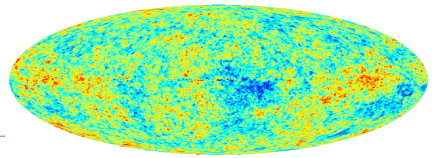
CITA ICAT Canadian Institute for Theoretical Astrophysics / L'institut canadien d'astrophysique theorique



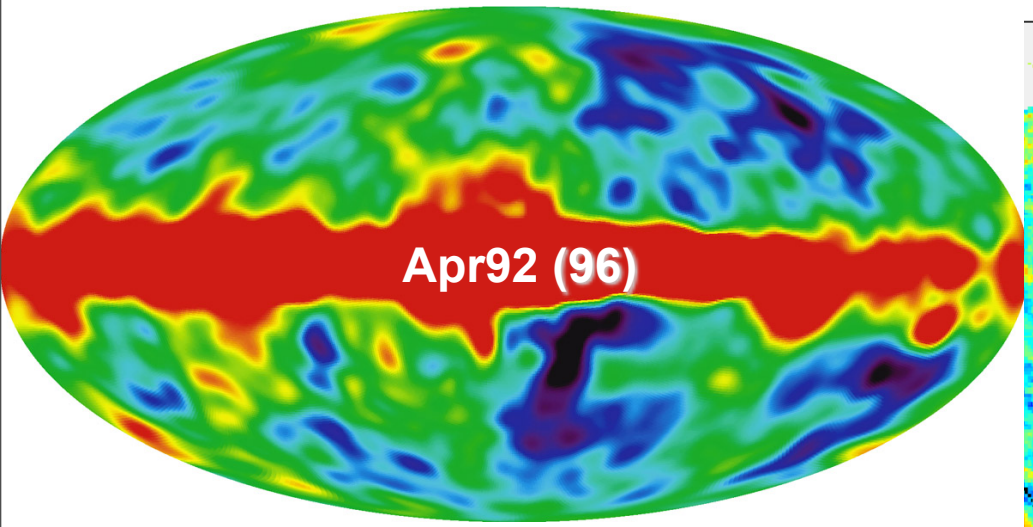
CIAR 25 years cifar

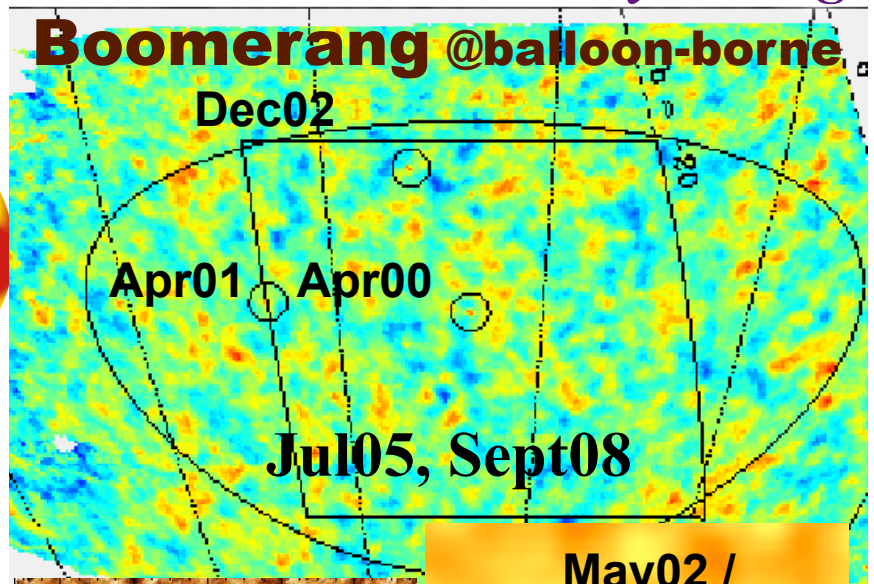
the Cosmology of now & then through first light

Dick Bond Canadian Institute for Theoretical Astrophysics, University of Toronto

COBE Nobel+Gruber 2006

13.65 -0.00038 billion years ago





Cosmic history: what is U made of?

How Structure in the Universe Arose:

Inflation & the Cosmic Web

CMB & *x*CDM, $x=\Lambda+tilt$,

status@Sept08

is there a y to x?@Sept11

Dec02, Oct06, Jan08, Sept08

May02 / Feb04

Sept04/05/08

CBI: Cosmic Background Imager

Atacama,Chile @5040m

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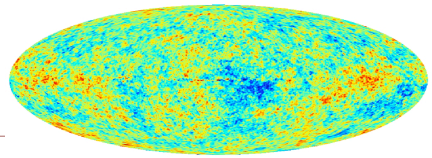
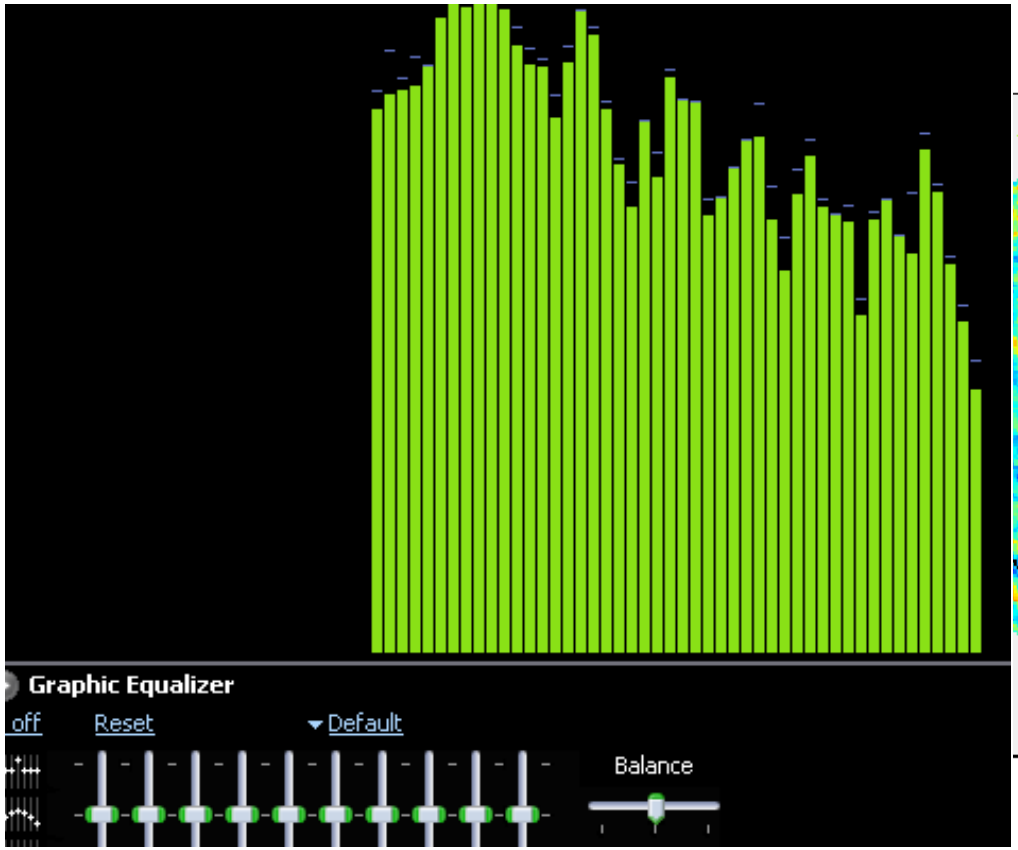
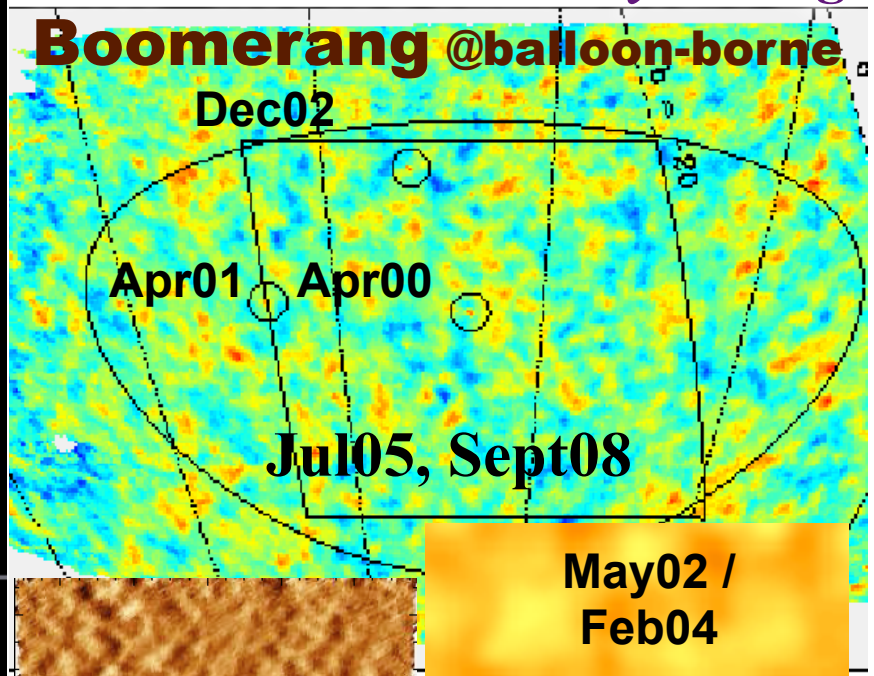


CIAR 25 years cifar



13.65 -0.00038 billion years ago



Dec02, Oct06, Jan08, Sept08

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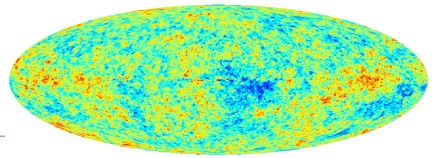

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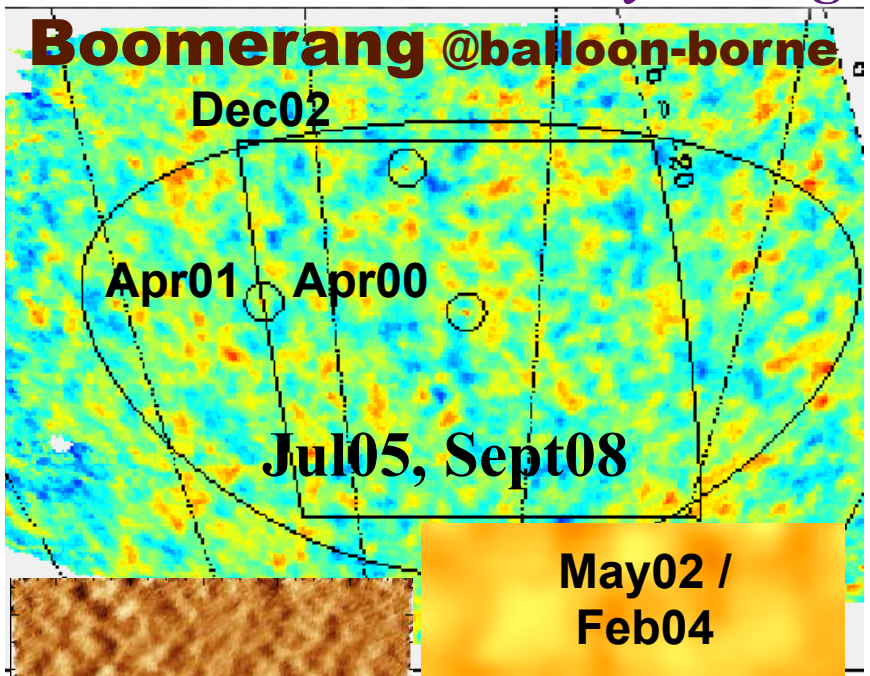

Dec02,
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Jan08,
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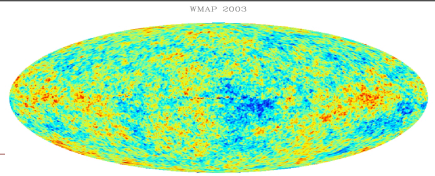
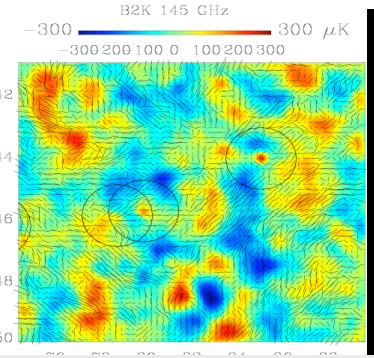
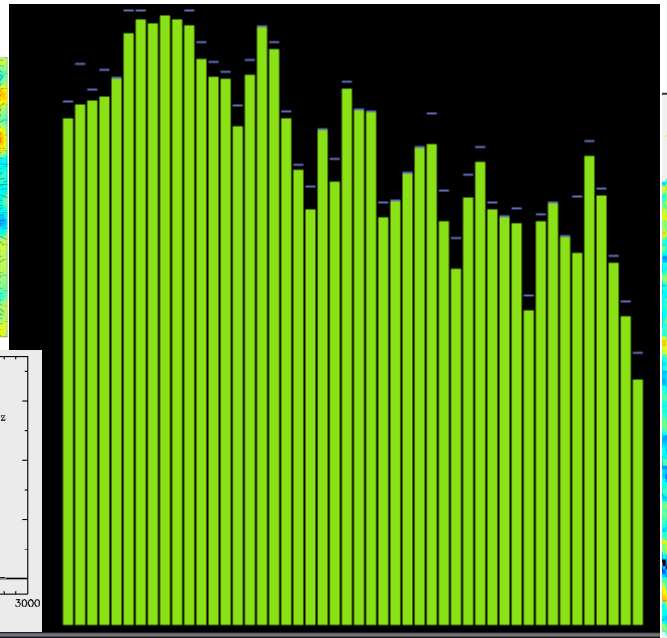
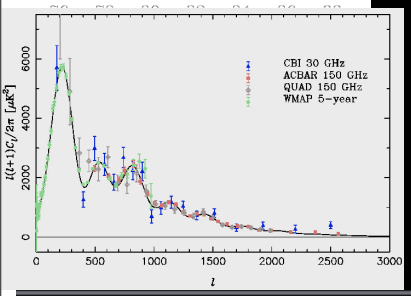


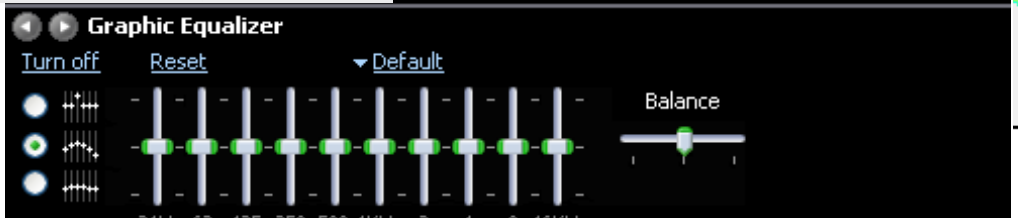
CIAR 25 years cifar

Boom05 deep









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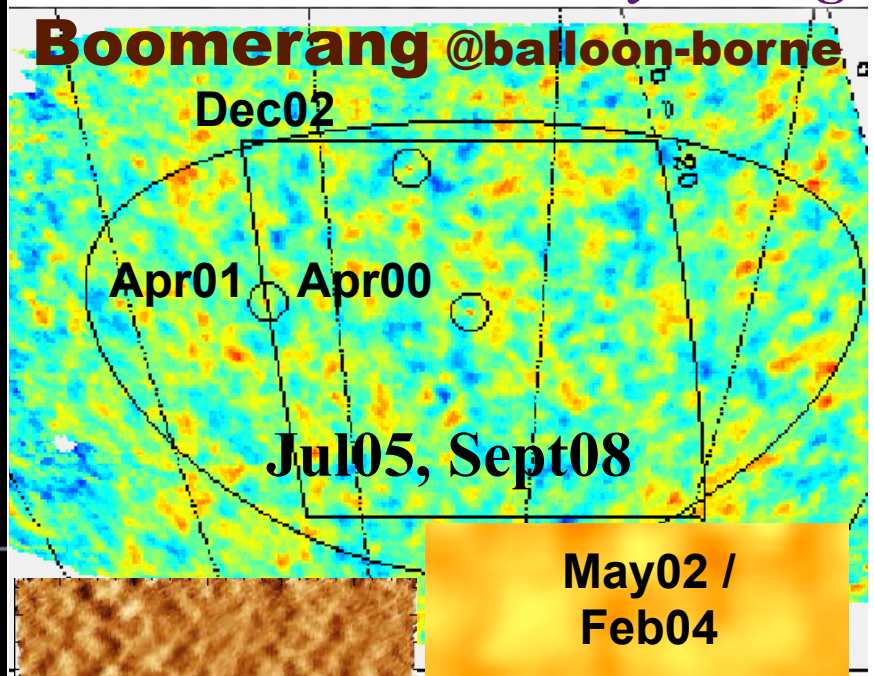

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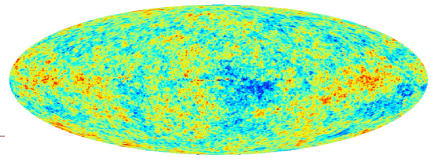
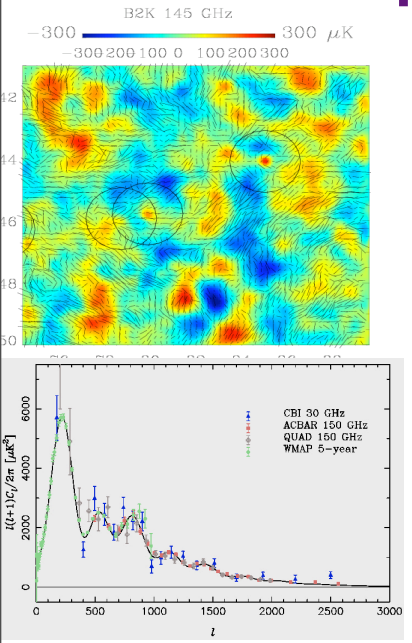


CIAR 25 years cifar

Boom05 deep



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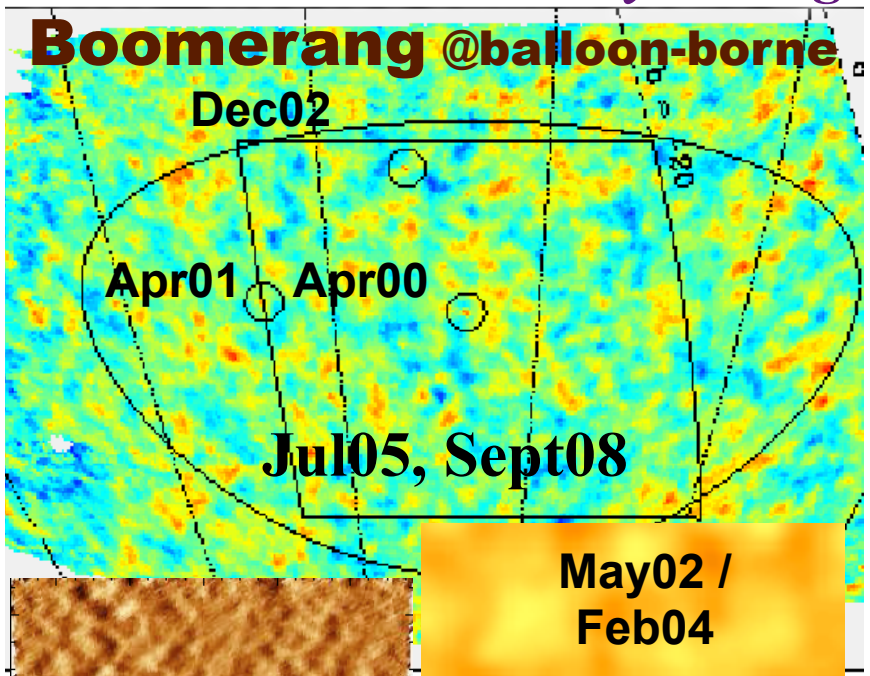

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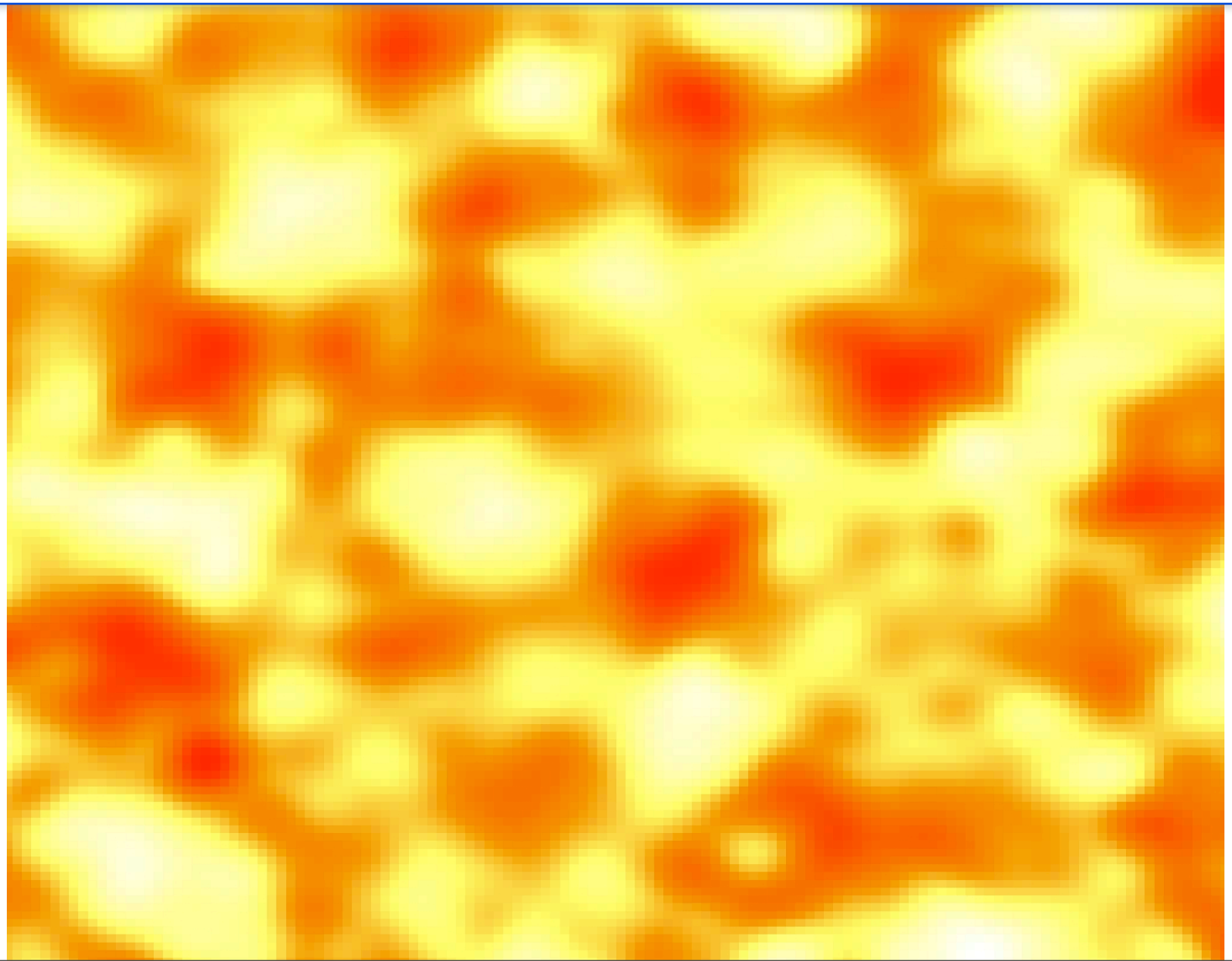
nonlinear Gas & Dark Matter Structure in the Cosmic Web the cluster/gp web “now”, the galaxy/dwarf system “then”



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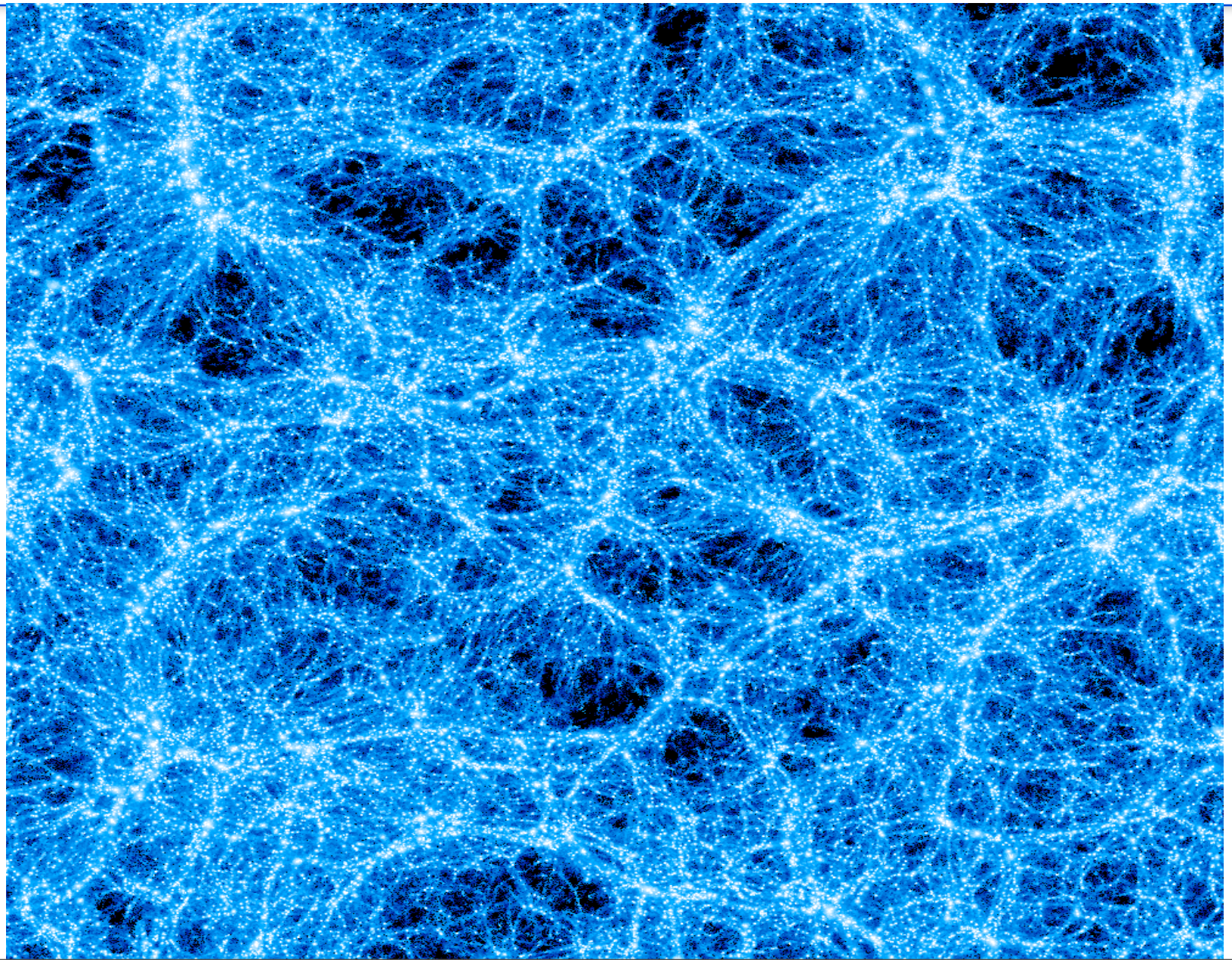

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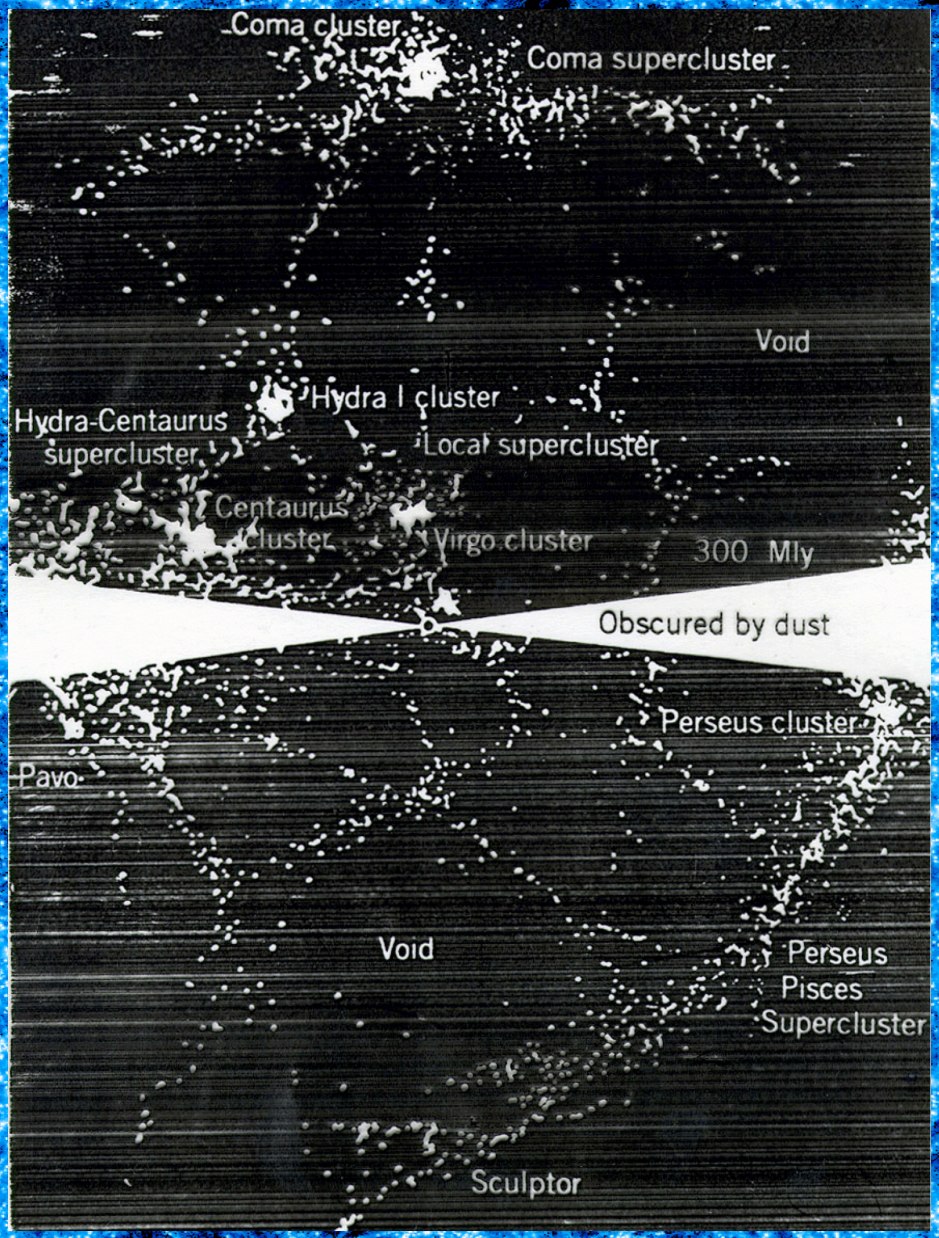
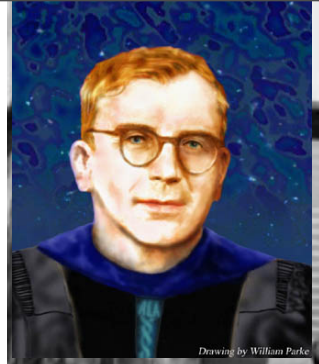
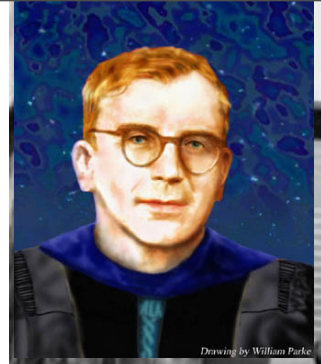




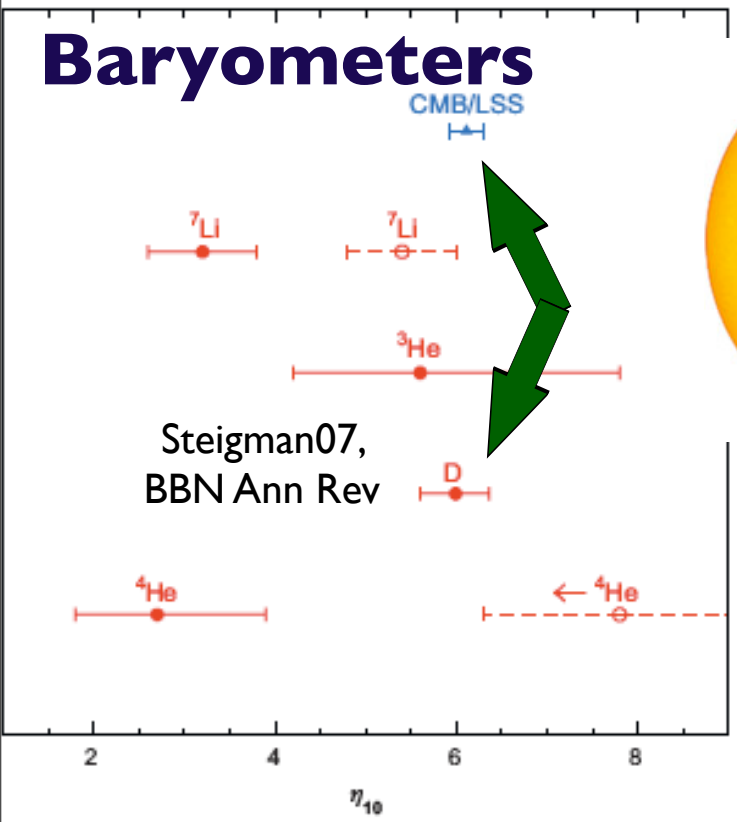
IOTA 1967, Cambridge

B^2FH 57, WFH 67, sn

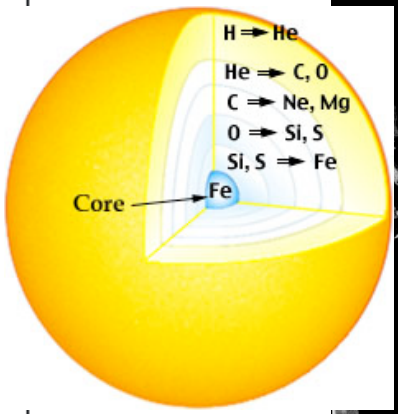


IOTA 1967, Cambridge B^2FH 57, WFH 67, sn

Baryometers



Steigman07, BBN Ann Rev



Nobel Prize 84 Willy Fowler + Chandra -sekhar

$$\eta_{10} \equiv 10^{10}(n_{\rm B}/n_\gamma) \equiv 274\ \Omega_{\rm B}h^2$$

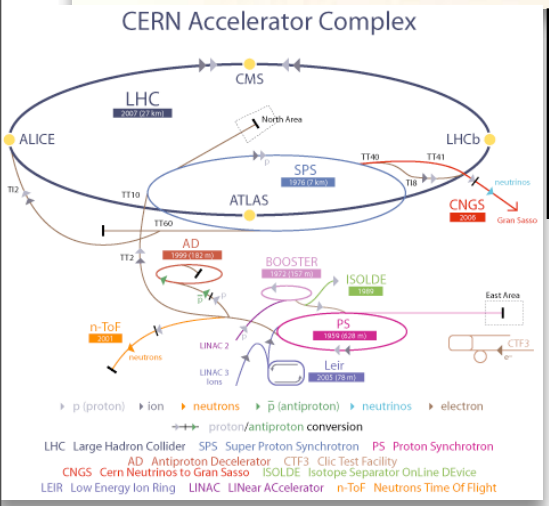
	January 2000	January 2002	June 2002	January 2003	March 2003
$\Omega_{\rm b}h^2$	$0.0339^{+0.0443}_{-0.0246}$	$0.0222^{+0.0025}_{-0.0021}$	$0.0221^{+0.0024}_{-0.0020}$	$0.0221^{+0.0023}_{-0.0018}$	$0.0233^{+0.0013}_{-0.0013}$

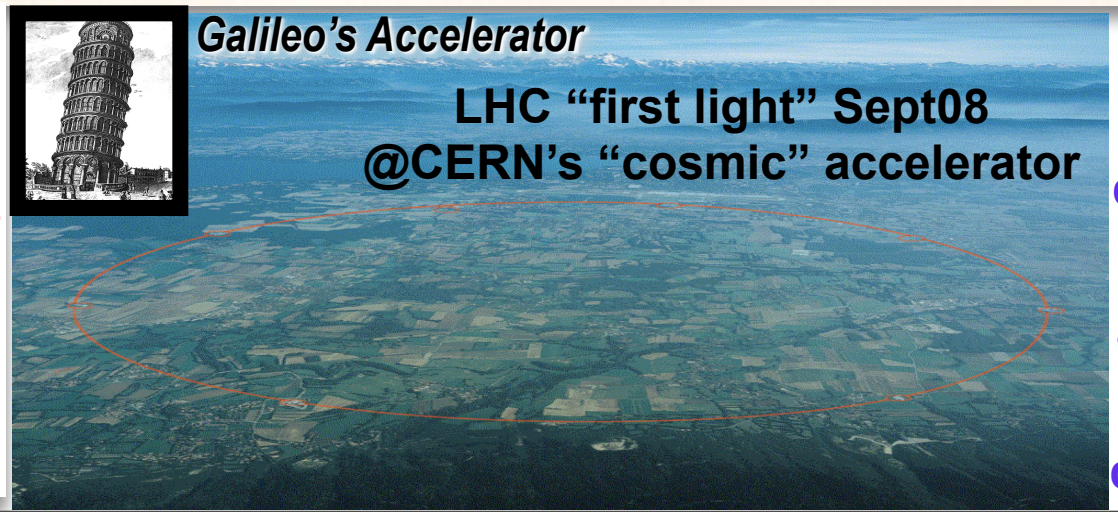
0.0223 ± 0.0007

0.0226 +- 0.0006 wmap3+acbar+cbi+... LSS

0.0233 +- 0.0005 wmap5+acbar+cbi+b03+.+WL+LSS+SN1+Lya

extra-“ordinary” matter



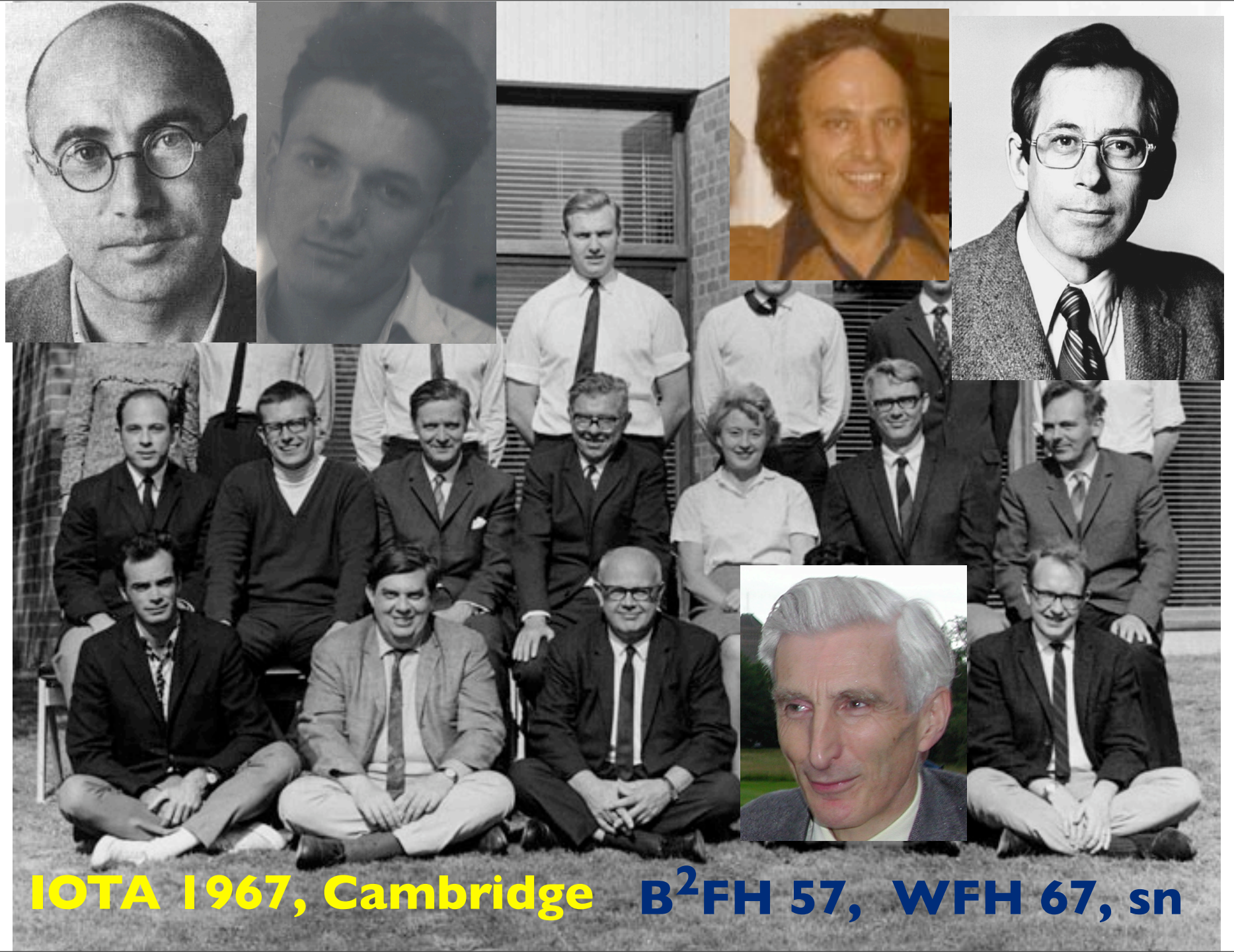


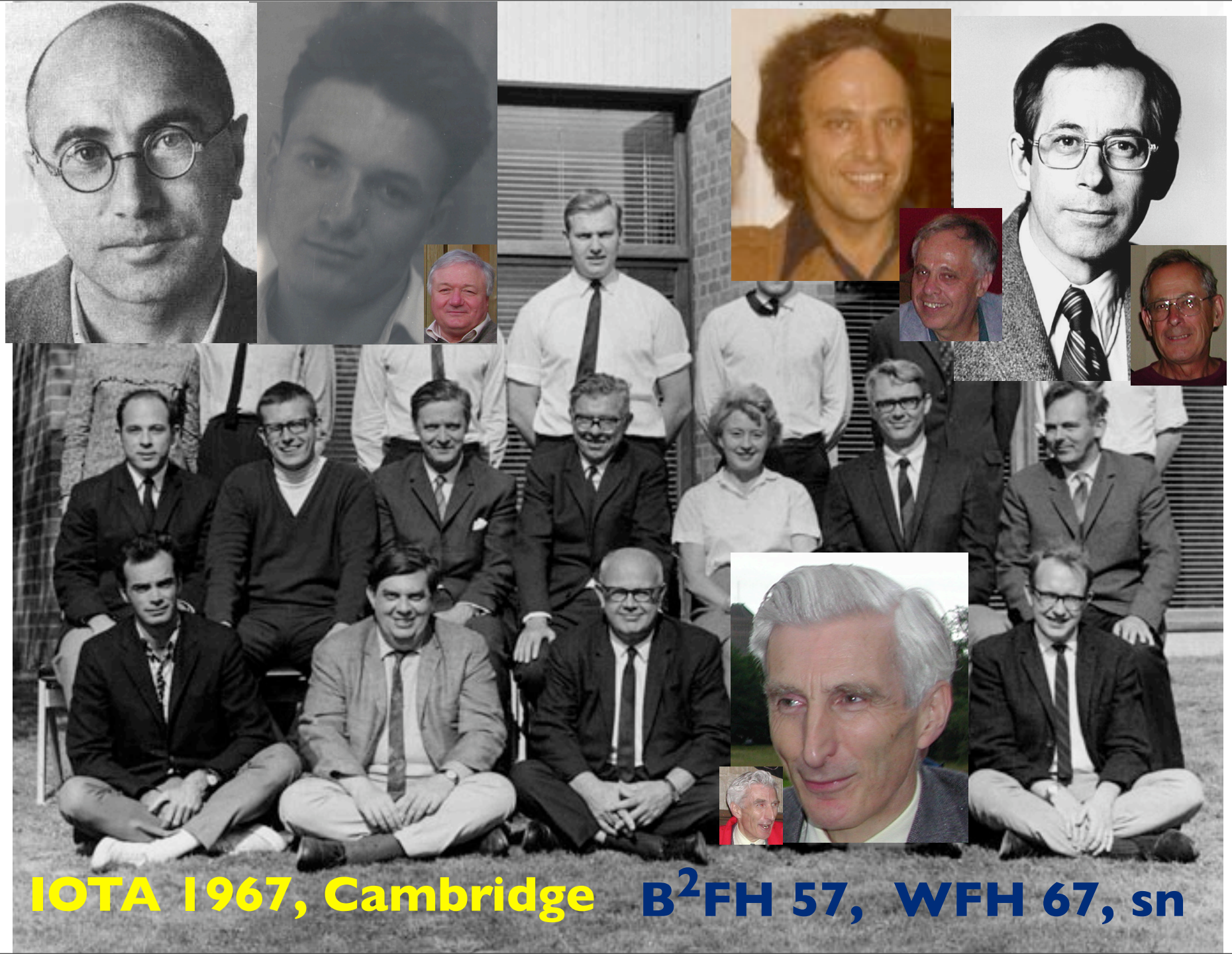
what is mass?

dark matter

antimatter asymmetry

extra dimensions


IOTA 1967, Cambridge
B2FH 57, WFH 67, sn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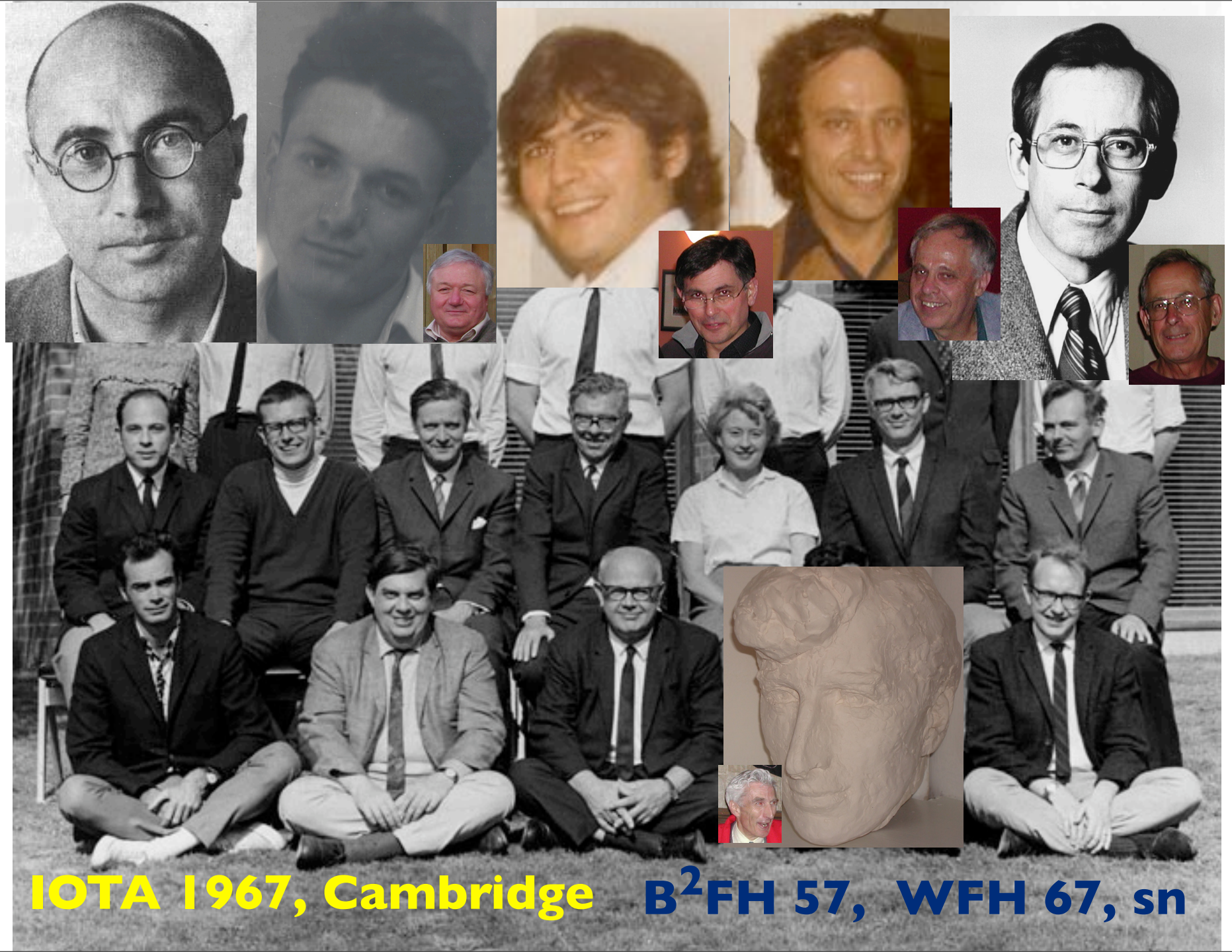

IOTA 1967, Cambridge
B2FH 57, WFH 67, sn

DELTA T OVER TEA WORKSHOP

1-2 May, 1987
Toronto, Canada

Sponsored by
The Canadian Institute for Theoretical Astrophysics and
The Canadian Institute for Advanced Research

Topics

Present and Future Experiments of Cosmic Microwave Background Anisotropies and Their Theoretical Interpretation on very small ($< 1'$), small ($1' - 1^o$), intermediate ($1^o - 10^o$) and large ($> 10^o +$ multipole angular scales

Contact: Dick Bond

CITA, McLennan Labs, University of Toronto

60 St George St., Toronto, Ontario, Canada, M5S 1A1

Phone (416) 978 6879 or 6874

Bitnet BOND@UTORPHYS

Organizers: J.R. Bond (CITA), D.T. Wilkinson (Princeton)

Delta T over Tea Workshop Participants

Bennett, Chuck, Goddard
Birkinshaw, Marc, Harvard *
Bond, Dick, CITA
Boughn, Steve, Haverford
Boynton, Paul, University of Washington
Cannizzo, John, McMaster
Carlberg, Ray, York
Cheng, Ed, MIT
Couchman, Hugh, CITA
Cottingham, David, Princeton
Daly, Ruth, Boston U
Davies, Rod, Jodrell Bank
Davis, Marc, Berkeley
Dragovan, Marc, Bell Labs
Dyer, Charles, U of Toronto
Efstathiou, George, Cambridge
Fitchett, Mike, CITA
Fomalent, Ed, NRAO
Gorski, Chris, Berkeley
Gulkis, Sam, Caltech
Gush, Herb, UBC
Halpern, Marc, UBC
Ip, Peter, U of Toronto
Juszkiewics, Roman, Berkeley
Henriksen, Dick, Queens
Kaiser, Nick, Cambridge
Kellerman, K, NRAO
Kronberg, Phil, Toronto
Lang, Andrew, Berkeley
Lasenby, Anthony, Cambridge
Lawrence, Charles, Caltech
Lee, Hyung-Mok, CITA
Legg, Tom, Herzberg Institute, Ottawa
Little, Blaine, Toronto
Lubin, Phil, Santa Barbara
Matarrese, Sabino, Padova
Mather, John, Goddard
Meyer, Steve, MIT
Meyers, Steve, Caltech
Moseley, Harvey, Goddard
Nelson, Lorne, CITA
Noriega-Crespo, Alberto, CITA
Occhionero, F., Rome *
Ostriker, Jerry, Princeton
Page, Lyman, MIT
Partridge, Bruce, Haverford
Peterson, J.B., Princeton
Radford, Simon, IRAM, France
Readhead, Tony, Caltech
Richards, Paul, Berkeley
Salopek, Dave, Toronto
Sargent, Wal, Caltech *
Schaeffer, Bob, Goddard
Silk, Joe, Berkeley
Silverberg, Bob, Goddard
Stebbins, Albert, Fermilab
Suto, Yasushi, Berkeley
Timby, Peter, Princeton
Tremaine, Scott, CITA
Timusk, Tom, McMaster
Unruh, Bill, UBC
Vishniac, Ethan, U. Texas Austin
Vittorio, Niccolo, Rome
Wilkinson, Dave, Princeton
Webster, Rachel, Toronto

Dave Wilkinson

Wilkinson Microwave Anisotropy Probe

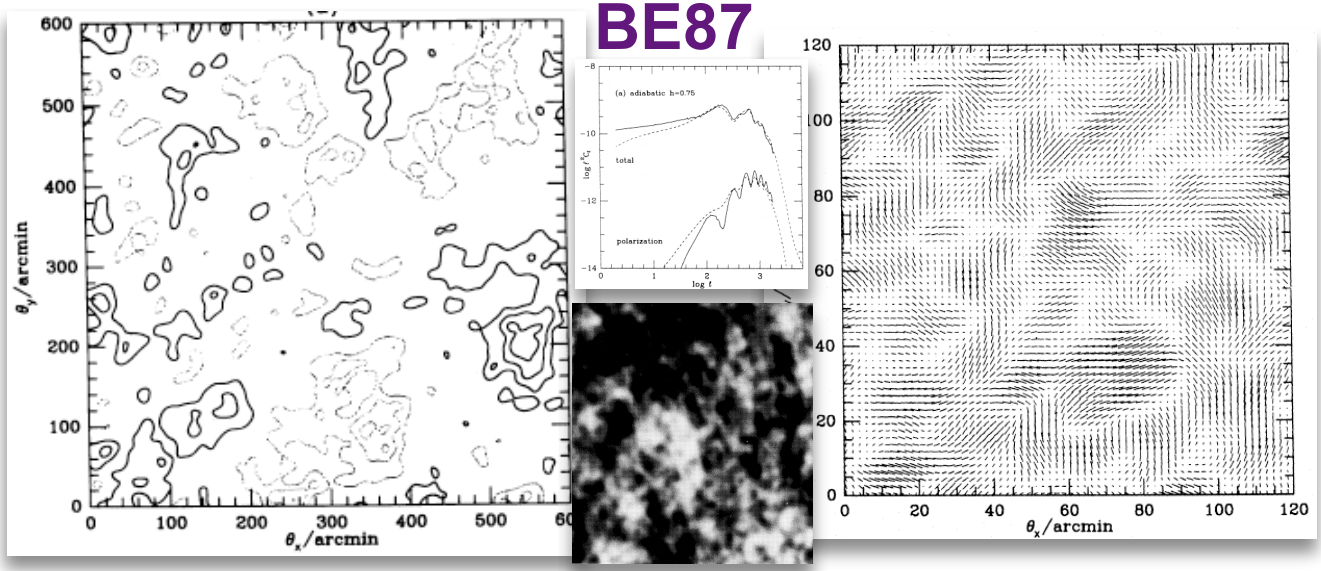
first dedicated CMB conference, exptalists+theorists, primary+secondary $\Delta T/T$

The focus of the meeting will be how best to mesh theory with results from current and future experiments to constrain models of the Universe. This is to be an experts' meeting so we can immediately get down to business. We believe that there are not enough opportunities for the experimentalists and theorists in this field to work together intensively on analysis procedures for the experiments which are approaching discovery level sensitivity for a large class of cosmological models. This workshop is meant to partially satisfy that

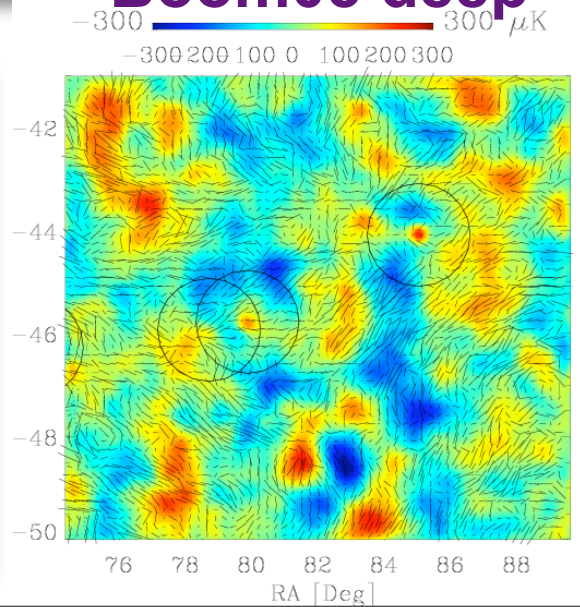
A tentative list of topics organized according to angular scale, with theory and observation intertwined, is:

- very small angle anisotropies - VLA results, secondary fluctuations via the Sunyaev-Zeldovich effect, primeval dust emission, and radio sources
- small angle anisotropies - current results, optimal measuring strategies, statistical methods for small signals in larger noise, which universes can we rule out, the reheating issue, future detectors and techniques, CMB map statistics, polarization
- intermediate and large angle anisotropies - $5^o - 10^o$ results, future experiments at $\sim 1^o$, COBE and other large angle analyses, theoretical $C(\theta)'s$ and their angular power spectra, Sachs-Wolfe effect in open Universes, the isocurvature CDM and baryon stories, $\Delta T/T$ from gravitational waves, the cosmic string story.

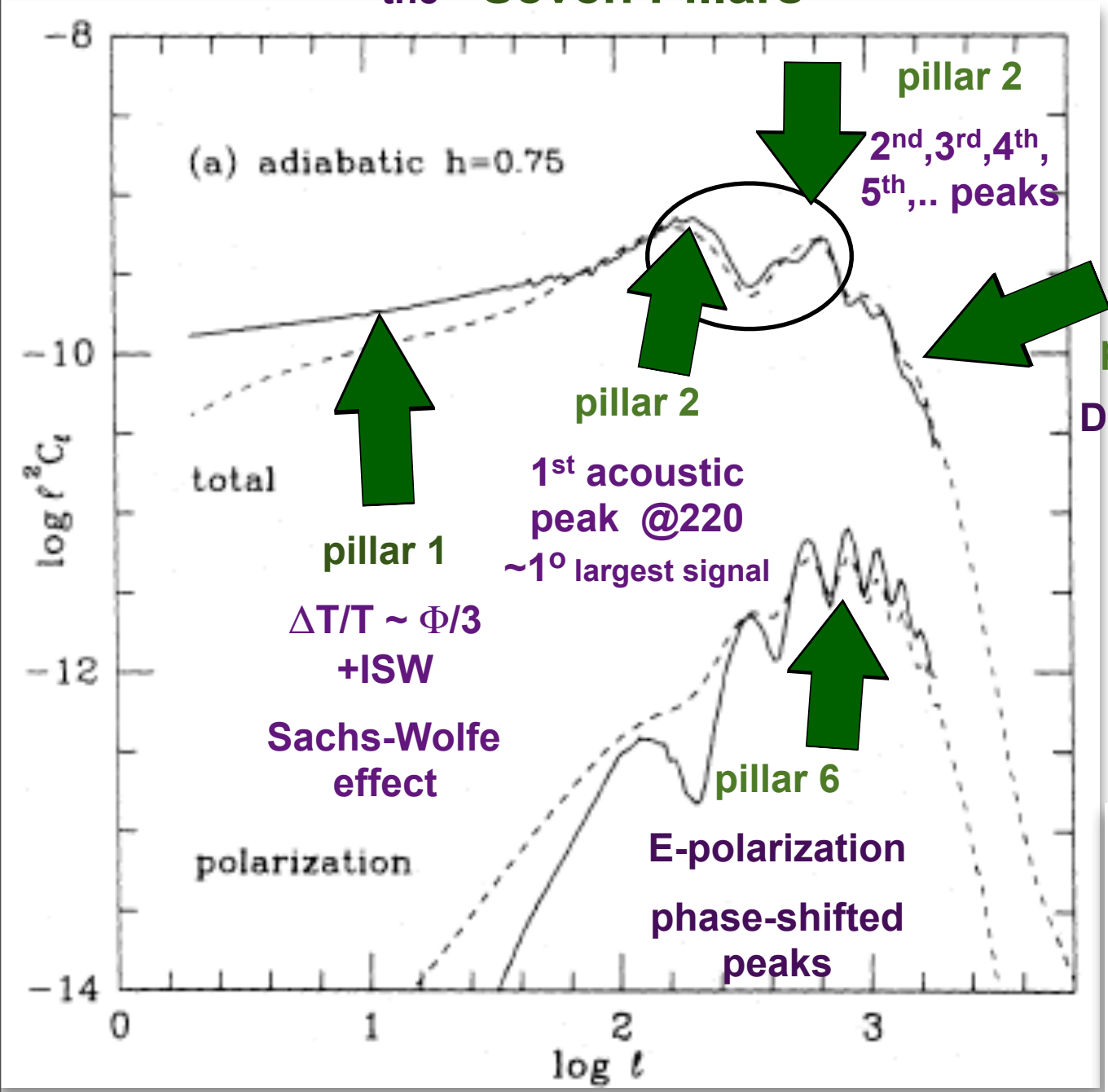
BE87



Boom05 deep



the "Seven Pillars"



pillar 1

$\Delta T/T \sim \Phi/3$
+ISW

Sachs-Wolfe effect

pillar 2

1st acoustic peak @220
~1° largest signal

pillar 2

2nd,3rd,4th, 5th,.. peaks

pillar 3

Damping tail

pillar 4

Gaussianity
maximal randomness
for given C_L

pillar 5

secondary ΔT
nonlinear
Compton SZ
weak lensing..

pillar 6

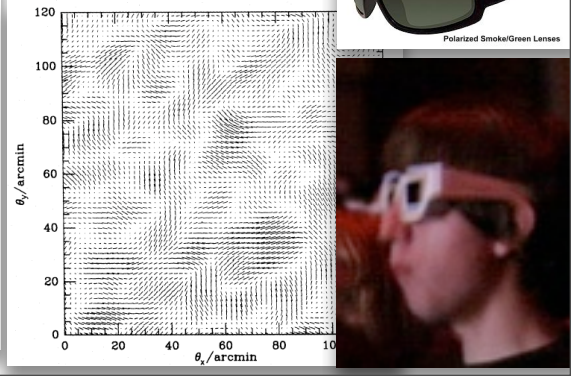
E-polarization

phase-shifted peaks

pillar 7

B-polarization

Gravity Waves



COSMIC PARAMETERS THEN

e.g., BBE1987: vary *x* in *x*CDM

for *x*CDM, predict CMB (6deg, 5min); LSS cluster-cluster, cluster-galaxy, bulk flows,

σ_8: redshift of "galaxy formation"

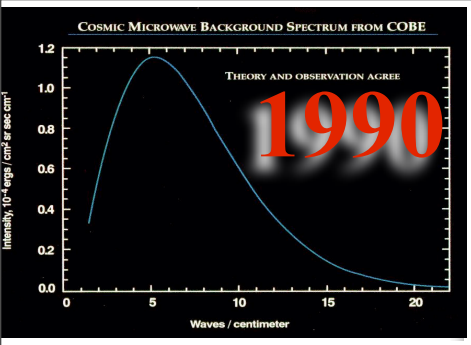
14 Gyr, Ω_Λ=0.8, H0=75, b~c,

50μK cf 30μK cobe, σ_8~0.72

***x*= s /H0 / Λ / Open/ is /is+ad/ h-c/ h+/ b/ b / Λ+b / Op+b /τ /BSI /BSI2**

PREDICTIONS FOR MODELS

Parameter	OBS	CDM	C40	VAC/C	OP/C	ISO/C	ISO/AD	HOT	HC	C + B	B + C	BCV	BCO	CDM + dec	(CDM + X)$_3$ (k_*^{-1} = 300)	(CDM + X)$_2$ (k_*^{-1} = 200)
Ω, Ω_B, H_0	...	1, 0.1, 50	1, 0.1, 40	1, 0.03, 50	0.2, 0.03, 50	1, 0.1, 50	1, 0.1, 50	1, 0.1, 50	1, 0.1, 50	1, 0.2, 40	1, 0.5, 50	1, 0.1, 75	0.2, 0.1, 75	1, 1, 50	1, 0.1, 40	1, 0.1, 50
$\Omega_X(\Omega_\nu)$, Ω_{vac}	...	0.9, 0	0.9, 0	0.17, 0.8	0.17, 0	0.9, 0	0.9, 0	(0.9), 0	0.5(0.4), 0	0.8, 0	0.5, 0	0.1, 0.8	0.1, 0	1, 0	0.9, 0	0.9, 0
b	...	1.7	1.8	1	1	1.7	1.7	0.53	1.7	1.8	1.7	1	1	1.7	1.8	1.7
t_0 (by)	GC: 14–22 NC: 13–26	13	17	22	17	13	13	13	13	17	13	14	11	13	17	13
$\sigma_0(R_g = 0.35)$ ...	...	2.9	2.4	2.7	2.7	1.6	2.5	2.0	1.3	2.2	1.9	2.4	2.4	6.8	2.2	2.7
z_g	...	3.7	2.9	2.3	4.0	1.3	3.1	1	1.1	2.5	2.0	1.3	2.0	13	2.6	3.4
$\sigma_0(R_{cl} = 5)$	...	0.42	0.39	0.75	0.75	0.43	0.42	1.4	0.44	0.40	0.44	0.72	0.72	0.47	0.41	0.43
$\langle v \rangle_c$	...	3.2	3.1	3.1	3.1	3.0	3.2	3.1	2.9	3.1	3.0	2.8	2.8	2.7	3.1	3.1
$\xi_{cc}(20)$	1.5	0.15	0.26	1.7	1.7	0.70	0.35	1.1	1.0	0.49	1.3	2.2	2.2	1.8	1.0	0.85
$\xi_{cc}(25)$	1.0	0.08	0.15	1.2	1.2	0.42	0.21	0.45	0.51	031	0.93	1.7	1.7	0.92	0.83	0.68
$\xi_{cc}(30)$	0.72	0.03	0.07	0.85	0.85	0.25	0.11	0.20	0.24	0.20	0.61	1.4	1.4	0.49	0.64	0.51
$\xi_{cc}(50)$	0.29	−0.01*	−0.006*	0.24	0.24	0.02	−0.01*	−0.009*	−0.02*	0.04	0.23	0.59	0.59	0.16	0.28	0.21
$\xi_{cc}(100$	0.08	−0.002*	−0.003*	0.02	0.02	−0.003*	−0.003*	−0.003*	−0.009*	−0.007*	−0.01*	036	0.36	0.02	0.08	0.06
$\xi_{cg}(20)$	0.49	0.13	0.17	0.57	0.57	0.32	0.19	0.96	0.44	0.23	0.50	0.76	0.76	0.70	0.39	0.32
$\xi_{cg}(25)$	0.33	0.04	0.06	0.37	0.37	0.16	0.08	0.35	0.23	0.11	0.32	0.54	0.54	0.42	0.26	0.20
$\xi_{cg}(30)$	0.24	0.01	0.02	0.25	0.25	0.09	0.03	0.12	0.11	0.06	0.22	0.41	0.41	0.24	0.19	0.15
$\xi_{cg}(40)$	0.14	−0.003	0.002	0.13	0.13	0.03	0.006	−0.001	0.02	0.03	0.13	0.26	0.26	0.09	0.12	0.10
$v(R_f = 3.2)$	610 ± 50	136–654	134–650	166–797	157–752	172–824	148–709	594–2850	185–889	149–714	208–1000	232–1120	218–1050	293–1399	280–1331	241–1151
$v(R_f = 15)$	599 ± 104	71–340	76–365	134–639	126–601	114–544	86–409	387–1850	124–587	95–450	154–735	206–987	194–928	244–1170	250–1190	202–970
$v(R_f = 25)$		53–250	56–269	115–550	108–516	89–421	64–309	419–1350	91–435	71–342	119–573	186–894	174–839	215–1028	233–1106	185–882
$v(R_f = 40)$	970 ± 300	35–180	40–192	95–456	90–430	66–315	47–221	200–958	65–311	52–251	87–419	160–771	151–724	184–879	214–1016	165–787
$\Delta T/T$ (4.5)	<25	5	6	20	70	...	...	20	...	6	8	10	80	...	...	...
$\times 10^6$ (6°)	<48	7	8	20	40	60	30	20	8	8	15	25	50	40	72 (98)	40 (64)

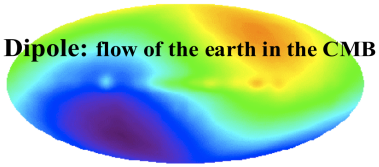


1992

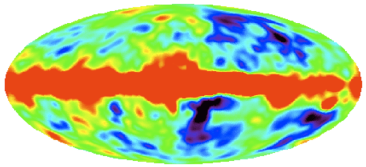
CMB

Nearly Perfect Blackbody

T=2.725 ±.001 K COBE/FIRAS

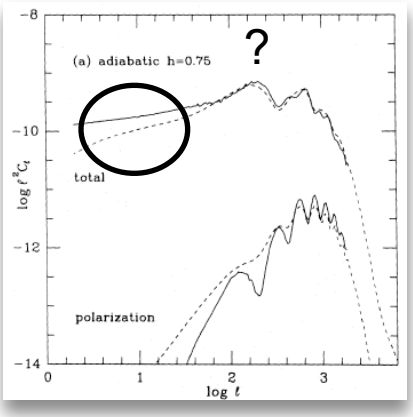


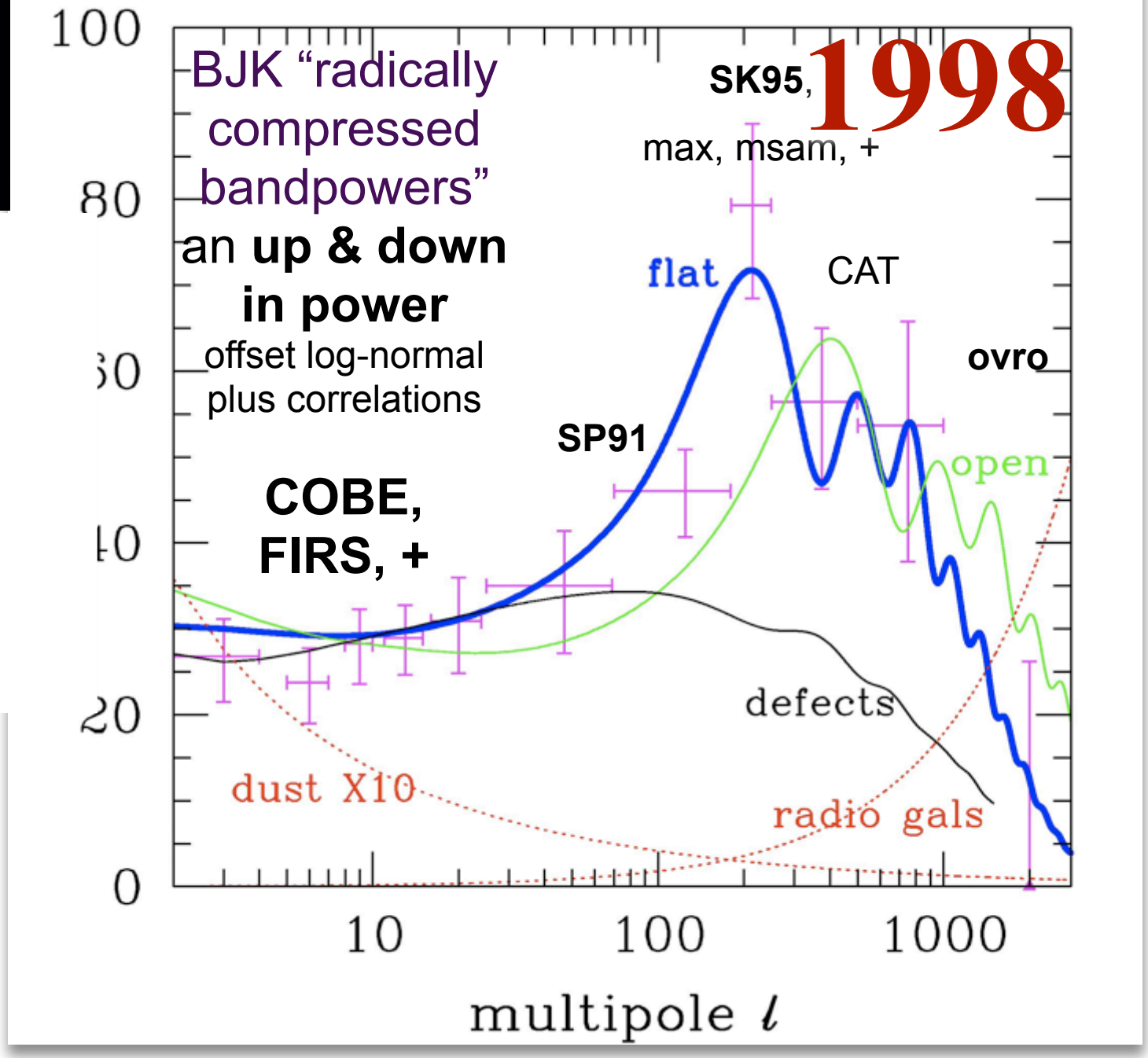
Dipole: flow of the earth in the CMB



COBE/DMR:

CMB + Galactic @7°





CMB ⇓ CMB ⊕ LSS ⇓

$n_s \simeq 1 \pm .05$

nearly SCALE INVARIANT FLUCTUAT^{N}S

CMB ⊕ LSS ⇓ oCDM << ΛCDM

SNIa ⇓

high z CLUSTERS ⇓

$\Omega_{cdm} \sim .3$

$\Omega_B \sim .04$

$H_0 \sim 65\text{-}70$

$t_0 \simeq 12\text{-}14\,Gyr$

$\Omega_\nu \sim .0014 \left(\frac{m_\nu}{.07eV}\right)^2 \frac{2\nu}{2}$

$(\ddot{x}, t) \approx \frac{2}{3}$

Λ vac φ LATE TIME

INFLATION is NOW

$\rho_\Lambda^{1/4} \sim$ milli eV

vintage 98 conclusions

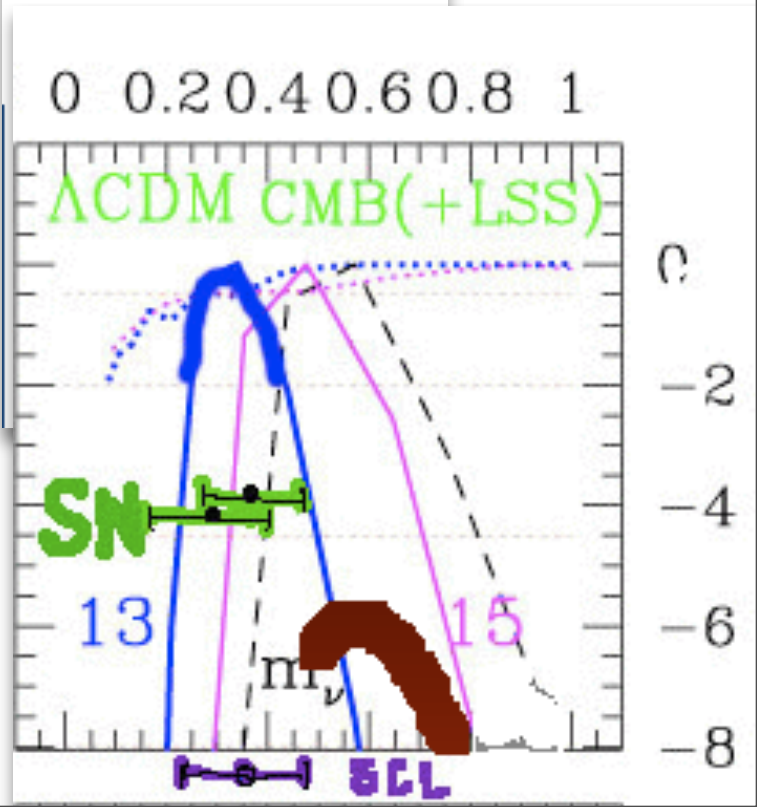
B+Jaffe'96,'98 $(13\,Gyr/t_0)$

$\Omega_\Lambda \approx 2/3 \pm .07$ +LSS

$n_s =$

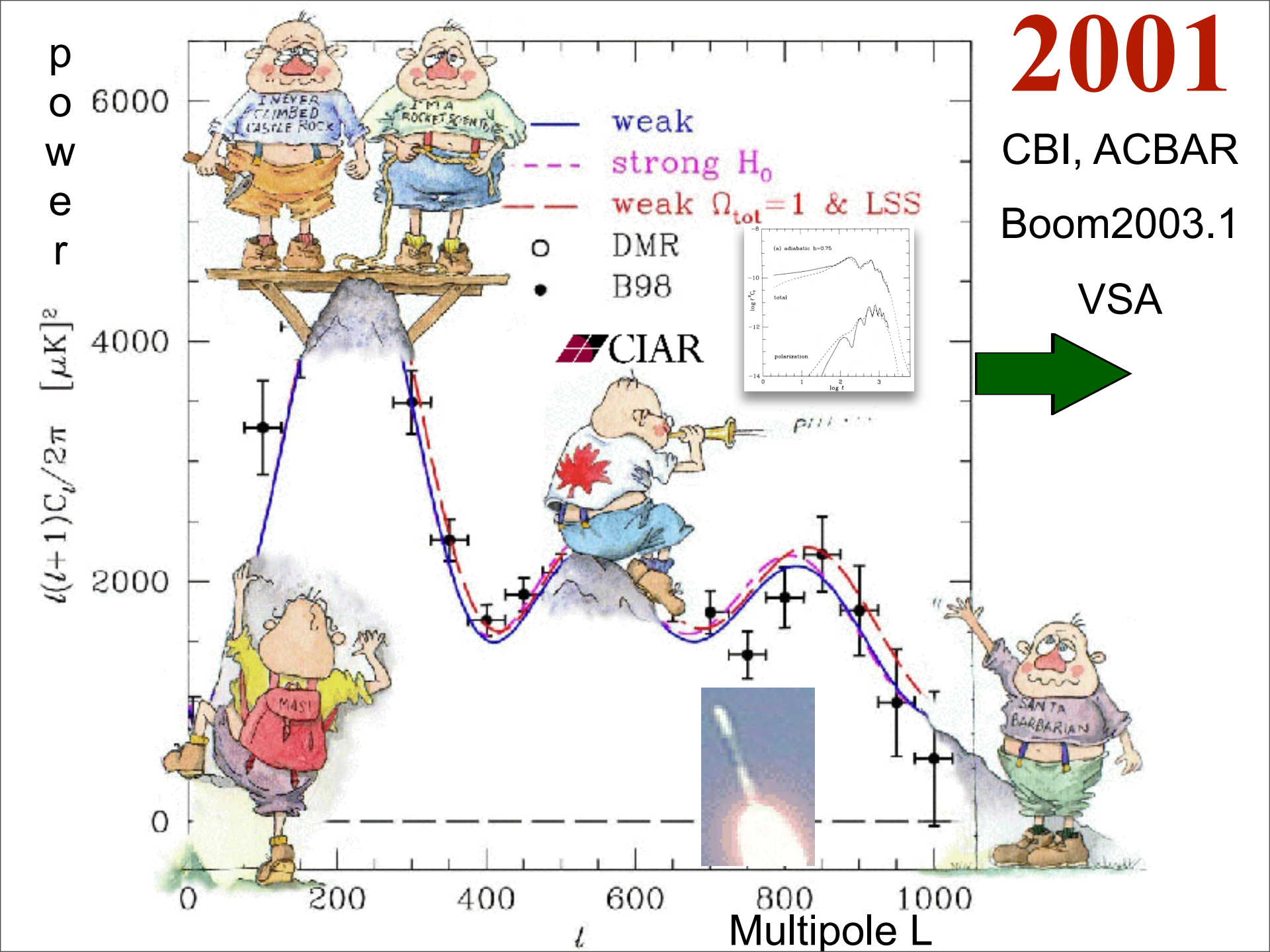
$.98 \pm .07$

$.96 \pm .06$



BOOM

2000


power
$\ell(\ell+1)C_\ell/2\pi$ [μK]^2
6000
4000
2000
0
0
200
400
600
800
1000
ℓ
Multipole L
weak
strong H_0
weak Ω_{tot}=1 & LSS
DMR
B98
CIAR
2001
CBI, ACBAR
Boom2003.1
VSA
I NEVER CLIMBED CASTLE ROCK
I'M A ROCKET SCIENTIST
MAS!
SANTA BARBARIAN
(a) adiabatic h=0.75
total
polarization
log t
log $^2C_\ell$

2002

NSF/Caltech /CITA/CIAR

May 23,2002

AAS Jun02

Grand unified spectrum

Adds

CBI mosaic

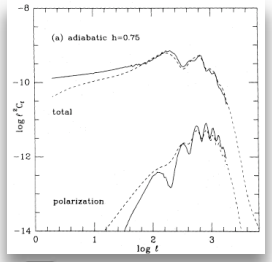
+CBI deep

+VSA

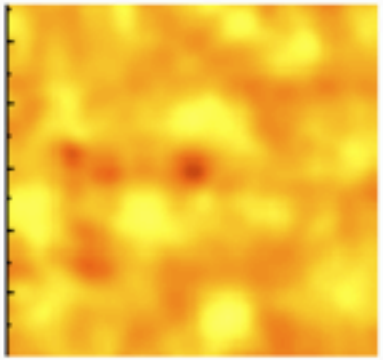
DMR+B98+DASI+MAX+CBIm0140+CBIdeep+VSA

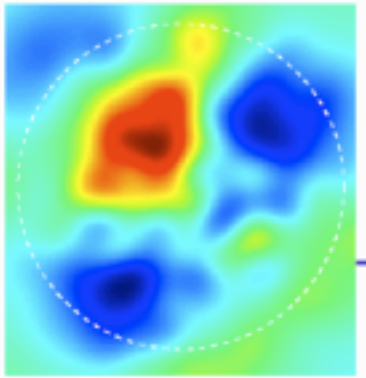
pillars 1,2,3,4

5 moons across X 3



1.5 moons X 3





pillar 5? "CBI excess"

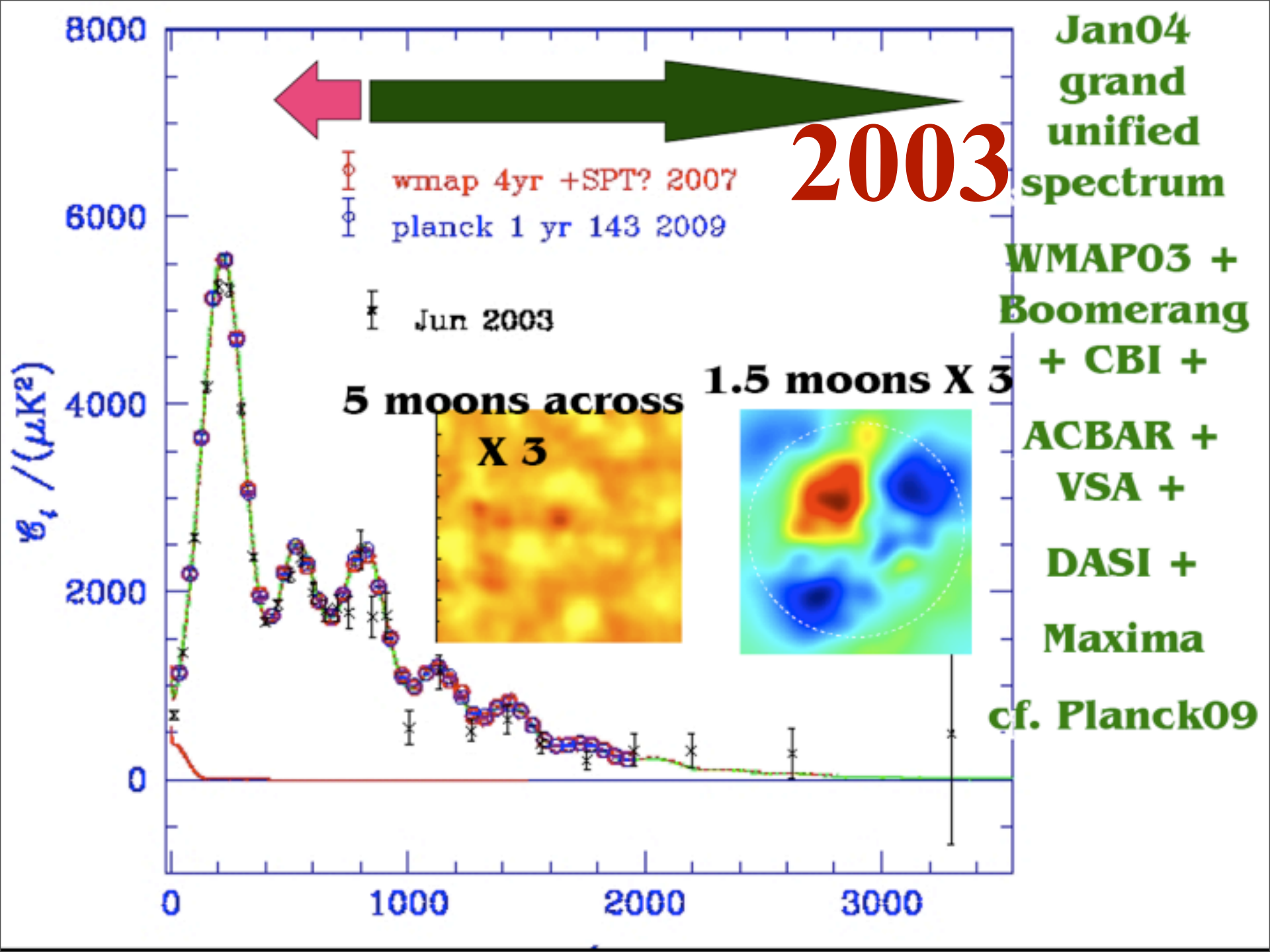
$\mathcal{C}_l$ /(μK^2)

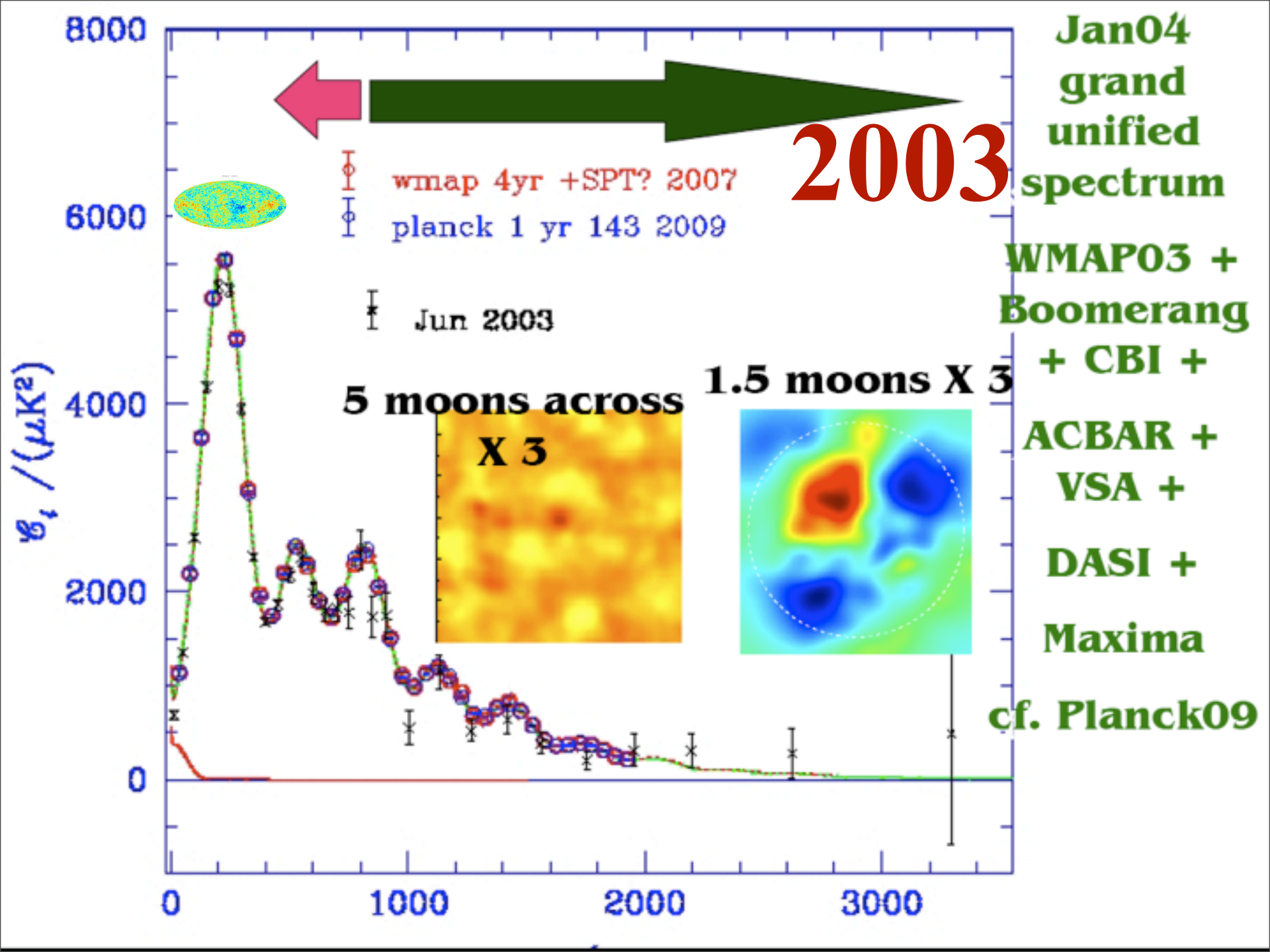
8000
6000
4000
2000
0

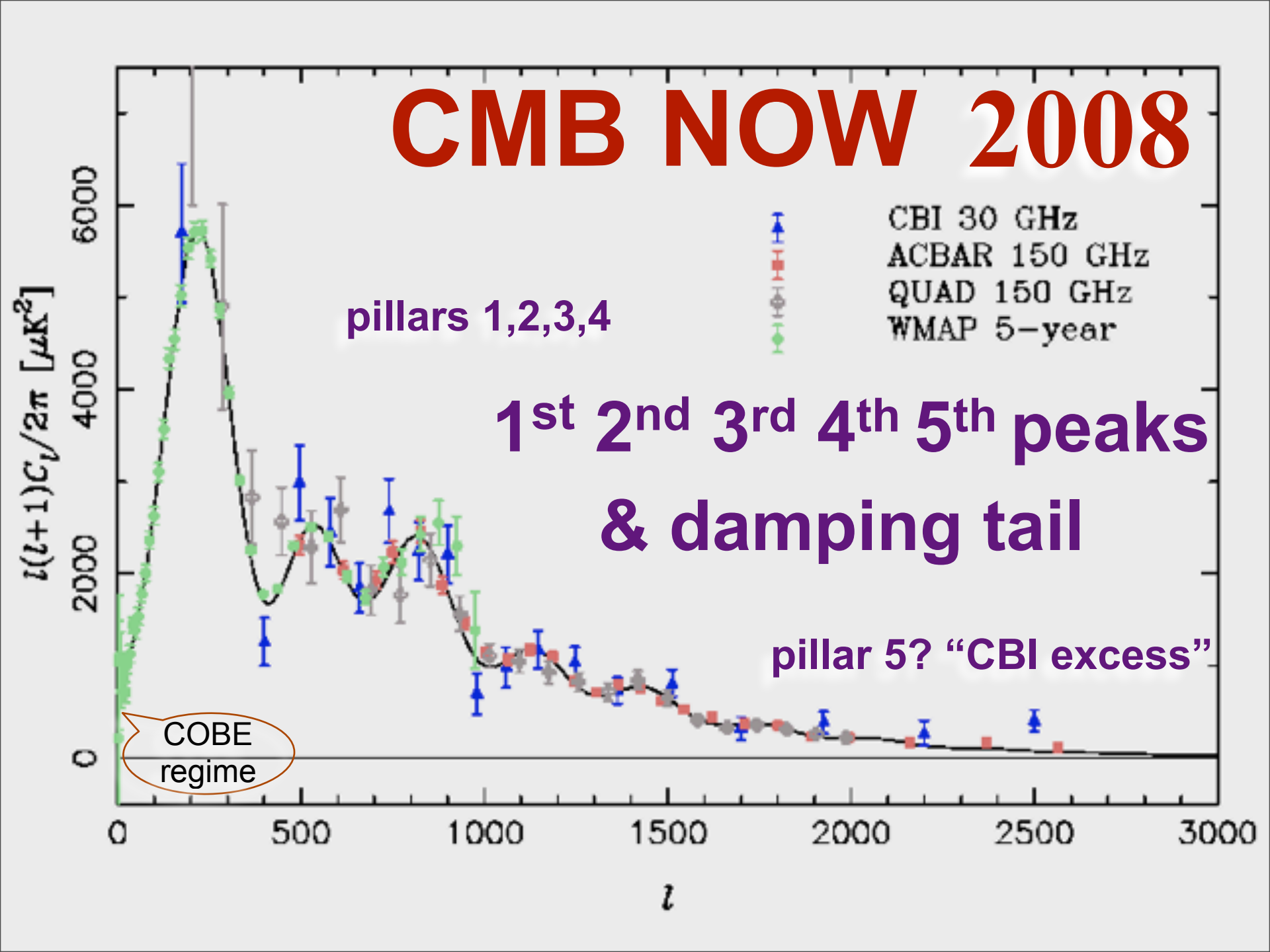
0
1000
2000
3000

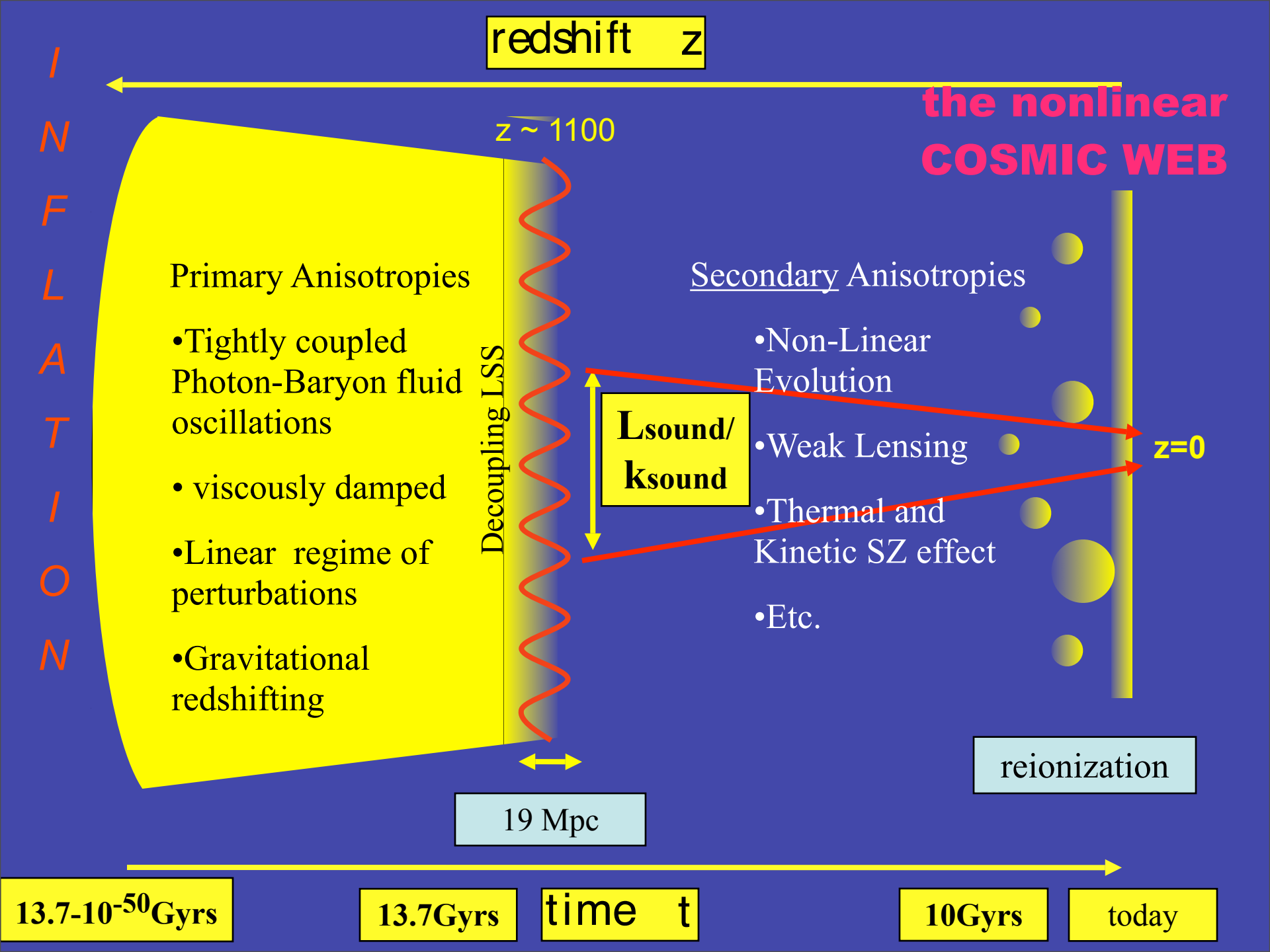
l


WMAP
launch
2001.6
Text
Dave Wilkinson
Rashid Sunyaev


8000
6000
4000
2000
0
0
1000
2000
3000
$\mathcal{C}_\ell$ /(μK^2)
2003
wmap 4yr +SPT? 2007
planck 1 yr 143 2009
Jun 2003
5 moons across
X 3
1.5 moons X 3
Jan04
grand
unified
spectrum
WMAP03 +
Boomerang
+ CBI +
ACBAR +
VSA +
DASI +
Maxima
cf. Planck09

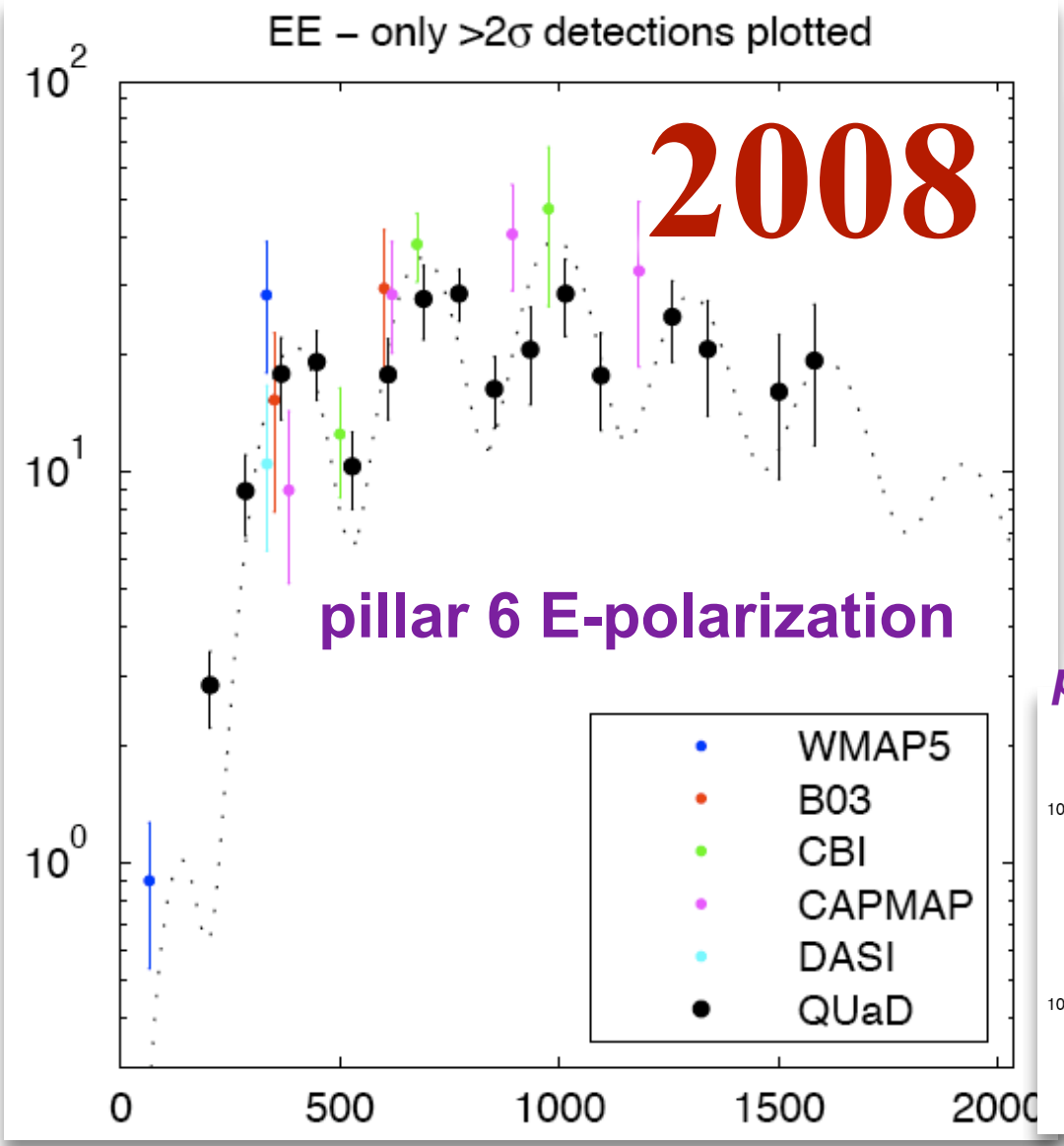

8000
6000
4000
2000
0
0
1000
2000
3000
$\mathcal{C}_\ell$ /(μK^2)
2003
wmap 4yr +SPT? 2007
planck 1 yr 143 2009
Jun 2003
5 moons across
X 3
1.5 moons X 3
Jan04
grand
unified
spectrum
WMAP03 +
Boomerang
+ CBI +
ACBAR +
VSA +
DASI +
Maxima
cf. Planck09

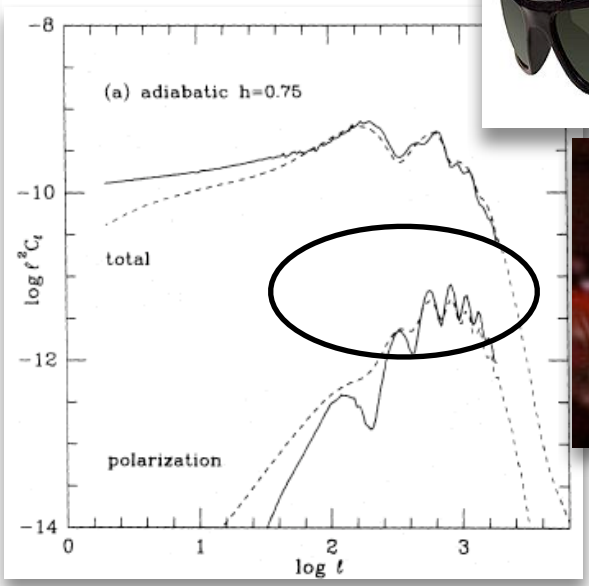

CMB NOW 2008
CBI 30 GHz
ACBAR 150 GHz
QUAD 150 GHz
WMAP 5-year
pillars 1,2,3,4
1st 2nd 3rd 4th 5th peaks
& damping tail
pillar 5? "CBI excess"
COBE
regime
$l(l+1)C_l/2\pi$ [μK^2]
0
2000
4000
6000
0
500
1000
1500
2000
2500
3000
l


redshift z
INFLATION
z ~ 1100
the nonlinear
COSMIC WEB
Primary Anisotropies
•Tightly coupled Photon-Baryon fluid oscillations
• viscously damped
•Linear regime of perturbations
•Gravitational redshifting
Decoupling LSS
Lsound/
ksound
Secondary Anisotropies
•Non-Linear Evolution
•Weak Lensing
•Thermal and Kinetic SZ effect
•Etc.
z=0
reionization
19 Mpc
13.7-10-50Gyrs
13.7Gyrs
time t
10Gyrs
today

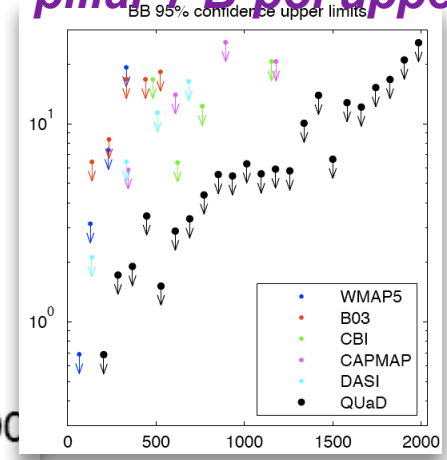
emergence of CMB polarization *power*

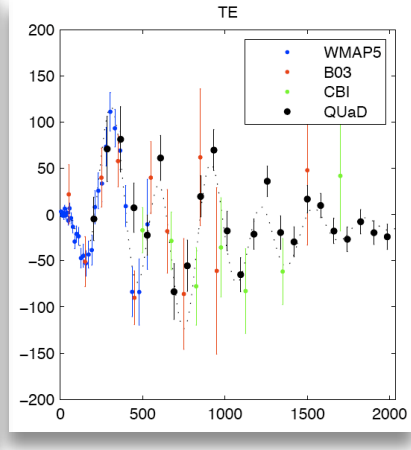
DASI02,04 CBI04 Boom05 CBI05 WMAP3,5 QUaD07,08

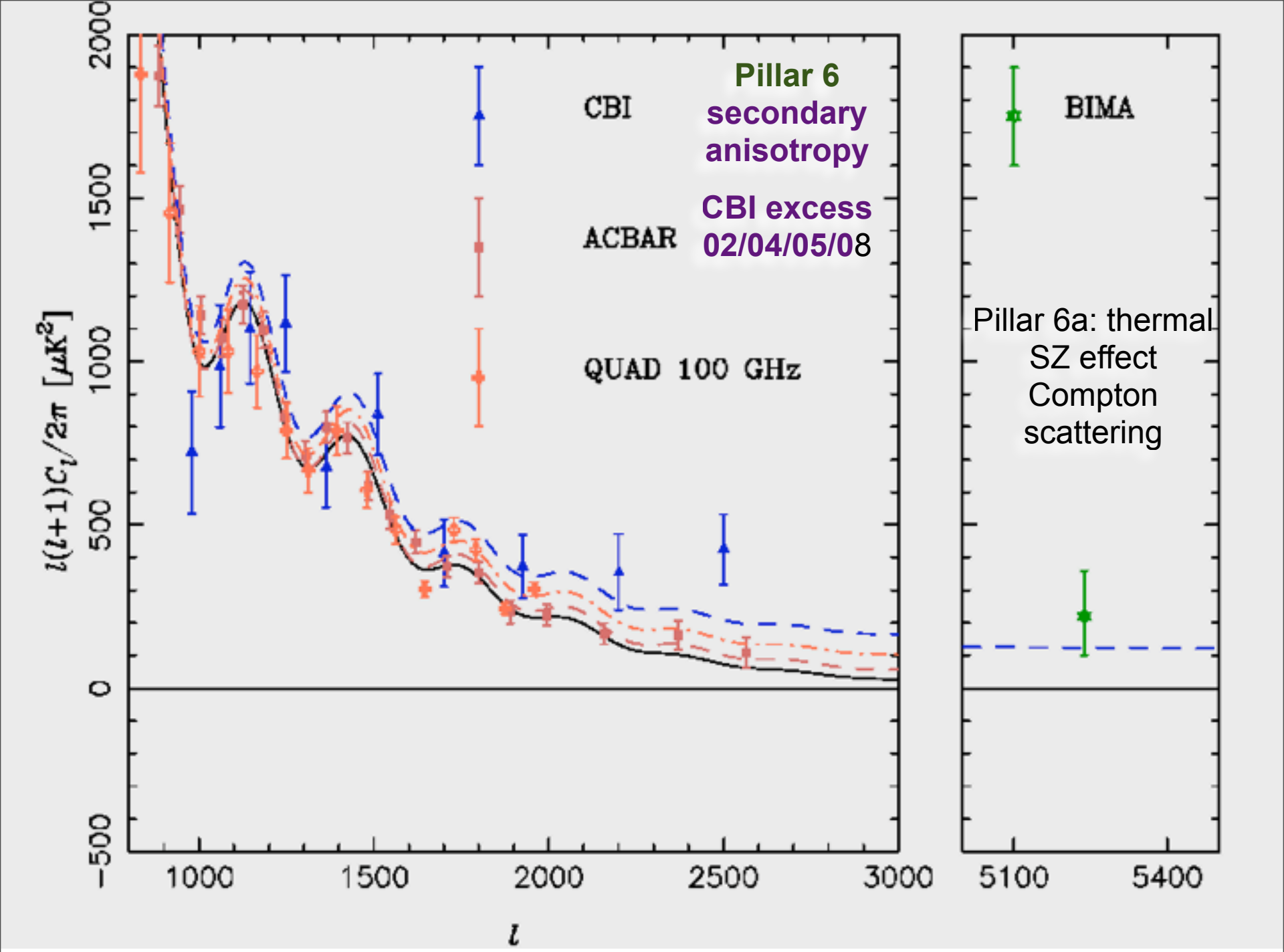


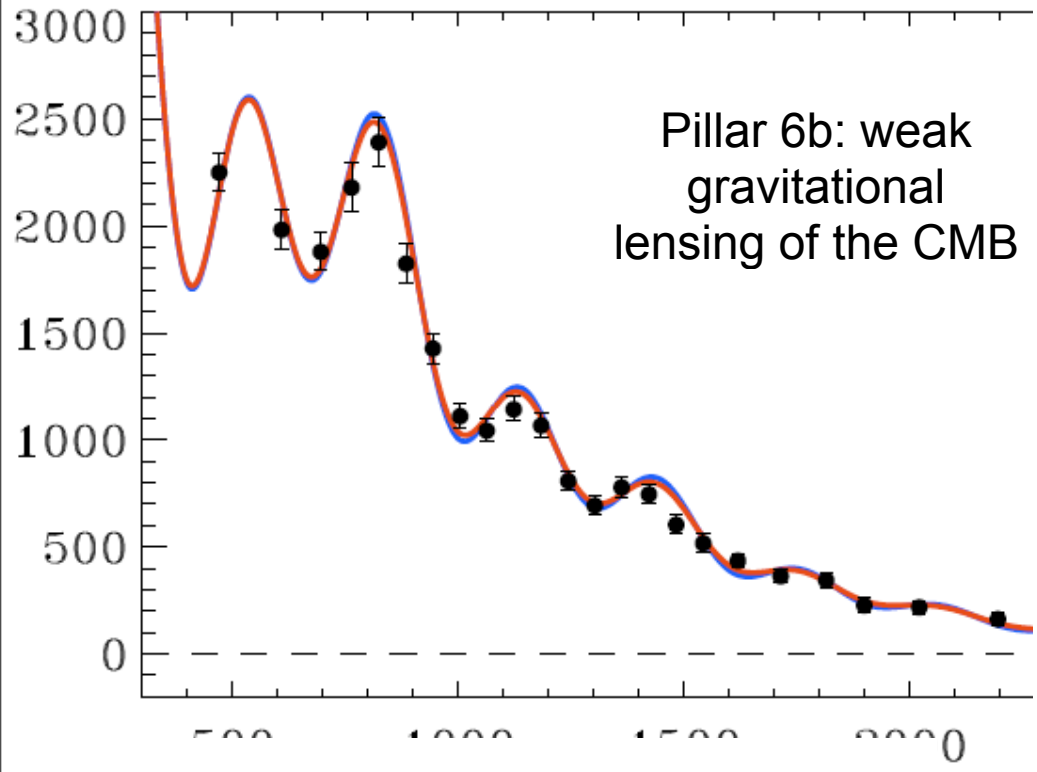


pillar 7 B-pol upper limits

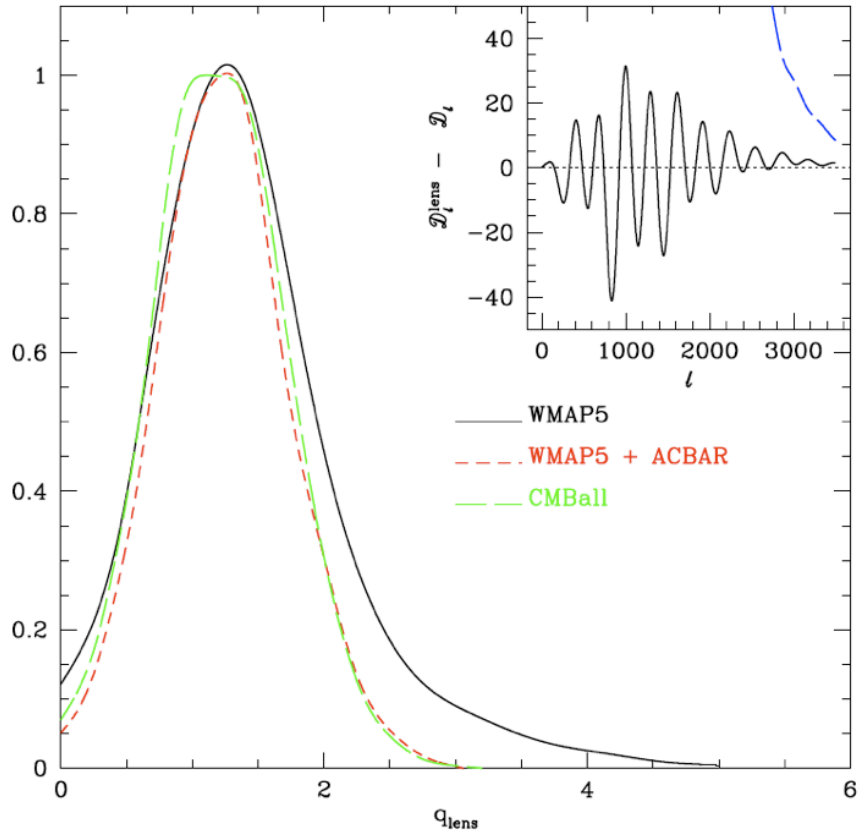





Pillar 6
secondary
anisotropy
CBI excess
02/04/05/08
CBI
ACBAR
QUAD 100 GHz
BIMA
Pillar 6a: thermal
SZ effect
Compton
scattering
$l(l+1)C_l/2\pi$ [μK^2]
2000
1500
1000
500
0
−500
1000
1500
2000
2500
3000
5100
5400
l



Pillar 6b: weak gravitational lensing of the CMB



$$C_\ell^{\rm lens} = C_\ell^{\rm no-lens} + q_{\rm lens}\Delta C_\ell^{\rm lens}$$

$$\Delta \ln \mathcal{E} = \ln[P({\rm lens}|data, theory)/P({\rm no-lens}|data, theory)]$$

wmap5+ acbar $q_{\rm lens} = 1.23^{+0.21(+0.83)}_{-0.23(-0.76)}$ $\Delta \ln \mathcal{E} = 2.89$

CMBall $q_{\rm lens} = 1.21^{+0.24(+0.82)}_{-0.24(-0.76)}$ $\Delta \ln \mathcal{E} = 2.63$

CBI pol to Apr'05 @Chile

Bicep @SP

Quiet2
(1000 HEMTs)

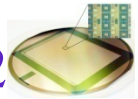
CBI2 to early'08

Acbar to Jan'06, 07f @SP

QUaD @SP

Quiet1 @Chile

SCUBA2
(12000 bolometers)
JCMT @Hawaii

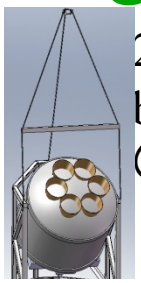


Spider
2312
bolometer
@LDB

SZA
(Interferometer)
@Cal

APEX
(~400 bolometers)
@Chile

ACT
(3000 bolometers)
3 frequencies @Chile



Clover
@Chile

Boom03@LDB

EBEX@LDB

2004 2005 2006 2007 2008 2009 2017

LMT@Mexico

SPT
(1000 bolometers)
@South Pole

LHC

Bpol@L2

WMAP @L2 to 2009-2013?

ALMA
(Interferometer)
@Chile

DASI @SP

Polarbear
(300 bolometers)@Cal

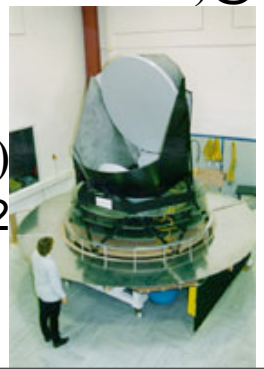
CAPMAP

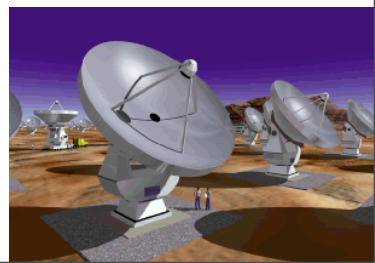
Planck09.2

AMI

(52 bolometers)
+ HEMTs @L2
9 frequencies

GBT





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Bicep @SP

Quiet2
(1000 HEMTs)

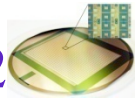
CBI2 to early'08

Acbar to Jan'06, 07f @SP

QUaD @SP

Quiet1 @Chile

SCUBA2
(12000 bolometers)
JCMT @Hawaii

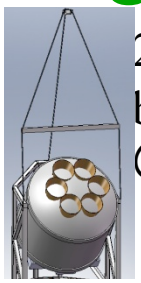


Spider
2312
bolometer
@LDB

SZA
(Interferometer)
@Cal

APEX
(~400 bolometers)
@Chile

ACT
(3000 bolometers)
3 frequencies @Chile



Clover
@Chile

Boom03@LDB

EBEX@LDB

2004 2005 2006 2007 2008 2009 2017

LMT@Mexico

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WMAP @L2 to 2009-2013?

SPT
(1000 bolometers)
@South Pole

LHC

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(Interferometer)
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CAPMAP

Planck09.2

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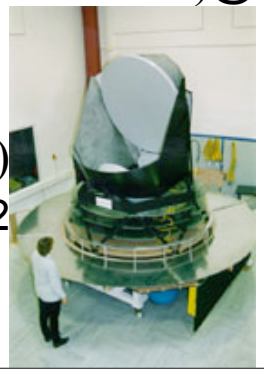
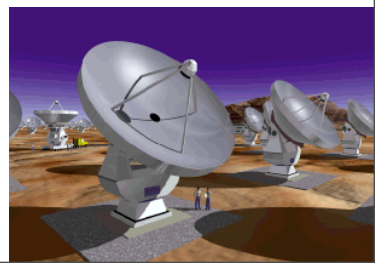
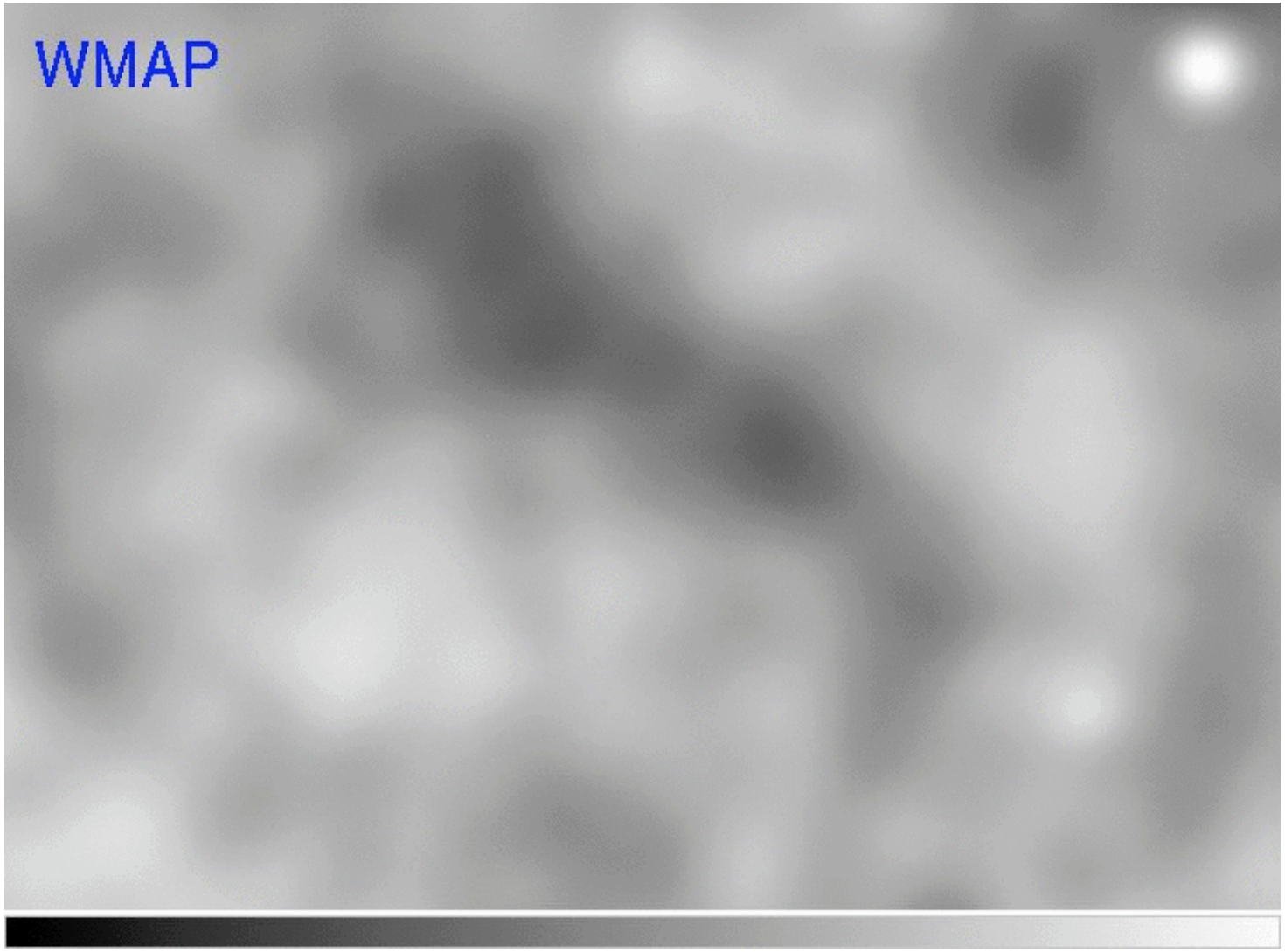
GBT

(52 bolometers)
+ HEMTs @L2
9 frequencies





WMAP-BOOM-ACBAR-ACT: the high resolution frontier



Toby marriage 01.08 for the act collaboration

ACT@5170m

why Atacama? driest desert in the world. thus: cbi, toco, apex, asti, act, alma, quiet, clover

CBI2@5040m

dark matter abundance Ω_m=0.268 +.012 -.012

	January 2000	January 2002	June 2002	January 2003	March 2003
$\Omega_{\rm cdm}h^2$	$0.198^{+0.088}_{-0.080}$	$0.130^{+0.031}_{-0.028}$	$0.124^{+0.026}_{-0.025}$	$0.125^{+0.021}_{-0.022}$	$0.111^{+0.010}_{-0.010}$

CMB-only history (weak-h prior). LSS-then drove to near current

0.1145 +-0.0023 CMBall+WL+LSS+SN+Lya

$$\rho_{dm}/\rho_b = 5.1$$

Ω_Λ	$0.34^{+0.28}_{-0.24}$	$0.52^{+0.17}_{-0.20}$	$0.53^{+0.17}_{-0.19}$	$0.57^{+0.14}_{-0.19}$	$0.73^{+0.06}_{-0.10}$

CMB-only history (weak-h prior). LSS-then drove to near current value

dark energy abundance Ω_Λ=0.736 +.012 -.012

& H_0 = 72 +-1 CMBall+WL+LSS+SN+Lya

$$\rho_m/\rho_{de} = .30$$

ε=-dlnH/dlna=1+q: now =3/2[Ω_{m0} +(1+w)(1-Ω_{m0})] **~0.40?, to 0?**

What is the Universe made of?

NOW: baryons + (cold-ish) dark matter + dark energy/inflaton + tiny curvature energy (+light neutrinos+photons). ??a bit of strings/textures/PBHs??

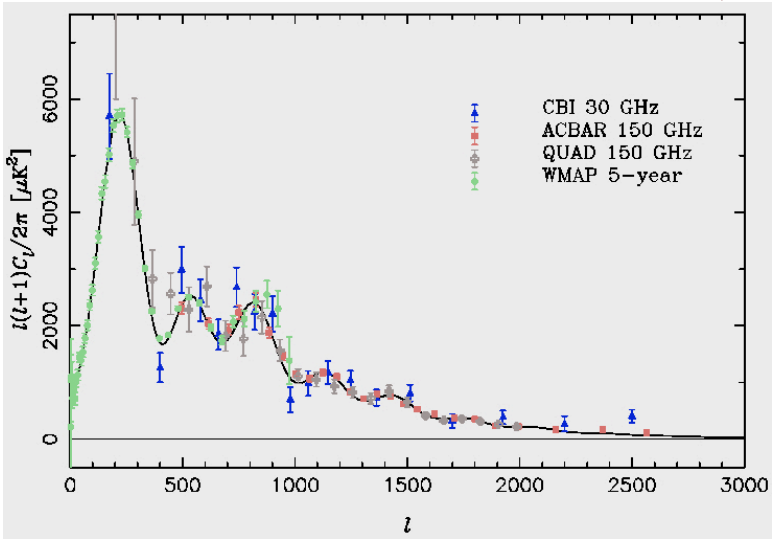
THEN: coherent inflaton /**"vacuum" energy plus zero-point fluctuations** in all fields. & then preheat through mode coupling to incoherent cascade to thermal equilibrium aka **quark-gluon plasma**

very early U early to middle to now U **very late U**

string theory/landscape/higher dimensions

inflation cyclic baryogenesis dark matter BBN γdec **dark energy**

$V_{eff}(\phi_{inf})$?
$K_{eff}(\phi_{inf})$?



$V_{eff}(\phi_{inf})$?
$K_{eff}(\phi_{inf})$?

n_b/n_γ ρ_{dm}/ρ_b z_{eq}/z_{rec} ρ_{curv} ρ_{de}/ρ_{dm} $\rho_{de} \sim H^2M^2_{Planck}$ $\rho_{m\nu}/\rho_{stars}$

Old view: **Theory prior = delta function of THE correct one and only theory**

New: **Theory prior = probability distribution** of **late-flows** on an **energy LANDSCAPE**

6/7 tiny extra dimensions

1980

R^2-inflation

Old Inflation

Chaotic inflation

New Inflation

Double Inflation

Power-law inflation

SUGRA inflation

Radical BSI inflation

variable M_P inflation

Extended inflation

1990

Natural pNGB inflation

Hybrid inflation

SUSY F-term inflation

SUSY D-term inflation

Assisted inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

N-flation

ekpyrotic/ cyclic

DBI inflation

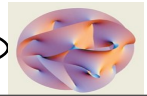
$D3-D7$ inflation

Tachyon inflation

Warped Brane inflation

Racetrack inflation

Roulette inflation **Kahler moduli/axion**



INFLATION
THEN

WHAT IS PREDICTED?

Smoothly broken scale invariance by nearly uniform braking (standard of 80s/90s/00s) r~0.03-0.5

or highly variable braking r tiny

(stringy cosmology) $r<10^{-10}$

INFLATION THEN

PROBES NOW

The Parameters of Cosmic Structure Formation

Cosmic Numerology: april08 cmb +LSS/WL/SN includes wmap5

	January 2000	January 2002	June 2002	January 2003	March 2003
n_s	$1.218^{+0.135}_{-0.163}$	$0.949^{+0.083}_{-0.049}$	$0.938^{+0.077}_{-0.042}$	$0.961^{+0.081}_{-0.047}$	$0.978^{+0.025}_{-0.020}$

n_s = .962 +- .013 (+-.005 Planck1)

.959 +- .011 CMBall+WL+LSS/BAO+SNunion

$r=A_t / A_s$ < 0.40_{cmb} 95% CL (+-.03 P1)

$dn_s /d\ln k$ = -.016 +- .019* (+-.005 P1)

WMAP5+ACBAR08 run

-9< f_{NL} <111 (+- 5-10 P1)

What is the Universe made of?

NOW: baryons + (cold-ish) dark matter + dark energy/inflaton + tiny curvature energy (+light neutrinos+photons). ??a bit of strings/textures/PBHs??

THEN: coherent inflaton /**"vacuum" energy plus zero-point fluctuations** in all fields. & then preheat through mode coupling to incoherent cascade to thermal equilibrium aka **quark-gluon plasma**

very early U early to middle to now U **very late U**

string theory/landscape/higher dimensions

inflation cyclic baryogenesis dark matter BBN γdec **dark energy**

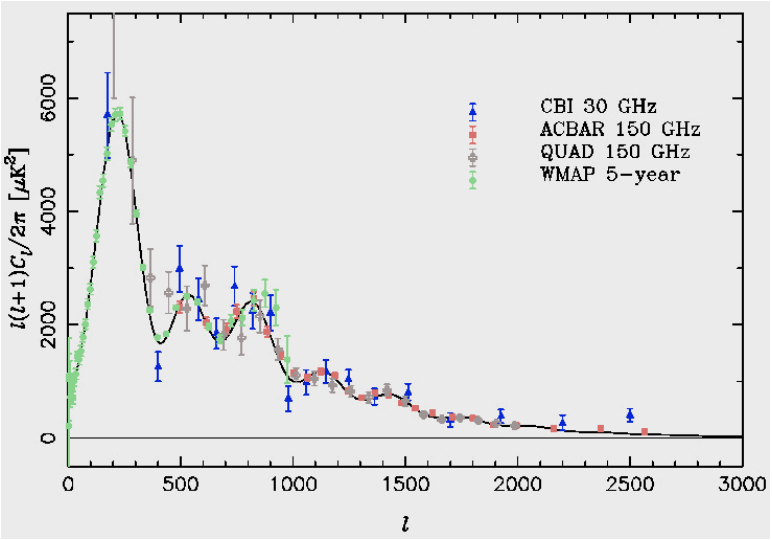
$V_{eff}(\phi_{inf})$?

$K_{eff}(\phi_{inf})$?

trajectory probability

$-d\ln\rho_{tot}/d\ln a/2$

$=\varepsilon(k)=1+q$, $k\sim Ha$



$V_{eff}(\phi_{inf})$?

$K_{eff}(\phi_{inf})$?

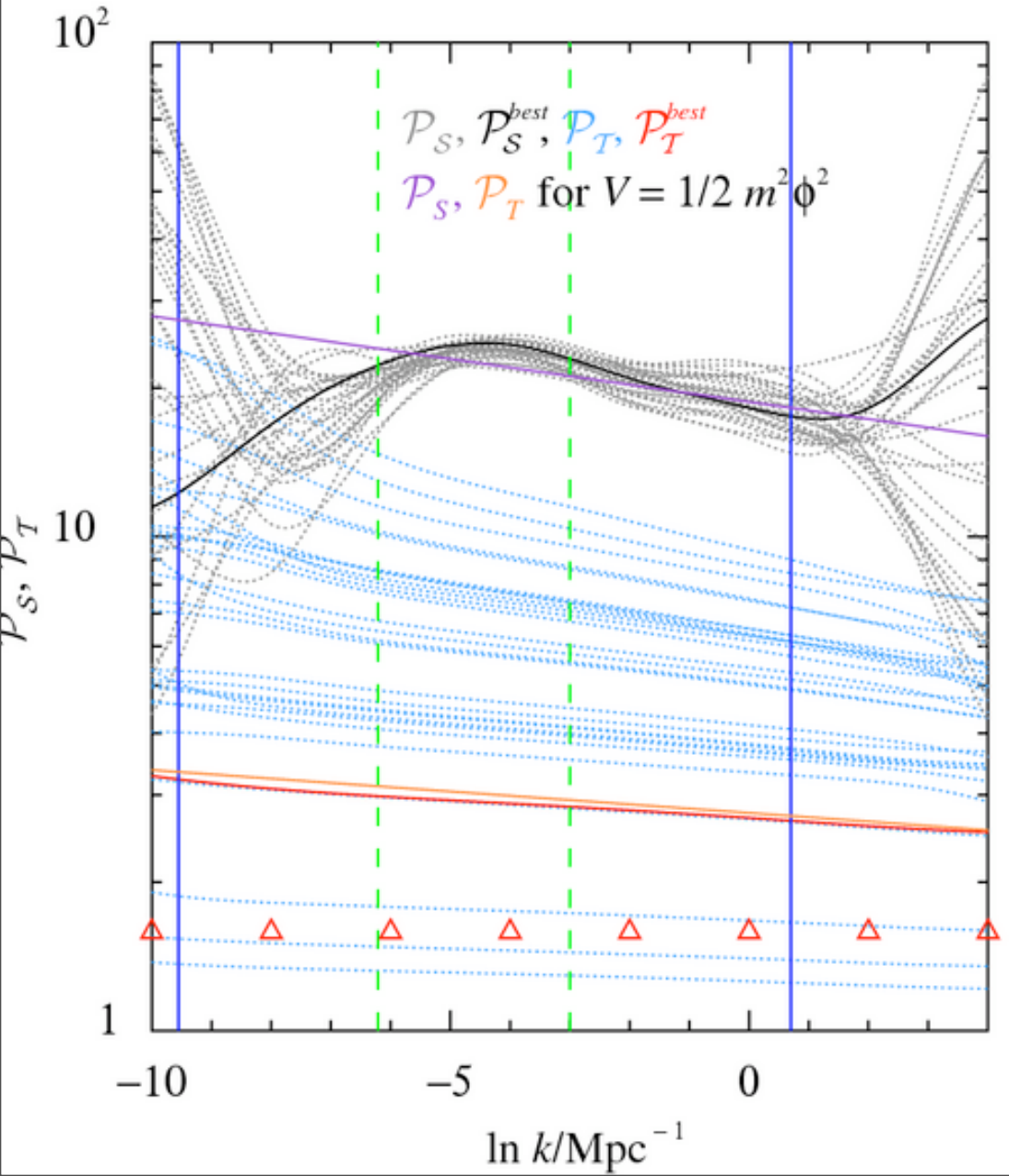
trajectory probability

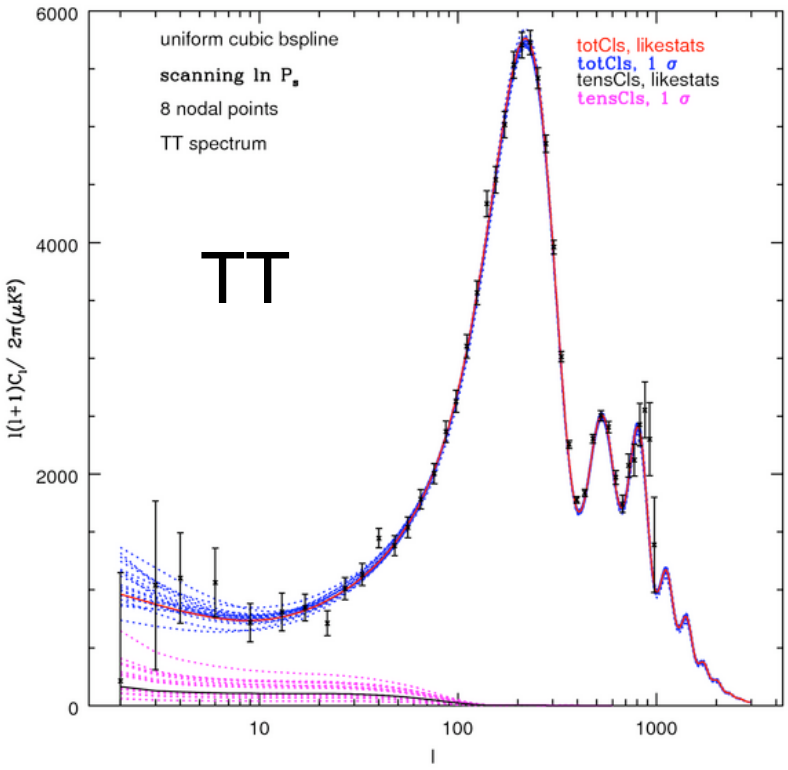
$-d\ln\rho_\phi/d\ln a/2$

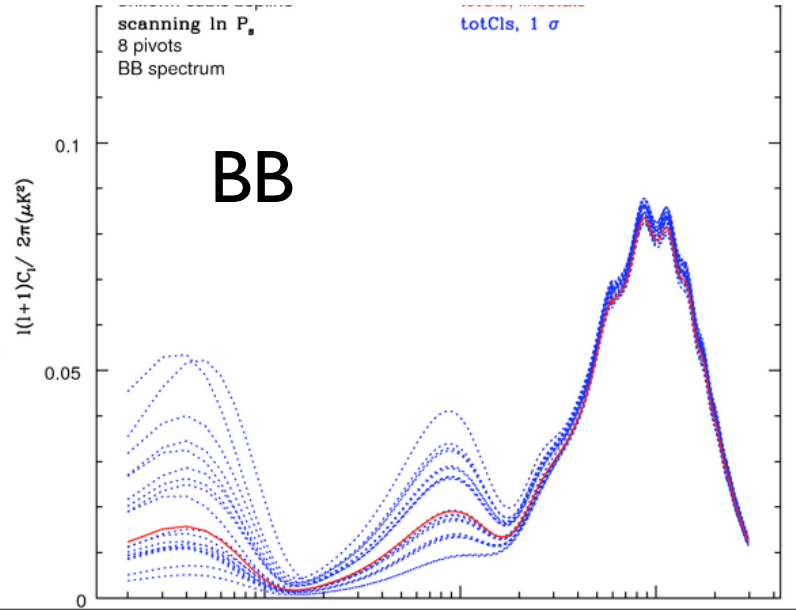
$=\varepsilon_\phi(a)=(1+w)2/3$

n_b/n_γ ρ_{dm}/ρ_b z_{eq}/z_{rec} ρ_{curv} ρ_{de}/ρ_{dm} $\rho_{de}\sim H^2M^2_{Planck}$ $\rho_{m\nu}/\rho_{stars}$

partially-blind acceleration trajecteries obeying tensor/scalar consistency relation. May08 data







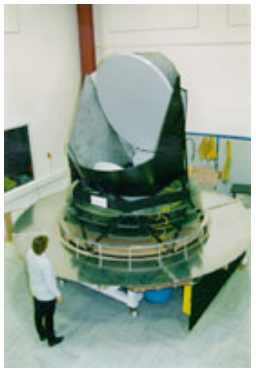
INFLATION
THEN

PROBES
THEN

Can we measure GW/scalar curvature: r to +- .02 **PL2.5+Spider; Bpol .001 ?**

BUT foregrounds/systematics? But **r(k), low Energy inflation**

Planck1 simulation: input LCDM (Acbar)+run+uniform tensor



blind order 5 expansions analysis recover input r to r ~0.05

and P_s P_t reconstructed

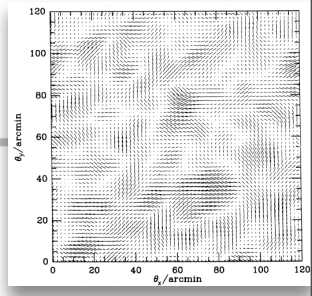
input of LCDM with scalar running & r=0.01 to 0.5

B-pol simulation: ~10K detectors > 100x Planck

stringent test of the ε-trajectory method: input recovered to r <0.001

SPIDER Tensor Signal

Pillar 7
Gravity Waves from Inflation

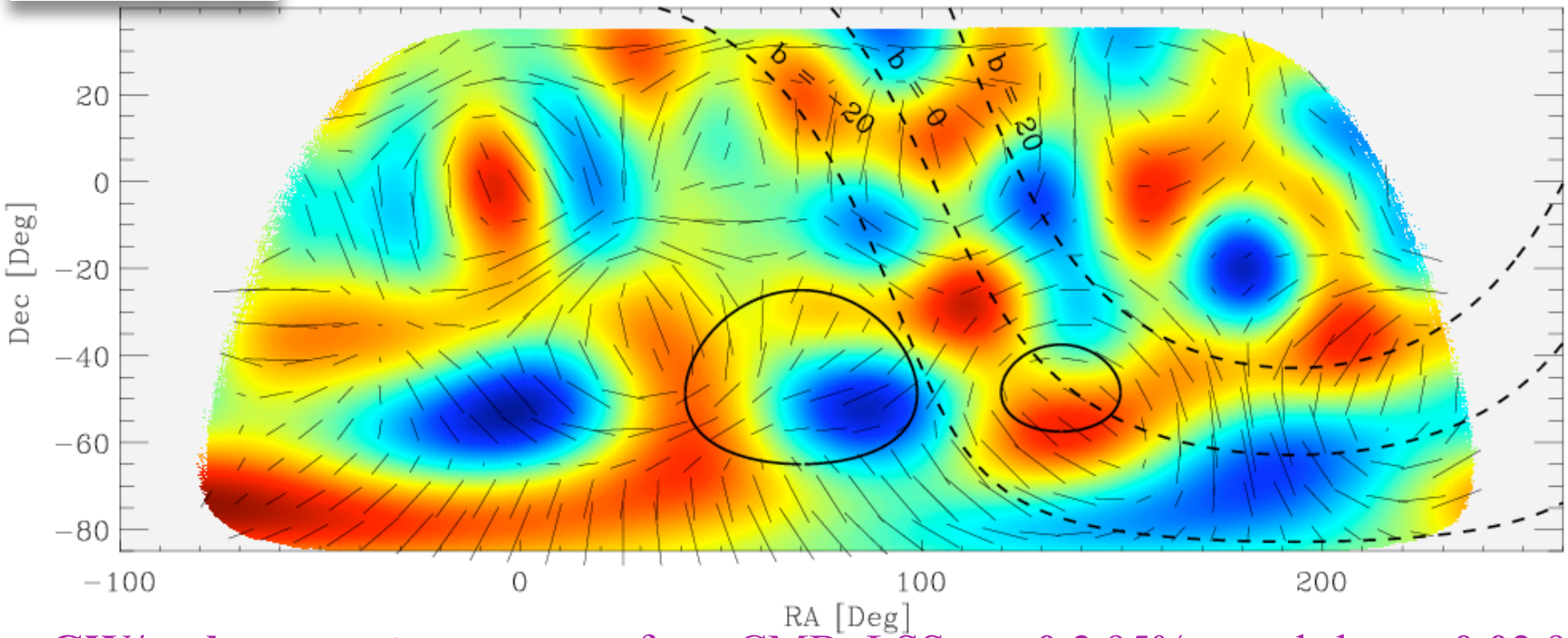


- **Simulation of large scale polarization signal**

http://www.astro.caltech.edu/~lgg/spider_front.htm

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

No Tensor



GW/scalar curvature: current from CMB+LSS: r < **0.3** 95%; good shot at **0.02** 95% CL with **BB polarization** (+- **.02 PL2.5+Spider**), **.01 target; Bpol .001** BUT foregrounds/systematics? But **r(k), low Energy inflation**

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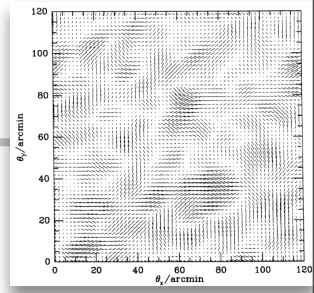

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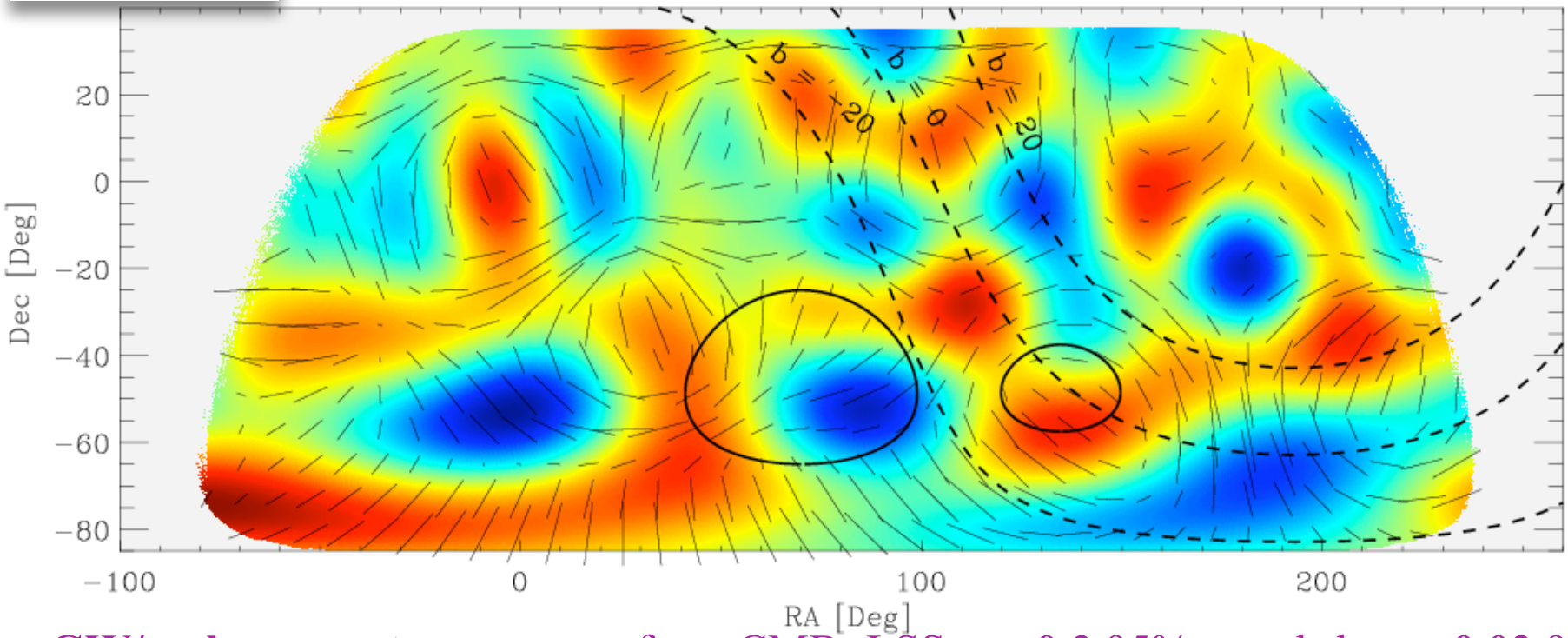

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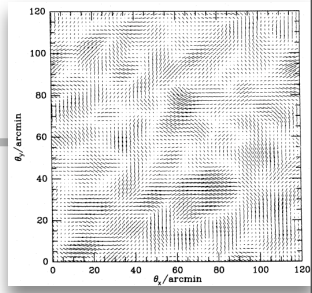

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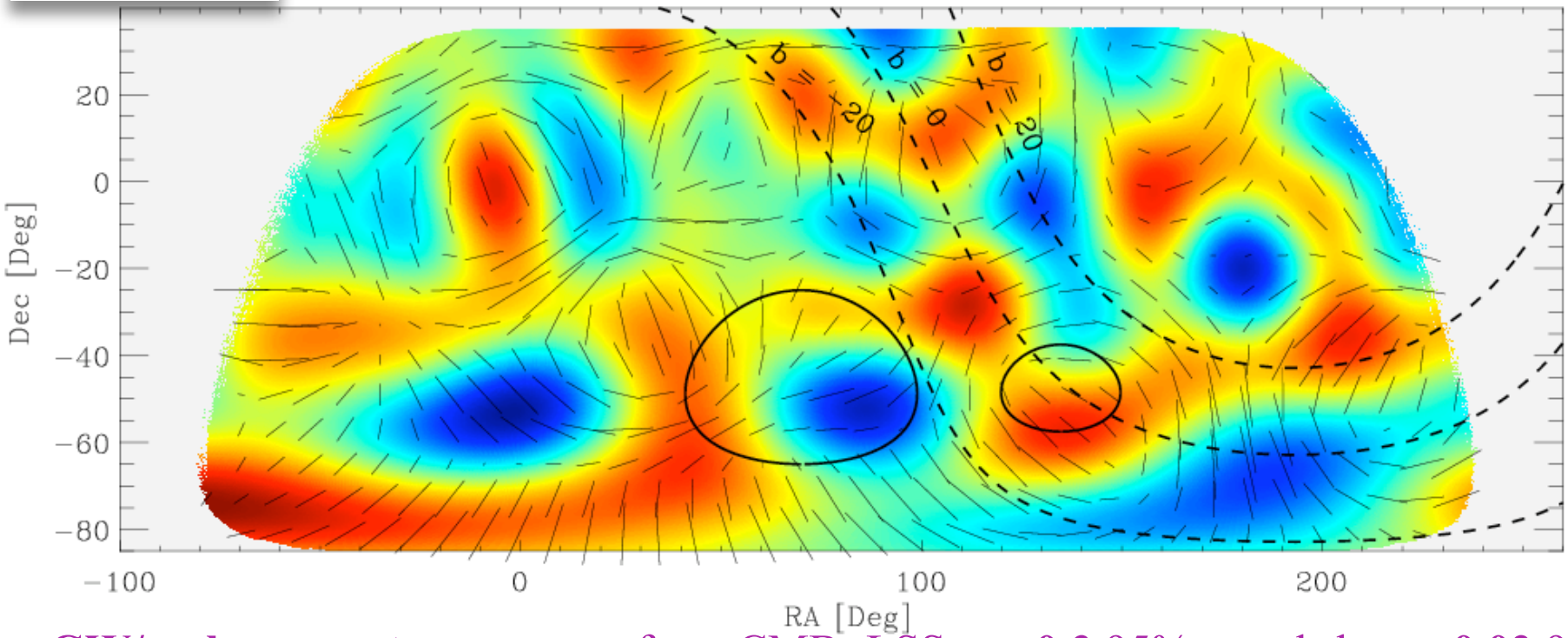

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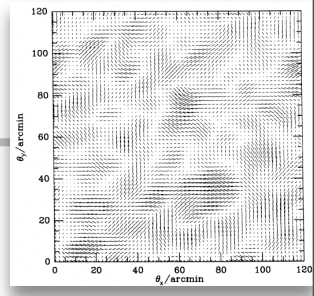

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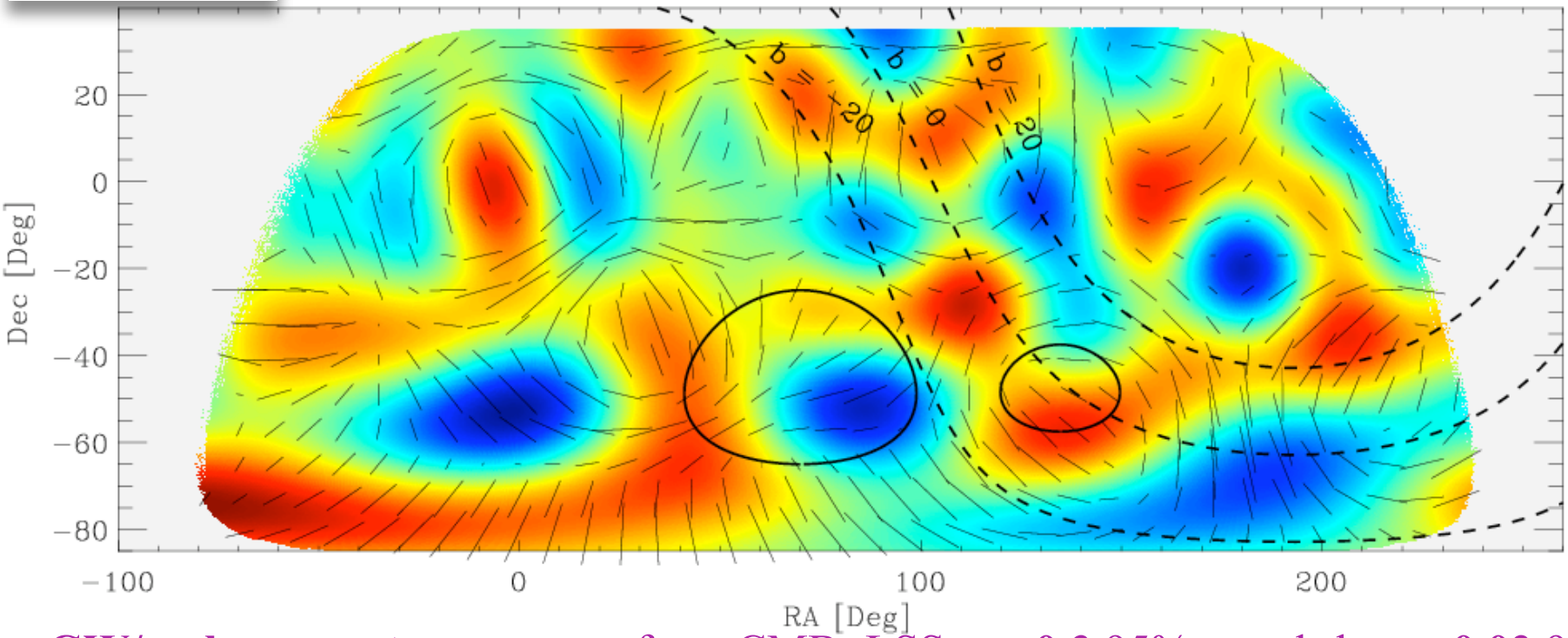

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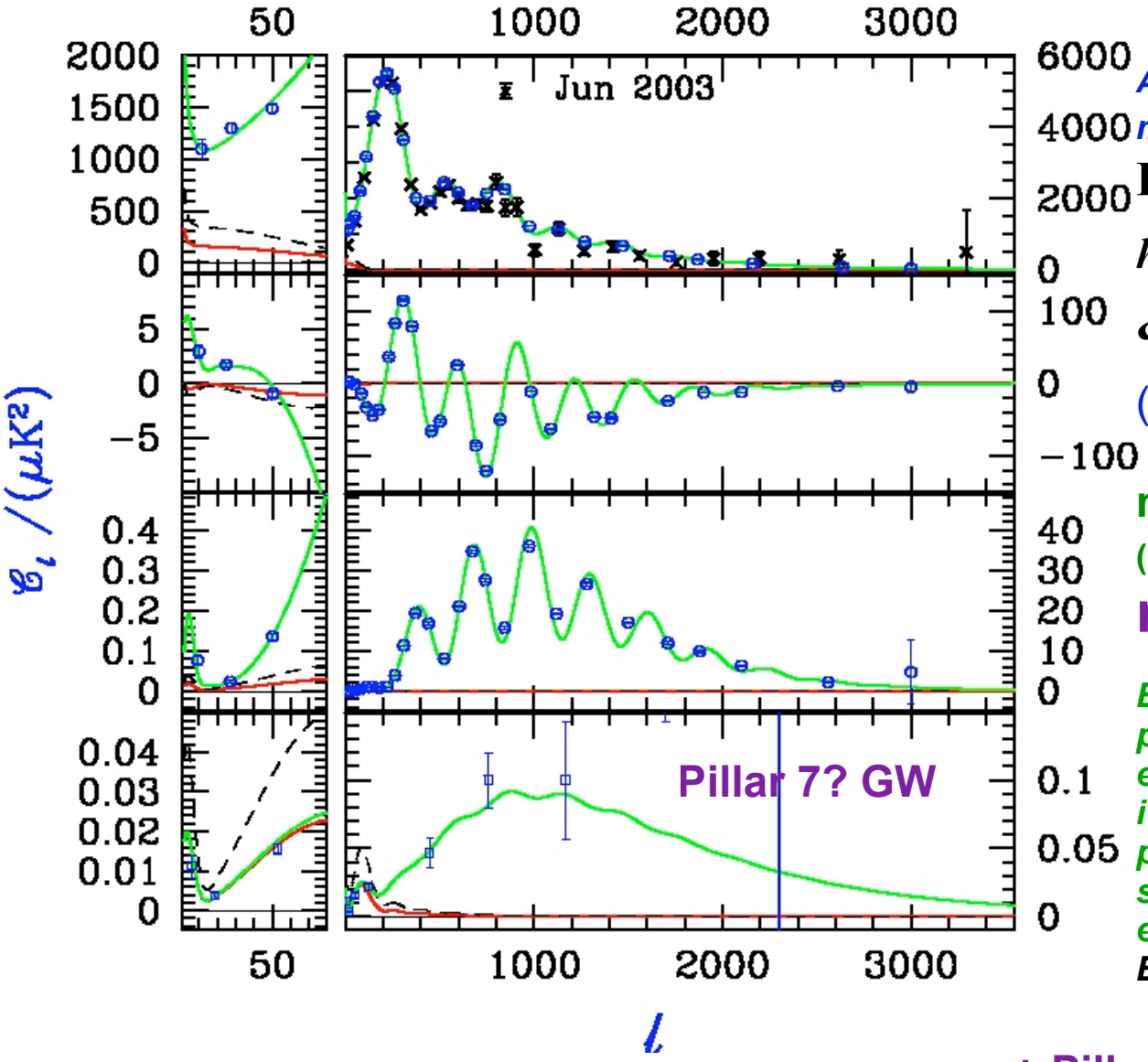
PRIMARY END @ 2012?



Pillar 7? Gravity Waves

An ensemble of trajectories arises in many-moduli string models.

Roulette inflation: ***complex hole sizes in 6D*** TINY **$r<10^{-10}$** ***& data-selected braking*** **n_s** (‘theorem’: $\Delta\psi<1$ -> **$r<.007$**)

nearly uniform acceleration (power law, exp, PNGB, ..potentials)

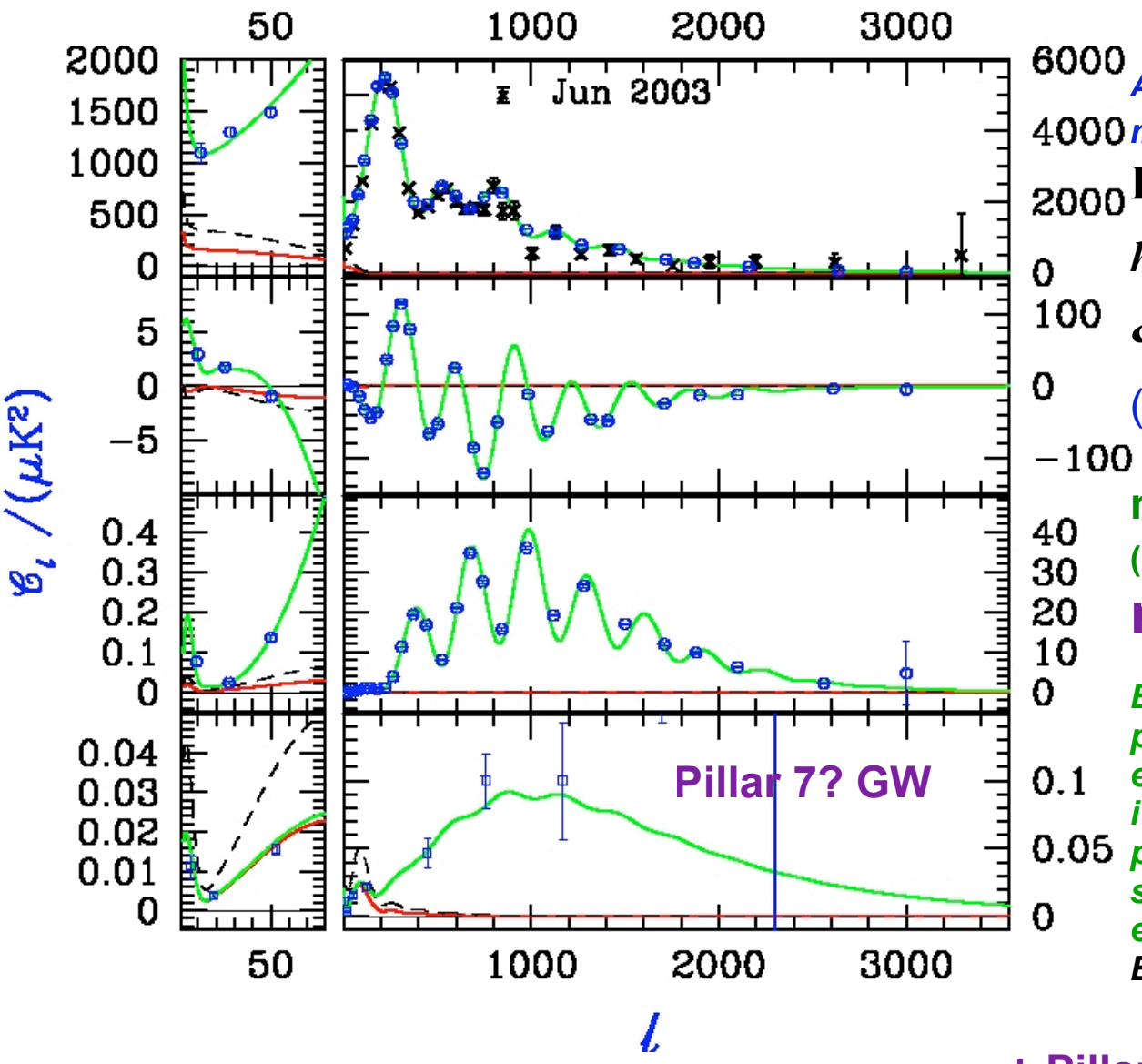
$r\sim.03$-.3 is $\Delta\psi\sim10$ deadly?

Even with low energy inflation, the prospects are good with Spider and even Planck to either detect the GW-induced B-polarization or set a powerful upper limit to point to stringy or other exotic models. Both experiments have strong Cdn roles. Bpol is ~ 20x0

+ Pillar 4: level of non-Gaussianity

PRIMARY END @ 2012?

CMB ~2009+ Planck1+WMAP8+SPT/ACT/Quiet+Bicep/QuAD/Quiet +Spider+Clover



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end