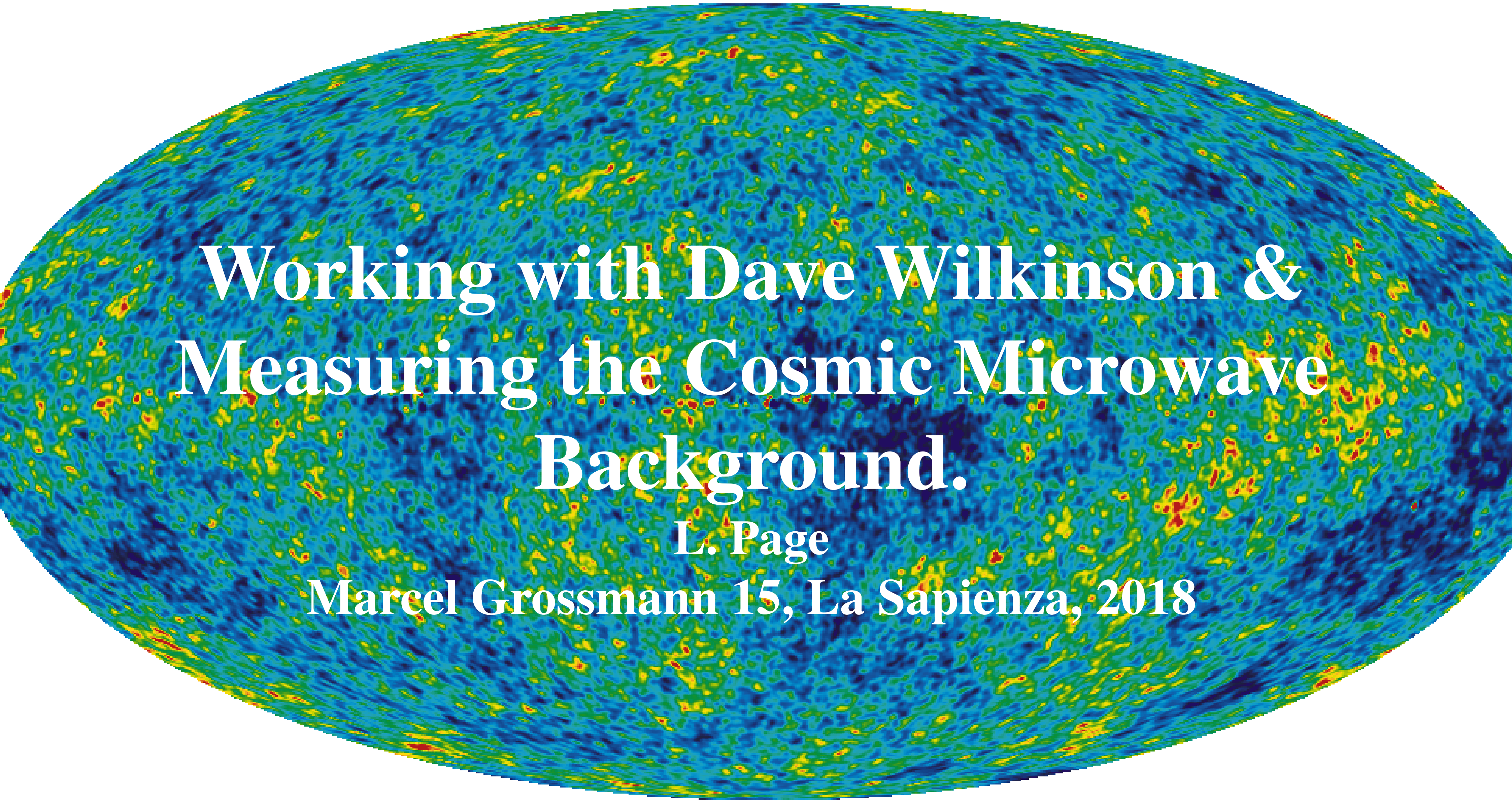

Working with Dave Wilkinson &
Measuring the Cosmic Microwave
Background.
L. Page
Marcel Grossmann 15, La Sapienza, 2018

Dave Wilkinson 1935-2002

hD with Richard Crane at U. Michigan on "A Precision
Measurement of the g-Factor of the Free Electron," (1962)

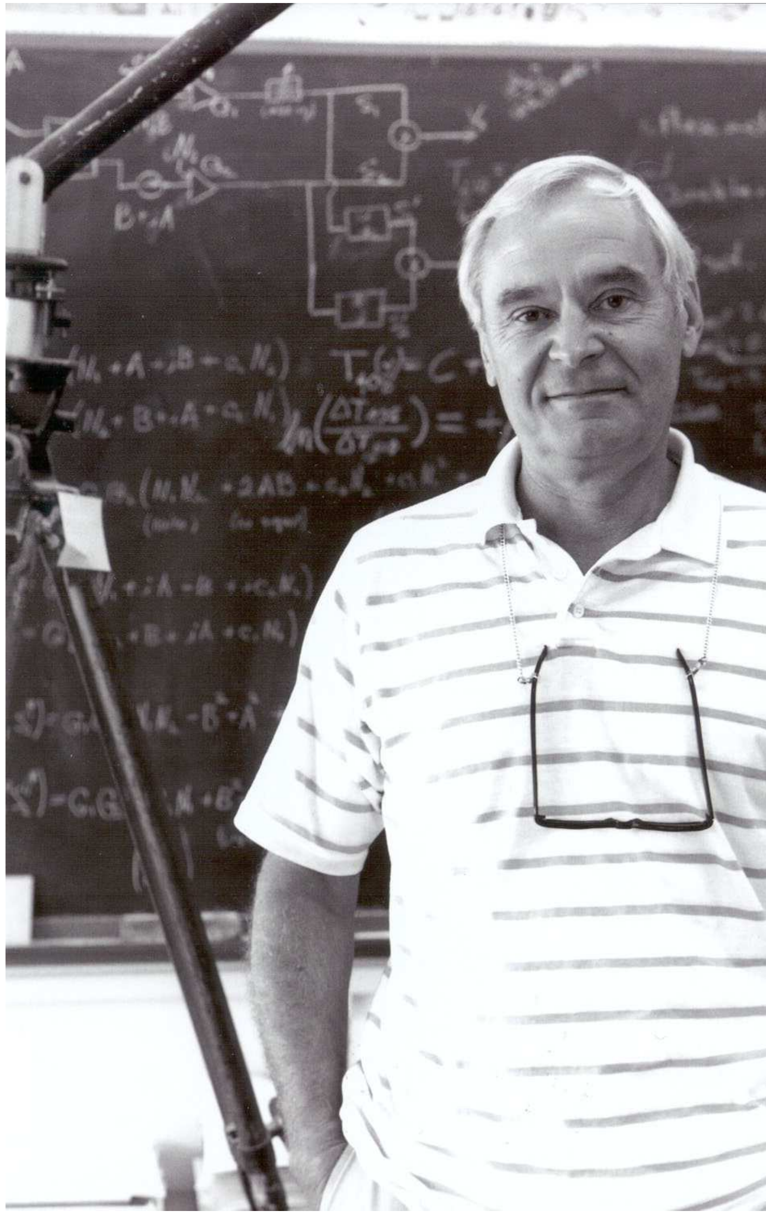
Moved to Princeton to work with Bob Dicke in 1963.

Working with Peter Roll to search for the CMB when it was
iscovered by Penzias and Wilson in 1965.

Many pioneering CMB measurements, including first dedicated
nisotropy measurement with Bruce Partridge (1967).

ounding member of the COBE satellite. First proposal (October 1974)
ith John Mather, Pat Thaddeus, Rai Weiss, Dirk Muehlner, Dave
ilkinson, Mike Hauser and Bob Silverberg.

ame to know Dave through MIT. Rai Weiss, lab head, was also
rt of Dicke’s group (‘62-’64); my advisor, Steve Meyer, was
ave’s student, “my postdoc” Ed Cheng was Dave’s student,
avid Cottingham was Steve Boughn’s student (Steve was in the
avity group), Peter Saulson was Dave’s student. When Dave
ked if I wanted to come to Princeton after graduate school….



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* ($> 10^o +$ *multipoles*)
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

The first meeting on CM
phenomenology.
(1987)

Organized by Dick Bon
with the helpful hand
Dave for the
experimentalists.

Covered GWs,
Polarization, SZ…

Princeton University: Physics Department

Jadwin Hall

To: Nancy Weiss Malkiel

From: David Wilkinson

Subject: AAS Meeting in Washington **Date:** June 10, 1994

Nancy,

You have probably already heard from Shirley that I can go to the AAS/NSF meeting on undergraduate science education, "Science Dean's Colloquium." (Please take note that this should in no way be construed to indicate any interest in future service to Princeton.)

In your reply, you might indicate that Princeton has 5 years of experience with a Science and Technology Council. If the steering committee wishes, I could 1)bring a written description of the Council and what we've learned; or 2) discuss our experience with the group or a sub-group.

Who pays for the travel? (I hate these "conference" hotels in Crystal City, etc. I couldn't bring myself to suffer and pay.)

David

DW:mrf

Dave was passionate about undergraduate teaching …but not about meetings in general

Dave's White Paper for CMB satellite for a NASA workshop, March 1991. 5 Pages !

DRAFT Dave

Mission Concept

rincipal investigator/ Co-investigator address and phone number:

Prof. David Wilkinson
Physics Department, PO Box 708
Princeton University
Princeton NJ 08544

upporting institution:

Princeton University

cience objectives:

The universe as seen today is very clumpy in its matter distribution -- galaxies, sheets and ains of galaxies, empty voids -- yet extremely smooth in its radiation component, the 2.735 K osmic microwave radiation (CMR). Measurements show that the CMR is isotropic to $\Delta T/T \leq$ a w x 10^{-5} on all angular scales between 5 arcminutes and 180°, where the Sun's velocity with espect to the CMR gives a $\Delta T/T \sim 10^{-3}$. The current limits on CMR anisotropy provide strong onstraints on theories of large-scale structure formation within the standard Big Bang osmological model. Indeed, if the anisotropy is not seen at $\Delta T/T \sim$ a few x 10^{-6}, most people gree that the standard model is in serious trouble. On the other hand, measurements of the CMR nisotropy, and its angular power spectrum, are the key to understanding the density perturbations at led to mass structure and the fundamental processes in the early universe that caused those erturbations. Most workers in the field would rank the discovery of CMR anisotropies as one of e two or three most important problems in cosmology.

This mission would map the CMR in Galactic pole regions to an accuracy of $\Delta T/T \sim$ a few x 0^{-6} at angular scales of 1° - 10°-scales where mass structure similar to that of the great attractor, e great wall, or giant voids would cause measurable anisotropy in the CMR. As a secondary bjective, the entire sky could be mapped at wavelengths not available from the ground.

Ieasurement objectives:

The DMR experiment on COBE is searching for CMR anisotropy on scales from 7° to 180° y mapping the entire sky. The goal is to reach $\Delta T \sim 100$ µK in each 7° x 7° sky pixel. Using adiometers 25 times more sensitive than the best DMR, this mission would map the Galactic polar aps with 1° angular resolution and an average instrumental sensitivity of $\Delta T \sim 6$ µK per 1° x 1° ixel. Maps of diameter (at least) 20° are highly desirable to study the distribution of anisotropy -- ital information about the early universe.

Nine frequency channels distributed between 40 GHz and 90 GHz would be used to measure nd remove foreground Galactic synchrotron, bremsstrahlung, and dust emission. The minimum f Galactic emission is known to be in this band; by extrapolating measurements at lower and igher frequencies, we estimate the Galactic signal to be about 90 µK at 40 GHz and 10 µK at 90 iHz.

Using its distinctive frequency signatures, the Galactic emission would be removed to xamine the CMR for anisotropy. Because Galactic emission is stronger at all other CMR equencies, isotropy is best studied at these frequencies. Unfortunately, ground-based neasurements are severely hampered between 45 GHz and 85 GHz by a strong absorption line in xygen.

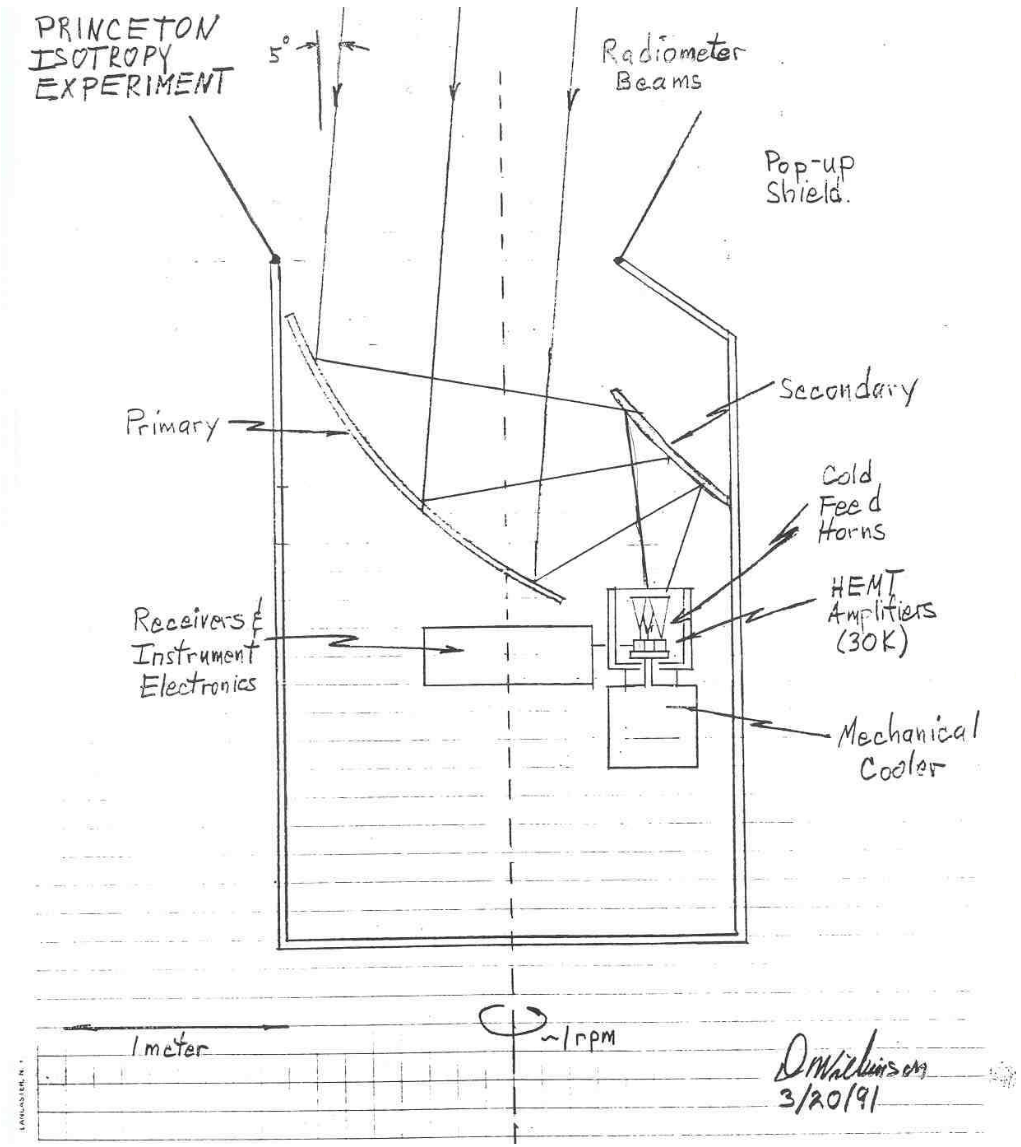
COBE/DMR Discovery, April 199

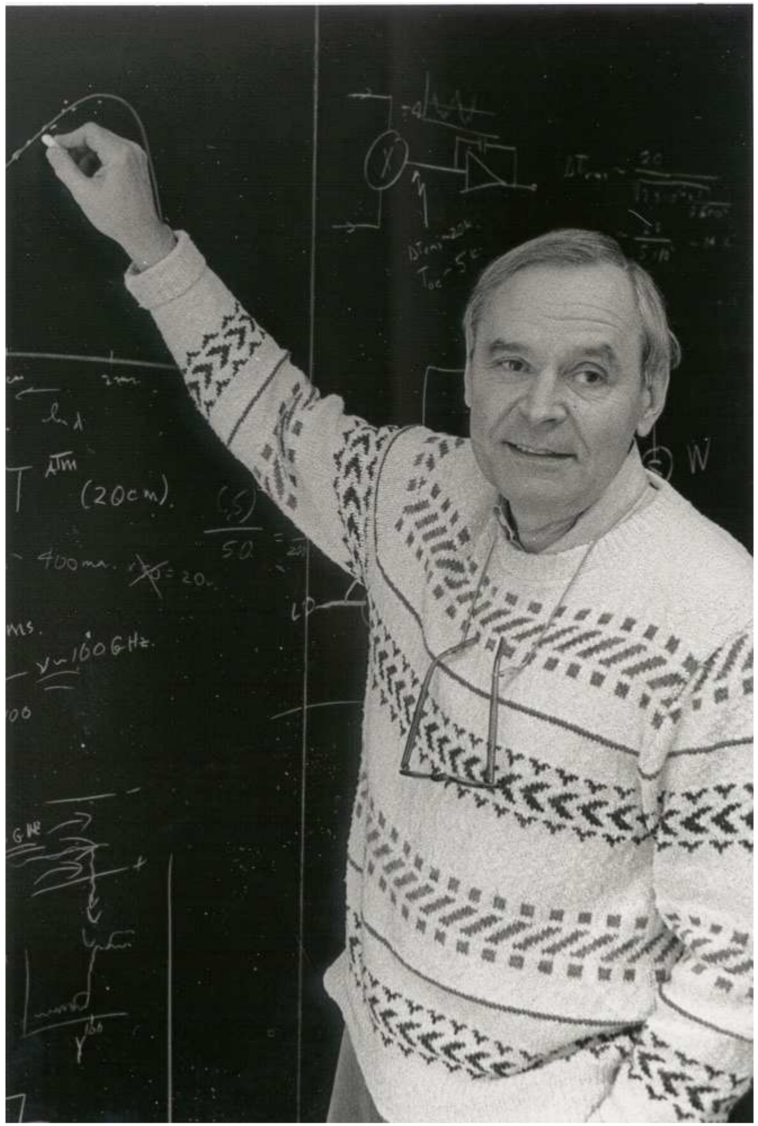
Payload Data Sheet

Estimated science instrument characteristics

Mass (150-300 kgs)	175 kg including structure
Width/Diameter (less than 200 cm, launch configuration)	200 cm
Height (under 300 cm, launch configuration)	See Sketch
Power (up to 250 Watts)	250W (with 2 mechanical coolers)
Average Data Rate (less than 100 kbits/sec)	5 kbits/sec
Pointing accuracy (up to 1 arcsecond with input from science instrument, 30 arcseconds without)	Pointing 10 arcminutes Pointing Readout 5 arcminutes
Lifetime needed to complete science investigation (1-3 years)	1-3 years
Optimum orbit: -Apogee -Perigee -Inclination -Period	 42,000 km 42,000 km 63° to equator 1 day
Time required for mission development (3-4 years)	4 years (mechanical cooler)
Instrument payload cost (FY91 dollars)	$10-15 M ~~if managed from Princeton~~ including spacecraft and data analysis software

Page 5, white paper





Dave Wilkinson

Princeton University

Department of Physics: Joseph Henry Laboratories
Jadwin Hall
Post Office Box 708
Princeton, New Jersey 08544

S. Weinreb
Martin Marietta Laboratories
Baltimore, MD.

FAX # 301-247-4939

Sandy,

schedule for May 23 looks fine. We will probably travel by Metroliner, arriving in Baltimore 8:25 am and take a cab to MML. The best train to take back will be leaving Baltimore at 5:30 pm. My colleagues, who helped write the concept and will help with the presentation & discussion are:

Norm Jarosik (Instructor)
Lyman Page (Instructor)
Ed Wollack (Ph.D. Thesis Student)

Thanks for arranging all of this; we're looking forward to the visit.

Dave

cc Jarosik
Page
Wollack

Our first meeting outside of Princeton.

Our first proposal.
Aug 1991

Independently, Chuck Bennett was working at NASA/GSFC to make a path for a CMB mission and associated RFP.

Research Proposal Submitted to the National Aeronautics
and Space Administration

by

Princeton University
Department of Physics
P. O. Box 708
Princeton, N.J. 08544-0708

An Educational Organization

A NOVEL APPLICATION OF FOURIER TRANSFORM SPECTROSCOPY WITH HEMT AMPLIFIERS AT MICROWAVE FREQUENCIES

August 1991

RFP: NRA-91-OSSA-13:ASTROPHYSICS
Period Covered: Jan. 1, 1992 to Dec. 31, 1995 Amount Requested:
This proposal not submitted to any other agency.

Endorsements:

Principal Investigators:	Chairman	Administrative Officer
David T. Wilkinson Lyman Page, Jr.	A. J. S. Smith	A. J. Sinisgalli
Professor 609-258-4406	Professor 609-258-4402	Director - ORPA 609-258-3090
Assistant Professor 609-258-5578		

This funded "SASK" on which WMAP was based.

L2

HEMTs 30-90 GHz

There are two main problems with making these maps. (1) Instrument sensitivity has been the main limitation to date. The CMB temperature is only 2.735 K (according to COBE) so to clearly see the expected anisotropy the error per map pixel should be $\pm$ 3 μK or less. The most promising technologies for reaching this level are bolometers for $\lambda \leq 2\,mm$ and high electron mobility transistor (HEMT) amplifiers at longer wavelengths. (2) Foreground radiation sources from Galactic electrons and dust will ultimately limit the accuracy of CMB anisotropy measurements. The Galactic window is around $\lambda = 3\,mm$ (100 GHz), but even here it will be necessary to subtract Galactic emission to reach the desired sensitivity. Therefore, course spectral information is needed in any high precision anisotropy project.

Another important idea that is being pursued by several groups is to develop a multi-beam observing system. Since integration times are long (hours) for even the lowest-noise instruments, having an array of detectors is a huge advantage for a mapping project. Bolometers and HEMTs show considerable promise for elements of arrays and several groups are working on this. Finally, since remote observations (South Pole, balloons, satellites) are involved in CMB isotropy experiments, system simplicity and reliability are important considerations. Here HEMTs have a significant advantage over other low-noise mm-wave detectors.

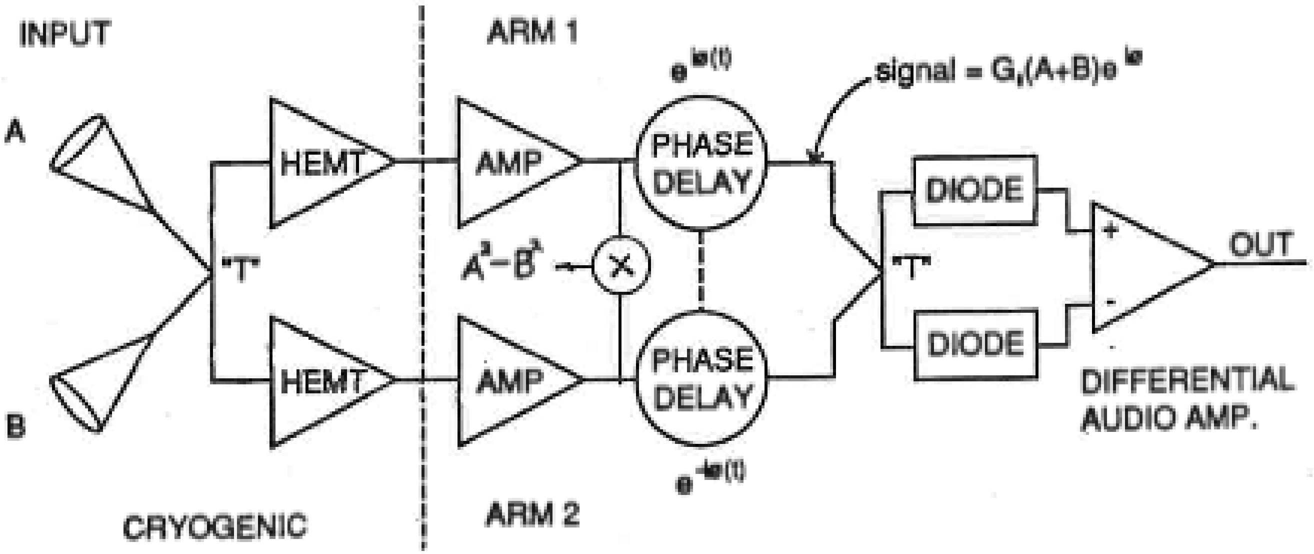
Most observations of CMB anisotropy at angular scales below 5° have been made from the ground. The atmosphere seriously degrades these measurements in two ways: (1) lumpy water vapor emission creates a large noise signal on most days, and (2) the smooth component of atmospheric emission increases system noise – the main limitation on ΔT for most well-designed experiments. Cold sites, balloons, and satellites are currently being used. To us (and to the Soviets) it is clear that a satellite at the solar L2 point is the ultimate platform for an anisotropy experiment. No atmosphere, greatly reduced Earth and Sun emission, simplified pointing, and long integration time are important advantages of a remote satellite.

The work proposed here is part of a program to capitalize on recent and expected advances in high-frequency, cryogenic HEMT technology. Viewed from the perspective of the problems mentioned above, HEMT amplifiers are very promising for high-precision mapping of the CMB anisotropy. We plan to help NRAO engineers to evaluate HEMTs for use at 90 GHz, and simultaneously to build radiometers using available 30 GHz and 40 GHz amplifiers. These radiometers will be evaluated on the ground and from balloons, with the ultimate goal a proposal to NASA for a Small Explorer mission to map the CMB anisotropy in the Galactic polar regions.

II. Project Description

HEMTs

HEMT amplifiers have become the detectors of choice for frequencies between 1 and 45 GHz wherever low noise, broadband, and stable amplifiers are required. They are relatively cheap and rugged devices well suited to satellite or remote observing applications. Their



HEMT FTS
FIGURE 1

The radiometer is now differential and includes phase switching.

Norm Jarosik independently proposed the version in WMAP.

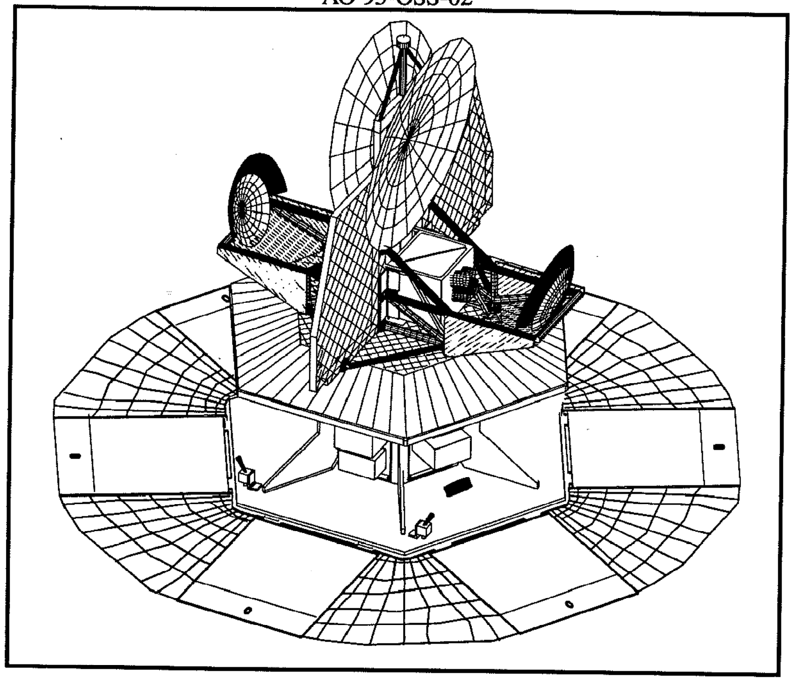
CONFIDENTIAL
LYMAN PAGE

MICROWAVE ANISOTROPY PROBE

MAP

A MIDEX Mission Proposal

submitted in response to
AO-95-OSS-02



Submitted June 1995 by

Charles L. Benett, Principal Investigator

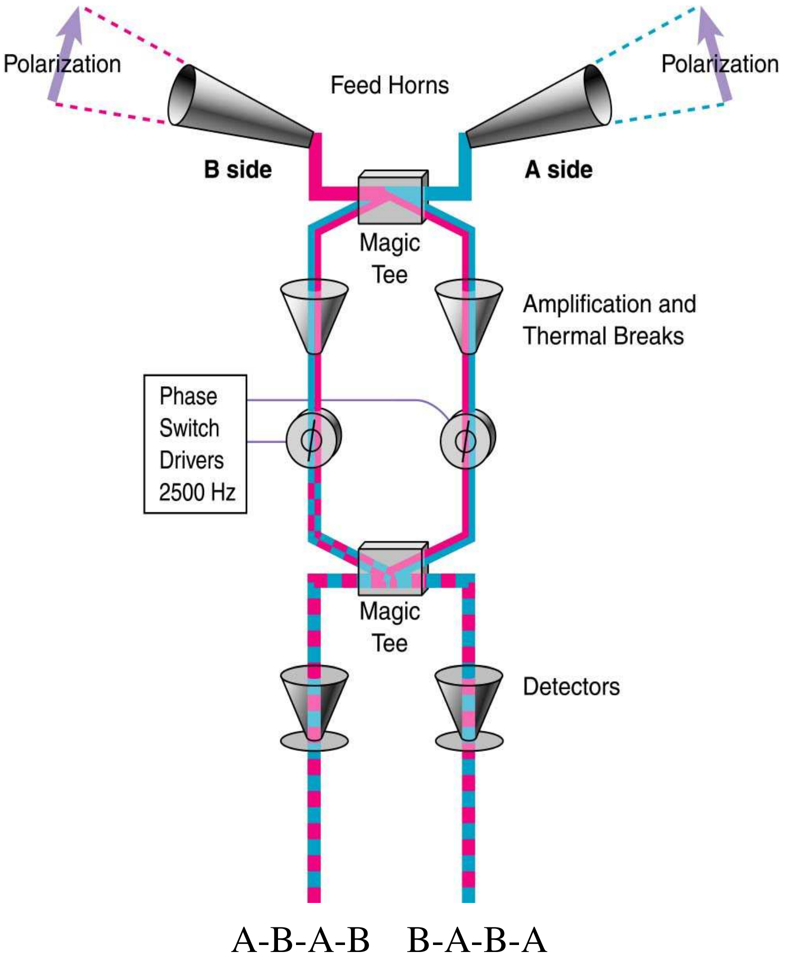
Goddard Space Flight Center
Greenbelt, MD 20771

in partnership with

Princeton University
Princeton, NJ 08544

WMAP Proposal (1995)

Chuck Bennett (PI)
Gary Hinshaw
Norm Jarosik
John Mather
Steve Meyer
Lyman Page
David Spergel
Dave Wilkinson
Ned Wright

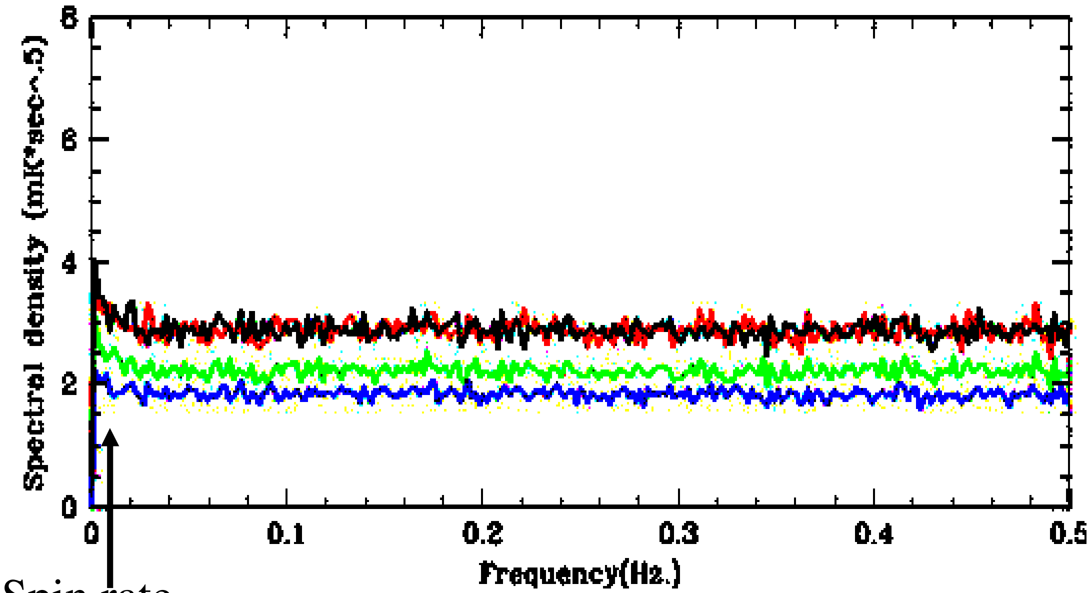


One of 20

Why low 1/f ?

Differential design...

….mK thermal stability



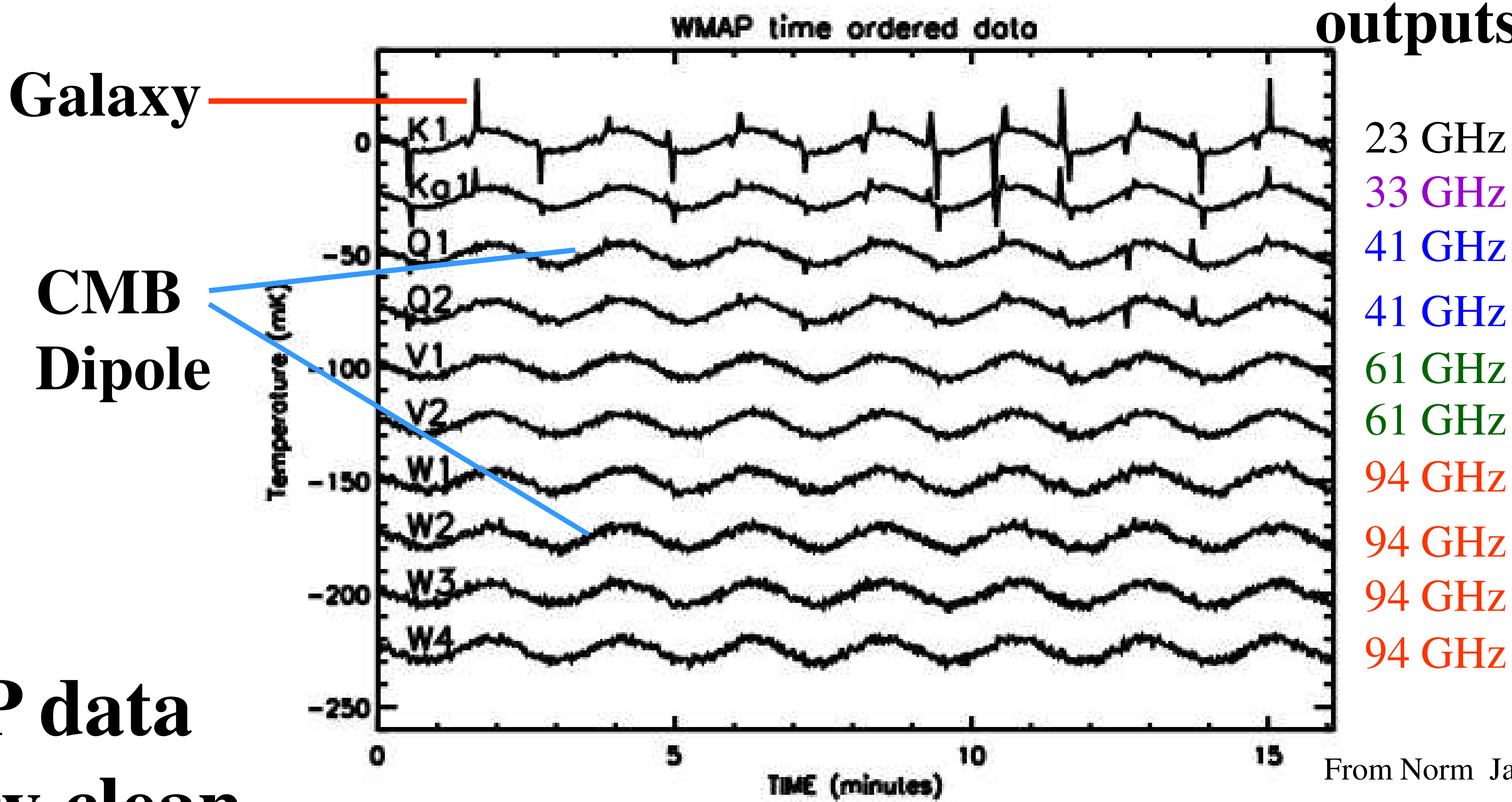
Amplifiers from NRAO, M. Pospieszalski design

Noise in maps Gaussian over five decades.

Jarosik et al.

Raw data w/1.5s smoothing.

Differential outputs.



From Norm Jarosik

WMAP data are very clean.

There are no instrumental "corrections" [e.g., No ADC issues, <1.5% raw data cut] made in producing the maps.

WMAP

Combined Science Team:

NASA/GSFC
Bob Hill
Al Kogut
Nils Odegard
Ed Wollack

Johns Hopkins
Chuck Bennett (PI)
Ben Gold
David Larson
Janet Weiland

UBC
Mark Halpern
Gary Hinshaw

Brown
Greg Tucker

Cornell
Rachel Bean

UCLA
- Ned Wright

Chicago
- Stephan Meyer

MPA
Eiichiro Komatsu

Microsoft
Chris Barnes

ICE
Licia Verde

Princeton
Jo Dunkley
- Norm Jarosik
- Lyman Page
- David Spergel

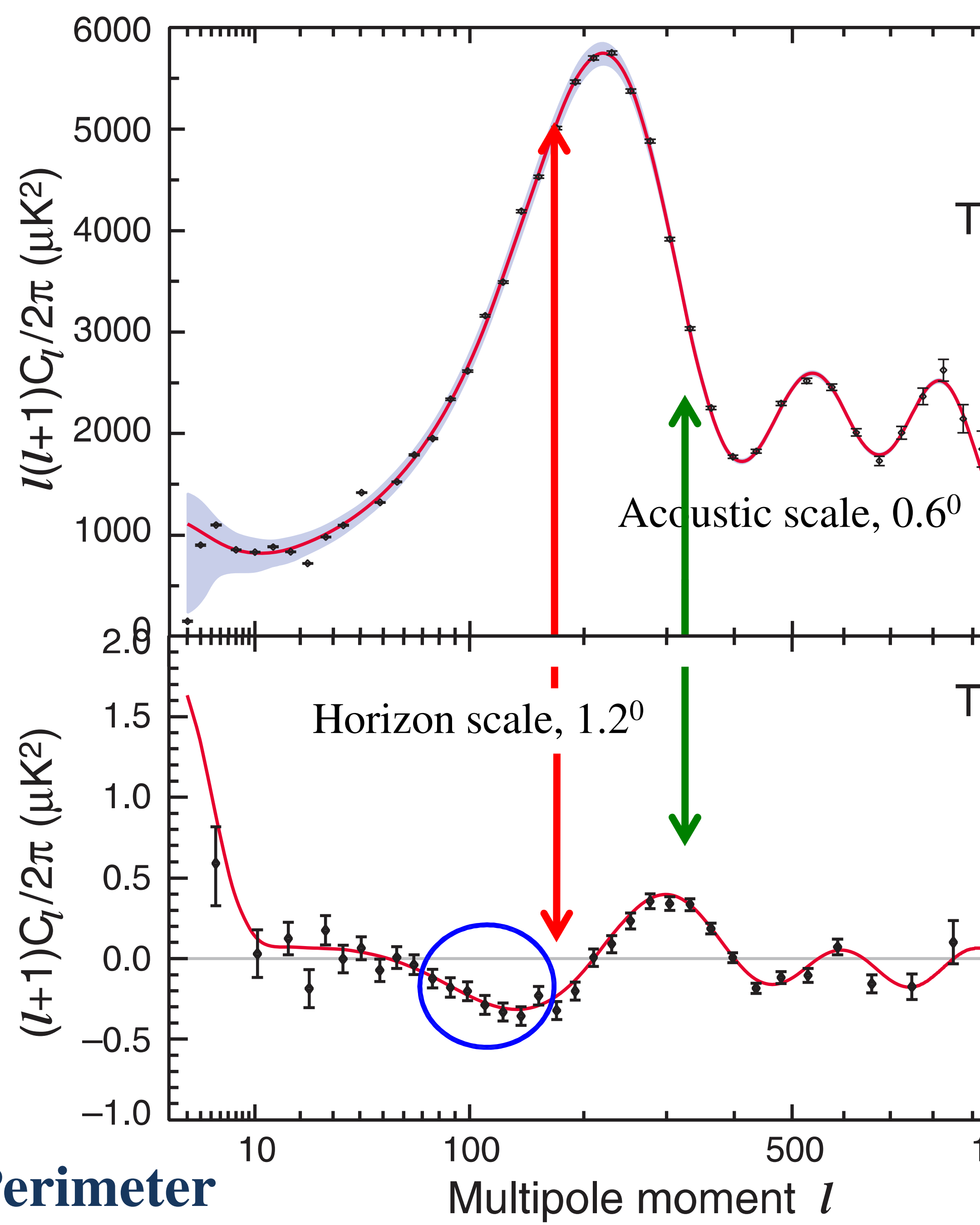
JPL
Olivier Dore

Penn
Michele Limon

UCL
Hiranya Peiris

CITA
Mike Nolta

Perimeter
Kendrick Smith



There's much more to learn from the CMB

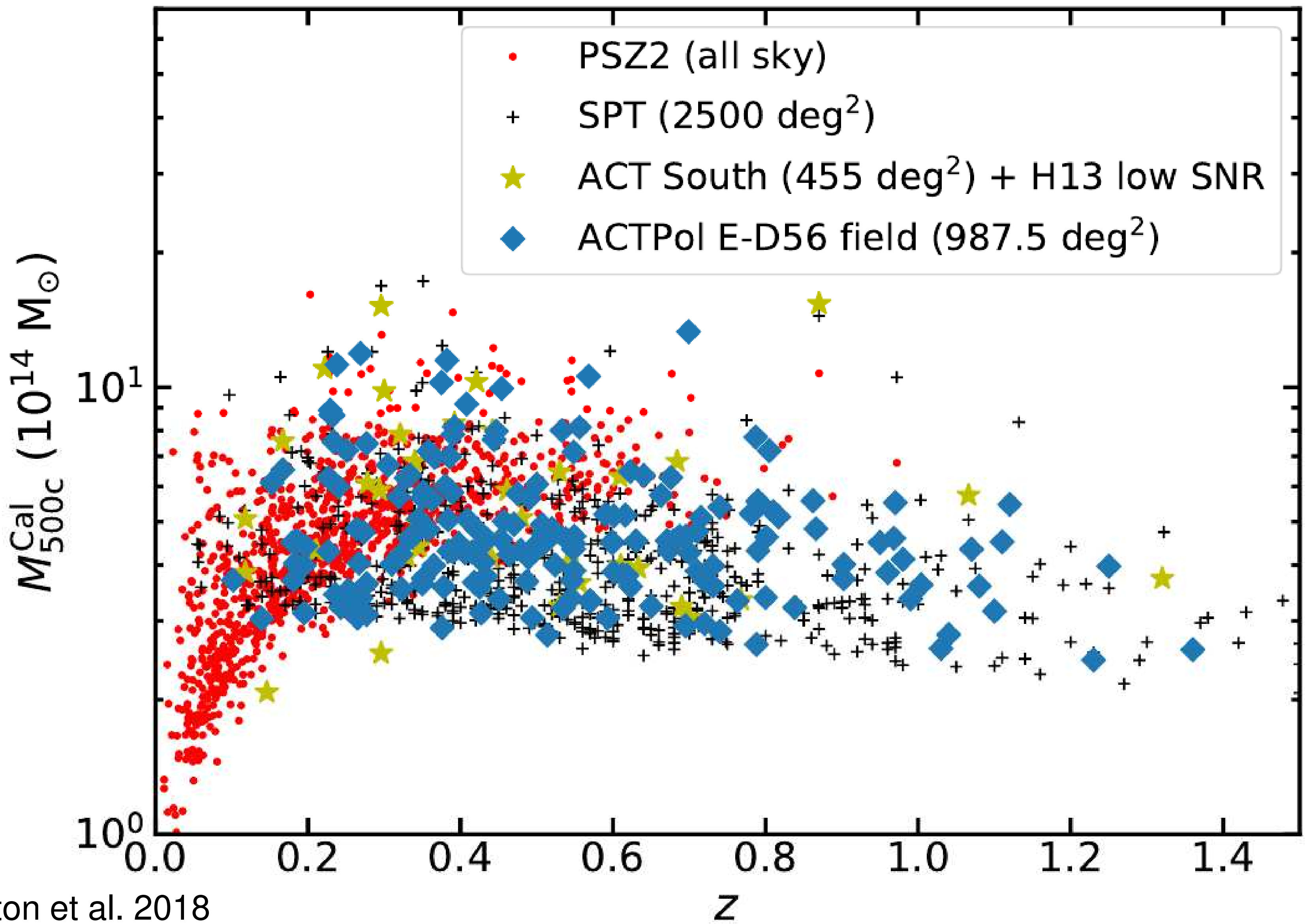
CMB Smörgåsbord

- Primordial B-modes: gravity acting on quantum scales.
- Independent assessment of cosmological parameters
- H_0
- Neutrino number and mass.
- Isocurvature modes from EE; the lowest hanging fruit?
- Testing GR/equation of state through the growth of structure.
- Calibrating LSST lensing and other surveys.
- Mass bias for quasars, radio sources, through lensing…
- Halo masses through stacking and lensing.
- Cosmic ionization history.
- Find thousands of galaxy clusters.
- Find high redshift dusty galaxies.
- …..
- Something new!

The Atacama Cosmology Telescope Collaboration

Suzanne Staggs is ACT's PI & Mark Devlin is ACT's co-director

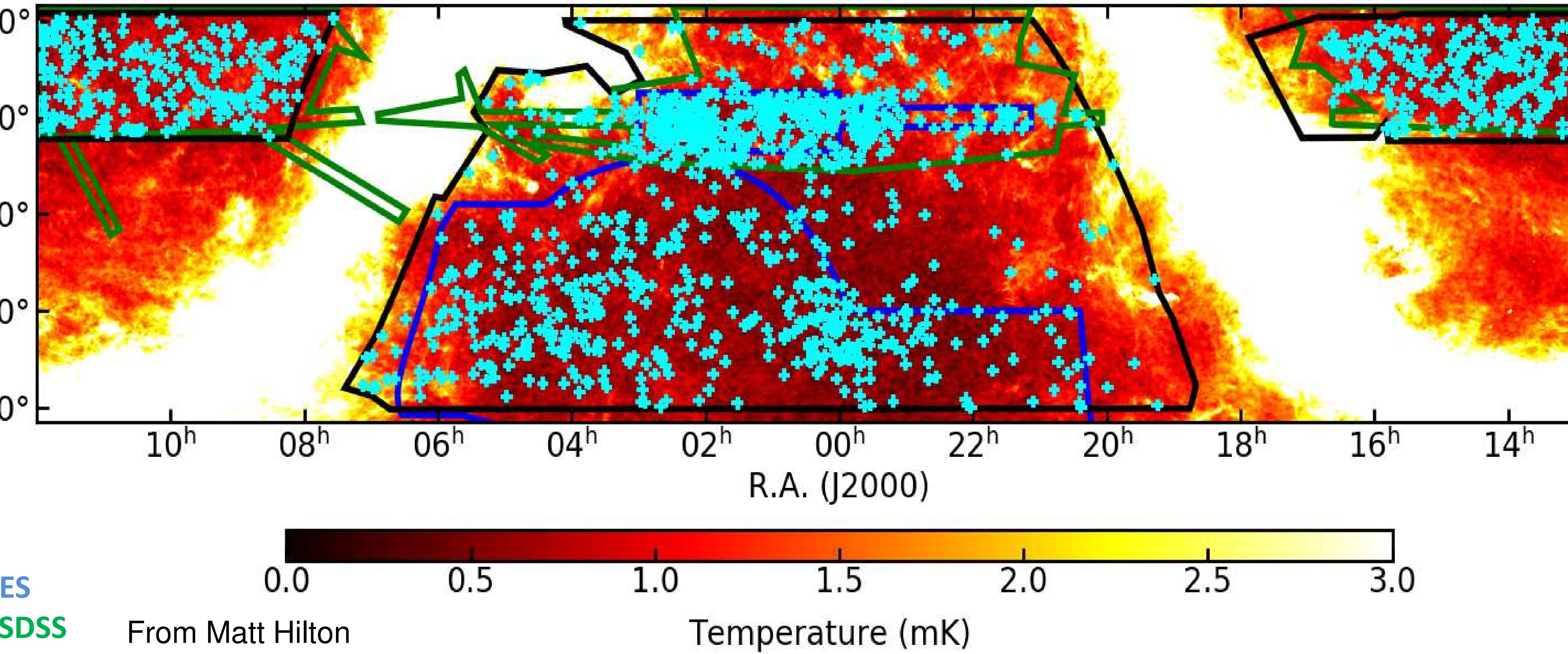
Published ACT cluster sample



Hilton et al. 2018
(arXiv:1709.05600)

1 season of Advanced ACT, 90 +105 GHz

>1000 clusters

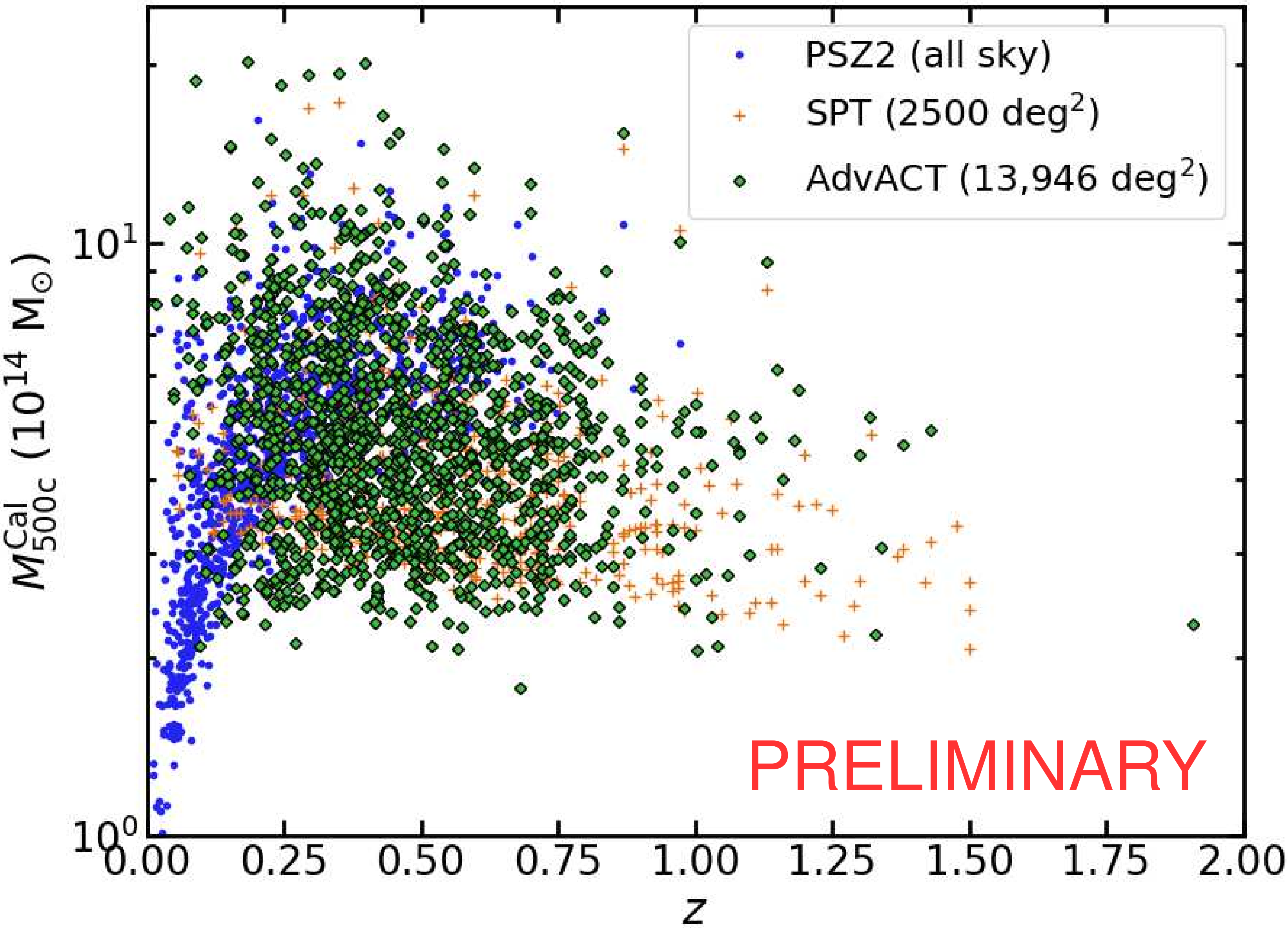


ES

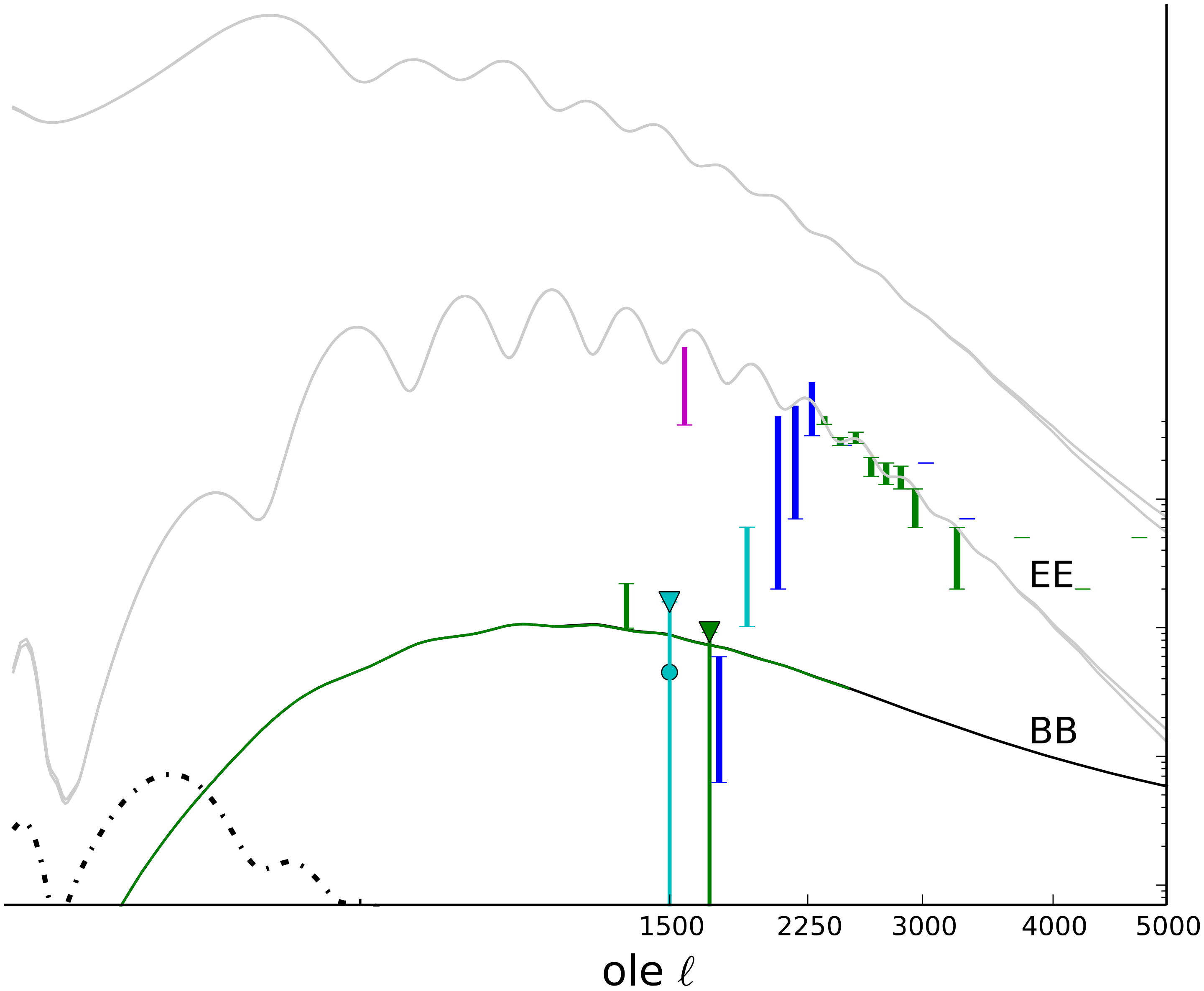
SDSS

From Matt Hilton

Preliminary Advanced ACT cluster sample



Recent Results



th data in
ıd for ACT
ς smaller
statistical
error bars