The APEX Sunyaev-Zel'dovich Survey

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Max-Planck-Institut für Radioastronomie

"SZ with ALMA"
Paris, 7. April 2005

12m primary, 16 micron surface rms 125t
optical pointing telescope
chopping secondary (AZ only)
ALMA common software (python)

beam ·8" at 350 micron,
18" at 870 micron,
45" (60") at 2 mm

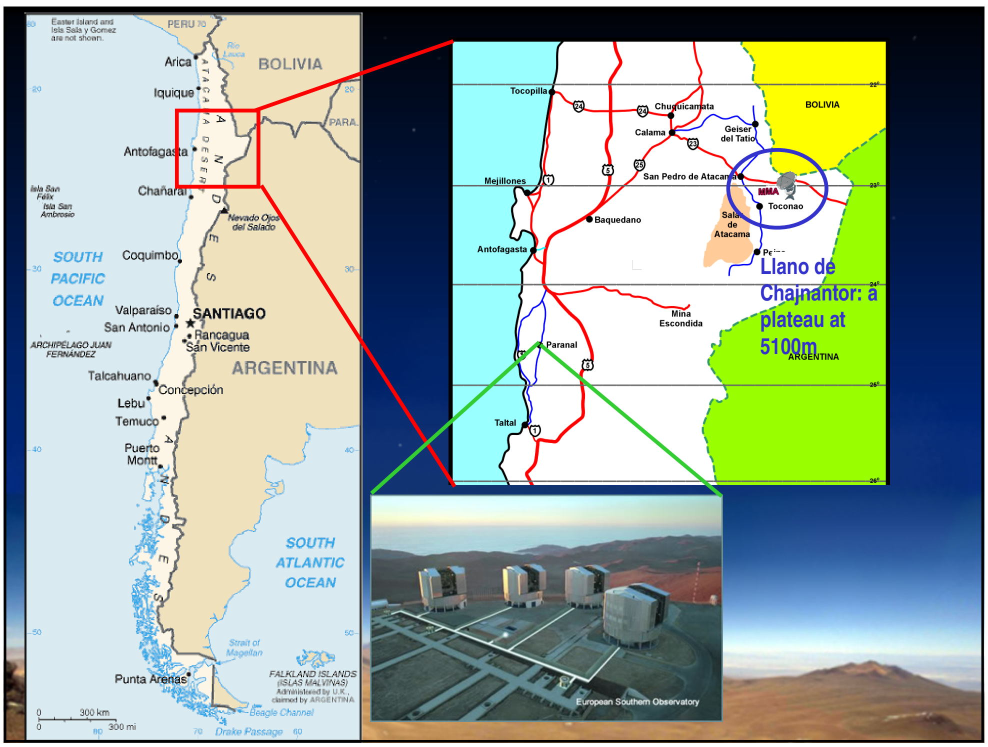
www.apex-telescope.org

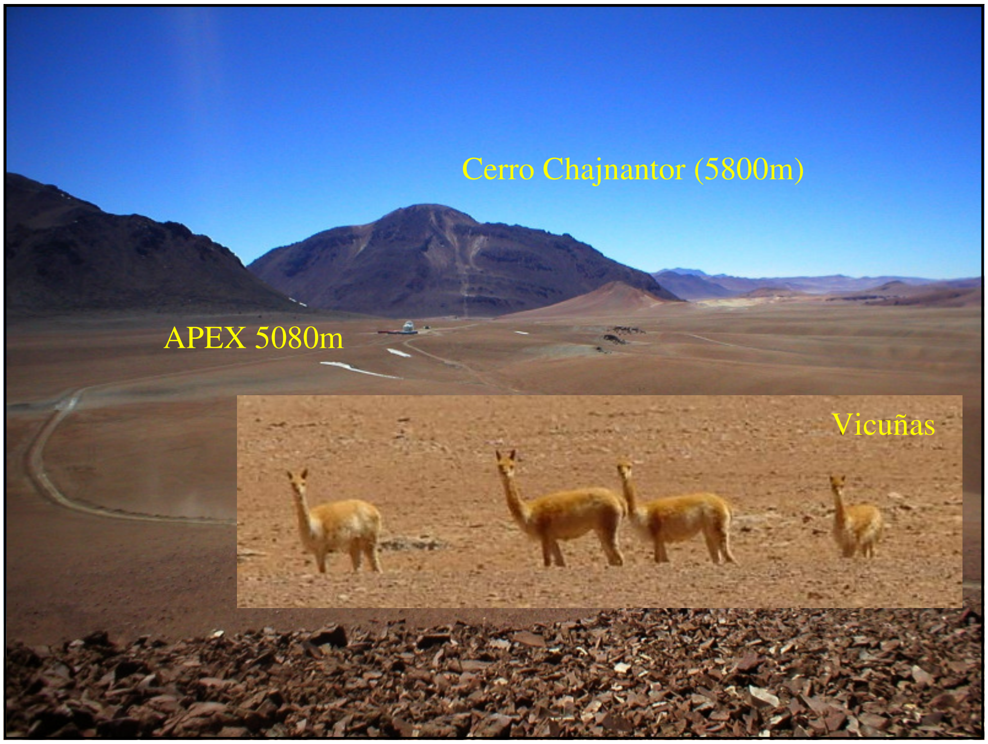
Max-Planck-Institut für Radioastronomie

PI:	Karl Menten
Project Manager:	Rolf Guesten
Project Scientist:	Peter Schilke
Station Manager:	Lars Ake Nyman +18 staff.
APEX astronomers:	Johansson, Vanzi, Reveret, Dumke

Atacama Pathfinder EXperiment

- Antenna built by VERTEX Antennentechnik, Duisburg
  - modified copy of US ALMA prototype
- Financed by Max-Planck-Gesellschaft
- Construction by Max-Planck-Institut für Radioastronomie, Bonn
- Infrastructure & operation by ESO and OSO
- Time allocation:
  - MPG: 45 %
  - European Southern Observatory (ESO): 24%
  - Onsala Space Observatory, Sweden (OSO) : 21%
  - Chile: 10 %




Cerro Chajnantor (5800m)
APEX 5080m
Vicuñas


Volcán Licancabur (5916 m), Volcán Juriques (5710 m), Cerro Toco (5780 m), Cerro Chajnantor (5800 m)
Volcán Lascar erupts, 20 July 2000

cantine

Control center

APEX Base Station near
San Pedro de Atacama
2400m, 76km from APEX

Radio link to Cerro Chico

Instrumentation

Bolometers

- **LABOCA-1**: 295-channel at 870 µm (MPIfR, Bochum, Jena)
  FOV: 11', beam 18" (same as MSX and Herschel 250µm)
- 37+-channel at 350 µm (MPIfR)
- 324-channel at 1.4/2 mm for Sunyaev-Zel'dovich survey (UCB, MPIfR)
  new software: BoA (Python/F95) www.openboa.de

Heterodyne

- 183 GHz water vapour radiometer
- 210-270 GHz (OSO)
- 270-375 GHz (OSO)
- 375-500 GHz (OSO) [currently: 460/810 GHz "FLASH"]
- 800-900 GHz (MPIfR, PI)
- CHAMP+   600-720/790-920 GHz, 2×7-elements (MPIfR, PI)
- FIR receivers: up to 1.5 THz = 200 micron (OSO, Köln)

Timeline

Telescope “ready”:	11 / 2003	
Holography	5 / 2004	
1.2 mm Bolometer	5 / 2004	- first light: May 29
460/810 GHz Rx	6 / 2004	← today
LABOCA:	5 / 2005	
Regular operation:	6? / 2005	
ASZCa	? / 2005	
CHAMP+	? / 2005	
350 micron bolometer	? / 2006	

The APEX Sunyaev-Zel'dovich Galaxy Cluster Survey

a collaboration between MPIfR and U.C. Berkeley
in association with RAIUB, MPE, MPA, OSO, …

Basu
Beelen
Bertoldi
Kreysa
Menten
Muders
Schilke
Cho
Dobbs
Halverson
Holzapfel
Kermish
Kneissl
Lanting
Lee
Lueker
Mehl
Plagge
Richards
Schwan
Spieler
White
Sunyaev
Böhringer
Horellou

- Discover and catalog several **1000 galaxy clusters** in a mass limited survey: map 200 deg^2 to ~10 μK rms per ~60" pixel.
- Constrain **cosmological parameters** such as σ_8 and dark energy equation of state, *w*.
- SZ contribution of z>10 Supernova-remnants.
- Observe **evolution of structure**, and test theories of structure formation.
- Study **clusters** in detail: structure, evolution, galaxy populations.
- Study **CMB secondary anisotropies**, weak lensing, Ostriker-Vishniac effect, quadratic Doppler effect, etc.

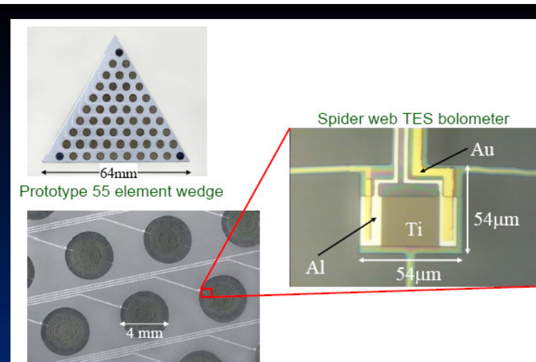
Zhang, Pen, Wang 2002

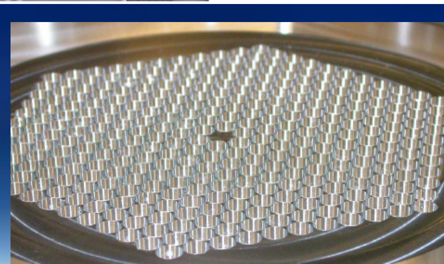
Current and future SZ surveys:

name	type	beam arcmin	telescope m	clusters	when
ACBAR	Bolo	4		few	?
Bolocam	Bolo 151	1	10	10s	?
SuZIE	Bolo	1	10	?	1997
BIMA	HEMT			few	2001
CBI	HEMT 13	4	0.9	?	?
SZA	HEMT 8	0.1	3.5	?	2005?
AMiBA	HEMT 19	2	1.2	100s	2006
AMI	HEMT 10	1	3.7	100s	2006
APEX	Bolo 325	0.75	12	1,000s	2006
ACT	Bolo 1000	1	6	1,000s	2007
Bolocam-2	Bolo	0.2	40	?	2007?
SPT	Bolo 1000	1	8	20,000	2007
Planck	Bolo	5	2	10,000	2008

Demonstrate new technologies that are scalable to even more powerful future experiments, i.e., SPT

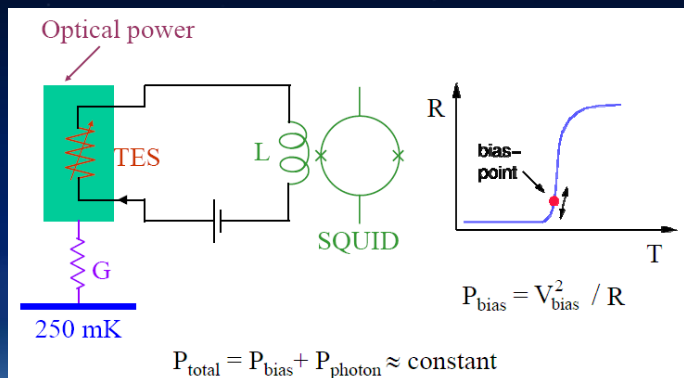
- TES spider web bolometers, monolithic fabrication
- SQUID readouts (individual bolometers on APEX-SZ, upgradable to frequency domain multiplexing)
- Pulse-tube cooler to eliminate liquid cryogens



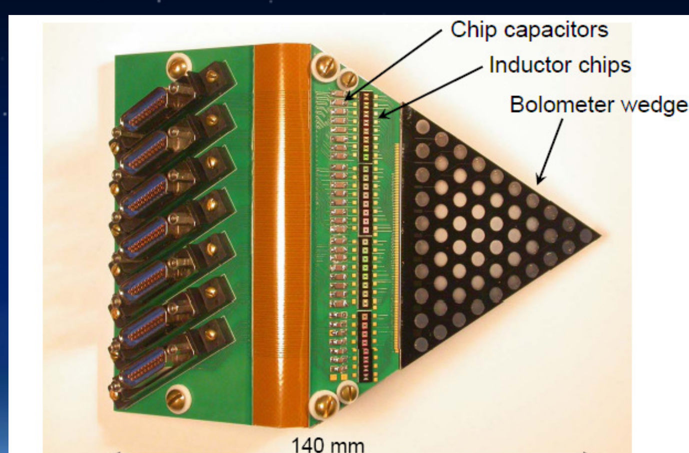


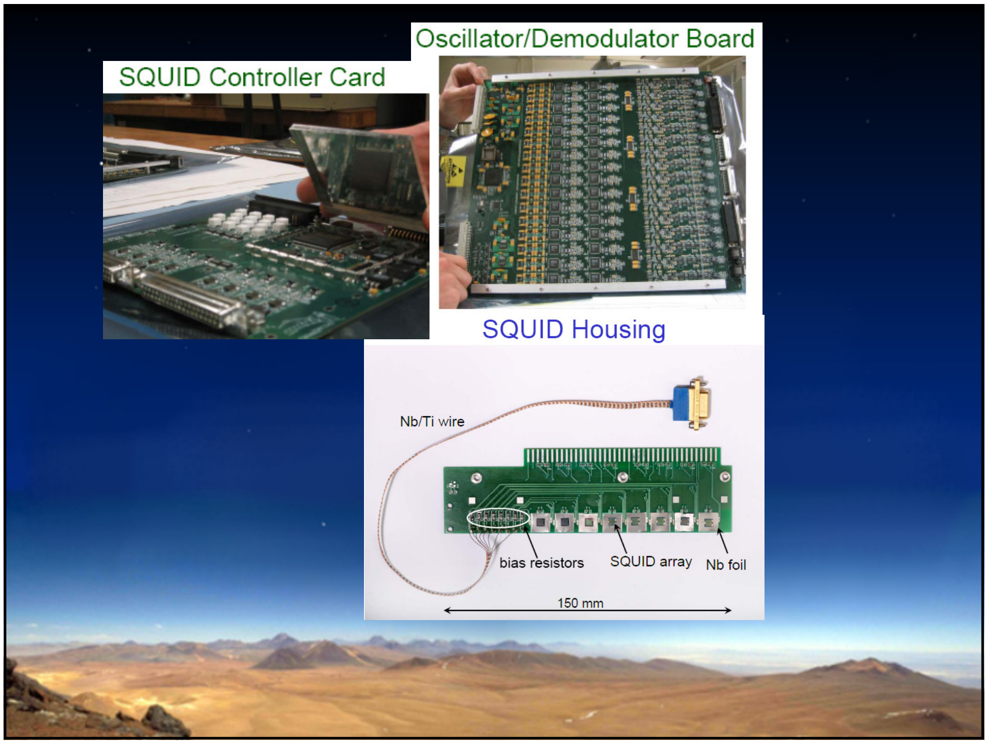
330 element horn-coupled array at 3.4, 2, 1.4 mm (swap horns & filters)

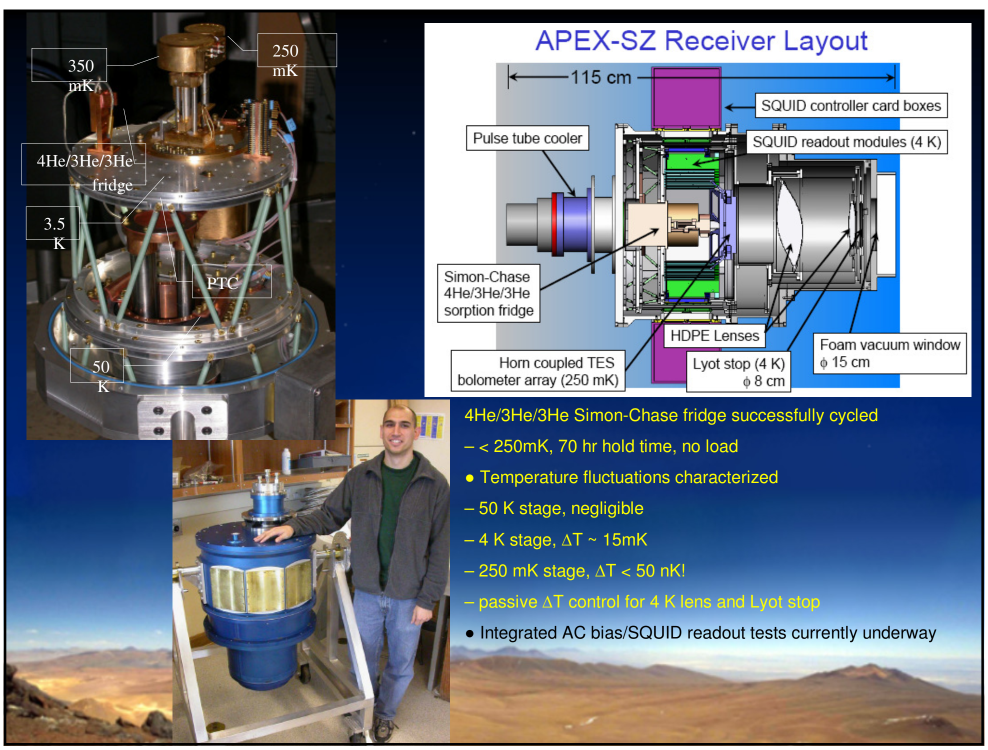
Voltage-Biased Superconducting Transition-Edge Sensor (TES) Bolometer

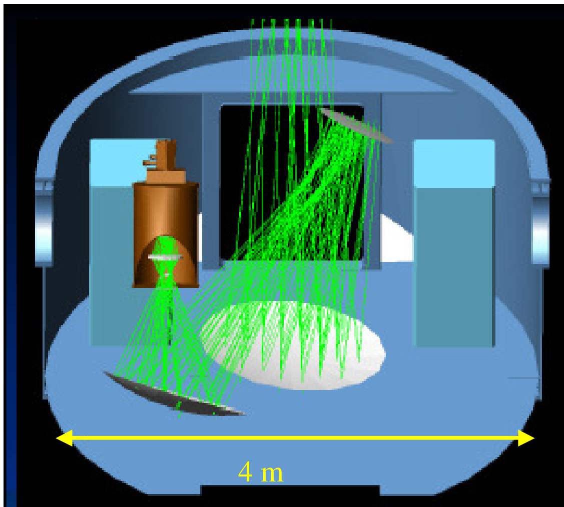


Bolometer Wedge and LC Board Assembly




Oscillator/Demodulator Board
SQUID Controller Card
SQUID Housing
Nb/Ti wire
bias resistors
SQUID array
Nb foil
150 mm


350 mK
250 mK
4He/3He/3He fridge
3.5 K
PTC
50 K
APEX-SZ Receiver Layout
115 cm
SQUID controller card boxes
Pulse tube cooler
SQUID readout modules (4 K)
Simon-Chase 4He/3He/3He sorption fridge
HDPE Lenses
Foam vacuum window ϕ 15 cm
Horn coupled TES bolometer array (250 mK)
Lyot stop (4 K) ϕ 8 cm
4He/3He/3He Simon-Chase fridge successfully cycled
– < 250mK, 70 hr hold time, no load
• Temperature fluctuations characterized
– 50 K stage, negligible
– 4 K stage, ΔT ~ 15mK
– 250 mK stage, ΔT < 50 nK!
– passive ΔT control for 4 K lens and Lyot stop
• Integrated AC bias/SQUID readout tests currently underway



Fast survey requires large field of view, well coupled to a large focal plane array

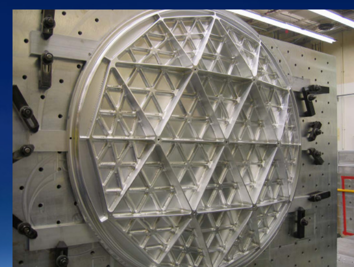
– 330 element horn coupled array

– 0.38 deg field of view

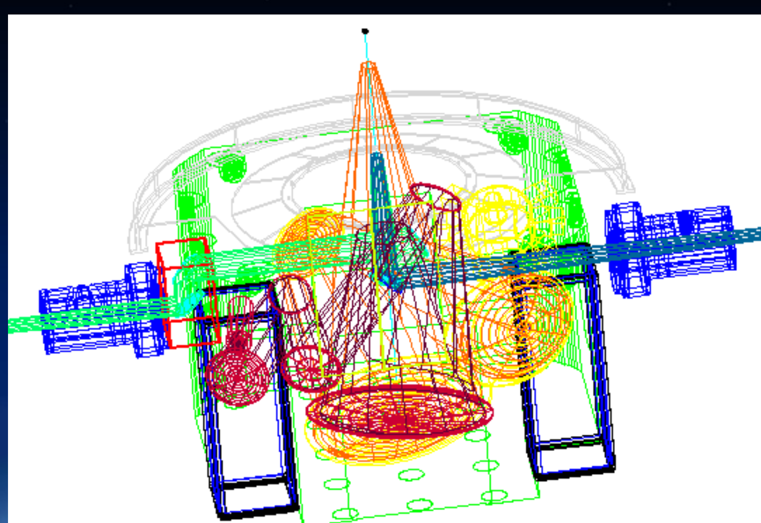
– f/2.3 at focal plane

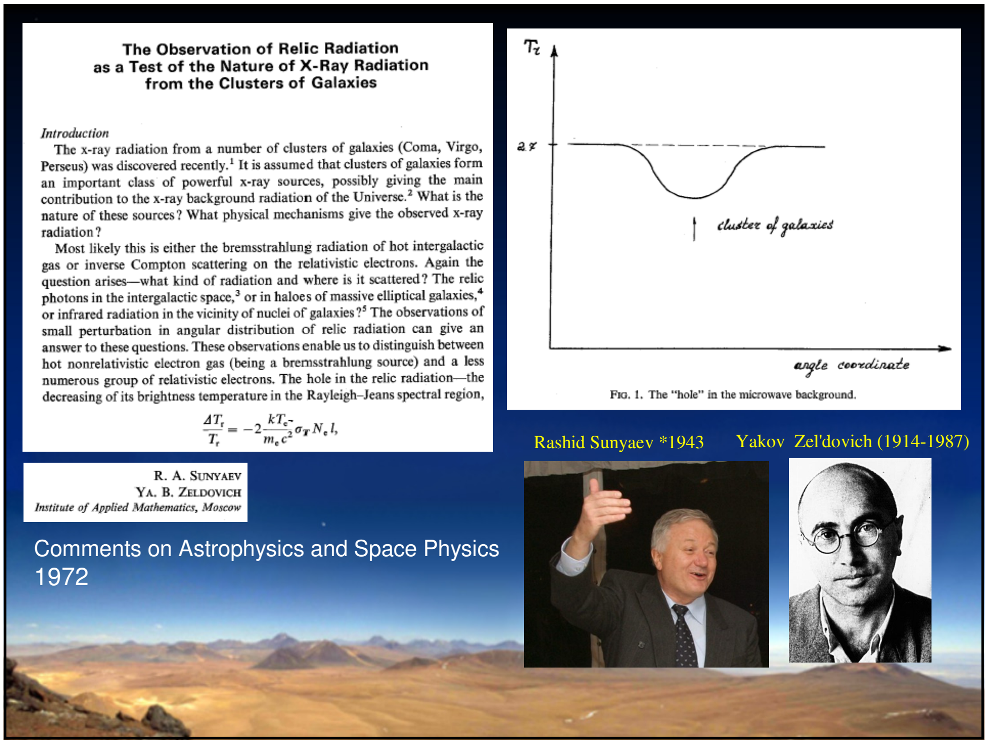
– 1.4 f λ diam horns

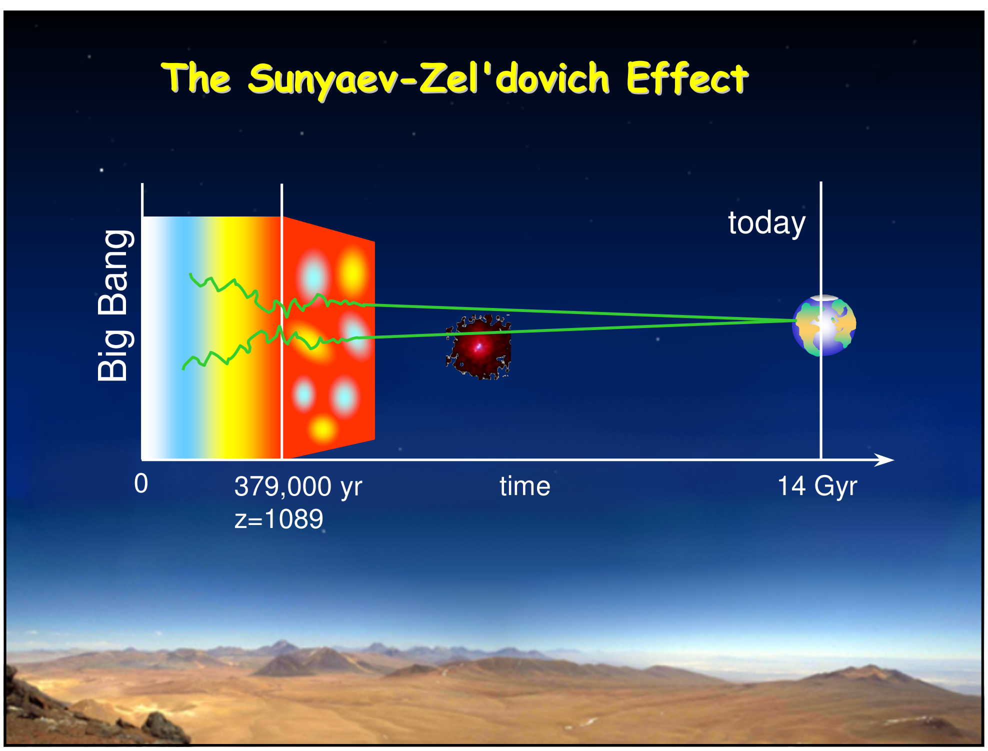
● Large throughput AΩ requires large reimaging optics

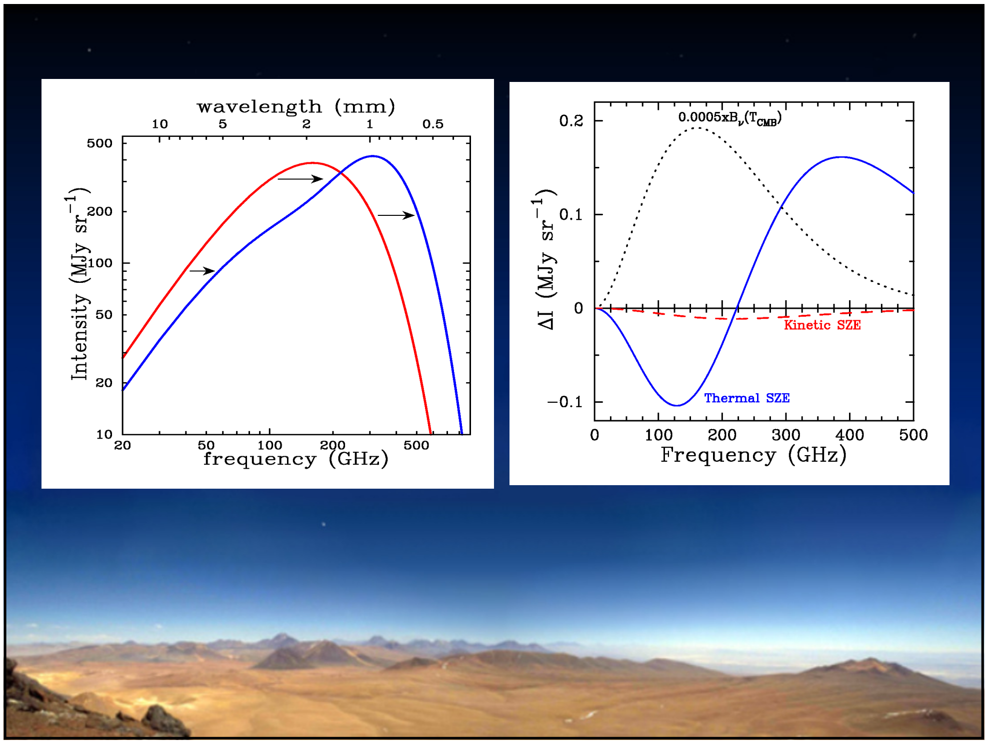


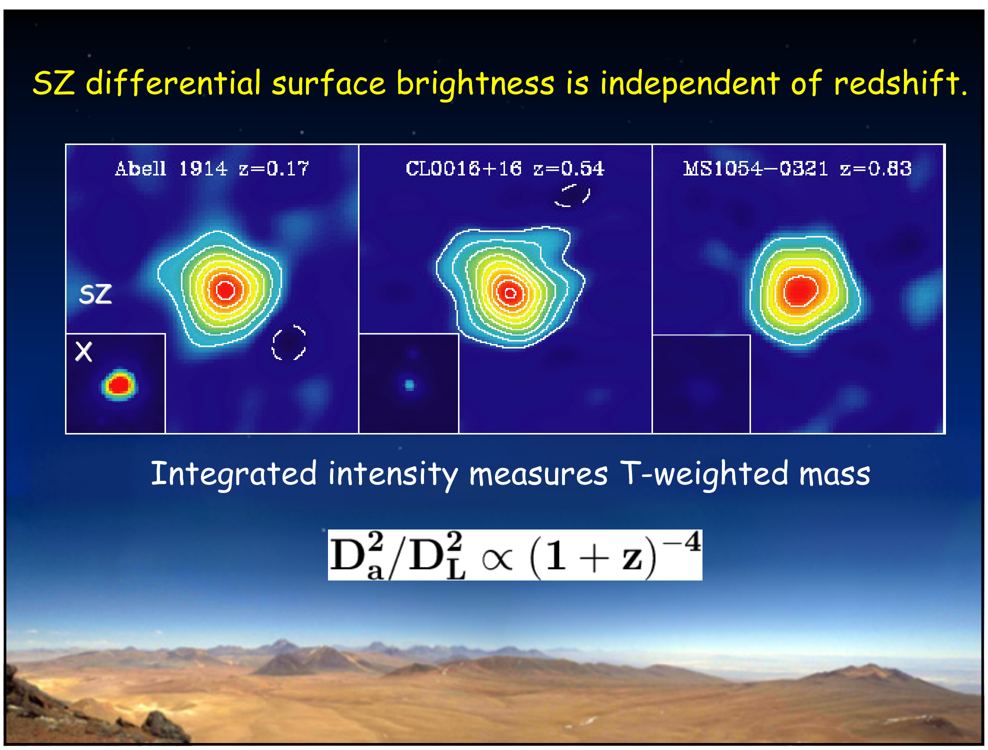
1.5m Tertiary mirror at LBL shop

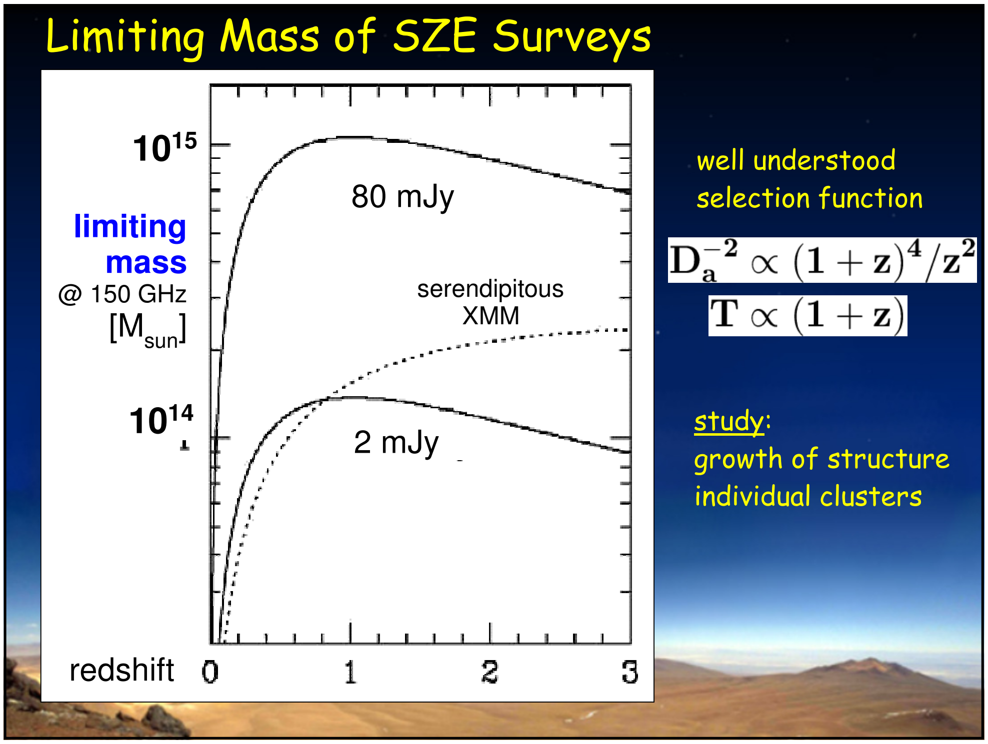


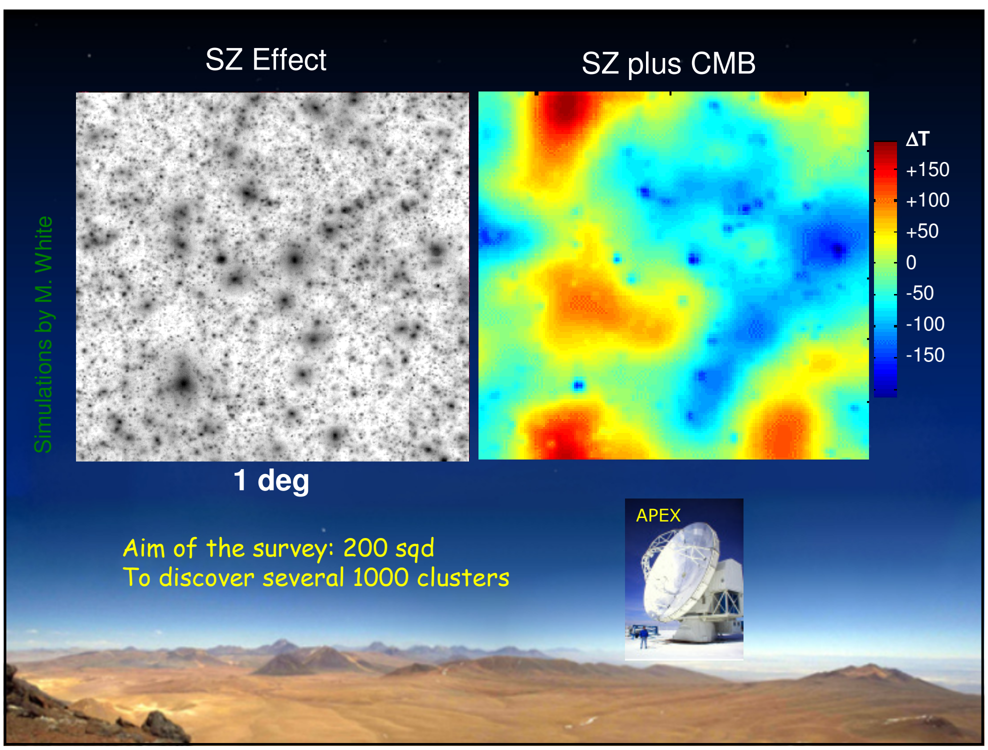

The Observation of Relic Radiation as a Test of the Nature of X-Ray Radiation from the Clusters of Galaxies
Introduction
The x-ray radiation from a number of clusters of galaxies (Coma, Virgo, Perseus) was discovered recently.[1] It is assumed that clusters of galaxies form an important class of powerful x-ray sources, possibly giving the main contribution to the x-ray background radiation of the Universe.[2] What is the nature of these sources? What physical mechanisms give the observed x-ray radiation?
Most likely this is either the bremsstrahlung radiation of hot intergalactic gas or inverse Compton scattering on the relativistic electrons. Again the question arises—what kind of radiation and where is it scattered? The relic photons in the intergalactic space,[3] or in haloes of massive elliptical galaxies,[4] or infrared radiation in the vicinity of nuclei of galaxies?[5] The observations of small perturbation in angular distribution of relic radiation can give an answer to these questions. These observations enable us to distinguish between hot nonrelativistic electron gas (being a bremsstrahlung source) and a less numerous group of relativistic electrons. The hole in the relic radiation—the decreasing of its brightness temperature in the Rayleigh–Jeans spectral region,
$\frac{\Delta T_r}{T_r} = -2\frac{kT_e}{m_e c^2}\sigma_T N_e l,$
R. A. SUNYAEV
YA. B. ZELDOVICH
Institute of Applied Mathematics, Moscow
Comments on Astrophysics and Space Physics 1972
T_r
2.7
cluster of galaxies
angle coordinate
FIG. 1. The "hole" in the microwave background.
Rashid Sunyaev *1943
Yakov Zel'dovich (1914-1987)

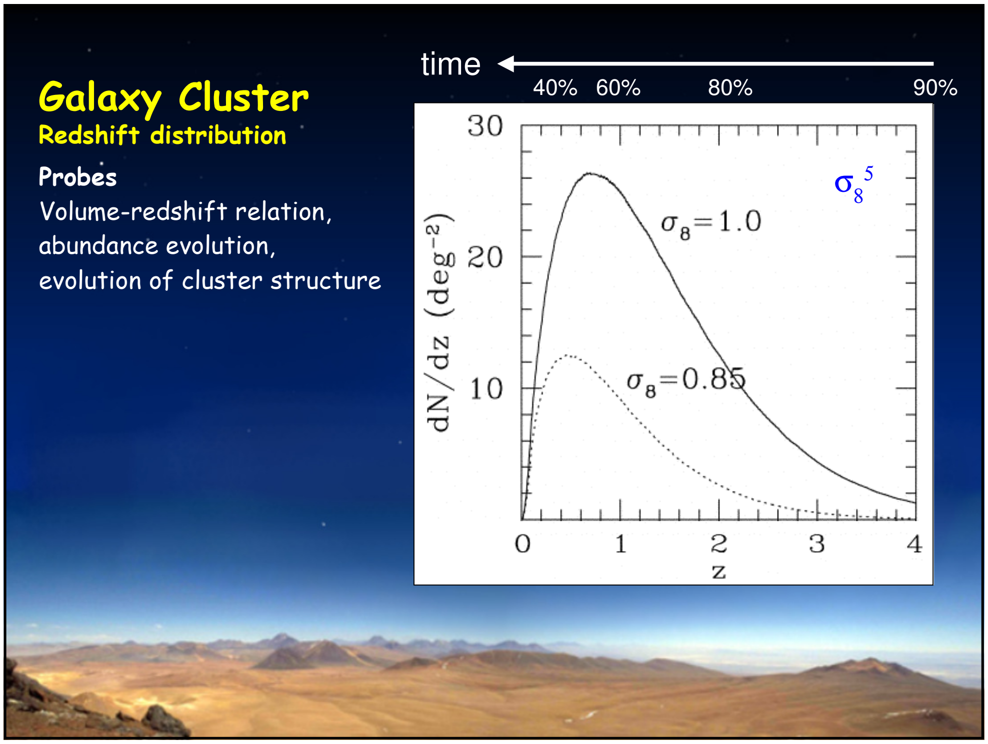

The Sunyaev-Zel'dovich Effect
Big Bang
today
0
379,000 yr
z=1089
time
14 Gyr


wavelength (mm)
10
5
2
1
0.5
Intensity (MJy sr⁻¹)
500
200
100
50
20
10
20
50
100
200
500
frequency (GHz)
0.0005xBν(TCMB)
ΔI (MJy sr⁻¹)
0.2
0.1
0
−0.1
Kinetic SZE
Thermal SZE
0
100
200
300
400
500
Frequency (GHz)


SZ differential surface brightness is independent of redshift.
Abell 1914 z=0.17
CL0016+16 z=0.54
MS1054−0321 z=0.83
SZ
X
Integrated intensity measures T-weighted mass
$\mathbf{D_a^2/D_L^2 \propto (1+z)^{-4}}$


Limiting Mass of SZE Surveys
10^{15}
limiting mass
@ 150 GHz
[M_{sun}]
10^{14}
80 mJy
serendipitous XMM
2 mJy
redshift
0
1
2
3
well understood selection function
$D_a^{-2} \propto (1+z)^4/z^2$
$T \propto (1+z)$
study:
growth of structure
individual clusters


SZ Effect
SZ plus CMB
Simulations by M. White
1 deg
ΔT
+150
+100
+50
0
-50
-100
-150
APEX
Aim of the survey: 200 sqd
To discover several 1000 clusters


Galaxy Cluster
Redshift distribution
Probes
Volume-redshift relation,
abundance evolution,
evolution of cluster structure
time
40% 60% 80% 90%
30
20
10
dN/dz (deg^{-2})
σ_8^5
σ_8=1.0
σ_8=0.85
0 1 2 3 4
z

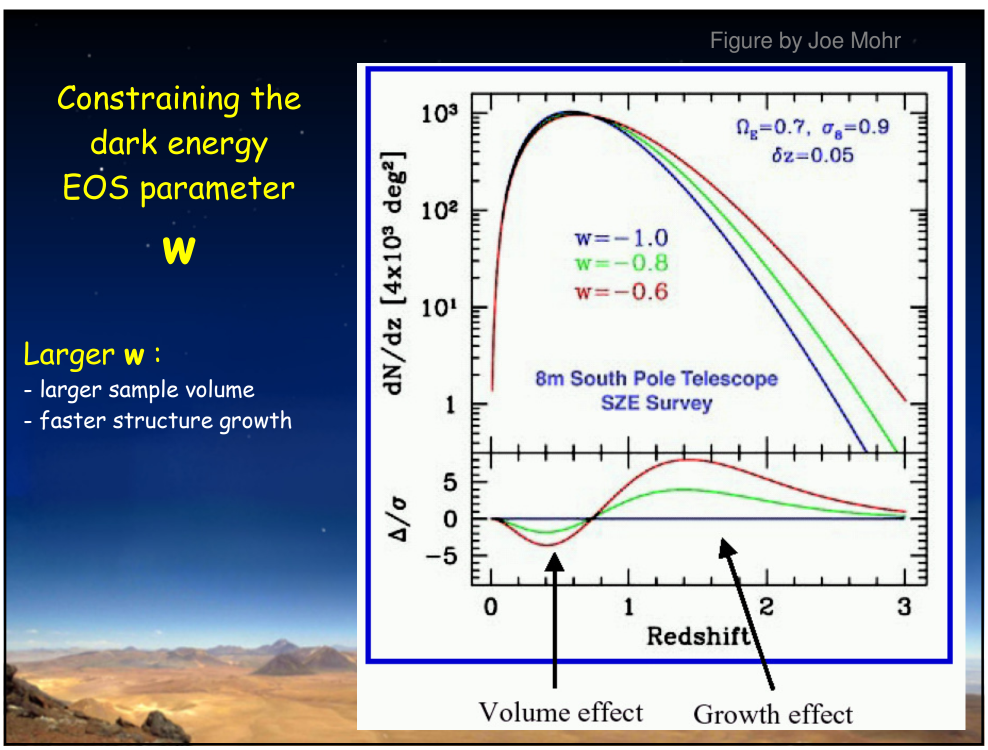
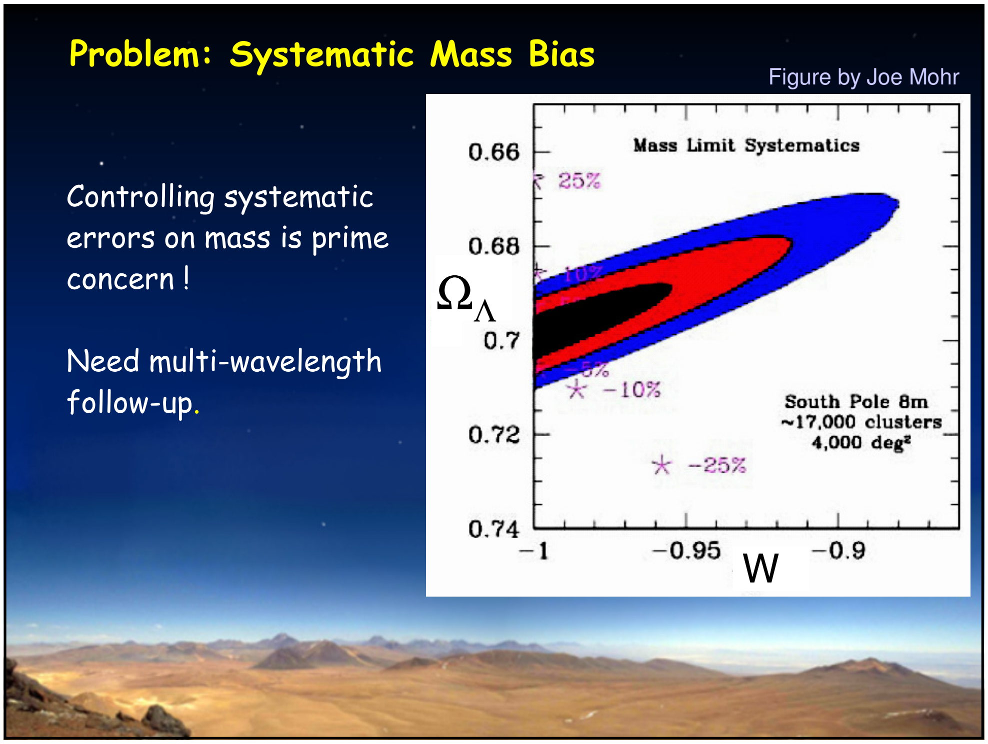
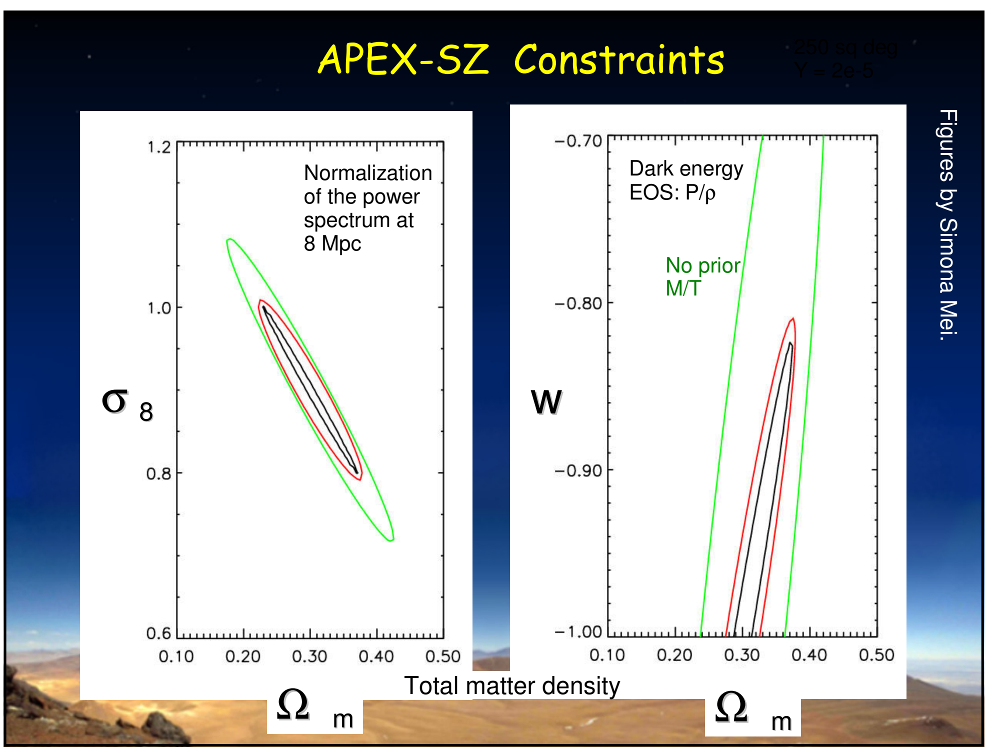
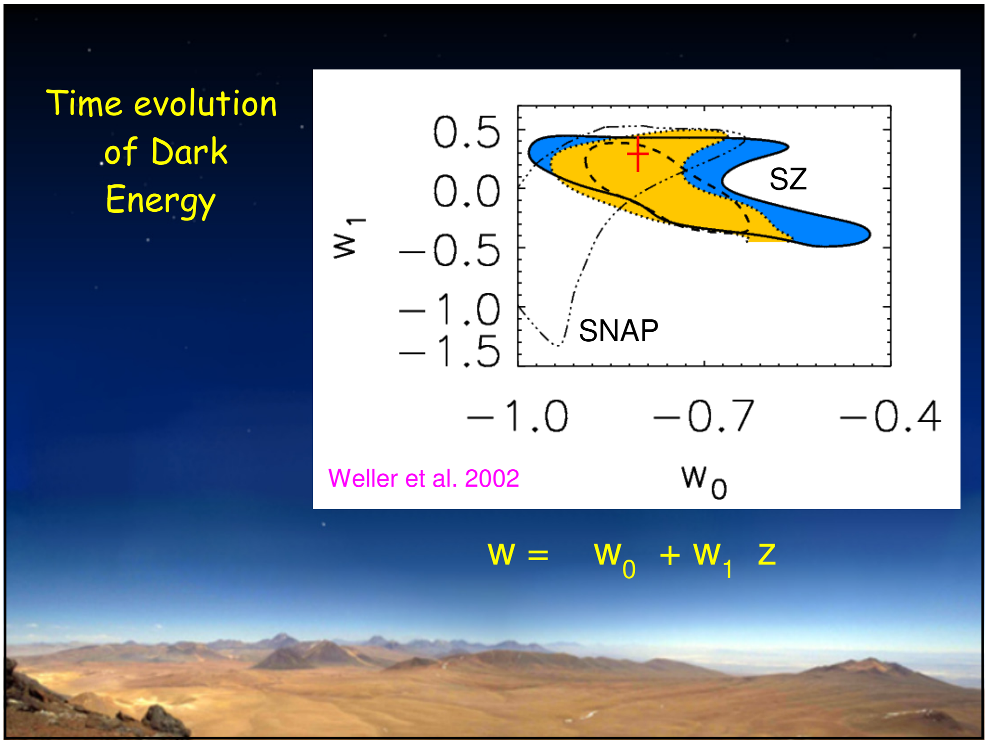
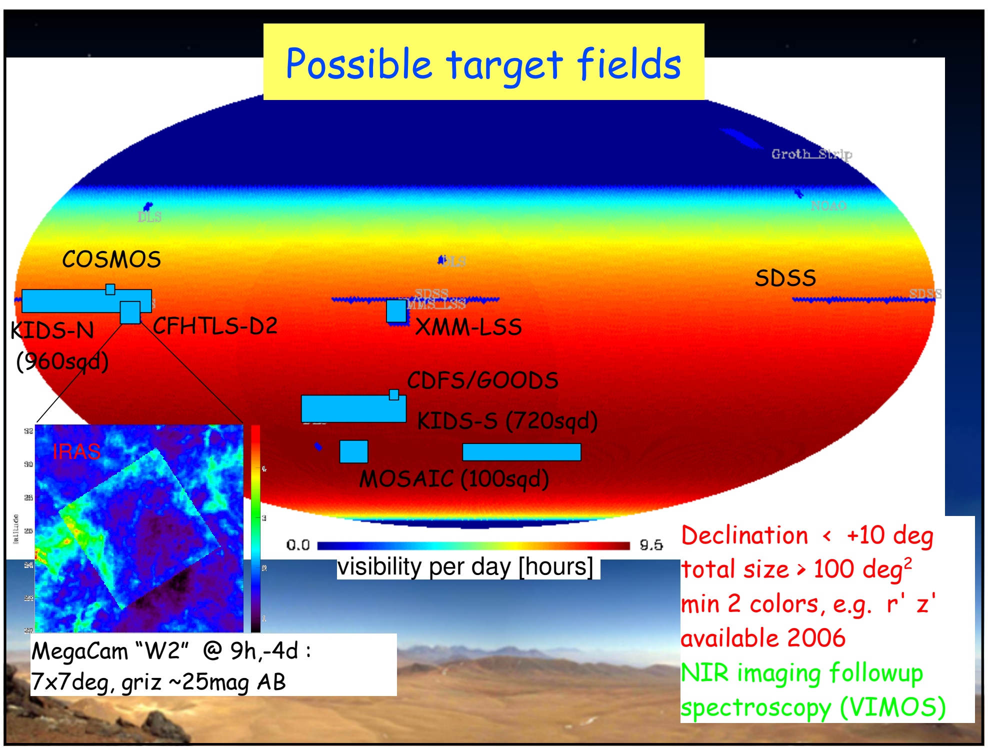


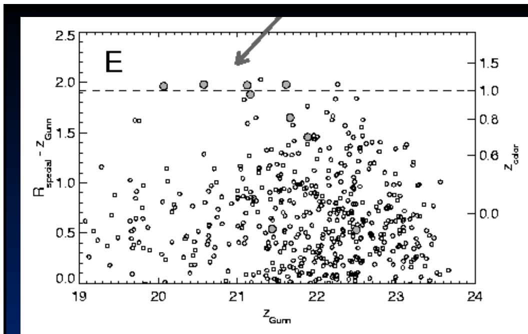
Figure by Joe Mohr
Constraining the
dark energy
EOS parameter
w
Larger w :
- larger sample volume
- faster structure growth
10^3
10^2
10^1
1
dN/dz [4x10^3 deg^2]
Ω_E=0.7, σ_8=0.9
δz=0.05
w=−1.0
w=−0.8
w=−0.6
8m South Pole Telescope
SZE Survey
5
0
−5
Δ/σ
0 1 2 3
Redshift
Volume effect
Growth effect


Problem: Systematic Mass Bias
Figure by Joe Mohr
Controlling systematic errors on mass is prime concern !
Need multi-wavelength follow-up.
Mass Limit Systematics
25%
10%
-5%
-10%
-25%
South Pole 8m
~17,000 clusters
4,000 deg²
0.66
0.68
0.7
0.72
0.74
Ω_Λ
-1
-0.95
-0.9
W


APEX-SZ Constraints
Figures by Simona Mei.
Normalization of the power spectrum at 8 Mpc
1.2
1.0
0.8
0.6
σ_8
0.10
0.20
0.30
0.40
0.50
Ω_m
Total matter density
Dark energy EOS: P/ρ
No prior M/T
-0.70
-0.80
-0.90
-1.00
w
0.10
0.20
0.30
0.40
0.50
Ω_m


Time evolution of Dark Energy
0.5
0.0
−0.5
−1.0
−1.5
w1
SZ
SNAP
−1.0
−0.7
−0.4
Weller et al. 2002
w0
w = w0 + w1 z


Possible target fields
COSMOS
SDSS
KIDS-N (960sqd)
CFHTLS-D2
XMM-LSS
CDFS/GOODS
KIDS-S (720sqd)
MOSAIC (100sqd)
IRAS
0.0
9.5
visibility per day [hours]
MegaCam "W2" @ 9h,-4d :
7x7deg, griz ~25mag AB
Declination < +10 deg
total size > 100 deg2
min 2 colors, e.g. r' z'
available 2006
NIR imaging followup
spectroscopy (VIMOS)

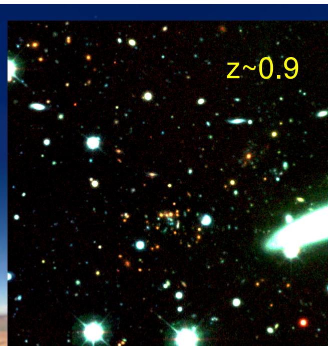


2-Color Photometric Redshifts

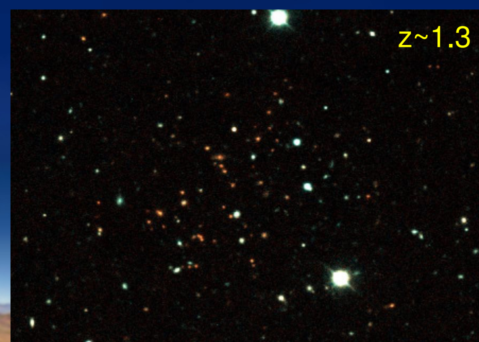
clusters show a "red sequence" of early-type galaxies

Gladders et al. @ CFHT

z' = 23.5 (5σ)
r' = 25 (5σ)



2.7 x 2.7 arcmin



2x3 arcmin

Prospects:

SZ surveys will produce precision cosmological constraints competitive with DEEP, SNAP and CMB anisotropy.

Tasks ahead and along:

- evolution of cluster properties:
  size, temperature, structure, virialization

Tune Observable-Mass relation !!

- Non-gravitational heating (star formation) and chemical enrichment.
- Evolution of galaxy populations in clusters (nothing known at z>1)