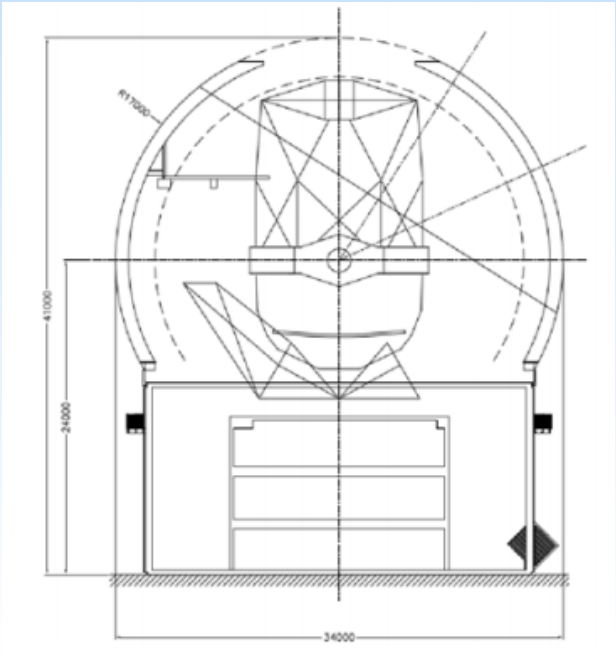
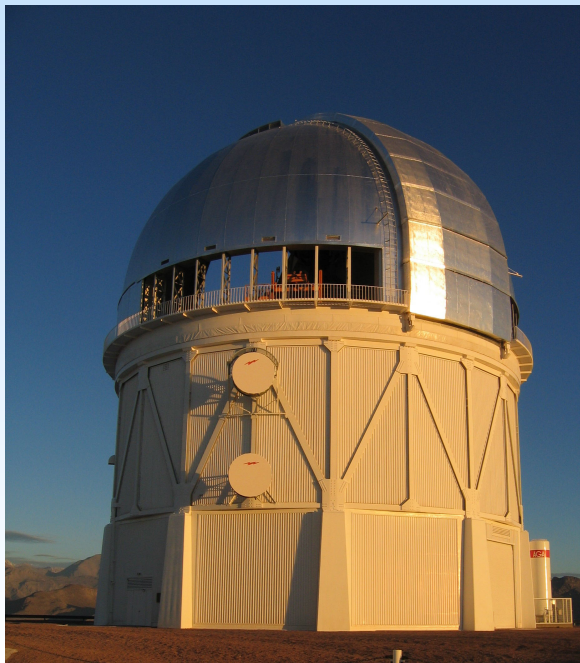
Cross-Correlation Science with SSSI

Lindsey Bleem
Argonne National Laboratory





Next generation surveys provide tremendous opportunities for multi-wavelength science

- Optical/Infrared
  - LSST, WFIRST, Euclid, Spherex
- CMB
  - Stage 3/ CMB -S4
- X-ray
  - eRosita (2017), Athena, X-ray Surveyor
- Sub-mm
  - LMT, CCAT-p, CSST, Far Infrared Surveyor
- 21 cm (see talks later today!)

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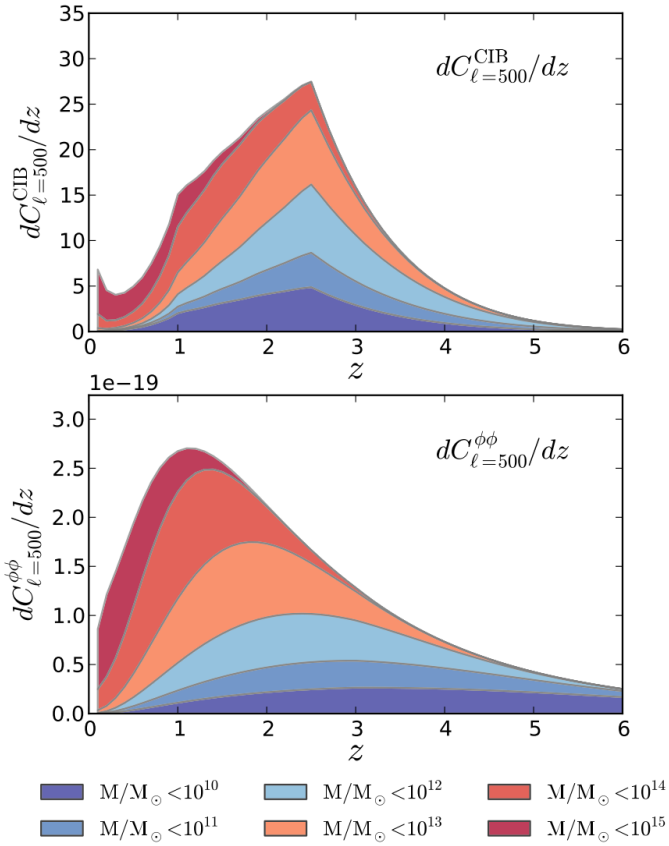

Planck Collab. 2013 XVIII.

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+ your favorite survey here!

CMB-S4
Next Generation CMB Experiment

Enhance Future Surveys science by overlapping coverage

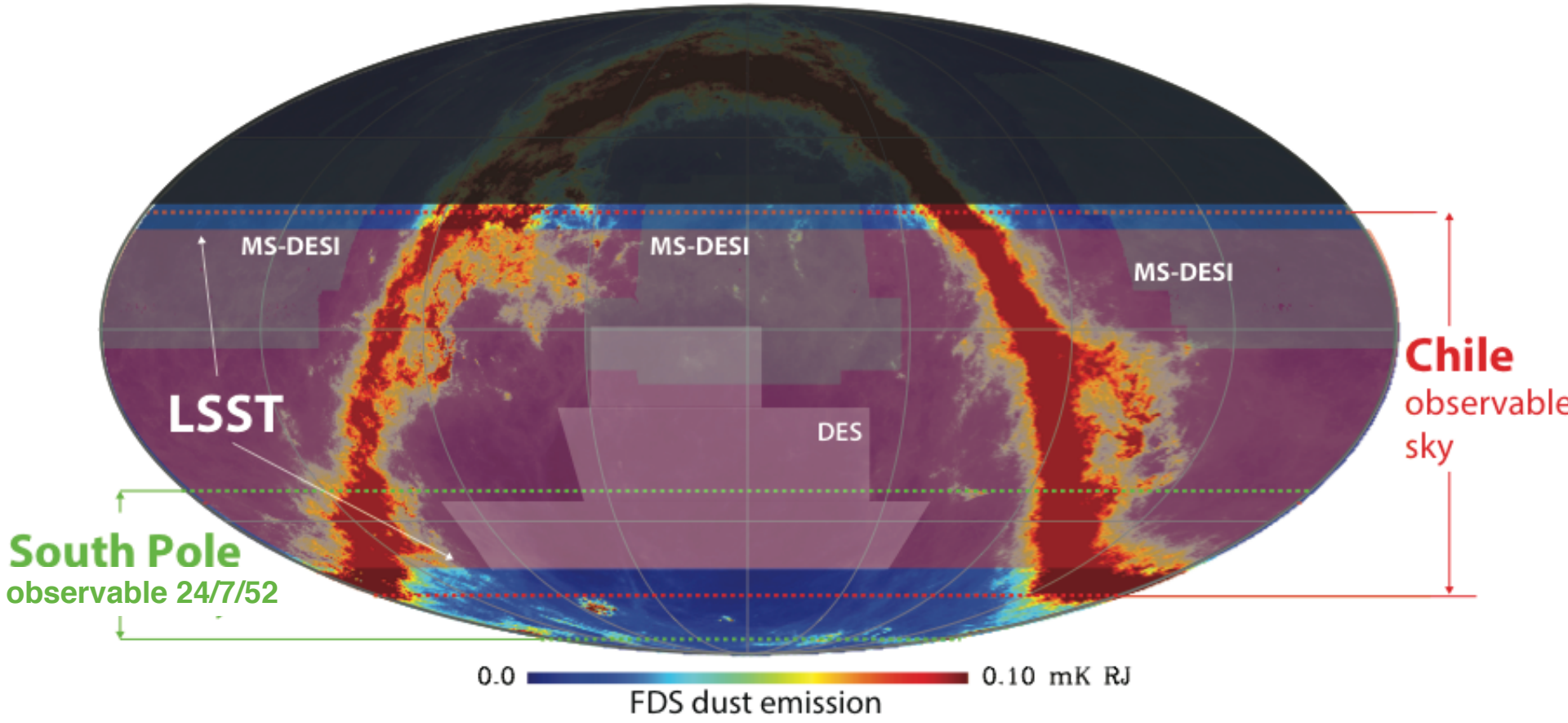
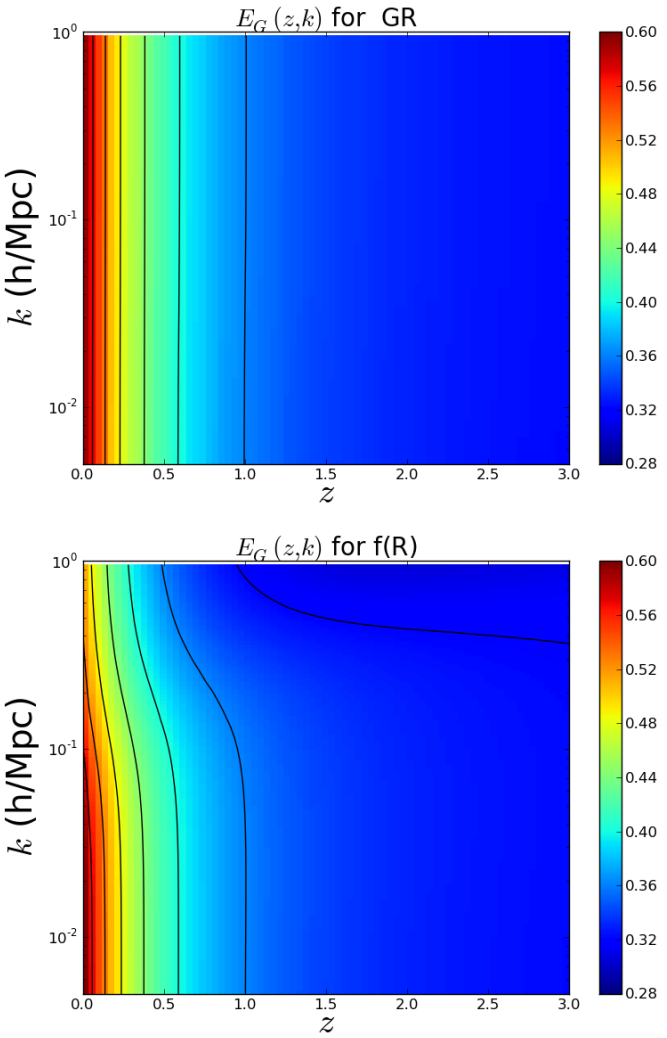


Figure from Jeff McMahon

SSSI x CMB

- E_g
  - Test of GR, modified gravity models

$$E_G(\ell) = \Gamma \frac{C_\ell^{\kappa g}}{\beta C_\ell^{gg}}$$

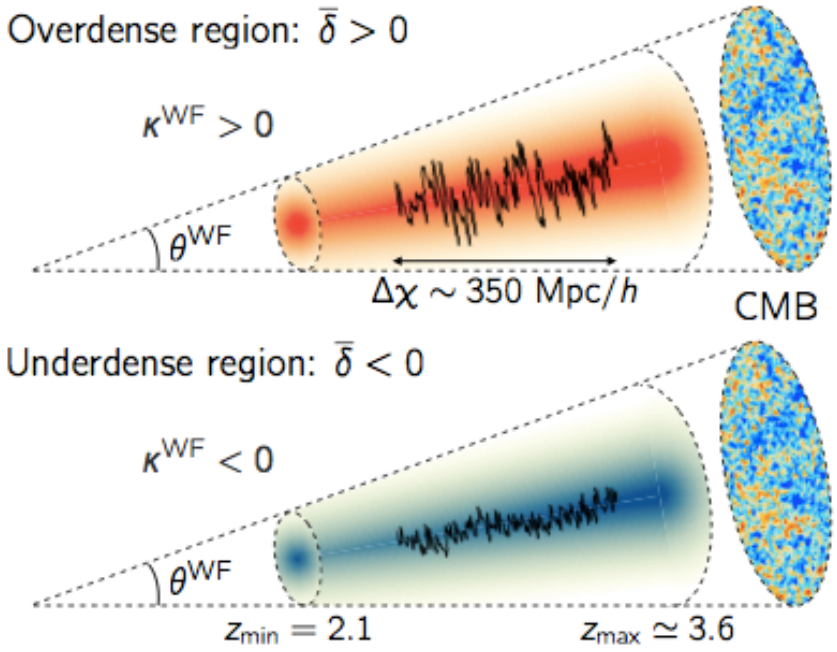


Pullen+15; MNRAS 449, 4326
See also
Zhang+07,PRL.99:141302
Pullen+16MNRAS.460.4098P

SSSI x CMB

- E_g
  - Test of GR, modified gravity models

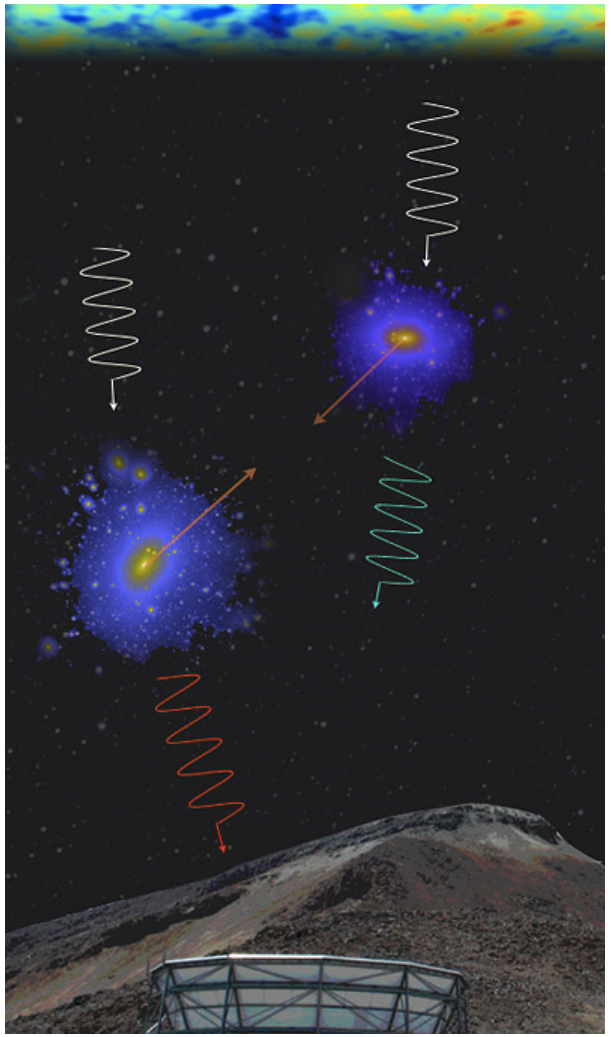
- Ly-α Forest x CMB lensing
  - First detection (5σ) July 2016!
  - Potentially powerful test of cosmology (sum neutrino mass, alternative models of DM)
  - interpretation limited by knowledge of baryonic physics



Doux+ 1607.03625v1
See also:
Zaldarriaga, Seljak, Hiu, ApJ 551,48 (2001)
Vallinotto+ 2009, PRL 103, 091304

SSSI x CMB

- **kSZ**
  - **CMB photons scatter off electrons with peculiar velocities with respect to the CMB rest frame**
  - **$\Delta T \propto \tau$ x velocity**
- **Useful for probing**
  - **Gravity (Keisler&Schmidt, 2013, Mueller2015)**
  - **Neutrinos (Mueller +2014,2015)**
  - **Astrophysics (Flender+ 16,Battaglia 16, Hill+16, Planck2016,**



Hand et al. 2012; PRL 109, 041101

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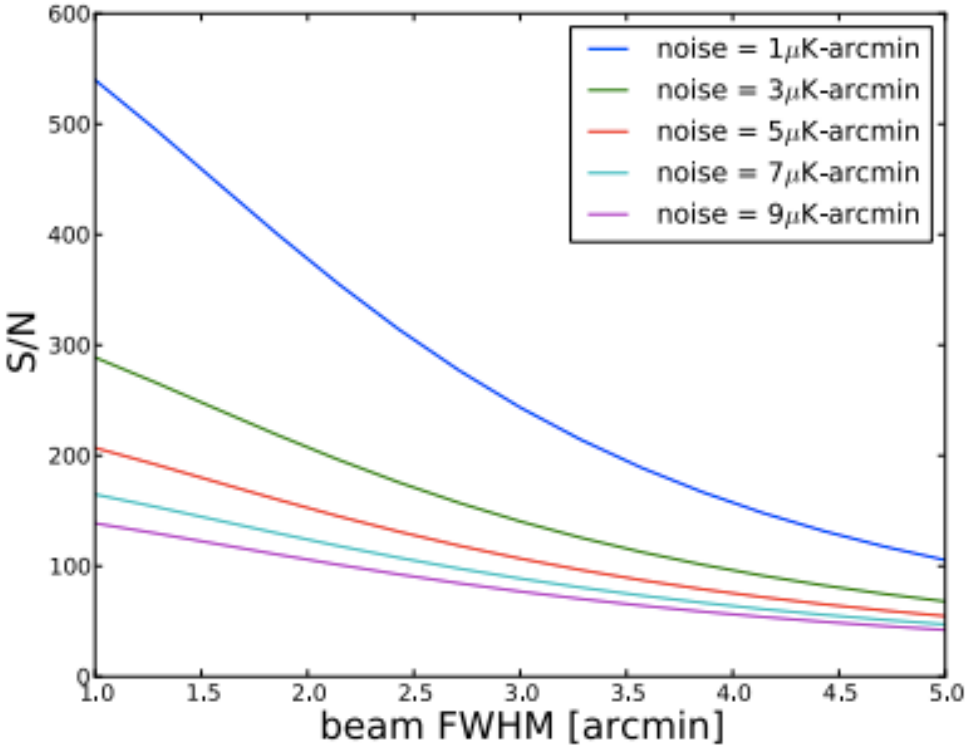
CMB S4 x DESI-like survey

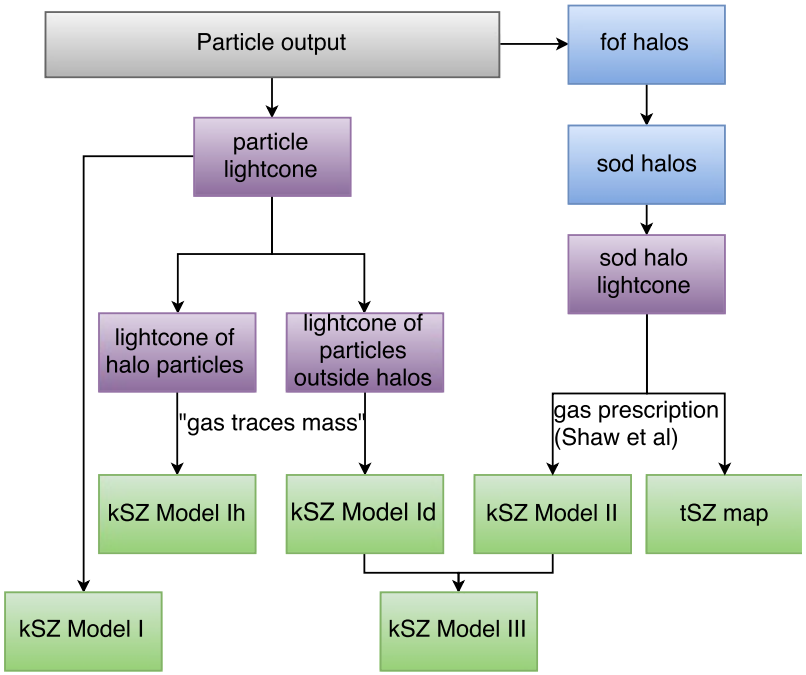


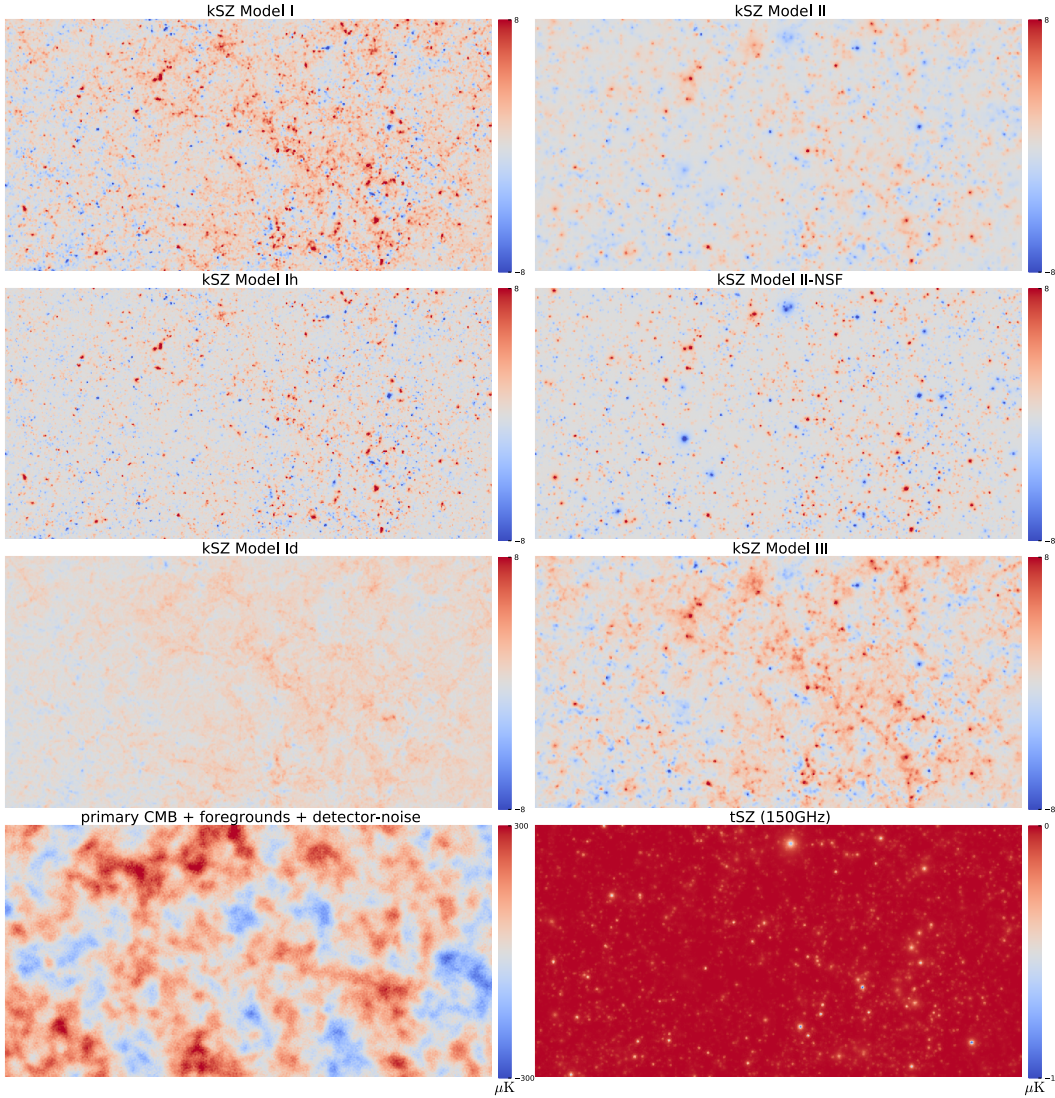
Ferraro

+ many more!!

See also Sugiyama+ 2016 arXiv:1606.06367

From N-body Simulations ….. To Realistic Mocks

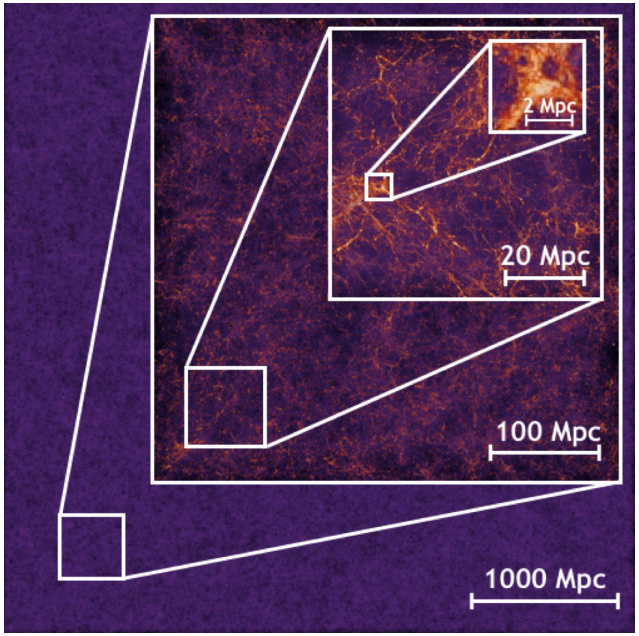




Flender+2016, ApJ, 823, 98F

From N-body Simulations ….. To Realistic Mocks

- **Outer Rim Simulation (HACC)**
  - N-body, 1.1 trillion particles with mass $2.6 \times 10^9 M_\odot$, $(4.225\ \mathrm{Gpc})^3$



Habib+14, arXiv:1410.2805

- **SSSI-like galaxy catalogs (Juliana Kwan)**
  - LRGs, ELGs*
- **mm-wave sky**
  - tSZ, kSZ (Sam Flender)
  - CMB lensing
  - CIB*

*in progress

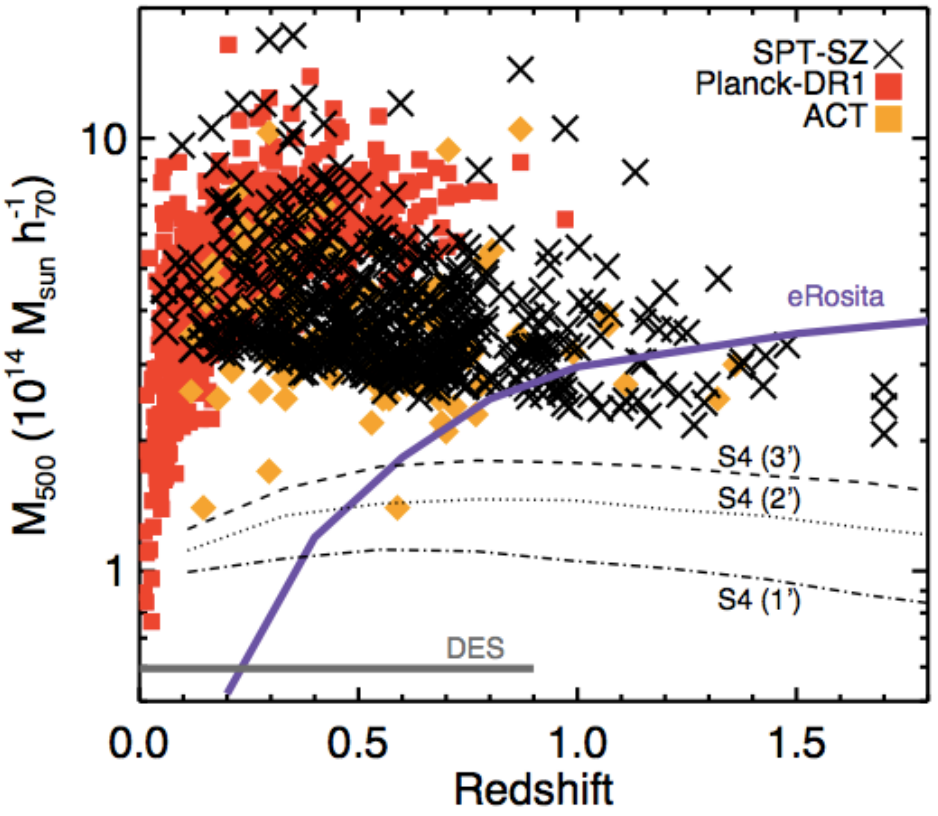

BUT WAIT
THERE'S MORE

SSSI & Clusters

• CMB-S4 will produce a mass-limited sample of ~100,000 clusters. Spectroscopic follow-up can enable studies of

• **Cosmology**:
  - precise redshifts/photo-z training
  - velocity dispersions

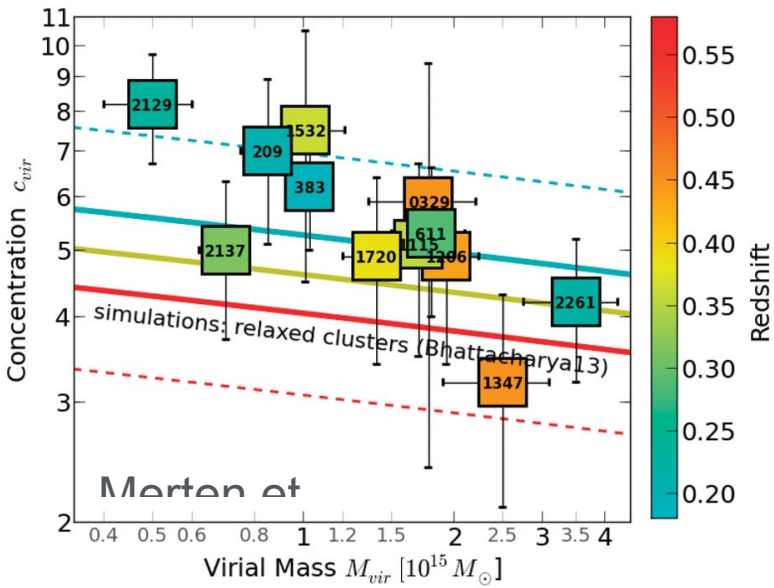
• **Astrophysics:**
  - Track across cosmic time star-formation/metallicity in cluster members and—combined with X-ray surveys (Athena, X-ray Surveyor)—probe the interplay between galaxies and gas in the most massive halos

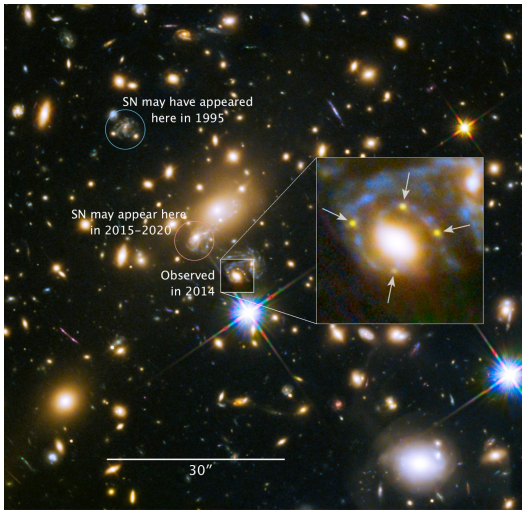


Benson; http://cmb-s4.org/

Strong Lensing Science

- **Direct test of structure formation:** Large N-body simulations provide predictions for the properties of Dark Matter haloes that are directly testable by using Strong Lensing as a probe the cores of massive systems
- **Improved Dark Energy Constraints from Cluster Surveys:** Joint Strong + Weak Lensing provides the best constraints on cluster masses
- **Cosmic Telescopes** - Strong lensing is a powerful tool with which to study the distant Universe
  - *Earliest galaxies (reionization!)*
  - *Expansion Rate of the Universe (e.g., SN Refsdal)*
  - *Dark Matter Substructure (SPT + ALMA)*





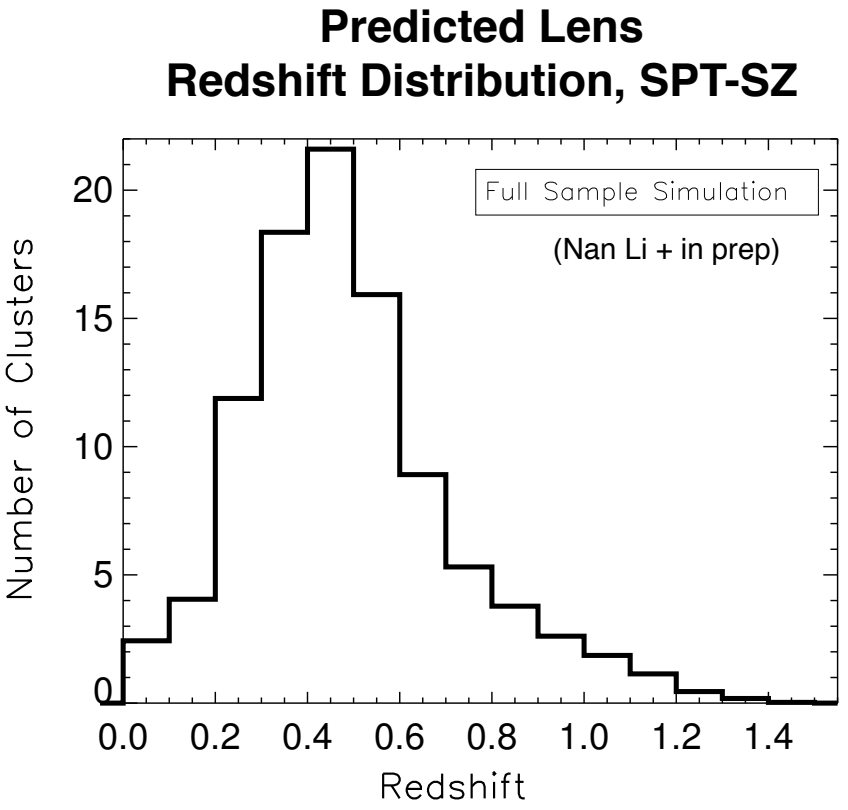
SZ Strong Lensing Samples:

• Expect >100 strong lenses to be detected in SPT-SZ cosmology sample with reasonable (<0.75”) ground-based imaging.

• Will be possible to measure the mean mass-concentration relation of massive halos to ~5%, and constrain its scatter to ~10% precision.

•SSSI observations of >**2,000** strong lenses from the full CMB-S4 sample along with LSST data will provide >20x statistics and will further probe the complex cores of these massive systems:

- stringent tests of MC relation (now with redshift evolution, mass-dependence)
- constraints on feedback, tests of hydrodynamic simulations



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