VLBI2010: Progress and Challenges

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Goals of the next generation system

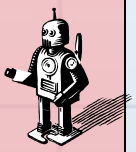
VLBI2010 Goals

1-mm position accuracy *(based on a 24-hour observation)*

- *Unprecedented, research*

Continuous measurements of station position and EOP

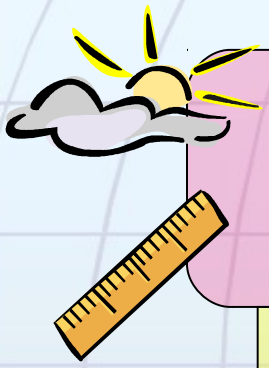
- *Increase automation*
- *Reduce data shipping costs*



Turnaround time to initial products < 24-hrs

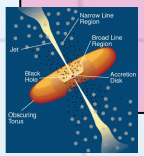
- *Use eVLBI*

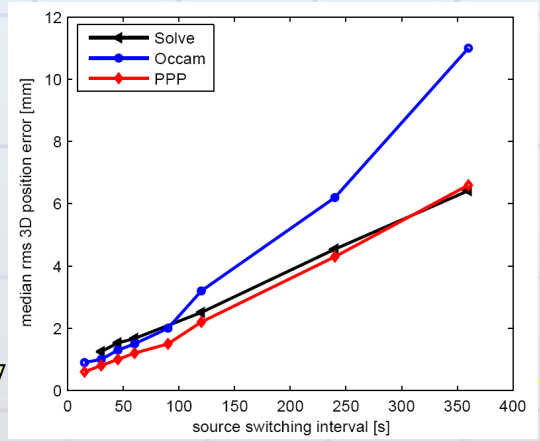
Strategy for VLBI2010 Goal #1: 1-mm accuracy



Reduce Random Errors:
Atmosphere
Clocks
Delay Measurement

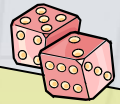
Reduce Systematic Errors:
Antenna Deformations
Source Structure
Electronics





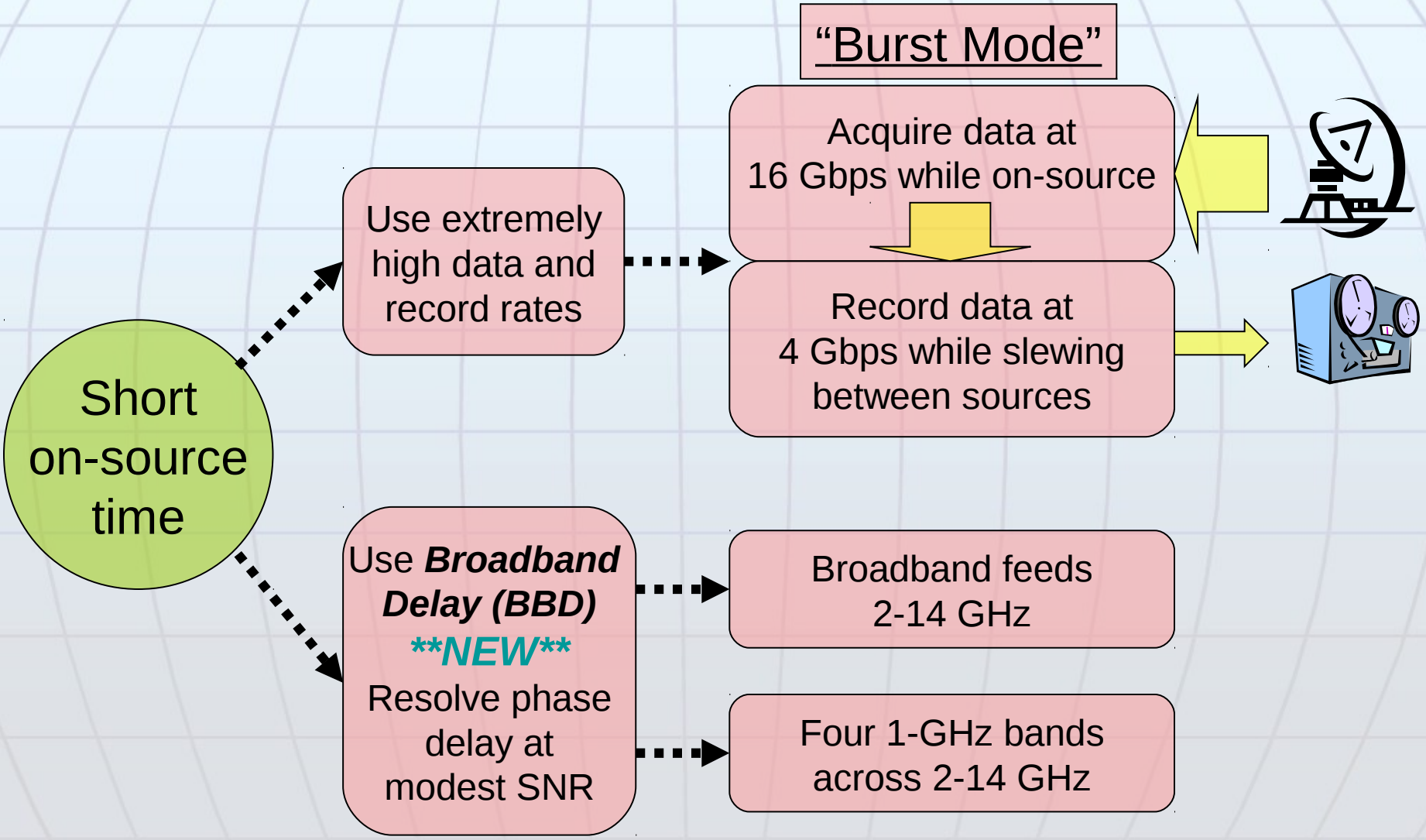
Remedy:
Careful design
Calibration

Remedy:
Reduce Source Switching Interval
Faster slewing antennas
Shorter “on-source” time



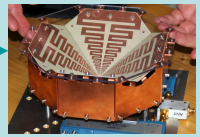
Monte Carlo Simulations

Need short on-source times too



VLBI2010 System

Pcal & Noise Cal



or

Feed/LNA/Cryo
2-14 GHz, v,h-pol

Fast antennas

Antenna structure

H-pol

V-pol

Stable cable to antenna

Fibre to control room

On-site

Up/down converter (4)

Digital Back End (4)

Recorder/ eVLBI

Maser

Automation & Remote Control - MCI

To Correlator

Control room

Off-site

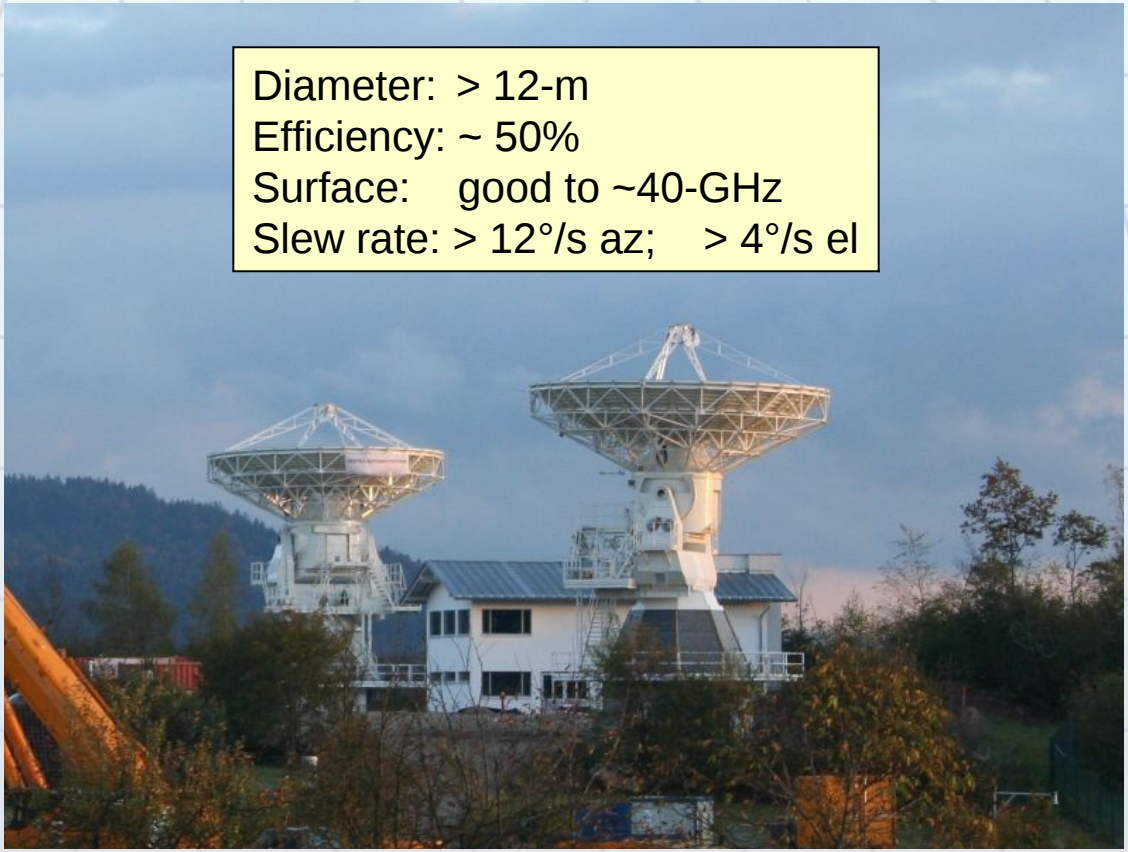
Analysis (update and automate)

Broadband "fringe" detect

Software correlator

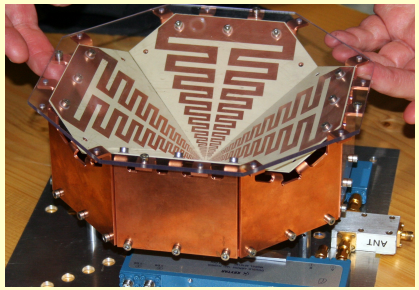
From other antennas

Antenna Progress



- VLBI2010 requirements successfully met (or approached) by a number of manufacturers
  - Vertex, MT Mechatronix, Intertronics

Feed/LNA Progress



Eleven Feed (~2009)
Chalmers University

Quadruple-Ridged Flared Horn (QRFH), Caltech

- Improved Eleven Feed
  - Expected to meet VLBI2010 spec over full 2-14 range
  - One is built but not fully tested yet
- QRFH is new since 2010
  - Simple to construct and robust; only one LNA per polarization
  - Can be custom matched to an antenna
  - Meets VLBI2010 spec: SEFD (2-14 GHz) ~ 2500-Jy
    - Under test on GGAO ‘Patriot’ antenna and Westford antenna

Calibration Progress

- Phase/Pulse Calibration (PCAL)
  - New PCAL generator (based on high speed digital components)
    - Well shielded and temperature regulated
  - All tones are now detected in post processing
- Cable Delay Calibration
  - Very stable cables are available (e.g. LMR-400: 0.5-ppm/°K)
    - perhaps making calibration unnecessary
  - Concepts for new Cable Cal systems are under study
- Noise Calibration
  - T_{Cal} set to ensure < 1% degradation of images

Flexible Down Converter

- Haystack Up-Down Converter operational since 2007

Digital Back End (DBE)

- Two models have been built
  - ROACH DBE (RDBE) by Haystack/NRAO/Goddard Group
    - Operational
  - DBBC VLBI2010 by Gino Tuccari
    - Prototyped
- Other VLBI2010 DBE developments
  - Russia, China, Japan
- Inter-comparisons required
  - Sharing of FPGA algorithms perhaps useful
- Direct sampling DBBC3 under development

Recorder Progress

- Recorders now achieve 4-Gbps sustained data rates
  - Mk5C is now operational at 4-Gbps
  - Mk6 is under development
    - 16-Gbps capability demonstrated.

- Media requirements
  - Data volume for VLBI2010 with 30-s source switching:
    2880 * 5-s * 16-Gbps = ~ 29-Gbytes/day
  - Current largest disk packs: 8 * 2-Gbytes = 16-Gbytes
    - 2 disk packs needed per session

Correlator Progress

- First VLBI2010-capable correlator approaching β-testing stage at Haystack
  - Uses a DiFX core
  - Includes an interface between DiFX and the post processing fringing software
  - Post processing software includes
    - Estimation of the ionosphere delay
    - Optimal combination of linear polarizations
    - Detection of all Pcal tones

Analysis Progress

- First release of nuSOLVE available:
  - Ambiguity resolution
  - Outlier detection
  - Automatic detection of clock breaks
  - Ionosphere calibration
- VieVS
  - New MATLAB-based analysis software from Vienna
    - Efficient for prototyping new functions
- Multi-technique software
  - C5++

Scheduling Progress

- Sked has evolved to handle many VLBI2010 needs
- VieVS is being actively used for scheduling research specifically for VLBI2010
  - Including antenna pairs

Automation Progress

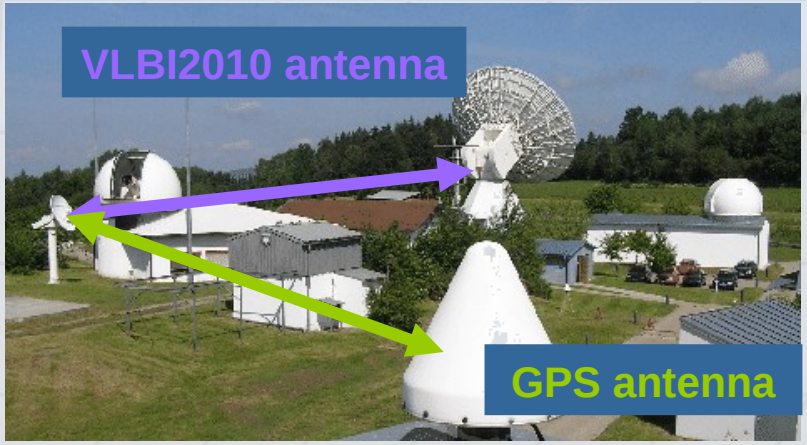
- On-site Automation
  - Monitor/Control (MCI) definition under development
  - Remote operation at some sites already a reality
    - Best known are the BKG sites: Wettzell, TIGO, and O'Higgins.
- Analysis Automation
  - From version 4 databases:
    - Intensives already very successful
    - Full sessions need more attention due to clock breaks, etc
  - Broadband fringe processing eliminates Database processing steps
    - no more group delay ambiguities (due to detection of all Pcal tones)
    - ionosphere estimation already done
- Full VLBI2010 system automation important for future
  - Sked -> operations -> correlation -> "fringing" -> analysis -> database

Antenna deformations progress

- Antenna deformations
  - Mitigated by smaller VLBI2010 antennas
  - Real time monitoring of reference point under development
  - Complete gravitational models have been developed (in a few cases)

e.g. COLD MAGIC

- Site ties
  - Use of a small reference antenna under consideration



NASA Broadband Delay Proof-of-concept Development Project

- **Purpose**:
  - Prove that Broadband Delay can be used operationally to resolve phase delay.
  - Develop the first generation of VLBI2010 electronics.
  - Gain experience with new VLBI2010 subsystems.
- **Status**
  - Complete VLBI2010 systems on GGAO ‘Patriot’ antenna and on Westford antenna
  - Ready for high sensitivity broadband observations

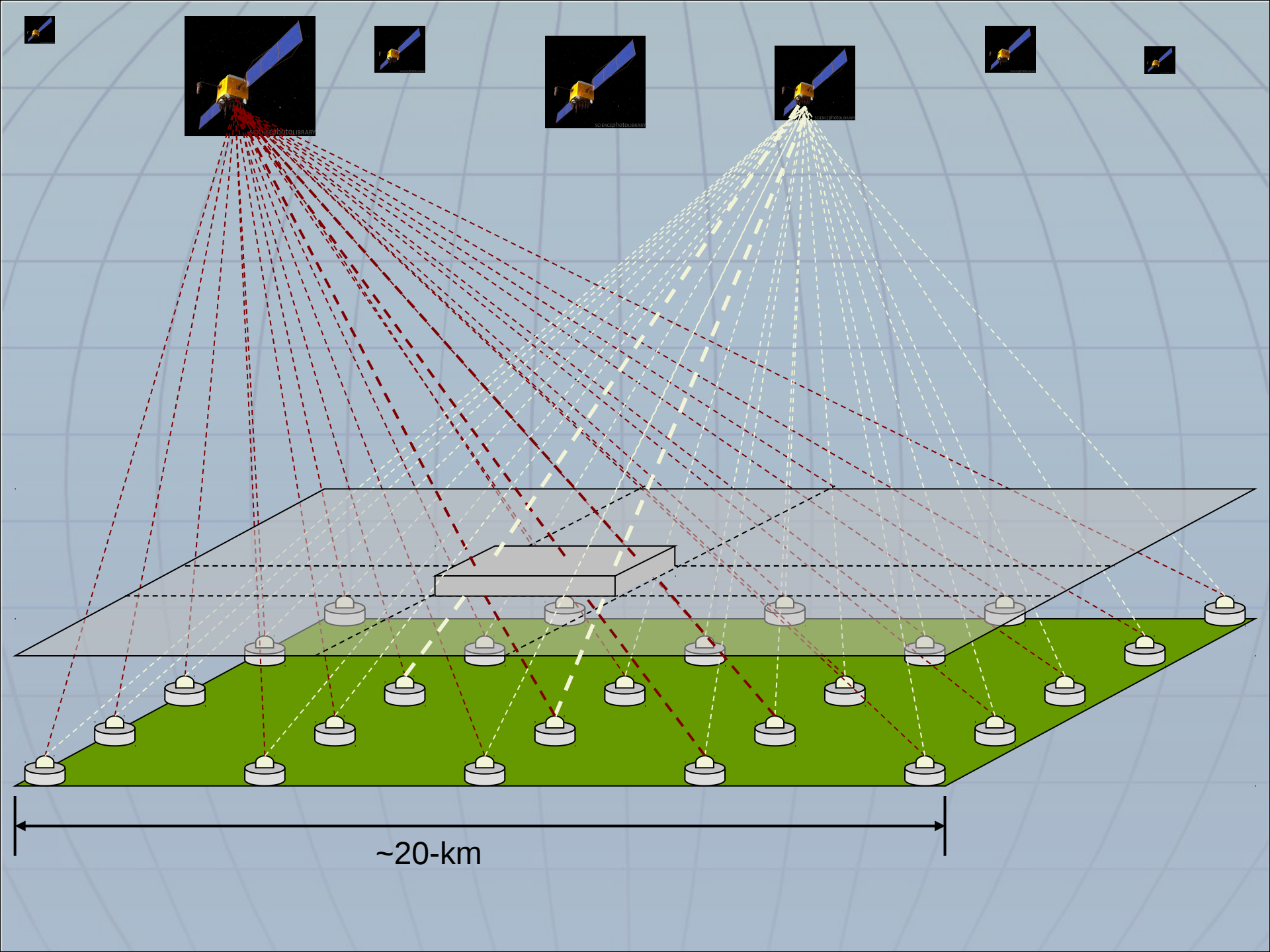
12-m Patriot antenna at GGAO

Challenges (1)

- RFI is a challenge for full 2-14 GHz operation
  - Possible mitigation approaches
    - Electronics with wider dynamic range (currently fibre bottleneck)
    - Splitting of input range at fibre (e.g. 2-4 GHz; 4-14 GHz)
    - Custom filters
- Source structure
  - Should be enough low-structure sources for initial operations
  - VLBA 4-8 GHz band (when it becomes available) could provide a development and testing opportunity for structure corrections

Challenges (2)

- Atmosphere remains the major error source for geodetic VLBI
  - CONT08 analysis indicates that atmosphere parameters used in original VLBI2010 Monte Carlo simulations are optimistic
- If we’re serious about the 1-mm goal
  - Are there alternate approaches for treating the atmosphere?


~20-km

Conclusions

- Great progress has been made towards the realization of VLBI2010
- First “broadband” light on the Westford-to-GGAO baseline is eagerly awaited.