RUSSIAN NATIONAL TIME SCALE LONG–TERM STABILITY

A.P.Al'shina, B.A.Gaigerov, N.B.Koshelyaevsky, S.B.Pushkin
Institute of Metrology for Time and Space, NPO "VNIIFTRI"
Mendeleevo, Moscow region, 141570, Russia

Abstract

The Institute of Metrology for Time and Space NPO "VNIIFTRI" generates the National Time Scale (NTS) of Russia – one of the most stable time scales in the world. Its striking feature is that it is based on a free ensemble of H–masers only. During last two years the estimations of NTS longterm stability based only on H–maser intercomparison data gives a flicker floor of about $(2 \rightarrow 3) \times 10^{-15}$ *for averaging times from 1 day to 1 month. Perhaps the most significant feature for a time laboratory is an extremely low possible frequency drift - it is too difficult to estimate it reliably.*

The other estimations, free from possible inside the ensemble correlation phenomena, are available basing on the time comparison of NTS relative to the stable enough time scale of outer laboratories. The data on NTS comparison relative to time scale of secondary time and frequency standards at Golitzino and Irkutsk in Russia and relative to NIST, PTB and USNO using GLONASS and GPS time transfer links gives stability estimations which are close to that based on H–maser intercomparisons.

INTRODUCTION

The time and frequency standards and time scales long term stability characteristics are of great importance especially for the national time keeping centers which usually deals with averaging time up to several years. Then one may use such stable time scales itself for frequency comparisons with primary Cs standards or as reference for fundamental researches.

The lions share of advanced time laboratories usually do not use output signal of individual, even extremely stable, clocks as the laboratory's time scale, but use a so–called "paper clock", which constitutes the set of time and frequency corrections applied to the output signal of individual clocks. These corrections originate from a time scale algorithm which use as input information clock ensemble intercomparison data. The sophisticated time algorithm may significantly improve characteristic of the "paper clock" compared to individual contributors, and may even produce a time scale which is better than every individual clocks, but nevertheless correlated frequency drift of the time keeping instruments can not be detected based on time comparison inside an ensemble only. That's why in order to estimate confidently and accurately time stability of individual clocks and "paper clock" one needs an additional comparison data relative first of all to primary Cs standards or at least stable enough time scales of outer laboratories.

STABILITY ESTIMATIONS BASED ON INTERCOMPARISON DATA

To begin with some words about operational H–masers. Nowadays our laboratory possess 10 commercially manufactured H–masers, four of them of similar design are installed at separate room and have operated since 1989, the other part consist of two groups of instruments: four instruments of quite different design the physical package of which is installed in a refrigerator at temperature about 0 °C started operation at the middle of 1992 and are located at two separate rooms. Two last instruments have the same design as first group, and have operated since this spring and locate together with their elderly brothers.

We present here, Fig. 1 and Fig. 3, a portion of H–maser intercomparison data for four elder masers (No. 47, 49, 50, 51) and one instrument which locates in refrigerate (No. 53). Due to some problems in data collection system the only actually available data for long term analysis are 1 pps time differences between H–masers at one day basis with resolution about 1 ns. One may find more detailed information on intercomparison technique details in [1].

Fig. 1 shows not original intercomparison data but ones with removed deliberate constant frequency difference between instruments and cut and pasted to remove all detected time steps. The Allan variance plot, Fig. 2, shows typical flicker floor for H–maser's time difference under consideration at level about $(2 \rightarrow 3) \times 10^{-15}$ for ten day averaging time. Somewhat worth results are depicted for shorter averaging time, but this is effect of inadequate resolution 1 pps signal measurements. Measurements with significantly better resolution using phase comparing technique confirm stability of every H–maser at a level about $(2 \rightarrow 3) \times 10^{-15}$ for averaging times from 1 hour to 1 day. Along with it the worth estimation of possible frequency drift gives value about $(5 \rightarrow 6) \times 10^{-17}$ per day for 49-51 difference. Because of the limited number of samples (432 samples at 1 day basis) confidence of Allan variance for 100 day averaging time is not high and the above mentioned estimation of frequency drift also is not reliable enough.

Next pair of Figures 3 and 4 depict H–maser comparison data relative to TA(SU) for the period about 1000 days starting the begin of 1991. The original data were subjected to the same processing as previous ones. Important remark – there is no difference between TA(SU) and UTC(SU) but constant bias and leap second embedded into UTC(SU). Perhaps the most striking feature of Fig. 3 is the obvious frequency drift of H–maser No. 51. As a matter of fact it does not pose significant problem for time scale generation because, as one sees, this is well predictable process. For example one may estimate value of this drift at one year basis and then get the clock reading prediction using second order model. The gained error for one year forecast is less than 300 ns, this value comparable with gained time error of non–drifting instruments.

The Allan variance plot depicted at Fig. 4 confirms the long term stability of individual H–masers which was presented in Fig. 2. Because of the limited number of 10 day samples (N = 101) the confidence level of estimations for 300 day averaging time is not too high. Nevertheless

H–maser No. 51 linear frequency drift estimation gives the same value as previously, about $(5 \rightarrow 6) \times 10^{-17}$ /per day. The other instruments under consideration do not show detectable frequency drift. Basing on at presented data of individual H–maser stability one may expect improvement of TA(SU) based on these 4 clocks up to factor two. Since as it was mentioned it is possible to predict more or less reliably frequency drift of H–maser No.51 one may expect stability level for TA(SU) about 3×10^{-15} for time intervals up to 1 year.

All presented estimations are based on H–masers intercomparison only, even results relative to TA(SU) which in turn is based on H–maser intercomparison data also. That is why it is interesting to compare these estimates relative to time scale of independent laboratories.

STABILITY ESTIMATIONS BASED ON TIME SCALE COMPARISON WITH REMOTE LABORATORIES.

Fig. 5 presents Allan variance plot for time scale difference between TA(SU) and atomic, that means uncorrected and based on H–maser intercomparison data only, time scales of two other laboratories inside Russia. These laboratories are Golitzino, which is located about 50 km from Mendeleevo and Irkutsk which situated in East Siberia in the vicinity of Baikal lake. Each laboratory is equipped with an ensemble of H–masers consisting of at least four instruments. Time difference data originates from GLONASS common–view manual sessions. For one month and more averaging time presented plot reflects time scale characteristics namely and shows the best relative stability level may be better than the 1×10^{-14} level.

Apart from internal estimates we would like to present here stability data relative to some world known time scales. For this presentation we have two sources of data. First of all this is BIPM Time Section official publications – Circular "T". Starting in 1992 time information in it concerning UTC(SU) and TA(SU) is based on GPS common view sessions data under international time comparison schedule. This publication gives us any time difference we like at ten day basis. We have chose four time scales from three laboratories. The other source of data is direct comparison with PTB basing on original GPS common–view session data exchange between two laboratories starting 1993. This last source gives us information on one day basis.

Allan variance plots for time differences between TA(SU) and some laboratories originate from above mentioned time transfer links are depicted at Fig. 6. First of all some commentaries to result based on Circular "T". Dependencies referred to TA(NIST) and TA(PTB) look qualitatively different from those for TAI, TA(NISA) and TA(USNO) – TA(SU) manifests white FM relative to TA(NIST) and TA(PTB) and somewhat similar to random walk frequency fluctuations relative to other scales.

Qualitative similarities in estimations based on TA(NIST) and TA(PTB) do not look astonishing because of these time scales are syntonized to cesium SI second – the first (TA(NIST) in software way[2] and the other in hardware. The difference between them and TA(NISA) and TA(USNO) is also obvious - each of the latter is based on a free ensemble of clocks.

Despite these remarks presented data show for averaging times of one month and more the best stability estimation of TA(SU) is about $(2 \rightarrow 4) \times 10^{-15}$. This value is quite similar to that based on H–maser intercomparison. We would like to underline that estimates based on direct comparison between two laboratories IMVP and PTB give similar results. The last result seems us to be very important because of this is comparison of time scales based on different physical processes – TA(SU) is based on a free ensemble of H–masers and TA(PTB) on continuously operating primary Cs standard.

TA(SU) as time scale of free running ensemble of H–masers looks in many extends similar to EAL (Echelle Atomique Libre, i.e. free atomic time scale) which is produced by BIPM Time Section and which is based on readings from more than 150 clocks located at various laboratories[3, 4]. Fig. 7 shows corresponding stability estimations of TA(SU) referred to TA(PTB) and EAL referred of Cs2 PTB. Due to many similarities in TA(PTB) and Cs2 PTB especially for 1992–93 one may consider Fig. 7 as very successful presentation of modern high stable H–maser's ability to contribute significantly to the EAL at least for moderate averaging time. One may see that possible value of TA(SU) frequency drift doesn't exceed corresponding value for EAL (about 2.5×10^{-17} per day) and we hope to obtain in the coming years additional data to get more confident estimation of its actual value.

Acknowledgements

The authors would like to express their gratitude to Head of PTB Time Laboratory Dr. A.Bauch for fruitful cooperation in time scale comparison and continuous interest to this work.

REFERENCES

[1] A. Al'shina, N. Koshelyaevsky, S. Pushkin and P. Daly, Proceedings of the 7th European Frequency and Time Forum, Neuchatel, March 1993, to be published.

[2] Comite Consultatif pour Definition de la Second, 11e session, Working Documents submitted to the 11th session, Document CCDS/89–16, Bureau International des Poids et Mesures, 1989, Pavillon de Breteil, F–92312 Sevres Cedex.

[3] B. Guinot, C. Thomas, Establishment of International Atomic Time, Annual Report of the BIPM Time Section, volume 1, part D, Bureau International des Poids et Mesures, 1988, Pavillon de Breteil, F–92312 Sevres Cedex.

[4] C. Thomas, The BIPM Time Section 1989–1993, Comite Consultatif pour Definition de la Second, 12th session, Working Documents submitted to the 12th session, Document CCDS/93–1, Bureau International des Poids et Mesures, 1993, Pavillon de Breteil, F–92312 Sevres Cedex, to be published.

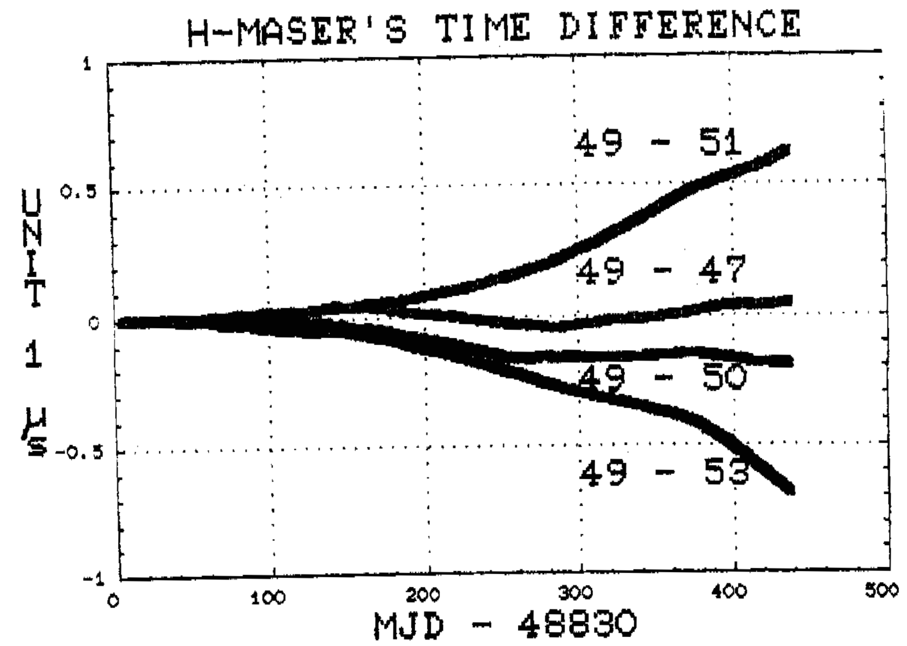

FIGURE 1

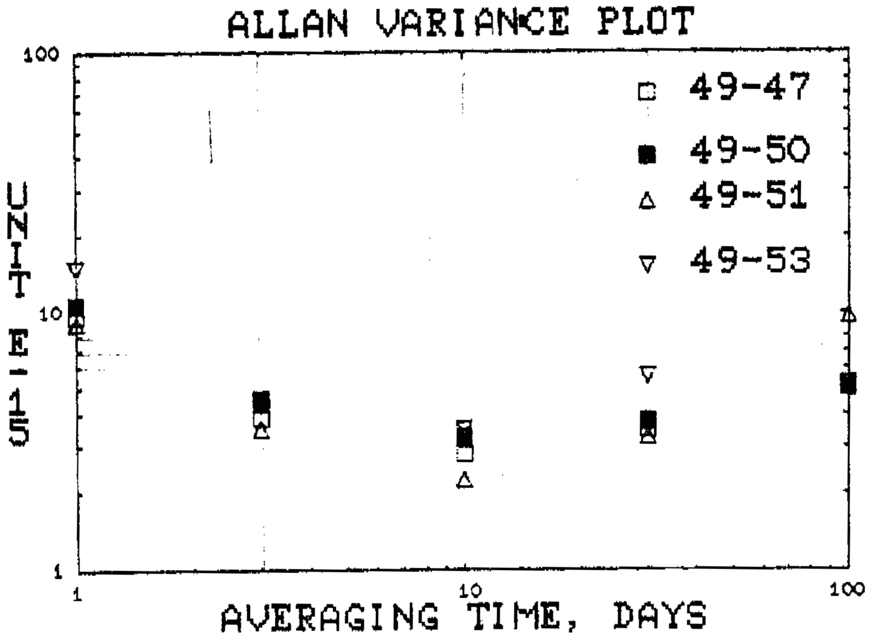

FIGURE 2

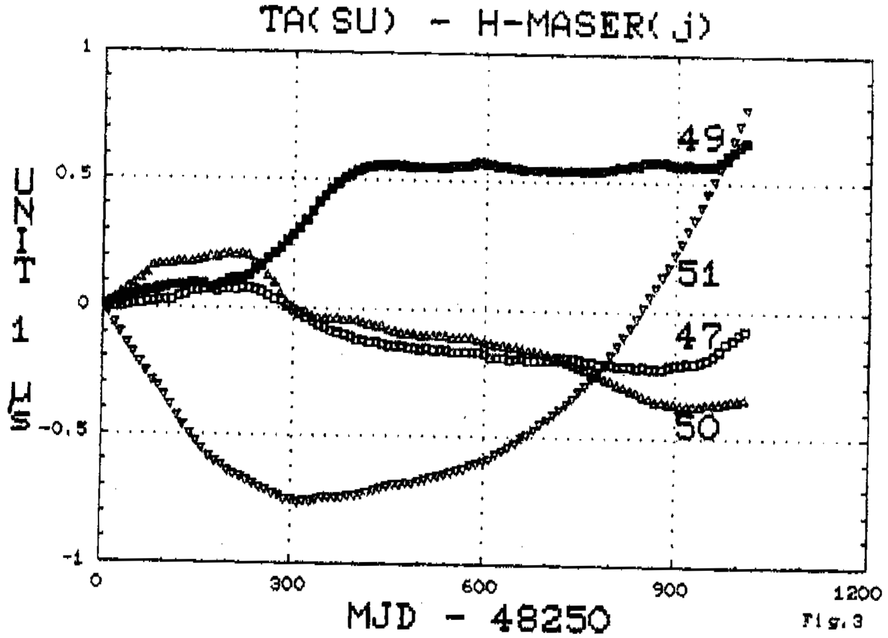

FIGURE 3

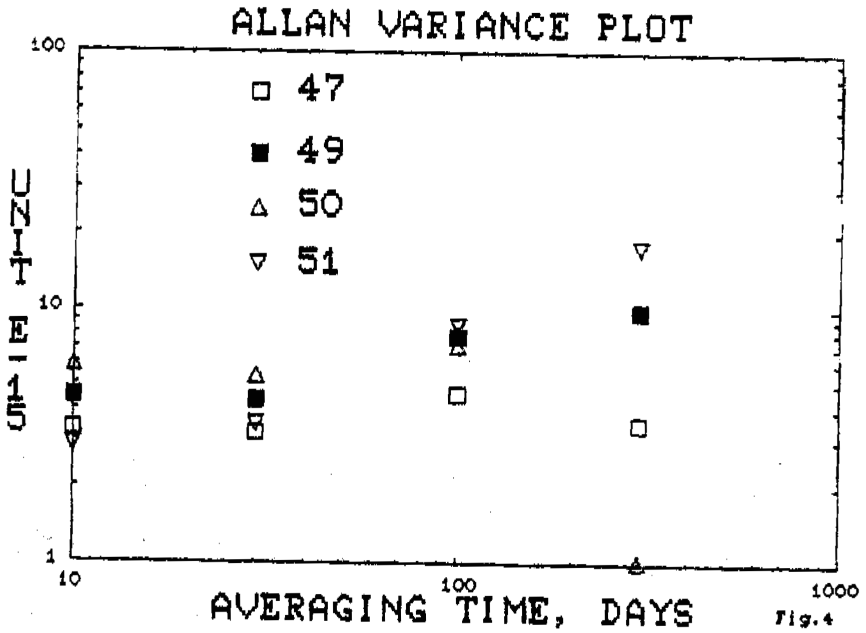

FIGURE 4

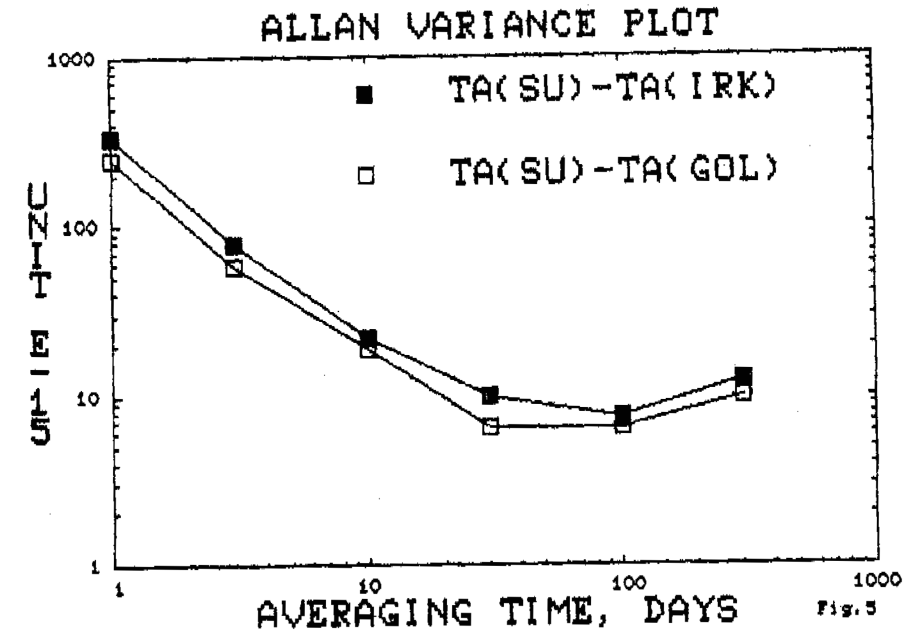

FIGURE 5

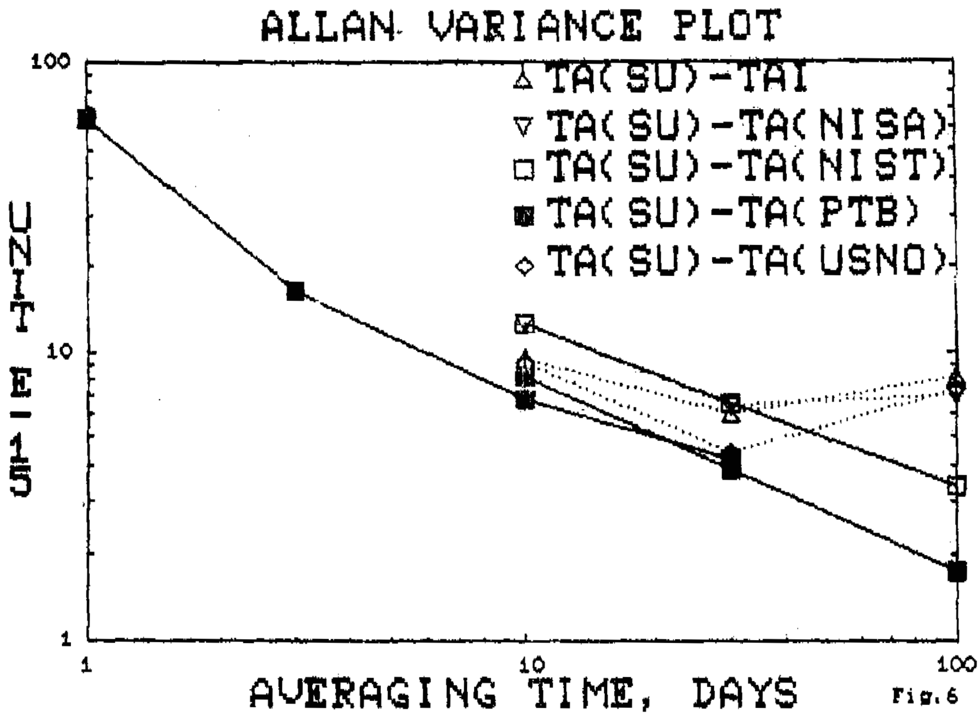

FIGURE 6

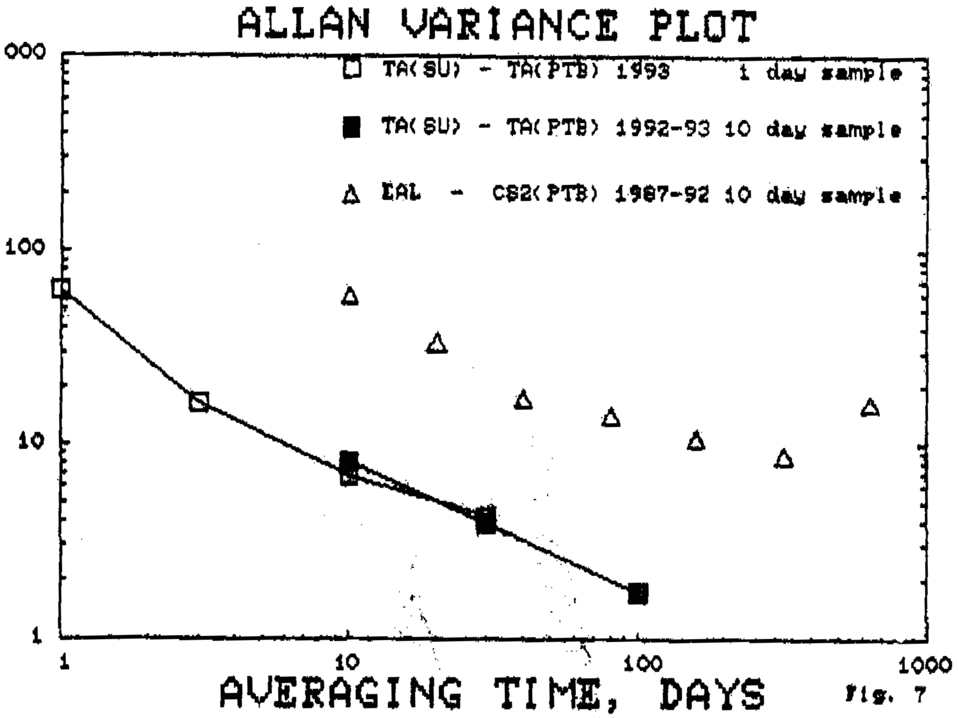
ALLAN VARIANCE PLOT
TA(SU) - TA(PTB) 1993 1 day sample
TA(SU) - TA(PTB) 1992-93 10 day sample
EAL - CS2(PTB) 1987-92 10 day sample
000
100
10
1
1
10
100
1000
AVERAGING TIME, DAYS
Fig. 7

FIGURE 7

QUESTIONS AND ANSWERS

Dr. Winkler, USNO: Have you seen any evidence that they have abandoned the meteor trail synchronization which they use between Moscow and Irkutsk and other stations in Siberia?

Mr. Allan: They, as near as I can tell, are still actively using the meteor trail technique.

Dr. Winkler: In addition to GLONASS?

Mr. Allan: Yes, it is quite embedded. I suspect with time, as GLONASS satellites become more and more prolific – they don't have a full constellation yet. And so I suspect until they do it will be a gradual transition. But it is quite embedded in their system and meteor trail technique.

J. Levine, NIST: Would you mind putting that slide back up? I just want to make sure I understand it. Does that mean that the red is TA(SU) minus TA(NIST) and it is better at 100 days than against TAI?

Mr. Allan: That's right.

J. Levine: This scale is free–running?

Mr. Allan: Yes. That is their claim.

J. Levine: Okay, that is not what I would have thought would happen.

Claudine Thomas, BIPM: You showed us two Allan variance plots. One, between a TA(SU) and Irkutsk, I think. And we see a minus one slope noise. And then something which is surely due to the performance of the hydrogen masers themselves or the time scales, which is, as I understand, about one part in ten to the fourteen.

Mr. Allan: Right.

Claudine Thomas: And then you showed us another Allan variance plot which was obtained in Moscow and Medeleevo between the different hydrogen maser charts. And then the number is much smaller.

Mr. Allan: Yes.

Claudine Thomas: It goes until only one or two parts in ten to the fifteen.

Mr. Allan: That's correct.

Claudine Thomas: Do you think that it means that the hydrogen masers we chart in Moscow are more or less correlated in the long–term or middle term?

Mr. Allan: You cannot rule out correlation. That is certainly true. Unfortunately the FAX machine cut off the data for longer integration times. They do have data out here and it does behave still in the same vicinity. But that doesn't say they are not correlated. So to answer your question, I don't know that you can rule out correlations.

Claudine Thomas: Yes, so we don't know the answer about that.

Mr. Allan: We really don't.

Claudine Thomas: Because, you know it is a concern for the BIPM because we are receiving all these hydrogen masers which are active hydrogen masers with an autotuning mode, but we are not sure that the autotuning mode is somewhere, and it helps to correlate them. And our concern, of course, is to have independent clocks. So this is the first time that I have seen these plots. The question is open.

Mr. Allan: The PTB number, which would be quite independent, you see that the PTB number and the NIST number are –

Claudine Thomas: Yes, TA(PTB) is PTB Cesium 2.

Mr. Allan: Yes, this is Cesium 2 and would be an independent clock. And that would maybe rule out correlation. So this number would agree with the laboratory numbers to some degree.

Claudine Thomas: TA(SU) is a very simple average of four or six hydrogen masers. And TA(PTB) PTB Cesium 2 – what can you conclude? I don't know if we can conclude something about that value. It is the last value for 100 days. It seems to be smaller than the stability coming from PTB Cesium 2 itself. So I don't know if we can conclude anything about that.

Mr. Allan: Well the question is maybe there is nothing with long–term data with which to compare it. But this would indicate that maybe there is validity to the very good long–term stability of the maser. PTB is independent.

Al Kirk, JPL: Did they give you the mechanism that causes the frequency of some of the masers drift negative and others as positive?

Mr. Allan: That drift is very tiny. I don't think they know. They do have servo–cavity tuning.