Balloon Borne Observations of the Cosmic Microwave Background Radiation

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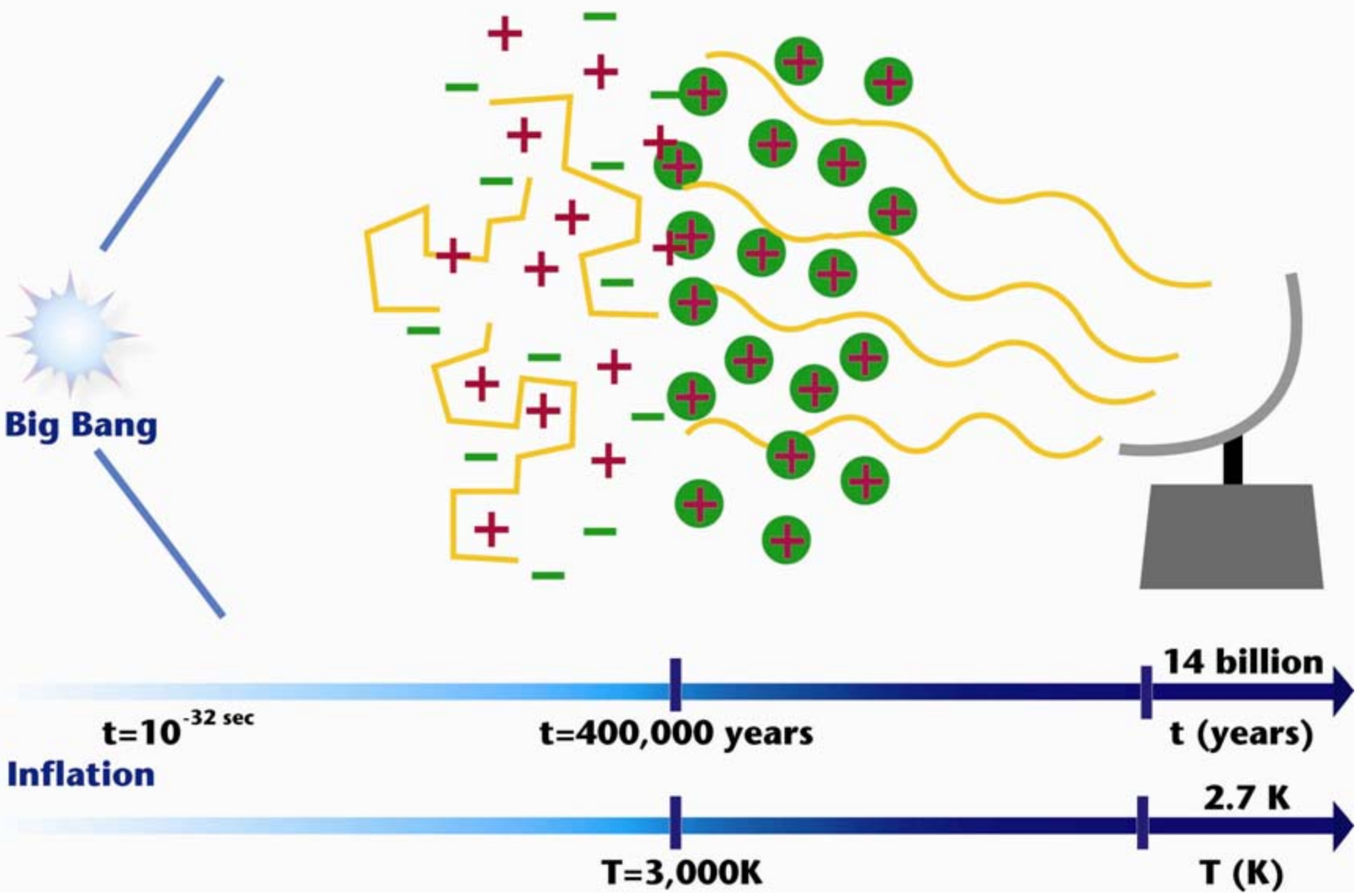
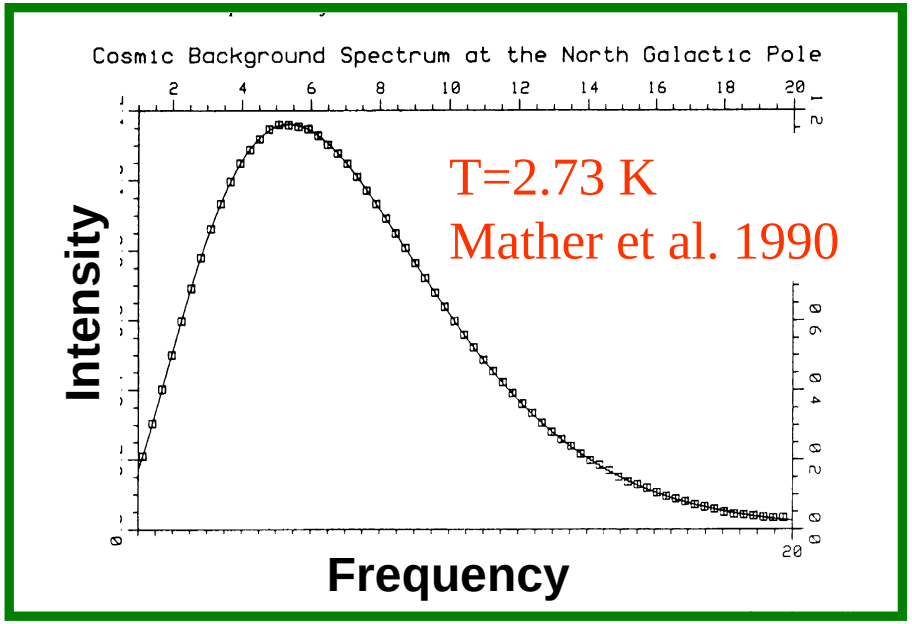
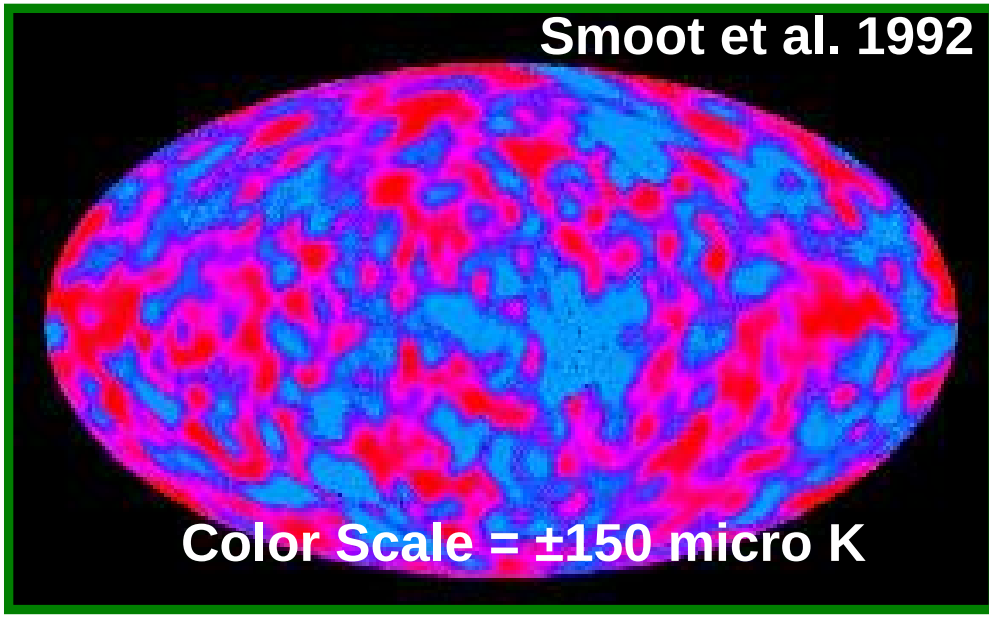
A BRIEF HISTORY OF TIME

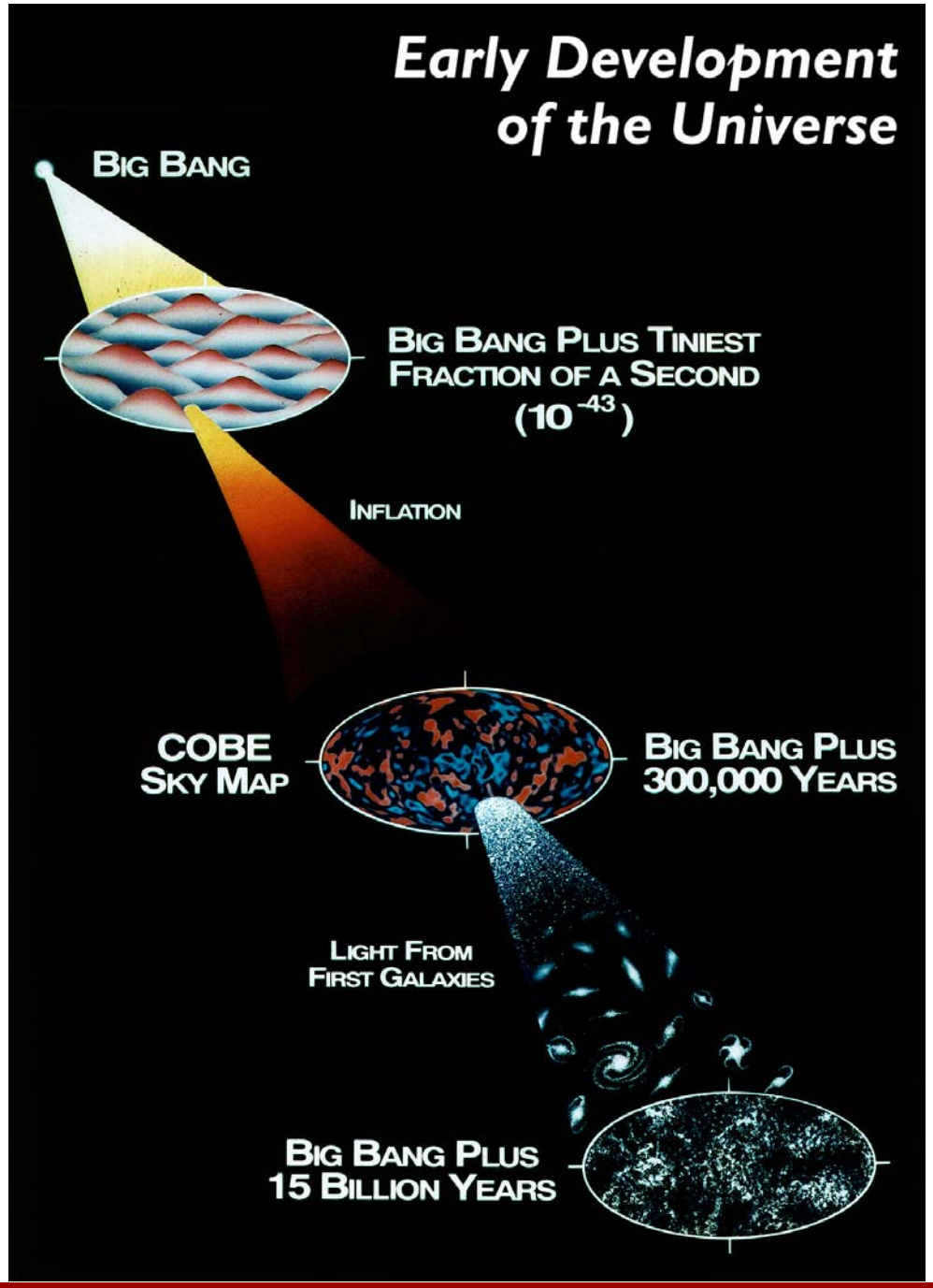



Penzias
Wilson


Mather
Smoot

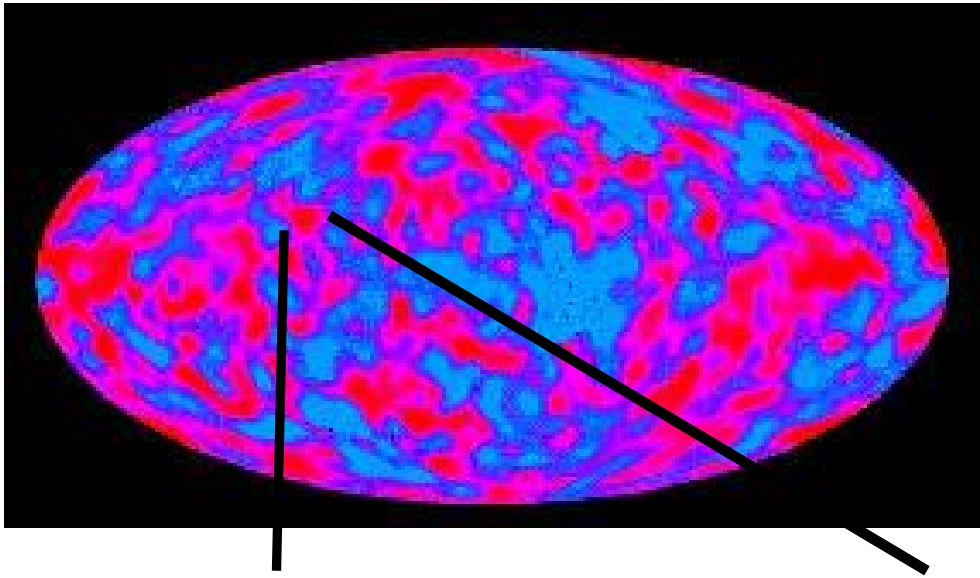

Cosmic Background Spectrum at the North Galactic Pole
2
4
6
8
10
12
14
16
18
20
Intensity
Frequency
T=2.73 K
Mather et al. 1990

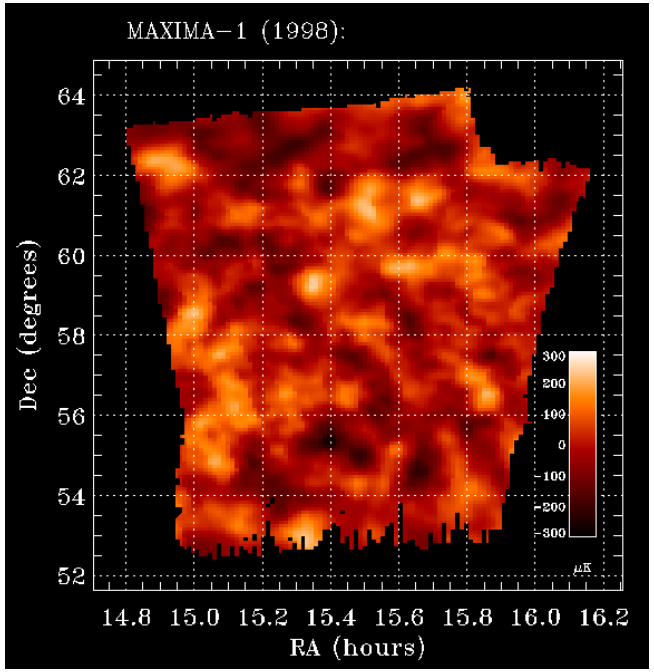

Smoot et al. 1992
Color Scale = ±150 micro K


Early Development of the Universe
Big Bang
Big Bang Plus Tiniest Fraction of a Second
(10 -43)
Inflation
COBE Sky Map
Big Bang Plus 300,000 Years
Light From First Galaxies
Big Bang Plus 15 Billion Years

• COBE had ~10 degree angular resolution

• Higher angular resolution encodes
  • geometry of space
  • total matter and energy content
  • constituents of matter and energy
  • evolution of the universe
  • …more

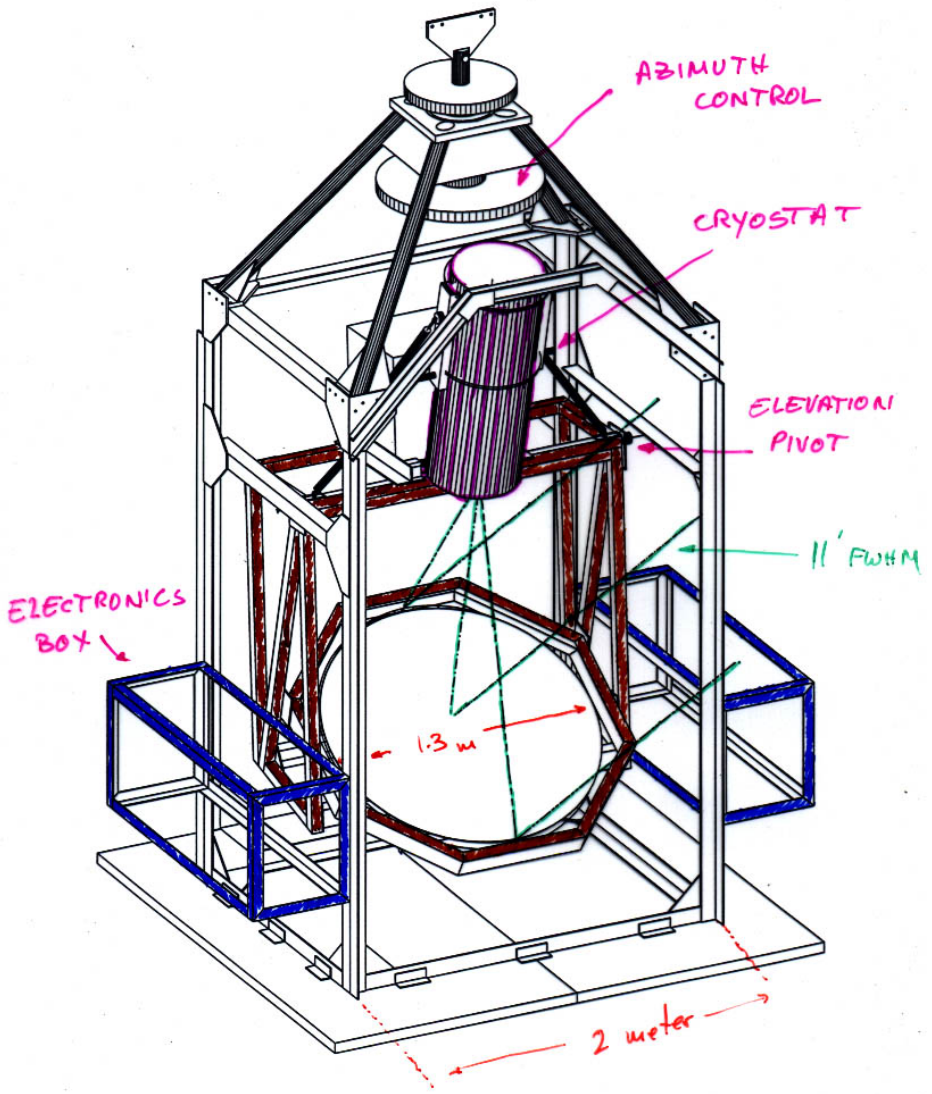




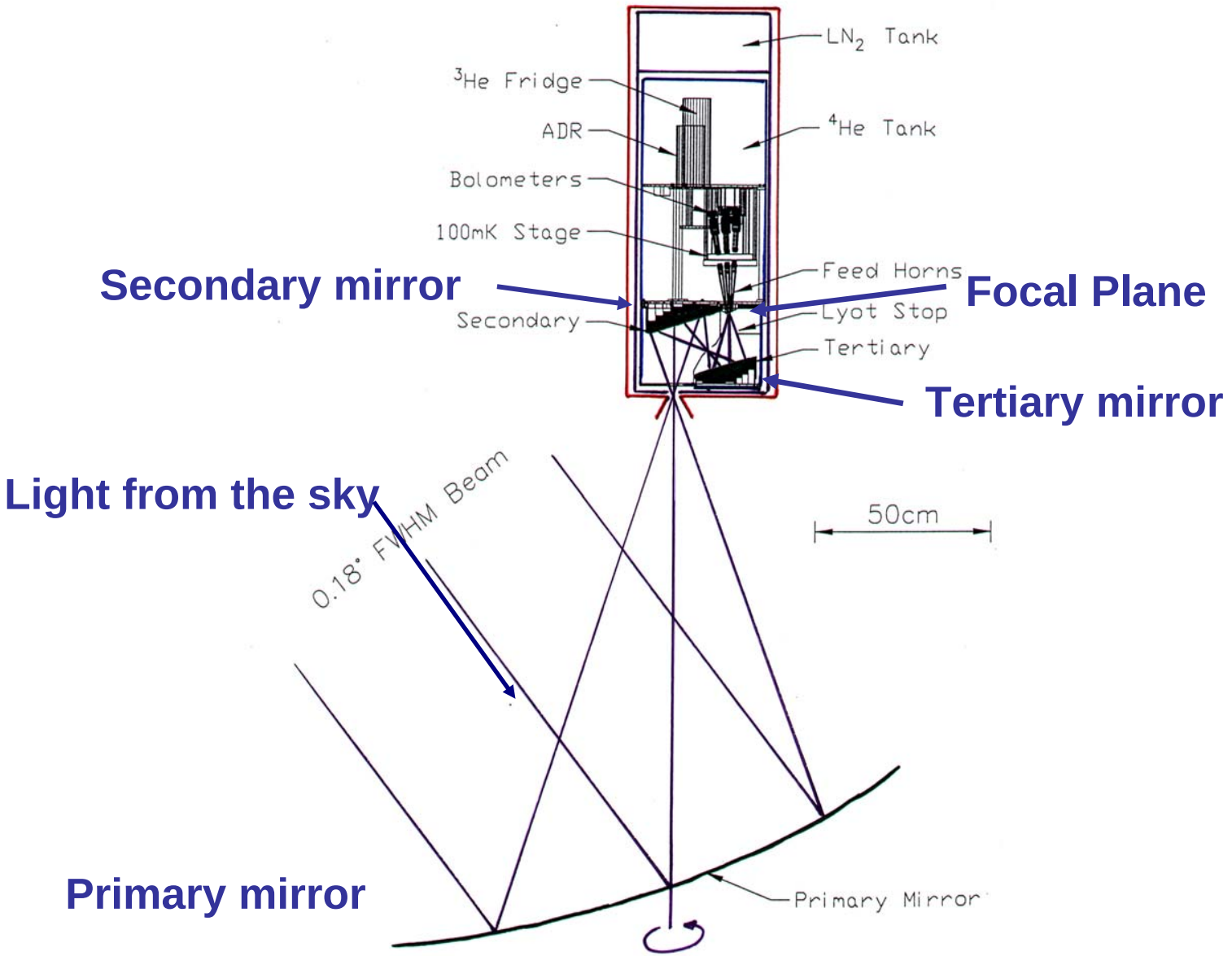
Hanany et al. 2000

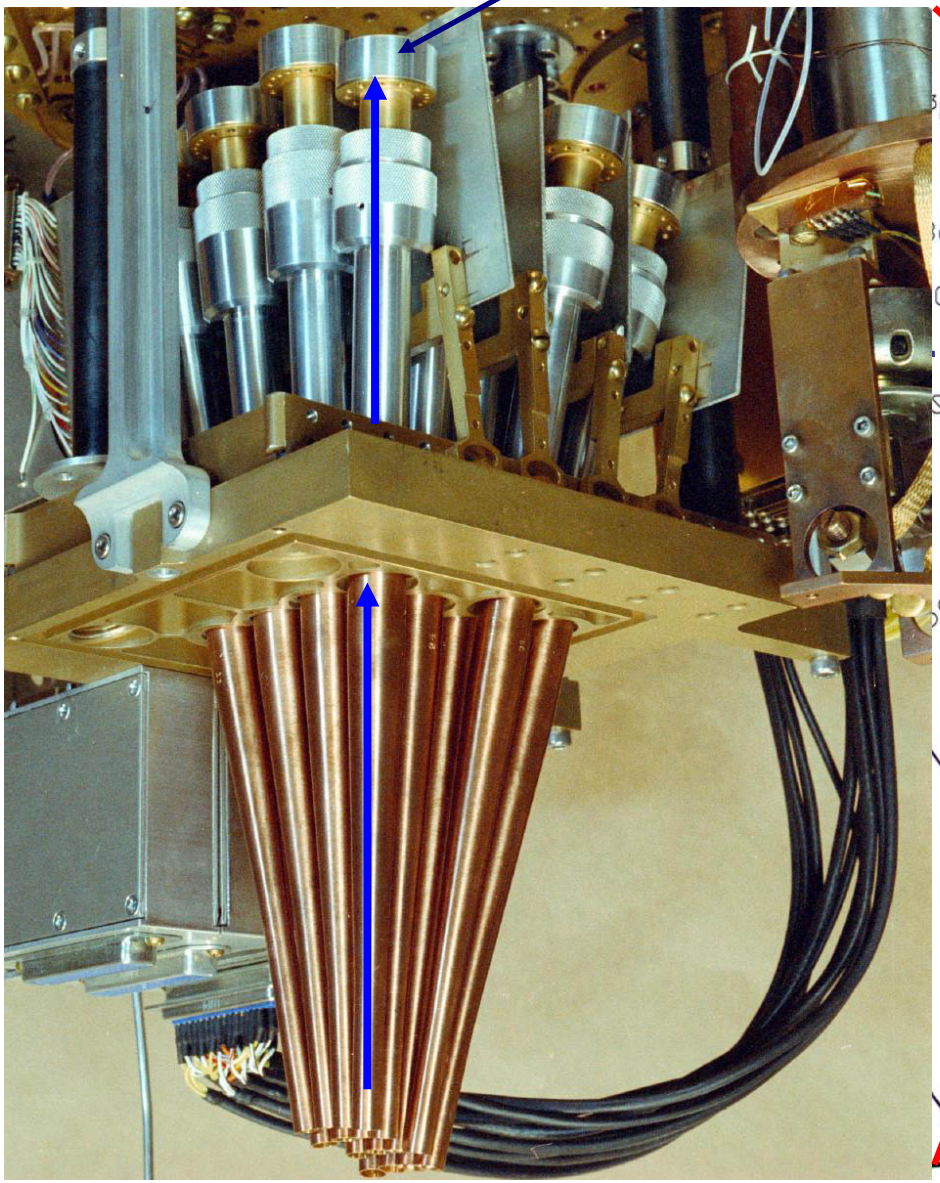
• **Balloons**
  • Atmosphere = source of emission
  • Higher resolution = larger aperture
  • Faster turnaround

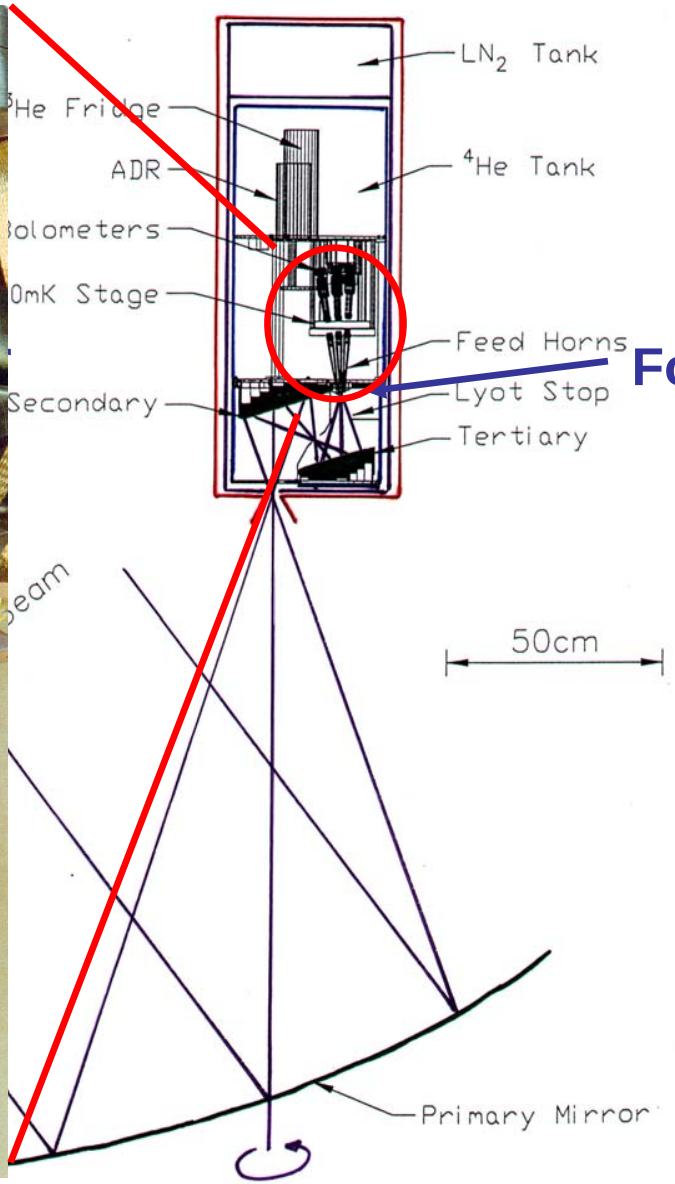
MAXIMA



- Collaboration: **UCB/U. Minn.** + CalTech,U. Rome, IROE Florence, QMW London
- North American balloon-borne
- Resolution: 10’
- Bolometers cooled to 0.1 K
- Funding from NASA/NSF (1993 - ~2001)


LN2 Tank
3He Fridge
4He Tank
ADR
Bolometers
100mK Stage
Feed Horns
Lyot Stop
Secondary
Tertiary
Secondary mirror
Focal Plane
Tertiary mirror
Light from the sky
0.18° FWHM Beam
50cm
Primary mirror
Primary Mirror

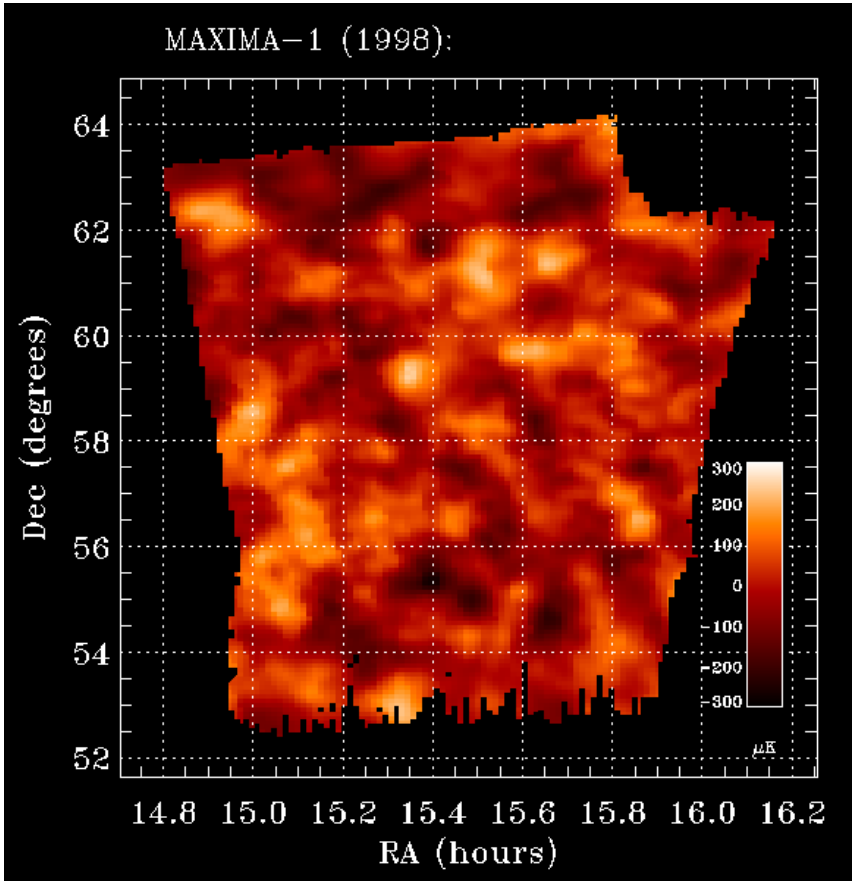

Bolometer


LN2 Tank
3He Fridge
ADR
4He Tank
Bolometers
0mK Stage
Feed Horns
Focal Plane
Secondary
Lyot Stop
Tertiary
Beam
50cm
Primary Mirror

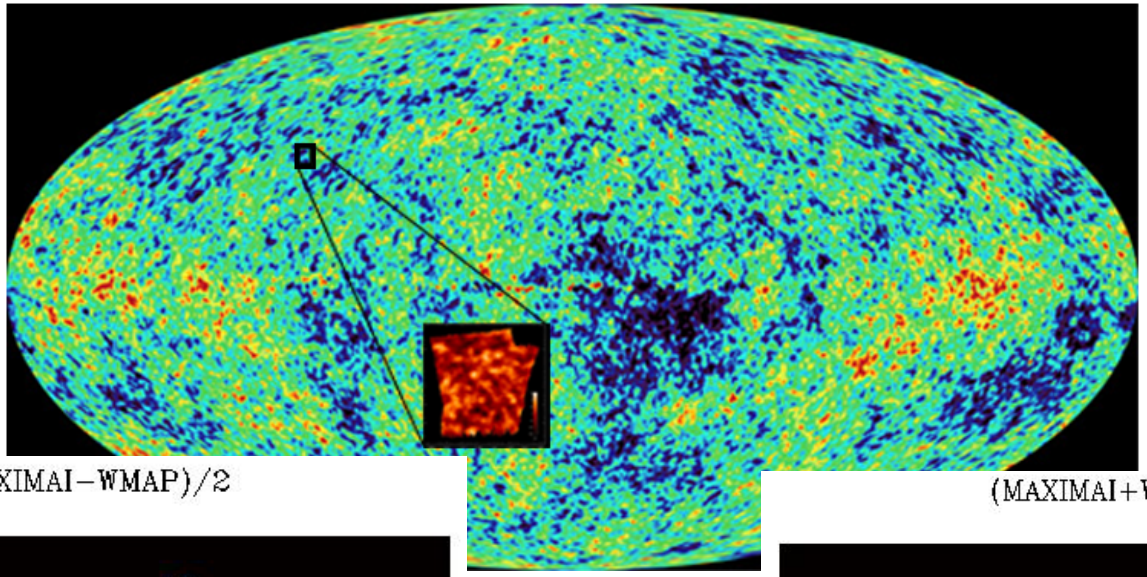
MAXIMA Results

- 3 hour flight from Palestine in 1998.
- Highest angular resolution image of the CMB
- Statistical properties of the CMB over broadest range of angular scales
- To this date: **Highest Instantaneous Sensitivity CMB Instrument**
- **Best determination of the total energy density of the universe** (contemporaneous with boomerang)
- Together with data from supernovae: **conclusive evidence for both dark matter and dark energy**

Hanany et al. 2000



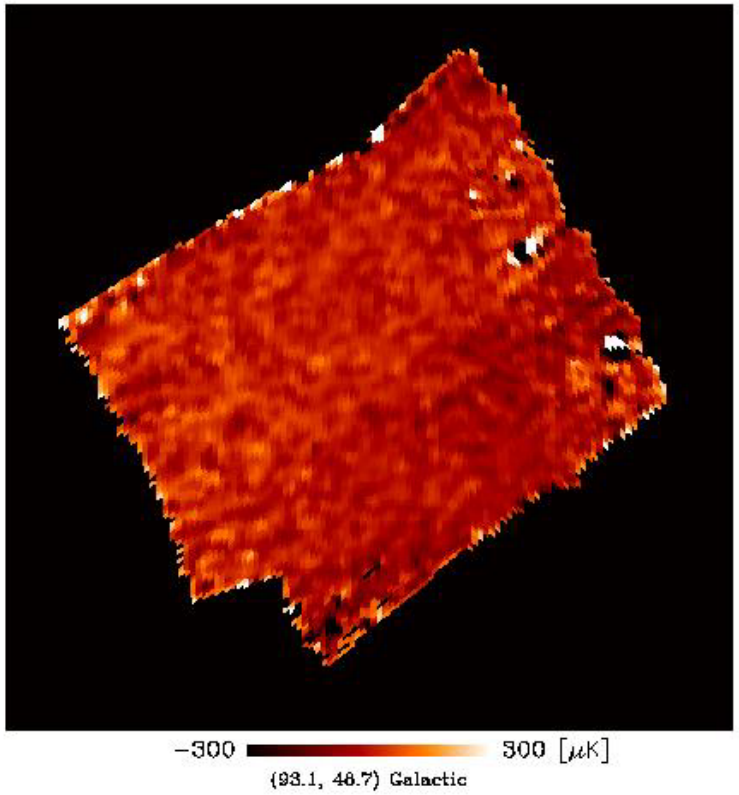
***Science* : "One of the ten most important scientific breakthroughs for the year 2000"**

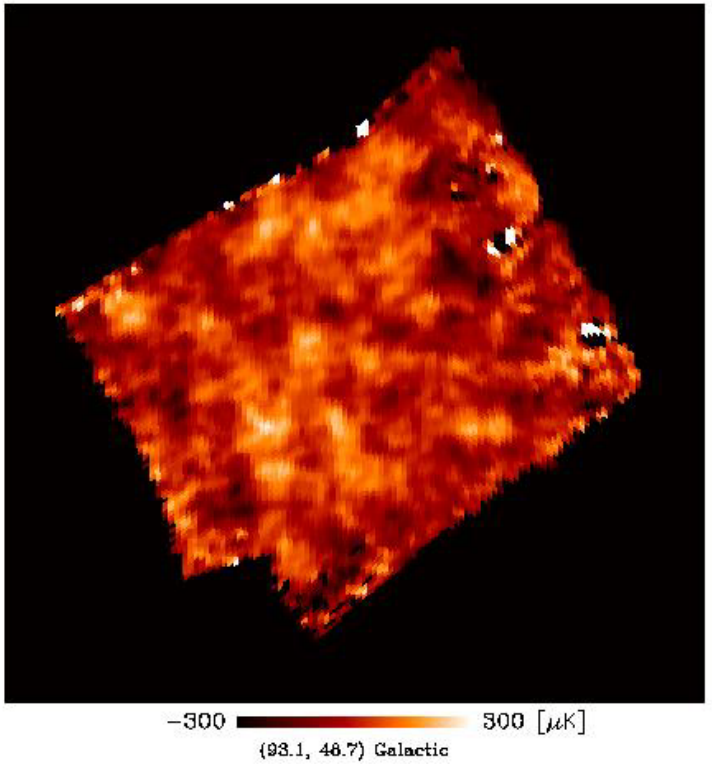


Bennet et al. 2003
WMAP Satellite

(MAXIMAI−WMAP)/2

(MAXIMAI+WMAP)/2





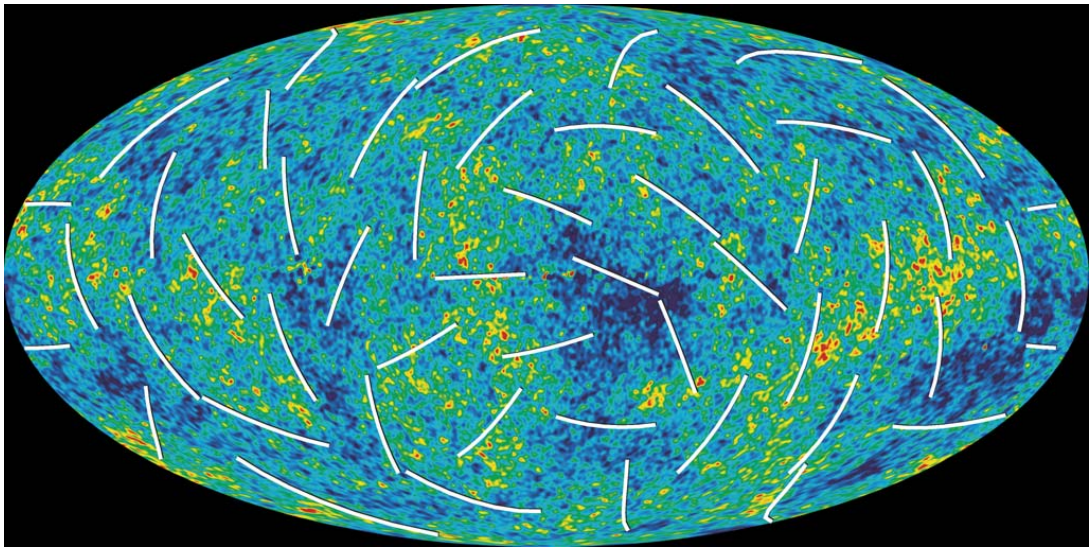
Abroe et al. 2004

The Next Frontier - Polarization

- CMB is polarized

- Convert ‘degree of polarization’ and ‘angle of polarization’ to: ‘E mode’ and ‘B mode’

- E mode originates at the epoch of decoupling



WMAP 2006

- **B mode is signature of the inflationary epoch ($t=10^{-35}$ sec)**

- **Detection of B mode would give un-ambiguous evidence for inflation**

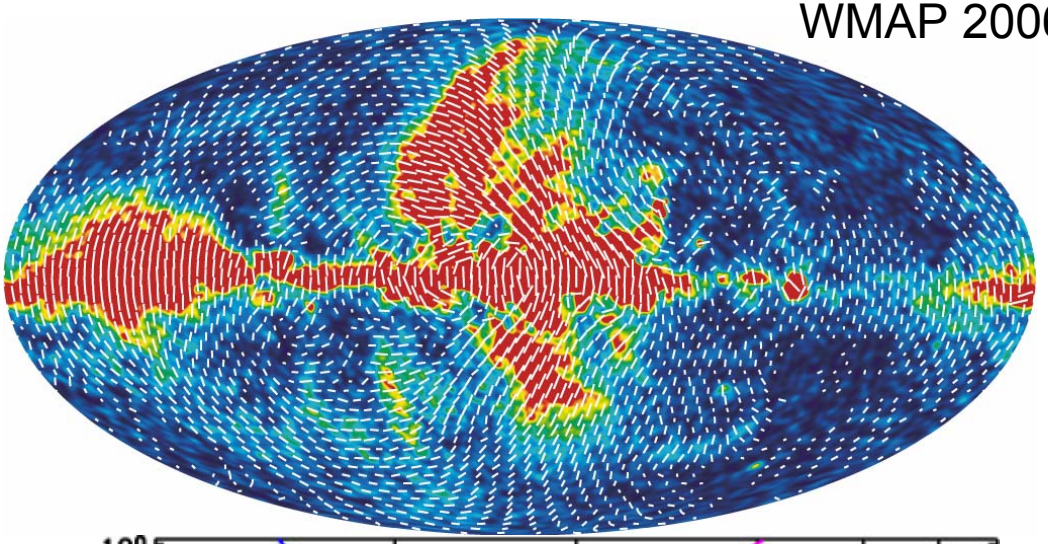
- **Detection of B mode would fix the energy scale of inflation**

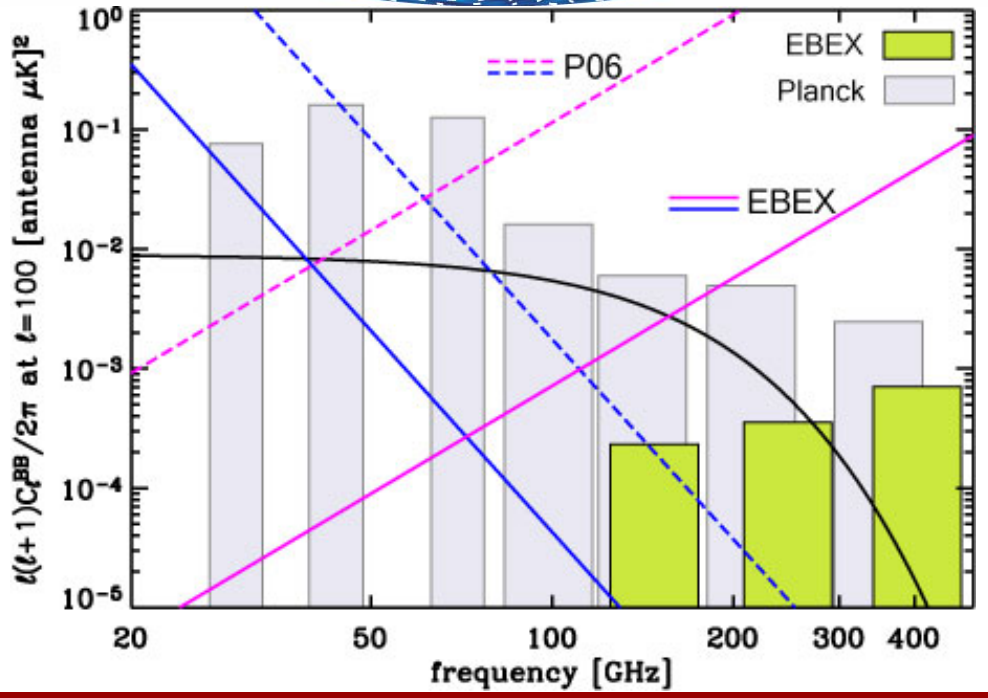
- **B mode polarization is the only known way to probe inflation directly**

B-mode Polarization Challenges

- Signal is less than 100 nanoK
- Energy scale of inflation is unknown to ~10 orders of magnitude
- Signal could be substantially less than 100 nanoK
- **Signal is expected to be dominated by foregrounds**

WMAP 2006





EBEX – E and B EXperiment

Shaul Hanany

University of Minnesota

Brown
- Andrei Korotkov
- Shawn Manchester
- Greg Tucker

Cardiff
- Peter Ade

Columbia University
- Will Grainger
- Amber Miller
- Britt Reichborn-Kjennerud

APC, Paris
- Radek Stompor

Harvard
- Matias Zaldarriaga

IAS
- Nicolas Ponthieu

SISSA/ISAS
- Carlo Baccigalupi

McGill
- Matt Dobbs

Oxford
- Brad Johnson

UC Berkeley, LBNL
- Sherry Cho
- Adrian Lee
- Helmuth Spieler

UC San Diego
- Tom Renbarger

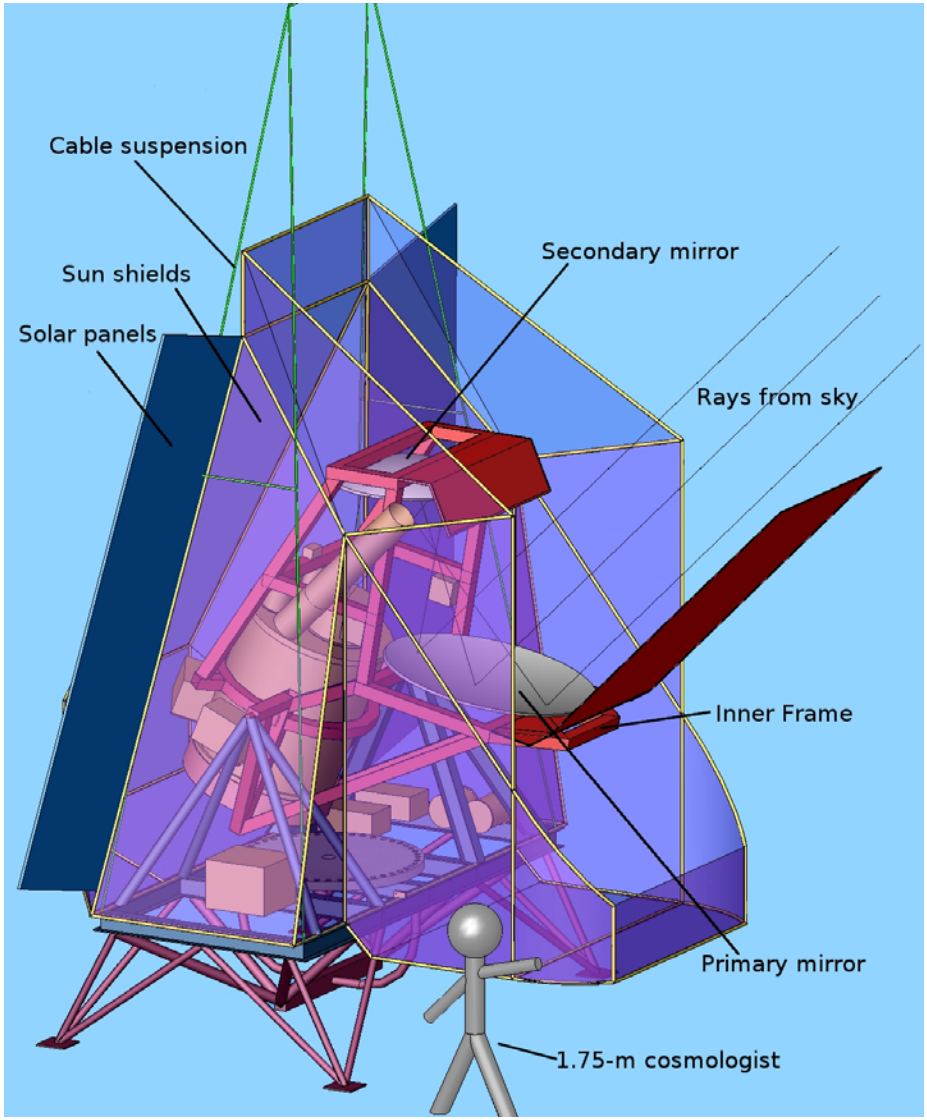
U. of Minnesota
- Sean Bryan
- Clayton Hogen-Chin
- Hannes Hubmayr
- Terry Jones
- Jeff Klein
- Tomotake Matsumura
- Michael Milligan
- Bob Wellington
- Kyle Zilic

U. of Toronto
- Enzo Pascale

Weizmann Institute of Science
- Lorne Levinson
- Ilan Sagiv

EBEX Science Goals

- Detect or improve current upper bound on B-mode by x10
- Characterize polarized foregrounds
- Detect B-mode lensing signal
- Provide high s/n measurement of E–mode polarization
- Test new technologies that are candidates for a future CMB polarization satellite



EBEX in a Nutshell

Sensitivity

- Long duration balloon borne
- Up to 1476 bolometric TES

Foregrounds

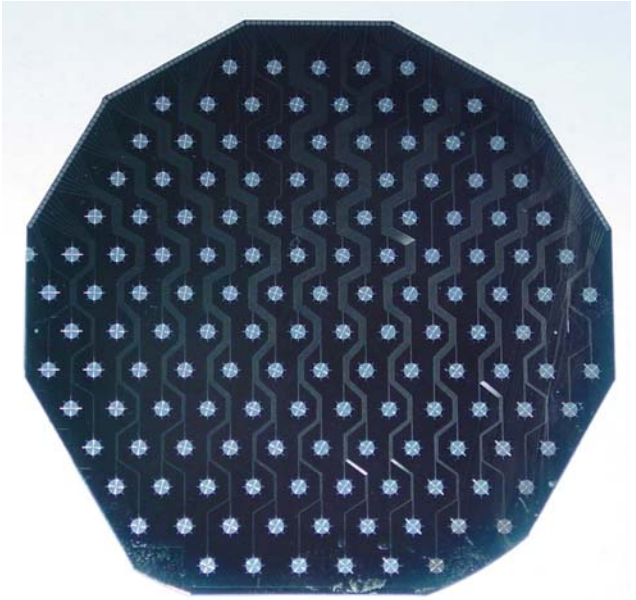
- Frequency range with only one foreground
- 3 Frequency bands: 150, 250, 420 GHz

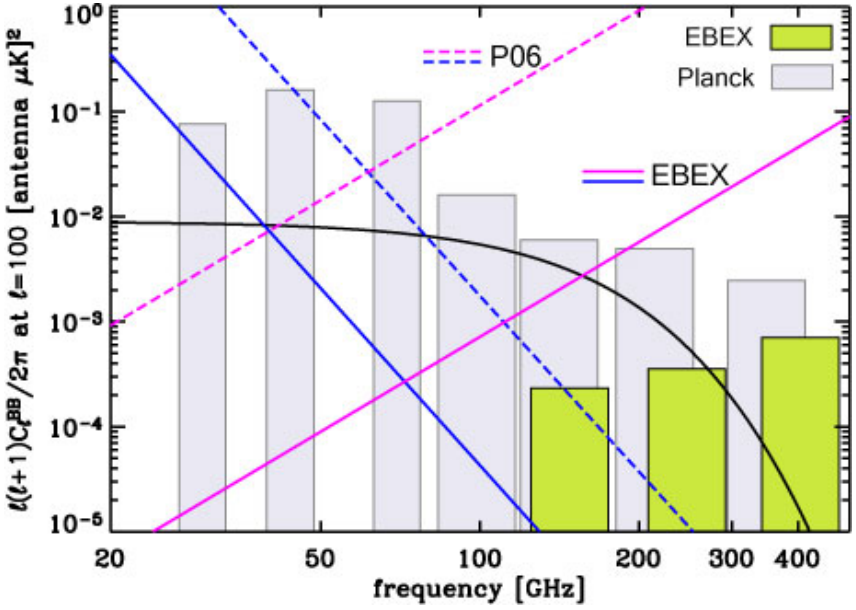
Systematic Error Rejection

- Polarimetry with half wave plate

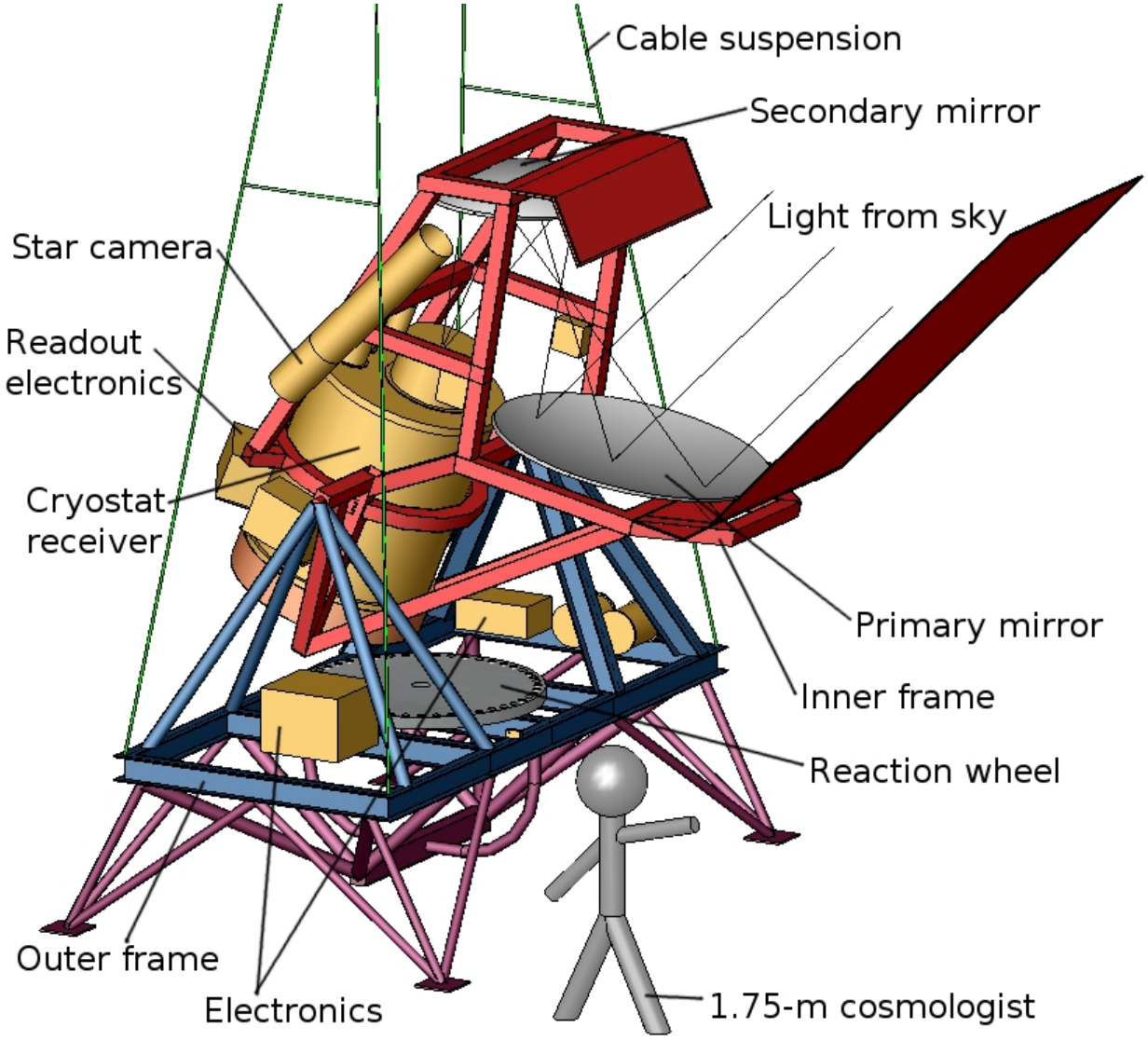
Schedule

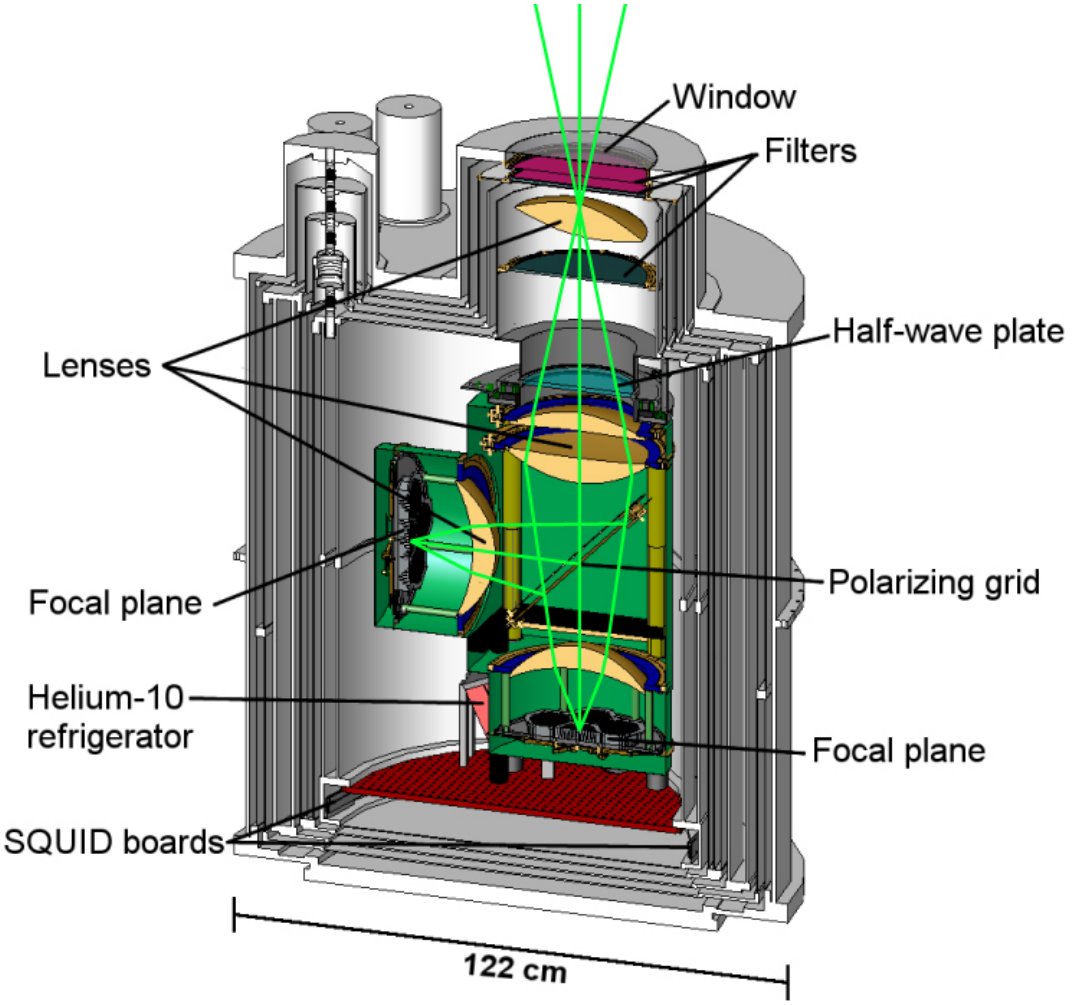
- Funded by NASA since March 05
- NA test flight 2008





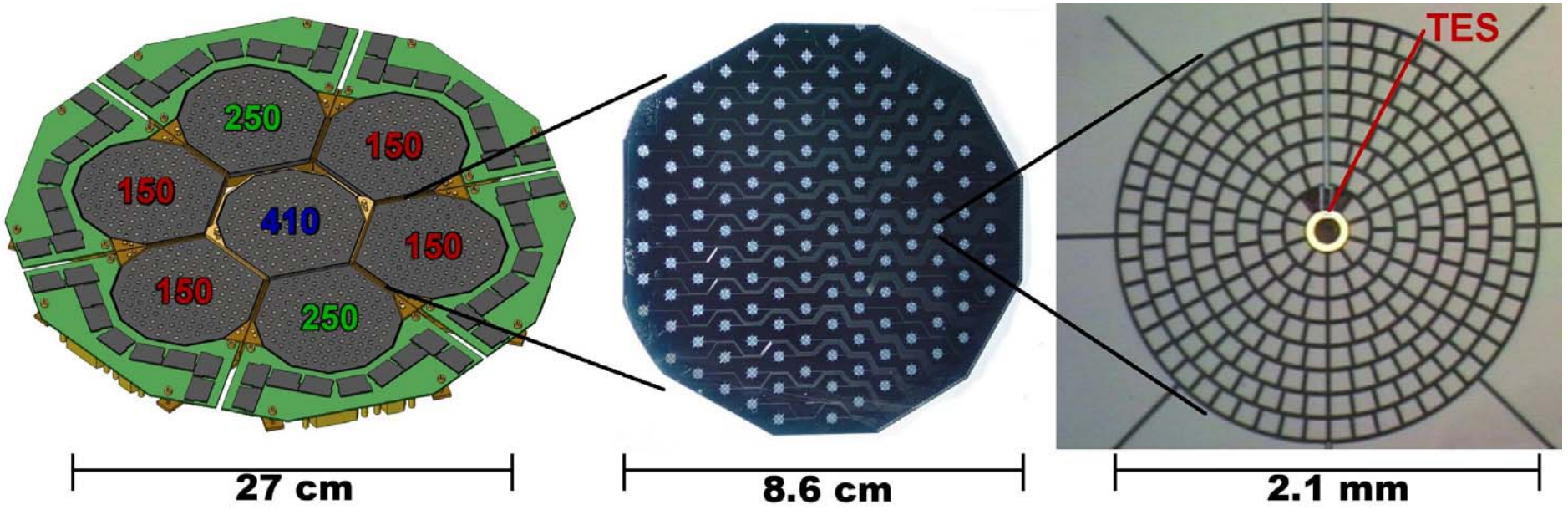
- Cable Suspension gondola (modelled after BLAST)
- 1.5 x 1.8 m primary
- 1 m secondary
- 1500 Lb cryostat
- Detectors maintained at 0.3 K




Window
Filters
Half-wave plate
Lenses
Polarizing grid
Focal plane
Helium-10
refrigerator
Focal plane
SQUID boards
122 cm

EBEX Focal Plane

738 element array | 140 element decagon | Single TES



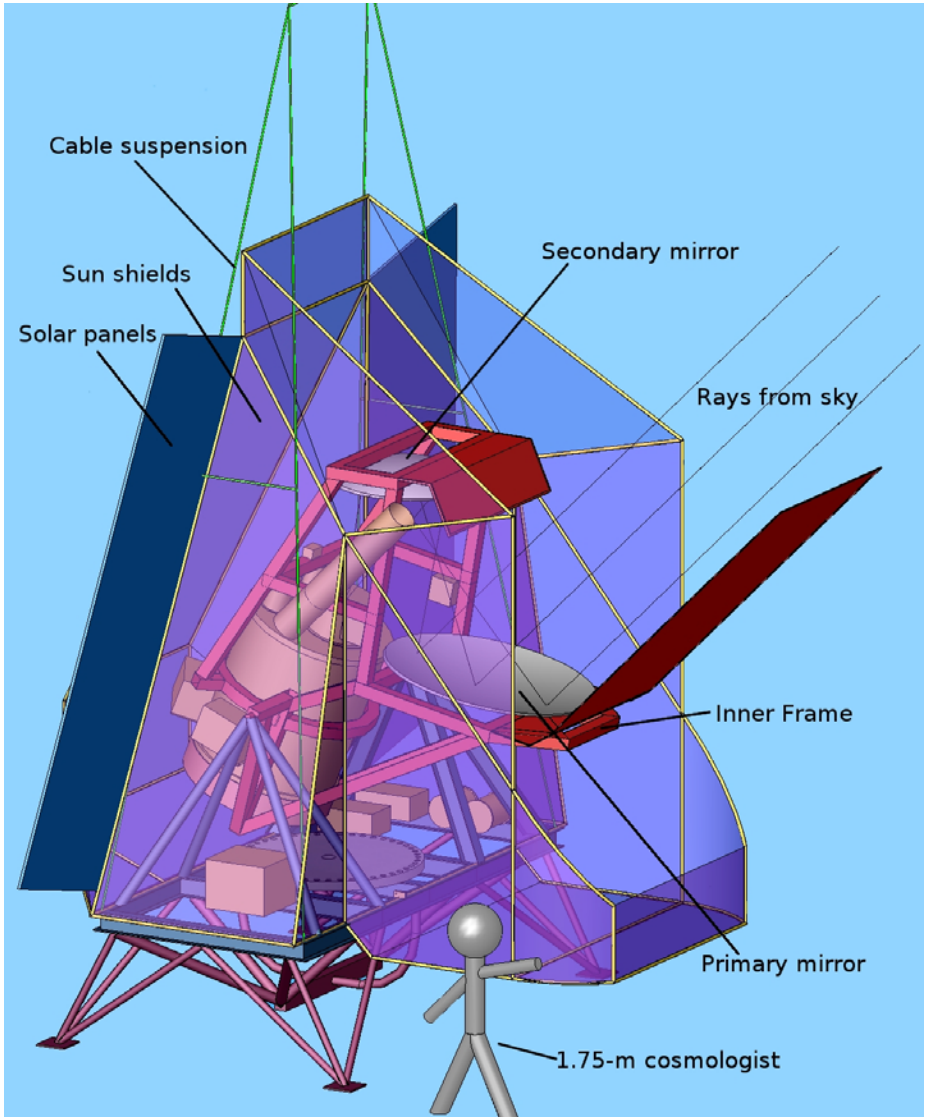
Lee, UCB

- Total of 1476 detectors
- Maintained at 0.27 K
- 3 frequency bands/focal plane

- G=15 pWatt/K
- NEP = 1.4e-17 (150 GHz)
- NEQ = 156 μK*rt(sec) (150 GHz)
- $\tau = 3$ msec,

Payload Specs

- Weight: 5000 Lb
- Moment of Inertia: 1920 Kg m^2
- Power: 1100 Watt
- Cryogen hold time: 24 days
- Data rate: 10 MBits/sec
- Data storage: 3 TBytes



Closing Words

- Balloon payloads have provided an extremely cost effective way to probe the cosmic microwave background radiation

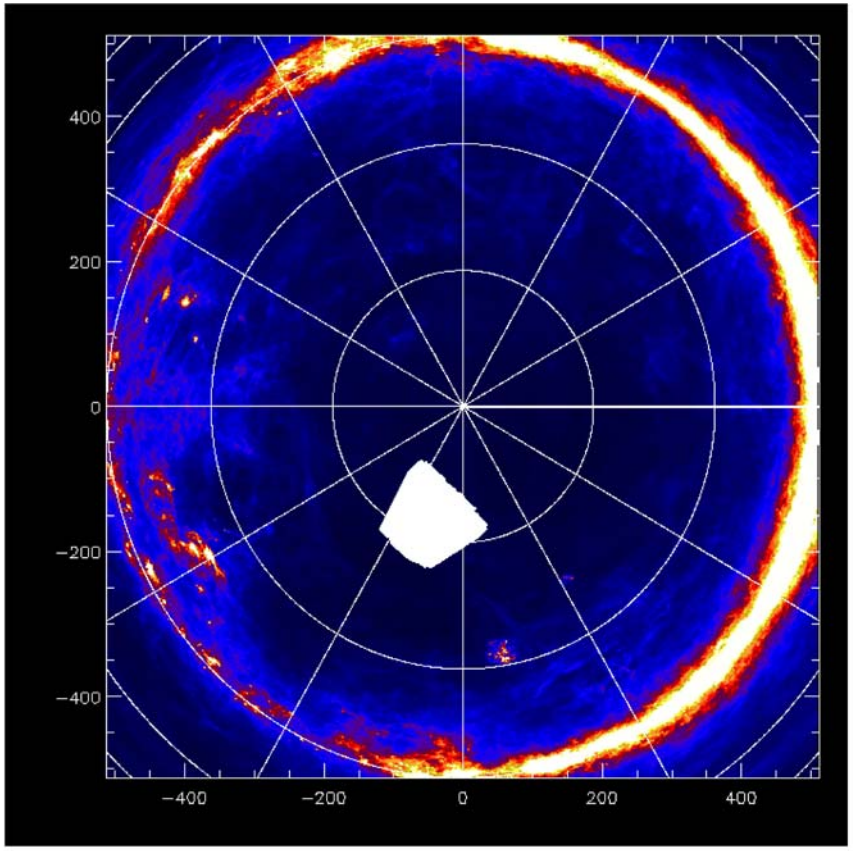
- They have a critical role in being pathfinders for future NASA missions

- They have a critical role in training the next generation of our technology leaders

- They have already produced cutting edge science (MAXIMA, Boomerang, MAXIPOL, Archeops) and they will continue to do so into the future

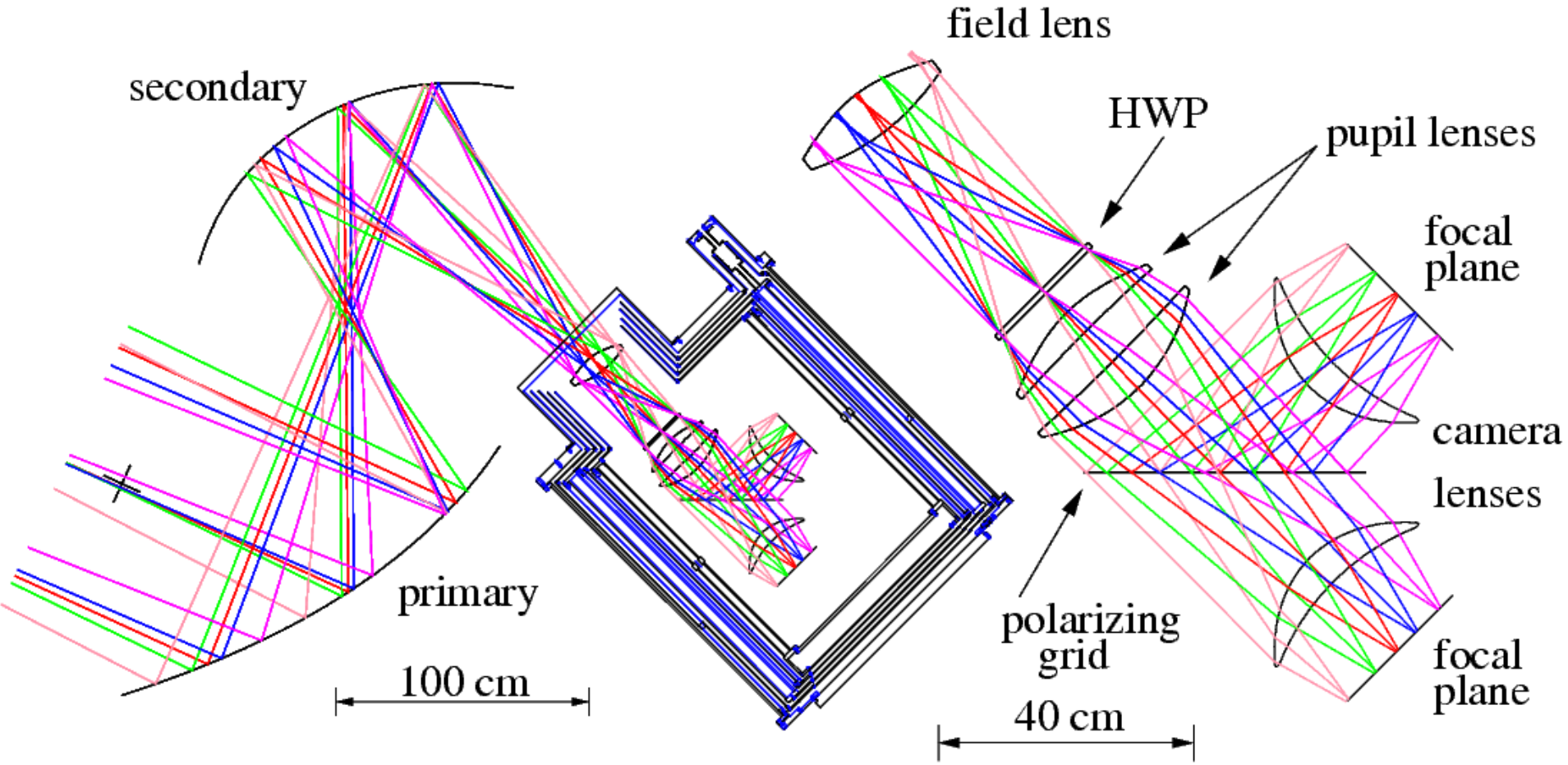
EBEX Flight Specifications

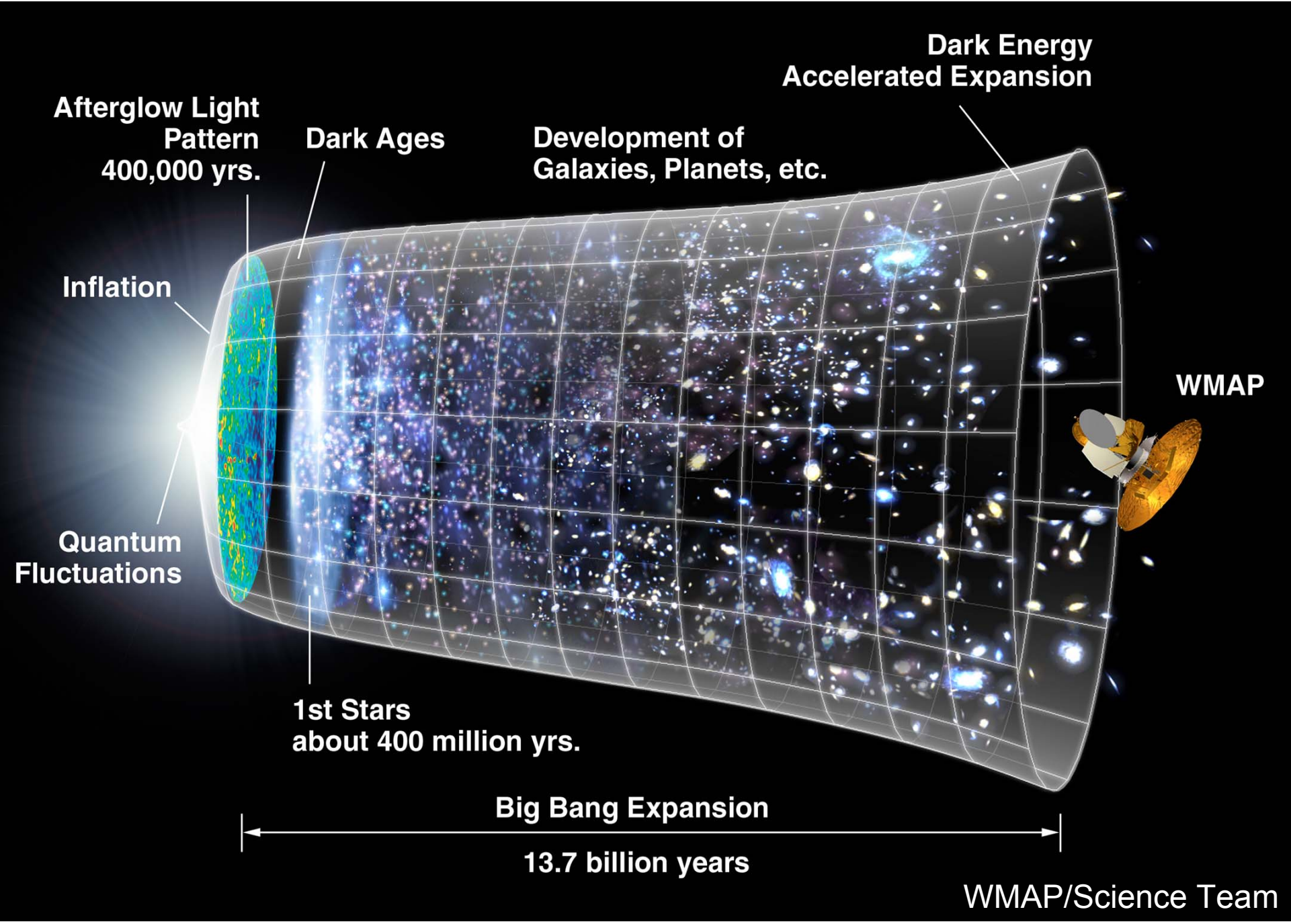
- 14 days
- 350 deg^2
- ~20,000 8’ pixels
- Low dust contrast (4μK rms)
- 796, 398, 282 TES detectors at 150, 250 ,420 GHz
- 0.7 μK/8’ pixel - Q/U;
  0.5 μK/8’ pixel - T



EBEX Optics

6 degree diameter, diffraction limited FOV; Strehl > 0.9




Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
WMAP/Science Team