The Green Bank Telescope Dynamic Scheduling System

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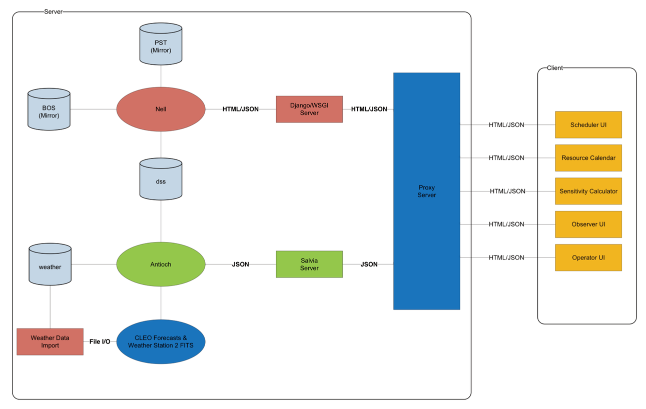
Abstract

The Robert C. Byrd Green Bank Telescope (GBT) Dynamic Scheduling System (DSS), in use since September, 2009, was designed to maximize observing efficiency while preserving telescope flexibility and data quality without creating undue adversity for the observers. Using observing criteria; observer availability and qualifications for remote observing; three-dimensional weather forecasts; and telescope state, the DSS software optimally schedules observers 24 to 48 hours in advance for a telescope that has a wide-range of capabilities and a geographical location with variable weather patterns. The DSS project was closed October 28, 2011 and will now enter a continuing maintenance and enhancement phase. Recent improvements include a new resource calendar for incorporating telescope maintenance activities, a sensitivity calculator that leverages the scheduling algorithms to facilitate consistent tools for proposal preparation, improved support for monitoring observations, scheduling of high frequency continuum and spectral line observations for both sparse and fully sampled array receivers, and additional session parameters for observations having special requirements.

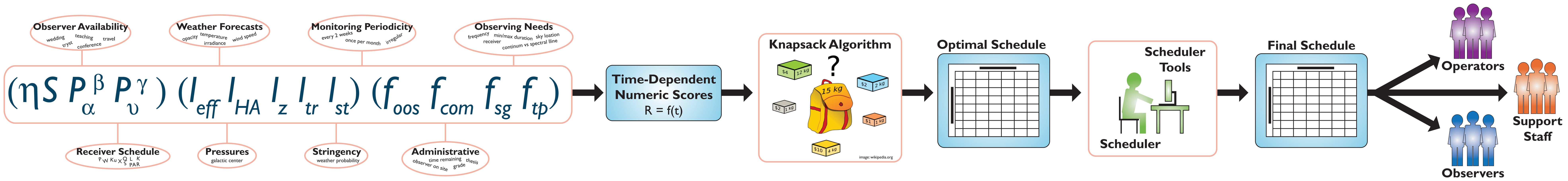
Under The Hood

The production DSS software employs a client-server architecture with two server components and several client interfaces. Most of the client interfaces are supplied through web application pages generated on the server. Apart from the scheduler's interface and sensitivity calculator (which required a more complex user interface). The DSS project has four source trees, tracked using git. Antioch, mostly written in Haskell, contains the science algorithm implementation such as scoring, factoring, packing, scheduling, and simulations. Nell, written in Python/Django, offers web services for the scheduler UI, observer UI, operator UI, resource calendar, and sensitivity calculator. The scheduler UI (nubbles) and sensitivity calculator UI (calculator_ui) are both implemented in GWT/GXT. All of these repositories can be found at http://www.github.com/nrao.



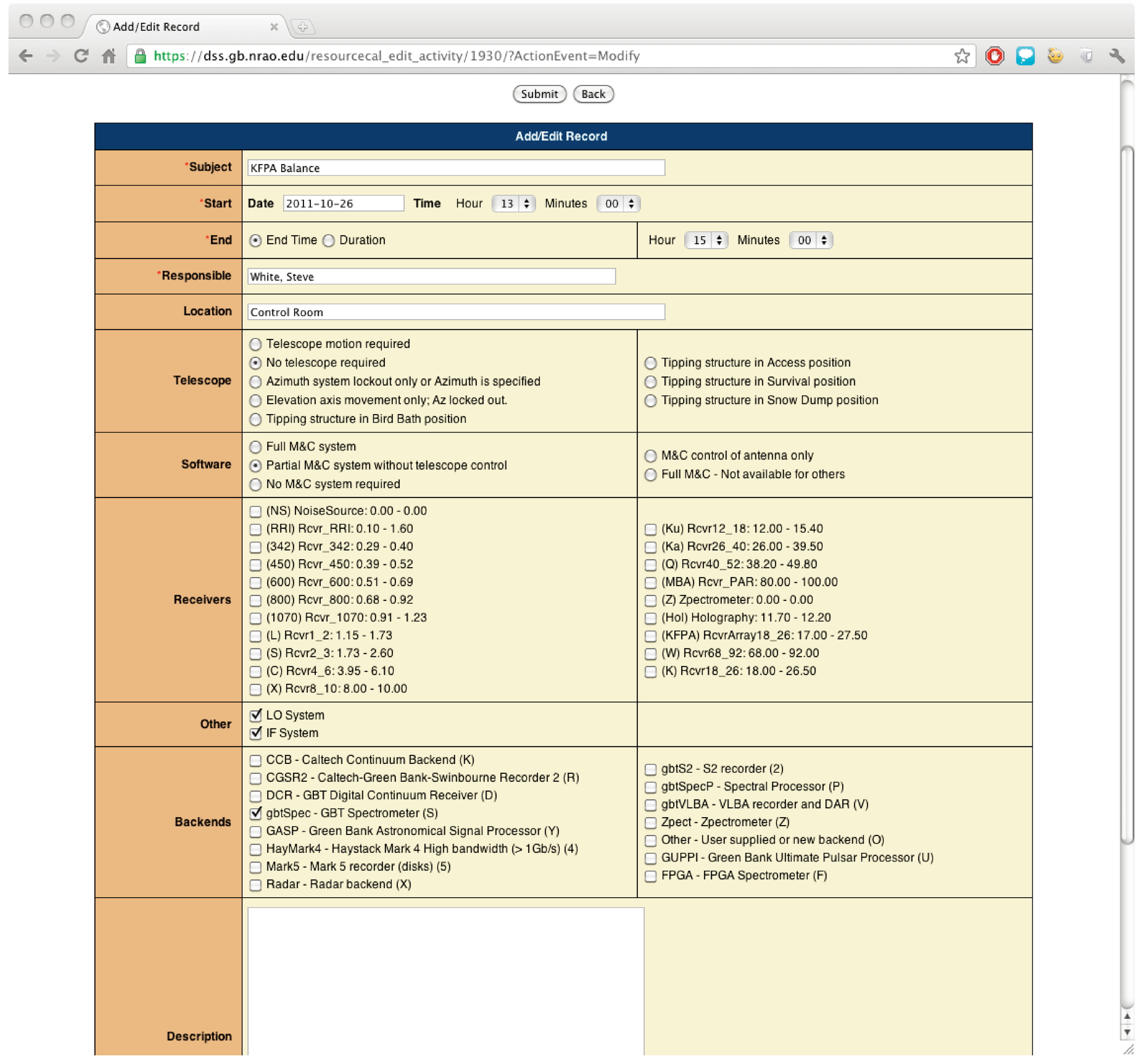
Overview

Our ranking algorithm provides a mathematical basis for compressing observing needs and weather forecasts to a single, time-dependent numeric value (R) thus allowing optimal scheduling by algorithm. All schedules are manually reviewed before being finalized, and tools for manually changing the schedule are readily available.

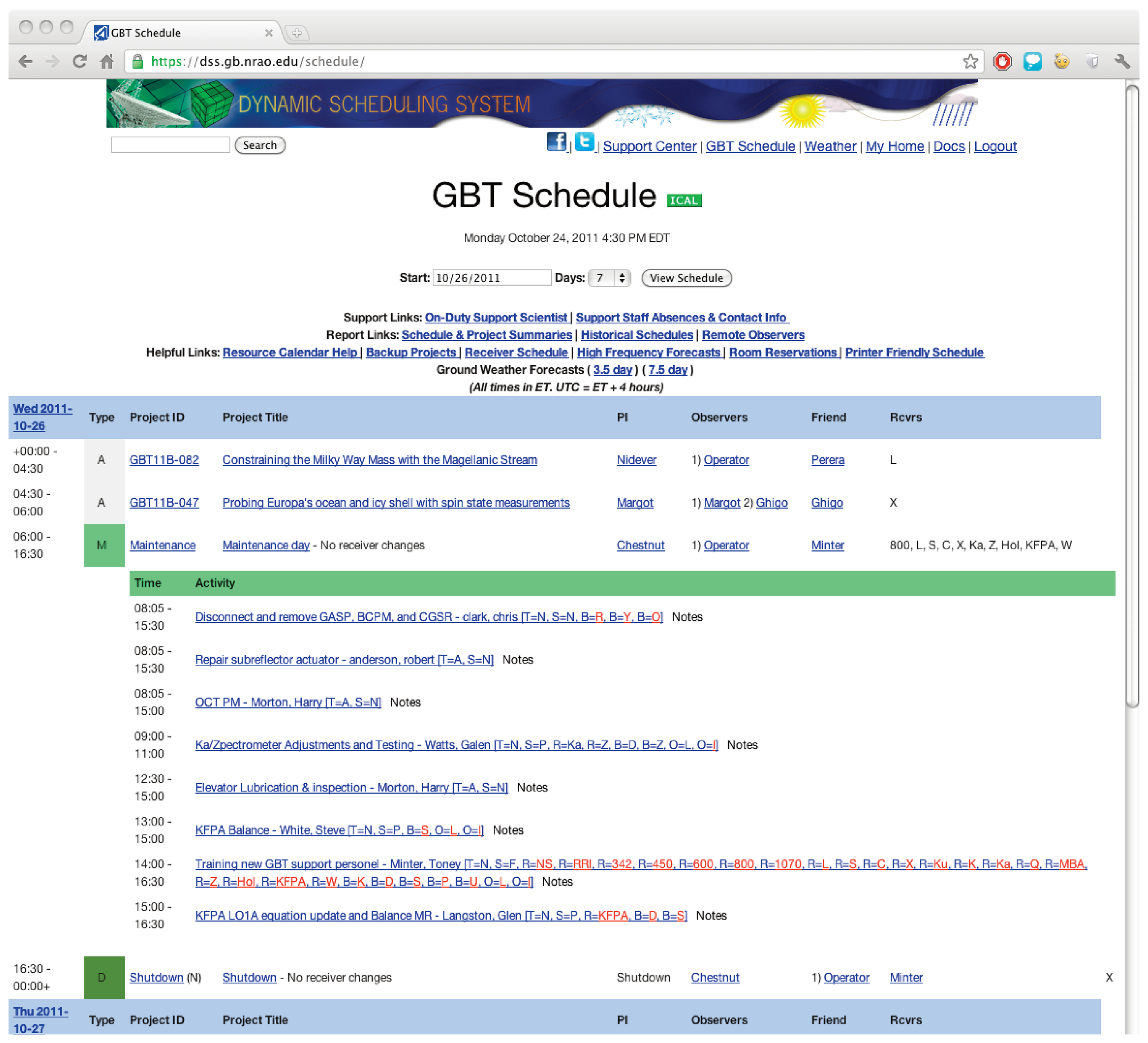


New Resource Calendar

The resource calendar, a tool used by the telescope operations team and scheduling team to coordinate maintenance activities, replaces an old resource. A new resource calendar was needed to encompass the concepts developed for dynamic scheduling. Under the DSS, maintenance days 'float' throughout the week. The support staff may create maintenance activities in the resource calendar before a maintenance day is scheduled. The resource calendar will keep track of the association between maintenance days and their activities. The figure below shows how maintenance activities are added to the resource calendar..



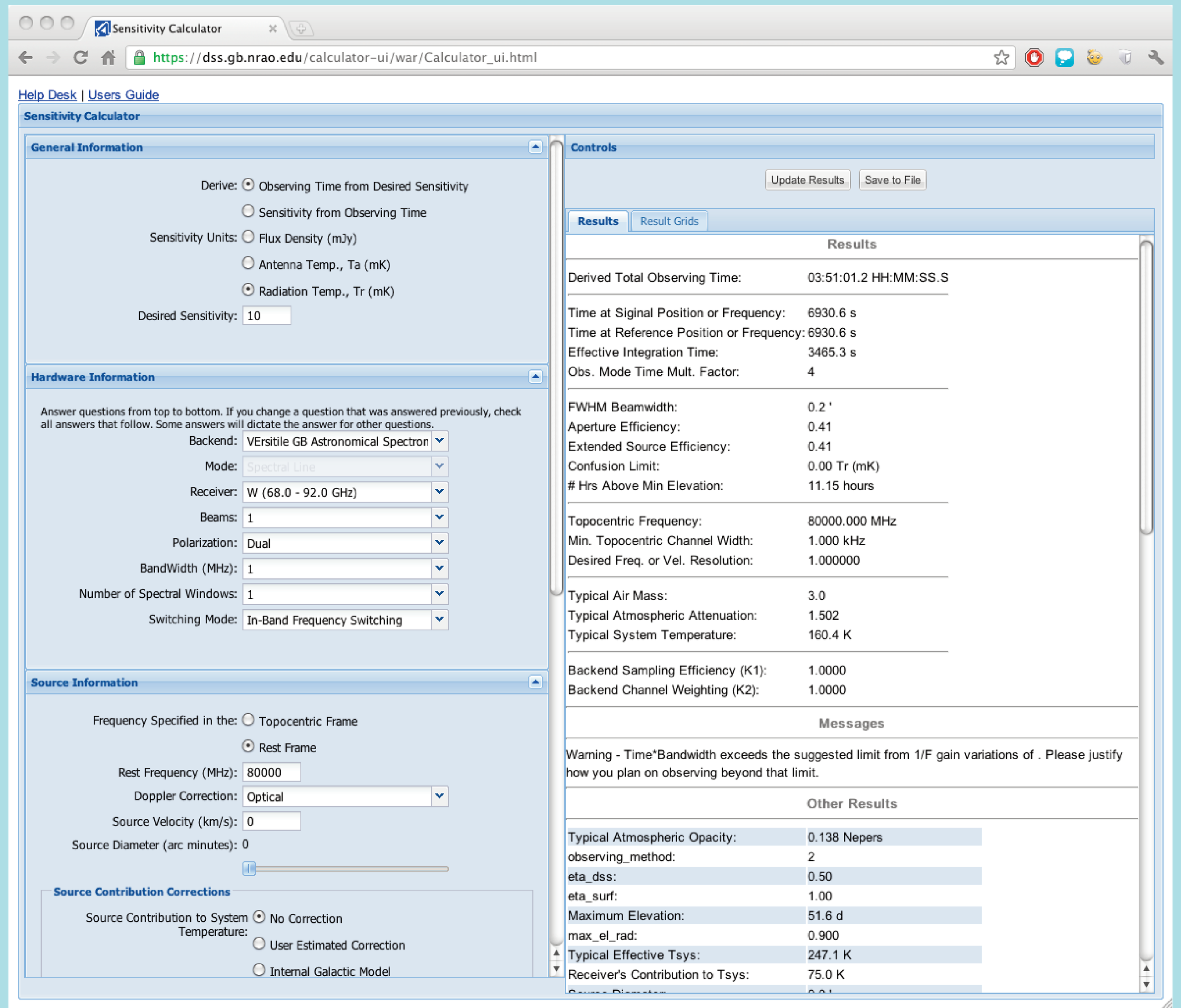
The telescope operations group can coordinate maintenance activities from the internal schedule page (see figure below). From the internal schedule page staff can see which activities are association with each maintenance day.



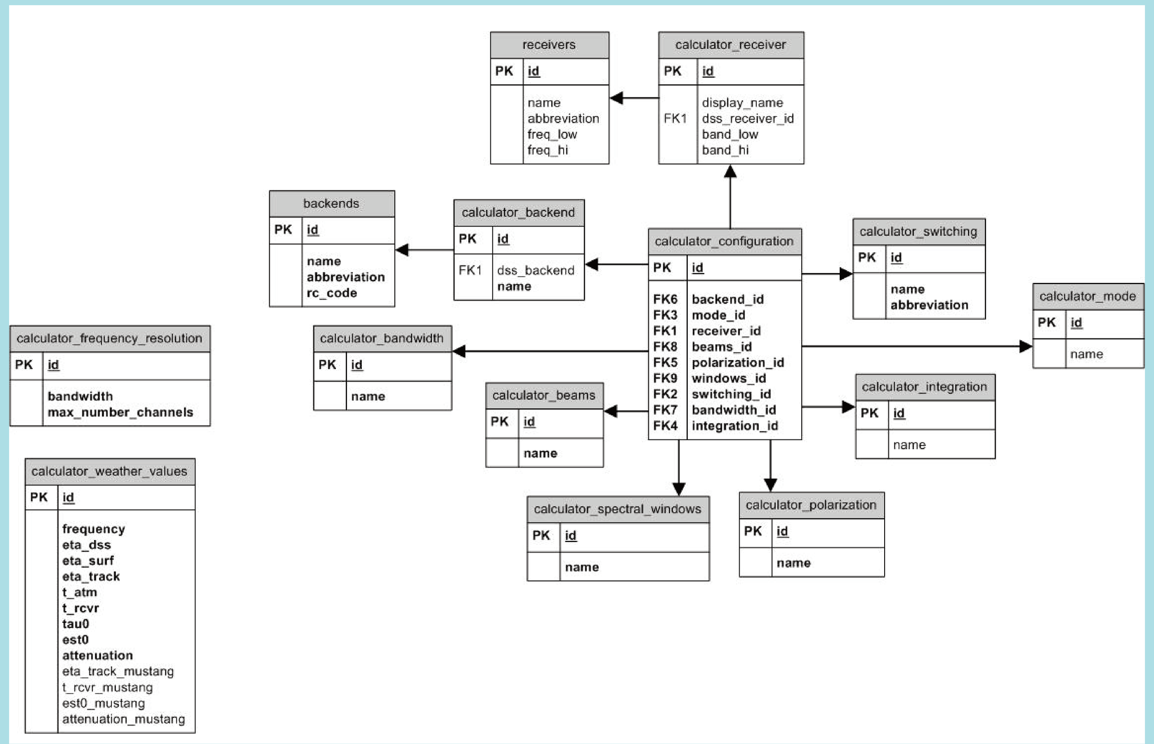
New Sensitivity Calculator

Every project scheduled by the DSS began as a proposal, where potential investigators estimate their observing requirements. Some have been using the GBT for years and are very well aware of its capabilities while others are new to radio astronomy all together. It is estimated that 25% of the users of the GBT were getting their time estimates wrong by a factor of two or more even when they used existing calculators. With the scoring algorithms for DSS we now have a much better idea of how to estimate the time required to achieve a desired level of sensitivity (Balser et al. 2009).

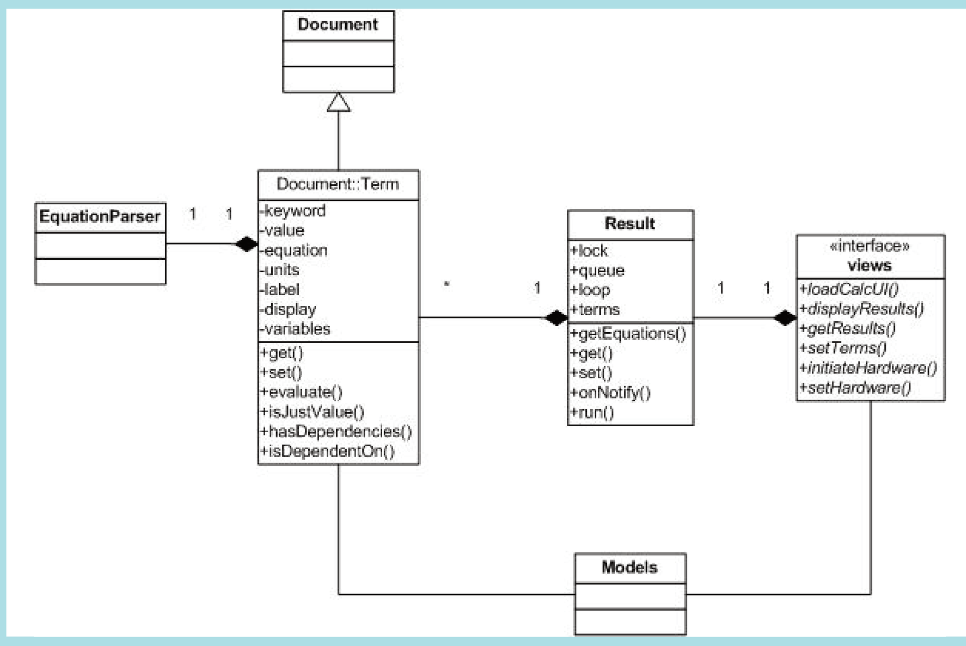
The new GBT Sensitivity Calculator has been designed to provide observers an easy way to determine the time needed to complete a proposed project or the expected sensitivity achieved by a project of a given length. In comparison with our previous calculator, the replacement is significantly more sophisticated and leads users through a complex web of decisions and choices astronomers make as they think out their sensitivity estimates. The new calculator should simplify the writing of a proposal's technical justification since a user can save the input parameters and results to a file, which can then be attached to a proposal. Since an attachment will contain very complete details, it will also reduce the chance that a reviewer will misinterpret the technical justification.



The hardware information section (seen in the figure above) contains all possible hardware configurations supported by the GBT, for which there are currently 8005. The configurations are managed by the science support staff and imported into the DSS database when updates are made. The hardware configuration database design follows a "star pattern", shown below.



One of the novel aspects of the sensitivity calculator is the calculation engine, which lies at the heart of the calculator. The software team was given a requirement that says the equations implemented by the calculation must be modifiable by scientific staff without modifying any code. The calculation engine's design makes this possible through a configuration file. In this file, terms are described by their equations. Terms may be dependent on other terms. A number of convenience functions have been placed in scope for acquiring information from the database and more complex (beyond mathematical) operations. The calculation engine was implemented using multiple threads primarily for flexibility rather than speed. This supports the dependencies between terms by allowing terms to be evaluated in a "batch mode" rather than sequentially. A results class holds all the terms, sets values provided by the user, and then asks all the terms to evaluate themselves. Terms that know all of their dependencies are calculated, others do nothing and wait for the next batch. An interface to the calculation engine is provided through a web interface, which is used by the client user interface.



Improved Support for Monitoring Observations

Initially, the DSS supported a simplistic system for recurrent observations (which are called monitoring observations in the DSS), where each 'Windowed' session would contain one or more windows. Each window was a time range in which the session was guaranteed to observe just one period. Recently, several enhancements have been added to this system to provide more flexibility to these types of observations.
The scheduling algorithms for the DSS have been developed and verified through the use of sophisticated simulations, which share the same code as the production systems. Initially, the simulations only included open sessions. Fixed and windowed sessions have recently been added to verify the affects of their distribution on the entire system.
In the past, windows could only be satisfied by one period, now they can be satisfied by multiple periods. This provides greater flexibility to monitoring observations, especially in the case of lost time.
By definition windowed sessions cover a continuous time range, in which one or more periods will get scheduled. A new cousin of windowed sessions was created, called elective sessions, which provide a discrete set of periods to choose from.
Depending on the scientific goals of a project, windowed and elective sessions may not necessarily need to be satisfied. In some cases, efficiency should not be sacrificed in order to meet the cadence desired. To handle these projects a 'Guaranteed' session flag has been introduced. All sessions are guaranteed by default, however if they are not, then a session's elective or window time range could elapse without observations taking place.

High Frequency Scheduling for Both Sparse and Fully Sampled Arrays

The atmospheric stability limit, ℓ_{st}, is a factor in the scoring algorithm (Balser 2009). It is used only for continuum observations, which are sensitive to atmospheric fluctuations. In the past, a forecast downward irradiance, I_{down}, threshold value of 300 W/m^2 was used to derive ℓ_{st}. A different metric has been developed for the 90 GHz Bolometer Array, MUSTANG, which uses the atmospheric system temperature (including hydrosols) at the target position elevation (DSPN 5.3).

The 4mm receiver is a dual-beam receiver that covers the low-frequency end of the 3mm atmospheric window from 68-92 GHz. It is primarily a spectral line receiver and provides a nice compliment to MUSTANG, a 90 GHz bolometer array. We have incorporated the 4mm receiver into the simulator to be able to assess how well we could schedule upcoming commissioning sessions (Fall/Winter 2011) and shared risk observing sessions (Winter/Spring 2012). Unlike MUSTANG the 4mm receiver is not a fully sampled array and therefore is more susceptible to tracking errors. Additionally, the current tracking performance model for the GBT is incomplete at W-band. The DSS simulations have indicated this by showing that the tracking error scoring factor prevents the scheduling of the 4mm receiver. Therefore, until the GBT tracking performance model is completed for W-band, we have temporarily loosened the constraints for scoring this receiver. Efforts currently being made to do complete the tracking performance model in the Precision Telescope Control System (PTCS) project. Additionally, we are experimenting with the DSS simulator to see how this issue should be addressed. The results of this on-going research are being feed back into the PTCS project.

Additional Session Parameter Specifications

A number of session parameters have been added to accommodate observations having special requirements.

- Tracking Error Threshold - the largest acceptable tracking error in units of the beam size (unit-less).
- Keyhole Limit – flag that when applied sets an elevation maximum to avoid observing in the telescope's keyhole.
- Irradiance Threshold - the value that is used to compare to a calculated irradiance for a given session when determining the atmospheric stability limit.
- Time of Day – can be set such that the session is constrained to observe during non-work hours to avoid RFI, or to observe only between a few hours after sunset to sunrise to avoid thermal degradation of the pointing, or with no constraints at all.
- LST Inclusion and Exclusion Ranges
- Solar Avoidance – flag that when applied will avoid observing too close to the sun when scheduling a session.
- Source size – Defaults to 0.0. Used to indicate an extended source and relax the tracking error constraints.

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