The ALMA Phasing Project

Design and Status

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On behalf of the ALMA Phasing Team

3rd International VLBI Technology Workshop
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Groningen /Dwingeloo

The ALMA Phasing Project

Goal: Phase-up the 64 ALMA dishes to form a single (VLBI) station

The ALMA Phasing Project (APP) is an international effort by several astronomical institutes:

Haystack observatory (PI & project management), NRAO, MPIfR, ASIAA, NAOJ, University of Conception, Onsala

Well-supported by ALMA

Project duration: 2011 (Kickoff) – 2015 (Commissioning)

Effort: >25 man years

Cost: > $4M

Funding: NSF MRI (Haystack, NRAO), separate funding for other partners

MIT HAYSTACK OBSERVATORY
NRAO
Max-Planck-Institut für Radioastronomie
University of Concepcion Chile
NAOJ
ASIAA
ONSALA RYMDOBSERVATORIUM CHALMERS TEKNISKA HÖGSKOLA

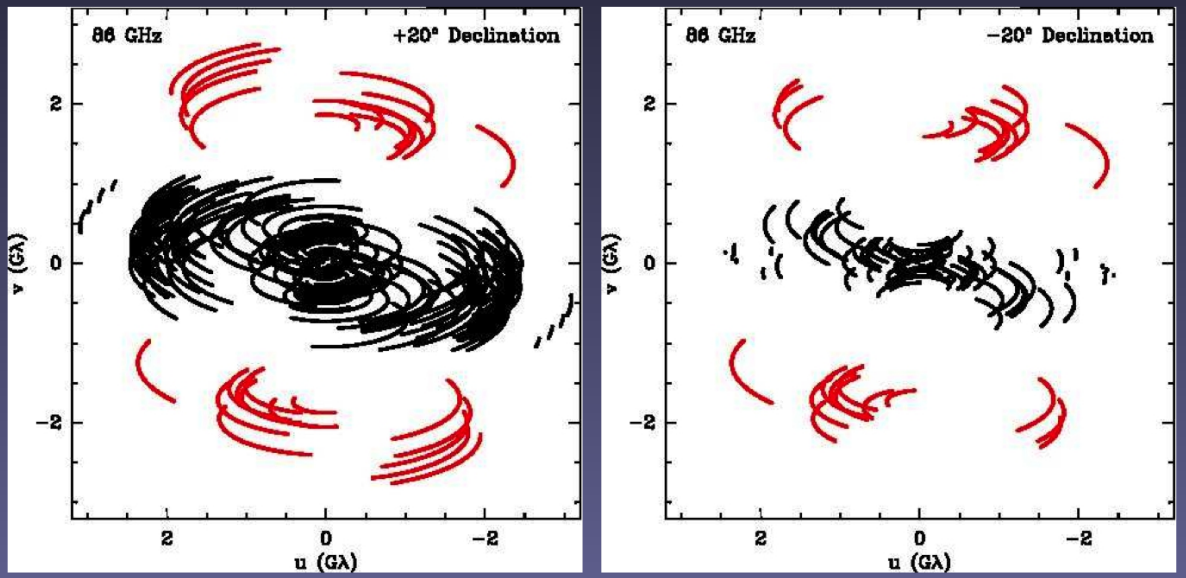
The ALMA Phasing Project

VLBI: Large increase in sensitivity and resolution

- Will reach a few tens of μarcsec!!
- Baseline sensitivity increase by factor >3

	PdB	CARMA	SMTO	APEX	ALMA
P. Veleta	0.063	0.076	0.201	0.169	0.024
PdB	-	0.058	0.153	0.129	0.019
CARMA	-	-	0.185	0.155	0.022
SMTO	-	-	-	0.413	0.059
APEX	-	-	-	-	0.050

Baseline sensitivity (Jy) at 1mm for 10s integration time



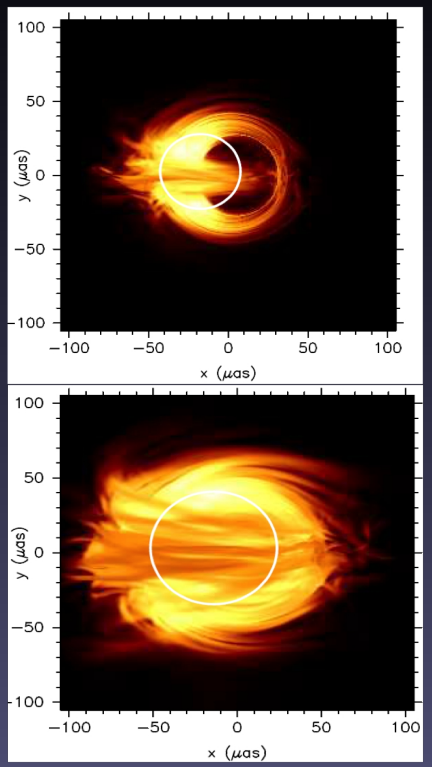
UV coverage of Global VLBI at 3mm
(ALMA in red)

See: Fish et al. (arXiv:1309.3519)

Broad Science Case

Phased-ALMA will enable new science

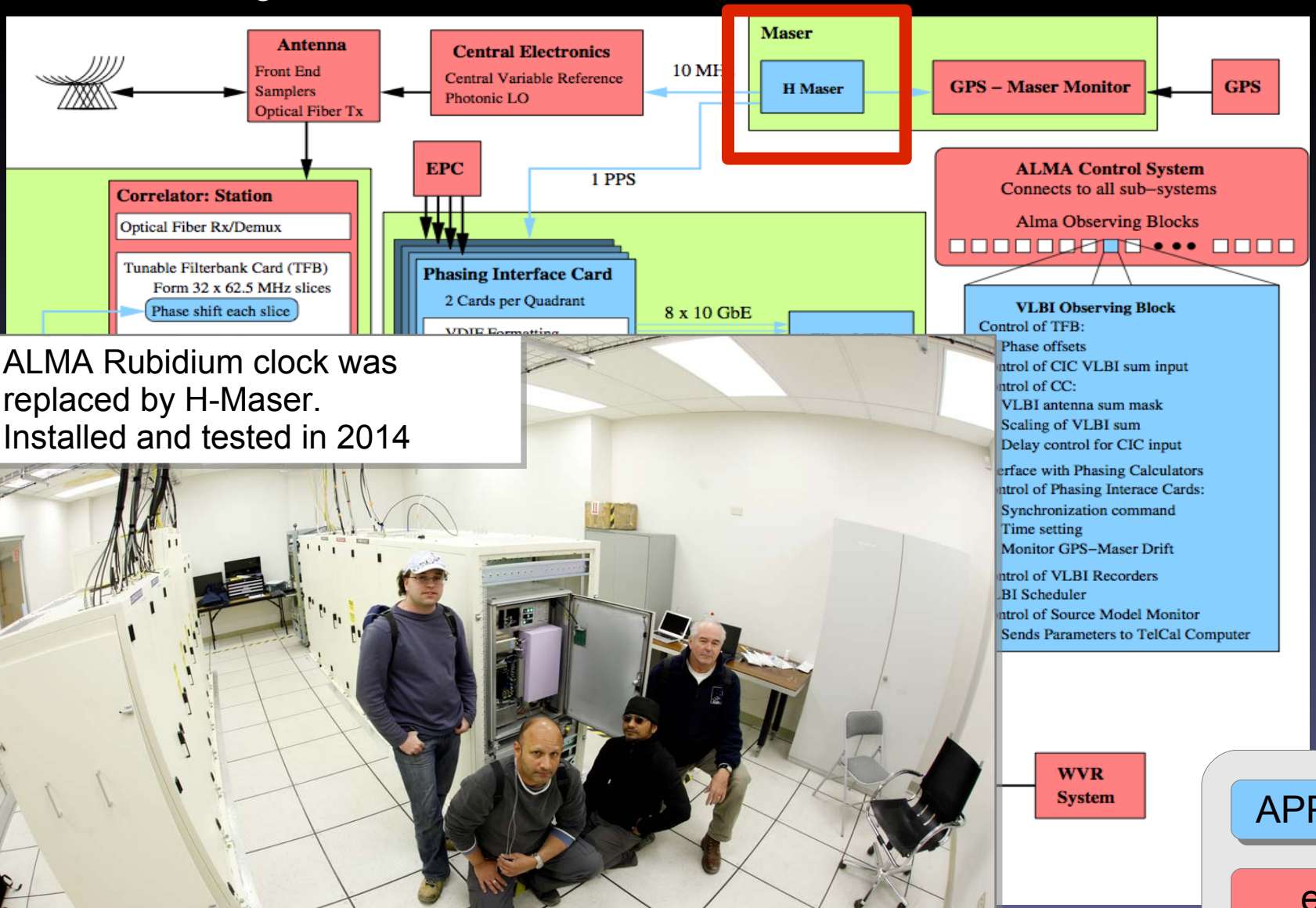
- Black hole studies / testing general relativity
- Accretion studies
- Jet formation
- Pulsar search close to galactic center
- ….and many more interesting things



See: Fish et al. (arXiv:1309.3519)

APP Design

ALMA blockdiagram



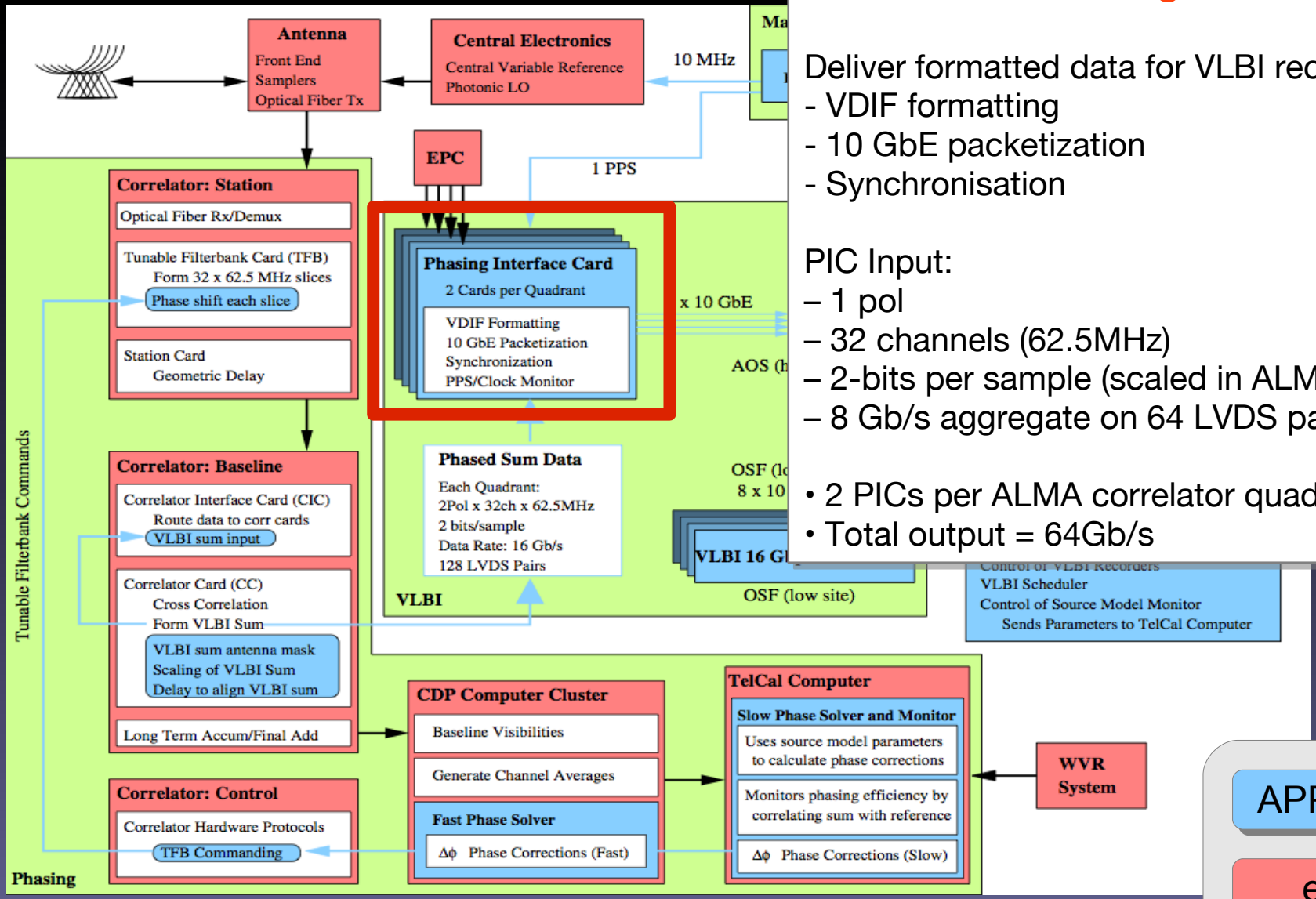
ALMA Rubidium clock was replaced by H-Maser.
Installed and tested in 2014

APP addition

existing

APP Design

ALMA blockdiagram



PIC = Phasing Interface Card

Deliver formatted data for VLBI recording
- VDIF formatting
- 10 GbE packetization
- Synchronisation

PIC Input:
– 1 pol
– 32 channels (62.5MHz)
– 2-bits per sample (scaled in ALMA correlator).
– 8 Gb/s aggregate on 64 LVDS pairs.

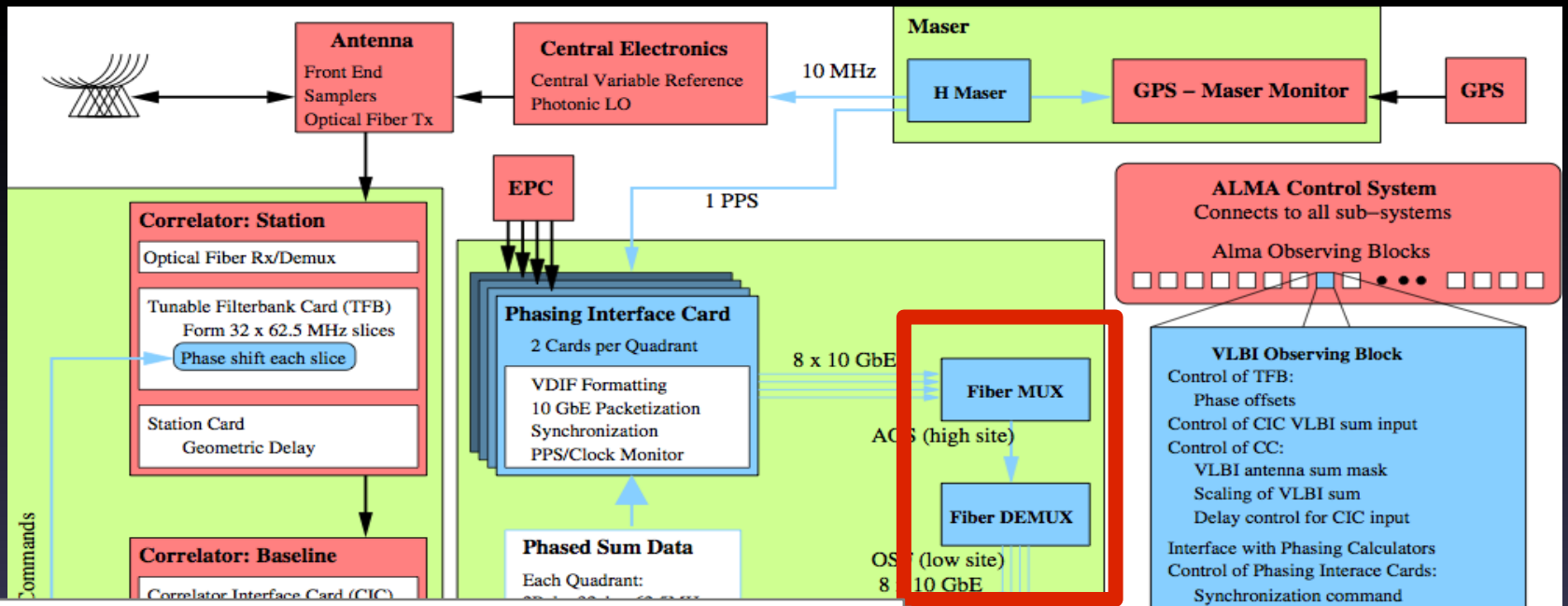
• 2 PICs per ALMA correlator quadrant (8 total)
• Total output = 64Gb/s

APP addition

existing

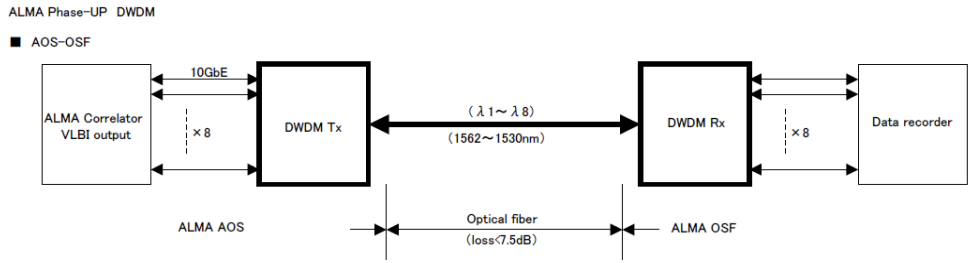
APP Design

ALMA blockdiagram



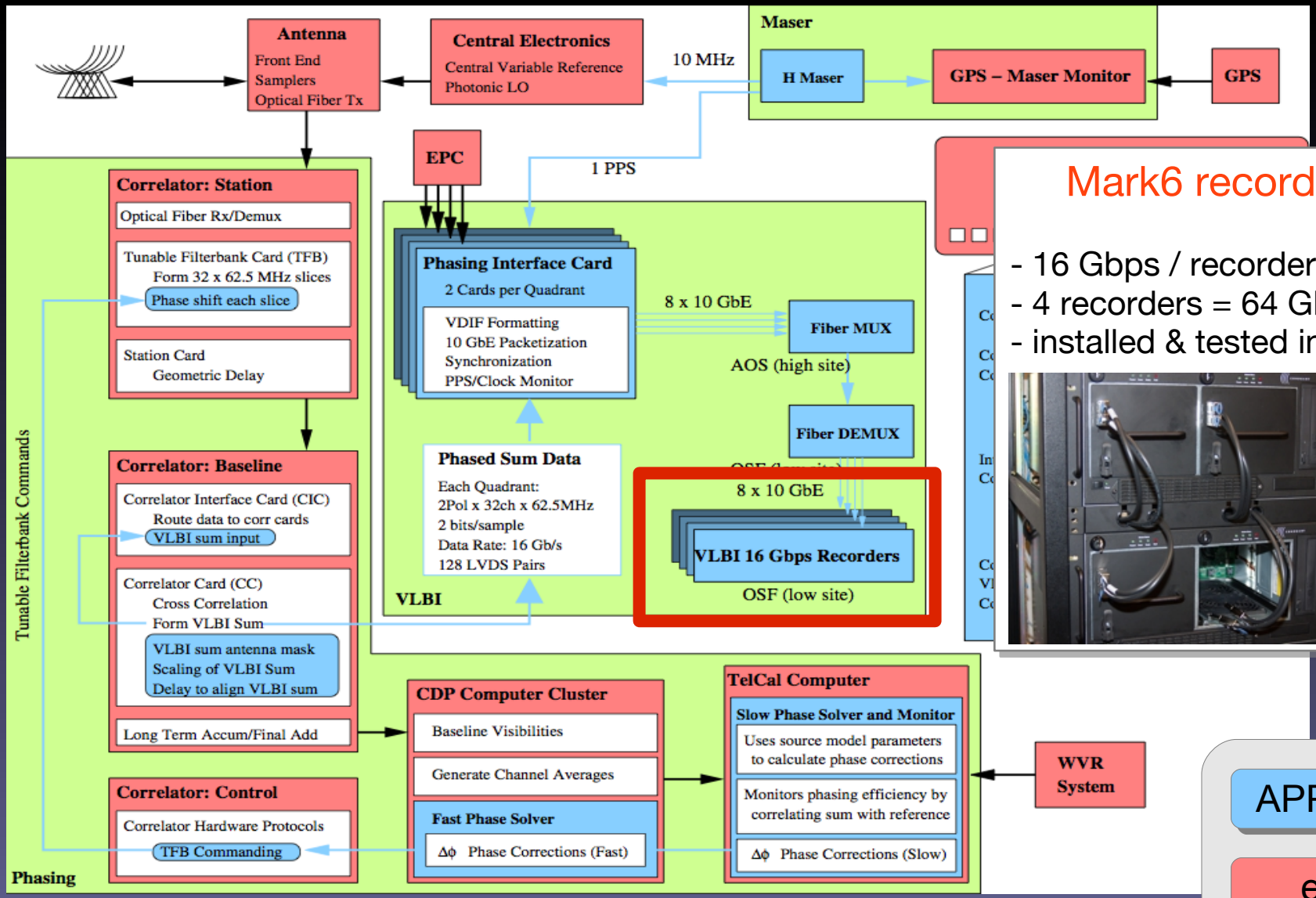
OFLS – Optical Fibre Line System

Data transport from
AOS : high altitude site (correlator)
to
OSF: low altitude site (recorders)
via optical fibre



APP Design

ALMA blockdiagram



Mark6 recorders

- 16 Gbps / recorder
- 4 recorders = 64 Gbps
- installed & tested in 2014

APP addition

existing

Phase Solver

For N antennas we need to calculate N-1 solutions (one ref. antenna) and we have N*(N-1)/2 baselines

=> Over-determined system. Can be solved for fairly easily (selfcal)

ALMA phasing strategy:

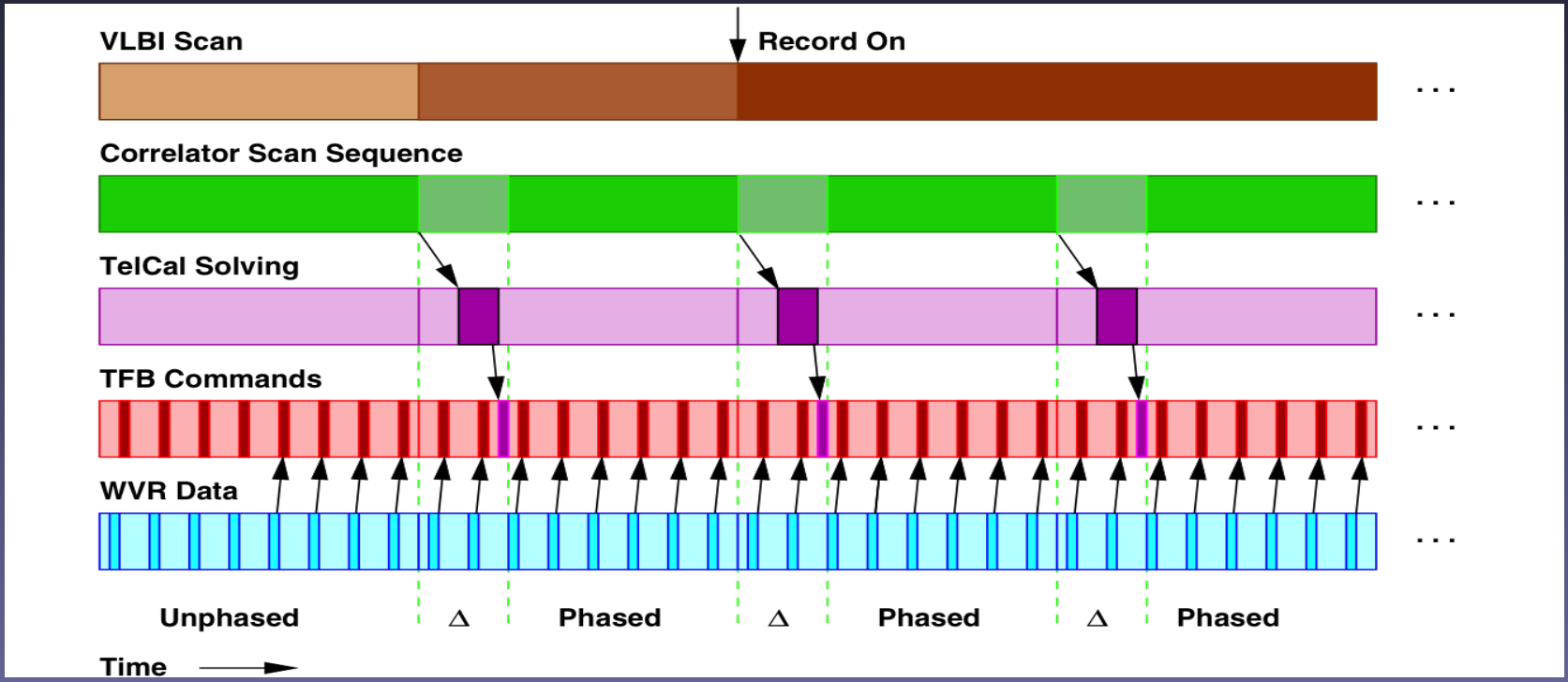
1) Phasing triggered by dedicated scan intent
2) Phase solutions calculated during the scan calibration stage (TELCAL)
3) Solutions fed back to the correlator and applied via the TFBs
4) Formation of antenna sum by correlator

Phasing is realized on two different timescales

- Fast Loop (~1 s)
- Slow Loop (scan boundaries, ~30s)

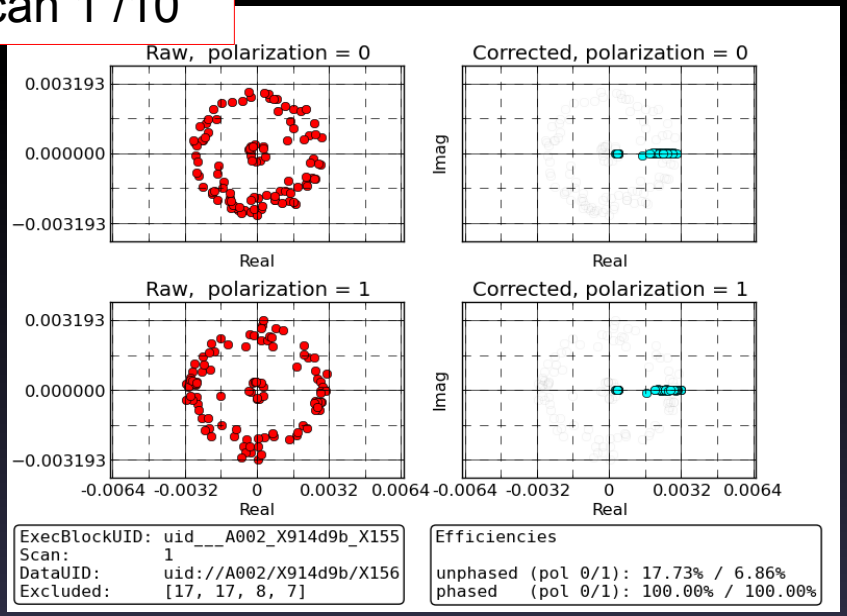
Phasing Loop Timing

- Fast Loop
  - Apply WVR phase corrections on a 1s timescale
- Slow Loop
  - Data available to TELCAL only on (ALMA) scan boundaries
  - Solutions applied during the following scan



Phasing Results

Scan 1 /10

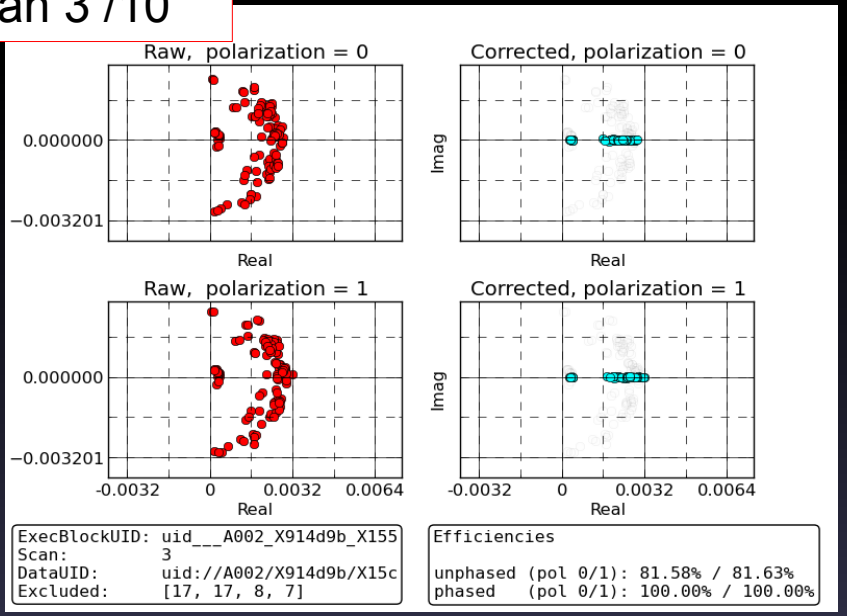



```
ExecBlockUID: uid___A002_X914d9b_X155
Scan:         1
DataUID:      uid://A002/X914d9b/X156
Excluded:     [17, 17, 8, 7]
```

```
Efficiencies

unphased (pol 0/1): 17.73% / 6.86%
phased   (pol 0/1): 100.00% / 100.00%
```

Scan 3 /10




```
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Scan:         3
DataUID:      uid://A002/X914d9b/X15c
Excluded:     [17, 17, 8, 7]
```
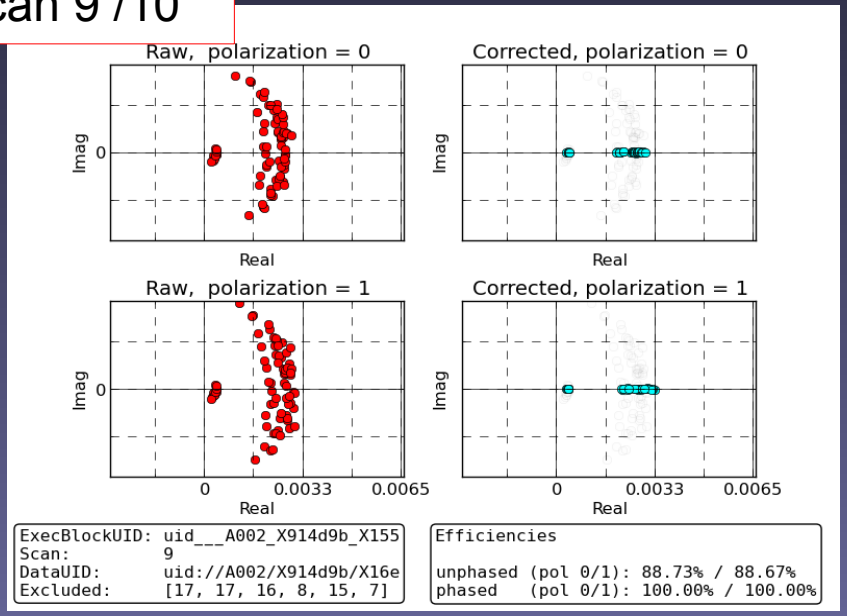

```
Efficiencies

unphased (pol 0/1): 81.58% / 81.63%
phased   (pol 0/1): 100.00% / 100.00%
```

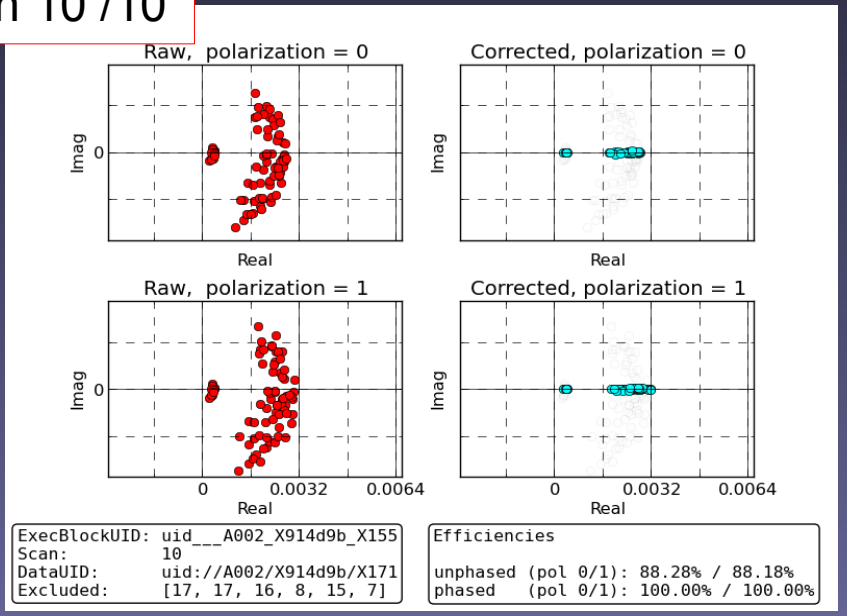
Scan 9 /10




```
ExecBlockUID: uid___A002_X914d9b_X155
Scan:         9
DataUID:      uid://A002/X914d9b/X16e
Excluded:     [17, 17, 16, 8, 15, 7]
```

```
Efficiencies

unphased (pol 0/1): 88.73% / 88.67%
phased   (pol 0/1): 100.00% / 100.00%
```

Scan 10 /10




```
ExecBlockUID: uid___A002_X914d9b_X155
Scan:         10
DataUID:      uid://A002/X914d9b/X171
Excluded:     [17, 17, 16, 8, 15, 7]
```

```
Efficiencies

unphased (pol 0/1): 88.28% / 88.18%
phased   (pol 0/1): 100.00% / 100.00%
```

Sampling / Channelization

ALMA LO and sampling system does not apply the 2^n scheme like VLBI

=> bandwidth 2.000 GHz vs 2.048 GHz

=> spectral bands of 62.5 MHz vs. 64 MHz

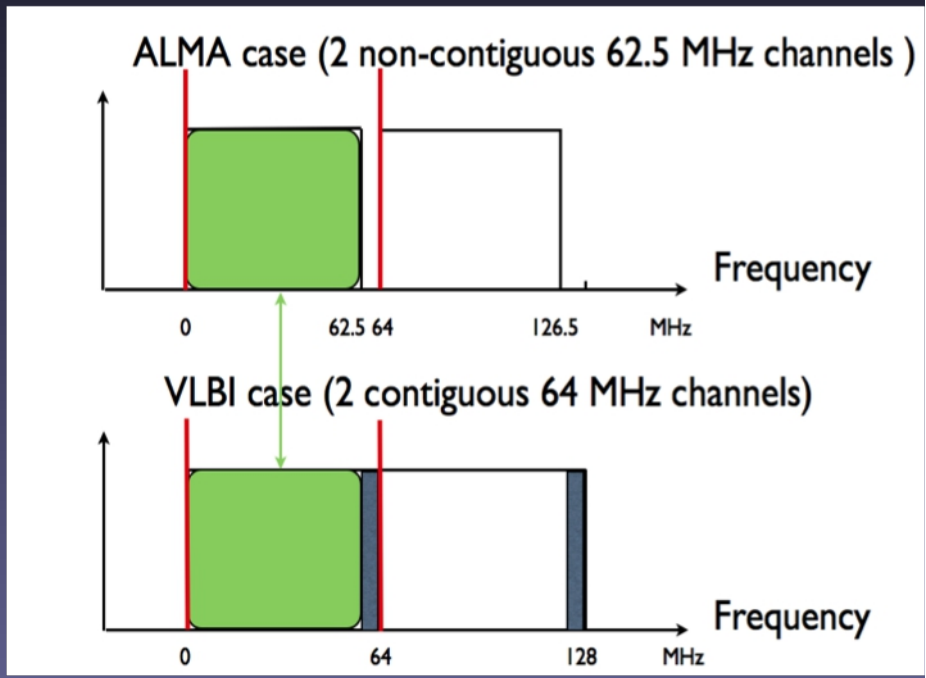
=> Sampling rate of 125MHz vs. 128 MHz

Can be handled in different ways:

1) Resample the ALMA data
   Too much effort

2) Use 125 MHz sampling for the VLBI stations
   DBBC can sample @125 MHz
   ..but RDBE/ R2DBE cannot

3) Use zoom-bands when correlating
   (small) loss of bandwidth



Polarization conversion

ALMA records X/Y polarization; VLBI stations typically use RCP/LCP

Strategy:

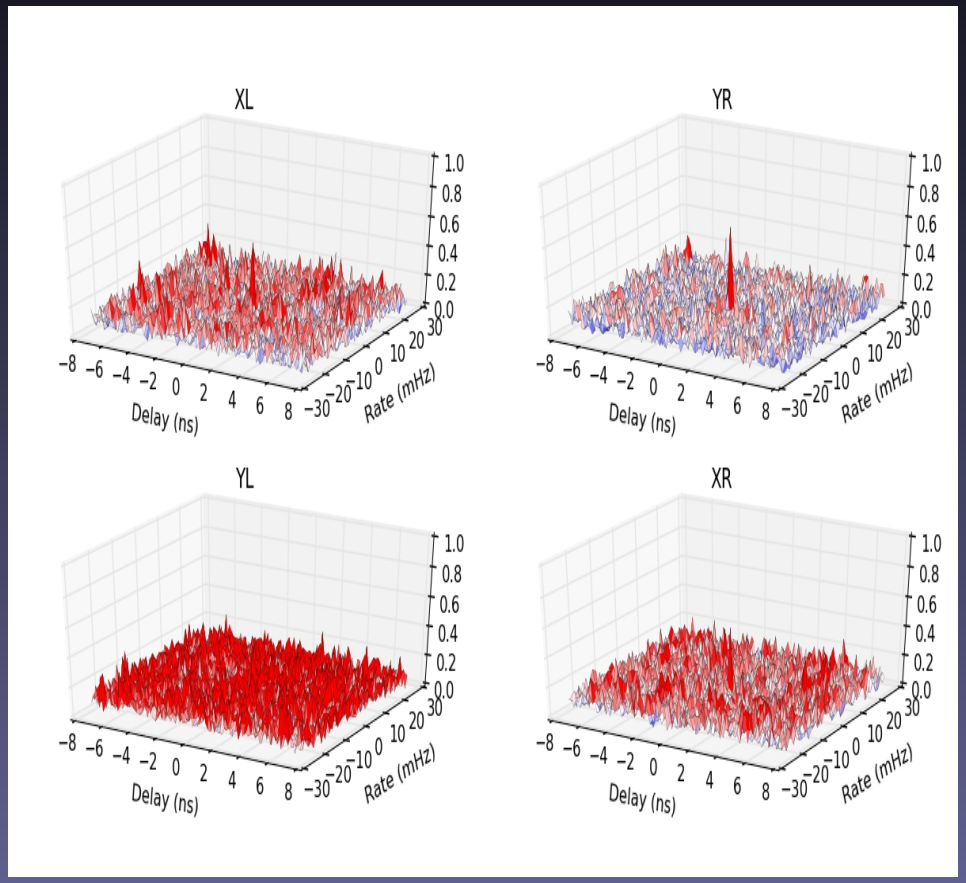
- Record X/Y phased-up streams at ALMA
- Record RCP/LCP streams at other stations
- Cross-correlate all polarization products: X/R, X/L, Y/R, Y/L, ...
- Convert to pure circular basis (RR,LL,RL,LR) after correlation

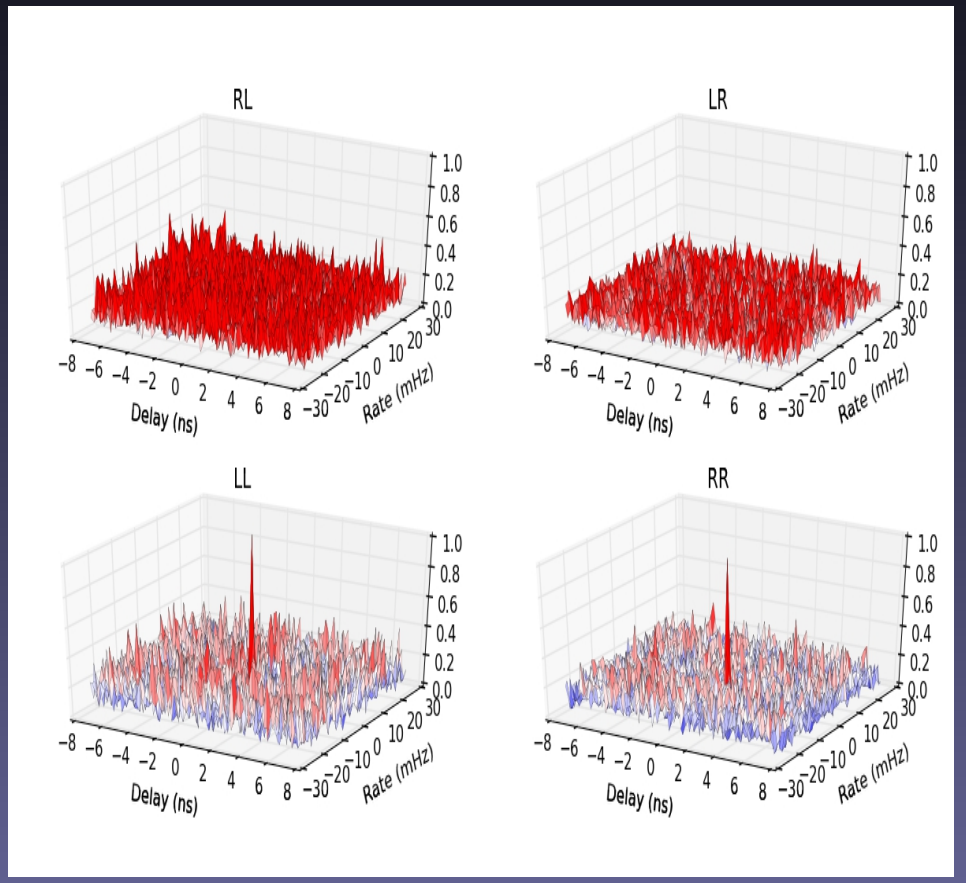
See Roy et al. (2013) APP polarization White Paper

Polarization conversion – cont.

First test @ 86 GHz between Onsala – Effelsberg

- Onsala recorded X/Y, Effelsberg recorded RCP/LCP
- Correlation with DiFX
- Run PolConvert software (written by I. Marti-Vidal) to convert to circular polarization

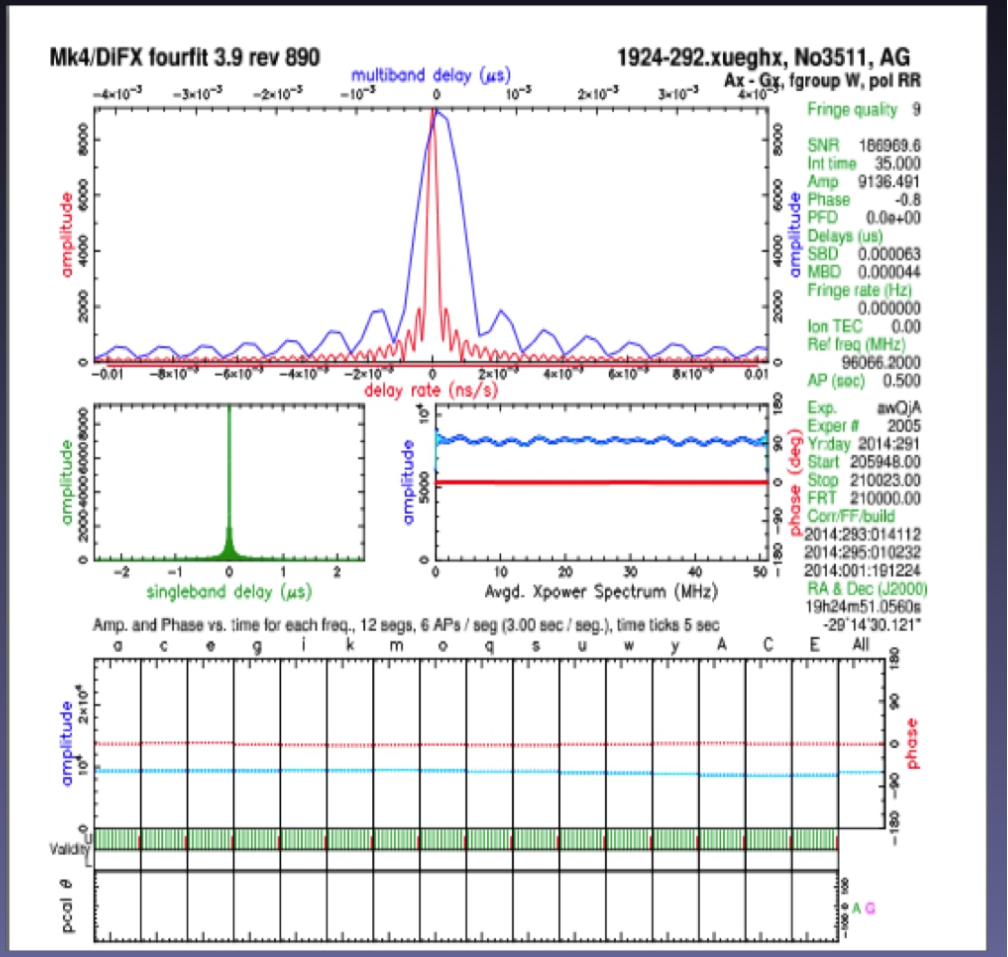




Current Status

Verification mission @ALMA in Oct 2014

- All components of the phasing system have been integrated and are operational!
  - Fast & slow loop corrections
  - Signal summation at correlator
  - OFLS & Mark6 recording

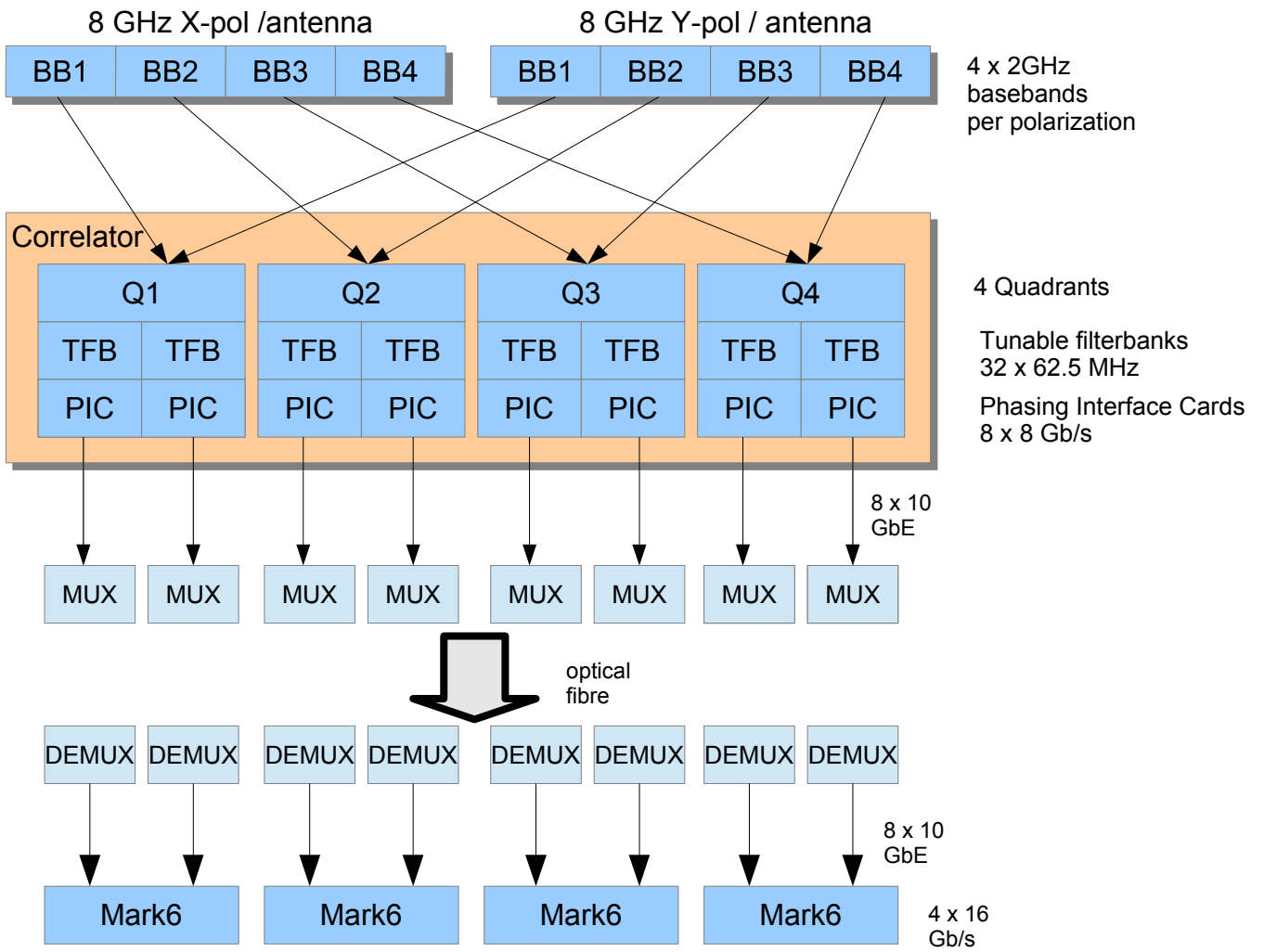


"zero-baseline" fringe plot. Correlated data from one antenna but processed by different quadrants of the ALMA correlator. 16 channels from

ALMA Phasing Project

Thank you!

APP Dataflow



The ALMA Phasing Team

Haystack: Shep Doeleman (PI), Mike Hecht (PM), Geoff Crew, Lynn Matthews, Vincent Fish,..

NRAO: Rich Lacasse, Matias Mora, Ray Escoffier, Joseph Greenberg, …

MPIfR: Walter Alef, Alan Roy, Helge Rottmann

NAOJ: Mereki Honma

ASIAA: Inoue Makoto, Nicolas Pradel

University of conception: Neill Nagar

Onsala: Ivan Marti-Vidal

Other people involved (far from complete)

Jonathan Weintroub, Robert Lucas, Dominique Broguire, Alain Baudry, Alejandro Saez, Rodrigo Amestica, Michael Lindqvist, Violette Impellizeri, Raphael Hiriart, and many others

NRAO

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ASIAA

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NSF