VLBI2010 Project for Geodesy and Astrometry

Arthur Niell
The VLBI2010 Committee
The Broadband Development Team

VLBI2010 Committee

Bill Petrachenko[1] (chair), Arthur Niell[2], Dirk Behrend[3], Brian Corey[2], Johannes Böhm[4], Patrick Charlot[5], Arnaud Collioud[5], John Gipson[3], Rüdiger Haas[6], Thomas Hobiger[7], Yasuhiro Koyama[7], Dan MacMillan[3], Zinovy Malkin[8], Tobias Nilsson[6], Andrea Pany[4], Gino Tuccari[9], Alan Whitney[2], Jörg Wresnik[4]

[1] *Natural Resources Canada, Canada*
[2] *Haystack Observatory, Massachusetts Institute of Technology, USA*
[3] *NVI, Inc./Goddard Space Flight Center, USA*
[4] *Institute of Geodesy and Geophysics, University of Technology, Vienna, Austria*
[5] *Bordeaux Observatory, France*
[6] *Onsala Space Observatory, Chalmers University of Technology, Sweden*
[7] *Kashima Space Research Center, NICT, Japan*
[8] *Pulkovo Observatory, Russia*
[9] *Radio Astronomy Institute, Italian National Astrophysical Institute, Italy*

Broadband Delay Team

Bruce Whittier[1], Mike Titus[1], Jason SooHoo[1], Dan Smythe[1], Alan Rogers[1], Jay Redmond[2], Mike Poirier[1], Arthur Niell[1], Chuck Kodak[3], Alan Hinton[1], Ed Himwich[3], Skip Gordon[2], Mark Evangelista[2], Irv Diegel[2], Brian Corey[1], Tom Clark[3], and Chris Beaudoin [1]

[1] MIT Haystack Observatory

[2] HTSI, Inc

[3] GSFC/NVI

Special thanks to Sandy Weinreb and Hamdi Mani

VLBI2010 Recommendations

- 1-mm position accuracy on global scales
- Continuous measurements for time series of station positions and Earth orientation parameters
- Turnaround time to initial geodetic results of less than 24 hours

Principal VLBI2010 Actions

- Numerical simulations
- Proof-of-Concept Development
- Progress report (through end of 2008)
  - Completed (last week!)
  - Available soon on IVS web site
    http://ivscc.gsfc.nasa.gov

Numerical Simulation Innovations

- More accurate atmosphere model that includes turbulence properties
- New approach to scheduling observations within a day
- Evaluation of effect of source structure

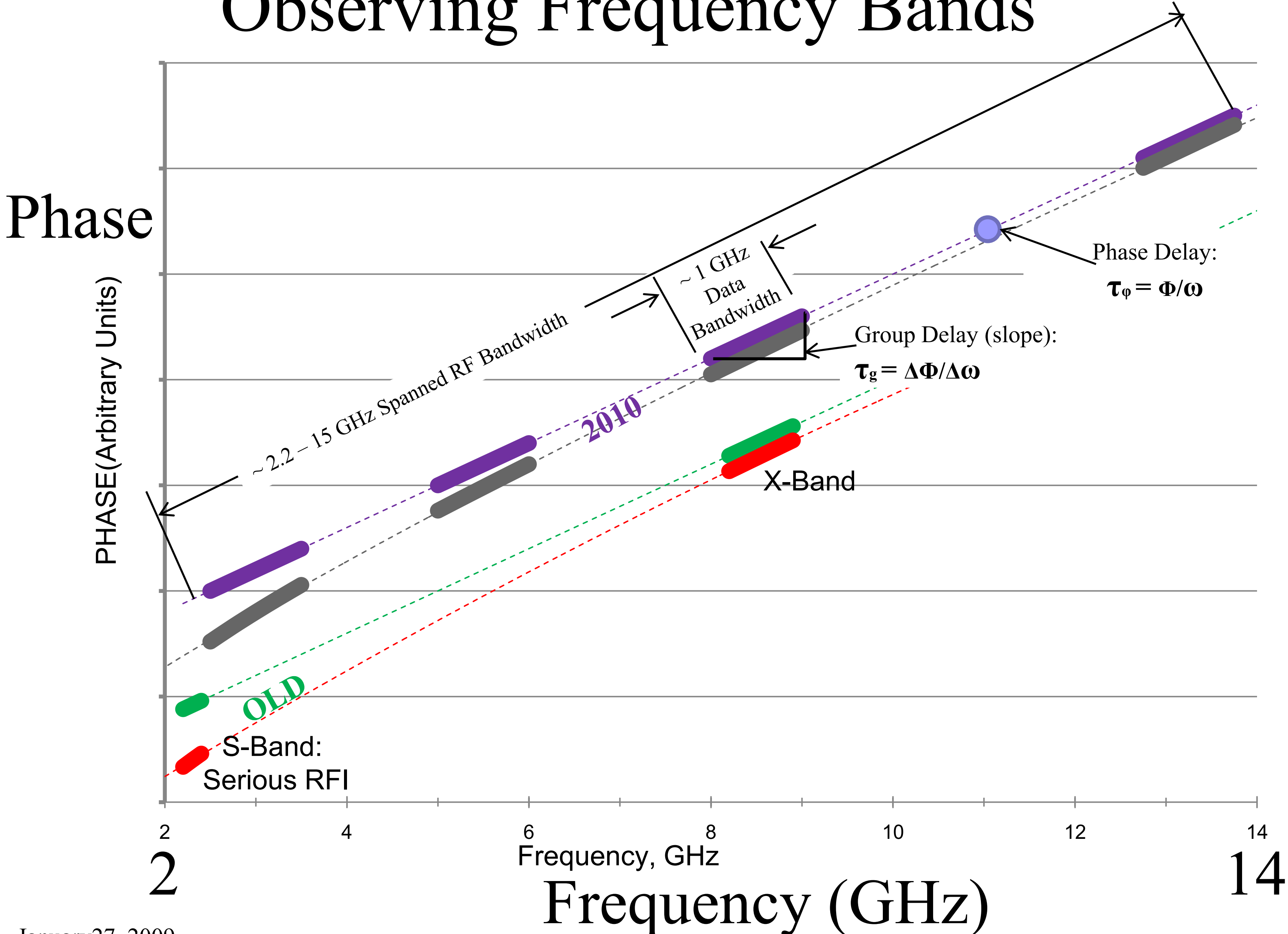
Recommendations from Simulations

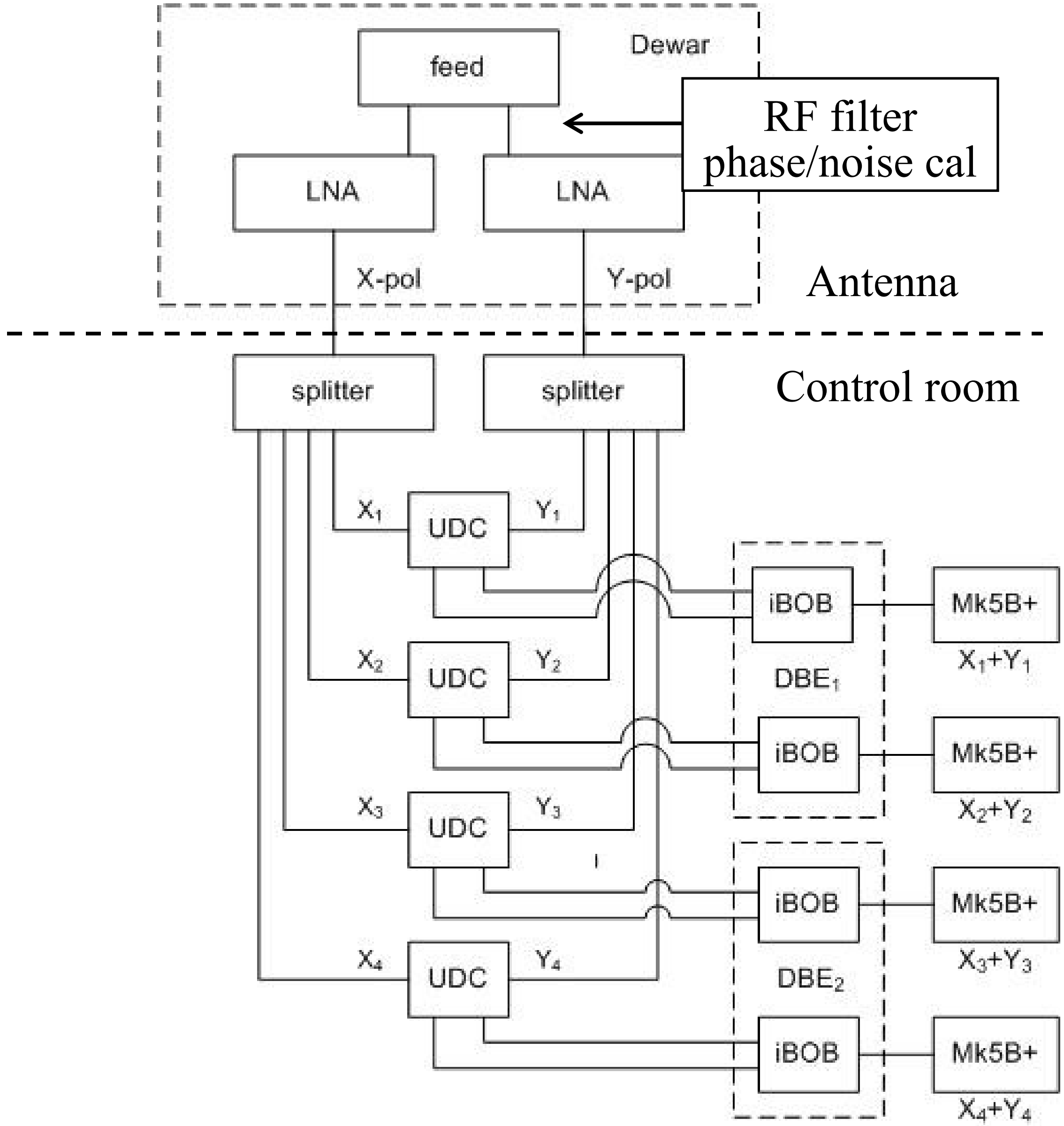
- Observe as many sources as possible per hour.
- Antenna diameter 12 m or greater
- Antenna slew rates
  - if only one antenna on site, higher than 10 /sec in az and 3 /sec in el
  - if possibly two antennas on site, ~5 /sec in az and 1.5 /sec in el
- Initially the frequency range should be 2.2 GHz to ~14 GHz.

Proof-of-Concept Development

- Develop the instrumentation to implement the broadband delay system as recommended by the V2C in the IVS WG3 Report
- Mount the equipment on two existing antennas
  - Westford 18m antenna, Massachusetts
  - MV-3 5m antenna, Washington, D.C.
- Make observations to demonstrate that broadband delay can be effectively used

Observing Frequency Bands





Feed and LNAs cooled to ~20K

Both senses of linear polarization used

Odd channels from each pol'n for one band output to each Mk5B+.

2 gigabits/sec recorded on each Mk5B+.

Total data rate: 8 gbps

MV-3 5M Antenna @ GGAO

Cryo LNAs & Feed
in Dewar

8 gigabit/sec LOs and back end

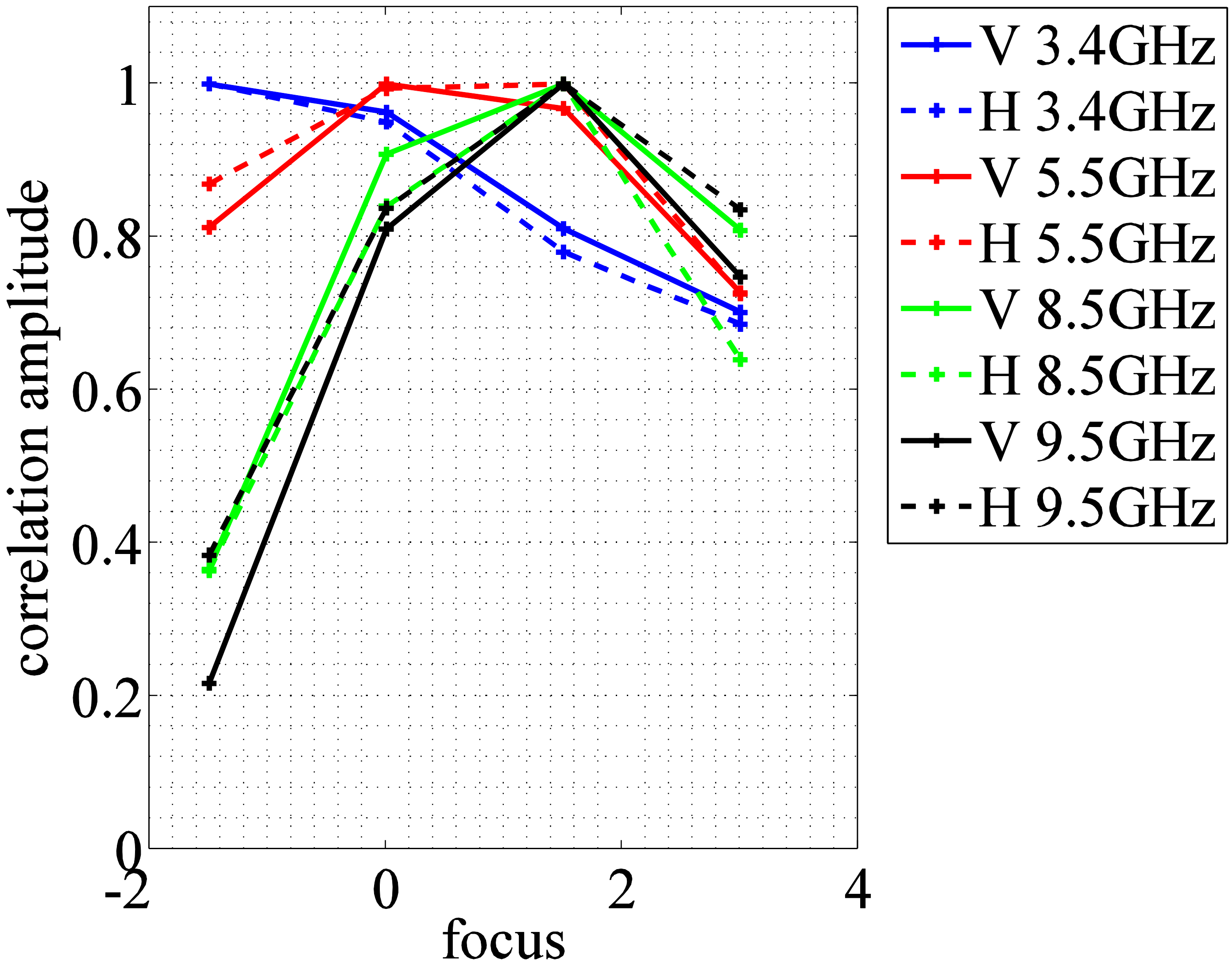
Proof of Concept System

- New equipment
  - Up Down Converter
  - New phase cal generator
  - Digital back end (DBE1 based on iBOB)
  - Mark5B+

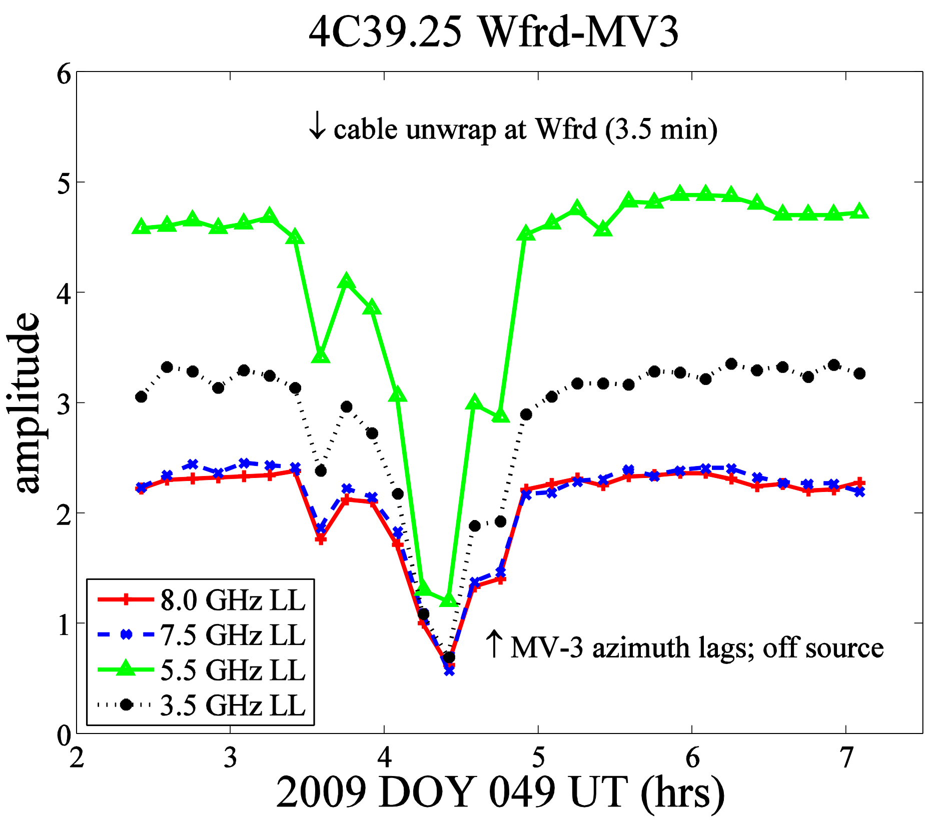
Recent Results

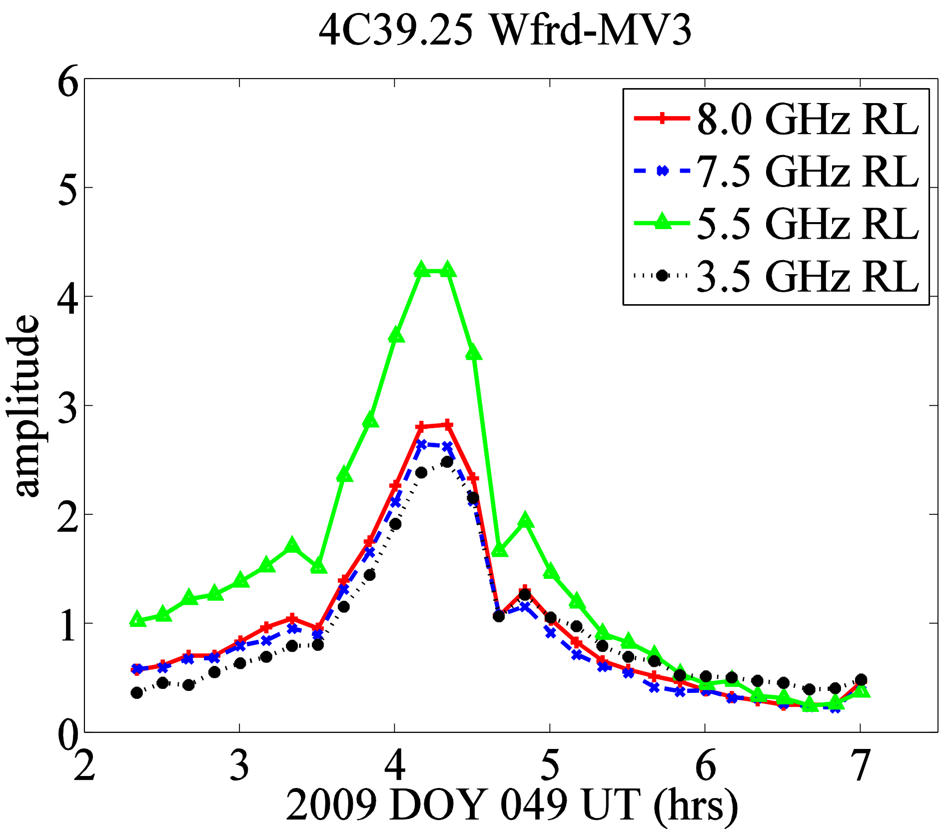
- Westford focus setting measurement
- Test sessions
  - Six hours with four bands identical frequencies
  - Five hours with bands contiguous -
  - Five hours on 4C39.25 polarization test

Westford focus measurement



Polarization test





Proof of Concept System

- Problems/challenges encountered
  - RFI from TV at 500 MHz saturated LNAs
    - High-pass filter: > 3.1 GHz (cooled)
    - Protection diodes on LNA leads
  - Controlling four signal chains at two sites
    - Scripts developed for setting frequencies, levels
  - Phase cal processing in correlator
    - 5 MHz spacing and 32 MHz channel bandwidth
    - "Only software"; fixed

Proof of Concept System Status

	Current	Next
Feed	Lindgren	Eleven?
RF filter	>3.1 GHz	$\geq$ 2.2 GHz
Phase cal	S/X pcal	“digital” pcal
DBE	DBE1(iBOB)	DBE2(ROACH)
Recorder	Mk5B+	Mk5C
Correlator	Mk4 (hardware)	Software (DiFX)

VLBI2010 Broadband System

On the antenna – cooled to ~20K

Feed

RF filters

Phase cal and noise diode injection

Low noise amplifiers

Send RF signals to the control room by optical fiber

In control room

Splitters to 4 bands (each polarization)

Flexible local oscillators

Digital back ends

Recorders or network connection

VLBI2010 Broadband System Characteristics

On the antenna – cooled to ~20K

Feed: 2 to 18 GHz

RF filters: >3.1 GHz

(falls off slowly above ~6 GHz)

Low noise amplifiers: 1 GHz to >12 GHz

In control room:

Flexible local oscillator (UpDown Converters):

1 to 13 GHz using 512 MHz Nyquist Zone filters

30 to 60 dB gain

Digital back end:

selects the eight odd 32 MHz channels from two 512 MHz inputs (V and H pol'n from one band)

Proof of Concept Demonstration

- Westford (Massachusetts):
  - 18m prime focus antenna
  - S/X receiver must be removed to install Dewar
- MV-3 (near Washington D.C.)
  - 5m Cassegrain antenna
  - Subreflector not matched to primary surface
- Signal chains are identical at both antennas
- All operations have been conducted from Haystack (except MV-3 antenna pointing)

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Recent Results

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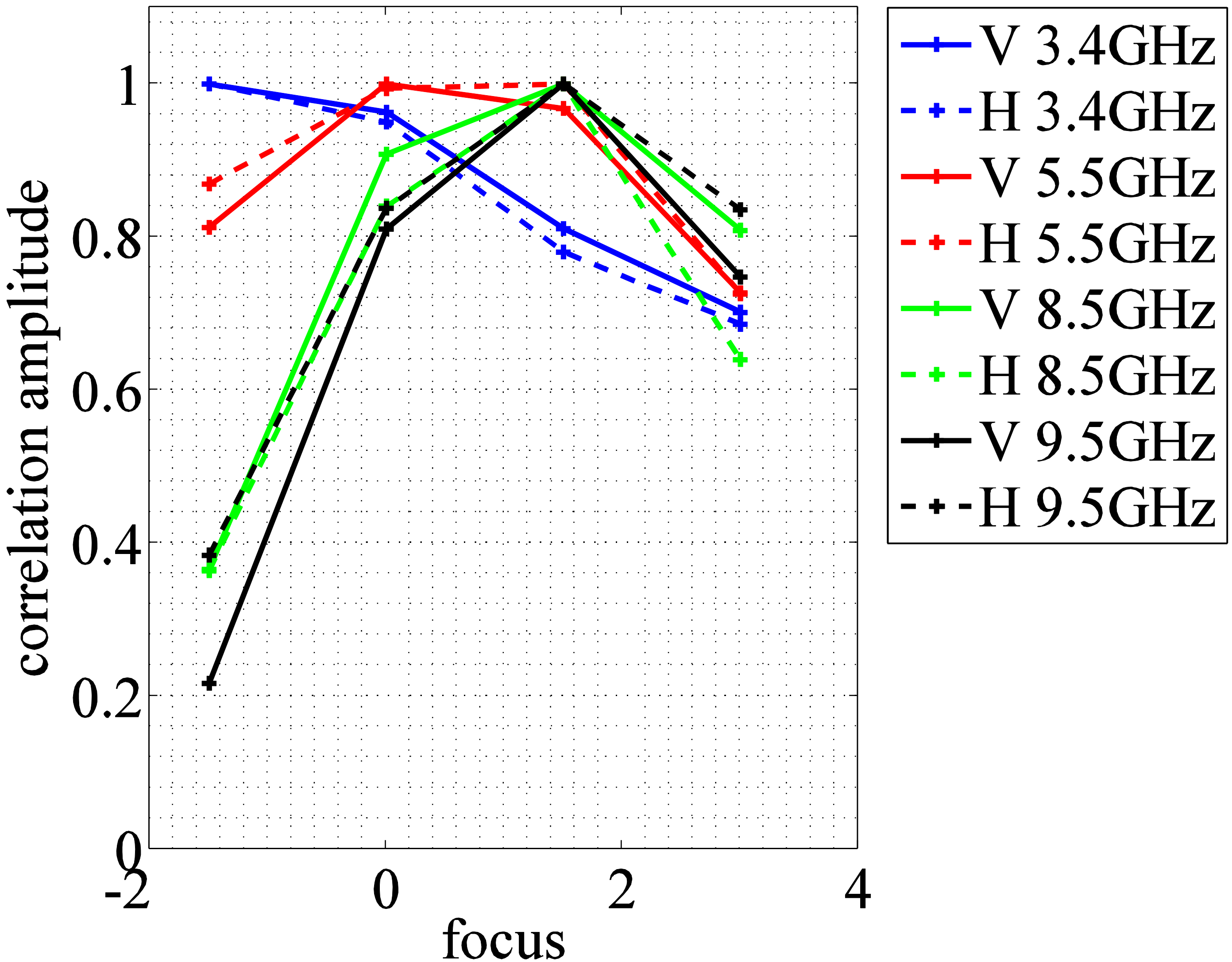
Westford focus measurement



Polarization session

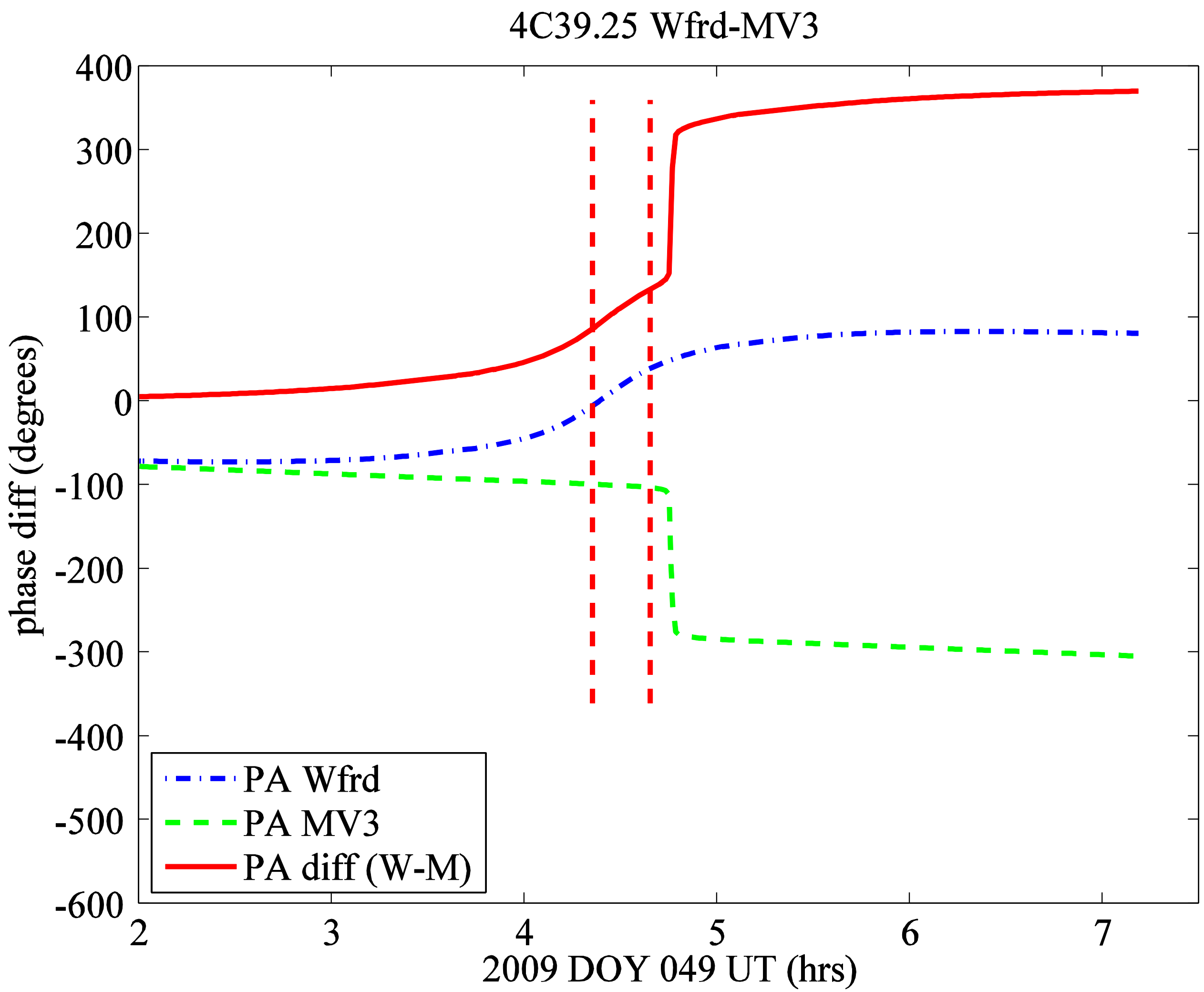
- Frequency coverage
  - 512 MHz bands
  - 3.5 GHz, 5.5 GHz, 7.5 GHz, and 8.0 GHz
- Source 4C39.25
  - Passes south of Westford and north of MV-3
  - Differential parallactic angle: +6 to +279
- Signal chains identical at both antennas
- All operations conducted from Haystack (except MV-3 antenna pointing)

Results

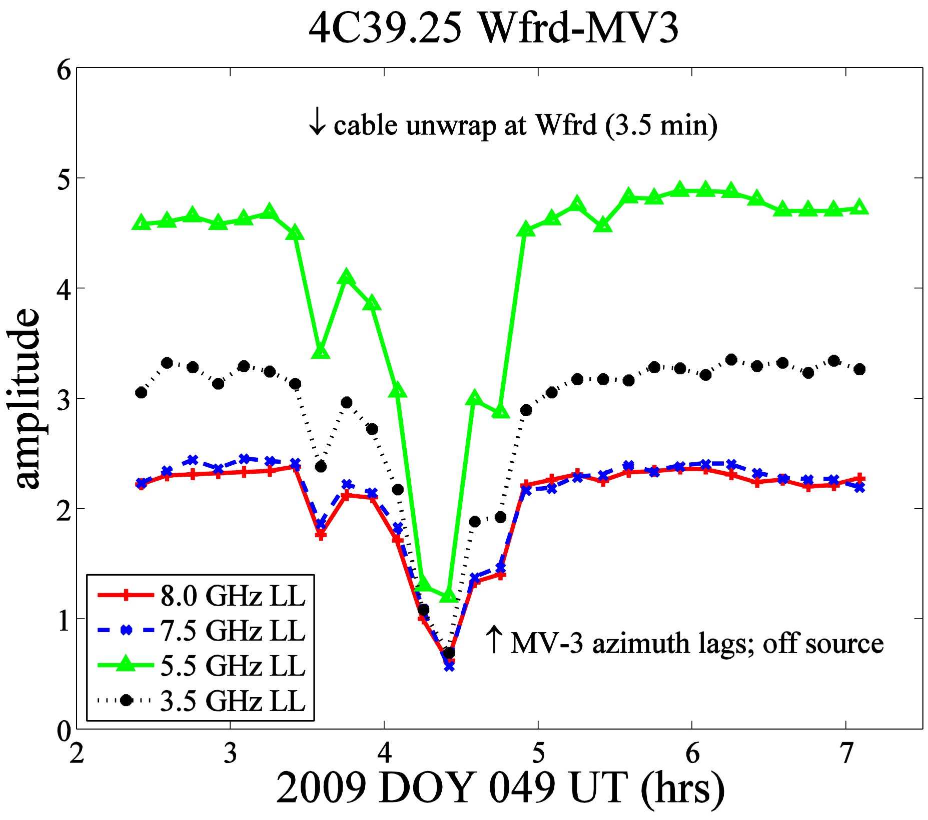
- Expected SNR ~250
  - BW = 256 MHz
  - Integration time = 570s
  - Correlated flux density = 10Jy
  - SEFDs = 3000Jy/100,000JY
  - Observed SNR (max)

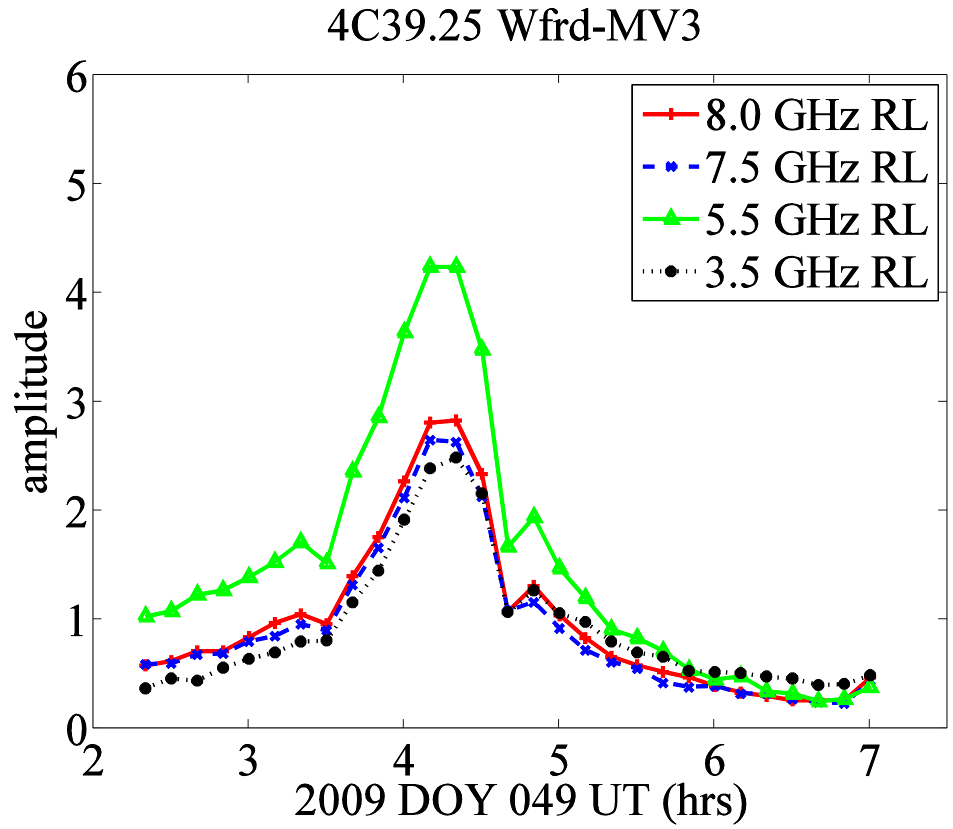
2009-040 freq (GHz)	3.5	5.5	7.5	8.0
	140	200	120	120

Parallactic Angle Differences



Polarization test





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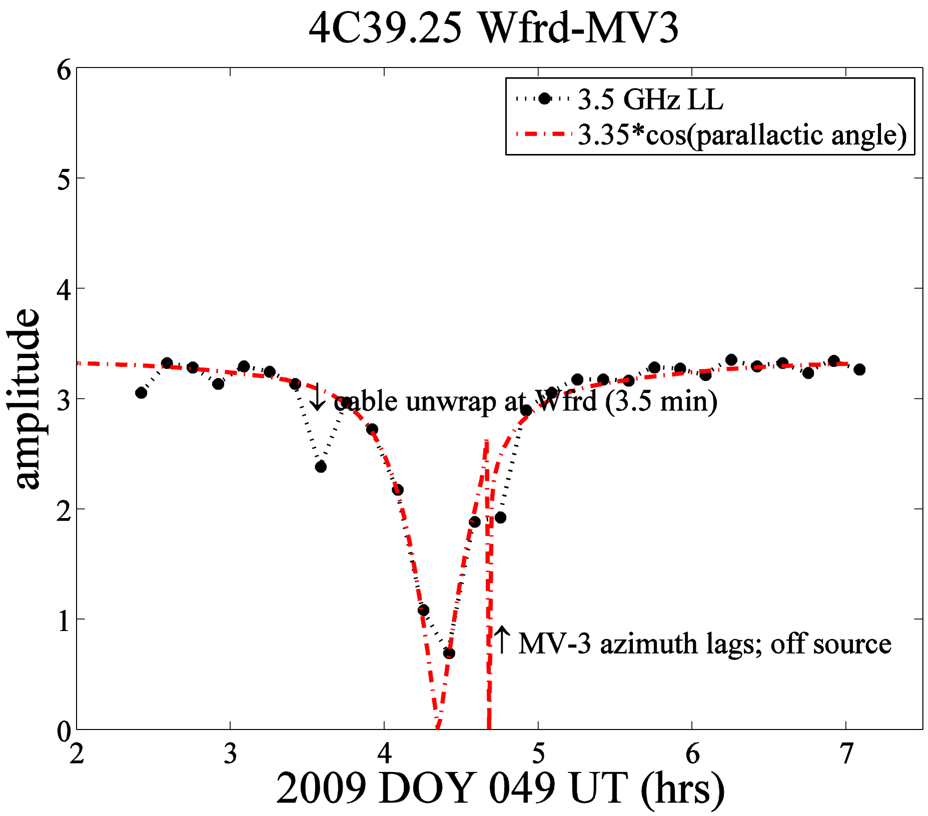
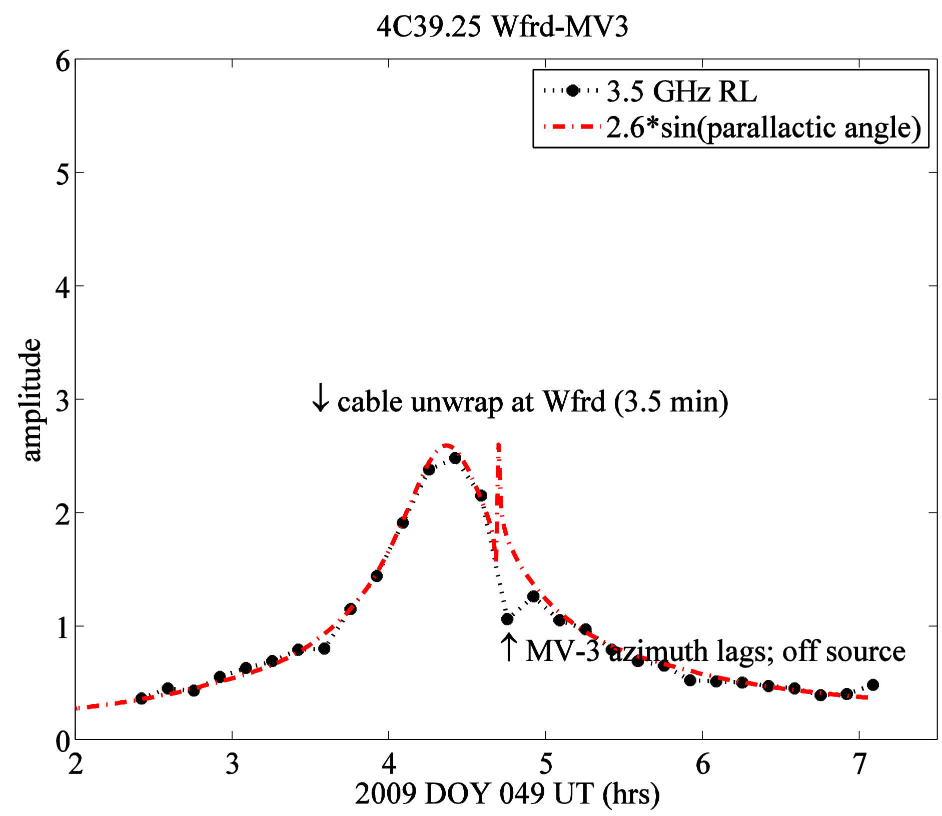
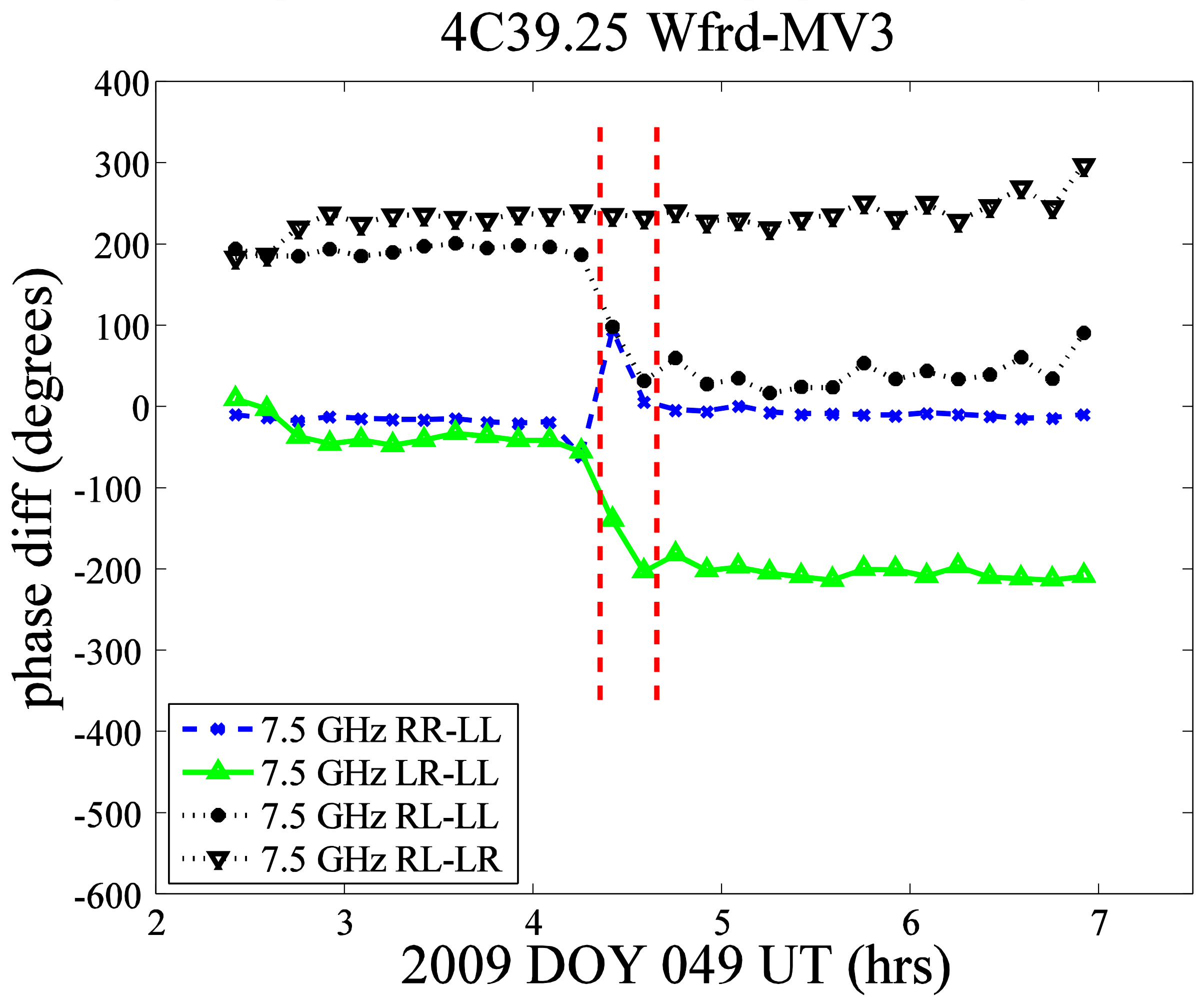


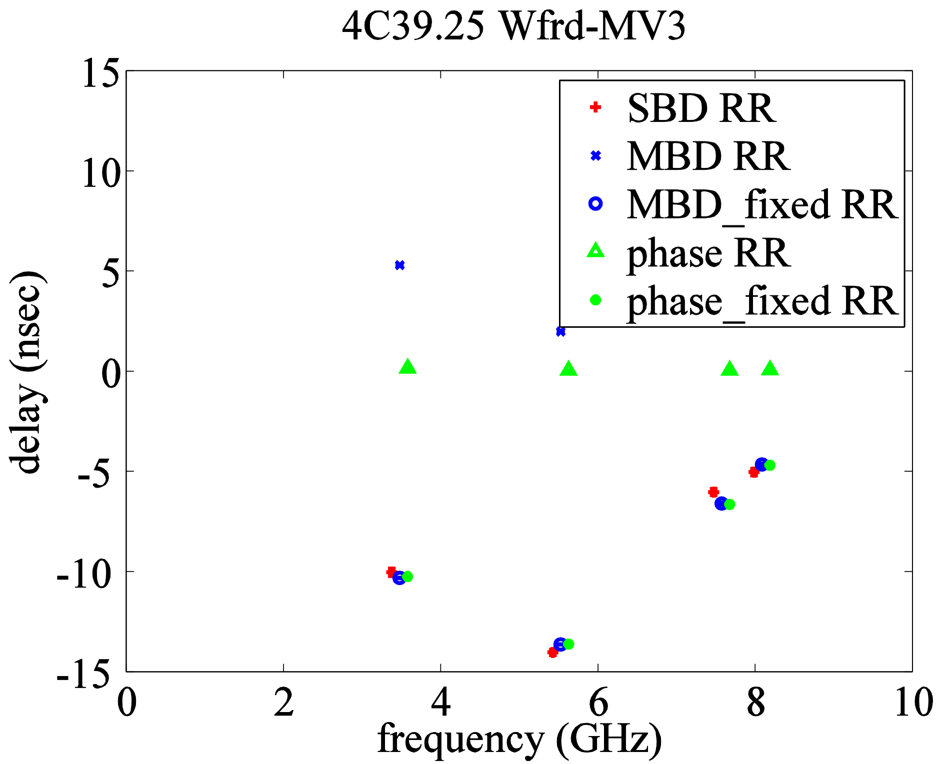


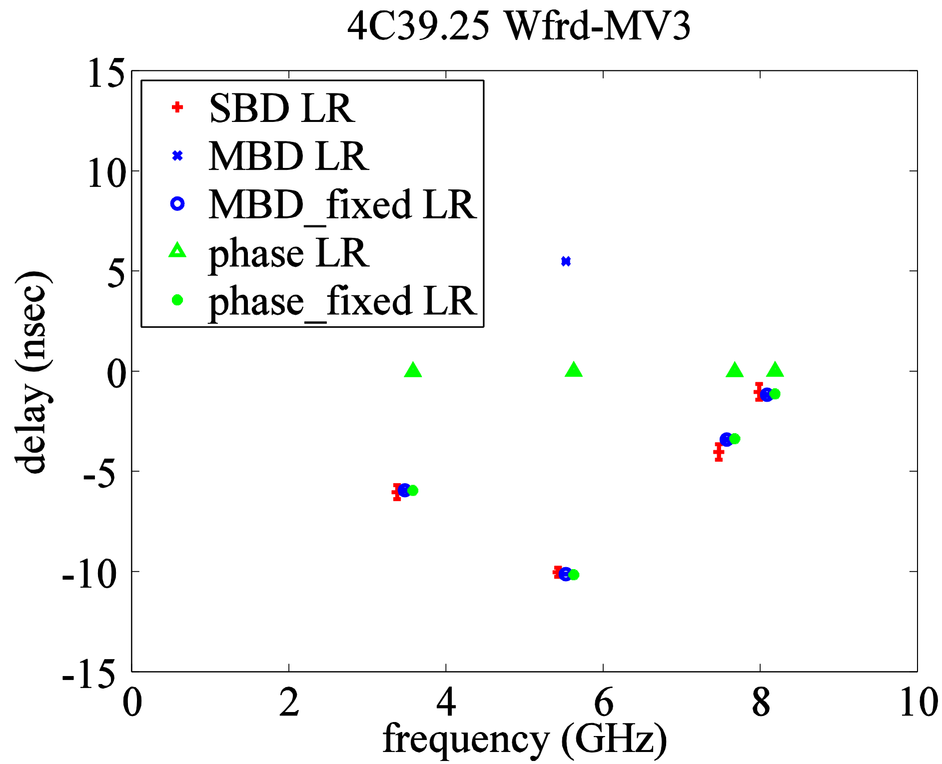
Polarization Phase Differences (no phase cal applied)



Phase diff plot; table of RMS phase diff RR-LL etc

Polarization test
(no phase cal applied)





Polarization test
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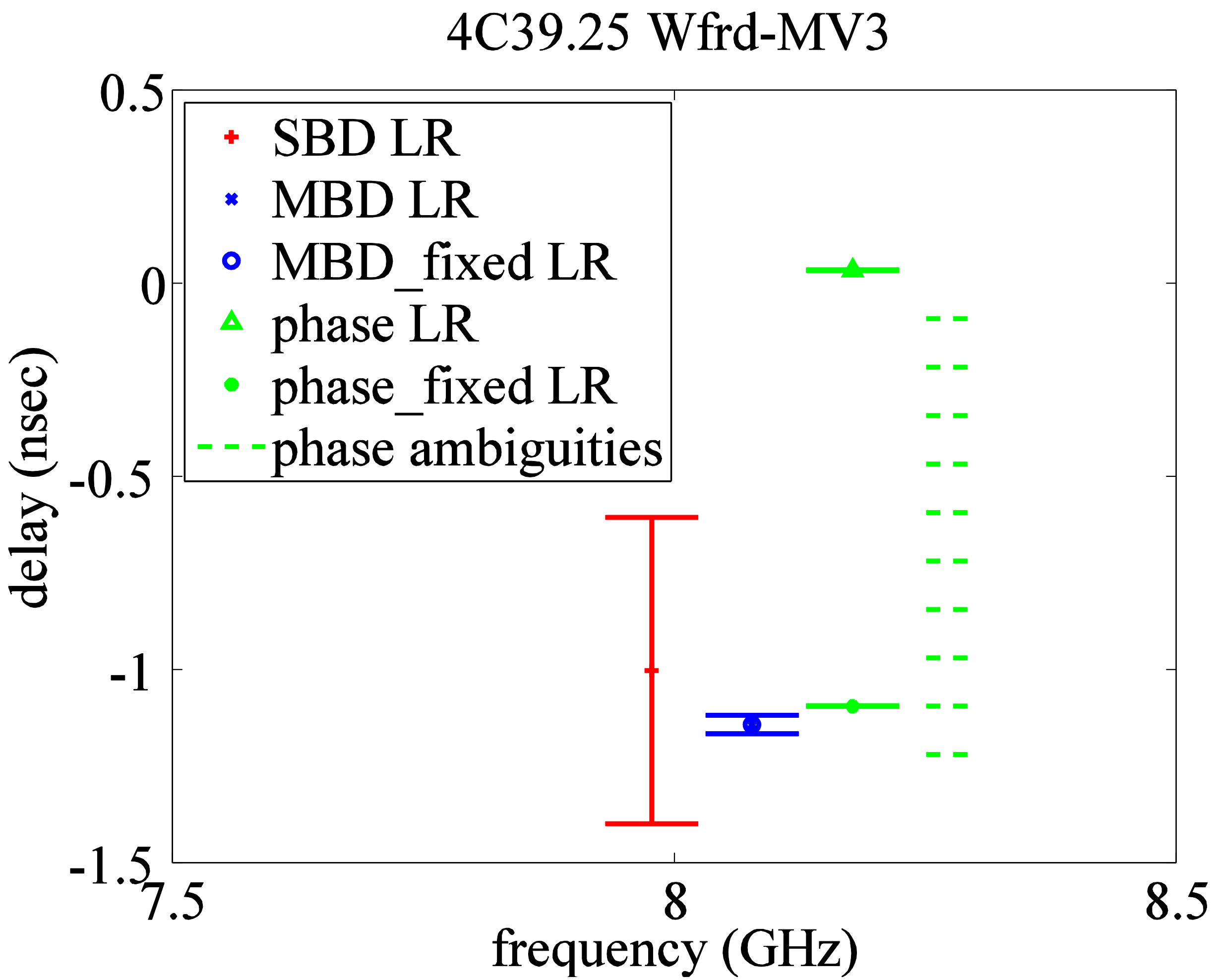

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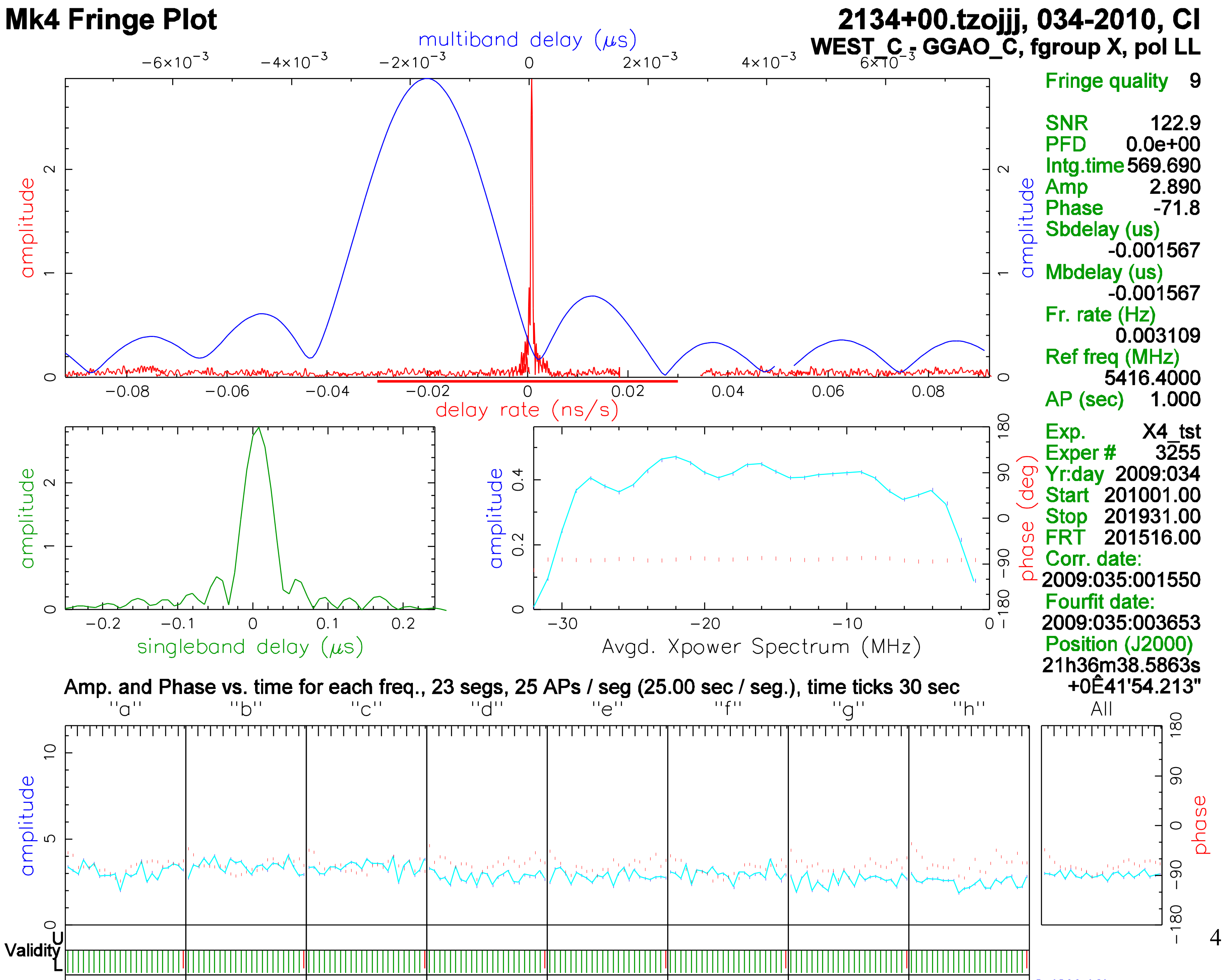
Benefits of Ku-Ka Band Reception

- Advantages
  - Sources more compact
  - Possibility of observing as a co-pointing WVR

Ku to Ka Band Reception

- Disadvantages
  - Antenna tolerances more exacting
    - Surface accuracy
    - Pointing
  - Antenna sensitivity lower
    - Tsys higher
    - Atmosphere contribution higher
  - Fewer sources with same correlated flux density on a given baseline


Mk4 Fringe Plot
2134+00.tzojjj, 034-2010, CI
WEST_C - GGAO_C, fgroup X, pol LL
multiband delay (µs)
delay rate (ns/s)
amplitude
Fringe quality 9
SNR 122.9
PFD 0.0e+00
Intg.time 569.690
Amp 2.890
Phase -71.8
Sbdelay (us) -0.001567
Mbdelay (us) -0.001567
Fr. rate (Hz) 0.003109
Ref freq (MHz) 5416.4000
AP (sec) 1.000
Exp. X4_tst
Exper # 3255
Yr:day 2009:034
Start 201001.00
Stop 201931.00
FRT 201516.00
Corr. date: 2009:035:001550
Fourfit date: 2009:035:003653
Position (J2000)
21h36m38.5863s
+0Ê41'54.213"
singleband delay (µs)
Avgd. Xpower Spectrum (MHz)
phase (deg)
Amp. and Phase vs. time for each freq., 23 segs, 25 APs / seg (25.00 sec / seg.), time ticks 30 sec
"a" "b" "c" "d" "e" "f" "g" "h" All
phase
Validity
U
L

VLBI2010 Broadband System

- Expected SNR for observed SEFDs (256 MHz,570s,10Jy,3KJy,100K)
  SNR = 0.8*sqrt(2*B*T)*Sc/sqrt(SEFD_Wf*SEFD_Gg)=250

2009-DOY040 freq	3.5	5.5	7.5	8.0
Observed SNR (max)	140	200	120	120

1. New equipment built especially for VLBI2010/uvlbi
   1. UDCs
   2. DBEs – modified for dual polarization recording
   3. Digital PCAL generator

Westford focus setting measurement

Test sessions

Dewar (1)

- Feed (for initial operations of VLBI2010)
  - 2.2 to ~14 GHz (possibly to 36 GHz eventually)
  - Phase center and beamwidth should be frequency independent (implies dual linear polarization now)
- Phase cal and noise cal
  - Signals split and injected to both polarizations following feed but before LNAs
  - Possibly external phase cal signal also for feed cal

Dewar (2)

- RF filter (if necessary)
  - TV at 500 MHz saturates unprotected LNAs
  - Cell phones about 2 GHz may be problem
  - Communication satellites above 10 GHz (but positions known)
  - Other ?
- Low Noise Amplifiers (one for each pol'n)
  - 2.2 to ~14 GHz

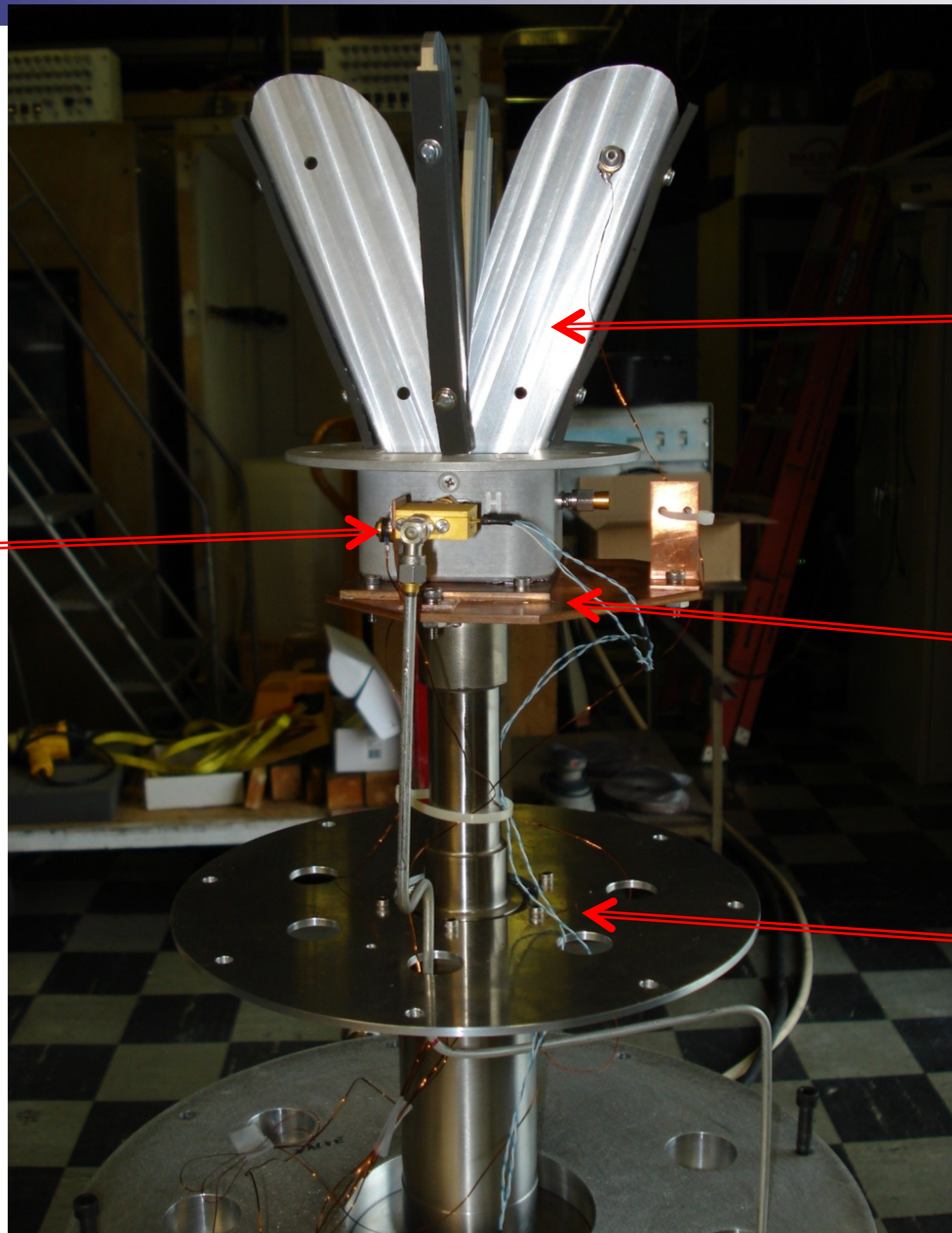
Backend (control room) - 1

- RF carried to control room via optical fiber
- Optical fiber receivers, amplifiers, 4-way splitters (both polarizations) in one chassis
- RF is down-converted directly to video
  - Alan Rogers' design also amplifies and NZ filters

Backend (control room) - 2

- Digital Back End
  - Analog-to-digital conversion
  - Poly phase filter and freq channel selection
    or
  - Baseband converters (DBBC)
- Data storage
  - Directly to disks
    or
  - Network to intermediate storage or correlator
- Real-time e-vlbi

LNA



Lindgren feed
(linear pol'n)

Cryo
Refrigerator
20K Station

77K Station

12 m Antenna