Universiteit Leiden
Leiden Observatory

Elena Rossi

Sjoert van Velzen

Observational constraints on the rate of stellar-mass **Black Hole mergers** inside luminous **Active Galactic Nuclei**

Niccolò Veronesi - 27th CAN Symposium - 21/06/2023

The most luminous AGN do not produce the majority of the detected stellar-mass black hole binary mergers in the local Universe

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ABSTRACT

Despite the increasing number of Gravitational Wave (GW) detections, the astrophysical origin of Binary Black Hole (BBH) mergers remains elusive. A promising formation channel for BBHs is inside accretion discs around supermassive black holes, that power Active Galactic Nuclei (AGN). In this paper, we test for the first time the spatial correlation between observed GW events and AGN. To this end, we assemble all sky catalogues with 1,412 (242) AGN with a bolometric luminosity greater than $10^{45.5}$erg s^{-1} (10^{46} erg s^{-1}) with spectroscopic redshift of $z \leq 0.3$ from the Milliquas catalogue, version 7.7b. These AGN are cross-matched with localisation volumes of BBH mergers observed in the same redshift range by the LIGO and Virgo interferometers during their third observing run. We find that the fraction of the detected mergers originated in AGN brighter than $10^{45.5}$ erg s^{-1} (10^{46} erg s^{-1}) cannot be higher than 0.74 (0.33) at a 95 per cent credibility level. Our upper limits imply a limited BBH merger production efficiency of the brightest AGN, while most or all GW events may still come from lower luminosity ones. Alternatively, the AGN formation path for merging stellar-mass BBHs may be actually overall subdominant in the local Universe. To our knowledge, ours are the first observational constraints on the fractional contribution of the AGN channel to the observed BBH mergers.

How can we learn where BBHs merge?

BINARY BLACK HOLE

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Detection of ElectroMagnetic transient counterparts

Graham+20, Graham+23, Ashton+21

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Predictions on parameters and comparison to observations

McKernan+20, Romero-Shaw+21, Gayathri+21, Karathanasis+22, …

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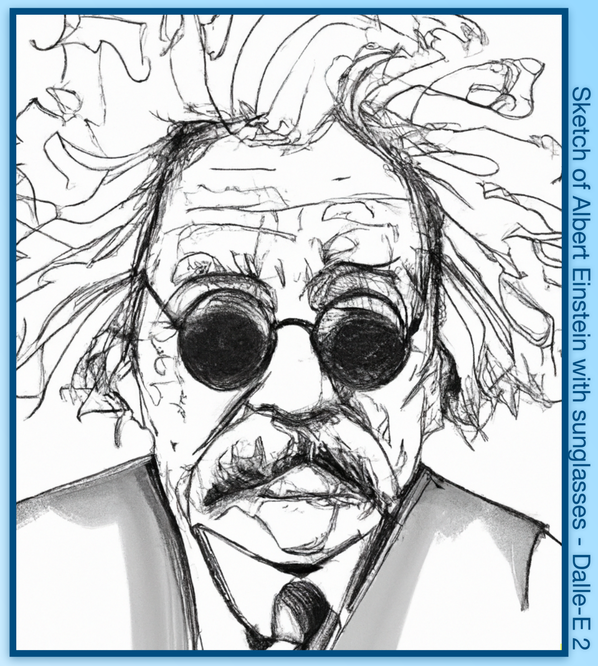

Sketch of Albert Einstein with sunglasses - Dalle-E 2

McKernan+20, Romero-Shaw+21, Gayathri+21, Karathanasis+22, …

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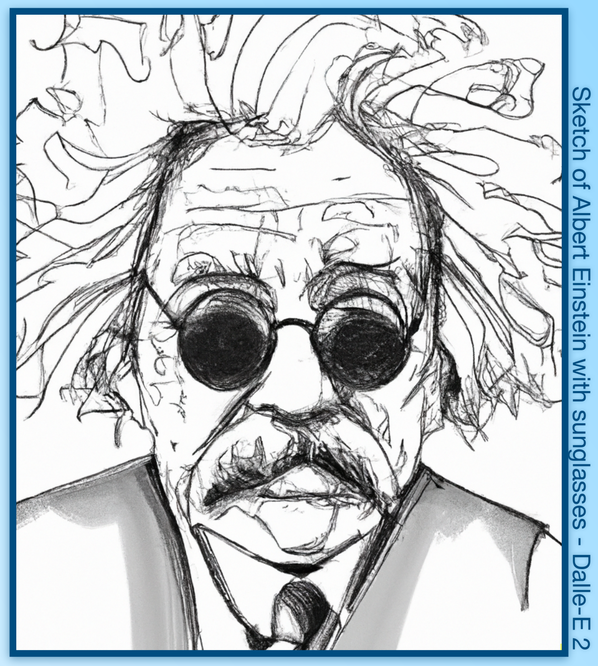

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Investigation of spatial correlation

Bartos+17, Corley+19, NV+22

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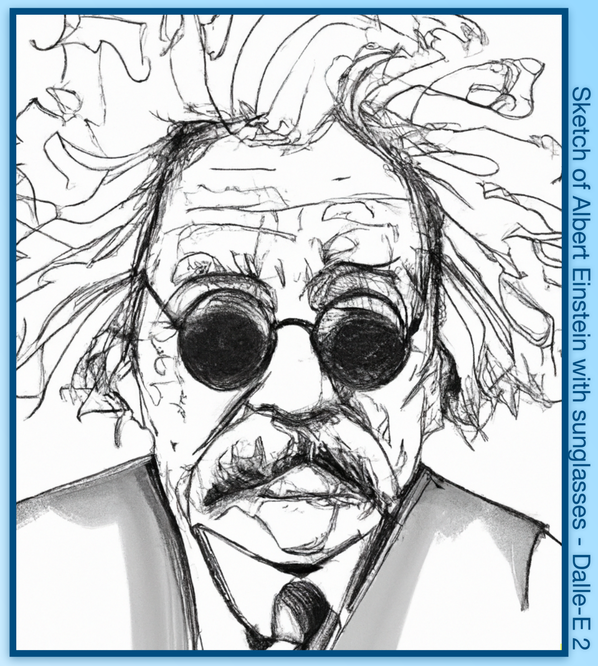

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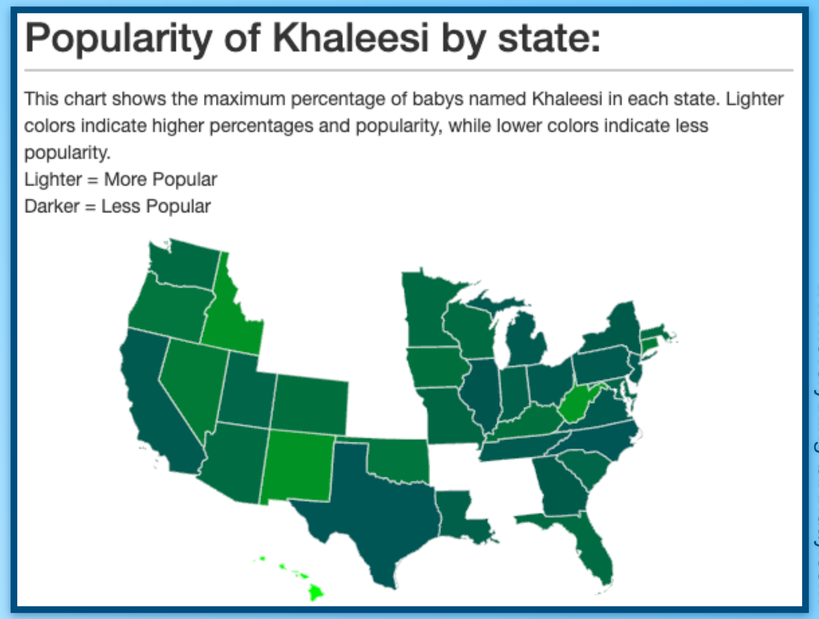

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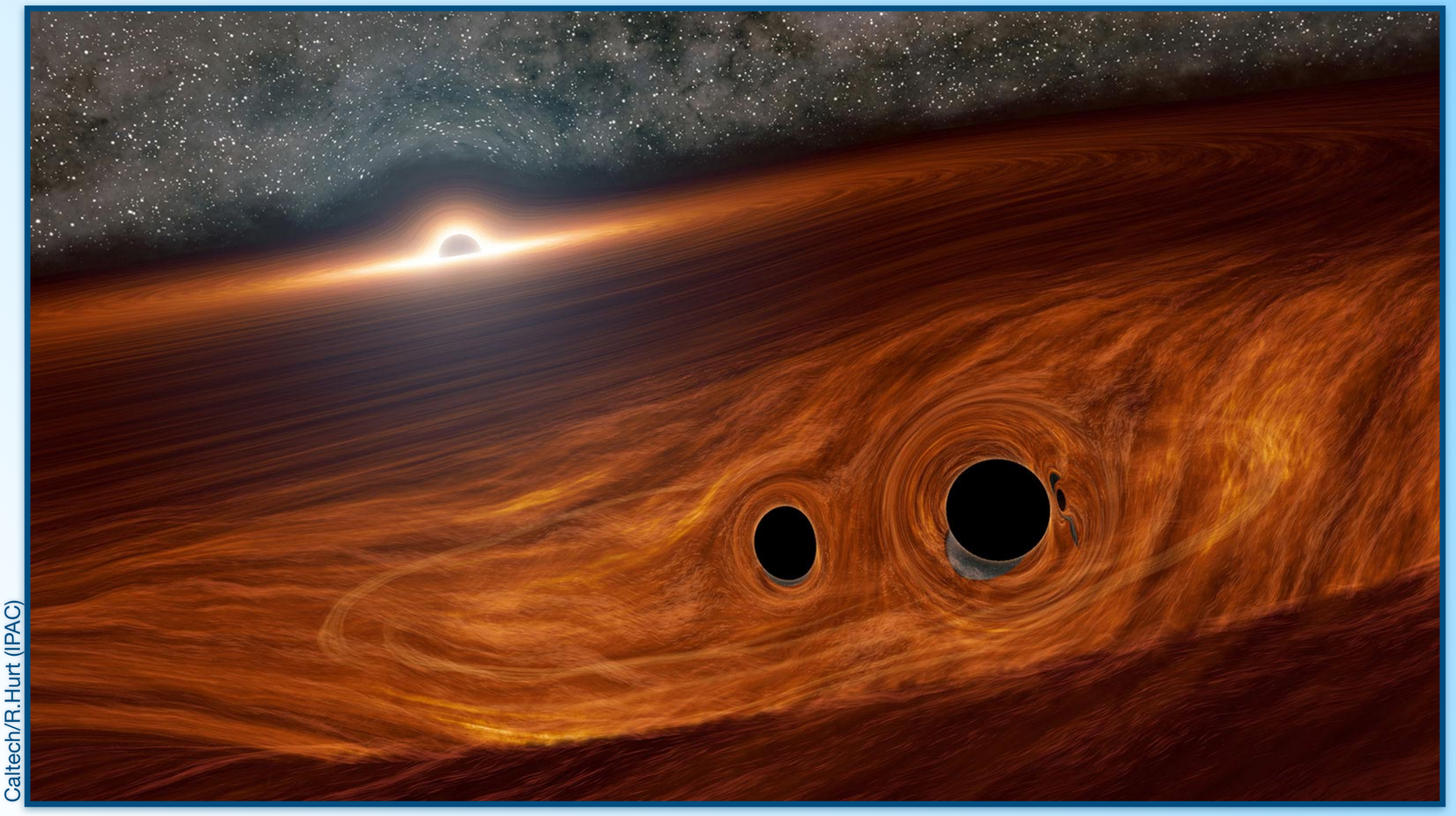
Bartos+17, Corley+19, NV+22

$$f_{\mathrm{AGN}} = ?$$

Why focusing on AGN?

ACTIVE GALACTIC NUCLEI



Caltech/R.Hurt (IPAC)

McKernan+11, McKernan+12,
Bellovary+16, Tagawa+20

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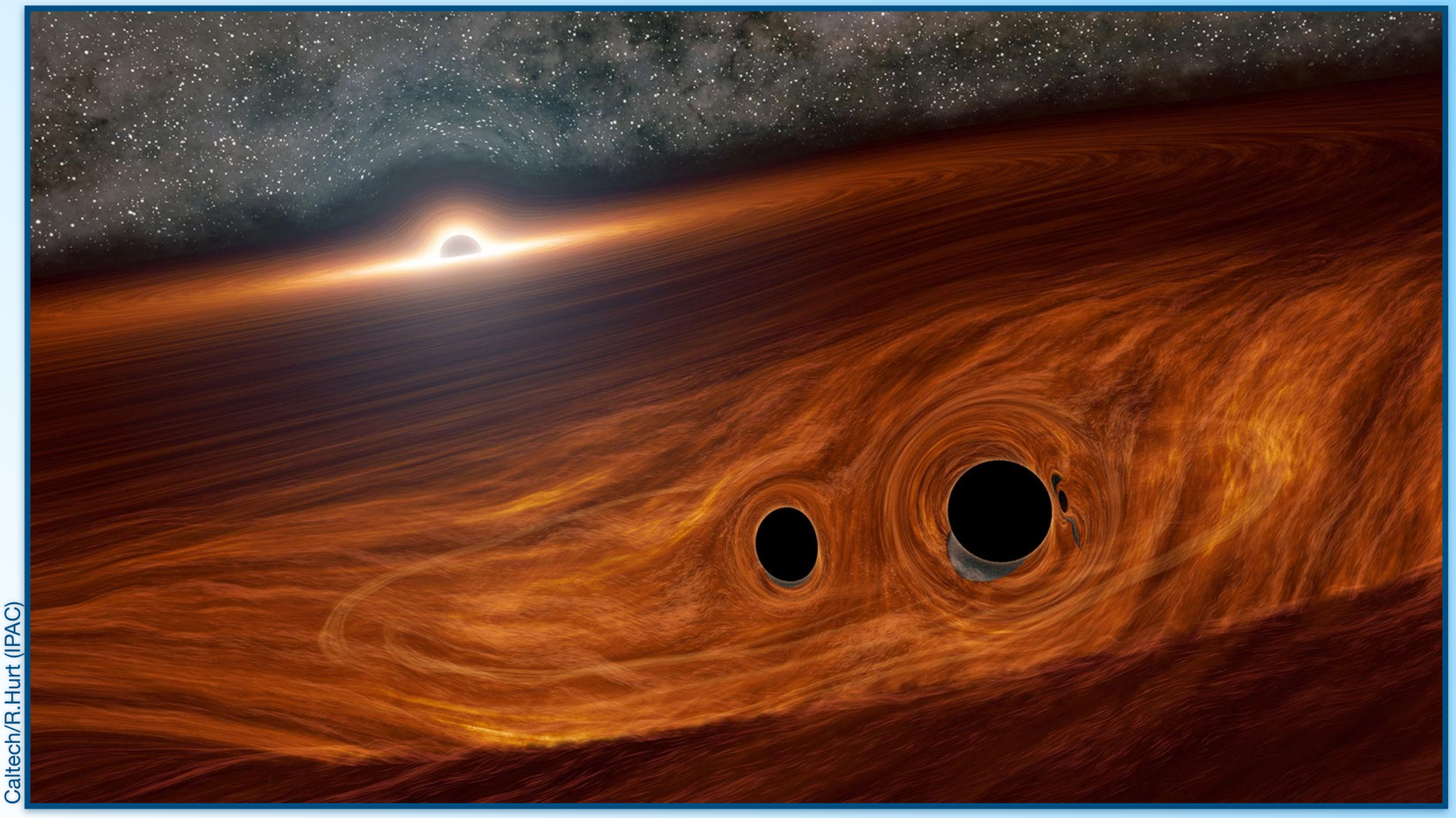
ACTIVE GALACTIC NUCLEI



Caltech/R.Hurt (IPAC)

- Dense dynamical environments
  High chance of binary formation

McKernan+11, McKernan+12,
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Why focusing on AGN?

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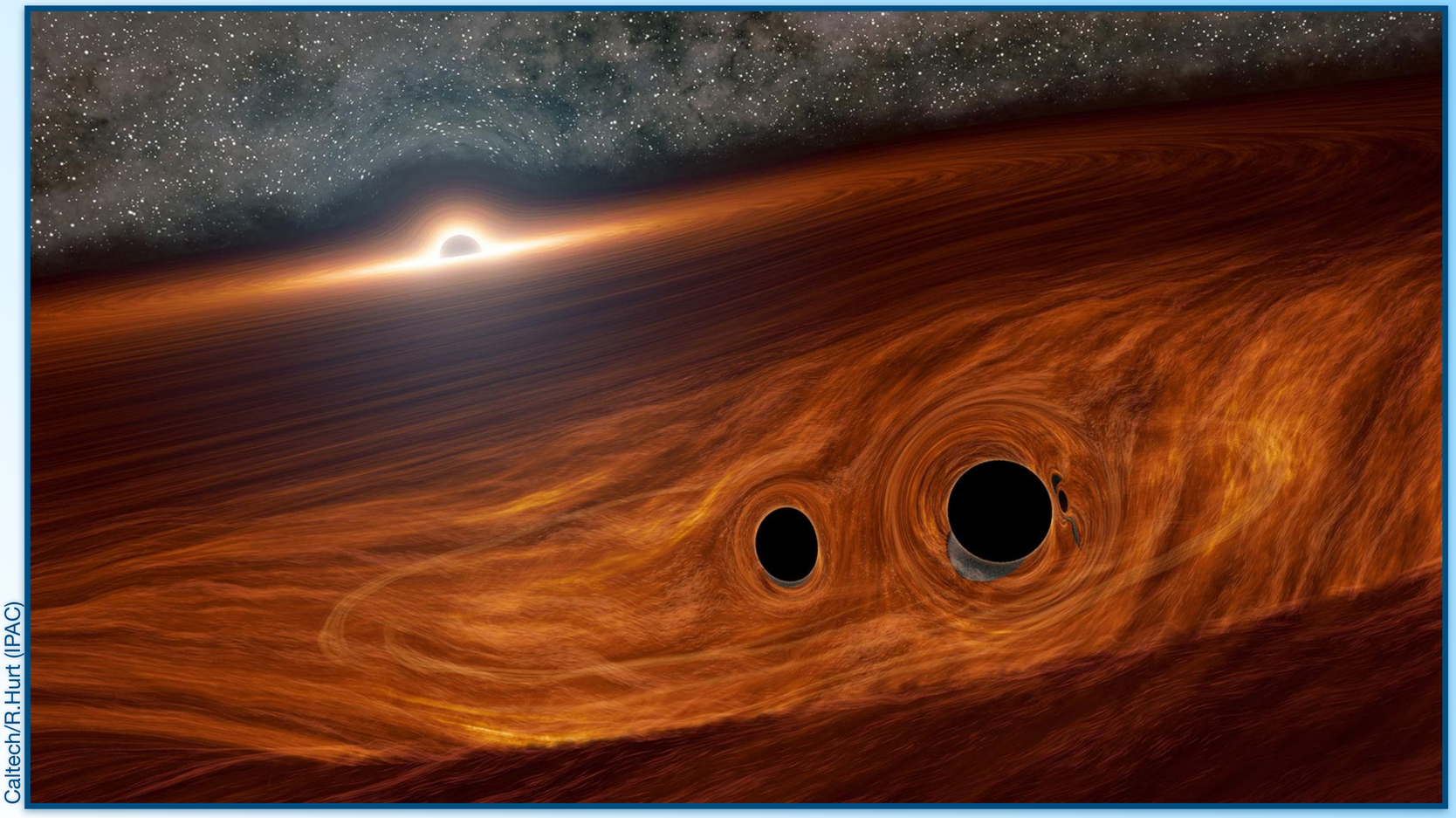

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- Deep gravitational potential
  Possibility of retain kicked remnants

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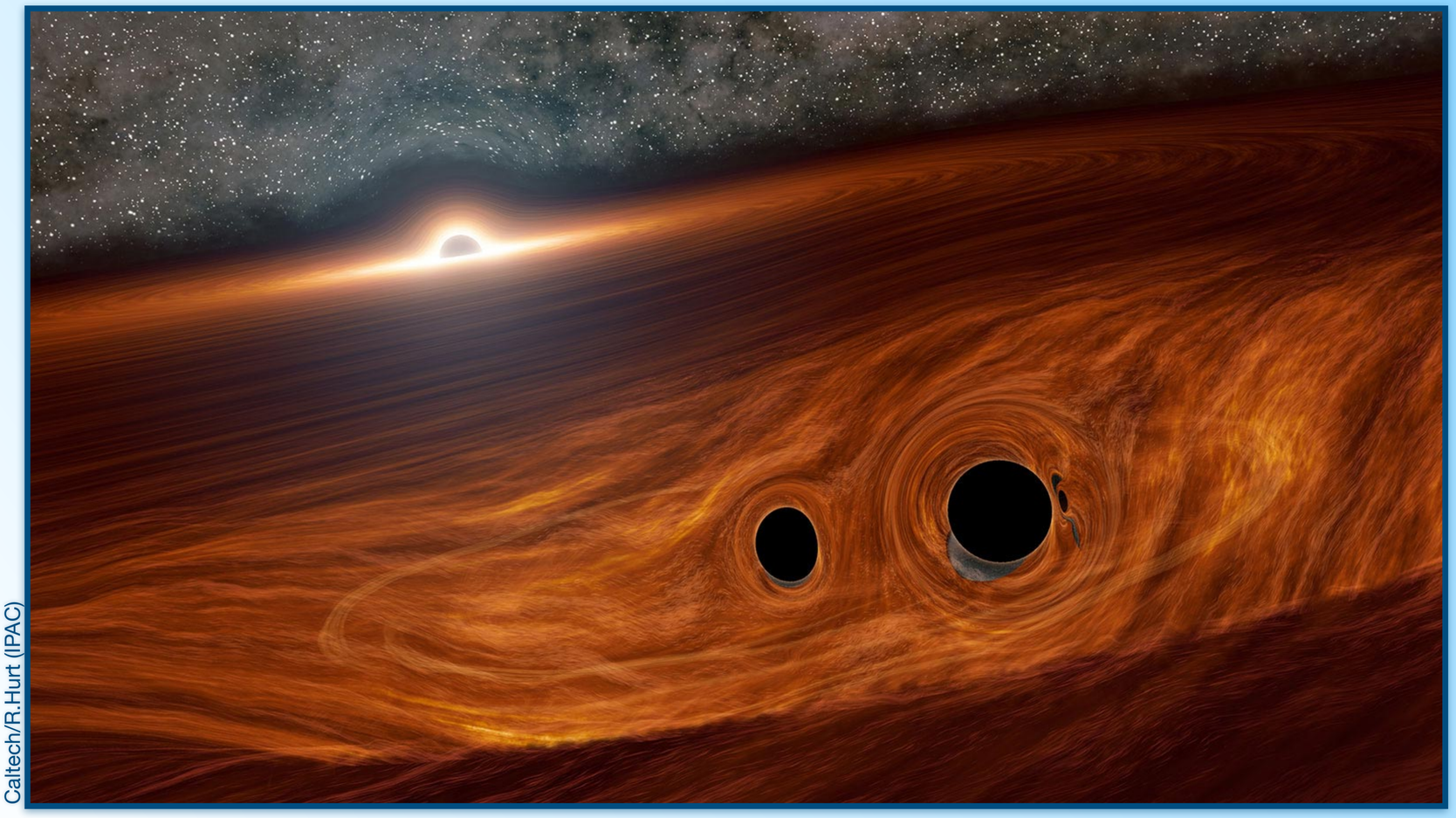
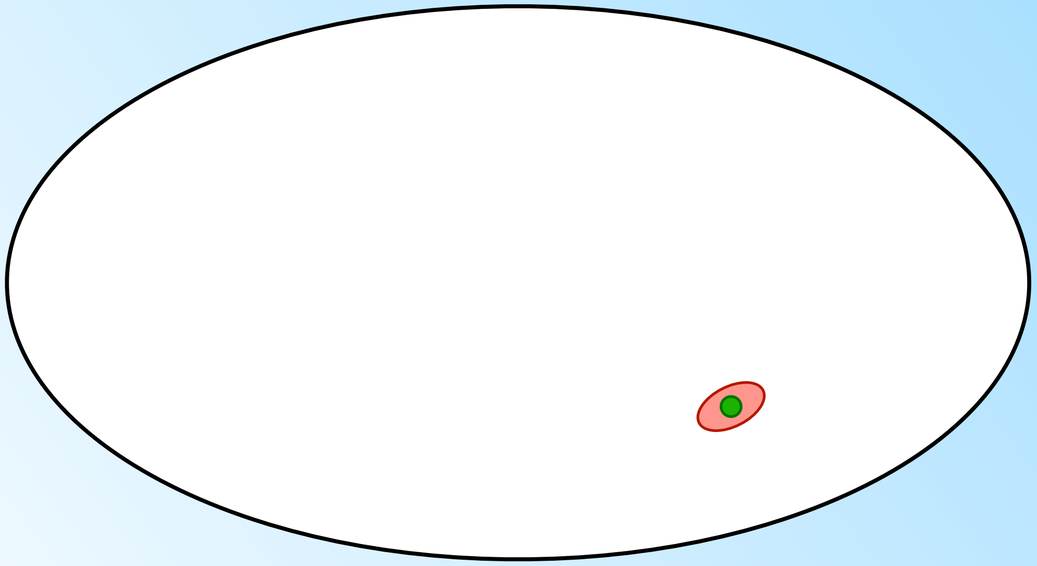


Caltech/R.Hurt (IPAC)

- Dense dynamical environments
  High chance of binary formation
- Deep gravitational potential
  Possibility of retain kicked remnants
- Migration (traps)
  Gathering many compact objects in the same region

McKernan+11, McKernan+12, Bellovary+16, Tagawa+20

If only it was this easy…



: GW localisation volume

: AGN position

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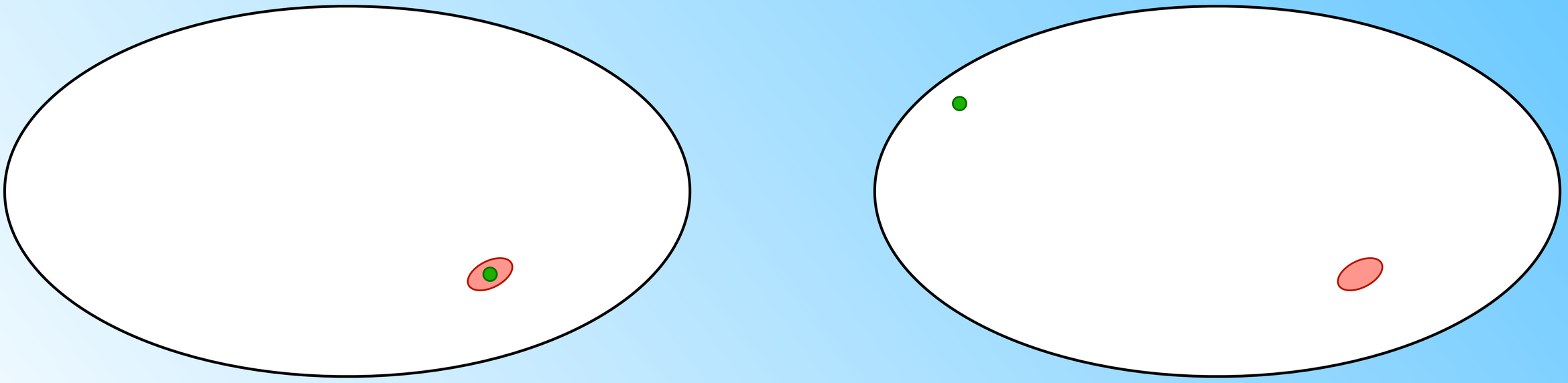
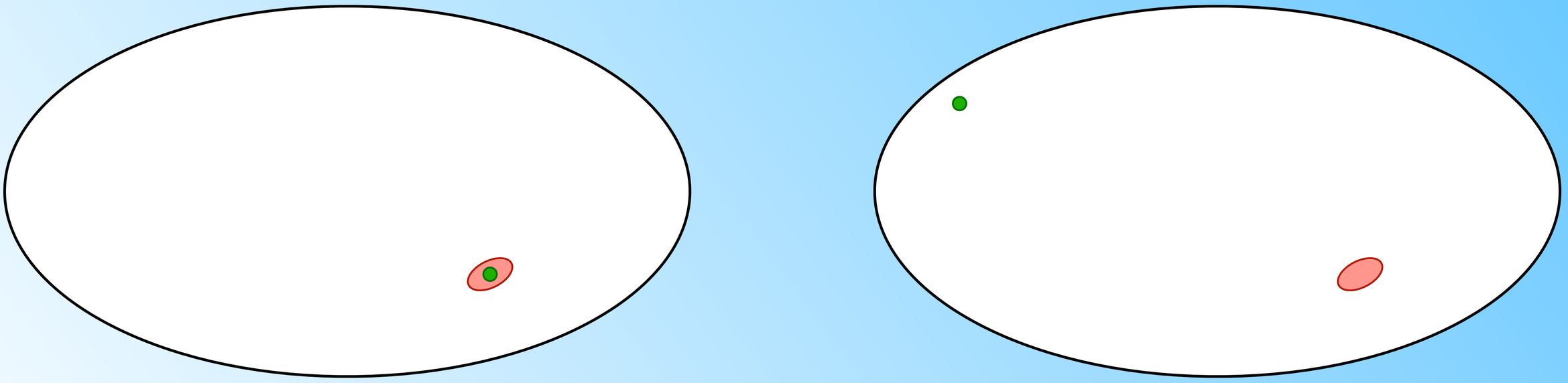


: GW localisation volume

: AGN position

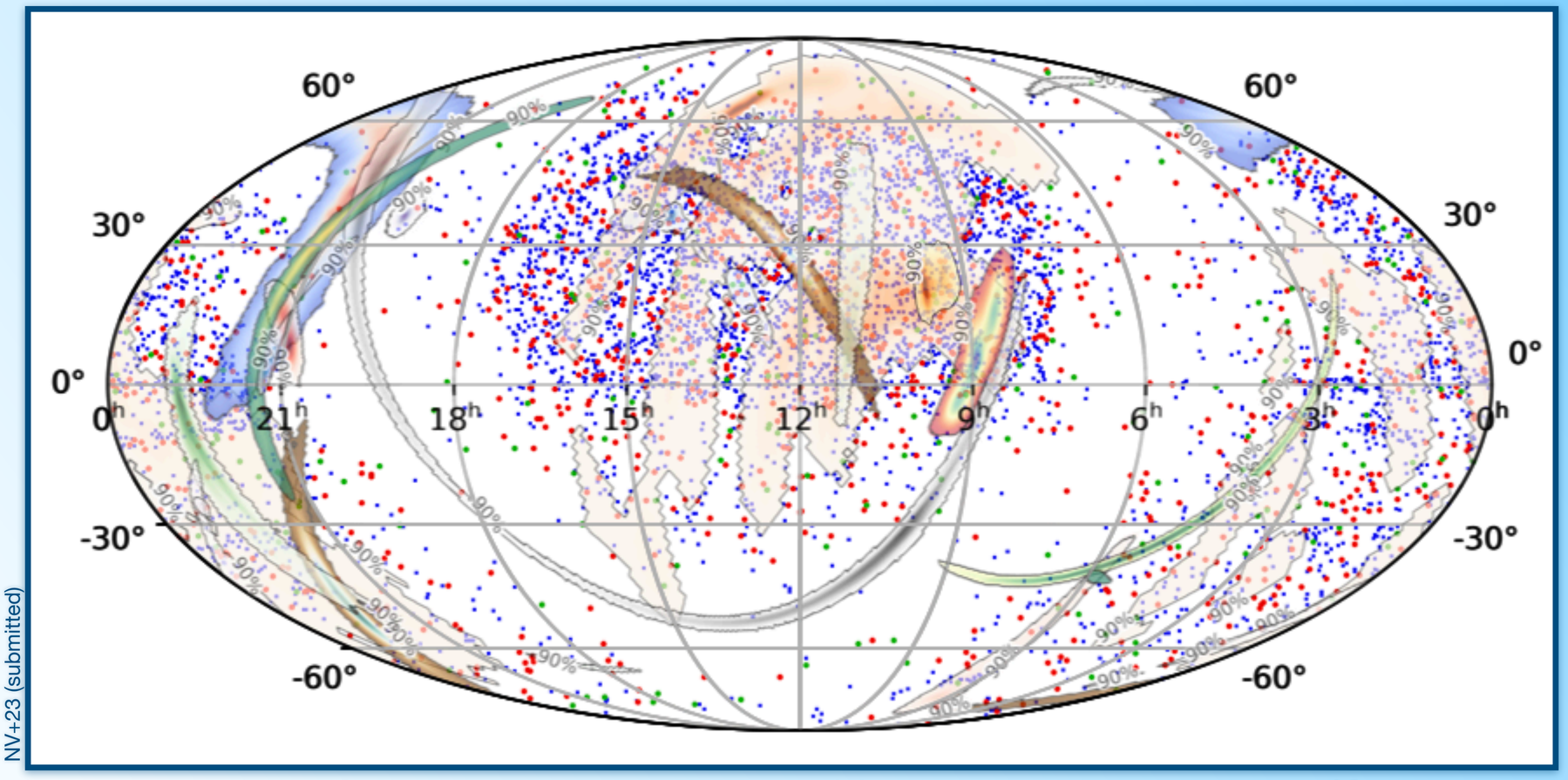
If only it was this easy…
(where would the fun be?)



: GW localisation volume

: AGN position

The real picture



NV+23 (submitted)

- $L_{\rm bol} \geq 10^{45}\,{\rm erg\,s^{-1}}$
- $L_{\rm bol} \geq 10^{45.5}\,{\rm erg\,s^{-1}}$
- $L_{\rm bol} \geq 10^{46}\,{\rm erg\,s^{-1}}$

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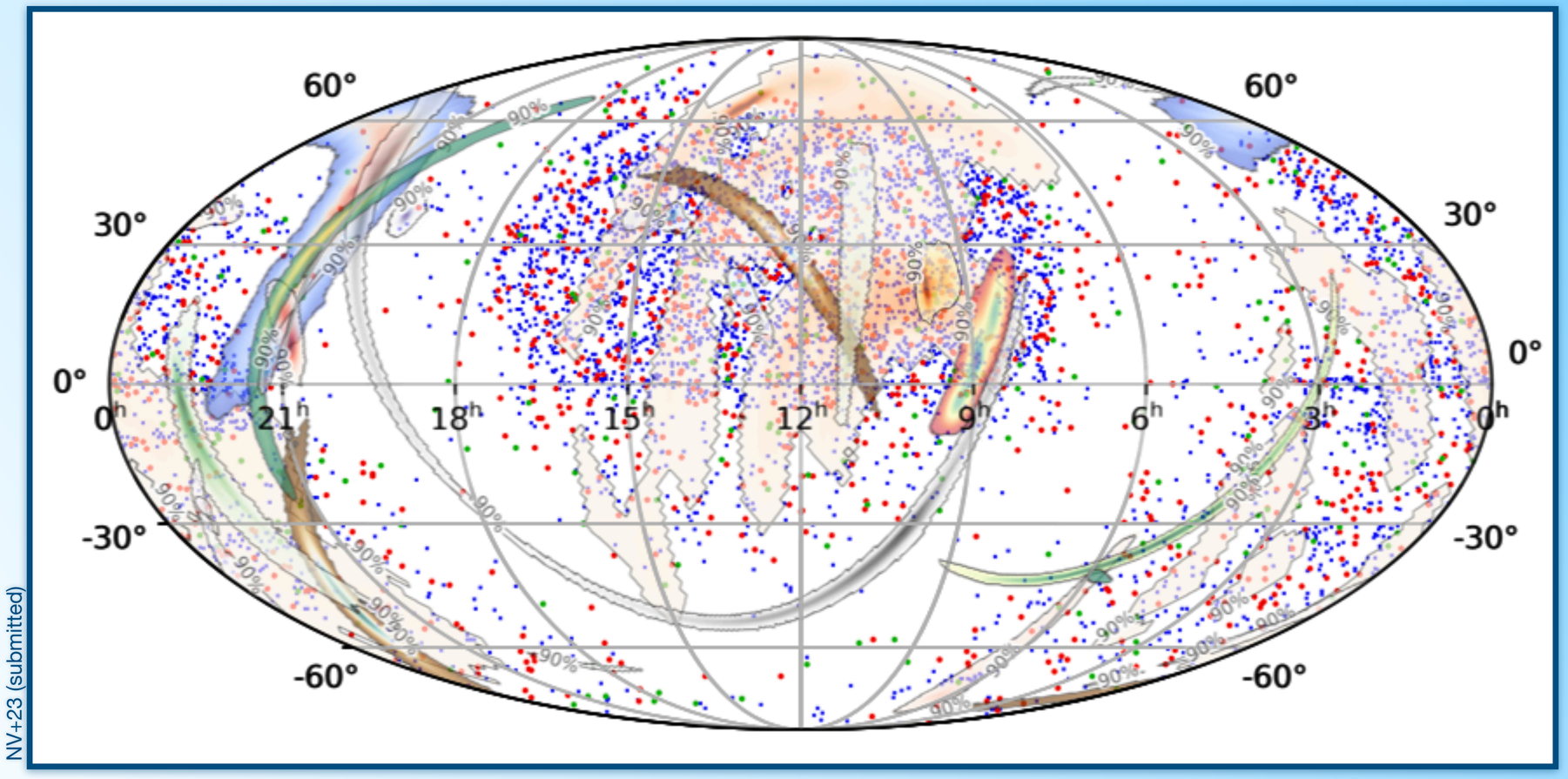

NV+23 (submitted)

- More AGN
  Bad

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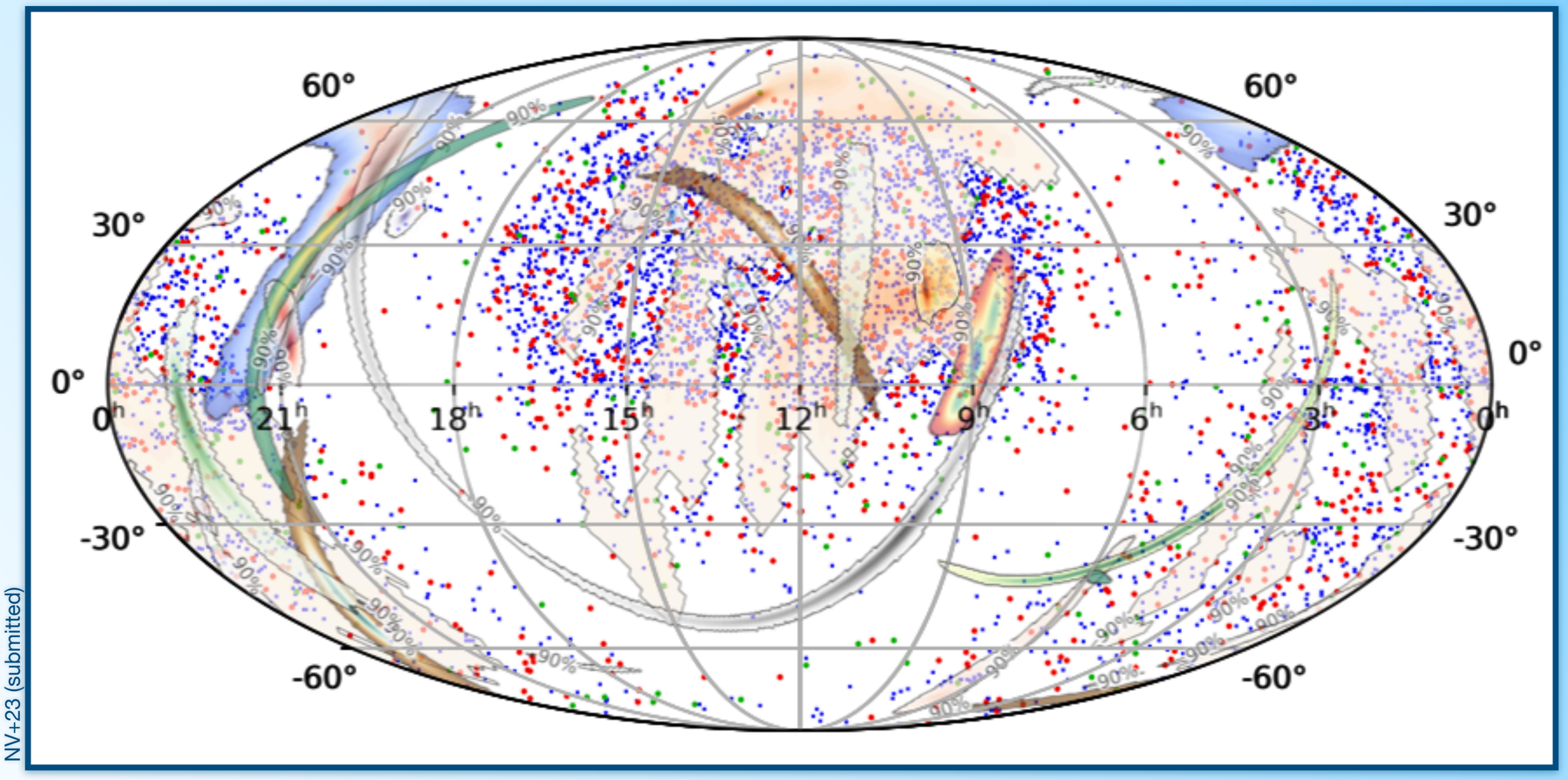

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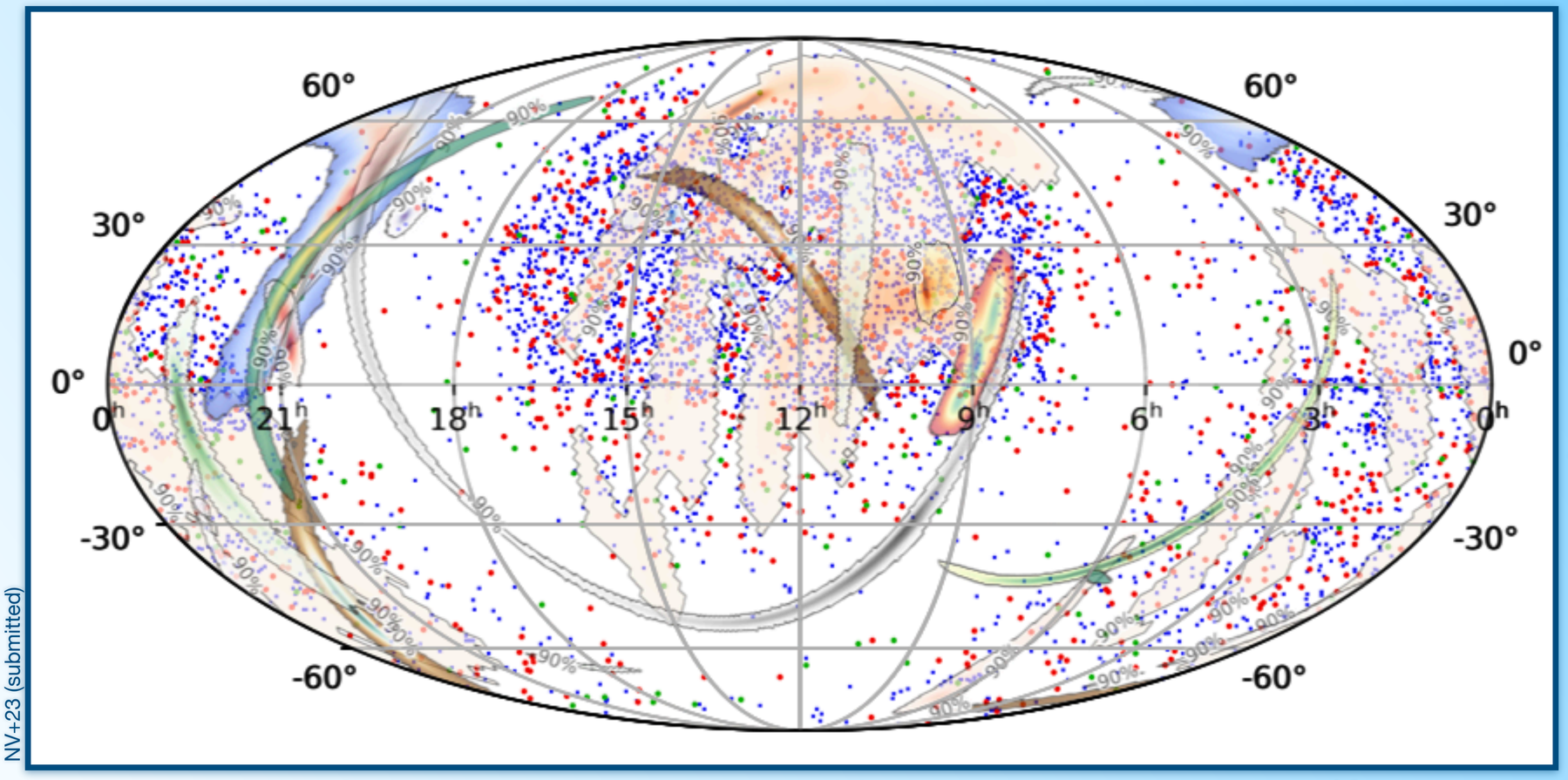
- More AGN
  Bad
- More detected BBH mergers
  Good

The real picture



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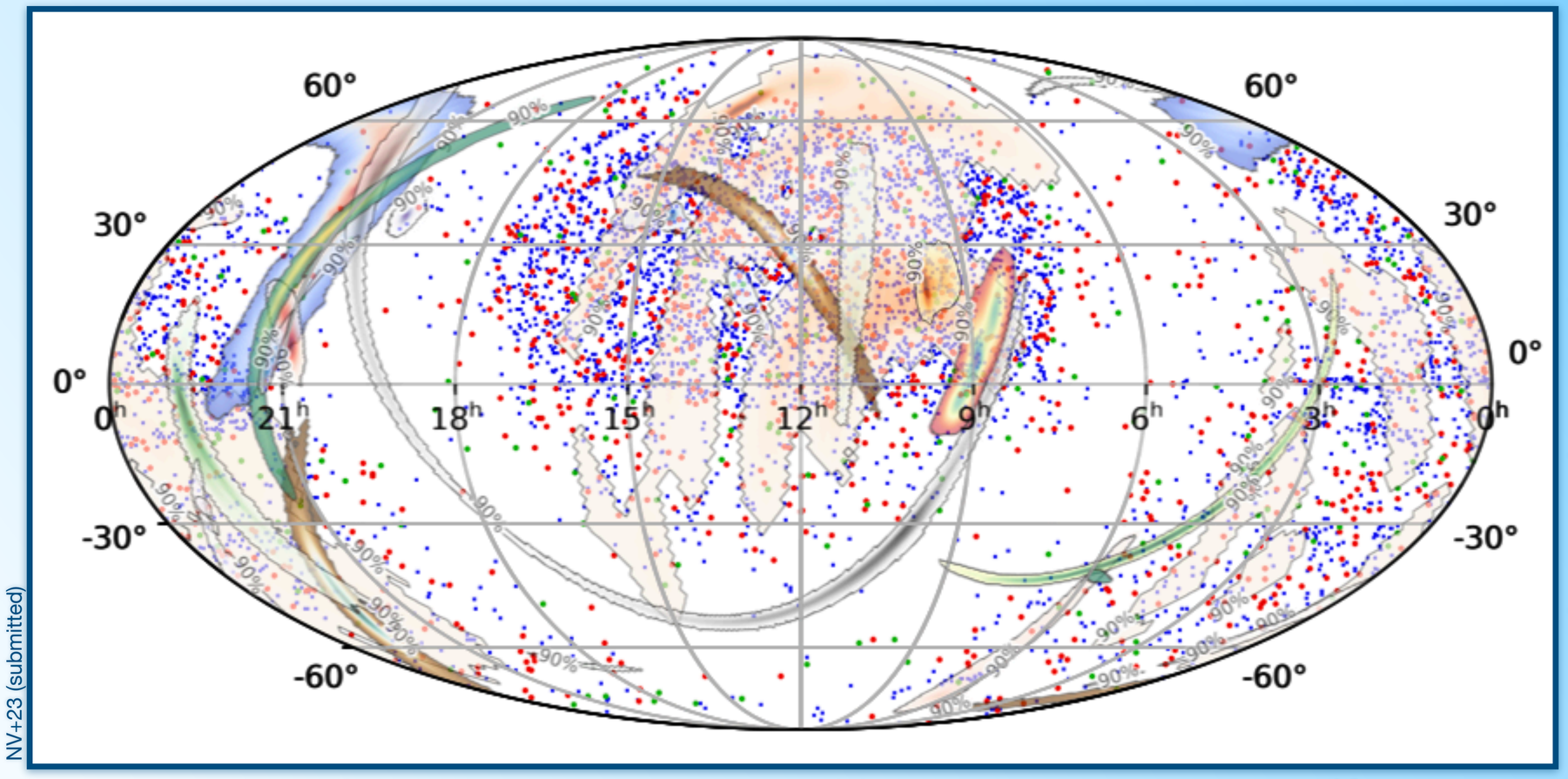
- More AGN
  Bad
- More detected BBH mergers
  Good
- Large localisation volumes
  Bad

The real picture



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- $L_{\rm bol} \geq 10^{46}\,{\rm erg\,s^{-1}}$

- More AGN
  Bad
- More detected BBH mergers
  Good
- Large localisation volumes
  Bad
- Incomplete AGN catalogues
  Bad

Our method

Our method

Multiple AGN ✓

Our method

Multiple AGN ✓

Multiple detected BBH mergers ✓

Our method

Multiple AGN ✓

Size of localisation volumes ✓

Multiple detected BBH mergers ✓

Our method

Multiple AGN ✓

Size of localisation volumes ✓

Multiple detected BBH mergers ✓

Number of AGN within localisation volumes ✓

Our method

Multiple AGN ✓

Size of localisation volumes ✓

Incompleteness of AGN catalogues ✓ NEW!

Multiple detected BBH mergers ✓

Number of AGN within localisation volumes ✓

Our method

Multiple AGN ✓

Size of localisation volumes ✓

Incompleteness of AGN catalogues ✓ NEW!

Multiple detected BBH mergers ✓

Number of AGN within localisation volumes ✓

Exact positions of AGN ✓ NEW!

Our method

Multiple AGN ✓

Size of localisation volumes ✓

Incompleteness of AGN catalogues ✓ NEW!

Multiple detected BBH mergers ✓

Number of AGN within localisation volumes ✓

Exact positions of AGN ✓ NEW!

↓

Likelihood maximization ($\mathscr{L}(f_{\mathrm{AGN}})$)

✓ NEW!

Our method

Multiple AGN ✓

Size of localisation volumes ✓

Incompleteness of AGN catalogues ✓ NEW!

Multiple detected BBH mergers ✓

Number of AGN within localisation volumes ✓

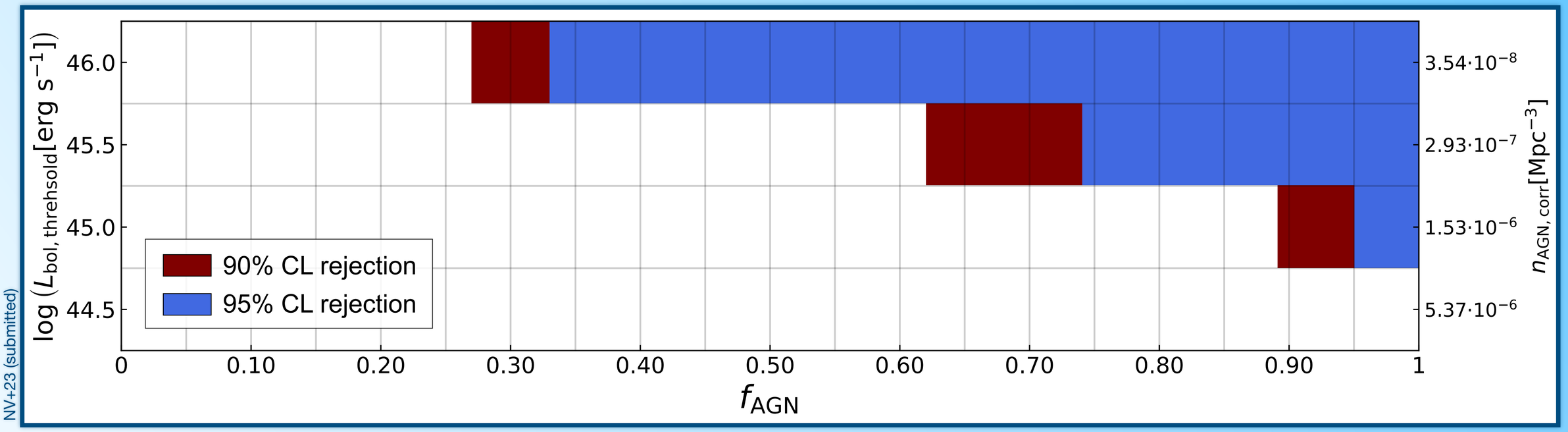
Exact positions of AGN ✓ NEW!

↓

Likelihood maximization ($\mathscr{L}(f_{\mathrm{AGN}})$) ✓ NEW!

Application to observed data ✓ NEW!

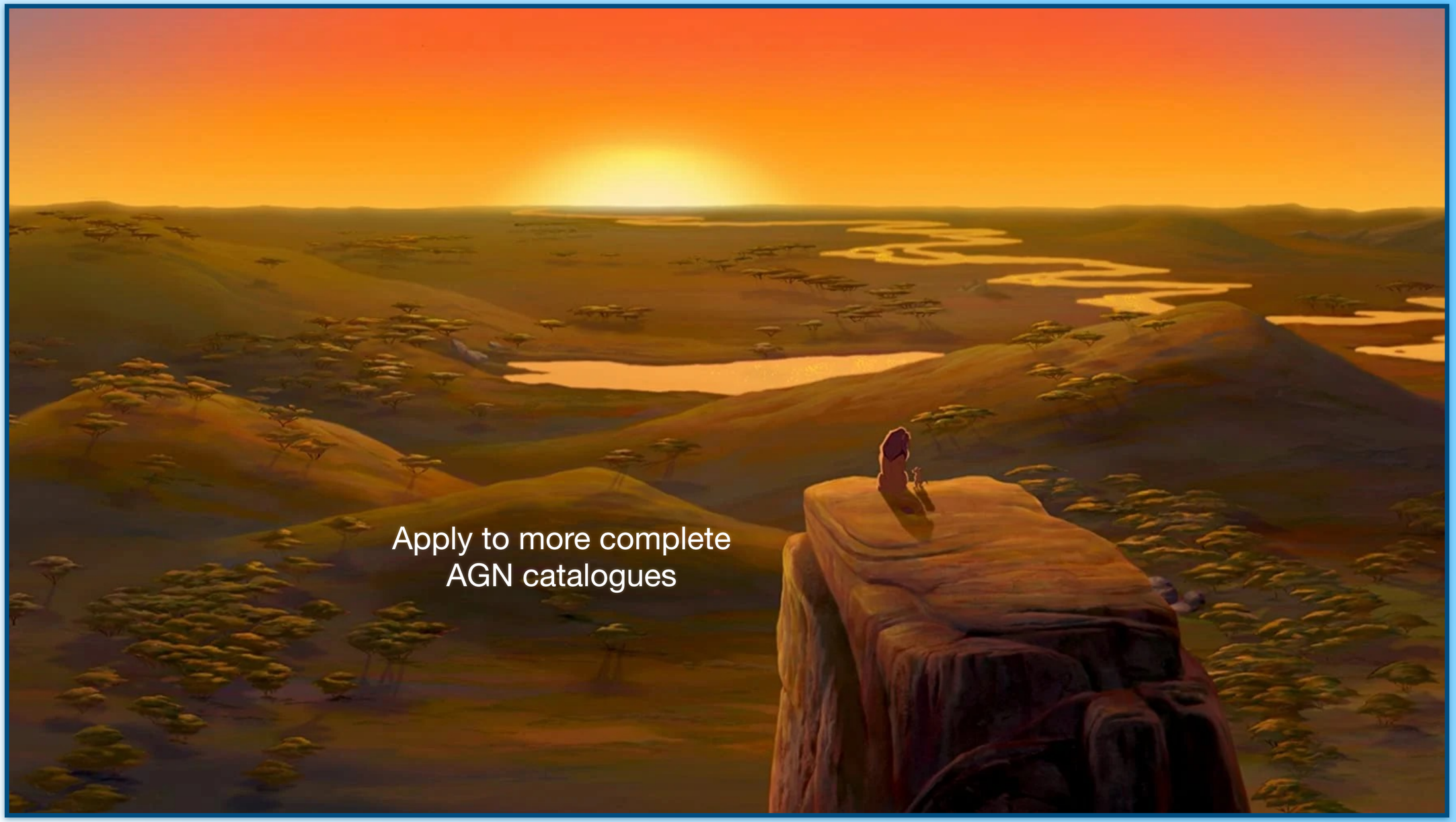
Results



NV+23 (submitted)

Future perspectives

Future perspectives



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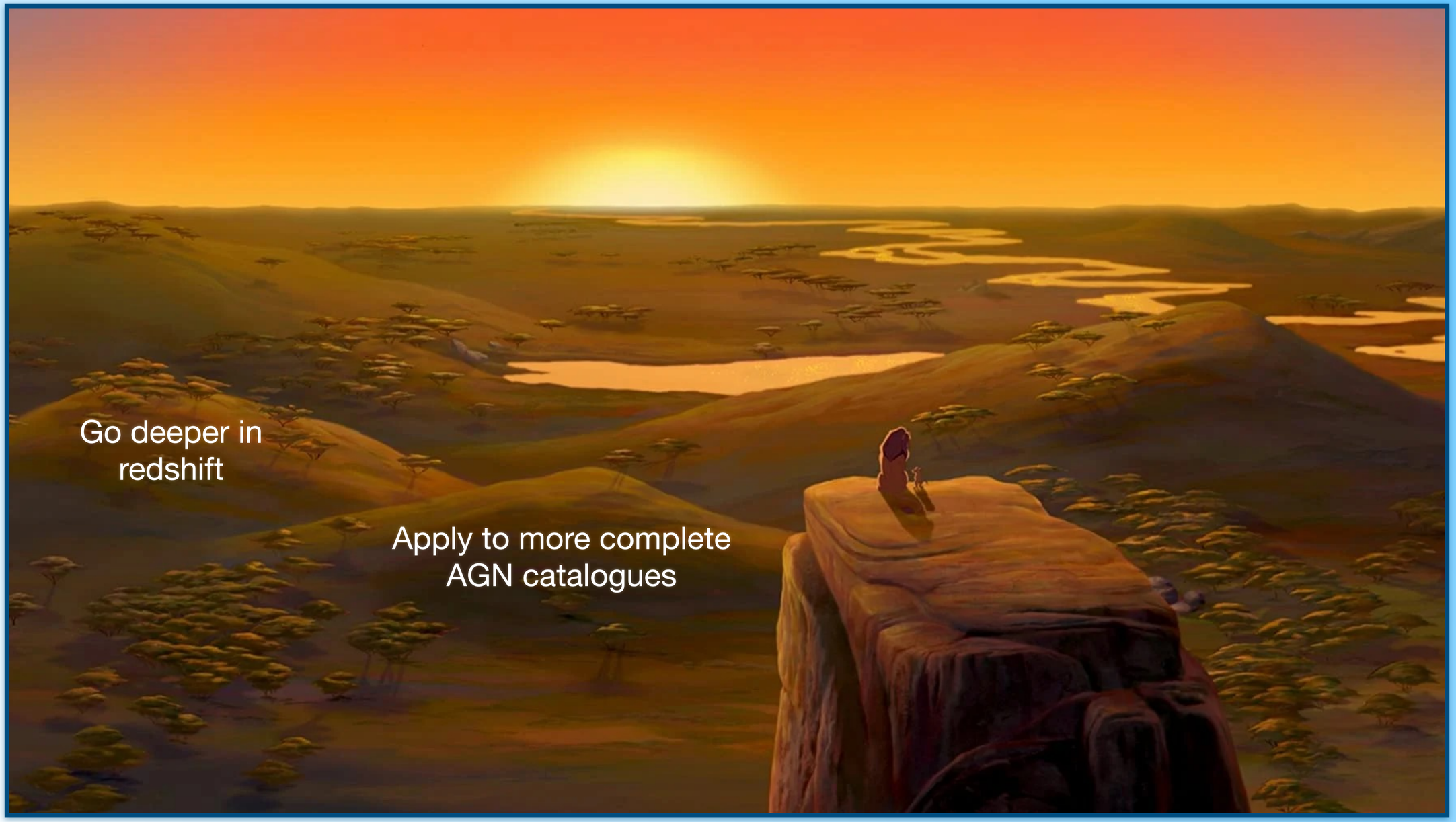

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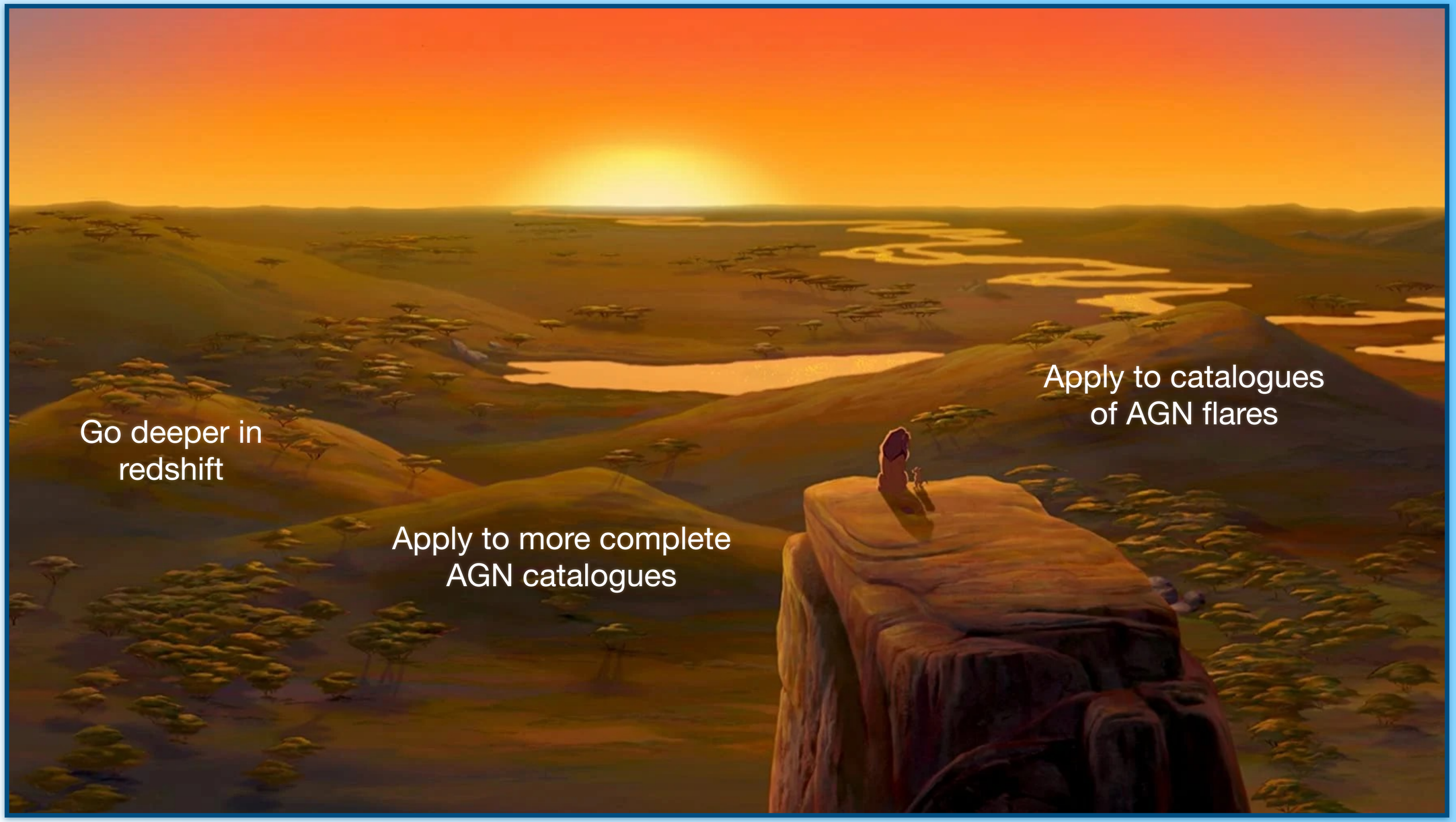

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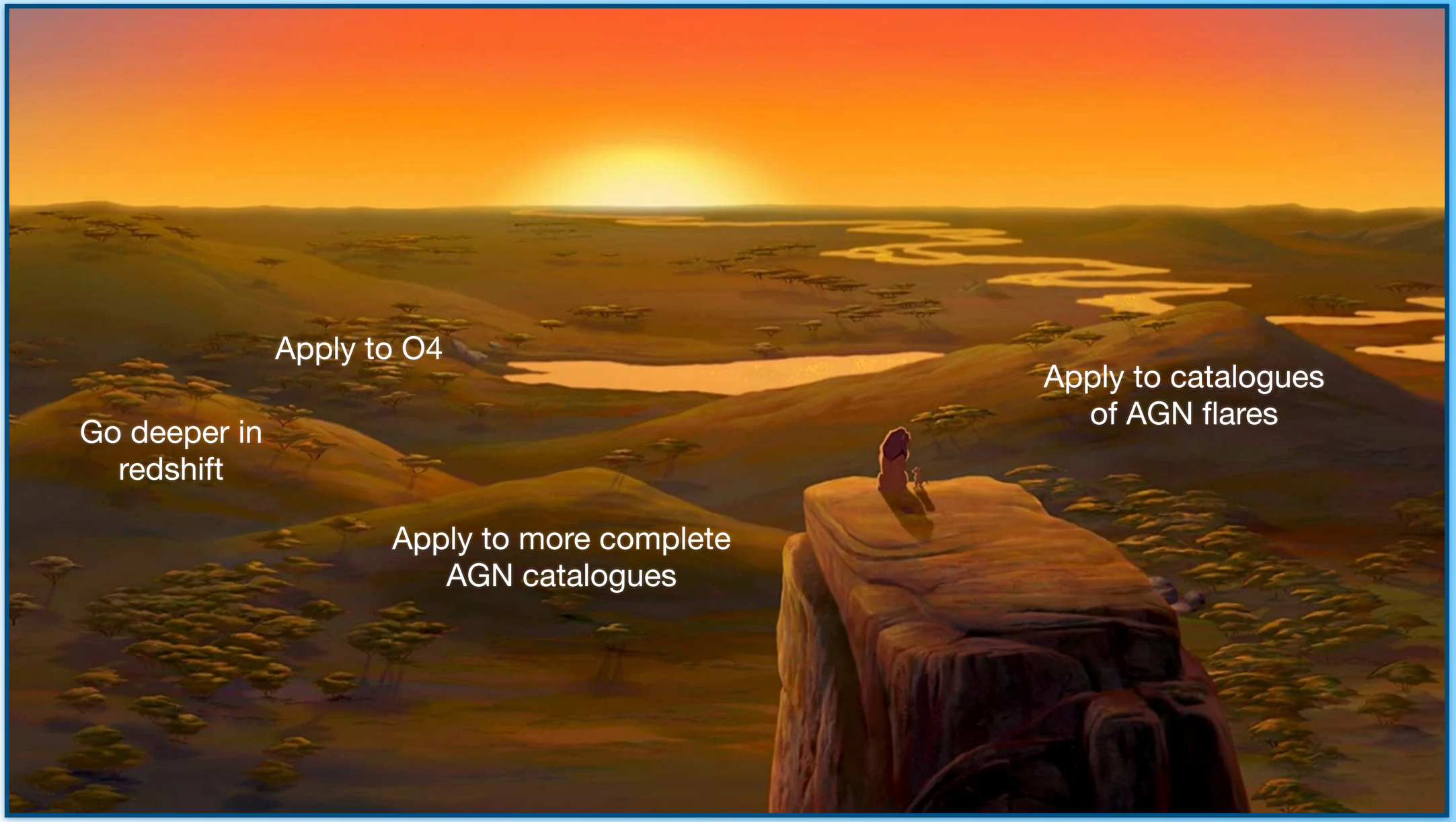

Future perspectives

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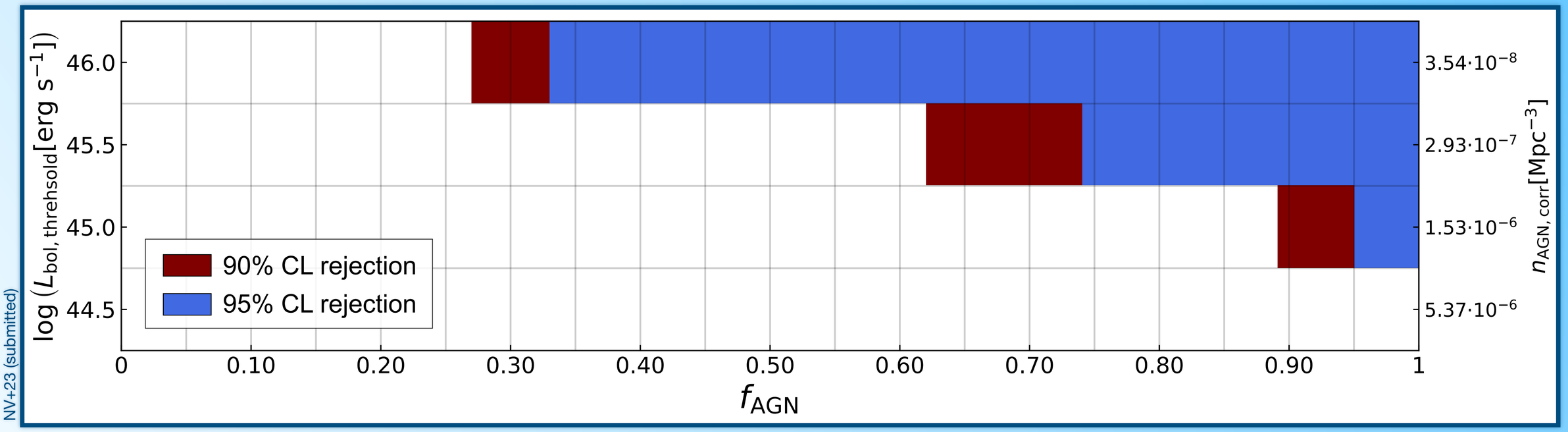
Thank you for your attention!



NV+23 (submitted)

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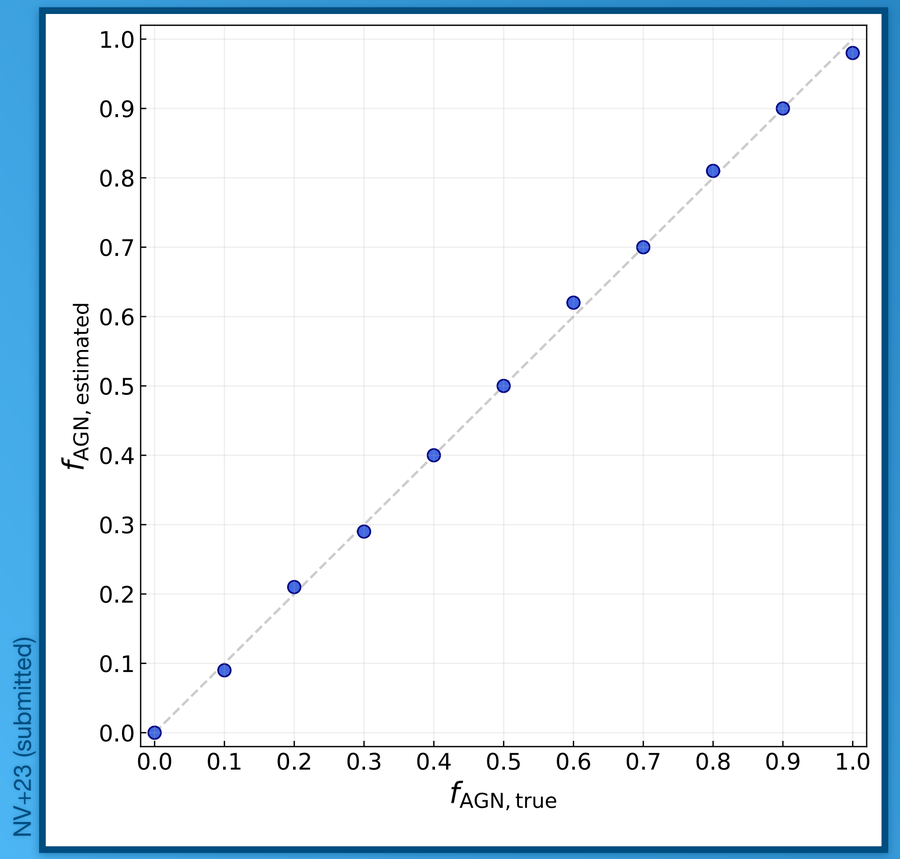
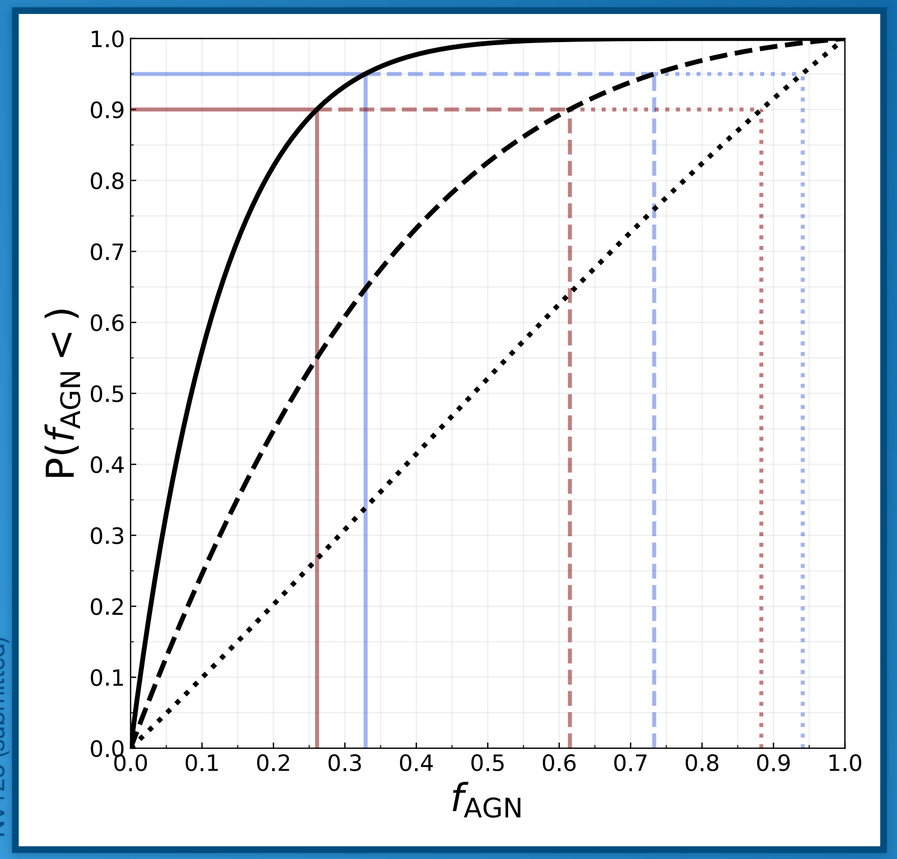
$$\mathcal{L}\left(f_{\mathrm{AGN}}\right) = \prod_{i=1}^{N_{\mathrm{GW}}} \left[c \cdot 0.9 \cdot f_{\mathrm{AGN}} \cdot \mathcal{S}_i + \left(1 - c \cdot 0.90 \cdot f_{\mathrm{AGN}}\right) \mathcal{B}_i\right]$$

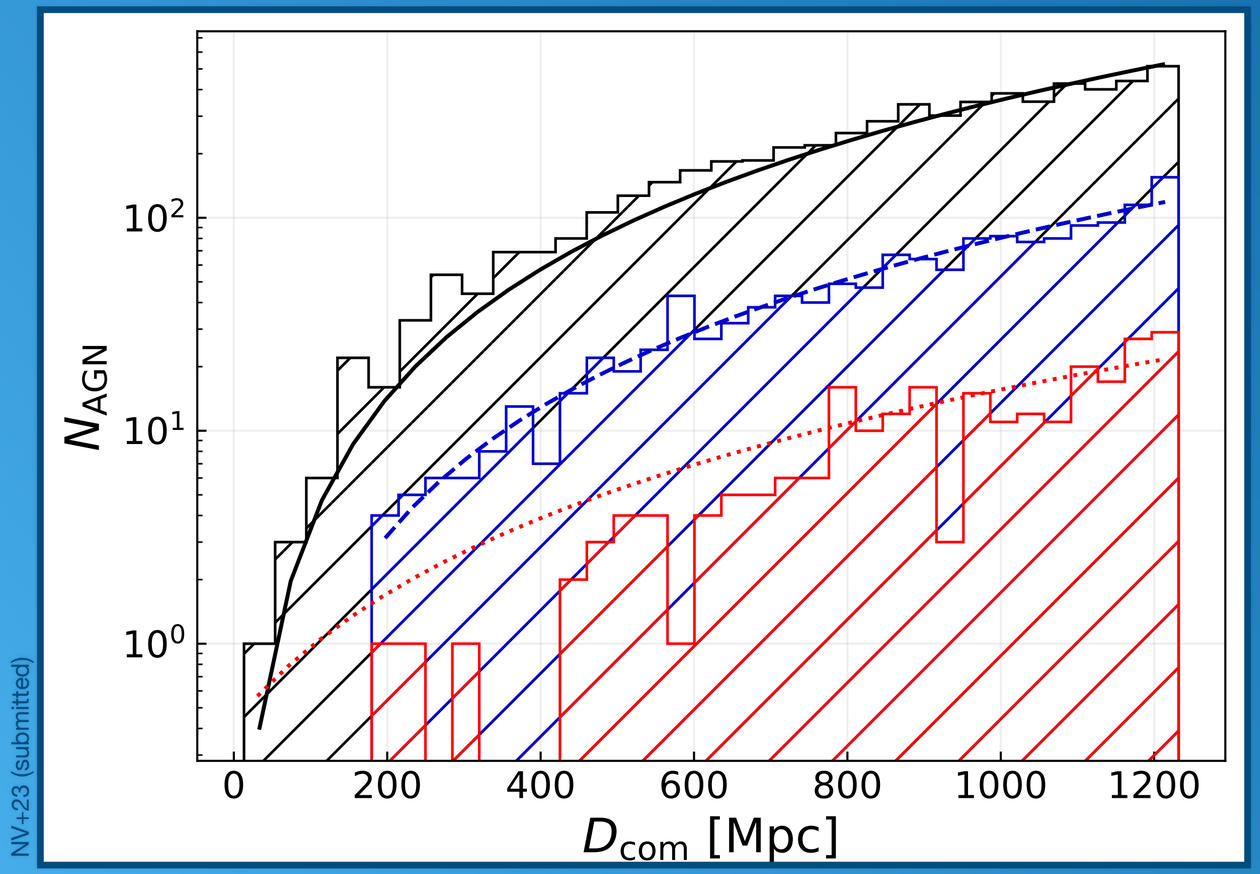
$$\mathcal{S}_i = \frac{\sum_{j=1}^{N_{\mathrm{V90}_i}} p_j}{n_{\mathrm{AGN}} \mathrm{V90}_i}$$

$$\mathcal{B}_i = \frac{0.9}{\mathrm{V90}_i}$$





Name	Citation for Name	unWISE ID [deg]	R.A. [deg]	Dec.	z	Citation for z	W1 mag	L_{W1} [erg s^{-1}]
UVQSJ000000.15-200427.7	Monroe et al. (2016)	0000m197o0005716	0.00065	−20.07433	0.291	Monroe et al. (2016)	13.65	$2.72 \cdot 10^{44}$
SDSS J000005.49+310527.6	Ahumada et al. (2020)	0000p318o0001234	0.02290	31.09102	0.286	Ahumada et al. (2020)	14.20	$1.58 \cdot 10^{44}$
PHL 2525	Lamontagne et al. (2000)	0000m122o0001902	0.10172	−12.76328	0.200	Lamontagne et al. (2000)	11.04	$1.29 \cdot 10^{45}$
2MASX J00004028-0541012	Masci et al. (2010)	0000m061o0015237	0.16774	−5.68361	0.094	Masci et al. (2010)	11.33	$1.90 \cdot 10^{44}$
RXS J00009+1723	Wei et al. (1999)	0000p166o0024250	0.23319	17.39413	0.215	Wei et al. (1999)	12.93	$2.64 \cdot 10^{44}$
SDSS J000102.18-102326.9	Lyke et al. (2020)	0000m107o0014745	0.25911	−10.39078	0.294	Lyke et al. (2020)	14.75	$1.01 \cdot 10^{44}$
RX J00013+0728	Tesch & Engels (2000)	0000p075o0010333	0.32534	7.47432	0.270	Tesch & Engels (2000)	14.06	$1.57 \cdot 10^{44}$
PGC 929358	Paturel et al. (2003)	0000m137o0004668	0.33219	−14.07310	0.087	Mauch & Sadler (2007)	11.65	$1.21 \cdot 10^{44}$
PGC 1698547	Paturel et al. (2003)	0000p242o0009501	0.38474	24.04179	0.104	Ahumada et al. (2020)	11.72	$1.65 \cdot 10^{44}$
RX J00015+0529	Tesch & Engels (2000)	0000p060o0003070	0.38896	5.48926	0.250	Ahumada et al. (2020)	12.67	$4.71 \cdot 10^{44}$



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