

Dick Bond **CITA** Past, Present & Future of CMB in Canada

GRAND UNIFICATION OF THE CMB COMMUNITY?



Suzanne Staggs @ CIFAR17

=> Grand unification of the Canadian CMB community **Stage3** -> **Stage4**
ground-based, balloon, space => Canada in international teams = modus operandi

managing the CMB

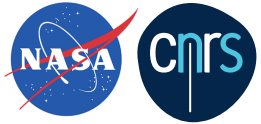
Stage 3 CMB
on to Stage 4 CMB



Advanced ACTPol
boomerang ~40/paper

planck

~250/paper, ~100 institutions



DTU Space
National Space Institute

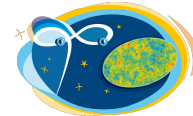
Science & Technology
Facilities Council

CSIC

National Research Council of Italy

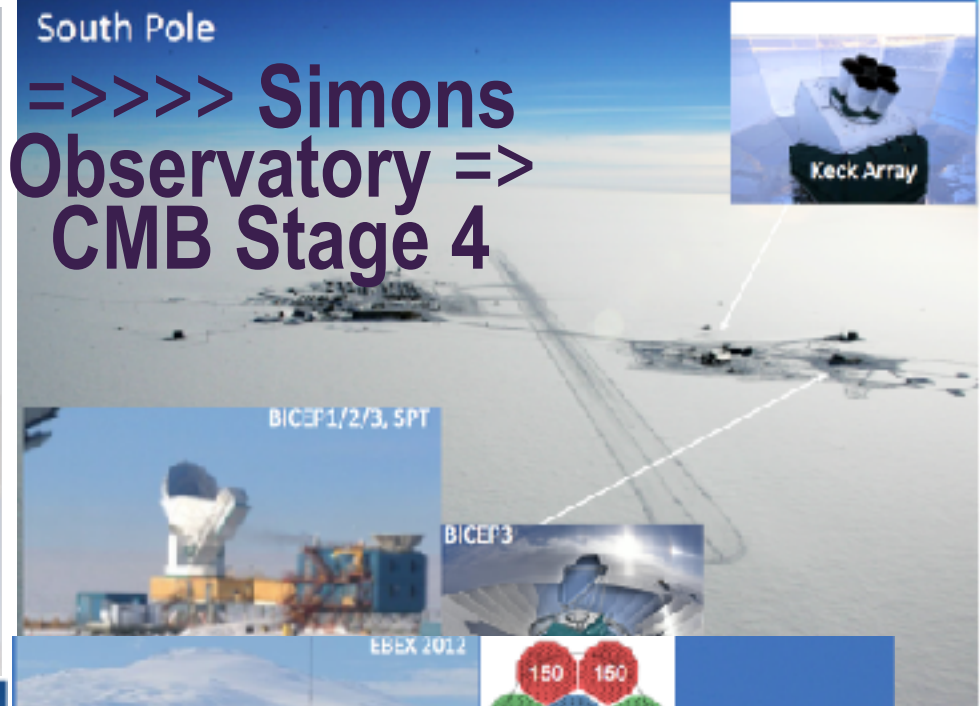
DLR
Deutsches Zentrum für Luft- und Raumfahrt e.V.

UK SPACE
AGENCY

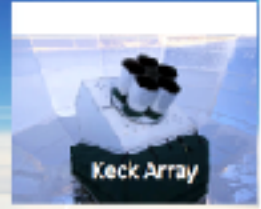




Atacama



South Pole
=>>>> Simons
Observatory =>
CMB Stage 4



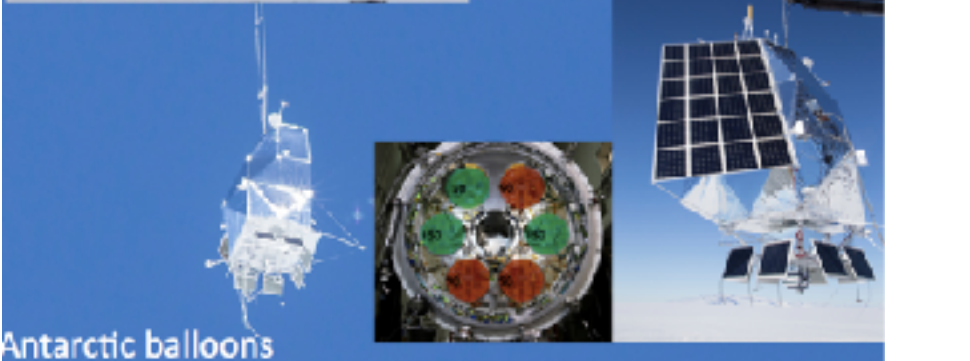
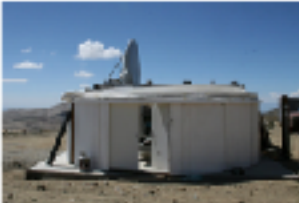
California+
South Africa
C-BASS 5 GHz



Tenerife (+South Africa?)
GONDOL 11, 13, 17, 19 GHz
(2015/16 - 30, 40 GHz)



California
E-Mech 40 GHz



Antarctic balloons

& futures S4, more ballooning, back into space

Advanced ACTPol => Simons Observatory => S4

CLASS 1.5m



Polarbear 2.5m



ACT 6m



Simons 2.5m



Simons 2.5m



development of CMB in Canada & the Canadian CMB professoriate:

Gush (Timusk): CMB distortions -> very good 2.725K blackbody

Bond “Delta T over Tea CITA 1987” OVRO, SP, COBE, FIRS, SK, **Planck**, Boom / Maxima, CBI, Acbar, **ACT**, **Spider 1/2**, ACTpol, AdvACT, **CCATp**, **Simons**, **Stage4**, BFore, post-Planck Bmode, **CHIME**, **COMAP**

Fich JCMT/Scuba, Herschel, **CCATp**

Halpern Cobra, BAM, **WMAP**, JCMT/Scuba, readout, **ACT**, **Bicep/Keck**, **Spider 1/2**, ACTpol, AdvACT, **CCATp**, **Simons**, **Stage4**, **CHIME**, **HIRAX**

Murray **CCATp**, **COMAP**

Scott **Planck**, JCMT/Scuba, **CCATp**, BFore

Netterfield SK, Boom, **Planck**, **Spider 1/2**, **Blast**, **Bicep/Keck**, BFore

Holder SPT, **Stage4** => Illinois but still CIFAR + PI

Dobbs SPT, **Polarbear**, **EBEX**, readout, **Simons**, **Stage4**, **Litebird**, **CHIME**, **HIRAX**

Hinshaw COBE, **WMAP**, **CLASS**, Pixie, **Simons**, **CHIME**, **HIRAX**

Vanderlinde SPT, **CHIME**, **HIRAX**

Hlozek **ACT**, ACTpol, AdvACT, **CCATp**, **Simons**, **Stage4**

Martin ISM: **Planck**, **BLAST**, Herschel

K Smith **WMAP**, **Planck**, **CHIME**

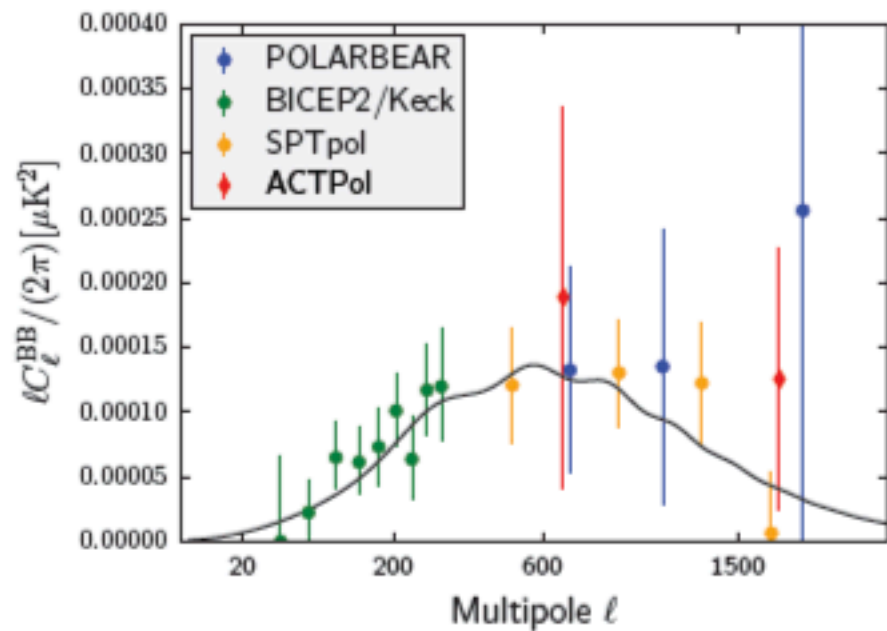
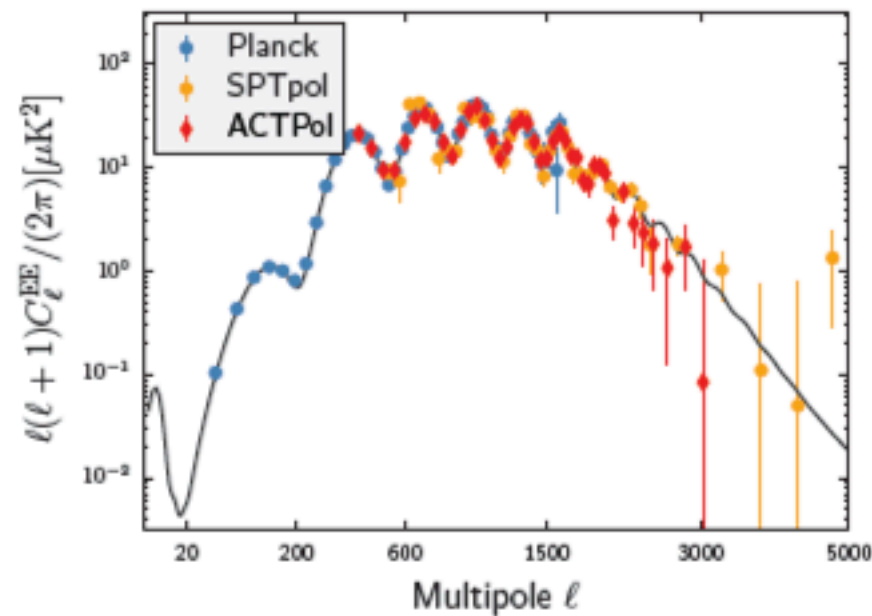
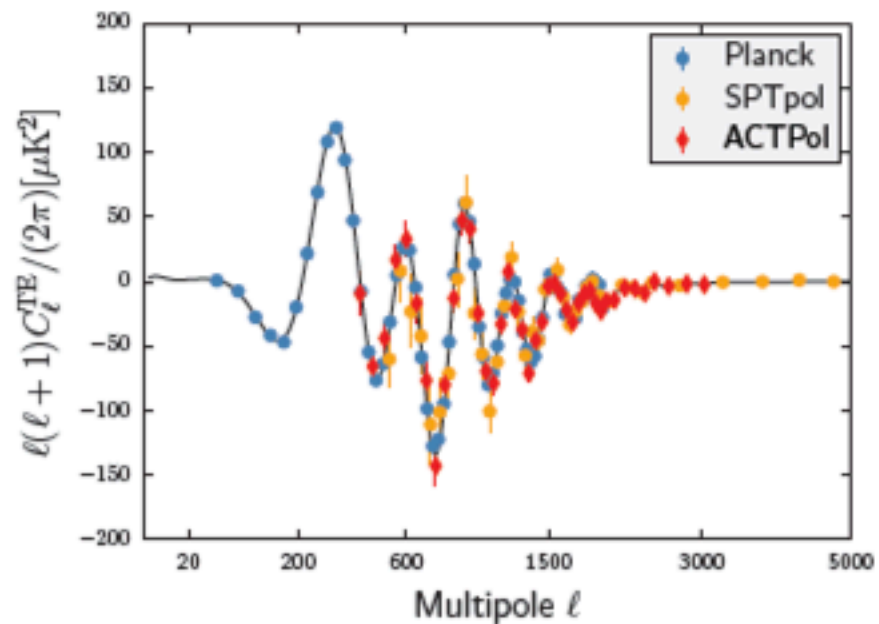
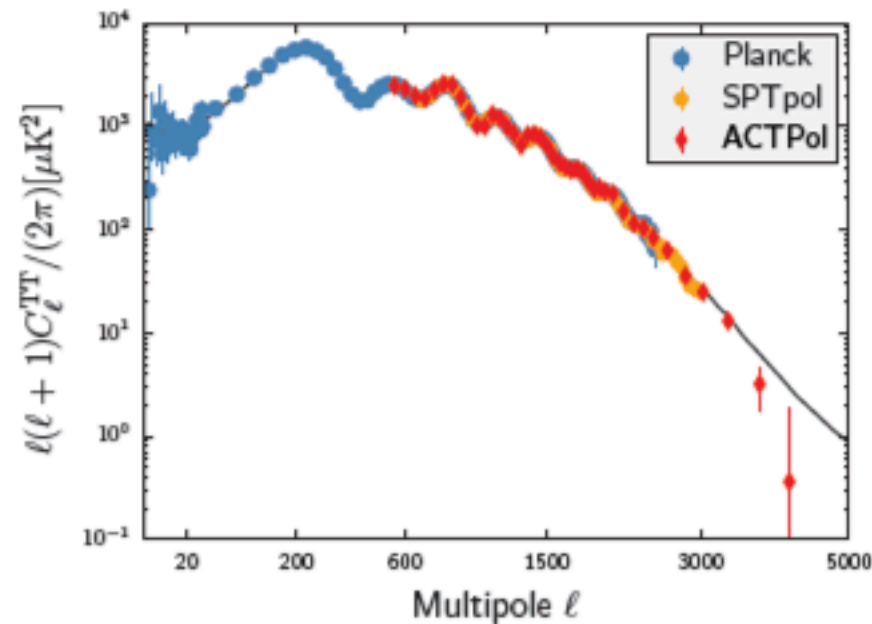
Frolov **Planck**, **Simons**, **Stage4**

Cynthia Chang **Planck**, **Bicep1**, **Spider**, **CBASS**, **Stage4**, **HIRAX**

Jon Sievers CBI, **ACT**, **Spider 1/2**, ACTpol, AdvACT, **CBASS**, **Simons**, **Stage4**, **HIRAX**

other faculty/staff **Nolta** **WMAP**, **ACT**, **Planck**, **CCATp** **Pogosyan** **Planck**, MJohnson **Brandenberger**

HQP: fantastic history of grad students & PDFs/SrRAs into and out of Canada => leaders in the field



triumph: Standard Model of Cosmology *established Λ CDM with high precision & accuracy*

goal: quest for “subdominant” **Beyond the Standard Model of Cosmology physics**

inflation: GravityWaves, *broken scale invariance*, isocurvature & non-Gaussianity (\Rightarrow multifield)

multi-band GW: $r < 0.11$ 95% CL cf. $r < 0.09$ uniform $n_s \Rightarrow 1$ sigma stage $3 \pm 0.006 \Rightarrow$ stage 4 ± 0.0005

neutrino testbed - limited by τ_C ($L < 10$) Planck (BFore, CLASS, Litebird, ..)

$\sum m_\nu < 220$ meV 95% *P15+Planck(cls)+BAO $\Rightarrow 1$ sigma stage 3 ± 60 meV \Rightarrow stage 4 ± 50 meV*

relativistic energy $> SMC$, number of ν species - already non-integer N_{eff} decaying DM, ...

energy density in relativistic particles $N_{\text{eff}} = 3.15 \pm 0.23$ cf. 3.046 SMC $\Rightarrow 1$ sigma stage $3 \pm 0.06 \Rightarrow$ stage 4 ± 0.027

SMneutrino_cosmology, SMbbn, looks good .. quest is for BSMnuc, BSMbbn

CMB lensing \Rightarrow dark energy dynamics / modified gravity

+ CMB anchors parameters for other probes, eg all LSS, 21cm ..

Challenge: *All expts correlated through common signals \Rightarrow joint analysis of expts*

quest for “fundamental” physics cf. (g)astrophysics, no real separation eg, delens all signals

the battle of small aperture a la bicep/keck cf large aperture a la SPT ACT fought for SO, S4

- evolving answer for S4: a mix 2.5m, 6m (CCATp, Simons 6m telescopes being built!)

high L science: **tSZ** now $\sim 2K$ clusters, AdvACT $\sim 20K+$, S4 100K ICM gas, feedback

kSZ - reionization, flows τ_C etc Xcorr

CIB sources (ULIRG, SMG, AGN etc. highL outliers) + CIB clustering confused

LineIntensityMapping CO, CII HI of course - low E radio = emerging fields

the **multi-messenger** vision DES DESI LSST Euclid WFIRST ... tSZ, kSZ, CIB, lens

ISM science - complex dust, AME, synchrotron, CO, .. B fields, HI data cubes, dedicated fgnd

expts. *how to simulate fgnds well?*

\Rightarrow **component separation of all signals** an ongoing and growing field

Evolution of CMB teams - going “industrial” => multi-institutional multi-country most funding US for ground/balloon *Stage4* for sure; *Planck* was/is pretty industrial, now *Simons* too

industrial: *hardware products - fabrication, backends, telescopes* + *software products - pipelines, processing tools - from forecasts to mocks to end-to-end analyses*

BigData: how to regularize software with individual / small team creativity -

BigLabs DOE, NASA, EuroLabs: cf. university-based (Canadian). pipeline,

BigComputation SciNET cf NERSC do we have a future in this?

analysis centres cf. distributed analysis: training of HQP exptalist/analyst and theorist/analyst

US ambition (Simons, S4, LDB McMurdo, ULDB, ..) **Euro ambition** (major lab funding, APC, .., space, Simons, Stage4) **UK ambition** (Simons, S4 10M pounds), **Japan ambition** (Litebird, Groundbird, Simons, Stage4), **China ambition** (CMB on Tibetan plateau)

Canada ambition (historically strong, but expt by expt; *CSA Planck, Litebird - Dobbs for Canada, balloons BLAST, Spider, EBEX*, Timmins; ground *NSERC, CFI* our Cdn group is unifying under Simons, Stage4 group unification. *CCATp to CFI*

buy ins - will Canada be out of the loop because of lack of avenues to buy in? cf. Europe, UK, Japan. *Simons example: ACT, Polarbear legacy + SciNET + service => we are in, but yr by yr review.*

ambitious theorist/analyst view: everything correlated with everything else through signals on the same sky - as if one grand collective cosmic experiment to analyze => a huge challenge/opportunity for the field and we want it all *Mocking Heaven @CITA/Toronto*

standard analysis approach: expt by expt compression on blind (map) parameters (pspec) => products

beyond independent product likelihoods: CMB_i, LSS_j => (CMB₁, ..., CMB_n, LSS₁, .. LSS_m)

non-Gaussian signals (cosmic, ISM, SZ, ..), non-Gaussian **nuisance, systematics**, need **unified comp sep**

multi-messenger analyses: *eg, optical/nearIR DES, Subaru, DESI, LSST, Euclid, SphereX, WFIRST X CMB*