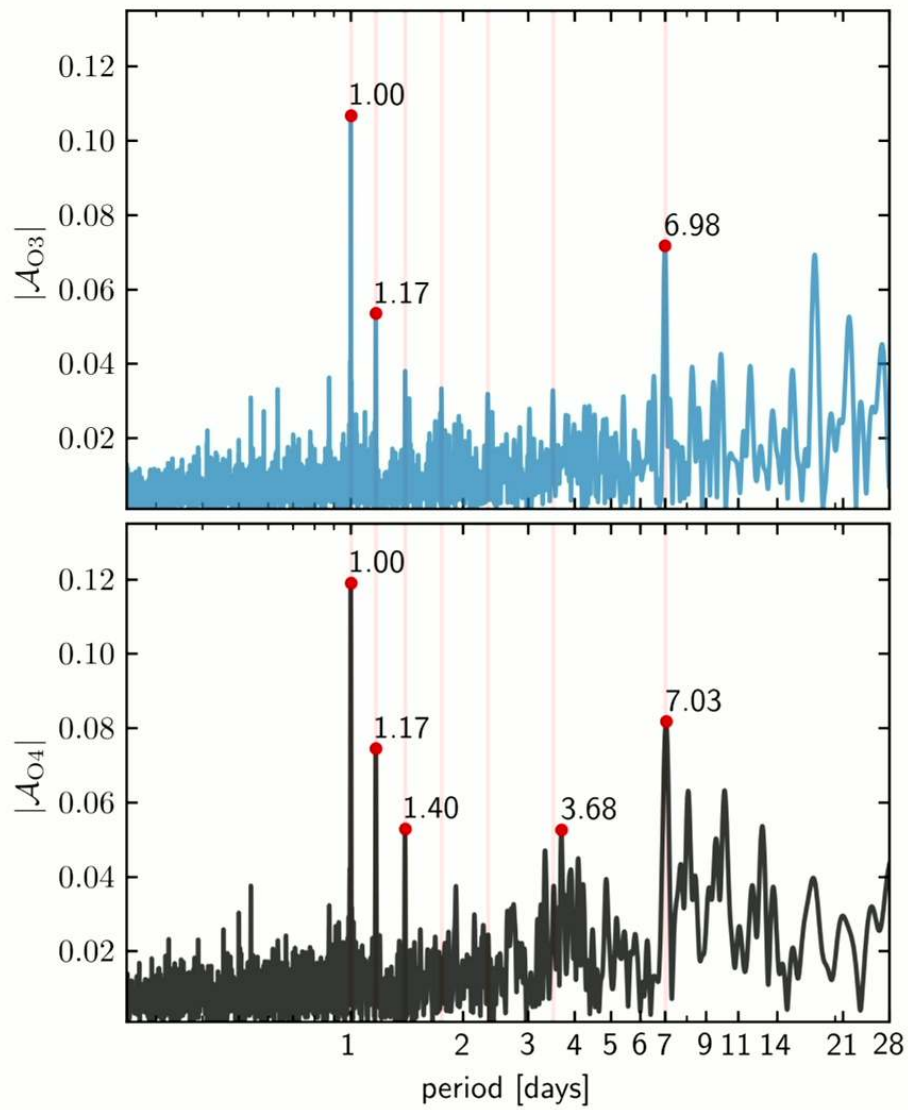
Direct measurements can surprise us!

$$\mathcal{A} = \int dt\, e^{-2\pi i f t} p(t|\mathbb{D})$$

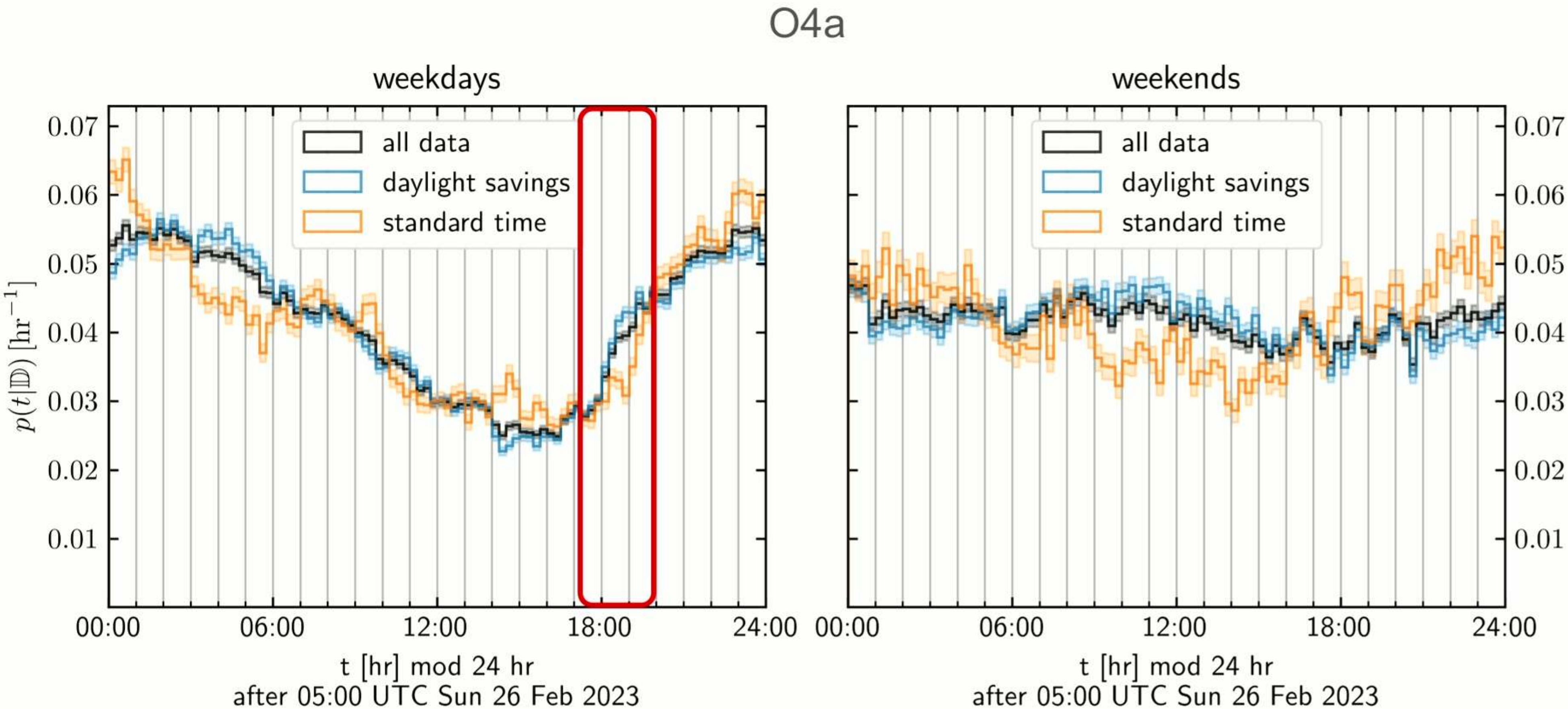
$$\approx \sum_k^N w_k e^{-2\pi i f t_k} \Bigg/ \sum_k^N w_k$$

O3

O4a



How?


O4a
weekdays
weekends
all data
daylight savings
standard time
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0.06
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0.02
0.01
$p(t|\mathbb{D})$ [hr^{-1}]
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06:00
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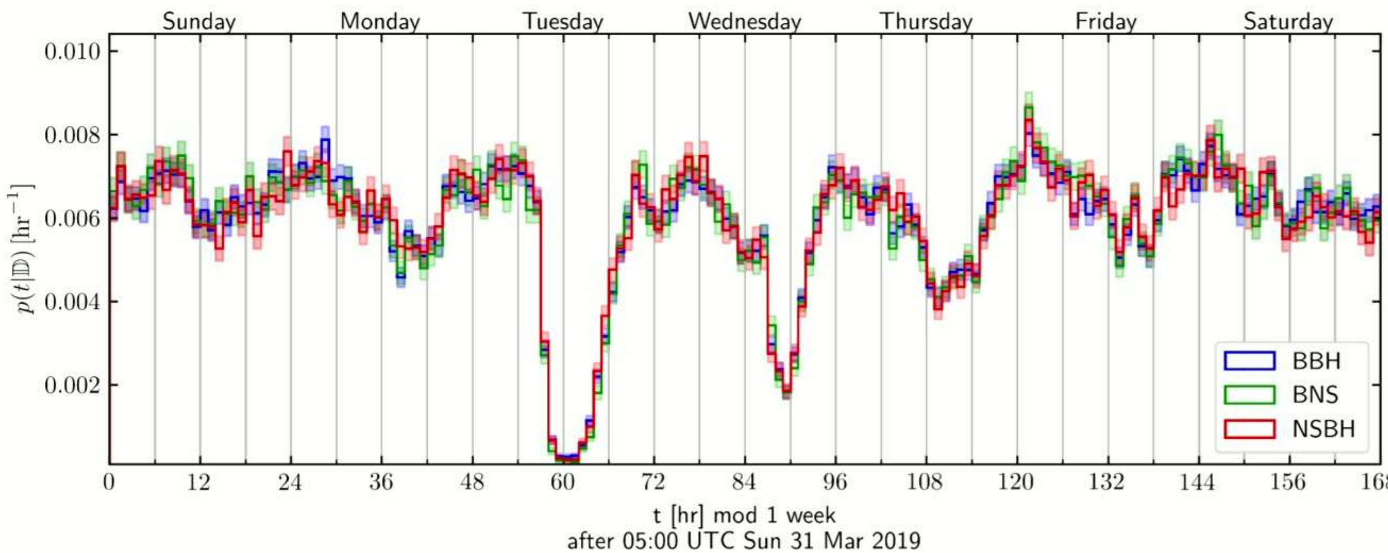
t [hr] mod 24 hr
after 05:00 UTC Sun 26 Feb 2023

How?

O3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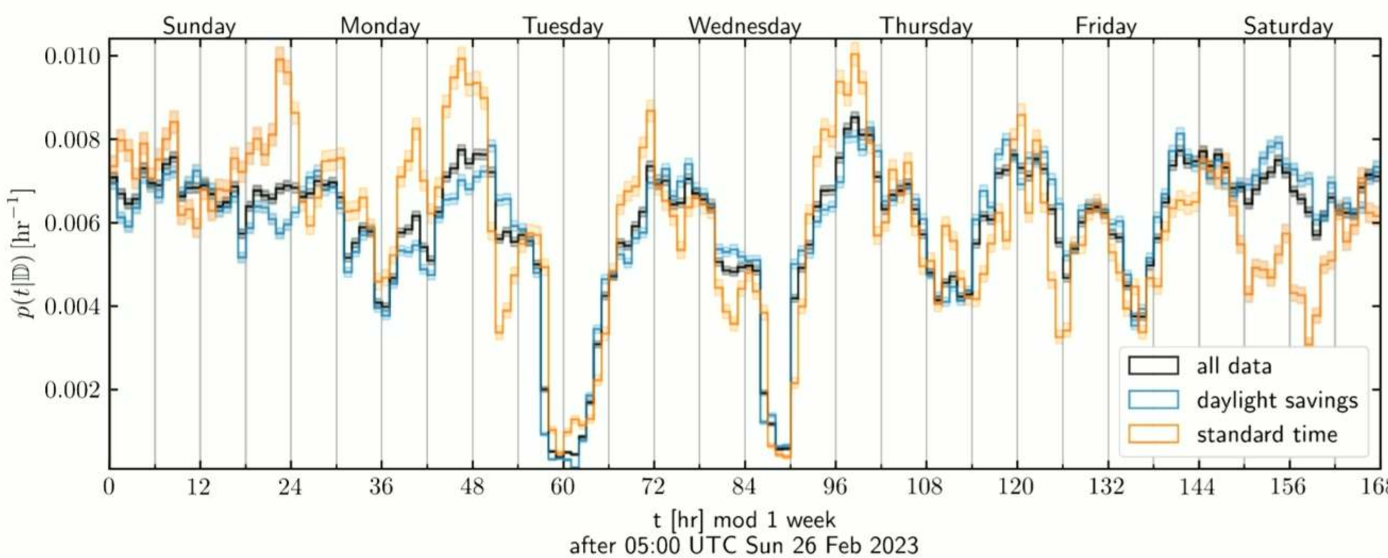
O4a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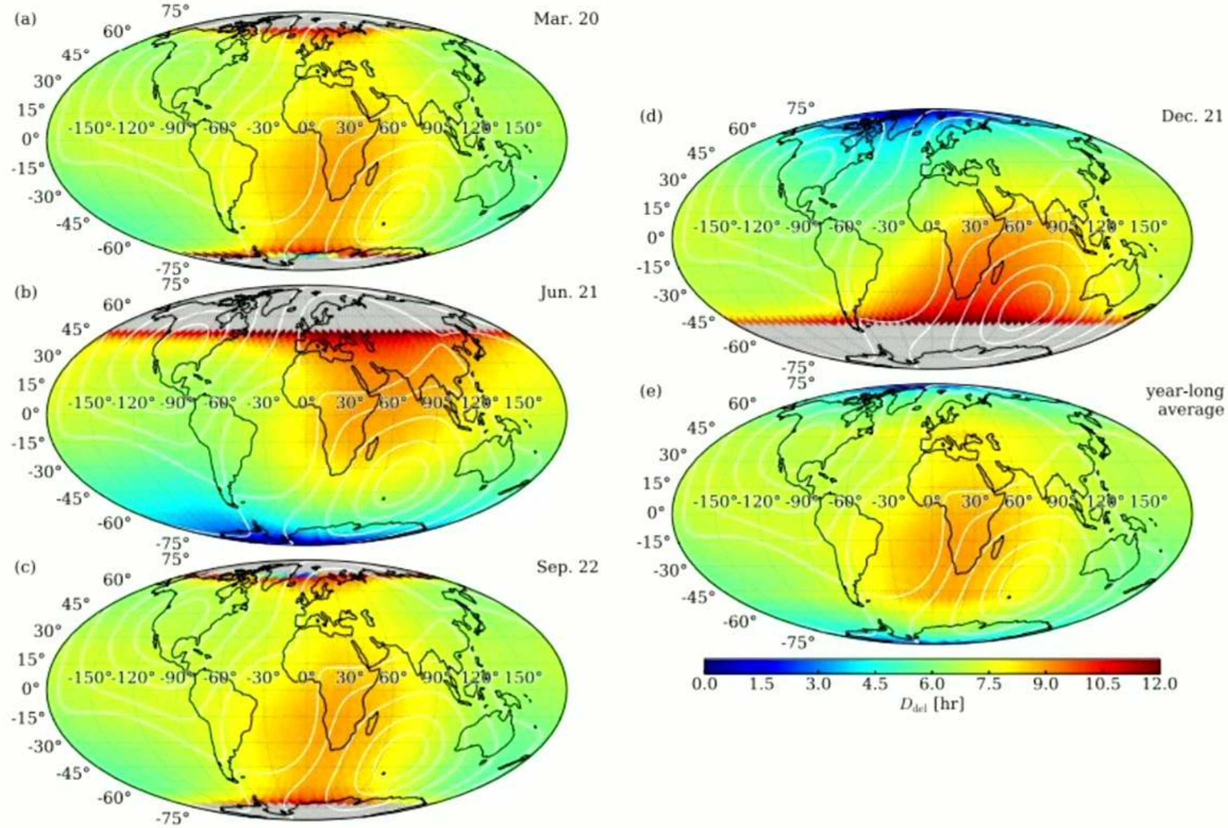
after 05:00 UTC Sun 26 Feb 2023

What?

Chen+ (2017)

Diurnal cycles affect how quickly EM telescopes can follow-up GW events



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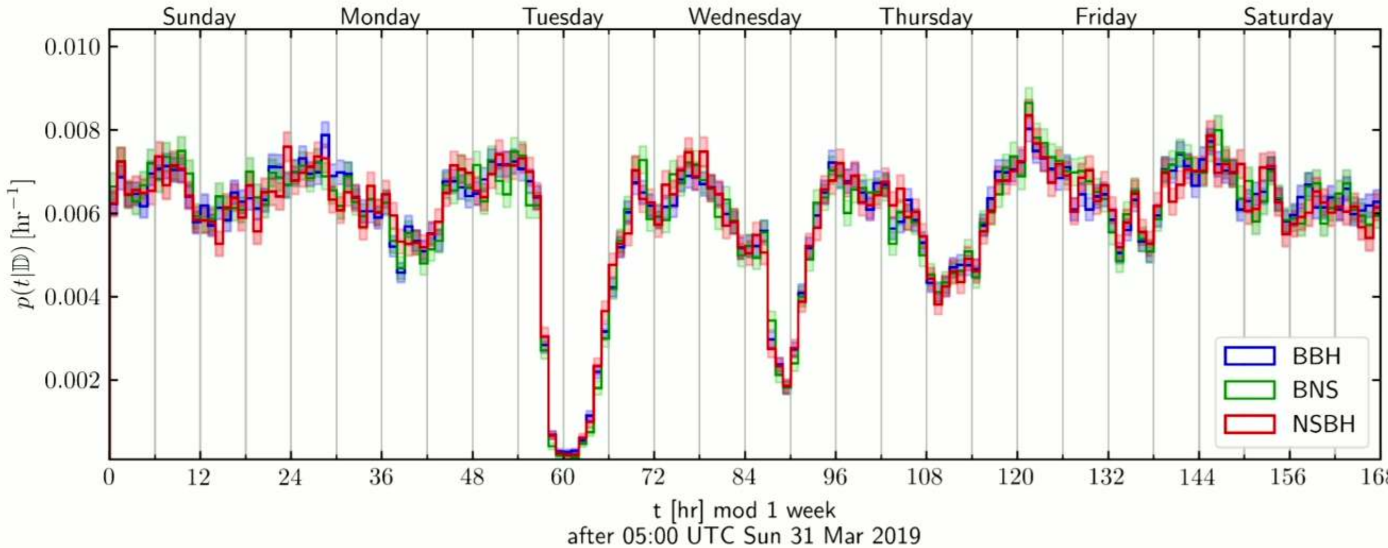

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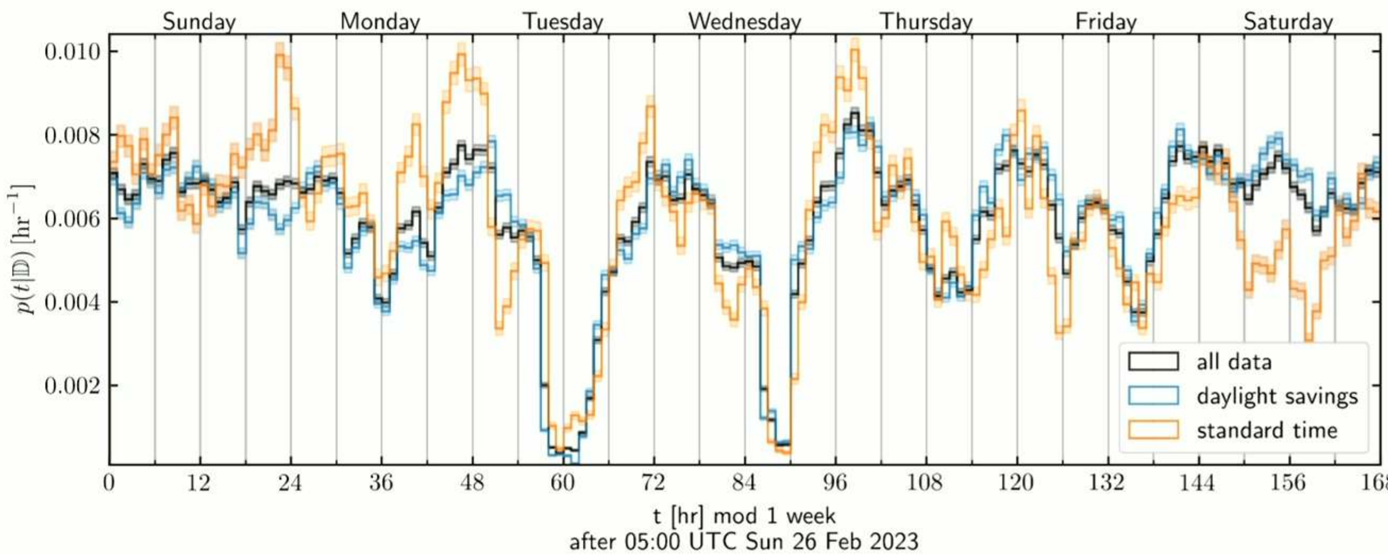

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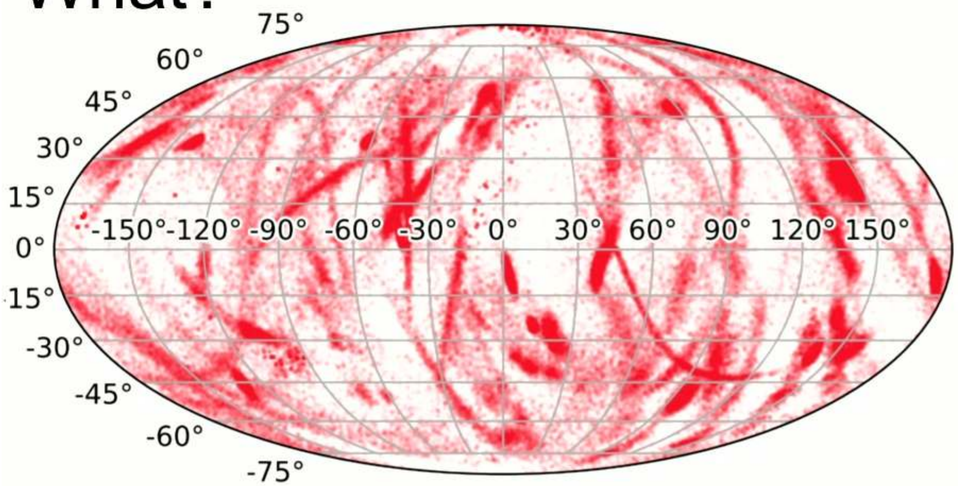
t [hr] mod 1 week
after 05:00 UTC Sun 26 Feb 2023

14

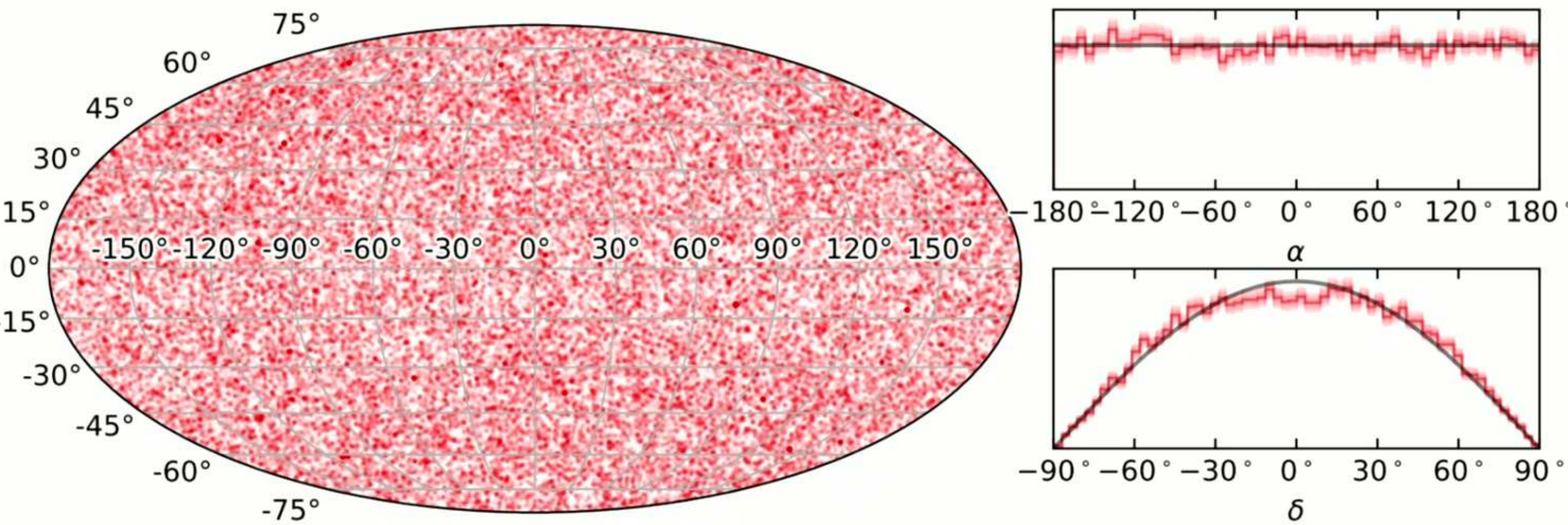
What?

O3

Essick+ (2023)



and induce a selection across the celestial sky



What?

O4a

Essick+ (2025)

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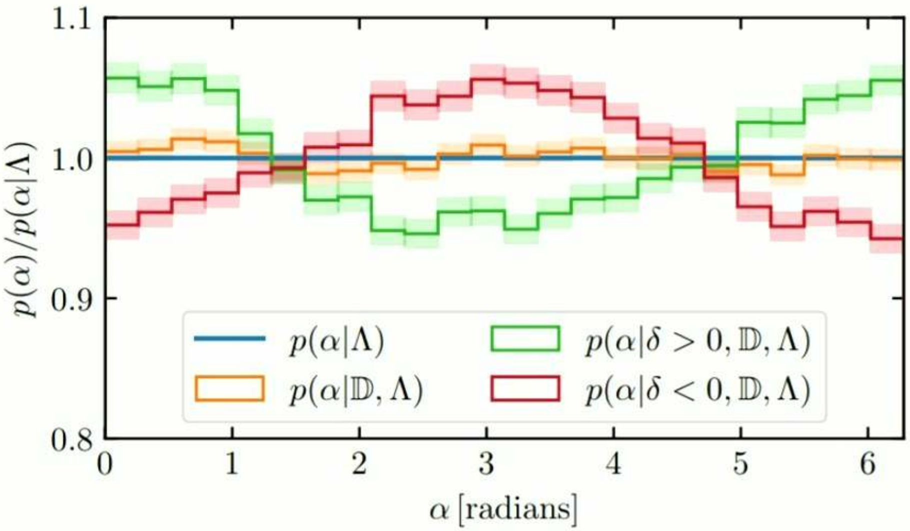

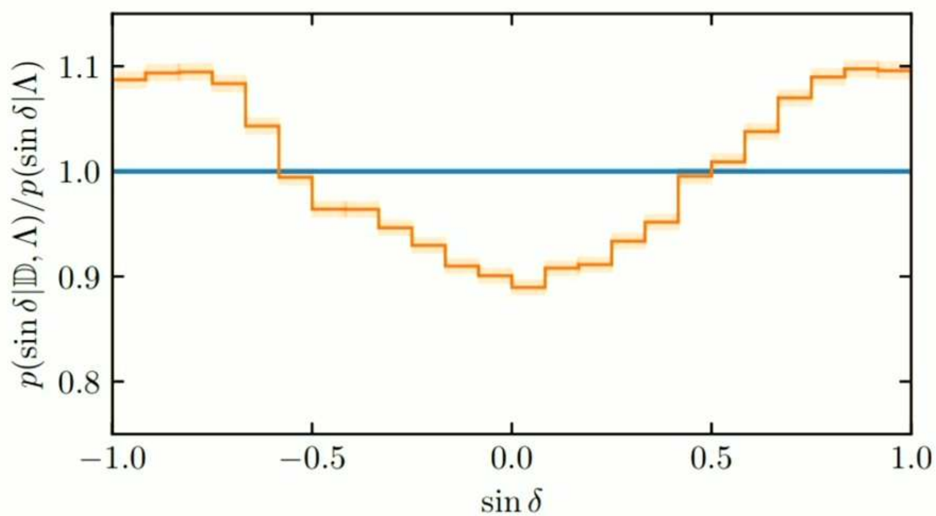

What?

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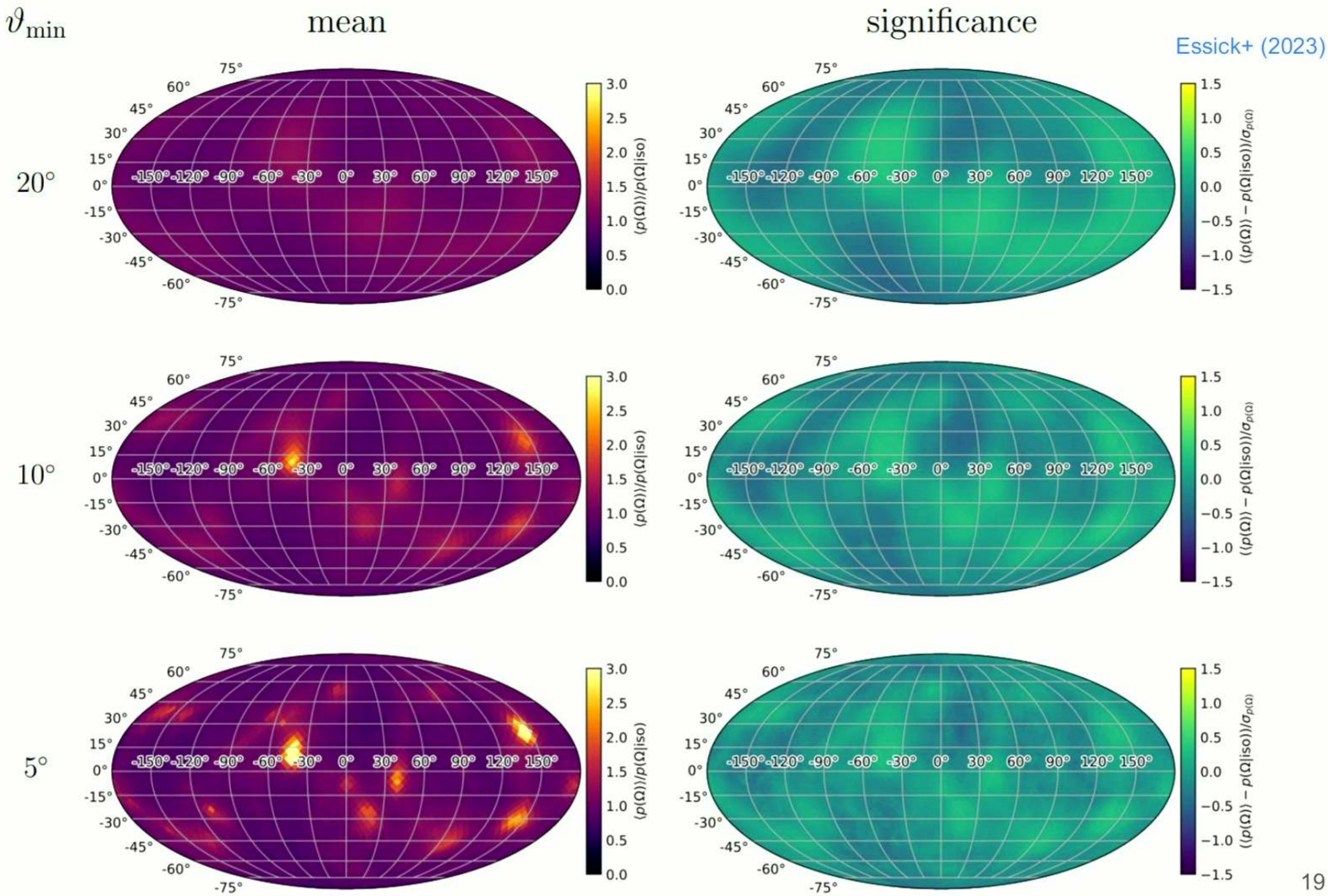


$\vartheta_{\min}$
mean
significance
Essick+ (2023)
20°
10°
5°
$\langle p(\Omega)\rangle / p(\Omega|\text{iso})$
$(\langle p(\Omega)\rangle - p(\Omega|\text{iso}))/\sigma_{p(\Omega)}$

References

Chen, Essick *et al*, *Observational Selection Effects with Ground-Based Gravitational Wave Detectors*, ApJ (2017)

Essick *et al*, *(An)isotropy Measurement with Gravitational Wave Observations*, PRD (2023)

Essick, *Semianalytic Sensitivity Estimates for Catalogs of Gravitational-Wave Transients*, PRD (2023)

Essick & Fishbach, *Ensuring Consistency between Noise and Detection in Hierarchical Bayesian Inference*, ApJ (2024)

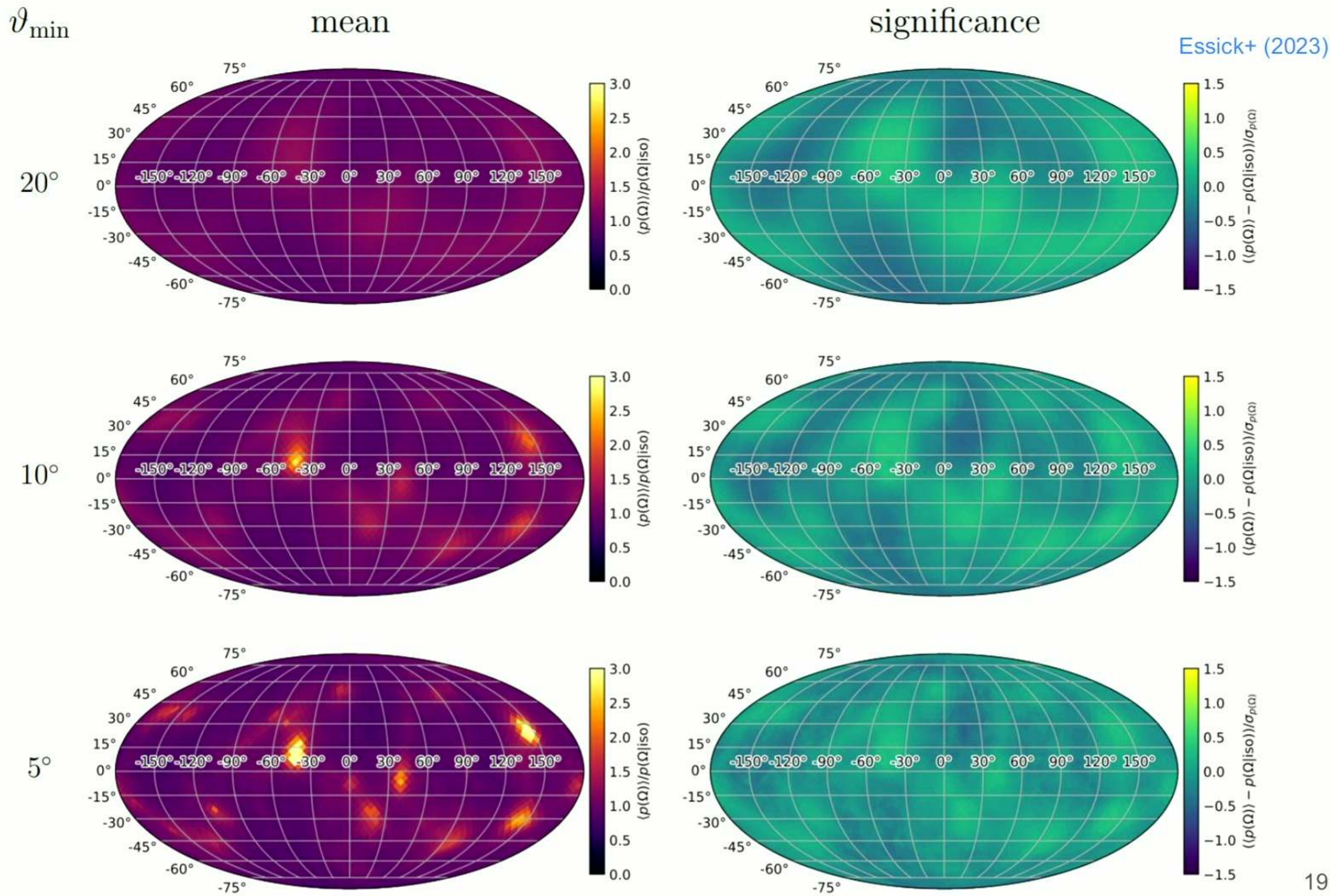
Callister, Essick, & Holz, *Neural Network Emulator of the Advanced LIGO and Advanced Virgo Selection Function*, PRD (2024)

Essick *et al*, *Compact Binary Coalescence Sensitivity Estimates with Injection Campaigns during the LIGO-Virgo-KAGRA Collaborations' Fourth Observing Run*, arXiv:2508.10638 (2025)

Slides

What?

O3



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mean
significance
Essick+ (2023)
20°
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5°
$\langle p(\Omega)\rangle / p(\Omega|\text{iso})$
$(\langle p(\Omega)\rangle - p(\Omega|\text{iso}))/\sigma_{p(\Omega)}$

Why?

Essick & Fishbach (2024)

Motivated by the observation

$$p(\theta|\Lambda) = \left(\frac{p(\theta|\mathbb{D},\Lambda)}{P(\mathbb{D}|\theta)}\right) P(\mathbb{D}|\Lambda)$$

It is tempting to fit for the distribution of true-parameters for detected events $p(\theta|\mathrm{D},\Lambda)$ from the observed data via

$$q(\{d_i\}|\{D_i\},N,\Lambda) = \prod_i^N \int d\theta\, p(d_i|\theta) q(\theta|\mathbb{D}_i,\Lambda)$$

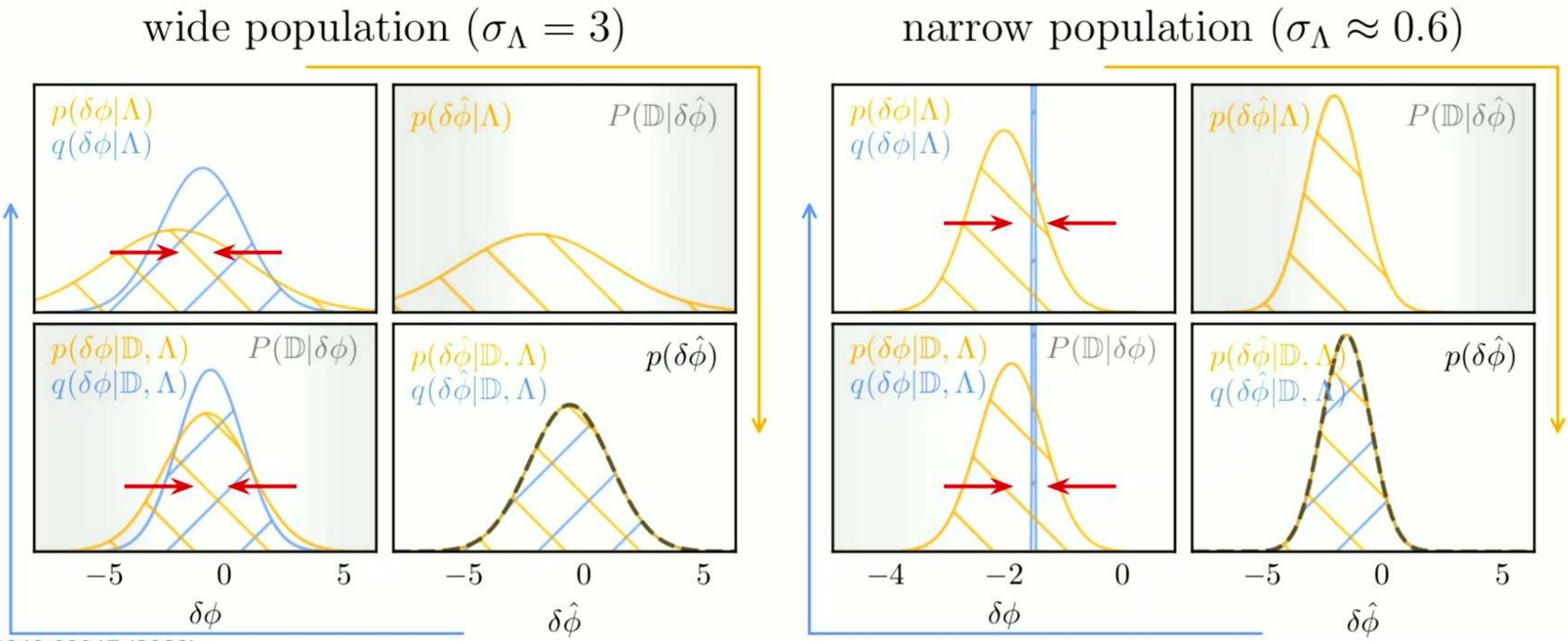
with a “flexible enough” model for $q(\theta|\mathrm{D},\Lambda)$ and then estimate the astro distribution

$$q(\theta|\Lambda) \propto \frac{q(\theta|\mathbb{D},\Lambda)}{P(\mathbb{D}|\theta)}$$

However, this procedure yields $q(\theta|\mathrm{D},\Lambda)$ that are too narrow, and therefore biased estimates of $q(\theta|\Lambda)$.

Why?

Essick & Fishbach (2024)



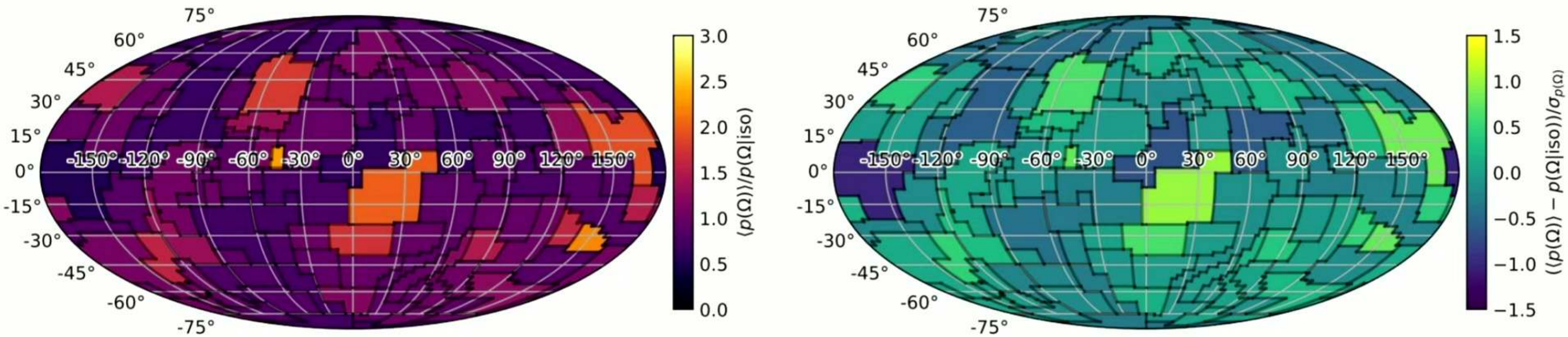
arXiv:2310.02017 (2023)

$$p(\delta\phi|\Lambda) = \mathcal{N}(\mu_\Lambda, \sigma_\Lambda^2) \qquad p(\delta\hat{\phi}|\delta\phi) = \mathcal{N}(\delta\phi, \sigma_o^2) \qquad P(\mathbb{D}|\delta\hat{\phi}) = \exp\left(-\frac{(\delta\hat{\phi} - \mu_D)^2}{\sigma_D^2}\right)$$

What?

Essick+ (2023)

O3



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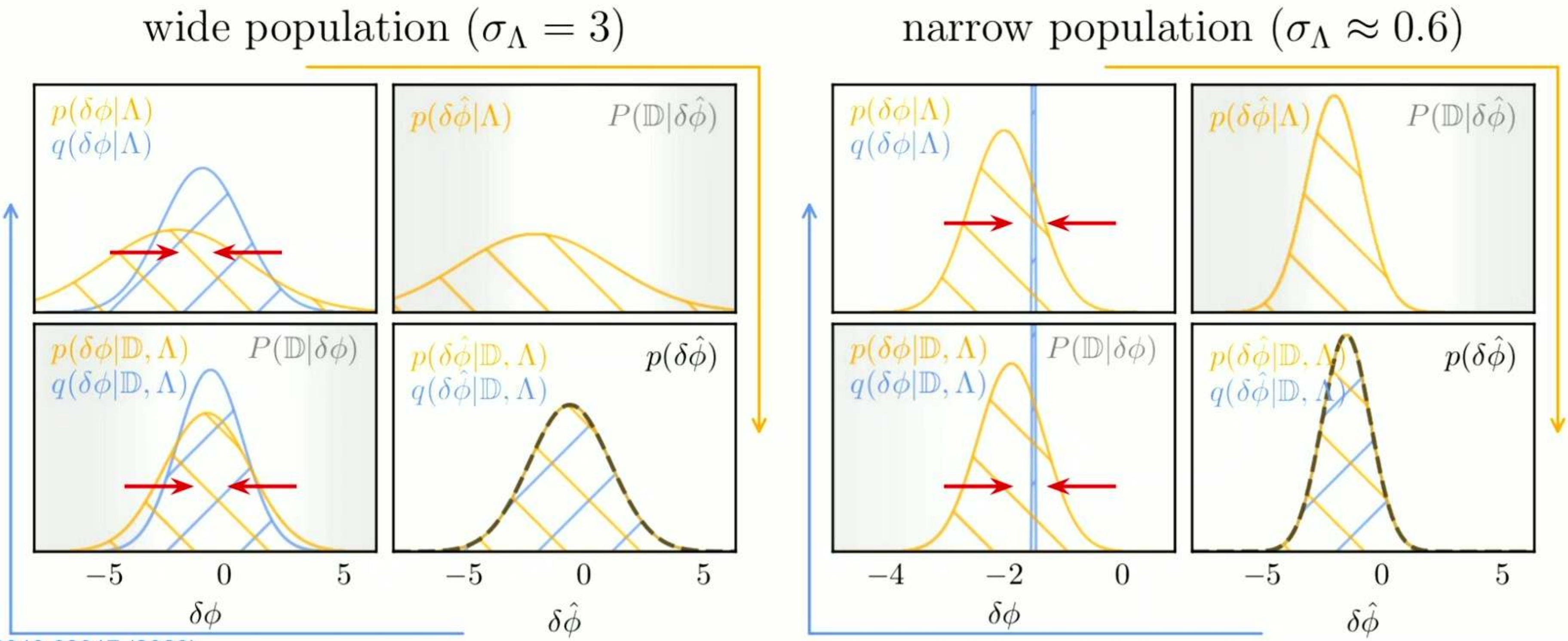

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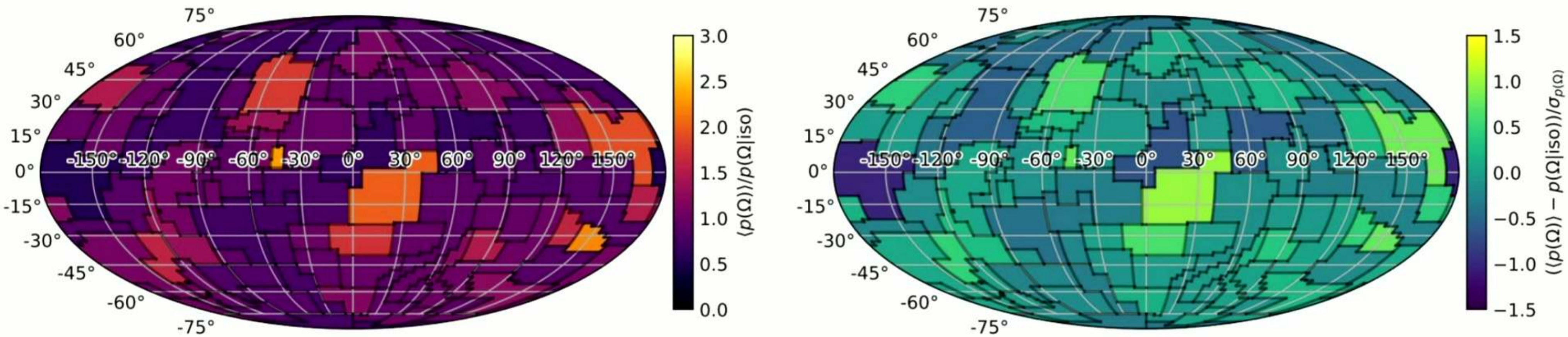

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