Coordinating, Scheduling, Processing and Analyzing IYA09

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Abstract

The IVS scheduled a special astrometric VLBI session for the International Year of Astronomy 2009 (IYA09) commemorating 400 years of optical astronomy and 40 years of VLBI. The IYA09 session is the most ambitious geodetic session to date in terms of network size, number of sources, and number of observations. We describe the process of designing, coordinating, scheduling, pre-session station checkout, correlating, and analyzing this session.

1. Introduction

To commemorate 400 years of optical telescopic observing, the International Astronomical Union (IAU) and UNESCO initiated the International Year of Astronomy 2009. Since the year 2009 also marked the 40th anniversary of geodetic VLBI, the 30th anniversary of regular S/X observing, and the 10th anniversary of the IVS, the IVS decided to schedule for 18 November 2009—as an activity for IYA09—the most ambitious astrometric VLBI session to date: a global network able to observe most of the celestial sphere with the largest number of stations possible.

A Task Force was formed that determined the key goals for the IYA09 session (see Table 1). The IVS Observing Program Committee (OPC) then initiated the realization of this very large astrometry session in collaboration with various groups and individuals. The Coordinating Center (CC) assumed the task of coordinating the session, the Goddard VLBI Group of preparing the schedule, the Goddard and Haystack groups of performing station checkout and troubleshooting, the Haystack Observatory of correlating the session, and the Goddard group of performing the preliminary analysis.

Table 1. Key goals of the IYA09 session of the IVS.

Scientific Goals	Strengthen ICRF2 by observing as many sources (243 out of 295) as possible in a single session.
	Measure arc-lengths between observed sources.
Outreach Goals	Press releases through IYA2009 (IAU), IVS, and other organizations.
	News coverage in regional and national media.
	Open doors at stations.
Ancillary Goals	Celebrate 40 years of geodetic and astrometric VLBI.
	Demonstrate capability of handling large networks.
	Tie stations into global frame.

2. Designing the Session

The Coordinating Center sent out a call for participation to which twenty-five stations responded positively. Following feasibility discussions with the VLBA, the CC submitted a 'Target of Opportunity' proposal to the VLBA which was accepted; the total number of stations thus increased to thirty-five (cf. Figure 1 and Table 2).
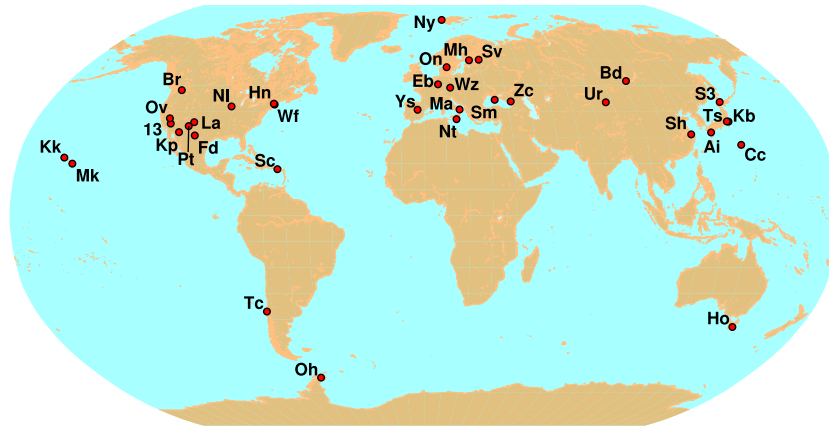

Figure 1. Geographical distribution of the 35 stations that agreed to participate in IYA09.

Apart from securing station and correlator resources, the availability of recording media also needed to be evaluated. First, the session involved many more stations than a typical IVS session. Secondly, because the correlator would have to make many passes ($\sim$20), the recording media would be tied up for many months while being processed. After numerous discussions media resources were identified for this session; however, a constraint was put on the maximum amount of data recordable at the stations.

Table 2. List of stations that agreed to participate in IYA09. (K5 translated to Mark 5B at Haystack.)

IVS	Mark 5A	HOBART26, KOKEE, MATERA, NOTO, NYALES20, ONSALA60, OHIGGINS, SESHAN25, SVETLOE, TIGOCONC, URUMQI, WETTZELL, ZELENCHK
	Mark 5B	BADARY, CRIMEA, WESTFORD, YEBES40M
	K5 to Mark 5B	KASHIM34, TSUKUB32
GARNET	K5 to Mark 5B	AIRA, CHICHI10, SINTOTU3
DSN	Mark 5A	DSS13
EVN	Mark 5A	EFLSBERG, METSAHOV
VLBA	Mark 5A	BR-VLBA, FD-VLBA, HN-VLBA, KP-VLBA, LA-VLBA NL-VLBA, PIETOWN, MK-VLBA, OV-VLBA, SC-VLBA

After looking at several possibilities, we settled on the standard 8-channel RDV mode. This has four X-band and four S-band channels; each channel is 8 MHz wide and uses two-bit sampling. The total data rate is 256 Mbps. The primary argument in favor was the participation of the VLBA, and because many stations had experience with this mode. We also considered a mixed

mode, where the VLBA would observe eight channels, and other stations fourteen. This would have had greater sensitivity for the non-VLBA stations, but it was ruled out because of insufficient media.

Eight stations could not observe in standard RDV mode but instead used a modification of it. In particular, AIRA, CHICHI10, CRIMEA, and SINTOTU3 had 4-MHz-wide channels; at AIRA, CHICHI10, CRIMEA, METSAHOV, NOTO, SINTOTU3, and URUMQI only two of the four X-band channels lay within the receiver passband; and DSS13 had only two S-band and two X-band channels. Furthermore, although CRIMEA could observe in full RDV mode, it had no AGC, and the power levels were increased for better 2-bit recording.

3. Scheduling

With 35 stations, IYA09 was by far the largest network ever scheduled, breaking the previous record of 23 stations. In order to schedule it, the maximum number of stations in *sked* was increased from 32 to 64. In the process of scheduling IYA09, we found and fixed many bugs related to the large number of stations.

The source list was the 295 defining sources in ICRF2. A design goal was to observe as many of these sources as possible. To reliably schedule these sources we needed good flux models. For most of the sources we used flux models generated from IVS data. For some of the sources we put in flux models obtained externally. For two of the sources we assumed fluxes of 0.25 mJy in both bands over all baselines.
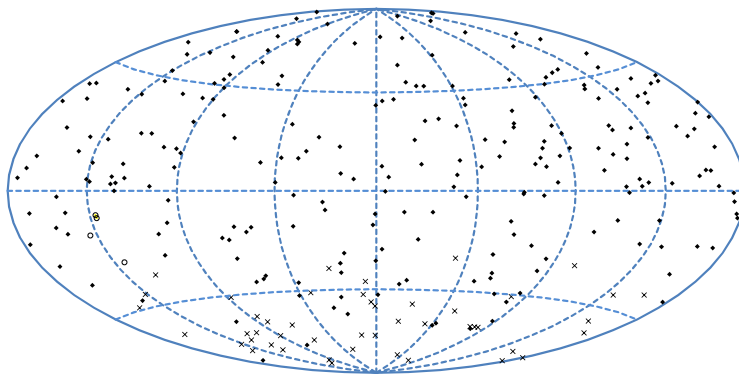

Figure 2. The 295 ICRF2 definining sources. Circles indicate sources too close to the sun to be observed. X's indicate southern sources that were not observed.

Goddard generated a reference schedule with 'plain vanilla' *sked* settings. This schedule had about 45,000 observations. Unfortunately, about 80 sources were observed sparsely or not at all. Four sources were too close to the sun to be observed. Most of the remaining sources were in the far south. We used the astrometric mode of *sked* to try to increase the number of observations of these southern sources. In astrometric mode the scheduler assigns observing targets for some set of sources, and *sked* will preferentially select scans involving these sources until they meet their targets. In spite of these efforts, many of the sources in the far south were not observed. Further investigation showed that it was impossible to meet the SNR targets on these sources because of the small size of two of the three southern stations.

4. Pre-session Station Checkout

Goddard and Haystack spent considerable time prior to the session to ensure that all stations would perform well. Special attention was paid to the Japanese GARNET stations. These stations had a maximum sampling of 8 Mbps (in contrast to the 16 Mbps of the other stations), so "data doubling" had to be used to make it possible to correlate the data. This reduced the sensitivity of these stations beyond that, due to the narrow bandwidth (4 MHz) they used. A fringe test was done prior to IYA09 to make sure that this would work. It was planned that all of the Japanese stations would be e-transferred to Haystack and translated from K5 to Mark 5B format. T. Kondo of NICT wrote the translation software. This was a new data-path, and it was exercised and debugged prior to IYA09. Goddard generated snap files for eight of the stations, because their field software was too old to support the number of stations in the schedule.

5. Correlation

The number of playback units determines the number of passes required to correlate the data. As a simple example, consider a 9-station session with four playback units. This session will have 36 baselines. With four playback units you can correlate six baselines at one pass. Naïvely you could do the correlation in six passes (i.e., 36 baselines with 6 baselines per pass). However, it is impossible to have all the passes independent. Inevitably some baselines will be correlated in more than one pass, which increases the number of required passes to eight (see Table 3).

Table 3. Correlating nine stations with four playback units.

Pass	1	2	3	4	5	6	7	8	9	New Bl	Old Bl	# NewBl
1	X	X	X	X						12, 13, 14, 23, 24, 34	–	6
2				X	X	X	X			45, 46, 47, 56, 57, 58	–	6
3	X						X	X	X	17, 18, 19, 78, 79, 89	–	6
4		X			X	X			X	25, 26, 29, 59, 69	56	5
5			X	X				X	X	38, 39, 48, 49	34, 89	4
6	X		X		X	X				15, 16, 35, 46	13, 56	4
7		X	X				X	X		27, 28, 37	23, 38, 89	3
8					X	X		X		58, 68	56	2

Two stations were not correlated. SVETLOE did not participate in IYA09 because of hardware problems. Haystack discovered problems with one of the X-band channels of DSS13. Since the data would be unusable for analysis, DSS13 was dropped.

Haystack had seven Mark 5A playback units and four Mark 5B units. Originally Haystack hoped to increase the number of playback units temporarily. Unfortunately they discovered that one of the programs limited the number of playback units to eleven.

The Japanese data was recorded on K5 disks and then e-transferred to Haystack. It would have been possible to translate the K5 data into either Mark 5A or Mark 5B format. It was translated to Mark 5B format to minimize the number of Mark 5A units.

The final correlation involved 33 stations: 24 Mark 5A stations and 9 Mark 5B stations. The total number of stations suitable for correlation in IYA09 was 33, with a total of 528 baselines. The

minimum number of passes required to correlate this is 17, which is constrained by the number of recording units of each type and the number of playback units. The actual number of passes made was 22. This was higher than required because the first seven passes were constructed to gain as much station and baseline coverage as possible, and not to minimize the total number of passes. Prior to the IVS 2010 General Meeting, Haystack sent Goddard a preliminary version of the database containing 29 stations, 240 sources, and 14,500 observations.

During correlation Haystack identified many limits in the processing software which had to be increased to handle IYA09. For example, the *tgen* and *a2t* programs were limited to handling 16 stations. The *HOPS* processing system had a file limit of 100,000 files which was increased to 300,000. *Corrman* and *aedit* were also modified.

Some correlator hardware related quirks had to be worked around as well. Two correlator station units exhibited byte-slip-type behavior in some data paths, requiring swapping headstack inputs to avoid the problems. One hardware path through the correlator board had to be avoided. This path had never been exercised prior to 11-station IYA09 scans.

6. Preliminary Analysis

Goddard analyzed the preliminary IYA09 database before the IVS General Meeting. The preliminary solution used 26 stations, 168 baselines, and 12,826 observations. The *Solve* postfit residual was 20.8 psec.

Table 4. Comparison of IAY09 with other IVS sessions.

Kind	#/yr	Typical	Date	# Stats	# Srcs	# Scans	# Obs
Int	200	I09240	2009-08-24	2	11	26	26
Rl	52	Rl397	2009-09-29	8	60	687	4,376
Euro	6	Euro97	2009-05-25	9	53	288	6,473
RDV	6	RDV77	2009-10-07	15	94	791	22,044
As scheduled		IYA09	2009-11-18	35	243	721	37,236
In database		IYA09	2009-11-18	32	239	658	28,920

The final database was made after the IVS meeting. Of the 33 stations, TIGOCONC had only 66 observations on seven baselines, and most were of very low SNR. Therefore, TIGOCONC was removed from the final database, leaving only 32 stations, which was the nominal limit of *Solve*. However, during analysis, it was found that many *Solve* routines actually had lower limits. These cases were corrected, and the *Solve* analysis was completed. The final database used 26,696 observations of 237 sources on 455 baselines. The *Solve* postfit residual was 22.5 psec.

7. Conclusions

The IYA09 session is the most ambitious VLBI session scheduled to date. It has posed, and continues to pose, challenges to all aspects of data analysis and dataflow. It is a useful precursor to VLBI2010 data.