

Probing the Universe with Lensing Cross-Correlations

Looking for WIMP Dark Matter with gamma rays and over
1000 deg² of weak lensing data

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KiDS

Why cross-correlations?

Probe relation between tracers:

- lensing
- galaxy catalogs
- gamma-rays
- X-rays
- tSZ
- ...

Ignore uncorrelated

- noise
- systematics
- foregrounds

Power of cross-correlations

Cross-correlations are insensitive to noise/systematics/foreground auto-correlations.

- Some measured fields

$$\begin{aligned}\hat{A} &= A + N_A \\ \hat{B} &= B + N_B\end{aligned}\tag{1}$$

- If noise/systematics/foregrounds are uncorrelated between the fields

$$\langle AN_B \rangle = \langle BN_A \rangle = \langle N_A N_B \rangle = 0\tag{2}$$

- Then

$$\langle \hat{A} \hat{B} \rangle = \langle AB \rangle\tag{3}$$

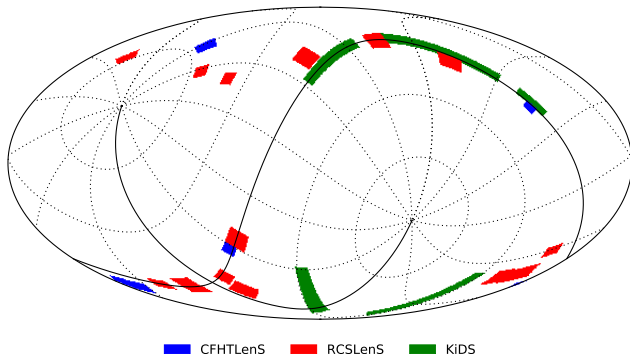
Lensing cross-correlations

Lensing is an unbiased probe of the underlying matter distribution.

Cross-correlate with, e.g.,

- gamma-rays → WIMP dark matter
- CMB lensing → massive neutrinos
- thermal Sunyaev-Zeldovich effect → warm gas

Lensing data-sets



- CFHTLenS, $\sim 150 \text{ deg}^2$, 14 arcmin^{-2}
- RCSLenS, $\sim 600 \text{ deg}^2$, 5.5 arcmin^{-2}
- KiDS, currently $\sim 450 \text{ deg}^2$, 8.8 arcmin^{-2}

Lensing estimators

Real-space

- tangential shear
- convergence (massmaps)

- insensitive to masking
- close to data

- covariance estimation is hard

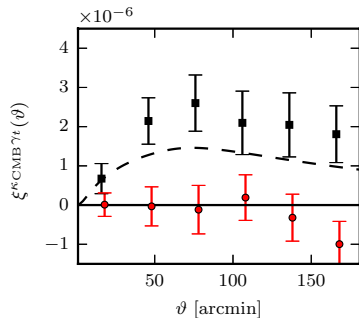
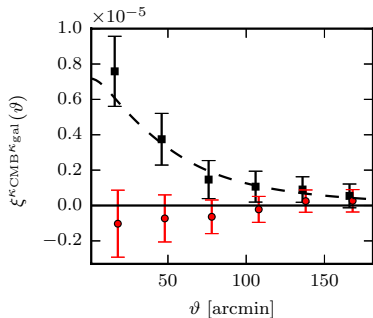
Harmonic-space

- shear E-mode
- convergence (massmaps)

- covariances are well behaved

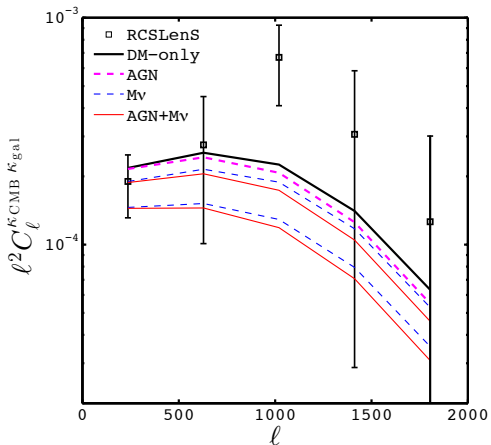
- masking can be non-trivial

CMB lensing



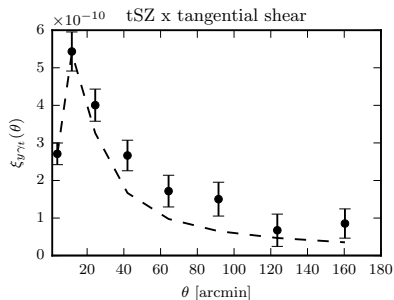
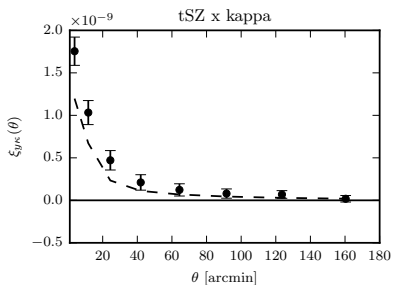
[Harnois-Déraps, Tröster et al, 2016]

Massive neutrinos?

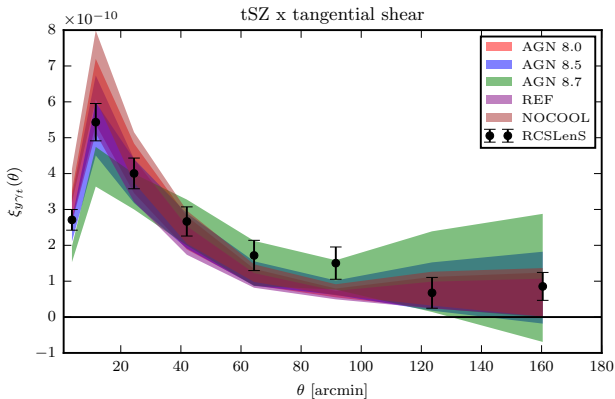


[Harnois-Déraps, Tröster et al, 2016]

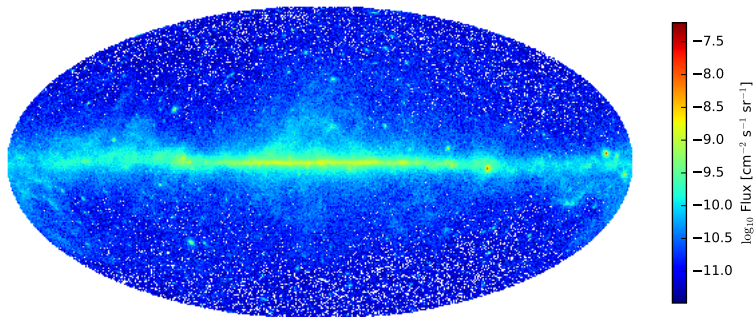
tSZ



AGN feedback



Gamma-rays



Why gamma-rays?

- Thermal relic WIMP dark matter has a non-zero interaction cross-section with the standard model
- Annihilation products would include gamma-rays
- Expect gamma-rays from regions with high dark matter densities
- Power of cross-correlation with lensing has been demonstrated [Camera 2013, Shirasaki 2014, Camera 2015]

Data

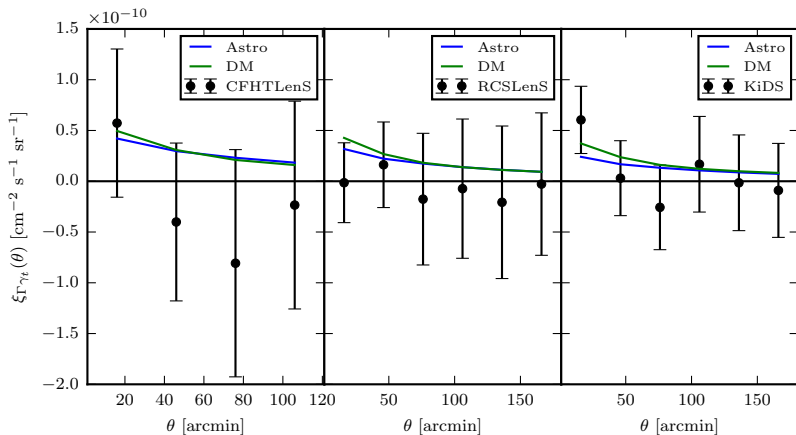
Fermi-LAT data:

- 7 years of data
- Pass 8 event reconstruction
- ultracleanveto photons
- $0.5 \text{ GeV} < E < 500 \text{ GeV}$

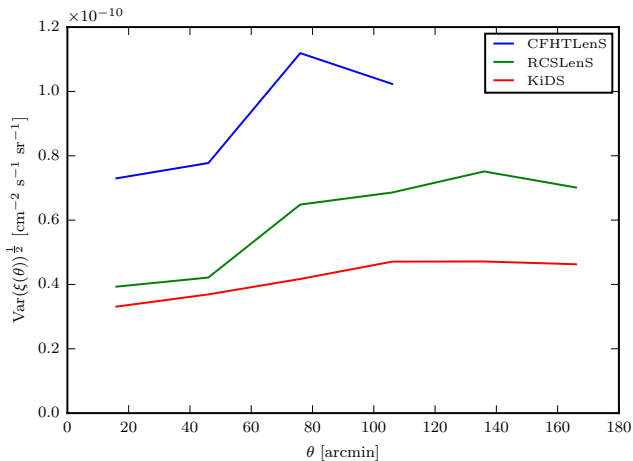
Lensing data:

- CFHTLenS
- RCSLenS
- KiDS (preliminary)

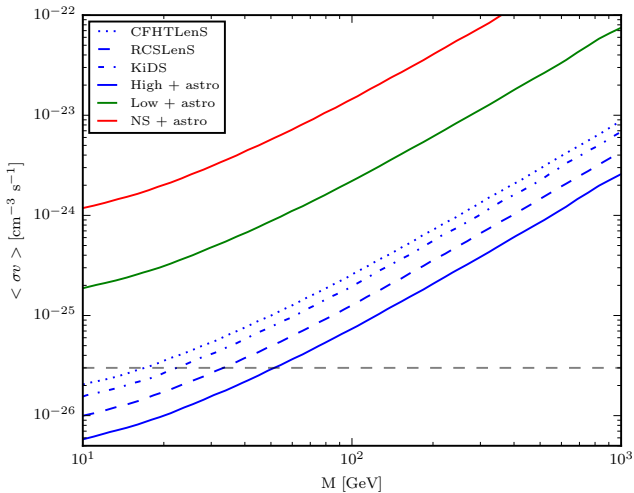
Gamma-ray cross-correlation



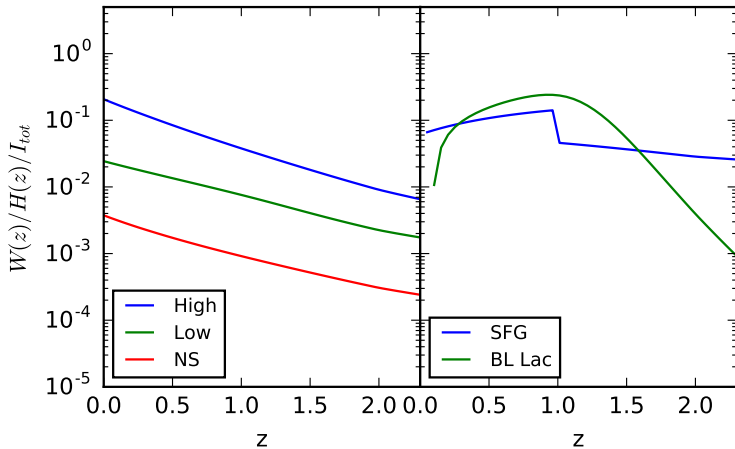
Improvement in sensitivity



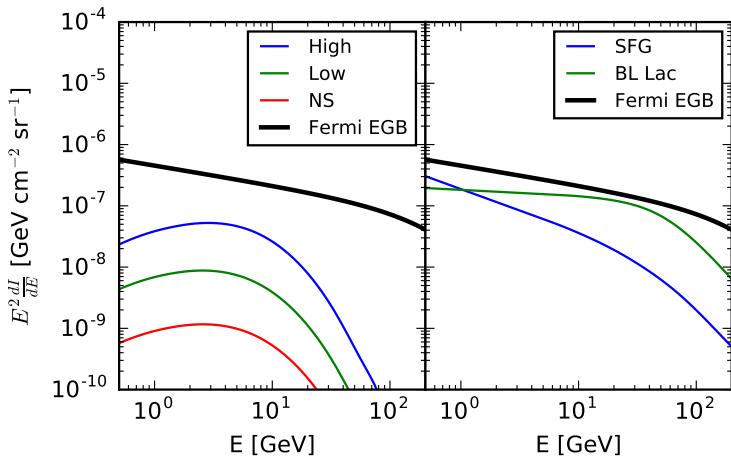
Limits LenS



Window function



Total intensities



Data binning

Use differences in z - and E -dependence of source populations
[Camera et al 2015]

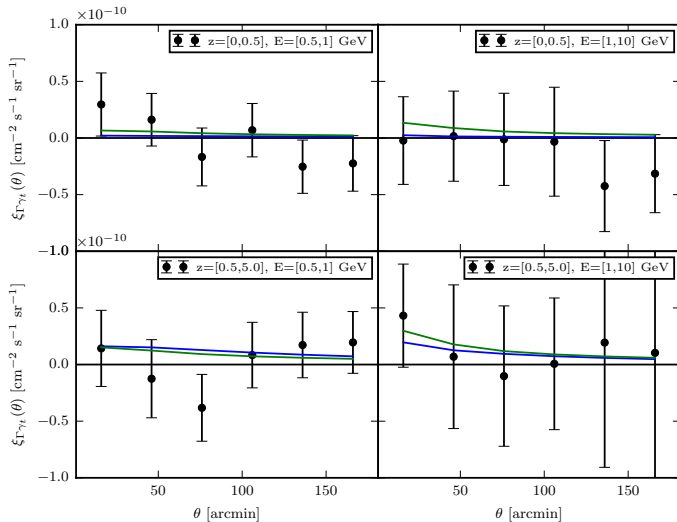
Redshift

1. $z < 0.5$
2. $0.5 < z$

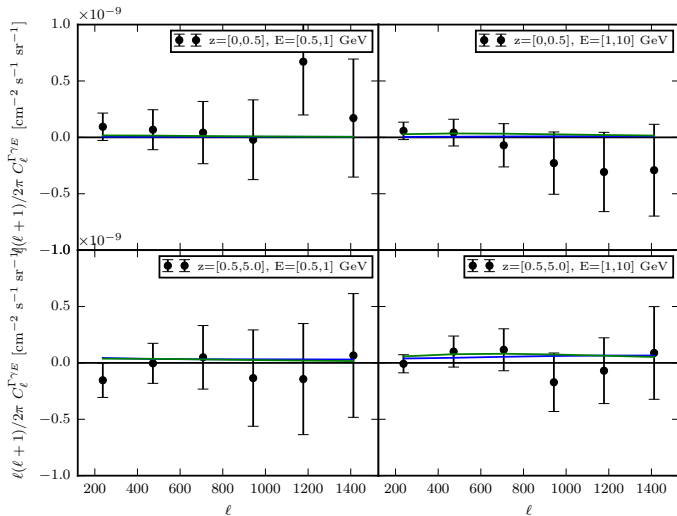
Energy

1. $0.5 \text{ GeV} < E < 1 \text{ GeV}$
2. $1 \text{ GeV} < E < 10 \text{ GeV}$

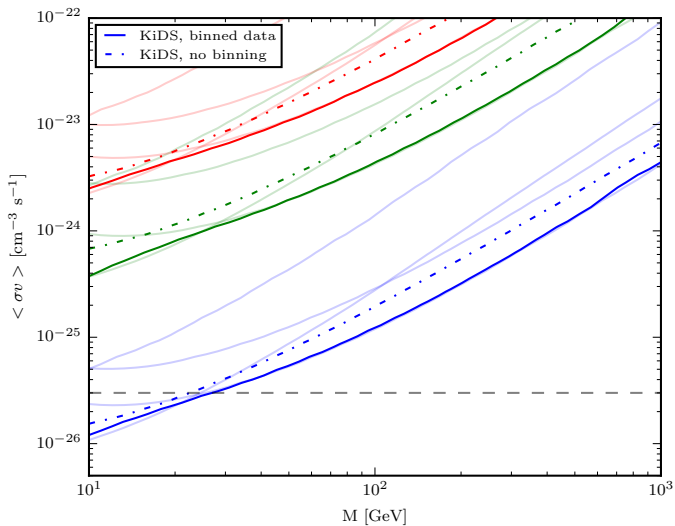
KiDS tomography



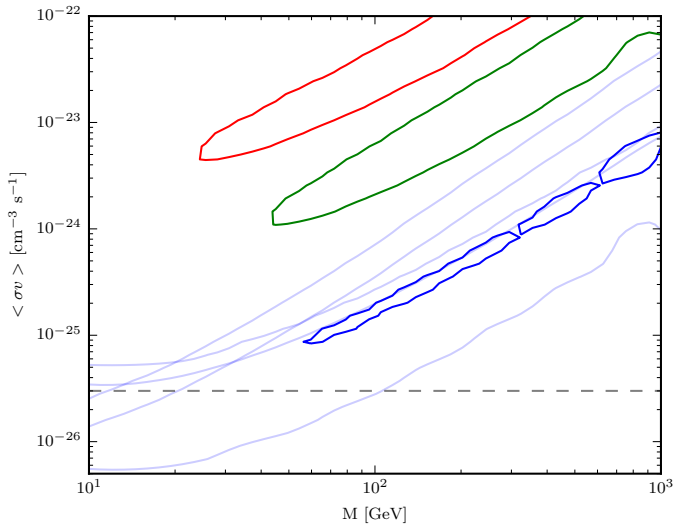
KiDS tomography harmonic-space



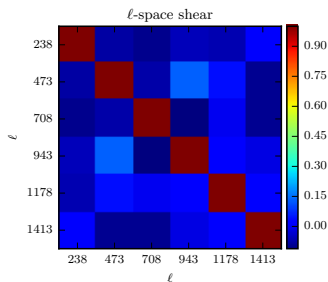
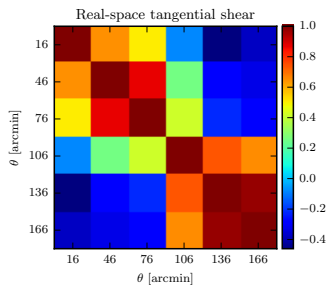
Limits KiDS tomography



Bad limits



Bad covariance



Summary

- Cross-correlations are a powerful tool to probe relations between various tracers
- Lensing is an unbiased tracer of the matter distribution and hence worthwhile to cross-correlate with
- Limits on WIMP annihilation from lensing cross-correlations are competitive and complementary to other probes