Array for Microwave Background Anisotropy

-- An Observational Cosmology Experiment --

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Talk Outline

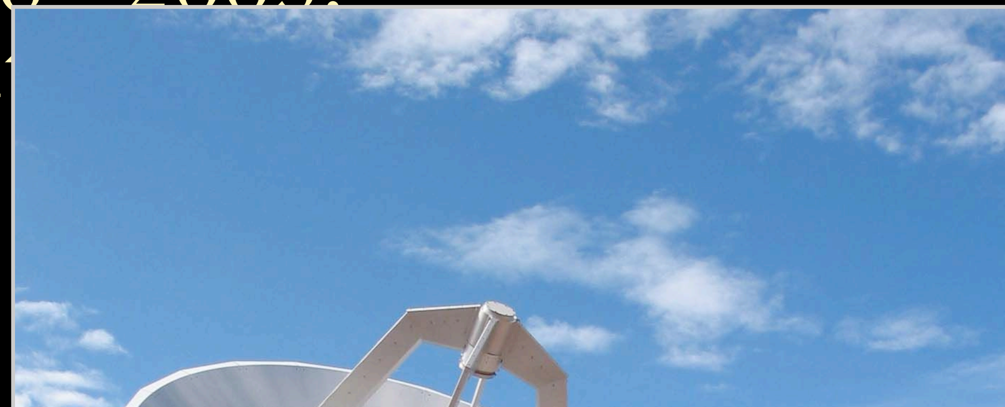
History and Work in ASIAA

Cosmology, CMB, SZE & AMiBA

AMiBA: 2000 - Present

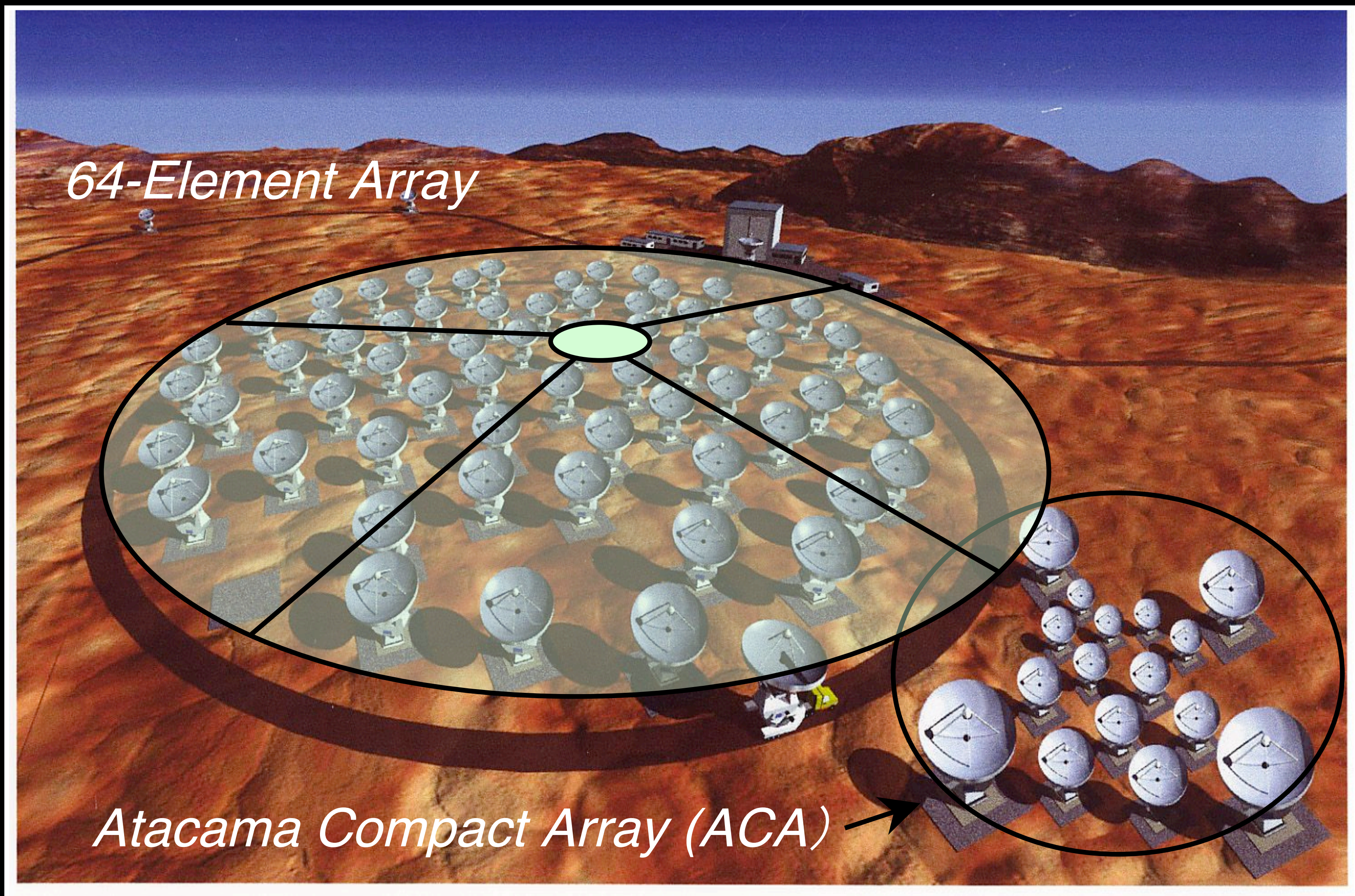
ASIAA Preview

1996 - 2003:
Submillimet



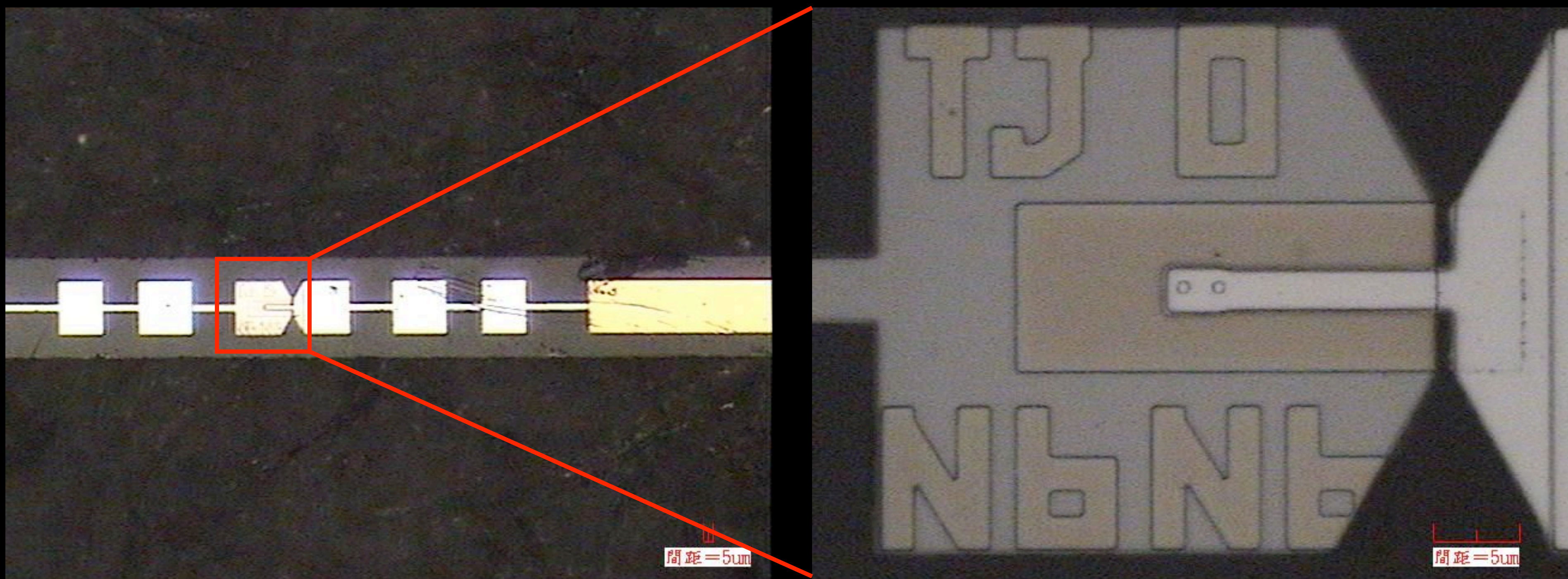
Submillimeter Array (SMA)

2006 - 2015
Atacama Large MM Array (ALMA)



Primary Focus

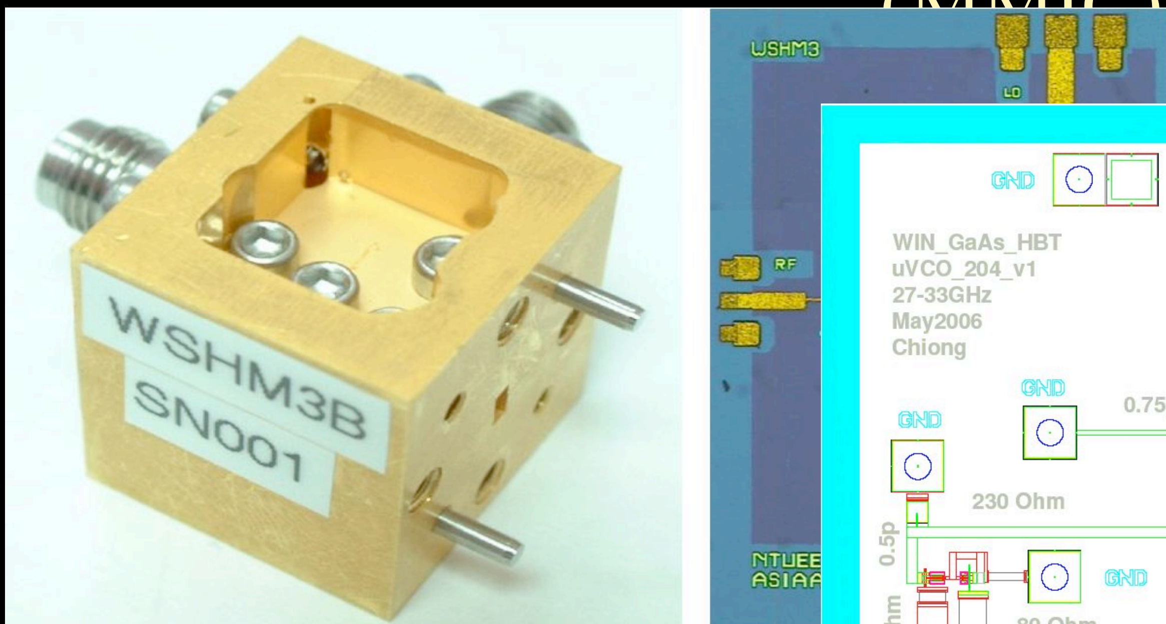
High frequency superconducting detectors



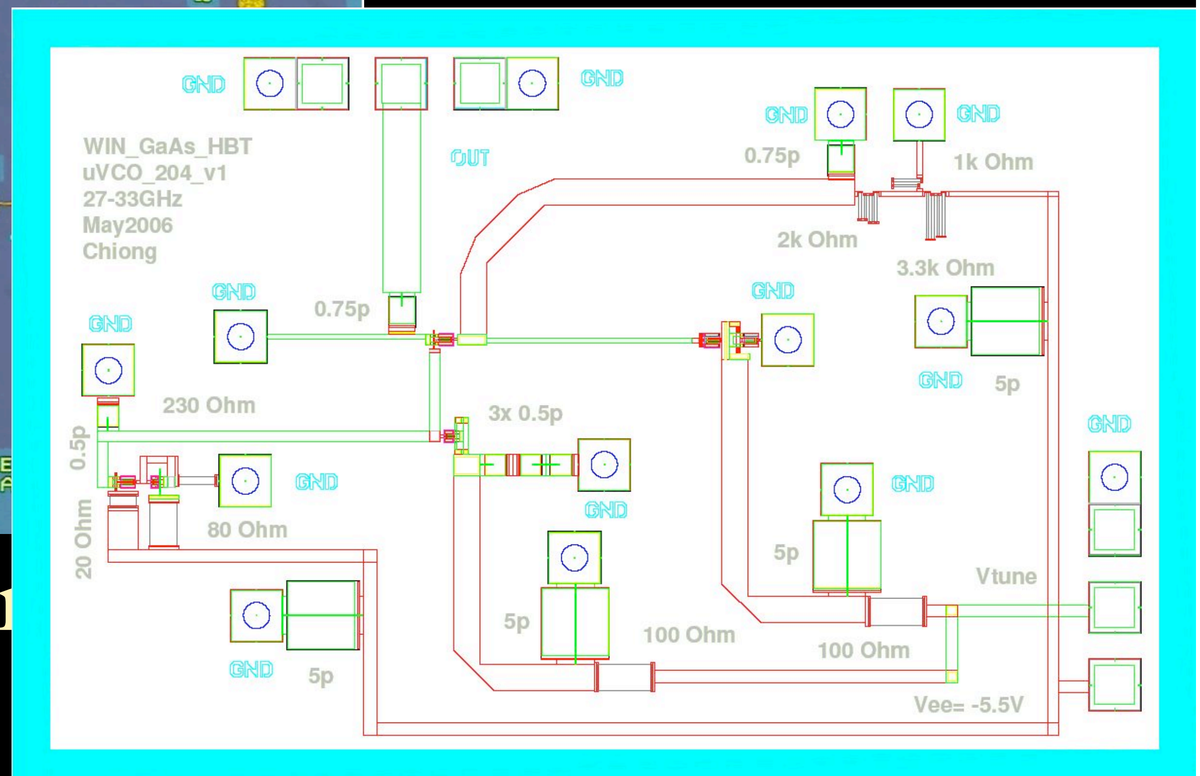
850 GHz SIS Mixer

Primary Focus

Monolithic microwave integrated circuit (MMIC)

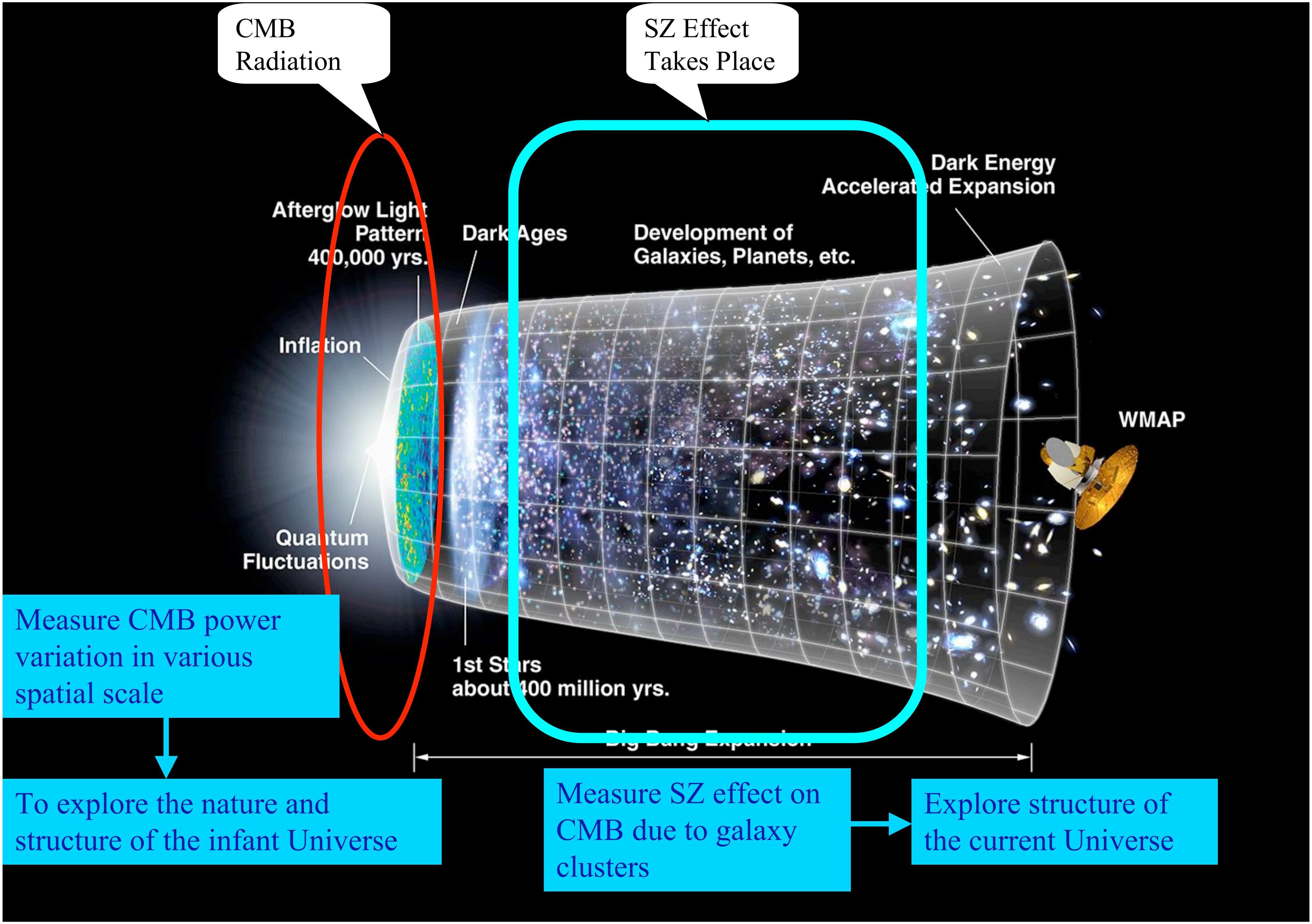


AMiBA Mixer



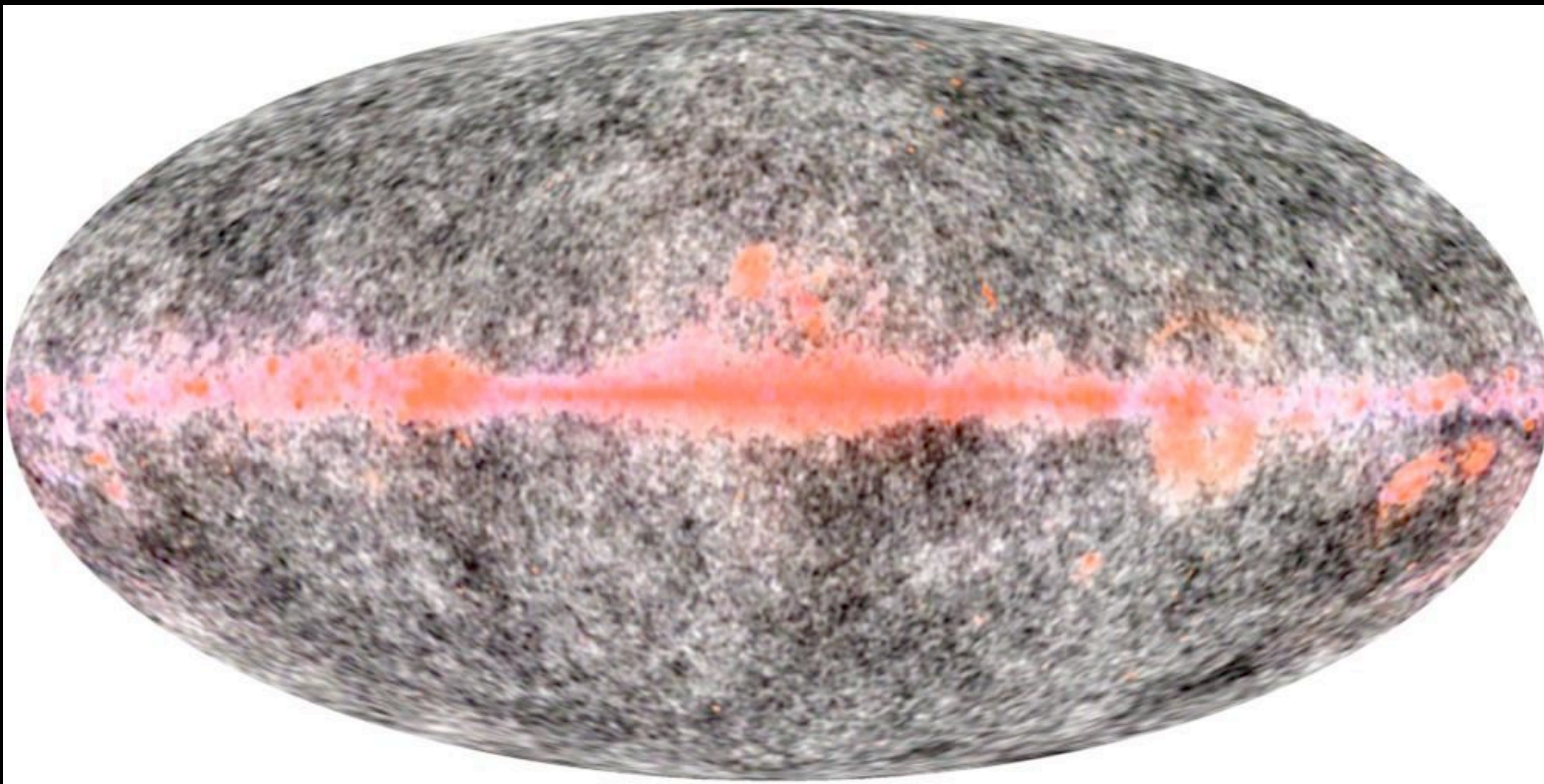
Wide-band VCO

CMB, SZE, & AMiBA



CMB
Radiation
SZ Effect
Takes Place
Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
Measure CMB power
variation in various
spatial scale
1st Stars
about 400 million yrs.
Big Bang Expansion
To explore the nature and
structure of the infant Universe
Measure SZ effect on
CMB due to galaxy
clusters
Explore structure of
the current Universe

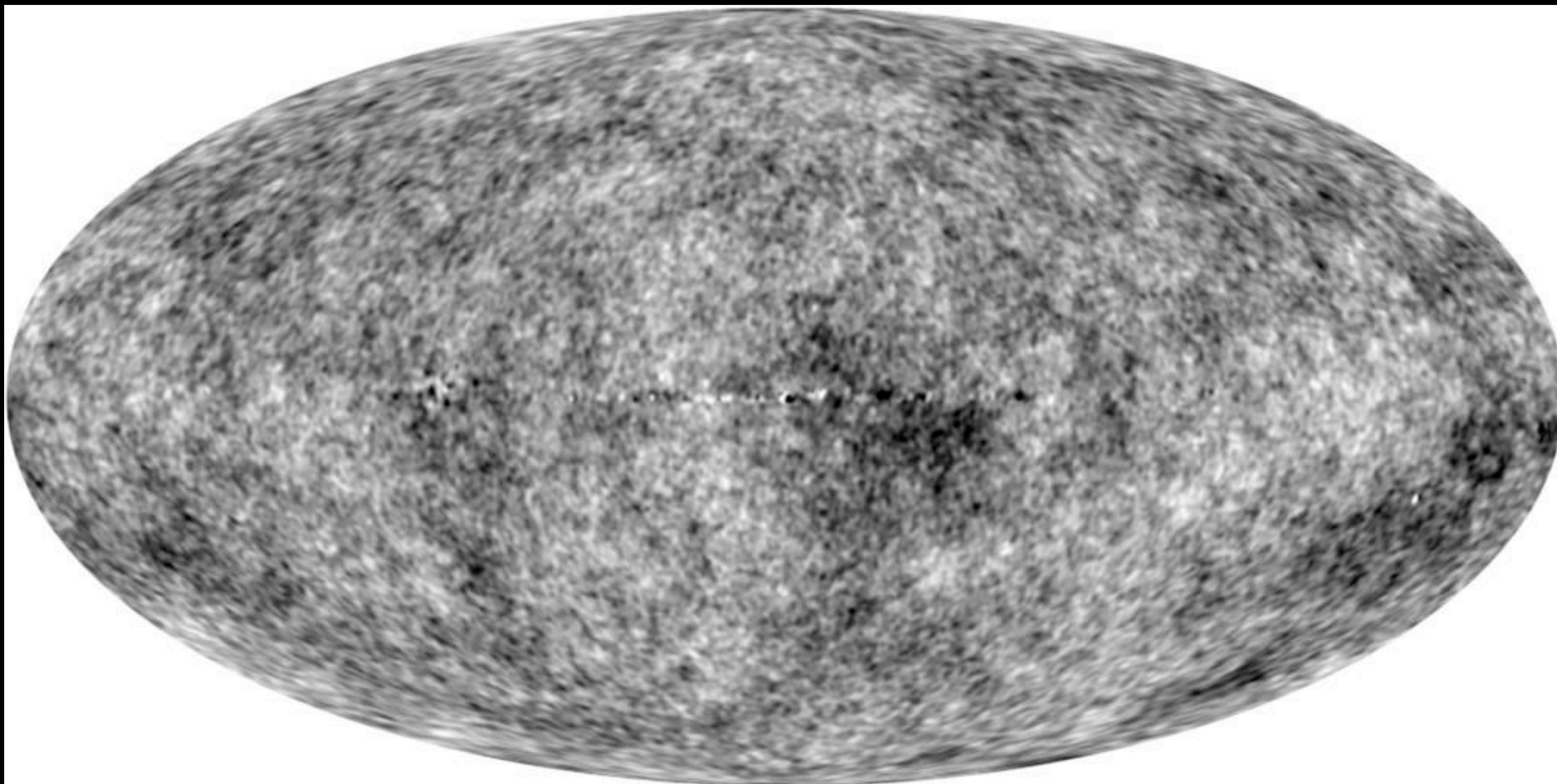
2003 WMAP Measurement



The Mollweide projection, equal-area projection, elliptical projection

Credit:Ned Wright's Cosmology Tutorial
WMAP 3-year

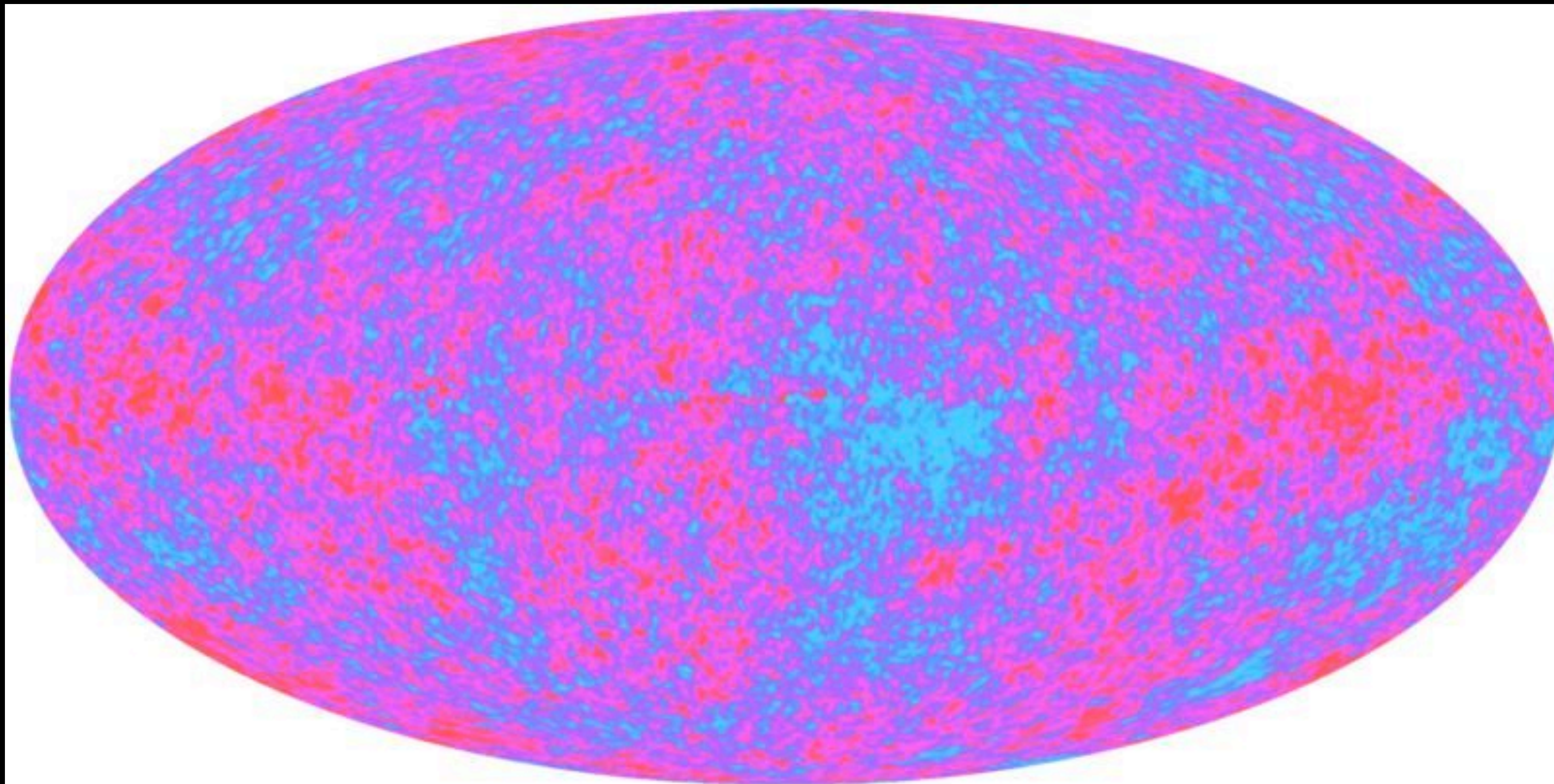
2003 WMAP Measurement



The Mollweide projection, equal-area projection, elliptical projection

Credit:Ned Wright's Cosmology Tutorial
WMAP 3-year

CMB in Color!



From WMAP satellite, 2003

0.0005 K from the coldest (blue) to the hottest (red) parts of the sky!

Angular Power Spectrum, C_l

- **Decomposing patterns of structures in spherical harmonics**

$$\frac{\Delta T(\theta,\phi)}{T} = \sum_l^{\infty} \sum_{m=-l}^{+l} a_{lm} Y_{lm}(\theta,\phi)$$

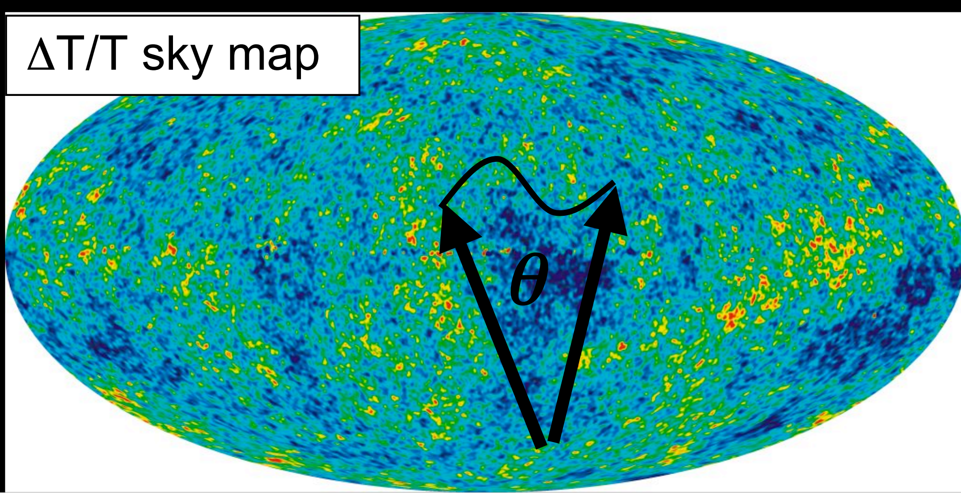
"Fourier transform" of anisotropy on the sphere

- **Rotational invariance** (averaging over *m*)

Angular power spectrum

$$C_l = \frac{1}{2l+1} \sum_m \left\langle a_{lm} a_{lm}^{\,*} \right\rangle$$

ΔT/T sky map



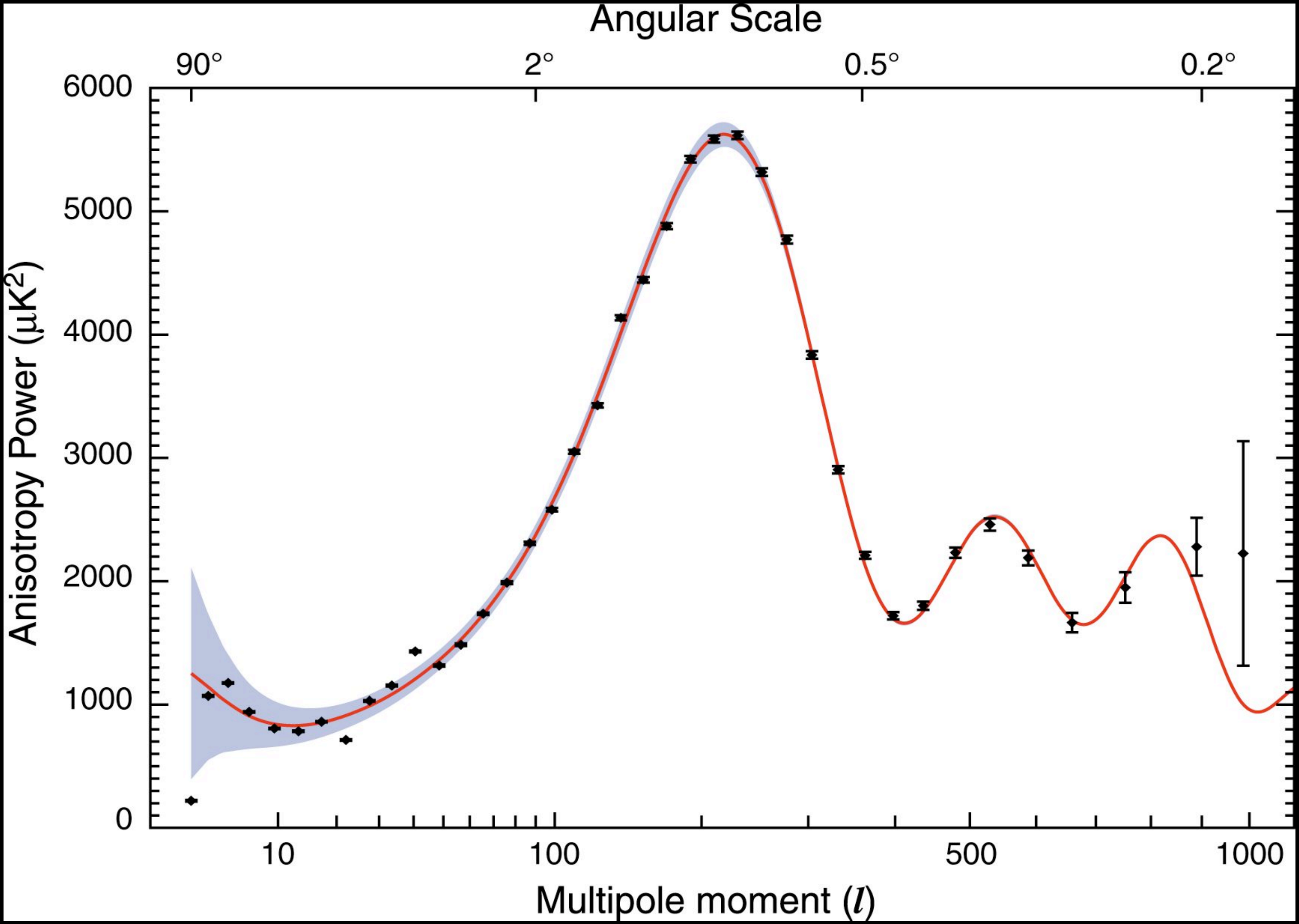
C_l is the variance of structures on scale l,

$$l \sim 180 \left(\frac{\theta}{1\deg} \right)^{-1}$$

$\Delta T \sim 100\ \mu K$

From U. Keiichi

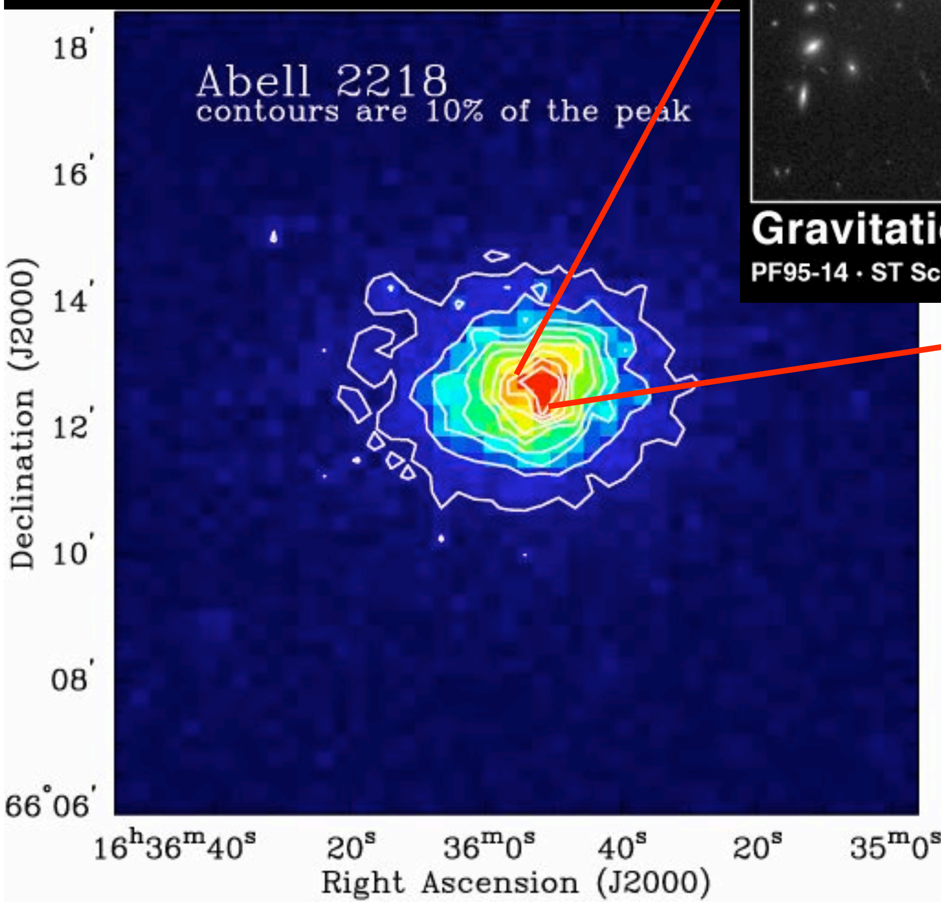
CMB Power Spectrum



Largest Structure in the Universe

Gravitational Lens in Abell 2218 HST • WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA



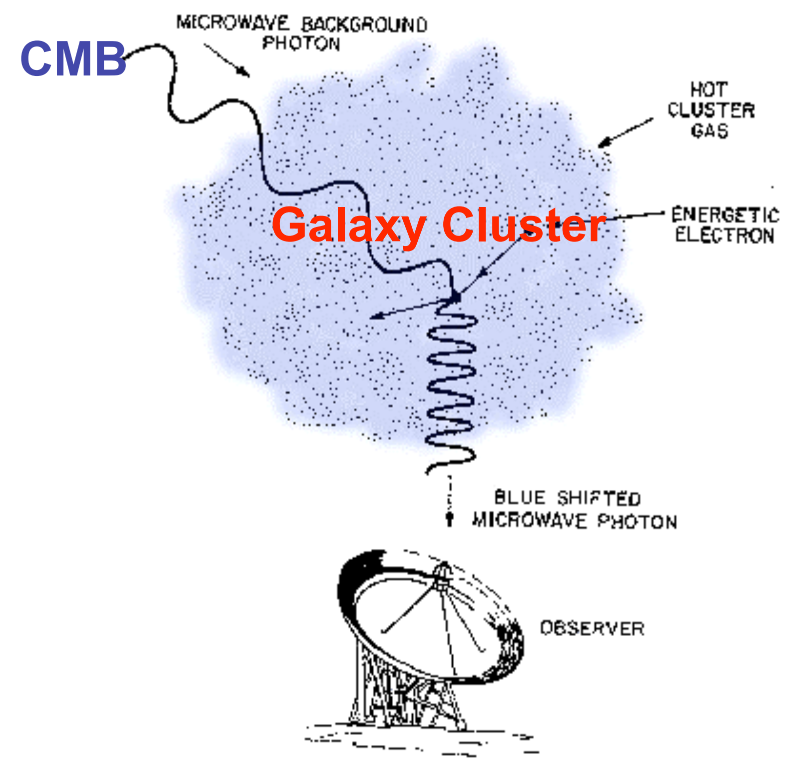
Galaxy Cluster (optical Image)

Sunyaev-Zeldovich Effect

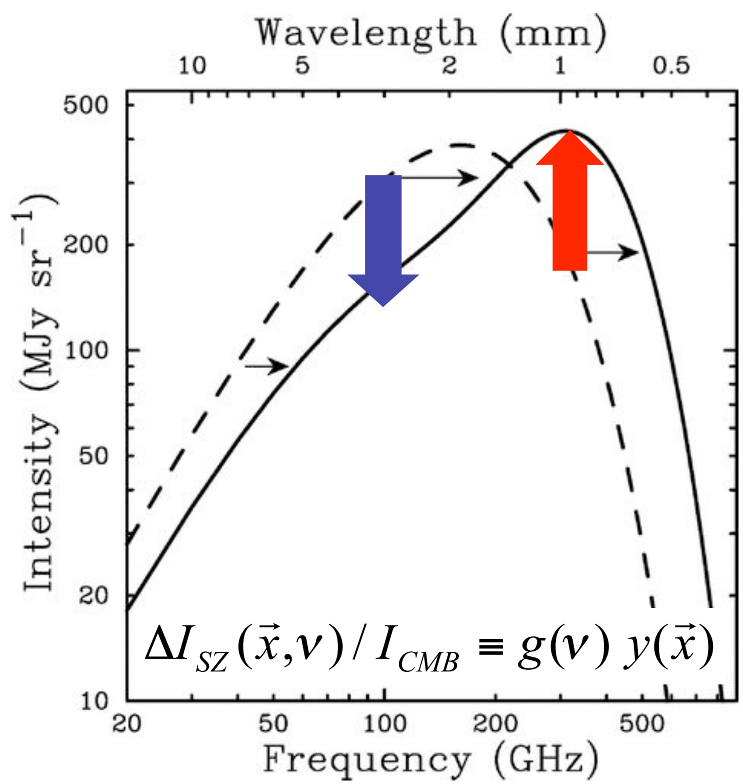
10^-2 10^-2

$$y \equiv \int_0^{\lambda_{\rm LSS}} d\tau \, \frac{k_{\rm B}(T_e - T_{\rm CMB})}{m_e c^2} \approx \int \frac{k_{\rm B} T_e}{m_e c^2} \sigma_{\rm T} n_e dl \propto \int dl \, P_e$$

Energy transfer from **hot cluster gas** to **cold CMB** via inverse Compton scattering



Spectral distortion of CMB spectrum

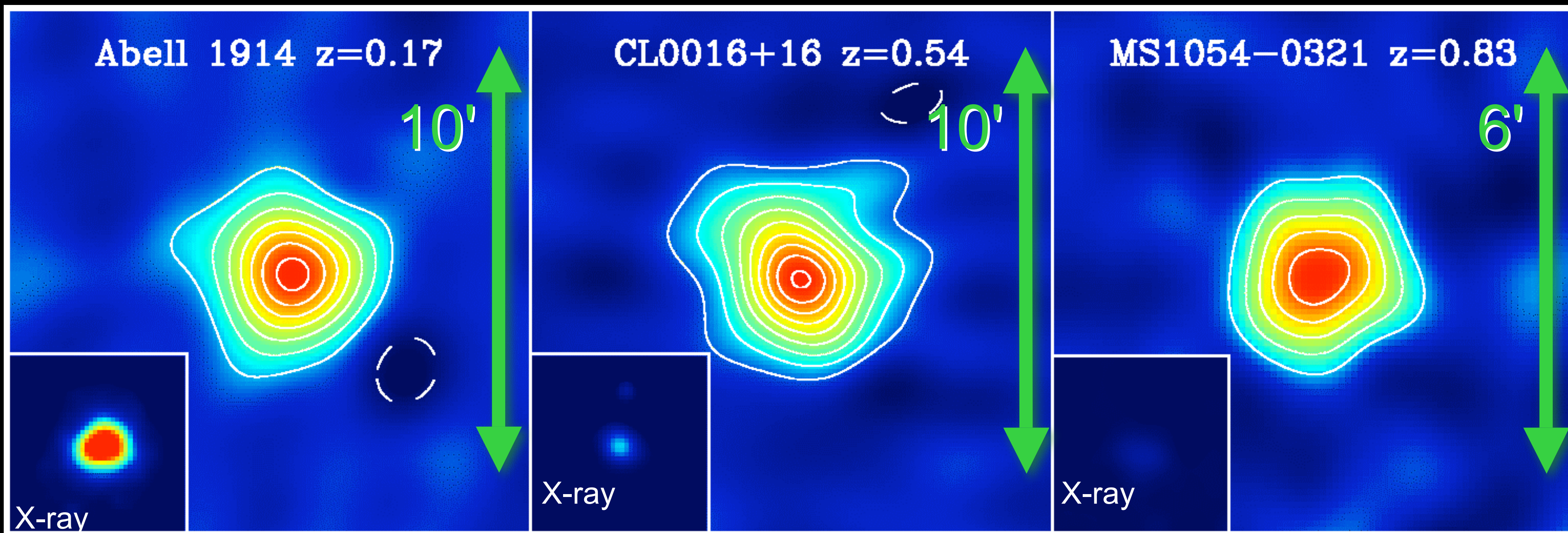


From U. Keiichi

SZE in Astrophysics

- Direct measurement of clusters -- potential for detail study
- Red-shift independent -- advantage over optical and x-ray obs
- Cluster structure and size
- Peculiar velocity at high z --cluster dynamic in CMB rest frame
- Hubble constant
- Cluster survey -- constrain cosmological models.

SZE & Redshift



(Carlstrom et al. 1999)

SZE brightness independent of distance (z),

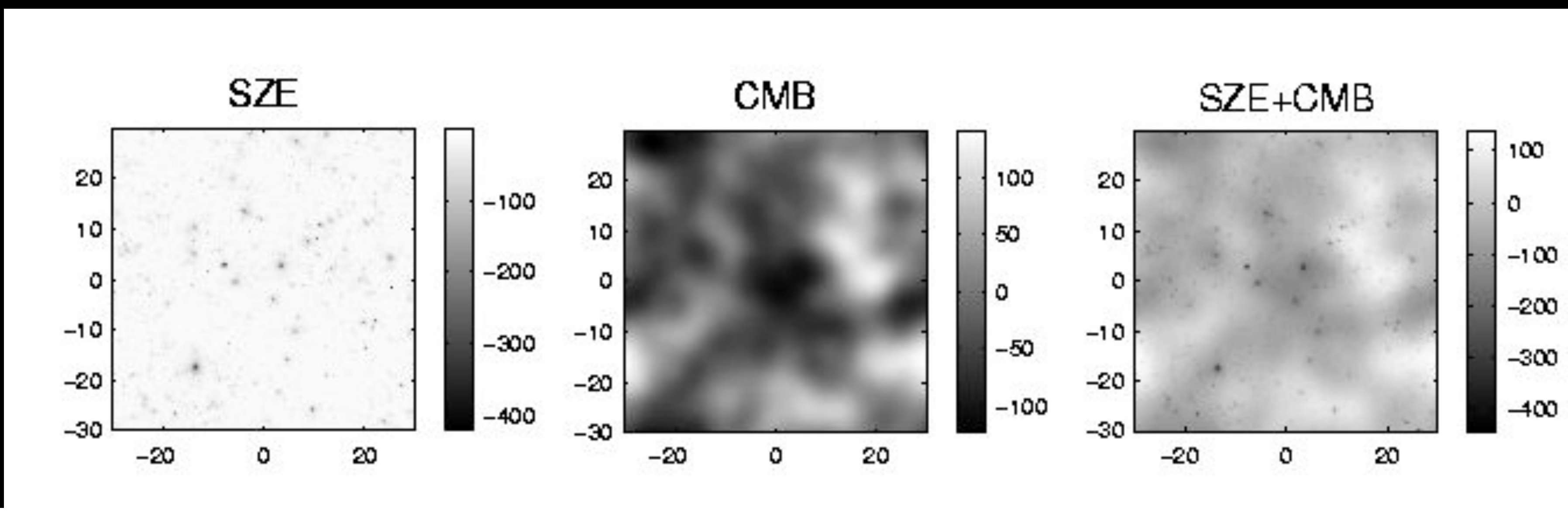
while X-ray/Optical/Lensing signal of clusters gets fainter

What we seek for is a 10-100 μK weak signal!!

From U. Keiichi

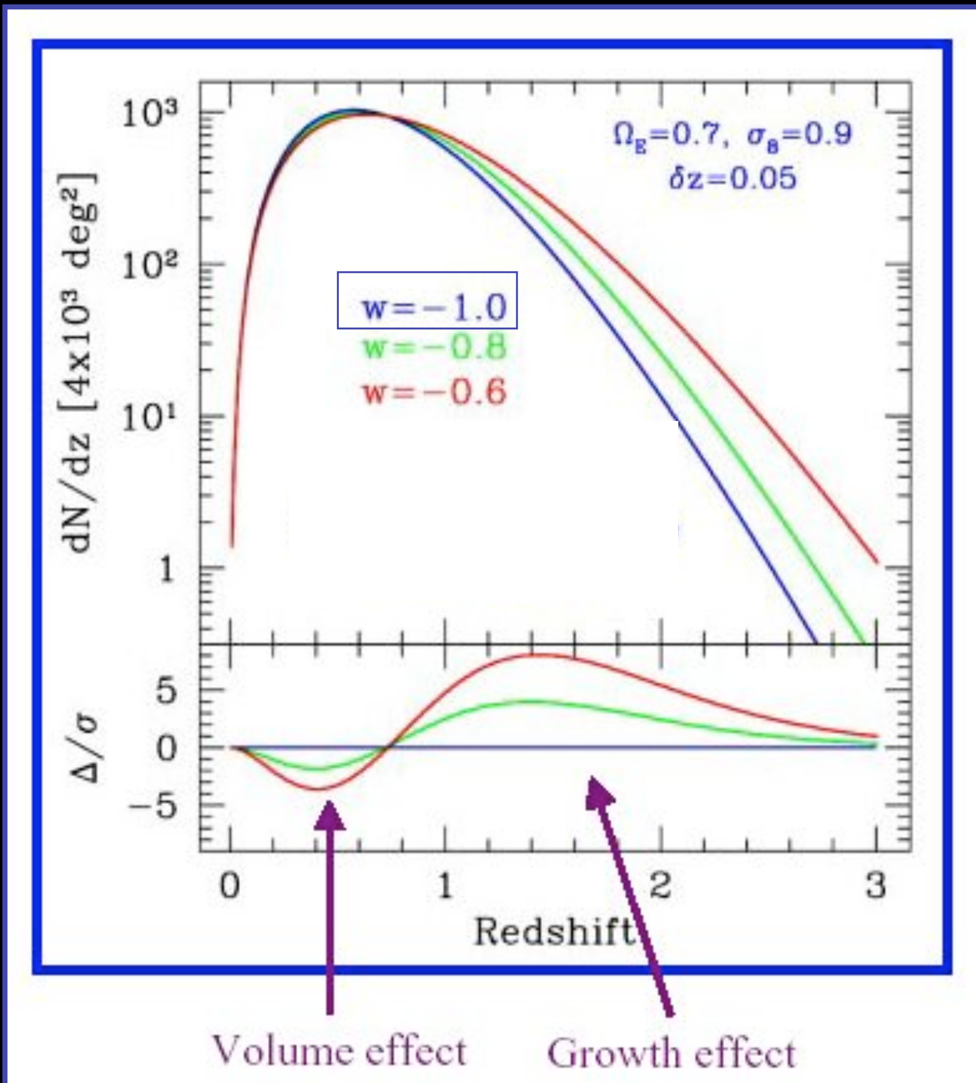
Experiment Challenge

- Very weak signal (< 100 uK)
- Large angular size (few arcmin and up)
- Foreground confusion
  - Milky way
  - Point source in radio (synchrotron)
  - Point source in mm/sub-mm (dust)
  - CMB itself
- Observation systematic



Cluster Survey via SZE

Evolution of Number Counts
of SZE Clusters



Cosmological test with structure formation (0<z<a few)

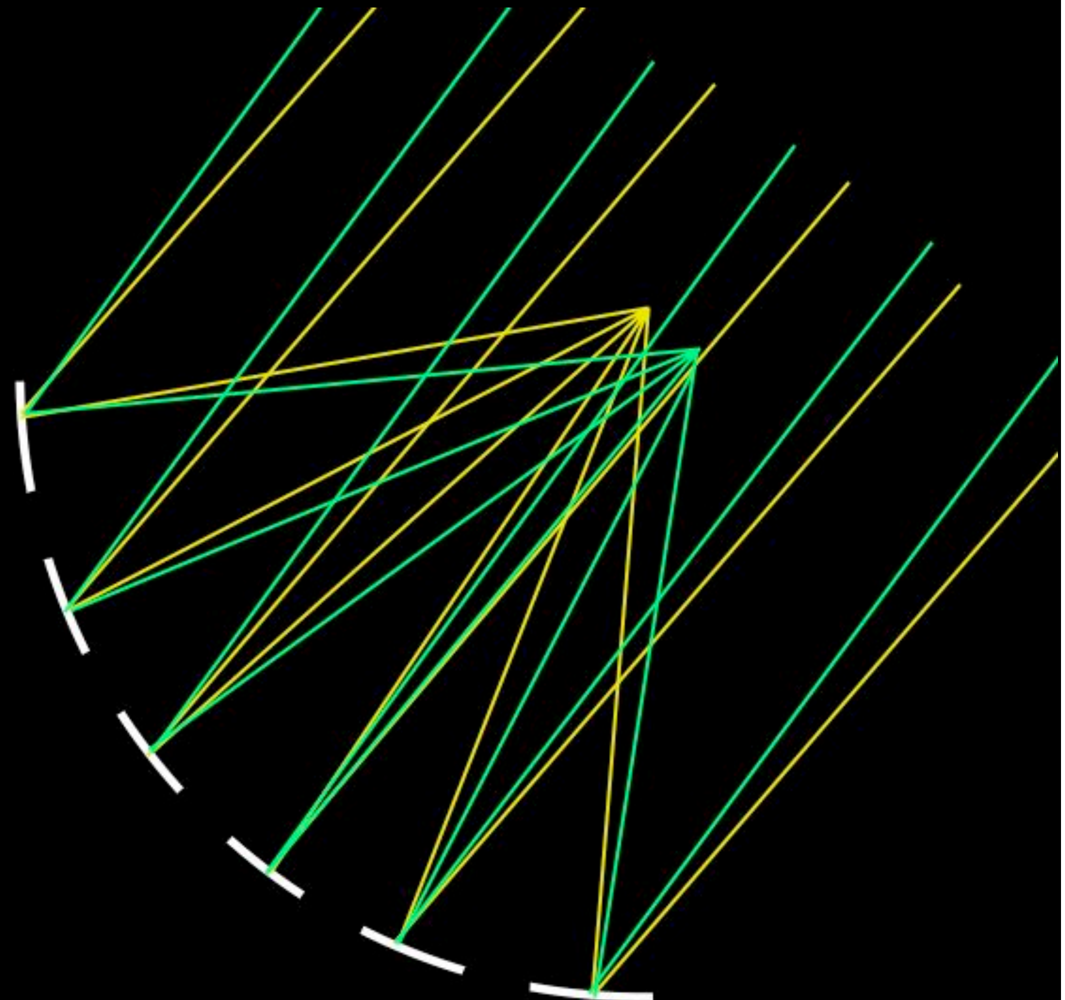
Complementary to CMB constraints on cosmology

Figure from literature (simulated SZE survey with 8m SPT)

Interferometry

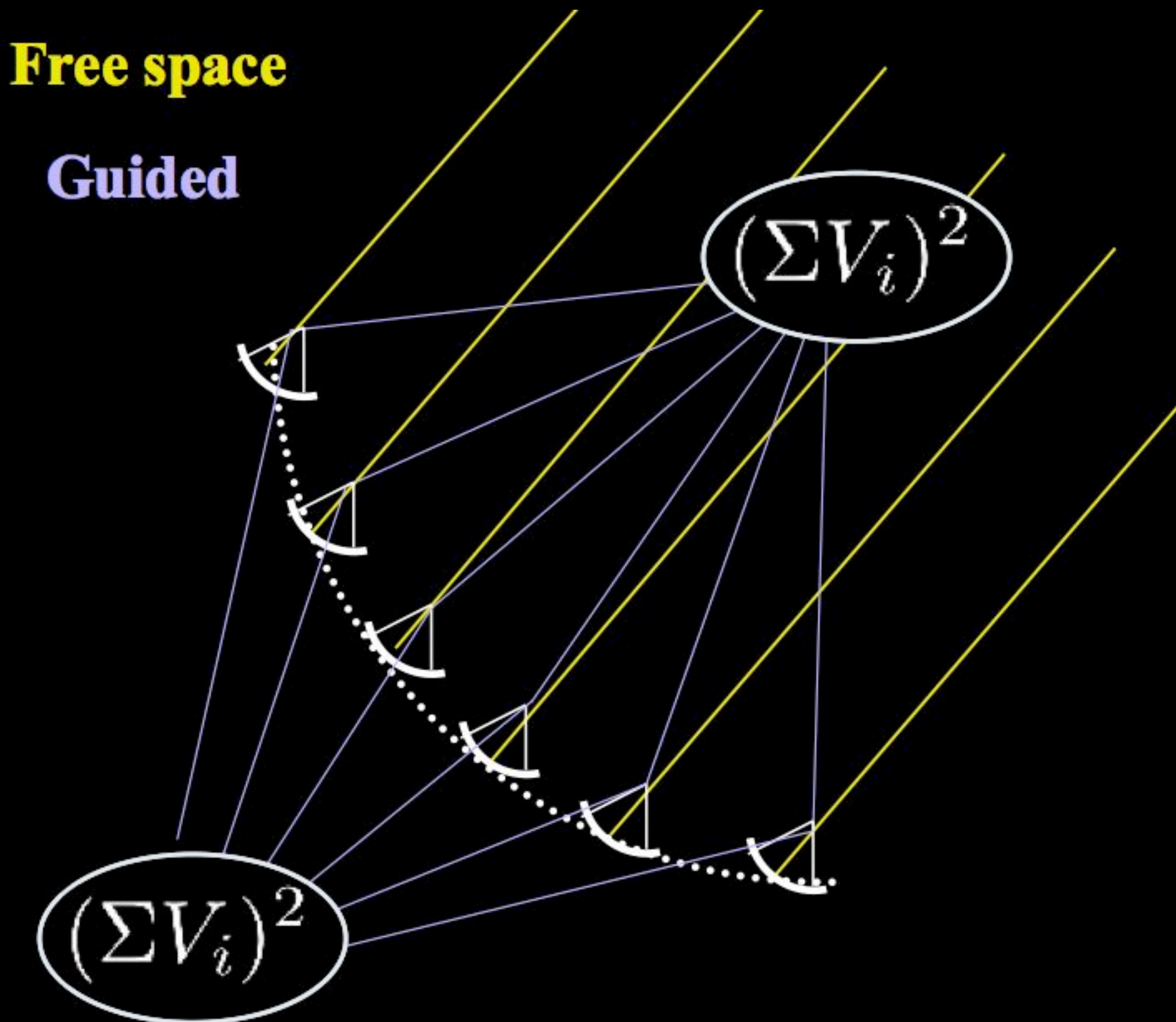
Following few pages are from
Philippe Edward of ATNF

Single Dish....



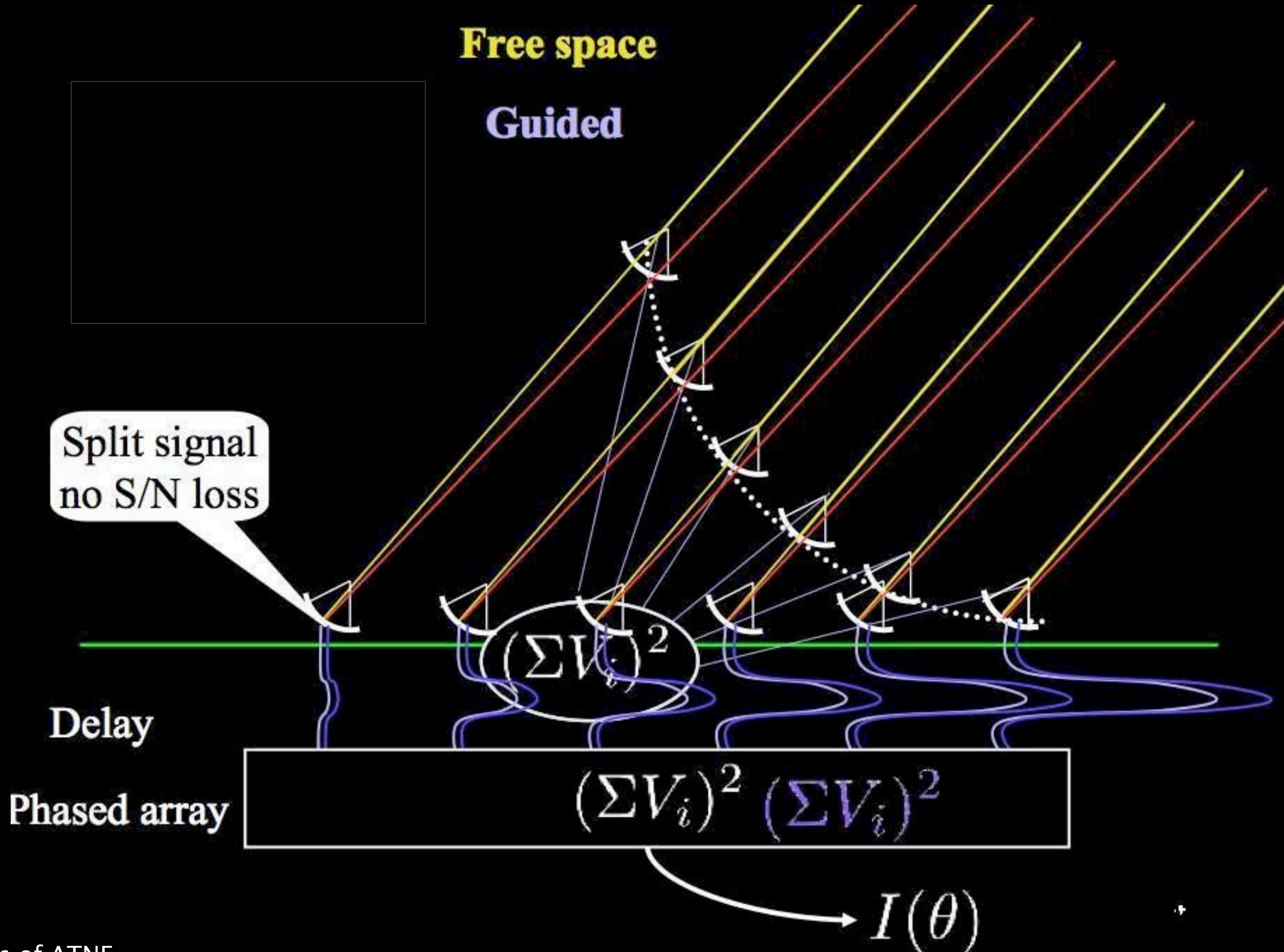
P Edwards of ATNF

Multiple Dishes....



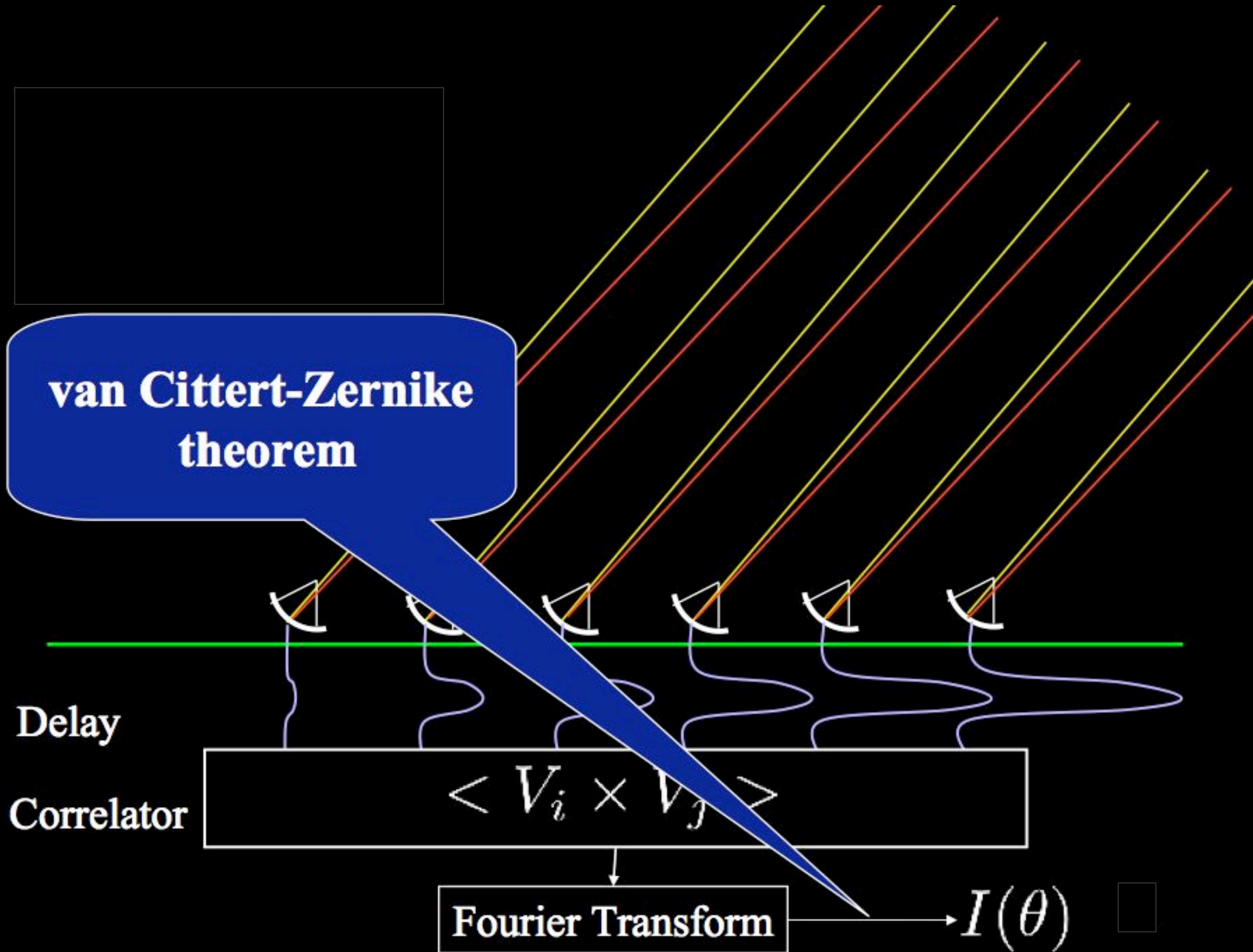
P Edwards of ATNF

Phase Array



P Edwards of ATNF

Aperture Synthesis



P Edward of ATNF

AMiBA

- AMiBA: started in year 2000, PI: Fred K. Y. Lo

- CosPA = Cosmology & Particle Astrophysics
  -- PI: Pauchy W.Y. Hwang, Co-PI: Fred K.Y. Lo
  -- Funded under Ministry of Education, Research Excellency Project

- Funding source:
  MOE: 2000 - 2004
  AS: 2003 - 2006, 2006 - 2009
  NSC: 2004 - 2008

OBJECTIVES

Science Objectives:

CMB structure @ l=800-10,000: **or Δθ= 20'-2'**

(1) CMB Power Spectrum and Structure at high-l [small scales]

Primary / Secondary (SZE) anisotropy (l=800-3000, l=1000-6000)

→ Initial condition of DM density fluctuations (σ_8)

(2) Galaxy-Cluster Survey via the Sunyaev-Zel'dovich Effect (SZE)

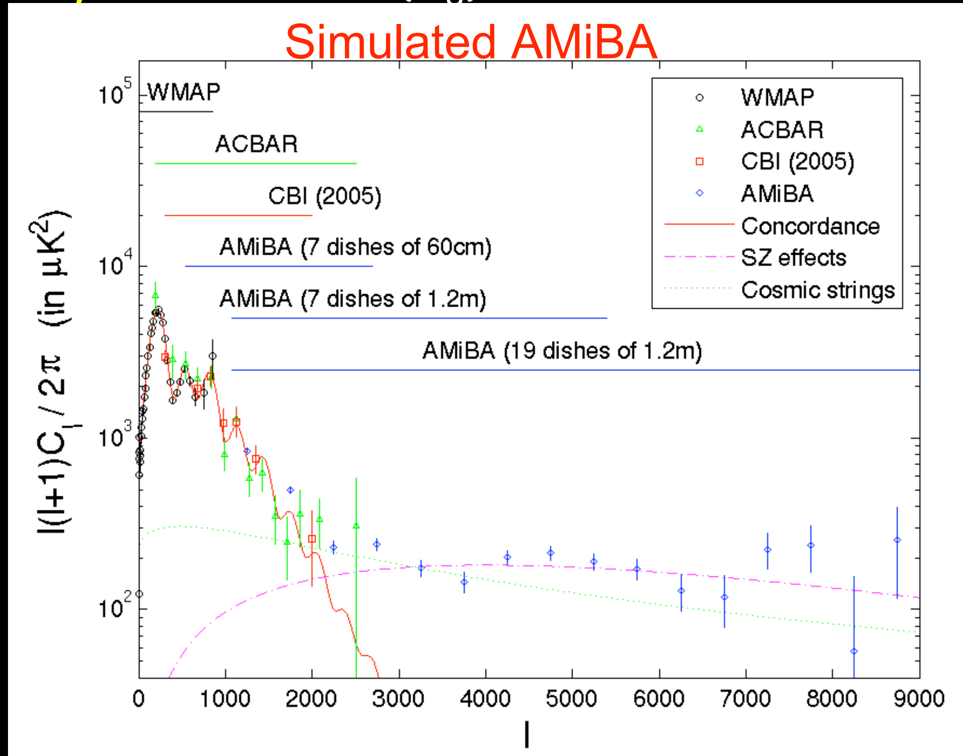
- Evolution of number counts of galaxy clusters, N(z)

  → Dark Energy Equation-of-State

- Clustering properties of clusters

  → information of large-scale structure formation

- Probing high-z universe (z>1)



Current Team Members

PI: Dr. Paul Ho

Project Scientist: Dr. Proty J.-H. Wu (NTU)

Science Lead: Keiichi Umetsu

System Engineer: Chao-te Li

Testing Leader: Kai-Yang Lin

System Scientist: Patrick Koch

Software Leader: Hiroaki Nishioka

Data Pipeline: GC Liu

Site Engineer: Pablo Altimirano

EE Tech: Peter Oshiro

Array Operator: Ken Chen

M Kesteven & W Wilson (ATNF)

M. Birkinshaw & Kati Lancaster (Bristol)

J. Peterson (CMU)

Project Administrator: Paul Shaw

Project Manager: Dr. Ming-Tang Chen

Structure Eng: Philippe Raffin

Control Eng: Homin Jiang

Microwave Eng: YJ (Eugene) Hwang

Rx Eng: CC (Johnson) Han

EE Eng: Pierre Matin-Cocher

EE Tech: SH (Joshua) Chang

EE Tech: CC (Mark) Chen

Nech Eng: Ted Huang

Mech Eng: YS (Johnny) Lin

Mech Eng: CH Chang

Microwave Eng: Su-wei Chang

Microwave Eng: Derek Kubo (part-time)

<u>NTU:</u> TH Chu, H Wang, P. JH Wu, TH Chieuh & CO.

7 -Element AMiBA Specifications

- 7 element, (expanding to 13)
- CFRP Platform(6m), with hexapod mount
- RF: 86 - 102 GHz, IF: 2 - 18 GHz
- Front-end cryogenic HEMT.
- Dual channel, linear polarizations (plan for circular)
- System temp: 80K
- Aperture sizes: 60 cm & 1.2 M
- 4-lag analog correlator, 2 frequency bands over 16 GHz
- Number of baselines: 21
- Synthesized beam: 2.7’
- 18 mJy in one hour
- Site: Mauna Loa

Site Development in Hawaii

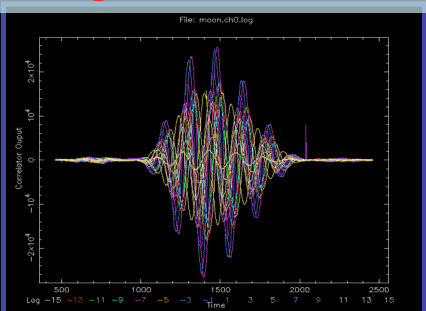
AMiBA

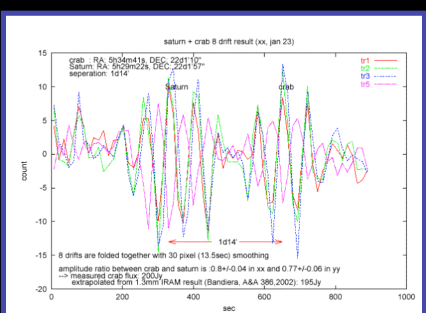
SMA

SMA & AMiBA
Base Facility

AMiBA 2-Element Prototype

Fringes from Moon





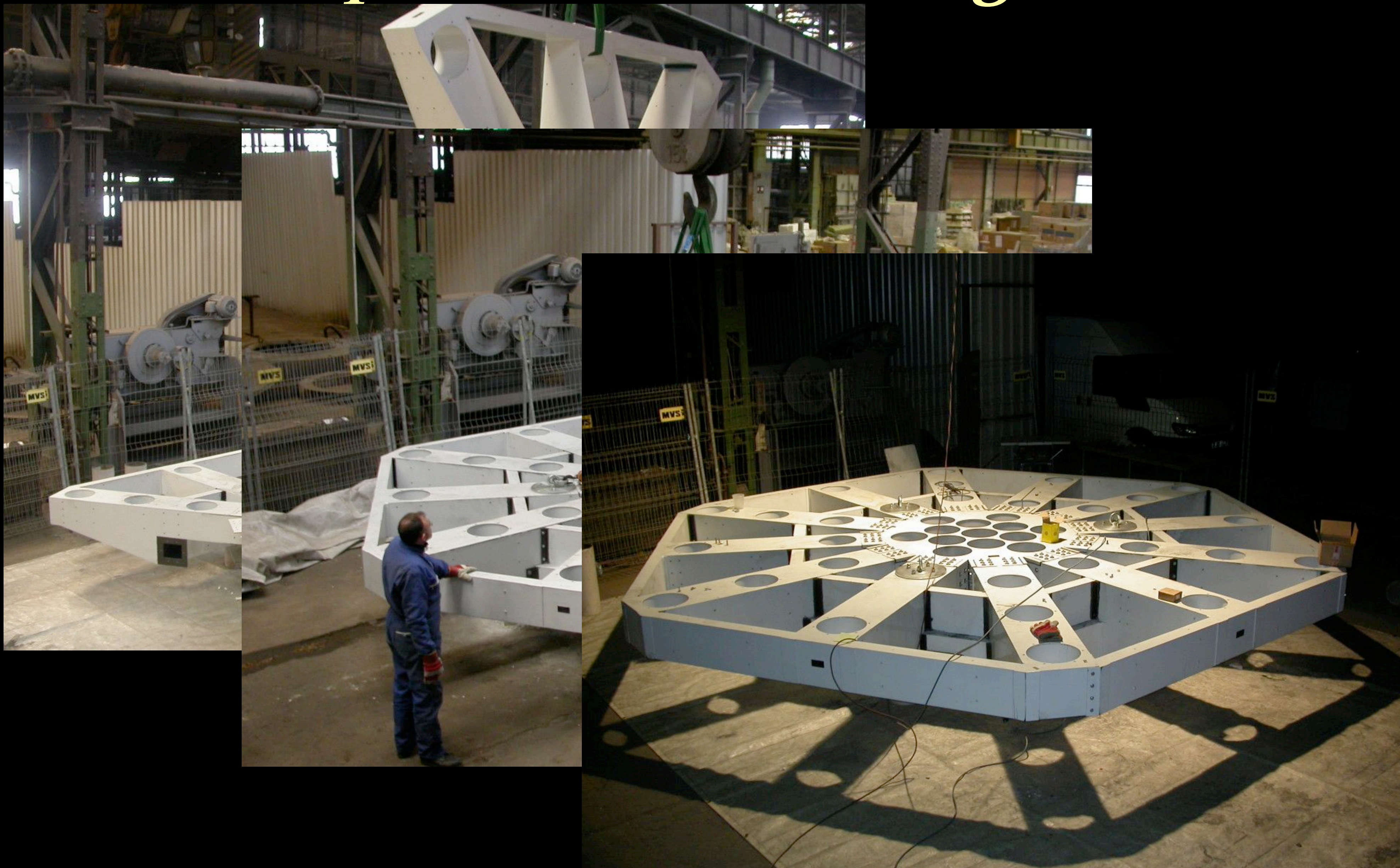
Fringes from Jupiter

Site Preparation

Hexapod Platform Integration

2005

Hexapod Platform Integration

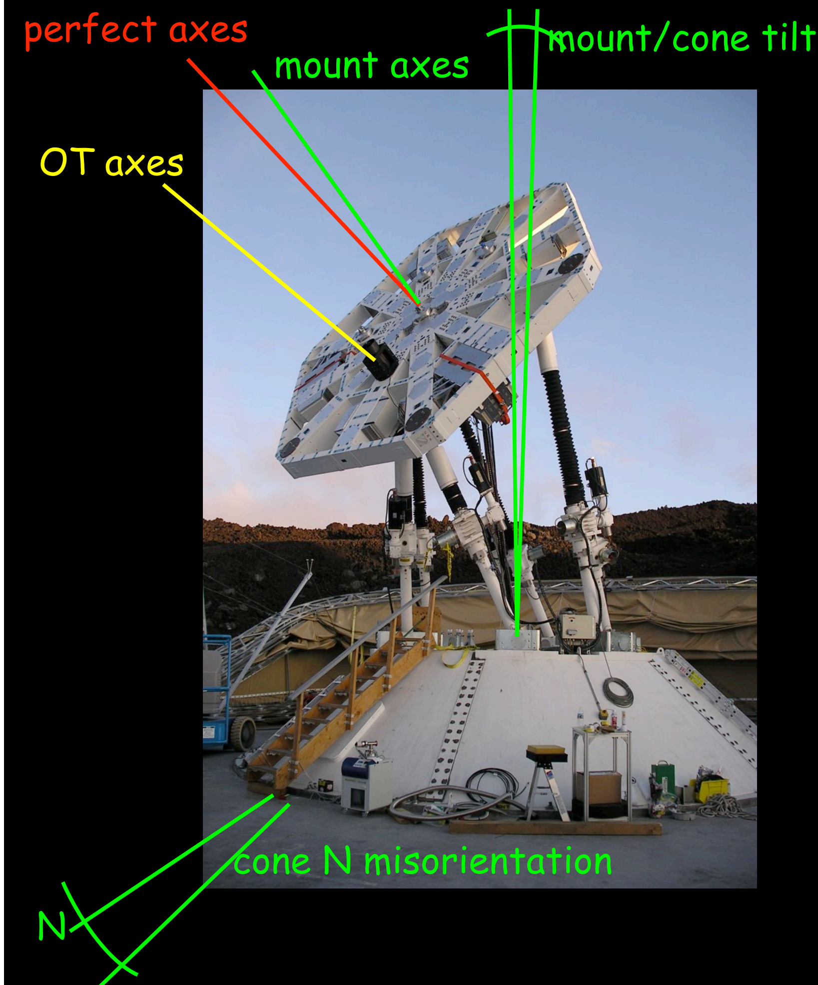


Installation on Mauna Loa

2005

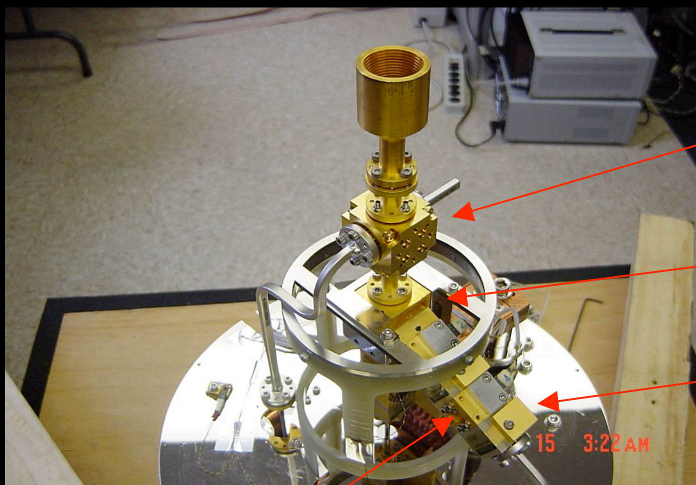
AMiBA Hexapod

Hexapod Mount Pointing



- Hexapod re-commissioning on MLO, took 16 months
- Pointing error roughly approaching 0.4 arcmin (spec: 12 arcsec)
- Day-to-day repeatability: 3 - 6 arcsec, as quoted by Vertex
- Long-term repeatability
- Pointing with various polarization
- System stability (control software)
- Pointing characteristic with load changing on platform
- Multiples optical telescope on platform
- Continue working with Vertex on pointing accuracy

Receiver

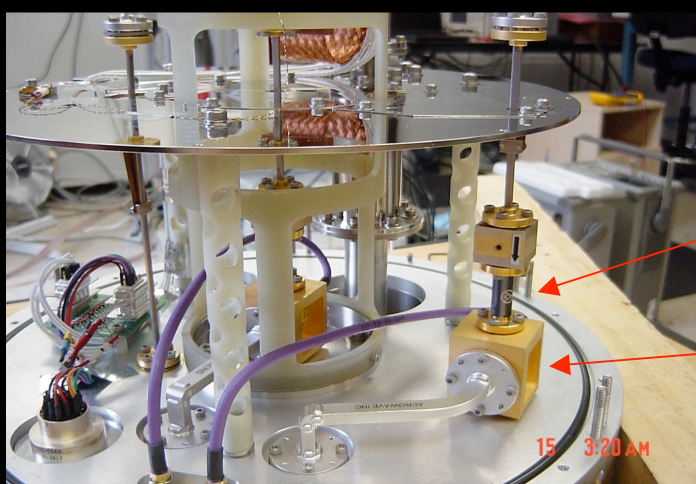


Noise Coupler

OMT

Isolator

LNA

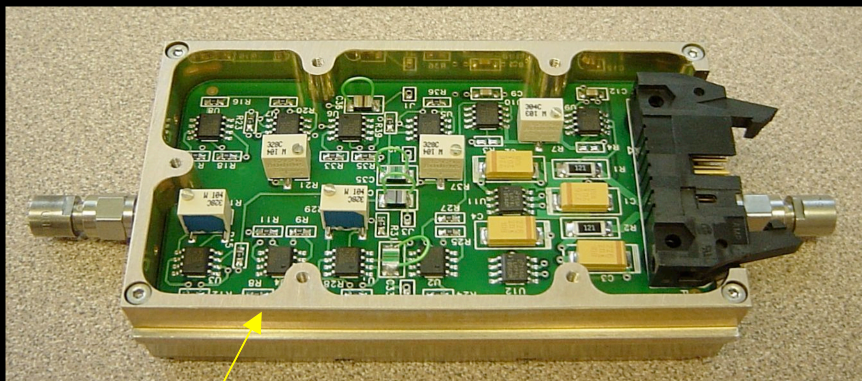


High-Pass Filter

Sub-harmonic Mixer

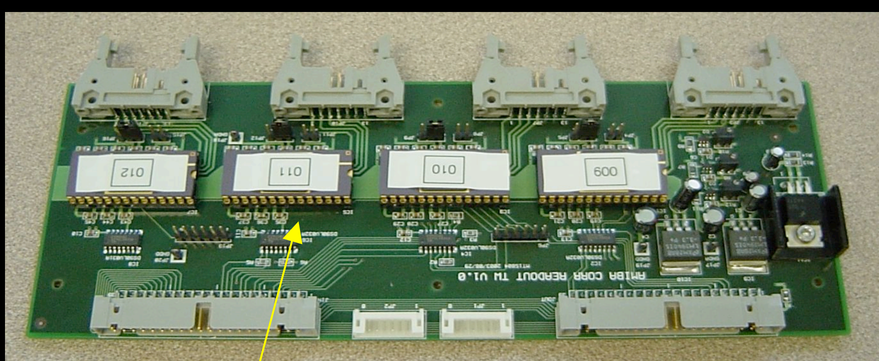
Correlator Components

BMA Connector

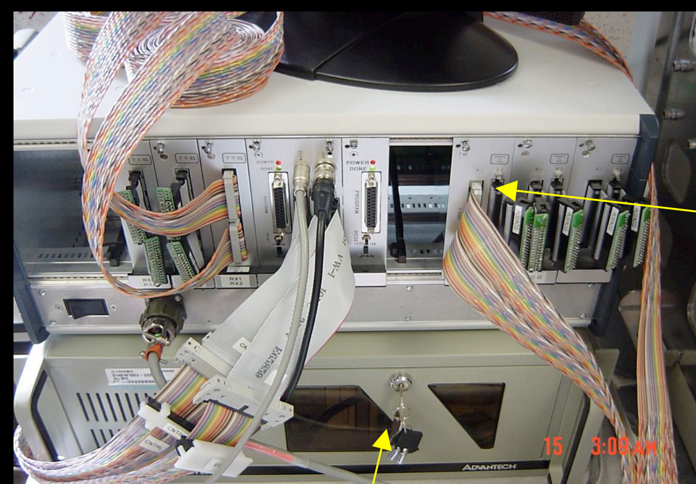


DC Amplifier

Correlator Module



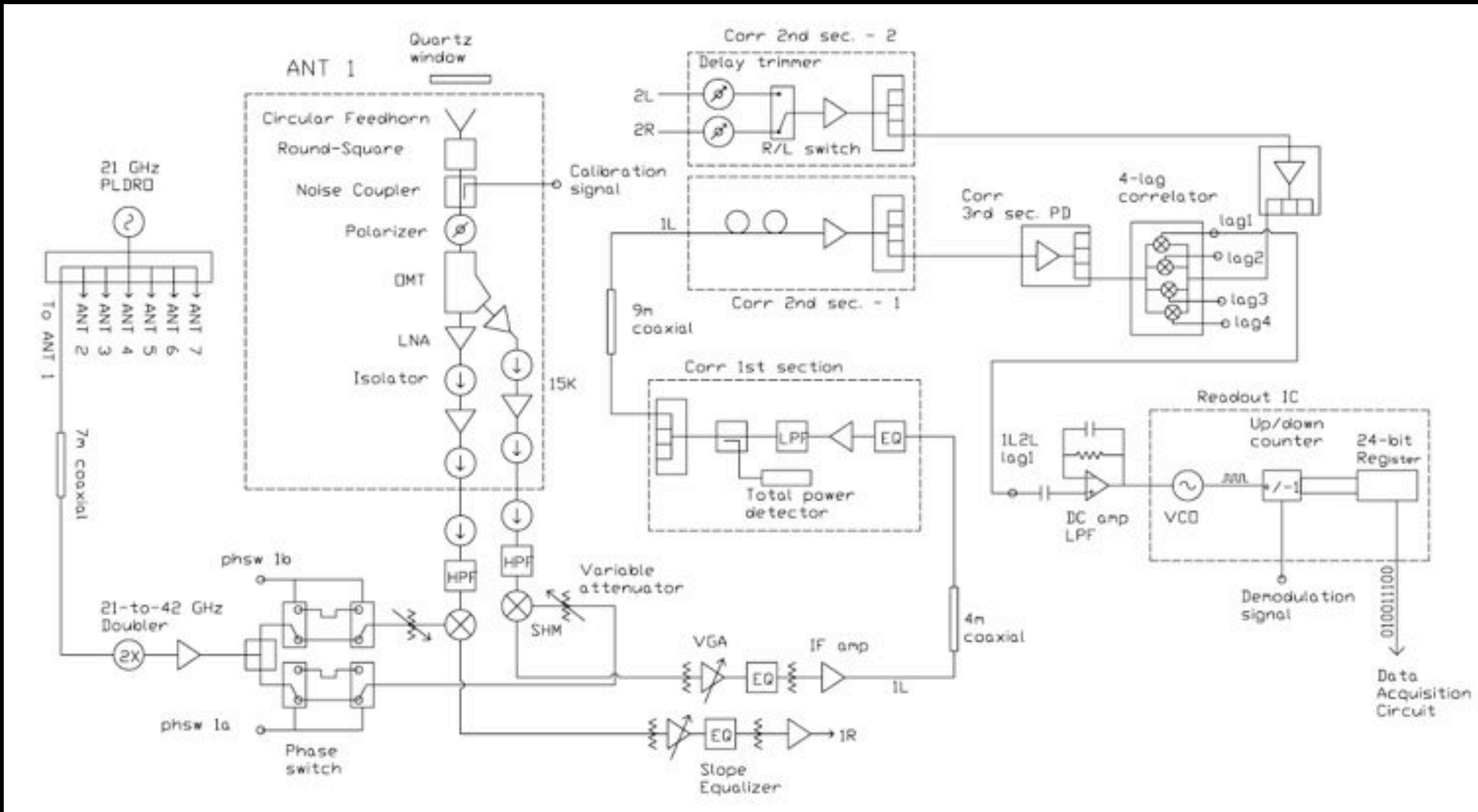
Readout (V-f) IC



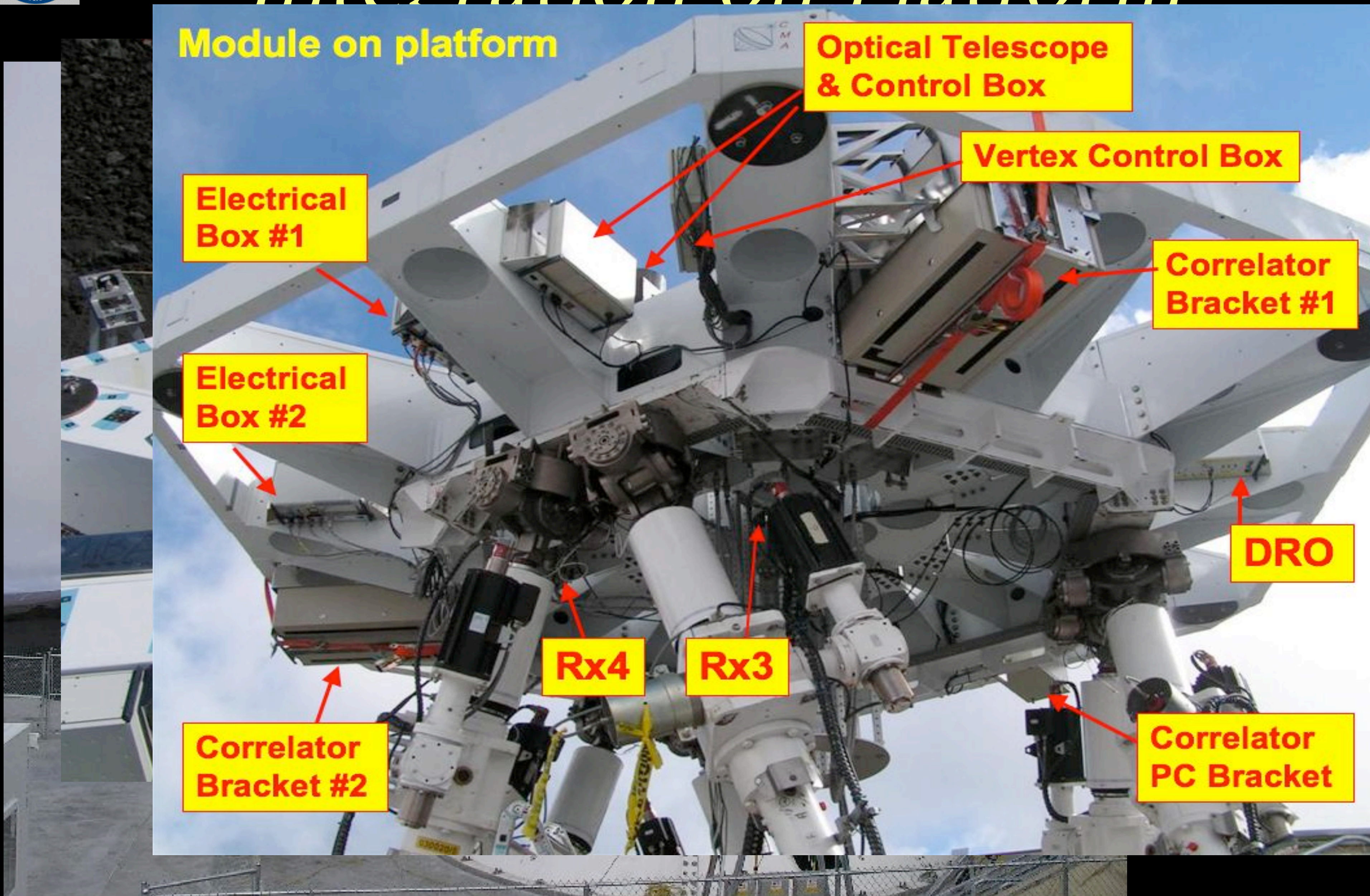
Data Acquisition Electronics

Correlator Control Computer (CCC)

System Block Diagram

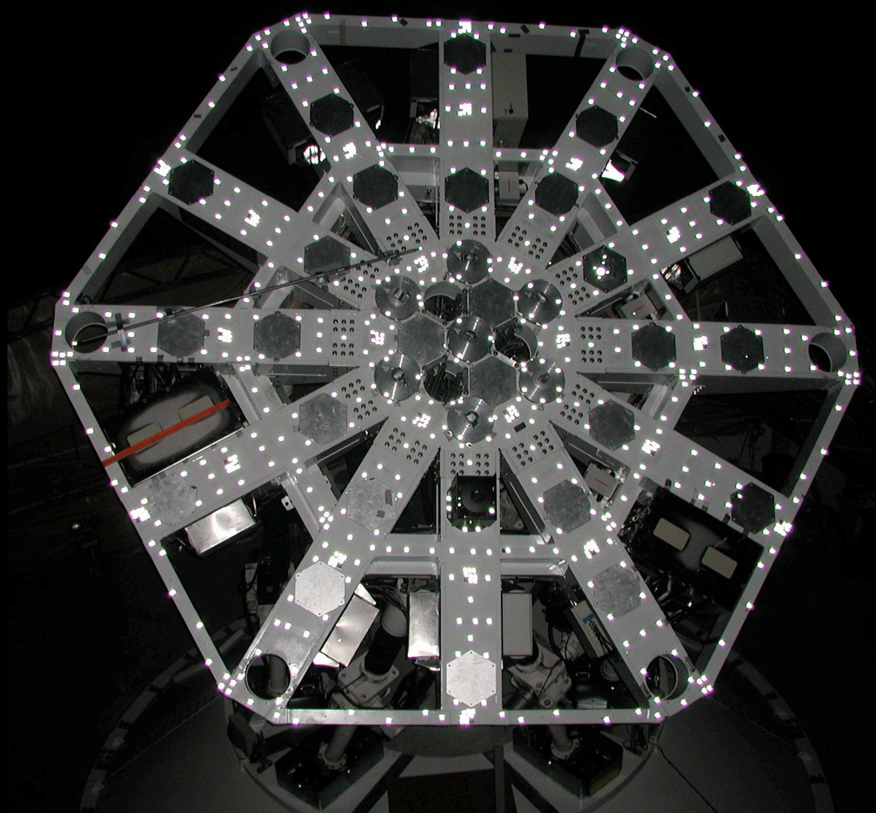


Integration on Platform



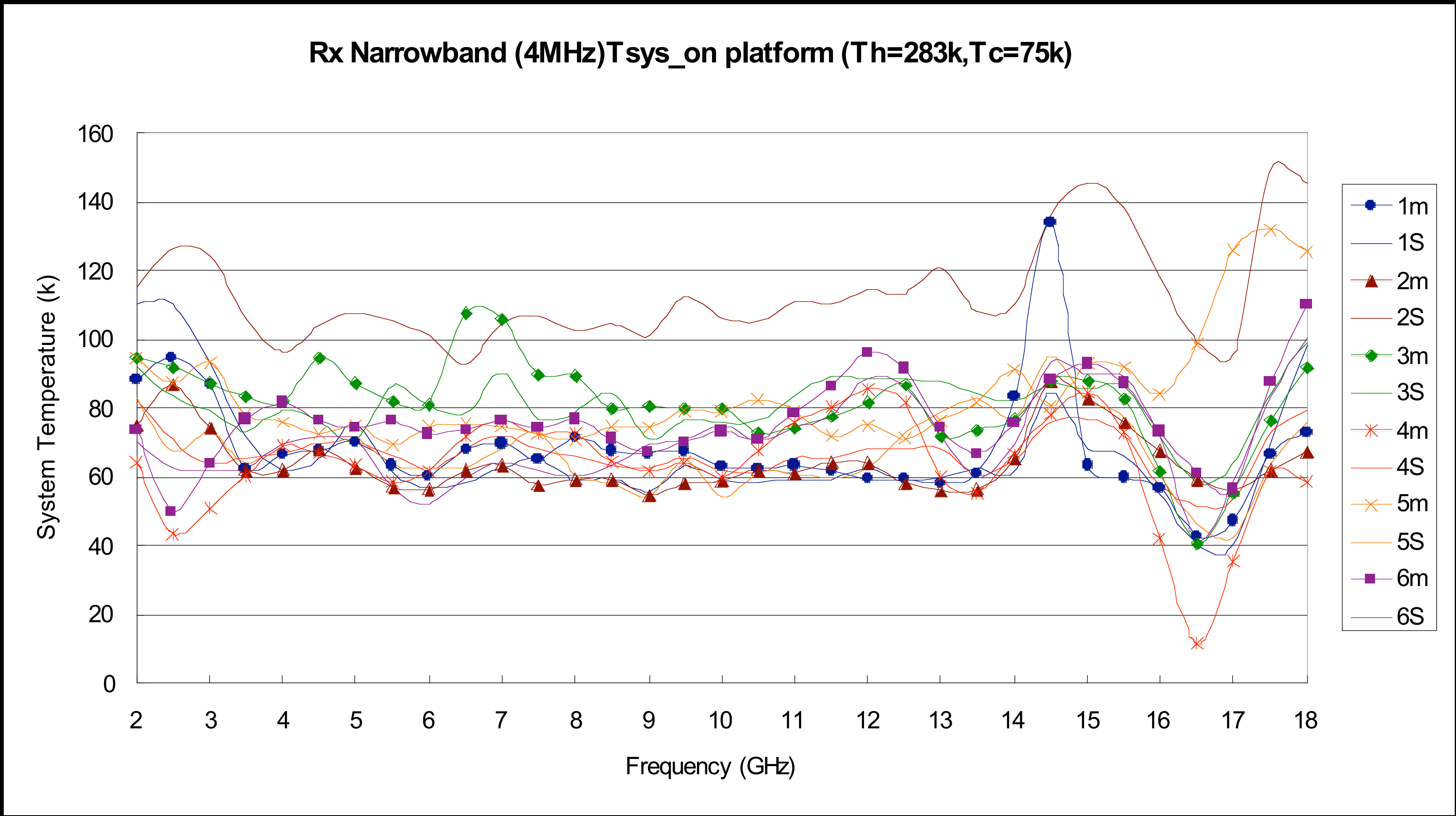
AMiBA

Platform Deformation

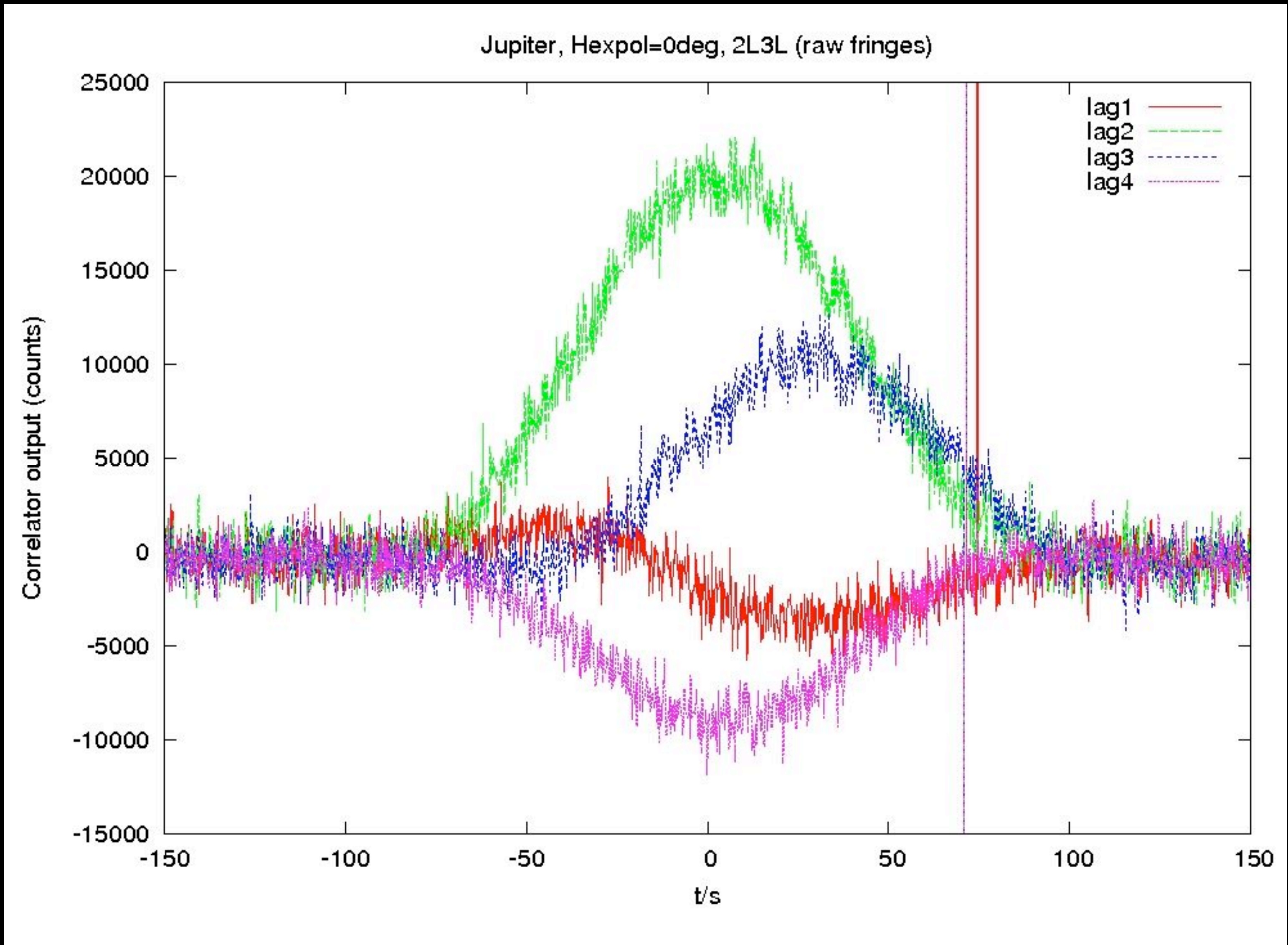


- Photogrammatry survey
  Compact configuration: pointing error is less than 2 arcsec.
  Outer positions have more serious error. Resolution is needed for longest baselines

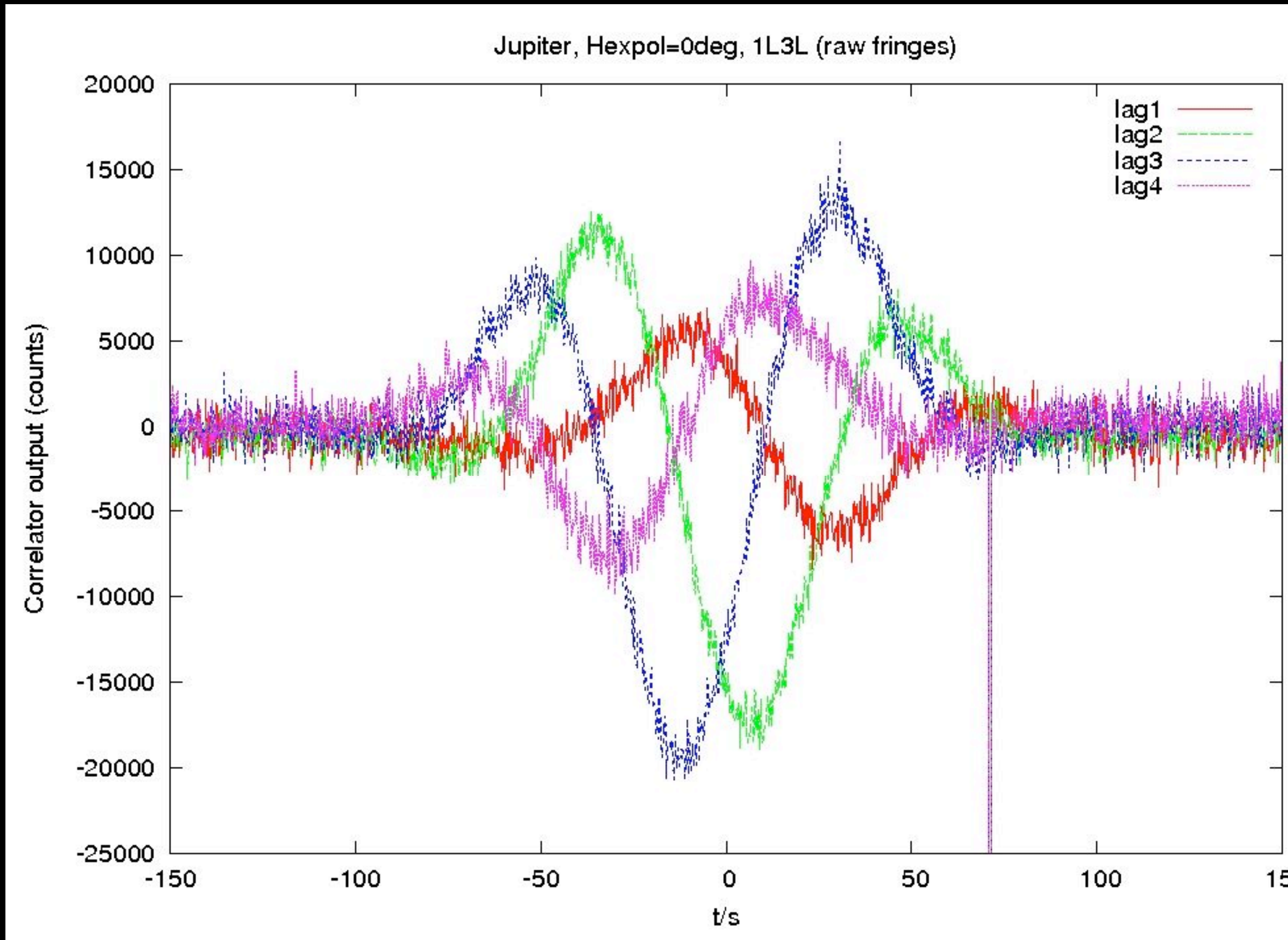
Receiver System Performance



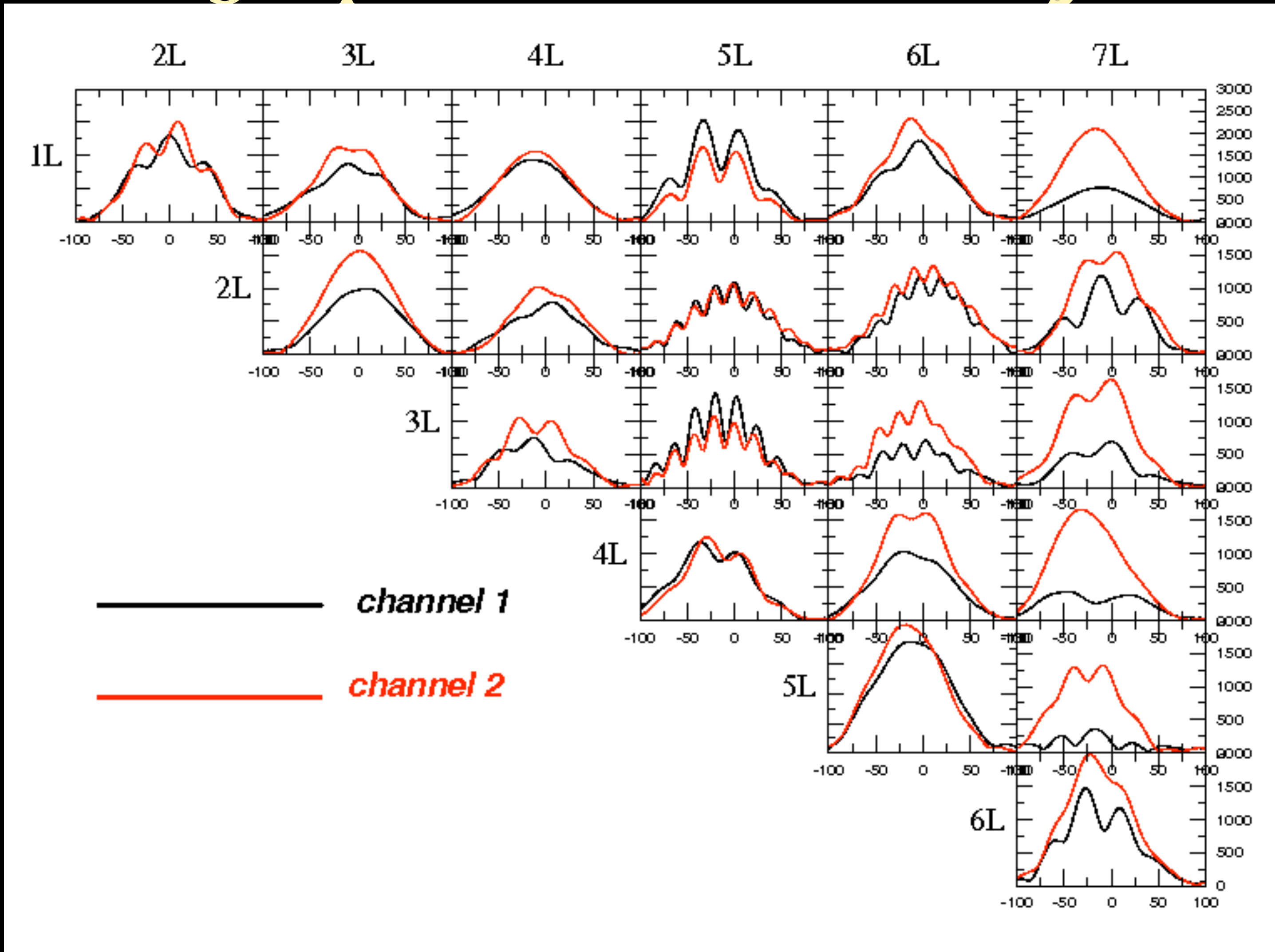
Jupiter Fringes



Jupiter Fringes



Jupiter Visibility



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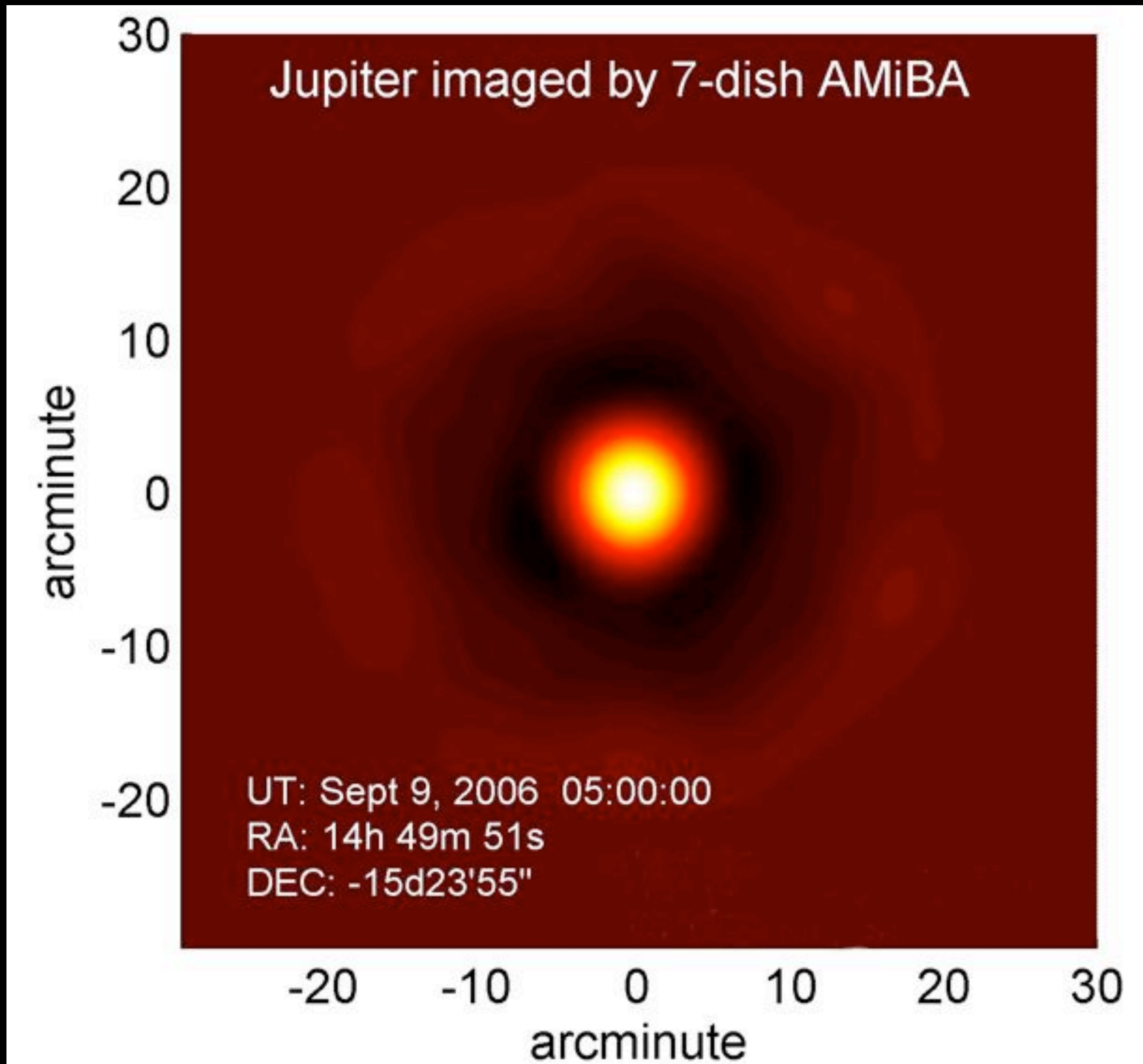


Jupiter imaged by 7-dish AMiBA
UT: Sept 9, 2006 05:00:00
RA: 14h 49m 51s
DEC: -15d23'55"
30
20
10
0
-10
-20
-20
-10
0
10
20
30
arcminute
arcminute

lication


宇宙背景輻射陣列望遠鏡啓用典禮
Array for Microwave Background Anisotropy Dedication Ceremony

Synthesized Uranus Image

- No signal seen in fringe domain for < 40Jy sources
- Signal only seen after image synthesis → faint

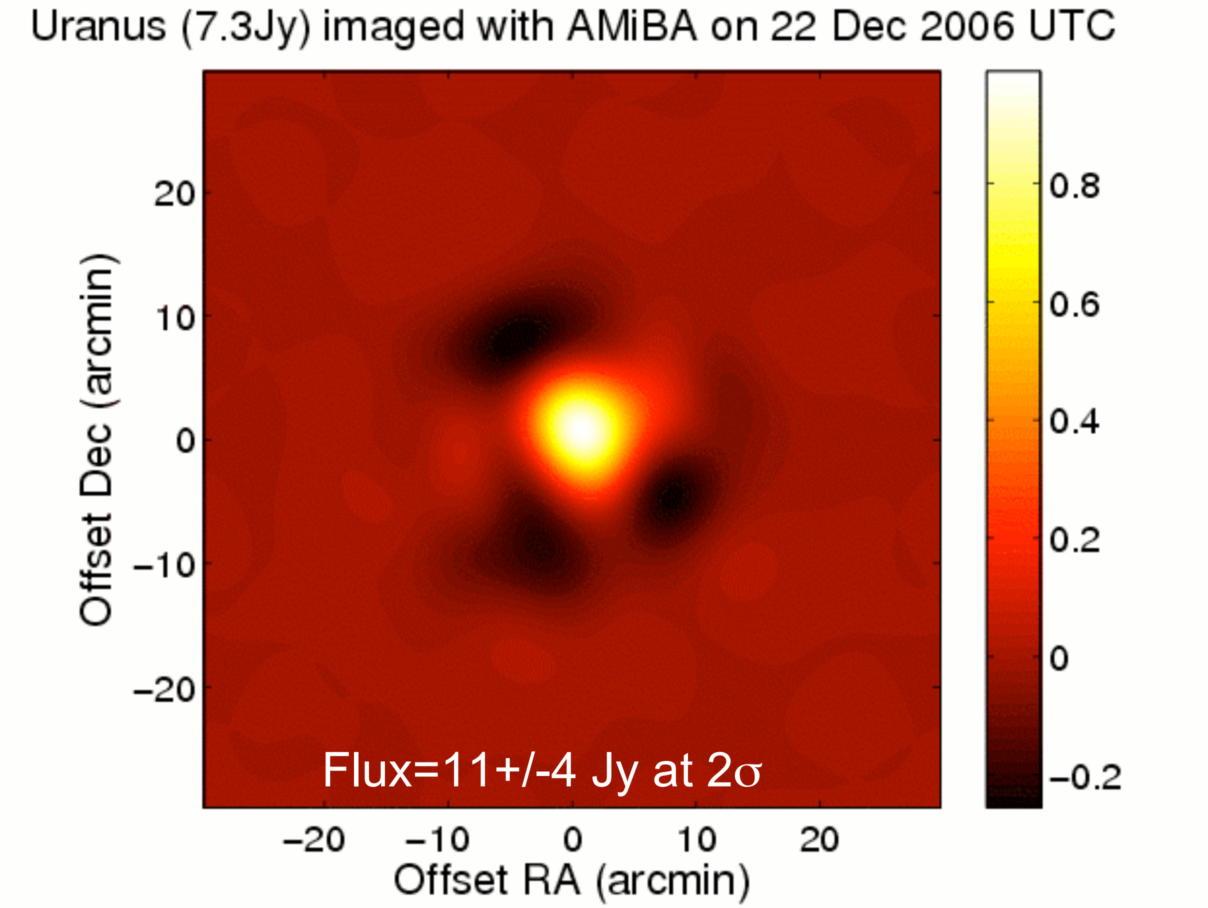


Image reconstruction from 16 drift-scans, with a net integration of 16s

Only 23 (/ 42) baselines available, having a poor UV-coverage, accordingly distorted image

TASKS AHEAD

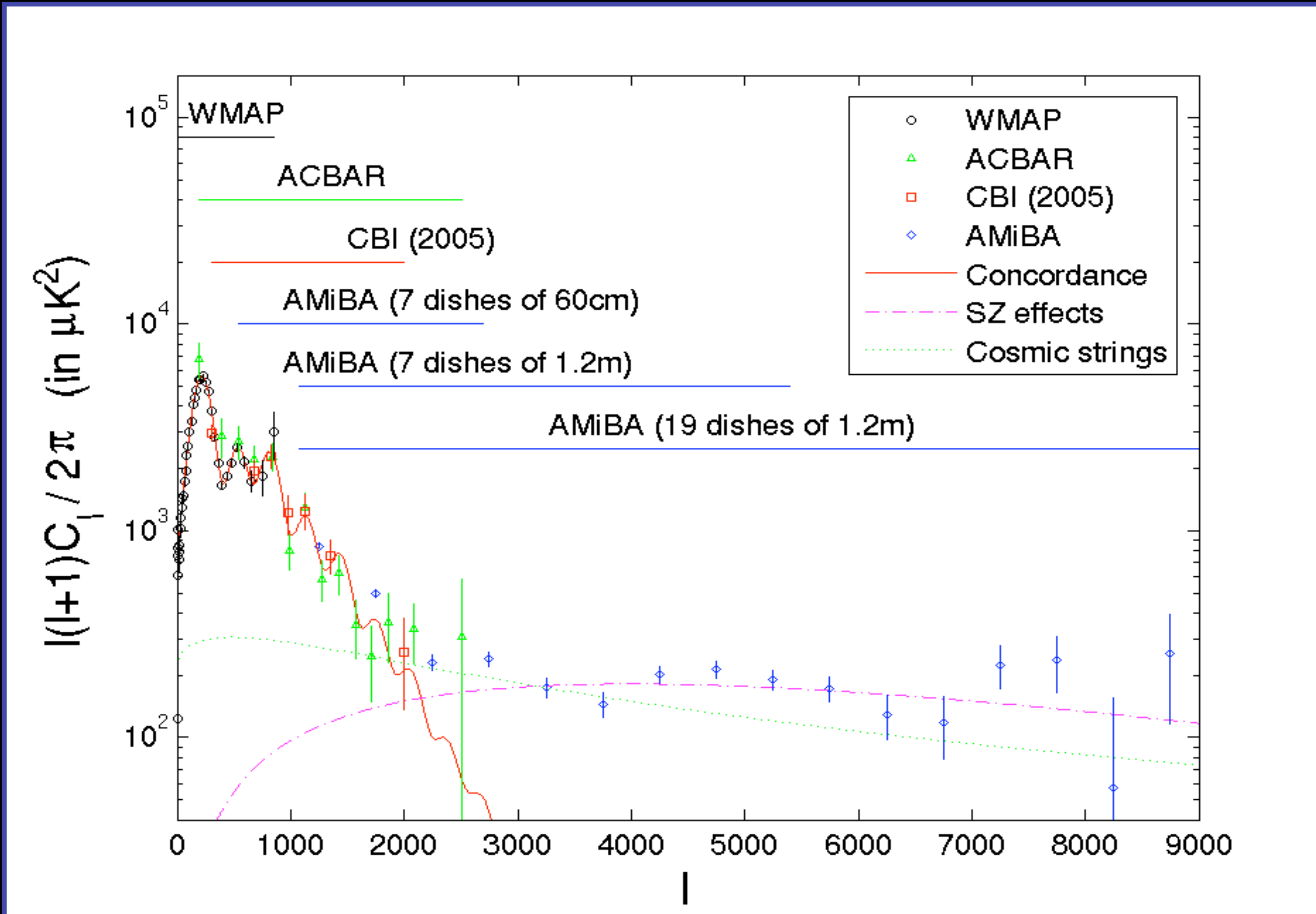
- System fine-tuning
- First CMB image with AMiBA
- 1.2 meter dish production
- AMiBA 13-element expansion
- A truly SZ telescope

By year 2008!

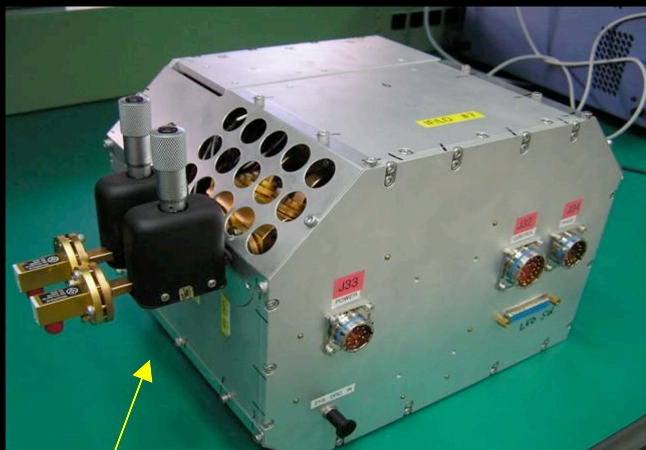
The End

The End

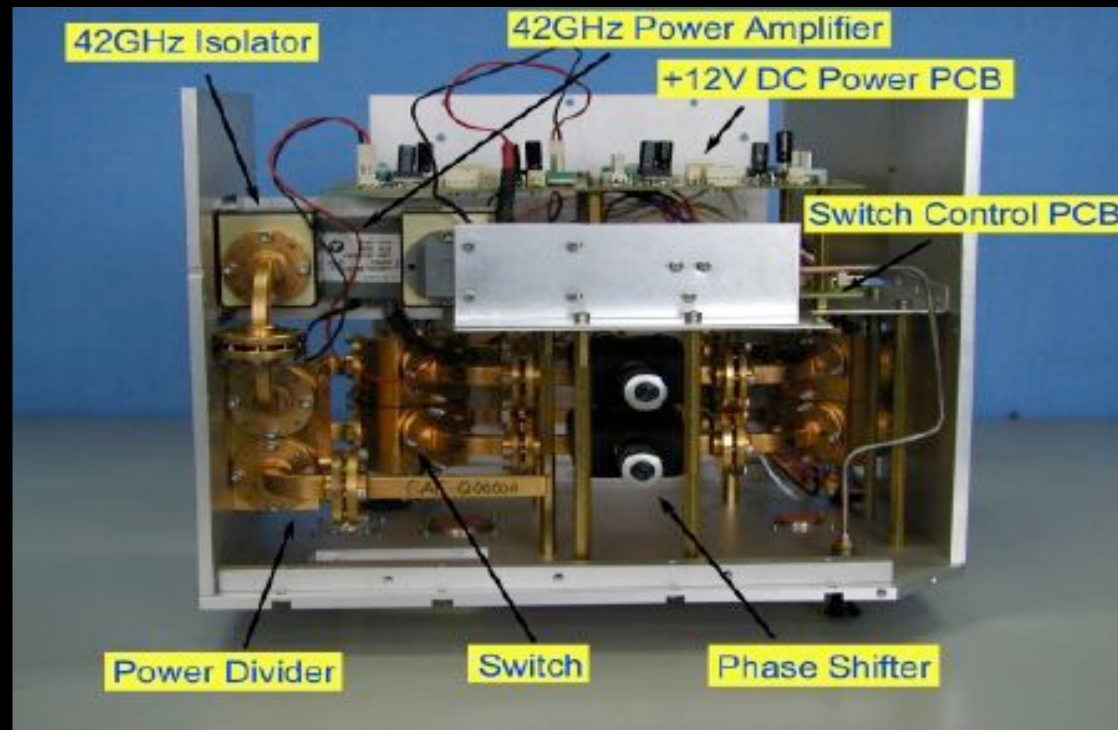
CMB + Diffuse SZ Power Spectrum

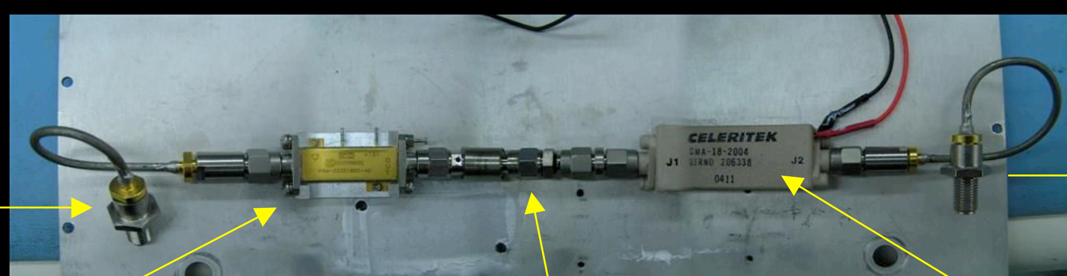


LO Doubler & Phase Switch



42 GHz Variable Attenuator





from SHM

to Correlator

Variable Gain Amplifier

Slope Equalizer

IF Amplifier

Hexapod Model