GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

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COSMOLOGICAL CONSTRAINTS ON THE KS AXIVERSE

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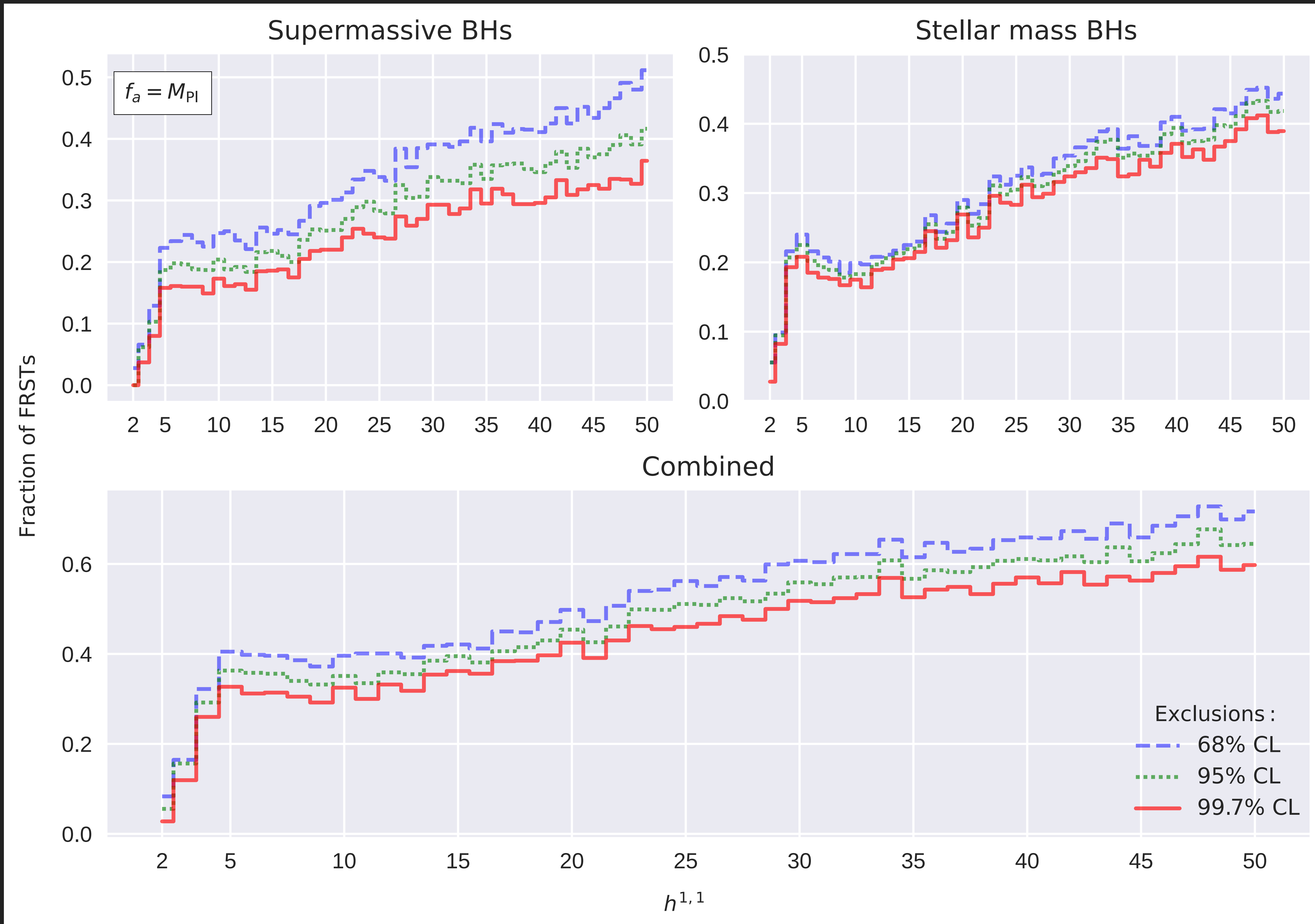
WITH DEMIRTAS, LONG, MARSH, McALLISTER, STOTT

2009.XXXXX

STRING PHENO SEMINAR SERIES

22 SEPTEMBER 2020

TAKE HOME MESSAGE: BLACK HOLES MAY CONSTRAIN STRING GEOMETRIES



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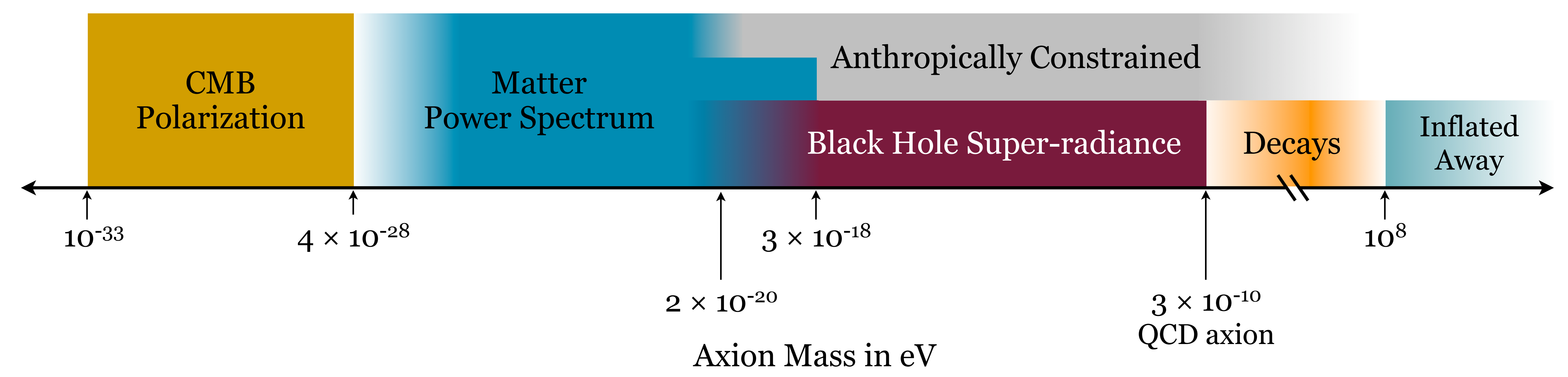
- Kreuzer-Skarke Axiverse
- Black Hole SuperRadiance (BHSR)
- Constraints

ARVANITAKI+ 2010



KREUZER-SKARKE AXIVERSE

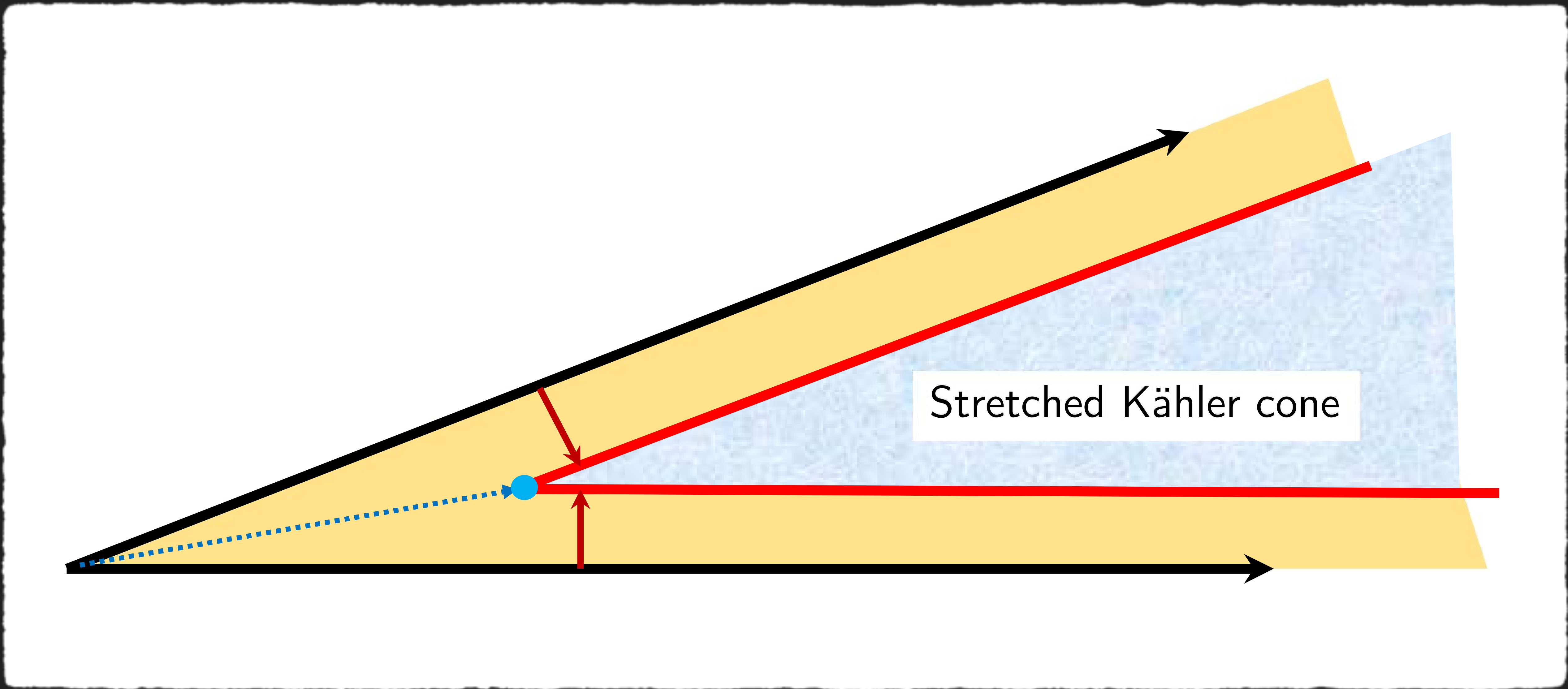
AXIVERSE

ARVANITAKI+ 2010

- pseudoscalar fields arise as zero KK modes of antisymmetric tensor fields
    - e.g. in Type IIB, C_0, C_2, C_4 all present
- their numbers can be determined topologically
    - i.e. number of 4-cycles ~ number of KK zero modes from C_4 ~ $h^{1,1}$
- number of cycles in $\mathcal{M}_6$ may be $\mathcal{O}(10^5)$
- masses of axions $\propto$ exp (– volumes of cycles)

STRING BACKGROUND

DEMIRTAS+ 2018



STRING BACKGROUND

- Type IIB compactified on a CY3, *X*
- Geometric data $\theta_i := \int_{D_i} C_4$
  - $$\tau_i := \frac{1}{2}\int_{D_i} J \wedge J \Longrightarrow T_i := \tau_i + i\theta_i$$
  - $$\mathcal{V} = \frac{1}{6}\int_X J \wedge J \wedge J \Rightarrow \mathcal{K} = -2\log\mathcal{V} \Rightarrow K_{ij} = \partial_i\partial_j\mathcal{K}$$

STRING BACKGROUND

Sample $\tau_i, \mathcal{V}$

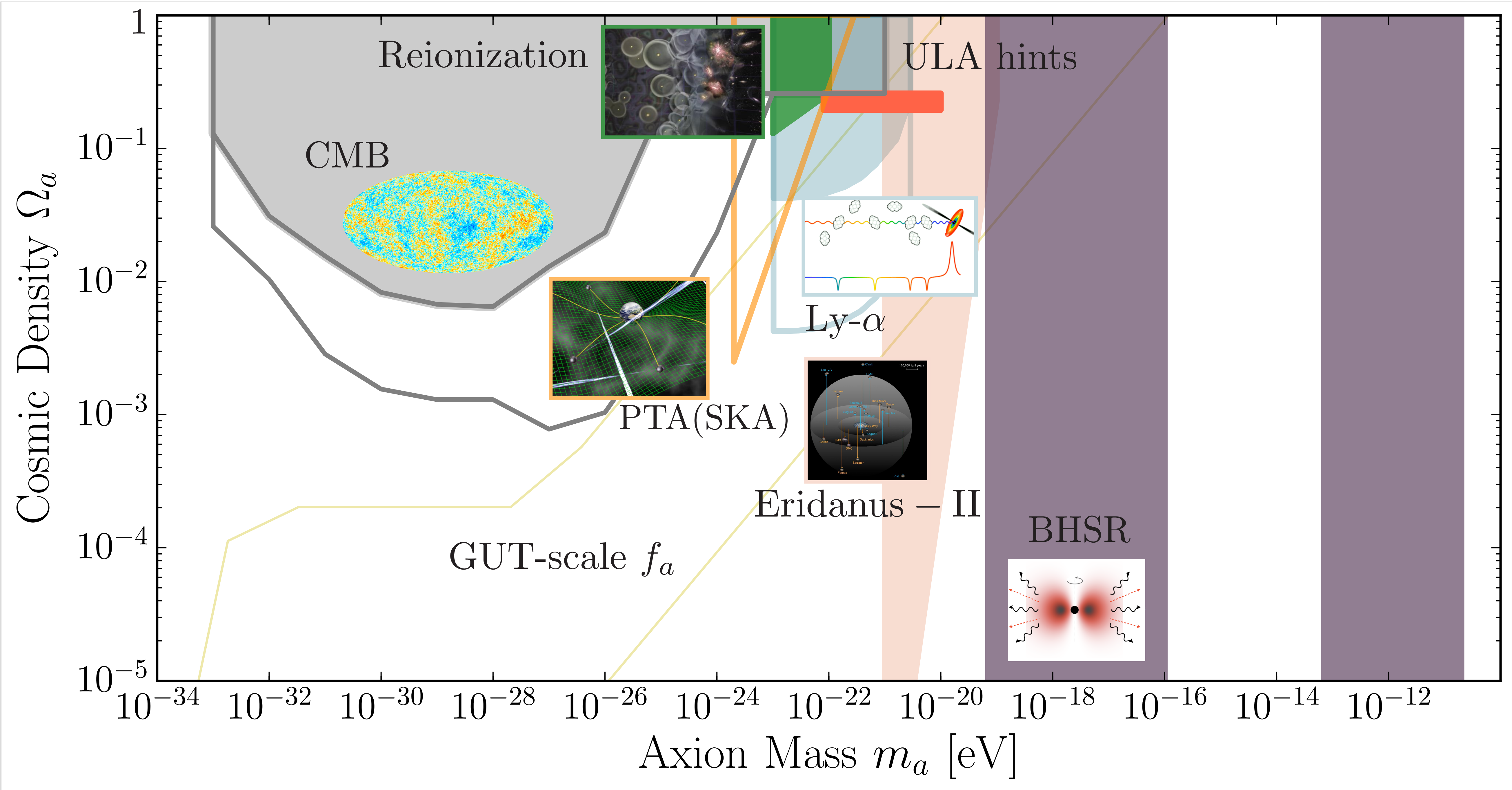
Prime effective divisors

$$\mathcal{L} = \frac{M_{\mathrm{P}}^2}{2} K_{ij} \partial^\mu \theta^i \partial_\mu \theta^j - \sum_{a=1}^{P} \Lambda_a \cos \mathcal{Q}_a^i \theta_i$$

$\sim e^{-2\pi\tau_i}$

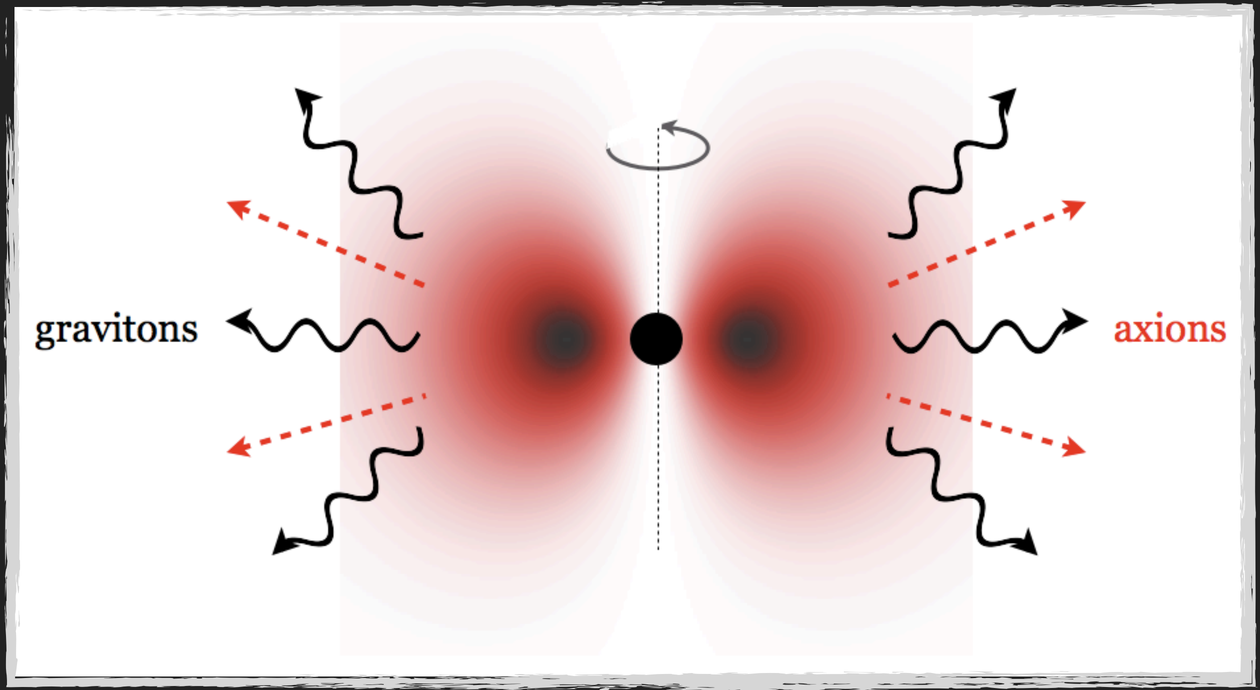
BLACK HOLE SUPERRADIANCE

BHSR EXCLUSIONS



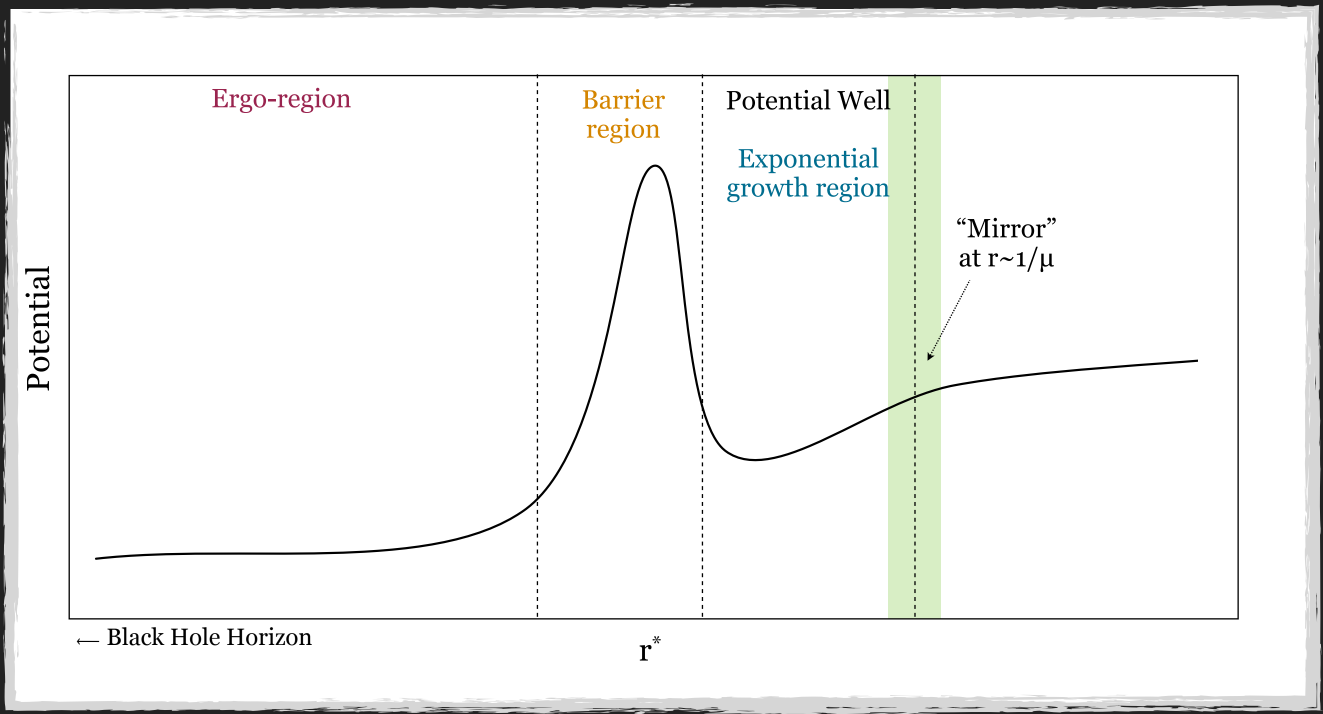
PENROSE PROCESS

- spinning BHs (Kerr) drag matter in *ergoregion* to corotate with BH
- ∂_t Killing vector becomes spacelike



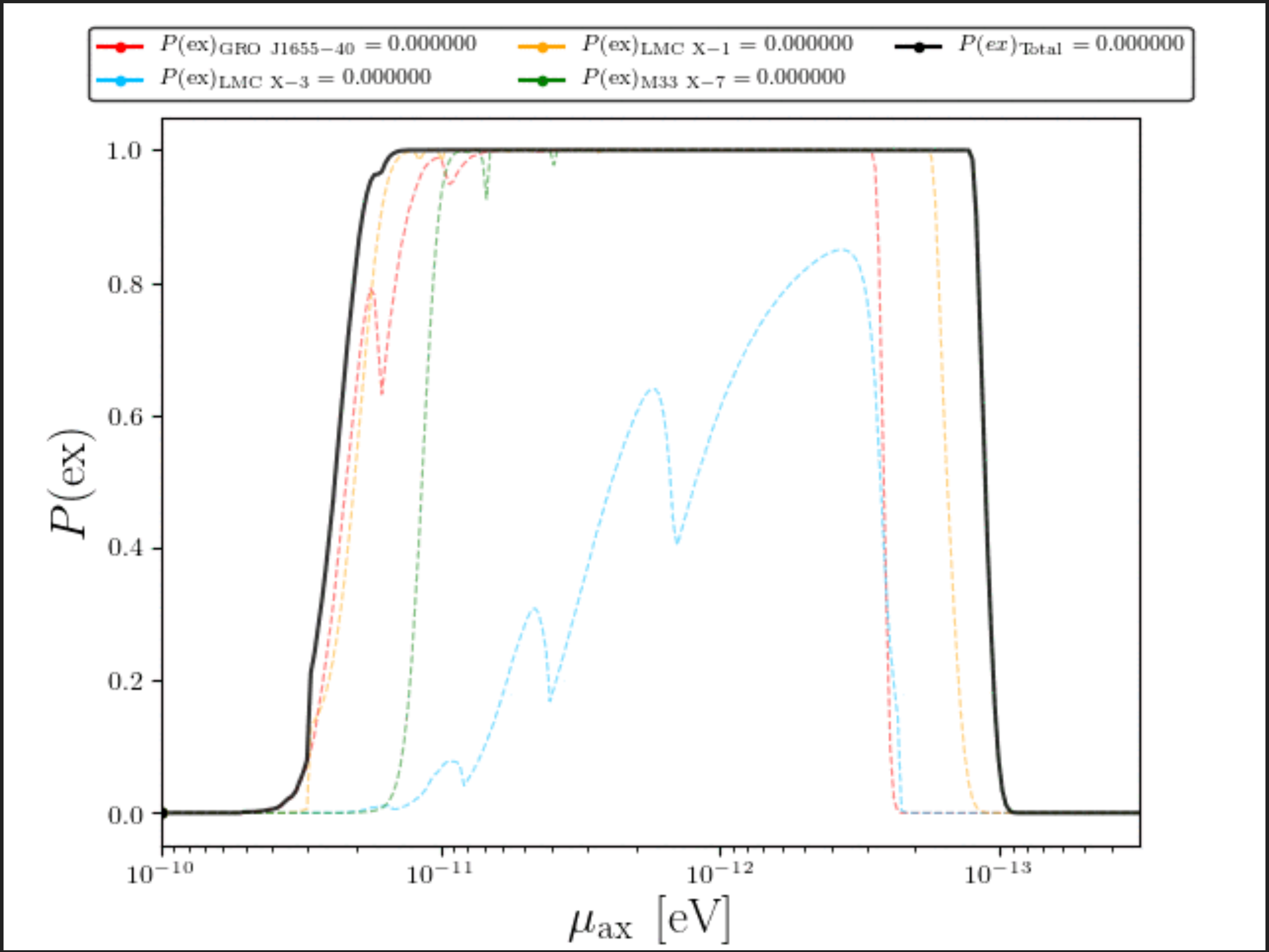
- instability efficiency determined by:
  - M_{BH}
  - m_a
- superradiance only when:

$$0 < \omega_a \lesssim \omega_+$$



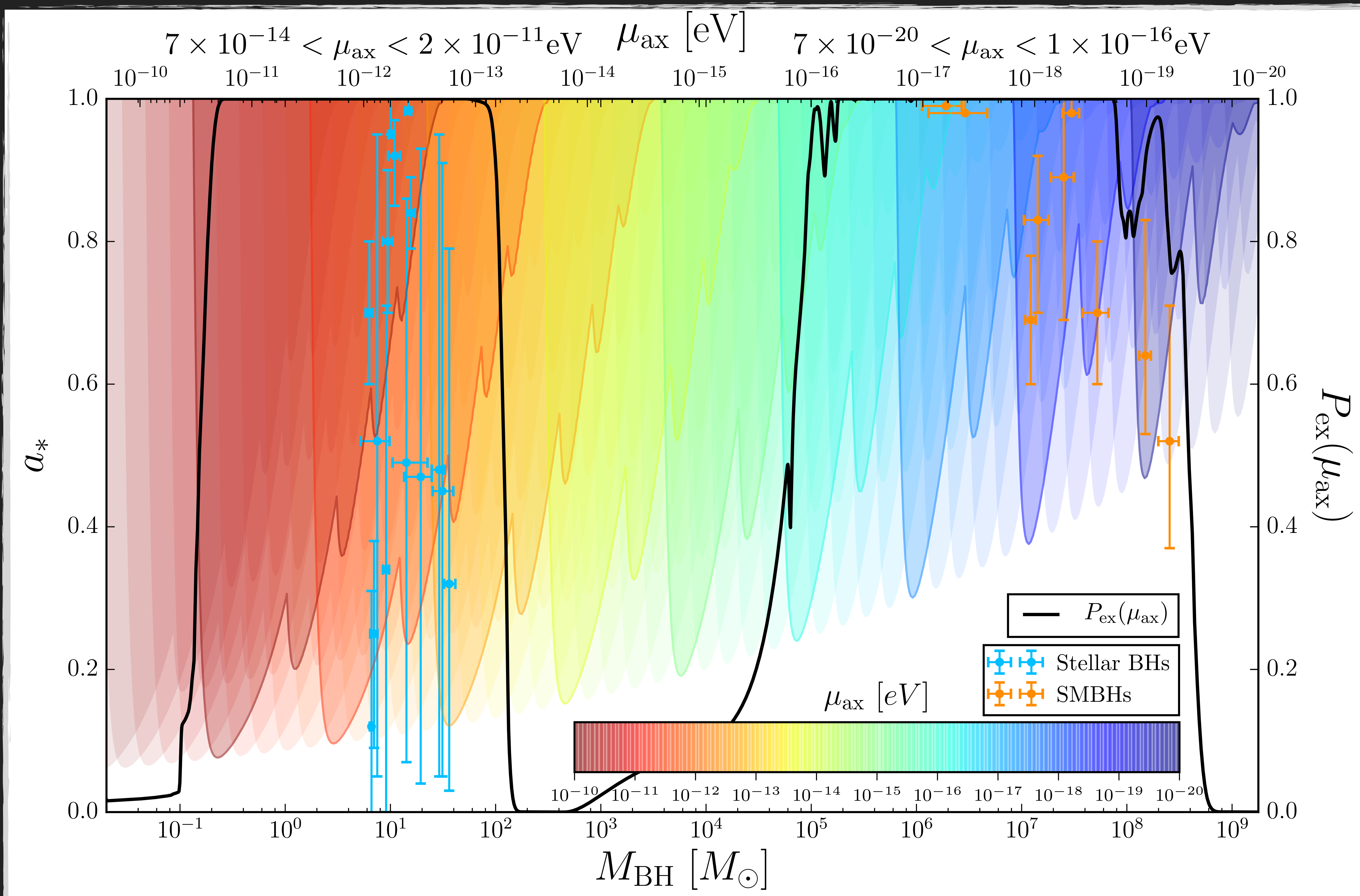
ARVANITAKI+ 2011

BHSR EXCLUSIONS

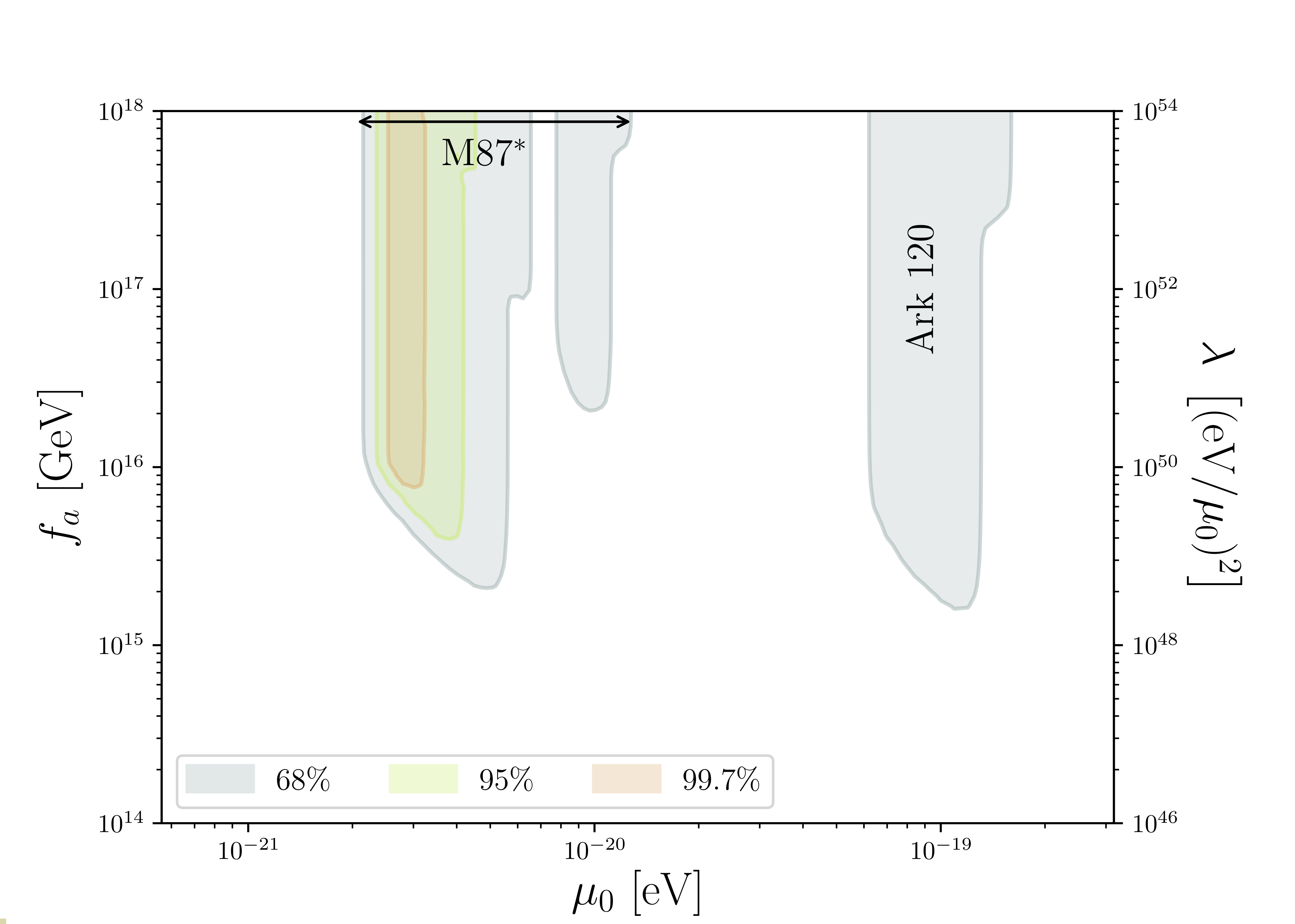


BHSR EXCLUSIONS

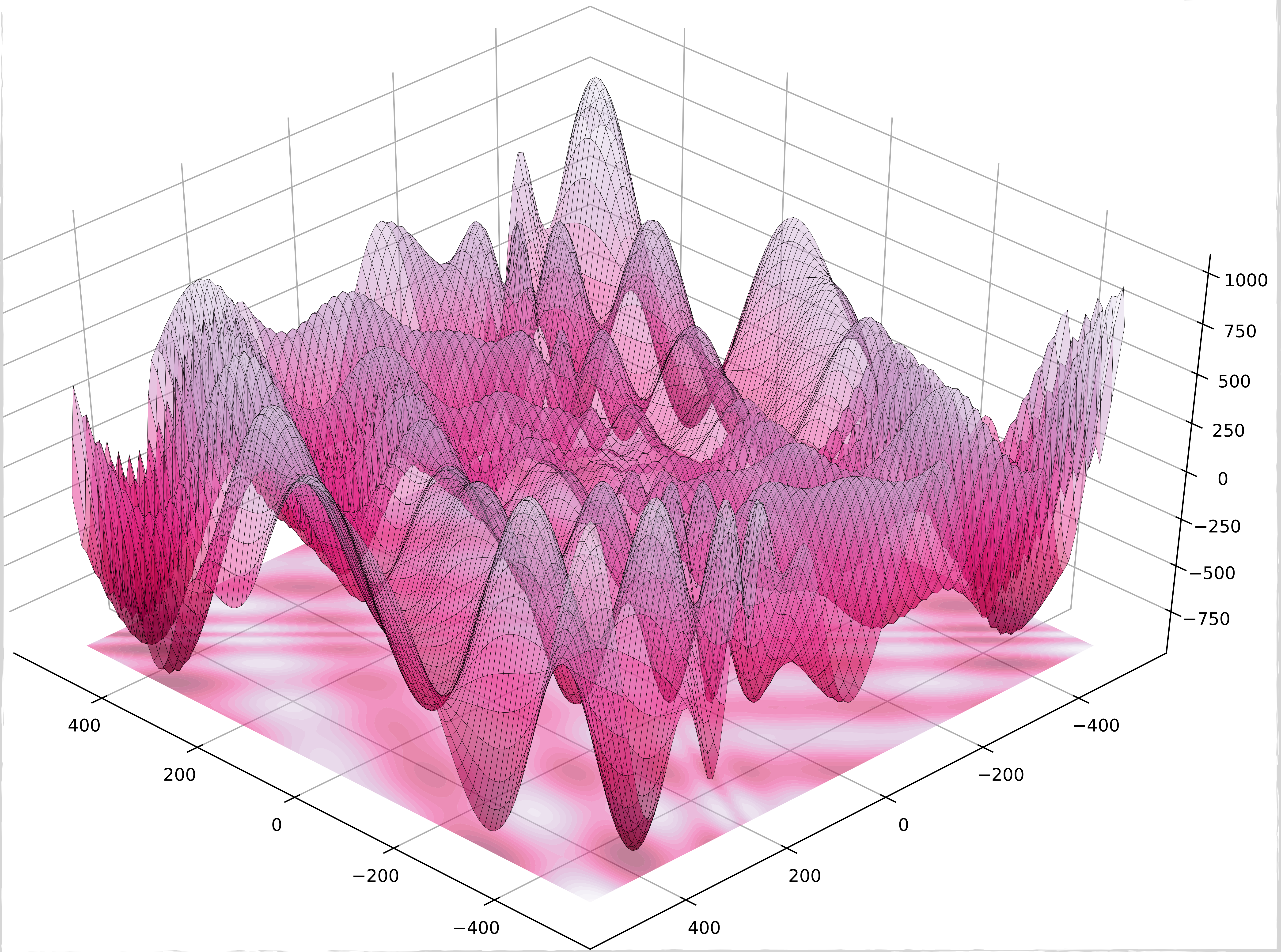
STOTT+ 2018



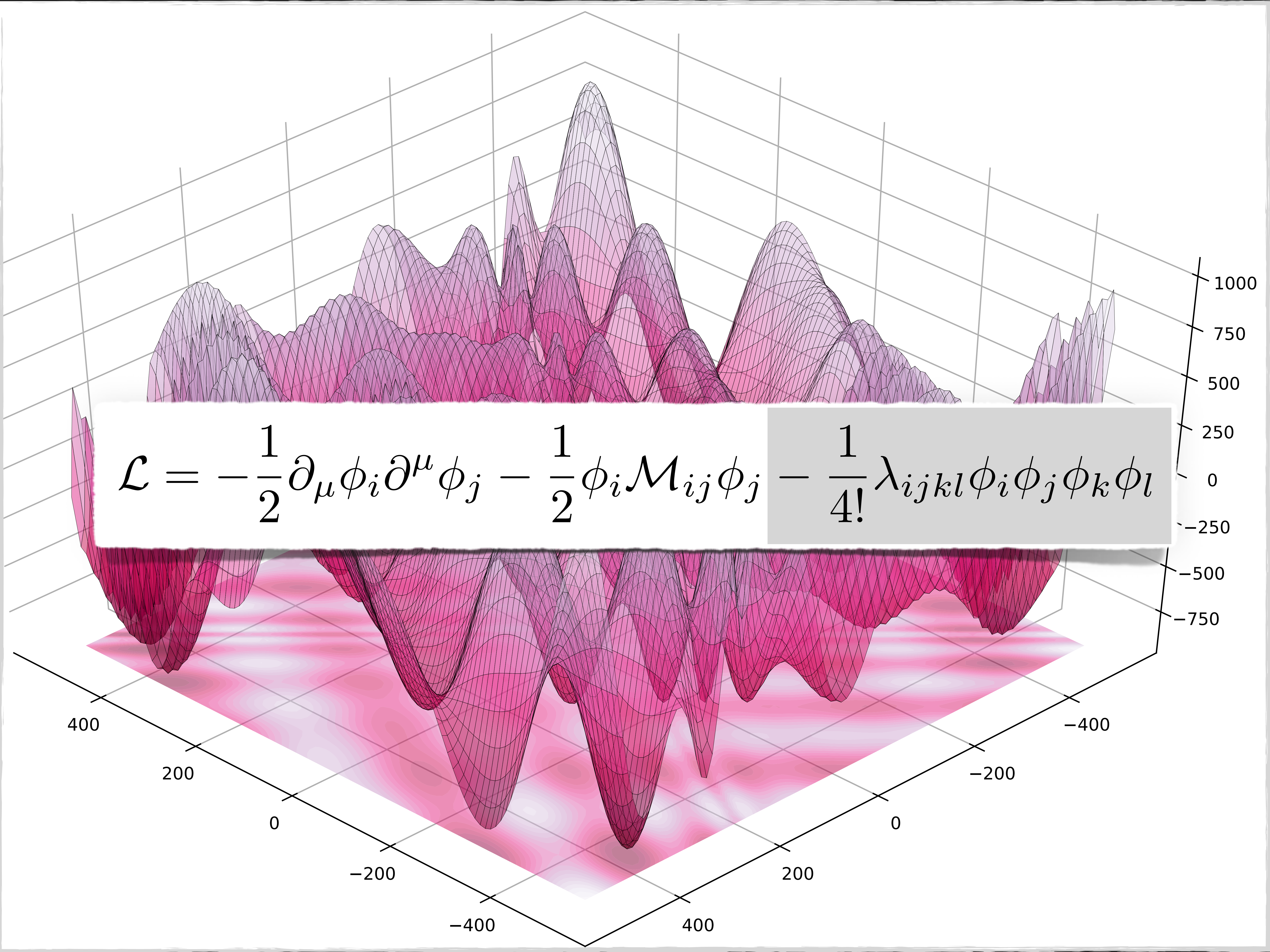
BHSR EXCLUSIONS



CONSTRAINTS ON THE KS AXIVERSE



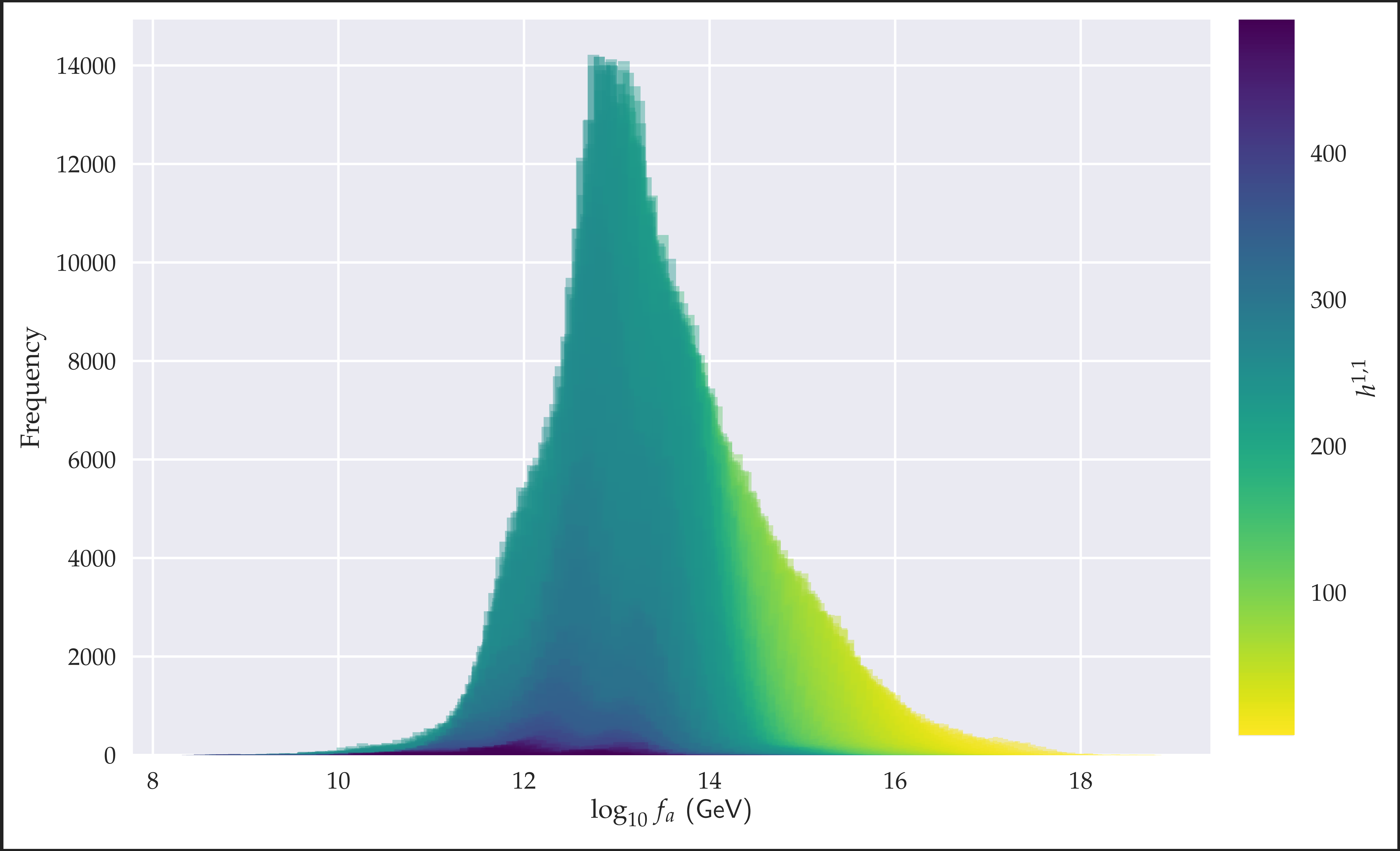
1000
750
500
250
0
−250
−500
−750
400
200
0
−200
−400
−400
−200
0
200
400



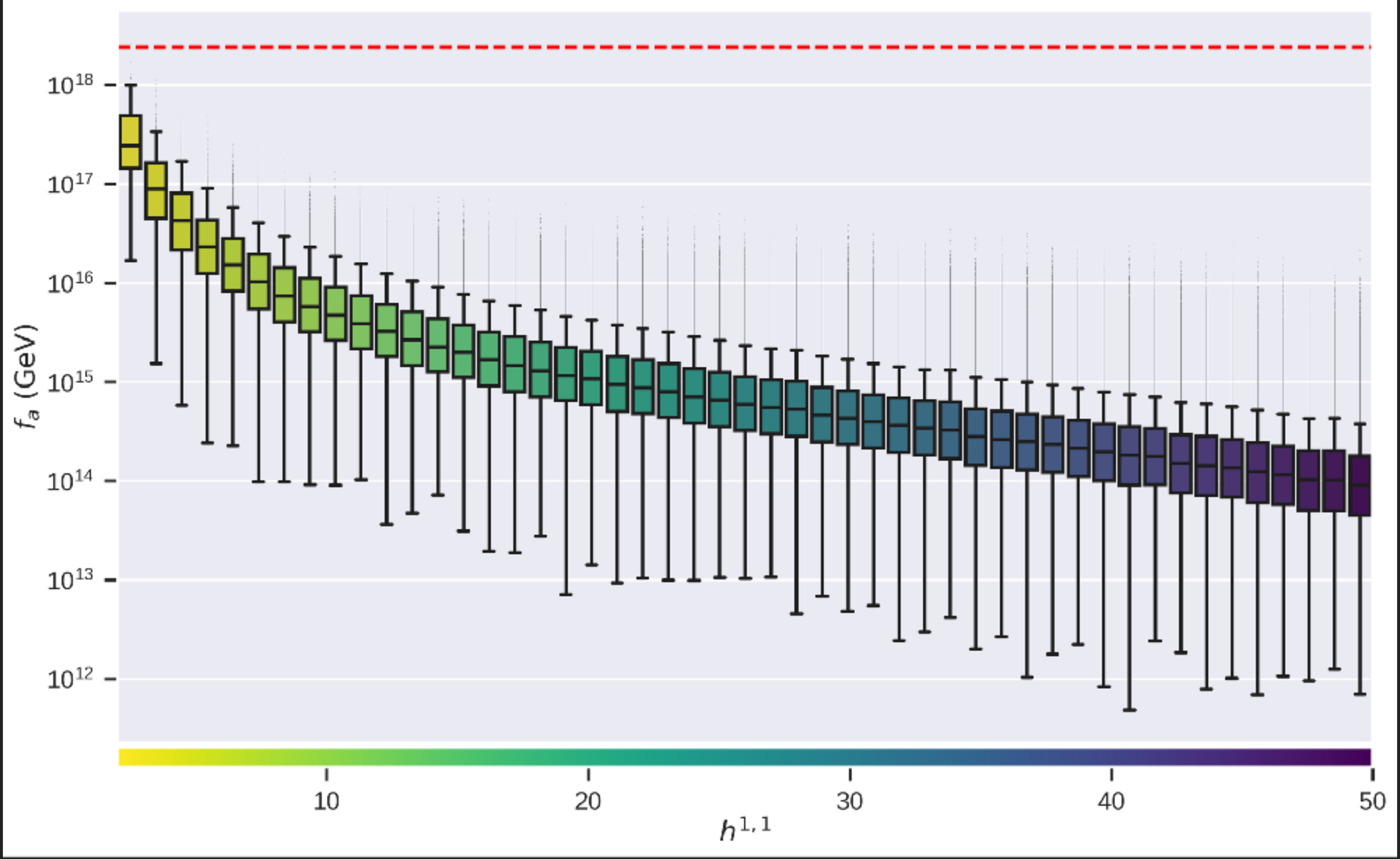
$$\mathcal{L} = -\frac{1}{2}\partial_\mu \phi_i \partial^\mu \phi_j - \frac{1}{2}\phi_i \mathcal{M}_{ij}\phi_j - \frac{1}{4!}\lambda_{ijkl}\phi_i\phi_j\phi_k\phi_l$$

CONSTRAINTS

PERIODICITIES



PERIODICITIES

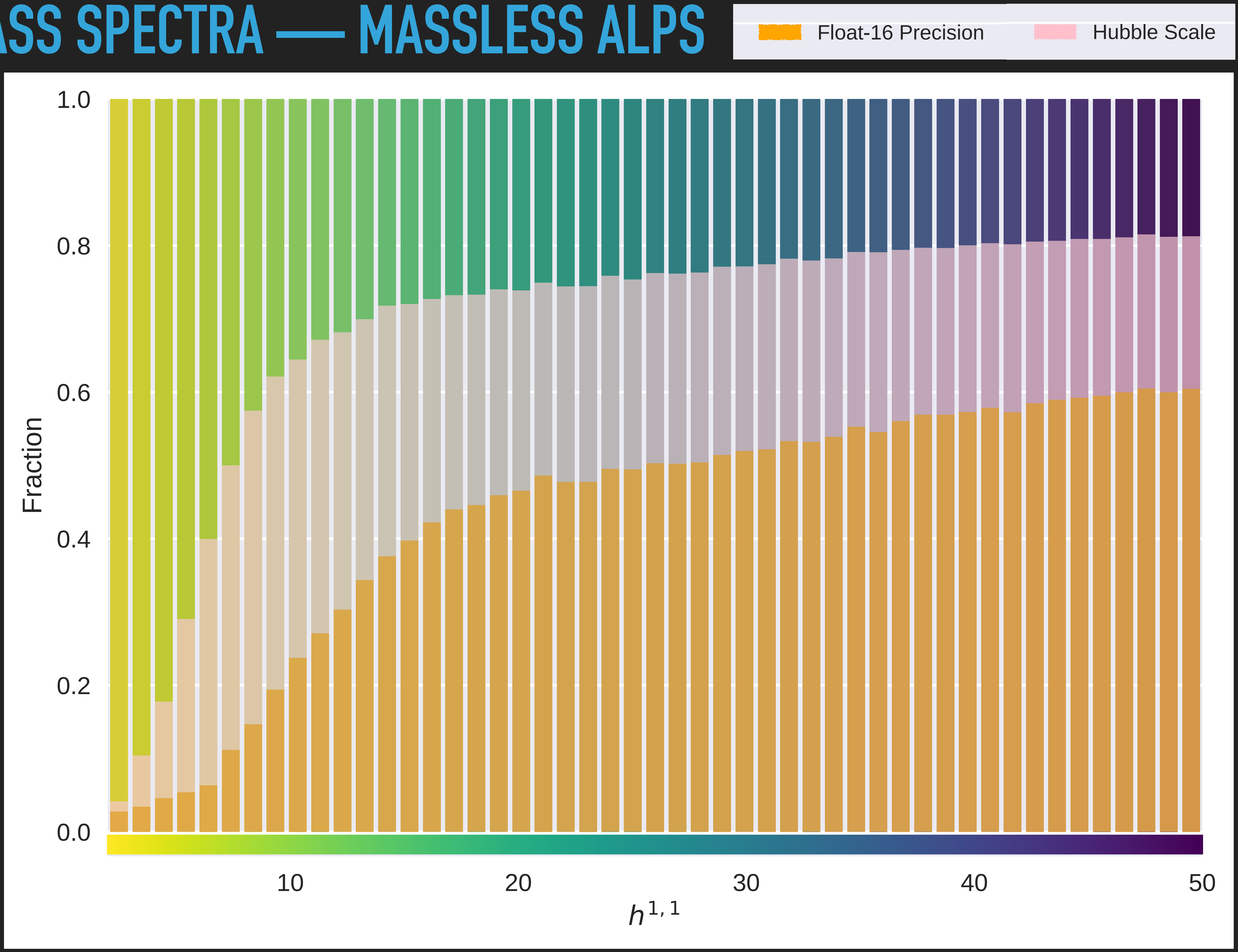


MULTIAXION POTENTIALS — PATH TO CONSTRAINTS

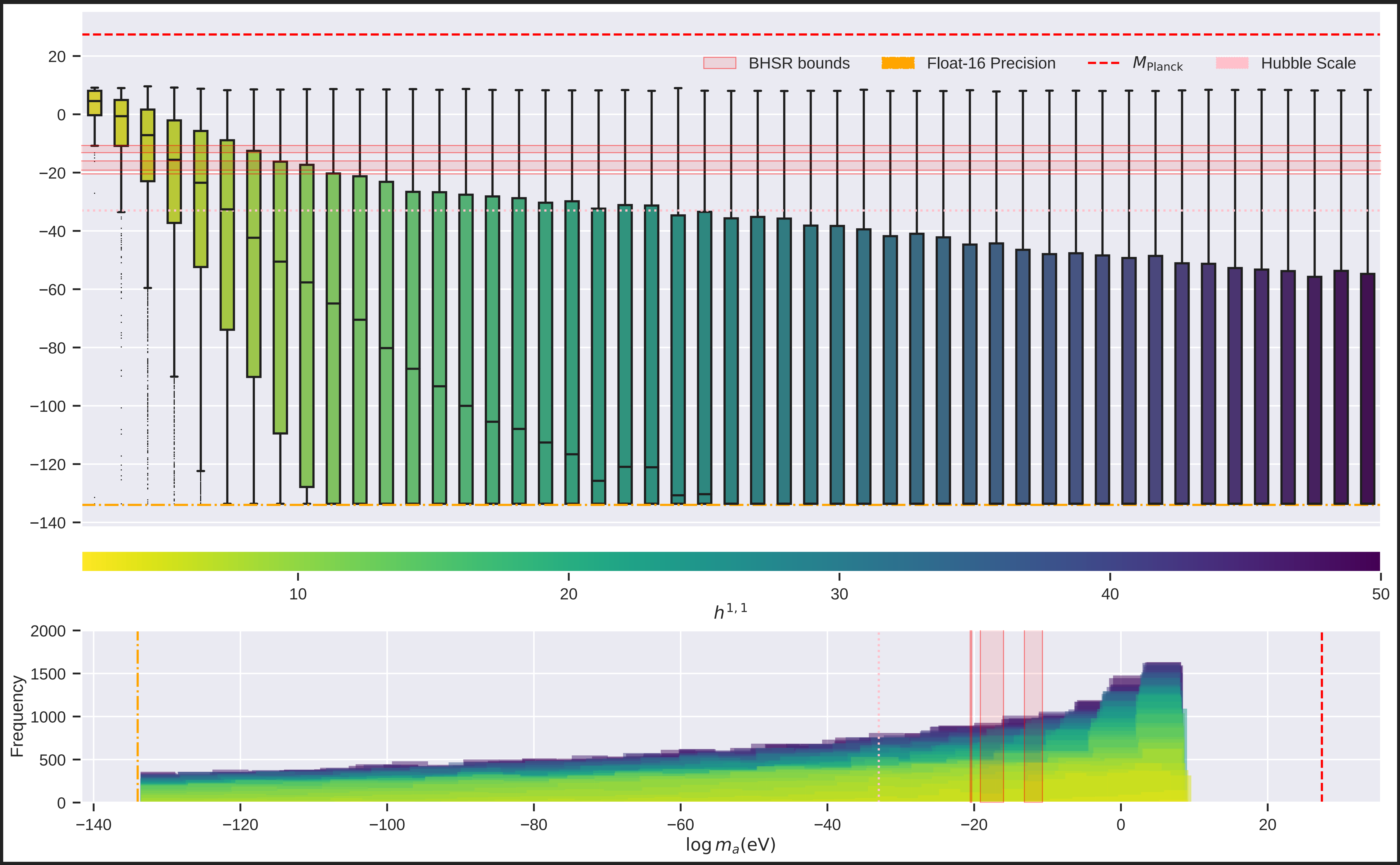
$$\mathcal{L} = -\frac{1}{2}\partial_\mu\phi_i\partial^\mu\phi_j - \frac{1}{2}\phi_i\mathcal{M}_{ij}\phi_j - \frac{1}{4!}\lambda_{ijkl}\phi_i\phi_j\phi_k\phi_l$$

- KS axiverse data:
  - disparate scales in potentials – volume hierarchies
  - flat directions – extremely light axions
  - decreasing decay constants with more ALPs
  - potentials have many cosine terms – $P \gg N$
  - some CPU hours later…

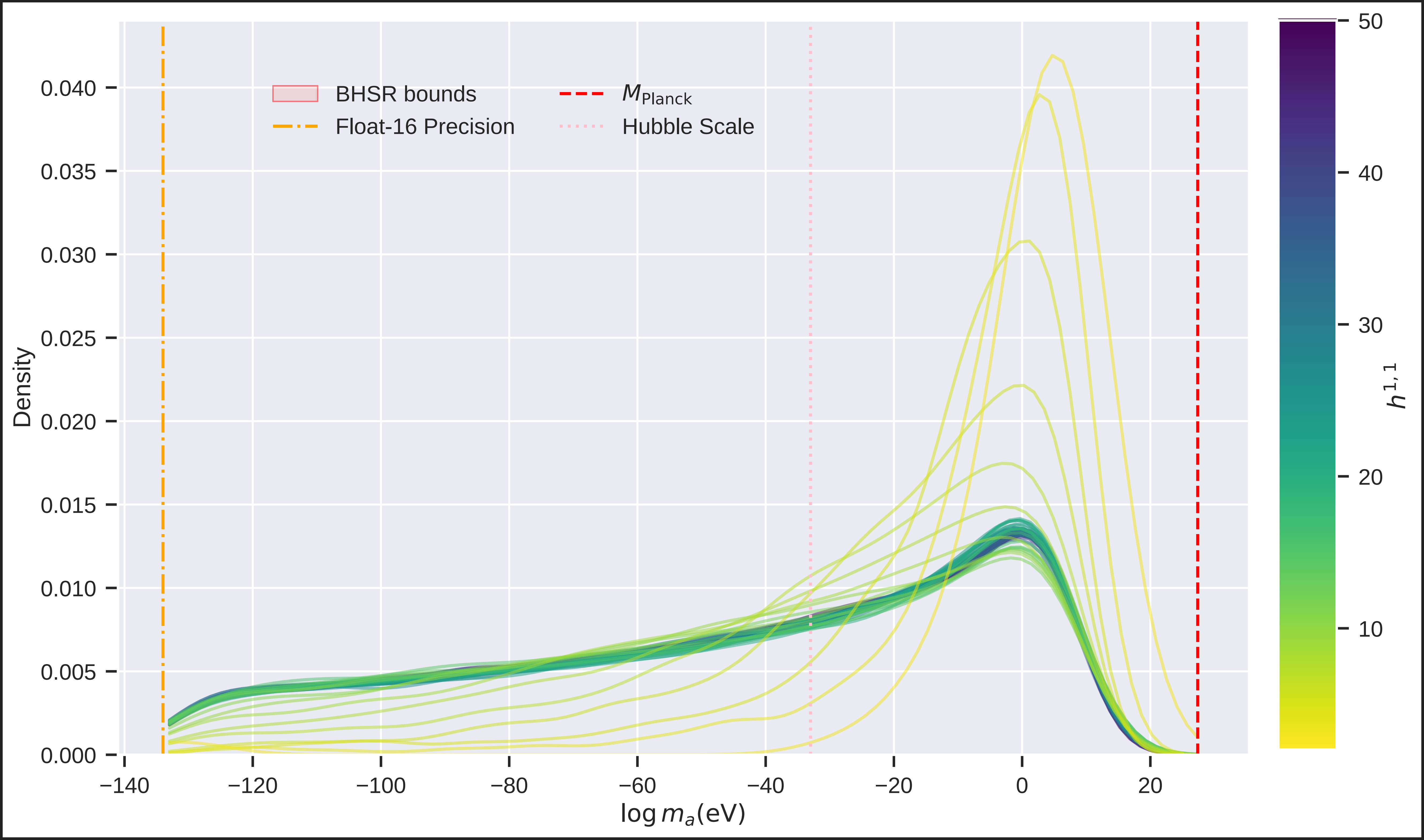
MASS SPECTRA — MASSLESS ALPS



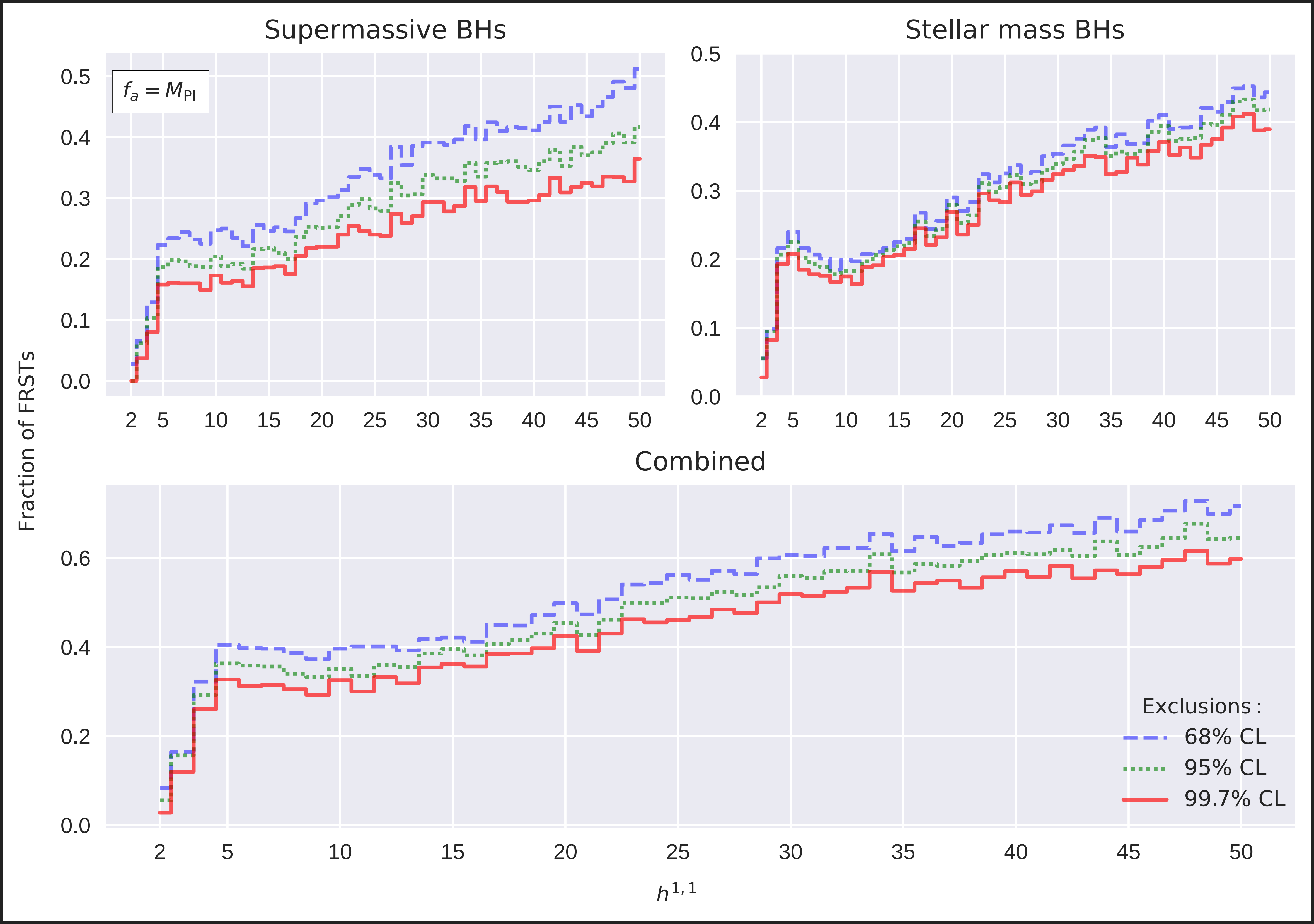
MASS SPECTRA



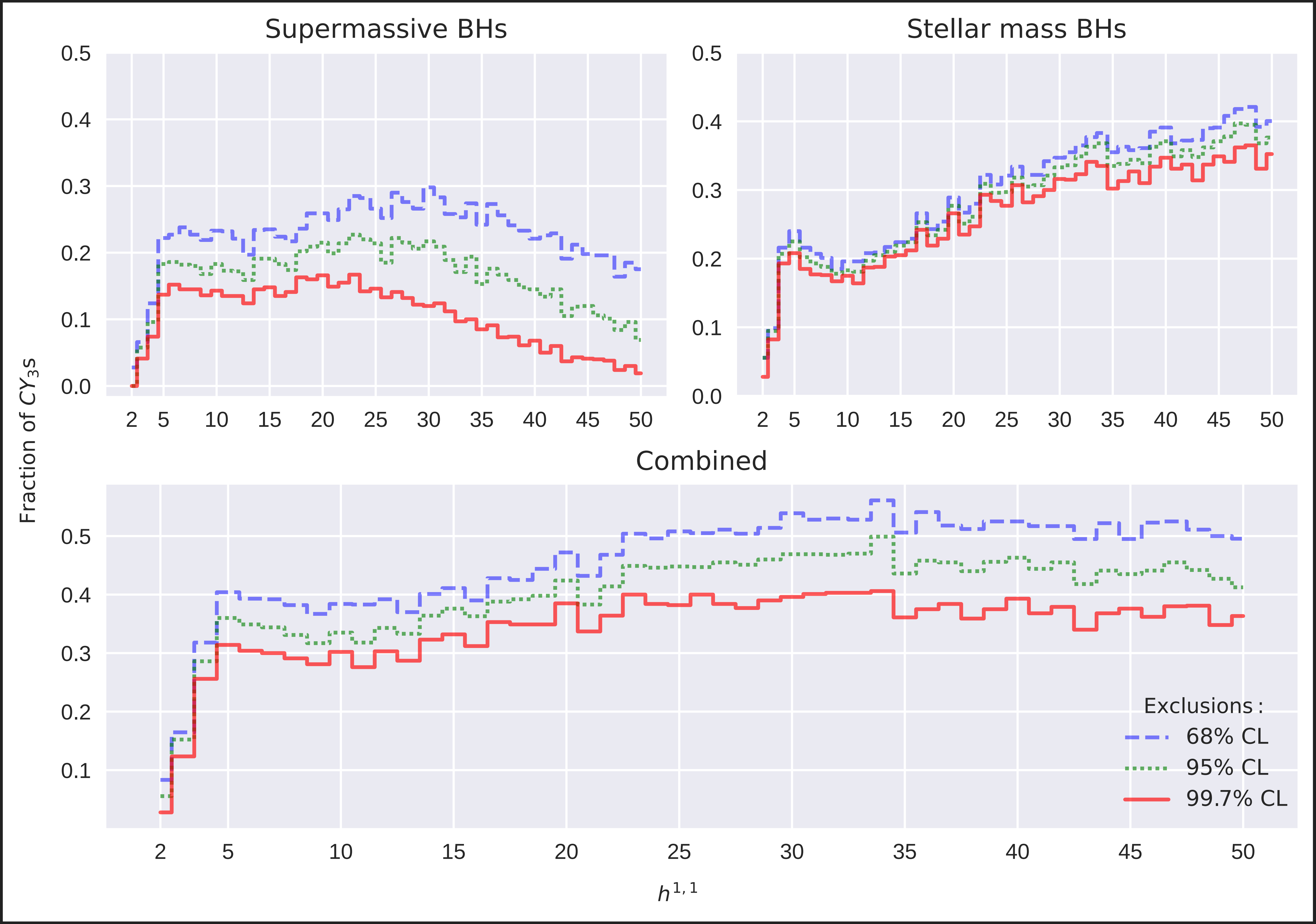
MASS SPECTRA



KS AXIVERSE POTENTIALS — BHSR EXCLUSIONS



KS AXIVERSE POTENTIALS — BHSR EXCLUSIONS



CONSTRAINING THE KS AXIVERSE WITH BHSR

- Generate multiaxion potentials from string data
- Compute masses *and quartics*
- Use BHSR bounds to exclude classes of geometries
- Q: Can the string axiverse be constrained with BHSR?

A: Yes!*

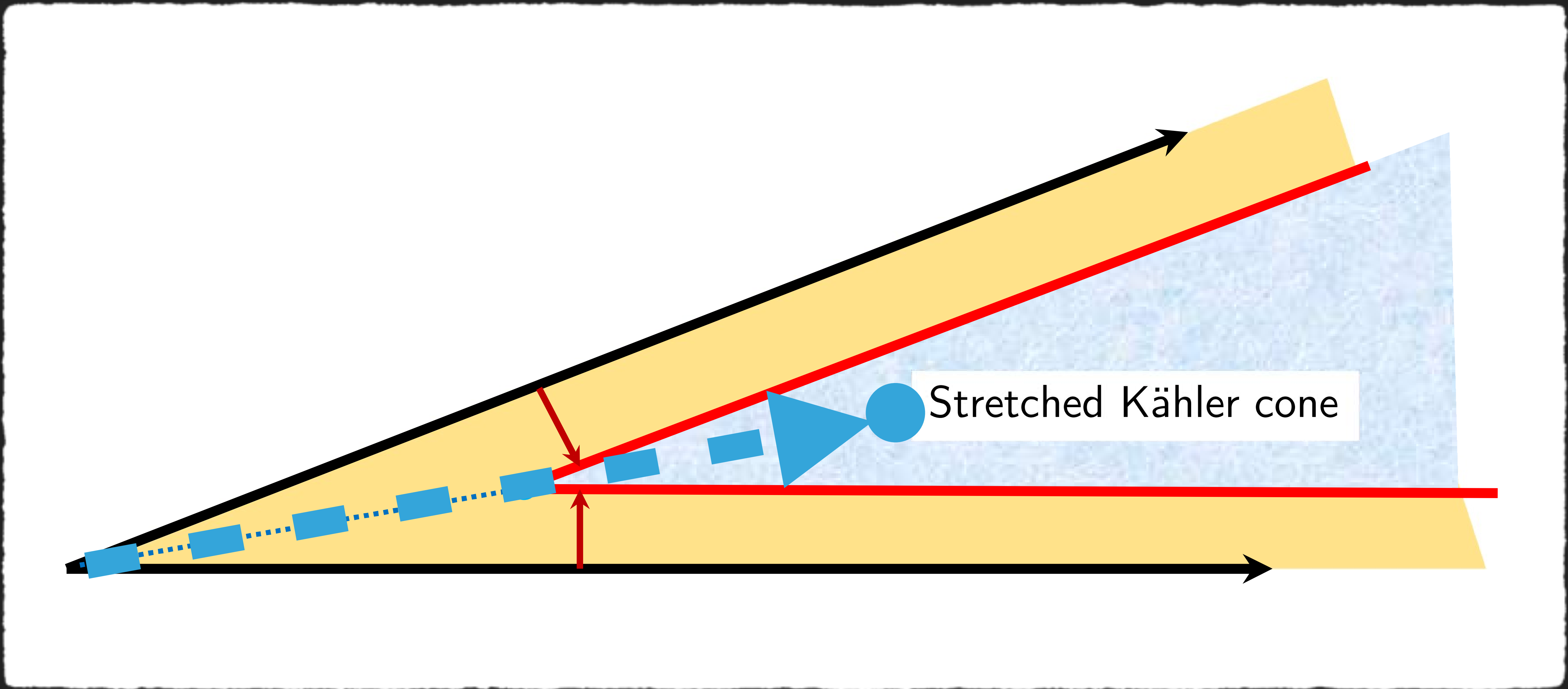
*up to assumed structure of string data

CONSTRAINING THE KS AXIVERSE

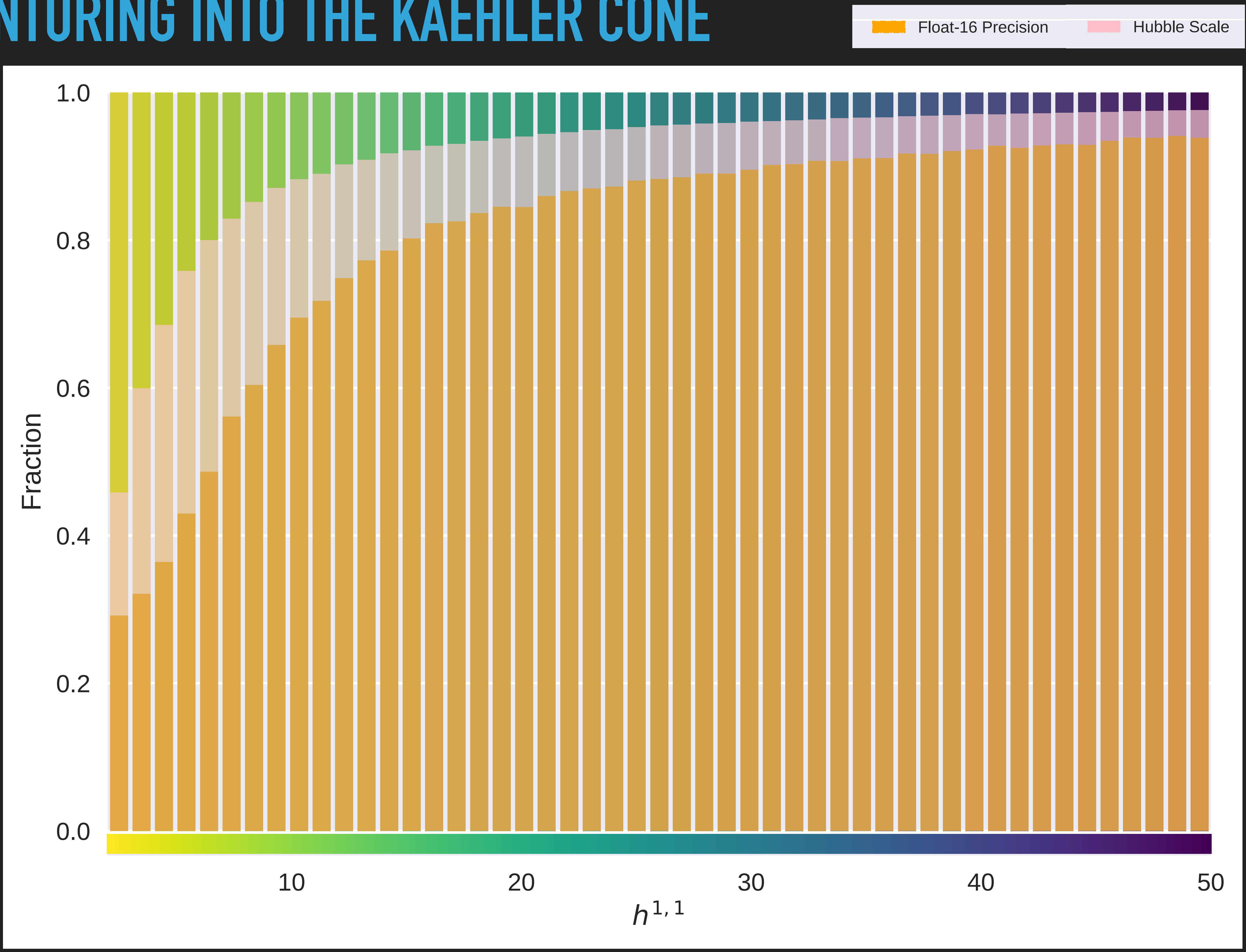
- Consider larger geometries – current optimised code could handle upto $h^{1,1}$ = 100 (?)
- Venture into the Kähler cone?
- Other physical constraints – pure gravity / massless fields – need to be model independent
- Use ML to generate distributions of masses and decay constants – use lower $h^{1,1}$ data as training set

THANKS!

VENTURING INTO THE KAEHLER CONE

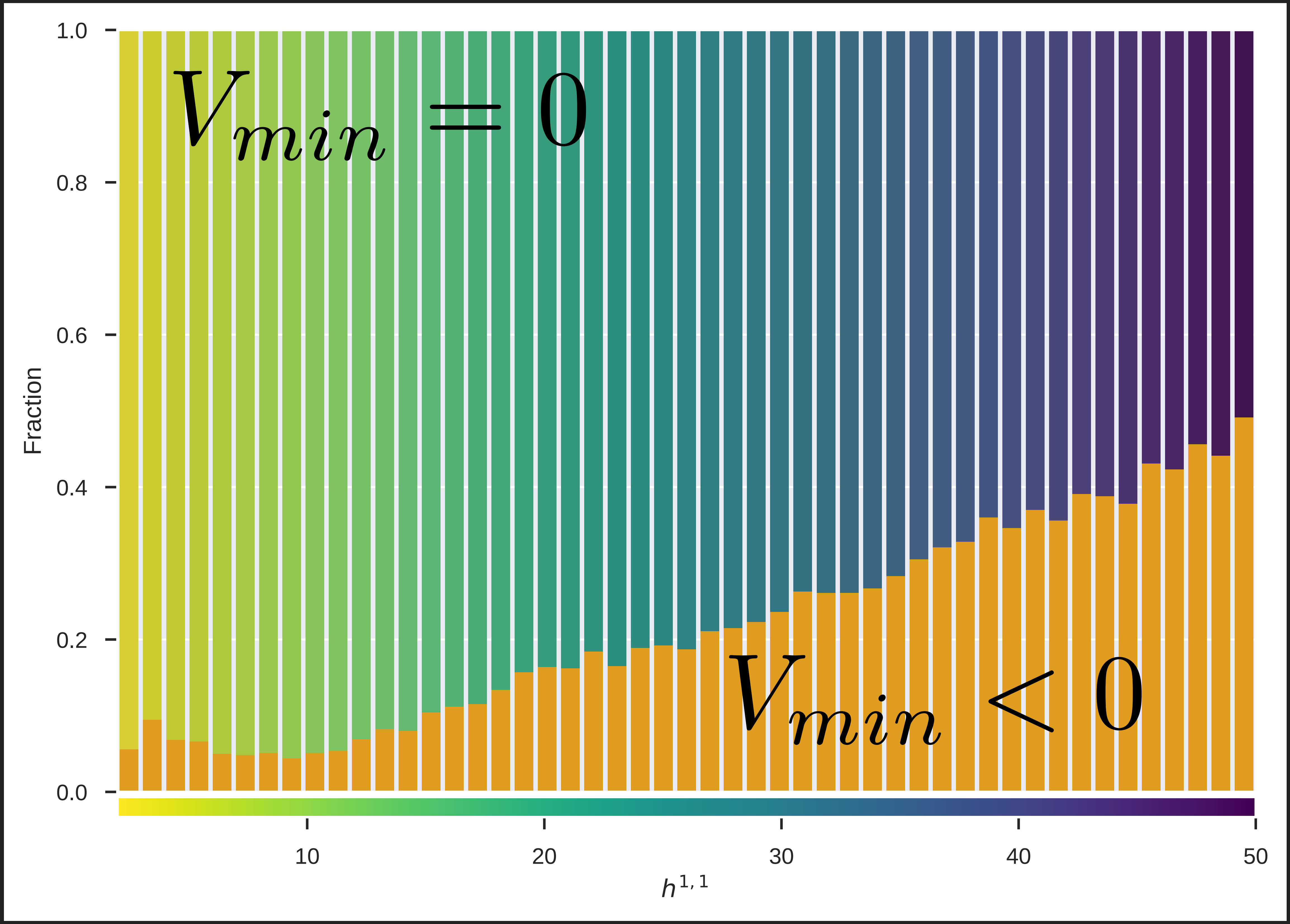


VENTURING INTO THE KAEHLER CONE



VENTURING INTO THE KÄHLER CONE

MINIMA



BLACK HOLES

STOTT+ 2018

Object	*Method*	*Mass* ($M_{\rm BH}$)	*Spin* (a_*)	*Mass CL*	*Spin CL*	*Ref.*
Stellar		$[M\odot]$				
GW150914 (Primary)	EOBNR+IMRPhenom	$36.2^{+5.2}_{-3.8}$	$0.32^{+0.47}_{-0.29}$	90%	90%	[68]
GW150914 (Secondary)	EOBNR+IMRPhenom	$29.1^{+3.7}_{-4.4}$	$0.48^{+0.47}_{-0.43}$	90%	90%	[68]
GW151226 (Primary)	EOBNR+IMRPhenom	$14.2^{+8.3}_{-3.7}$	$0.49^{+0.37}_{-0.42}$	90%	90%	[68]
GW151226 (Secondary)	EOBNR+IMRPhenom	$7.5^{+2.3}_{-2.3}$	$0.52^{+0.43}_{-0.47}$	90%	90%	[68]
GW170104 (Primary)	Eff+Full precession	$31.2^{+8.4}_{-6.0}$	$0.45^{+0.46}_{-0.40}$	90%	90%	[78]
GW170104 (Secondary)	Eff+Full precession	$19.4^{+5.3}_{-5.9}$	$0.47^{+0.46}_{-0.43}$	90%	90%	[78]
Cygnus X-1	Continuum (KERRBB2)	$14.8^{+1.0}_{-1.0}$	≥ 0.983	1σ	3σ	[79]/[80]
XTE J1550-564	Continuum (KERRBB2)	$9.10^{+0.61}_{-0.61}$	$0.34^{+0.37}_{-0.34}$	1σ	90%	[81]/[82]
A 0620-00	Continuum (KERRBB2)	$6.61^{+0.25}_{-0.25}$	$0.12^{+0.19}_{-0.19}$	1σ	1σ	[83]/[84]
4U 1543-475	Continuum (KERRBB)	$9.4^{+1.0}_{-1.0}$	$0.8^{+0.1}_{-0.1}$	1σ	1σ	[85]/[86]
GRO J1655-40	Continuum (KERRBB)	$6.30^{+0.50}_{-0.50}$	$0.7^{+0.10}_{-0.10}$	95%	1σ	[87]/[88]
GRS 1915+105	Continuum (KERRBB2)	$10.1^{+0.6}_{-0.6}$	≥ 0.95	1σ	1σ	[89]/[90]
LMC X-1	Continuum (KERRBB2)	$10.91^{+1.41}_{-1.41}$	$0.92^{+0.05}_{-0.07}$	1σ	1σ	[91]/[92]
LMC X-3	Continuum (KERRBB2)	$6.98^{+0.56}_{-0.56}$	$0.25^{+0.13}_{-0.16}$	1σ	1σ	[93]/[94]
M33 X-7	Continuum (KERRBB2)	$15.65^{+1.45}_{-1.45}$	$0.84^{+0.05}_{-0.05}$	1σ	1σ	[95]/[96]
Supermassive		$\times 10^6 [M\odot]$				
Mrk 335	Reflection (Suzaku)	$14.20^{+3.70}_{-3.70}$	$0.83^{+0.09}_{-0.13}$	1σ	90%	[97]/[98]
Fairall 9	Reflection (Suzaku)	$255.0^{+56.0}_{-56.0}$	$0.52^{+0.19}_{-0.15}$	1σ	90%	[97]/[99]
Mrk 79	Reflection (Suzaku)	$52.40^{+14.40}_{-14.40}$	$0.70^{+0.1}_{-0.1}$	1σ	90%	[97]/[100]
NGC 3783	Reflection (Suzaku)	$29.80^{+5.40}_{-5.40}$	≥ 0.98	1σ	90%	[97]/[101]
MCG-6-30-15	Reflection (Suzaku)	$2.90^{+1.80}_{-1.60}$	≥ 0.98	1σ	90%	[102]/[103]
NGC 7469	Reflection (Suzaku)	$12.20^{+1.40}_{-1.40}$	$0.69^{+0.09}_{-0.09}$	1σ	90%	[97]/[104]
Ark 120	Reflection (Suzaku)	$150.0^{+19.0}_{-19.0}$	$0.64^{+0.19}_{-0.11}$	1σ	90%	[97]/[98]
Mrk 110	Reflection (Suzaku)	$25.10^{+6.10}_{-6.10}$	≥ 0.89	1σ	90%	[97]/[98]
NGC 4051	Reflection (Suzaku)	$1.91^{+0.78}_{-0.78}$	≥ 0.99	1σ	90%	[97]/[105]

CHANGING BASIS

$$\mathcal{L} = -\frac{M_{\mathrm{P}}^2}{2} K_{ij} \partial_\mu \theta^i \partial^\mu \theta^j - \sum_{a=1}^{P} \Lambda_a \cos \mathcal{Q}_a^i \theta_i$$

Canonical basis:

$$\tilde{\phi} = M_{\mathrm{Pl}} \, \mathrm{diag}\left(\vec{f}_a\right) \mathbf{U} \, \theta$$

$$\mathbf{U} = \mathrm{eigenvector}(\mathbf{K}) \qquad \vec{f}_a = \sqrt{\mathrm{eigenvalue}(\mathbf{K})}$$

Mass eigenbasis:

$$\phi = M_{\mathrm{Pl}} \mathbf{V} \, \mathrm{diag}\left(\vec{f}_a\right) \mathbf{U} \, \theta$$

$$\mathbf{V} = \mathrm{eigenvector}(\tilde{\mathcal{M}})$$

$$\mathcal{L} = -\frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi_j - \frac{1}{2} \phi_i \mathcal{M}_{ij} \phi_j - \frac{1}{4!} \lambda_{ijkl} \phi_i \phi_j \phi_k \phi_l$$

BACKUP

SUPERPOTENTIAL

$$\mathcal{A}_\alpha(\text{CS moduli}) \equiv 1$$

$$W = W_0 + \sum_\alpha \mathcal{A}_\alpha \exp\left(-2\pi \underbrace{q_\alpha^i T_i}_{\text{Divisor volume}}\right)$$

$$W_0 \equiv 1$$

AXION POTENTIAL

$$V = -\frac{8\pi}{\mathcal{V}^2}\left[\sum_\alpha q_\alpha{}^i \tau_i e^{-2\pi q_\alpha{}^i \tau_i} \cos\left(2\pi q_\alpha{}^i \theta_i\right)\right.$$
$$+ \sum_{\alpha > \alpha'} \left(\pi (K^{-1})_{ij} q_\alpha{}^i q_{\alpha'}{}^j + (q_\alpha{}^i + q_{\alpha'}{}^i)\tau_i\right)$$
$$\left. \times \; e^{-2\pi\tau_i (q_\alpha{}^i + q_{\alpha'}{}^i)} \cos\left(2\pi\theta_i (q_\alpha{}^i - q_{\alpha'}{}^i)\right)\right]$$