Title: CMB and LSS, now and then, and inflation, then and now

Date: Oct 27, 2005 09:30 AM

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Abstract:

Dick Bond

CMB+LSS Probes, Now & Then, & Inflation, Then & Now

CMB: polarization frontier (CBI, B03 & B-futures, Carrie MacTavish, Jon Sievers, Olivier Dore, Mike Kesden, Mike Nolta, Licia Verde)

WMAP2/3 still ~month. Now – CBIpol (Sept 9 05), Boomerang03 (Jul 21 05), Acbar (~weeks), & Then (QuAD/Bicep, ACT/SPT, Quiet, Planck, Spider & more)

CMB: high L nonlinear frontier (e.g. CBI excess & SZ, Act/SPT, Verde)

Cluster/group system in SZ, optical, weak lens, X-ray (Subha Majumdar, Christoph Pfrommer, Jon Sievers)

lensing Weak (Dore, Pat McDonald, Eric Linder) first results from CFHTLS (Hoekstra, van Waerbeke); **strong lensing (Neal Dalal)**

z-surveys (Pat McDonald SDSS)

Lyman alpha forest & Galaxy Formation (McDonald SDSS forest)

21(1+z) cm (Ilian Iliev)

SN (Goobar, Linder)

Timelines: CMB, LSS (optical etc.), Galaxy Formation; Cosmic HE & particle

CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

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CMB/LSS Phenomenology

CITA/CIAR here

- Bond
- Contaldi
- Lewis
- Sievers
- Pen
- McDonald
- Majumdar
- Nolta
- Iliev
- Kofman
- Vaudrevange

- Dalal
- Dore
- Kesden
- MacTavish
- Pfrommer

UofT here

- Netterfield
- MacTavish
- Carlberg
- Yee

& Exptal/Analysis/Phenomenology Teams here & there

- Boomerang03
- Cosmic Background Imager
- Acbar
- WMAP (Nolta, Dore)
- CFHTLS – WeakLens
- CFHTLS - Supernovae

CITA/CIAR there

- Mivelle-Deschenes (IAS)
- Pogosyan (U of Alberta)
- Prunet (IAP)
- Myers (NRAO)
- Holder (McGill)
- Hoekstra (UVictoria)
- van Waerbeke (UBC)

Parameter datasets: **CMBall_pol**

SDSS P(k), 2dF P(k)

Weak lens (Virmos/RCS1; CFHTLS, RCS2)

Lya forest (SDSS)

SN1a “gold” (157, 9 z>1), CFHT

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Parameters are the goal - Information Compression - but of all sorts.

Fundamental parameters:

Early Universe – Acceleration Histories H(ln k_H), & the Inflation Landscape; curvature, tensor, isocurvature; broken scale invariance, weak & strong; heating; defects; topology

Material parameters: physical densities $\Omega_b h^2$ $\Omega_c h^2$ $\Omega_\nu h^2$ $\Omega_{er} h^2$ Ω_k Ω_Λ

Late Universe – acceleration histories and Λ, w(ln a) phenomenology (quintessence etal)

Gastrophysical parameters τ_C bias$_{gal}$ σ_8

Phenomenological Parameters: Compression, External (Prior) & Internal Info

Maps, multi-frequency or "separated components" - CMB, SZ, synch, bremms, dust, …

Bandpowers (statistical isotropic - or not), 3,4,… point spectra parameters

Foreground parameters (templates, point source vetoing, …)

Calibration parameters (amplitude, beam, mass-richness, mass-temperature, mass-Y_SZ)

Systematics parameters – unwanted, marginalize – spin synchronous modes

Bayesian framework: conditional probabilities, Priors/Measure sensitivity, …

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Parameters & Priors of the "Cosmic Standard Model"

Even for minimal Gaussian inflaton-generated fluctuations 17+, here 6+2+2+2 +2 ++

EARLY UNIVERSE: power spectra, non-Gaussian 3,4,.. Point, topology

$A_s n_s$ A_t n_t A_{iso} n_{iso} @normalization point k_n

Features & functions(k) k_{run}, $\{k_{BSI}\}$

$\Omega_b h^2$ $\Omega_c h^2$ $\Omega_\nu h^2$ $\Omega_{er} h^2$ CMB PHOTON **TRANSPORT@Decoupling**

Ω_k Ω_Λ $(\Omega_Q$ $w_Q)$ **TRANSPORT@ Late Time** ISW Effect & GEOMETRY

$k_{sound,dec}$, $k_{damp,dec}$, $k_{m\nu}$

Near Parameter Degeneracies in CMB need: LSS, SN1a,$n_{clusters}$,…

Map $L_{sound,dec}$ = **R**(z@dec) $k_{sound,dec}$, want TOMOGRAPHY **R**(z)

e.g., **R**(z) angular-diameter-distance. BROKEN by ISW. SN1a (**R_L**(z) luminosity distance). z-surveys: Acoustic peaks (z). Abundances: Volume(z), perturbation growth rate (z).

τ_C z_{reh} **GASTROPHYSICS:** Compton Depth from Reionization redshift

σ_8^2 h Ω_m Ω_b **LSS:** k_{Heq} aka Γ $k_{sound,dec}$, $k_{m\nu}$

CBI ongoing to Sept'05+

Acbar ongoing to Sept'06+

Bicep

QUaD

Quiet1

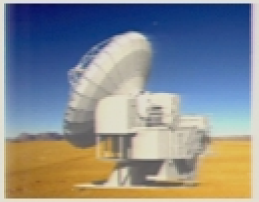
Quiet2
(1000 HEMTs)
Chile

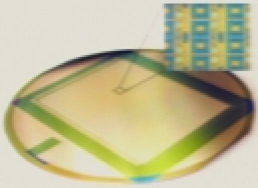
APEX
(~400 bolometers)
Chile

SCUBA2
(12000 bolometers)
JCMT, Hawaii

Spider
(1856 bolometer LDB)

SZA
(Interferometer)
California





ACT
(3000 bolometers)
Chile

Clover

2017
CMBpol

Boom03

2003 2005 2007

2004 2006 2008

WMAP ongoing to 2009

SPT
(1000 bolometers)
South Pole

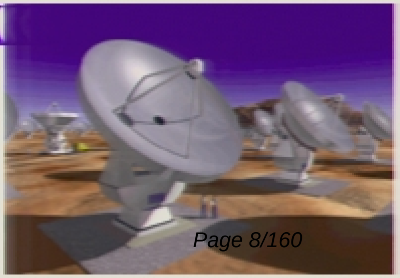
ALMA
(Interferometer)
Chile

DASI

Polarbear
(300 bolometers)
California

CAPMAP

Planck
(84 bolometers)
HEMTs L2



AMI

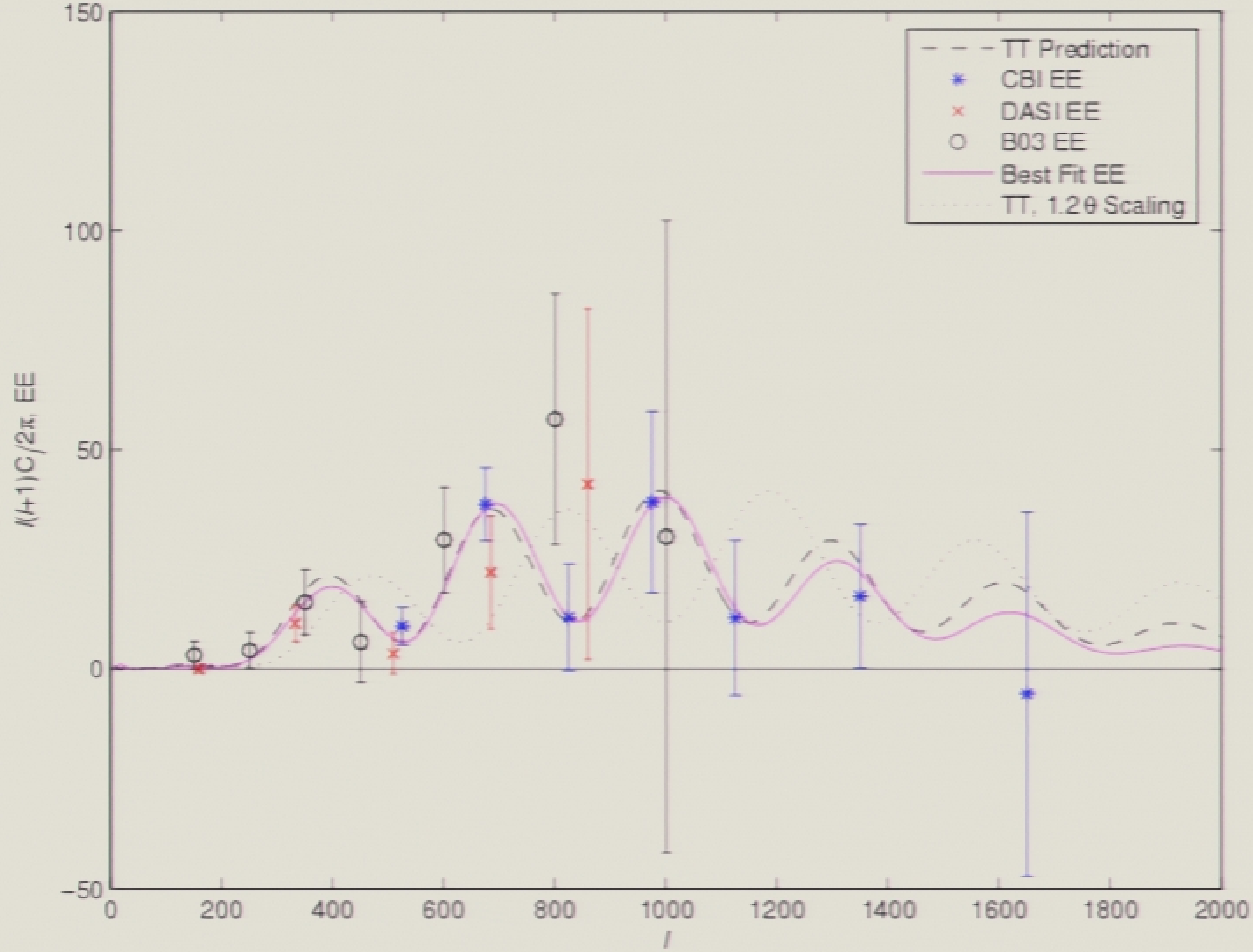
GBT

Physical cosmology Probes of Early & Late universe physics

CMB: polarization frontier (CBI, B03 Carrie MacTavish, Jon Sievers, WMAP3 Olivier Dore, Mike Nolta, Licia Verde)

Polarization EE: 2.5 yrs of CBI, Boom03, DASI

(CBI04, DASI04, CAPmap04 @ COSMO04) & DASI02 EE & WMAP1 '03 TE



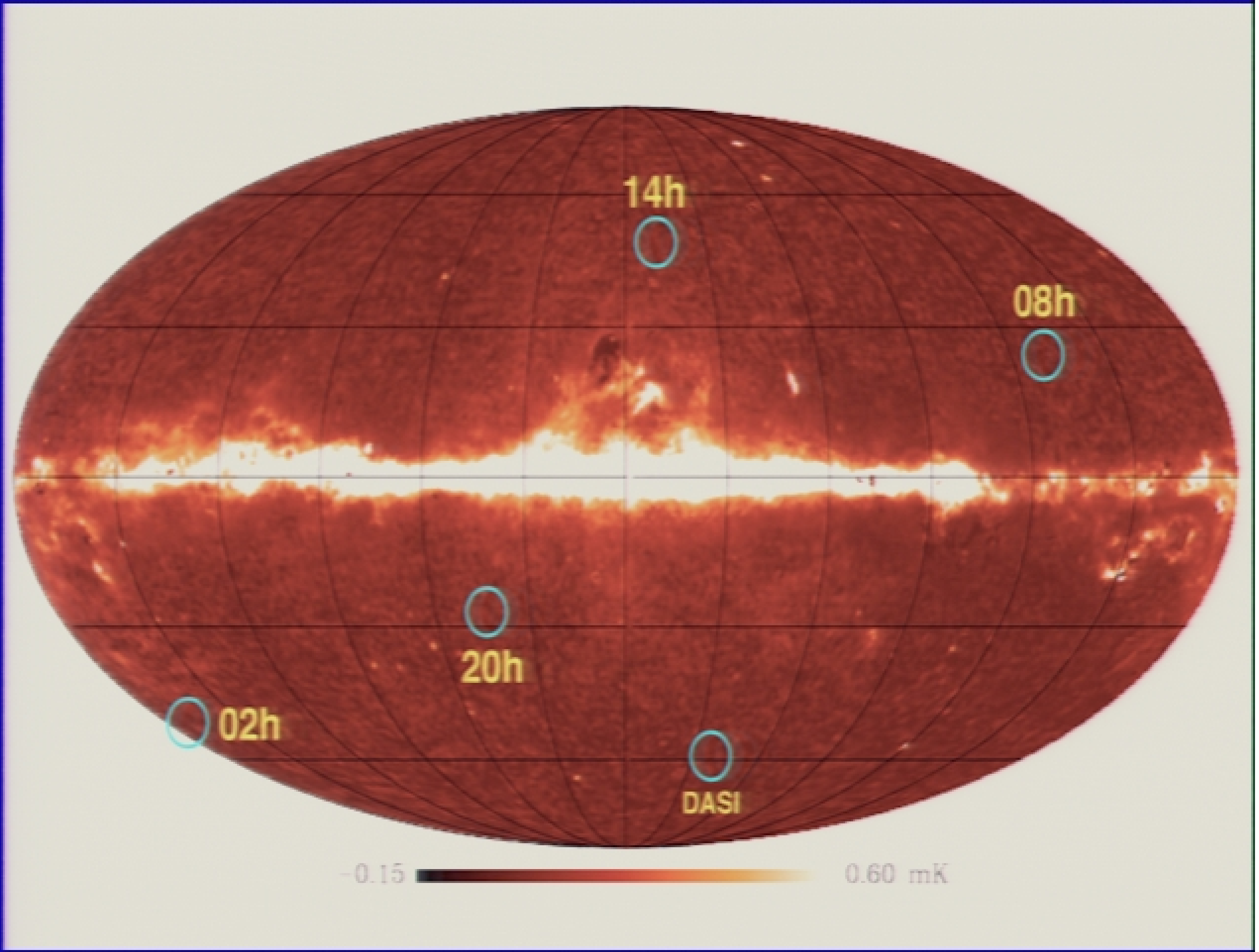
[Sievers et al. astro-ph/0509203]

[Montroy et al. astro-ph/0509203]

[Readhead et al. astro-ph/0409569]

CBI Dataset

- CBI observes 4 patches of sky – 3 mosaics & 1 deep strip
- Pointings in each area separated by 45’. Mosaic 6x6 pointings, for 4.5^{o2}, deep strip 6x1.
- Lose 1 mode per strip to ground.
- 2.5 years of data, Aug 02 – Apr 05.

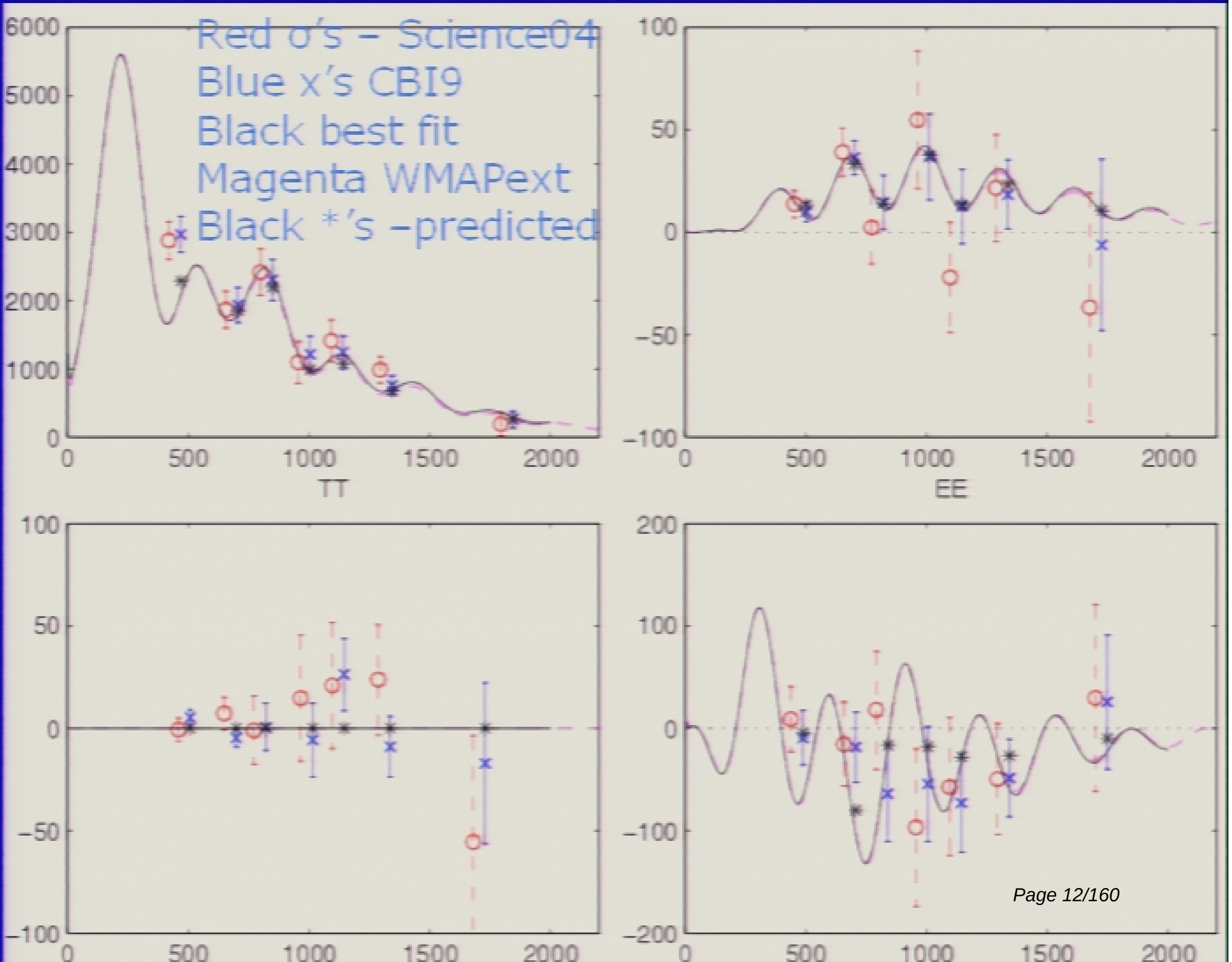


CBI Polarization Power Spectra **Sept 05**

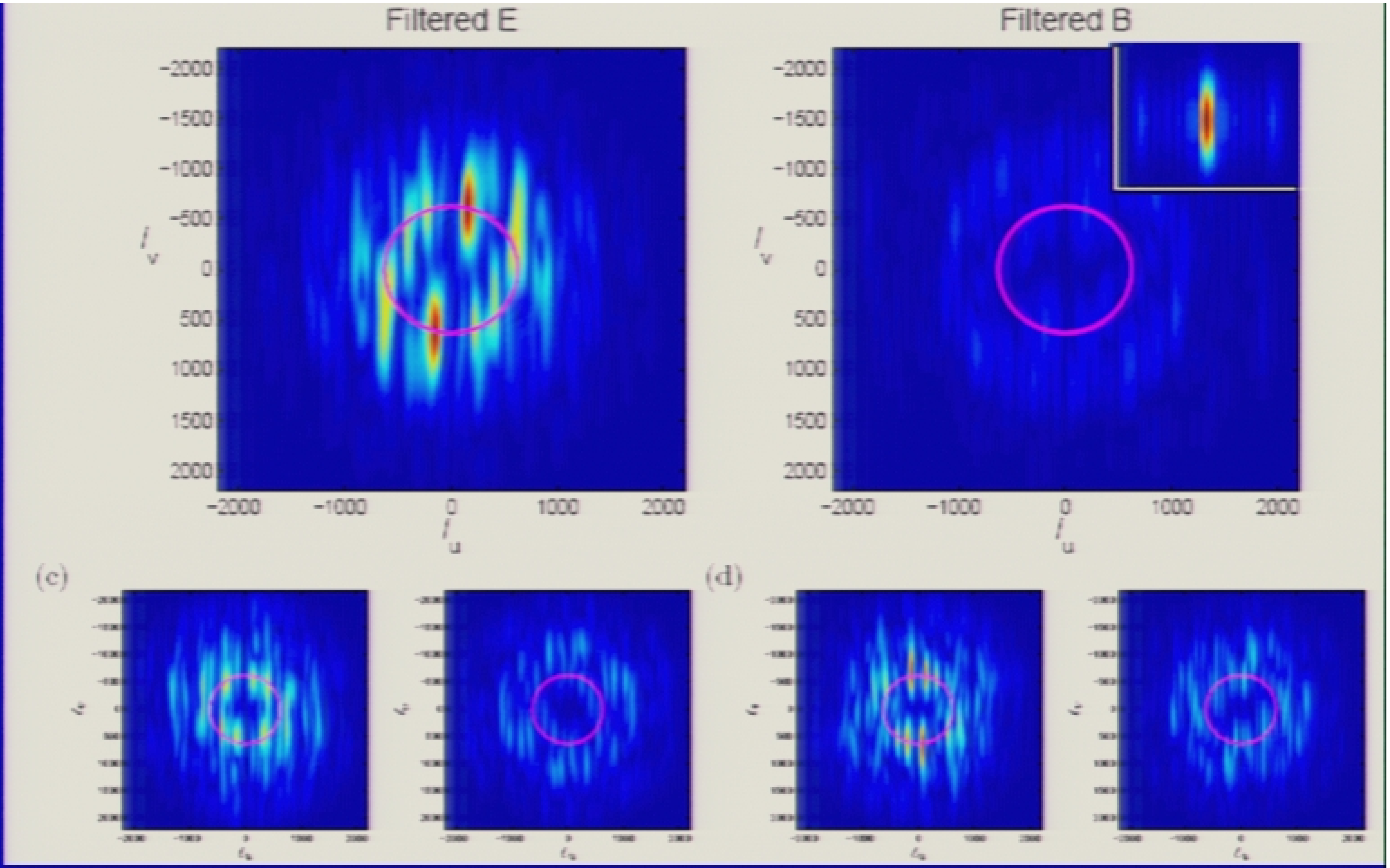
CBI8 pol'n detection – *Science* 306,836; CBI9 Astro-ph/0509203 +54% 10σ

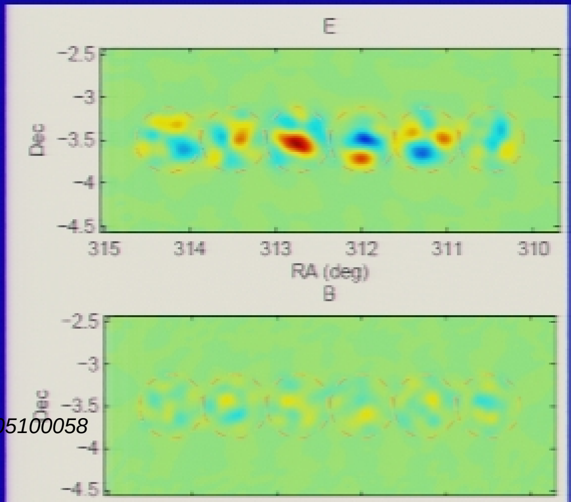
- 2nd measurement of E-type CMB polarization spectrum, best so far (DASI02, CBI04, DASI04, CAPmap04 @ COSMO04) & WMAP1 '03 TE, B03, CBI9, WMAP2/3 -soon

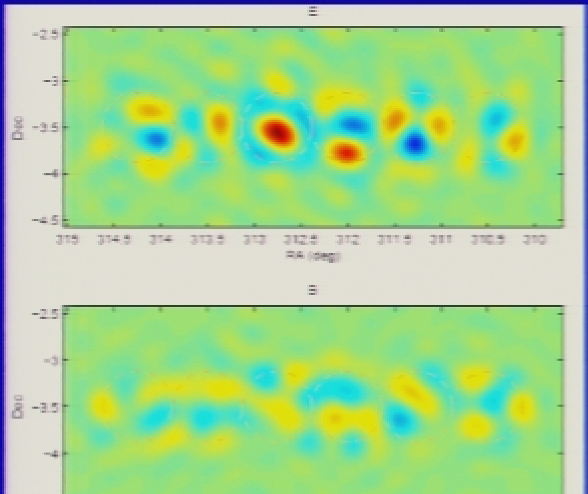
- 7-band spectra ($\Delta l = 150$ for $600<l<1200$)
- Polarization data consistent with WMAPext model (TT from WMAP, Acbar, 00+01 CBI) & best-fit from TT



E/B Deep Strip signal maps cf. “raw”







Variance of E in raw data 2.45 times B ($\ell<1000$). B consistent with noise. E,B mixing ~5% in power.

BOOMERanG '03 Flight

Caltech, Cardiff University, Case Western Reserve University, Imperial College, IPAC, JPL, NERSC, Universita di Roma La Sapienza, Universita di Roma Tor Vergata, University of Toronto, CITA, IROE, ENEA, ING

- Polarization sensitive receivers 145/245/345 GHz (PSBs - same as PLANCK detectors)

Flight January 2003

- 195 hours of science data $f_{sky} = 1.8\%$
- First results published in July 2005
  - Masi et al. astro-ph/0507509
  - Jones et al. astro-ph/0507494
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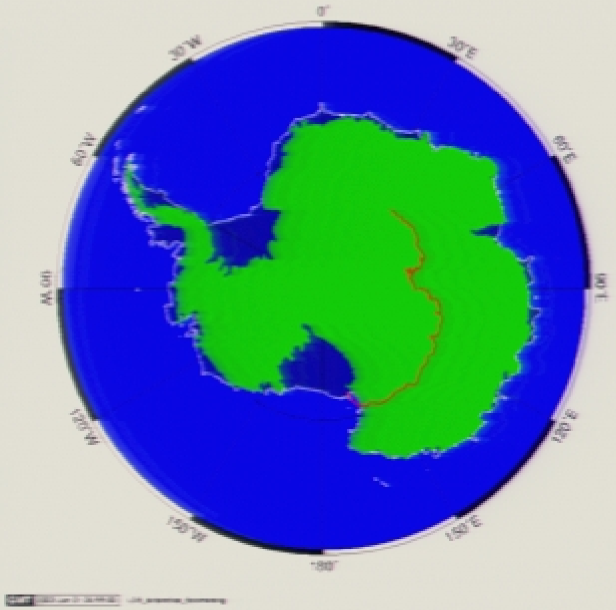

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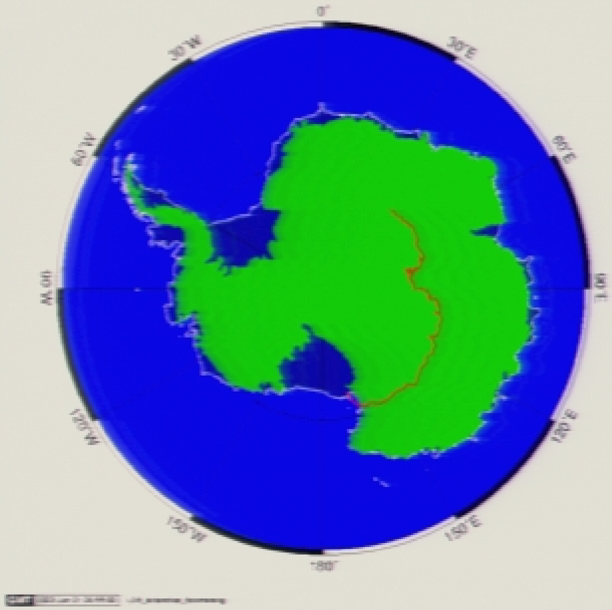

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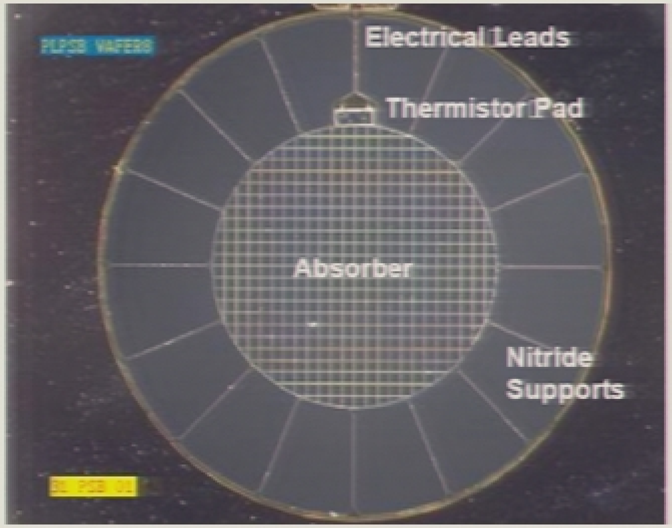
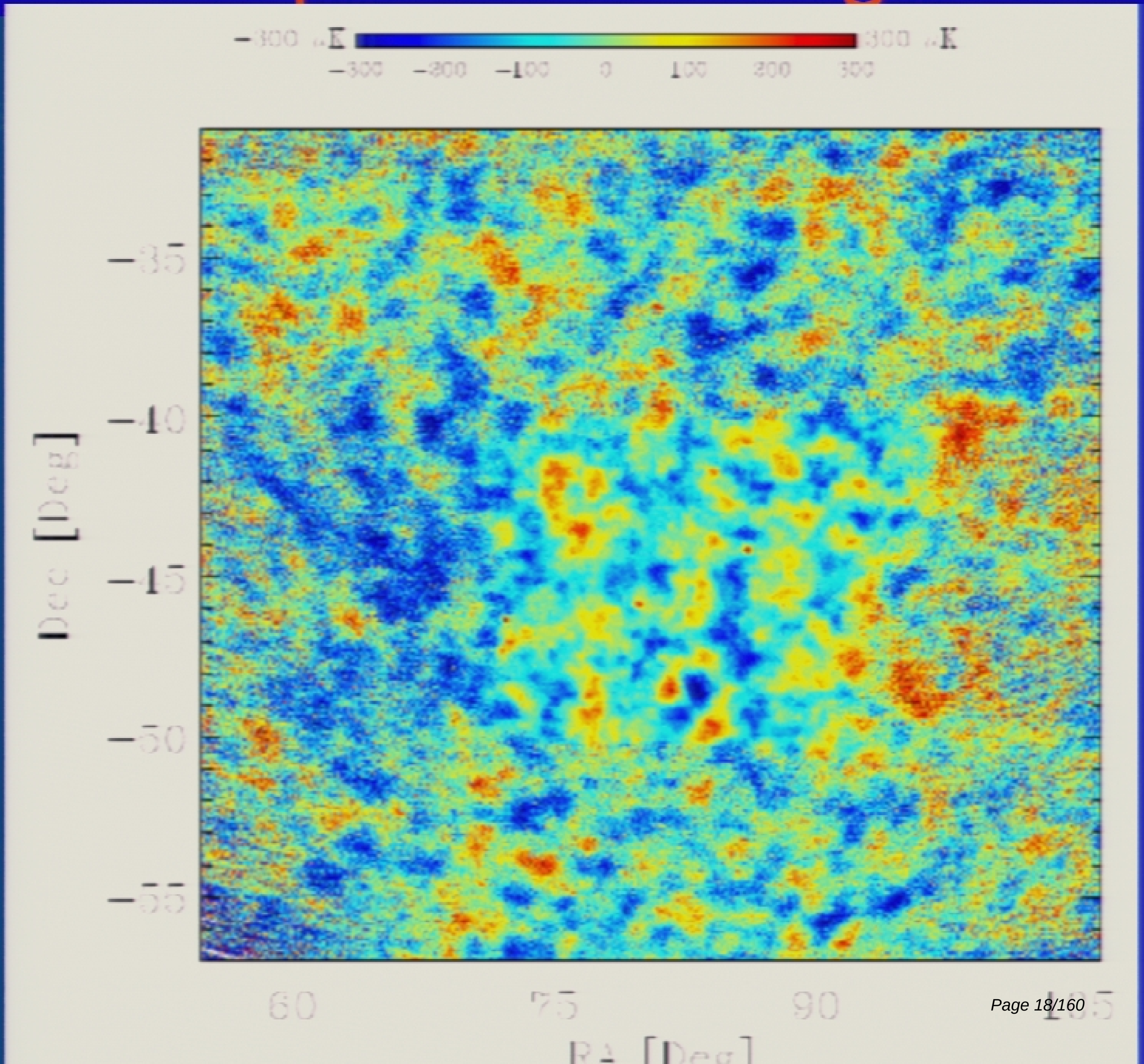


Boom03 T deep & shallow regions

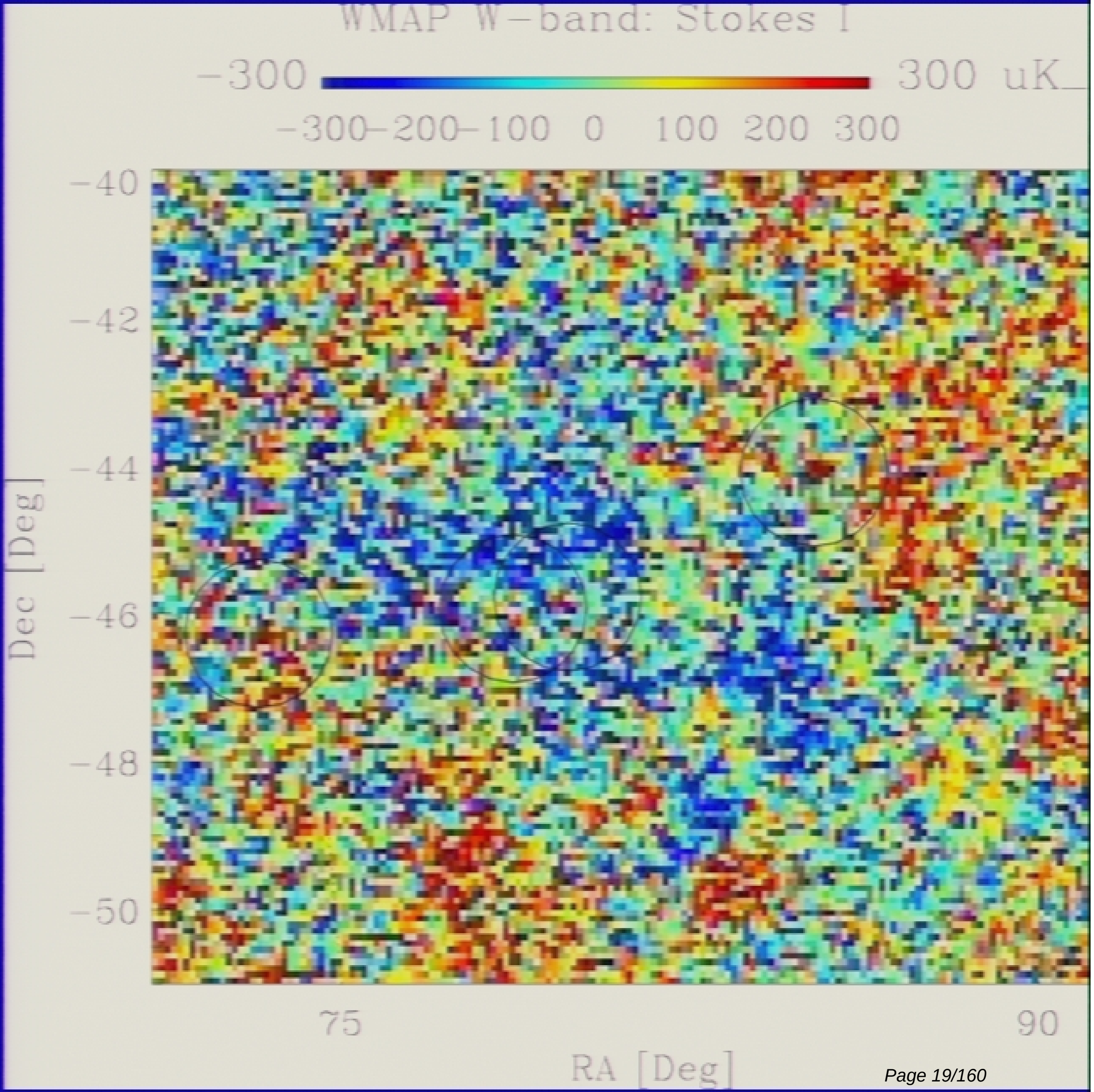
- 'Shallow' scan, 75 hours, f_{sky}=3.0%, large scale TT
- 'deep' scan, 125 hours, fsky=0.28%, x20 integration time for polarization.
- Galaxy plane scans for polarized foreground characterization.



Boom03 T deep

- 7-bands (for 100<l<1000)
- Consistent with LCDM inflation paradigm. Parameters similar to Jan04/Jun03

Same bolometers as for Planck deep & shallow regions



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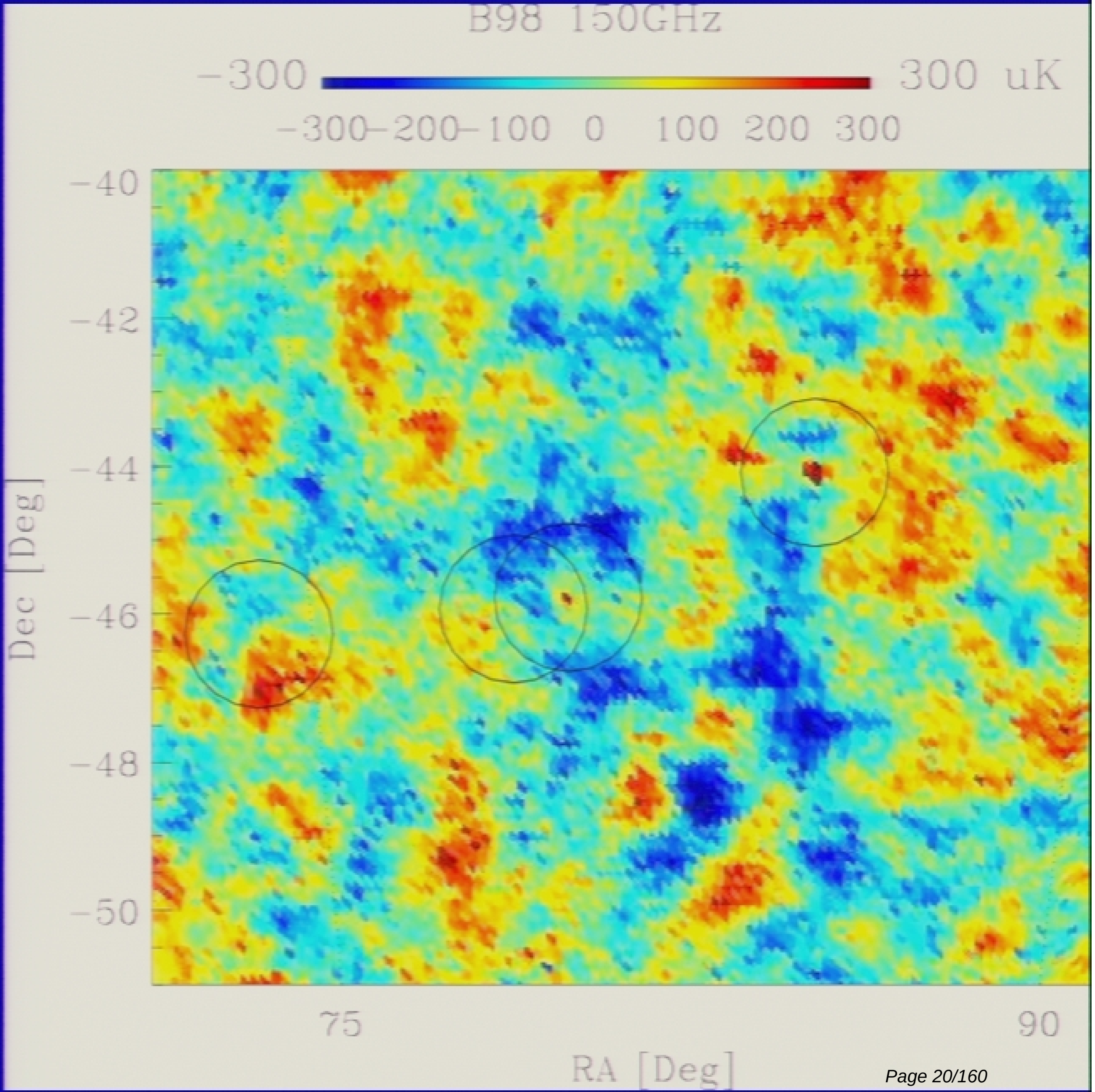

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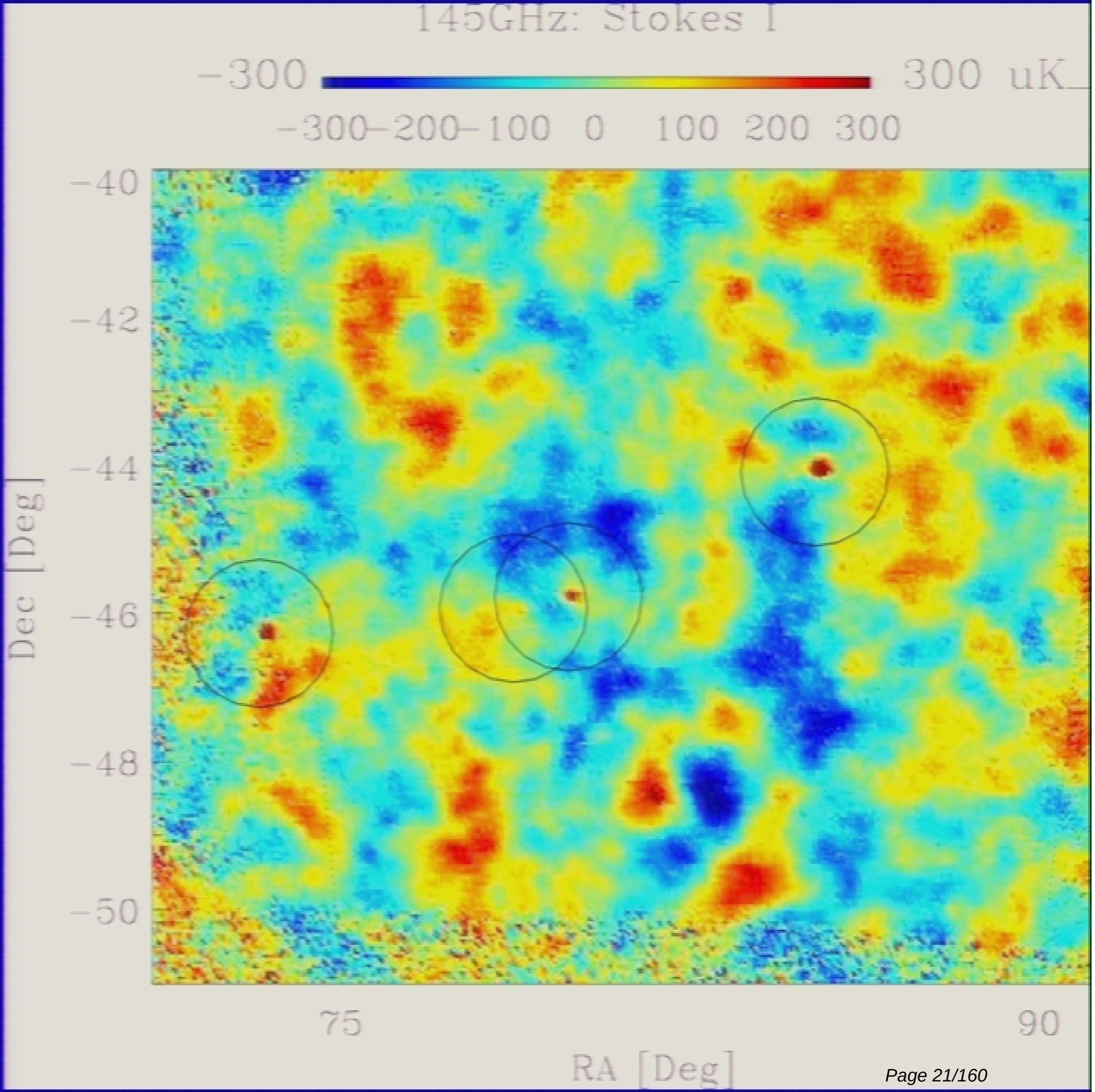

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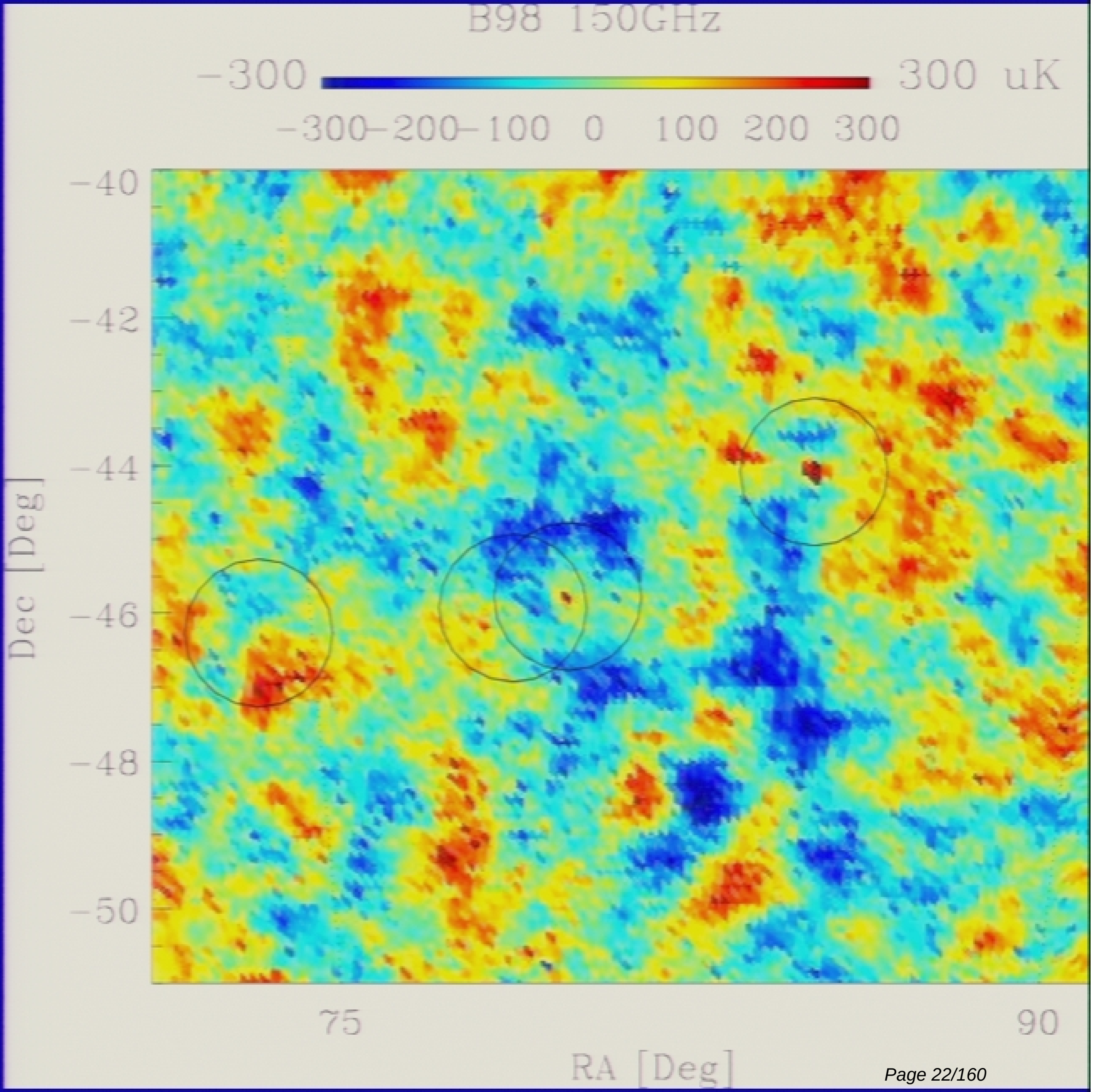

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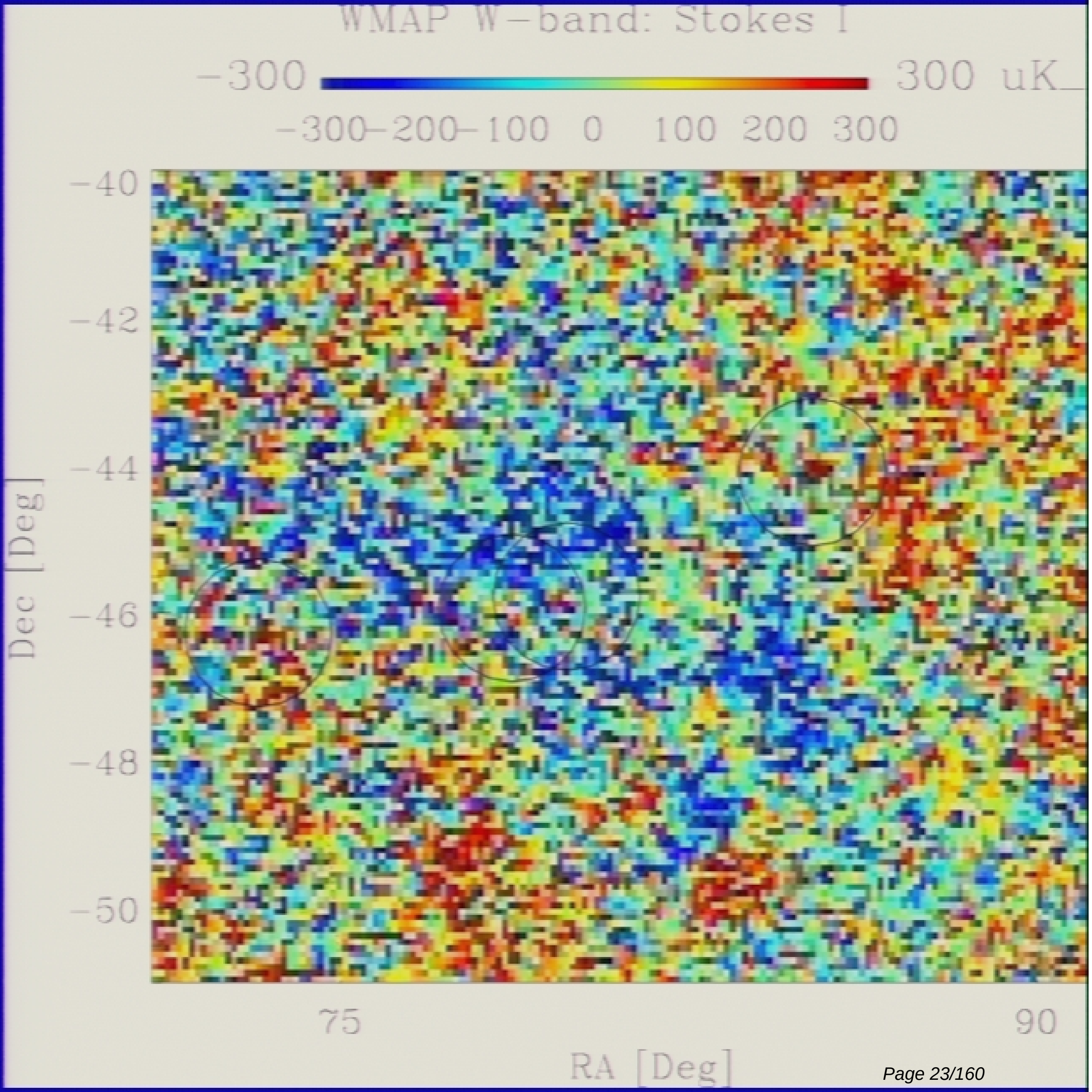

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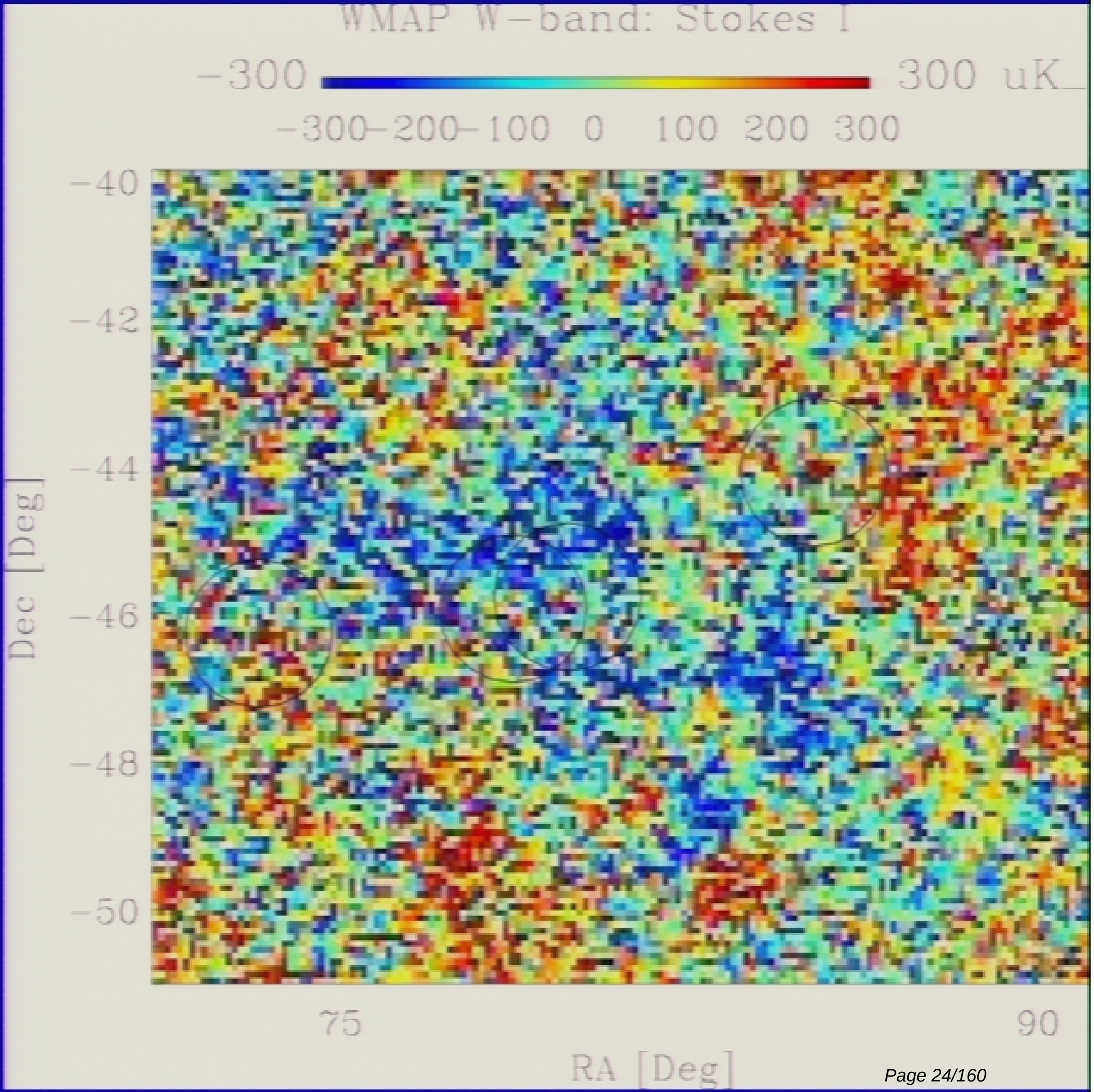

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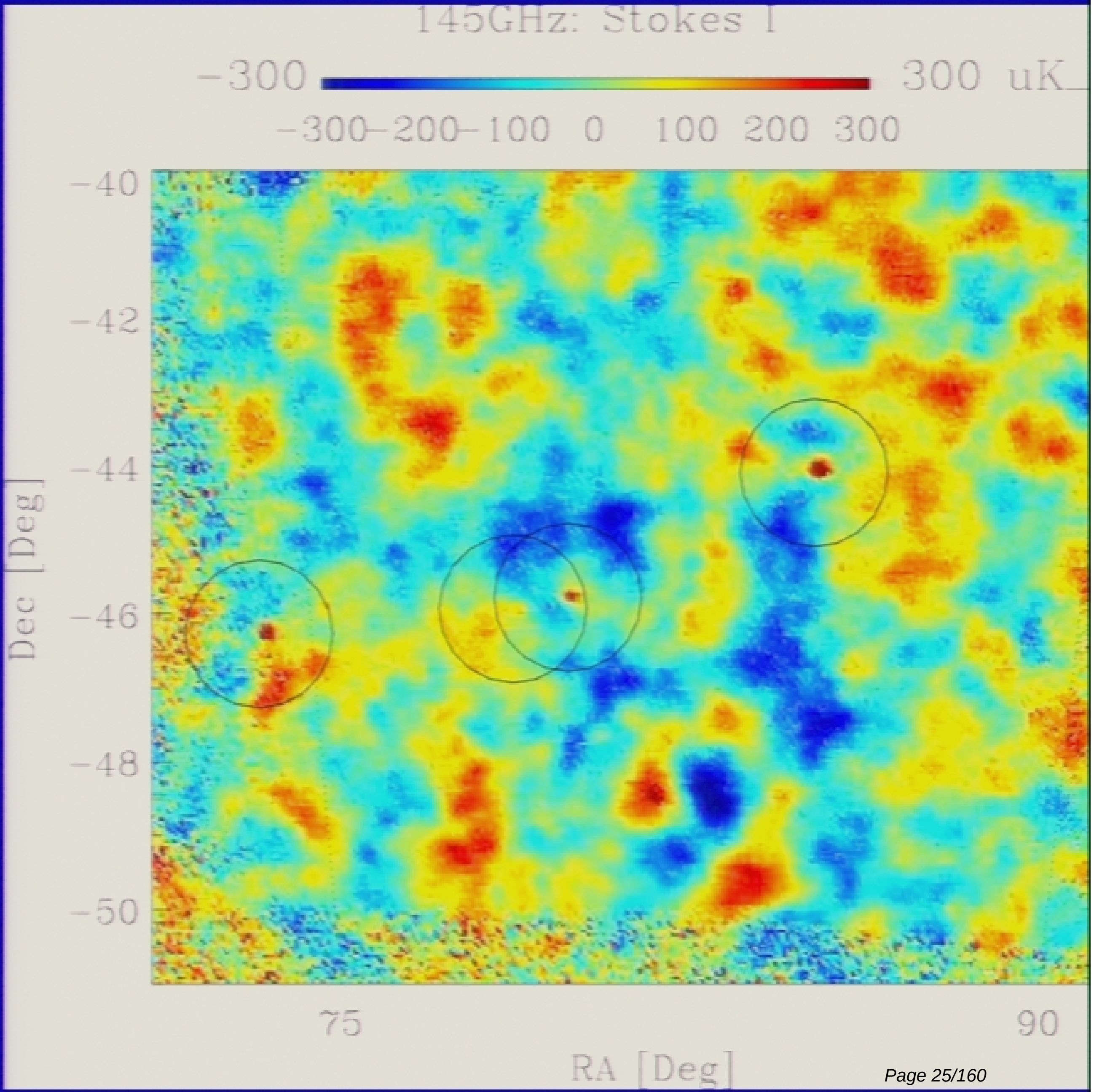
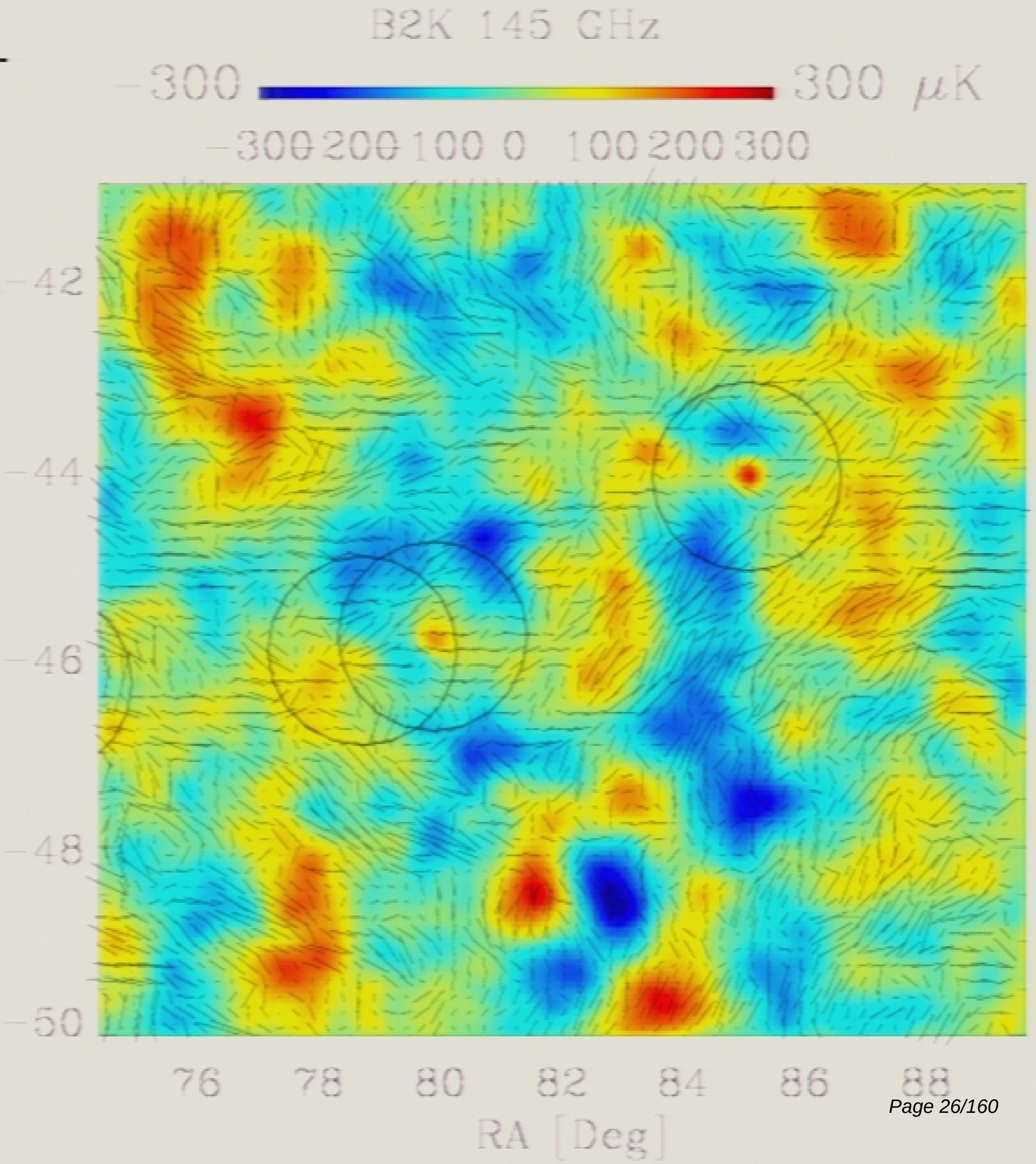


B03 Polarization Map – deep region

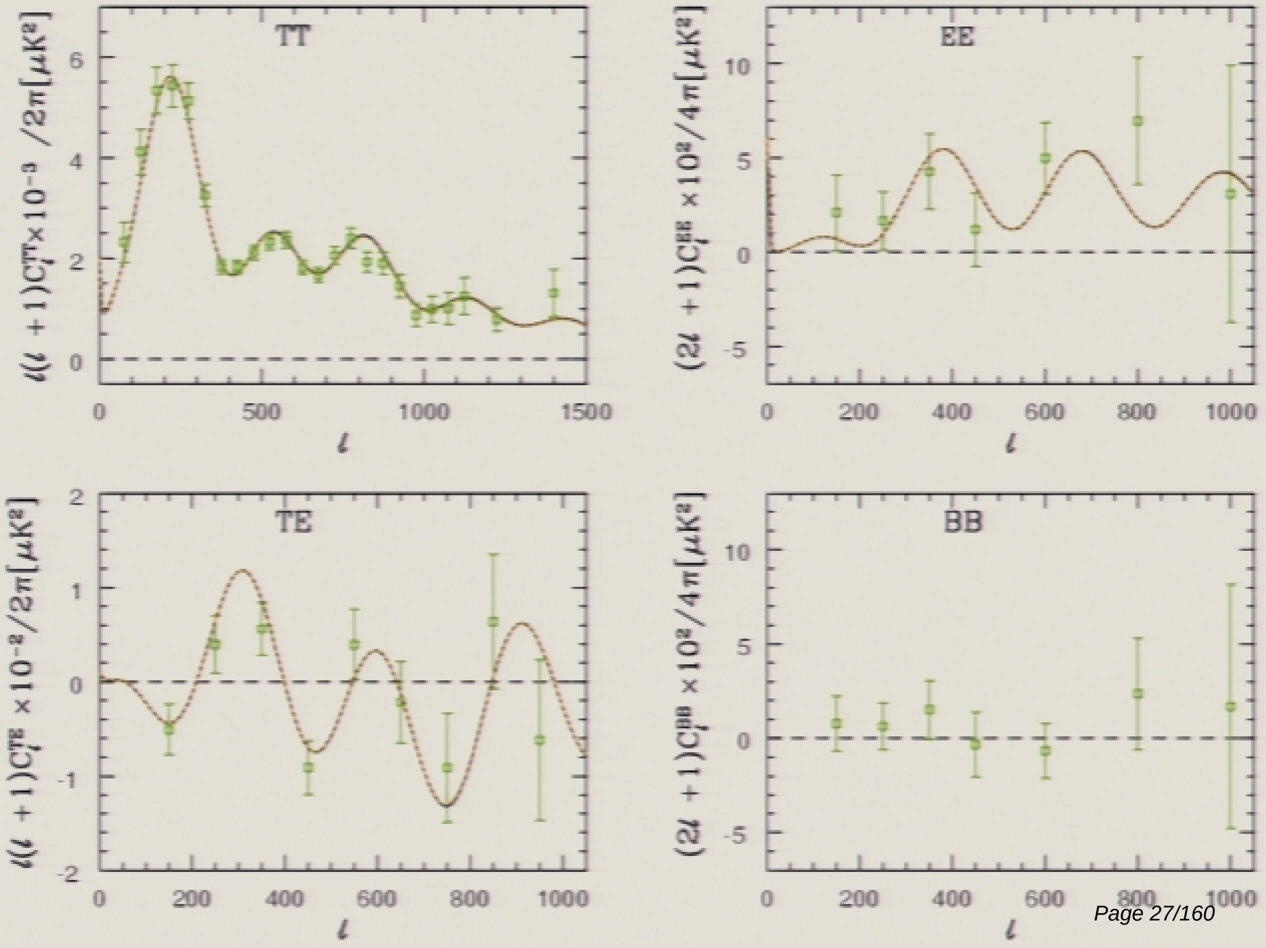
- Lots of systematics checks (jack-knives etc., timestream, map domains) [Piacentini et al., Montroy et. al.]
- Synchrotron and dust signals are sub-dominant (few 0.1μK vs. e.g. ~ 3 μK for WMAP ΛCDM EE).
- TB, BB, and EB all consistent with zero



Boom03 Polarization Power Spectra

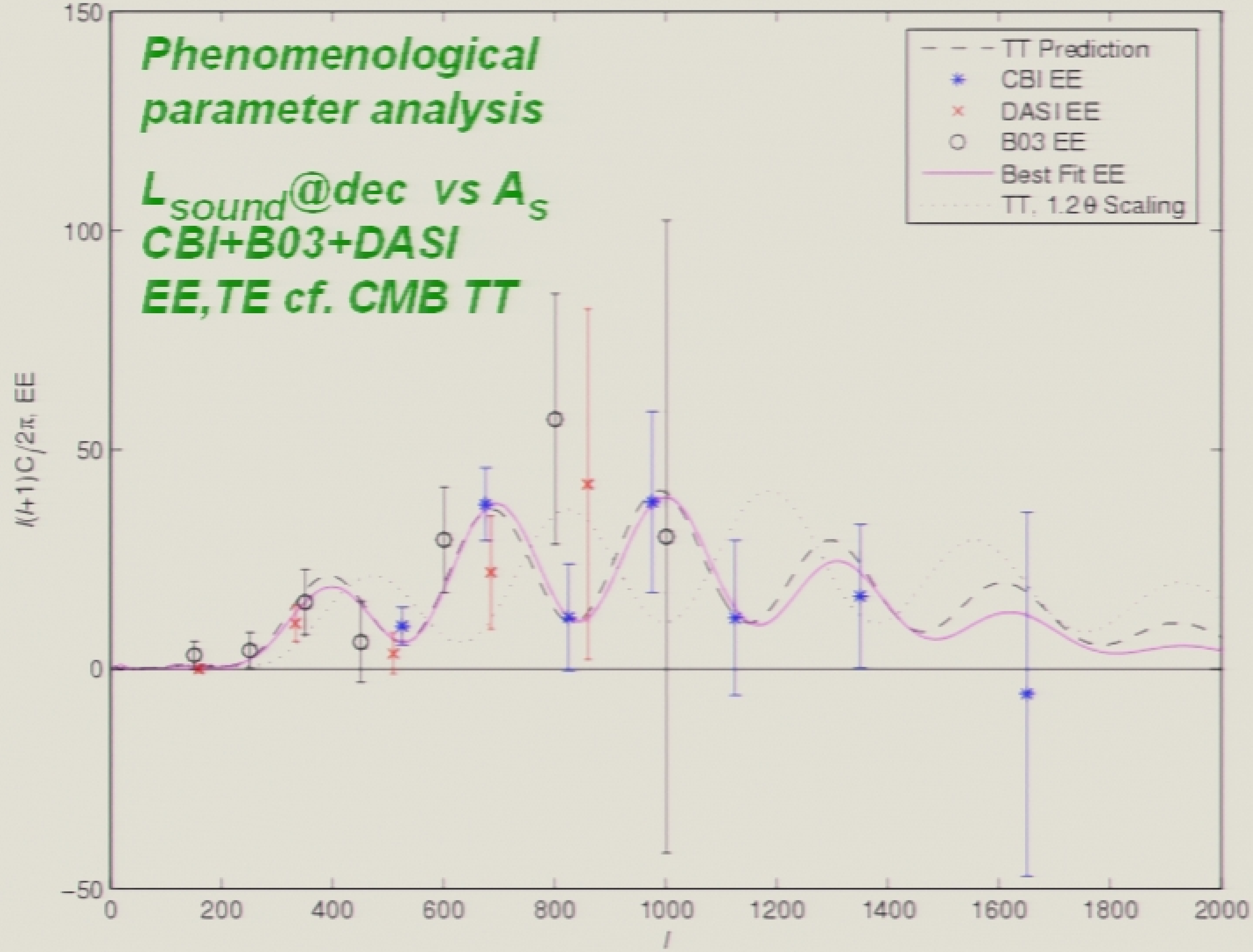
Same bolometers as for Planck deep & shallow regions

- 7-bands (for $100<\ell<1000$)
- Consistent with LCDM inflation paradigm. Parameters similar to Jan04/Jun03
- 5 Boom03 papers on astroph
- MacTavish etal 05 "parameters"



Polarization EE: 2.5 yrs of CBI, Boom03, DASI

(CBI04, DASI04, CAPmap04 @ COSMO04) & DASI02 EE & WMAP1 '03 TE



Phenomenological parameter analysis

L_{sound}@dec vs A_s

CBI+B03+DASI

EE,TE cf. CMB TT

[Sievers et al. astro-ph/0509203]

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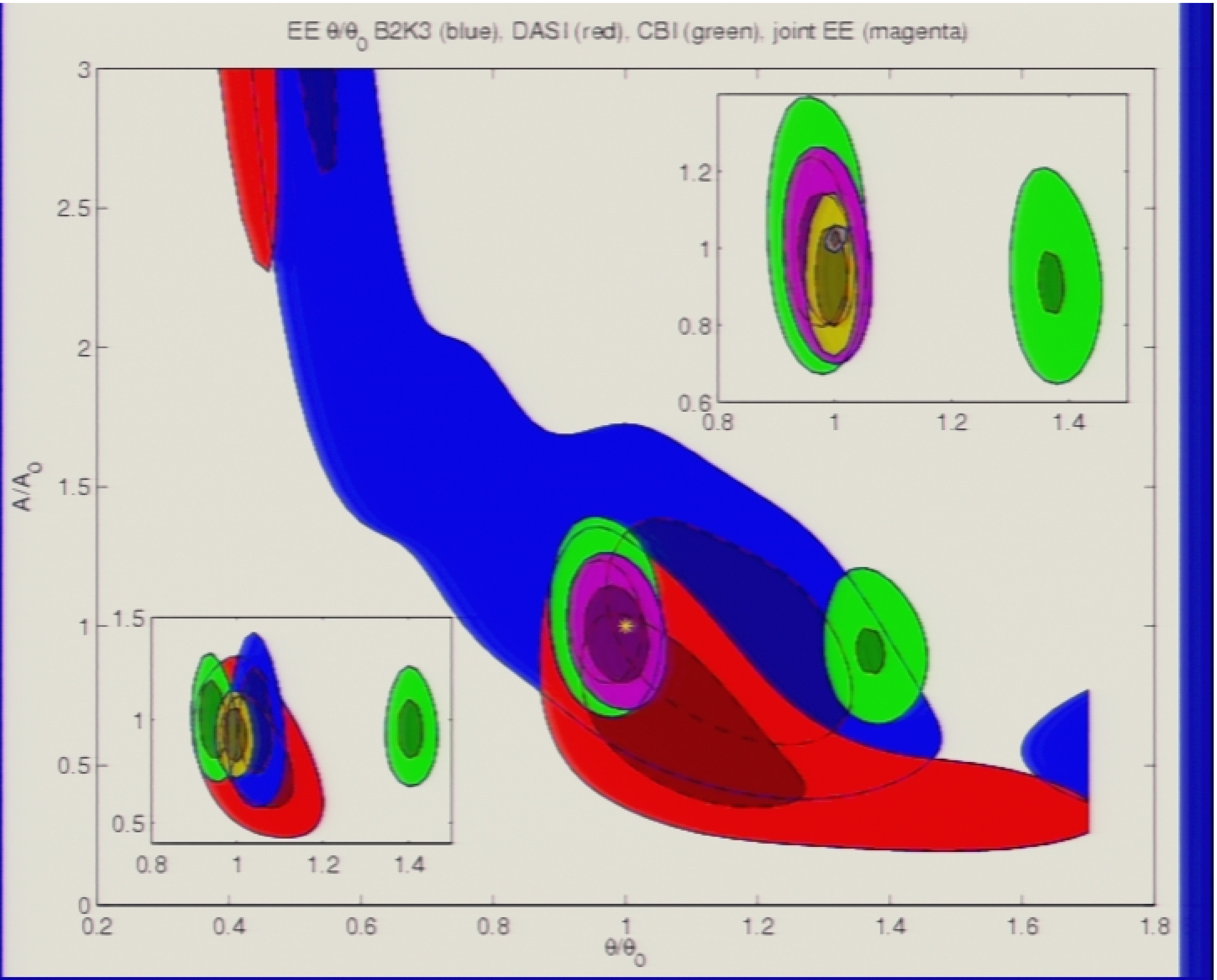


pattern shift parameter 1.002 +- 0.0043 WMAP1+CBI+DASI+B03

TT/TE/EE Evolution: Jan00 11% Jan02 1.2% Jan03 0.9% Mar03 0.4%

EE: 0.973 +- 0.033, phase check of CBI EE cf. TT pk/dip locales & amp

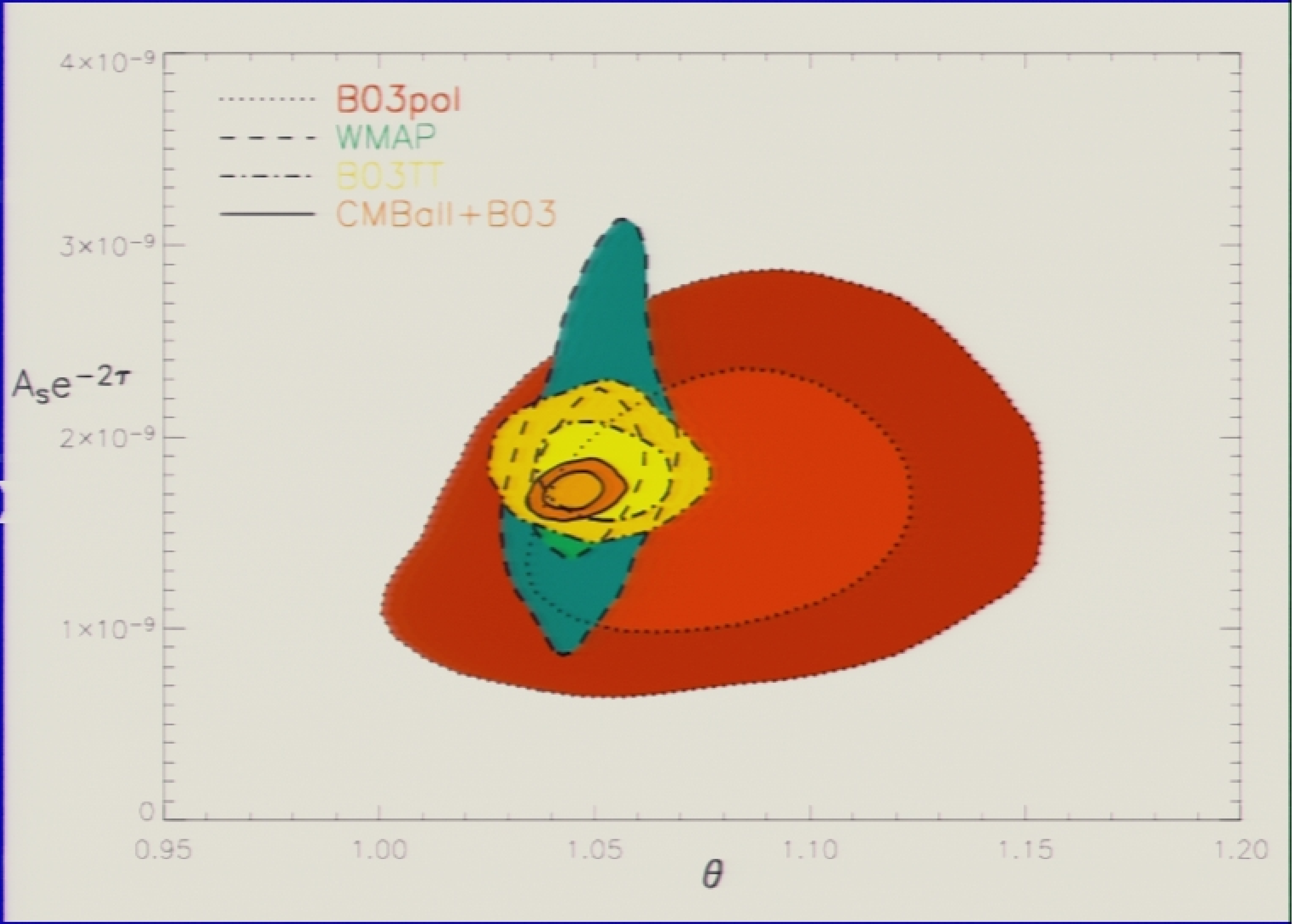
EE+TE 0.997 +- 0.018 CBI+B03+DASI (amp=0.93+-0.09)

BOOM03 version USING ONLY BOOM03pol DATA of θ

Boom03 TE and EE alone zeroes in on proper peak with few % accuracy. (1.08 +- .03 cf. 1.045 +- 0.004)

Amplitude matches TT prediction as well.

MacTavish etal Jul 21'05



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τ_C z_{reh} **GASTROPHYSICS:** Compton Depth from Reionization redshift

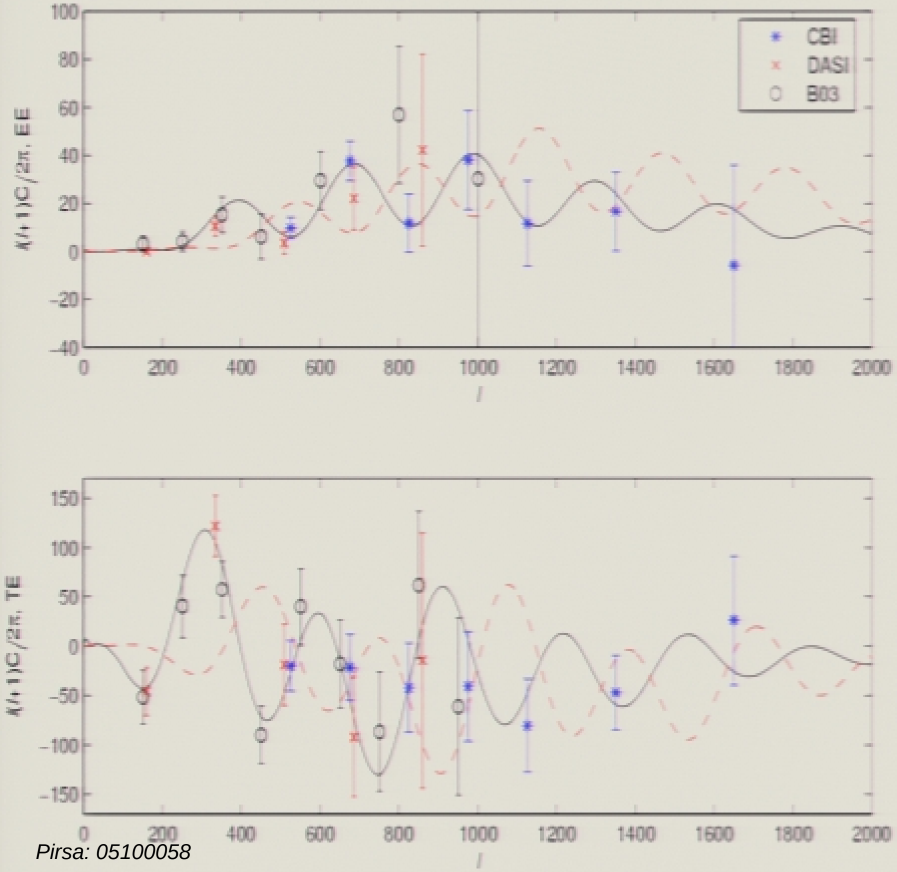
σ_8^2 h Ω_m Ω_b **LSS:** k_{Heq} aka Γ $k_{sound,dec}$, $k_{m\nu}$

Subdominant Isocurvature Phenomenology

Add Isocurvature CDM model, amp&index

$P_{iso} / P_s < 0.27$ large scale, < 1.7 small scale $n_{iso} = 1.1\pm0.6$

WMAP1+B03+CBI+DASI TT+TE+EE



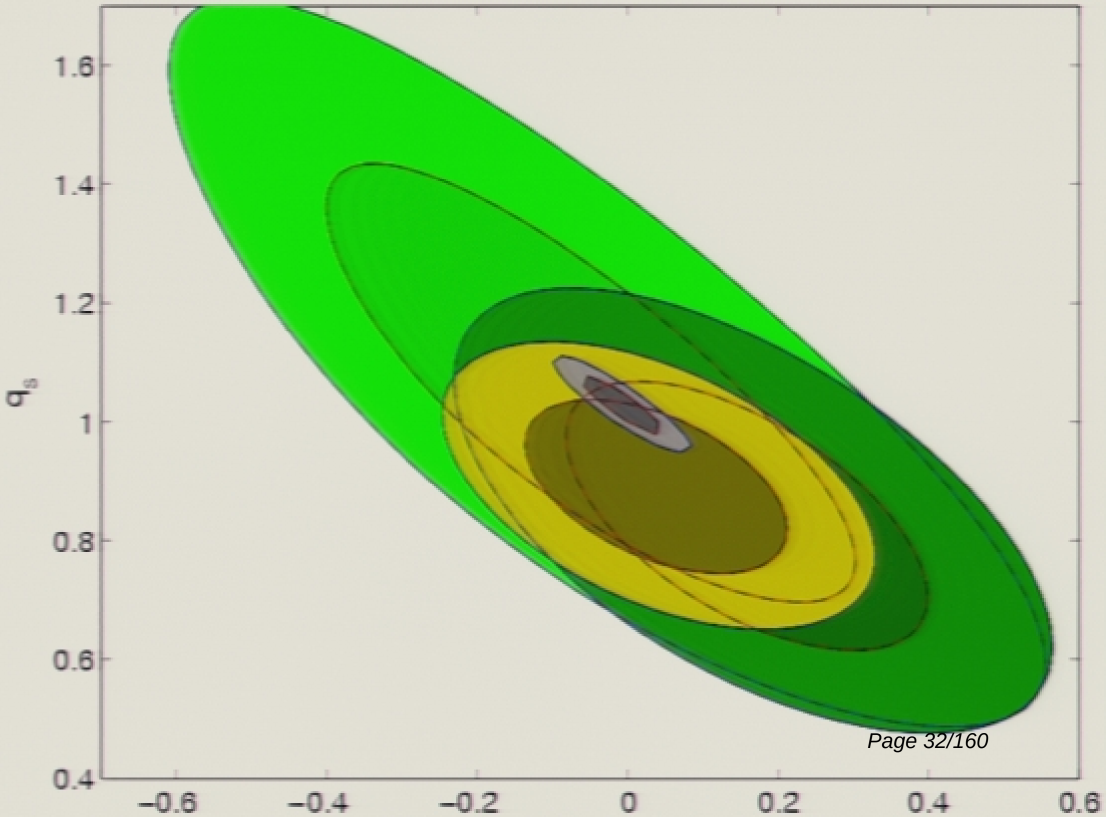
Restrict n_{iso}=3 isocurvature seed model

CBI EE

CBI EE+TE

CBI+B03+DASI EE+TE

CBI+B03 TT

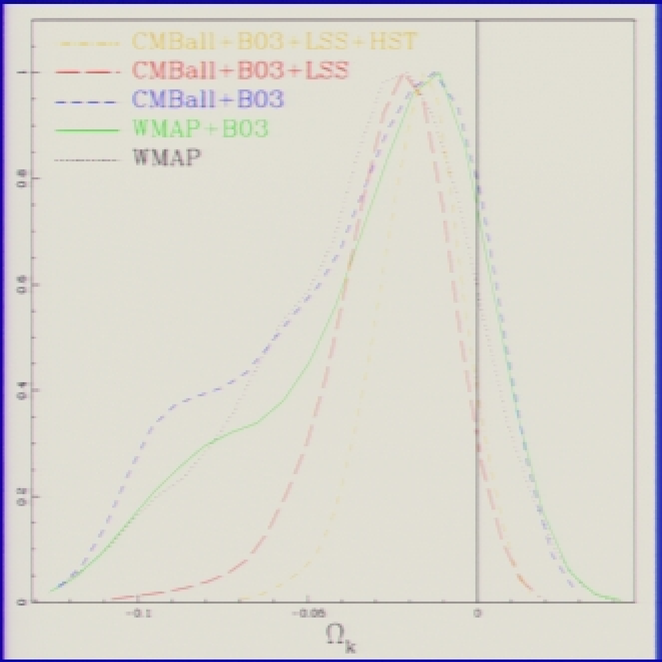


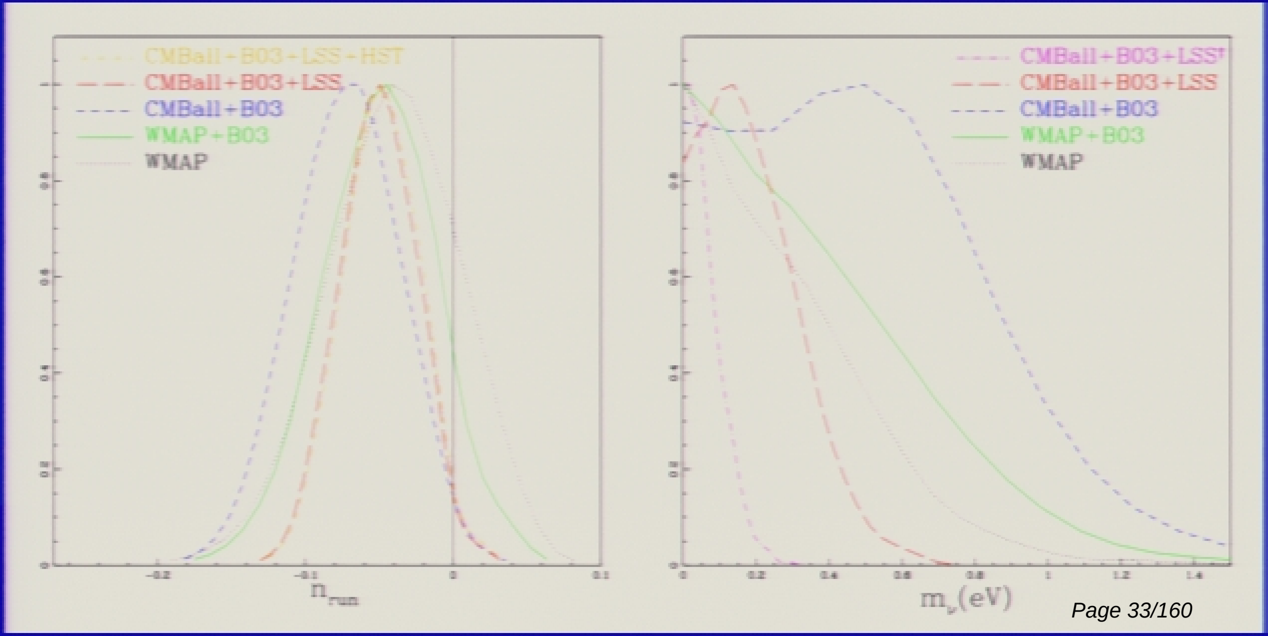
B03 Basic Model Extensions

- Curvature
- Running of the spectral index
- Tensor modes
- Massive neutrinos

$$\begin{aligned} \Omega_k &= -0.022 \pm 0.015 \\ n_{\rm run} &= -0.051^{+0.027}_{-0.026} \\ A_t/A_s &< 0.36 \\ f_\nu &< 0.093 \\ m_\nu &< 0.40\text{eV} \end{aligned}$$

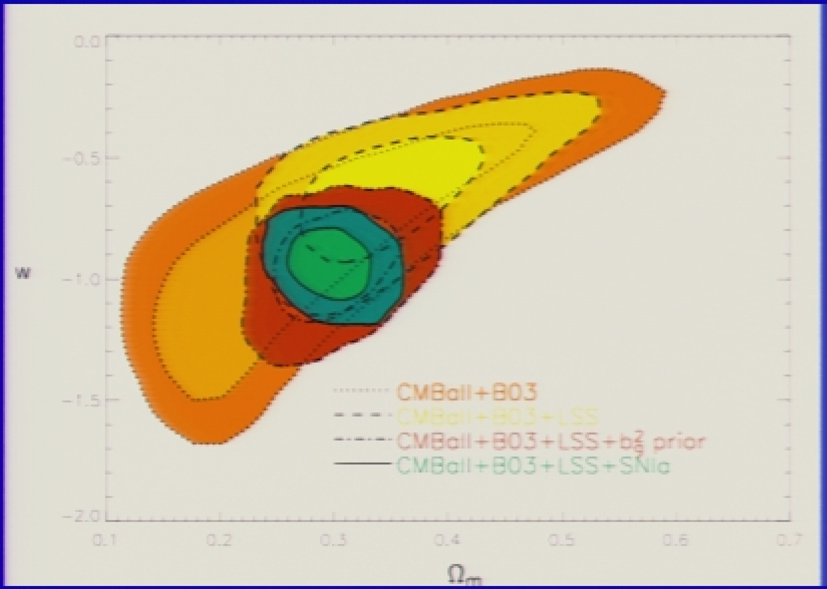
'CMBall' + B03 + LSS





B03 Basic Model Extensions

- Constraints on dark energy equation of state w (perturbations in dark energy included)



$$w \;=\; -0.94^{+0.094}_{-0.096}$$

'CMBall' + B03 + LSS + SN1a

- + Sub-dominant CDM isocurvature modes. Primordial isocurv/adiabatic amplitude ratios R_1 (@ 0.005Mpc^{-1}), R_2 (@ 0.05Mpc^{-1}) → $R_1 < 0.28$, $R_2 < 2.3$
- Isocurvature white noise 'seed' model (n_{iso}=3.0), $R_2 < 3.0$

$$\frac{C_B^{TT(iso)}}{C_B^{TT(adi)}} \;\sim\; (0.005)R_2 \sim 0.01$$

Physical cosmology Probes of Early & Late universe physics

CMB: polarization frontier (B-futures, Carrie MacTavish, Jon Sievers, Olivier Dore, Mike Kesden, Mike Nolta, Licia Verde)

tensor (gravity wave) power to curvature power, a direct measure of (q+1), q=deceleration parameter during inflation

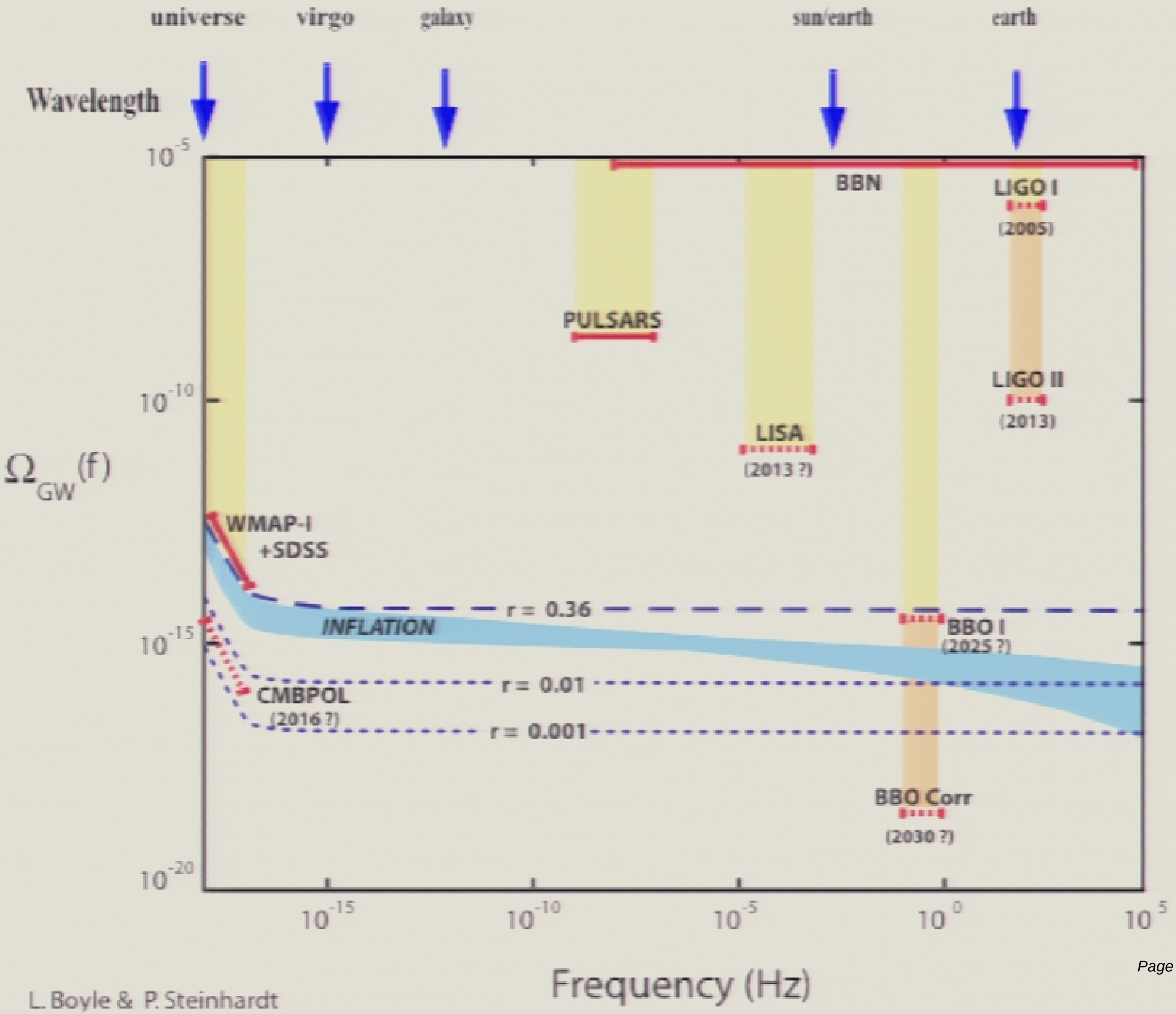
q may be highly complex (scanning inflation trajectories)

many inflaton potentials give the same curvature power spectrum, but the degeneracy is broken if gravity waves are measured

(**q+1**) =~ 0 is possible - low scale inflation – upper limit only

Very very difficult to get at this with direct gravity wave detectors – even in our dreams

Response of the CMB photons to the gravitational wave background leads to a unique signature within the CMB at large angular scales of these GW and at a detectable level. Detecting these B-modes is the new "holy grail" of CMB science.



L. Boyle & P. Steinhardt

CBI ongoing to Sept'05+

Bicep

Quiet2

(1000 HEMTs)
Chile

QUaD

Quiet1

Spider

(1856 bolometer LDB)

EBEX

ACT+

(3000 bolometers)
Chile

Clover

2017

CMBpol

Boom03

2003 2005 2007

2004 2006 2008

WMAP ongoing to 2009

SPT+

(1000 bolometers)
South Pole

Polarbear

(300 bolometers)
California

DASI

CAPMAP

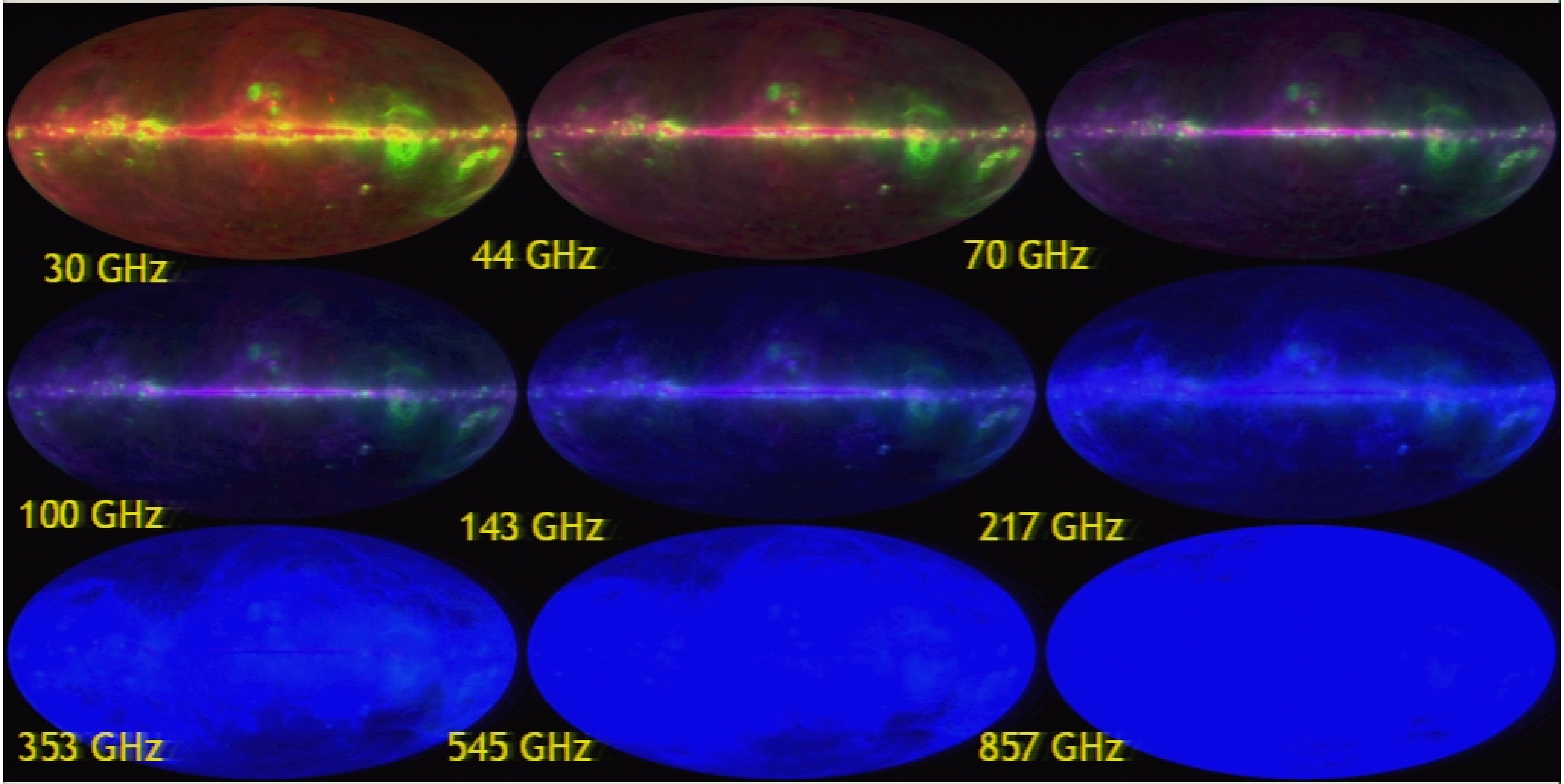
Planck

(84 bolometers)

HEMTs L2

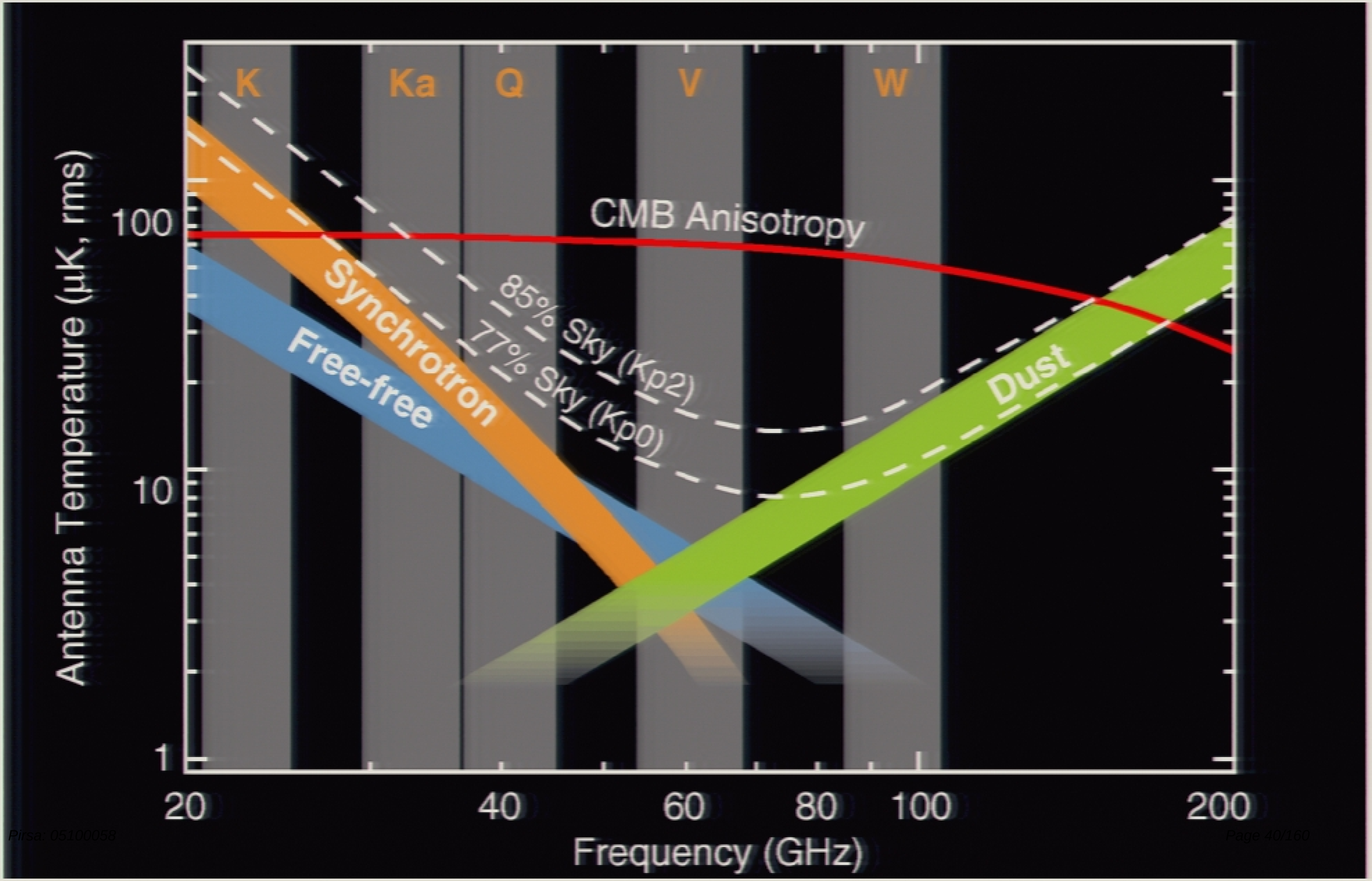
3-Colour Foregrounds

Synchrotron
Bremsstrahlung (Free-Free)
Thermal Dust



$\Delta T = \delta f / df_{cmb} / dT$ in deg K, linear in sqrt(ΔT), 1K threshold

Foreground Spectra



SPIDER LDB Polarization Experiment

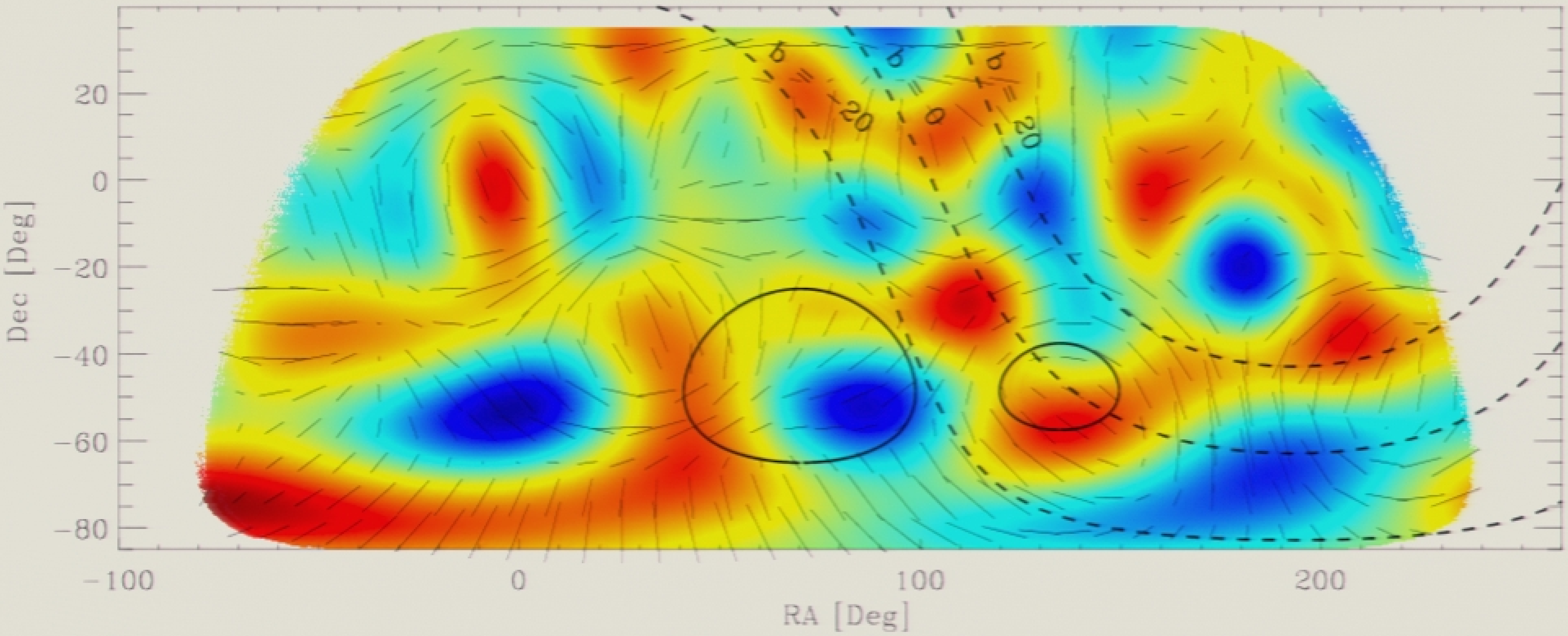
Institute	Responsibilities
Caltech-JPL	Antenna-coupled bolometer arrays, optics, receiver assembly/testing
Cardiff University	filters, optics
Case Western Reserve University	cooled ½ wave plates and rotating mechanisms, optics
CEA (Grenoble)	He3 refrigerator
Imperial College	data analysis, theory
NIST	SQUID Multiplexers
University of Toronto-CITA	Gondola, tracking, data analysis
University of British Columbia	Readout electronics

SPIDER Tensor Signal

- Simulation of large scale polarization signal
- This is what we are after!!

$$\boxed{\frac{A_T}{A_S} = 0.1}$$

No Tensor



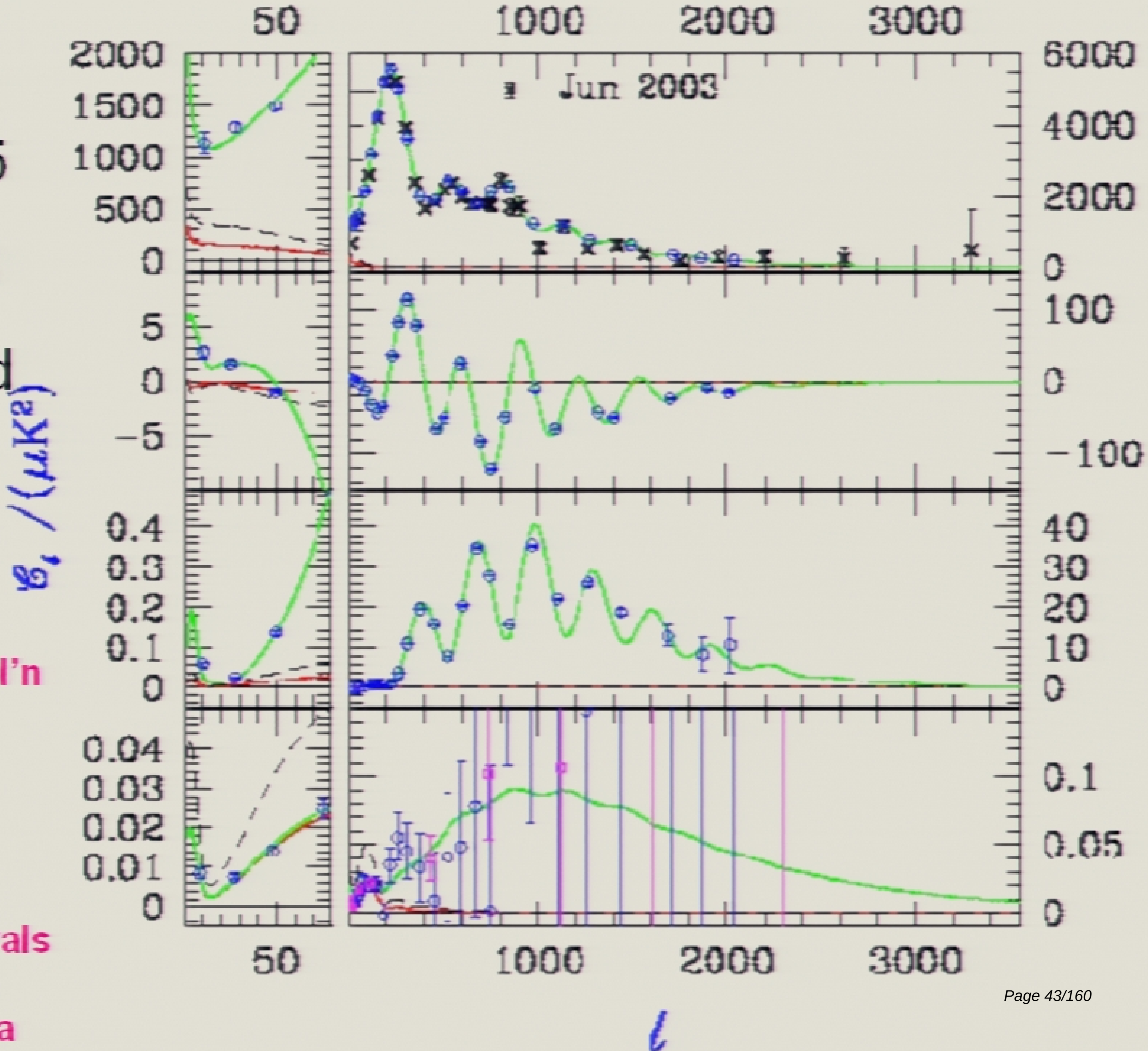
forecast

Planck2.5

100&143

Spider10d

95&150



Synchrotron pol'n

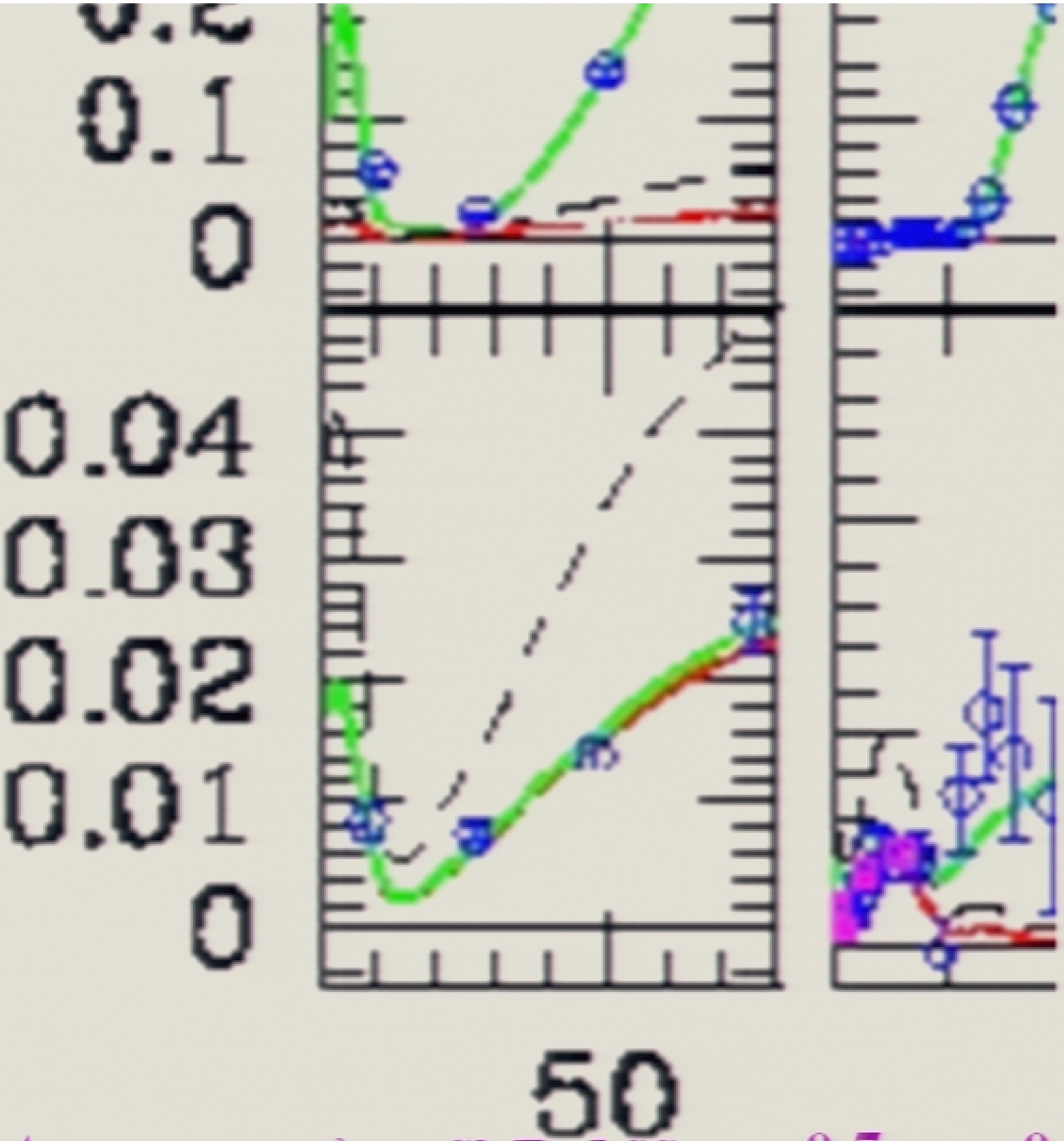
< .004 ??

Dust pol'n

< 0.1 ??

Template removals from multi-frequency data

forecast
Planck2.5
100&143
Spider10d
95&150



GW/scalar curvature: current from CMB+LSS: r < **0.7** or < **0.36** 95% CL; good shot at **0.02** 95% CL with **BB polarization** (+- .02 **PL2.5+Spider**)

BUT fgnds/systematics?? But **e.g .01+- .003 CMBpol-ish** Verde etal 05

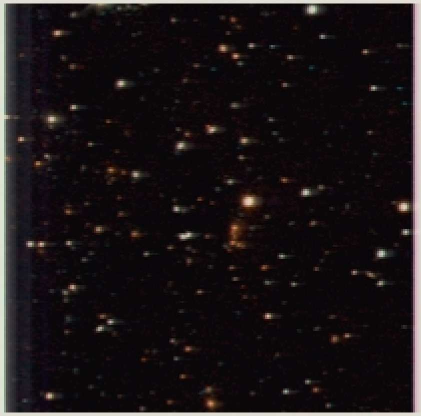
Physical cosmology Probes of Early & Late universe physics

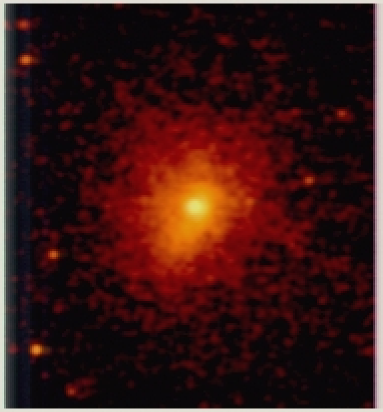
CMB: high L nonlinear frontier (e.g. CBI excess & SZ, Act/SPT, Verde)

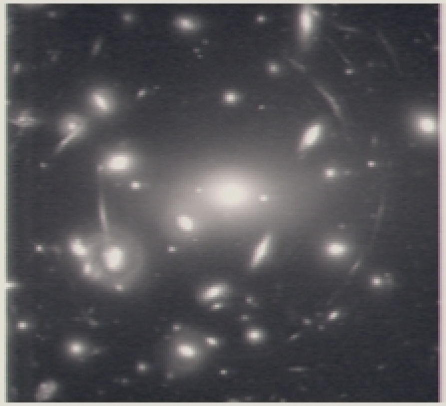
Cluster/group system in SZ, optical, weak lens, X-ray (Subha Majumdar, Christoph Pfrommer, Jon Sievers)

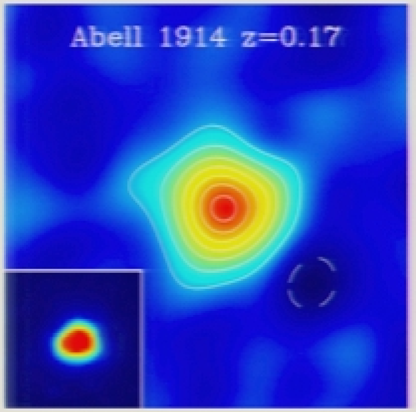
Galaxy Clusters

- The most massive, collapsed structures in the universe. They contain galaxies, hot, ionized gas (10^{7-8}K) and dark matter. They are good probes, because they are massive and "easy" to detect, but they have complex interiors.









CBI ongoing to Sept'05+

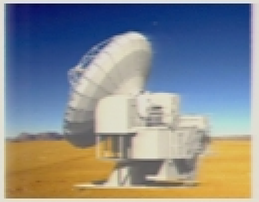
Acbar ongoing to Sept'06+

Quiet2

(1000 HEMTs)
Chile

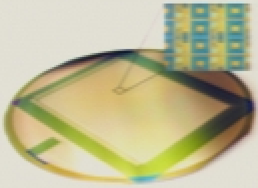
APEX

(~400 bolometers)
Chile



SCUBA2

(12000 bolometers)
JCMT, Hawaii



SZA

(Interferometer)
California

ACT

(3000 bolometers)
Chile

Clover

2017

CMBpol

2003

2004

2005

2006

2007

2008

SPT

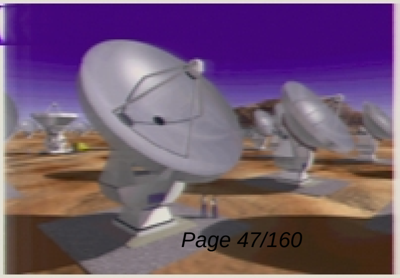
(1000 bolometers)
South Pole

ALMA

(Interferometer)
Chile

Planck

(84 bolometers)
HEMTs L2

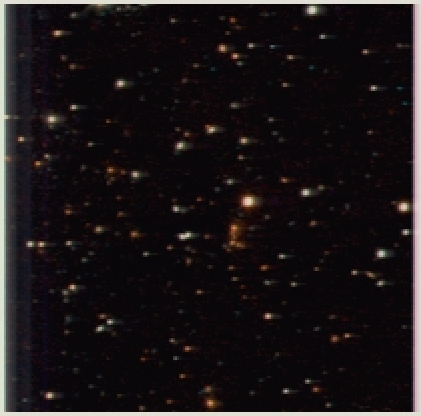


AMI

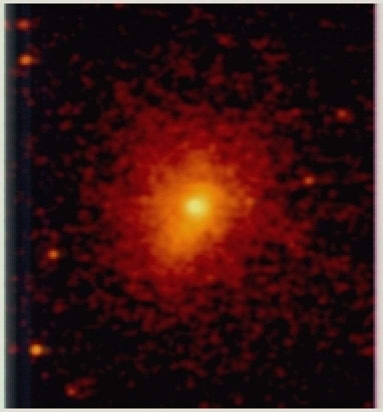
GBT

Galaxy Clusters

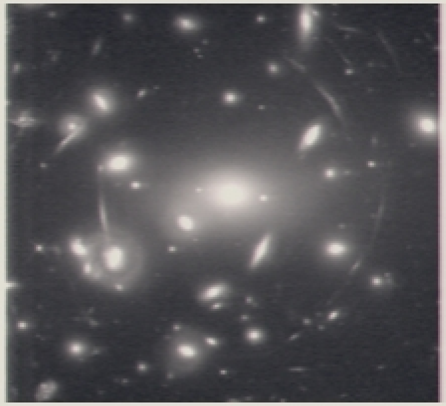
- The most massive, collapsed structures in the universe. They contain galaxies, hot, ionized gas ($10^{7\text{-}8}$K) and dark matter. They are good probes, because they are massive and “easy” to detect, but they have complex interiors.



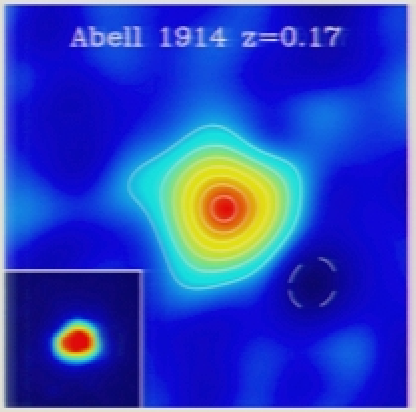
Light from galaxies



X-ray emission



Gravitational lensing



Sunyaev-Zel’dovich Effect

CBI ongoing to Sept'05+

Acbar ongoing to Sept'06+

Quiet2

(1000 HEMTs)
Chile

APEX

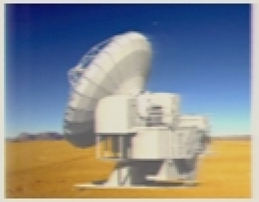
(~400 bolometers)
Chile

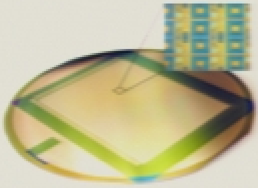
SCUBA2

(12000 bolometers)
JCMT, Hawaii

SZA

(Interferometer)
California





ACT

(3000 bolometers)
Chile

Clover

2017

CMBpol

2003 2005 2007

2004 2006 2008

SPT

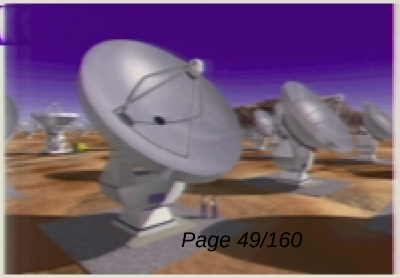
(1000 bolometers)
South Pole

ALMA

(Interferometer)
Chile

Planck

(84 bolometers)
HEMTs L2



AMI

GBT

WEAK LENSING:

Oct04: RCS1 53 sq deg, Virmos-Descart 11 sq deg +

Pan-STARRS
LSST

Deep Lens Survey ongoing 28 sq deg

JDEM
space

CFHT-Legacy ongoing to 08 (first results 05, 22+4 sq deg) 170 sq deg

RCS2 ongoing 1000 sq deg

KIDS (960 sq deg), UKIDS

SDSS ongoing

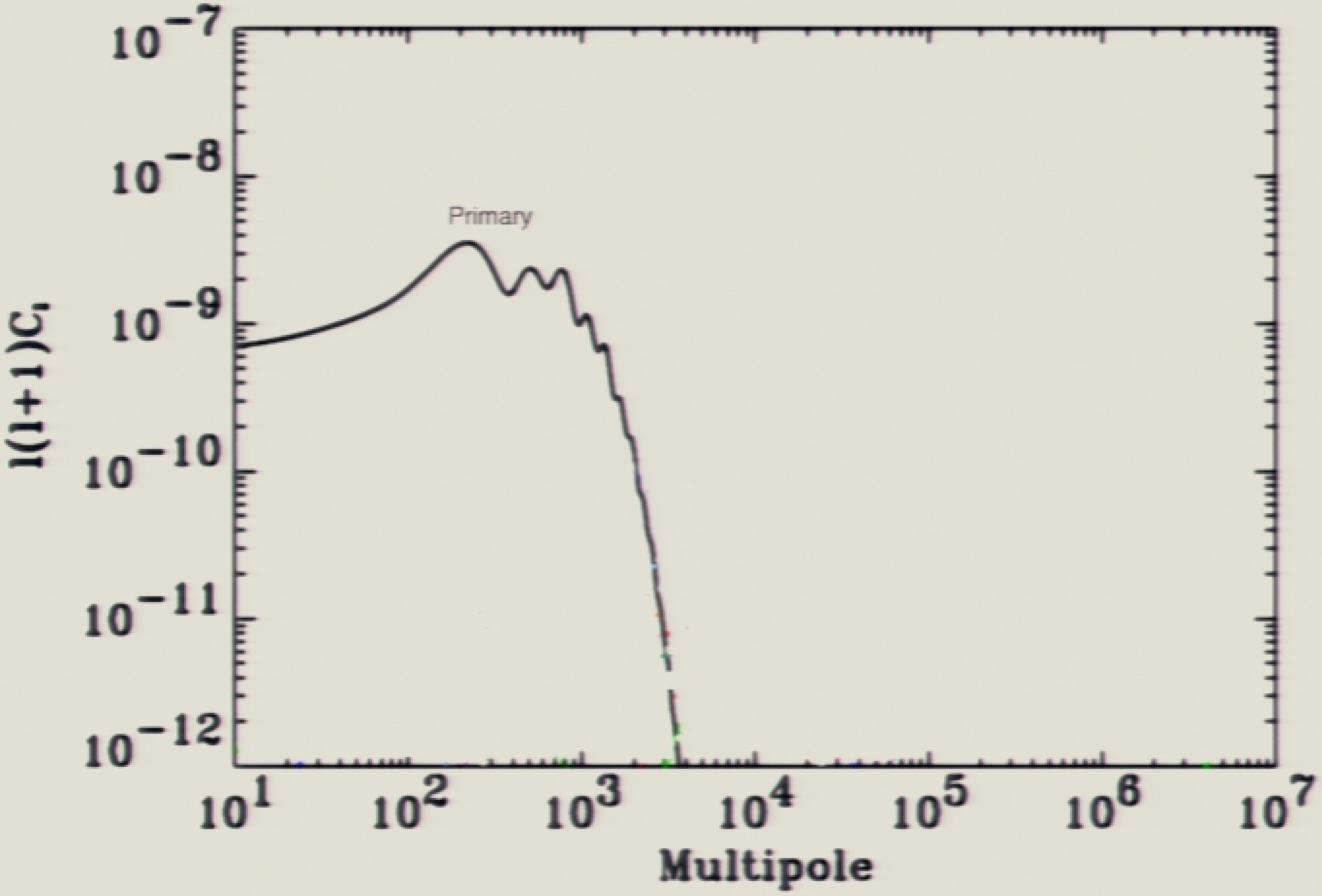
CLUSTER/GROUP system in the Cosmic Web

SZ/ PVmeasure: SZA, APEX, GBT, AMI, ACT. SPT, Planck, ALMA

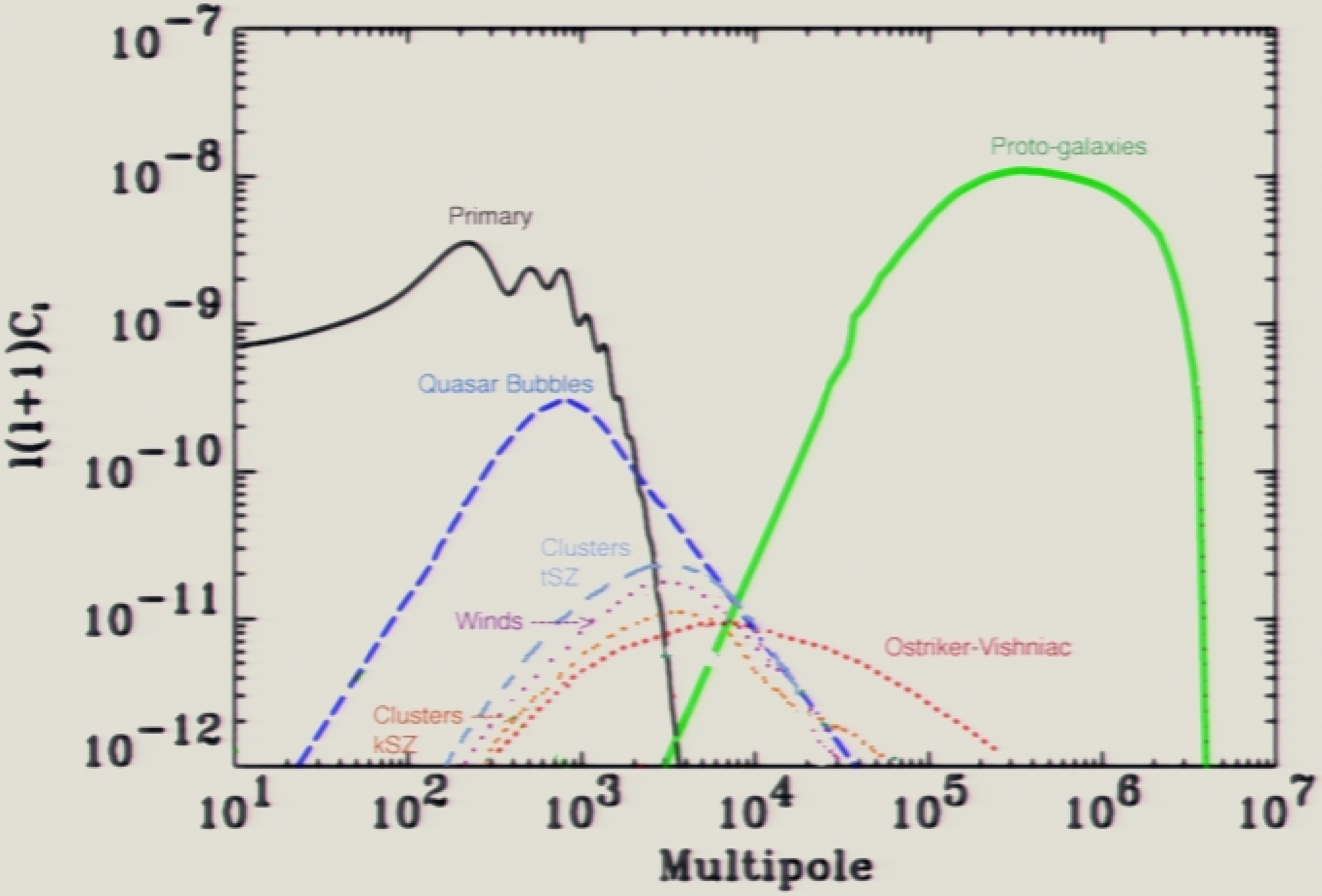
Optical: RCS, RCS2, SDSS + ongoing

Large Optical Surveys for

Secondary Anisotropies & High L



Secondary Anisotropies & High L



a forecast ~ 2008+

Planck1 +

WMAP4 +

SPT/ACT

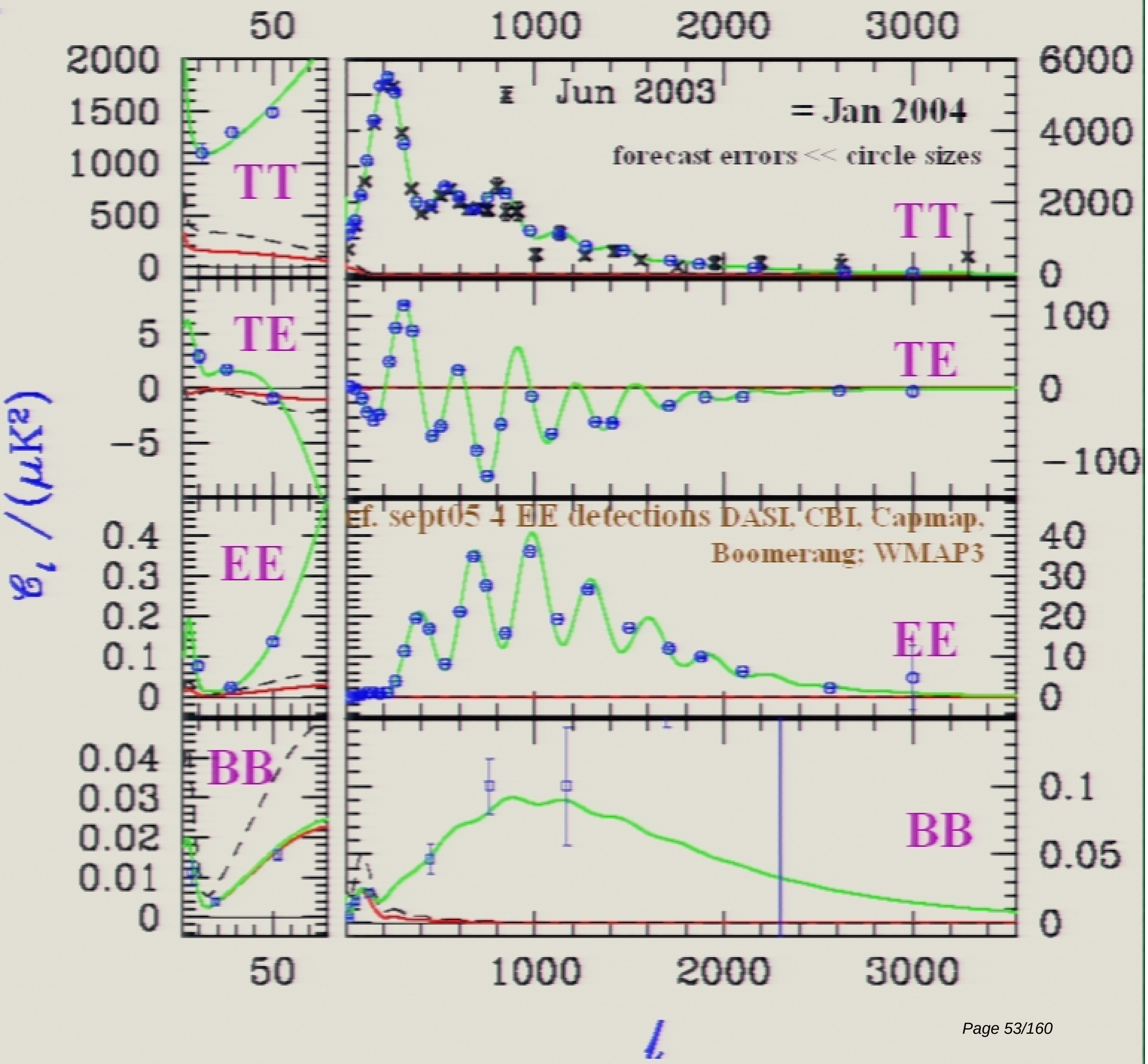
if (PSB arrays

& 1000 sq deg)

+ QuAD

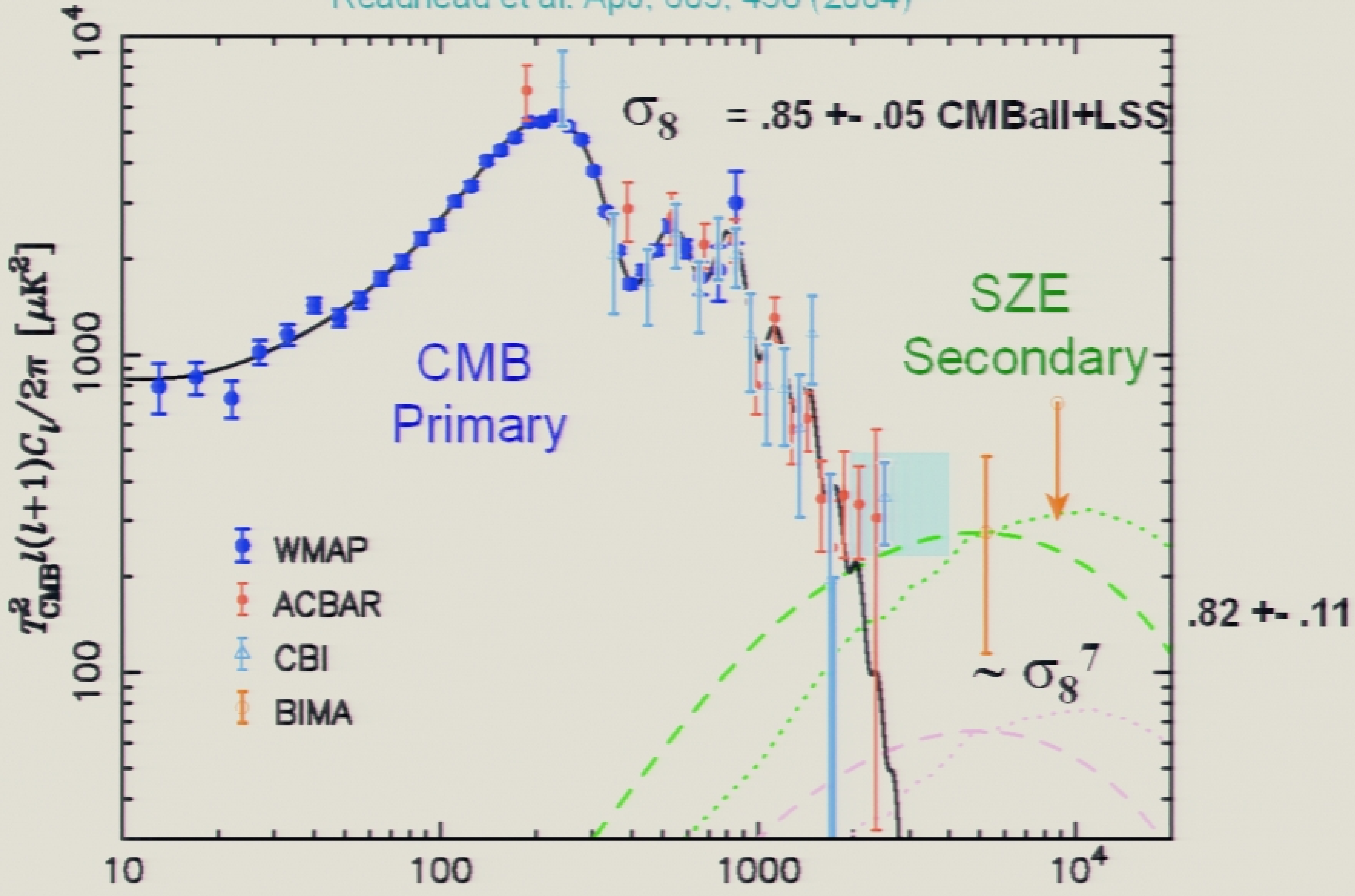
+ BiCEP

+ Quiet2



CBI 2000+2001, WMAP, ACBAR, BIMA

Readhead et al. ApJ, 609, 498 (2004)



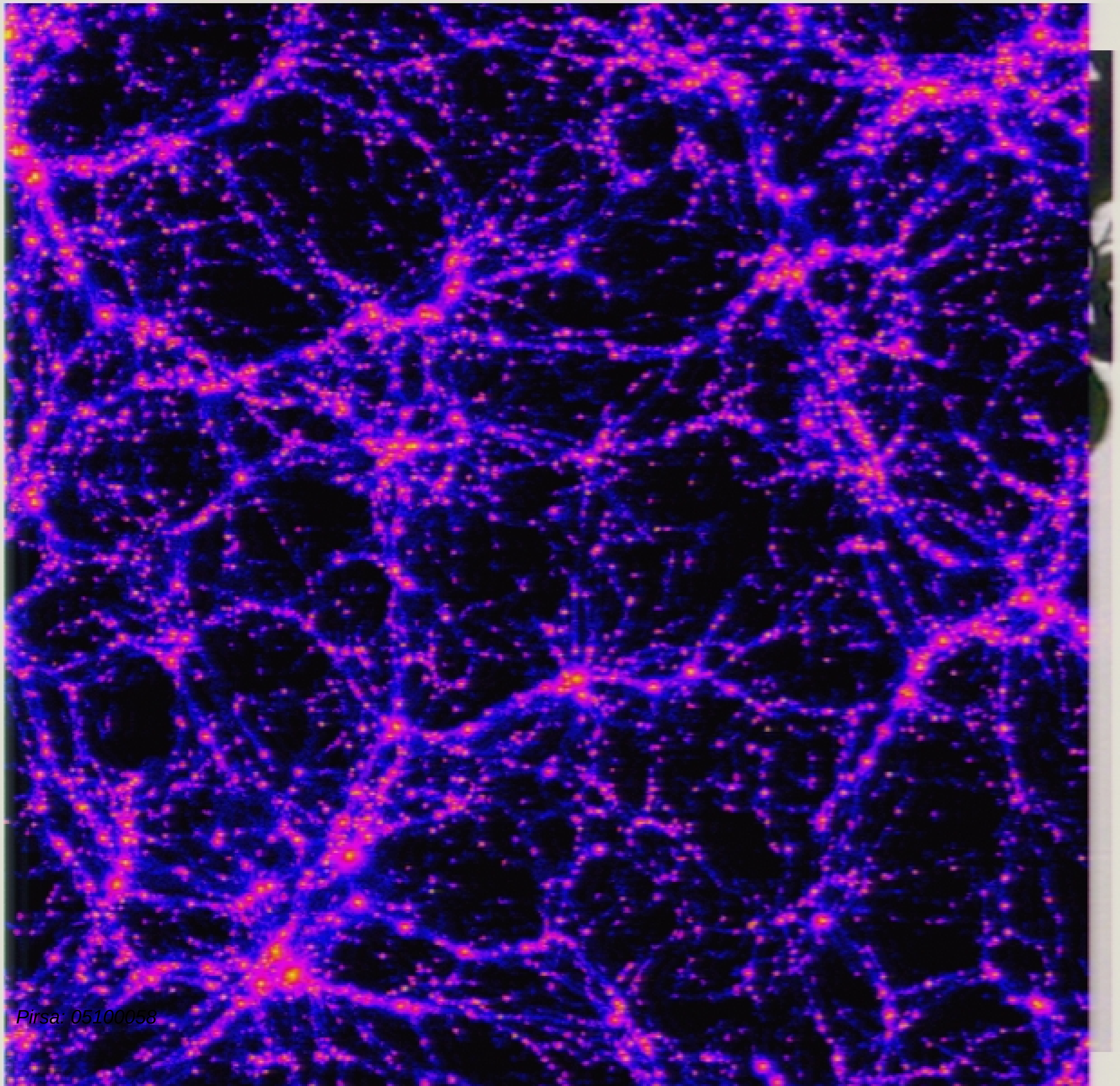
Kuo et al. (2005, in prep)

The SZ & cluster frontier

σ_8 issue will be resolved (soon?) but cluster complexity must be fully addressed for high precision on other parameters to be realized.

combine **SZ at varying resolution + optical + gravitational lens + X-ray + embedded source observations**

Cosmic Web & Superclustering: a natural consequence of the gravitational instability of a hierarchical Gaussian random density field



massive clusters:

$\delta > 100$, peak-patches

Filaments $\delta \sim 5\text{-}10$

bridge clusters, groups bead the bridges

Membranes: $\delta \sim 2$

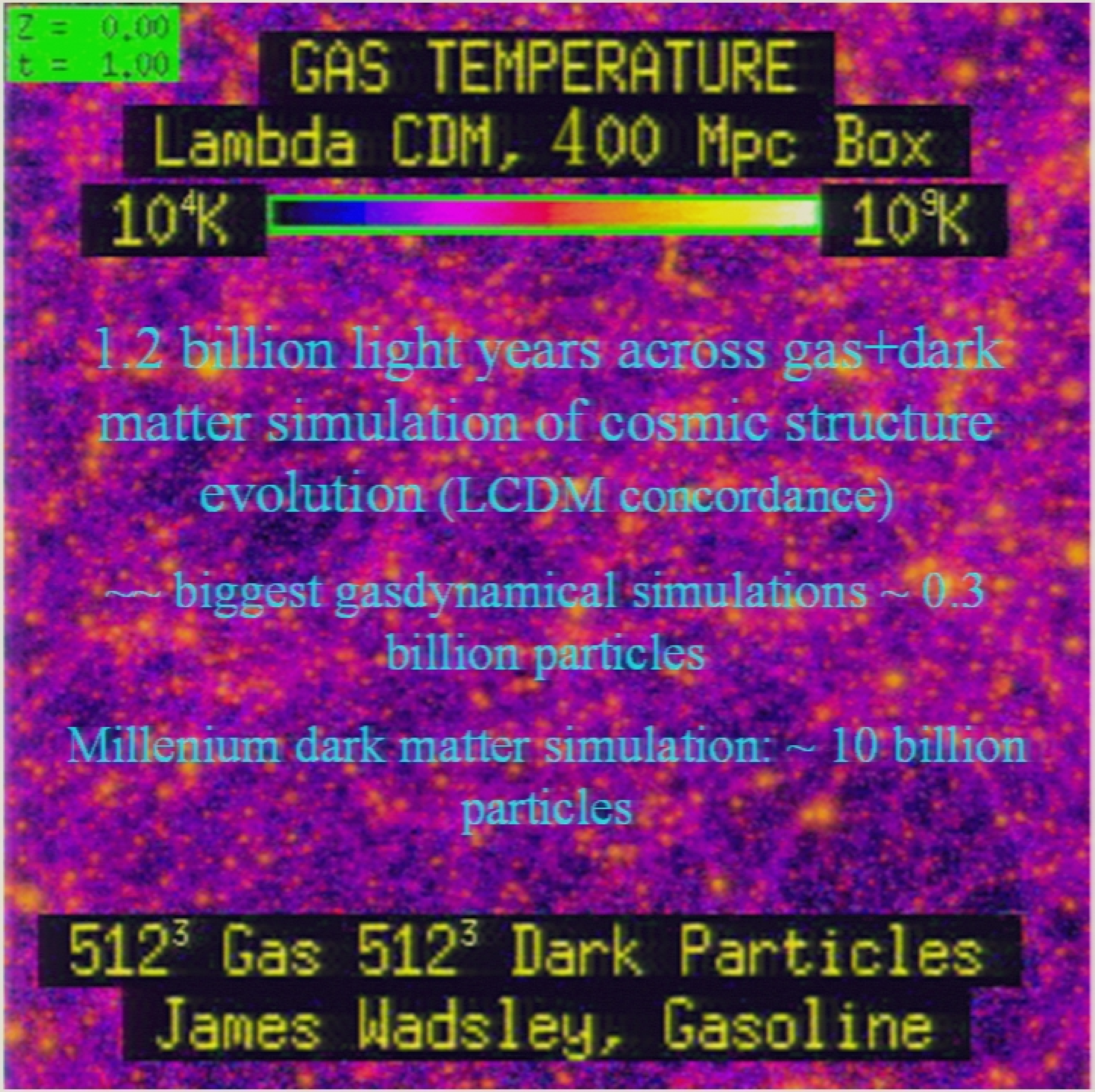
Voids: $\delta < 0$

“Molecular” picture

⌨CDM z=0

Gas Density

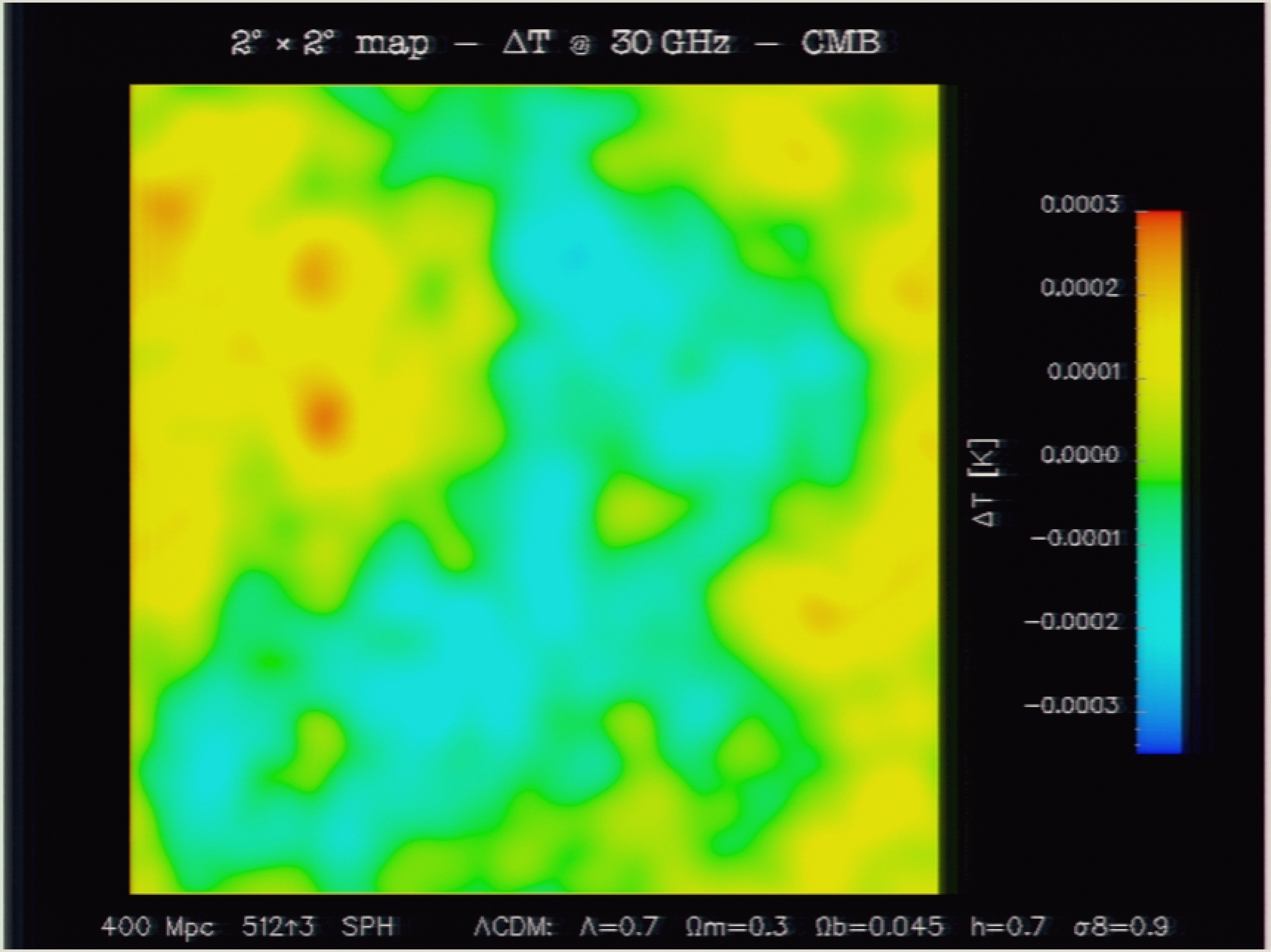
200 Mpc, 256^3 x 2



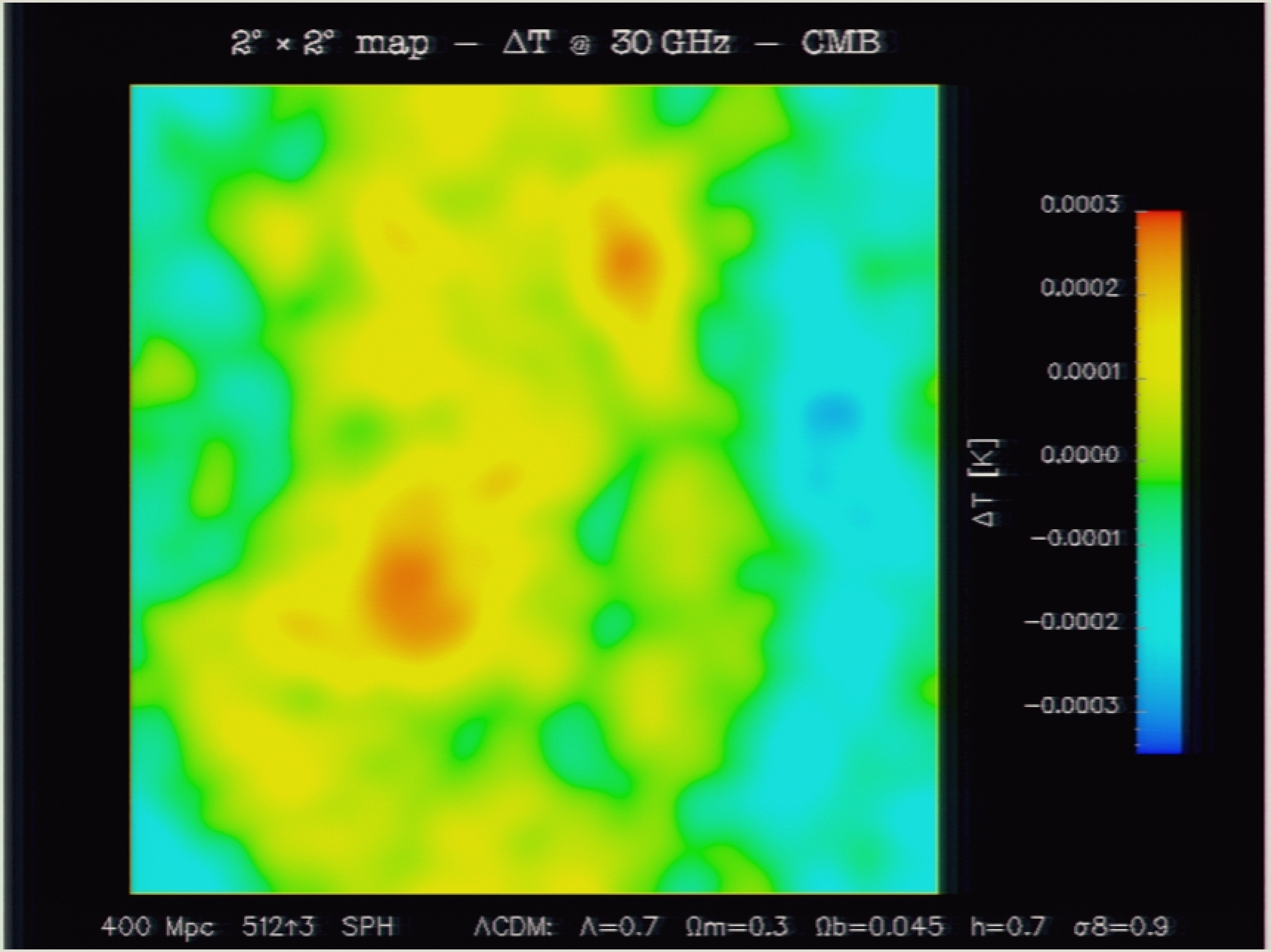
1.2 billion light years across gas+dark matter simulation of cosmic structure evolution (LCDM concordance)

~~ biggest gasdynamical simulations ~ 0.3 billion particles

Millenium dark matter simulation: ~ 10 billion particles



pass the CMB thru the cosmic web: CBI extra power??



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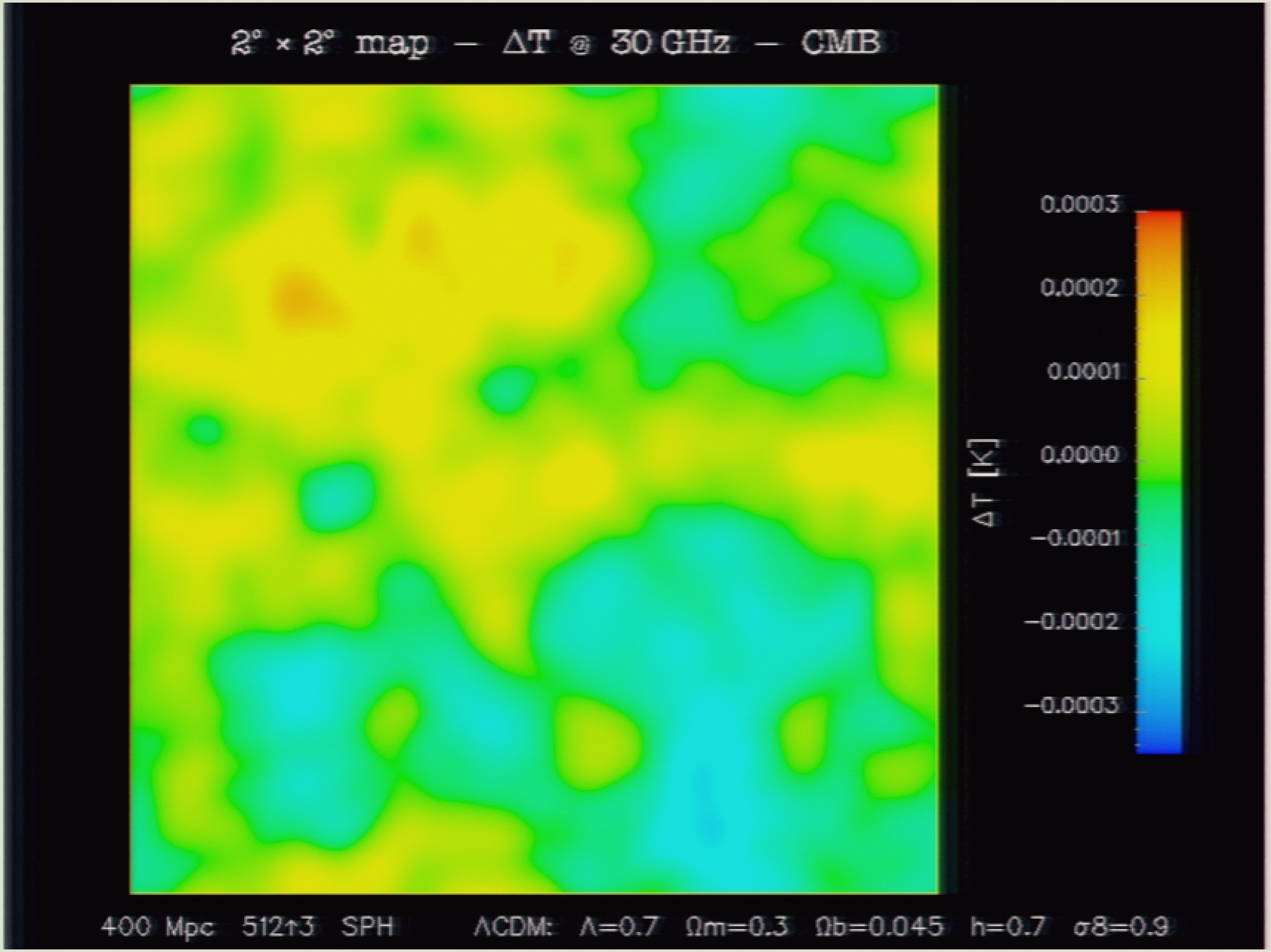

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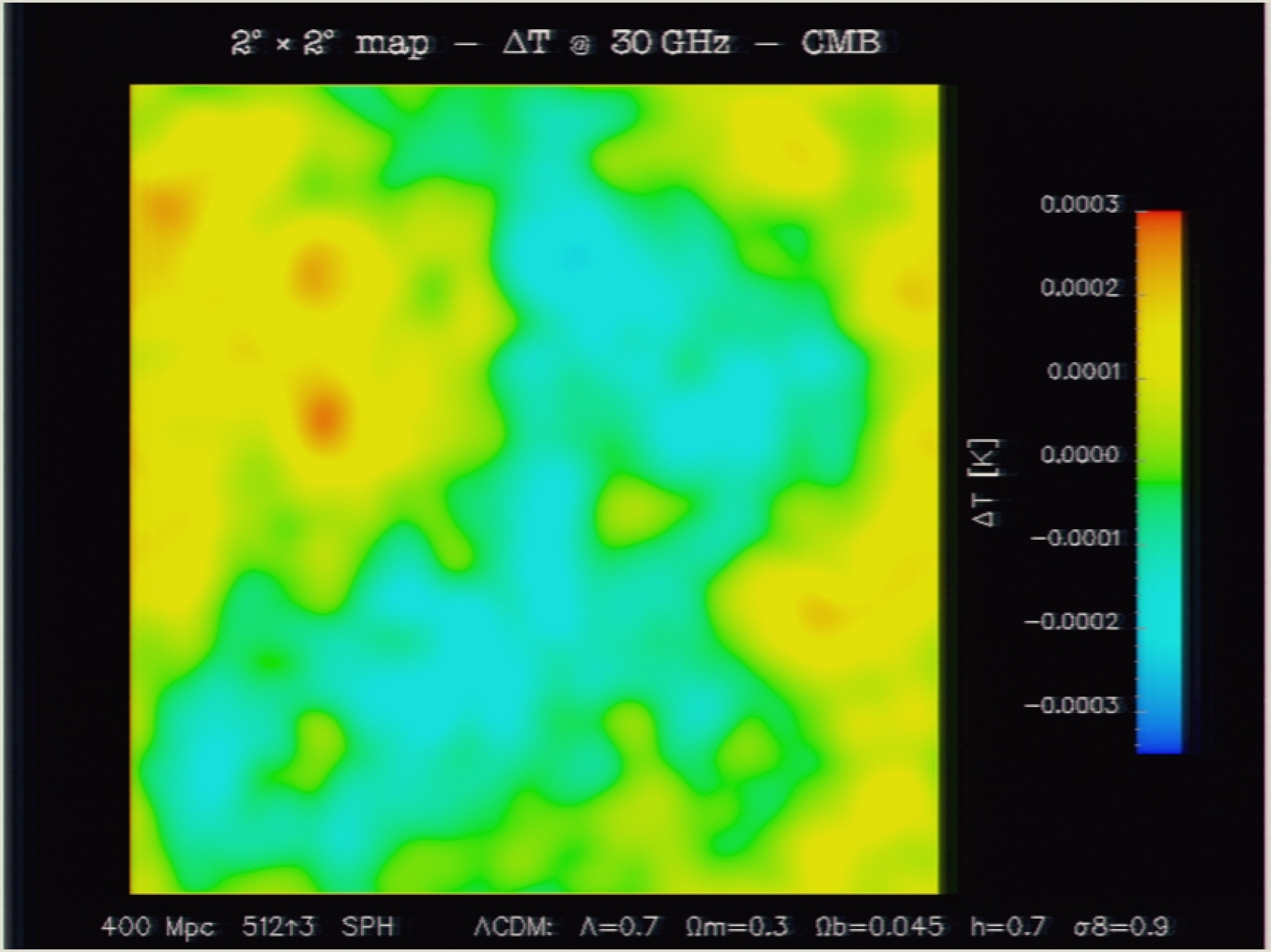

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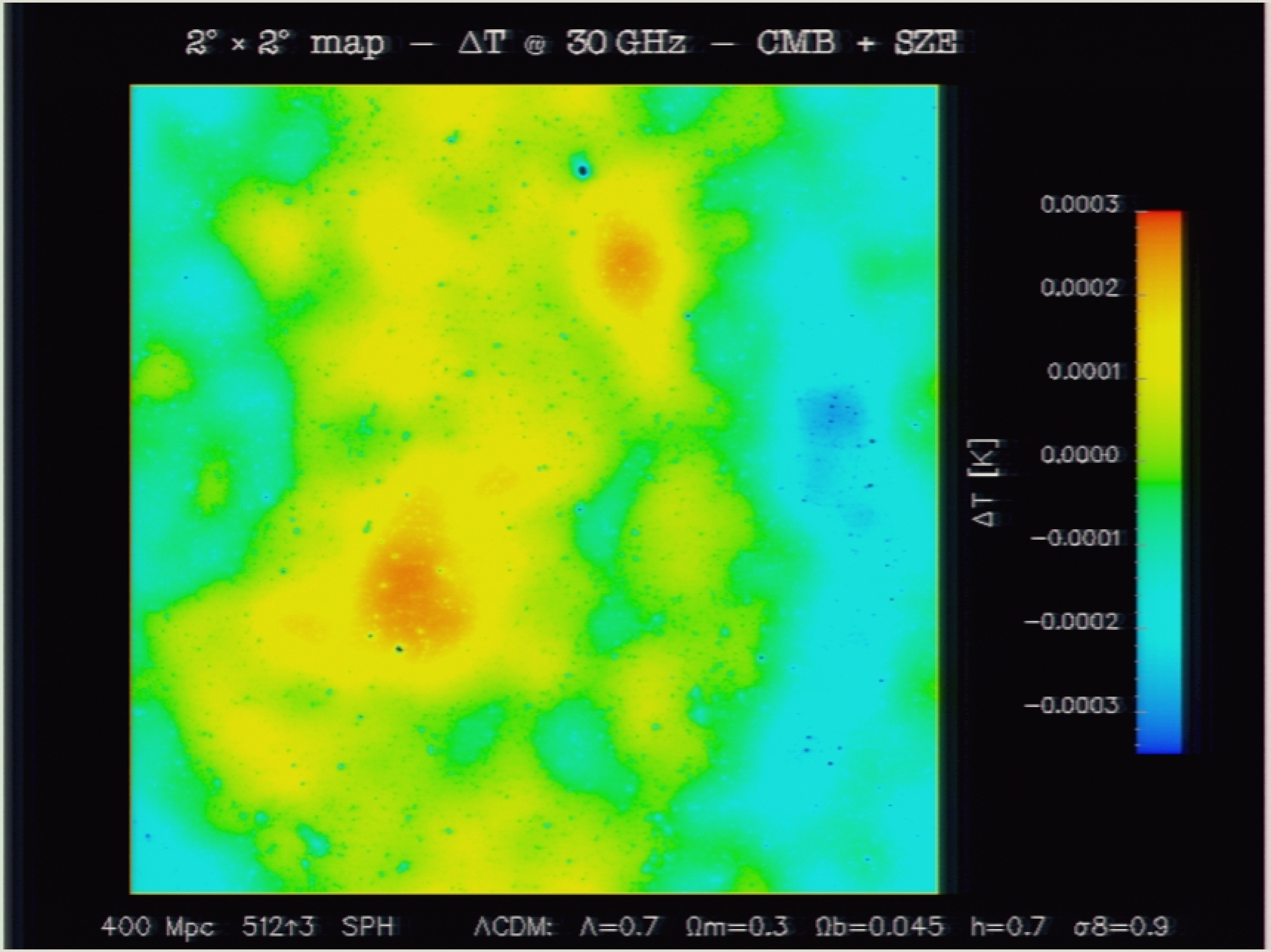

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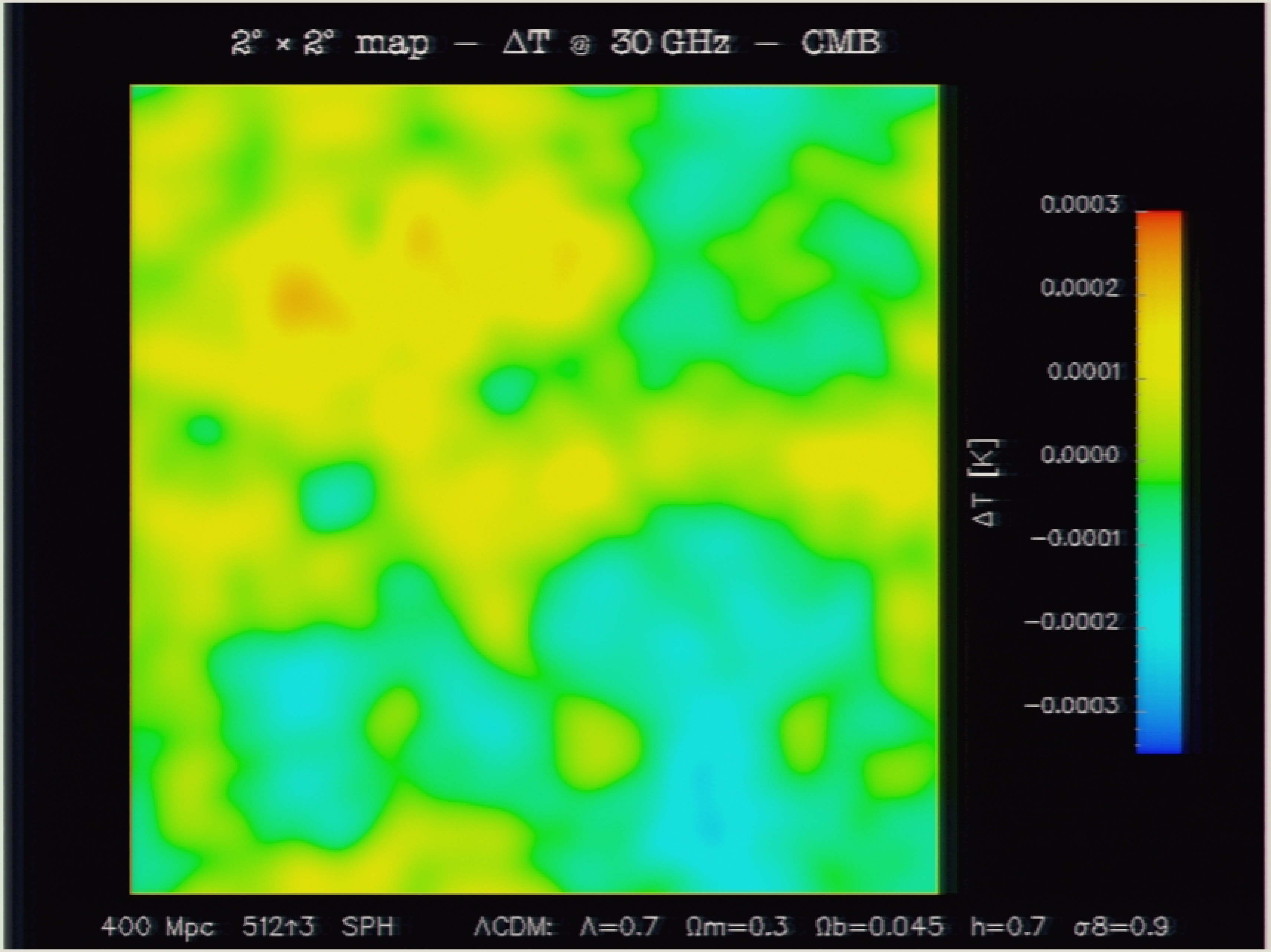

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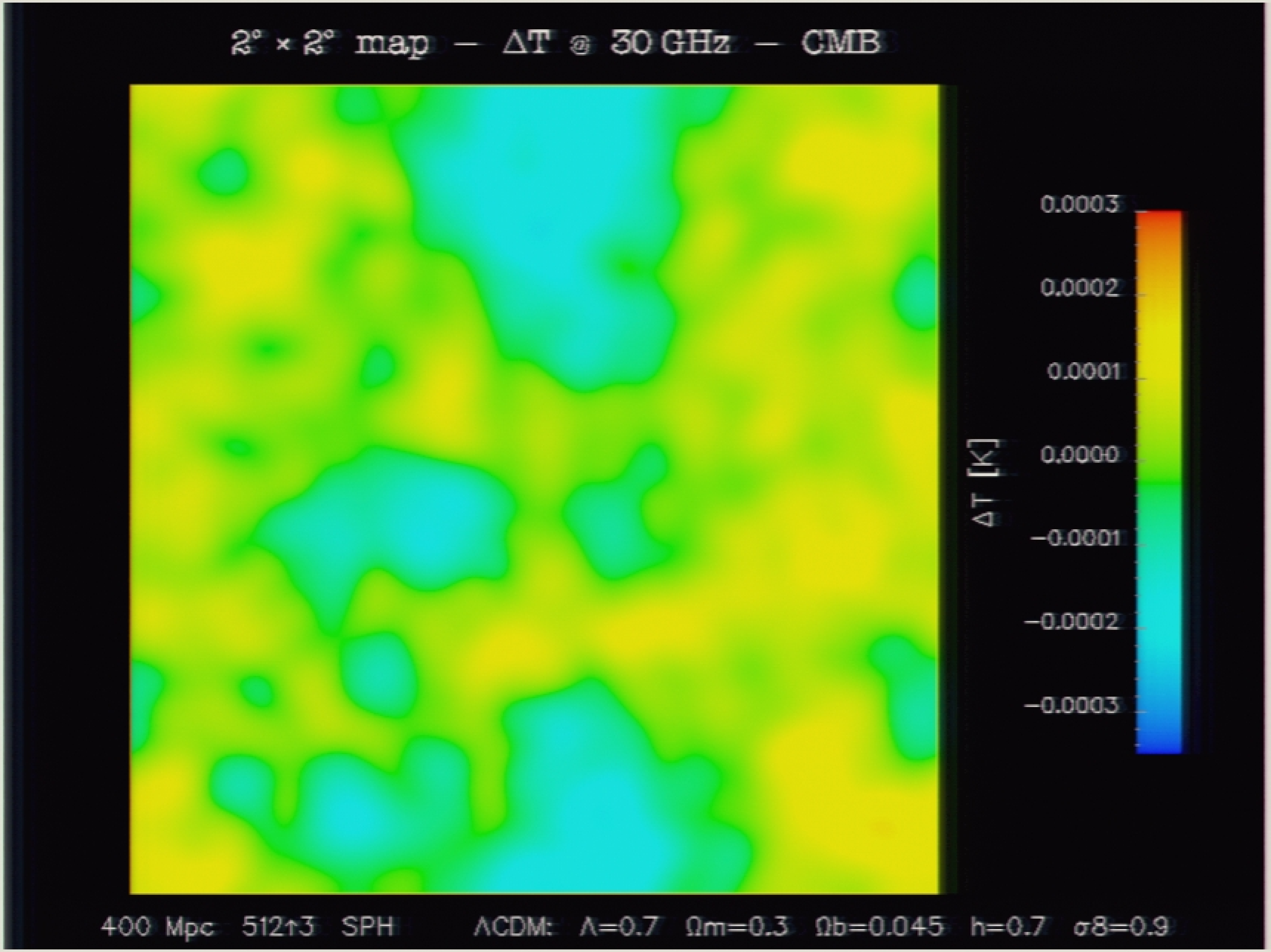

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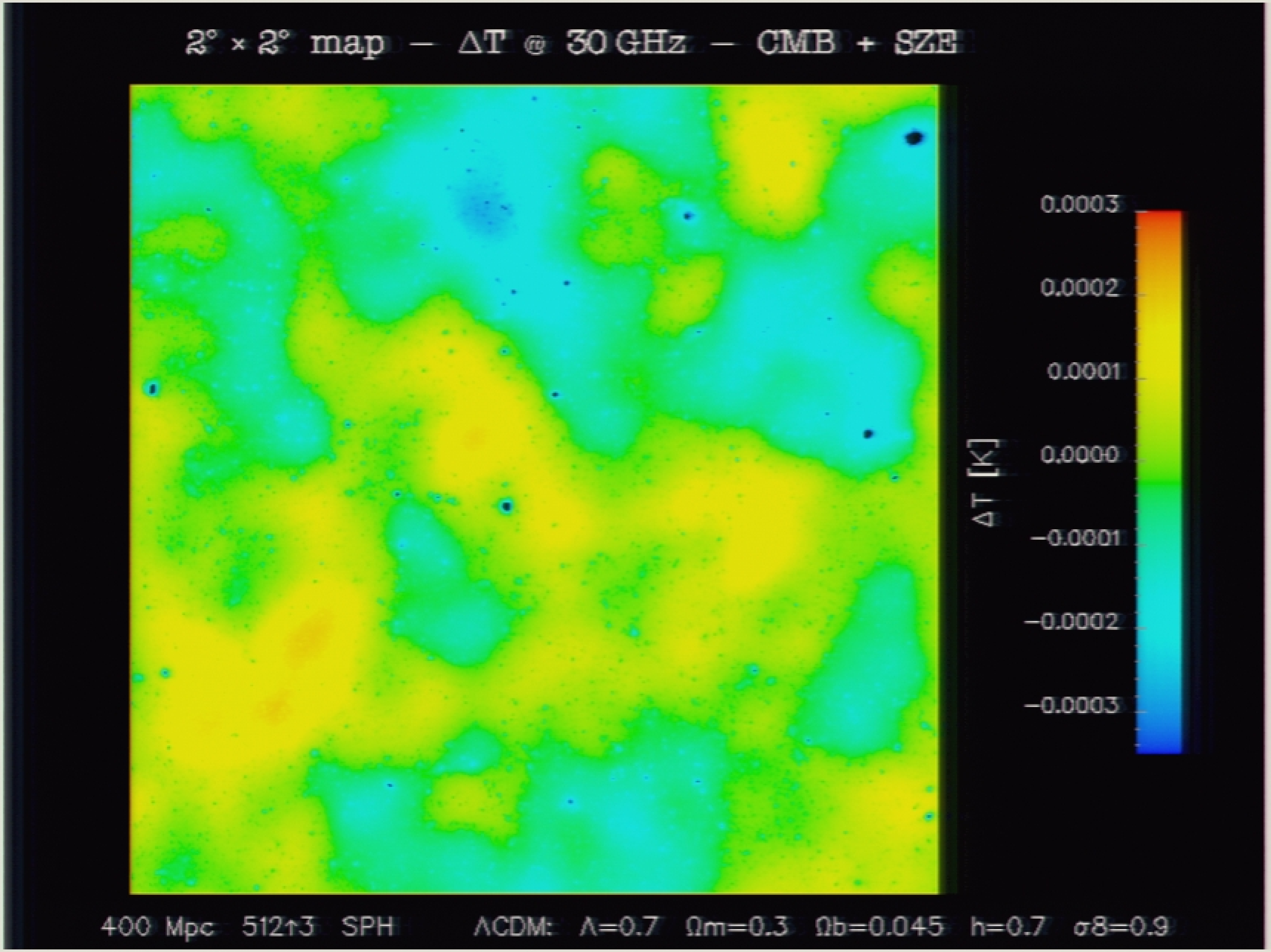

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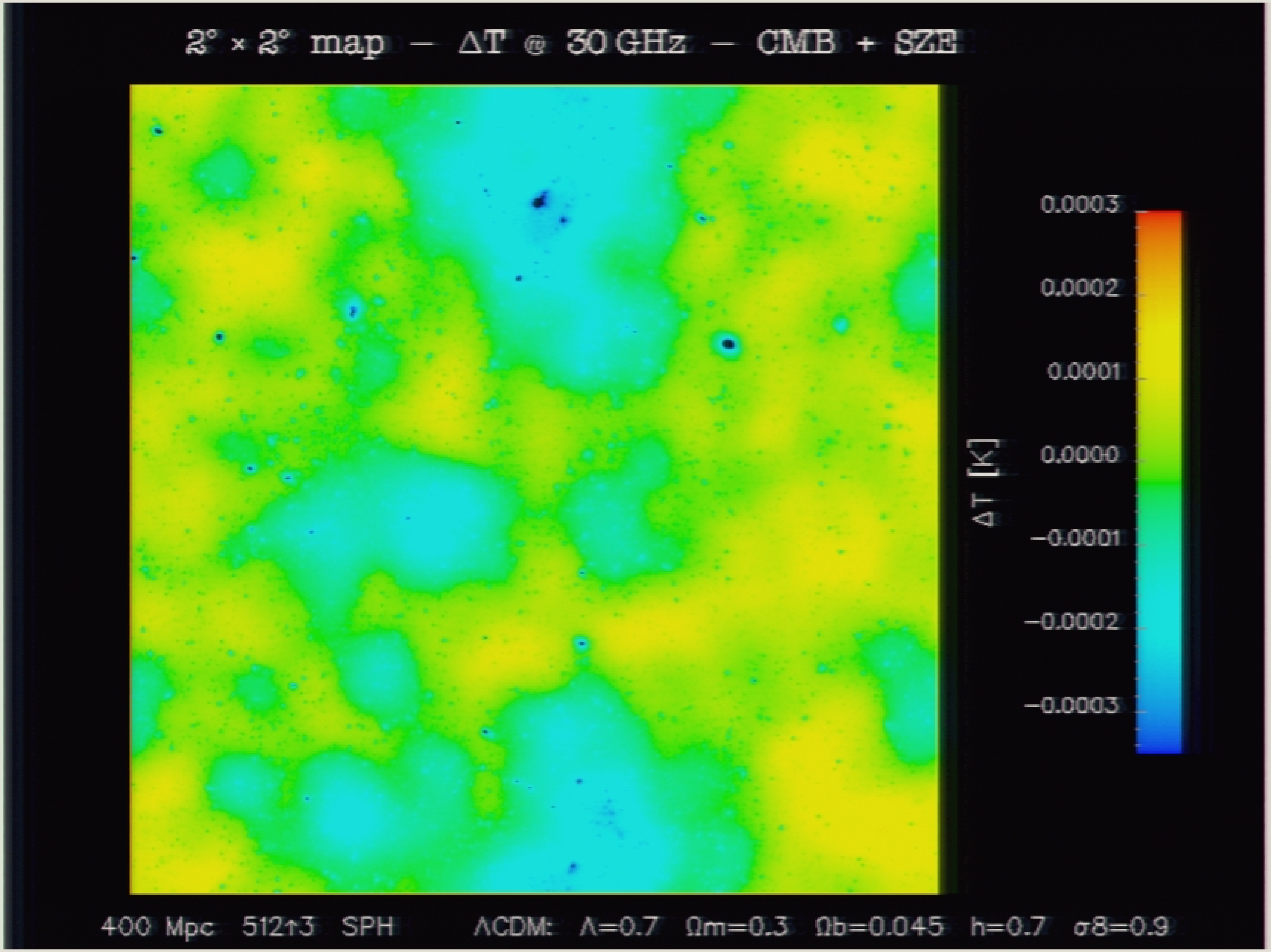

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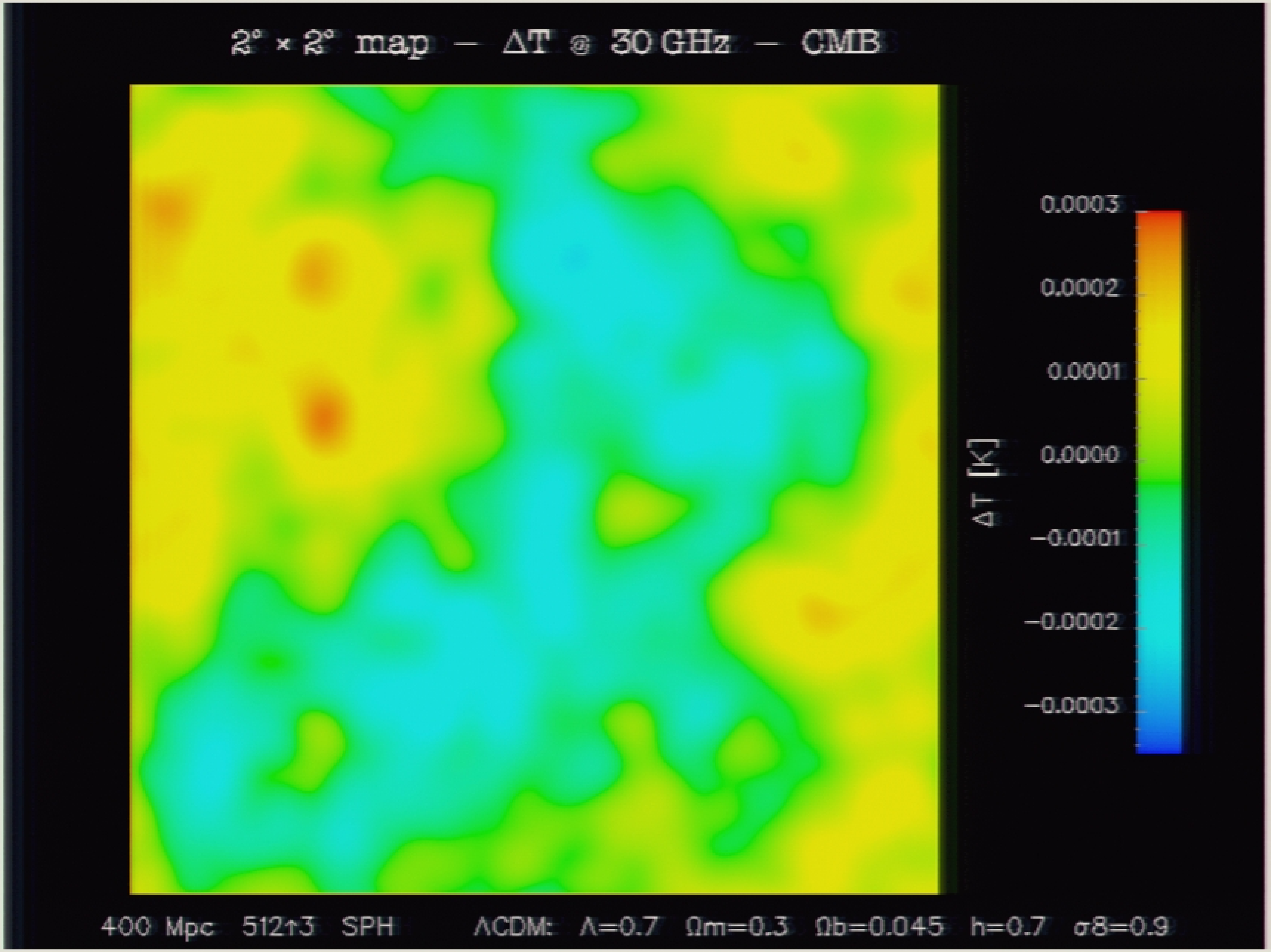

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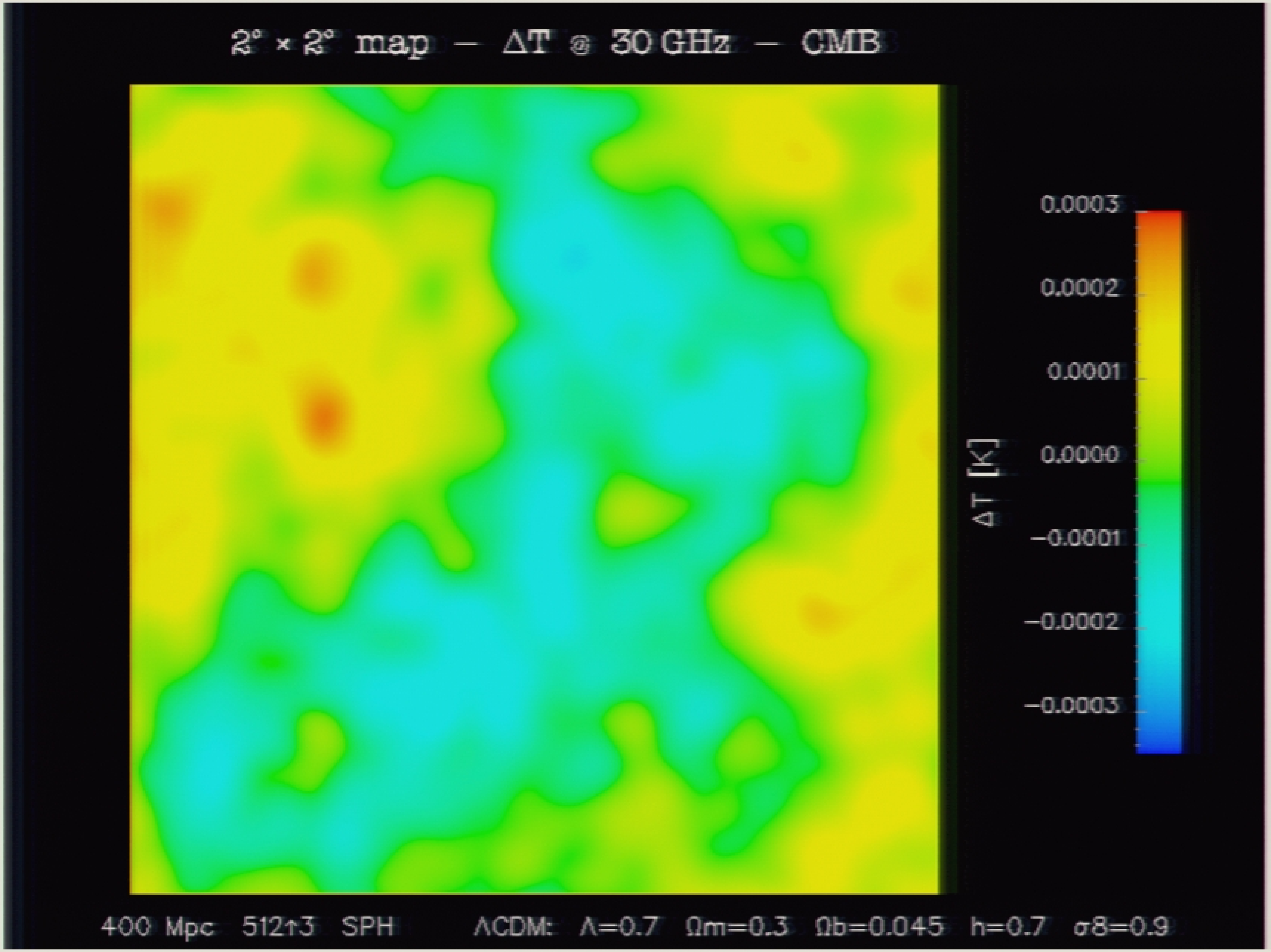

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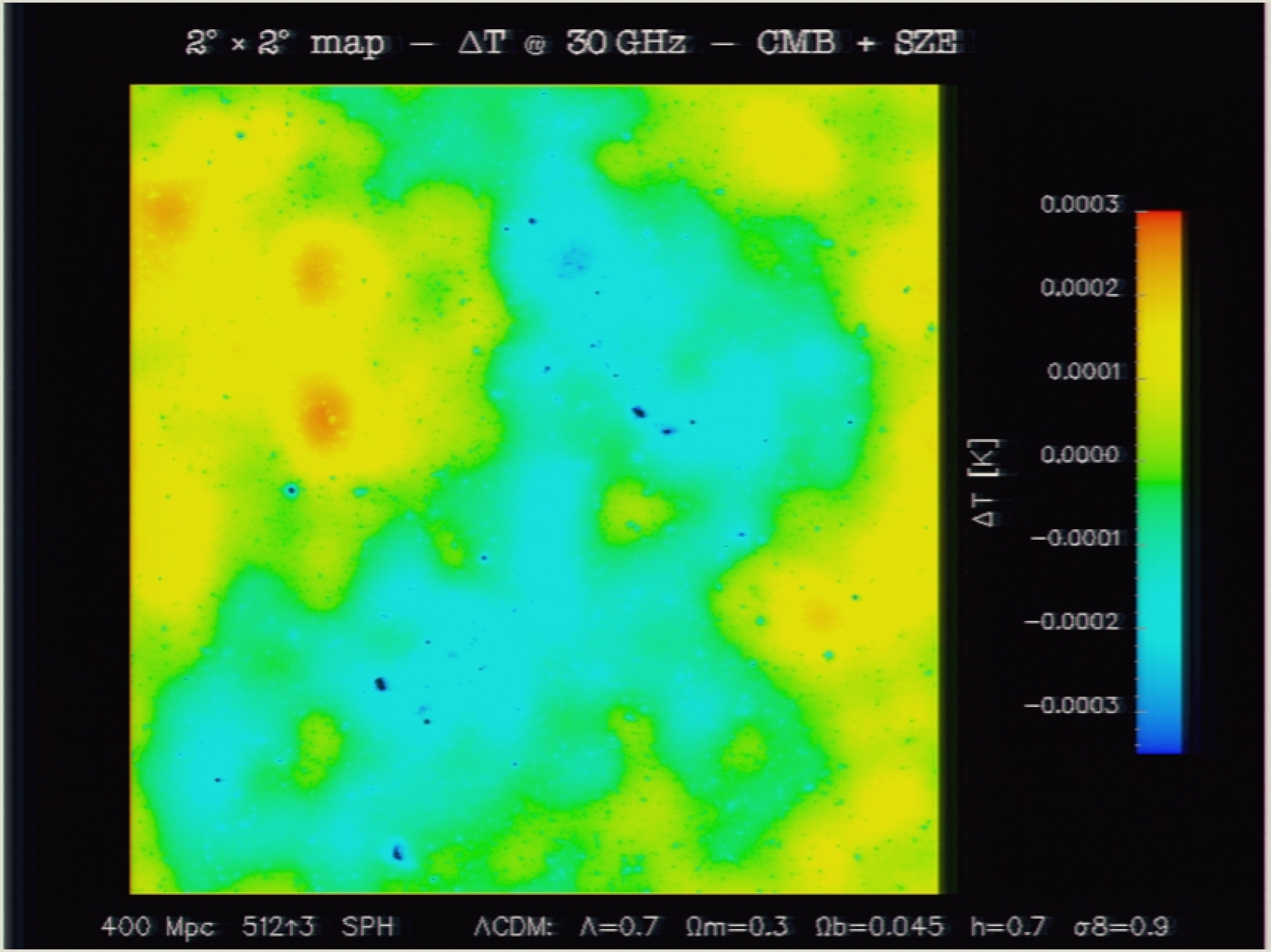

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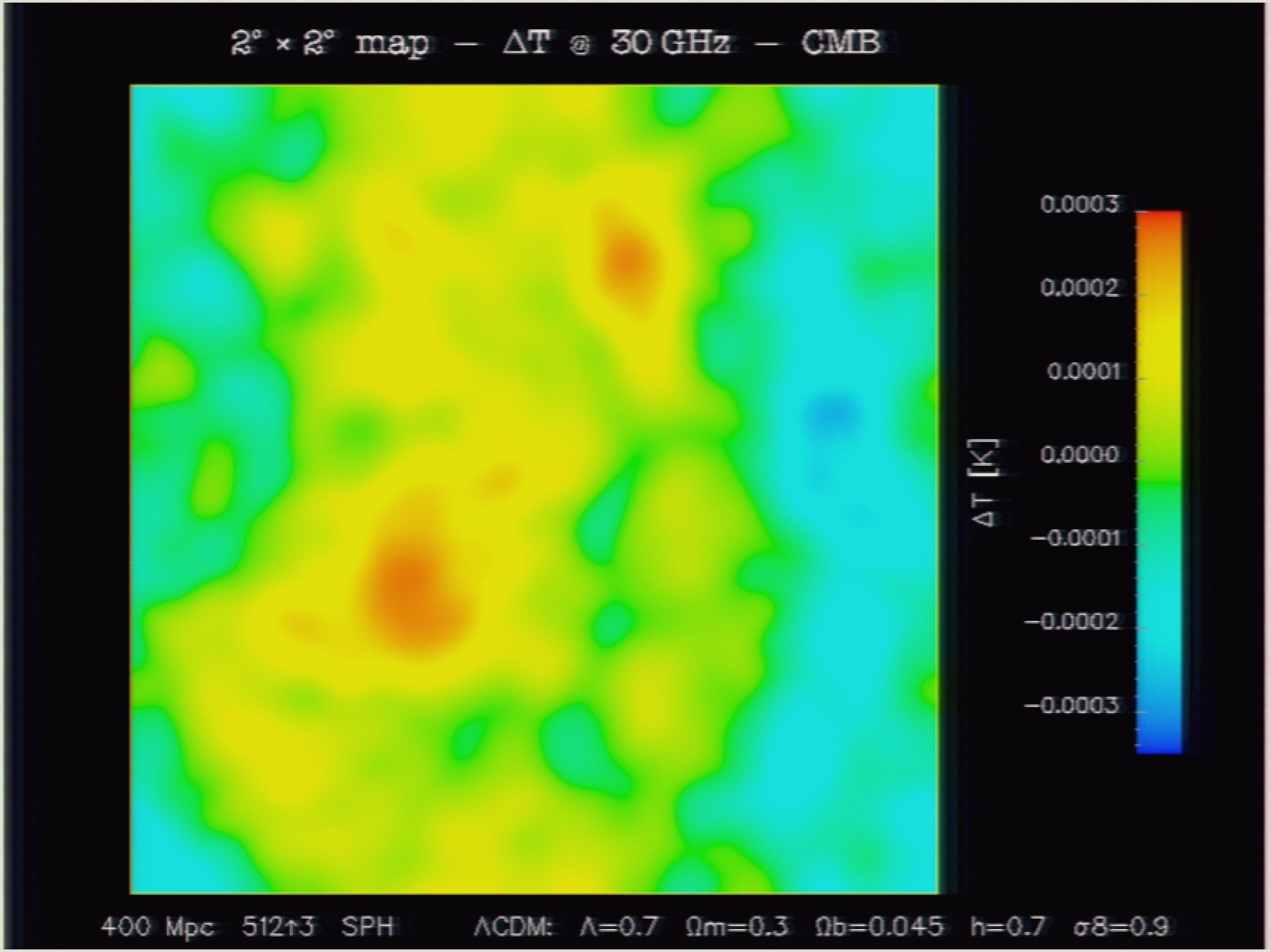

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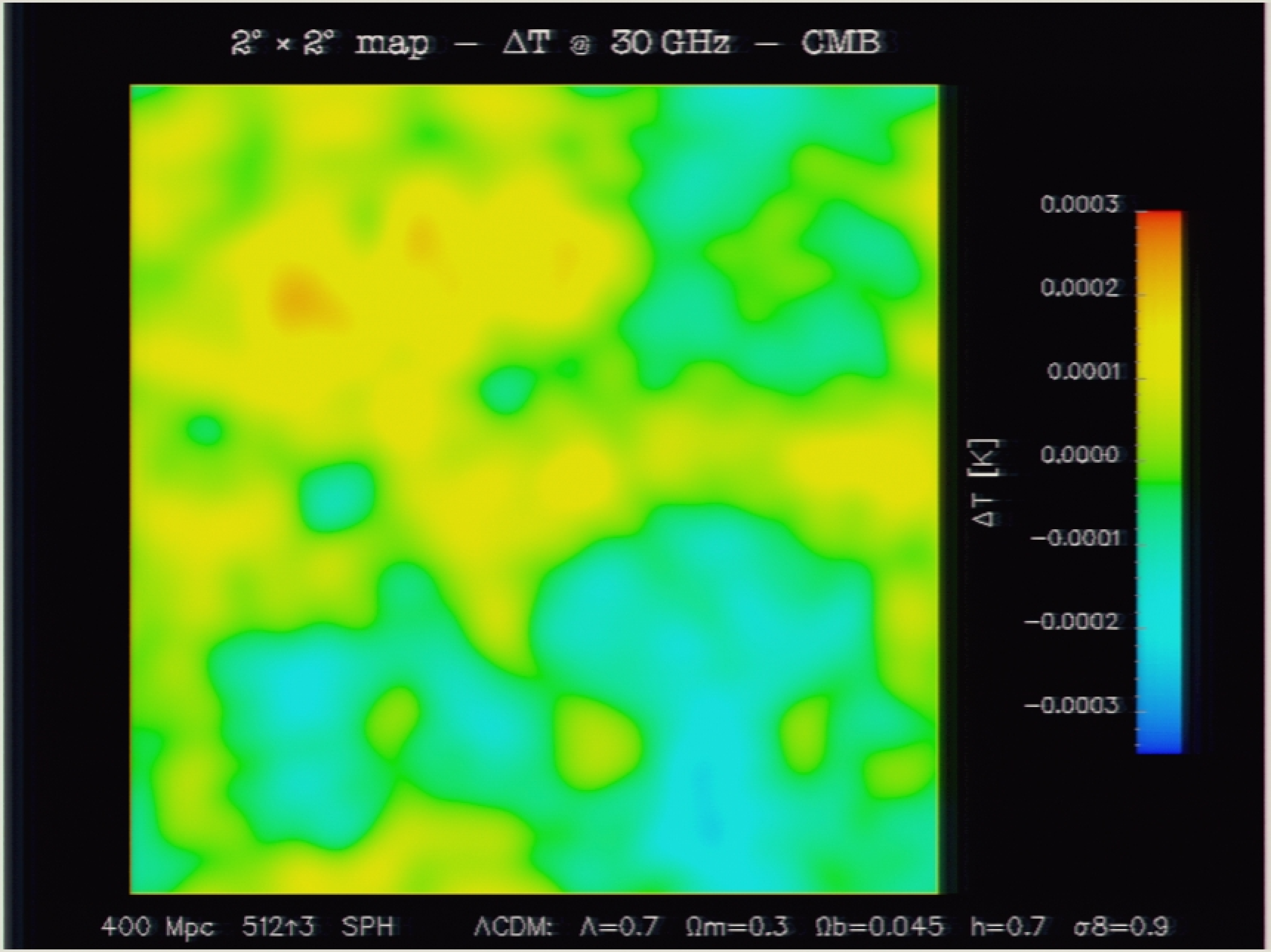

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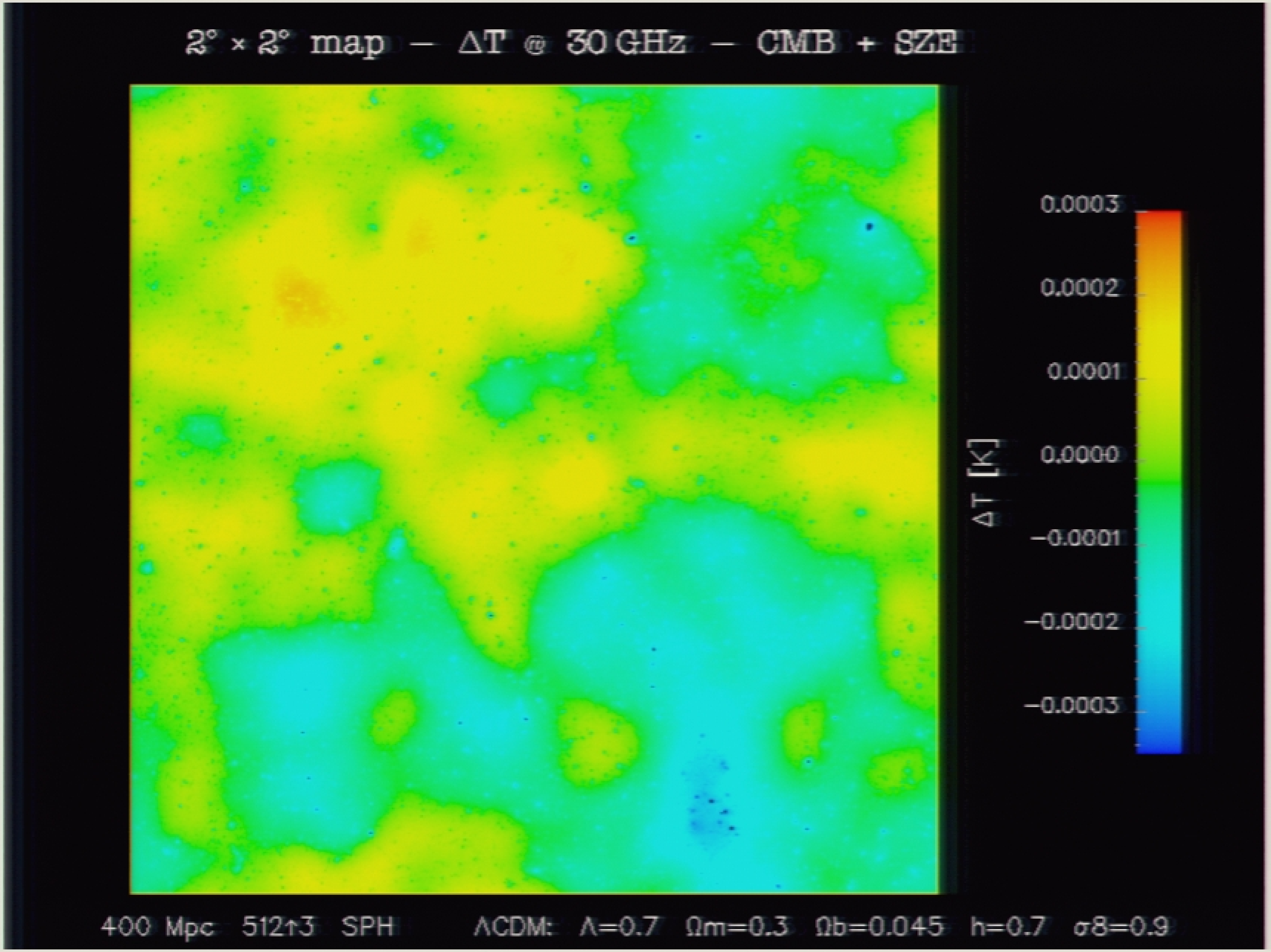

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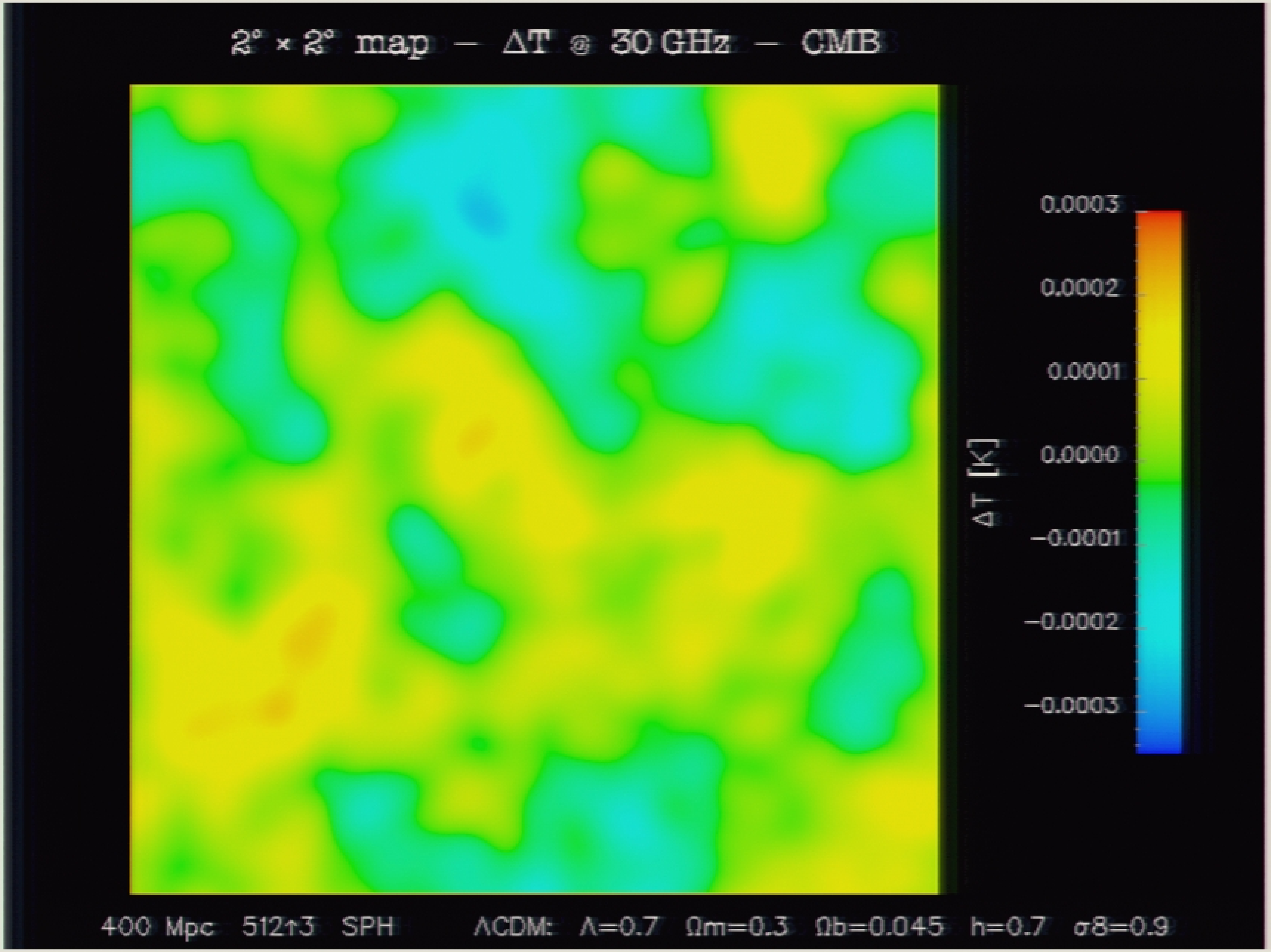

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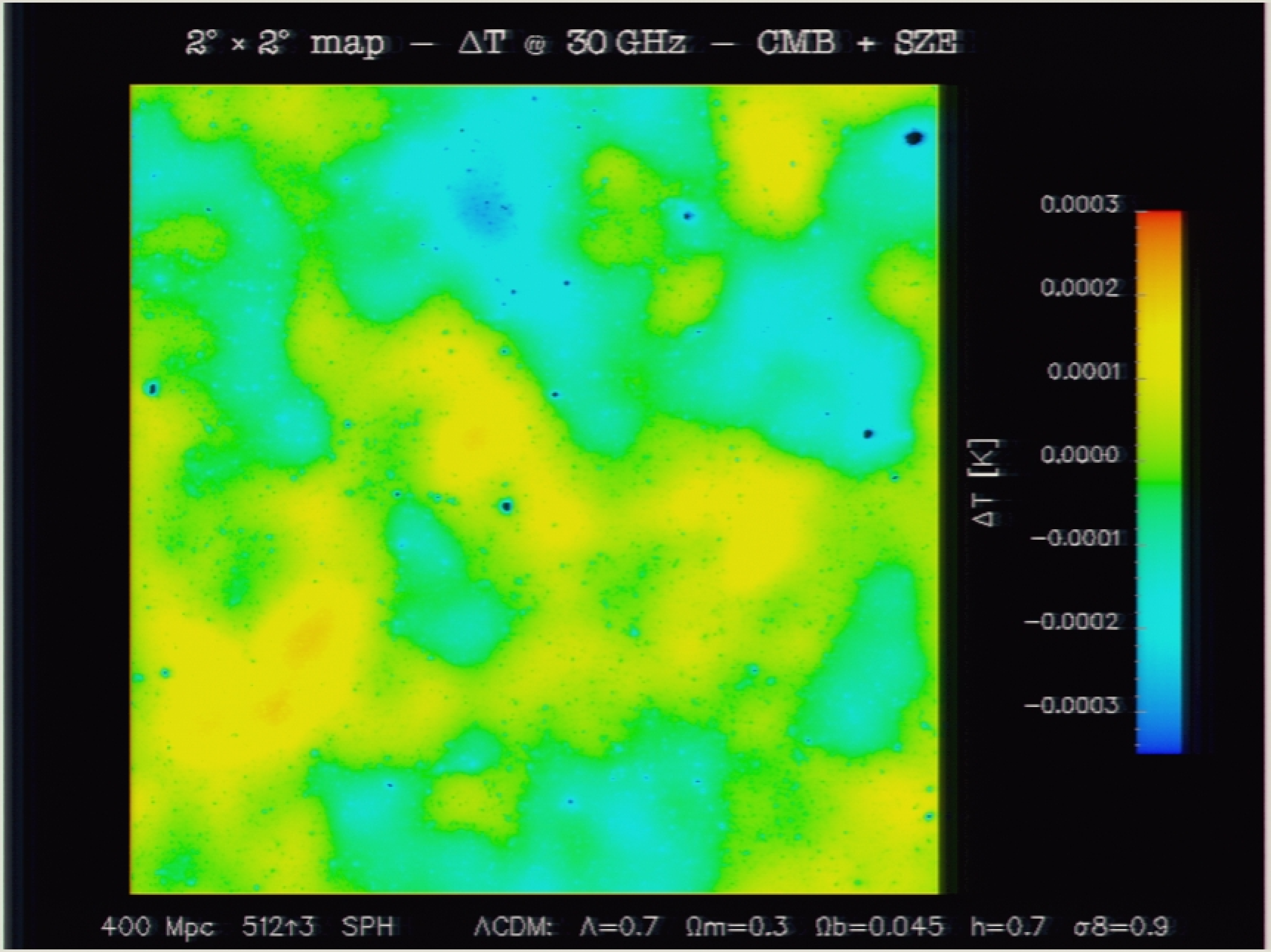

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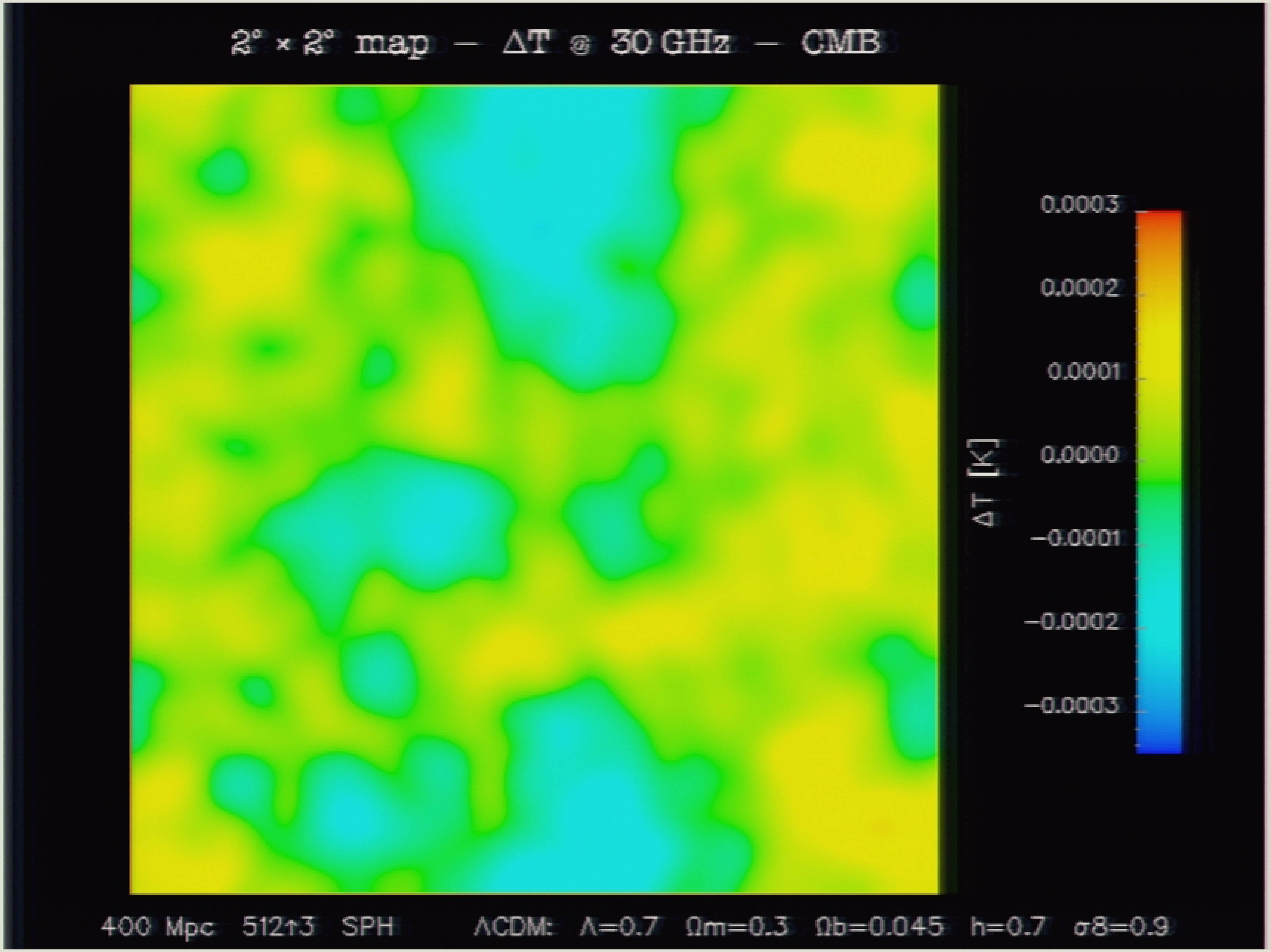

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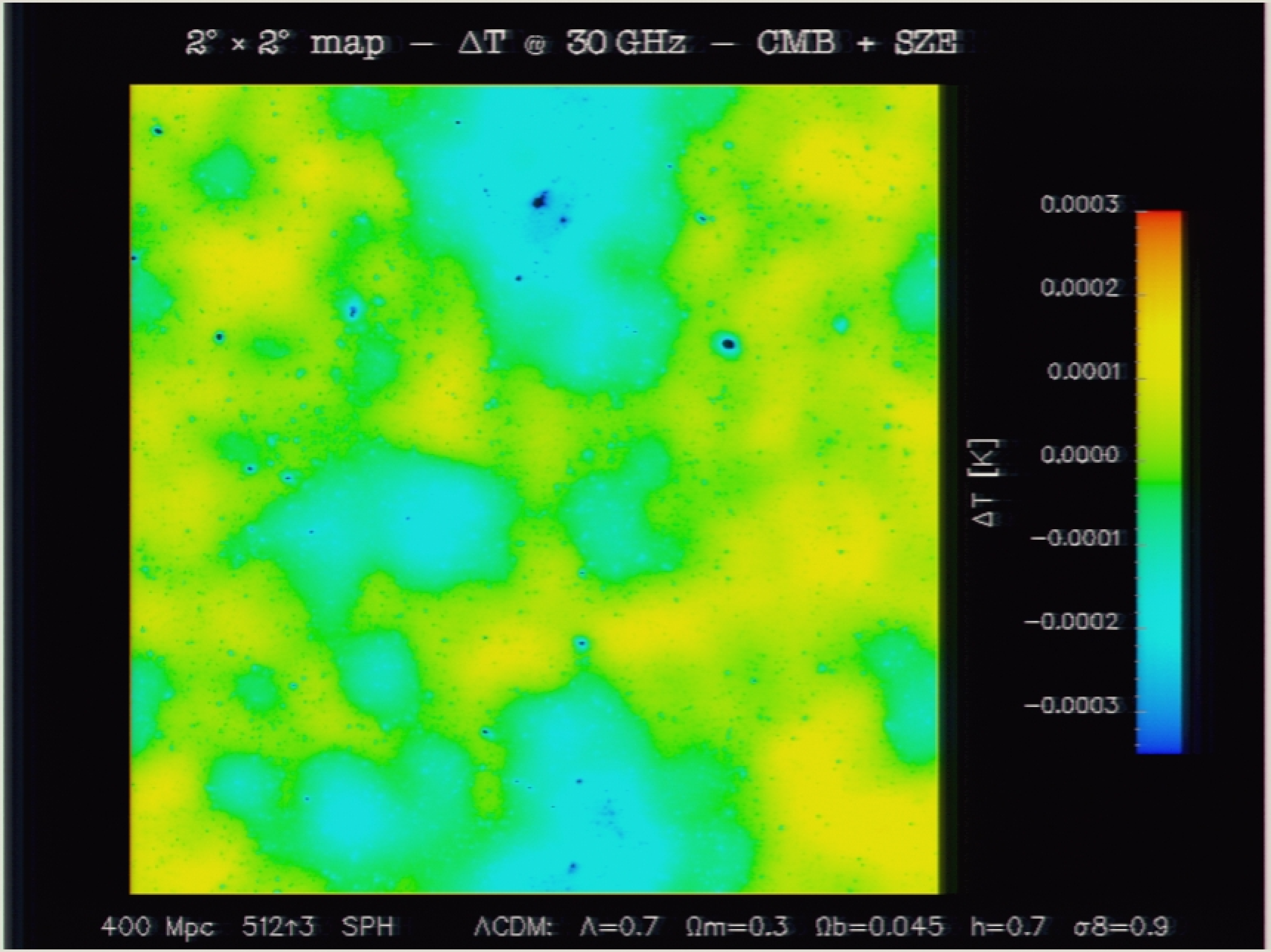

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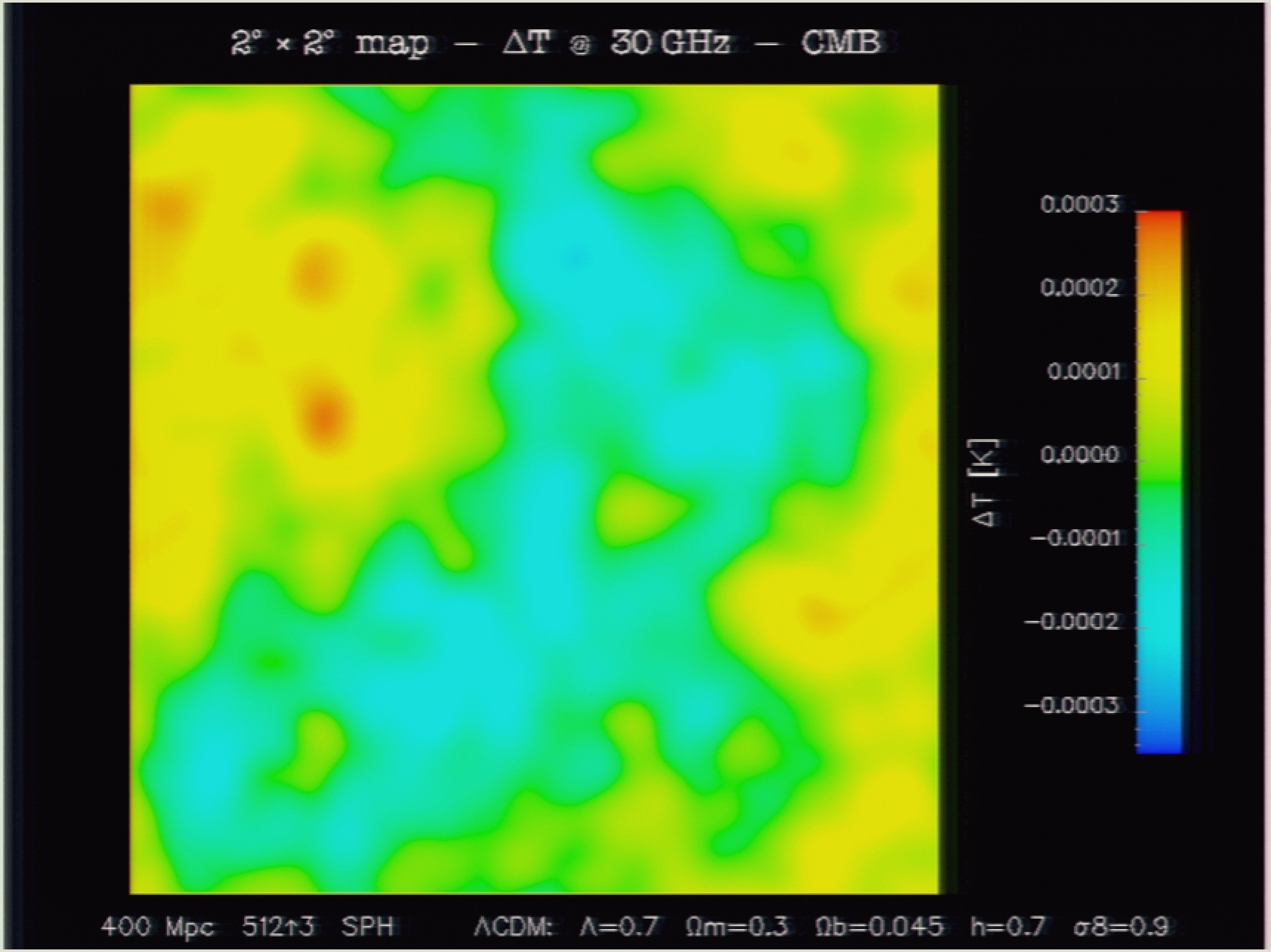

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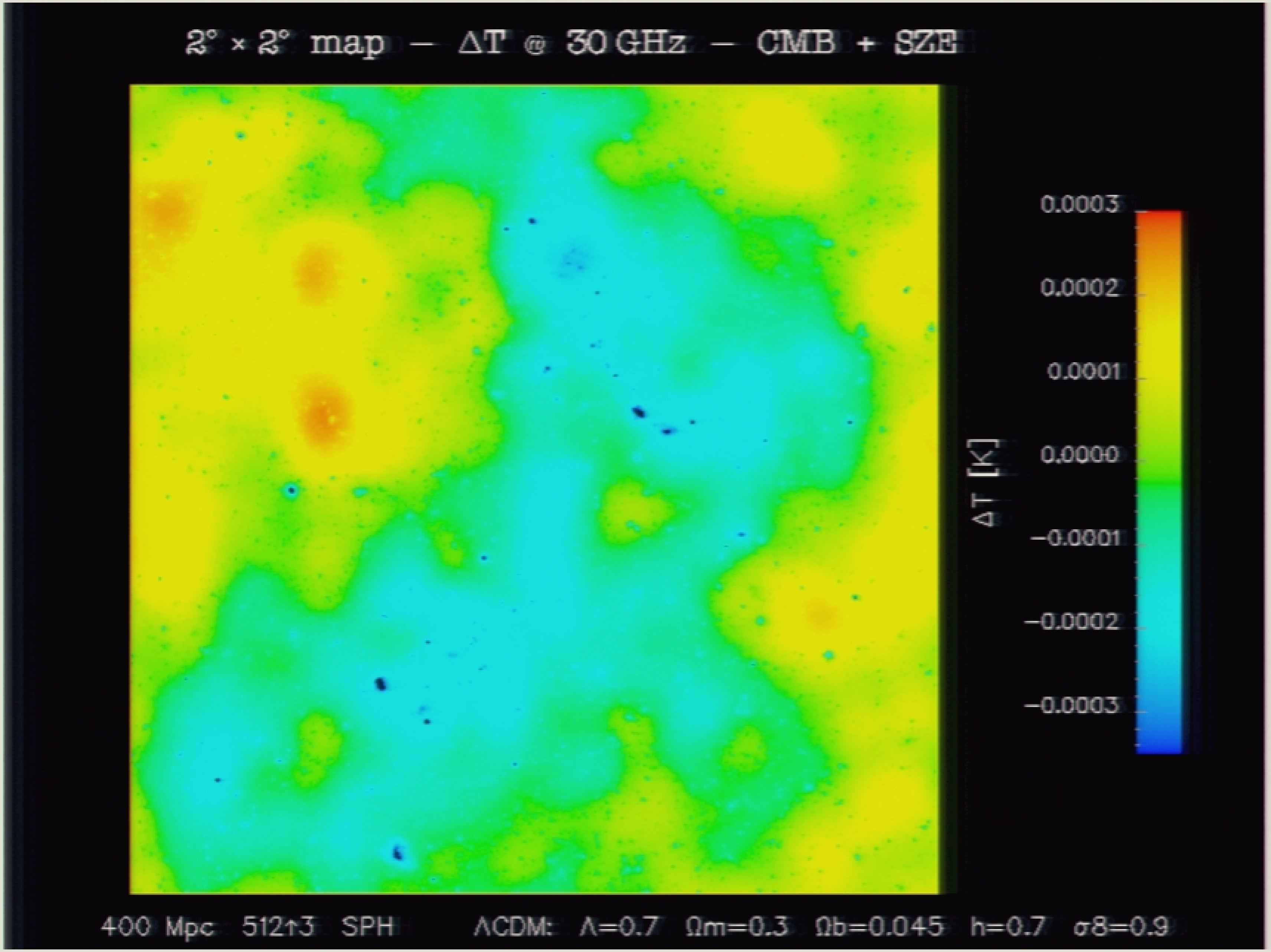

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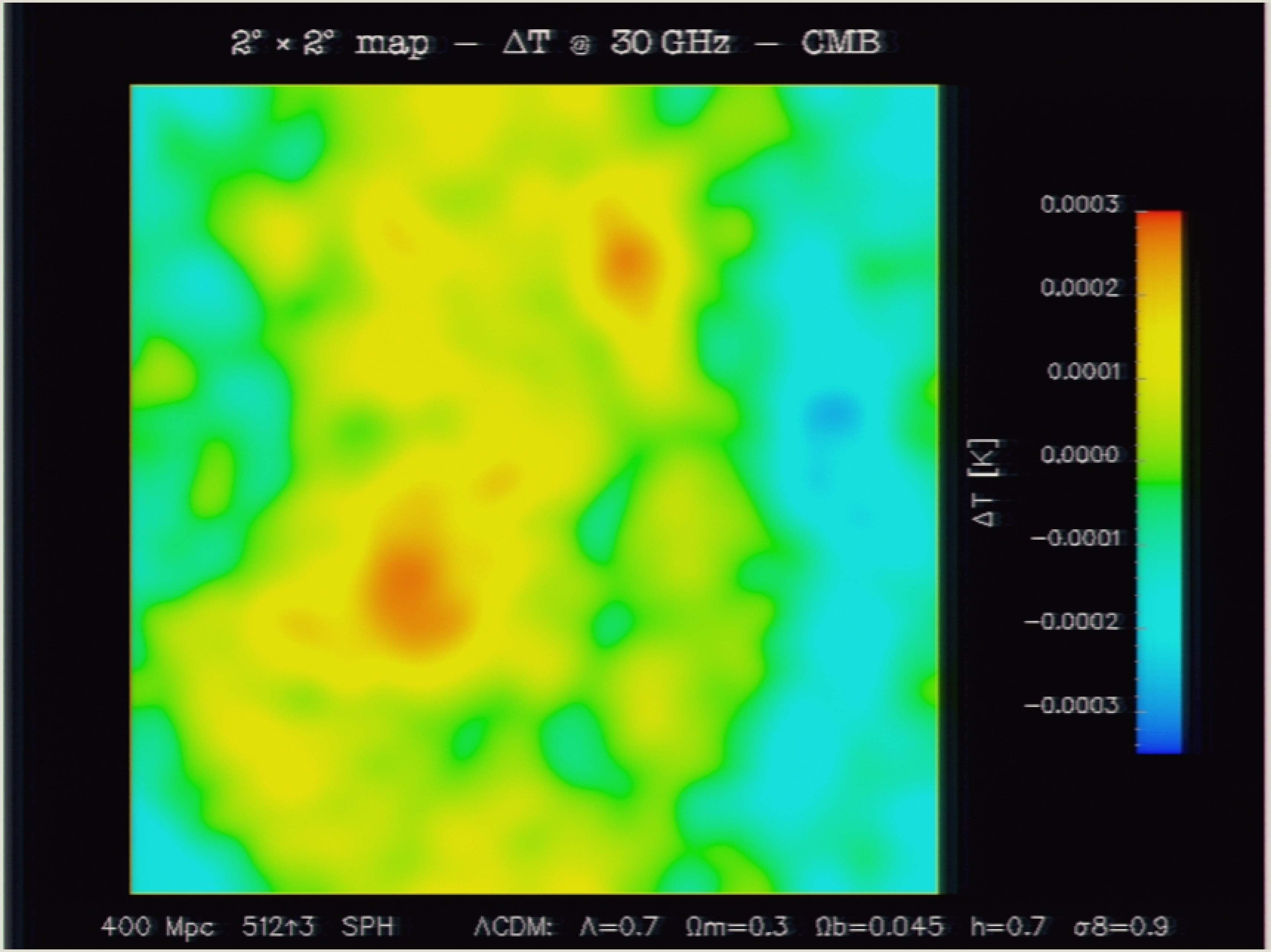

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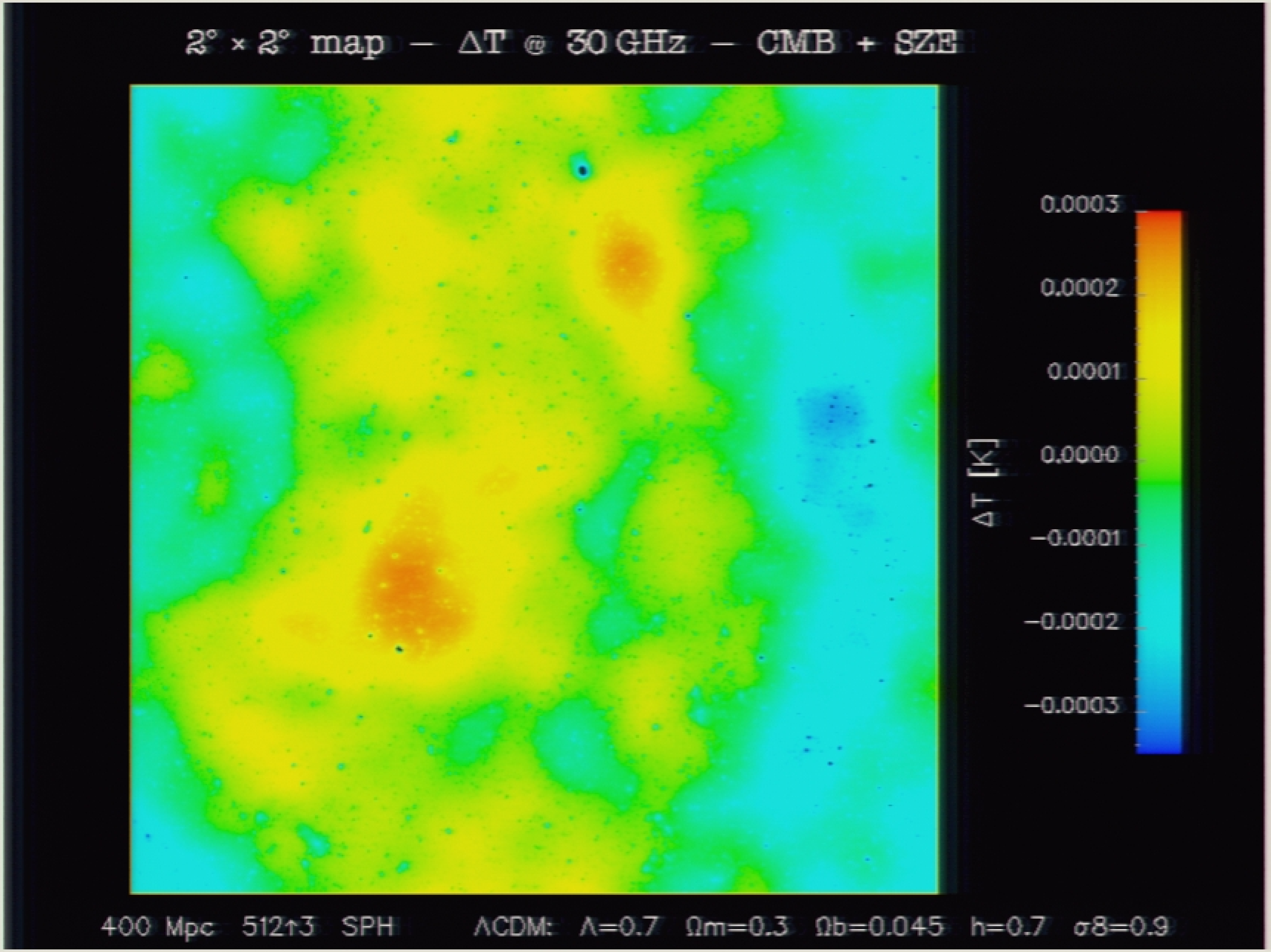

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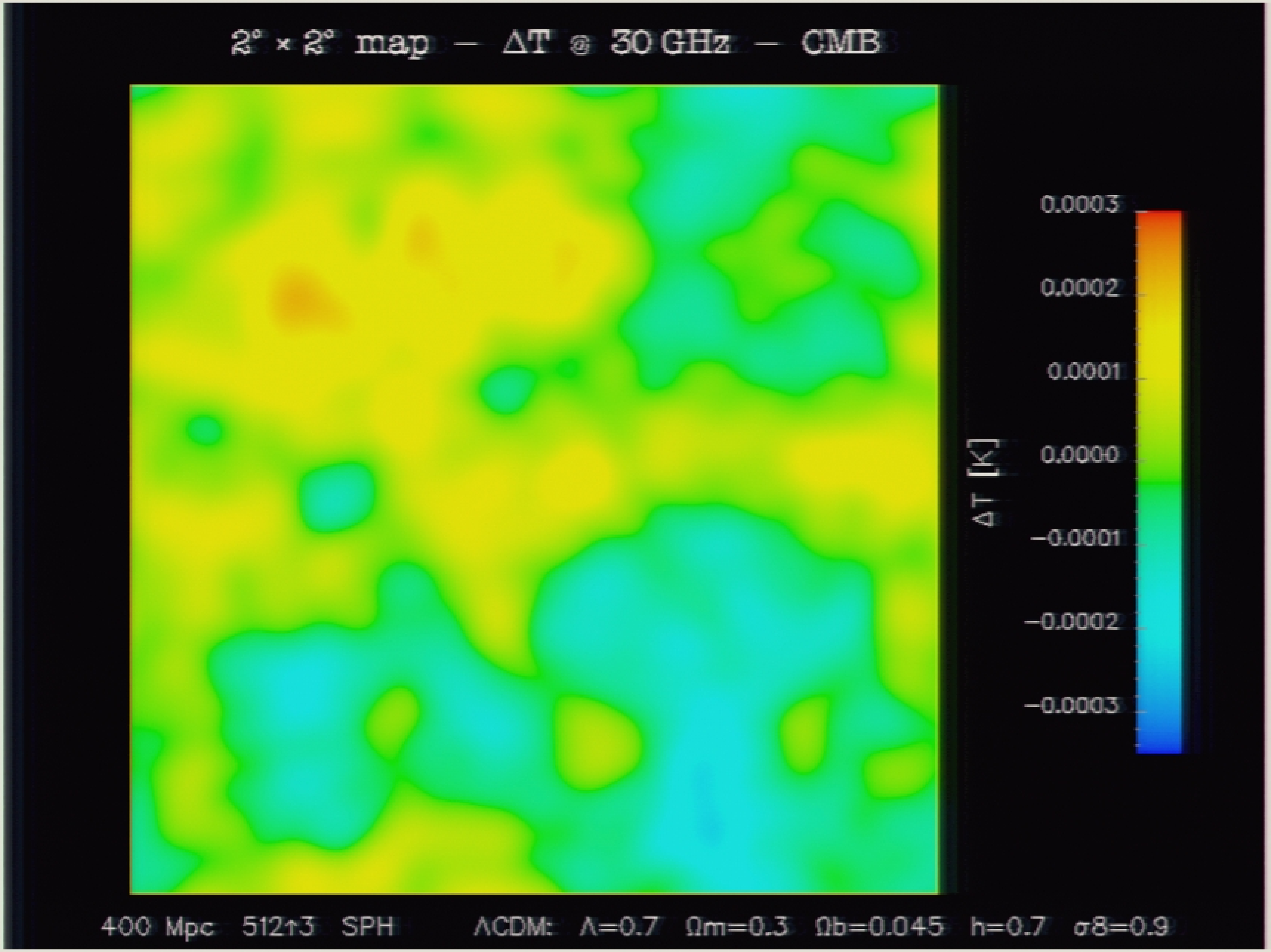
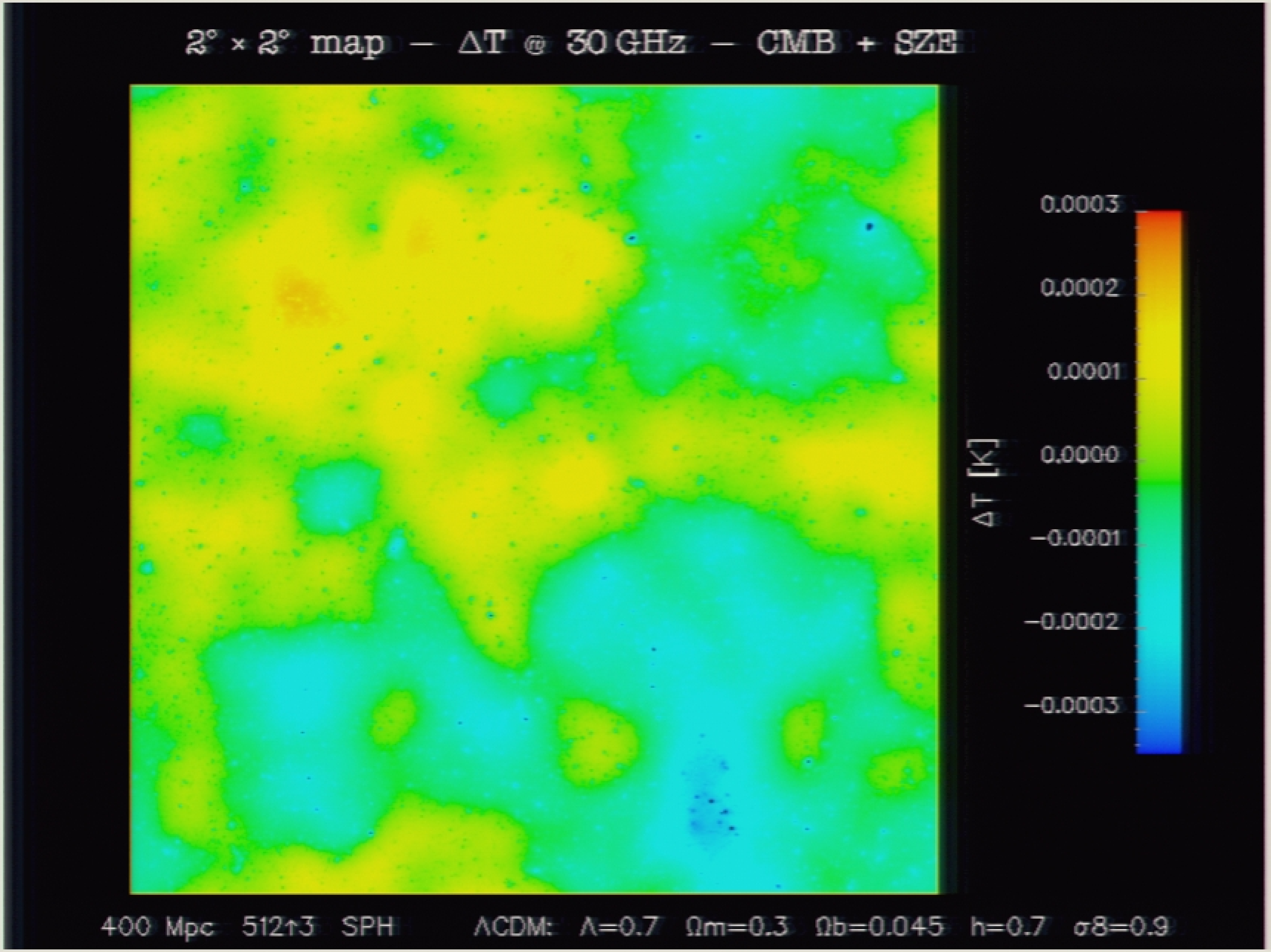


pass the CMB thru the cosmic web: CBI extra power??



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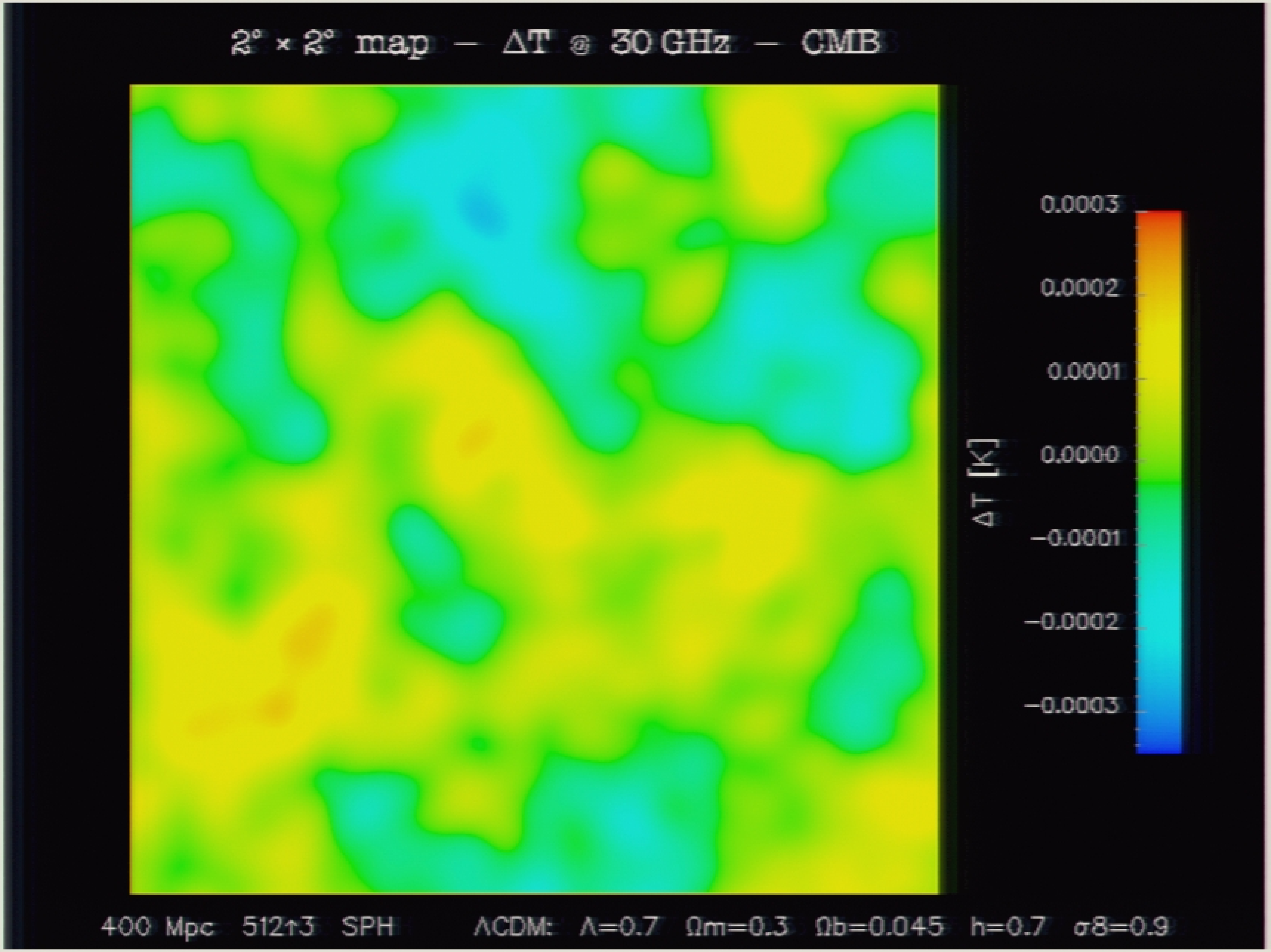

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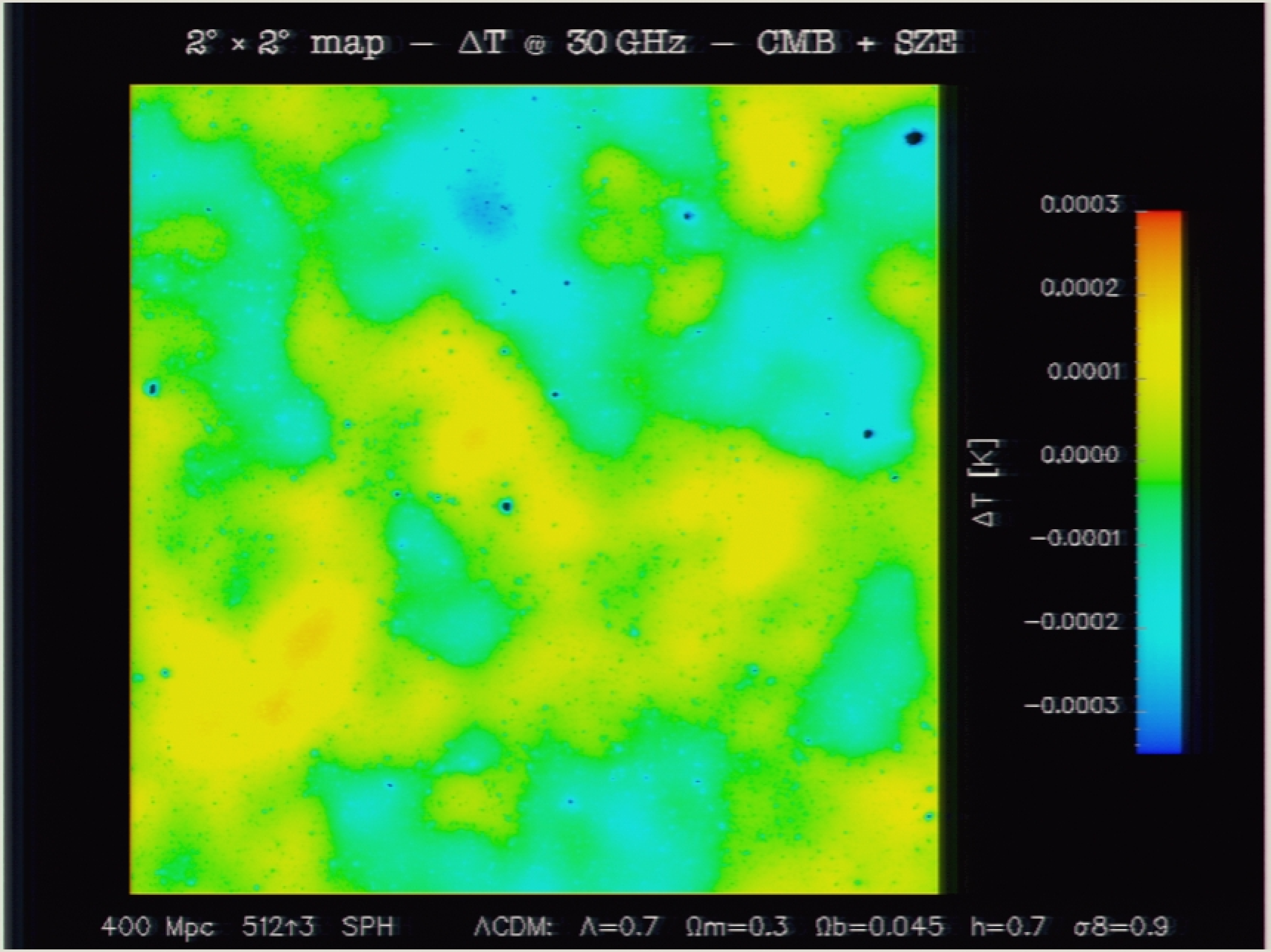

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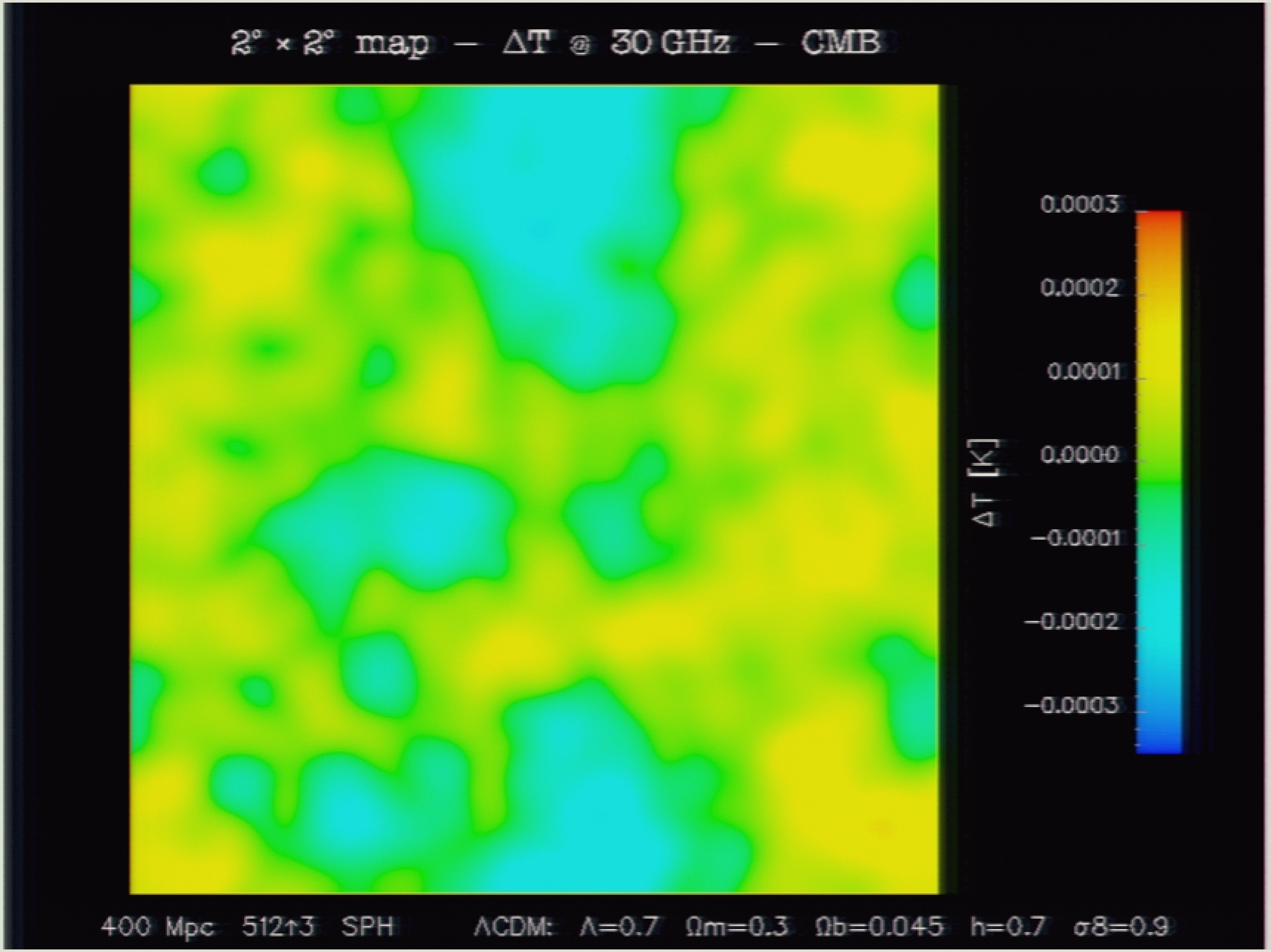

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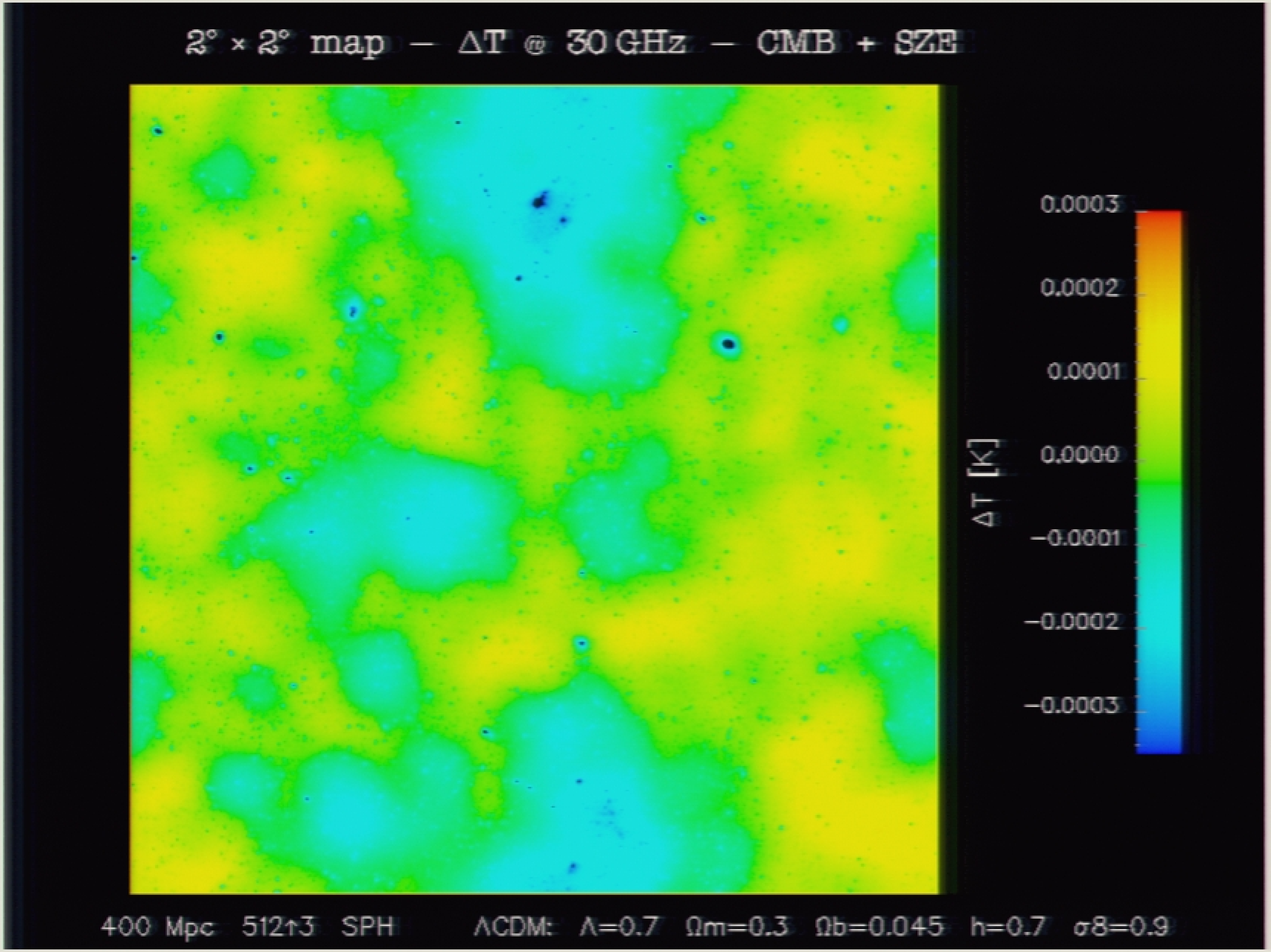

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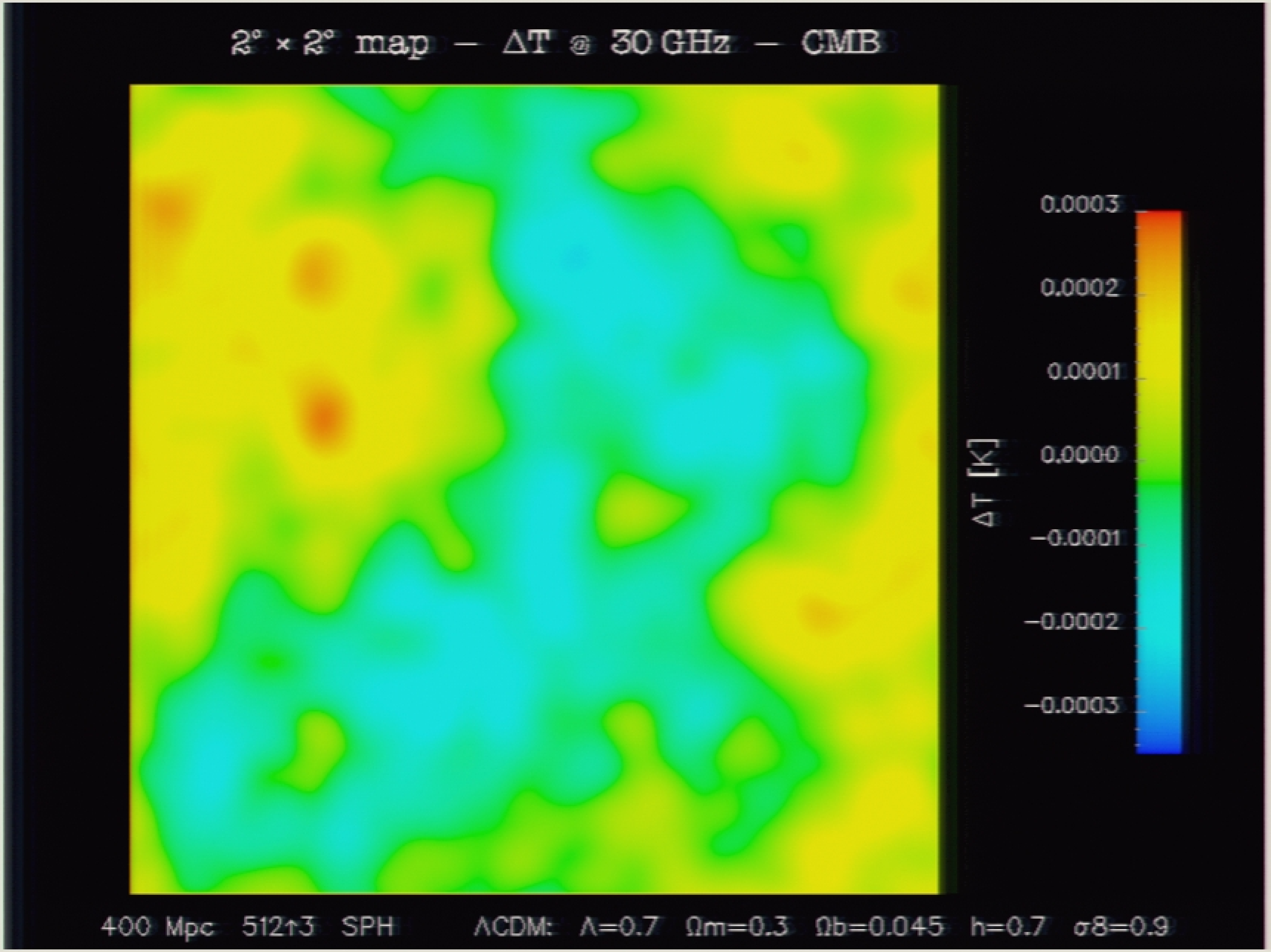

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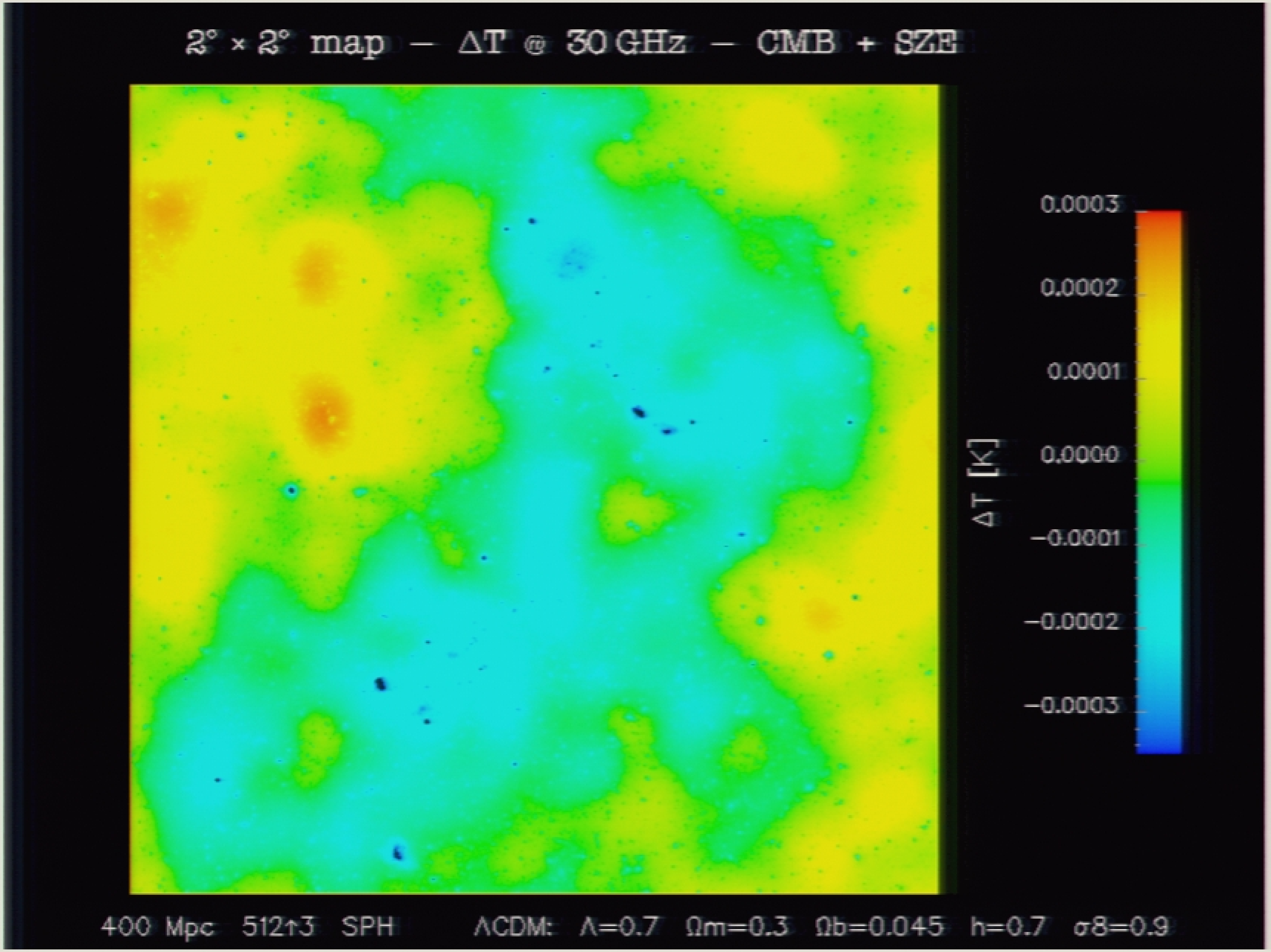

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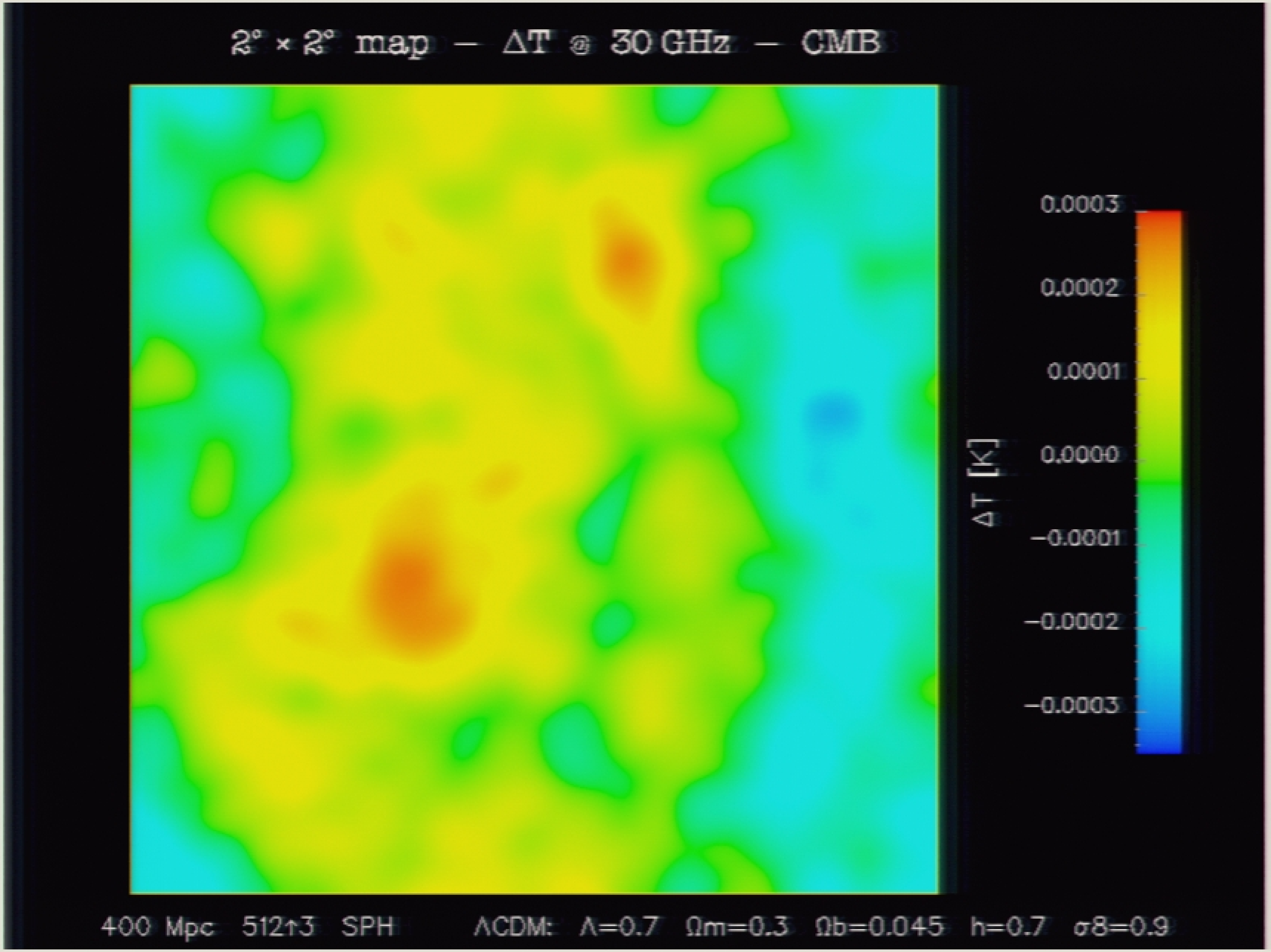
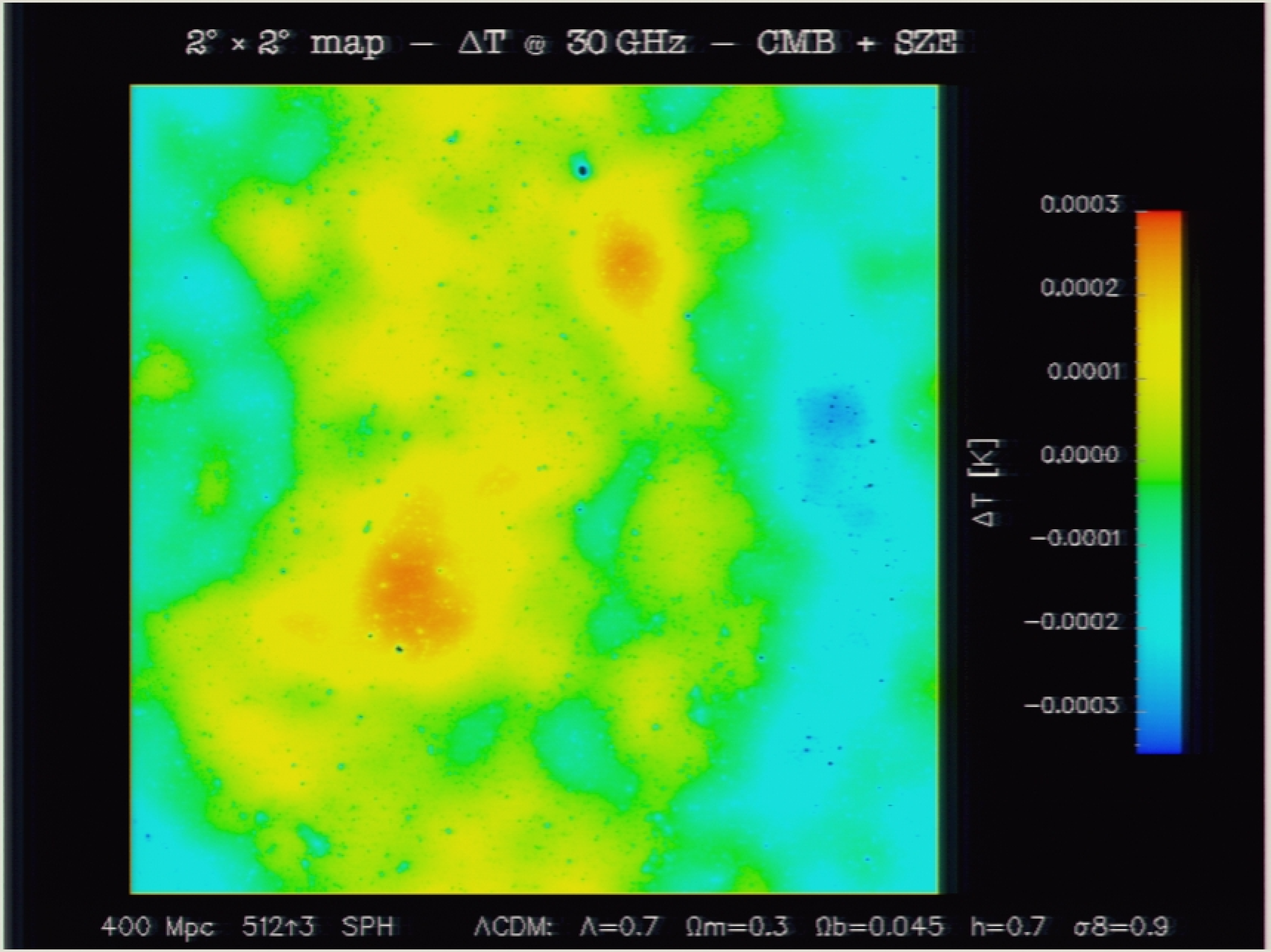
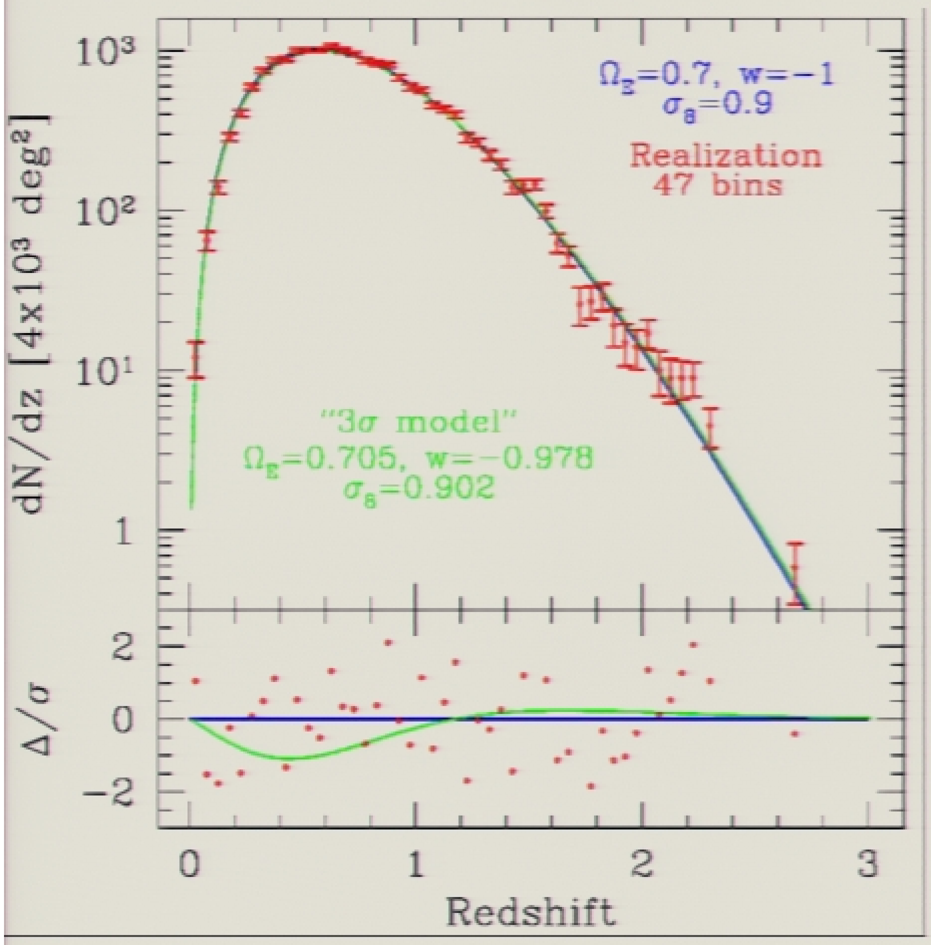


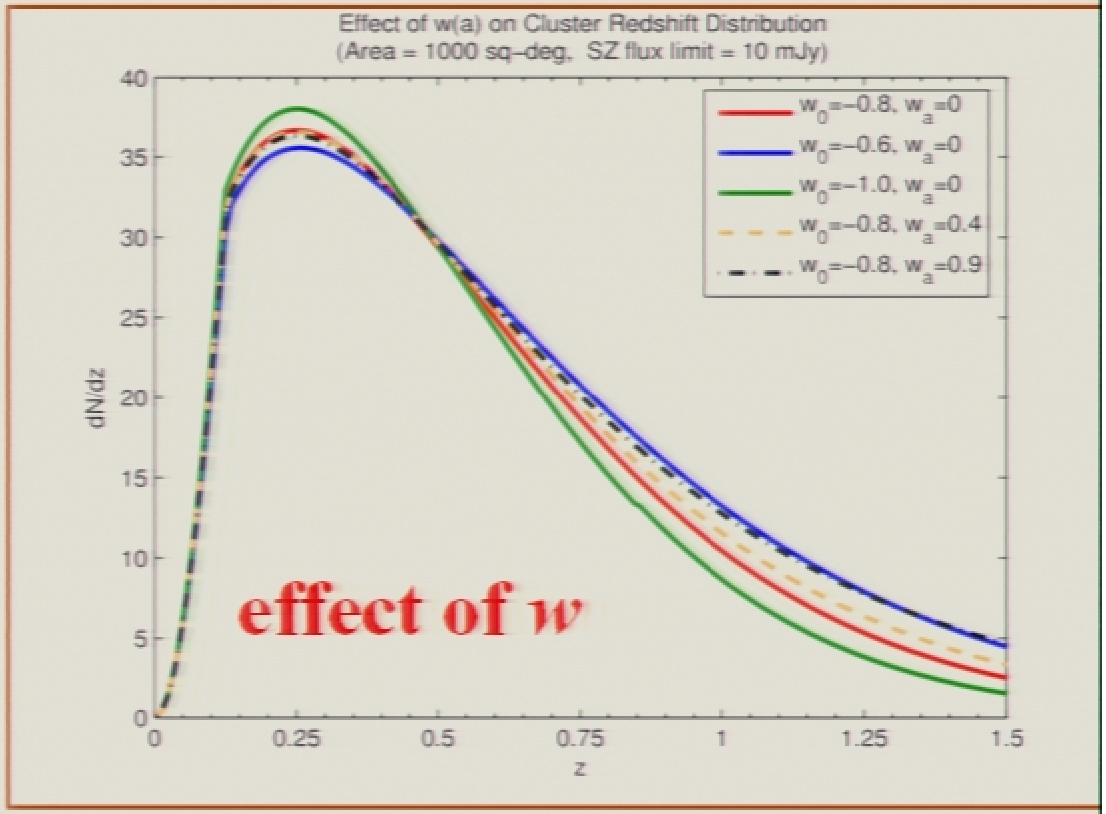
pass the CMB thru the cosmic web: CBI extra power??



pass the CMB thru the cosmic web: CBI extra power??

Sample forecast for SZ cluster surveys

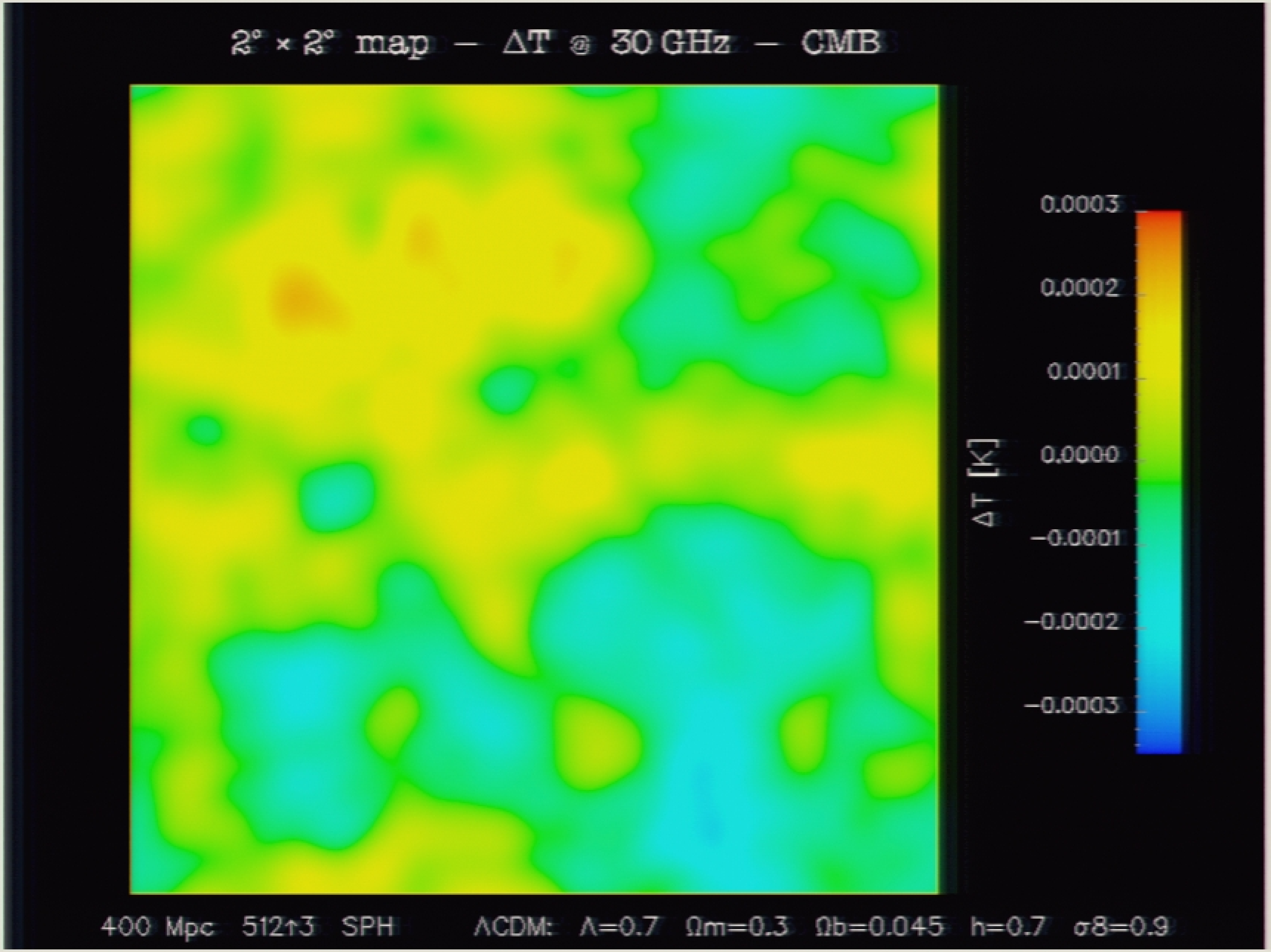




4000 sq deg with SPT, 22000 clusters **Subha Majumdar & Graham Cox CITA04**

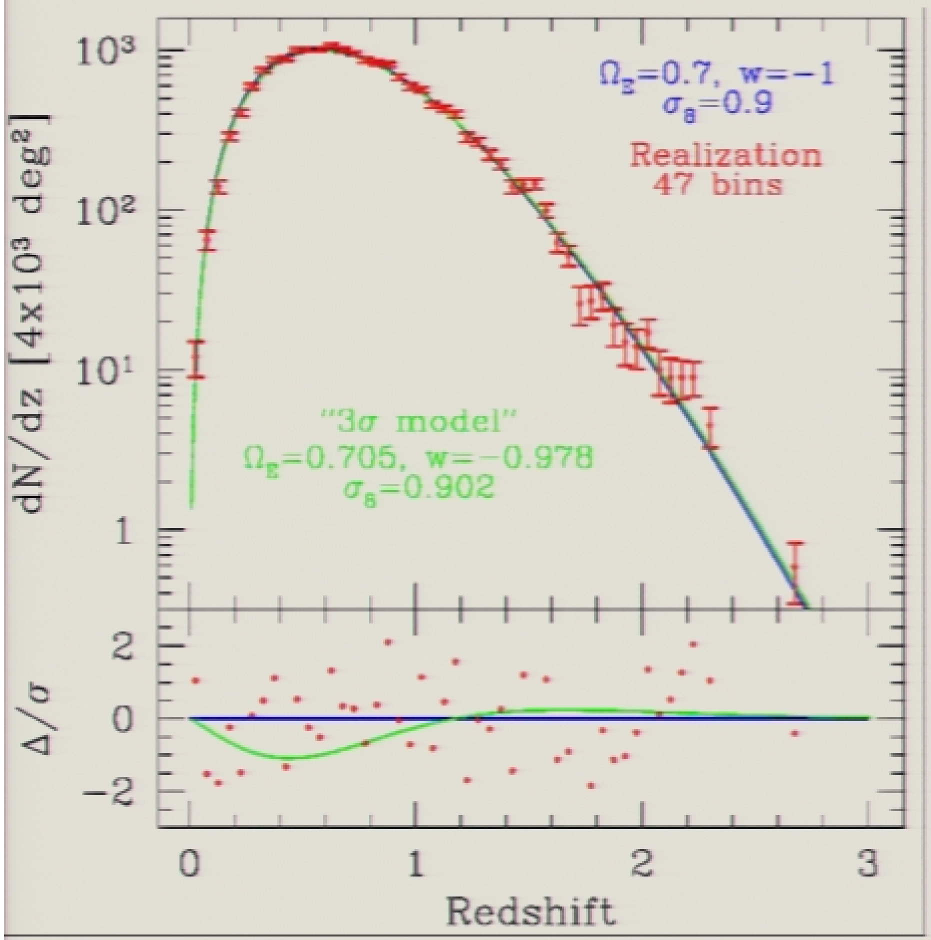
$$\frac{dN(z)}{dz\,d\Omega} = \frac{dV}{dz\,d\Omega}\,n(z) = \frac{c}{H(z)}\,d_A^2\,(1+z)^2 \int_0^\infty dM\, f(M)\,\frac{dn(M,z)}{dM}$$

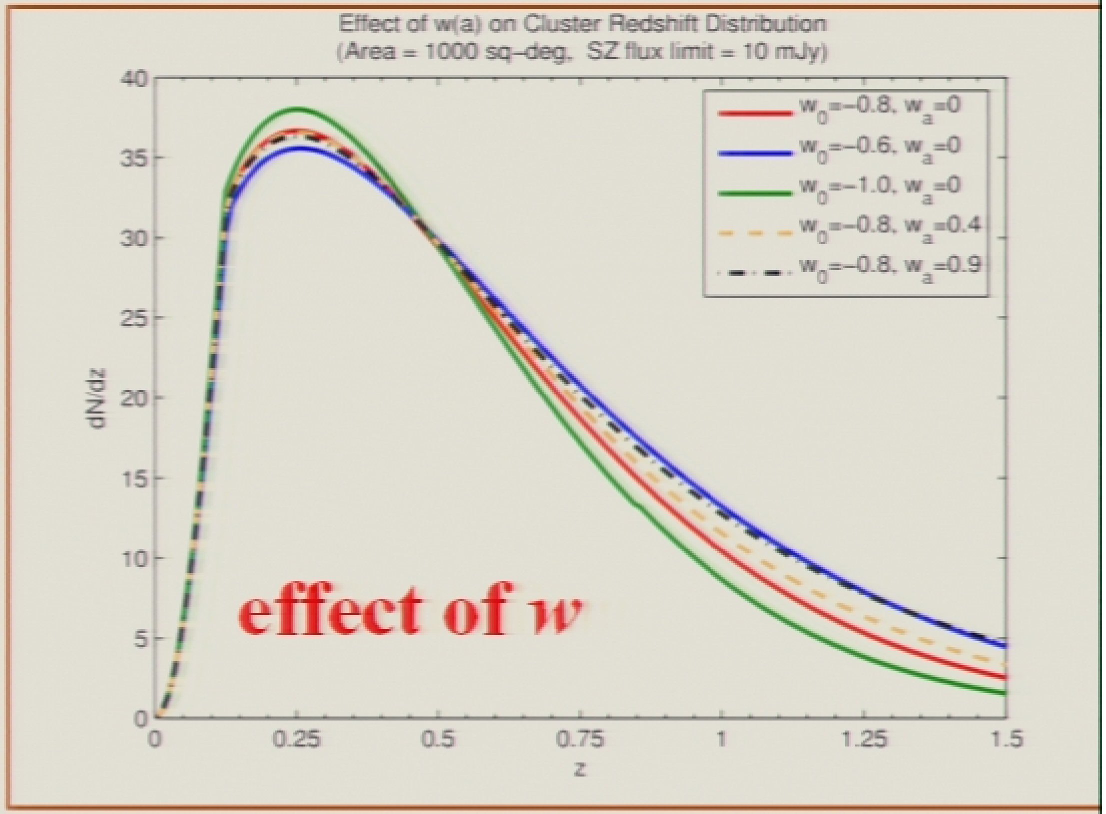
f(M) connects massive halos and real observables



pass the CMB thru the cosmic web: CBI extra power??

Sample forecast for SZ cluster surveys




Effect of w(a) on Cluster Redshift Distribution
(Area = 1000 sq–deg, SZ flux limit = 10 mJy)

4000 sq deg with SPT, 22000 clusters **Subha Majumdar & Graham Cox CITA04**

$$\frac{dN(z)}{dz\,d\Omega} = \frac{dV}{dz\,d\Omega}\,n(z) = \frac{c}{H(z)}\,d_A^2\,(1+z)^2 \int_0^\infty dM\; f(M)\,\frac{dn(M,z)}{dM}$$

f(M) connects massive halos and real observables

Past Cluster Surveys

- Example from XRay:

SURVEY	Fluxlim (erg/s/cm^2)	Area (deg^2)	No of clusters
XBACS (96)	5.0E-12	All Sky	276
BCS (98)	4.5e-12	13,578	199
RASS1BS (99)	3-4E-12	8,235	130
Ledlow (99)	~	14,155	294
Ebcs (00)	3.0E-12	13,578	299
HiFLUGS (02)	20.0E-12	13,578	63
NORAS (00)	3.0E-12	13,578	378
NEP (01)	0.03E-12	80.7	64
CIZA (02)	5.0E-12	14,058	73
SGP (02)	3.0E-12	3,322	112
MACS (01)	1.0E-12 (z>0.3)	22,735	120
REFLEX (01)	3.0E-12	13,905	452 (2460)

Upcoming/Planned Surveys

Survey	Sensitivity	Area (deg^2)	No of clusters
Planck	~5mK (HFI)	All sky	5,000-20,000
SPT	>1mK	4000	>15,000
ACT	~1mK	100	1000-2000
APEX-SZ	~1mK	150-200	1000-2000
SZA	<1mK	12	> 100 (detail)
RCS-2	$2.10^{14}\,M_{sun}$	1000	5000-10,000
XMM-LSS	1.25e-14	64	~1000
XMM-Serendpt	3.75e-14	800	~ 5000
DUO (declined)	2.1E-13; 2.85e-14	6000; 200	8000; 1600

RCS1 complete, with 1000 cluster candidates

Optical data state-of-the-art 05

RCS1 analysis:

Gladders, Hoekstra, Majumdar, Yee 0

~1100 clusters over 76 sq deg with Bg
300, z=0.3-1.0, pk at z=0.6-0.7

7 params: 4 cosmic + 3 Cluster self-
calibration parameters, using CMB pri
on h & ns

compatible with CMB Ω_m & σ_8

$\Omega_m = 0.34 \pm 0.064$

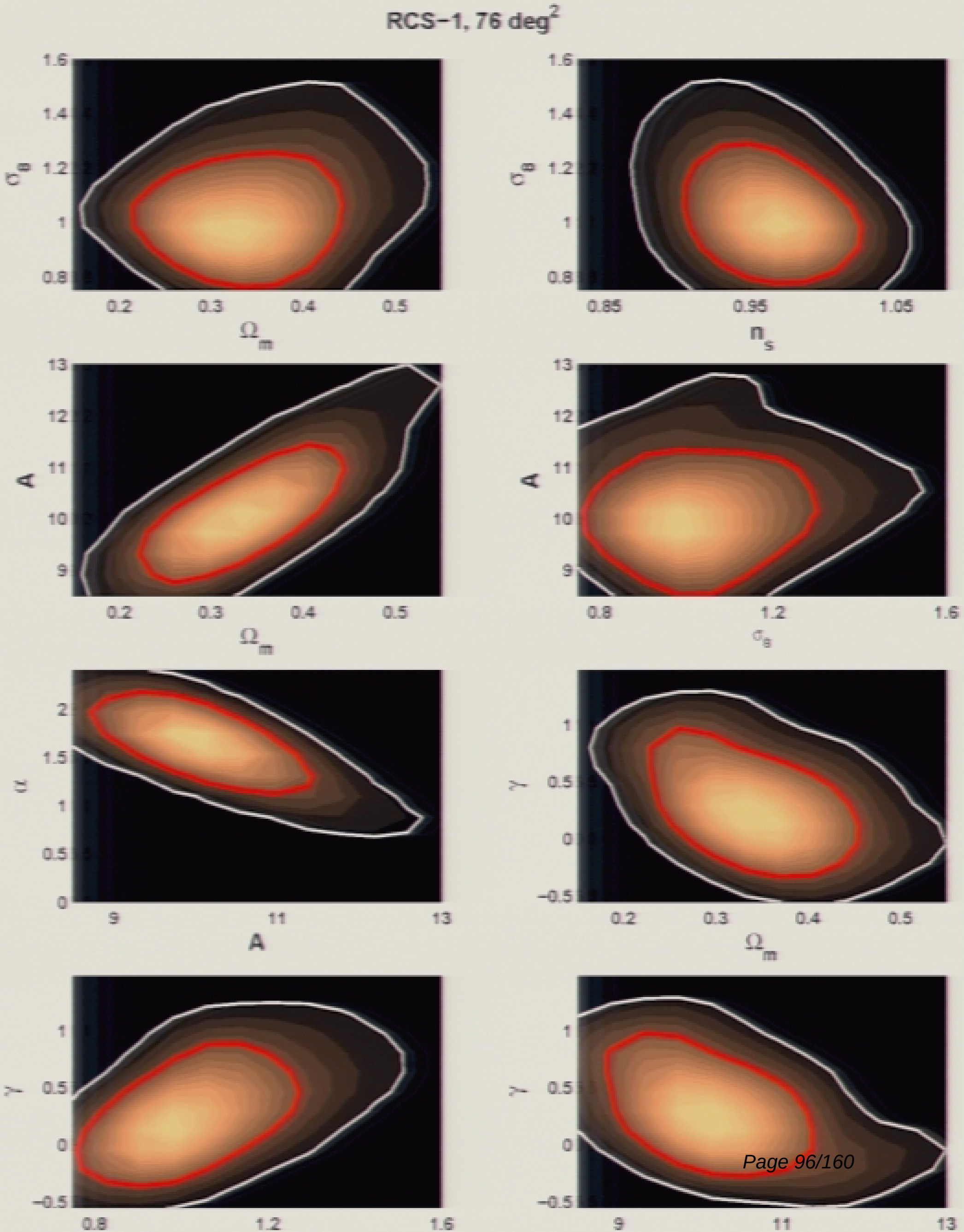
$\sigma_8 = 1.05 \pm 0.14$

& CNOC+Xray observations of cluste
mass & Bgc

log(amp Bgc-mass) = 10.24 +- 0.78 cf. 10.05 +- 0.

α(slope Bgc-mass) = 1.59 +- 0.27 cf. 1.64 +- 0.3

γ= 0.28 +- 0.35 cf. -0.5 +- 0.5



SPT analysis: Majumdar 05

~22000 clusters over 4000 sq deg

SZ data future 05

Forecast errors Ω_m & σ_8

$\Omega_m = 0.26$ +- 0.025

$\sigma_8 = 0.935$ +- 0.07

w0 = -1.06 +- 0.30

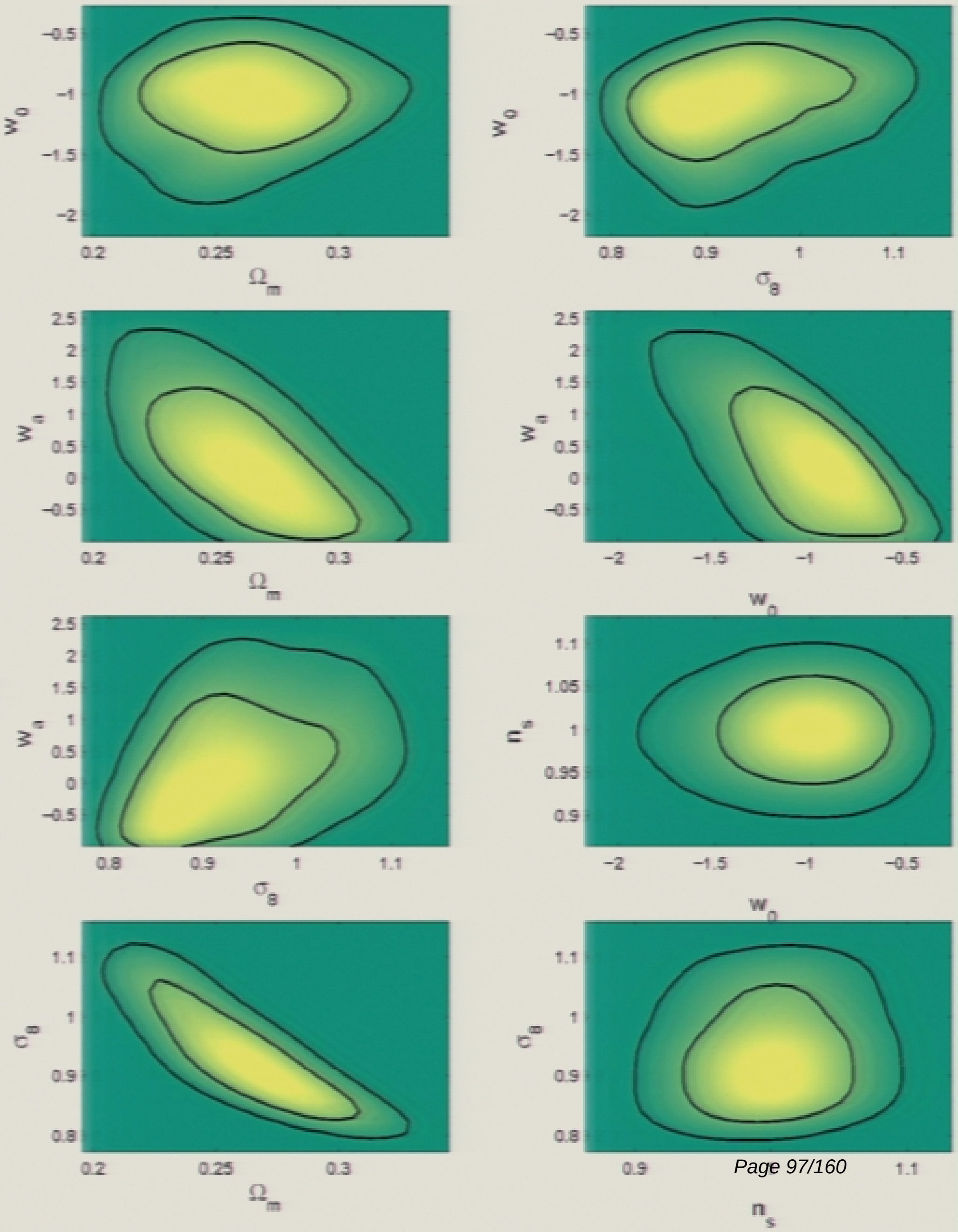
w1 = 0.28 +- 0.75

& "internal" self-calibration parameter

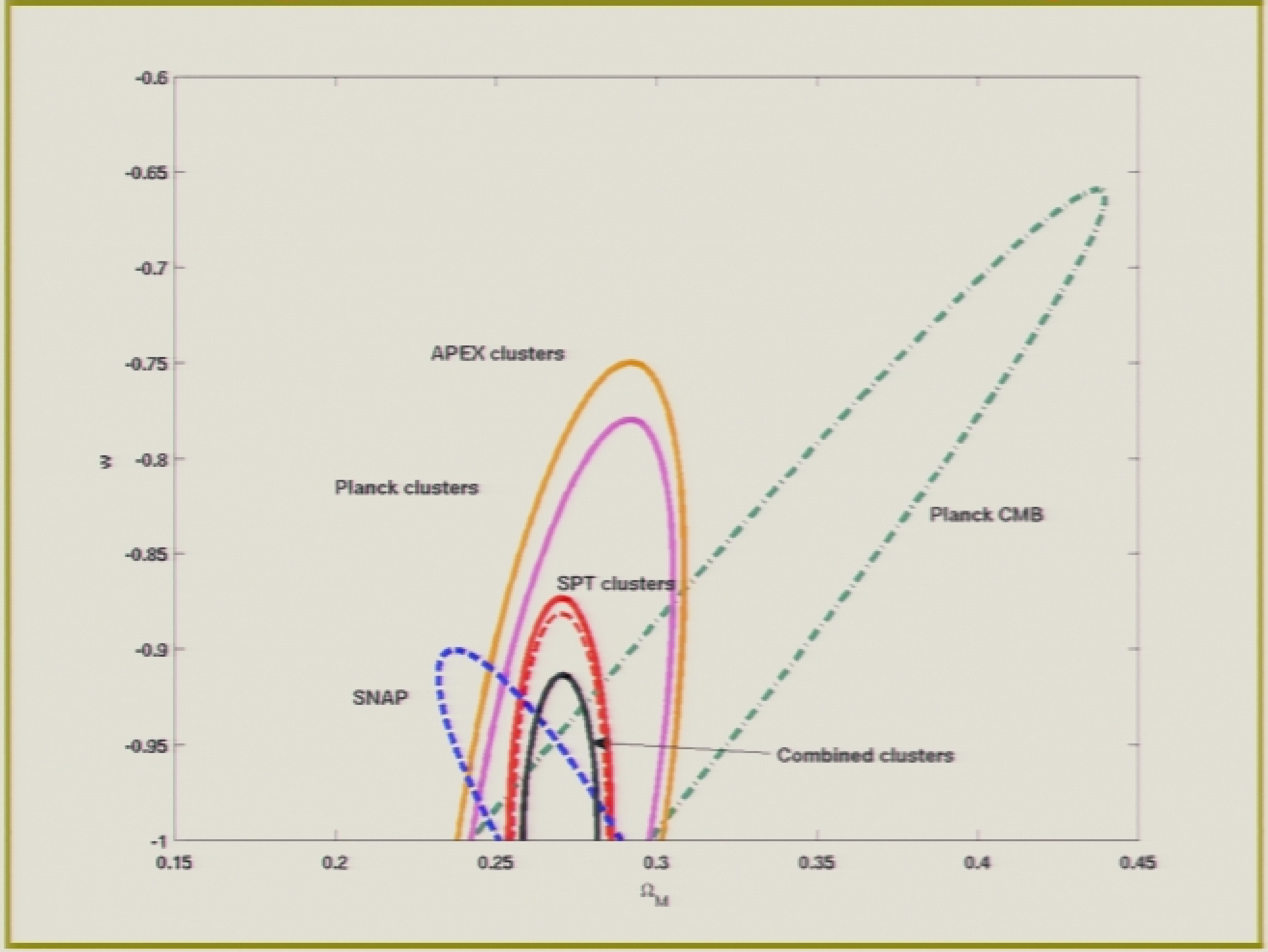
log(amp SZ-mass) = 16.7 +- 0.42

α(slope SZ-mass) = 1.68 +- 0.03

Also SZ Flux relation



Adding different cluster surveys



Only dN/dz, no extra information.

Majumdar 2005

Example:
Planck ~ 10000 clusters
APEX ~ 1500 clusters

Adding them together:
(in presence of w1)

i)reduces Planck error on w0 by factor of 2.5

ii)reduces APEX error on w0 by factor > 4

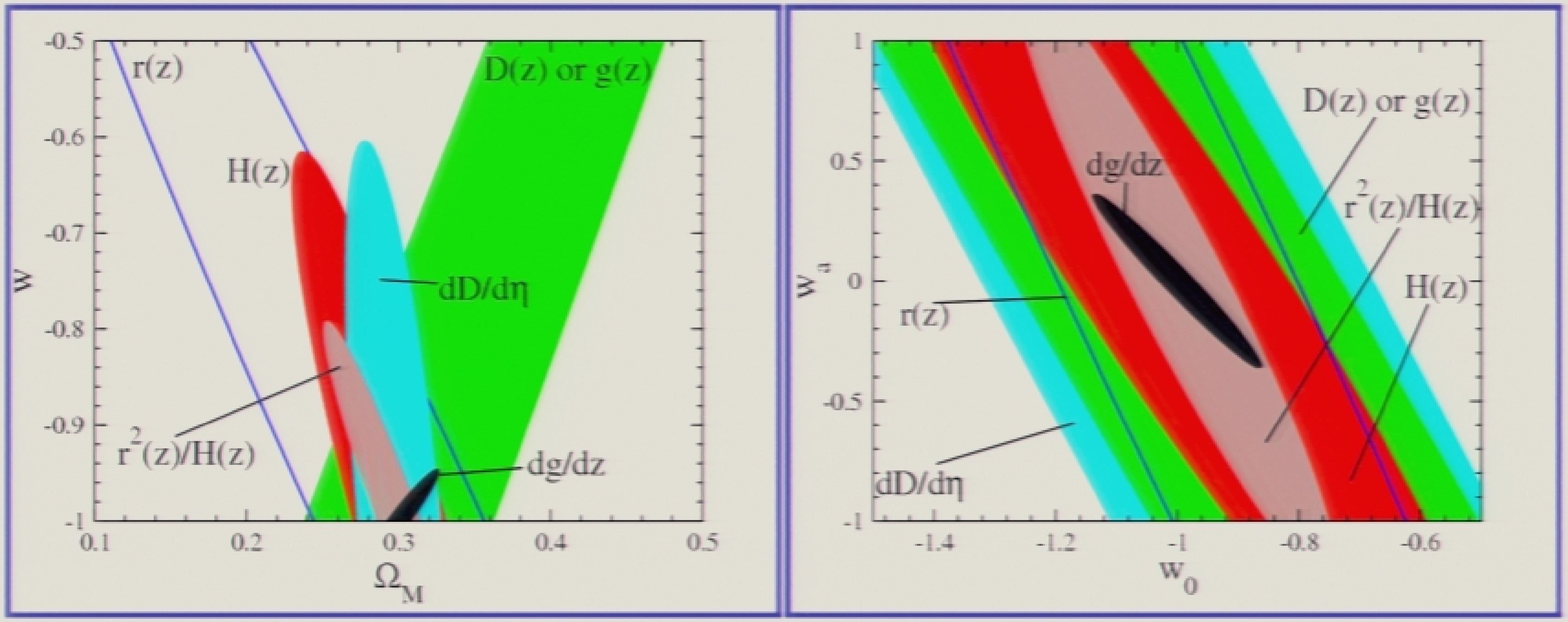
Majumdar 2005

- Cluster surveys as probes of dark energy are complimentary and competitive with other probes (e.g., SNe+Lensing+Lyman-alpha). Upcoming surveys can constrain w_{eff} to ~5-10% or w_0 to ~20% and w_1 to ~50% (with reasonable priors).

- Gastrophysics cf, fundamental cosmology: Uncertainty in cluster structure and evolution can dilute the predictive power of these surveys to constrain dark energy.

- Techniques now exist that can overcome this:
- “external-calibration”, “self-calibration”, e.g. reducing mass-observable uncertainties.
- Sample sub-selection from very large cluster datasets – “gold-plated”. Follow-up observations.

‘Underlying’ probes of *w* : *where do clusters fall?*



Cooray etal 2004

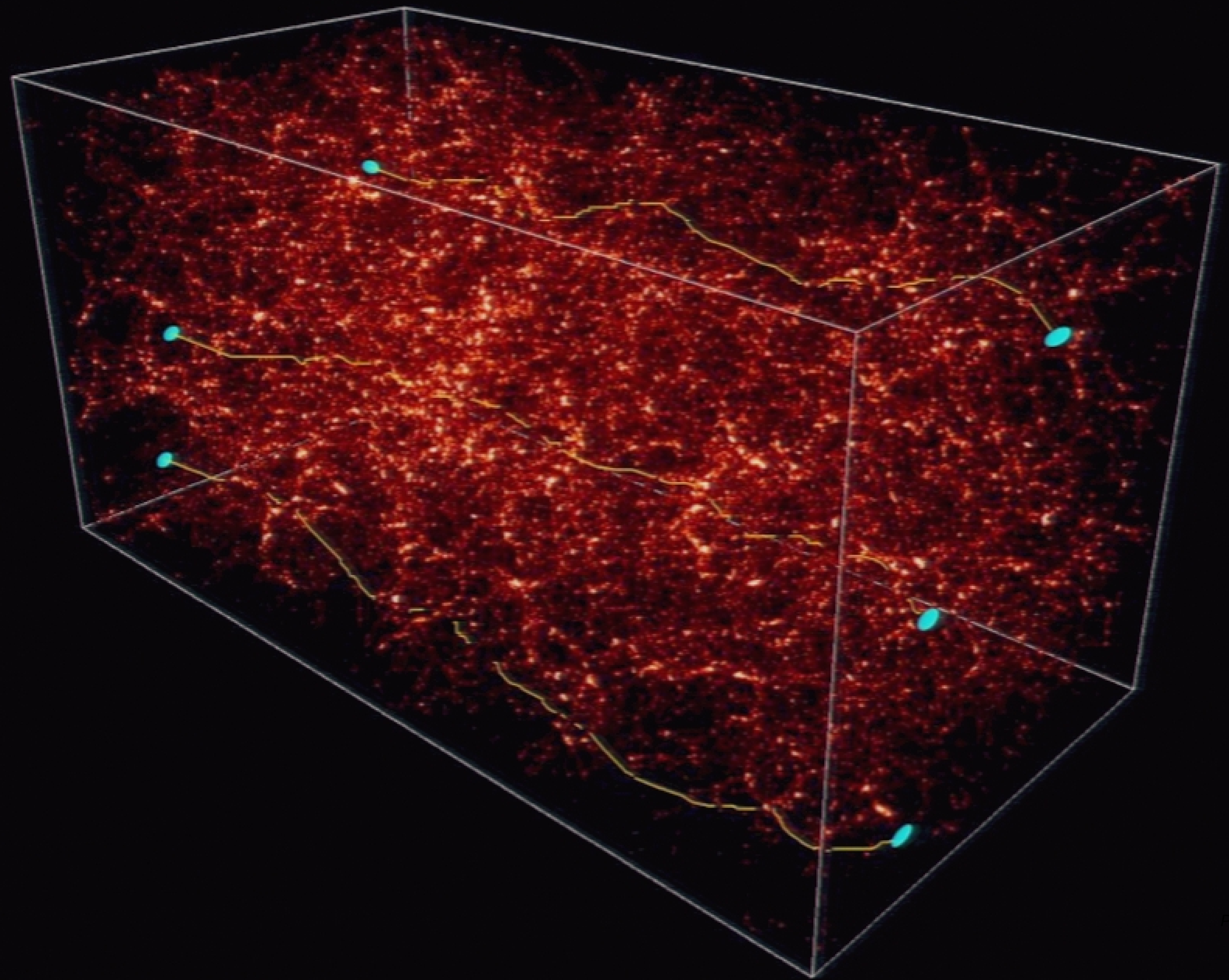
10% error on expansion history, distance, volume, growth and rates of change of growth

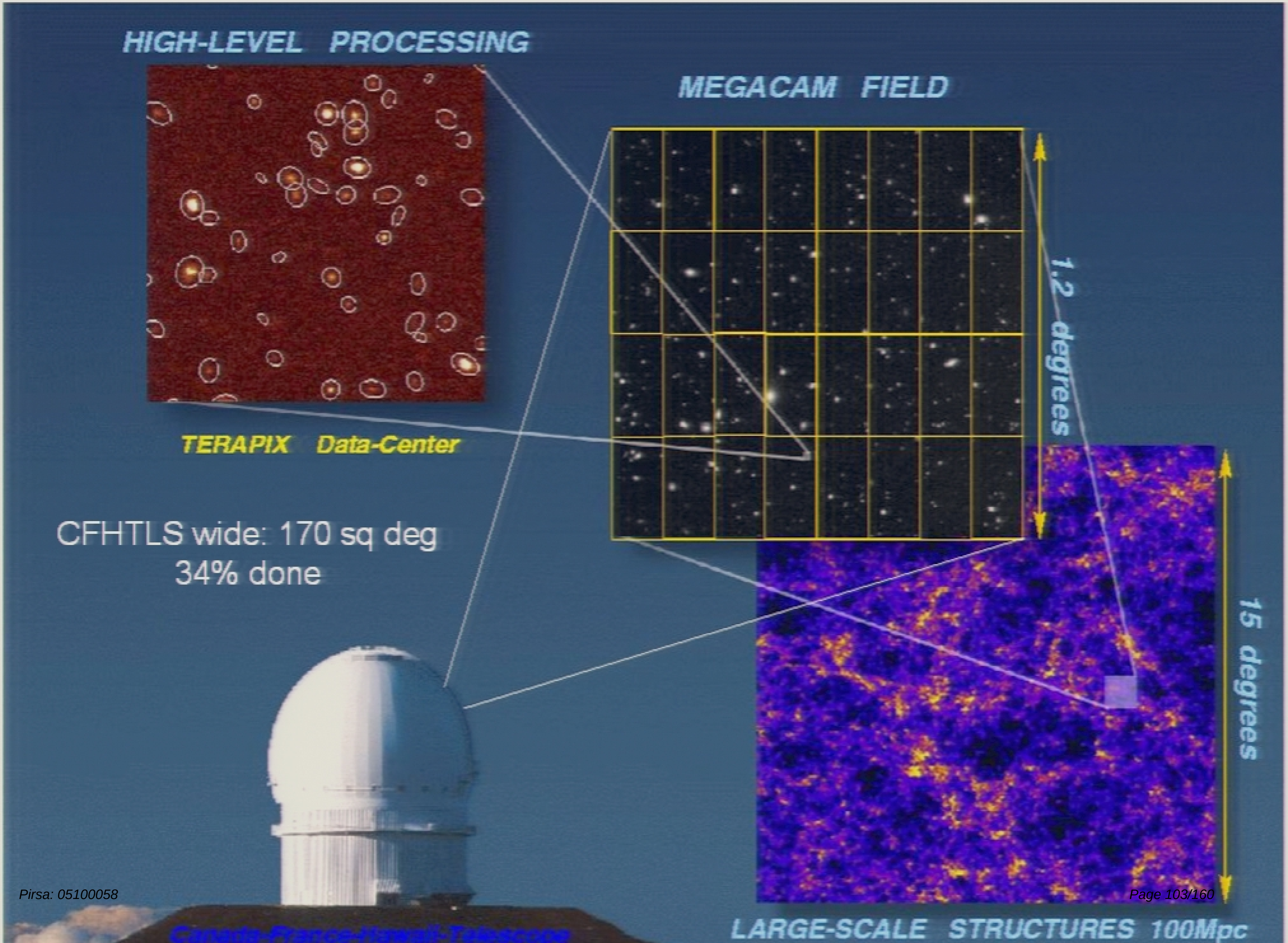
Physical cosmology Probes of Early & Late universe physics

Weak lensing (Dore, Pat McDonald, Eric Linder)

strong lensing (Neal Dalal)

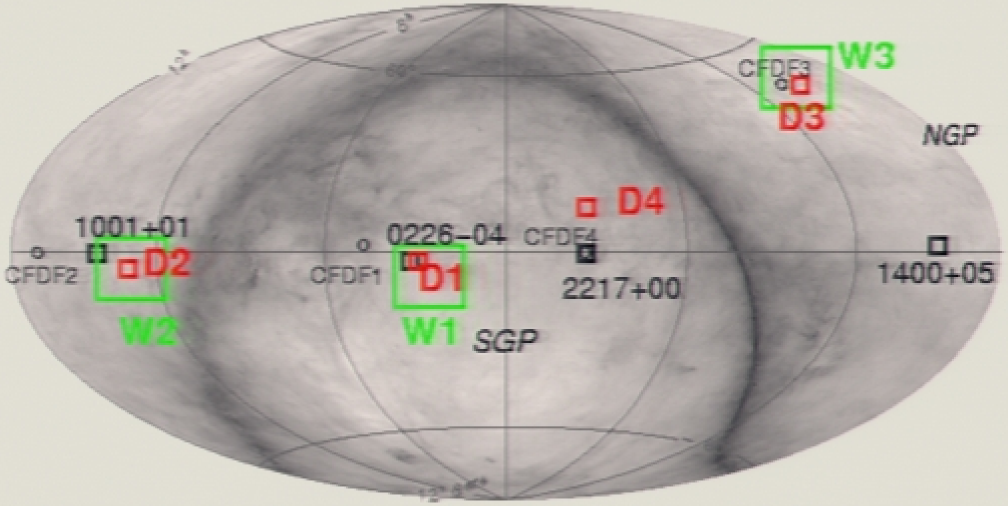
DEFLECTION OF LIGHT RAYS CROSSING THE UNIVERSE, EMITTED BY DISTANT GALAXIES



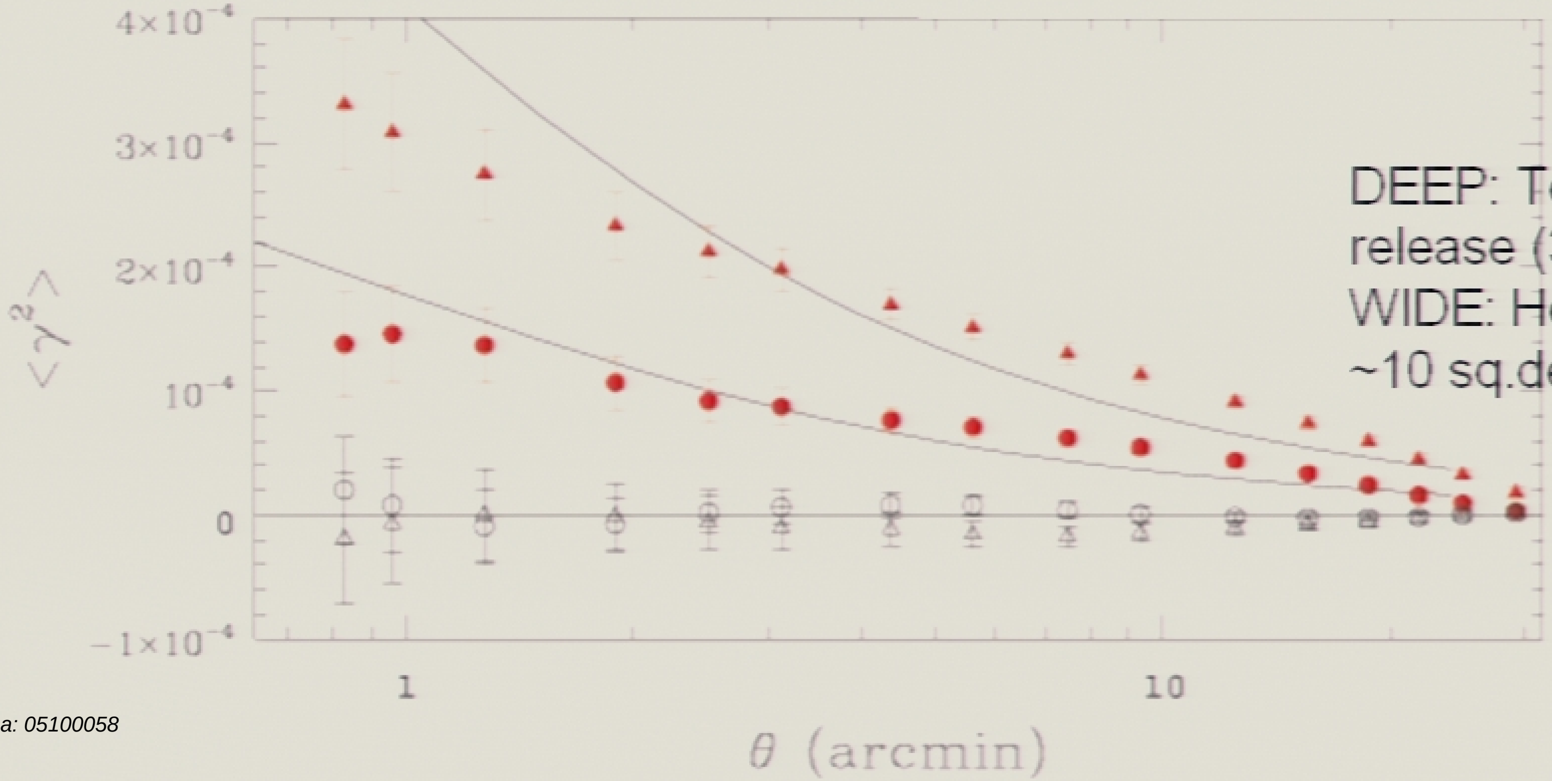


CFHTLS wide: 170 sq deg
34% done

Canada France Hawaii Telescope Legacy survey



Low and high z cosmic shear in the DEEP fields

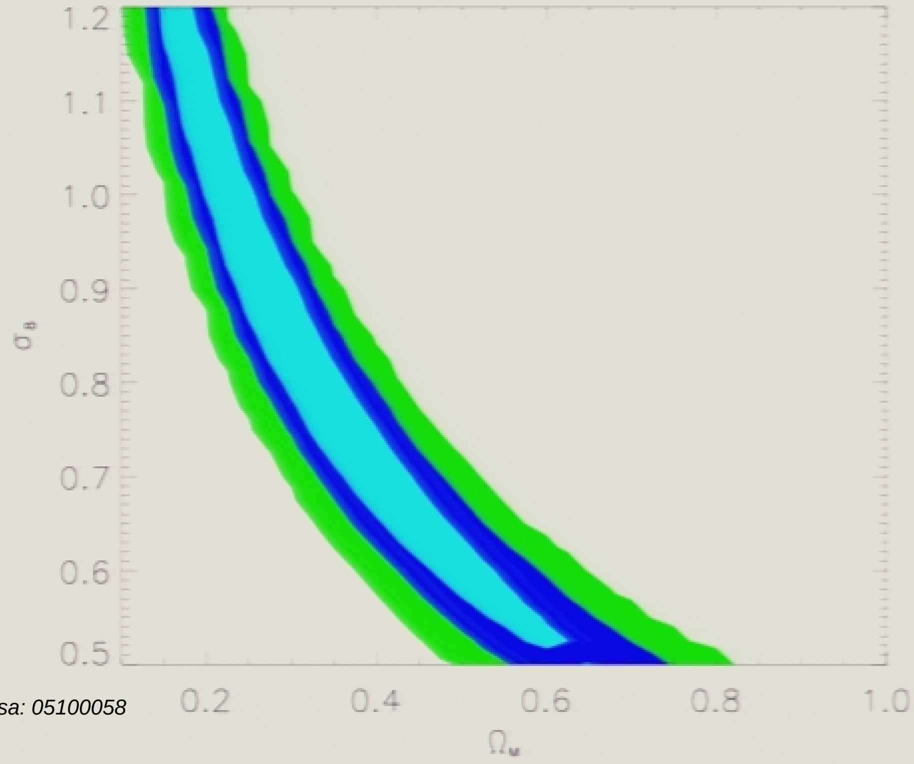


DEEP: Terapix T0001 release (3 sq.deg)
WIDE: Hoekstra (~17 & ~10 sq.deg.)

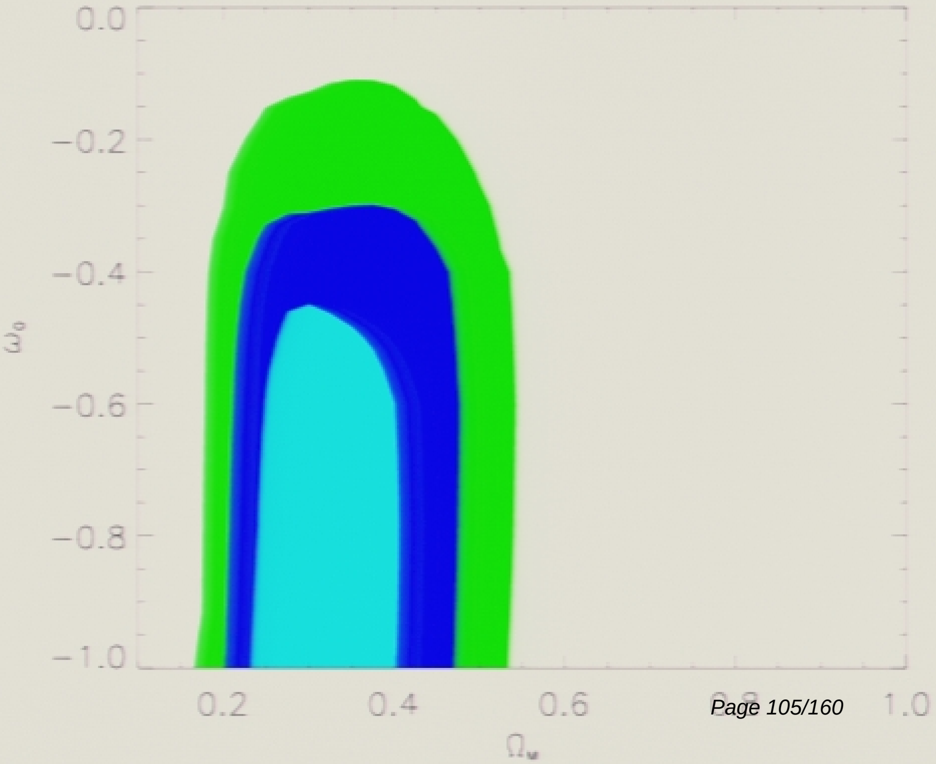
Measurements from the WIDE (22 sq deg of 170 sq deg, <zs>=0.81) and DEEP (4 sq deg) CFHTLS lensing survey

Hoekstra et al. Oct05. Semboloni et al. Oct05

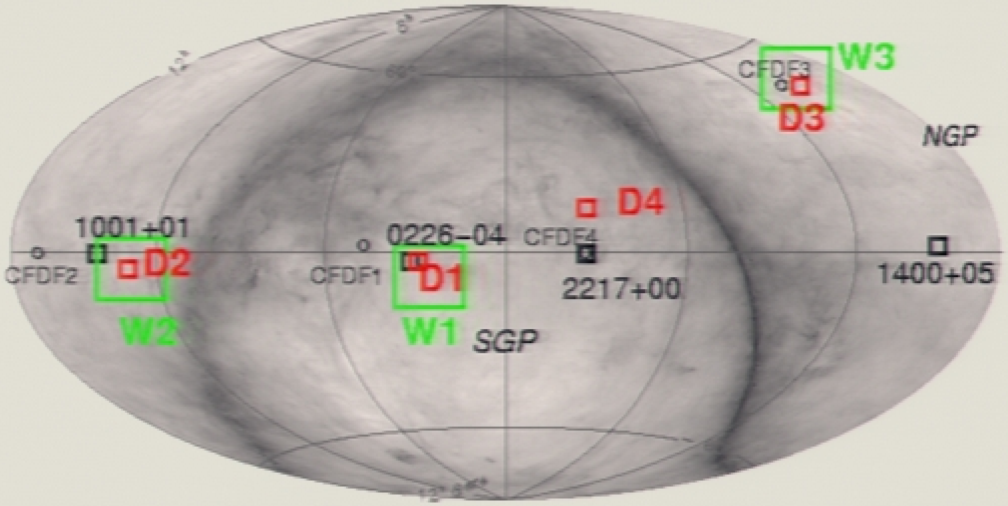
Constraints on $\Omega\!-\!\sigma_8$ 0.85 +- 0.06



Constraints on $\Omega\!-\!w < -.45\ (1\sigma)$



Canada France Hawaii Telescope Legacy survey



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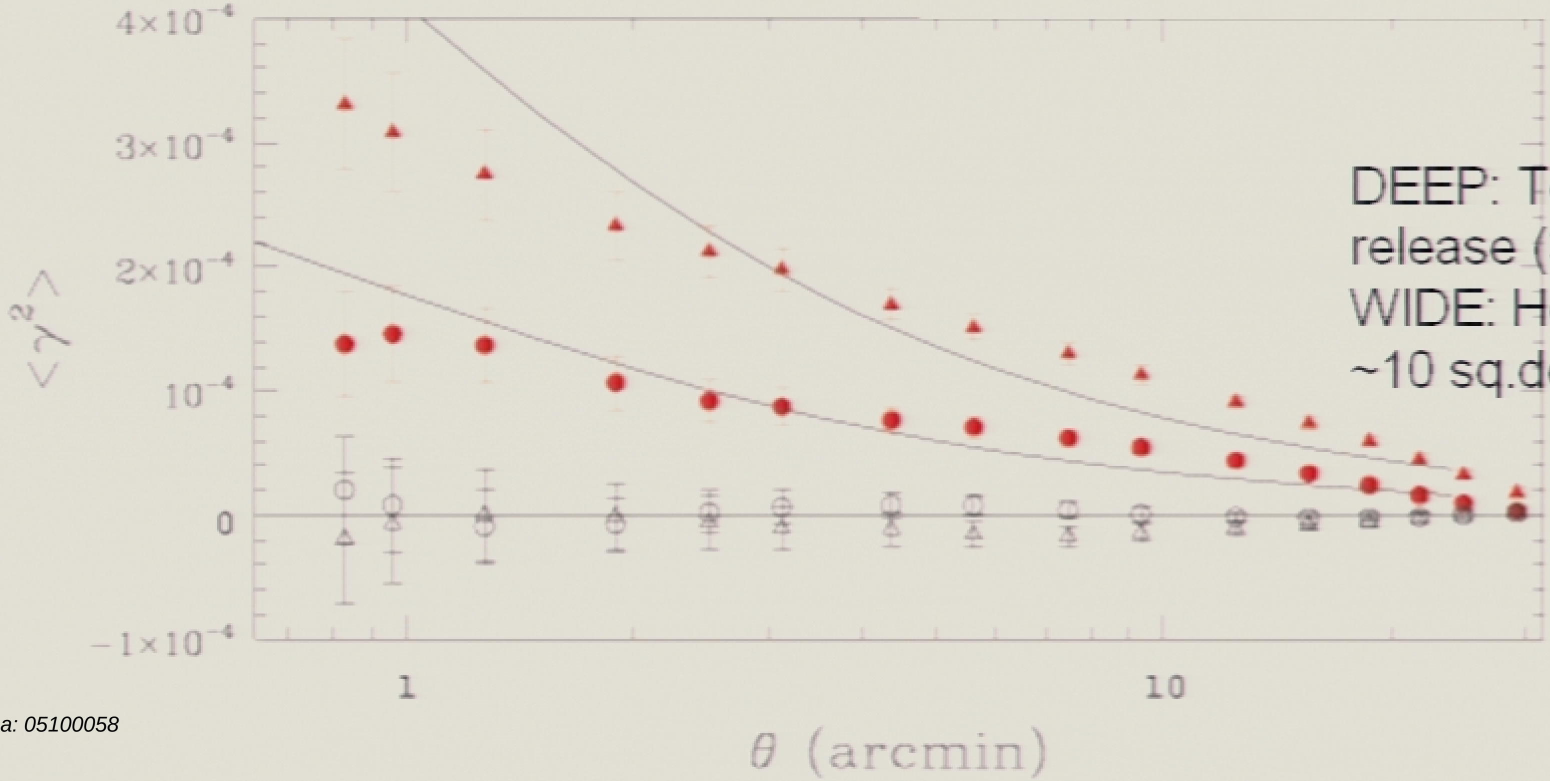

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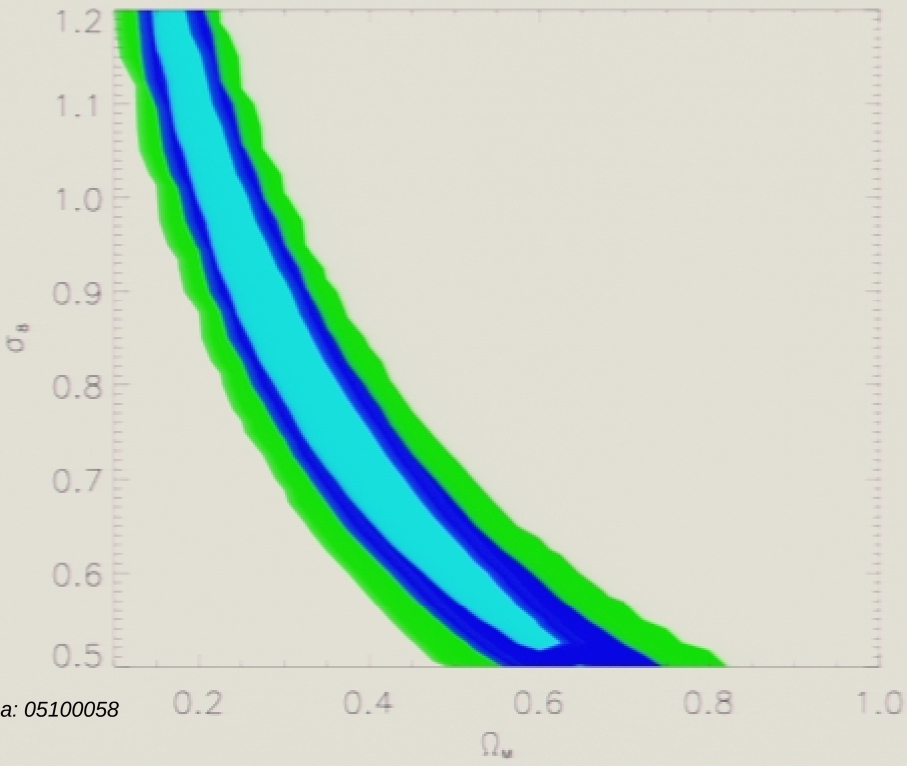
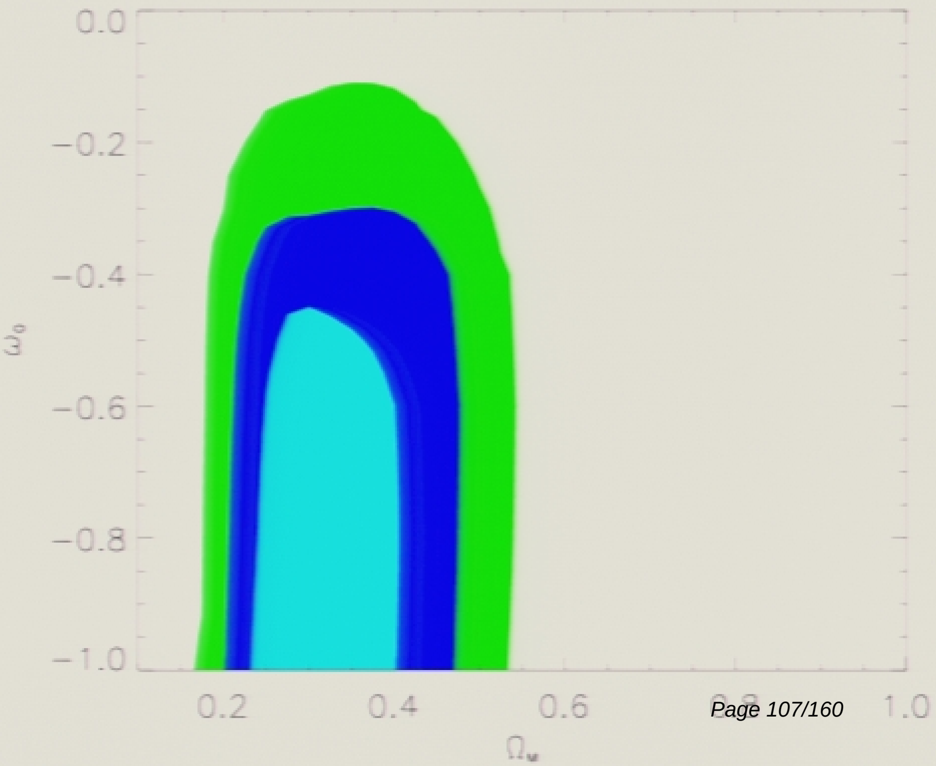
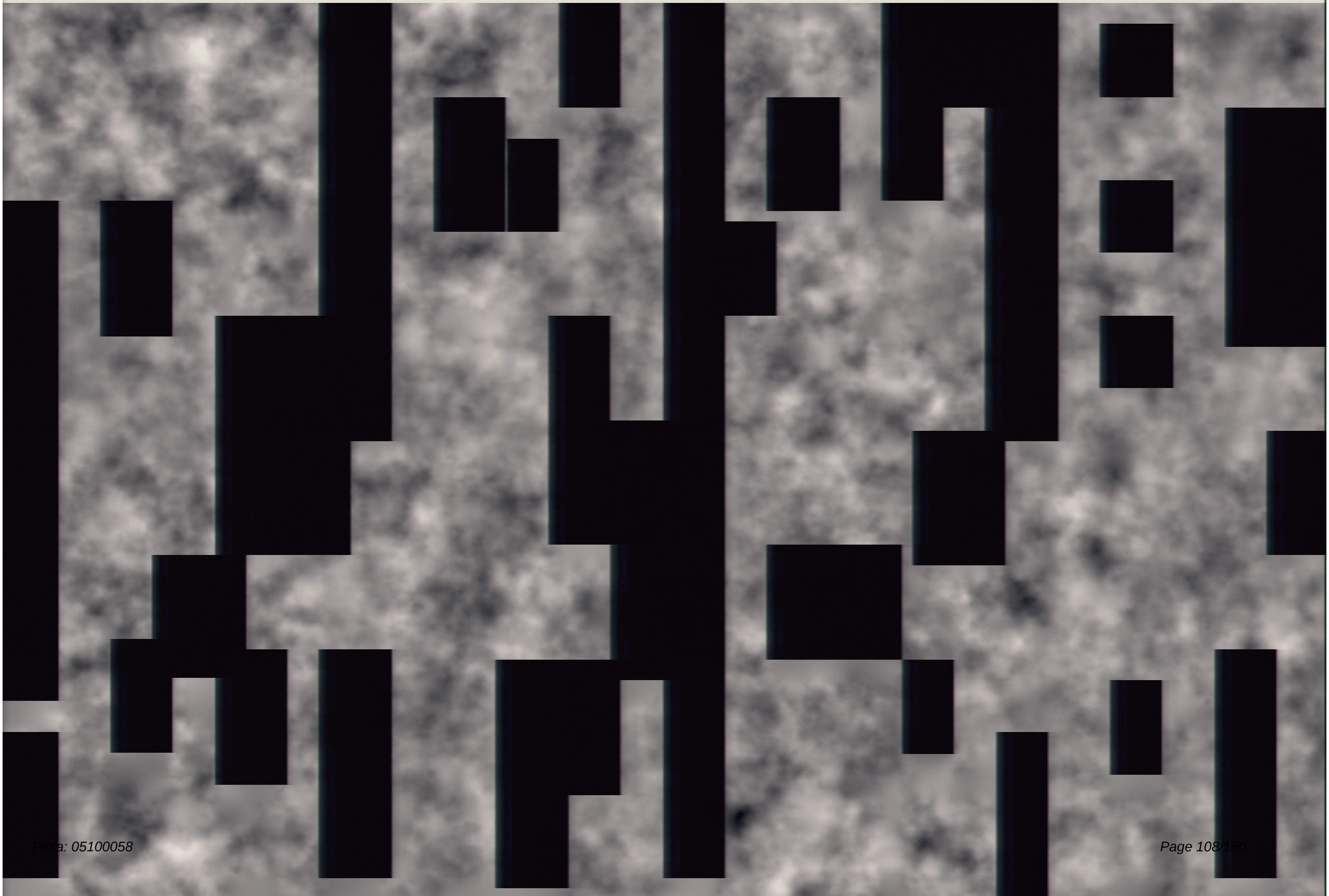


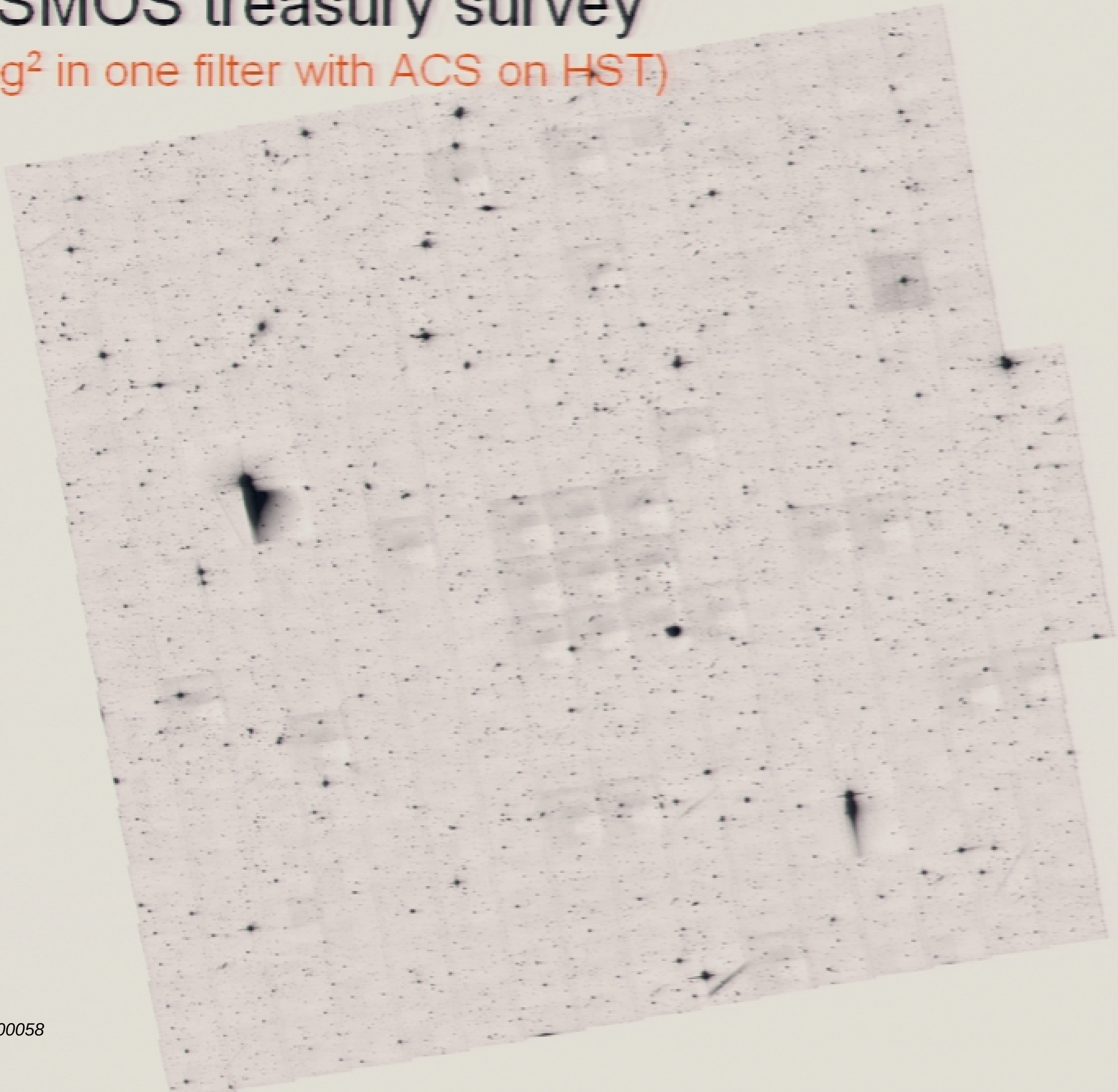
Constraints on $\Omega-w < -.45$ (1σ)





The largest optical survey from space: COSMOS treasury survey

(2 deg^2 in one filter with ACS on HST)



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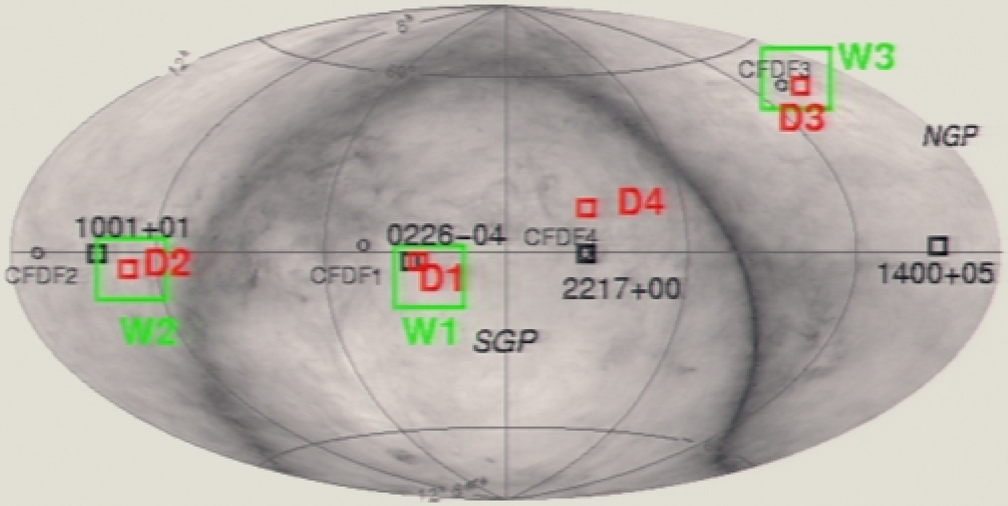

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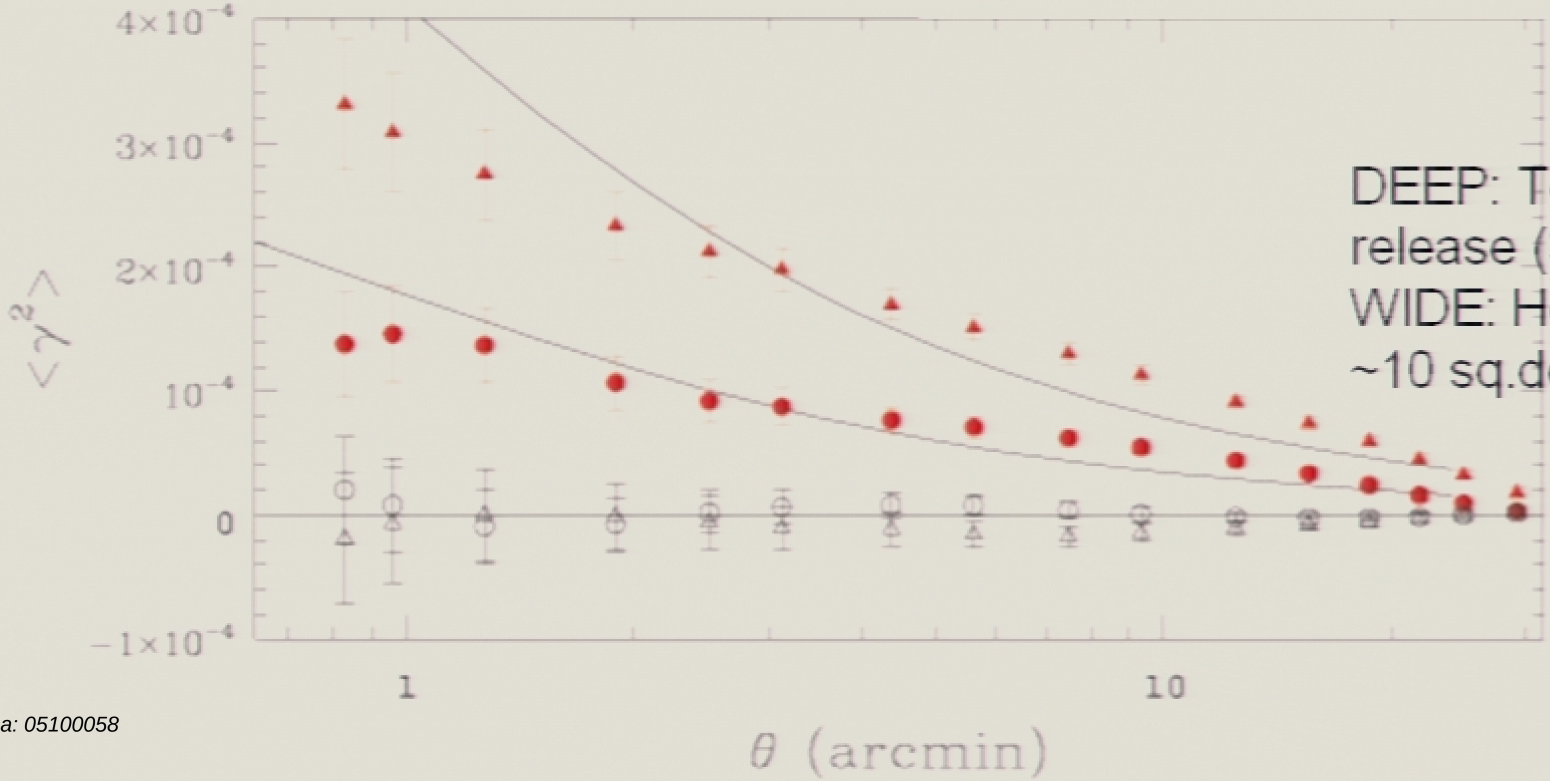

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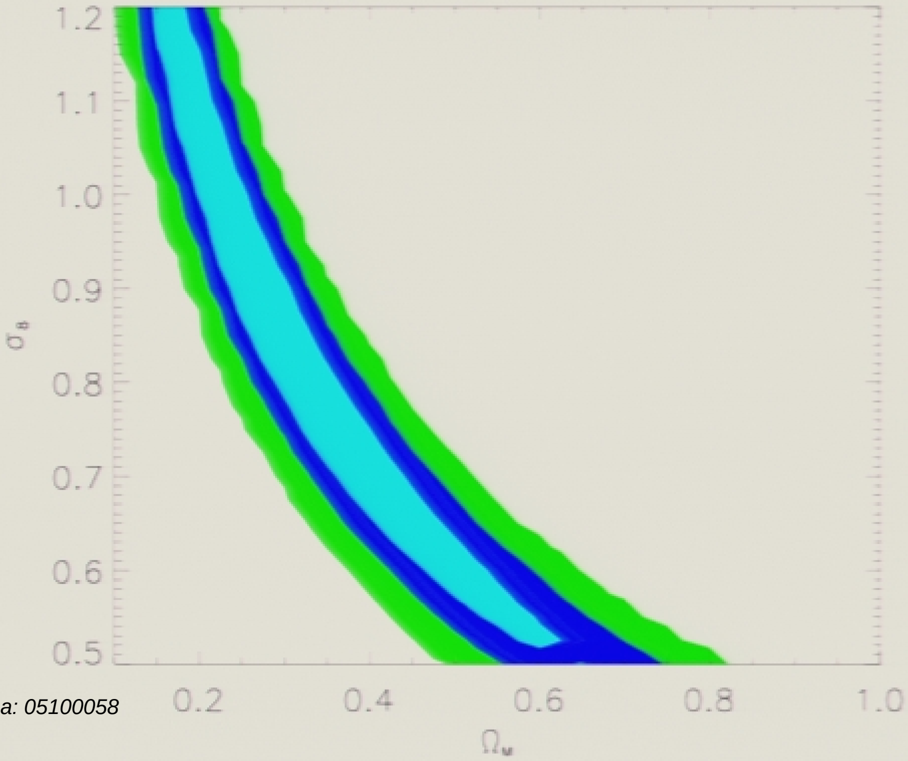

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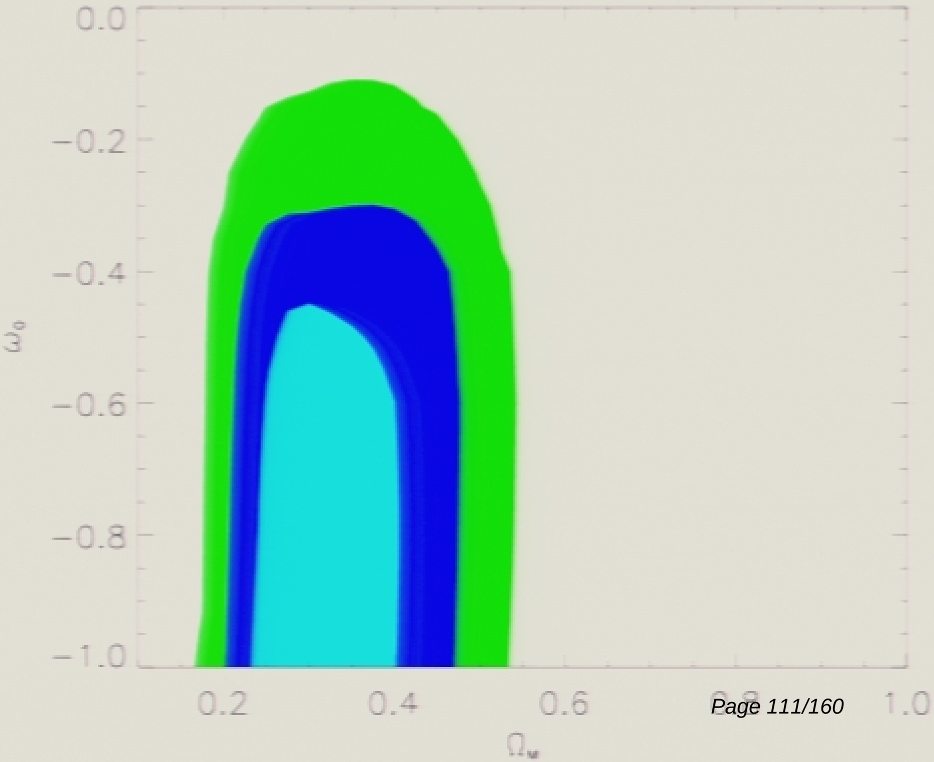
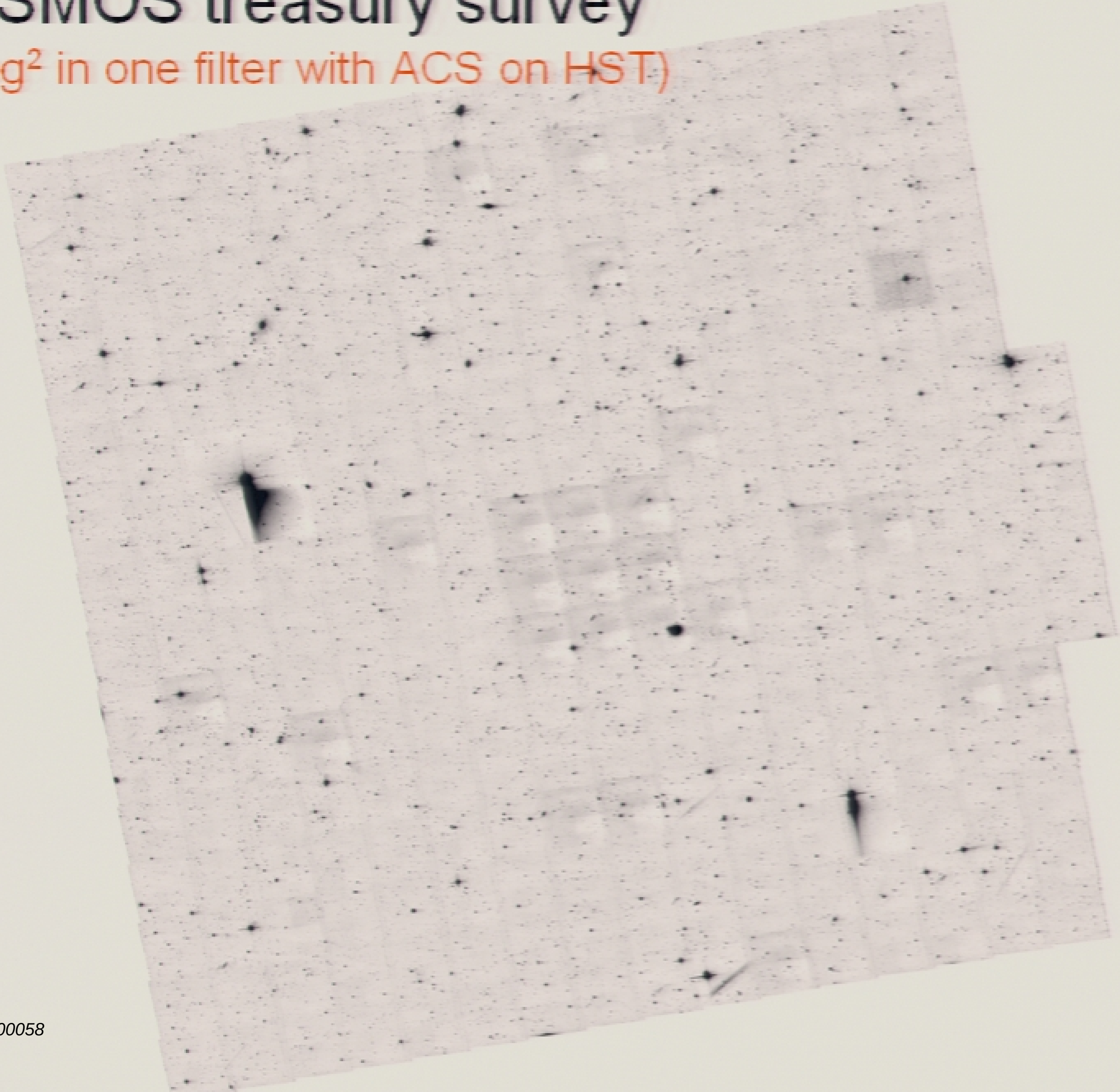


The largest optical survey from space: COSMOS treasury survey

(2 deg^2 in one filter with ACS on HST)



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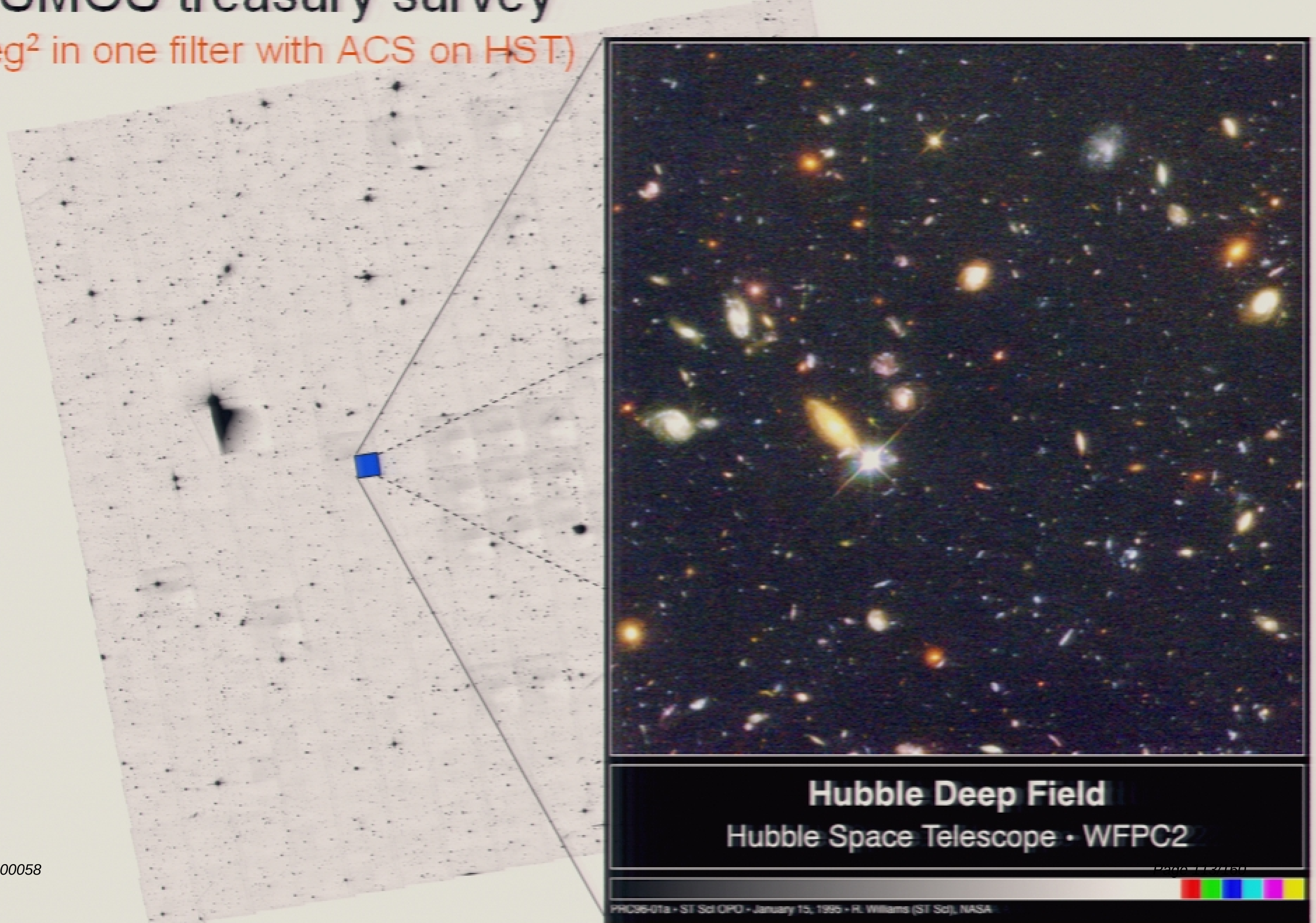


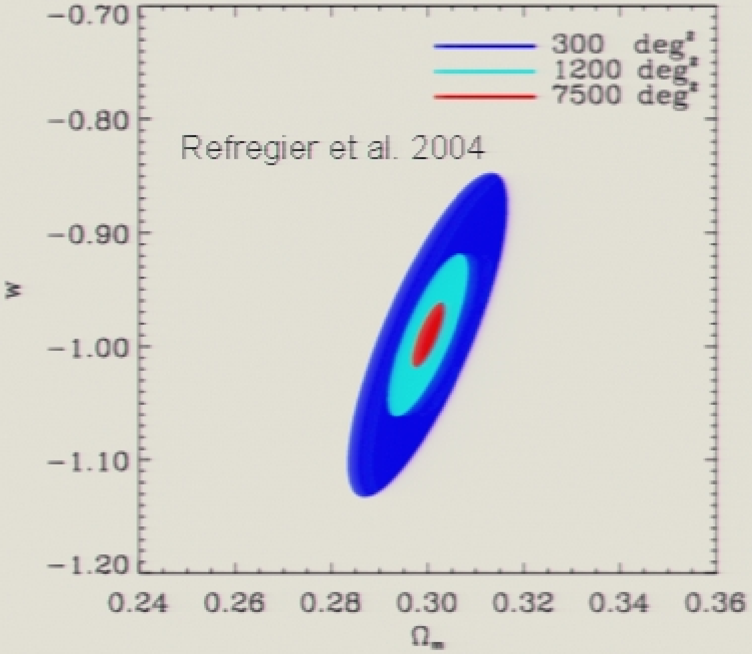
Comparison of DUNE vs COSMOS

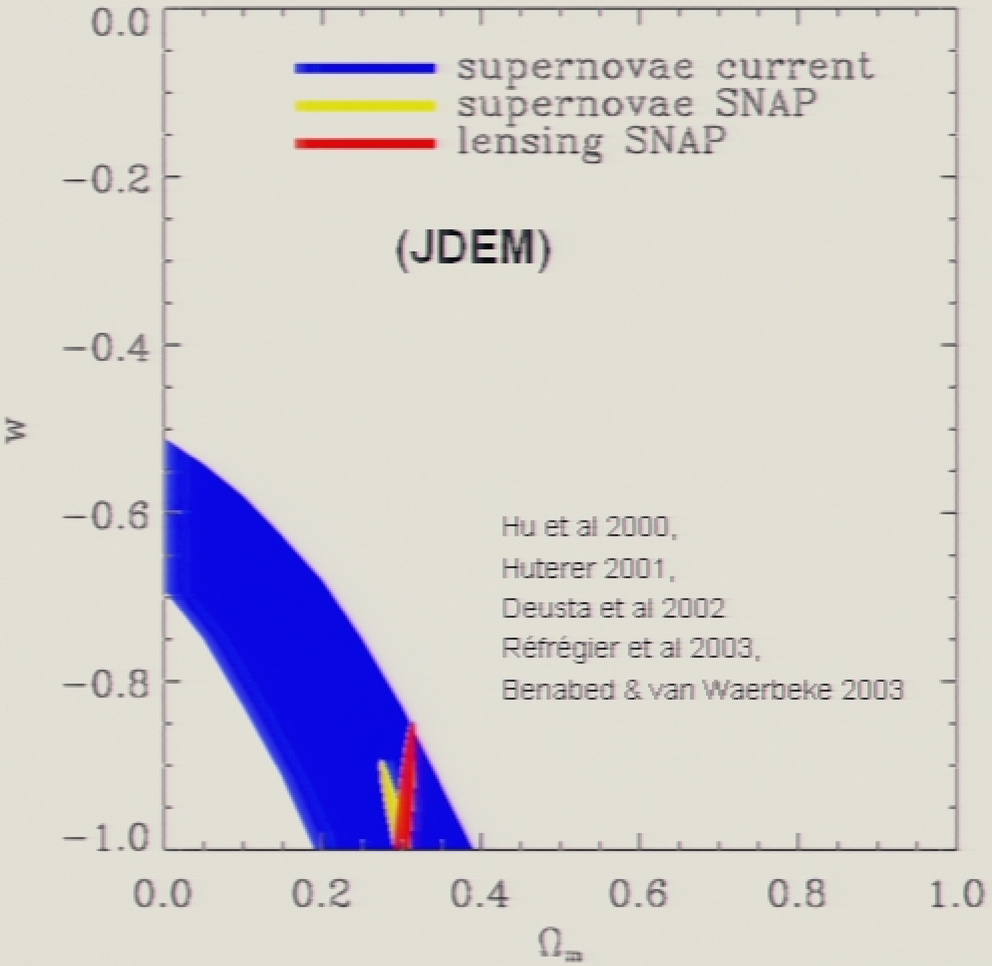
DUNE

5+ filters (including NIR)

Cosmos
single filter

Cosmic shear surveys in space DUNE JDEM





1.2-1.5 meter telescope,

Goals: P(k,z), galaxy distribution

- Dark energy: cosmic shear, SNIa, clusters of galaxies
- Inflation: spectral index and running spectral index: cosmic shear
- Biasing: as function of scale and redshift: cosmic shear and galaxy properties
- Redshift distribution of galaxies: photo-z

Physical cosmology Probes of Early & Late universe physics

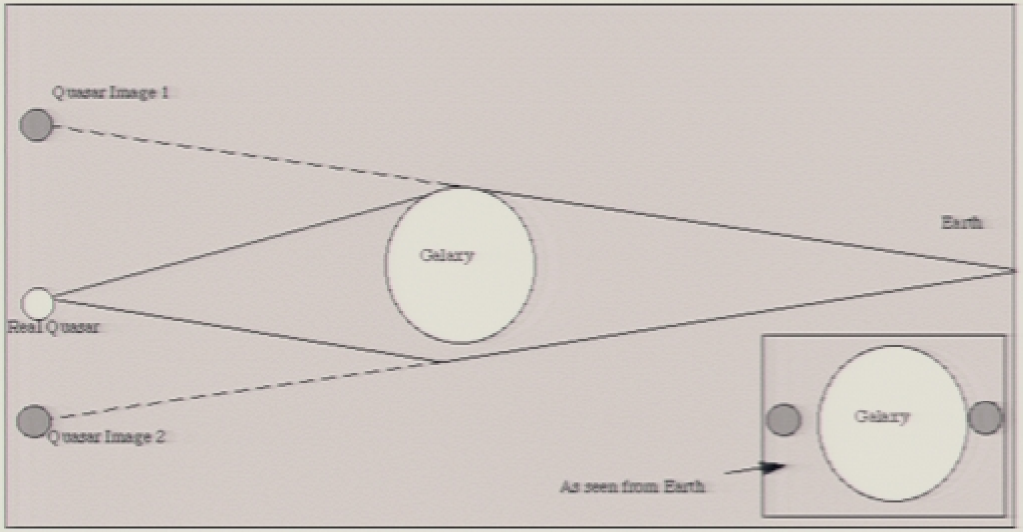
strong lensing (Neal Dalal)

Strong Lensing & ΛCDM

Neal Dalal (IAS)

with:	Chris Kochanek (OSU)
	Jackie Chen (Chicago)
	Gil Holder (CITA)
	Joe Hennawi (Berkeley)
	Paul Bode (Princeton)
	Jerry Ostriker (Princeton)
	Mike Gladders (OCIW)
	Chuck Keeton (Rutgers)

Strong lensing

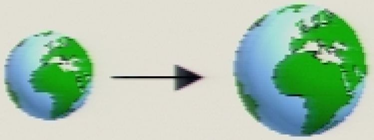


Multiple imaging of background sources by foreground masses (e.g. stars, galaxies, clusters,…)

Each image's appearance governed by the (inverse) magnification matrix

$$\mathbf{A} = \mathbf{M}^{-1} = \left(\frac{\partial(\mathrm{img})}{\partial(\mathrm{src})} \right)^{-1} = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

convergence κ produces uniform dilation

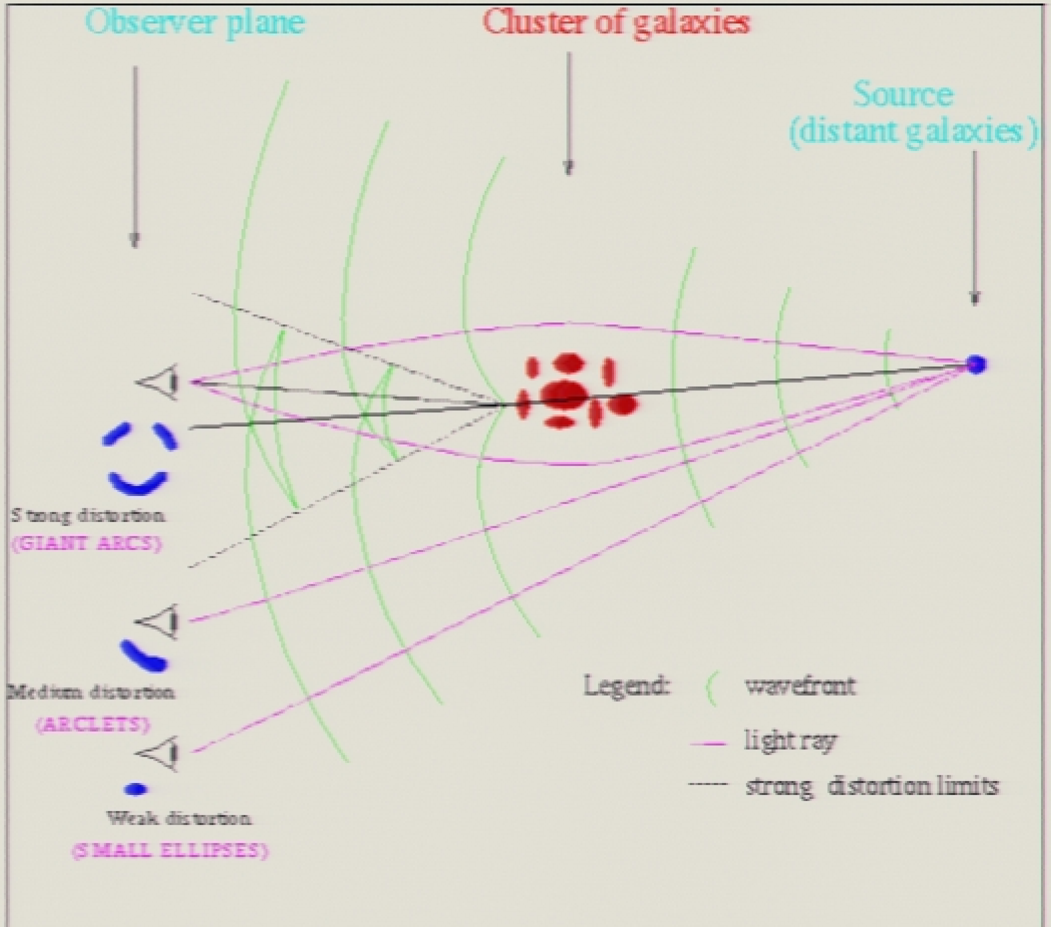


shear γ produces anisotropic distortion.

Critical curves & caustics

$$\mathbf{A} = \mathbf{M}^{-1} = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

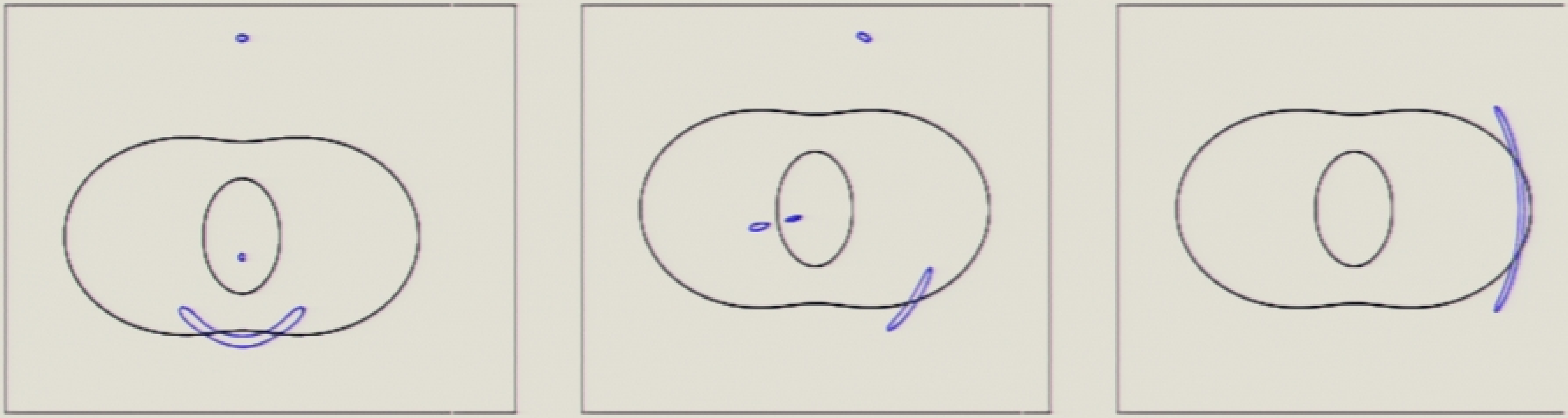
M becomes singular where $1-\kappa-|\gamma|=0$, $1-\kappa+|\gamma|=0$. This set of points is called the *critical curve*(*s*). As a source enters (or leaves) the strong lensing region, images appear (or disappear) on the critical curves.



The 3 gravitational distortion regimes

Arcs & critical curves

Arcs generally occur on the critical lines:



Critical lines are where $1-\kappa-|\gamma|=0$, $1-\kappa+|\gamma|=0$. So it's easy to see how the critical lines behave as the lens properties are varied….

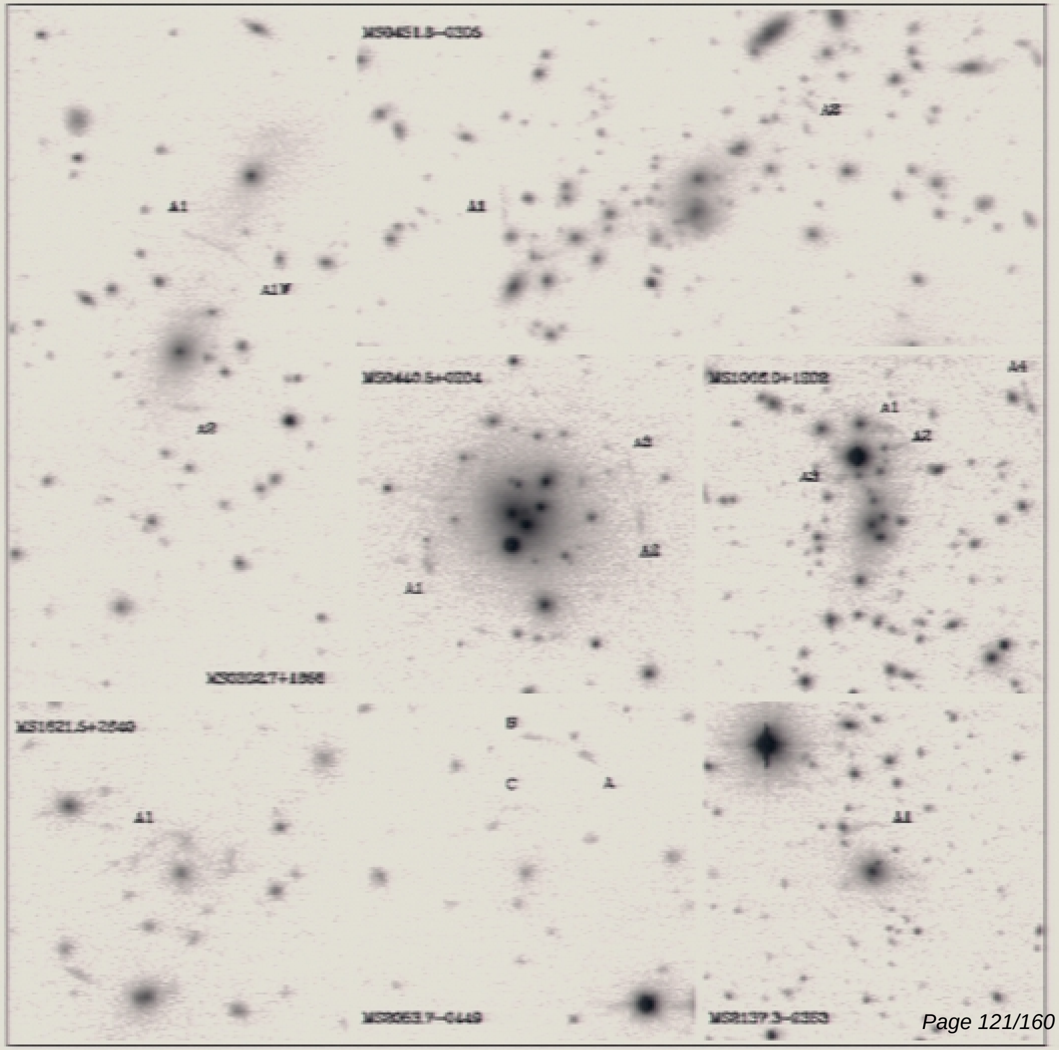
$$\text{Aside : for spherical lens, } |\gamma| = \langle\kappa\rangle - \kappa, \text{ so } 1-\kappa-|\gamma| = 0 \Rightarrow \langle\kappa\rangle = 1.$$

Compare predictions with observations

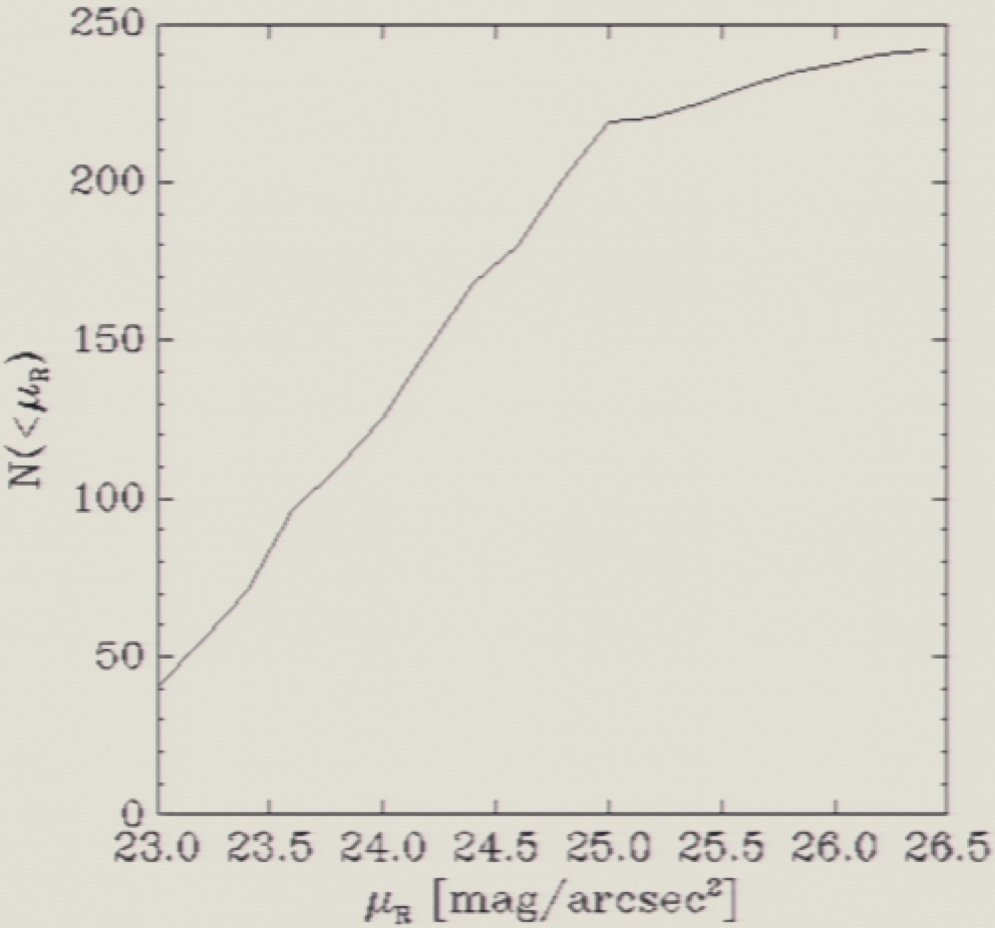
To date, largest sample comes from EMSS (Le Fevre et al. 1994, Luppino et al. 1999).

Also:
LCDCS (Zaritsky & Gonzalez 2002)
RCS (Gladders et al. 2003)

Ongoing:
MACS (Ebeling et al.),
RCS-2 (Gladders et al.)

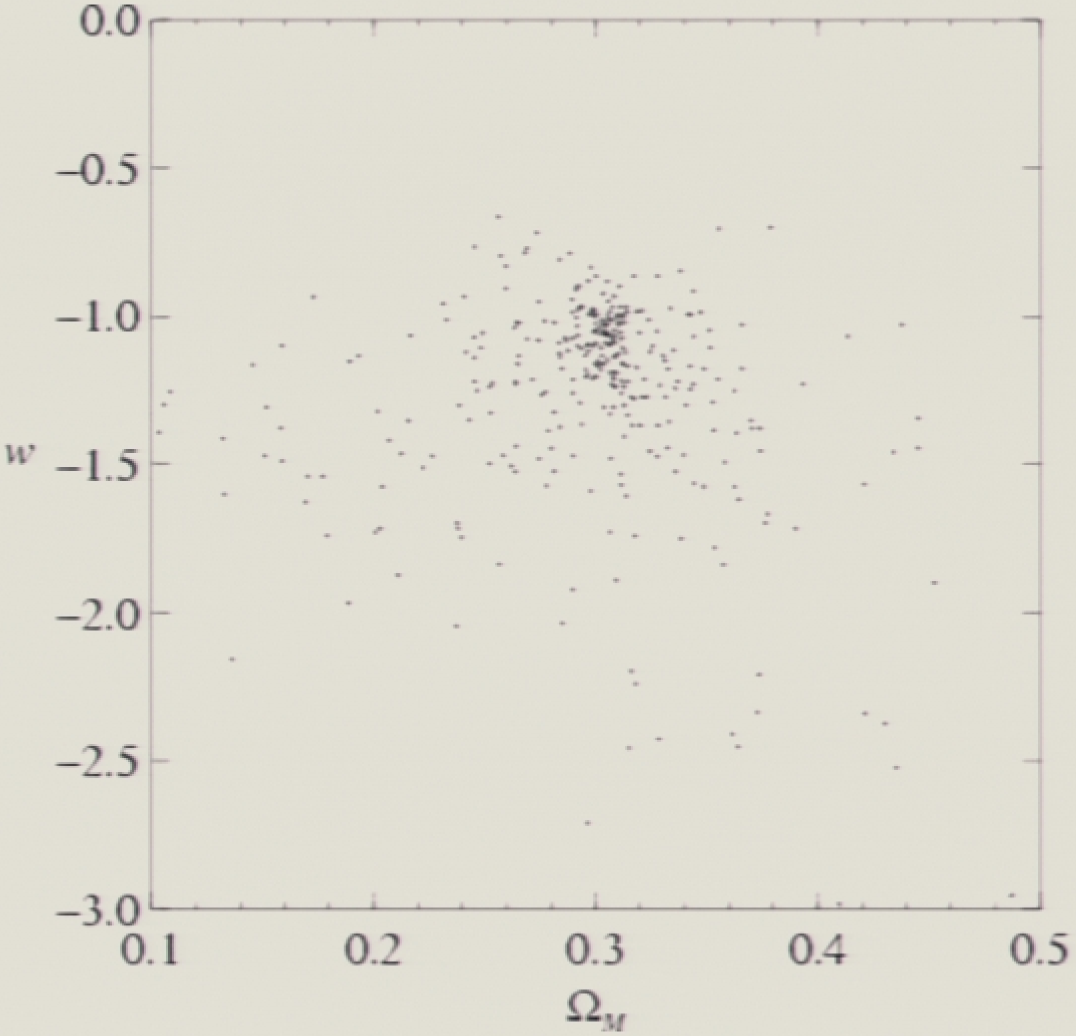


Number of arcs expected in 6000 deg^2



Precision cosmology with giant arcs

50 arcs per realization, including line-of-sight mass fluctuations

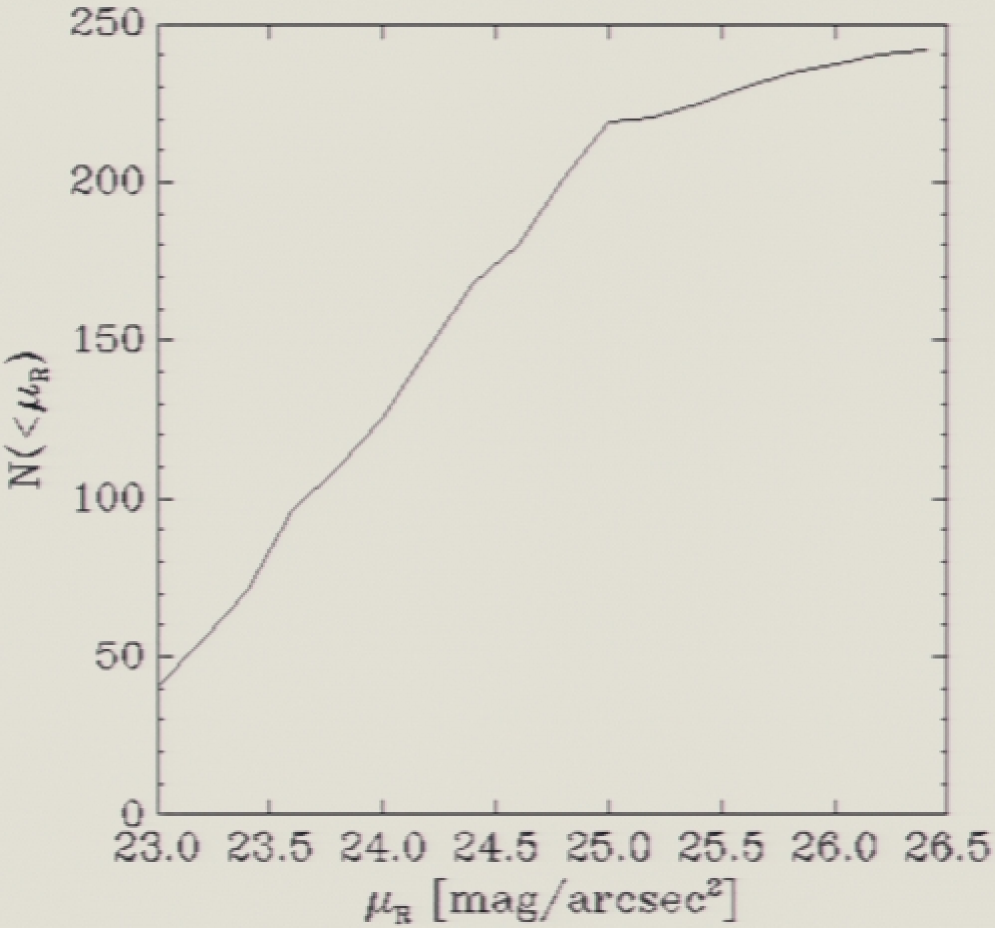


Physical cosmology Probes of Early & Late universe physics

z-surveys (Pat McDonald SDSS)

Lyman alpha forest & Galaxy Formation (McDonald SDSS forest)

Number of arcs expected in 6000 deg^2



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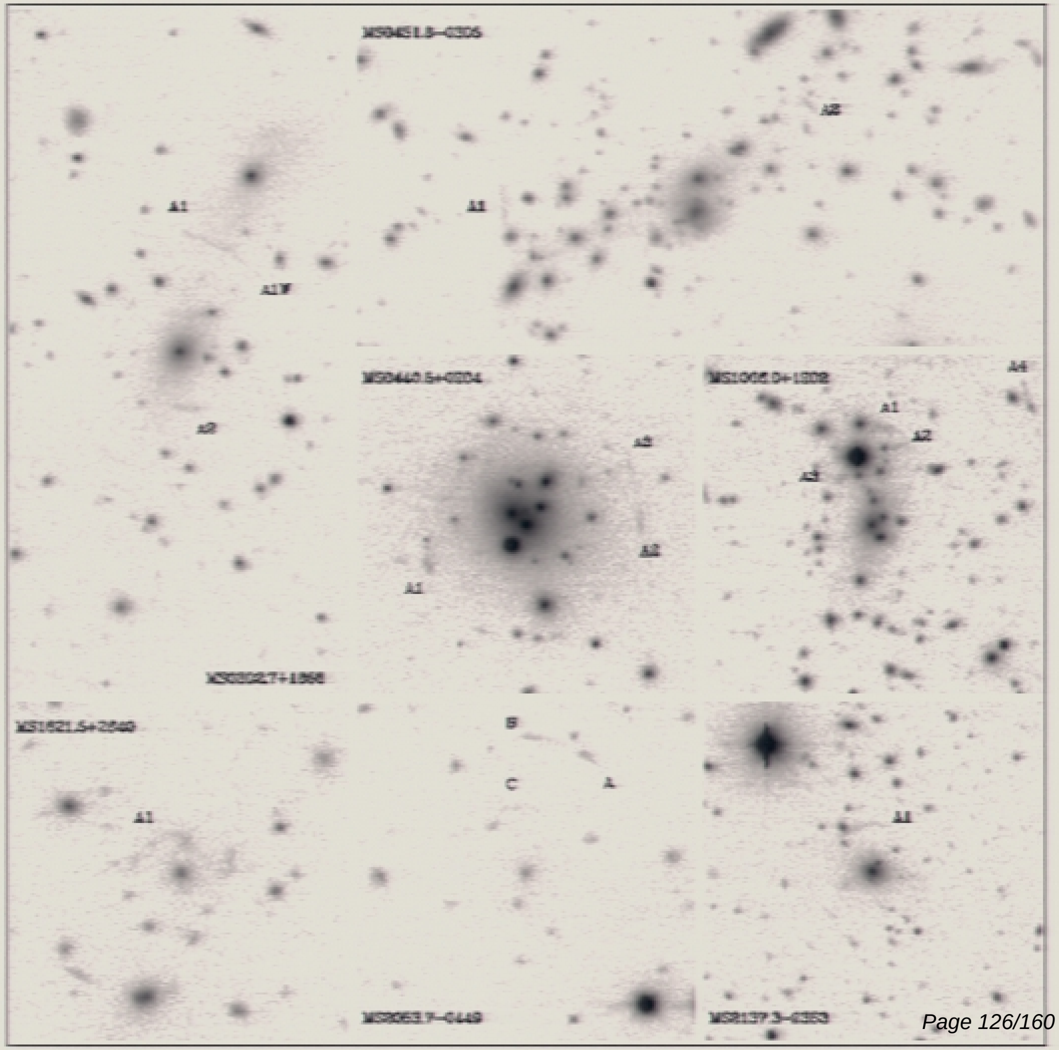
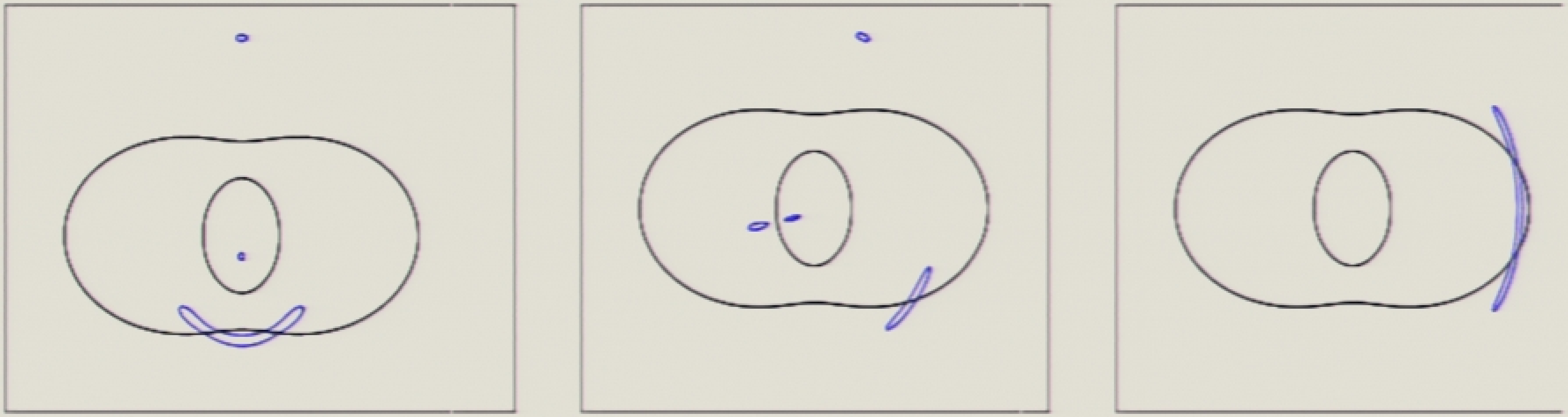
LCDCS (Zaritsky & Gonzalez 2002)
RCS (Gladders et al. 2003)

Ongoing:
MACS (Ebeling et al.),
RCS-2 (Gladders et al.)



Arcs & critical curves

Arcs generally occur on the critical lines:



Critical lines are where $1-\kappa-|\gamma|=0$, $1-\kappa+|\gamma|=0$. So it's easy to see how the critical lines behave as the lens properties are varied….

Aside : for spherical lens, $|\gamma| = \langle\kappa\rangle - \kappa$, so $1-\kappa-|\gamma| = 0 \Rightarrow \langle\kappa\rangle = 1$.

Detailed modeling of individual systems

Abell 1689
Broadhurst
et al. (2004)

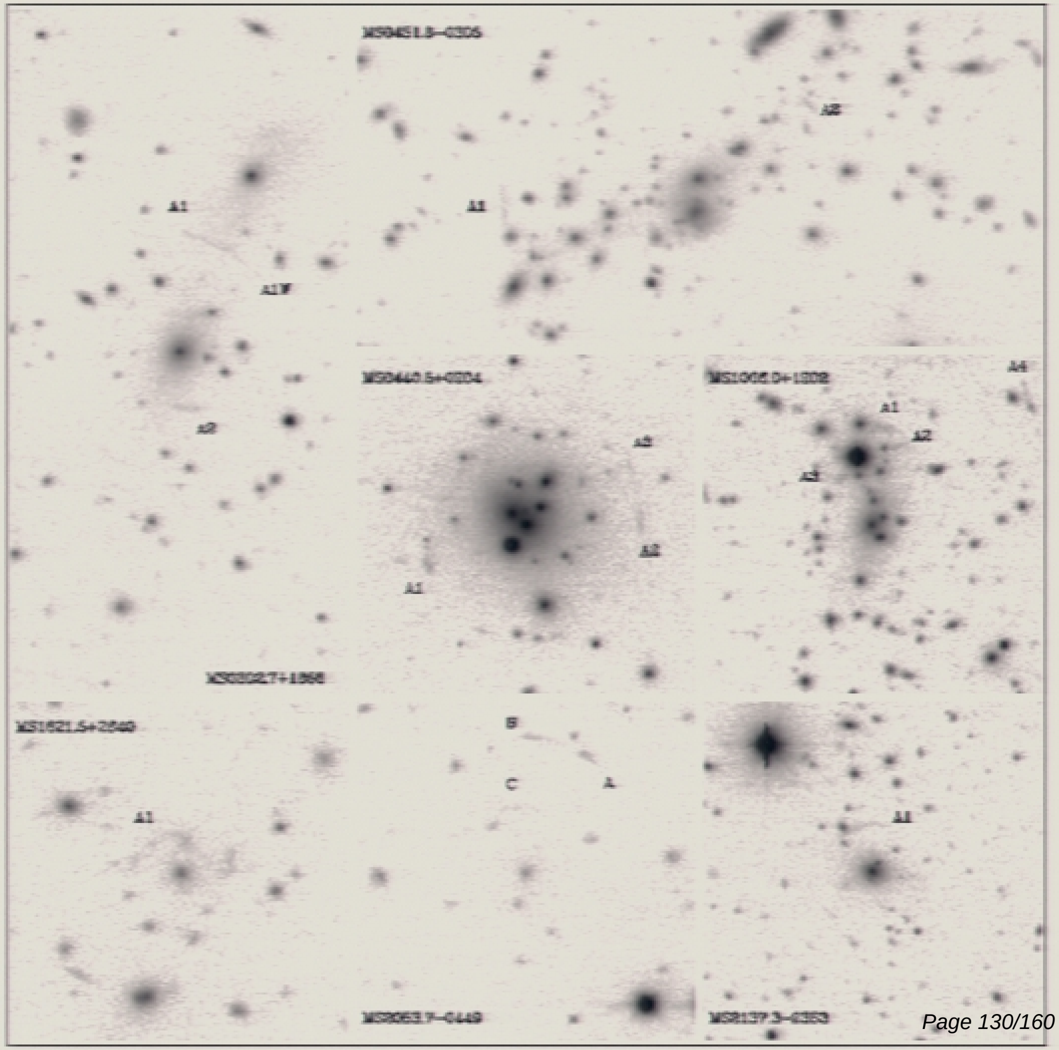
Physical cosmology Probes of Early & Late universe physics

z-surveys (Pat McDonald SDSS)

Lyman alpha forest & Galaxy Formation (McDonald SDSS forest)

Compare predictions with observations

To date, largest sample comes from EMSS (Le Fevre et al. 1994, Luppino et al. 1999).



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Physical cosmology Probes of Early & Late universe physics

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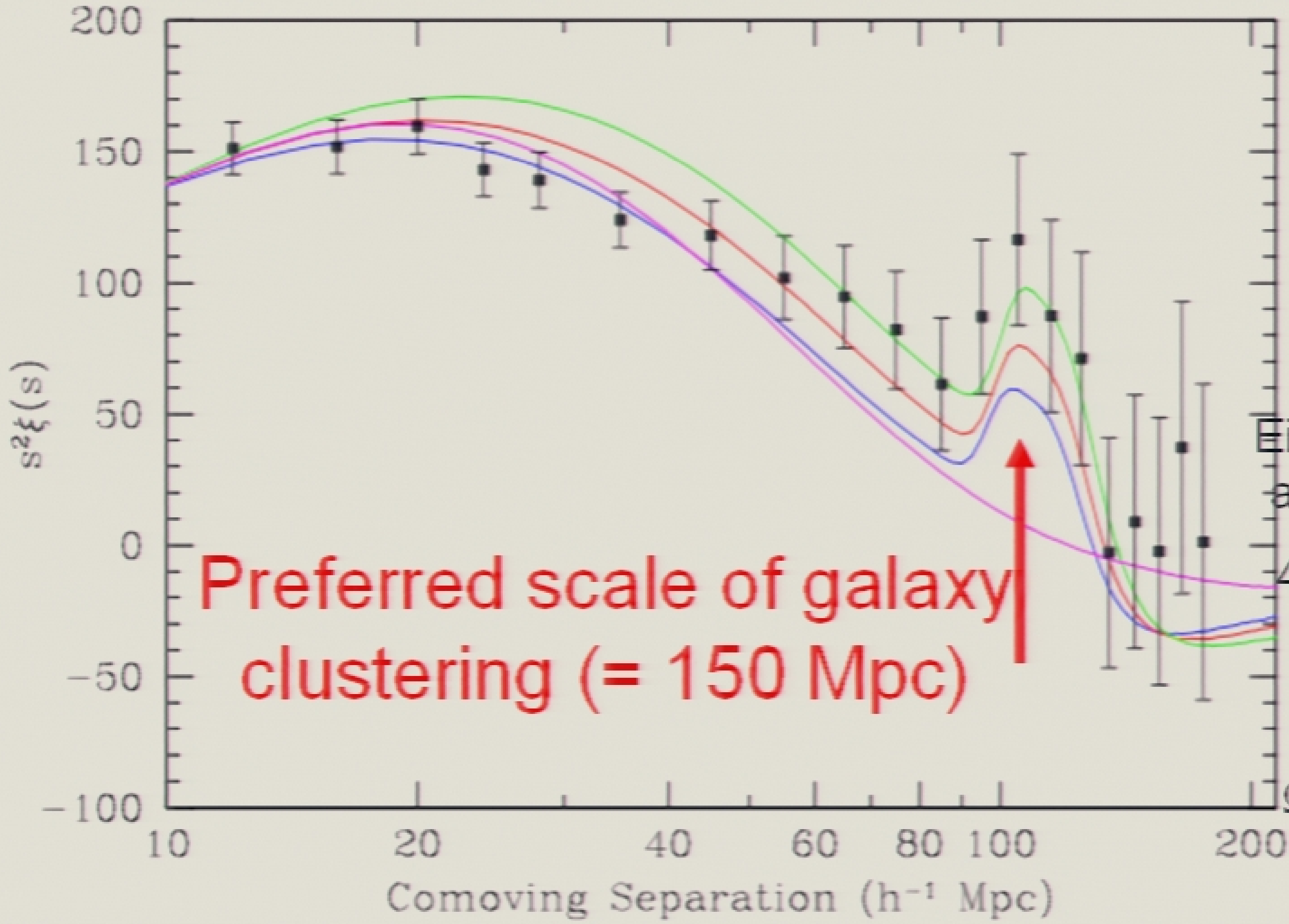
Baryon acoustic peaks in galaxy clustering: SDSS Luminous Red Galaxies to z~.35 (2dF to 0.1)



Preferred scale of galaxy clustering (= 150 Mpc)

Eisenstein etal
aph/0501171

47000 LRGs

Correlation function

Ωm OK with CMB

Galaxy Formation Developments Timeline

OBSERVATIONS

HST, Spitzer,
GALEX, XMM,
CHANDRA,..

SDSS

CFHTLS

SCUBA

2dFGRS

deep

RAVE

2003 **2005** **2007**

Photometric Surveys:
VISTA, UKIRT, VST, etc

Submillimeter:
SHADES, BLAST,
SCUBA2, ..

LOFAR

Spectroscopic
Surveys:
VIRMOS, KAOS,
FMOS, WFMOS, ..

TMT?
ELT?
OWL?
SKA?

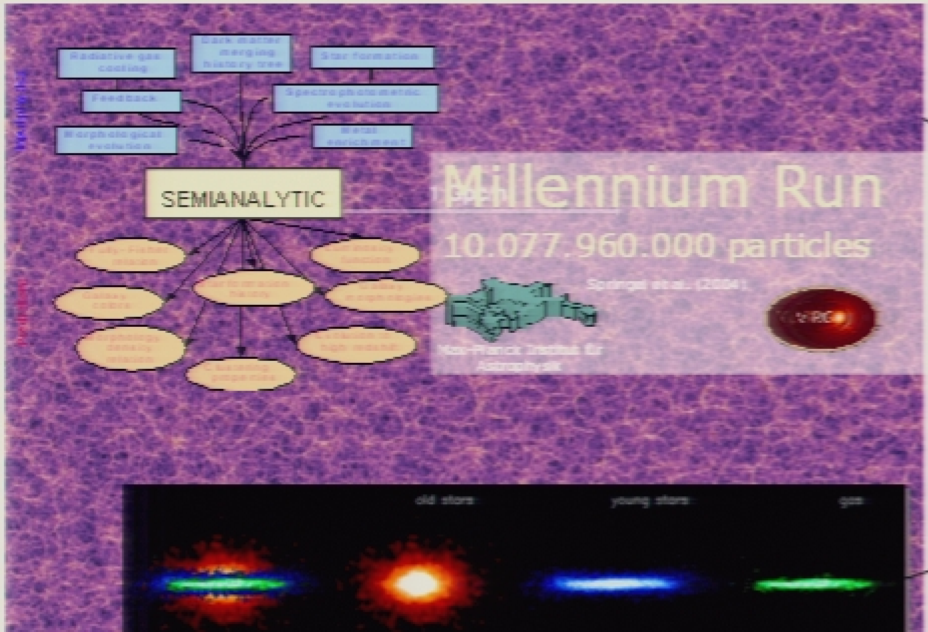
Gaia

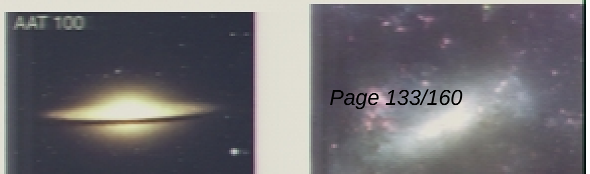
HERSCHEL

JWST

ALMA

THEORY





Last Updated: Wednesday, 12 January, 2005, 11:05 GMT

Sky surveys reveal cosmic ripples

By Jonathan Amos
BBC News science reporter

The unimaginably big of today has its explanation in the fantastically small of 13 billion years ago.

Astronomers have shown how the present pattern of galaxies in the cosmos grew from tiny fluctuations in the density of matter just after the Big Bang.

In one sense, this work essentially explains why we are here

The work draws on results from two scientific teams conducting sky surveys based in Australia and the US.

"It's an amazing new insight into how the Universe works," said Prof Carlos Frenk, of the University of Durham, UK.

"These are two teams separated by many thousands of miles that are completely independent - they have one member in common - and they have both, using different techniques and different data, arrived at the same conclusion," he told the BBC News website.

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Observational possibilities

Observational possibilities

- Next generation of wide-field optical spectrographs on large telescopes (IMACS, FMOS, KAOS)

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- Radio surveys of HI-emission galaxies with the SKA (or its prototype)

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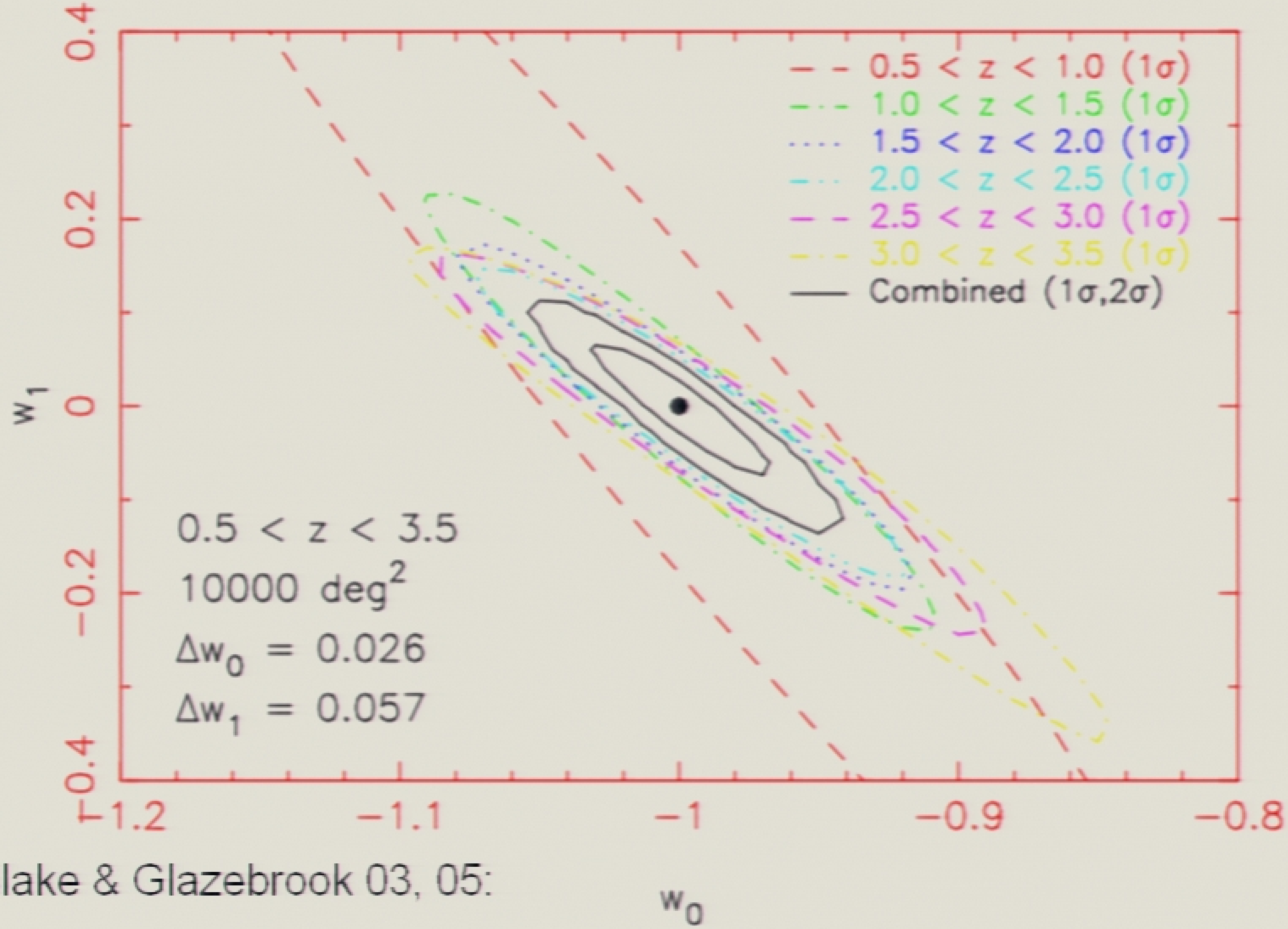
- Space-based slitless grism survey of emission-line galaxies

Forecast: large deep surveys using acoustic peak tomography



Blake & Glazebrook 03, 05:

Physical cosmology Probes of Early & Late universe physics

21(1+z) cm (Ilian Iliev)

Gastrophysical parameters τ_C

Radio Astrophysics

SKA

LOFAR

2005 2010 2015

Green Bank Telescope

GMRT, India

CBI, VSA, AMI

Reionization: Simulations and Observational Signatures

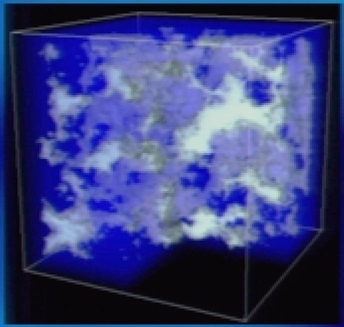
Ilian T. Iliev

CITA

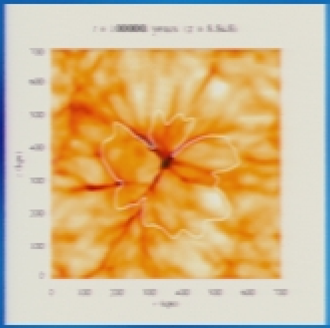
with Garrelt Mellema (ASTRON),

P. Shapiro, M. Alvarez (Austin), U.-L. Pen, H. Merz (CITA)

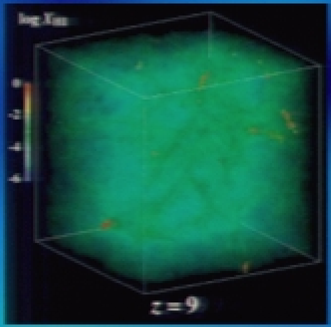
Cosmological radiative transfer codes



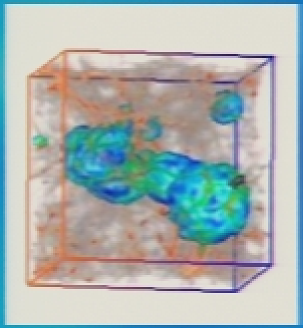
SimpleX (Ritzerveld)



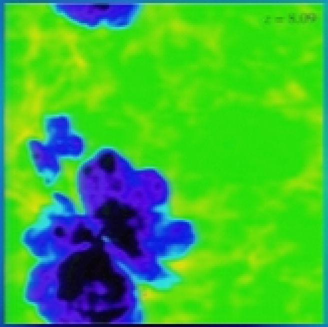
C²-Ray (Mellema, Iliev)



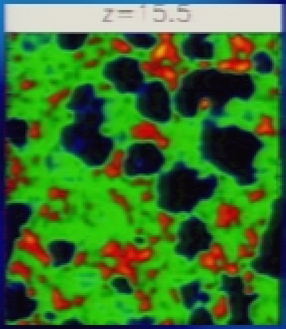
Nakamoto, Umemura, Susa (2001)



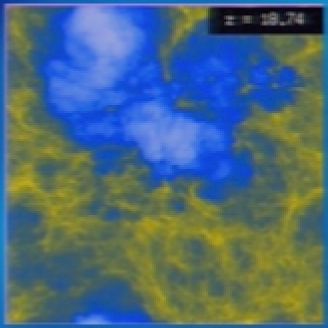
OTVET (Gnedin)



Razoumov et al. 2002



Crash (Ciardi, Masseli)



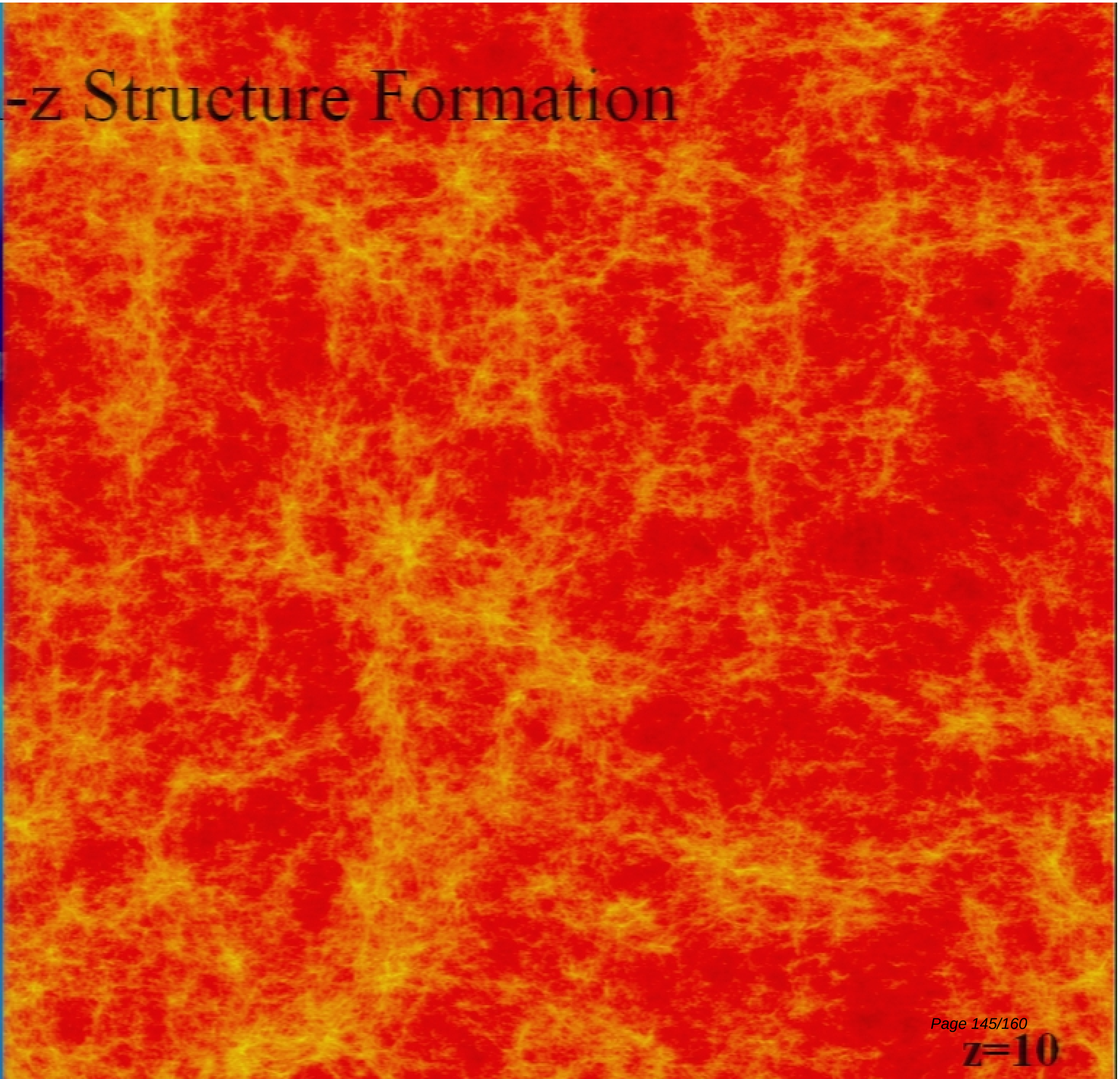
Sokasian et al. 2002

Requirements for Simulations of Reionization

- Detailed knowledge of structures forming at high-z:
  - number and distribution of sources – down to dwarf galaxies of ~$10^8 M_{solar}$
  - density fluctuations (photon sinks) – self-shielded (MH) or not.
- Large computational boxes – due to strong bias HII regions are large; and degree scale on the sky and multiple MHz in bandwidth for observational predictions
- Physical models for the ionizing sources (photon production, star-formation efficiencies, escape fractions)
- Precise, high-resolution radiative transfer

High-z Structure Formation

- Very high resolution N-body simulations of structure formation using PMFAST code developed at CITA (Merz, Pen & Trac 2004)
- 100/h Mpc box 1624^3 particles (4.3 billion), 3248^3 cells. Up to 1.3 million halos (at z=3) (with >100 particles/halo $=2.5\times10^9\ M_{solar}$

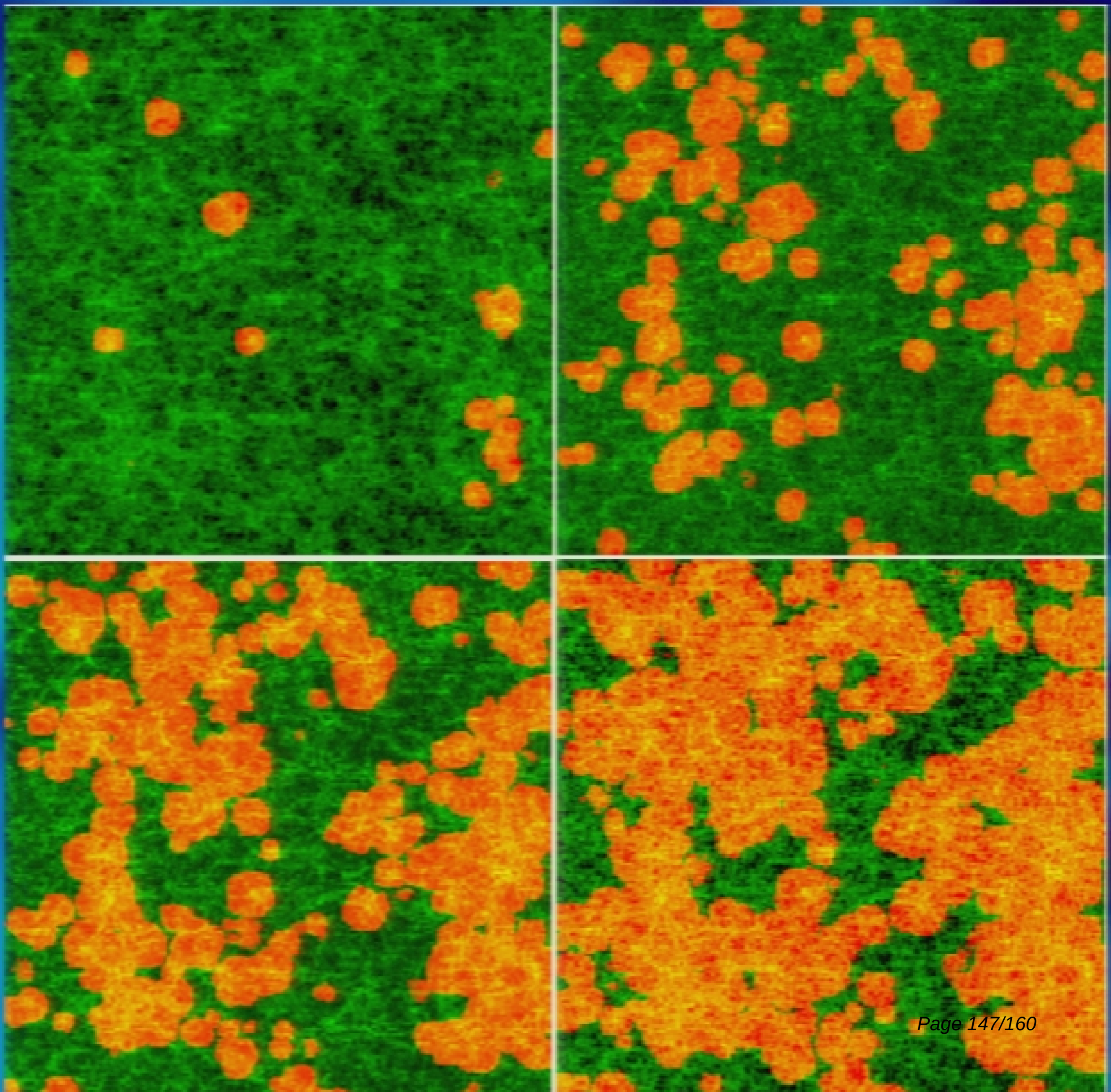


Reionization Calculation

- We postprocess this volume (regridded to 203^3, 406^3 and 812^3) with our radiative transfer code C^2-Ray.
- 100 time-slices of density and corresponding halo list (10-20 Myr between slices).
- Sources are all resolved halos. M/L=const, fixed (2000,250) photons/atom escaping (Iliev, Scannapieco & Shapiro 2005).
- Sub-grid gas clumping is also included.

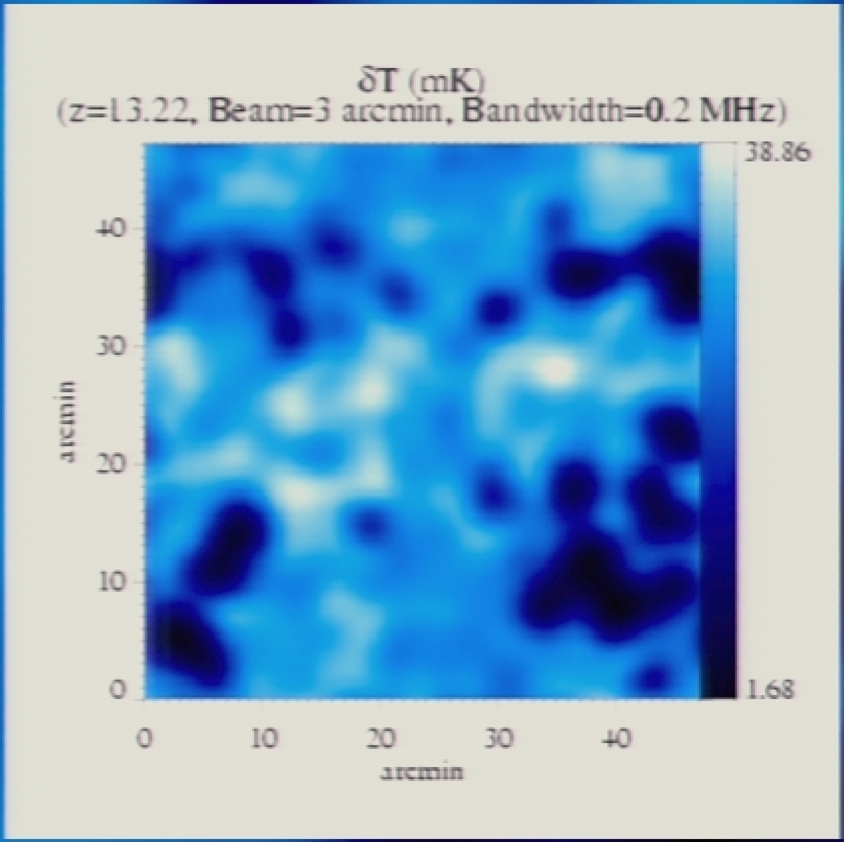
Topology of Reionization: HII Region Evolution

- Evolution from z=21 to 11.
- HII regions of individual sources and groups start overlapping.
- The topology of the ionized / neutral regions is complex.
- At z=11 nearly the whole box is ionized (52,000 sources).



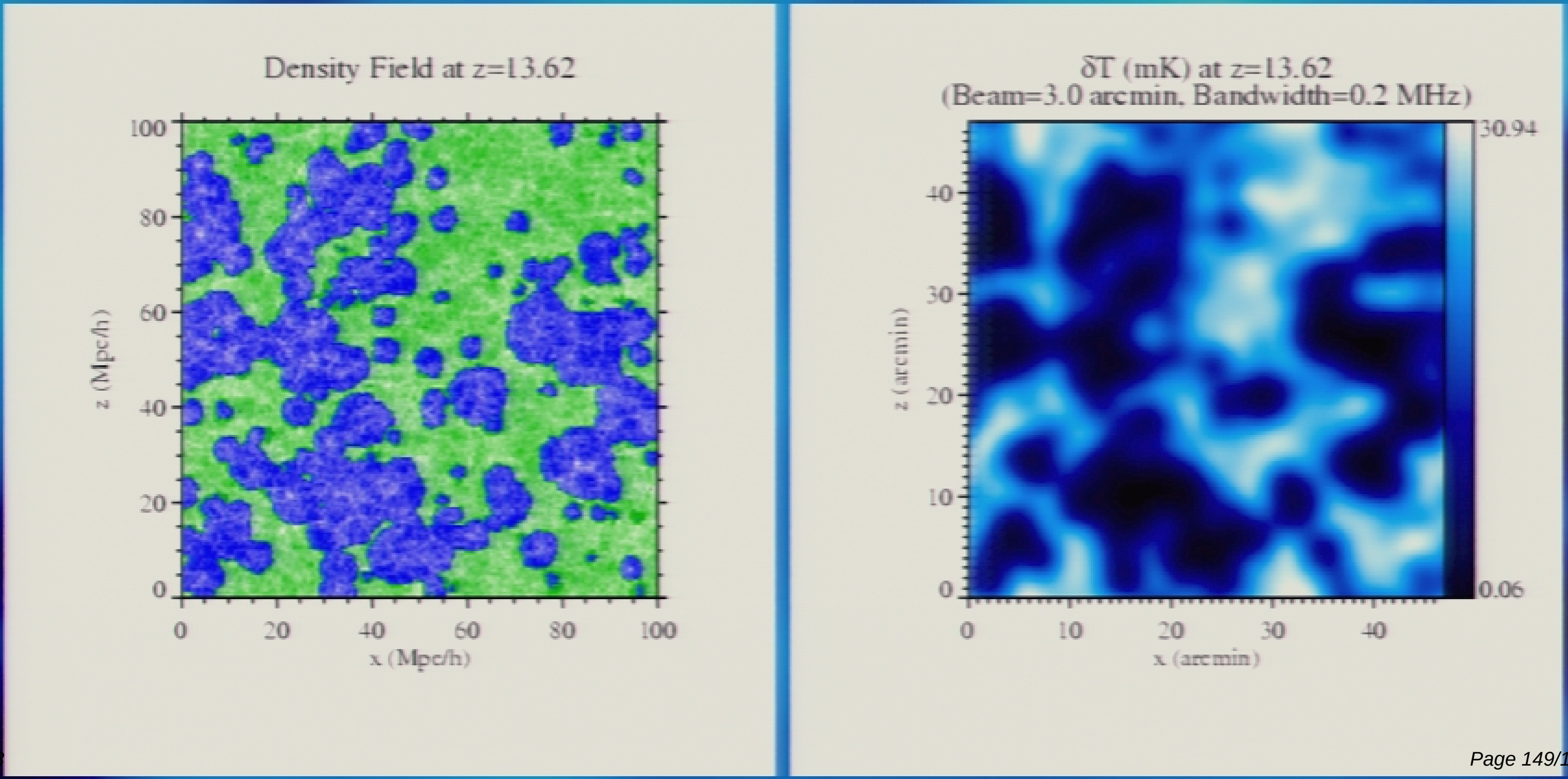
Predictions for 21-cm Observations

- The large box and high resolution allow for the first detailed predictions of the 21-cm reionization signal for LOFAR, PAST, or SKA.
- Currently we assume Ly-α- pumped IGM and $T_S >> T_{CMB}$.

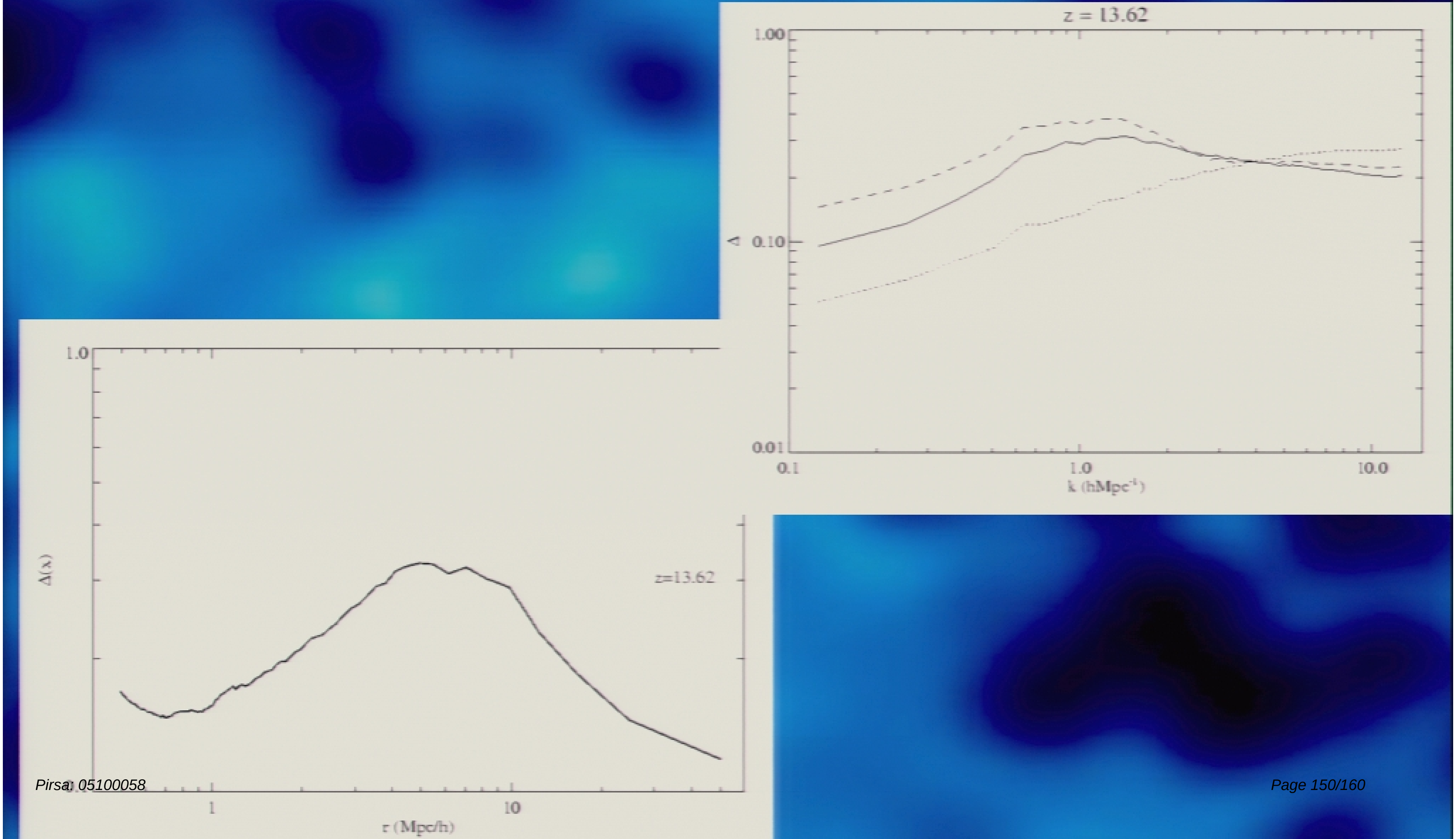


EOR Topology seen in radio

Z=13.6

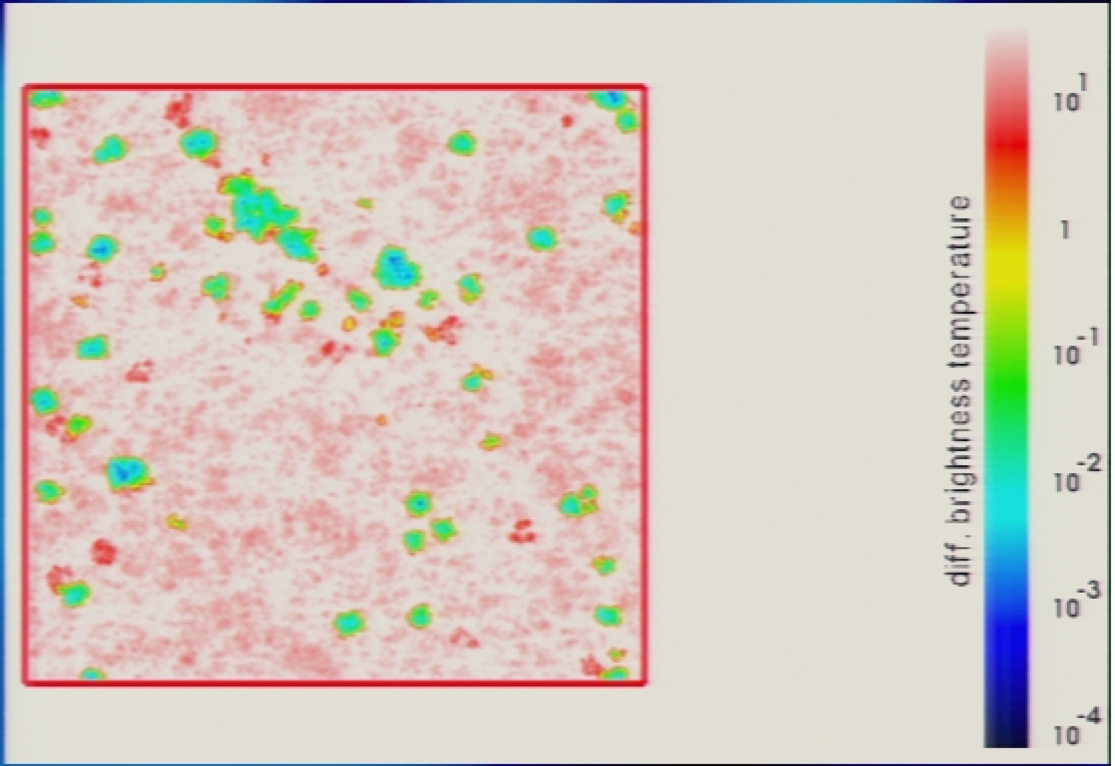


Density Power Spectrum and size distribution of H II regions



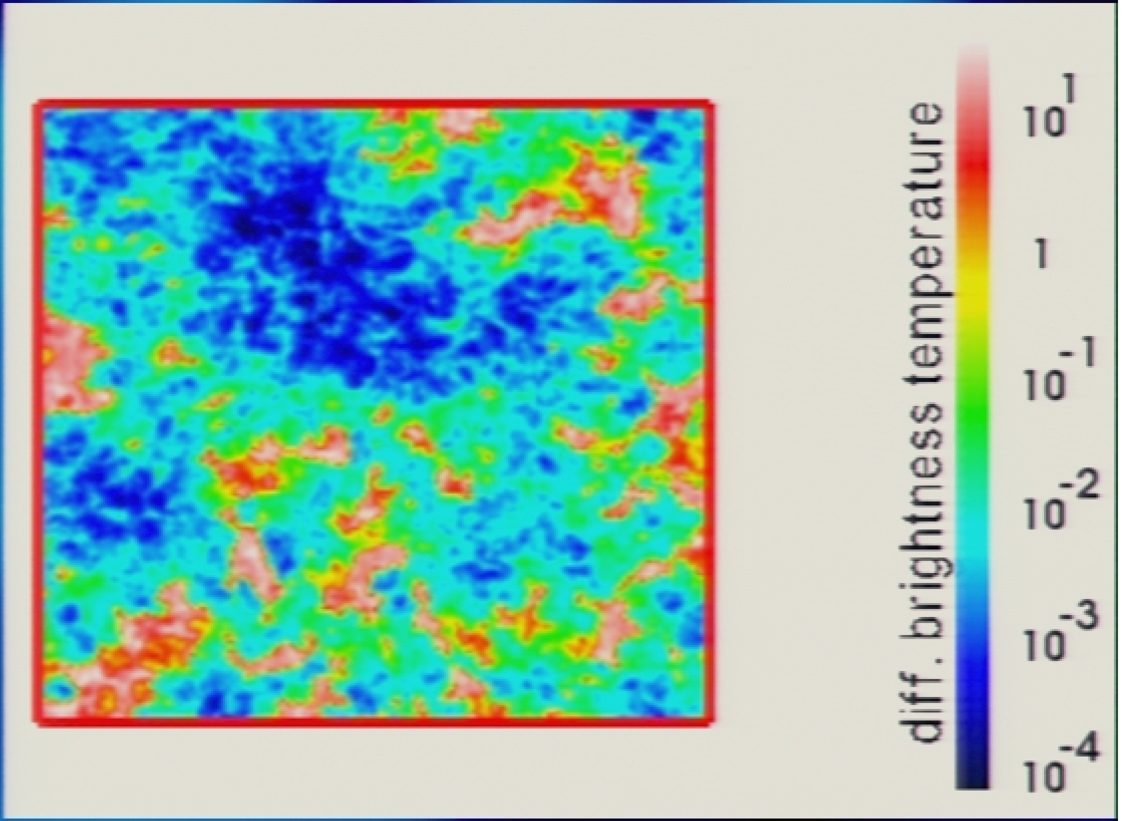
The future: 21-cm at very high-z: seeing the Pop. III

- 406^3 radiative transfer grid, largest ever
- High-resolution map at z=18
- 35/h Mpc box
- small ionizing sources (down to 10^8 M_{solar}), HII regions of a few Mpc, or ~1', possibly could be seen by SKA?



21-cm at high-z: Pop. III to Pop. II transition and small-source suppression

- 203^3 grid map at z=12
- HII regions grow bigger, up to few arcmin
- many “relic” HII regions form (green) due to suppression of small Pop. III source and take-over of reionization by larger, less efficient Pop. II sources



Looking Ahead

- **Complications in EoR simulations:**
  - small-scale structure (gas clumping, minihaloes)
  - Ionizing source types, photon production and star-formation efficiencies, escape fractions => run many models to allow robust predictions.
  - Transition from top-heavy to normal IMF?
  - heating by X-ray background, Ly-α.
- **Code development – additional physics:**
  - direct coupling to N-body (in addition to the gas-dynamics).
  - Helium (He^0, He^+, He^{2+}) photo-ionization.
  - metals ionization and cooling (C, N, O, Ne, S)
  - Secondary ionizations ($h\nu > 25$ eV).
  - Molecular hydrogen.

Physical cosmology Probes of Early & Late universe physics

SN (Goobar, Linder)

CBI ongoing to Sept'05+

Acbar ongoing to Sept'06+

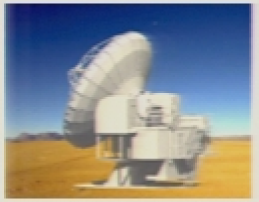
Bicep

QUaD

Quiet1

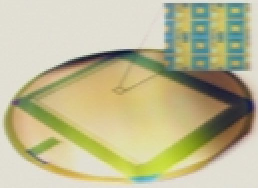
Quiet2
(1000 HEMTs)
Chile

APEX
(~400 bolometers)
Chile



SZA
(Interferometer)
California

SCUBA2
(12000 bolometers)
JCMT, Hawaii



Spider
(1856 bolometer LDB)

ACT
(3000 bolometers)
Chile

Clover

2017
CMBpol

Boom03

2003 2004 2005 2006 2007 2008

WMAP ongoing to 2007+

DASI

CAPMAP

AMI

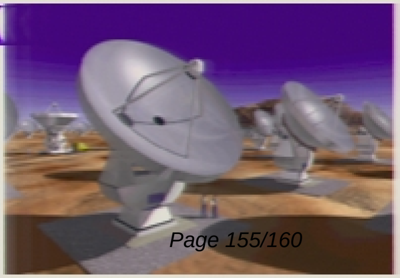
GBT

Polarbear
(300 bolometers)
California

SPT
(1000 bolometers)
South Pole

Planck
(84 bolometers)
HEMTs L2

ALMA
(Interferometer)
Chile

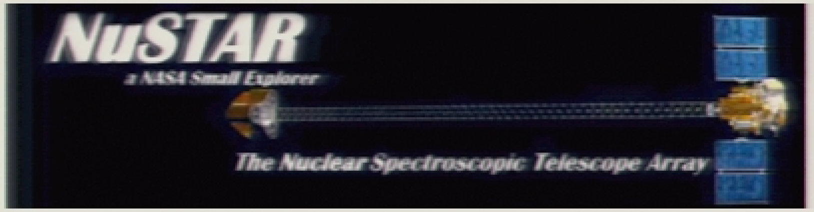


High Energy Astrophysics

Chandra

HETE2

Agile

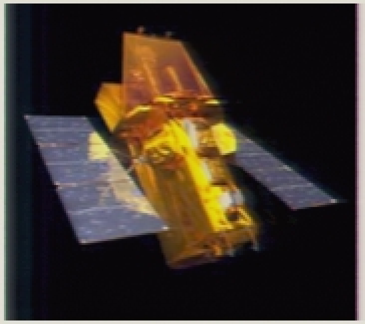


NuSTAR

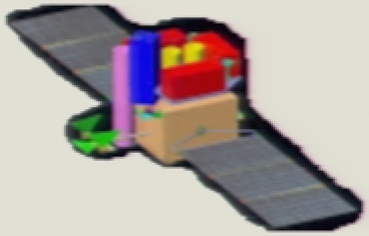
2005

2010

XMM-Newton



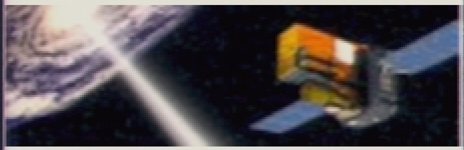
SWIFT



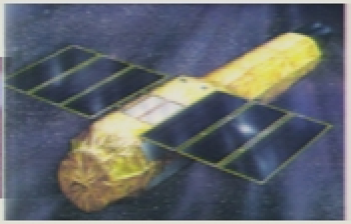
Astrosat

Constellation X

RXTE

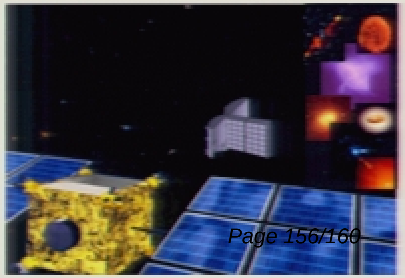


Integral



ASTROE2

GLAST



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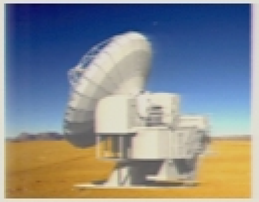

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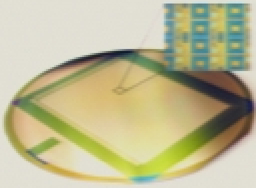
JCMT, Hawaii



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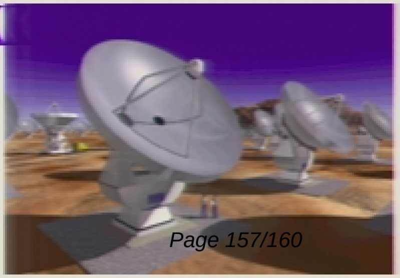
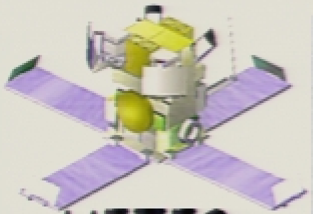


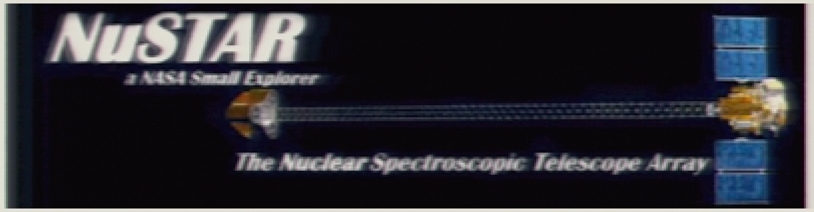
High Energy Astrophysics

Chandra



HETE2

Agile



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2005

2010

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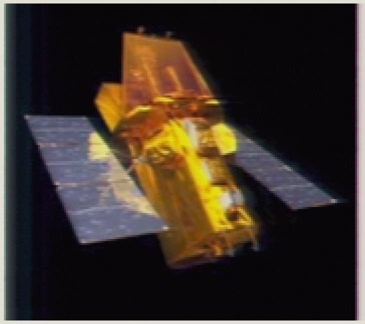
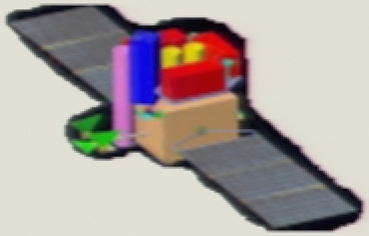


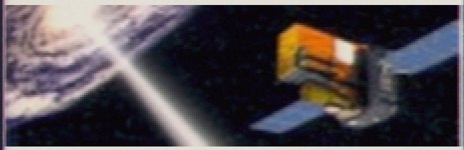
SWIFT



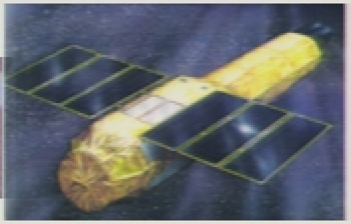
Astrosat

Constellation X

RXTE

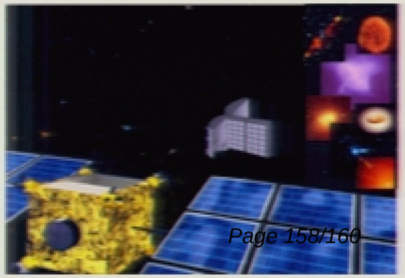


Integral



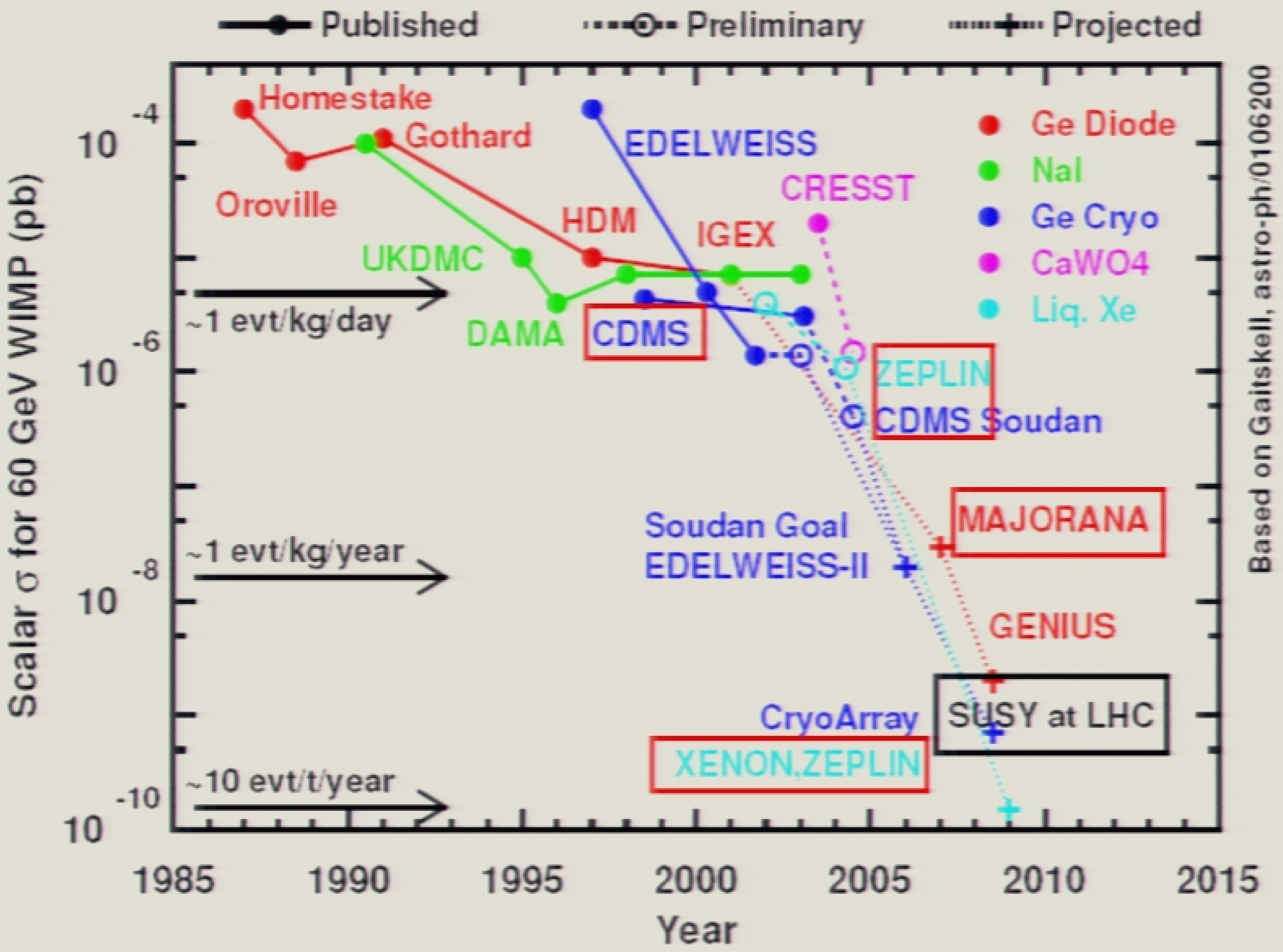
ASTROE2

GLAST



XEUS

Evolution of Direct Searches



Dick Bond

CMB+LSS Probes, Now & Then, & Inflation, Then & Now

Parameters are the goal, **Information Compression,** but of all sorts.

Fundamental parameters:

Early Universe – Acceleration Histories & the Inflation Landscape;

Late Universe – acceleration histories and Λ, w(ln a) phenomenology (quintessence etal)