# Mass Estimation of Galaxy Clusters with Deep Learning

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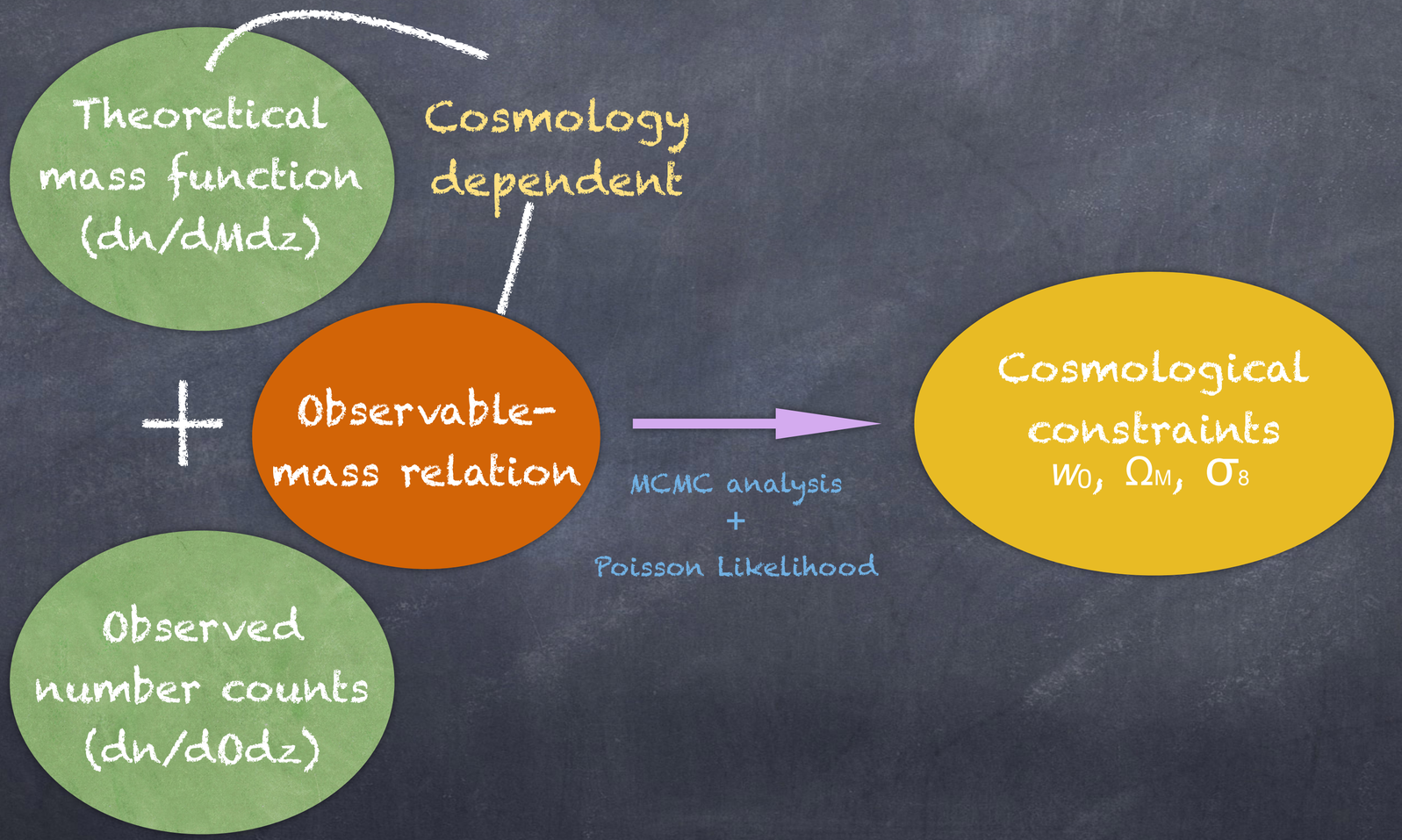
Credit: Geoffrey Chen

# Outline

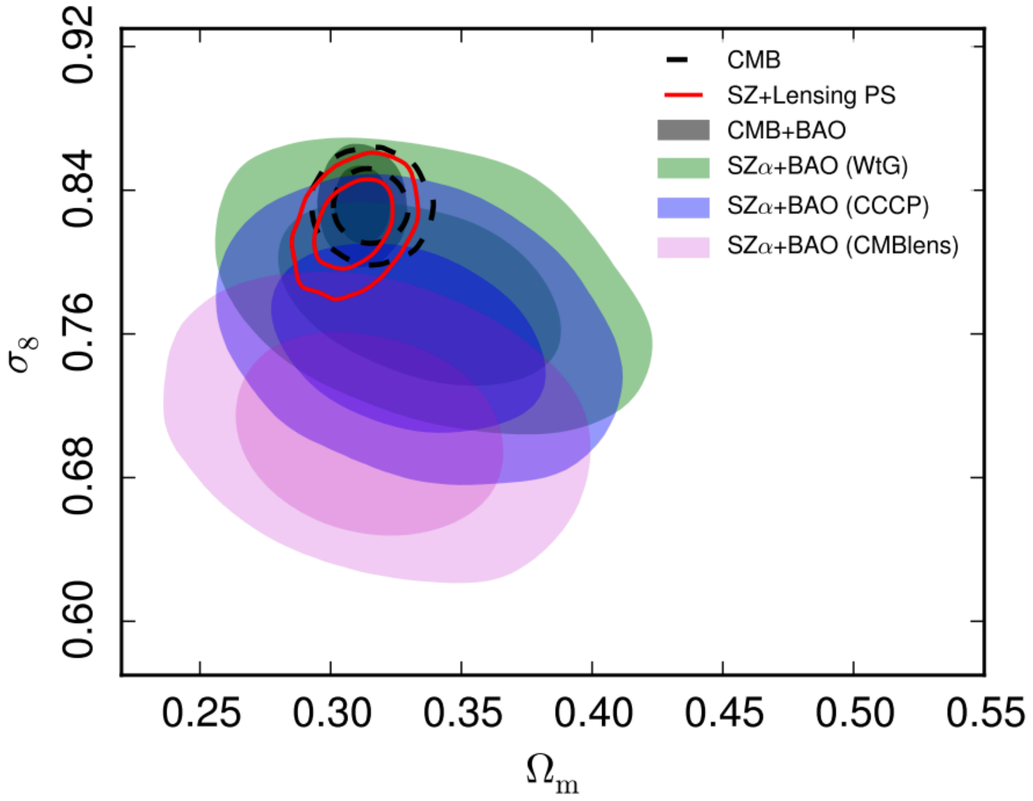
- Why are we interested in mass of galaxy clusters?
- Overview of Sunyaev Zel'dovich (SZ) Effect.
- The deep learning model.
- Estimating SZ mass directly from the images of the microwave sky.

# Galaxy Clusters for Cosmology

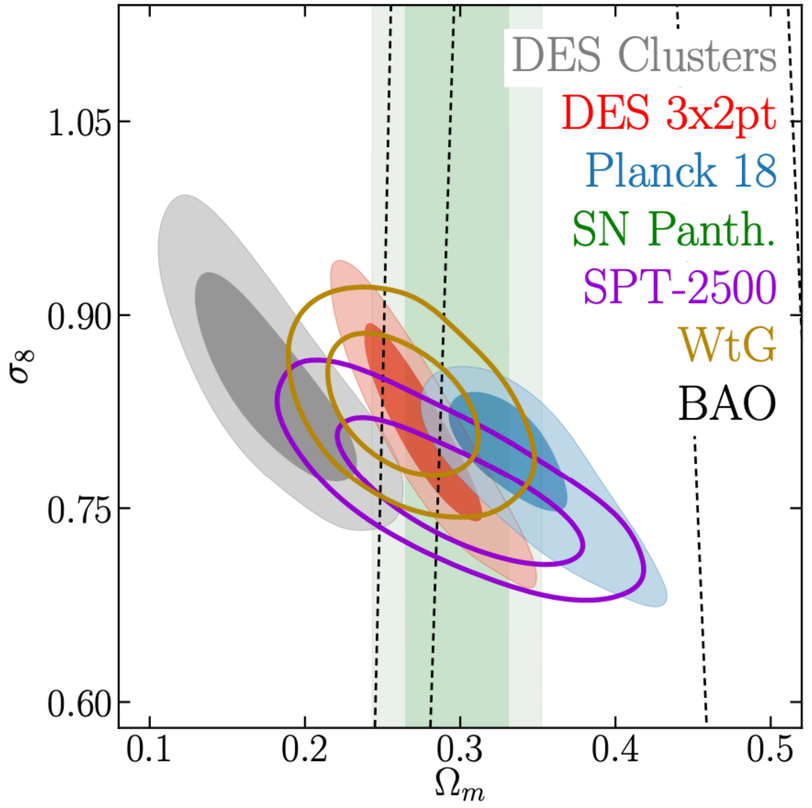


# Why galaxy cluster masses are crucial?

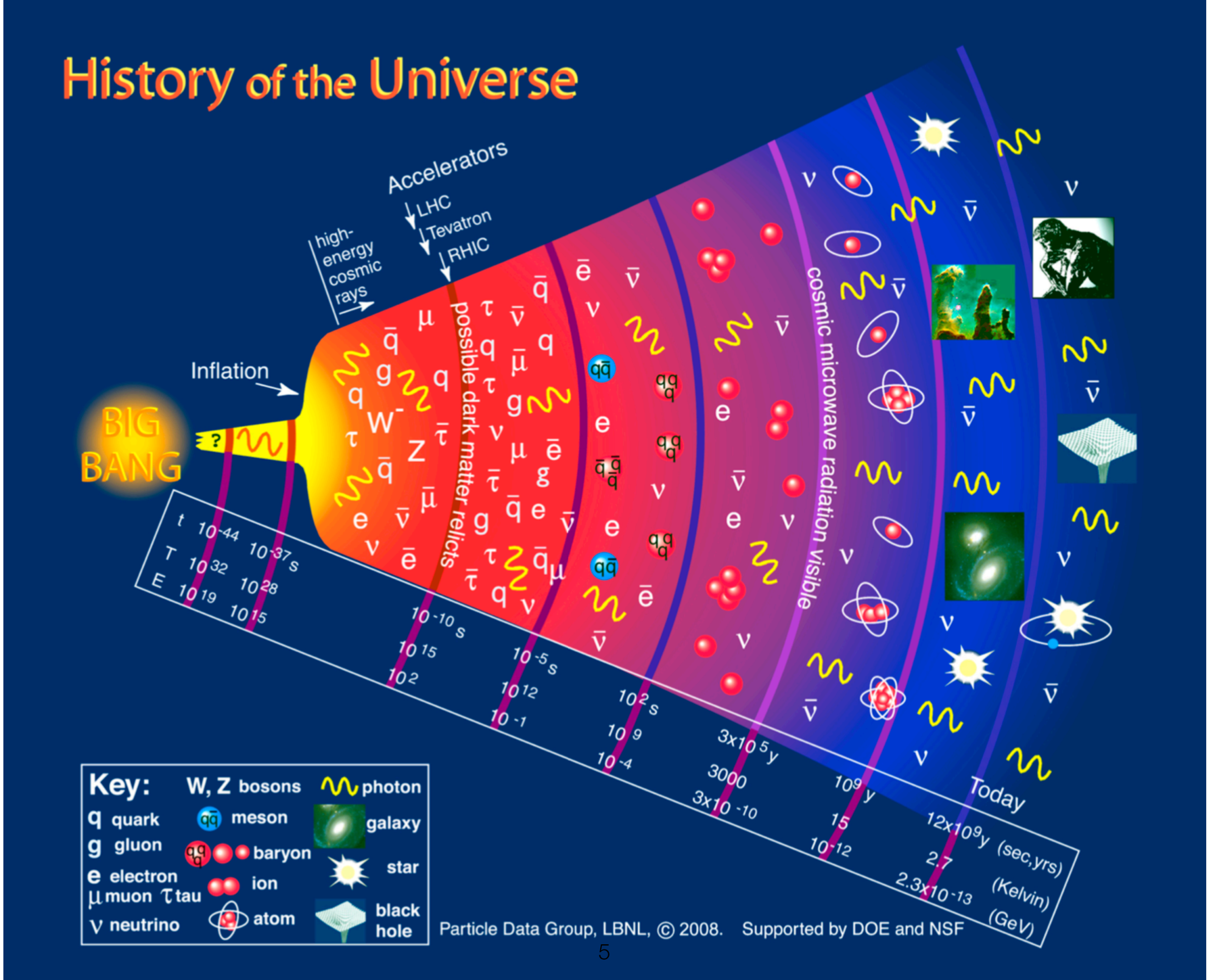
- At present, cluster abundance studies are limited by the ability to calibrate the relation between halo mass and the observable.



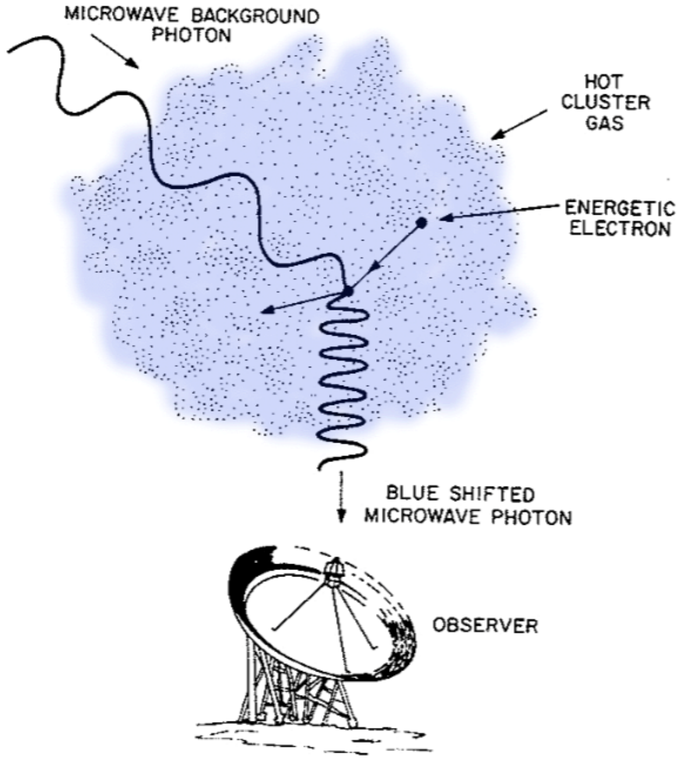

Planck Collaboration (2015)



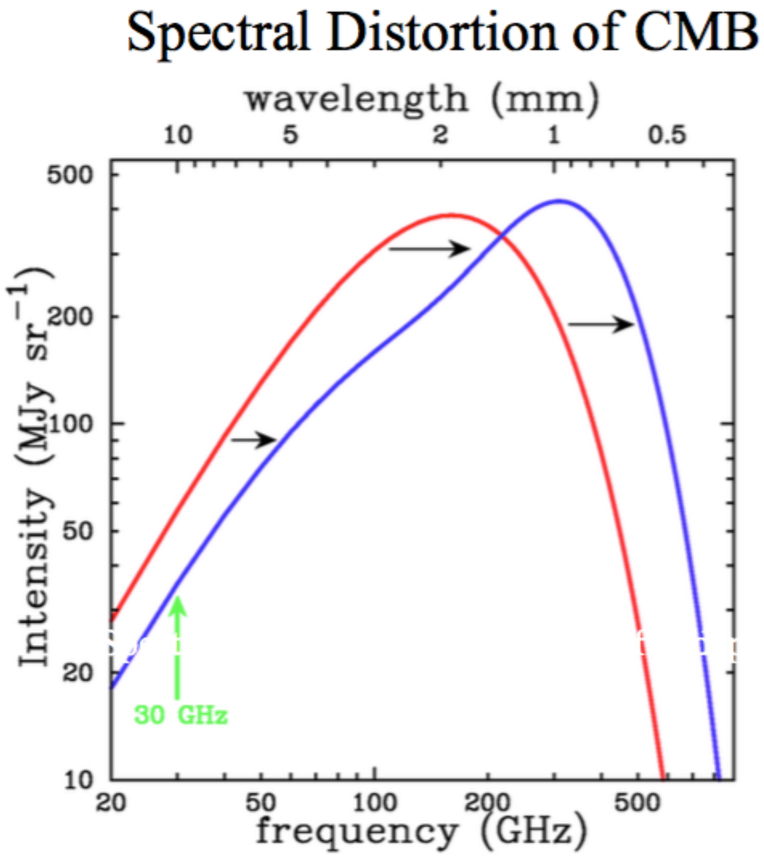

DES collaboration (2020)


History of the Universe
Accelerators
LHC
Tevatron
RHIC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Today
Key:
W, Z bosons
photon
q quark
meson
galaxy
g gluon
baryon
star
e electron
ion
μ muon τ tau
atom
black hole
ν neutrino
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF
(sec,yrs)
(Kelvin)
(GeV)

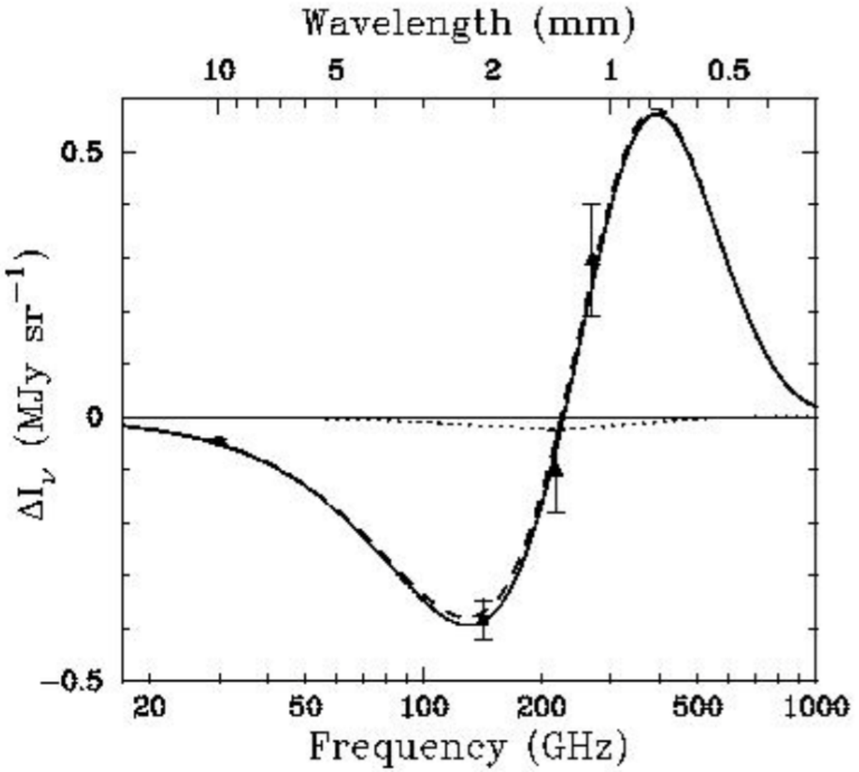
# Sunyaev Zel'dovich (SZ) Effect




Adapted from L. Van Speybroeck

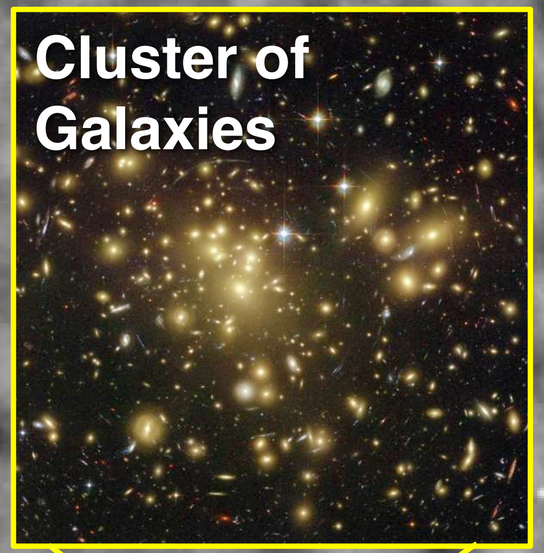



Sunyaev & Zel'dovich 1970, 1972

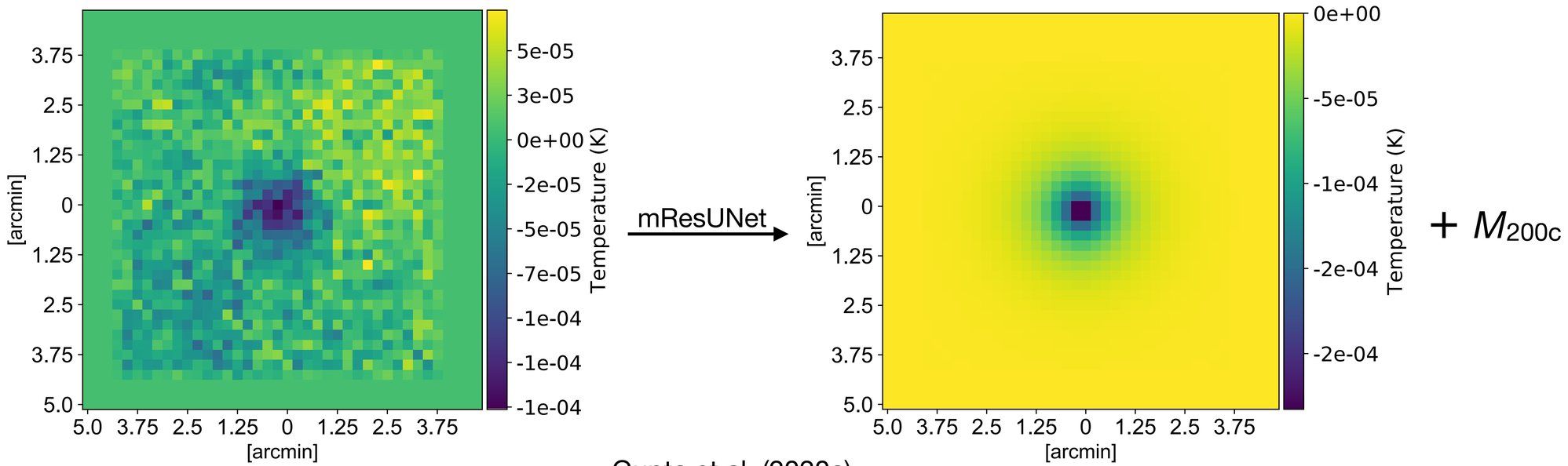


# *SPTpol*
## 150 GHz
## 50 deg$^2$

**Clusters of Galaxies**
"Shadows" in the microwave background from clusters of galaxies. The **Sunyaev-Zel'dovich (SZ)** effect



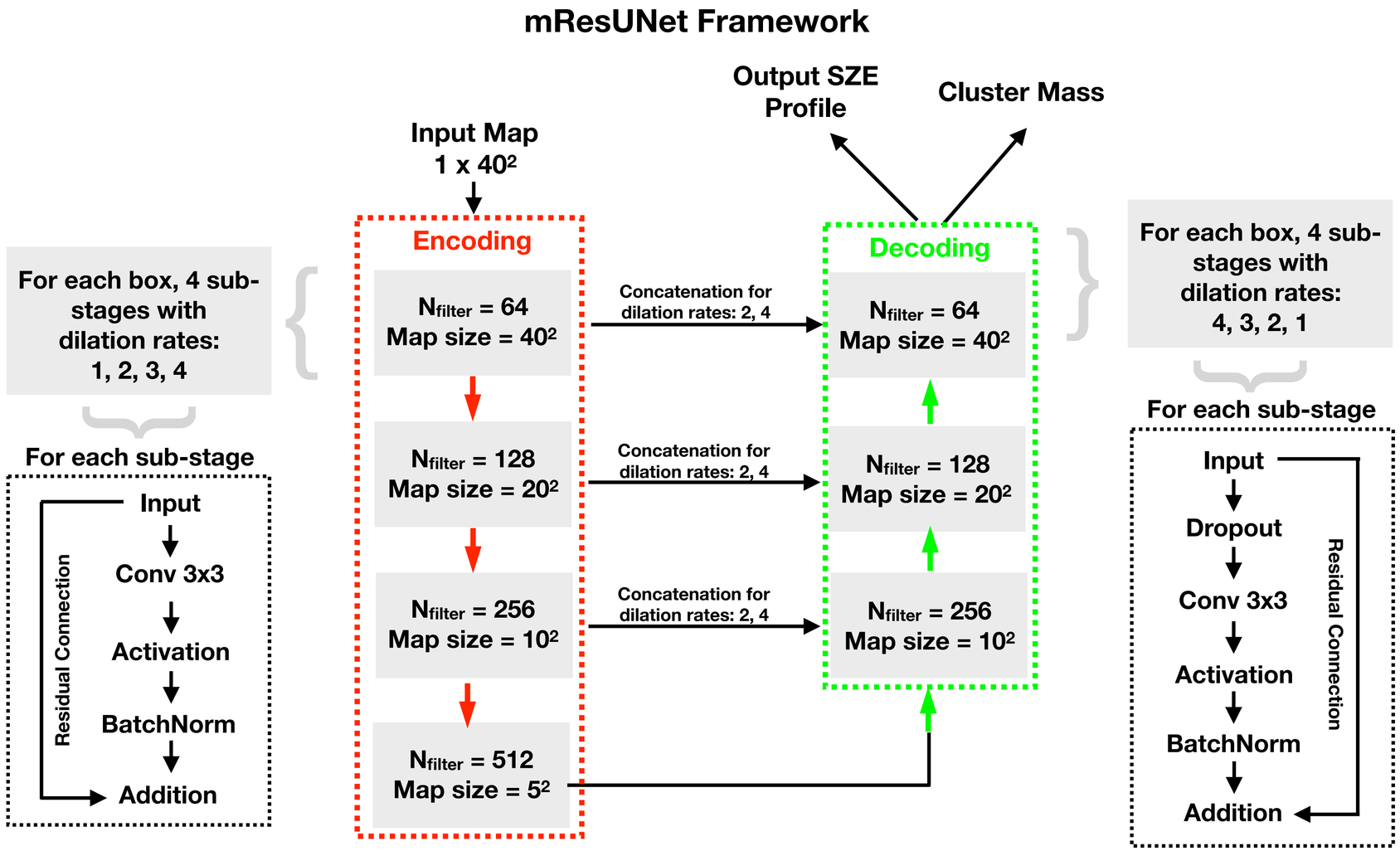
# Simulations




Gupta et al. (2020a)

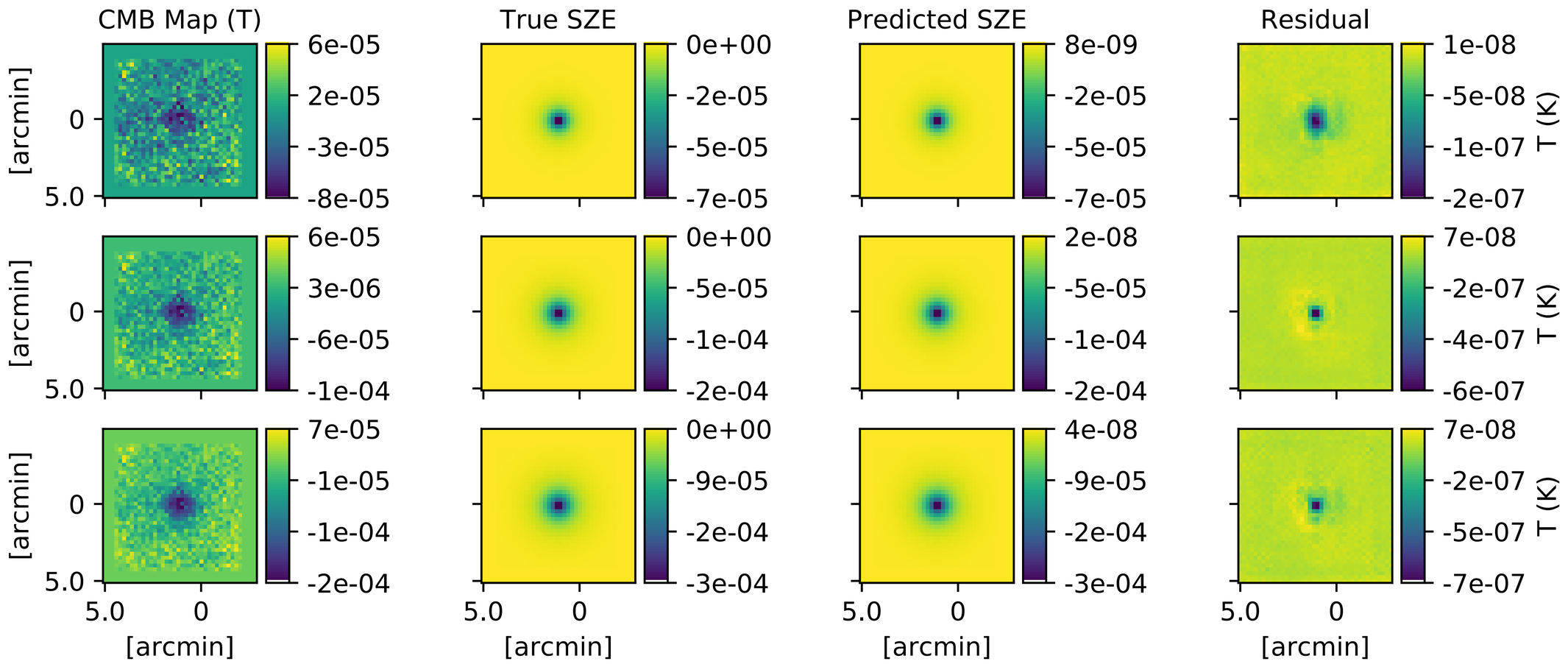
- 19 distinct set of simulations for galaxy clusters with $M_{200c}$ = (0.5, 0.75, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 9, 10)×$10^{14}$ $M_{sol}$ at z = 0.7
- Microwave sky: Gaussian realisations of CMB + Astrophysical foregrounds (George+ 2015) + 5 uK-arcmin noise + 1 arcmin beam smoothing + SZ signal (Arnaud+ 2010) + 20% log-normal scatter on SZ.
- Training + Validation sample —> 400 + 200 maps for each cluster mass.
- Testing the trained model —> 200 maps for each cluster mass.

# Deep learning model



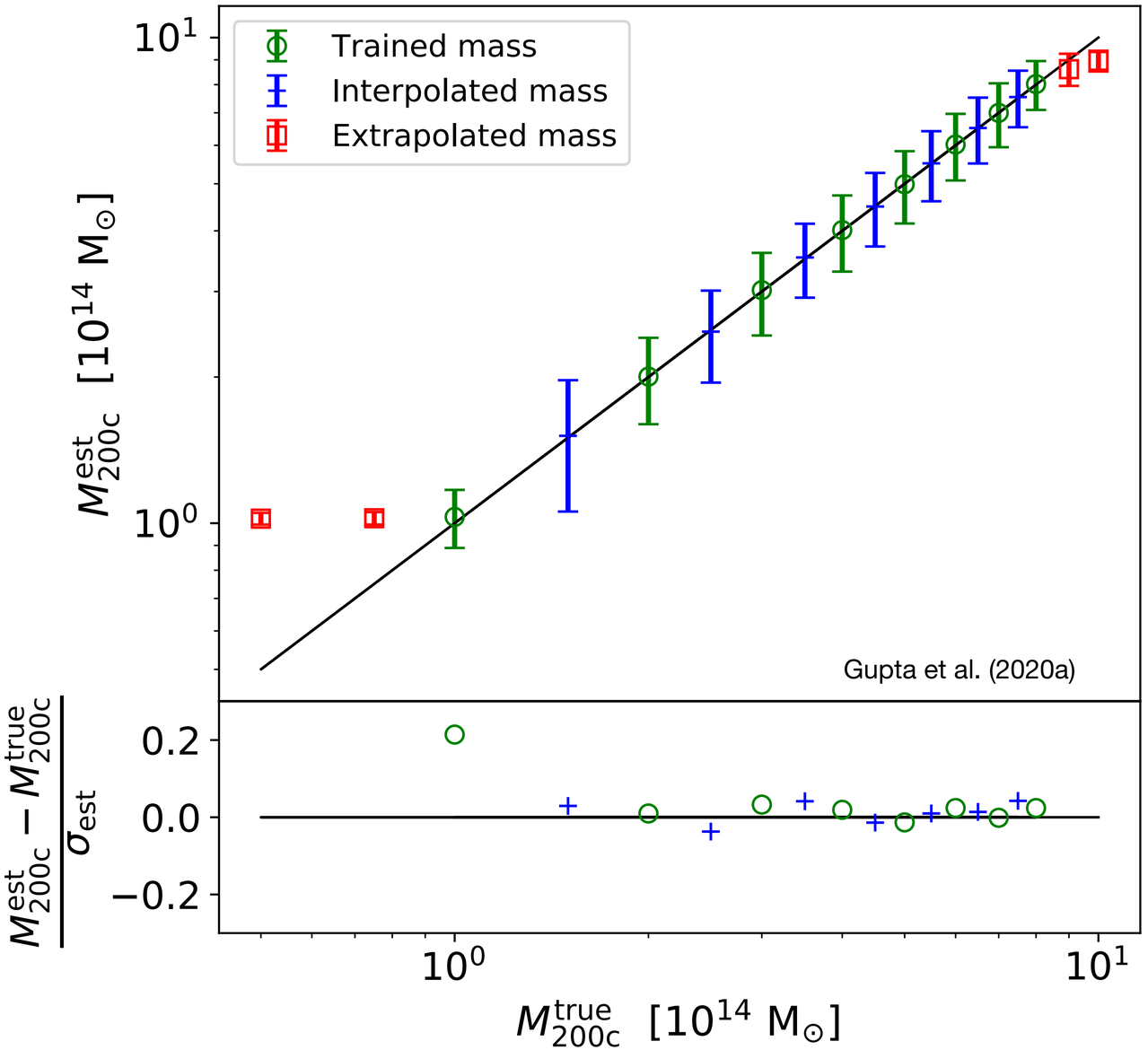

Gupta et al. (2020a)

# Results: SZE profiles




Gupta et al. (2020a)

# Results: Mass Estimations



# Conclusions

(see Gupta et al. 2020a, arXiv:2003.06135, accepted in APJ)

- We can now estimate the mass of galaxy clusters just by looking at them in the microwave sky using deep learning/ computer vision models.
- The log-normal scatter (observational + intrinsic) for $M_{est}$ as a mass proxy is consistent with intrinsic scatter for SZ *Y* signal.

# Not discussed today!

(CMB cluster lensing with deep learning; see Gupta et al. 2020c, arXiv:2005.13985, accepted in APJ)