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INTERFEROMETERS, USERS AND SCIENCE - THE SOFTWARE LINK

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ABSTRACT

A sometimes under-emphasized element in the development of new observing facilities tools is the software. While often representing 5 to 20% of the cost of a new system, it can easily be taken for granted in the planning and construction until relatively late in the development program. This talk will review the role and character of interferometer software required to vet the hardware, meet the needs of the user community and in shaping the character of the science that a new facility can achieve. The talk will be illustrated with the experience of RHESSI (which does Fourier transform solar imaging in hard x-rays and gamma-rays), and the plans for FASR (the Frequency-Agile Solar Radiotelescope), and will attempt to relate these experiences to the BDA.

INTRODUCTION

The purpose of this talk is to review the role and character of interferometer software in vetting the hardware, in meeting the needs of the user community and in shaping the character of the science that a new facility can achieve. I will begin with some general software considerations as they relate to solar facilities, illustrate these considerations with RHESSI and FASR and then suggest how they might be relevant to the BDA. The treatment will be very general, and much of what I will say is quite mundane, and for this I apologize in advance. If, however, there are bits that are controversial, then perhaps this will provide the basis for useful discussions.

GENERAL CONSIDERATIONS

Software provides the interface between an interferometer's hardware and its users. As such the software and hardware have comparable impacts on the ultimate success of a facility. It represents a growing fraction of the cost of modern facilities, often more than 20% of the total facility cost. Despite this, software is sometimes taken for granted in the planning and implementation of a program and not given much attention in planning until relatively late.

The role of software has some additional implications; its development provides an excellent way to involve students; its development can provide an effective vehicle for involving remote collaborators. In the longer term, upgrading the software provides a powerful and cost-effective way to upgrade the performance and capabilities of an instrument.

BROAD FACTORS AFFECTING SOFTWARE DESIGN

In designing the software for a solar interferometer, there are several rather basic questions which much be considered.

"What are the goals of the facility?" There are many possibilities here: to support technology development, either locally or globally; to provide a tool for educating students; to act a prototype for a future facility; to provide observational support to other instrumentation; to provide a significant advance in capability of previous similar instruments; to provide synoptic data in support of solar activity forecasting or nowcasting; to be an exploratory instrument operating in a previously unexploited observational domain. The relative importance of these and other possible goals for a given facility has profound effects on how its software should be designed.

What type of operation is planned for the interferometer? Will it be operated for a few times or for many years to come? Will it be user-controlled with a series of custom observing programs or in a standardized way? Will there be professional operators, by the users themselves or is it fully-automated?

Who are the users? Are they students (perhaps inexperienced, but eager to learn and contribute)? Are they hands-on scientists with broad experience in the field? Are they scientists in closely-related fields with interest in the data but limited time to learn the observing or data reduction techniques? Are they members of other science communities, who are interested in only the final results?

There are many 'customers' who will be using the software, each with their own needs and preferences. For example the operators, who interact with the control software need real-time feedback on broad aspects of array performance and in some cases, in the current state of solar activity. The engineering staff needs to have effective access to data for failure identication and to evaluate quantitative aspects of array performance. The science staff needs to be able to effectively edit and calibrate the data, evaluate the more subtle aspects of array performance and generate the data products upon which the subsequent science is based. The external community not only needs access to the final calibrated data products (e.g. light curves, images and/or spectra), but also to the metadata that serves as an index to what is available. For this community, convenience is critical.

For the data analysis software, the anticipated data volume and processing requirements are of course fundamental factors. The anticipated RFI environment and atmospheric attenuation can also be important. Less obvious is the question of whether the analysis will be done by full-time or 'guest' analysts and what is the 'style' of the analysis. This can range from case-by-case custom reduction to routine procedures to fully-automated pipelines.

What are the programming resources available? The experience and language-familiarity of the software team is obviously a factor here as is of course, the available time, budget and computing hardware. Also relevant is whether the software development is to be subcontracted to a commercial concern, or be done by in-house software professionals, by done by scientists or by students.

Almost all of the possibilities suggested above could be illustrated by one or more existing or planned facilities. I'll illustrate this with two current examples of solar facilities.

RHESSI

The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) is a NASA small explorer mission launched in 2002, that provides high spatial and spectral resolution observations of x-rays and gamma-rays in solar flares. Why is it relevant to an interferometer workshop? First, like the solar program of the BDA, its observation program is directed to transient phenomena rather than a variety of fixed targets. Like an interferometer, it uses indirect imaging techniques (as opposed to pixelated detectors in a focal plane) and so requires image reconstruction. In fact its image reconstruction is the precise mathematical analog to that required to convert interferometer data to images.

RHESSI is an exploratory instrument, doing the first imaging spectroscopy at x-ray energies and the first solar gamma-ray imaging. As such, many of parameters of its targets (e.g. size scales) and some of its current uses (e.g. a search for axions) were not foreseen. Although there are many in the solar community who are keenly interested in the data, there was and is a very limited population of those that combine knowledge of both high-energy solar x-rays and the image reconstruction techniques.

RHESSI's data volume was moderate by current standards (1.8 GBytes/day) but its handling still required some consideration since over 6+ years this has built to ~4 Terabytes. The character of the data provided both special problems and opportunities. The transmitted data was based on the arrival time and energy of each detected photon. This provided the opportunity to choose the 'exposure time', field of view, imaging parameters, energy range and resolution when the data were analyzed in response to the event and objectives under study rather than at the design phase. While this flexibility has magnified the effectiveness of the data, it has provided users with an unfamiliar array of decisions. It also implied that almost all science analyses start from level-0 (raw) data, rather than from higher-level data products. Figure 1 shows the overall operations and data flow.

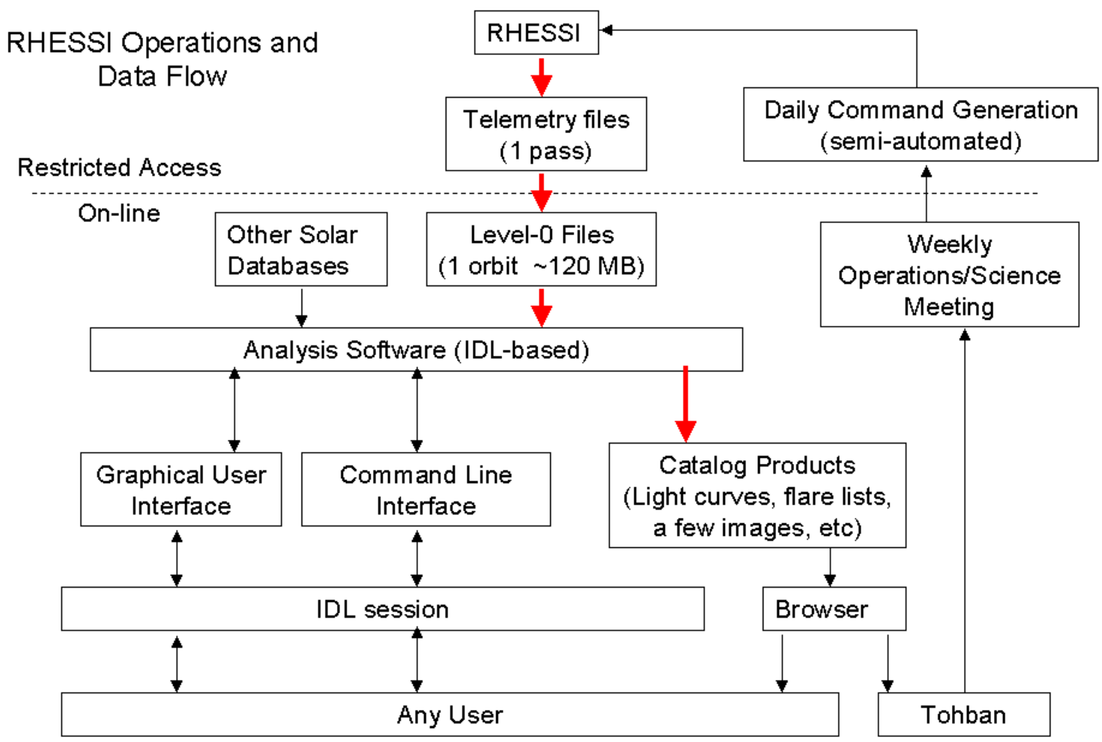

Fig. 1 - RHESSI Data Flow.

FASR

FASR is a proposed interferometer that represents quantum step forward in terms of its combination of radio imaging and frequency coverage. Its parameters are shown in Table 1.

The primary challenges here are threefold – first, as with RHESSI, the majority of the user community has little experience with the techniques required to analyze the data; second the RFI environment is an important factor, and third, the data volume and processing requirements are rather substantial. For example the output of the correlator is ~500 Mbytes/second (~25 Tbytes/day) which is to be reduced to an archival data volume of ~50 Gbytes/day. Figure 2 illustrates the current approach towards addressing this task.

Table 1 – FASR Parameters

Angular resolution	$20/\nu_{GHz}$ arcsec
Frequency range	50 MHz – 21 GHz
Number data channels	2 (RCP + LCP)
Total instantaneous BW	2 x 500 MHz
Frequency resolution	1% or 5 MHz
Time resolution	**A** (2-21 GHz): 3 s [snapshot 1 s] **B** (0.3-2.8 GHz): 1 s **C** (50-350 MHz): 0.2 s
Polarization parameters	IQ/UV
Number antennas	**A** (2-21 GHz): 45 **B** (0.3-3 GHz): 15 **C** (50-350 MHz): 15
Antennas correlated per integration cycle	30
Size antennas	**A** (2-21 GHz): 2 m **B** (0.3-3 GHz): 6 m **C** (50-350 MHz): LPDA
Array size	2.9 km EW x 3.8 km NS
Absolute positions	1 arcsec
Absolute flux calibration	<10%

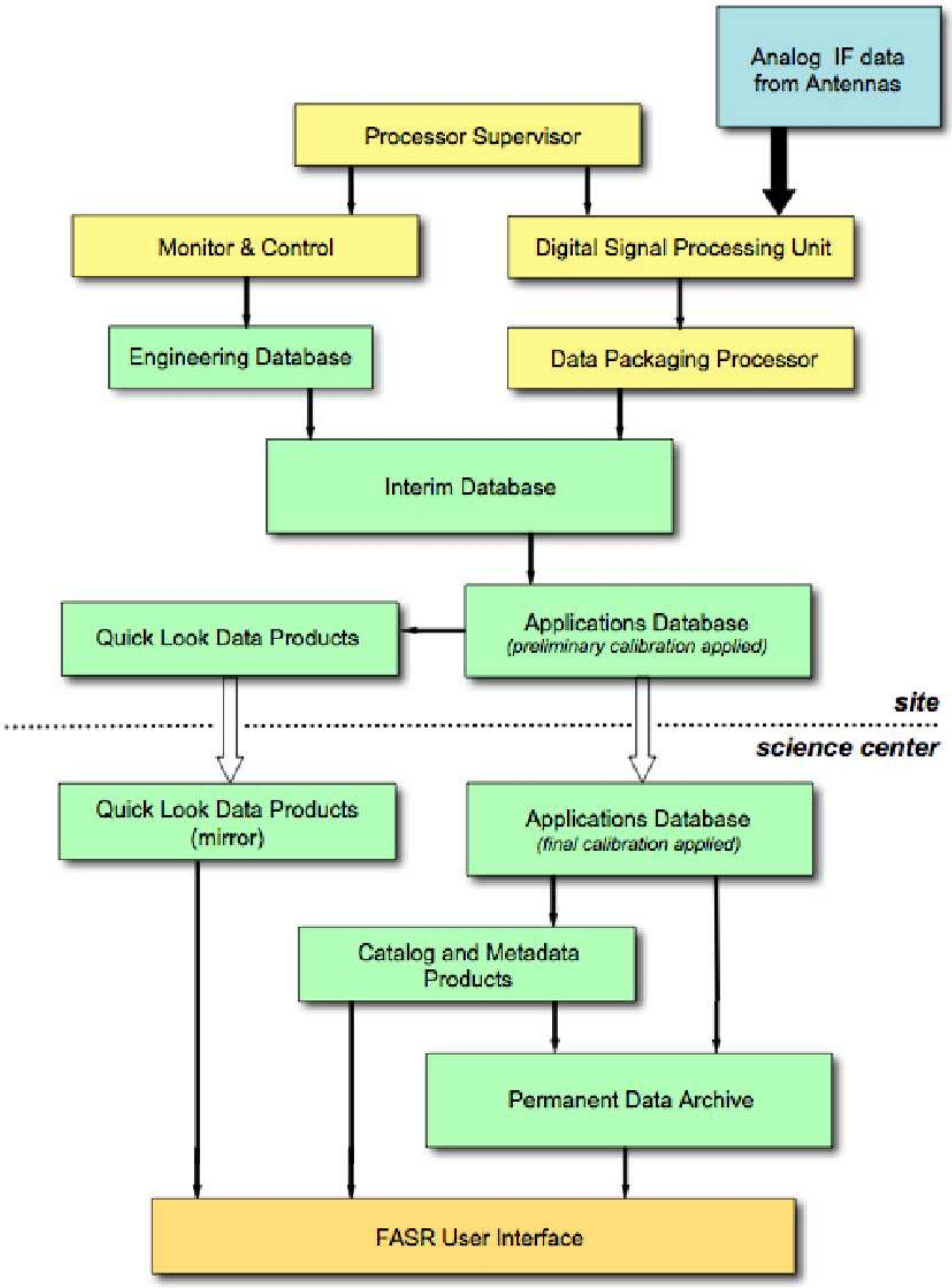

Fig. 2 - FASR Data Flow.

APPLICATION TO THE BDA

To illustrate how these considerations might be applicable to the BDA, let me take the risky step of reviewing some of the BDA's potential impacts. I'll ask your forgiveness in advance for my mis-state the case.

At the national (Brazilian) level, the BDA is providing an excellent vehicle for developing technology infrastructure. It also provides a rich resource for student training and involvement in engineering, astronomy and software. As this meeting illustrates, it encourages international scientific and technical collaboration. Through the joint study of specific events, it will also provide the basis for effective access to internationally sources of other solar data

On a worldwide level, the BDA will provide high-sensitivity radio coverage of solar activity in a distinct (and under-represented) longitude range. It can provide burst positions and flux values valuable for joint interpretation with other data. Continuous operation would provide a new synoptic database for solar activity.

SOFTWARE IMPLICATIONS FOR THE BDA

What do such potential impacts have to do with software design?

Maximizing the impact on technology development requires effective, quantitative feedback on array performance (e.g. phase stability). Maximizing its impact in the broader technical and general communities can be helped by the BDA website and by public outreach programs.

Student involvement, for example in software design, requires choosing software approaches that encourage contributions and adaptation, rather than the direct adoption of existing legacy packages which, in some cases, can present a formidable barrier to modification.

The exploitation of the BDA's longitude advantage would be aided if plans called for daily operation. That in turn has implications for the desirability of automation of both the control and analysis software.

Possible application to synoptic monitoring of solar activity, would also require a program of daily observations, but it would also place demands on the robustness and speed of routine data product generation.

To exploit its capability for burst position measurements, considerable effort in phase stability and calibration protocols are required.

Finally, to exploit its role in the international solar community, it is a fact of life that any modern facility must provide access to calibrated data products to non-specialists that is both convenient and timely.

REFERENCES

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