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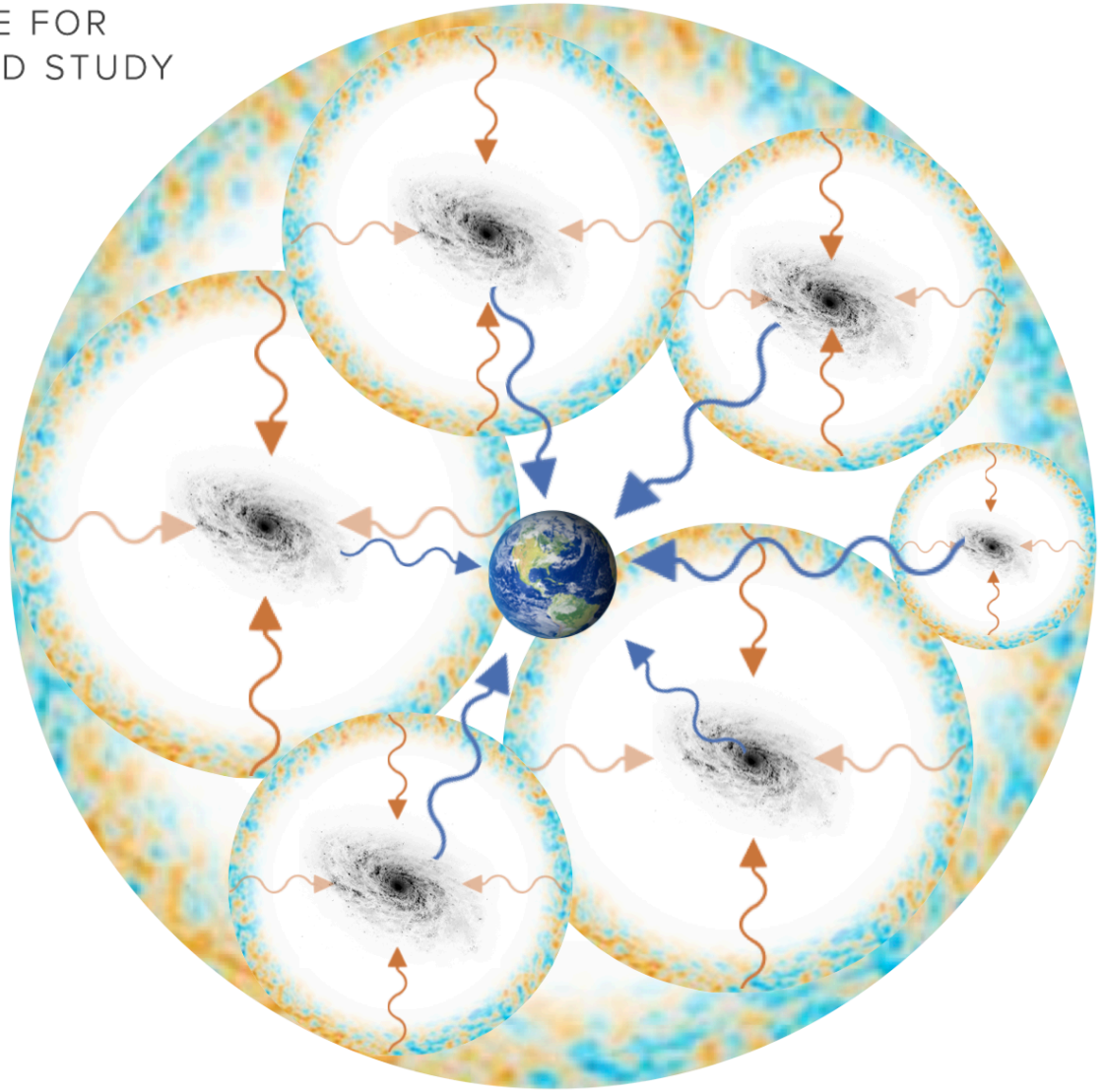
Can We Learn Anything from pSZ x Shear?

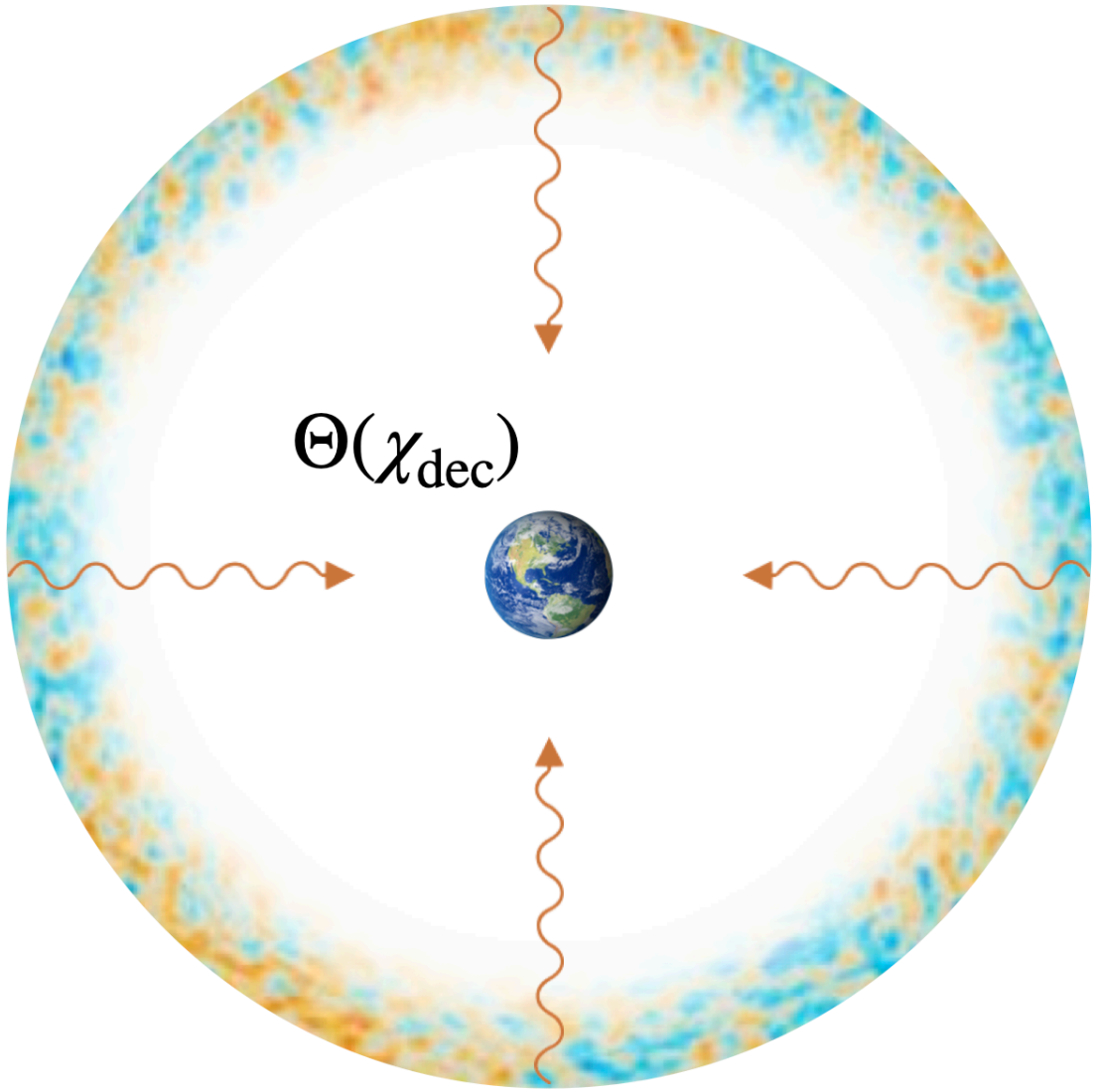


Oliver Philcox (Princeton / IAS)
(with Matt Johnson)

SZ Workshop, *June 2022*

THE pSZ EFFECT: A BRIEF INTRODUCTION

See Matt + Selim's talks for more!



- The primary CMB probes the temperature fluctuations, Θ, **as seen at the Earth**

e.g. Loeb+, Baumann+, Deutsch+, Sazonov+

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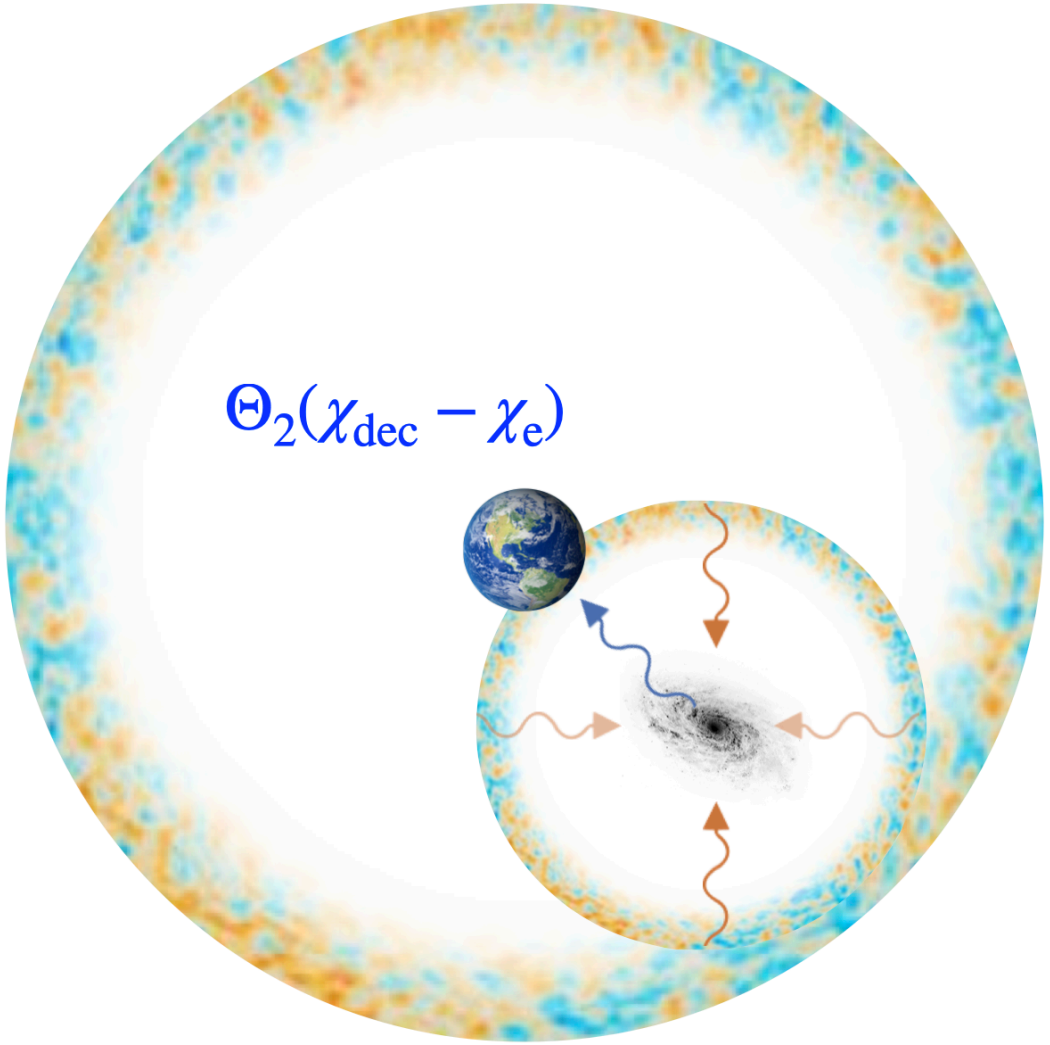

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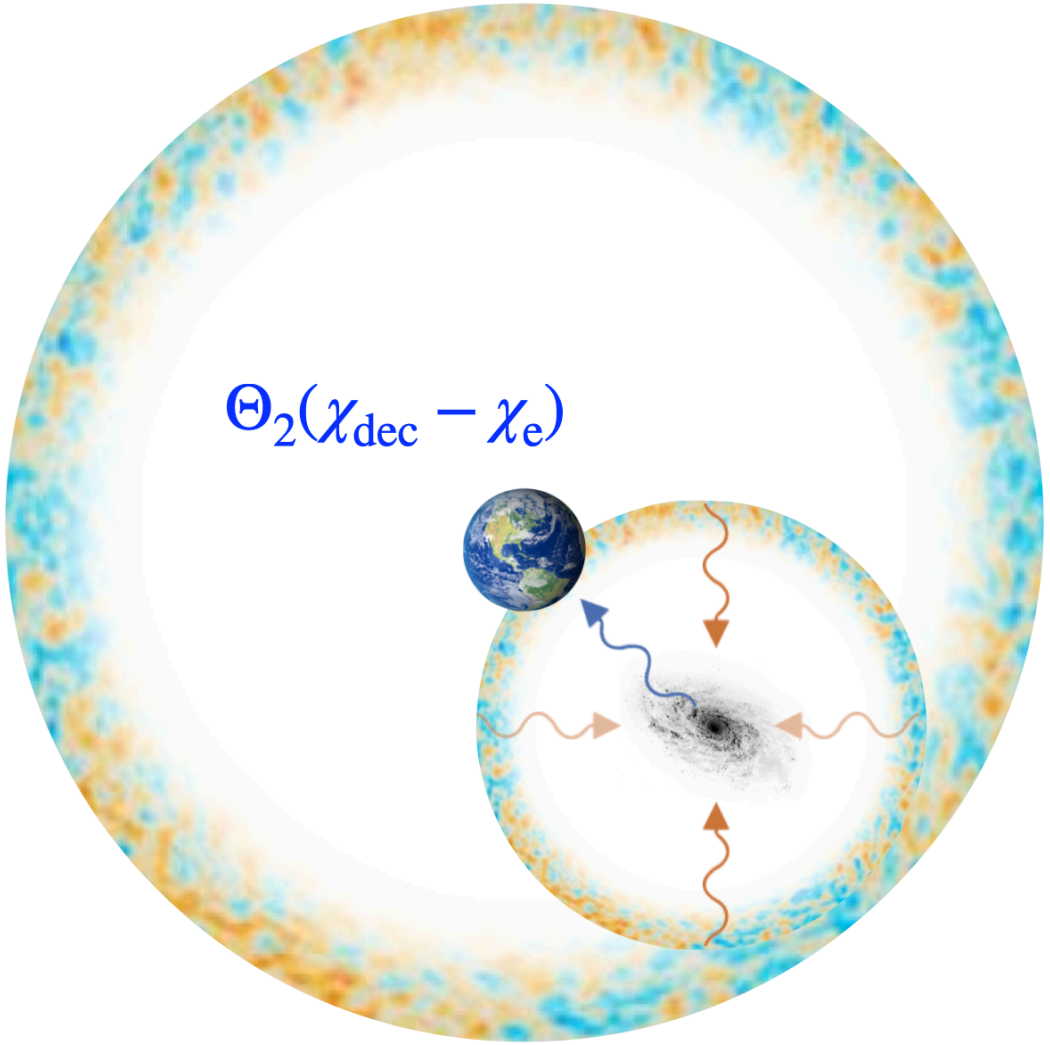

- The primary CMB probes the temperature fluctuations, Θ, **as seen at the Earth**
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- We can reconstruct CMB quadrupole:

$$\widehat{\Theta_2}\,(\chi_{\rm dec} - \chi_{\rm e}) \sim \langle \delta_g(\chi_e)(Q \pm iU)_{\rm CMB} \rangle$$

e.g. Loeb+, Baumann+, Deutsch+, Sazonov+

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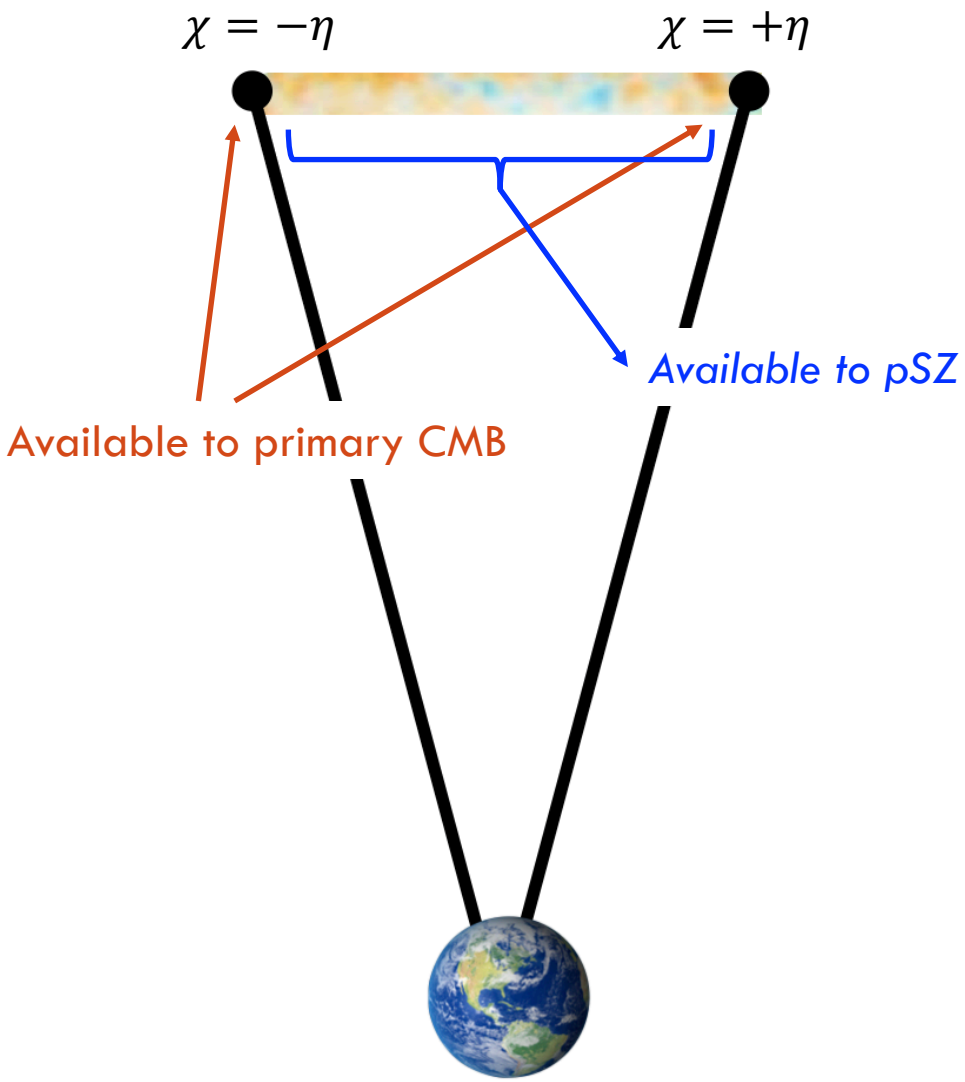

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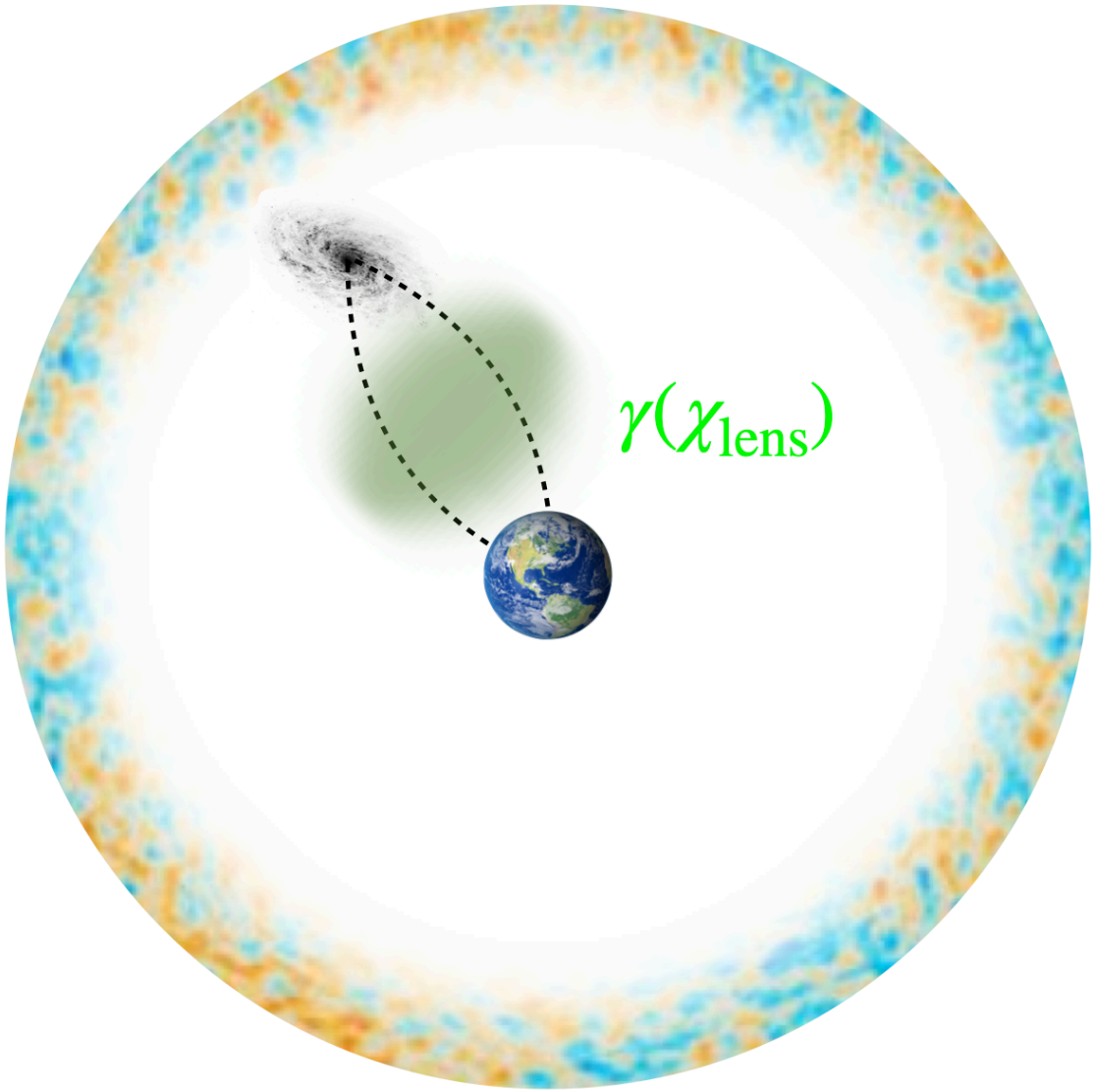
COSMIC SHEAR: A BRIEF INTRODUCTION



- Cosmic shear probes the **shape distortions** of galaxies

$$\gamma^E(\chi_{\rm lens}) \sim \int_0^{\chi_{\rm lens}} d\chi \, \nabla^2 \Phi(\chi)$$

- Correlates also with **tensor** perturbations

e.g. Bartelmann+, Castro+, Schmidt+

HOW DO WE ANALYZE pSZ OBSERVATIONS?

Option #1: Compute $\langle pSZ \times pSZ \rangle$

- This Probes $\langle \boldsymbol{\delta}_{\mathbf{g}} \boldsymbol{\delta}_{\mathbf{g}} (\mathbf{E} \pm \mathbf{iB})(\mathbf{E} \pm \mathbf{iB}) \rangle$ trispectrum, *but*
  - Noise profile is complex
  - Systematics can enter

e.g. Deutsch+, Johnson+

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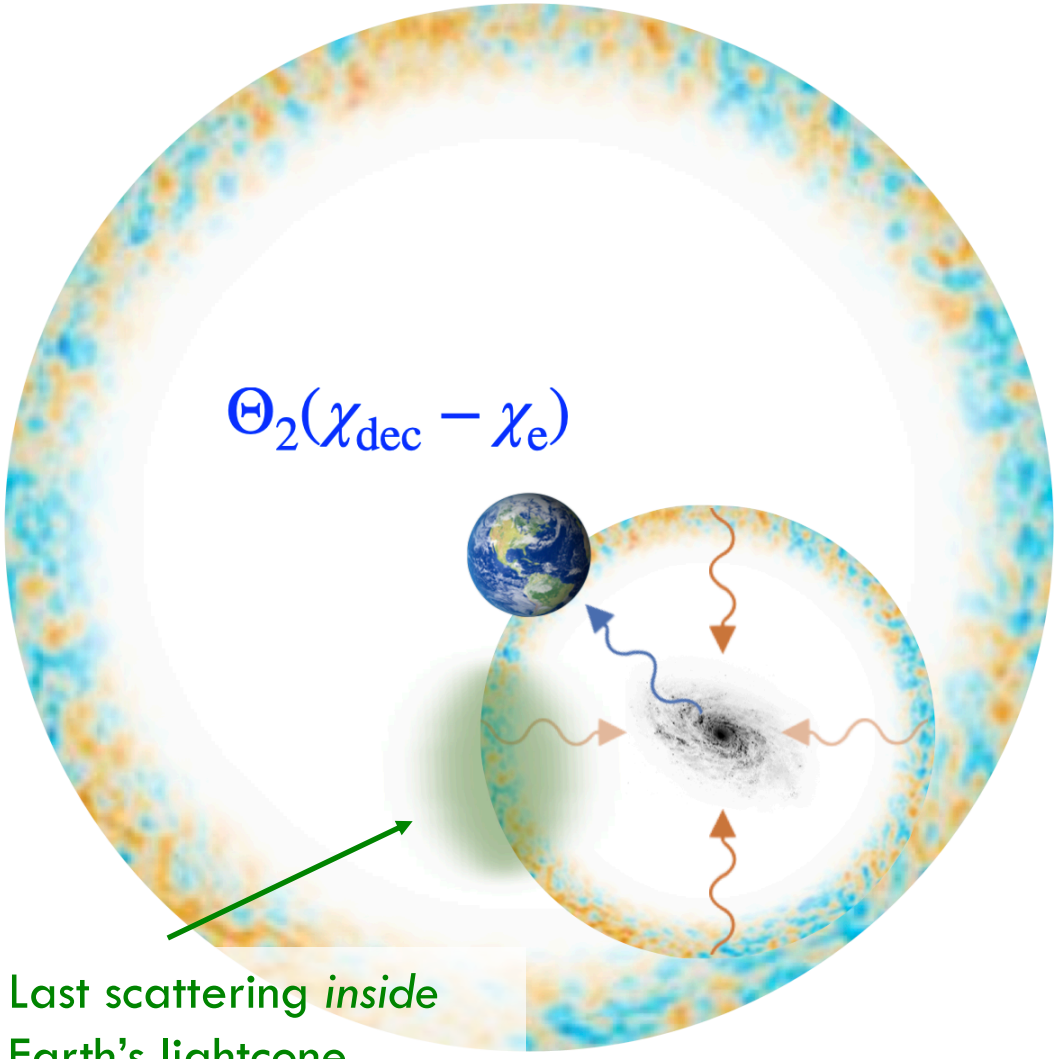
  - Systematics can enter

Option #2: Use cross-correlations, e.g. $\langle \mathrm{shear} \times pSZ \rangle$

- This Probes $\langle \boldsymbol{\delta_g \gamma (E \pm iB)} \rangle$ bispectrum:
  - No noise (except in covariance)
  - Systematics (largely) cancel

e.g. Deutsch+, Johnson+

pSZ X SHEAR: UNEQUAL-TIME SW EFFECT [HIGH-z]



- Most pSZ signal comes from the **Sachs-Wolfe** effect

$$\mathrm{pSZ} \sim \Phi(\chi_{\rm dec}, \mathbf{r})$$

Philcox & Johnson (in prep.)

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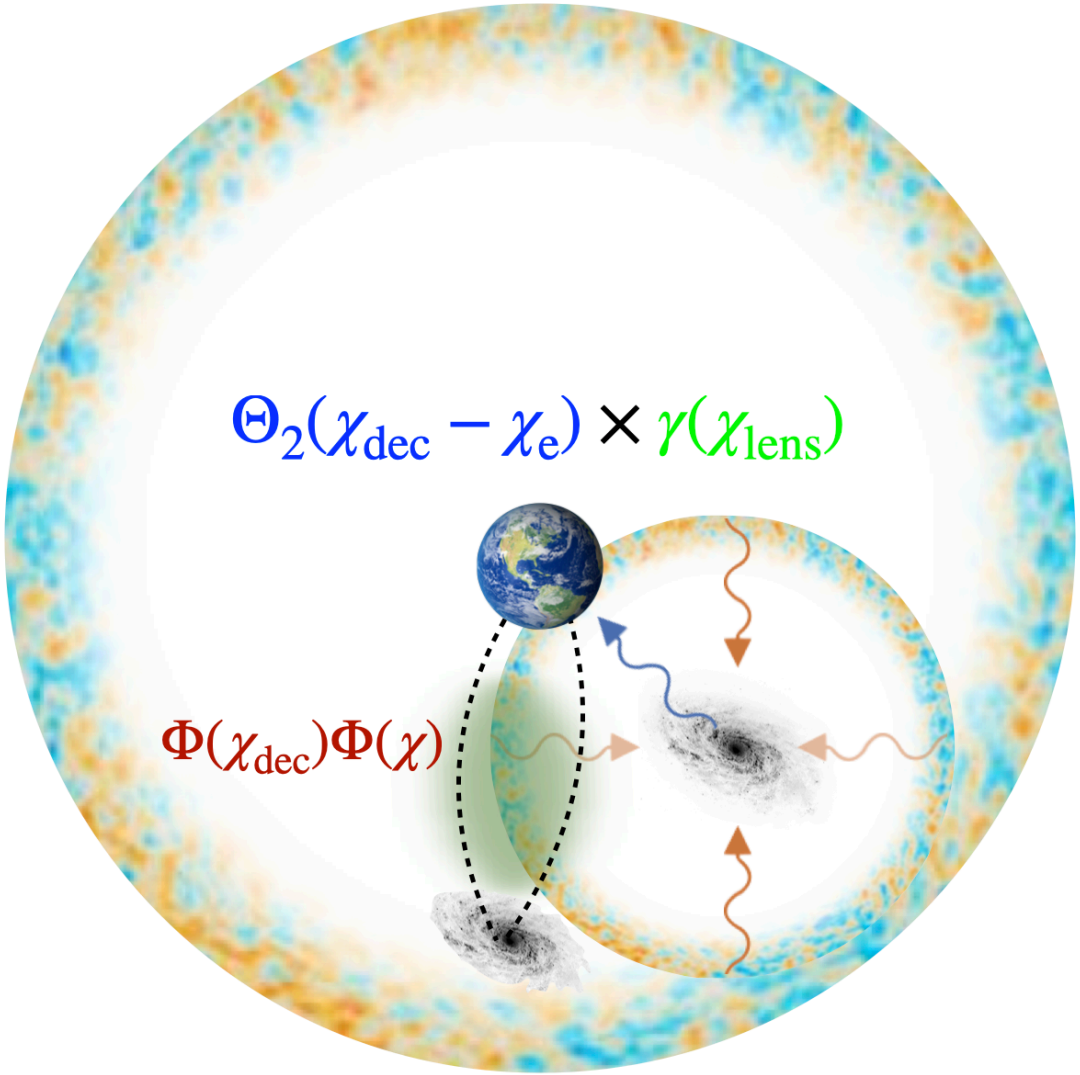


- Most pSZ signal comes from the **Sachs-Wolfe** effect

$$\mathrm{pSZ} \sim \Phi(\chi_{\rm dec}, \mathbf{r})$$

- Cosmic shear probes the potential at the same location

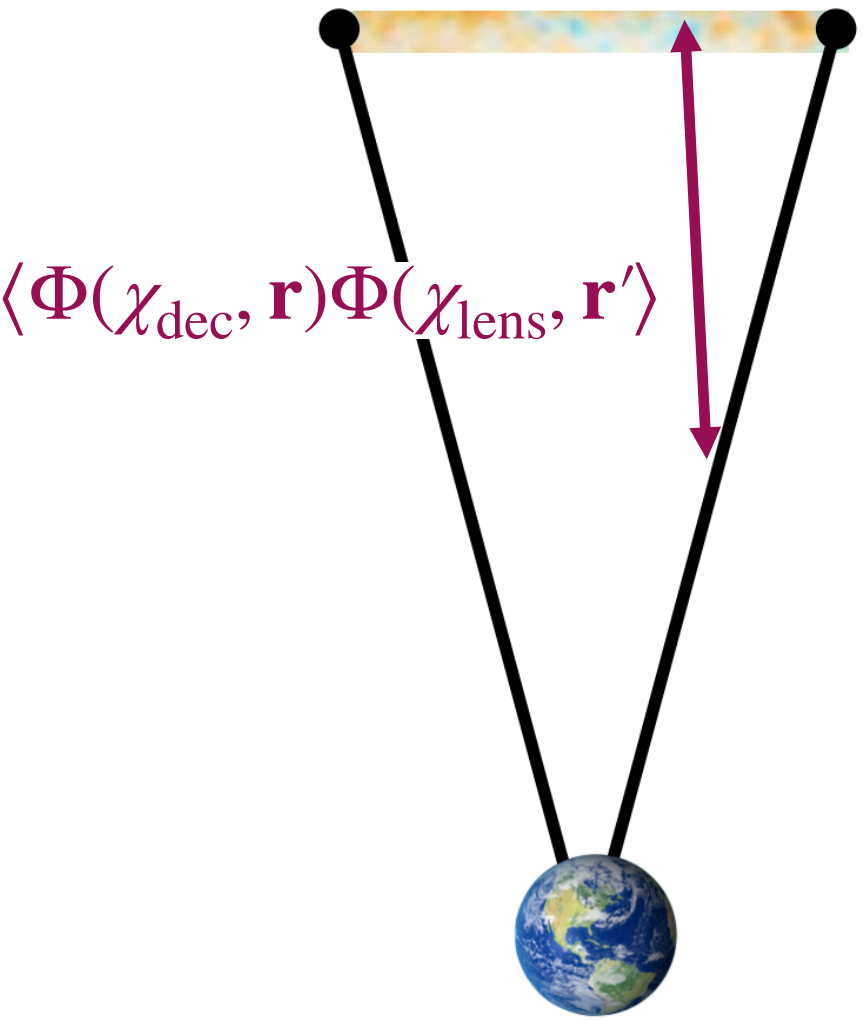
$$\gamma \sim \Phi(\chi_{\rm lens}, \mathbf{r}') \qquad |\mathbf{r}' - \mathbf{r}| \ll r$$

- Measures **very** unequal-time correlation:

$$\langle \Phi(\chi_{\rm dec}, \mathbf{r}) \Phi(\chi_{\rm lens}, \mathbf{r}') \rangle$$

Philcox & Johnson (in prep.)

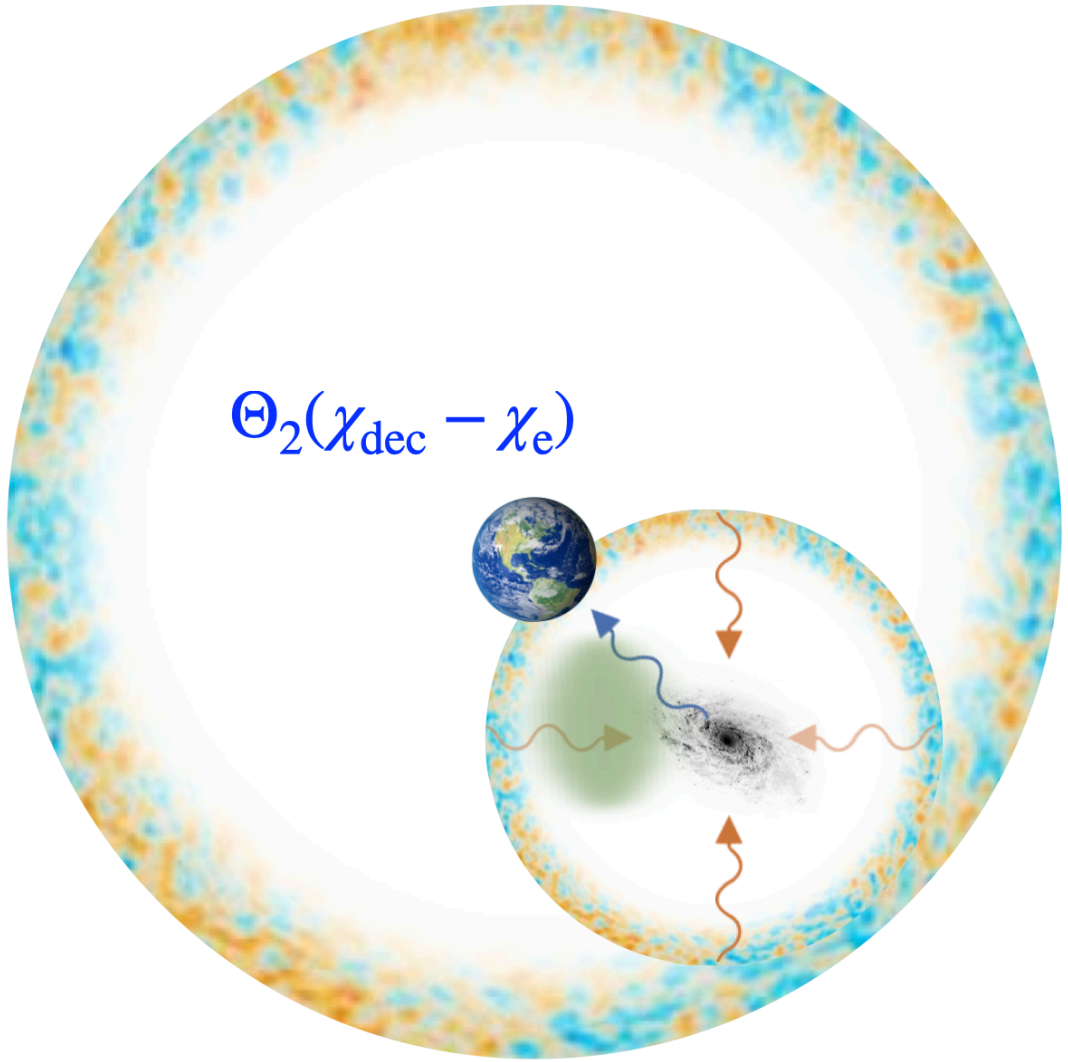
pSZ X SHEAR: UNEQUAL-TIME SW EFFECT [HIGH-z]



- Unequal-time correlation is **not** on the lightcone
- Could get angular **map** of $D(\chi_{\rm dec})/D(\chi_{\rm lens})$
- Probe whether growth is different in voids?

Philcox & Johnson (in prep.)

pSZ X SHEAR: ISW EFFECT [LOW-z]

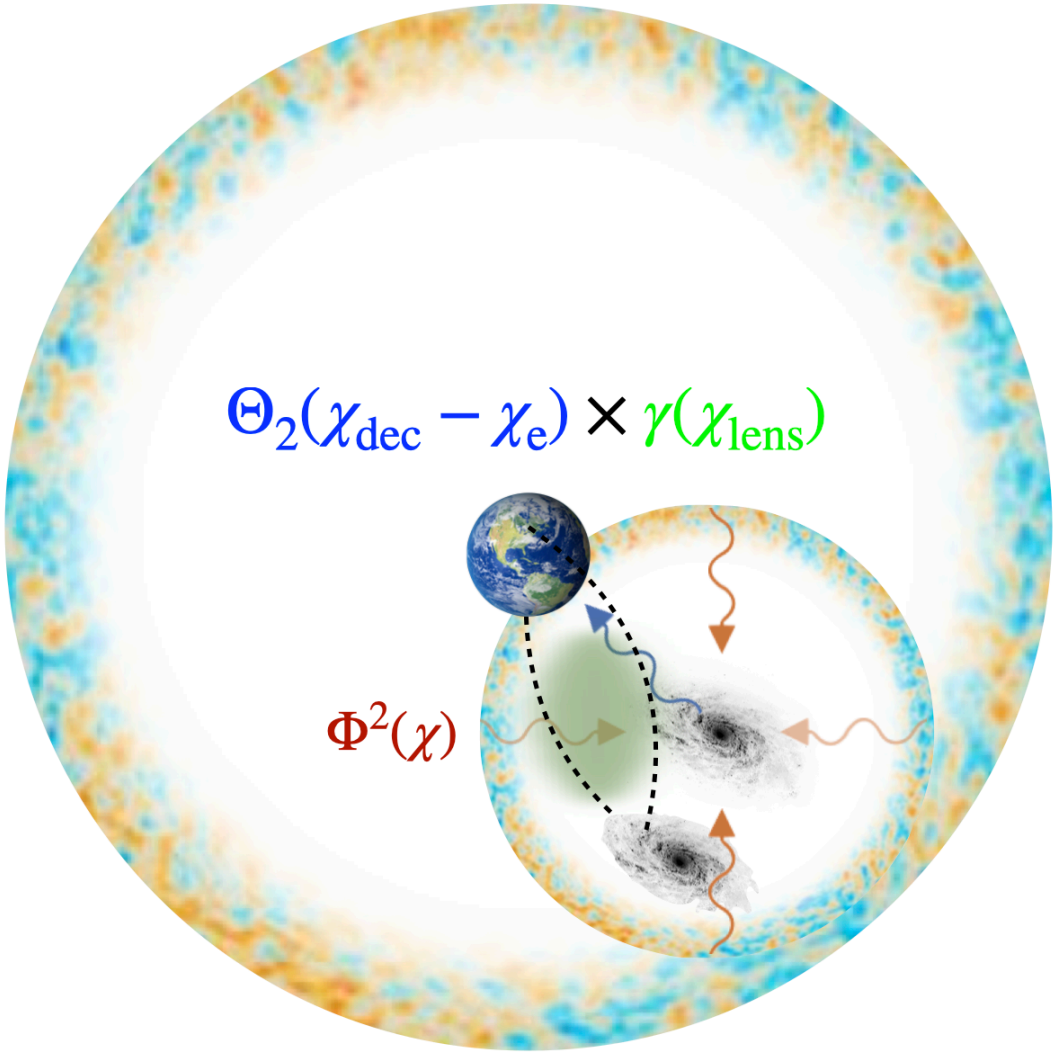


- pSZ signal also contains ISW contribution

$$\mathrm{pSZ} \sim \int d\eta\, \dot{\Phi}(\chi, \mathbf{r})$$

Philcox & Johnson (in prep.)

pSZ X SHEAR: ISW EFFECT [LOW-z]



- pSZ signal also contains ISW contribution

$$\mathrm{pSZ} \sim \int d\eta\, \dot{\Phi}(\chi, \mathbf{r})$$

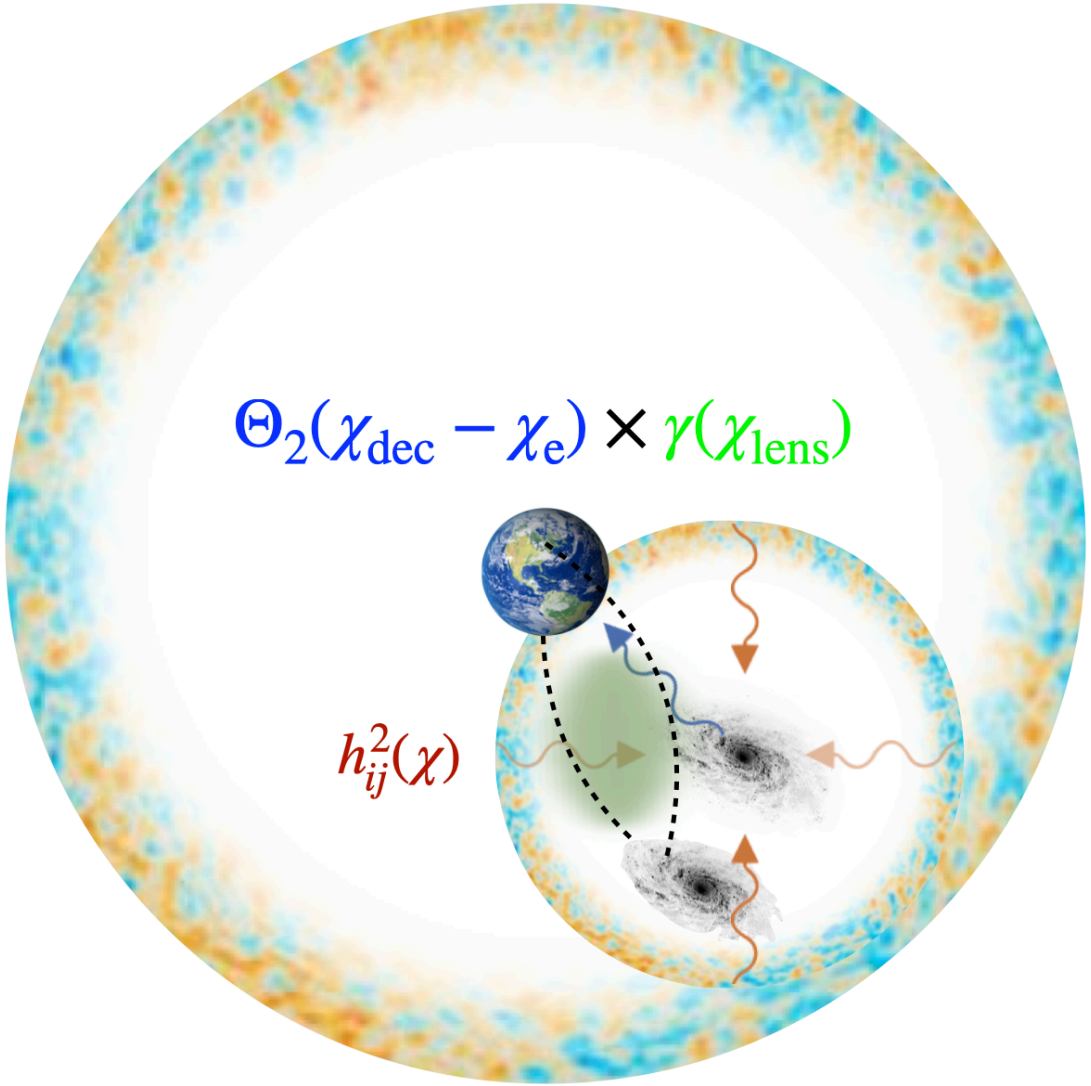
- This is important at $z \lesssim 1$ and correlates with shear

$$\gamma \sim \Phi(\chi_{\rm lens}, \mathbf{r}') \qquad |\mathbf{r}' - \mathbf{r}| \ll r$$

- Could probe ISW effect better than primary CMB?

Philcox & Johnson (in prep.)

pSZ X SHEAR: GRAVITATIONAL WAVES



- pSZ E- and B-modes are sensitive to gravitational waves

$$\mathrm{pSZ} \sim \int d\chi\, h_{\pm}(\chi, \mathbf{r})$$

- Shear E- and B-modes are also sensitive to gravitational waves

$$\gamma \sim \int d\chi'\, h_{\pm}(\chi', \mathbf{r}')$$

- Cross-spectrum at high-z probes tensors with less systematics!

$$\langle h_{\pm}(\chi_{\rm dec}, \mathbf{r}) h_{\pm}(\chi_{\rm lens}, \mathbf{r}' \rangle$$

e.g. Hirata, Schmidt+, Philcox & Johnson (in prep.)

EXPERIMENTAL SET-UP

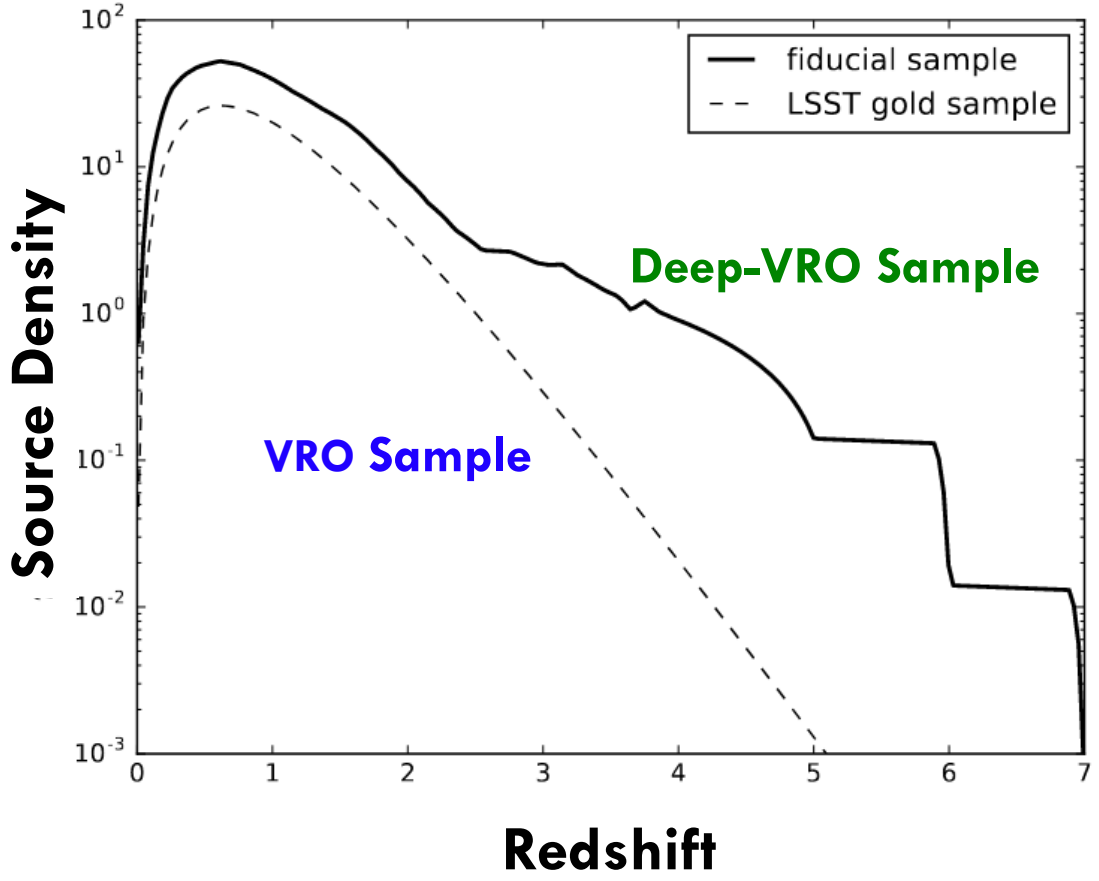
Forecast in two regimes:

#1: CMB-S4 x VRO

1 μK-arcmin noise, $1'$ beam, 40 arcmin^{-2} sources

#2: CMB-HD x deep-VRO

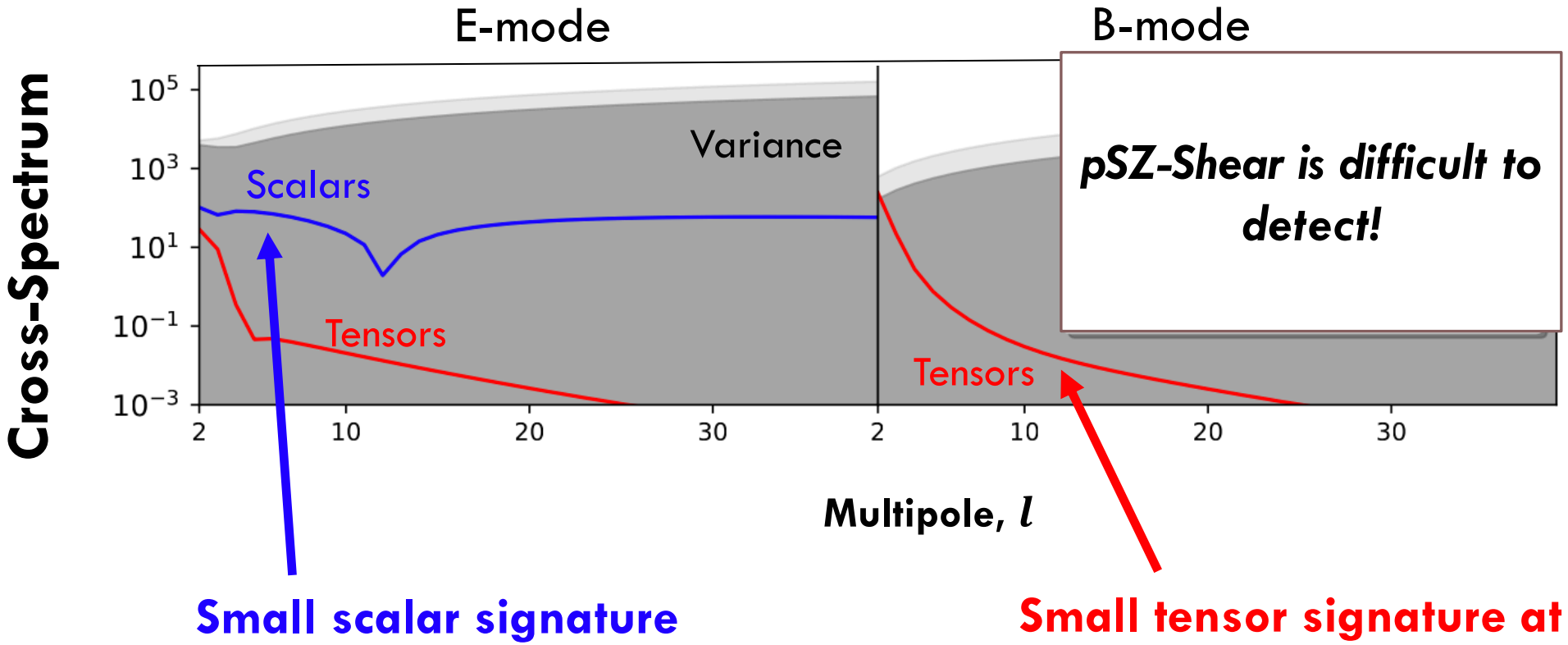
0.5 μK-arcmin noise, $0.25'$ beam, 66 arcmin^{-2} sources



Using 6 tomographic bins with $z \in [0,6]$, and assuming $\delta_e \propto \delta_m$

LSST, Ferraro+

pSZ X SHEAR POWER SPECTRA



$(z \approx 1)$

Philcox & Johnson (in prep.)

DETECTING SCALAR CROSS-CORRELATIONS

- From a full tomographic Fisher-forecast:

	CMB-S4 / VRO	CMB-HD / Deep-VRO
pSZ x pSZ	8σ	50σ
pSZ x Shear	$\mathbf{2\sigma}$	$\mathbf{6\sigma}$

- ***Just*** about detectable with future surveys

- $\approx 5\sigma$ ***detection*** *of ISW and SW separately*

Philcox & Johnson (in prep.)

DETECTING GRAVITATIONAL WAVES

- 1σ limits on *r*:

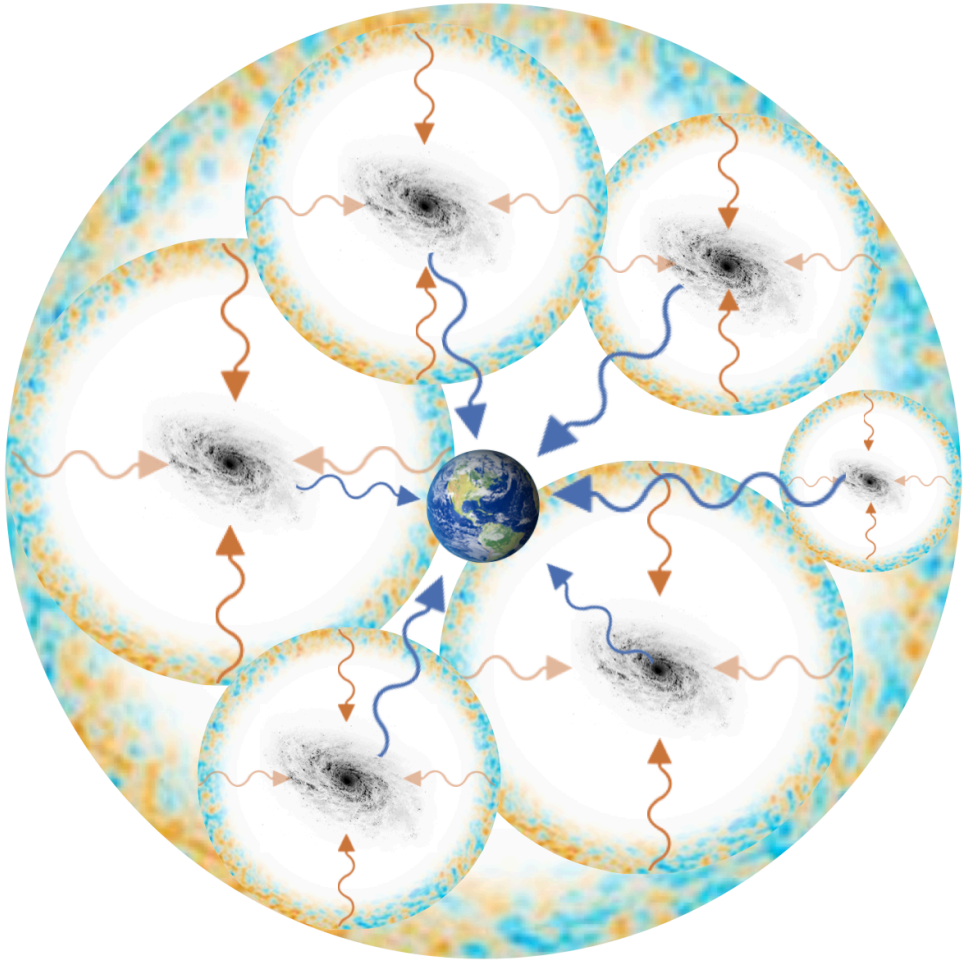
	CMB-S4 / VRO	CMB-HD / Deep-VRO
Shear x Shear	50	10
pSZ x pSZ	0.02	0.003
pSZ x Shear	**0.9**	**0.1**

- **Unlikely** to be competitive, but maybe a useful cross-check?

- pSZ better for parity-odd tensors: $\sigma(r_{\rm odd}) = 0.02$ for CMB-S4 [no CV limit]

Philcox & Johnson (in prep.)

CONCLUSIONS



- pSZ x Shear could measure:
  1. **Unequal** time **SW** correlators
  2. **ISW** effect beyond CMB
  3. **GWs** without systematics

- In practice, it's **hard**

- Needs low CMB noise and many high-z galaxies!

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Paper coming soon!