

CIAR Cosmology & Gravity Program 1986-2012 +

The Cosmic Quest for Fundamental Physics

12 fellows (all but 3 new/repatriated Cdns)

1 institute fellow

6 scholars (all new/repatriated Cdns)

all in Canada (UVic, UBC, UofA, McMaster, PI, UofT, CITA, Queens, McGill)

22 Associates

US, UK (4), Canada (3, incl 2 ex-fellows)

7 Board Members (treated as associates for interaction)

US (4), Germany (1), Canada (2)

+ 47 PDFs, 51 grad students (+ undergrads) in Canada

i.e. a big program, but also a VERY successful program in all aspects

Directors: Unruh 86-96 – Tremaine 96-02 – Bond 02-12

Cosmology and Gravity Program Advisory Committee

British Columbia

Matthew Choptuik, Fellow
University of British Columbia
Henk Hoekstra, Scholar
University of Victoria
Werner Israel, Fellow
University of Victoria
Julio Navarro, Fellow
University of British Columbia
William G. Unruh, Fellow
and Founding Program Director
University of British Columbia
Ludovic Van Waerbeke, Scholar
University of British Columbia

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(Chair)
Department of
Astrophysical Sciences
Princeton University

Roger Blandford
Department of Physics
Stanford University

Gary Horowitz
Department of Physics
University of California
at Santa Barbara

Art McDonald
SNO Institute
Department of Physics
Queen's University

Chris Pritchett
Department of Physics
and Astronomy
University of Victoria

Paul Steinhardt
Department of Physics
Princeton University

Simon White
Max-Planck-Institut
für Astrophysik

Alberta

Valeri Frolov, Associate
University of Alberta
Don Page, Associate
University of Alberta
Frans Pretorius, Scholar
University of Alberta

Ontario

J. Richard Bond, Fellow,
and Program Director
CITA/University of Toronto
Ray Carlberg, Fellow
University of Toronto
Mark Chen, Fellow
Queen's University
Hugh Couchman, Fellow
McMaster University
Lev Kofman, Fellow
CITA/University of Toronto
Robert Myers, Fellow
Perimeter Institute for Theoretical
Physics, and University of Waterloo
Barth Netterfield, Fellow
University of Toronto
Amanda Peet, Scholar
University of Toronto
Ue-Li Pen, Fellow
CITA/University of Toronto
Christopher Thompson, Associate
CITA/University of Toronto

Quebec

Andrew Cumming, Scholar
McGill University
Gilbert Holder, Scholar
McGill University
Victoria Kaspi, Fellow
McGill University

International

Lars Bildsten, Associate
Univ. of Cal., Santa Barbara, USA
George Efstathiou, Associate
University of Cambridge, UK
Richard Ellis, Associate
California Institute of Technology, USA
Wendy Freedman, Associate
Carnegie Observatories, USA
Carlos Frenk, Associate
University of Durham, UK
David Garfinkle, Associate
Oakland University, USA
Shamit Kachru, Associate
Stanford University, USA
Nicholas Kaiser, Associate
University of Hawaii, USA
Renata Kallosh, Associate
Stanford University, USA
Luis Lehner, Associate
Louisiana State University, USA
Simon Lilly, Associate
ETH Zurich, Switzerland
Andrei Linde, Associate
Stanford University, USA
P. James E. (Jim) Peebles, Associate
Princeton University, USA
Joseph Silk, Associate
University of Oxford, UK
Eva Silverstein, Associate
Stanford University, USA
Leonard Susskind, Associate
Stanford University, USA
Alexander Szalay, Associate
Johns Hopkins University, USA
Robert Wald, Associate
University of Chicago, USA

Cosmology & Gravity Program 20th Year External Review June 11-13, 2006

Dr. Bruce Winstein (Chair)
Laboratory for Astrophysics and Space Research
University of Chicago

Dr. Charles Akroff
Harvard-Smithsonian Center for Astrophysics
Harvard University

Dr. L. Samuel Finn
Center for Gravitational Wave Physics
Pennsylvania State University

Dr. Edward (Rocky) Kolb
Particle Astrophysics Center
Fermi National Accelerator Laboratory

Dr. Ramesh Narayan
Harvard-Smithsonian Center for Astrophysics
Harvard University

Dr. Bernard Schutz
Astrophysical Relativity Group
Max Planck Institute for Gravitational Physics

Dr. Stephen Shenker
Stanford Institute for Theoretical Physics
Stanford University

Dr. W. John McDonald
(CIAR Research Council representative)
Professor Emeritus
Department of Physics
University of Alberta

**CIAR is a fundamental “Pillar of Support” of
CITA, one of 3 NSERC, Arts & Science@UofT**

CIAR Cosmology and Gravity Program

✓ **critical node of the CIAR Cosmology and Gravity Program
(the 3 Fellows Bond, Kofman, Pen will continue 2007-12.
Current Associate Thompson will likely become a Fellow.
Possibility of Scholar for the CRC II Roman Rafikov
replacement if the field is right (e.g., HEA)**

CIAR's Cosmology & Gravity role in recruitment/retention in Canada

- J. Navarro**, University of Victoria **CITA**  **ICAT** Council
- H. Hoekstra**, University of Victoria **CITA**  **ICAT**
- M. Choptuik**, University of British Columbia **CITA**  **ICAT**
- I. Affleck**, University of British Columbia
- L. van Waerbeke**, University of British Columbia **CITA**  **ICAT**
- D. Page**, University of Alberta
- F. Pretorius**, University of Alberta **CITA**  **ICAT**
- V. Frolov**, University of Alberta
- H. Couchman**, McMaster University **CITA**  **ICAT**
- R. Bond**, University of Toronto **CITA**  **ICAT**
- B. Netterfield**, University of Toronto
- A. Peet**, University of Toronto
- L. Kofman**, University of Toronto **CITA**  **ICAT**
- U. Pen**, University of Toronto **CITA**  **ICAT**
- M. Chen**, Queen's University
- V. Kaspi**, McGill University
- G. Holder**, McGill University **CITA**  **ICAT**
- A. Cumming**, McGill University

Retention

Bond, Carlberg, Navarro, (Kaiser Lilly Tremaine)
CITA  **ICAT** **CITA**  **ICAT** **CITA**  **ICAT**

String theory

branes & compactified extra dimensions

the landscape

“environmental selection”
anthropic

emergence of space/time

Particle Astrophysics

Experiment

SNOlab, LHC

Physical cosmology

Early universe physics & Inflation

Dark matter, Dark Energy probes

Cosmic Microwave Background

Redshifted 21 cm

Galaxy formation & properties

Large scale structure

Weak lensing, z-surveys

Supernovae

Clusters in CMB, optical, X

Strong Gravity

Strings

Early Universe

Black holes

HEA

Numerical relativity

colliding black
holes in 3D

High Energy Astrophysics

neutron stars

Black holes

High energy cosmic rays

Magnetars, double pulsars

Gravity Waves

CMB/LSS Phenomenology [CITA/CIAR there](#)

[CITA/CIAR here](#)

[UofT here](#)

• **Mivelle-Deschenes (IAS)**

• Dalal

• Netterfield

• **Pogosyan (U of Alberta)**

• Bond

• Dore

• Carlberg

• **Prunet (IAP)**

• **Contaldi**

• Kesden

• Yee

• **Myers (NRAO)**

• **Lewis**

• MacTavish

• **Holder (McGill)**

• Sievers

• Pfrommer

• **Hoekstra (UVictoria)**

• Pen

• Shirokov

• **van Waerbeke (UBC)**

• McDonald

[& Exptal/Analysis/Phenomenology
Teams here & there](#)

• Majumdar

• Boomerang03

Parameter datasets: CMBall_pol

• Nolta

• Cosmic Background Imager

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

• Iliev

• Acbar06

**Weak lens (Virgos/RCS1;
CFHTLS, RCS2)**

• Kofman

• WMAP (Nolta, Dore)

Lya forest (SDSS)

• Vaudrevange

• CFHTLS – WeakLens

SN1a “gold”(157,9 $z > 1$), CFHTLS

Prokushkin

• Huang

• CFHTLS - Supernovae

futures: ACT SZ/opt, Spider,

• El Zant

• RCS2 (RCS1; Virgos-Descart)

Planck, 21(1+z)cm

CBI pol to Apr'05

Bicep

Quiet2

CBI2 to Apr'07 (1000 HEMTs)

Acbar to Jan'06

QUaD

Quiet1 Chile

APEX

SCUBA2

Spider

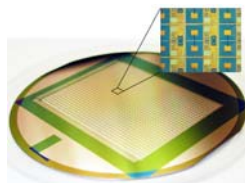
(~400 bolometers)

(12000 bolometers)

(2312 bolometer LDB)

SZA

Chile



JCMT, Hawaii

ACT

Clover

(Interferometer)
California



(3000 bolometers)

Chile

2017
CMBpol

Boom03

2003

2005

2007

2004

2006

2008

WMAP ongoing to 2009

SPT

ALMA

DASI

(1000 bolometers)
South Pole

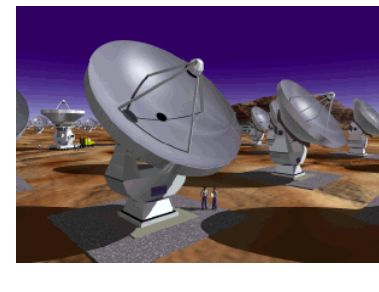
(Interferometer)
Chile

Polarbear

Planck

CAPMAP

(300 bolometers)
California



AMI

(84 bolometers)
HEMTs L2


GBT

2.2 Selected Research Highlights 2001-2006

2.2.1 Physical Cosmology:

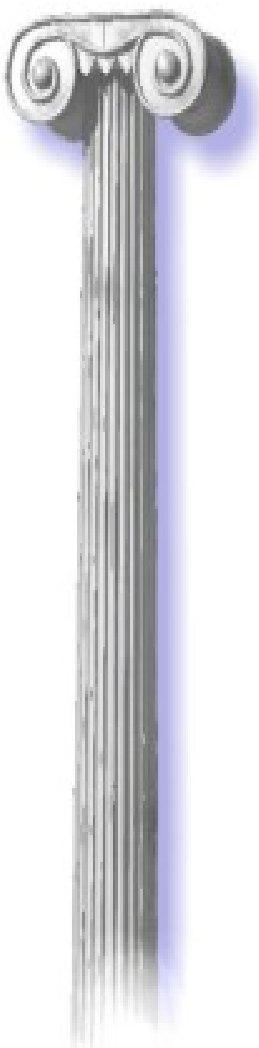
2.2.1a CMB Primary CMB Anisotropies **CITA** **ICAT**

Boomerang 2001, CBI 2002, Boomerang 2002, Acbar 2002, CBI 2004, CBI 2006

CMB Polarization CBI 2004, Boomerang 2005, CBI 2005 **CITA**  **ICAT**

Secondary CMB Anisotropies CBI 2002/04/06 + **CITA**  **ICAT**

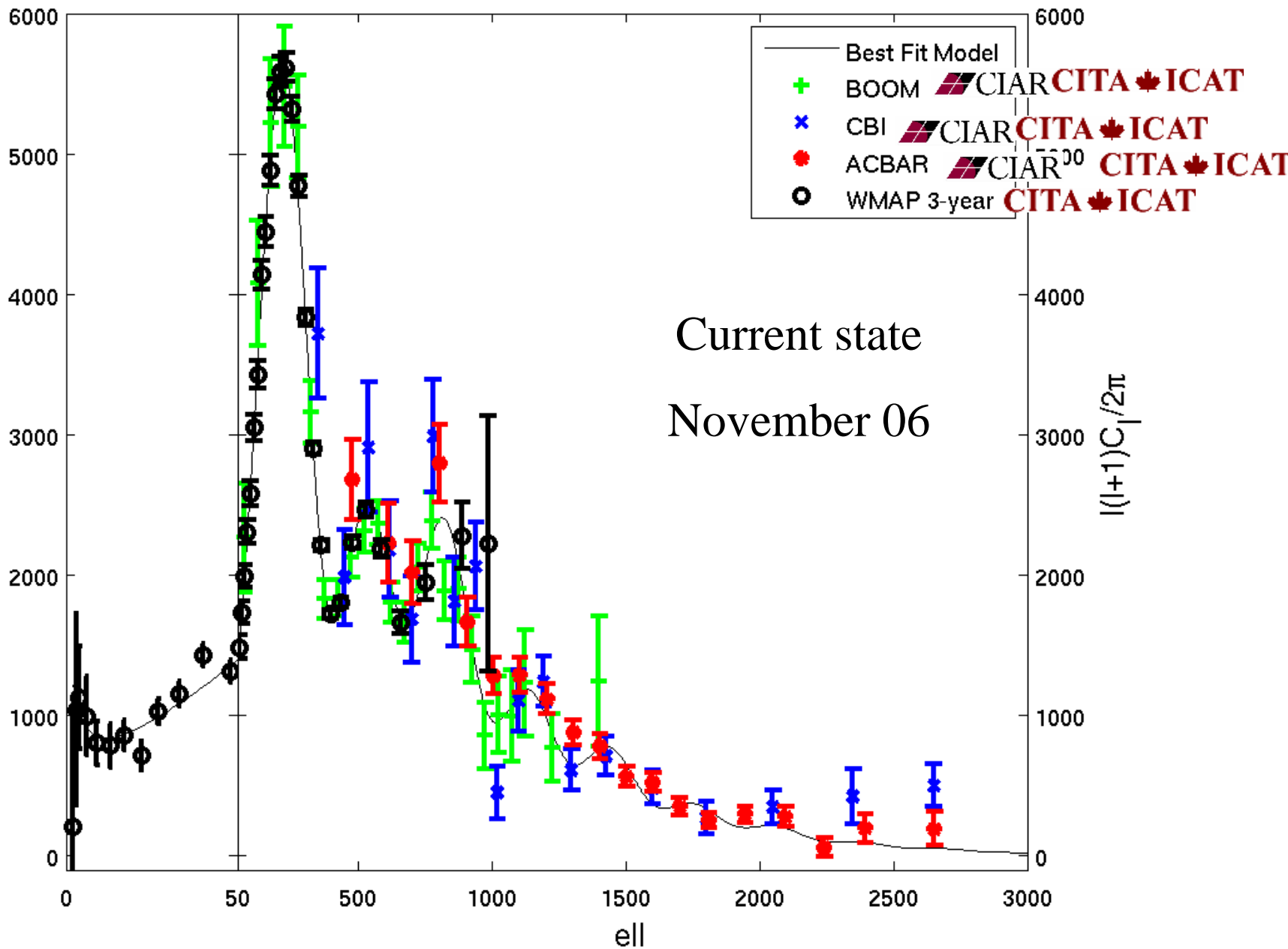
7 pillars
of
Inflation
in the
CMB (6?)

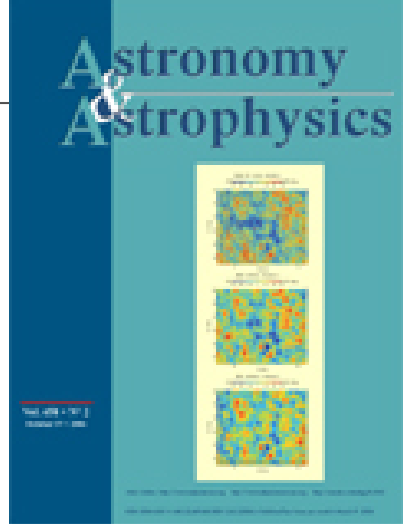
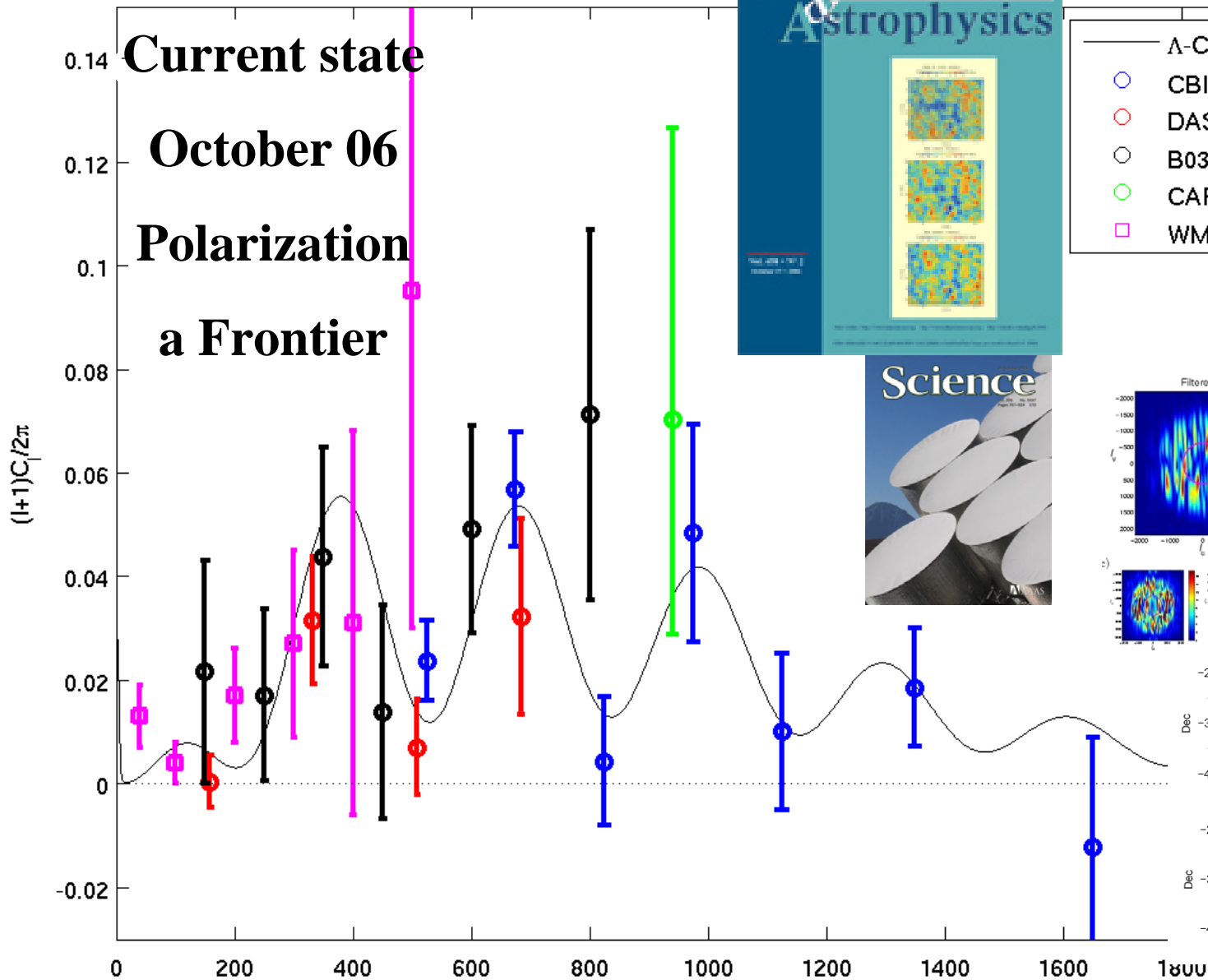


- 1: **large scale gravitational potential** *Sachs-Wolfe*
(*COBE/DMR, FIRS 1992, ...*)
- 2: **acoustic peaks/dips** *Geometry of the Universe 222 +/- 3*
(**1st pk:** *Apr'99 data, Toco, Boom-NA, Boom+Maxima 2000*)
multiple peak/dip pattern *passive/coherent/adiabatic*
(**2nd, 3rd peak, 1st, 2nd dip:** *Boom+DASI 2001*)
(**2nd, 3rd, 4th, 5th peaks, 3rd, 4th dips** at 1-sigma: *CBI 2002*)
- 3: **damping tail** *shear viscosity, width of recombination,*
 $L_D = 1358 \pm 22$, $R_D = 10 \pm 3$ Mpc; $R_S = 145 \pm 2$ Mpc
(*CBI 2002*) *also epoch of reionization*
- 4: **polarization:** *Must be there at the ~ 7% level. Now seen.*
(*DASI 2002, Pique, 2003 CBI, B2K2, MaxiPol, Map, ...*)
- 5: **Gaussian Primary Anisotropies:** *DMR, Maxima, Boom, CBI 02*
- 6: **Secondary anisotropies:** *Must be there, SZ thermal, kinetic, weak lensing, inhomogeneous reionization CBI, BIMA*
- 7: **Tensor perturbations:** *induced by gravity wave quantum noise. too small to detect? Primary B-mode Polarization*

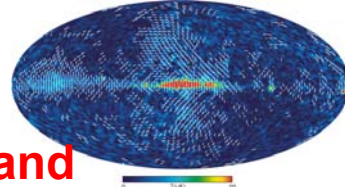
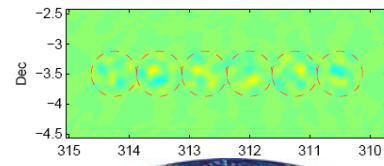
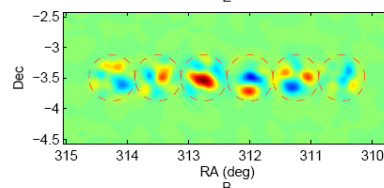
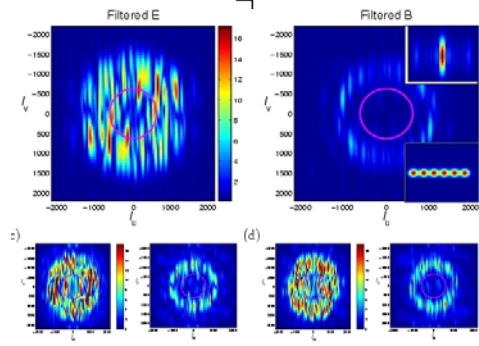
Pre-WMAP1
slide

< 2003.2



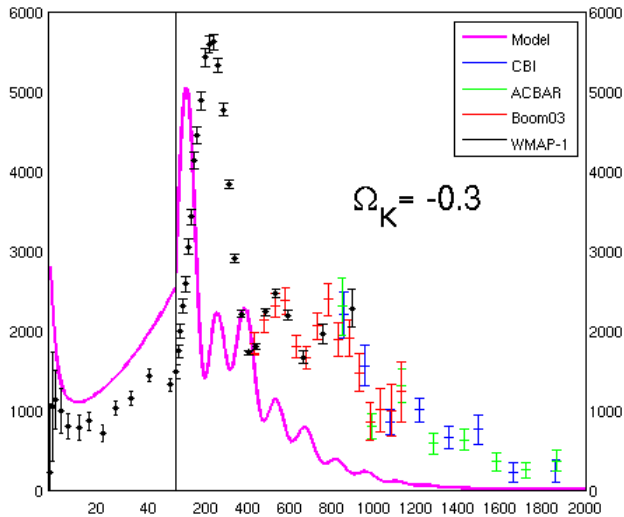


- Λ -CDM
- CBI CITA
- DASI
- B03 CITA
- CAPMAP
- WMAP-3 ICAT



WMAP3 V band

Does TT Predict EE (& TE)? (YES, incl wmap3 TT)



Inflation OK: EE (& TE) excellent agreement with prediction from TT

pattern shift parameter 0.998 ± 0.003

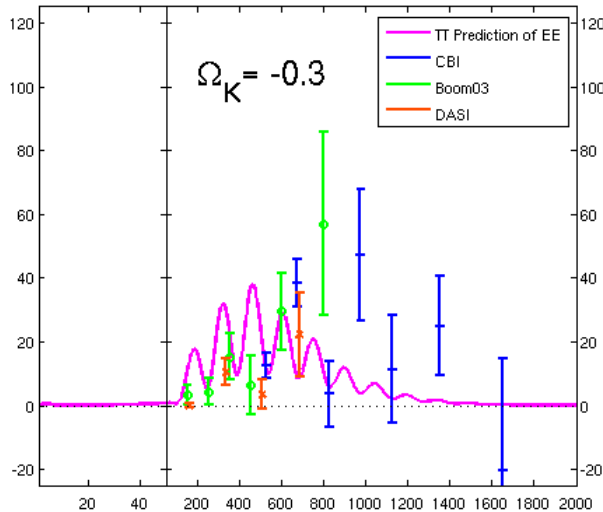
WMAP3+CBI+DASI+B03+ TT/TE/EE

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%

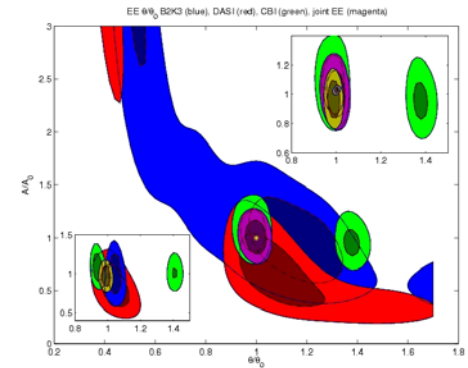


EE: 0.973 ± 0.033 , phase check of CBI

EE cf. TT pk/dip locales & amp **EE+TE**


0.997 ± 0.018 CBI+B03+DASI

(amp= 0.93 ± 0.09)



2.2.1b Supernovae, Weak Gravitational Lensing and Large Scale Structure:

CFHTLS supernova, first paper Fall 2005, much bigger than the competitor ESSENCE

CFHTLS weak lensing, first paper Fall 2005 **CITA**  **ICAT**

Earlier RCS1, Virmos-Descart **CITA**  **ICAT**

Through associates, connected to 2dF and SDSS **CITA**  **ICAT** as well

2.2.1c Forming Galaxies

Very large simulations **CITA**  **ICAT**

Dark matter distribution in galaxies **CITA**  **ICAT**

Redshifted 21 cm **CITA**  **ICAT**

Other (e.g. Julio's galaxy streams)

2.2.2 String/M-theory, Strong Quantum Gravity and Early and Late Universe Ideas

Landscape, associates

Inflation developments, including preheating **CITA**  **ICAT**

2.2.3 High Energy & Particle Astrophysics, Gravity Waves & Numerical Relativity

CITA  **ICAT**

CITA  **ICAT**

2.2.3a Particle Physics and Astrophysics

SNO

2.2.3b Compact Objects

Magnetars Thompson **CITA**  **ICAT** as AXP, Kaspi

Double psr theory, Thompson **CITA**  **ICAT**

2.2.3c Computational Gravity

3D colliding holes, 2005-06 **CITA**  **ICAT**

Black strings

2.3 Interactions, Annual Meetings, Conferences and Focus Groups

Associate/Fellow/Scholar Exchanges

Annual meeting

Focus groups - been successful

CIAR C&G Role in Larger Meetings

Connecting Canadian & International Networks

2.4 Awards and National and International Recognition 2001-2006

alot/enough – we are a reasonably distinguished crew by any standards

2.5 Leadership Role

strong, in Canada especially e.g., CITA, TMT, CFHTLS, SciNet, SharcNet, Planck (BLAST, Boomerang03), C4

2.6 Research Training

Very good, e.g., 47pdfs/51 grad students snapshot for 2004-05

2005

Annual Program meeting, Mt. Tremblant, Quebec March 3-7, 2005 (Organizer: D. Bond), 39 participants including 11 guests

“Gravity: The Dark Side of Extra Dimensions”, May 12-14, 2005, BIRS, Banff (Organizers: V. Frolov, D. Page). The organizing committee members and 6 of the invited speakers were Program members. This meeting attracted 43 participants, including 7 other program members.

“Black Holes V: Theory and Mathematical Aspects”, May 14-18, 2005, Alberta (Organizers: V. Frolov, D. Page, A. Zelnikov). Two of the organizing committee members and 7 of the invited speakers were Program members This meeting attracted 80 participants, including other program members.

“Theory Canada I”, June 3-5, 2005, UBC (Organizers: M. Paranjape, Montreal and R. MacKenzie, M. Shegelski)

“Strings 2005”, July 11-16, 2005, Toronto (Organizers: R Myers, A. Buchel, J. Gomis, K. Hori, A. Peet). This open meeting attracted over 400 participants. Seven program members were invited speakers and several other members of the program attended.

“Neutron Stars at the Crossroads of Fundamental Physics”, Summer, 2005, UBC (organizer: J. Heyl, V. Kaspi, F. Ozel, K. Rajagopal, C. Thompson, M. van Kerkwijk, UBC). Two members of the organizing committee and 5 of the invited speakers were Program members. This meeting attracted 49 participants.

Cosmology and Fundamental Physics, PI, October 2005 (Organizer: R. Myers etal.)

Focus Group Meetings

“Double Pulsar Focus Workshop”: Jan. 26-29, 2005, Toronto (Organizer: C. Thompson)

“HPC: Numerical astrophysics & relativity & Canada's supercomputing future”, January 2005, Toronto (Organizer: U-L. Pen)

“Early Universe/Strings: joint PI/CITA/UofT/McMaster”: April 2005, Waterloo (Organizers: L. Kofman, R. Myers, D. Bond)

“Cosmological Radiative Transfer”: CITA, May 12-14, 2005 (Organizer: I. Iliev, CITA)

“Flash Workshop”: CITA, March 23-24, 2005 (Organizer: J. Dursi, CITA)

“HEA: X-ray satellites and the Canadian Space Agency”, March 2005, McGill (Organizer: V. Kaspi)

“Gravitational Aspects of String Theory”: May 2-6, 2005 (Organizer: A. Peet)

“Early Universe Cosmology: joint PI/CITA/UofT/McMaster”, Dec. 2005, CITA (Organizers: L. Kofman, R. Myers, D. Bond)

2006 (as of June when the CIAR review occurred)

Annual Program meeting, Banff, Feb. 16-20, 2006 (Organizers: D. Bond, H. Hoekstra, L. van Waerbeke), 44 participants including 8 guests

Focus Group Meetings

“Observational HEA”, 2006, McGill (Organizer: V. Kaspi)

Clusters, Vancouver, April 2006 (Organizer: H. Hoekstra, G. Holder, L. van Waerbeke)

Unruh/Wald Fest, UBC, Aug. 2006 (Organizers: M. Choptuik, D. Garfinkle, D. Bond)

massively parallel computations in Canada @CIAR

CIAR C&G and SciNet, SharcNet, Westgrid, Tier I
computing in Canada

Very large datasets and data mining, statistical analysis
– in theory and experiment, simulation- nonlinear,
dissipative, feedback, of fields and particles, Monte
Carlo Markov Chain, probability landscapes

e.g., SciNet ~20K processors 2007, 1K 2006, 0.5K 2003 CFI

Simulation of theory / analysis of data, ~ 25% of bob cycles
used for CMB. With Spider, Planck, ACT demands increase to
meet the rising computing capability.

Renewal


3.1 General Goals

Dark energy, dark matter, inflation/string, extreme astrophysics

3.2 Core Research Directions and Sample Specific Goals

CMB: CBI2, Planck, Spider, ACT, Blast2, GBT, **CITA**  **ICAT** SPT

Weak lens CFHTLS **CITA**  **ICAT** snap/jdem/dune?, panstarrs through associate

Clusters: RCS2, ACT, **CITA**  **ICAT** SPT; galaxy structure RAVE; galaxy clustering

SN CFHTLS, jdem? **CITA**  **ICAT**

21 cm GMRT, CLAR, SKA **CITA**  **ICAT**

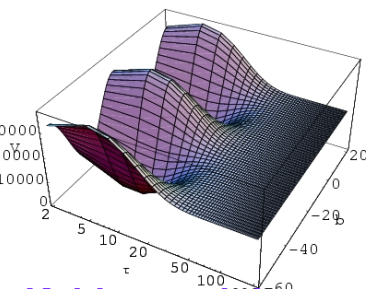
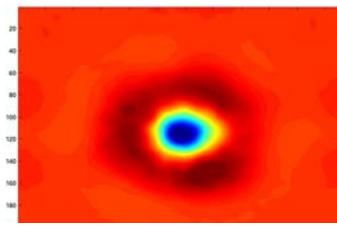
SNO2 solarnu, SNOlab DM **CITA**  **ICAT**

HEA: ALFA, POLAR?

Membership Strategy need to make some new appointments in 07-12: best people and targets of opportunity, any of our areas; HEA, GW and NR under-represented. Experimental cosmology under-represented.

CMBology

Probing the linear & nonlinear cosmic web



Kahler modulus
potential $T = \tau + i\theta$

Inflation Histories
(CMBall+LSS)

Secondary
Anisotropies (CBI, Acbar, ACT)
(tSZ, kSZ, reion)

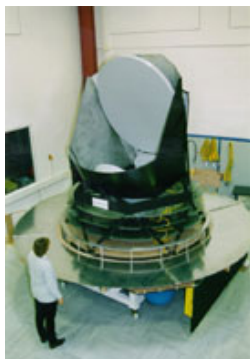
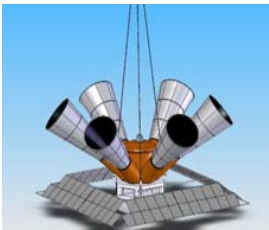
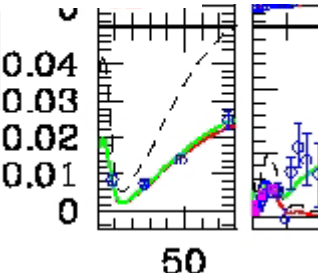
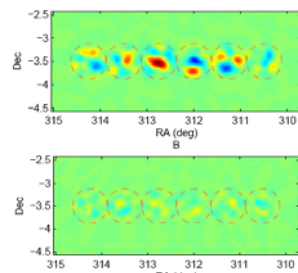
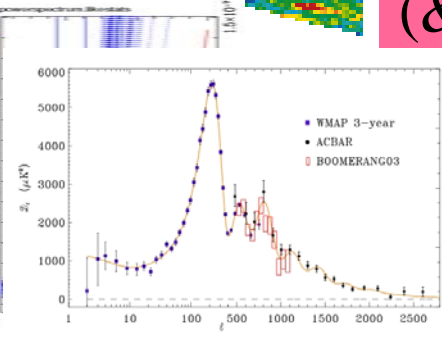
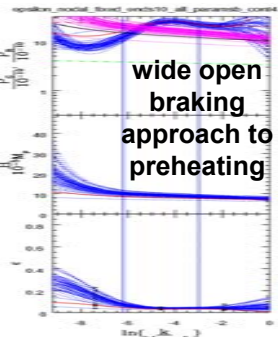
subdominant
phenomena
(isocurvature, BSI)

Foregrounds
CBI, Planck

Non-Gaussianity
(Boom, CBI, WMAP)

Polarization of
the CMB, Gravity Waves
(CBI, Boom, Planck, Spider)

Dark Energy Histories
(& CFHTLS-SN+WL)

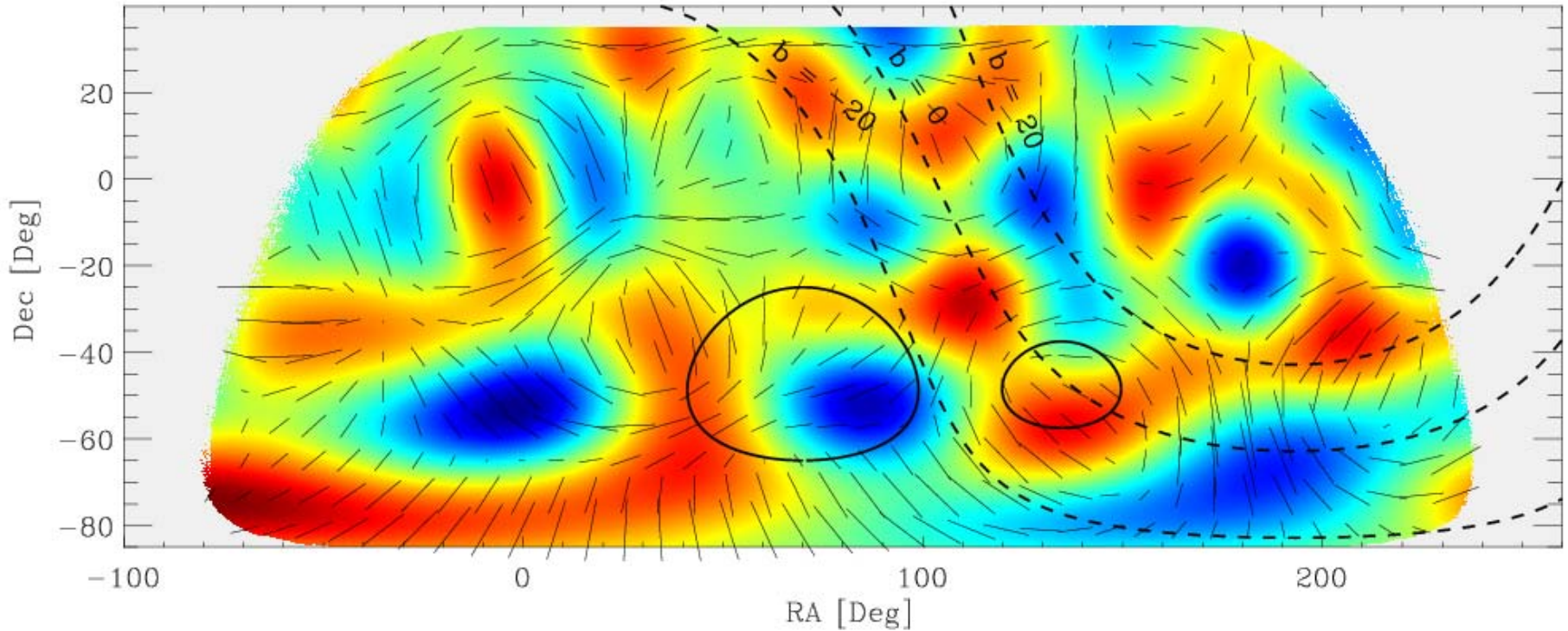


SPIDER Tensor Signal

- Simulation of large scale polarization signal

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

Non-Tensor



CBI2 “bigdish” upgrade June2006 + GBT for sources

Caltech, NRAO, Oxford, CITA, Imperial by about Sept07



σ_8 primary

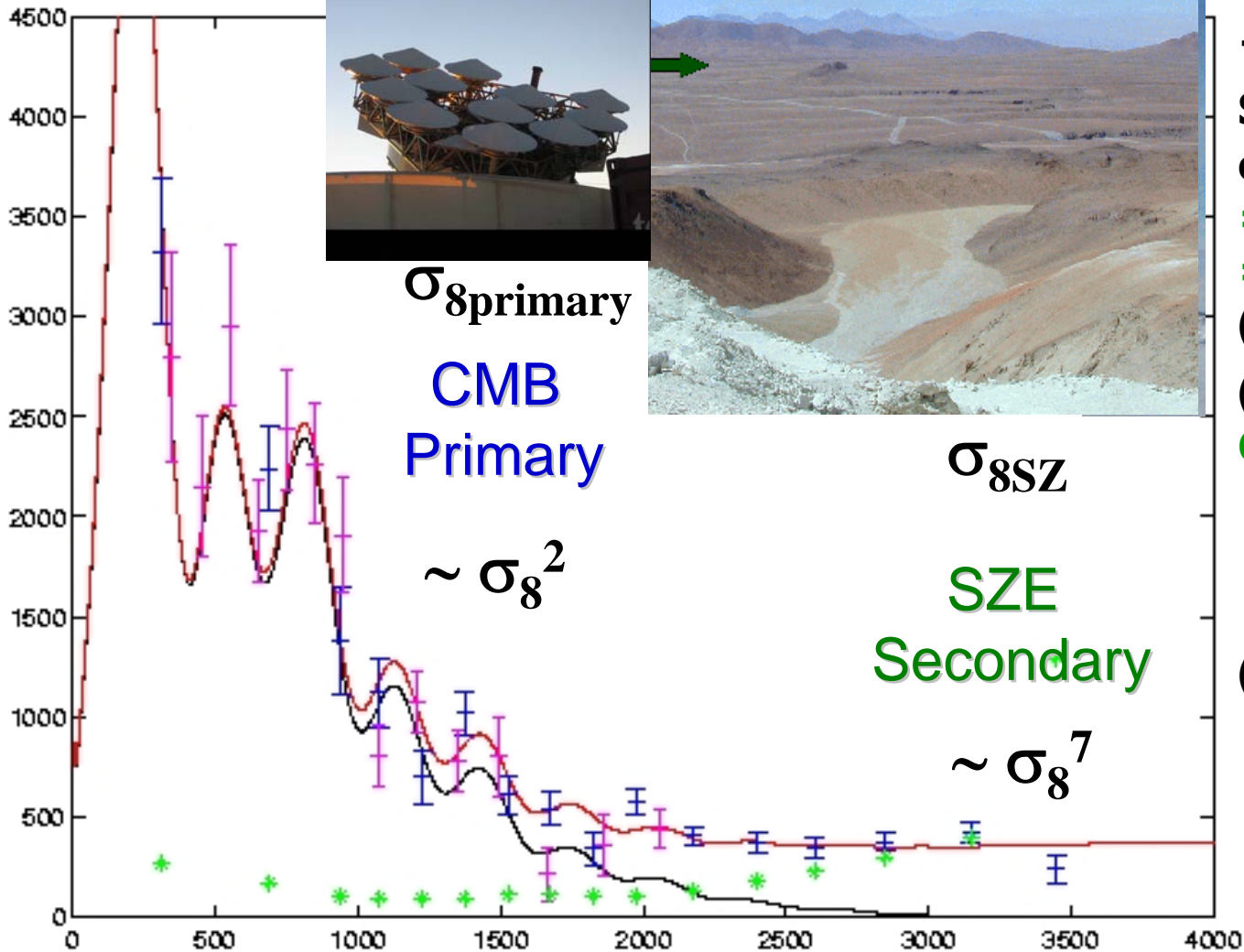
CMB
Primary

$\sim \sigma_8^2$

σ_8 SZ

SZE
Secondary

$\sim \sigma_8^7$



astroph/0611198

WMAP3'+B03+cbi
+acbar03+bima

Std 6 + σ_8 SZ⁷

σ_8 CMBall

= **0.78 ± 0.04**

= **0.92 ± 0.06** SZ

($\Omega_m = 0.244 \pm 0.031$)

($\tau = 0.091 \pm 0.003$)

CMBall+LSS

= **0.81 ± 0.03**

= **0.90 ± 0.06** SZ

($\Omega_m = 0.274 \pm 0.026$)

($\tau = 0.090 \pm 0.0026$)

CFHTLS lensing'05:
0.86 ± .05 + Virmos-
Descart & non-G

errors $S_8 = 0.80 \pm$
.04 if $\Omega_m = 0.3 \pm .05$

on the excess as SZ; (Acbar07); SZA, APEX, ACT, SPT will also nail it