Observing galaxy clusters in SZ with the SKA

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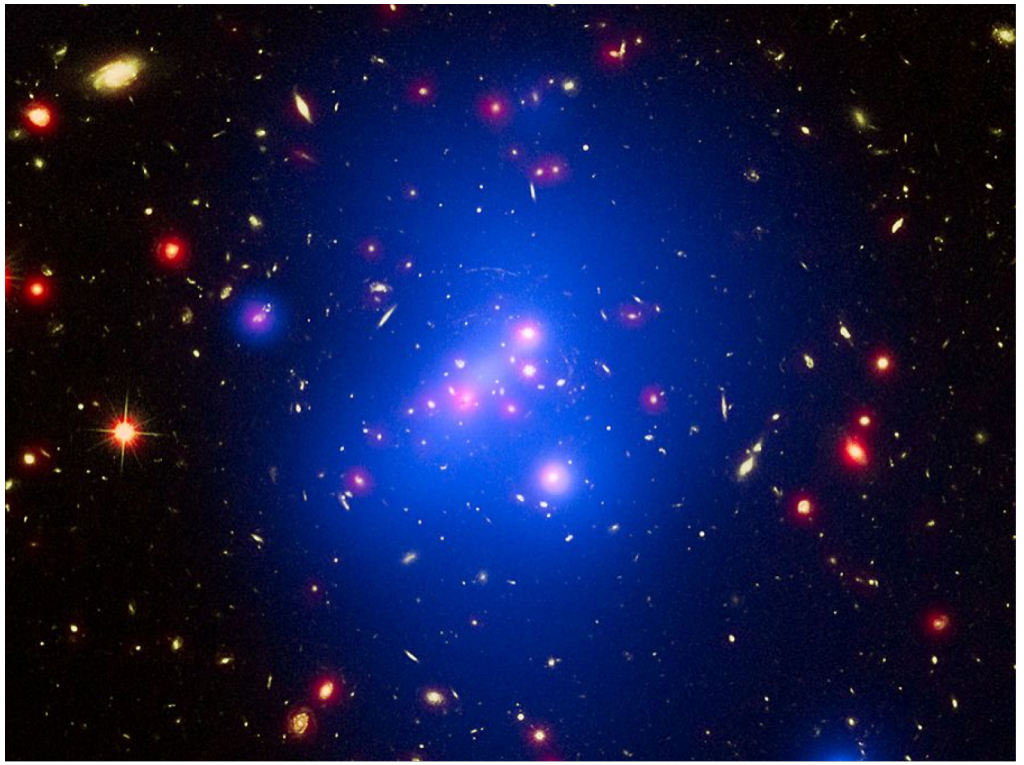
S4SKA, AUT 13/02/2018

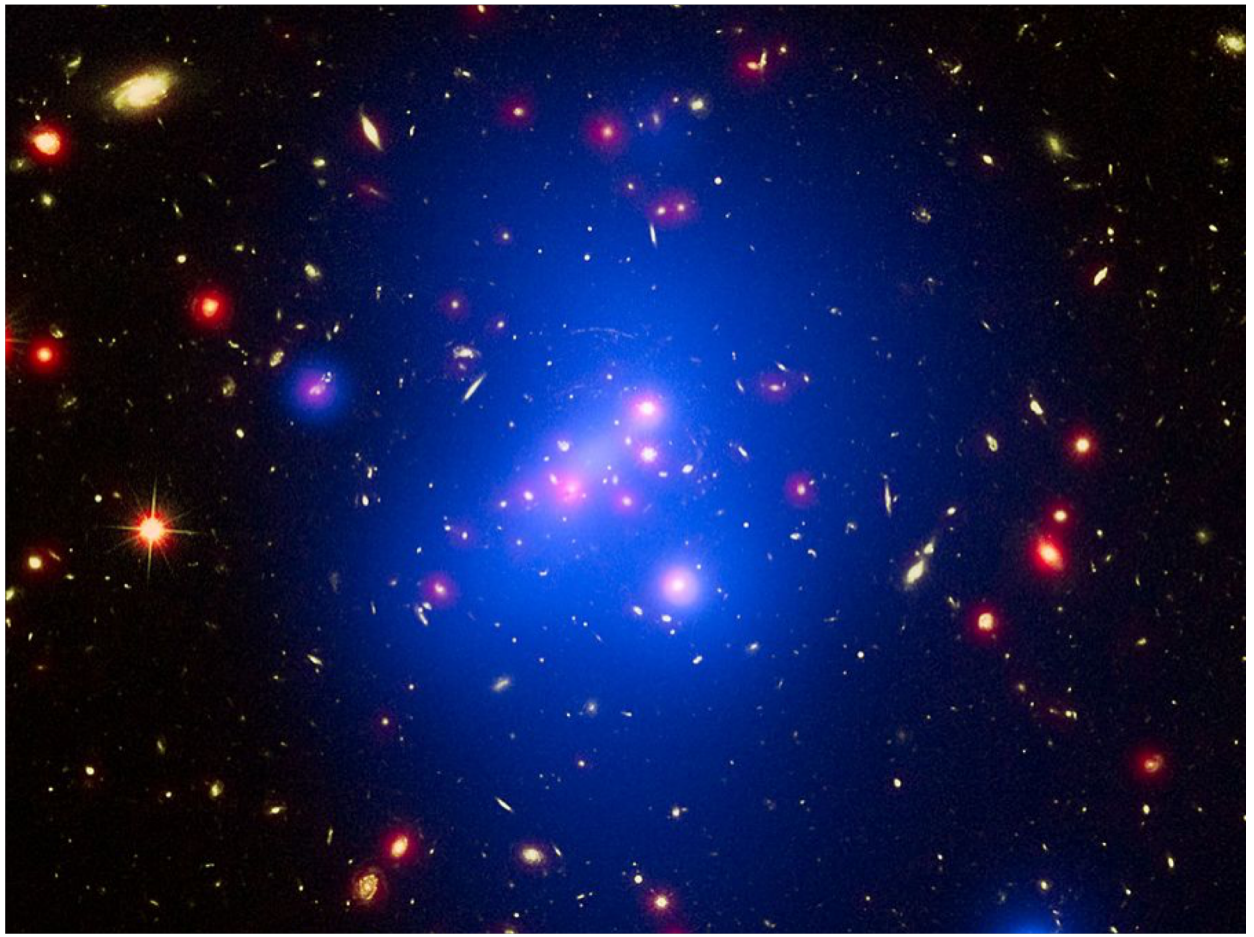
Galaxy clusters



Galaxies	~1%	Can contain ~100 to 1000 galaxies
Intracluster gas	~9%	Mostly ionised H and He, temperatures of 10-100 MK
Dark matter	~90%	Largest component but difficult to observe!

- Total mass ~10^{14} – 10^{15} solar masses
- Typical diameter ~2 – 10 MPc

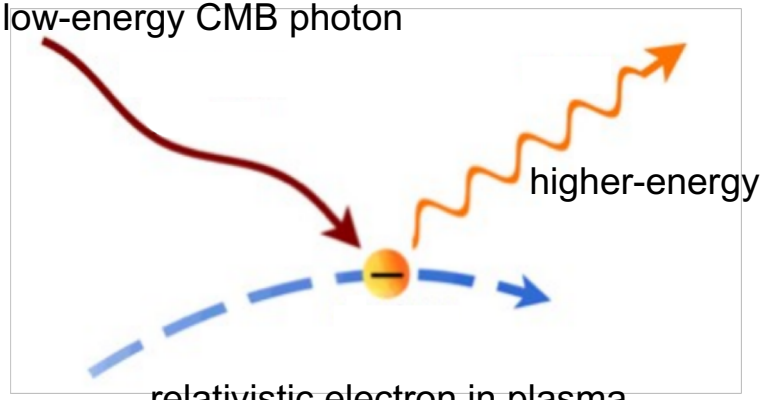
Observing the gas - SZ



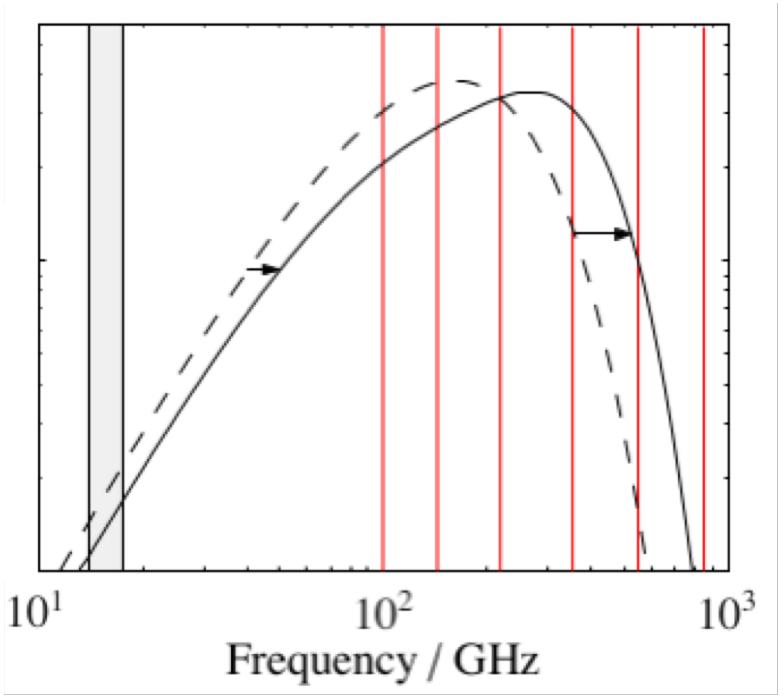
- Can observe the gas in X-rays (thermal Bremsstrahlung)
- Hot gas also interacts with Cosmic Microwave Background photons via an inverse-Compton-scattering process, the Sunyaev-Zel'dovich effect

Sunyaev-Zel'dovich Effect

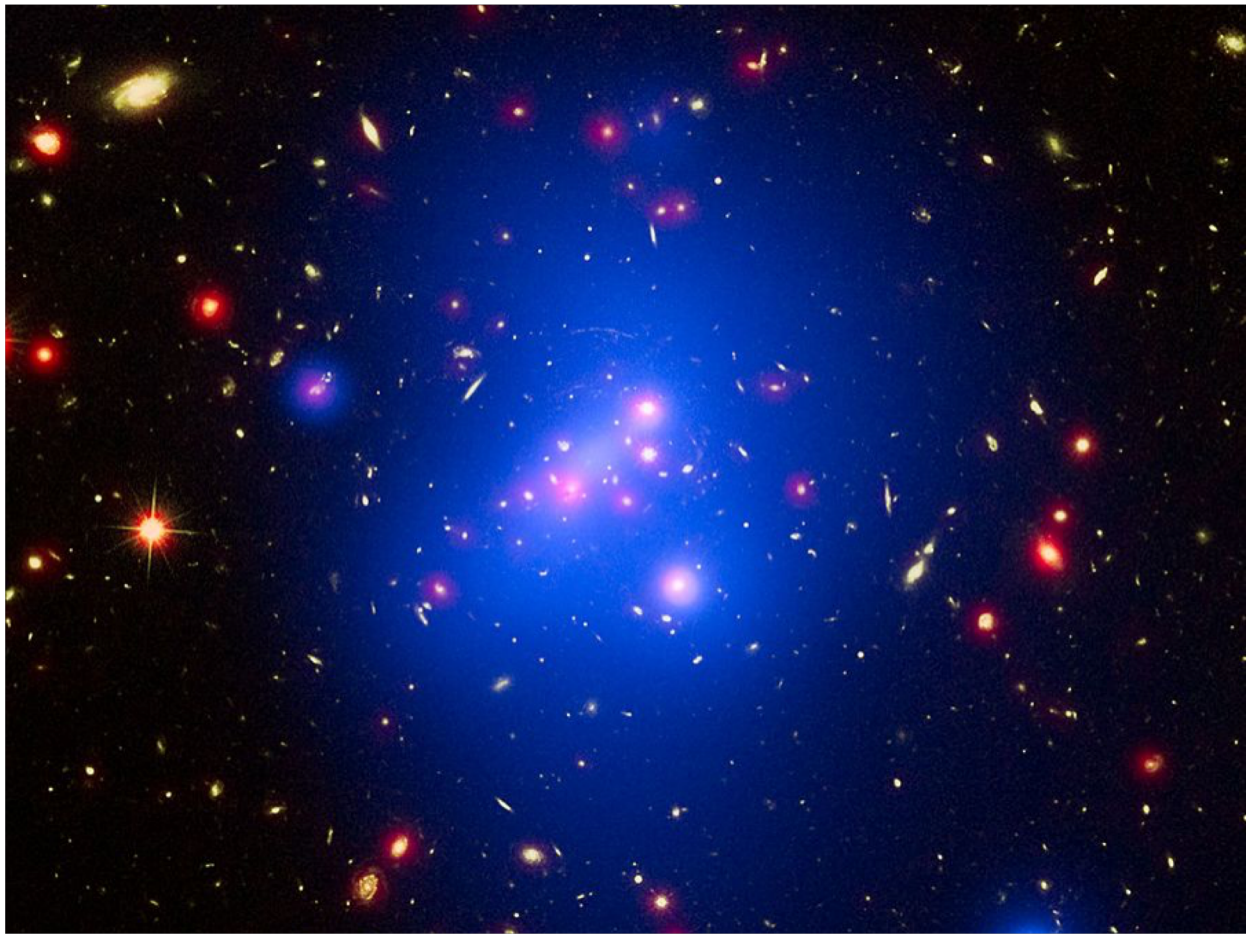
Inverse Compton scattering process



Change to mean CMB temperature



Observing the gas - SZ

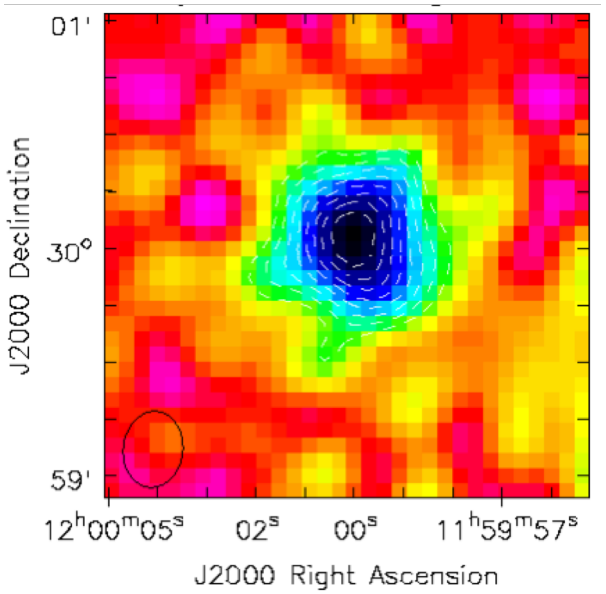


- SZ effect is proportional to the pressure of the gas
- Good correlation with total mass of cluster
- Relatively insensitive to redshift since it's a scattering effect

SZ with the SKA

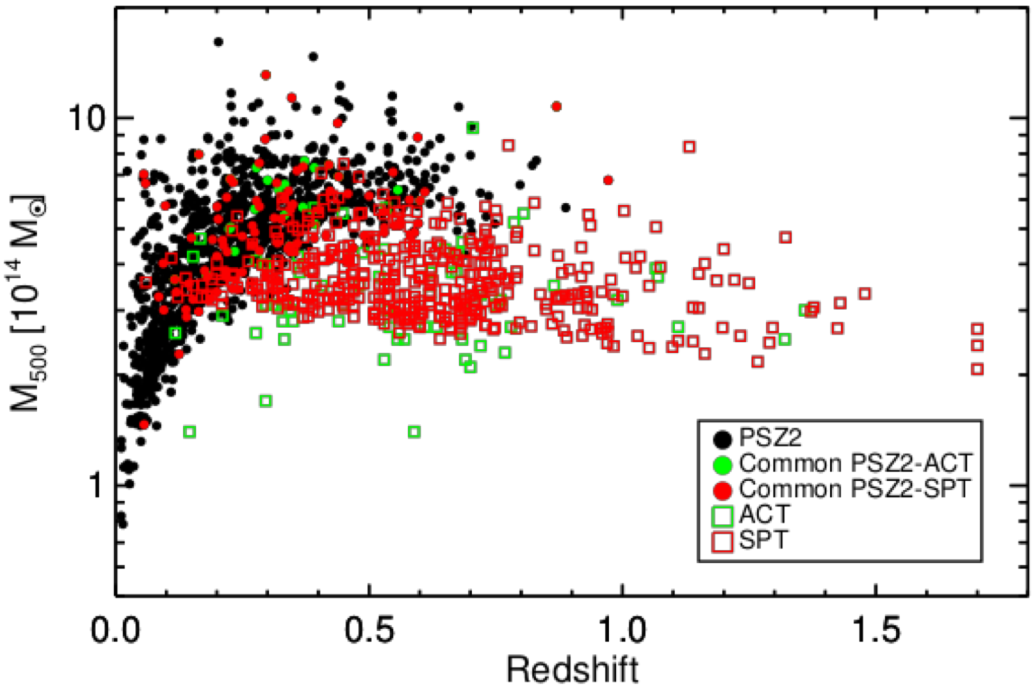
Artist's impression of SKA-mid in South Africa (www.skatelescope.org)

- Top frequency band will go high enough to measure SZ effect
- SKA1-MID will have 133 antennas, baselines up to 100,000m



- >10σ detection of a 4×10^{14} solar mass cluster at z=1.83 in one hour!
- cf 3σ detection in 18 hours with AMI...

Advantages of the SKA

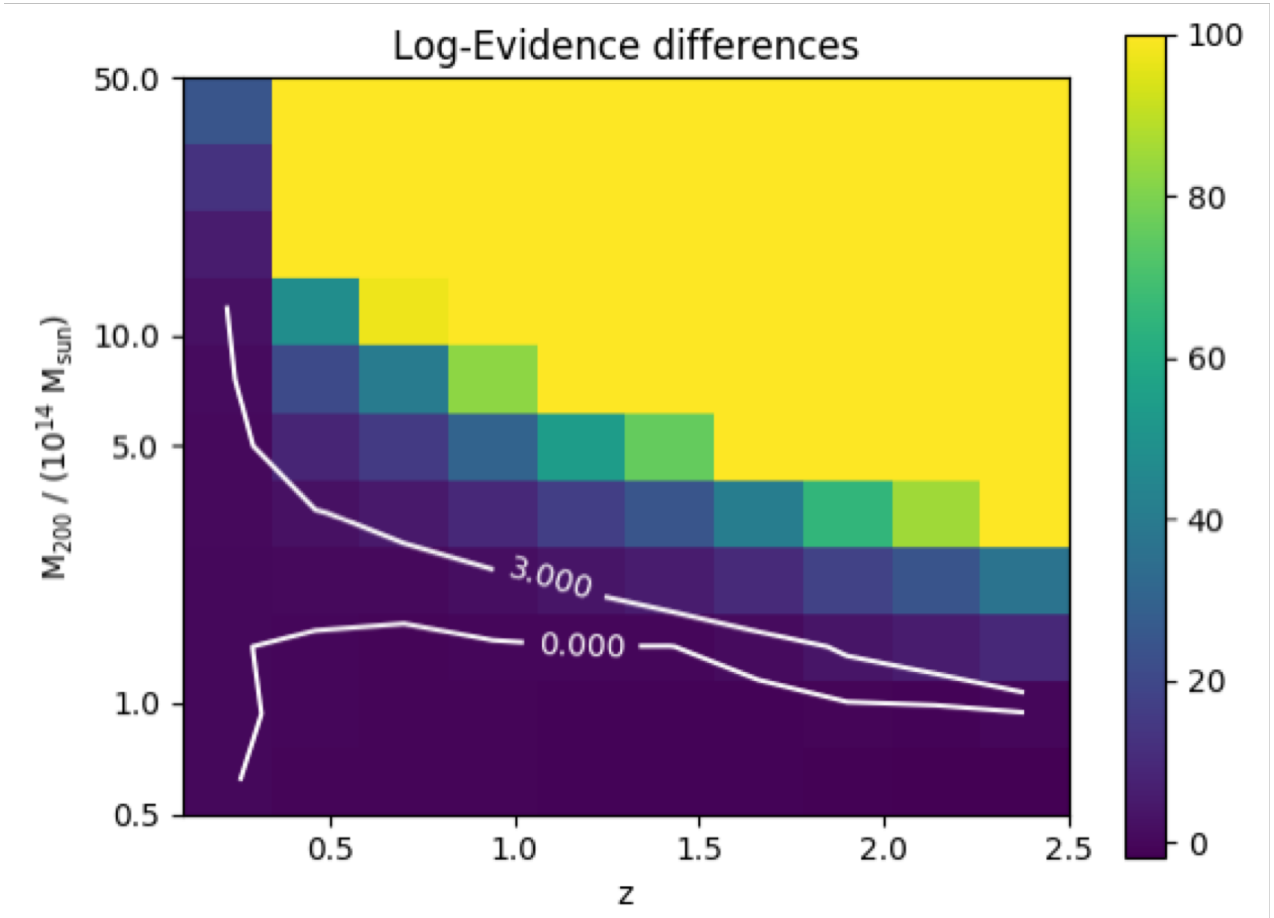


From Planck 2015 results XXVII

Current SZ instruments

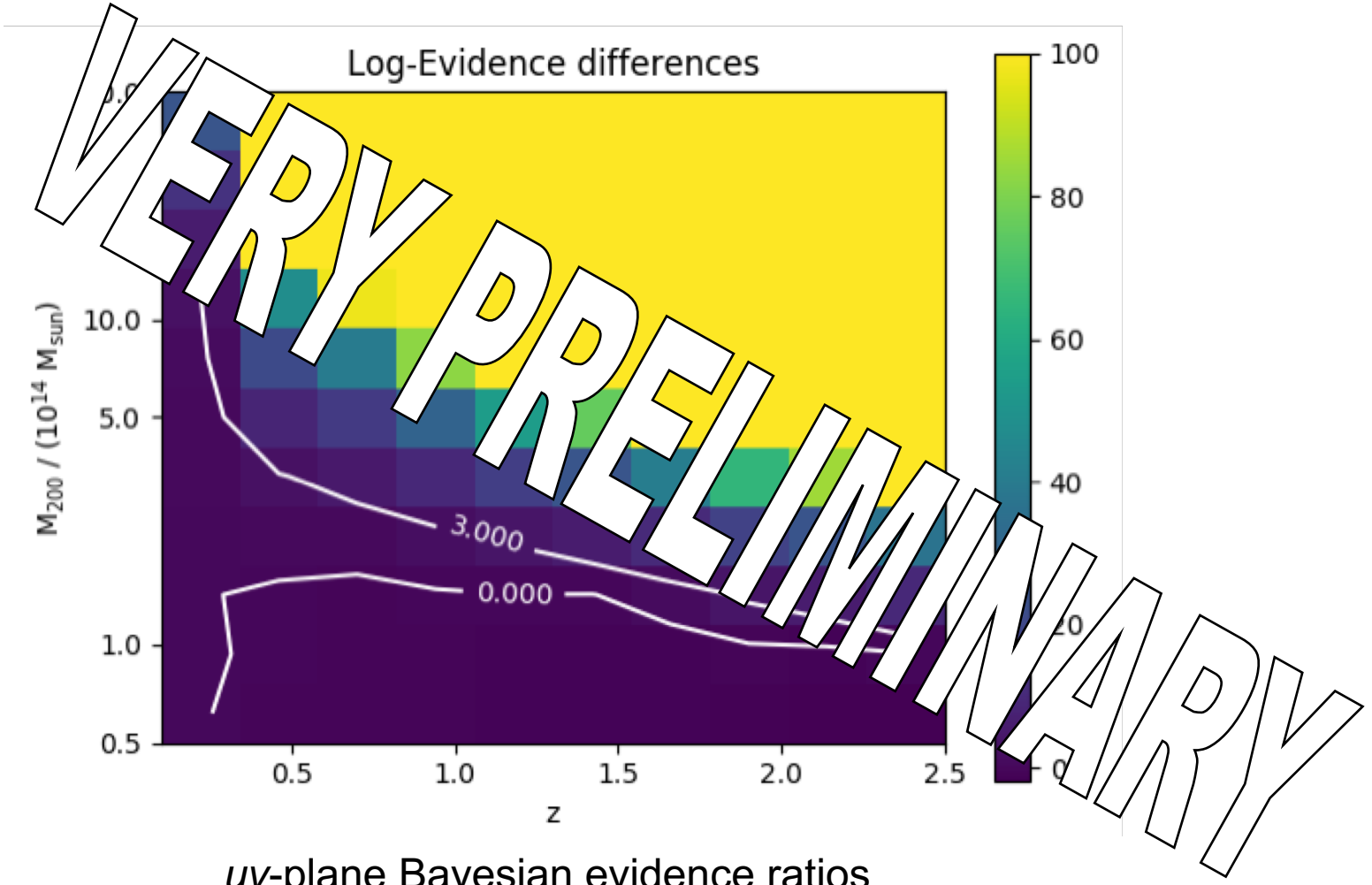
Instrument	Resolution	Area surveyed
Planck	~5 arcmin	Full sky
ACT(Pol)	~1.4 arcmin	987.5 deg^2
SPT	~1 arcmin	2500 deg^2
AMI	~3 arcmin	Follow-up (~24 hrs / cluster)
NIKA2	~15 arcsec	Follow-up (~10 hrs / cluster)
SKA	~0.04 arcsec to 2 arcmin	Follow-up (~1 hr / cluster)

Cluster detections with SKA – 1 hr



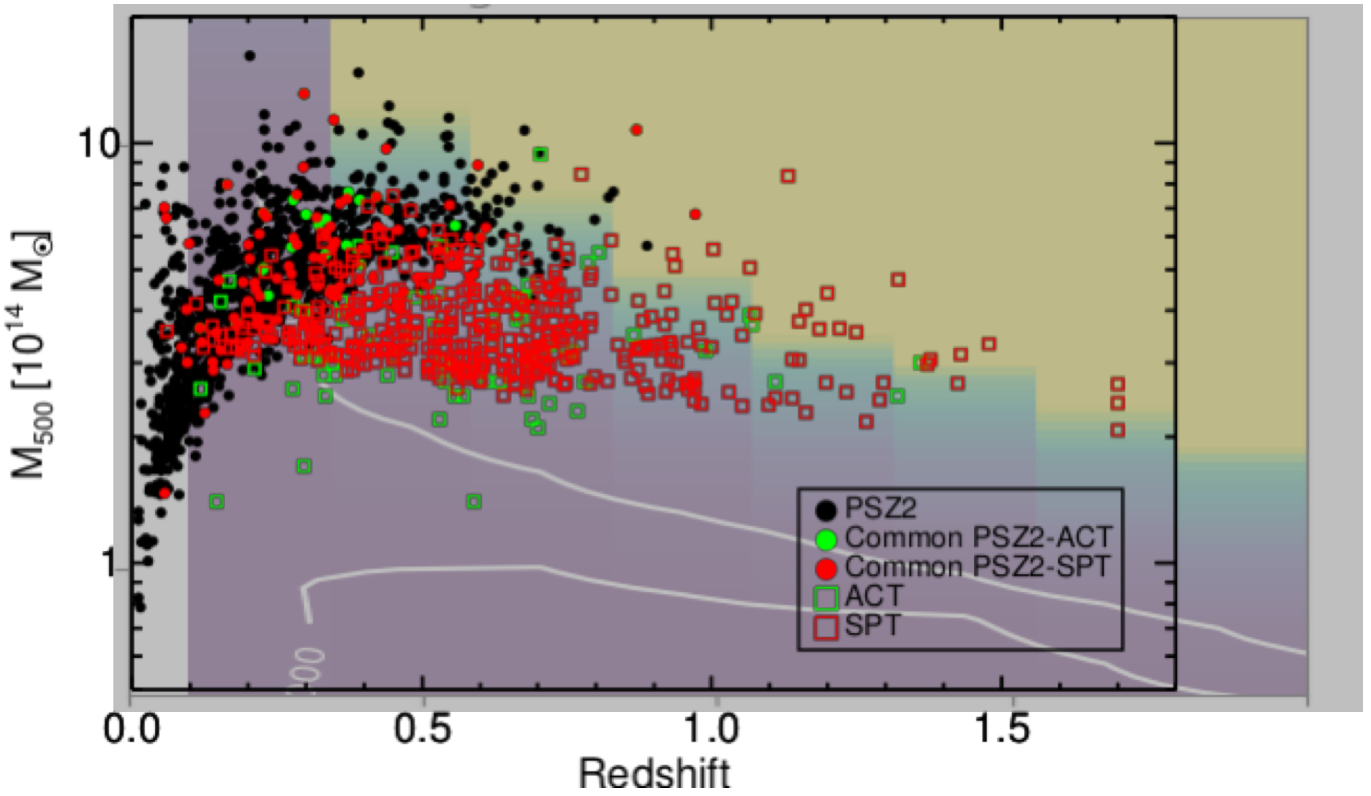
uv-plane Bayesian evidence ratios

Cluster detections with SKA – 1 hr



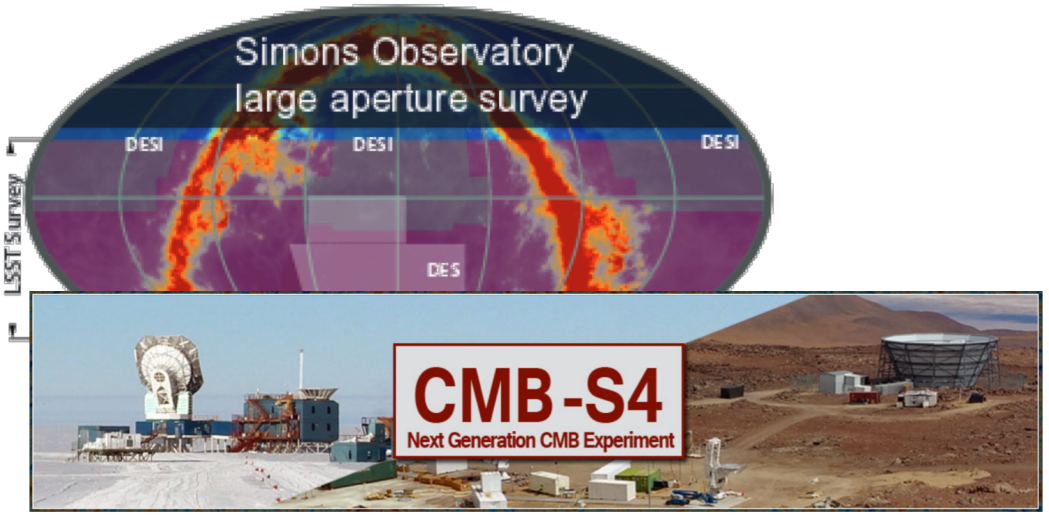
uv-plane Bayesian evidence ratios

Cluster detections with SKA – 1 hr

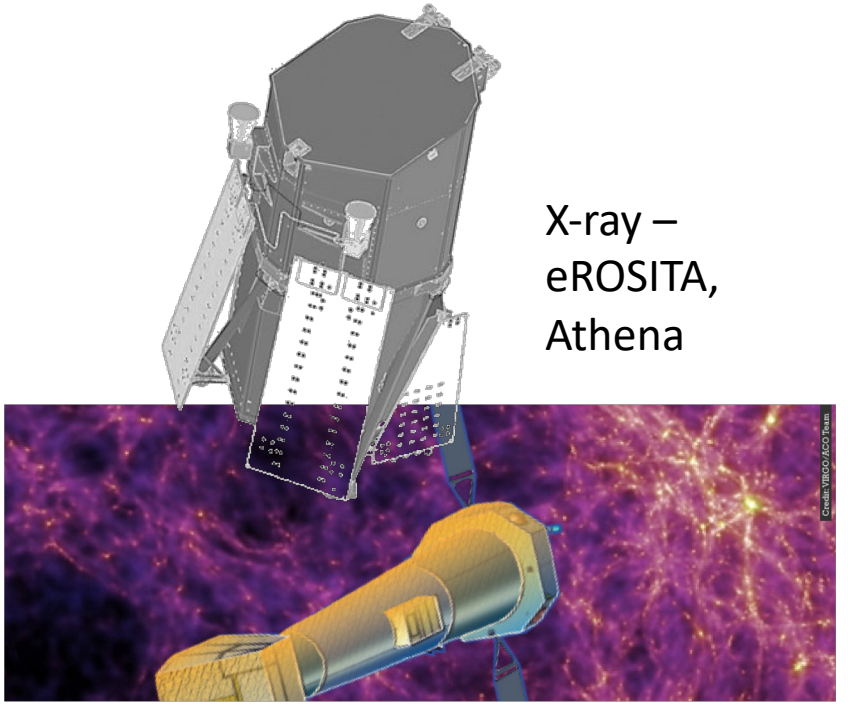


Current SZ surveys nowhere near as deep, even deep surveys on small patches (ACT, SPT)

Synergies with upcoming observatories



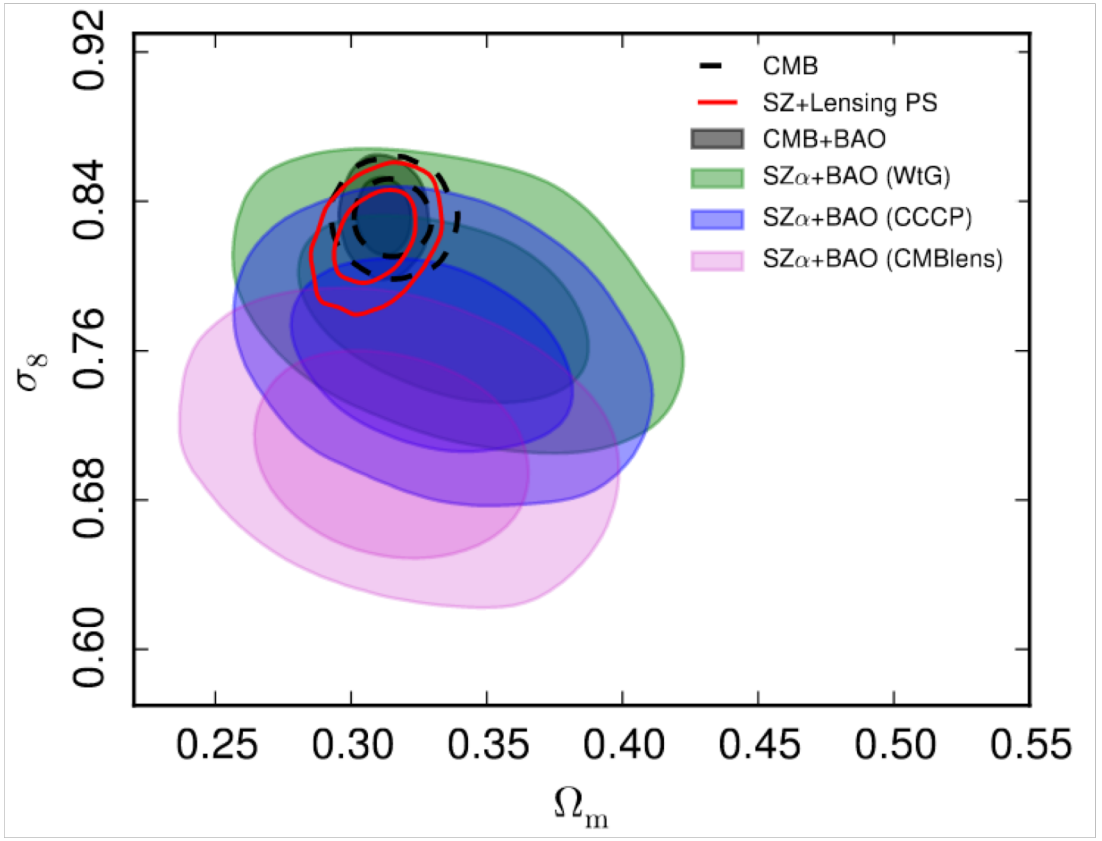
SZ – Simons Observatory, CMB-S4



X-ray – eROSITA, Athena

Optical – DES, LSST, Euclid

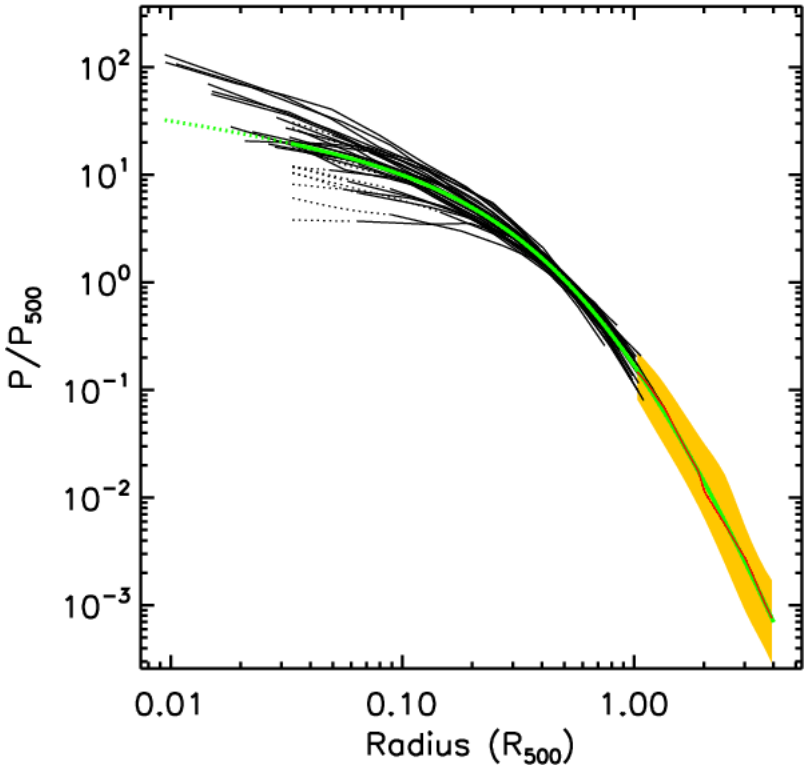
Planck cluster/CMB tension



From Planck 2015 results XXIV.

- Cosmological constraints derived from latest Planck cluster number counts are in tension with CMB constraints
- One problem is certainly the mass-observable calibration…

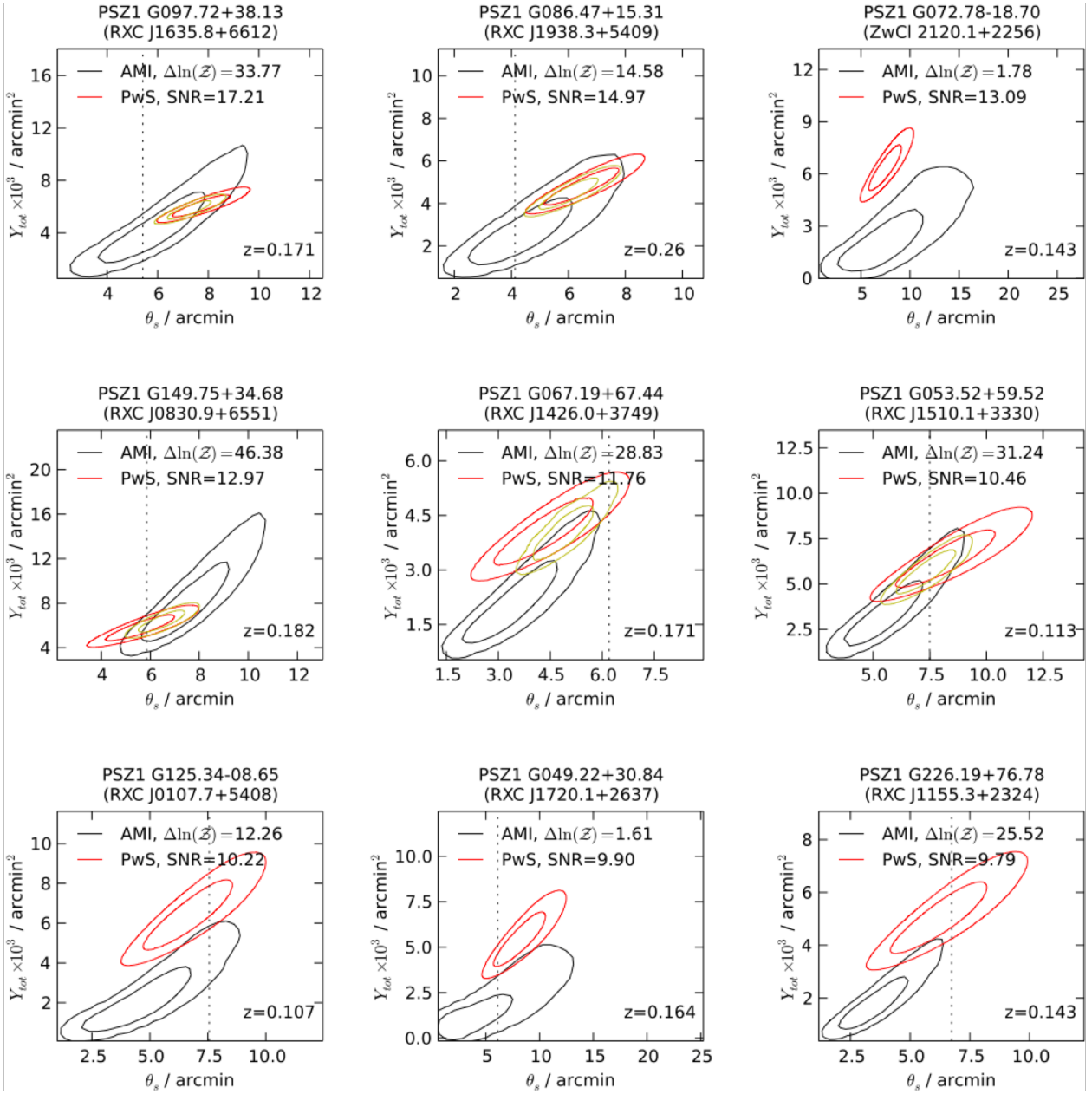
Modelling the observable



From Arnaud+ 2010. Scaled profiles (black) and average profile (green)

- Common practice for modelling SZ and X-ray is to use the ”Universal Pressure Profile” (UPP)
- Only free parameters are θ_s (angular stretch parameter) and Y_{tot} (flux scaling parameter)
- Other shape parameters γ, α, β are fixed to the average values fitted to the stacked profiles in Arnaud+ 2010.

Modelling the observable

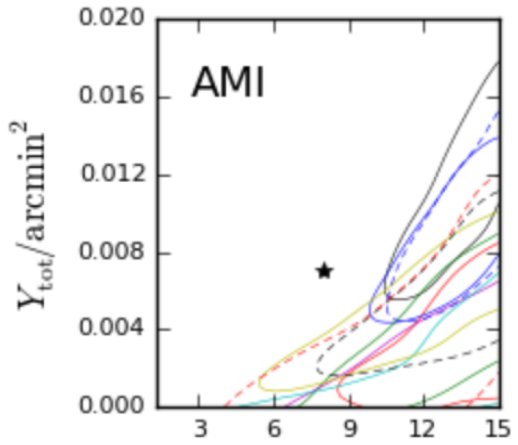


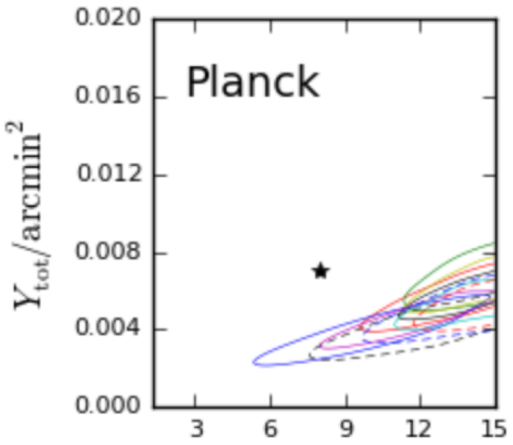
- In Perrott+ 2015 we showed that parameter constraints on θ_s and Y_{tot} derived from AMI interferometric SZ data were discrepant with the Planck values
- This could be explained by the pressure profile deviating from the UPP shape

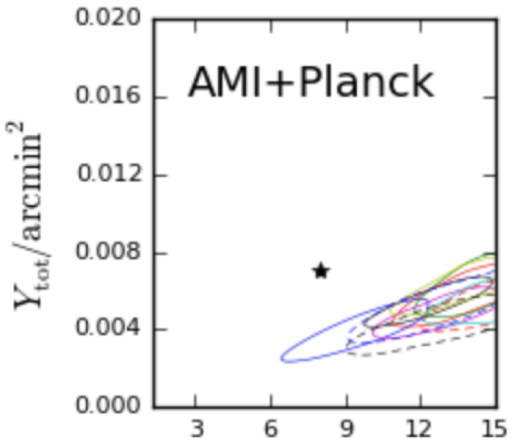
Modelling the observable

- In Perrott+ 2019 we show that having different pressure profiles does matter, even for Planck
- Eg parameter constraints when assuming the UPP in analysis, but cluster is generated with a different profile:

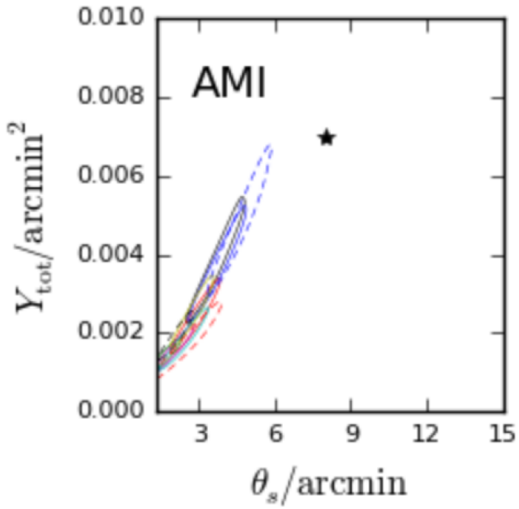
Planck Intermediate profile

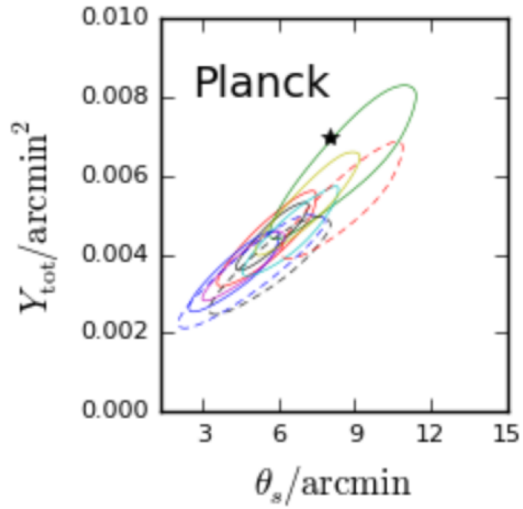


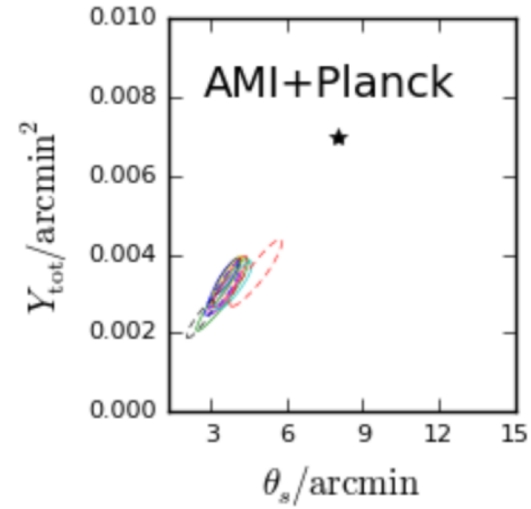




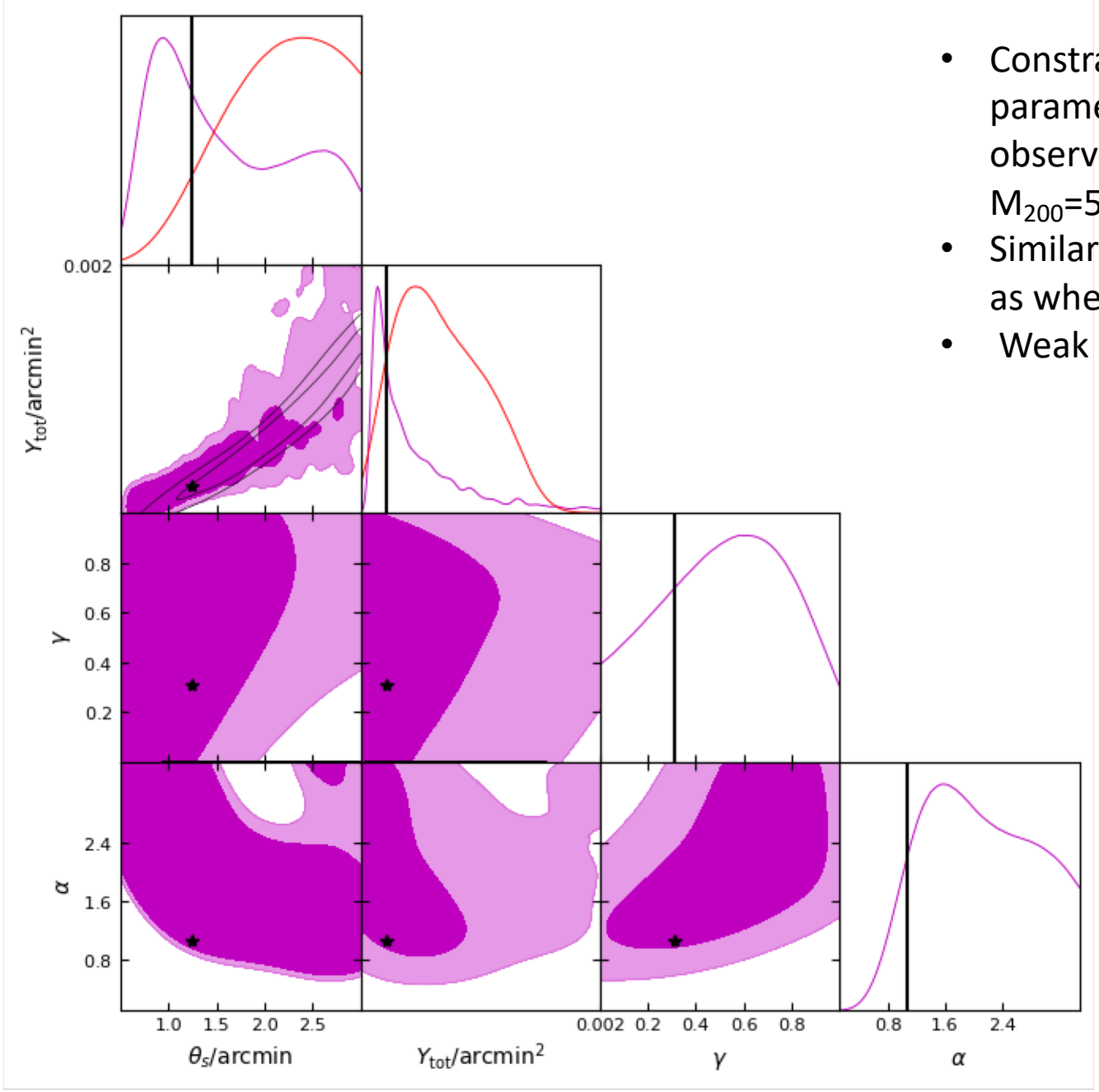
Extreme profile from REXCESS







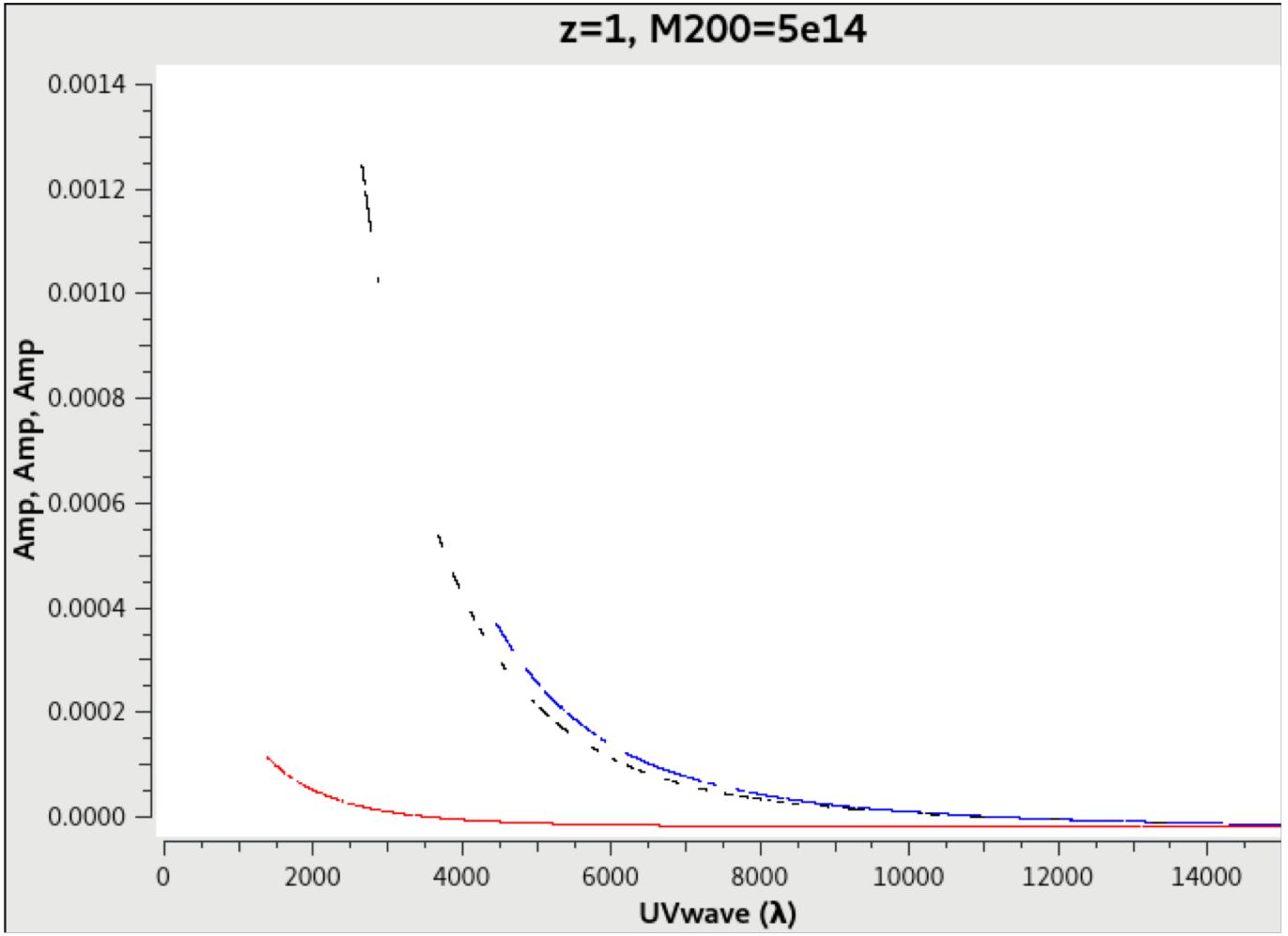
Varying shape parameters



- Constraints on cluster model parameters for a one hour observation of a z=1, M_{200}=5x10^{14} M_{sun} cluster
- Similar constraint on θ_s and Y_{tot} as when fixing shape parameters
- Weak constraints on γ, α

Pink = all parameters varying
Black/red = only θ_s and Y_{tot} varying
Black stars, lines = true values

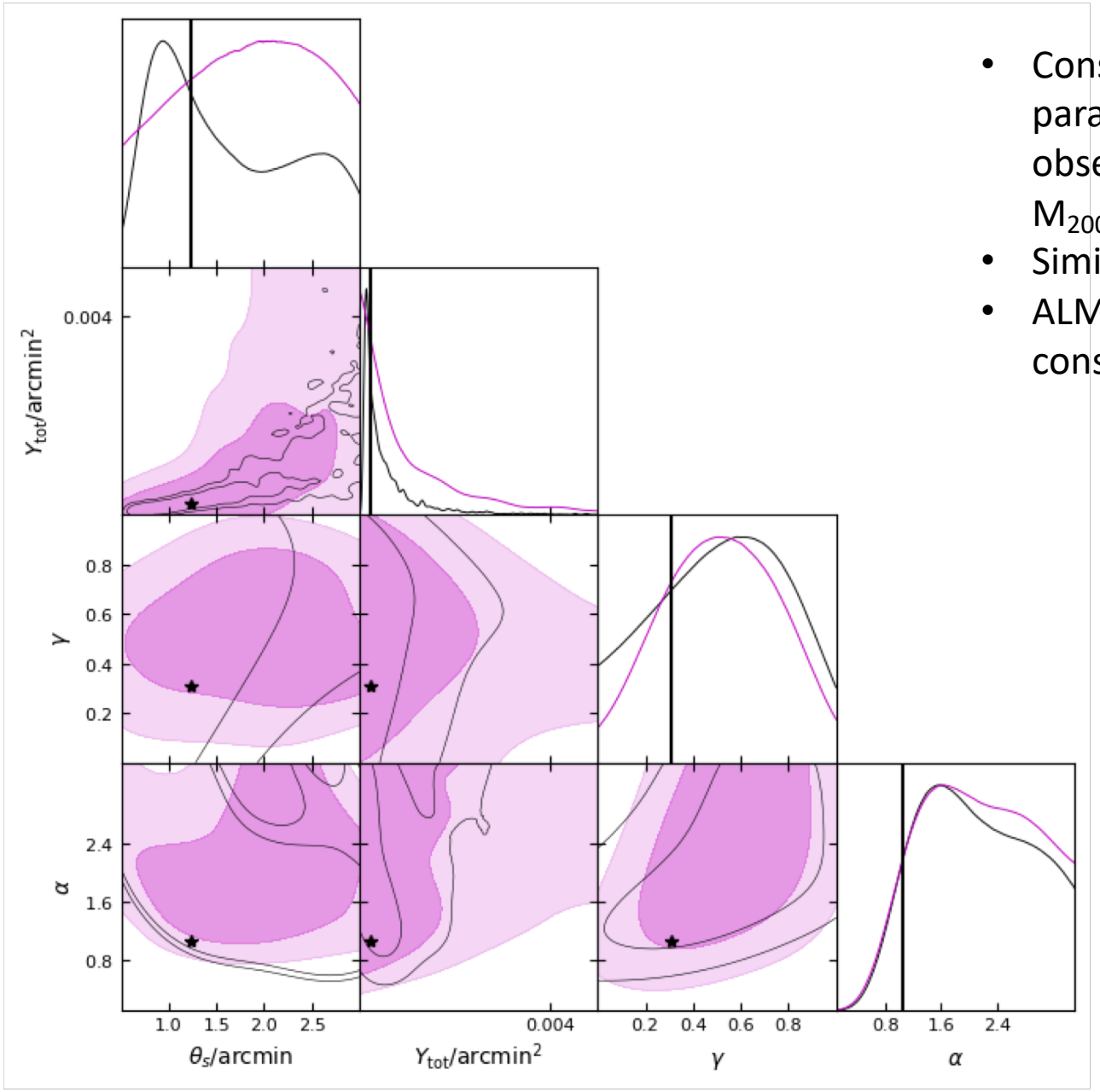
cf ALMA



- Profile of the same cluster in the uv-plane
- NB θ_s = 1.2 arcmin corresponds to uv-distance = 2800 λ

Red = SKA
Black = ACA
Blue = ALMA

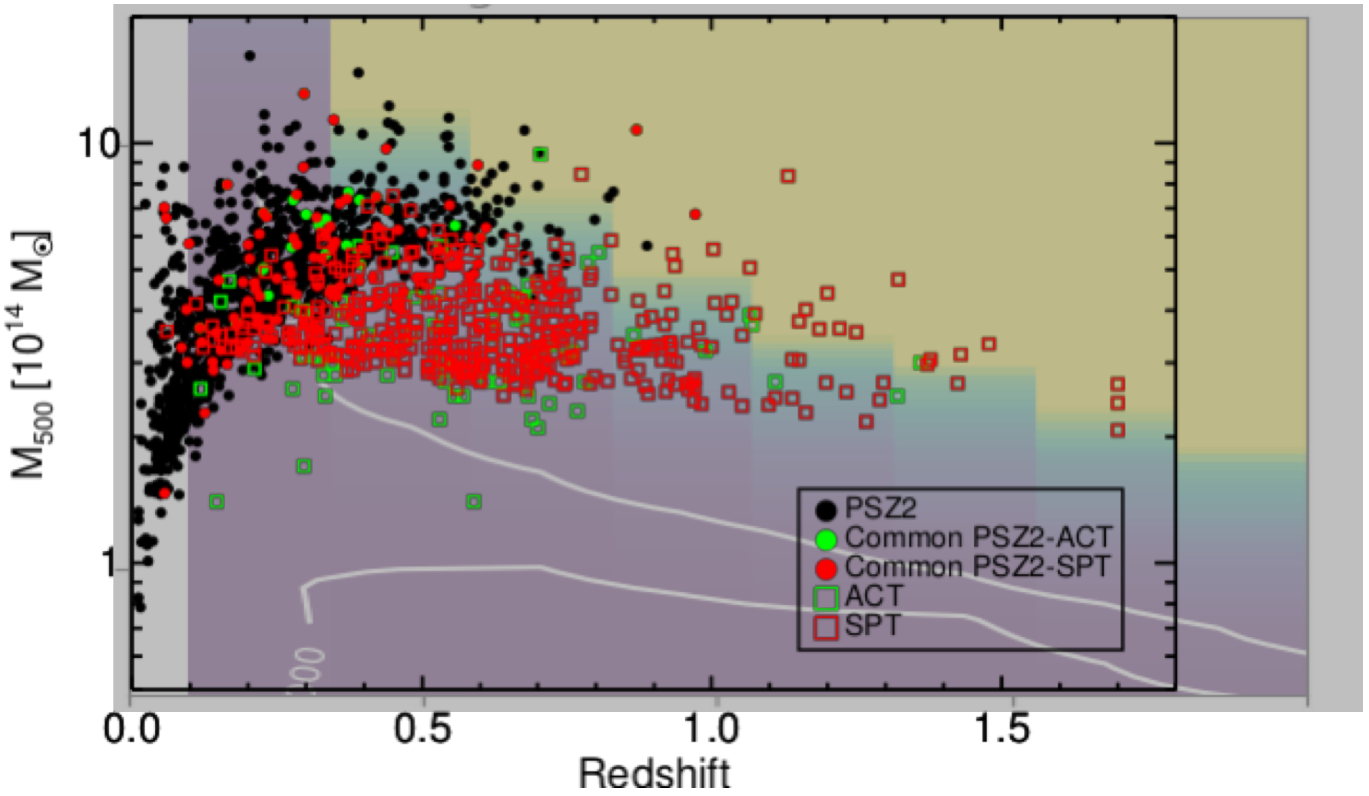
cf ALMA



- Constraints on cluster model parameters for a one hour observation of a z=1, M_{200}=5x10^{14} M_{sun} cluster
- Similar weak constraints on γ, α
- ALMA+ACA gives much worse constraint on θ_s and Y_{tot}

Pink = ALMA + ACA
Black = SKA
Black stars, lines = true values

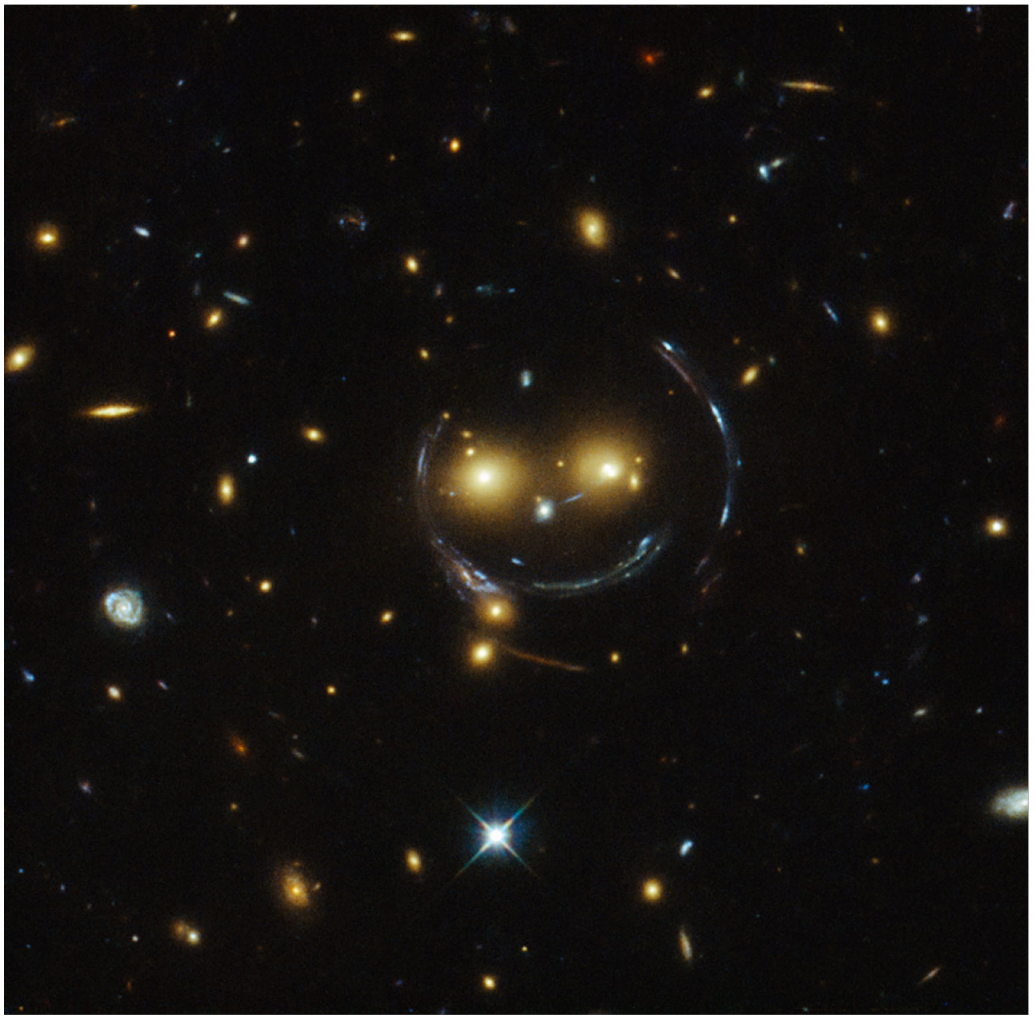
Cluster detections with SKA – 1 hr



Current SZ surveys nowhere near as deep, even deep surveys on small patches (ACT, SPT)

- Higher angular resolution will aid in better characterisation of the SZ signal

Thank you!



“Smiley cluster”: NASA/ESA