The Allen Telescope Array

Splitting the Aperture

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ATA Project Manager
SETI Institute

LBNL Colloquium
October 19, 2005

The Allen Telescope Array

SETI Institute

- Rob Ackermann
- Larry D’Addario
- Mike Davis
- Dave DeBoer
- John Dreher
- Gerry Harp
- Girmay-Keleta
- Jill Tarter

RAL

- Leo Blitz
- Douglas Bock
- Geoff Bower
- Calvin Chang
- Matt Dexter
- Greg Engargiola
- Ed Fields
- Matt Fleming
- Colby Kraybill
- Dave McMahon
- Doug Thornton
- Lynn Urry
- Jack Welch
- Mel Wright

Other

- Ed Ackermann
- John Andersen
- Charlie Cox
- Niklas Wadefalk
- Sandy Weinreb

Outline of Talk

- An Age-Old Question
- Radio Astronomy
- Splitting the Aperture
- The ATA Project
- Selected Instrumentation

An Age-Old Question

An Age-Old Question

- Epicurus - “there are infinite worlds both like and unlike this world of ours” (ca 300 BC)
- Lucretius - “it is in the highest degree unlikely that this earth and sky is the only one to have been created” (ca 70 BC)
- The Pythagoreans pictured spectacular lunar creatures who did not defecate (!?)

However …

an age-old question

- Plato – "there is and ever will be one only-begotten and created heaven" (ca 400 BC)
- Aristotle rejected multiple worlds via a complex metaphysical argument (ca 350 BC)

And we know who won!

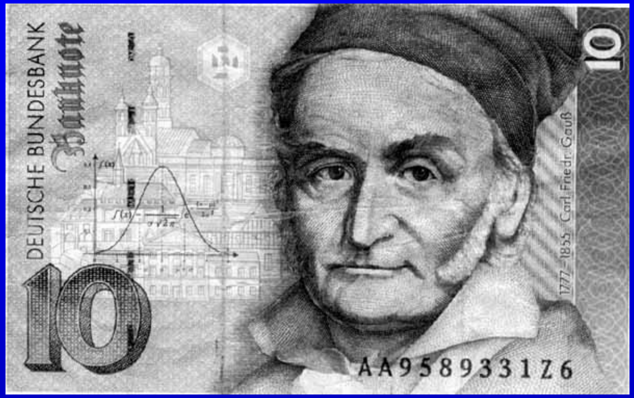
- The early church later opposed the concept of multiple worlds

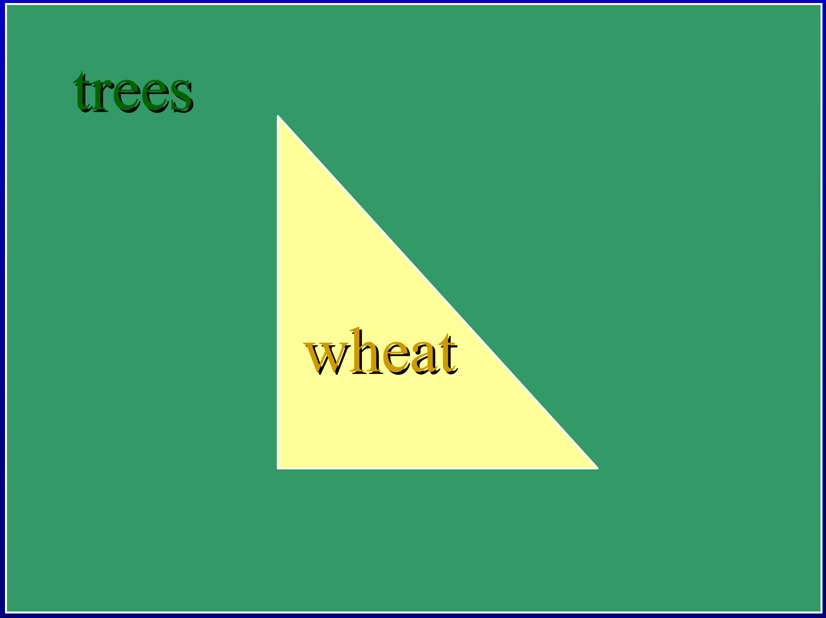
an age-old question

- Early thinkers had no physical framework with which to approach the problem, only philosophical and theological musings
- Middle-ages (ca 1300) resurgence of “multiple worlds” and the tools to start thinking about it somewhat critically.

Are we alone?

Early SETI
(***S***ignalling ***ETI***)





- Karl Friedrich Gauss (ca 1800)

Large right triangle in Siberia – “Hello, we are here”

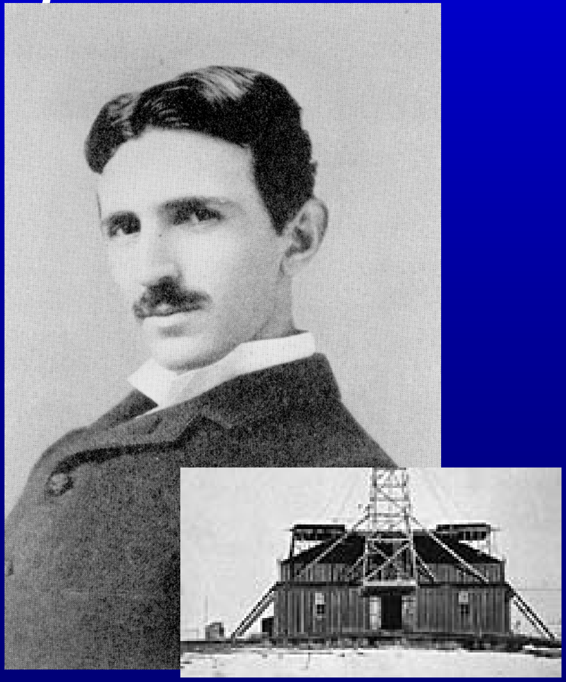
early S(ignalling)ETI

- Charles Gros advocated France building a gigantic mirror to signal Mars

- Joseph von Littrow advocated digging a large trench in the Sahara in some geometrical form, filling it with kerosene and igniting it

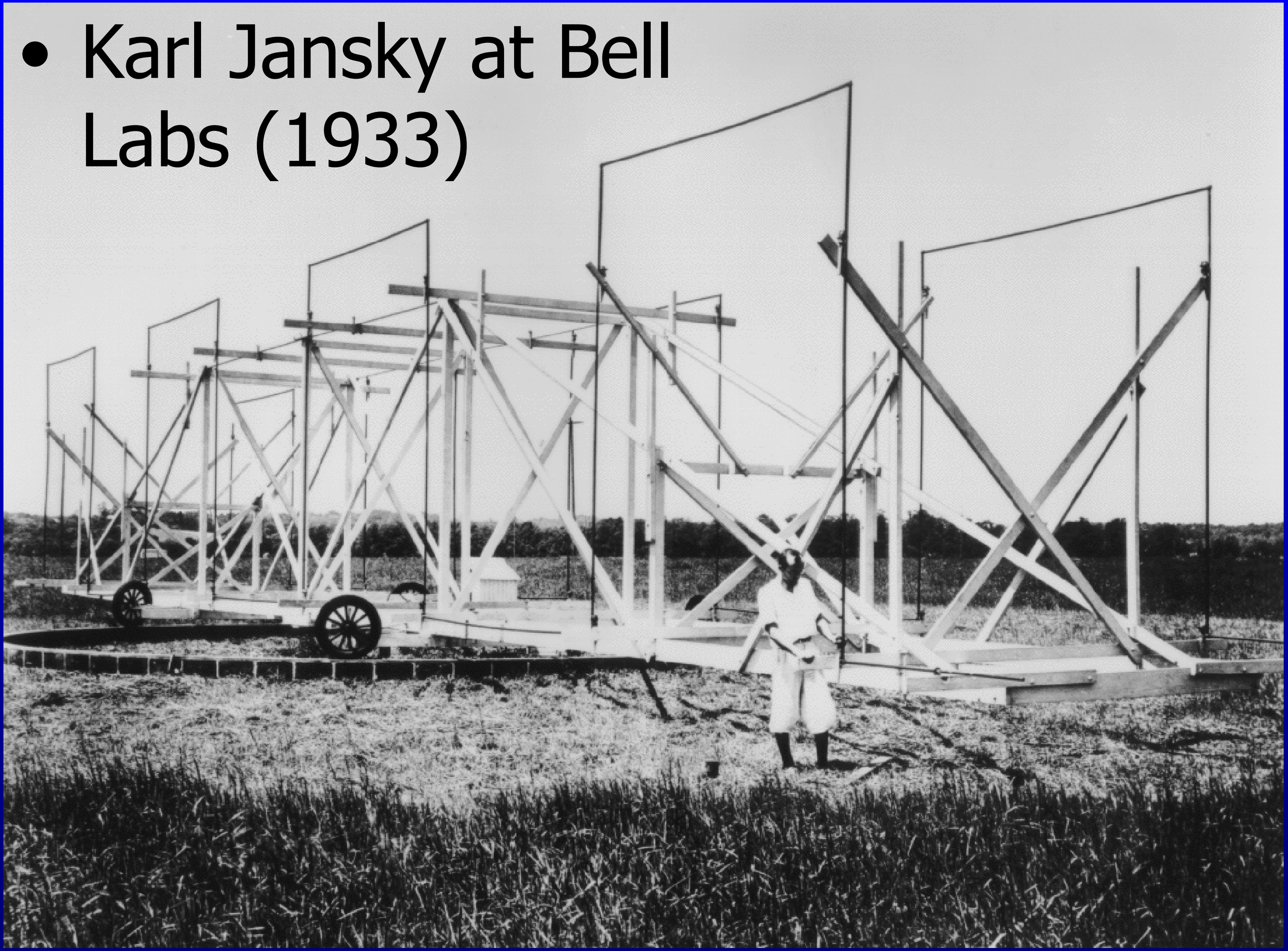
Early SETI
(***S***earch for ***ETI***)

- No less than Nicola Tesla and Gugliemo Marconi thought they had detected signals from another planet.



Early Radio Astronomy

- Karl Jansky at Bell Labs (1933)



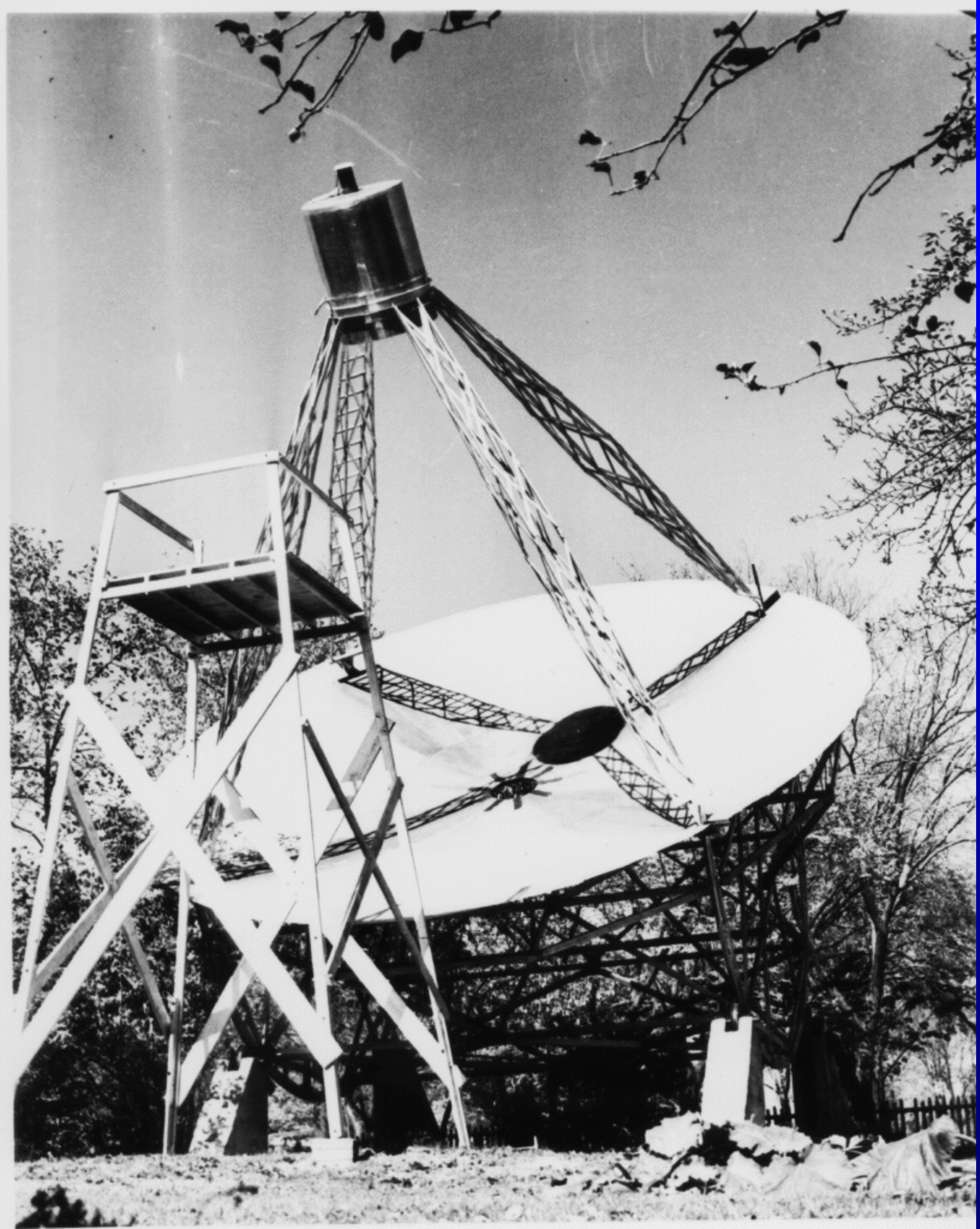
Radio Astronomy and Why

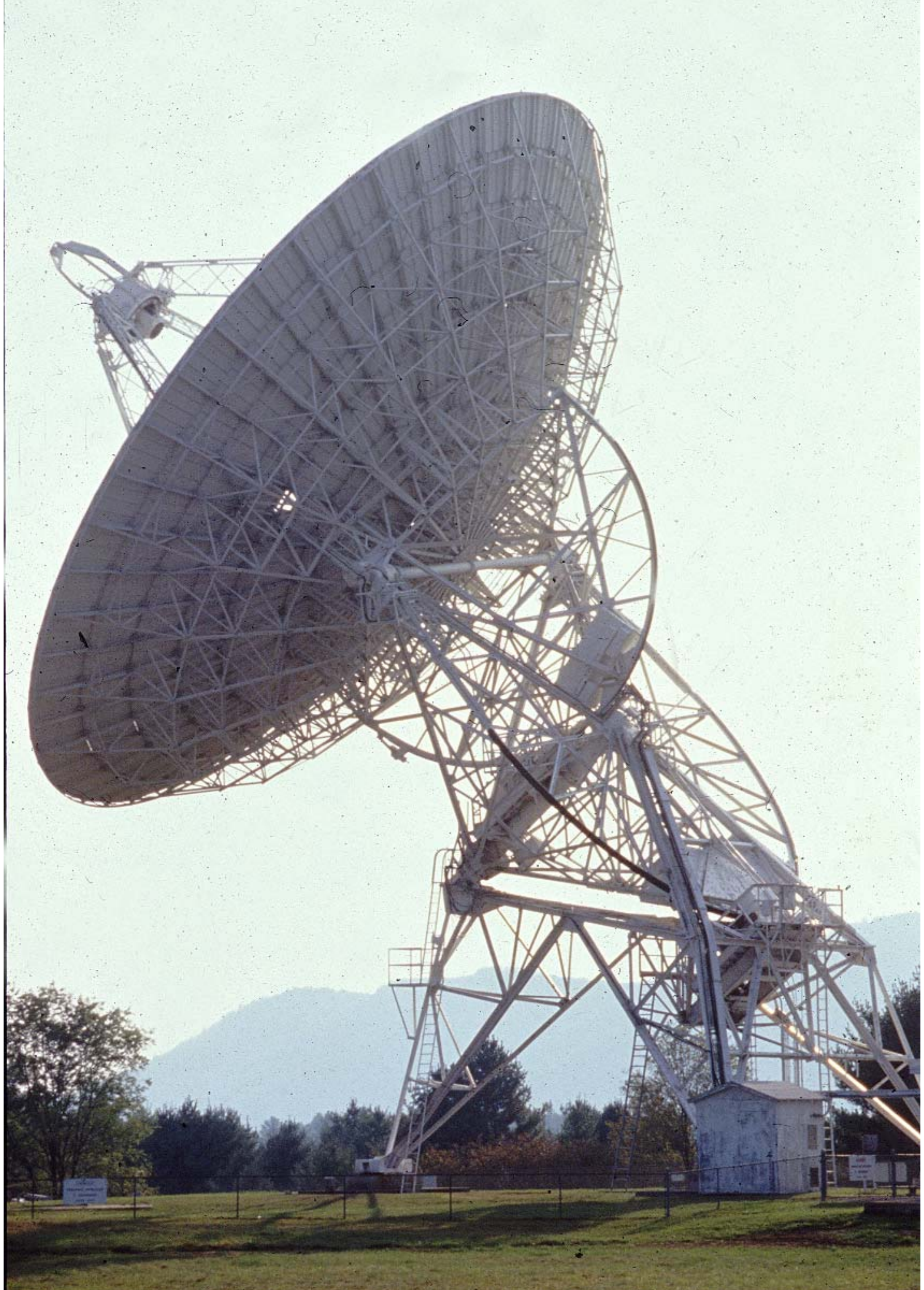
- Many different physical phenomenon govern how the universe works – different frequencies probe different processes
- Regions are obscured at some wavelengths and not others – dust at optical not much of an issue in radio

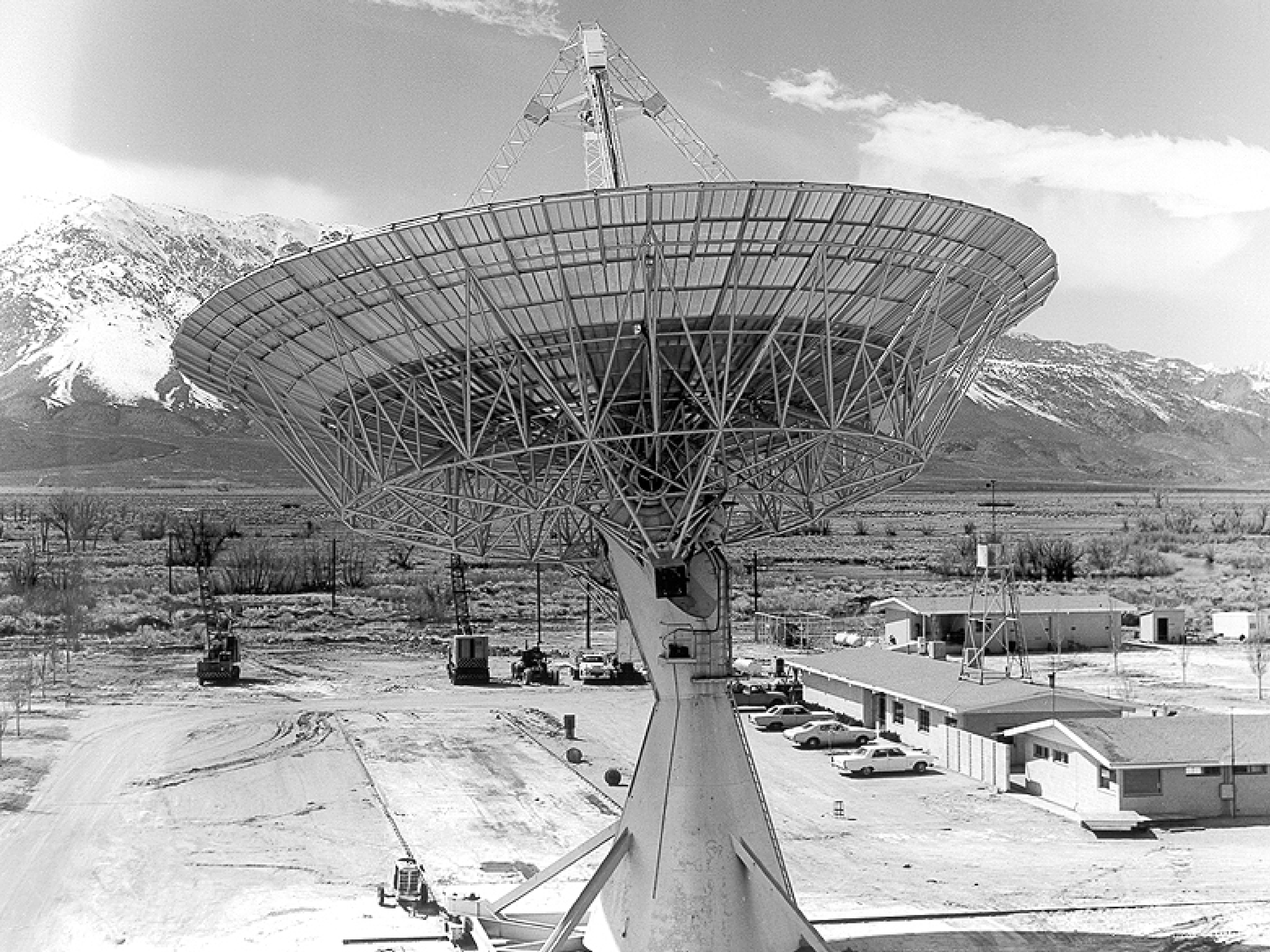
Radio Astronomy

- Thermal
- Non-thermal
- Spectral line

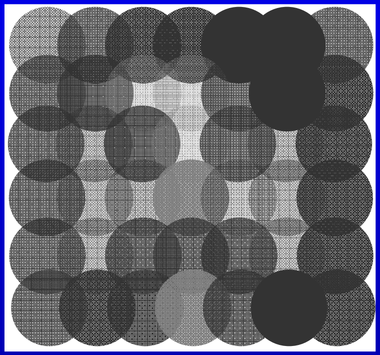
Crab



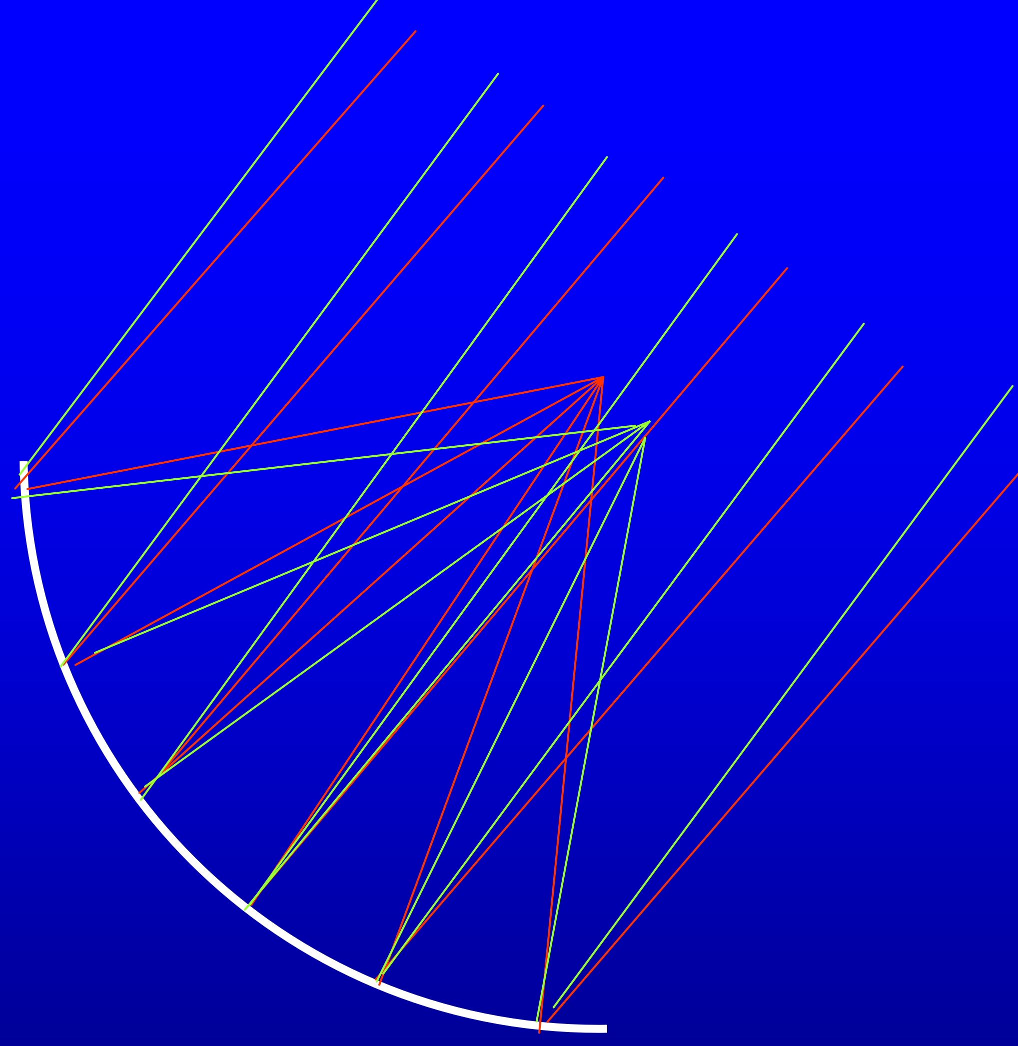




Single Dish

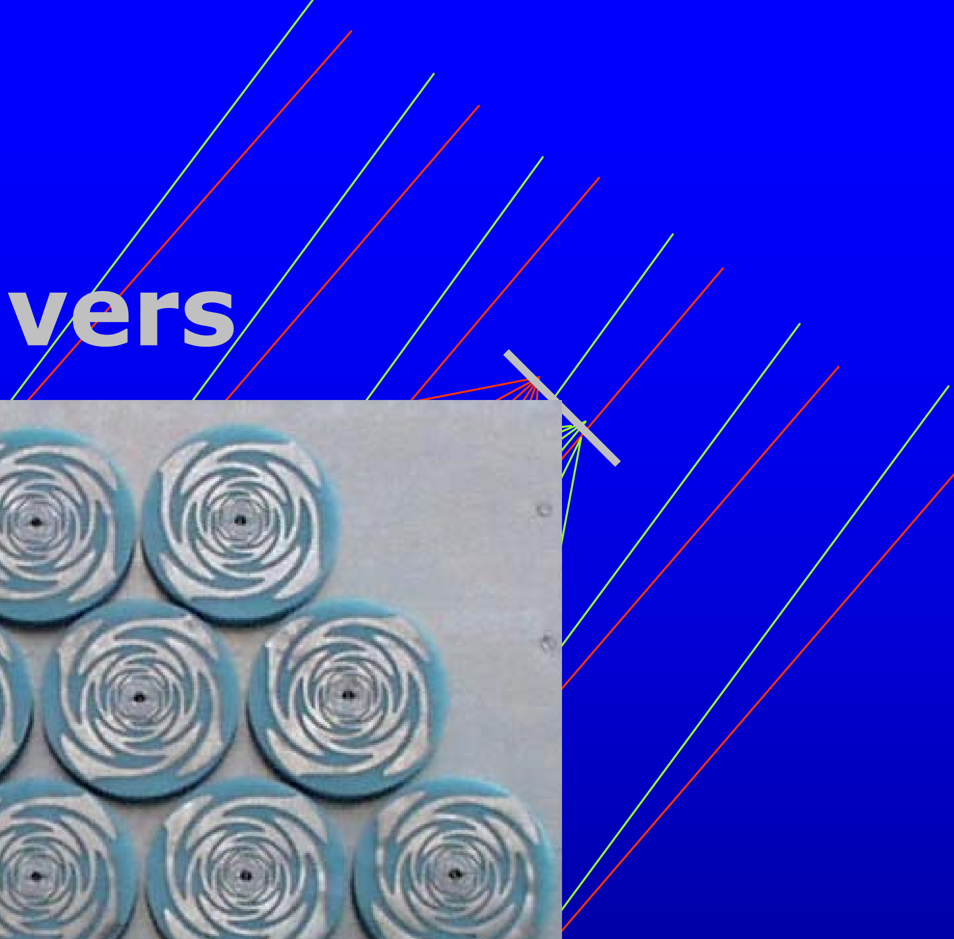


Single Dish



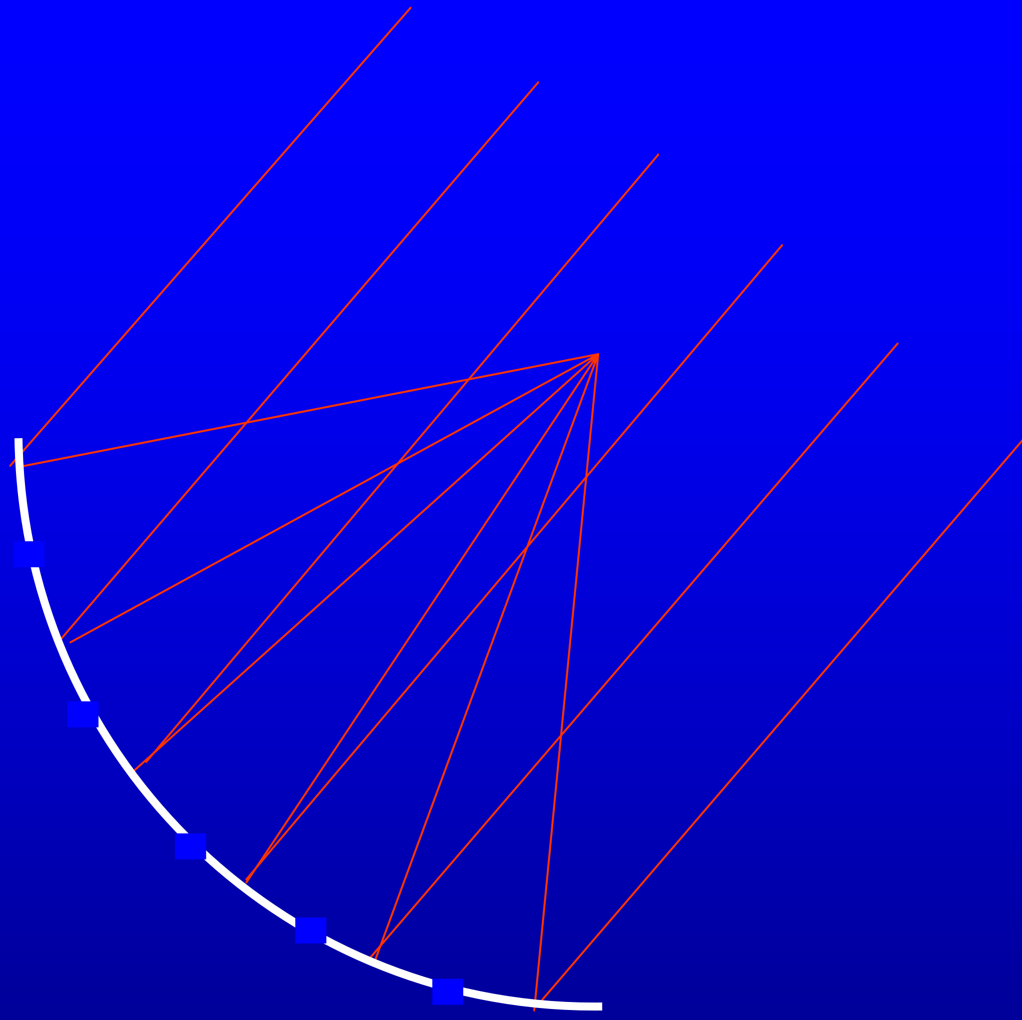
R.D. Ekers

Single Dish
+
Focal Plane Receivers



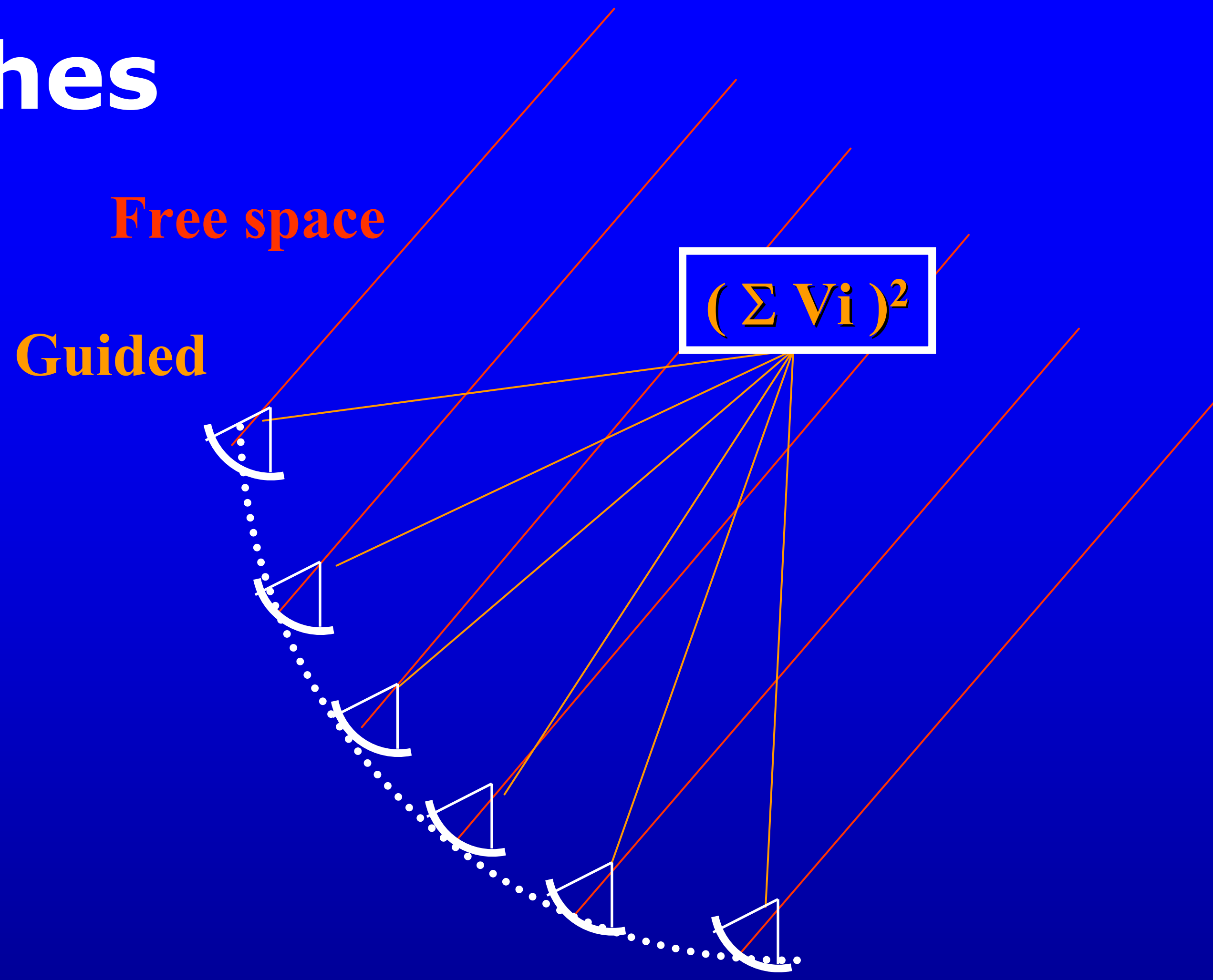
R.D. Ekers

Dish of Panels



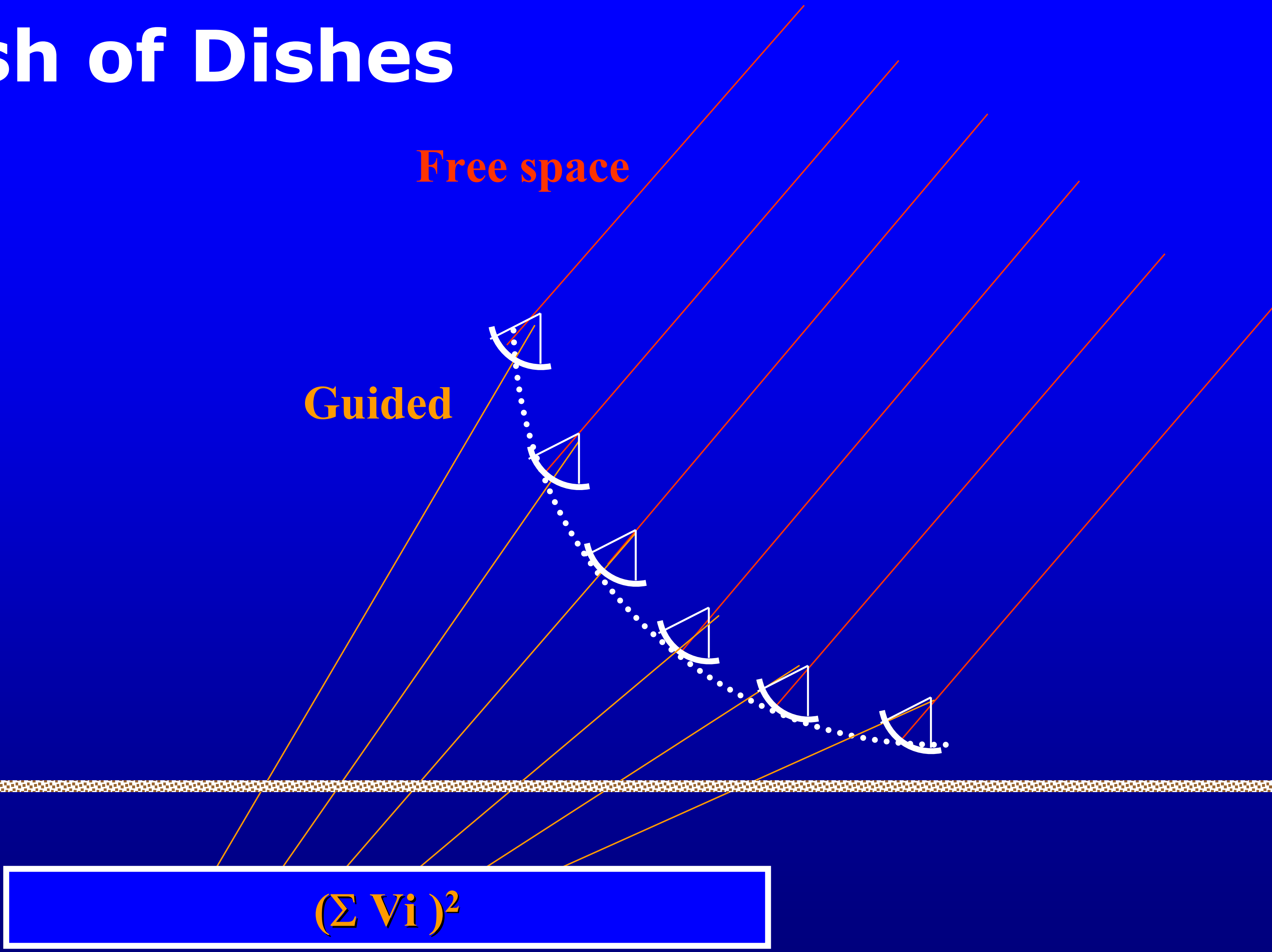
R.D. Ekers

Dish of Dishes



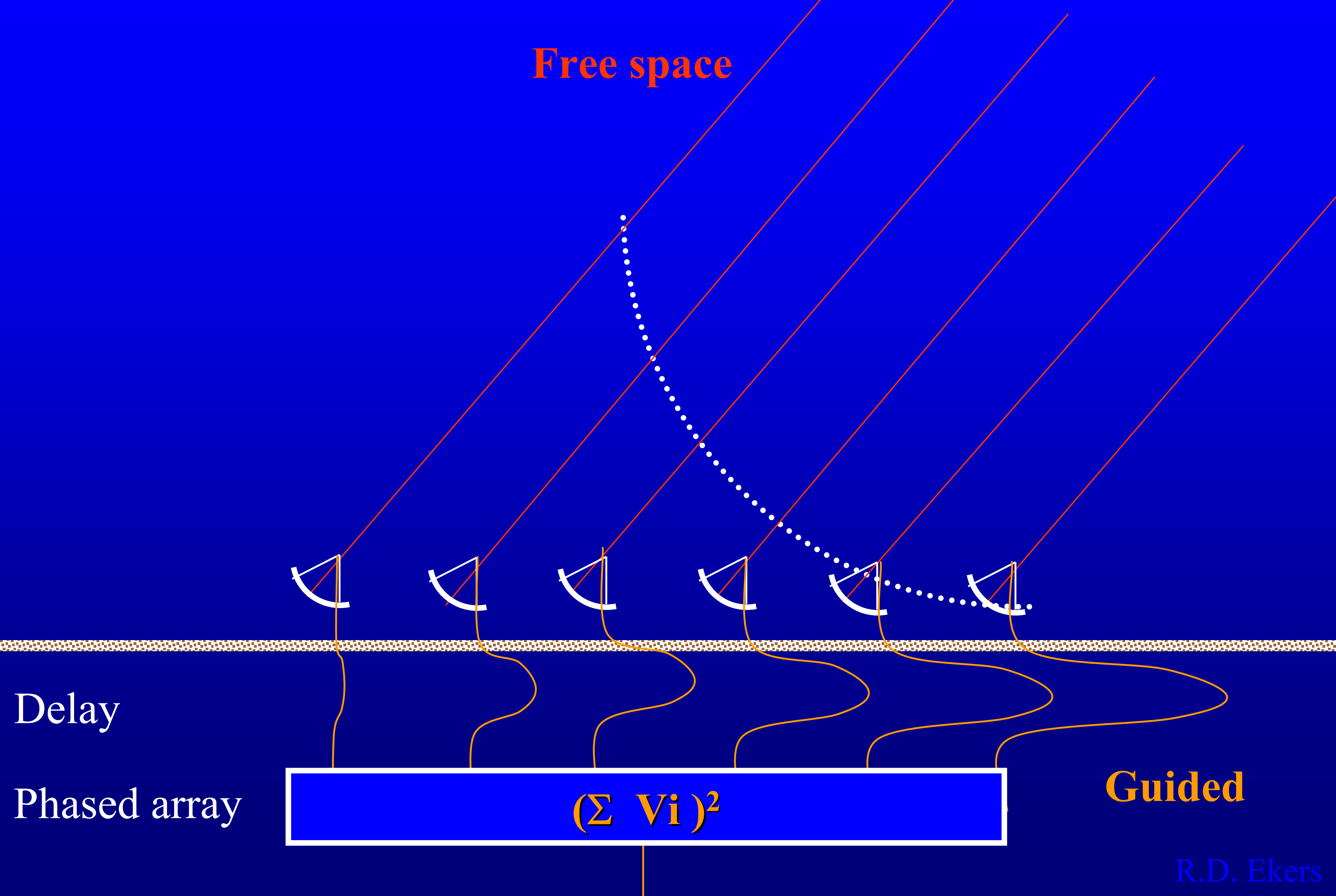
R.D. Ekers

Dish of Dishes



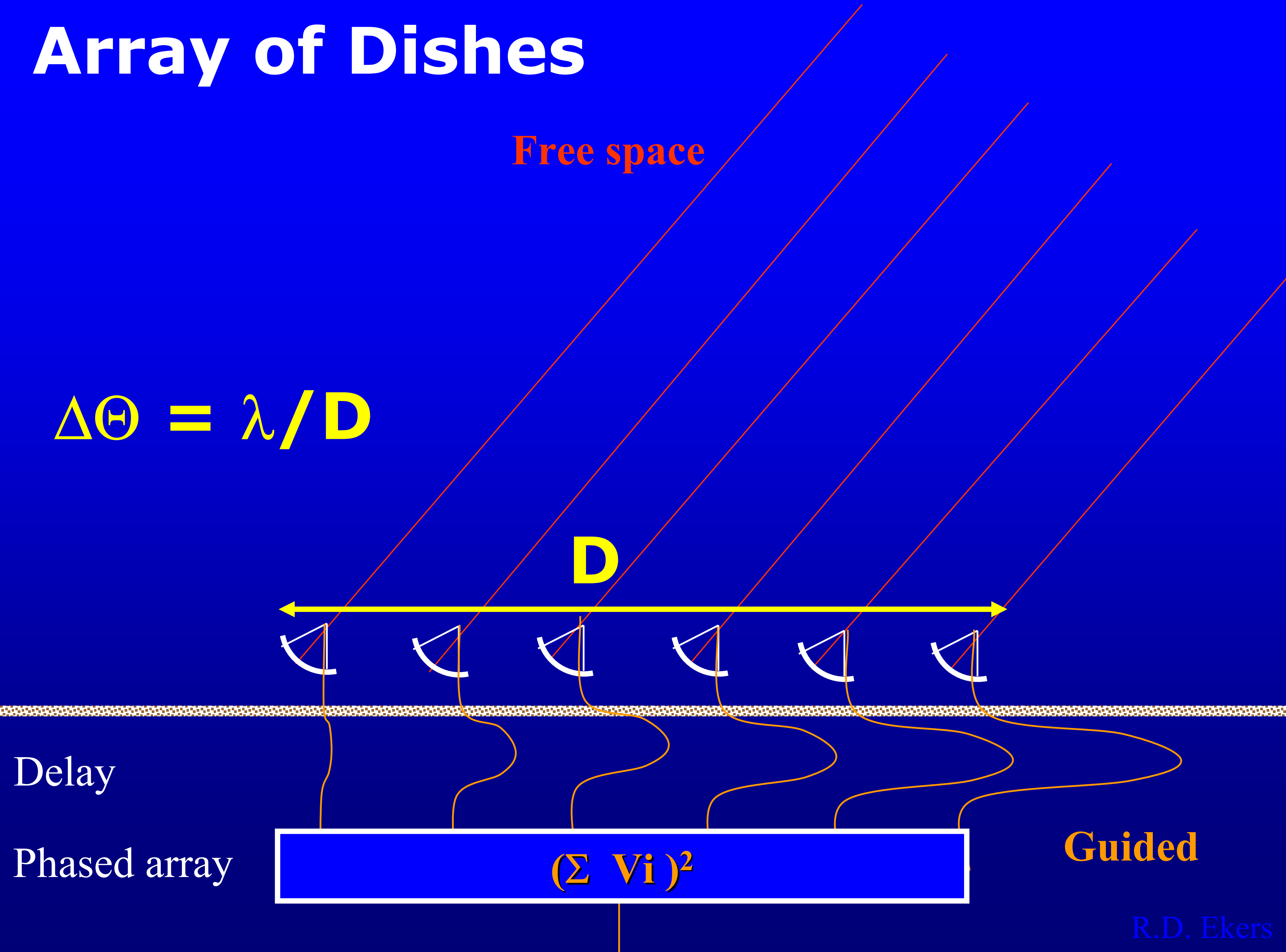
R.D. Ekers

Array of Dishes

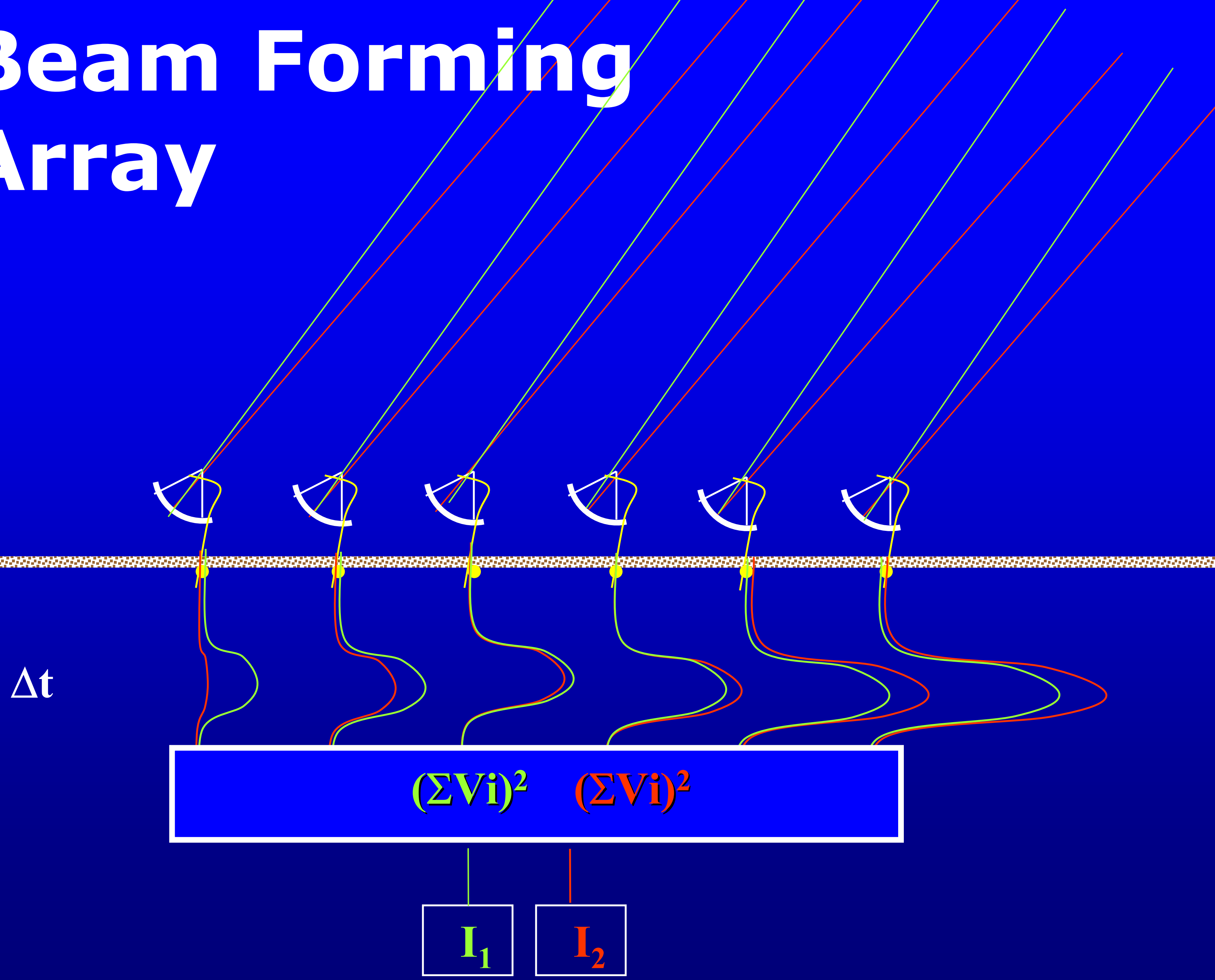


Array of Dishes

$$\Delta\Theta = \lambda / D$$

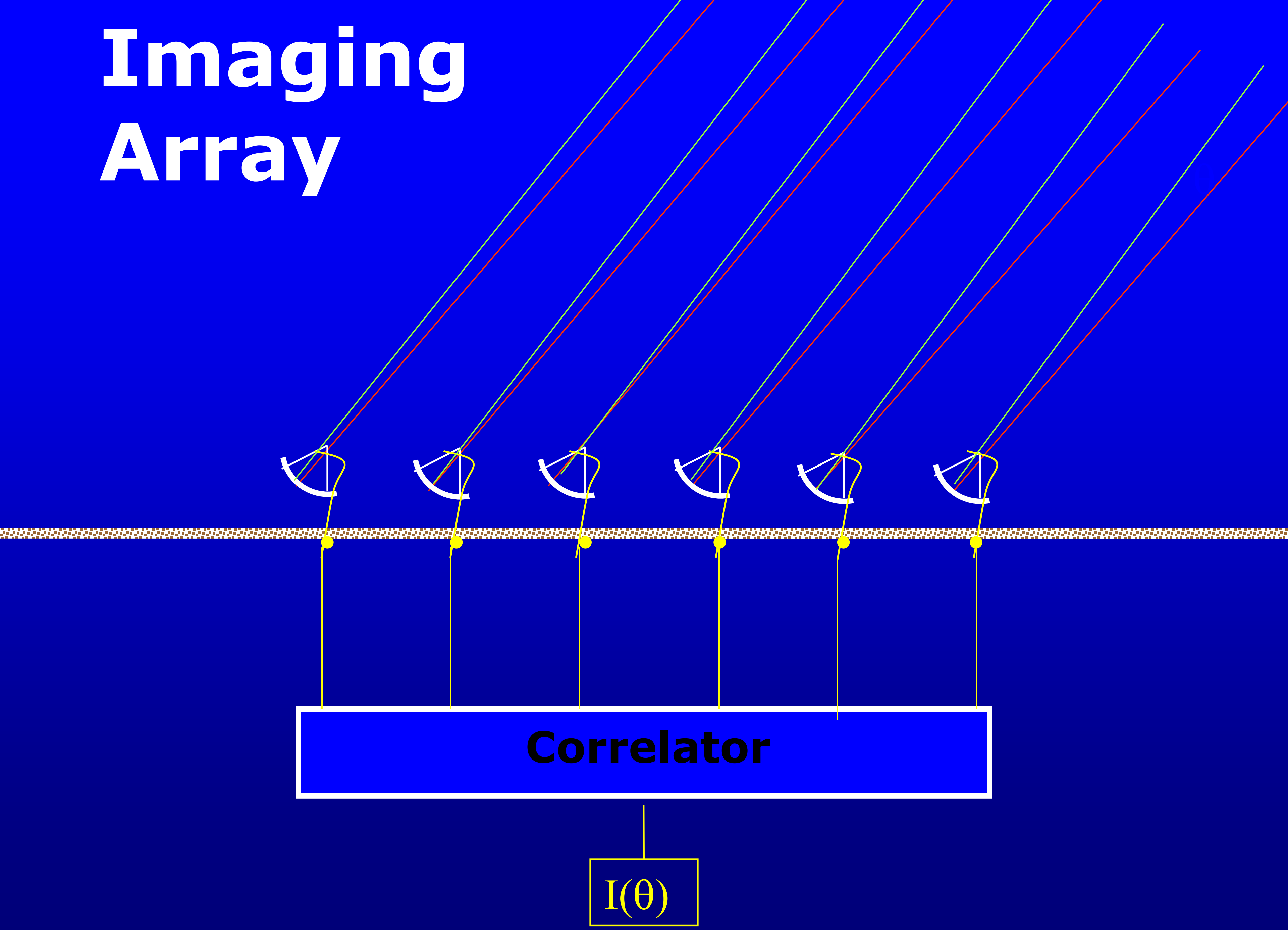


Beam Forming Array



R.D. Ekers

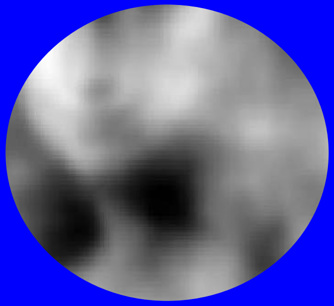
Imaging Array



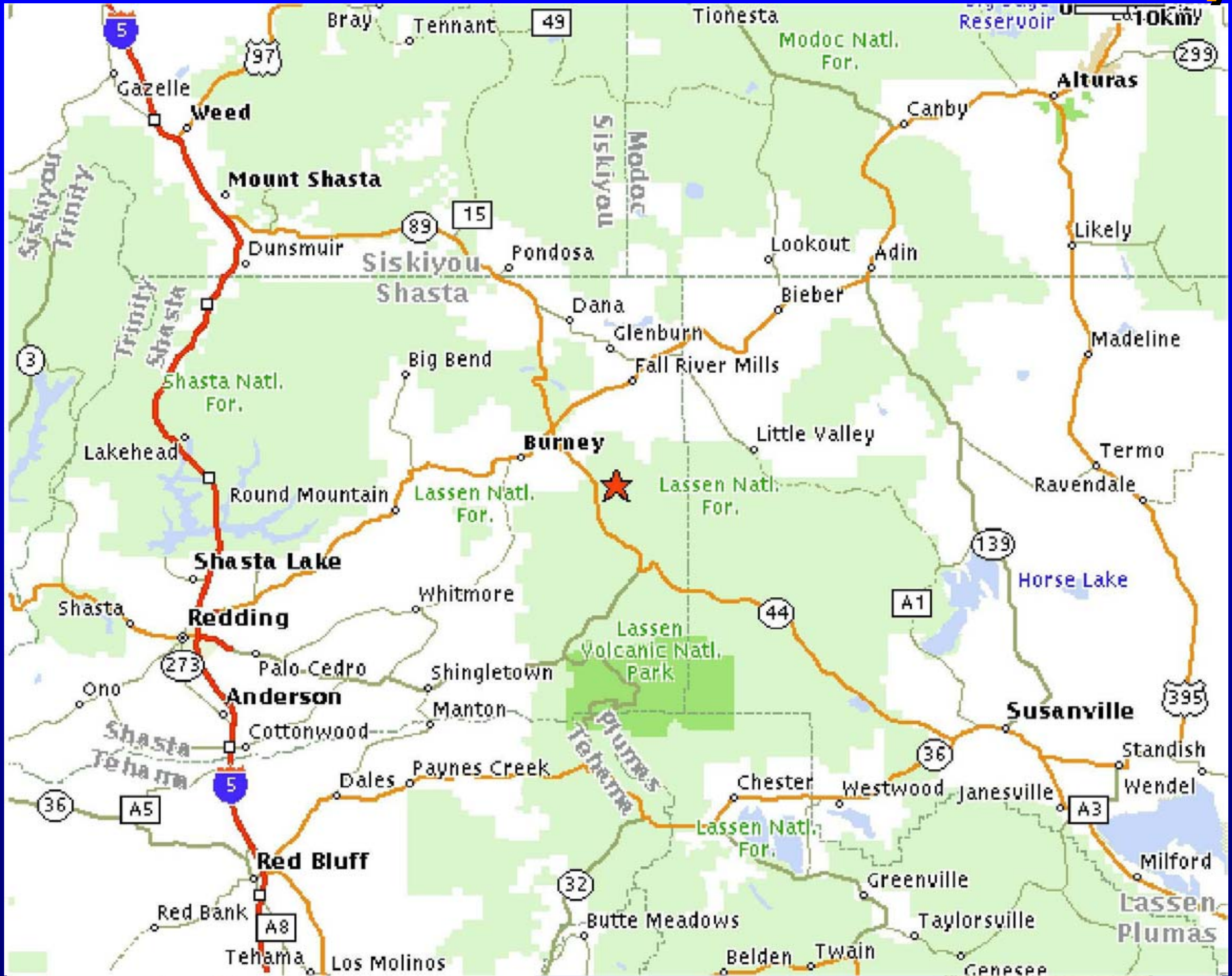
R.D. Ekers


The Very Large Array
New Mexico

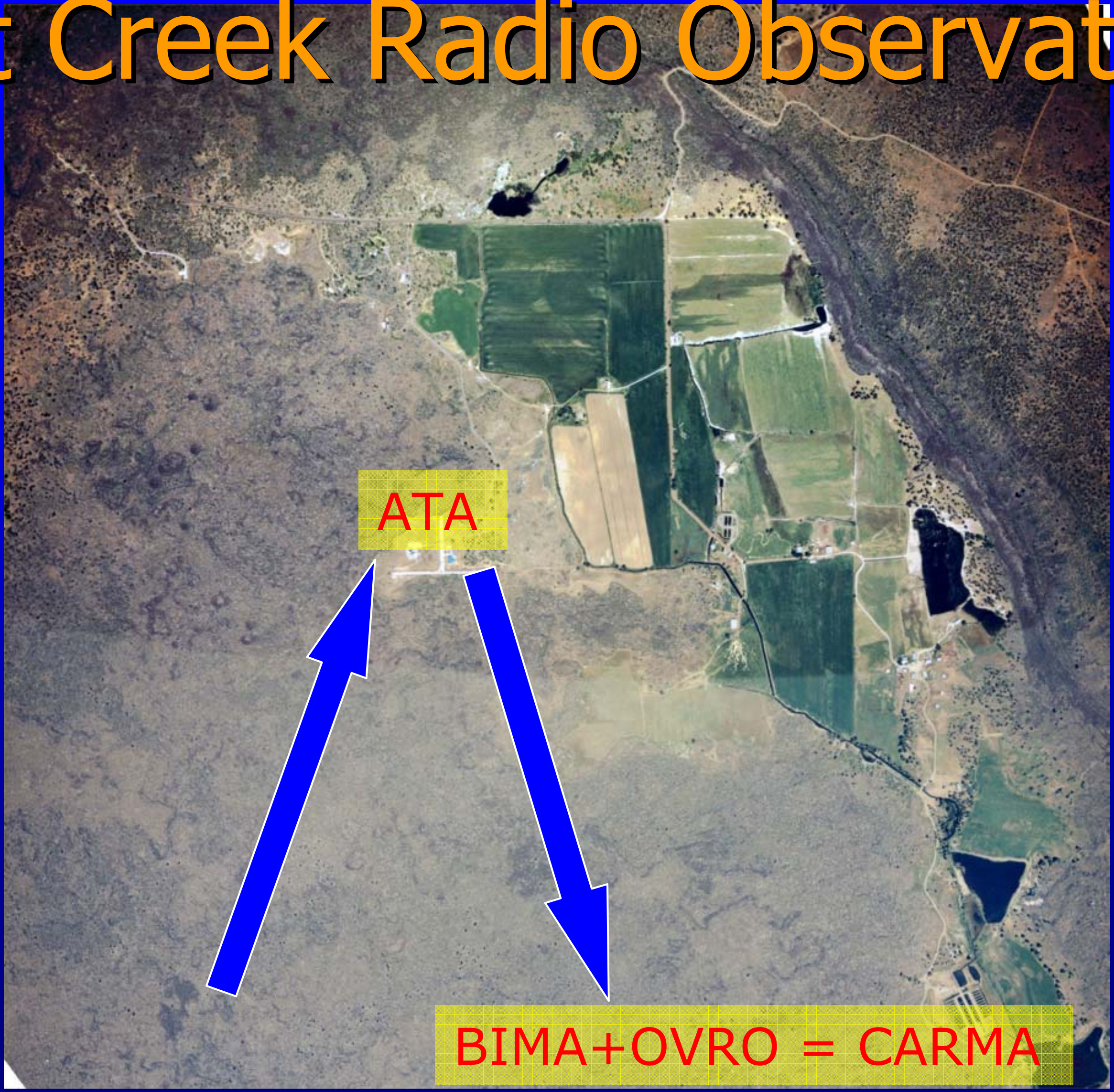
VLA D-configuration



Hat Creek Radio Observatory



Hat Creek Radio Observatory

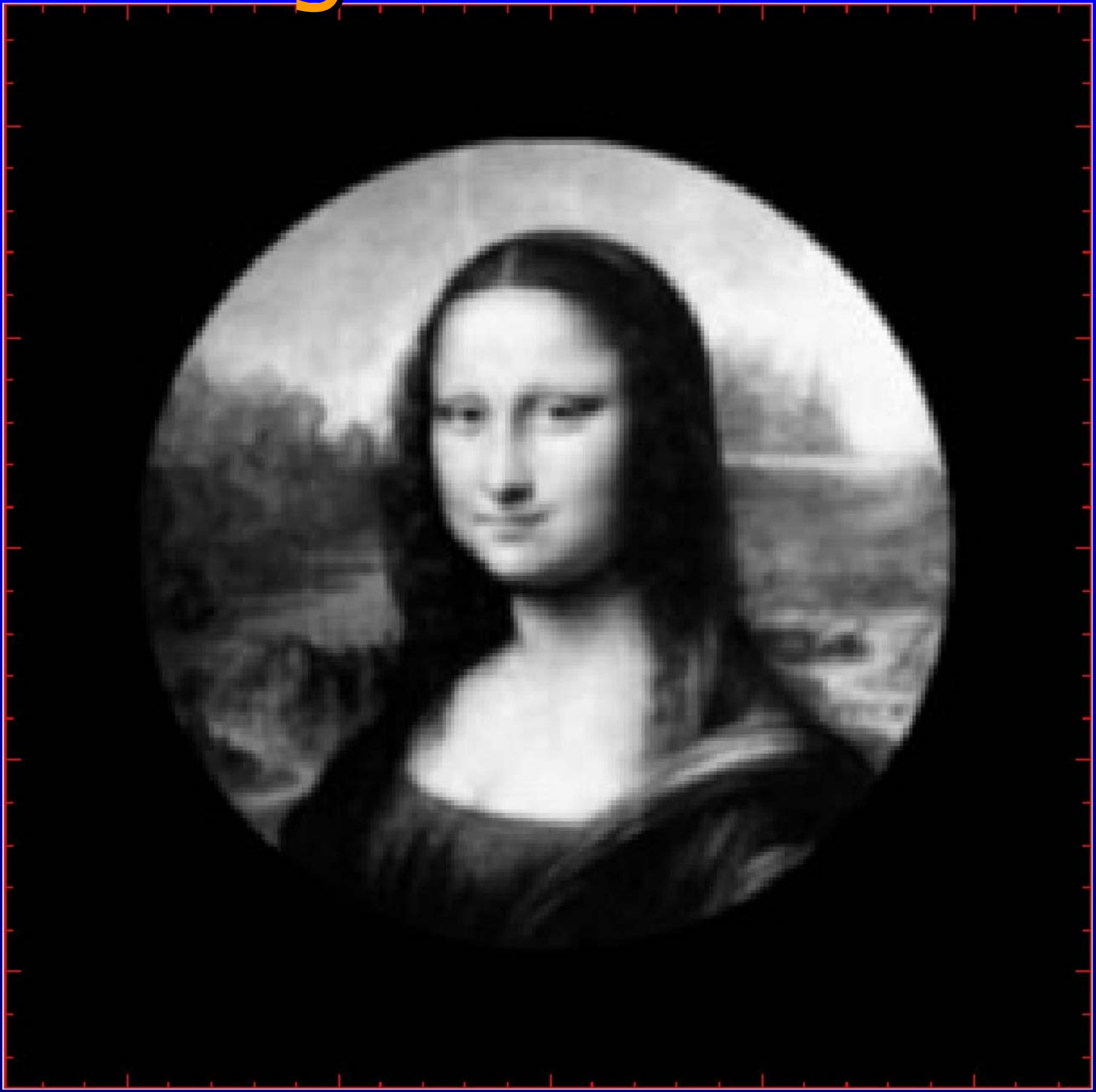


The Allen Telescope Array

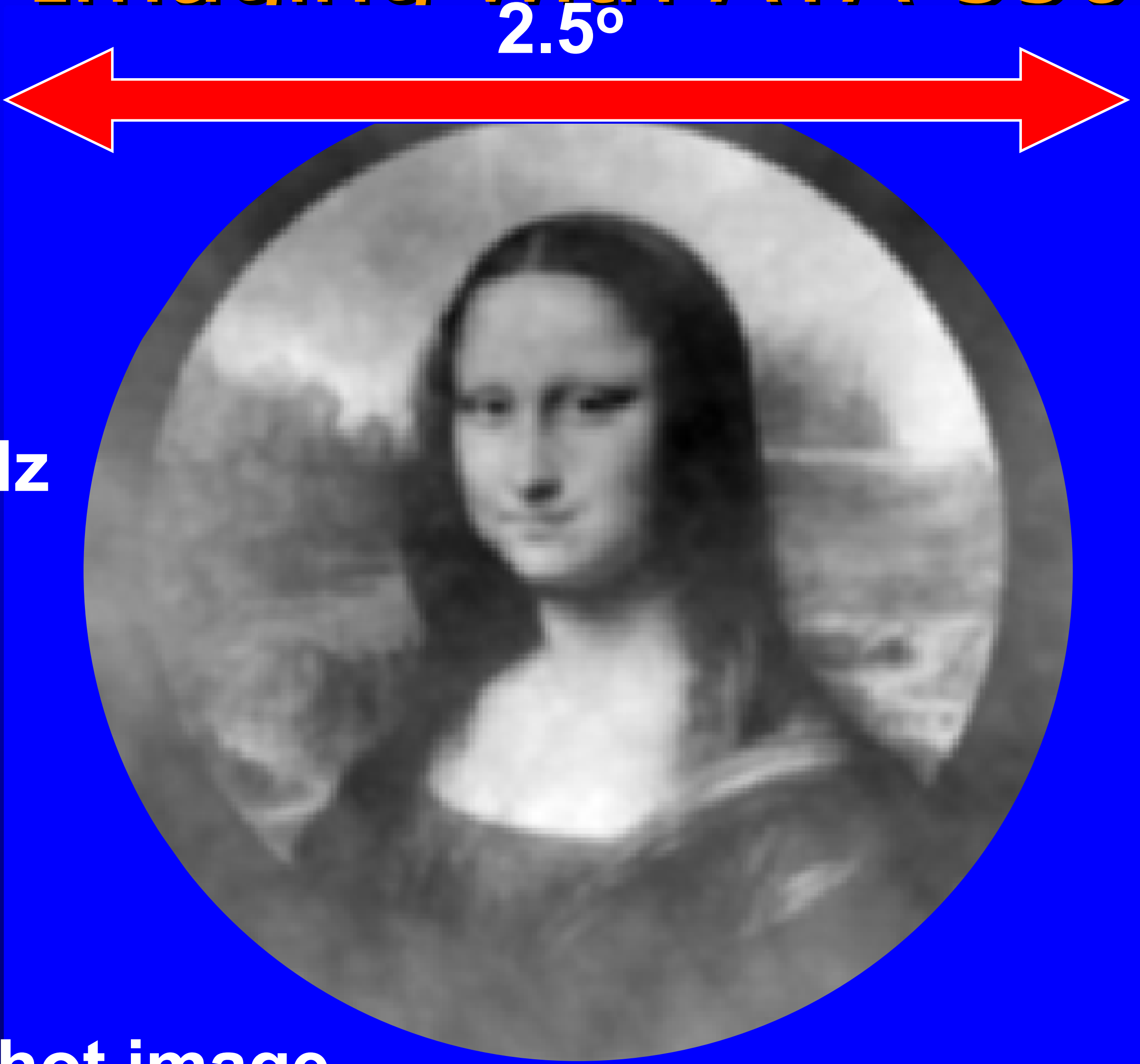
- Joint project between SETI Institute and UCB Radio Astronomy Lab
- Located at Hat Creek in N. CA
- Goal of 350 6.1-meter antennas (and beyond)
- Funded to-date primarily by Paul G. Allen Foundation

ATA-350

Original "Nebula"



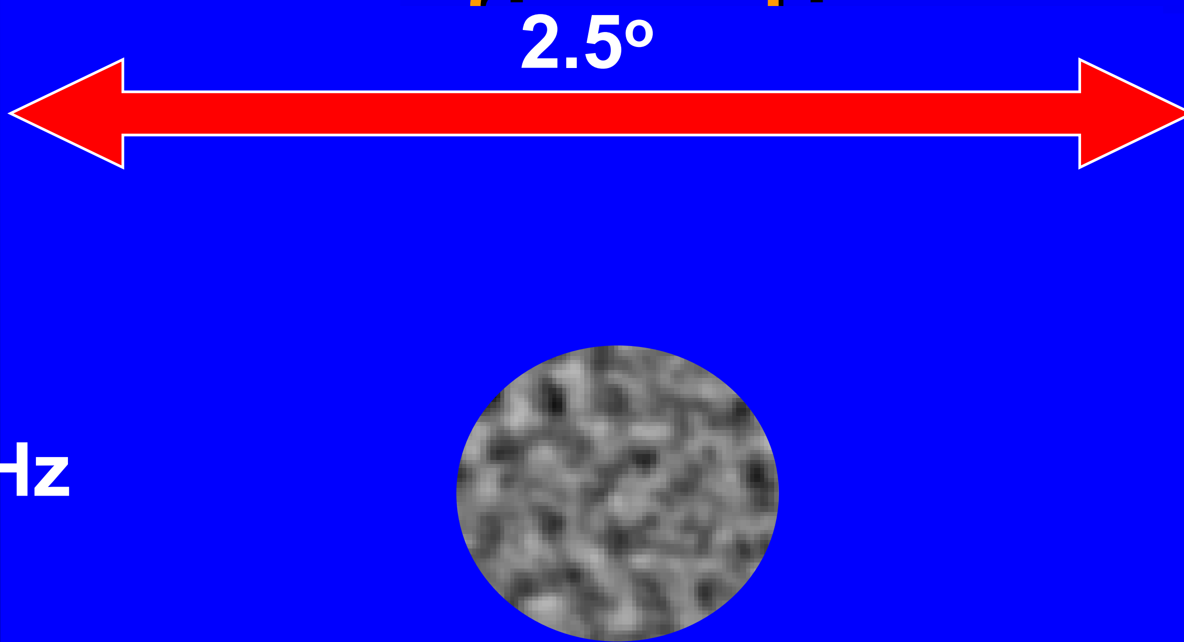
Imaging with ATA-350



1420 MHz

Snapshot image

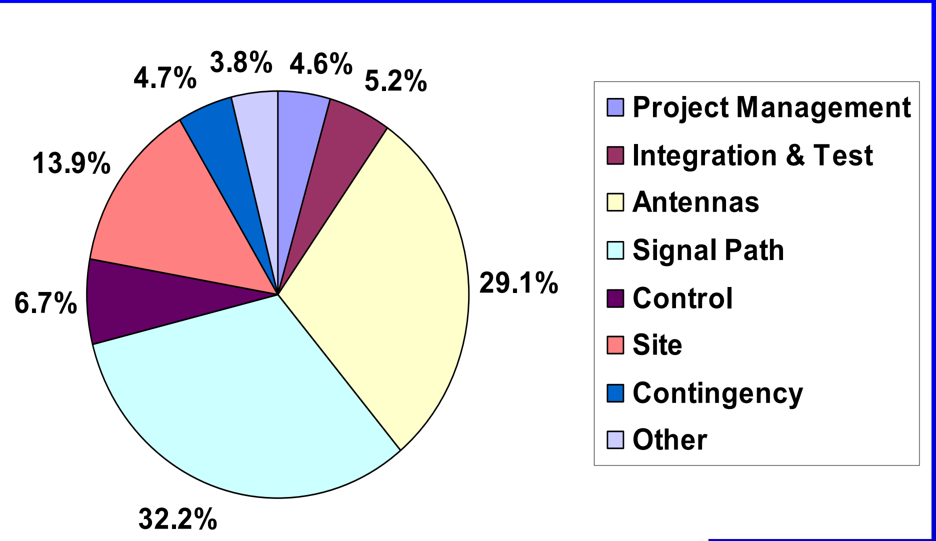
Imaging with VLA E-

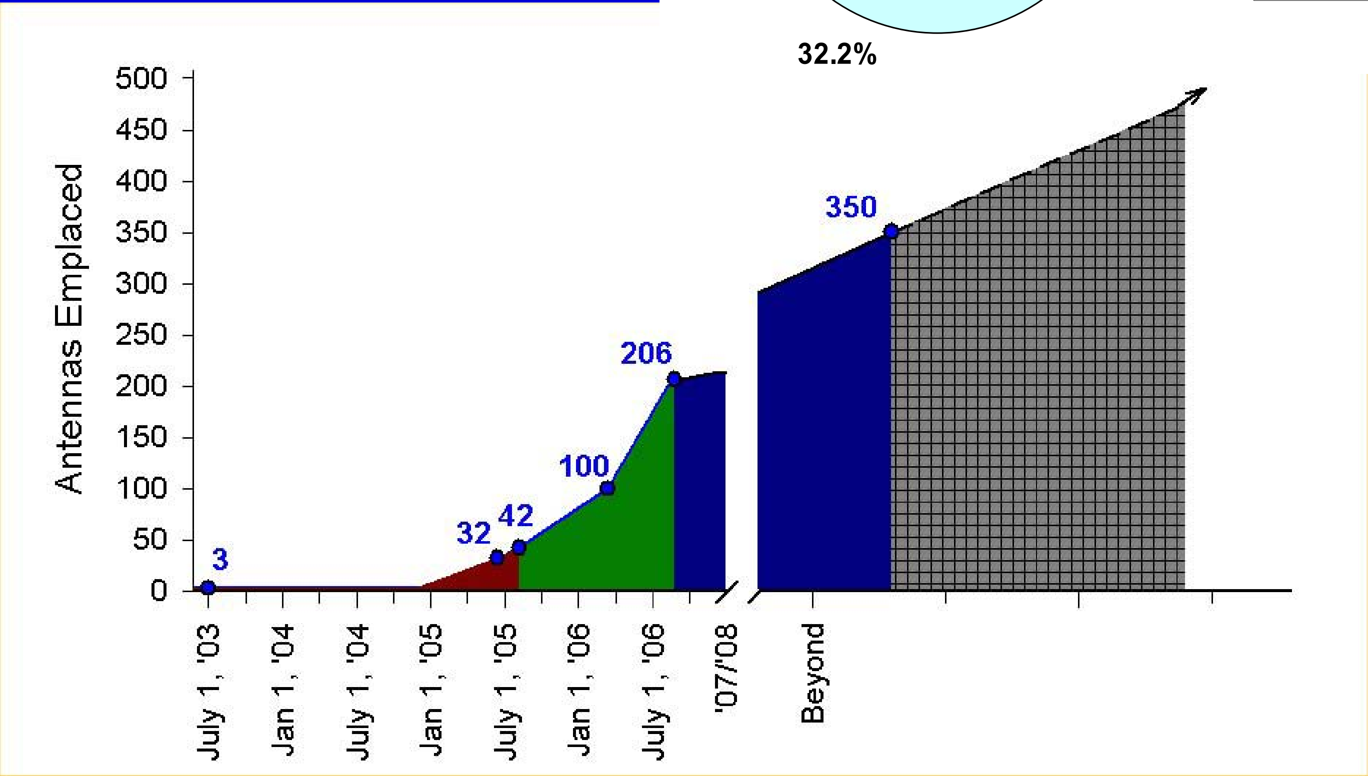


1420 MHz

Snapshot image

Number of Elements/Schedule

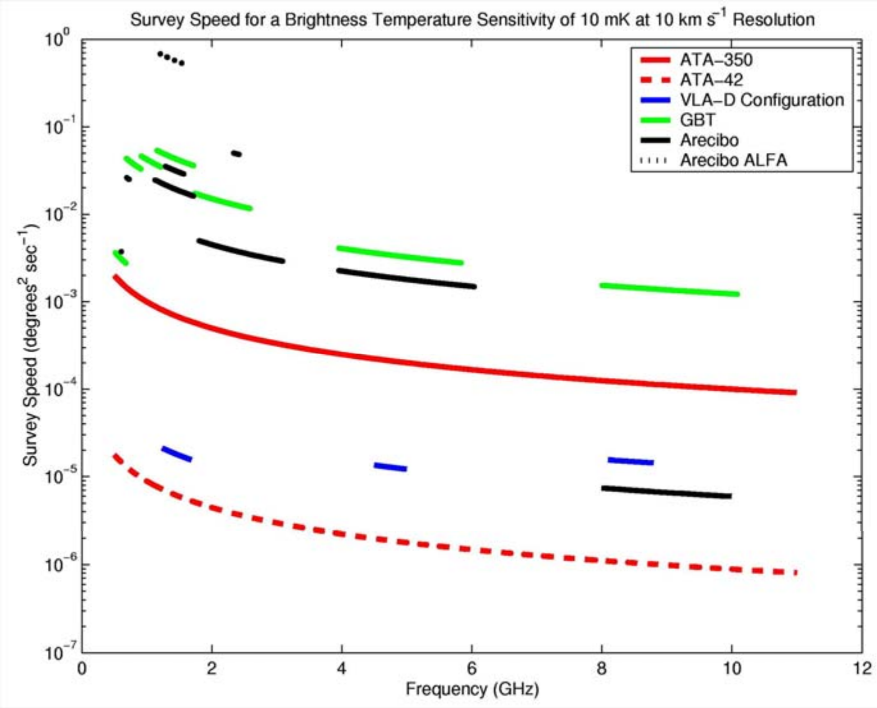


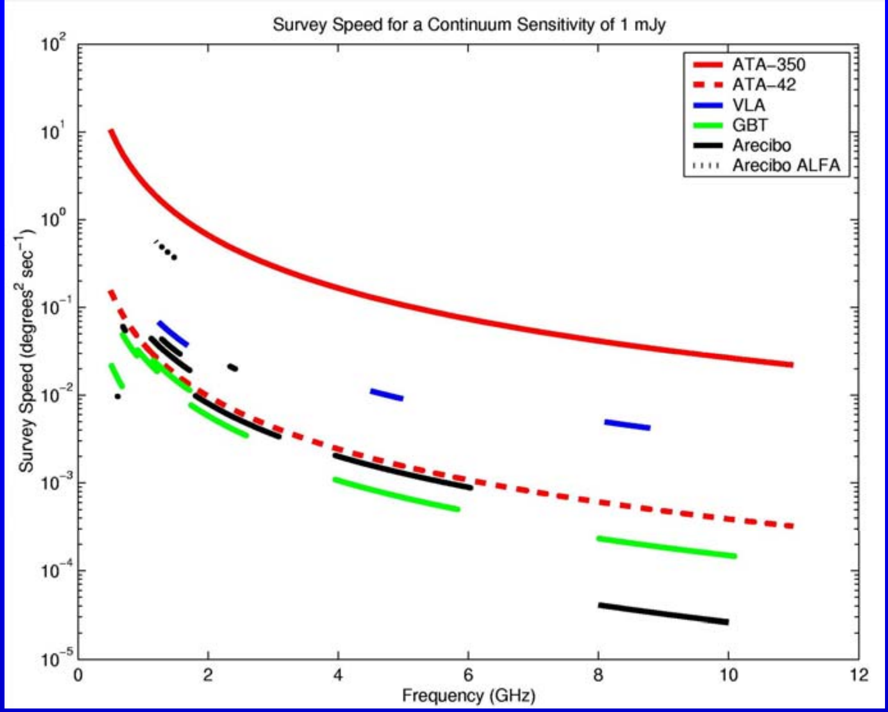


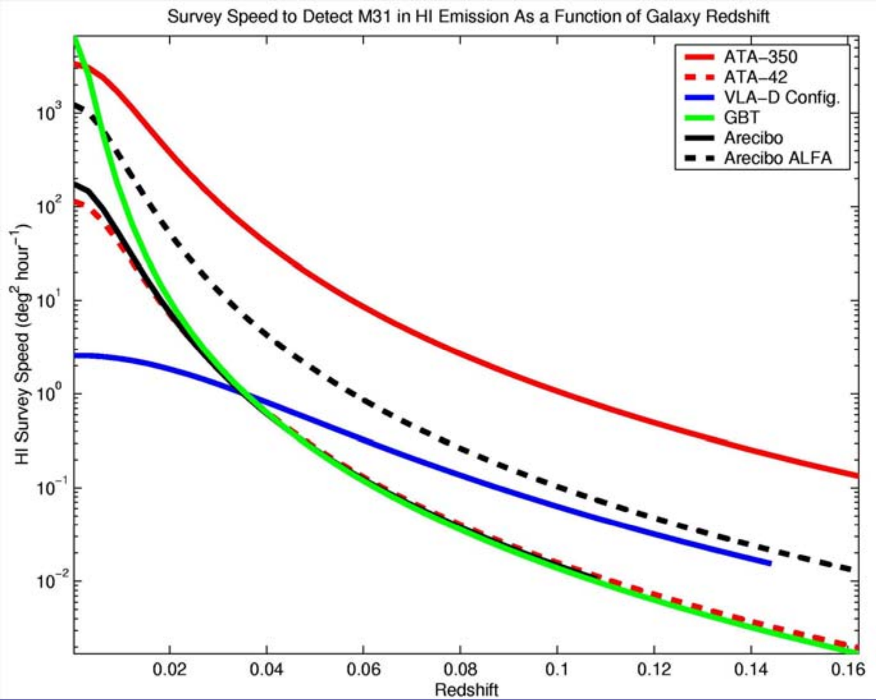
Science Goals

- 3 year survey to map all Galaxies out to 300 Mpc and extragalactic clouds in HI
- Frequent, fast all-sky surveys to explore transient phenomenon (~5 days)
- Pulsar monitoring survey
- Magnetic field transition regions (Zeeman)
- Large-scale surveys at other frequencies (e.g. CCS, H_2CO, H_2CS, C_4H, CH_3OH, OH, CH, CH_2NH, CH_3NH_2, HCOOH, HC_5N, HC_7N, HC_9N)
- SETI

Multiple concurrent







Surveys

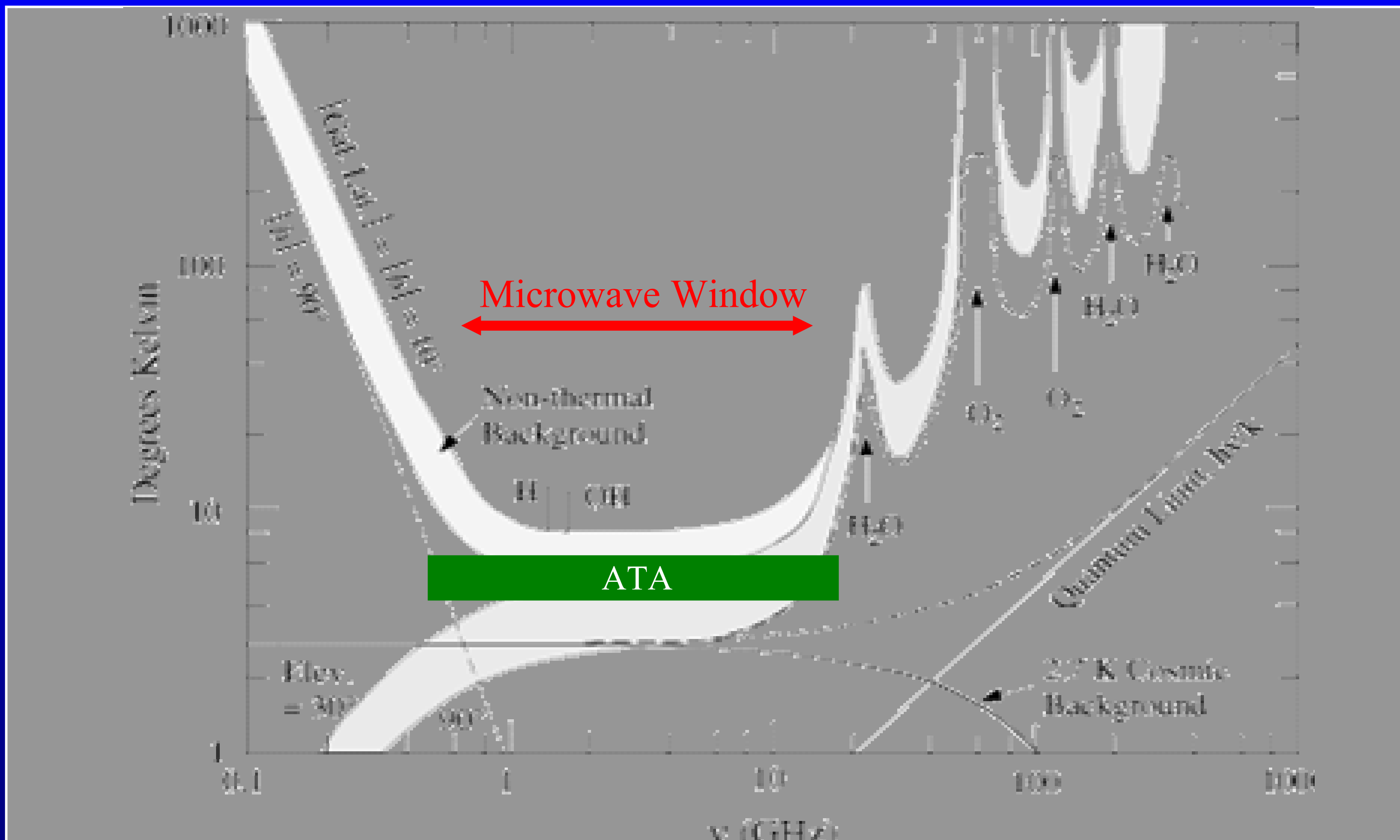
Surveys

Surveys

Design Goals for the ATA

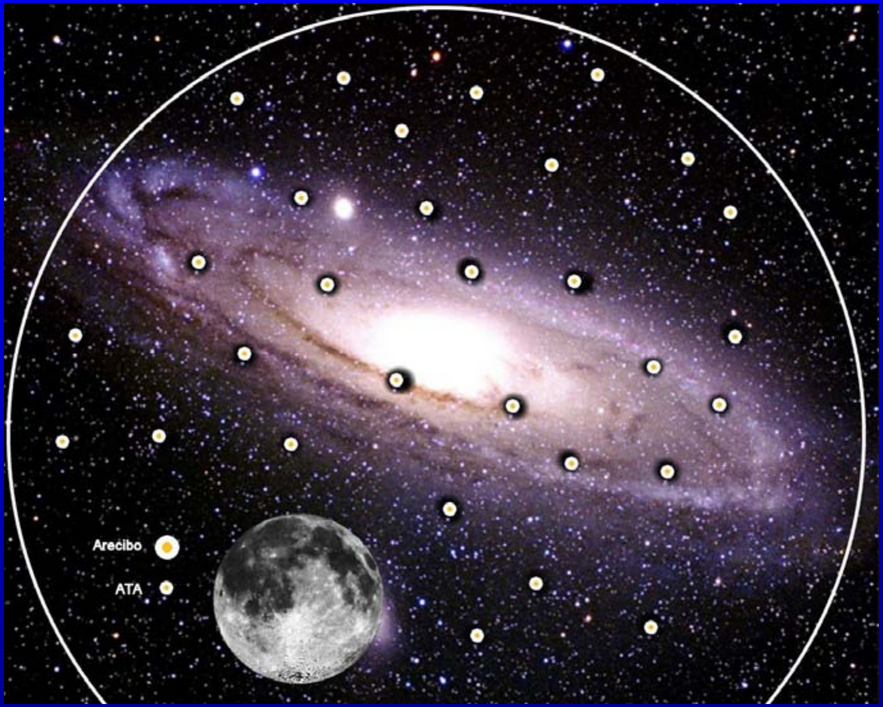
Number of elements	350		
Element diameter	6.1	m	
Total geometric collecting area	10,229	m^2	
	114	m	Diameter equivalent
Frequency	0.5	11.2	GHz
Aperture efficiency	60	%	
Effective area	6,137	m^2	
	2.2	K/Jy	
System temperature	42	K	At 80 K
A_e/T_{sys}	146	m^2/K	~1% SKA
Effective diameter	700	m	Natural weighting
Number of beams	16		Dual-pol
FoV	40	0.07	deg^2 (5 deg^2 at 1420 MHz)
Synthesized beam	216	9.8	arcsec

The Electromagnetic Sky



Flexibility

Beam former generates 16 dual-pol pencil beams anywhere in the sky (100 MHz)



Flexibility

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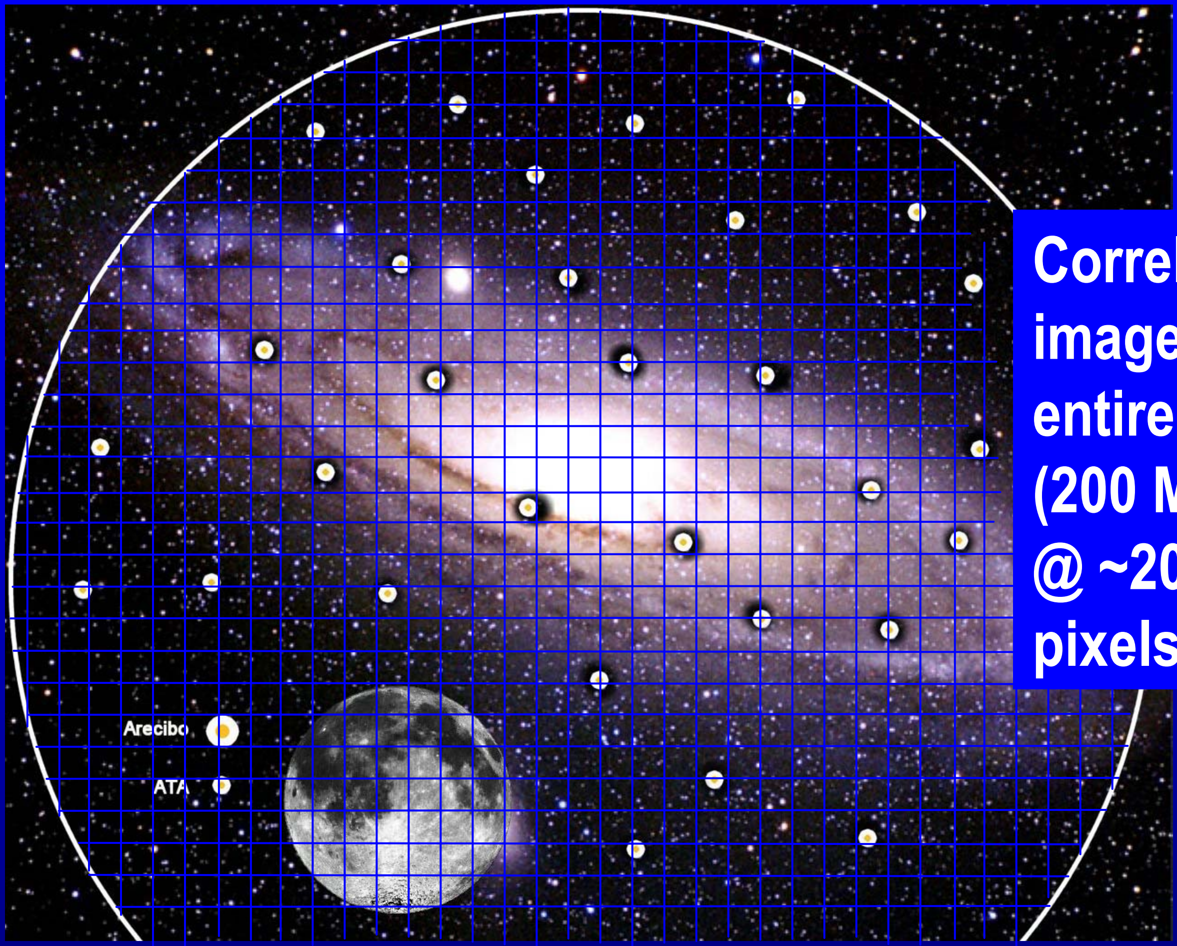
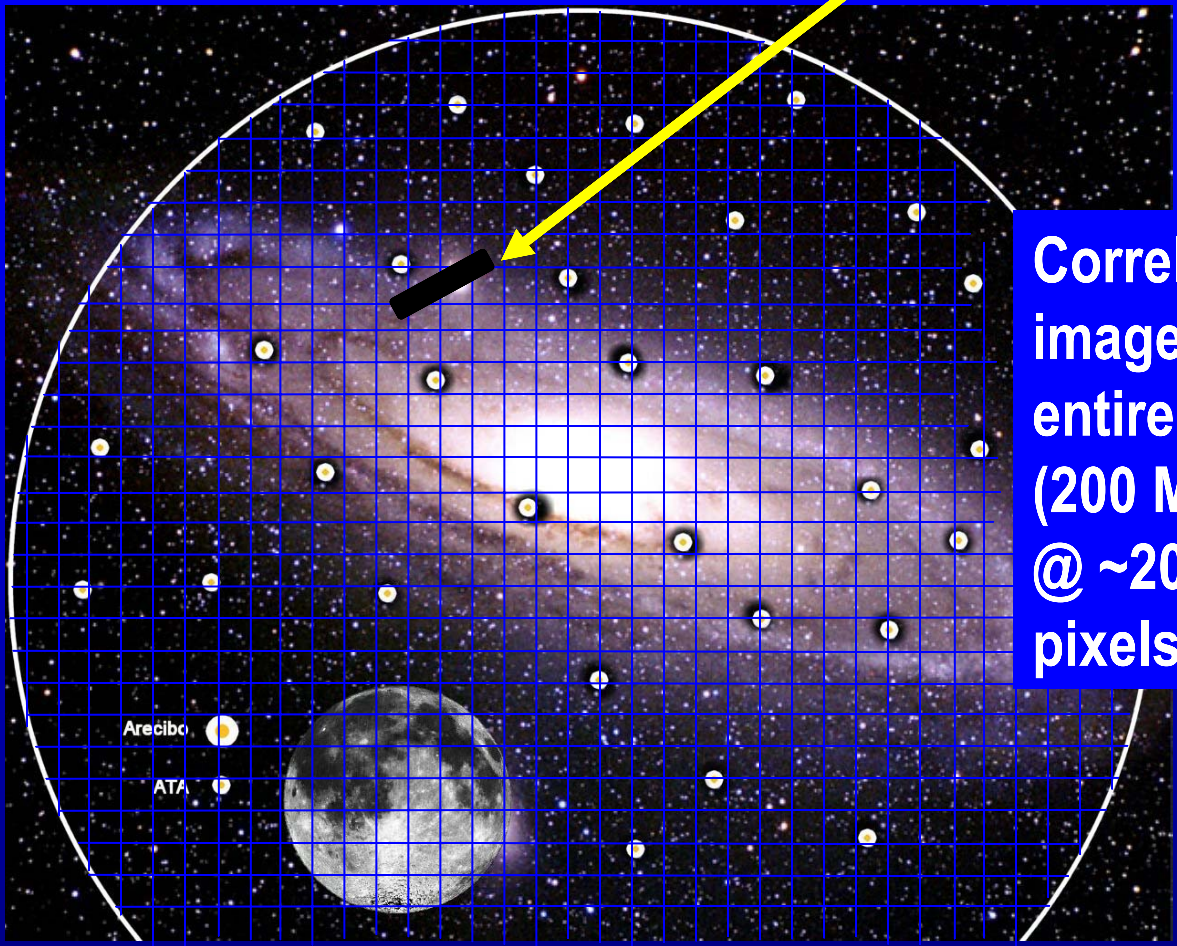


Correlator images the entire FoV (200 MHz) @ ~20,000 pixels

Flexibility

NULL

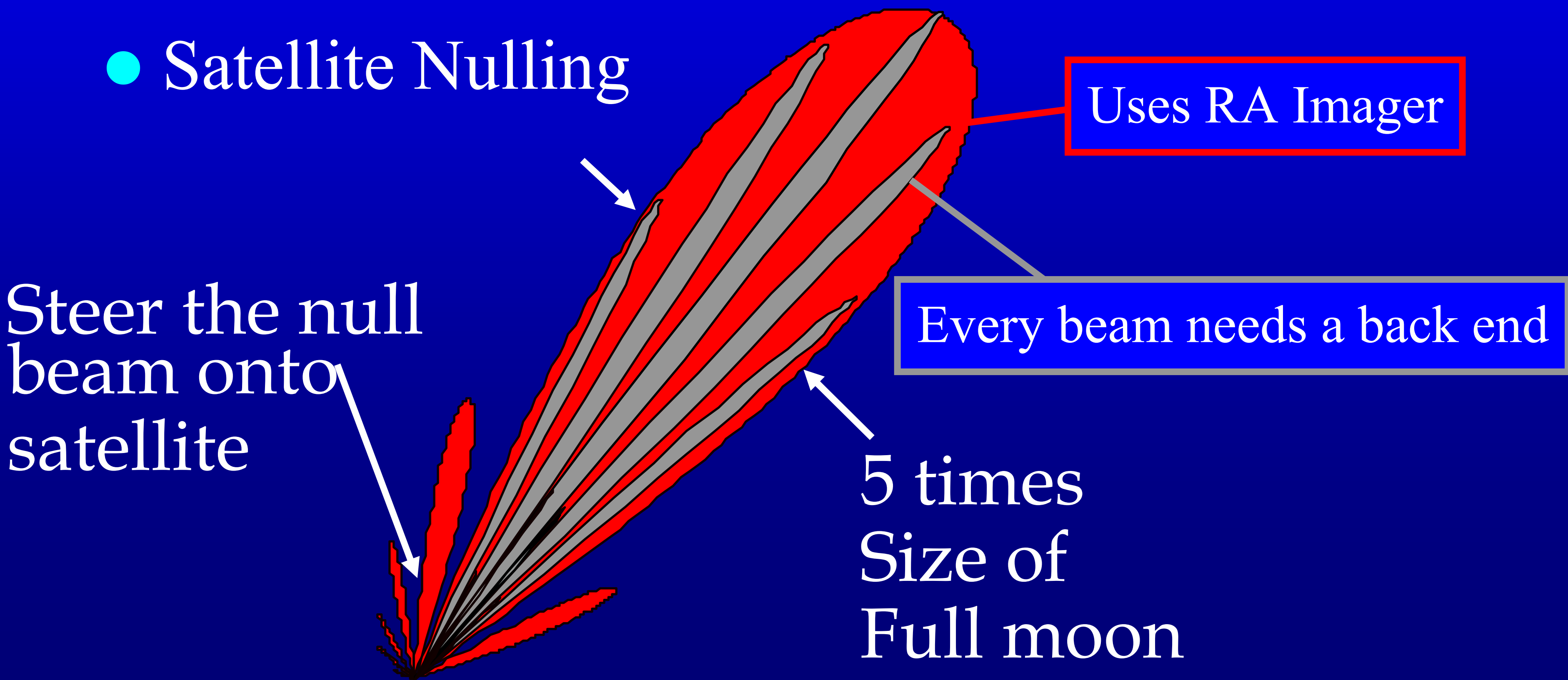


Beam former generates 16 dual-pol pencil beams anywhere in the sky (100 MHz)

Correlator images the entire FoV (200 MHz) @ ~20,000 pixels

Not Just Cheaper, but Better

- Exploits Large Primary FOV
- Enables Simultaneous SETI and RA
- Satellite Nulling



Nulls

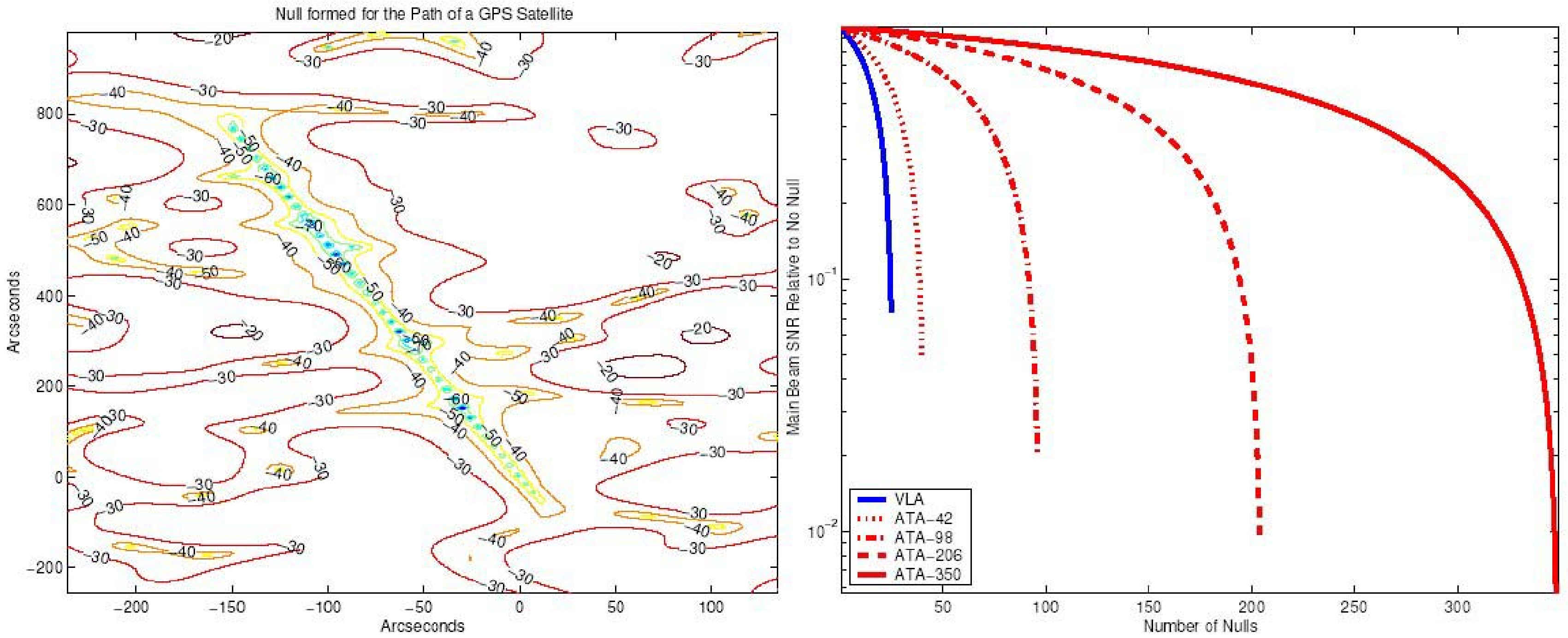


Figure 6: *Left:* Null formed for the path of a GPS satellite with the ATA-350. Fifty individual nulls were placed along the 1.5 second path of a GPS satellite. Contours are decibels of RFI suppression. *Right:* Effect on the main beam of a phased array signal as a function of number of nulls placed on the sky to suppress interference for the VLA and four stages of ATA development. The large N character of the ATA gives it exceptional flexibility in handling interference for spatial nulling and post-correlation RFI mitigation.

Cancellation

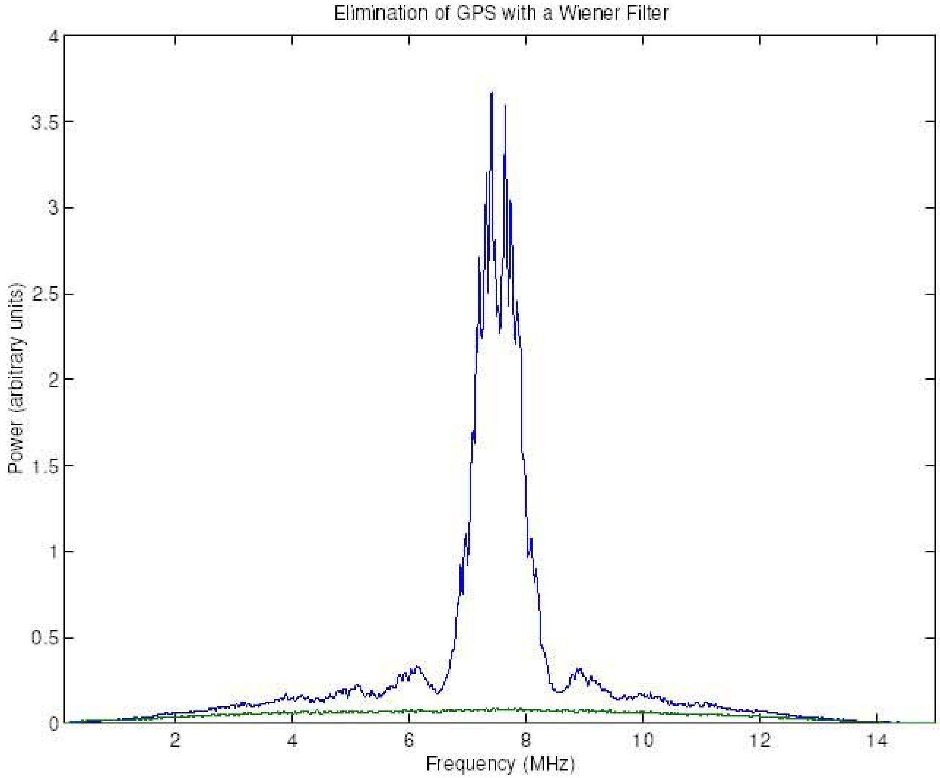
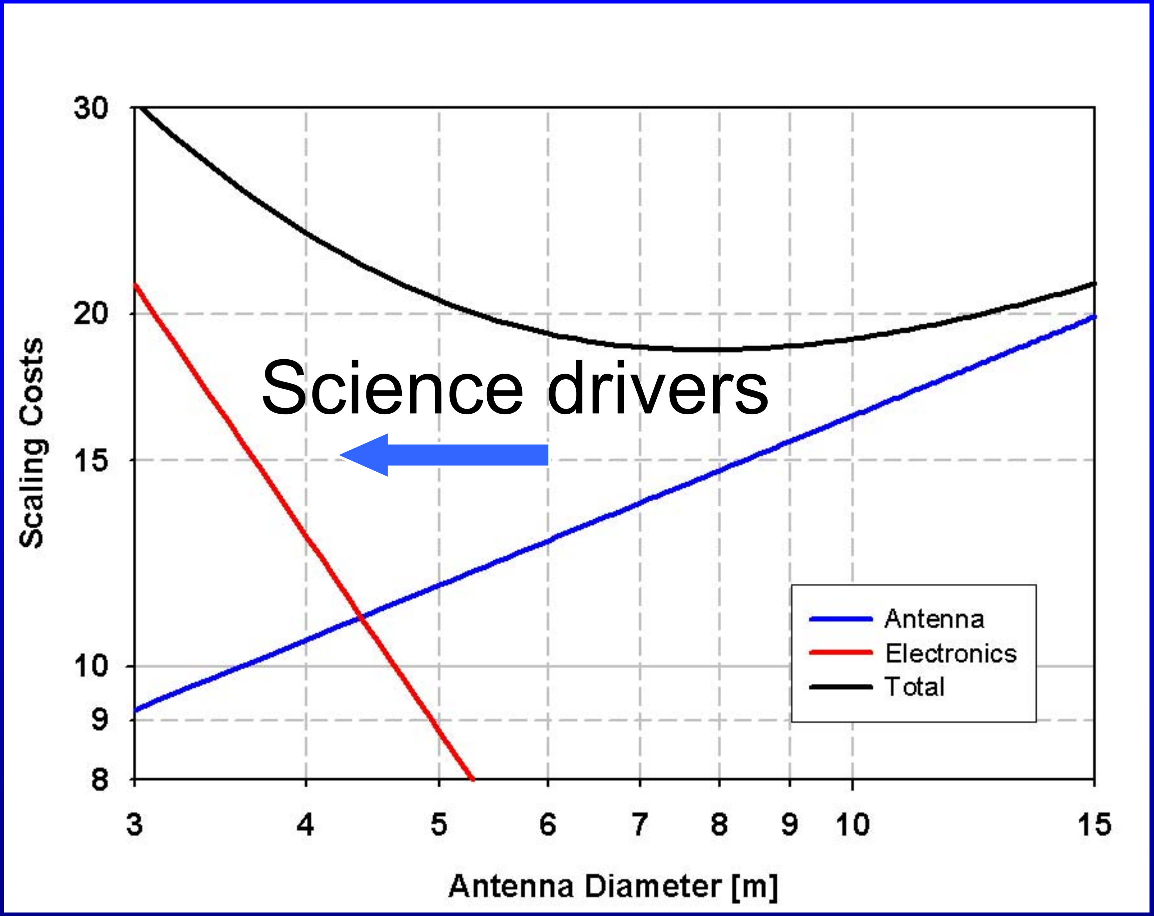


Figure 17: Adaptive cancellation of a Global Positioning System signal using a reference antenna and Wiener filter method. The blue curve is the primary spectrum including GPS. The green curve is the residual spectrum after cancellation. Over 30 dB of interference rejection is achieved.

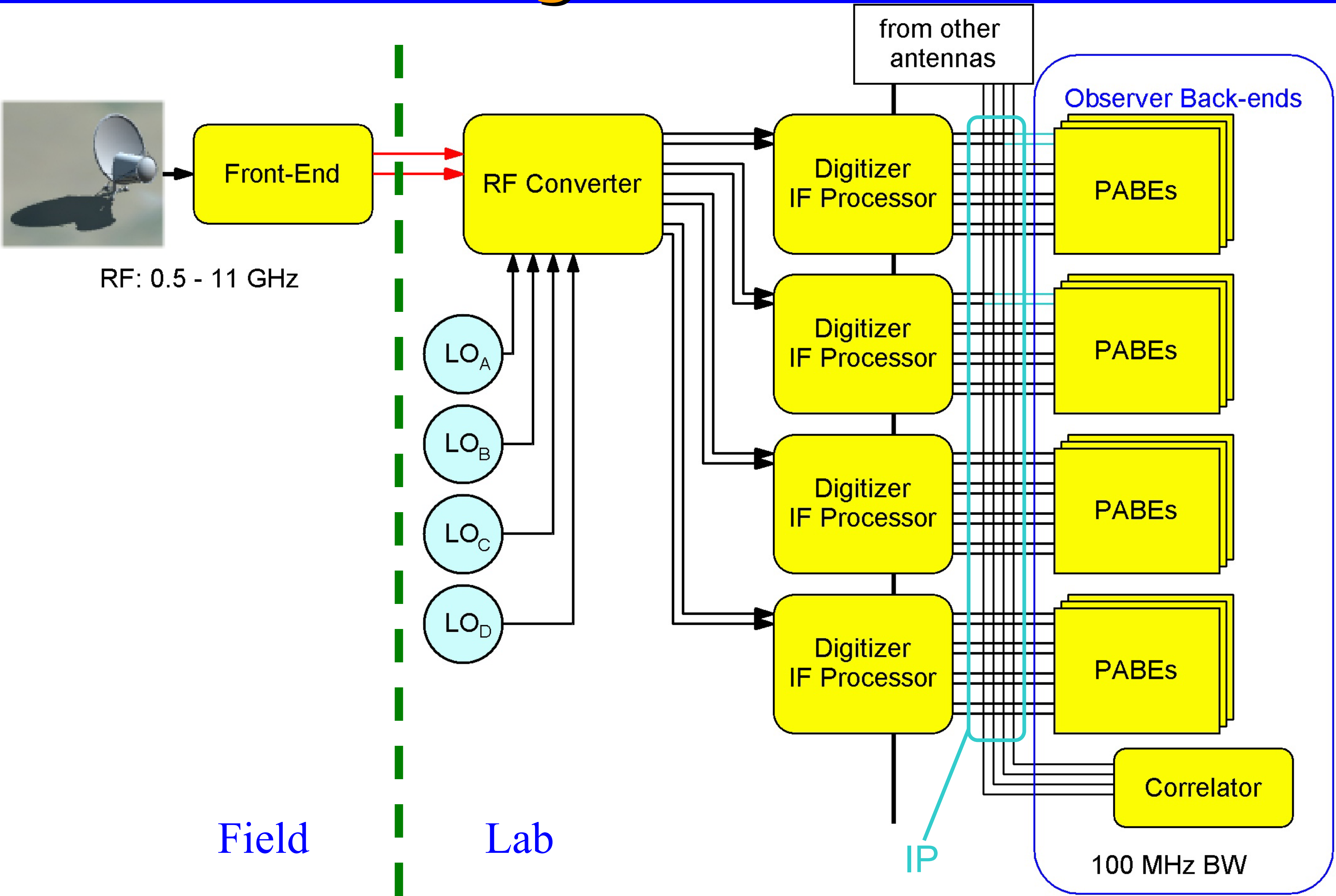
Cost Curve

Fixed area

Fixed UWB



Signal Path



from other antennas
Observer Back-ends
Front-End
RF Converter
Digitizer
IF Processor
Digitizer
IF Processor
Digitizer
IF Processor
Digitizer
IF Processor
PABEs
PABEs
PABEs
PABEs
RF: 0.5 - 11 GHz
LO_A
LO_B
LO_C
LO_D
Correlator
IP
100 MHz BW
Field
Lab

ATA Signal Path for PABEs (by Antenna by Card)

The following components may be used to construct descriptors that denote data streams or hardware through which data streams pass:

zone (1-35)
element (a-m)
polarization (X|Y)
tuning (A|B|C|D)
delay set (1-4)

For example:

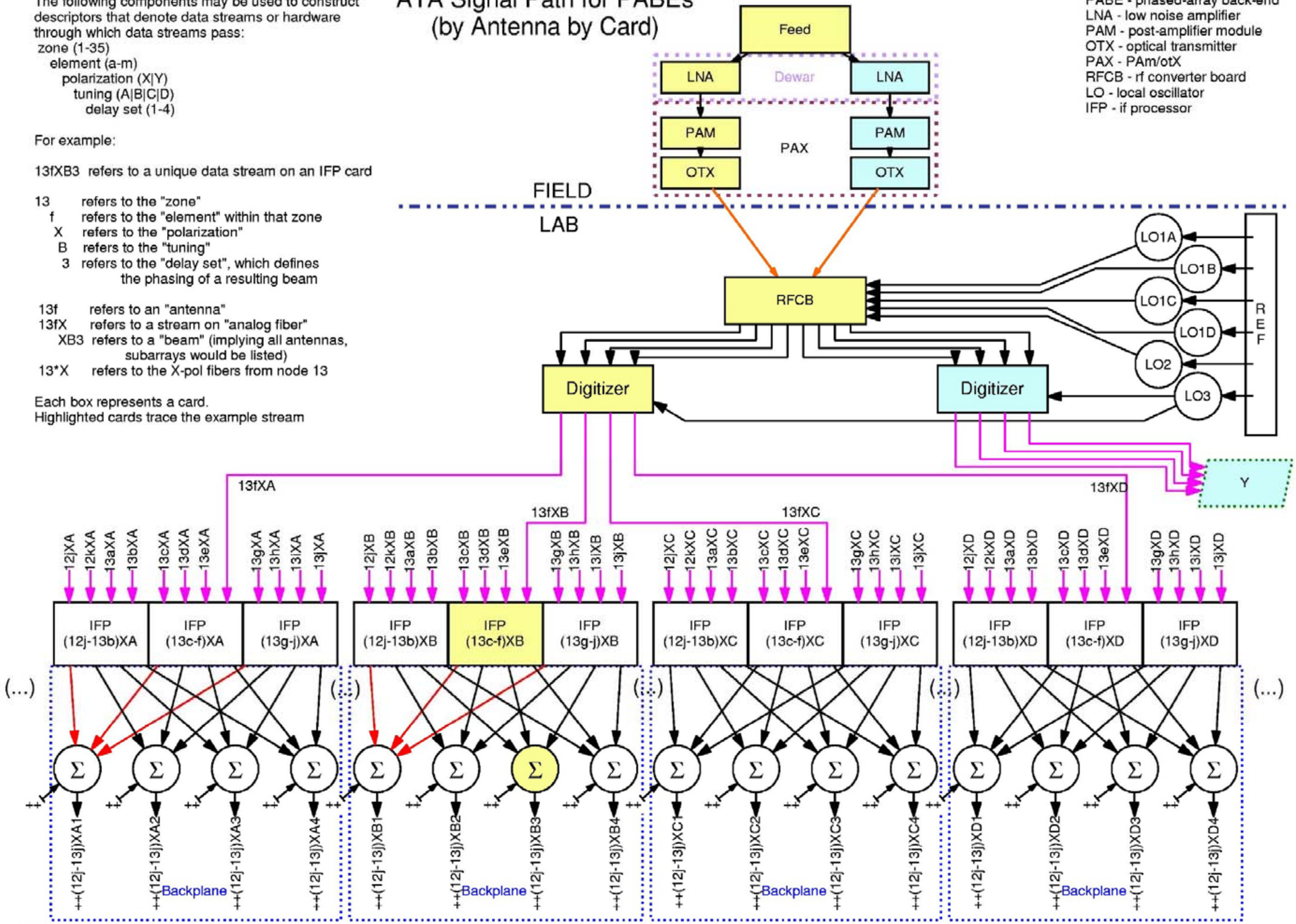
13fXB3 refers to a unique data stream on an IFP card

13 refers to the "zone"
f refers to the "element" within that zone
X refers to the "polarization"
B refers to the "tuning"
3 refers to the "delay set", which defines the phasing of a resulting beam

13f refers to an "antenna"
13fX refers to a stream on "analog fiber"
XB3 refers to a "beam" (implying all antennas, subarrays would be listed)
13*X refers to the X-pol fibers from node 13

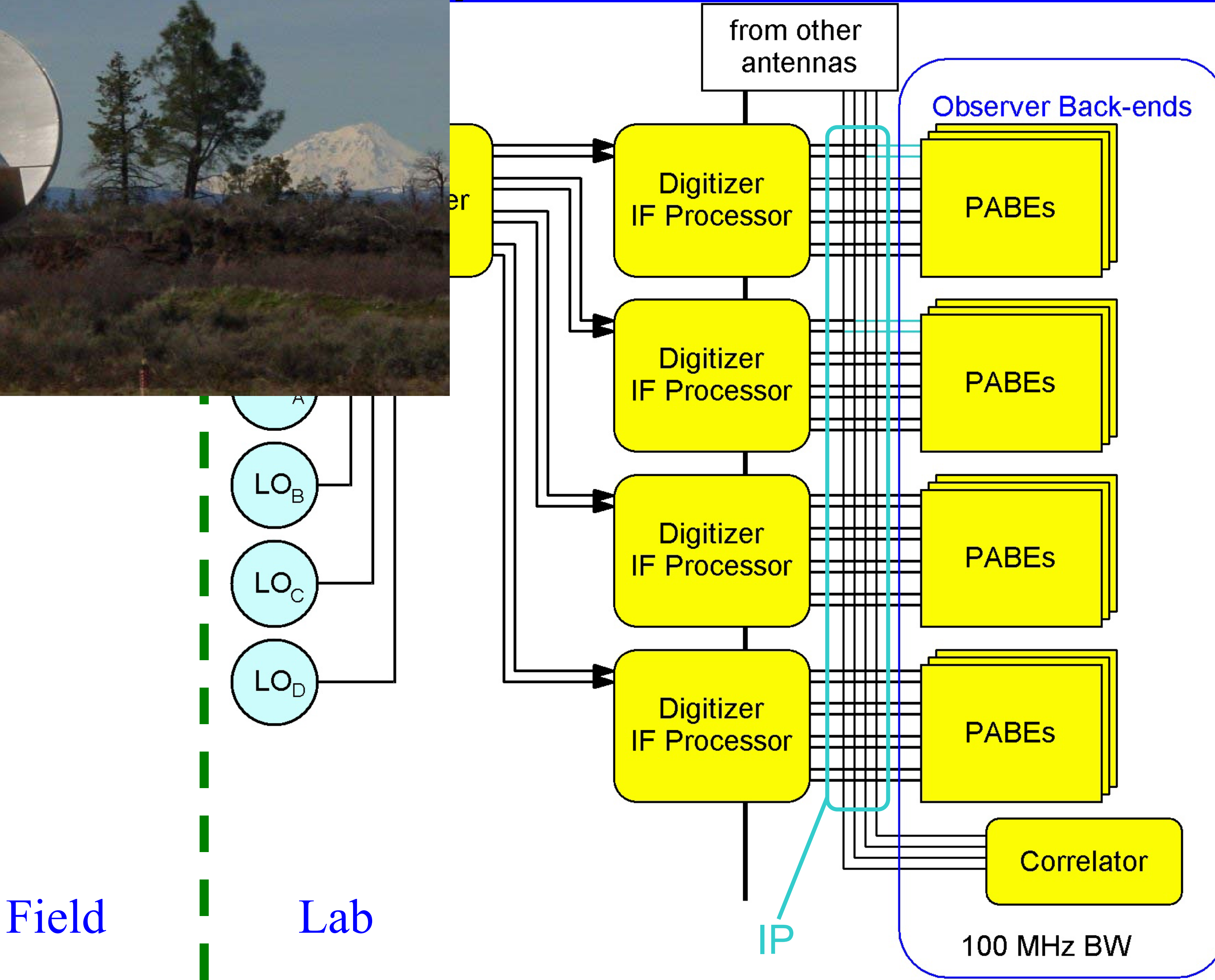
Each box represents a card.
Highlighted cards trace the example stream

PABE - phased-array back-end
LNA - low noise amplifier
PAM - post-amplifier module
OTX - optical transmitter
PAX - PAm/otX
RFCB - rf converter board
LO - local oscillator
IFP - if processor



DRD 2/12/2004

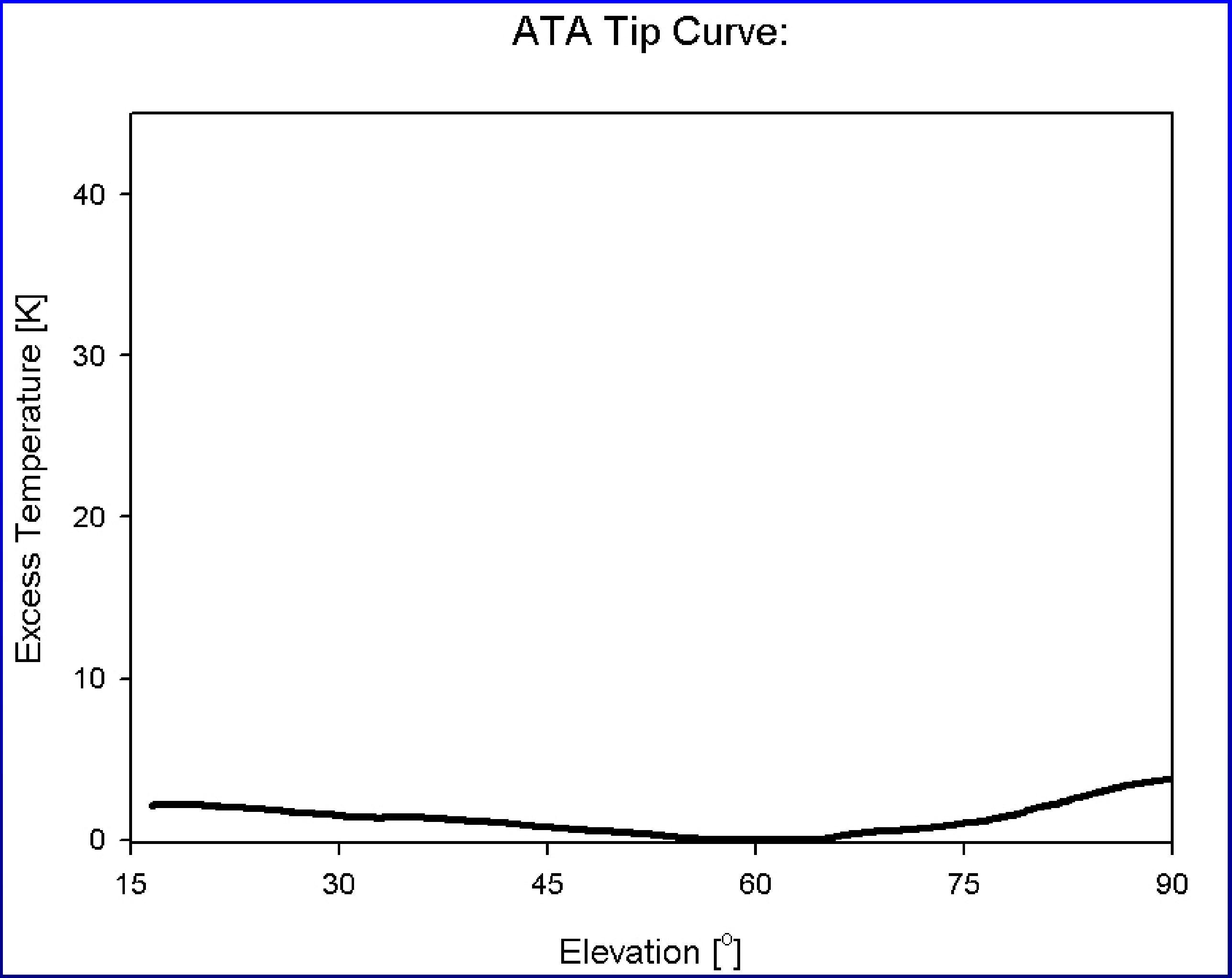
Antenna/Front-end



Antenna

- 6.1-meter offset Gregorian (2.4-meter secondary)
- rim-supported, hydroformed dishes

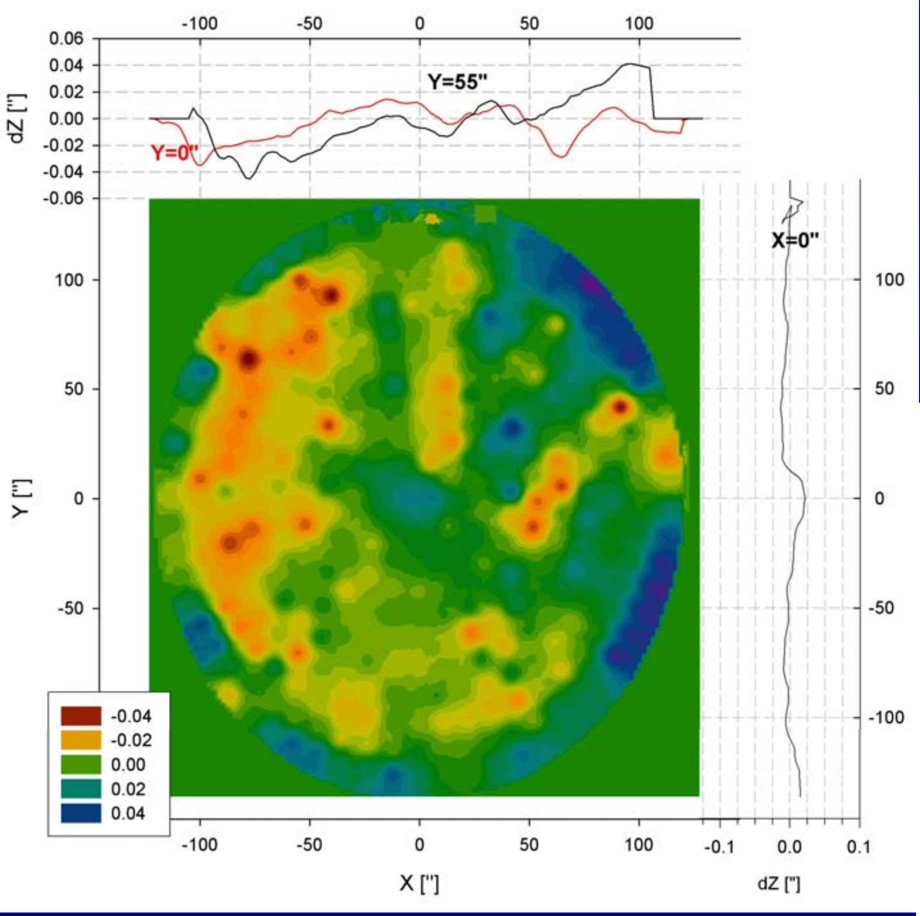
Tip Curve



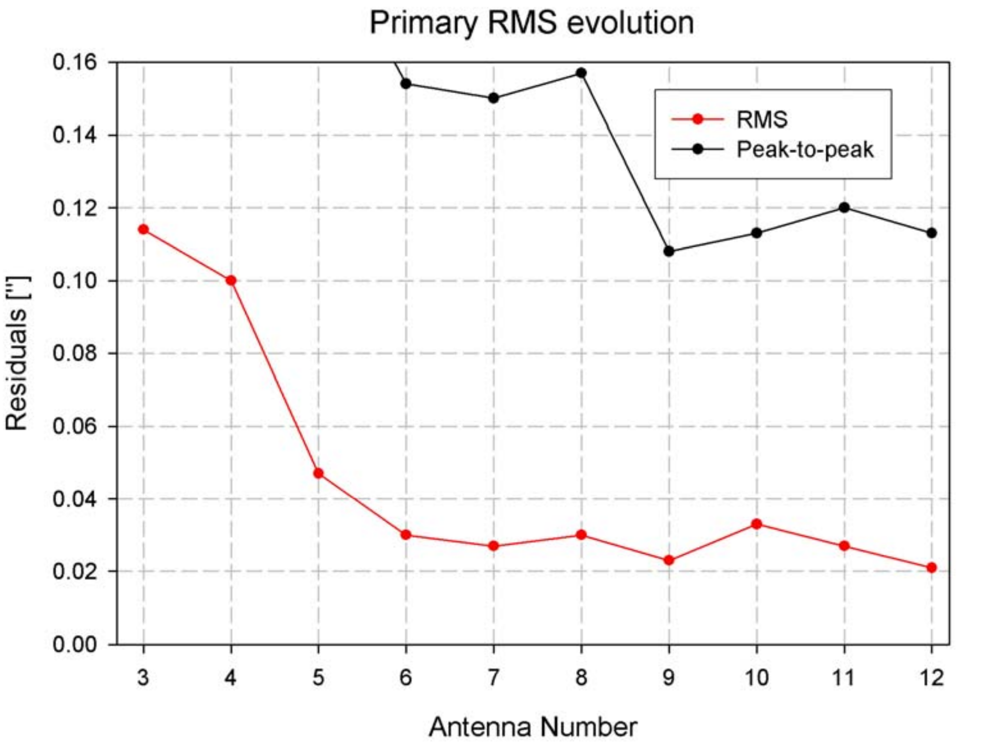
ATA Tip Curve:
Excess Temperature [K]
0
10
20
30
40
15
30
45
60
75
90
Elevation [°]

Antenna

Antenna Surface



- rms: 0.022” (0.56mm)
- p-p: 0.118” (3mm)

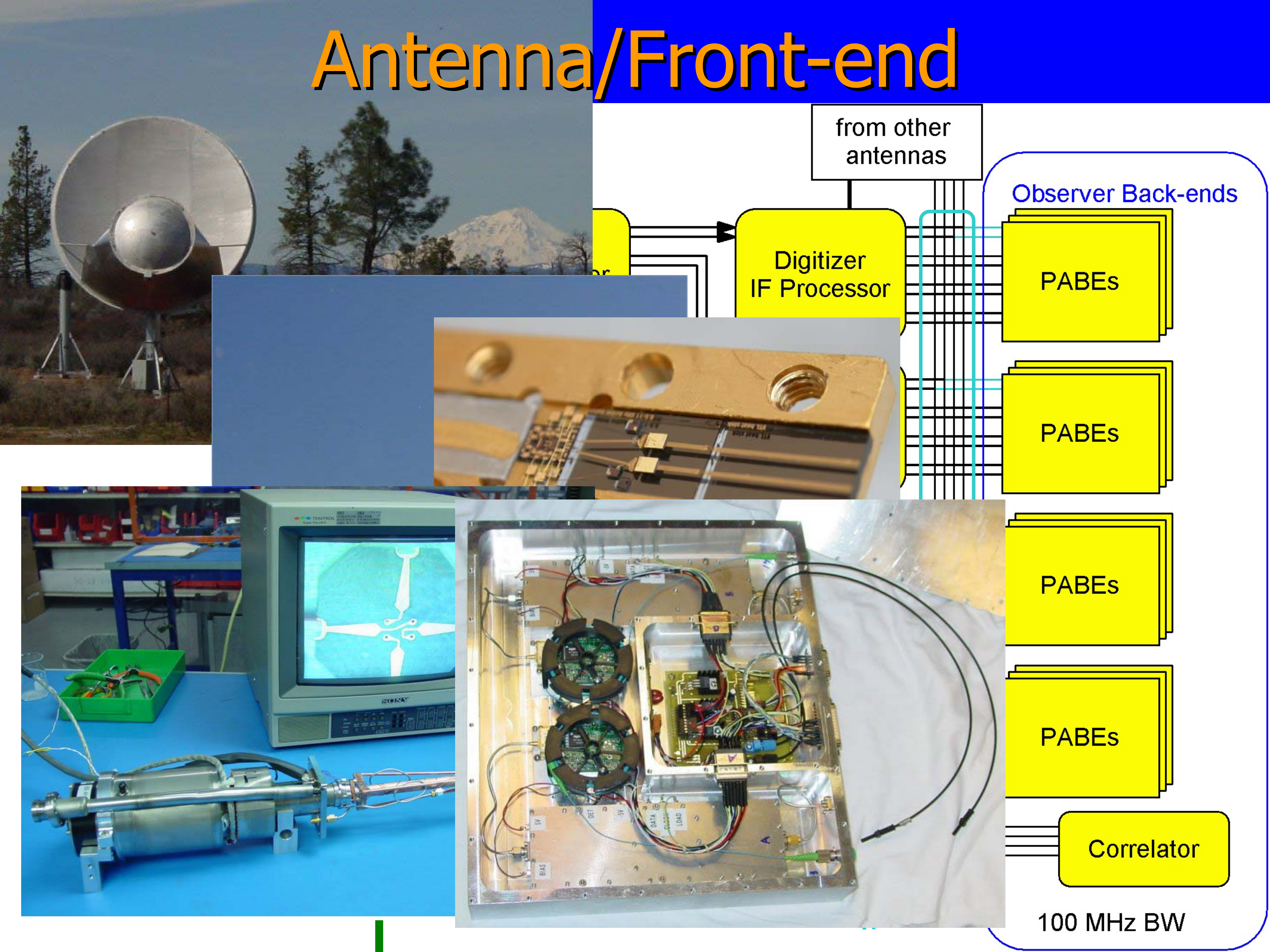


Construction Tent

mbly

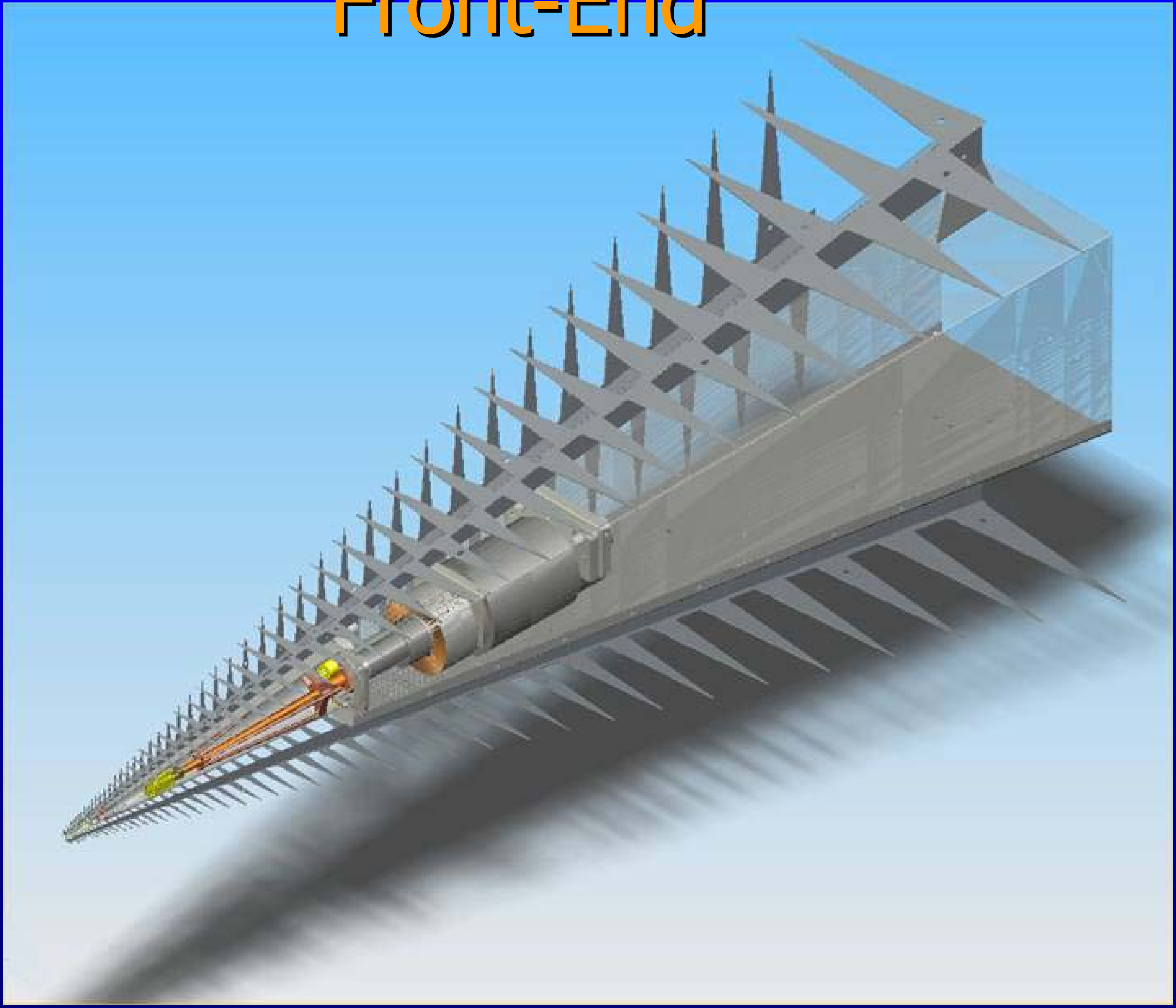

SS-836

Antenna/Front-end

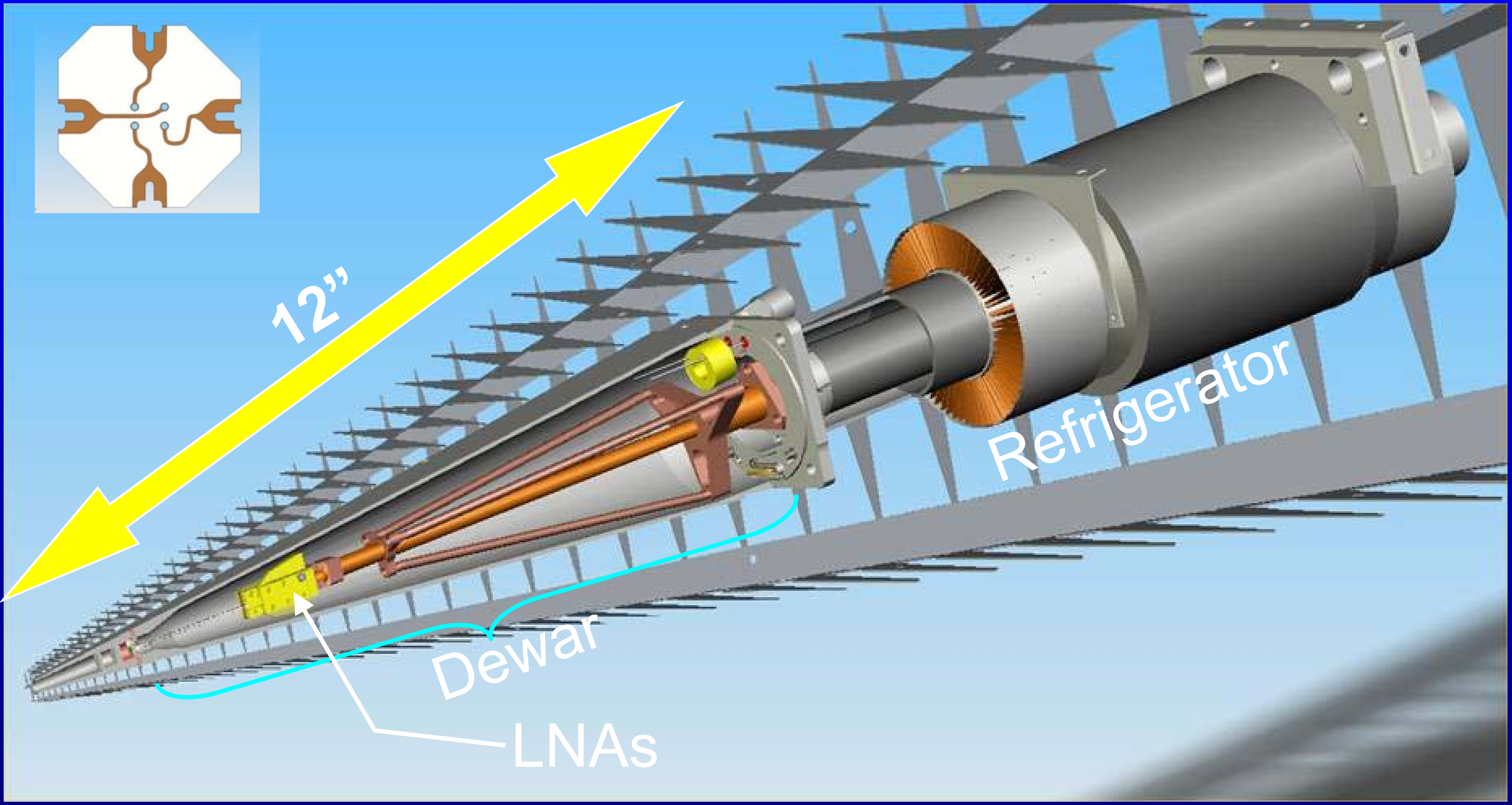


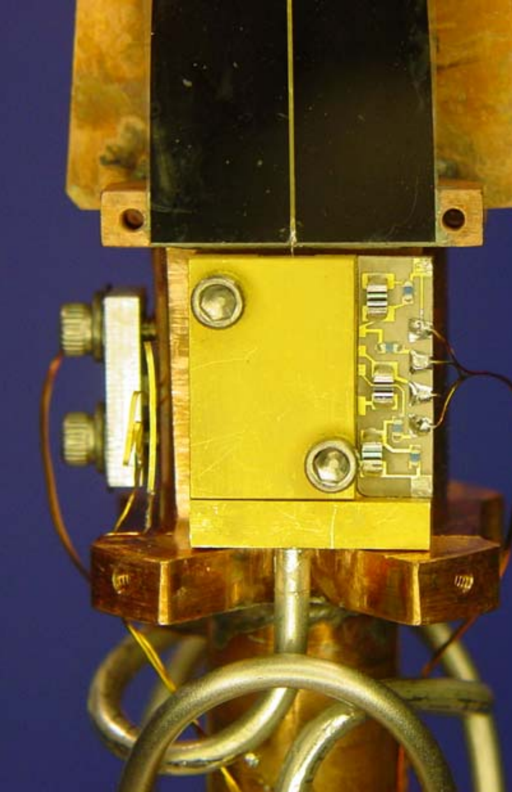

0.5 – 12.0 GHz

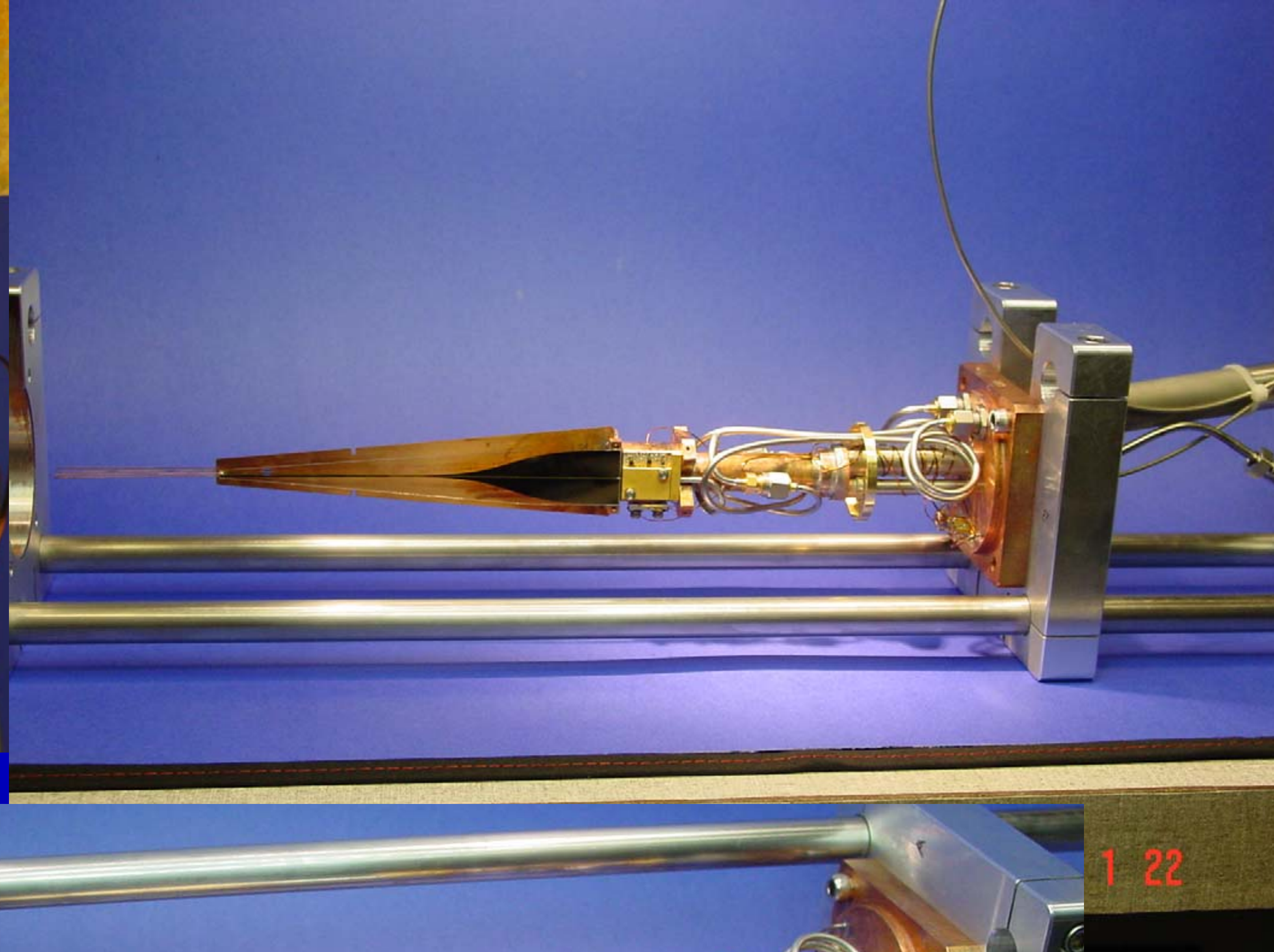
Front-End



Dewar/Cryo



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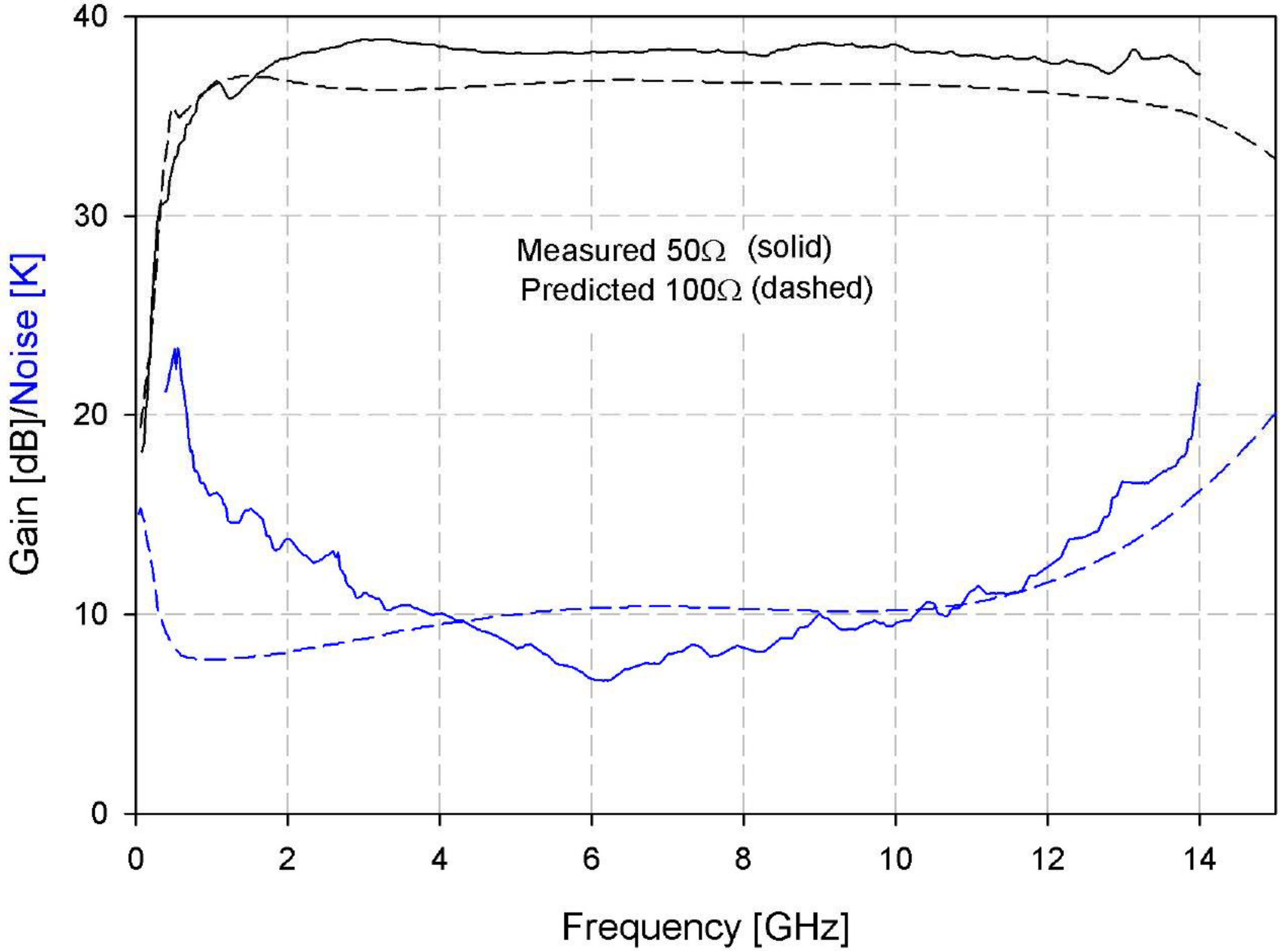
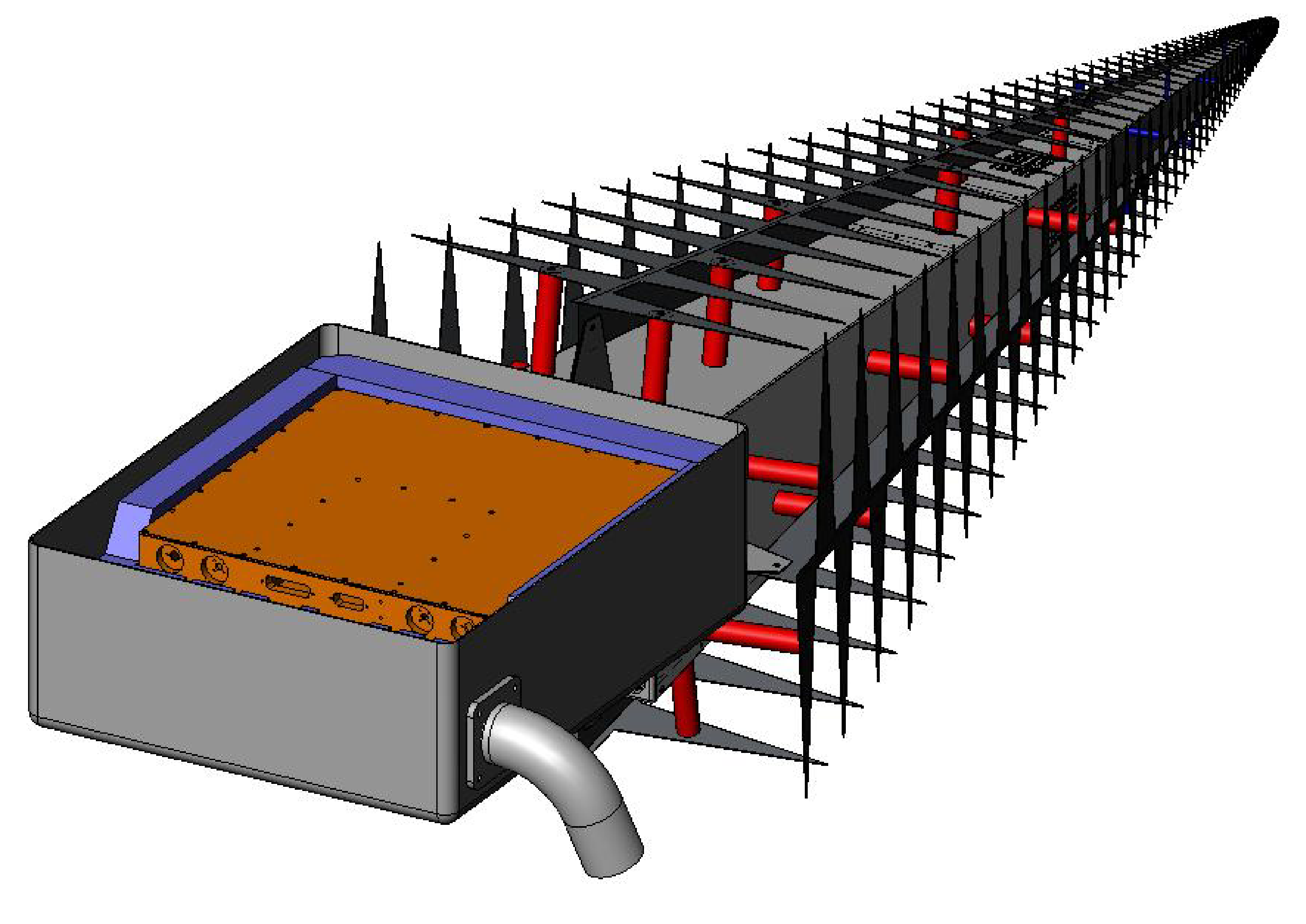


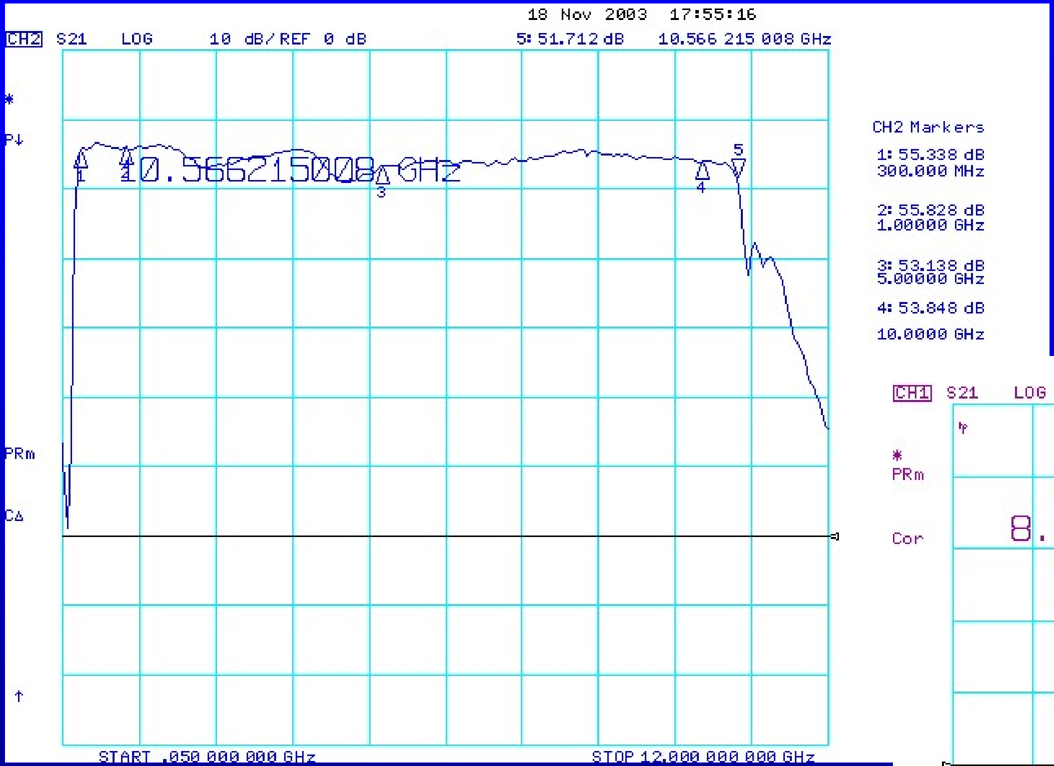
40
30
20
10
0
Gain [dB]/Noise [K]
Measured 50Ω (solid)
Predicted 100Ω (dashed)
0
2
4
6
8
10
12
14
Frequency [GHz]

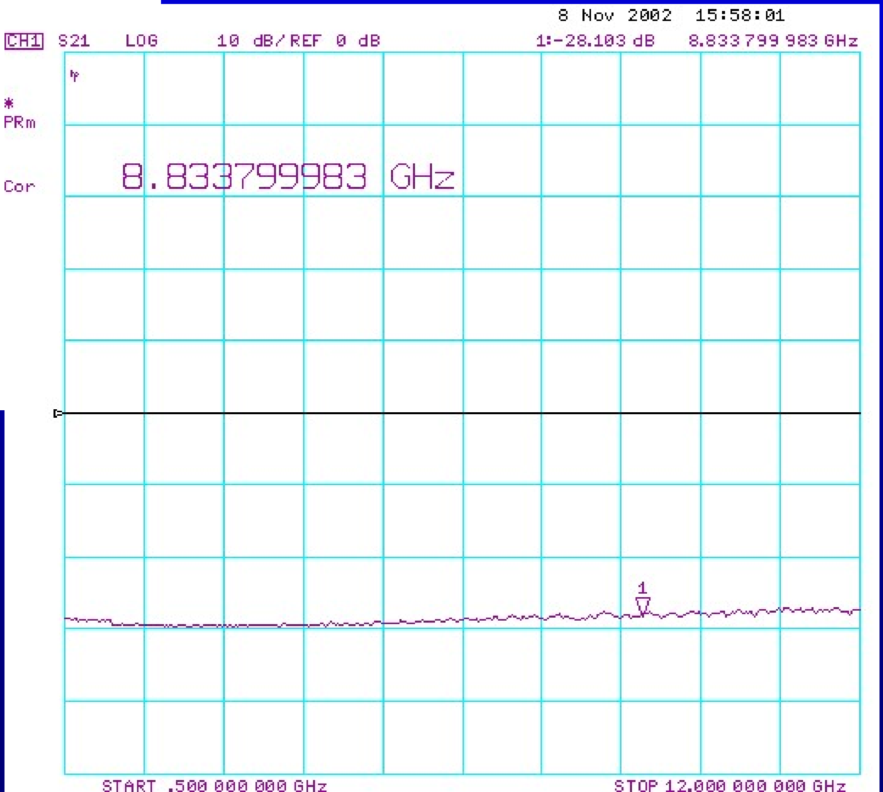


PAX

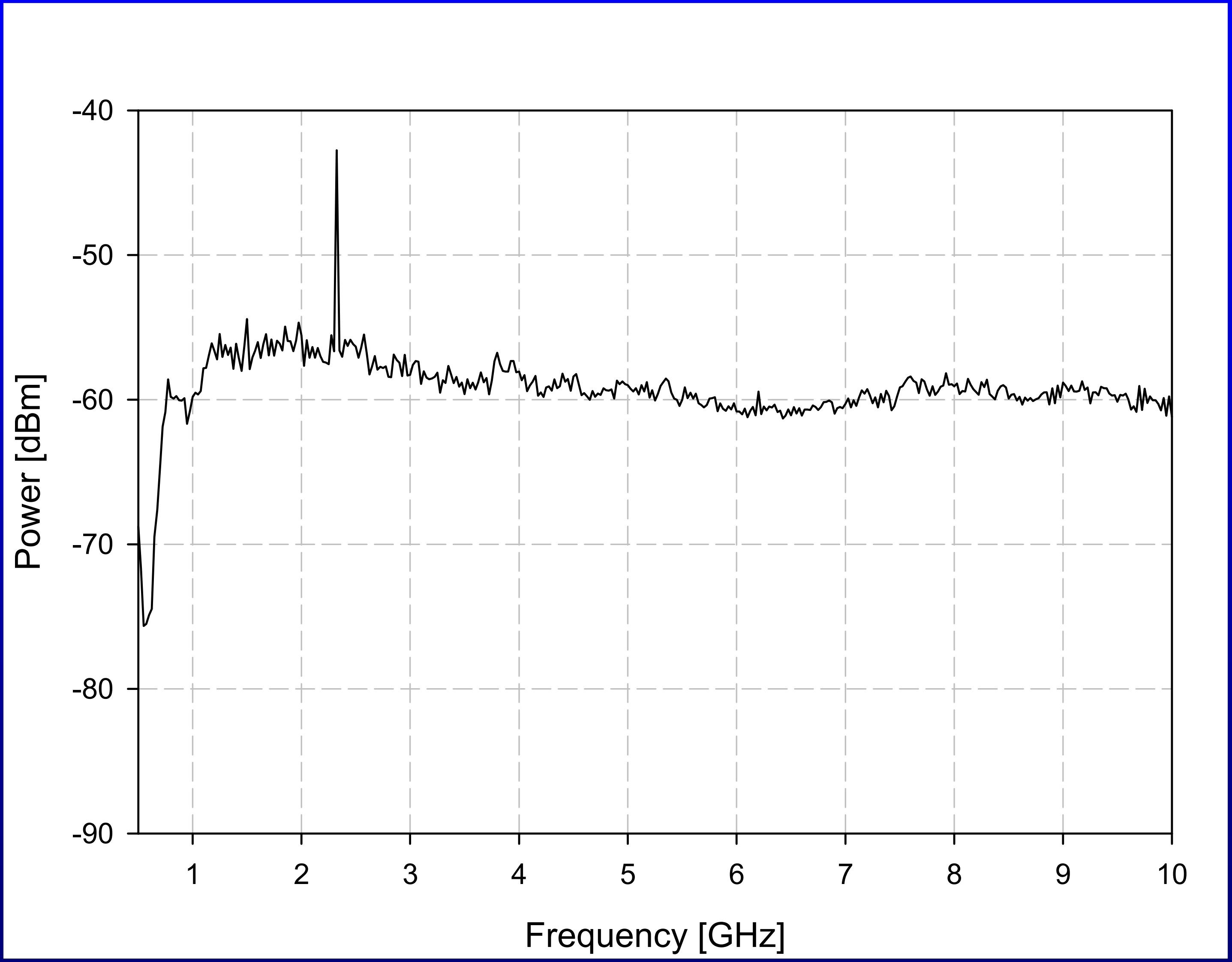
PAM

OTX

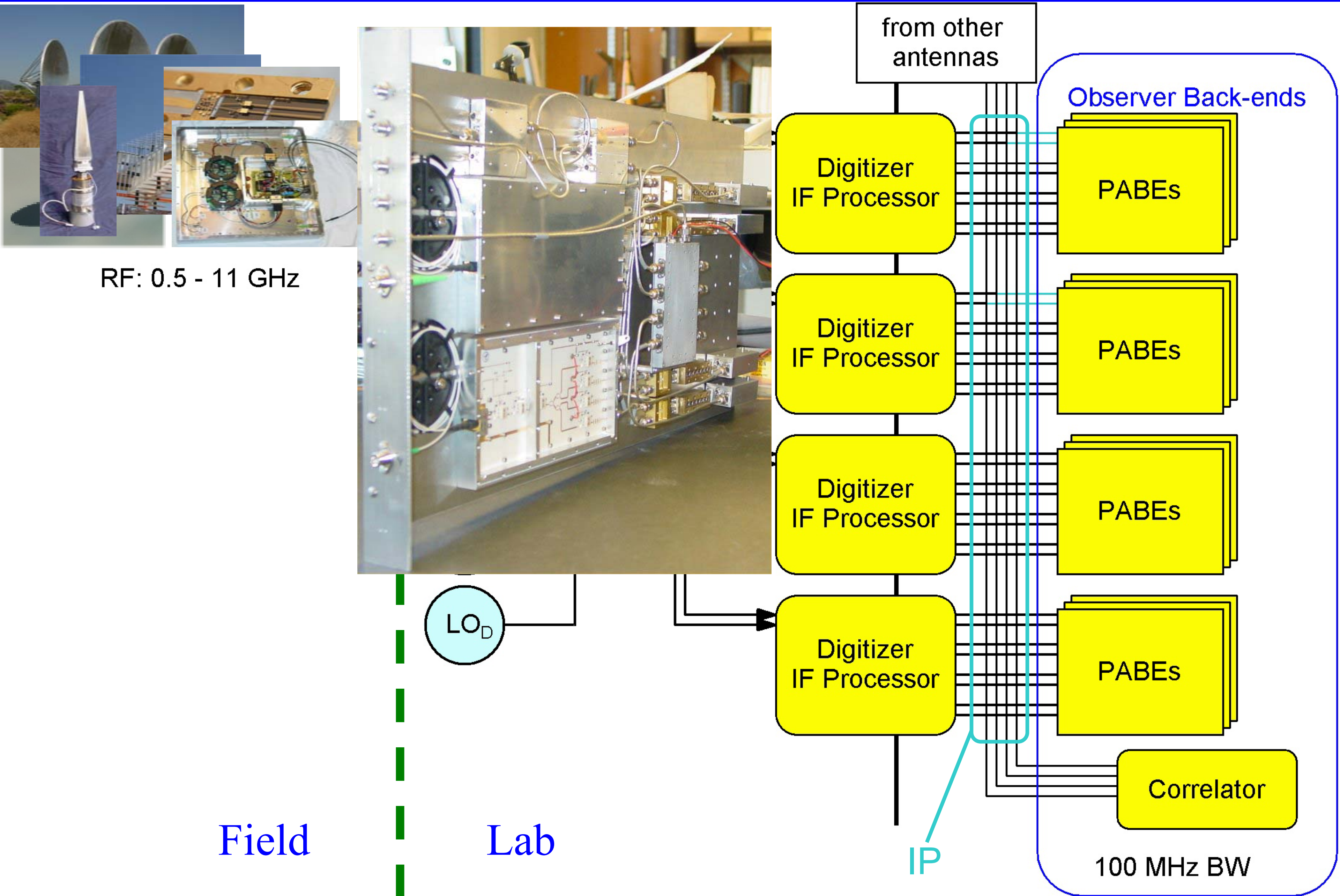

18 Nov 2003 17:55:16
CH2 S21 LOG 10 dB/ REF 0 dB 5: 51.712 dB 10.566 215 008 GHz
10.566215008 GHz
CH2 Markers
1: 55.338 dB
300.000 MHz
2: 55.828 dB
1.00000 GHz
3: 53.138 dB
5.00000 GHz
4: 53.848 dB
10.0000 GHz
START .050 000 000 GHz
STOP 12.000 000 000 GHz


8 Nov 2002 15:58:01
CH1 S21 LOG 10 dB/ REF 0 dB 1:-28.103 dB 8.833 799 983 GHz
8.833799983 GHz
PRm
Cor
START .500 000 000 GHz
STOP 12.000 000 000 GHz

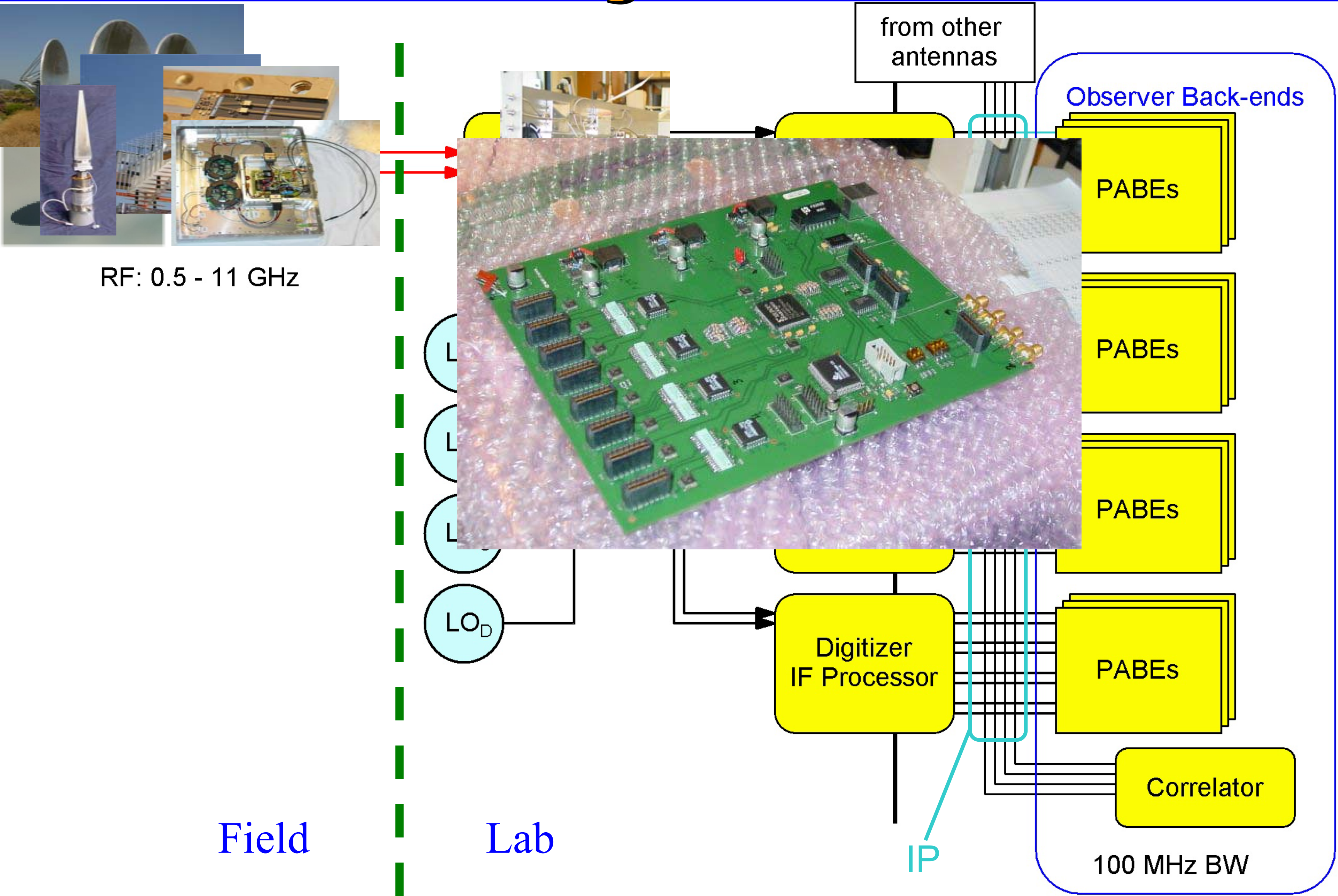
Full Spectrum



RF Converter

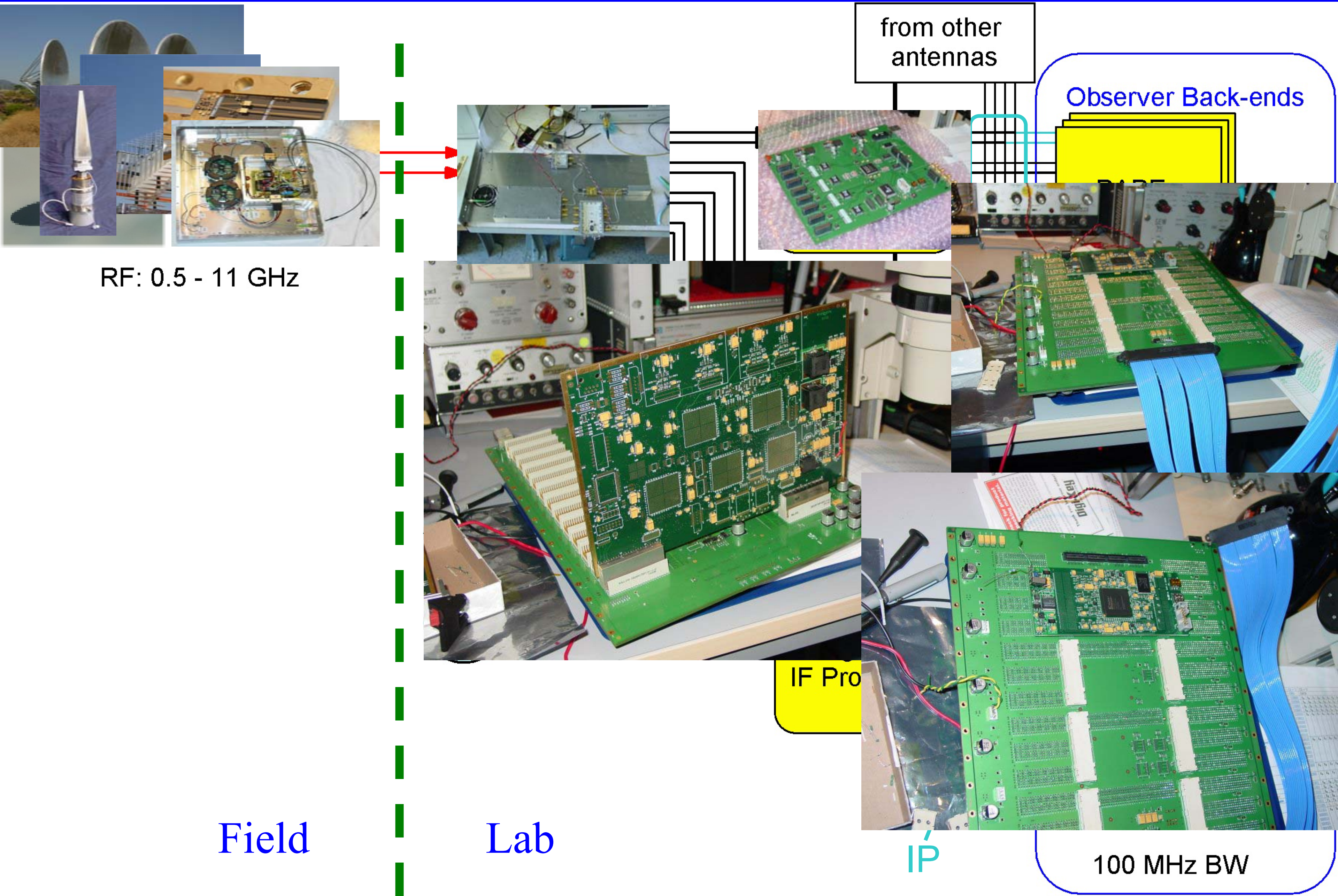


Digitizer

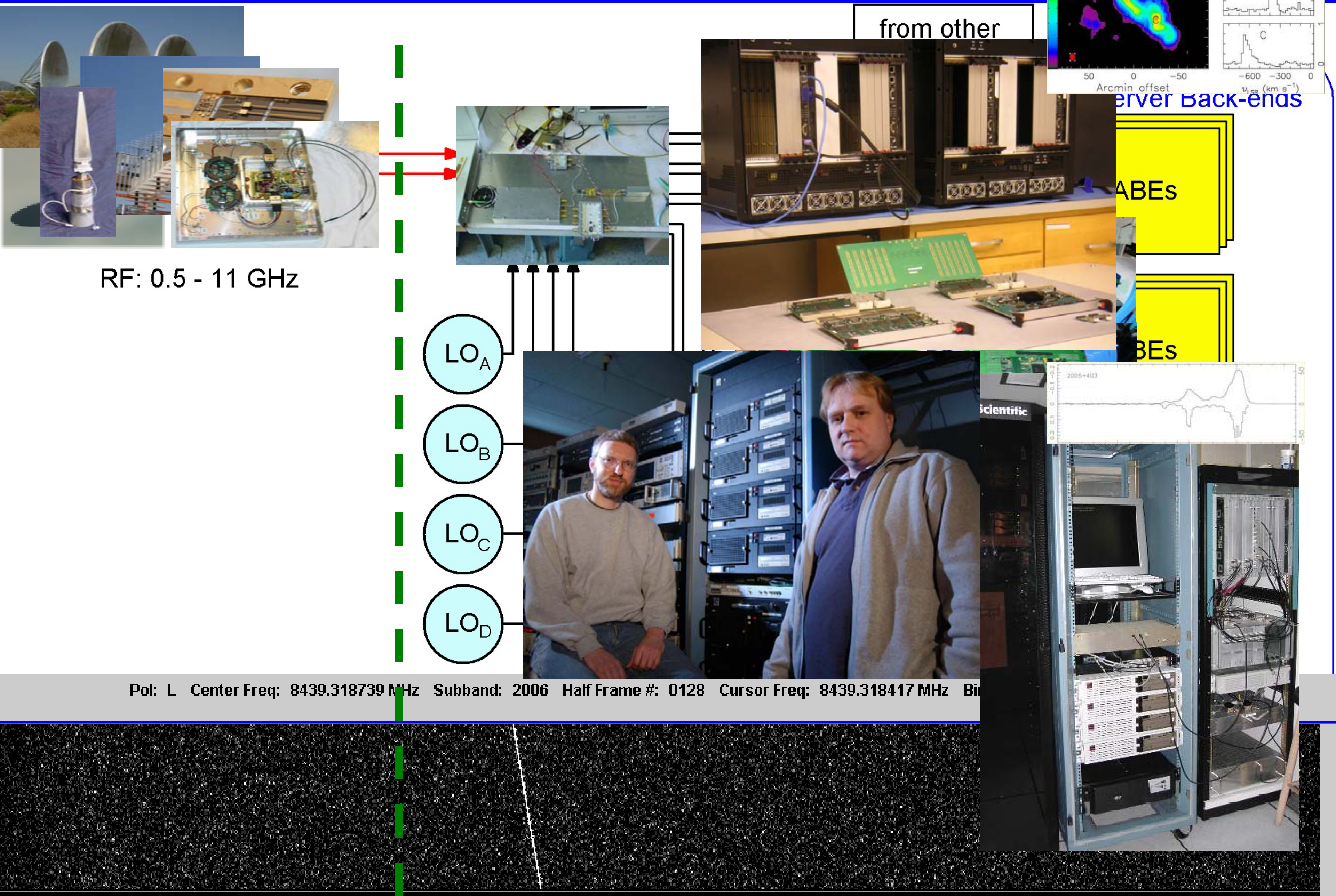


from other antennas
Observer Back-ends
PABEs
PABEs
PABEs
PABEs
RF: 0.5 - 11 GHz
LO$_D$
Digitizer IF Processor
Correlator
IP
100 MHz BW
Field
Lab

IF Processor

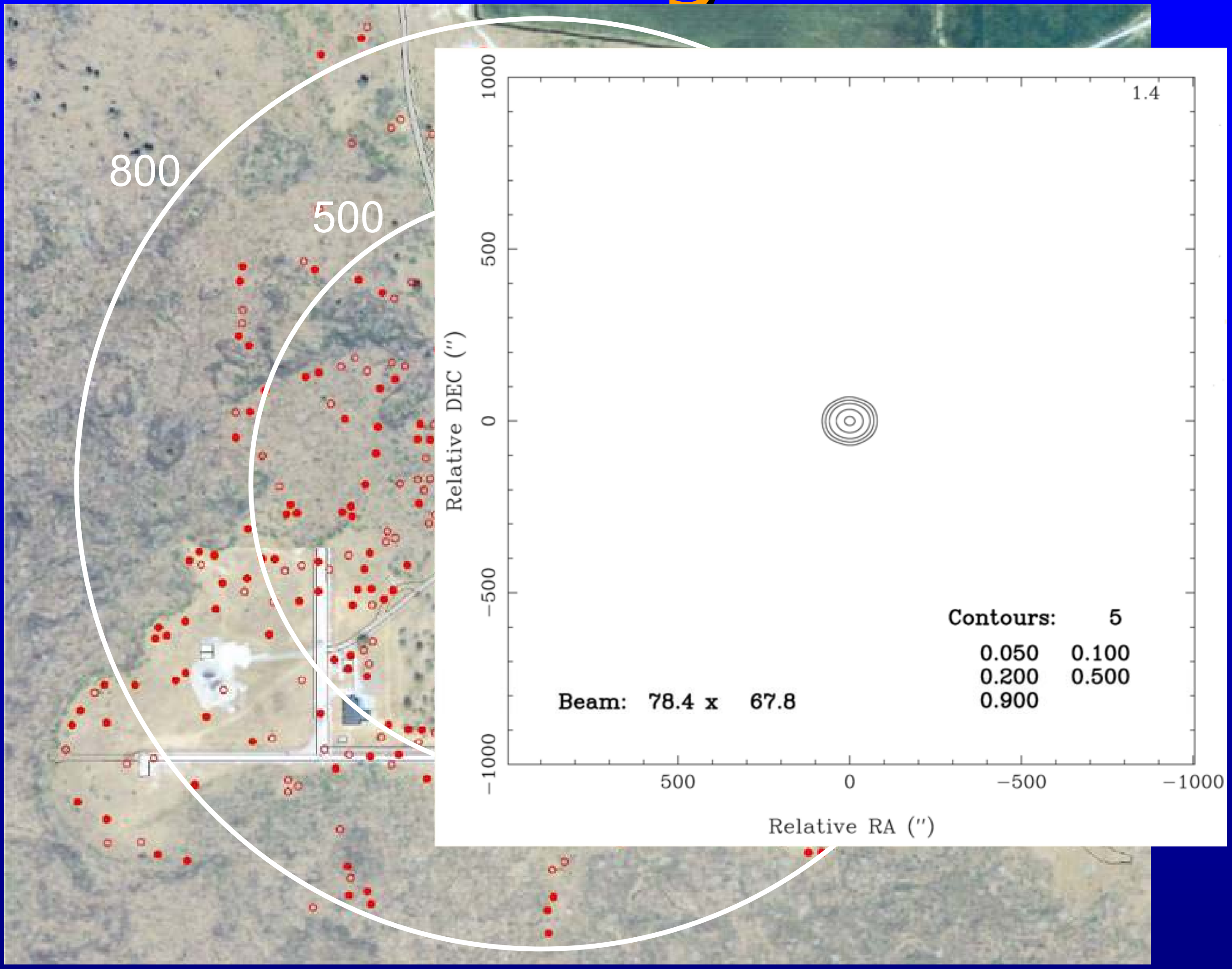


Back-ends

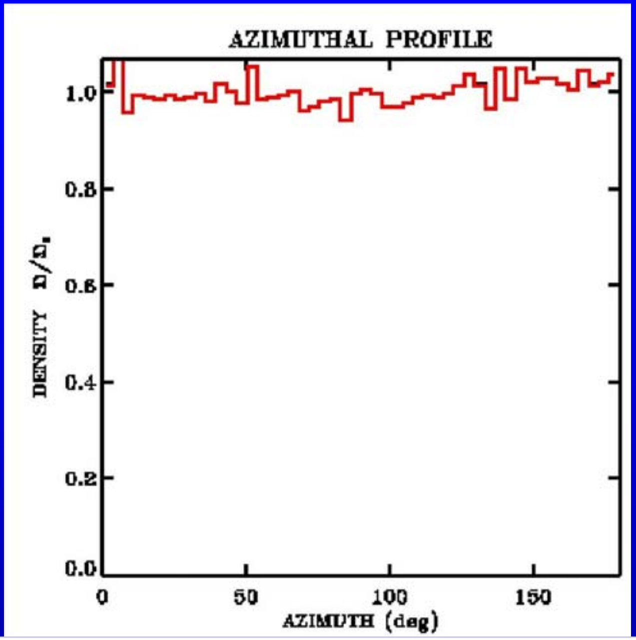


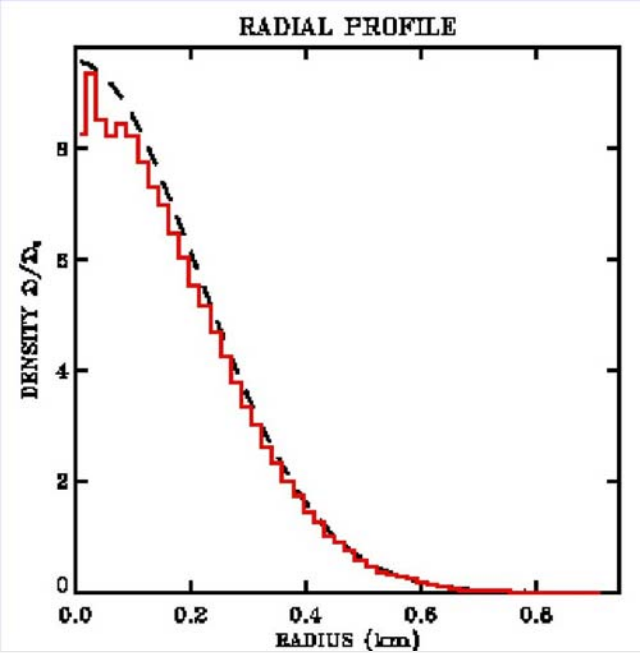
from other
erver Back-ends
ABEs
BEs
RF: 0.5 - 11 GHz
LO$_A$
LO$_B$
LO$_C$
LO$_D$
Pol: L Center Freq: 8439.318739 MHz Subband: 2006 Half Frame #: 0128 Cursor Freq: 8439.318417 MHz Bi
Scientific
A
B
C
50 0 -50
Arcmin offset
-600 -300 0

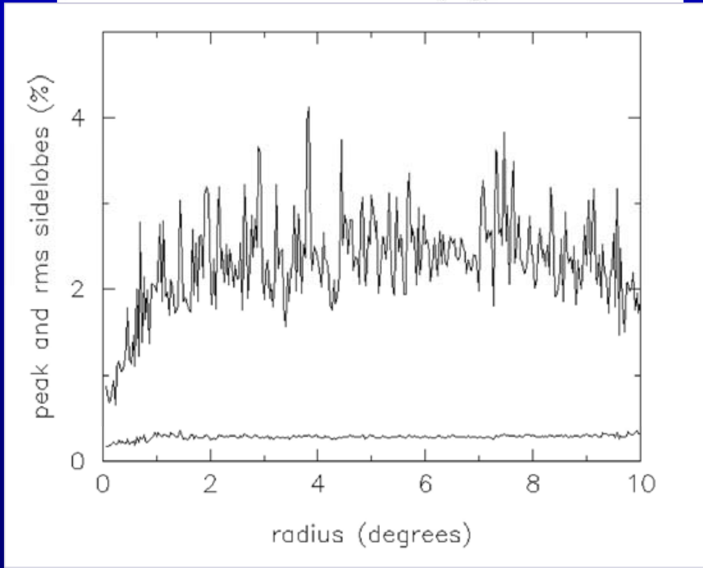
ATA-350 Configuration

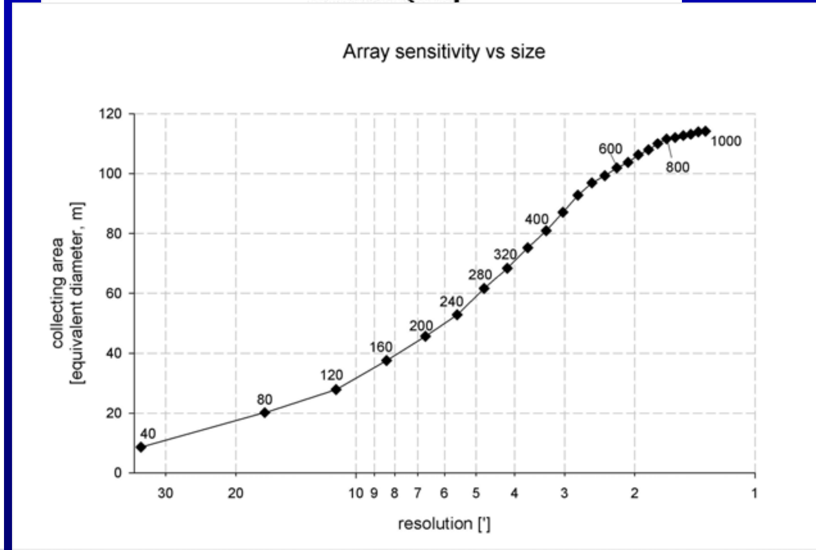


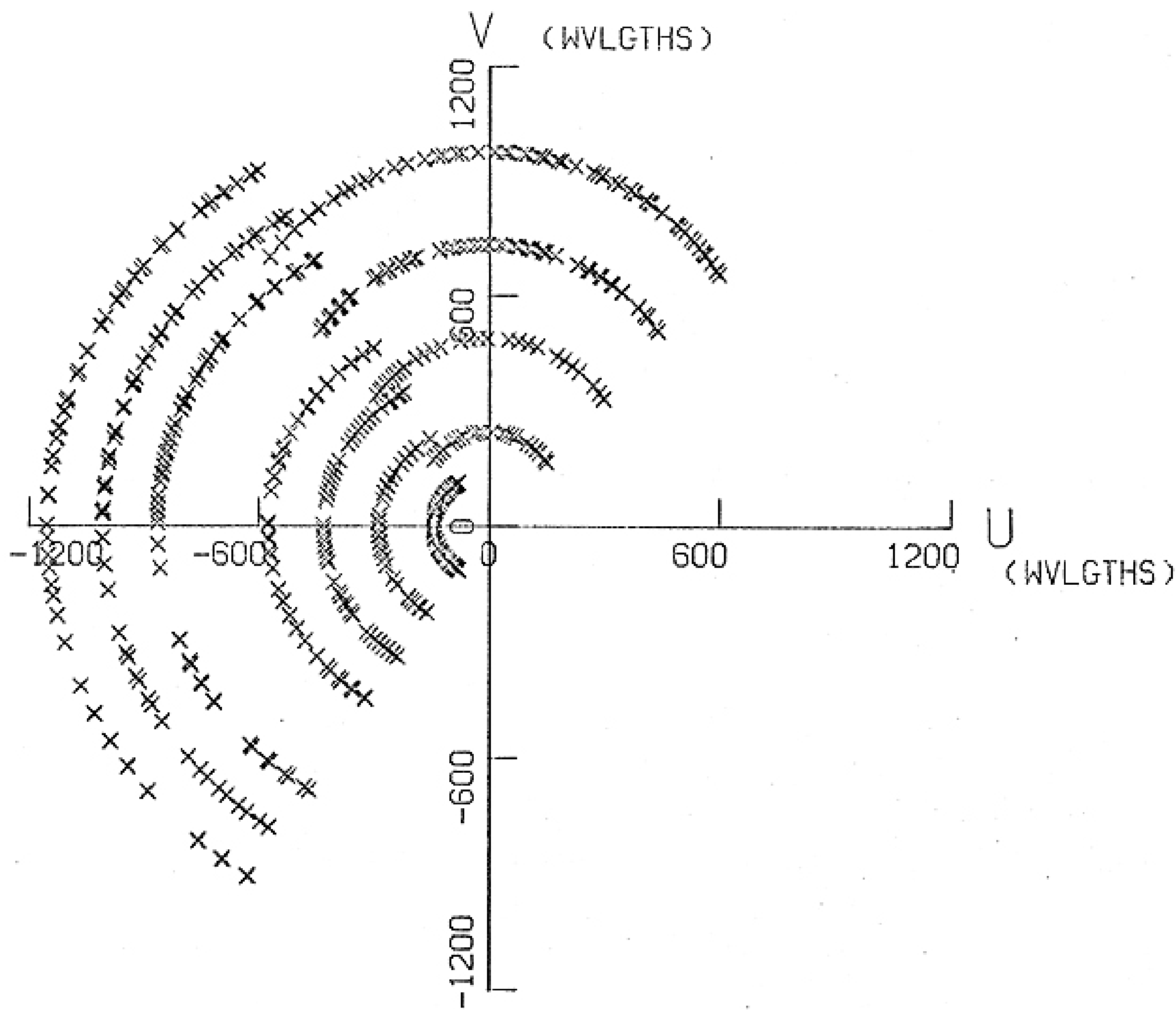
UV Distribution

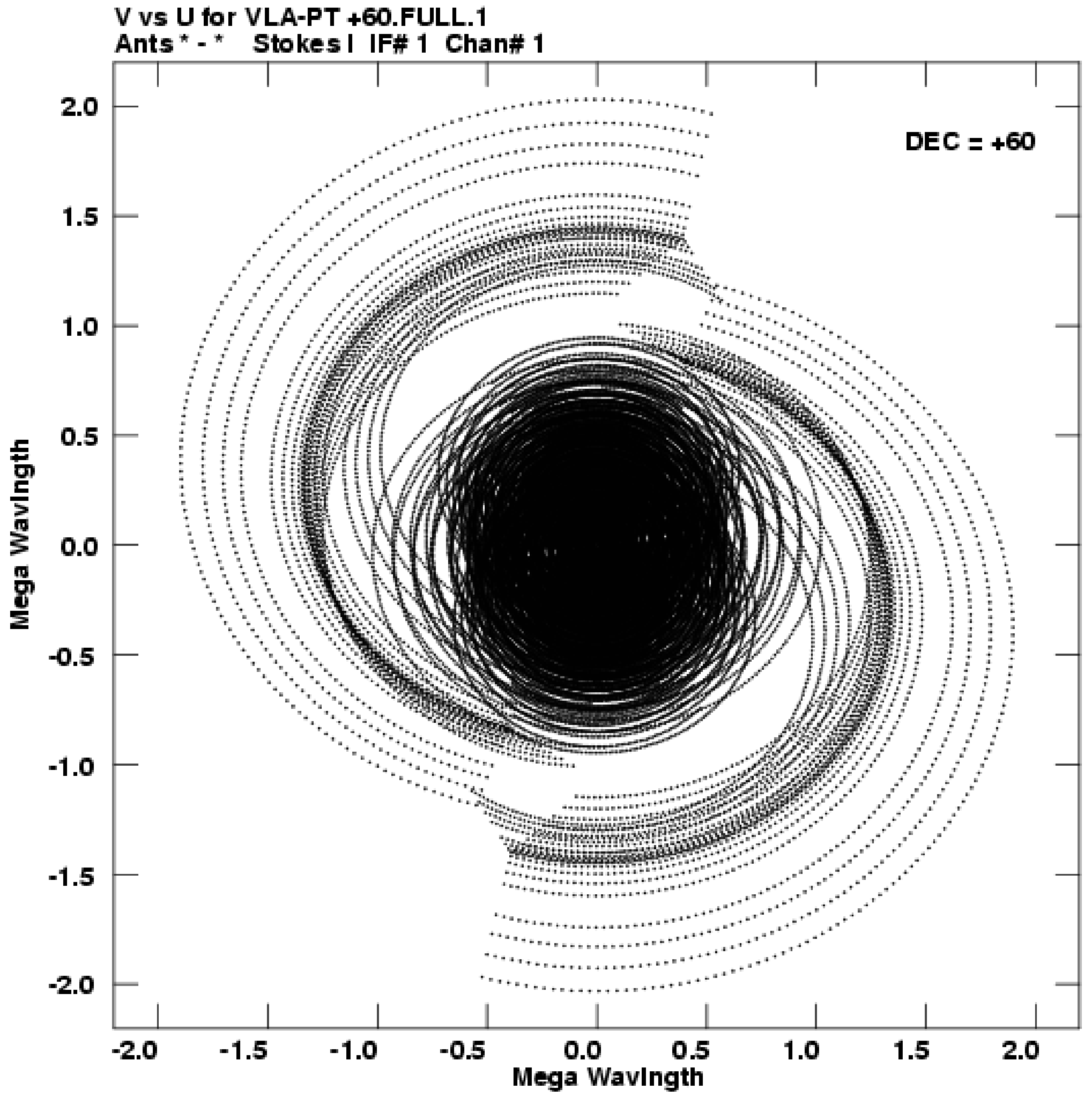


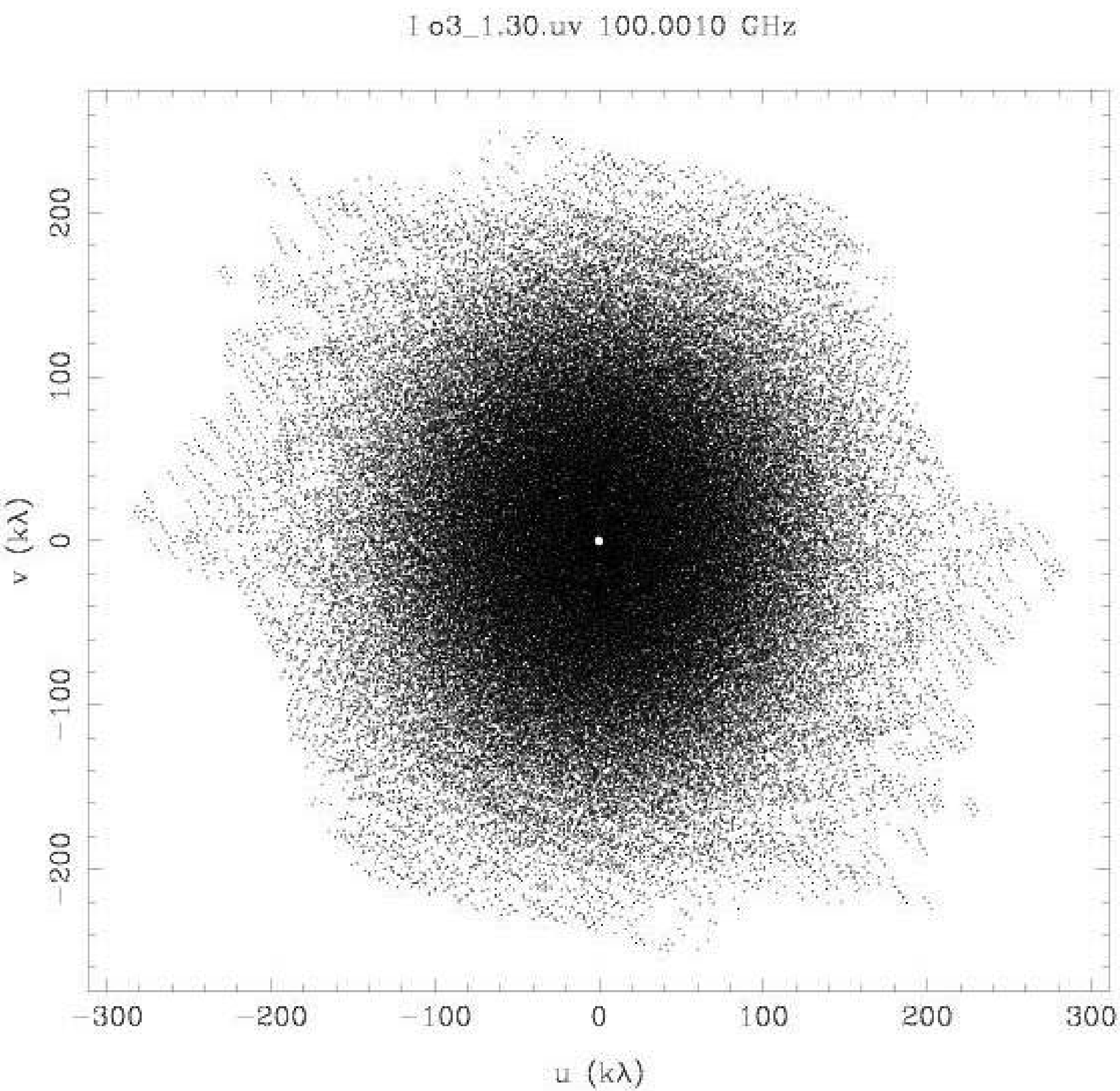







V (WVLGTHS)
1200
600
0
-600
-1200
-1200
-600
0
600
1200
U (WVLGTHS)

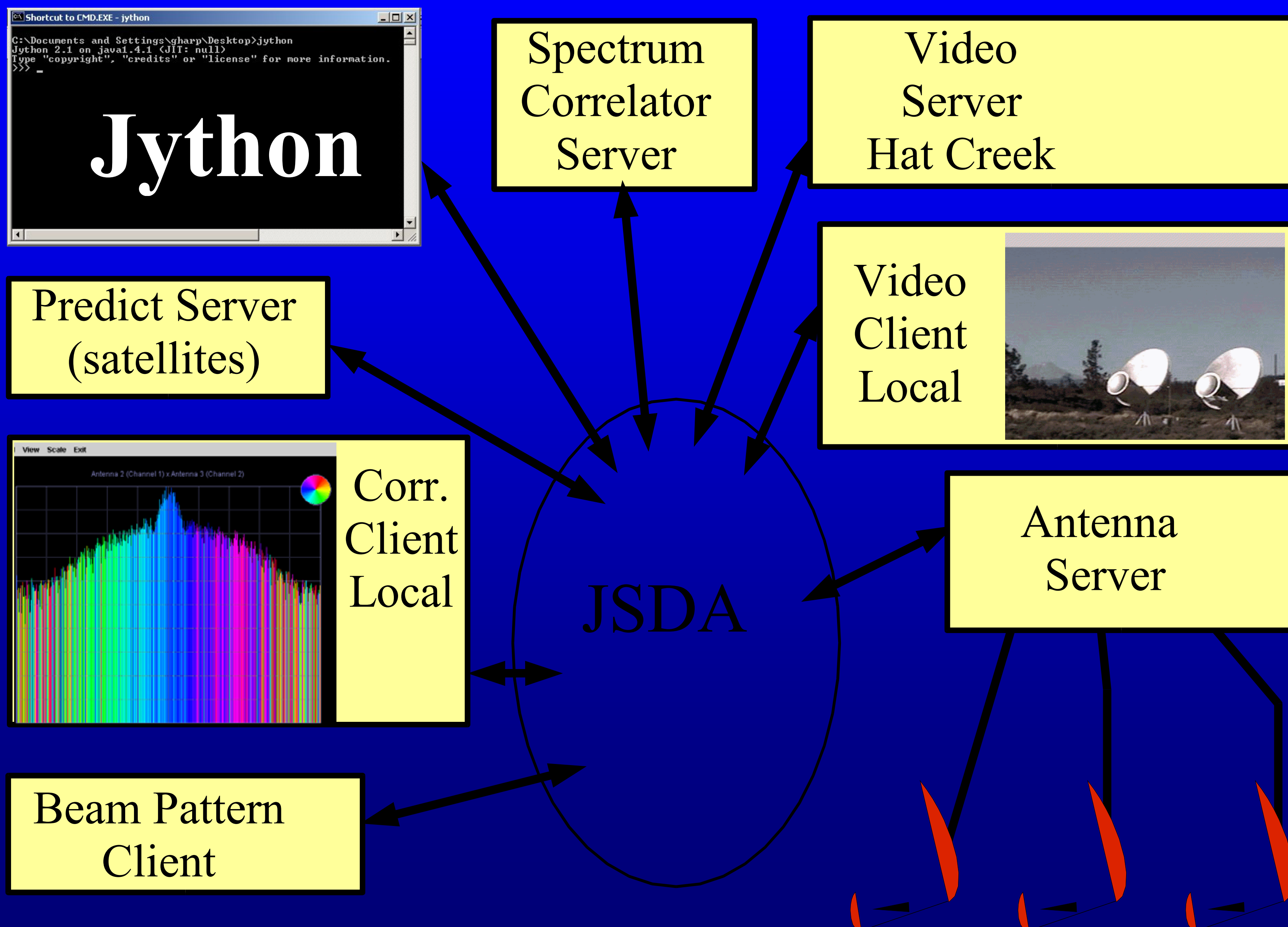

V vs U for VLA-PT +60.FULL.1
Ants * - * Stokes I IF# 1 Chan# 1
DEC = +60
Mega Wavlngth
Mega Wavlngth
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0


I o3_1.30.uv 100.0010 GHz
v (kλ)
200
100
0
-100
-200
-300
-200
-100
0
100
200
300
u (kλ)

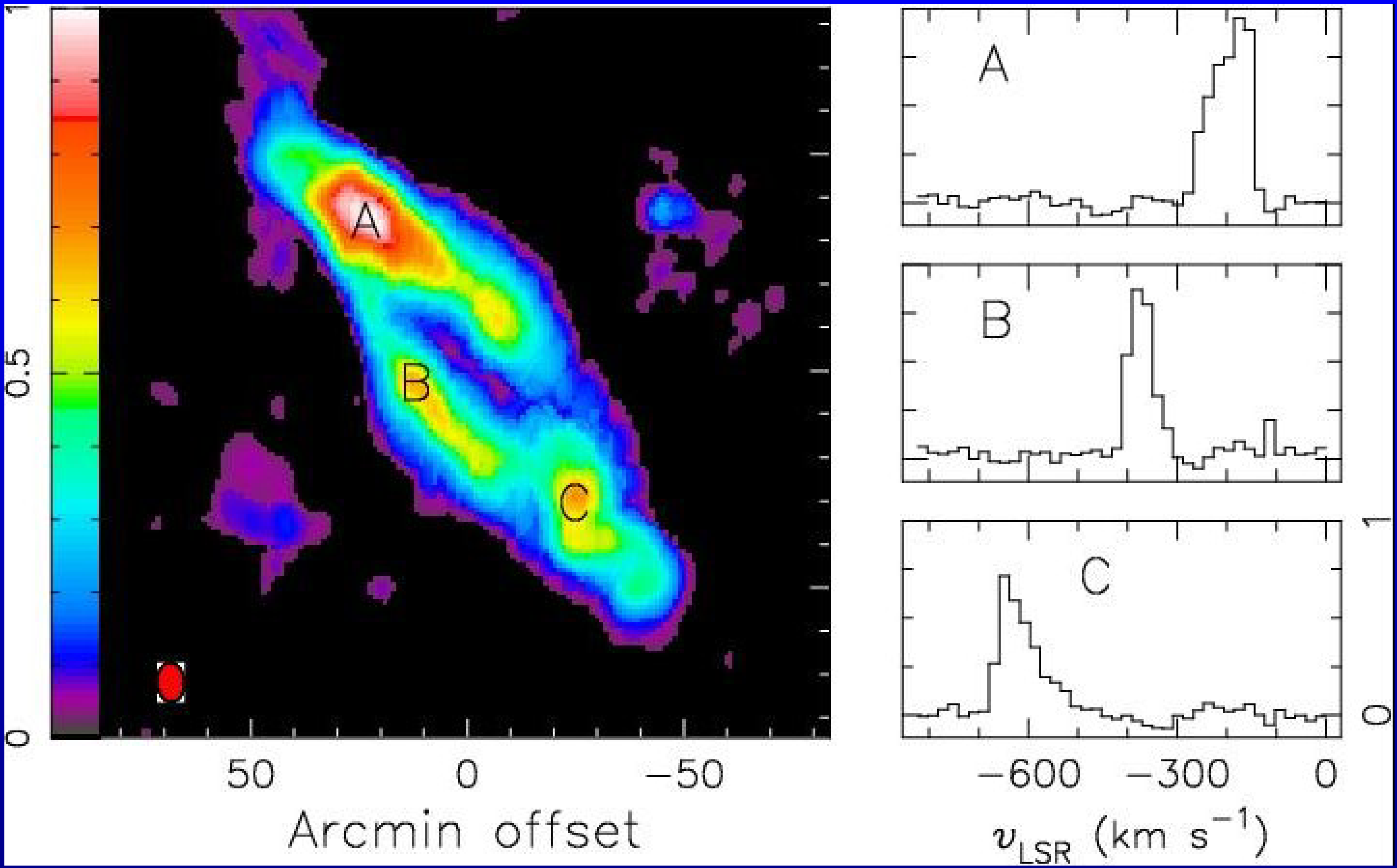
Control

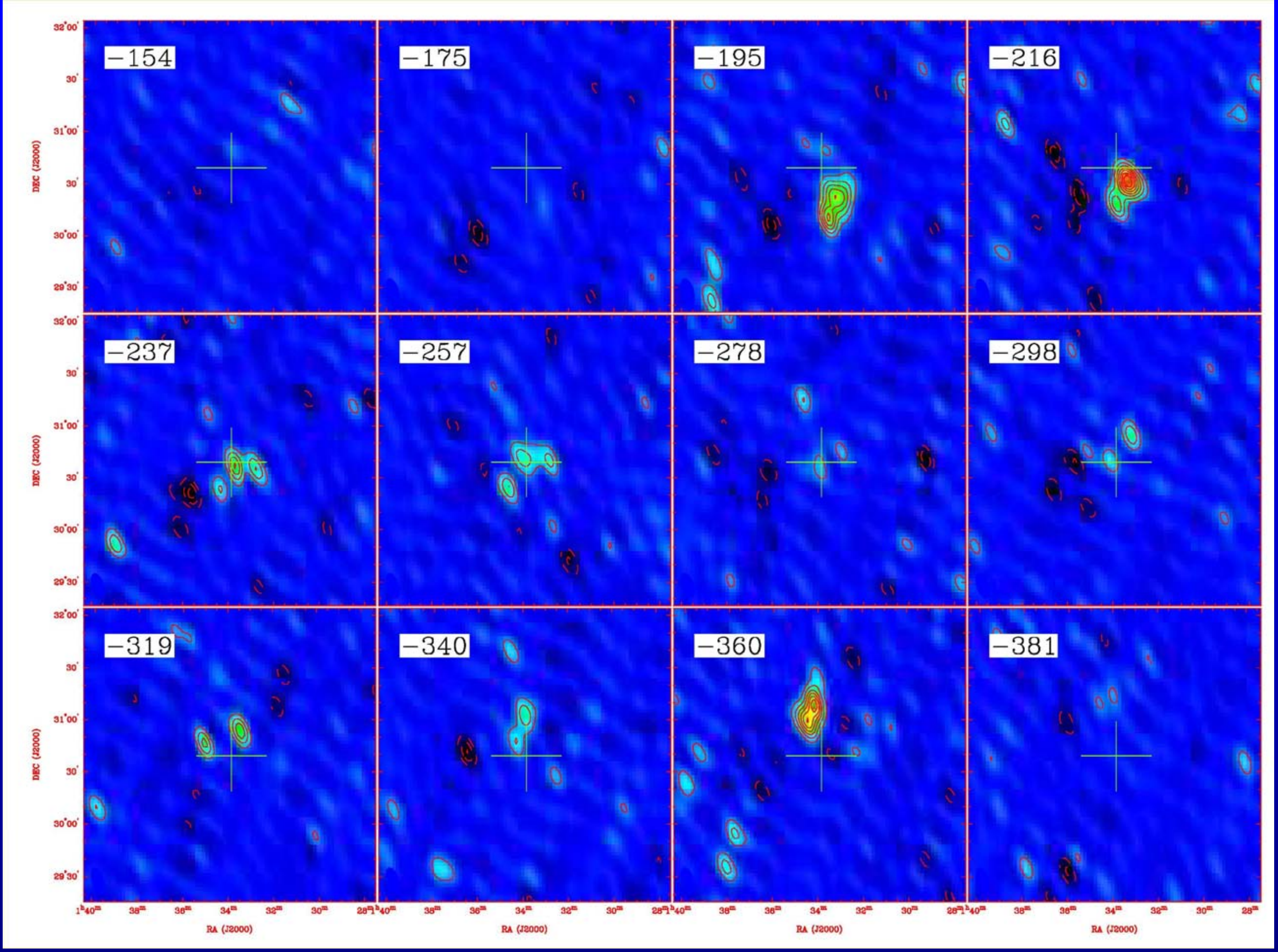
- Java–based client-server JSDA (Java Simple Distributed Architecture)
- TCP/IP, UDP/IP
- Jython scripting
- SBC at each antenna does it's own housekeeping
- Hierarchical controllers thru processor
- Monitor – less is more

Beam Pattern Client

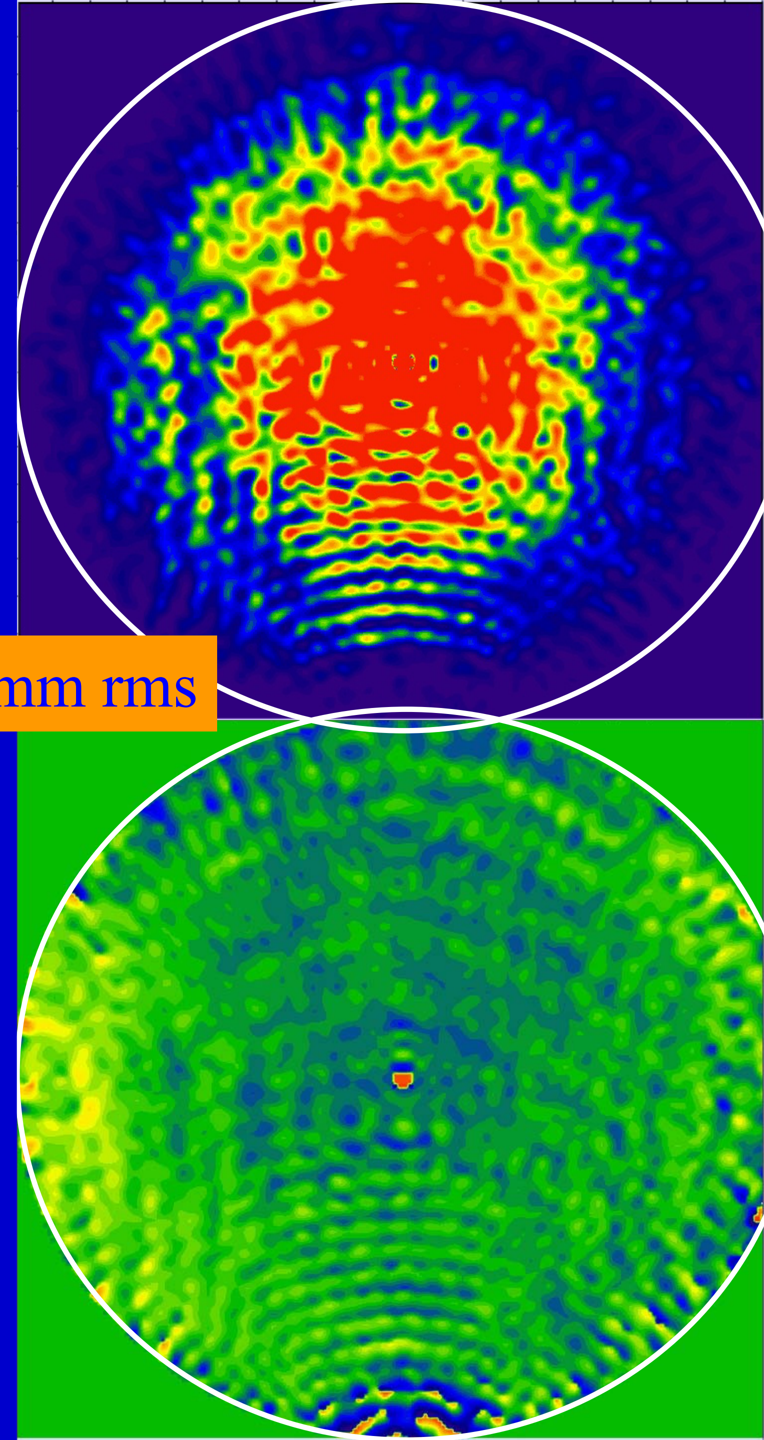


M31

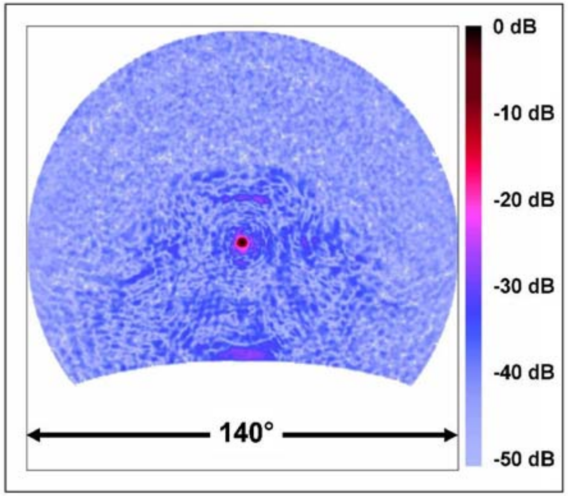


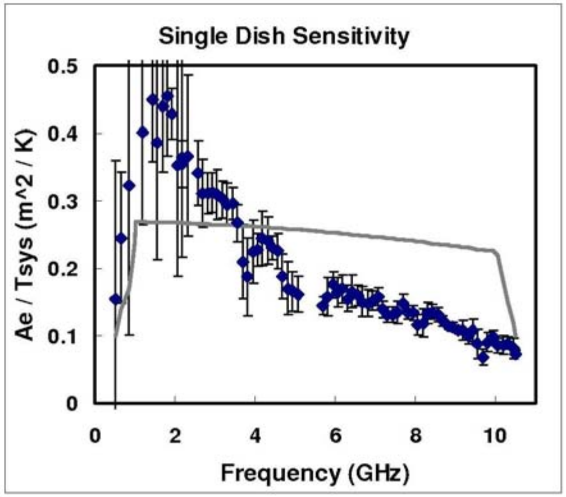


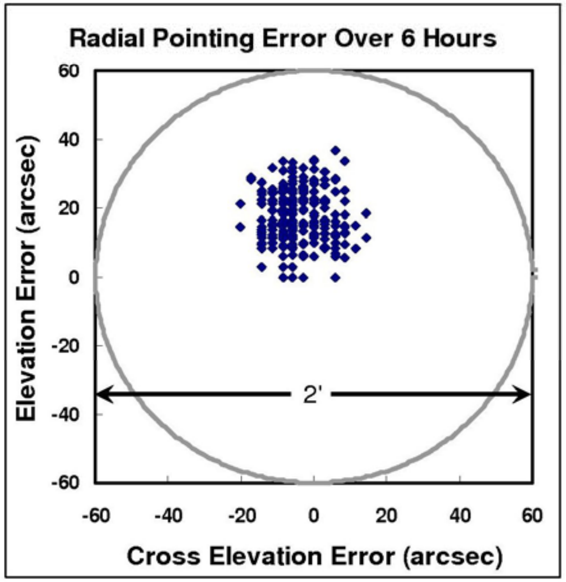
−154
−175
−195
−216
−237
−257
−278
−298
−319
−340
−360
−381
DEC (J2000)
RA (J2000)

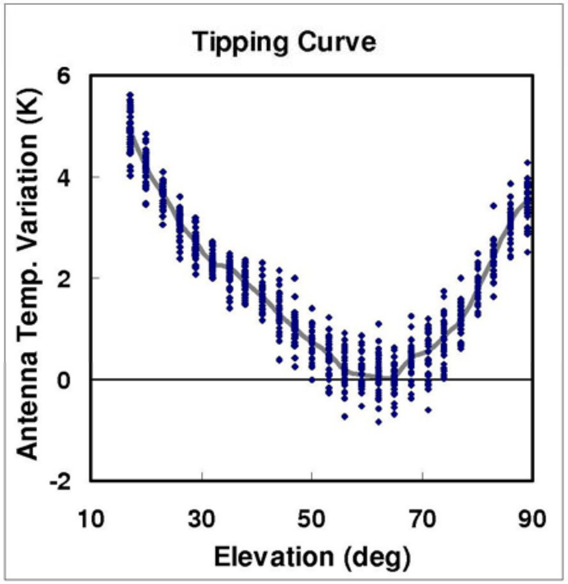


< 1mm rms


0 dB
-10 dB
-20 dB
-30 dB
-40 dB
-50 dB
140°

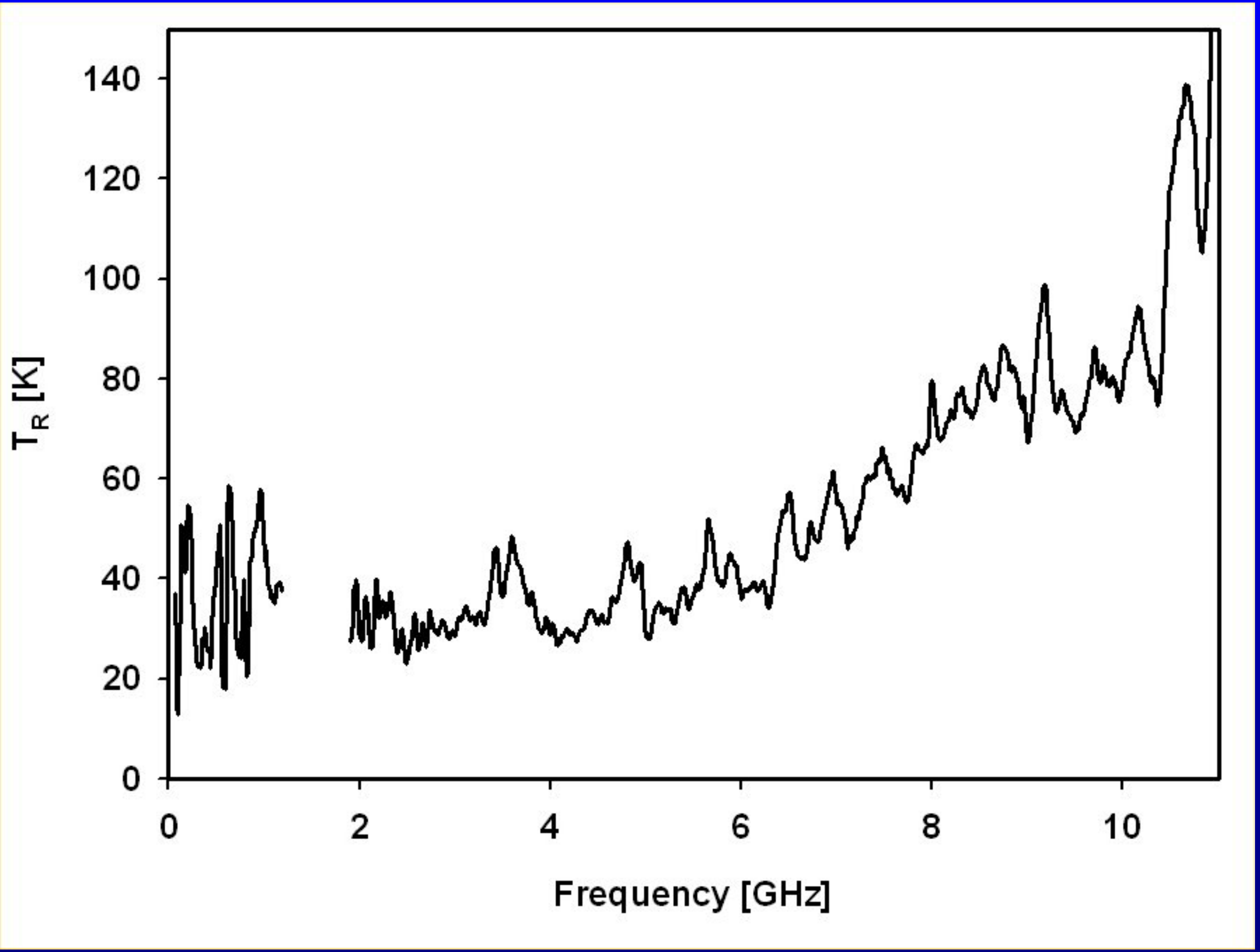

Single Dish Sensitivity
Ae / Tsys (m^2 / K)
Frequency (GHz)


Radial Pointing Error Over 6 Hours
Elevation Error (arcsec)
Cross Elevation Error (arcsec)
2'


Tipping Curve
Antenna Temp. Variation (K)
Elevation (deg)


2005 8 19
Oxford
University

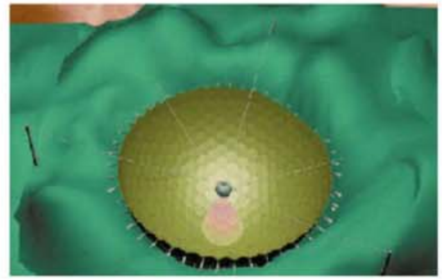
Receiver Temperature

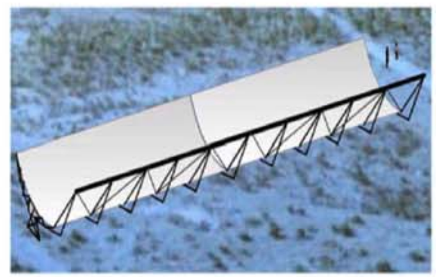


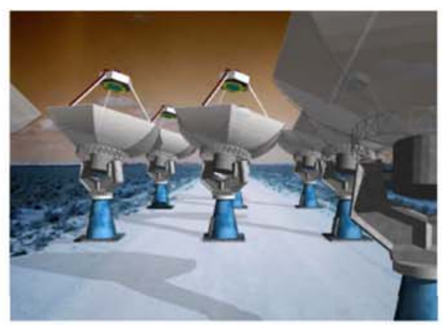
SKA
SQUARE KILOMETRE ARRAY

SKA Antennas

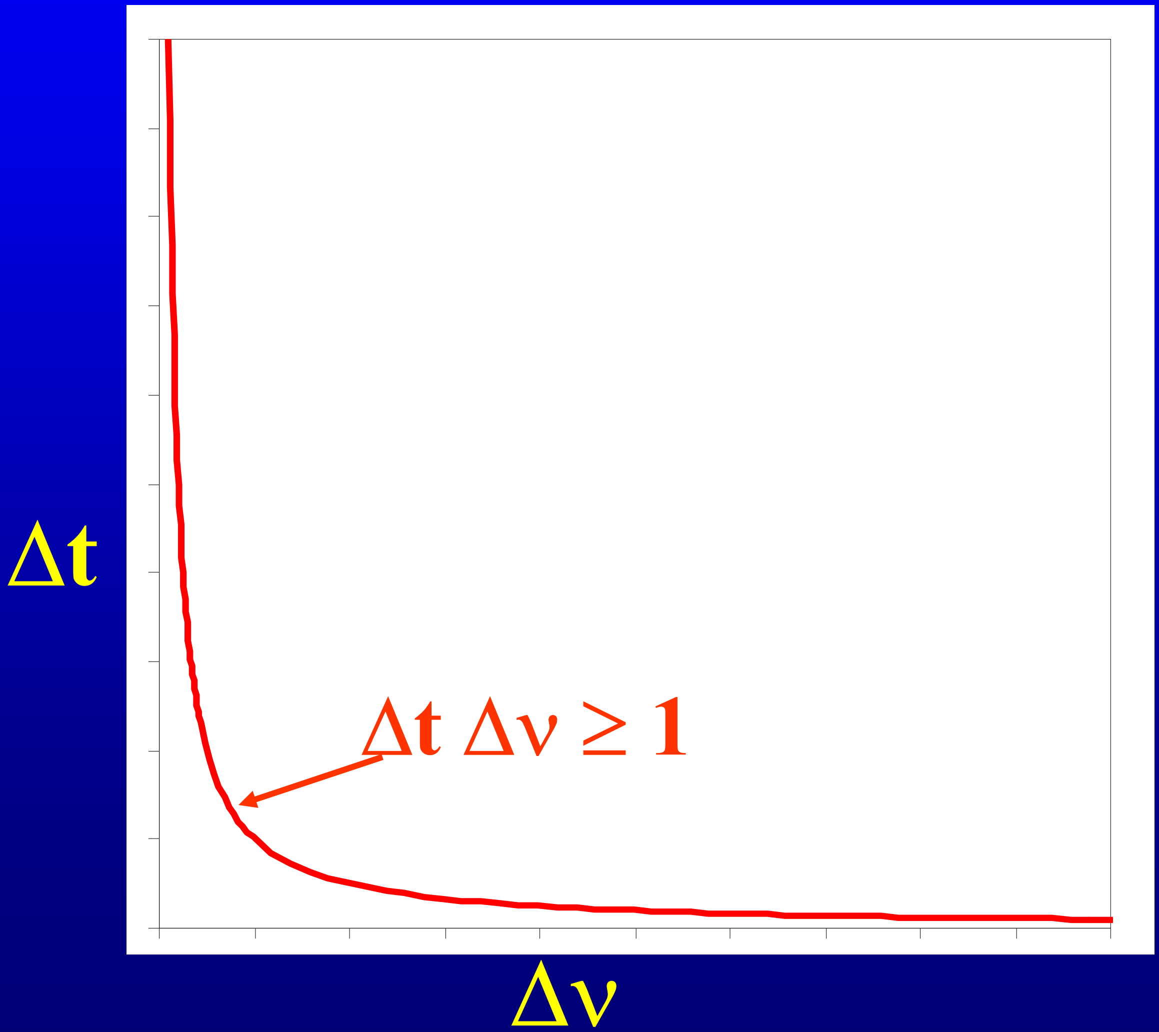
- **Range of possible solutions**
  - Aperture phased arrays
  - Flux concentrators (dishes)
- **Need at least two antenna types to meet current spec**
  - Cost effective high-frequency solutions don't provide enough area at low frequencies
  - Want good efficiency at high frequency AND multi-fielding (or at least wide field-of-view) at low frequency
  - The "hybrid" approach
- **SKA concepts have different antennas BUT much post-antenna system similarity**



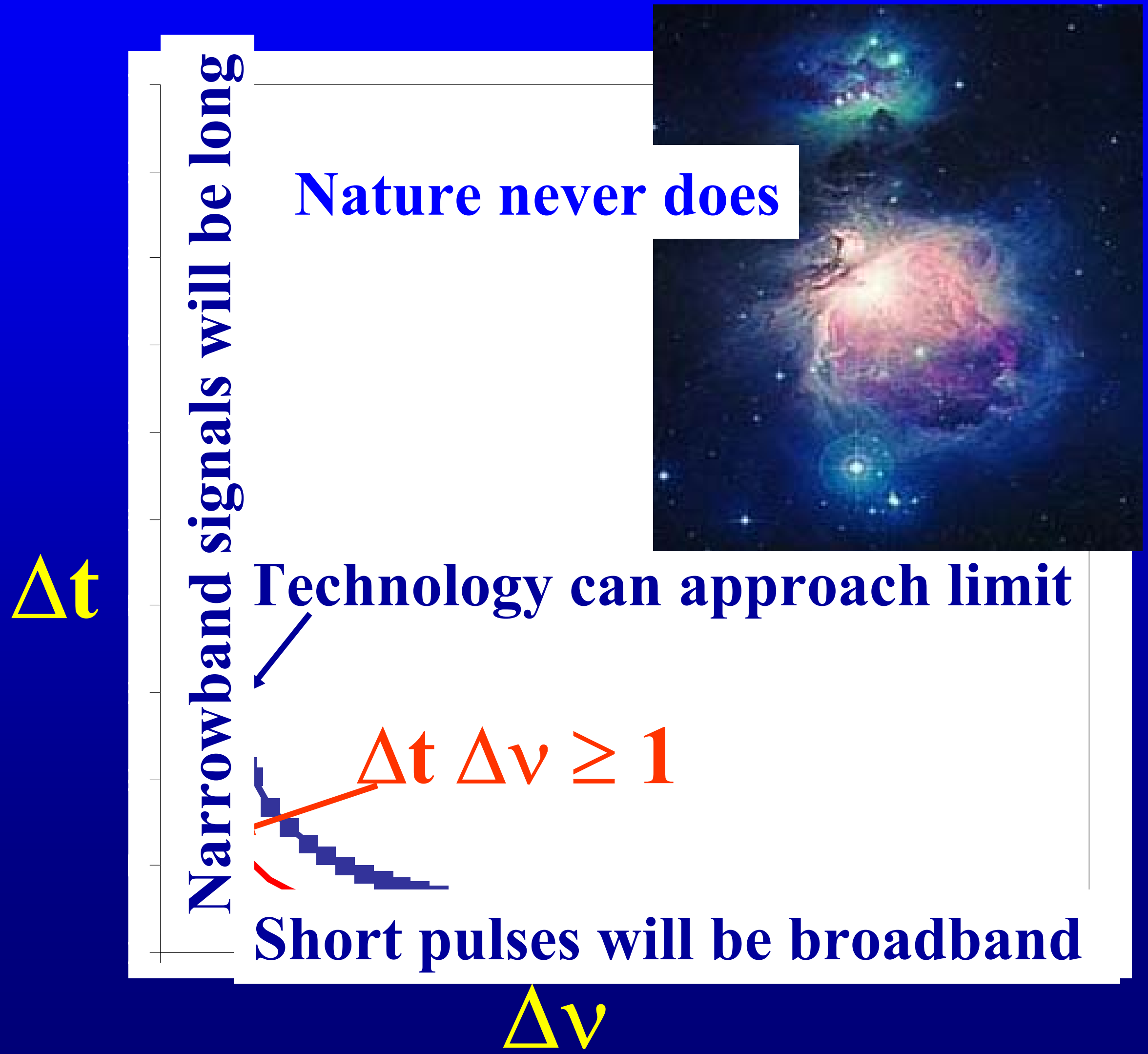




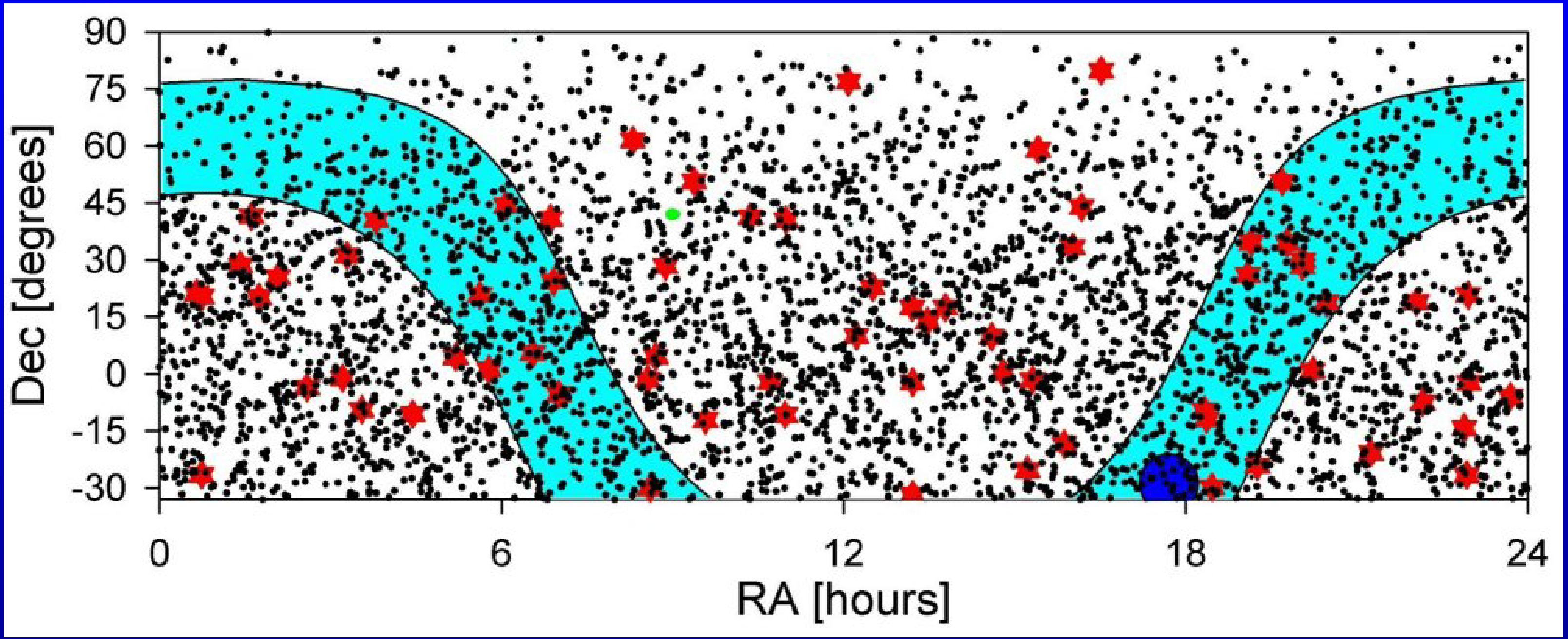

Uncertainty Principle



Uncertainty Principle



SETI Targeted Search



$n_o = 2.3 \times 10^{-4} \frac{N_*}{\nu^2}$ stars/PFOV

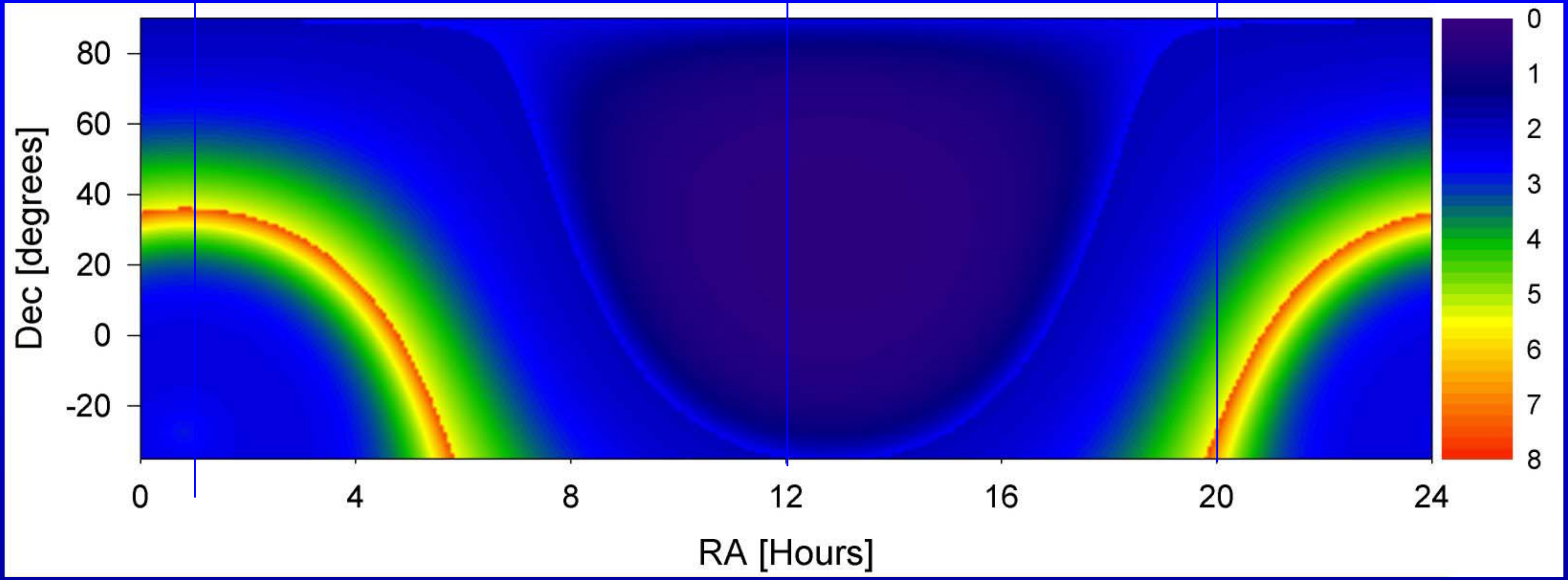
$N_* > 4288 \nu^2$ stars

Targeted Search

N_*	ν_{max} [GHz]	D_{max} [pc]	N_{civ}	Weather radar at D_{max}	AOPR at D_{max}
10^3	0.5	30	10^8	9	0.006
10^4	1.5	65	10^7	40	0.03
10^5	4.8	140	10^6	200	0.12
10^6	15.3	300	10^5	900	0.6

$\nu < \sqrt{2\times10^{-4} N_*}$ GHz

Near Sky Survey

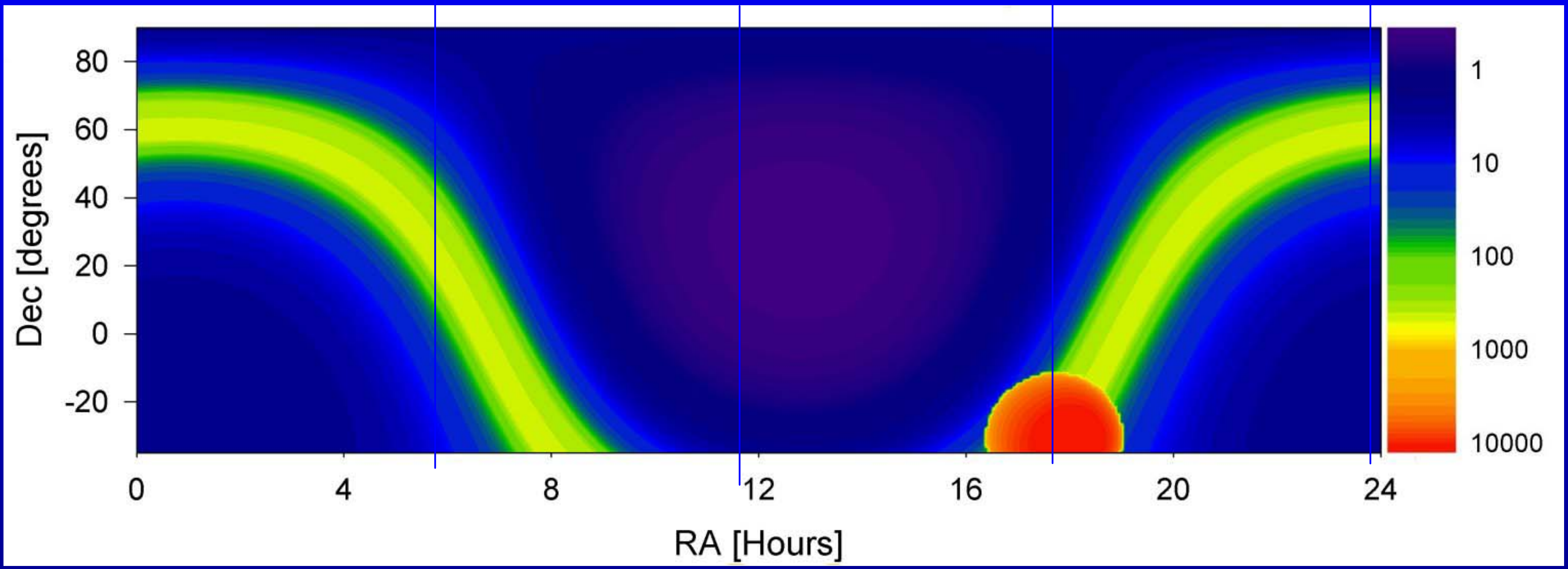


For 1 beam

20 AOPR (1 SKA) at 1.5 kpc

10^8 stars → 1000 civilizations

Far Sky Survey



For 1 beam

700 APR at 10.5 kpc

www.seti.org

astro.berkeley.edu/ral

SETI INSTITUTE