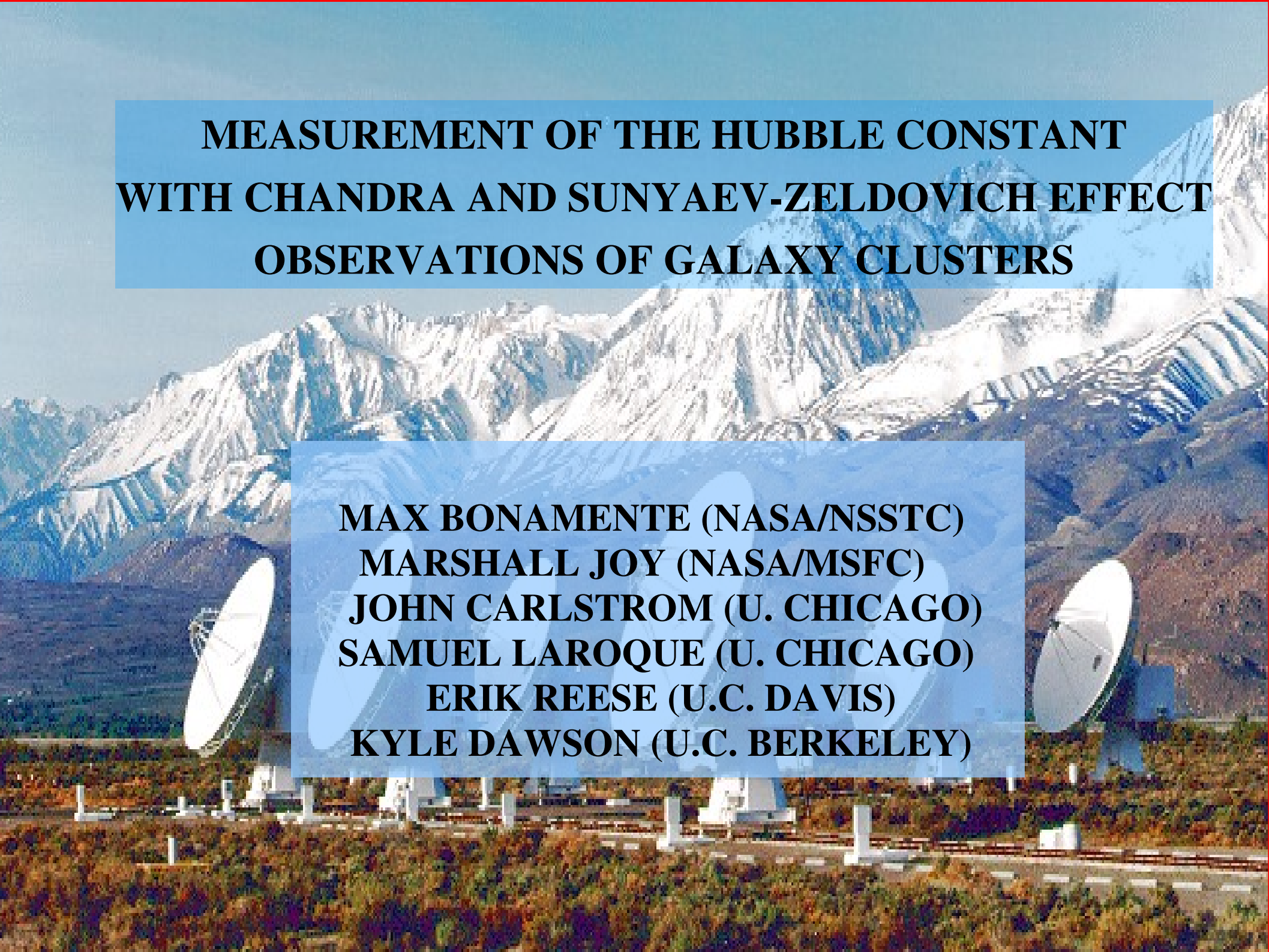
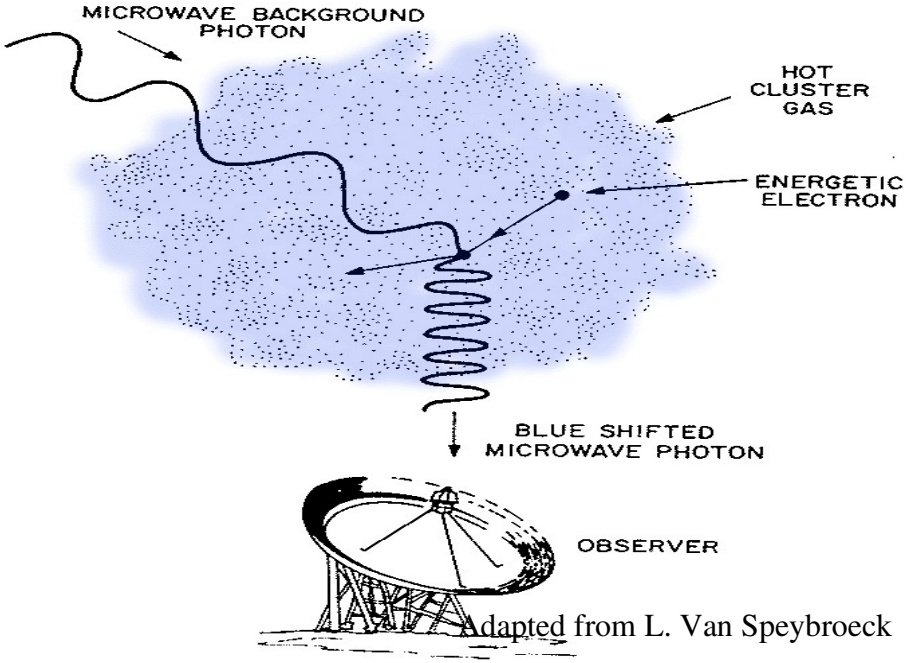


# MEASUREMENT OF THE HUBBLE CONSTANT WITH CHANDRA AND SUNYAEV-ZELDOVICH EFFECT OBSERVATIONS OF GALAXY CLUSTERS

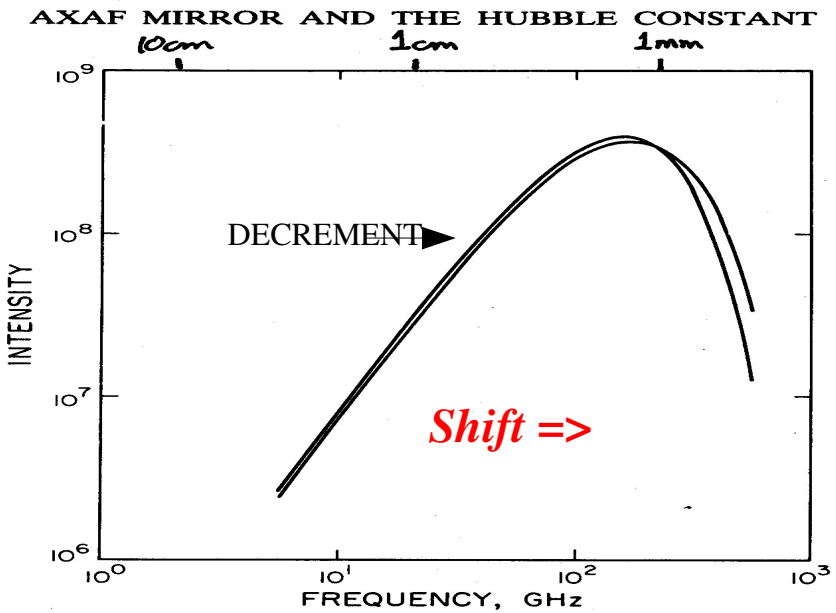

MAX BONAMENTE (NASA/NSSTC)
MARSHALL JOY (NASA/MSFC)
JOHN CARLSTROM (U. CHICAGO)
SAMUEL LAROQUE (U. CHICAGO)
ERIK REESE (U.C. DAVIS)
KYLE DAWSON (U.C. BERKELEY)

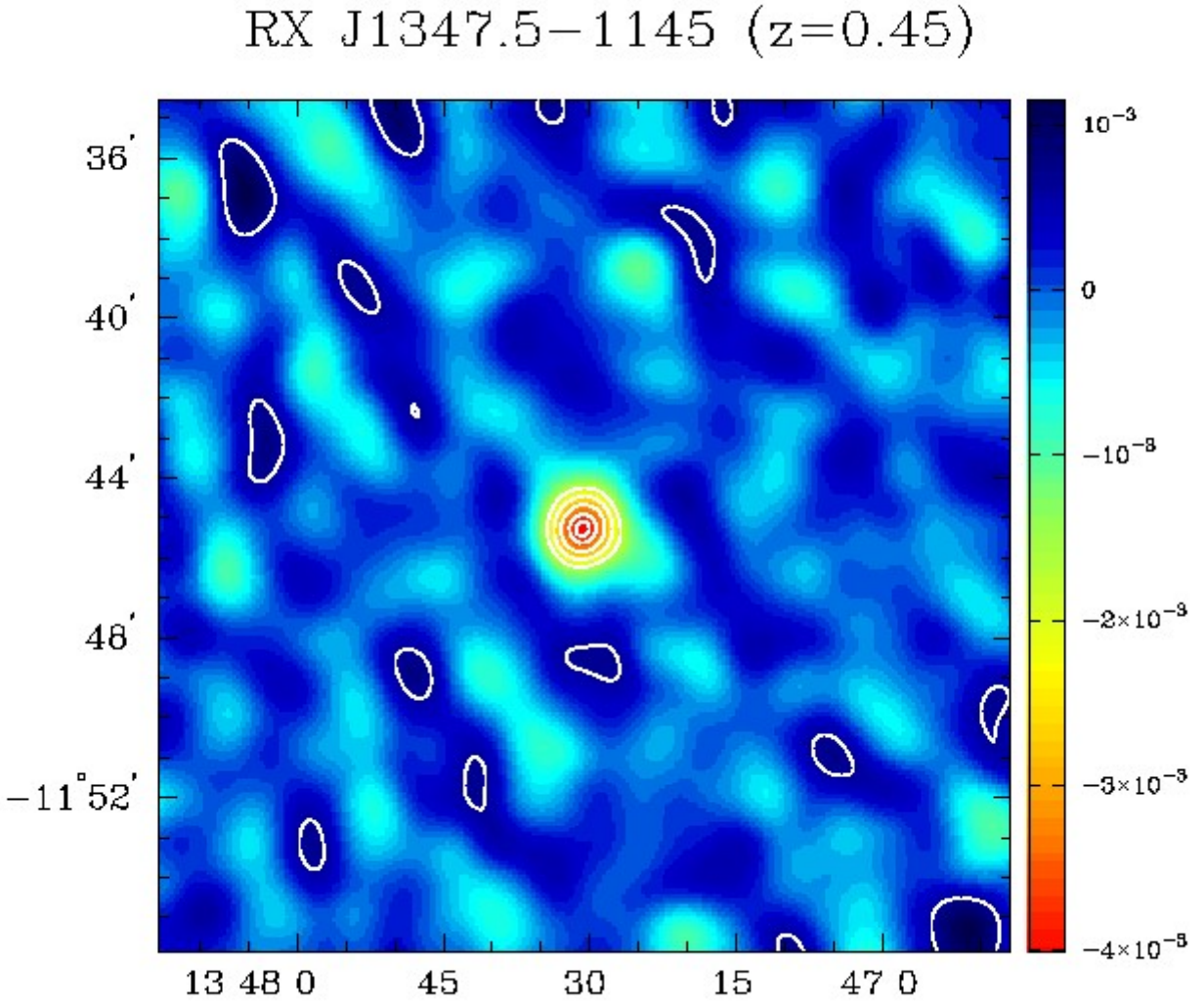
# THE SUNYAEV-ZELDOVICH EFFECT


INTERFEROMETRIC
RADIO IMAGES 30 GHz

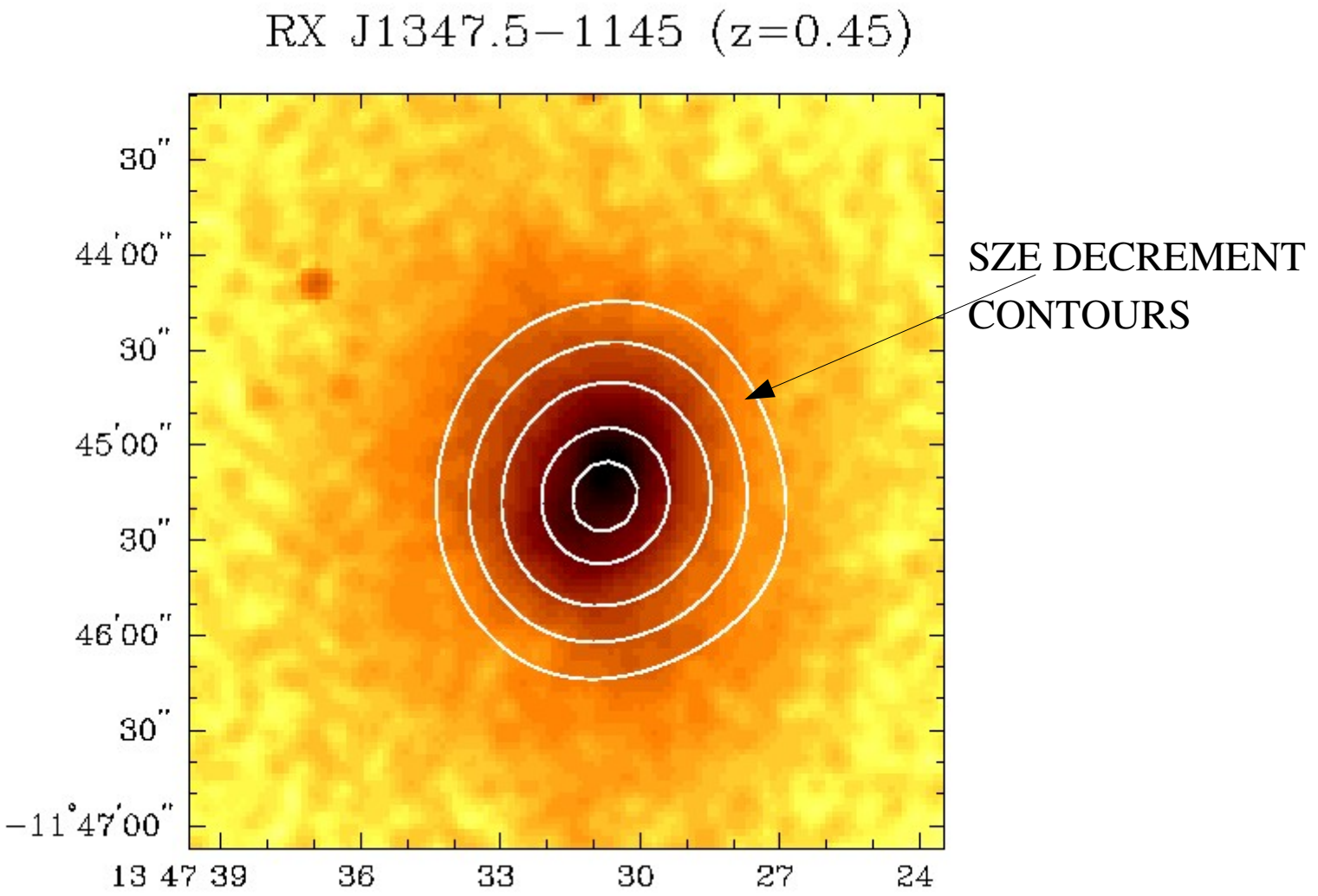




Adapted from L. Van Speybroeck



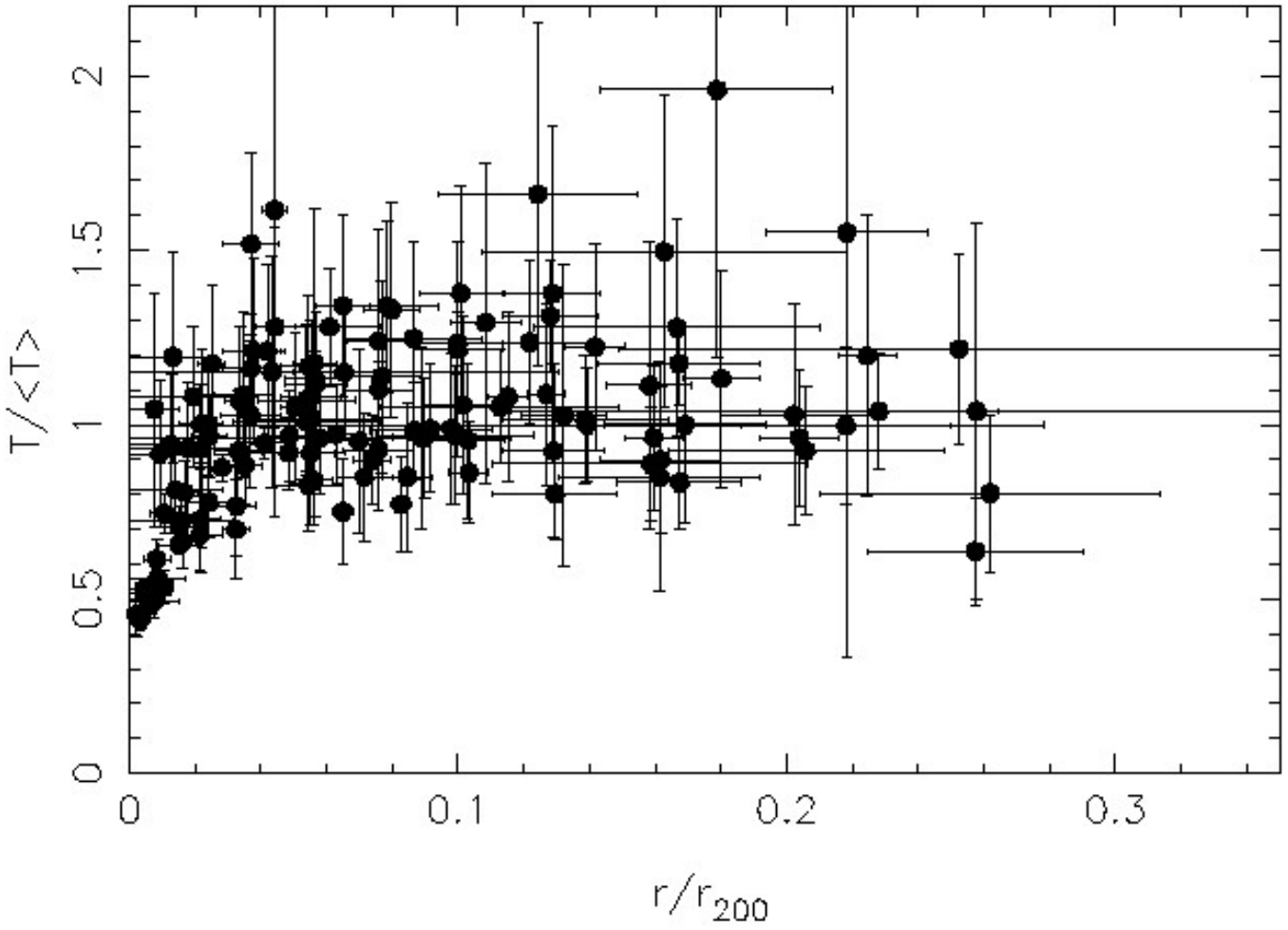

RX J1347.5−1145 (z=0.45)
36′
40′
44′
48′
−11°52′
13 48 0
45
30
15
47 0
10−3
0
−10−3
−2×10−3
−3×10−3
−4×10−3

(30 GHz)

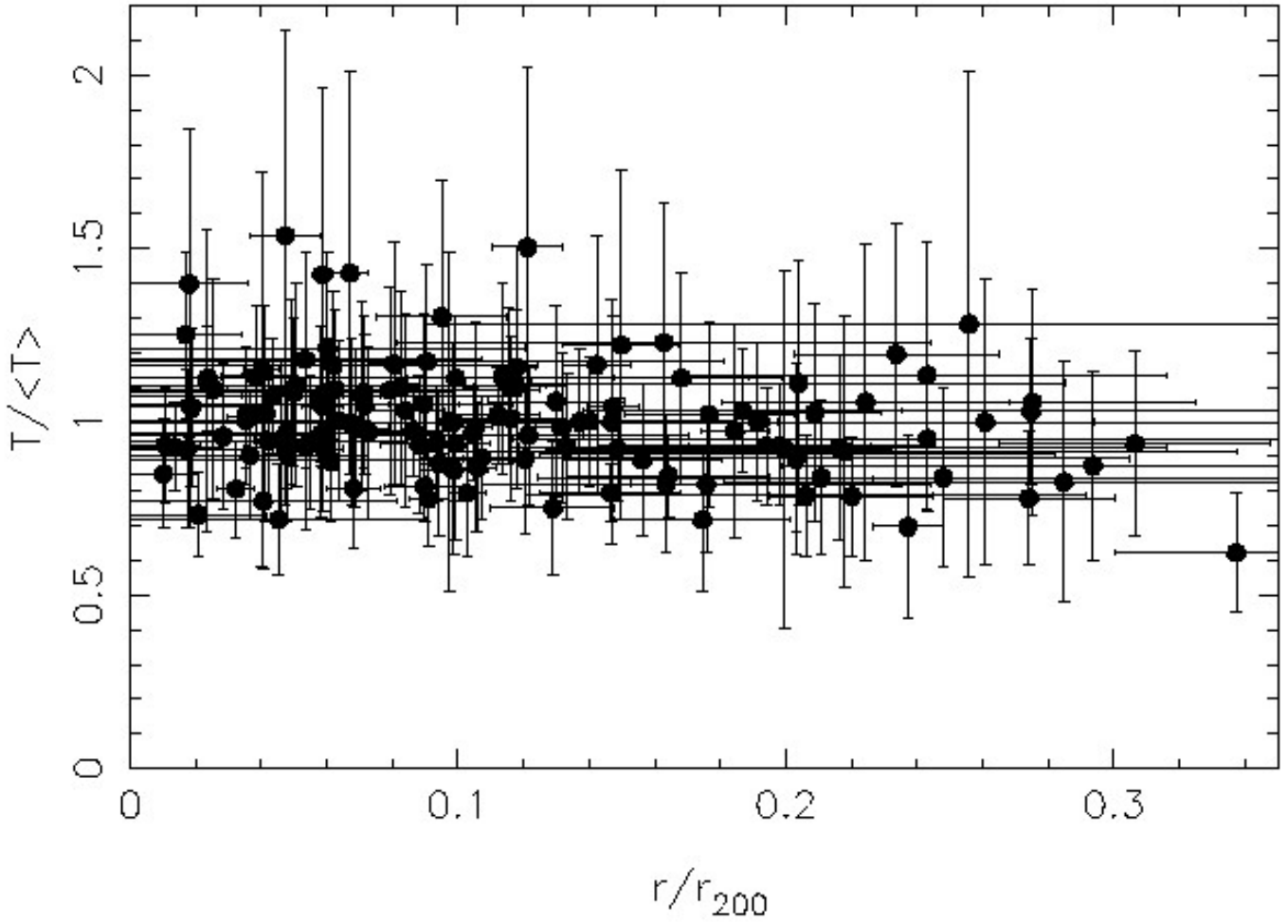

RX J1347.5−1145 (z=0.45)
30″
44′00″
30″
45′00″
30″
46′00″
30″
−11°47′00″
13 47 39
36
33
30
27
24
SZE DECREMENT
CONTOURS

| CLUSTER | Z | CLUSTER | Z |
|---|---|---|---|
| CL 0016+1609 | 0.541 | ABELL 1689 | 0.183 |
| ABELL 68 | 0.255 | RX J1347.5-1145 | 0.451 |
| ABELL 267 | 0.230 | MS 1358.4+6245 | 0.327 |
| ABELL 370 | 0.375 | ABELL 1835 | 0.252 |
| MS 0451.6-0305 | 0.550 | MACS J1423.8+2404 | 0.545 |
| MACS J0647.7+7015 | 0.584 | ABELL 1914 | 0.171 |
| ABELL 586 | 0.171 | ABELL 1995 | 0.322 |
| MACS J0744.8+3927 | 0.686 | ABELL 2111 | 0.229 |
| ABELL 611 | 0.288 | ABELL 2163 | 0.202 |
| ABELL 665 | 0.182 | ABELL 2204 | 0.152 |
| ABELL 697 | 0.282 | ABELL 2218 | 0.176 |
| ABELL 773 | 0.217 | RX J1716.4+6708 | 0.813 |
| ZW 3146 | 0.291 | ABELL 2259 | 0.164 |
| MACS J1115.2+5320 | 0.458 | ABELL 2261 | 0.224 |
| MS 1054.5-0321 | 0.826 | MS 2053.7-0449 | 0.583 |
| MS 1137.5+6625 | 0.784 | MACS J2129.4-0741 | 0.570 |
| MACS J1149.5+2223 | 0.544 | RX J2129.7+0005 | 0.235 |
| ABELL 1413 | 0.142 | MAC J2214.9-1359 | 0.450 |
| CL J1226.9+3332 | 0.890 | MACS J2228.5+2036 | 0.412 |
| MACS J1311.0-0310 | 0.490 | | |

# CHANDRA TEMPERATURE PROFILES FOR COOLING CORE CLUSTERS



# CHANDRA TEMPERATURE PROFILES FOR NON-COOLING CORE CLUSTERS



# X-RAY/SZE METHOD TO OBTAIN CLUSTER DISTANCES:

$$S_X \propto \int n_e^2 \Lambda \, dl$$

X-RAY SURFACE BRIGHTNESS

$$\Delta T_{CMB}^2 \propto \int n_e T_e \, dl$$

SZE DECREMENT

ANGULAR DIAMETER DISTANCE $D_A = dl / d\theta$

$$D_A \propto \frac{\Delta T_{CMB}^2 \Lambda}{S_X T_e^2}$$

ADDITIONAL INGREDIENTS: HYDROSTATIC EQUILIBRIUM AND DARK MATTER

$$\frac{dT_e}{d\theta} = -\left[\frac{\mu m_p G M}{k_B D_A \theta^2} + \frac{T_e}{n_e}\frac{dn_e}{d\theta}\right]$$

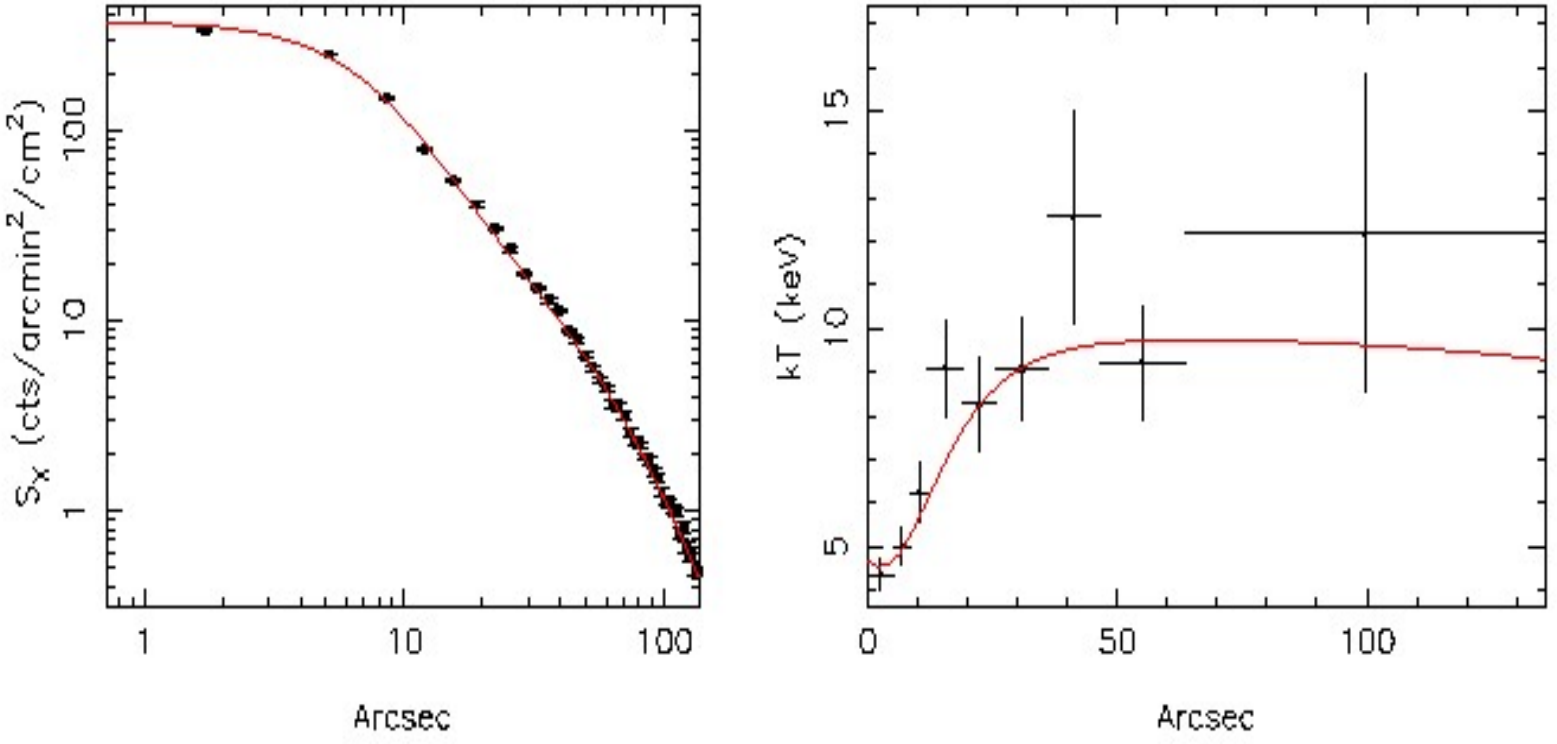
**MCMC FOR PARAMETER ESTIMATION**

- USE A DOUBLE β MODEL FOR GAS DENSITY:

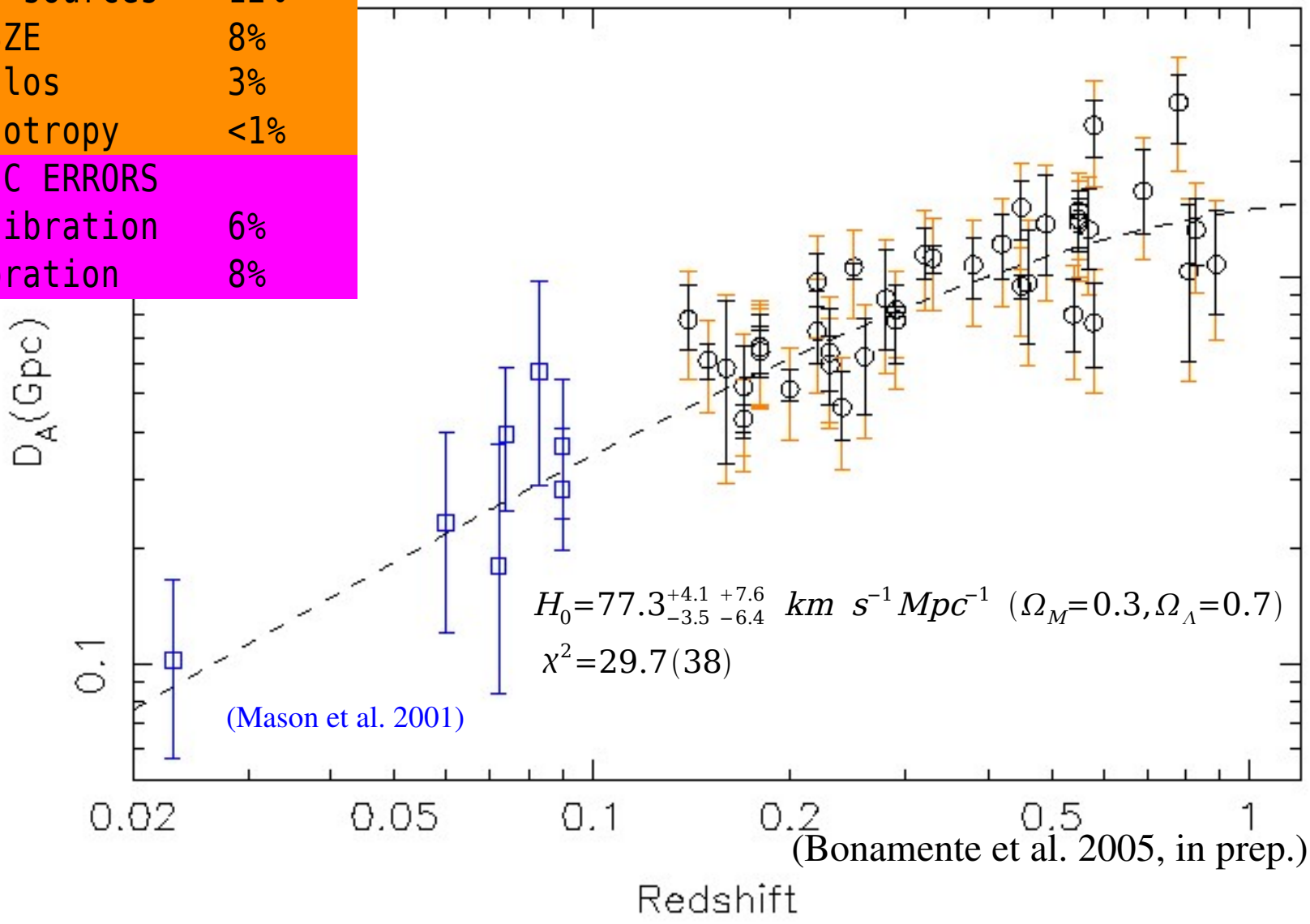
$$n_e = n_{eo}\left[f\left(1+\frac{r^2}{r_c^2}\right)^{-3/2\beta} + (1-f)\left(1+\frac{r^2}{r_c^2}\right)^{-3/2\beta}\right]$$

- AND NFW DARK MATTER PROFILE.

ABELL 1835



| STATISTICAL ERRORS | |
|---|---|
| Galactic NH | <1% |
| Asphericity | 15% |
| SZE point sources | 12% |
| Kinetic SZE | 8% |
| Radio halos | 3% |
| CBM anisotropy | <1% |
| **SYSTEMATIC ERRORS** | |
| X-RAY calibration | 6% |
| SZE calibration | 8% |

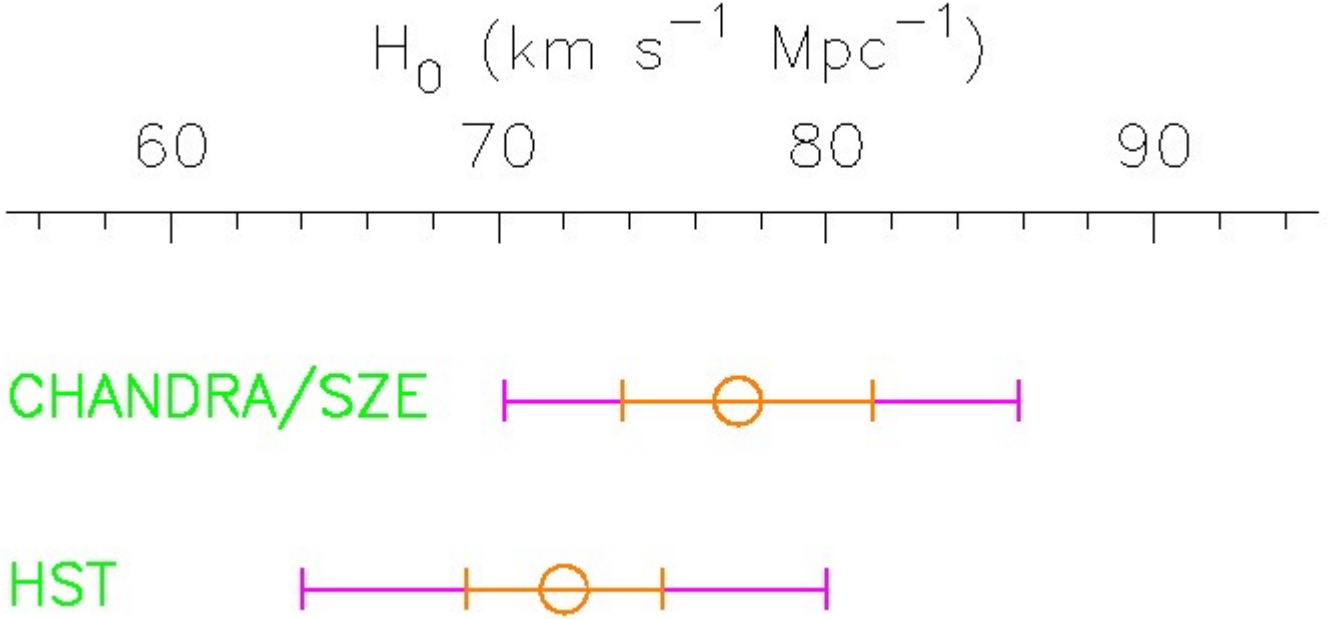



(Bonamente et al. 2005, in prep.)

HST KEY PROJECT: $H_0 = 72 \pm 3 \pm 7 \;\; km \;\; s^{-1} \, Mpc^{-1}$ Freedman et al. (2001)

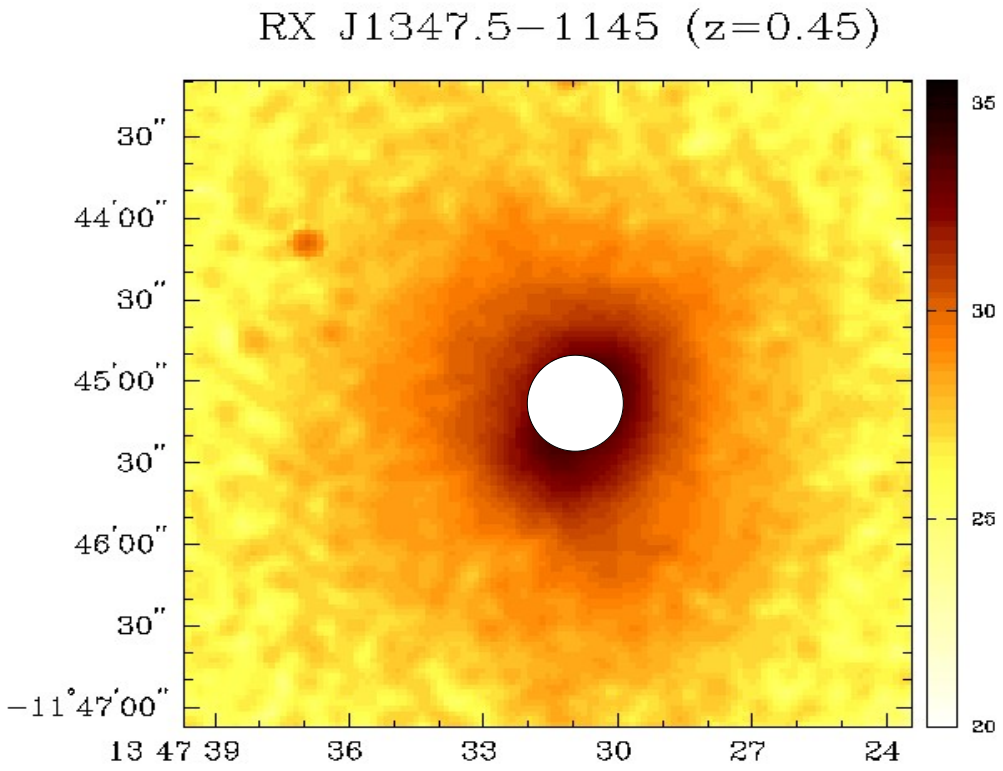
CHANDRA/SZE PROJECT: $H_0 = 77.3^{+4.1}_{-3.5} \; ^{+7.6}_{-6.4} \;\; km \;\; s^{-1} \, Mpc^{-1} \;\; (\Omega_M = 0.3, \Omega_\Lambda = 0.7)$

*DIRECTLY PROBES THE HUBBLE FLOW TO Z~1*

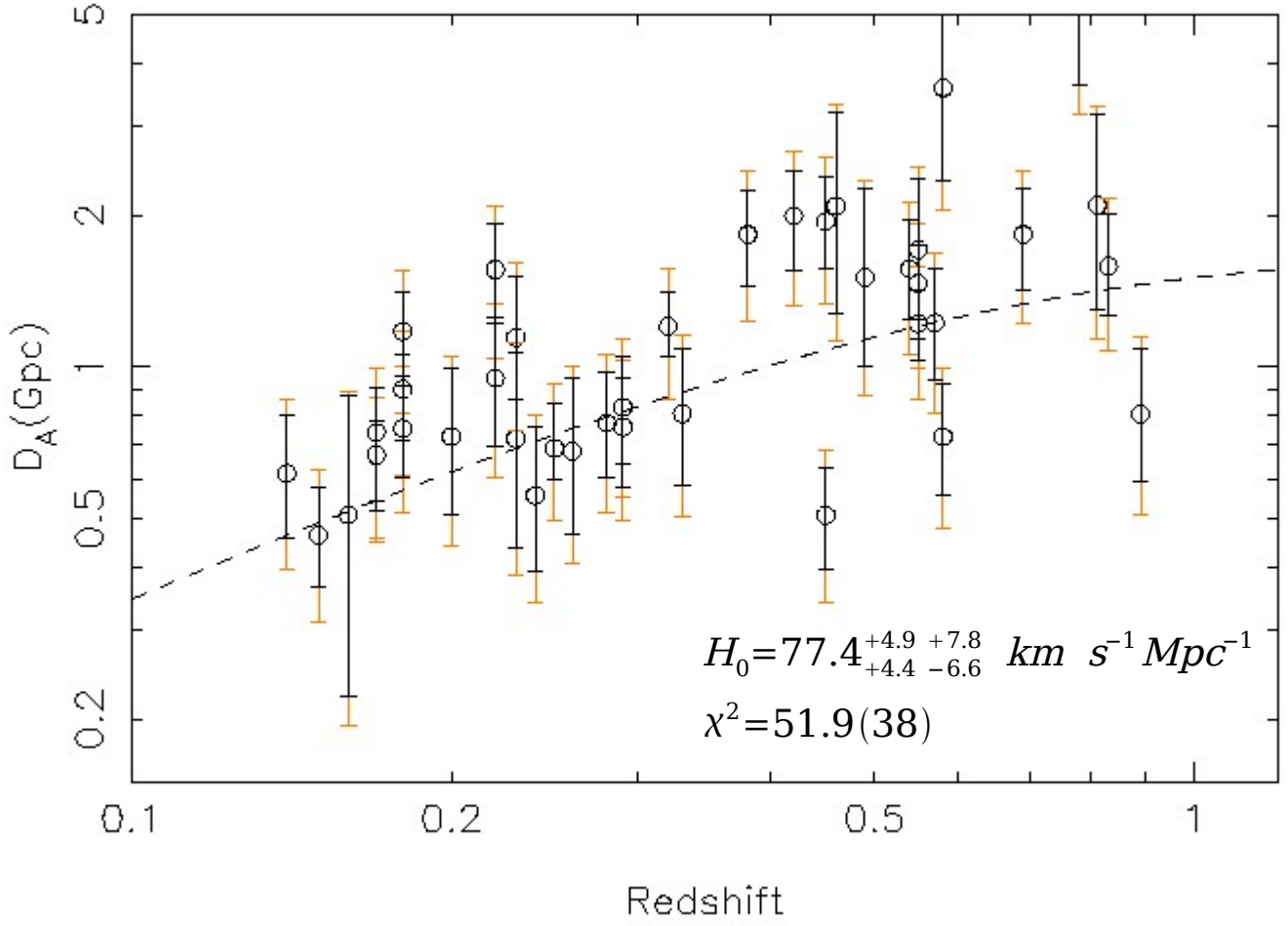


# ALTERNATIVE MODEL: 100 Kpc-CUT, SINGLE β-MODEL AND ISOTHERMAL

## NO HYDROSTATIC EQUILIBRIUM ASSUMPTION



(100 Kpc-CUT MODEL)



# CONCLUSIONS:

- ANALYZED SAMPLE OF 39 CLUSTERS AT z=0.14-0.89
- HIGH QUALITY X-RAY AND SZE OBSERVATIONS
- NON-ISOTHERMAL, DOUBLE-β MODEL , HSE
- MEASURED HUBBLE CONSTANT: $H_0 = 77.3^{+4.1\ +7.6}_{-3.5\ -6.4}\ km\ s^{-1}\ Mpc^{-1}$
- SAME ANSWER USING ISOTHERMAL, SINGLE-β MODEL