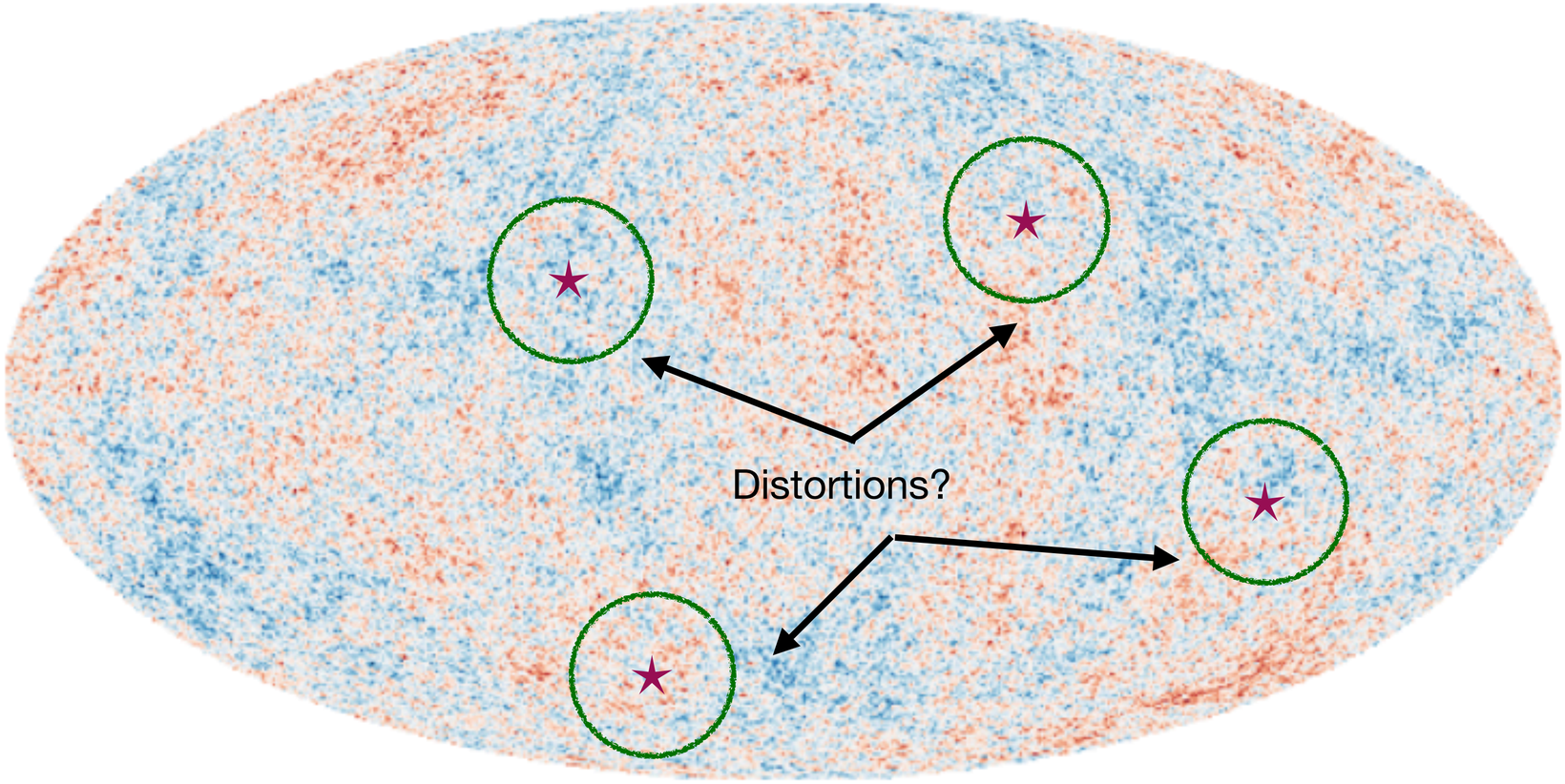
# Searching for **Massive** Particles in the CMB




Oliver H. E. Philcox (with Soubhik Kumar & Colin Hill)

https://arxiv.org/pdf/2405.03738

From PT to AI Workshop, Split 2024

(But neither PT nor AI)

# Non-Perturbative Non-Gaussianity

- Let's imagine **a massive field** $\sigma$ as well as the inflaton $\phi$
- Usual assumption: shift symmetry - $\mathscr{L} \supset \partial\phi, \partial\sigma$
- Let's break this assumption with **time-dependent** masses:

$$\mathscr{L}(\phi, \sigma) \supset -\frac{1}{2} m_\sigma^2(\phi)\sigma^2$$

$$m_\sigma^2(\phi) = {M_0}^2 + g^2(\phi - \phi_\star)^2 \qquad \textit{or} \qquad m_\sigma^2(\phi) = {M_0'}^2 + 2g^2 f^2 \cos\left(\frac{\phi - \phi_\star}{f}\right)$$

- This is specified by the **minimum mass** and the **coupling**

Flauger+16, Munchmeyer+19, Kim+21,23

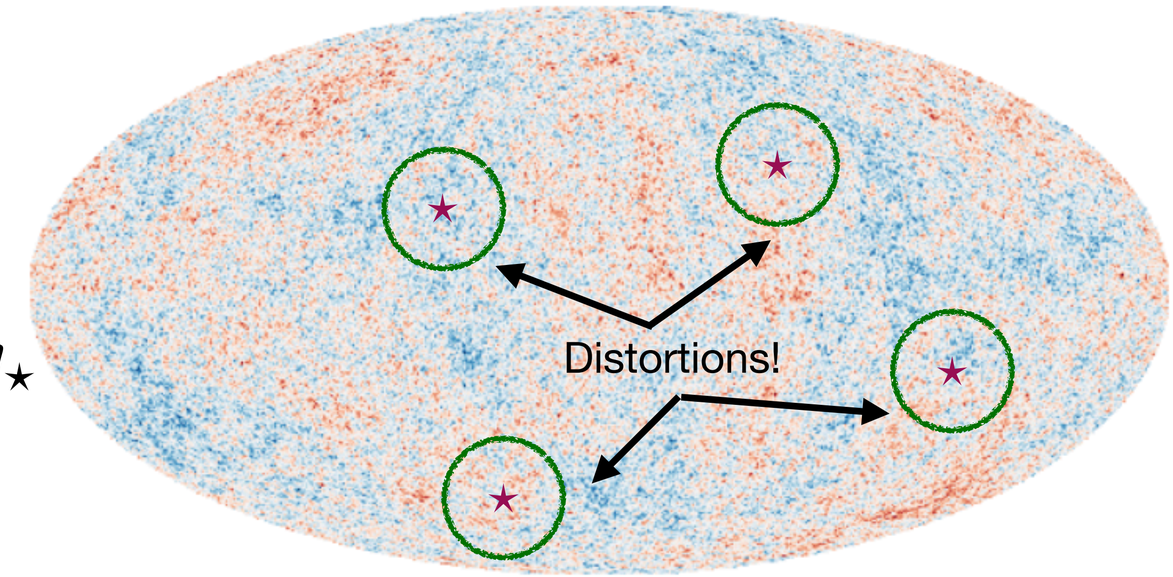
# Non-Perturbative Non-Gaussianity

- Phenomenology:
  - **Intermittent particle production**

    [set by minimum mass]
  - *Gravitational* coupling

    [set by mass evolution]
  - **Local distortions** on horizon scale $\eta(\phi_\star) \equiv \eta_\star$

$$N_{\text{production}} \sim e^{-\pi M_0^2/g|\dot{\phi}|}$$




- This probes **large masses:**

$$M_0 \sim \mathcal{O}(100 H_\star) \lesssim 10^{16}\,\text{GeV}$$

Flauger+16, Munchmeyer+19, Kim+21,23

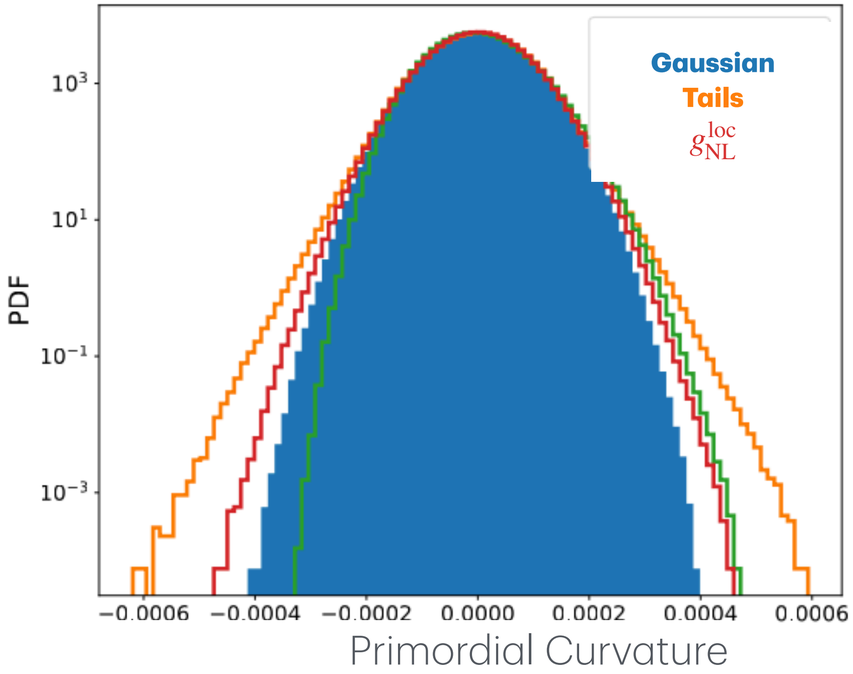
# Impact on the CMB

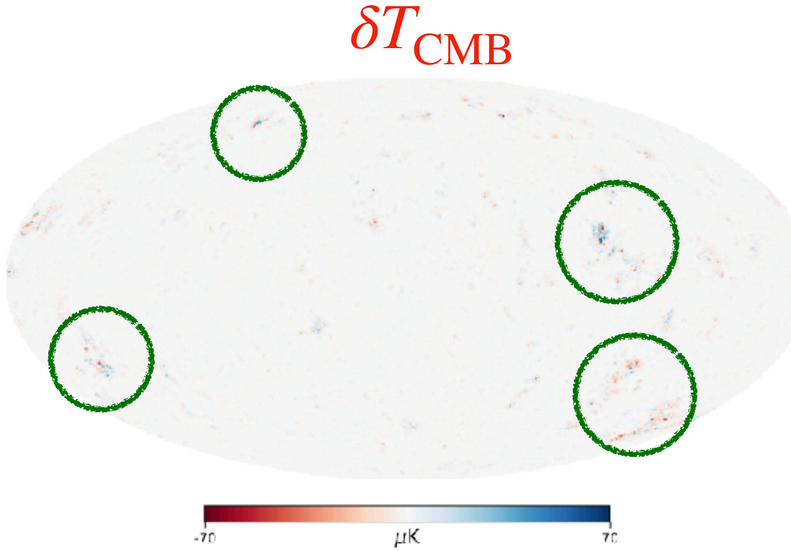
- This produces *rare* and *local* events, just like primordial tails [cf. Will's talk]

- This *barely* affects the power spectrum but leads to *localized hotspots* in the CMB

$$\delta T_{\rm CMB} \sim \int \mathrm{Transfer(k)} \langle \zeta(\mathrm{k}) \rangle$$

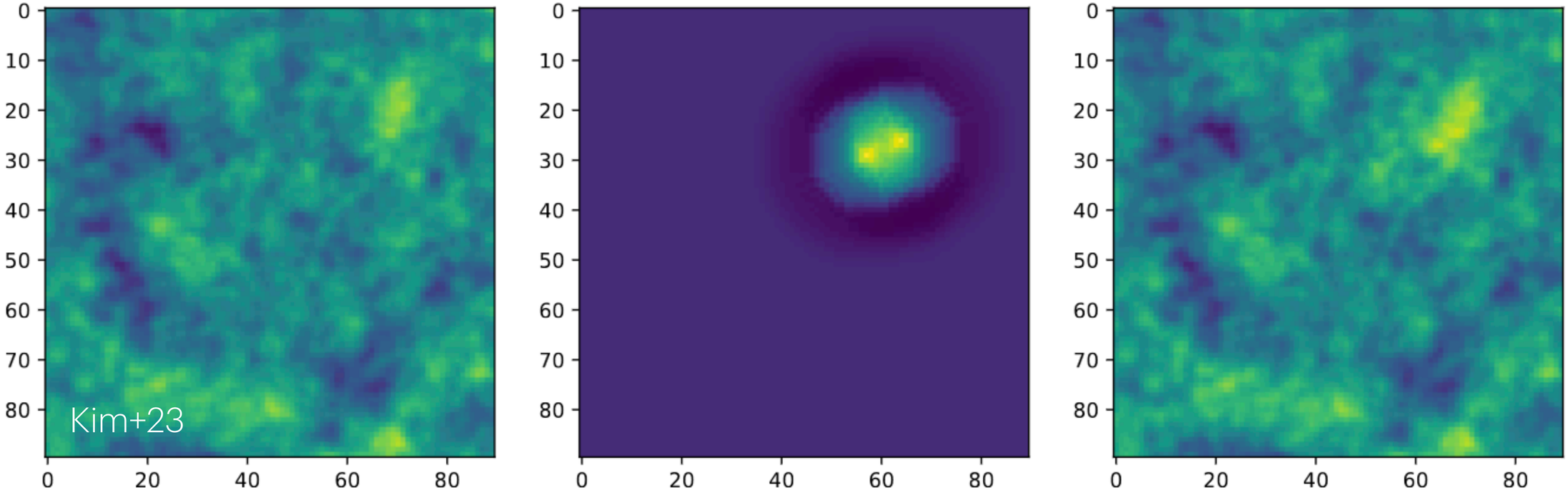
- **How do we search for these in data?**




Kim+21,23, Coulton, **Philcox**+24, **Philcox**+24

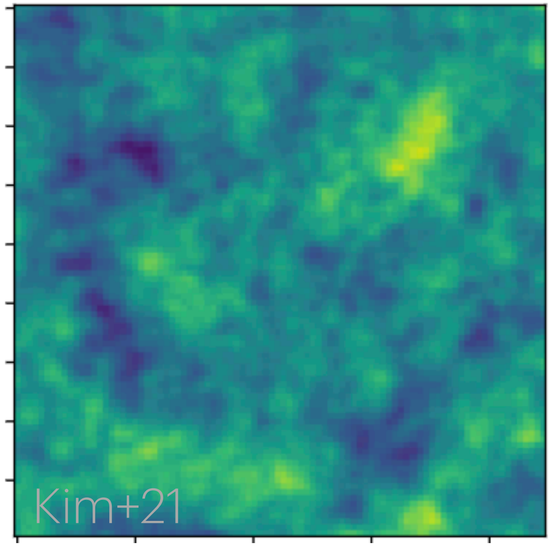
# How to Search for Hotspots




Gaussian CMB + Particle Production Signal = Less Gaussian CMB

Kim+21, 23, **Philcox**+24

# How to Search for Hotspots



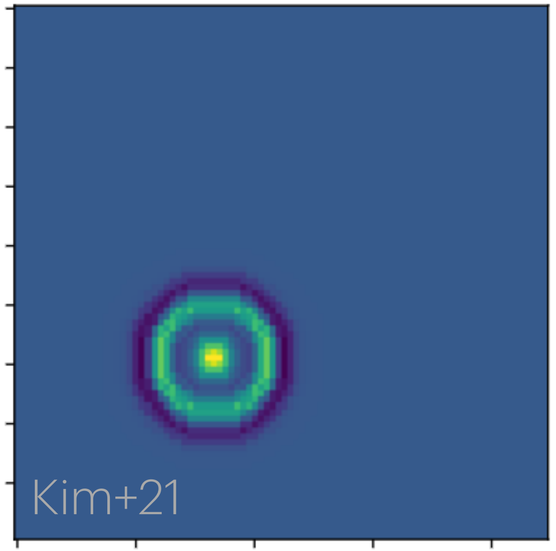

**Option 1**:

- Machine learning fun 🥲 [Kim+23]

**Option 2**:

- Linear theory 😄

$$S(\vec{\theta}) = \left[\hat{T} * T_{\rm hotspot}(g, \eta_\star)\right](\vec{\theta})$$




- The optimal approach is a **matched filter / profile finder**.
- *This is equivalent to summing N-point functions up to high N* [Munchmeyer+19]

Kim+21, 23, **Philcox**+24

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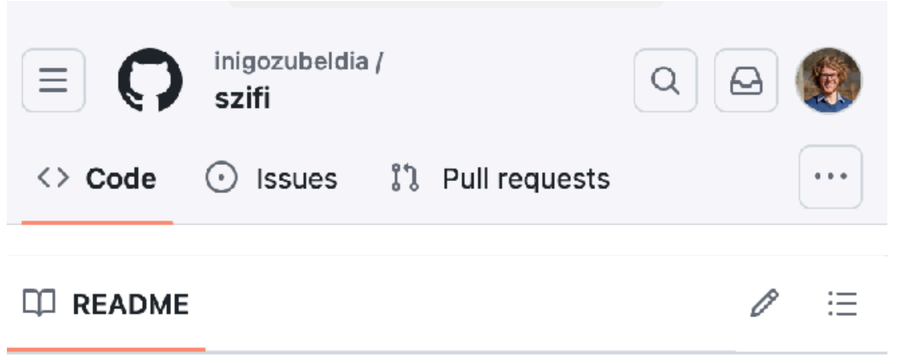
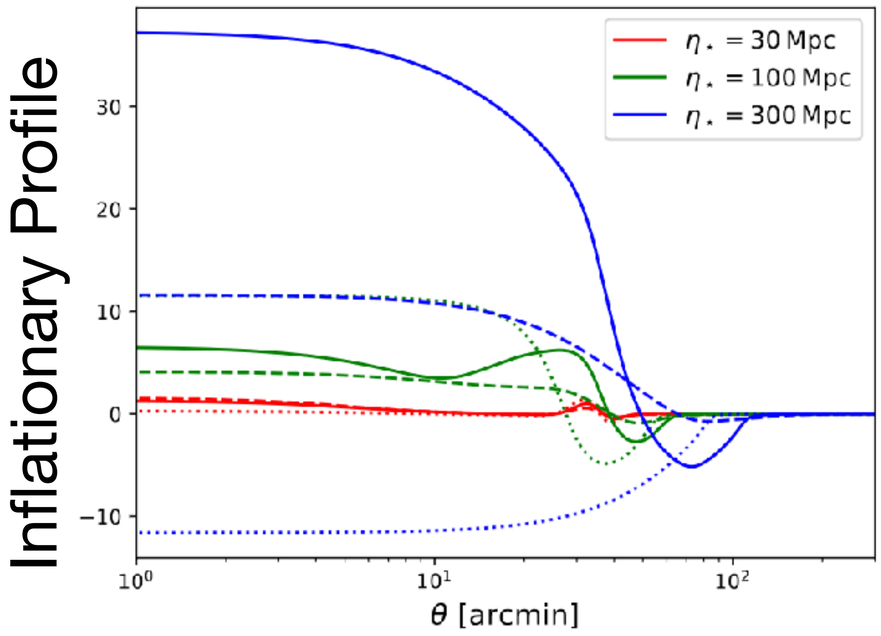



- We already know how to do profile finding in the CMB!
  - This is **exactly** what thermal SZ analyses do

**Plan of Attack:**

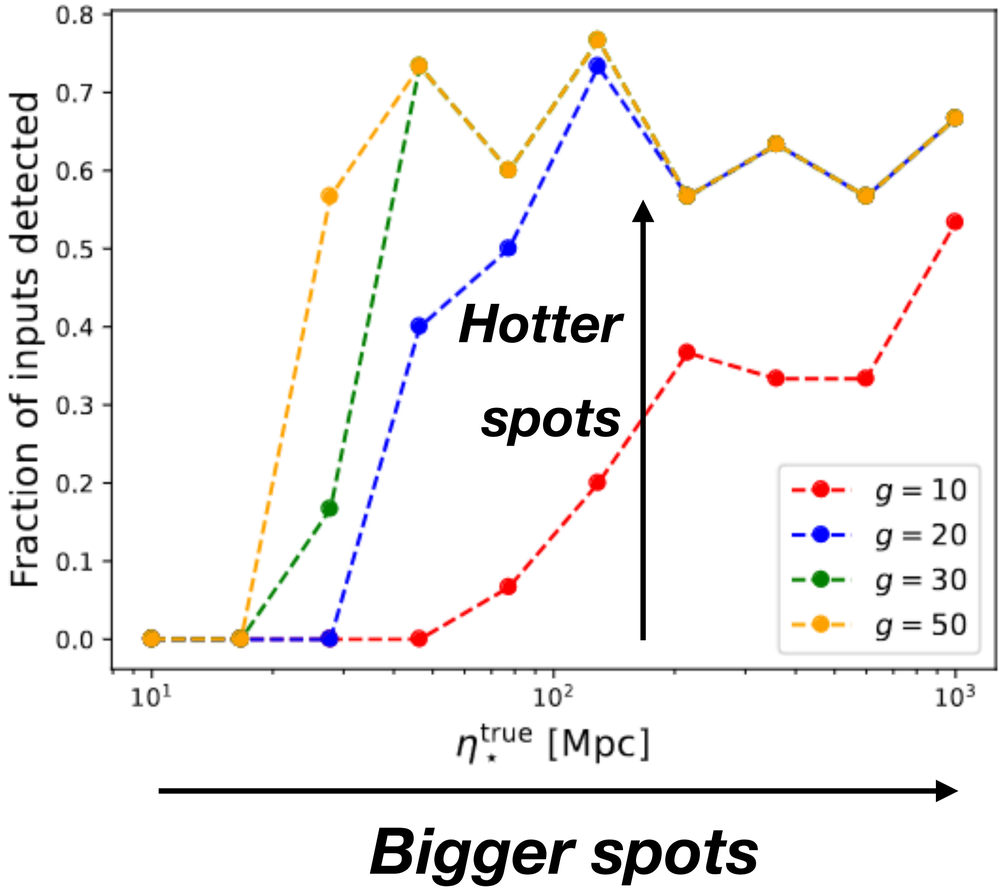
1. Download tSZ Code: ***szifi*** [Zubeldia+21-23]
2. Hope it's documented 😭
3. Swap out the cluster profile for an inflationary profile
4. Apply to Planck [PR4] temperature data
5. Submit paper




Zubeldia+21, 22, 23, Kim+21, 23, **Philcox**+24

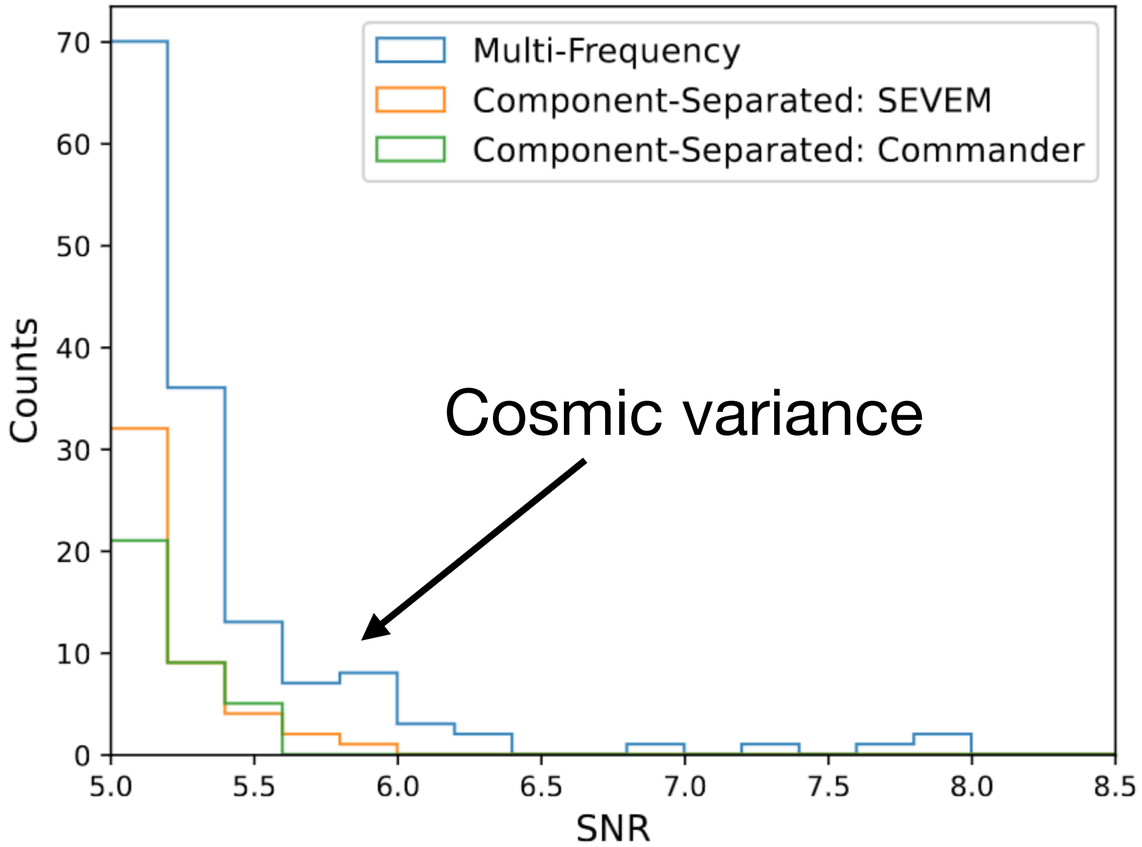
# Constraints from Fake Data

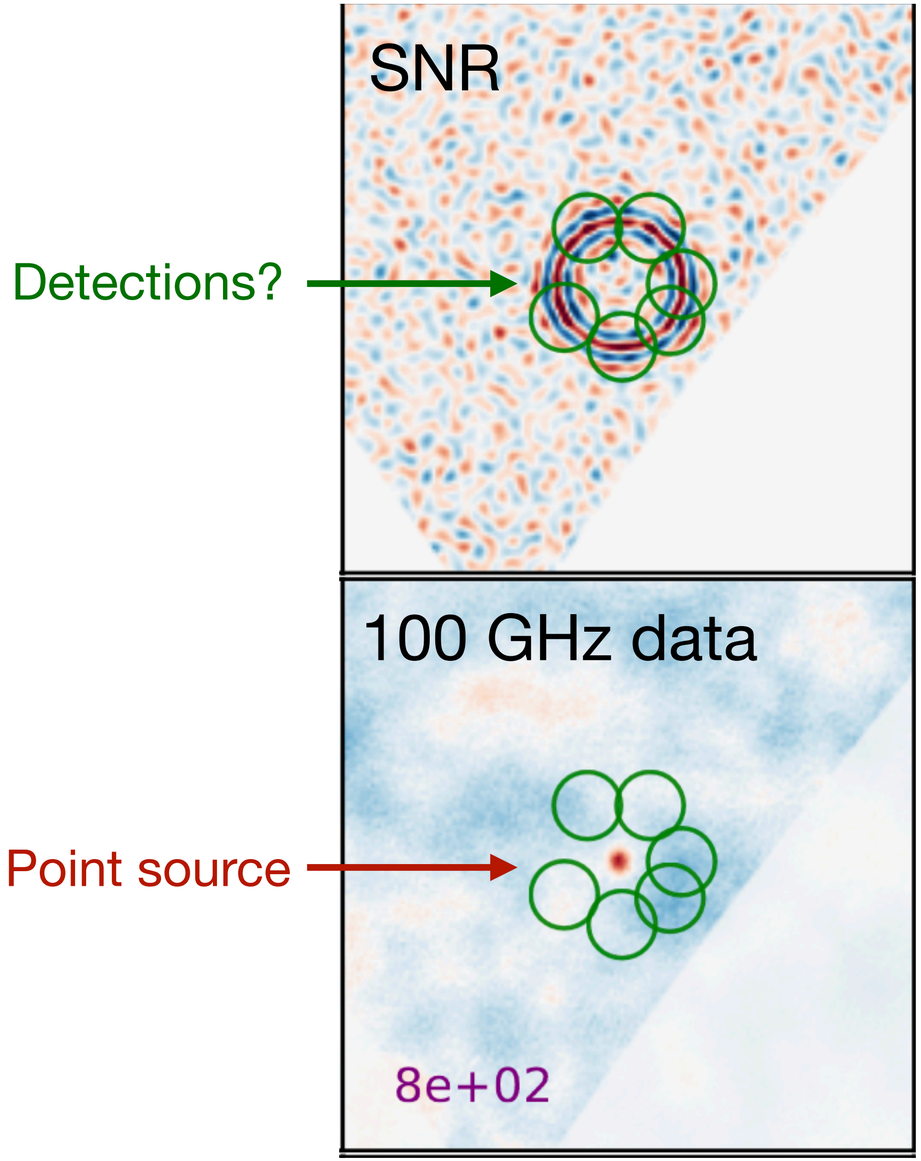
- Constraints depend on:
  - Coupling strength: $g \rightarrow$ amplitude
  - Horizon size: $\eta_\star \rightarrow$ template size
- Constraints do ***not*** depend on mass, $M_0$
- Validate with contaminated CMB simulations
  - Use a **frequentist** analysis
  - Apply to 6 frequency maps *or* component-separation
  - Mask point sources and SZ clusters



# Constraints from Planck

- No strong detections!
  - But a few false detections…



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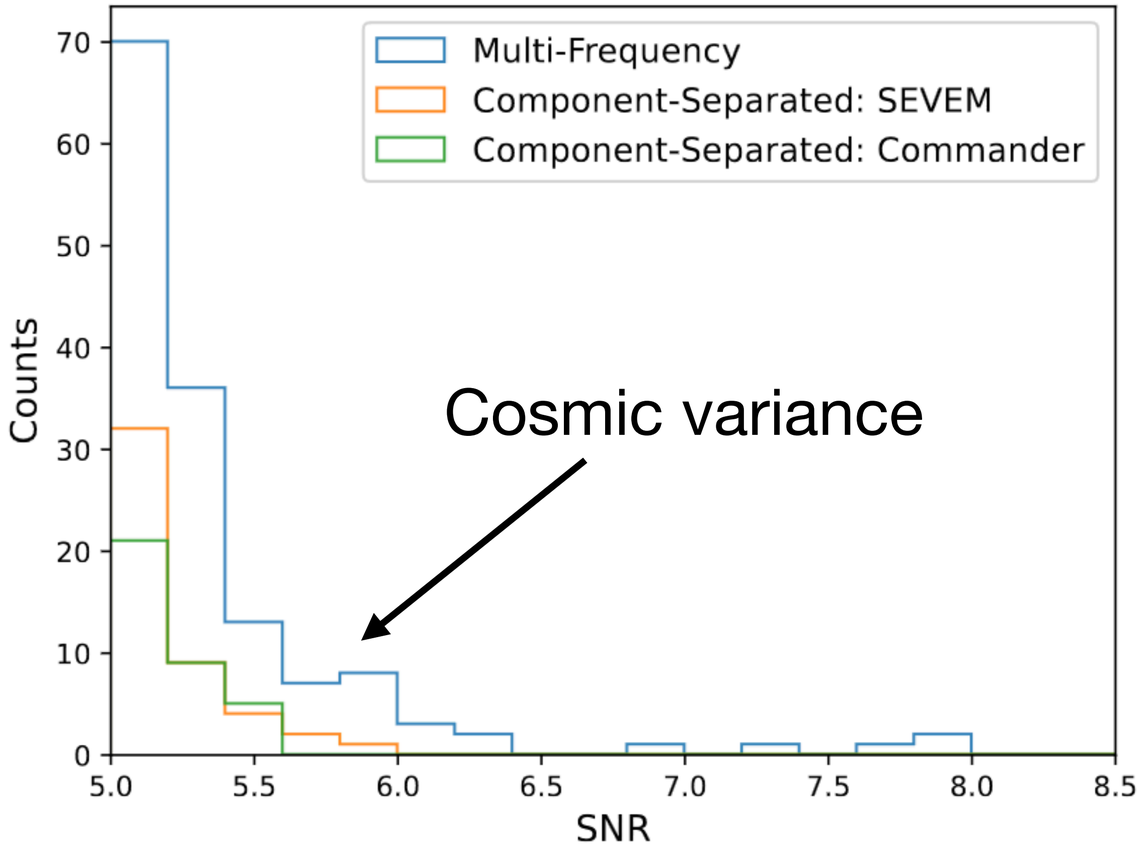
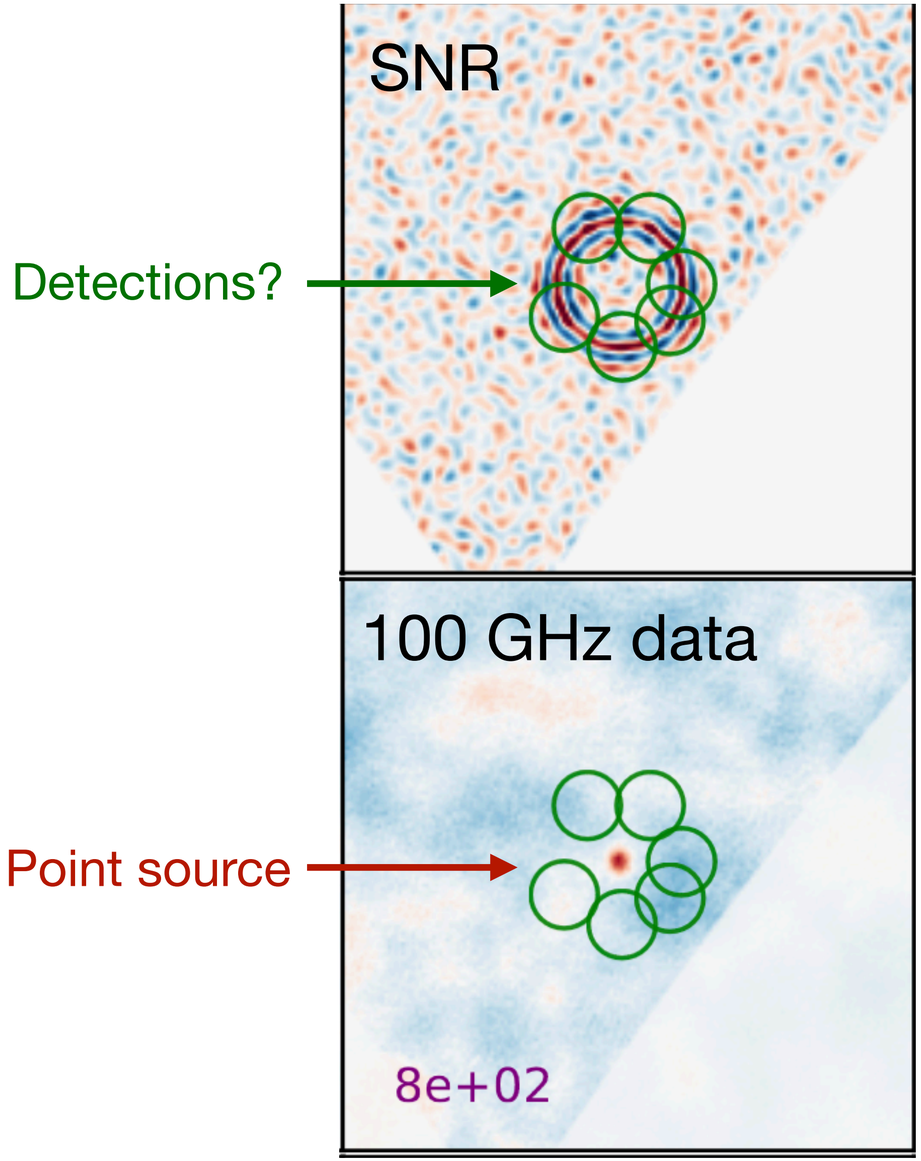


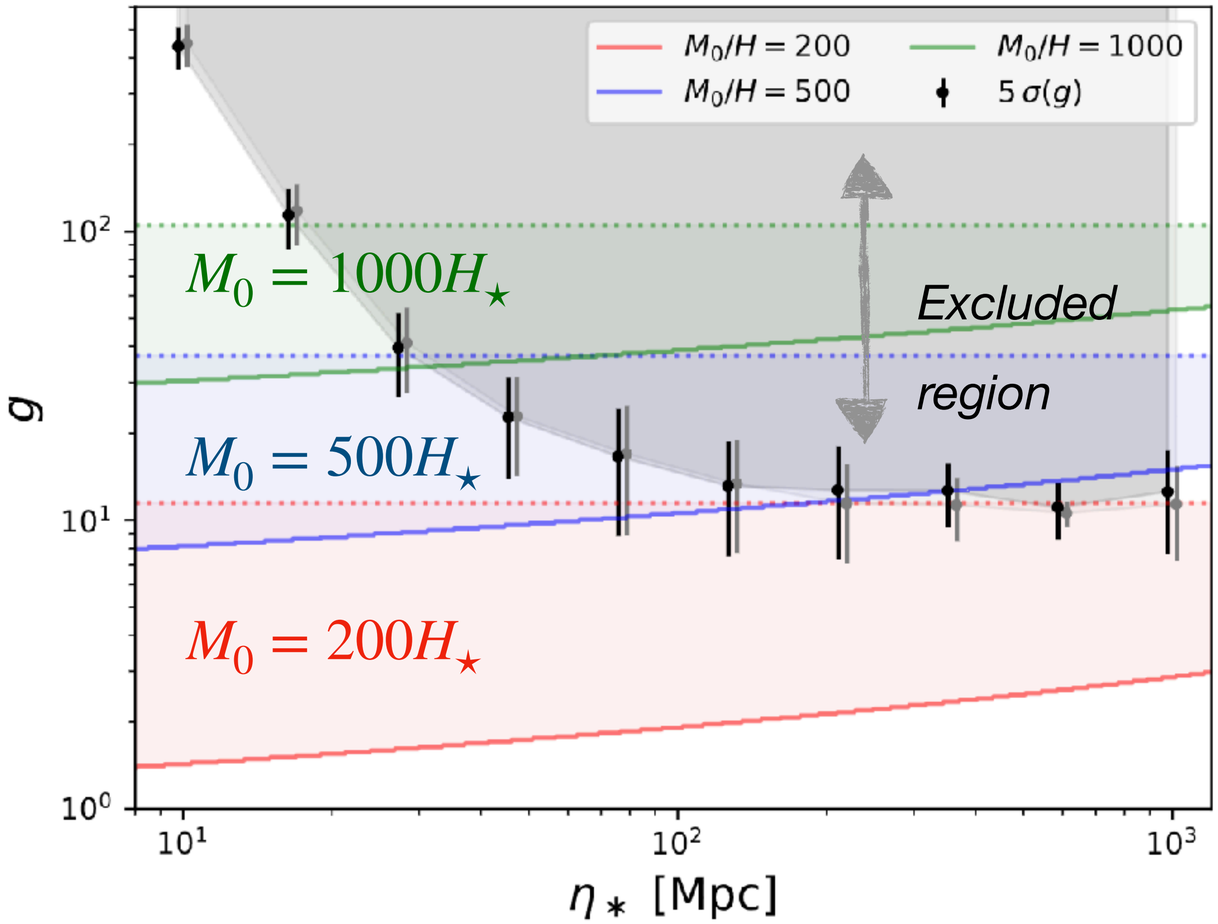



# Constraints from Planck

- We **exclude** hotspots from $M \gtrsim 500 H_\star$ particles!

  *(Probably the highest energy experiment ever)*

- This depends on size, $\eta_\star$:
  - Smaller spots are lost in the beam
  - Bigger spots are limited by cosmic variance



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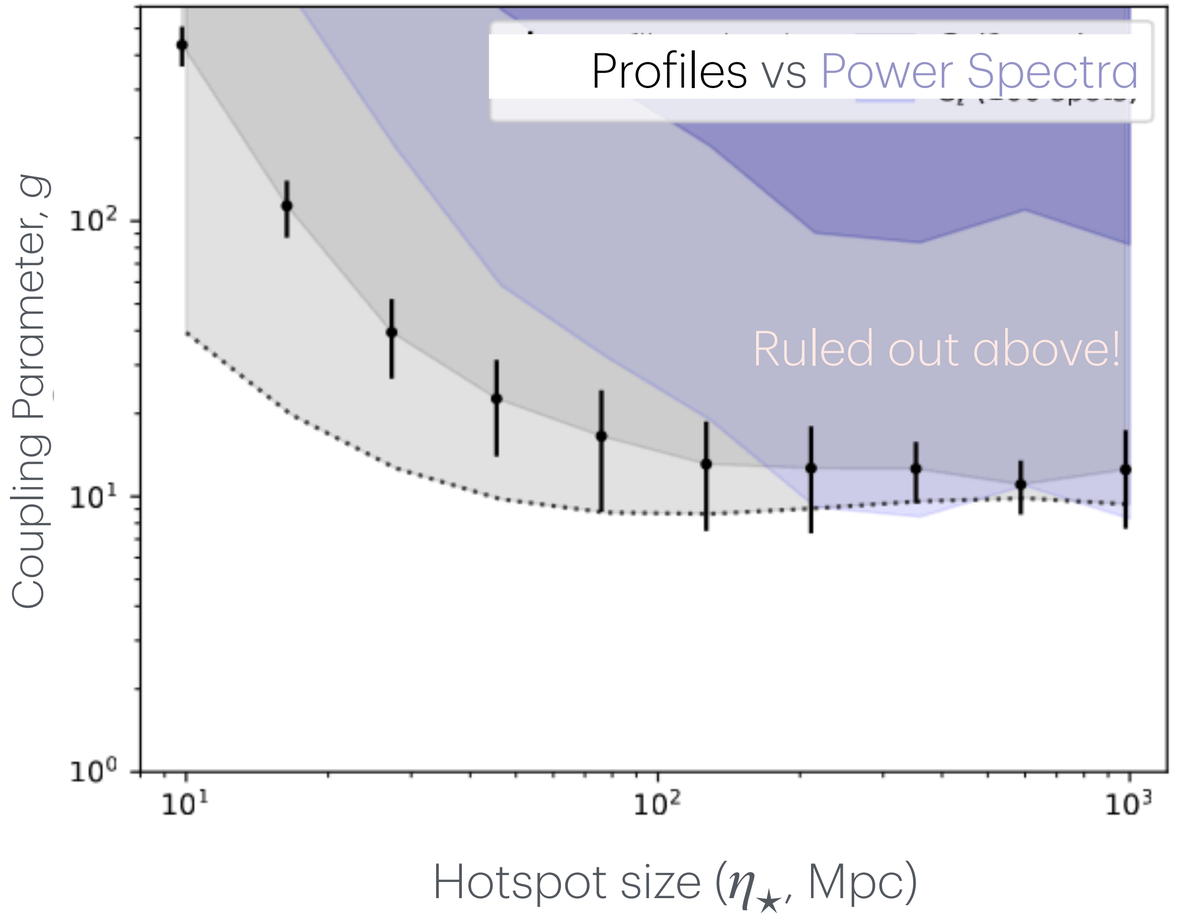
- Constraints are *much* better than the power spectrum for rare events



# Conclusions

- *Rare events* need *non-perturbative* treatments.
- For the CMB, this is **easy** - just use cluster-finding tools.
- For LSS, the implications are unknown.
- We (unsurprisingly) don't find anything.