Determining the Cosmic Distance Scale with Galaxy Clusters

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Cast of Characters

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- Gil Holder
- Erik Reese
- Sam LaRoque
- Daisuke Nagai
- Amber Miller
- Mike Joffre

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- Marshall Joy
- Cheryl Bankston
- Sandy Patel (UAH)

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- Laura Grego

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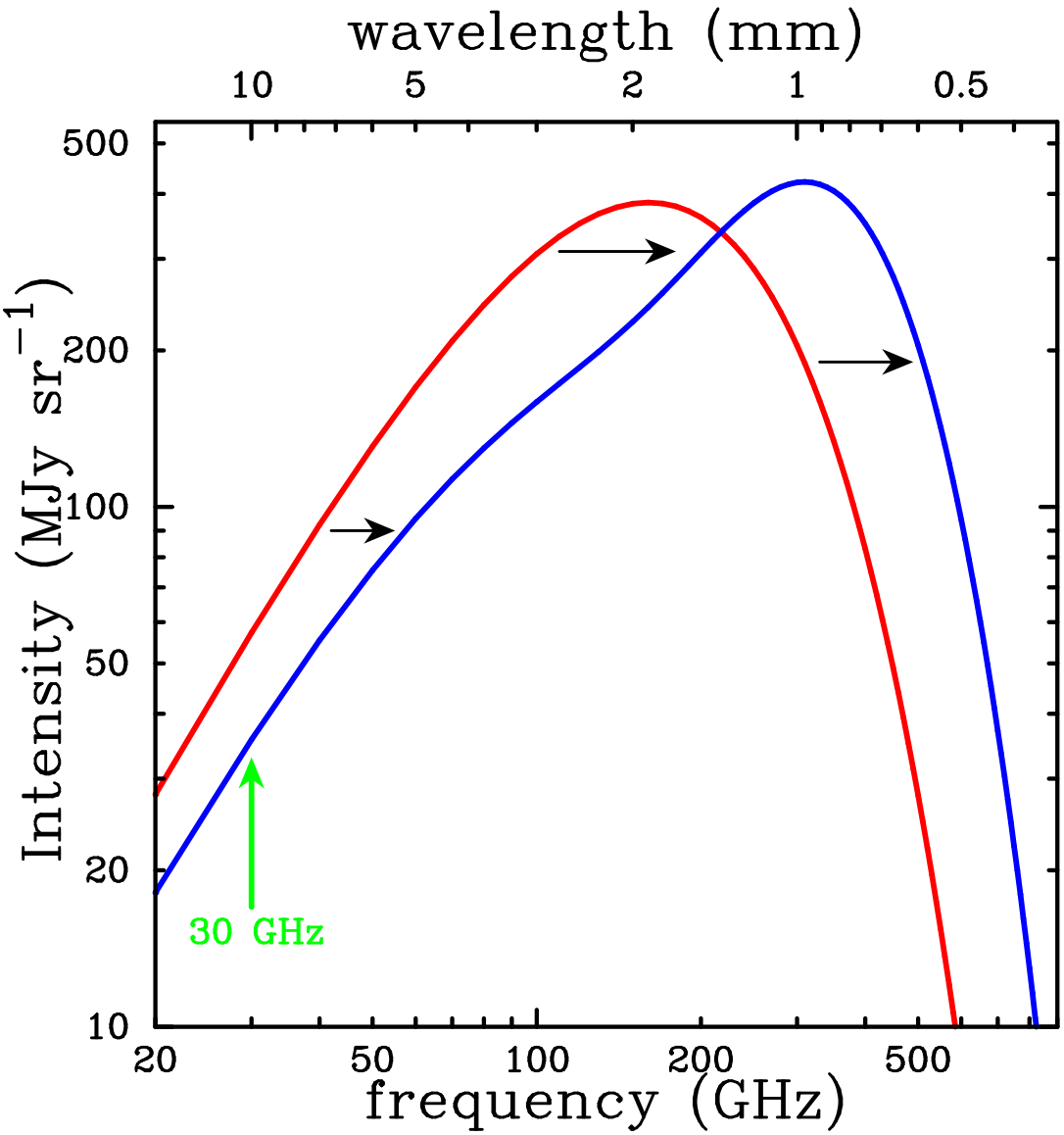
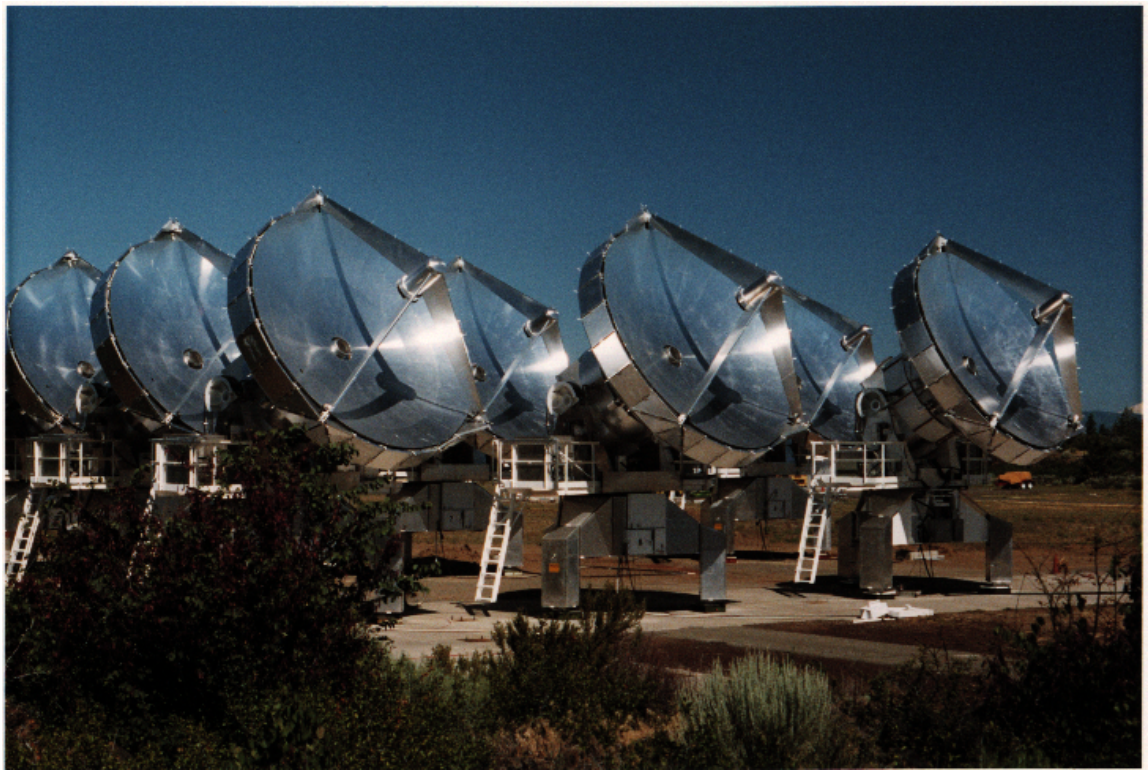
Rutgers University
- Jack Hughes

OVRO
- David Woody
- Steve Padin
- Steve Scott

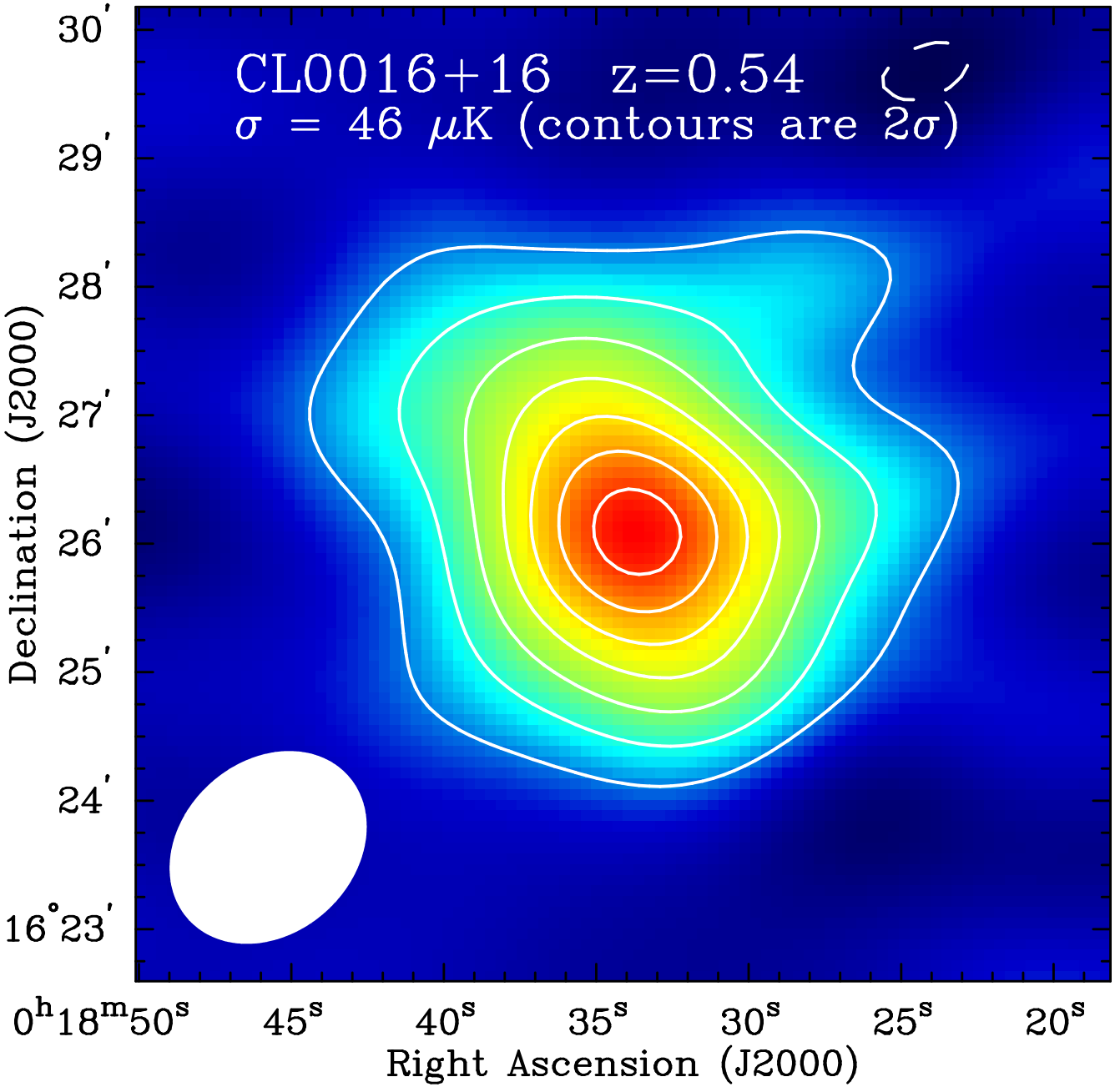
BIMA
- Dick Plambeck
- John Lugten
- Rick Forster

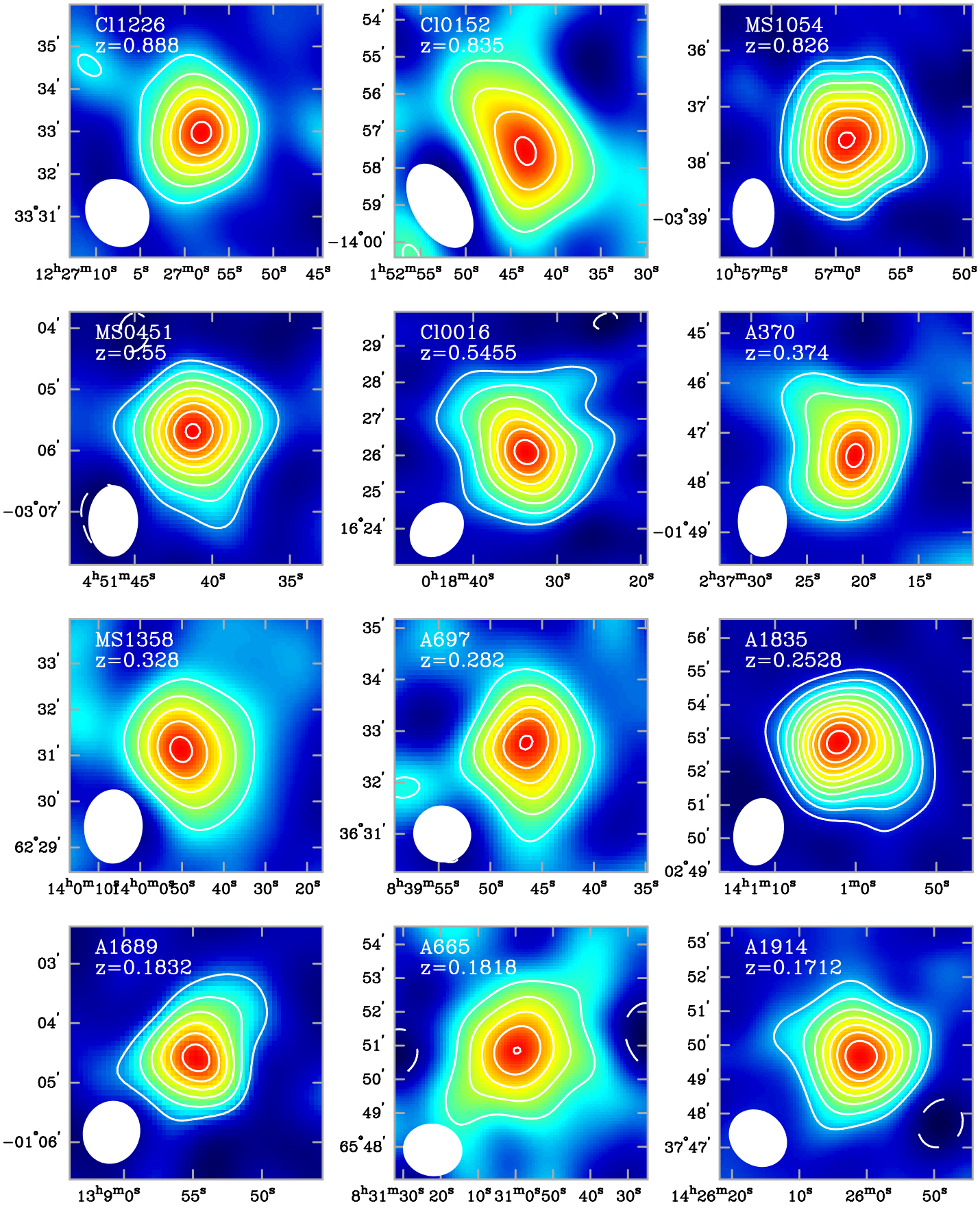


(Adapted from Sunyaev & Zel'dovich 1980 ARAA)

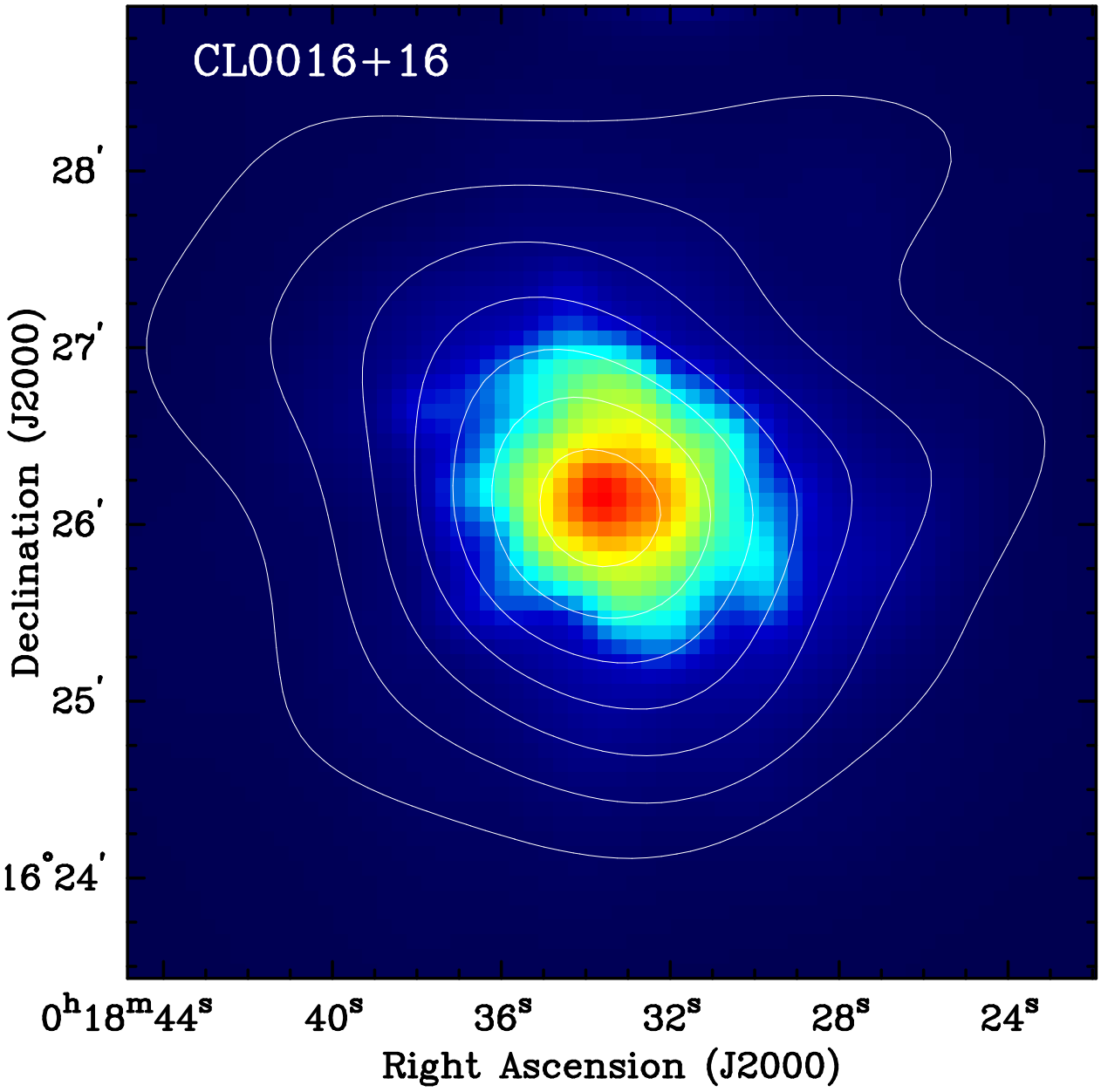


Sunyaev–Zel'dovich Effect Image




Cl1226
z=0.888
Cl0152
z=0.835
MS1054
z=0.826
MS0451
z=0.55
Cl0016
z=0.5455
A370
z=0.374
MS1358
z=0.328
A697
z=0.282
A1835
z=0.2528
A1689
z=0.1832
A665
z=0.1818
A1914
z=0.1712

SZE (contours) & X-ray (colorscale) Overlay



Hubble Constant

$$\Delta T \propto \int d\ell n_e T_e \Rightarrow \Delta T_0 \sim n_e T_e L$$

$$S_x \propto \int d\ell n_e^2 \Lambda \Rightarrow S_{x0} \sim n_e^2 \Lambda L$$

$$\Rightarrow L \propto \frac{(\Delta T_0)^2 \Lambda}{S_{x0} T_e^2}$$

with geometry of cluster

$$L = \theta D_A$$

with z and geometry of the universe

$$\Rightarrow H_0 \propto \frac{S_{x0} T_e^2}{(\Delta T_0)^2 \Lambda}$$

Independent of the distance ladder!

Analysis Method

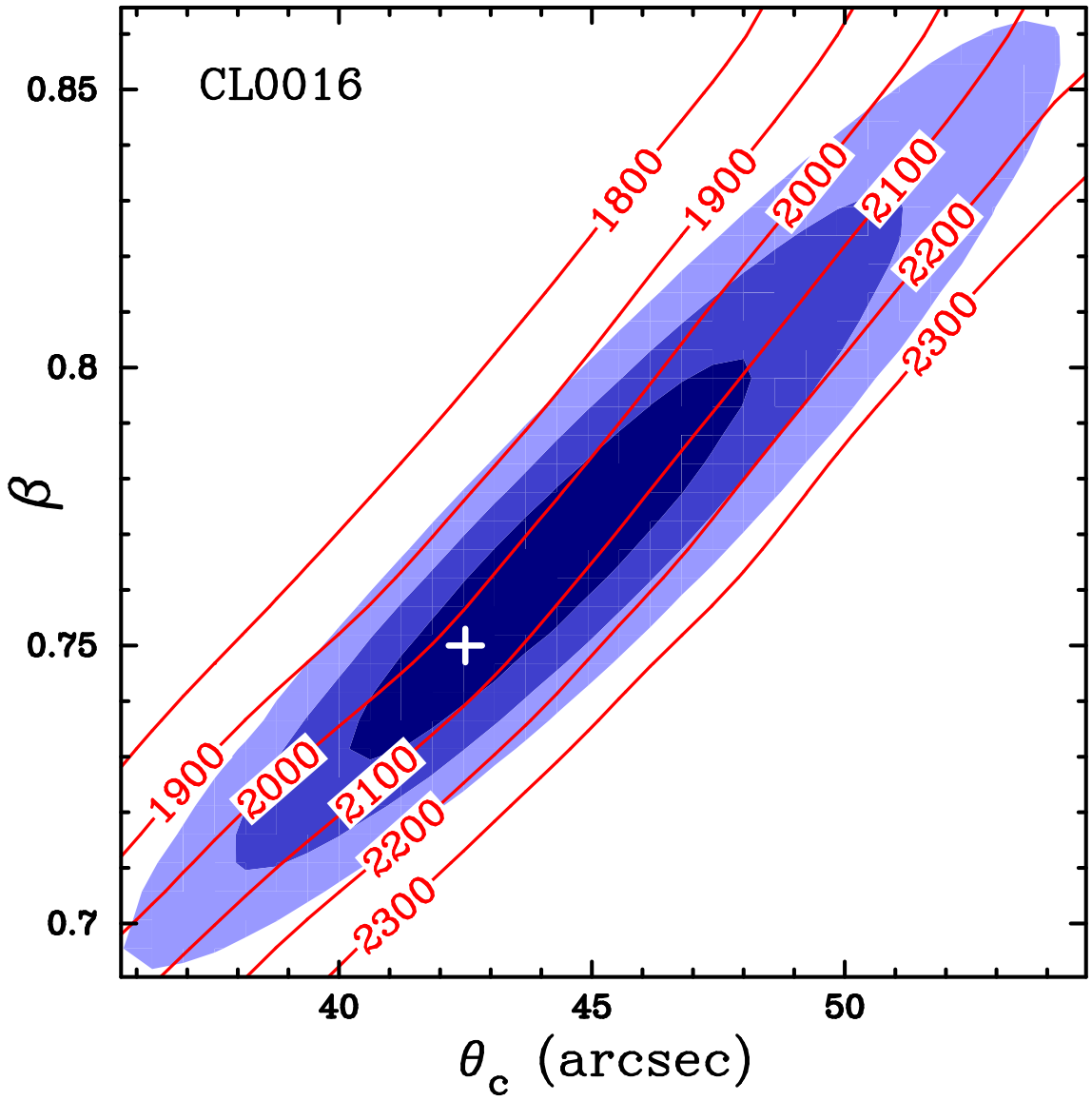
Fit data with a spherical isothermal β-model

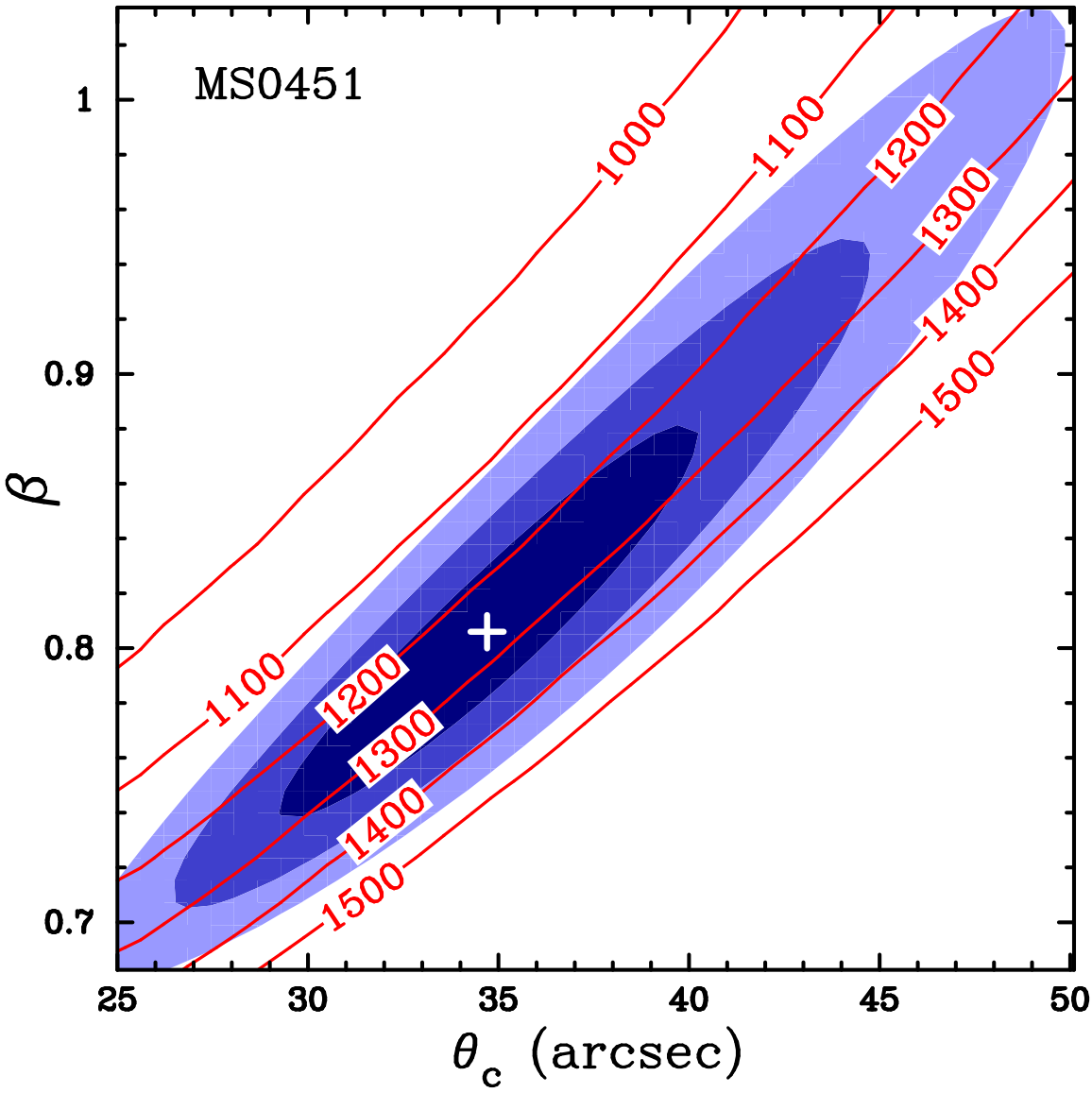
$$n_e(r) = n_{e0}\left(1 + \left(\frac{r}{r_c}\right)^2\right)^{-3\beta/2}$$

Maximum likelihood jointfit to SZE & X-ray data

- **SZE**
  - **data fit directly in Fourier plane**
  - **β-model + point sources**
  - **Gaussian statistics**
- **X-ray**
  - **Snowden ESAS reduction software (R4-R7 $\Leftrightarrow$ 0.5-2.0 keV)**
  - **β-model + background**
  - **mask point sources**
  - **Poisson statistics**

(Reese et al. 2000 ApJ 533 38)


CL0016
1800
1900
2000
2100
2200
2300
1900
2000
2100
2200
2300
0.85
0.8
0.75
0.7
β
40
45
50
θc (arcsec)


MS0451
1000
1100
1200
1300
1400
1500
1100
1200
1300
1400
1500
1
0.9
0.8
0.7
β
25
30
35
40
45
50
θc (arcsec)

Uncertainties on H_0

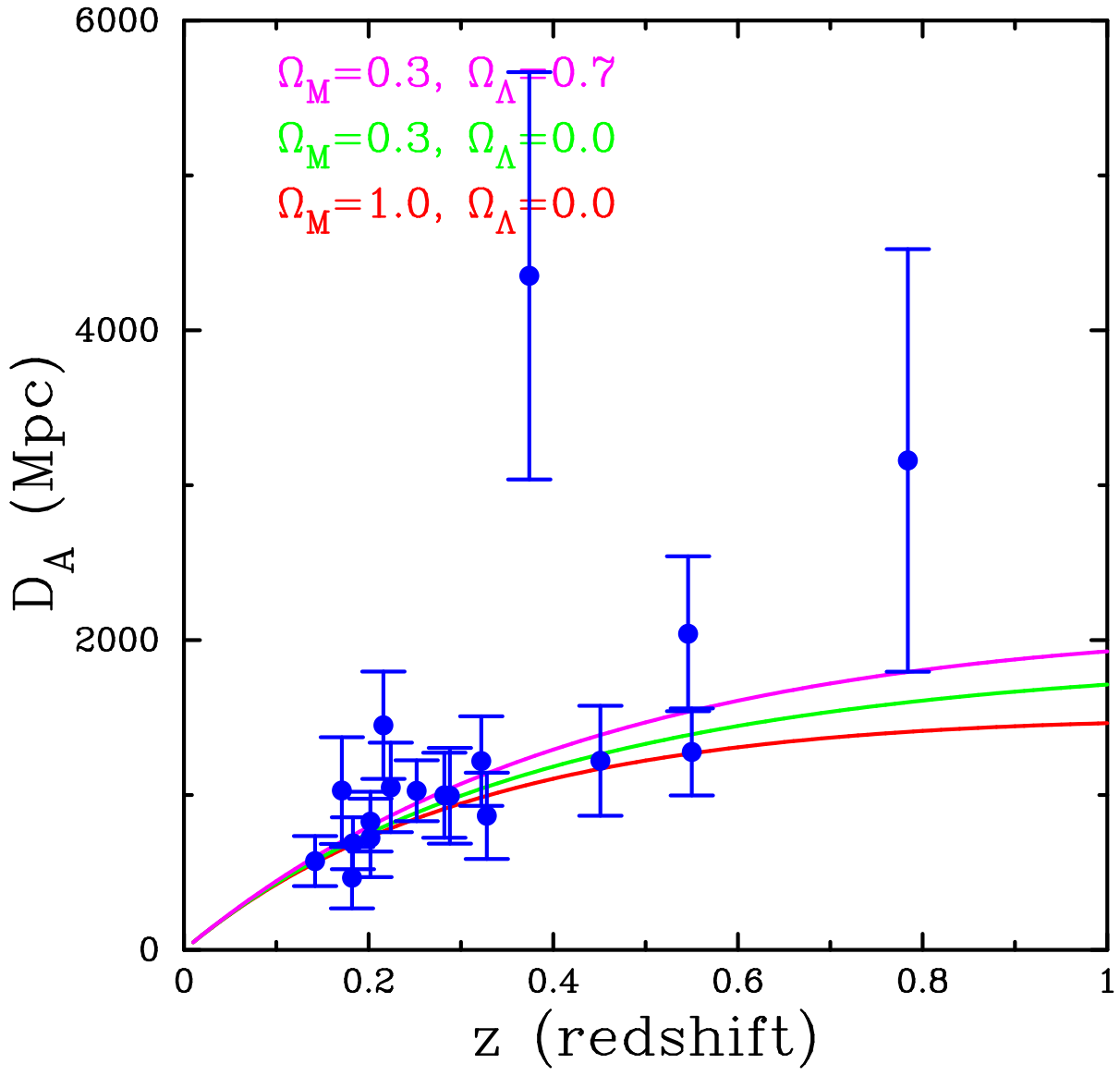
Statistical

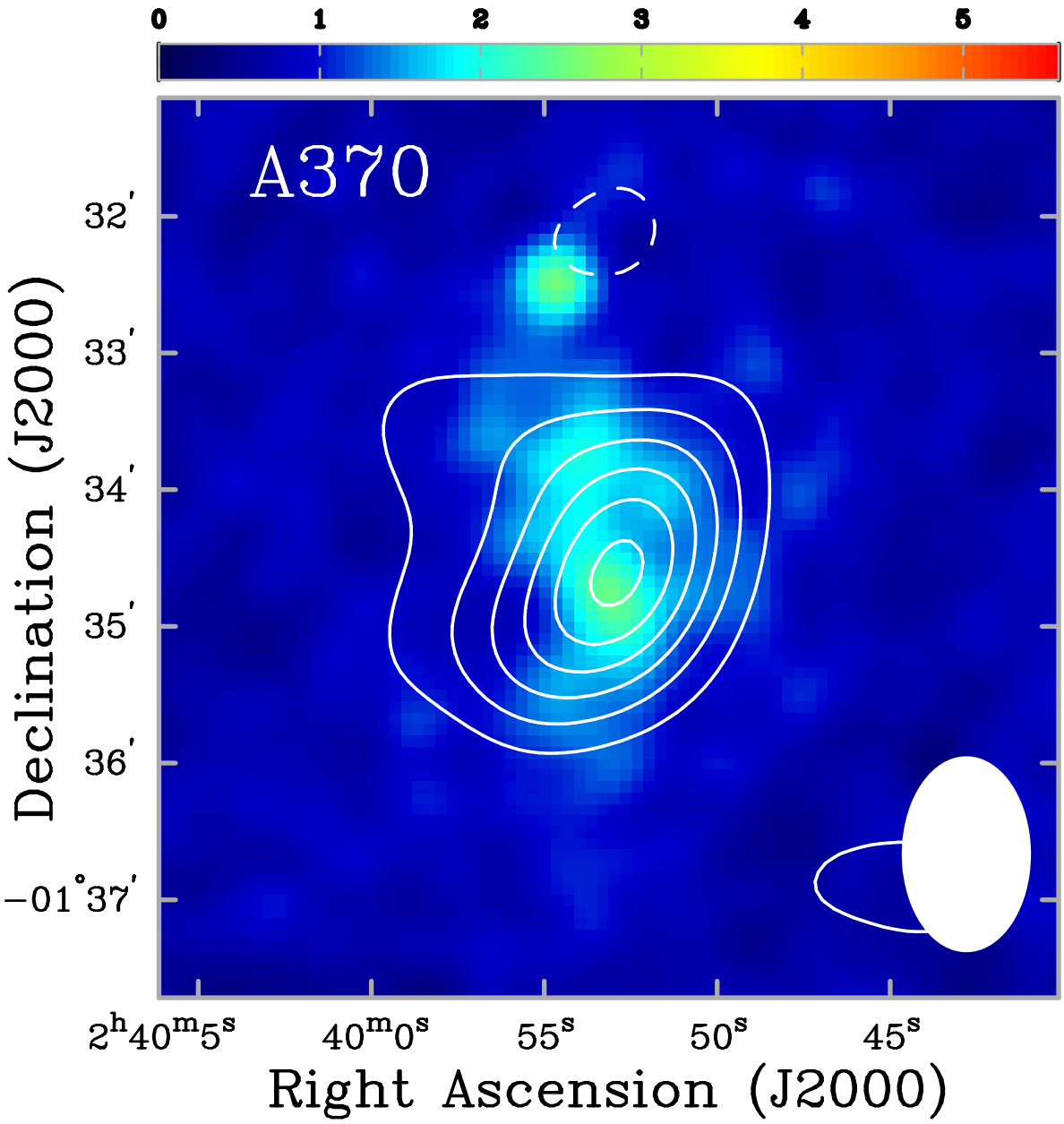
T_e ($H_0 \propto T_e^2$)	20%
Parameter fitting	15%
Metallicity	1%
N_H	1%

Systematic

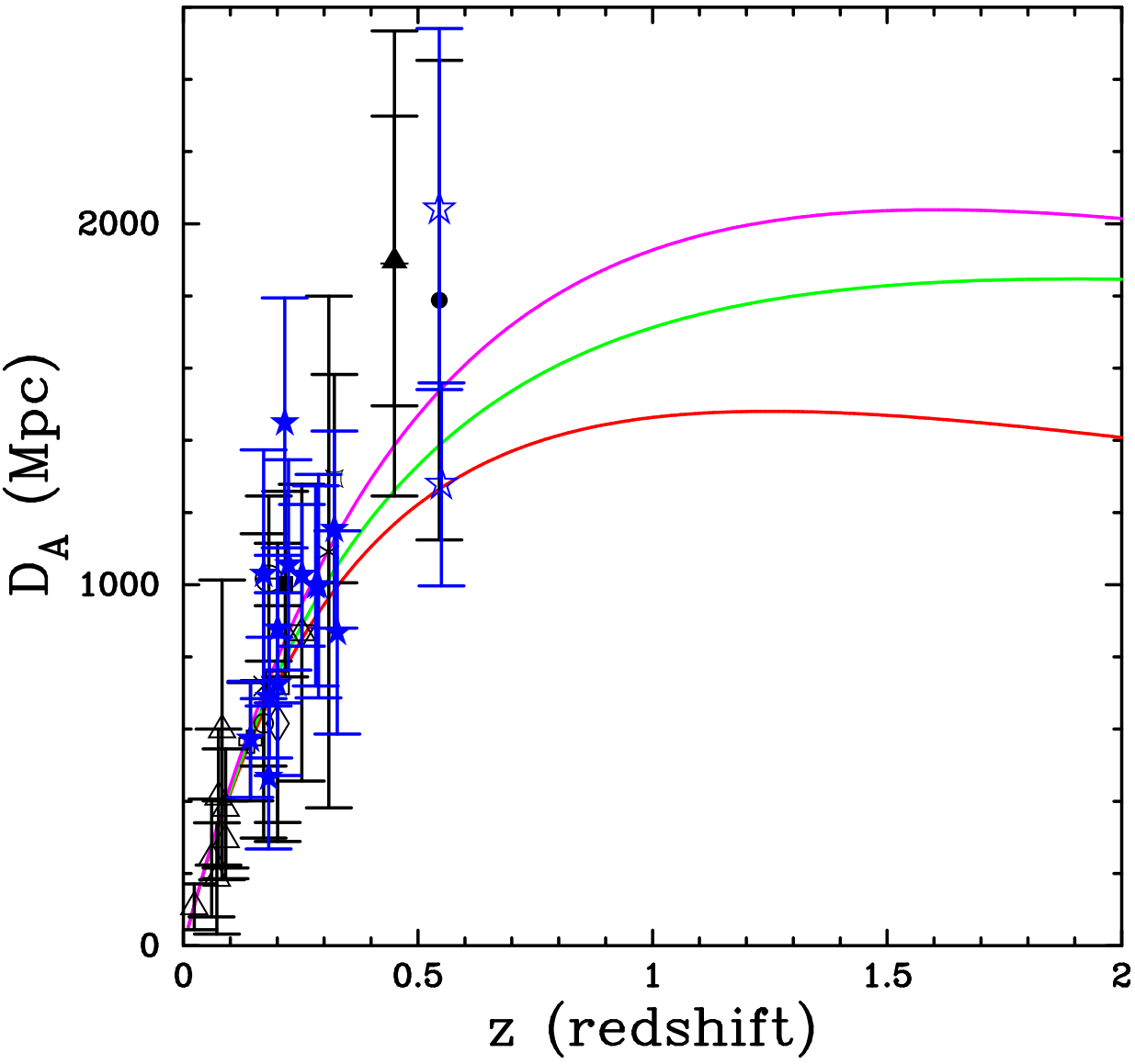
SZE calibration [$H_0 \propto (\Delta T_0)^{-2}$]	± 8%
X-ray calibration	±10%
N_H	± 5%
Asphericity•	± 5%
Isothermality	±10%
Clumping	−20%
Undetected radio sources	±12%
Kinetic SZE•	± 2%
Primary CMB	± 1%
Radio Halos	± 4%
Primay Beam	± 3%
Total	+22% −30%

$$H_0 = \begin{cases} 60^{+4\,+14}_{-4\,-19}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}; & \Omega_M{=}0.3,\ \Omega_\Lambda{=}0.7 \\ 56^{+4\,+13}_{-4\,-17}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}; & \Omega_M{=}0.3,\ \Omega_\Lambda{=}0.0 \\ 53^{+4\,+12}_{-3\,-17}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}; & \Omega_M{=}1.0,\ \Omega_\Lambda{=}0.0 \end{cases}$$



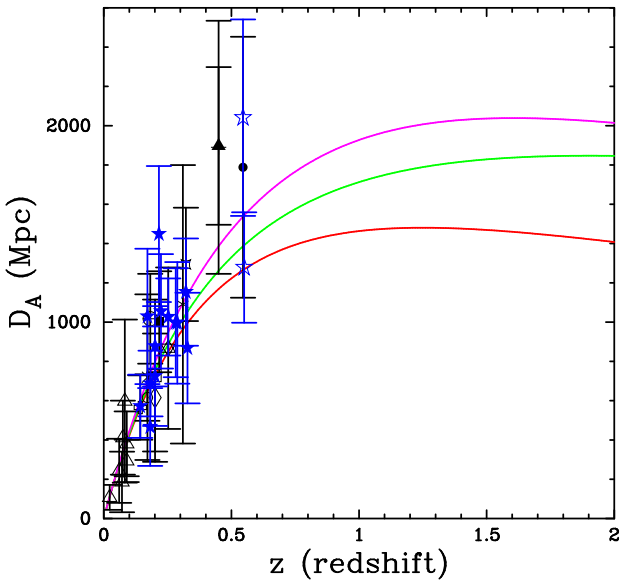

0
1
2
3
4
5
A370
32′
33′
34′
35′
36′
−01°37′
Declination (J2000)
2h40m5s
40m0s
55s
50s
45s
Right Ascension (J2000)

D_A Present & Future



Summary

- **H_0 independent of distance ladder**
  $H_0 = 60^{+4\ +13}_{-4\ -18}$ km s^{-1} Mpc^{-1}; $\Omega_M, \Omega_\Lambda = 0.3, 0.7$
- **Systematics are approachable**
  Chandra/XMM-Newton, VLA, SZE calibration, Simulations...



- **Ready to Determine Geometry of Universe**
- **SZE Surveys**
  redshift independence of SZE