# International VLBI Service (IVS)

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on behalf of the IVS

GGOS Days 2019

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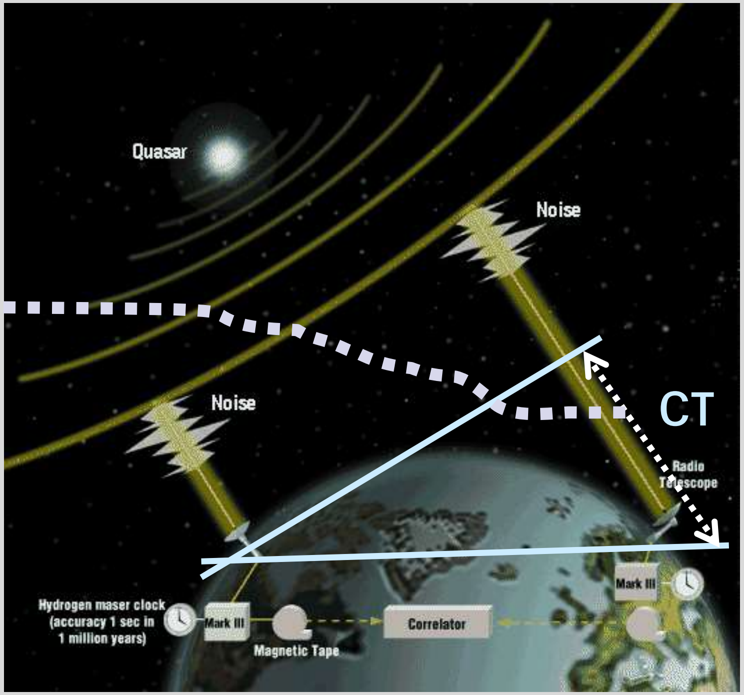
# Geodetic VLBI: How does it work?

A network of antennas observes a quasar

The delay between times of arrival of a signal is measured

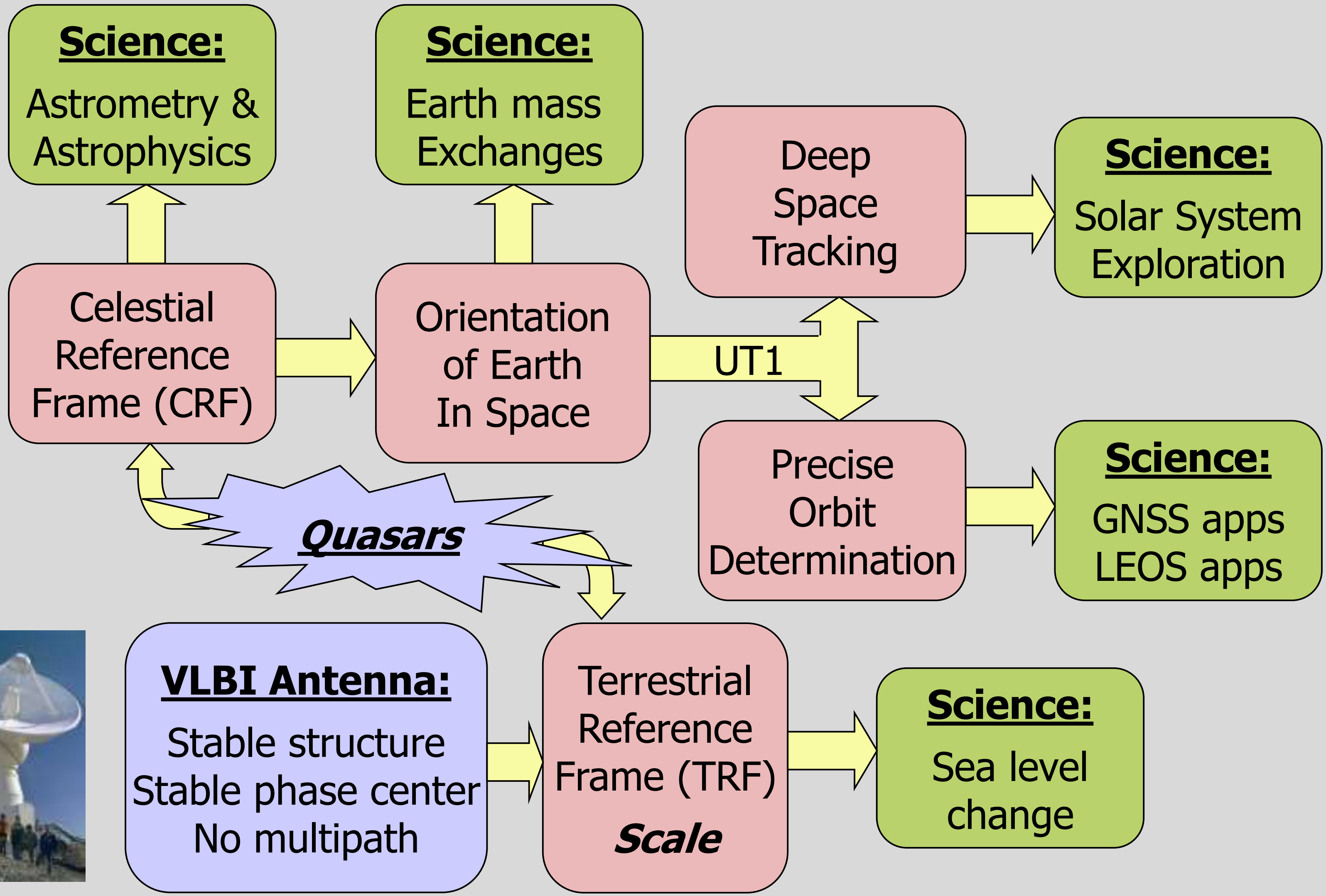
Using the speed of light, the delay is converted to a distance

The distance is the component of the baseline toward the source




By observing many sources, all components of the baseline can be determined.

# Role of VLBI in Science




# What is the IVS?

The **International VLBI Service for Geodesy and Astrometry (IVS)** is an international collaboration of organizations which operate or support Very Long Baseline Interferometry (VLBI) components:

- IVS inauguration was on **1 March 1999**.
- 83 permanent components supported by 41 institutions in 21 countries.
- ~300 Associate Members.

**IVS is a recognized service of**

- **IAG** – International Association of Geodesy
- **IAU** – International Astronomical Union
- **WDS** – ISC World Data System

# IVS Goals and Activities

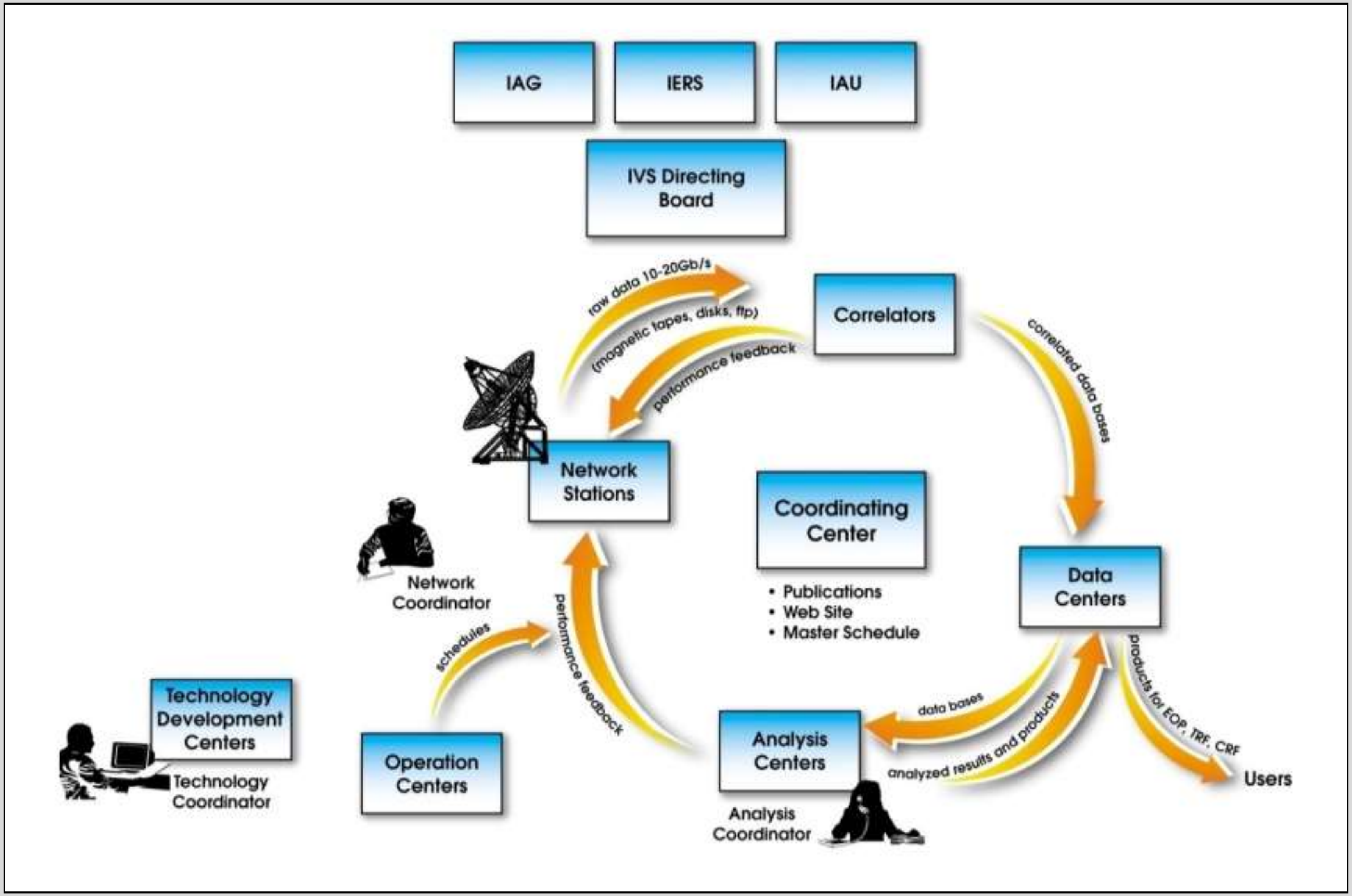
The **goals** of the IVS are to:

- provide a service to support geodetic, geophysical, and astrometric research and operational activities;
- promote research and development in the VLBI technique;
- interact with the community of users of VLBI products and integrate VLBI (as a part of GGOS) into a global Earth observing system.

The **main activities** of the IVS are to:

- provide EOP, maintain ICRF, and support maintenance of ITRF;
- coordinate VLBI observing programs;
- set performance standards for the observing stations;
- establish conventions for data formats and products;
- issue recommendations for analysis software;
- set standards for analysis documentation;
- institute appropriate product delivery methods in order to insure suitable product quality and timeliness.

# Organization of the IVS



# IVS: Training and Meetings (1/2)

## IVS Technical Operations Workshop (TOW)

- Hands-on training of technical station staff
- Organized every two years at MIT Haystack Observatory
- Most recent: 10th TOW, May 5–9, 2019
  https://www.haystack.mit.edu/workshop/TOW2019/index.html


## VLBI School

- Schooling of young researchers in VLBI
- Organized every three years at different venues
- Most recent: 3rd VLBI School, March 14–16, 2019, Gran Canaria
  http://wp.portal.chalmers.se/evga/ivs-cte/

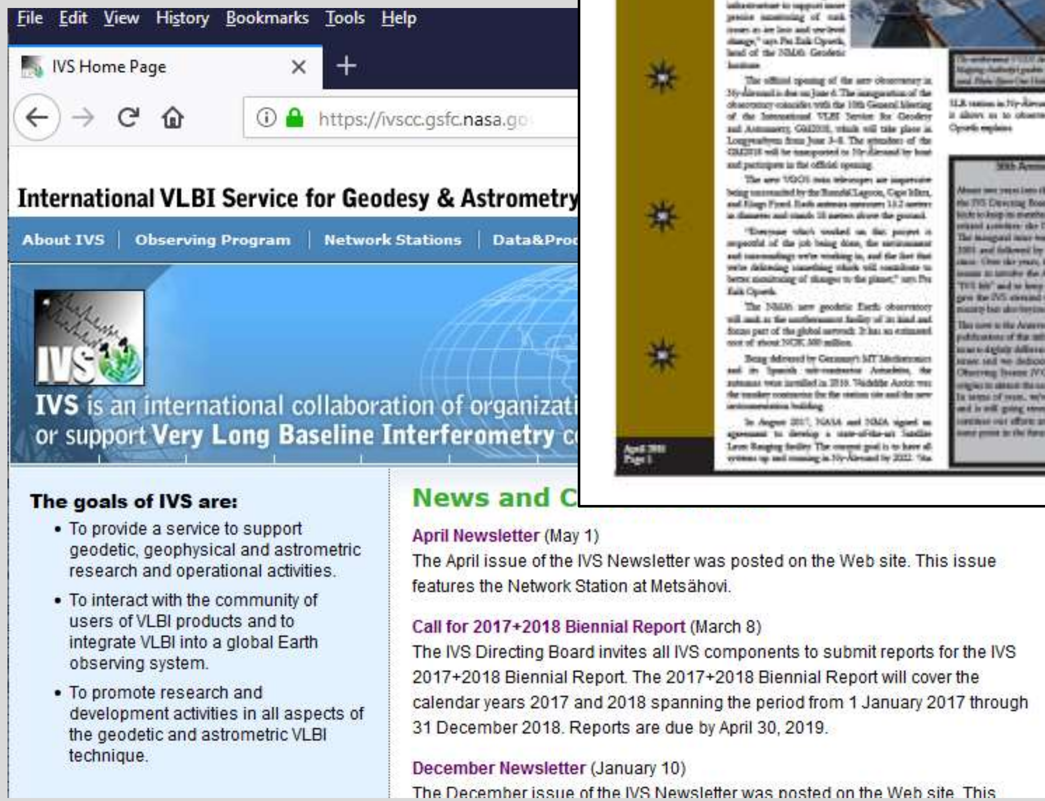
# IVS: Training and Meetings (2/2)

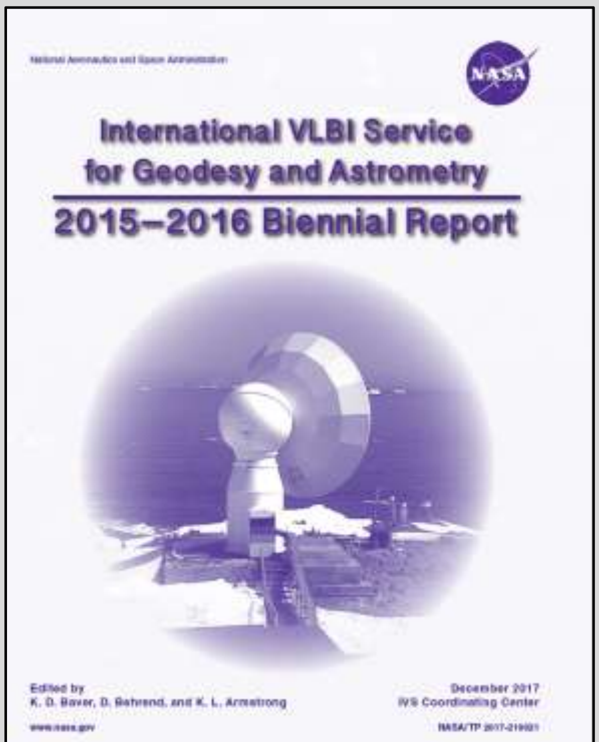
- **IVS General Meeting (GM)**
  - Technical Meeting for all IVS components and interested scientists
  - Organized every two years at different venues
  - Next GM: 11th General Meeting, March 22–28, 2020 in Annapolis, MD, US; https://ivsgm2020.com/


- **Meetings with special topics/groups**
  - IVS Analysis Workshop: organized yearly
  - VLBI Technology Workshop: organized yearly
  - VLBI Observations of Near-Field Targets
  - IVS Directing Board: twice a year

# IVS Publications and Web Presence

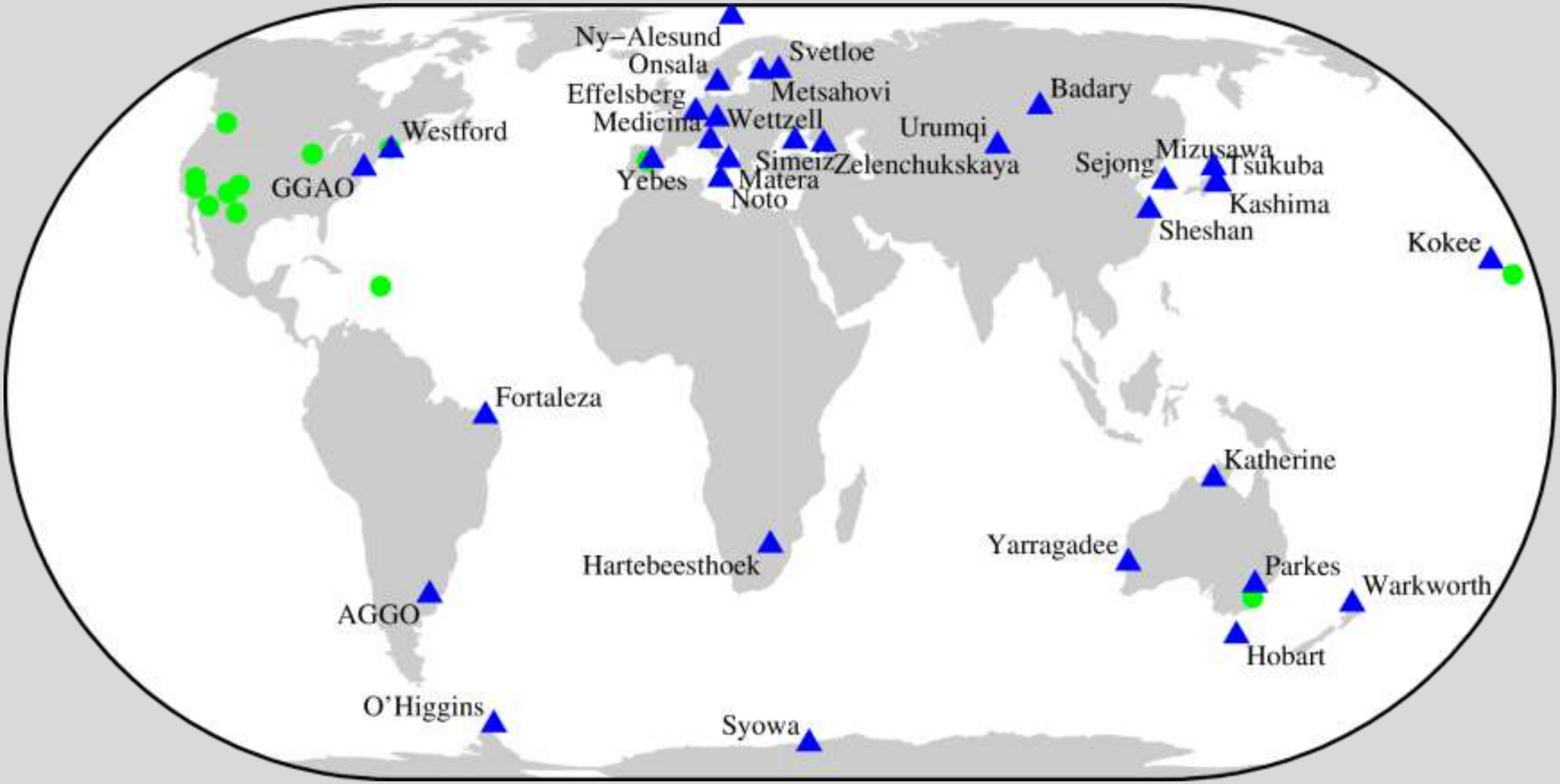
- **IVS Newsletter**: thrice a year
- **IVS Biennial Report**: every two years
- **GM Proceedings**: every two years
- **Web site**
- **Mailing lists**


https://ivscc.gsfc.nasa.gov/

# IVS Network Stations




▲ IVS Network Station

● Cooperating VLBI Site

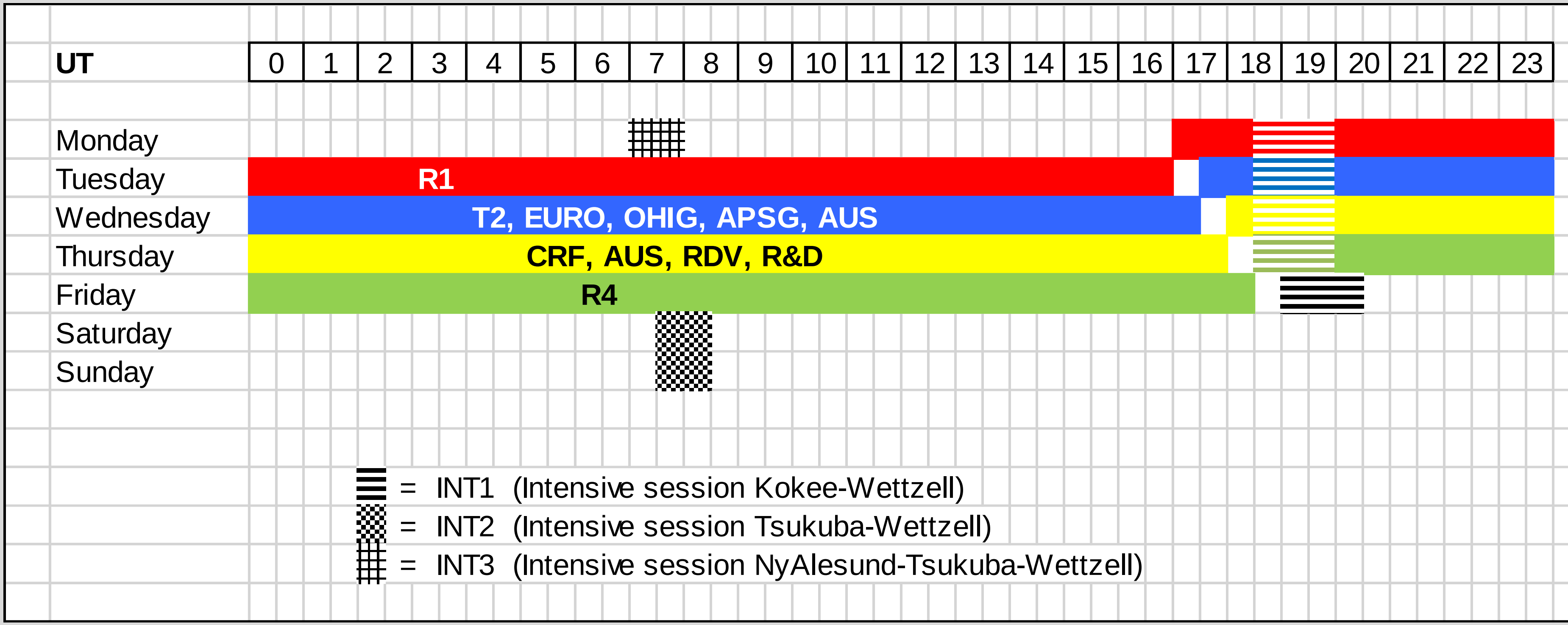
# VLBI Sites in South America

Fortaleza, Brazil

AGGO, La Plata, Argentina

# IVS Observing Program: S/X System

- Typical weekly layout for IVS observing sessions



# IVS Products

- Earth Orientation Parameters (EOP):
  - 24-hour sessions (all EOP)
  - 1-hour Intensives (UT1−UTC)
- Terrestrial Reference Frame (TRF)
  - VLBI Terrestrial Reference Frame (VTRF)
- Celestial Reference Frame (CRF)
- Daily EOP + station coordinates (SINEX-files)
- Tropospheric Parameters (TROPO)
- Baseline Lengths (BL)

# IVS Observing Program

**Note**: Although certain sessions have primary goals, such as CRF, all sessions are scheduled so that they contribute to all geodetic and astrometric products.

- **EOP**: two rapid turnaround sessions each week, 10−11 stations, depending on station availability. Data bases are available no later than 15 days after each session.
- **TRF**: bi-monthly sessions with 12–14 stations using all stations at least two times per year; regional sessions for Europe, Antarctica, Asia-Pacific, Australia.
- **CRF**: astrometric sessions to observe mostly southern sky sources, plus bi-monthly RDV sessions using the VLBA together with up to ten geodetic stations.
- **R&D**: ~monthly sessions to investigate instrumental effects and study ways for technique and product improvement.
- **CONT**: triennial ~two-week continuous sessions to demonstrate the best results that VLBI can offer.

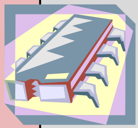
# VGOS: Why do we need it?

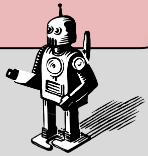
***Aging systems (now ~40 years old):***

- Old antennas
- Obsolete electronics
- Costly operations
- RFI

***New technology:***

- Fast, affordable antennas
- Digital electronics
- Hi-speed networks
- Automation





New system

***New requirements:***

- Sea level rise
- Earthquake processes
- 1-mm accuracy
- GGOS

# VGOS: Goals of new system

**VGOS Goals**

- **1-mm position accuracy *(based on a 24-hour observation)***
- **Continuous measurements of station position and EOP**
- **Turnaround time to initial products < 24-hrs**

# VGOS (VLBI Global Observing System)

**Features:**

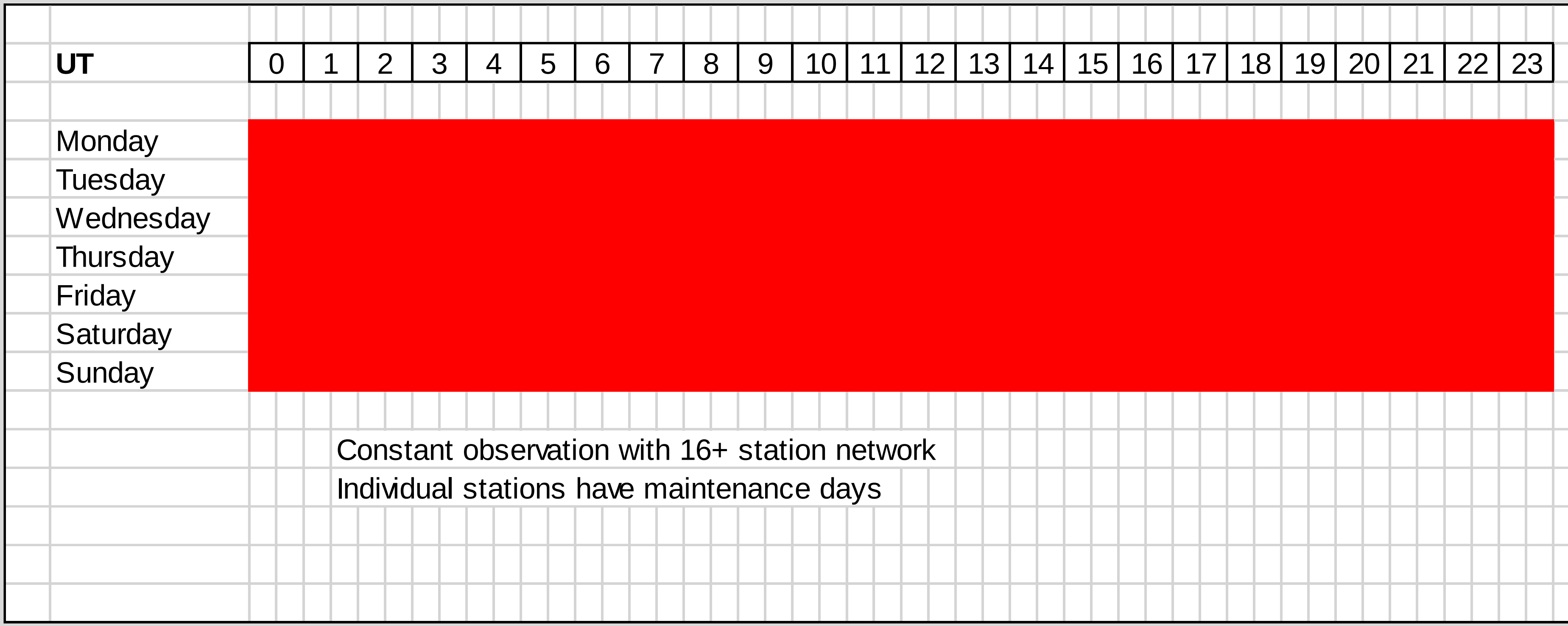
- small and agile telescopes
  - small: 12–13 m dish diameter
  - fast: 12º/s and 6º/s slew speeds
- large bandwidth: 2–14 GHz
- flexible frequency allocation
- dual linear polarization

**Implies:**

- dense sampling of atmosphere
- up to 2 observations per minute (2880/day)

# IVS Observing Program: VGOS

- Expected weekly observing coverage for VGOS (mid-2020s)



# New VGOS Radio Telescopes

Ny-Ålesund (NO)

*Courtesy D. Behrend*


Ishioka (JP)

*Courtesy Y. Fukuzaki*

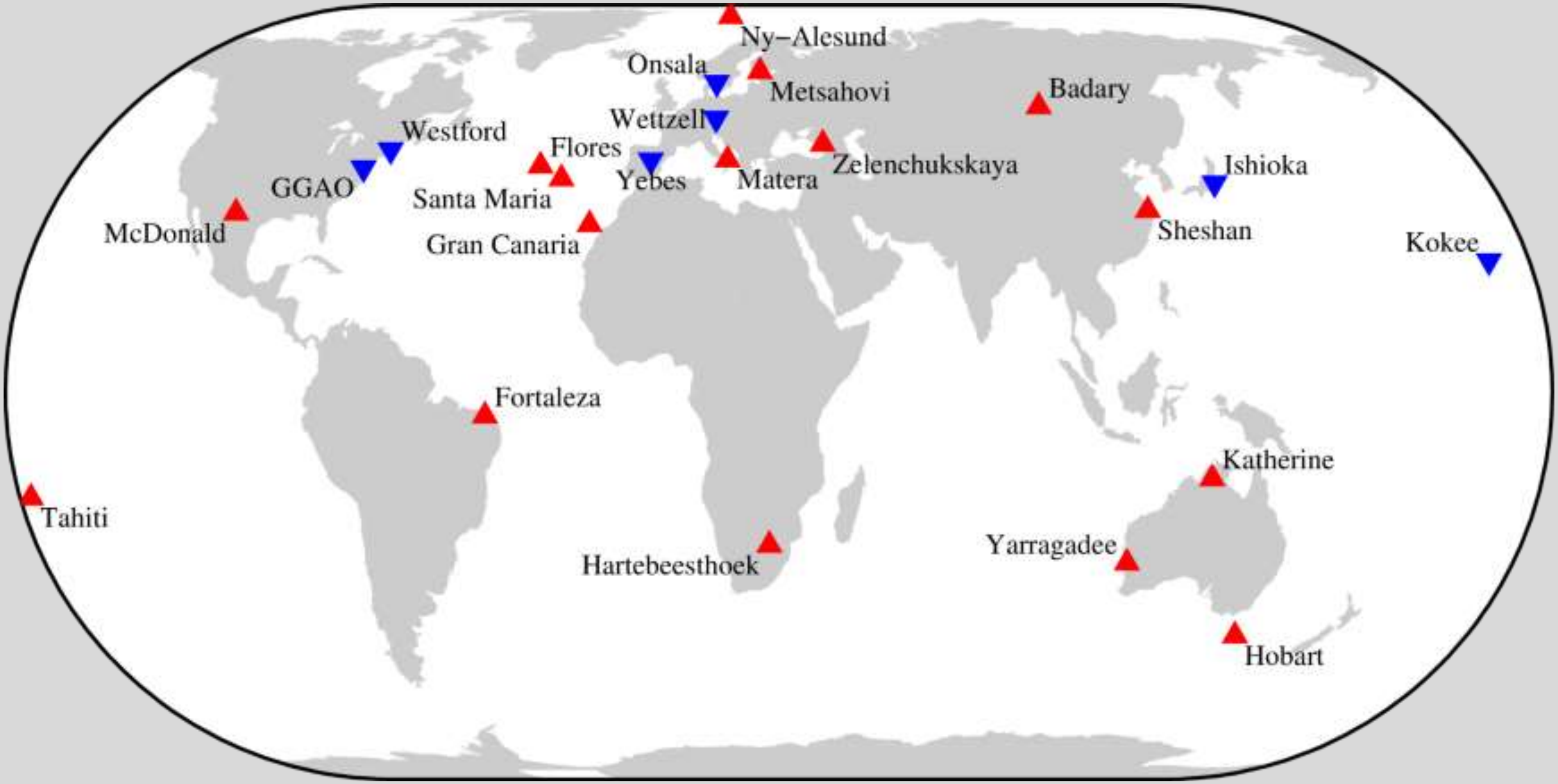
GGAO (US)

*Courtesy A. Niell*

Metsähovi (FI)

*Courtesy N. Zubko*

# Projected VGOS Network by early 2020s

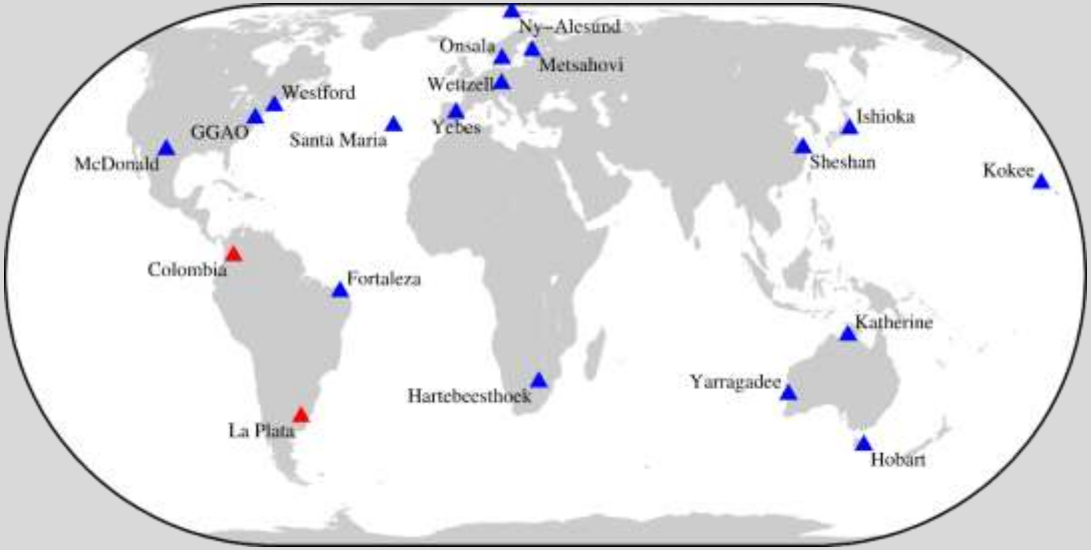



▼ VGOS antenna broadband ready

▲ VGOS antenna under construction or planned

# VGOS in So. America: EOP Simulations

- Monte-Carlo simulations
- 24-hour session
- Simulated delay from clock noise, tropospheric turbulence, and observation noise




| | Xp [μas] | | Yp [μas] | | UT1 [μs] | | Xnut [μas] | | Ynut [μas] | |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 stations | 12.6 | | 16.2 | | 0.88 | | 17.2 | | 18.0 | |
| 17 − FT | 14.0 | −11% | 18.6 | −15% | 0.94 | −7% | 18.5 | −8% | 19.7 | −9% |
| 17 + LP | 12.4 | +2% | 14.1 | +13% | 0.87 | +1% | 15.8 | +9% | 15.9 | +12% |
| 17 + Co, LP | 12.3 | +2% | 13.5 | +17% | 0.83 | +6% | 14.7 | +15% | 15.0 | +17% |

# VGOS: Data Transport, Correlation

**Data transport (raw data) in early 2020s:**

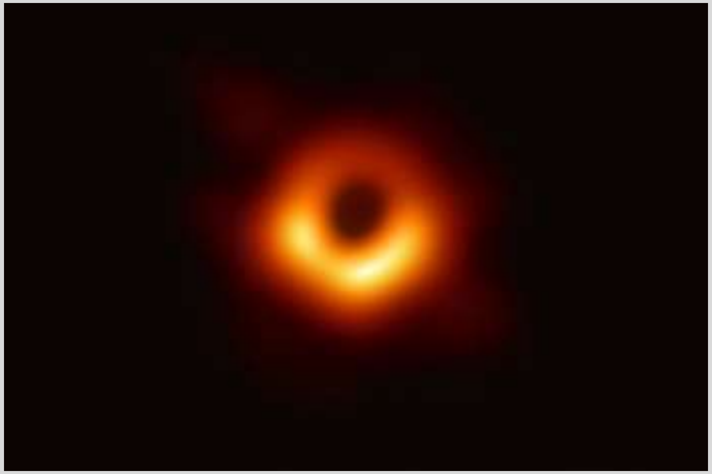
- ➢ Legacy S/X network: ~2000 TB/year
- ➢ VGOS: ~1000 TB/day (~40 TB/day/site)
- ➢ Required network data rates at...
  - each site: 5.6 Gbps *[now ~1–10 Gbps]*
  - correlator: 134 Gbps *[now 1–20 Gbps]*
- ❖ Challenges: transport bandwith, storage capacity

**Correlation:**

- ➢ Software correlator on PC cluster with off-the-shelf components (scalable)
- ❖ Challenge: power consumption (for processors and cooling)

# VGOS Technology in EHT

- The Event Horizon Telescope (EHT) project has just unveiled the first direct image of a black hole (in the Messier 87 galaxy)
- EHT and VGOS both used the same broadband VLBI technology synergistically developed at MIT Haystack Observatory
- EHT operates at 230 GHz, VGOS at 10 GHz, but the signal chain backends (i.e., RF distributors, down-converters, digitizers, recorders) are the same
- The broadband cluster correlator and post-processing software are leveraged efforts between both projects at MIT



*Black Hole Image*

*Mark 6 recorder*

*Broadband EHT/VGOS correlator*

# Comparison: S/X vs. VGOS

| | Legacy S/X System | VGOS System | Benefit |
|---|---|---|---|
| Antenna size | 5–100 m dish | 12–13 m dish | reduced cost |
| Slew speed | ~20–200 deg/min | ≥ 360 deg/min | more observations for troposphere |
| Sensitivity | 200–15,000 SEFD | ≤ 2,500 SEFD | more homogeneous |
| Frequency range | S/X band [2 bands] | ~2–14 GHz [1 broadband w/ 4 bands] | increased sensitivity, data precision |
| Recording rate | 128, 256, 512 Mbps | 8, 16, 32 Gbps | increased sensitivity |
| Data transfer | usually e-transfer, some ship disks | e-transfer, ship disks when required | |
| Signal processing | analog/digital | digital | stable instrumentation |

# VGOS: Possible Product Portfolio

| Product | Granule | Update every | Expected Accuracy (WRMS) | |
|---|---|---|---|---|
| Ultra-rapid | 0.5 hours | 0.5 hours | UT1−UTC: | 7 µs |
| Rapid w/ continuous near-real time correlation | 3 hours | 3 hours | UT1−UTC:<br>Polar motion:<br>Nutation offsets: | 5 µs<br>75 µas<br>75 µas |
| Rapid w/ batch correlation of 3-hr or 24-hr blocks | | 3–24 hours | | |
| Intermediate w/ continuous near-real time correlation | 3 hours | 24 hours | UT1−UTC:<br>Polar motion:<br>Nutation offsets: | 3 µs<br>45 µas<br>45 µas |
| Intermediate w/ batch correlation of 3-hr or 24-hr blocks | | 24 hours | | |
| Final | 3 hours | 7 days | UT1−UTC:<br>Polar motion:<br>Nutation offsets:<br>Telescope coord.:<br>Source positions: | 1 µs<br>15 µas<br>15 µas<br>3 mm<br>15 µas |

# Has a kangaroo pressed…

**Serious design flaw:**

- It happened at Yarra-gadee in Western Australia.
- You cannot think of everything.
- pedestal emergency stop button at head-height for a kangaroo
- kangaroo pressed e-button
- extension of experiment checklist

| | |
|---|---|
| Antenna: pad clear of obstructions | ☑ |
| Antenna: has a kangaroo pressed the pedestal e-stop button? | ☐ |
| Antenna: Time OK (i.e. SNTP server OK) | ☑ |

# Thanks for your attention!