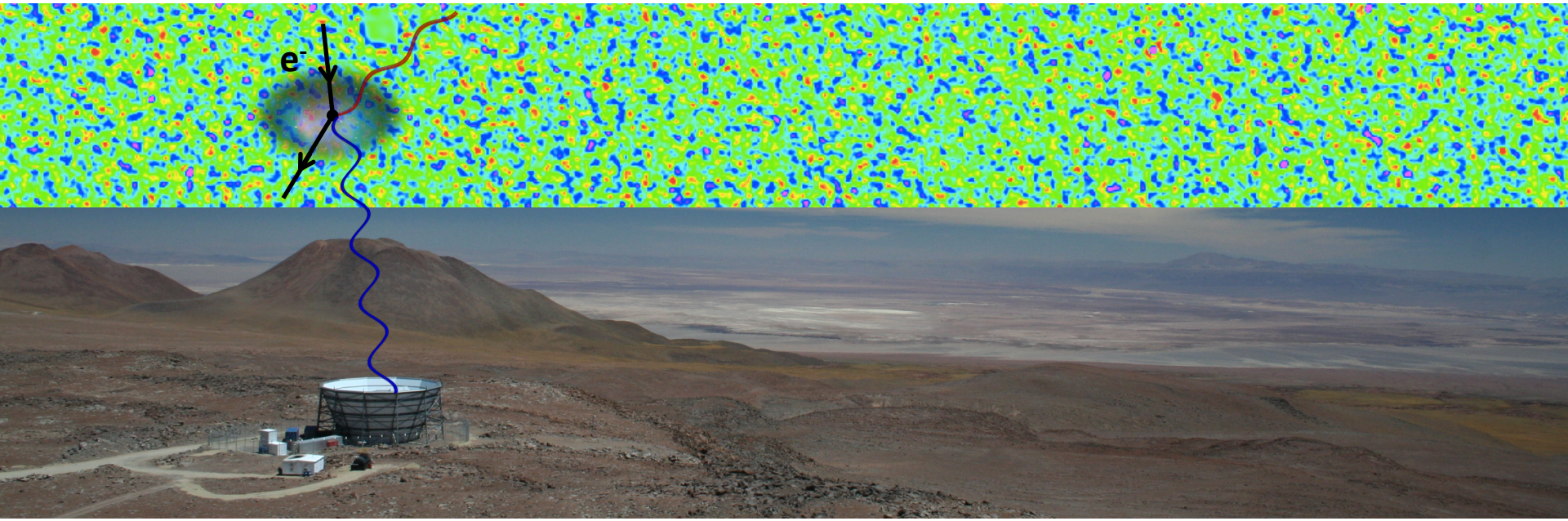
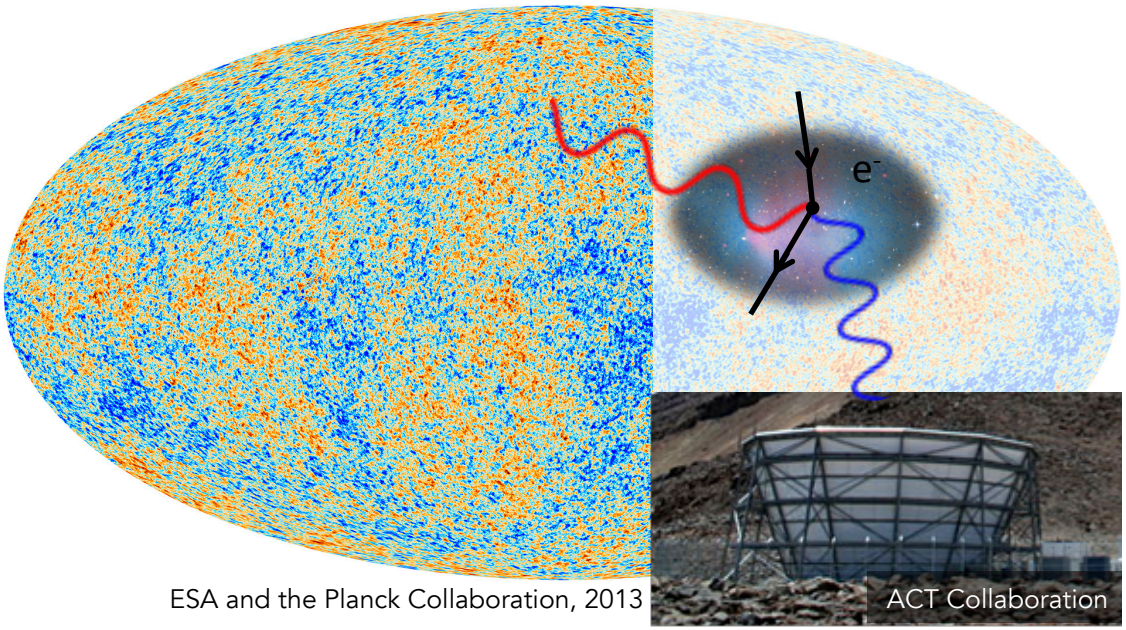
Measuring the Pairwise Kinematic Sunyaev-Zel'dovich Effect with the Atacama Cosmology Telescope



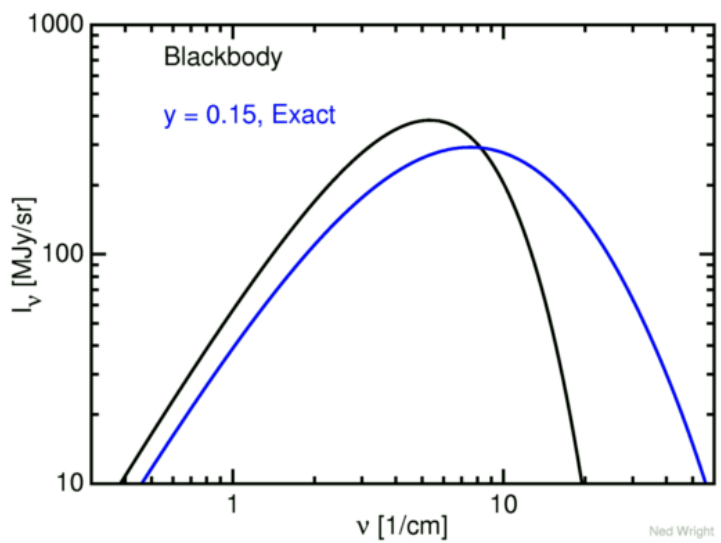
Eve M. Vavagiakis
Cornell University

The Sunyaev-Zel'dovich Effects



ESA and the Planck Collaboration, 2013

- Thermal SZ effect (tSZ): $\Delta T \propto$ integrated electron pressure



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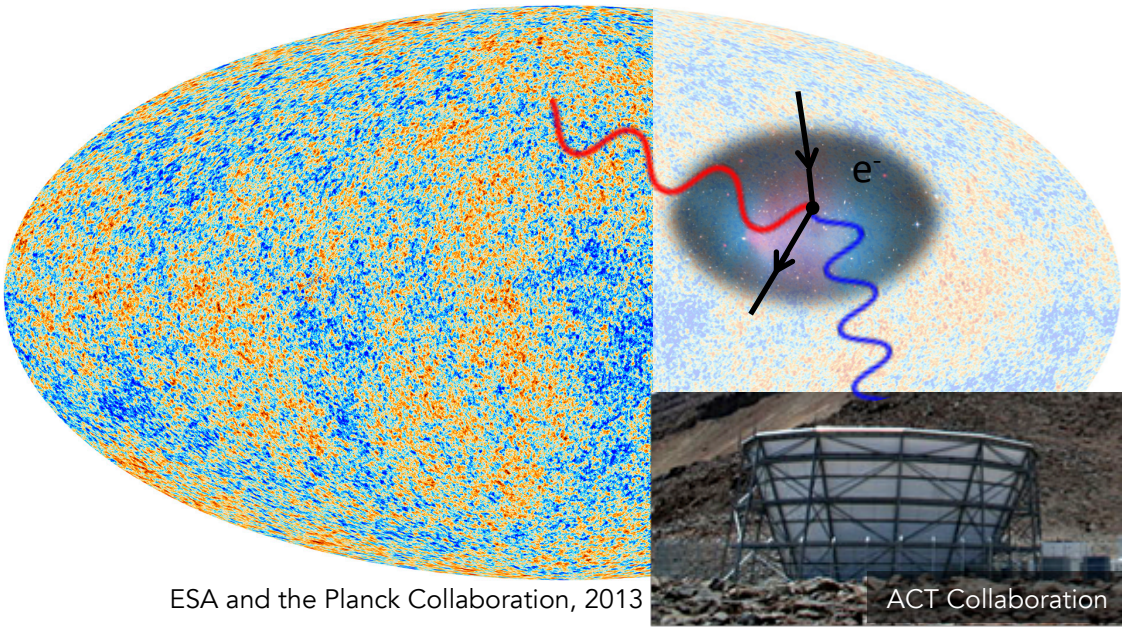

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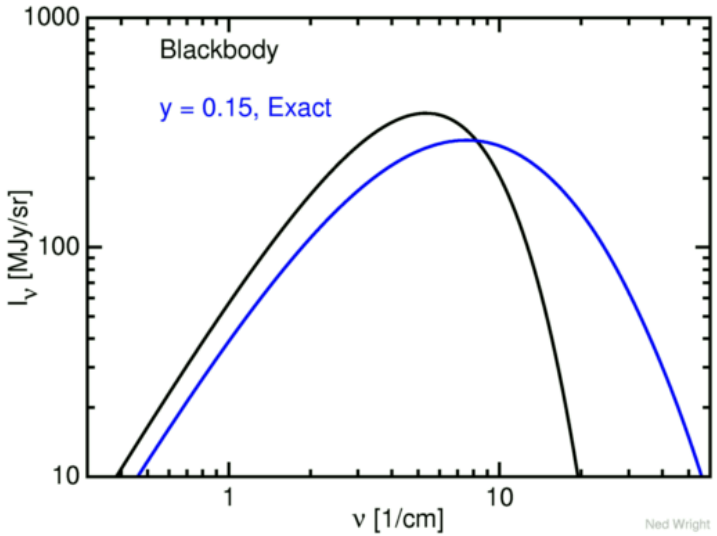
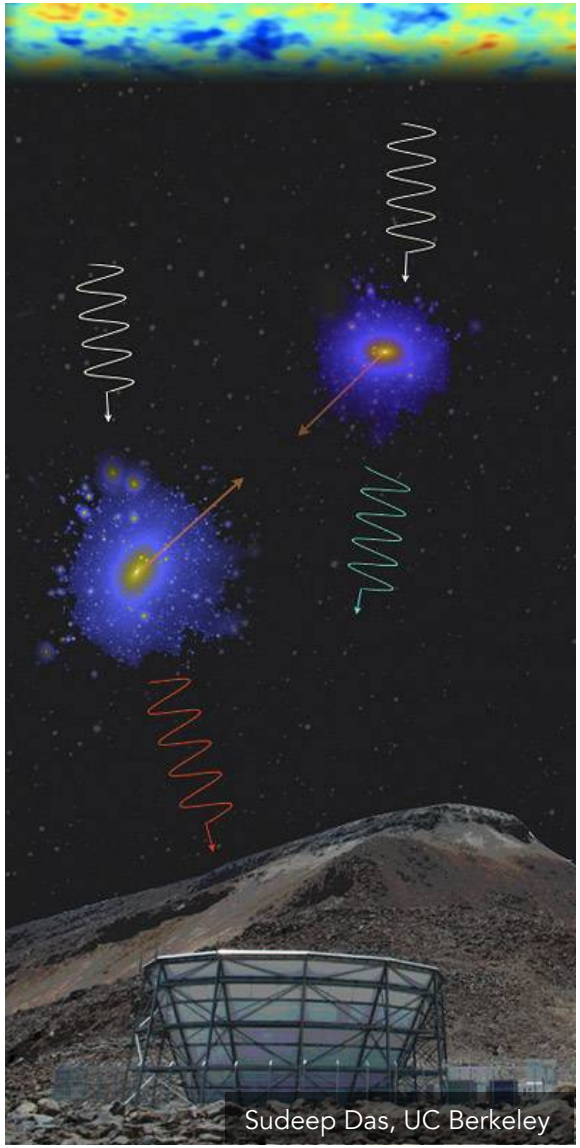
$\longrightarrow \tau$





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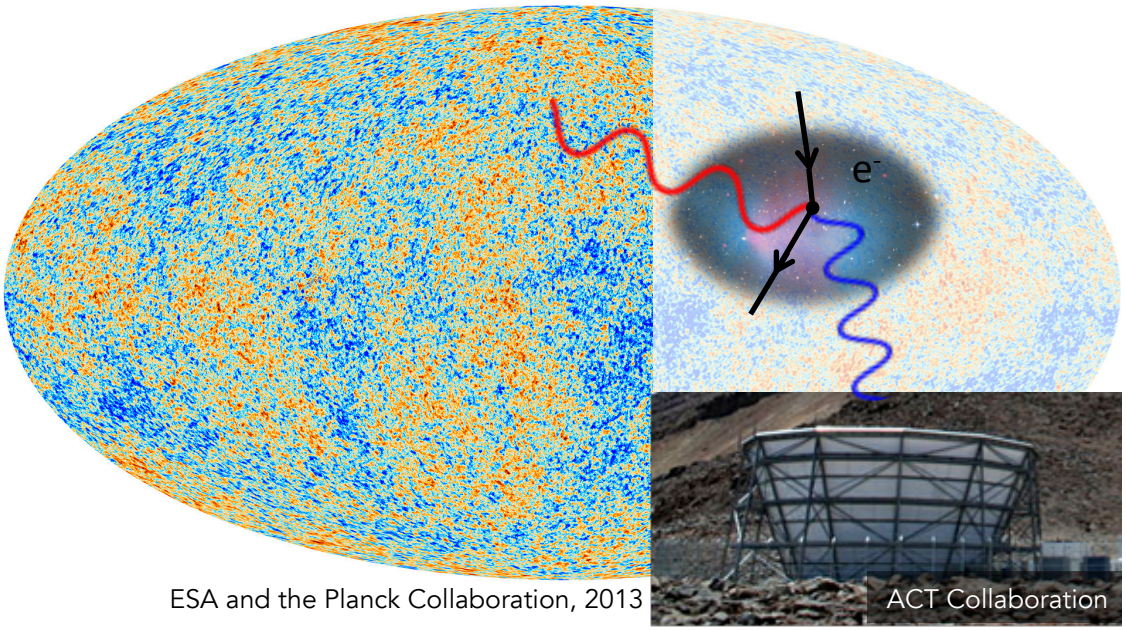

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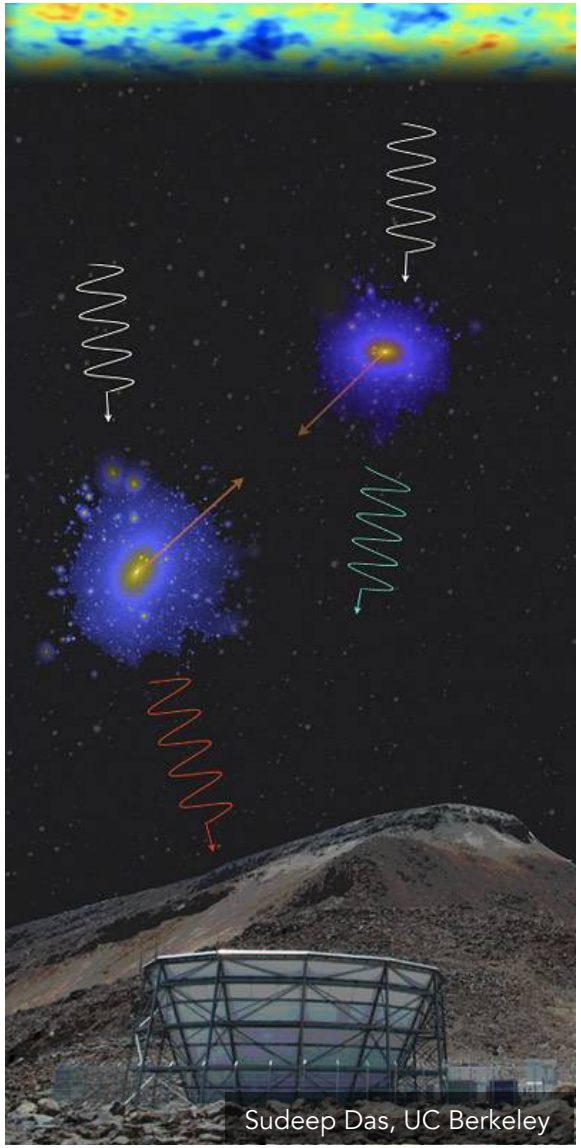

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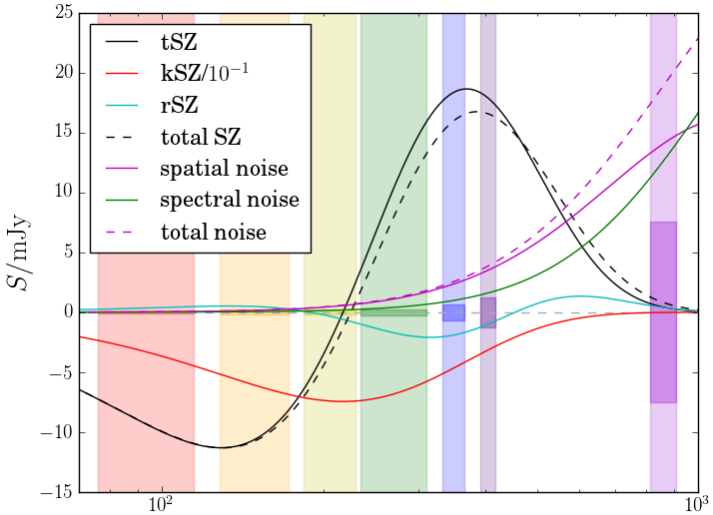
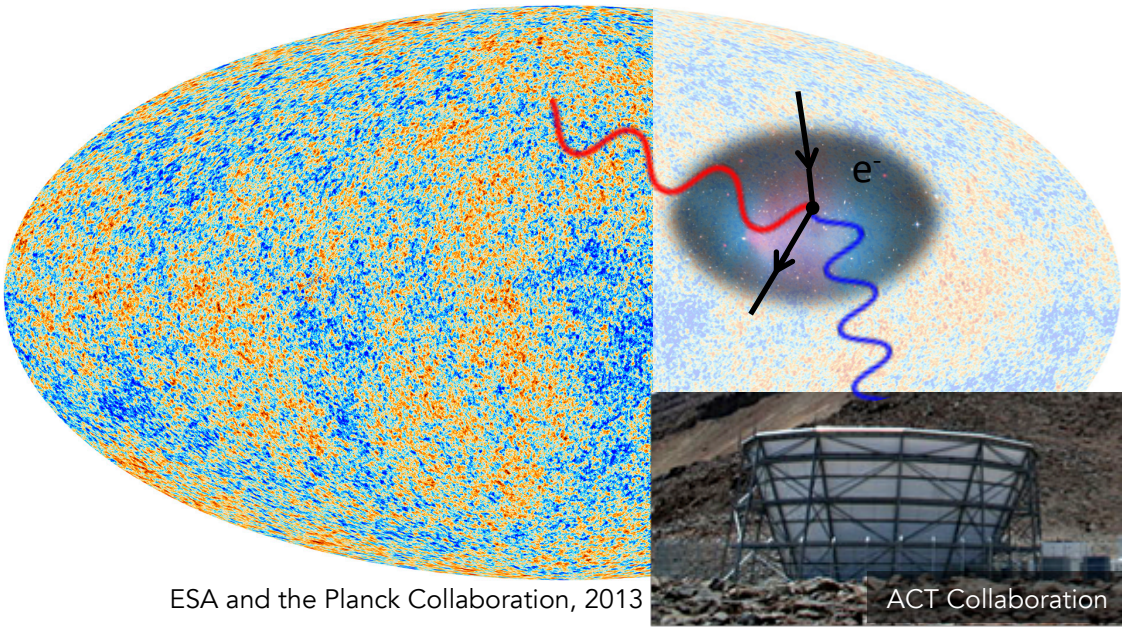


Mittal et al. (2017), in prep.

The Sunyaev-Zel'dovich Effects



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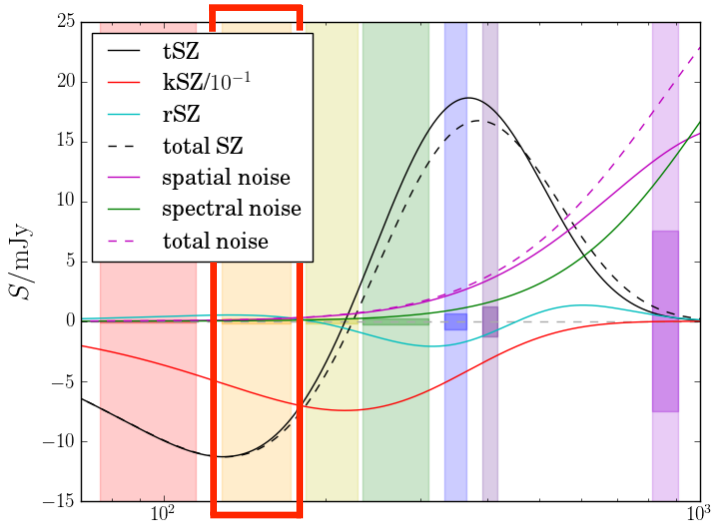

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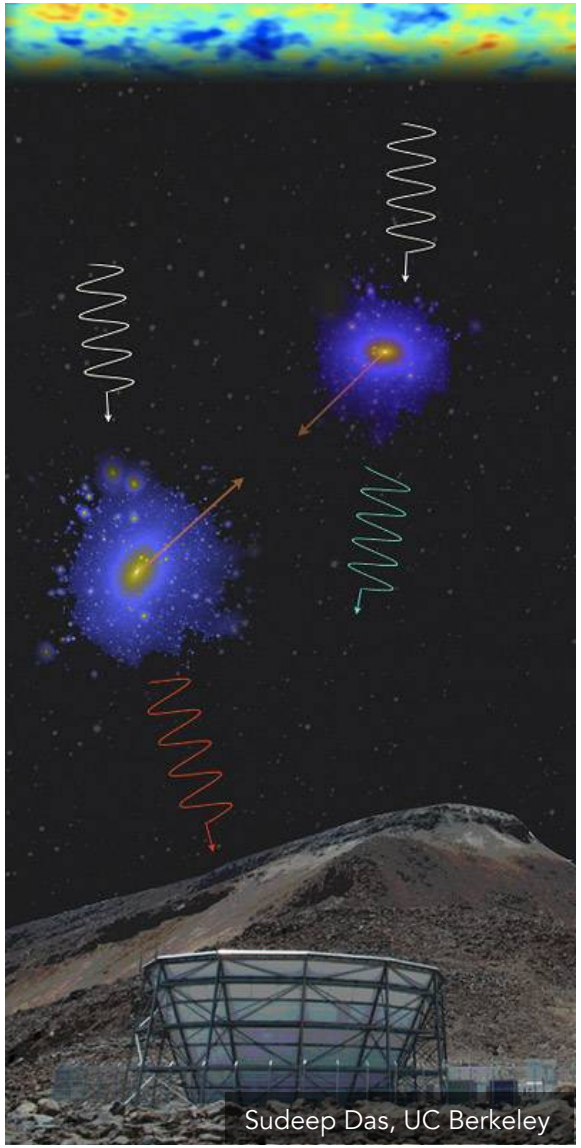
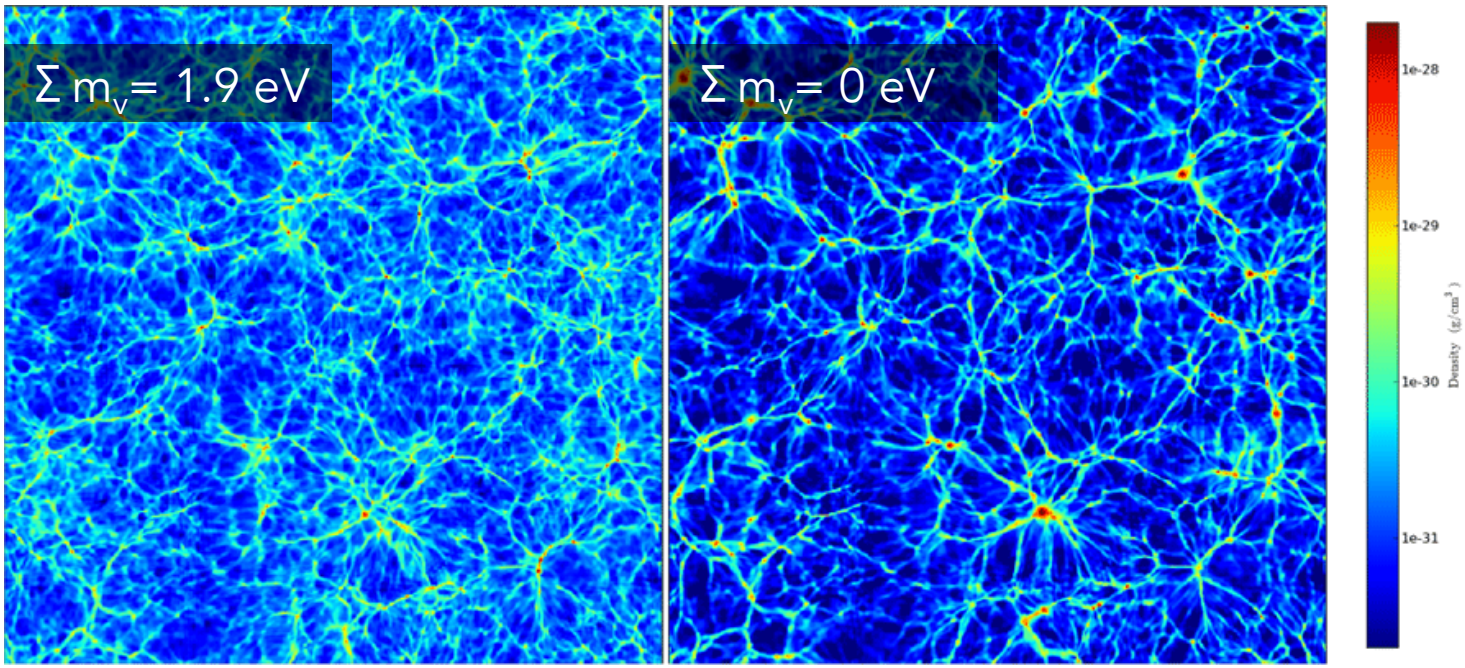


Motivation: Pairwise kSZ

- Massive neutrinos affect growth of structure



S. Agarwal, H. Feldman, Mon. Not. R. Astron. Soc. (2011)

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- Massive neutrinos affect growth of structure
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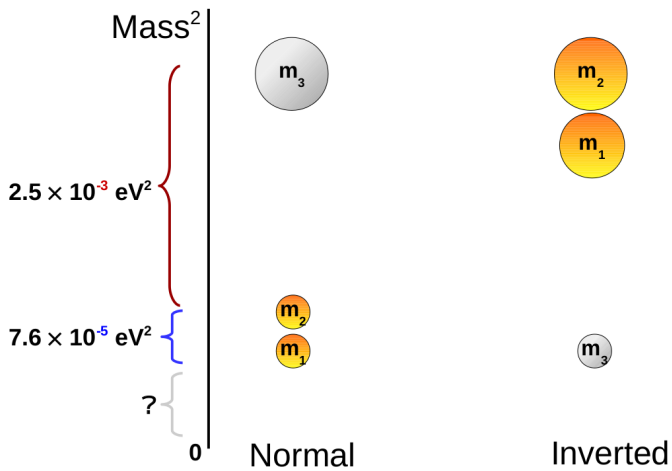
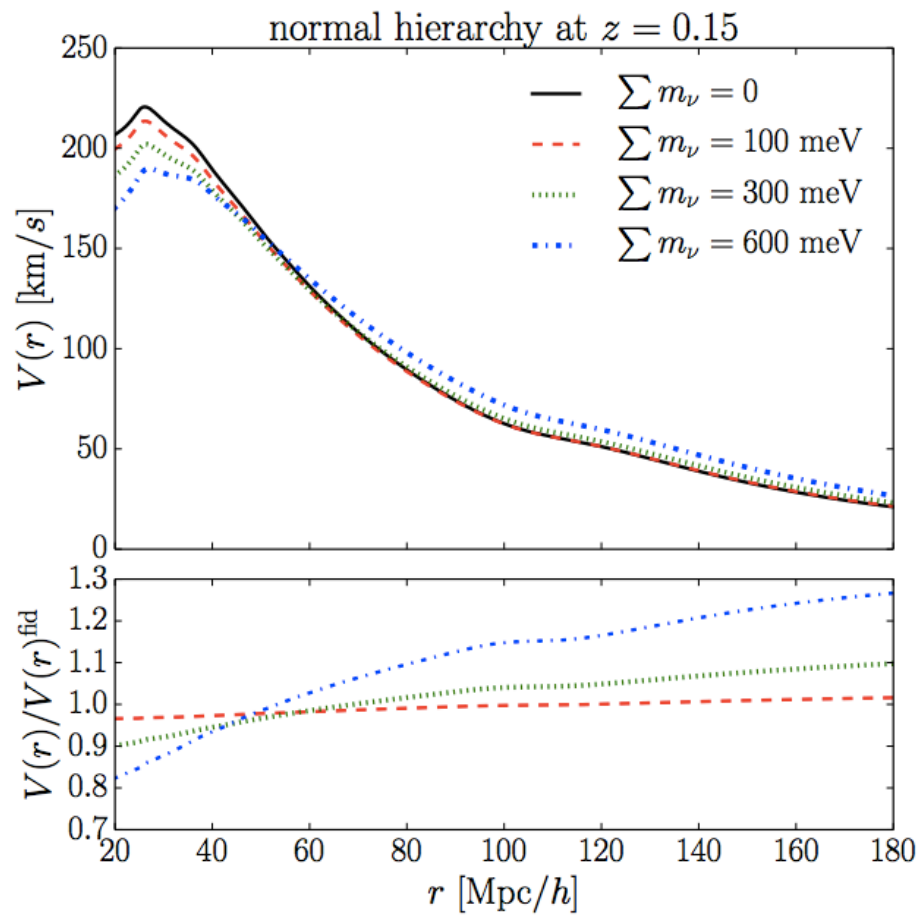


Hyper-Kamiokande (2015)



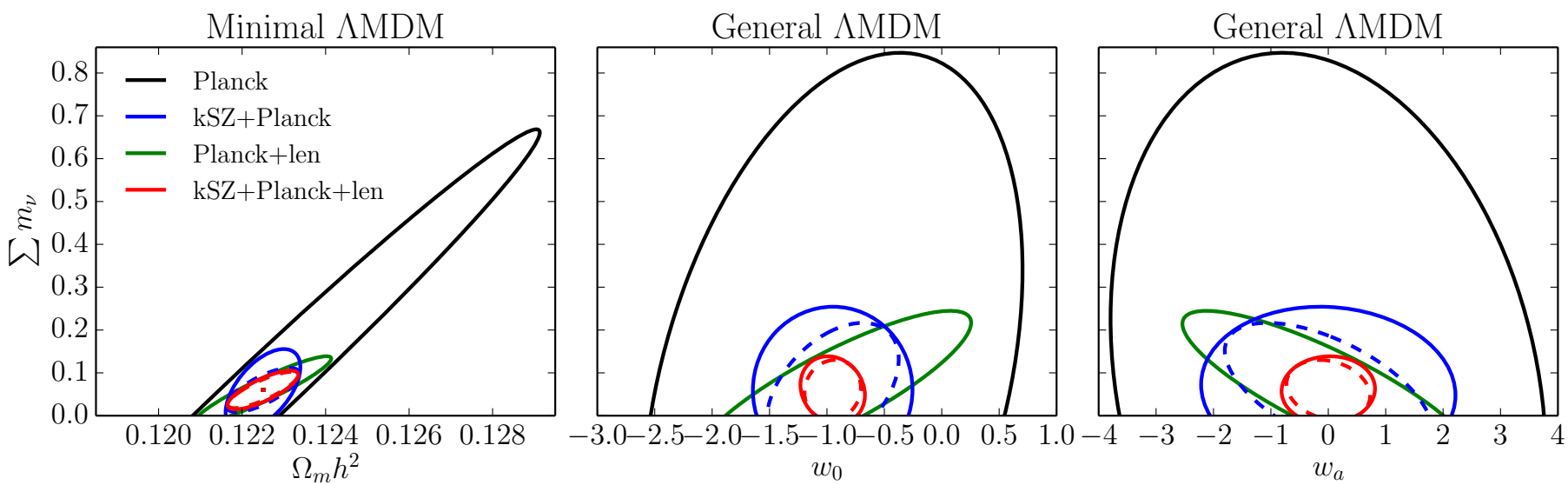
E.-M. Mueller, F. de Bernardis, R. Bean, M. Niemack (2014), 1412.0592

Eve M. Vavagiakis, Cornell University

Motivation: Pairwise kSZ

- Massive neutrinos affect growth of structure
- kSZ effect probes peculiar velocities at cosmological distances
- Constrain Σm_ν
- Probe gravity and dark energy

- With kSZ information from CMB-S4:



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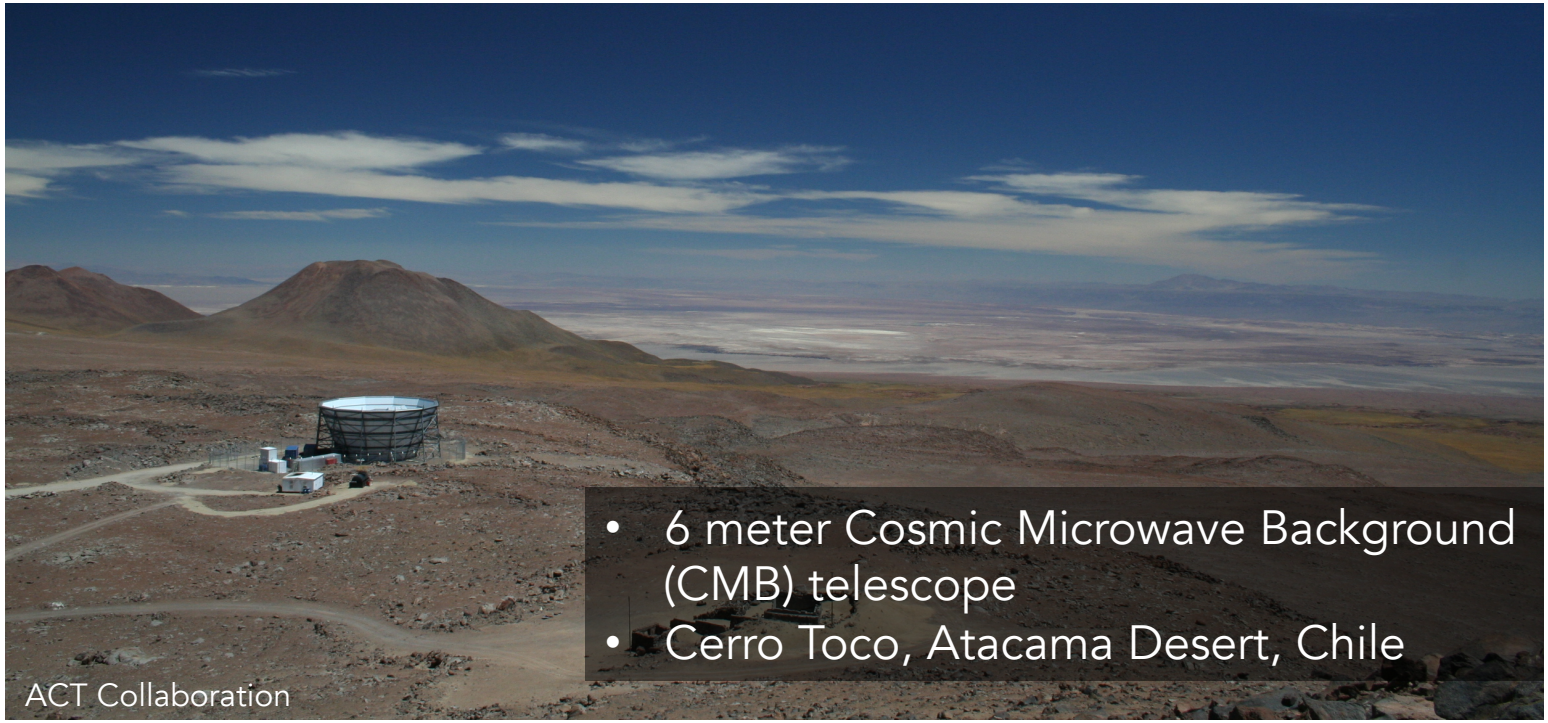
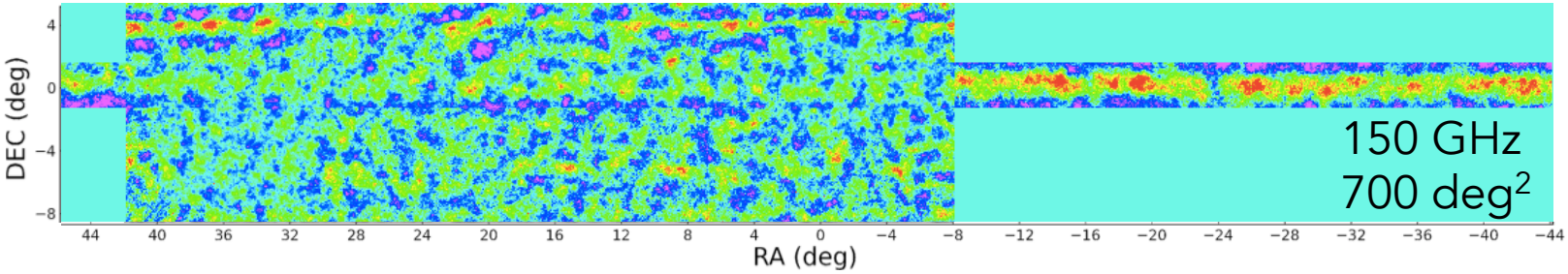
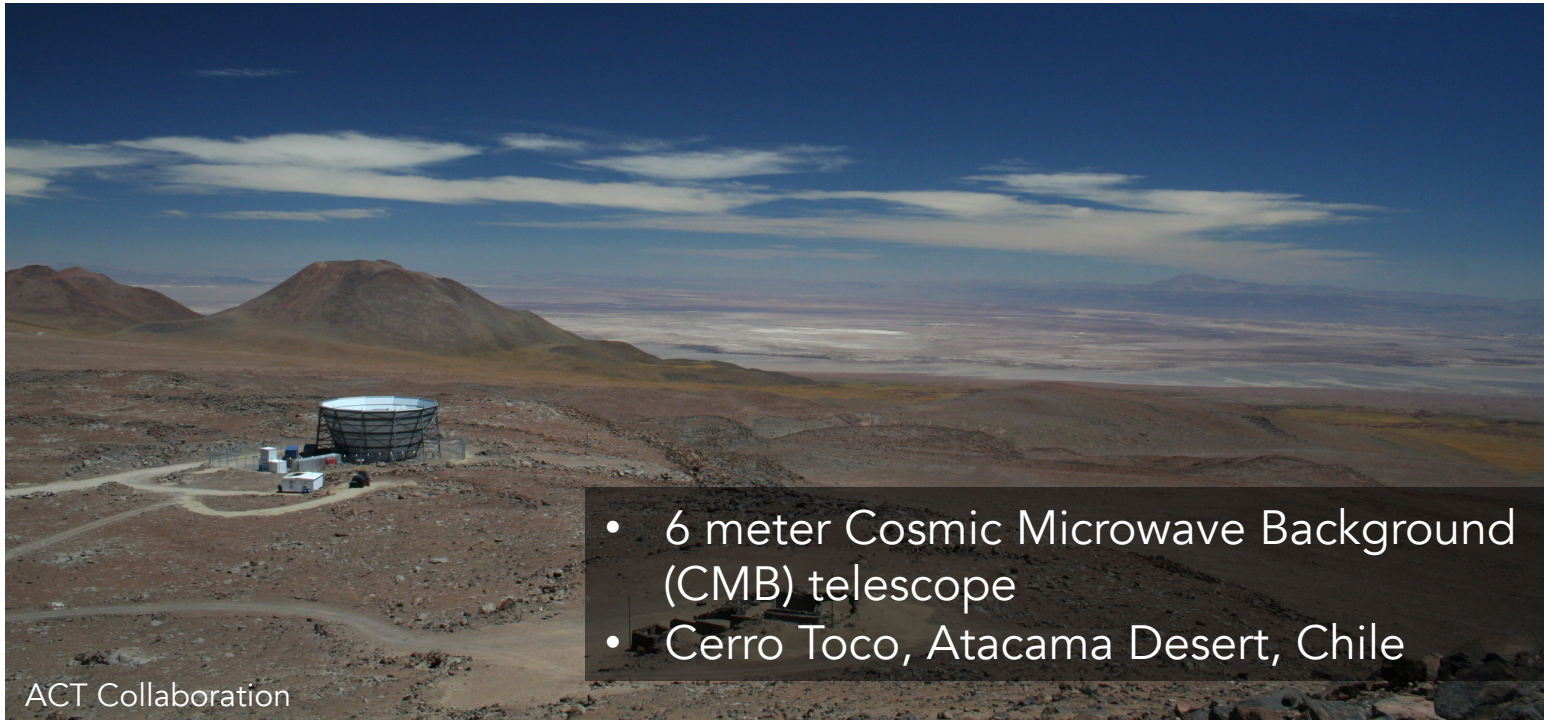
Atacama Cosmology Telescope Polarimeter (ACTPol) Data



- 6 meter Cosmic Microwave Background (CMB) telescope
- Cerro Toco, Atacama Desert, Chile

Atacama Cosmology Telescope Polarimeter (ACTPol) Data





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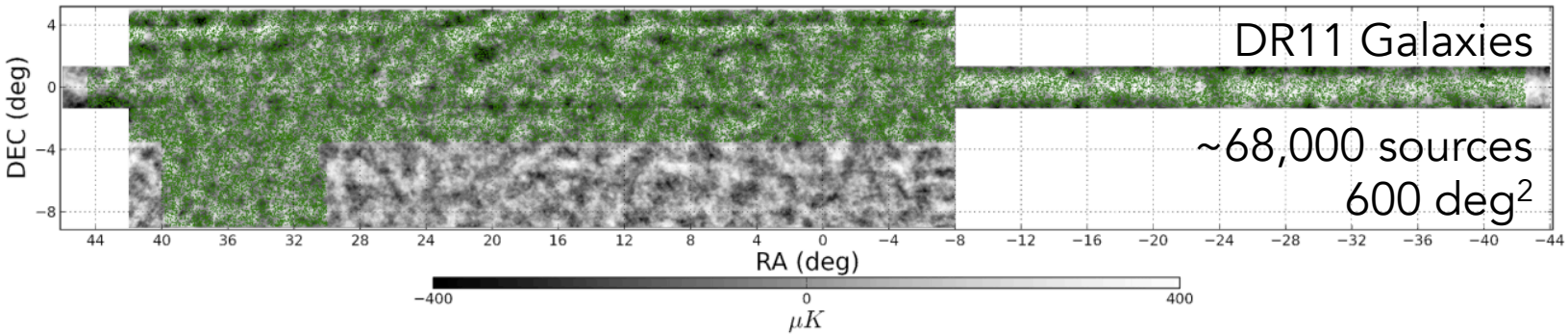
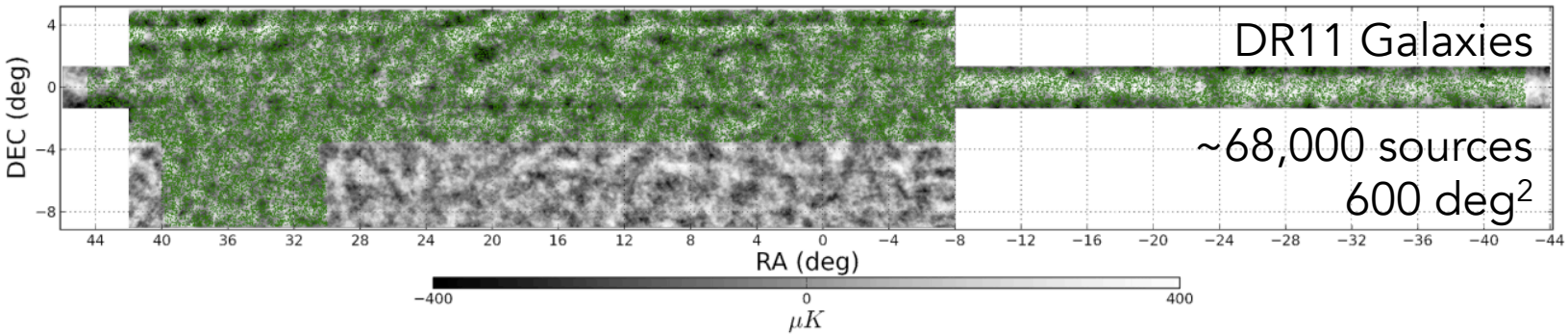
BOSS-SDSS Data

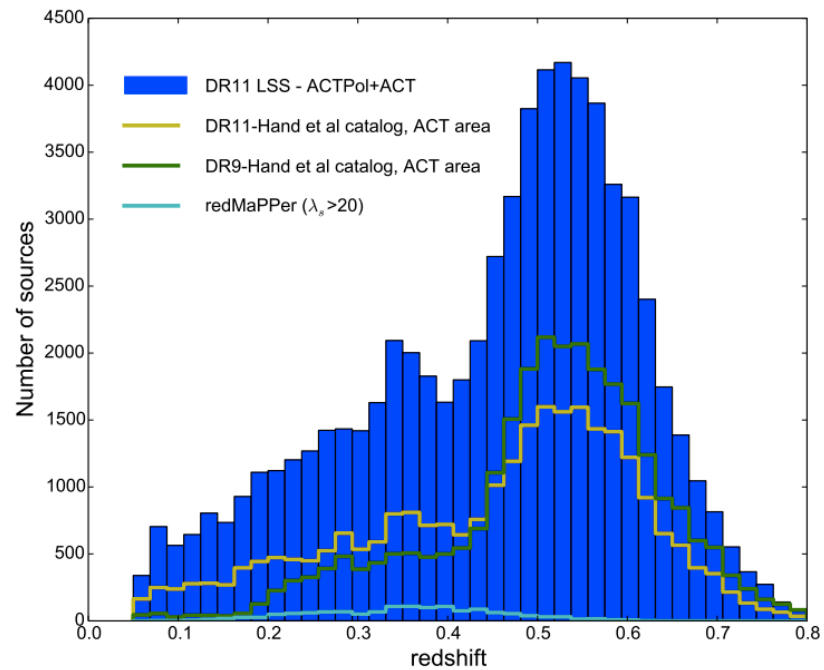


F. de Bernardis, S. Aiola, E.M. Vavagiakis, M.D. Niemack (2016), 1607.02139

BOSS-SDSS Data



Number of sources per redshift bin



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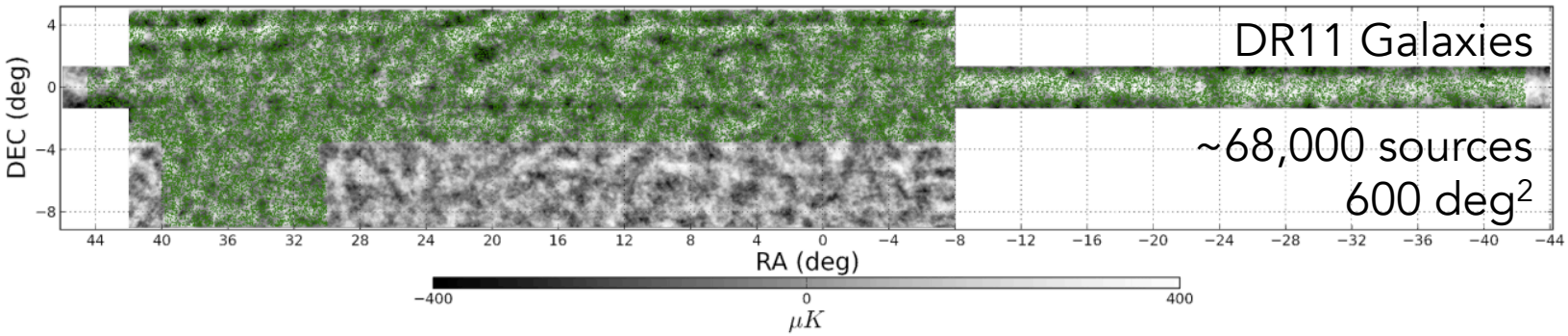
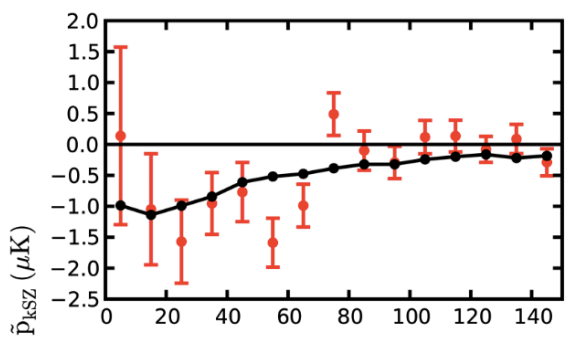


- Overlaps with ~2.5x as many sources as used in previous ACT measurement

Previous result:
Hand 2012 using DR9



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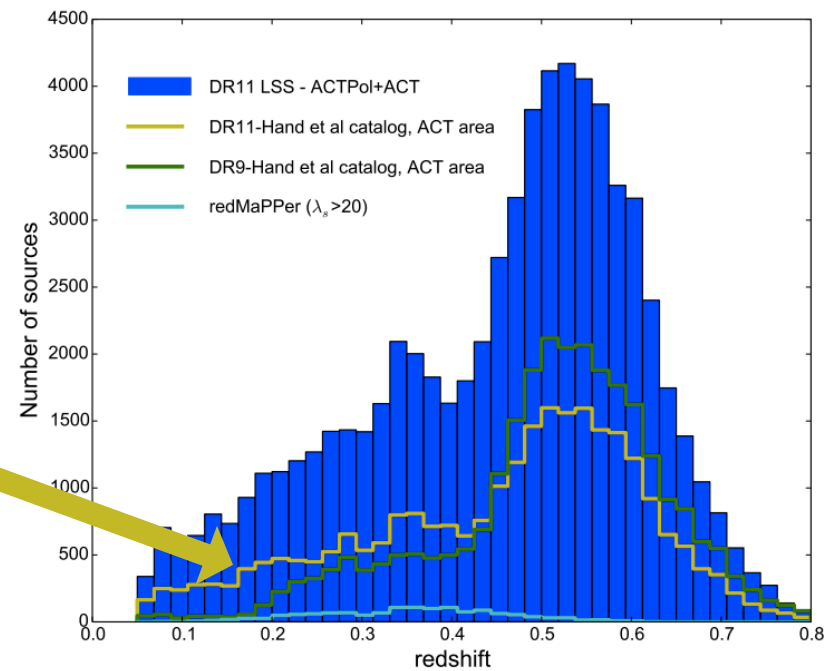


F. de Bernardis, S. Aiola, E.M. Vavagiakis, M.D. Niemack (2016), 1607.02139

Pairwise Estimator

Linear differences of temperatures at cluster positions average out other signals:

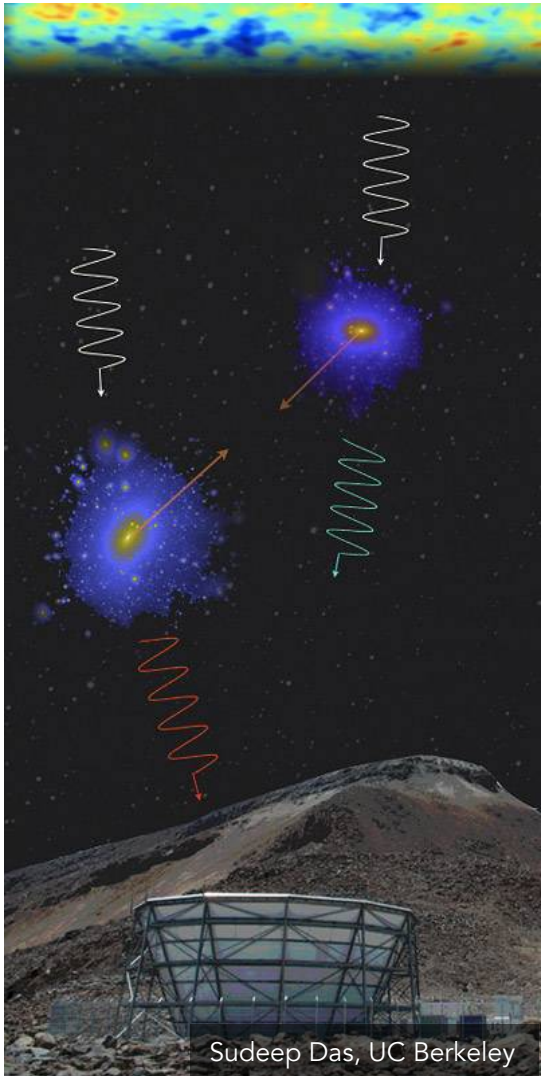
$$p_{est}(r) = \frac{\sum_{i<j}[(\Delta T_i - T_z(z_i)) - (\Delta T_j - T_z(z_j))]c_{ij}}{\sum_{i<j} c_{ij}^2}$$

c_{ij} geometrical factor, depends on z.

For each source:

$$\frac{\Delta T}{T} \approx -\tau \frac{v}{c}$$

Need optical depth to get velocities!



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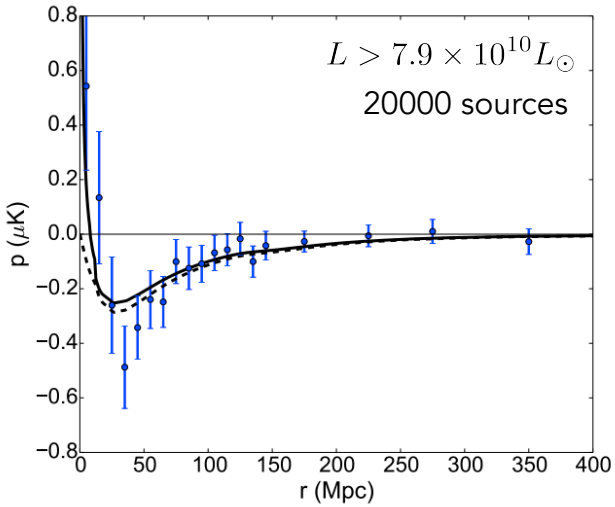
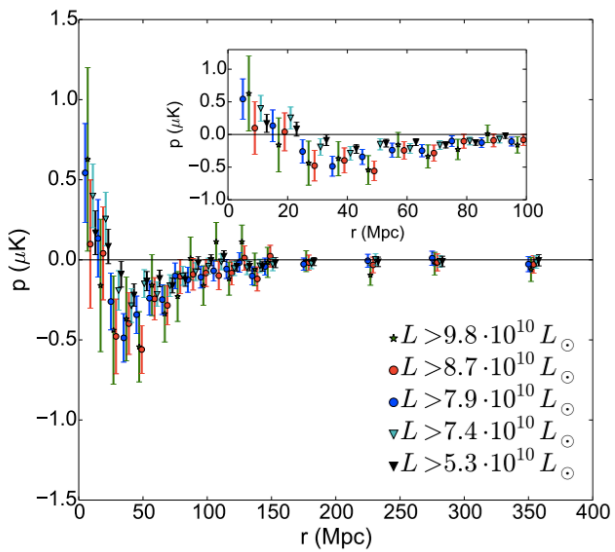
Results

Pairwise momentum and best fit model



Pairwise momentum, various L cuts



- 4σ measurement of kSZ effect over a range of luminosity cuts

F. de Bernardis, S. Aiola, E.M. Vavagiakis, M.D. Niemack (2016), 1607.02139

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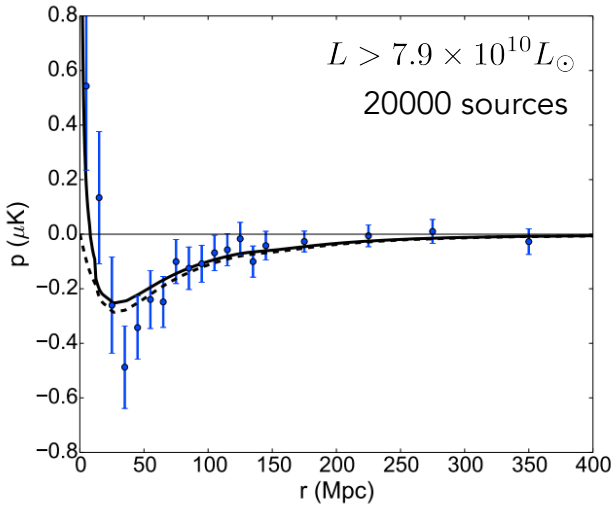
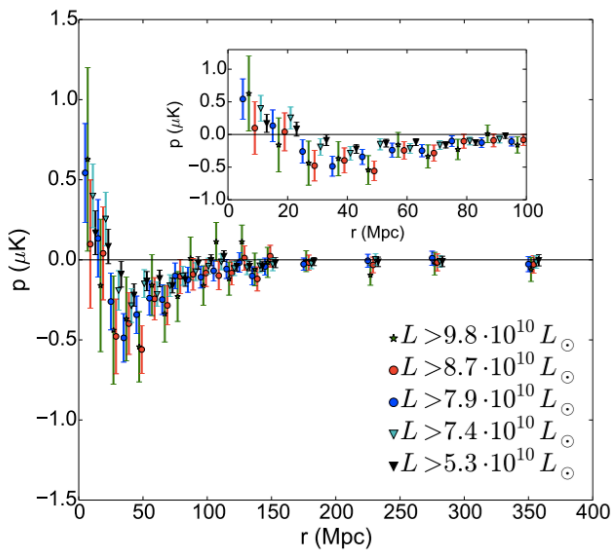
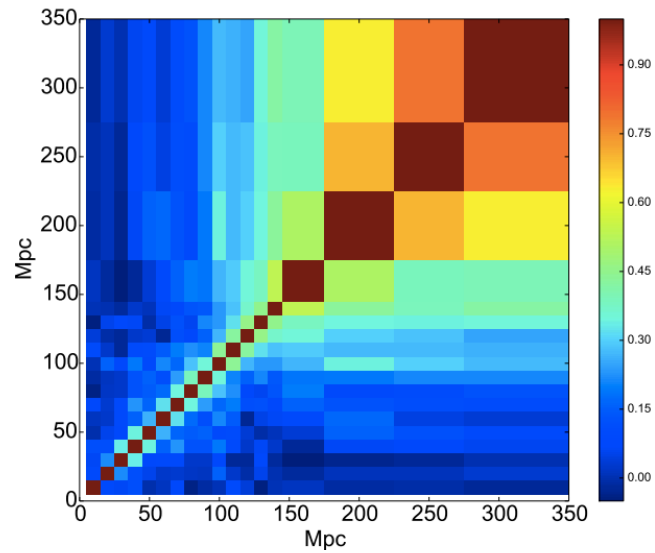


- 4σ measurement of kSZ effect over a range of luminosity cuts
- CMB simulations, jackknife evaluation, bootstrap estimates
- Measurement consistent with Planck, SPT, DES

Pairwise momentum, various L cuts



Binned covariance matrix from simulations

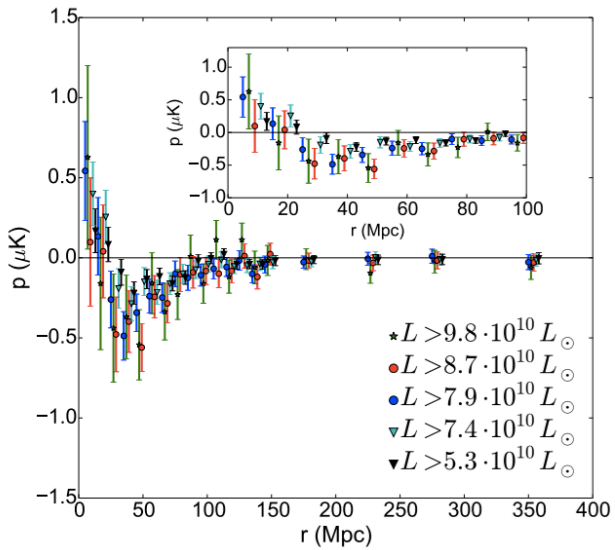


F. de Bernardis, S. Aiola, E.M. Vavagiakis, M.D. Niemack (2016), 1607.02139

Results: Cluster Optical Depths

- tSZ signal and cluster simulations could convert pairwise momentum into velocity: necessary for cosmology

Pairwise momentum, various L cuts

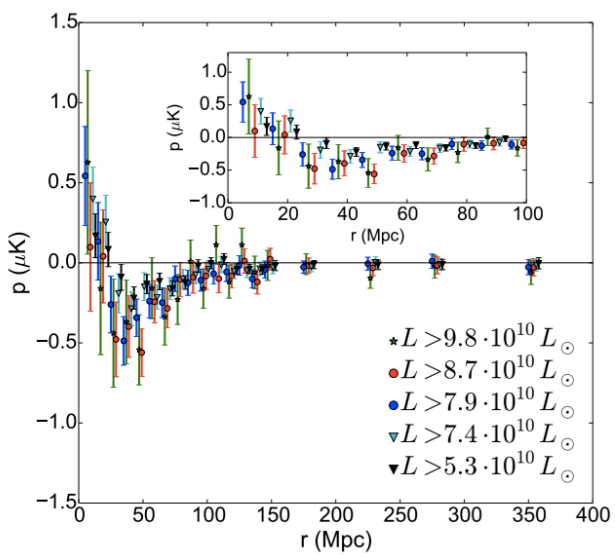


F. de Bernardis, S. Aiola, E.M. Vavagiakis, M.D. Niemack (2016), 1607.02139

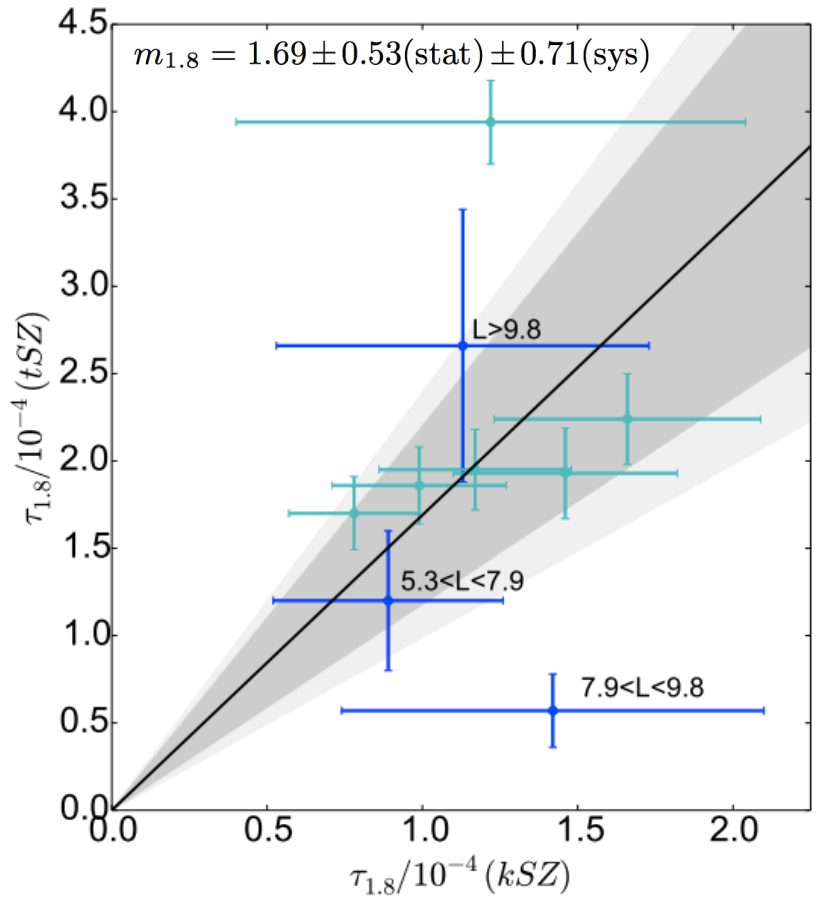
Results: Cluster Optical Depths

- tSZ signal and cluster simulations could convert pairwise momentum into velocity: necessary for cosmology
- Battaglia (2016) hydrodynamical simulations extract optical depths from tSZ signal
- Future: measure optical depths directly

Pairwise momentum, various L cuts



τ from tSZ vs. τ from kSZ



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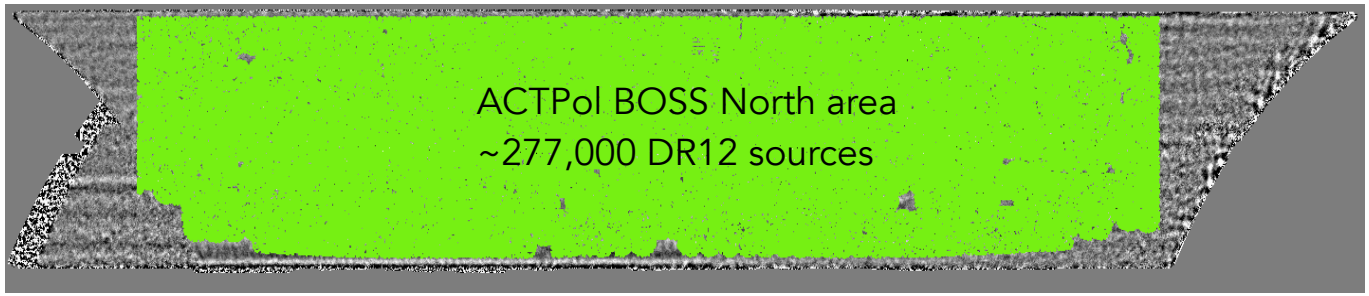
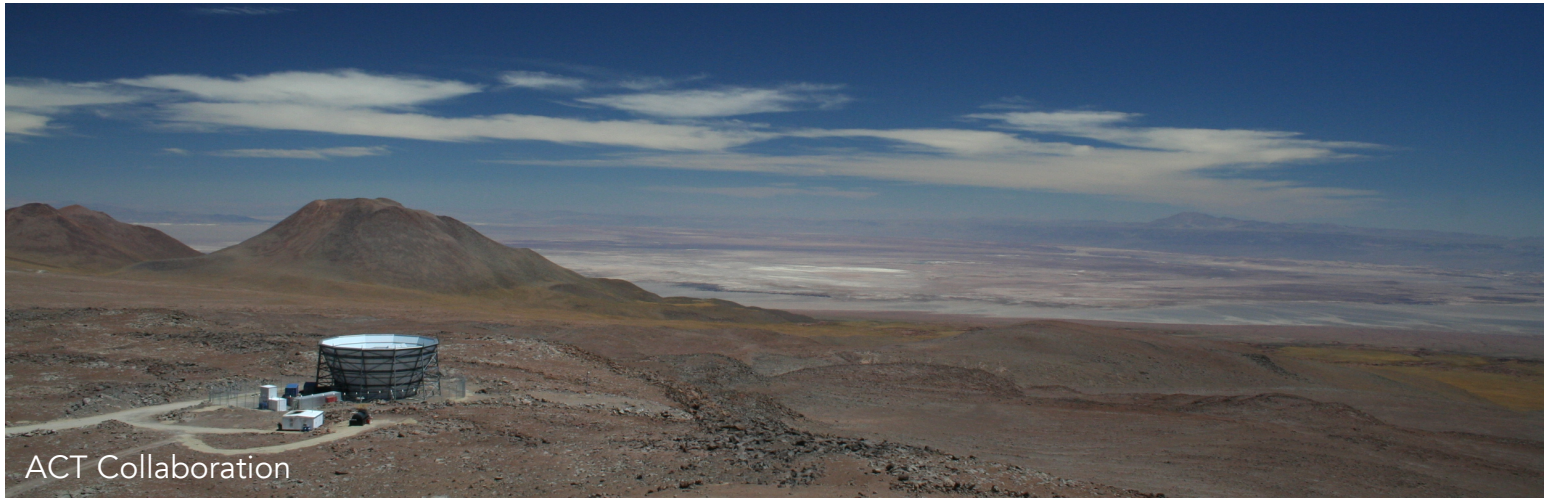
Future

- Upcoming data from ACTPol and Advanced ACTPol



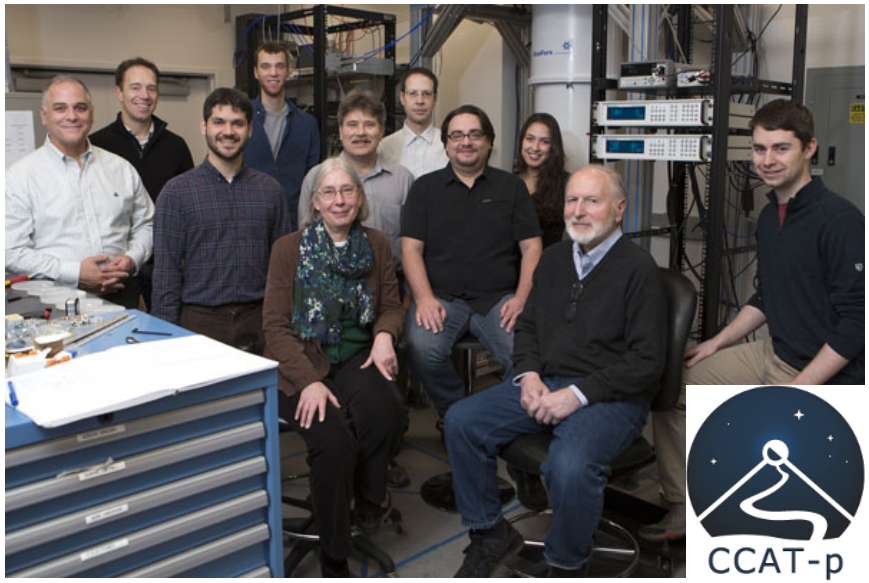


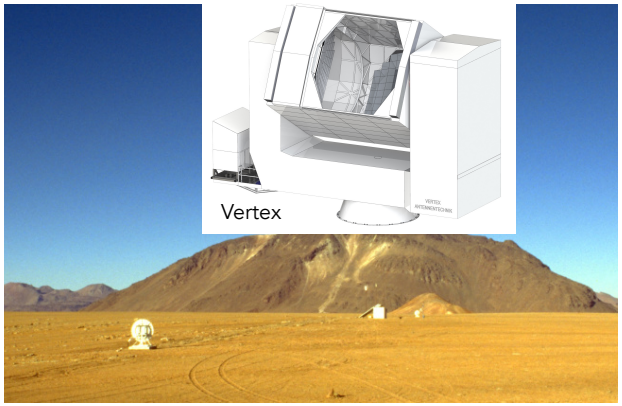
Future

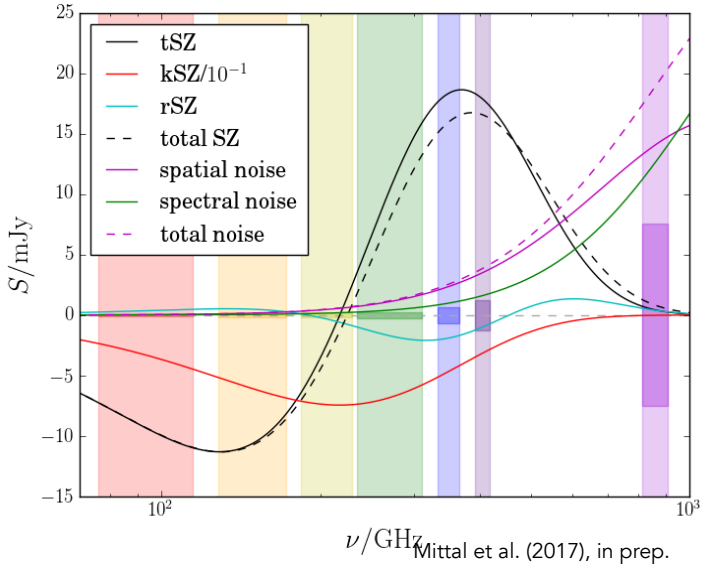
- Upcoming data from ACTPol and Advanced ACTPol
- Improved measurements with CCAT-prime, Simons Observatory, CMB-S4

CCAT-prime:

- 6m aperture off-axis sub-mm telescope
- 5600m elevation on Cerro Chajnantor







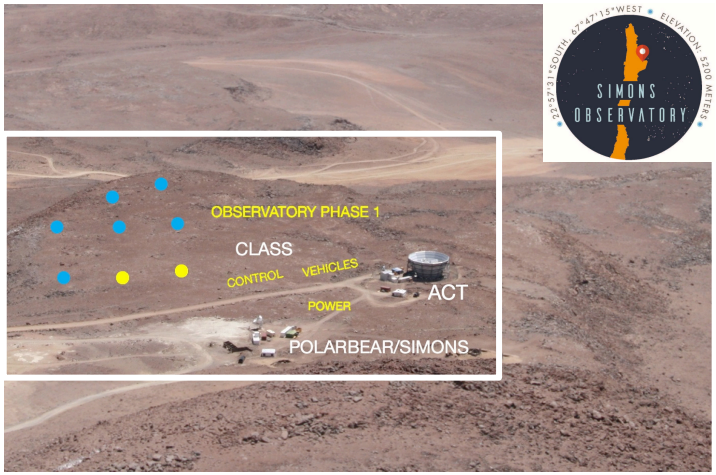
Mittal et al. (2017), in prep.

Future

- Upcoming data from ACTPol and Advanced ACTPol
- Improved measurements with CCAT-prime, Simons Observatory, CMB-S4

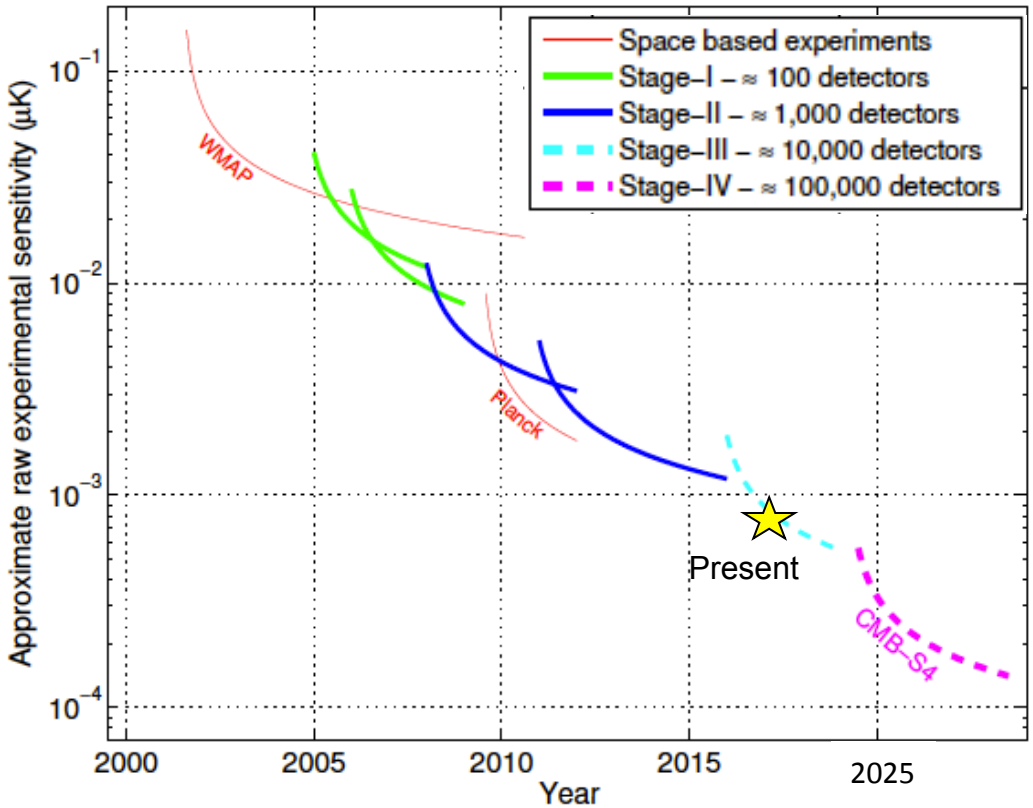
Simons Observatory:

- Array of several new CMB telescopes
- 5200m elevation on Cerro Toco in Chile



Conclusions

- Pairwise kSZ signal poised to become cosmological tool able to constrain fundamental physics
- New CMB maps from ACTPol and AdvACT observations and future surveys will improve SZ measurements



Learn more:

CMB-S4 Science Book
[arXiv:1610.02743]

CMB-S4 Technology Book
[arXiv:1706.02464]

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