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An overview of the process of scheduling and scheduling algorithm for the GMRT observations

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ABSTRACT

This report outlines the scheduling process for observations with the upgraded Giant Metrewave Radio Telescope (uGMRT). As the world's most sensitive meter-wavelength radio interferometer, the uGMRT offers enhanced sensitivity and nearly seamless frequency coverage from 100 to 1460 MHz. Its versatility is further enhanced by simultaneous interferometric and beam-mode recording capabilities, along with spectral line observing facilities. A large collection of scientific proposals are pre-selected by the GMRT Time Allocation Committee (GTAC). The observations for these proposals are scheduled up to six months in advance. The goal in scheduling is to assign each observation to an appropriate time slot while minimizing constraint violations. This report provides a detailed overview of the complex scheduling process, which accounts for a variety of constraints, including astronomical, instrumental, and logistical factors. The scheduling scheme, following the quratile rank order for the observing proposals provided by the GMRT time allocation committee (GTAC), implemented in since GTAC cycle 38, described in this report achieves a scheduling efficiency of 95% or higher, with only 5% or less manual intervention needed. Unlike previous schedulers, this one eliminates unnecessary splitting of a single slot into multiple segments. The present scheduler can handle highly constrained observations, seamlessly incorporates changes in observing bands between slots, and efficiently schedules multiple observations of the same frequency bands consecutively.

1. INTRODUCTION

The uGMRT is an array of 30 antennas, each 45 meters in diameter, operating across four bands between 100–1460 MHz. It is a highly sensitive, wide-bandwidth instrument and stands as the world's largest radio telescope at meter wavelengths. The GMRT is managed by the National Centre for Radio Astrophysics (NCRA), which is part of the Tata Institute of Fundamental Research (TIFR). The GMRT offers various observing modes, including interferometric (imaging as well as spectral lines) and beam modes for time-domain observations. The telescope operates in two five-month observing cycles each year, with two months reserved for maintenance. These cycles begin in April/May and September/October. Proposals for observations are solicited bi-annually in January and July for participation in these cycles. The scheduling process aims to allocate specific observing slots to the scientific proposals approved for GMRT observations during each cycle. The Section 2 describes the history of how the scheduling process worked with the GMRT. An overview of scheduling process is provided in Section 3. The quratile ranked scheduling is reported in Scetion 3.1. Section 4 presents a statistics of the telescope usage. A summary and related discussion along with future scope is detailed in Section 5.

2. HISTORY OF SCHEDULING WITH THE GMRT

Following is a brief outline of history of the scheduling process with the GMRT since it's inception.

(i) **Manual scheduling 2002–2008:**
Between 2002 to 2008, observatory staff manually crafted the observing schedule. This way of scheduling the observations demanded considerable manual intervention and time investment. Given the paramount importance of optimizing constraints, it required substantial learning and iterative efforts to reach an optimal schedule. However, the experience gleaned from scheduling GMRT observations highlighted the necessity of exploring automation methods to minimize constraint violations within the allocated time frame.

(ii) **TRDDC scheduler 2008–2020:**
In 2006, an MoU was established between NCRA and TRDDC (the research arm of TCS), with the optimization of GMRT scheduling identified as a collaborative project. By 2008, TRDDC had developed an algorithm capable of generating observing schedules. This algorithm prioritized optimizing constraint violations rather than solely considering available telescope time. Further details regarding this software can be found in Gharote et al., 2009 [1]. The scheduling process is detailed in Katore et al. 2011[2]. However, the schedules generated in this process had two notable drawbacks, observations were fragmented into smaller segments and distributed across different days, and proposals were not scheduled contiguously. Attempts to resolve these issues at the optimization routine level proved unsuccessful, leading to the exploration of heuristic approaches. Increase in the number of highly constrained proposals after the GMRT upgrade lead to added difficult in the scheduling procedure. Moreover, previously there was no provision for taking input from the proposal ranking provided by the GTAC. Ultimately, we envision the need for developing an in-house software solution to facilitate the scheduling process for GMRT observations.

(iii) **In-house scheduler 2020–2024:**
The functionality of the in-house software package is detailed in the following sections.

3. OVERVIEW OF SCHEDULING PROCESS

Steps followed in the automated scheduling of the GMRT observations are detailed in the following,

(1) **Call for proposal with a dummy schedule:** A call for submitting scientific proposals is announced bi-annually with time line to submit proposals by 15th December and 15th June in the respective GTAC cycles. Tentative starting dates and durations for the upcoming GTAC cycles are decided by the GMRT operations. A blank schedule with the science slots marked is available at http://indrayani.ncra.tifr.res.in/~secr-ops/sch/c47webfiles/gtac_47_dummy_schedule.html. Additionally the availability of the useful LST hours plot is prepared for the users reference which is available at http://indrayani.ncra.tifr.res.in/~secr-ops/sch/c47webfiles/gtac_47_lst_availability.pdf. One month's time window is given to the users for proposal submission, after the deadline, GTAC committee reviews the received proposals and allocates the time as per the ranking.

(2) **Revision of coversheet:** After the time allocation, GTAC communicates to the scheduling team to inform the scheduling decision. Data for all the proposals (cover sheet of the proposals plus the scientific and technical justification) are now available on the NAPS (NCRA Archive and Proposal System) page (https://naps.ncra.tifr.res.in/naps/login), here the first step for the scheduling team is to send emails (via NAPS) to the users to revise the observing requirements in the coversheet for those who were allotted less time than requested. Typically one week is given to the users for proposal revision and a reminder email (via NAPS) is also sent.

(3) **Downloading the proposal data from the NAPS:** Once the "time request" and "time allocated" values mach on the NAPS with the users revising the coversheet, data for all proposal is downloaded and saved in an csv file, named "input2.txt", containing proposal code, slot number, observing time, frequency band, RA-DEC, hour angle, LST rise-set/range, IST range, preferred date window etc.

(4) **Identifying the scheduling constraints:** The scheduling team then reads proposals one by one and notes down the specific constrains and required scheduling strategy for each proposal. If some information is missing or is not clear from the cover sheet, scientific justification or technical justification then the scheduling team communicates with the user for clarification. While reading the proposals we tabulate the constraints in the "input2.txt" file. Information on preferred dates, co-ordinated observations with other observatories, LST rise set time, night time (IST time), total number of slots, merging slots, splitting slots, etc are tabulated.

(5) **Process of scheduling:** As a part of evaluation of the proposals the GTAC provides a quartile rank to all the proposals since cycle 36. In order to consider the rank order provided by the GTAC in the process of scheduling so that the observing constrained provided by the users are satisfied according to their ranks provided by the GTAC, we have developed quartile ranking scheduler (referred as "qr_scheduler" in rest of the report). This "qr_scheduler', has been implemented since GTAC cycle 38. Once all inputs (input2.txt: proposal data + constraints) are ready, we run through "qr_scheduler", which needs three input files, the first is "input1.txt" which has a quartile ranking wise sorted list of proposal codes, the second is "input2.txt" which has proposal data (source list + band info + constraints) and the third is "sch1.txt.org" which has blank schedule. It keeps doing iterations to get minimum constraint violations. At the end it produces the result in form of output file, "sch1.txt". Most of the time it converges within the reasonable number of iterations (20 to 50) with no constraints violations. But sometimes the output keeps on repeating with the same constraints violations. In such cases there is a clash between the proposals, i.e. two or more proposals are demanding the common time slots. We sort out these situations by communicating with the users. The level of observing constraints received varies between the observing cycles. Normally we get 100% results for harder constraints and 90% or above for lighter constraints. The remaining part of the scheduling is adjusting the lighter constraints and cosmetics like (uniformly spread through the cycle) is done manually. This process of scheduling is described in Figure 1 and detailed in below (Section 3.1).

3.1. *Automated quartile ranking scheduler*

Following are the algorithm steps followed for the automated quartile ranking scheduler.
(1) Reading the quartile rank wise sorted list of proposal codes from NAPS file: "input1.txt".
(2) Reading the proposal data i.e. source list, band info, constraints, slots from revised cover sheet from NAPS file: stored in "input2.txt"
(3) Reading the blank schedule file: "sch1.txt.org".
(4) Scheduling process starting with the following steps
(i) Scheduling begins with the first iteration(iteration loop), considering one of the proposals (proposal loop) with quartile rank 1 and corresponding constraints for the first observing epoch (epoch loop), generally proposals request for multiple observing epochs.
(ii) Generate the possible solution set for the requested epoch which satisfy the constraints.
(iii) Inside the solution loop, check the availability of the solution in the solution set.
(iv) If the solution is available then schedule it and exit the solution loop.
(v) If no solution available at the end of solution loop then try to find the solution outside of the solution window (by violating the preferred date constraints).
(vi) If the solution is available outside of the solution window then schedule it and print warning message.
(vii) If no solution available even outside of the solution window then print error message and proceed for the next epoch/slot.
(viii) Repeat steps ii-vii for all proposals and their all epochs.
(ix) Count the number of warnings and errors at the end of proposal loop.
(x) If the count is zero then exit the iteration loop (convergence is occurred and the scheduling is over).
(xi) If the count is nonzero then reorder the proposal list by moving the unscheduled or not well scheduled epochs/slots upward (provide the highest priority) and proceed for next iteration.
(xii) if the warnings and error messages are repeating (never converging) then stop the scheduler manually and resolve the conflicting constraints (same slots requested by more than one user), and re-run the scheduler.
(xiii) If the maximum number of iterations reached then exit the iteration loop and stop the scheduler.
A flowchart describing the above process is presented in Figure 1. After a certain number of iterations (typically 20 to 50), we normally achieve nearly 100% convergence. Next we investigate the schedule and make it more optimal with manual checks and repairs (refer to Section 6 for details). Finally we generate a schedule that satisfy all the constraints provided by the users and the scheduling process is complete.

3.2. *Informing users and releasing schedule in the NCRA web-page*

We upload this schedule on the NCRA and GMRT web-pages and release it for individual users for checking or confirmation. More details regarding the web display can be found in Section 6. The emails regarding the schedule to the individual users are sent by in house developed tool (described in Section 6). Again a few days time is given to the users to come back for any observing requirement that has not been satisfied with the scheduling. After resolving all these we make the schedule open for everyone which is typically a week prior to the GTAC cycle start.

Finally, the schedule is handed over to GMRT operation for dynamic scheduling and conducting the observations (see Section 6 for more detail).

4. STATISTICS OF THE TELESCOPE USAGE

In following we present the statistics of usage of the GMRT for cycle 38 onwards. Few plots are generated for visualization. Figure 2 plots the distribution of the observing time in the cycle 46, similar plots are generated for each observing cycle. It can be noted that night time is more crowded, as the astronomers generally prefer night time observations to ensure reduced RFI occurrences. Figure 3 plots the distribution of the GTAC time in various observing modes available at the GMRT. The distribution of the GTAC time in the available observing bands over the GTAC observing cycles is plotted in Figure 4, indicating band 4 to be the most used observing band over the cycles. Figure 5 plots the user type for the NCRA and non-NCRA over the past GTAC cycles. Figure 6 plots the users of Indian and non-Indian origin over the past GTAC cycles. Figure 7 shows a summary of the GTAC time usage for past GTAC cycles. It is evident that more optimised scheduling made it possible to allocate increasing amount of observing time with the GMRT over the observing cycles.

5. DISCUSSION, SUMMARY AND SCOPES

Unlike previous schedulers, this scheduler has no issue of fragmentation (i.e. unwanted splitting of single slot into multiple). This scheduler can accommodate highly constrained observations, takes care of adding the changing observing bands between the slots and the schedules multiple observations of the same frequency bands next to each other.

The scheme for scheduling described in this report is built in-house with the experience of the previous years. For the previous scheduler developed around 2009, scheduling efficiency (i.e. fraction of total GTAC time scheduled automatically) was up to 70% for the legacy GMRT observations and the remaining 30% or more was done manually. Later, after the upgrade of the GMRT around 2016, the observing constraints were increased (e.g. more number of users, request for simultaneous multi-band observations, increased number of beam former observations, increased number of multiple short duration observations spanned over the cycle) and so automated scheduling efficiency drastically reduced down and hence the more manual efforts were increased, making it almost impossible to handle. The "qr_scheduler" presented in this report achieves scheduling efficiency up to or above 95% and only 5% or less manual efforts are required.

Even though the scheduling process is mostly automated, there are few aspects which are not yet addressed by the scheduler. Following are few features that we would like to implement in future,
(i) Some proposers requests for simultaneous or quasi-simultaneous observing for multiple observing bands. At present this is addressed with manual intervention. We aim to automate the procedure for scheduling these observations as well.
(ii) Adding provision for providing alternate LST window on the same day while scheduling will be implemented. This will allow us to address constraints from multiple users with less manual effort.
(iii) To optimise scheduling we would like to implement consideration of the distance between the observing target from the sun.

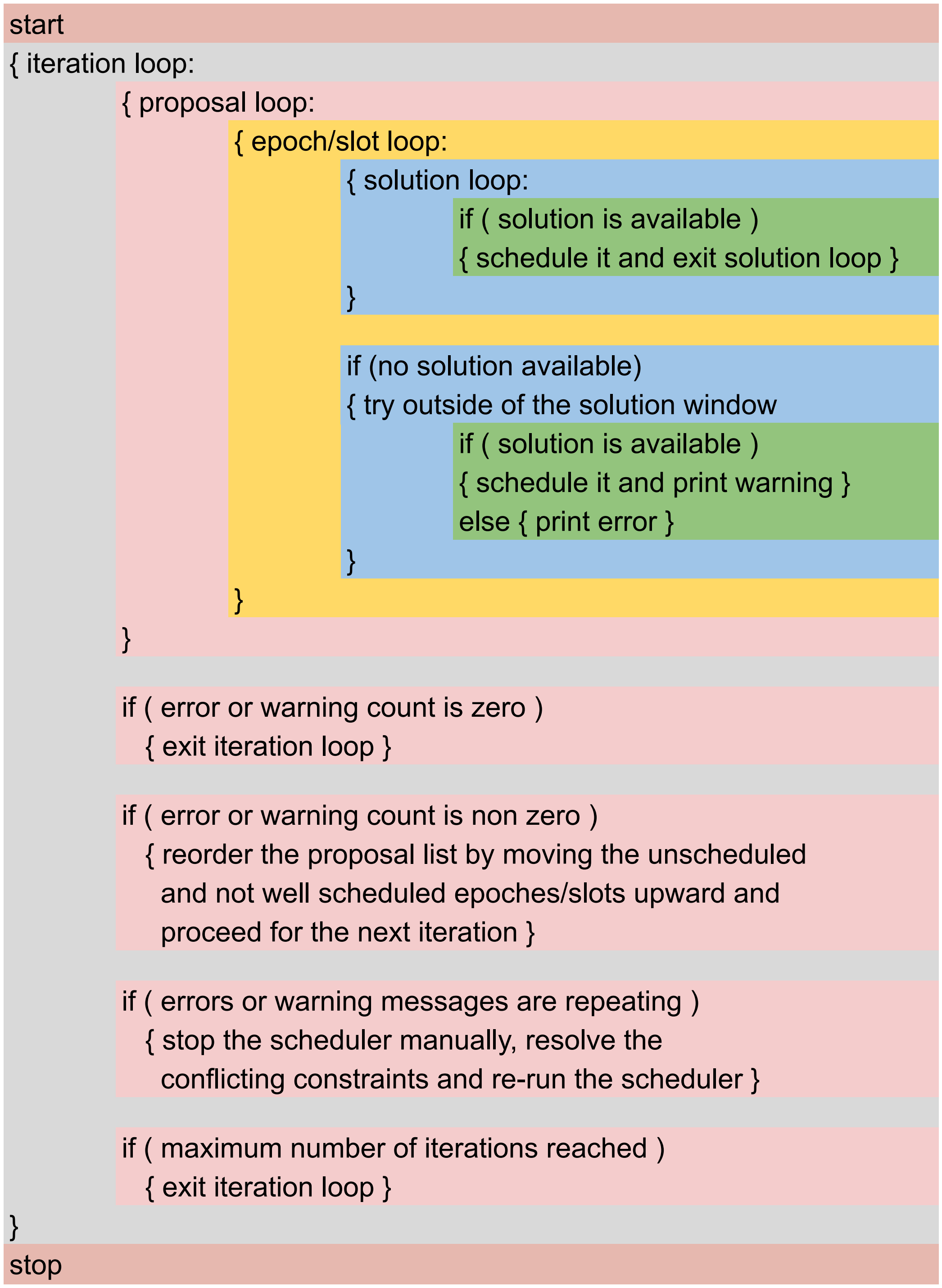

Figure 1: Flow chart describing the algorithm for scheduling GMRT observations discussed in Section 3.1.

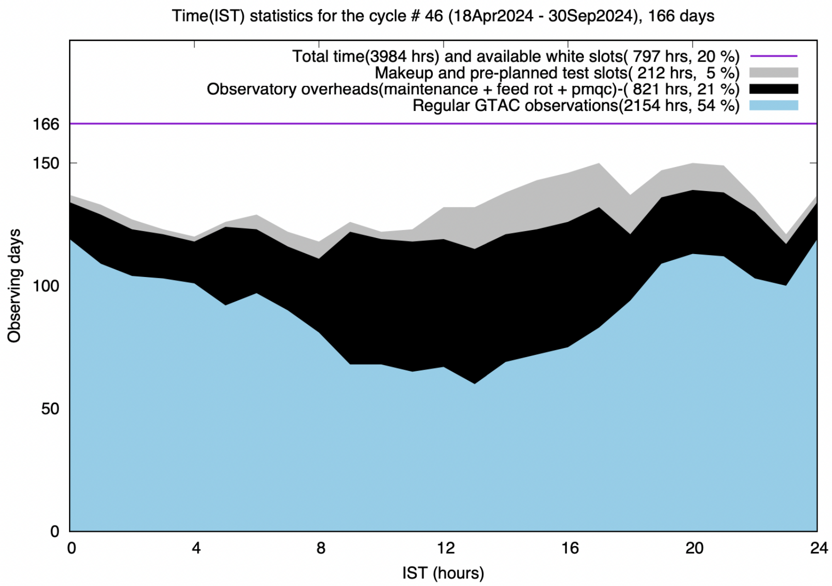

Figure 2: Distribution of requested observing time in Indian standard time (IST) for cycle 46, indicating higher demand for night time observations.

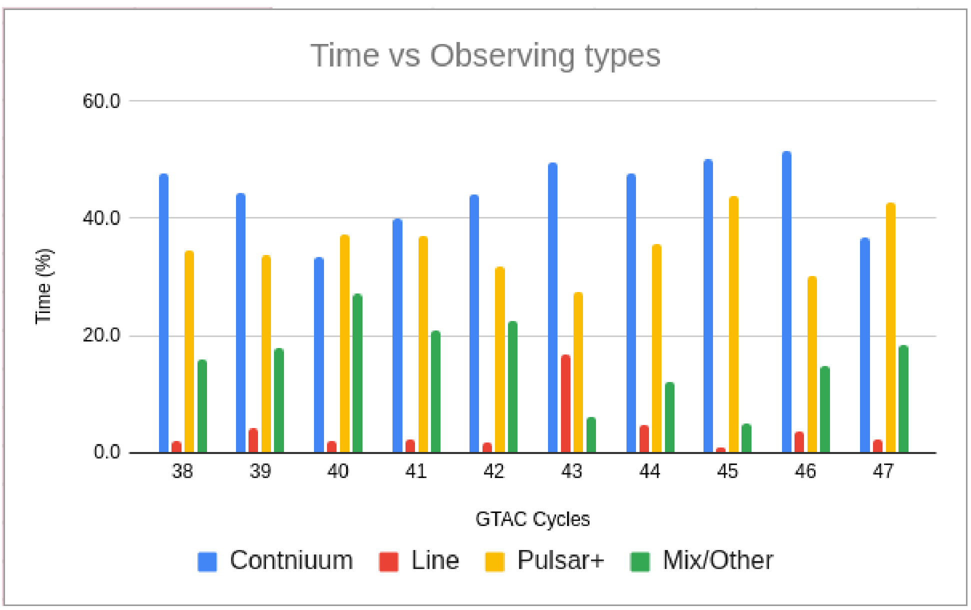

Figure 3: GMRT observations in various observing modes, e.g. continuum, line, pulsar/beam mode (for time domain observations and any combination of these.

To summarise, the "qr_scheduler"is implemented since GTAC cycle 38 allowed us to optimise the process of scheduling the GMRT observations. We are in the process of continuously upgrading the scheduler by adding new features to it. For example, the scope of using iteration loops was added in cycle 43. The choice of night time (IST) option to reduce radio frequency interference was added in cycle 44 and the UTC at the display was added in cycle 45.

6. APPENDIX: ADDITIONAL SOFTWARE PACKAGES

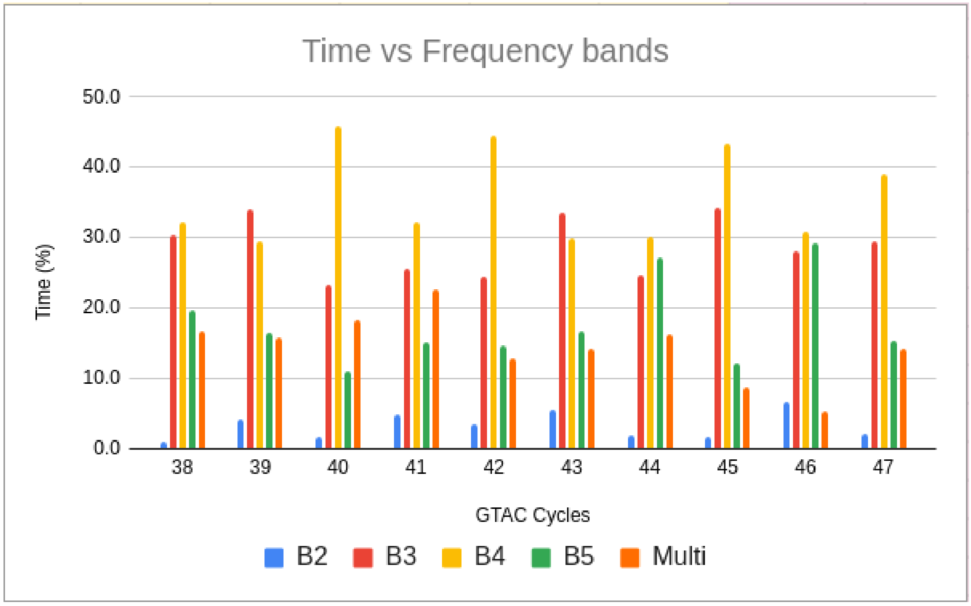

Figure 4: GMRT observations in various frequency bands, e.g. band 2, band 3, band 4 and band 5

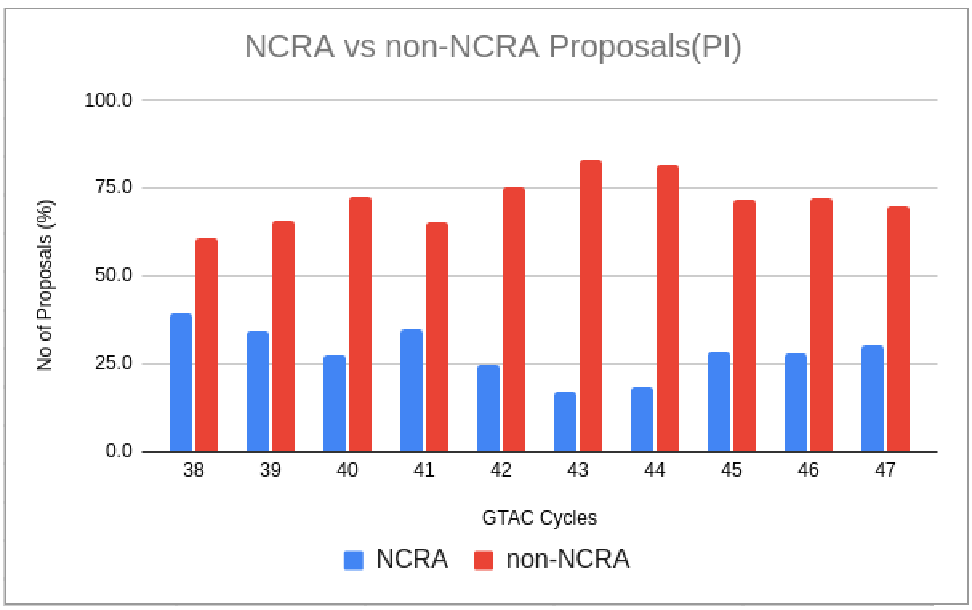

Figure 5: Figure showing the distribution of NCRA and non-NCRA users over the years

Along with the main scheduling algorithm ("qr_scheduler" described in this report) there are few other software tools which are required for the scheduling are described below.

(1) **Web disply (HTML):** The output of the qr_scheduler i.e. "sch1.txt" is an array having project codes and observing duration only. To display the schedule in HTML format, there is another script (HTML converter) which reads the scheduler's output file, "sch1.txt" and the proposal data file, "input2.txt" and generates a HTML file. This HTML file displays the schedule in tabular format and also displays the various information related to the schedule i.e. slot length, rise-set time,

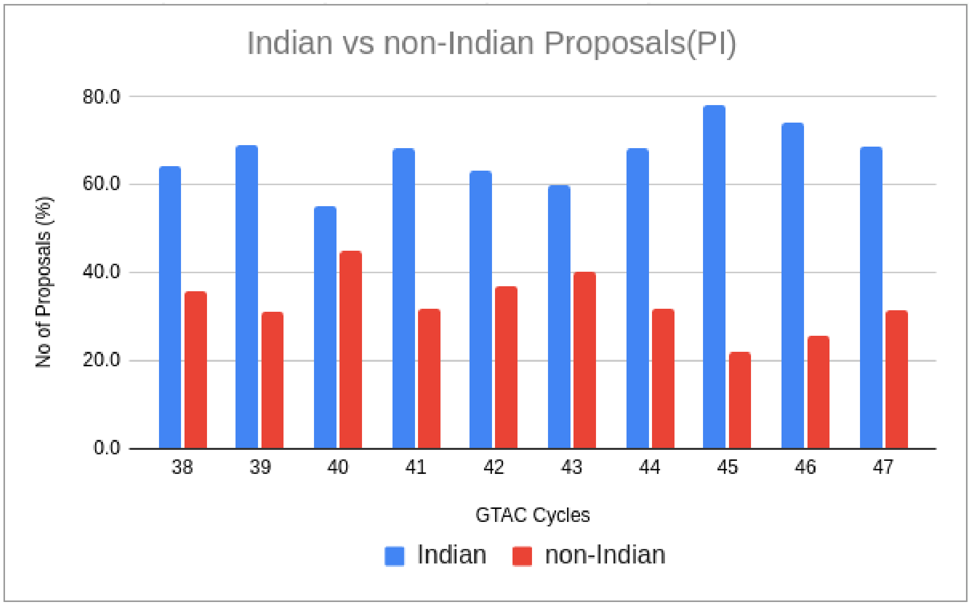

Figure 6: Figure showing the user type of the GMRT over the years for Indian and non-Indian origin users

GTAC Observing hours														
Cycle No	Pre Maint	Cycle Length hours	Regular	ToO	Total Allocation	makeup from previous cycle	Other Planned tests	PMQC+ maint+ feed+ other	Initial White Slots	DDT used	TOO used	MKP used	Any other Tests + feed	Final White Slots
47	16 days	4008 (167 days)	2066	302	2368	154	52	847	889	144	49	169	207	320
46	16 days	3984 (166 days)	2154	196	2350	139	73	821	797	170	49	80	115	383
45	23 days	3816 (159 days)	2175	169	2344	0	56	743	842	166	29	87	203	357
44	16 days	3984 (166 days)	2003	200	2203				1079	285		51	312	431
43	23 days	3816 (159 days)	1999	162	2161				883	180		73	208	422
42	16 days	3984 (166 days)	1944	150	2094				1114	133		73	544	364
41	16 days	3816 (159 days)	1809	118	1927				919	144		52	427	296
40	30 days	3816 (159 days)	1795	112	1907				1000	296		145	280	279

Figure 7: Figure showing the distribution of GTAC time over the past GTAC cycles

frequency, current LST, IST, UTC and the PI name etc. This tool is developed by Santaji Katore.

(2) **Schedule editing (manual):** To fix or to make some changes in the schedule slots, we edit the schedule (sch1.txt) manually. In this process we just edit the "sch1.txt" file using LibreOffice Calc and make the required changes. There is another version of HTML converter to view the schedule during this edit process. It highlights any specific proposals and shows the constraint violations like error in the rise-set time, frequency band, preferred dates and the distance from the sun. This tool is developed by Santaji Katore.

(3) **Automatic email sending to users:** This tool sends the emails to individual users. It needs a text file containing draft with variables and the text file containing the list of proposal codes. It searches all corresponding email ids in the data file and sends email to each individual user. One can also send the attachment with this email. Previously we used to send these emails manually. This

tool is developed in python by Deepak Bhong.

(4) **Dynamic scheduling (MKP+TOO+DDT+TST):** Some vacant slots (white slots) where no GTAC observations are scheduled are available in the schedule. During the ongoing GTAC cycle, these white slots are allotted, whenever approved for makeup(MKP) of existing GTAC observations, Target of opportunity (TOO) observations, Director's Discretionary Time (DDT) as well as for system-test (TST) observations. These observation codes are added to another file called "wht.txt", this is a similar file like "sch1.txt". This file is separately maintained to avoid the frequent edit of the main schedule file, "sch1.txt". Finally the HTML converter reads both files, "sch1.txt" and "wht.txt" dynamically during the page loading in the web-browser and displays the actual schedule. The dynamic edit of the "wht.txt" is handled by the "white slot requester tool" and it is developed by Sachin Sherkar.

7. ACKNOWLEDGEMENTS

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