



## IVS Contribution to ITRF2020

– John Gipson, NVI Inc./NASA GSFC

The International Terrestrial Reference Frame (ITRF) serves as a foundation for geophysics and is crucial to monitoring such things as sea-level rise and land subsidence. A global reference frame allows you to connect observations which are separated in space and/or time. For my non-scientists friends I like to use the following example: If you have a house on the beach and the water level is rising, without a global reference system you do not know if the land is sinking or the sea level is rising. By comparing measurements separated in time we can determine the rate of sea-level rise which allows us to plan for the future.

Since the mid-1980s there have been a series of successively better ITRFs with the upcoming ITRF2020 promising to be the most accurate and useful ever. Beginning in 2005 the ITRF was constructed using the normal equations submitted by the geometric services: IDS, IGS, ILRS, and IVS. Each technique has its own set of strengths and weaknesses, and by combining data you obtain a product which is more accurate and robust than the individual techniques. For example, VLBI, together with SLR, is important because it sets the overall scale of the ITRF.

The IVS contribution to ITRF2020 is a major effort of the entire IVS community. This includes past and present station personnel who are responsible for taking the data, correlator personnel who correlated the data, analysts who did the initial data processing, and the many scientists responsible for the current submission. Our submission will include ~6,600 24-hr sessions starting in 1979 and going through 2020. The total effort required for the IVS contribution is on the order of at least 100 man-years.

Eleven Analysis Centers using six different software packages are contributing to this effort. Each AC submits SINEX files containing the unconstrained normal equations for station position and source coordinates. These SINEX files are submitted to the IVS Combination Center which combines the data and produces a single SINEX file per session. The Combination Center provides an important quality control mechanism and provides feedback to the ACs. When all of the ACs have completed their submission, the IVS combination center will submit a single SINEX file per session to the IERS.

Analysis Center	Software
ASI CGS	Calc/Solve
BKG	Calc/Solve
DGFI-TUM	DOGS-RI
GFZ Potsdam	PORT
IAA	Quasar
GSFC	Calc/Solve
NMA	Where
Paris Observatory	Calc/Solve
Onsala	ASCOT
TU Wien	VieVS
USNO	Calc/Solve

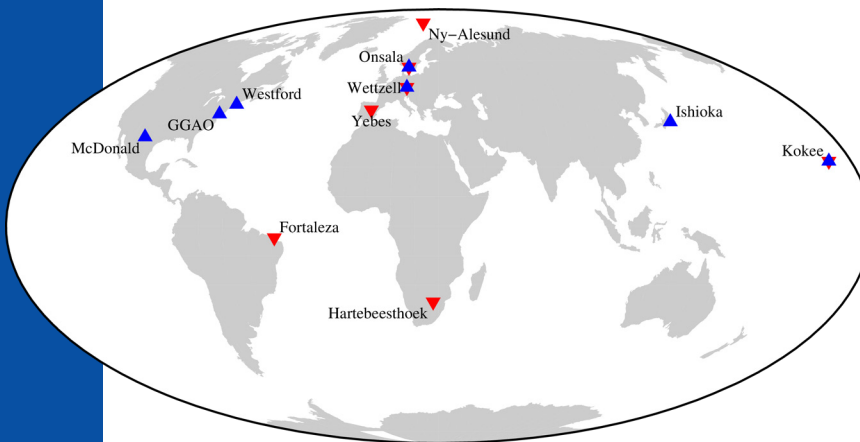
The table below gives some deadlines. Ideally the IVS would like to include all data taken through 2020-Dec-31. However, because of lags introduced by shipping, correlating, and initial data analysis, there is a delay between when the data is taken and when it is available. For the Rapid sessions this delay is supposed to be under 14 days. Because of this we should be able to include all of the R1/R4 sessions through 2020.

Important Deadlines	
Initial submission by IVS-AC to IVS Combination Center	2020-Aug-01
First combined solution by	2020-Nov-01
Final contributions by AC	2021-Jan-20
Contribution of IVS Combination Center to IERS	2020-Feb-10

### Issue on Reference Frames

The IVS provides a number of data products, as is outlined, for instance, in the Terms of Reference. Among the core products feature the celestial reference frame, which is defined and maintained uniquely with VLBI data (for the time being), and the terrestrial reference frame, where VLBI is an important contributor to defining the scale. This issue of the IVS Newsletter focuses on the CRF and TRF work of the IVS. We hope that it makes the reference frame work done within the service more accessible to and appreciated by the larger community.

– The Editors



*Observing network of the mixed-mode R&D session rd2006 with eight VGOS stations (blue triangles) and seven S/X stations (red inverted triangles).*

### Inclusion of VGOS Stations

This will be the first time that we include VGOS sessions in the ITRF. In 2017, six VGOS stations successfully participated in CONT17 for five days. In addition, over the past two years a network of up to nine VGOS stations has been observing every two weeks. Our submission will include all (~40) of the operational VGOS sessions which have been correlated by December 31. The VGOS stations are the future of the IVS, and we are at the very beginning of the transition from the S/X to the VGOS network. I believe that this marks an inflection point, and that going forward the VGOS networks will become more and more important.

In addition to the VGOS sessions, there will be a few mixed-mode sessions which include both S/X and VGOS stations scheduled together. (Mixed-mode observing was demonstrated in RD1810 where WESTFORD, GGAO12M, and KOKEE12M were tagged along. Since there were only three VGOS stations, and they were tagged along, the results were suboptimal, and this should be viewed as a proof-of-concept.) In 2020 we scheduled three mixed-mode sessions: RD2005, RD2006, and RD2007, each of which had ~16 stations, half of which were S/X and half VGOS. Haystack is working hard to correlate as many of these as possible for inclusion in ITRF2020. These mixed mode sessions are important because they allow us to directly tie the two networks together. We will continue to schedule mixed-mode sessions going forward to strengthen the tie between the two networks.

In closing I want to discuss some other ways the IVS submission differs from previous ones.

**Loading Effects.** The IVS has incorporated the effect of pressure loading for over 20 years in its routine analysis. This is something that the other techniques still do not do. Because of this, for the past ITRFs, the IVS has done special

solutions with pressure loading turned off so that our results are consistent with the other techniques. In the new submission we include loading effects, but the SINEX files have enough additional information that the effect can be removed.

### Gravitational Deformation of VLBI

**Antennas.** VLBI antennas undergo gravitational deformation as the elevation changes. This changes the path length through the antenna, which results in changes to estimated parameters, primarily local up. As of 2019, we had models for the delay as a function of the elevation for six IVS antennas: EFLSBERG, GILCREEK, MEDICINA, NOTO, ONSALA60, and YEBES40M. These models are used by all ACs which are contributing to ITRF2020. Very recently, in November 2020, a group produced a deformation model for NYALES20. This is important because NYALES20 participates in so many IVS sessions. Unfortunately, this model arrived too late to be used for ITRF2020, although we will start to include it in routine analysis in the near future.

**Sources.** In a departure from the past, the IVS SINEX files will include the sources in the normal equations. In previous submissions, source coordinates were eliminated from the normal equations. Inclusion of source coordinates will allow non-IVS members to generate their own Celestial Reference Frame from IVS data.

A webpage, which gives more information on ITRF2020 including the current status of submissions, is available at: [https://ivsec.gsfc.nasa.gov/IVS\\_AC/IVS-AC\\_ITRF2020.htm](https://ivsec.gsfc.nasa.gov/IVS_AC/IVS-AC_ITRF2020.htm).

### Results of the Representative Elections

We are pleased to inform you of the results of the elections for the representative positions on the IVS Directing Board. IVS Associate Members have voted for a Networks representative and an Analysis and Data Centers representative in the period November 11–25, 2020.

184 Associate Members cast votes, out of 344 eligible Members (~53% voter turnout). The elected representatives are:

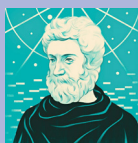
- Networks representative: Pablo de Vicente, Yebes Observatory, Spain
- Analysis and Data Centers representative: Oleg Titov, Geoscience Australia, Australia

Their four-year term runs from February 2021 to February 2025. We thank all of the candidates who were nominated for their willingness to serve on the Board. We also thank the IVS Associate Members for their participation in the election.

– Election Committee

## Celestial Reference Frames: Past – Present – Future

*The story of the International Celestial Reference Frame (ICRF) spans four decades. With the adoption of the ICRF3 in 2018 and the release of Gaia's 3rd frame scheduled for December, we take a moment to revisit the history of the VLBI-based celestial frame work. Newsletter Editor Hayo Hase interviewed several CRF veterans and experts via e-mail: David Gordon [DG], Chris Jacobs [CJ], Patrick Charlot [PC], and Alet de Witt [AdW]. The outcome is a smorgasbord of information, stories, and other tidbits. Enjoy!*



*"No great thing is created suddenly, any more than a bunch of grapes or a fig. If you tell me that you desire a fig, I answer that there must be time. Let it first blossom, then bear fruit, then ripen."*

– Epictetus

*David, you have worked for decades in the generation of Celestial Reference Frames (CRF). Can you tell us how and when you got involved in CRF work?*



David Gordon

[DG] I got involved in CRF work while processing and analyzing the VCS sessions, starting around 2000. ICRF2 was being planned by a closed working group and it seemed that they needed someone who understood the data well enough to clean up whatever problems were in the data. So, in 2008, I asked Chopo Ma if I could help. I ended up fixing many problems, such as multiple source names, incorrect ambiguities, and bad data points and I generated many test solutions and

then the final solution. Dan MacMillan also got involved and made the estimate of the noise floor.

*What is a CRF?*

[DG] Well, first you need to define a celestial reference system (CRS), which gives the definitions and specifications of the system, such as its origin and axes, and what constants and models are to be used. This system is then 'realized' by a celestial reference frame (CRF) of precise celestial coordinates of many 'fixed' sources in the sky. Distant quasars represent the ideal 'fixed' sources since they are so far away that they should not show any measurable proper motions and VLBI has been the only tool capable of very precise measurements until recently with Gaia. The current ICRS was adopted by the IAU in 1997 and there have since been three ICRF realizations from VLBI measurements.

*How is an ICRF created?*

[DG] There are several major steps in creating an ICRF. One first needs to make a global solution of thousands of VLBI sessions using the latest geophysical models and solve for source positions as well as site positions, site velocities,

and daily EOPs. The new CRF needs to be aligned with the previous standard; for ICRF3, this alignment was made by imposing a no-net-rotation constraint on the 295 ICRF2 defining sources during the solution. And a new set of defining sources needs to be selected to define the new CRF's axes. These sources should be stable and frequently observed sources that are well distributed around the sky. And a noise floor can be estimated by doing solutions of subsets of the data and seeing how well the resulting source catalogs agree. This noise floor is then used to inflate the source position errors to more realistic values. Finally, for the new CRF to become the 'International' CRF, it must be adopted by the IAU.

*Why are there different ICRFs, like ICRF1, ICRF2, ICRF3? On which radio frequencies are they based?*

[DG] Each one was a successive realization of the ICRF, being more precise and larger than the previous. ICRF1 used S/X geodetic VLBI data through mid-1995 and had 608 sources and an estimated noise floor of 250 micro-arcseconds. ICRF2 used data through 2009 and had 3414 sources and an estimated noise floor of 40 micro-arcseconds. But 2/3 of those sources were from the first generation VLBA Calibrator Surveys (VCS) with much larger position uncertainties than the other 1/3. Both ICRF1 and ICRF2 used all the available S/X sessions and these were taken mainly for geodesy or for a phase reference catalog. ICRF2 had only a small amount of data from sessions dedicated to CRF astrometry. This changed though with ICRF3. I led the VCS-II campaign with 8 VLBA sessions in 2014–2016 to re-observe the VCS sources and improved their precision approximately 5-fold. And then, fortunately for ICRF3, the USNO took over half of the VLBA funding, and we made 25 additional VLBA S/X astrometry sessions through March 2018 for use in ICRF3. The ICRF3 S/X catalog has 4,536 sources and an estimated noise floor of 30  $\mu$ as. And ICRF3 also has two smaller catalogs at higher radio frequencies. It has a K-band catalog of 824 sources, made from around 50 new dedicated astrometry sessions from the VLBA and the HartRAO–Hobart baseline and 15 earlier VLBA (2002–2007) sessions. And it also has an X/Ka band catalog of 678 sources observed on single baselines using large DSN and ESA spacecraft tracking antennas. The ICRF3 is further unique in that the effect of galactic aberration is modeled in all three frequency catalogs.

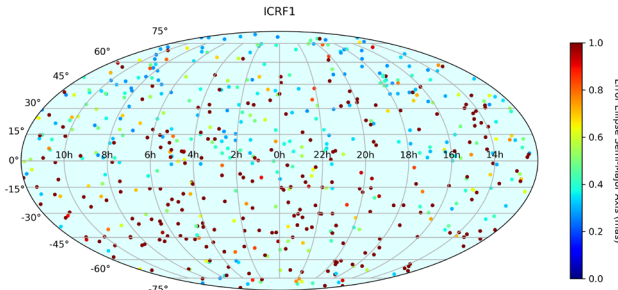
*Which one of the different ICRFs does an analyst use for historical VLBI data: the most recent one or the one valid at that time?*

[DG] Source positions are more accurately known for ICRF3, so that is the one that should be used. ICRF2 replaced ICRF1 in 2010, and ICRF3 replaced ICRF2 in 2019 as the International Celestial Reference Frame.



*The Terrestrial Reference Frames are numbered with a year as an epoch. Why do the ICRFs not follow a similar scheme?*

[DG] The first one was initially just called the ICRF, without the ‘1’. For the next one, a ‘2’ was appended to distinguish it from the first one. For the ITRFs, there is a year (epoch) associated with the site positions and a velocity with which to interpolate to other epochs, so appending the epoch makes some sense. However, there were no particular epochs associated with ICRF1 or ICRF2; the source positions were assumed to be constant. ICRF3 now does have a galactocentric epoch (2015.0) associated with it, but there was no desire to change the naming scheme.



*Improvement in the source distribution and position accuracy for the three successive ICRF realizations (plots kindly made available by Sébastien Lambert). Here: ICRF1.*

this idea to enable “sailing” the solar system for exploring the planets. Related to that work, we use the radio sources to track the motion of the planets and thus improve our knowledge of the planetary ephemeris. Even farther from home, the CRF enables differential astrometry of the position, parallax, and proper motions of objects in our galaxy such as water masers which trace out the spiral arms of our galaxy. Calibrators from the CRF are also used to phase calibrate images of other extra-galactic radio sources.

By observing changes in the apparent positions of extragalactic sources, we can also test the theories of special relativity (aberration) and general relativity (gravitational delay/“bending”). Returning nearer to Earth, VLBI signals contribute to atmospheric studies by measuring the ionosphere and troposphere. And, of course, the CRF is essential to geodesy which measures both motions of the stations (tidal motions, plate tectonics) as well as the orientation of the Earth in space. VLBI is the premier technique for measuring UT1–UTC and nutation from which we get a deeper understanding of the interior of the Earth.

*Chris, can you share with us some of the early history of the CRFs?*

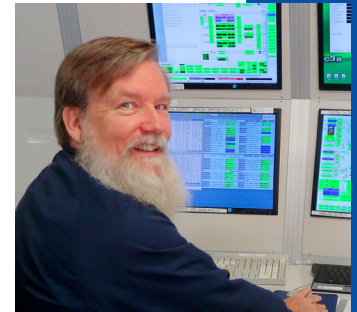
[CJ] By the 1980s it had become clear that the proper motions of stars in our galaxy were increasingly a limitation on the stability of the IAU’s fundamental celestial reference frames. Accordingly, IAU resolutions in the late 1980s and 1990s began to lay the formal ground work for moving from star-based, optical catalogs to extragalactic objects for which the VLBI technique had recently enabled high-accuracy (mas) radio positioning.

International coordination of VLBI-based CRFs started well before the formal adoption of the ICRF in 1998. The IERS under Martine Feissel and Felicitas Arias coordinated radio CRFs in the 1980s and 1990s. In fact, the conventional orientation of the ICRF originates from the IERS frames. Under the leadership of chairman Chopo Ma, the ICRF1 was adopted by the IAU in 1997 and then the ICRF2 in 2009. The ICRF3 was adopted in 2018, and is the first multi-wavelength frame and as such paves the way for the inclusion of the Gaia optical frame in the future. In summary, dual-band S/X observations started in 1978, with each subsequent step taking a decade and the entire effort spanning more than 40 years.

*What are common applications of the CRF?*

[CJ] A CRF provides fiducial points on the sky for measuring angles. The main advantage of VLBI vs. artificial satellite techniques such as GNSS and DORIS is that the “orbits” of the VLBI sources are stable over decades using only two parameters to describe their position. This extreme stability of the CRF gives a corresponding stability to the many applications of VLBI. But what are these applications?

For millennia travelers both on land and especially at sea used the stars to navigate by. We have now extended



*Chris Jacobs*

*The geodesists in our readership are familiar with the CRF as a quasi-inertial system that enables to study Earth orientation. That’s why we would like to learn how the CRF can be used in deep space missions? How is the navigation in space done with CRF sources?*

[CJ] In deep space, there are no GNSS satellites with which to navigate. One has to rely on observations of naturally occurring objects such as quasars. Spacecraft angular positions are measured by doing a differential VLBI group delay measurement between an ICRF source and the spacecraft radio signal. This data is combined with measurements of radial distance (range) and velocity (Doppler) to the complete position and velocity in three dimensions.

*We know of the efforts to construct, next to the classical S/X-band observation-based CRF, alternatives based on higher radio frequency observations. What do you gain with the higher frequencies in space and on Earth?*

[CJ] There are both negative and positive factors driving the decision to move from S/X-band observations to K (24 GHz) and/or X/Ka (8/32). Observations in the S/X-band

are becoming increasingly difficult due to increasing RFI at S-band. In fact, many VGOS antennas may not support the spectrum near 2 GHz.

**K-band:** Many, if not most, radio astronomy observatories already support K-band, including the VLBA, HartRAO, and Hobart, which have served as the core observing sites for the K-band CRF. Together these sites have gathered close to a million CRF observations making the K-band Right Ascension precision comparable to S/X. Moreover, there are enough K-band stations to allow the sources to be imaged so that structure can be studied. We also note that K-band has done the best of the three CRF radio bands at observing near the galactic plane which is important for studying Milky Way objects such as water masers. The challenges for K-band are to add north-south baselines and to get GNSS based ionosphere calibrations at all sites.

**X/Ka-band:** In the spacecraft networks many S/X antennas are being retired: NASA's DSS 15 at Goldstone, the 45-m at Tidbinbilla, and eventually DSS 65 at Robledo. The Japanese space agency, JAXA, is replacing its 64-m S/X antenna at Usuda with a 54-m X/Ka antenna nearby at Misasa. The European Space Agency (ESA) antenna at Malargüe, Argentina never had S-band. So, in the spacecraft tracking world, S/X is rapidly diminishing as a supported frequency combination especially given that S-band spacecraft missions are becoming a thing of the past. Moving to X/Ka not only avoids S-band RFI, but it greatly reduces plasma effects near the Sun where missions such as NASA Parker Solar Probe, ESA's Bepi-Columbo, and JAXA's Hayabusa-2 are now operating.

Astrophysically, the radio sources that we observe often have jets with steep spectra. This means that as one moves to higher frequencies (K or Ka), the jet fades making the sources more compact and point-like. This should reduce source structure effects which show signs of being a limiting error for VGOS.

*How do you determine the accuracy of celestial reference frames? Are they dependent on the number of observations or the observed wavelengths?*

[CJ] The formal precision in all three components of the ICRF3 (S/X, K, X/Ka) is quite good for well-observed sources, generally better than 100  $\mu$ s. So, the accuracy is limited by systematic errors. We quantify the systematics by inter-comparing the three independent S/X, K, and X/Ka frames. We also compare against the Gaia optical frame which is an independent technique (space vs. ground, optical

vs. radio, pixel centroiding vs. interferometry).

All three radio frames suffer from a deficit of long north-south baselines which leads to Declination precision being a factor of two or more worse than Right Ascension precision, depending on the region of the sky being observed. The S/X frame has the most sources, but most of these are observed in only a few sessions. The S/X frame also has source structure issues. The K-band frame has limited observations in the south as well as imperfect ionosphere calibrations due to the lack of dual-band observations. The X/Ka frame has the largest zonal errors due to its reliance on just two baselines for 85% of its data. As the X/Ka network geometry adds stations, these errors are being reduced.

*What is needed to keep the CRF up-to-date or to improve it?*

[CJ] One of the key advantages that VLBI has over space-based missions, such as Gaia, is the potential to maintain a continuous history of observations and thus a continuous

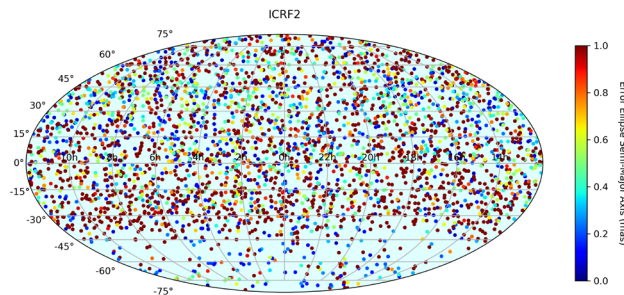
history for all VLBI products such as CRF, TRF, and EOP. While our VLBI sources have no measurable parallax or proper motion, effects such as galactic acceleration create effective proper motions that over the decades integrate up into significant position changes. The ICRF3 is the first frame to model this galactic acceleration and

refinements will surely be needed to maintain the long-term stability of the frame.

In addition to maintaining temporal continuity, our ICRF work needs more observations on north-south baselines to improve declinations. There are also long-standing issues from stochastic variations in clocks and tropospheres, which will be difficult to eliminate entirely. On the analysis side, there are issues with modeling source structure as well as accounting for the correlated nature of stochastic errors when weighting solutions.

*Patrick, the new VGOS systems are equipped with broadband receivers, observing more spectrum in the range of theoretically 2–14 GHz and practically 3–11 GHz. How will VGOS contribute to the CRF? Will VGOS define a third CRF or can it be matched with S/X, K, or X/Ka?*

[PC] The level to which VGOS will contribute to the CRF, in particular how many sources may be observed, is still to be evaluated. Depending on the conclusions, VGOS observations may want to concentrate on a set of core sources, e.g., the ICRF3 defining sources, ideally ultra-compact, and push their position accuracy to the limit. In any case, the VGOS CRF will not match any of the current S/X, K, or X/Ka band realizations, because the source



*Distribution and position accuracy of ICRF2.*

positions do not coincide at the different bands due to the changing source morphology with frequency. Looking at the next stage, the future ICRF is likely to be multi-waveband, incorporating also the optical realization by Gaia into a fully unified multi-waveband frame. All those realizations (possibly including a VGOS one) should cohabit peacefully, not trying to win over each other, for the benefit of the entire field, and contribute to improving our understanding of the physics of the underlying objects.

*You are responsible for the Bordeaux VLBI Image Database (BVID, <http://bvid.astrophy.u-bordeaux.fr>), where you archive thousands of VLBI maps. Sources exhibit different properties. How do you classify sources? Which sources enter into the CRF and which cannot make it?*

[PC] Before answering, I first want to give credit to Arnaud Collioud who is generating all these maps from the RDV sessions and who is also the technical lead for the database. Sources in the BVID may be selected according to their ICRF3 categories (defining and non-defining), but also according to their physical properties: flux density, structure index (a quantity that quantifies the source structure contribution to the VLBI delay for all possible Earth-based VLBI baselines), source compactness (a similar statistics for the ratio of the correlated to total flux density). Of course, the usual selection by name, date, session, and band is also available. In general, no sources are excluded from the CRF, except possibly those that have the most extreme structures (e.g., extending over tens of milliarcseconds). However, when it comes to the time of choosing defining sources, source structure becomes critical and only those sources that are compact enough can make it. In the case of ICRF3, the VLBI images and the above structure indicators, plus their variability with time, have been examined for more than 800 sources, pre-selected based on their position stability, before making the final selection.

*It has been noticed that the higher precision of VGOS resolves source structure. Can you explain why?*

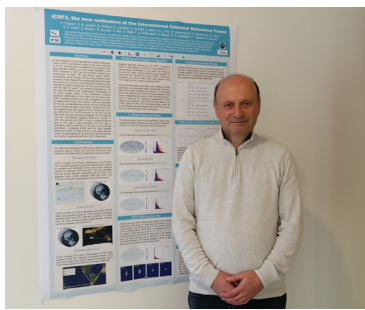
[PC] In the context of imaging, “resolved” may not be the most appropriate wording. The angular resolution of the VGOS network is not higher than that of the legacy network. In this respect, the sources are, therefore, not more resolved with VGOS. However, since the broadband delay is more precise, the consequence is that source structure effects stick more easily above the noise level in those measurements than in standard S/X measurements.

*Is observed source structure a disqualifier for CRF, or does it need to be modeled properly in order to increase the accuracy in the CRF?*

[PC] Source structure is a disqualifier if your ambition as

a source is to enter the very select club of defining sources—in that case, better hide your jet! Otherwise, you can remain safe, nobody will kick you out unless you behave very, very badly. Ideally, source structure should be accounted for. However, such modeling is facing many issues in practice, from temporal variability to frequency dependence, which makes the identification of an appropriate structure feature

that is stable over time and frequency for every source not so easy—this is why the issue has been around for the past thirty years. Achieving this goal would require more or less quasi-permanent imaging. We are not yet there but are progressing toward it, which may be achieved with VGOS when the full network is established. Ultimately, the limitation will then come from the VLBI core component stability, that is, from the source physics.



Patrick Charlot

*Do we need special observing programs to address open research topics when striving for the best CRF?*

[PC] We must assess the current dedicated observing programs and determine whether IVS could do better with the available resources for the benefit of the CRF. Which sources, which network, and which observing strategy are the major points to be addressed in this respect. The results of this assessment will then drive the evolution of the CRF observing programs, whether with the legacy network or VGOS.

*Alet, you have worked with radio sources for a long time and you recently got elected to chair the IVS CRF Committee. What was the reason to form the CRF Committee?*



Alet de Witt

[AdW] The CRF Committee was established to ensure that the S/X observing programs by the IVS are aligned with the goals of the ICRF and that these programs be continued and developed along the recommendations put forward in the IAU 2018 Resolution B2 on ICRF3. The recommendations require that “appropriate measures be taken to continue to develop these programs, at multiple radio frequencies and with a specific effort on the southern hemisphere, to both maintain and improve the ICRF3.” We know that no single person or entity can implement and monitor these programs on their own, and the CRF Committee of the IVS aims to bring together a group of experts with a shared goal for maintaining and developing the S/X CRF.

*How does the committee think to improve the CRF?*

[AdW] One of the first tasks of the CRF Committee will be to assess the current CRF observing programs, e.g., the number of sessions, the session types and setups,



the antennas and network combinations that are used, scheduling strategies, source lists, data rates, correlation, and so on. Based on this assessment, the committee will then make recommendations to the IVS Directing Board on observing programs and strategies to ensure that we provide proper data for maintaining and developing the S/X CRF. The committee will also take on an operational role for the implementation and monitoring of these programs.

*Who will work with you on the CRF? Do you need more scientists joining the effort and how could they connect to this type of CRF work?*

[AdW] The CRF Committee is composed of members selected among the IVS associate members. The initial members were selected in accordance with the Terms of Reference of the CRF Committee, and membership was approved by the IVS Directing Board. The Terms of Reference and member list are both available from the webpage of the committee: <https://inscc.gsfc.nasa.gov/about/com/crfc/index.html>.

*You have always been promoting CRF observations in the southern sky in order to close the gap around the southern celestial pole. What would you need to keep up with the accuracy of northern hemisphere sources: more observation time or more network stations in the southern hemisphere?*

[AdW] Catalogs of compact radio sources are generally weaker in the south by factors of 2 or more, in both density and precision. This is mainly because of the much smaller number of network stations in the south, compared to the north. Even though the ICRF3 showed significant improvement over the ICRF2, the current S/X frame still shows deficiencies by factors of 2–3 in the south. So yes, we do need more southern stations—a VLBA equivalent in the south would be fantastic! Also, as Chris mentioned earlier, we need more observations on north-south baselines to improve declinations.

I should mention that in an attempt to further improve the CRF in the south, we have recently increased the sensitivity of southern IVS CRF observations by a factor of 2 or more, which allows us to now include more and weaker sources in these sessions. This, in turn, has already improved the source density and spatial coverage in the

south, as well as the position accuracy of southern sources, in both coordinates. We have also optimized the scheduling of these sessions to allow imaging to map the structure and evolution of these southern CRF sources. However, many of the Australian 12-m telescopes, that were previously part of these dedicated southern IVS CRF sessions, are now transitioning to broadband and will not be available for S/X observing in the future.

*How does the CRF Committee address the needs for the VGOS observations regarding source structure and its models?*

[AdW] For now, the networks that we will target for CRF observations will be the legacy networks. However, the potential of the VGOS network as a contributor to CRF development will be studied and assessed (including source structure effects in VGOS data), as one of the first tasks of the newly-established CRF Committee.

More information on the newly established IVS CRF Committee and its activities are available from the IVS webpage: <https://inscc.gsfc.nasa.gov/about/com/crfc/index.html>.

*Finally, you are working so much with radio sources. We would like to know, whether you have a favorite radio source and why?*

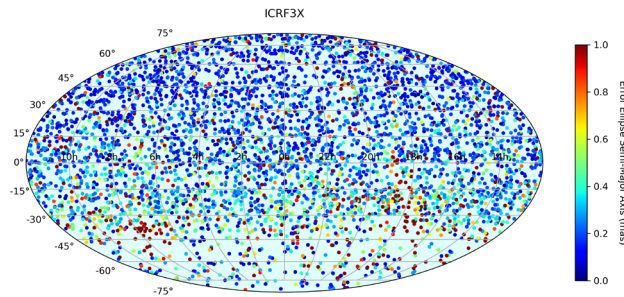
[DG] I pick IIIZW2. It is from the class of blue compact galaxies that Zwicky identified from Palomar Sky Survey plates. My PhD thesis was a neutral hydrogen survey of around 100 such objects using the Arecibo and NRAO 300-foot antennas.

[CJ] Definitely 0851+202 (OJ287)! It has a super-super massive blackhole and a secondary object that rips through the main accretion disk at predictable times. Also, on a practical level, it has always been a great fringe finder.

[PC] Very difficult to answer as I have several favorite sources! I will go for 0851+202 (OJ287), a source that I first studied some 25 years ago using Crustal Dynamics Project data. It shows a helical jet trajectory and is suspected to harbor a supermassive binary black hole.

[AdW] My favorite source is the circumpolar source 0454-810. This quasar is a strong and very, very compact source at all radio wavelengths. Although 0454-810 is quite characterless compared to many other extra-galactic radio sources, it is infallible as a calibrator source. It is also an ICRF3 defining source.

*Thank you very much for this interview and keeping track of our most remote radio sources. Next time I do VLBI observations I will watch out for your favorite source in the observation schedule!*



Distribution and position accuracy of ICRF3.



ICRF3 final working group meeting in Bordeaux (2018).

## Wetzell, Wien, Zürich: New OC Advances Schedule Writing Automation

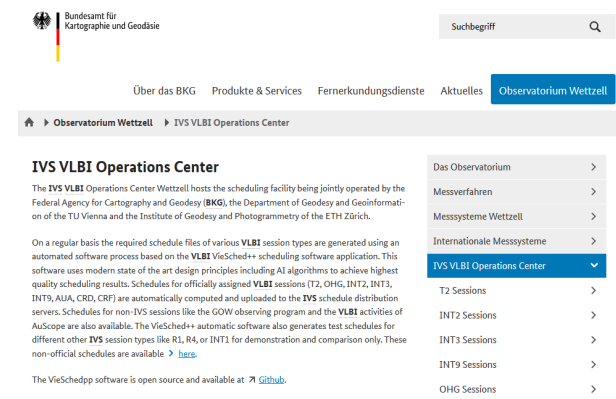
– Christian Plötz, Thomas Klügel, Torben Schüler (BKG), Matthias Schartner, Benedikt Soja (ETHZ), Johannes Böhm (TUW)

The Geodetic Observatory Wettzell (GOW), jointly operated by the Federal Agency for Cartography and Geodesy (BKG) and the Technical University of Munich (TUM), was accepted as an IVS Operation Center (OC) on November 19, 2019. This addition complements BKG's substantial contribution to the IVS and its continuous and long-term VLBI observation programs. Recently, the OC in cooperation with ETH Zürich (ETHZ) and TU Wien (TUW) added automated schedule generation to its capabilities.

specific local VLBI sessions as well as VLBI test sessions making use of the VLBI network Wettzell, AGGO, and O'Higgins. However, as BKG has a formal cooperation with the TU Wien and many of the transferred observation programs were already scheduled using a different software, namely VieSched++, it was decided to use VieSched++ for routine scheduling operations at the new OC. With the change of Matthias Schartner, the main developer of the VieSched++ software package, from TU Wien to ETH Zürich, a third institution joined the cooperation, so that today the BKG, the ETH Zürich, and the TU Wien jointly perform the assigned scheduling tasks in the context of the Operation Center Wettzell.

In terms of quality of service of an Operation Center, where aspects of reliability, availability, transparency, and a reproducible generation of highly optimized schedules play an important role, the capabilities of VieSched++ were extended by a Python scripting framework allowing a very high degree of automation and quality control. This allowed the concept of an automated scheduling server located at the Geodetic Observatory Wettzell, where a daily scheduling task, controlled by a cron job based on the master schedules, generates (in a simplified view) related VLBI scheduling files for all available VLBI session types. Furthermore, the VLBI sessions assigned to the OC are automatically uploaded to the official distribution servers for further VLBI stations' observation purpose.

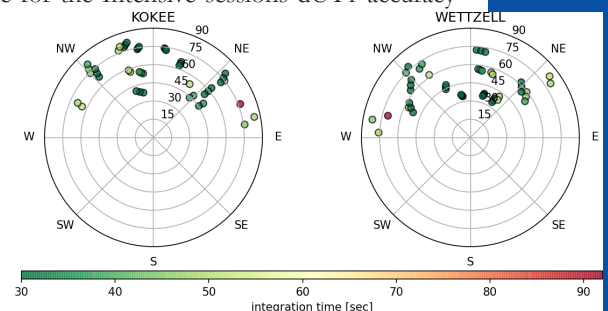
For the scheduling task itself, a dedicated scientific goal was defined for every observation program. For example, for the T2 program the average station coordinate accuracy is of highest importance and is the primary session goal, for the OHG program special emphasis is placed on the station O'Higgins, while for the Intensive sessions dUT1 accuracy is of most importance. In general, the definition of the scientific goal is represented by a combination of many metrics that often include the number of observations or the sky-coverage at the stations.



Website of the Operation Center hosted at BKG. [https://www.bkg.bund.de/DE/Observatorium-Wettzell/IVS-VLBI-Operations\\_Center/IVS-VLBI-Operations\\_Center](https://www.bkg.bund.de/DE/Observatorium-Wettzell/IVS-VLBI-Operations_Center/IVS-VLBI-Operations_Center)

The main motivation for establishing an IVS operation center at Wettzell was to continue the scheduling tasks of the Institute of Geodesy and Geoinformation of the University of Bonn (IGG)—Arno Müssens, who had maintained the scheduling activities for over 30 years, was no longer available for that task due to retirement. The official IVS session types supervised at Bonn were historically focused on sessions with participation of BKG's VLBI radio telescopes, that is, Geodetic Observatory Wettzell, AGGO in Argentina (the former TIGO VLBI station in Chile) and O'Higgins (the VLBI station on the Antarctic Peninsula). This included the legacy S/X VLBI sessions of the following types: OHG (O'Higgins southern hemisphere network), T2 (Global terrestrial reference network), EUR and EUR-D (European VLBI network session, which are now discontinued), and the Intensive session on Monday INT-3. In this context, the scheduling activities of BKG at the VLBI group in Leipzig, including the scheduling of the weekend Intensives INT-2, were also transferred to the new OC.

Before Wettzell's designation as Operation Center, the traditional and well-established software application for generating VLBI observation schedules 'sked' was used to generate VLBI observation schedules, initially for Wettzell-



Sky coverage of session Q20341.

The scheduling framework itself does not only generate one schedule per session, but it also automatically generates hundreds or even thousands of different schedules using varying parameters and scheduling approaches. Every one of



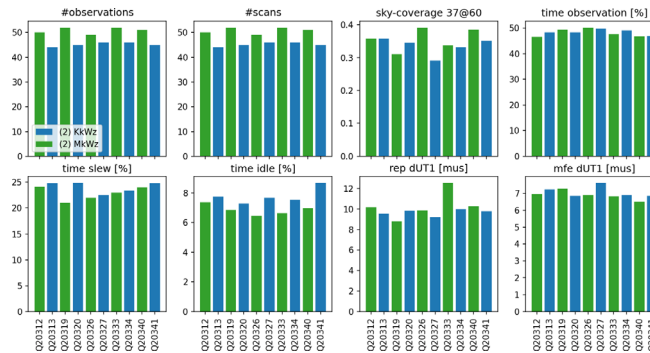
these schedules is further simulated 1000 times with random errors to receive trustworthy simulated formal errors and repeatability values. Most recently, approaches using Artificial Intelligence, in particular evolutionary strategies, are used as well to further optimize the generated schedules. Based on the simulated accuracy values of the geodetic parameters and the defined scientific goal of the observation program, the best schedule is identified and the responsible persons are notified via e-mail that a new schedule was generated. The e-mail includes not only the schedule files but additional statistics, plots, and comparisons with previous sessions of the same observation program to make it easy for the responsible person to decide if some modifications are necessary. In case no modifications are necessary, the schedule is automatically uploaded to the IVS servers.

Besides providing a reliable automatic workflow, the capability of the Operation Center includes fast reaction to external feedback, as VLBI stations might, for instance, drop out due to technical problems, want to “tag-along” for testing, or maybe the cryogenic temperature of the receiver is not maintained. In that case, qualified manual intervention is necessary. This means that designated personnel at the station receives and processes this information with fast reaction time. Additionally, all experts at Wettzell, ETH Zürich, and TU Wien are in the information loop to handle these events and provide all necessary expertise. Furthermore, continuous software maintenance and development provides the necessary basis for today’s VLBI scheduling challenges in the context of the establishment of the VGOS network. Another important point in order to reach a high level of service quality

is the provision of a long-term orientated environment for all of the necessary IT infrastructure with hardware redundancy and data backup procedures. These aspects are especially emphasized at the Geodetic Observatory Wettzell to provide a robust infrastructure concerning a potential failure analysis to reach quality-oriented requirements as OC.

Since our scheduling approach works very well and only requires minimal human interaction, it is now used for a variety of different observing programs such as the official IVS programs AUA, CRDS, CRF, INT2, INT3, OHG, T2, and VGOS-B sessions as well as for non-IVS programs such as southern hemisphere Intensives and BKG internal sessions. For testing purposes, all other IVS programs such as INT1, R1, R4, and VGOS sessions are also scheduled but not uploaded to the IVS servers. Every schedule, as well as additional statistics and plots, is uploaded to the OC webpage. The source code of the software routines including the automation framework is open source and can be found on GitHub (<https://github.com/TUW-VieVS>). In case other groups are interested in using our routines for their sessions or for comparison and testing purposes, they can contact us and we are happy to support them as much as possible.

In summary, the jointly established Operation Center at the Geodetic Observatory Wettzell, ETH Zürich, and TU Wien will be a stable and reliable component of the IVS for providing long-term VLBI operation center services and a platform for state-of-the-art scheduling and simulation software innovations.



*Statistics of scheduled INT2 sessions. These types of plots are automatically generated and distributed every time a new schedule is generated to make it easy for the scheduler to see if there is an error and a need for human intervention.*

## Upcoming Meetings...

AGU Fall Meeting Online Everywhere December 1-17, 2020	11th IVS TOW Virtual Workshop May 3-5, 2021
25th EVGA Working Mtg postponed (Mar 2021) tbd	URSI General Assembly Rome, Italy Aug 28 – Sep 4, 2021
EGU General Assembly vEGU21: Gather Online April 19-30, 2021	

<https://ivscc.gsfc.nasa.gov/meetings>

The IVS Newsletter is published three times annually, in April, August, and December. Contributed articles, pictures, cartoons, and feedback are welcome at any time.

Please send contributions to the General Editors (see below).

The editors reserve the right to edit contributions. The deadline for contributions is one month before the publication date.

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<https://ivscc.gsfc.nasa.gov/>.

## Data Unlimited – The IVS Seamless Auxiliary Data Archive

– Alexander Neidhardt, TU Munich; Stuart Weston, Auckland University of Technology

During the Analysis Workshop of the IVS 2014 General Meeting in Shanghai, there was an idea put forward to collect and offer auxiliary data continuously. Auxiliary and meta data are usually recorded in log files which are created by the NASA Field System (FS) during and especially for the time of an observation session. Therefore, these data points—like meteorological values, clock offsets, cable calibrations, other calibration information, and so on—are just sporadically available from time to time between start and stop of an observation. In some cases, data sets must be extrapolated to time periods before and after a session, so that, for instance, starting conditions show a smooth behavior. Nevertheless, the data is usually available continuously and with regular sampling rates at the location of the telescopes/stations.

Data and especially auxiliary data become more and more important on the way to the accuracy of VGOS, because they help to improve data, correlation, and analysis quality. This means that more and more data with higher time resolution are being recorded in the log files. As a result, the log files are becoming very large, while the problem of missing data before and after a session as well as the continuous sampling is not solved. Another aspect is the missing real-time overview during sessions, so that missing data, problems, or reduced performance can only be seen during the post-processing.

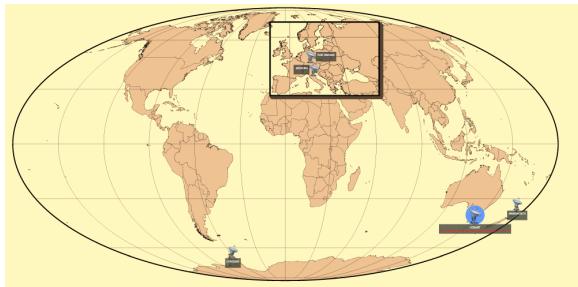
But all of these aspects might be solved now: Wettzell started the first seamless auxiliary data center for the IVS under <https://vlbisysmon.evbi.wettzell.de/zabbix> (account information can be requested from the authors). While such a data center has been operative at Wettzell for years collecting data of antennas operated by Wettzell staff, the new IVS network coordinator, Stuart Weston, promoted this idea again for other telescopes. Three further telescopes—Warkworth, Hobart, and Medicina—jumped on board and started sending meteorological data and clock offsets in real-time into the archive. Almost two months of data have now been collected with one data set per minute over the whole time period.

The three added antennas use the basic model especially designed for IVS partners. Stations do not have to install additional software. They just get an SSH key for a restricted user account on the archive server in combination with a special command to directly inject data. New data can directly be visualized on the server web page. The data archive currently supports 112 different items available in the FS. While basic users must send data using their own scripts (although example templates can be provided by Stuart Weston), stations can also install Wettzell's e-RemoteCtrl software to automatically support all possible items. The premium

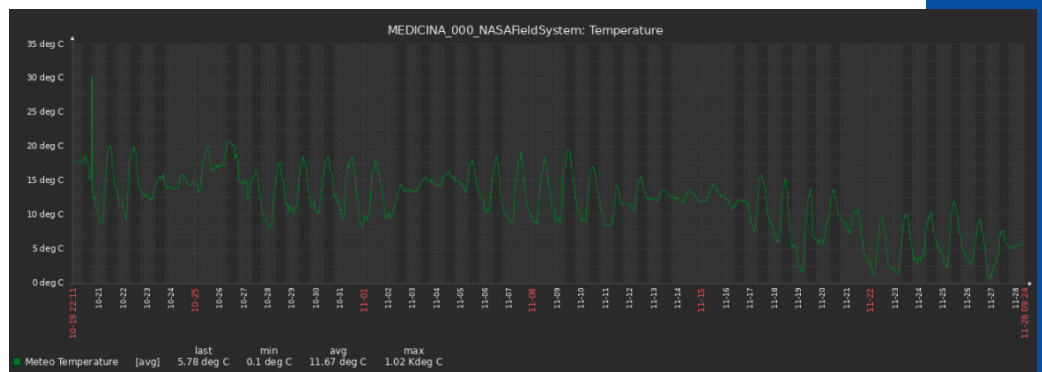
version used for the Wettzell antennas additionally allows to collect status parameters for many additional items not covered by the FS, such as from frontends, backends, servers, network, UPS, air conditioning, and so on. This can provide a more complete overview of your systems at a control center, for autonomous operations or for historical review and fault analysis.

Finally, a pretty nice aspect is offered to analysts, as they can use a Python interface to seamlessly request data sets from the server according to their individual requirements. It is a start towards unlimited possibilities and is also part of the EVN Jumping JIVE initiative. In due course the IVS Directing Board will provide a resolution for stations to try and adopt this service.

Acknowledgement: We want to thank Jamie McCallum from Hobart and Giuseppe Maccaferri from Medicina for their immediate support and enthusiasm. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730884 - JUMPING JIVE.



World map with status information of participating antennas.



Air temperatures from Medicina sent in real-time continuously over 40 days.

# How To...

## Fiber Optic Cleaning and Care

– Alex Burns and Mike Poirier, MIT Haystack Observatory

As newer technologies emerge, the many ways a station has to maintain their infrastructure evolve. Now, instead of coax cables, much of the RF path at the Westford radio telescope is fiber optic. This has many benefits, but also some challenges. Extreme precautions need to be taken whenever

mating a fiber optic connector, to maintain cleanliness. There is also the fact that it is made of glass, so it is fragile!

First, let's make sure we are mating the correct fibers together. The fiber comes in many different wavelengths and connectors; so, let's make sure you are mating two compatible connectors. Multi-mode fibers (usually for things like RS-232 or network) are typically ST or SC connectors, which can only mate with other ST or SC connectors. Single-mode fiber (which, as the name implies, allows only one mode of light to pass through it) is used for RF, as the bandwidth is higher and distortion is lower.

There are different connectors for single mode; we use FC-APC connectors, where the APC means 'angled polished connector', because the connector end is angled at 8 degrees and is polished for less insertion loss. Another thing to note with connectors, especially something like APC, is that the connector is keyed so the angles match each other. These

keys are not all the same! For FC, there are 2-mm-wide keys and 2.14-mm-wide keys. You can imagine what happens when you try and put a connector with a wide key, into a receptacle with a smaller key slot. It won't fit! The other way is also a problem, as a too-wide key slot can mean that you are not maintaining the proper alignment of the two fibers. The wider key is called "NTT" (or "type N") and the smaller key is seen as "reduced" (or "type R").

OK, now that you have learned some vocabulary words, and have the right fiber connectors, let's connect two fibers together. You will have a chassis-mounted bulkhead, or a fiber optic patch panel, with many different bulkheads inside. Take the caps off the bulkhead and off one of your fiber ends. Clean your fiber end, before inserting into the bulkhead. You can use a click-type cleaner, which might be easier to carry if you are climbing, or a (our preferred) cassette-type cleaner. These are both designed to remove any dirt oil or impurity from the end of the cable. Insert the first fiber into the bulkhead, without contacting any other surface on the way, and tighten the threads. It does not take much contact to dirty up a fiber connector! Make sure to clean the other fiber end, line up the keys, and now light is getting from end to end!

Hopefully you have been enlightened by this article.



The NeoClean-E3 fiber connector cleaner from US Conec, a click-type cleaning tool.



The palm-sized OPTIPOP-R2 fiber optic connector cleaner with two slots, a cassette-type cleaning tool.

## New Ingest at Data Centers in the Works

– Dirk Behrend, NVI Inc./NASA GSFC

The IVS is supported by three primary data centers: CDDIS, BKG, and OPAR. While for the first 18 years or so of the service's existence identical software was used to handle incoming data and products, which ensured having identical data holdings, a divergence occurred a couple of years ago. At CDDIS a new software was written and then implemented in April/May 2019, resulting in a slightly different processing plus adding the ability to ingest vgosDB. Roughly a year ago, work began to create yet another software suite based on a more modular design.

The main part of this new ingest software at CDDIS is integrated into a larger suite (for all geodetic techniques) that cannot be reasonably disentangled for outside usage. However, building blocks can be exchanged with other data

centers to obtain basically identical behaviors. The GSFC VLBI Group is working with staff from all data centers to write and test a main software that can be used at BKG and OPAR replicating the CDDIS properties. The work is nearing completion.

As part of the new ingest software suite a validation step (QC) was inserted into the processing chain. That means that every data type is validated prior to be added to the data repository, in addition to the filename check. The validation routines and the accompanying data description files form the modular pieces that can be exchanged between the data centers. We anticipate that in the second quarter of next year the data centers will run the new software and once again sport identical holdings.



## Lo and Behold: Reveries of a Virtual TOW

– Dirk Behrend, NVI, Inc./NASA GSFC

In a world that has become ever more connected and gone “virtual” in many ways, in particular during the time of a global pandemic, flesh and blood interactions almost feel like remnants of the past. However, in a time of social distancing the value of person-to-person interaction also has become more apparent. This forms the backdrop for discussing future meetings and workshops that will happen before we may go back to normal human interactions, which will hopefully unfold once inoculation programs gain a foothold on a global scale.

The IVS organizes the hands-on Technical Operations Workshop (TOW) for station operators every odd-numbered year. The next installment would nominally happen in 2021 and was put into the meeting calendar for the first week of May. The Program Committee and the teachers of the last TOW discussed the feasibility of a TOW. There was general agreement that an in-person meeting would not be possible and a decision had to be made between completely cancelling the TOW, postponing it by some time, or holding it virtually. Eventually, the majority opted for organizing a reduced TOW in a virtual setting.

So, attention station operators, while the details still need to be hashed out, there will be a virtual TOW held May 3–5, 2021 (followed by a mixed-mode correlator workshop the next day, also virtually). The strawman plan is to spread the event over three half-days (e.g., mornings in the US), cover three topics per half-day with a virtual presentation followed by a Q&A period, have no parallel classes, and have some lectures pre-recorded for pre-meeting viewing. This will allow for about one third to one half of the normal class load to be covered. Of course, other interactions between students as well as students and teachers will fall by the wayside. We anticipate that it will be necessary to vet the participants’ list, that is, we do not plan to have open classes. Nonetheless, we hope that this setup will facilitate the training of the technical staff of the stations; it felt wrong to have a gap of four years between in-person workshops.

Please feel free to contact the author with suggestions for the format of the workshop or any topic that you would like to see covered.

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