International VLBI Service (IVS)

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on behalf of the IVS

Implementation of the GGRF in Latin America

Buenos Aires, Argentina

September 18, 2019

VLBI Site: E.g., Onsala Space Obs.

Courtesy R. Haas

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 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.

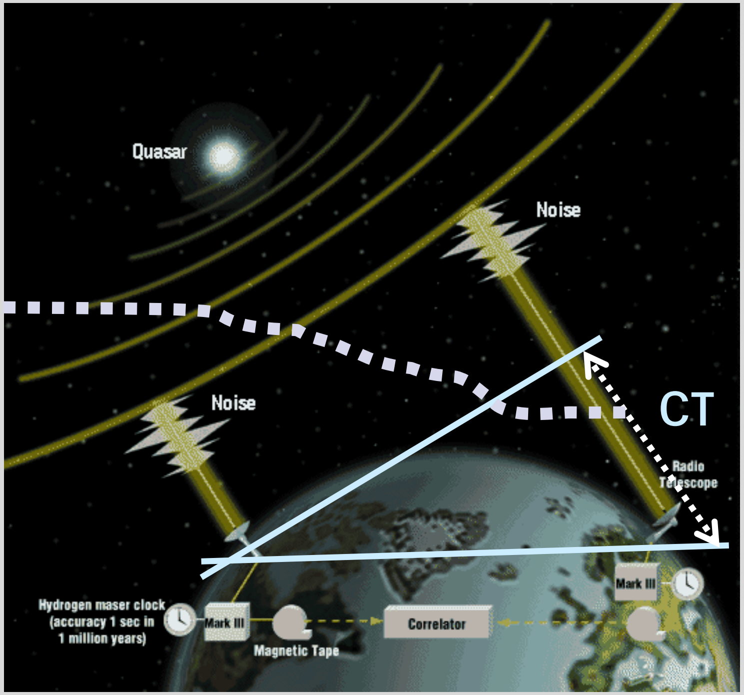
Geodetic VLBI: How does it work?

A network of antennas observes a Quasar

The delay between times of arrival of a signal is measured

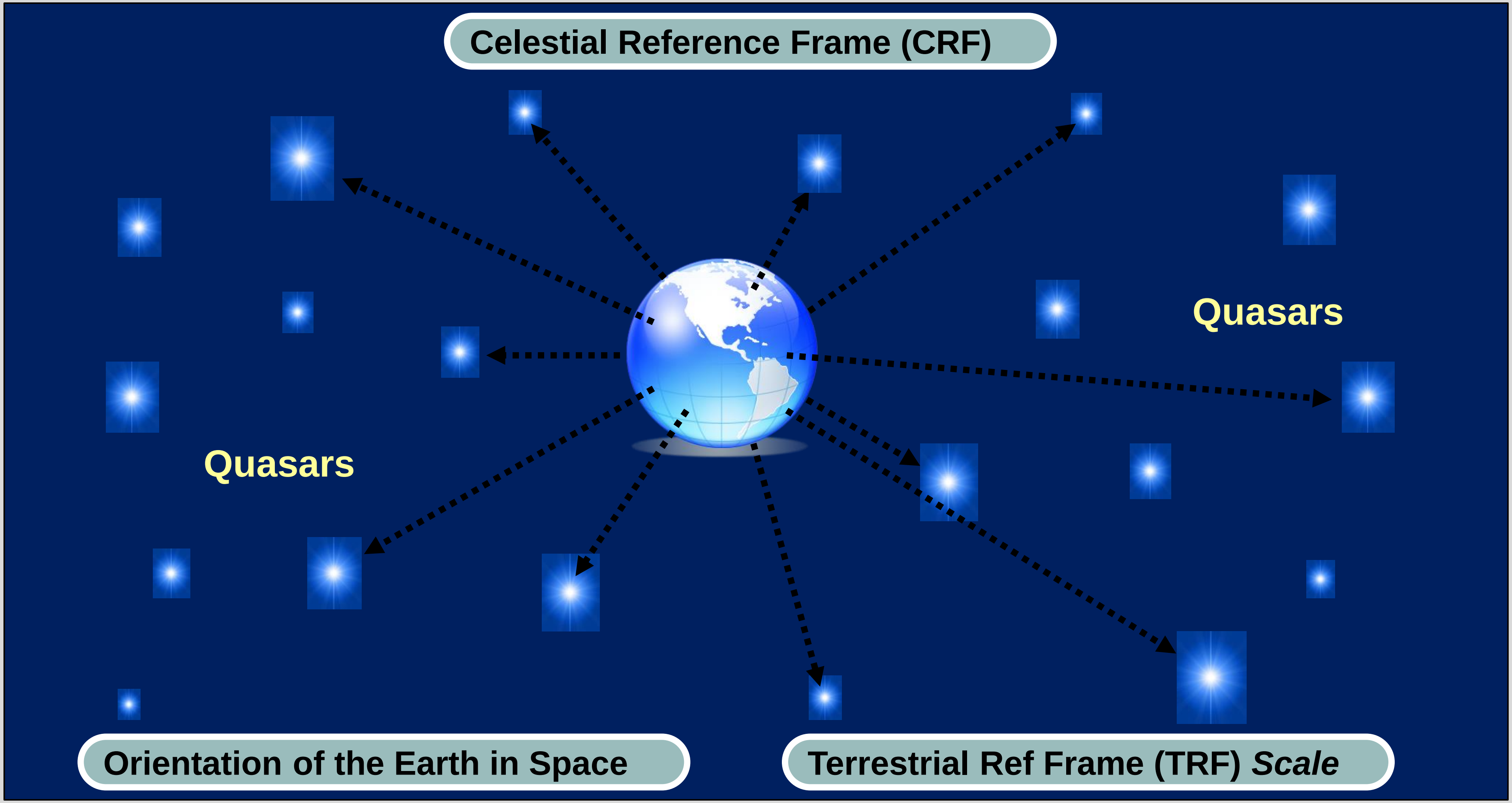
Using the speed of light, the delay is converted to a distance

The distance is the component of the baseline toward the source

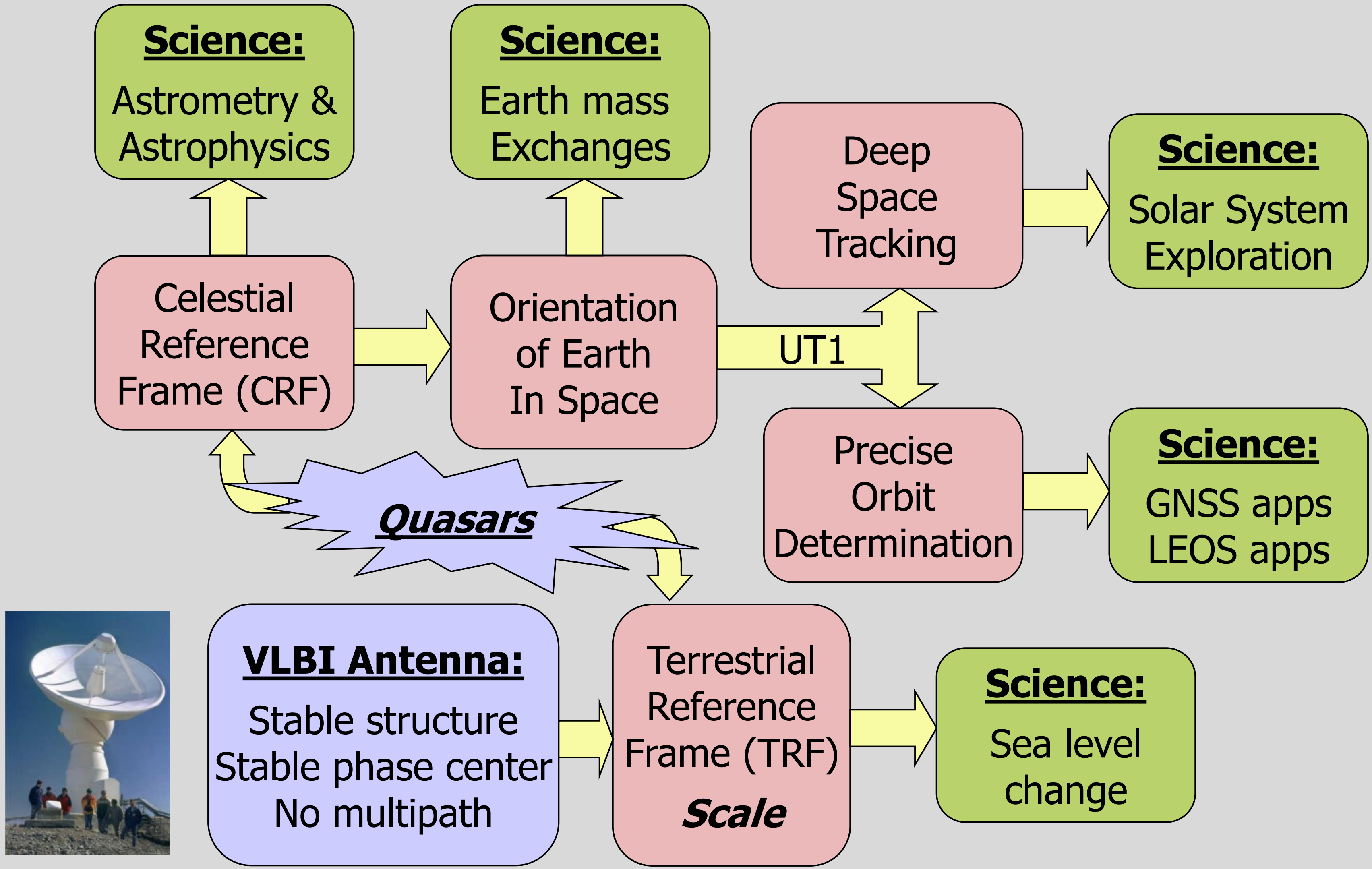


By observing many sources, all components of the baseline can be determined.

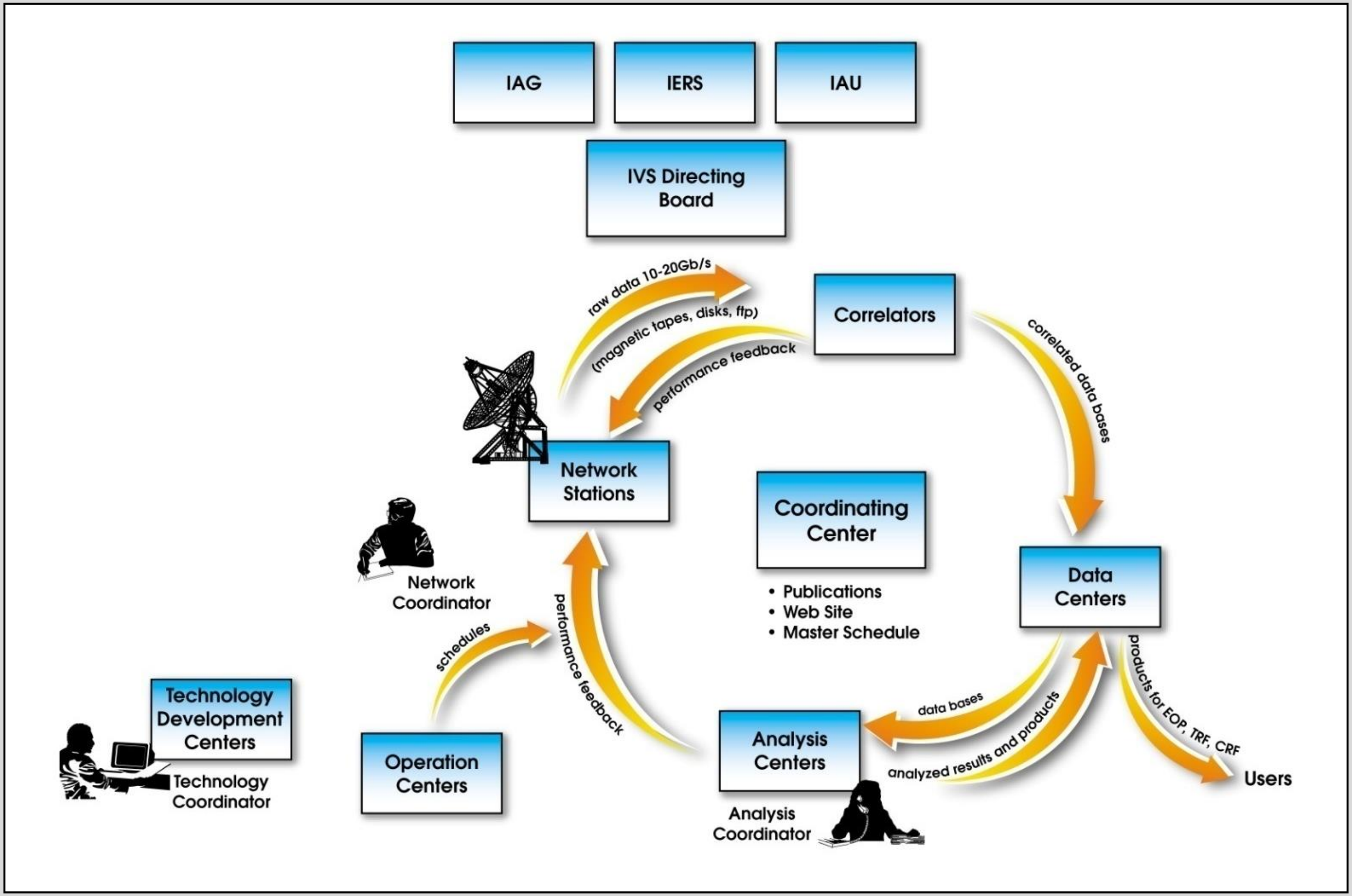
Role of VLBI in Geodesy



Role of VLBI in Science



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)

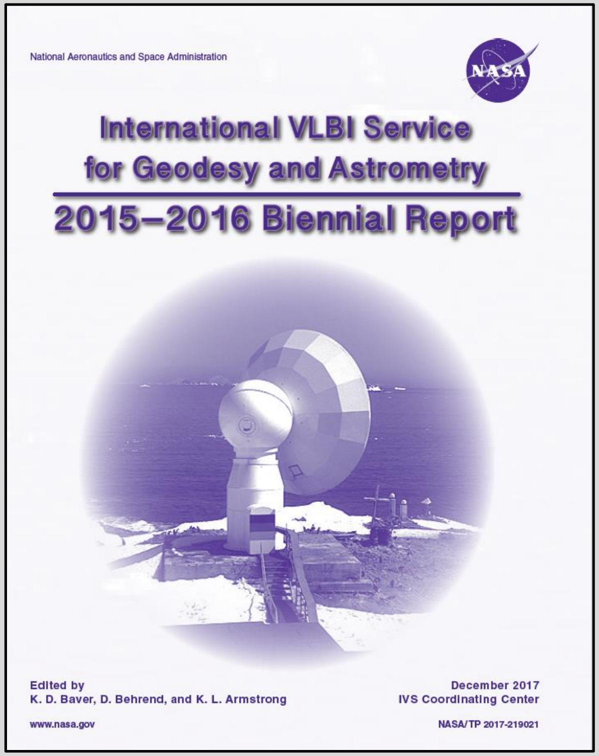
- Technical Meeting for all IVS components and interested scientists
- Organized every two years at different venues
- Next GM: 11th General Meeting, March 22–28, 2020 in Annapolis, MD, US; https://ivsgm2020.com/

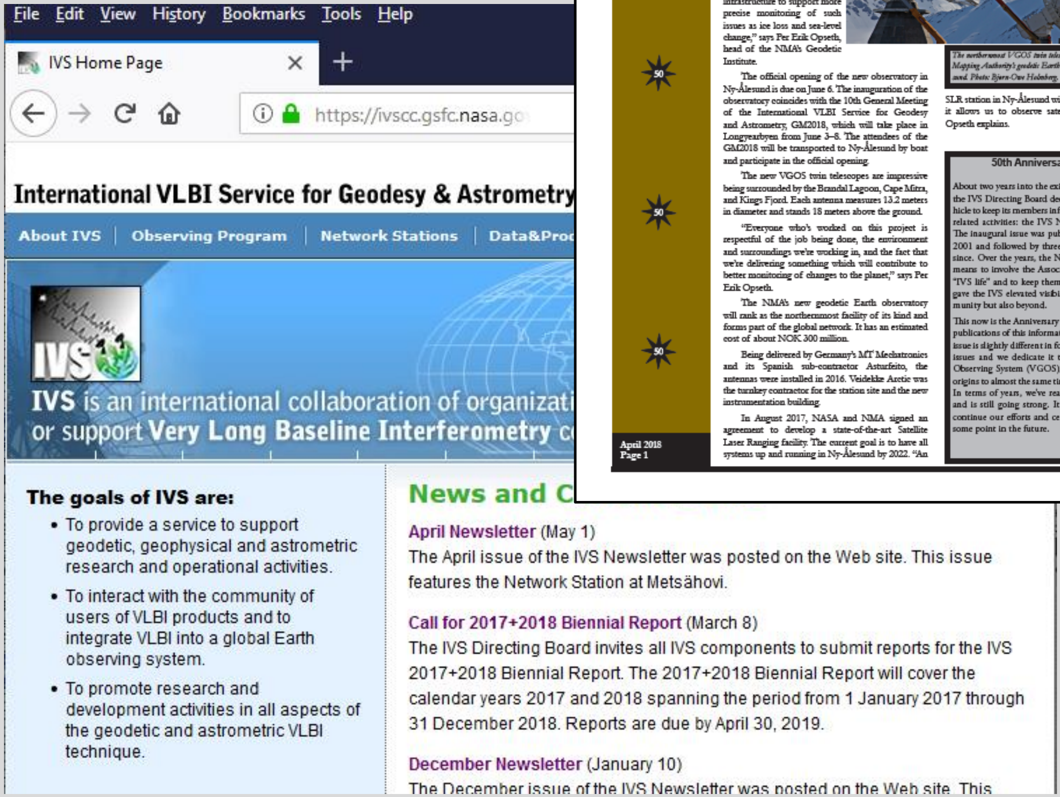
➢ Meetings with special topics/groups

- 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**






IVS Newsletter

Issue 50, April 2018

Ny-Ålesund – A Cornerstone for Global Geodetic Infrastructure

– Anne Jørgensen, Norwegian Mapping Authority

The new geodetic Earth observatory built by the Norwegian Mapping Authority (NMA) in Ny-Ålesund, 79 degrees north, will be inaugurated in June. "Ny-Ålesund will thereby host a station which will be a cornerstone of the global infrastructure to support more precise monitoring of such issues as ice loss and sea-level change," says Per Erik Opseth, head of the NMA's Geodetic Institute.

The official opening of the new observatory in Ny-Ålesund is due on June 6. The inauguration of the observatory coincides with the 10th General Meeting of the International VLBI Service for Geodesy and Astrometry, GM2018, which will take place in Longyearbyen from June 3–8. The attendees of the GM2018 will be transported to Ny-Ålesund by boat and participate in the official opening.

The new VGOS twin telescopes are impressive being surrounded by the Brandal Lagoon, Cape Mitra, and Kings Fjord. Each antenna measures 13.2 meters in diameter and stands 18 meters above the ground.

"Everyone who's worked on this project is respectful of the job being done, the environment and surroundings we're working in, and the fact that we're delivering something which will contribute to better monitoring of changes to the planet," says Per Erik Opseth.

The NMA's new geodetic Earth observatory will rank as the northernmost facility of its kind and forms part of the global network. It has an estimated cost of about NOK 300 million.

Being delivered by Germany's MT Mechatronics and its Spanish sub-contractor Asturfeito, the antennas were installed in 2016. Veidekke Arctic was the turnkey contractor for the station site and the new instrumentation building.

In August 2017, NASA and NMA signed an agreement to develop a state-of-the-art Satellite Laser Ranging facility. The current goal is to have all systems up and running in Ny-Ålesund by 2022. "An SLR station in Ny-Ålesund will be important because it allows us to observe satellites in polar orbits," Opseth explains.

The northernmost VGOS twin telescopes at the Norwegian Mapping Authority's geodetic Earth observatory in Ny-Ålesund. Photo: Bjørn-Owe Holmberg.

50th Anniversary Issue

About two years into the existence of the service, the IVS Directing Board decided to launch a vehicle to keep its members informed about service-related activities: the IVS Newsletter was born. The inaugural issue was published in December 2001 and followed by three issues per year ever since. Over the years, the Newsletter served as a means to involve the Associate Members in the "IVS life" and to keep them abreast of events; it gave the IVS elevated visibility within the community but also beyond.

This now is the Anniversary Issue to celebrate 50 publications of this information tool. The golden issue is slightly different in format to the standard issues and we dedicate it to the VLBI Global Observing System (VGOS), which can trace its origins to almost the same time as the Newsletter. In terms of years, we've reached "sweet sixteen" and is still going strong. It is our aspiration to continue our efforts and celebrate 100 issues at some point in the future.

– The Editor Team

April 2018
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https://ivscc.gsfc.nasa.gov/

IVS Products

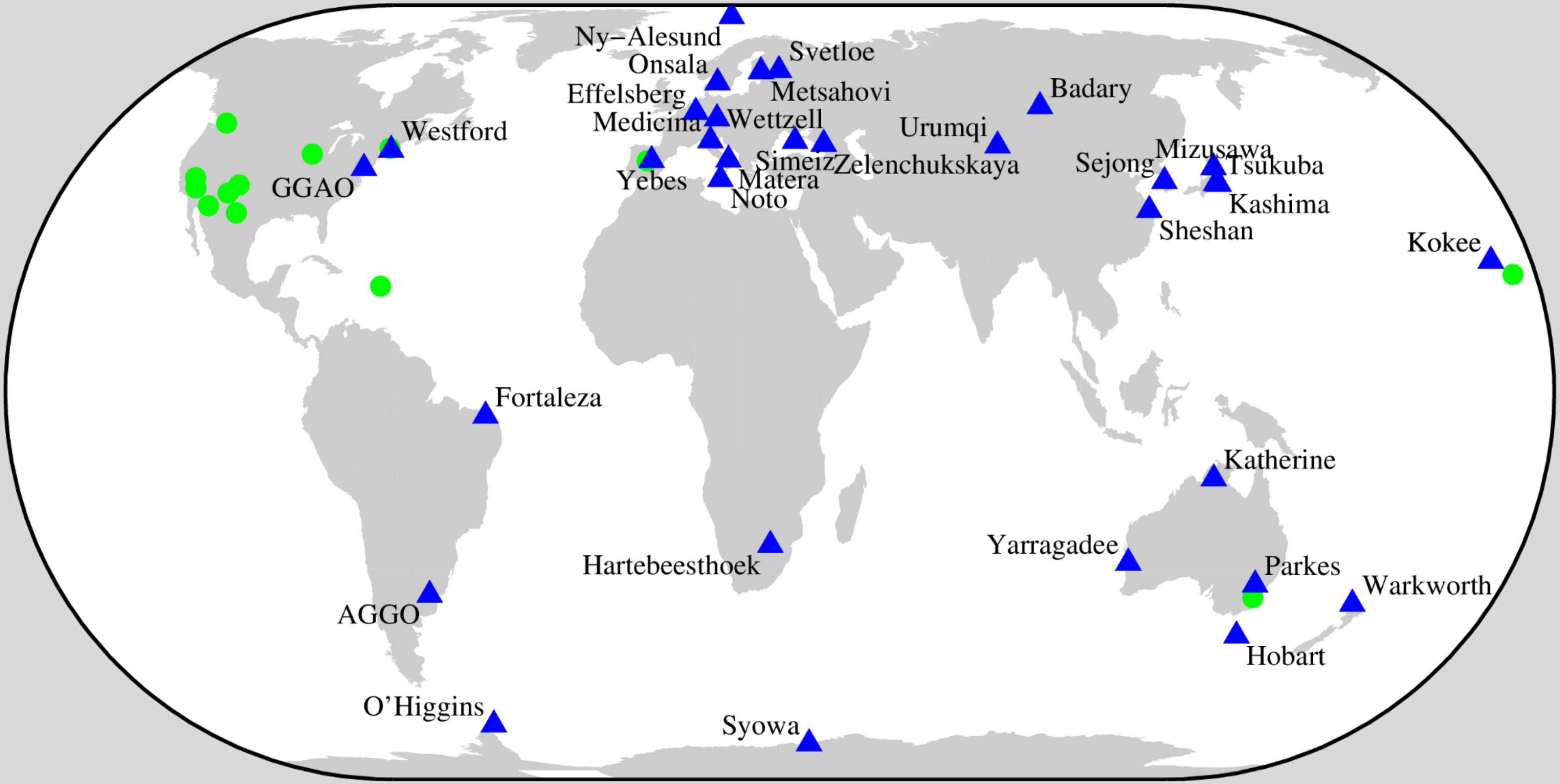
- Earth Orientation Parameters (EOP):
  - 24-hour sessions (all EOP)
  - 1-hour Intensives (UT1−UTC)
- Terrestrial Reference Frame (TRF)
  - VLBI Terrestrial Reference Frame (VTRF)
- Celestial Reference Frame (CRF)
- Daily EOP + station coordinates (SINEX-files)
- Tropospheric Parameters (TROPO)
- Baseline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

VLBI Sites in South America

Fortaleza, Brazil

AGGO, La Plata, Argentina

IVS Network Stations



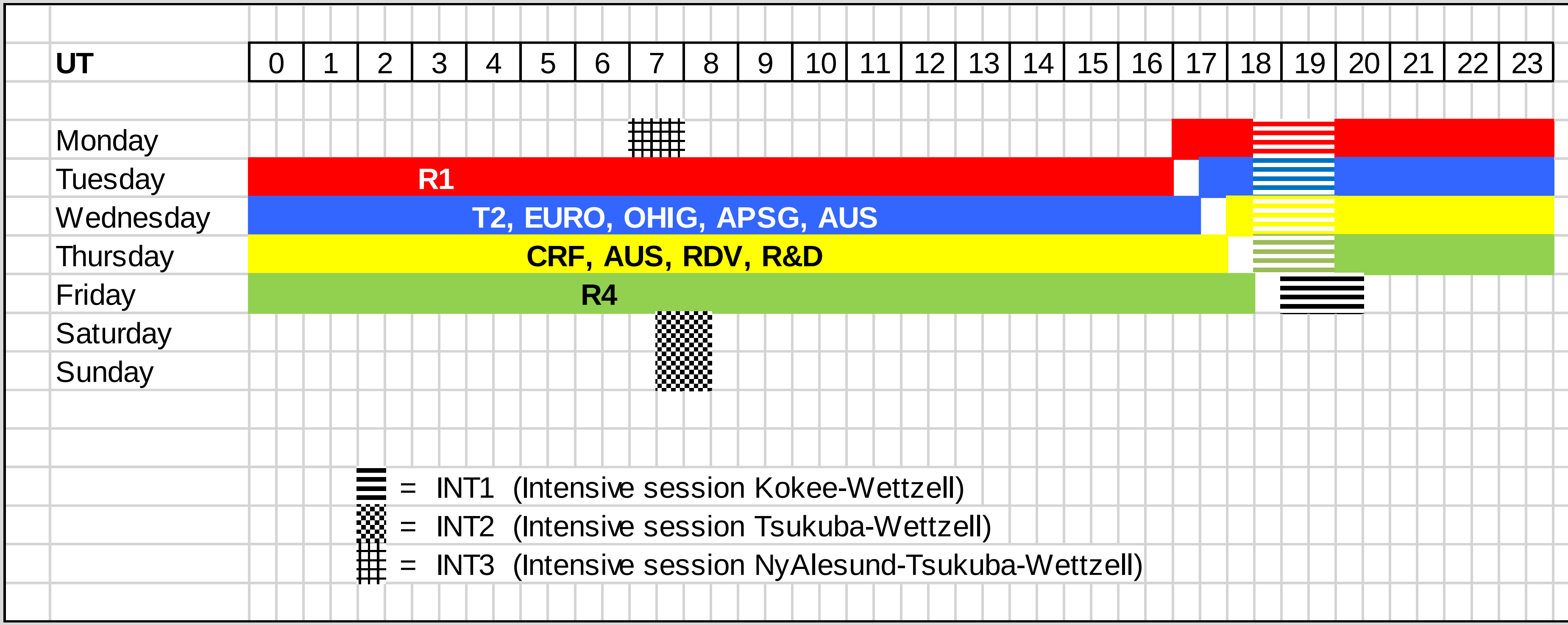
IVS Network Station
Cooperating VLBI Site

IVS Observing Program

- about 180 sessions per year, 3.5 sessions per week
- Complete EOP in two weekly 24-hr sessions:
  - R1 on Mondays, R4 on Thursdays
  - 15-day rapid turnaround
- UT1−UTC in daily 1-hr Intensive sessions
- CRF sessions: CRF, CRD (CRF with emphasis on deep south)
- TRF sessions: global (T2); regional (EURO, OHIG, APSG, JADE, AUSTRAL)

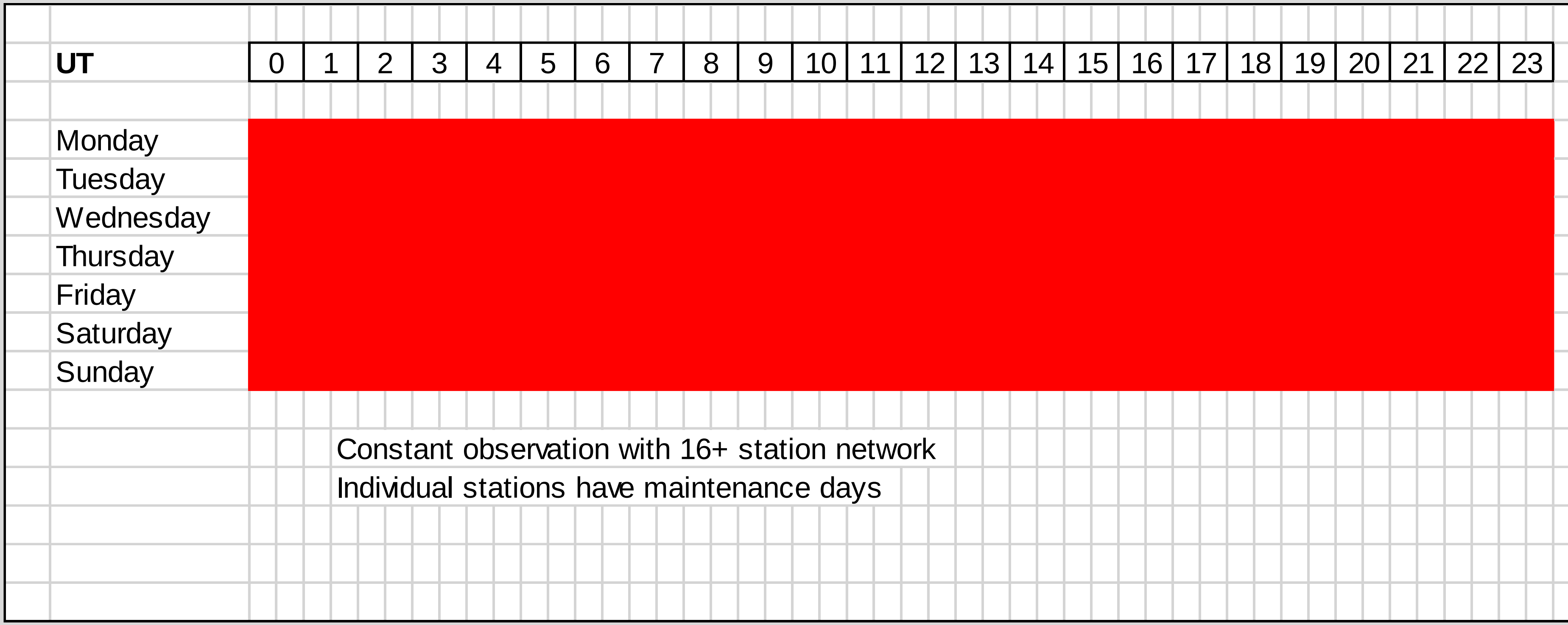
IVS Observing Program: S/X System

- Typical weekly layout for IVS observing sessions



IVS Observing Program: VGOS

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



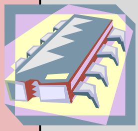
VGOS: Why do we need it?

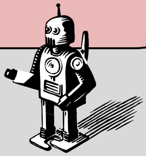
Aging systems (now ~40 years old):

- Old antennas
- Obsolete electronics
- Costly operations
- RFI

New Technology:

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



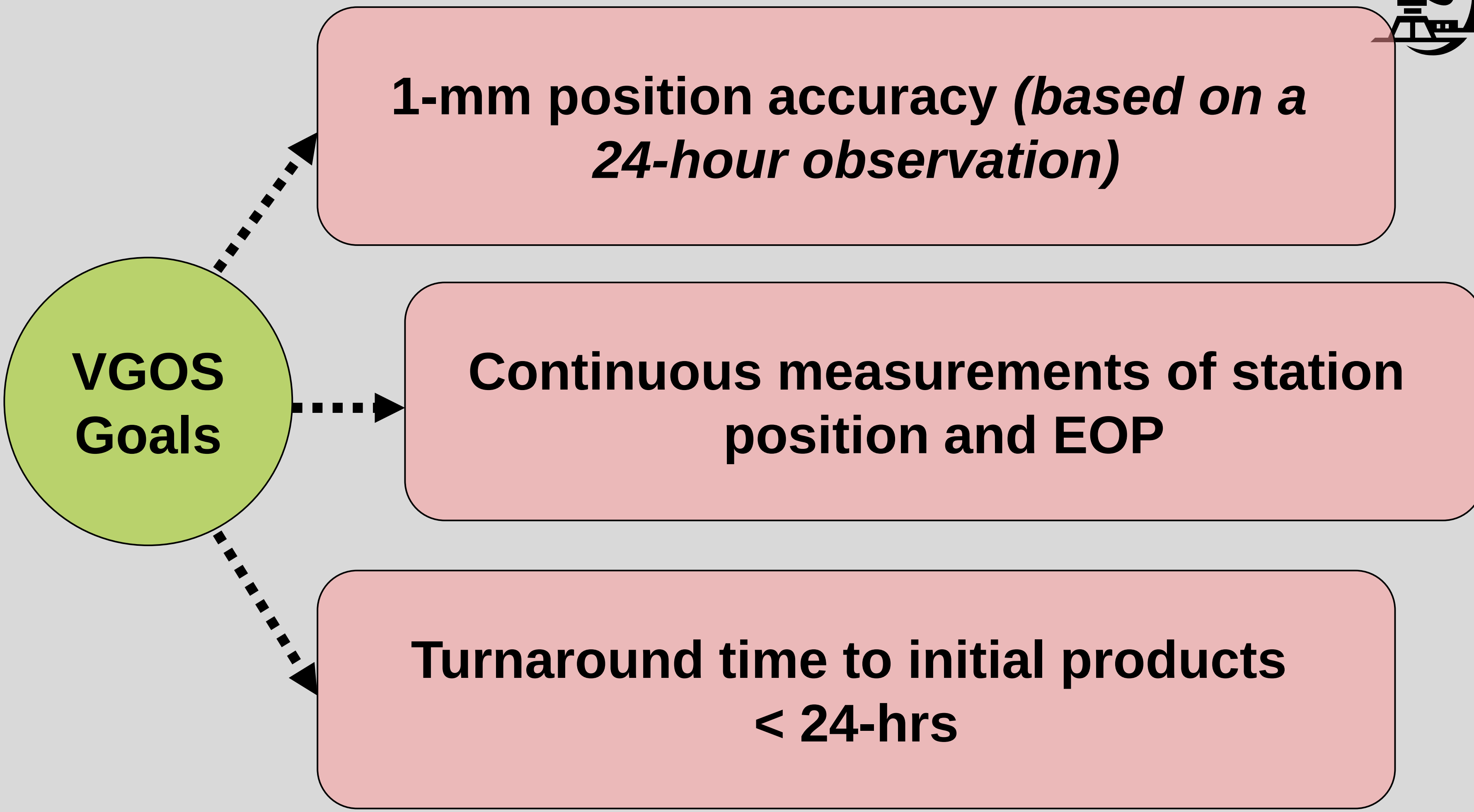


New system

New requirements:

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

VGOS: Goals of new system



VGOS (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)

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

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

Status of RAEGE Project

Yebes (Spain) *Courtesy J.A. López Fernández*

Santa Maria (Eastern Azores, Portugal)
Courtesy F. Colomer

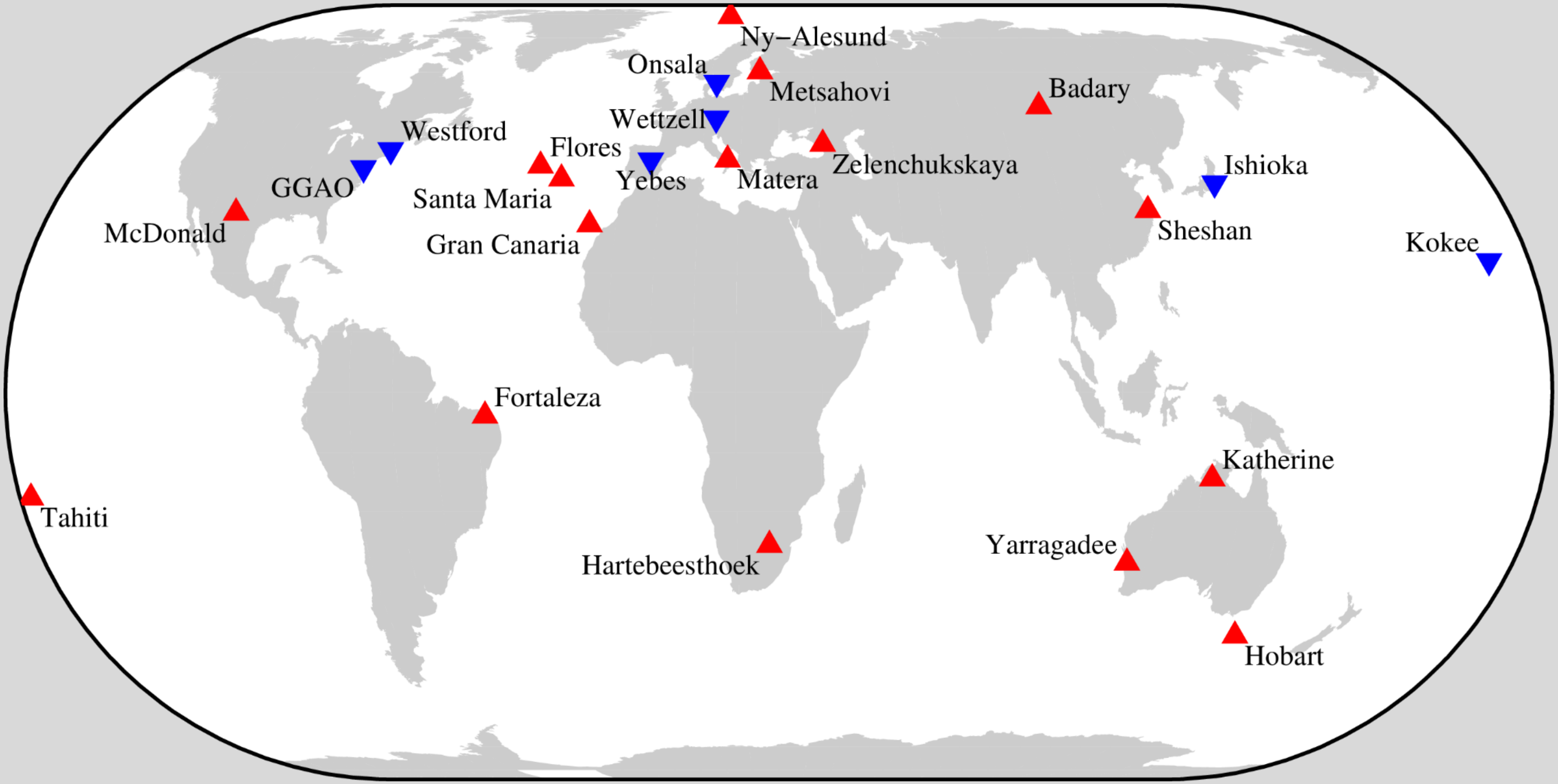
VGOS Roll-out Status (1/2)

Station	Recent milestone	VGOS broadband
GGAO	VGOS CONT17, VT sessions	ready
Westford	VGOS CONT17, VT sessions	ready
Wettzell South	VGOS CONT17, VT sessions	ready
Yebes	VGOS CONT17, VT sessions	ready
Ishioka	VGOS CONT17, VT sessions	ready
Kokee Park	VGOS CONT17, VT sessions	ready
Onsala (Oe, Ow)	VT sessions	ready
Badary	Fixed broadband system	2017 (S/X/Ka)
Zelenchukskaya	Fixed broadband system	2017 (S/X/Ka)
AuScope (Hob-art, Katherine)	Successful fringe tests	Q4 2019
Santa Maria	Started S/X observing	end 2019
AuScope (Yarragadee)	Upgrade work in progress	early 2020

VGOS Roll-out Status (2/2)

Station	Recent milestone	VGOS broadband
Sheshan	Fringe test	2019
Ny-Ålesund South	Started S/X observing	2019
Ny-Ålesund North	Installation of broadband receiver	end 2019
HartRAO	RT erected, signal chain work	2019
Svetloe	RT erected, stability tests	2019 (S/X/Ka)
McDonald	First fringes	end 2019
Gran Canaria	RT in warehouse, civil works	2020
Metsähovi	RT SAT, signal chain work	2020
Tahiti	Site selected, RFI survey	2022
Brazil (Fortaleza)	Under discussion	2022
Flores	RFI surveys	2022+

Projected VGOS Network by early 2020s

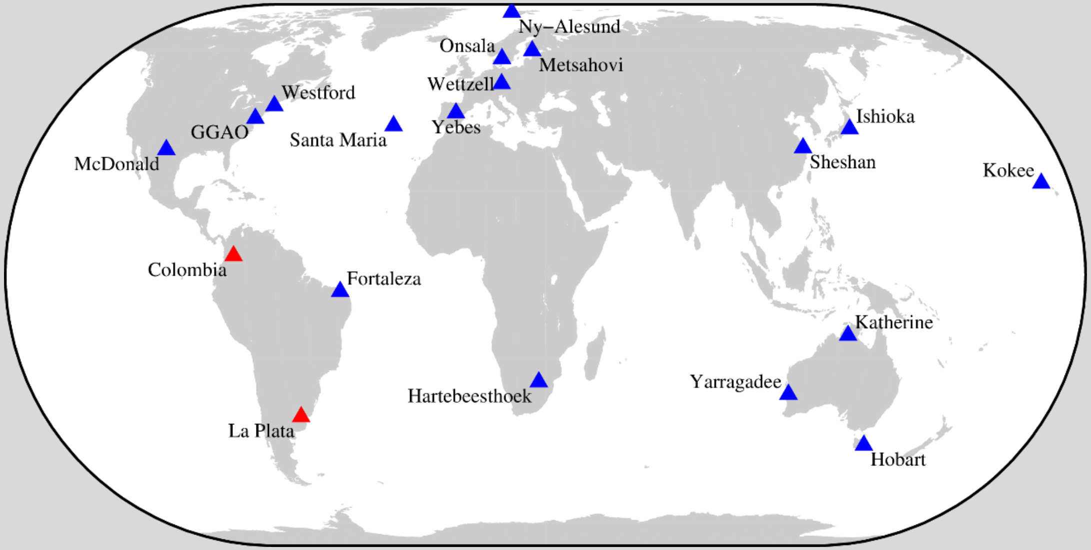


▼ VGOS antenna broadband ready

▲ VGOS antenna under construction or planned

VGOS in So. America: EOP Simulations

- Monte-Carlo simulations
- 24-hour session
- Simulated delay from clock noise, tropospheric turbul-ence, 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: Data Analysis

Analysis:

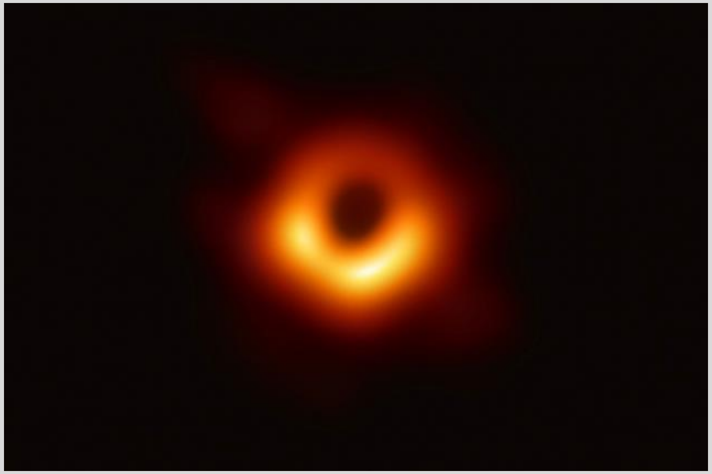
- Tremendeous increase in observables
- High degree of automatization required
- Different levels of latency (next slide)
- Dependency on rapid availabilty of auxiliary data, e.g.,
  - Meteorological data
  - Mapping functions from numerical weather models

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: Polar motion: Nutation offsets:	5 µs 75 µas 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: Polar motion: Nutation offsets:	3 µs 45 µas 45 µas
Intermediate w/ batch correlation of 3-hr or 24-hr blocks		24 hours		
Final	3 hours	7 days	UT1−UTC: Polar motion: Nutation offsets: Telescope coord.: Source positions:	1 µs 15 µas 15 µas 3 mm 15 µas

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

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)	☑

Questions?