The Sunyaev Zeldovich Effect from Quasar Feedback

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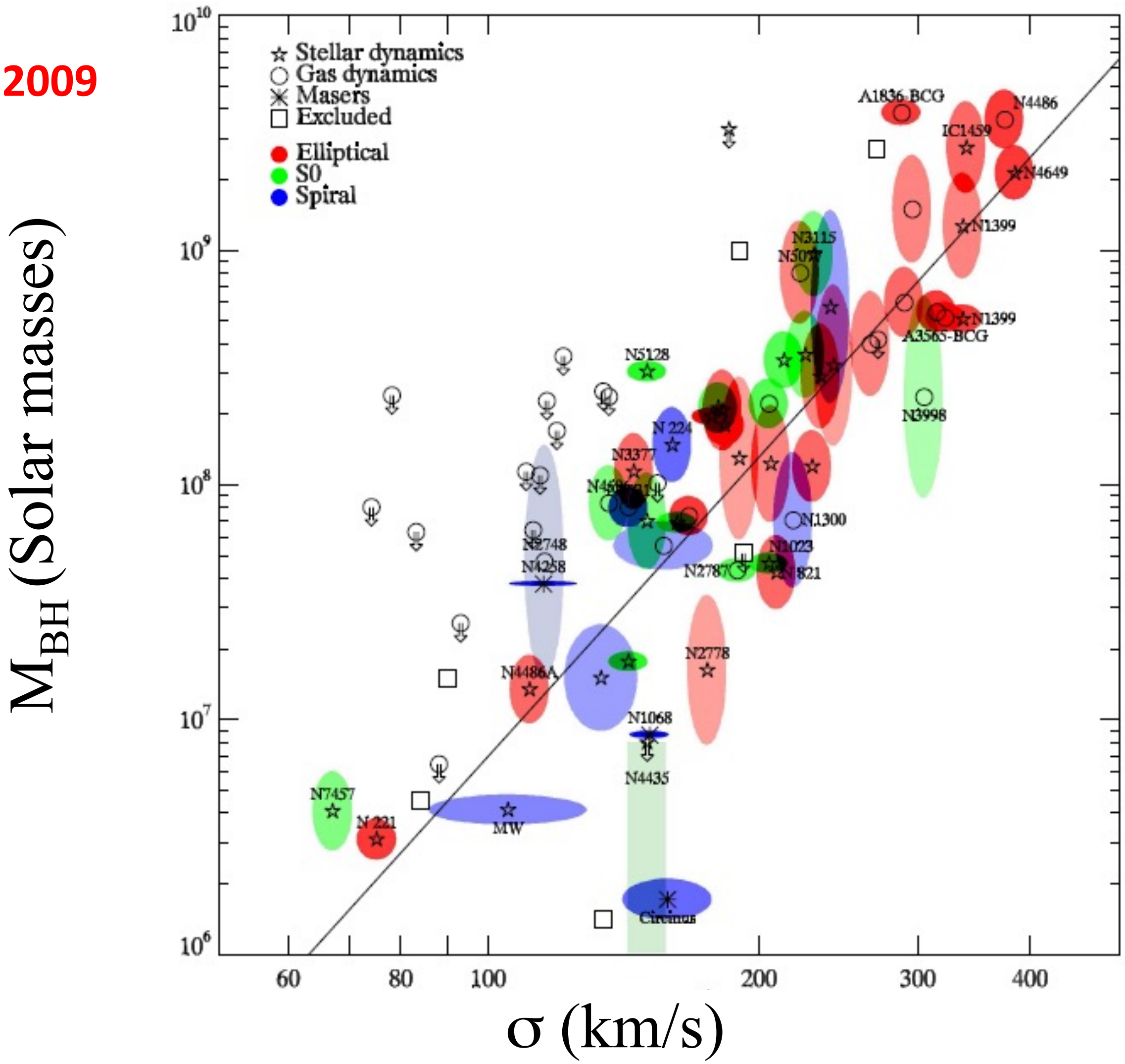
Cosmology: The Next Decade
ICTS: 22/1/19

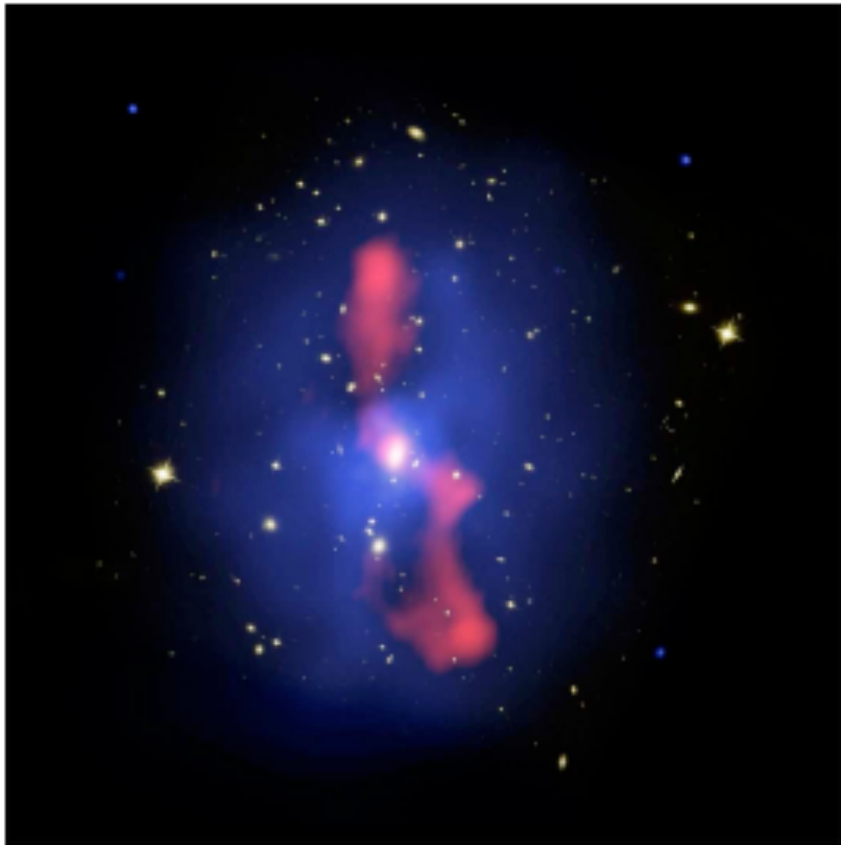
M-σ relation

Gultekin et al. 2009



Galaxy Evolution-Black Hole Growth are connected

Black Hole Feedback



HST image of MS0735.6 + 7421 cluster
Chandra X-ray image in blue
VLA radio image in red

McNamara & Nulsen 2007

Detecting AGN Feedback with the SZ Effect

- Inverse Compton scattering of the CMB Photons by hot electrons present in the line of sight of the CMB.
- Departure from a blackbody

(Natarajan & Sigurdsson 99, Platania et. al 02, Lapi et. al 03)

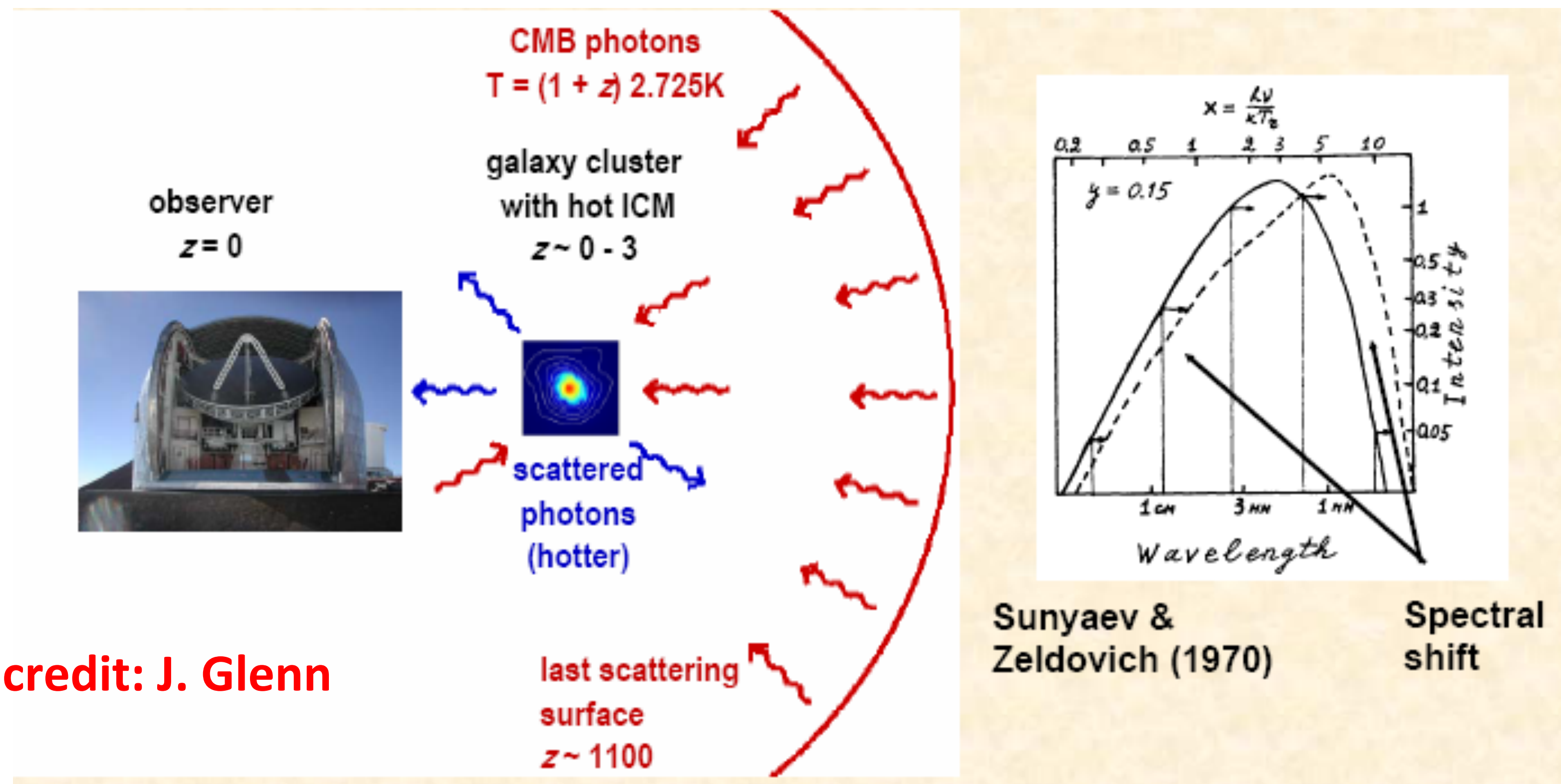
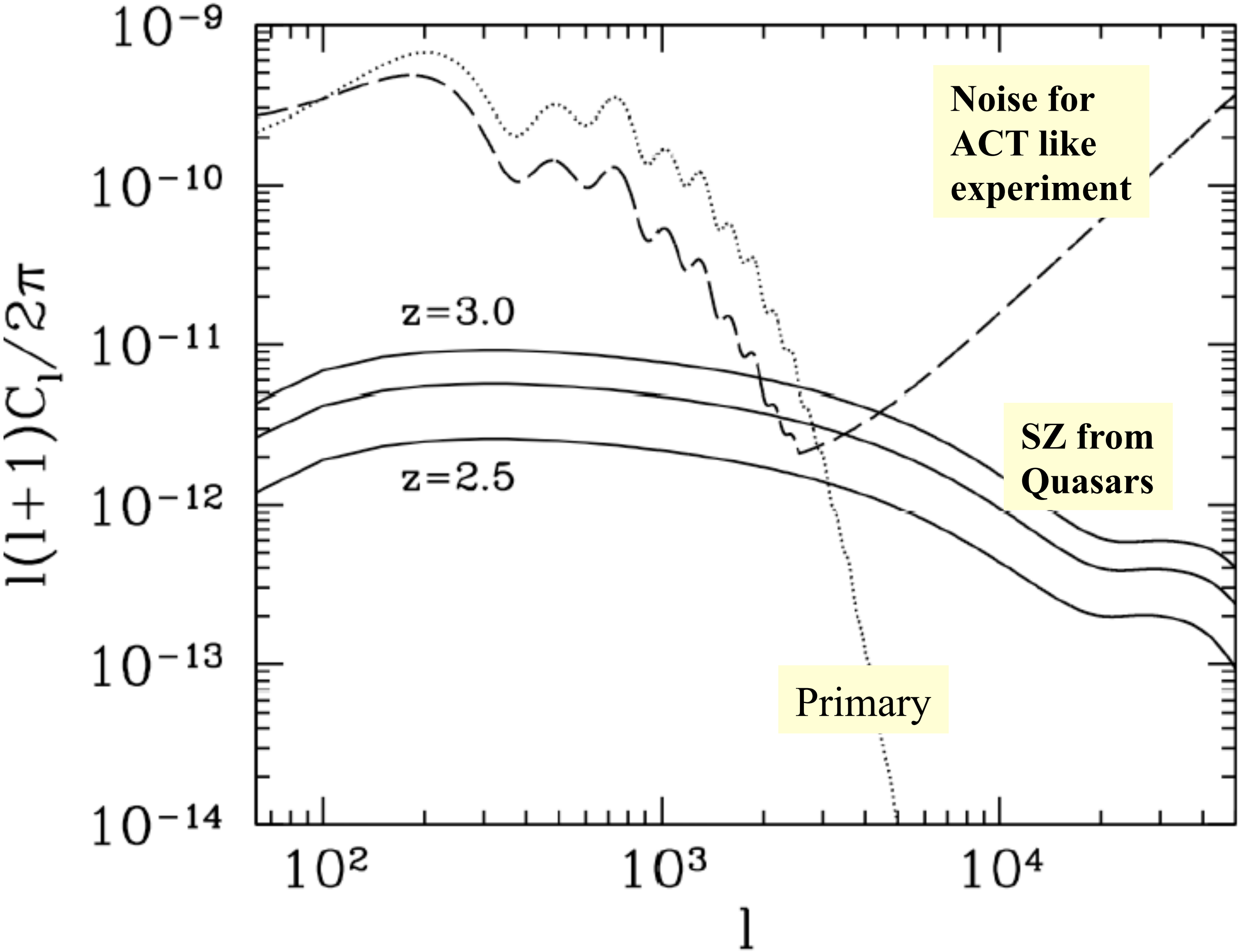


Image credit: J. Glenn



Chatterjee & Kosowsky 2007

ALMA SENSITIVITIES FOR AN INTEGRATION TIME OF AN HOUR

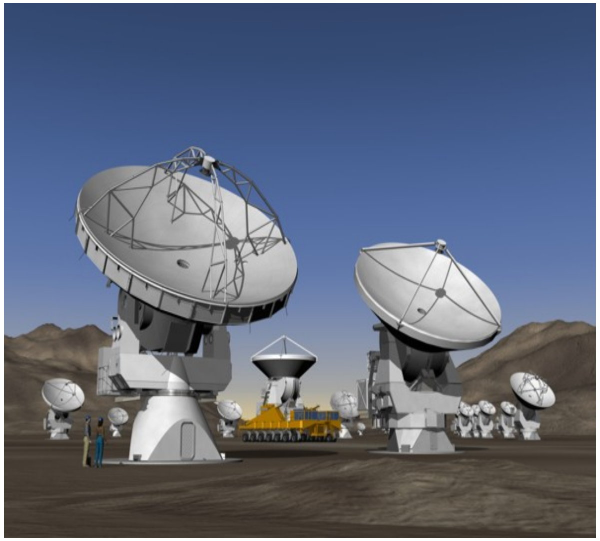
Frequency (GHz)	Resolution (arcseconds)	Baseline (Km)	Sensitivity (μK)
145	15	.0284	2.41
145	5	.0853	21.74
220	15	.0187	1.76
220	5	.0562	15.84
265	15	.0156	1.63
265	5	.0467	14.63

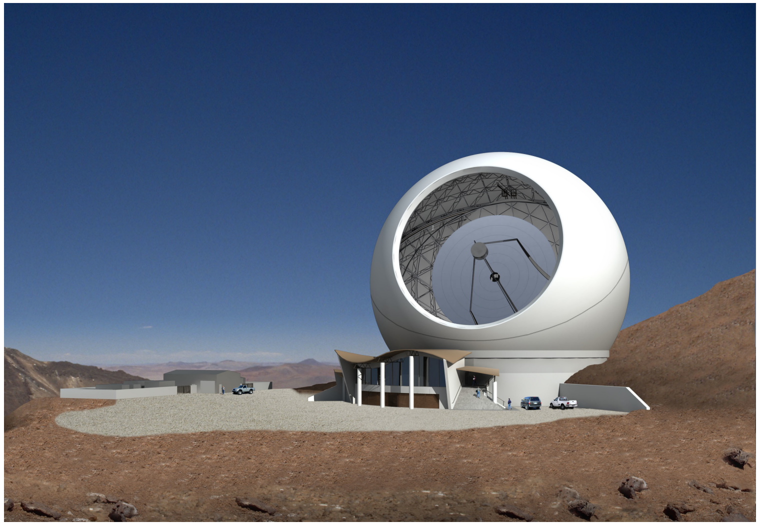
(Chatterjee & Kosowsky 07)

Detection Schemes

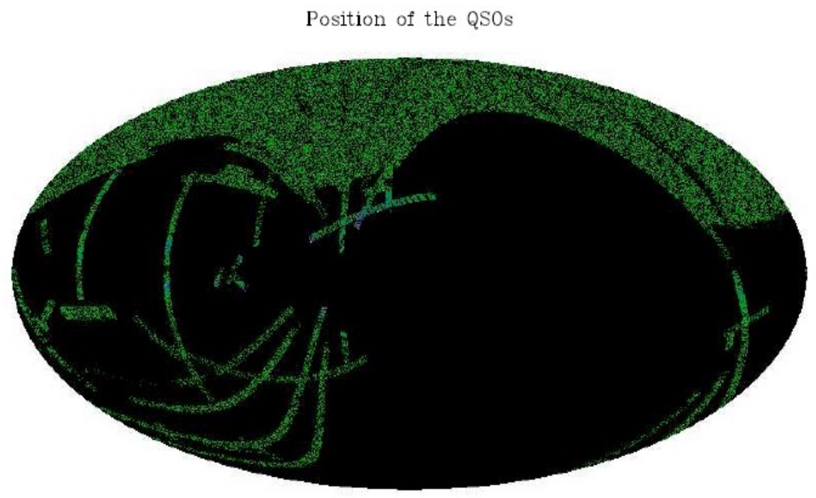
- **Direct Observations by millimeter wave telescopes**
  - Spatially resolve the source
  - Prospects are marginal with Atacama Large Millimeter Array (ALMA), Cornell Caltech Atacama Telescope (CCAT)
- **Stacking Microwave Maps in the direction of known Quasars**
  - Cross-correlate quasars from Optical surveys with CMB maps
- **SZ power spectrum**

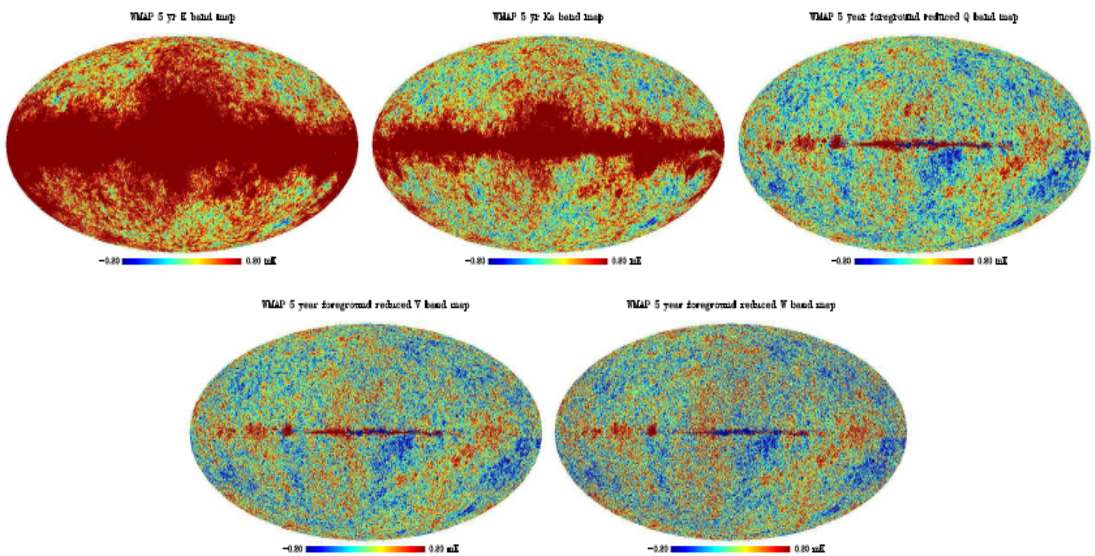
(Chatterjee & Kosowsky 2007; Scannapieco et al. 2008; Battaglia et al. 2010)





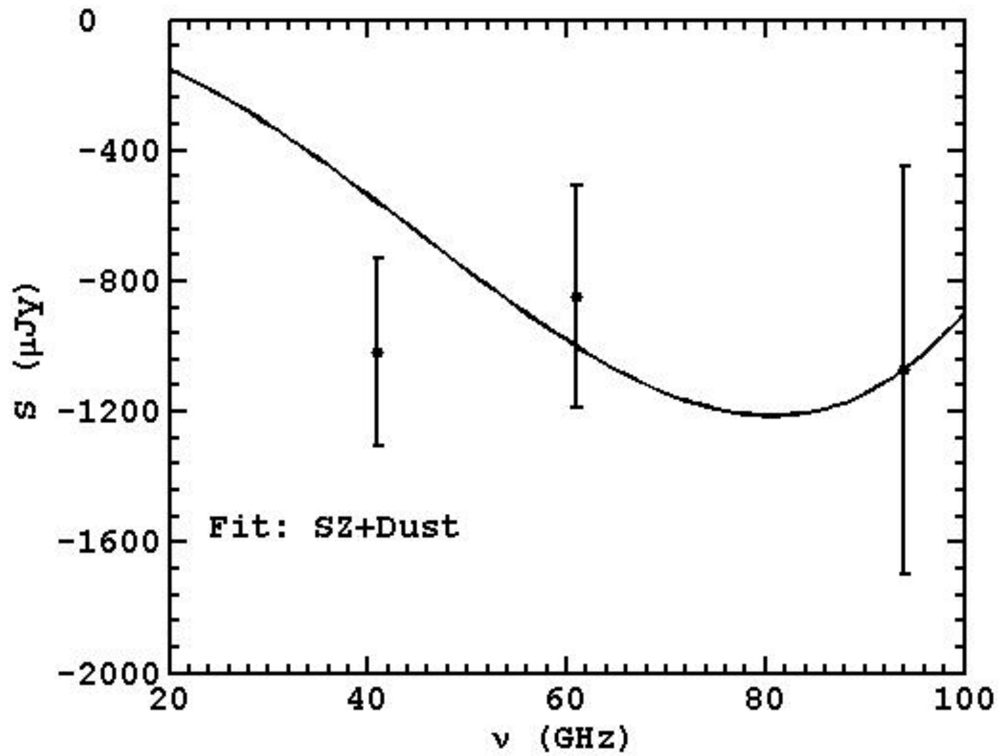
SDSS Quasars and WMAP CMB Maps





(Data credit: WMAP Science team): Figure (Chatterjee : Thesis)

Spectrum



Chatterjee, Ho, et al. 2010

We report a decrement and show that quasars are significantly correlated with temperature pixels in WMAP

Detections from Cross-Correlations

Ruan et al. (2015) using Planck and SDSS
Verdier et al. (2016) using Planck and BOSS
Chrichton et al. (2016) using ACT Sloan and Herschel
Spacek et al. (2016) using SPT

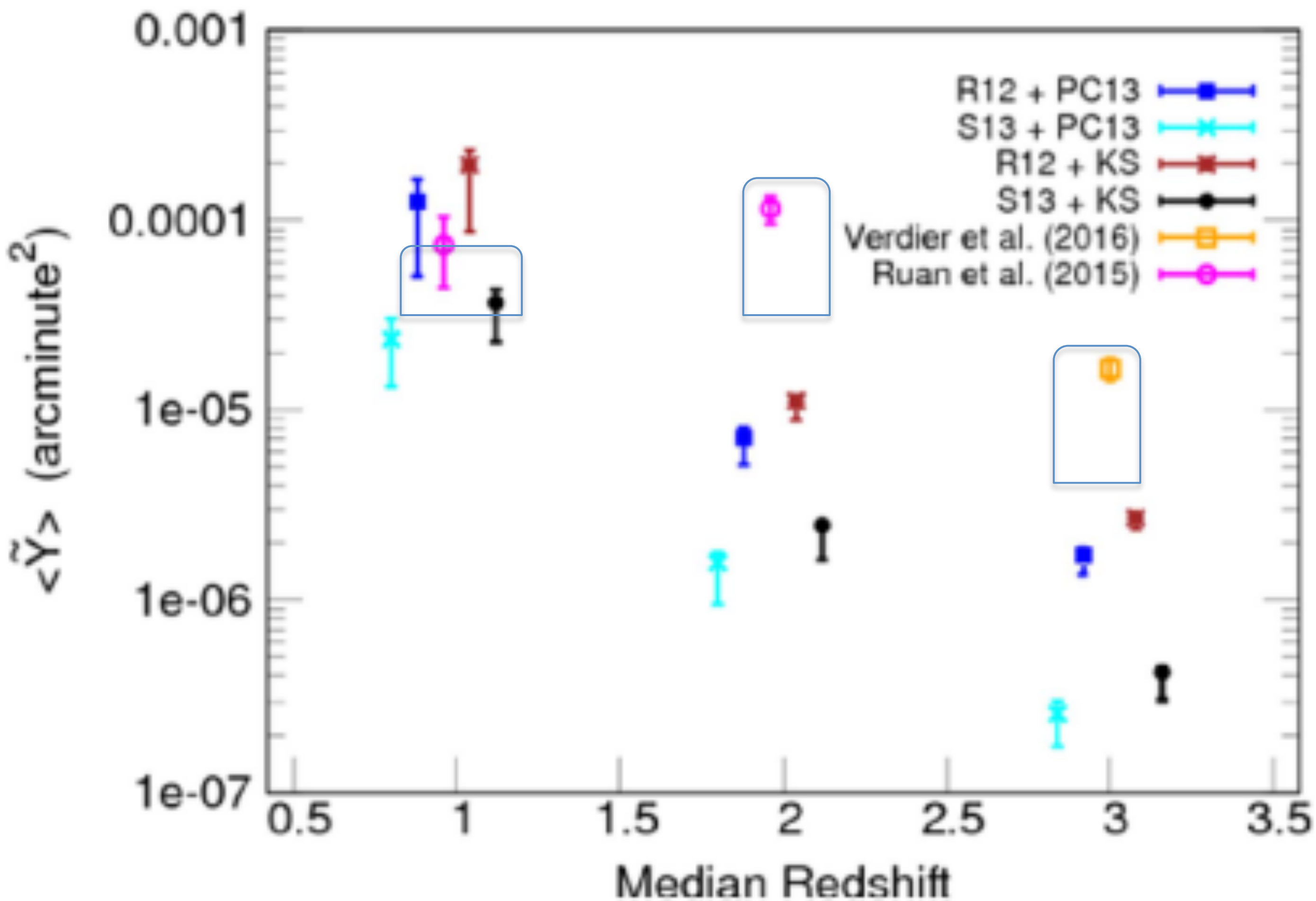
……….

$$\langle \tilde{Y} \rangle = \frac{\int_{z_{\min}}^{z_{\max}} \int_{M_{\min}}^{M_{\max}} \tilde{Y}(M, z) \, \langle N(M) \rangle \frac{dn}{dM} \, dM \, \frac{dV}{dz} \, dz}{\int_{z_{\min}}^{z_{\max}} \int_{M_{\min}}^{M_{\max}} \langle N(M) \rangle \frac{dn}{dM} \, dM \, \frac{dV}{dz} \, dz},$$

Quasar host halo mass distribution.
Need for the Halo Occupation Distribution of Quasars

Duttachowdhury and Chatterjee 2017

The Effect of the Host Halos of Quasars



It is shown that there is substantial confusion on the SZ signal due to the uncertainty in the host halos of quasars at low redshift, but there is indication of enhanced signal for high redshift.

Duttachowdhury and Chatterjee 2017

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Direct detection of quasar feedback via the Sunyaev–Zeldovich effect

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Direct Detection Observations

Lacy et al. 2019

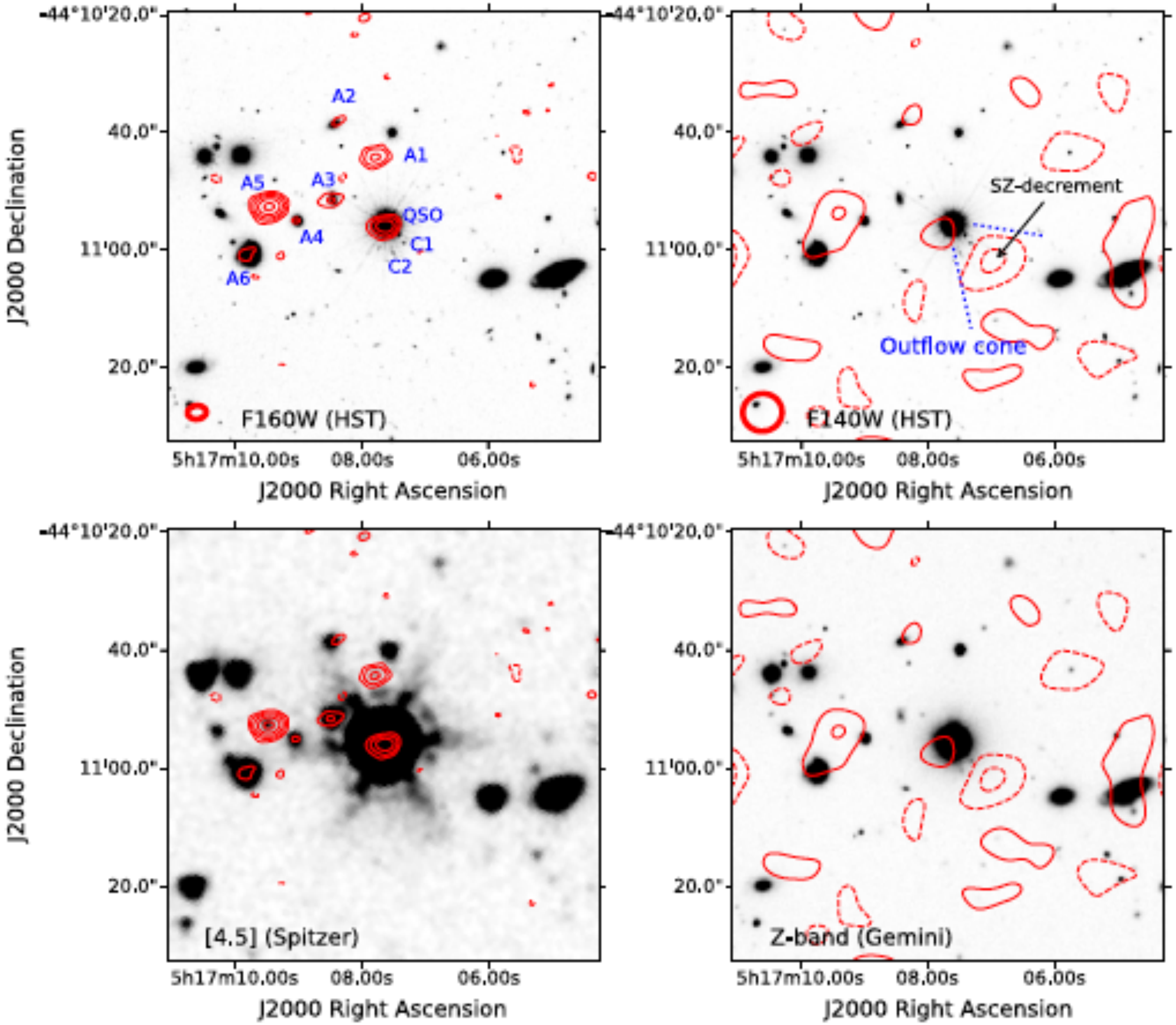
- **Atacama Large Millimeter Array** 130 GHz Observation
- $\theta_{FWHM} \sim 0.7$ arcseconds for subtracting point sources
- $\theta_{FWHM} \sim 2.7$ arcseconds SZ observations
- HE-0515-4414: z = 1.7, brightest quasar that is radio quiet in the FOV
- Image was tapered to obtain a dip in the flux density of ~ -26 μJy

Detection is **3.5 σ** Peak SZ flux 37 μK

- Follow up observations from HST (arxival imaging and spectroscopy), Gemini (GMOS and FLAMINGOS) and Spitzer (3.6 and 4.5 μm) to study the quasar environment
- $M_{BH} \sim 4.3 \times 10^{10} M_{sun}$, $L_{bol} \sim 1.3 \times 10^{15} L_{sun}$
- Typical kinetic luminosity $L_k \sim 1.7 \times 10^{11} L_{sun}$

Extremely model dependent **(Barnaby & Silk 2011**; needs careful study, (stay tuned)

Lacy et al. 2019



Red: ALMA contours

A1, A3, A5: point sources

Gemini and HST show
Outflow, confirmed
With HST spectroscopy

Poor cluster in the field
(Bielby et al. 2017)

Mass ~ 6x $10^{12}M_{sun}$

Conclusions

- ❖ SZ effect proves to be an interesting probe to study quasar feedback: Galaxy evolution meets CMB
- ❖ Stacking CMB maps has turned out to be a useful machinery toward detecting the signal
- ❖ Needs very well understanding of the HOD of quasars and their redshift evolution (Stay Tuned)
- ❖ First direct detection using the Atacama Large Millimeter Array
- ❖ Interpretations are model dependent: need many more systems to have some concrete understanding

THANK YOU