October 27, 13 700 002 006 ABB

Probing the opposite ends of time with the

Cosmic Microwave Background Radiation

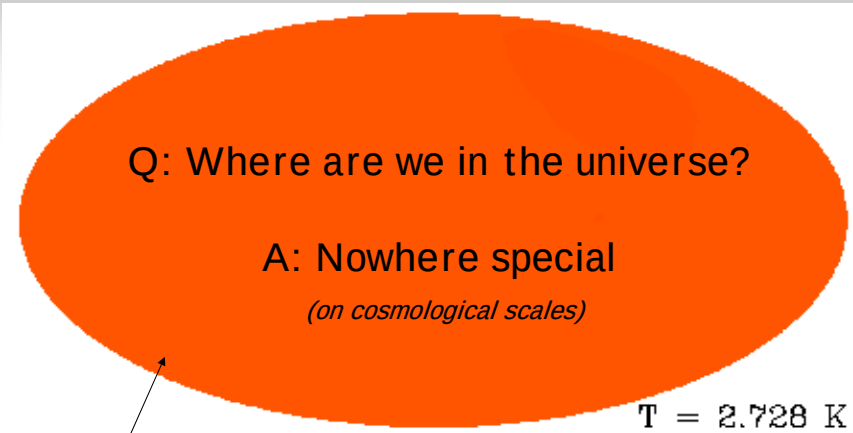
Matt Dobbs

From our perspective as optical observers, the universe is a rich place full of structure, detail and beauty.

Q: Where are we in the universe?

A: Nowhere special

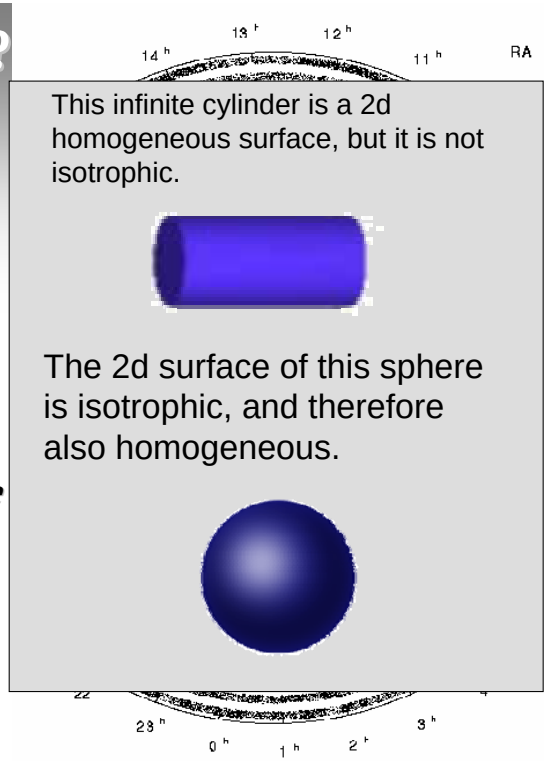
(on cosmological scales)



"Photograph" of the universe in the Microwave band.
Real Experimental DATA from the COBE satellite, 1992.

What is cosmology?

- Step back to larger scales, and the universe that surrounds us is extremely uniform–
- on large (Cosmological) scales, the universe is
  - homogenous (the same everywhere)
  - isotrophic (looks the same in every direction)
- Loosely put, ***cosmology is the study of our universe on these scales***.

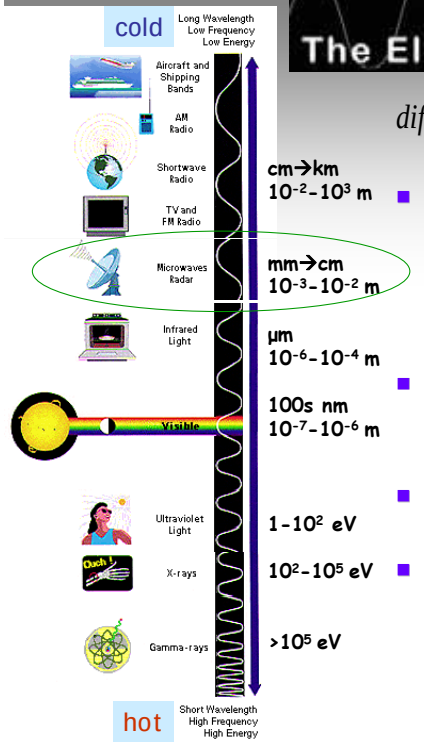


This infinite cylinder is a 2d homogeneous surface, but it is not isotrophic.

The 2d surface of this sphere is isotrophic, and therefore also homogeneous.

EM Spectrum

The Electromagnetic Spectrum



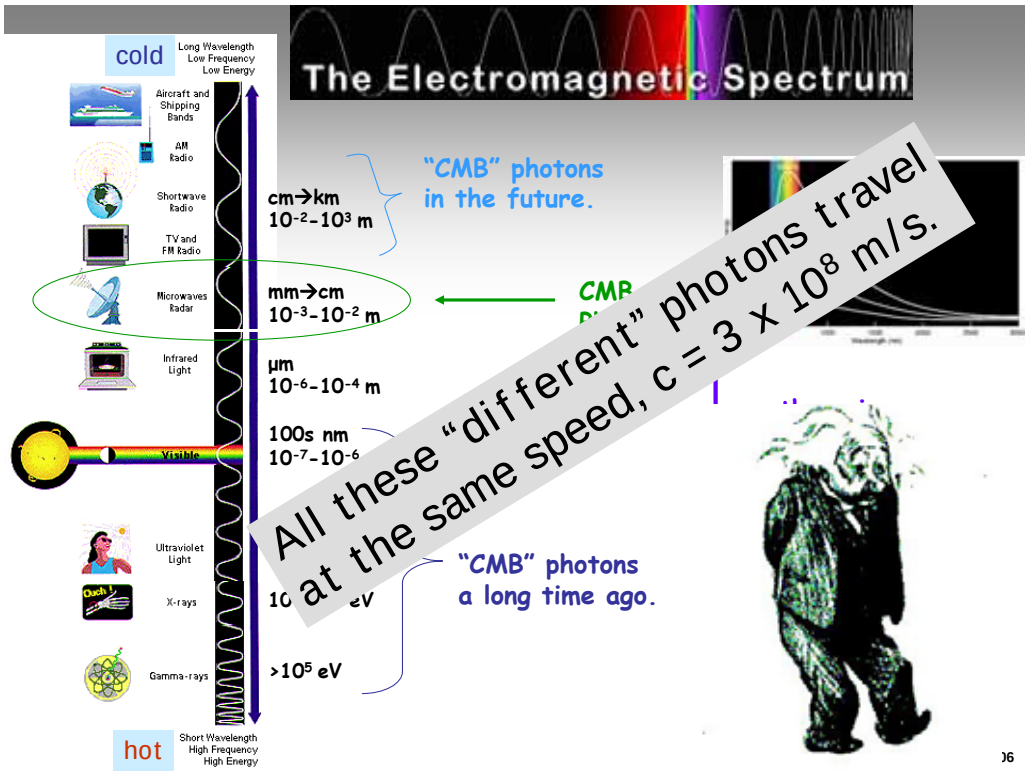
different information is encoded in different bands.

- radiowaves: i.e. radar

CMB Photons now.

- visible: this is how we see the world around us.
- x-rays: i.e. dentist/doctor.
- gamma-rays: highest energy particles we know of…

The Electromagnetic Spectrum

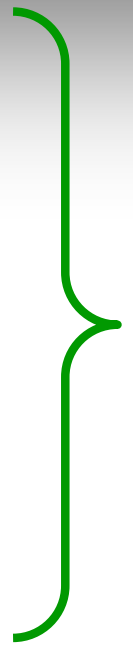


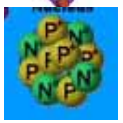
The Horizon

- light – and indeed any information – cannot be transmitted faster than the *speed of light, c*.
- For a universe that is L=13.7 billion years old, information could be exchanged over a maximum distance Lc.
- This defines "*our horizon*".
- As time moves forward, our horizon increases!.
- *The Horizon problem*: we see structures (e.g. the universe!!) that are uniform on super-horizon scales.

- Since light coming from further away takes longer to get here, the objects that emit the light are from an earlier time, because the light was emitted a long time ago.

observations of distant objects are observations of our universe at a younger age.

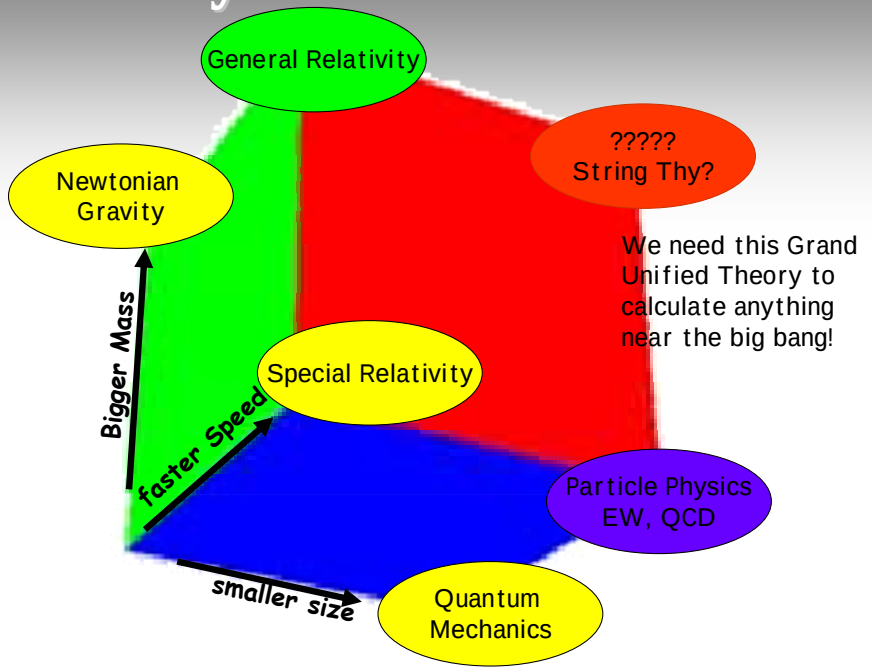


Size (m)	Object		Force	Expert
10^{21}	>= Galaxies		Gravity	Cosmologists
10^{6}	Stars & planets			Astronomers
1	Living Things		Instinct Romance Biology	Psychologists Taxi Drivers Biologists
10^{-9}	Molecules		Electromagnetism	Chemists Pharmacists
10^{-10}	Atoms			
10^{-15}	Neutrons/protons		Weak Force Strong Nuclear Force	Nuclear & Particle Physicists

Thanks to A. De Rujula for this slide idea.

on different length scales, different forces are relevant– and so we use different theories and equations.

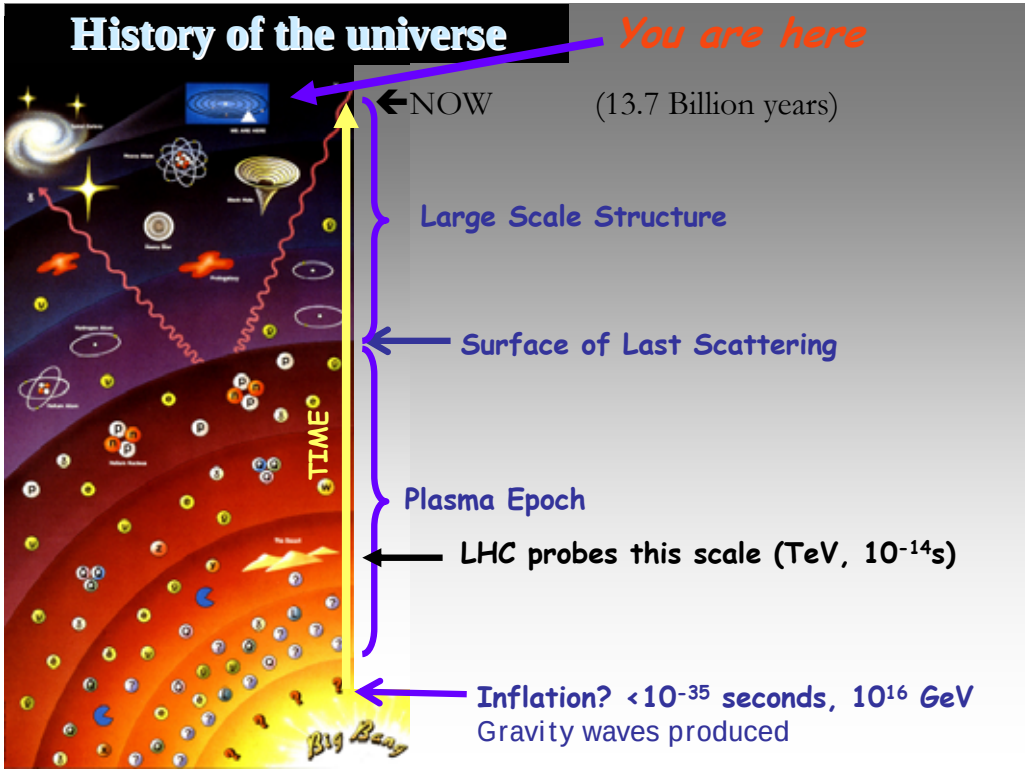
Physics Theories



The History of the Universe

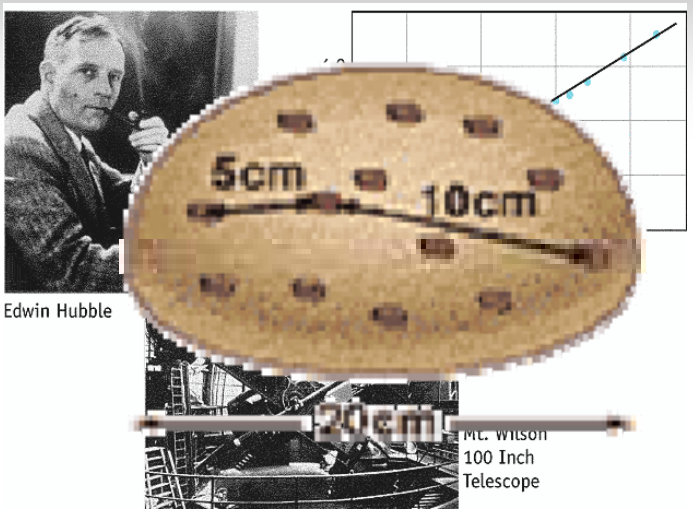
a photon's journey from the opposite ends of time

History of the universe



History of the Universe

The Big Bang



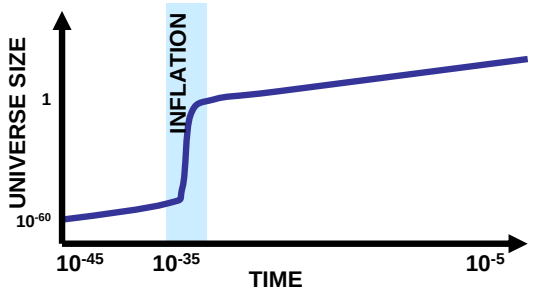
- 1920s & 30s: Hubble observed the universe is expanding ★

History of the Universe

Inflation

- at t~10^{-35} s ABB, the universe undergoes a phase transition causing an explosive 10^{30} exponential expansion

→ Inflation explains the horizon problem: why CMB is isotropic



History of the Universe

Plasma Epoch, t <~ 400 000 years

- the universe is opaque to light
- matter and radiation are tightly coupled ***in thermal equilibrium***

History of the Universe

Recombination t~379 000 years ABB, T=3000K

- protons combined with electrons to form neutral hydrogen
  - recombination is sudden.
- this is the "***surface of last scattering***"

History of the Universe

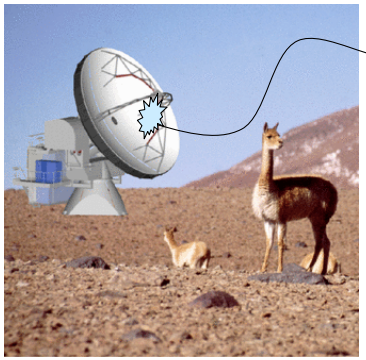
Large Scale Structure Formation Epoch

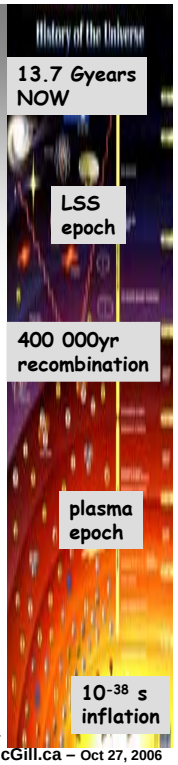
- Matter collapses under gravity to form the rich structure (including us!) of the universe.
- photons are (almost!) unaffected
- Why the difference between Matter & Radiation now??
  - → *radiation pressure* resists the pull of gravity.

History of the Universe

NOW

- **t~13 700 002 006 years ABB**
- **T=2.7 K (-270^0 C)**

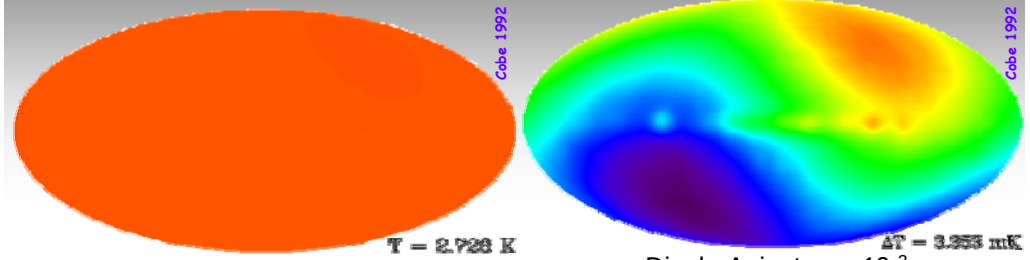




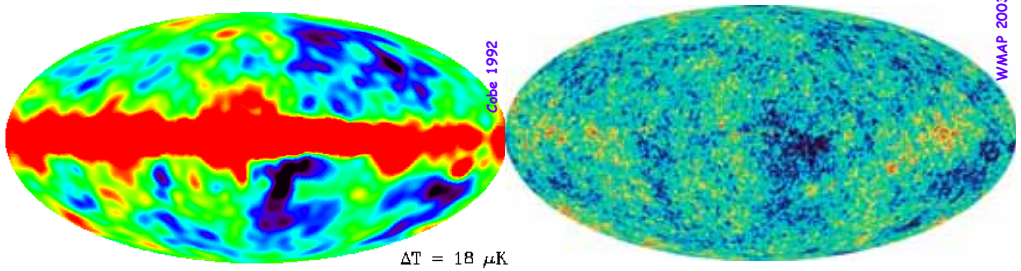
End of the line for a precious few of the photons, as we trap them in our detectors and glean a little information about the universe in which we live.

The Cosmic Microwave Background Radiation

Cosmic Microwave Background

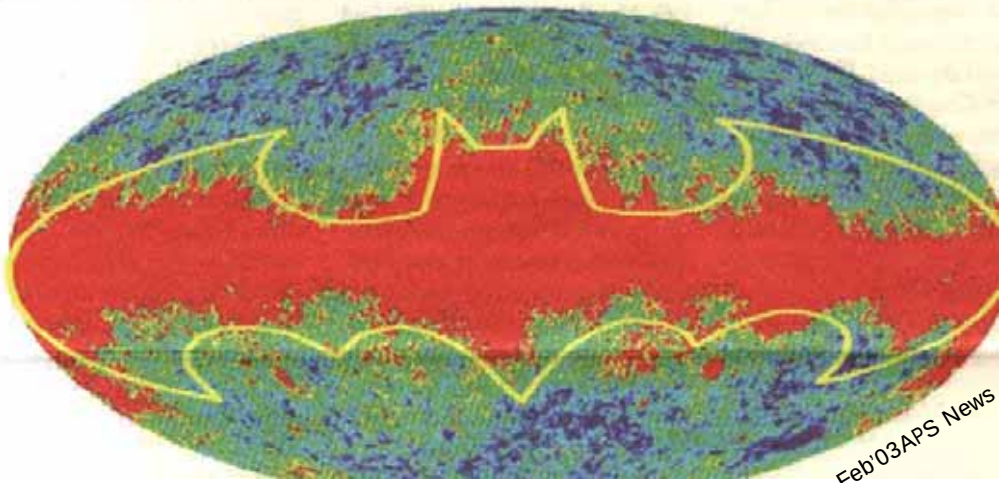


Dipole Anisotropy 10^{-3}



Large Scale Temp Anisotropy, 10^{-5}

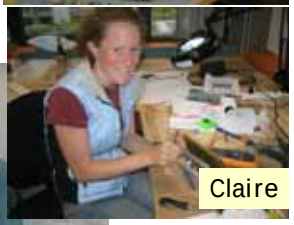
Is the Universe Trying to Tell Us Something?



from: Feb'03APS News
S. Coutu

The Team

(Kareem)



(Robert)

Matt.Dobbs@McGill.ca – Oct 27, 2006

the APEX-SZ Experiment

U.C. Berkeley / LBNL
Hsiao-Mei Cho
Bill Holzapfel
Zigmund Kermish
Ruediger Kneissl
Adrian Lee
Martin Lueker
Jared Mehl
Tom Plagge
Paul Richards
Dan Schwan
Helmuth Spieler
Martin White

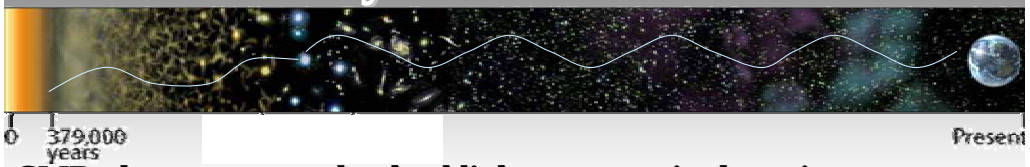
C.U. Boulder
Nils Halverson

McGill University
Matt Dobbs
Trevor Lanting

Max Planck IfR, Bonn
Kaustuv Basu
Frank Bertoldi
Rolf Guesten
Ernst Kreysa
Karl Menten
Dirk Muders
Peter Schilke

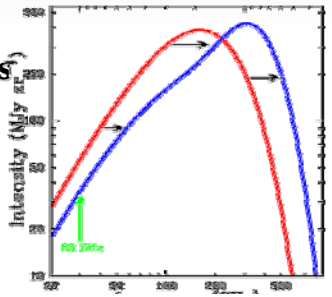
Cardiff
Peter Ade

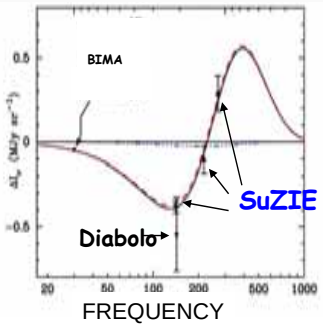
Galaxy cluster searches



CMB photons are used to backlight structure in the universe.

- **1-2% of CMB photons traversing galaxy clusters are inverse Compton scattered to higher energy– the *Sunyaev Zeldovich Effect.***





- **Tool for mapping expansion history**

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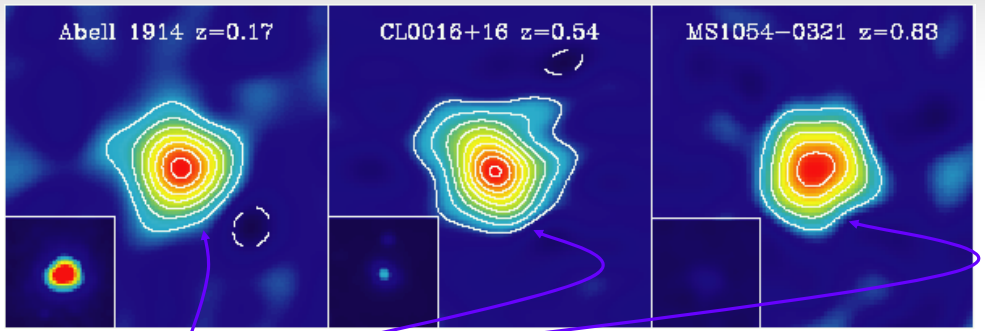
Galaxy cluster searches

- optical / X-ray sky→clusters fade away at high redshift.



Carlstrom et al.

- SZ observations do not fade away over large distances

→ ***Clusters can be seen at any distance.***

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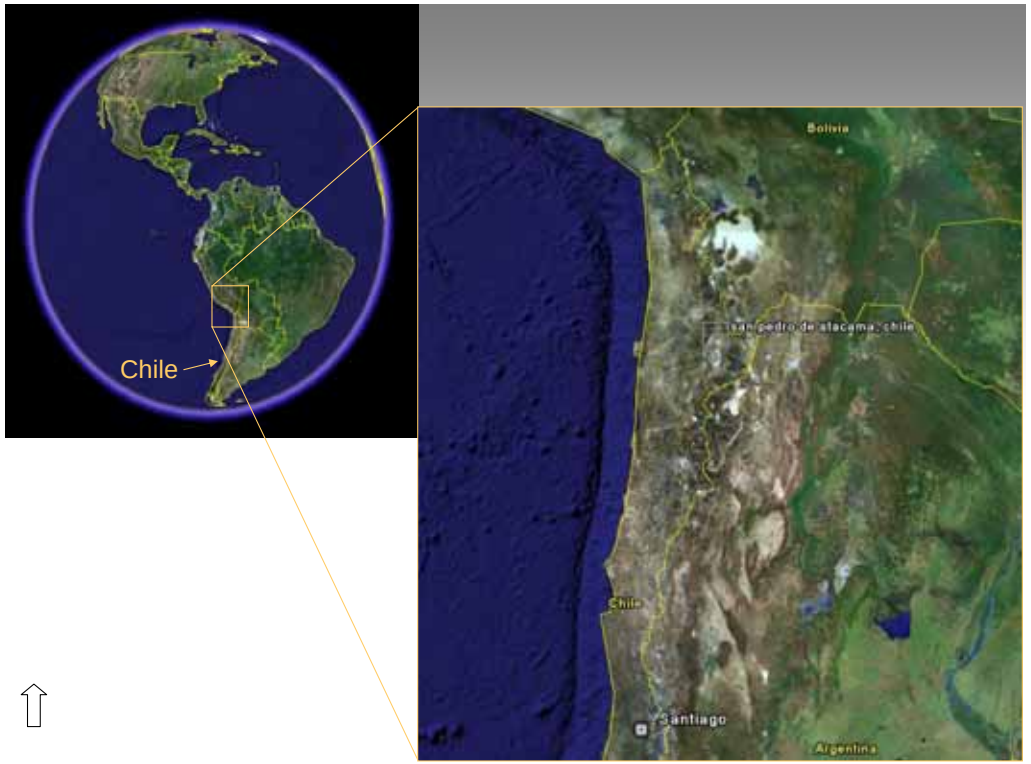
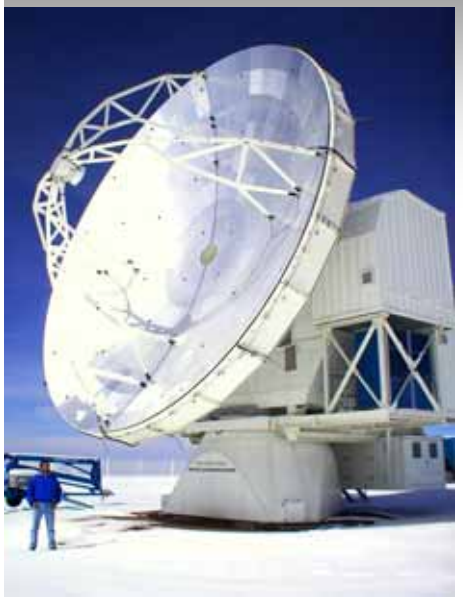

Chile
Bolivia
san pedro de atacama, chile
Chile
Santiago
Argentina


CHILE
BOLIVIA
Lago
Verde
Volcan
Licancabu
san pedro de atacama, chile
APEX-SZ

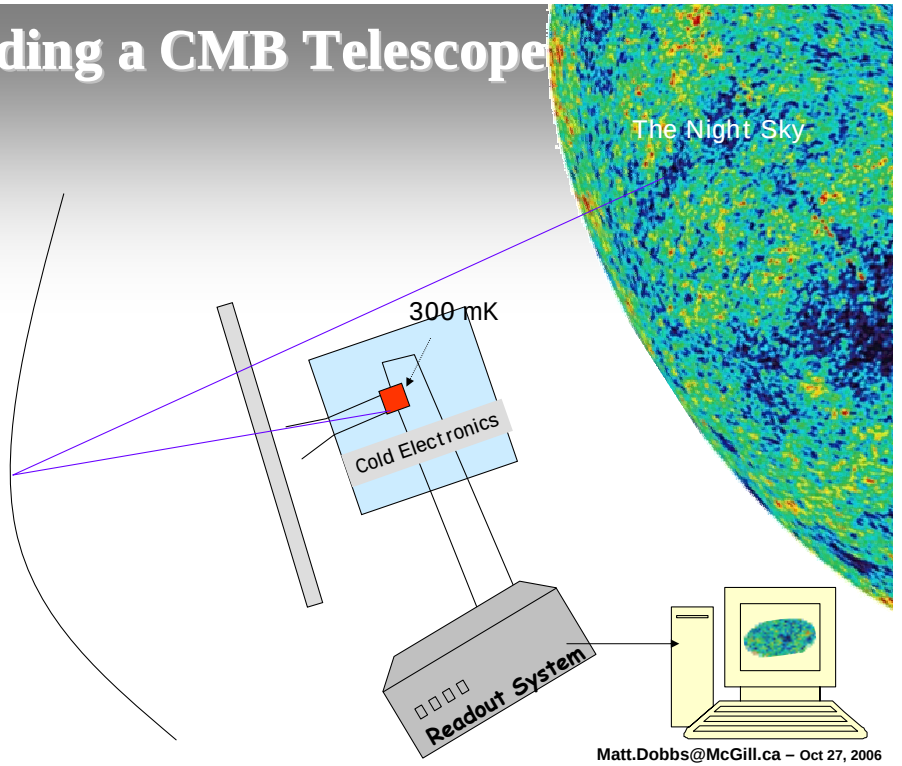

Volcan
Licancabu
Lago
Verde
BOLIVIA
San Pedro
de Atacama
APEX-SZ
CHILE

APEX-SZ

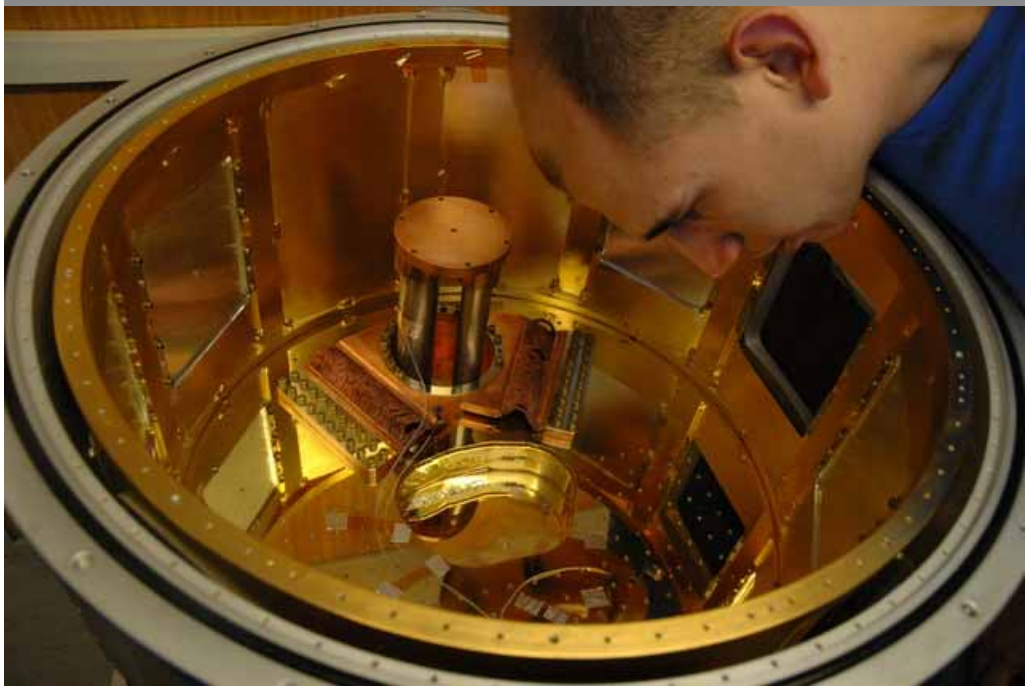


- 320 element TES bolometer array
- pulse tube cooler w/ ^{3}He sorption fridge
- MHz biased bolometers + multiplexing
- Telescope: 12m Cassegrain, ALMA prototype built by Vertex
- Chajnantor site, 5100m Atacama Plateau, Chile
- First light, Dec 2005
- 1' resolution at 2mm
  (under-filled primary)
- 0.4 degree FOV

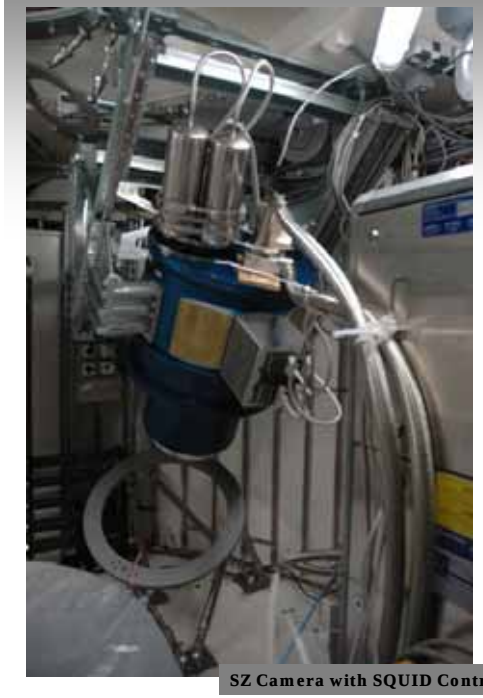
Building a CMB Telescope



SZ Camera Installed Dec 13

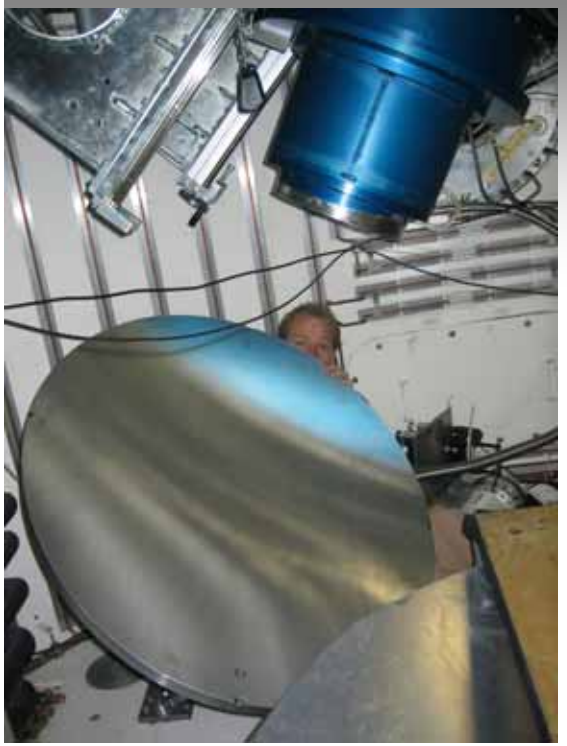


APEX-SZ Readout System

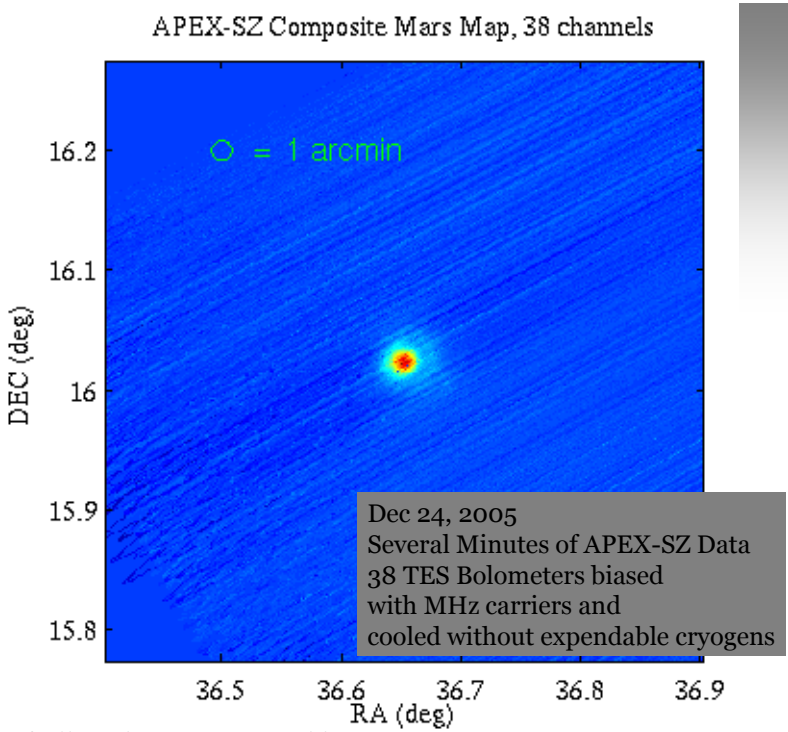


SZ Camera with SQUID Controllers

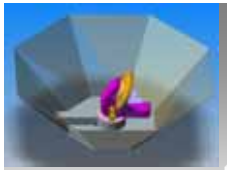
Readout Create with Osc/Demod boards



APEX-SZ Field Team

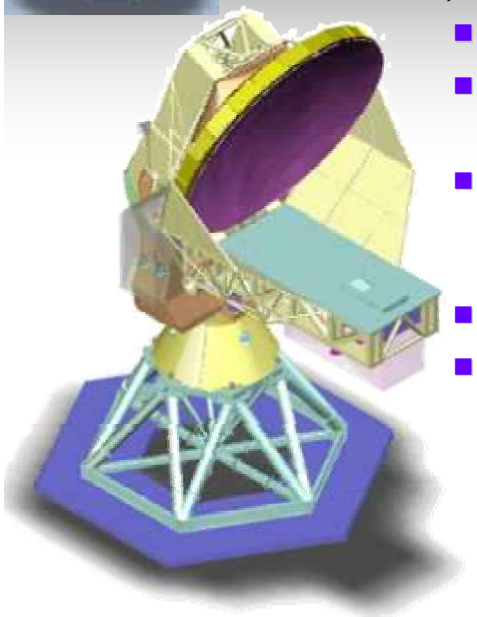


Plot courtesy of Nils Halverson, CU Boulder



South Pole Telescope

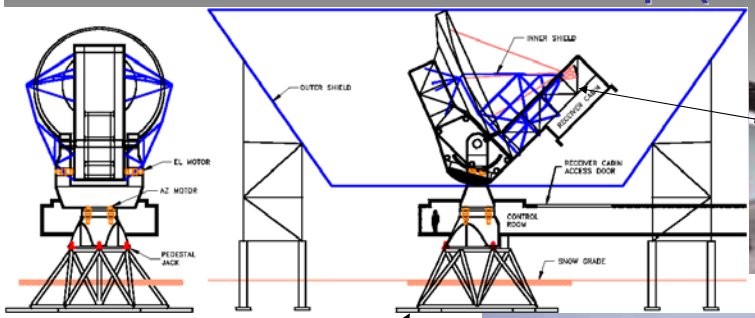
U. Chicago, UC Berkeley, Case Western R., CU Boulder, U. Illinois, LBNL, McGill, Harvard SAO



- 10m off axis Gregory telescope
- 1 deg FoV, 1 arcmin beam at 2mm
- 1000 element bolometer array
  - frequency domain multiplexed readout
- deploy to pole January 2007
- factor 10 faster mapping speed than APEX
  - 4000 deg^2 at 10 μK/pixel

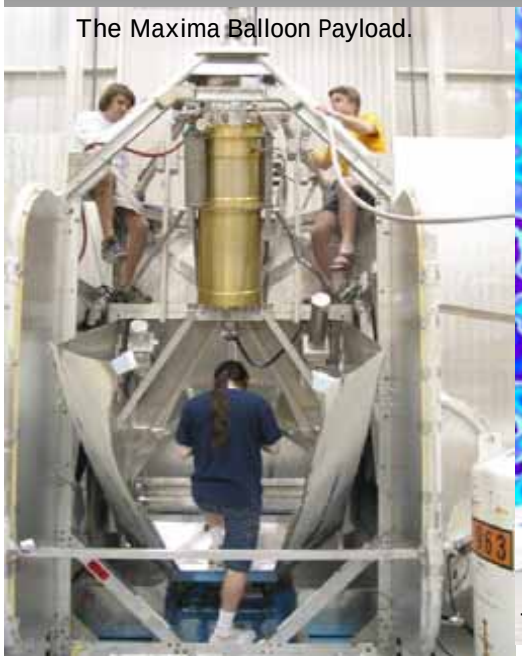
  → ~10^4 clusters

South Pole Telescope (SPT)

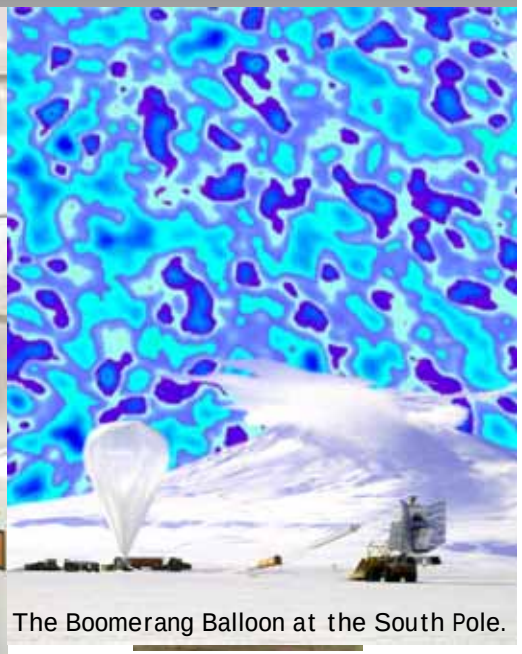


Dec 11, 2005

Balloon-Borne Instruments

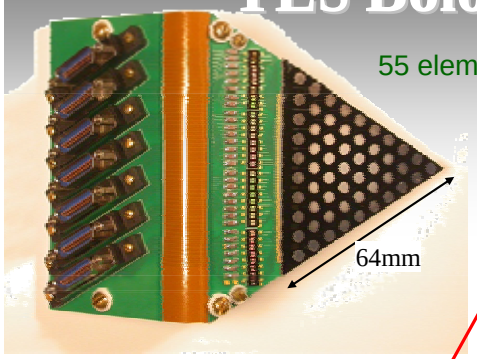


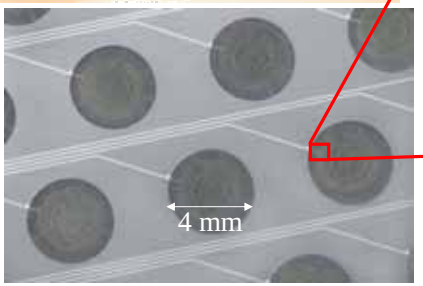
The Maxima Balloon Payload.

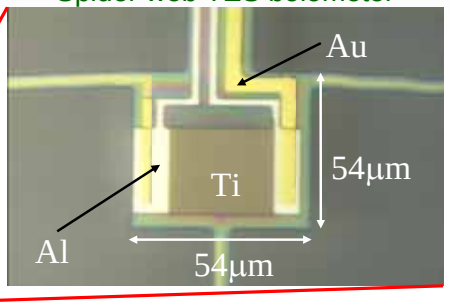


The Boomerang Balloon at the South Pole.

TES Bolometer Array

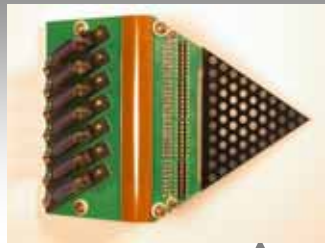


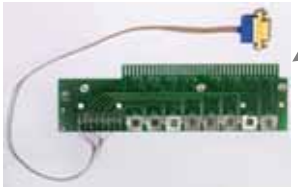


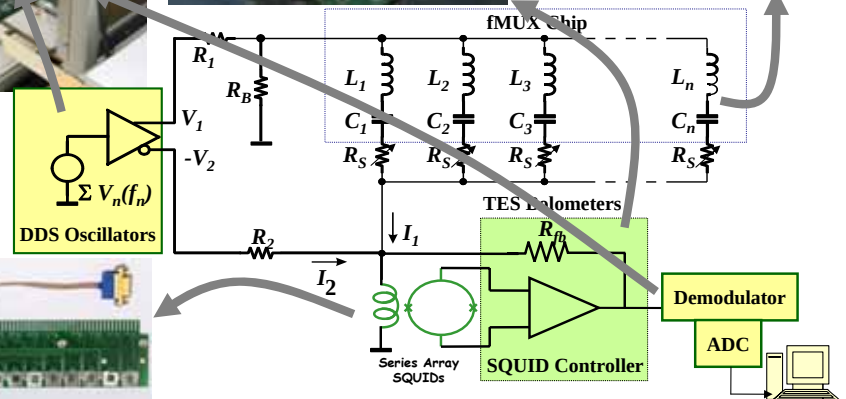


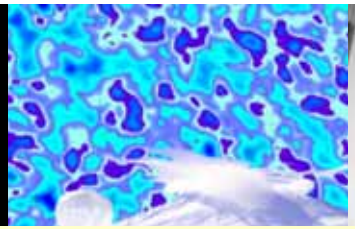
G ~ 400 pW/K
τ ~ 7-9 ms

Readout System

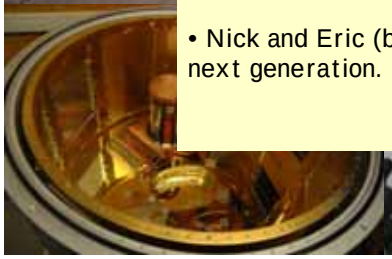












Special thanks to the staff that make things happen at McGill:

- John and Robert, who have put together a first rate lab and made it happen fast.
- Eddie and Steve, who always tell me it's nearly impossible to build, then build it.
- Diane (who's fighting the overhead monster with me)
- Sonia (who's helping build our next electronics board)
- Elizabeth, Louise, and Paula, who make everything happen.

- Nick and Eric (borrowed from UdM), who are building the next generation.