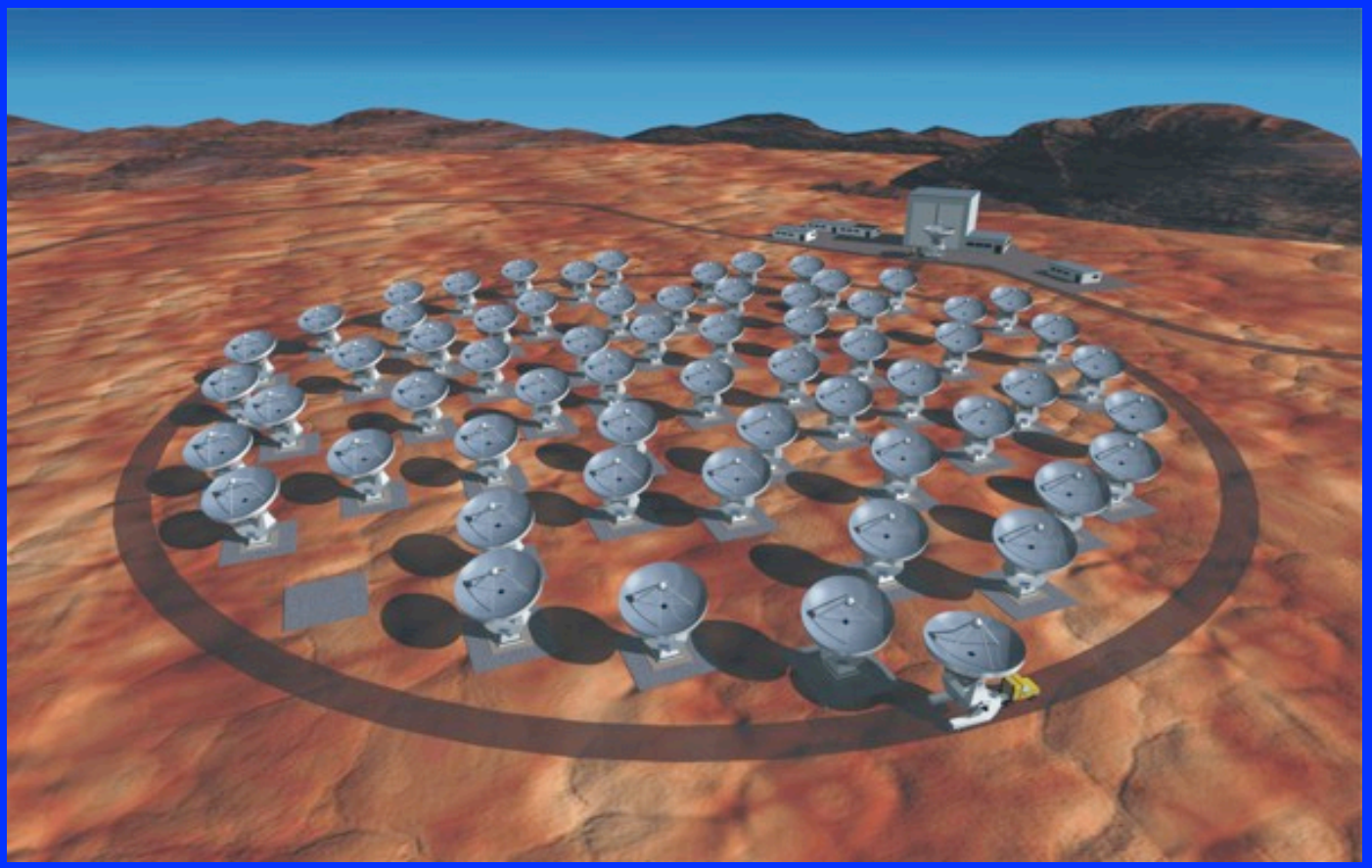
ALMA Beamforming Project



Phasing ALMA for Beamformed Science

- Creates a ~90m (sub)mm aperture.
- Becomes central element of (sub)mm VLBI Event Horizon Telescope.
- Increases sensitivity and N/S resolution for mm VLBI arrays.
- Provides powerful new (sub)mm pulsar/ magnetar search/timing capabilities.

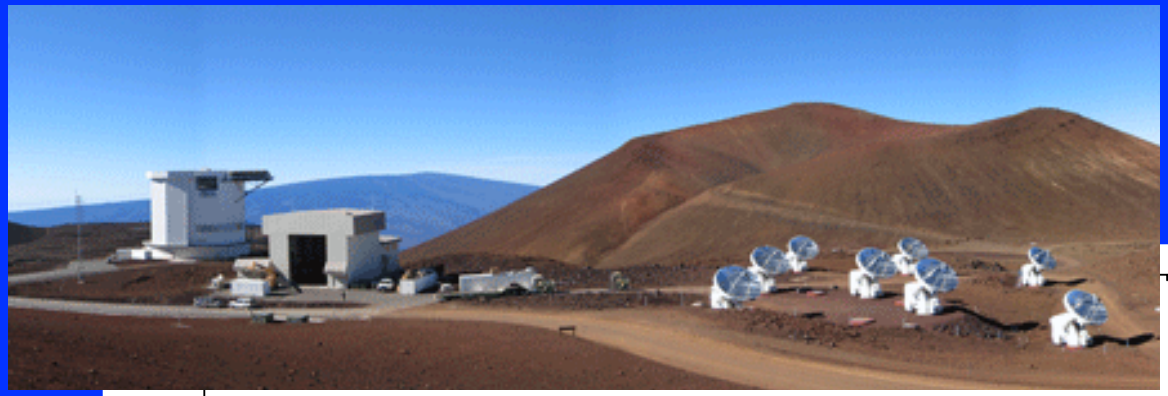
Broad Science Case

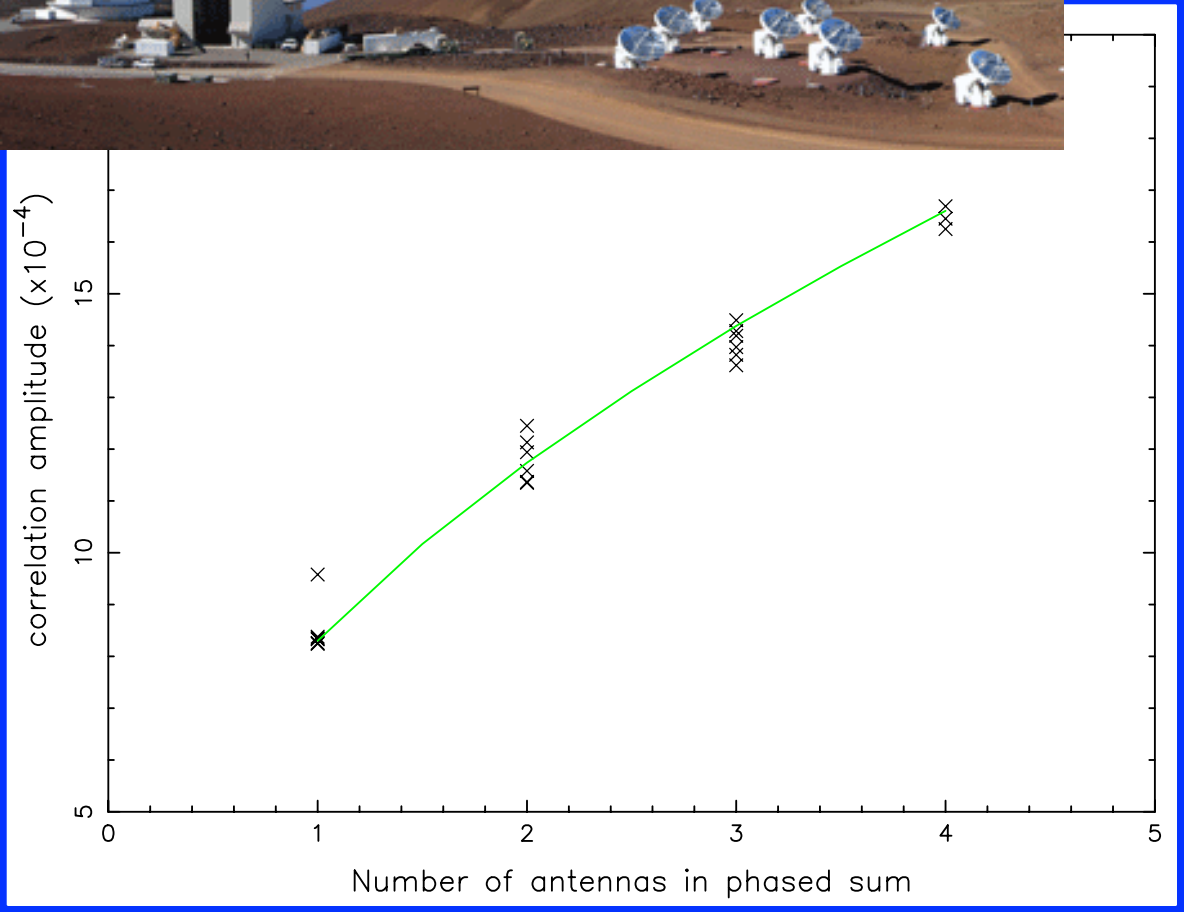
- Masers: SiO, HCN, methanol, water towards evolved, proto-stars, ISM.
- Spectral line absorption.
- AGN: evolution of flares with GeV/TeV emission.
- Pulsar searches towards GC
- High frequency magnetar timing studies.

ALMA Phasing History

- 2009: 1st design completed by phasing group.
- Sept 2009: proposal to ALMA Board declined.
- 2010: new design completed
  - International team assembled.
  - ALMA Correlator and Computing IPTs review plan.
- Jan 2011: ALMA Board endorses NSF proposal.
- Sept 2011: NSF Awards MRI grant (30% international cost sharing).
- Kickoff meeting mid-Dec 2011.
- Project Plan submission to ADSC (Summer 2012).
- Target ALMA Board approval: Nov 2012

Phasing Arrays: SMA, CARMA, PdeBure, EVLA



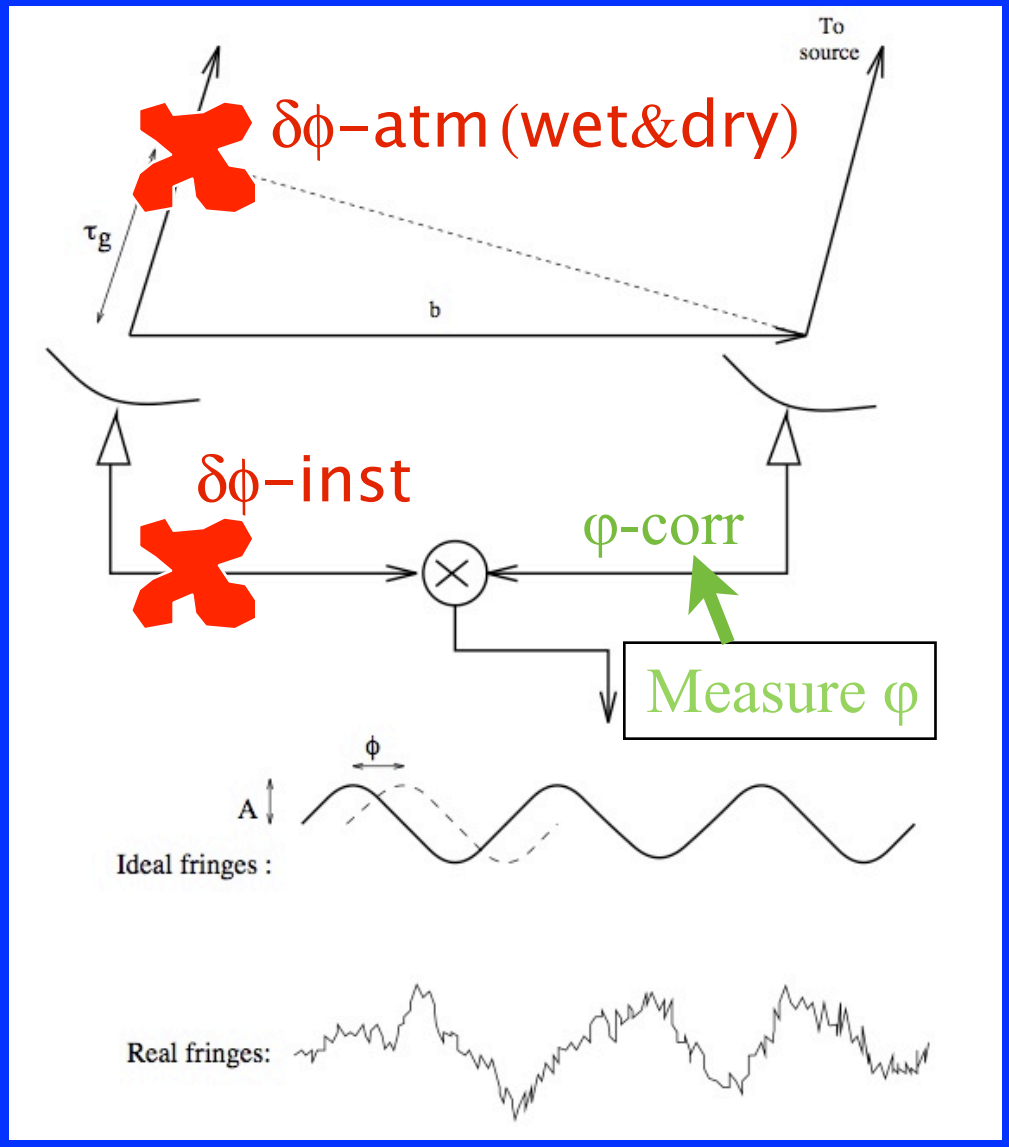


SMA: Weintroub, Primiani, et al

CARMA: Wright, McMahon, Dexter, et al

PdBure: Torres et al

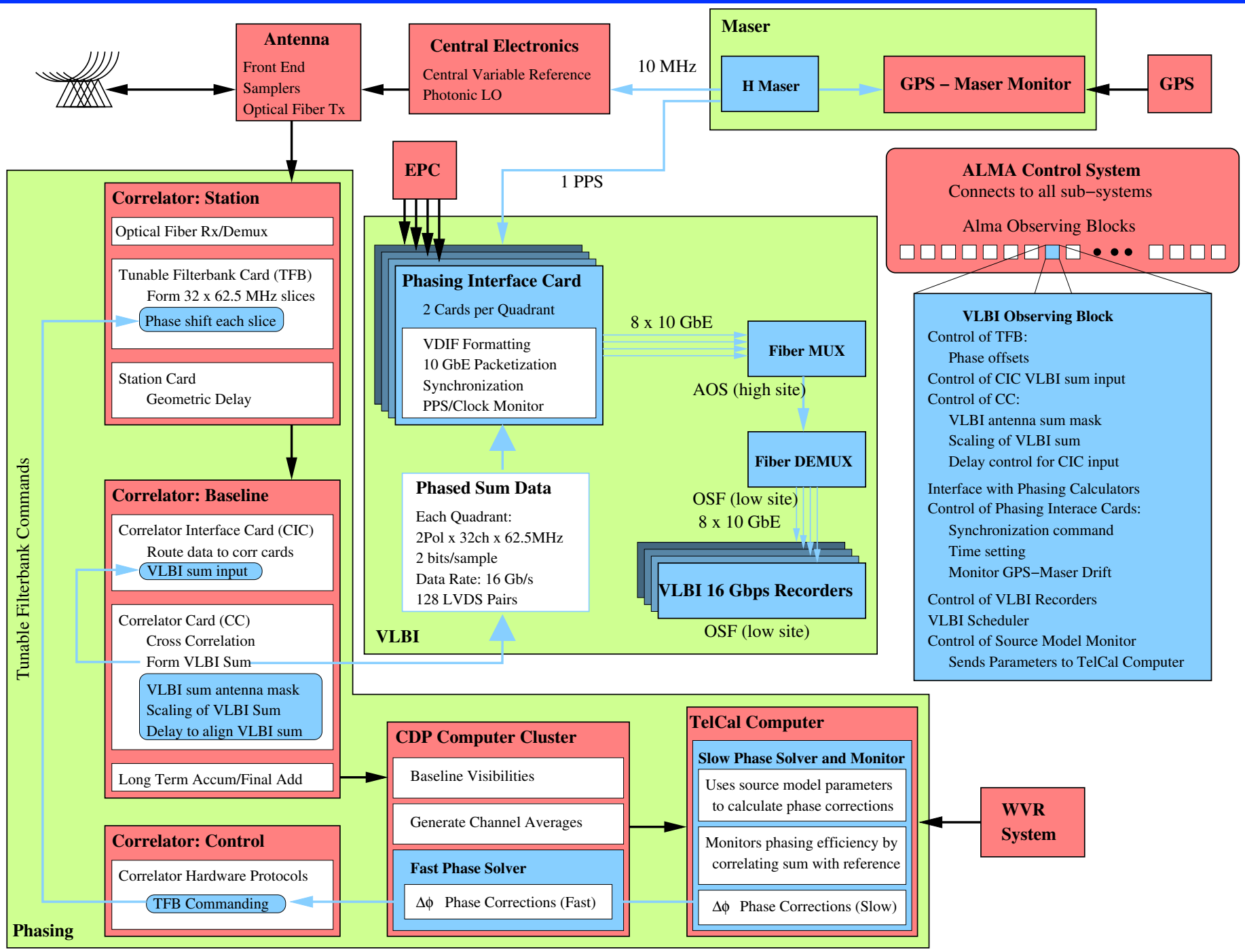
Basic System



Site testing (Butler et al): on 300m baselines, 10s rms path length fluctuations are 0.13mm (50th percentile). Time scale: 1-10 sec.

These fluctuations correspond to ~1.2 degrees across the 8GHz BW of ALMA.

Granularity of ALMA delay model is 15.625ps, which is 45 degrees over the 8GHz ALMA BW.

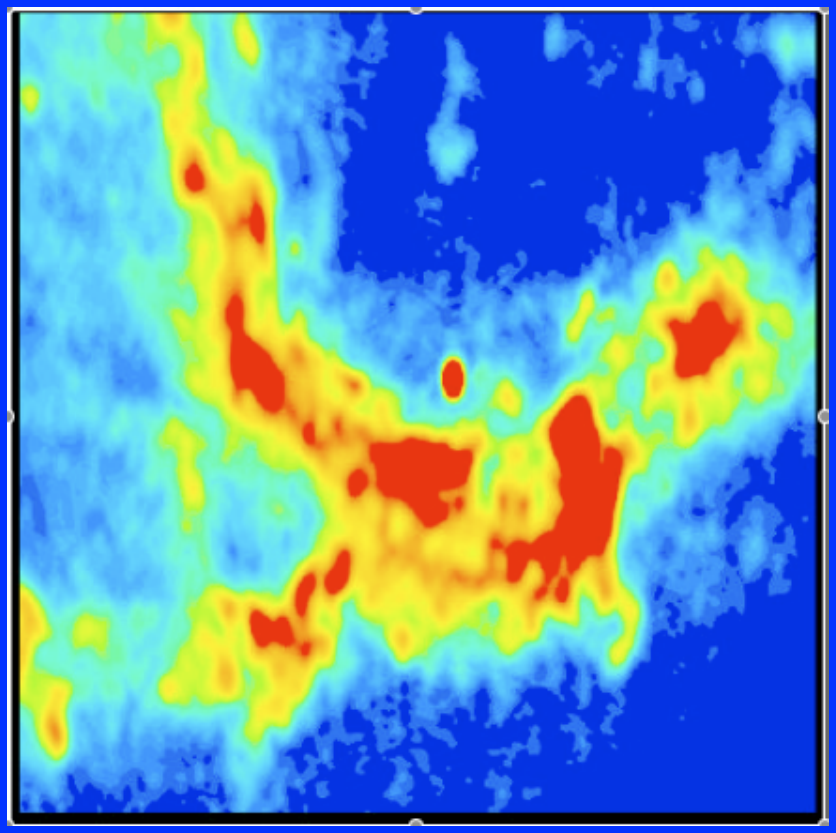

Antenna
Front End
Samplers
Optical Fiber Tx
Central Electronics
Central Variable Reference
Photonic LO
10 MHz
Maser
H Maser
GPS – Maser Monitor
GPS
EPC
1 PPS
ALMA Control System
Connects to all sub–systems
Alma Observing Blocks
VLBI Observing Block
Control of TFB:
Phase offsets
Control of CIC VLBI sum input
Control of CC:
VLBI antenna sum mask
Scaling of VLBI sum
Delay control for CIC input
Interface with Phasing Calculators
Control of Phasing Interace Cards:
Synchronization command
Time setting
Monitor GPS–Maser Drift
Control of VLBI Recorders
VLBI Scheduler
Control of Source Model Monitor
Sends Parameters to TelCal Computer
Tunable Filterbank Commands
Correlator: Station
Optical Fiber Rx/Demux
Tunable Filterbank Card (TFB)
Form 32 x 62.5 MHz slices
Phase shift each slice
Station Card
Geometric Delay
Phasing Interface Card
2 Cards per Quadrant
VDIF Formatting
10 GbE Packetization
Synchronization
PPS/Clock Monitor
8 x 10 GbE
Fiber MUX
AOS (high site)
Fiber DEMUX
OSF (low site)
8 x 10 GbE
VLBI 16 Gbps Recorders
OSF (low site)
Phased Sum Data
Each Quadrant:
2Pol x 32ch x 62.5MHz
2 bits/sample
Data Rate: 16 Gb/s
128 LVDS Pairs
VLBI
Correlator: Baseline
Correlator Interface Card (CIC)
Route data to corr cards
VLBI sum input
Correlator Card (CC)
Cross Correlation
Form VLBI Sum
VLBI sum antenna mask
Scaling of VLBI Sum
Delay to align VLBI sum
Long Term Accum/Final Add
CDP Computer Cluster
Baseline Visibilities
Generate Channel Averages
Fast Phase Solver
Δϕ Phase Corrections (Fast)
TelCal Computer
Slow Phase Solver and Monitor
Uses source model parameters
to calculate phase corrections
Monitors phasing efficiency by
correlating sum with reference
Δϕ Phase Corrections (Slow)
WVR
System
Correlator: Control
Correlator Hardware Protocols
TFB Commanding
Phasing

Phase Solver

- SNR of Ant. Phase corrections
  - Require (n-1) phases and we have n(n-1)/2 baselines.
  - $$snr_a = \eta_b \left[\sqrt{n/2}\right]\left[\frac{\sqrt{2B\tau}}{SEFD}s\right]$$
  - For 8GHz BW, n= 25, s=3Jy, SEFD = 5200: SNR=700 in 10sec.
  - Use channel averages from CDP (62.5MHz slices).
  - For weaker sources or spectral line sources: phase referencing and/or WVR.
  - Phase I: simple corrections; Phase II: WVR inclusion; Phase III: predictive filtering (2-D modeling).

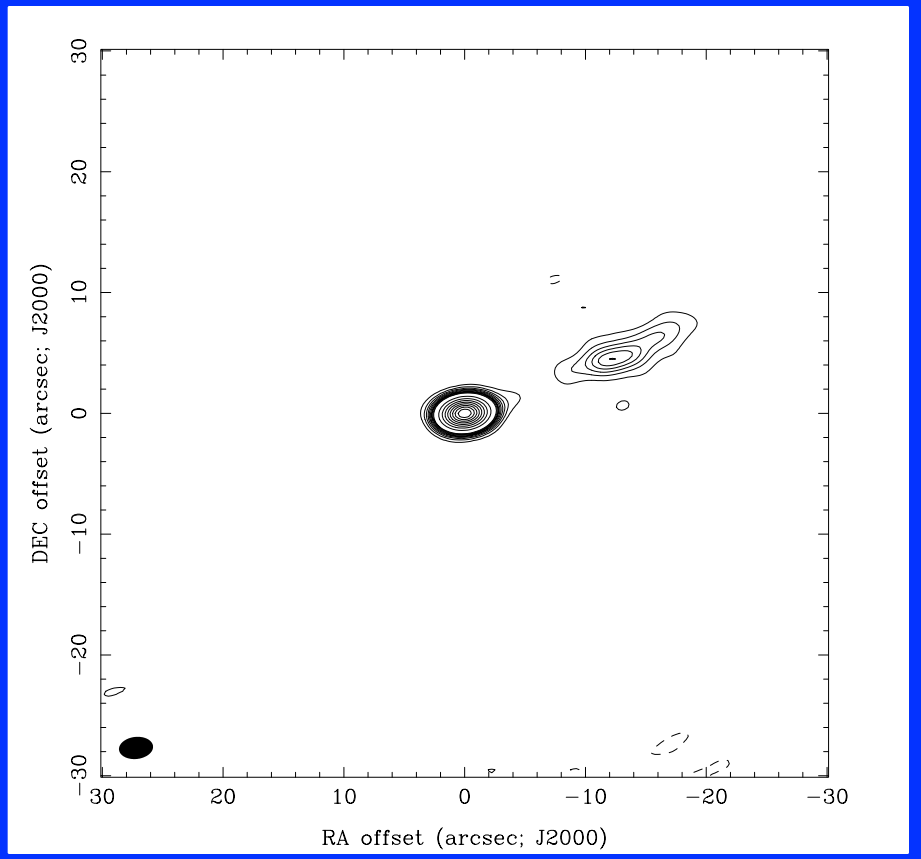
Source Models Needed

SgrA* (2cm)



1 arcmin

M87

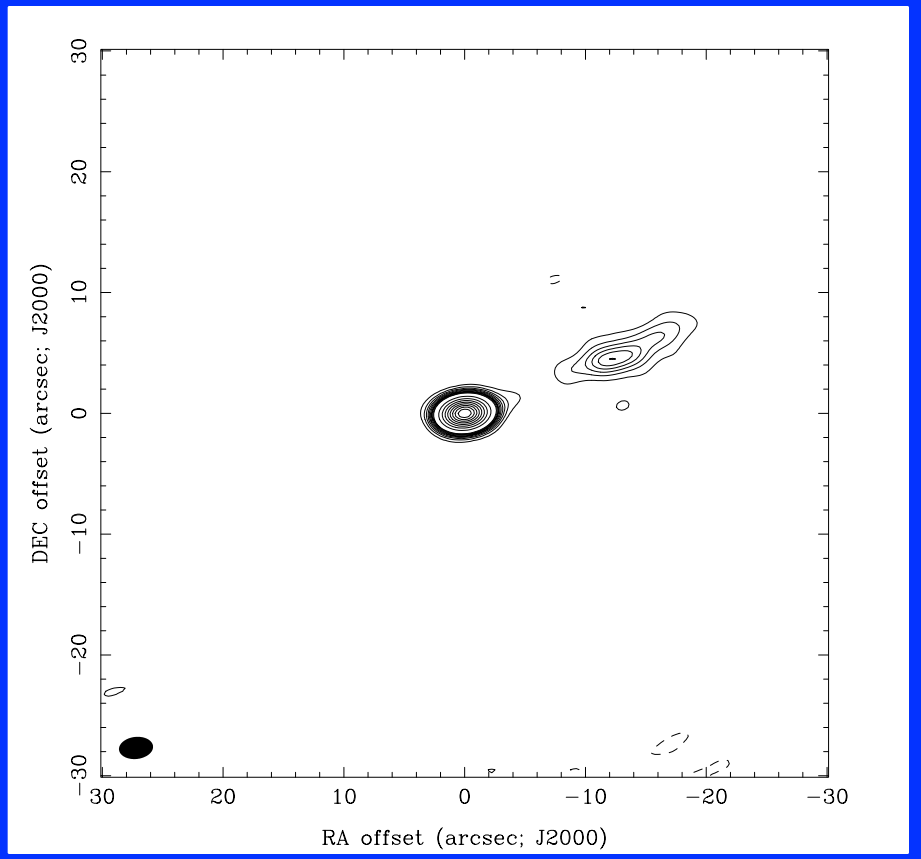


Large phase signatures for ALMA baselines < 1km (0.25 as).

Source Models Needed

SgrA* (2cm)

M87



1 arcmin

Large phase signatures for ALMA baselines < 1km (0.25 as).

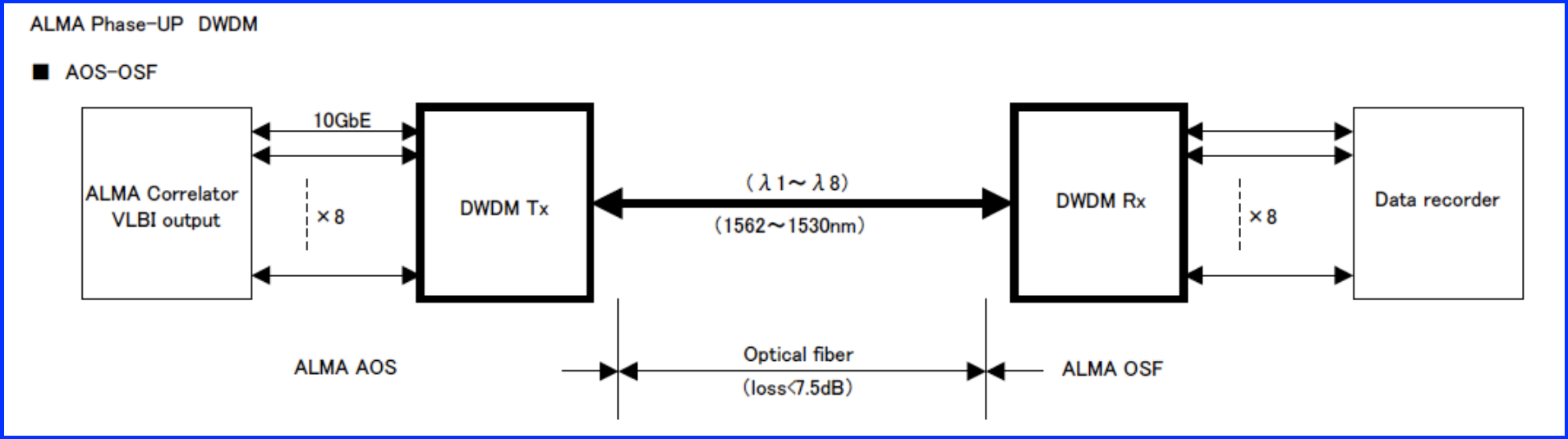
H-Maser

- H-maser for 230/345 GHz is commodity item (e.g. T4Science or Symmetricom).
- Requires:
  - power (100W)
  - internet (monitor, settings)
  - connections: 1 PPS, 5/10/100MHz.
  - software switch b/w maser and rubidium.
- Counter/Scope for GPS comparison.

Correlator + Phasing Interface Card

- Correlator Mods: phasing mask, phased sum routed back to correlator, TFB commands.
- 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.
- Total output = 64Gb/s per subnet.
- VDIF headers attached.
- 10GbE packetized.

Optical Link



Dense Wavelength Division Multiplex: 8 x 10GbE on one fiber.

VLBI Recorder

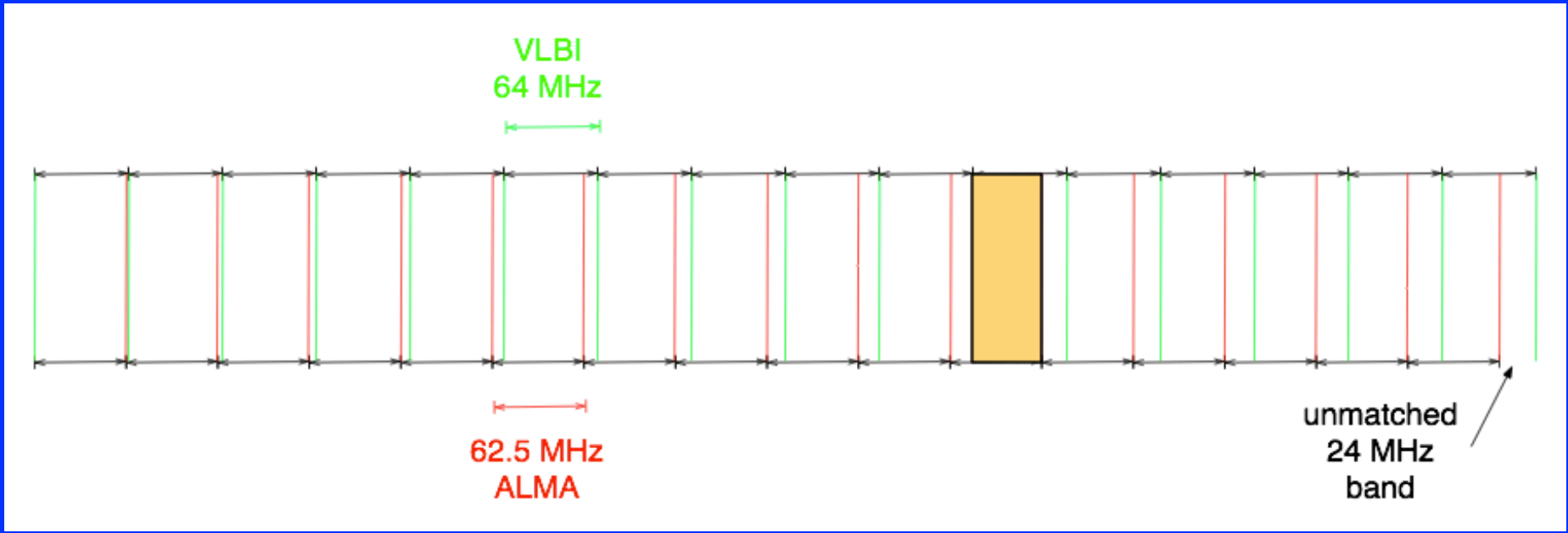
Require 64 Gb/s.
Currently prototyping Mark 6: 16Gb/s COTS recorders.

Software

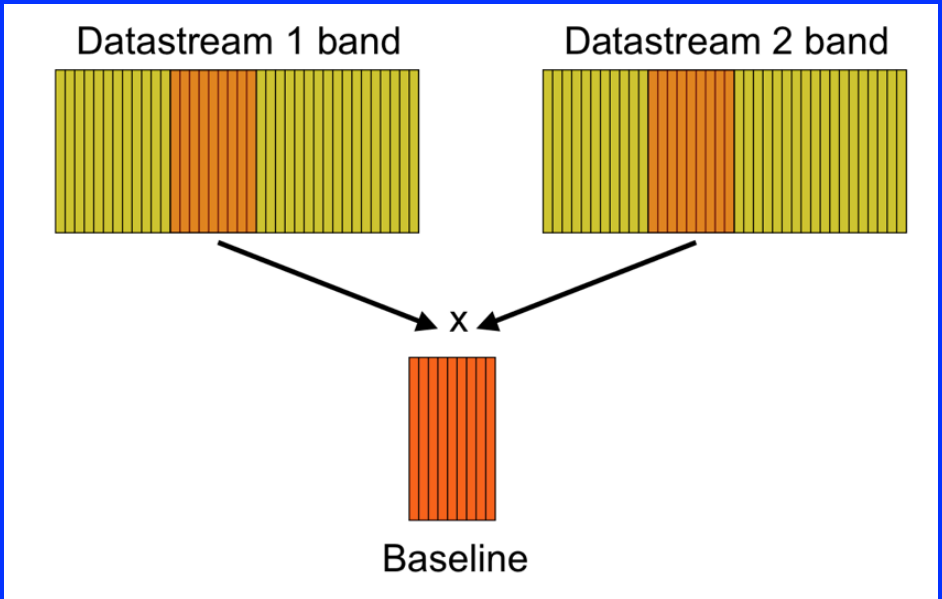
- The glue for the entire system.
  - VOM: VLBI Observing Mode
  - New Correlator Commands: PIC, phasing corrections, fast-solver.
  - TelCal: access to ALMA correlator data, WVR, source models, and slow-solver.
  - New devices: maser, recorders, GPS-maser, optical fiber.
  - Scheduler: translate VLBI schedule into UTC time-tagged ALMA commands.
  - DiFX Enhancements: polarization, mismatch in sampling rates.
  - CASA: mmVLBI routines and VLBI capability.

ALMA Sampling (In)compatibility

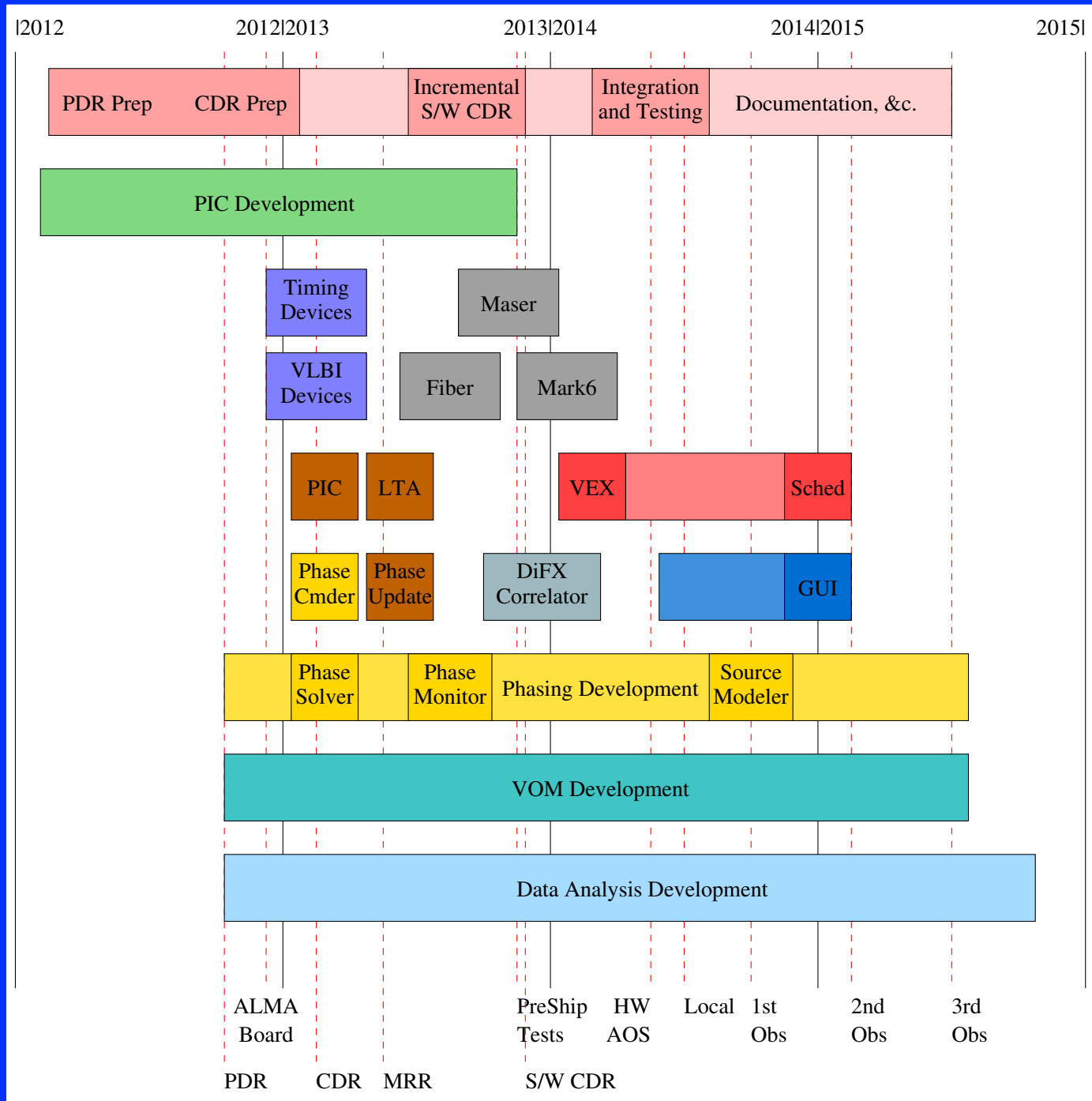
- VLBI Standard: 1MHz x 2^n (128MHz)
- ALMA Standard: 1GHz / 2^m (125MHz)
- Need to correlate 64MHz channel against a 62.5MHz ALMA slice.



DiFX Solution



- Channelize to common divisor: 0.5MHz
- Match corresponding channels prior to multiply.
- Depends on: accurate bookkeeping, non-power of 2 FFT.


|2012
2012|2013
2013|2014
2014|2015
2015|
PDR Prep
CDR Prep
Incremental S/W CDR
Integration and Testing
Documentation, &c.
PIC Development
Timing Devices
Maser
VLBI Devices
Fiber
Mark6
PIC
LTA
VEX
Sched
Phase Cmder
Phase Update
DiFX Correlator
GUI
Phase Solver
Phase Monitor
Phasing Development
Source Modeler
VOM Development
Data Analysis Development
ALMA Board
PreShip Tests
HW AOS
Local
1st Obs
2nd Obs
3rd Obs
PDR
CDR
MRR
S/W CDR

Summary

- ALMA Phasing design at an advanced stage.
- International expert team: WBS ongoing.
- Close interaction and consultation with:
  - ALMA management
  - ALMA technical groups
  - ALMA partners
- Assembling Broad science case: this means you!
- Significant new capability for ALMA and community.