Phasing ALMA for VLBI

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Collaboration

- ALMA Phasing collaborators: NRAO, Haystack, MPIfR, ASIAA, NAOJ, U. Concepcion
- Other (sub)mm VLBI collaborators:
  - JCMT
  - SAO/CfA, SMA
  - CSO
  - ARO/SMT
  - CARMA
  - UCBerkeley
  - IRAM

- GR Model
  - 7 Stations
  - 13 Stations
On all three days, calibrator 1924-292 is stable, but SgrA* increases in flux density on day 97, without a change in size (43uas).

VLBI Traction on Black Hole Orbits

Upper left: hot spot in accretion flow orbits BH at Innermost Stable Circular Orbit (ISCO). Upper right: triangle of stations - SMTO, ALMA, SMA. Lower left: closure phase as a function of time. Note that orbit period is ~30 min, so many orbits observed during a single night. Extraction of orbital period gives an estimate of BH spin.
Tracking Black Hole Orbits with VLBI

Spin = 0.9
Hot-spot at $\sim 6R_g$
Period = 27 min.

Shows time variable closure phases due to orbiting hot spot as number of phased ALMA antennas increases.
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ALMA Vitals

- 64 x 12m dishes: 96m effective dish.
- Excellent site
  - SEFD (1.3mm) ~ 100Jy
  - SEFD (3mm) ~ 70Jy
  - SEFD (7mm) ~ 40Jy
- VLBA-ALMA baselines x10 sensitivity of single VLBA-VLBA baseline at 3mm.
- N-S uv coverage to VLBA sites is roughly equivalent to VLBA_MK to VLBA_SC in length.
Design for Real-time ALMA phasing

Correlator: Station
- Optical Fiber Rx/Demux
- Tunable Filterbank Card (TFB)
  - Form 32 x 62.5 MHz slices
  - Digital Gain
  - Phase shift each slice
- Station Card
- Geometric Delay

Central Electronics
- Central Variable Electronics
- Photonic LO

Antenna
- Front End Samplers
- Optical Fiber Tx

ALMA Control System
- Connects to all sub-systems
- Alma Observing Blocks

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

Correlator: Control
- Correlator Hardware Protocols
  - TFB Commanding

GPS
- 1 PPS

Phasing Interface Card
- 2 Cards per Quadrant
- VDIF Formatting
- 10 GbE Packetization
- Synchronization
- Maser-GPS Monitor

Phased Sum Data
- Each Quadrant:
  - 2Pol x 32ch x 62.5 MHz
  - 2 bits/sample
  - Data Rate: 16 Gb/s
  - 128 LVDS Pairs

VLBI Observing Block
- Control of TFB:
  - Digital gains and 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 Interface 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

VLBI Recorders
- Location of recorders:
  - Initial Tests: AOS (high site)
  - Commissioning: OSF (low site)

CDP Computer Cluster
- Baseline Visibilities

Phase Solver
- Δϕ Phase Corrections

WVR System
- Source Model Weights

Source Model Monitor
- Monitors phasing efficiency by correlating sum with reference
- Calculates source model weights and phases for solver in CDP

TelCal Computer
- Telescope Calibration Subsystem
ALMA Phasing Timeline

- Start 2011 (Fnding Proposal Submitted to NSF)
- Integration, First light (1,3mm): 2013
- User Capability onwards.

- Implemented in parallel with normal ALMA construction: will not impact ALMA timeline.
7mm, 3mm VLBI with ALMA

• M87: jet genesis, collimation
• AGN: polarization, pan-chromatic studies
• SiO maser astrometry:
  – link IR-radio at Galactic Center
  – possible distance to LMC
• Gravitational Lenses: central images
• High resolution molecular absorption:
  – PKS 1830-211: isotopic abundances, evolution of fundamental constants
• LMT/GBT: parallax of SgrA* with VLBA (3mm)