Half a century of Space VLBI: *lessons learned*

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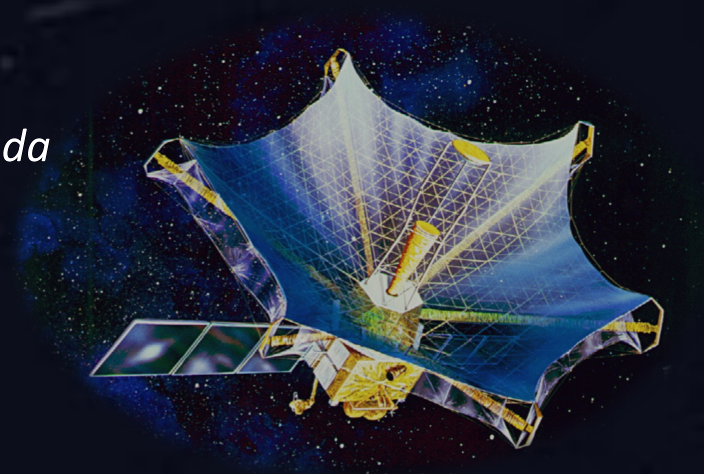
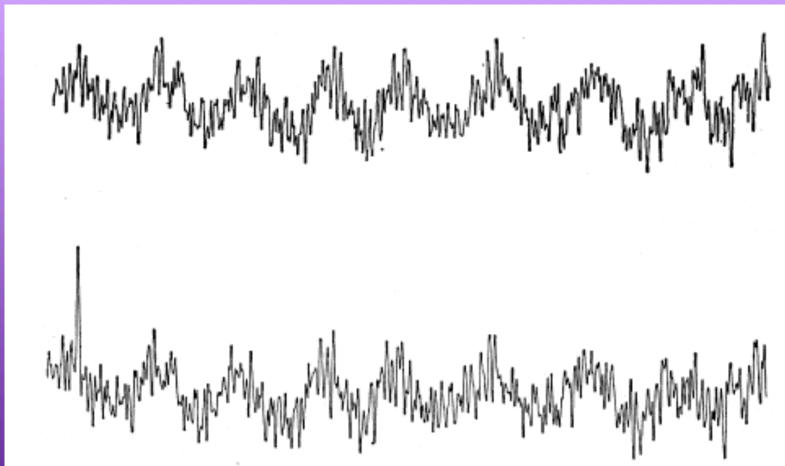
August 2017

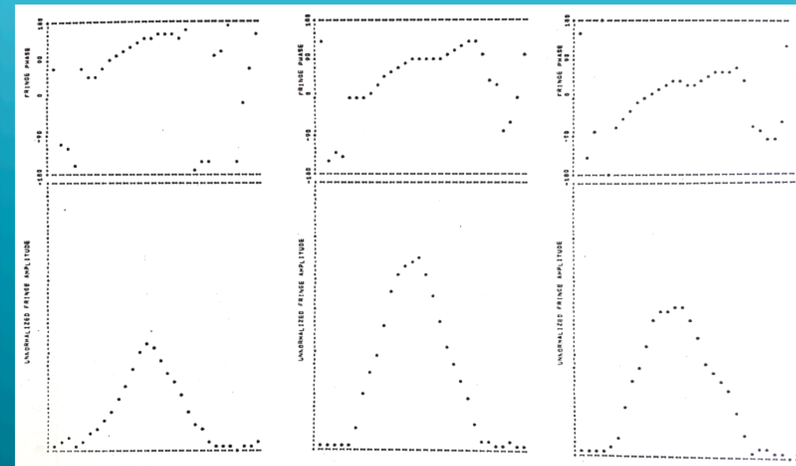


2017: 50 years of first VLBI fringes



VLBI fringes on 3C 294 (short baselines), VLBI technology demo

Broten et al. 1967, Science 156, 1592-93



VLBI detections (OH) Haystack–NRAO, observed 1967.06.08

Moran 1968, PhD thesis, MIT

Table 1. Interferometer fringe visibility. S_0, 21.5×10^{-26} watt/m² per hertz assumed flux for 3C 286 at 610 Mhz; S/S_0, assumed ratio of flux to that of 3C 286; F/F_0, ratio of fringe amplitude to that of 3C 286; γ, fringe visibility.

Source	S/S_0	F/F_0	γ
3C 237	0.51	0.37	0.71
3C 273B	.82	.86	1.02
3C 286	1.00	1.00	0.97
3C 287	0.49	0.54	1.07

VLBI detections NRAO-USNO

Bare, Clark, Kellermann, Cohen, and Jauncey 1967, Science 157, 189-191

For first-hand history details – see *Moran J.M. 1998, ASP Conf. Ser. v. 144*

Early 1960s: origins of VLBI

ИЗВЕСТИЯ ВЫСШИХ УЧЕБНЫХ ЗАВЕДЕНИЙ
Том VIII, № 4 РАДИОФИЗИКА 1965

Поступила в редакцию
27 января 1964 г.,
после доработки
14 января 1965 г.

ON RADIOINTERFEROMETER WITH A LARGE BASE

L. I. Matveenko, N. S. Kardashev, G. B. Sholomitsky

The radiointerferometer system without retranslation has been considered. The signal registration at the intermediate frequency is carried out independently by each antenna (by recording on a magnetic tape) with subsequent common processing of these results. The usage of two independent heterodynes imposes the following condition for their frequency stability $\sqrt{\overline{\Delta f_h^2}}/f_h \leqslant 1.6 \cdot 10^{-11} D$ (D is the base length in km). The merits of such interferometer have been discussed.

Table 3. Early VLBI Experiments

Observ.[a] Date	Pub. Date	Ref[b]	Freq (MHz)	Station[c]	B (Km)	θ ($''$)	Type[d]	Sys[e]	Source[f]	Fate[g]
1964–65	1965	1,2	18	XY	55	62	I	F1	J	S
67/01/17	68/01	3,4	18	XZ	218	16	C	F2	J	S
67/01–02	1988	5	610	GP	2550	0.04	C	M1	Q	F
67/02	67/06/23	6	448	AA	0.2	690	C	C	Q	S
67/03/15	67/07/14	7	610	GG	0.7	145	C	M1	Q	S
67/04/13	67/07/01	8	448	AD	3074	0.04	C	C	Q	S
67/05/06	67/07/01	8	448	AO	250	0.6	C	C	Q	S
67/05/09	67/07/14	7	610	GN	226	0.4	C	M1	Q	S
67/06/08	68/09	9	1665	GK	845	0.04	C	M1	Q	S
67/06/08	67/08/11	10	1665	GK	845	0.04	C	M1*	M	S
67/06	67/09/09	11	2295	TW	110	0.2	I	A	Q	S
67/06/29			1665	GK	845	0.04	C	M1	Q	F
67/06/29	1968	12	1665	GK	845	0.04	C	M1*	M	F
67/07/22	>67/09	13–15	1665	GH	3506	0.01	C	M1	Q/M	S
67/07/29	67/10/07	16	448	AD	3074	0.04	C	C	Q	S
67/08/17	1968	12	1665	GJ	5870	0.006	I	J1	M	F
67/08	70/04	17	610	GP	2550	0.04	C	C	Q	S
67/10	1969	18	448	AD	3074	0.04	C	C	Q	S
68/01/27	1968	19	1665	GKHS	<7720	0.005	C	M1	Q/M	S
⋮										
68/06	1969	18	408	AJ	5127	0.03	C	C	Q	S
68/09		20	610	JP	6470	0.02	C	J2	Q	S

VLBI in 1963: technically feasible, but pointless as all sources ought to be resolved?

WRONG!

Moran J.M., “Thirty years of VLBI”, 1998, IAUColl #164, ASP ser .144

Space VLBI “conspiracy”

Matveenko, Kardashev, Sholomitsky 1965 (manuscript of 1963)

- Предлагаемую систему удобно также использовать для радиоастрономических наблюдении с ИСЗ. Система из двух антенн, установленных на ИСЗ, работающая по описанному выше принципу, позволит получать при больших базах не только амплитудные, но и пространственно-фазовые характеристики интерференции, а, следовательно, детально исследовать распределение яркости дискретных источников очень малых угловых размеров. В этом случае устраняются ионосферные и тропосферные флуктуации, являющиеся основным препятствием при измерении фазы.
- The [interferometric] system proposed here can be used conveniently for radio astronomy observations from artificial Earth satellites. A system consisting of two antennas, placed on satellites, would allow getting not only amplitudes but also spatial phase parameters of interference on long baselines, thus enabling investigation of detailed brightness distribution in discrete radio sources of very small angular sizes. In this case, ionosphere and troposphere fluctuations that make phase measurements very difficult are eliminated.

SVLBI science drives

- The quest of high brightness in extragalactic sources
  - related physics of the innermost regions in AGN
    - *pro memoria*: tackling high T_B needs physically long baselines!
    - Earth (~10^4 km) matches perfectly T_B ~10^{12} K in ~ 1 Jy source
- Enigmatic (stellar) maser sources known to be compact
- Above all: pushing the parameter space envelope

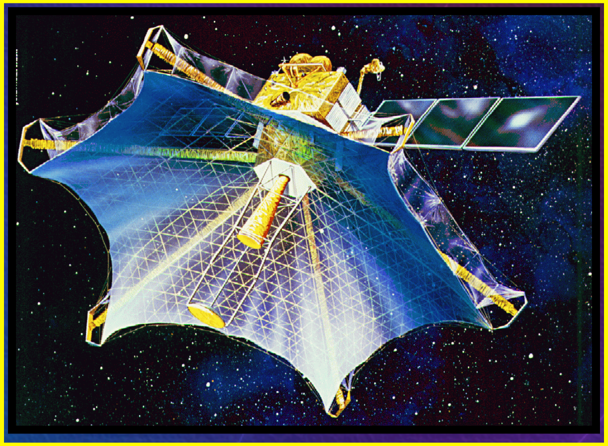
("We do it not because it's simple but because it's hard" – JFK, May 1961)

Three generations of Space VLBI

1986-88

TDRSS-OVLBI, Ø 5m

1997-pt



VSOP, Ø 8m

RadioAstron, Ø 10m

>2030

?

Must be more sensitive!
Must be versatile
Must be more efficient
Must be user friendly

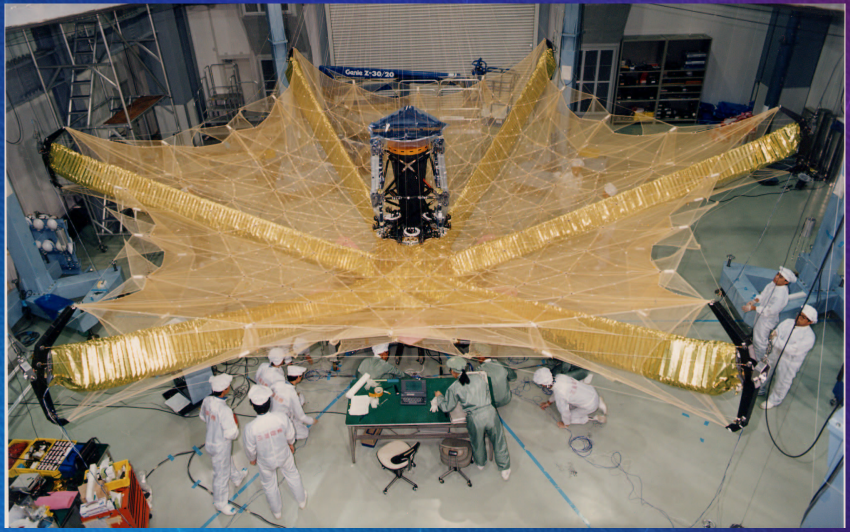
Broader band downlink
Is likely to be driven by
industry:
10 Gbps routine in 2035?

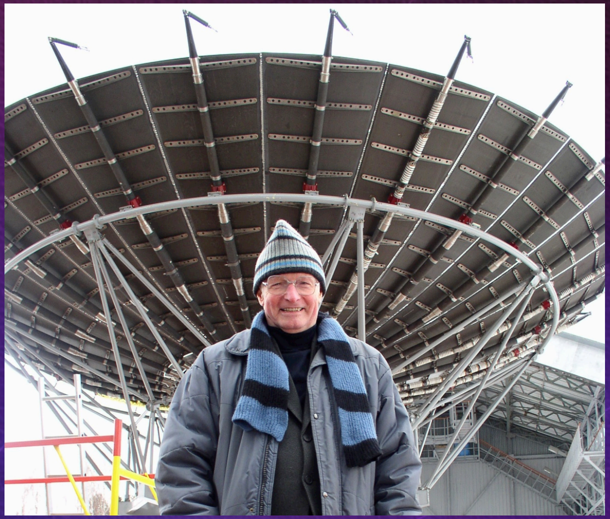
Design studies:

- **KRT-30 (1978-82)**
- **QUASAT (1980s)**
- **IVS (1987-91)**
- **ALFA (1990s)**
- **(i)ARISE (2000s)**
- **VSOP-2/Astro-G**
- **Chinese SVLBI**

SVLBI space-borne hardware (TRL=?)

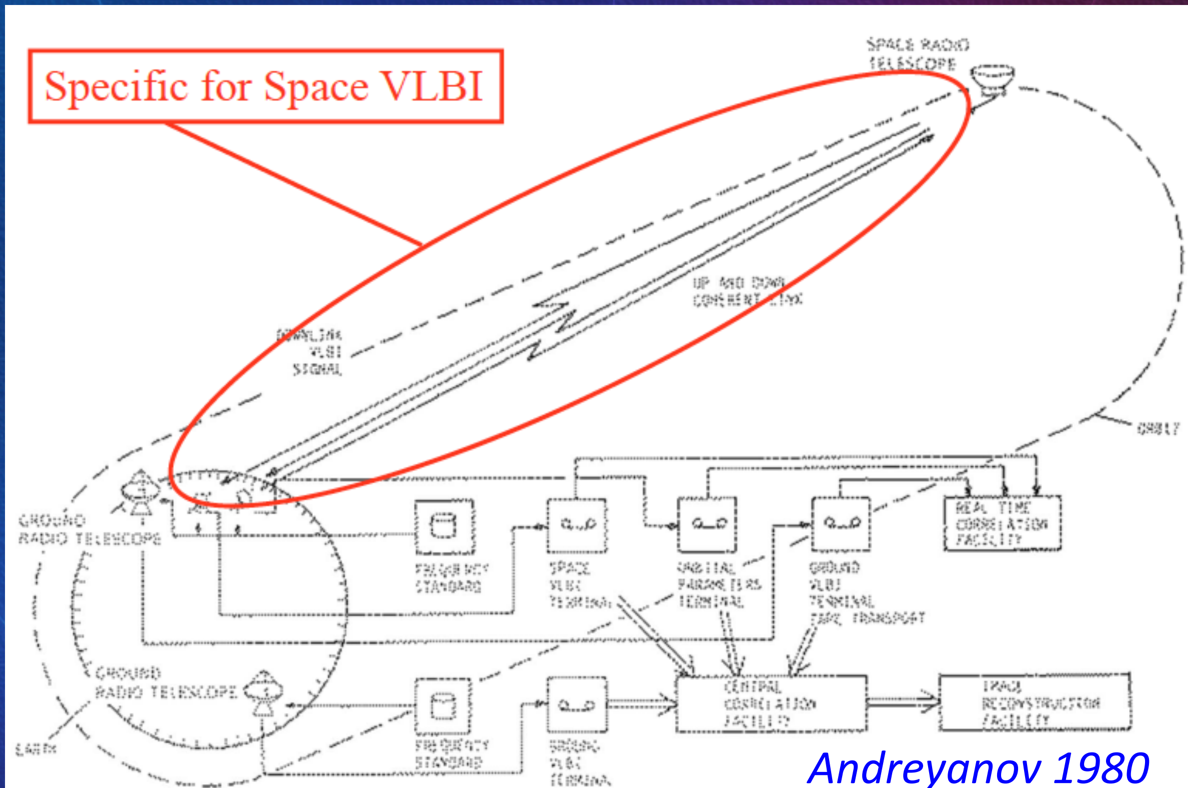
- Antennas ~10 m and larger: tests, tests, tests…





- “Analogue” instrumentation *(yes, tests…)*
  - HALCA: 22 GHz
  - RadioAstron: 5 GHz
- Digital instrumentation: well behaving, but
  - Data rate lower than needed

It's about coherency…



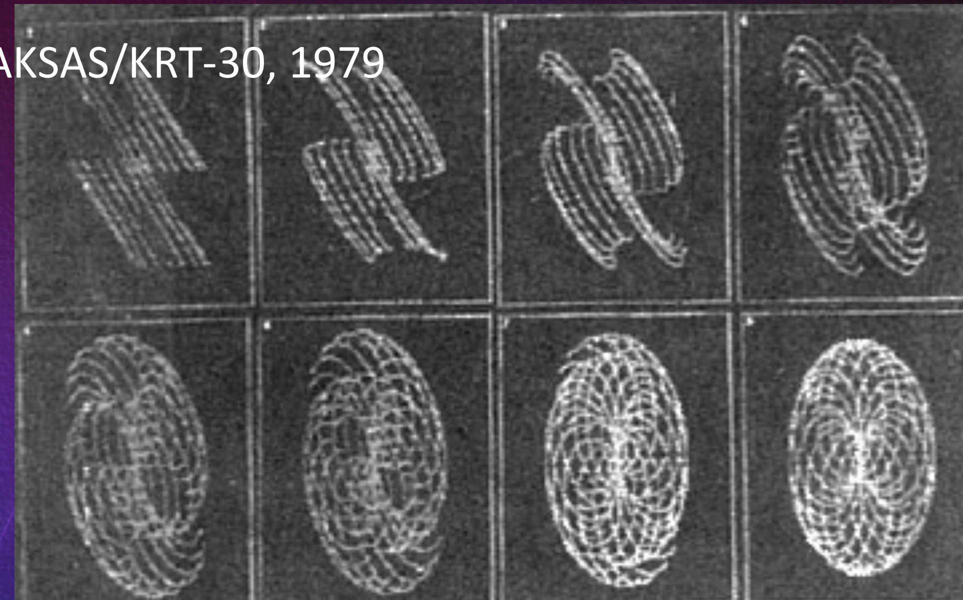
Active H-maser
ASC, ~2008

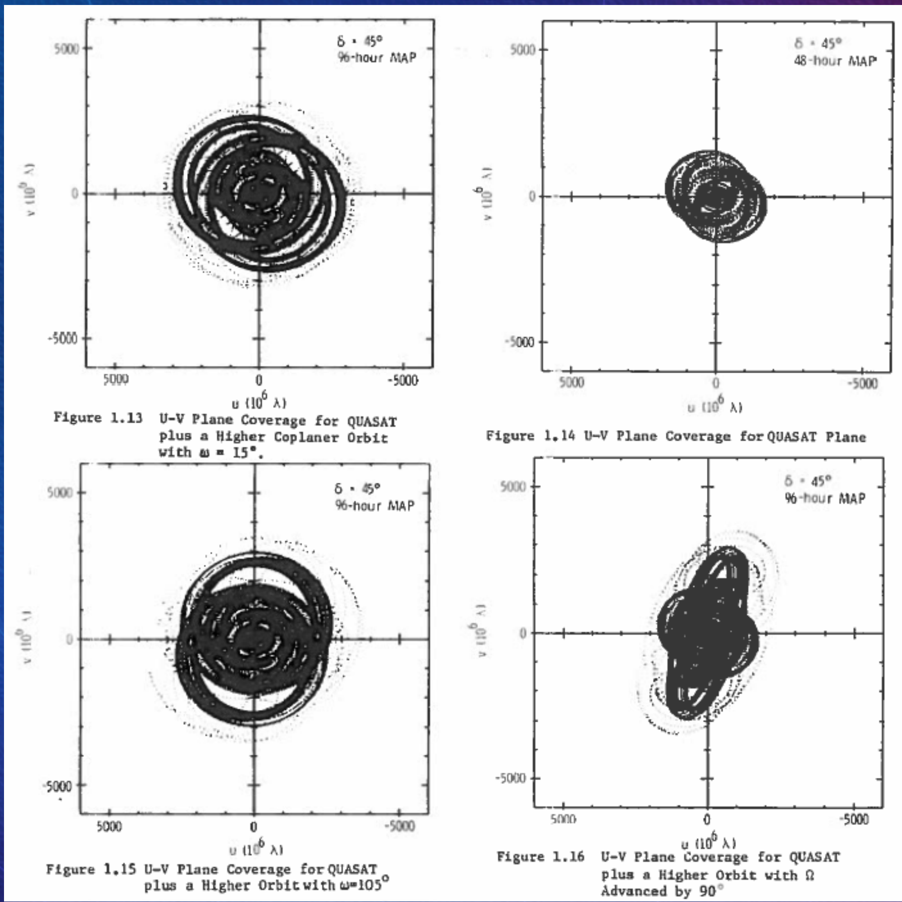
- Both, PLL (HALCA and RadioAstron) and on-board H-maser (RadioAstron only) worked fine
- So, optimise the cost or operational parameters

Key parameters of SVLBI-I and -II

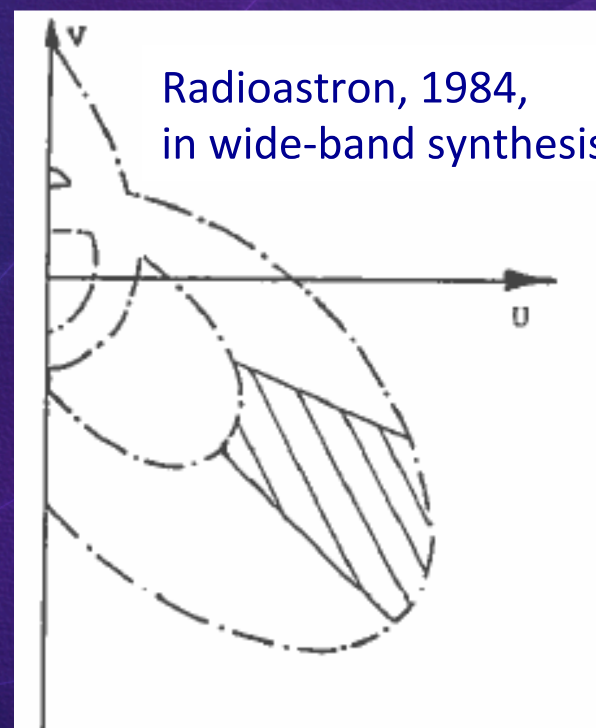
Mission	VSOP (1997)	RadioAstron (2011)	ARISE	VSOP-2
Mission Type	Engineering	Science/ exploration	Science/ imaging	Science/ imaging
Aperture	8 m	10 m	25 m	9 m
Frequencies (GHz)	1.6, 5	0.327, 1.6, 5, 22	8, 22, 43, 86	8, 22, 43
Polarization	LCP	Dual	Dual	Dual
Data Rate	128 Mbps	128 Mbps	8 Gbps	1 Gbps
Apogee Ht.	20,000 km	350,000 km	40,000 km	25,000 km
Phase Ref.?	NO	NO	NO	YES (8 GHz)
Highest res.	~ 300 μas	~7 μas	~25 μas	~40 μas

uv-dreams...





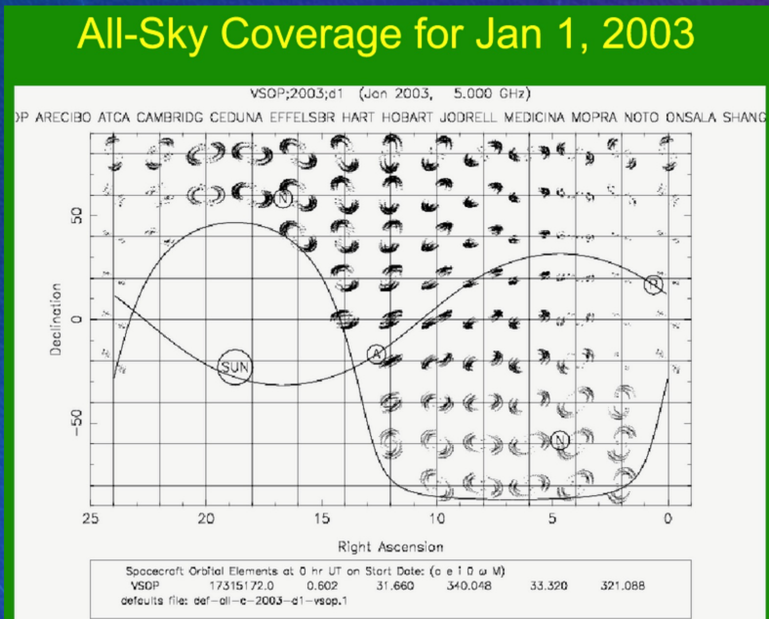
QUASAT, 1984



Radioastron, 1984,
in wide-band synthesis mode

uv- and sky coverage: the reality

VSOP



RadioAstron

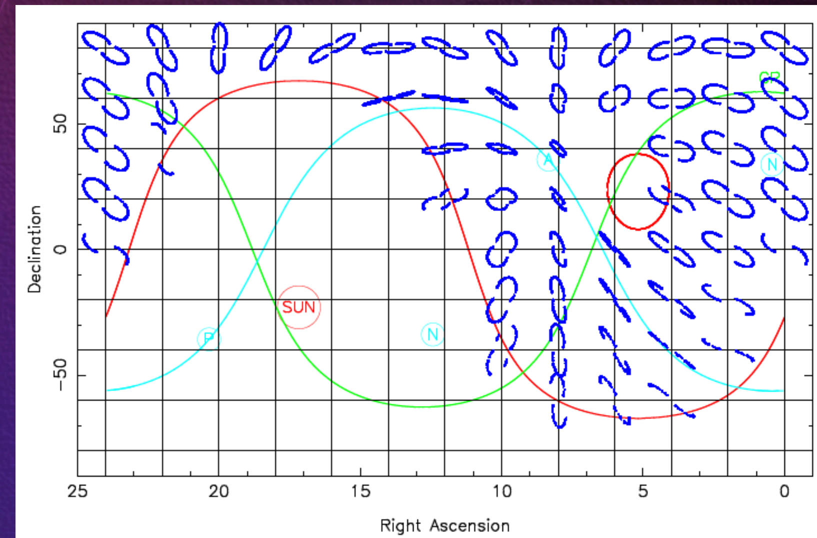


Figure 6: December 2015

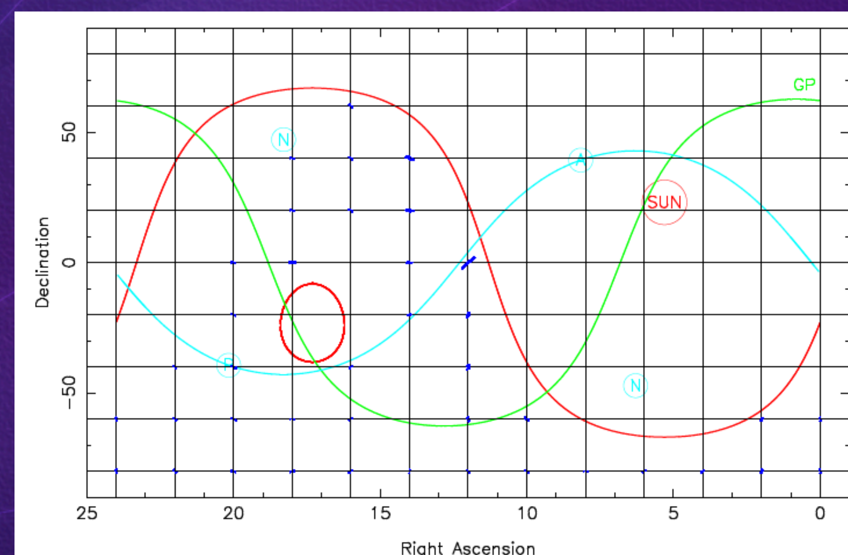


Figure 12: June 2016

- The impact of functional restrictions grossly underestimated!
- For any future SVLBI mission: think about functional restrictions first
    - including dynamic restrictions (e.g. RadioAstron thermal duty cycle)

“Sociology” of SVLBI

- 3 SVLBI telescopes operational (from ~30 proposed)
- Evolving science case
  - Drive for extremely high resolution remains topical
- Demography of (Space) VLBI:
  - ~1500 professional radio astronomers around the world
  - ~400 of them did/do VLBI
  - ~200 of the latter ready to deal with SVLBI
  - **Need to appeal to broad scientific community!**
- Arguably, SVLBI is the most difficult space science activity...
- Is SVLBI a facility (*e.g. Hubble*) or an experiment (*e.g. Planck*)?
  - None of those; something in-between

International (global) cooperation

- International cooperation – inescapable in SVLBI
  - *Both dedicated SVLBI missions – global*
- The "*ISC's" (RISC and VISC) – a success?
  - "International Steering Committee"

    or
  - "International Science Council"
- IACG (*Inter-Agency Consultative Group*) – a single-trick show
- GVWG (*Global VLBI Working Group*) – a success that no longer with us

7 November 1986, Rome: Space-VLBI WG formed by IACG (Inter-Agency Consultative Group of Space Agencies)

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  - *Both dedicated SVLBI missions – global*
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Onsala Space Observatory, Sweden, May 1993


VSOP-2 Planning Meeting
view of M-V

Summary

- Space VLBI: inevitable, difficult but doable
- Science legacy:
  - Brightness in AGN is somewhat above theory limits
  - No "stunning" T_B values?
  - Stellar and mega-masers: brighter than expected?
  - Refractive scattering at work?
- The first generation SVLBI missions were not yet true community facilities
- Design optimisation MUST take into account operational and functional realities
- The main technical bottle-neck – data downlink (data rate!)

The pioneers

Vladimir Andreyanov

Haruto Hirosawa

Nikolay Kardashev

Hisashi Hirabayashi

Gerry Levy