64 Gbps with ALMA

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Phasing up ALMA for 1mm VLBI

TOG meeting Wettzell January 2014

January 23, 2013

Presented by W. Alef on behalf of the ALMA phasing team

ALMA Phasing Project

People involved (far from complete)

- Haystack: Shep Doeleman (PI), Mike Hecht (PM), Geoff Crew (PE), Vincent Fish (PS), Chet Ruszczyk, Lynn Matthews, Victor Pankratius...
- NRAO: Rich Lacasse, Joseph Greenberg, Mathias Mora, ...
- UDEC: Neill Nagar, ...
- MPIfR: Walter Alef, Alan Roy, Helge Rottmann, James Anderson
- ASIAA: Inoue Makoto, Nicolas Pradel, ...
- NAOJ: Mereki Honma …
- ALMA: Alejandro Saez ….
- Onsala: Michael Lindqvist, Ivan Marti, ...
- ESO/IRAM: Dominique Broguiere
- CFA: Jonathan Weintroub
- UJF: Robert Lucas
- LAB: Alain Baudry

Size of the project

- 4-5 years
- Cost: > 4 M$
- 25 WY
- Funding via
  - NSF MRI (Haystack, NRAO)
  - ASIAA, MPIfR, NAOJ, U. Conception secured separate funding
    - which enabled MRI

Location, Location, Location

Sept. 2012

OSF at 2900m

AOS at 5000m

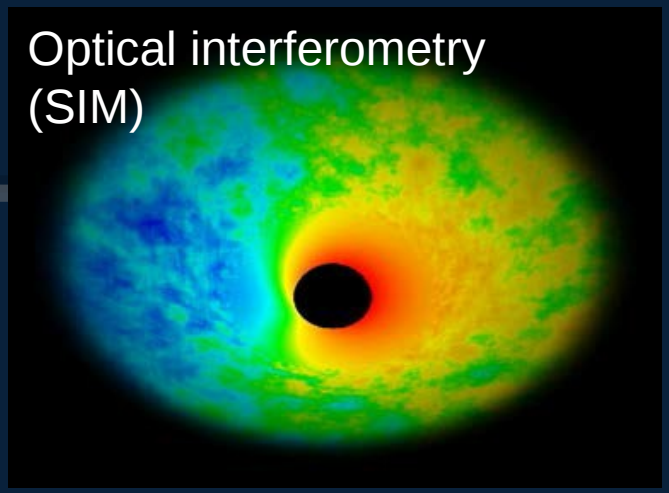
Why?

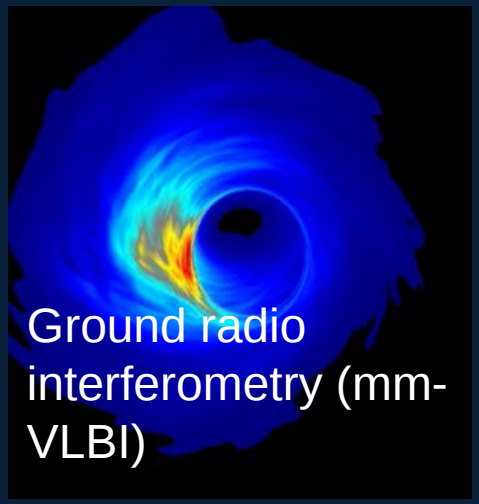
- 3mm VLBI: CMVA → GMVA
  - Regular observations, though more difficult than at cm
  - Sensitivity sufficient for observing a few 100 sources
  - Now with 2 Gbps factor 2 more sensitive
- Few tests at 2 and 1 mm, lack sensitivity
  - Increase sensitivity with phased arrays !
    (Add signals of antennas of a local array coherently)
  - Done at Plateau de Bure for mm-VLBI (GMVA)
    - Still ~95% efficient at 1 mm!!
  - CARMA, SMA...
- ALMA !! (also offers very long baselines)
  - EHT (1mm), GMVA (3mm), VLBA (7&3mm), EVN (7mm)

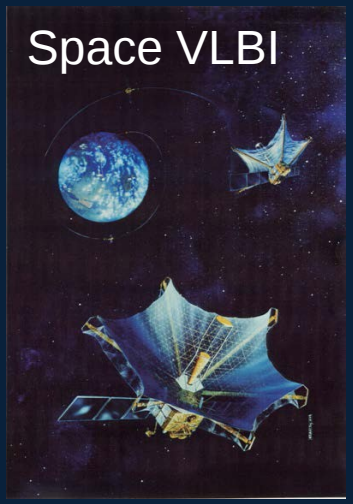
Observing the BH vicinity

- X-ray: spectroscopy (1D, model dependent); interferometry (not available)
- Optical, IR: interferometry (good uv-coverage, phase closures)
- Grav. waves: interferometry
- Radio: pulsar timing (GR extended test, needs PSR-BH system)
- Radio: interferometry, ground (2D, calibration), space (2D, orbit determination)

Slide by A.P. Lobanov





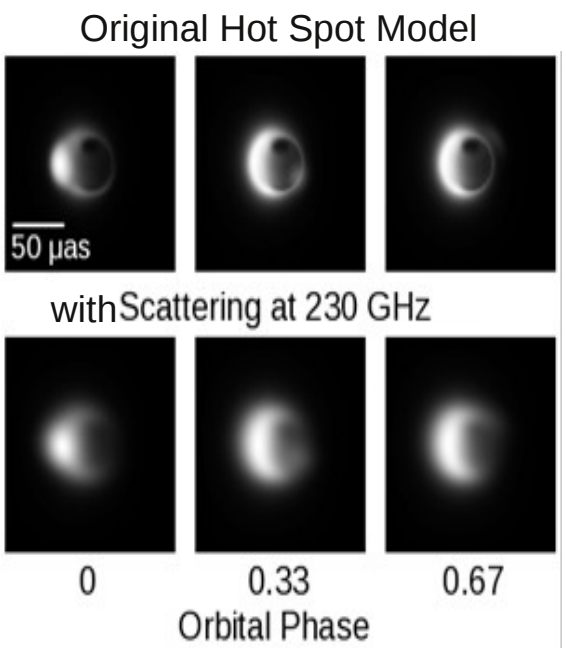


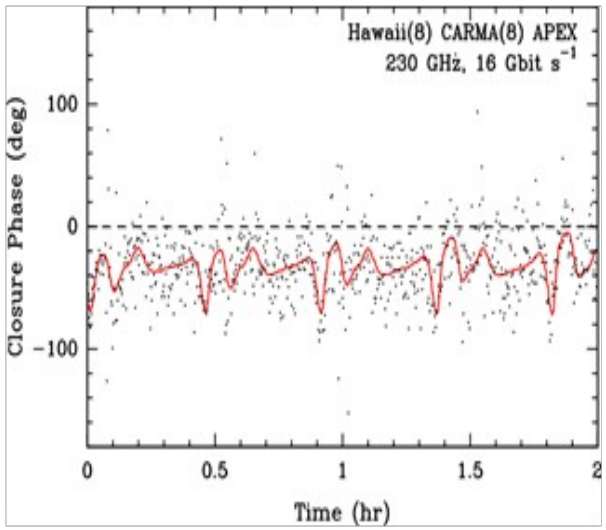
Testing General Relativity

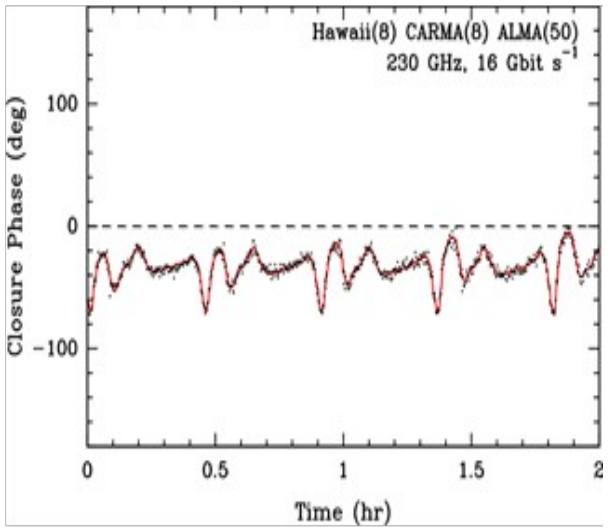
- BH: mass, spin & charge
- Spacetime curvature produces a circular shape, with diameter proportional to mass
- Understanding processes of accretion

Image: D. Psaltis & A. Broderick

The Power of Phased ALMA

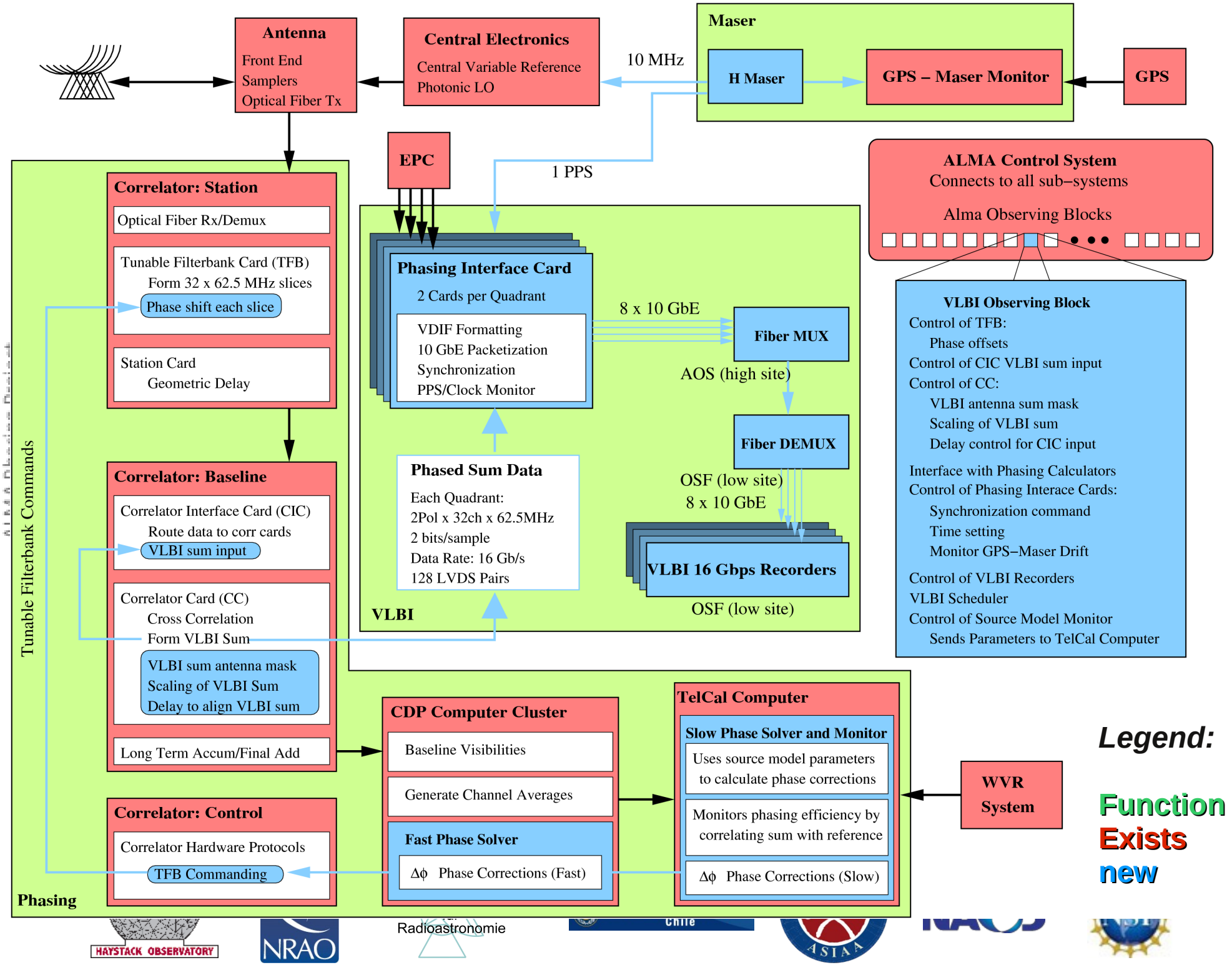






SNR ~ sqrt(#antennas)

Signature of a hot spot orbiting a black hole at a radius of 3 r with a period of 27 minutes. The model is shown at three equally-spaced orbital phases, with and without interstellar scattering. The plots show the expected closure phases on a triangle of stations including the phased SMA, phased CARMA, and either a single telescope in Chile (e.g., APEX, middle) or phased ALMA (right). The red curve shows the expected closure phase signal in the absence of noise, and the black points show simulated data at a time cadence of 10 seconds. The substantial sensitivity improvement provided by phased ALMA will allow rapid time-domain studies of the variable accretion flow in Sgr A*. (Figure adapted from Doeleman et al. 2009).


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
Legend:
Function
Exists
new

VLBI data acquisition

- 64 Gbps max data rate is envisaged
  - from 2 x 8 GHz bandwidth
- 16 Gbps recorders
  - Mark 6 (2 ~Mark5 chassis, 4 disk modules)
    - First prototypes can be purchased
    - Software under development at Haystack
- Disks do not work well at 5000 m
  - Transport data via fiber to OSF
- 288 TB in 10 hours recording
  - 16 modules with 3 TB disks last 13 hours
  - “Big” observation can be more than 2 PB

How to implement

- Q2/3 2012: Start of the project
- Special rules have to be followed
  - Develop hardware/software at simulators
  - Follow ALMA documentation and verification rules
  - Minimize impact on ALMA operations
  - Implement on site when all requirements have been fulfilled
- First observations planned for Q3/2014
- Test phase early 2015 will also be used for some first astronomical observations at 1 mm