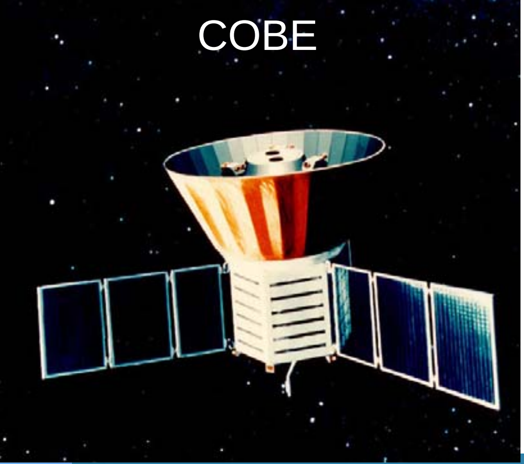
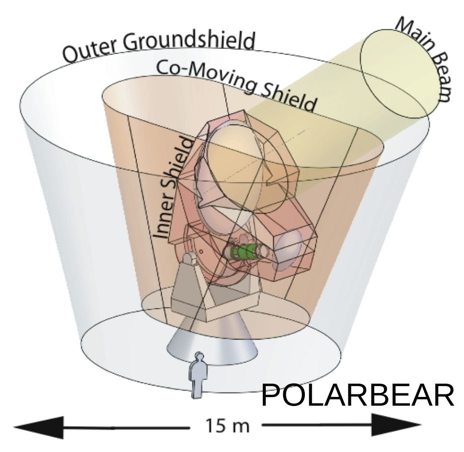
China-US Bilateral Workshop on Astronomy

April 21-25 2008

Tony Readhead

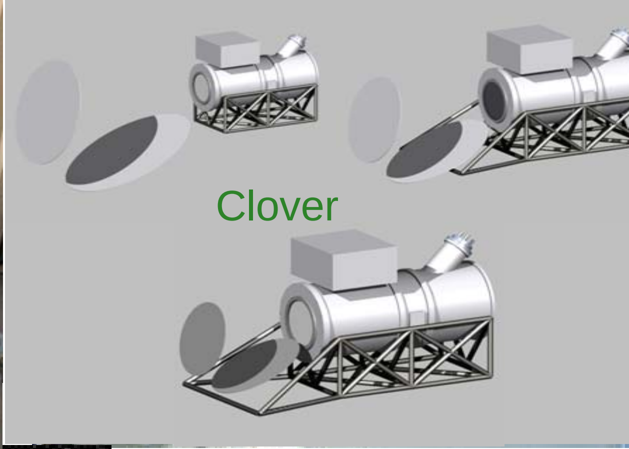
CARMA
The Chajnantor Observatory
The Owens Valley Radio Observatory

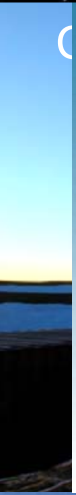

COBE



POLARBEAR

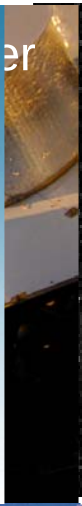

Bicep

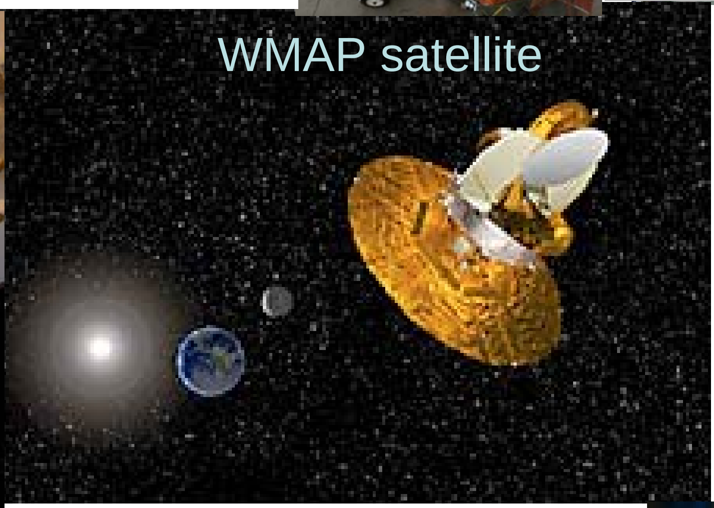

Clover

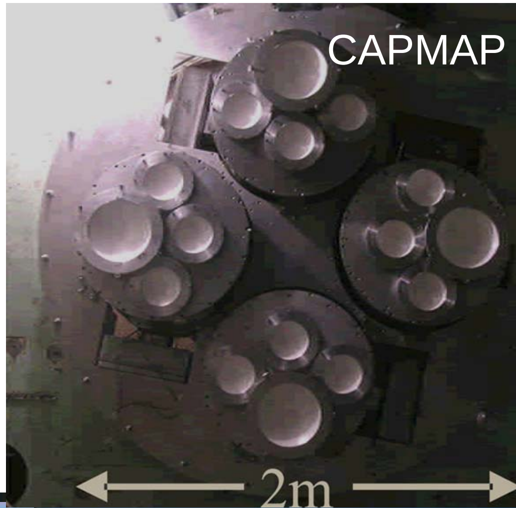


QUIET

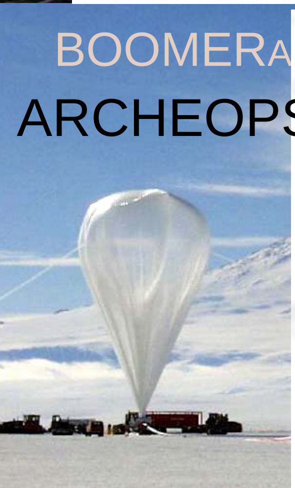
Q/U Imaging Experiment



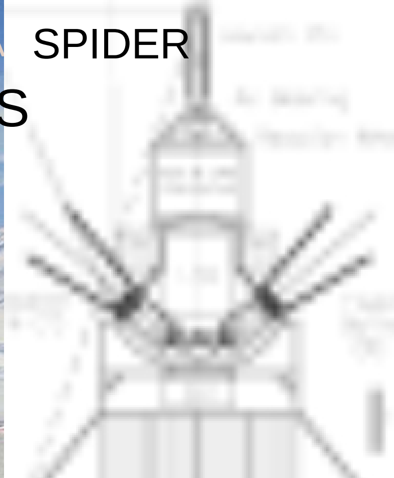

WMAP satellite

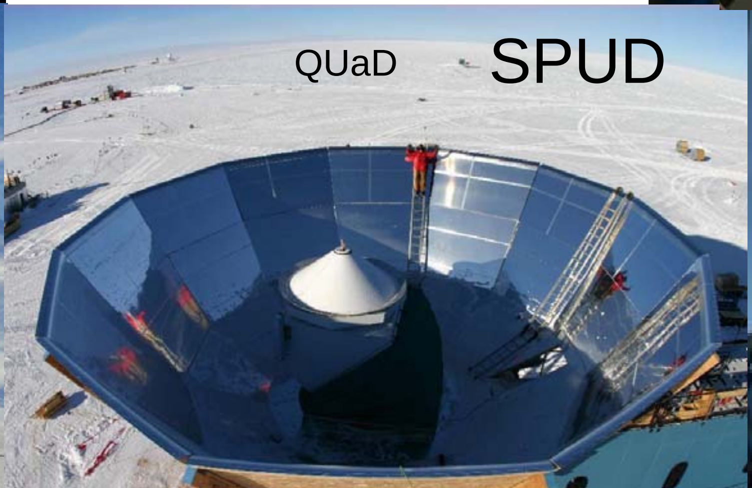


CAPMAP


BOOMERA

ARCHEOPS

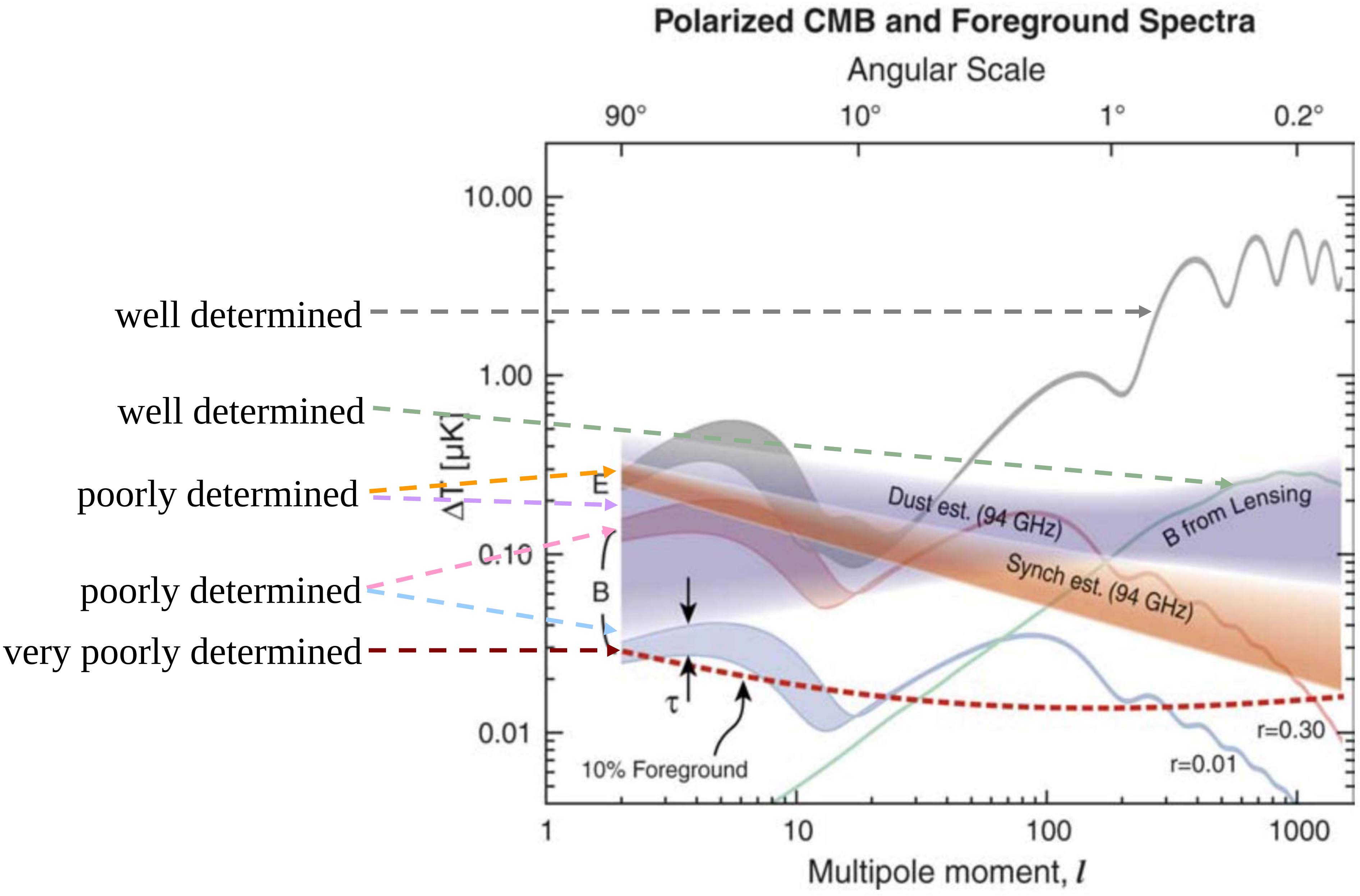

SPIDER


QUaD

SPUD


ACBAR - South Pole

EBEX



well determined

well determined

poorly determined

poorly determined

very poorly determined

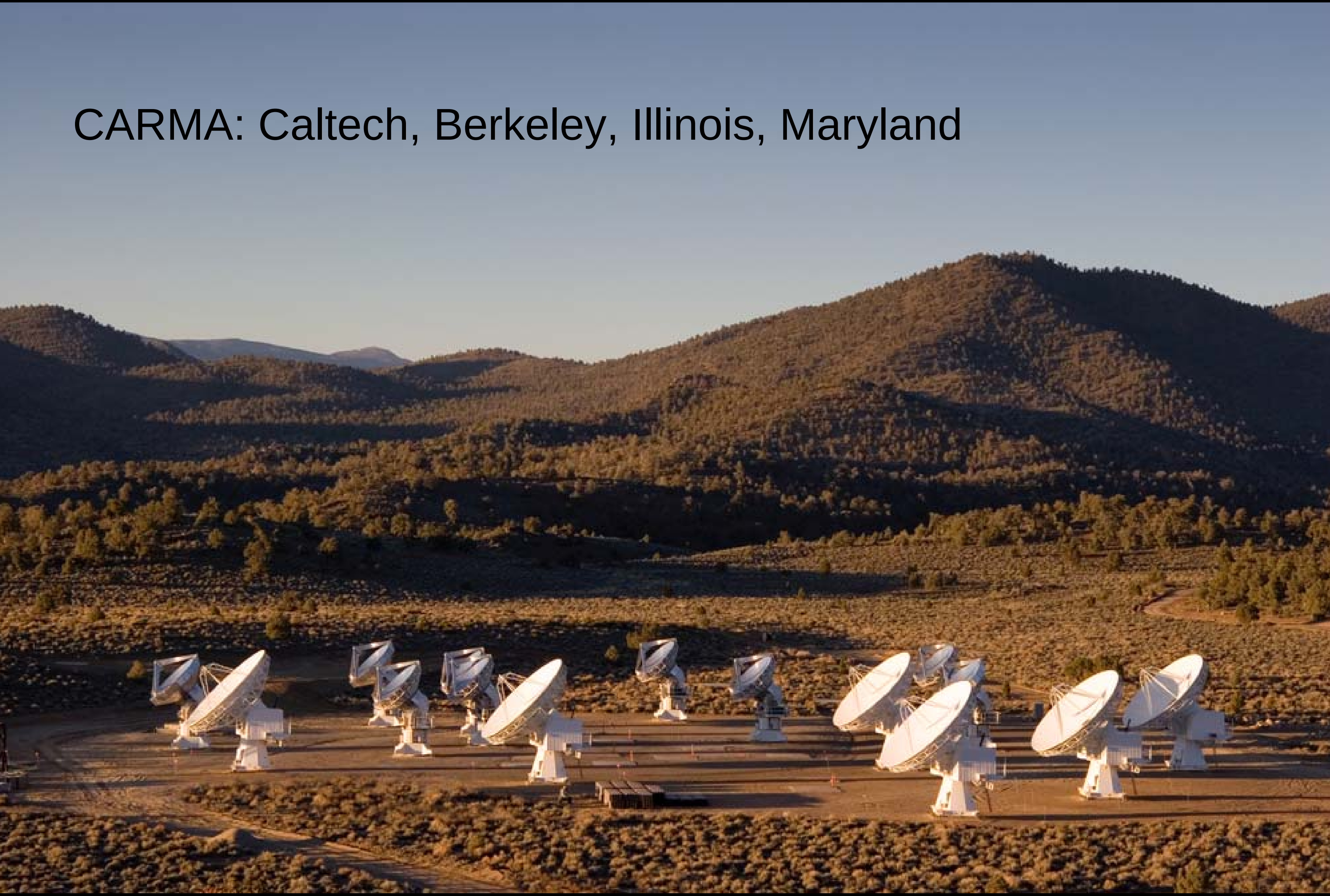

BROTHERS AND SISTERS, AT THE TIME OF 10^{-33} SECONDS AFTER THE BIG BANG, THE HEAT WAS ENORMOUS.
VERILY, IT WAS OVER 10^{32} DEGREES!
MATTER AND ANTI-MATTER AROSE!
HALLELUJAH – THEY ANNIHILATED EACH OTHER.
AND THE UNIVERSE WAS FILLED WITH PARTICLES...
AMEN! QUARKS
AND GLUONS.
YEA, LEPTONS
BELIEVE
S. Harris


BROTHERS AND SISTERS, AT THE TIME OF 10^{-35} SECONDS AFTER THE BIG BANG, THERE WAS INFLATION!
THE UNIVERSE EXPANDED BY 10^{30}!
AND A SCALE-INVARIANT PERTURBATION SPECTRUM AROSE
VERILY, WE MAY IGNORE DISCREPANCIES OF 10^{120}!
HALLELUJAH- IT WAS MADE FLAT!
AMEN!
DARK ENERGY
AND DARK MATTER.
YEA, WIMPS
BELIEVE
S. HARRIS

Chajnantor Observatory

Owens Valley Radio Observatory

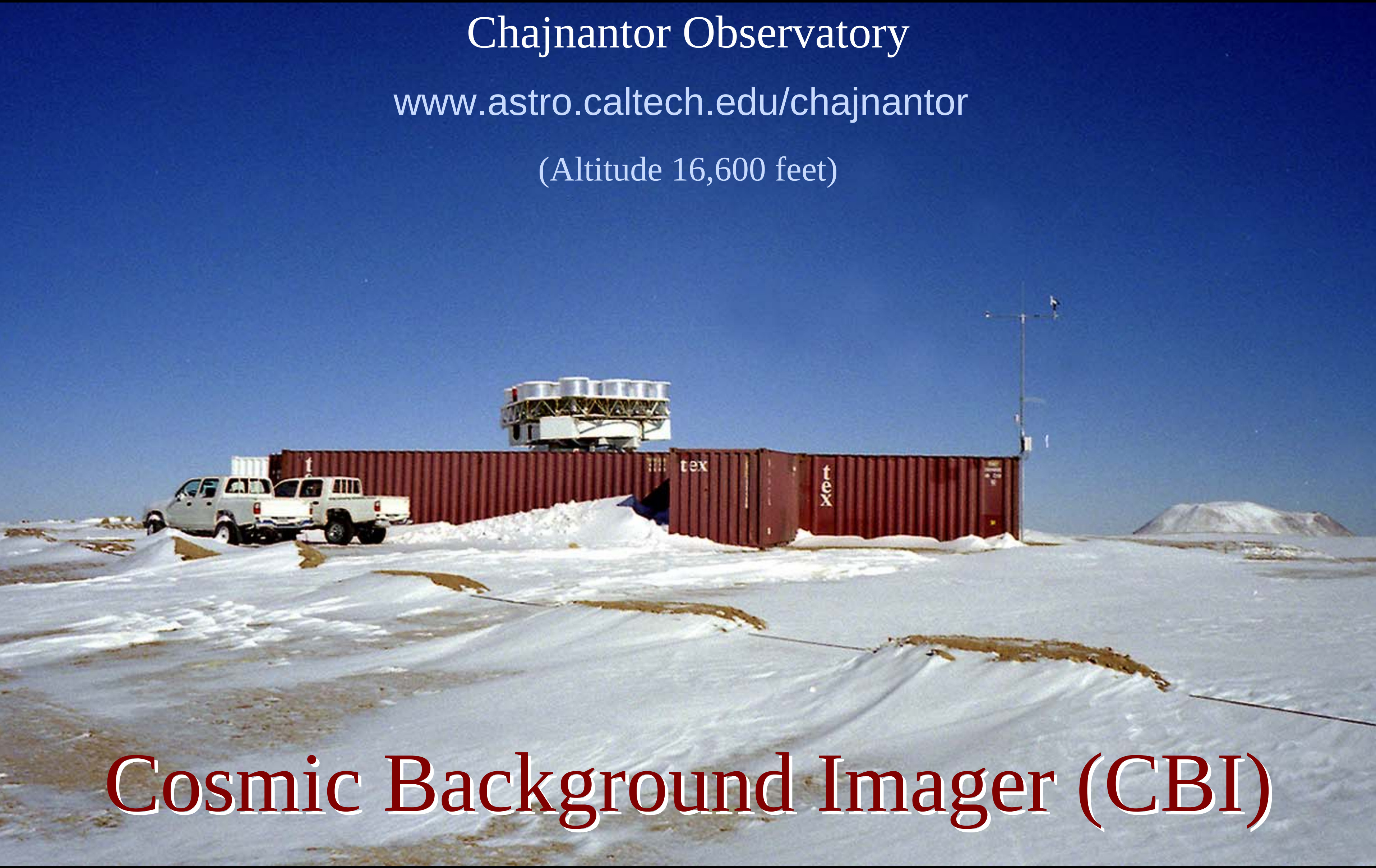
CARMA: Caltech, Berkeley, Illinois, Maryland



Chajnantor Observatory

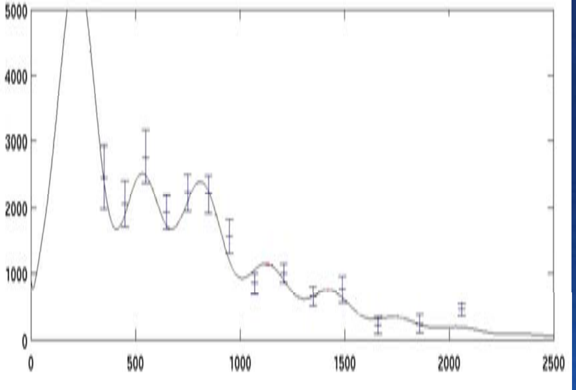
www.astro.caltech.edu/chajnantor

(Altitude 16,600 feet)

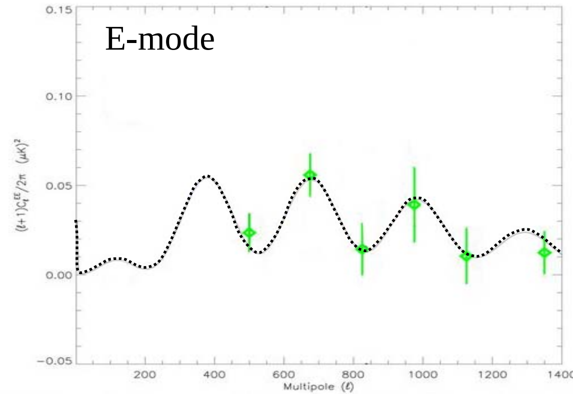


Cosmic Background Imager (CBI)

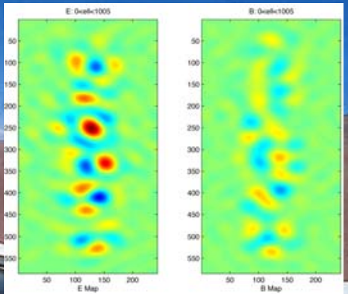
Cosmic Background Imager



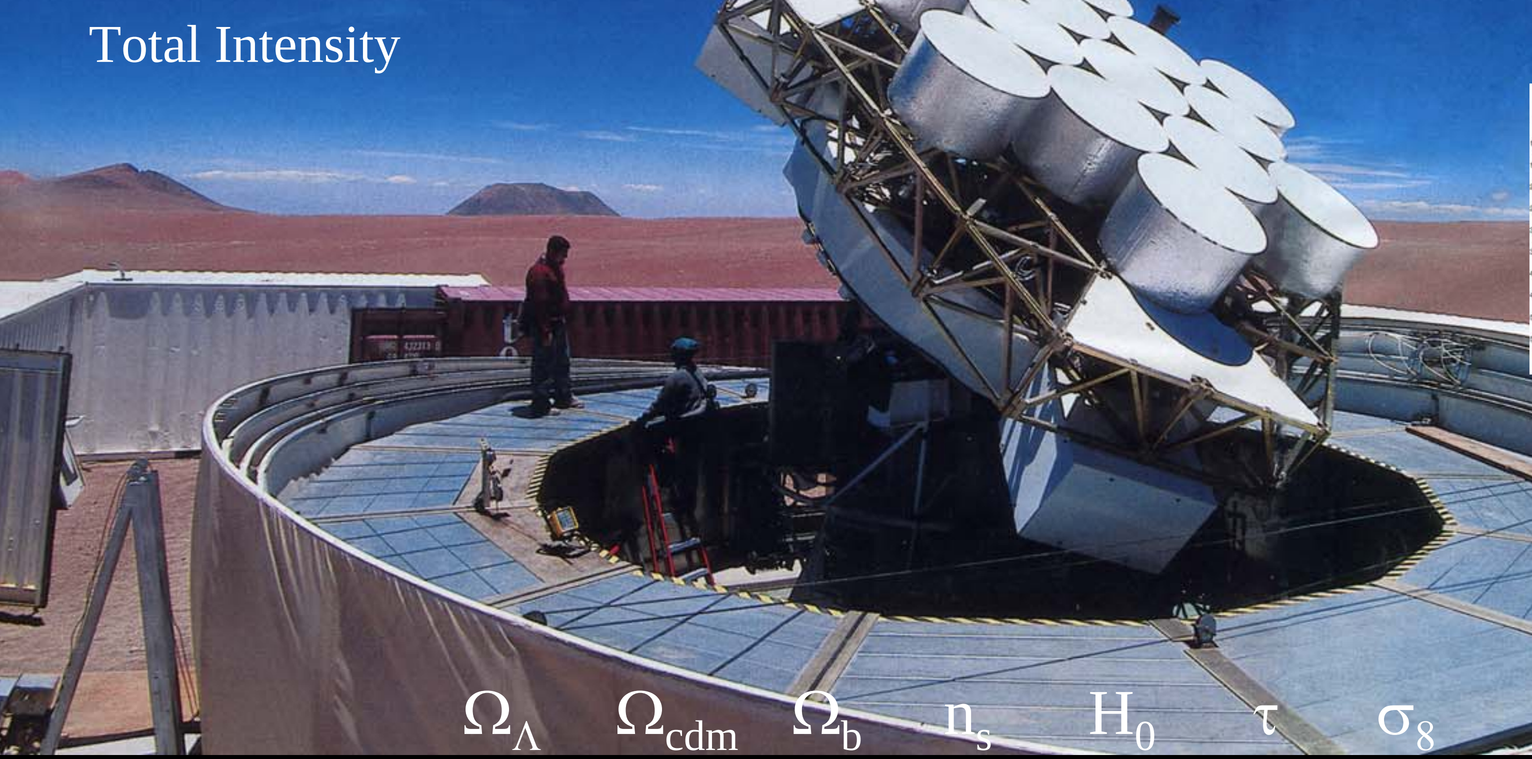
Total Intensity



Polarization



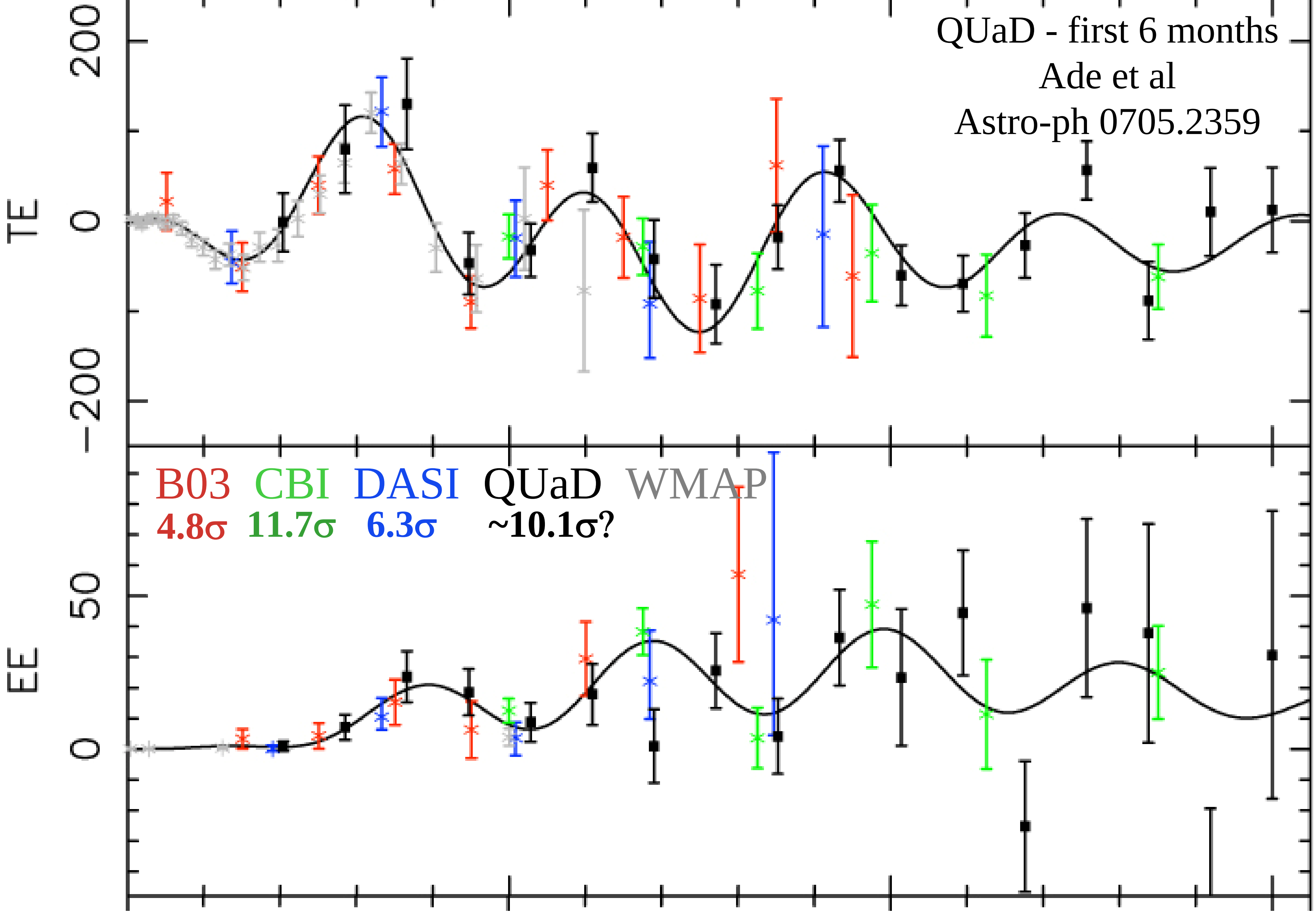
E-mode B-mode

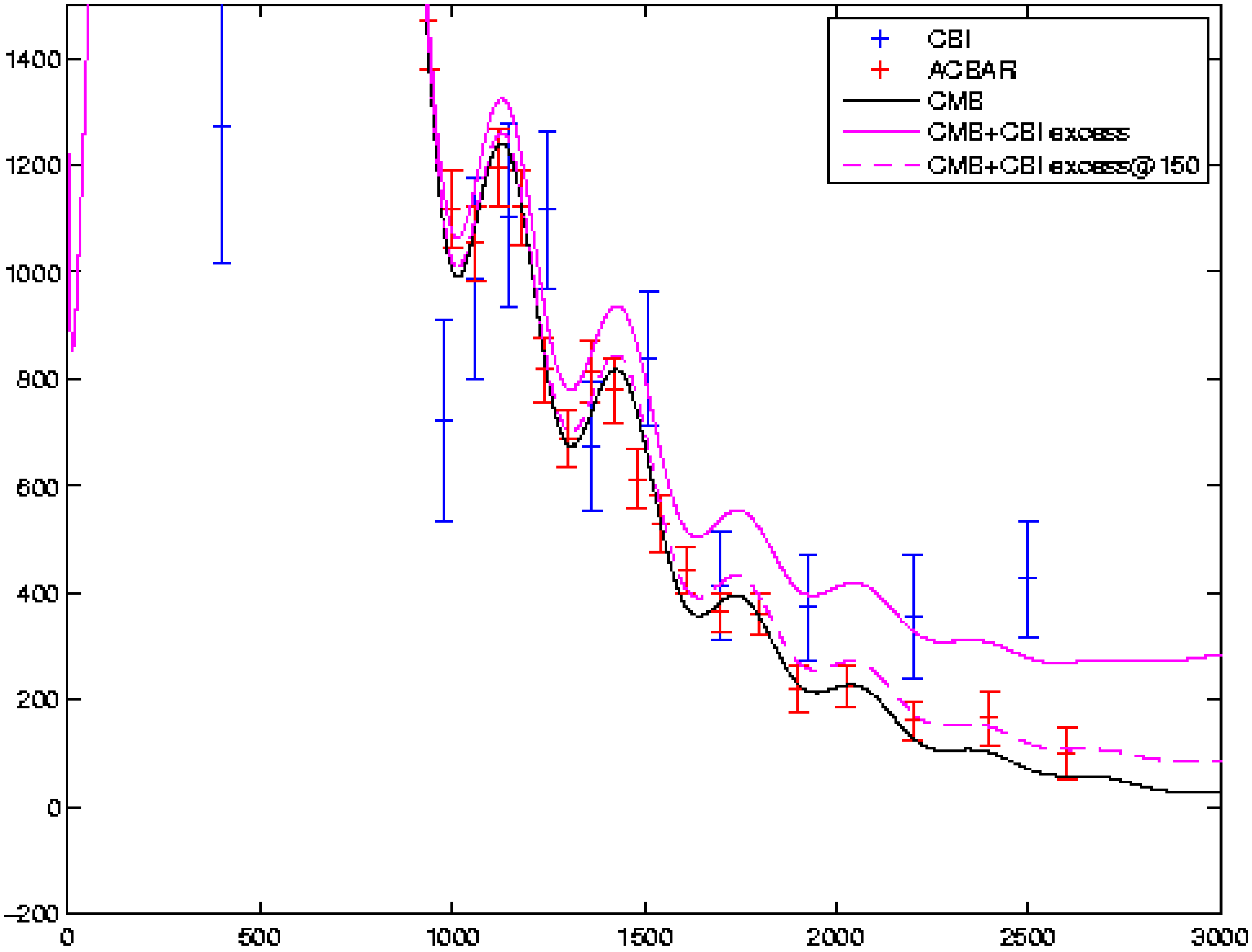


Ω_Λ Ω_{cdm} Ω_b n_s H_0 τ σ_8

CBI Discoveries: Total Intensity -- anisotropies on the scale of galaxy clusters and superclusters damping tail, high-l excess. Polarization -- small-scale anisotropy.

Other CBI Results: Total Intensity -- independent confirmation of ΛCDM model & constraints on key parameters based on high-l. Polarization -- small-scale phase relative to TT.


QUaD - first 6 months
Ade et al
Astro-ph 0705.2359
TE
200
0
−200
EE
50
0
B03
CBI
DASI
QUaD
WMAP
4.8σ
11.7σ
6.3σ
~10.1σ?



CBI
ACBAR
CMB
CMB+CBI excess
CMB+CBI excess@150
1400
1200
1000
800
600
400
200
0
−200
0
500
1000
1500
2000
2500
3000

SAINT

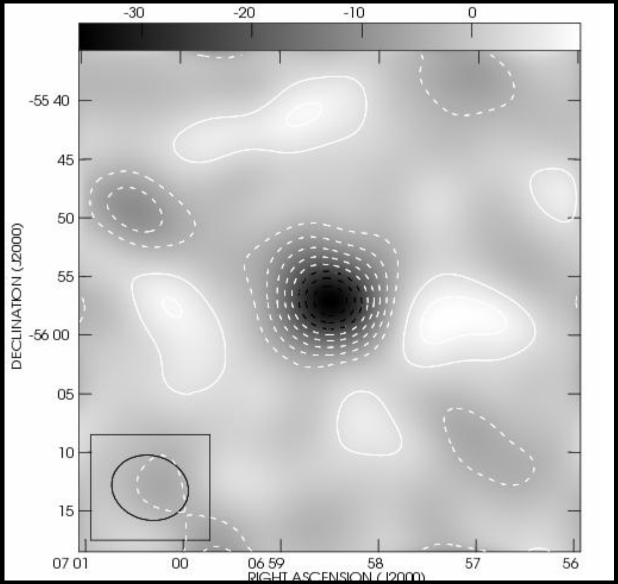
(Strategic Alliance for the Implementation of New Technologies)

13 Partners: (MoU signed 1 December 2005)

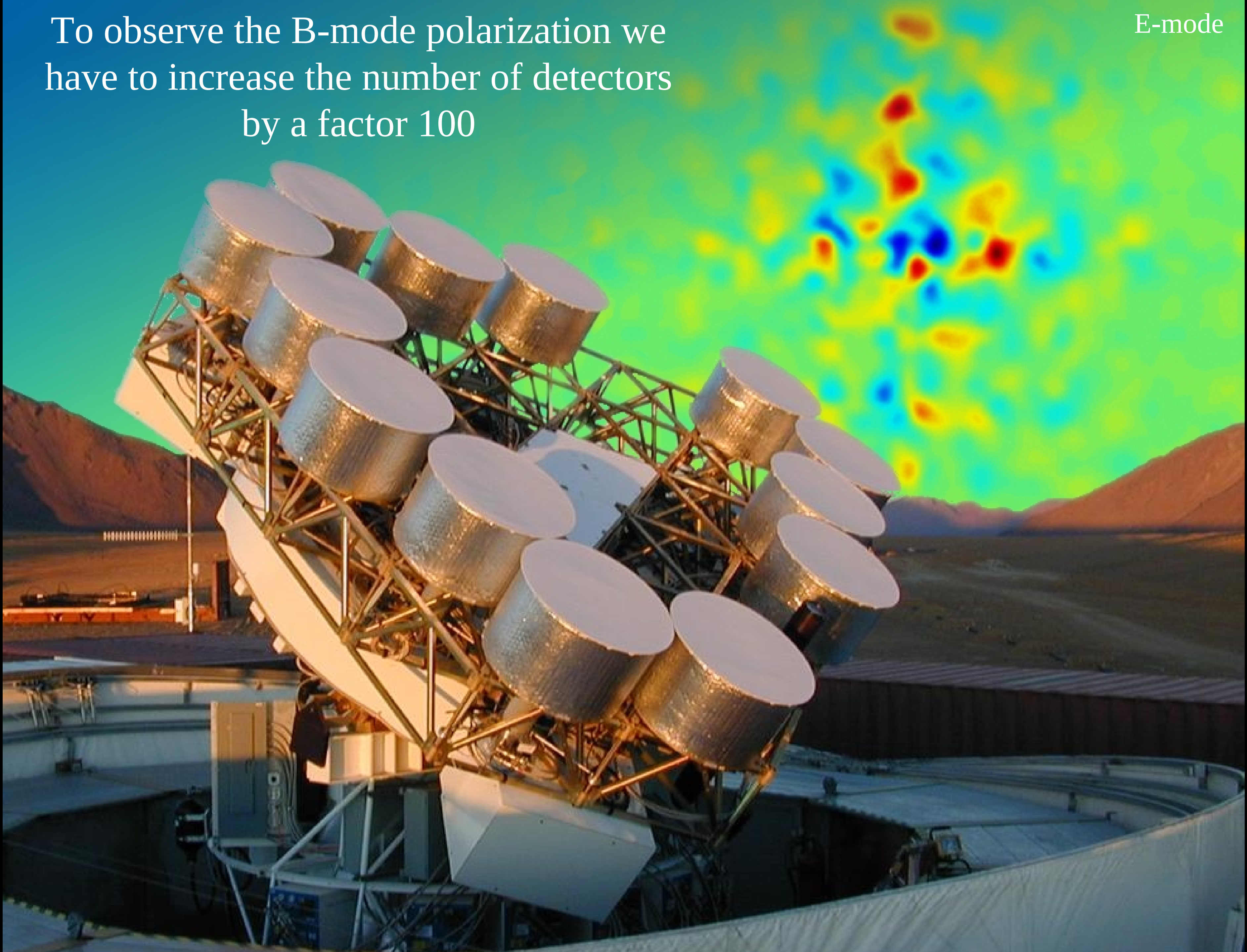
Caltech
Chicago
Columbia
Jet Propulsion Laboratory
KEK (High Energy Accelerator Research Organization) - joined January 2008
Manchester University
Max Planck Institute for Radio Astronomy (Bonn)
Miami University
Oslo University - joined August 2007
Oxford University
Princeton
Rutherford Appleton Laboratory - joined January 2006
Stanford
(Cambridge would like to join)

Primary Objective: Develop and exploit new technologies for studying CMB and foregrounds at frequencies up to 2 THz at present site and on Cerro Chajnantor summit

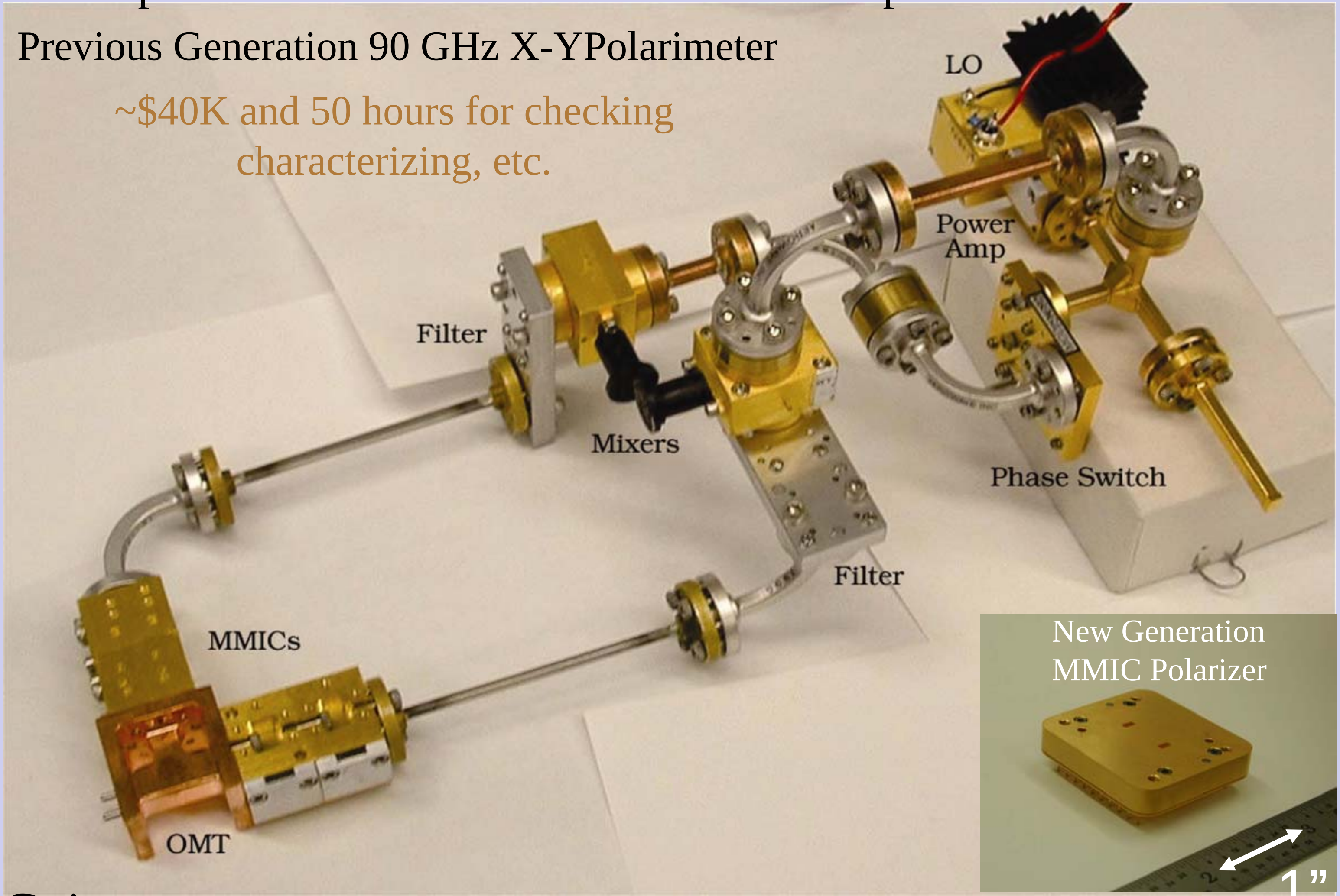

1E 0657–56
Chandra 0.5 Msec image
0.5 Mpc
z=0.3


-30
-20
-10
0
-55 40
45
50
55
-56 00
05
10
15
DECLINATION (J2000)
07 01
00
06 59
58
57
56
RIGHT ASCENSION (J2000)

To observe the B-mode polarization we have to increase the number of detectors by a factor 100



Monolithic Microwave Integrated Circuits (MMICs) are advancing rapidly in a powerful collaboration between Northrop Grumman and JPL



Previous Generation 90 GHz X-YPolarimeter

~$40K and 50 hours for checking characterizing, etc.

New Generation MMIC Polarizer

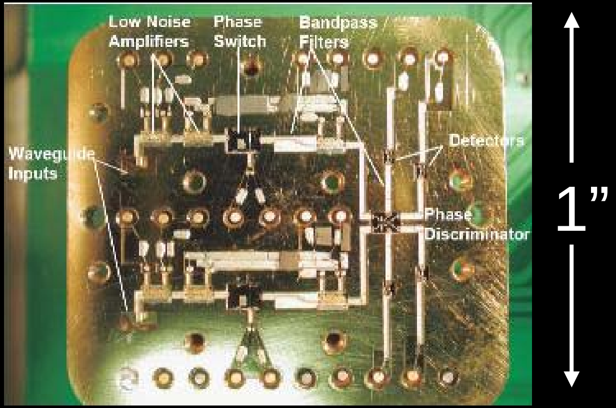
Todd Gaier
Mike Seiffert
Charles Lawrence
Erik Leitch

Kieran Cleary (Moore)
Joey Richards (Moore)
Tony Readhead
Martin Shepherd

~$500 and automated assembly and test, completely scaleable, making MMIC Arrays possible

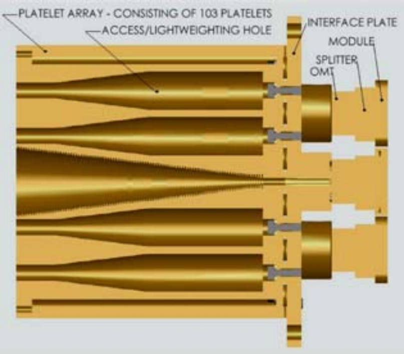
QUIET-Q/U Imaging ExperimenT

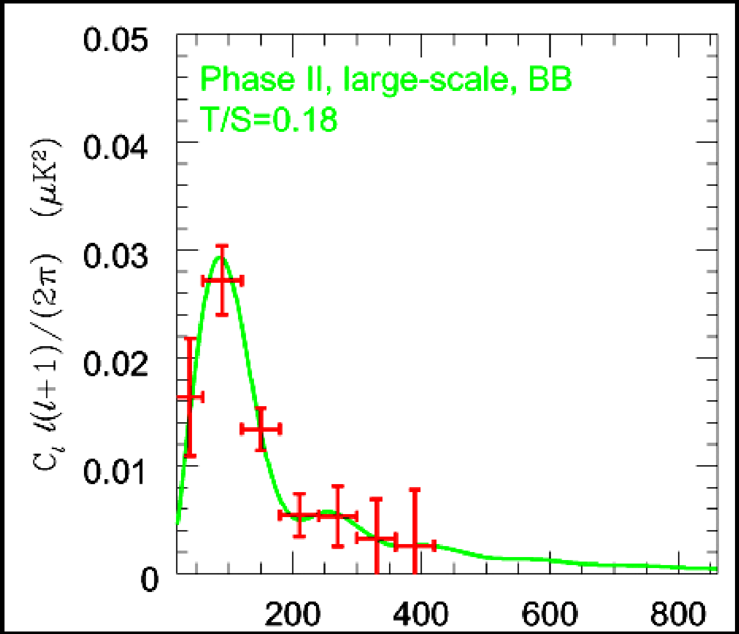
(The search for signals from inflation @10^{-38} s)

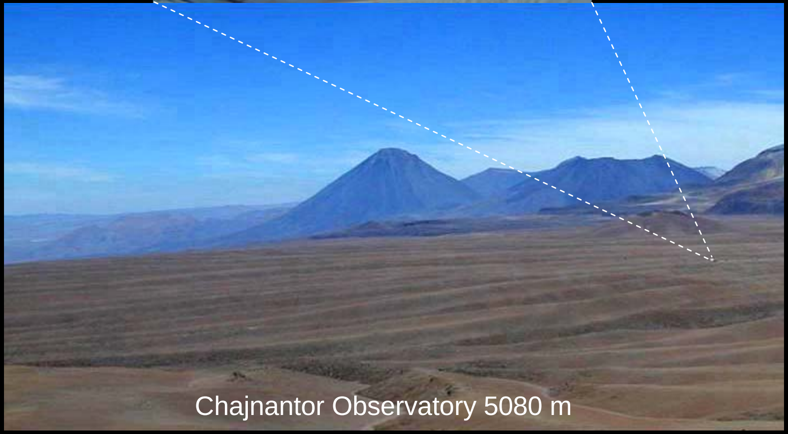


Q & U are measured simultaneously with a single module

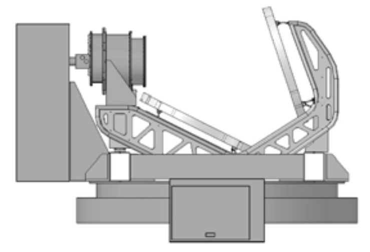
91-element feed (phase 1)
~1000-element feed (phase 2)

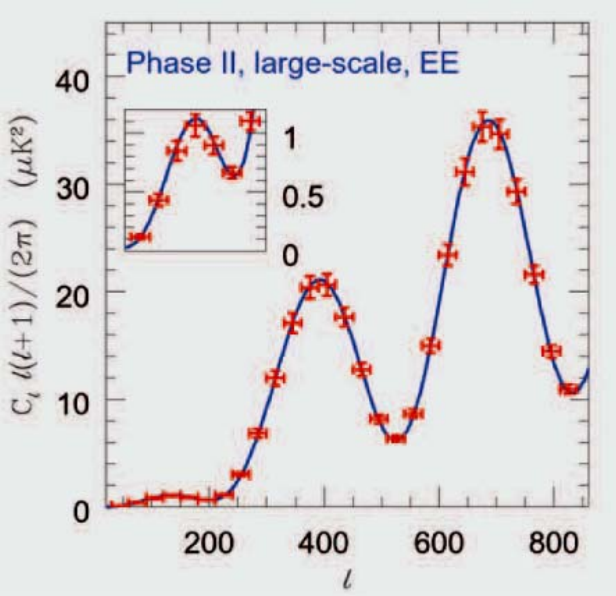






QUIET will use the CBI mount with new optics





Caltech & JPL Berkeley Chicago Columbia Miami Max-Planck Oxford Princeton Stanford

MMIC arrays and MMIC array spectrographs, with ~1000 detectors, will revolutionize GHz-THz astronomy over the next decade, in continuum and spectral line observations, and on single dishes and interferometers. During this period, thanks to Moore’s Law, we expect to develop the capability of correlating the signals from ~1000-element interferometers over 30 GHz bandwidths, and we can then use interferometry for B-mode cmb observations.

Shown here are some of the instruments on which we are already collaborating to deploy **JPL/NGST** MMIC arrays

CARMA

for surveying with MMIC arrays it will outperform ALMA

CCAT 25 m

GBT 100 m

IRAM 30 m

Bonn 100 m

Sardinia 64 m

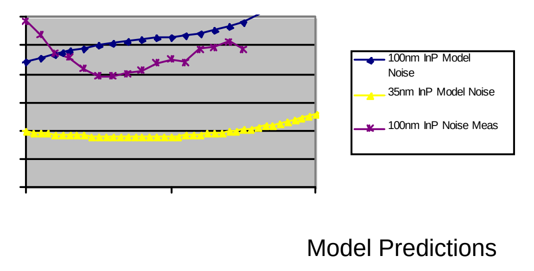
These devices will be revolutionary , 3QL up to 100 GHz and 5 QL at 150 GHz

CMB Measurements: S-Z interferometric arrays, polarization (ground and space)

MMIC Array Spectrometers: focal plane arrays for galactic mapping and high z identification- OVRO, GBT etc

Focal Plane Arrays for Interferometers: increase mapping speed by n for large area surveys

Earth Science Instruments: all weather sounding, atmospheric chemistry with limb sounding



Model Predictions

NGST has recently made very significant advances in short gate (35 nm) InP, and also Sb-based HEMTs

Owens Valley Radio Observatory

Renaissance of activity on the valley floor

AIMMS

(Alliance for International Microwave and Monitoring Surveys)

Partners:

Caltech
Cambridge
Jet Propulsion Laboratory
Max Planck Institute for Radio Astronomy (Bonn)
Stanford
VERITAS
UNM

Bristol University
Manchester University
Miami University
Oxford University

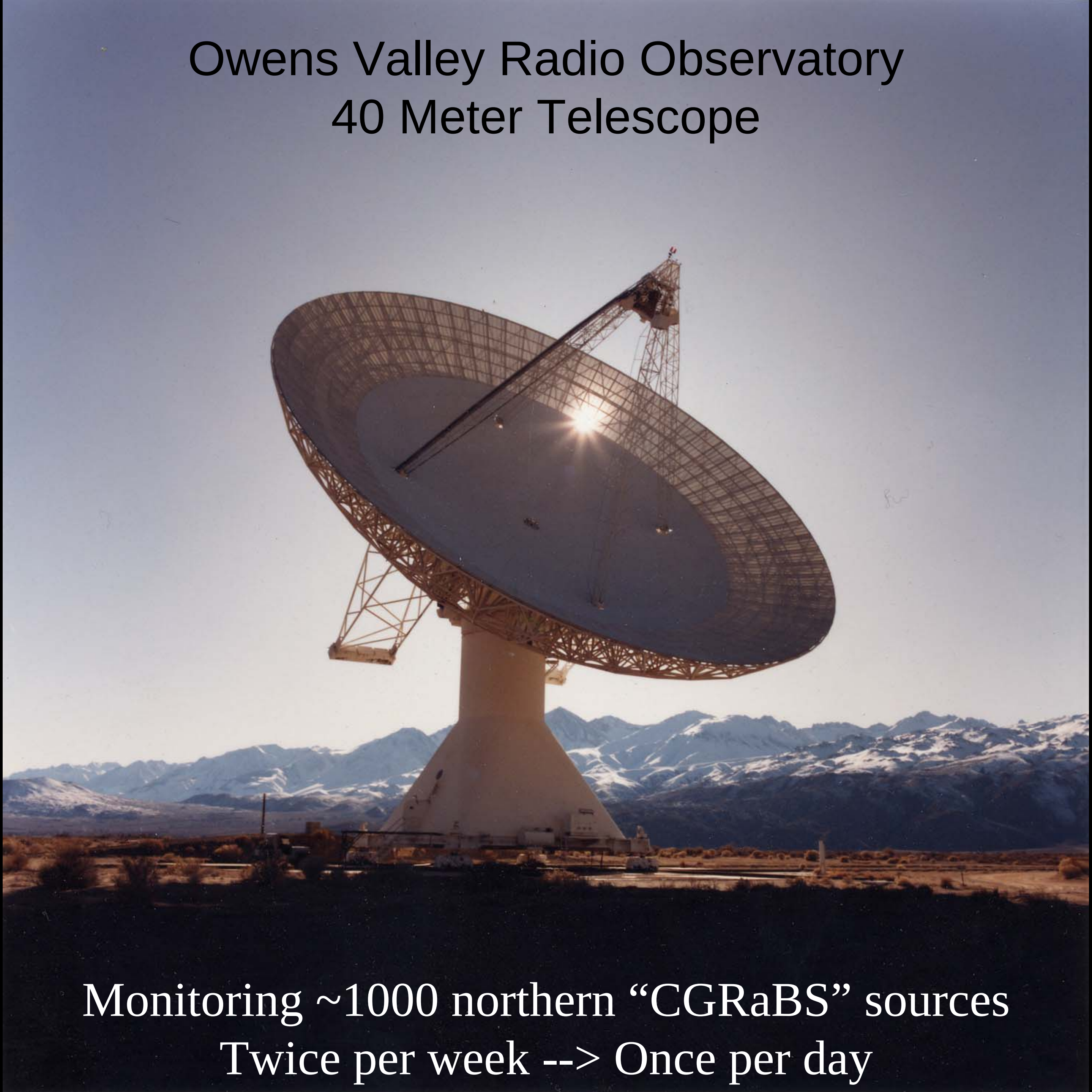
Gamma-ray Large Area Space Telescope
GLAST (launch date >16 May 2008)

40 M GLAST Program: Max-Moerback, Stevenson, Weintraub, Pearson, **Romani**, Blandford, Zensus, Taylor, Browne, Wilkinson, Kus, Cotter, Readhead (Associate Scientist)

Caltech, Stanford, MPIfR, Oxford, Manchester, Torun

- GLAST is expected to spur a re-invigoration of AGN (especially Blazar) science
  - Many thousands of sources to be measured
  - large AΩ allows study of blazar variability probing jet physics
  - good sensitivity probes to high redshift, may allow EBL studies
  - From EGRET, the vast majority of these sources are powerful jet-dominated radio emitters.

Owens Valley Radio Observatory
40 Meter Telescope



Monitoring ~1000 northern “CGRaBS” sources
Twice per week --> Once per day

THE ASTROPHYSICAL JOURNAL, 441:79–95, 1995 March 1

PAIR CASCADES IN EXTRAGALACTIC JETS. I. GAMMA RAYS

R. D. BLANDFORD AND A. LEVINSON
Theoretical Astrophysics 130-33, Caltech, Pasadena, CA 91125

Received 1994 February 11; accepted 1991 September 9

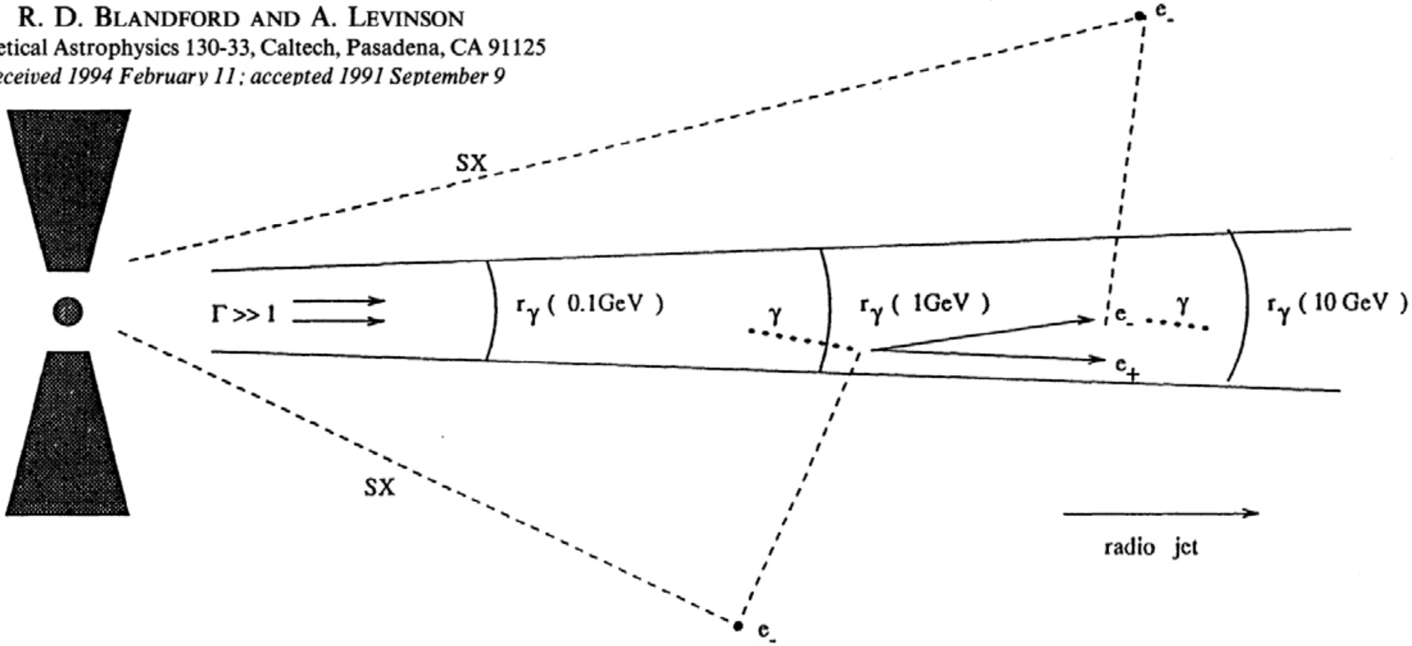
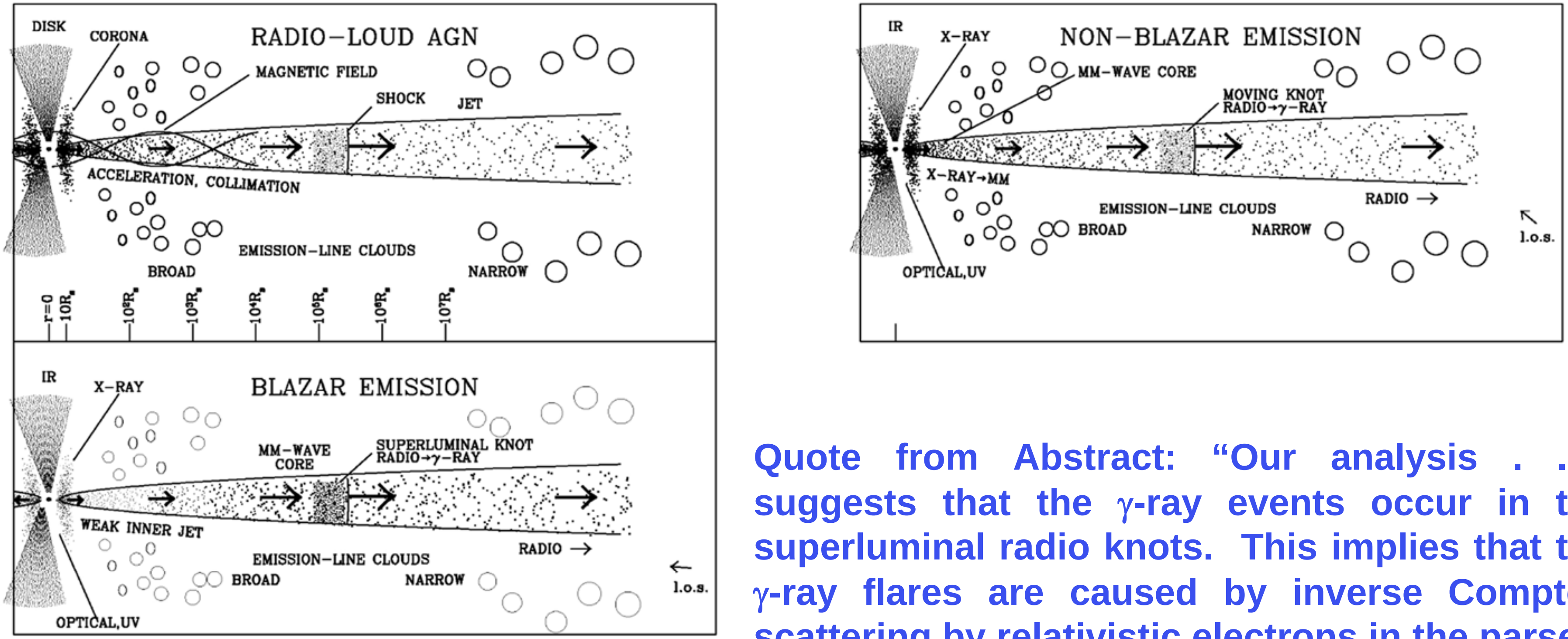


FIG. 6.—Schematic representation of the pair cascade model. A relativistic jet is formed parallel to the spin of a massive black hole orbited by a thick accretion disk. Soft X-ray photons denoted SX emitted near the black hole may be Thomson-scattered into the jet. There they can both combine with γ-rays to form electrons and positrons and be inverse Compton scattered by electrons and positrons to form γ-rays. In this way a pair cascade can develop. Also shown are the γ-spheres for $E_\gamma = 0.1, 1, 10$ GeV.

Jorstad, Marscher, et al. Ap.J. 556, 738, 2001



Quote from Abstract: "Our analysis . . . suggests that the γ-ray events occur in the superluminal radio knots. This implies that the γ-ray flares are caused by inverse Compton scattering by relativistic electrons in the parsec-scale regions of the jet rather than closer to the central engine."

Fig. 1 Rough sketch of the structure and emission regions of a radio-loud active galaxy with a relativistic jet. Note the logarithmic scale on the bottom for the distance down the jet. In the two emission panels—one for jets viewed almost end-on (a blazar) and the other for those seen at a wider angle (a typical radio galaxy)—the likely waveband of photons that can be emitted at each site is indicated. If the jet accelerates out to parsec scales, the inner jet between the mm-wave core and the black hole may be essentially invisible in blazars, while in radio galaxies bright emission might extend down to the base of the jet. (Adapted from Marscher 2005.)

Radio Rapid Response Network (RRRN)

Partners:

- Caltech
- IRAM
- Michigan
- MPIfR
- Shanghai
- Torun

ATCA
Metsahovi

C-BASS
C-Band All-Sky Survey

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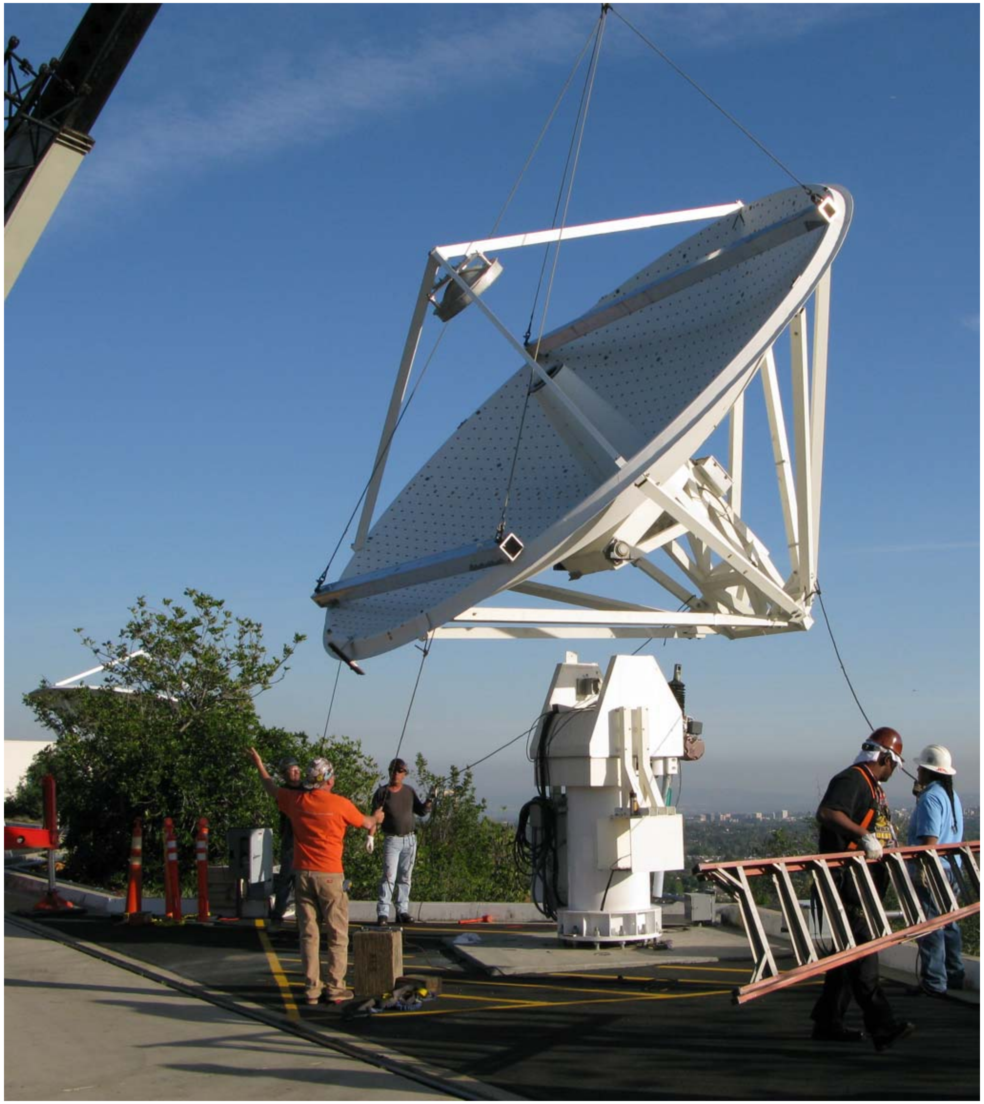
Collaboration

- Caltech: Northern survey, OVRO antenna, backend and data acquisition
- Oxford University: Feed optics, receiver and polarimeter, cold loads
- Manchester University: Low-noise amplifiers
- South Africa (Rhodes University and the Hartebeesthoek Radio Astronomy Observatory): Southern survey

Antennas



JPL 6.1m being disassembled for move to OVRO (March 2008)

7.1m antenna in South Africa

C-BASS

- Image the whole sky at 5 GHz (“C band”).
- Both brightness and polarization.
- Broad-band (1 GHz) correlation polarimeter and correlation radiometer.
- Two telescopes: one in California, and another in South Africa.
- Resolution 0.85 deg, sensitivity < 0.1 mK/beam rms in Stokes I, Q, and U.
- Completion in 2010 to support *Planck* analysis.

Science Goals

- First survey of diffuse Galactic emission at a frequency low enough to be dominated by synchrotron radiation but high enough to be uncorrupted by Faraday rotation effects.
- Enable accurate subtraction of foreground contaminating signals from higher-frequency CMB polarization sky surveys, including *WMAP* and *Planck*.
- Major resource for studying the interstellar medium and magnetic field of the Galaxy.

Ku-Band All Sky Survey (KuBASS): **Readhead** (PI), Gundersen, Grainge, Hobson

Caltech, Cambridge, Miami, Stanford, Rhodes

AN ANOMALOUS COMPONENT OF GALACTIC EMISSION

E. M. LEITCH, A. C. S. READHEAD, T. J. PEARSON, AND S. T. Myers[1]
California Institute of Technology, 105-24, Pasadena, CA 91125

Received 1997 February 26; accepted 1997 June 12

ABSTRACT

We present results from microwave background observations at the Owens Valley Radio Observatory. These observations, at 14.5 and 32 GHz, are designed to detect intrinsic anisotropy on scales of $7'$–$22'$. After point-source removal, we detect significant emission with temperature spectral index $\beta \simeq -2$ toward the north celestial pole (NCP). Comparison of our data with the *IRAS* 100 μm map of the same fields reveals a strong correlation between this emission and the infrared dust emission. From the lack of detectable Hα emission, we conclude that the signals are consistent either with flat-spectrum synchrotron radiation or with free-free emission from $T_e \gtrsim 10^6$ K gas, probably associated with a large H I feature known as the NCP Loop. Assuming $\beta = -2.2$, our data indicate a conversion $T_f/I_{100\mu\mathrm{m}} = 7.5 \times 10^{-2} \nu_{\mathrm{GHz}}^{-2.2}$ K (MJy sr^{-1})$^{-1}$.

The detection of such a component suggests that we should be cautious in any assumptions made regarding foregrounds when designing experiments to map the microwave background radiation.

Subject headings: cosmic microwave background — dust, extinction — H II regions — supernova remnants

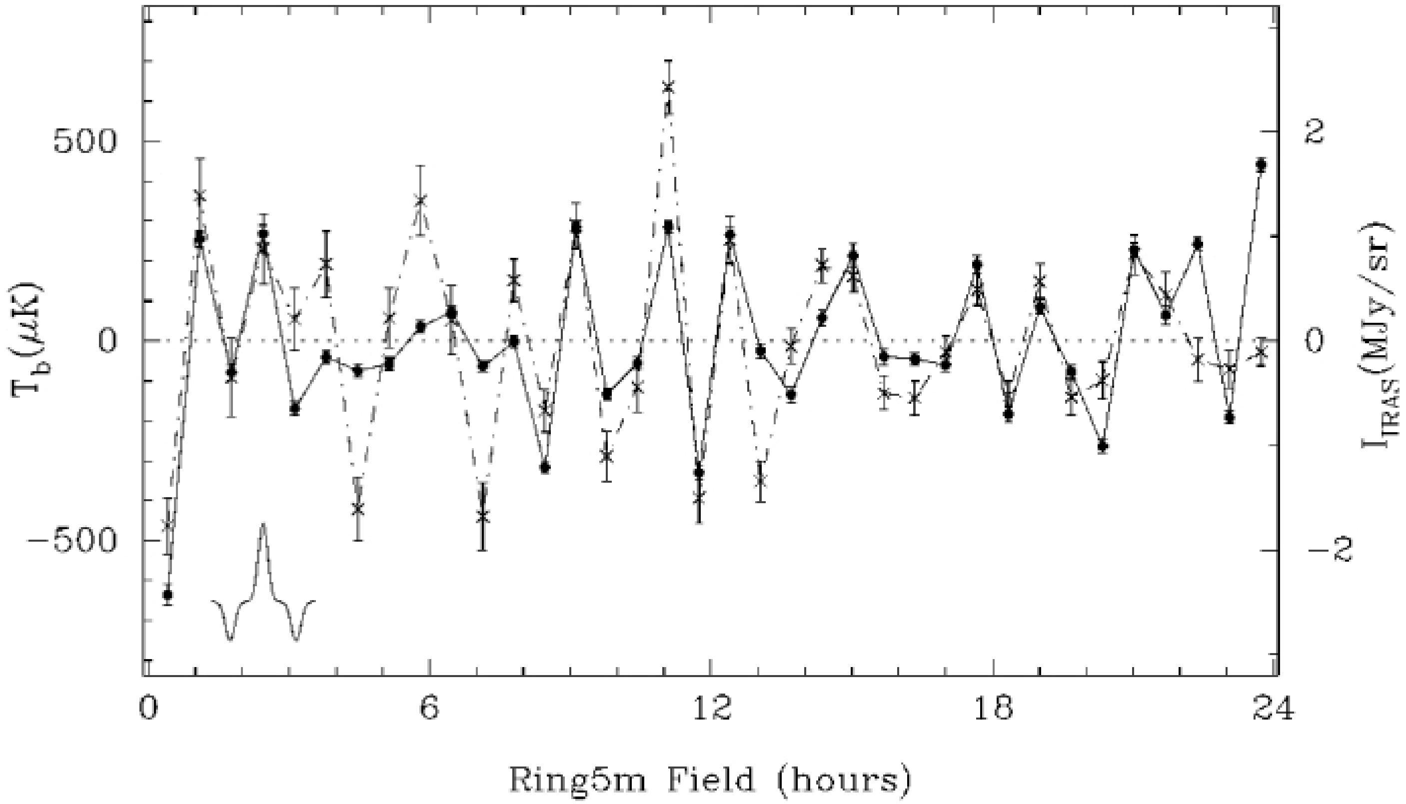


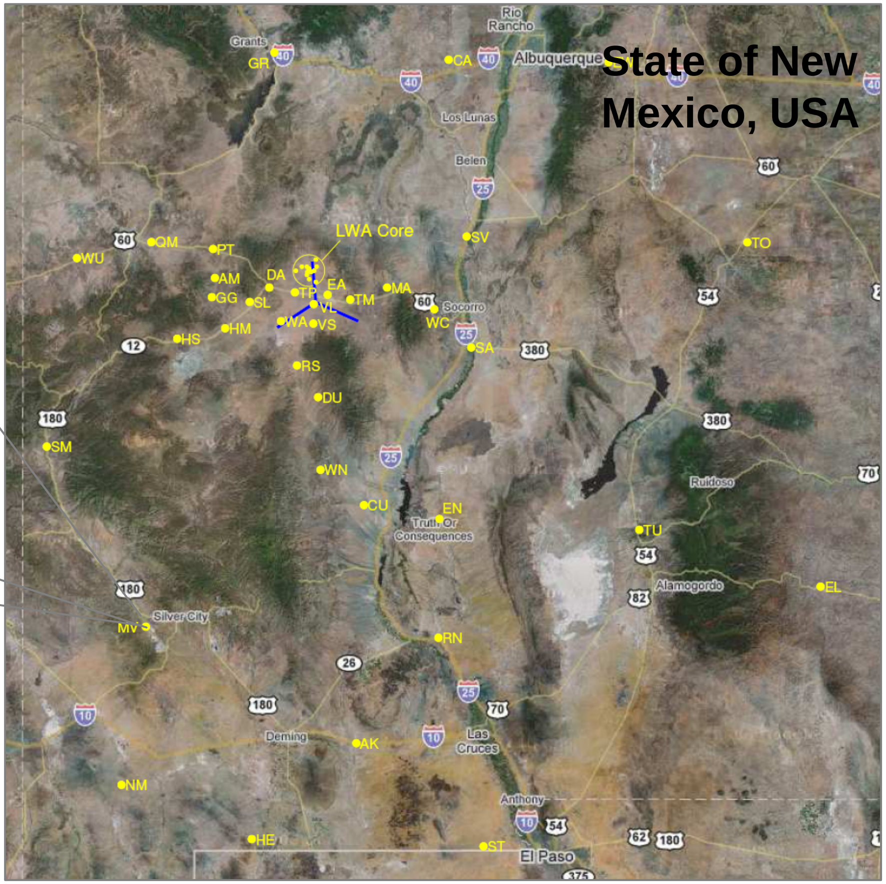
FIG. 2.—Comparison of the 14.5 GHz data (*solid line*) in μK, with the *IRAS* 100 μm convolution (*dot-dashed line*). Errors for the *IRAS* data points are the estimated standard deviation of the convolution. The dotted line essentially coincident with the x-axis is the free-free signal, in μK, inferred from Hα images of the NCP fields, assuming T_e = 10^4 K. At bottom left is the "triple beam" pattern due to the double switching.

The Long Wavelength Array

LWA

Long Wavelength Array

The Long Wavelength Array (LWA)



20-80 MHz tuning range (at least)

Baselines up to 400 km for (also possibly to OVRO) resolution [8,2]’’ @ [20,80] MHz

53 “stations” - mJy-class sensitivity

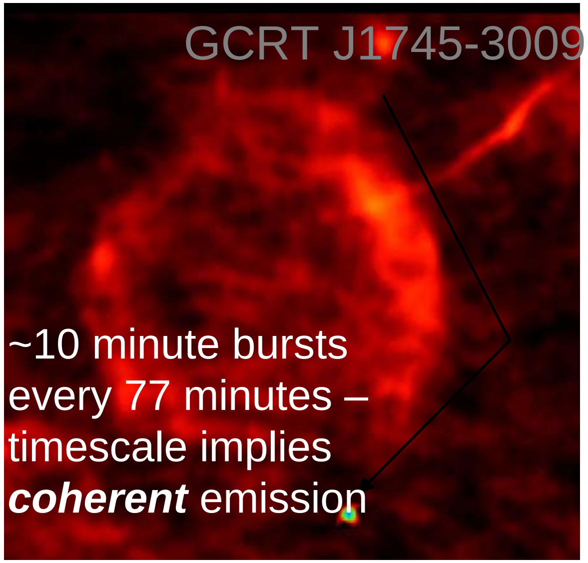
Each station is an array of dipole-like elements in 100 m diameter aperture for FOV = [8,2]

Motivation

- The LWA will open one of the last and most poorly explored regions of the EM spectrum below 100 MHz – a prototype instrument for probing the Dark Ages
  - Multi-beam, multi-frequency array
  - Key science drivers include Cosmology, Acceleration physics, Plasma Astrophysics, & Solar and Space Weather Physics, ionospheric physics
- Exploration of the Transient Universe
  - ***Possible new classes of sources***
  - ***Magnetar Giant Flares***
  - ***Extra-solar planets***
  - ***Prompt emission from GRBs***
- The LWA will provide the high spatial and temporal resolution needed to understand the ionosphere
  - Multi-beam provides multiple pierce lines

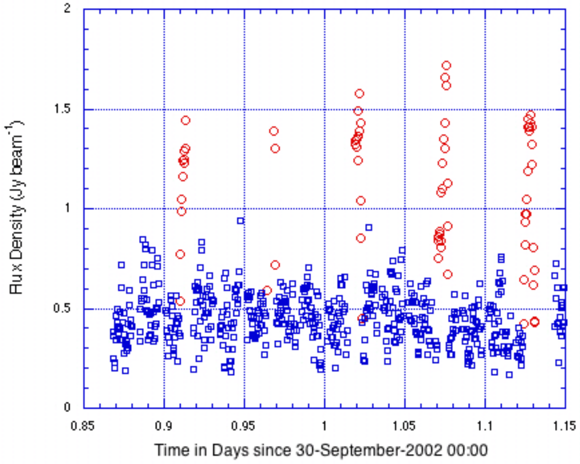
- Even the first LWA station LWA-1 can do exciting science

LWA-1 Transient Science: Known Galactic Examples



GCRT J1745-3009

~10 minute bursts every 77 minutes – timescale implies ***coherent*** emission



- Consider GCRT J1745-3009 (Hyman et al. 2005)
  - Bursts: ~ 1 Jy at 330 MHz, ~10 minutes duration
    - If coherent ($S \alpha \lambda^6$) – up to 10^4 boost at 74 MHz
  - LWA-1 Detectability
    - 5 min, 8 MHz, 74 MHz: 1σ ~63 mJy
    - Situation 10X worse towards GC
      - T_{sys} ~10^4 K towards GC, A_e down by 2X
      - 1σ ~0.6 Jy; $\geq 5\sigma$ detection if $\alpha \leq -1$
- Consider recent eruption of SGR 1806-20
  - ~ 0.5 Jy at 240 MHz
  - α ~ -2.1 => 5 Jy at 74 MHz – lasts for many days
  - 1 hr, 8 MHz, 74 MHz: 1σ~0.4 Jy➔ >12 σ detection
- These known cases look very feasible
  - Especially considering leverage in ⮙*t space

LWA-1 can do exciting transient work!

Table 2. Science-Driven Requirements.

	Required	Desired
Frequency Range	ν_l - ν_u = 20 - 80 MHz	ν_l - ν_u = 3 - 88 MHz
Instantaneous Bandwidth[a]	$\Delta\nu_{max}$ = 8 MHz[b]	$\Delta\nu_{max} \gtrsim$ 50 MHz
Minimum Channel Width	$\Delta\nu_{min} \lesssim$ 100 Hz	$\Delta\nu_{min}$ = 10 Hz
Angular Resolution [@ 80 MHz]	$\theta \lesssim 2''$	$\theta \lesssim 1''$
Minimum Temporal Resolution	$\Delta\tau$ = 10 ms[c]	$\Delta\tau$ = 1 ms[c]
Primary Beam Width [@ 80 MHz]	PBW = 2°	PBW $\gtrsim$2°
Largest Angular Scale [@ 80 MHz]	LAS = 1°	LAS = 2°
Baseline Range	200 m - 400 km	100 m - 600 km
Sensitivity[d]	σ = 1 mJy	$\sigma \lesssim$ 1 mJy
Dynamic Range @ 20, 80 MHz[e]	DR = 10^4, 10^3	DR = 10^5, 10^4
Polarization[f]	dual circular $\gtrsim$ 10 dB	dual circular $\gtrsim$ 20 dB
Zenith Angle Coverage	Z$\lesssim$ 60°	Z$\lesssim$ 74°
Number of Beams[g]	Beams=4	Beams$\gtrsim$ 7
Configuration	2D array	2D array
Number of Stations	N=53	N$\gtrsim$ 53
Operation model is a user-oriented, open facility that solicits proposals from the entire scientific community		

The Frequency Agile Solar Radiotelescope (FASR)

NRAO/AUI
Berkeley
Caltech
NJIT
Obs. de Paris
Univ Maryland
Univ Michigan

Endorsed by the Decadal Surveys

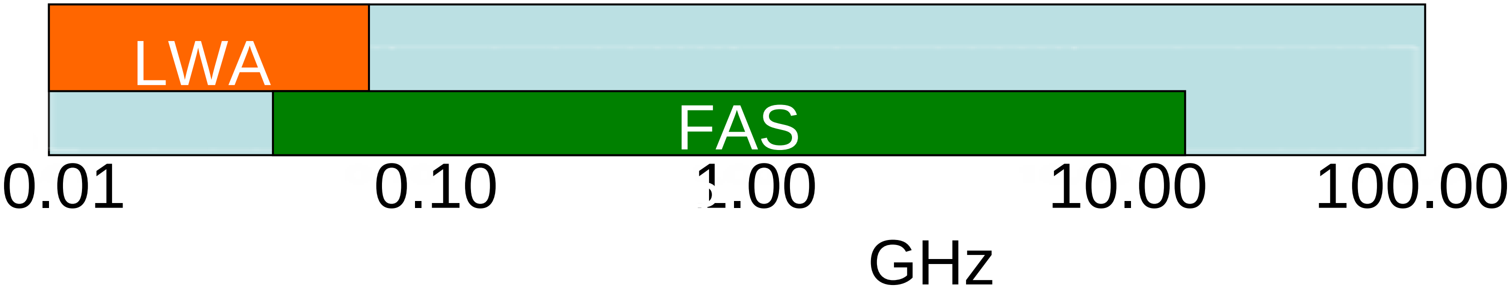
The *Astronomy & Astrophysics Decadal Survey*

The *Solar and Space Physics Decadal Survey ranked FASR as the number one small (<$250M) project*

FASR at Night

- Source monitoring (flux spectrum)
- Radio transients – e.g., XRBs, recurrent novae
- RISS/DISS/extreme scattering events
- Foreground sources
- Coherent emitters
- Jovian emissions

FASR-LWA Synergy



Numerous science synergies!

- Transients
- AGN
- Shock formation & propagation
- Coronal energy release & electron acceleration
- Solar wind magnetic field, waves, turbulence

- FASR C and LWA could cross-calibrate over 50-80 MHz
- LWA could be an important adjunct to FASR B and C *night time* science