BP

Long Range Planning Retreat
Green Bank, WV

April 22-24, 1999

Long Range Planning Retreat
April 22, 23, 24

THURSDAY

08:30	GIACCONI	INTRO
08:50	VANDEN BOUT	INTRO + NRAO OVERVIEW
09:20	JEWELL	GREENBANK OVERVIEW
10:00	BREAK	
10:20	GOSS	SOCORRO OVERVIEW
10:50	SRAMEK	VLA/VLBA ELECTRONICS
11:10	ULVESTAD	VLBA + SPACE VLBI
11:30	EMERSON	12M + TUCSON OVERVIEW
12:00	LUNCH	
13:30	BROWN	MMA OVERVIEW
14:00	WEBBER	CDL OVERVIEW
14:30	CORNWELL	AIPS++
15:10	BREAK	
15:30	BRIDLE	OBSERVATORY-WIDE COMPUTING
16:00	HEATHERLY WOOTTEN	EDUCATION (GB, REU)
16:30	BEASLEY	PUBLIC RELATIONS
17:00	THOMPSON	SPECTRUM MANAGEMENT
18:00	DINNER	
19:30	GOSS	VLA UPGRADE - INTRODUCTION
19:45	PERLEY	OVERVIEW
20:15	RUPEN	SCIENCE BENEFITS
20:45	SRAMEK	TECHNICAL PLAN
21:15	VANDEN BOUT	TIMING/FUNDING

Friday

08:30	Romney	VLBA Upgrade
09:00	Ulvestad	ARISE
09:30	Bastian	FASR
10:00	break	
10:20	Simon	SPEX
10:50	Perley	Low Frequency Array
11:20	Fisher	SKA
12:00	lunch	
13:30	Mckinnon	NRAO Systems for the GBT
14:00	Hjellming	GBI
14:30	Bradley	RFI initiatives
15:00	break	
15:20	+ GBT tour	
18:00	dinner	
19:30	+ Reception in Lounge	

Saturday

08:30	d'Addario	Technological Innovation in Radioastronomy
09:00	Payne	Photonics in Radioastronomy
09:30	Owen	Future NRAO operations in MMA era
10:00	Kellerman	NRAO staffing/Observatory structure
10:30	Vanden Bout	General discussion/Closing remarks

WHERE DO WE WANT NRAO TO BE FIVE YEARS FROM NOW? TEN YEARS?

A GOOD TIME TO ASK —

CHANGE IS POSSIBLE:

— AUI will propose this year for a new cooperative agreement to run the NRAO;

— there is a "new AUI";

— the decade survey is underway now.

National Radio Astronomy Observatory:

— to design, build, and operate large radio telescope facilities for use by the scientific community;

— to develop the electronics, software, and other technology systems that enable new astronomical science;

— to support the reduction, analysis, and dissemination of the results of observations made by the telescope users;

— to support the development of a society that is both scientifically and technically literate through educational programs and public outreach;

— to support a program of staff scientific research that enables leadership and quality in all these areas.

Facilities

Green Bank Telescope
(replacing the 300 Foot and 140 Foot)

Millimeter Array
(replacing the 12 Meter)

Very Large Array Expansion

Very Long Baseline Array
and participation in space VLBI (ARISE)

Participation in the:

Frequency Agile Solar Radiotelescope

Long Wavelength Array

Long Range Definition and Development:

Square Kilometer Array
Sub-mm Probe of the Evolution of Cosmic Structure

Challenges

Maintaining our high standards for telescope performance and operations, while improving user support;

Conducting the technology development in instrumentation and software that is necessary to advance the state-of-the-art in radio astronomy;

Finding new ways to work with university-based radio astronomy groups;

Developing new mechanisms for integrating the user community into the long range planning process of the NRAO;

Finding ways to work effectively with a growing number of international projects;

Continuing to build Observatory programs in education and public outreach.

Radio Community Challenge

Growth in the astronomy budget at the NSF has been inadequate to support all of ground based astronomy, particularly in face of the enormous growth in NASA supported (space) astronomy.

This problem is particularly acute for radio astronomy in that NSF is its *only* federal source of support, in contrast to IR/optical astronomy which gains support from both NSF and especially NASA.

A proposal from AUI for an NRAO program of excellence, one that embraces change and reaches out to the universities in new ways, would be endorsed and could gain NSF support.

GOALS FOR 1999

Secure a new cooperative agreement for AUI to operate the NRAO, with a commitment from the NSF to seek adequate funding for the long range plan presented in proposal.

Complete the construction of the GBT.

Public release of AIPS++.

Conclude international partnership for ALMA; meet all milestones for ALMA D&D.

Submit a proposal for the VLA Expansion.

Establish long range planning and budgeting procedures; appoint an outside committee for review of strategic plans and initiatives.

Clarify scientific staff appointment policy.

1 # Green Bank: Long Range Plans

Long Range Planning Meeting

April 22-24, 1999

Green Bank

P. R. Jewell

2 ## Green Bank Mission

- *The primary mission of the Green Bank Observatory is to maximize the scientific potential of the GBT, and to help the astronomical community exploit this potential fully.*

3 ## Getting the Most from the GBT

- The GBT must be commissioned efficiently and successfully to meet its design specifications, including full implementation of the metrology system.
- GBT operations must be flexible and user-friendly.
- The GBT must have a complete suite of advanced instrumentation that maximizes its potential.
- While exploiting its own unique capabilities, the GBT should be developed in a way that complements the missions of the MMA, VLA, and VLBA.

4 ## GBT Commissioning

- Our focus over the next 1+ years is to commission the GBT.
  - We must commission
    - The antenna
    - The software control, data acquisition and reduction
    - All frontends and backends
  - Commissioning will not be complete until Phase III (closed loop metrology) is fully operational.
- This will occupy the entire GB scientific and engineering staff.
- *(Details discussed by Mark McKinnon on Friday)*

5 ## GBT Operations

- GBT Operations must be flexible, user friendly, and modern in concept. We must provide
  - All popular observing capabilities, including on-the-fly imaging.

- Excellent interactivity between telescope control, data acquisition, data reduction and the observers.
- A state-of-the-art remote observing capability.
- Dynamic (adaptive) scheduling.

- This will require substantial software development and staff scientific support.

6 **Instrument Development for the GBT**

- Day-1 Instrumentation for the GBT is excellent:
  - Nearly full suite of 1-4 beam Rx's
  - Powerful new 256,000 channel spectrometer.
- Next priority is to complete systems in the queue:
  - Q-band (4-beam, dual polz., 40-50 GHz Rx)
  - Ka-band (26-40 GHz)
- Expand to 3 mm band next
- Want large-scale imaging instrumentation!!
  - 3 mm spectroscopy and continuum imagers
  - Low frequency, beam-forming arrays
  - Imagers at K-band and other frequencies

7 **Complementarity with other NRAO Instruments**

- The GBT will operate from ~100 MHz to ~115 GHz
  - Covers all VLA & VLBA bands, and through 3 mm for MMA
- The GBT has 7850 m^2 of collecting area
  - 108% that of 64 x 12 m MMA/LSA
  - 59% that of VLA
- With focal plane arrays, the GBT can provide the astrophysical context to the smaller fields imaged by the VLA and MMA, and with comparable raw sensitivity.
- These instruments should work in concert.

8 **Other Green Bank Missions**

- Quiet Zone Administration and RFI mitigation
  - >150 FCC applications processed each year
  - Propagation studies and calibration
  - Suppression and mitigation of RFI
- Contract services for the USNO and NASA

        - USNO Earth-rotation VLBI station
        - NRAO Earth Station for Orbiting VLBI
    - Education and Outreach
        - Teacher, student, and tour programs
        - New Science Education Center

9 **Other Green Bank Issues**

- Build staff and facilities for skills and services required:
    - Engineering: Advanced instrumentation development
    - Scientific: Support of dynamic scheduling
    - Computing: Advanced observing and scheduling tools
    - Eng/Admin: RFI mitigation and Quiet Zone preservation, & central services for the Observatory
- Site Infrastructure
    - Basic Plant is 40 years old
    - Must plan for another 25+ years
    - A renewal program is required

10 **Green Bank Long Range Plans -- Summary**

- Develop the GBT to its maximum potential:
    - Successful commissioning
    - Excellent flexibility and services
    - Advanced instrumentation
    - Complementarity with other NRAO instruments
- Carry out secondary missions for
    - NRQZ, Contract Services, Education and Outreach
- Solve other issues:
    - Staff and facility needs
    - Plant renewal

VLA -VLBA Operations

Green Bank - 22 April 1999

W.M. Goss presentation to

Long Range Planning Meeting

Speakers are :
M.Goss - introduction
D.Sramek - electronics
Jim Ulvestad- VLBA,Space VLBI

Outline :

1) Our mission
2) Personnel at the AOC-Array Operations Center
3) Budget Issues
4) User Base and scheduling

The Mission of VLA and VLBA Operations :

Provide state of the art instrumentation for radio interferometry from 74 MHz to 50 GHz.

Angular resolutions from 0.1 mas to arc mins

Support the U.S. User Community

Provide Scientific Leadership

Personnel at the AOC and the VLA

Plus VLBA sites

Staff at the AOC and the VLA
162
VLBA sites
21
Total 183

and in Socorro about 30
additional- basic research,fiscal
and MMA

Scientific Services -14 people
Jim Ulvestad is new division head.
Loss of many key people in the last years : VLBAers such as Tony Beasley,Phil Diamond,Alan Roy, Amy Mioduszewski, and internal transfers such as C.Bignell,A. Kemball,B. Butler

In 1999 three new KEY appointments at the AOC in the scientific staff :

1- Debra Shepherd from OVRO to start October - 1999

2- Claire Chandler from Cambridge to start February - 2000

3- Steve Myers from Penn-Sept 1999

- Dick Sramek remains the deputy assistant director and has responsibility for electronics
- Dick also has MMA and VLA expansion activities

Budget Issues Relating to the AOC

- Budget problems continue in 1999

	Total	% Personnel
1991	$8.7 M	57
1992	$9.6 M	61
1993	$11.1M	60
1994	$11.7M	61
1995	$11.4M	63
1996	$11.2M	64
1997	$11.4M	66
1998	$11.8M	64
1999	$11.3M	66

- And in 1999 the Research budget (RE) is only at $200 K for all of NRAO. Hope to increase this to $600K. In 1998 VLA/VLBA electronics was $456 K -mainly for K band at the VLA. VLA computing was $57.5 K in 1998- AOC server etc.
- --

- A major result of these budget problems is VLA maintenance : "WYE" budget in 1999 is $85K compared to $325K in 1998. Tie replacement is at about the 5000 per year (out of a total of at least 70,000 of the total 200,000 ties that are in poor shape).

- Painting in 1999 : $100 K to paint at SC, HN and NL plus two VLA antennas to be painted in 1999. We painted NO antennas in 1998. At present 14 of the 28 antennas have been repainted. Cost of paint per antenna is $25K and the labor involved over several weeks is $9K. Rust continues to be a problem.

- Other chronic problems are waveguide manhole replacements

- Azimuth bearing replacements - $40 K per bearing

It is essential to increase the VLA and VLBA budget allocations by at least $750 K per year. As an example we should be replacing 10000 railroad ties /year. Cost about $500 K /year.

If the VLA expansion does not materialize , the VLA/VLBA RE electronics budget of at least \$1M per year is required to continue at least two front end projects/year and to start the fiber optic replacement for the waveguide

Scheduling for the VLA and the VLBA
and our User base

The productivity of the VLA and the VLBA is about one publication per observing proposal. In a typical year there are 350-400 publications and 8-12 Phd theses.

- Scheduling Committee in 1999
- VLA and VLBA : meets three times /year

- Members : B. Clark , M.Goss, L.Greenhill -of CfA replacing M.Reid, E.Fomalont to be replaced by F.Lockman in August 1999, K. Kellermann
- 32 referees serving typically 3 years . There are 13 scientific categories .
- The outside NRAO member has been a big success but I find it is very tough to find someone who has 3 plus weeks per year to read 200 proposals and spend 3 times 3 days in Socorro per year !

- As an example take the meeting of 3 weeks ago where we looked at the A array proposals for the period mid June to late September 1999 - no hybrid array for this meeting. eg next meeting we look at BnA and B array for late 1999-early 2000.
- We had at the 1 February 1999 deadline : 135 VLA and 44 VLBA and one global proposals. Of these 180 , 166 arrived by email and of these 102 arrived in 1 February .
- During the meeting we looked at 163 VLA proposals and 74 VLBA proposals due to continuations .

A array 1999 allocation
1875 hours .
Requested 2737 hours
76 percent is US
24 percent is non US.

There are 401 total proposers
with 273 unique names

VLBA (includes dynamic scheduling)

1000 hours (still 400 -500 hours Halca)- Requested 1536 hours
68 percent US
32 percent non US
There are 186 total proposers with 133 unique names

NRAO Long Range Planning, April 1999
VLA and VLBA / Engineering

- **Highest priority must be the VLA Expansion**
  - **NRAO cannot continue into the 21st century with 1970's instrumentation on the VLA**

- **Until the VLA Expansion Project begins, $1.0 M/year RE needed, incremental upgrade.**
  - **New Receiver systems, feed cone**
    - **perhaps 33 GHz, 3GHz parallel build**
  - **Install fiber optic cable**

- **Maintain the infrastructure, an additional $750k /year needed.**
  - **Rail system,**
  - **Antenna mechanical**
  - **Antenna painting**

Electronics Division

18 - 26 GHz - New K-band Rcvr - VLA Upgrade

Installed on four antennas at end of 1998.
Tsys improved ~ 160 K on old rcvr ~ 55 K on new
1998 RE purchased materials for eight more, install 1999
Tuning limited to 19 to 25 GHz at this time

12 receivers in operation by end of 1999
20 receivers in operation by end of 2000
28 receivers in operation by end of 2001

But $320 k /year from RE needed to maintain this program!

Atmospheric phase error correction radiometer
A 3-channel water vapor radiometer is under development
Prototypes were installed on Rcvr #3 and #4 for evaluation

VLA- PT Link

Funded in September 1997 for three years - **MRI**
    $466k NSF
    $200k from AUI (30%)
4 x 70 MHz over 103 km fiber optic link
Analogue IF, digital M/C, possible LO reference
Single IF demo - December 1998,
Correlator delay mods - June 1999
Four IF observations - October 1999
A regular user instrument by October 2000.

40 - 50 GHz Receivers   Q-band   VLA Upgrade

Funded September 1998 for three years - **MRI**
$417k NSF
$279k (DM 485k) from MPIfR
13 receivers operational since 1995
six more in 1999 (underway)
six in 2000,
five in 2001 (RE or VLA Upgrade)

80 - 96 GHz on VLBA   W-band

PT - December 1996   LA - April 1998
MK - October 1998   FD - March 1999
$\varepsilon \sim 15\%$ Tsys ~ 130 K
problems: high Tsys and ripple;
leaking vacuum window
MAP protoamps; return loss good > 90GHz
All four receivers to AOC, May 1999.
new LNA's   80 - 96 GHz
new vacuum windows
new dewars (#1 and #2)

Proposed for September 1999 **MRI** (also 1998 MRI)
$744k NSF
$321k from MPIfR   ($290k at NRAO)
7 rcvrs to finish VLBA + one VLA + one GBT
+ one 100-m Bonn
photogrametry system (demo at VLA)

RFI Countermeasures

Proposed for September 1999 **MRI**

$894k NSF

$627k from ATNF

$100k from SETI Inst.

Digital Notch Filter for RFI excision for VLA

prototype FIR filter 50 MHz BW

possible development towards VLA Upgrade

RFI Canceller CDL /GB

VLA Upgrade

K-band and Q-band

feed cone segments being installed

System Design

Specs and costing LO/IF/FO in conjunction with MMA

Low noise synthesizer design

FO design, digital and analogue

L-band feed evaluation - Srikanth (CDL)

What is lowest frequency with adequate G/T?

Staffing (rft)

17 Engineers

1 Visiting Engineer

30 Technicians

23 VLBA Field Group (3 at AOC)

Time ~80% maintenance
~20% new initiatives

Division Head plus nine groups, by function:

LO/IF	Data Acquisition	VLBA Field
Correlator	Front End	Lab Services
Monitor/Control	Cryogenics	Staff Engineers

Engineering Services

VLA Antenna Panel Adjustments

20 VLA antennas done (5 in 1998)
Includes all 13 Q-band antennas done
Q-band: improved $\varepsilon \sim 15\ \%$ to $\varepsilon \sim 40\ \%$
As new Q-band rcvrs are installed, surfaces will be reset.

VLA Rail System Maintenance

Major effort on rail tie replacement continues
5000 ties in 1998 and 1999
Grow to 10,000 ties per year in 2000 and beyond

Antenna Painting

Only quadrupod legs in 1998 (no funds for material or crew)
Two VLA antennas in 1999 **plus**
VLBA antennas at SC and HN
Three per year in 2000 and beyond

VLBA Tiger Team Visits - 1999

MK March 22 -27
SC June 22 - 27
HN August 16 - 21

VLA Antenna Pointing

Antenna 23 encoder / elevation axle coupling
 elevation pointing improved to 13 arc-sec rms
Prototype encoder interface - late 1999
Installation 2000 - 2001
 approx $150k project

VLA Antenna Overhauls

New round of overhaul began in January 1999
Install feed cone segments for K-band and Q-band rcvrs.

VLA Waveguide Manhole Replacement

Three planned in 1999
A few per year until fiber optic system installed

VLA Azimuth Bearing Replacement

Bearing in antenna 1 replaced in Oct '97
No funding for work in 1998 or 1999
one per year 2000 thru 2005

VLBA Azimuth Rail Grout Repair

MK in June 1997
Return to MK in 2000

Staffing (rft)

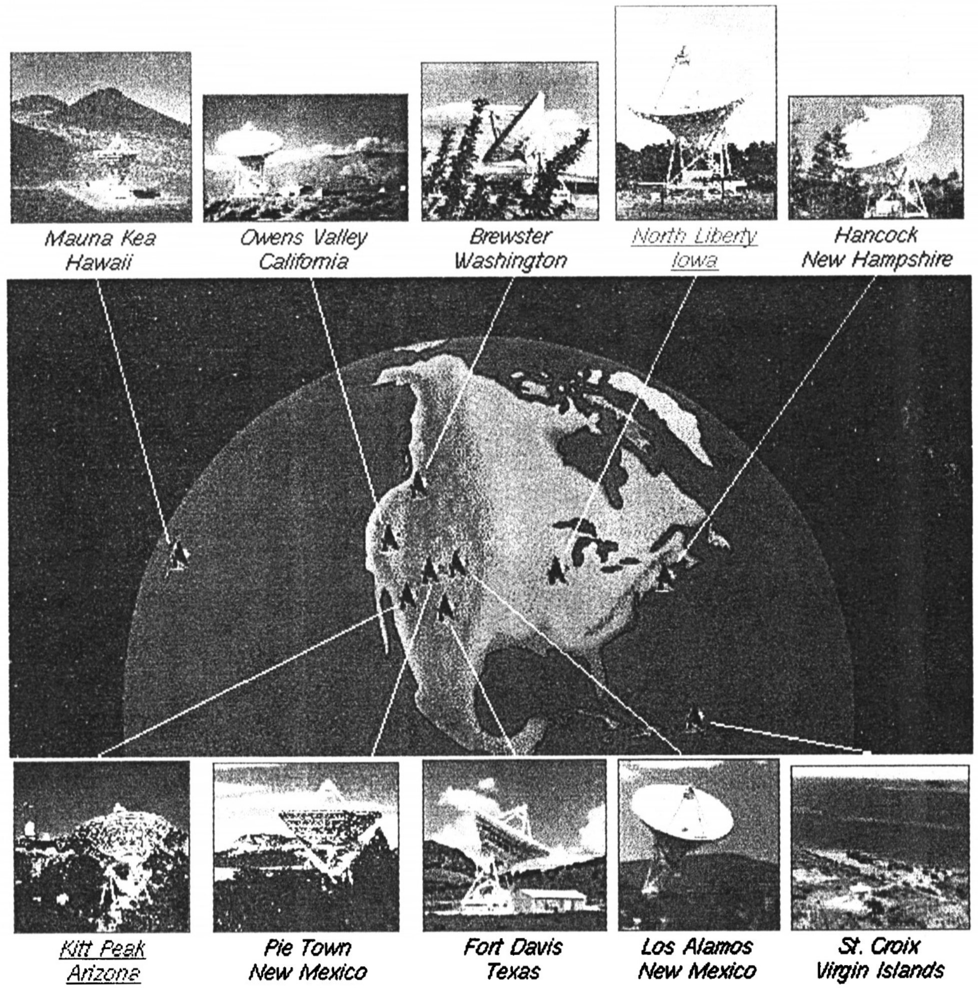
6 Engineers
44 Technicians and other support

Division Head, Deputy DH, plus six groups, by function:

Administration	(includes custodians)
Engineering	(includes machine shop, drafting)
Site & Wye	(carpentry, vehicles, track, B&G)
Antenna	(includes transporters, welding)
Electrical	(includes HVAC, Servo)
Scheduler	

R. Sramek
April 16, 1999

VLBA Overview



Jim Ulvestad — April 22, 1999

NRAO Long-Range Planning Workshop

Outline

- VLBA Mission
- Primary Issues and Challenges
- 1998–1999 Activities
- Organization and Staffing
- Outreach Efforts
- Near-Term Plans
- How is the VLBA Doing?

VLBA Mission

- Operate state-of-the-art VLBI telescope
- Attract and support vibrant U.S. user community

  ⇒ produce exciting high-resolution science
- Maintain stimulating research environment for staff and visitors
- Communicate with, and educate astronomical community and general public

Primary Issues and Challenges

- Small U.S. user community

  Destruction of university VLBI groups

  Education of students

- Attrition in scientific support staff

- AIPS support at critical level

- Operations still too cumbersome

- Long-term monitoring of array is marginal

- Path to enhanced capabilities is unclear

Operational Activities

- **Efficiency and User Friendliness**

  Automatic tape allocation: mid-1998

  Dynamic scheduling: began February 1999

  Calibration transfer for VLBA telescopes: began April 1999

- **Operational Highlights**

  Primary data center for VSOP Space VLBI mission

  30% of VLBA science usage dedicated to VSOP

  Typical science usage 54%; peak month 63% (goal is 70%)

  Correlator released 1000th project in April 1998

  20% increase in number of programs correlated in 1998

  "Routine" incorporation of European stations

Scientific and Technical Activities

- Technical Developments

  Gated correlation for pulsars in 1998

  First tests of 512 Mbit s^{-1} in late 1998

  Development of ARISE future Space VLBI mission

  Full Y2K test in February 1999

  Fourth 86-GHz system installed in March 1999

- Scientific Highlights

  Discovery of circular polarization in radio jets

  Imaging of gas in inner parsecs of active galaxies

  First movie of a "breathing" star

  Geometric distance to NGC 4258

Organization and Staffing

- Operational staff mature and stable
- Management turnover, re-organization: 1997–1999
- Scientific staff attrition

  Reduction from $\sim$ 10 to $\sim$ 5 FTEs in VLBA support since early 1997

  Significant impact on scientific productivity

  3 new hires in scientific services division by early 2000

  Re-alignment likely in late 1999

- AIPS has 5 FTEs observatory-wide (3 Soc, 2 CV)

  VLBI code development impacted

Outreach Efforts

- New operational tools enhance user convenience

  Enhanced documentation for VLBI beginners in progress

  Calibration/imaging service would require additional resources

- Topical session in June AAS – "High Angular Resolution Science with the NRAO VLBA"

- Connection to space community (ARISE)

- Sky & Telescope article on VLBA in August/September

- Web site badly in need of re-engineering

U.S. VLBI Revitalization Team

- Purposes

  Attract more U.S. users

  Revitalize U.S. university groups

- Primary Approaches

  Significant changes in VLBA support system

  Make VLBA much easier to use for novices

  Enable large projects

- Draft recommendations due in May 1999

Near-Term Plans

1999 MAY	Revitalization team recommendations
1999 JUN	Significant dynamic scheduling
1999 SEP	86-GHz MRI decision
1999 OCT	Estimated death of HALCA/VSOP
1999 NOV	Phase-2 calibration transfer
1999 DEC	Scientific staff re-alignment
2000 JAN	512 Mb s^{-1} capability
2000 JAN	VLBA Upgrade workshop
2000 JUN	Phase-1 operational mgmt. system
2000 DEC	Large-project evaluation
2002 DEC	86 GHz on line (if MRI is funded)
2003 DEC	Enhanced recording density

How is the VLBA Doing?

- Operate state-of-the-art VLBI telescope ⇒ B
- Attract/support vibrant U.S. community ⇒ D

⇒ produce exciting high-resolution science ⇒ C+

- Maintain stimulating research environment for staff and visitors ⇒ C+
- Communicate with, and educate astronomical community and general public ⇒ C−

Overall Grade: C+

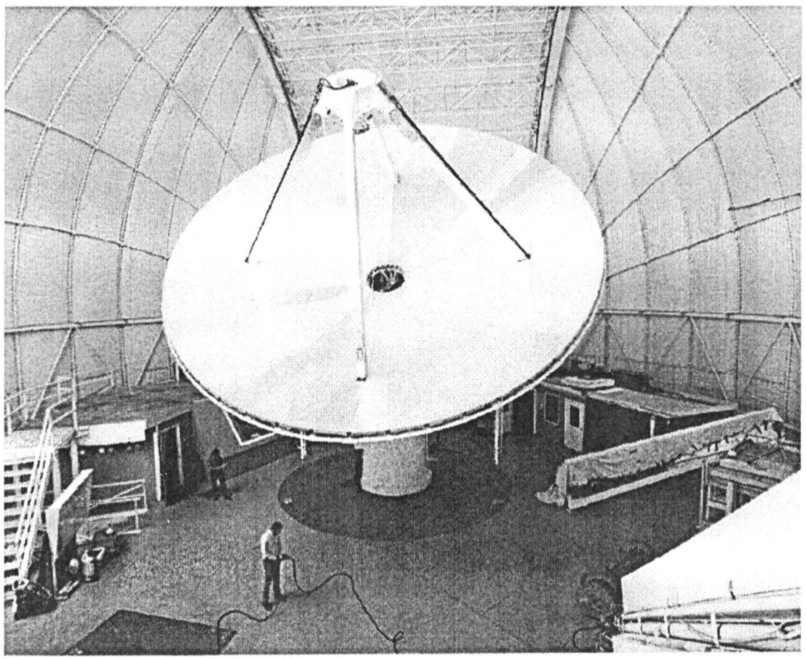
NRAO Tucson

Jeffrey G. Mangum
Darrel Emerson

NRAO Tucson Projects

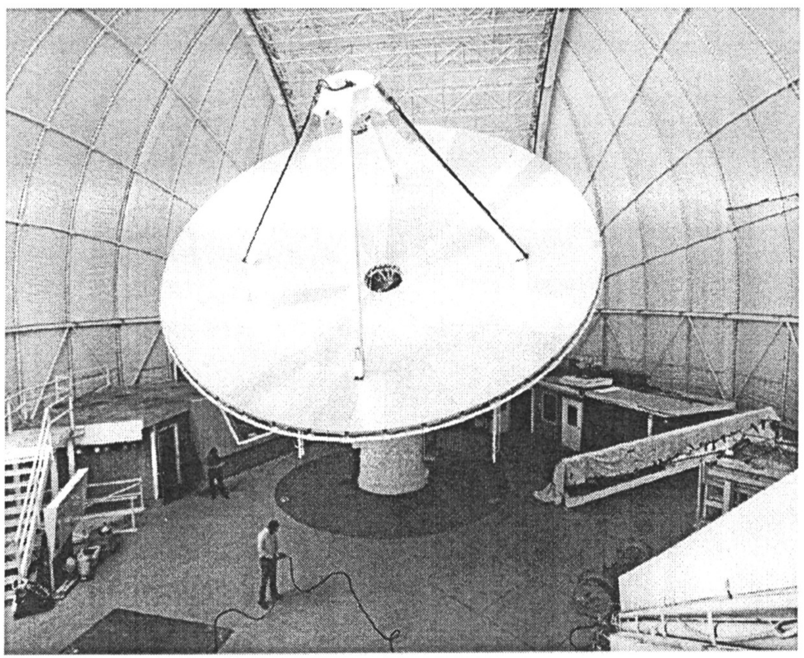
- 12 Meter Telescope
- Atacama Large Millimeter Array (ALMA)

12 Meter Telescope



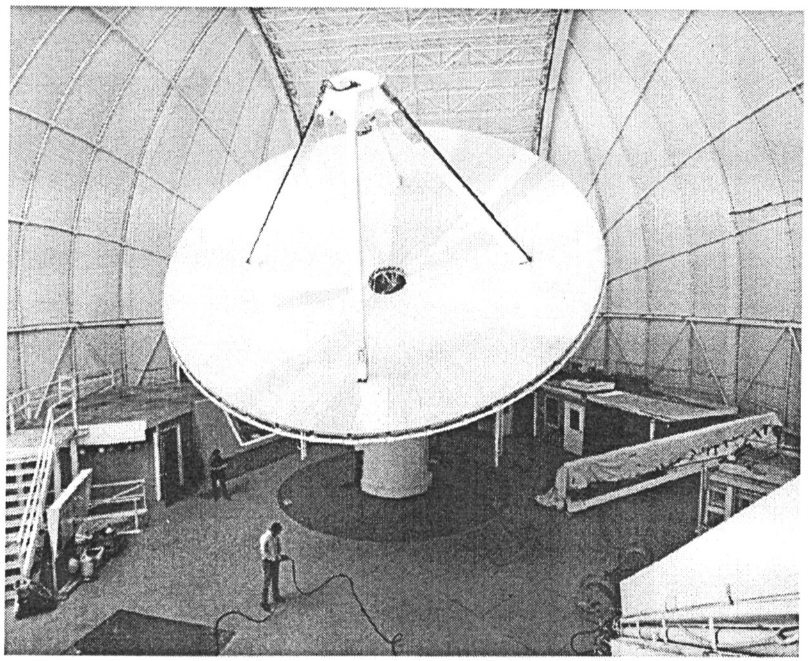
- Operational Characteristics
  - Only US national millimeter facility
  - Covers all atmospheric windows from 67 to 300 GHz with dual-polarization SIS receivers
  - Filter bank and digital correlation spectrometers
  - Spectral line or continuum operation with single and multi-beam systems

12 Meter Telescope



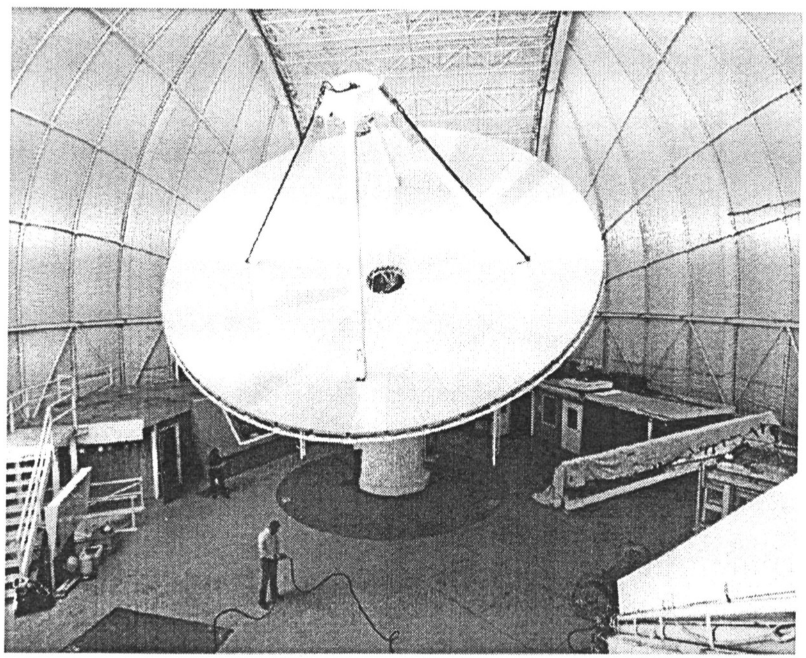
- Operational Characteristics
  - VLBI operation at 3 and 1mm
  - MMA prototyping

12 Meter Telescope

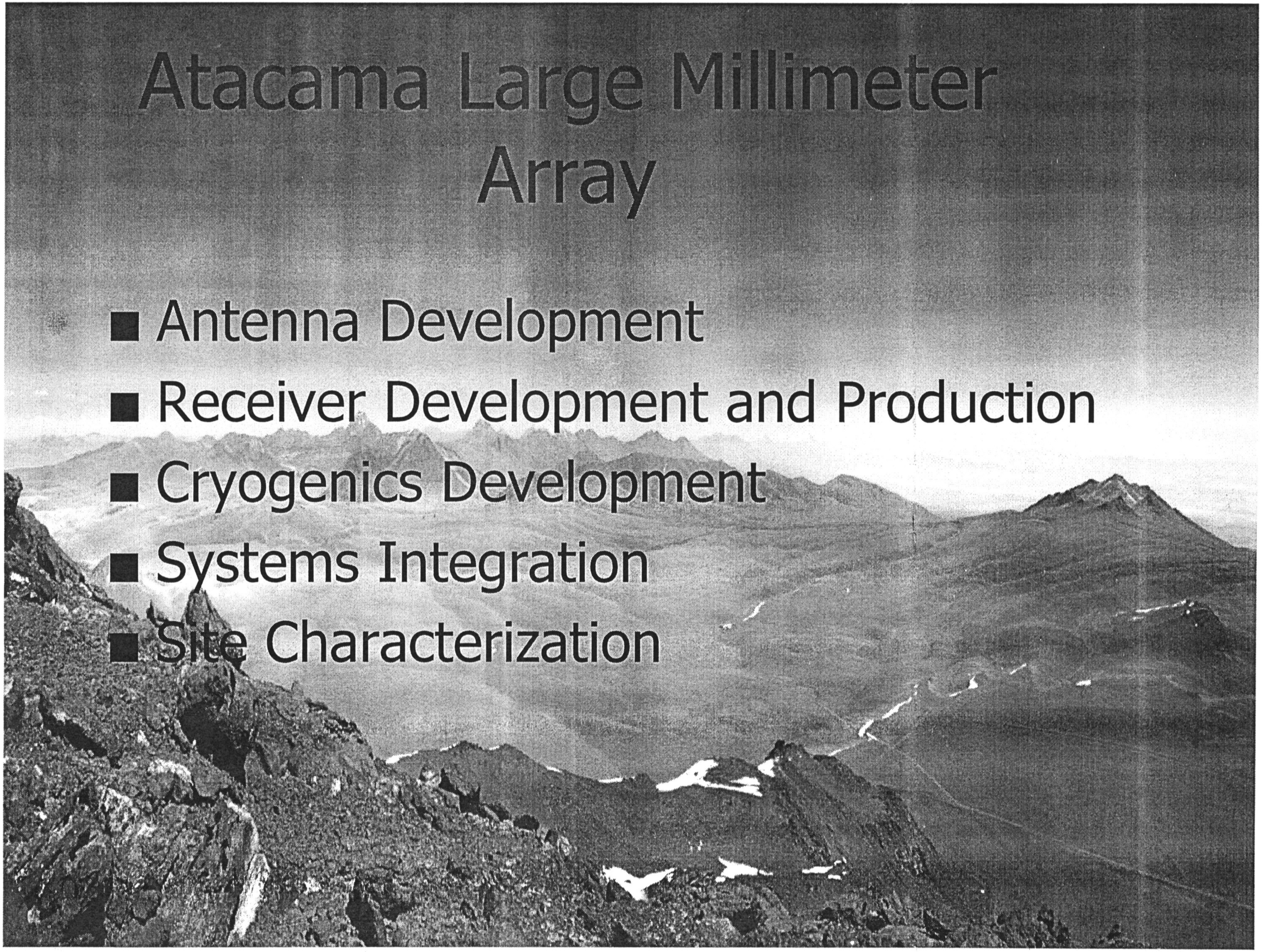


- Recent Major Projects
  - 1mm SIS Array receiver
  - Central cold-load tuning and calibration system
  - New Millimeter Autocorrelator (MAC)

12 Meter Telescope



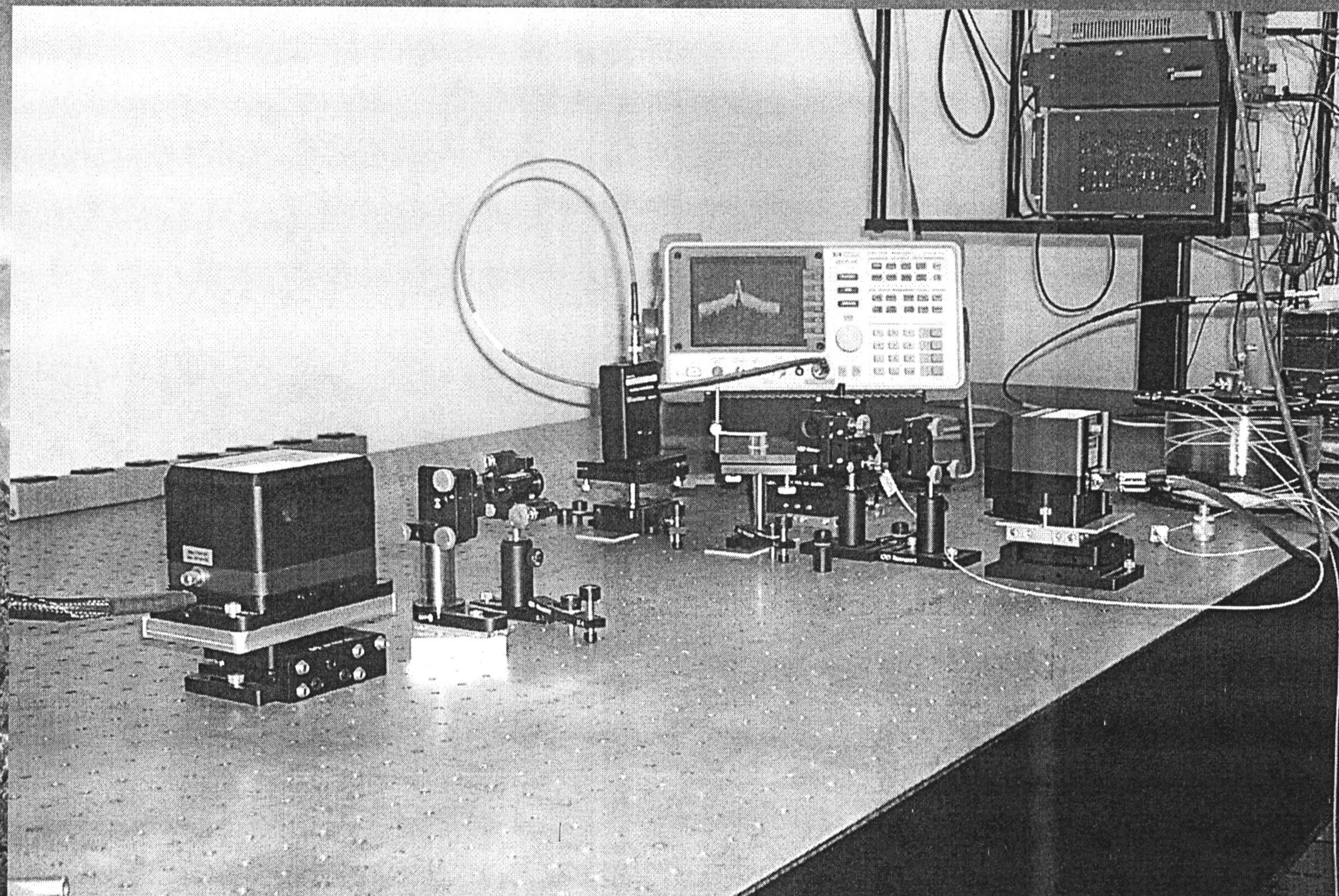
- Major Projects Underway
  - Dome cover replacement
  - 3mm 8-channel 4-beam Array
  - Quadrant detector and subreflector servo feedback system
  - New OTF observing modes
  - Expanded scanning mode capabilities

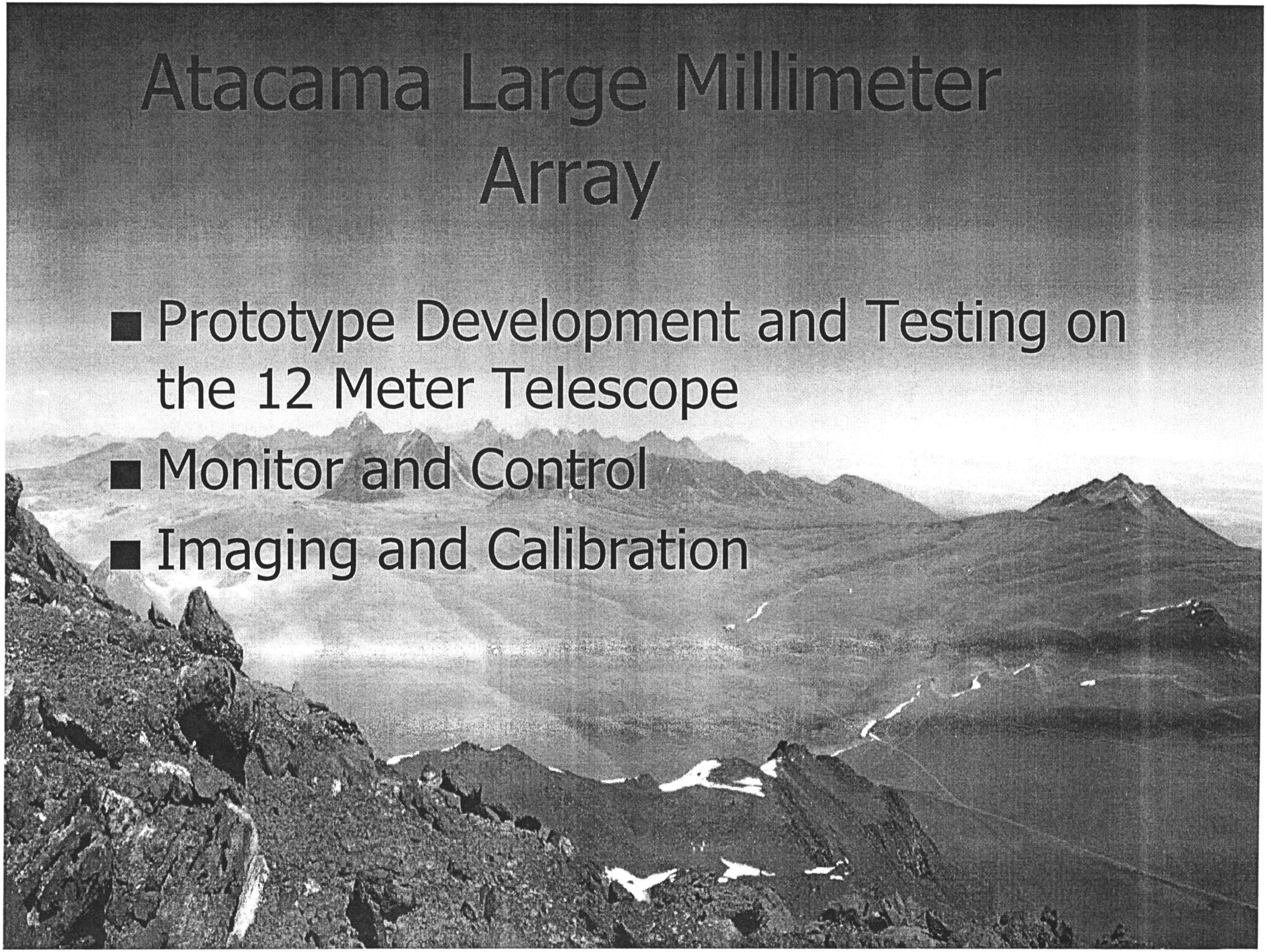

Atacama Large Millimeter Array
Antenna Development
Receiver Development and Production
Cryogenics Development
Systems Integration
Site Characterization

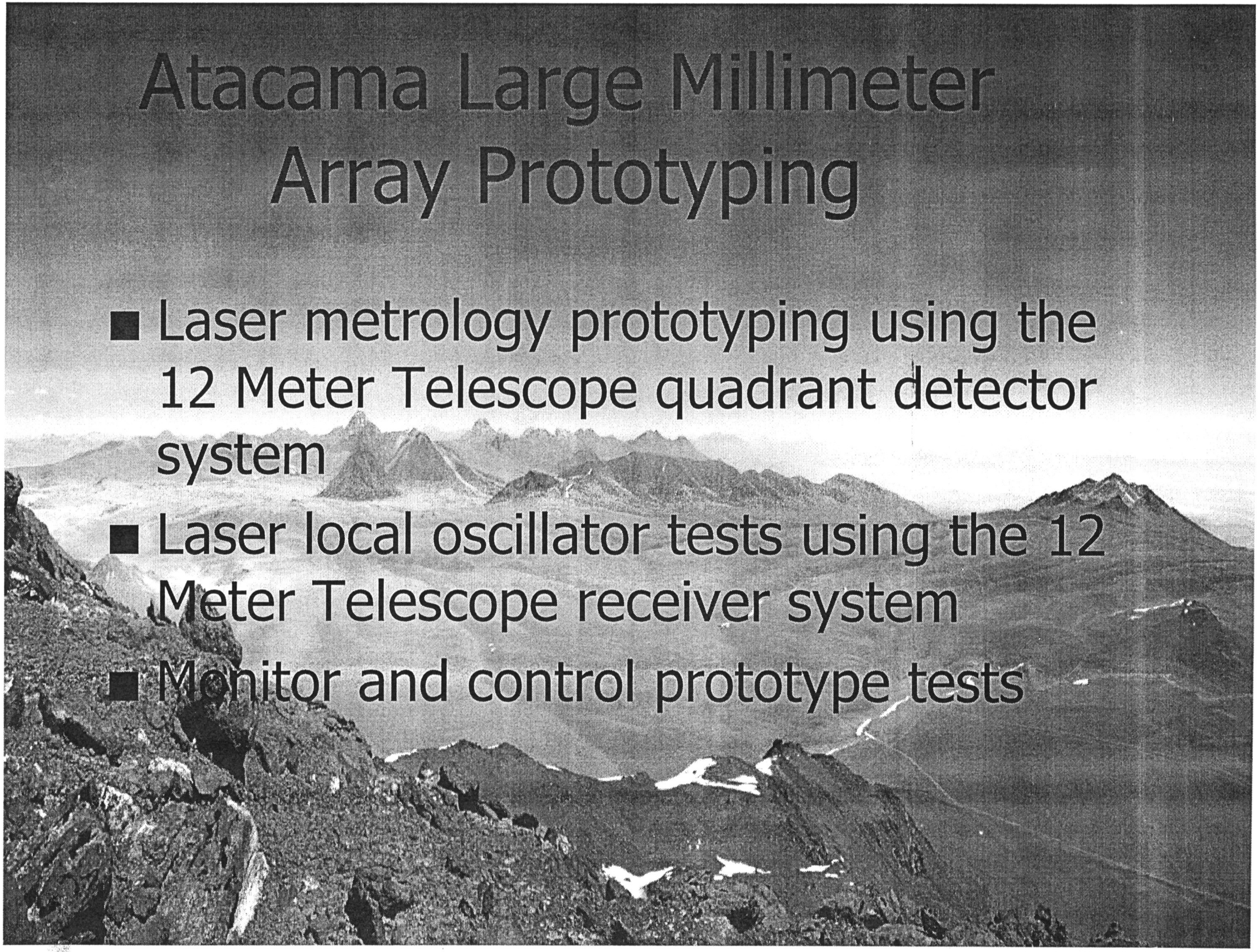
Atacama Large Millimeter Array

- Photonics Development
  - Millimeter/submillimeter photonic local oscillator
  - Phase calibration system
  - Local oscillator distribution and round-trip delay tracking
- Prototype Development and Testing on the 12 Meter Telescope

Photonics Development

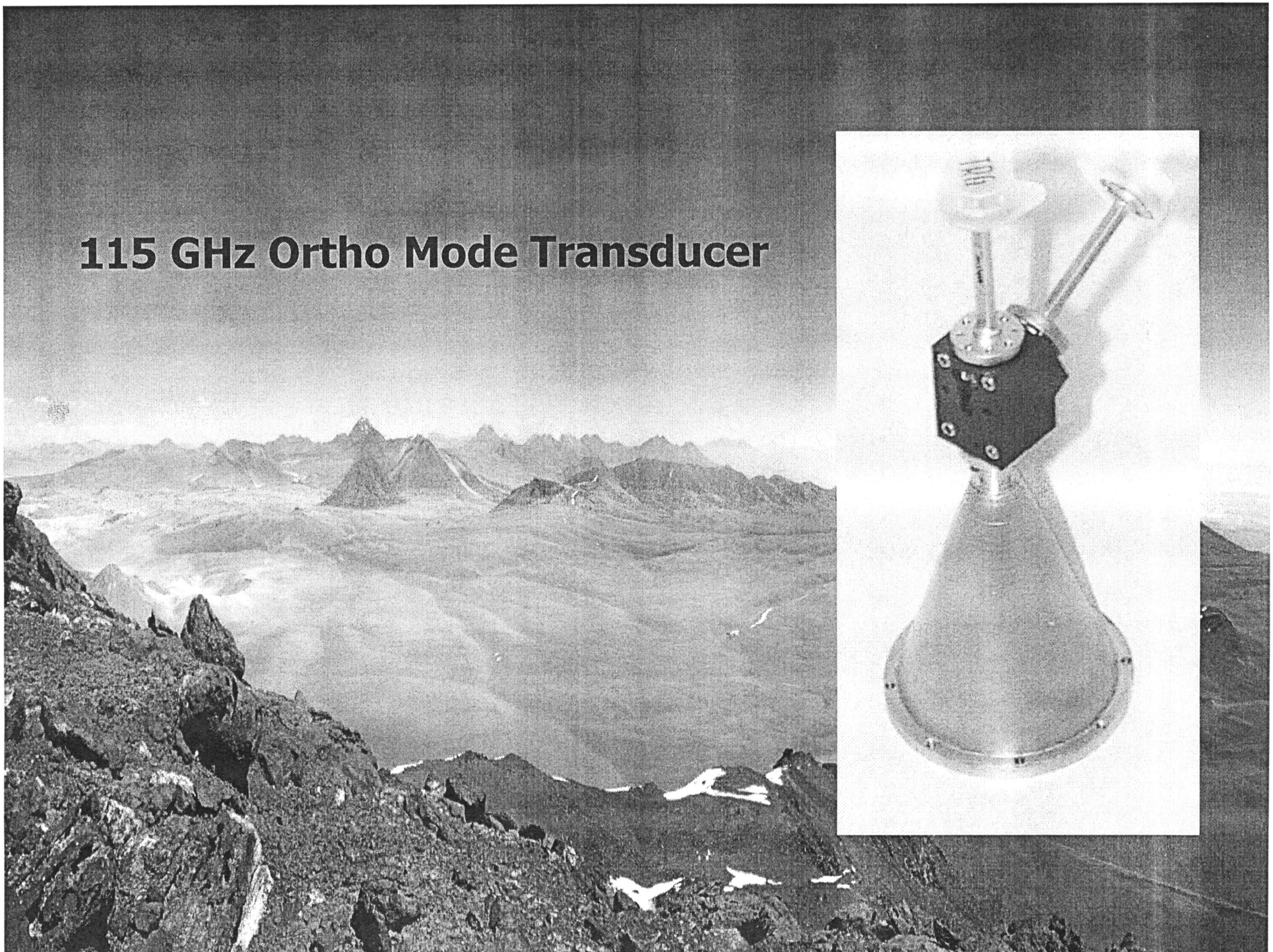



Atacama Large Millimeter Array
Prototype Development and Testing on the 12 Meter Telescope
Monitor and Control
Imaging and Calibration


Atacama Large Millimeter Array Prototyping
Laser metrology prototyping using the 12 Meter Telescope quadrant detector system
Laser local oscillator tests using the 12 Meter Telescope receiver system
Monitor and control prototype tests

Atacama Large Millimeter Array Prototyping

- Linear feed cross-correlation tests using the Millimeter Autocorrelator (MAC)
- Millimeter receiver component tests
- Ortho Mode Transducer (OMT) development
- Optical pointing system


115 GHz Ortho Mode Transducer

NRAO Tucson
The Next Five Years

- Continue to improve and operate the 12 Meter Telescope
- Develop and prototype ALMA instrumentation

MILLIMETER ARRAY PROJECT

PROJECT STATUS

- **Entering Second Year of 3-year, $26M, Design and Development Phase**

- **Project Staff**
  - **NRAO: 41.3 FTE**
  - **MDC: 6 FTE**

- **Beginning Transition to International ALMA Project**

PROJECT GOALS AND ORGANIZATION

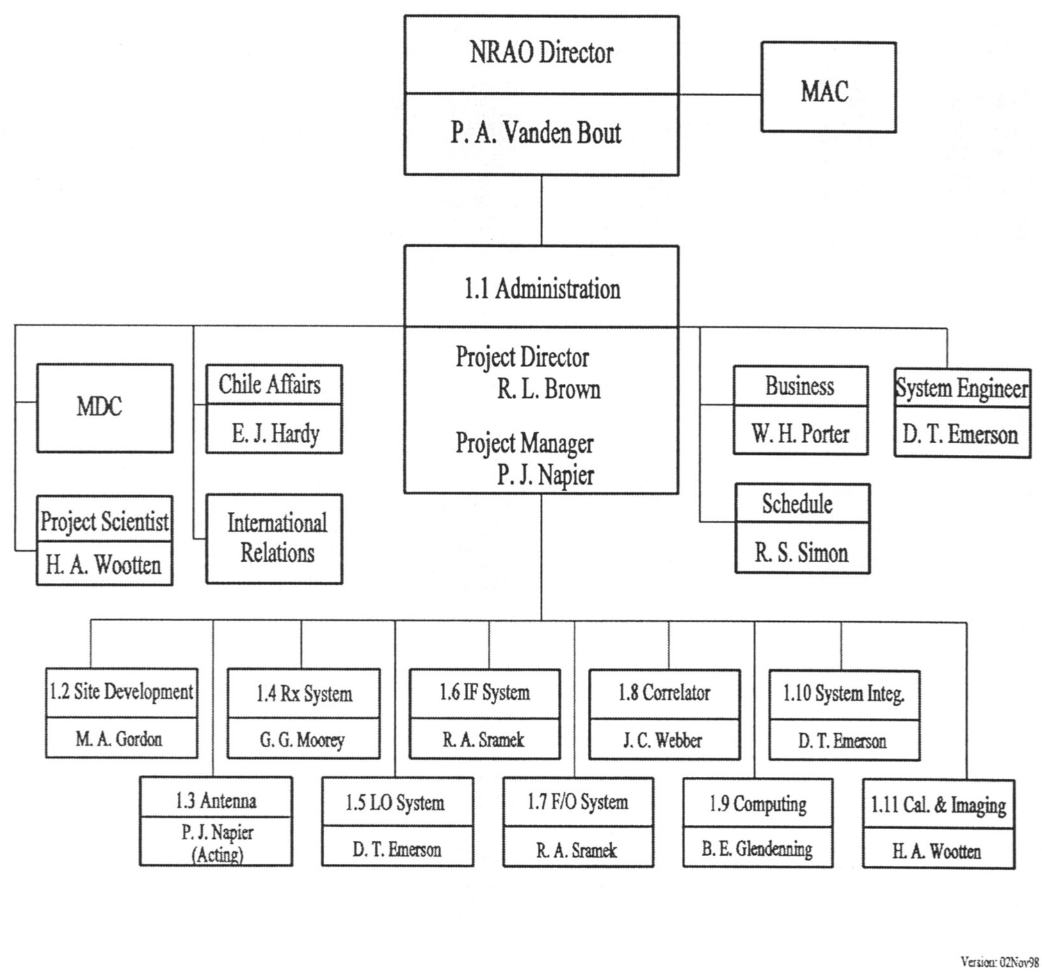
- **Project Book for the Design and Development Phase**

  http://www.tuc.nrao.edu/~demerson/project_book/

- **Management Plan for the Design and Development Phase (includes WBS and Dictionary)**

http://www.cv.nrao.edu/nrao-only/management_plan.ver2.pdf

MMA Design and Development



DELIVERABLES OF THE DESIGN AND DEVELOPMENT PHASE

- **The Complete Array System Diagram**
  - **Engineering Analysis of Design Alternatives**
  - **Design Decisions: Hardware and Software**
  - **Prototype of Key Instrument Modules**
  - **Prototype Antenna**

- **The Construction Phase Work Breakdown Structure Used as the Basis for the Array Cost Estimate**

- **An International Partnership in the Project**

- **Appropriate Use Permission for the Site**

DESIGN AND DEVELOPMENT RESPONSIBILITIES AT THE NRAO

TUCSON (14.3 FTEs)

- System Engineering
- Antenna Design
- Receiver System Design
- Cryogenics System
- Fabrication of Receivers to Test Prototype Antenna(s)
- Photonics Applications
- Site Testing Hardware and Data Interpretation
- Site Development Planning
- Configuration Studies
- System Integration

SOCORRO (11 FTEs)

- Software and Computing
- LO Reference System
- Optical Fiber Transmission System
- IF System

CHARLOTTESVILLE (15 FTEs)

- SIS Mixer Design and Fabrication
- HFET Amplifier Design and Fabrication : Pospieszalski
- Multiplier Chain Local Oscillator : Bradley
- Correlator(s): Design and Assembly : Escoffier
- Digital Design Studies
- Project Administration

SKETCH OF CONSTRUCTION PHASE SCHEDULE: MMA PLAN
(to be superceded by ALMA Project Plan)

2001 Test Interferometer Operational at VLA Site
- Antenna Evaluation
- Computing Environment Assessment

Bid Site Civil Works
Begin Design/Fab 211-275 GHz & 602-720 GHz SIS Rx Module

2002 Begin Site Civil Works Construction
Begin Design/Fab 275-370 GHz & 91-119 GHz Rx Module

2003 Contract for Production Antennas
Begin Design/Fab 163-211 GHz & 385-500 GHz Rx Module

2004 Site Civil Works Complete
First Quarter of Correlator Delivered to Site
Antennas #3-5 Verified on Site
First Fringes in Chile
Begin Design/Fab 125-163 GHz SIS Rx Module

2005 Antennas #6-14 Verified on Site
Second Quarter of Correlator Delivered to Site
Third Quarter of Correlator Delivered to Site
Interim Science Operations

2006 Antennas #15-25 Verified on Site
Fourth Quarter of Correlator Delivered to Site

2007 Antennas #26-35 Verified on Site

2008 Antenna #36 Verified on Site
Commissioning Phase Operations

INTERNATIONAL ALMA PROJECT

ALMA: Atacama Large Millimeter Array

<u>Project Goal</u>: A homogeneous array of 64 12-meter antennas equipped with receivers for all the atmospheric windows at millimeter and submillimeter wavelengths.

- **ALMA is formed from a merger of the MMA with the LSA**
- **ALMA is to be an equal partnership between the NSF and a collaboration of five European organizations (in the initial design and development phase)**
- **The MOU for the design and development phase of the ALMA Project was initialed March 30**

<u>Participating European Organizations</u>

1. **European Southern Observatory**
2. **Centre National de la Recherche Scientifique (CNRS), France**
3. **Max-Planck-Gesellschaft (MPG), Germany**
4. **Netherlands Foundation for Research in Astronomy/Nederlandse Onderzoekschool Voor Astronomie (NfRA/NOVA)**
5. **United Kingdom Particle Physics and Astronomy Research Council (PPARC)**

The ALMA Project begins when the MOU is signed by all participating organizations.

ALMA PROJECT ORGANIZATION

ALMA Coordination Committee (ACC)

- **Overall Project Responsibility**
- **ACC Composed of six members appointed by the NSF and six members appointed by the European collaboration**
- **Oversees the work of the Executive Committee**

ALMA Executive Committee (AEC)

- **Responsible for the management and coordination of the U.S. and European Phase 1 efforts, including the formulation of the Management Plan and work program for the construction phase of the project**
- **The AEC is composed of the U.S. Project Director and Project Manager, appointed by the NRAO under the authority of the NSF, and the European Project Manager and Project Scientist, appointed by the European Coordination Committee under the authority of the European MOU.**

Advisory Committees

- **Joint Management Advisory Committee**
- **Joint Scientific Advisory Committee**

ALMA PROJECT SCHEDULE

PHASE 1

- **Phase 1 begins when the MOU is signed and expires on 31 December 2001 or at the time that an Agreement for Phase 2 is signed;**

- **Within 120 days after the MOU comes into effect the AEC will present to the ACC a joint work program and management plan for Phase 1.**

PHASE 2

- **A work breakdown structure for Phase 2 and a cost estimate and schedule derived from that WBS will be completed in approximately one year from initiation of Phase 1;**

- **The Phase 2 WBS will be used to *value* the tasks in the project and it will serve an important input to the NSF/European negotiation for Phase 2 of the ALMA Project.**

- **Duration of Phase 2 is TBD but will extend beyond 2008**

NRAO Central Development Lab

- Development of electronic and electromagnetic devices and systems
- Support of NRAO radio telescopes, construction projects, and other organizations conducting research in radio astronomy
- Responsibility for SIS mixers, amplifiers, LO multipliers, correlators, feeds, polarizers, other components

CDL Activities

- Development of new devices exploiting new technologies
- Production for use in instruments
- Support of equipment now in the field
- Sales of unique components to other research organizations

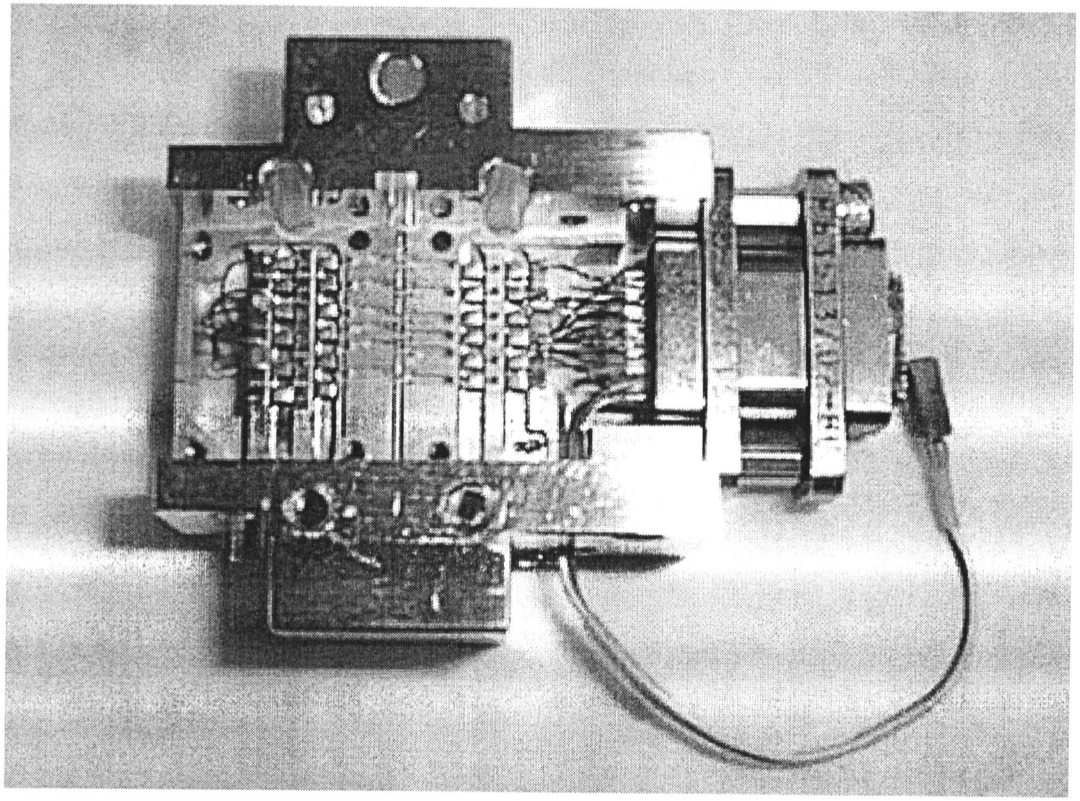
Recent CDL developments

- Low-noise amplifiers (LNAs) from 0.3 to 110 GHz for VLA, GBT, VLBA, and MMA
- Space-qualified LNAs for MAP project
- Tunerless 230 GHz sideband-separating and balanced mixers for 12-meter telescope and MMA
- Tunerless frequency multipliers (55-110 GHz) for MMA
- Digital correlators for GBT, 12-meter; designs for MMA
- Wideband feeds and polarizers for VLA at 22 GHz
- Prototype array and interference rejection receivers (with Green Bank)

CDL Amplifiers

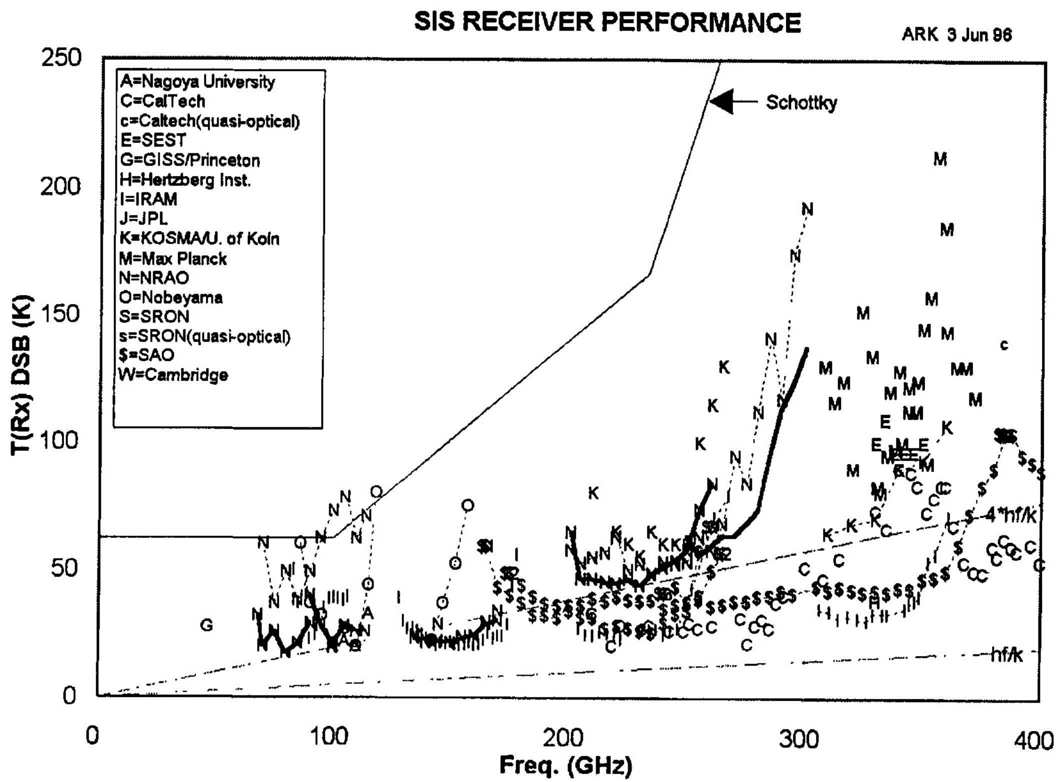
Band (GHz)	Noise (K)	Comment	Band (GHz)	Noise (K)	Comment
0.29-0.40	2.0	balanced	3.95-5.85	9.3	
0.40-0.52	2.0	balanced	8-10	10	
0.51-0.69	2.0	balanced	12-18	12	
0.68-0.92	3.0	balanced	18-26.5	9	InP
0.91-1.23	3.0	balanced	26.5-40	14	InP
1.15-1.73	3.0		40-50	18	InP
1.73-2.60	4.5		65-90	45	InP
2.60-3.95	5.2		75-110	60	InP

CDL Amplifiers

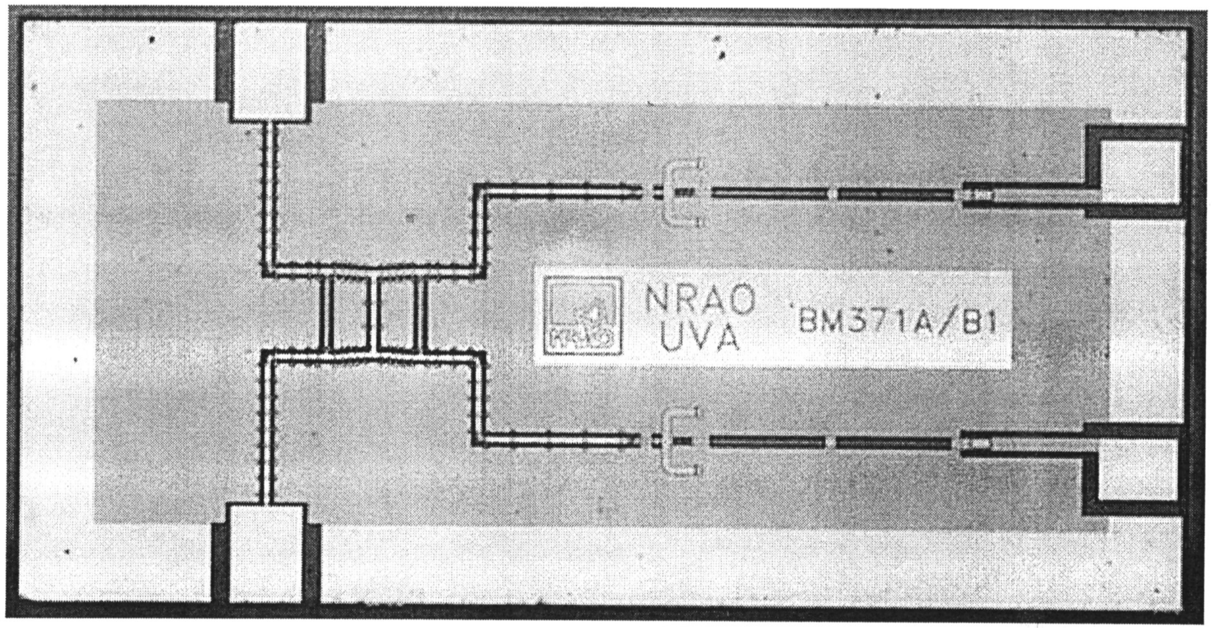


90 GHz MAP amplifier

CDL SIS Mixers

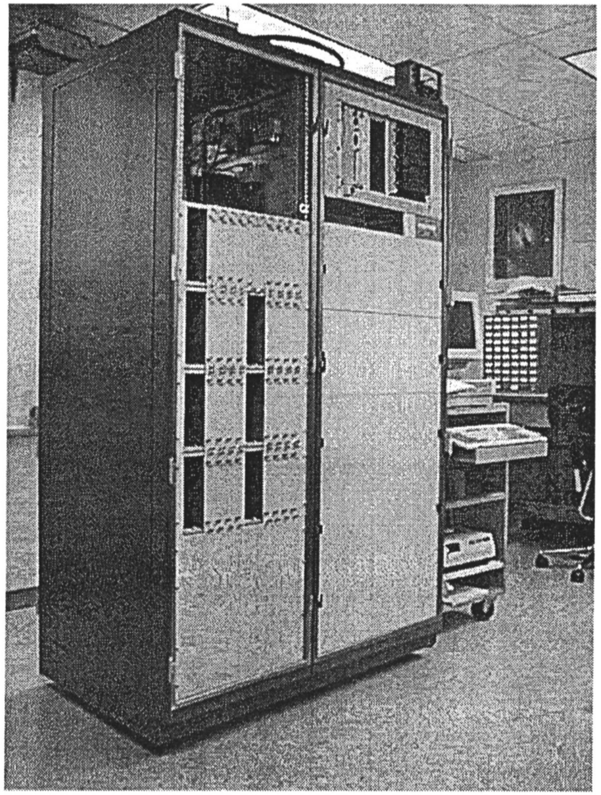


CDL Balanced SIS Mixer

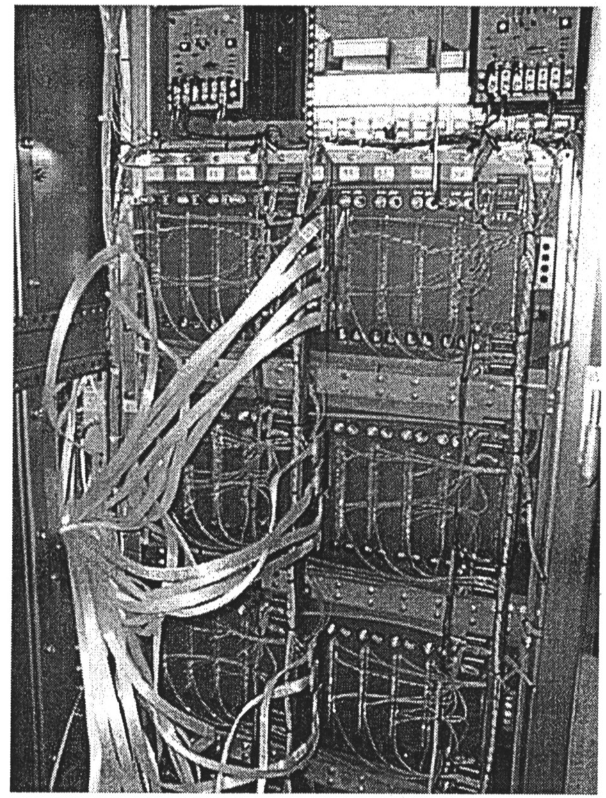


Balanced SIS mixer chip, 1 X 2 mm, showing input pads for RF and LO, 90-degree hybrid, two elemental mixers, and two output IF pads.

CDL Correlators



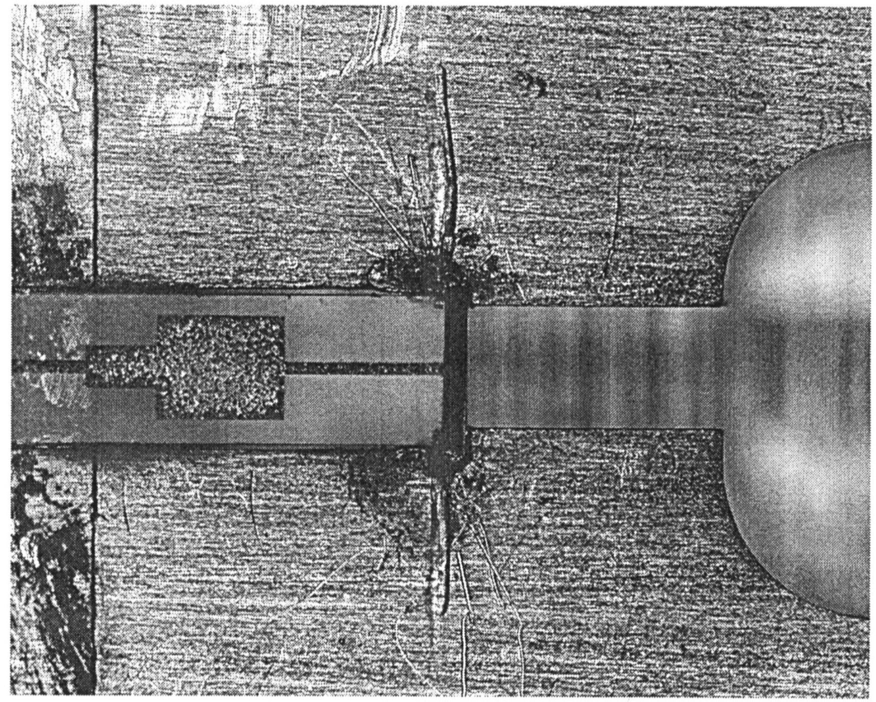
GBT Spectrometer



Rack wiring

CDL Frequency Multipliers

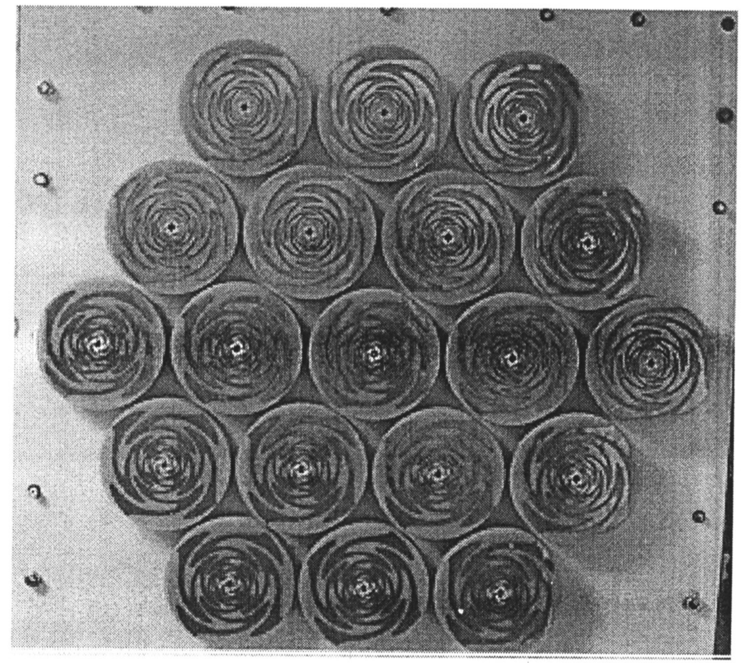
- Intended to generate LO power for MMA receivers
- Will be completely electronically tunable
- Aiming for high performance and low cost in quantity production
- Prototypes have been developed for 40-80, 80-160, 55-110, and 110-220 GHz doublers



55-110 GHz doubler block showing input waveguide, diode assembly, and output microstrip on quartz substrate

Array Feed Receiver

- Previous array receivers use standard feeds spaced by more than 2 beamwidths to avoid feed crosstalk
- Experimental receiver spiral feeds completely fill the inner portion of the aperture plane and provide full sampling for multiple beam generation or direct sky mapping
- First version demonstrated concept successfully
- Second version with much improved noise now under construction



19-element spiral antenna array for L-band prototype receiver

CDL Development Plans

- LNAs: push upper frequency to 115 GHz, use InP devices at 4-18 GHz, develop balanced amplifiers up to 2 GHz
- SIS mixers: combine 230 GHz sideband separation and balanced features; integrate IF amplifier into mixer body; automate testing; extend present technique to 700 GHz
- Frequency multipliers: complete LO chain for 230 GHz
- Correlators: built correlator for MMA antenna tests; perform detailed design work for final MMA correlator
- Electromagnetics: build polarizer for 30 GHz; design feeds for VLA upgrade

CDL Staffing

- 1 Division Head
- 1 Administrator/Secretary
- 7 Ph.D. Engineers
- 8 M.S. and B.S. Engineers
- 1 Graduate student
- 13 Technicians/specialists
- Open positions for 2 engineers and 3 technicians

Current Issues

- Space in current building: tight, but just enough to handle foreseeable developments and first year of MMA construction
- Projected space in building addition to Edgemont Road: sufficient to handle development and construction for MMA and VLA upgrade projects
- Much fabrication and test equipment is antiquated and ought to be replaced over the next few years
- Difficulties encountered in hiring due to high demand for electrical engineers and modest NRAO salary scale

Building Addition

- Requirements:
  - Increase communication among scientists, engineers, administrators Double laboratory space
  - Provide offices for expanded MMA construction staff
  - Consolidate & expand libraries
- Schedule highlights:
  - June 1998: studies initiated
  - November 1998: advertised for architect/engineering firms
  - May 1999: architect selected
  - January 2000: preliminary design approved
  - October 2000: detailed design approved
  - December 2000: construction begins
  - July 2002: occupancy

Antiquated Equipment

- Fabrication:
  - Much improvement from MAP funding; ~$150K spent
  - Shop equipment 10-30 years old; need ~$150K
  - Dicing saw 20 years old; need ~$100K
- Test:
  - Much improvement from MAP/MMA funding; ~$250K spent
  - Replace Apple II-based systems; need ~$150K
  - Vector Network Analyzer for >100 GHz; need ~$250K
  - Oscilloscopes, spectrum analyzers, power meters etc.; ~$250K
  - Calibrated references, adapters, etc.; ~$100K

Hiring Difficulties

- Electrical engineers much in demand
  - Offer turned down by a recent PhD recipient: our salary offer was 25% less than offer from a local company
  - Offer turned down by an experienced SIS receiver engineer: our salary offer was not competitive with his present academic employer's offer
- Technicians scarce
  - Cellular telephone companies pay technicians about 30% more than our salary scale
  - Few skilled applicants; those who might have gotten into ham radio now just sit in front of computers

AIPS++

- Astronomical Information Processing System
- C++, scripting, GUI's, libraries, toolkits and applications
- Designed by a team of astronomers and programmers
- Developed by an international consortium of observatories
- Release due at Chicago AAS

http://aips2.nrao.edu

Jump to first page

AIPS++ Mission Statement

- Adopted by the AIPS++ Steering Committee on 16th October 1993
- *A telescope requires post-processing software for calibration, editing, image formation, image enhancement, and analysis of images and other data streams. This software is an integral part of the radio telescope engineering. The **Astronomical Information Processing System** (AIPS++) project is designed to produce such a software product.*
- *Although AIPS++ is primarily targeted at radio astronomy, it is anticipated that it will also be used in other branches of astronomy and for other applications in image processing and data analysis.*

AIPS++ Deliverables

- Production system
  - Standard capabilities for NRAO telescopes
- Operational support
  - Maintenance
  - Help, workshops
- Development
  - Environment for development of new capabilities
- Support of NRAO Telescopes
  - *e.g.* GBT commissioning and observations
  - RT support
- Scheduling -> Scientific analysis

4/6/99

Jump to first page

AIPS++

Achievements '98

- Start transition to operations
- Improved user interface
- Display Library
- Integration of library capabilities into high-level applications
- Improved functionality all around
- First Nature paper
  - (*Putnam et al. August 13 on Parkes Multi-beam observations*)
- First parallelized application
  - Spectral-line Clean
- JCMT, NPOI/NRL

AIPS++ Timeline

- "Essentially complete" 2000
- First release by June AAS
  - VLA filler, some VLA calibration
  - All synthesis imaging
  - Early mosaicing package
  - Dish program
  - Display Library
- Second release by late 1999
  - Improved VLA calibration, visualization
  - VLBA Filler, some VLBA calibration
  - Single dish imaging
  - Improved mosaicing

AIPS++ Timeline

- Third release by mid 2000
  - VLBA calibration
  - Final mosaicing package
- Adopt AIPS++ Update capability
  - Frequent update over the Internet

AIPS++ Staffing

- Socorro
  - 4 scientists
  - 1 parallelization programmer (NCSA funded)
  - 1 visiting scientist (NCSA funded)
  - 0.5 Information services (shared with MMA)
- Charlottesville
  - 2 scientists
  - 1 scientific programmer analyst
- Tucson
  - 1 scientist
- Green Bank
  - 1 scientist
- Non-NRAO
  - Nine people, about 4.5 FTEs

AIPS++ Budget

- Minimal
  - $23K M&S
  - $37K Travel
- Last year augmented by collaboration with NRL
  - $67K -> parallel computer at Socorro for wide-field imaging

AIPS++ Challenges

- AIPS++ staffing ~ constant but partial shift to support
- Integrate AIPS++ Project into NRAO
- NRAO should start utilizing AIPS++ as much as possible
  - Offers solutions for many software-related issues
- Need to re-evaluate user facilities
  - Observer interaction with telescopes
  - Deliver images, etc. to observers
  - Consolidate and simplify data-base access e.g. NRAO archives

AIPS++ Challenges

- Internal workshops at NRAO
  - After code freeze (early April)
- NRAO AIPS++ User Committee
  - Form mid-year
  - Advises on NRAO interests, priorities
- AIPS++ User Group
  - Consortium-wide
  - Meet later this year
- AIPS++ Technical Group
  - Meet in 1999 Q3-Q4

AIPS++ Production

- Processing of data from consortium telescopes
  - our main (but not only) job!
- Standard algorithms
  - on new architectures and systems
- Front-line algorithms
  - to users asap
- Automated processing
  - expand user base for VLA, VLBA
  - promised for MMA

AIPS++ Operations

- Core functions
  - Maintenance, distribution, development
- Astronomer and programmer support
  - Help, education and training, library and contributed code
- Quality Assurance Group
  - Testing, code reviews
- Need more staff here
  - Support at each telescope

AIPS++

Development

- Standard processing model
  - Synthesis and single dish in same model
- Tool-kit model
- Both form a basis for research by scientists
  - Algorithms
  - Instrumental development
  - Simulation
- Programmer/Scientist collaborations

Support of NRAO telescopes

- AIPS++ as conduit for information flow in a telescope
  - Observing file generation
  - Table system for RT system
  - Fill to AIPS++ MeasurementSet
  - Archive in FITS
  - Tools for operators, observers
- RT system as consumer
  - Measures system
  - Table system
  - Glish
- Already in-place at GBT, WSRT, Parkes

AIPS++

Support of NRAO telescopes

- GBT:
  - remote-observing, data, etc delivered to observer (12m model)
  - Proposal to NSF
- VLA:
  - Filler now in progress
  - Extend later to RT filling
  - STI data into AIPS++ (GPS, radiometer later?)
  - Automated imaging
- VLBA:
  - Data quality tests in AIPS++
  - Automated imaging

AIPS++

Software Engineering

- Planning
  - Requirements and specifications
  - Scheduling
  - Tracking
- Code reviews
  - code and documentation
- Testing
  - C++, Glish, directed and un-directed user testing
- Observatory-wide interfaces
  - e.g. distributed objects
- Virtual organization

Observatory-Wide Computing

Each NRAO site/project can purchase individual computers/software <$5,000 from its own budget.

Observatory-Wide Computing budget provides:

- communications/networking (equipment/software)
- maintenance
- materials/services
- computing hardware/software >$5,000

Observatory-Wide Computing co-ordinates:

- inter-site networking/communications
- hardware purchasing and maintenance contracts
- systems administration
- 3rd-party software: purchasing/licensing/upgrades
- common computing environments
- computing policies, including security
- Y2K inventories, compliance assessment
- long-range planning
- reporting (NSF, NRAO Visiting & Users' Committees, Y2K, NCSA)

Observatory-Wide Computing

Budget

	1998 Actual	1999 "Wish List"	1999 Estimate
Travel/Training	$25k	$45k	$25k
Maintenance	$102k	$120k	$95k
M/S	$348k	$434k	$275k
RE	$168k	$406k	$100k?
Totals	$643k	$1005k	$495k?

Notes:

Budgets do not include communications costs and equipment, administered separately by J.Desmond

The "Wish List" includes all items requested by NRAO sites. As budget numbers change through year, the Computing Council prioritizes Wish List items to match funds available.

Observatory-Wide Computing

Workstation Inventory

	End of 1997	End of 1998
Tucson	32	35
Socorro	116	148
Green Bank	47	50
Charlottesville	65	72
Totals	260	305

Notes:

Multi-processor w/s included as single systems:
22 in 1997, 26 in 1998

Must average about 60 workstation upgrades/yr for 5-yr replacement cycle.

Observatory-Wide Computing

Site/Project Computer Staffing Summary

	1998 Positions	1999 Positions
Tucson	2.5	3.5
Socorro Operations	21.5	21
Green Bank	7.5	8
AIPS++	9.5	11.5
Charlottesville*	8	8.5
MMA		6.5
Observatory-Wide*	1	1
Totals	50	60

* some Charlottesville staff provide observatory-wide services, particularly network management

Observatory-Wide Computing

Personnel

- **Ruth Milner**
  Assistant to the Director for Computing

  reports directly to NRAO Director
  advised by Computing Council

Computing Council	
Chair	Alan Bridle (Sci. Staff)
Head, GB Computing	Gareth Hunt
Head, CV Computing	Pat Murphy
Head, AOC Computing	Gustaaf van Moorsel
Head, TUC Computing	Jeff Mangum
Head, MMA Computing	Brian Glendenning
AIPS Project Manager	Tony Beasley (A/D)
AIPS++ Project Manager	Tim Cornwell (A/D)

meets monthly by phone, by email as needed

subgroups work on special issues:
e.g., proposals to NSF, policies

Observatory-Wide Computing

Co-ordination Mechanisms

Computing Council

Inter-site Conference Meetings

- Computing Heads + all Sysadmins (biweekly)
- PC support staff (biweekly)
- NT domain setup/administration (as needed)
- Security (as needed: break-in action/postmortem)

Internal email lists/advisories

- PC support/administration
- Security risks
- Workstation technology
- World Wide Web technology

Inter-site Workshops

- April 12-14 1999: Real Time Programmers
- Goal: one internal workshop per year

Observatory-Wide Computing

Networking/Communications

Site networks

- GB old Jansky Lab needs upgrade to fiber
- CV-ER needs upgrade to consolidate with CDL
- AOC needs higher-speed backbone (backups)
- Tucson needs fiber all the way from mountain to carry 12-meter OTF data

Intranet

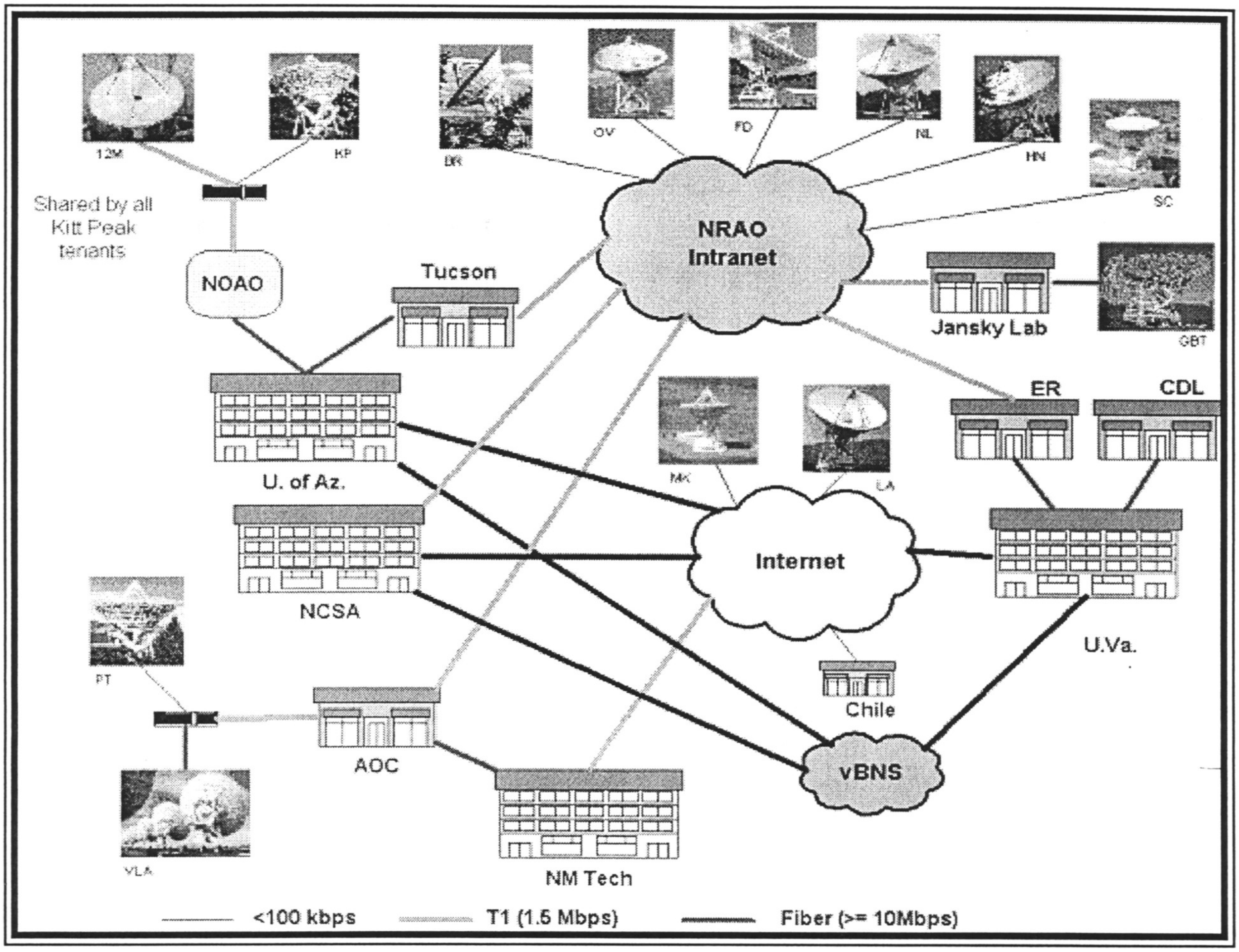
- Greater inter-site b/w needed for large data volumes
- Support inter-site telecollaboration tools
- Merge IP/voice/video communications

Wide-area connectivity

- Commodity Internet does not provide bandwidth or quality of service required for real-time data transfers from NRAO telescopes to user community
- Pursue formal vBNS/Internet2 connections for all major sites via “local” universities.

Observatory-Wide Computing

Current NRAO Wide-Area Connectivity



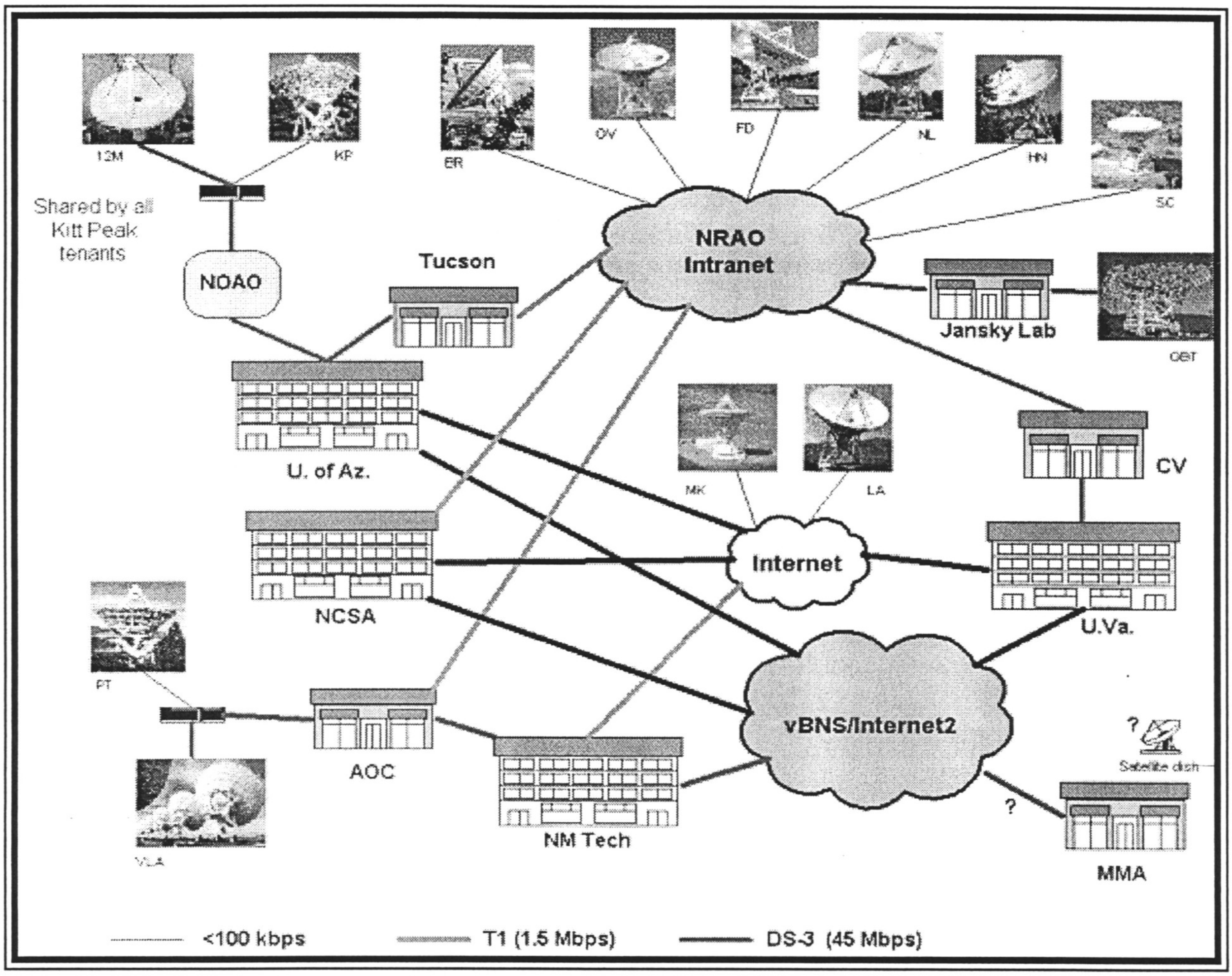
Deficiencies

- Max data rates at 12-m > capacity of mountain T1 line
- WAN access from AOC limited by T1 lines
- WAN access from GB limited by T1 lines

- no formal access to high-performance WAN

Observatory-Wide Computing

Future NRAO Wide-Area Connectivity



Adds:

- DS-3 access to WAN for 12-m via U. of Arizona
- DS-3 access to WAN for VLA/AOC via NM Tech
- DS-3 access to WAN for GB (shown via CV/U.Va. but other options will also be explored)

- D3-3 link from VLA to AOC to meet correlator upgrade

Observatory-Wide Computing
Non-proliferation

Issues

- Minimize number of different platforms used for general-purpose computing
- Restrict non-standard platforms to special purposes for which originally intended, e.g. support of NRAO-supplied software on platforms of interest to users, special purpose applications
- Centrally serve software updates & licenses where practical

Practices

- Request purchase order review of all computing hardware/software for which support will be expected
- Full support only for Solaris, Linux, WinNT and Win95
- Standardize third-party software, co-ordinate upgrades among NRAO sites (may also reduce costs, provide more flexible licensing arrangements)
- Windows: move to observatory-wide NT domain to simplify maintenance
- Unix: encourage standard environments to simplify support and user migration

Observatory-Wide Computing
Security

Issues

- Network security only as strong as weakest link
- Need for co-ordinated and timely patch installation
- Balance security/integrity of systems vs. ease of access for remote users/traveling staff
- Need for crisis management guidelines and post-mortems

Practices

- Anti-viral software for PC's
- Activity logging for network services
- Filters to block common intrusion mechanisms
- Restricted access to on-line systems
- ssh for login, especially by system administrators
- Restrict provision of access services (WWW, ftp) from individual workstations
- Internal mailing lists for security alerts
- Integrity-checking programs for critical systems
- Retain Intranet for most sensitive communications, especially personnel/financial data

Observatory-Wide Computing
Personnel Issues

- **Sites/projects hire all computing staff**
- **OWC advisory to NRAO Director, A/D's only**

Issues

- Non-competitive salaries (hiring/retention issues)
- High workloads for support staff from hardware, software and OS proliferation
- Small sites have many single-person failure modes
- Need to promote inter-site interactions and to standardize environments where possible: to share experience among sites and allow more inter-site support
- Training and professional development programs are needed for skill improvement and morale, but are expensive
- Face-to-face contact (inter-site travel) promotes understanding and co-operation among sites and intensive support when needed, but is expensive

Observatory-Wide Computing
General Issues

- Unix systems: migration from Sun to Linux

- Tighter networking of PC's for support/device access
- Higher network bandwidths needed at all levels to support greater data volumes/faster hardware
- Increased need for supplementary proposals to fund development, e.g. high-performance computing (NCSA), higher-bandwidth WAN access
- DS-3 connectivity soon needed for all sites to support high-volume data transfers, remote observing needs
- Closer partnering needed with nearby universities and statewide networking infrastructures
- Distributed nature of NRAO: groupware and tele-collaboration should play larger role, need network bandwidth and high quality of service to support

- Lack of industry standards for high-volume/archive media
- Need for observatory-wide database tools
- Need for observatory-wide document standards

- Improve on-line access to observatory services (proposal submission, data archives) for NRAO users

- Need for A/D for Computing?

NRAO Summer Research Programs

Forty Years of Educating Young Astronomers

- Objective: To encourage science students to pursue seriously a career in astronomy
- The program has been successful
- Many former summer students are astronomers
- Several AAS Warner and Pierce prize winners are former summer students

HISTORY

- 1959-1969 NSF Undergraduate Research Program
  - Operating funds increasing, NSF decreasing through period
  - NSF terminated program 1969, funded by operating funds thereafter
- 1970-1986 NRAO Program
  - High of 30 students mid-70s, low of ten in 1986
- 1987-1999 NSF Research Experiences for Undergraduates Program
  - Third five-year cycle, funding somewhat decreased
  - 10-12 week program for undergraduate research
  - 15-18 students per summer
  - Since 1998, augmented by NRAO-funded graduate student positions

CURRENT PROGRAM

- Covers astronomy, electrical engineering and computer sciences at all four sites; funded through 2002
- Main thrust is direct student participation in research project or equipment construction with staff mentor
- Students also attend colloquiua, use libraries and computers, interact with staff and visiting astronomers
- Staff present lectures to students, who tour sites, interact with staff and each other, and may execute a joint observing project
- Students produce written report, present it orally, and may present it at a professional meeting

MECHANICS

- Advertised nationally through posters, newsletter and WWW sites
- Project descriptions solicited early each year by site coordinator are confronted with available positions to choose mentors
- About 100 applications received by late January are distributed to sites for consideration by mentors during early February
- Choices made, letters sent on 1 March
- Students respond during March, generally arrive in late May or early June and depart by September
- To finish research or present it, further travel can be supported

UNDERGRADUATE PROGRAM RESULTS

- NSF REU Program 1992-1996
  - 27 published papers and reports
  - Approximately 1/3 sought professional astronomy degree
  - Three of six 1992 REUs have Ph. D. and are employed in astronomy

Former NRAO Student Program Participants
Now Active in Astronomy
(partial listing)

The success of the NRAO student program over the years can, in part, be judged by the number of its participants who continued on in the field of astronomy. This list is offered as a partial testimony on the program's impact.

E. Fomalont	1961
K. Seidelmann	1961
P. Usher	1961
R. Barnes	1962
D. Hall	1962
C. Heiles	1962/63
J. MacLeod	1962
J. Moran	1962
Y. Terzian	1962/63
W. R. Burns	1963
J. Linsky	1963
H. Aller	1964
M. Ewing	1964
M. Friedel (Aller)	1964
K. Gordon	1965
N. Remage (Evans)	1965
T. Barnes	1966
E. Churchwell	1966
P. Schwartz	1966
D. Shaffer	1966
A. Davidson	1967
R. Sanders	1967
D. Roberts	1967
B. Balick	1968
B. Draine	1968
E. Chaisson	1968
J. Gallagher	1968/69
T. Gergely	1968
M. Jura	1968
A. Witzel	1968
J. Baldwin	1969
K. Nordsieck	1969
F. Owen	1969
V. Pankonin	1969/70
R. Giovanelli	1970/71
P. Hemenway	1970
C. Leung	1970
R. Predmore	1970
A. Rots	1970
D. Koo	1971
C. Lada	1971
R. Mutel	1971
H. Smith	1971
S. Tapia	1971
T. Thuan	1971
T. Bania	1971/72
F. J. Lockman	1972
J. Rubin (Young)	1973
S. Hawley	1973/74
R. Malina	1973
T. Balonek	1974
J. Burns	1974/75
M. Haynes	1974
D. Stinebring	1974
A. Marscher	1975
R. J. Buta	1976
M. McGrath	1976
S. Neff	1976/77
B. Peterson	1976
C. Urry	1976
D. Cioffi	1977
T. Vestrand	1977
E. Bertschinger	1978
R. Fiedler	1978
C. Heiligman	1978
R. Hanisch	1978
T. Herter	1978
R. Norrod	1978
S. Tereby	1978
F. Verter	1978
J. Ulvestad	1978
J. Biretta	1979
E. Phinney III	1979
D. Hough	1979
K. Mitchell	1979
S. Kulkarni	1980
K. Lind	1980
C. O'Dea	1980
P. Coleman	1981
D. Croker	1981
S. Baum	1983
J. Schmeltz	1983
M. Greason	1984
M. Murison	1984
R. Foster	1984
P. Knezek	1984
D. Wood	1984
A. Clegg	1985
E. Lada	1985
G. Hennessy	1985
D. Murphy	1985
E. Nicholas	1986
M. McKinnon	1986
J.-H. Zhao	1986
J. Boisseau	1987
M. Johnston	1987
J. Mangum	1987
M. McKinnon	1987
R. Plante	1987
E. Wilcots	1987

Education Programs at Green Bank

TEACHER TRAINING

NSF Funded Teacher Enhancement

- K-12 Teachers
- residential programs since 1987
- over 400 inservice teachers trained
- core experience: research projects on the 40'
- supported by NSF Teacher Enhancement Grants
- current program: RARE CATS

  partnership with WVU and WVDE

  2-year, includes Hands-On Universe

Preservice Teacher Program

- one-week residential program
- target group: college students in teacher ed. program
- imbedded in college "methods" course
- NSF funded 1994-1997
- 130 trained
- Glenville State College (WV) continues at their own expense

Chautauqua

- 3-day residential program
- Targets undergraduate college faculty
- goal: enhance content knowledge in Radio Astronomy.
- participants use 40' telescope
- coordinated by University of Dayton
- since 1988, ~ 300 trained

INFORMAL SCIENCE EDUCATION

Observatory Tours

- Free hourly bus tours, and slide show
- Demonstrations
- Memorial Day through Labor Day + Weekends in Fall
- 1998: 22,000 Tourists (up 10% from 1997)
- supported by NRAO, and gift shop
- New! Special programs series

Field Trips

- day trips: extended tours, experiments, activities
- "overnights": small groups (<25) use the 40' telescope. Groups range in education level from 5th grade to graduate student.

Local Outreach

- Green Bank Middle School: Our Place in the Universe
- After School Science Program for elementary students
- National Youth Science Camp
- WVDE Telecourses for Science Teachers
- Regional Science Bowl (High School)

Future Educational Programs

Next Step: Expanded Programs, Year Round

Improve Tour Program - bring the science to the public

- interactive exhibits
- demonstrations
- see a telescope in action
- programs

Direct Services to K-12 Students

- New Field Trip Programs
  - half-day programs for large class groups
  - increase opportunity for overnight field trips
- Outreach into Schools: NRAO in a box activities
- Virtual field trips
- Summer Science Day Camps for Children
- Internet courses

Services to College Students and Teachers

- Expand preservice teacher institutes
- Internet Courses
- Residential Short Courses

Facilities Needed

Our ability to expand our educational presence is limited by the physical plant in Green Bank.

- **Science Education Center**
  classrooms, auditorium, exhibit hall, gift shop, plus outdoor exhibits

- **Dorm Space**
  Distances are too great for many groups to travel to Green Bank and back in one day. Dorm space for 30-40 people.

Current Funding

Tour Program

$1.1 M from NSF Education Directorate for Exhibits and Program Development.

Educational Programs

$67,500 from West Virginia State Legislature

$50,000 from Pocahontas County

$30,000 in equipment from Apple Computers, Inc.

Funding Needs, Education Center

Science Center Building Estimate

Total Gross Square Footage: 13,500 Square Feet

Construction $2.8 Million

Site Work (depends on location) - est. at $1.1 Million

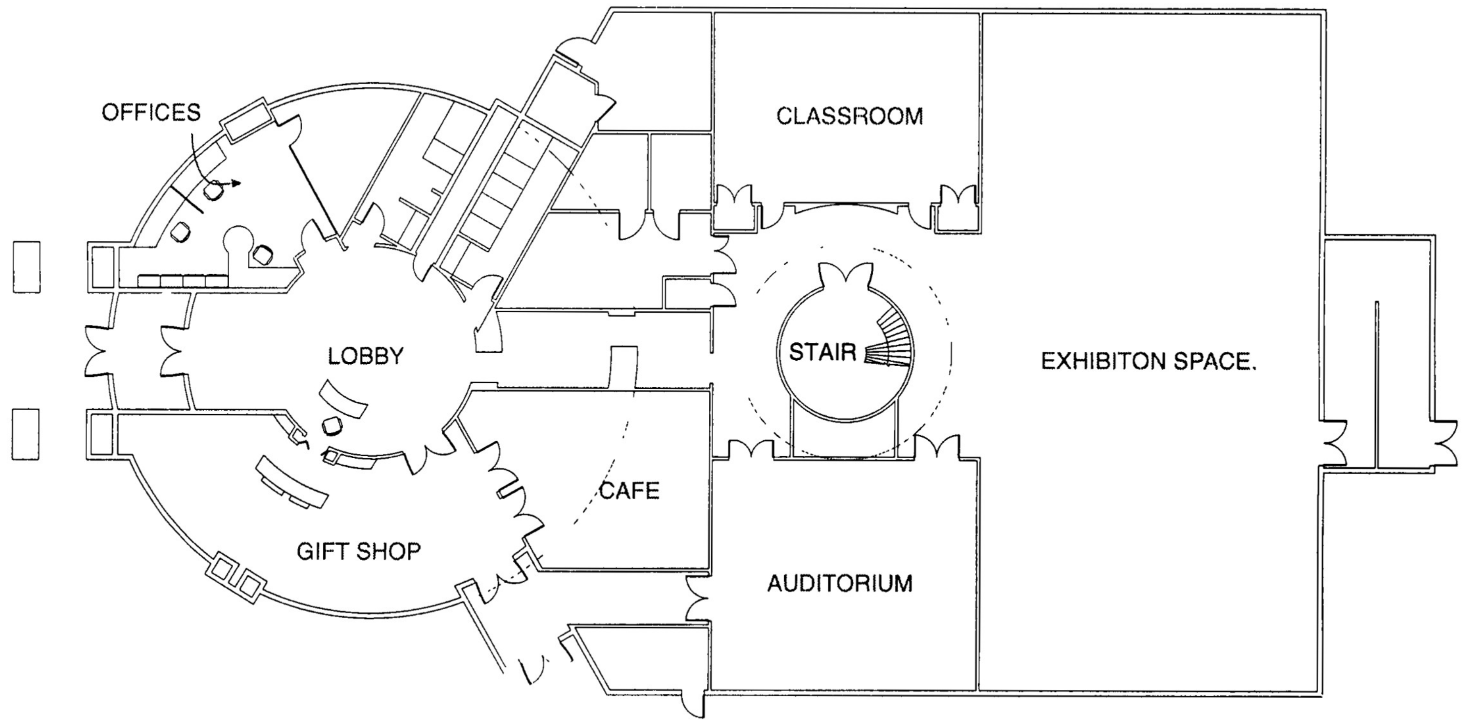
Operations

Education Center can be self sufficient though revenues from the gift shop and fees for programs.

Estimated annual costs = $250,000 (salaries + maintenance, utilities)

Fees: $3-2.00/person @ 60,000 annually = $130,000 K

Gift Shop Sales: $130,000 K



FLOORPLAN

NRAO TOUR AND EDUCATION CENTER

CALLOWAYJOHNSONMOOREWEST

ARCHITECTURE•ENGINEERING•INTERIOR DESIGN

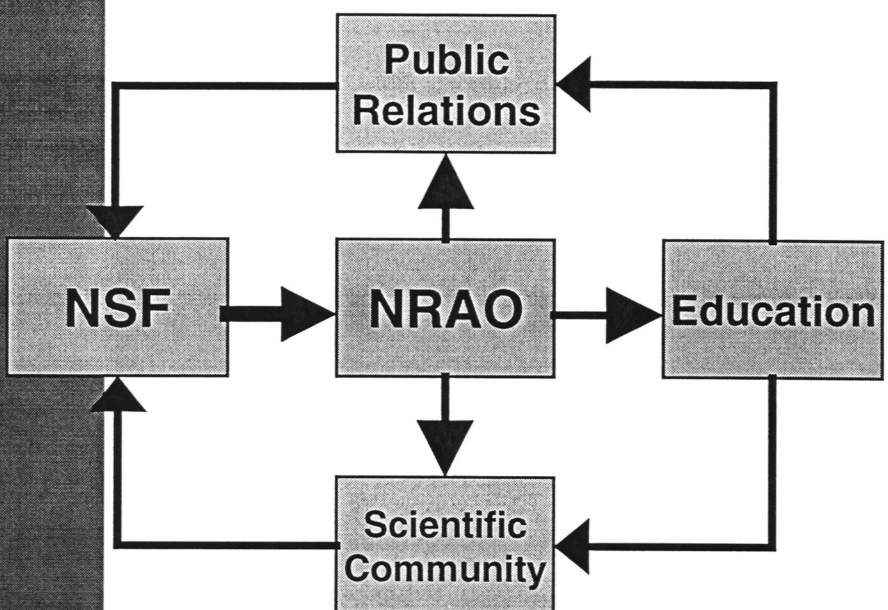
NRAO PR/Education

A.J. Beasley

- Motivation/trends
- Public relations (PR)
- Education (ED)
- Scientific community (SC)
- Documentation - WWW
- Staff - Budget
- 1999 action items

NRAO mission

- Help produce a scientific & technically-literate society
- Develop new technologies



  - Carry out relevant basic research
  - Stay near leading-edge of technology
  - Communicate results

Trends

- PR: growing NASA dominance; 10% PR budgets, interest in space, cutting-edge technologies
- ED: multimedia, interactive displays, WWW, software, science archives, courses
- SC: grants, data archives, auto. image/cal, strong user support, PR support, soft-money market
- Professional displays, documentation, data products

Visitor Centers

- VLA
  - 70000 visitors/yr
  - Self-guided, walking tour
  - Upgrade planned
    - NSF planning grant for exhibit development pending
    - Charge for entrance, tours, make self sustaining?
    - Add gift shop, education officer? (Owen - Finley)
- Green Bank
  - 22000/yr
  - Staffed, organised tours, arranged in-depth tours

- Upgrade planned
  - "Catching the Wave" $1.1M grant to develop exhibits for tourists/students
  - Science Learning Center- $3M planned classroom, gift shop, auditorium, observatory
- 12m
  - KPNO Visitor Center
  - 100000/yr; informal 12m tours
  - Display, video need updating
- Ongoing efforts at Mauna Kea, Apache Pt.
- Little coordination between the sites

Press Releases

- 1997(9), 1998(13), 1999(4+)
  - M87
  - TXCam
- NYT, Washington Post, LA Times + state/regional papers
- ABC, NBC, CNN, Discovery channel, NPR
- Wire services: AP, Reuters
- S&T, Astronomy
- Distributed to ~1000 science journalists
- Finley - AOC

- Coordinate with NSF public affairs, home institutes
- Good area of competition (if playing field level…)

- Lectures (public, high school, interested groups)
- Movies/videos/TV etc.

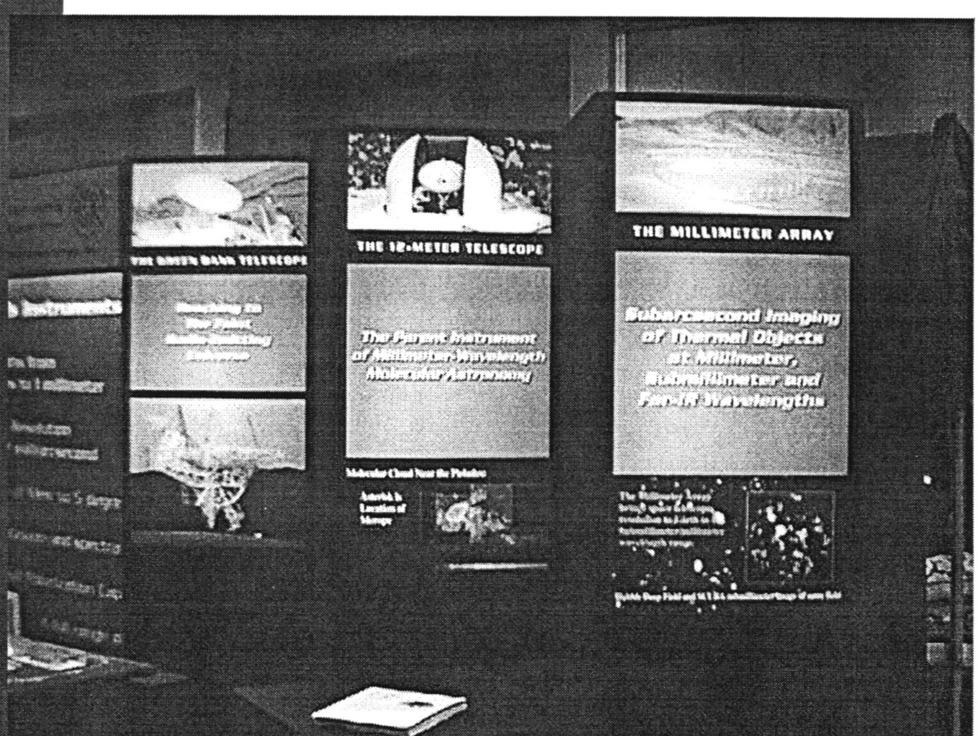
Education

- Teacher instruction
  - SCOPE: info, materials
  - Project ASTRO (ASP, NSF) teacher-astronomer pairing
  - Chautauqua short course in radio astronomy for small-college faculty (30+)
  - Science Teachers' Institute
    - Two-week course
    - >500 teachers since 1987
    - NSF-supported
  - Extended visits of STI grads + students (1998: 450)
  - GB: "Catching the Wave", Science Learning Center

- High-school lectures, science fairs, student mentoring
- NRAO Schools
  - VLBA school
  - 6th Synthesis Imaging School - June 1998
  - Future GBT, MMA...
- NSF REU students
- Graduate students
- Co-op students
- National Internet Radio Observatory (GBI initiative)

Scientific Community

- Instruments
  - Call for proposals ✔
  - Proposal process ✔
  - Scheduling ✔
  - Observing ✔
  - Data reduction ✔✔✔✔
  - Communicate results, PR, page charges ✔✔✔
- AAS
  - New display - Jan 1999
  - More documentation, CDs, posters - <u>more hardware</u>
  - VLBA - special session + posters - June 1999


THE 12-METER TELESCOPE
THE MILLIMETER ARRAY
The Parent Instrument of Millimeter-Wavelength Molecular Astronomy
Subarcsecond Imaging of Thermal Objects at Millimeter, Submillimeter and Far-IR Wavelengths
Molecular Cloud Near the Pleiades

Documentation

- Revise tri-fold instrument descriptions - may need two levels (public/scientist)
- Development projects (MMA, VLA Upgrade) need sexy brochures
- Observatory reports, statistics etc. need reformatting
- Newsletter
  - Under revision, adding science pieces, reformat (Turner, Hibbard) - Oct 1999

- Return to widespread US mailing + call for proposals
- Integrate/expand email news, couple to paper version

WWW

- Statistics/day
  - 700 sessions (200k/yr)
  - 7000 pages
  - 18000 hits
  - 260 MB (100 GB/yr)
- Complex dual role: public face + instrument support
- Current design poor
- Planned 1999
  - complete redesign - theme
  - page standards
  - site mirroring

- Radio Science Depository
  - WWW-based archive - CV
  - collect radio images, spectra, results with attached descriptions
  - searchable, indexed
  - public interest, student resource, PR resource
- NRAO Virtual tour
  - wander through NRAO using browser - history, sites, resources, archives
  - instrument displays, live site/building cameras, ?

Staffing/Budget

- Finley (NM), Heatherly (WV)
- New CV position - mid 1999
- Display \$18k, panels ~\$3k
- Document suite, posters, newsletter ~\$40k
- WWW projects ~\$40k
- CDs -NVSS, 2mm survey, science archive ~\$25k
- Projected 1999 \$100-150k, allocated ??
- External funding? NSF/AUI?

Ideas

- Upgrade Visitor centers
  - McDonald exhibit (200k/yr)?
- Data Products
  - auto images/cal. data
  - complete NRAO reduction
- Data archives on-line, interactive observing
- Radio telescope kit - single dish + interferometer for HS, colleges
- NRAO colloquium suite - canned modular talks on instruments, science
- real RE e.g. GBT Q-band

Award NRAO grants with observing time

- student and researcher support, page charges, accommodation, travel
- support long-term key projects
- recreate and help support the university community

1999 Action items

Get to the minimum level

- Redo NRAO documentation
- Rebuild WWW system
- Develop AAS display, more press releases, data chase
- Radio Science depository, virtual tour
- Data/Image CDs + software
- Explore technical ideas
  - instrument data products, real-time displays, on-line archives
- hard RE decisions

VLA VISITOR CENTER

Emphasis - THINK BIGGER

>50,000/yr now, potential 200,000/yr

Need Dedicated Staff of 5-10

Ultimately Self-supporting

Store/small admissions charge

New building or renovate Cafeteria building

K–12 education/general tourist focus

VLA open-houses

PRIVATE FUNDING

A New AUI Organization:

The JANSKY LAB

Goal: Raise private money to advance radio astronomy

Research and Education.

Who would give money to the "NRAO" or AUI ?

A separate Jansky Lab should do better.

Connected to NRAO through AUI but not NRAO

A. R. Thompson, April 22, 1999

Spectrum Management

Three principal areas:

International: ITU-R
National (US): FCC, IRAC
Local: e.g. NRQZ

Radiocommunication Sector, International Telecommunication Union (ITU-R)

Difficulties of Radio Astronomy within the Regulatory Systems

- Extreme sensitivity of RA instrumentation compared with communications systems
  - Band sharing: RA cannot share under line-of-sight conditions
  - Spurious emissions provide no protection (particularly from satellites)

- Allocations within relatively narrow bands
  - below 96 GHz, two bands at ~2%, others mostly .01-0.3%

  RA allocation at L-band, 1400-1427 MHz.
  e.g. VLA L-band survey used
  1340-1390 MHz and 1410-1460 MHz

- Time sharing between RA and communications systems:
  - possible in some cases, but difficult (e.g. Iridium)
  - Special cases: comets, supernovae, etc.

Some Current Issues

Iridium

Agreements with radio astronomers based on time of low traffic density after midnight.

Agreement with European RAs pending until May 1999.

Also problem of main emission (1621.35-1626.5 MHz) at VLA.

Task Group 1-3, limits on spurious emissions (1994-96) Rec. SM.329-6

Unwanted emissions (= spurious emissions + out-of band emissions):

Spurious emissions

Greater than 2.5 x "necessary bandwidth" from band center
Intermodulation products, harmonics, etc.
Attenuation below power supplied to antenna,
(43 +10 log P) dB, or 60 dB, whichever is less stringent.
Space services, spurious power measured within 4 kHz band
limits are design objectives (until WRC-2000)

Task Group 1-5, limits on out-of-band emissions, currently proceeding.

WRC-2000 (World Radiocommunication Conference)

Reconsideration of allocations to passive services above 71 GHz.
Hope to get RA bands moved towards centers of atmospheric windows.

Protection of RA in the 42.5-43.5 GHz band from emissions of the FSS (Fixed Satellite Service) in the band 41.5-42.5 GHz.

Some Current Issues (continued)

Protection of RA from emissions of High Altitude Platforms near 47 GHz

Two bands 300 MHz wide.

Possible change to frequency near 30 GHz

Percentage of time that RA can accept interference above the harmful threshold

Proposal: 5% total but not more than 2% from any one system

(Important for Monte-Carlo calculations of interference models)

Protection and sharing criteria for RA observations from space.

Final Analysis Proposal

Feeder links for a Little LEO system.

Earth-to-space 1390-1393 MHz

space-to-Earth 1429-1432 MHz

WRC-2003

Frequency Allocations above 275 GHz likely to be on the agenda.

Approaches to Interference Mitigation

Coordination Zones around observatories

ITU-T Recommendations RA.1031-1 and RA 1272

Coordination zones are responsibility of administrations

Use of spectral correlators

Useful for narrow-band interference

Adaptive cancellation

Barnbaum and Bradley, Astron. J., 116, 2598-2614, 1998.

To provide and effective solution sensitivity must approach that for the no-interference condition

Need to receive signals to be canceled with antenna gain 10 dB or more.

Steering of sidelobe minima towards interfering sources

Possible in principle with large array.

Spectrum Management Organization

ITU-R Study Group 7, Science Services

Four working parties: WP7A (time and frequency)
WP7B & C (space research)
WP7D (radio and radar astronomy

International Chairman of WP7D: J. B. Whiteoak (CSIRO)

Chairman of U. S. WP7D: T. Gergely (NSF)

U. S. representatives at last international meeting of WP7D (Geneva, March 3-11)
T. Gergely
W. D. Brundage (NRAO)
M. M. Davis (NIAC)
V. Altunin (JPL)

Committee On Radio Frequencies (CORF) of National Science Foundation
Chairman: P. Steffes, Georgia Tech.

Frequency Coordination within NRAO

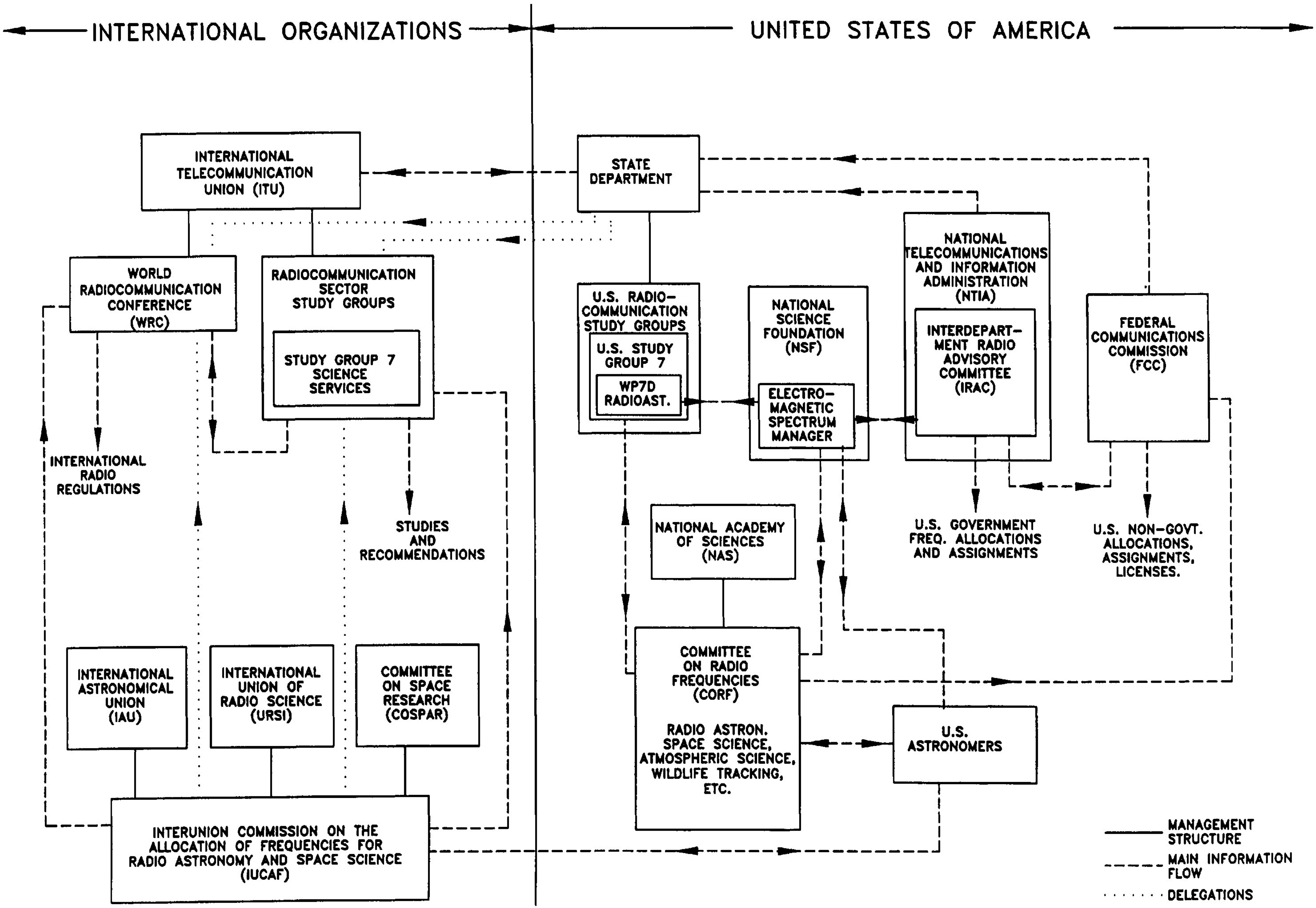
Some people involved:

Green Bank: M. M. McKinnon (CORF), W. Sizemore

Socorro: W. Brundage, D. Mertely G. Taylor

Tucson: D. Emerson (CORF)

Charlottesville: P. Vanden Bout, A. R. Thompson



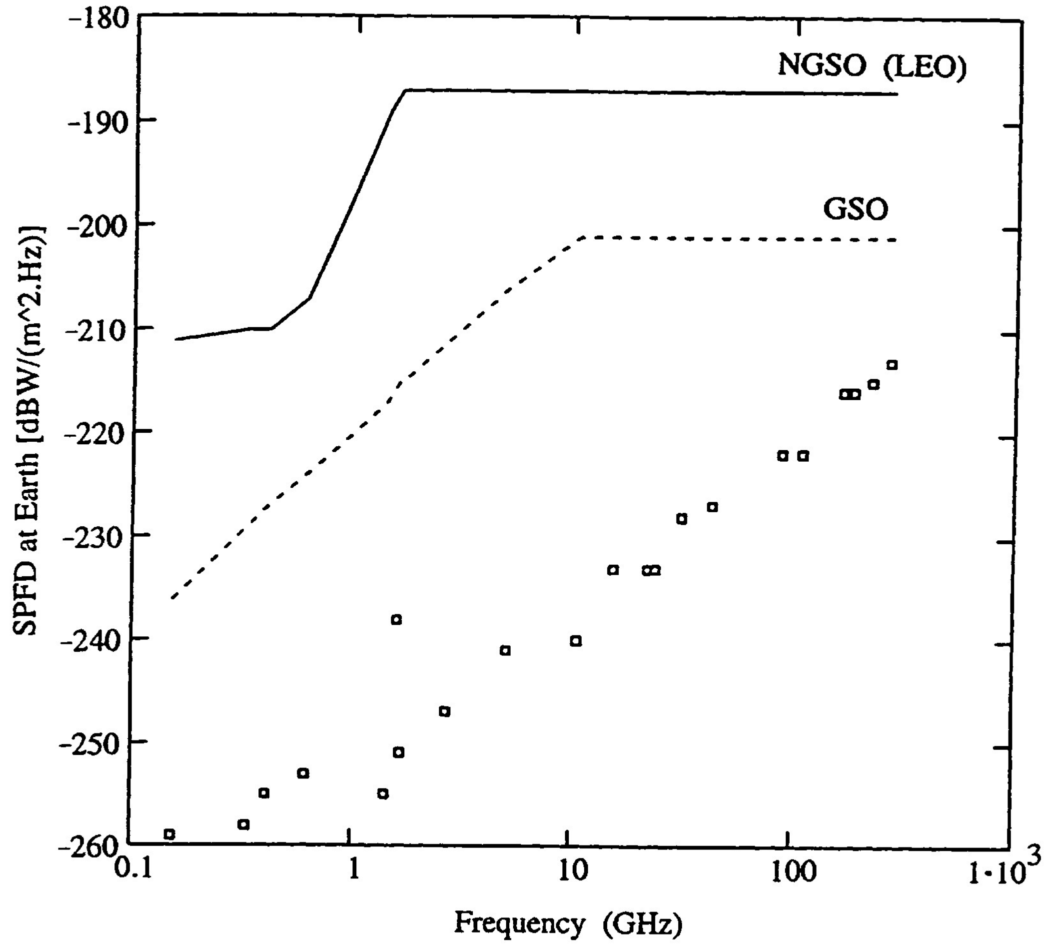
International and U.S. Spectrum Management System, as it Affects Radio Astronomy.

A.R.T., V.P., 4/19/94
rev. 3/12/99 [redacted]

13.36 - 13.41 MHz	P
25.55 - 25.67 MHz	P
37.50 - 38.25 MHz	S
73.00 - 74.60 MHz	P
79.75- 80.25 MHz	P
150.05 - 153.00 MHz	P
322.00 - 328.60 MHz	P
406.10 - 410.00 MHz	P
608.00 - 614.00 MHz	P S
1 400.00 - 1 427.00 MHz	P (Pas)
1 610.60 - 1 613.80 MHz	P
1 660.00 - 1 670.00 MHz	P
1 718.80 - 1 722.20 MHz	S
2 655.00 - 2 690.00 MHz	S
2 690.00 - 2 700.00 MHz	P (Pas)
4 800.00 - 4 990.00 MHz	S
4 990.00 - 5 000.00 MHz	P
10.60 - 10.70 GHz	P
10.68 - 10.70 GHz	P (Pas)
14.47 - 14.50 GHz	S
15.35 - 15.40 GHz	P (Pas)
22.21 - 22.50 GHz	P
23.60 - 24.00 GHz	P (Pas)
31.30 - 31.50 GHz	P (Pas)
31.50 - 31.80 GHz	P
42.50 - 43.50 GHz	P
48.94 - 49.04 GHz	P
86.00 - 92.00 GHz	P (Pas)
97.88 - 98.08 GHz	P
105.00 - 116.00 GHz	P (Pas)
140.69 - 140.98 GHz	P
144.68 - 144.98 GHz	P
145.45 - 145.75 GHz	P
146.82 - 147.12 GHz	P
150.00 - 151.00 GHz	S
164.00 - 168.00 GHz	P (Pas)
174.42 - 175.02 GHz	S
177.00 - 177.40 GHz	S
178.20 - 178.60 GHz	S
181.00 - 181.46 GHz	S
182.00 - 185.00 GHz	P (Pas)
186.20 - 186.60 GHz	S
217.00 - 231.00 GHz	P (Pas)
250.00 - 251.00 GHz	P
257.00 - 258.00 GHz	S
261.00 - 265.00 GHz	P
262.24 - 262.76 GHz	P
265.00 - 275.00 GHz	P

Bands Allocated to Radio Astronomy

(from ITU Handbook on Radio Astronomy)



Broad-band Interference

Figure 2. The square points indicate the threshold levels of detrimental interference to radio astronomy in terms of W/(m^2.Hz) as specified in Recommendation ITU-R RA.769. For the particular case of GSO satellites, the interference thresholds are 15 dB lower in spfd than the values indicated by the points and this should be taken into account in comparing the relative levels of the points and the curve for the GSO satellite. The solid curve is the spfd at the Earth from a Low Earth Orbit (NGSO) satellite at a height of 700 km radiating a broadband signal with power spectral density -79 dBW/Hz. This power spectral density is equal to -43 dBW in a reference bandwidth of 4 kHz, which is the proposed Category-A limit for Space Services transmitters with power up to 5 W. The dashed curve is for the same signal radiated from a GSO satellite. The gains used for the satellite downlink antenna are given in Table A1 for both cases. The curves represent worst-case values for interference as explained in section 4.

NRAO Long Range Planning Retreat

Green Bank, WV
22/23 April 1999

The Very Large Array Expansion Project

Rick Perley
NRAO/Socorro

Why Should We Improve the VLA?

- The VLA is as productive, and heavily subscribed as ever.

- So, why should we want to improve it?

  Two reasons:

  1) The potential information collecting ability of the array far exceeds the current.

  2) The science potential of this untapped capability is vast.

- Why should we think to implement these improvements now?

  1) The technology now exists to collect, convey, process, and record multi-GHz bandwidths.

  2) The next generation centimeter-wave array is at least a decade away.

VLA Expansion Project Assumptions

The fundmental principle in The Project is to refurbish the existing facility, not build an entirely new one.

We assume the following:

- Use the Existing Antennas

  - modifications to improve performance are included.

- Use the Existing Array Configurations

  - But definition of new configurations permitted.

- Use ready, or nearly-ready technologies.

  - Implementation of evolving technologies is o.k.

- Make maximum use of the ALMA design.

  - Much of the upgrade can be implemented in parallel with ALMA.

Upgrade Goals

The overall goal of the VLA Expansion can be summarized very simply:

A factor of >10 improvement in all key instrumental parameters of the VLA.

These parameters lie in the following categories:

1. Sensitivity
2. Frequency Tunability
3. Spectral Capability
4. Surface Brightness Sensitivity
5. Angular Resolution

Some latitude is needed in the definition of a factor greater than 10!

Expansion Plan Overview

Specific goals for the project are:

Sensitivity

Analysis leads us to set as a goal:

< 1 MicroJy Continuum Sensitivity Between 2 and 40 GHz.*

This will be attained by a combination of:

- Wide bandwidths (up to 8 GHz/polarization)
- More sensitive receivers
- Improved antenna efficiency (higher frequencies).

Line sensitivity improvements are much more modest -- because we don't have the bandwidth factor to take advantage of.

* Defined as rms noise on a Stokes' I image made with 12 hours' data at full continuum bandwidth.

Frequency Tuning Range.

- There are many scientific benefits of unlimited frequency coverage.

- As the reflector performs well from 200 MHz to 50 GHz, should we ask less of the electronics?

- Thus, we set as a goal:

Complete Frequency Coverage from 1 to 50 GHz from the Cassegrain Focus Ring.

- This can be achieved with 8 frequency bands.

    - Three of these (L, S, C) have 2:1 BWR and may require transmission of linear polarization
    - The others are 1.5:1, for which conversion to circular polarization at the feed seems feasible.

- Design of efficient feeds below 1.2 GHz is difficult, due to diffraction and the small subreflector.

Provided that the high frequency goals (sensitivity, frequency coverage) are not compromised, we set a secondary goal:

Continuous Low Frequency Coverage from 1 GHz to 200 MHz or lower, from the Prime Focus.

Requires access to the prime focus.

To enable this access, a plan to rebuild the FRM and quadrupod legs has been developed.

Spectral Capability

- The existing correlator is completely inadequate for current work. A great instrument in 1980, when it was designed.
- The chief limitations are in:
    - ⇨ Number of channels
    - ⇨ Available bandwidth
- Both limitations can be adequately addressed now.
- The design goal is:

A correlator for 40 stations, 8 GHz per polarization, and up to 8192 spectral channels per polarization product.

- The MMA correlator design is an excellent match to the science goals of the VLA Expansion. Joint development, and production, is clearly desirable.
- These correlators are BIG! -- a sustained data flow of 10 MB/s needs to be anticipated.
- A new correlator needs to include the possibility of new antenna stations on baselines up to 400 Km.

Surface Brightness Sensitivity -- (The 'E'-configuration)

- A configuration compressing the 27 antennas into an area of 300 meters maximum extent would provide:

  ⇨ Faster low-surface brightness imaging
  ⇨ More sensitivitity to extended emission
  ⇨ Much improved fidelity in mosaiced images.

Higher Angular Resolution -- The A+ Configuration

- The VLA's maximum spacing of 35 Km, and the VLBA's minimum spacing of about 200 Km leaves a gap in resolution which has serious ramifications in science.

- Many objects are unresolved to the VLA, but are not visible to the VLBA.

- Many objects cannot be imaged at constant resolution over the entire available frequency range.

The goal:

Expansion of the VLA's Resolution by a Factor of 10, with Imaging Performance Characteristic of the Current VLA

- How many antennas? Some realistic simulations have suggested that 10 antennas in two rings will do nicely, while 6 antennas in a more distributed configuration will introduce significant errors in imaging complex objects.

- More studies with realistic models and errors, and with different array designs are needed. It's easy to state 'More is Better', but harder to show how much better.

- These new antennas would be used as part of at least three different arrays:
    - VLA, when in the 'A' configuration.
    - VLBA, when VLA in other configurations.
    - As a standalone array.

Project Costs, Priorities, and Schedule

The project has been grouped into four elements, listed below roughly in order of priority and length of time of development.

Group A: Correlator, Data Transmission, On-Line Computing, Monitor/Control, Archiving.

- By far the most urgent need, and that which gives the most new science over the broadest range of subjects to the most users.
- Also requires the longest development and implementation time.
- Well matched to ALMA technology development.

Total Cost:	$25M (plus contingency)
Total FTE:	185 Person-years.
Total Time:	8 years.

Group B: New and Improved Receivers Giving Complete Frequency Coverage from 1 -- 50 GHz.

- Eight receiver/feeds at the Cassegrain focus will span this frequency range.
- Two new bands (S and Ka) required.
- All other bands to be upgraded (two of these already underway -- Q and K bands)
- Priority order for band upgrade/implementation would be established later.

Total Cost:	\$16M (plus contingency)
Total FTE:	117 Person-years
Total Time:	8 years for all 8 bands.

A plan for funding Groups A and B is being developed now, and is due at the NSF on June 1.

Group C: The A+ Configuration

- Up to 8 new antennas, sited within ~300 km of the VLA, and connected to the new correlator with optical fiber.

- VLBA recorders for each new antenna required, sited at the AOC.

- These new antennas, along with the VLA and inner VLBA antennas, constitute a very flexible and powerful instrument:

  ⇨ With the VLA: 10 times better resolution with the ultimate sensitivity.
  ⇨ With the VLBA: Doubles the sensitivity and greatly enhanced imaging flexibility.
  ⇨ As a standalone array: Gives the sensitivity of the VLA with the resolution of MERLIN -- and much better imaging characteristics -- full time.

- A very strong and broad science case.

Rough Estimated Cost:	\$75M
Total Time:	6 years.

Group D: Other New Capabilities

- Includes smaller-budget items which may overlap capabilities being developed on other instruments.

- Two major components:

  ⇨ Low frequency, prime-focus capability (50 MHz - 1.1 GHz)

  ⇨ E-Configuration.

Total Cost:	$12M
Total FTE:	45
Total Time:	2 - 6 years.

Summary

The VLA Expansion Project will:

- Unlock new science unavailable to any other instrument.
- Make maximum use of existing infrastructure -- a leveraged investment!
- Increase operational costs only modestly.
- Offers the most new science for the least money.
- Benefit from ALMA development.
- Produce an effectively new array (with a new name!) with unprecedented power and flexibility in the meter to millimeter wave bands.

It is a low-risk, high return, makes-sense project.

NRAO Long Range Planning Retreat

Green Bank, WV
22–24 April 1999

THE VERY LARGE ARRAY EXPANSION PROJECT

Michael P. Rupen
NRAO/Socorro

Outline:

- **What is the VLA Expansion Project?**
- **Why should I care?**
- **How much would it cost?**
- **How long would it take?**

OVERVIEW OF THE PROJECT

The VLA Expansion Project consists of:

- **wider bandwidths: 8 GHz vs. 100 MHz per polarization**
- **new correlator: 16,384 vs. 8 channels in 100 MHz**
- **new receivers: continuous, 0.2–50 GHz**
- **longer baselines: 4mas vs. 50mas at 45 GHz**

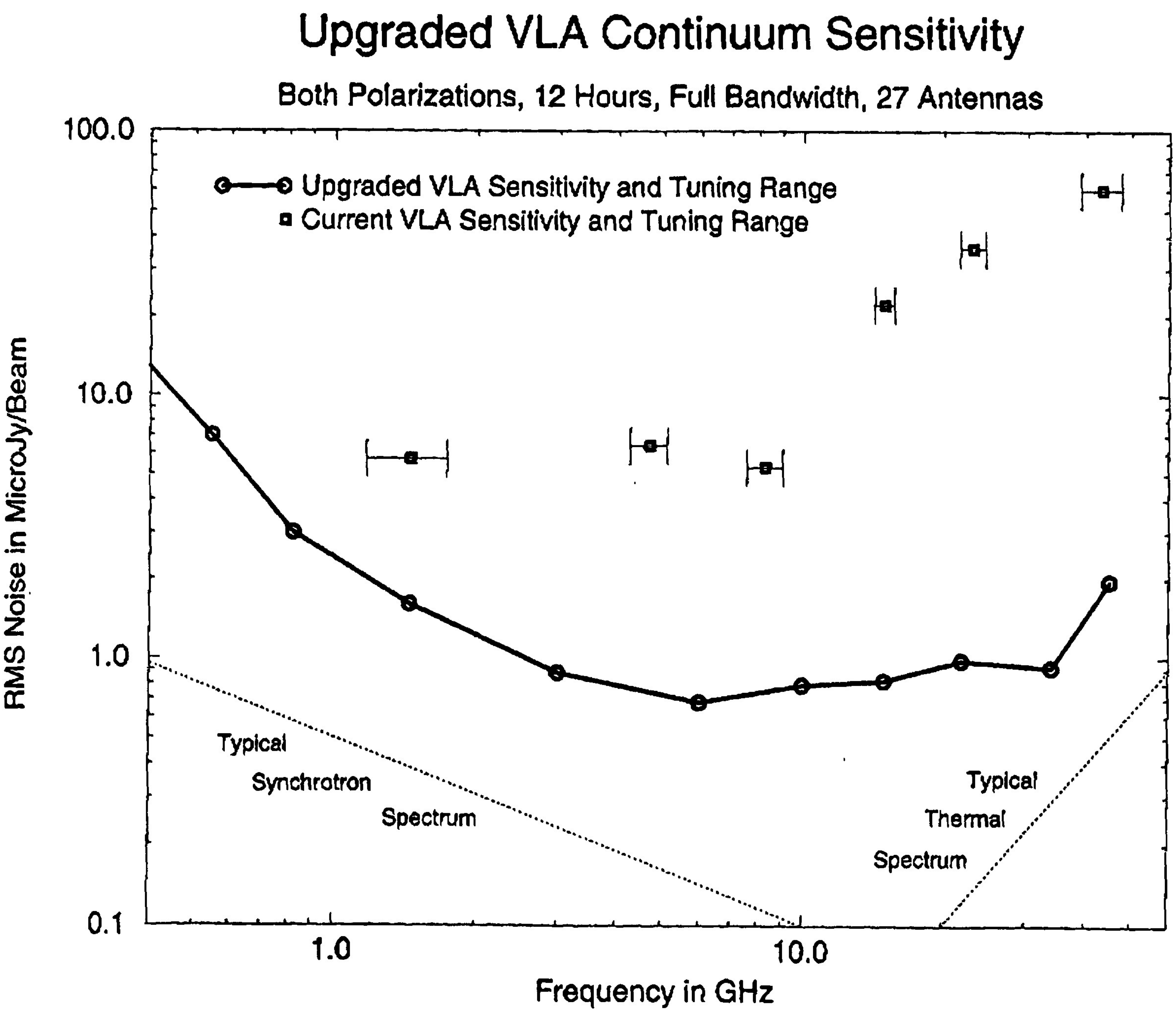
⇒ **continuum sensitivity** ($\sim 1\mu$Jy **vs.** $\sim 5\mu$Jy **in 12hrs)**

⇒ **instantaneous spectral indices, rotation measures, uv-coverage**

⇒ **instantaneous velocity coverage** ($53,300\,$km/s **vs.** $666\,$km/s **at 45 GHz)**

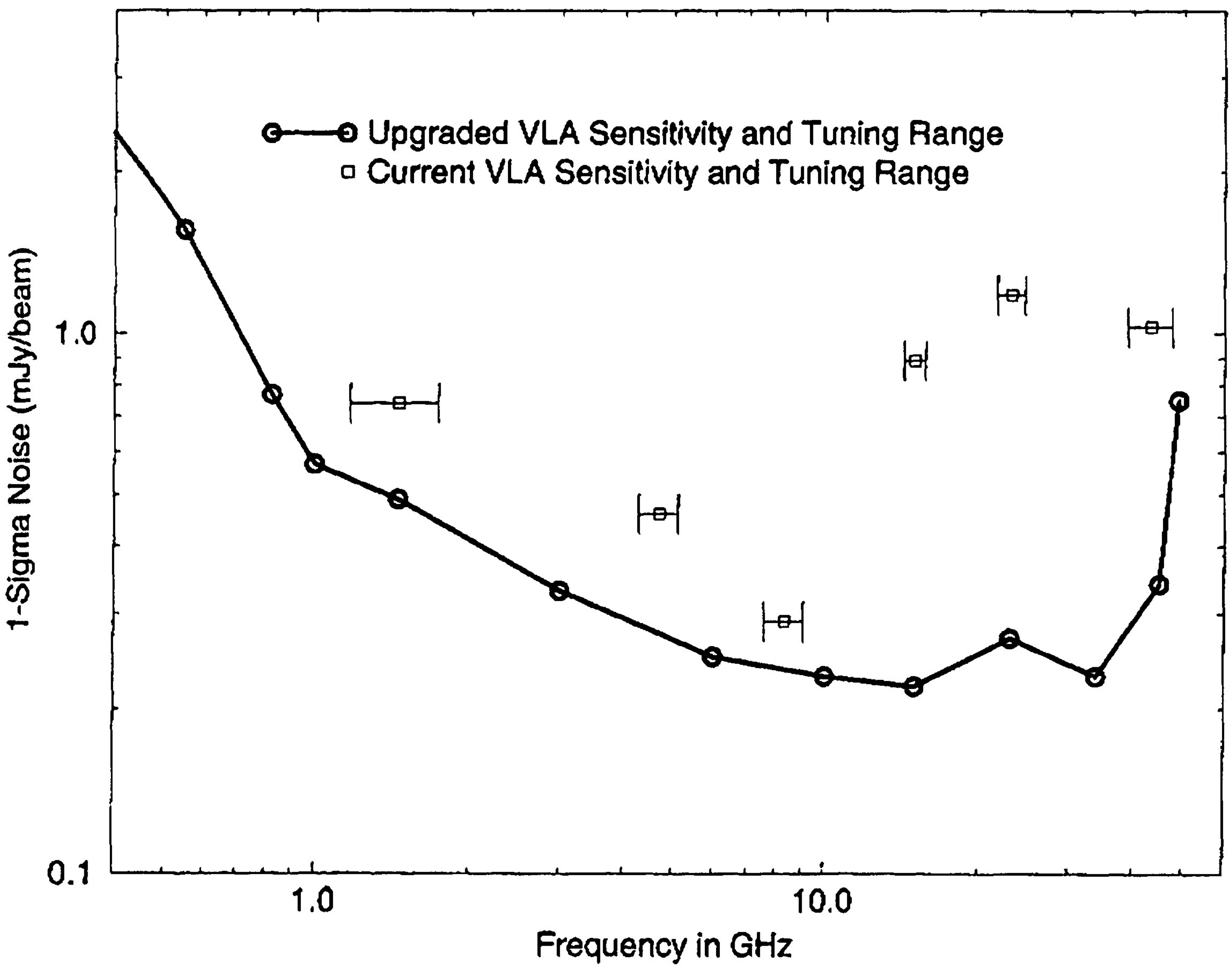
⇒ **lines at arbitrary redshift**

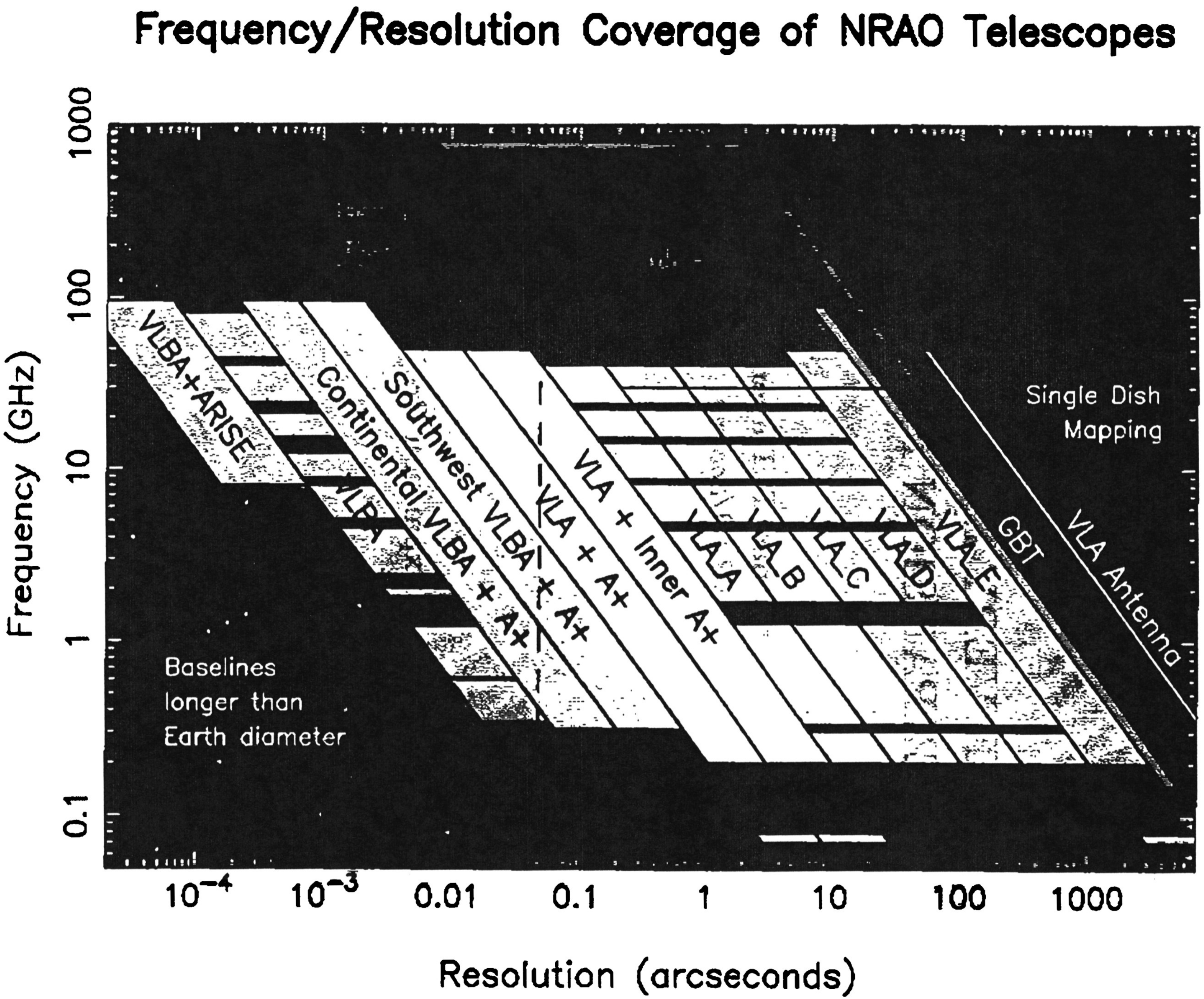
The improvement between the expanded and the current VLA roughly corresponds to the difference between a fully-equipped HST and a ground-based telescope with photographic film and no spectrograph.


Upgraded VLA Continuum Sensitivity
Both Polarizations, 12 Hours, Full Bandwidth, 27 Antennas
Upgraded VLA Sensitivity and Tuning Range
Current VLA Sensitivity and Tuning Range
RMS Noise in MicroJy/Beam
100.0
10.0
1.0
0.1
Typical
Synchrotron
Spectrum
Typical
Thermal
Spectrum
1.0
10.0
Frequency in GHz

Line Sensitivity of an Upgraded VLA

12 Hour Integration, Dual Polarization, 1 Km/sec




Frequency/Resolution Coverage of NRAO Telescopes
Frequency (GHz)
1000
100
10
1
0.1
VLBA+ARISE
VLBA
Continental VLBA + A+
Southwest VLBA + A+
VLA + A+
VLA + Inner A+
VLA A
VLA B
VLA C
VLA D
VLA E
GBT
VLA Antenna
Single Dish Mapping
Baselines longer than Earth diameter
10^{-4}
10^{-3}
0.01
0.1
1
10
100
1000
Resolution (arcseconds)

THE MAGNETIC UNIVERSE

Centimeter-wave astronomy is intimately connected to magentic phenomena, and hence provides the most direct probes available of the magnetic field distribution, orientation, and strength:

- Synchrotron emission
- Faraday rotation
- Anisotropic scattering
- Gyrosynchrotron emission
- Zeeman splitting
- Cyclotron masers
- Razin-Tsytovich effect
- Synchrotron self-Compton
- Maser polarization

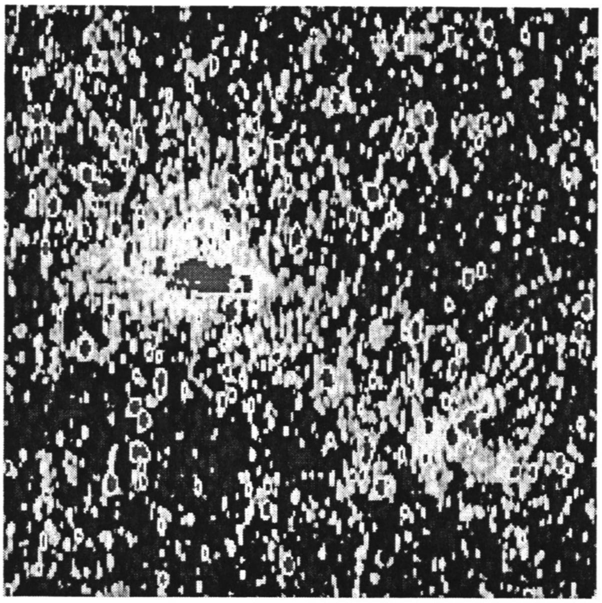
Expansion Project offers

- cyclotron emission at different depths (due to frequency coverage)
- unambiguous rotation measures (due to frequency coverage & spectral resolution)
- much less depolarization (due to spatial & spectral resolution)
- > 100 sources per beam (vs. the current one or two) suitable for scattering & polarization studies at low frequencies (due to sensitivity)

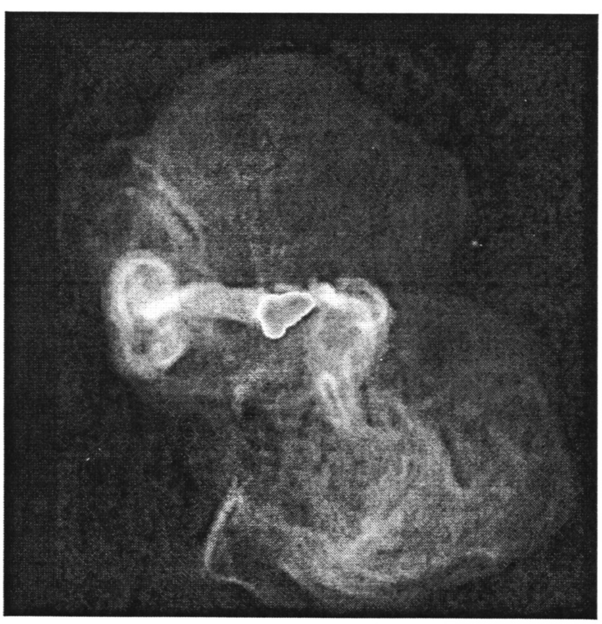
Possible observations include

- **3D solar tomography (cyclotron lines at different depths)**
- **imaging the dynamic heliosphere (through scattering & RM)**
- **Galactic Center magnetic fields on scales of 0.1 to 100s of pc, with unambiguous RM**
- **galaxy disks & haloes: spectral index & polarization mapping of all local (**$\sim 10\,\mathrm{Mpc}$**) spirals and irregulars; relatively bright spirals to** $\sim 50\,\mathrm{Mpc}$
- **galaxy clusters (RM; synchrotron mapping)**
- **intergalactic magnetic fields: Faraday rotation vs. redshift; Faraday rotation along adjacent lines-of-sight**
- **high-redshift sources (RM, synchrotron mapping)**

Galaxy Clusters with the Expanded VLA



Coma Cluster at 90cm (courtesy L. Feretti)



M87 at 90cm (courtesy F. Owen)

- **Detailed imaging of fainter haloes**
- **Polarization mapping**
- **Faraday rotation towards 1mJy sources**
- **With X-rays, obtain detailed maps of the magnetic field strength and electron density across entire clusters**
- **Jet bending due to ICM (FR I) to $z > 3$**
- **Radio source heating of ICM to $z \sim 0.2$**
- **Extend Butcher-Oemler studies to z$\sim$ 1–2**
- **Distinguish star formatio from AGNs to z$\sim$0.5**
- **Weak lensing (more background sources)**

THE OBSCURED UNIVERSE

Centimeter-wave observations allow one both to see through dust, and to study obscuring material directly, at high resolution:

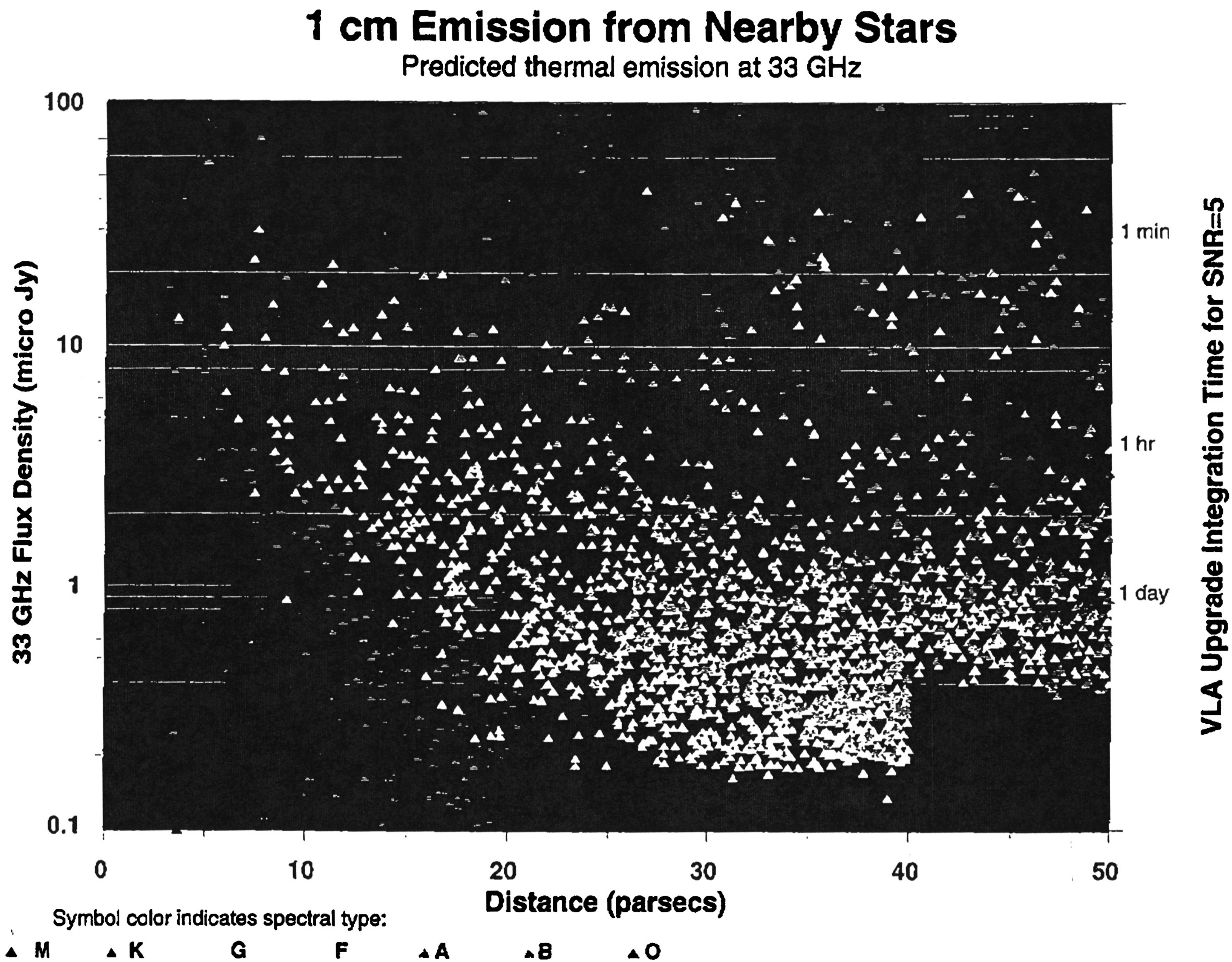
Generally low broad-band opacities
Free-free emission
Free-free absorption
H I, NH_3, masers, ...
Self-absorption
Synchrotron emission
Black-body emission
Scattering

Expansion Project offers

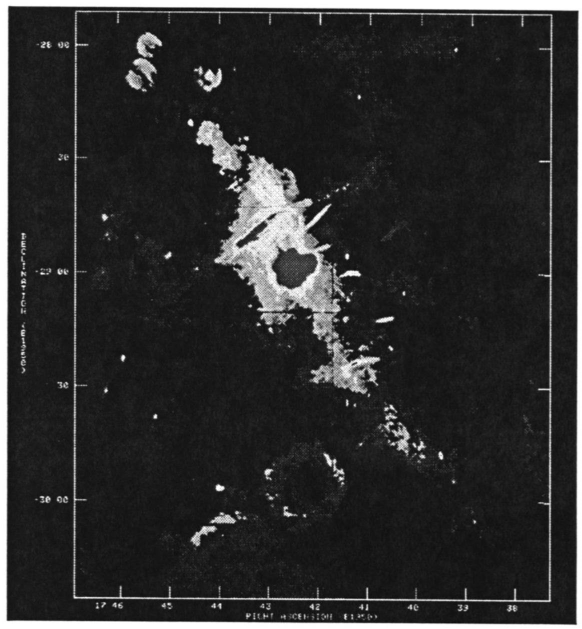
- **direct mapping and measurement of star formation throughout the universe (sensitivity, spatial resolution)**
- **clean separation of dust from synchrotron emission (frequency coverage, spatial resolution)**
- **much improved dynamical probes: proper motions & spectral lines (wide bandwidths, frequency coverage, sensitivity, spatial/spectral resolution)**

Possible observations include

- **imaging the photospheres and winds of giant stars**
- **imaging disks and jets (and separating dust and free-free/synchrotron emission) in YSOs**
- **simultaneous phase-referenced images of high-density molecular gas (NH_3), 22 GHz continuum, and water masers associated with YSOs**
- **3D dynamics of the Galactic Center**
- **dust-free source counts & mapping of extragalactic H II regions and SNRs out to Virgo**
- **radio continuum absorption & RRLs in Seyferts, ULIRGs, starburst nuclei**
- **understanding the X-ray background: star formation vs. AGNs**
- **high column density QSO absorption line systems: H I absorption towards 1.5 mJy sources, z=0–0.8; CO, HCN, HCO^+ absorption from z=0.8 to 3.0**


1 cm Emission from Nearby Stars
Predicted thermal emission at 33 GHz
33 GHz Flux Density (micro Jy)
100
10
1
0.1
0
10
20
30
40
50
Distance (parsecs)
VLA Upgrade Integration Time for SNR=5
1 min
1 hr
1 day
Symbol color indicates spectral type:
M
K
G
F
A
B
O

The Galactic Center with the Expanded VLA: 3D Dynamics & Feeding the Nucleus



Galactic Center at 90cm (courtesy K. Anantharamaiah)

- find and measure motions of high-velocity masers
- radio recombination lines: high velocity resolution over full velocity range; stack lines for sensitivity
- proper motions near SgrA* measurable within one year: stars & ionized gas
- YSO winds down to $10^{-6}\,M_\odot/\mathrm{yr}$
- high-resolution images of the compact H II regions
- better maps of large-scale structure

THE TRANSIENT UNIVERSE

Radio observations are sensitive to many phenomena naturally associated with highly-variable sources:

- **Interstellar scattering and scintillation $\Rightarrow$ selects compact sources**
- **Nonthermal processes $\Rightarrow$ rapid flux variations on small size-scales**
- **Relativistic particle emission (synchrotron and geosynchrotron) $\Rightarrow$ jets, shocks, acceleration in compact objects**
- **Wide variety of timescales (can observe 24hrs/day, every day of the year, with consistent flux scale) $\Rightarrow$ wide range of variable sources**

Expansion Project offers

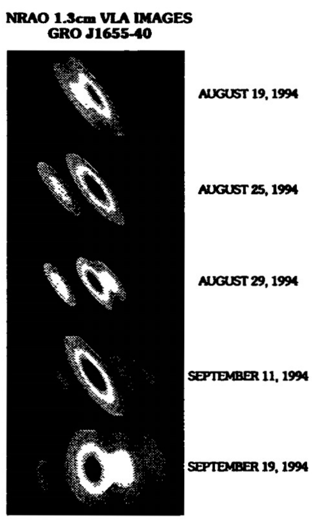
- **excellent instantaneous sensitivity:** $\boxed{\sigma \propto \frac{\mathrm{T_{sys}}}{\sqrt{\Delta\nu\,\Delta \mathrm{t}}}}$
  - **intrinsically fainter sources**
  - **more distant sources**
  - **more detailed and longer-lasting light curves**
- **high-quality, rapid imaging at $\sim$ 0.01 arcsec resolution, available all the time (A+)**

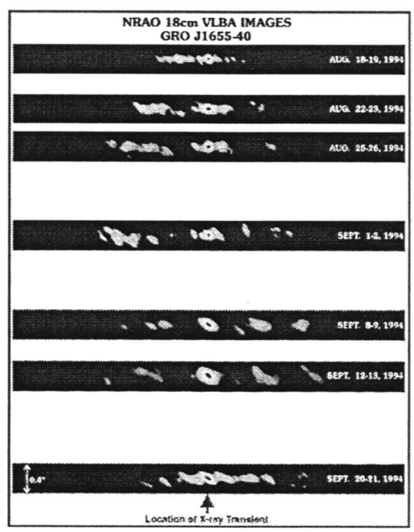
Possible observations include:

- **maps of solar type IIIdm bursts: when and where is the energy released?**
- **stellar activity: thousands of normal (as compared to pathological) stars; entire coeval populations in open clusters**
- **novae: image all Galactic novae (30/year) [only 2 imaged so far] $\Rightarrow$ trace emission from optically thick to thin; direct measures of mass and clumpiness**
- **superluminal Galactic transients**
- **extreme scattering events: monitoring $\sim 10^4$ sources at low frequencies (four pointings)**
- **radio supernovae: 10's per year (vs. current 1–2/yr); visible to $z = 1$; possibly standard candles; more complete temporal/spectral coverage**
- **gravitational lenses: better time delays (high frequency, and continuous observation)**
- **gamma-ray bursts**

Galactic X-ray Binaries with the Expanded VLA

- more rapid and more sensitive follow-up to X-rays: do disk instabilities (seen in X-rays) always trigger relativistic particles (seen in radio)? (cf. 1915+105)
- rapid, regular, and reliable imaging of many sources:
  - is the radio emission always in a jet?
  - does the jet speed indicate mass, rotation, ...?



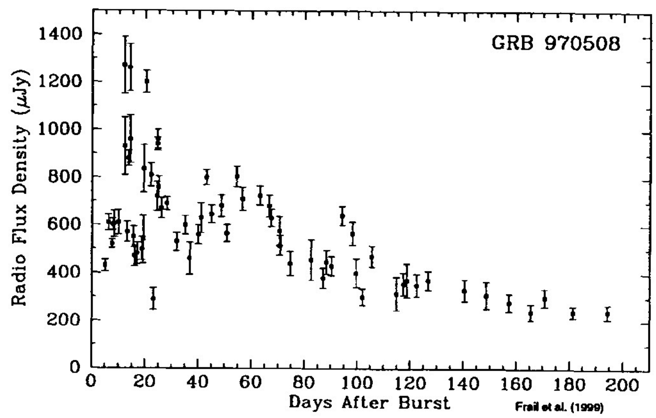


- are all superluminal jets associated with black holes? do they always have special X-ray characteristics (e.g. power-law tails)?

  - checking jet prejudices: one-sided, flip-flopping, pattern speeds, orientation wrt. disks

- are quiescent sources radio emitters (per ADAFs)? What are the implied accretion rates?
- deeper imaging of surrounding ISM: what impact do jets have? (cf. W50)

Gamma-ray Bursts with the Expanded VLA



- find & track ~ 100/yr (vs. current 1/yr)
- measure size and expansion rate (from scintillation)
- follow evolution (temporal and spectral) from ultrarelativstic to non-relativistic shock
- progenitors: where do they live? (astrometry)
- detection statistics $\Rightarrow$ are they optically obscured?
- types of GRB: SGR, SNe, classical GRB all distinguishable at radio wavelengths
- deep, sensitive, repeated survey gives the γ-ray beaming angle (from number of transients with no GRB counterparts)

THE EVOLVING UNIVERSE

Radio emission is ubiquitous, broad-band, and difficult to obscure; further, mm/submm emission is shifted into the centimeter range at high redshift. Multifrequency observations at the same resolution can distinguish thermal and non-thermal processes, map each independently, and provide rough redshift estimates.

Expansion Project offers

- **appropriate resolution (A+) for imaging YSOs and high z sources**
- **ability to observe intrinsically faint YSOs (sensitivity)**
- **ability to observe a wide range of redshifts (sensitivity and frequency coverage)**
- **excellent spectral search capability (broad bandwidths with many channels)**
- **numerous high-z targets for absorption and RM studied, over wide fields**

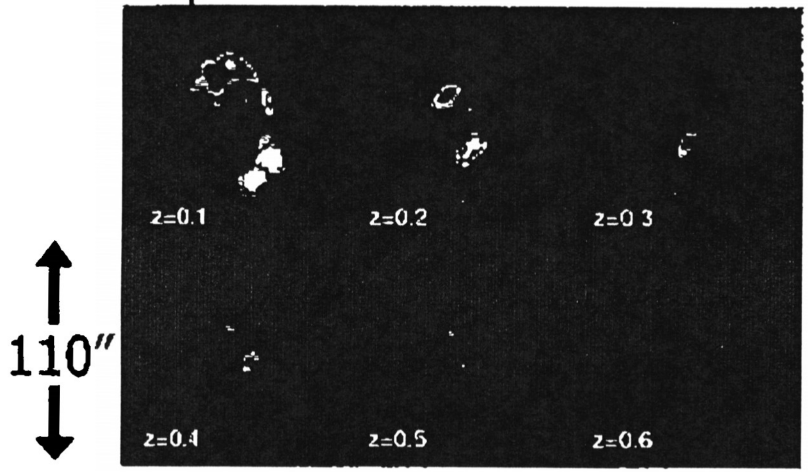
Possible observations include:

- **exploring the pre-solar nebula: compositions**
  - **detections of comets (lines & continuum)**
  - **multi-wavelength observations of small bodies**
- **distinguishing dust and free-free emission, disks and jets in local star formation regions**
- **winds of MS stars: $\mathbf{Li^7}$ dredging, general stellar evolution**
- **wide-bandwidth searches for RRL, H I, etc. in *all* observations of normal galaxies**
- **star formation at high redshift:**
  - **radio/FIR correlation gives "spectral index" redshift**
  - **mapping star formation at z of a few**
  - **direct detection of thermal (dust) emission at $z > 10$**
- **finding galaxy clusters at high z (through blind searches for high RM)**
- **H I and radio continuum deep fields**

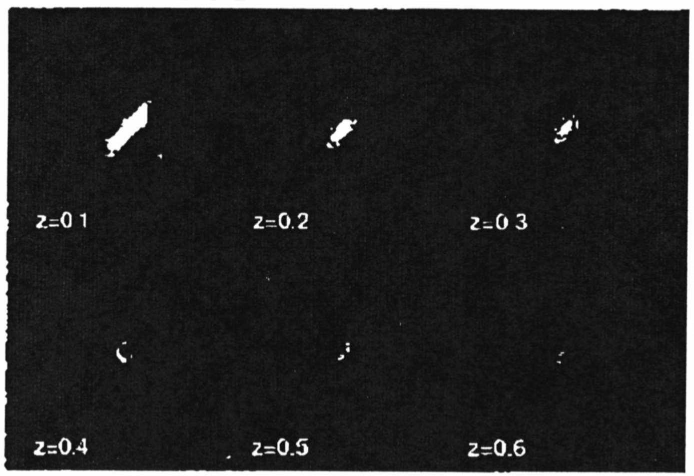
HI Deep Field

- 50′ x 50′ field from z=0.2 to 1.0
- 7″ and 20 km s^{-1} resolution

Arp 299



NGC 4565



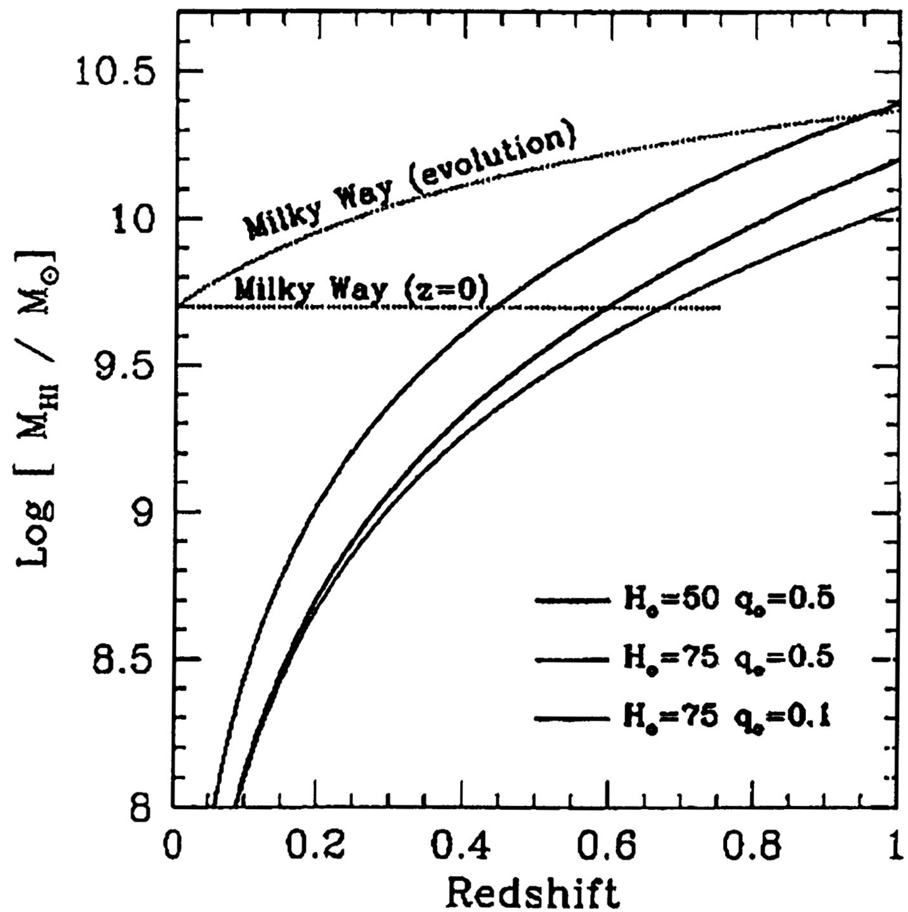
Assuming NO evolution:

- Velocities and HI masses for 2500 galaxies, 30% at z>0.6
- spatial and kinematic mapping to z=0.5
- unique survey of gas-rich galaxies, unbiased to stellar content or SFR
- explore dynamical evolution of peculiars/irregulars for z=0.2-0.5
- measure evolution of Ω_{gas} to z=1

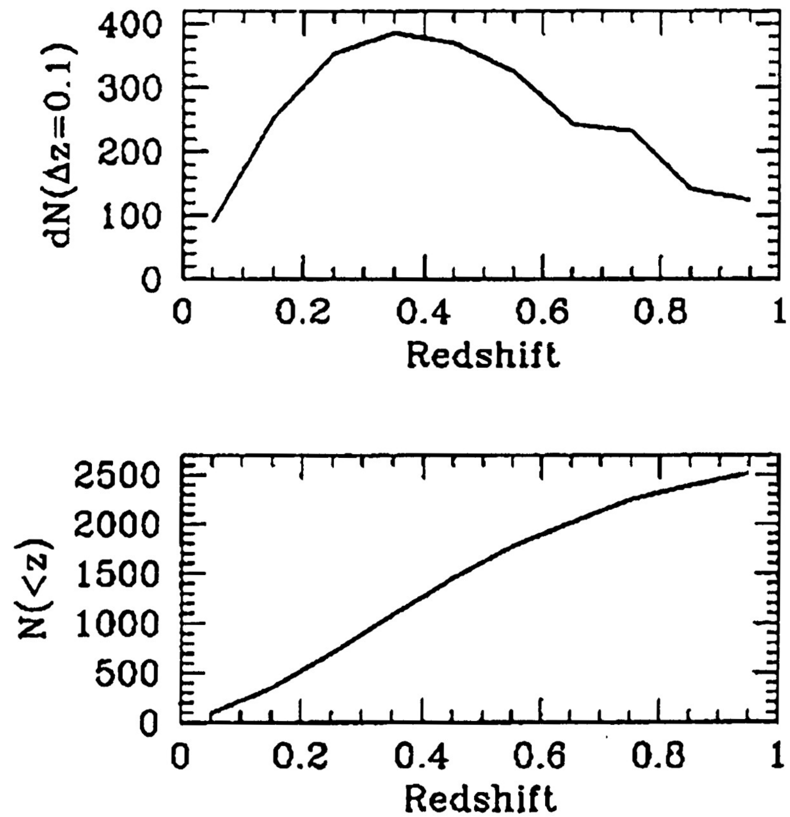
Assuming simple evolution:

- triple detection rate for sources between z=0.5-1.0

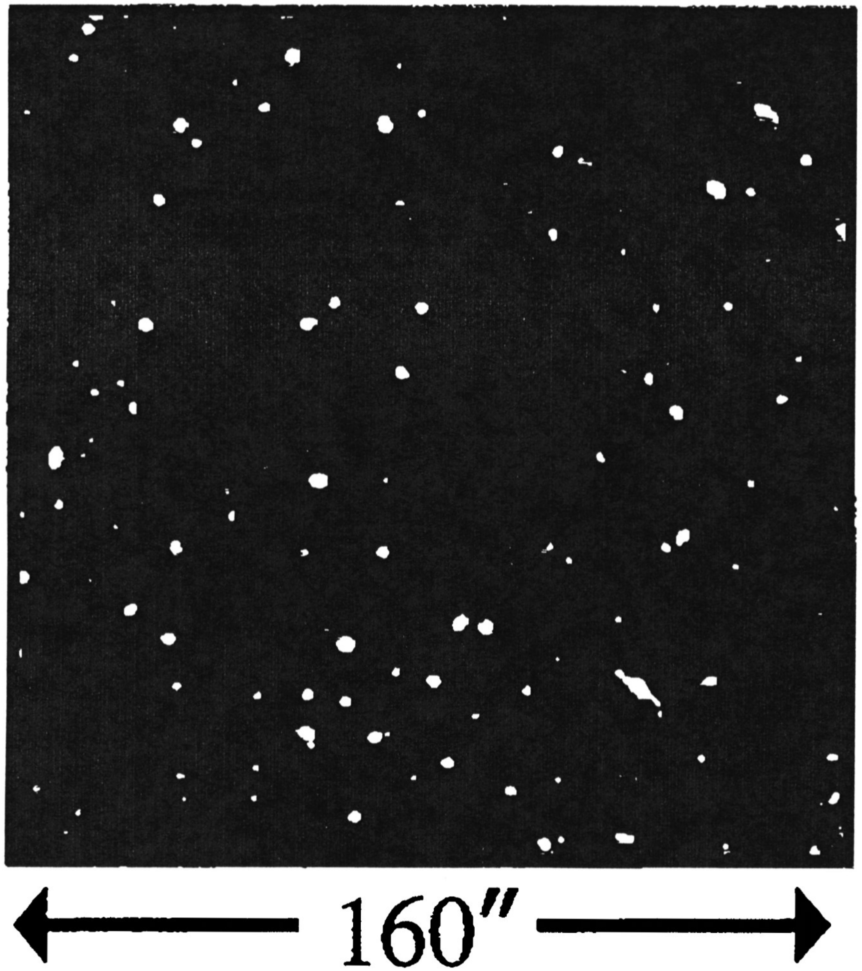
HI Deep Field



No evolution, S/N=5

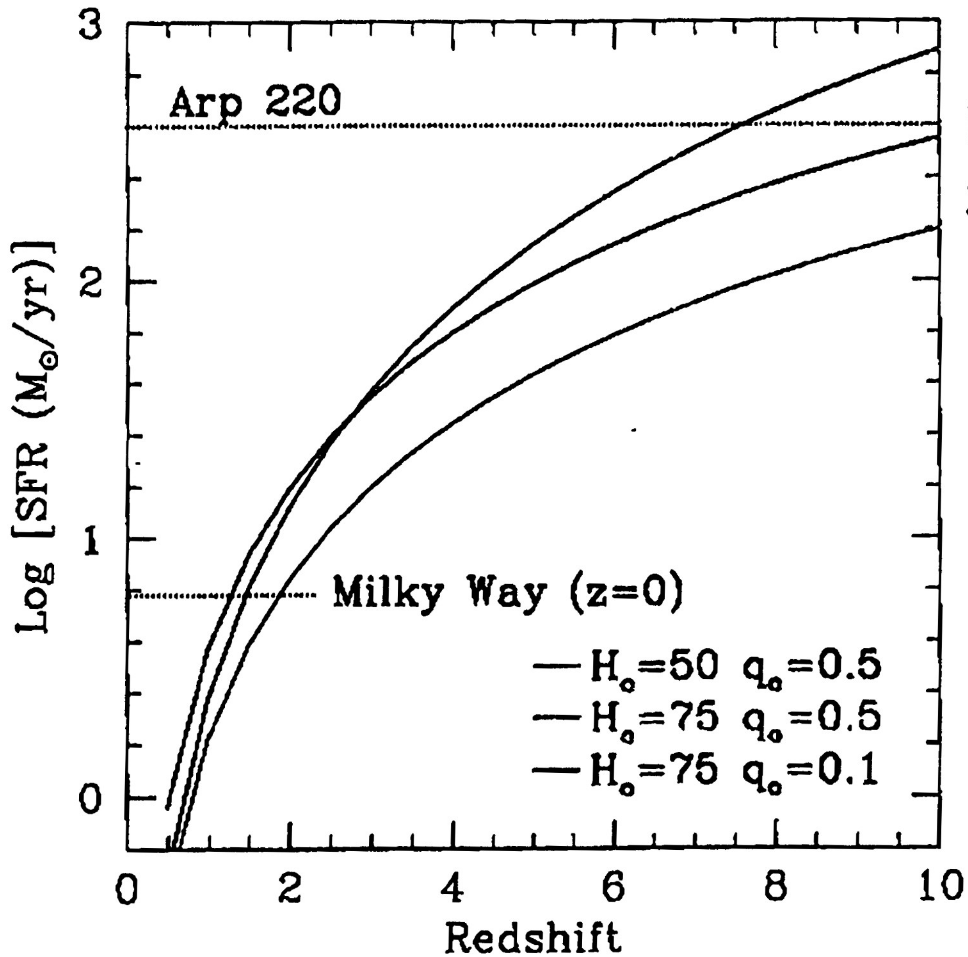


Radio Continuum Deep Field



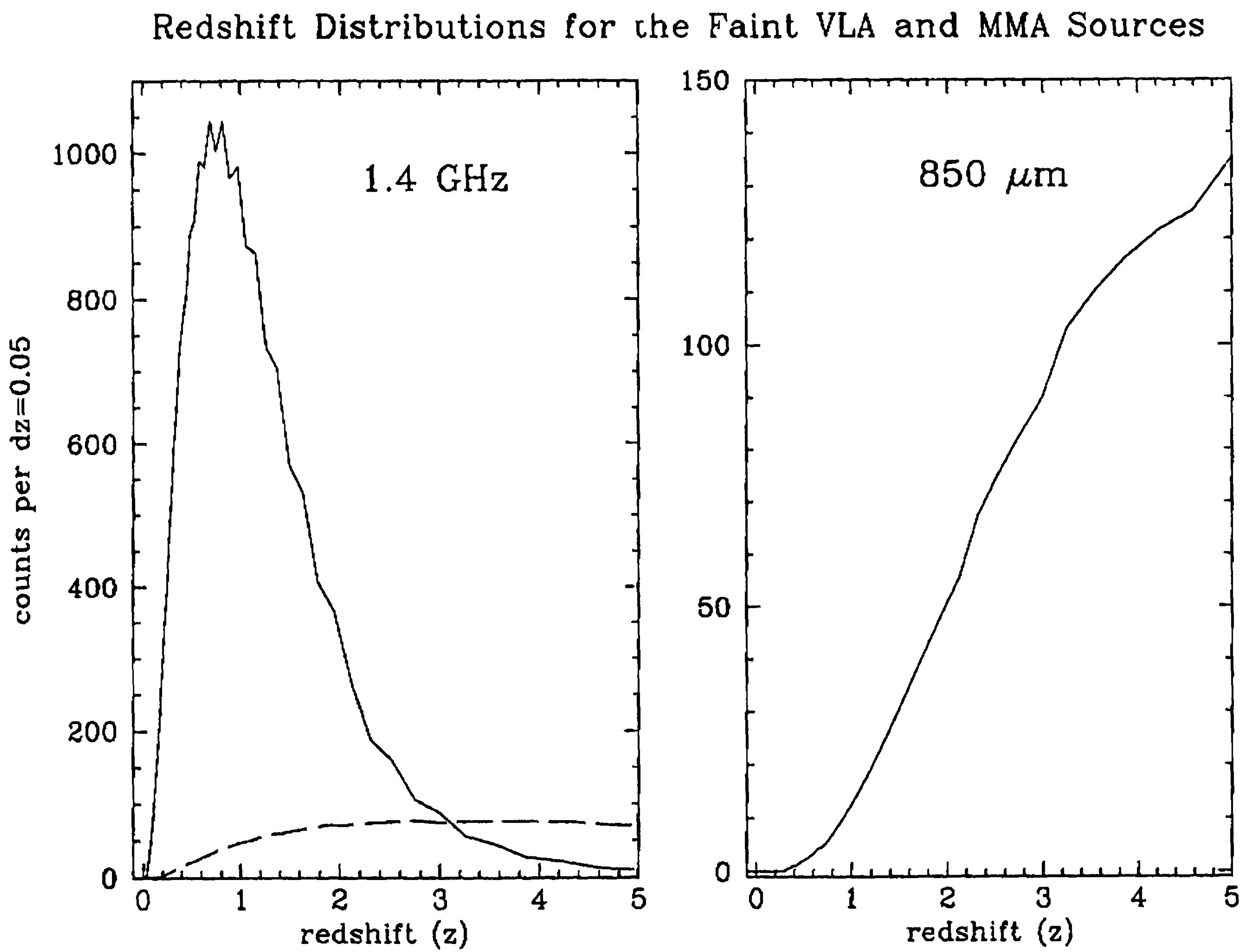
- 40,000 sources
- detections to 0.5 μJy at 2″ resolution
- 1000 rotation measures for large-scale magnetic field structure
- traces star formation history of the Universe, irrespective of dust extinction:
  Milky Way to z=1
  Arp 220 to z=10

Radio Continuum Deep Field



BW=500 MHz

S/N=8



Redshift Distributions for the Faint VLA and MMA Sources
1.4 GHz
850 μm
counts per dz=0.05
redshift (z)
redshift (z)
0
200
400
600
800
1000
0
50
100
150
0
1
2
3
4
5
0
1
2
3
4
5

WHY YOU SHOULD CARE

The true strength of the VLA will remain its ability to make essential contributions across the entire breadth of modern astronomy.

- **Radio observations can map out magnetic fields, and peer down into the cores of proto-stars and galaxies from which optical and even IR photons cannot escape.**
- **By indicating and mapping both star formation and nuclear activity, radio observations directly trace two of the most important processes in the evolution of the universe.**

From the solar wind to galaxy clusters, from stellar jets to QSO absorption line systems, the VLA Expansion Project would make a unique and fundamental contribution to our understanding of the universe.

VLA UPGRADE
Schedule and Budget

- Minimize disruption to operations;
  Avoid shutdown > 4 months.

- Need about 2 years for Design & Development

- Upgrade duration set by mechanical overhaul.
  6 antennas per year => 5 year sched.

- Build VLA Upgrade correlator in parallel with MMA correlator. Complete in 2006.

- D&D funding 2000 & 2001
  Prototype evaluation 2001

- Start major construction funding 2002.

- Finish by 2007

VLA UPGRADE
Schedule and Budget

Correlator Development

	MMA	VLA Upgrade
Preliminary Design Review	99 Aug	
Chip Design	00 Sep	
Final Corr. Board Test	02 Jan	
Corr. Chip Production Run	02 Jul	
Prototype Corr. to Test Array	03 Mar	
Deliver 1st 1/4 Correlator	04 Jun	04 Jun
Deliver 2nd 1/4 Correlator	05 Mar	05 Mar
Deliver 3rd 1/4 Correlator	05 Dec	05 Dec
Deliver 4th 1/4 Correlator	06 Oct	06 Oct

VLA UPGRADE - Budget

A. The Core Plan for the VLA

WBS		Cost ($k)
1.	Project Management	2500
2.	System Integration & Testing	1200
3.	Civil Construction	600
4.	Antenna Mechanical	2000
5.	Cassegrain Receivers	12000
6.	Local Oscillator Sys	6000
7.	Fiber Optic System	5100
8.	IF System	4700
9.	Correlator	9000
10.	Computing / Monitor-Control	1200
		44300
	Contingency (15%)	6600
	Total	$50,900

B. Completion of the VLA

11.	UHF/VHF Prime Focus	2400
12.	Ant Apex, Mechanical	4700
13.	E - Configuration	5000
		12100
	Contingency (20%)	2400
	Total	$14,500

VLA UPGRADE

To do in 1999 & 2000:

- **System Design**
  Digital or Analogue FO Transmission
  Transition Plan

- **K-band Installation**
  Continue at 8 rcvrs per year

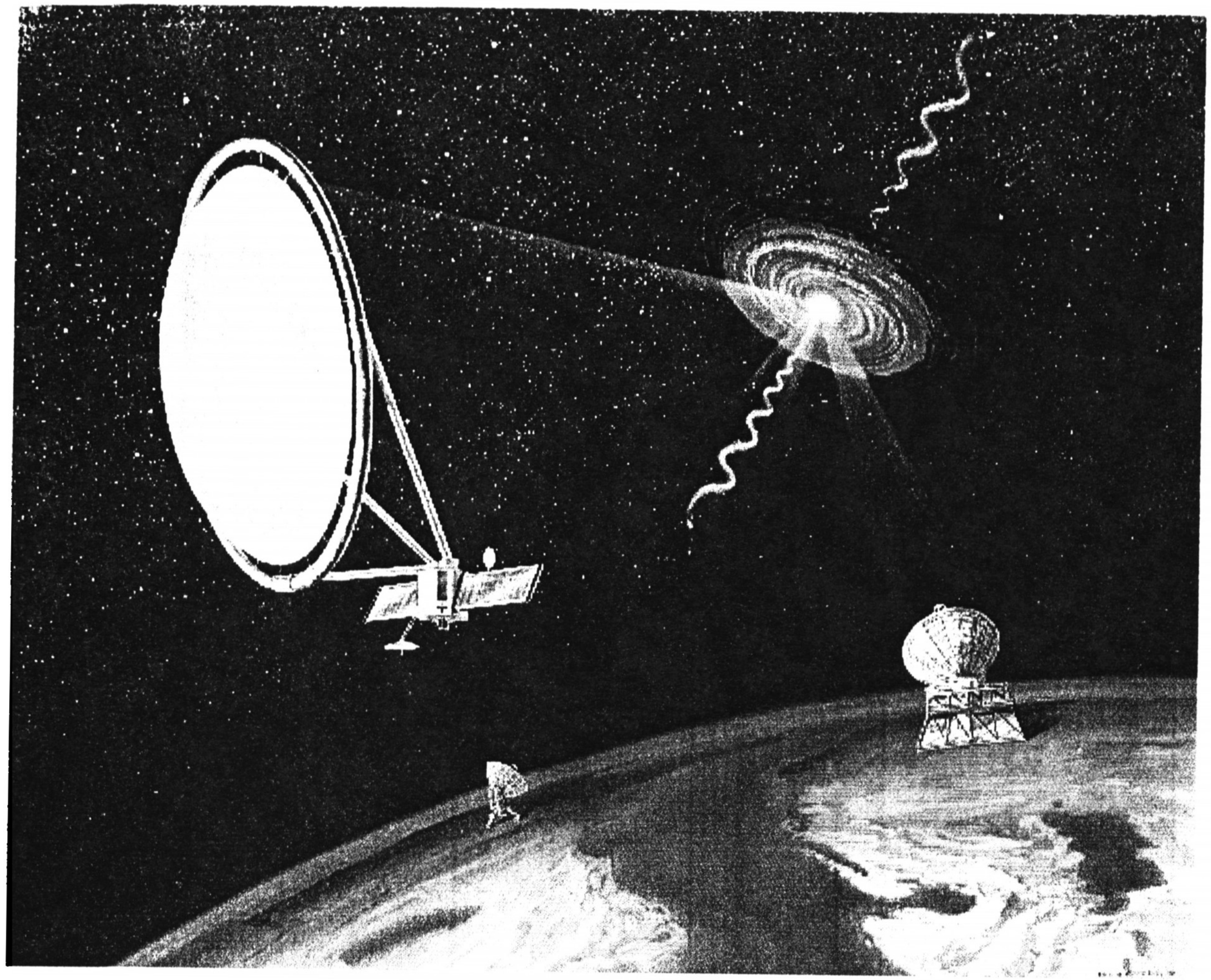
- **Q-band Installation**
  Continue at 6 rcvrs per year

- **L-band Feed Design**

- **Prototype new L, S, C, Ku, Ka rcvrs**

- **Prototype Feed-cone**
  Install on test antenna

ARISE: Zooming in on Black Holes



Jim Ulvestad — April 23, 1999

NRAO Long-Range Planning Workshop

Outline

- Science Goals and Mission Requirements
- Relevance to Community Goals
- Technical and Programmatic Issues
- Summary

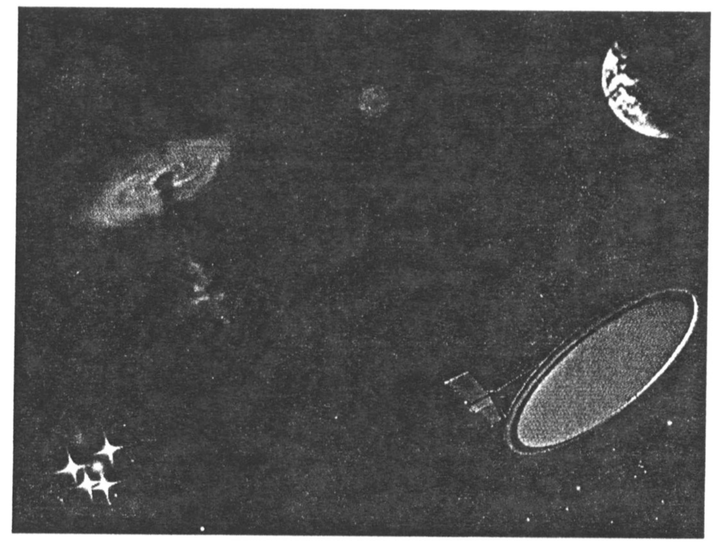
ARISE Science Advisory Group

A. Marscher, Chair	Boston Univ.	R. Linfield	Caltech/IPAC
P. Diamond	England	C. Moore	Netherlands
M. Elitzur	Univ. Ky.	D. Murphy	JPL
D. Gabuzda	Netherlands	R. Mutel	Univ. Iowa
M. Garrett	Netherlands	S. Neff	Goddard
L. Greenhill	CfA	R. Preston	JPL
L. Gurvits	Netherlands	J. Romney	NRAO
J. Hewitt	MIT	R. Taylor	Canada
H. Hirabayashi	Japan	E. Valtaoja	Finland
A. Königl	Univ. Chicago	A. Wehrle	Caltech/IPAC
J. Krolik	Johns Hopkins	A. Zensus	Germany

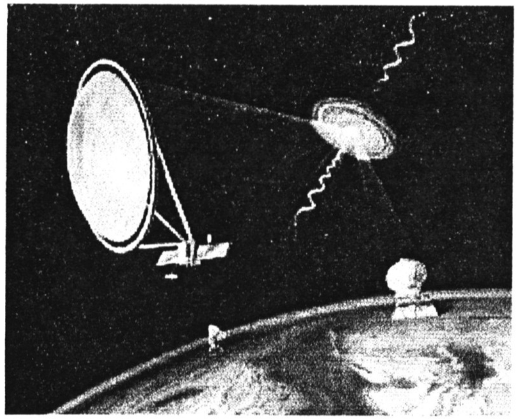
ARISE Primary Science Goals

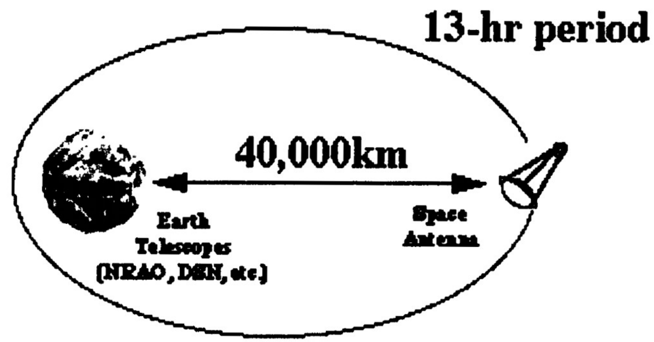
Key science goal: image and understand the environments of supermassive black holes

Primary Science Goals of ARISE
<u>Supermassive Black Holes and Radio Jets</u>
AGN Fueling
Relativistic Jet Production
Generation of High-Energy Photons
<u>Accretion Disks and H_2O Megamasers</u>
Masses of Supermassive Black Holes
Nature of Megamaser Disks
Accretion Processes
Geometric Distance Measurements
<u>Cosmology</u>
Gravitational Lens Studies
High-Redshift Radio Sources



ARISE Mission Description





VLBI Observing Parameters	Programmatics	
• Orbiting 25 m inflatable radio telescope in conjunction with arrays of ground telescopes to image compact radio sources with resolution of 10-100 microarcseconds.	• Potential New Start	2005
• Observing bands: 8, 22, 43, 86 GHz	• Potential Launch	2008
• Data Rate: 1-8 Gbit/s	• Mission life	3 yr
• System Noise Temperatures: 10-40 K	• Launch Vehicle	Delta

Primary Science Requirements

- Imaging of blazars at 86 GHz

  Imaging capability for at least 100 objects

  Resolution < 100 light days for significant number

- Imaging of H_2O megamasers at 22 GHz

  Resolution of 0.03 pc (6 beams across inner disk) at 100 Mpc

  50-mJy detection threshold with large ground telescope

  Spectral resolution of 0.1 km/s

- Imaging of gravitational lenses

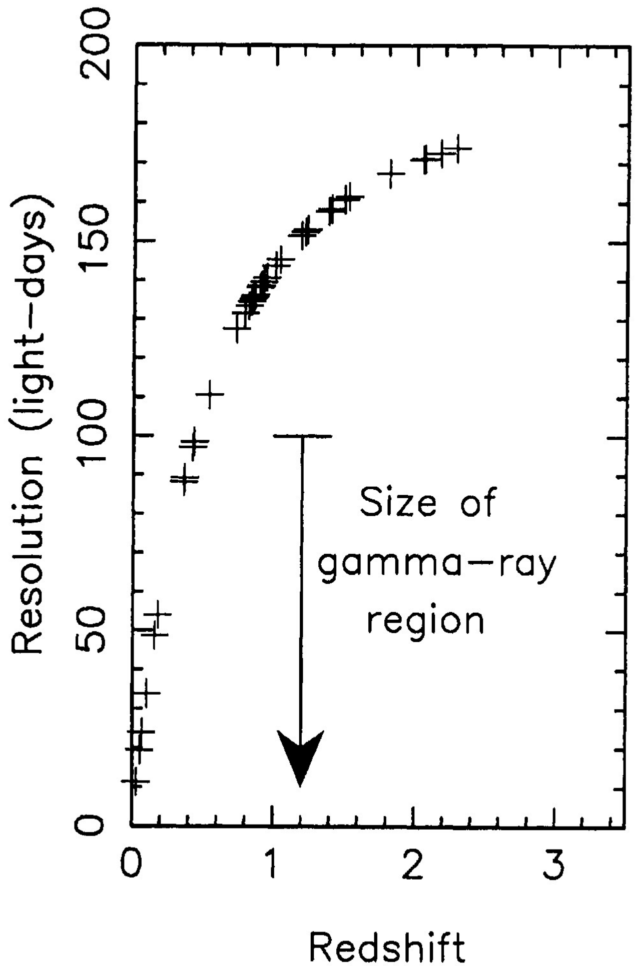
  Resolution $\leq 150\ \mu$as to detect $< 10^6 M_\odot$ objects

  2-mJy detection threshold at 8 GHz

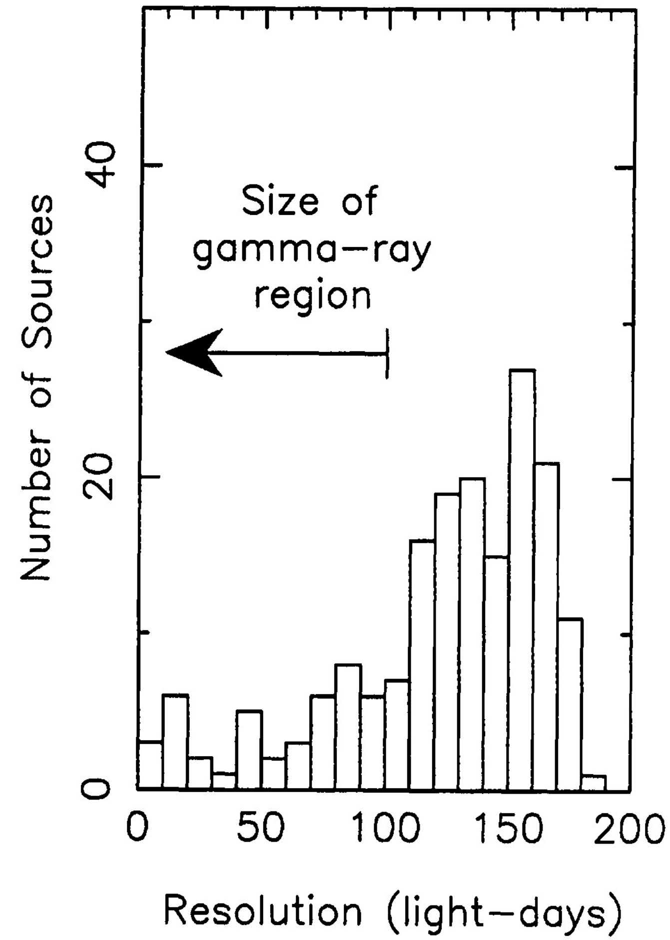
  Some detectable at 86 GHz for 1-μas intrinsic resolution

Blazar Source Counts

EGRET Blazars



179 Blazars, S(86) > 0.5 Jy

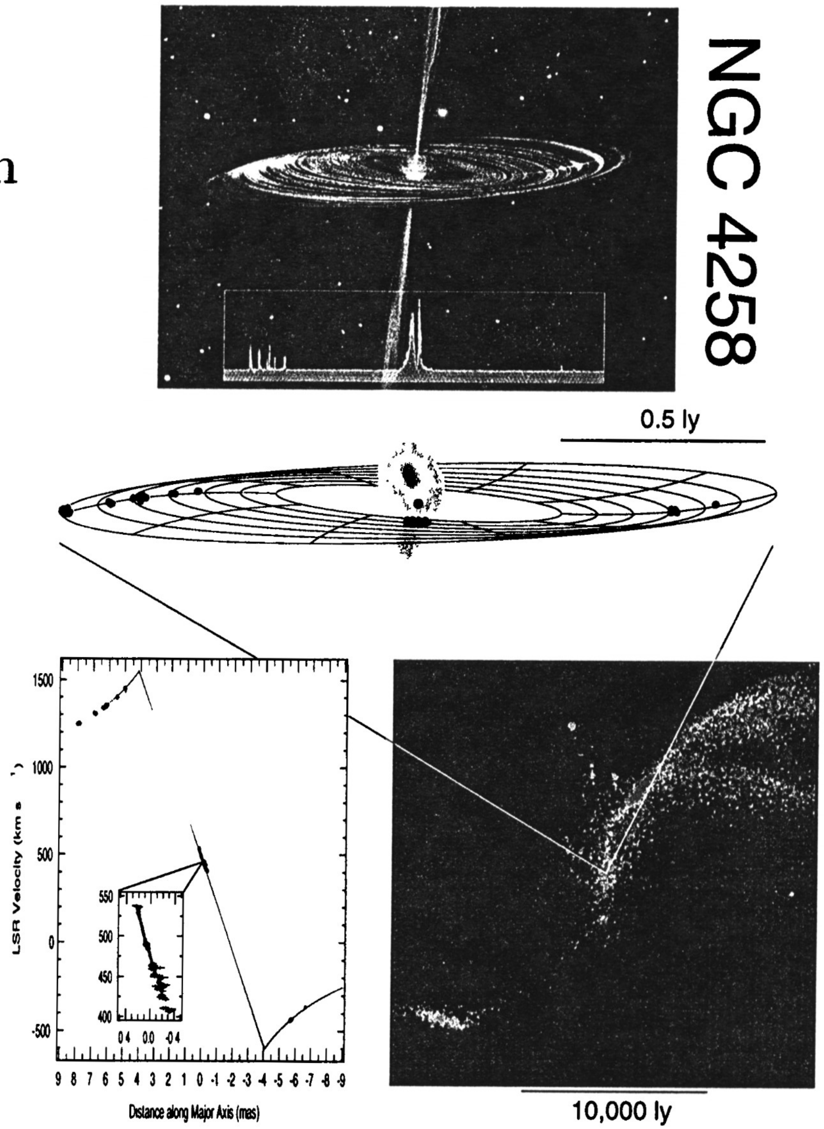


NGC 4258 – A Megamaser Galaxy

Maser Line Emission

Warped Maser Disk

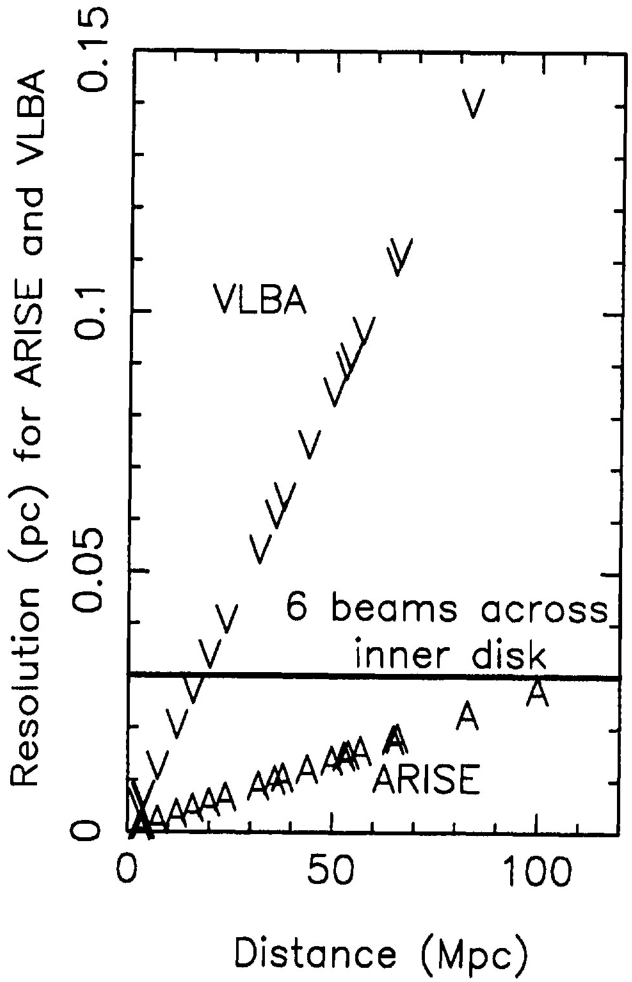
Keplerian Rotation



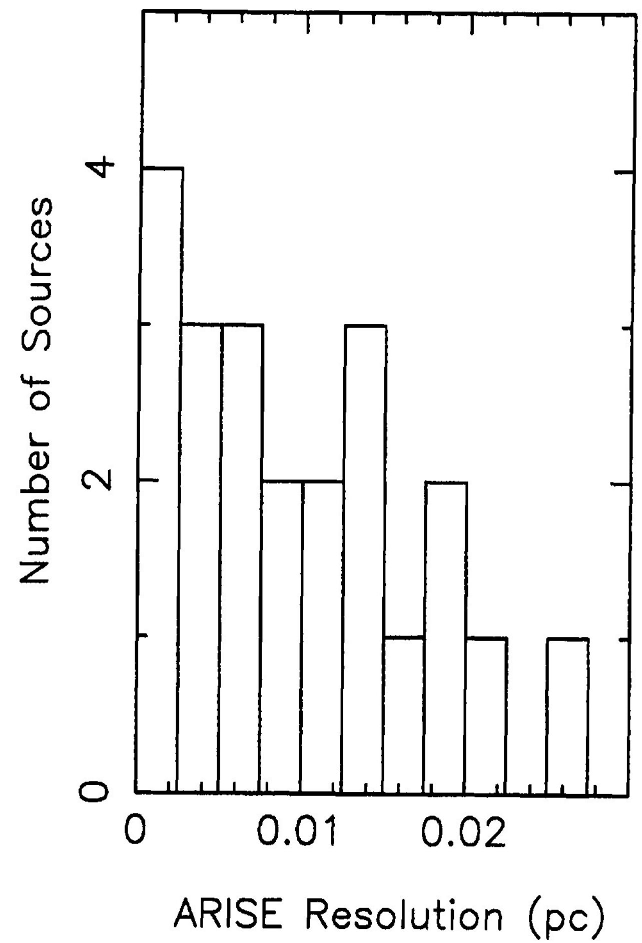
VLA Image

Currently Known Water Megamasers

ARISE-VLBA Comparison



ARISE Resolution



SEU Quests

- "To explain the structure of the Universe and forecast our cosmic destiny"

  Dark matter distribution in gravitational lenses

- "To explore the cycles of matter and energy in the evolving Universe"

  Accretion disks feeding black holes in megamaser galaxies

- "To examine the ultimate limits of gravity and energy in the Universe"

  Energy generation and relativistic jet acceleration near supermassive black holes

SEU Research Campaigns

- Dark matter and how it shapes galaxies and clusters

  Search for $\leq 10^6 M_\odot$ gravitational lenses

- Gas flow in disks and cosmic jet formation

  Accretion disks feeding black holes

  Relativistic jet formation in blazars

- Sources of gamma-ray bursts and high-energy cosmic rays

  Particle acceleration in jet shocks

- Strong gravity near black holes and effects on early Universe

  Image near supermassive black holes in AGNs

  Statistics of black hole masses in megamaser galaxies

Community Involvement in ARISE

- Large U.S. and international Science Advisory Group
- Addresses NASA and NSF science goals and techniques
- Massive black holes – cornerstone of NASA's SEU program
- Strong relation to upcoming X- and gamma-ray missions

  GLAST will detect thousands of blazars

  Black-hole mass and accretion disk properties from ASTRO-E, Constellation-X
- Observatory facility

  Proposals selected in open scientific competition
- Capability for imaging a range of objects

  Stellar coronae, young supernovae, Seyferts, galactic masers, high-z sources

Technical Issues

- Inflatable antenna

  Current inflatable antenna development program in DoD

  FY2000 NASA initiative on "gossamer spacecraft"

  ≥ 6 flight demonstrations by 2003

    e.g., NGST sunshield, inflatable solar arrays, SAR, solar sail

  Mechanical backup options from TRW, Harris

- High data rates

  Technically feasible, implementation challenging

  Opportunity for strong international collaboration

    Heritage from Mark 4 and/or S2 VLBI systems

  Correlator heritage from MMA and VLA Upgrade

  Downlink in 37–38 GHz band

Programmatic Issues

- ARISE continues successful NASA/NSF cooperation

  Long history of collaboration in radio astronomy:
  Voyager-Neptune encounter, VSOP, MAP

  Takes advantage of $1 billion in ground infrastructure

- Presented to radio panel of decade committee in February 1999

- On long-term roadmap of NASA SEU theme

- International Collaboration

  Strong participation in Science Advisory Group

  European VLBI community and ESA

  Recording systems and correlators – Canada & Europe

  Simultaneous flight with VSOP-2?

Relevance to NRAO

- A science-driven Space VLBI mission

- Relation to VLBA upgrade

  Space antenna capabilities similar to a VLBA antenna

  Time scale may be similar, 2008–2012

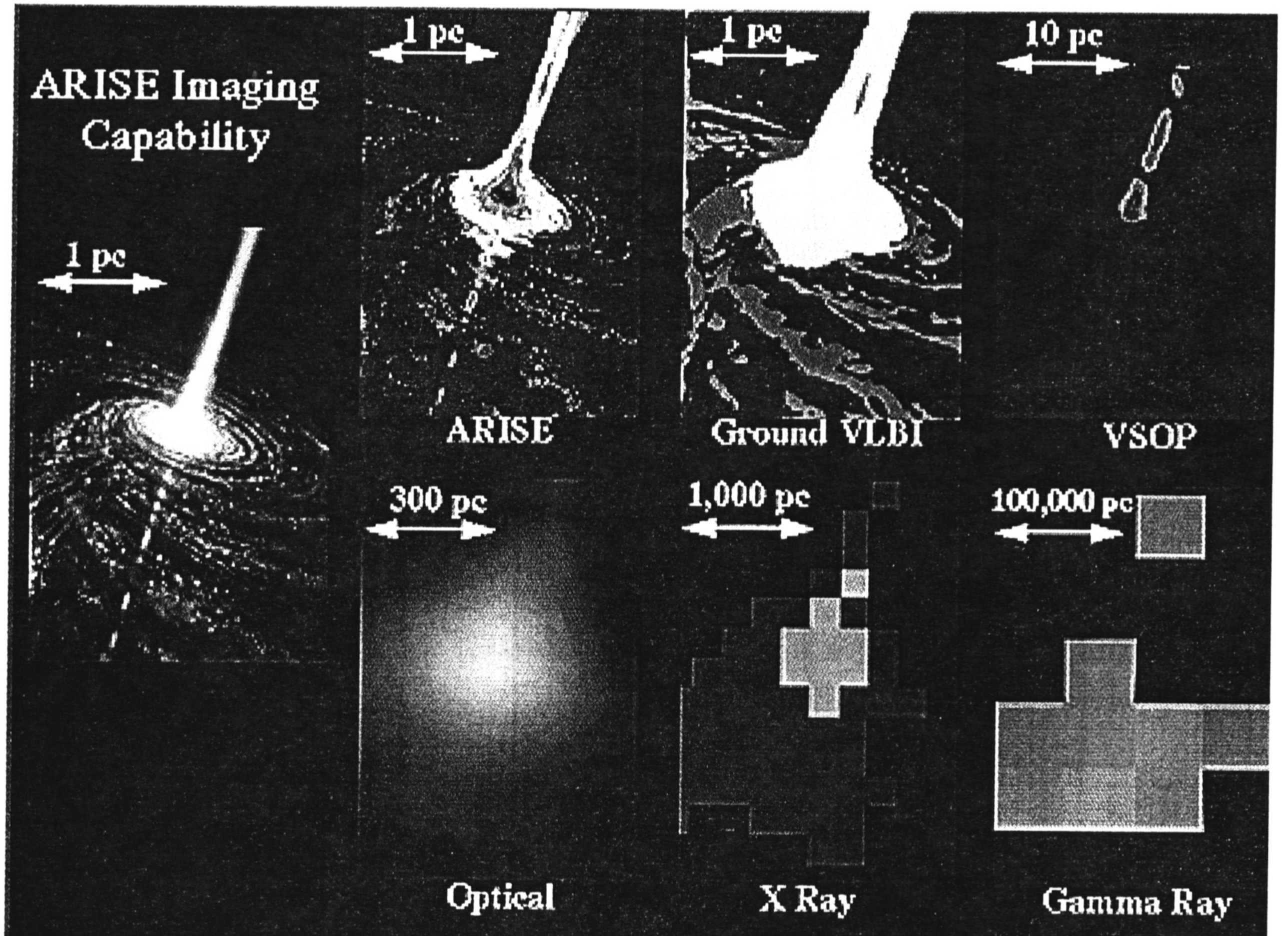
  Increased bandwidth critical for VLBA upgrade

  86 GHz important for ground and space

- Can make use of MMA and GBT for weak sources

- Possible new funding source for radio astronomy

Resolution Comparison



Potential for Unexpected Discoveries

- Superb resolution

  3000 times better than HST

  5–10 times better than ground VLBI

- Unique science return

  Acceleration and collimation of relativistic plasma

  Jet relation to gamma rays

  How do accretion disks feed AGNs?

- Some high-risk, high-payoff possibilities

  Detection of dark masses of 10^4–$10^6 M_\odot$

  1–10 μas intrinsic resolution with lensing

  Breakout of young supernovae

  Gamma-ray bursts/hypernovae

The Frequency Agile Solar Radiotelescope

The FASR is a solar-dedicated instrument designed to perform broadband imaging spectroscopy.

FASR FREQUENCY-AGILE SOLAR RADIOTELESCOPE

FASR Specifications

Frequency range	0.3 - 30 GHz
Frequency resolution	1%, 0.3 - 30 GHz 3%, 3 - 30 GHz
Time resolution	<1 s, 0.3 - 30 GHz <0.1 s, 3 - 30 GHz
Number antennas	~100 (~5000 baslines)
Size antennas	D = 2 - 5 m
Polarization	Dual
Angular resolution	(20 / ν_9) arcsec
Field of view	~ 1125 / ($D\nu_{9}$) arcmin

FASR Science

- Transient energetic phenomena
  - Energy release
  - Plasma heating
  - Electron acceleration and transport
  - Formation and destabilization of large scale structures
- Nature and evolution of coronal magnetic fields
  - Measurement of coronal magnetic fields
  - Temporal and spatial evolution of coronal magnetic fields
  - Role of coronal electric currents
- The solar atmosphere
  - Coronal heating
  - Structure of the chromosphere in AR, QS, and CH
  - Formation and structure of prominences and filaments

FASR "Uniqueness Space"

The FASR will be a unique instrument designed to do unique science.

Coronal magnetic fields.

Energy release site.

Comprehensive coverage of energetic phenomena over an energy range <1 keV to >1 MeV.

Three-dimensional view of the thermal state of the the solar atmosphere.

Impact of Solar-Terrestrial Phenomena on Technology

Ionosphere Variations

- wireless signal reflection, propagation, & scattering
- satellite signal interference, scintillation
- induction of electrical currents in the Earth

Radiation

- solar cell damage
- semiconductor device damage, misoperation, or failure
- spacecraft charging
- astronaut safety
- airline passenger safety

Magnetic Field Variations

- attitude control of spacecraft
- compasses

Solar Radio Bursts

- excess noise levels in wireless communications

Atmosphere

- low altitude satellite drag
- attenuation and scatter of wireless signals

FASR User Communities

- Solar physics
- Space Physics
- Forecasting
- Synoptic

- Magnetospheric physics
- Ionospheric physics
- Aeronomy

FASR Consortium

- New Jersey Institute of Technology - D.E. Gary, H. Wang
- Bell Labs, Lucent Technology - L. Lanzerotti
- National Radio Astronomy Observatory - T. Bastian
- S.M. White - University of Maryland
- G. J. Hurford - Berkeley/Space Sciences Lab

NRAO

Lucent Technologies

NJIT
New Jersey Institute of Technology

NRAO Long Range Planning Meeting

Green Bank WV

April 23, 1999

LOW FREQUENCY RADIO ASTRONOMY at HIGH RESOLUTION

Re-Opening a Neglected Astrophysical Window.

Rick Perley
NRAO/Socorro

Of What Scientific Value is Low Frequency Radio Astronomy?

Unique information of great astrophysical relevence.

Examples:

- **Synchrotron emission at very low frequencies unaffected by radiation/i.c. losses. -- We observe objects in their 'original' state. Especially relevent for high redshift objects.**

- **Long wavelength radiation is strongly affected by plasmas -- a good or bad thing depending on your interest:**

<u>Bad:</u> Emitting/propagating medium corrupts wavefront -- must use processing to recover information. ISS/IPS/Ionosphere 'blurs' the emitting region.

<u>Good:</u> If the plasma is itself of interest.

Examples of propagation effects of potential astrophysical interest:

- **Thermal absorption**

- **Synchrotron self-absorption**

- **Razin-Tzitovich effect**

- **Low-frequency cutoffs of synchrotron source**

- **Scintillation**

- **Coherent plasma processes**
    - **pulsars**
    - **flare stars**
    - **emission from giant planets**
    - **solar bursts**

Low frequency astronomy offers a unique window to important processes.

- **Cosmic Evolution**

Low frequency (< 100 MHz) essential to properly count the early universe population. High frequency counts inevitably biased by extinction due to i.c. and synchrotron losses.

Detection of observational signatures from the 'Era of First Light'. Theoretical predictions of HI in absorption or emission at redshifts of 5 to 10 require a sensitive instrument below 200 MHz.

- **Cosmic Rays**

CRs with E > 200 Mev create Gamma rays by relativistic bremsstahlung, and low frequency synchrotron emission. Observation of both allow separation of B from Ne. Radio emission can be observed direction, or in front of optically think HII regions.

- **CMEs**

These have significant effect on Earth communictions. Should be able to uniquely predict via low frequency observations.

Using reflected radar signals, and proper motion, will be able to determine 3-D motion of 'solar weather'.

How Do We Make a Proper Low Frequency Radio Astronomy Telescope?

Low Frequency Radio Astronomy has been limited by special problems:

- ⇨ **<u>Insensitive</u> -- due to high galactic background temperature.**
- ⇨ **<u>Low resolution</u> -- diffraction limited.**
- ⇨ **<u>Calibration difficulties</u> -- ionospheric refraction**

All of these can now be overcome.

<u>Sensitivity.</u>

- **Although increased bandwidths will help (along with RFI countermeasures), there are not a lot of Hz to draw from, so we must go for large area -- 1 Sq. Km. is about right.**
- **Fortunately, collecting area is pretty cheap at these frequencies.**

Resolution.

- Only one way to go here -- long baselines. It is scientifically desirable to go to ISS scintillation limit -- 1000 Km.
- But we know how to transport signals over long baselines now, so this should pose no major technical hurdle.

Calibration (the ionosphere).

- The VLA's 74 MHz system has shown that this problem can be easily beaten with modern self-calibration software.
- Needed in the future is a angular variant form of self-cal, to work around the expected change in calibration within the primary beam.

Confusion (by outside sources).

- Although not as serious as expected, this form of ’noise’ is still expected to be a limiting factor in sensitive low frequency work.
- Good primary beam design is the key factor. More powerful computing (along with short time constants and narrow channelwidths) will also help.

Imaging (the ’3-D’ problem).

- The principles of this are well understood, and the computing is nearly within range, even for ’A’-configuration, full-beam, imaging.
- Moore’s law should take care of this problem.
- The necessary computing is a strong function of the primary beamsize.

What can we Expect?

Scaling up from the VLA's 74 MHz trial, 8-hour rms sensitivities of better than 100 microJy at 74 MHz should be achievable.

With 'wire' arrays, (for which the collecting area is proportional to wavelength^2), I expect the sensitivity to be about proportional to wavelength.

LOFAR/LWA -- the way to go?

The NRL (Kassim, Lazio, Erickson) and NFRA (Butcher, Bregman) are exploring the costs and benefits of a large low frequency array. Although design details differ between the groups, the general goals are:

10 - 150 MHz

Ae scales with (lambda)^2

1 Sq. Km. at lower frequency end.

Resolution of a few arcseconds at low freq end (Baselines up to 500 Km).

Sensitivity better than 1 mJy.

Cost est. at less than $25M (not including communications)

<u>Can/Should the NRAO becomes involved with this initiative?</u>

Pro:

- ⇨ Exciting original science.
- ⇨ Inexpensive (relatively speaking)
- ⇨ Technology fairly straightforwards
- ⇨ Definition of outer stations, with communications (fiber-optics?) could leverage A+ configuration development.
- ⇨ Most development will be done by others.
- ⇨ NRAO would be the host and operator.
- ⇨ Has interesting connections to the SKA.

Con:

- ⇨ Significant distraction -- could retard VLA Upgrade.

SQUARE KILOMETER ARRAY

S K A

Formation and Evolution of Galaxies

- The Dark Ages
- Very Deep Fields
- Probing Dark Matter with Gravitational Lensing
- Circumnuclear Mega-Masers
- Active Galactic Nuclei
- Interstellar Processes
- Magnetic Fields

Formation and Evolution of Stars

- Stellar Phenomena
- Transient Phenomena (GRBs,...)
- Gravity Waves and General Relativity

Formation and Evolution of Life

- Solar System Science
- SETI
- Deep Space Network

III. SKA Strawman Specifications

Aeff/Tsys: 2×10^4 m^2/K

Sky coverage: $> 2\pi$ steradians incl. central Galaxy

Frequency range 0.03 - 20 GHz

Imaging Field of View: 1 square deg. @ 1.4 GHz

Number of instantaneous pencil beams: 100

Maximum primary beam separation:

low frequency: 100 deg
high frequency: 1 deg @ 1.4 GHz

Number of pixels: 10^8

Angular resolution: 0.1 arcsec @ 1.4 GHz

Surface brightness: 1K @ 0.1 arcsec (continuum)

Instantaneous bandwidth: $0.5 + f/5$ GHz

Number of spectral channels: 10^4

Number of widely spaced, simultaneous frequency bands: 2

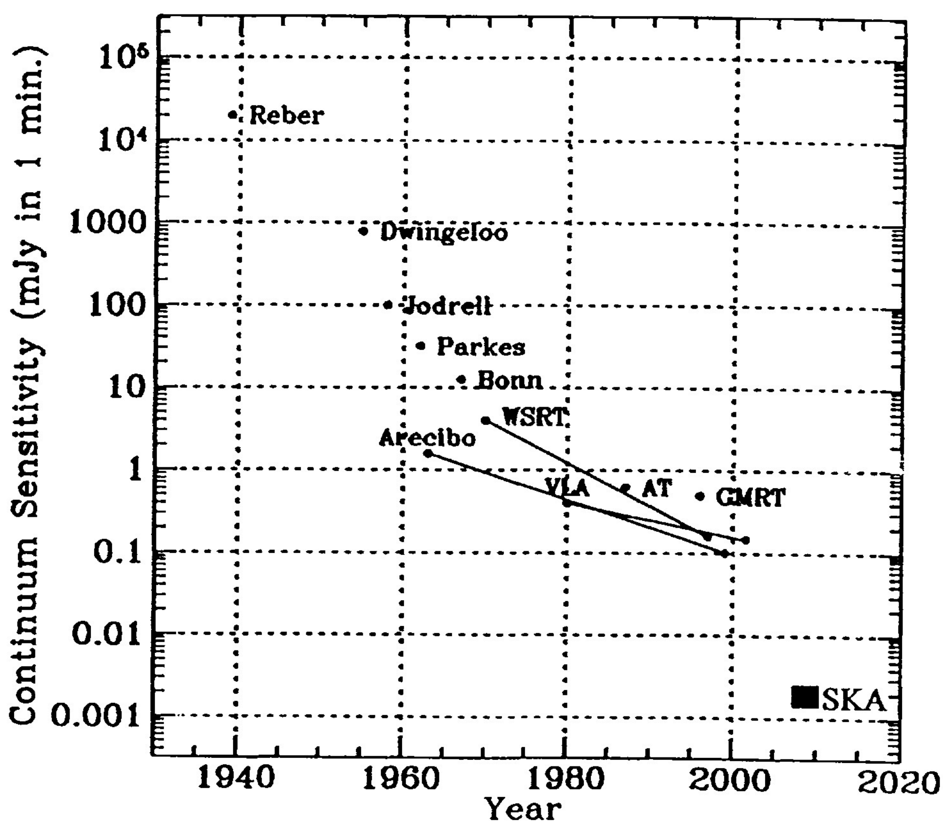
Clean beam dynamic range: 10^6 @ 1.4 GHz

Calibratable polarisation purity: -40 dB

The Square Kilometre Array

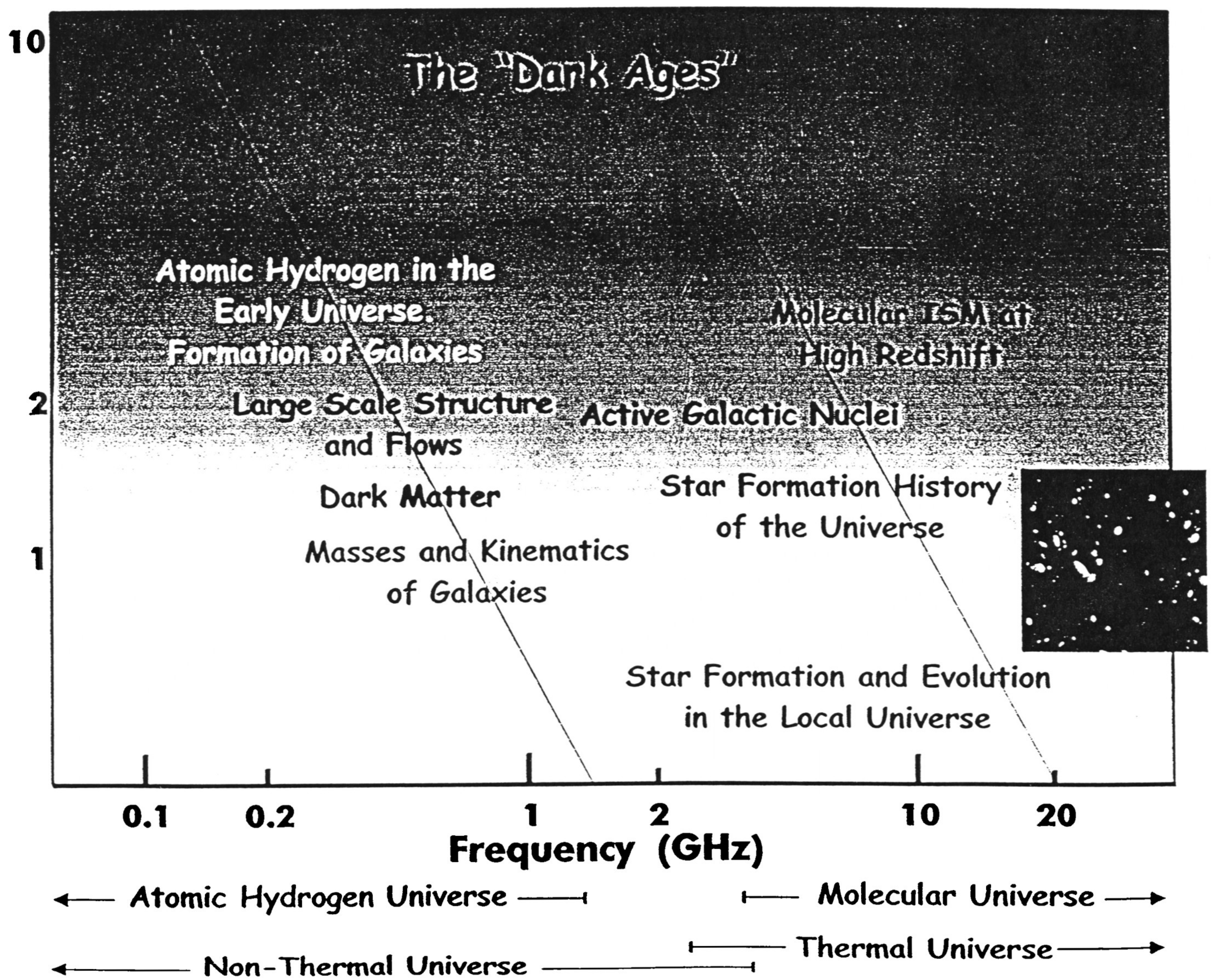
A sentiment attributed to Ken Kellerman....

".... any idiot can figure out that an improvement in sensitivity by a factor of 100 will lead to fundamental scientific advances...."



The Square Kilometre Array

Galaxy Evolution over Cosmic History



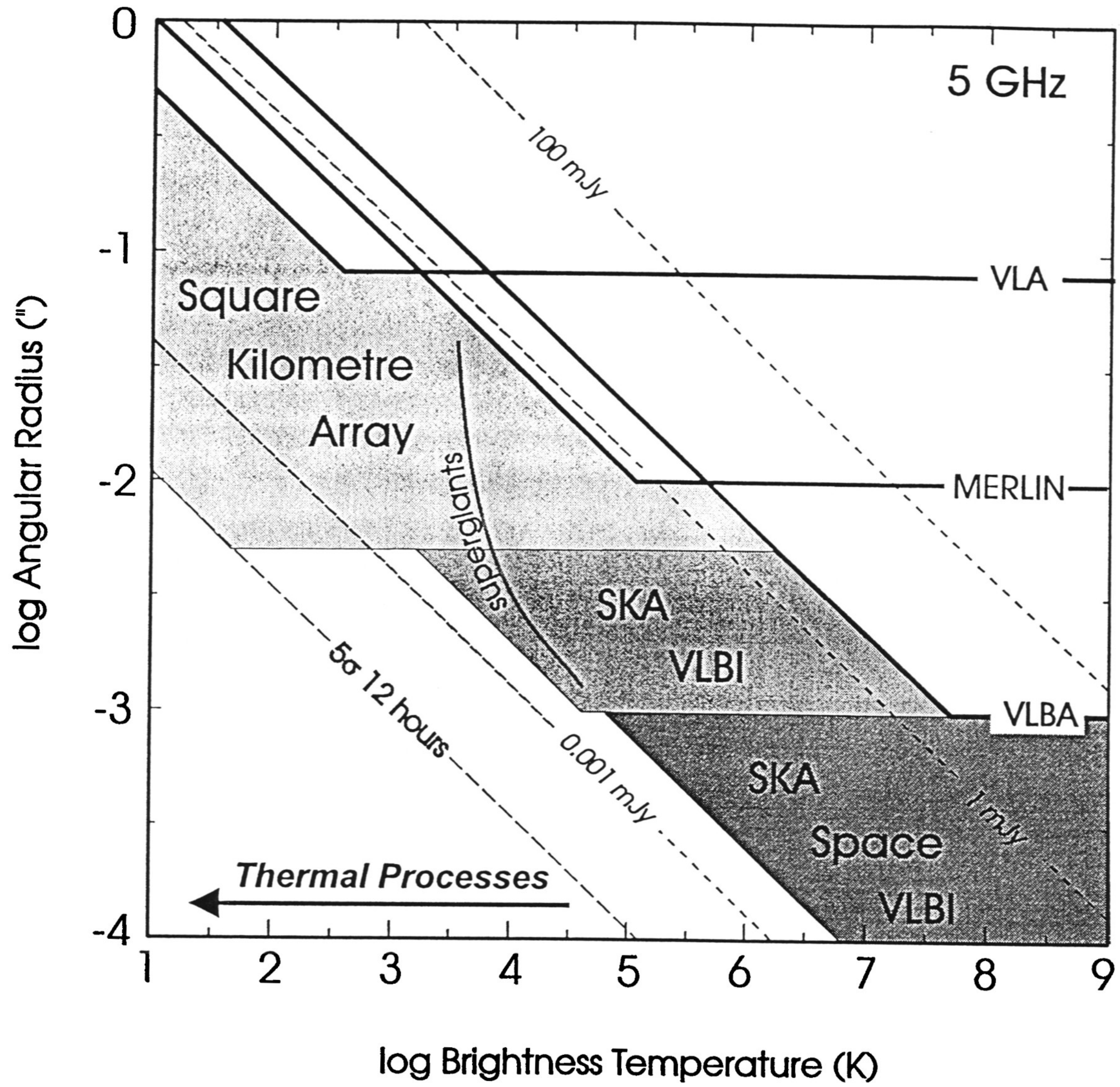
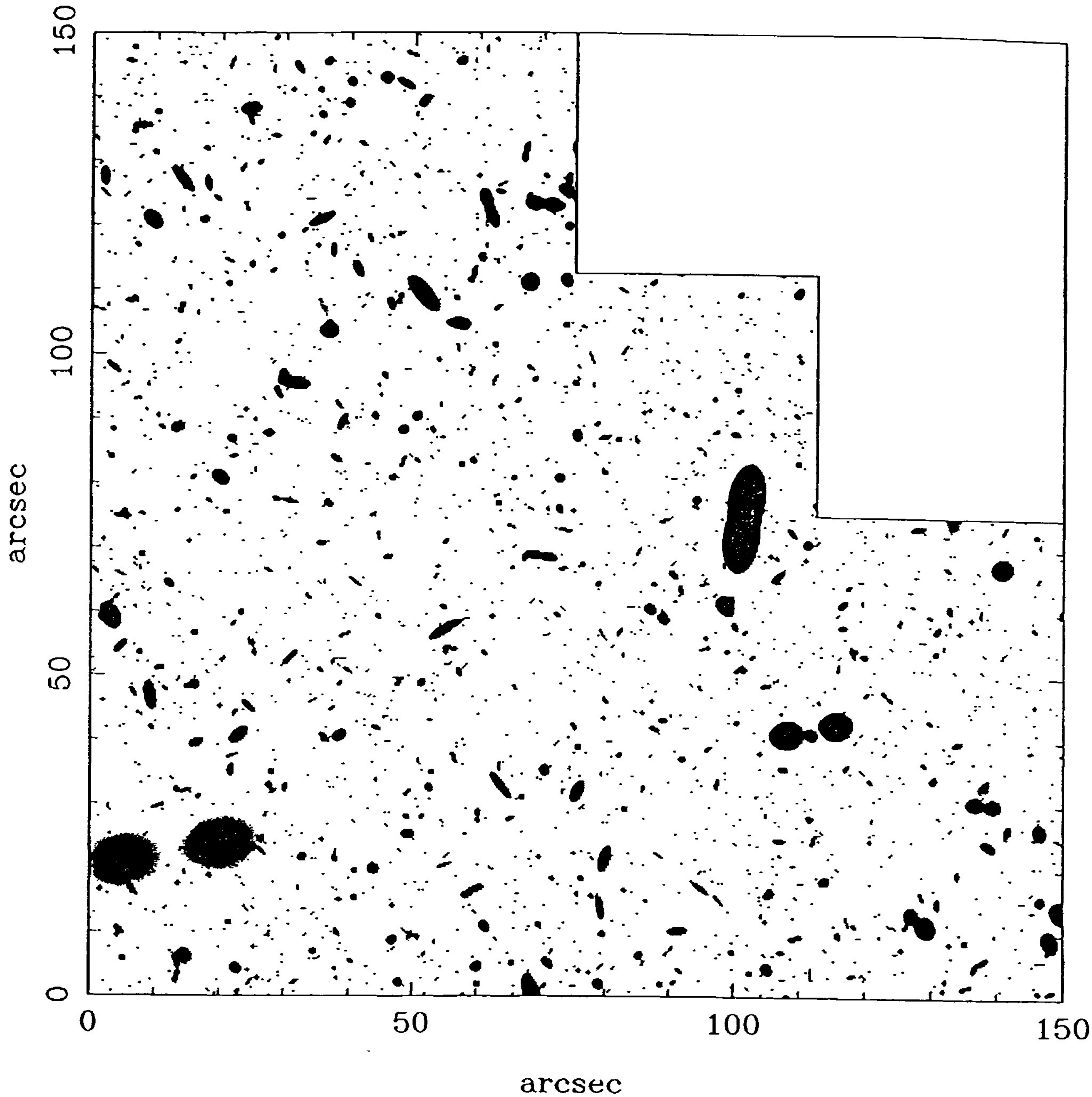


Figure 3.2: The area of brightness temperature – angular size space that will be opened up by the SKA. Photoionized hydrogen gas ata temperature of 10^4 K and below will be imaged at resolutions of a few milli-arcseconds. The temperatures and angular radii for stars in the supergiant branch at a distance of 1 kpc are also shown.



SSF = SKA Shallow Field

Simulation of galaxies detected in a region the size and shape of the Hubble Deep Field in a 8 hour integration at 1.4 GHz (~~rms~~ SS = 100 nanoJy).

blue = starburst galaxies
red = radio galaxies and AGN.

2700 sources

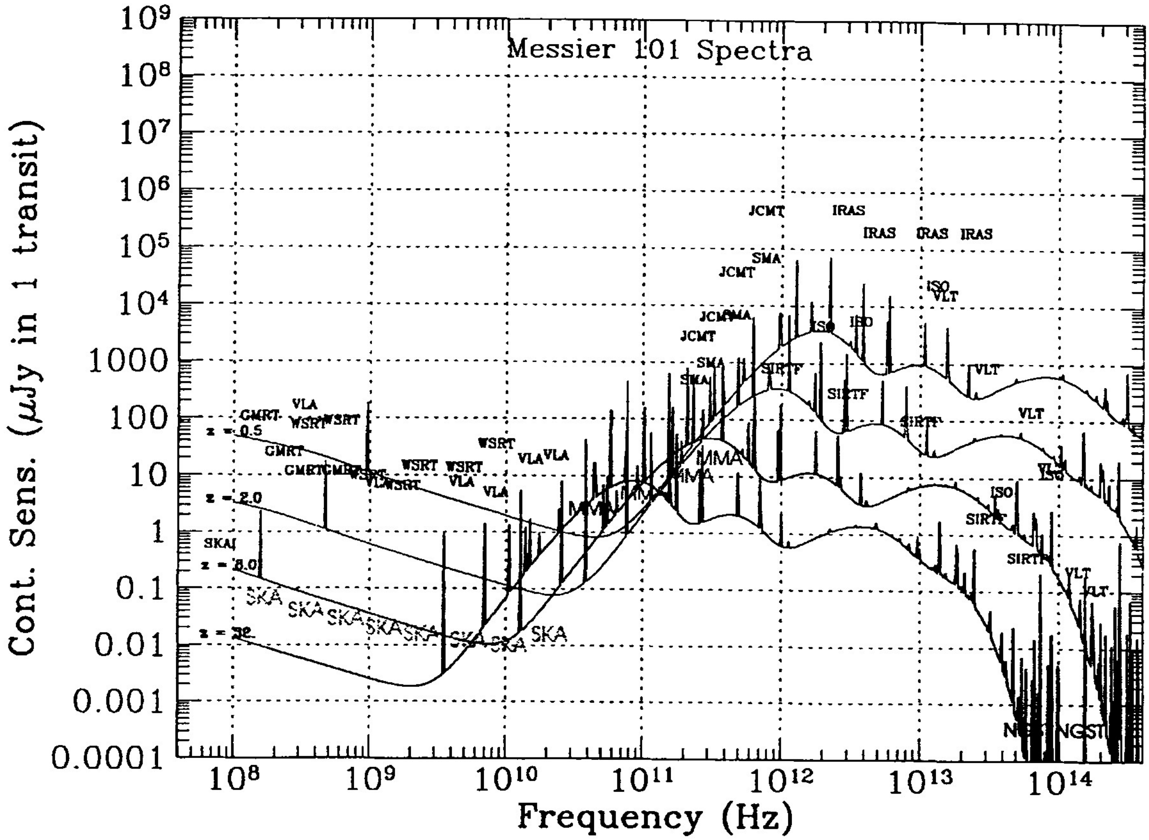


Figure 1.3: Simulated spectra of the spiral galaxy M101 as in Fig. 1.2 but with the instrumental sensitivity of broad-band continuum observations overlaid.

Freq. (MHz)	Total Band. (MHz)	A_{eff}/T_{sys} (m^2/K)	Cont. rms (nanoJy)	Line rms (μJy)
40	20	500	5140	364
80	40	3×10^3	610	43.
160	80	2×10^4	64	4.6
320	160	2×10^4	45	3.2
640	320	2×10^4	32	2.3
1280	640	2×10^4	23	1.6
2560	1280	2×10^4	18	1.1
5120	1500	2×10^4	15	0.80
10240	2500	2×10^4	11	0.57
20480	4500	1×10^4	17	0.80

Table 1.2: Instrumental Sensitivity per Polarisation in 8 hours

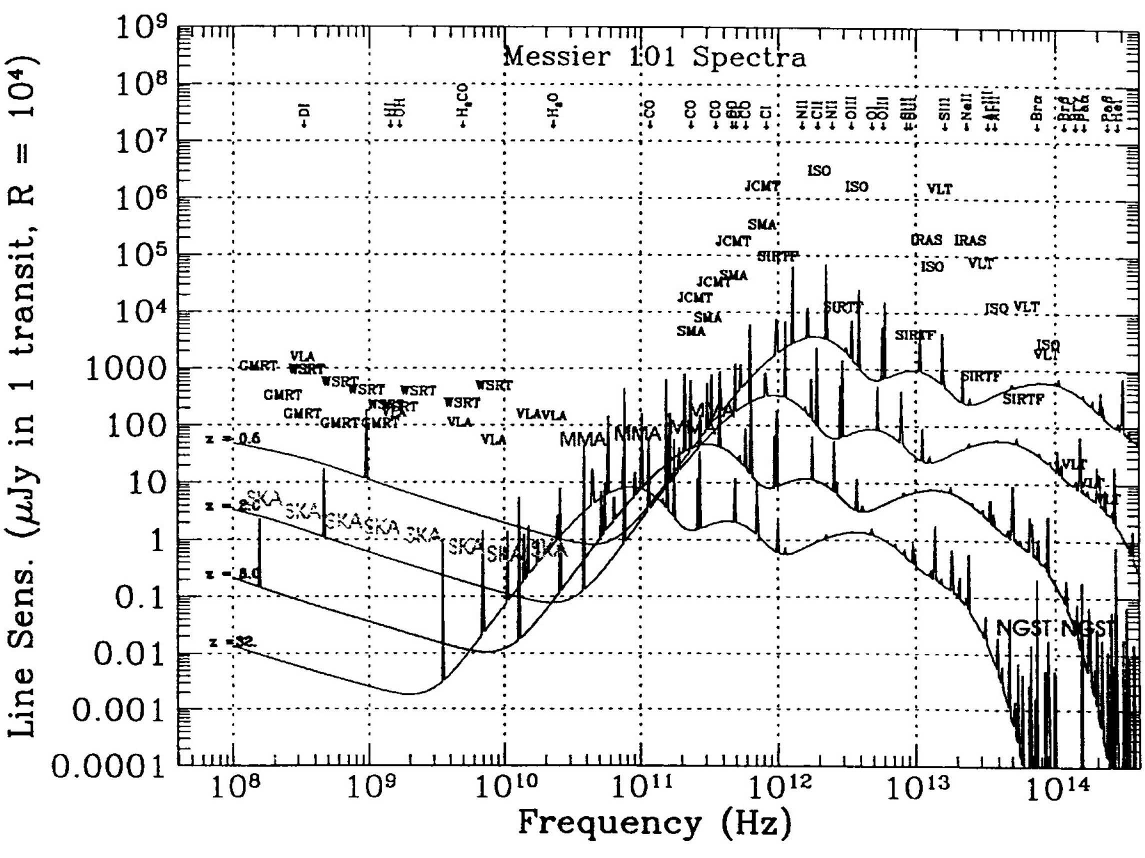


Figure 1.2: Simulated spectra of the spiral galaxy M101 are shown for frequencies between about 10^8 and 10^{14} Hz after being red-shifted to z = 0.5, 2, 8 and 32, under the assumption of no spectral evolution. Instrumental sensitivities (1σ) of existing and planned instruments are overlaid for spectral line observations. Spectral line IDs for some of the major emission lines are indicated at z = 0.

SQUARE KILOMETER ARRAY

S K A

International Consortium

The directors of the following eight institutes have so far signed the "Memorandum of Agreement" committing each to cooperate in a technology study program for a future Very Large Radio Telescope:

- ATNF - Australia Telescope National Facility.
- Herzberg Institute of Astrophysics, Canada.
- Beijing Astronomical Observatory, China.
- National Centre for Radio Astrophysics, India
- Netherlands Foundation for Research in Astronomy.
- SETI Institute, CA, USA.
- National Astronomy and Ionosphere Center, NY, USA.
- Ohio State University Radio Observatory, USA.

US SKA Consortium

Univ. of California, Berkeley

MIT including NEROC/Haystack

SETI Institute

Cornell Iniv.

Caltech

Georga Tech

at-large: Kellermann, Erickson, Fisher

Active SKA Approaches

Pure array of small elements (The Netherlands)
 7 x 10^7 elements at 21 cm
 LOw Frequency ARray 15 to 150 MHz

Shallow reflector with aerostat feed (Canada)
 30 200-meter apertures, F/D ~ 2.5

Paraboloid in a sphere (China)
 10 500-meter spheres, 300-m illuminated

Array of 3 to 10-meter paraboloids (SETI Institute)
 planning 10^4 square meter array

Array of 30 to 70-meter paraboloids (India)
 extension of 45-meter GMRT antenna

Hybrids (Australia)

Constraint

Cost: $600M => $400 per square meter + electronics

SQUARE KILOMETER ARRAY SKA

1,000,000 m^2 (.05) 0.3 - 20 GHz

λ = 1 m - 1.5 cm

GBT	7,850 m^2	0.05 - 100 GHz
VLA	13,200	0.3 - 40
ARECIBO	50,000*	0.3 - 10
GMRT	60,000	0.05 - 1.4

TOTAL EXTENT OF SKA ≃ 500 Km

RESOLUTION ≃ 0.″005 - 0.″5

0.″1 @ 21 cm HI line

COST $600 M → $400/$m^2$

GBT $10,000/$m^2$

GMRT $400/$m^2$

EVOLUTIONARY THEME:

$1 of PROCESSING POWER DOUBLES EVERY 18 MONTHS

×100 IN 10 YEARS

×1000 IN 15 "

Some Technical Problems to be Solved for the SKA

Array configuration (resolution and surface brightness sensitivity)

Optimum reflector size

Digital beam-forming architecture

Multi-octave, power matched array elements for frequencies above 200 MHz

Electrically short array elements below 200 MHz

Mutual coupling in small-element arrays

Decade-bandwidth feed for a reflector antenna

Adaptive RFI rejection

Receiver system dynamic range

Optical signal processing

Low loss signal transmission

Low cost amplifier refrigeration

Arrays as reflector feeds

NRAO SYSTEMS FOR THE GBT, 1998-1999

PROJECT COORDINATION

- 1998 GBT Advisory Committee
- GBT Science Workshop
- Future receivers (Q, L-FPA, Ka, W)
- Scientific requirements for metrology

ELECTRONICS

- Prime focus receiver 2 (0.9-1.2 GHz)
- GBT IFs
- Spectrometer cooling
- Communications systems
- Cryogenic lines
- Emergency stops

INTEGRATED TESTING

- GBT holography system at 140-Foot
- Receiver room attenuation (60 dB)
- Continuous operation of subreflector servo

SOFTWARE DEVELOPMENT

- Commissioning core capabilities (M&C v2.7)
- Operating platform independence (M&C v2.
- Support integrated testing
- Spectrometer integration
- Data archive system

ACTIVE SURFACE

- Route actuator cables
- Master monitor software
- Slave status monitor
- Actuator calibration
- Cable termination

METROLOGY

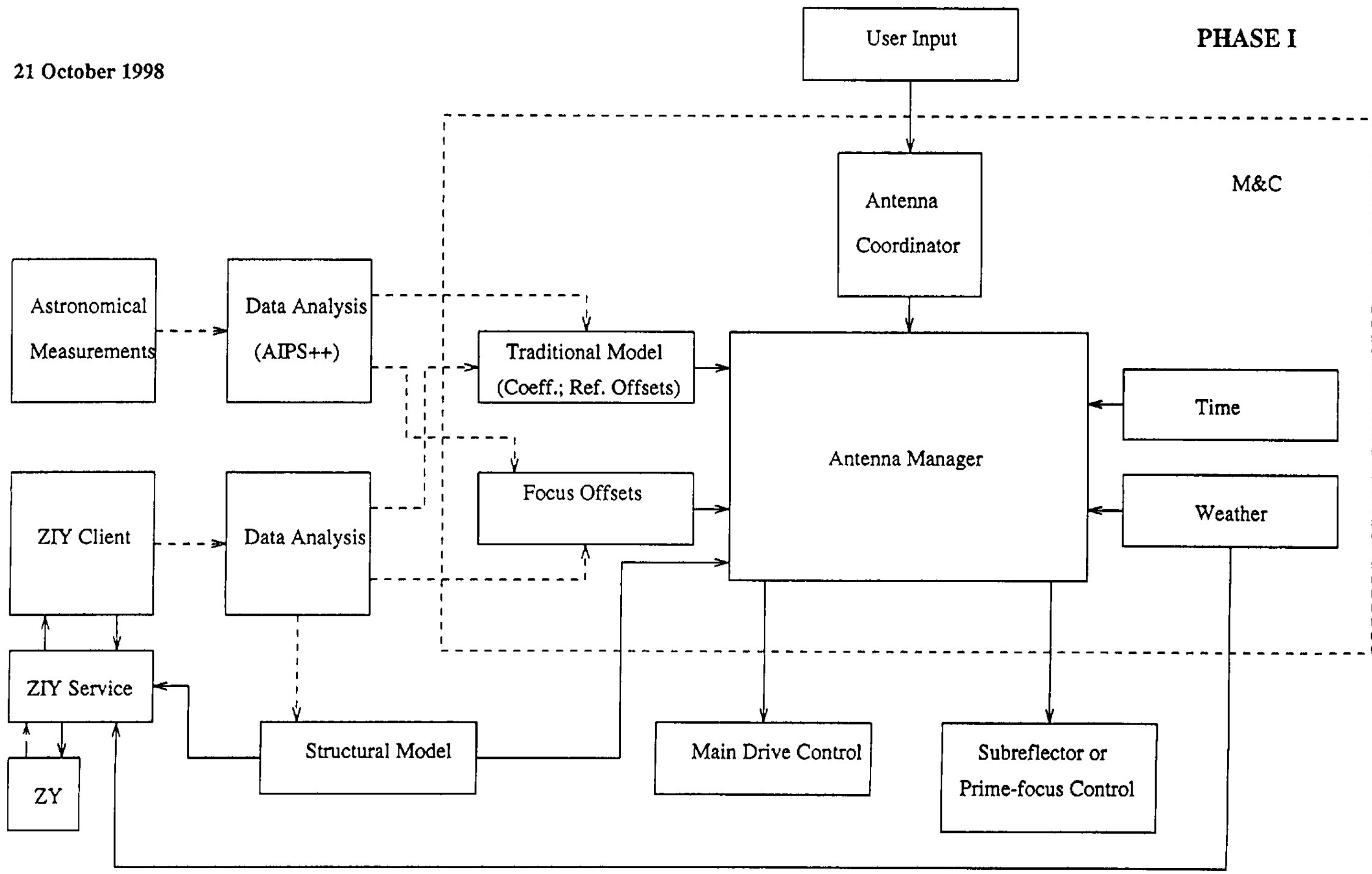
- Point-to-point measurements
- Pointing/metrology integration working grou
- Retroreflector visibility
- Spherical retroreflectors

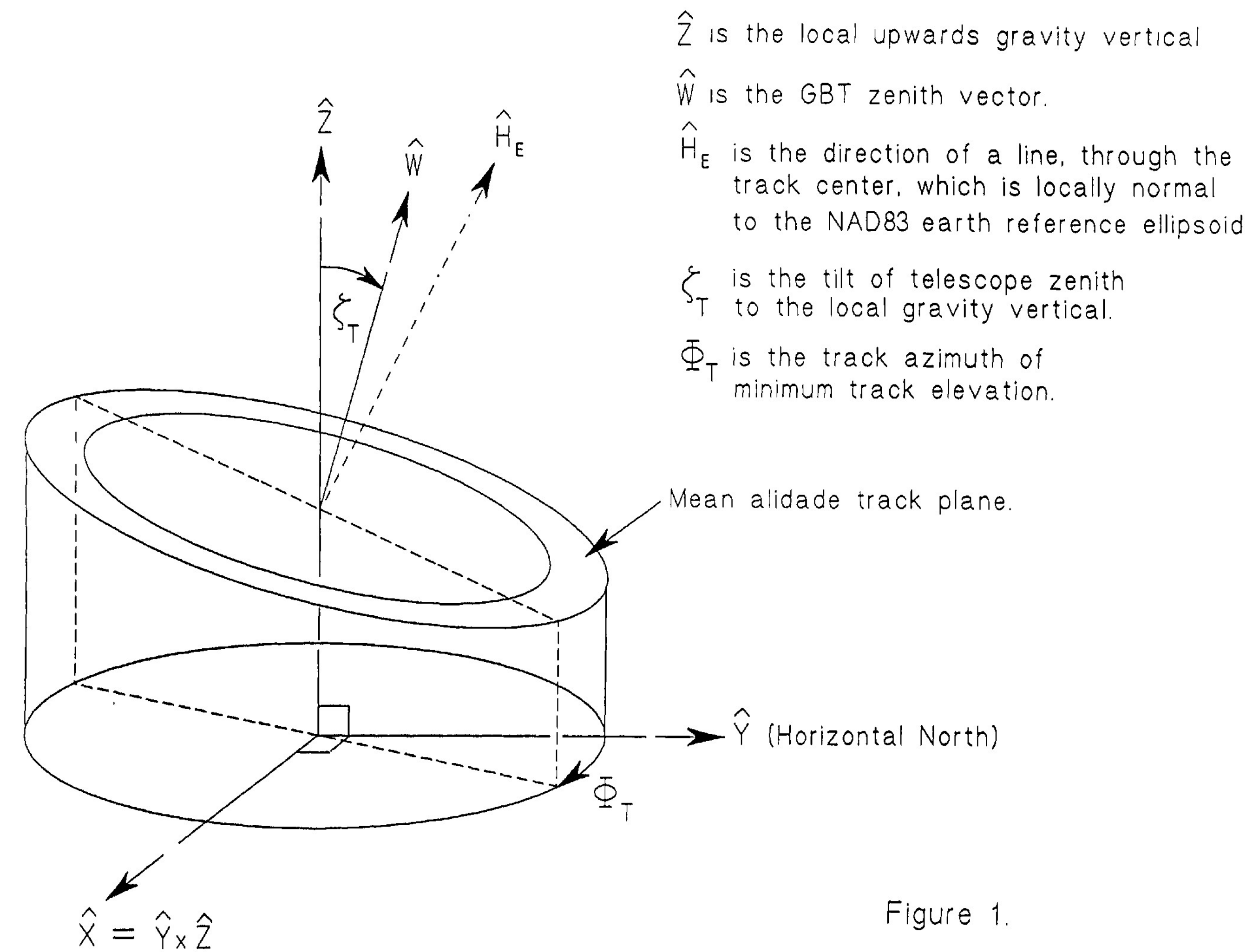
OPERATIONS

- Hired four new operators
- Assist in testing and outfitting
- Documentation system
- Operations and maintenance infrastructure

21 October 1998

PHASE I





$\hat{Z}$ is the local upwards gravity vertical
$\hat{W}$ is the GBT zenith vector.
$\hat{H}_E$ is the direction of a line, through the track center, which is locally normal to the NAD83 earth reference ellipsoid
ζ_T is the tilt of telescope zenith to the local gravity vertical.
Φ_T is the track azimuth of minimum track elevation.
$\hat{Z}$
$\hat{W}$
$\hat{H}_E$
ζ_T
Mean alidade track plane.
$\hat{Y}$ (Horizontal North)
Φ_T
$\hat{X} = \hat{Y} \times \hat{Z}$

Figure 1.

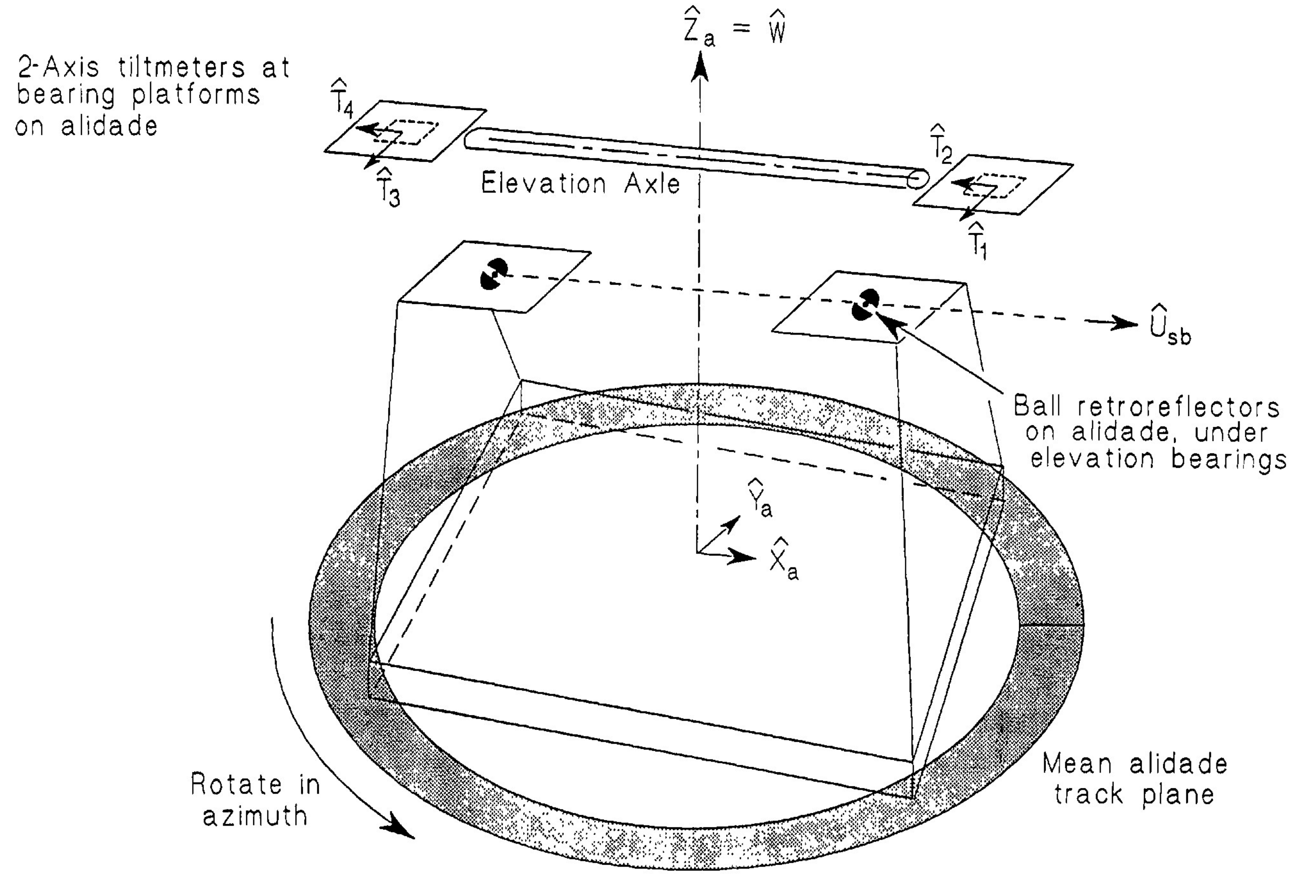

$\hat{Z}_a = \hat{W}$
2-Axis tiltmeters at bearing platforms on alidade
$\hat{T}_4$
$\hat{T}_3$
$\hat{T}_2$
$\hat{T}_1$
Elevation Axle
$\hat{U}_{sb}$
Ball retroreflectors on alidade, under elevation bearings
$\hat{Y}_a$
$\hat{X}_a$
Rotate in azimuth
Mean alidade track plane

Figure 2.

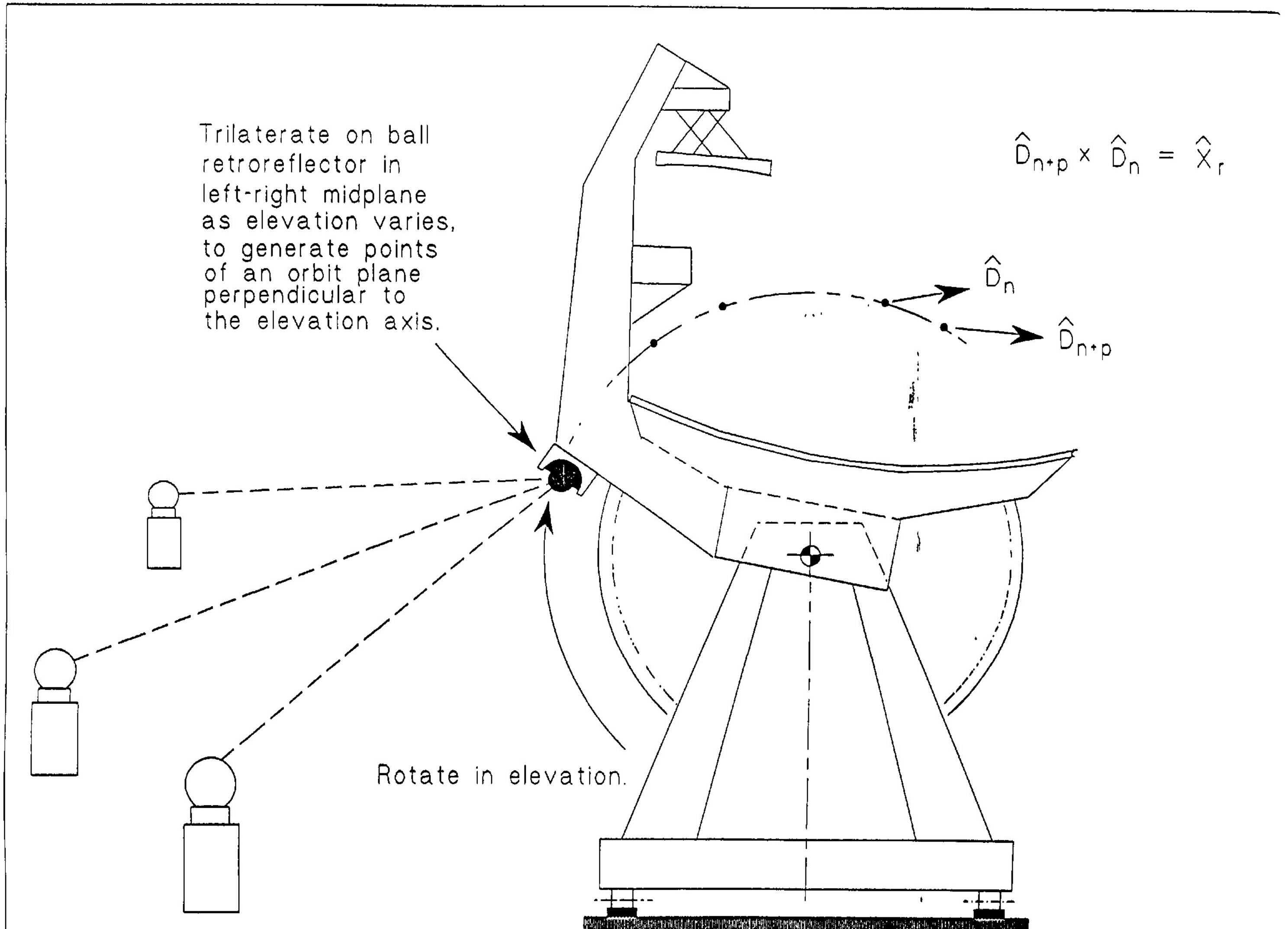


Figure 3. Rangefinder Determination Of The Elevation Axis.

The Green Bank Interferometer Monitoring Program and Internet Outreach

R. M. Hjellming
National Radio Astronomy Observatory

NRAO

Outline

- Basic capabilities of the GBI
- The 1996-1998 GBI-NASA Program for monitoring X-ray sources
- New collaboration between NASA, NRAO, NRL, and USNO formed in June 1998 to continue monitoring of X-ray sources
- Some examples of GBI/*CGRO* BATSE/*RXTE* ASM results
- Plans for Internet outreach program and a National Internet Radio Observatory
- Conclusions

Basic Capabilities of the GBI

- Two element interferometer to observe unresolved radio sources simultaneously at 2.25 and 8.3 GHz and two circular polarizations

- 24-hour monitoring of program of ~30 X-ray sources

- Rapid observation of new X-ray transients

- Data currently calibrated and put into public domain on the Internet on a daily basis

NRAO

The 1996-1998 GBI-NASA Program for monitoring X-ray sources

- GBI shut down April 1, 1996 when NRL/USNO astrometric program was no longer funded
- Operation monitoring X-ray source began in Nov. 1996 with NASA funding, mainly from *CGRO* BATSE and *RXTE*
- Manpower for daily operations supplied in small pieces by NRAO, NRL, and USNO
- Daily alerts for radio-activity states of X-ray sources to initiate TOO programs on *RXTE*, *CGRO*, *ASCA*, and *ROSAT* … and VLA, VLBA, EVN, ATCA, Ryle Telescope, WSRT ...

Monitoring X-ray Sources - Nov. 1996-Present

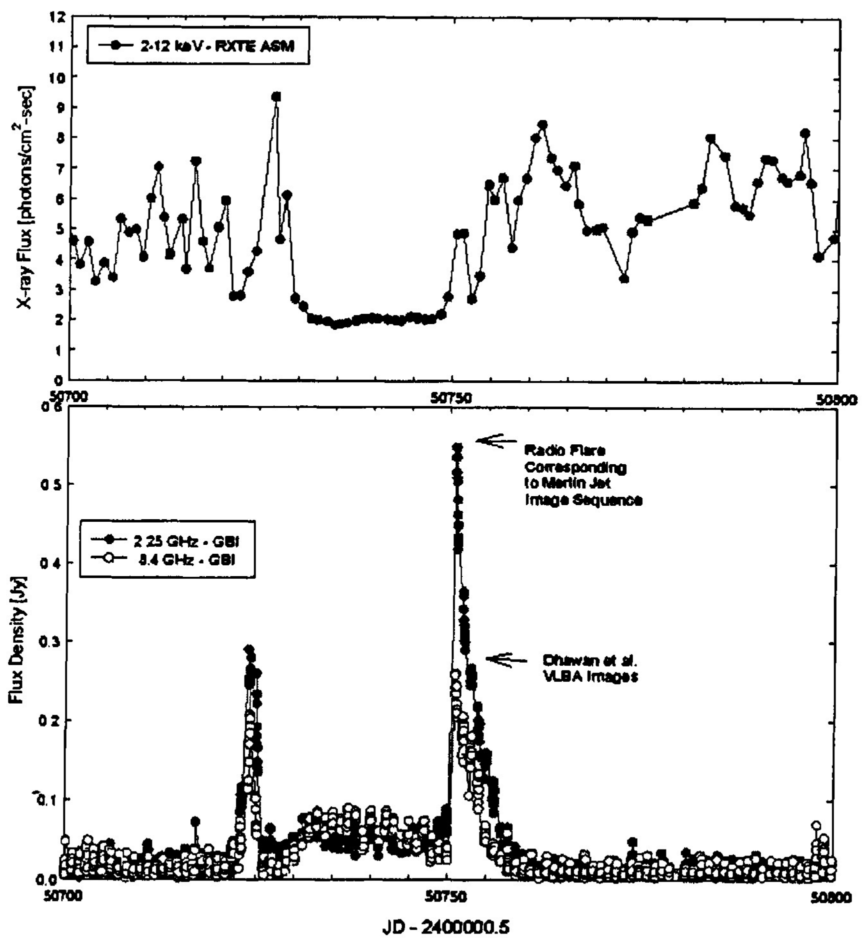
- NASA funding of operation to monitor old (and new) radio-emitting X-ray sources (and a few interlopers)

- ~ 30 sources per day, daily to hourly monitoring

- A few examples:
  - **GRS 1915+105**, special radio-XR coupling
  - **CI Cam**, XR-radio flare and radio afterglow
  - **XTE J1748-288**, superluminal jet ejection events
  - **Cyg X-3**, state changes and radio-XR relationships
  - **Sco X-1**, Hard XR flares before strong radio flares

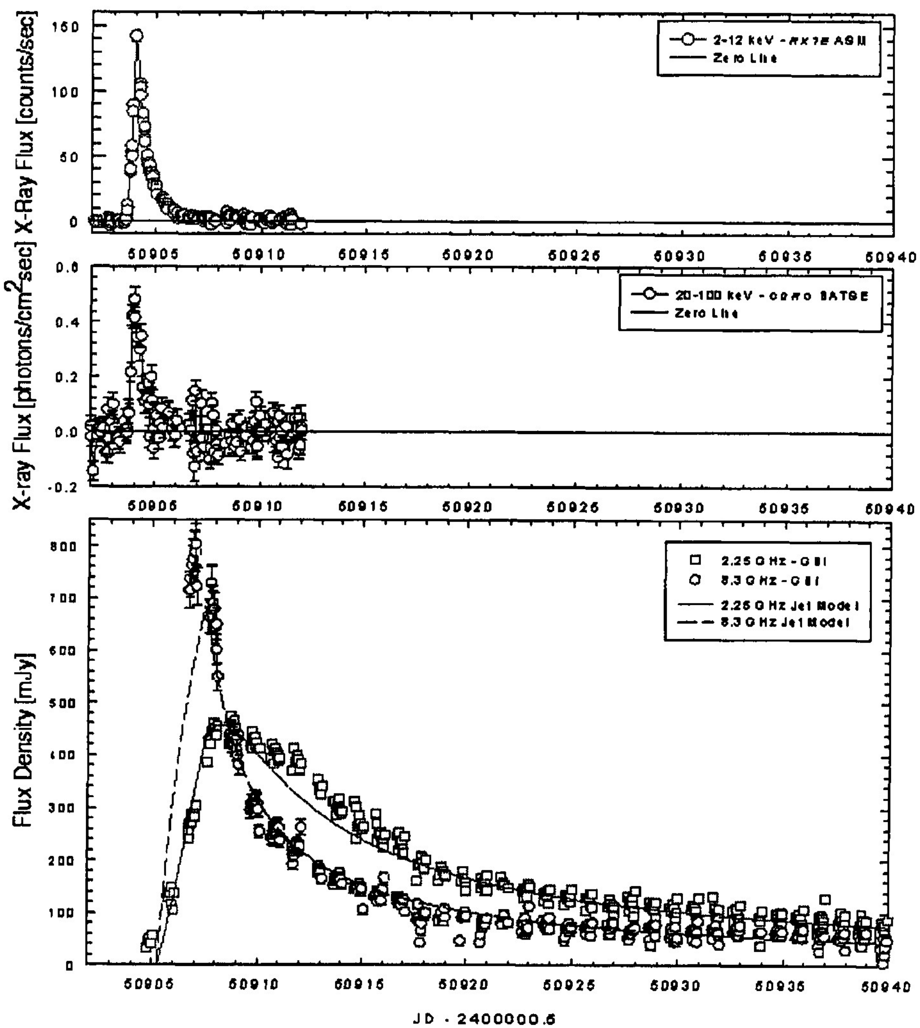
NRAO

GRS 1915+105 Radio-XR Correlations



- X-ray state changes from soft/fluctuating to hard/steady begin and end with radio flares
- Optically thick radio plateau associated with hard, steady XR state
- This 1997 event triggered Merlin and VLBA imaging of superluminal jet ejection
- Many RXTE, CGRO, ASCA, etc., proposals triggered based on radio behavior

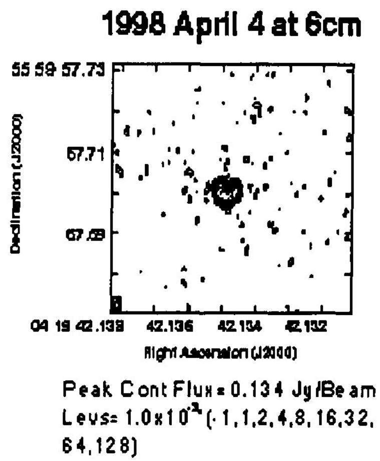
XTE J0421+56 (CI Cam) Radio-XR Events

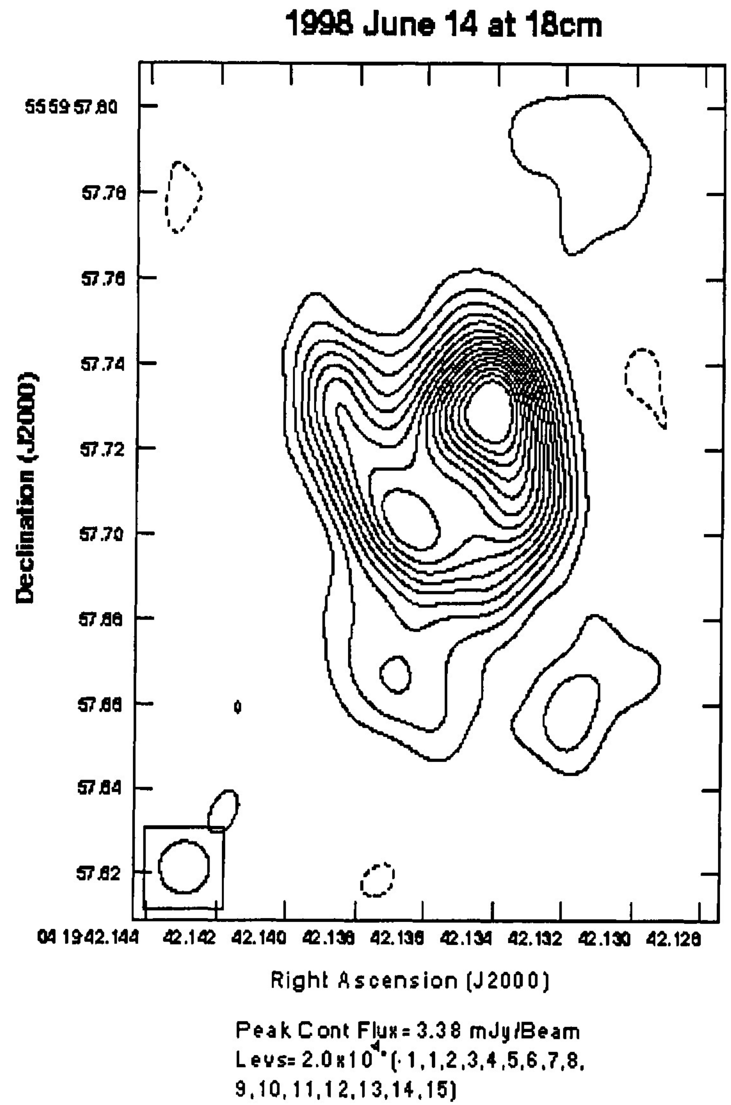


- Mar. 31-Apr. 1, 1998 X-ray event observed in radio by GBI within 24 hours of start of X-ray event

- Slow decay, changing from t^(-1.1) to t^(-0.9), is signature of jet-like ejection at ~1000 km/sec imaged with VLBA by Mioduszewski et al. (next slide)

VLBA Images of CI Cam (Mioduszewski et al.)





Phase 1 - Improved GBI Operations

- Will extend current practice of putting all data in public domain within 24 hours to nearly real-time calibration and data availability on Internet
- Replace DDP-116 control computer with PC control from Jansky telescope control center
- Replace vulnerable hardware components for receivers, data transmission, and correlator to allow easier maintenance
- Improved real-time software for automatic data editing, calibration, and data transfer to Internet-accessible data base computer

NRAO

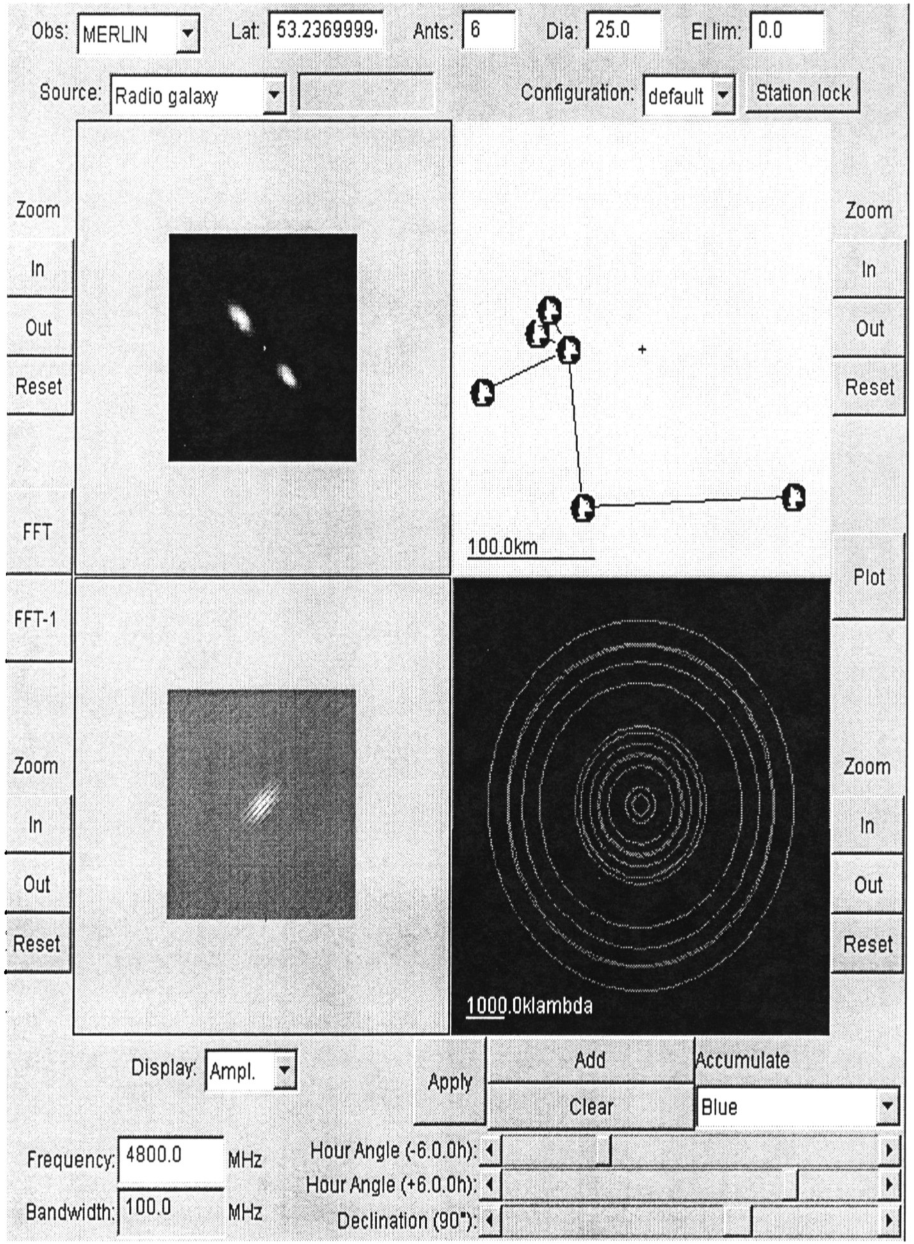
Phase 2 - Internet Outreach

Add National Internet Radio Observatory (NIRO) to NRAO

- Develop real-time availability of GBI data as beginning of real-time data delivery to Internet
- Add 85-3 pulsar telescope data to real-time delivery to Internet
- Develop Java-driven web pages with access, display, and analysis software
- Make data from all NRAO telescopes available on the Internet, password protected access for proprietary levels of data.
- Make PC systems running NIRO software available at all NRAO Visitor Centers, starting at Green Bank and the VLA
- Submit proposals to educational sources for some funding of people and equipment

NRAO

Virtual Radio Interferometer Program



- Example of Java data analysis and display program for Web browsers
- Java applet written by Nuria McKay, Derek McKay and Mark Wieringa
- Simulates ATCA, Merlin, WSRT observations
- FFT and Inverse FFT operations

Conclusions on Advantages

- Improved support of event-driven X-ray & radio observations of sources using the GBI
- Continuous GBI radio coverage of major variable X-ray and other sources
- Improved availability of pulsar data from 85-3
- Develop National Internet Radio Observatory (NIRO) dimension of NRAO to make telescope data, some with password protection, available to astronomers
- Use NIRO for outreach to students and public by making selected archival and real-time radio astronomy data available for science projects

RFI Mitigation Initiatives

Richard F. Bradley

NRAO-CDL
Charlottesville, Virginia

Stages of RFI Environmental Control

- ☞ **Frequency Allocations**

  Very Important

  However, there is a lot of science that must be pursued outside the protected radio astronomy bands.

- ☞ **National Radio Quiet Zone**

  Very Important

  However, it does not protect us from RFI sources from satellites.

- ☞ **Control of the Site Environment**

  We are beginning to take an aggressive approach to on-site RFI control through improved testing techniques and consistent mitigation action.

- ☞ **RFI Tolerance and Excision**

  ✓ **Improvements in the dynamic range of receivers.**

  ✓ **Time and frequency domain data deletion.**

  ✓ **Spatial domain adaptive cancellation (observe at the *same* time and frequency as the interference).**

Comprehensive Approach to RFI Excision

Acknowledge the following:

- ❒ There is no "magic bullet" for RFI excision.
- ❒ RFI excision can become a complicated and expensive endeavor.
- ❒ We must begin to make hard choices between new astronomy instrumentation and RFI excision equipment.
- ❒ We must build a "body of knowledge" and expertise at NRAO in this area.

Suggested Plan:

- ➪ Study the interference environment carefully.
- ➪ Gain experience and knowledge of advanced excision techniques.
- ➪ Use the above to build, evaluate, and improve RFI excision equipment for the telescopes.

RFI Monitoring Station

- Highly-sensitive, DSP-based direction finding
  (source identification)

- Characterization
  - Field strength measurement
  - Bandwidth
  - Nature of the modulation
  - Spatial polarization
  - Propagation effects (spatial coherence, multi-path, etc.)

- Statistical record keeping

- Data recording (for excision studies)

Gaining Experience and Knowledge through Collaborations

Brigham Young University

SAR and SONAR

ATNF

Null Steering

Ohio State University

Communication Systems, Modern Wireless

SETI

Adaptive DSP
Null Steering

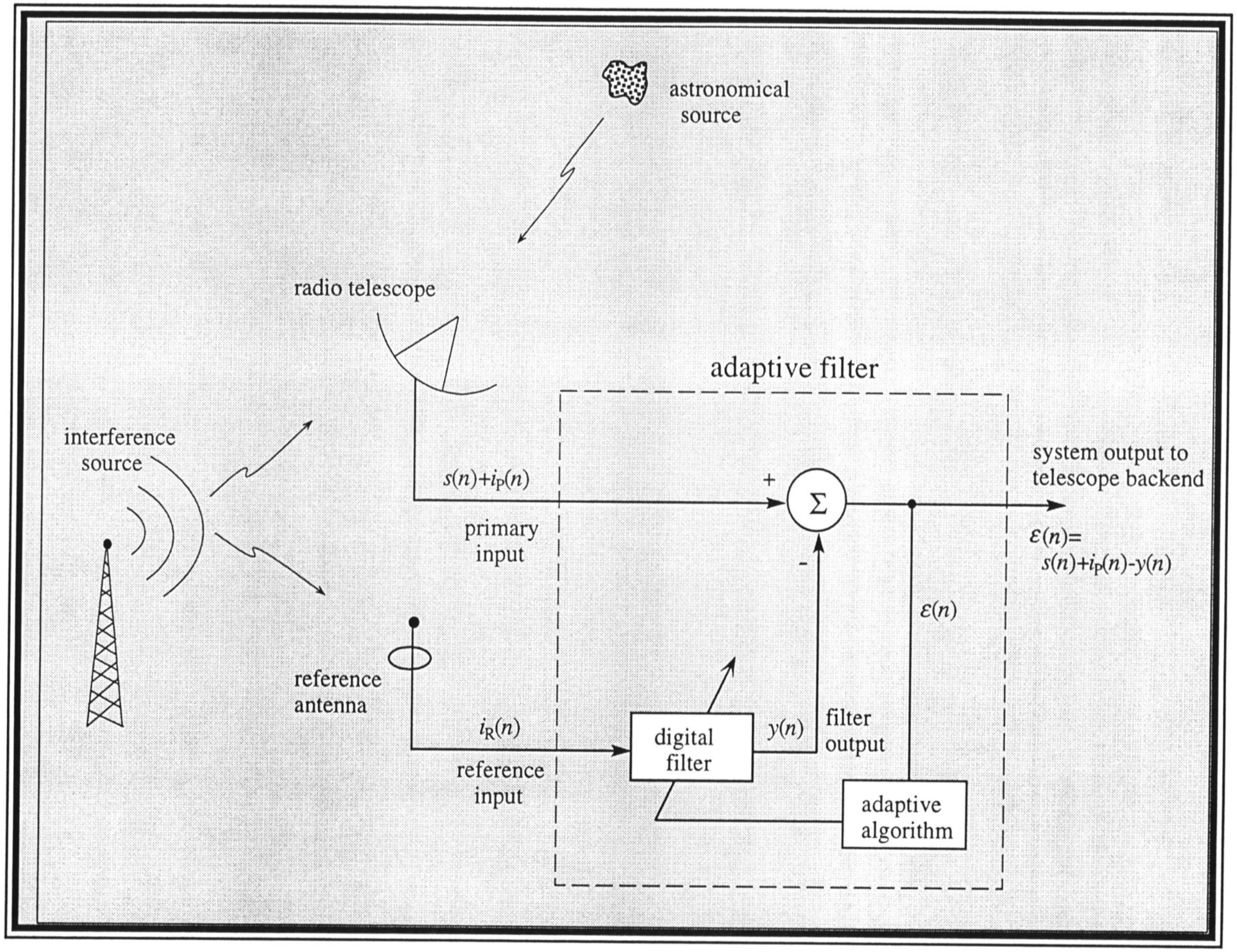
NFRA & Technical University at Delft

Adaptive DSP

Square Kilometer Array

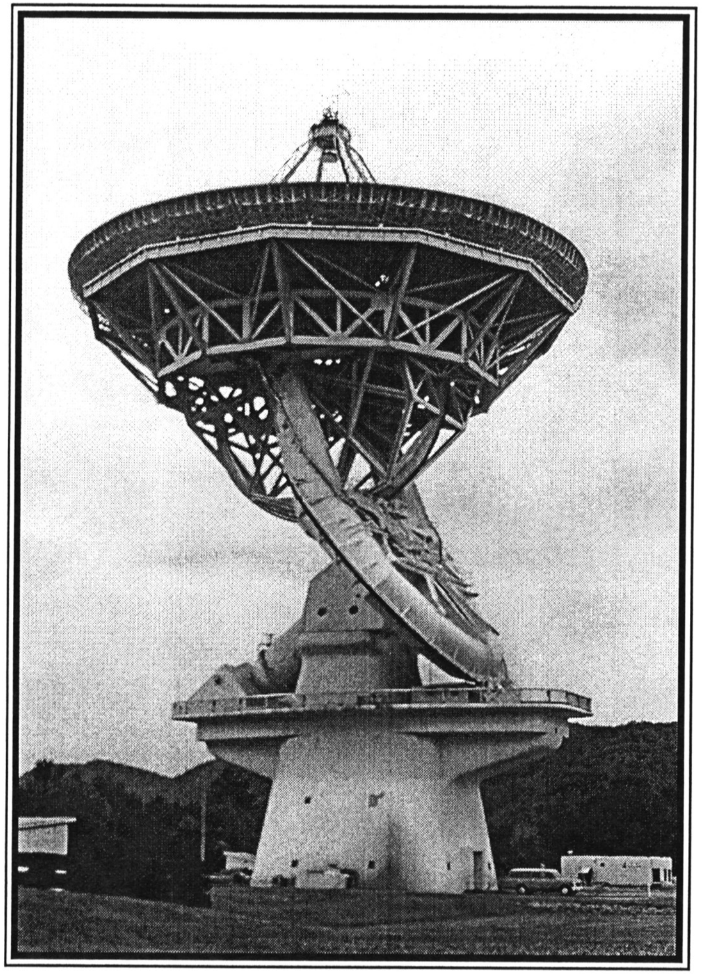
Adaptive DSP
Null Steering

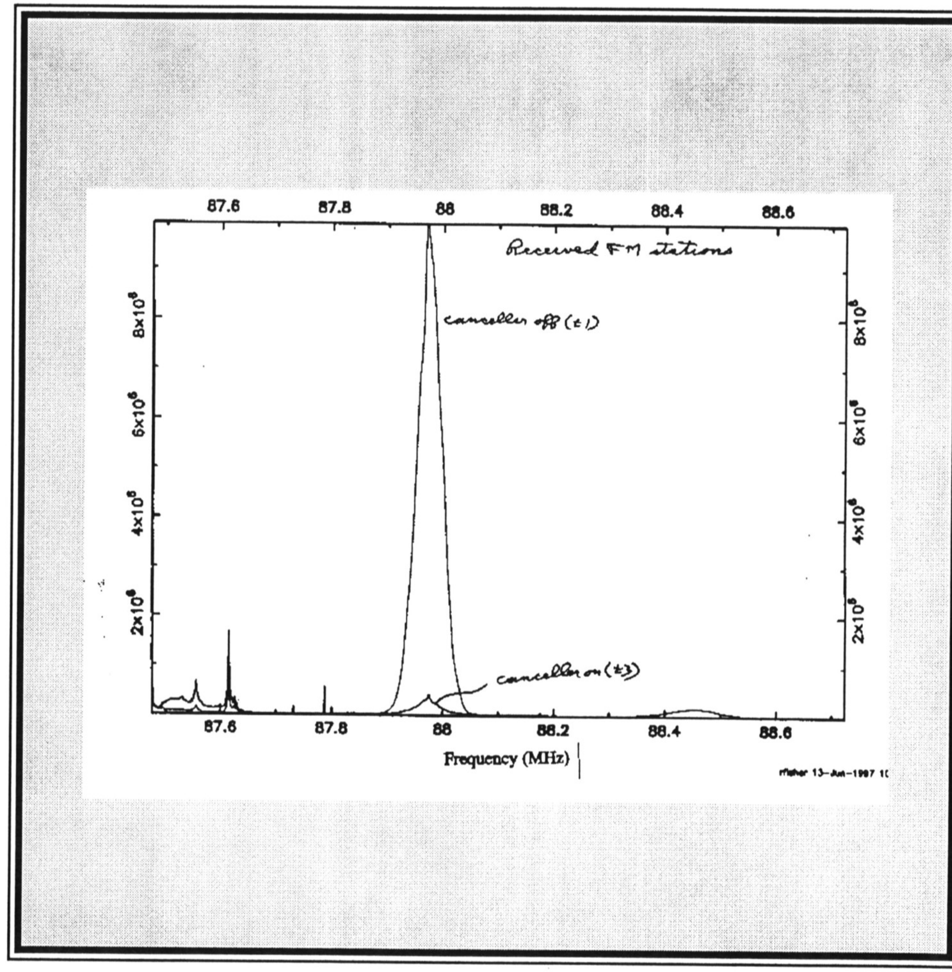
A Conceptual View of Adaptive Interference Canceling



Our adaptive canceler consists of two receivers: the *primary* channel (input from the main beam of the telescope) and a separate *reference* channel. The primary channel receives the desired astrophysical signal corrupted by RFI coming through the telescope sidelobes. The separate reference antenna is designed to receive only the RFI. The reference channel input is processed using a digital adaptive filter and then subtracted from the primary channel input, producing the system output. The weighting coefficients of the digital filter are adjusted by way of an algorithm that minimizes, in a least-squares sense, the power output of the system. Through an adaptive-iterative process, the canceler locks onto the RFI, and the filter adjusts itself to minimize the effect of the RFI at the system output.

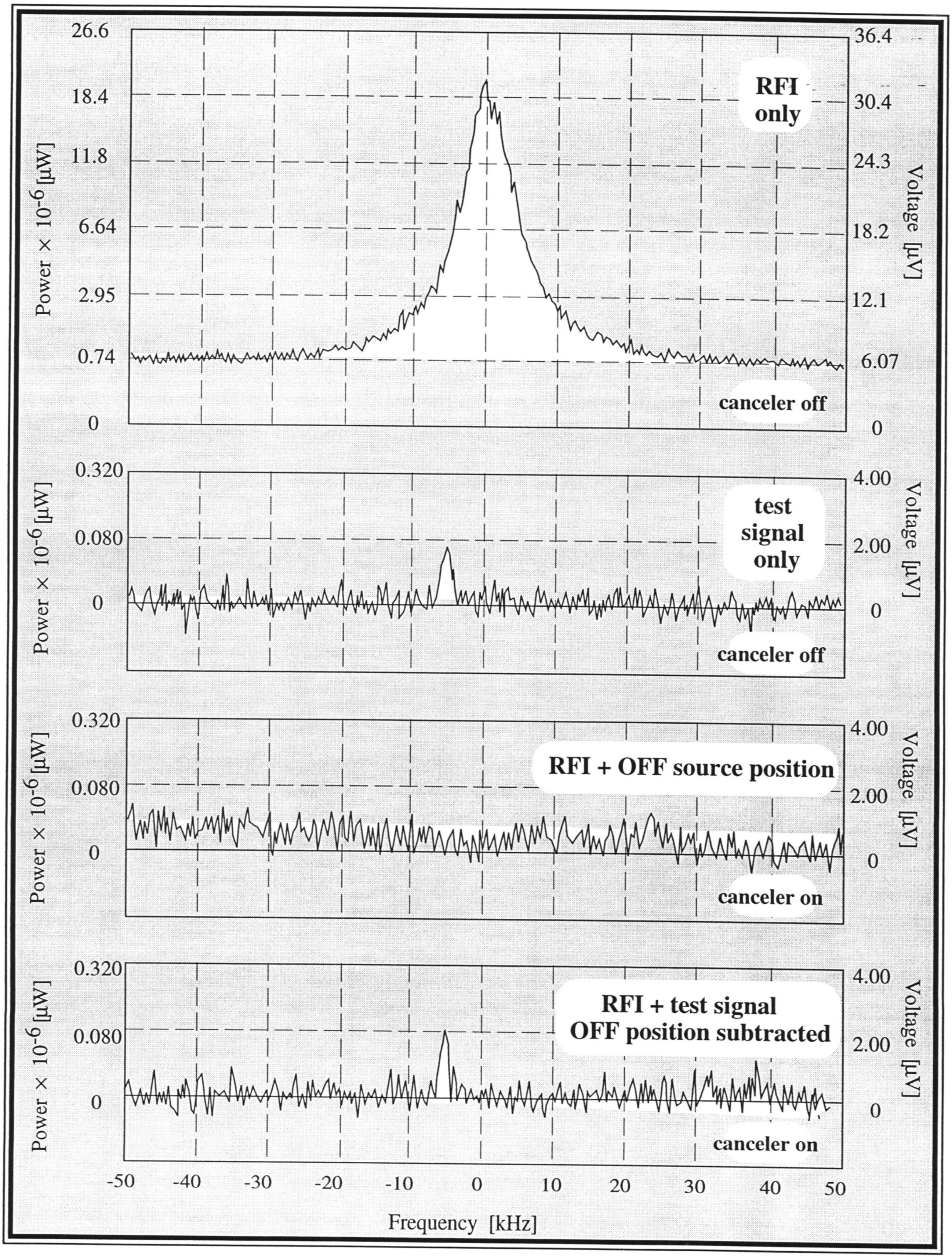
System Compatibility Tests on the 140 Foot in Green Bank



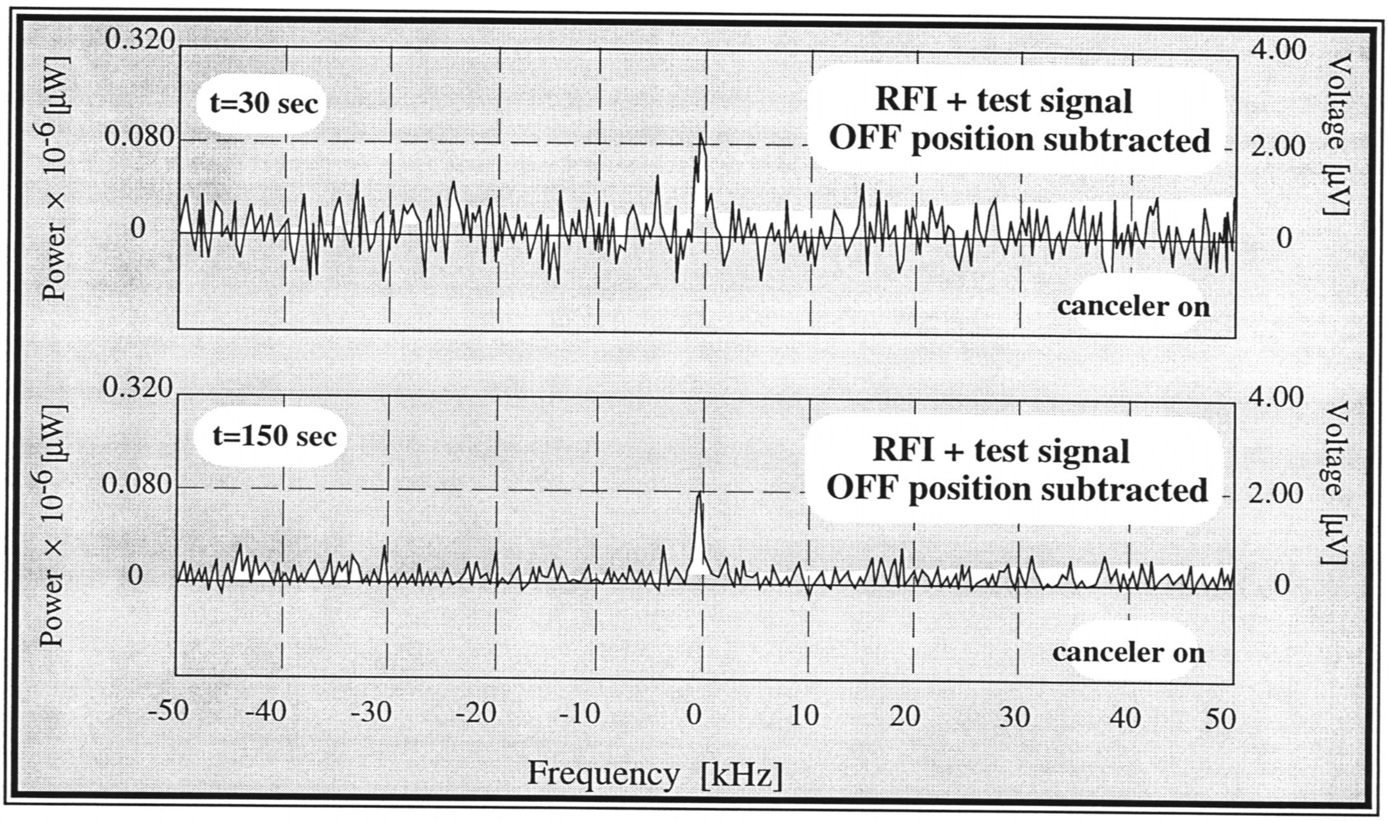


System tests were performed in June 1997 to explore the problems associated with interfacing the prototype canceler with the 140 telescope instrumentation. We choose the FM broadcast band for this initial evaluation. The primary receiver feed was a crossed-dipole located at the prime focus and the reference receiver feed was a pair of yagi antennas located above the prime focus (and pointing toward the horizon as shown). As expected, these tests revealed a number of problems including reference channel spatial depolarization, local interference from the 140 foot electronics, aliasing at the spectral processor input, and multiple interference signals in the passband (our prototype can only handle one at a time). These problems will be addressed in the future. Despite the problems, we managed to attenuate an FM broadcast band signal by better than 20 dB.

Results: Test signal buried in strong wideband RFI (stationary case)



Results: Test signal buried in strong wideband RFI (NONstationary case)



Near-Term Plans

- ❐ Make basic improvements to the current system.
- ❐ Study the noise characteristics and limits of the canceler.
- ❐ Begin to concentrate on developing excision equipment for a telescope to address a specific RFI source at a given frequency.
  - ✓ Enhance our understanding of RFI characteristics.
  - ✓ Improve upon our modeling and simulations.
  - ✓ Explore more advanced adaptive algorithms.

Major Research Instrumentation Proposal to NSF

Development of Interference Countermeasures for High-Sensitively Radio Astronomy

J. R. Fisher, R. F. Bradley, R. A. Perley, and R. A. Sramek

- ☞ Eight prototype 50 MHz bandwidth digital notch filters integrated into the VLA.
- ☞ High dynamic range low-noise amplifier (ATNF).
- ☞ A 5 MHz bandwidth, eight reference channel, digital adaptive canceler.
- ☞ Adaptive canceler and adaptive null-steering simulation software (with ATNF and SETI).
- ☞ Algorithms and software for array feed RFI suppression and synthesis array null steering (with ATNF).

Long Range Plans

Dynamic Excision of RFI from Satellites

Scope of the Problem:

- ❒ Moving sources
- ❒ Multiple sources
- ❒ Complex modulation
- ❒ Complex electromagnetic issues

One possible approach to the solution:

- ✓ A microprocessor controlled system for automatic excision.
- ✓ Small array for RFI source identification and direction of arrival.
- ✓ Multiple high-gain reference antennas for tracking the RFI.
- ✓ Multiple channel adaptive canceler with advanced algorithm.
- ✓ Appropriate interface to telescope system.

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TECHNICAL INNOVATION IN RADIO ASTRONOMY:
WHAT IS NRAO'S ROLE?
===

Thesis (of which I hope to convince you today):

NRAO once led the world in technology development for radio astronomy.

This is no longer the case. In most areas, we are at best keeping up with developments elsewhere.

Questions (which I will not attempt to answer):

Is this an acceptable situation for a national observatory?

Is there anything that can be done about it?

vg1
LRD4/99

SOME TECHNOLOGIES RELEVENT TO RADIO ASTRONOMY

	---- NRAO's Involvement as of Jan 1999 ---			
	Leading	KeepingUp	Following	Ignoring
Optical fiber		?		x
Photonics		x		
Cryogenics		?	x	
Superconducting elec.		x		
Digital ASICs			x	
CAD		x		
Micromachining				x
MMICs (incl mm wave)				x
High density data storage				x
Wideband communication			x	

vg2

SOME TECHNOLOGIES RELEVENT TO RADIO ASTRONOMY

	----- NRAO's Involvement as of Jan 1999 -----			
	Innovator	Contractor	Purchaser	NotInvolved
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Photonics	x	x		
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CAD		x		
Micromachining				x
MMICs (incl mm wave)				x
High density data storage				x
Wideband communication			x	

? = a little

vg3
LRD4/99

APPLICATIONS IN RADIO ASTRONOMY

	---- NRAO's Involvement as of Jan 1999 ---			
	Leading	KeepingUp	Following	Ignoring
cm wavelength rcvrs				
cooled LNAs	x			
MMICs				x
multibeam		x		
mm wavelength rcvrs				
SIS mixers	x			
HEB mixers			x	
Bolometers			x	
signal sources	?			x
multibeam		x		
passive components			x	
wideband signal transmission		x		

correlators/spectrometers	x	
large antenna design	x	
large antenna metrology	x	
VLBI		
space		x
recording		x

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EXAMPLES

(to be explained in some detail in the talk)

- o VLBI recording systems
- o Cryogenics
- o Multibeam receivers
- o Photonics (see John Payne's talk)

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RECOMMENDATIONS

- o Several senior engineers should be required, as part of their regular duties, to keep track of technology advances that may be important to radio astronomy. They should do this by attending conferences, visiting companies and other research groups, and making regular reports to NRAO management.

- o Significant funds from the regular operating budget should be allocated to advanced research and development. We cannot afford to pursue everything, but we should identify and fund work on the technologies that look most promising. We should have a long-term in-house capability in areas that are clearly critical to our mission.

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High density data storage				x
Wideband communication			x	

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LRD4/99

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vg3
LRD4/99

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space			x	
recording				x

vg4
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MICROWAVE PHOTONICS AND RADIO ASTRONOMY

John M. Payne
NRAO, Tucson

NRAO

MICROWAVE PHOTONICS

Rapid development made in fiber communications over the past several years has led to the joining of the microwave and optical regions of the spectrum. For the past five years, an international meeting on this new technology, "Microwave Photonics," has been held annually.

What are the opportunities for applying this new technology to Radio Astronomy?

NRAO

POSSIBLE APPLICATIONS TO RADIO ASTRONOMY

- Wide bandwidth low loss optical fiber links. -1Tb/s over single fiber demonstrated.
- High speed a/d converters.
- Generation and distribution of mm-wave over optical fiber for picocellular wireless networks.

Very strong commercial drivers for all the above.

Preferred optical wavelength - 1.5 microns (200 THz). Complete range of components developed for this optical wavelength.

AN EXCITING APPLICATION

- Over the past several decades radio astronomy observations have been made at ever increasing frequencies. 10 GHz in the 60's -- 900 GHZ with the MMA.
- To permit high resolution spectroscopy, heterodyne techniques require a highly stable, highly coherent local oscillator signal.
- In the past, to reach the higher frequencies, a low frequency has been multiplied up. Gets more difficult the higher the frequency.
- Now, with tunable, narrow linewidth laser, a pair of lasers oscillating at 200 THz and differenced can cover all frequencies for ground-based radio astronomy.

NRAO

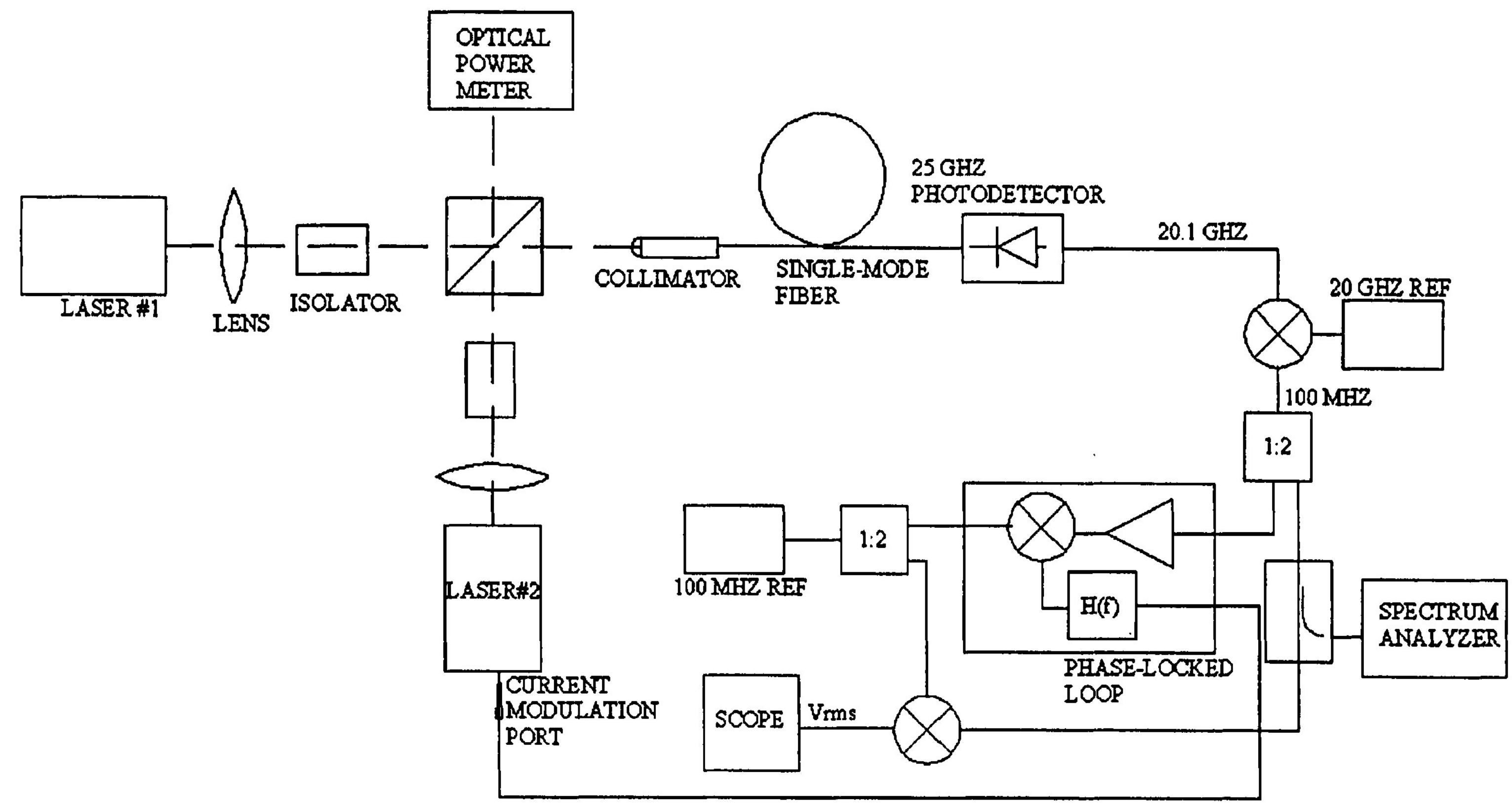
MMA APPLICATIONS

① Generation of mm and sub-mm local oscillator signals using high spectral purity lasers. Distribute optical signals over fiber (loss $\cong$ 0.2 dB/Km) from a central location to each antenna. In receiver generate LO signal in photomixer.

② Generate calibration system for injection of CAL signal directly into each antenna. Complete instrumental calibration.

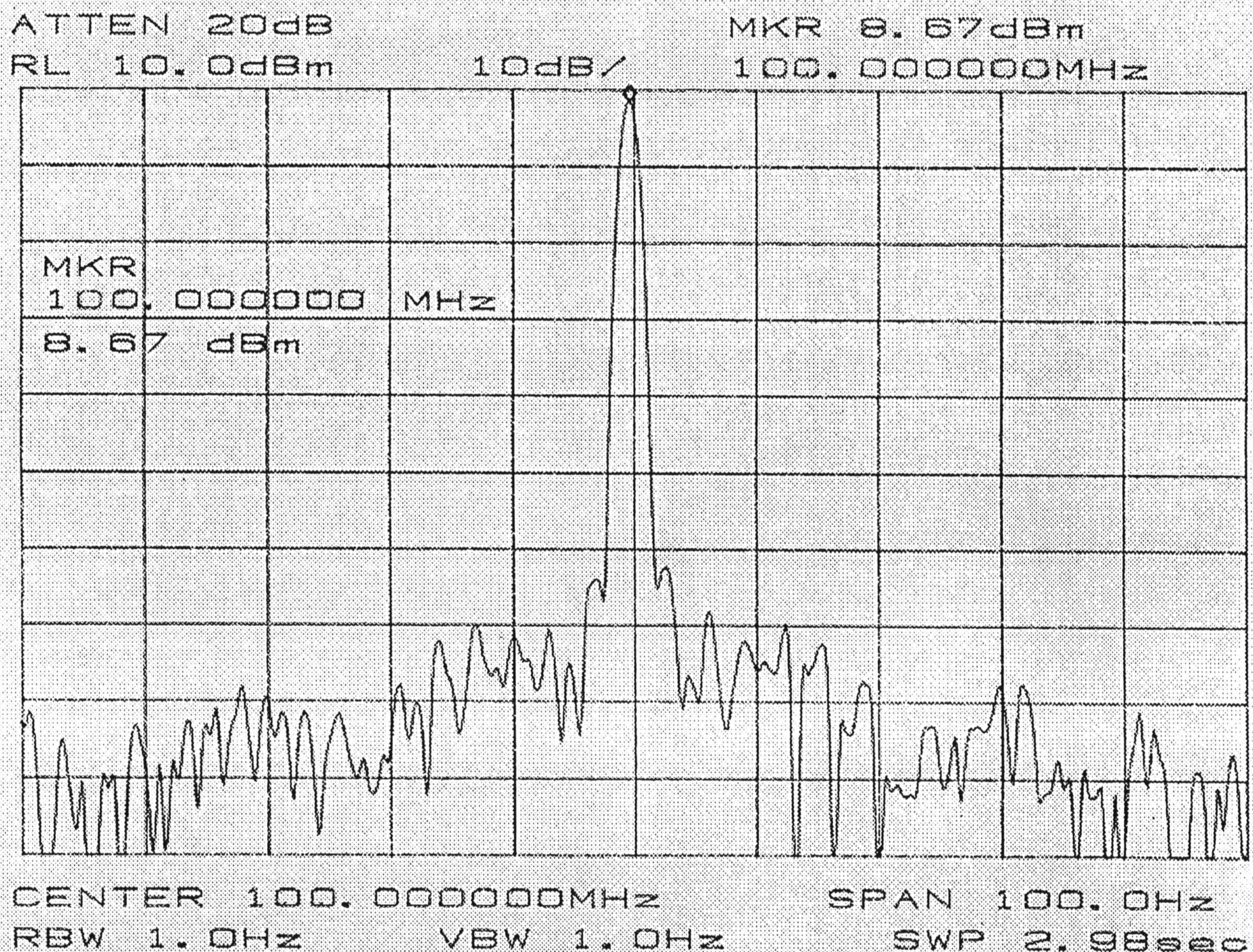
③ For both ① and ② incorporate a continuous correction system to eliminate changes in fiber path length due to temperature and mechanically induced stress. Use a long coherence length, highly stable erbium-doped fiber laser as an interferometer. Closed loop using piezo electric line stretcher.

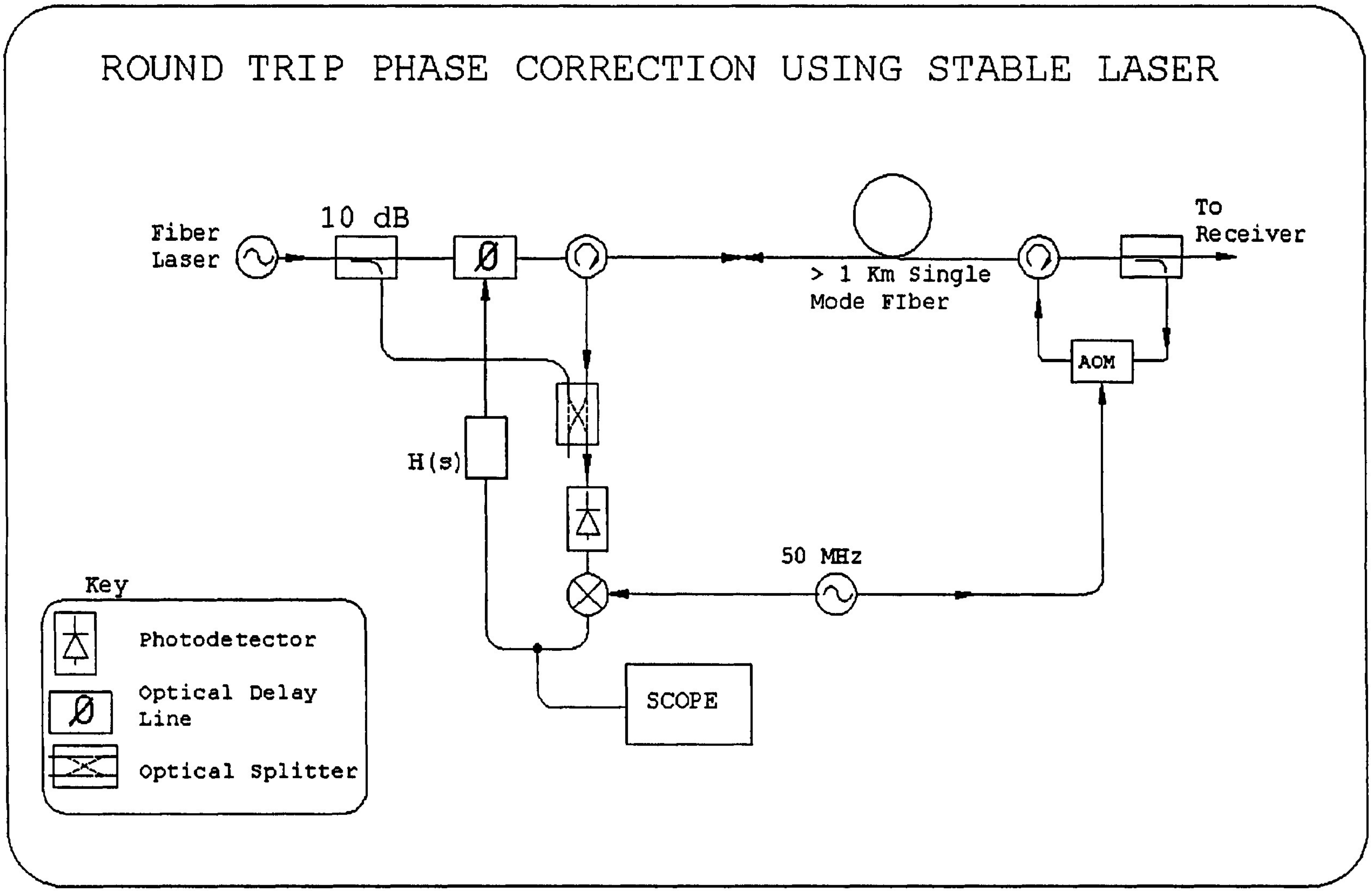
NRAO



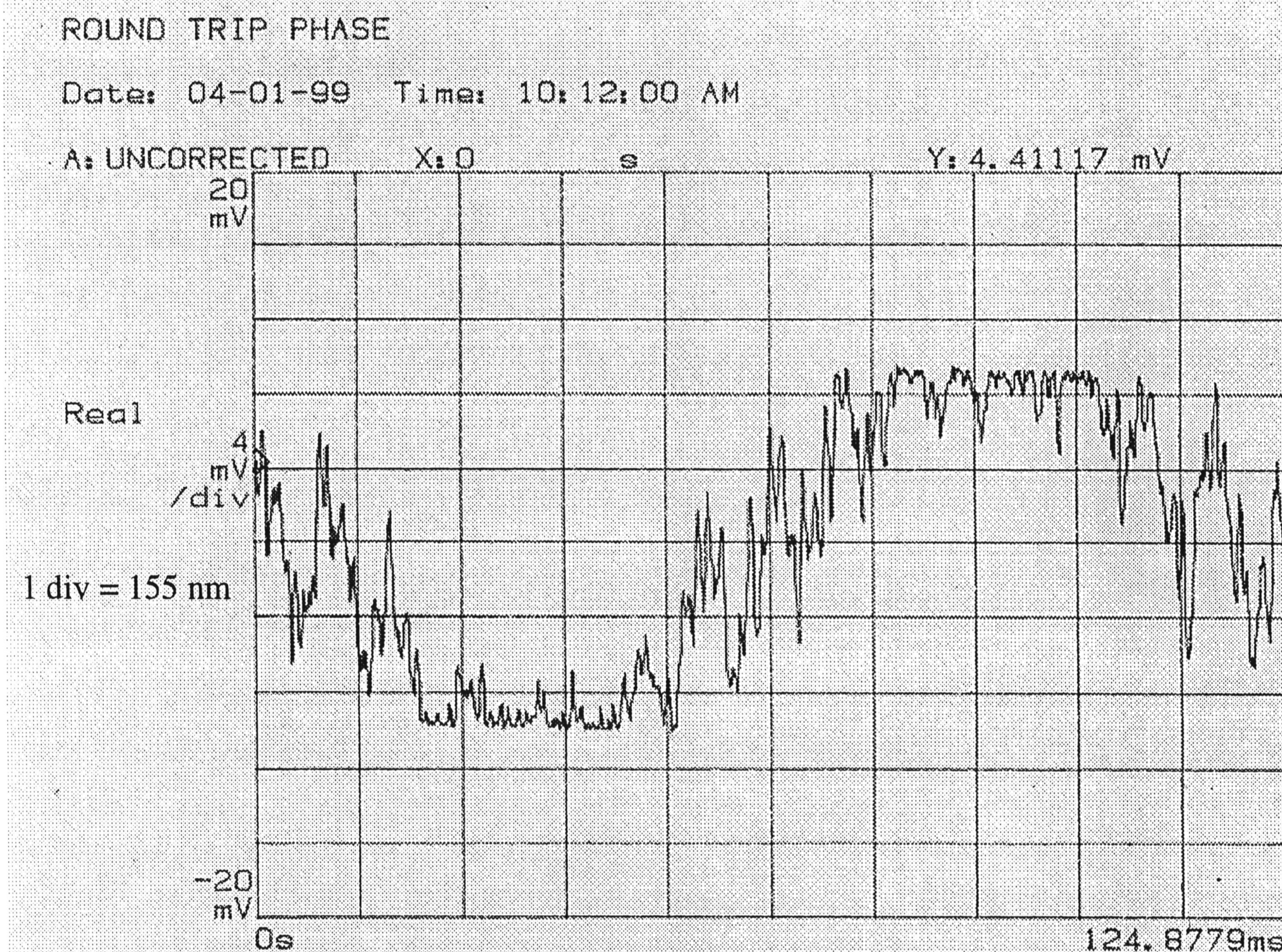
OPTICAL BENCH SETUP FOR LASER HETERODYNE PHASE-LOCK EXPERIMENT

Spectrum of the phase-locked beat frequency between two lasers

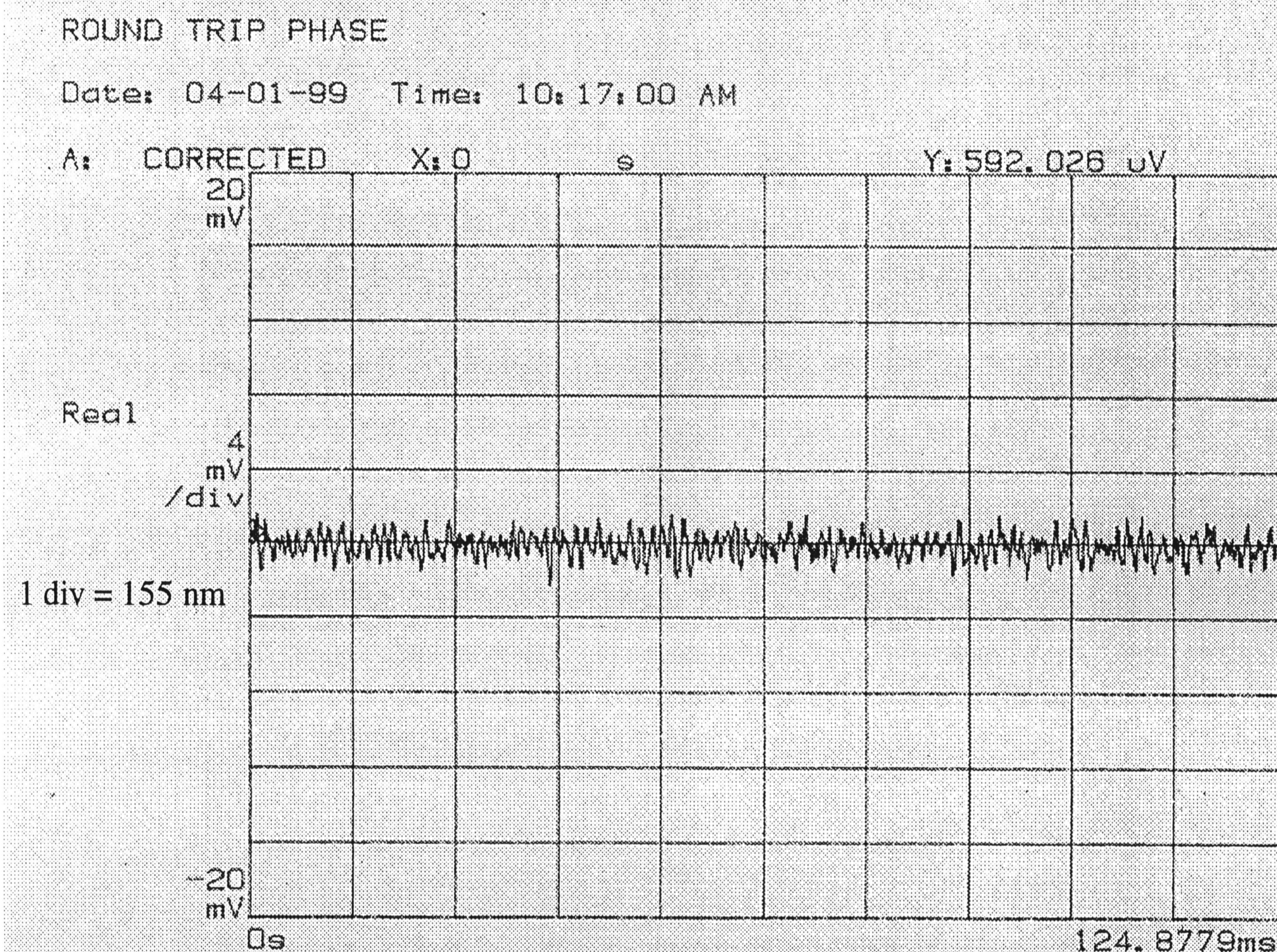




ROUND TRIP PHASE CORRECTION USING STABLE LASER
Fiber Laser
10 dB
Ø
> 1 Km Single Mode FIber
To Receiver
AOM
H(s)
50 MHz
SCOPE
Key
Photodetector
Optical Delay Line
Optical Splitter



ROUND TRIP PHASE
Date: 04-01-99 Time: 10:12:00 AM
A: UNCORRECTED X: 0 s Y: 4.41117 mV
20 mV
Real
4 mV /div
1 div = 155 nm
-20 mV
0s
124.8779ms


ROUND TRIP PHASE
Date: 04-01-99 Time: 10:17:00 AM
A: CORRECTED X: 0 s Y: 592.026 uV
20 mV
Real
4 mV /div
1 div = 155 nm
-20 mV
0s
124.8779ms

PROGRESS

- For generating both the LO signal and calibration signal spectral purity of locked beat frequency is sufficient and is independent of beat frequency.
- Initial experiments over 1 Km length of fiber indicate a continuous correction system is feasible using commercial components.
- High frequency photodiodes are a problem.

Simplified NRAO History:

Green Bank

Charlottesville + Green Bank

Now: CV + GB + AOC + Tucson

2010: CV + AOC + Chile + GB + Tucson ?

Unity with Current Spread-out Staffing Difficult

Post-ALMA Construction Worse

Original GB/CV scientific staff will be retiring

Their "Glue" will be lost

What is the nature of NRAO and its Sci Staff in 2010

Will NRAO be a "holding company" for observatories

How do we keep involvement of Sci staff in general NRAO goals ?

Do we want to ?

Suggestions now to keep some Unity then:

1) Make Upgraded VLA and ALMA look as much alike as possible

as well as VLBA, GBT.

2) Colloquium Exchange Policy

3) Regular Retreats

BUT

Nature of the Staff at different sites will probably diverge.

NRAO may become more like the collection of NASA centers.