Astrophysical Implications of Gravitational Wave Observations

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on behalf of a lot of people

PASCOS 2018

LIGO-G1801065

fundamental physics

Tests of General Relativity (see talks by **Neil Cornish**, **Alex Nielson**, and **Tom Callister**)

speed of gravity/mass of graviton: ApJL 848, 2 (2017)
implications for early-universe cosmology: PRD 97, 084005 (2018)
deviations from post-newtonian waveform: PRL 116, 221101 (2016)
scalar, vector vs. tensor polarizations: PRL 119, 141104 (2017)
limits on the number of spacetime dimensions from GW170817: arXiv:1801.08160 (2018)
and many more!

Neutron Star Equation of State measurements (see talk by **Les Wade**)

Tides!: arXiv:1805.11579 (2018)
Equation of State inference: arXiv:1805.11581 (2018)

stellar and galactic physics

GW150914 (see ApJL 818, 2 (2016))

Big black holes exist and merge!

→ Relatively weak stellar winds (at low metallicities)

→ SN kicks must be relatively small to keep system bound

Possible formation channels

→ isolated evolution

→ dynamical interactions within Globular Clusters

These could be distinguished by the component spins and their alignment with the orbital angular momentum or by the precise merger rate as a function of redshift.

GW170817 (see ApJL 850, 2 (2017))

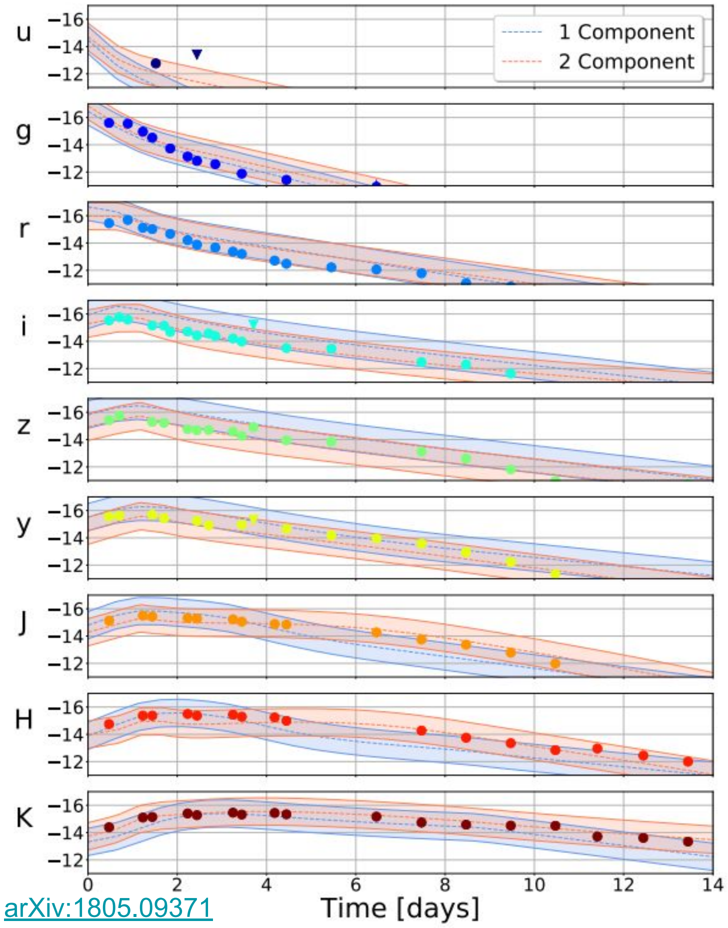
As long as merger delay times are $\gtrsim$ 1 Gyr, constraints do not strongly depend on Galaxy profile, Star Formation Rate, etc

→ at a projected distance of ~ 2kpc, dynamical timescales within the galaxy are ~20 Myr

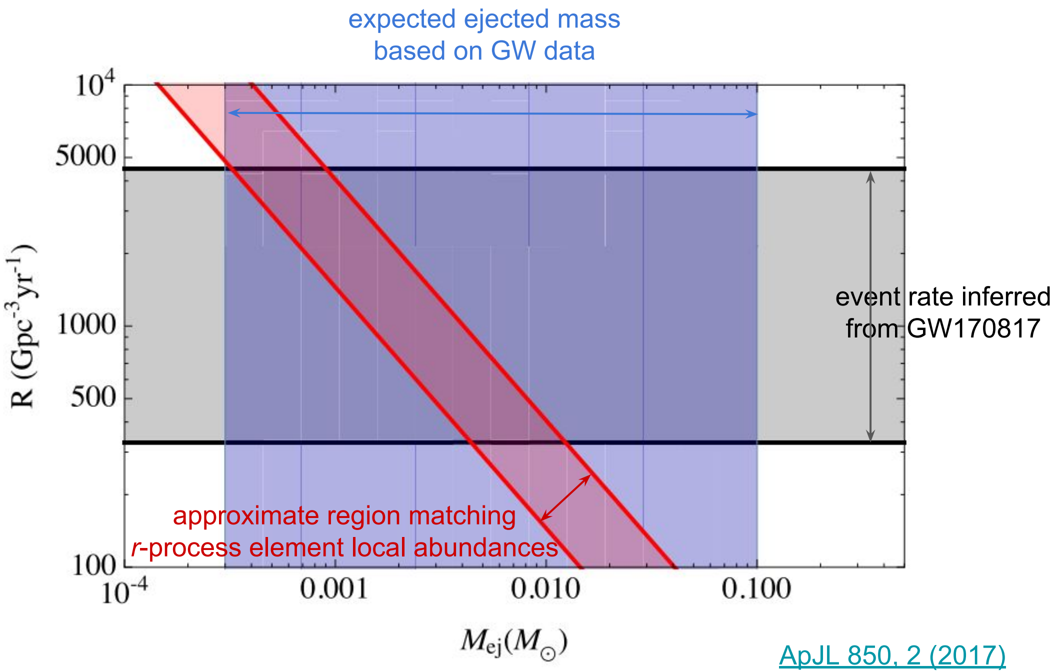
→ SN kicks must be relatively small to keep system bound

"An increased source sample resulting from future GW data will of course better constrain the merger rates, but will also allow us to probe the mass distributions and any dependence on redshift. To go beyond the current, mostly qualitative discussion, and move toward comprehensive model constraints, ***it will be important to develop frameworks that account for observational biases and for appropriate sampling of the model parameter space including relevant parameter degeneracies***."

stellar and galactic physics: chemical enrichment

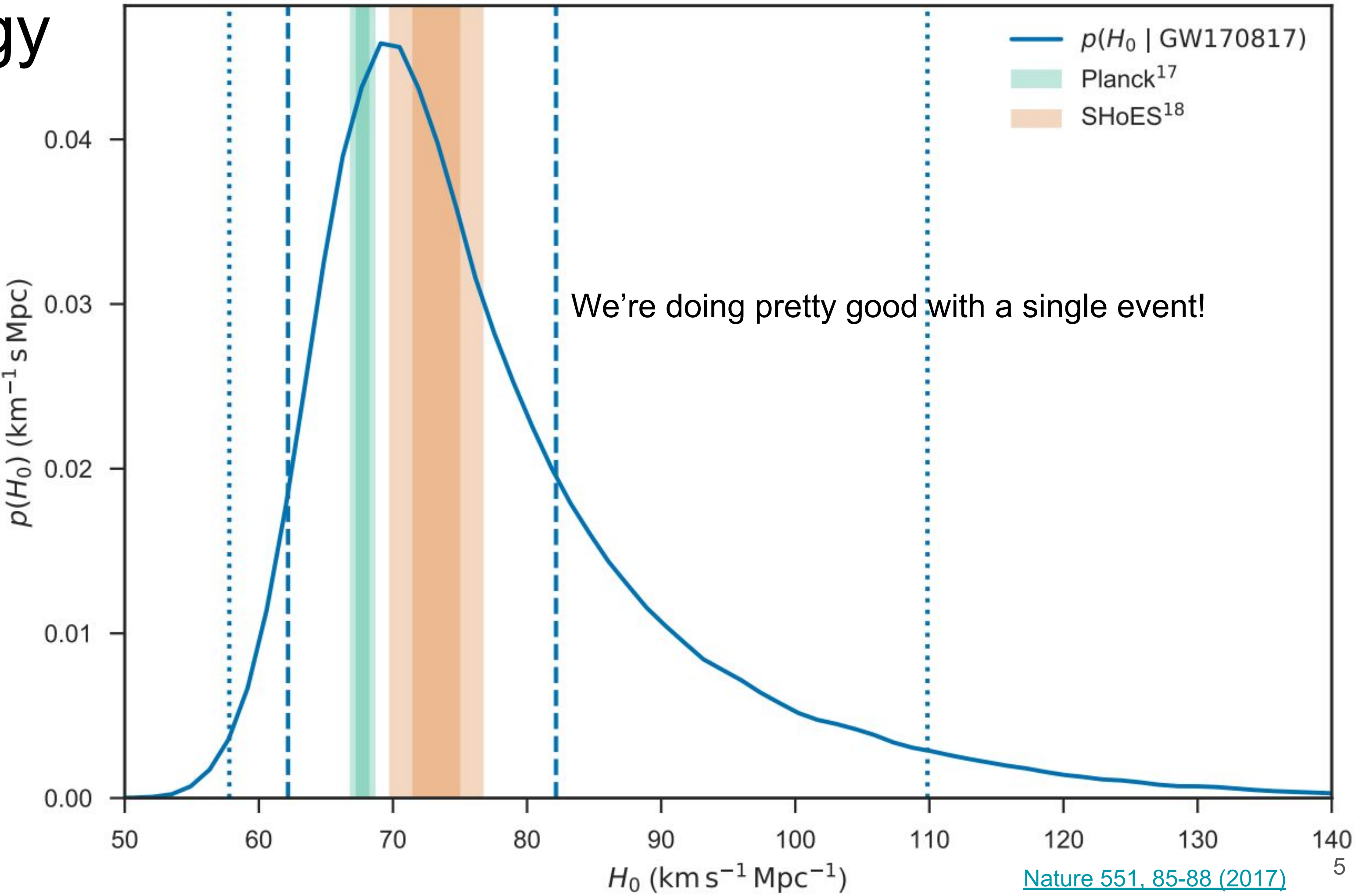


arXiv:1805.09371



ApJL 850, 2 (2017)

cosmology



We're doing pretty good with a single event!

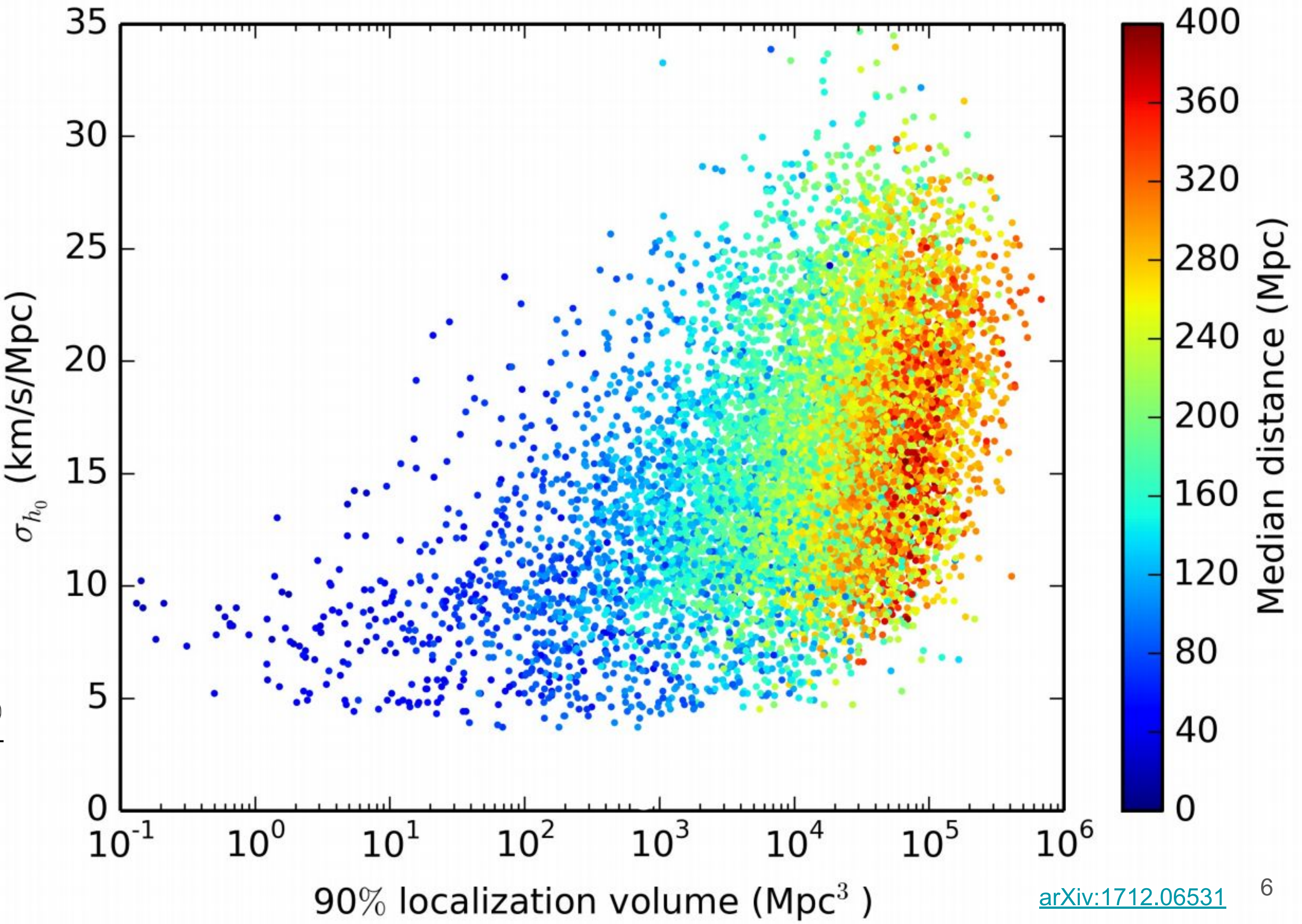
Nature 551, 85-88 (2017)

cosmology

As we collect more observations, the closest signals are the best localized and dominate the measurement.

check out arXiv:1712.06531 to learn how our measurement scales with and without an EM counterpart!

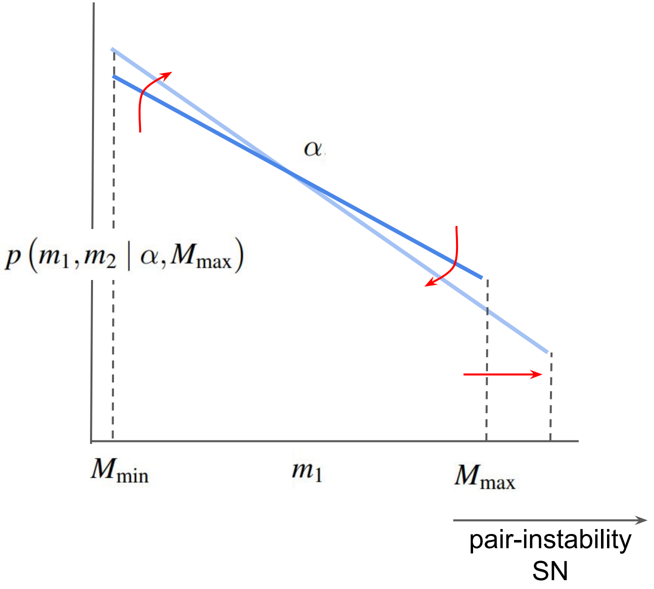
$$\frac{\sigma_{H_0}}{H_0} \sim \frac{15\%\text{–}40\%}{\sqrt{N}}$$

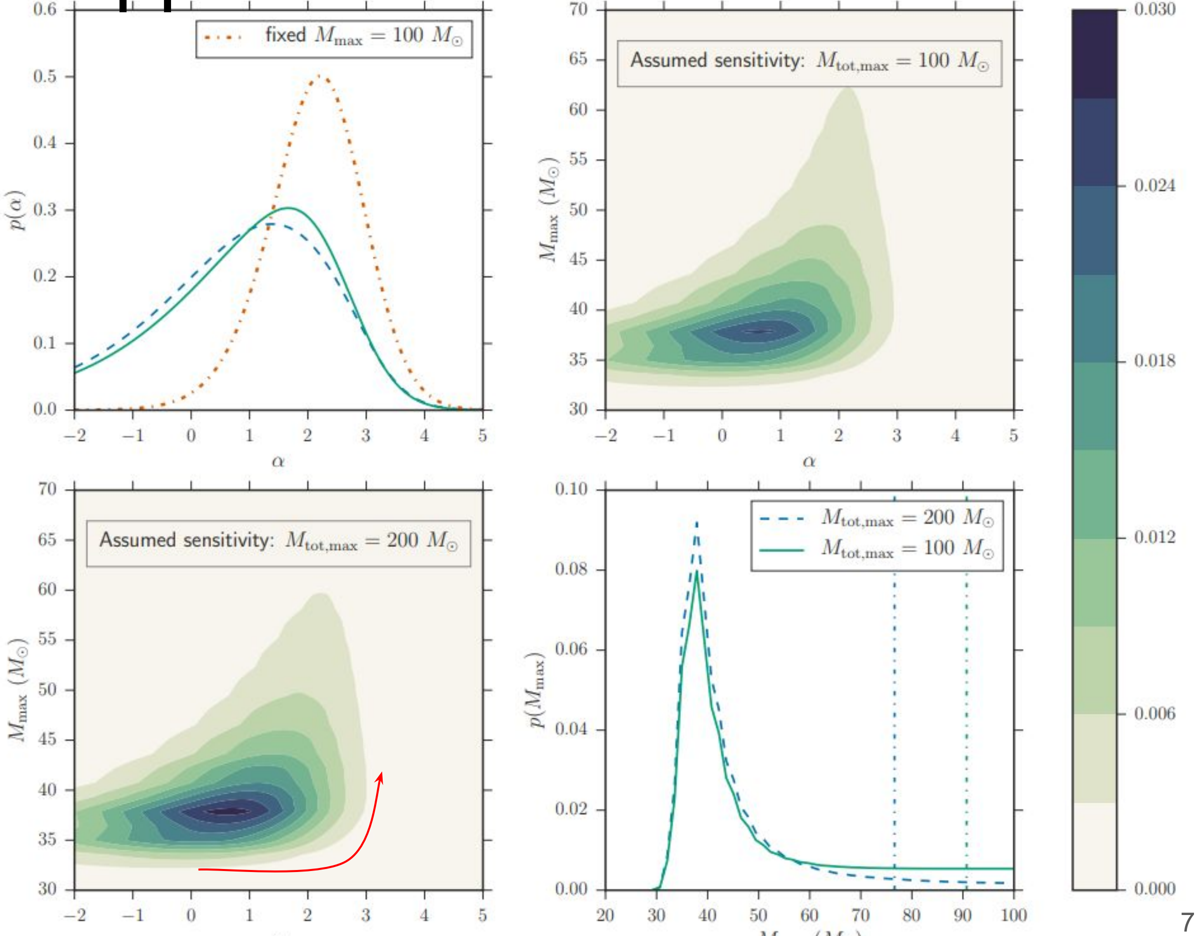


arXiv:1712.06531

source distributions: upper mass cut-off

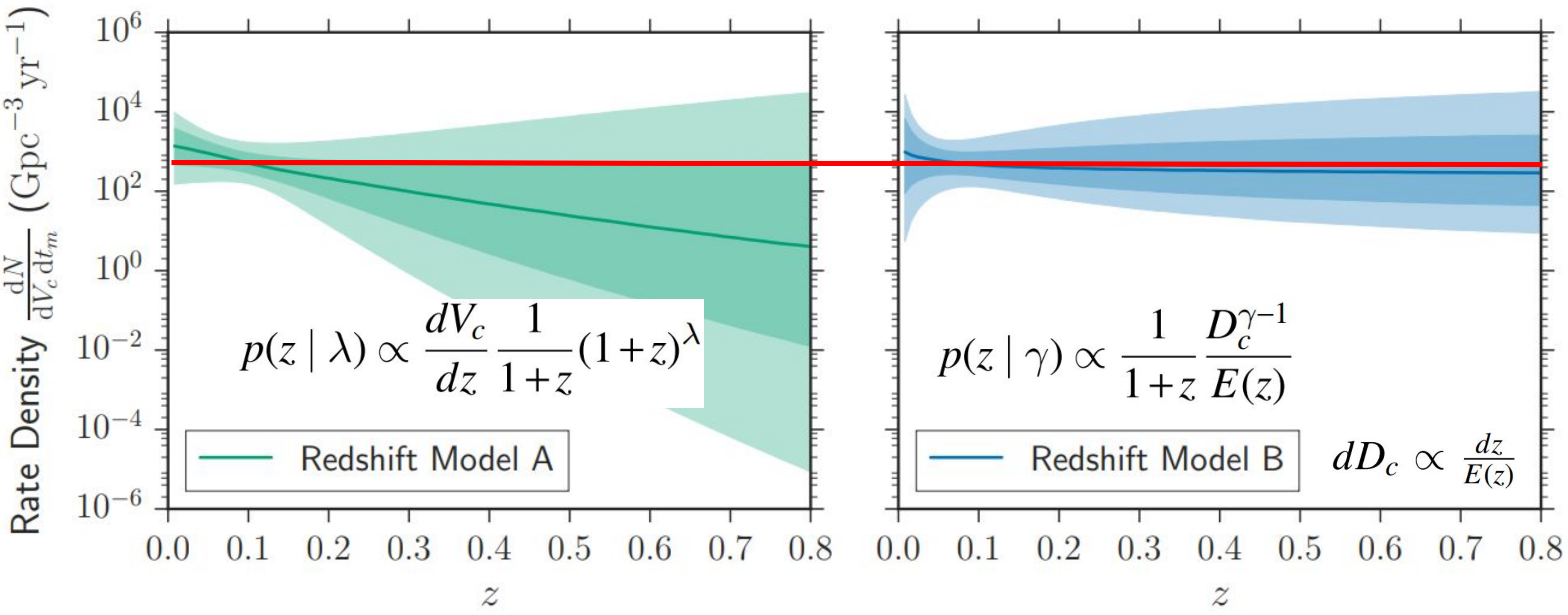
$$p\left(m_1, m_2 \mid \alpha, M_{\max}\right) \propto \frac{m_1^{-\alpha}\, \mathcal{H}(M_{\max} - m_1)}{\min(m_1, M_{\mathrm{tot,max}} - m_1) - M_{\min}}$$





arXiv:1709.08584

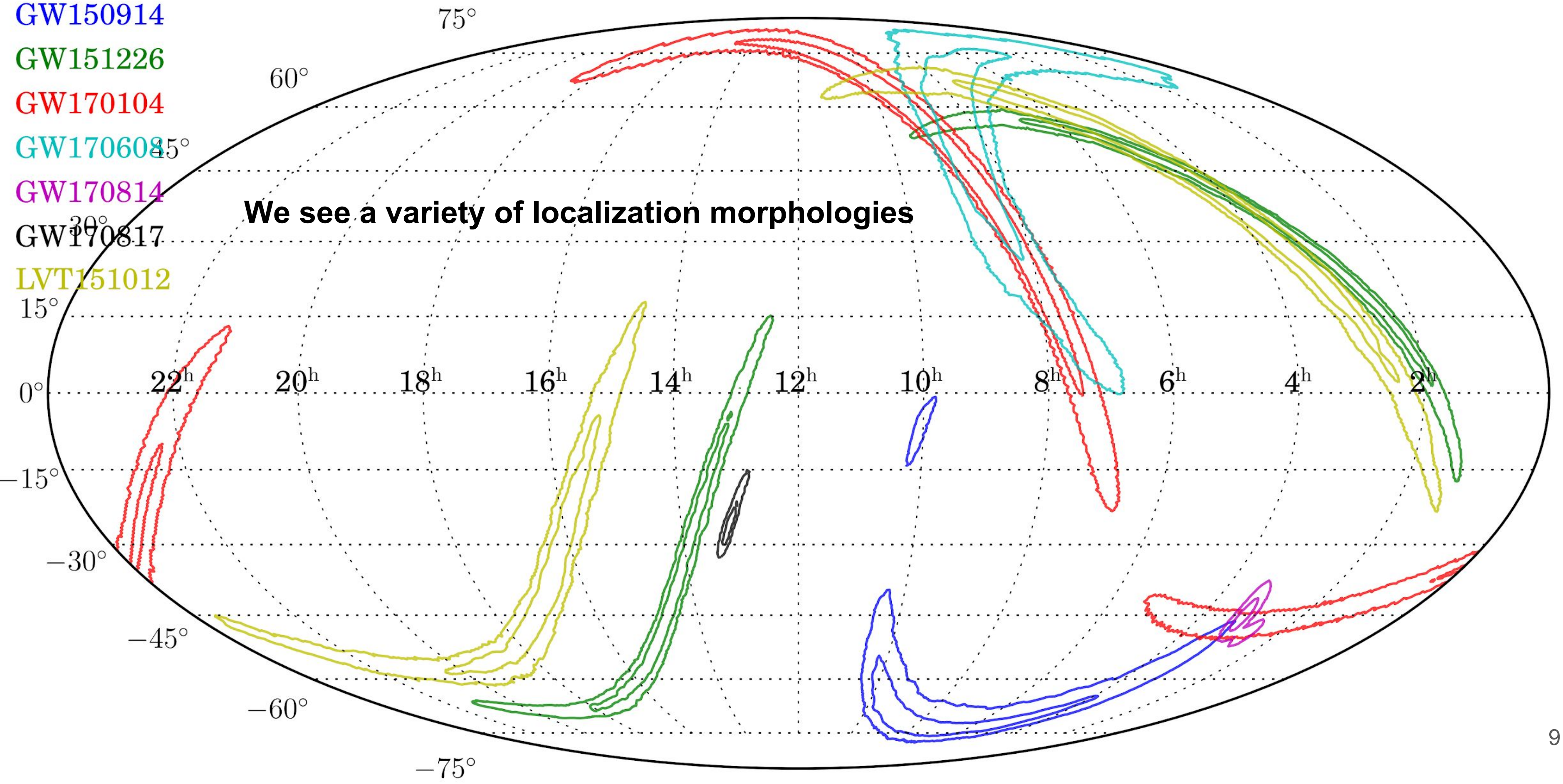
source distributions: redshift evolution



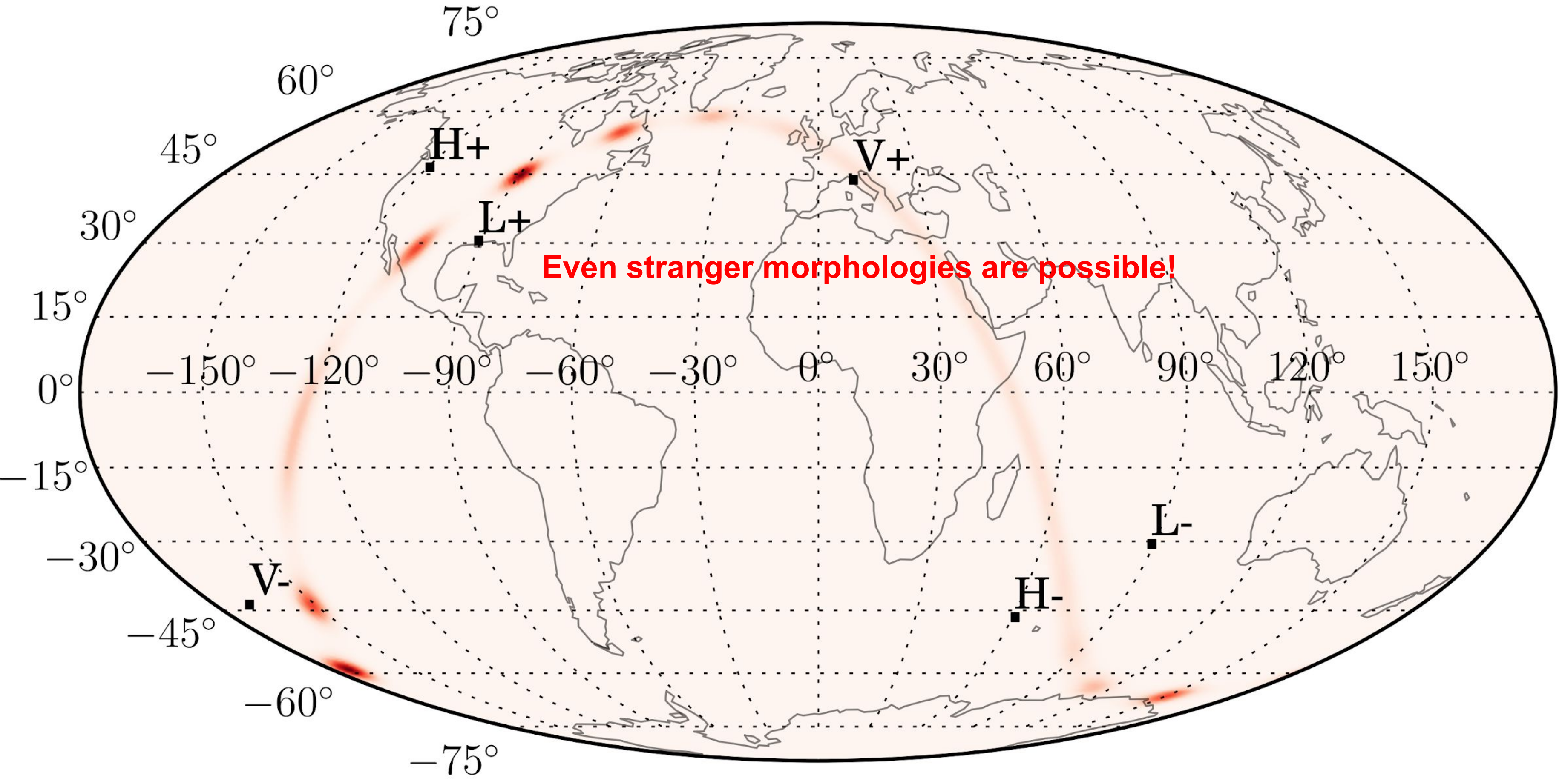
2 ~ad hoc models, both are consistent with a constant merger rate as a function of redshift.

arXiv:1805.10270

source distributions: spatial distributions



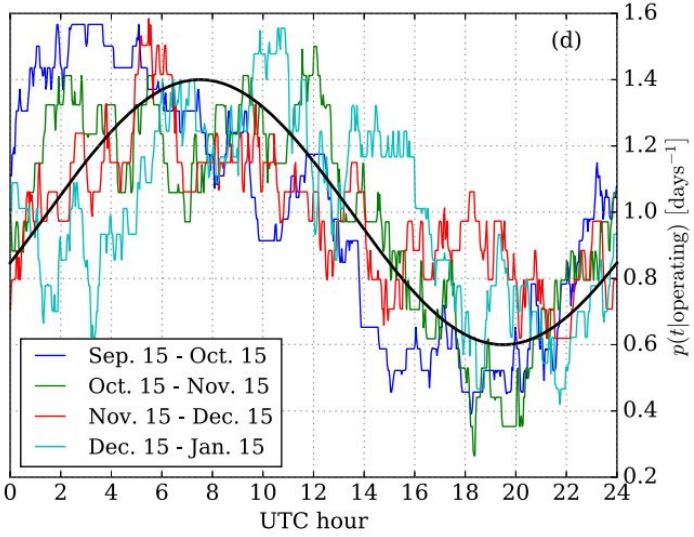
source distributions: spatial distributions

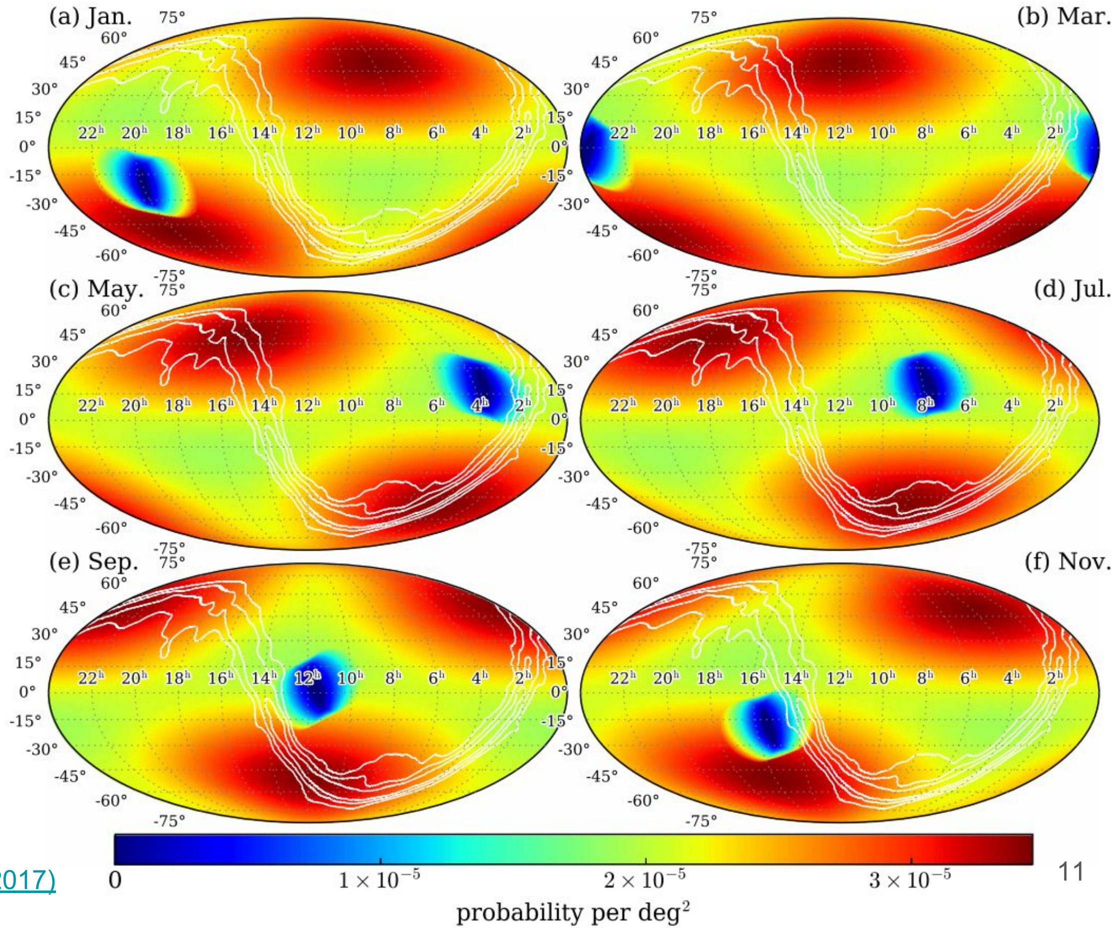


Even stranger morphologies are possible!

source distributions: spatial distributions

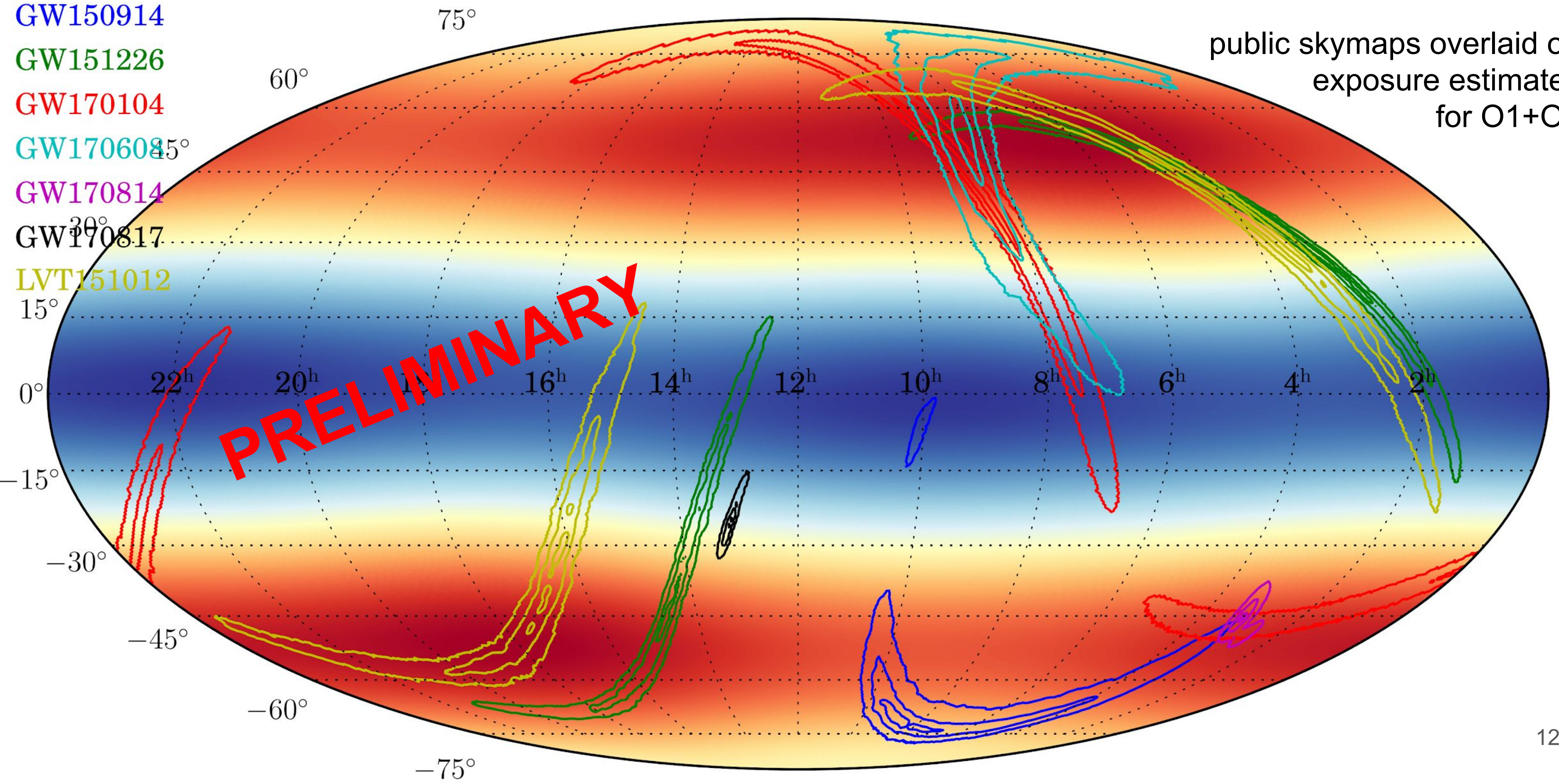
Gravitational-wave detectors are not uniformly sensitive over the sky. They also don't operate uniformly in time!





ApJ 835, 1 (2017)

source distributions: spatial distributions



public skymaps overlaid on exposure estimates for O1+O2

References

Limits on the number of spacetime dimensions from GW170817. arXiv:1801.08160

Astrophysical Implications of the binary black hole merger GW150914. ApJL 818, 2 (2016).

Speed of gravitational waves and black hole hair. PRD 97, 084005 (2018).

GW170817: Measurements of neutron star radii and equation of state. arXiv:1805.11581 (2018).

Properties of the binary neutron star merger GW170817. arXiv:1805.11579 (2018).

GW170814: A three-detector observation of gravitational waves from a binary black hole coalescence. PRL 119, 141101 (2017).

Tests of General Relativity with GW150914. PRL 116, 221101 (2016).

Gravitational waves and gamma-rays from a binary neutron star merger: GW170817 and GRB170817A. ApJL 848, 2 (2017).

Estimating the contribution of dynamical ejecta in the kilonova associated with GW170817. ApJL 850, 2 (2017).

On the progenitor of binary neutron star merger GW170817. ApJL 850, 2 (2017).

How many kilonovae can be found in past, present, and future survey data sets? ApJL 852, 1 (2017).

A gravitational-wave standard siren measurement of the Hubble constant. Nature 551, 85-88 (2017).

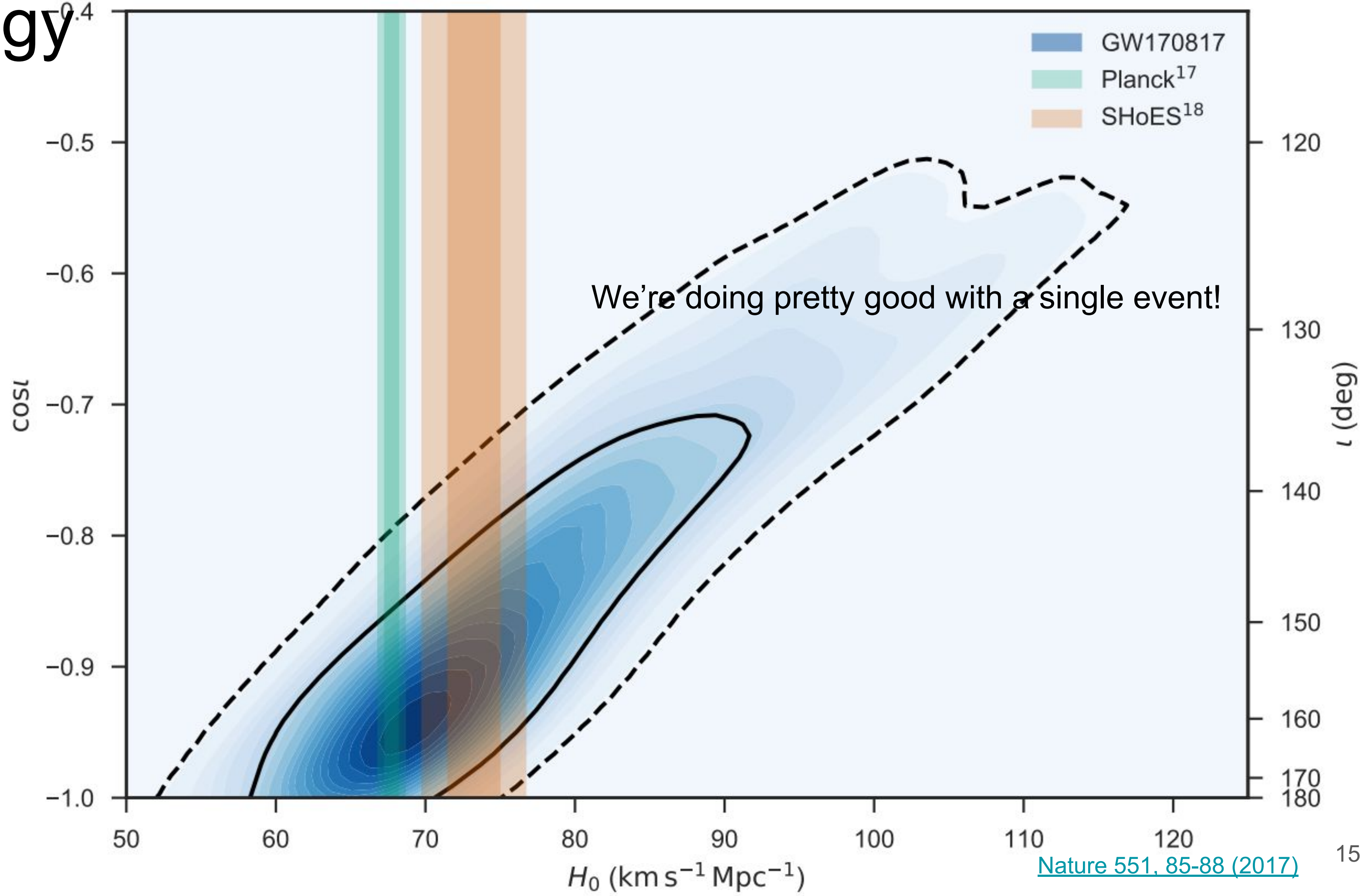
Precision standard siren cosmology. arXiv:1712.06531 (2017).

Where are LIGO's big black holes? ApJL 851, 2 (2017).

Does the black hole merger rate evolve with redshift? arXiv:1805.10270 (2018).

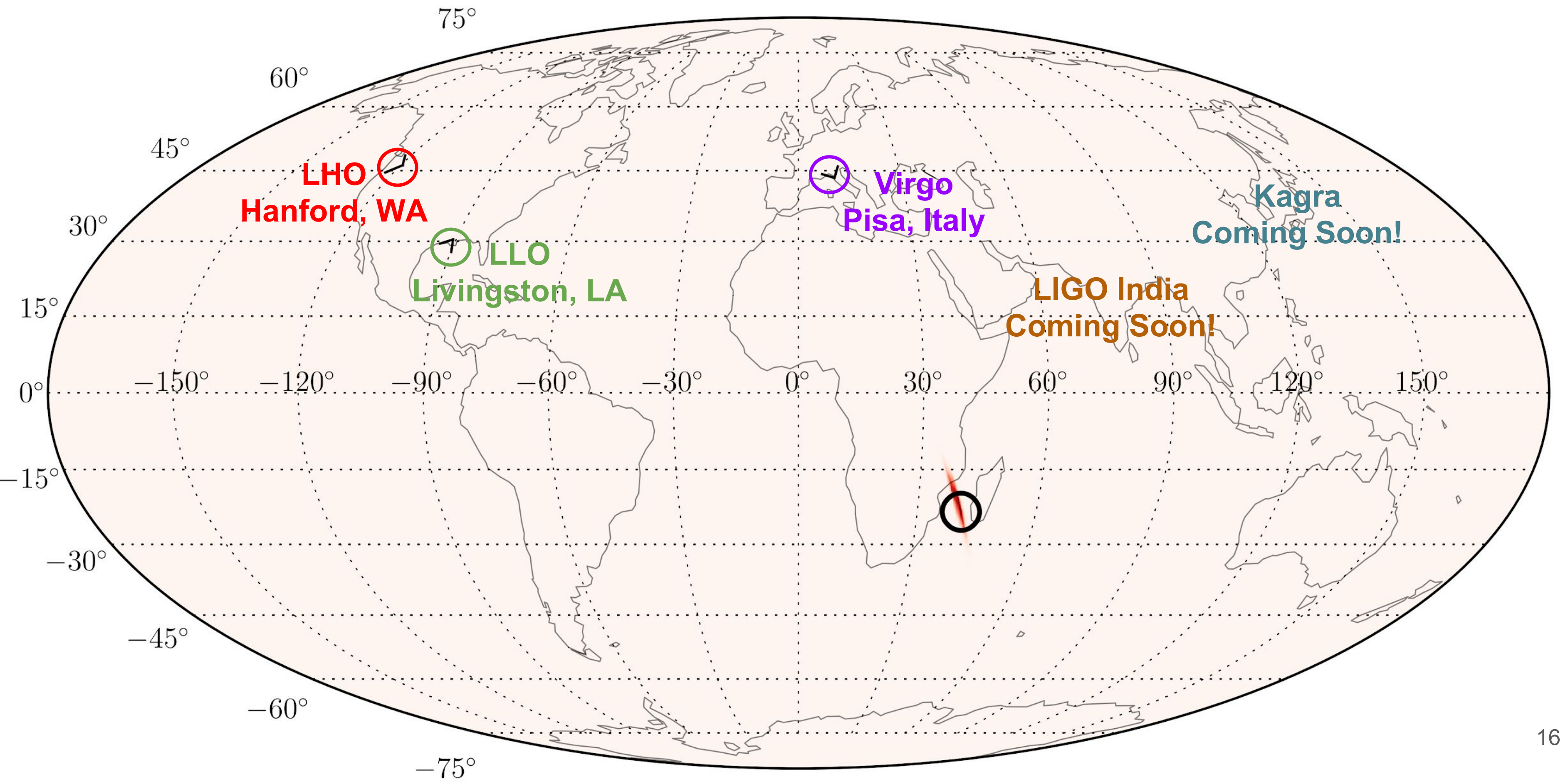
Observational selection effects with ground-based gravitational wave detectors. ApJ 835, 1 (2017).

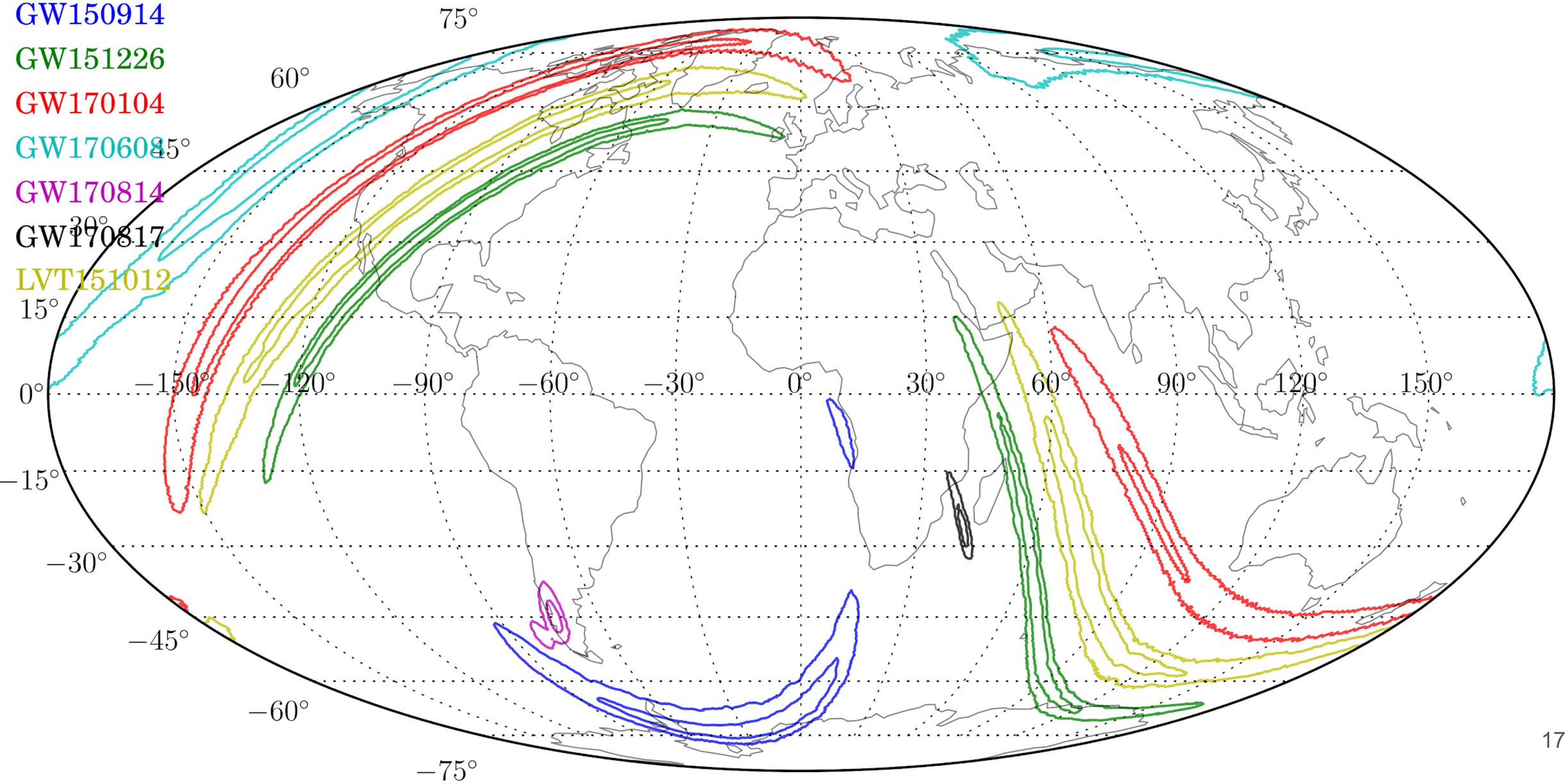
cosmology

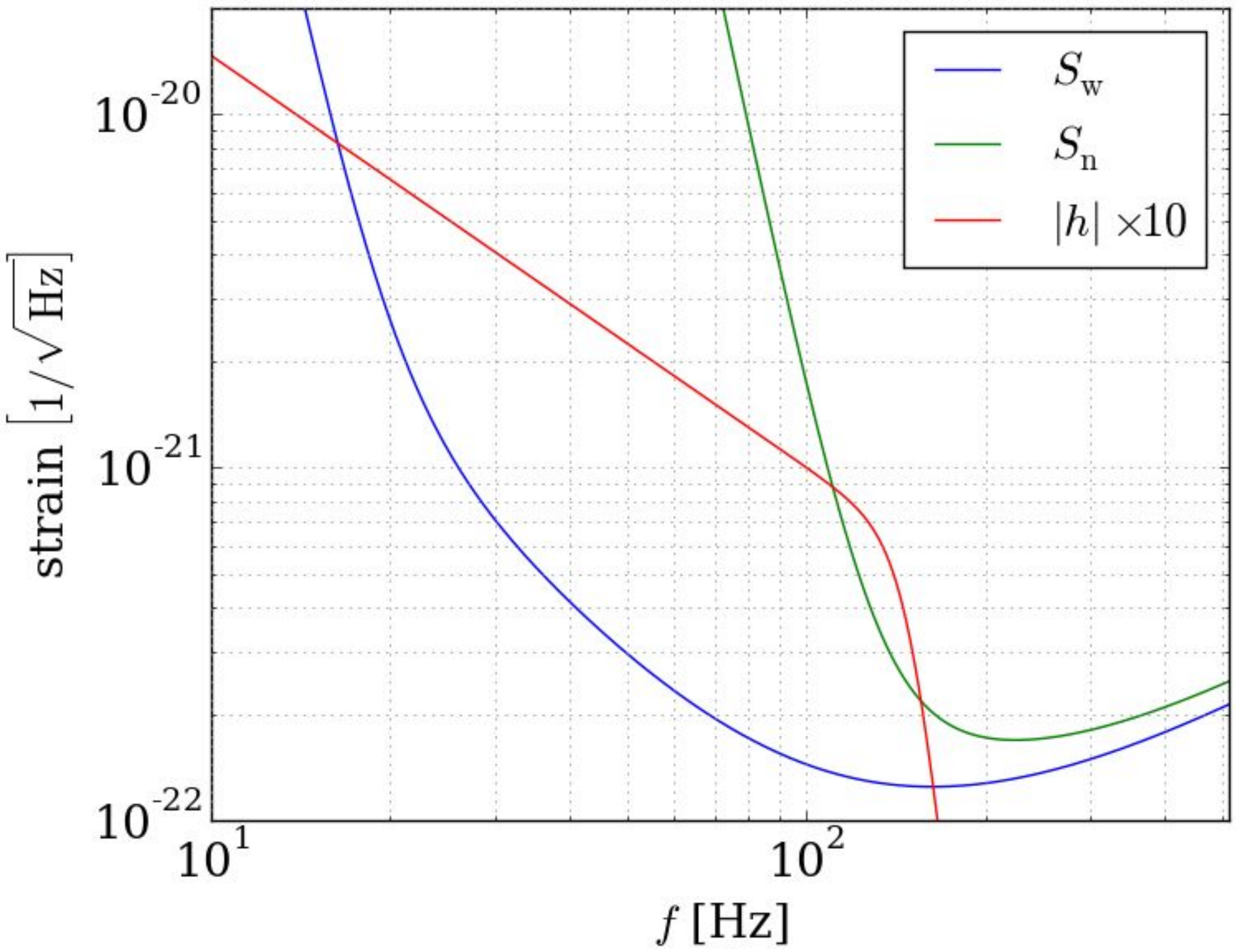


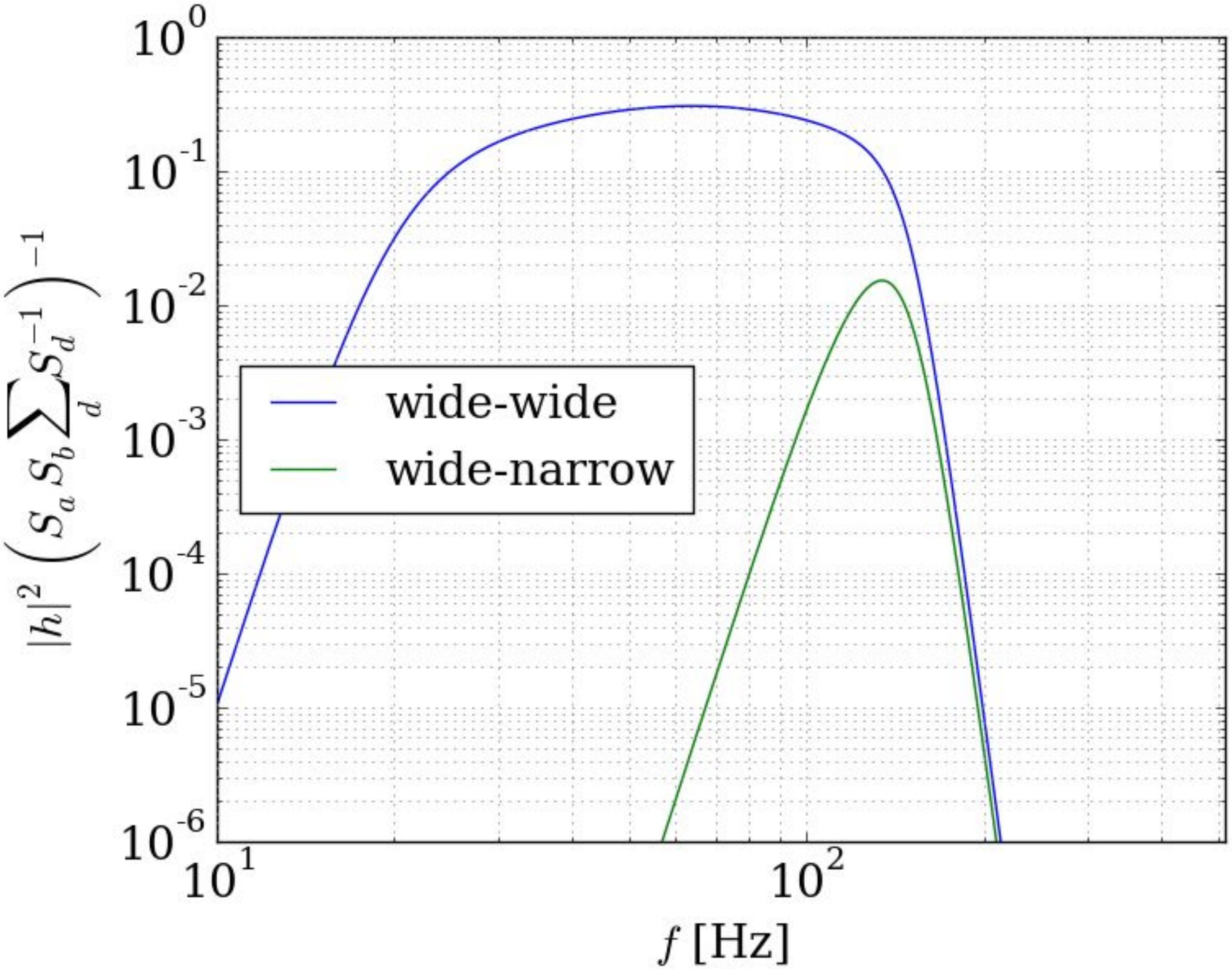
We're doing pretty good with a single event!

Nature 551, 85-88 (2017)

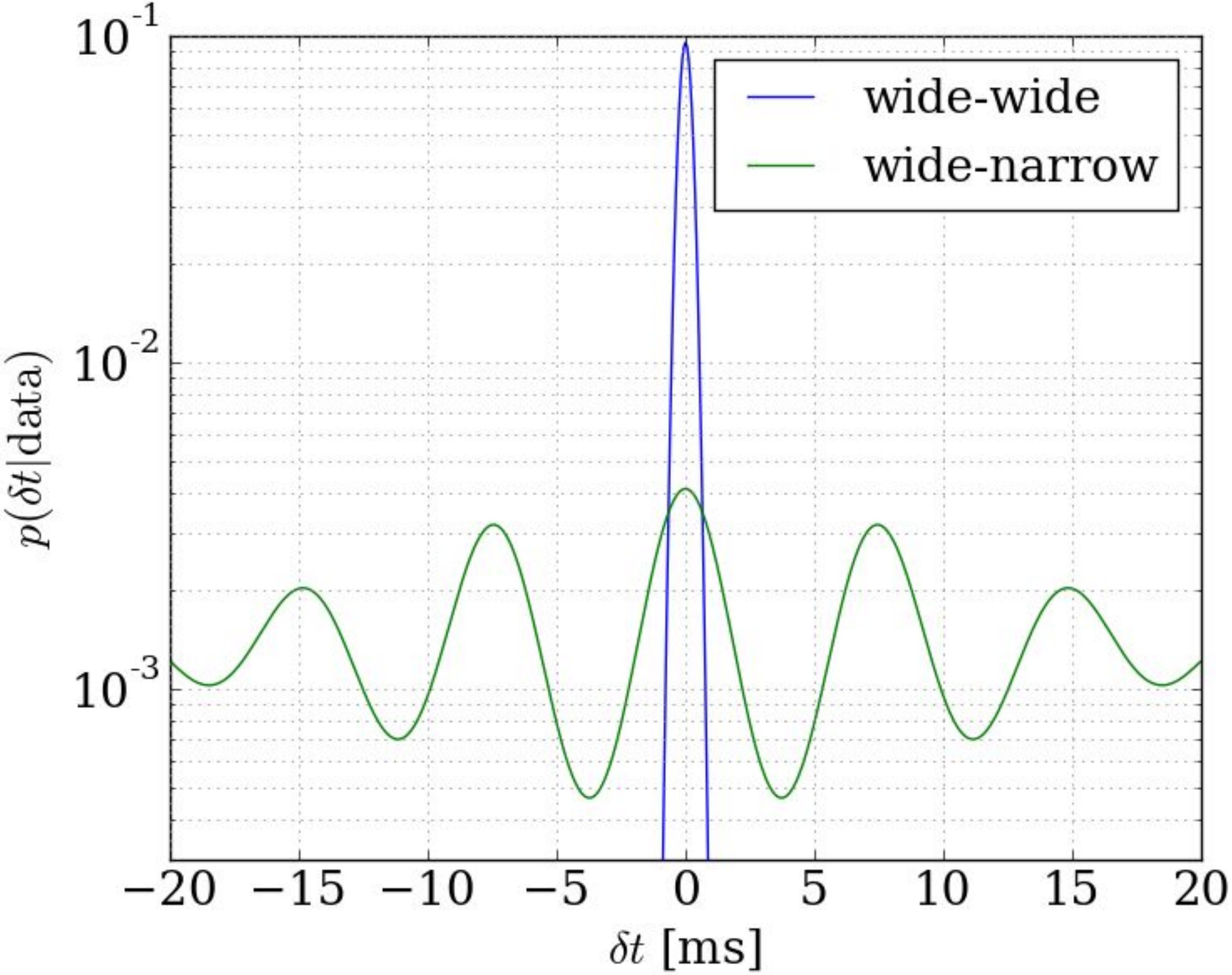

LHO
Hanford, WA
LLO
Livingston, LA
Virgo
Pisa, Italy
Kagra
Coming Soon!
LIGO India
Coming Soon!
75°
60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
−75°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°


GW150914
GW151226
GW170104
GW170608
GW170814
GW170817
LVT151012
75°
60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
−75°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°

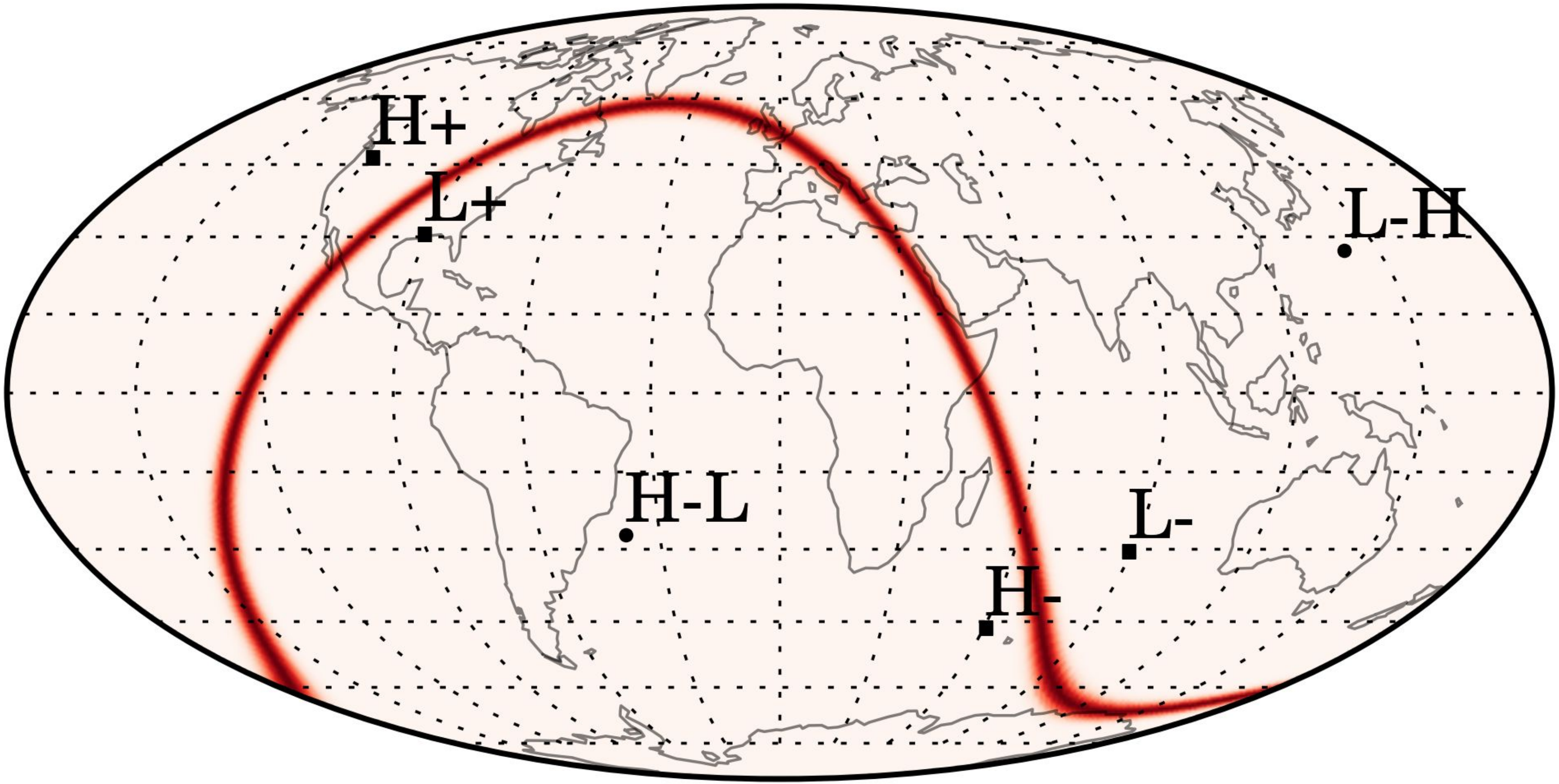

S_w
S_n
$|h| \times 10$
10^{-20}
10^{-21}
10^{-22}
10^1
10^2
strain $[1/\sqrt{\text{Hz}}]$
f [Hz]

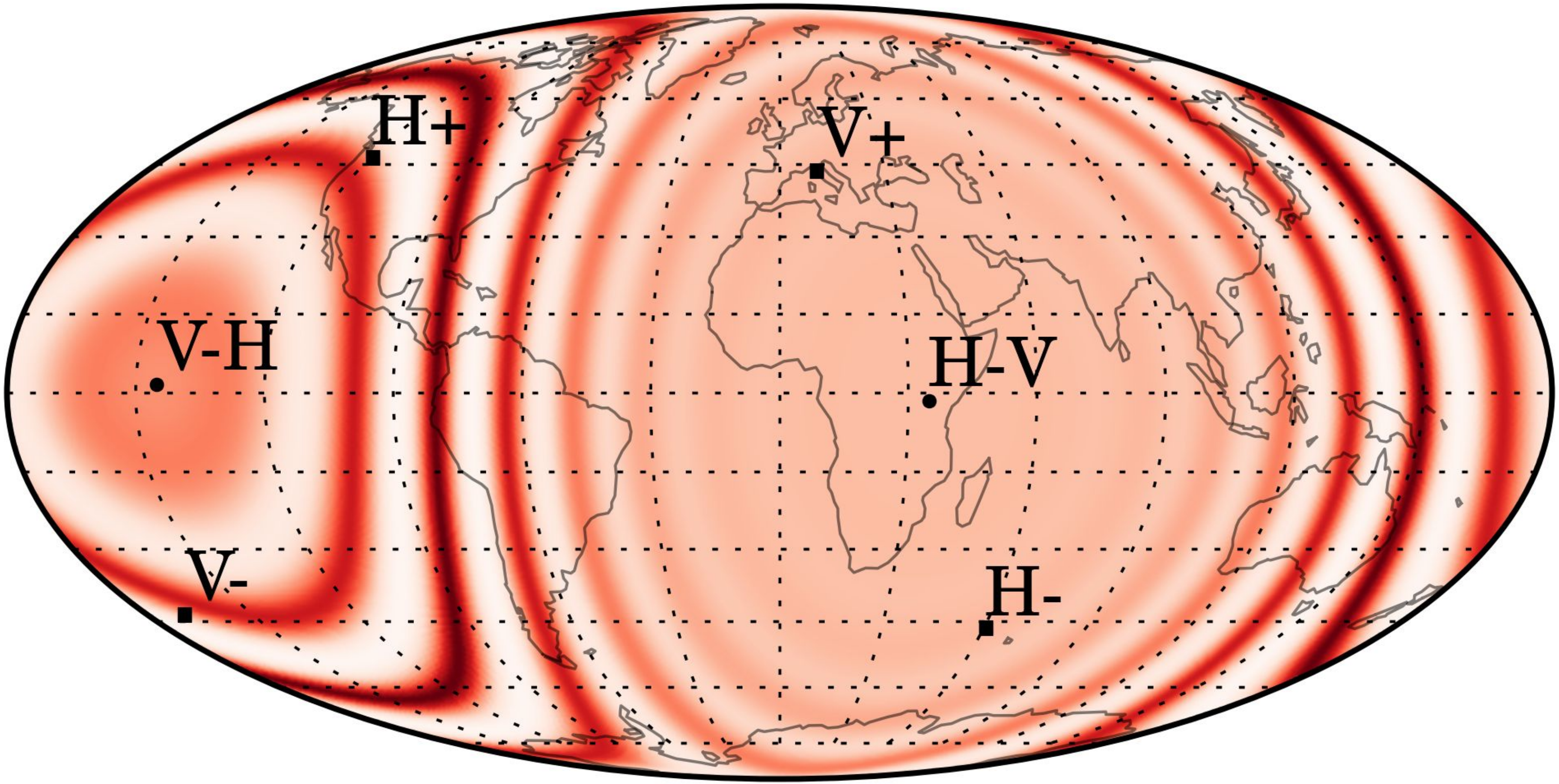


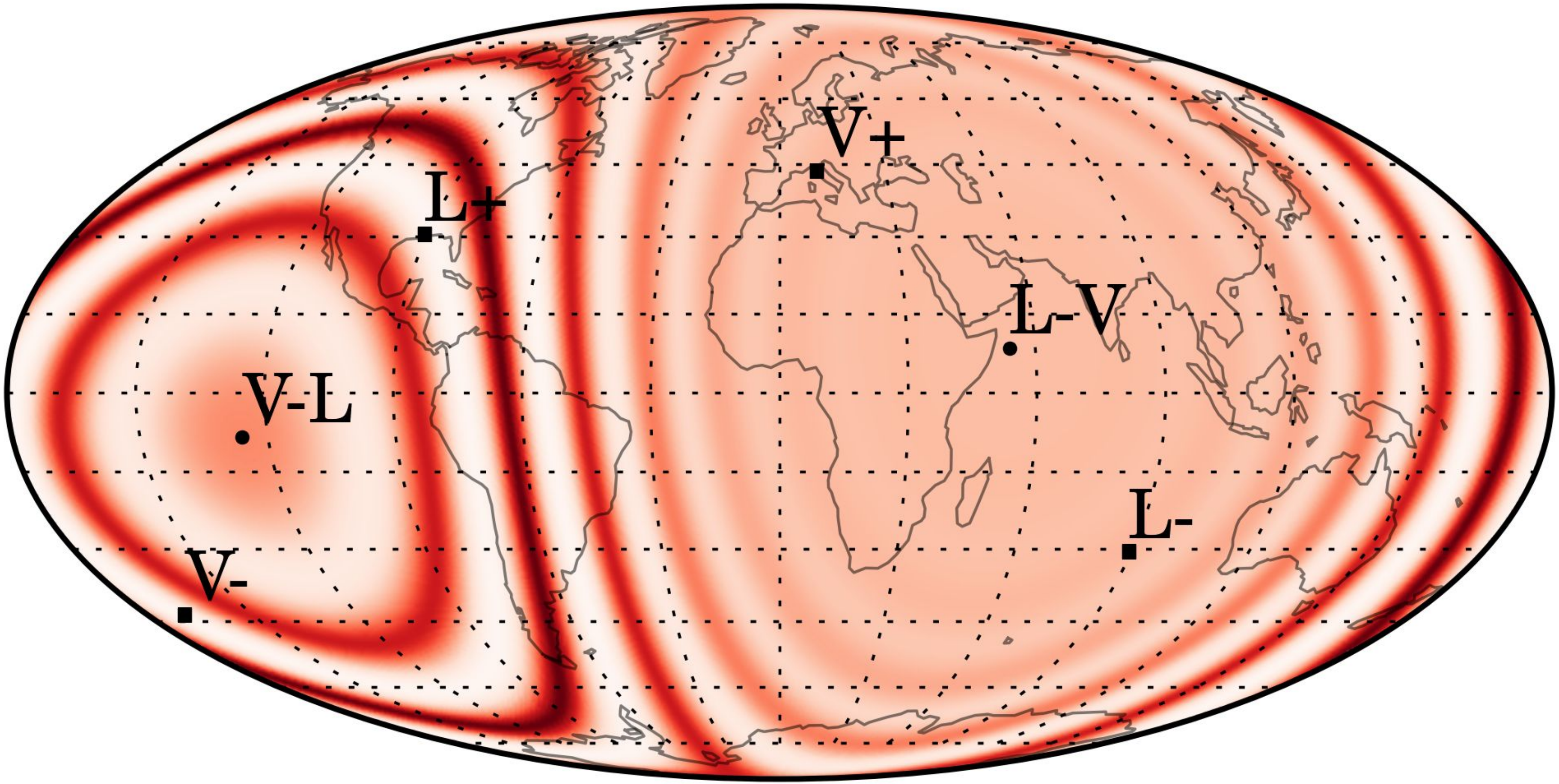
$|h|^2 \left(S_a S_b \sum_d S_d^{-1} \right)^{-1}$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^1
10^2
f [Hz]
wide-wide
wide-narrow



10^{-1}
10^{-2}
10^{-3}
$p(\delta t|\mathrm{data})$
wide-wide
wide-narrow
−20
−15
−10
−5
0
5
10
15
20
δt [ms]


H+
L+
L-H
H-L
L-
H-


H+
V+
V-H
H-V
V-
H-


V+
L+
L-V
V-L
L-
V-