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A Graphical Planning and Scheduling Toolkit for Astronomical Spacecraft

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Abstract. A small yet powerful planning and scheduling toolkit has been built for the *Submillimeter Wave Astronomy Satellite* (*SWAS*) Small Explorer spacecraft. It makes extensive use of graphics to illuminate the planning and scheduling process. The simple design, minimal resource requirements and easy extensibility of the *SWAS* planning and scheduling toolkit should make it useful for other space astronomy missions. A release of the toolkit for general use is planned shortly.

1. The SWAS Mission

SWAS is a NASA Small Explorer spacecraft to be launched in low Earth orbit in 1995. It will investigate the chemistry and energetics of star forming molecular clouds via the simultaneous observation of the O_2, C I, H_2O and ^{13}CO spectral lines in the 487–557 μm (538–615 GHz) range. The mission was proposed by the Smithsonian Astrophysical Observatory in Cambridge MA, which has the responsibility for the scientific component of the mission. The mission is managed by the Goddard Space Flight Center (GSFC).

The science instrument consists of a 0.65 m dual receiver radio telescope with an acousto-optical spectrometer backend. The spectrometer is read out every two seconds for the life of the mission, producing 100 MB of raw data every day. *SWAS* will observe 50–100 targets per day. The minimum planned mission duration is two years.

SWAS is the first astronomical Small Explorer, a series of missions to be developed under a "smaller, cheaper, faster" imperative. The turnaround time for *SWAS*, for example, should be about five years from acceptance of proposal to launch. The SAO Science Operations Center responsible for the development and operation of the science ground system consists of six scientists, including Principal Investigator Gary Melnick and Project Scientist John Stauffer. The planning toolkit described below was designed and written in two years by the *SWAS* Planning Scientist.

2. The SWAS Planning and Scheduling Toolkit

This stand-alone toolkit provides all the planning and scheduling functions for the *SWAS* spacecraft, including processing of the NASA predictive ephemerides, target visibility calculations, long range planning and short term (orbit-to-orbit)

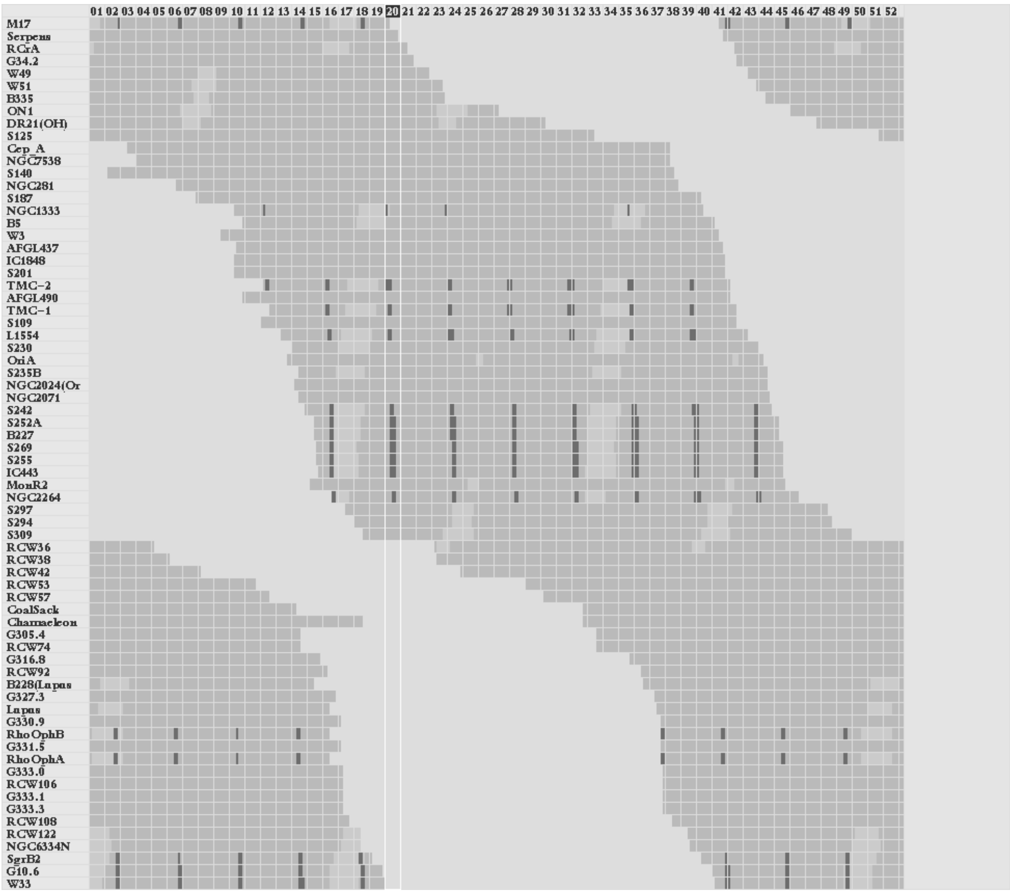

Figure 1. One-year planning display for week 20. Fifty-two weeks run across the top of the display. The shading indicates days when a target is visible or when Earth, Moon or Sun constraints are violated.

scheduling, slew constraint checking, nominal roll calculations, guide star selection, and generation of detailed spacecraft timelines for conversion into command uploads. The toolkit displays its calculations graphically and makes extensive use of coordinate transformations in order to avoid any brute force calculations, a concept recognized by David Koch of NASA/Ames Research Center in his development of a prototype scheduler for *SWAS*. A new guide star catalog for CCD star trackers has also been developed (Stauffer 1993). The toolkit is currently generating timelines to support pre-launch testing of the flight operations facilities at GSFC.

The toolkit has a minimalist design, consisting of independent tools or 'filters' which operate on a single stream of scheduling events. Events include orbital ascending node crossings, the rising or setting of a target above the Earth horizon and the entry and exit of a target into pointing avoidance regions around the Sun and the Moon. The toolkit is extended by defining new events and adding the appropriate filters. Since *SWAS* uses the planets for calibration, the toolkit can also schedule planetary pointings. Calculations are done in orbit

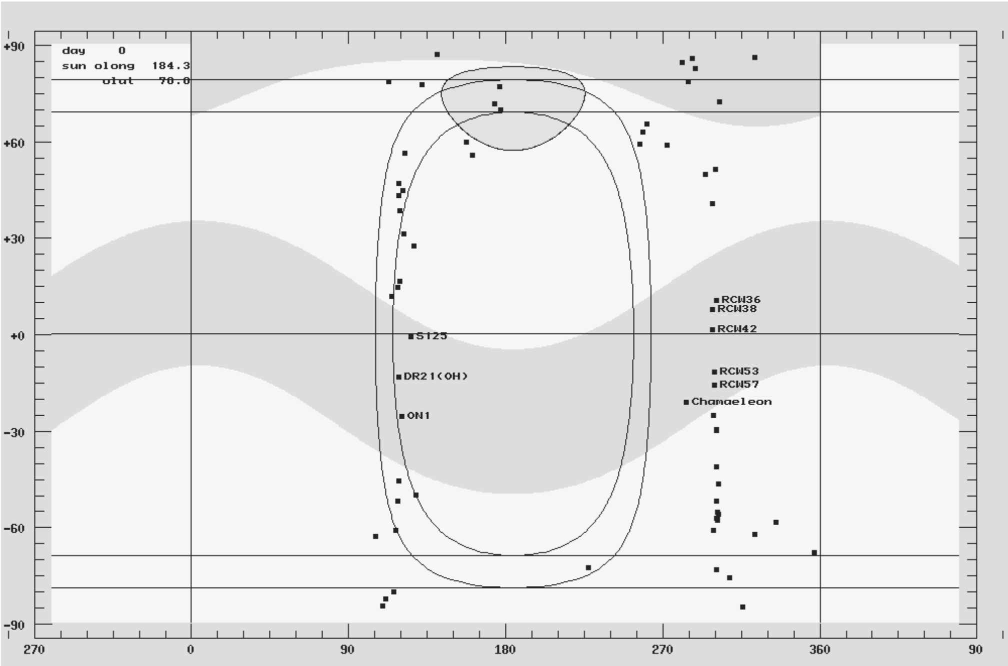

Figure 2. Pointing Constraint Display. The horizontal scale is orbital longitude, the vertical scale orbital latitude. The labeled targets in the central swath satisfy the Sun, Earth and Moon pointing constraints.

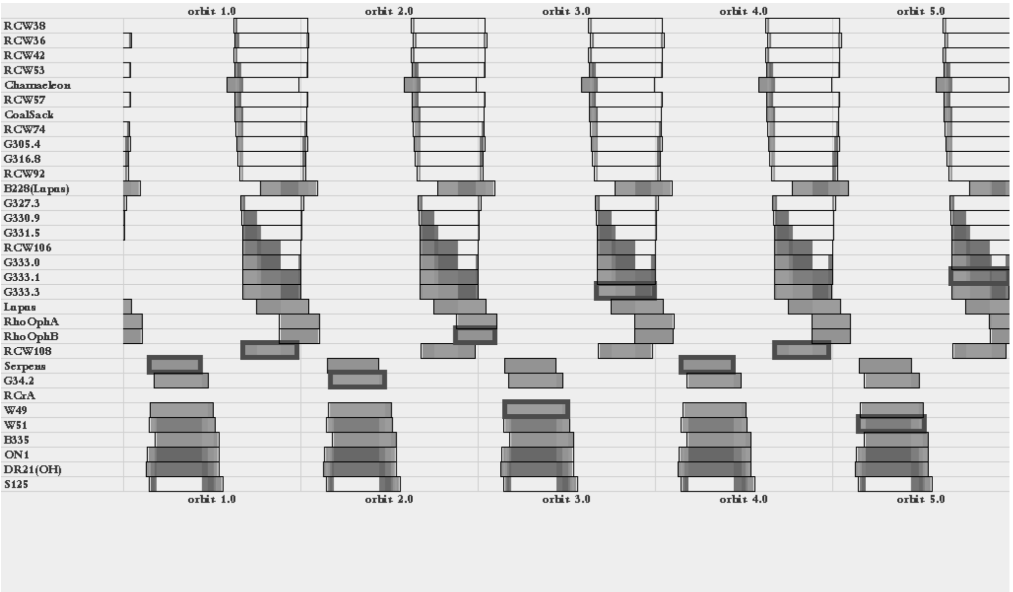

Figure 3. Scheduler Display for Five Orbits. The rectangles are target rise-and-set events shaded according to their scientific value and scheduling efficiency. The heavily outlined targets have been selected for scheduling.

relative time rather than absolute time to minimize the effect of uncertainties in predictive ephemerides. The toolkit is fast enough that the same tools are used both for long range planning and short term scheduling. The planning toolkit consists of about a dozen tools, less than ten thousand lines of ANSI C code in total. It makes only plain Xlib calls for the graphics and does not make any Unix system calls.

3. SWAS Planning and Scheduling Graphics

Figure 1 is a planning display showing target visibilities over the course of the year. The lighter bands running from top left to bottom right are days in which the target is too close to the Sun. (*SWAS* must point within 75°–105° of the Sun, and more than 40° from the Earth and more than 15° from the Moon.) We have found by experience that long term planning is driven primarily by the position of the Sun with respect to the target. Therefore, for any given week targets going into the Sun soonest are given the highest scheduling priority.

Figure 2 shows pointing constraints as seen from the orbital plane. The Sun is near the north orbital pole and the lighter swaths are regions of the sky which violate the *SWAS* Sun pointing constraint. The small black squares are potential targets, but only those which satisfy the pointing constraints at some time in the orbit are labeled by the software.

Figure 3 is the interactive scheduling display showing five orbits. Each rectangle represents the rise and set of a target during an orbit. The rectangles are filled and shaded according to the target's scientific interest and scheduling efficiency. The scheduling scientist uses a mouse to point and click to select or de-select a target for inclusion into the timeline sent to the spacecraft, as indicated by their heavy black outline around selected targets.

4. Distribution of the SWAS Planning and Scheduling Toolkit

The relatively severe time and manpower constraints for the development of the *SWAS* Planning and Scheduling toolkit have forced it to remain small and simple. Nonetheless, it had to be powerful enough to support production scheduling for the *SWAS* spacecraft and flexible enough to do year-long mission planning.

During the development of the toolkit, we realized that these attributes, together with its ease of modification and extension, should make it useful for other space missions and for astronomers developing future missions. We have received a small NASA Astrophysics Data Program grant to package the toolkit for general distribution. We anticipate a release of the toolkit shortly. Please contact the author for sample products and more information.

References

Stauffer, J. 1993, "Creation of a Guide Star Catalog for the BASG CT-601 Startracker," SWAS Technical Memorandum