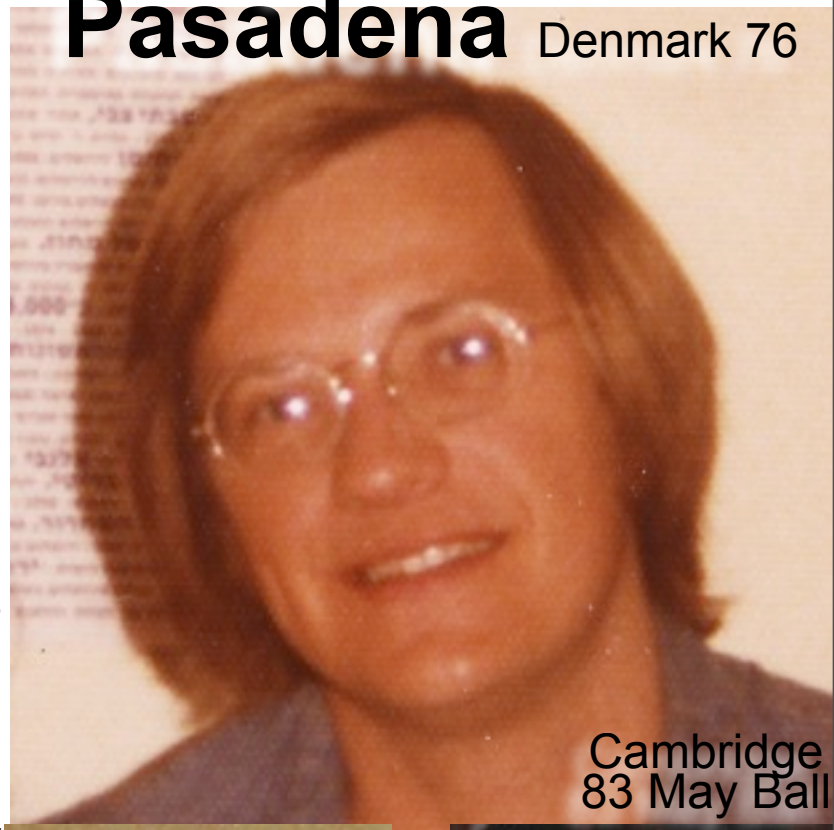
Paths in our Cosmic Landscape:
60 years of Bond-Aging

Pasadena



Bond 1978 thesis: Neutrino Production and Transport During Gravitational Collapse

And when I beheld my devil, I found him serious, thorough, profound, and solemn: it was the Spirit of Gravity - through him all things are ruined.

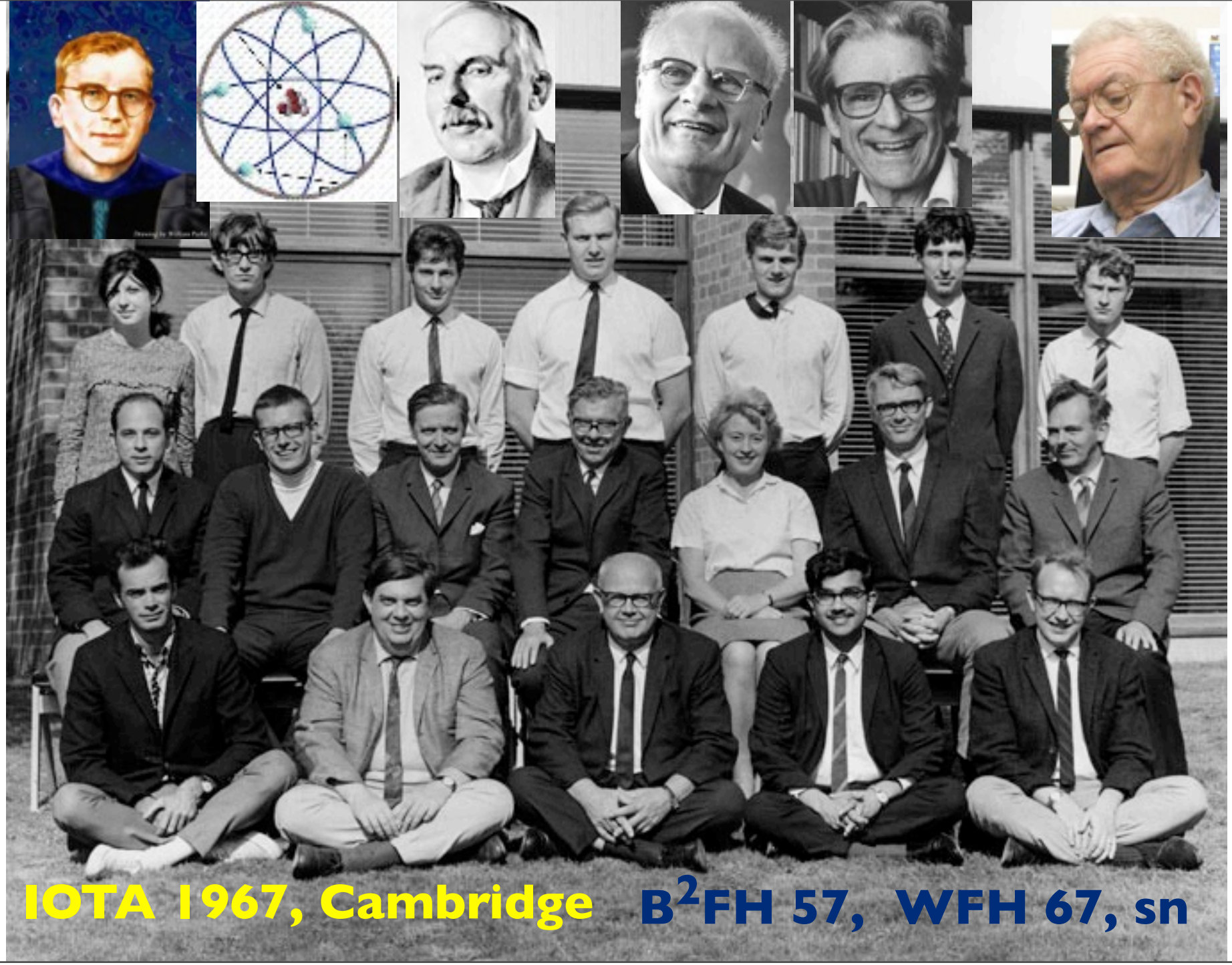
One does not kill by anger but by laughter. Come, let us kill the spirit of gravity!

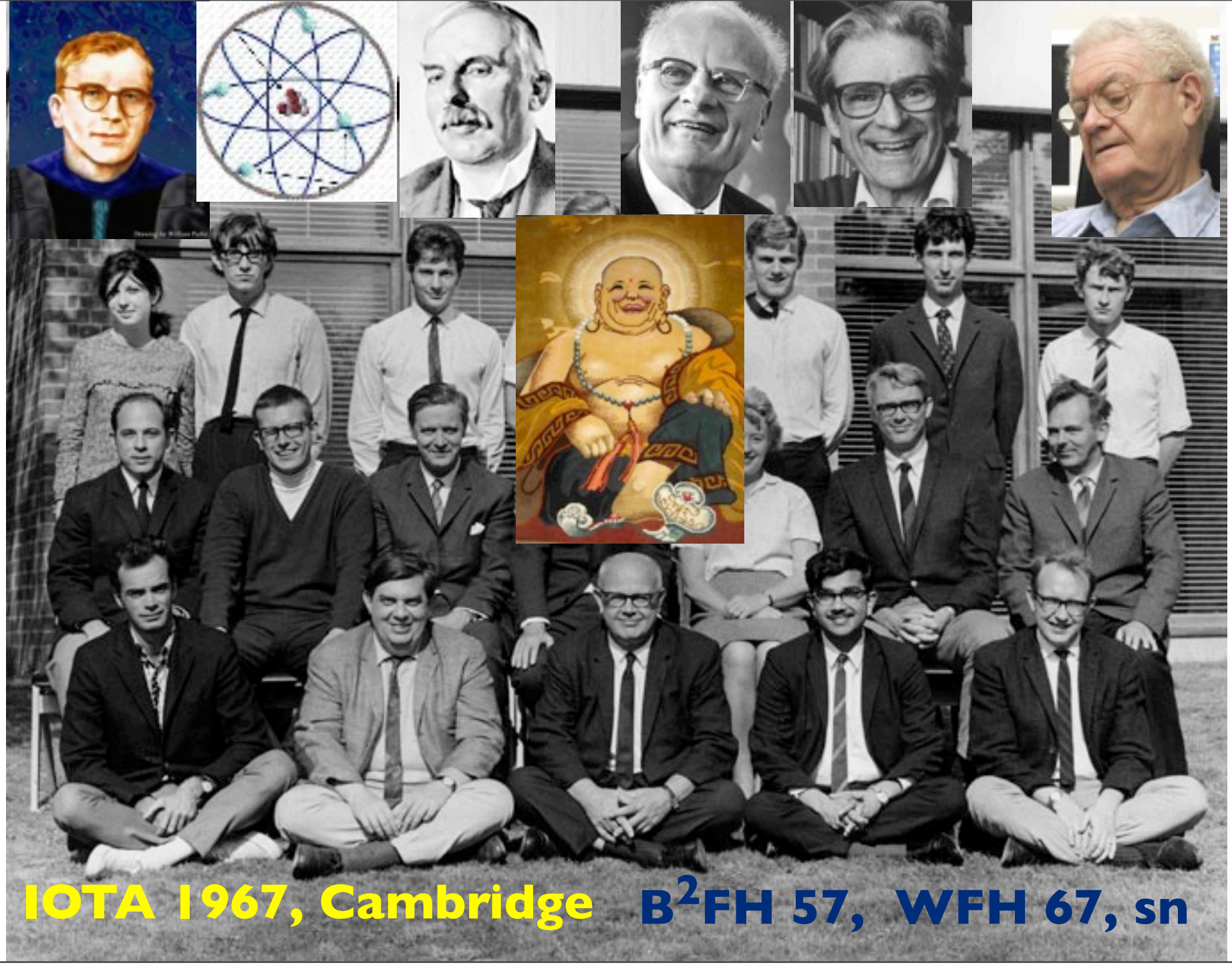
Friedrich Nietzsche 1885 *Also sprach Zarathustra*

And thus I was transported with my neutrinos into light-ness and the exhilarating freedom of unbridled cosmic speculation, armed with theory - of "fundamental" particles and fields, and GR, of black holes, neutron stars and supernovae, of the ***collective*** *phenomena and* ***entropy creation*** *in dense matter, and the* ***transport*** *of light and* ν.

And learned about experiments and observations through "doing implications", the ***entropy*** *=lnP* ***of data and theory***. ***the Cosmotician's Agenda***

Cambridge
83 May Ball


IOTA 1967, Cambridge
B²FH 57, WFH 67, sn


IOTA 1967, Cambridge
B²FH 57, WFH 67, sn

CITA and CIFAR Henriksen & Martin 1984; Tremaine & Bond 1985; Kaiser 1988; Murray 1993; Kofman & Pen 1998; Thompson 2000; Rafikov 2005; Pfeiffer 2008

Willy Caltech/Kellogg postdoctoral fellow place 60s (Dick, Scott)

Fred Hoyle Cambridge IoA (Peter Martin, ... Scott, Dick)

John Bahcall Institute for Advance Study (Scott)

Thus **CITA** emphasis on Postdocs (and Senior Research Associates) ~24!!!

CIFAR Cosmology and Gravity Program

Unruh, Israel, Bond (Peebles, Wise, Fairbanks) (Peter Martin altruism)

Kaiser, .., Frolov's dad, ..., Tremaine, ...

many many friends as Fellows, Scholars, Associates and Board Members

Fraser Mustard (pulled me from Stanford). Peter Allen enabled.

CITA and CIFAR

Willy Caltech/Kellogg postdoctoral fellow place 60s (Dick, Scott)

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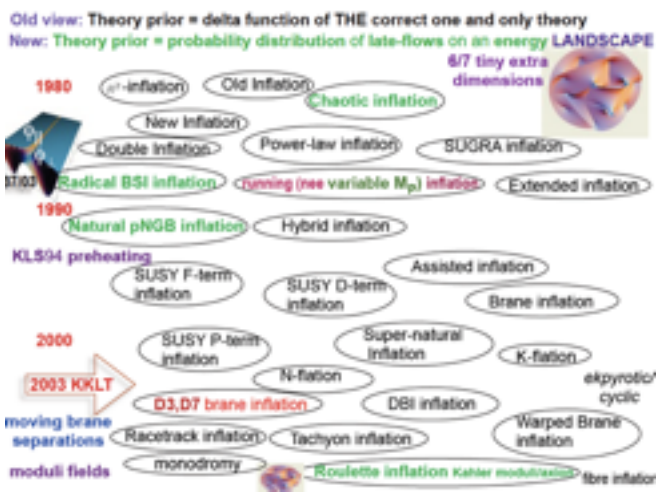
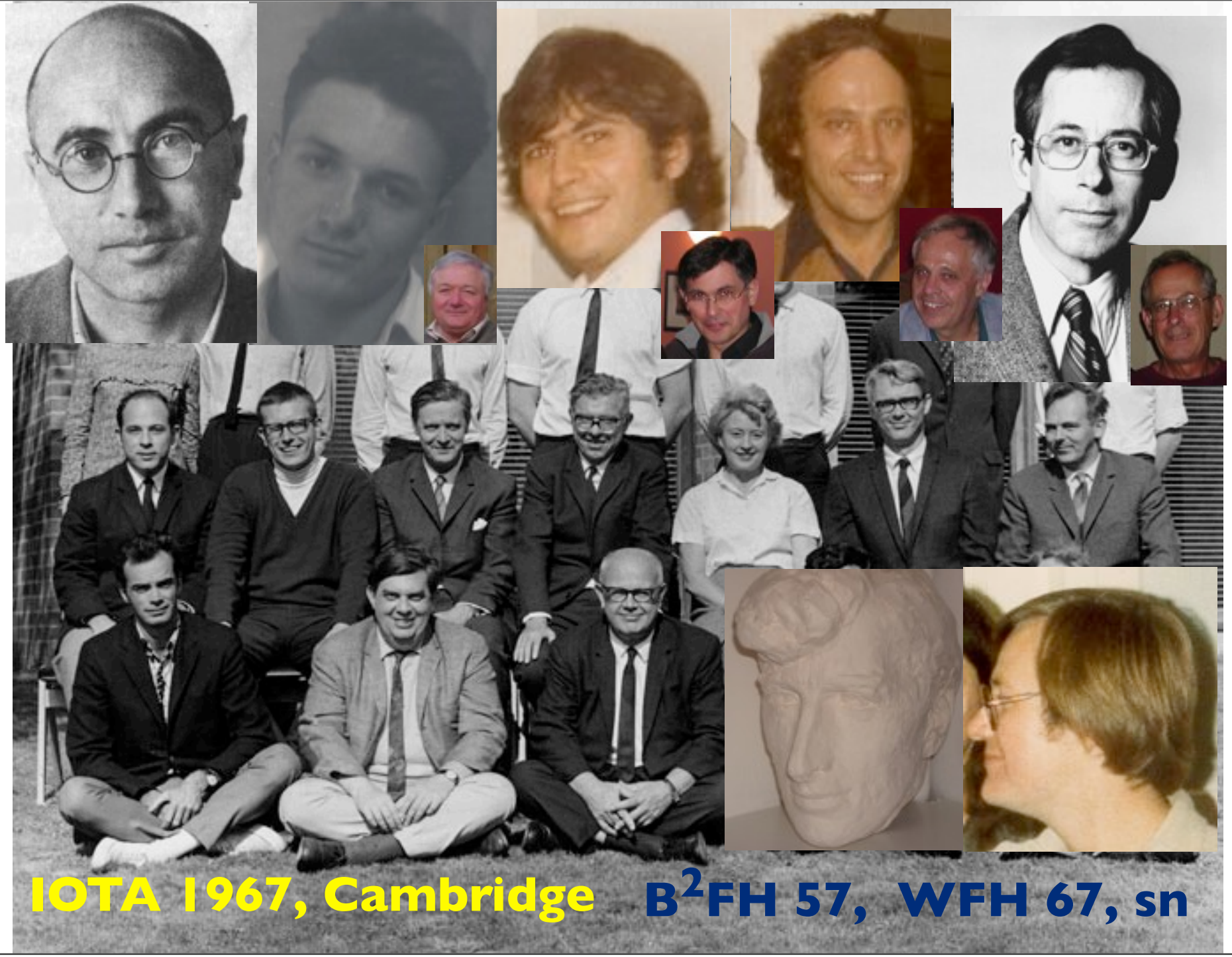
the Willy unit
(Sverre Aarseth 2009 @KICC opening);

complexity of slides

1 bond = 1 milli-willy




IOTA 1967, Cambridge
B²FH 57, WFH 67, sn

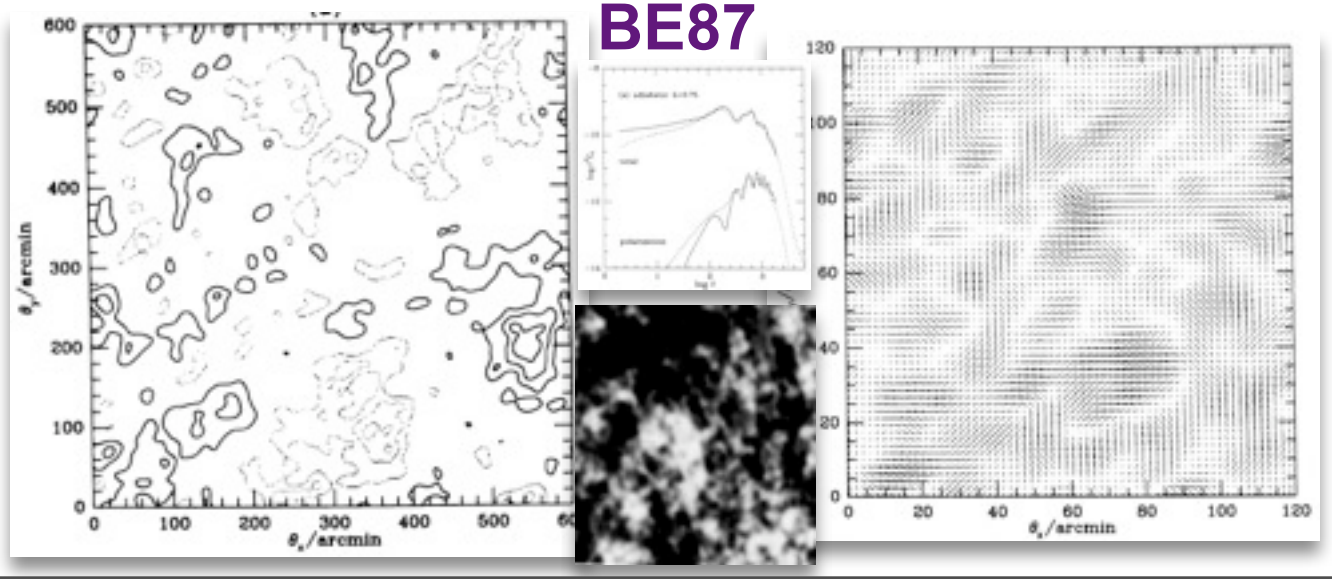
Delta T over Tea Toronto May 1987: first dedicated CMB conference, exptalists+theorists, primary+secondary ΔT/T

Primary Cosmic Microwave Background Radiation ~ a statistically isotropic all-sky GRF on the 2-sphere $C_L = \langle |\Delta T_{(LM)}|^2 \rangle$ *with target* C_L *shapes*

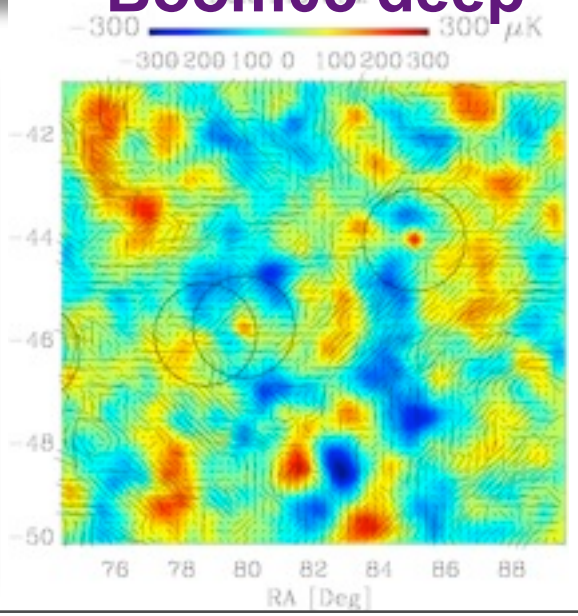
A tentative list of topics organized according to angular scale, with theory and observation intertwined, is:

- 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



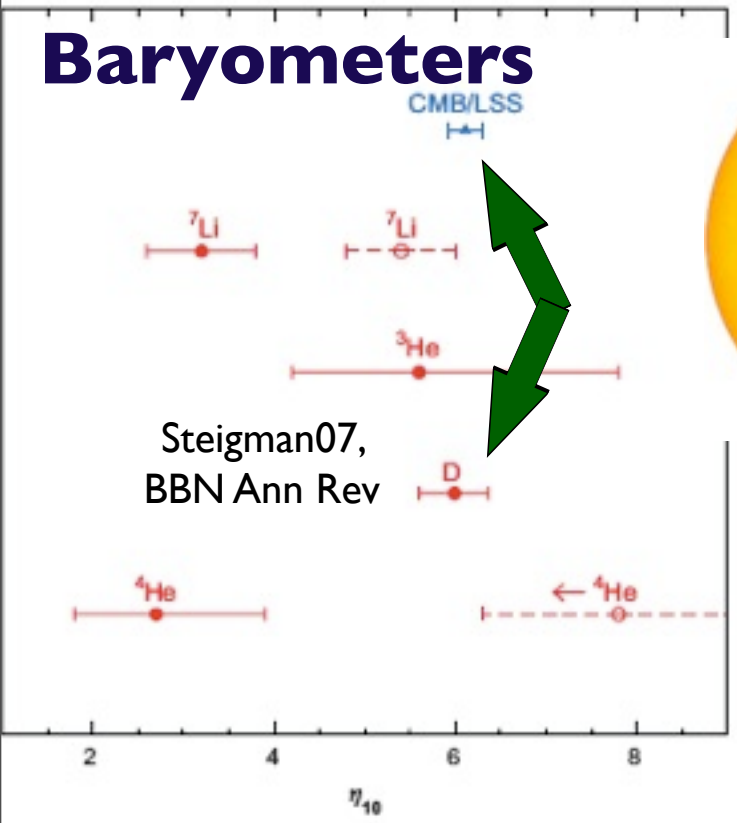
Boom05 deep



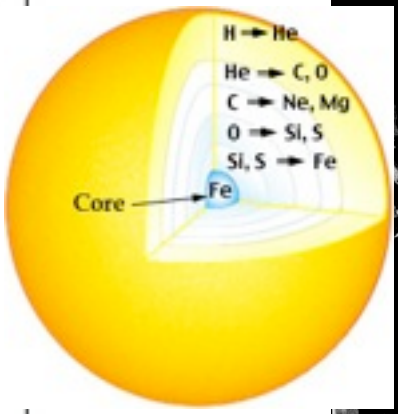
$$\Delta t/t_{bond} \Rightarrow 0$$

$$\text{as } t_{bond} \Rightarrow t_U$$

Baryometers



Steigman07, BBN Ann Rev



Nobel Prize 84 Willy Fowler + Chandra -sekhar

$$\eta_{10} \equiv 10^{10}(n_B/n_\gamma) \equiv 274\ \Omega_B h^2$$

$\Omega_b h^2$

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

$\Omega_b h^2$

0.0223 ± 0.0007 0.0226 +- 0.0006 wmap3+acbar+cbi+... LSS

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

cosmic baryon number $\mathbf{n_b}$=0.261 ±.005 /m^3

$\Omega_{dm}h^2$=0.1145 ±0.0023 Ω_m=0.268 ±.012 Ω_Λ=0.736 ±.012

Computing Cosmologies Apr28-29, 1989

Andy Albrecht (Fermilab)
Bruce Allen (Tufts)
Josh Barnes (Institute for Advanced Study)
Dave Bennett (Princeton)
Ed Bertschinger (MIT)
Dick Bond (CITA)
Francois Bouchet (Institut d'Astrophysique, Paris)
Robert Brandenberger (Brown)
Ray Carlberg (Toronto)
Renyue Cen (Princeton)
Joan Centrella (Drexel)
Matt Choptuik (CITA)
Shaun Cole (Oxford)
Hugh Couchman (Toronto)
Marc Davis (Berkeley)
Avishai Dekel (Hebrew University)
John Dubinski (Toronto)
Martin Duncan (Queen's University)
Charles Dyer (Toronto)
George Efstathiou (Oxford)
Gus Evrard (Berkeley)
Mike Fitchett (Space Telescope Institute)
Jim Gelb (MIT)
Brett Gladman (Queen's University)
Dalia Goldwirth (Hebrew University)
W.G. Habashi (Concordia University)
John Hawley + student (Virginia)
Lars Hernquist (Institute for Advanced Study)
David Hobbill (Illinois)
Yehuda Hoffman (Technion, Israel)
Satoru Ikeuchi (Tokyo)
Peter Ip (Toronto)
Roman Juszkiewicz (Copernicus Centre, Poland)
Nick Kaiser (CITA)
Hyesung Kang (Minnesota)
Neal Katz (Princeton)
Pablo Laguna (Texas)
Lev Kofman (Tartu)
Hannu Kurki-Suonio (Drexel)
Kayll Lake (Queen's University)
Per Lilje (CITA)
Pat Mann (University of Western Ontario)
Hugo Martel (Cornell)
Adrian Melott (Kansas)
Warren Miller (AFWL/AWPP, Kirtland Air Force Base)
John Peacock (ROE, Scotland)
Jim Peebles (Princeton)
Gerald Quinlan (Cornell)
Tom Quinn (CITA)
Dongsu Ryu (Fermilab)
Varun Sahni (CITA/Toronto)
Dave Salopek (Toronto)
Bob Scherrer (Ohio State)
Sergei Shandarin (Institute for Physical Problems, Moscow)
Paul Shapiro (University of Texas at Austin)
Paul Shellard (MIT)
Albert Stebbins (CITA)
Peter Thomas (CITA)
Chris Thompson (Caltech)
Scott Tremaine (CITA)
John Tsai (MIT)
Neil Turok (Princeton)
Masayuki Umemura (Tokyo)
Bill Unruh (University of British Columbia)
Jens Villumsen (Ohio State University)
Rachel Webster (CITA)
David Weinberg (Princeton)
Mike West (Michigan)
Simon White (Arizona)

Computing Cosmologies Apr28-29, 1989

REGISTRATION FEE: $50 Canadian; FRIDAY NIGHT DINNER: $15-20 *The overview of the techniques and main issues should last for about 10 minutes. The presentations of work will be between 5-8 minutes, rigorously enforced by the chairperson. Finally we hope for extended open discussion, guided by a discussion leader.*

FRIDAY APRIL 28 1989 MORNING: 9:00 INHOMOGENEOUS EARLY UNIVERSE AND INFLATION (Chair: Bond) Unruh --- Overview; Miller, Hobill, Feldman, Goldwirth, Kurki-Suonio; Salopek --- Stochastic Inflation Simulations

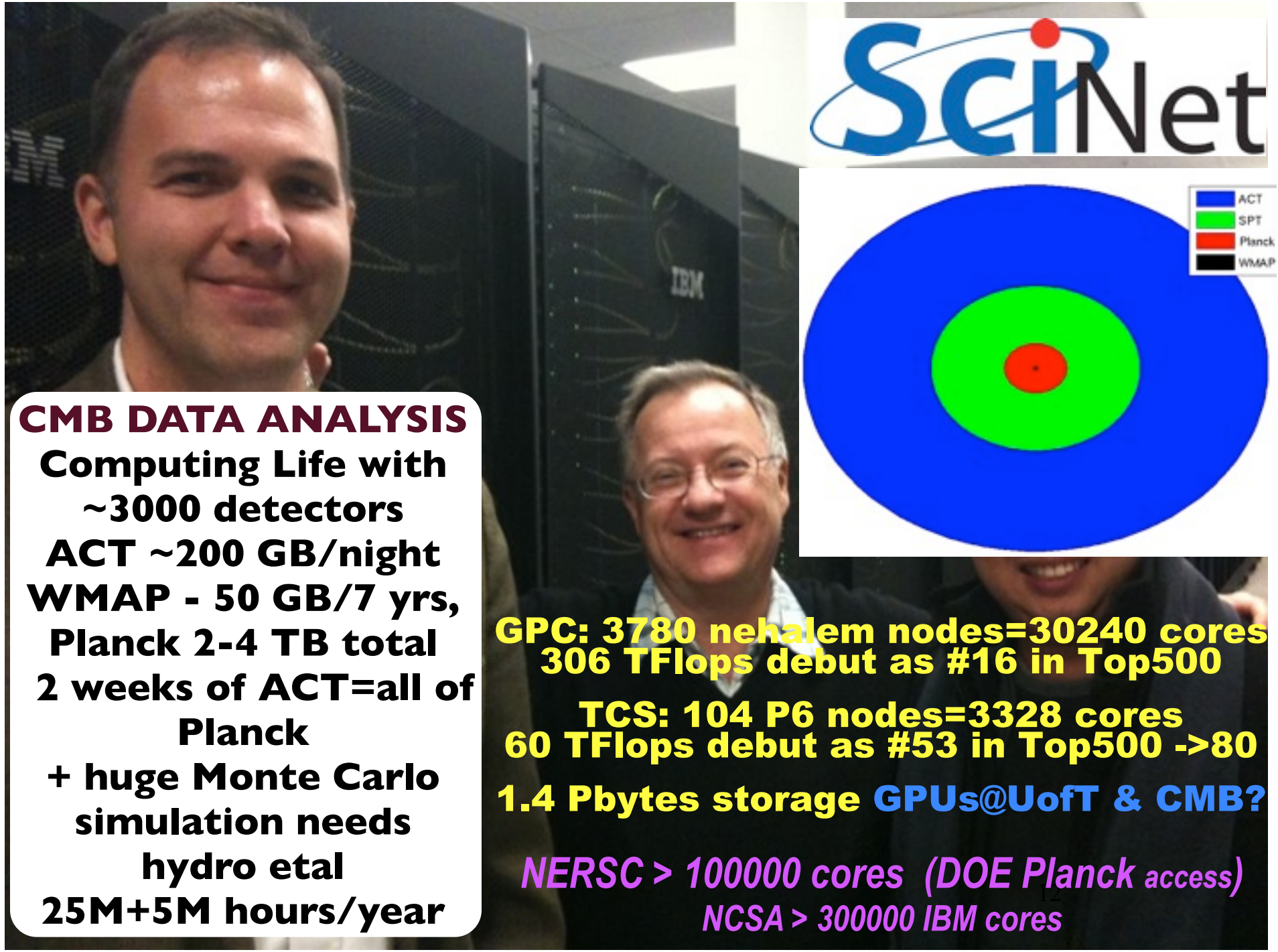
11:00 COSMIC STRINGS (Chair: Kaiser) Albrecht; Bennett; Allen/Shellard; Stebbins; Laguna; Discussion Leader: Stebbins

FRIDAY APRIL 28 AFTERNOON: 1:45 N-BODY CALCULATIONS (Chair: Efstathiou) White; Bouchet; Centrella; Melott, Villumsen, Couchman, Barnes; Duncan; Discussion Leader: Peebles

4:15 BURGER'S EQUATION AND OTHER APPROXIMATE METHODS (Chair: Carlberg) Shandarin; Kofman/Sahni/Shandarin; Weinberg, Dekel; Peebles --- Yet Another Numerical Method; Ikeuchi - Explosion Voronoi Tessellation; Thompson; Discussion Leader: Dekel

7:30 CONFERENCE DINNER (Chinese: Hsin Kuang Restaurant)

SATURDAY APRIL 29 MORNING: 9:00 COSMOLOGICAL HYDRODYNAMICS (Chair: Peebles) Hernquist; Katz; Evrard; Bond --- An SPH/MGGS Code and Application to Lyman Alpha Clouds; Carlberg; Kang; Shapiro; Thomas; Umemura; Bertschinger; Hydro Discussion Leaders: Hawley; Shapiro 2:00-5:00 INFORMAL DISCUSSION


SciNet
ACT
SPT
Planck
WMAP
CMB DATA ANALYSIS
Computing Life with
~3000 detectors
ACT ~200 GB/night
WMAP - 50 GB/7 yrs,
Planck 2-4 TB total
2 weeks of ACT=all of
Planck
+ huge Monte Carlo
simulation needs
hydro etal
25M+5M hours/year
GPC: 3780 nehalem nodes=30240 cores
306 TFlops debut as #16 in Top500
TCS: 104 P6 nodes=3328 cores
60 TFlops debut as #53 in Top500 ->80
1.4 Pbytes storage GPUs@UofT & CMB?
NERSC > 100000 cores (DOE Planck access)
NCSA > 300000 IBM cores

400 Mpc

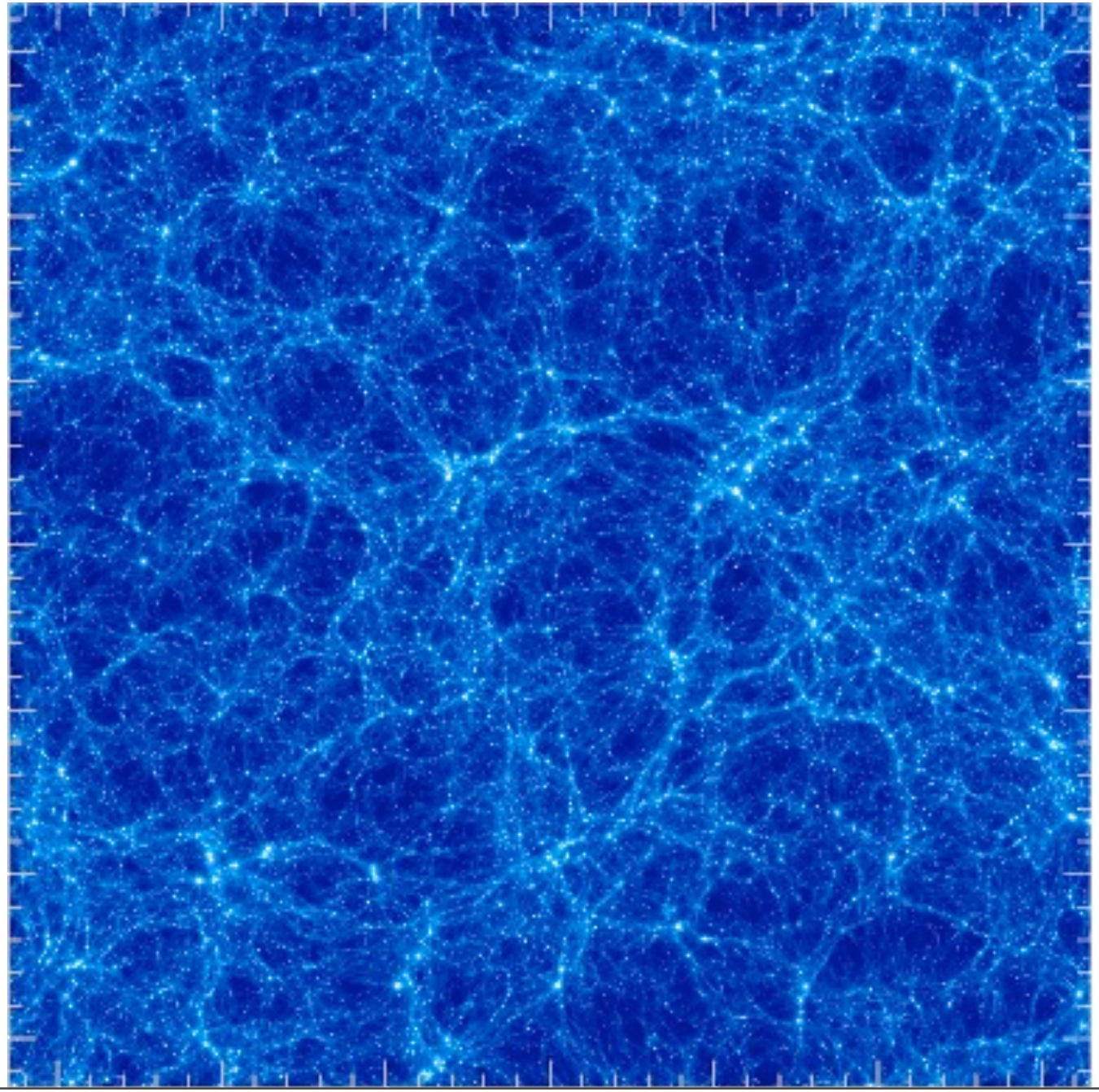
ΛCDM

WMAP5

gas density

Gadget-3 SF+ SN E+ winds +CRs

512^3



CMB gets entangled in the cosmic web

aka the descent into the real astronomy of IGM/ISM weather, dust storms & turbulent times

400 Mpc

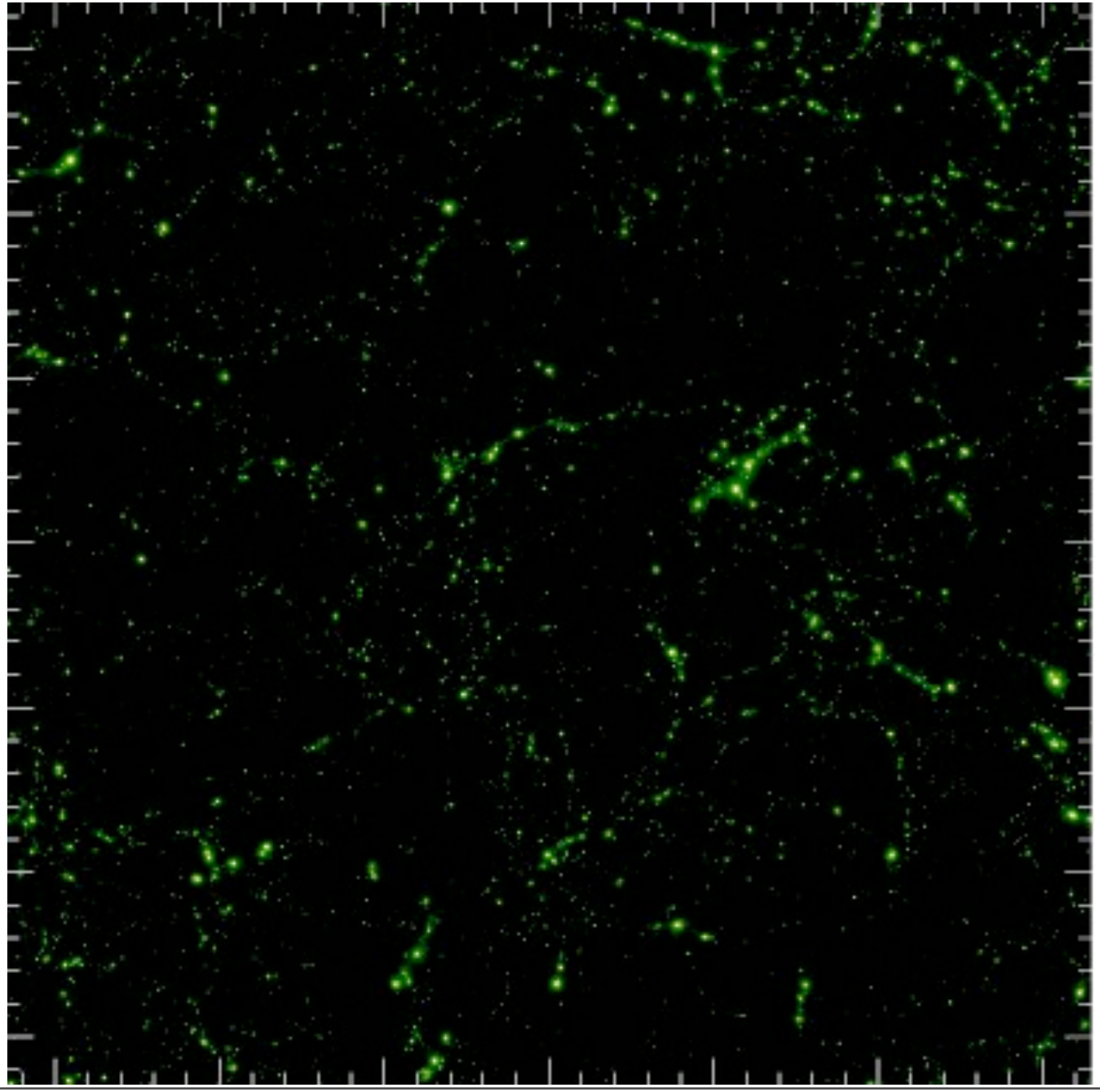
ΛCDM

WMAP5

gas pressure

Gadget-3 SF+ SN E+ winds +CRs

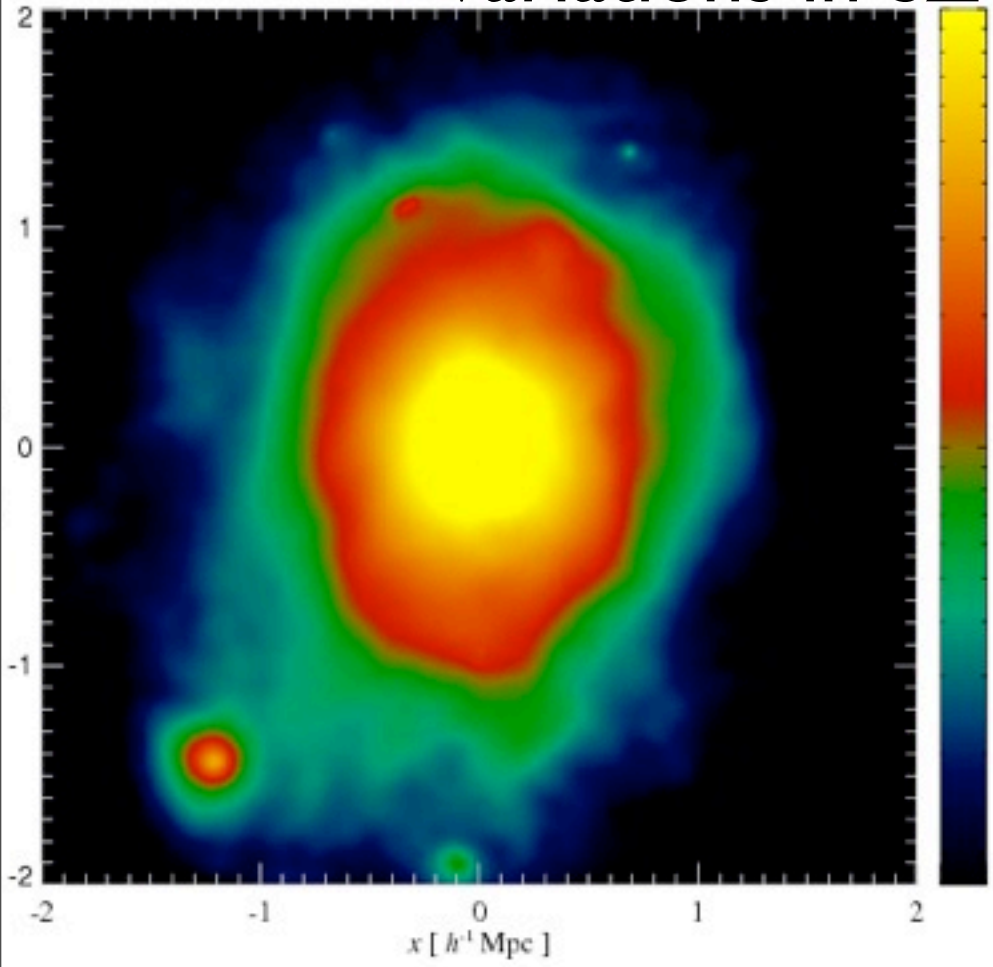
512^3

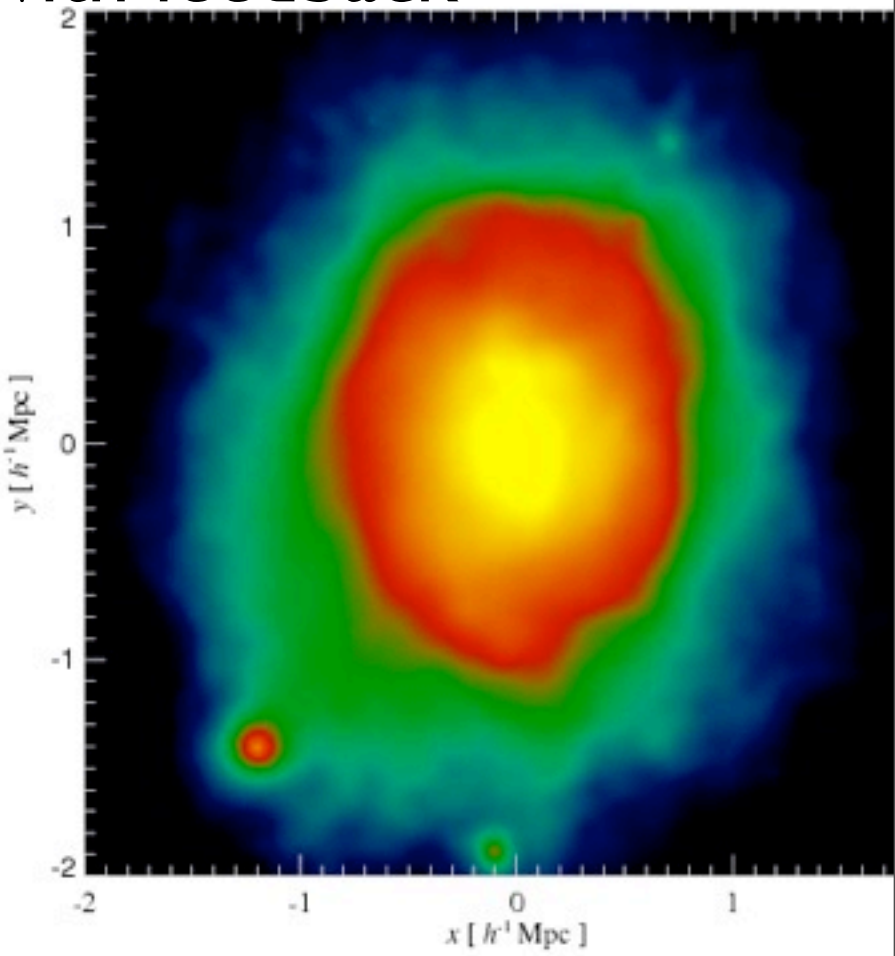


CMB gets entangled in the cosmic web

aka the descent into the real astronomy of IGM/ISM weather, dust storms & turbulent times

Variations in SZ with feedback





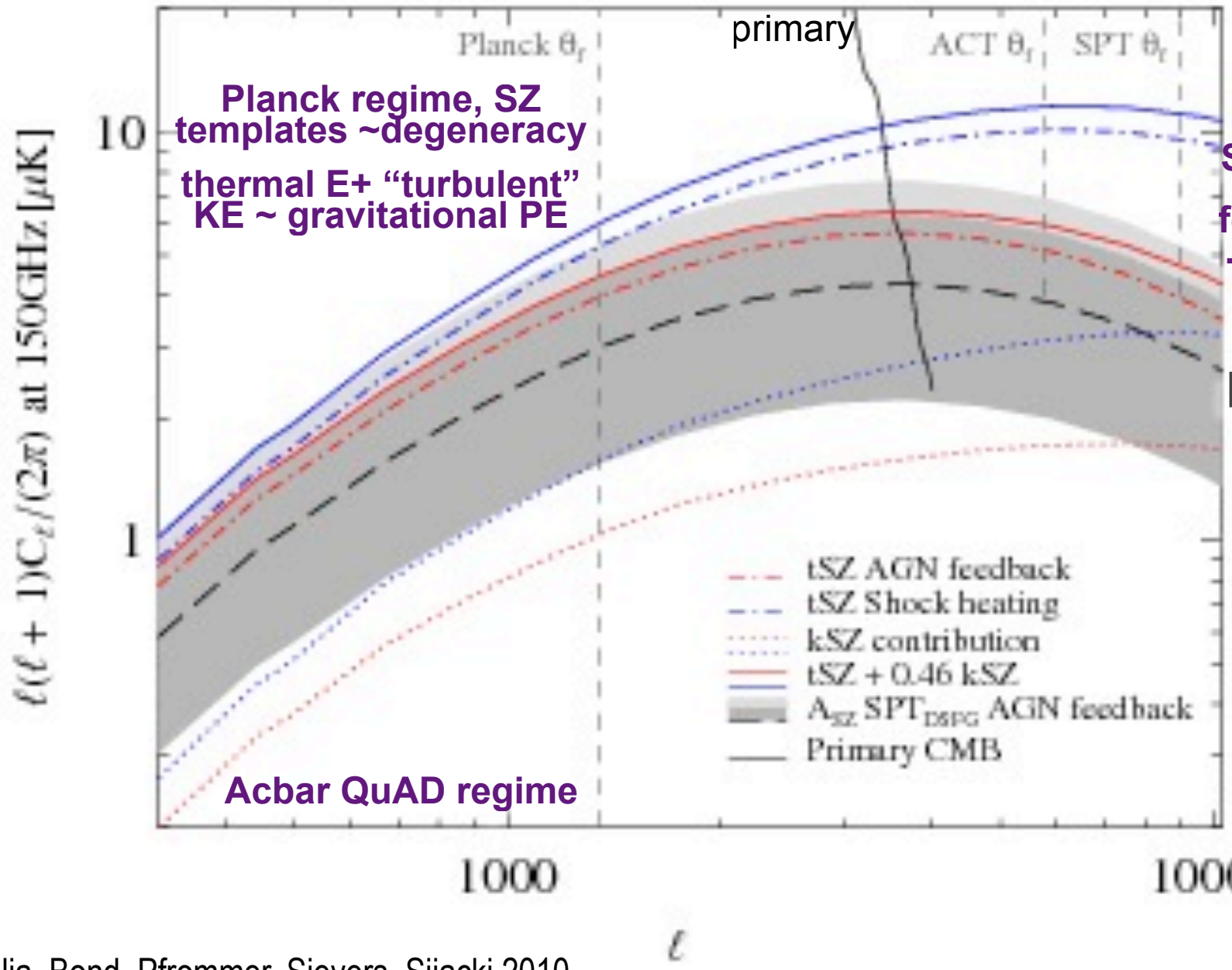
+ gas cooling + star formation +CR

+ "AGN" feedback

high res ICM follow-ups are essential to make a robust cluster catalogue for cosmology ...

Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010

the high resolution frontier: SZ power spectra



Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010

CBI pol to Apr'05 @Chile

CBI2

QUaD @SP

Quiet1 @Chile

Quiet2 1000 HEMTs

Boom03@LDB

Bicep @SP

Bicep2

Keck/Spud@SP

EBEX @LDB

ABS@ Chile

WMAP @L2 to 2010

Planck09.4

Spider

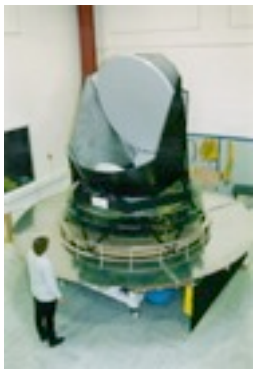
DASI @SP

CAPMAP

52 bolometers + HEMTs @L2

9 frequencies

Herschel



2312 bolos @LDB

CHIP

BLAST

2004 2006 2008 LHC 2011

Bpol @L2

2005 2007 2009

Acbar to Jan'06, 08f @SP

SZA @Cal

SPT 1000 bolos @SPole

BLASTpol

Clover @Chile

Polarbear 300 bolos @Cal/Chile

ACT 3000 bolos 3 freqs @Chile

SPTpol

ACTpol

ALMA

AMI

APEX ~400 bolos @Chile

SCUBA2 12000 bolos JCMT @Hawaii

GBT

CCAT@Chile

LMT@Mexico

BOOM 2000

TOCO, Boom test 1999

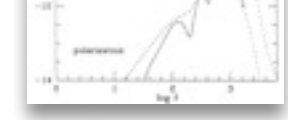
Maxima 2000

2001

CBI, ACBAR

Boom2003.1

VSA



+DASI 2001

Carlo Contaldi

Simon Prunet

Dmitri Pogosyan

Carrie MacTavish

jrb & ael

CITAzens taking over Cambridge

you are all CITAzens of the world

WMAP3 aka Nolta can now talk to us. gastrophysical Susur Lee

Planck 93!-02-09-14! & Europe-endless aka Paris Cambridge Munich Imperial & sunny/warm Caltech/JPL Princeton ... cast of >500 !!!


LIVEBOAT

Frontiers in our Cosmic Landscape:
60 years of Bond-Aging

the horizon seen from the 70s, 80s, 90s, 00s

** the high resolution frontier: the insides of clusters via SZ (SuZie,.., Acbar, QUaD, ... CCAT, CARMA++,ALMA,GBT,... ACT, SPT, **Planck**)

the polarization frontier: down the damping tail, through Planck (and ACTpol, SPTpol, ...)

the CMB computational horizon: simulations & Monte Carlos

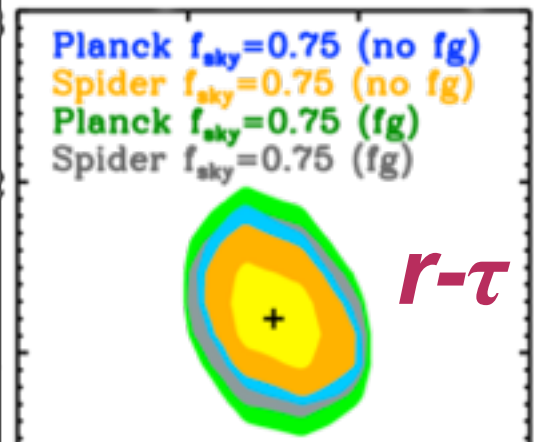
the CMB computational horizon: optimal de-nuisanced maps from large-format arrays; algorithmic advances, foreground/source issues

** Theory of inflation & dark energy: the non-Gaussian frontier (beyond f_{NL} templates $-4 < f_{NL} < 80$ now to $f_{NL} \sim \pm 5$ Planck; *will Gravity Wave B be big enough to detect r(k)?* DE w (z|V(ψ),IC) trajectories

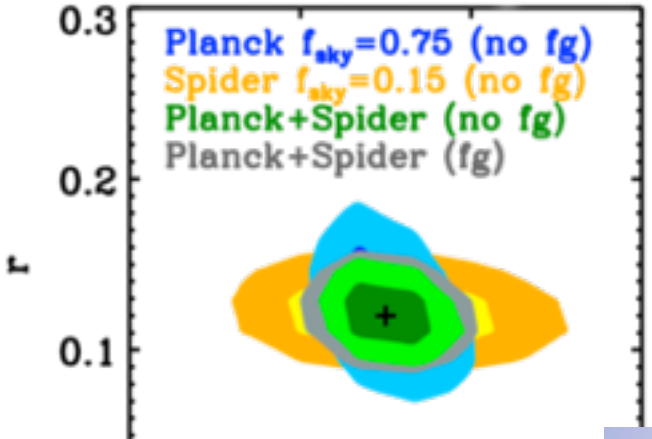
beyond the SM: in quest of the sub-dominant & the anomalous

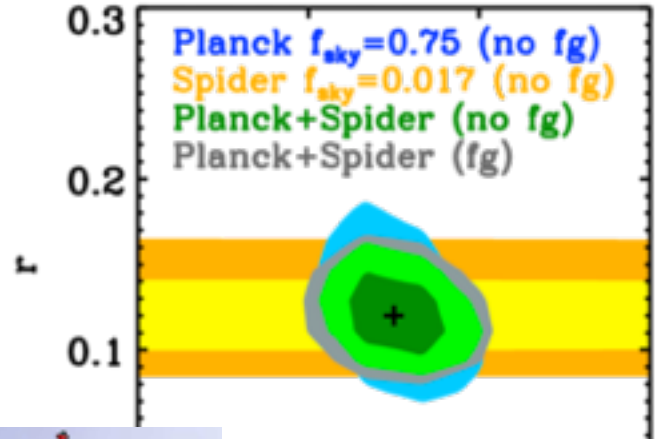
** the polarization frontier: the quest for B-modes and primordial gravity waves - small-sky (Bicep, KECK, Spider), Planck+small-sky, need for a CMBpol??

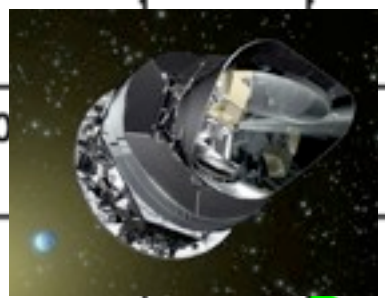
Spider-24d (fsky) cf. Planck-2.5yr. QUIET/KECK/ABS/EBEX... similar

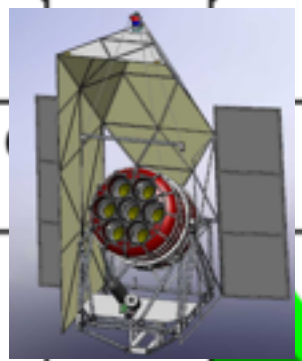


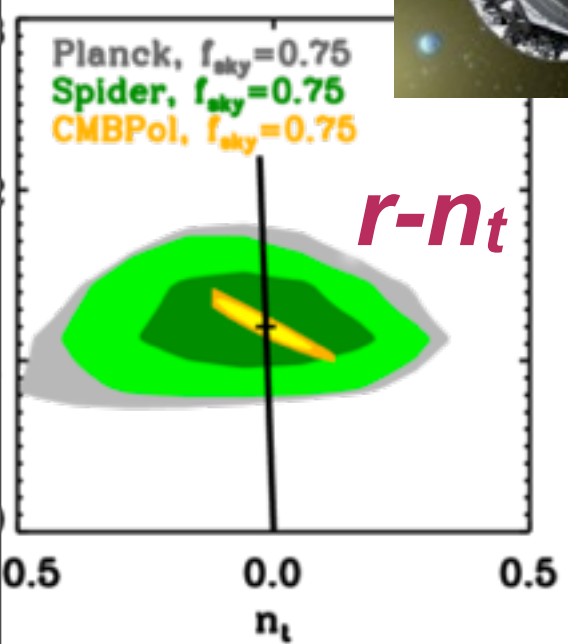
r-τ



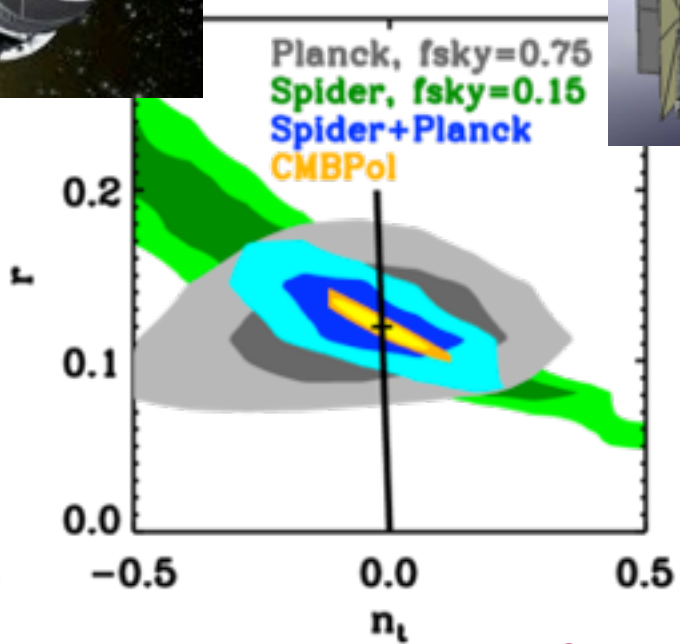


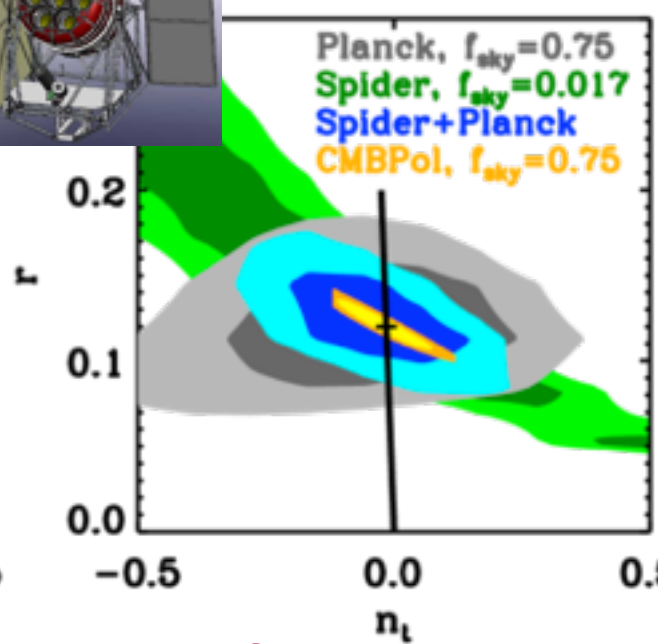






r-n_t





forecasting QU not EB $2\sigma_r \sim 0.02$ *for* $0.02 < f_{sky}\,0 < 0.15$

standard inflation space: n_s $dn_s/d\ln k$ $r = T/S$ @k-pivots

What can be observed?

forecasting QU not EB

Spider $2\sigma_r \sim 0.02$ for $0.02 < f_{sky}\, 0 < 0.15$

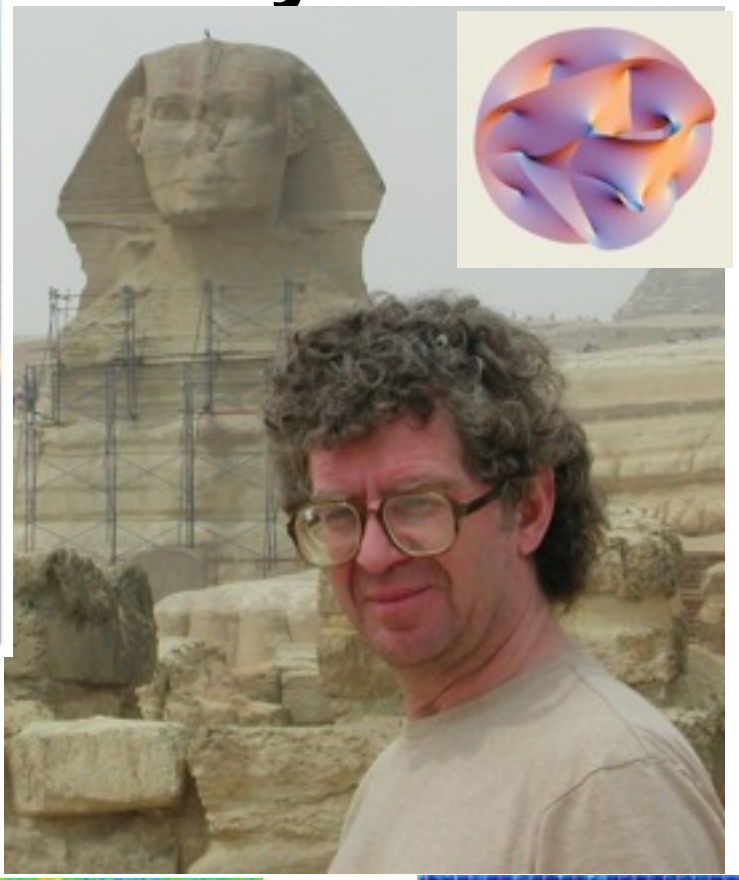
Planck2.5yr $2\sigma_r \sim 0.02$ => ~0.05 (foregrounds)

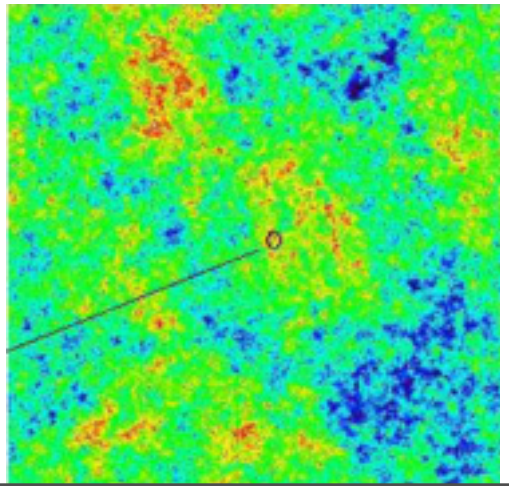
Marzieh Fahrang, Bond, Dore & Netterfield 2010

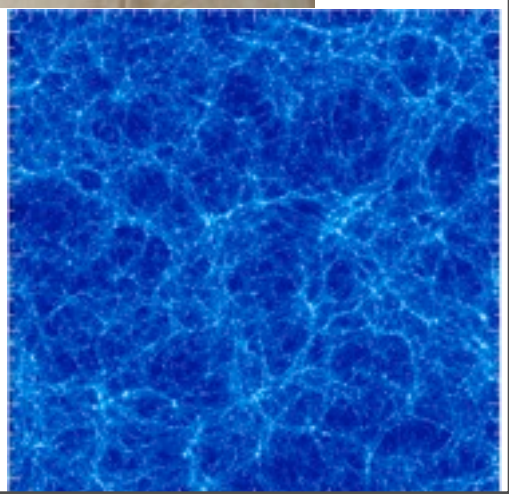
What is predicted? ???

$0<r<0.5$, $-12<\log(r)<-0.3$

22 yrs with Lev

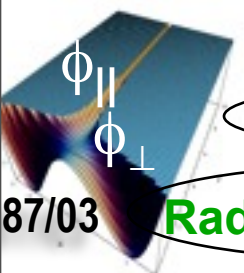






Old view: Theory prior = delta function of THE correct one and only theory

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

87/03 Radical BSI inflation

running (nee variable M_P) inflation

Extended inflation

1990

Natural pNGB inflation

Hybrid inflation

KLS94 preheating

SUSY F-term inflation

SUSY D-term inflation

Assisted inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

N-flation

2003 KKLT

D3,D7 brane inflation

DBI inflation

ekpyrotic/ cyclic

moving brane separations

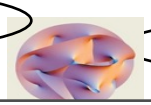
Racetrack inflation

Tachyon inflation

Warped Brane inflation

moduli fields

monodromy



Roulette inflation Kahler moduli/axion

fibre inflation

standard inflation space: n_s $dn_s/d\ln k$ r =T/S @k-pivots

WHAT IS PREDICTED?

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

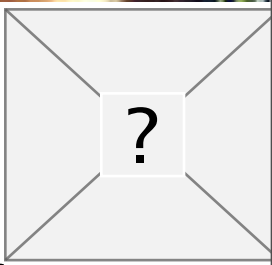
large field inflation (field moves > Planck mass) or highly variable braking r tiny

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

small field inflation (field moves < Planck mass => r<.007)

Bond, Kofman, Prokushkin,Vaudrevange 07, **Roulette Inflation with Kahler Moduli and their Axions**

Barnaby, Bond, Zhiqi Huang, Kofman 09, **Preheating after Modular Inflation**



monodromy (V=cosine+linear) & fibre inflation give larger r

current r constraints (95%CL) - prior sensitive

r < 0.16 (no running, all data sets)

r < 0.32 (no running, CMB-only data sets)

r < 0.27 (with running, all data sets)

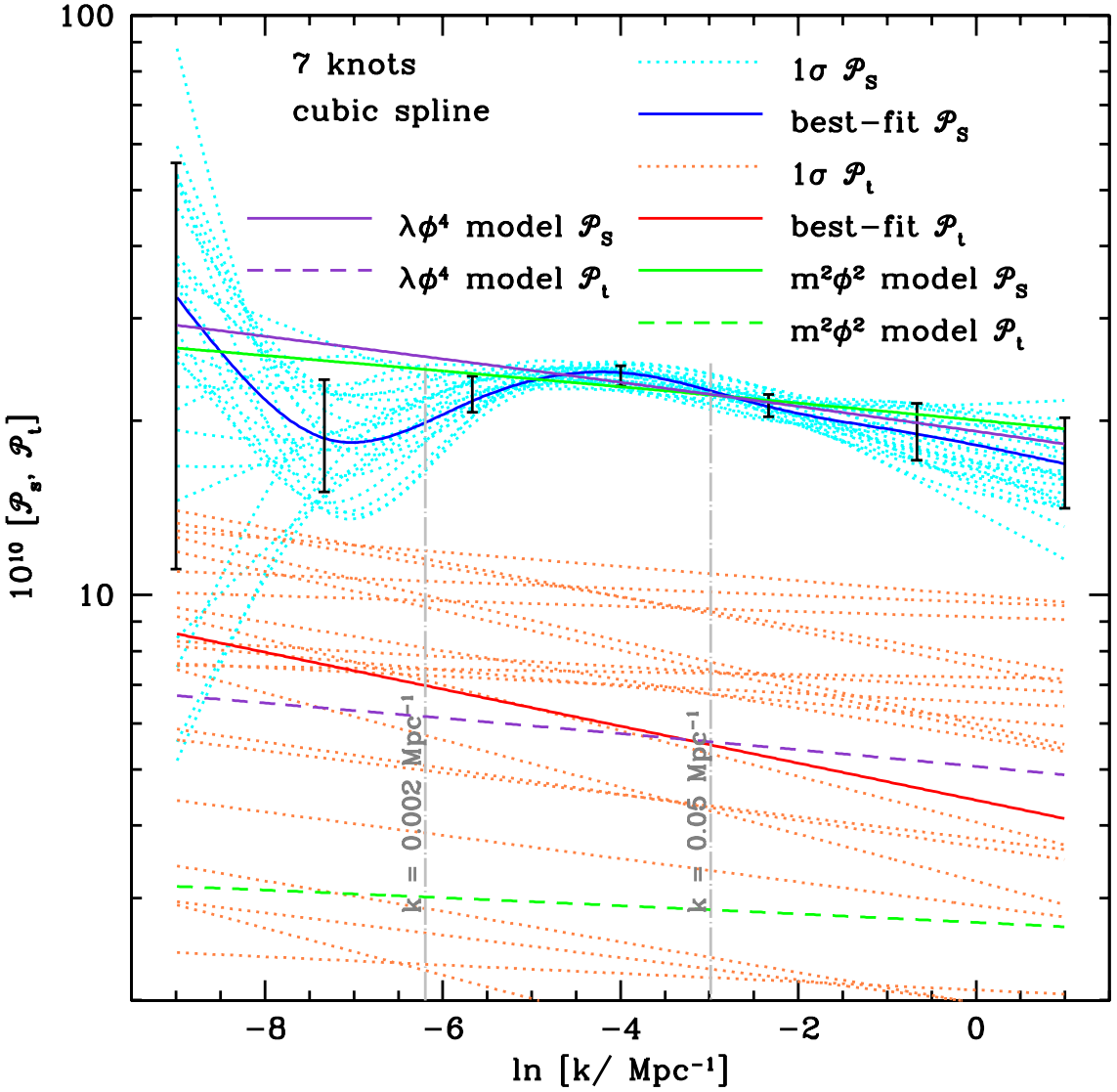
inflation consistency

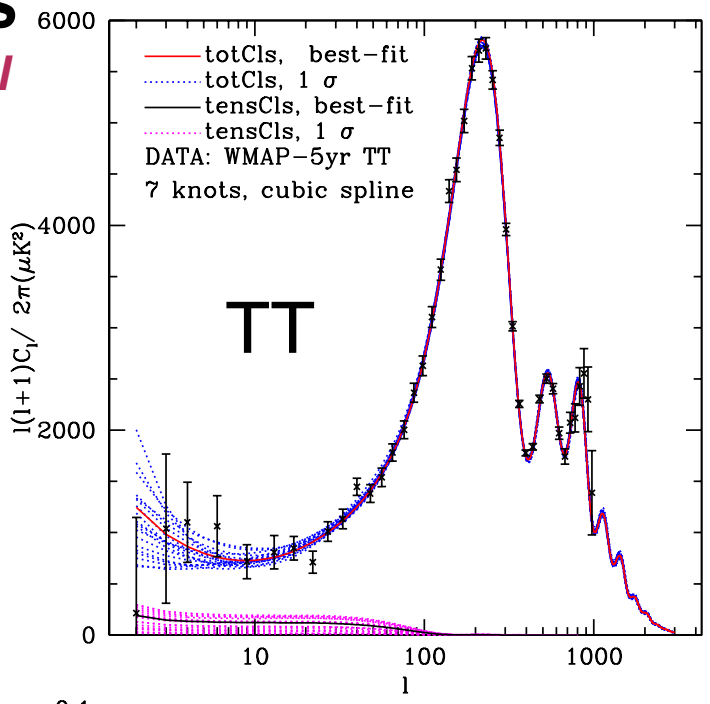
$-n_t \approx r/8 \approx 2\varepsilon(k)$

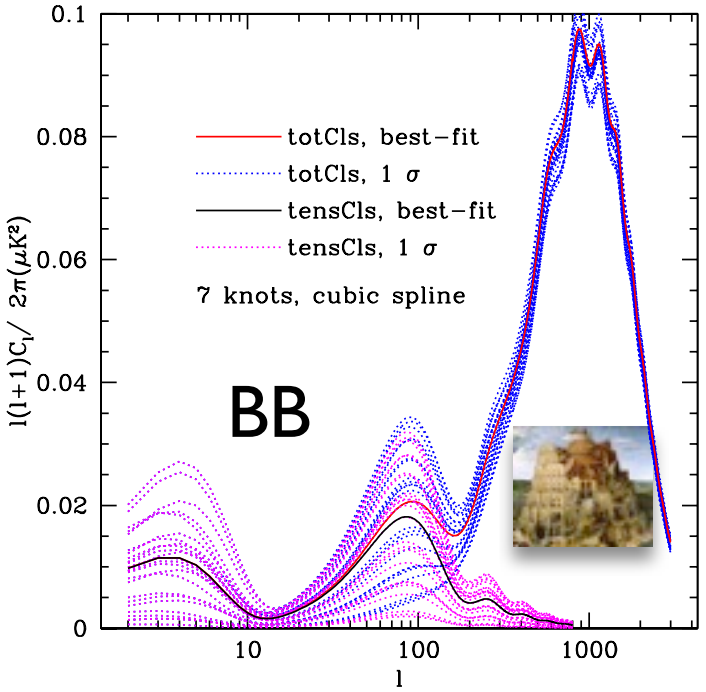
$1-n_s \approx 2\varepsilon + d\ln\varepsilon/d\ln Ha$

compress data onto non-top-hat k-modes

partially-blind scalar ln-power trajecteries & usual r-n_t tensor - no consistency relation. Nov09 data



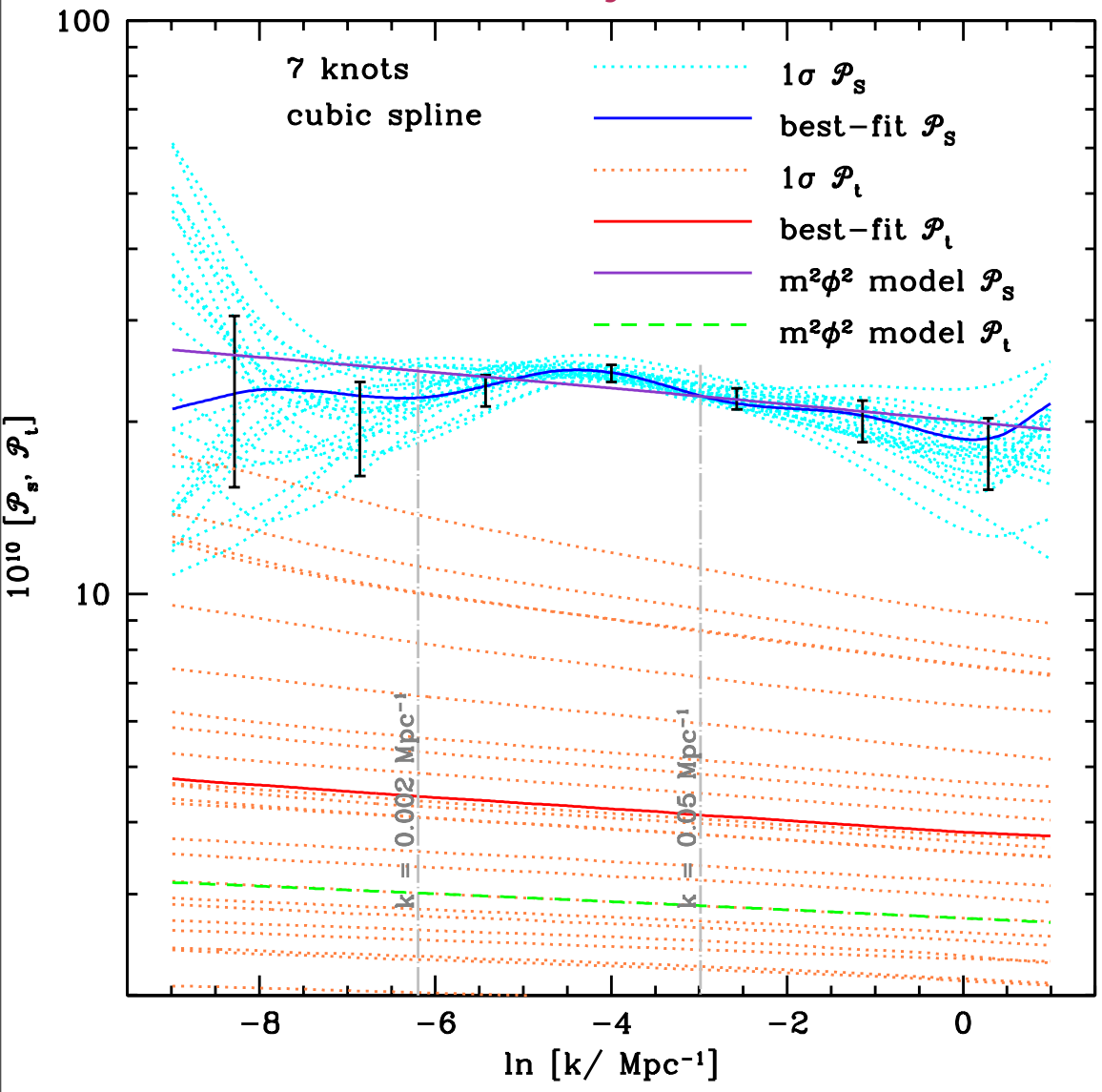


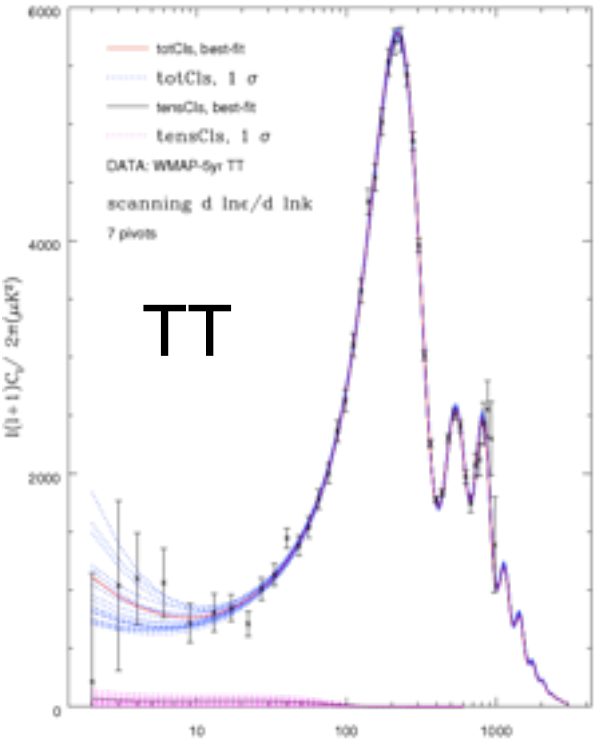


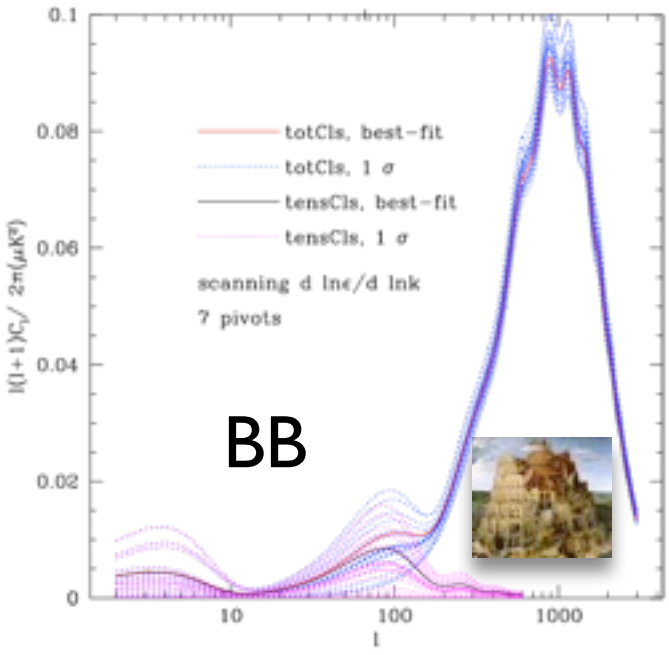
Bond, Contaldi, Huang, Kofman, Vaudrevange 2010

compress data onto non-top-hat k-modes

partially-blind acceleration trajecteries obeying tensor/scalar consistency relation. Nov09 data



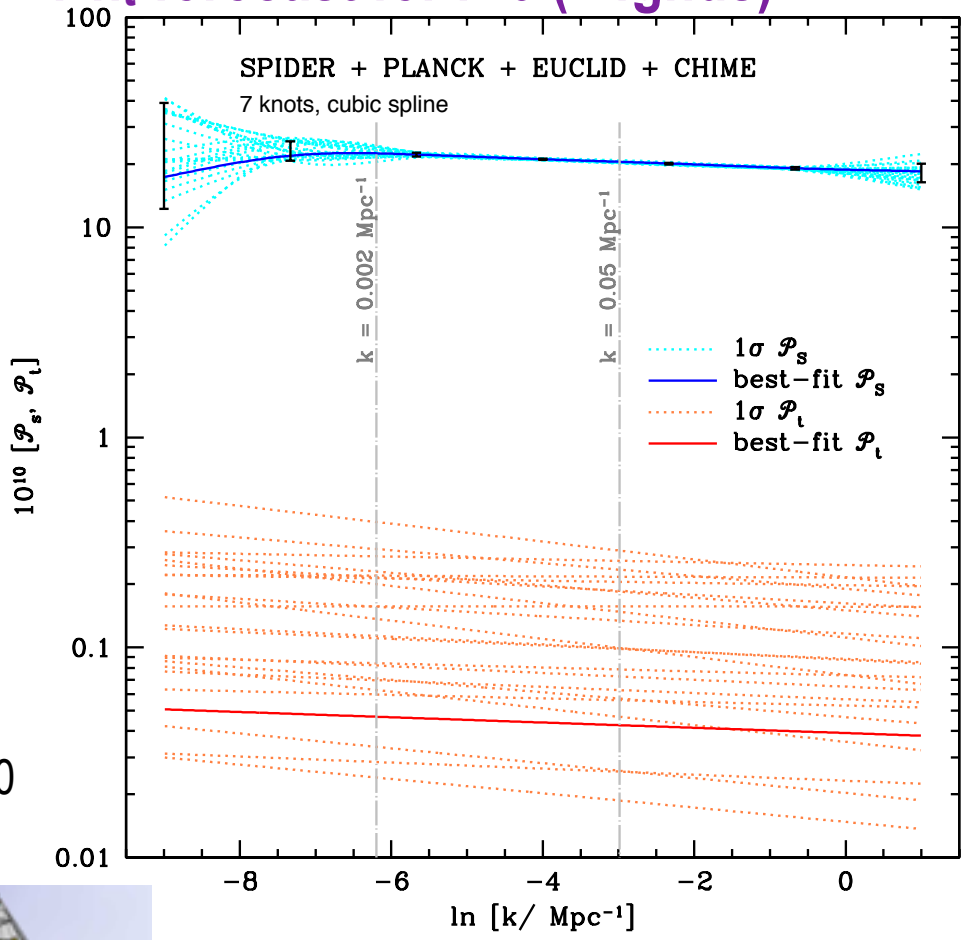




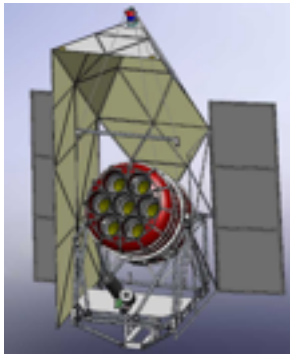
Bond, Contaldi, Huang, Kofman, Vaudrevange 2010

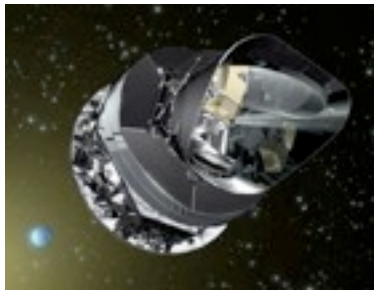
compress data onto non-top-hat k-modes

Spider-24days + Planck-2.5yr + ... 7 knot $\ln P_s$ +r-n_t forecast for r=0 (+ fgnds)



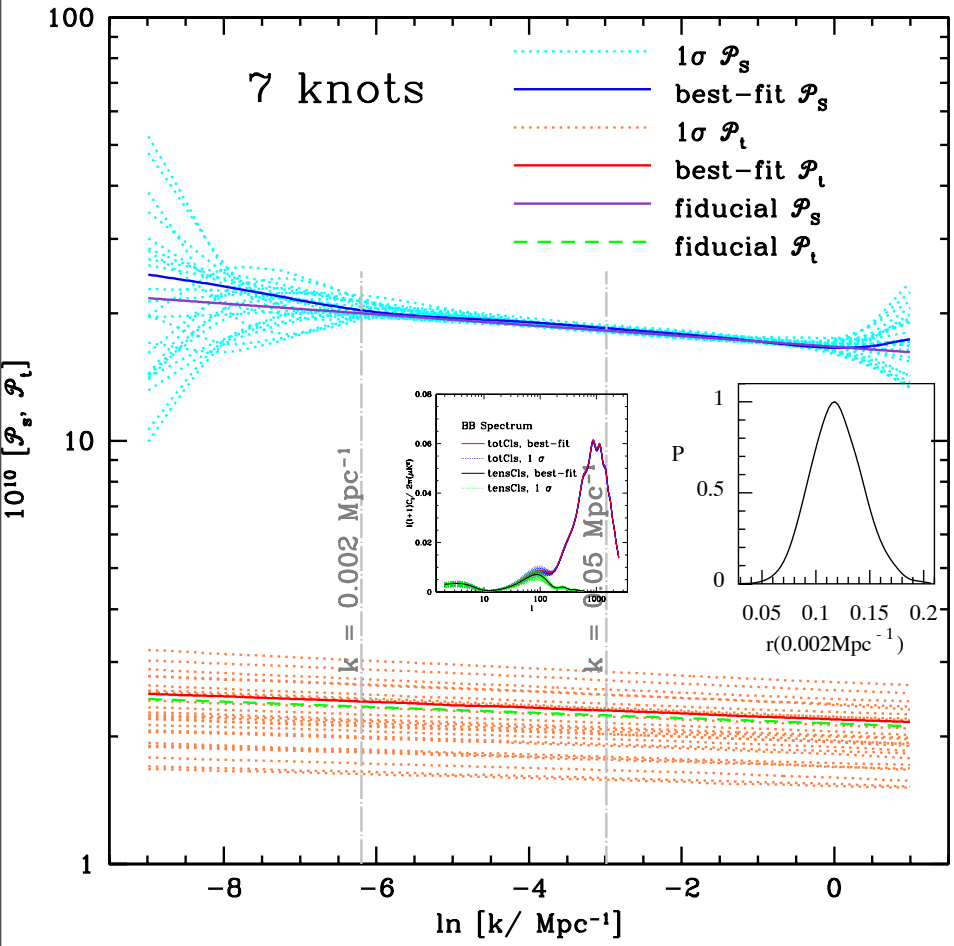
Bond, Contaldi, Huang, Kofman, Vaudrevange 2010

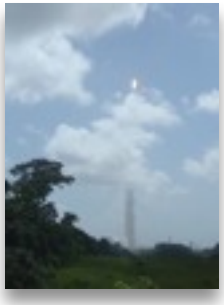


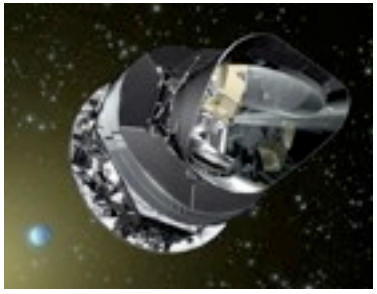


compress data onto non-top-hat k-modes

Planck2.5 7 knot forecast with inflation consistency; input r=0.12 $m^2\varphi^2$

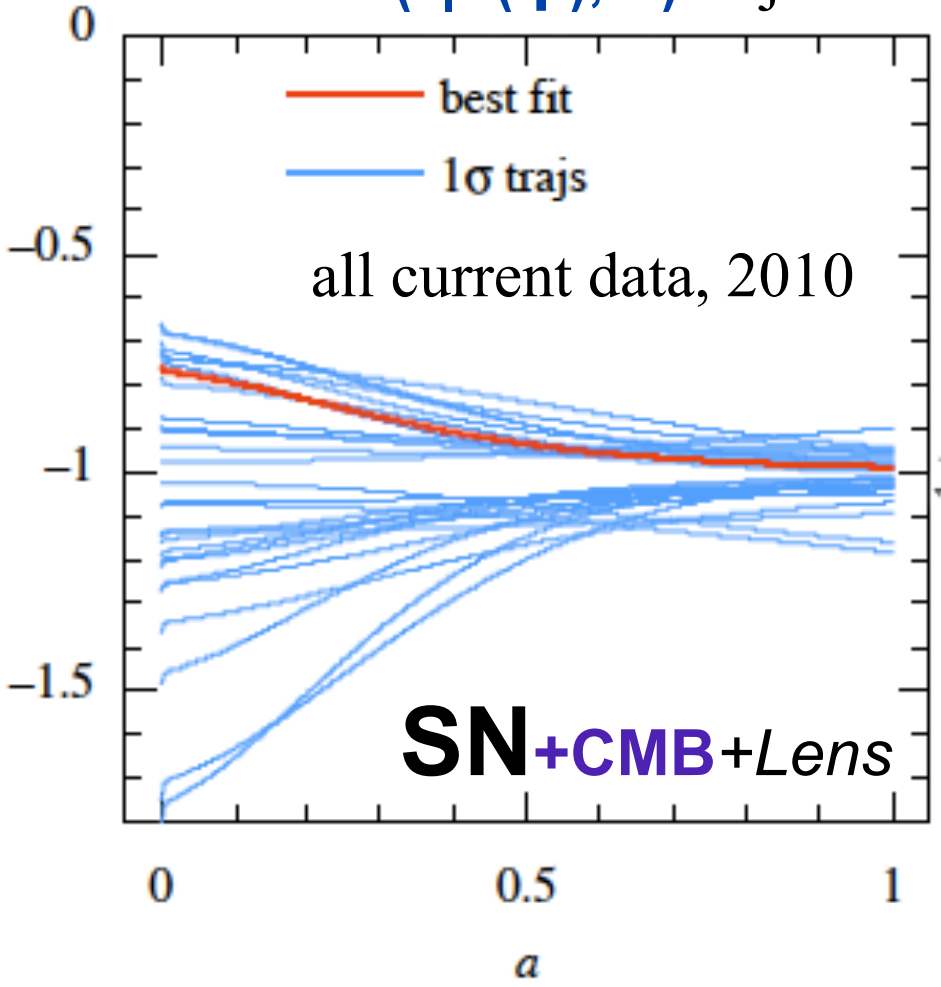




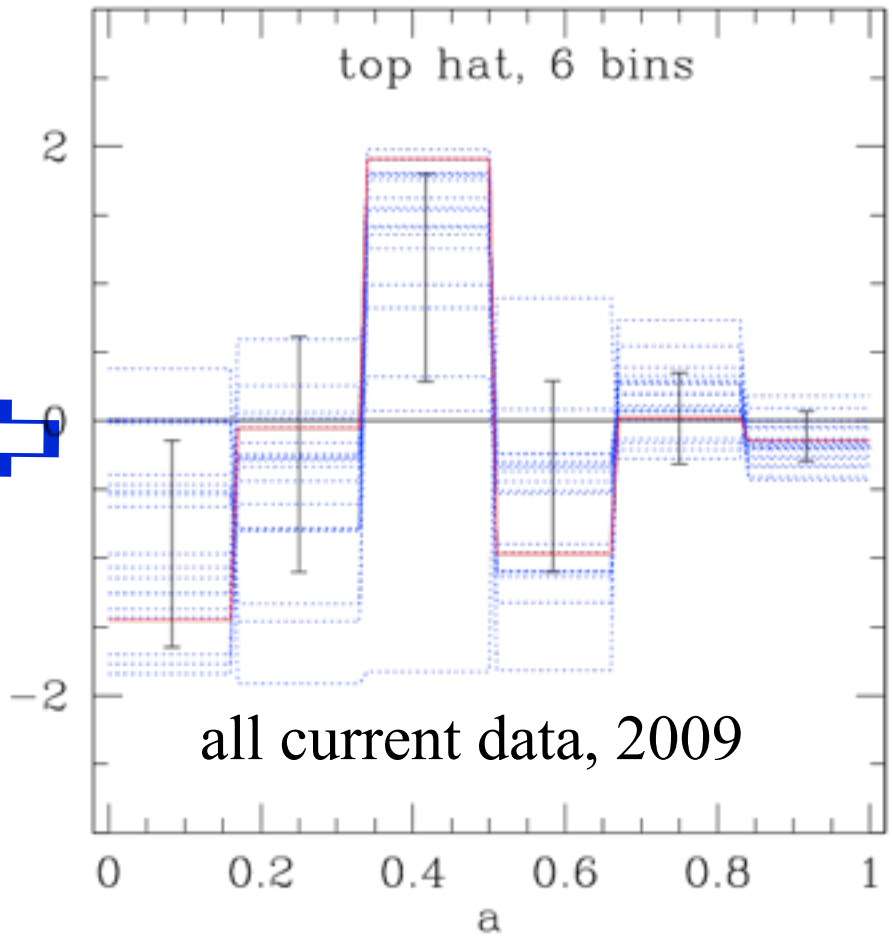


is the dark energy "vacuum potential energy" ?

3-parameter paves even wild late-inflaton **w (z|V(ψ),IC)** trajectories



semi-blind mode expansion



TEST: within errors, energy-density does not change with expansion ⇨Einstein's cosmological constant is best fit so far

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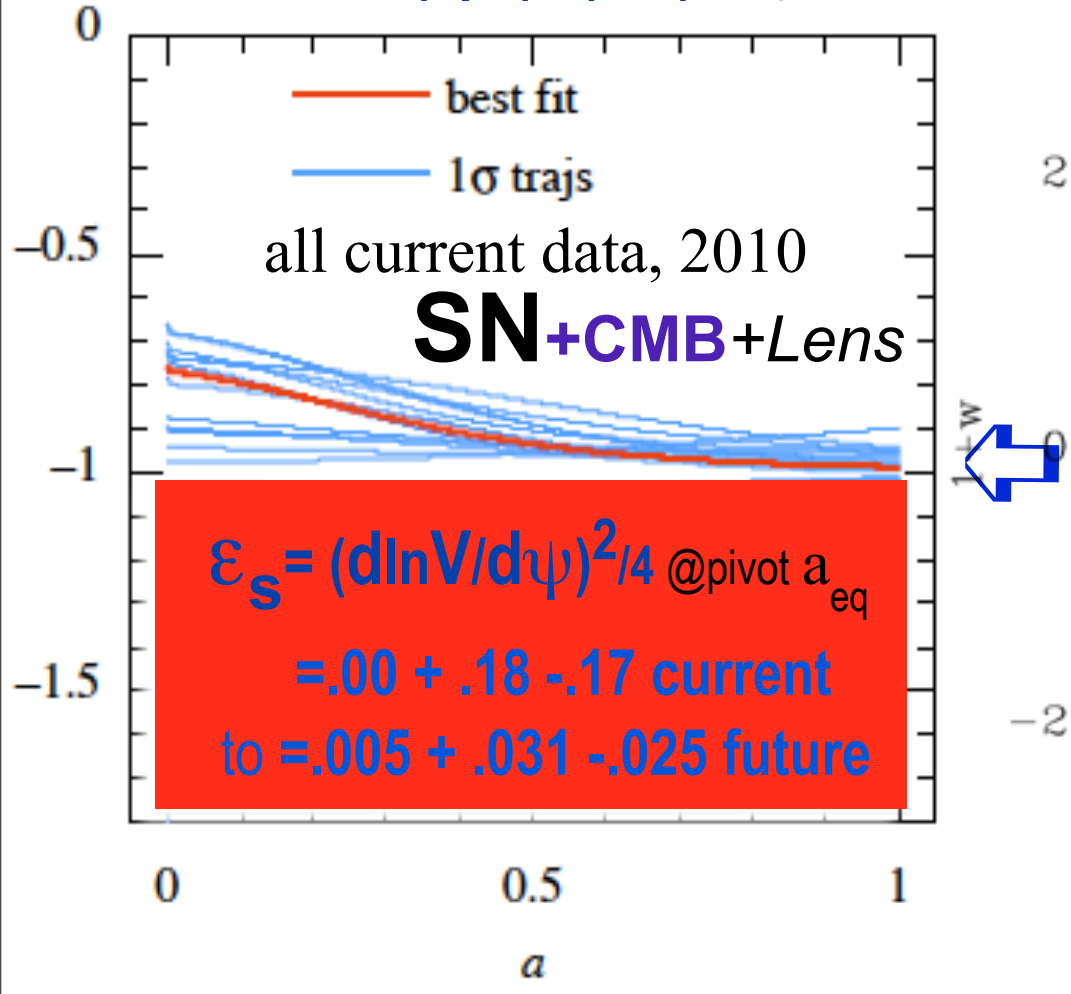

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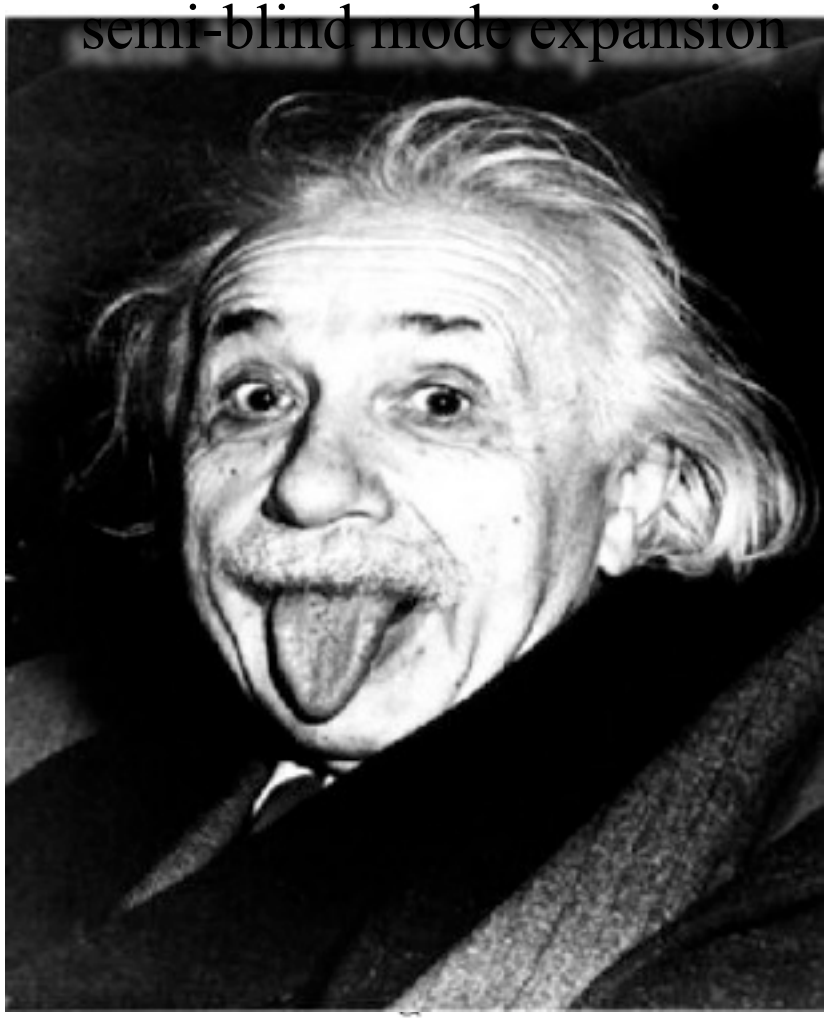

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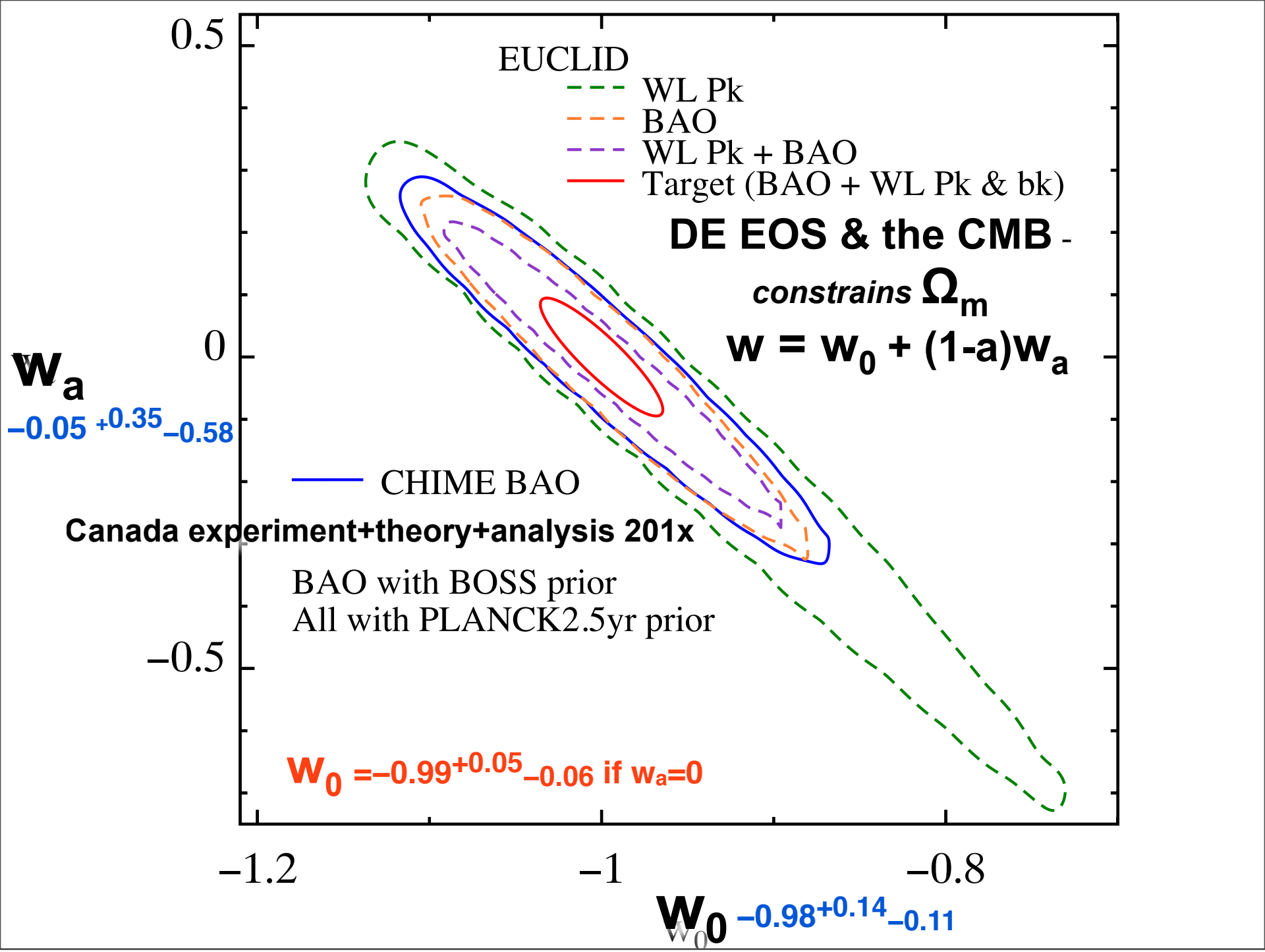
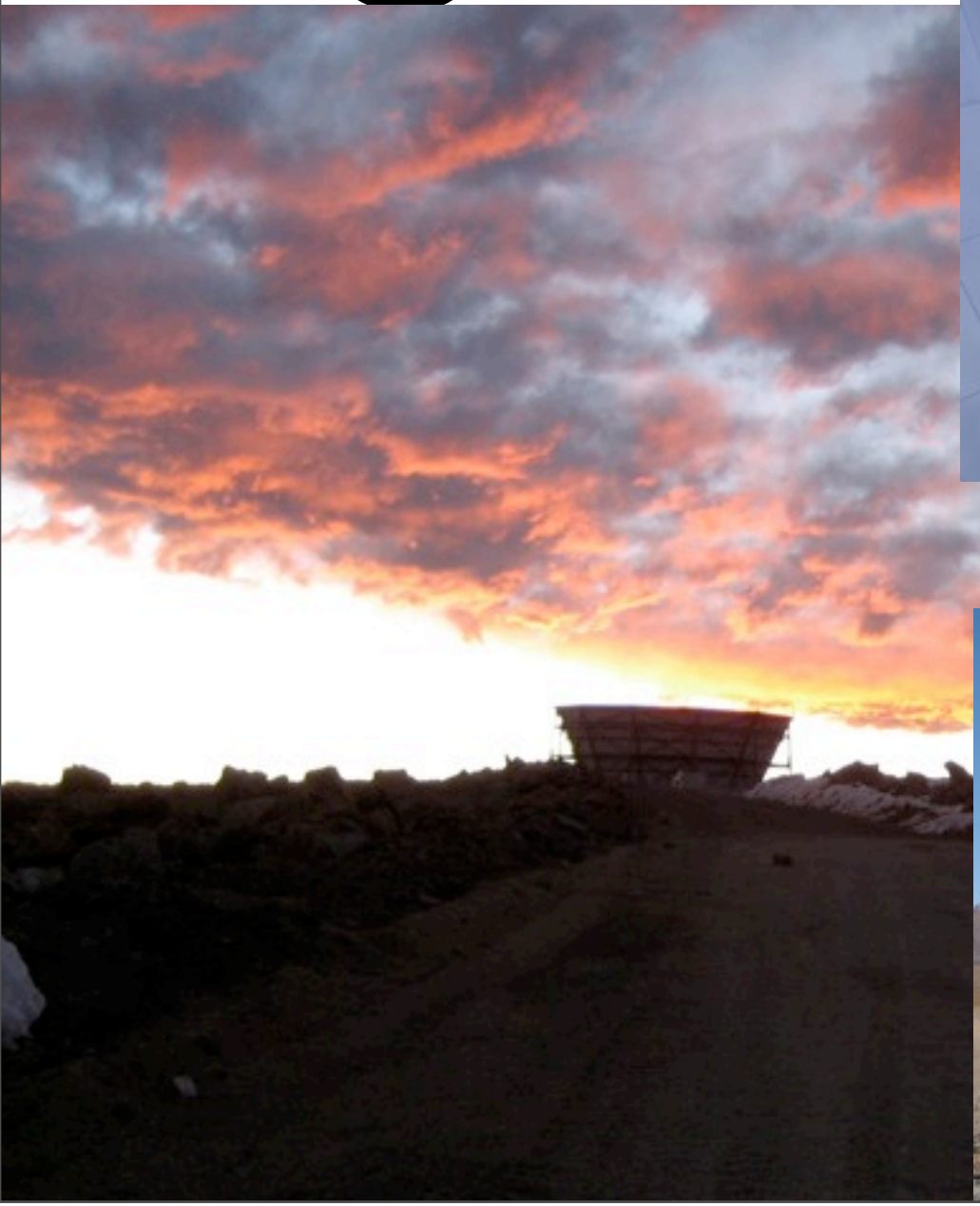
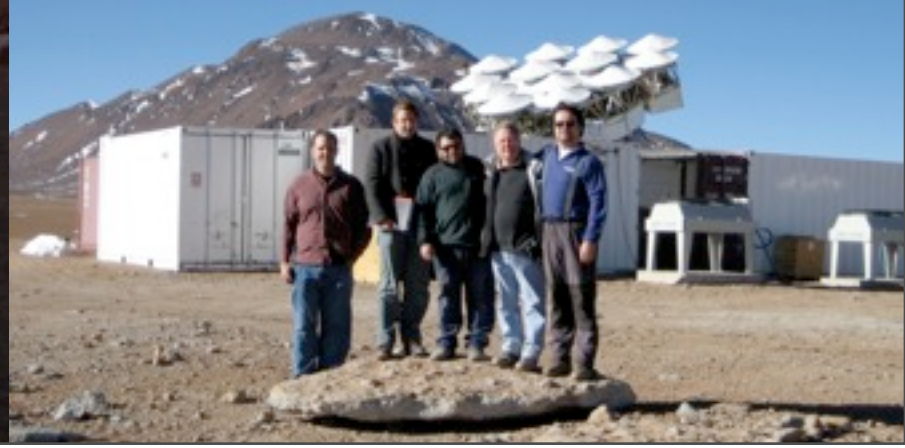

0.5
0
−0.5
−1.2
−1
−0.8
EUCLID
WL Pk
BAO
WL Pk + BAO
Target (BAO + WL Pk & bk)
DE EOS & the CMB -
constrains Ωm
w = w0 + (1-a)wa
wa
−0.05 +0.35 −0.58
CHIME BAO
Canada experiment+theory+analysis 201x
BAO with BOSS prior
All with PLANCK2.5yr prior
w0 =−0.99+0.05−0.06 if wa=0
w0 −0.98+0.14−0.11
w0

ACT@5170m



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

CBI2@5040m



the horizon seen from the 10s

if we are lucky,...we have been, are & will be

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

BI2@5040m

this is what happened in Paris in Dec 1982

there was George & Nick & Dick

& guru Joe Silk

& graduate student Albert Stebbins

Task: initiation into the cosmic way

end

oops ... Bond runs out of time yet again