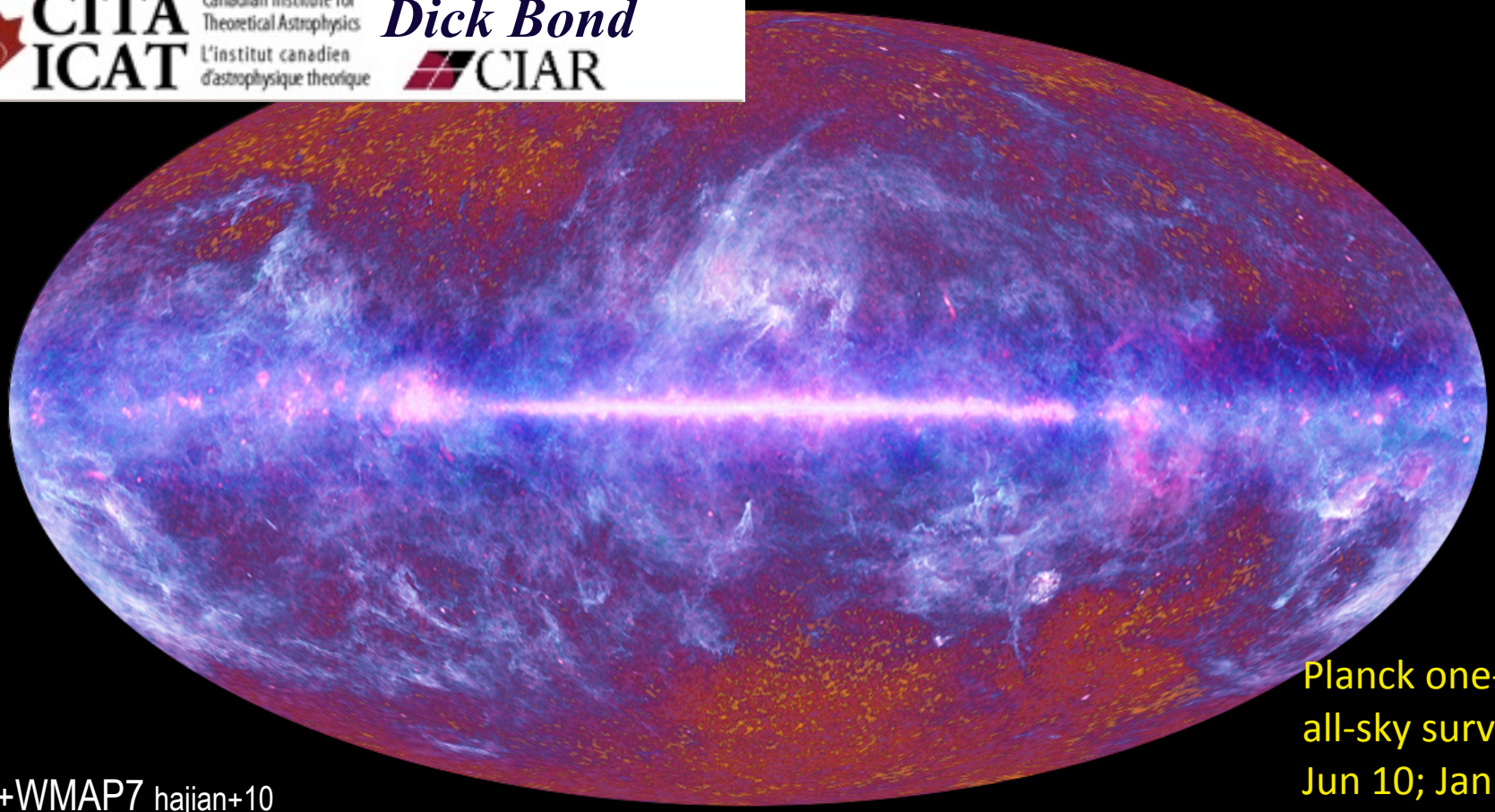
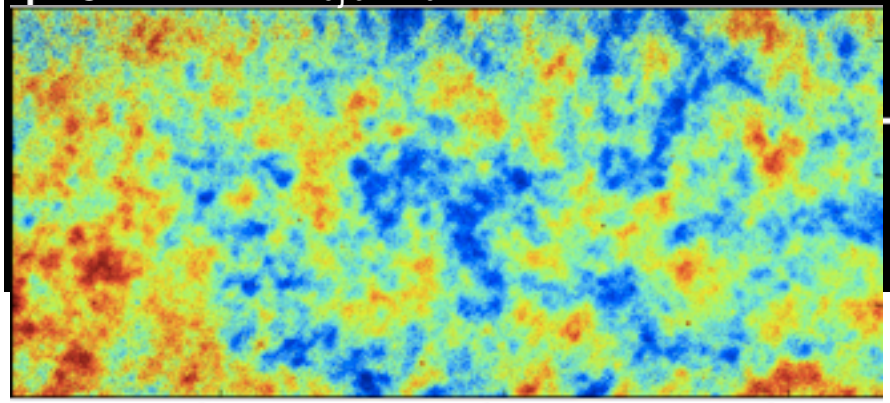
Cluster Information from Compton Heating of the CMB: ACT, Planck & Theory

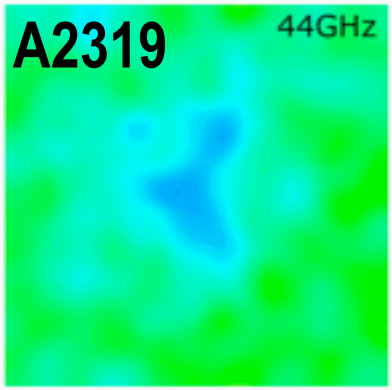
CITA ICAT Canadian Institute for Theoretical Astrophysics / L'institut canadien d'astrophysique theorique
Dick Bond
CIAR

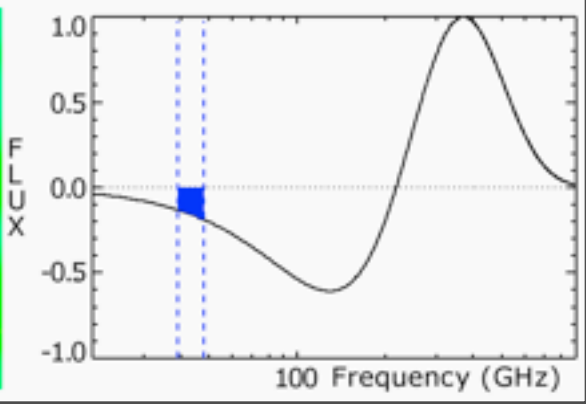


Planck one-year all-sky survey
Jun 10; Jan 11

ACT+WMAP7 hajian+10







CBI pol to Apr'05 @Chile

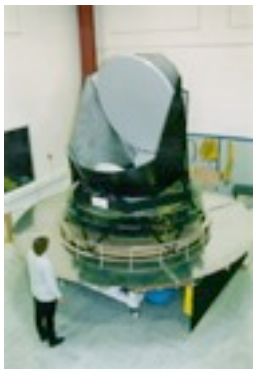
CBI2

QUaD @SP

Planck09.4

52+ bolometers
+ HEMTs @L2

9 frequencies



WMAP @L2 to 2010

2004 2006 2008 LHC 2011 Bpol @L2

2005 2007 2009

Acbar@SP

AMIBA

SPT
1000 bolos
@SPole

>96
OVRO
/BIMA
array

SZA@Cal

AMI

APEX
~400 bolos@Chile

ACT
3000 bolos
3 freqs @Chile

SCUBA2
12000 bolos
JCMT @Hawaii

SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

80s-90s
Ryle
OVRO

GBT Mustang

fluctuations in the **early universe "vacuum" grow** to ***all*** **structure**

400 Mpc

ΛCDM

WMAP5

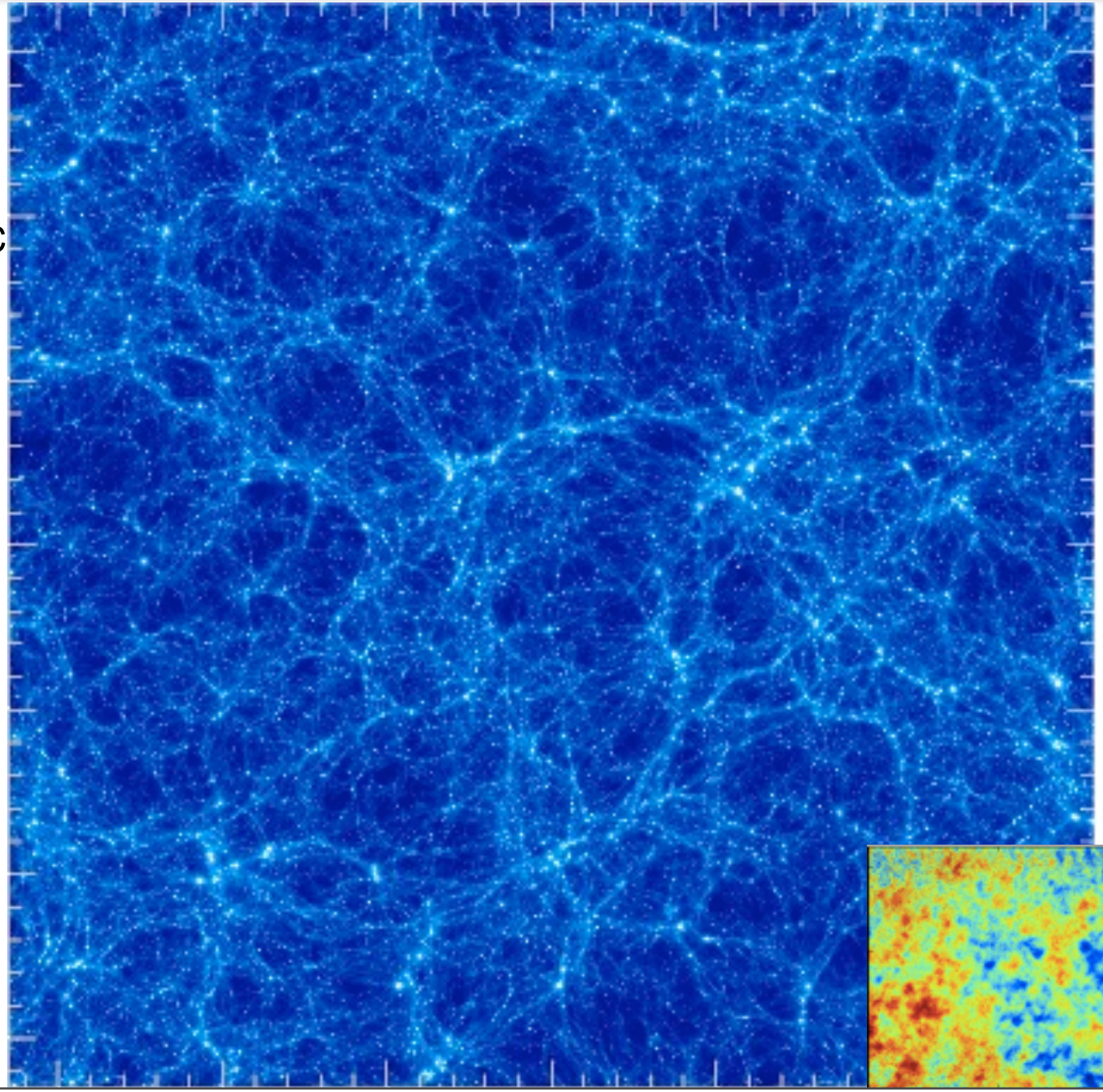
gas density

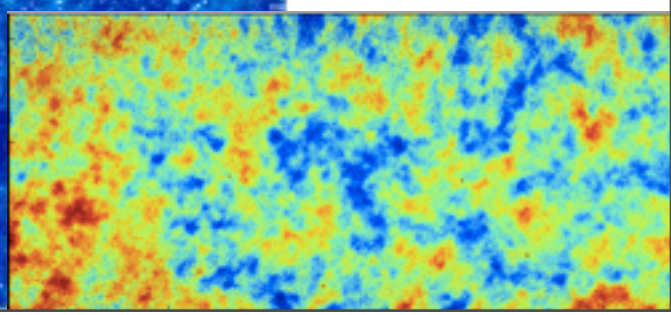
Gadget-3

SF+ SN E+ winds +CRs

512^3

BBPSS10





all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential aka dark energy

pressure intermittency *in the cosmic web, in cluster-group concentrations probed by* **tSZ**

400 Mpc

ΛCDM

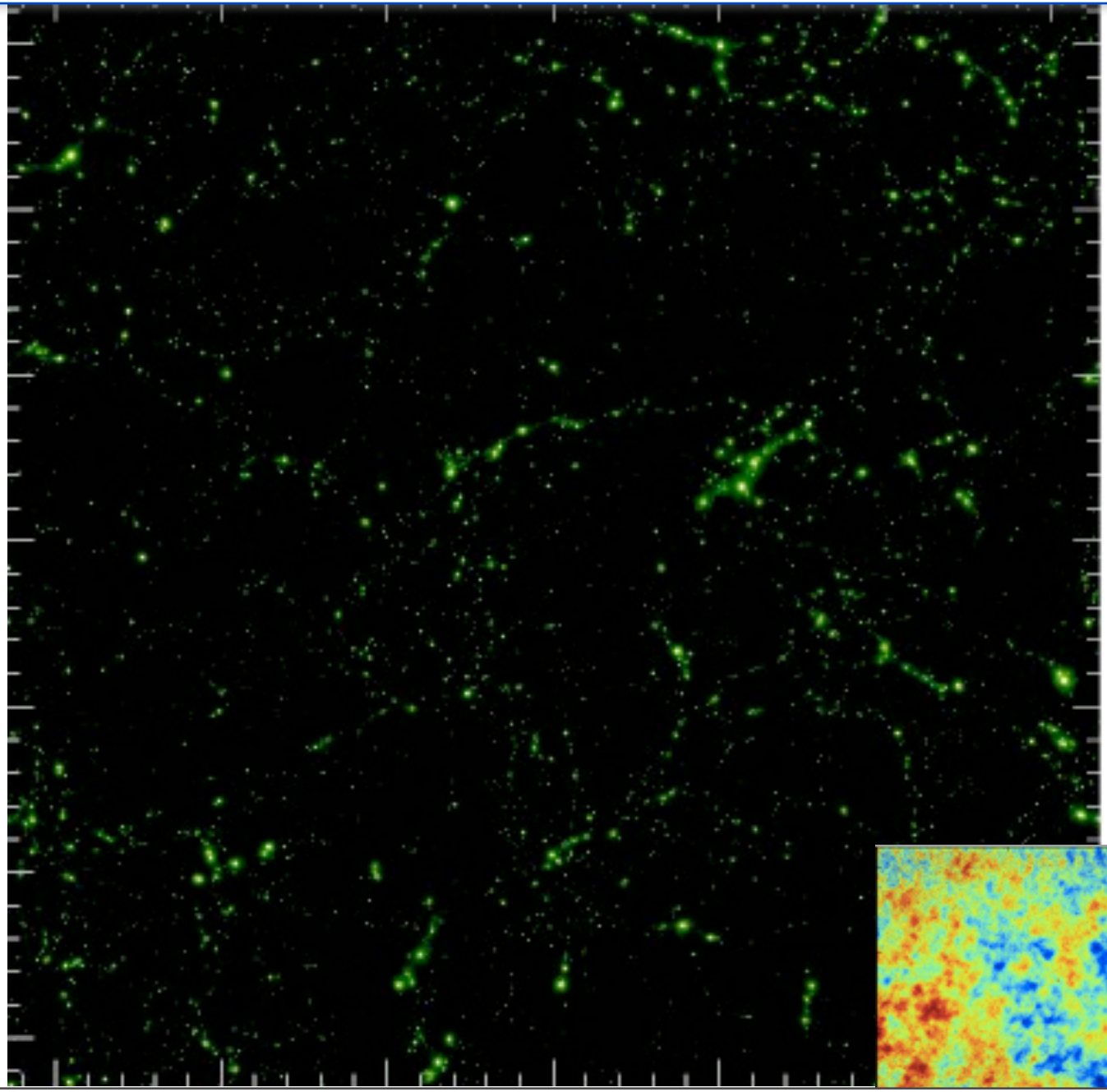
WMAP5

gas pressure

Gadget-3 SF+ SN E+ winds +CRs

512^3

BBPSS10



CMB gets entangled in the cosmic web

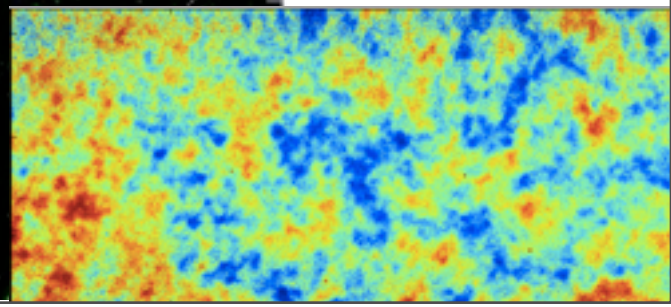
descending into the real gastrophysics

of

cosmic weather

the energetic, turbulent, dissipative, compressive

life of the IGM/ICM/ISM



inner space outer space chicago apr 1984 from ITP84


inner space outer space chicago apr 1984 from ITP84


cita@25/bond@classified toronto 2010


cifar@05 mt tremblant, quebec:
the dangers of probing high peaks

CBI pol to Apr'05 @Chile

53+35 cls (>=40)

CBI2

QUaD @SP

189 +10 cls (>=1000)

Planck09.4

52+ bolometers
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9 frequencies

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2004 2006 2008 LHC 2011

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2005 2007 2009

21+26~50 (>=750)

Acbar@SP

~1 blind

AMIBA

6 cls

SPT

1000 bolos
@SPole

>96

OVRO /BIMA

array

38 cls

SZA@Cal

3 cls (z>1), x?

ACT

23+27~50 cls

3000 bolos

3 freqs @Chile

AMI

7+1 cls >=50+25

APEX

~400 bolos@Chile

~25 cls

SPTpol

ACTpol

ALMA

80s-90s

Ryle

OVRO

GBT Mustang

4 cls (~25 CLASH)

SCUBA2

12000 bolos

JCMT @Hawaii

CCAT@Chile

LMT@Mexico

CBI pol to Apr'05 @Chile

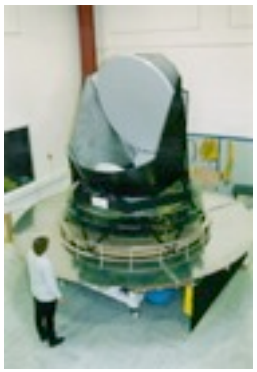
CBI2

QUaD @SP

C_L^{SZ}

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies



WMAP @L2 to 2010

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LHC

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ALMA
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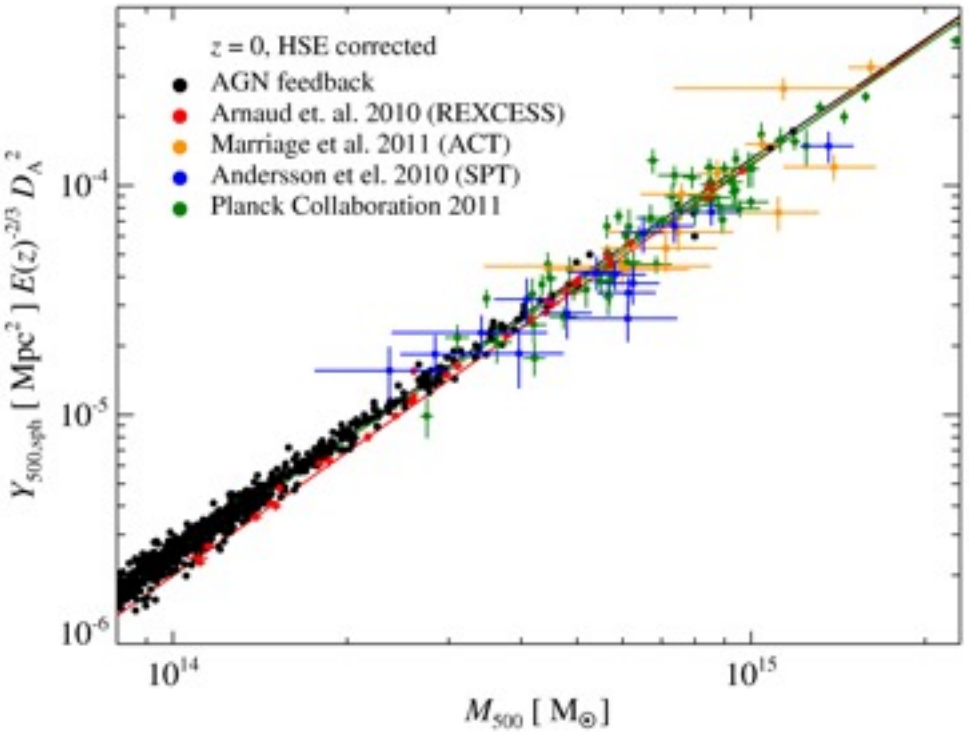
LMT@Mexico

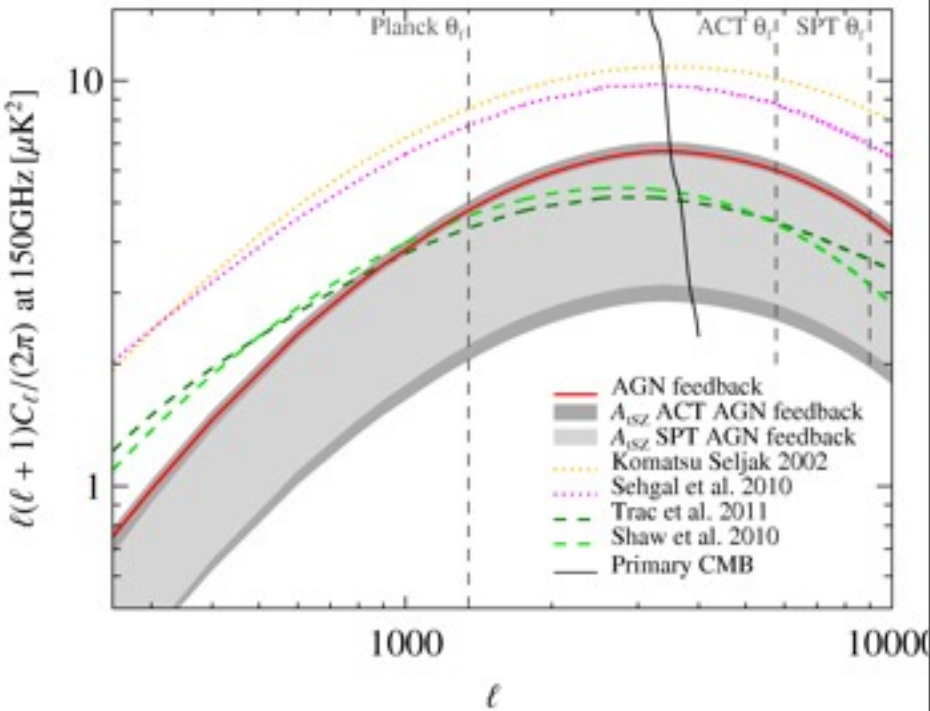
80s-90s
Ryle
OVRO

Cluster Coarse-Grained Feedback Sims cf. SZ data ACT, SPT, Planck

Cluster counts $n_{cl}(M(Y))dM$ + tSZ/kSZ Power spectrum

Battaglia, Bond, Pfrommer, Sievers 2011: I,II,III,IV; BBPS+Sijacki 2010





both are sensitive to gastrophysics:
resolution, feedbacks(M,z), kinetic $\langle\delta V\delta V^\dagger\rangle$ cf. thermal pressure, $\langle\delta X\delta X^\dagger\rangle$anisotropy, p&ρ-clumping, non-equilibrium cluster-outskirts

Cluster Coarse-Grained Feedback Sims cf. SZ data ACT, SPT, Planck

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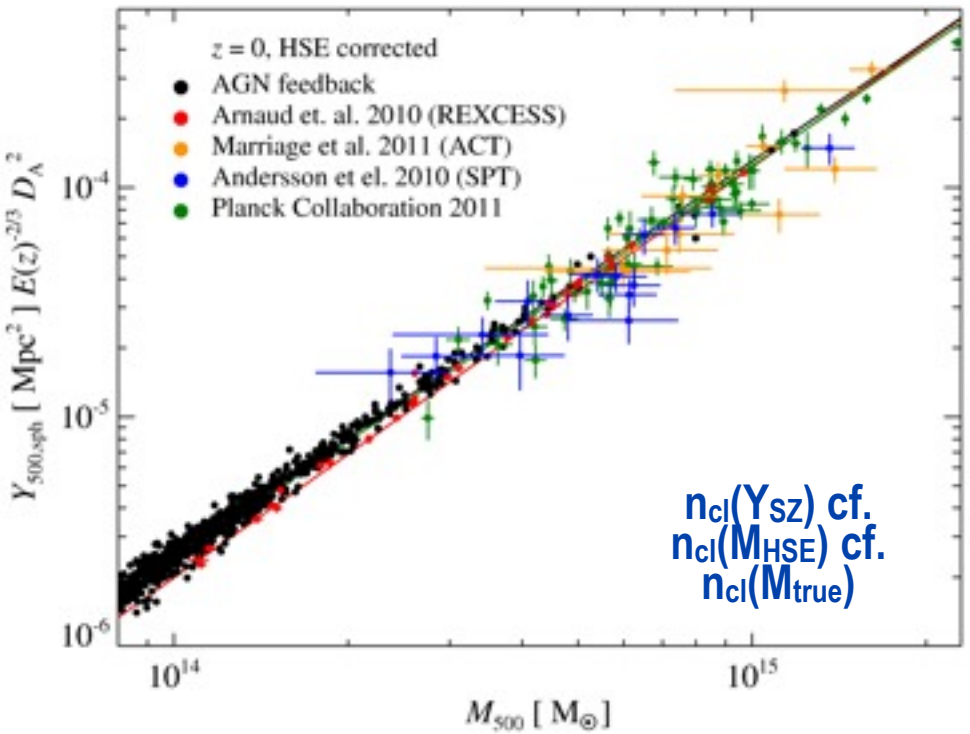
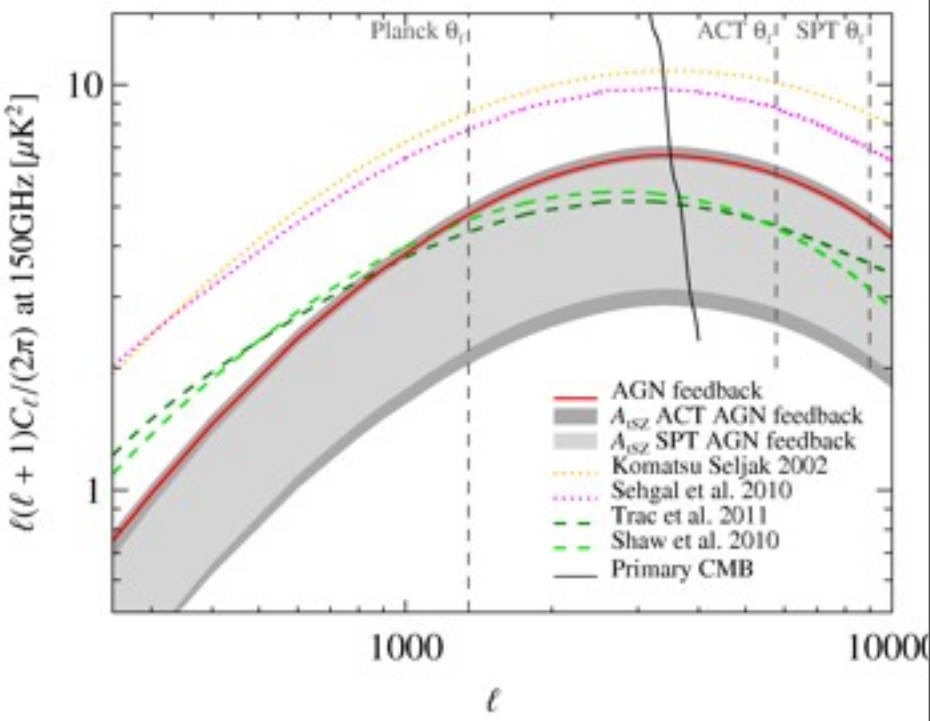




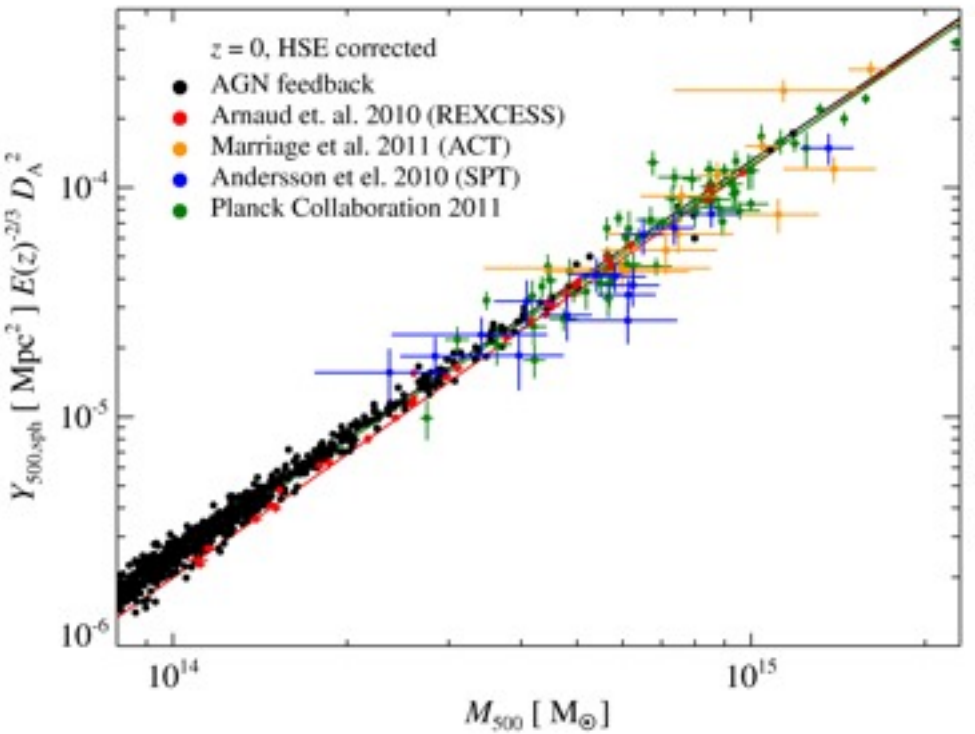
YSZ-M (Planck, ACT) and YX-M (ROSAT) offset when stacked at optical positions (e.g., maxBCG). Hint for sub-populations? Optical selection? Mx cf. MLens cf. Mbias?...

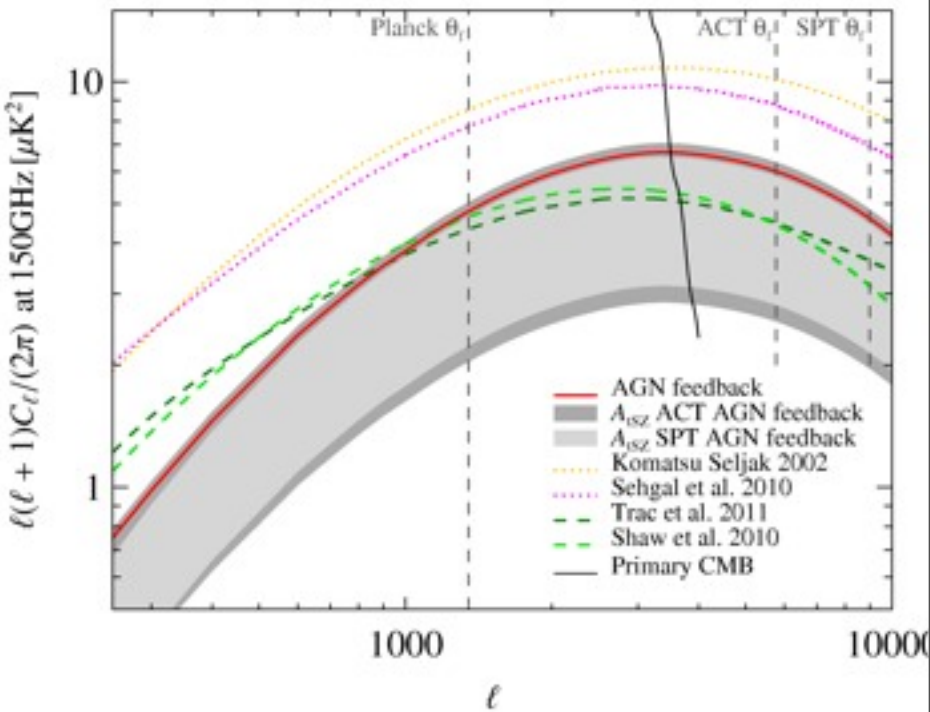
σ_{8SZ} a little low cf. $\sigma_{8primary}$ (ACT,SPT) but within ~1 sigma with feedback, KS-style analytics were way off, incrementally corrected, in response to our sims. the full ACT data is being analyzed now. Planck CLSZ will come in Jan 2013.

Cluster Coarse-Grained Feedback Sims cf. SZ data ACT, SPT, Planck

Cluster counts $n_{cl}(M(Y))dM$ + tSZ/kSZ Power spectrum

Battaglia, Bond, Pfrommer, Sievers 2011: I,II,III,IV; BBPS+Sijacki 2010





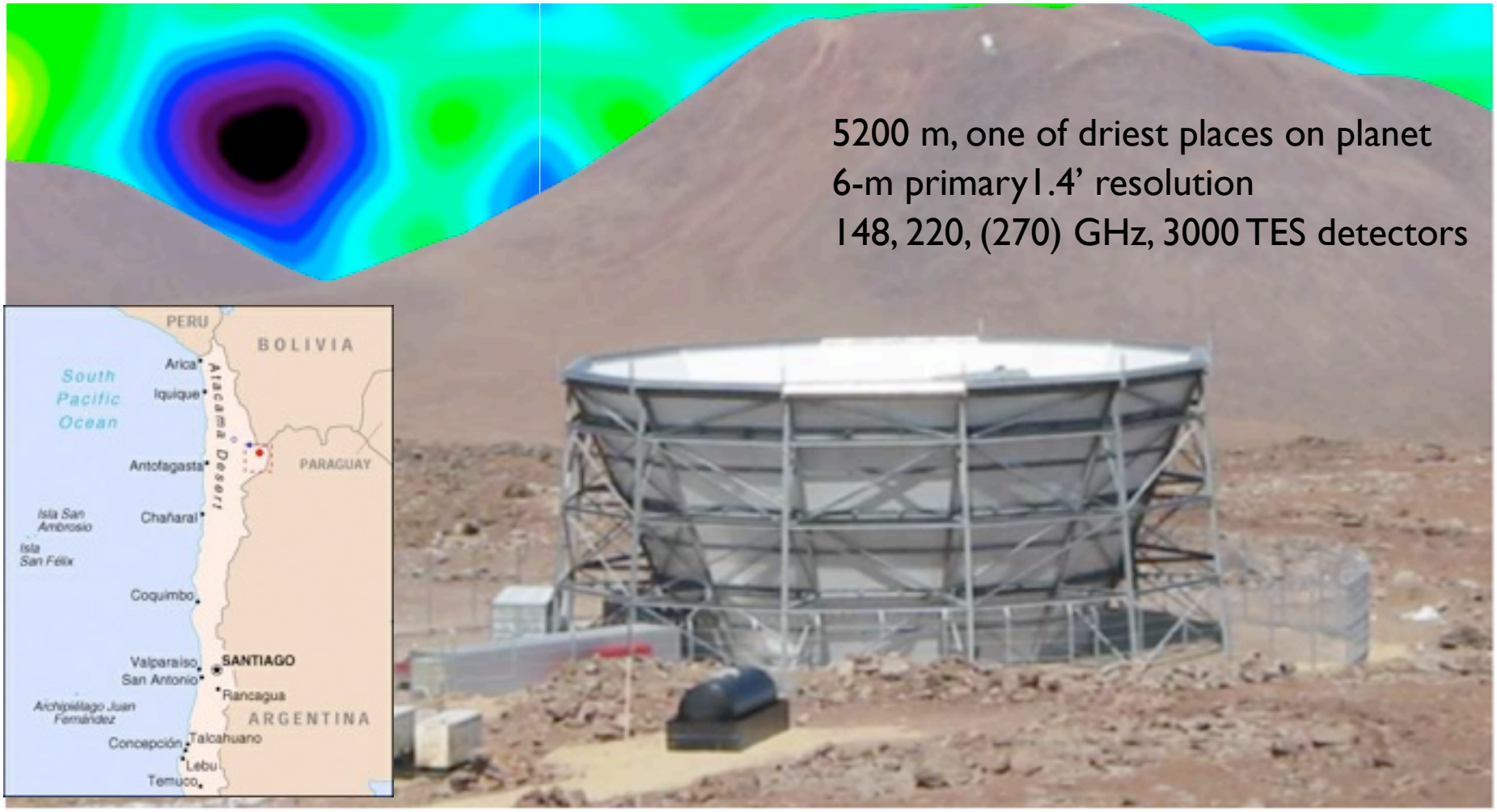
"turbulence" p_{kin}/p_{th}**~20% effect**

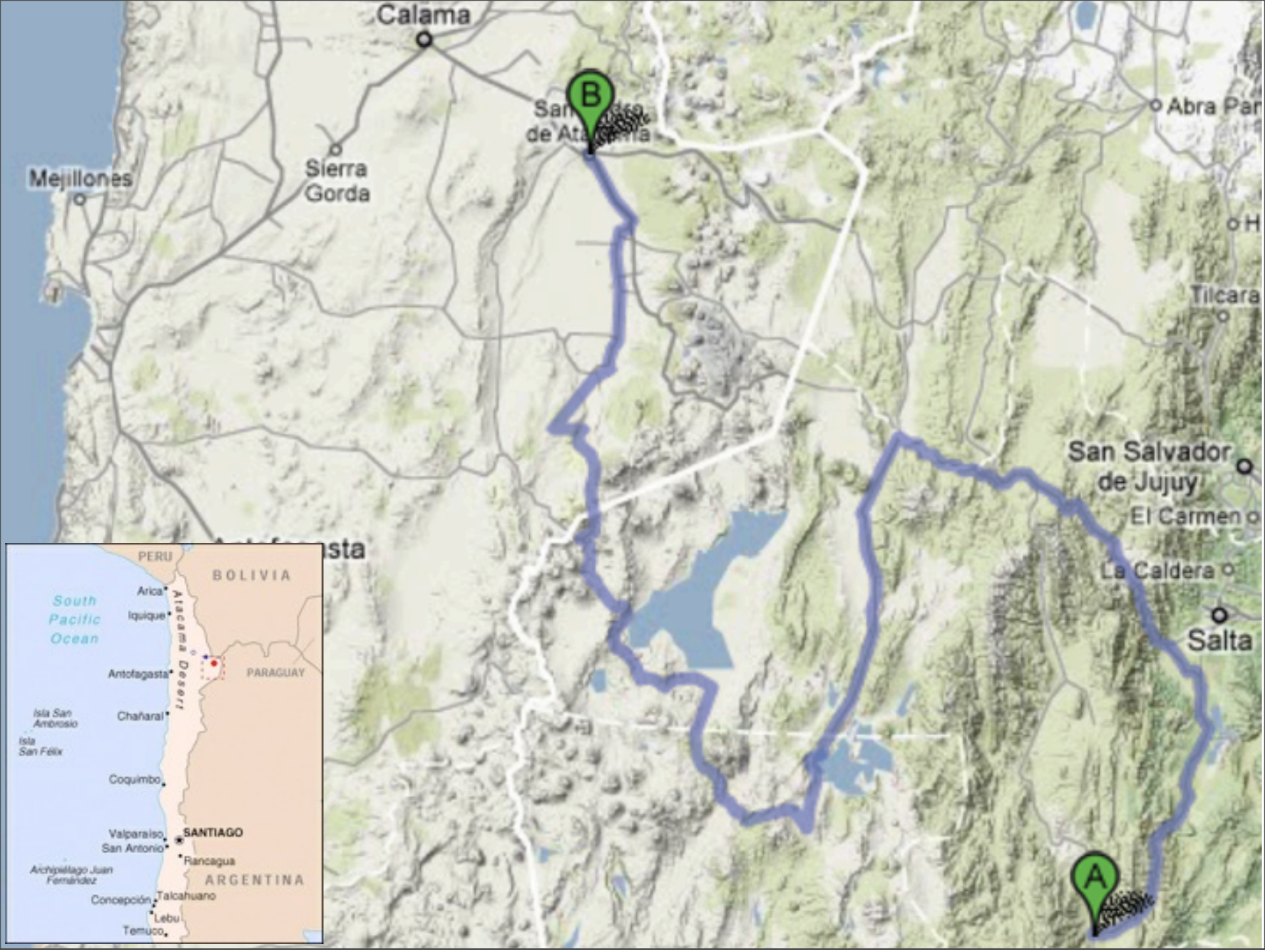
asymmetry long/short **<20%**
effect; cf. spherical **~30%**

Δ input physics ~30% effect

Cosmology From 17,000 Feet:

Results From the Atacama Cosmology Telescope




Calama
B
Mejillones
Sierra Gorda
Abra Par
Tilcara
San Salvador de Jujuy
El Carmen
La Caldera
Salta
A
PERU
BOLIVIA
South Pacific Ocean
Arica
Iquique
Atacama Desert
Antofagasta
PARAGUAY
Isla San Ambrosio
Isla San Félix
Chañaral
Coquimbo
Valparaíso
San Antonio
SANTIAGO
Rancagua
Archipiélago Juan Fernández
ARGENTINA
Concepción
Talcahuano
Lebu
Temuco

V. Acquaviva [1,2]
P. Ade [3]
P. Aguirre [4]
M. Amiri [5]
J. Appel [6]
E. Battistelli [7,5]
J. R. Bond [8]
B. Brown [9]
B. Burger [5]
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S. Dicker [2]
W. B. Doriese [11]
J. Dunkley [12,6,1]
R. Dunner [4]
T. Essinger-Hileman [6]
R.P. Fisher [6]
J.W. Fowler [6]
A. Hajian [6]
M. Halpern [5]
M. Hasselfield [5]
C. Hernandez-Monteagudo [13,2]
G. Hilton [11]
M. Hilton [14, 15]
A. D. Hincks [6]
R. Hlozek [12]
K. Huffenberger [16,6]
D. Hughes [17]
J. P. Hughes [18]
L. Infante [4]
K.D. Irwin [11]
N. Jarosik [6]
R. Jimenez [19]
J.B. Juin [4]
M. Kaul [2]
J. Klein [2]
A. Kosowsky [9]
J.M. Lau [20,6]
M. Limon [21]
Y.T. Lin [22,1,4]
R. Lupton [1]
T.A. Marriage [1,6]
D. Marsden [2]
K. Martocci [23,6]
P. Mauskopf [3]
F. Menanteau [18]
K. Moodley [14]
H. Moseley [10]
B. Netterfield [24]
M.D. Niemack [11,6]
M.R. Nolta [8]
L.A. Page (PI) [6]
L. Parker [6]
B. Partridge [25]
H. Quintana [4]
B. Reid [19,1]
N. Sehgal [20,18]
J. Sievers [8]
D. Spergel [1]
S.T. Staggs [6]
O. Stryzak [6]
D. Swetz [2]
E. Switzer [23,6]
R. Thornton [26,2]
H. Trac [27,1]
C. Tucker [3]
L. Verde [19]
R. Warne [14]
G. Wilson [28]
E. Wollack [10]
Y. Zhao [6]

[1] Princeton University Astrophysics (USA)
[2] University of Pennsylvania (USA)
[3] Cardiff University (UK)
[4] Pontifica Universidad Catolica de Chile (Chile)
[5] University of British Columbia (Canada)
[6] Princeton University Physics (USA)
[7] University of Rome "La Sapienza" (Italy)
[8] CITA, University of Toronto (Canada)
[9] University of Pittsburgh (USA)
[10] NASA Goddard Space Flight Center (USA)
[11] NIST Boulder (USA)
[12] Oxford University (UK)
[13] Max Planck Institut fur Astrophysik (Germany)
[14] University of KwaZulu-Natal (South Africa)
[15] South African Astronomical Observatory
[16] University of Miami (USA)
[17] INAOE (Mexico)
[18] Rutgers (USA)
[19] Institute de Ciencies de L'Espai (Spain)
[20] KIPAC, Stanford (USA)
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[22] IPMU (Japan)
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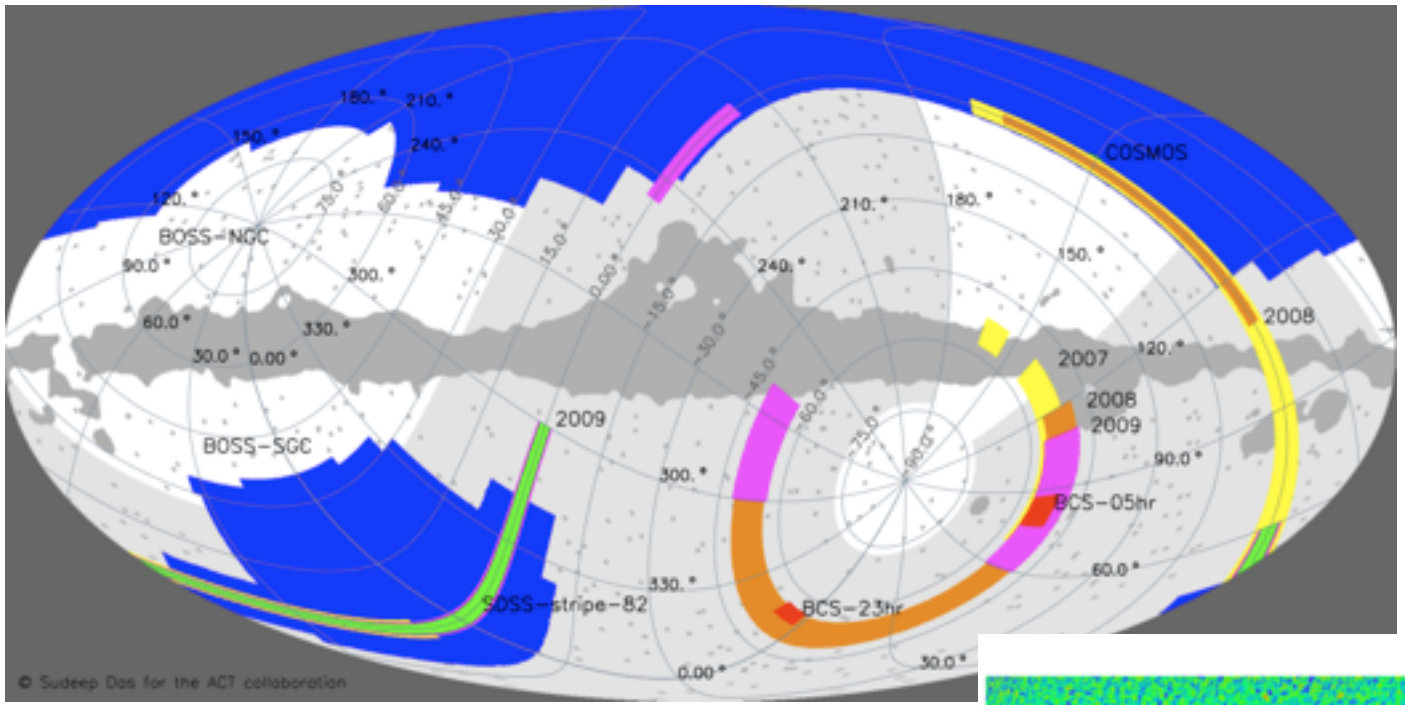
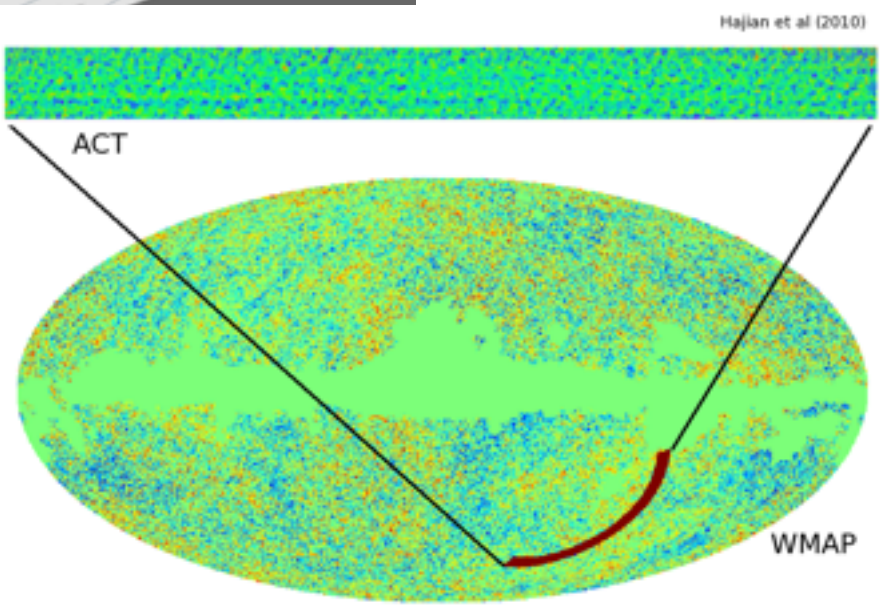
[24] University of Toronto (Canada)
[25] Haverford College (USA)
[26] West Chester University of Pennsylvania (USA)
[27] Harvard-Smithsonian CfA (USA)
[28] University of Massachusetts, Amherst (USA)
[29] BCCP UC Berkeley and LBL (USA)

end observing 2011: ACT has finished completion of 3rd full season, over ~1300 deg^2, maps@CITA. next step is ACTpol





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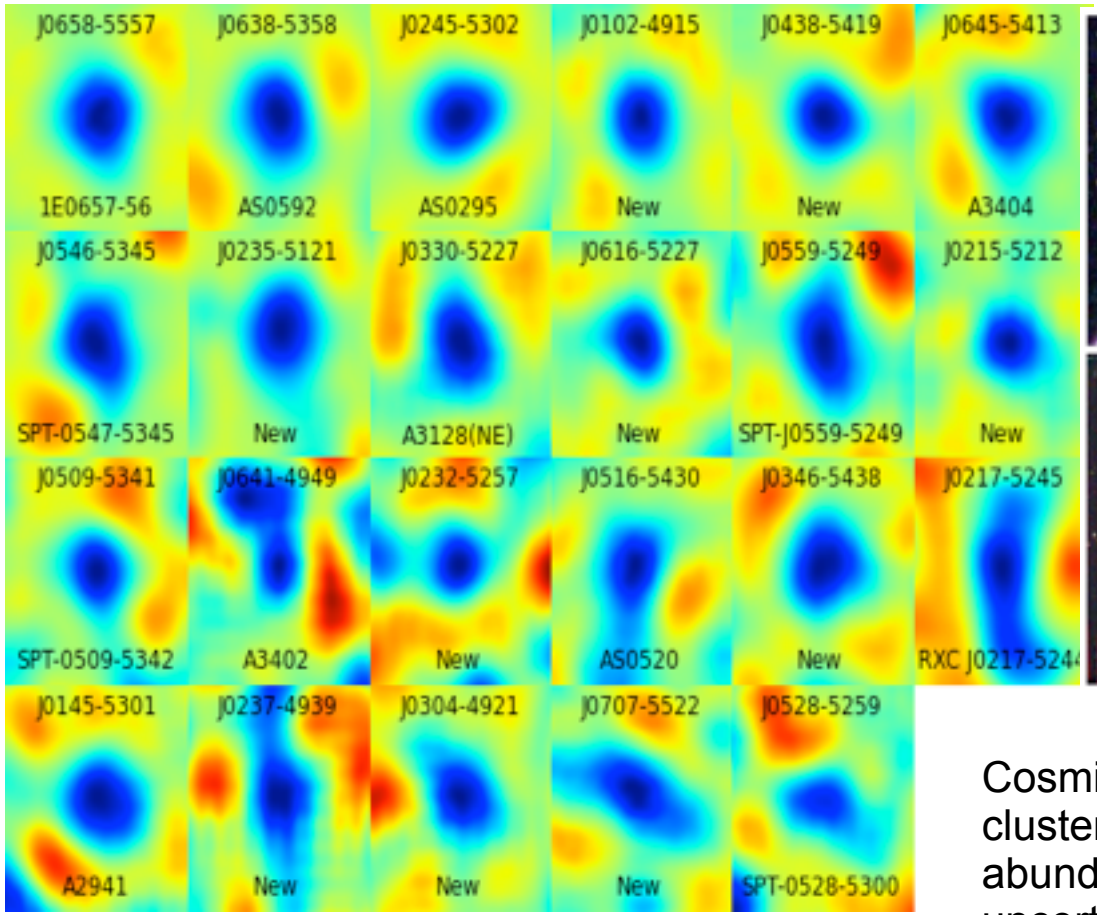
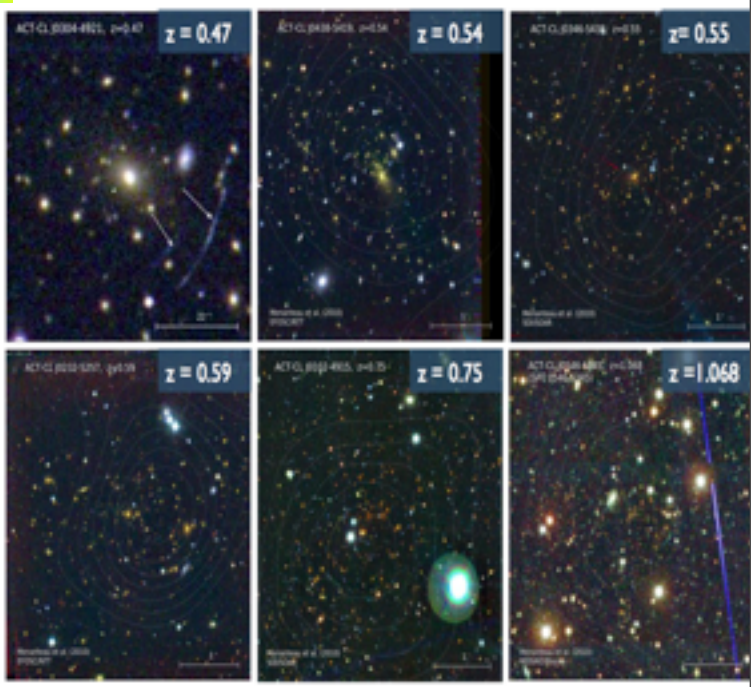
23 Galaxy Clusters Found by ACT via SZ Signal

Marriage et al 2010 (1010.1065)



Optical Observations Menanteau et al 2010 (1006.5126)



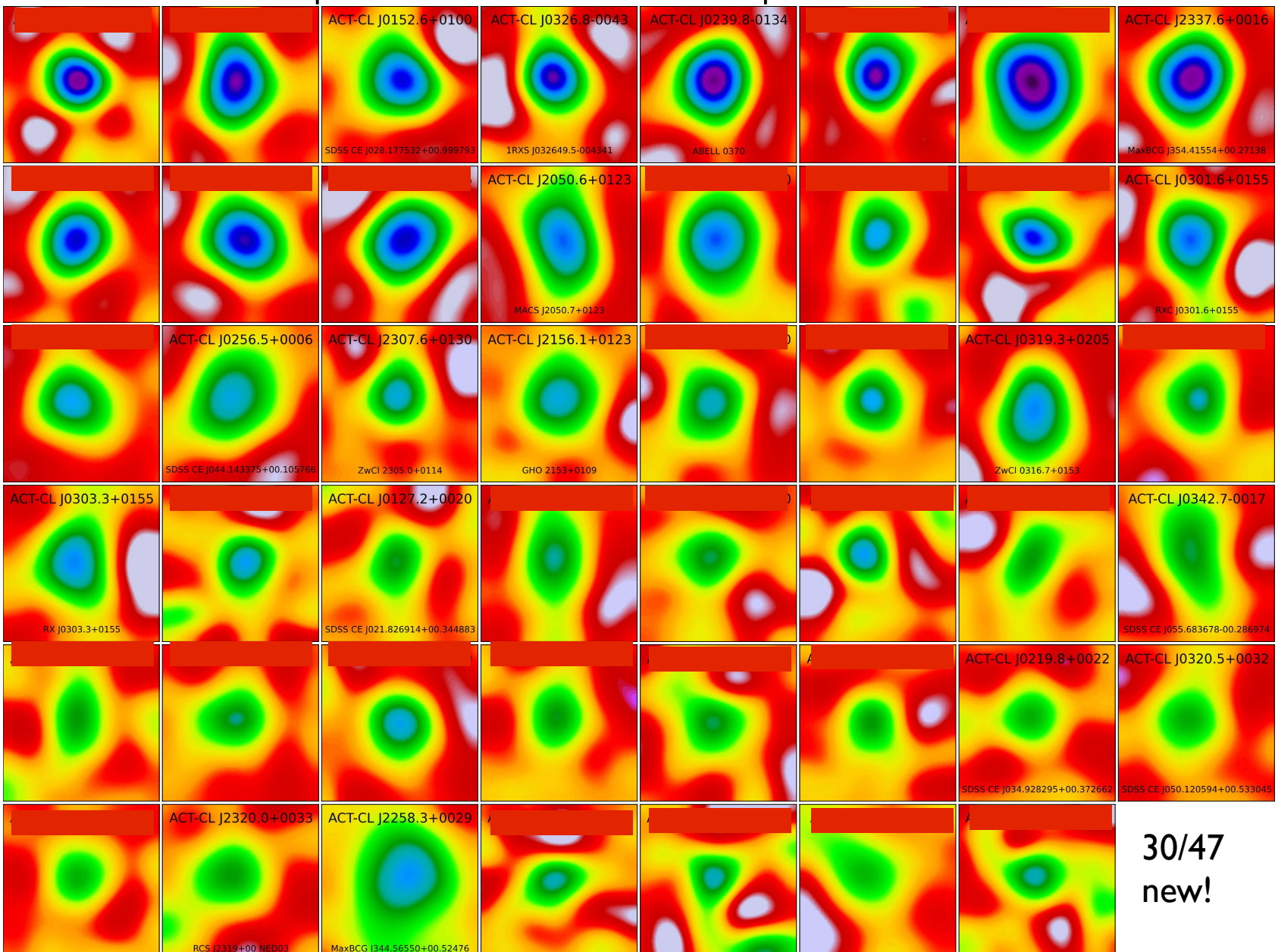
Cosmic Parameters from 9 confirmed clusters (Sehgal et al.2010) using cluster abundances => mass calibration still too uncertain (e.g. σ_8=0.82±0.05 to 0.85±0.12). attempt at Dark Energy equation of state, little leverage

With the ACT equatorial strip, >50 clusters.

Menanteau+11, in prep, “bullet”-like Cluster at z~0.87, discovered in 2009 data by Manenteau+10, highest SZ in 755 sq deg Marriage+2011, much follow-up

Optically Confirmed Equatorial Clusters

some SZA follow-up Riess+ 2011 further follow-up on GBT+SZA



30/47
new!

cluster ENTROPIES: coarse-grained information

ln p_{th} & *ln* ρ_g & *ln* ρ_{dm} & Φ_{dm+g}

$s_X \sim T_e / \rho_g^{2/3}$

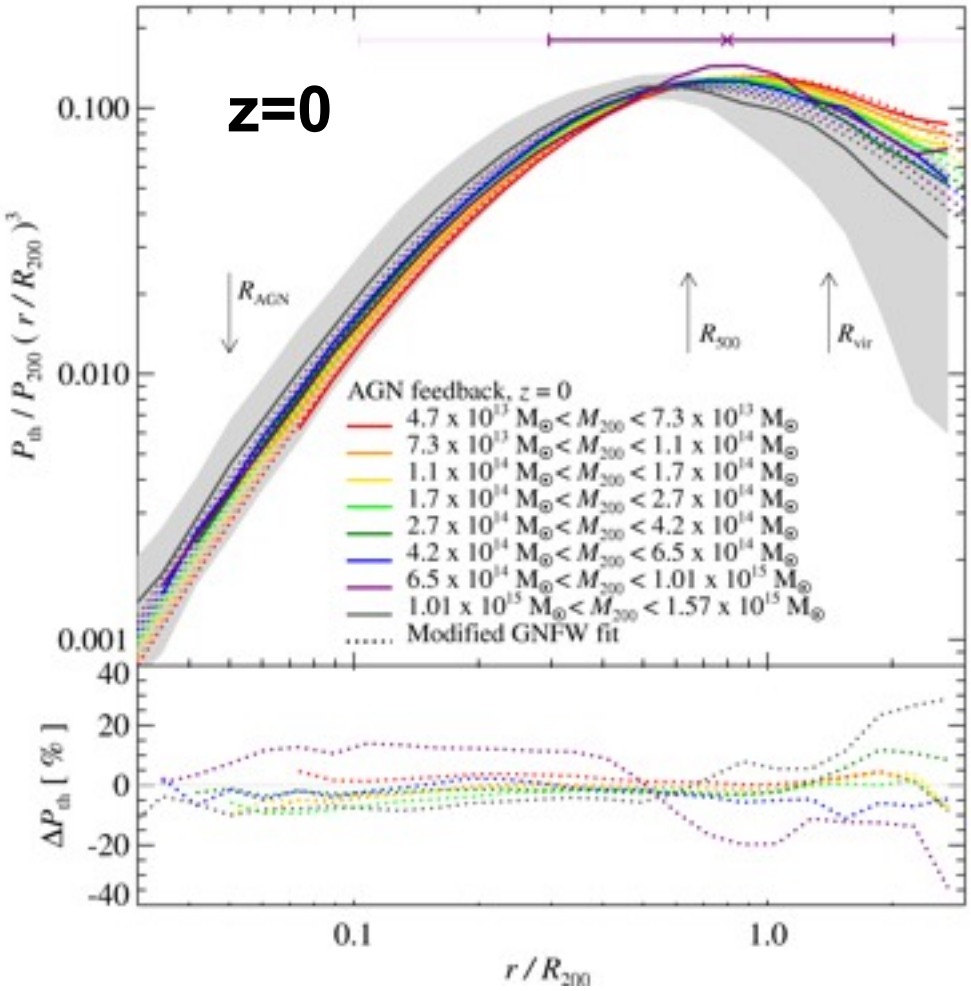
but it is p_{tot} *in the virial equation (& more)*

(10+10+20 256^3 gas+DM) (1+1+1 512^3 gas+DM) *ΛCDM* *sphericalize-scale-stack* cluster profiles, with Y_{SZ} weighting, also M & z bins.

for fast MCMC C_L^{SZ}*(cosmic & internal-cl parameters) with nonG statistics a la peak patch or ..*

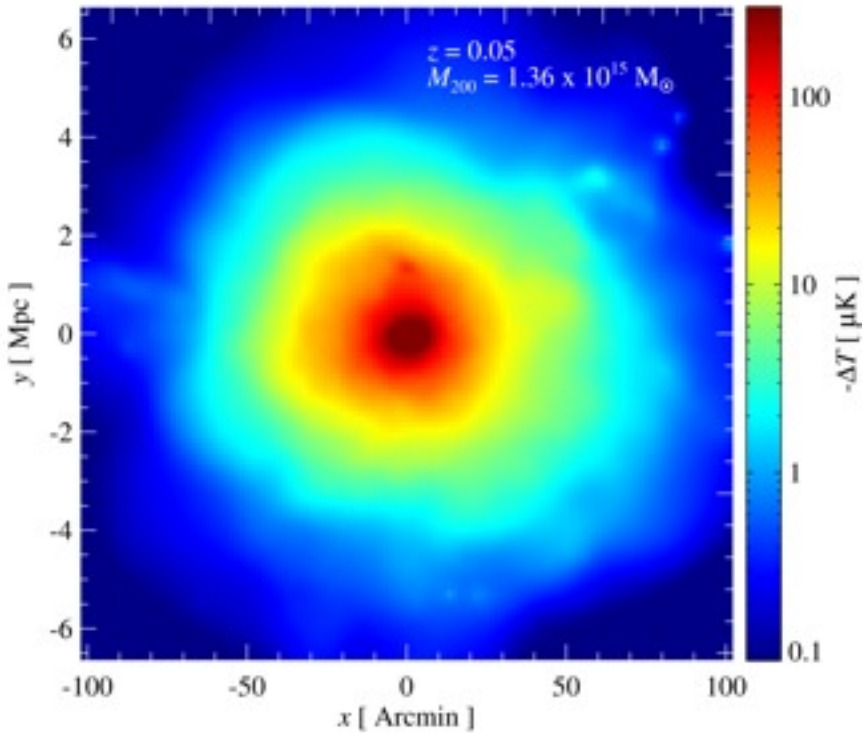
includes all non-th & non-eq effects

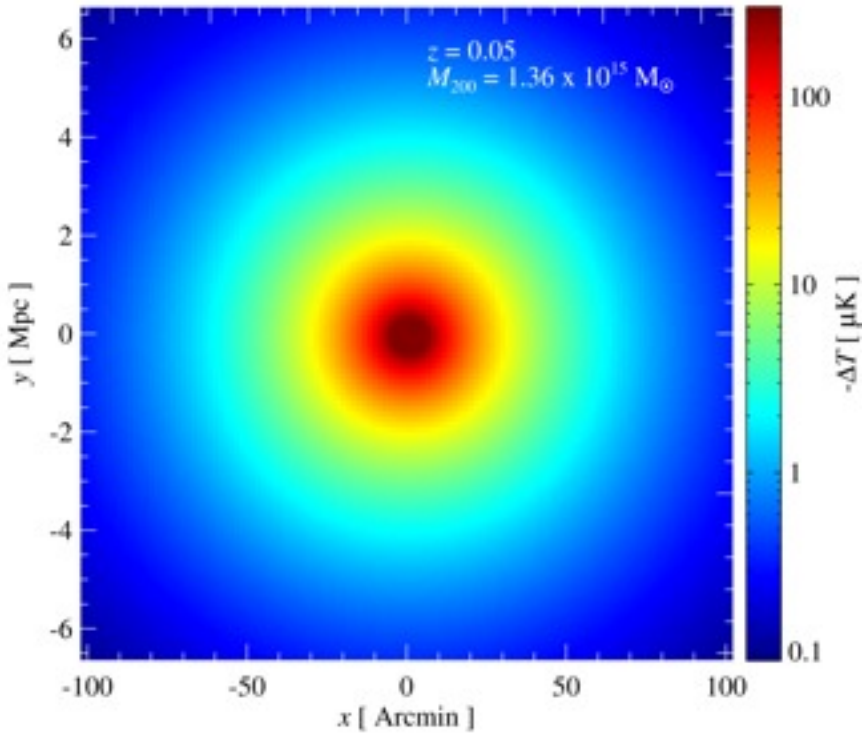
better to ***rotate-into-principal-axes - scale-stack*** **profiles**



GNFW-fit(M,z) accuracy <10%

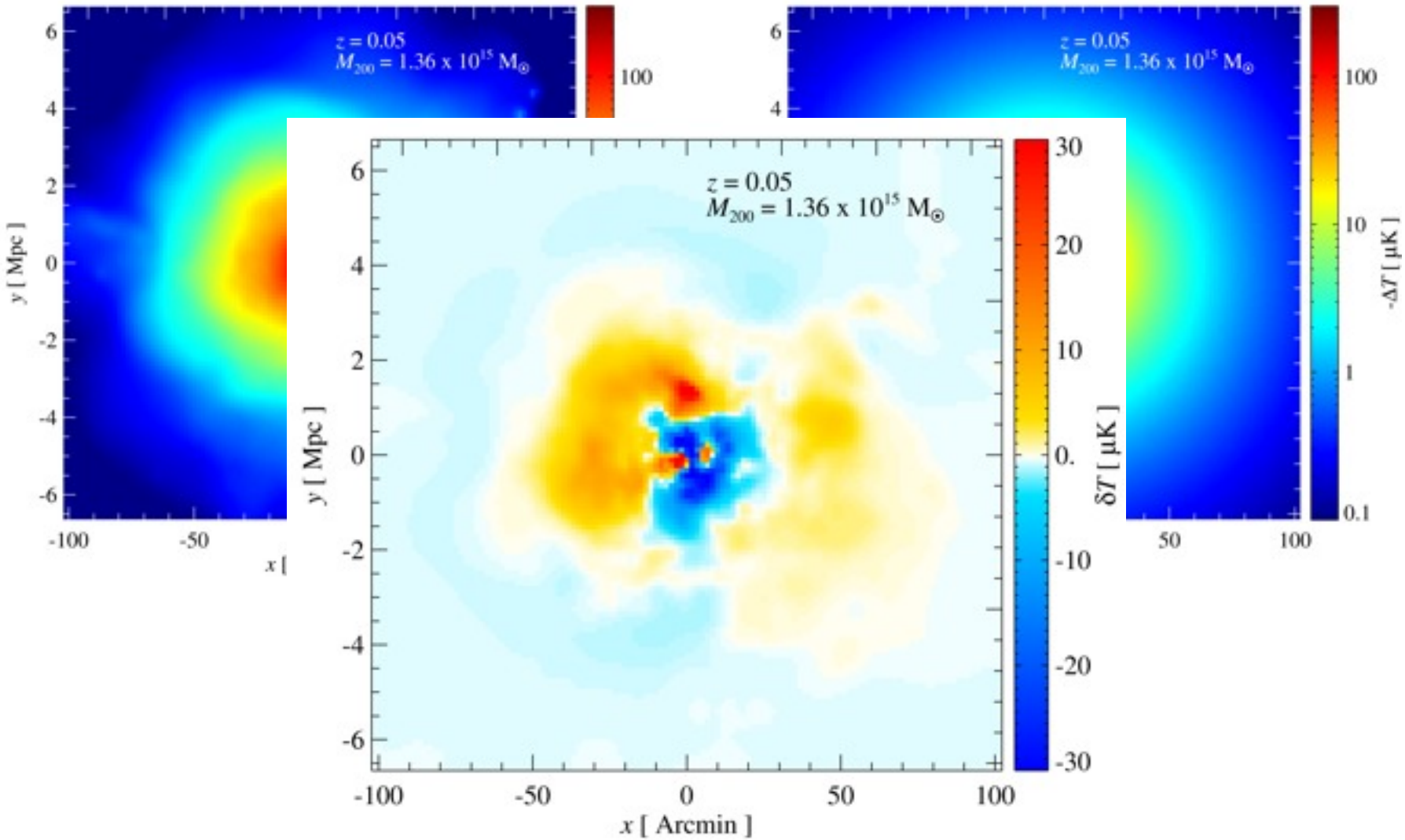
2D pressure exact vs. fit ➪ pressure sub-structure



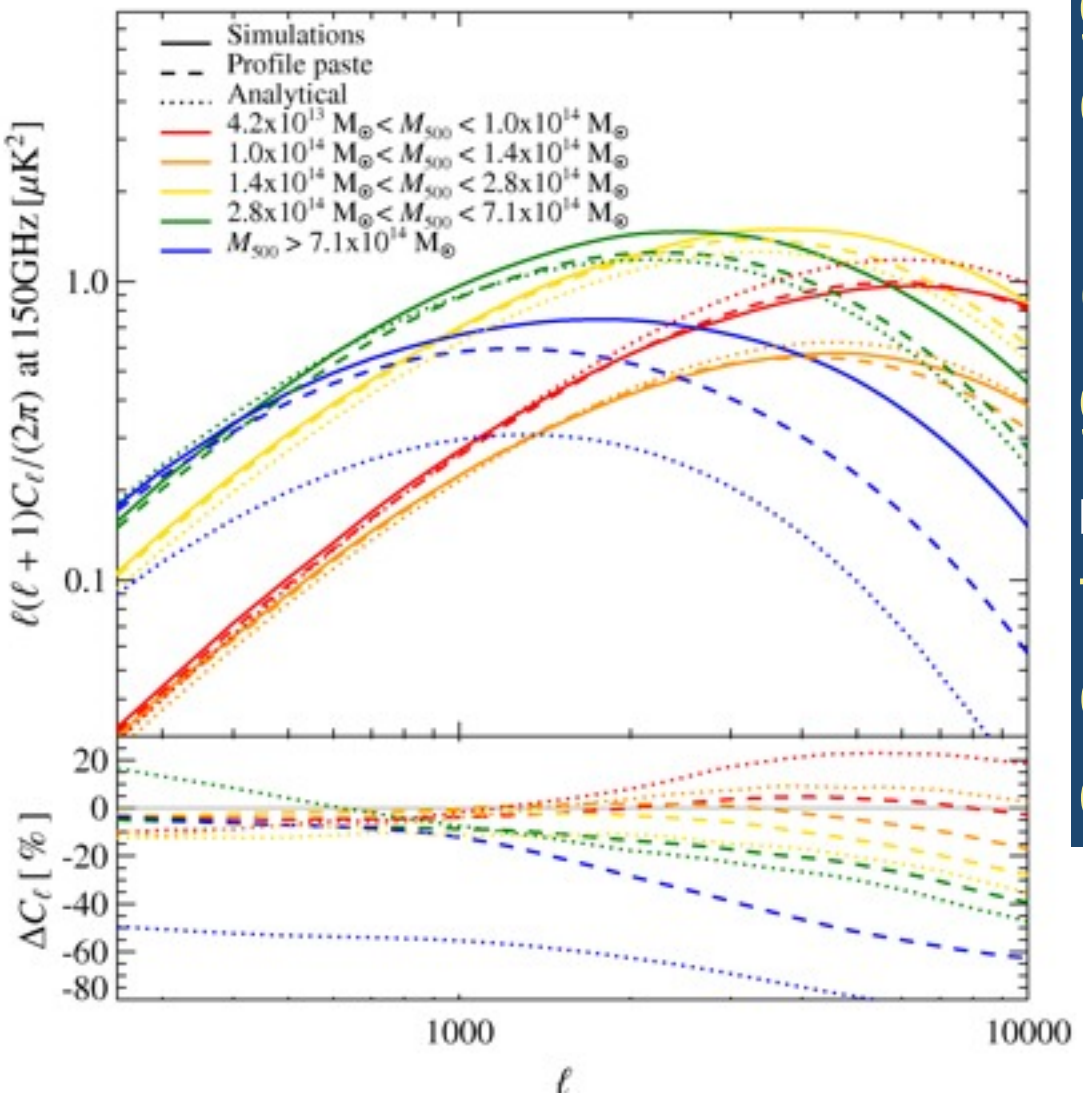


Same cluster (pasted on GNFW according to mass) @ 30 GHz, z = 0.05 Mass ~10^{15} M_{sun}

2D pressure exact vs. fit ➪ pressure sub-structure



pressure sub-structure contribution to C_L^{SZ}



given the cluster catalogue from sims, paint on spherical GNFW-fit (M,z). good, not perfect.

pressure-**sub-structure** the bigger difference cf. full analytics is due to mass function

My new/old passion: see JFN

Studying the Cosmic Tango

My new/old passion: see JFN

Studying the Cosmic Tango

en-Tango-ment, the dance of S+R=U
Universe=System(s)+Reservoir,
=Signal(s)+Residual *noise*,
observer(s)+observed,
ruled by (information) entropy,
entangled. *the fine grains in the coarse grains*

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the coherent and the entropic, in all its forms, from ultra-early-U to ultra-late-U

coherence from driven zero-point vacuum fluctuations ⇨ V **inflaton**, gravity waves; decohere

entropy generation in **pre-heating** from the coherent inflaton (origin of all matter)

information in nearly-Gaussian random fields of U: spatial coarse-grained **CMB entropy** & how we capture it. How Shannon info-entropy flows from bolometer timestreams to marginalized cosmic parameters via Bayesian chains from prior to posterior.
Shannon entropy = von-Neumann entropy
= Trace ϱ ln ϱ^{-1} = full non-equilibrium S
ϱ(U) = ϱ(S,R) = ϱ(R|S) ϱ(S) **entanglement of phase & probability**

sims of **MHD turbulence** with cooling & grain polarized emission - a CMB fgnd

My new/old passion: see JFN

Studying the Cluster Tango

en-Tango-ment, the dance of S+R=U
U = Hubble patch, oft-realized
S = a *scaled-rotated-stacked-cluster-radial-bin* (non-local, i.e., disconnected)
R = other radial bins + the web outside

resolution dimension **$\lambda = -ln\ r/r_0$ to $-ln\ r/r_\Delta$** when res-synchronized 1D (or 6D λij)
Shannon information entropy
S(λ |coarse-grained-measures) deals with the non-equilibrium and non-thermal entropy in cls, includes DarkMatter coarse-grained entropy -

S(λ |coarse-grained-measures) can treat the entropy of protocluster patches and of peak patches -maybe.

gravitational entropy, although somewhat included, remains a **mystery** - to me at least.
recall the **gravo-thermal catastrophe** of negative specific heat, what gravity wants is to localize concentrating mass into black holes and make accelerating voids to straighten out U.

My new/old passion: see JFN

Studying the Cluster Tango

en-Tango-ment, the dance of S+R=U
U = Hubble patch, oft-realized
S = *scaled-rotated-stacked-cluster-radial-bin* (non-local, i.e., disconnected)
R = other radial bins + the web outside

resolution dimension $\lambda = -ln\ r/r_0$ to $-ln\ r/r_\Delta$ when res-synchronized (or 6D λ_{ij})
Shannon information entropy
S(λ |coarse-grained-measures) deals with the non-equilibrium and non-thermal entropy in cls, includes DarkMatter coarse-grained entropy -
the observer observes sim-cls or sky-cls,
a structured way of looking at what we do anyway.
finer res observations lower the info-S.

e.g., $P_{tot,ij} \sim \langle \delta V_i\ \delta V_j \mid \lambda \rangle$, $I_{,ij} \sim \langle \delta X_i\ \delta X_j \mid \lambda \rangle$

$\langle \delta ln\rho\ \delta ln\rho \mid \lambda \rangle$ detailed measures in BBPS11-1234
kinetic pressure tensor & turbulent cascade
space-space fluctuations & ...
pressure & density clumping
higher order measures

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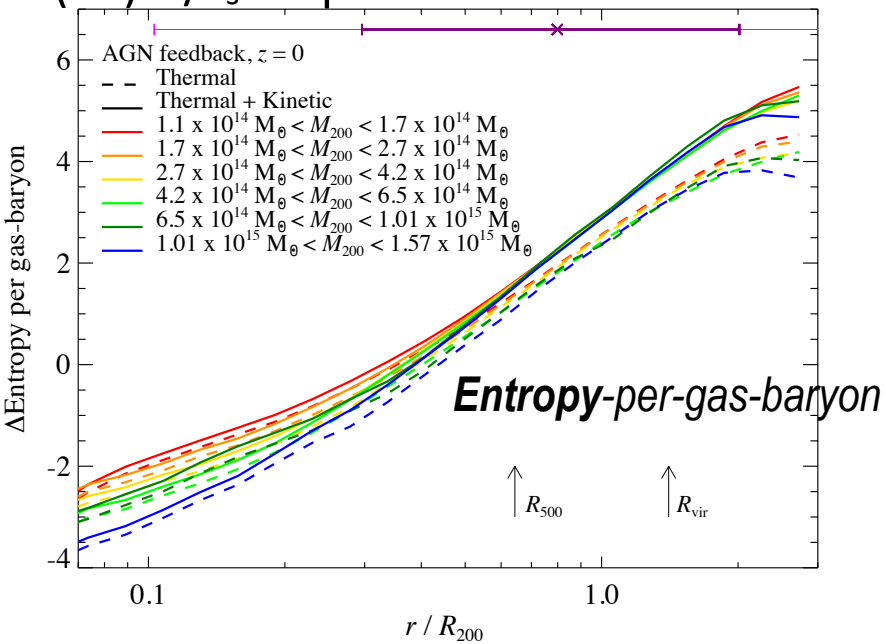
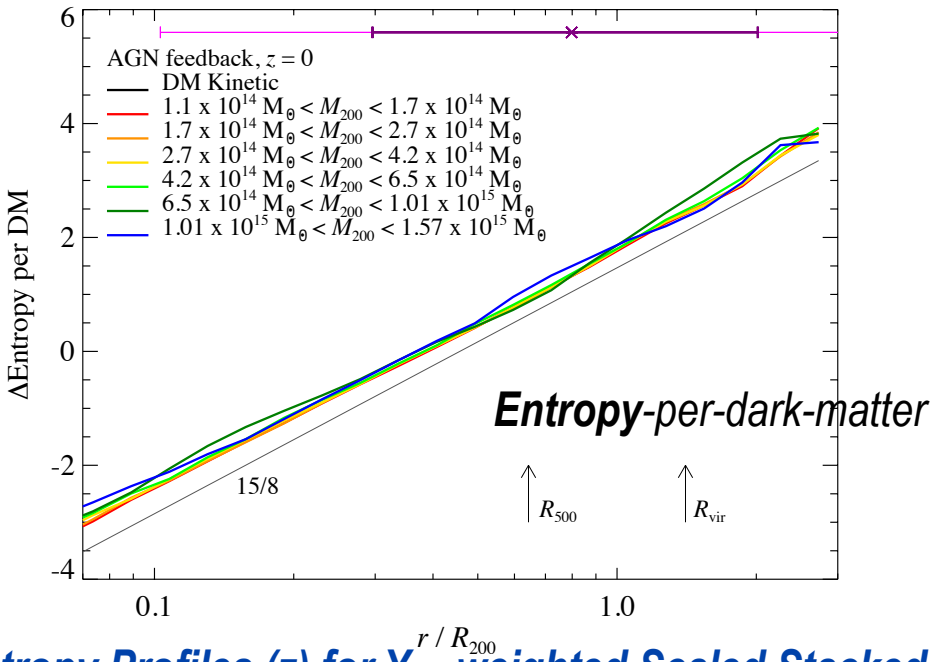
higher order measures
fine-*macro-small*-grain 10^6 baryons in cubic metres sph--*macro-large*- grain 10^{65} baryons. ~26 dims per sph-grain, huge dimensional reduction, scaled-radial-*resolution*-grain further dim reduction.
entanglement of fine & coarse & EFT. feedback.

P_{kin}/P_{th}~0.1-0.6!

$<(\Delta v)^2>/c_s^2$ impt in HSE

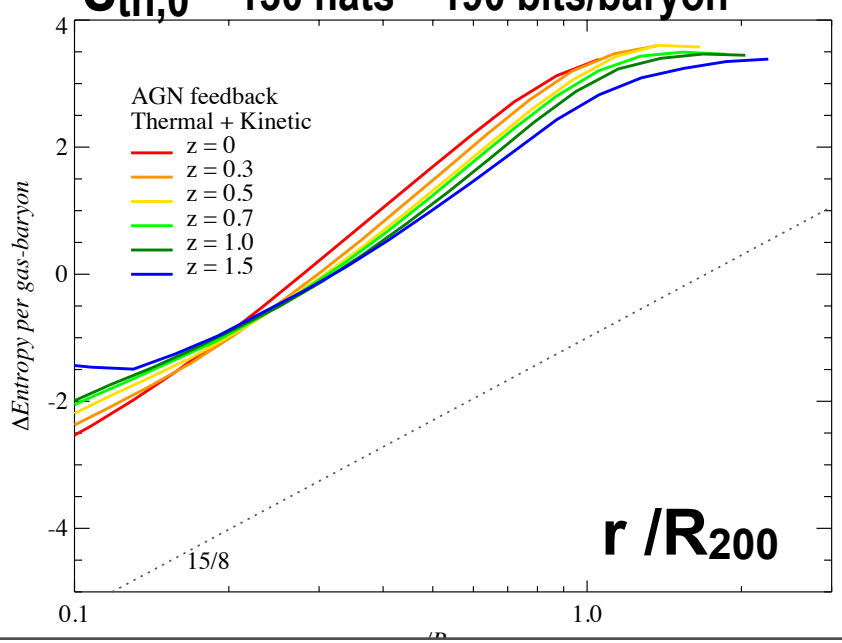
Entropy Profiles (M/z=0) for M-binned Scaled Stacked Cls

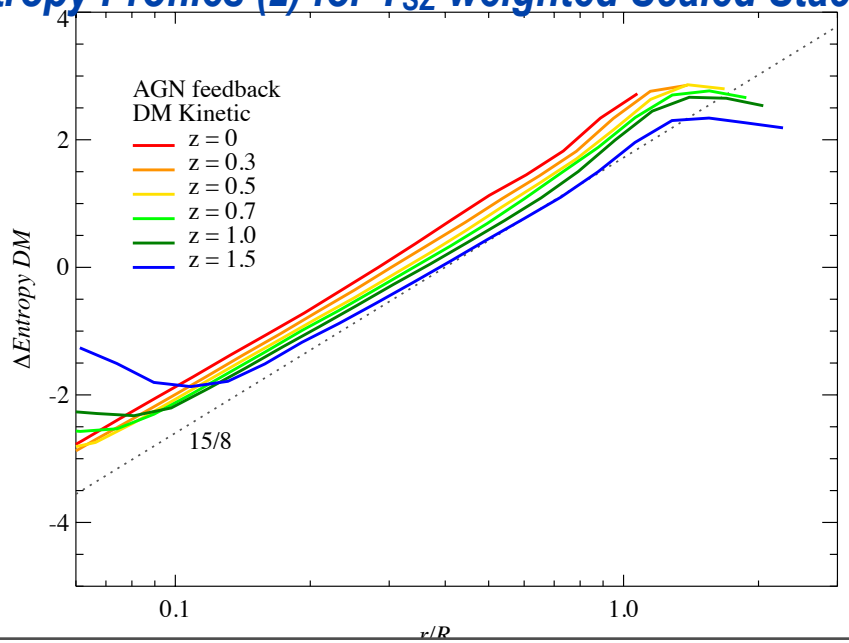




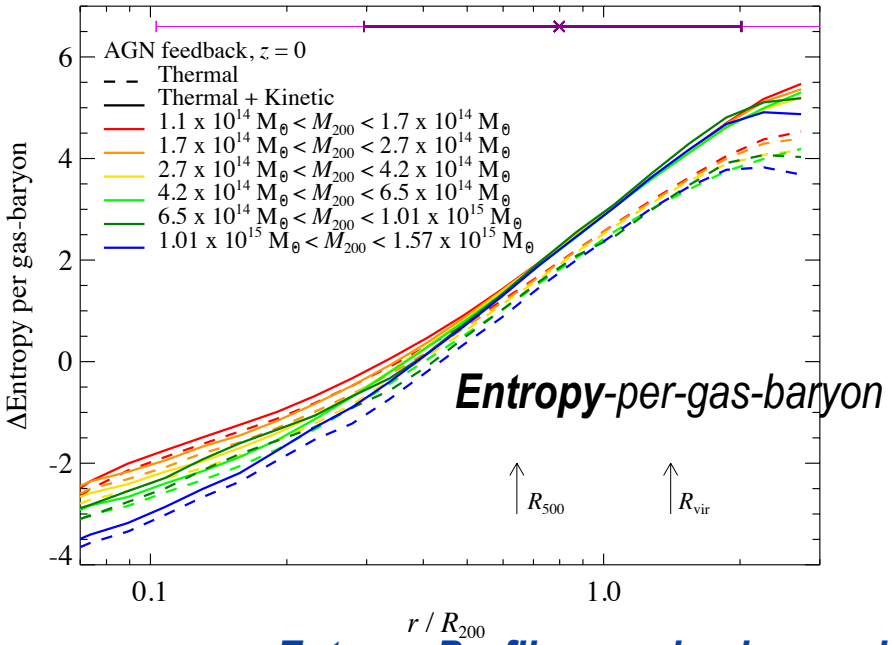
$S_{th,0}$ ~ 130 nats ~ 190 bits/baryon

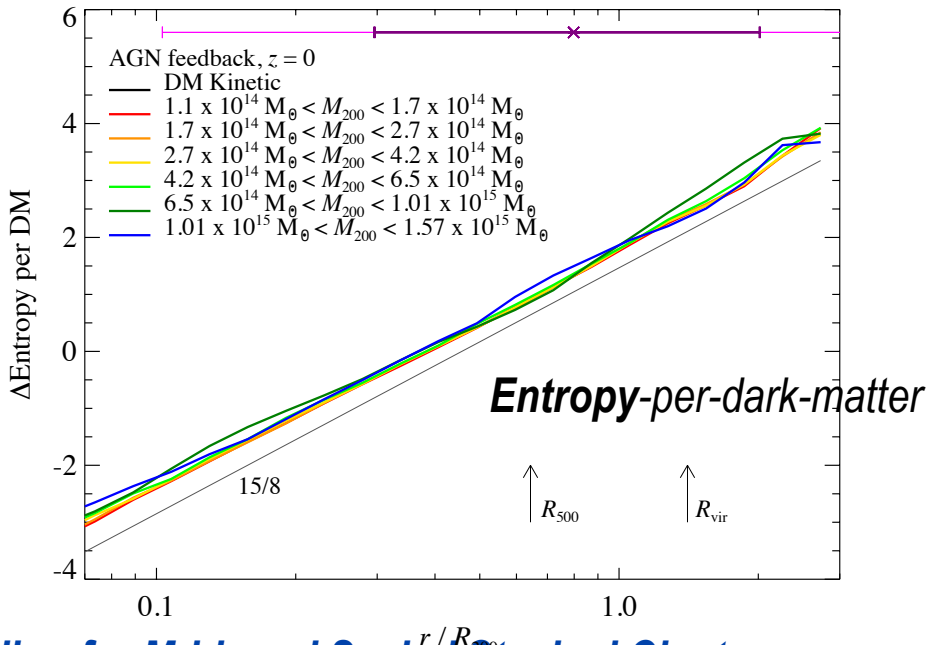
Entropy Profiles (z) for Y_{SZ}-weighted Scaled Stacked Cls



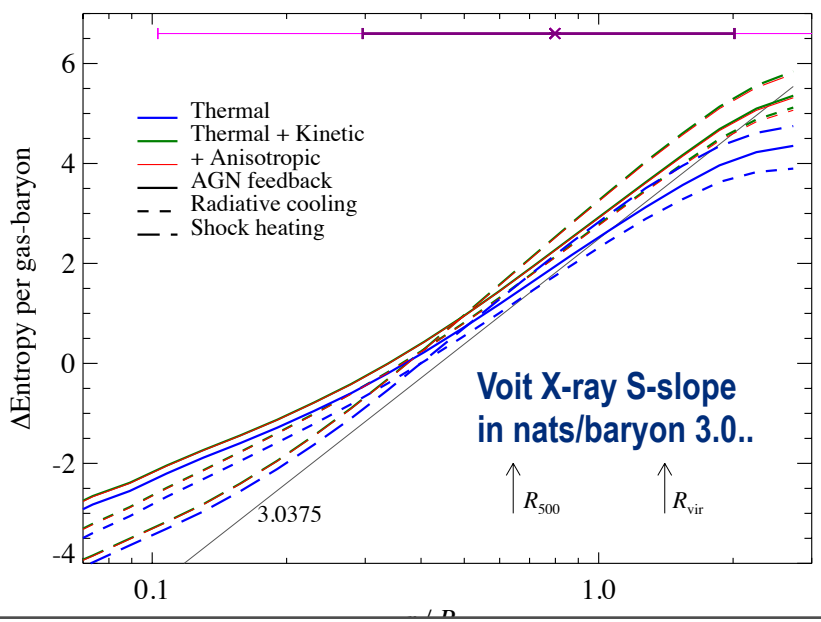


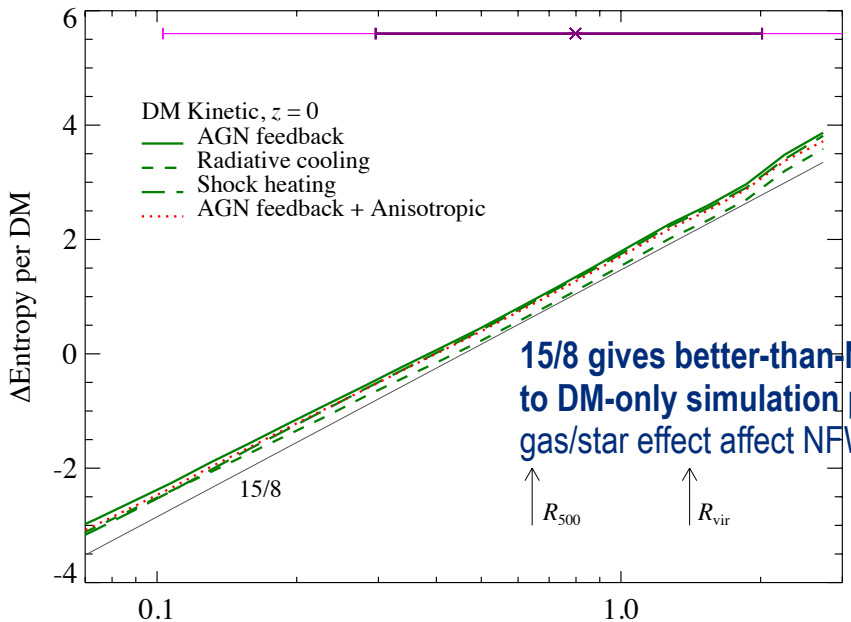
Entropy Profiles (M/z=0) for M-binned Scaled Stacked Clusters



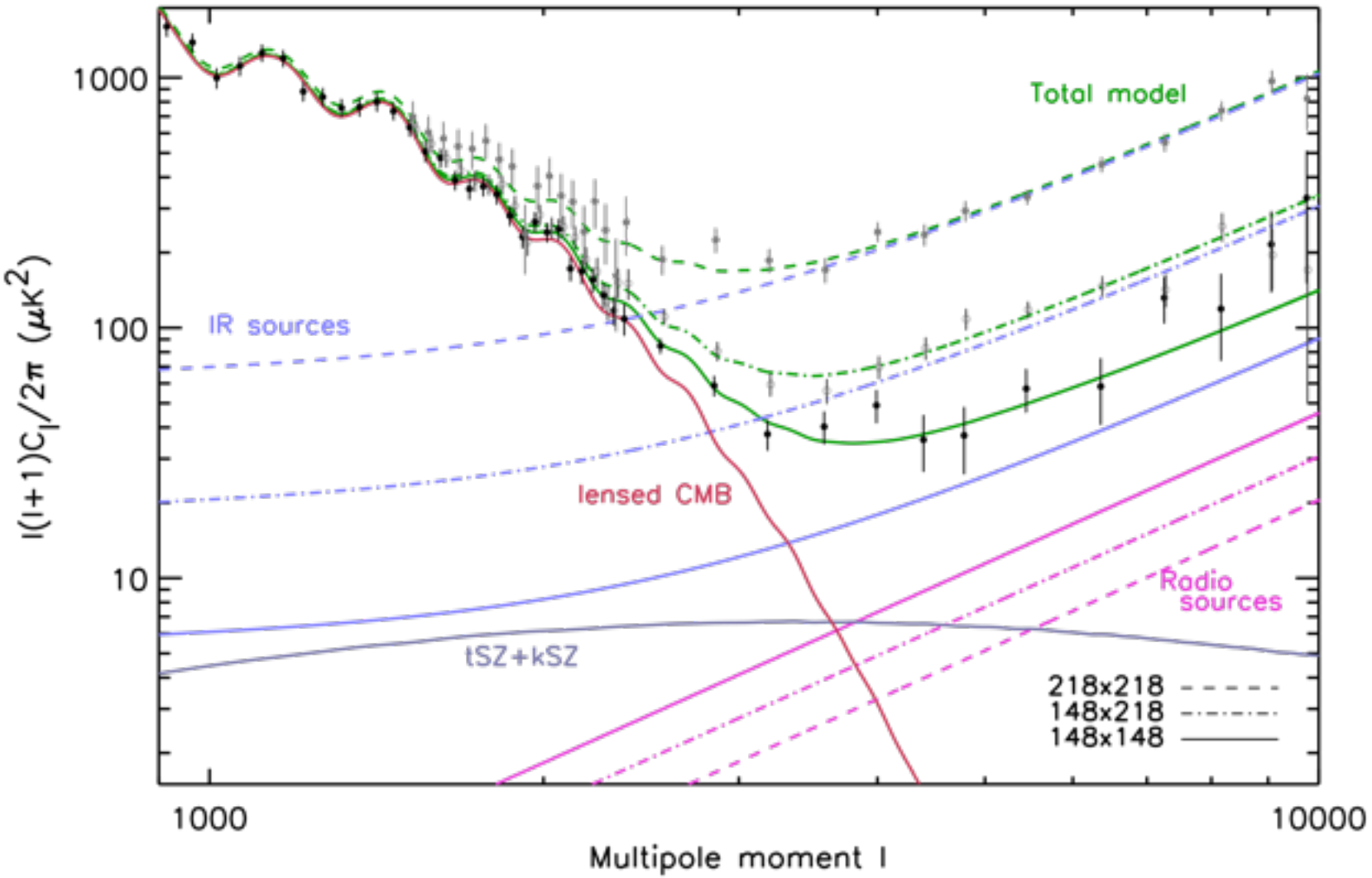


Entropy Profiles vs physics modeling for M-binned Scaled Stacked Clusters



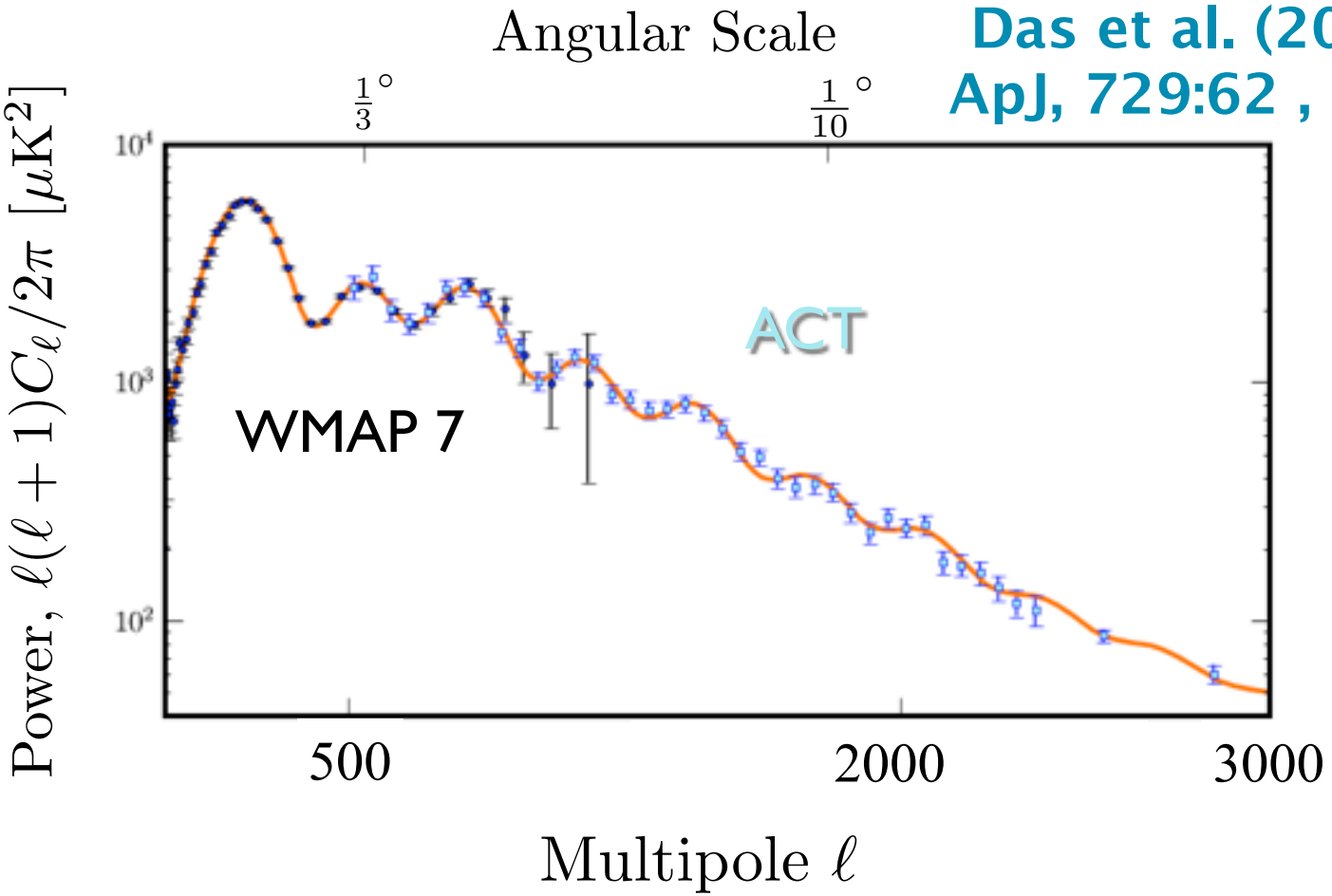


primordial (lensed) CMB + veils, *the veils = radio sources, the CIB, tSZ and kSZ (& Milky Way dust and synchrotron at lower multipoles)*



Dunkley+. 2010

HIGH RESOLUTION POWER SPECTRUM FROM ACT

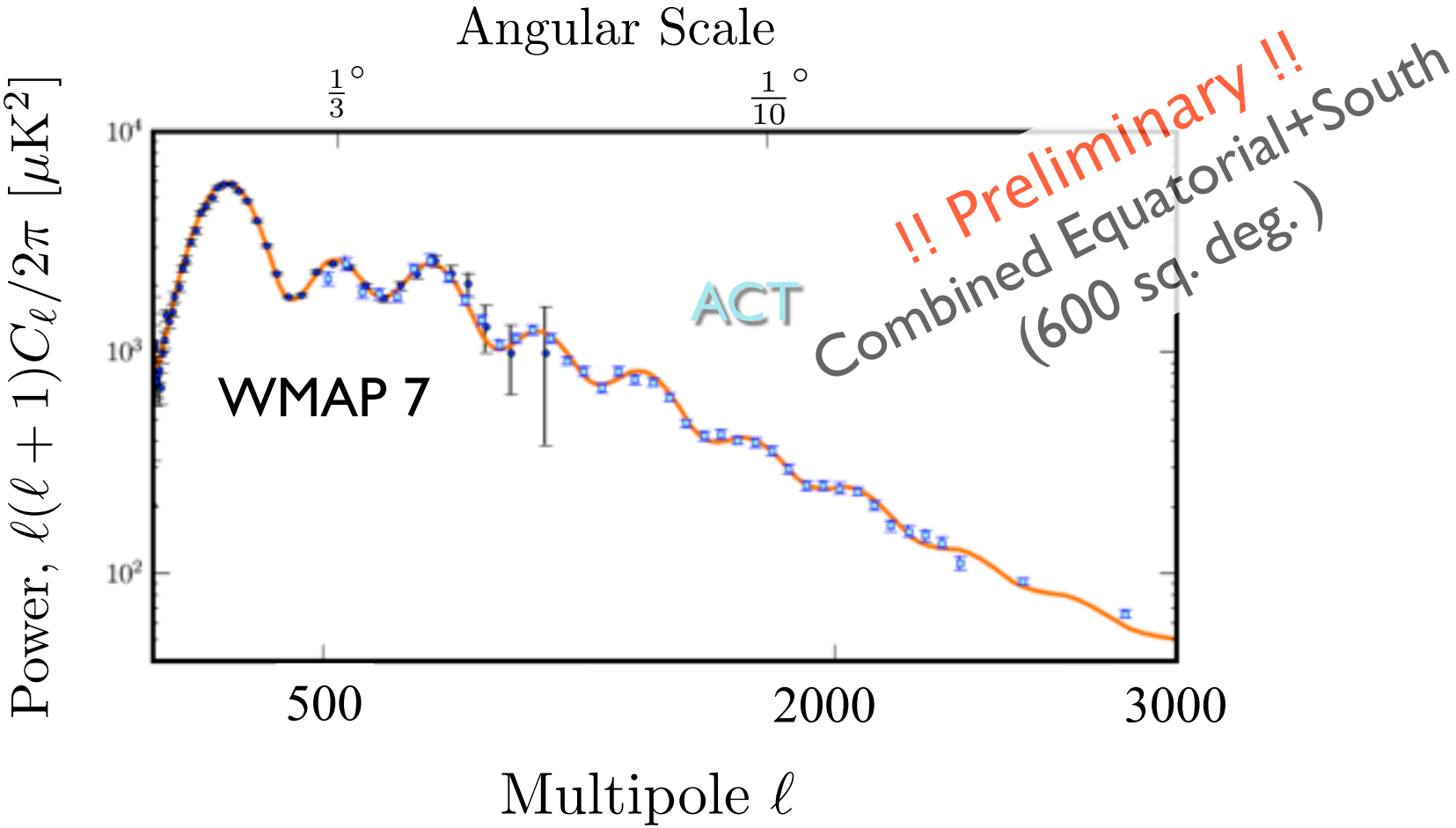


Das et al. (2011), ApJ, 729:62 , 2011

tilted ΛCDM a very good fit (n_s constant); data are good enough to search for subdominant cosmic parameters

Dunkley+. 2010

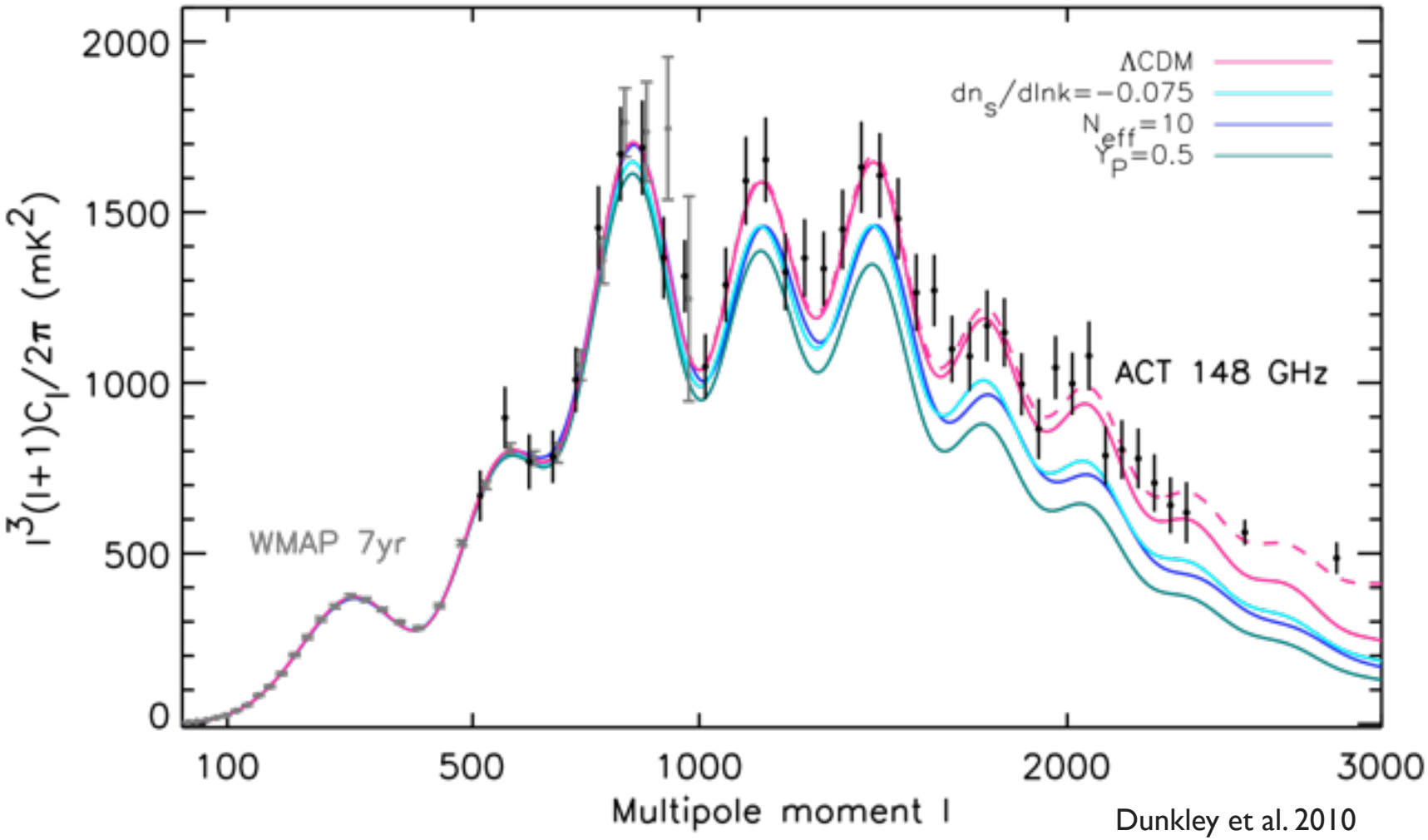
HIGH RESOLUTION POWER SPECTRUM FROM ACT: NEW RESULT!



tilted ΛCDM a very good fit (n_s constant); but data are good enough to search for subdominant cosmic parameters

Sievers+. 2011

‘low-L’ part of ACT’s power spectrum

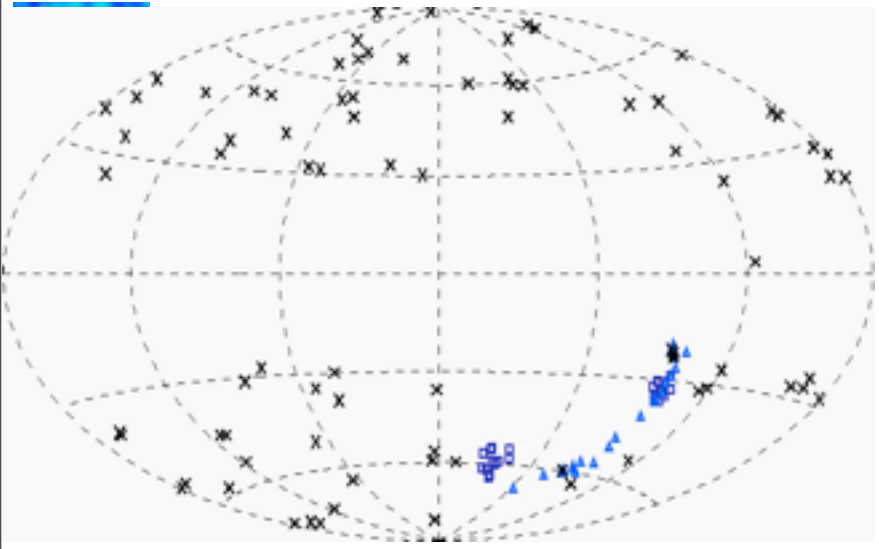


Dunkley et al. 2010

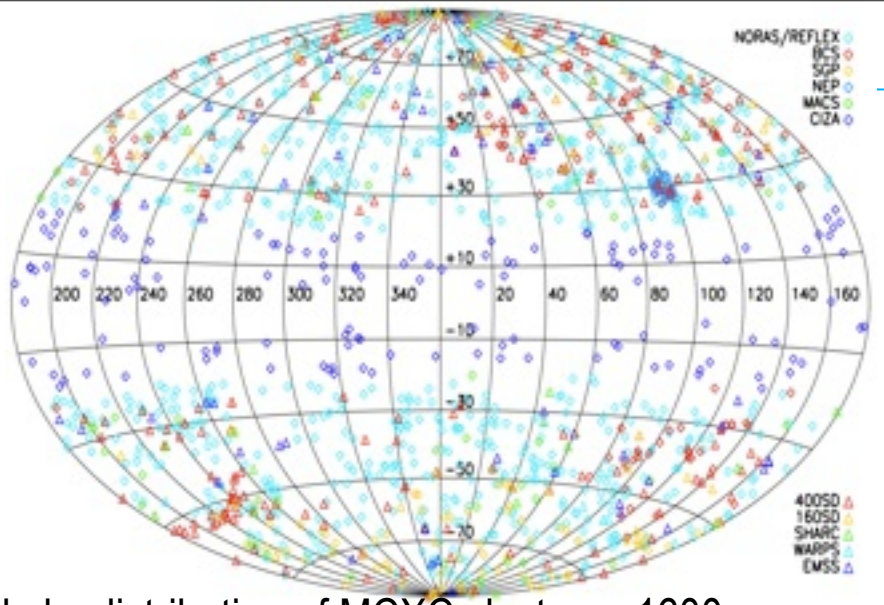
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

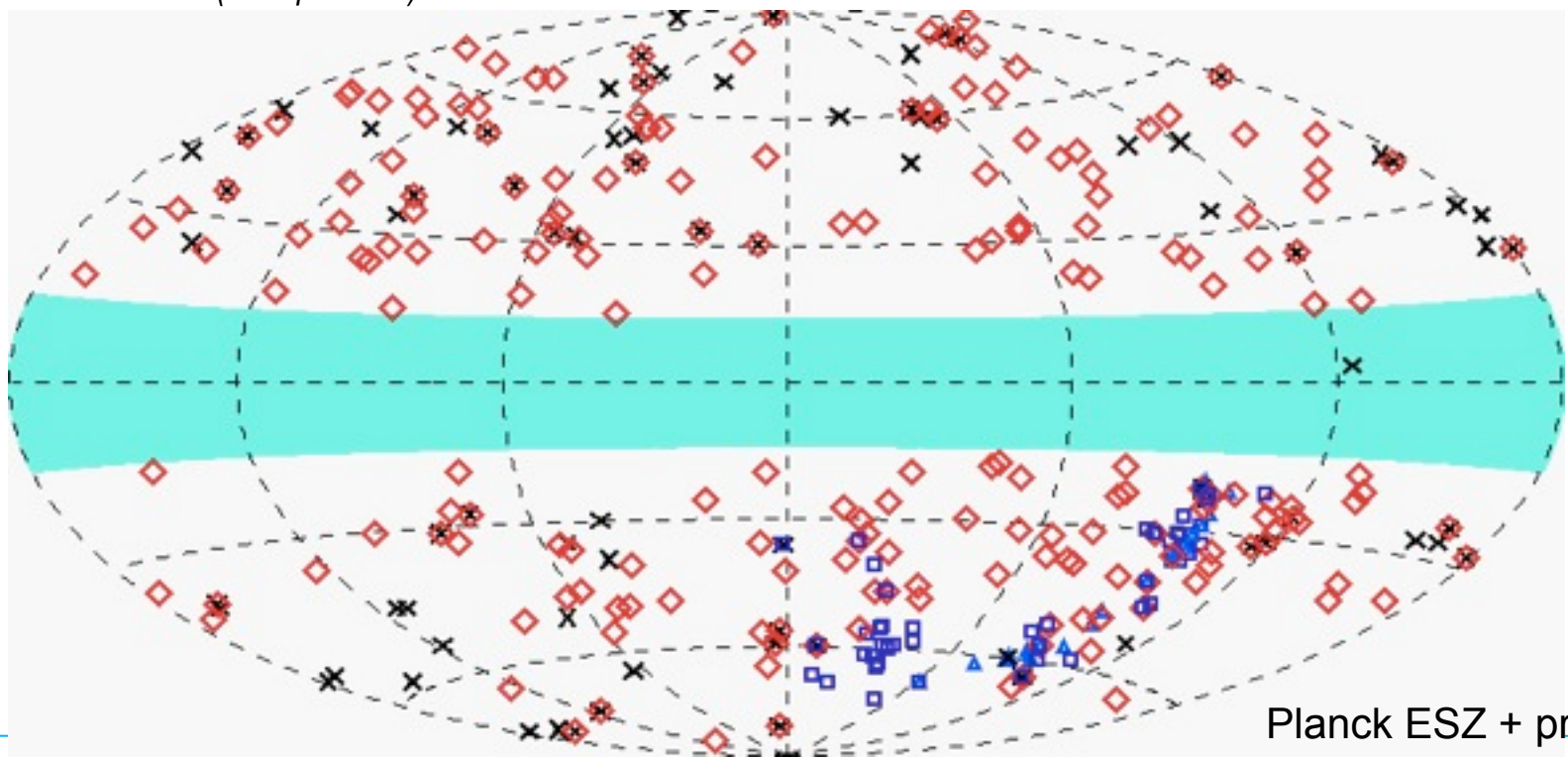
Bond since 1993, Canada since 2001, 1st CSA pre-launch contract 2002-09, post-launch 2010-11, 2011-13



All-sky compilation of first generation SZ clusters
(Douspis et 11)



All-sky distribution of MCXC clusters ~1600 *(Piffaretti et 10)*



Planck ESZ + prior-SZ