Lessons-learned from VSOP-2 - the unseen space-VLBI project

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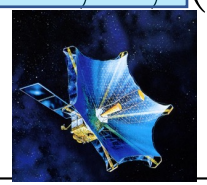
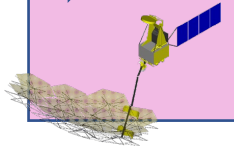
Comparison of VSOP-2 with VSOP/RadioAstron

Engineering test satellite | **Science mission**

Specification	VSOP	VSOP-2	RadioAstron
Antenna Diameter (m)	8	9.2	10
Apogee (km)	21500	25000	320000
Orbit period	7.5 hours	6.3 hours	9.5 days
Polarization	LCP[a]	LCP/RCP[a]	LCP/RCP
Data downlink rate	128 Mbps	1 Gbps	144 Mbps
Frequency (GHz)	1.6, 5, (22[b])	8, 22, 43	0.3,1.6,5,22
Highest angular resolution (microarcsecond)	360	38	7





a) LRC: Left Circular Polarization, RCP: R…larization

b) After launch, the 22 GHz band receiver …ely degraded for observations.

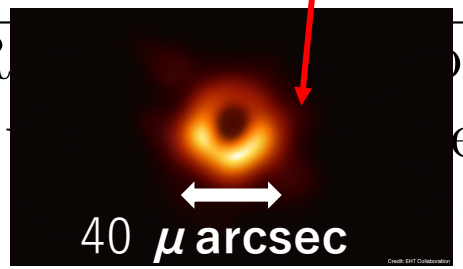


Image credit: EHT collaboration

Hagiwara 2018

A brief history of VSOP-2 (2007-2011)

2007.7 Project formally started - Basic design review

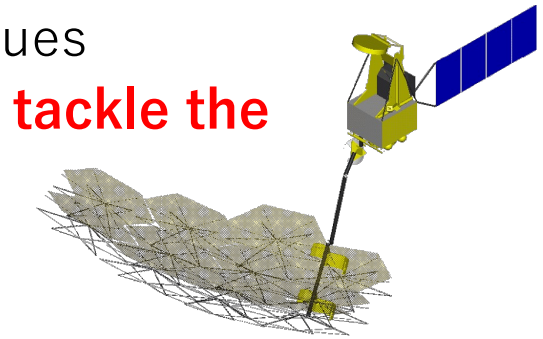
: Launch in 2012, budget 14 billion JPY, LDR (large deployable reflector) with 0.4mm rms surface accuracy for 7mm (43G) observation)

2008.6 PDR

2009.7 Technical issues found in the LDR. Project suspended.

2009.8-9 ISAS evaluation team formed to understand the technical issues

2009.10-2010.6 Technical evaluation team ("Tiger team") formed to tackle the LDR technical issues



2010.10 Outcome of the evaluation

- **The LDR surface estimated to 1.0mm rms) => Difficulty in 7 mm (43G) obs**
- Launch will be in **2016 at the earliest (<= 2012)**
- **Budget re-estimated to 23.2 billion JPY (<= 14 billion JPY)**

=> **ISAS asked VSOP-2 SWG whether we continue the project or not**

, with remarks "Once you decide to restart the project, you can no longer stop whatever happens in future".

=> VSOP-2 /VLBI community replied their wish to continue the project, re-organizing the community support, along with support letters of VISC-2.

2010.7-10 Project "termination" suggested by ISAS Science Steering Committee

<= **The mission is no longer able to achieve the primary science goal**

2011.6-8. Project termination review approved at JAXA , and a review at MEXT (Ministry of education, science, …).

2011.11 The project termination formally approved at the MEXT.

2010.10-2011.11. Discussions of project summary continued within both Radio astronomy and VLBI consortium in Japan

Conclusions at ISAS Science Steering Committee

- **The primary science goal promised to the community (Imaging an accretion disc or black hole silhouette of M87 at 38 μarcsec resolution) is no longer attained due to the LDR surface accuracy of 1mm rms.**

- **Suggested to organize a new working group and start over from the basic development of a main reflector, etc.**

- The mission is based on a **"smaller" domestic user community** and "fragile" supporting system, compared to, for example, the X-ray astronomy community.
  - 70-80 users of S-VLBI data including ph.d students in Japan
    (e.g. > 500 users in the X-ray community)

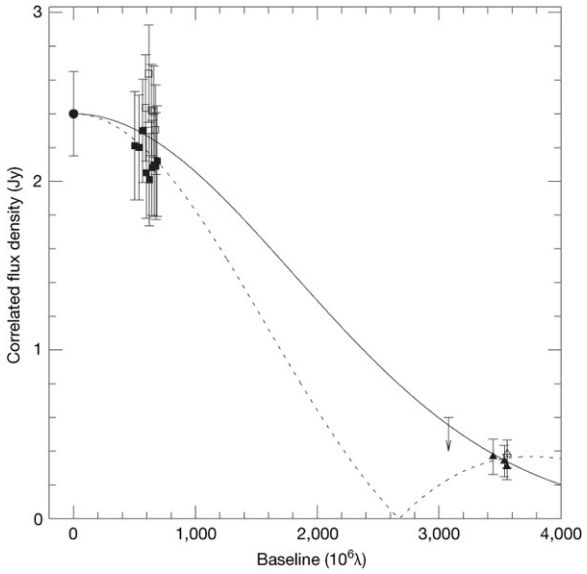
- Lack of **strong leadership to continue** the mission

- **Other points**

- Are the mission science goals attainable ONLY with S-VLBI?
  - An accretion disc can be imaged with the ground sub-mm VLBI ?

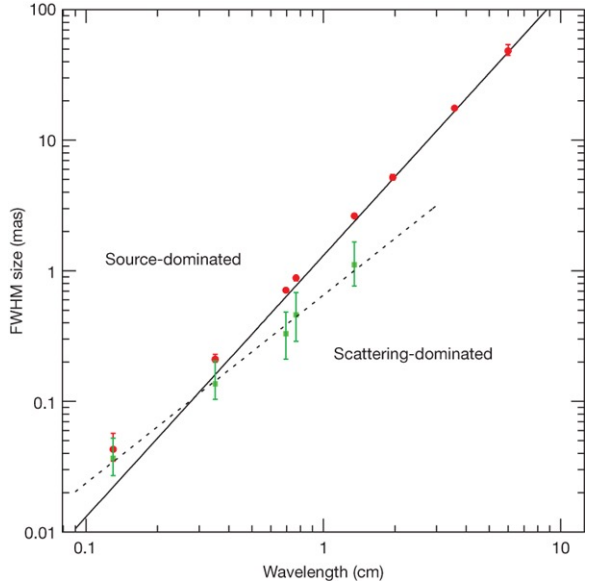
  (**e.g. Doeleman+ 2008, Nature**) **?**

<= X-ray observations are not possible on the ground so that they need a satellite.



<= Fitting the size of SgrA* **with 1.3mm wavelength VLBI.**

Observed and intrinsic size of SgrA* as a function of wavelength =>



nature SS Doeleman *et al. Nature* **455**, 78-80 (2008)

The VSOP-2 summary discussion at the Japanese VLBI consortium meeting (~2010)

- General points discussed

- **Was the summary/review of VSOP-1 (”HALCA") properly made?**
  For example, the 22GHz receiver didn't work well.
- Science that could not be achieved by HALCA was not well reviewed before starting VSOP-2.
  => **Was HALCA's experience of success too strong to look back the past?**
  => VSOP-2 started before **lessons-learned from HALCA.**

- Opinions

- **Few people who "risked their lives"** to continue the project. (“Harakiri” concept?)
  For the next project, we need to have several people like that.
- Too many difficult demands in science: **The most difficult 43 GHz observation was emphasized too much.**
- There were potential S-VLBI data users, but the spread of the community was not enough.

Lessons-learned from VSOP-2 – Personal views

1. The setup of the Science goals

- **Emphasis put on the accretion disc imaging at 43 G**
- Why not including more science cases **at 22 G?**
  (e.g. H_2O Megamaser Cosmology)
  <= **The LDR with 1mm rms surface accuracy is still capable of it!**
  - Maybe, due to distinguishing from the science goals (H_2O MM) of i-ARISE?
- 8/22 G-band Science cases not well implemented to science goals
- **Acquiring more users required setting broader science goals**

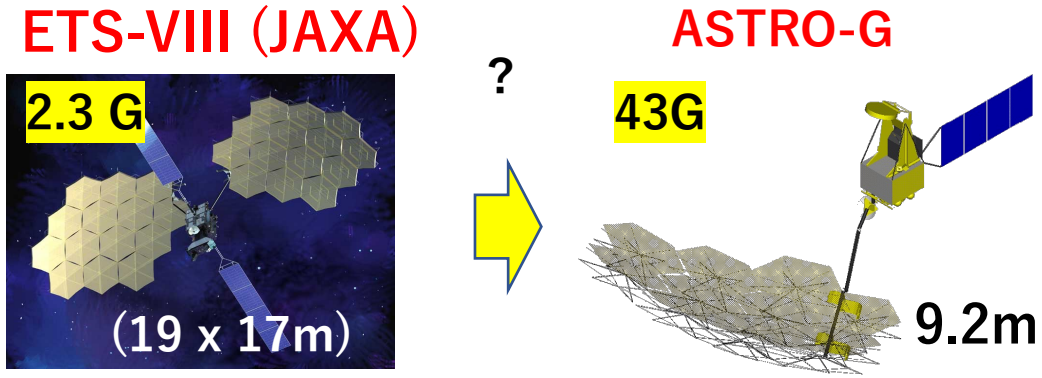
2. Collaboration with International community

- Was the international community well involved with the satellite design at an earlier stage of the project ?

e.g. Did we have sufficient discussions, before deciding on the observing frequencies of **8/22/43GHz? VSOP-1 frq was 1.6/5/22 GHz.**

3. Were the satellite instruments technically feasible and really necessary for the mission science?

- **Deployable mesh antenna** was the best solution for 43 G observations ?
- Technology (seems to be) based on **the 2.3 GHz deployable antenna for the S-band** communication satellite
- Fast-switching (~1min) for Φ referencing
- Precise orbit determination at 1cm level



4. Ground tracking (Data-link) stations

- **One of the most important issues for S-VLBI**
- **VSOP (HALCA) had 5 tracking stations - they were expected for both HALCA and RadioAstron (RA).**
- **In a way, HALCA benefited from RA's setup**

- For VSOP-2 tracking stations, the MoO proposal ("**SAMURAI**", led by D.Murphy) submitted to NASA in Jan 2008 **was not selected**.
- Nevertheless, the **science cases in SAMURAI highly evaluated**.

- Instead, we had a "Plan B" - What to do if it is rejected.
  - **Yebes (OAN) 14m as a dedicated tracking stations** – looked fairly certain support !
  - Potential support offered from South Africa and Taiwan, however, the number of stations was far enough to fully consider

SAMURAI

Image redit: H.Hirabayashi

What should've been done?

Upon an ISAS/JAXA decision, we were not allowed to continue the mission.

- After the project termination, should we organize a new WG and re-start VSOP-2 as suggested by the ISAS steering committee?

- VSOP-2 core members did have little capacity to do so. In particular, it is true that they were exhausted both physically and mentally from the technical verification team (Tiger team) work that lasted nearly for a year.

- Maybe, they (or I myself) should've consulted the international community through VISC-2 etc. on what to do next, but **the disappointment on the Japanese side was so great that they did not have an energy to look to the future.**

Lessons-learned from VSOP-2

“Learn only from the past, look to the future, but live in the present.”

What required for a next S-VLBI mission

1) **Strong science cases**
   - To set up the goals that will be worth for at least 10 years

2) **Technical feasibility**
   - The technical feasibility necessary for the scientific goal should be possible **at the time of proposing a mission**
   - Engineering scientists should be involved as well as astronomers

3) **Strong community (not only "user" community)**
   - Astronomers encouraged to participate the instrumentation

4) **Budget feasibility** - relevant to 2)
   - No matter how good a plan is, **a project without a well-considered budget plan** ***will fail.***

Comparison of VSOP-2 with ng S-VLBI

Check	VSOP-2	ng-SVLBI (high-f, > 230G)
Strong science case	○ (Accretion discs in M87 etc)	◎ (**BH shadows**: Testing relativity or a new physics under strong gravitational fields etc.)
Technical feasibility	✕ (1mm rms for 7mm obs)	○ **(e.g.,** RadioAstron 10m solid panel ant., JWST)
Strong community	△ (smaller community in a hosting country)	◎ (> **300 people**)
Budgeting	✕	

Final thoughts

With more efforts, the VSOP-2 mission might have been saved.

But we couldn't. We have to admit our "failure" as a reality.

Overall, VSOP-2 science case was right. In a sense,

, thanks to the EHT imaging of BH shadows, part of our science goals has been justified

A next-generation S-VLBI mission will be realized in near future - the time is ripe with the great achievement of EHT!